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SPECTRUM OF VISIBILITY: AN EXPLORATION OF ASTRONOMICAL TECHNIQUES OF VISUALIZATION

Dissertation submitted in 2011 for the MA Material and Visual Culture

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Spectrum of Visibility:
An Exploration of Astronomical Techniques of Visualization

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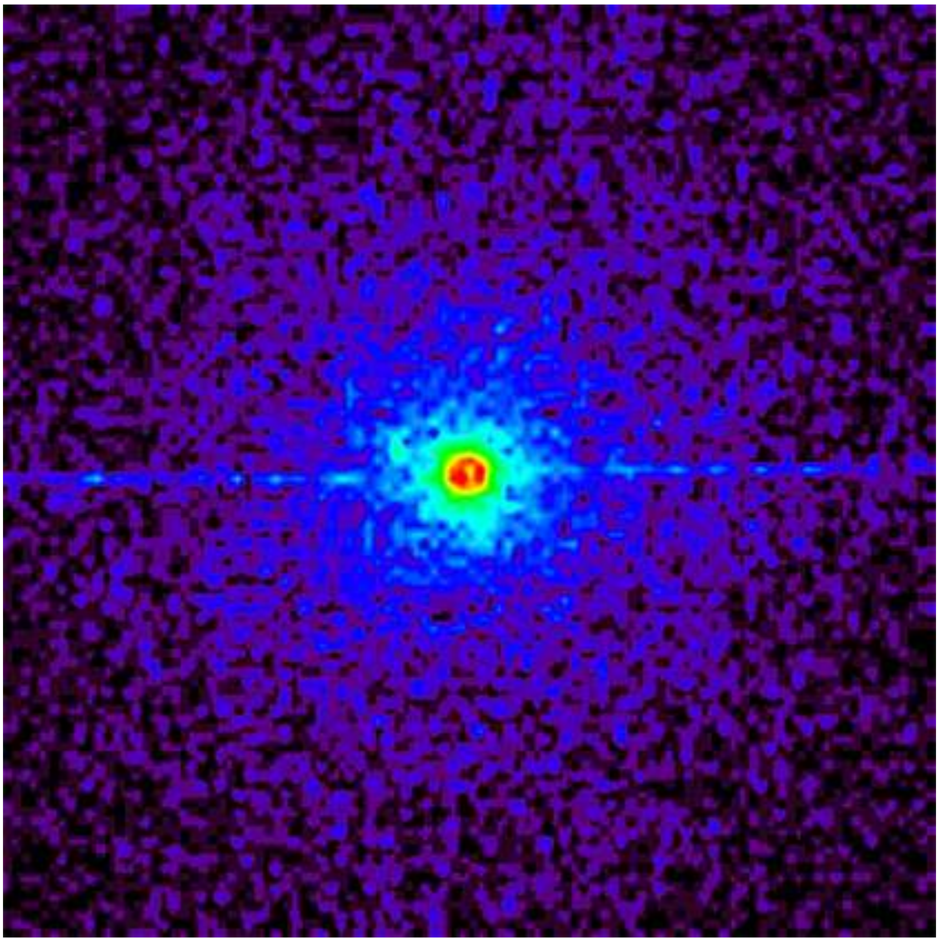

Figure 1: Chandra visualises halo around the X-ray source Cygnus X-3 (NASA, SRON, MPE, 2000)

This paper is based on a dissertation submitted in 2011 as part of the MA in Material and Visual Culture in the Department of Anthropology, UCL.

Abstract

Based on research conducted with the Astrophysics Group at Imperial College London, this paper examines astronomical images to illuminate the practices and categories of the visual within astronomy. By identifying the origin of these images in an initial transformation of light, I frame astronomical image making as a technical process. This study is an initial attempt at a Latourian inspired 'visual-symmetrical' anthropology which gives equal weight to the roles of the human and non-human, and spheres of the visible and invisible, through a tentative anthropology of light.

The paper first gives an overview of the literature and theoretical approaches to the study of images. It then examines the techniques of visualisation through which photons are transformed into data, then images, then mediators which are made to refer back to the original celestial phenomenon. The study goes onto explore how astronomical images lie at the intersection of processes of mediation and mediality, and then perception and technology.

I conclude by considering the category of the visual in astronomy, which is shown to be constructed in tandem with these images. The images themselves emerge at the triadic confluence of techniques, reference and the visual. I propose the concept of a 'spectrum of the visible' to expose how the visible/invisible binary is collapsed within these images and to highlight how the visual, both within and without astronomy, is a fragmented, heterogeneous, hybrid movement.

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In memory of Thomas Heath.

Introduction

The world – that tricky category – turned its eyes upwards last week with excitement and anticipation with the news that a star had exploded in another galaxy and would be visible through binoculars from the planet Earth (BBC News, 2011). This twenty-one million year old *image* thus imprinted itself upon the retinas of countless humans, *mediated* by a simple *network* comprised of one human unit and two non-human units: light and binoculars. In this paper I propose to investigate similarly ancient and distant, although more densely mediated non-human images (of those very non-human things: astronomical phenomena) and how they are mobilized and produced within the scientific discipline of astronomy.

These images are both the starting and end points of the following analysis, as my research quickly taught me that we have "*nothing to see* when we do a freeze frame of scientific practice and focus on the visual itself instead of the movement, the passage, the transition from one form of image to another" (Latour, 1998:421, original emphasis). The astronomical image can only be illuminated by an investigation into its coming into being in techniques of visualization through which light is gradually mobilised and transformed. And, just as light is translated, deconstructed and constructed through these networks, so is the category and practice of the visual and visible.

As such, I propose to study the visual culture of astronomy via the material culture of light, and I approach visualisation as primarily a technical process which, in the hard sciences, is geared towards the labour of reference. Inspired by Bruno Latour(1993a)'s call for a 'symmetrical anthropology', my analysis will delve into both human and 'non-human' vision and, following Mitchell, it will give equal weight to the role and category of the visible, as well as the "invisible, the unseen, the unseeable" (2002:170) in forming astronomical images and informing astronomy's visual culture.

In an effort to contextualize both the astronomical image and how I approach it, I begin by locating the image within different disciplinary projects (*Chapter 1*). I investigate the relationship between images and academic disciplines, firstly in terms of how they are studied in the social sciences and humanities (the image as unit of analysis) and secondly, in terms of how they are created and used as methodology in the social and hard sciences (image as tool for analysis). The image-discipline axis will be explored further through my own methodological considerations, as a student in a discipline conducting research with images from another discipline (*Chapter 2*). In the first section, the form of my analysis follows its content: the trajectory and network of light. I will begin by uncovering the indigenous astronomical category of light by tracing the techniques of visualisation-observation used in astronomy, and through which light becomes data (*Chapter 3*). I will then explore how these networks become images, by charting the transformation of data into images engendered by techniques of visualization-imaging (*Chapter 4*). The second section will return to and focus on ideas latent in the primary analysis, and their implications for broader theoretical questions in both social anthropology and the study of visual culture: the relationship between mediality and mediation (*Chapter 5*) and the question of perception in astronomical visualisation (*Chapter 6*). I will conclude my analysis by considering the status of the visible, the invisible and the visual both within astronomy and as broader analytic categories (*Chapter 7*).

1. Literature Review

1.1 Imaging Disciplines

An anthropological-study-of-astronomical-images demands deconstruction, knotted as it is in layers of images and disciplines. It is my task here to "slip these superimpositions out of focus" (Foster, 1988: ix) (in order to then recombine them). My starting point is an acknowledgement of my position as an anthropologist studying astronomy and how this simple *mise en abyme*, where my work represents the study of one discipline by another, throws up a set of interesting dynamics around the image-discipline axis.

At this early stage, it is worth differentiating between images-in-the-world, the image as a topic or subject of intellectual inquiry and the image as methodology, used as a method, tool and instrument of investigation, whether in the 'hard' or social sciences. These three image-incarnations are separated here by heuristic boundaries, and they overlap and interpenetrate nowhere more so than 'across the university' (Elkins, 2007), within its disciplines. Different disciplines cut through and combine these three image incarnations at different points, through the study of images (as in art history and aesthetics), the production of images, or both (as in anthropology and hard sciences such as astronomy).

Whilst I acknowledge that indulging in academic anxieties can lead to a tautological exercise which can drown out the image's voice (Mitchell, 1992) – the question of disciplinary boundaries is an expression of larger "universal semiotic anxieties about where or how to draw boundaries between persons and things" (Hornborg, 2006: 21), including images. To carve out the image as an appropriate unit of analysis, to understand it and theorize it, it is thus essential to take a detour into disciplinary projects, to look at "those places where images have differentiated themselves from one another on the basis of boundaries between different institutional discourses" (Mitchell, 2006:297).

The image has been harnessed by various disciplines concerned with the visual (and sometimes the not so visual), as art history, aesthetics and media studies decide what a worthy image is and submit it to their various paradigms. Such restrictions are increasingly dissolved, giving way to an 'interdisciplinary image' developed under the umbrella field of visual culture studies. This still scattered and embryonic discipline has its etymological origin in the works of Michael Baxandall (1972). His 'visual culture' concept was more fully theorized in Alpers' (1983) analysis of Dutch painting, which she argues can only be understood as part of a wider cultural context of visual, optical and perceptual practices.

The ensuing dismantling of frontiers between the various "medium-based historical disciplines" (Alpers, et al., 1996:25) reflects a fundamental shift in the conceptualization of 'the visual', which has undergone a horizontal and vertical broadening, dislodging the 'art image' from its epistemological pedestal and reaching out to forms of "vernacular visuality or everyday seeing" (Mitchell, 2002:178). Despite the general suspicion and resistance with which the academic community greeted this new field (as expressed in the October Questionnaire (1996)), visual culture studies has "allow[ed] us to trace relations previously obscure or ignored" (Gunning, 1996:38) by "recognizing commonalities among visual media" (Rodowick, 1996:60) – opening the path for "networks" (Pinney, 2006) of the visual to shed light on continuities (and discontinuities) within and between histories and technologies of the visual. In this vein Martin Kemp (2006) has mapped the continual re-emergence and interconnection of practices, representations and techniques structuring the seen/unseen dialectic in art and science over the last four centuries.

For all its interdisciplinarity, whether aspired or achieved (Elkins, 2003), there is one boundary which reoccurs in the literature. Visual studies' final frontier is, crucially and curiously, that of the image. This fact, that images simultaneously occupy the field's centre and periphery is perhaps the epitome of the "paradoxes of the visual" (Rodowick, 1996:59). The image, as a unit of analysis, is a node of (disciplinary) articulation between image studies and visual studies. Epistemology is here determined by ontology as images and visuality overlap without being mutually reducible, and it is above all the superimposition of this pair that needs to be slipped "out of focus" (Foster, 1988: ix).

The question of disciplinarity rears its head once more, as a new field or project of Image Studies (Manghani et al. 2006) has grown out of the same criticisms levelled by art historians towards visual culture studies, which is accused of epistemologically reifying the division of the senses and perpetuating "the horizontal narrowness entailed in modernism's fetish of visuality" through its privileging of the optical (Crow, 1996:39. The image-in-the-world has been transformed into an image as analytical unit caged within Hal Foster's emphasis on "vision and visuality" (1988). The image has essentially been cannibalized by the "pictorial turn” (Mitchell, 1994:16) which has ostracized those “members of the family of images” (Mitchell, 2006:5) not amenable to ocularcentrism.

It is important to reverse this process and recognize how images inhabit the full spectrum between the visible and the invisible and find graphic, optical, perceptual, mental and verbal expression in the form of “pictures, statues, optical illusions, maps diagrams, dreams, hallucinations, spectacles, projections, poems, patterns, memories and even ideas”(Mitchell, 2006:297). Following this, Hans Belting subscribes to the idea that “internal and external representations or mental and physical images [are] two sides of the same coin” in his exploration of the translations between “endogene” and “exogene” images (2005:304). He offers an elegant definition of images, as living from the “paradox that they perform *the presence of an absence* or vice versa” (*ibid*: 312, original emphasis). We are here confronted with yet another paradox of the visual, born out of our experience of relating presence to visibility.

If visual culture studies is to take seriously the idea that “dreams and icons are dependent on each other” (*ibid*) in order to integrate the image in all its incarnations - including the “strange creatures that haunt the border between physical and psychological accounts of imagery” (Mitchell, 2006:298), between presence and absence - then it is has to delve into its ‘Other’: the invisible. I follow Mitchell in calling for a visual culture studies built on a “meditation on blindness, the invisible, the unseen, the unseeable, and the overlooked” (Mitchell, 2002:170) in order to take seriously and fully engage with the paradoxes of the visual.

1.2 Images in the Sciences and the Science in the Images

There are two parts to the scientific image, referring as it does to the image in the sciences and crucially, to the science in the image. Interestingly, scientific images simultaneously personify the three incarnations of the image previously outlined, though their order of transformation/circulation is often reversed: whereas the image within the purview of visual studies outlined above is plucked from the world to become a topic of inquiry, scientific images are born out of method, become the subject of analysis before entering/being disseminated into the wider world. As images circulate, their uses, contexts, viewers and mediality shift accordingly.

The crucial point of difference is that *scientific* images are produced (and not only studied) by the discipline in question. As manifestations of the dual properties of evidence as information and tool (Engelke, 2008), these images are 'scientific' by virtue of their propositional content (Elkins, 2007) and the fact that they are not only the results of method, but are themselves the material/visual expression/form of method. Visual practices are methodological practices, they therefore play a central role in "evidentiary protocols" (Engelke, 2008) which have a disciplinary specificity and yet are enmeshed in related/common webs of documentation, objectivity and visualism. Following Engelke's discussion of the role of evidence in anthropology where he argues that, "if we want to engage with the work that grows out of" other disciplines "it makes sense for us to consider where our own approaches might fit in" (*ibid*: 3), I propose a detour into the role of the visual within anthropology, as a familiar 'way in' into the role of visualization within the sciences.

Anthropology's "epistemological unconscious" (Steinmetz, 2005, cited in Engelke, 2007:1) is rooted in and strives toward the empiricist and positivist ideals of western scientific rationalism and accordingly manifests itself in a tendency towards what Johannes Fabian calls "visualism": "a cultural, ideological bias toward vision as the 'noblest sense' and toward geometry qua graphic-spatial conceptualization as the most 'exact' way of communicating knowledge" (1983:106). The second partner of participant observation is determined by this ideal of an "objectivist knowledge" (Bourdieu, 1977:3) structured according to a visual-spatial theory of knowledge. The onus on "quantification and diagrammatic representation so that the ability to 'visualize' a culture or society almost becomes synonymous for understanding it" (Fabian, 1983:106) has led to the production of "non-indexical and often non-figurative" (Banks, 2001:23) images within anthropology such as charts, tables and maps (see Halliwell, 1996). The most emblematic of these is the kinship diagram, the visual form of the "genealogical method of anthropological inquiry" (Ingold, 2007:109) developed by W.H.R. Rivers. Its genealogical line acts as "scientific notation" (*ibid*), "visual equipment" and "graphic shorthand" (Bouquet, 1996:43), to map out relatedness along a visual-spatial grid. The anthropological emphasis on evidentiary visualism can also be found in the operational sequence method (Lemonnier, 1992) and uses of photo-documentation (Banks, 2001:112).

Although imaging has become problematic for many contemporary anthropologists (see Pinney, 2011), visualism runs deep within the discipline. As Timothy Mitchell (1991) observes, practices of 'enframing' deriving from western ontological dualism are foundational to anthropology. This enframing manifests itself in the disdipline's core structuring distinction between observer and observed, from which has sprung the method of participant *observation* and the 'anthropological gaze'. Maurice Bloch (2008) traces this twinning of vision and knowledge to an almost universal association of truth with sight, since the latter is seen to bypass the deceit inherent in linguistic communication.

This implicit visualism underpinning anthropology takes centre stage within the 'hard' sciences in which images of the most varied and heterogeneous kind proliferate. The still nascent social scientific literature on natural scientific imaging is located half-way between theories on science and theories on images, as art historians (notably Elkins, 1995 and 2008) and historians and sociologists of science (see for example Tucker, 2005; Latour & Woolgar, 1986) have steadily crept towards this new field of inquiry from opposite ends of the disciplinary spectrum.

From this has emerged studies of extraordinary diachronic and synchronic breadth, emphasizing how 'artistic' and 'scientific' imaging practices are not merely intertwined, but have been structured by historically criss-crossing patterns of visualization and representation (see for example the chapters in Galison and Jones (1998)'s *Picturing Science, Producing Art*) which disappear only to periodically recur/erupt at nodal points over the last four centuries like some kind of a visual uncanny (Kemp, 2006). It is through such investigations into the "domain of images" (Elkins, 1999) and mappings of "the history of visuality" (Elkins, 1995:557) that the art/science dichotomy is revealed to be not a 'really real' separation but the result of the modern constitution's many acts of 'purification' (Latour, 1993). And in turn, when considered together through contrast and comparison, art and science images illuminate both the history and ontology of visuality (Elkins, 1995, 2008).

'Artistic' conventions such as linear perspective and chiaroscuro have thus been shown to contribute heavily to the goal of naturalistic representation in scientific imaging, and Lynch & Edgerton (1996) have researched this influence in relation to astronomical images. An important contribution to the literature on scientific imaging and representation centres on the development of changing conceptions and practices of objectivity and realism. Objectivity is shown to be a composite and layered concept whose current form as a mechanized and moral ideal of scientific representation emerged in the 19^{th} century, as typified in the atlas (Daston & Galison, 1992). Inversely, the notion of scientific subjectivity and its relation to the image has been investigated through the shifting role of judgement and the techniques of the observer (Pang, 1998; Crary, 1990).

Further dynamics of realism and naturalism, whilst predating the invention of the camera and transcending medium specificity, have exemplified debates on the role of photography (and its many hybrid offshoots, including astrophotography (Pang, 1998) in science (Jay, 1995; Tucker, 2005; Wilder, 2009)). Scientific images have in this way been looked at through the prism of the “visual as language” (Pinney, 2006:132) via theories of reference and signification, and in particular Piercian semiotics which have defined (and for some, plagued) the wider understanding of photography (Elkins, 2006a). This ‘linguistic turn’, often criticized for contributing to the disembodying of the image, has been productively put into dialogue with investigations of scientific practices, leading to a growing body of work on the materialities of scientific communication and signification (Lenoir, 1997) and the connections between image, texts and instruments within the sciences (Latour & Woolgar, 1986; Lynch & Woolgar, 1990).

It is crucial to note that such investigations into science imaging would have been impossible without, and directly derive from, the recognition of science and technology as fields amenable to social scientific analysis. If Mitchell’s idea that ”the social construction of the visual field has to be continuously replayed as the visual construction of the social field” (2002:175) is to mean anything here, then science itself has to be understood as a social field, along with techniques and technology. This has been done via the anthropology of techniques (see for example Lemonnier, 1992) and the sociology of science, which have brought attention to the sociological construction of facts and artefacts (Pinch and Bijker, 1989). Scientific knowledge was brought into the purview of sociological study in the 1970s, notably through Bloor(1976)’s call for a “strong programme” which finds explanations for the emergence, acceptance or rejection of scientific “beliefs” in the social and not natural world, irrespective of their ‘truth’ or ‘falsity’. In this way, the Sociology of Scientific Knowledge approach is analogous to the calls for methodological atheism in the study of religion and methodological philistinism for art (Gell, 2006). This framework paved the way for the interdisciplinary Science and Technology Studies, which sought to investigate the contents of scientific knowledge through the investigation of scientific *practices* (Lynch & Woolgar, 1988). Borrowing from ethnography and ethnomethodology, this resulted in a number of laboratory studies which identified the contents of scientific knowledge as manifested through the production, transformation, interrelation and circulation of “inscriptions”: documents, texts, “graphs, diagrams, equations, models, photographs, instrumental inscriptions, written reports, computer programs, laboratory conversations, and hybrid forms of these” and of course images (*ibid*: 99). These tell the story of the embodiment of scientific knowledge in representational objects, and the embeddedness of visual representations in scientific practices – working from and towards the simple but crucial idea that scientific representations are “not simply pictures of natural objects” (*ibid*: 103) (Amann and Knorr-Cetina, 1988; Latour & Woolgar, 1986; Lynch, 1991; Lynch, 1988; Tibbets, 1990).

Most studies on scientific imaging are medium and science specific, grounded in the particularity of visualization unique to each field – in relation both to its practices and to the nature of its subject matter. These reveal what Latour and Woolgar identify as the “heterogeneity of representational order” (*ibid:* 100) in the hard science. Investigations into visualization and representational practices in astronomy are characterized more by forays than any coherent systematic theoretical engagement; resulting in a surprisingly thin literature on what is arguably the most image-obsessed and visual of the sciences.

Schaffer(1998)’s study of 19th century astronomical drawing reveals the embeddedness of visual culture by locating the observatory as a meeting point between the development of picturing techniques and wider socio-political shifts regarding the role of progress, civilization and debates around the evolution paradigm. Other historical based studies draw upon insights into the relation between objectivity and judgement and various visual techniques outlined above (Daston & Galison, 1992) to illuminate photo-engraving techniques in astronomy (Pang, 1998). Such pointed historical incursions contrast with and are completed by Elizabeth Kessler(2007)’s study which, instead of concentrating on one imaging technique, looks at one particular image – or rather the imaging of the same astronomical object, the M51 Nebula – from the 18th century to current Hubble observations. This method demonstrates the shifts and especially the striking continuities of depiction which span four centuries and radically different imaging technologies. This work, along with Elkins’ approach of juxtaposing astronomy with other artistic and scientific fields of visualization engaging with the “end of representation” (2008: xv) echoes Kemp’s previously outlined emphasis on the continuities and patterns of visualisation across history and techniques.

The sparse research on contemporary visual practices in astronomy can be characterized by a shared concern with aesthetics. This conceptual emphasis becomes the meeting point of art historical (Kessler, 2006, 2007) and sociology of science (Lynch & Edgerton, 1988, 1996) approaches. This aesthetic lens is in line with the 'art/science' dialogue mentioned above, and it holds all the more sway here given the 'beauty' of many astronomical images. These works are commendable in their exploration of the influence of what are traditionally considered 'non-scientific' practices within the sciences.

1.3 Towards An Anthropology of Light (see Bille and Sorensen, 2007)

At this point of the analysis, the reader has hopefully noticed the conspicuous absence of one of the image's incarnations, its primary incarnation or 'pre-incarnation': the referent. The "represented object" (Tibbets, 1990:69) is doubly present within its sign-image, in its content (whether through a relationship of iconicity, indexicality or other) and in its form – or what Belting calls "the what of an image" and its "how" (2005:304). The two of course overlap, due to their origin in and connection to a common source. The image is an image of something, and that something directly determines its formation, its manifestation in form. The image's 'how' or form is in turn a reflection of the nature of the sign, photos being indexes (and often icons), and paintings icons. The content/form distinction can be reconceptualised as that between the image and its medium: "a medium *is* form, or it transmits the very form in which we perceive images" (*ibid*). The medium/form, which transmits the image by permitting its visibility, is born out of a set of techniques of visualization. These techniques are organized around and adapted to the object to be represented (the referent to be).

The pre-incarnations or referents of astronomical images include stars*, planets, black holes*, nebulae*, galaxies*, galaxy clusters* and the universe at large. These are often located between hundreds and billions of light-years* away, making astronomy an [observational] science at a distance, both spatially and temporally. Things are however not quite as straightforward, as astronomy does involve the manipulation of matter, that of light. The large 'black hole' so to speak, between referent and sign, star and image, is shown on closer inspection to be filled with photons*. It is this level of ‘in-betweenness’ that interests me – how light photons, strung across wavelengths, connect (or crucially, are made to connect) matter and form, referent and sign to crystallize into astronomical images.

As Latour argues, one cannot jump directly from the world to words, referent to sign, but “always through a risky intermediary pathway” (1999:40). The end product of reference, where the “circulating reference” is stabilised in the image’s form, cannot be separated from its formation - its technical coming into being - via techniques that trans*form* matter into form, stars into images. I chose to prioritize the trope of visualization over that of the image, in order to transcend the ‘fixity’ of images and emphasize how these are results of processes. The many tiny translations, delegations, displacements and transubstantiations that intervene between the referent and its sign (Latour, 1999) - that slowly translate the light of a star into its image - can be studied as techniques of visualization which are also techniques of reference.

In mobilising the concept of technique, I am not being merely metaphorical. Both reference and techniques involve a balancing act between transformation and stabilisation, the former defined as a “way of keeping something *constant* through a series of transformations” (Latour, 1999:58) whilst the latter are “a series of operations involved in any transformation of matter (including our own body) by human-beings” (Lemonnier, 1992:26). Interestingly, light falls under both energy and matter, two of Lemonnier’s five elements combined within the technical process. The ‘something’ kept constant in scientific techniques of visual reference is the “immutable mobile” (Latour, 1990) which it is my task to identify.

Images have a partial and peculiar self-reflexivity: they reveal (and indeed re-present) their referent but not their process of reference. This is rooted in the inherent invisibility of techniques: it is because they are processes than we cannot *see* techniques (Sigaut, 1994). This is the paradox of the visual: images here make astronomical bodies visible whilst simultaneously masking their own production, as all artefacts do. It is thus only by making techniques of visualization visible that I can peer into the process of astronomical imaging and unravel the spectrum of visibility via “networks” of light (Latour, 1993). What follows is the work of a migrant worker (Mitchell, 2002) bringing together the fields of visual anthropology and the anthropology of techniques, as well as insights from Science and Technology Studies on visual representations - in order to re-embody, re-materialize and *illuminate* the astronomical image.

2. *Methodology*

2.1 Symmetrical Anthropology

The presence of photons and black-holes may seem out of place in a classic (read asymmetrical) anthropological analysis, though I contend that these are no stranger topics of research than the immune system (Martin, 1990) menstruation practices (Stewart, 1997) or reindeer spirits (Willerslev, 2007). This investigation into astronomical visualization is a direct response to Bruno Latour's call for a "symmetrical anthropology", which "brings together not only human and non-human in the ordering of social life, but also insights from both modern and pre-modern societies" (Strathern, 1996: 522) – by bridging the Internal Great Divide erected between Nature and Society in order to bridge the External Great Divide between 'Us' and 'Them' (Latour, 1993a). Anthropology can only be truly comparative if it no longer "rules out studying objects of nature" (Latour, 1993:91) and engages with nature as it does so with culture in order to recognize that we are in fact dealing with networks and collectives of "natures-cultures" (*ibid*:96). Latour thus urges the anthropologist to "come home from the tropics" (*ibid*:100) in order to study the [non]modern world in the same way she does other cultures. Too often, anthropology at home relegates itself to studying the margins and crumbs of western culture, in direct opposition to its goal of inspecting the centres and totalities of culture abroad. Latour calls upon the anthropologist to be as bold at home as she is abroad, and explicitly emphasizes the need to study the hard sciences in particular – to analyse science and society, knowledge and beliefs, black holes and flying saucers in the same manner (*ibid*:92-3).

This is why I chose to study light; that most 'natural' of things, as my starting point. Moreover, as photon and wave, energy and matter, light is a quintessential hybrid, and the study of this "quasi-object" (*ibid*: 96) will enable me to "occupy a central place from which the symmetry of nature and culture is made visible, to position myself "at the median point where [I] can follow the attribution of both nonhuman and human properties" (*ibid*:96) within astronomical imaging. Following this, I will use the idea of the 'network' to structure both the form and content of the following analysis, following the network of light to navigate between the referent and the sign. As will be discussed in more detail, I also use the operational sequence (Lemonnier, 1992) as a rough sketch to guide both my research and analysis. Through its sequential emphasis, the operational sequence method is useful in both drawing out the processual nature of techniques, as well as providing a narrative template for their analysis.

2.2 Photo-eliciting the Expert

I began this project somewhat naively and romantically envisaging undertaking my research in an observatory but I soon found out this was an almost outdated view of astronomy. Most established observatories (such as Greenwich) are now too small, old, obsolete and misplaced to serve as anything more than bases for teaching or public-outreach programmes. The real science, so to speak, happens on and is extracted through satellite based space telescopes (such as the Hubble Space Telescope and the Chandra X-ray Observatory), temporary balloon satellites and a number of ground based observatories located at high altitudes.

The bulk of work done on and through images happens within research centres, many based within universities, including at the University College of London. I approached this department but ended up doing most of my research within Imperial College's Physics Department, with members of the Astrophysics Group who generously gave me desk space along with "Visiting Researcher" status and an Imperial card to facilitate my access within the building and for administrative purposes. The images presented in the following paper, and on which my analysis is based, derive from my research and interviews conducted with Imperial astronomers. I supplement these with further desk-based research drawing from the rich and publically accessible online data provided by various astronomical research centres and universities.

I realised almost too late that Latour's *We Have Never Been Modern* should be a compulsory ethnographic guidebook given to all those about to embark on any form of participant observation with non-humans. It offered me a sense of boldness and legitimacy to counter-act both the alienation I often felt as a trained *social* anthropologist entering such *non-human* "image-worlds" (Benjamin, 2005:512) – as well as the underlying sense of inadequacy, apprehension and illegitimacy I experienced through my encounter with 'the expert'. Experts are born out of the alignment of power and knowledge which coalesces into academic disciplines, within which 'truth-tellers' (Foucault, 2001; 2002) compete for what Bourdieu calls 'scientific capital' (1975). Academic disciplines produce and discipline such experts, as well as what counts as appropriate and legitimate knowledge (Foucault, 2002). Having been thoroughly schooled in the science versus humanities debate at the heart of anthropology, I entered the department of astronomy with my discipline's epistemological insecurities as baggage, acutely aware as I crossed the "threshold of positivity" (*ibid:* 106), that my knowledge was no longer as legitimate in this alien academic territory. This is perhaps one reason why my repeated approaches to the UCL Astronomy Department fell on deaf ears.

