Miniaturized Cameras – The Eyes of Space Exploration

UCL Space Domain One O’Clock Lecture

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Buc, France
Space Cameras: For what purpose?

Photograph of Earth taken by NASA’s Voyager I, in 1990
Space Cameras: Multiple Applications

Visible imaging

Visible Spectral Wavelength

Earth observation

New Space applications

Planetology/Mineralogy

Navigation/RDV applications

Monitoring applications
Space Cameras: Multiple Applications

Near Infrared Imaging

Optical Telecommunications

IR bandwidth link, SWIR Acquisition and Tracking Camera

Earth Observation

Better Flora segregation

Planetary Mineralogy

Rocks Reflexion

Better ground segregation

Defense

Night Glow
Space Cameras: Multiple Applications

UV/IR Imaging

- UV Bandwidth
- Visible
- Proche infrarouge
- IR Bandwidth

Earth/Planetary observation
- Sun observation

Multispectral imaging

Spectrography

IR Astrophotography

ISO map of M31:
(wavelength of 175 microns)
North is up, east is left.
Camera Design: **The constraints to consider**

- **Temperature**
  - Operational and non-operational extremes
    - Martian night: -130°C
    - Solar irradiance vs space background
  - Complex to regulate in the vacuum of space

- **Vibrations/shocks**
  - Launch, landing, pyrotechnic separation

- **Vacuum**
  - Outgazing

- **Radiations**
  - Impact on electronics components and especially image sensors
  - Damaging effects

- **Instrument considerations**
  - Weight and size
  - Power consumption

![Hot pixels on image sensor are a typical results of radiation effects](image.png)
3D PLUS Company

- French company founded in 1995
  - Location: Buc, France (Paris Region)
  - People: 270 employees

- Manufacturer of electronics products and System-in-Package for high reliability and high performance applications
  - Production: 800 pcs/week, delivery of more than 30000 products in 2020
  - More than 180 000 modules in space mid of 2021
  - Business regions: 35% Europe, 35% Asia, 30% North America

- ESA and CNES approved manufacturing line for Space Applications
- ITAR Free products
- Line of space products: Memories, Interfaces, Point of Load, Protections, Computer Core, Microcameras
3D PLUS Stacking Core Technology

Flow 1: 3D PLUS Historical Stacking Process

Stacking of TSOP + connection lines

Cube molding

Cube sawing

Cube Platting

Laser grooving

Flow 1
3D PLUS Stacking Core Technology

Flow 2: 3D PLUS System-in-Package

1) Flex Design

2) Components attachment

3) Circuit Test & Screening

4) Layers Stacking

5) Cube Molding

6) Cube Sawing

7) Cube Plating (Ni + Au)

8) Circuit interconnection by laser processing

9) Cube Test & Screening
3D PLUS Stacking Core Technology

Flow 3 WDoD™: 3D PLUS High density Stacking process
3D PLUS Cameras: Heritage
18 years of experience of supplying space qualified camera heads

- SMART-1, Moon Mission, ESA
- MARS EXPRESS, Mars Mission, ESA
- ROSETTA / PHILAE, Deep space mission, ESA
- CAMISRA, Science Camera, ISRO
- PROBA 2, Earth Observation, ESA
- MSL / CURIOSITY, Mars mission, NASA
- SENTINEL 1A, GMES, ESA
- EYESAT, CubeSat, CNES
- MARS 2020 / PERSEVERANCE, NASA
- OneWeb, constellation, USA

Years:
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
3D PLUS Cameras : The beginning
Rosetta / Philae : the first Camera

- Electronics design : IAS
- Packaging Technology : 3D PLUS
3D PLUS Cameras : The beginning
Rosetta / Philae : the first Camera

- Spare used on Curiosity’s ChemCam instrument

ChemCam

ChemCam monochrome images
3D PLUS Cameras: A generic product

Aiming to answer to the growing needs for Imaging in Space Applications

- RdV, Navigation & Docking, Startracking
- Satellite monitoring
- Earth wide-angle observation
- Rover navigation, Payload monitoring
- Imaging of extraterrestrial soil
- Atmospheric aerosol measurements