The anthropologist traditionally holds the status of the expert when conducting ethnography, though here the roles were reversed (or at least spread out) to the extent that I often felt like a school-child in a science class, echoing the nature of fieldwork as a process of child-like socialization. The astronomers I spoke with are also of course academics who were no doubt mixing their teaching and public-outreach roles when interacting with me. Our 'tutorial-interviews' were also however forms of collaboration, as our mutual embeddedness within the space of the university provided a relationship of familiarity and contextualization. Both my informants and I were conducting research (my research was researching theirs), a fact they often brought up in moments of recognition which probably rendered my presence there, if mildly bewildering and curious, at least intelligible.

More than anything else, our common interest in the visual (for very different reasons) opened up a space for dialogue between my informants and I, quite literally. The interviews I conducted were anchored in a quest for visualization for reasons which go beyond the topic of this analysis, as I was often subjected to incredibly abstract astronomical ideas and processes which I realised I could only grasp by *seeing* what they were talking about. My confusion alone could have fuelled the conversations and it made me experience first-hand how intertwined knowledge and visualization really are.

These informal interviews were conducted with individual astronomers between July and August 2011 and structured around "photo-elicitation" (Pink, 2001; Banks, 2001), a method "based on the simple idea of inserting a photograph into a research interview" (Pink, 2001:240). Collier's idea that it is only through interviews that a photo's information can be accessed by the researcher (Collier 1967 – in Pink, 2001) was especially true in my case – where the scientific content was otherwise inaccessible to me. I started interviews by asking the astronomer to introduce and explain their research interests and show me examples of images they had produced. Crucially, the photo-elicitation was done via computers. After my first informant spontaneously proposed to being her laptop to the interview, it was the screen and not fixed, isolated paper pictures that became the “neutral third party” (Banks, 2001:88) of all the encounters - although in light of recent scholarship on the agency of things, the idea of a neutral, passive machine is problematic (see for example Latour, 1993a; Gell, 2006)). The computer became a third and crucial partner in the interviews, acting as a go-between and interface between me and the human-interviewee who became almost an astronomer-computer, much like Bruno Latour’s ‘man-with-a-gun’ (1999). The digital medium opened up a space for interactivity, with my interviewees drawing from the internet, moving images and ‘non-visual’ data files and demonstrating for me with the use of software the transformation and manipulation of images which changed before my eyes (see Banks, 2001:95). Through the interviews, the astronomers were provoked into what Mitchell calls “showing seeing”, as their “visual culture [was] made to seem strange, exotic, and in need of explanation” (2002: 176) by the presence of a non-astronomer anthropologist.

2.3 Writing Inconceivable Worlds

The epistemological and methodological issues pertaining to anthropological writing have been well documented and debated (Marcus & Clifford, 1986) and have more recently been explored within material and visual anthropology in relation to the particularity of its subject matter (Taussig, 2009; Olsen, 2006). Those within this field face the tricky paradox of how to write about *things* given that “material culture *is* in the world in a fundamentally different constitutive way from texts and language” (Olsen, 2006:97).

Elkins adds a new twist by broaching the problems inherent in writing - this time about science and its images from a social science and humanities point of view – bringing us back to the tricky topic of inter-disciplinarity. Elkins castigates the “failure of metaphor” (2008:12) which so often plagues the work of anyone “who sets out to interpret another discipline”, particularly a hard science, because social scientists simply cannot escape from their own discipline’s “programme of interpretation” which loses touch with its subject: the actual science that is going on. Elkins includes Latour and Hacking as scholars who instead engage in flights of metaphor through which scientific “disciplines are being explained – or *explained away* – by someone who does not really understand them” (*ibid*: 18, emphasis added).

At this point I have to make a disclaimer: I am not an astronomer and my scientific knowledge goes little beyond school level. My research process has however included attempts to familiarize myself with astronomical theory, and I can only hope the following analysis does justice to, and does not misinterpret, the work of my informants, in the same way as anthropologists more generally have to face the consequences when their subjects of study become readers – and sometimes critics - of their work.

Chapter 3: The Operational Sequence of Light: From Photons to Data

Technical processes are exactly that: *processes*. It is from this that the question of (in)tangibility derives its ambiguity; it is due to their processual nature that techniques exceed materiality and are not straightforwardly tangible. To borrow from Latour, technical processes are a *verb* and not a noun, as they spill over tools, bodies and artefacts, into "processes of making and ways of doing" (Coupaye, 2009:451), through a "complex series of actions, intentions and transformations" (*ibid*: 438). It is because they are processes than we cannot *see* techniques (Sigaut, 1994), but "only people doing things" (Coupaye, 2009:438), on things, through actions, movements and materialities. We could thus perhaps argue that technical processes are an expression of the "union of the visible and invisible in human experience" (Tilley, 2008:25). The tricky quality of invisibility could be said to index and manifest the intangibility of technical processes and raises the methodological issue of how to fully visualize, in order to analyse, them.

Coupaye points out that "processes can only be made visible when transcribed in a medium" (2009:438). This transcription can be understood as a move of 'translation' "of human and non-human competence" (Latour, 1993b:389), 'delegating' the process of visualization to material (written, filmic, photographic) forms. The operational sequence is used by 'technographers' (Sigaut, 1994) as a methodological tool for observing, describing and recording the trajectories of techniques and the coming into being of artefacts.

I propose to use the chaine operatoire as a guide to follow networks of light as they are transformed through techniques of visualization, in order to understand the series of elements and components which are brought together in the production of astronomical images. Although techniques are never isolated (Coupaye, 2009) and potentially endless, containing and contained by smaller and larger technical processes in an almost fractal-like fashion (Lemonner 1992), technographers are free to choose their scale of observation and zoom in and out of technical systems according to their research needs. Here, I chose light and images as my beginning and end points - whilst acknowledging that I am using them as artificial boundaries to 'cut' the network (Strathern, 1996) which would otherwise continue into, amongst other things, funding considerations, experimental work and theoretical conclusions (see Lenoir, 1997 for the relationship between the latter two and scientific inscriptions) – in order to record the "series of operations which brings a raw material" (light) "from a natural state to a manufactured state" (the image) (Cresswell, 1976:6).

In this paper I will attempt to side-step the dualist research programme identified by Latour, according to which we would "*star[t] from* a list of factors taken from nature, matter, ecology and society" before "weigh[ing] the relative influence of these factors in shaping artefacts" or technical processes for that matter (1993: 376, original emphasis). In other words, we cannot assume as our starting point the pure category of the 'visual' but can only potentially end there, by investigating how it is achieved from "the distribution and allocation of categories, labels and entities in a specific setting" (*ibid*). In line with this distributed monism, I am taking seriously the indigenous categories (Latour, 1993b) used be astronomers – namely that of light, as well as its particular materiality which crucially gives me the opportunity to "take the artefact itself as the empirical point of entry" (Coupaye, 2009:437). Light is here placed alongside other nature-culture hybrids studied within Material and Visual Culture Studies such as yams (Coupaye, 2009) and pebbles (Tilley, 2011), and the chaine operatoire provides a way to chart the life-cycle or 'biography' (Kopytoff, 1988) of light as it is mobilised into technical imaging processes and simultaneously to chart its trajectories in space and time.

Lemonnier identifies five basic components of technical systems: matter, energy, objects, actions and knowledge which "interact together to form a technology" (1992: 5-6, 8). Although they offer clarity for methodological and comparative purposes, these components should not be taken for granted and unproblematically imposed on indigenous categories, such as the *Jewaai*, a part matter, part substance, part tool carried within humans and actively participating in the Abelam yam cultivation process (Coupaye, 2009:446-7). In this case, my informants made my task easier as they tended to spontaneously describe their work in terms of these five elements. The *objects* or tools used by astronomers include primarily the instrument of observation (ground based or satellite telescopes which are comprised of networks of cameras, detectors and other instruments – or other forms of detectors like atmospheric balloon) and the computer which one of my informants characterized as '*a tool to analyse the data*', a tool where hardware and software, materiality and knowledge (the fifth component) intersect:

'*so for some specific experiments, lots of people will write some software... In a sense, the instrument is like hardware, it will take the raw data, the information, the data coming* *directly from the observations, and this raw data we need to make scientific images with that, and for the process we use some software'*.

As my informants explained, software programmes can come pre-packaged, developed within the astronomical community for specific instruments and observational experiments, before being circulated and *learnt* by other astronomers conducting research on those observations. Individual astronomers, including some of my informants, can also directly write and develop their own codes and software specific to their research, embodying their knowledge and know-how within these digital tools. The *knowledge* required by astronomers includes the ability to compute and programme, an understanding of physics, instrumentation and electronics.

The *matter* which is transformed is raw data, itself a transformation of another *matter*: light, which is understood in modern physics and astronomy as at once *energy* and *matter*, (and a property of things which is emitted by them) and is mobile, travelling at the speed of light. What is traditionally understood by non-scientists as light is merely the visible tip of the iceberg, that amenable to human visual/optical perception; our common-sense category of light results from our bodily experience and perception of it. Within physics however, visible light is part of a much wider spectrum of electromagnetic radiation, which is classified into gamma rays, X-rays, ultraviolet, optical/visible, infrared and radio waves according to the frequency, wavelength and photon energy of the radiation (Henbest & Martin, 1996; Montwill & Breslin. 2008). The photon is the smallest unit of the electromagnetic spectrum and, according to the wave-particle duality in quantum physics, light can either act as an electromagnetic wave or behave like a particle according to the circumstances (Montwill & Breslin, 2008:578) (see *Figure 2*). The different types of radiation are all "basically similar in nature, 'waves' consisting of rippling electric and magnetic fields spreading out from a source – be it star, pulsar or quasar", with the point of difference coming "in the *wavelength* of the undulation, the distance from 'crest' to 'crest' of the electric wave, visualised very like the succession of waves at sea" (Henbest & Marten, 1996:7).

The gradual discovery of non-optical forms of radiation has revolutionised astronomy as well as our concept of the Universe over the 20th century. With their discovery have come new technological barriers and advancements, with "new instruments of visualisation" developed to "enhance the image" and "conspire with the visual characteristic of things" (Latour, 1990:39-40).

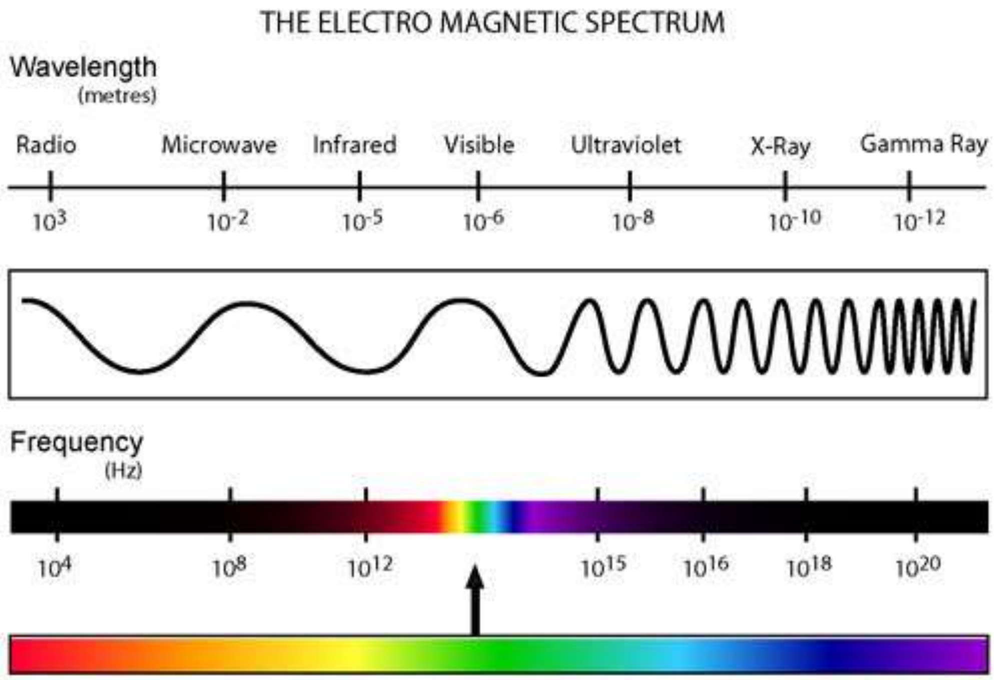

Figure 2: *The electromagnetic spectrum* (Noelombrog Blog, n.d.)

My astronomer-informants were each specialised in particular astronomical subfields, their research structured around specific astronomical sources (black holes*, quasars*, dark matter*, the Cosmic Microwave Background*) or processes (star or galactic formation) and therefore worked within different slices of the electromagnetic spectrum with different kinds of light, accordingly using various types of instrumentation (in terms of the observing instruments and image processing techniques). Whilst my research is based on all the work of the astronomers I interviewed, as well as on astronomical practices writ-large, my analysis is particularly anchored in the following studies.

1) The X-ray Astronomer

Elise Laird is an astronomer specialising in X-ray astronomy and in particular in Active Galactic Nuclei* (AGN), a type of supermassive black hole at the centre of galaxies, observed principally through the Chandra X-ray satellite observatory. X-ray photons are focused by mirrors onto two detectors, the High Resolution Camera (HRC) and Advanced CCD Imaging Spectrometer (ACIS), which record their number, position, energy and time of arrival and work with other scientific instruments on board to "record and analyze X-ray images of celestial objects" (Chandra, 2011a). The information gathered is transmitted back to Earth and accessed by Laird and others who process the data into three different types of images: x-y spatial images (see for example *Figure 3*), spectra and light curves*.

The Operational Sequence of Chandra X-Ray Visualization and the trajectory of X-Ray Light is as follows:

(1) Light is emitted from AGN
(2) (2.1) light travels millions of light-years
(2) (2.2)astronomers submit proposals for observation
(3) The science instruments are controlled by commands transmitted from the Operations Control Center in Cambridge, Massachusetts which sends observation commands to the telescope for execution
(4) photons enter the Chandra telescope and are funnelled towards its detectors and instruments (*see fig. 8*)
(5) photon-event
(6) photons are converted into electric signals
(7) this X-ray data is stored on the Chandra telescope for 8 hours
(8) and transmitted to Earth via the Deep space network
(9) the astronomer downloads the data as a file from the internet
(10) digital image processing
(11) images are created
(12) the image refers back to the AGN referent

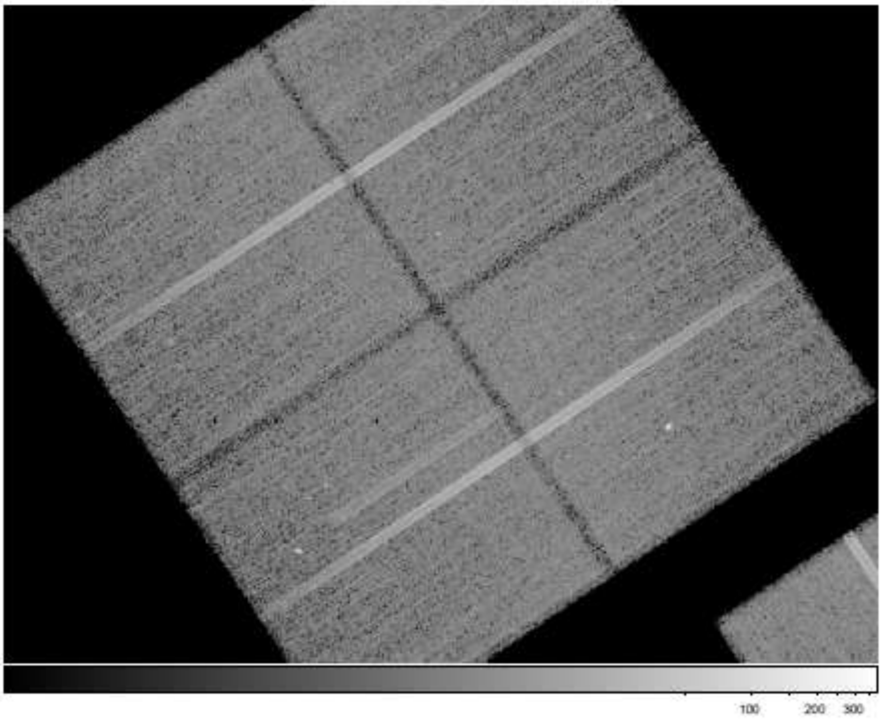

Figure 3a: *Chandra X-Ray image of AGN, raw data* (supplied by astronomer, courtesy E. Laird)

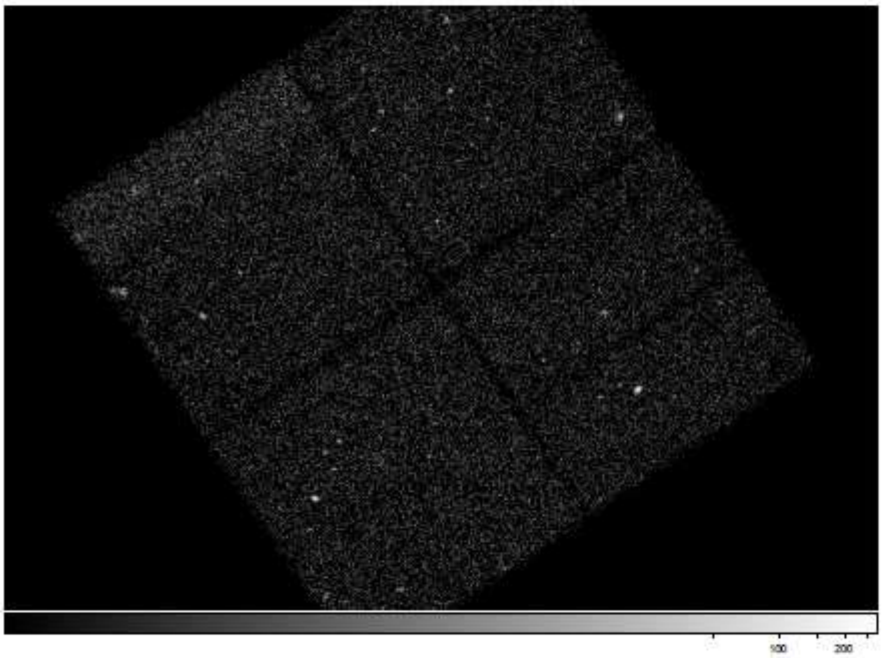

Figure 3b: *Chandra X-Ray image of AGN, cleaned version of Figure 3.a* (supplied by astronomer, courtesy E. Laird)

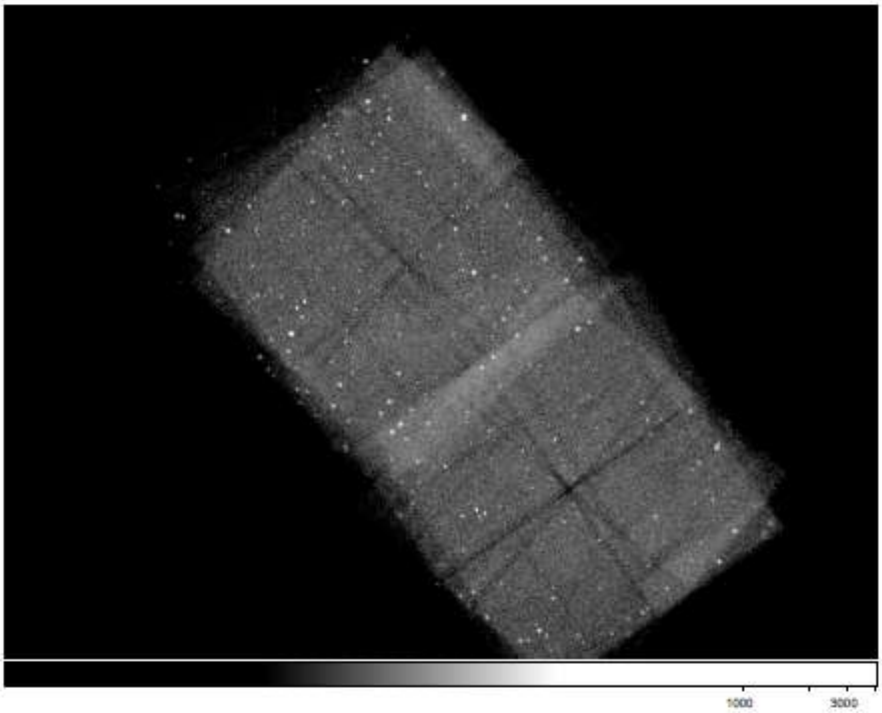

Figure 3c: *Chandra X-Ray Image, Stacked* (supplied by astronomer, courtesy E. Laird): combining several cleaned images of the same area of sky giving a longer, deeper total exposure time

2) The Quasar Astronomer

Daniel Mortlock (2011) and his team recently discovered the most-distant quasar* ever found, the ULAS J112010641 *(Figures 4, 5, 6*).

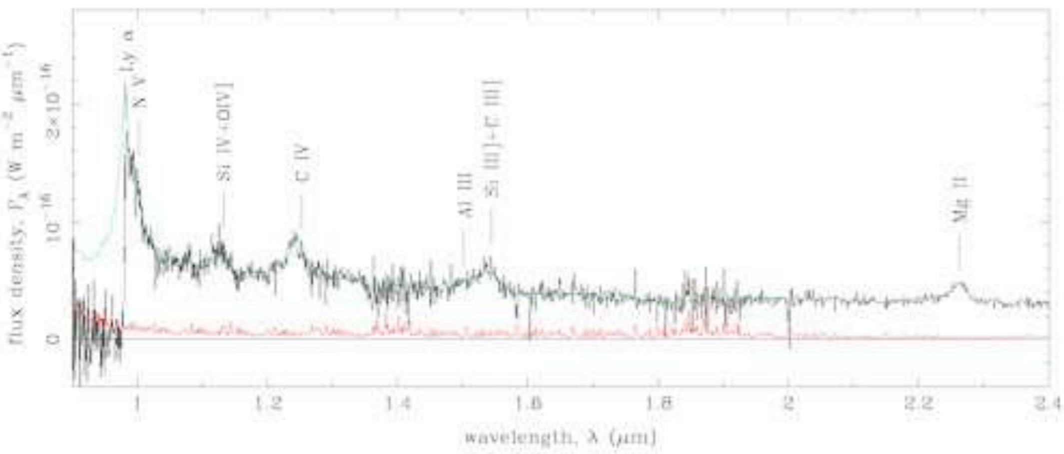

Figure 4: *A spectrum of the quasar ULAS J112010641* (supplied by astronomer, courtesy D. Mortlock)

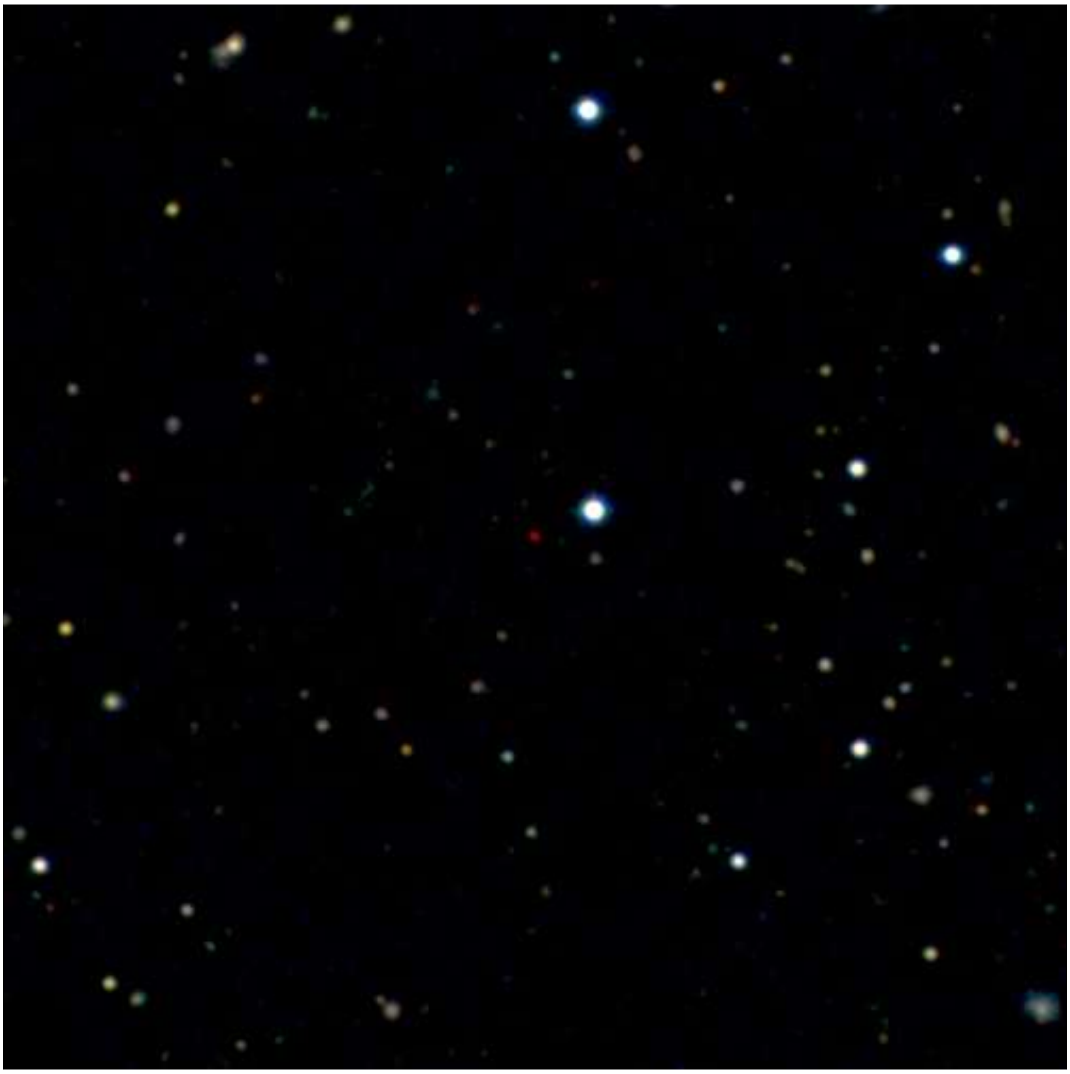

Figure 5: *An Infrared Image of the quasar ULAS J112010641* (the red dot in the middle). This is the most detailed image possible (supplied by astronomer, courtesy D. Mortlock).

The moment of contact, where/when matter is transformed, when the wave interacts with the telescope's observation instruments (with the HRC and ACIS in the case of X-ray photons and Chandra) is termed a '*photon-event*' according to my informant. The technical process however begins long before. Just as yam cultivation starts long before seed plantation (Coupaye, 2009), the photon-event is itself the culmination of a pre-history, being the meeting point of the construction and launch of the telescope-satellite, the requests made by astronomers for observing particular sources and regions of sky, and the space-time trajectory of light.

Figure 6a: *Inspection images of potential quasars from the SDSS image server:* located at http://cas.sdss.org/astro/en/tools/chart/list.asp (supplied by astronomer, courtesy D. Mortlock)

Figure 6b: *Inspection images of potential quasars from the SDSS image server* with background inverted (supplied by astronomer, courtesy D. Mortlock)

The time taken by light to reach us and our instruments is a crucial ‘technical’ element, as it informs astronomers of the distance and age of its source-object, and influences both the properties of this light and the ability of astronomic instruments to detect this light (Henbest & Martin, 1996). To generalise, the further an object, the further the “look-back time”: “the time in the past at which the light we now receive from a distant object was emitted” (Chandra, 2011b) - and the fainter its light. Here as elsewhere, temporality dictates materiality/matter. Astronomical techniques of visualisation are thus structured around a “temporal unfolding” (Shlanger, 2005:25) common and specific to all technical processes. It is the processual nature of techniques which hints at their inherent temporality, inscribed as they are in varying time-scales whilst being composed of a “sequence of events each one with a specific duration” (Coupaye, 2009:439).

The concept of ‘photon-*event’* is prescient in light of Edward Casey (1996)’s idea that events are the meeting and gathering point of space and time. Although astronomical theory has its own versions of this phenomenological concept of the chronotope (Bakhtin, 1981), most obviously in the category of light-year*, what concerns me here is the interesting enmeshing of “temporal, spatial and material elements that intervene” (Coupaye, 2009:439) in technical processes in general and particularly within those through which astronomical phenomena are visualized.

The photon’s eventmental character is emphasised and activated through its contact with the telescope’s CCD-like detector which acts as a ‘place’ whose “very power of emplacement...bring[s] space and time together in the event” (Casey, 1996*:*38). It does so by literally “gathering” (*ibid*) (as all places do) photons by reflecting them at a grazing angle as they enter the funnel shaped telescope to be focused on an electronic detector (Chandra, 2011a). The detector simultaneously gathers the photon’s spaciotemporal coordinates by recording both its time of contact, and place of contact on the detector, which refers back to its spatial origin/position in a region of ‘Space’. The photon’s space-time coordinates are then positioned and visualised in the image as will be discussed below.

More generally, the spatial and temporal elements determine observational and visualisation techniques through the allocation of a specific quantity of observation *time* to astronomers in order to observe a particular region of *space* – with the nature of the observed object (and the *materiality* of its light) determining the time needed. Observing time is highly sought and expensive (Kessler, 2007), and can range between seconds and hundreds of hours - as with the Hubble Deep Field (*Figure 26*) (see Elkins, 2008) - depending on the distance of the object, the brightness of the light it emits and therefore the exposure time needed. The chosen exposure time can lead to over or under-saturation – the ‘shutter’ is kept open longer to detect fainter objects, or for greater resolution, resulting in the brighter objects becoming saturated (Kessler 2007:487).

The sequential nature of visualisation techniques is most apparent in the repetition of observations/exposures: the restricted view of telescope cameras requires multiple pointings to capture the totality of a region/object, often resulting in the “mosaicking [of] different exposures together” (Kessler, 2007:488) (*see Figure 7)* . Other observations require a scanning of the sky, leaving a pattern of ‘strips’ on the resulting image, a visual trace of the temporality and movement of both the technical process and the data gathering (collected over a stretch of space and time), resulting in what one of my interviewees calls a ‘*time train of data*’. The management of time structuring such techniques also has to take into account the weather and movement of the sky relative to the earth in relation to ground-based observatories – where ‘Space’ moves with time so to speak. The temporality of techniques is intangible, and is instead indirectly present and indexed in the movement and transformation of bodies (both human and non-human bodies such as satellites) and matter (light) which is then partly seen in the image – because frozen. Indeed, we cannot properly see fluxes (of time and motion) unless they are cut (Strathern, 1996)– hence the need to literally interrupt light’s movement in time, simultaneously cutting its ‘life’ short, in order to visualise it.

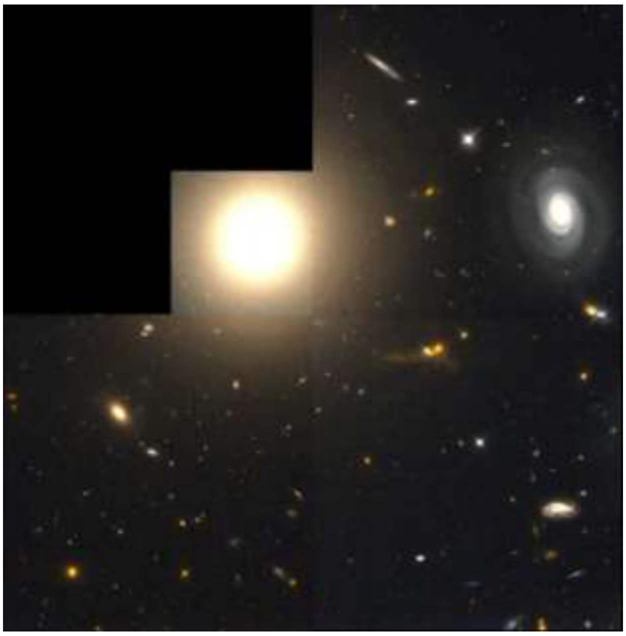

Figure 7: *Elliptical Galaxy NGC 4881* taken by the Hubble Space Telescope. It is “a mosaic of images recorded with three Wide Field cameras and one higher resolution camera in the upper left”. (NASA and STScI, 1995)

The order of a technical process' events is thus determined by non-humans and humans, who order it according to material as well as social appropriateness, the former relating to inherent properties and compatibilities of different kinds of matter (here, of light) (Lemonnier, 1993). Law explains that this capacity of "ordering through time" is one of relational durability: "some materials are more durable than others and so maintain their relational patterns for longer" (2003:6). This tension between transformation and durability of matter, which is played out through the temporalising effects of techniques, can be understood as a property of 'translation' (Latour, 1990, 1999), which implies at once "transformation and the possibility of equivalence, the possibility that one thing (for example an actor) may stand for another (for instance a network)" (Law, 2003:5-6). Translation is thus a movement of reference, via techniques, and it is this crucial second partner which enables us to ground this Latourian concept which is too often used as a postmodern flight of metaphor.

Light, as a durable and mobile matter is the perfect form of translation, where "durability is about ordering through time", and "mobility about ordering through space" (*ibid*:6), both actions being manifest in the category of 'light year'. These translation properties, through which light 'stands for' its source-object, are coupled with an impressive capacity for mediality/mediation. Light, according to Friedrich Kittler, is the ultimate medium, "one of those things by which something occurs" (Peters, 2010:16), and which holds a carrying and transmission capacity: carrying and transmitting information from astral bodies.

Light's translation and medial capacities have to be mobilised and extracted by technical processes and indeed *translated* into a form of durability and mobility amenable to human and scientific intervention (in images) – light needs to encounter humans in order to form a human-non-human network. This *happens* during the 'photon-*event*' – when one more non-human (light) is mobilised into a pre-existing and already heterogeneous network of humans and non-humans constituted by the techniques, practices and tools of astronomical visualisation. These pre-existing networks of satellites, telescopes, computers, cameras, balloons, astronomers, funding bodies, equations, spectrographs, electrons "are set up behind the phenomena" (photons), "*before* the phenomena manifest themselves, *in order* for them to be manifester" (Latour, 1999:49, original emphasis). The network of light, its trajectory, is cut (Strathern, 1996) by the telescope and tied into another network. The 'photon-event' is the first "moment of substitution, the very instant when the future sign is abstracted from" light (Latour, 1999:49), it is a move of translation when the photon is re-ordered spatially and temporally by being embodied in a more durable, more mobile and more manipulable form, in electronic signals. It is by being “embodied in and performed by a range of durable materials” (Law, 2003:6) that networks are stabilised, and indeed the faint, fleeting light - ancient light from dead stars and other ‘things’ - is here rendered stable and durable, preserved in a digital-electronic amber.

These detectors bear a striking resemblance to the ‘pedocomparator’ studied by Latour (1999) and used by his scientist-informants for their analysis of the soil at the forest-savannah frontier in Boa Vista (*see Fig. 8*). This square drawer is divided into rows and columns of cardboard cubes numbered and “coded in x and y coordinates” when clumps of extracted soil are deposited there (*ibid*: 47-50). The pedocomparator is a strange hybrid, belonging simultaneously to ‘things’ (through its three-dimensionality and physicality of wood, cardboard, frame) and to ‘signs’ via the “regularity of its cubes, their disposition in columns and rows, their discrete character and the possibility of freely substituting one column for another” which all transform earth into Cartesian coordinates (*ibid*:48). The same power of translation, reference and transubstantiation characterizes the astronomical detector. The Chandra Telescope’s ASIS for example, like most astronomical detectors, is constituted by a set of ten charged coupled devices (CCD's), a more sophisticated version of the one found in digital cameras, each of which is structured as a grid of pixels (*see Fig. 9*). Like the pedocomparator’s cubes, these pixels form “a Cartesian grid of cells” (Mitchell, 1994:5), effectively making the detector a hybrid sign-thing. Like the pedocomparator, these instruments are one more empty form “set up *behind* the phenomena, *before* the phenomena manifest themselves, *in order* for them to be manifested” (Latour, 1999:49) when, in this case, light falls on a pixel and loses its materiality to become a sign (literally, an electric signal). These ‘empty forms’ thus facilitate the first of many jumps from matter to form, through which a “field of light emission” becomes a (spatial) “field of reference” (Frizot, 2007:278).

Figure 8: *The pedocomparator* (Latour, 1999)

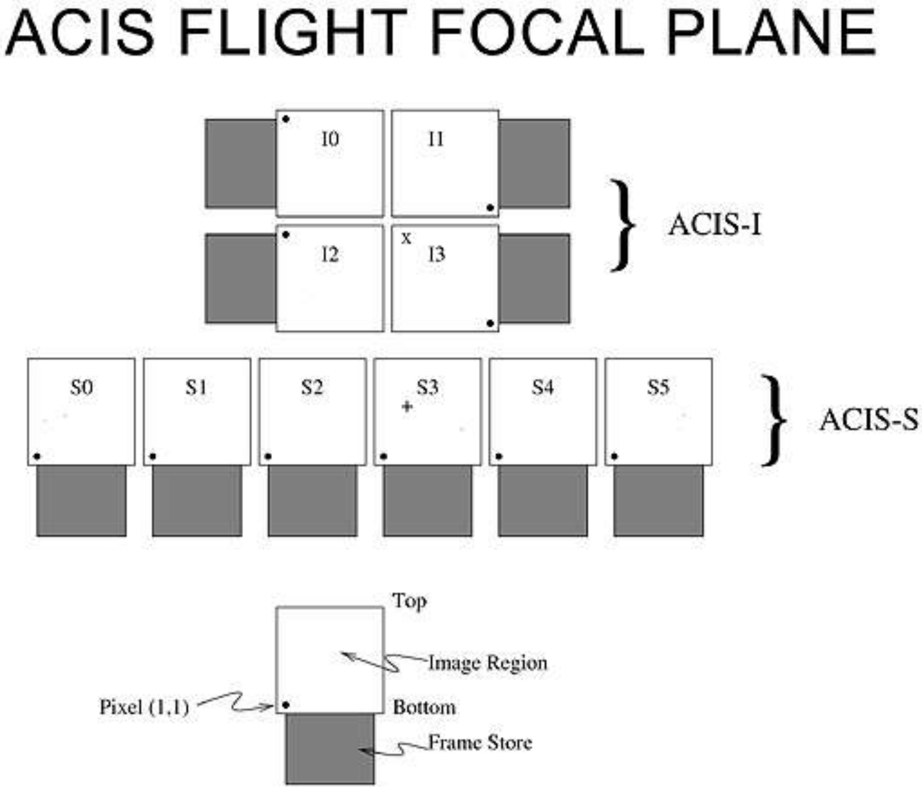

Figure 9: *Chandra X-ray Telescope's Advanced CCD Imaging Spectrometer (ACIS)* (Chandra, 2011c)

As the photon crosses (or disappears within) this tiny innocuous gap from which reference emerges, light is digitized, where one media cannibalizes another. Techniques are a manifestation and means of translation and mediation as they are constituted by the human and non-human "action of mediators": tools and bodies and artefacts which do not merely "'express', 'symbolise', 'reflect', 'reify', 'objectify', 'incarnate'" social-material and indeed visual relations, but "they make them, form them" (Latour, 2000:19).

Law argues that such translations "create the possibility of transmitting...immutable mobiles" (2003:6) – inscriptions ordered by and structuring movements of transformation and equivalence, through their simultaneous durability and mobility. As seen, this transmission is here literal (through electronic-digital signals), but points to a general property of mediality at the core of technology and technical processes which, like media, are not merely a means "but a mode of revealing" (Heidegger 1993: 319, cited in Kittler 2006a:12). Heidegger argues that through technology "the energy concealed in nature is unlocked, what is unlocked is trans-formed, what is transformed is stored up, what is stored up is distributed, and what is distributed is switched about ever anew" (1993: 322). The idea that technology's "unlocking, transforming, storing, distributing, and switching are ways of revealing" (*ibid*) and bringing forth is particularly prescient when considering astronomical techniques of visualisation, where light is literally shown, visualised and *revealed* in images, via techniques.

This act of revealing is one half of a dialectical tension structuring technical processes, which reveal things whilst (and by) simultaneously partly concealing themselves. Due to the invisibility of technical processes and their temporary nature (they have a beginning and an end), and in the cases where an end-object is produced, the resulting artefacts "are often all we have" left (Sigaut, 2002:430). Interestingly, the invisibility of technical processes outlined above is mirrored and reproduced in the object, in so far as the object conceals them. Techniques are generally invisible during their occurrence, and after the fact. This capacity of objects to conceal their own becoming is an intrinsic part of the enchantment of technology, whereby an artefact bewitches us "by its technical means, the manner of its coming into being" (Gell, 2006:167) which escape us. Hence the aesthetic of shock, awe and wonder caused by astronomical images (Kessler, 2007), which to most are opaque in their coming into being. Objects resist our intellectual possession of them, leading to "the difficulty I have in mentally encompassing their coming-into-being as objects in the world accessible to me by a technical process which (...) transcends my understanding" (*ibid:* 169).

How does this concealing work? If we conceive of technical processes as heterogeneous networks constituting (and constituted by) actions, objects and actors, then these networks "come to be deleted, concealed from view" (Law, 2003:5). Through a simplificatory process of punctualisation, and by acting "as a single block" (where the image is an act), networks disappear via the "*appearance* of unity" (*ibid*, emphasis added), to be replaced by single actions, actors or artefacts. And the way these are generated (their coming into being by heterogeneous networks) is rendered invisible and irrelevant, "so it is that something much simpler - a working television, a well-managed bank or a healthy body – comes, for a time, to mask the networks that produce it" (*ibid*). Such 'enchanting' networks of technical processes are re-condensed in the object (Strathern, 1996), made hidden, absented and thus rendered intangible.

This is part of the dynamic of translation which rests on the possibility of transformation and equivalence according to which one thing (an actor or object) can come to stand for another (a network for example) (Law, 2003). This is also a translation from what Heidegger calls 'readiness to hand' to 'presence-at-hand' (1962): we engage with artefacts and tools on a daily basis through a practical knowledge which renders such things implicit, without us having to "understand the 'why' and 'how' of the workings of these technological devices" in order to use them (Willerslev, 2004:402). Such objects are qualified by a "readiness-to-hand" (Heidegger, 1962: 103), they serve their functions in an almost taken for granted, invisible way. By using a tool or object, we experience it as ready-to-hand, and it "withdraws" (1962:99): here the technical process of visualization withdraws behind the astronomical image in the same way that media often withdraw behind their image (Belting, 2005).

All is not 'lost in *translation*' however, as the movement of concealment is joined by an inverse process of revealing. Technical processes can be disclosed through material traces, such as those on flaked axes which hint at and index the movement used to produce them, thus revealing "the secret of their formation" (Shlanger, 2005:26).

Chapter 4: The Imaging of Light: From Data to Images

Technical networks of light continue the task of visualisation as they re-gain Earth. They are mobilized into digital imaging processes through which such networks are punctualised and gathered into the astronomical image, lending it their capacities for mediation. Networks are punctualised or gathered into inscriptions, which are then scattered and transmitted across more networks (via mediation and translation), before being punctualised again. Through these processes of punctualisation which are "never achieved once and for all" (Law, 2003:5), the image is *temporarily* stabilised into the realm of the visible. It is primarily through digital image processing that these astronomical techniques of visualisation and networks of light "come to be deleted, concealed from view" (Law, 2003:5) via punctualisation.

This second half of the networks of light, where raw data is translated into images, is in many ways mobilised to the task of erasing the first half, where light was converted into data. In one stroke, the latter set of visualisation techniques renders the former invisible, whilst enabling the visualisation of images and rendering them amenable to analysis. This is done most notably through the erasure, rejection and concealment of what astronomers call '*noise*' through image processing techniques. This category comprises both non-astrophysical signals such as cosmic rays or background glow and what one of my informants referred to as '*instrumental effects*'.

These are "visual presentations which turn out to be effects of the instrument rather than of the referent thing" (Ihde, 1998:185), like the halos or auras which Galileo perceived through his telescopes, misinterpreting them as physical properties of stars invisible to the human eye and thus as signs that the telescope was a superior optical instrument. Modern astronomical "instrumental artefacts" include thermal or electric effects or an electronic bias which can result in overexposed or burnt out pixels (Lynch & Edgerton, 1988:207), visual traces of the scanning/pointing movement of telescopic observation, or artefacts of the very detector – all of which are distinguished from the sought-after 'astrophysical signal'. These instrumental effects index the networks of light previously outlined, as they are the direct by-product (now classified as unwanted side effects) of technical processes of visualisation and traces of their tools. This can be seen in *Figure 3*, the grid of four small squares organised into a larger square in the X-ray image directly mirror the structure of ACIS I (*Figure 9*, top), the grid where the photons now positioned on an image once fell. Here, a trace of the materiality of the technical process of visualisation persists and visually structures the image it engendered – and interestingly, this structure was preserved during the electric-digital transmission of the data, hinting at the 'constant' and durable element within translation, which gives this X-ray image the status of an "immutable mobile" (Latour, 1990:29) as will be developed below.

An example of these is the diffraction spike, which creates an effect reminiscent of 'twinkling stars' and is created by the optics and other detector imperfections within the telescope (*see Fig. 10*). According to my informant, with diffraction you get '*extra light*' and these instrumental luminous artefacts and other non-astrophysical signals are '*different to other pixels of 'real' light*' – suggesting an interesting emergence of different categories of light apart from the already classified electromagnetic spectrum. What counts as 'real' light is purified and differentiated, both technically/visually and conceptually, from other forms of illegitimate light.

The latter can be understood as an 'intermediary' form of light, interrupting and clouding the trajectory of 'real' light emanating from the observed sources. It is doubly intermediary, resulting from the technical medium and therefore located uneasily between 'nature' and 'culture' as a strange hybrid form of light (Latour, 1993), a 'quasi-light' to be purified or rejected at all costs. It is thus no surprise that this illegitimate intermediary light is thrown out of the category of the visual altogether, to become 'noise', constituting a separate sense-data altogether.

Noise is characterized by a lack of information - to the point that it is interchangeable and often removed to limit the size of the data being processed – and in turn impedes the retrieval of information by obscuring the '*nice points of light*' characterising astronomical sources. As one of my interviewees put it, '*the raw stuff from the telescope is basically a mess. It has stripes all over it. You can barely see sources in it*'. The first images received from telescopes are thus not only images of stars, galaxies and other astronomical phenomena, but simultaneously images *of* the telescopes themselves. What my interviewees called '*fuzz*', '*blur*' and '*background*' is removed through digital image processing, transforming what they classify as 'raw data' into its cleaned version.

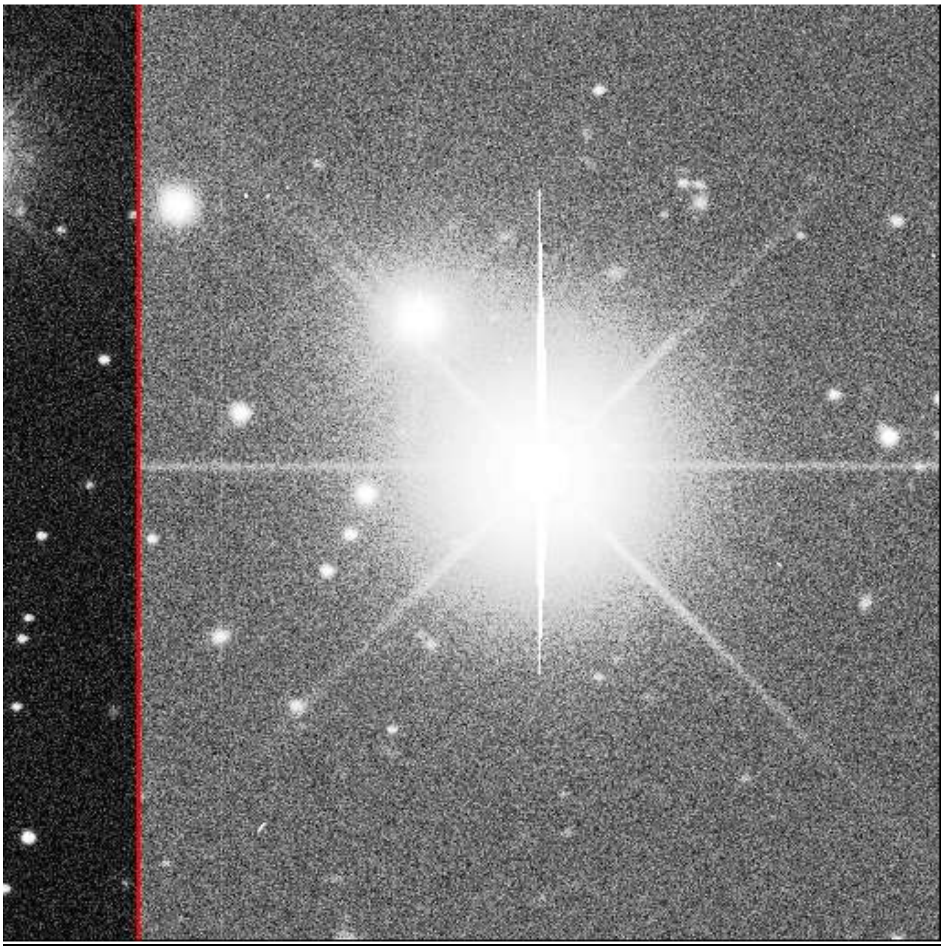

Figure 10: *An example of a diffraction spike in a raw data image* (Princeton, 2011)

This ‘cleaning’ is a move of purification (Latour, 1993a), teasing out one instrument (the telescope) from the “represented object” (Tibbets, 1990:69), by using another instrument (the computer) to conceal the traces of the techniques and tools preceding it – thus punctualising networks of light. The cleaning metaphor-technique purifies the visual from the material, from its materialisation, removing all traces of reference from the referent. This process is done ‘manually’ and visually by astronomers via software (see Lynch & Edgerton, 1988) or digitally via algorithms which mask the cleaning process and visual transformations. Raw data is thus cooked (Levi-Strauss, 1983) and cleaned (Douglas, 1991) in order to create the illusion that “mediators function as so many transparent intermediaries” (Latour, 1998:424) - and through which the network disappears and is punctualised in the image. For an example of raw data see *Figure 3.1*, and its cleaned equivalent in *Figure 3.2*; and *Figure 11* below.

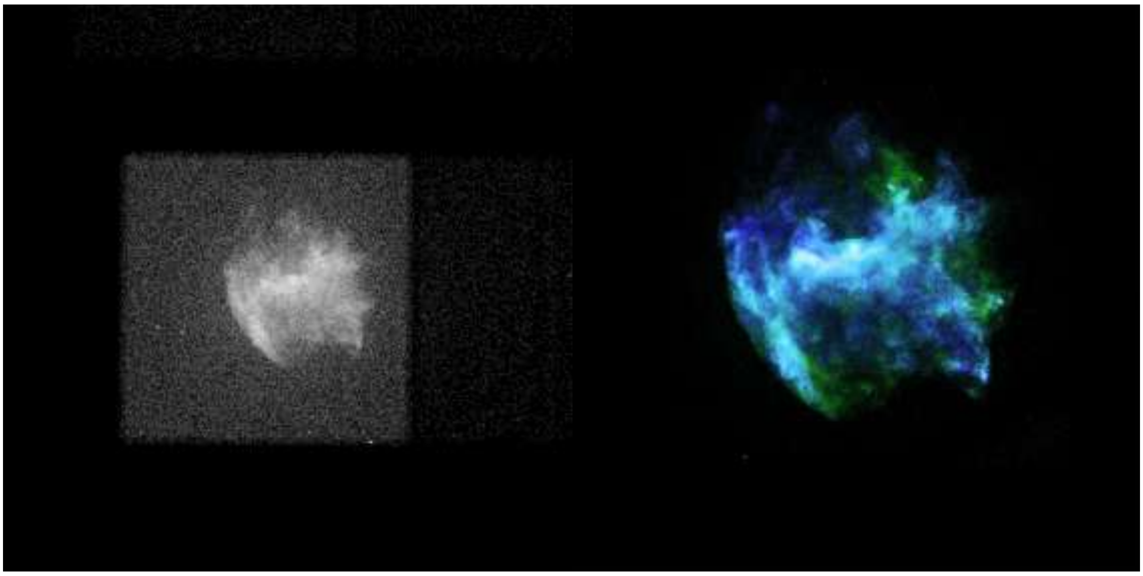

Figure 11: *Raw and cleaned data of the supernova remnant* W49B*

Left: Raw data of W49B (Chandra, 2013a), deriving from a single x-ray observation with the Chandra telescope. As in *Figure 3*, the CCD detectors (see *Fig. 9*), "illuminated by background radiation", are clearly visible (DePasquale, 2013). Right: The final cleaned and colourized version (Chandra, 2013).

The cleaning of noise from images is an explicit form of data reduction and data compression, a term and practice which reoccurred during my interviews. As the data is compressed and reduced, information is gradually extracted. This 'imaging' technique crucially takes place mostly below the radar of the visual/pictoral. This process can be done 'manually' and visually by astronomers using software tools by clicking 'buttons' or typing in specific command-lines (lines of code) in software programmes. At other times, the process is more explicitly 'digital' – or rather the digital masks the visual when ready-made algorithms are used to directly clean images/files/data before the first image is even seen by the astronomer (see Princeton, 2011 for a detailed visual illustration of an automated data cleaning process) . The steps are automated; the cleaning steps and visual transformations are masked to collapse the gap between the raw data and the resulting image. The 'raw'/'clean' data dichotomy can be positioned at the intersection of the raw/cooked (Levi-Strauss, 1983) and dirty/clean binaries (Douglas, 1991) and, of course, nature/culture division. Raw data is thus cooked and cleaned in order to create the illusion that "mediators function as so many transparent intermediaries" (Latour, 1998:424), that images merely express and reflect their referents without creating them. Interestingly, here the 'raw' data is located on the side of culture, having to be re-naturalized by removing the culturally mediated traces of technology, to produce a more natural, unmediated picture of ‘real’ light, striving for the scientific ideal of objectivity (Daston & Galison, 1992).

To play with Walter Benjamin’s concept, this image’s “optical unconscious” (2005:512) – not here the “structure, cellular tissue” [of its referent] that it reveals, but more *its own* structure and cellular tissue - is a world of code, text, numbers and equations fed and organized by ‘command lines’ of letters and numbers typed into a software programme. According to one of my interviewees, these command lines create “*intermediate images that will be transformed again and again*” but not directly visualised, although they remain visualisable at given points if the astronomer choses to see them. This process of image manipulation via data compression is one manifestation of a data-image dialectic and tension which lies at the core of astronomical visualising techniques. Astronomical images are propositional: the images are “extracted from the mass of data” gathered by observational instruments and, in a second move, “data can be extracted from them” as “they contain measurable forms” (Elkins, 2007:36-40), partly encoded in pixels.

The question of which comes, or is *seen* first, the data or the image, turns out to be a ‘chicken and egg’ question. As I found out in my interviews, my repeated attempts to tease out the category of ‘image’ from that of ‘data’ was often misguided; images are visualised or pictorial forms of data, and are of course used as data/evidence. They can perhaps best be understood as a *performance* of data, which is transformed into a picture through what Bakewell calls an “image act” (1998:22). This is an adaptation of Austin’s (1962, as cited in Bakewell, 1998) notion of the speech-act (through which language does not just communicate but instantiates and performs things, in the way that the term ‘I do’ actually *makes* two people married), and is here especially relevant given the fact command-lines (a mute and digital form of *speech*, and a manual *act* via typing) are creating images.

Since the gathered data can “be used to generate all sorts of other images” (Elkins, 2007:36), it can be ‘visually performed’ in a variety of ways, leading to the proliferation of very different images representing the same referent (*Figures 4* and 5 are for example of the same source; as are *Figs. 11, 12* and *31*; *Figs. 26* and *33*; and *Figs. 40a* and *40b* respectively). These different image-incarnations are translated and transformed into each other via ‘data’, engendering a “back and forth between visualizable and statistical analysis”, creating chains of “image to data to image to data to image to theory” (Galison, 2002:316). This relationship between data and image can also be illuminated by and reframed within Lyotard (2002)'s distinction between discourse and figure (Carrol, 1988) according to which discourse belongs to the realm of language and communication, and figure is that of "form, colour, visual figures" (*ibid:* 30). The nature of the scientific image as propositional, and its encoding in data (or the 'language' of code), suggest a collapse of the figure/discourse binary, at the intersection of which one could locate the astronomical picture.

Peter Galison eloquently describes this as a process through which "images scatter into data, data gather into images" (2002:316). We can think of this as the pulsating rhythm of networks as they dis-*appear* through punctualisation into the image, before unravelling and then re-condensing into other images through digitized translation. According to Galison, the image-data frontier is the locus of a war between iconophiles and iconophobes within science, where the epistemological and metaphysical "tension[s] between the picture and proposition", "image/logic" (*ibd:* 320), and concrete/abstract dichotomies are played out. Astronomers are generally found on the side of scientists "wanting to know with eyes-open" rather than those "wanting to know with eyes-closed" (*ibid*: 301), their "movements back and forth across the pictorial/analytic divide" (*ibid:* 322) are always more visually-oriented, tending towards the pictorialisation of data.

Galison identifies the "fusion of pictures and numbers into the production of the manipulable image" (Galison, 2002:321), specifically enabled by digitality (and manifesting itself most notably via pixels), as the defining change in science over the last half-century. As a consequence, neither "the 'pictorial-representative' nor the 'analytic-logical' exist as fixed positions" as their manifestations in astronomical images and data are not static but involved in a constant mutual metamorphosis, resulting in the image being "constantly in the process of fragmenting and reconfiguring" (*ibid*: 322). The astronomical image is "always on the verge of being resorbed by the computer, snatched from human eyes and transmuted back into the whirl of numbers" (*ibid*: 319), in a constant oscillation between a visual-'optical conscious' and a digital-"optical unconscious" (Benjamin, 2005:512).