RdV, Navigation, & Docking, Startracking

Satellite monitoring

Earth wide-angle observation

Rover navigation, Payload monitoring

Imaging of extraterrestrial soil

Atmospheric aerosol measurements
3D PLUS Camera : A fruitful collaboration
A development in collaboration with the Centre National d’Etudes Spatiales (CNES)

- Technological watch on COTS CMOS image sensors by CNES
  - Technological evaluation of several sensors
  - Radiation testing (TID, SEE)
  - Quality tests (World first) on color filters and microlenses
  - Final sensor selection

- Electronics design by 3D PLUS
  - Architecture design
    - 4Mpixels Color CMOS Sensor
    - FPGA based architecture with memories
    - Power supplies and protections (Latch-up current limiter)
  - Components selection for Space environment
  - 3D prototype manufacturing

- Camera cube selected as RMI on the SuperCam instrument
  - Qualification of the sensors and camera modules
  - Flight models manufacturing

Project : Mars 2020’s SuperCam Instrument
**3D PLUS Cameras: the first catalog Space Camera**

Characteristics of the Space Camera

- **Microcamera Features:**
  - Advanced CMOS Image sensor
    - 2048x2048 pixels, 5.5μm pitch, 10-12 bit images, 10ke− FWC
  - Flash-based FPGA with associated processing and storage memories
    - Allow up to 16 frame/s with LVDS interfaces
  - Embedded power supplies (<2W) and protections
  - Optimized thermal/mechanical interface
  - Radhard by design: TID > 40 krad(Si), SEL LET > 62 MeV.cm²/mg
  - Highly miniaturized:
    - 62g
    - 35x35x23 mm³

CASPEX Microcamera
Sensor qualification:
- Components screening
- Specific qualification of samples
  - Moisture testing
  - Vibrations and shock
  - Thermal cycling
  - On/Off

Components Qualification:
- 3D PLUS Expertise

Camera Qualification:
- Destructive Physical Analysis
- Life Test
- Thermal Cycles
- Humidity
- Mission Specific Cycles
- Radiation Testing
3D PLUS Cameras: the first catalog Space Camera

Multiple configurations and options development

- Electrical interfaces solutions
- Space Grade Objectives solutions
- Mechanical Interfaces/enclosures solutions
- Firmware and development options, Test equipment
3D PLUS Cameras : First Flight Heritage!
EyeSat’s IRIS Instrument : Launched in December 2019

- Nano-Sat 3U
- Applications:
  - Zodiacal Light Analysis
  - Milky Way Imaging

EyeSat’s IRIS Instrument:
- IRIS instrument integrating 3D PLUS 4Mpx CMOS Camera Head (*)
- EyeSat’s IRIS instrument schematic view of the camera (*)
- EyeSat nanosatellite 3D Model (*)

(*) Credits images : EyeSat Team
3D PLUS Cameras: Parallel Camera Development

SODERN's AURIGA Star Tracker: OneWeb Constellation

- Highly Miniaturized Star Tracker for high volume satellite constellation
  - 2000 Cameras (more than 1000 already manufactured)
- First Launch in March 2019

OneWeb satellite constellation
Credit: Airbus

AURIGA CMOS Camera Head
3D PLUS Cameras: The Mars 2020 mission

Perseverance’s SuperCam Instrument

• The SuperCam Instrument:
  • LIBS (Laser induced Breakdown Spectroscopy)
  • Raman
  • Spectrometers
  • Context color imager (Remote MicroImager – RMI)

• Landed in March 2021
3D PLUS Cameras: The Mars 2020 mission

3D PLUS Camera on Mars

- Applications of the Camera:
  - Martian Soil Monitoring
  - Atmospheric Analysis
  - Long Distance Imaging

Yeehgo rock target, sol 16;
Credit: NASA/JPL-Caltech/LANL/CNES/IRAP

RMI in ‘Telescope’ mode – Ingenuity helicopter from 62m
Credit: NASA/JPL-Caltech/LANL/CNES/IRAP

RMI in ‘Telescope’ mode – Mesa South of Delta – Sol 63
Credit: NASA/JPL-Caltech/LANL/CNES/IRAP
3D PLUS Cameras: The Mars 2020 mission

First images of the RMI

Remote Micro-imaging

Mastcam-Z (Sol 3)
NASA/JPL-Caltech/MSSS/ASU

Martian meteorite

Geometric targets

Diamond

2cm

SuperCam RMI mosaic
Calibration targets (Sols 11, 12, 13)
NASA/JPL-Caltech/LANL/CNES/CNRS
Maaz target (Sol 12) - LIBS spectrum