Astronomical images gather not only data but space and time. This ability to "accumulate other places far away in space and time, and present them synoptically to the eye" (Latour, 1990:32) - otherwise shared by maps - here directly mirrors and derives from the photon-event previously discussed where the telescopic detector gathers space and time of light (via lightyears) through light. By *presenting* light, these images *presence* locations and regions within the universe (space), whose light is from the distant past and often gathered/detected over many days (time). Through this spatio-temporal gathering of light/light years, the astronomical image can be understood as a kind of 'place'. Edward Casey argues that places "not only *are,* they *happen*" (1996:27, original emphasis). Places, as events, *gather* space and time, they are not the "mere occasion for happenings positioned in... space and time". Instead "place itself would be the happening, and space and time what *it* occasions, what *it* specifies in determinate and measurable sites" (*ibid*: 38). Like places, images too "*happen,* they *take place*" according to Belting (2005:302, original emphasis) – they happen via transmission (and then perception); their own transmission via media and the transmission of photons which are emplaced within the image – along with the time and space they translate – and according to a temporal-spatial grid. Astronomical images can thus be understood as types of events and places, which happen and emplace space and time "in determinate and measurable sites" (Casey, 1996: 38), recording cosmological events and places and thereby creating what Benjamin calls "image worlds" (2005:512).

Space and time (of the referent) are reconfigured within the image through techniques of "optical consistency" (the epitome being that of perspective) which open a "regular avenue through space" (Latour, 1990: 27) through which objects can be transported and translated without corruption - enabling the transportation *of* place and the transportation *between* place (see *Figures 6a* and *6b* for an example of the 'grid' used to ensure optical consistency, as well as *Figs. 3* and *9).* In other words, space/time is reconfigured both 'vertically' and 'horizontally': the same processes which condense space/time within the image, linking it to its referent, enable the spatial and temporal circulation of images which become immutable mobiles (*ibid*: 26). Astronomical images "perform the presence of an absence" (Belting, 2005:312), an absence which is at once spatial and temporal, as they picture astral phenomena as they were when and where they emitted their light. What was absent is now present, and what was "previously more 'distant' is now 'closer'" (Ihde, 1998:154) through magnification, dimensional transformation and scalar modification, all of which enable the literal gathering of space, by making it smaller whilst maintaining its internal proportions (Latour, 1990) – enabling the images to be handled and dominated by human hands and eyes. A two-way connection is thus established, joining the sign and its referent through a collapsing and punctualisation of the intermediary networks.

Through the production of these images, "all the instants of time and all the places in space" that they refer to "can be gathered in another time and place" (Latour, 1990:45) - that of the present, on planet Earth - by being gathered in the mobile place of what are effectively image-map hybrids. The AGN data-images (*Figure* 3) are made by a gradual plotting of light-sources by positioning the photons according to an x-y grid. According to my interviewee, '*this is a map of what's plotted here [the tables containing rows and columns of information relating to each gathered photon] – the map could be a light curve or a spectrum but this is just an x-y, spatial map'*.

Like many images across the sciences, astronomical images are often imaged through an "analogic appeal to topographical maps" (Elkins, 1995:566) (*Figure 12*), their status as 'places' here expressed pictorially. The most striking example of astronomical maps I encountered was that of the CMB* (the Cosmic Microwave Background, essentially the visual echo of the Big Bang*) – which is often represented in an oval shape in flat images. I surprised however to find that two of my interviewees had 3D air-filled plastic CMB 'globes' in their offices (see *Figure 13, bottom left*). The 'visual analogy' (Stafford, 1999) is here explicit, with the CMB globe constructed through a similar system of latidunal and longitudinal coordinates as globes of planet Earth, which are here galactic coordinates. As my informants explained, in the same way that the map of our world is oval because it is the flattening of a sphere, the CMB map is oval because its referent is present all around us, coming from all directions. It thus forms a kind of sphere on the sky from an Earthling viewpoint, where we are looking at the equivalent of the inside of a spherical surface. The globe to map, sphere to flat oval transformation is also one of translation via optical consistency.

More generally, the idea of the astronomical image as a place representing a place from 'outer space' can be seen through the landscape metaphor which, according to Kessler (2006, 2007) structures 19th century and modern Hubble telescope astronomical images, which she refers to as 'spacescapes'. These, she argues, draw from the visual language of 19th century Romantic paintings of the American West, manifesting the same Romantic pictorial theme of the sublime, and sharing a concern with the theme of frontiers and discovery. This is especially true of astronomical 'pretty pictures', as will be explored below. Note also how this is in line with Kemp's documentation of the synchronic and diachronic "structural intuitions" (2006: 8) common to artistic and scientific ways of seeing over the last few centuries, showing how the history of the visual is patterned by analogy.

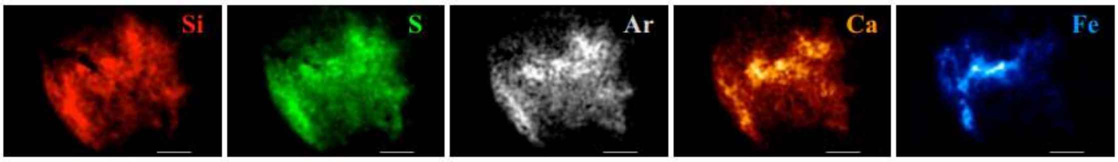

FIG. 3.— Exposure-corrected, continuum-subtracted images of Si XIII and Si XIV, S XV and S XVI, Ar XVII and Ar XVIII, Ca XIX and Ca XX, and Fe XXV. Images have been smoothed with a Gaussian kernel of $\sigma = 5$ pixels. The scale bar is 1′ in length; North is up and East is left. Fe XXV emission is weak in the West of W49B, while the other ions are more homogeneously distributed. The "hole" in the Si image in the Northeast of the SNR is caused by the large absorbing column $N_H \sim 10^{23}$ cm^{-2} there.

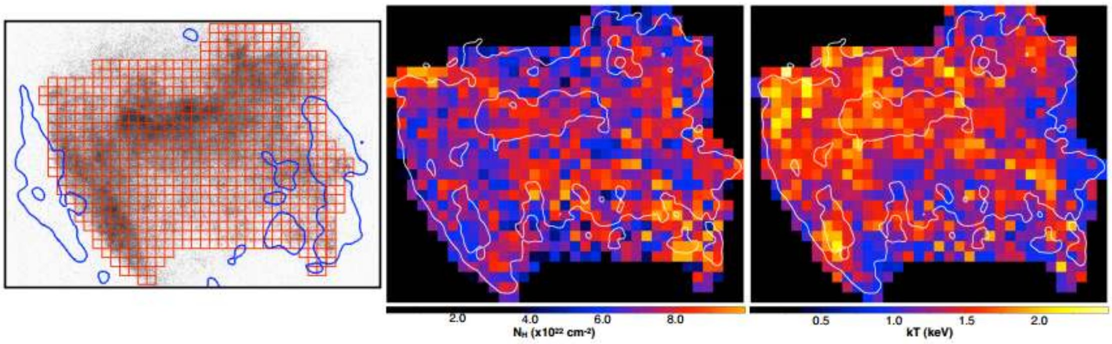

FIG. 4.— Left: Grid of 713, 7.5″× 7.5″ regions where spectra were extracted. Contours show the location of warm H_2 (at 2.12 μm; from Keohane et al. 2007). In the East, the ejecta are impacting the molecular material, while the ejecta are likely freely expanding in the West. Maps of best-fit values from spectral analyses for absorbing column density N_H (middle) and electron temperature kT_e (right). Overplotted are the X-ray full-band image contours to guide the eye.

Figure 12: *Journal Illustration of Supernova Remnant W49B*
Above: images of supernova remnant W49B, the same referent as *Figures 11* and *31*
Below: Maps showing the results of "spatially-resolved spectral analyses" of the same object, with the above "x-ray full-band image contours" overplotted "to guide the eye" (Lopez et al., 2013:2-3).

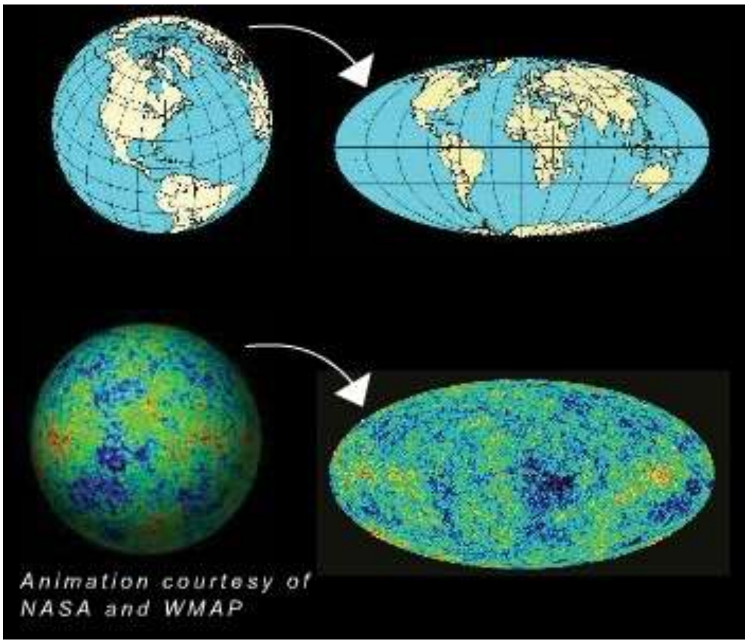

Figure 13: *The dimensional translations of the CMB as globe and as flat map* (NASA and WMAP, 2007)

In a second move, the reconfiguring of space/time leads to the horizontal proliferation and circulation of immutable mobiles, through the creation of quasi-'copies' and the interchangeability of representations which can contain and "represent *other* representations in complex socio-technical networks" (Lynch & Woolgar, 1990:5, original emphasis) in a fractal fashion reminiscent of the Chinese-box quality of technical processes (Coupaye, 2009). Inscriptions are made to be "reproducible", "reshuffled and recombined" (Latour, 1990:45), creating hybrid or quasi-images through strategies of optical consistency which structure images through metrology: the "organization of stable measurements and standards" (*ibid*: 57). Optical consistency in astronomy is ensured by, among other things, the metrological properties of colour and the pixelised grid.

Regarding the former, astronomical images are often composites of light from different wavelengths through the superimposition of, for example, an optical and an x-ray picture of the same source, with each wavelength range represented by a different colour. This engenders composite images that "combine very different sources that are blended through the intermediary of a homogenous graphical language" (Latour, 1999:66) – that of colour (*Figure 14*). As explained on its website, it is "by assigning different parts of the X-ray range that Chandra observes to colours recognizable to the human eye, [that] we are allowed to see the invisible" (Chandra, 2011d) and, according to my interviewee, '*get the full pictur'*" not possible by using a single light wavelength. Elkins would call these "Frankenstein pictures" which cobble together a variety of sources, "not all of them visual" (2007:36). In an extraordinary move, the 'visible' itself, like units of weight and time, takes on metrological form, becomes a homogenous graphical language, through the metrological unit of colour.

Like the colour that it encodes, the pixel too acts as a metrological unit, encoding a huge amount of information about the light that encountered its material counterpart in the astronomical detector. When a data set is visualized, or projected into an image, each pixel encodes information, representing the intensity of radiation or light when it hits a particular site on the detector, or other information such as spectral frequency or red-shift. This numerical matrix can then be represented as a greyscale image (with each pixel value shown as a shade of grey) or a colour image where each colour represents a range of pixel values in what astronomers call a 'colour palette' (Lynch & Edgerton, 1988; Rector, 2007).

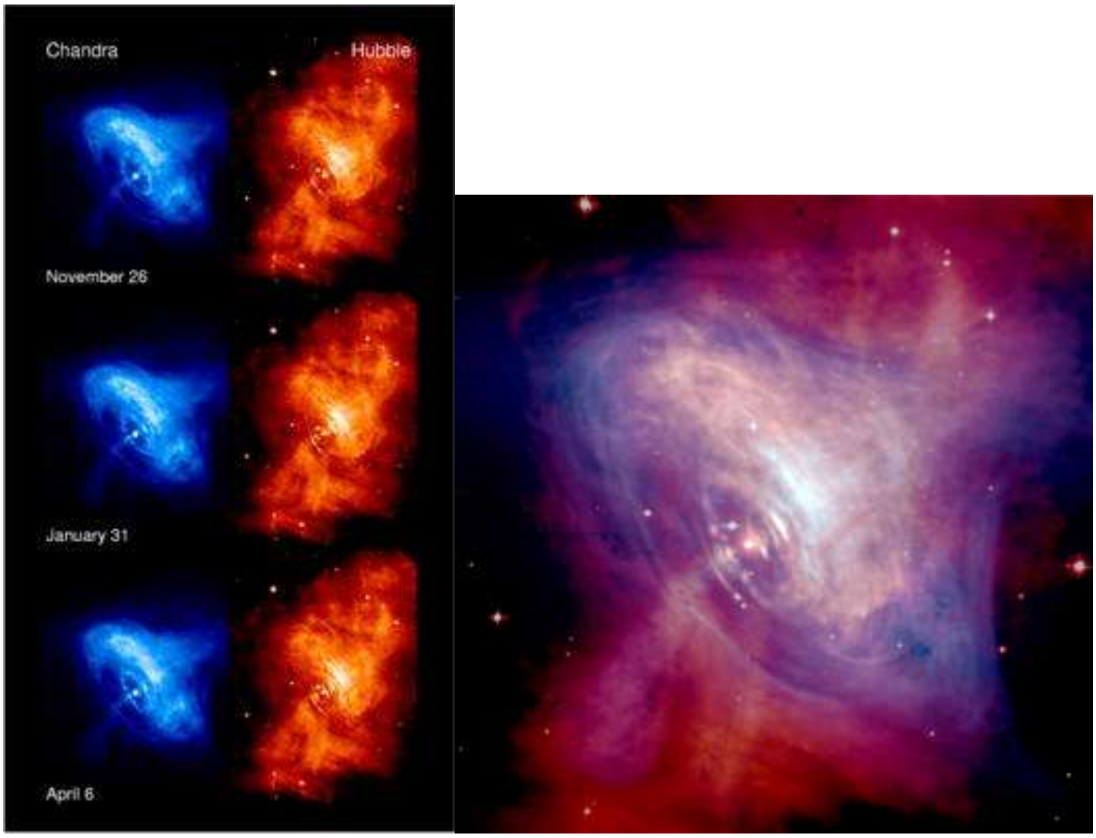

Figure 14: *The Crab Nebula*

Left: Comparison between the Chandra (blue) and Hubble (red) images of the Crab Nebula. *Right*: The resulting composite image of the Crab Nebula showing the X-ray (blue), and optical (red) images superimposed (Hester et al., 2002a; 2002b).

The pixel is a flattening and stacking and superimposition of that other basic unit: photons. Through its irreducibility the pixel in astronomical images acts as a constant common to all images, thereby facilitating their mobility and transformation. Organised in the Cartesian grid of the screen, pixels form a "matrix that can be saved and replicated later on in different forms while still remaining the same" (Frizot, 2007:278), thus facilitating the durability and mobility of translations. They are also a great simplifier, recording fragments of space and fragments of time (*ibid*), and condensing huge amounts of information. Through this common matrix of pixels, the computer screen and the CCD-like telescope detector act as two sides of the same coin, complementing each other. As networks of light gather in the detector and disappear into the digital-optical unconscious, they resurface, unravel, and are revealed by and in the screen – acting as some kind of portal of transubstantiation: material photons are captured on one end, to become digital-electrical signals revealed visually at the other end, on the computer monitor.

The screen performs two crucial actions, projecting images and embodying that other kind of 'screen', a "grid used to sift gravel, flour, or other physical materials to a particular size or consistency" (Wilson, 2006:348). The computer screen used by astronomers is a filter, filtering out 'noise' as previously discussed and more generally acting as a locus and means of data-reduction or filtering and abstraction (Latour, 1999) through its constituent pixels. Although astronomical vision has been gradually "mechanically stabilized" (Ihde, 1998: 156), culminating in the fixity of the computer monitor (as opposed to the body moving with the hand-held telescope), this tool's 'screenness' (Thrift, 2005) has greatly accelerated the mobility of images. The instantaneous mutability and 'movement' of images on screen, through zooming and the manipulations of colour and brightness, is coupled by their increased mobility through digital circulation. The computer thus materializes and amplifies the 'immutable mobile' process, its fixity being a locus for mobility.

All of these actions of punctualisation - where networks of visualization are concealed and condensed through the cleaning of noise, the image-data dialectic, the reconfiguration of space/time and pixelised transubstantiations – perform tiny, connected and connecting movements of abstraction, where matter is transformed into form, light into in*form*ation "which is never simply transferred, it is always radically transformed from one medium to the next" (Latour, 1998:425). Through these translations, some 'thing' nevertheless has to remain constant and durable, precisely in order to enable mobility (and reference). If matter is not made into and partly preserved in form then, "there is no travel nor transportation and the only way to know something is 'to be there'" (Latour, 1998:424) – something resolutely impossible in astronomy.

What makes radically different astronomical images versions-of-eachother (like *Figures 4* and *5; 11, 12 and 31; 26 and 33*) is their common source in a very particular light-trajectory emanating from an astronomical phenomenon. Families of image-incarnations can be aligned with eachother because they can be aligned and traced back to (paradoxically) what they have engendered: a referent. In astronomical images, a particular space and time are thus mobilised – to be rendered *mobile,* in the place that is an image-world – in order to refer back to and travel back to that original space-time. As matter is lost, something else is gradually accreted and gained: a way back to the star, quasar, galaxy (Latour, 1999). And this is the tour de force of scientific visual practices: it is precisely through these processes of punctualisation, abstraction, translation and mediation that the image is made into a mediator.

All of the above techniques of astronomical visualisation, which mediate light (and transform the ‘matter’ of light) whilst partly erasing this mediation as they jump onwards from matters to forms, are practiced in order to produce images and, crucially, transform these into mediators. The process of visualisation therefore does not proceed in a single direction, but is a reversible chain. The ‘visible’ within astronomy is essentially a “return ticket” (*ibid*: 69), spawning a mediator which mediates by virtue of masking its own mediation. And by doing this, the image disguises itself into a passive ‘intermediary’ (as opposed to the agentive mediator (Latour, 2000)) to clear the path back to the referent, to disguise a space opaque with networks of light and techniques of visualisation with a cloak of transparency. Astronomical images are thus fully fledged “mediators”, “at once a means and an end” (Latour, 2000:19) – they are the end (of techniques of visualization) before becoming a means – back to their source-object, hence the notion of “circulating referent” (Latour, 1999: 45).

Chapter 5: On Mediations and Mediality

These movements and to-ing and fro-ing between sign and referent constitute one of the transaction sites which, according to Latour, are the "only viable locus of enquiry" (1993b:396) – situated as they are between the poles formerly known as 'nature' and 'society'. Having sketched the "intermediary risky pathway" (Latour, 1999:40) between astronomical light and image, it is thus worthy to retreat back into, and interrogate, this "median space" (Latour, 1993a:64). After following the network of visualisation to identify some of the 'work of mediation' which produces images, I want to now pause on this concept of 'mediation' which, when opened up, reveals another kind of mediation, specific to the visual and to the realm of images more generally.

Here I am bringing back the image's other half, its medium: the "agent by which images are transmitted" (Belting, 2005:302), or which "transmits the very form in which we perceive images" (*ibid*: 305) in the sense of the written, visual, digital or photographic medium for example, in order to explore how this property of "mediality" (*ibid*: 304) and the Latourian mediations mirror each other as concepts and processes. Both originate in the notion and space of 'the middle'/medium, a liminal area "betwixt and between" things (Turner, 1967:93), and through which things pass, are transmitted and revealed and, crucially, are trans-formed, just as children leave the liminal space of an initiation ritual as adults. Through mediality and mediation, a relationship of immediacy gives way to a space of movement and metamorphosis. This is the place where the astronomical image emerges, or happens, at the nexus of two different but interconnected processes of mediation.

The first is what Latour (1993a) refers to alternatively as the work of mediation, translation or hybridization which continuously produces quasi-objects via the intermixing of categories and substances, forming chains of associations, linkages and heterogeneous assemblages through which these hybrids form networks. As seen, the astronomical quasi-image is one such hybrid: a sign-thing, caught at the cusp of the digital with the visual, always simultaneously data and image/pictorial, channelling the traffic of and between photons, electronic signals, pixels and numbers. The second process of mediality fits easily into this framework, participating in the Latourian work of mediation. Mediality denotes something inherently processual, it captures a quality of in-betweenness and as such is a useful trope to think with, helping us to navigate between the pitfalls of fixed purified categories. Media are "intermediary by definition" (Belting, 2005:313): they are themselves hybrid entities, part matter, part form; and this hybridity can be traced back to the inseparability of images and their media outlined at the beginning of this paper. As Belting shows, mediality cannot simply be substituted "by the materiality of images", and instead breaks down the "old distinction of form and matter" (Belting, 2005:305).

Media are almost nestled in those little gaps between matter and form which criss-cross chains of reference (Latour, 1999) and visualization, jumping the gap through their work of transmitting images and structuring exchanges between images and bodies through perception (Belting, 2005). The work of media, and their relationship to images and bodies, denotes the same processual quality of 'in-betweenness' which characterizes the process of mediation and translation, and the formation of networks and hybrids over pure entities. This is especially true for digital media, which Bryant & Pollock describe as a "consistent process of *becoming* (and *unbecoming*) based on the binary sequencing of zeros and ones that creates a constant relay of appearing and vanishing, of presence and absence" **(**2010:8, original emphasis).

The similarity and parallels are more than merely either metaphorical or etymological. The processes of mediation and mediality mirror each other – if you look at one you see the other at work. The paradigm and work of mediation can be understood as rooted in a general property of mediality - of carrying and transmitting (Kittler, 2010) - which it stretches out beyond the visual and iconographic into materiality, sociality and technology in general – as with the Berlin Key (Latour, 2000). Mediality in turn is a concrete, distilled, and especially visual, manifestation of mediation. Their relation is one of metonymy and homology. Media technically and visually enact the principles of mediation: translating, transmitting by recreating, enducing a "technical shifting to another matter" (Latour, 1992:171) of a referent into a sign, light into image, where the light of a star is broken down into photons, abstracted into electric signals and recomposed into pixels to form an image of a star which should carry the caption 'this is not a star' underneath. In this instance, the screen and larger electronic-digital medium participate in the work of reference (via mediation and translation) that creates these hybrid images. Mediality (when resulting in visual images) can be understood as a *visually* specific kind of mediation. I would argue that this is what makes the Latourian framework so conductive to the study of (scientific) images - even before looking at his ideas on scientific reference. The medium-mediation dynamic is another point of contact to that of inscription-reference, both articulated by the visual.

According to Latour's distributed monism, the phenomenon or artefact is always already hybrid, enmeshed along networks through mediations and translations which need to be teased out if we are to unpack the artefact. When the artefact in question is a scientific image, it brings together this mediation (of technology) with the condition of mediality inherent to all images – that which permits their visibility (Belting, 2005). Both are at work in its formation. These two forms of mediation are thus refracted through the prism of the image, into a kaleidoscopic and fractal-like pattern of mediations, putting into play several medial roles and properties – including that of light. What results is a cycle of mediations which includes those outlined in the previous chapter: the images here are created through a complex technical apparatus of *mediation* which intervenes between the astronomical source and the human eye, to make the former apparent to the latter. The image is transmitted and revealed to the eye through a digital *medium*. Beyond its isomorphism with its medium, the image itself acts as a *medium*, by transmitting and presenting a message, its content, its "what" (Belting, 2005:304). Indeed, Latour defines the image as something which "acts as a mediation to access something else" (2002:14). And, as seen, it does this in such a way that it acts not only as a medium, but as a *mediator*, giving access to this 'something' whilst changing it.

The transformation and medial multivocality through which the astronomical *image* is transmitted and perceived takes place in, and through, the wider work of mediation/hybridization (making it into a hybrid *quasi-image*), echoing the "fractal logic" of networks recognized by Strathern (1996:523). Just as there are networks within networks, here we are confronted with mediations within mediations. These hybrids are "condensed networks" (*ibid*) and once unravelled, reveal mediations. As with the reveal/conceal dialectic, I would argue that the medium-mediator pairing also hints at a certain recursivity of the visual. Like all artefacts, images conceal their technical coming into being whilst partially betraying it. They however go one step further than many artefacts, revealing their referent by this very process of concealment**.** The idea that the visual adds an extra dimension is seen here too, where the mediation of the visual (mediality) is added to the mediation of matter and technology - a dynamic punctualised in and enacted by the mediator.

Both mediation and mediality are acts of translation. This is not the Benjaminian conception of translation as transparent, which he argues in relation to the written image or linguistic medium, "does not cover the original, does not block its light" (1985:79, cited in Sassoon, 2004:200). Here the medium is not a container which preserves and merely carries a content;

instead, something is made into a content through the process of translation, as it passes through a medium. The image is not simply carried and revealed by its medium but made and happens during its transmission (Belting, 2005); the image is on the resulting side of this transmission, with light on the first side.

For Latour (1991, 1992, 2000), translation/ mediation is an 'AND/OR' relationship, involving a movement of association and substitution, equivalence and transformation, through which networks are slowly built up, through the action of mediators. As a mediator, the image can no longer be understood as a passive neutral window, and instead becomes "a social actor, an agent, an active being" (Latour, 2000:19). There are two agentive processes at work here, which are entangled in the image, and collapsed into the concept of 'image-act' (Bakewell, 1998). As outlined in the previous chapters, it is in itself a "collapsed act" (Mead, 1912:401) performing data, and resulting from whilst substituting a technical system of actions which it punctualises (Law, 2003). In a second move and following Bakewell, "images do things**"** (1998: 30). They are then simultaneously the result and source, 'means and end' of action, born out of and contributing to the work of mediation.

In her study of Hubble pictures, Elizabeth Kessler (2007) shows that one of the things these astronomy images do to us is to provoke feelings of awe, shock, wonder and mystery in the viewer. In other words, I would argue, they *enchant* us (Gell, 2006). Kessler argues that this is done through their aesthetic characteristics – presenting multi-coloured cosmological portraits of the universe which are visually inspired from and share the romantic aesthetics of 19th century American landscape paintings. These are known within the astronomical community as 'pretty pictures' which are clearly distinguished from 'scientific images' (Lynch & Edgerton, 1988; Kessler, 2007). The former, characterized by vibrant colours and striking light contrasts, are highly stylized and tailored towards public consumption and display, used for promotional purposes, scientific outreach and communication. They are not used for scientific analysis and are instead made on the basis of visual aesthetic appeal. See *Figures 15 to 22* for examples of pretty pictures, and notice the stark contrast between these and the images from my informants' 'scientific' research presented so far and in the following chapters. Indeed, scientific images tend to be visualised through a more subdued or black and white colouring.

Figure 15: *A "Rose" Made of Galaxies Highlights Hubble's 21st Anniversary* (NASA, ESA, Hubble Heritage,2010). This 'pretty picture' is a composite image of Arp 273, a pair of interacting galaxies called Arp 273.

Figure 16: *Starburst Galaxy M82*: celebrating Hubble's 16 year anniversary (NASA, ESA, Hubble Heritage, 2006)

Figure 17: *Visible View of Pillar and Jets* (NASA, ESA, STScI (2010), a pretty picture produced for Hubble Telescope's twentieth anniversary, to celebrate two decades "of awe and discovery" (STScI, 2010).

Figure 18: *Hubble Snaps a Splendid Planetary Nebula.* A pretty picture of Nebula NGC 2818, produced by the Hubble Heritage Team (NASA, ESA, Hubble Heritage Team, 2008).

Figure 19: *Supernova Remnant N 63A Menagerie* (NASA, ESA, Hubble Heritage Team, 2005). A pretty picture produced by the Hubble Heritage Team, to be compared with the non-pretty picture, scientific version of the same object in Figure 18.

Figure 20: *Starburst Cluster Shows Celestial Fireworks*. The nebula NGC 3603 in the constellation Carina, located 20,000 light-years away (NASA et al., 2010).

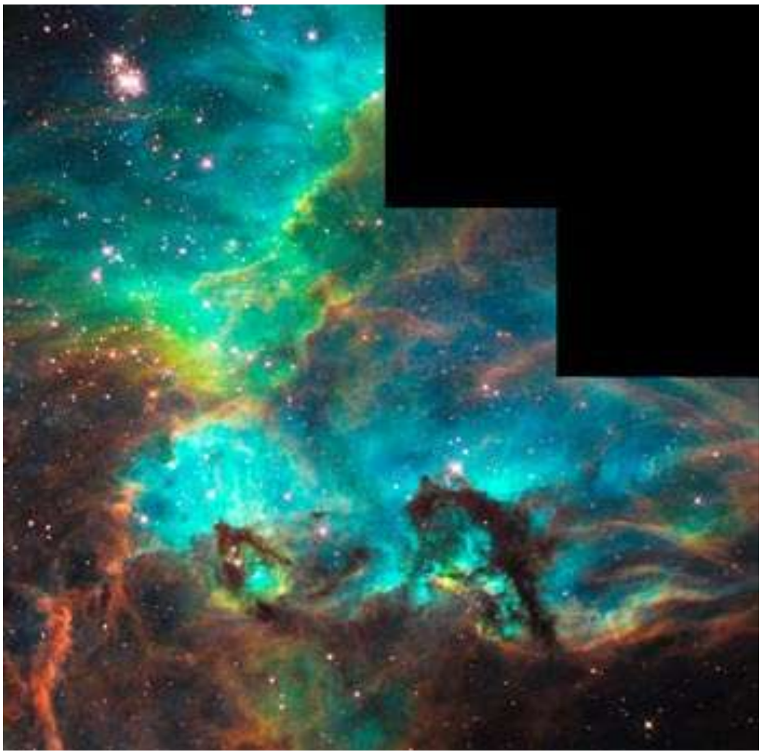

Figure 21: *Star Cluster NGC 2074 in the Large Magellanic Cloud* (NASA, ESA, Livio, 2008), taken to celebrate Hubble's 100,000th orbit, showcasing a "100-light-year-wide fantasy-like landscape" (STScI, 2008a).

Figure 22: *Spitzer and Hubble Create Colorful Masterpiece* (NASA, et al., 2006), of four massive stars named the Trapezium, "sprinkled throughout the image in a rainbow of colours" (STScI, 2006).

Although astronomical pretty pictures are undoubtedly beautiful and as visually dazzling as the Trobriand canoe-boards investigated by Gell (2006), I would argue that their enchanting effects are also shared by their less 'pretty' counterparts: the often black and white, blurry, opaque astronomical images of faint or formless things (like *Figure 3*, *5*, *11 left*, *26* and *35* to *40*) presented to me by my astronomer-informants and which Elkins (2008) explores in his study of the ends of representation (as will be discussed in *Chapter 7*). Like the Trobriand canoes then, these images enchant us not so much because of their dazzling visual effects or aesthetic features, but “via the enchantment cast by [their] technical means” (Gell, 2006:167), because of “the difficulty I have in mentally encompassing their coming-into-being as objects in the world accessible to me by a technical process which, since it transcends my understanding, I am forced to construe as magical” (*ibid*: 169) - through the previously discussed concealing of techniques in their artefacts. And this applies just as much to the pretty pictures that are so glossy and majestic that we do not know that they are made, as well as to the barely-pictures of things so far away that we do not know, cannot grasp, how they *could* be made (see Elkins, 2008).

In his discussion on the technology of enchantment, Gell distinguishes between painting and photography, emptying the latter of its capacity to bewitch us by relegating it to the realm of the natural. For him, the photographic process is “like the metamorphosis of caterpillars into butterflies” (2006:171), producing images which, however beautiful, are closer to “beautiful horses” or sunsets, than to being “beautifully *made*, or *made* beautiful” (*ibid*: 163, emphasis added). Photographs do not share the enchanting effects of art objects because they do not have the same quality of made-ness; for Gell it seems, photos are taken, not made. For an object to enact enchantment, its coming into being must be bracketed by two requisites: that it results from human agency, but one which is in part hidden and mystified. There is a tension at work here, where an agency is so impossibly human that it is perceived as a magical, occult agency. The agency at work in the technical process of photography as Gell conceptualizes it is however not quite human enough, falling instead into the realm of natural agency, thus bypassing enchantment. Gell does point out however, that when the nature of the photo-technical process becomes difficult to conceptualize and reconcile with the photograph, it can gain the capacity to enchant – and one could argue that this applies to digital photography and imaging.

Directly at issue in this question of human agency is the role of *mediation* – whether there is a human hand at work in the production of images – be these artistic, religious or scientific (Latour, 2002). Our difficulty in ascribing works of art to the technical abilities of a human agent portrays these as almost magically produced, bypassing the human hand and thus cloaking mediation with immediacy. The same can be said for religious icons which are perceived as emanating *directly* from god (*ibid*). And the exact same process is at work when scientific images are understood as being *direct* representations of 'truth', the 'real', or indeed as resulting from the “uncanny processes of a natural...order” (2006:171) that Gell ascribes to photography. In sum, the Gellian concept of enchantment can be partly recast as one of mediation: the higher the perceived complexity of (the mediation or agency in) a technical process, the more its source in human agency and mediation becomes unintelligible. Mediation is thus hidden, and the deception of immediacy that ensues results in enchantment. Mediation is collapsed and truncated in enchantment.

Following this, the ideal of objectivity in scientific representation manifests some of the characteristics of enchantment. Gell's idea that the technical process of photography owes more to natural than human agency is reminiscent of 19^{th} century understandings of the camera as mechanical eye and ‘pencil of nature’ (Talbot, 1844), bypassing the distorting effects of human mediation to achieve a morally superior non-interventionist, mechanical objectivity (Daston & Galison, 1992; Jay, 1995). The enchantment of objectivity is so strong that “to begin with, for most people, they are not even images, but the world itself” (Latour, 2002:19). The ‘made-ness’ of scientific images is denied so that *Figure 23* for example is not an image of a galaxy, but a galaxy.

Figure 23: *Hubble Photographs Grand Design Spiral Galaxy M81* (NASA, ESA, and the Hubble Heritage Team, 2007), located 11.6 million light-years away.

This is representative of the dialectic of opacity and transparency at play in technology and mediating machines (Van Den Eede, 2010), where only the medium or the image can be in focus at once (Belting, 2005), the technical process or the referent. In its ‘ready-to-handness’ (Heidegger, 1962), the medium disappears behind the image so that in a family portrait for example, you see the people and not the photo. In this instance and with the aid of enchantment, it is the medium which “withdraws” (*ibid*: 99) behind the image with its ‘how’ giving way to its ‘what’, paralleling how the technical process withdraws behind the astronomical image-medium, as previously discussed.

With astronomical images then, we find an interesting criss-crossing of Gell’s three implied categories: like Gell’s beautiful horses or sunsets, these are beautiful galaxies and nebulae, but they are also beautifully made, because they are also photographs. Here again, the visual-representative (or iconologic) dimension of the artefact adds another twist, further complicated by the fact we are not faced with straightforward entities: like yams, light is not purely artefactual, it is a nature-culture hybrid, a quasi-object which, when ‘cultivated’ on the telescope detector, becomes a sign-thing (Latour, 1999) in its images. Art and other objects derive their enchantment from the “technical virtuosity” which created them – one which is built on a “transubstantiation” of ideas and materials into something else, through which the “occult technician” (Gell, 2006:173) makes “what is not out of what is, and…what is out of what is not” (ibid:174).

In astronomical visualization, the transubstantiation is also achieved between Gell’s three categories: the world itself or beautiful galaxies are made into objects and specifically photographs. More importantly, when what is made is not just an object but an image, and a scientific image in particular, there is a more radical and multiplied transubstantiation which occurs at every gap between matter and form along the chain of reference. This is a “technical shifting to another matter” (Latour, 1992:171) constituted by visualizing techniques of *reference*, and one which does not merely, for example, transform oily pigments into a composition of letters and ribbons (Gell, 2006:170), but goes so far as to transform the Forest of Boa Vista into the papers of a journal article (Latour, 1999), quasars into equations, galaxies into pixels, things into signs.

The “magic which is exerted inside the picture” through this occult transubstantiation mirrors the “magic exerted over the beholder by this picture” (Gell,2006:170), which in turn reflects the enchantment cast by a human agent’s technical virtuosity, one which eventually bewitches us into certain social relations and views of the world, or networks of intentionality. At the heart of this cascade of enchantments we find another kind of *mediation*, whereby the astronomical image is "a physical entity which *mediates* between two beings, and therefore creates a social relation between them" (*ibid*: 172, emphasis added). What the object mediates along the way (and therefore *transforms*, *betrays*) is the sense of agency: how the artist-technician performs an agency, which is then fed into and embodied into the object, which transmits it to the beholder, who understands it differently. The object, here an astronomical image, in a sense 'refracts' the flow of agency, so that it appears as "achieved both by human agency but at the same time by an agency which transcends the normal sense of self-possession of the spectator" (*ibid*: 171). Agency here falls prey to the artefact or image's (the mediator) action of translation and *mediation*: the agency is "no longer simply *transported*" by the image, "but in part constituted, moved, recreated, *modified*, in short expressed and *betrayed*" (Latour, 2000:18, emphasis added).

The beholder and technician's asymmetrical technical agentive relation to the object creates an asymmetrical social relation between them, manifesting the homology between technical production and the production of social relations (Gell, 2006). The enchantment of the former (the enchantment of technology) contributes to the astronomical image's *objectivity*, whilst the enchantment of the latter (the technology of enchantment) consolidates the 'occult' astronomer's role as an *expert*, lending her authority and power over non-scientists. In astronomy the enchantment of technology within the image, and the image as technology of enchantment, come together most notably in the creation and use of 'pretty pictures'. As my informants confirmed, these are implicitly and explicitly used by astronomers to generate interest among the general public, for outreach programmes, and especially presented to funding bodies and organizations to justify and cultivate financial and governmental support for their scientific projects, such as for new, more powerful telescopes. As such, by promoting astronomical research, these non-scientific images nevertheless contribute to the work of 'doing' science (Lynch & Edgerton, 1988). Through this enchantment, the human work of persuasion is thus 'delegated' (Latour, 1993b) to non-human actors, and the extra-scientific interests of governments and funding bodies are "enrolled" (*ibid*, 1999:103) in the support of astronomical projects. Ultimately, it is both the agency of humans and non-humans which is in turn hidden; the former concealed through enchantment, and the former recast as the work of men and human agency.

The mismatch between the layman-beholder's "internal awareness of his own powers as an agent and the conception he forms of the powers possessed" (Gell, 2006:172) by the artist/ technician/ scientist/expert fosters a state of what Maurice Bloch calls "deference", which makes "holding something true without understanding it possible" (2005:128), and which he investigates in relation to ritual and its ability to cultivate the authority of tradition. One can believe or do something without understanding it, because that understanding is deferred to 'someone else', who therefore accrues power and authority – like the astronomer-expert. Bloch shows how this 'someone else' is however constantly deferred to another, leading to an indeterminacy in the original intentional mind or source of authority which instead becomes a shadowy "phantasmagorical quasi-person who may be called something like 'tradition'…'our way of doing things'…even perhaps 'God'" (*ibid:*:134) or, in this case, 'Science', 'Truth', 'The Real', or 'Technology'. The present cascade of deference therefore also mobilizes non-humans – lending and distributing authority to both images and astronomers as spokespeople of The Real.

The translation of deference from the realm of ritual, religion and tradition to science is a shift which signifies the gradual "disenchantment of the world" (Weber, 1946:20). Max Weber argues that through rationalization, intellectualization and scientific progress there are no longer "mysterious incalculable forces that come into play" (*ibid*: 8), and no need to have recourse to magical means and spirits, to understand and master the world – which is instead achieved by calculation, technical means and science. Crucially, we do not each as individuals have a greater understanding of the conditions under which we live; instead what is gained is the "knowledge or belief that if one but wishes, one *could* learn it at any time" (*ibid*, original emphasis) – the understanding is thus deferred towards others or the quasi-person of Science and Technology. Following this, Weber argues, like Heidegger (1962), that we do not need to know how things work in order to use them: through 'deference', our relation to the world and to things is one of 'readiness-to-hand'. The application of Gell's theory to astronomical images (as part of the larger class of scientific artefacts) should temper a straightforward view of the world as disenchanted through science and technology, as these both also participate in a re-enchantment of the world, through the enchantment of technology.

The 'image-act' is an agent of enchantment. Its impact has a broader reach however for, as a mediator, the image/medium "creates what it translates as well as the entities between which it plays the mediating role" (Latour, 1993a:78): the referent and the human beholder. Images “do things, and they do these things to us”: they can enchant humans and they can “alter human experience” (Bakewell, 1998:30). The image acts on the process of reference and on our own *perception* or, to paraphrase Kittler (2006b), like media, images make sense by making our senses, as will be explored in the following chapter.

Chapter 6: From Light to Sight: *the Perception of Astronomical Images*

6.1 Techno-sensorial translations

Techniques are processes by which we create, transform and *perceive* the 'world', both materially and conceptually (see Coupaye, 2009; Naji and Douny, 2009). They relate materials, body, and the human mind through processes of physical, sensorial and mental interaction, through which techniques manifest translational, perceptual, and revealing properties. They at once result from and structure how we perceive things, that is to say understand and categorize them. But in this instance, when they produce images, techniques also enable and structure how we see and perceive the world, literally. Astronomical images, and the techniques they punctualise, act on and transform our perception by enabling and expanding our visual experience (of the world), simultaneously making their referent sensorial and opening it to our senses. Images perceptually mediate the referent.

No discussion on visual techniques and images is complete without taking into account the senses. Although the body and its subjective phenomenological experience has historically been viewed as impeding the search for objective truth through the distorting effect of the senses (Daston & Galison,1992; Abram, 1996), it is essential here to find the human body nestled amongst all these machines and numbers – to look at the human in the networks/ chains of humans and non-humans (Latour, 1991; 1993a; 2000) – in order to understand how vision and visuality are configured in and by astronomy in relation to "their precondition: visibility" (Waite,1996:63) – and thus implicitly its other, invisibility. Here, I am shifting the analytic focus from light to sight (see Bille & Sorensen, 2007).

The focus on the body is doubly pertinent given the present emphasis not only on astronomy as a science, but astronomical visualisation as a technical process. Stripped from all the hyper-technology of telescopes and software, these techniques are based on actions, and the components of technical action include gestures and knowledge (Lemonnier, 1992). Their combination manifests itself into skills, or know-how, through an embodiment of knowledge which directs the perceptual skills of astronomers, guiding their production and reading of images.

This brings us to the last element in Belting's triadic constellation of image, medium, body – which he advances as a new approach to iconology, and which opens up another of those 'transmission sites', or spaces of exchanges; those between humans and non-humans, through perception. Images happen somewhere between being transmitted by their media, and being perceived by the body. As Belting shows, images "are negotiated between bodies and media" (2005:311), in this case digital media, as well as the complex technical apparatus that comes before them. In astronomy, this is very much a perceptual, sensorial negotiation where the perceptual capacities of the medium/telescope have to be negotiated with those of the human body and eye, overcoming the disjuncture in how sense-data is processed.

By presencing and representing cosmological bodies, "we often forget that [these images] only simulate the immediacy of a perception, one that seems to be our own but, in fact, is theirs" (*ibid*: 313). These phenomena are generally absent from our space and time but through their light, they are somehow "present and yet remain invisible" (*ibid*) – emitting light in slices of the electromagnetic spectrum beyond human vision. Through our immediate bodily perception, they exist for us only as an "absence from sight" and "we are entirely dependent" on images and technology – mediators - "in order to make these worlds present to our sight" (*ibid*).

By giving us access to sight beyond sight, astronomical instruments and images provoke in us what is known in phenomenology as "horizonal experiences" (Ihde,2011:110)– the experience and awareness of our perceptual limits. As Don Ihde explains, this happens for example when we hear the sound of a gong, which gradually fades away and, although we can no longer hear it, if we place our hands on it we can feel the gong continue to vibrate, giving us an experience and then awareness of "sound beyond sound" (*ibid*:109). Similarly, we have experienced a gradual cascade of "sights beyond sights" (*ibid*: 110) with the successive discovery of infrared, ultraviolet, gamma ray and x-ray radiation and radio waves, each extending the electromagnetic spectrum, every one of them "lying beyond the human visual horizons" (*ibid*: 112) and thus invisible to the unaided human eye; offering us every time a different kind of and new glimpse into "light beyond light" (*ibid*:115), each carrying new information and a different vision of celestial objects and the universe (see *Figure 24*).

Figure 24: *Stars Bursting to Life in the Chaotic Carina Nebula (*NASA, ESA and the Hubble SM4 ERO Team, 2009)

The top image, taken in visible light shows gas and dust shaped by the radiation and particle winds emerging from stars which are invisible in this image but clearly revealed in the image below, taken in near-infrared light, where the gas clouds disappear. The stars are prominent here "because infrared light, unlike visible light, can pass through the dust", demonstrating how multiple-wavelength visualization gives "a much more complete view" of objects (STScI, 2009).

These horizonal experiences are instrumentally mediated. Crucially, it is technology that *simultaneously* gives us an awareness and recognition of our perceptual limits, whilst also *breaching* these limits. It gives us access to phenomena that lie well beyond our bodily-perceptual horizon – but this horizonal recognition and the ensuing perceptions are always "presented by the instrument" (*ibid*). Without reference to Latour's theories, Ihde coins the term "translation mediation" (*ibid*: 112) to refer to the forms of technological mediations resulting in extra-horizonal perceptions. As Ihde justly points out, and despite attempts to negate the role of the body in scientific experimentation, we remain "embodied humans whose observations are those of bodily-perceptual creatures" and so to become available to us, the information/data/images gathered "must be transformed, *translated*, into what is open to our anthropological constant, an embodied human" (*ibid*: 113, emphasis added) – in order to become present to our sight by being made humanly visible.

Through things and techniques, our perceptual boundary is shown to be mobile, moved gradually farther as the phenomenon (light) is dragged in the opposite direction across the human visual threshold and into our sensorial range, thereby pulling the invisible into the realm of the visible. Astronomical images are *techno-sensorial translations,* and through astronomical techniques, sight and perception are in part 'delegated' to non-humans (Latour, 1999) as visual mediating machines take on a prosthetic function. Vision is thus 'distributed' (ibid,1991) across networks: in human eyes, computers, on screens, in numbers, in the CCD monitors of telescope detectors and so on – circulating along, and coalescing or being fixed at certain nodes in this assemblage.

Each glimpse into light beyond light peels back another layer of the "optical unconscious" *(*2005:512), Benjamin's idea that "a different nature opens itself to the camera than opens to the naked eye", revealing "entirely new structural formations of the subject" (*ibid,* 1968:236), of its space and its time; revealing the too-small or too-fast for our eyes through enlargement and slow-motion respectively. The spatio-temporal structural formations of astronomical subjects opened up to human consciousness are of a slightly different order, revealing the infinitely big and far, and the infinitely old, as well as another kind of '*optical* unconscious': the light that lies beneath and beyond *optical* light (see for example *Figure 24*). These are things which are "covert enough to find a hiding place in waking dreams", things we can look at but cannot see – like the forms of "totem poles" and "ancient columns" (*ibid,* 2005:512) which Blossfeldt's camera uncovers in everyday plants, and their astronomical equivalent of the sea-shell like structure of spiral galaxies (*Figure 25*).

The optical unconscious, a technically mediated visual experience beyond the limits of our experiential horizons, makes us vulnerable to that same tension that comes with the awareness of our perceptual limits: we are offered a simultaneous awareness of a presence, with its absence from (unmediated, human) sight. There is a blindness that comes with sight – an invisible couched in every visible – and with astronomical visualization has come the recent realization that the whole sky is an "unconsciously penetrated space" (Benjamin, 1968:236). Where our eyes alternatively see it as blue and black with silver specks, the camera-telescope reveals billions upon billions of stars, galaxies and myriad other recently discovered objects.

a b c

d e

Figure 25: *An assortment of spirals*: 'entirely new structural formations of the subject' are revealed in the optical unconscious.
(a) Visible Image of galaxy M51 (NASA, ESA, Hubble Heritage, 2011) *(b)* seashell
(c) Whirlpool Galaxy (M51) and Companion Galaxy (NASA et, al. 2005) *(d)* seashell
(e) Spiral Galaxy NGC 4622 (NASA, Hubble Heritage, 2002)

Indeed, the Hubble Deep Field (HDF) image (*Figure 26*) - an aggregate of 342 separate exposures taken in 1995 over more than 100 hours – revealed thousands of galaxies never before seen, often in their stages of formation and therefore of irregular, unexpected shapes (see Elkins, 2008). It is a very narrow "keyhole" view of the universe, taken of a largely empty (from the view of ground-based instruments) patch of sky which "covers a speck of sky 1/30th the diameter of the full Moon" and at the time was the "deepest" (STScI, 1996) ever view of the universe. These are some of the most distant, and therefore dimmest, objects ever seen, "about four-billion times fainter than can be seen by the human eye" (*ibid*), and some of the galaxies in the field only range a few pixels across. It stretches back to near the visible horizon of the universe, covering a range of more than 10 billion years – that is it shows the universe (simultaneously, in one image) at many different stages in time, depicting some galaxies as they were over 10 billion years ago (*ibid*). Here, the optical unconscious revealed is of things that found a "hiding place" in time (in the past), as well as space (Benjamin, 2005:512).

By opening up the optical unconscious, the camera gives us access to a whole new realm of human *consciousness*. Through the perception of these "image worlds" (Benjamin, 2005: 512"), "the 'world' is changed" (Ihde, 2011:114) – our understanding of it having expanded from being comprised of only one single galaxy, our own, to billions in the space of the last eighty years. This is a Kuhnian paradigm shift brought about by the imbrications of perception and technology, revolutionizing our understanding of the world by *revealing* the world differently (Kuhn 1970, cited in Riis, 2008). Belting would see this as illustrating how perception and imagination flow into each other through the merging of external and internal images. Importantly, what is at work here is once more the *revealing* work of technology and techniques explored by Heidegger (1977), who posits that in its essence, it is a process which "frames the ways we interact, think about and visualize the world" (Riis, 2008:290). This is what Latour discusses when urging us to investigate how categories (here, those of 'light', 'the visible' and 'the world') are coalesced through techniques and networks.

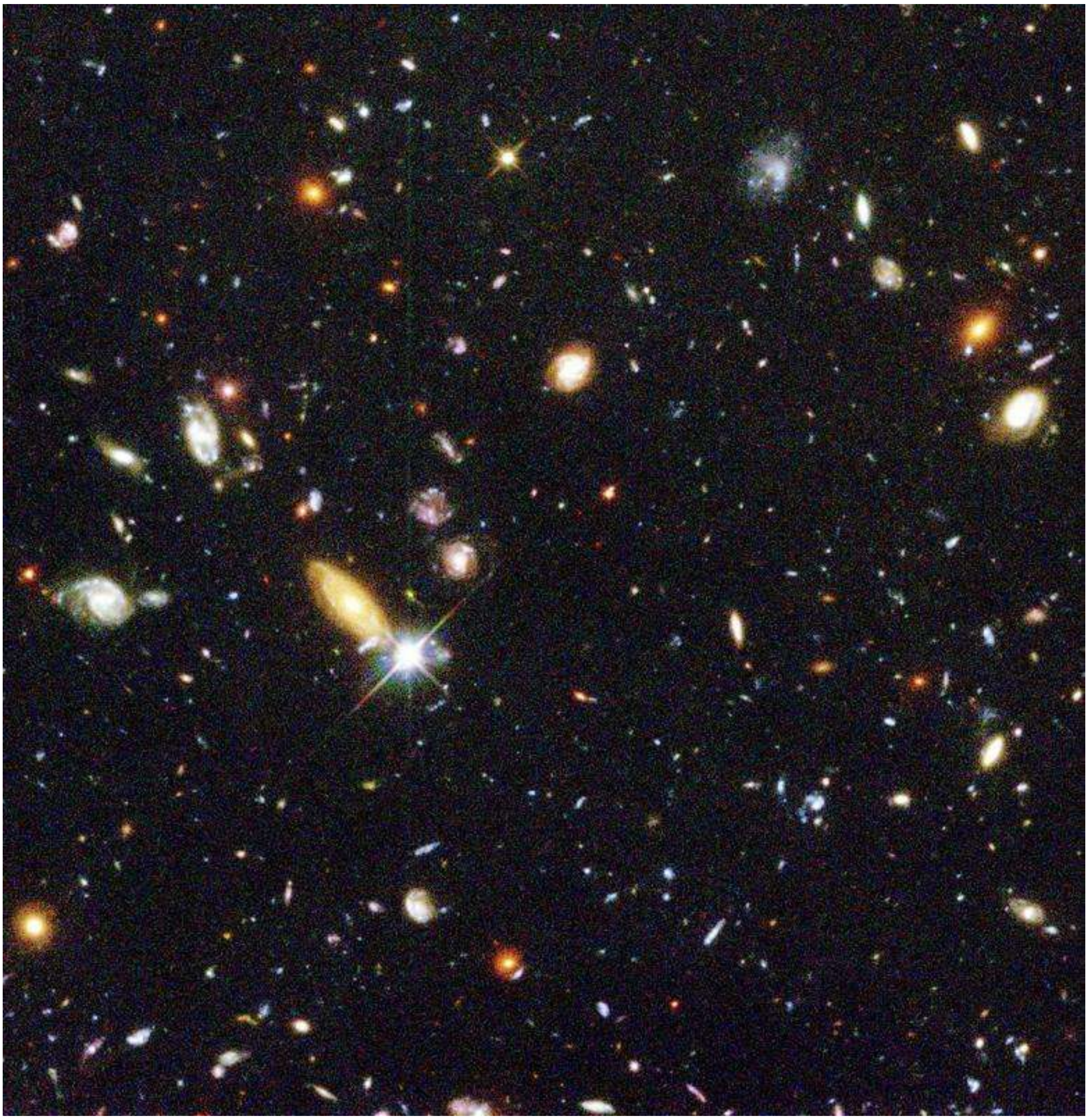

Figure 26: *Hubble Deep Field – North* (STScI and NASA, 1996) revealing entire new "image-worlds" (Benjamin, 2005:512).

6.2 What Colours do in Astronomical Images

These images travel back and forth across our visual threshold with the aid of colour. They are *chromatically* adapted and tailored to human visual embodiment: when the phenomena they represent are "emissions of the spectrum…outside our colour horizons, translation mediation supplies colours we *can* see" (Ihde, 2011:113 original emphasis) and invisible light is translated into visible colour. In astronomy, colours lie at the intersection of concerns with perception and reference. Although colours are an increasingly appealing means of data visualisation in astronomy, the mismatch between this data and the wavelength sensitivity of the human eye induces an inherent "ambiguity in the usage and interpretation of colour" (Rector, 2007:598), one which is implicitly and explicitly acknowledged by astronomers (Lynch & Edgerton, 1988, 1996) and goes hand in hand with the flexibility enabled by digitization.

Diana Young (2006) argues that anthropologists should be asking not just what colours mean, but what colours do, as well as what people do with colours. Returning to astronomical visualization as a technical system, and the five elements Lemonnier (1992) uses to describe these, colour is used as a *tool* by astronomers, to produce specific effects and to "structure knowledge" (Young, 2006:174). It is used according to a body of *knowledge* and *skills,* as previously outlined, as well as two kinds of "bodily-perceptual skills" (Ihde, 2011:113): those held by the human body in terms of the capacities and tendencies of our visual-optical apparatus, and those specific to trained astronomers and science imaging experts. For them, "to 'read' the image…is both to perceive the image gestalt, and to 'decode' or interpret it in its beyond-experience context" (*ibid*: 115) through a learned "visual grammar" (Rector, 2007:607) which can be understood as the perceptual skills and embodied know-how - making up the specific technical knowledge (Lemonnier, 1992) – of astronomers engaged in *techniques* of visualization and imaging.

This helps guide them in their colour choices when creating images, which otherwise offer endless possibilities for visualizing data. According to Lynch and Edgerton (1996), 'aesthetic choices' are also at play in their use of colour and contrast to make images more visually attractive, though I argue these should be understood as part of the broader concept of 'technical choices', which Lemonnier (1993, 1986) uses to counter the view of techniques as materially determined. Lemonnier argues that to discriminate among the "universe of possible techniques" (here, the endless colour combinations), societies exercise choices which are "established by means of 'criteria' which are not at all material" (1986: 155) but informed by various sociocultural and symbolic considerations which create arbitrary variations in both the "stylistic" *and* "functional" (*ibid*: 160) aspects of tools, tool-use and resulting artefacts.

Astronomers have developed a highly pragmatic use of colour which is used to highlight structure, temperature, depth, radiation intensity and to map various physical properties. The choice of colour depends on several factors: the source object, its wavelength emissions, the software used, the target audience, and what information they are trying to analyse and present. Through all of this, colours participate in the task of transforming information into visual depiction and making the referent sensorial, by translating invisible and perceptually inaccessible electromagnetic data into sensible pictorial images – as part of the larger role of the image in mediating the referent, by giving us perceptual/visual access to it, and enabling astronomers to "see the physics" (Lynch & Edgerton, 1996:111).

When looking at astronomical images, non-scientists - myself included - often ask: 'But is that what we'd really see, with our own eyes, if we were for example in a spaceship just outside [the galaxy, nebula etc]?' (Atkinson, 2007; Lynch & Edgerton, 1996). The answer can be found in how colours are conceptually and pragmatically classified in astronomy. Different colour 'palettes' or 'Look Up Tables' translate the quantitative data sets into a combination of either 'true', 'natural', 'representative', 'mapped', 'enhanced', or 'false' and 'pseudo' colours (Credner, 1999; NASA, 2010; Rector, 2007). 'Natural colour' and 'true colour' describe optical images (of an object emitting in the optical/visible wavelength) obtained with filters that roughly match the red, green and blue colour-detecting cones within the human eye: grey-scale black and white images are taken separately through red, green and blue filters and then combined to show an object in the way the human eye would see it if it were extremely sensitive, as in *Figure 27* (Credner, 1999; Rector, 2007). Through this additive process, "the light itself is mixed" (Credner, 1999).