- Ultraviolet
- Violet
- Visible & Near Infrared

Normalized Intensity

Wavelength (nm)

- Silicon
- Iron
- Magnesium
- Aluminum
- Calcium
- Titanium
- Sodium
- Oxygen
- Hydrogen
- Carbon
- Potassium
- Calcium
- Silicon
- Iron
- Magnesium

First images of the RMI
"Perseverance rover reveals ancient delta-lake system and flood deposits at Jezero crater, Mars", N. Mangold et al., Science, October 7th, 2021

Artist view of how the Jezero crater would have looked like 3 billion years ago
On going CNES Collaborations:
- ELR Rashid moon rover (with MBRSC) : Moon in 2022
- Martian Moon eXploration (CNES/DLR/JAXA) : Phobos in 2024

Applications
- Wheel monitoring
- Navigation

Camera Head assembled with one of the MMX camera heads mechanical interface and objective mounted on EGSE test board

ELR Rashid
Credits : MBRSC

MMX Martian Moon Rover
Credits : CNES/DLR
3D PLUS Cameras: Future Missions

PROSPECT Instrument

- PROSPECT Instrument / LUNA RESURS
  - LEONARDO/ROSKOSMOS: Moon 2025

- ProSEED Drill Monitoring

PROSPECT Imaging System (EM) with illumination system – Kayser subcontractor for mechanical design and illumination system.
3D PLUS Cameras : Future Missions
Mars Sample Return Missions

• Mars Sample Return – Earth Return Orbiter
  • AIRBUS/NASA

• Application :
  • 7 off-the-shelf cameras and 1 control unit
  • Multi-Camera Monitoring System
    • Antennas / Solar Panel deployment
    • SpaceCraft units separation
    • Sample recuperation

Camera Heads preliminary concept

Earth Return Orbiter spacecraft – artist rendering
Credits : ESA
3D PLUS Cameras : Future Missions
SPEXOne Aerosol Polarimeter

• **SPEXOne Instrument**
  - SRON/AIRBUS NL
  - Launch : 2023

• **Application :**
  - Aerosol Measurements using a spectro-polarimeter

Rendition of SPEXone instrument
Credits : AIRBUS NL / SRON

Pace spacecraft – artist rendering
Credits : SRON
Developments of MultiSpectral and Hyperspectral Capabilities

Galileo, 1992

VIS-NIR Lunar image, S. Le Mouélic (LPGN), S. Maurice (IRAP)
3D PLUS Cameras: Future Developments

Developments of New Space Cameras

- Developments of new high performances Space Cameras
  - Higher resolution
  - Higher SNR
  - Higher processing power

- CNES Collaboration on sensors evaluation and selection

- Two New Cameras ongoing developments:
  - 12 Megapixels High Performances Visible Space Camera (3D Prototypes under tests)
  - 1.3 Megapixels SWIR Camera (3D Prototypes soon-to-be manufactured)
3D PLUS Cameras: Generic Off-the-shelf Space Cameras

Applications Targets for 3D PLUS Space Cameras

1st Gen → 4 Mpxls

- Context imaging for Scientific applications
- Plateform/Payload monitoring plate-forme, RDV/Docking Camera, Star Tracker
- Interest scene detection

2nd Gen → 12 Mpxls

- High Perf Imager (embedded processing)
- Highly miniaturized High Resolution Earth Imaging
- Orbit Observation (Planet, Moons, Small objects)
- Monitoring and Surveillance Camera (Defense)

1st Gen Multi/hyperspectral

- Spectral Composition and mineralogy
- Hyperspectral Camera: Oceans color, Flora, Soil/water quality

2nd Gen → 12 Mpxls

- High Perf Imager (embedded processing)
- Highly miniaturized High Resolution Earth Imaging
- Orbit Observation (Planet, Moons, Small objects)
- Monitoring and Surveillance Camera (Defense)

- SWIR Camera
  - Optical Telecommunication tracking
  - Mineralogy imaging
  - Earth observation (Visible complement)
  - Night Glow

VIS-NIR Lunar image, S. Le Mouëlic (LPGN), S. Maurice (IRAP)