Figure 27: *Two natural colour images* created by combining images taken with green, blue and red colour filters. Left: Sombrero Galaxy M104 (NASA, Hubble Heritage, 2003); Right: Warped Edge-On Galaxy ESO 510-G13 (NASA, Hubble Heritage, 2001)

Representative, mapped and false colour are used (materially and conceptually) to refer to and create images taken at non-optical wavelengths of 'invisible' light: colours are mapped onto different bands of the electromagnetic spectrum and/or various physical properties or intensities (and used to 'represent' these), resulting in either "natural appearing" (Credner, 1999) images (see *Figure 28*), or more obviously 'false colour' images (for example, *Fig. 29*) (NASA, 2010). These visualize objects - or features of an object - that would ordinarily be invisible to the human eye. Different images (or data-sets) can be combined or 'layered' (Rector, 2007), resulting for example in images of one source object visualized simultaneously in several wavelengths – represented by different colours – with each wavelength/colour yielding new information regarding the object: its temperature, molecular make-up, even its age and distance (see *Figure 14* and *30, 31* below).

Figure 28: *The Bubble Nebula* (NGC 7635):

Left: As a 'natural appearing', but mapped/representative colour image combining filters in order to determine chemical make-up and temperatures of the object. The filters are placed at different wavelengths represented by blue, green and red denoting the elements oxygen, hydrogen and sulphur respectively (Bonev et al., 1998). ***Right***: a natural/true-colour image of the same object, as it would be seen by the human eye (Malin/IAC/RGO, 1992)

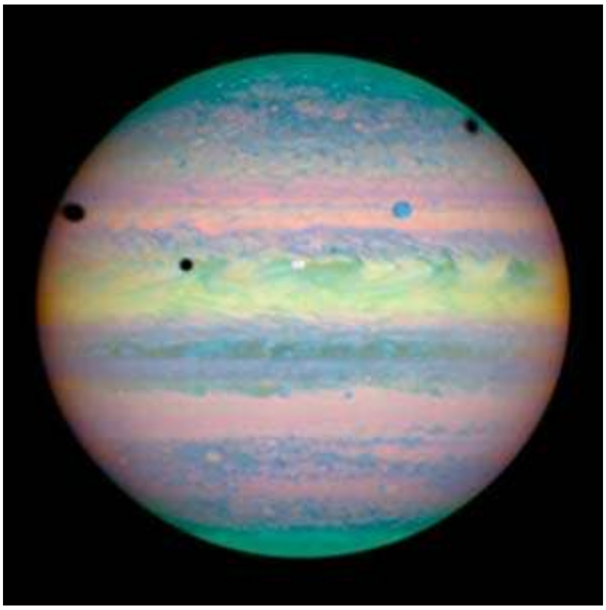

Figure 29: *Three Moons Cast Shadows on Jupiter* (NASA, ESA, Karkoschka, 2004):

False/representative colour image of the planet Jupiter, taken in near-infrared light. Images taken in three near-infrared wavelengths were combined to make this colour image, with the different colours denoting the chemical composition and cloud altitude of the represented object.

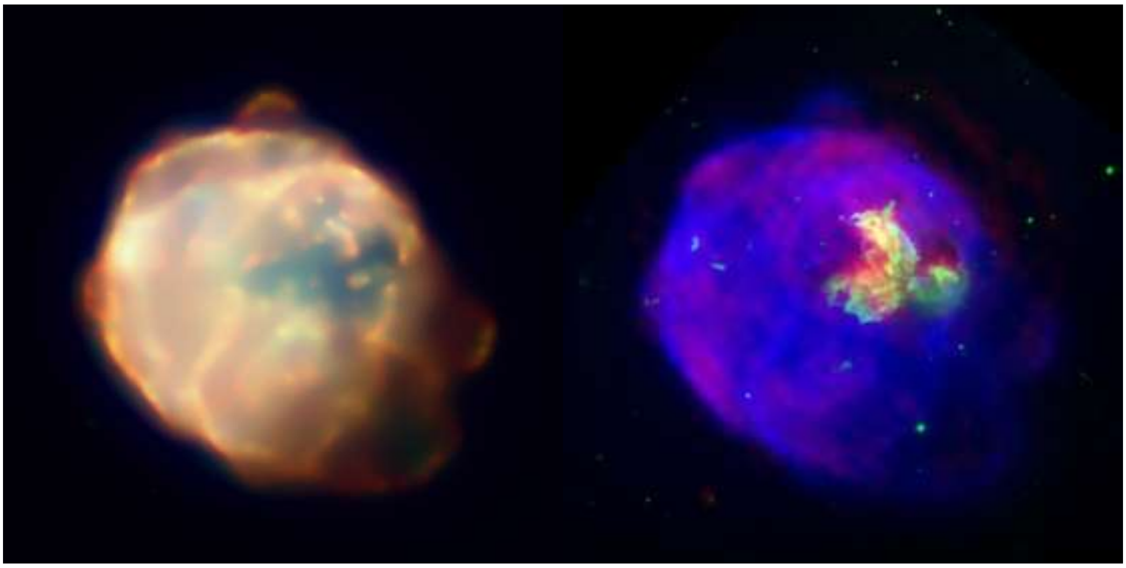

Figure 30: *Supernova remnant N 63A visualised in x-ray (left) and composite (right) images*. Both are examples of false and/or representative colour images.

Figure 30a (left): *Chandra 3-Color X-ray Image of N 63A* (NASA et al.,2005): Supernova remnant* N 63A seen in x-ray light. The colors red, green and blue in the image correspond to (are *mapped* onto) low, medium and high-energy X-rays, respectively.
Figure 30b (right): *Supernova Remnant LMC N 63A in X-Ray, Optical and Radio Radiation* **(**NASA, STScI, 2005): Composite, multi wavelength image of N 63A. X-rays from Chandra (blue), combined with optical (green) and radio (red) data, reveal new details in the supernova remnant.

It is important to note that there is a lack of definite conventions in the use of colours, and especially 'false colours', amongst astronomers (Lynch & Edgerton, 1988). Moreover, there are strong disagreements in the terminology used: whilst some astronomers alternatively use 'false', 'representative' and 'mapped' colour to refer to all images which are not 'natural' or true colour/optical, others draw a strict distinction between false/pseudo and mapped/representative colour usage. For the latter group, false-colour usage is akin to a "'colour-mapping' (or 'paint-by-numbers') to display a black and white image with colours that are completely unreal" (Villard and Levay, 2002: 34), with many different and arbitrary selected colours chosen and used in any one colour bar, but which "have nothing to do with the real intrinsic colours of the shown object" (Credner 1999) (see for example *Figures 32* and *33* as well as the maps in *Figure 12*, bottom). The colours displayed "do not represent anything to do with colour at all" (Villard and Levay, 2002: 34). They are instead used to analyse the data and reveal small variations in hue, enhance the range of intensities that are visible or emphasize structural details – none of which would be easily distinguishable with a simple black and white image with values mapped on a greyscale range of intensities (as shown in *Figure 32*). This use of false colour can be distinguished from representative-false colour, which visualises non-optical wavelengths, mapping these onto the red, green and blue colour bars, thus showing true wavelength differences, as in *Figure 14* (right), *Figure 28* (left), *Figures 29, 30,* and top left in *Figure 31* below. Although there remains a lack of guidelines and conventions surrounding the use of (and colours included within) colour-palettes, those who uphold the division between false and representative colour also generally discern a distinction between the kinds of colours used, with representative images resulting in relatively unsaturated and pastel colours, as opposed to both false colour images and pretty pictures (Villard and Levay, 2002).

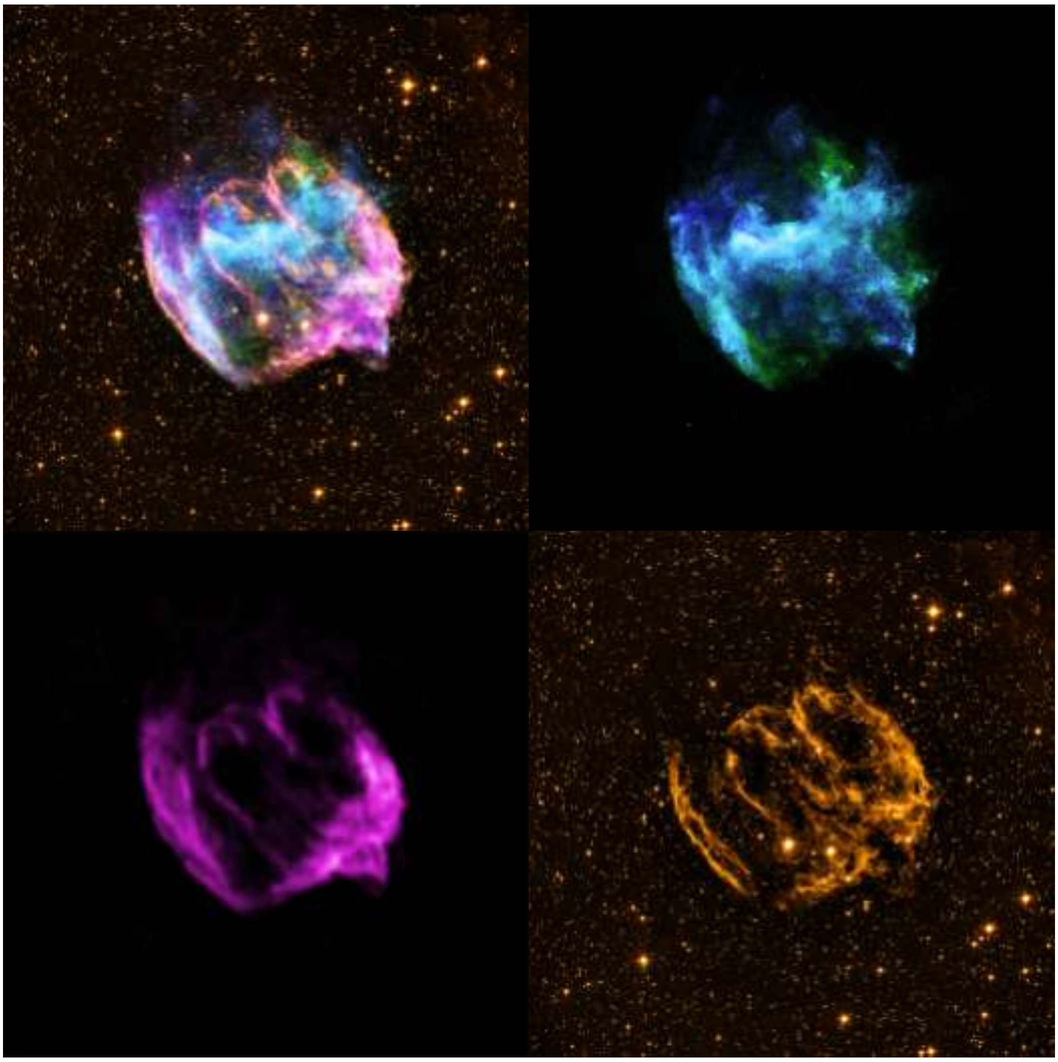

Figure 31: *Four images of W49B supernova* remnant*, viewed in x-ray (**top right**) (NASA et al., 2013), radio (**bottom left**) (NSF/NRAO/VLA, 2013) and infra-red light (**bottom right**) (Palomar, 2013); and viewed as composite image combining x-ray, radio and infra-red data (**top left**) (Chandra, 2013B). Compare with raw x-ray image (*Figure 11)*, and journal illustration (*Figure 12*) of the same referent.

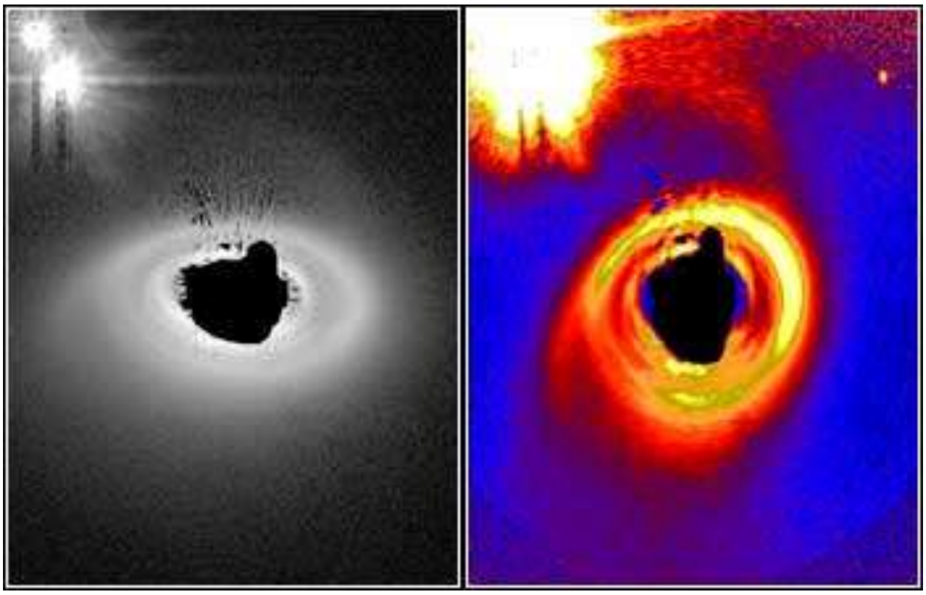

Figure 32: *Complex Dust Disk, Expected Birthplace of Planets, Around Star HD 141569A* (NASA, STScI, ESA, 2003). This is an example of a visible/optical light image (left) with its false colour version (right). The images represent a young 5 million year old star located 320 light-years away in the constellation Libra. The photo on the left is a "processed visible light image. In the photo on the right, the disk has been geometrically altered to simulate a face-on view, and false-colour has been applied to enhance the disk structure. The black centre marks regions where light from the star has been masked out" (STScI, 2003a).

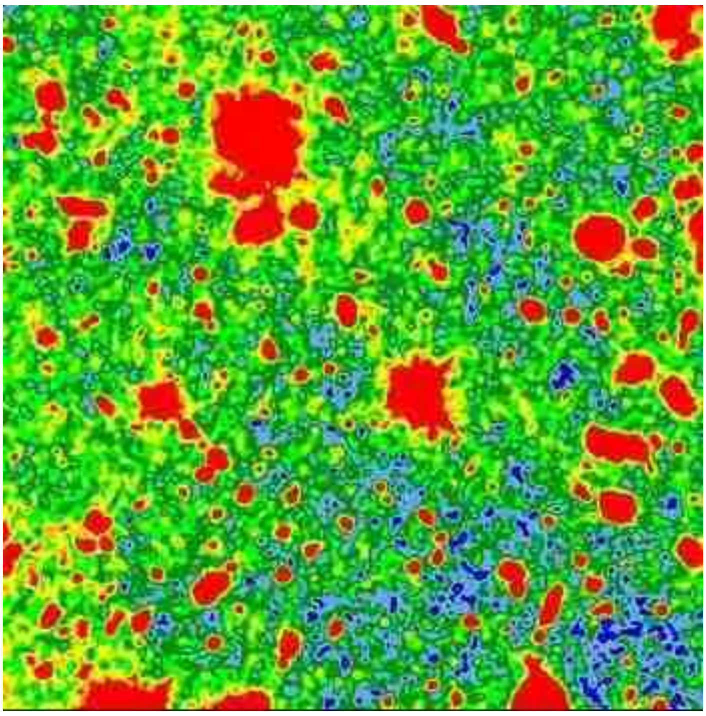

Figure 33: *Hubble Deep Field: False-Colour Image Showing Distant Galaxies and Stars in Red* (Vogeley, 1998).

This is a false-colour image version of the Hubble Deep Field (see *Figure 26*), used to map and detect variations in light between the galaxies. The red regions in the image correspond to galaxies and stars that Hubble detects.

From all of this, colours can be seen to have "have shifting meanings" (Kessler, 2007:488) within astronomical images, which can incorporate several modes of representation through a "merging of iconic, graphic, and semiotic features within the same frame of a pictorial field" (Lynch & Edgerton, 1996: 119), cobbling together a variety of sources into "Frankenstein pictures" (Elkins, 2007:36), as in *Figures 12* and *34*. The iconicity of colours is present in optical, 'true' colour images – which 'look like' their object- although Lynch and Edgerton argue that similarly iconic uses of colour also structure other ('false') astronomical images, with for example a "naturalistic" (1988:201) dark blue or black used to indicate the featureless sky, and reds, yellows and whites used for intense sources. This is not of course the Piercian icon, since the resemblance is not between the sign and the referent, but between the sign and our own visual conventions or expectations, coalescing in a "notional referent" (Bryant & Pollock, 2010:10) which manifests Belting's idea that "digital technology pursues the mimesis of our own imagination" (2005:309), demonstrating how digital images and mental images (our imagination) inspire each other.

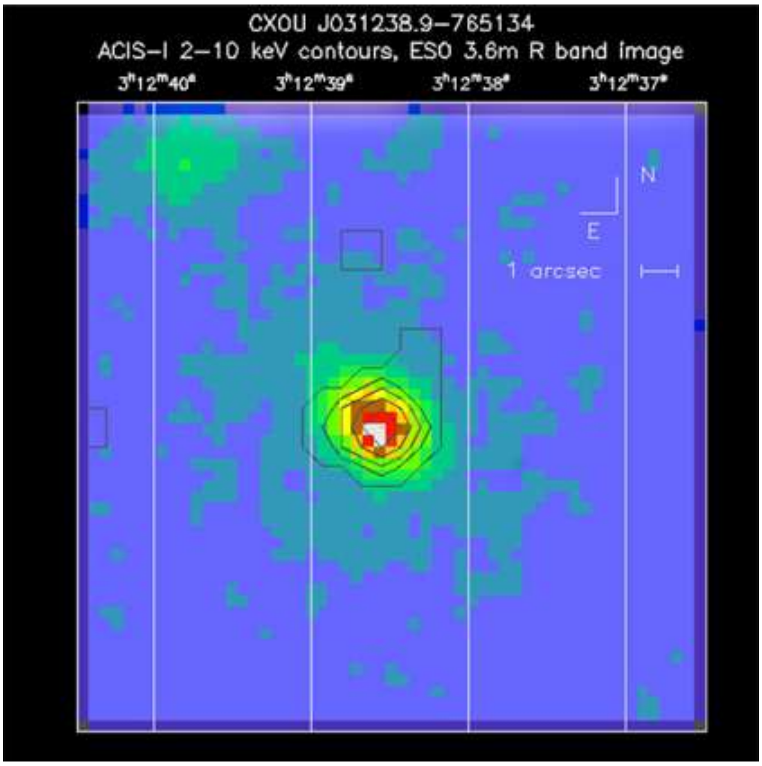

Figure 34: *A Possible Type 2 Quasar Veiled Black Hole* (NASA, et al., 2000)

Chandra x-ray image overlaid on optical image of a powerful x-ray source in a galaxy located 2.5 billion light-years away. The x-ray contours and optical image colours represent brightness levels, and "vertical lines in the image are part of a grid to locate the source in the sky" (Chandra, 2009).

These images could more appropriately be understood as mobilizing the property of "colour as analogy" recognized by Young – whereby colours connect things in "a network of resemblances" (2006:180). The most common example of this in astronomy is the use of blue to denote ultraviolet light, which is often described as light which is "bluer than blue" (RAS, 2013) - since with shorter wavelengths, ultraviolet comes just before blue or violet visible light in the electromagnetic spectrum - or the colour red signifying infrared (a 'redder than red' light), opening the way for "optical consistency" (Latour, 1990: 27). Following this, the colour as analogy dynamic manifests itself in the aforementioned use of colour as a "homogenous graphical language" (*ibid*: 66) in astronomy, enabling images to combine different wavelength sources which are blended through colour (*see Figure 14, 17, 29, 30, 31).*

Moreover, the use of red, green and blue filters *mimics* the working of the human eye – bringing the transmission of light, the transmission of the image, and human perception into focus through technical analogy, enabling the image to "mirror visual perception" (Kessler, 2007:488). The analogic use of colour hints at the process of translation at work: through tiny technical jumps of 'AND/OR' (Latour, 1991; 1992), or movements of association and substitution, a relationship of equivalence and transformation is created, clearing a path to reference. Blue for example, is made into the *equivalent* of ultraviolet light (reference) – which is *transformed* into the colour blue (technical transformation of raw material). The chain of reference rests on a delicate balance of continuity and discontinuity.

Colour is *dematerialized* in astronomical techniques of visualization, as it is in both the hard sciences generally and within anthropology (Young, 2006) – manifesting another of those jumps from matter to form. In the former, colour is "dematerialized into light" (*ibid*: 175) (in the electromagnetic spectrum) following the Newtonian legacy where it is not a property of things, but the amount of a certain kind of light reflected off things. Anthropology compounds this dematerialization by privileging the symbolic nature of colour, as "standing only for a meaning that lies elsewhere, beyond the colours of things" (*ibid*: 174). Both approaches intersect in astronomical images: they enact a largely symbolic use of colours, which "stand for something else beyond and in this sense are representational" (*ibid*: 178) – this 'something' being the underlying physical processes and properties of stars, galaxies, etc. Moreover, colours here are symbols in the Piercian sense: they have primarily – and even necessarily - an arbitrary relation to their referents (Peirce, 1977), used in conjunction with "contrast, exposure and scale" as ultimately "arbitrary ways of presenting an invisible phenomenon" (Lynch & Edgerton, 1988: 200). This symbolic/arbitrary status is nevertheless geared towards representational ends, where the goal of colours is to represent knowledge and communicate it (Young, 2006) to fulfil the propositional purpose of the image.

These categories of colour are problematic, both in terms of their relationship to perception and to reference. The 'false', 'pseudo' and 'true', 'natural' colour terms denote contentious categories within the astronomical community. Astronomers view the first two as misleading because they imply that their images are fabricated, fake or misrepresentative (Rector, 2007**;** Spitzer Science Centre, 2010), preferring the terms 'representative' or 'mapped' (Credner, 1999). This is indeed how many non-scientists understand them when discovering that the colours are applied after the fact through digital image processing, demonstrating the stubborn assumption that "objectivity is supposed to be acheiropoiete, not made by human hand" (Latour, 2002:16). Moreover, the categories 'true' or 'natural' can never be wholly accurate descriptions since "no astronomical image accurately represents the appearance of an object, as the human eye's sensitivity to colour is very complex and nonlinear" (Rector, 2007:607) – they can not perfectly reproduce the object's visual appearance, but only mirror our visual perception. The answer to the question 'is this what it would really look like/what we would see' is in short no, but this is ultimately a misplaced question, since "the purpose of a telescope is to show what the eye cannot see" (*ibid*).

The uncomfortable use of the term 'false colour' within astronomy, the shock which many lay-people feel when discovering that most astronomical images are 'false colour' and not what we would really see, and their ensuing assumption that they are thus somehow fake or untrue, all derive from and point to the stubborn association of truth with (human) sight. This conceptual pairing has haunted photographic images since the invention of the daguerreotype (Jay, 2005), attributing to the camera the status of 'pencil of nature' (Talbot, 1844). Astronomical imaging is viewed with the same "assumption of photography's fidelity to the truth of visual experience" (Jay, 1995:345) – though it shouldn't be taken for granted that it is the truth of *human* visual experience that orients lay interpretations of the photograph's veracity. For astronomers however, working with techniques, media, images and of course phenomena which are materially and conceptually detached from an *anthropocentric* 'view' of colour and light, the 'truth to nature' link is ruptured, and from it bleeds something akin to Michael Taussig's implicitly phenomenological concept of colour as "polymorphous magical substance"; as a heterogeneous, hybrid and metamorphic "chameleon substance" (2008: 4) (see *Figures 17* to *22*). Indeed, as Jim Bell, the lead scientist for the Pancam colour imaging system on the Mars Exploration Rovers (MER) explains:

We actually try to avoid the term 'true colour' because nobody really knows precisely what the 'truth' is on Mars. Colours change from moment to moment. It's a dynamic thing. We try not to draw the line that hard by saying 'this is the truth!' (Atkinson, 2007).

Don Ihde suggests calling false colour "relative colour", since "the implication of a 'true colour' is frankly irrelevant" (2011:113). Behind all of this is the hint of a colour mutually out there and in the mind, or a colour (technically) made to negotiate both; in Paul Cezanne's words, "colour is the place where our brains and the universe meet" (Merleau-Ponty, 1964:180, as cited in Young, 2006:176). The image becomes a median place where colours are "mutually constituted by things and persons" (2006:176), echoing the intersubjective view of colour found in phenomenology and which now prevails in colour science. But here, it is also a literal and *technical* mutual constitution of colours by things and people, or humans and non-humans, the body and the medium: in networks where telescope filters mimic the colour-cones and sensitivity of the human eye, where images are created through a mixing of aesthetic choices and machinistic perception (Lynch & Edgerton, 1996), are filtered through a computer screen's still limited colour range and are tailored to the colour horizons of our eyes.

From all of this, we can discern a gradual "distribution and allocation of categories" (Latour, 1993b:376) of colours (and by extension light) as these are mobilized along the network of techniques, undergoing the work of *purification* (at once conceptual and material) done by astronomers *and* image-mediators – and through which the categories of the (in)visible take shape. Colour is purified and abstracted through "metrology", the "organization of stable measurements and standards" (Latour, 1990:57): colours are carved up into wavelengths of light, quantified into pixels and bits and grids where "visual phenomena are parcelled out in discreet pieces" (Elkins, 2008:66) and distributed along a classificatory spectrum which stretches between the two poles of 'true' and 'false', categories which in part shadow human optical perception. These techniques influence the way we *perceive* the world, bodily, materially and *conceptually*.

And yet, the lack of convention and consensus in the uses and classification of colours, the mixing and layering of colours, their shifting meanings, all hint at the instability of these categories. Astronomical images play out the "struggle to systematize unruly colour" (Young, 2006:178), and yet are built upon hybrid colours which borrow from the human and non-human spheres, mixing natures and cultures (Latour, 1993a): human *nature* (our bodily perceptual capacities), a *nature* 'out there' (in light, physical-chemical processes), and the *culture* of astronomers, techniques, technologies and media. All are mixed in the narratives and methods wielded by astronomers, and in their images, producing colours that *melt* through and across them, like that polymorphous magical substance, demonstrating how "colours seem to be too many things at once" (Young, 2006:174). As Taussig puts it, "neither fish nor fowl, colour is anarchic, spreading across categories and disrupting them" (2009: 244). Through its inherently metamorphic character which enables it to slip through categories and neutralize boundaries, colour manifests the process of mediation and hybridization (Latour, 1993).

The false, true, representative, enhanced colour categories are nestled in and oscillate between these different 'natures' and 'culture', and overlap much like the different colour filters are made to. Light and its colours are transacted between and translated across these different realms. Importantly, the chromatic imaging techniques and concepts outlined above are mobilized and built up through the *simultaneous* work of purification (creation of bounded categories) and work of mediation (proliferation of hybrid entities, including multi-wavelength composite images) done by astronomers and their images, and play out Latour(1993a)'s argument that these processes go hand in hand in the realm of the [non-] moderns.

6.3 Astronomical [Un]realism

Following Young's call to look at what colours do, here colours do the work of both perception and reference. Colours let us 'see' the referent, and as such perception is enfolded into reference. As hinted above however, the relationship of reference, and the representation of the referent, is complicated by the non-visibility of the referent.

The interrogation of sight and denaturalization of visual experience, instigated by the invention of the camera and leading to a crisis of occularcentrism in 20th century French thought (Jay, 1995), are intensified in astronomical visualization. The images of telescopes are structured by this same tension, best expressed by Jay when he writes that, "photo-unrealism always shadowed the camera's celebrated ability to provide a truthful image of the real" (*ibid*: 350). According to Lynch and Edgerton, the image processing and cleaning of raw data previously explored manifest a certain "representational realism" (1988:200): images are made more visually coherent and tidy by sharpening contours, enhancing resolution and so on; both to facilitate analysis and to make them appear more natural or realistic. Moreover, this represented realism is no doubt what underscores astronomers' disapproval towards the 'false' colour term, since colours are assigned in images according to their representational significance.

This is however mostly a *simulated* naturalism or realism, guided by the spectre of the 'notional referent', since the image is "shaped according to assumptions about what the object should look like" (Lynch, 1991:211), as can be seen with the comparison between a 'real' and simulated source (*Figure 35*). This in turn expresses a mediated and interventionist realism (and a mechanical, interventionist objectivity), and not one based on verisimilitude and isomorphism. Here, the term and practice of realism contains its opposite, an 'unrealism' guaranteed by the phenomenon's invisibility. They cannot be directly observed and thus, like the biological representations studied by Lynch, astronomical images are "the only way phenomena can become materially witnessable" (1991:208). Even more so than with the DNA strands, bird migration routes or brain cells visualized in biology, there is no way to compare a representation of a galaxy or quasar "to the 'real' thing, since the thing becomes coherently visible only as a function of representational work" (*ibid*); the referent is made within the image.

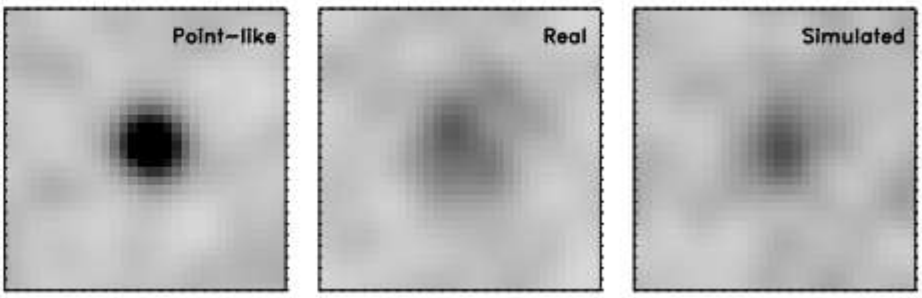

Figure 35: *Comparison between x-ray image of distant galaxy cluster (centre), a point source (left) and a computer model* (right) (Rosati et al., 1999). The image labelled 'Real' is what the telescope actually saw. To ensure the referent wasn't a point like source like a star or quasar, they programmed a simulation to compare it to "what a galaxy cluster in that part of the sky *might* look like" (Elkins, 2008: 83), and the resulting "Simulated" image confirms it is of the right shape and intensity (see also Elkins, 2008).

Thus, questions of resemblance, verisimilitude and naturalism become tangential, since the referent is absent – we only have the almost stand-alone sign-image, one half of the sign-referent pair, which in a sense folds into or collapses onto itself – echoing the recursivity or self-reflectivity of the visual. This is reminiscent of Derrida (1976)'s deconstruction of the sign, through which he posits that the signified could itself be a trace of the signifier, an idea taken up by Lenoir in his study of mediating machines and inscription practices in science where he argues that they "create the space within which the scientific object exists in a material form" (1997:12), where it takes residence. This is another instance of the image-act, where the image in a sense makes the referent and acts on the phenomenon. As a mediator, the image doesn't merely *reflect* its referent, or *mirror* its visual appearance – instead it makes and forms it, at the very least, visually.

In other words, as Latour shows in relation to scientific inscriptions, the astronomical image "does not resemble anything. It does *more* than resemble" (1999:67, original emphasis). In the most concrete and immediate sense, the goal of these images is not primarily to see the object, but to see the physics [of the object], thus shifting their role "from being a 'photograph' to being a representation of the science" (Rector, 2007:598). Interestingly, this purpose - not to show the 'true' appearance of the object or "at least not as defined by human vision" (*ibid*), but to illustrate its underlying physical properties –resonates with Merleau-Ponty (1964)'s phenomenological approach to vision and particularly his analysis of painting.

Significantly, William Mitchell (1994) aligns digital imaging processes with painting and not analog photography. Indeed Lynch and Edgerton explore at length the painterly qualities inherent to the technical process of astronomical digital image processing, and the pixel-by-pixel modification of images via what they call "electronic brush-strokes" (1996:117). For Merleau-Ponty, the graphic trait and brush stroke do not aim for mimetic representation and instead are attempts to give form to the internal equivalents present in the painter's visual experience. From this, painters, much like astronomers, strive to open up new visual configurations and ultimately reveal the "invisible of the visible" (Foti, 2003:73). The subjective phenomenological and objective scientific methods travel in opposite directions but in this instance meet again in similar concerns with the (in)visible, with both painting (Merleau-Ponty, 1964) and technology (Heidegger, 1977) invested in processes of un-concealing and revealing.

Astronomical images do more than resemble: they "tak[e] the place of the original situation" (Latour, 1999:67) which is technically packaged into the format of an immutable mobile, substituting in one move both the phenomenon and the technical process. The image makes this original situation retraceable, by "allow[ing] for *passage* between what precedes and what follows it" (*ibid*, original emphasis), namely other images and inscriptions (including equations and eventually journal texts). Here again we find the image as place and as pathway, or as image and as medium. Although not 'realistic', Latour argues that scientific images manifest 'the real' in ways over and beyond resemblance. Digital photography is generally viewed as having lost its analog predecessor's privileged relationship to the 'real' (see for example Elkins, 2006a). Born out of the actual reaction of light on chemically sensitive material within the camera, the traditional photograph maintained a direct material causative link to its referent and, as a trace of the real, it attained the status of the Peircian index (Peirce, 1977). With its infinite malleability and inherent mutability, the digital's ability to tell the truth and show the real (or rather, the ease with which it represents what is false and fake) is continually put into question by the uncertainty which now structures the relationship between signified and signifier.

However, it is these very properties which make the digital the perfect medium, and its image the perfect mediator, for scientific reference and visualization, as shown for example through its chromatic mobilizations. The direct referent-sign link in analog photography is longer (more mediated) and more opaque in digital imaging – which is to say that the latter extends the chain of reference and networks of techniques, increasing the immutable mobile's mobility and enabling the increased circulation and multiplication and transformation of images and inscriptions. And, the longer a network or chain of associations, the more 'real' and durable it is (Latour, 1991). As Latour argues, "constructing a phenomenon in successive layers renders it more and more real" (1999:76), hence the use in astronomical visualization of multiple, convergent threads of reference, images and thus evidence (see Galison, 2002); the practice of layering multiple data sets (or images) into one composite image; juxtaposing and comparing the real, possible and simulated image versions of a phenomenon (*Figure 35*). All of these practices work to "stabilize" (Lenoir, 1997:12) the represented object.

The real is accrued along the network and technically achieved through, amongst other things, data reduction and image cleaning. Although the data/image captured by the telescope is endlessly transformed, this "does not imply that the 'raw data' gave a more accurate picture of reality than did a processed image" (Lynch, 1991: 211). Instead, the latter "can be held to provide more ‘trustworthy’ or ‘authentic’ evidence than the raw data” (*ibid*), which is constituted by a lot of surplus or erroneous details (blurriness, instrumental effects, other sources) which obscure the ‘*real light*’ and are thus framed and rejected (via the labour of realism during the technical process) as “‘noise’ to be eliminated rather than guarantors of the authenticity of the product” (*ibid*: 221).

Lynch writes that, emptied of its moral and epistemic primacy, the notion and role of the ‘original representation’ as closer to the truth and the real (an analog legacy) is destabilized in digital and scientific imaging. The difficulty in speaking of an ‘original’ image of any particular astronomical phenomenon can be traced back to that chicken and egg question of what comes first, the data or the image. Instead, the original is lost or spread out in a proliferation of copies where we find endless performances of the same data: pictures, tables, maps, graphs, simulations and even formulae which metamorphose into each other at the touch of a few keys, to the extent that “no single visible rendering ‘stands for’ the original object” (*ibid*).

Where the real in analog photography is understood as residing in the original, in digital scientific imaging, the real is to be found at the end (when culminating in theory), and especially all along, a chain of visualizations. In other words, whilst the referent *adheres* in the analog photograph, which “always carries the referent with itself” (Barthes, 1993:5), in digital and scientific visualization the referent *circulates* along and across a chain of images (Latour, 1999). Here, the relationship of reference is not immediate, but one of mediation – where the phenomenon is momentarily punctualized in images, enabling what Knorr-Cetina (1988) refers to as the ‘fixation’ of visual evidence.

Chapter 7: The Spectrum of Visibility

7.1 The Visual as Excessive and Elusive

Every stage in this chain is separated from the stage that follows by "a gap that no resemblance could fill" (Latour, 1999:69) as things travel from matter to form, a gap structured by a "dialectic of gain and loss" (*ibid*: 70) where the phenomenon sheds matter and gains form in a process of abstraction and filtering, loses particularity, locality and materiality but accrues standardization, calculation, circulation and *visuality* in the same move of representation. Ultimately, argues Latour, they forfeit resemblance for reality/reference. This 'gap that no resemblance could fill' also runs along our visual horizonal limits and, as phenomena cross this boundary, there is also a gain and loss of the visual. In the image the phenomenon is made visible, it *gains* a human visibility – and yet as it circulates across these technologies and is filtered through the screen and moulded to our senses, as it undergoes data compression and image processing, other kinds of visibility are lost: it is chromatically distorted and simplified, some of its light is excluded as noise, its full brightness cannot be visualized by our computer screens or reproduced in our colour print outs.

These phenomena are at once visually *excessive* and *elusive*; their light alternatively exceeds and eludes their images-to-be. The technologies can be blinded by these lights (as with the diffraction spikes) which spill over the images, as they struggle to contain the referent/light through simplification and abstraction (for example, the brightness or light intensities and range of colours actually exceed not only the perceptual capacities of our eyes, but the representational capacities of digital monitors). And somehow, they are not visual or visible enough, as can be seen by astronomers' constant battle against the tide of recurring blur, fuzzyness and irresolution of referents which remain "elusive, ill-defined, mobile" (Elkins, 2008:60; see also Lynch & Edgerton, 1988) (see especially *Figures 3, 4, 5, 6, 26, 32, 35*, and *Figures 36* to *41* below). This is especially relevant and visually explicit in the non-pretty scientific pictures presented by my astronomers, but is also true of the 'pretty pictures' where 'blur' and elusiveness are denied – made invisible even - and hidden under a veneer of visual plenitude, the visual *excess* of techni-colour and twinkling stars (*Figs. 15* to *22*).

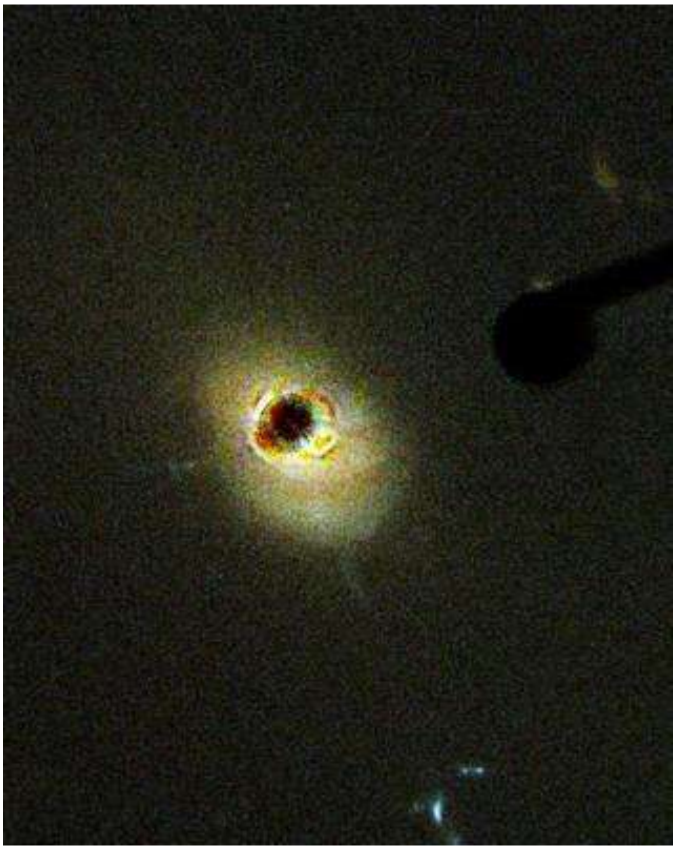

Figure 36: *Nearby Quasar 3C 273* (NASA et al., 2003)

Previously unseen features of a galaxy are revealed in this image as the light from its central quasar is blocked out by the instrument, which is present through the 'instrumental effects' of the black shape towards the top (STScI, 2003b).

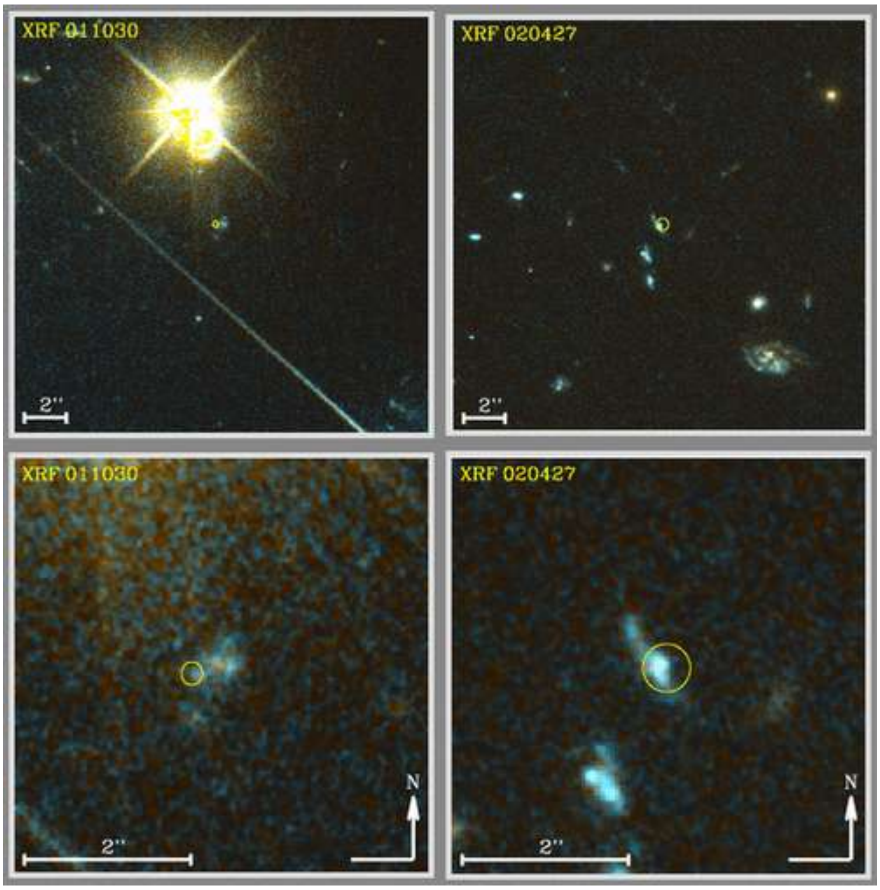

Figure 37: *Images showing location and host galaxies (blue objects) of two x-ray flashes* (NASA, van Dokkum, Bloom, 2003).

The bottom panels show (inadequate) close ups of the galaxies with "circles representing the Chandra X-ray positions of the "afterglow" light from the flashes" (CXC, 2003)

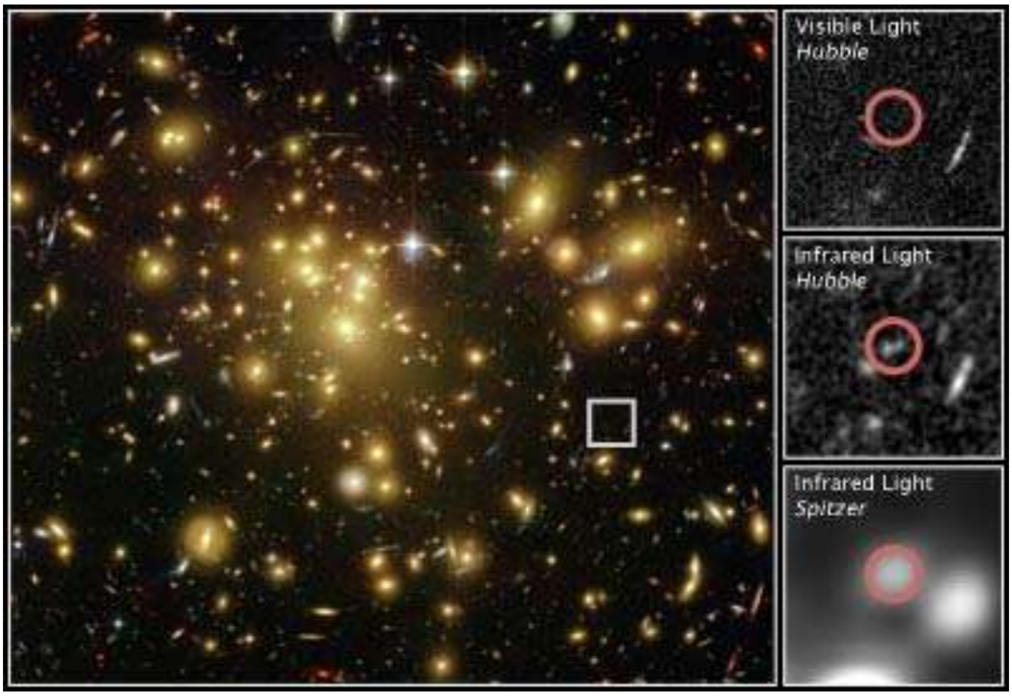

Figure 38a: *Galaxy Cluster Abell 1689 and galaxy A1689-zD1* (NASA, et al., 2008a)

A massive galaxy cluster located 2.2 billion light-years away and named Abell 1689 (left) acts as a natural cosmic ‘zoom lens’. Through the process of gravitational lensing, it bends and magnifies the light of much older and fainter galaxies located far behind it, revealing “one of the youngest and brightest galaxies in the early Universe" (STScI, 2008b): A1689-zD1 (images on right) estimated to be 12.8 billion light-years away.

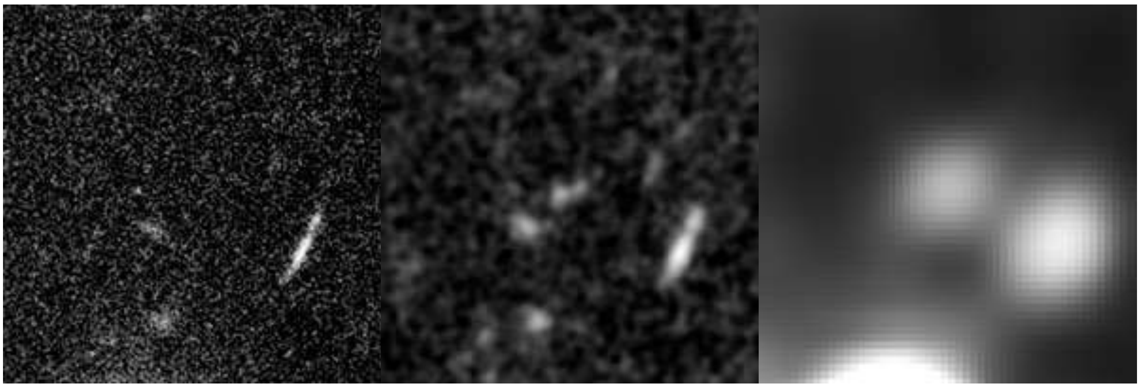

Figure 38b: *Three close ups of galaxy A1689-zD1* (NASA, et al., 2008b)

The galaxy is so far away it does not show up (is invisible) in the visible-optical light image (left); it “appears as a grayish-white *smudge*” in the Hubble infrared image (center) and as a “whitish *blob*” in the Spitzer infra-red close-up view (right) (STScI, 2008, emphasis added). It remains an irresolvable blur in these images.

These are fragile images, which need to be fixed and stabilized. This oscillation between fragility and stabilization is another duet in this play of gain and loss. This is a fragility that Latour argues we need to recognize in all mediators and technologies, which depend for their durability on their alignment with other non-humans and humans in long chains and networks which, when ruptured, reveal the “eminent weakness” (2000:19) of things (see also Latour, 2002). When these are chains of reference, this fragility underlies scientific signification, which breaks down when one node in the network is removed (ibid: 1999). But this is also a “visual fragility” (Elkins, 2008:89) of images which, in inadequately representing or signifying the original phenomenon, simultaneously signifies both its existence at dizzying reaches of space and time (the images in *Figs. 38, 39, 40* depict objects that are only a few hundred million years younger than the universe itself), as well as the indeterminacy, inadequacy and incompleteness which Elkins (2006b) argues are inherent in all visual representation but are brought to the fore and rendered *visible* in these extreme images. Elkins (*ibid)* develops the three working concepts of the unrepresentable, the unpicturable and the inconceivable to explore this idea.

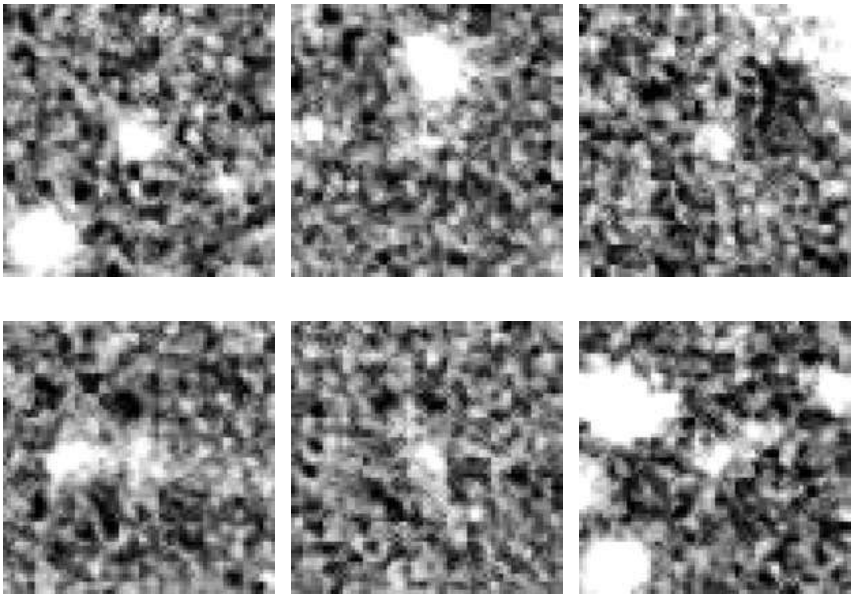

Figure 39: *Six Primordial Galaxies at the End of Representation* (NASA, et al., 2012) Each image visualizes a newly discovered galaxy from the Hubble Ultra Deep Field, the follow up to the Hubble Deep Field. These are previously unseen primitive galaxies which formed more than 13 billion years ago and are amongst the very oldest and farthest objects ever detected.

The excessive and elusive quality of astronomical images can be traced back to the realm of the unrepresentable which denotes "whatever is understood to be not susceptible to representation within any given image-making practice or context" (*ibid*: 4) due to the limits of the medium. It is therefore mostly a technical matter: temporal sequences and texture are for example unrepresentable by and in still photography. Astronomical images are often "inadequate representations of their subjects" (*ibid*) because they are made at the limits of visual instrumentation, one which is however constantly improved, as will be seen when the new generation of super telescopes are put into operation over the next decade (McKie, 2011). As Elkins writes, "unrepresentability narrows with each successive medium and technical innovation", the unrepresentable is thus "a continually shrinking domain" (*ibid:* 6). The unrepresentable is transformed into the representable as new technologies activate and expand the visual, thereby shifting the boundary between the visible and invisible.

This mobile boundary is porous however, and as blurry, fuzzy and ambiguous as the images that cross it, hovering between resolution and irresolution. A lot of these images are made at the limits of instrumentation and lie at the "end of representation" and as such are the epitome of "images that d[o] not simply depict objects, but demonstrate how some objects resist depiction" (Elkins, 2008: xv). Although, as images, these remain squarely within the realm of the *visual*, the 'what' of the image, the objects they try to depict, can sometimes only be described as both *visible* ("in the sense that they are unambiguously recorded") and *invisible* ("in the sense that there is almost nothing to see") (*ibid:* 111) (see especially *Figures 5, 38, 39, 40* and the flat, hollow, colourless and almost counter-intuitive image in *Figure 41*).A lot of these referents are barely seen, their properties partially retrieved, so that many a galaxy is known only as a few hundred pixels or less (as in *Figure 40a*), which is all we have to see instead of the millions of stars and dust particles that actually comprise it (Elkins, 2008). The images taunt us with their faint, blurry, pixelated, formless, unresolvable, dot-like referents which force astronomers and laymen alike to confront the question of what counts as an 'object' . And just as when we have a blurred, out of focus vision, we are seeing and also not-seeing; these images denote the unseen just as much as they depict the seen, precisely because what is seen is so strikingly lacking and inadequate. They are "just barely sharp enough to provide something to see", or even "to prove that there is something out there to be seen" (*bid*: 91), and yet properties of the objects have been retrieved, visually and otherwise, so that the image, however inadequate and partial, can eventually attain the status of referent.

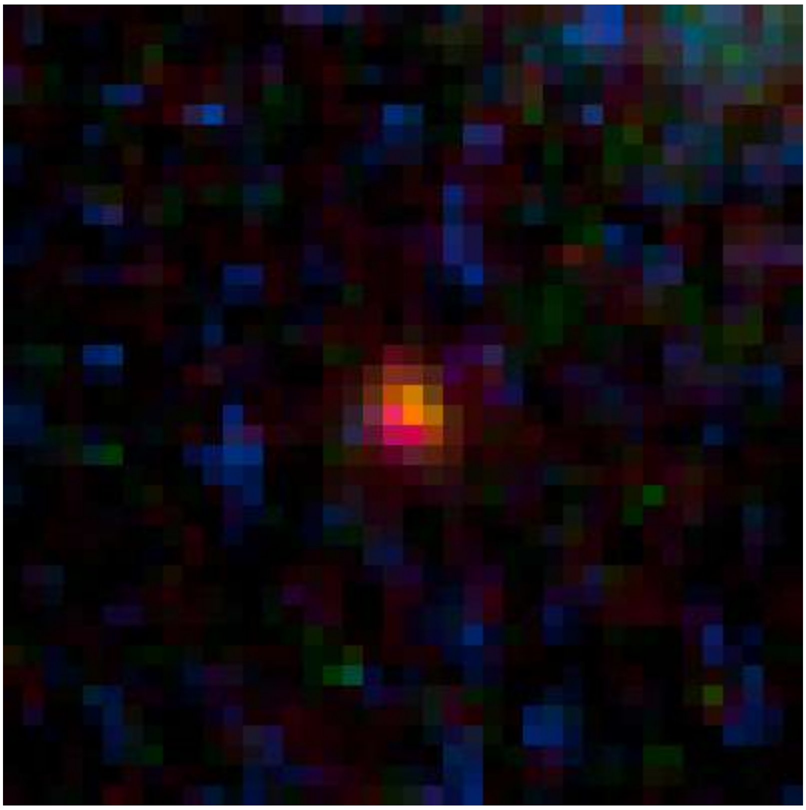

Figure 40a: *Lensed Object MACS0647-JD1* (NASA, ESA, STScI, 2012)

This galaxy is observed 420 million years after the big bang, its light having travelled 13.3 billion years to reach Earth. It is a candidate for the most distant galaxy ever seen (STScI, 2012)

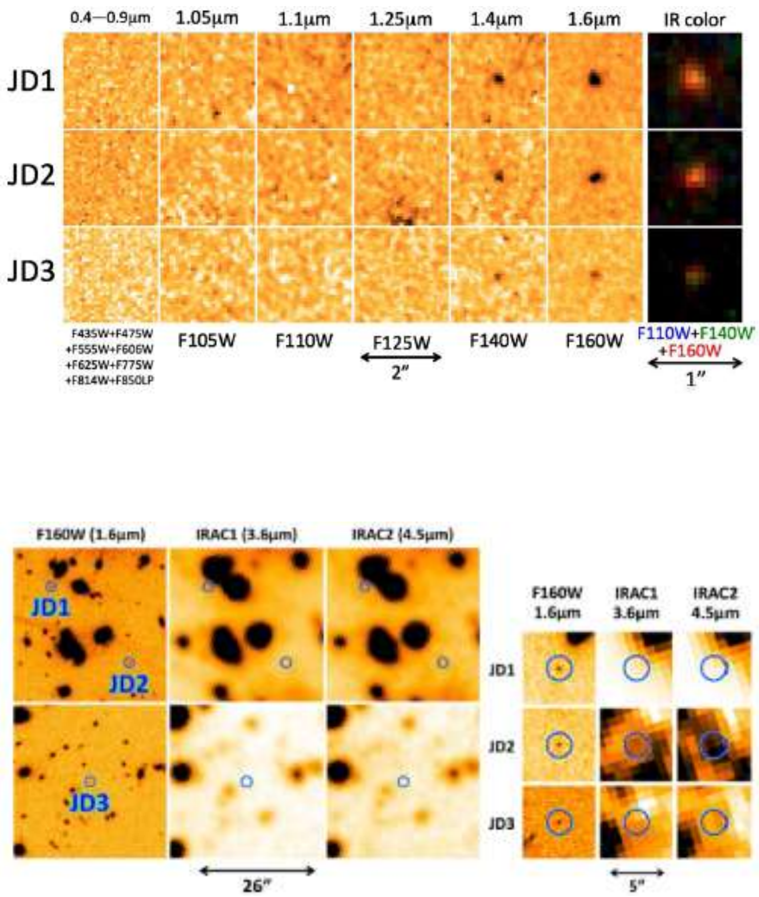

Figure 40b: *Three Strongly Lensed Images of a Candidate z≈11 Galaxy.*

Images of same galaxy as *Figure 40a*, MACS0647-JD, used as journal article illustrations, taken from The Astrophysical Journal article (Coe, et al., 2013)

These figures visualize three separate images taken of MACS0647-JD, shown in various filters and taken with various telescope cameras.

Because of its great distance, the galaxy's light "took a detour along multiple paths around" (STScI, 2012) a massive galaxy cluster which acts as a natural telescope, magnifying the galaxy and creating several images of it. Through this process of gravitational the research team observed three separate magnified images of MACS0647-JD with the Hubble telescope, shown as JD1, JD2 and JD3 above.

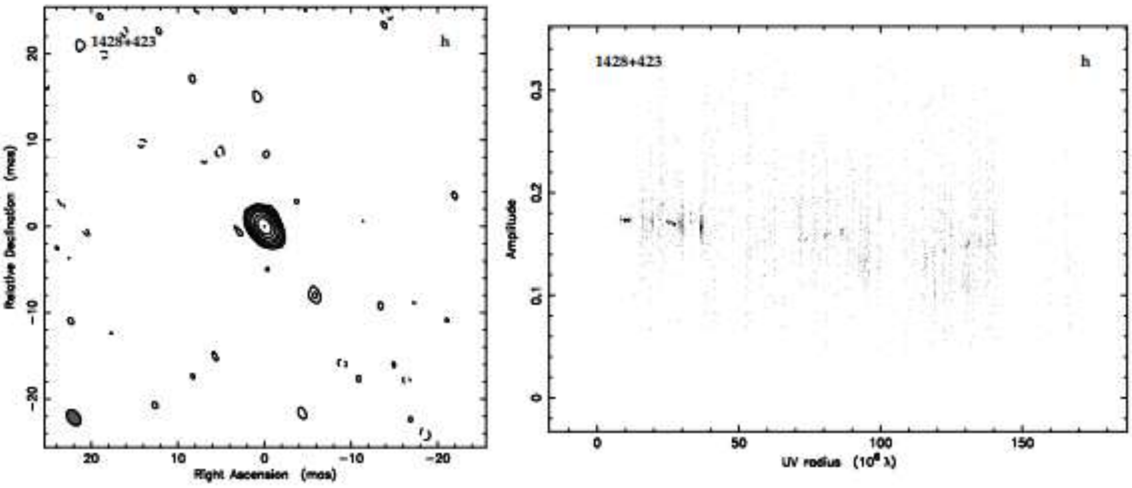

Figure 41: *A radio-loud quasar with redshift z=4.72* (Paragi et al., 1999). This “barely resolved” (*ibid*: 1) quasar (left) was at the time the most distant of its kind seen. It needed eight different radio antennas to be seen. The information they gathered, including strength of signal, is plotted on the right. The image on the left is closer to a “graph posing as a naturalistic picture – asking to be read, illegitimately, as a picture” (Wrixon, Callanan, Elkins, 2007).

These are objects which lie not simply beyond our own visual threshold, but beyond the visual horizons of our instruments, objects which are “waiting to be seen” (*ibid*: 104). Following this, astronomical visualization points towards a ‘second order’ optical unconscious; they hint at things “covert enough to find a hiding place”, not this time in *our* “waking dreams” (Benjamin, 2005:512) and experience, but *in the images themselves*. This is seen most clearly with the Hubble Deep Field images, which have undergone repeated attempts by physicists to discern “entirely new structural formations of the subject” (*ibid*, 1936:236-7) among and beyond the dark pixels, to see if even fainter galaxies and objects are hidden in the darkness [of the image] – especially given the background in the Hubble Deep Fields (*Figure 26*) is not a uniform black (see Vogeley, 1997; Park and Kim, 1997, as cited in Elkins, 2008).

Elkins defines the unpicturable as a “conceptually amorphous realm of experiences that are understood to be outside the realm of representation”, that which contributes to the making or taking of the image, is “conceptualized by the maker or the initial viewers, but not in visual form” (2006b: 5), although it can leave traces in the image. As an example of this, Elkins cites the affective experience felt by the maker of the picture, or of those pictured in it. Following from the first part of this paper however, I argue that what is primarily and most interestingly unpicturable in astronomical (and other) images is the technical process through which that image came into being – since, as previously argued, techniques are essentially unseeable (Sigaut, 1994).

Another kind of invisible present (or absent) in the image is the inconceivable: everything that "does not present itself to the maker's or viewer's imagination at all, either as a picture or as an unpicturable property", or that which does "not present itself as a visual phenomenon that [i]s appropriate, necessary, or possible" (Elkins, 2006b: 5) for imaging. This is an open ended category, since "all things not part of the conceptualization of a picture belong to it" (*ibid:* 9). The concept of the inconceivable becomes particularly intriguing and productive when paired with *scientific* images. Indeed, in terms of their relation to theory, and their roles as agents of discovery, they have a broader scope for the inconceivable. Given how they reveal the optical unconscious, they show what is previously unseen and thus what is previously unimaginable and often unimagined, as shown by the unexpected revelation of the Hubble Deep Fields. Moreover, due to their specialized propositional content, the realm of the inconceivable in scientific images varies radically according to the viewer; the information which reveals itself to an astronomer is concealed, often inconceivable, and thus invisible to a layman. Another, more underlying dimension of the inconceivable structures astronomical images: they represent scales and orders of magnitude such as the distance, size or age of objects in the universe with are so vast they are "inaccessible to intuition" (*ibid,* 2008:89 and literally unimaginable.

In his discussion of Immanuel Kant's conception of the mathematical sublime, Elkins (2008) discusses how calculation takes over from intuition in images in physics and astrophysics which represent such magnitudes (whether in the micro or macro realms). Moreover, not a lot within these images at the end of representation "is visible without mathematical help" (*ibid*: 108) (see also Lynch (1988) on the 'mathematization' of visual objects in science). And so, just as in order to see stars we need to look down at images, to properly see these images, we need to look to mathematical calculations and simulations (*Fig. 35*). There is something of the Medusa in these cat and mouse games of the visual, as neither she nor astronomical phenomena (or indeed their images) can be gazed at directly. If Medusa can only be looked at via a mirror, then the latter are only seen through a metaphorically broken mirror: the visual in astronomy is always already deferred, mediated and fragmented. This is literally the case when considering gravitational lensing, through which celestial objects are fragmented into separate images which are then detected by telescopes (see *Figure 40*).

The ‘visible’ and ‘invisible’ emerge from all of this as crude and clunky terms and analytic categories. Indeed, within the invisible we can discern different modalities of the unseen or unseeable, starting with Elkins’ (2006b) unrepresentable, unpicturable and inconceivable. In this sense, images do not merely “perform an absence, which they make visible” (Belting, 2005:313) (the absent referent), but they perform these other kinds of absences, which remain paradoxically invisible whilst still being somewhat present in the image. These three absences/invisibles explored by Elkins influence and undermine each other and their image, and structure images differently, depending on the specific ‘what’ and ‘how’ configurations of each image, as well as the ‘who’ is seeing them.

7.2 The Movement of the visual.

Astronomical images are strange creatures. Whether on screen or paper, they are flat and smooth, existing in an inconspicuous and apparently effortless format. These images are however thin slices of incredibly complex space-time-human-non-human networks of light and techniques which have gathered and shed matter and visibility along their trajectories. The visual and the visible are constructed, not only as categories, but *materially*, by non-humans and human astronomers engaged in the *technical* works of purification and mediation of imaging and visualizing techniques.

Looking at an astronomical image in isolation misplaces the visual, which should instead be understood *as* a movement and process. It is always in the process of being transmitted, whether from the image to the eye (Belting, 2005), or from a star to a telescope. The visual, especially in scientific practice, should instead by located and *seen* through “the series of transformations for which each image is only a provisional frame” (Latour, 1998:421). The punctualisation, or stabilisation, from which the astronomical image emerges, “is a process or an effect, rather than something that can be achieved once and for all” (Law, 2003:5); spawning immutable mobiles which elude fixity. There is thus “*nothing to see* when we do a freeze frame of scientific practice and focus on the visual itself instead of the movement, the passage, the transition from one form of image to another” (Latour, 1998:421, original emphasis). It is in these medial spaces of in-betweenness, the "transaction sites" (*ibid*, 1993b:395) between humans and no-humans, the dark "interplaces" (Casey, 1996:32) between images that the visual germinates and awaits activation into visibility, and prepares to perform the visible through the 'image-act'. One could argue that the *visual* is always present and possible (or at least it has been since a few hundred million years after the Big Bang, before which the Universe was opaque to photons) but not always *visible*. It instead resides in a state of *potentiality*, which is probed and activated through astronomical techniques of visualisation.

The visual is in effect always in the process of visualisation, de-visualisation and re-visualization, here in the technical-induced movements between light and images, and exchanges between humans and non-humans. Techniques of visualization and their images - or the visual verb and its noun, to paraphrase Law (2003) – flit in and out of focus in a game of hide and seek. Whilst techniques render images visible, images tend to hide their techniques. When networks are concealed, we have the 'visible', and when networks are revealed and unravelled, the image disintegrates, and the invisible returns. Networks and techniques of visualization enable the stabilisation of light, as well as that of the visual – though only momentarily.

On closer examination, visualization is shown to be not one single 'thing', but a composite, heterogeneous process, formed by the cumulative and successive work of techniques, mediality (including digitality) and perception. These are all mediating processes, each a mode of revealing and unconcealing (and at times, concealing) which unravel the visual into and out of the image and compound the primary revelatory property of the visual. They allow for the passage, transition and transformation of light through its material, electronic, digital and visual states; transforming light into images into signs through a parallel movement of visualisation and "*movement* of reference" (Latour, 1999: 74, emphasis added) by which astronomical phenomena are technically seen and signified. Indeed, as Lynch and Edgerton write, astronomers are "faced with having to 'make' their objects at the same time that they reveal what those objects are" (1996: 122). As seen, this is not a one-way, but reversible and retraceable movement, wherein visualisation clears the path for the circulating referent, which ceases to refer when its movement is interrupted (Latour, 1999).

Moreover, these are not continuous, linear, uninterrupted movements, but processes which are propelled by a delicate balance of continuity and discontinuity, elegantly portrayed in

Latour (1990)'s imagery of the 'cascade' of traces or inscriptions separated by gaps. These are [discontinuous] transformations, transubstantiations and substitutions (change of state, from light to images, things to signs), displacements of immutable mobiles where something nevertheless remains constant (so reference is possible). This translational 'AND/OR' property is shared here by reference - a "way of keeping something *constant* through a series of transformations" (Latour, 1999:58) - and techniques, since this is a transformation of matter (Lemonnier, 1992)) where something of the original raw material is always present in the end product. Astronomical images are located (and to be studied) at the centre of this triadic constellation of reference, techniques and the visual. The visual's movement is also discontinued, or paused, when it is punctualized in the provisional frame of the image, which can perhaps be conceptualized as the material '*purification*' (and coalescence) of the visual, which also undergoes conceptual purification.

The visual within astronomical imaging practices is not a fixed, pre-existing or homogenous category. It is accrued, coalesced and, crucially, also lost along these networks of visualisation, circulated by a reference whose mediations involve a dialectic of gain and loss (Latour, 1999), including the simultaneous gain and loss of the visual. Indeed, astronomers have their own implicit and explicit hierarchy of the visual which filters out the visual, purifying and crafting their own categories of the visible, the invisible and the worthy of visualization, as seen in the discussion on real light. Indeed, when discussing his discovery of the farthest, oldest ever quasar (in *Figs. 4* and *5*), my astronomer-informant was very reluctant to show me the pictorial image reproduced here in *Figure 5*. For him it is an irrelevant and inconsequential image, it was not important enough to show, or even see, because the referent/light's 'real' information was contained instead in the spectrum in *Figure 4* and other inscriptions. This highlights how visualization is above all an epistemological process, and the visual in astronomy is shaped and discriminated according to what counts as appropriate evidence, whilst this evidence is itself "embodied in visibility" (Amann & Knorr-Cetina, 1988:134) - literally, in images. In their study of representations in molecular biology, Amann and Knorr-Cetina distinguish between data and evidence, and recognize visualization as the gradual transformation of the former (in the laboratory) into the latter (in journal articles), whereby visual objects undergo the process of "evidence-fixation" (*ibid*: 135). Thus, the thread of this analysis, in following the flow of photons to data to images, could have been reframed and redirected to chart the path of photons to data-image to evidence.

The visual culture of astronomy derives in part from the previously explored "distribution and allocation of categories, labels and entities" (Latour, 1993: 376) through imaging practices and techniques. It must be remembered, however, that they also have a highly theoretical origin, couched in indigenous scientific understandings of light, physics and optics which are beyond the remit of this paper. Those identified and examined here include the categories of the 'visible', the 'invisible', light, '*real light*', noise, the pixelised grid, the separate wavelengths and colours of the electromagnetic spectrum, true colour, false colour, natural colour and scientific versus pretty pictures; categories which are structured by conceptual and material processes of purification and mediation. These categories coalesce into a particular understanding of 'the visual' in astronomy, and its performance in images.

They are distributed along networks of (and *seen* by) humans and non-humans, and are partly formed (conceptually and materially) along technical processes of imaging. These visual categories are also *visible* categories, materially and technically made visual in images where light is transferred to the remit of sight, and light and colours are seen and perceived. They are still see-able, sensate visual and material forms or 'things'. Importantly however, these categories dissolve at the moment of perception, where the eye does not [sensorially] discriminate between the light from a diffraction spike and starlight, or between the 'false' colours in pretty pictures and the 'true' colours in less pretty pictures.

The visual in general terms holds a high position in this hierarchy, as the science of astronomy manifests a tendency towards what Elkins calls "habitual" and "compulsive visualization" (2007:29) (see also Galison, 2002). Indeed, one of my interviewees insisted that if an astronomical journal article contained no images, "*if you just have text, I don't even know if anyone would read it to be honest. So whilst [graphs, images are] not completely necessary, it would be a mistake not to include it*". This particular combination of word-image-data produced by astronomers is no doubt what Elkins (2008) refers to when discussing the particularity of scientific writing. Moreover, the balance of the visual in astronomy is heavily tilted towards the 'visible', as the invisible is gradually emptied out, and the unrepresentable narrowed, through progressive scientific discoveries and technological innovations stemming the tide of blur. The perfect example of this is the strange 'visualisation' of dark matter (which is by definition invisible, emitting no photons) or the Hubble Deep Field images.

Techniques of visualisation do not however weave a straightforward linear path from the invisible to the visible, just as it makes little sense at this stage to think in terms of a fixed visible/invisible binary. Several orders of the (in)visible come into play: the visuality of the technical process and the visuality of the referent together structure the astronomical image and both need to be taken into consideration in its study. Techniques and referents are both, but separately, at once invisible and visible. Techniques are inherently invisible and yet sometimes leave traces in the image. The referents in astronomical images are often only partially, inadequately seen and thus share qualities of the invisible and visible. When both technical and referential dynamics of (in)visibility come into play in the image, a dialectic of opacity and transparency, of yet another play between the visible and invisible, is set into motion. Astronomical technical processes (which engender the image) are concealed, thereby revealing the referent (in the image), activating the image into a referent, into a transparent mediator-disguised-as-intermediary pathway back to the original phenomenon. We are no longer dealing with a visible/invisible binary but several invisibles and visibles; a hybrid category of the (in)visible.

The fragmentation of the visual into a plurality of visibles and invisibles is further compounded by the counter-intuitive fact that the visible stands for the invisible. Firstly, the visible (stabilized, punctualized) image stands for the invisible network (see Law, 2003) (in the forms of the technical process and the digital swirl of data). Secondly, within the image, the visual becomes a metronomic tool as visible light and colour are used to represent and signify humanly invisible light, forcing us to consider both human and non-human orders of the visible and invisible. Moreover, the image – that most visual of objects – does not always exist on the level of the visual or visible within astronomy, when it is in the form of data (Galison, 2002). All this hints at the presence of different gradients of 'invisible' present in or structuring images, which alternatively frame or exclude things which are unpicturable, unrepresentable, inconceivable. As discussed, these images do not perform or presence a single absence (Belting, 2005), but a plurality of absences.

What results from all of this, emerging from astronomical images, imaging techniques and visual practices, is a whole greyscale stretching out between the two poles of the (in)visible, a 'distribution' of the visual (Ranciere, 2006) throughout a whole *spectrum of the visible*. In its broad usage, the concept of spectrum (originally meaning 'image' in Latin) denotes variations on a continuum, related things which are ordered and classified in a series or sequence. In the electromagnetic spectrum, the category of light indigenous to astronomers, “there are no hard boundaries to each spectral region; they just blend together into a continuum of smoothly changing wavelengths” (Blair, 2004) like the colours of the rainbow, and even the boundaries themselves are ill-defined to the extent that the different regions overlap (see *Figure 42*). In coining this concept, I am using an optical analogy to emphasize how light’s spectral properties are mirrored in its sign-image, as astronomical images are structured according to, and manifest, a *spectrum* of visibility, which, like the original electromagnetic spectrum, incorporates the invisible. The spectrum of visibility – the spectral quality of the visual and visible in astronomical imaging - is manifested in the fragmentation of the visual, it is constituted by variations on a visual/visible continuum, overlapping visual entities and different kinds of visibles and invisibles which blend into each other, yet are ordered and classified and distinguished, but again along ill-defined boundaries. Inherent in all of this are the alternating, complementary processes of mediation and purification which Latour (1993) argues are inextricable in the modern world and which are also latent in the indigenous astronomical spectrum of light: a pure but heterogeneous category, internally structured by the purifications and hybridizations of its composite wavelengths.

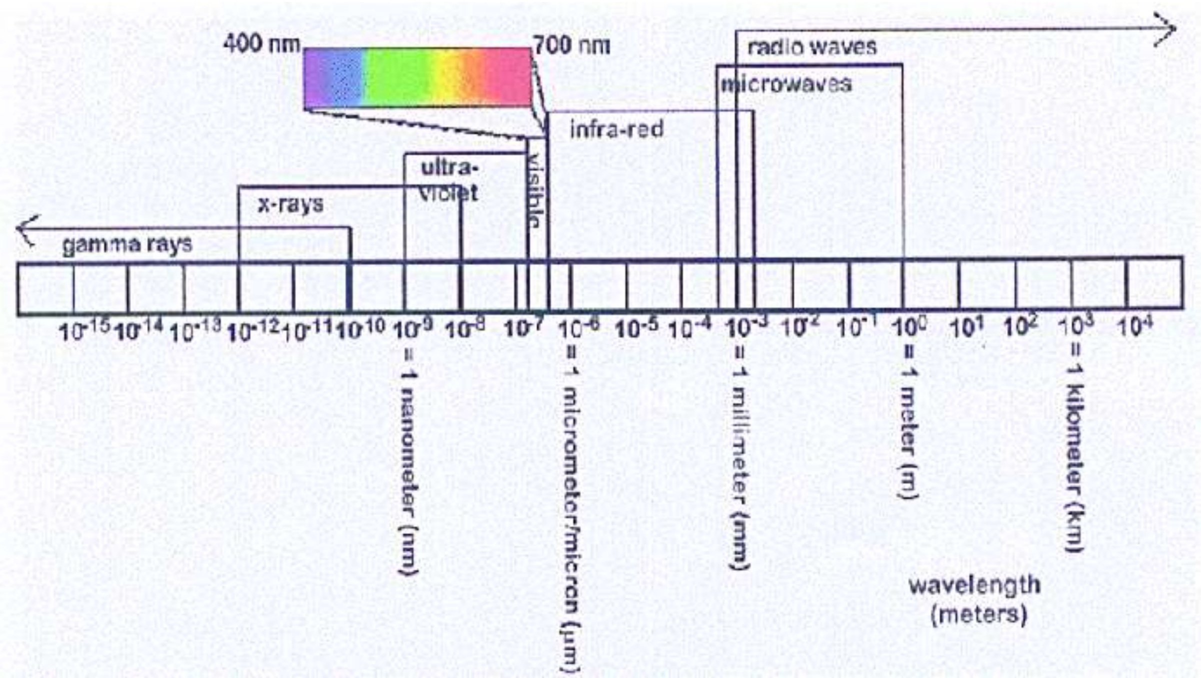

Figure 42: *The electromagnetic spectrum, showing the different regions of light overlapping.* For example, a part of the x-ray and ultraviolent light ranges occupy the same wavelength frequency.

In this sense, there is a complementarity or affinity between the trope of the spectrum and the framework of networks underpinning the present analysis. They share a topography of linkages, connections and “mixture”, acting as scaffolds for the “intermeshing of phenomena” (Strathern, 1996: 522) as well as their stretching out, fragmentation and distribution – in this case of the visual. Moreover, this spectrum of visibility is as much technical as it is visual, it is the exact counterpart and result of the networks of light and imaging techniques charted thus far. These lend themselves to the bricolage of what is essentially a very strange ‘hybrid-visual’ entity manifested in the part digital, part material, sometimes visual, mostly encoded, pixelised image built out of a hierarchy of light.

The visible and the visual in astronomy are forever skipping between these different categories and processes and manifestations because it can never be totally and permanently stabilised. The visual itself is an immutable mobile within astronomy, jumping from one host-matter or form to the next like a spirit in search of a medium, having to spread itself so thinly across a fragile and dispersed ‘spectrum’ or network of things – because of the very simple and strange fact that the phenomena it is trying to render visible exist in temporal and spatial scales so vast they are beyond intuition and stable visualization; they lie at the end of representation (Elkins, 2008). It is for this reason that astronomical visual practices have to make their referent-images more concrete, just as much as they are about making them more abstract, than the original phenomenon. More concrete, “since we can grasp in our hands, and see with our eyes, the essence” (Latour, 1999:66) of the galaxy cluster or quasar which become literally tangible, and more concrete since astronomical images have so many different incarnations or stages of reference, and combine and layer so many “routes of reference” (Elkins, 1995: 564), making them more real and stable, minimizing uncertainty and pulling “presence back into the image” (*ibid*, 2008: 84).

The bulk of the images underpinning this analysis are not the typical astronomical ‘pretty pictures’ through which non-astronomers, including myself, know both the discipline and especially its subject of study, the Universe. Indeed, the images found during my time at Imperial College came as a shock, refusing to yield the “polymorphous magical substance” (Taussig, 2009: 11) that their pretty counterparts enchant the viewer with. Their blurry, fuzzy, pixelized, cloaked surfaces and often not straightforwardly pictorial forms demanded a *two-fold* “meditation on blindness, the invisible, the unseen, the unseeable, and the overlooked” (Mitchell, 2002:170) as they exist within the image and within the technical processes – to see how they simultaneously inhere in *both* the content and formation of the astronomical image, its ‘what’ (content, referent) and its ‘how’ (technical process). This involves looking into the ‘overlooked’ vision of non-humans, and visuality’s precondition of visibility; ultimately revealing how what is visual and visible is made of invisible and unvisual parts.

And in this way astronomical images remind the visual anthropologist and the anthropologist of science of a valuable point, that, as one of my interviewees put it, ‘*the visible is in the eye of the beholder*’. If we are to truly engage with either or both the visual and the non-human realms, we must take a step back from a “*human* besotted *vision* of reality” (Pinney, 2005: 259, emphasis added). It is no longer enough to move beyond the male white gaze, as we need to attempt to shed the anthropocentric view of the visual to properly engage with astronomical and other spectrums of visibility.

Conclusion

In this paper, I have sketched out a biography of astronomical images through a tentative anthropology of light, framing the latter as amenable to study within the purview of material and visual culture studies, by giving a technological and scientific slanted response to Bille and Sorensen (2007)'s call for an anthropology of light. The very existence of this paper, that I have been able to trace the trajectory of light and coming into being of images in astronomy, is enabled by and implicitly confirms the notion of the 'circulating referent', that the stages of reference and technical transformations are reversible and retraceable. Moreover, in relation to the introductory discussion of visualism within anthropology, it must be noted that this paper has not only analysed, but *used* astronomical images, reproduced here as objects of evidence for my own anthropological claims (Lynch & Woolgar, 1988). As Latour (1999) points out in relation to his work on the Boa Vista Forest and its scientists, in studying inscriptions, this paper in a sense extends the 'network of light' but not its chain of reference. Indeed, my text "do[es] not transport that of which I speak" – light – in the same way that its astronomical images do, highlighting the different nature of scientific and social scientific analysis and evidenciary procedures. Instead, I hope this paper answers Olsen's call for a Material and Visual Culture study that "mak[es] manifest a nearness to things" (2006: 98).

I have approached images as visual artefacts, to expose how, like all made and re-made objects, they come into being via technical processes which mobilise humans and non-humans in the gradual transformation of matter whereby photons become data become images. There are three routes to this process: as this 'matter' is transformed, it is also visualized and signified which is why astronomical techniques of visualization are also techniques of reference. Moreover, as they make images, these techniques simultaneously construct the realm and categories of the visual. This processual approach follows Latour(1993b)'s call to look at the medial spaces of exchanges and translation, to demonstrate how these images emerge and happen through the intersection of divergent processes, or axes of exchange.

The focus on techniques underscored the thing-like quality of (albeit digital) images – that these are "flexible visual objects" (Amann & Knorr-Cetina, 1988) - and how their production and subsequent transformations hinge on the 'material' – on non-human actants such as telescopes, computers, software as well as the image's pre-incarnation as light - whilst taking seriously the extra dynamics and dimension brought by their specific property of visuality: that these are objects which refer, represent and visualize. In using the operational sequence as a way in to the analysis, I hope to have shown how techniques, whilst making up networks, are also systems. That is to say they are made of up different discrete elements - the raw 'matter' of light, the 'objects' of CCD detectors, observatories and media, the 'gestures' and 'knowledge' of astronomers (Lemonnier, 1992) – which are all made to interact and interrelate with each other (*ibid*: 1986) within a technical *process* - made up of the processes of imaging, mediality and perception discussed in chapters 3 and 4, 5 and 6 respectively.

Indeed, I have attempted to show how these images emerge from the intersection of mediation and mediality, and from the enmeshing of technology and perception. As such they act as the perfect analytic window through which to investigate each process in light of the other, and the internal dynamics and complementarity of each pairing. Moreover, I hope to have shown how astronomical images can productively be used as a theoretical synthesizer, putting into dialogue the anthropology of techniques, the anthropology of science, and visual anthropology. Thus, like Gunning argues in relation to visual culture studies, anthropology too – and, I would argue, *especially*, given its holistic approach - "allow[s] us to trace relations previously obscure or ignored" (1996:38) within the domain of the visual.

Indeed, the study of techniques too can be illuminated by the anthropology of the visual, as images are very particular and specific kinds of artefacts which depend on and emphasize certain properties of technical processes. It is through the minute and detailed study of the techniques of visualization and image processing that astronomical images unfold and reveal themselves. In particular, these images are shown to be the true offspring of their techniques and media, becoming in turn mediators and tools of reference, opening themselves up in a moment of transparency to allow movement through them, back to their referents. These are temporary and fragile portals however, as these immutable mobiles disappear into networks of data and translations, only to reappear part similar, part transformed. The astronomical quasi-image in this sense expresses a certain visual and non-human 'uncanny' (Freud, 1919), a repetitious disappearing then reappearing of something now transformed. The image's counterpart, the visual, follows in many ways the same oscillating movement, fragmenting itself into 'Spectrum of the Visible' which is only ever momentarily punctualised, with the visual/visible structured by this rhythm of distribution and coalescence.

Above all, these are extreme kinds of images. As James Elkins so eloquently put it, “these are pictures of objects that literally don’t exist – that couldn’t exist as they are pictured – but somehow do” (2008: xv), leading us back to the paradox of the visual. They call attention to the prerequisite and underlying structure of all photographic-like images: light. They thus force the spotlight on the very nature of the visual and visible, and their study shows that these cannot be taken for granted. When visibility and visuality are unfocused, when the former is no longer taken for granted in the latter, the importance and roles of non-human vision and the invisible are illuminated. This study of astronomical images should be located as an attempt to engage with a *visual-symmetrical* anthropology, one which gives equal weight to both human and non-human visuality, and to both the visible and invisible, within the visual.

Glossary (Chandra 2011b)

Active Galactic Nucleus (AGN): The central region of a galaxy that shows unusual energetic activity. A galaxy with a somewhat less active supermassive black hole is called an Active Galaxy and its black hole is called an "Active Galactic Nucleus" or AGN

Big Bang: The event that most cosmologists consider to have been the beginning of the universe, in which space-time originated in a state of enormously high temperature and density and subsequently expanded and cooled.

Black holes: A dense, compact object whose gravitational pull is so strong that - within a certain distance of it - nothing can escape, not even light. Black holes are thought to result from the collapse of certain very massive stars at the ends of their evolution.

Cosmic microwave background radiation (CMB): The microwave radiation coming from all directions that is believed to be the redshifted glow of the Big Bang.

Dark matter: A term used to describe the mass in galaxies and clusters of galaxies that can be inferred to exist from its gravitational effects, but has not been directly detected by electromagnetic radiation.

Galaxy: A gravitationally-bound system of stars, gas, dust and dark matter

Galaxy cluster: Galaxies can swarm together to form groups and clusters of galaxies held together by their mutual gravity. X-ray observations show that these enormous systems of galaxies are filled with colossal clouds of hot gas. These clouds have temperatures as high as a hundred million degrees and contain as much mass as all the stars in the galaxies in the cluster.

Light curve: The variation in brightness of a star with time.

Light year: The distance that light, moving at a constant speed of 300,000km/s, travels in one year. One light year is about 10 trillion kilometers.

Look-back time: The time in the past at which the light we now receive from a distant object was emitted.

Nebula: General term used for any "fuzzy" patch on the sky, either light or dark; a cloud of interstellar gas and dust.

Photon: Individual packet of electromagnetic energy that makes up electromagnetic radiation.

Quasar: Originally, a distant, highly luminous object that looks like a star. Strong evidence now exists that a quasar is produced by gas falling into a supermassive black hole in the center of a galaxy

Red shift: Change in the wavelength of light emitted from a source moving away from us. The relative recessional motion causes the wave to have an observed wavelength longer (and hence redder) than it would if it were not moving. The cosmological red shift is caused by the stretching of space as the universe expands

Star: A glowing ball of gas held together by its own gravity and powered by nuclear fusion in its core

Supernova: Explosive death of a star, caused by the sudden onset of nuclear burning in a white dwarf star (Type Ia), or gravitational collapse of the core of massive star followed by a shock wave that disrupts the star(Type II, Type Ib, Ic). A supernova is one of the most energetic events of the universe and may temporarily outshine the rest of the galaxy in which it resides. [

Supernova remnant: The expanding glowing remains from a supernova

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