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 ?

Photgraph of Earth taken by NASA's Voyager I, in 1990

Space Cameras : Multiple Applications

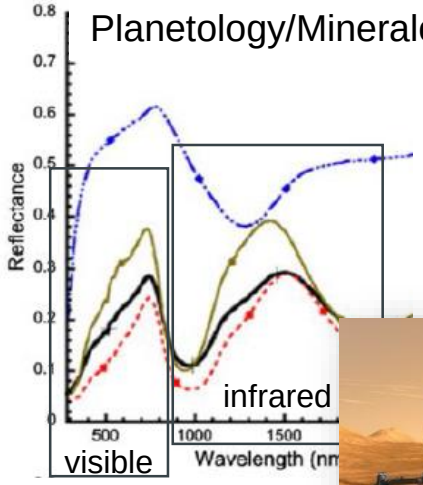
Visible imaging

Visible Spectral Wavelength

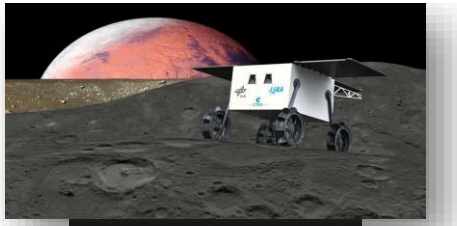
Earth observation

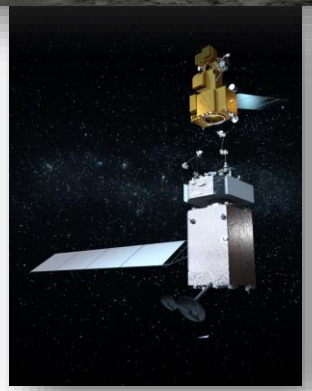
New Space applications

Planetology/Mineralogy

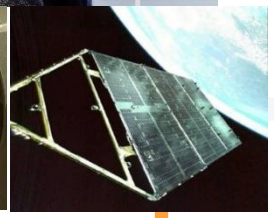


Navigation/RDV applications



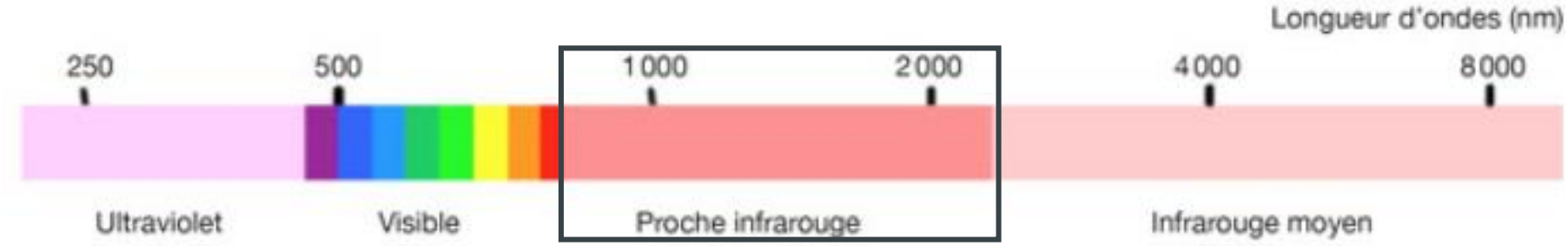


Monitoring applications



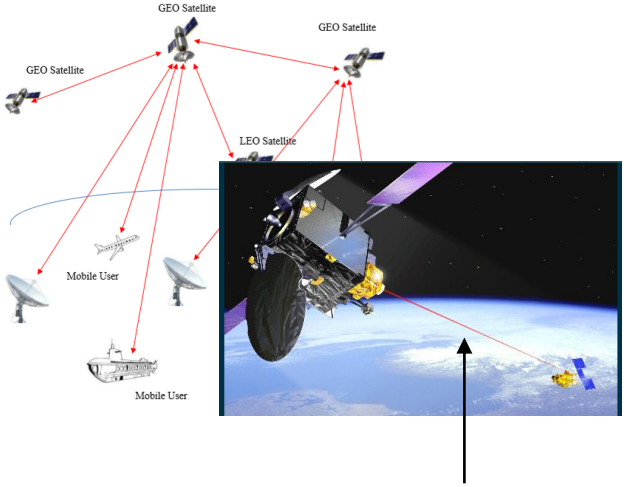
Space Cameras : Multiple Applications

Near Infrared Imaging



Near Infrared Wavelength

Optical Telecommunications



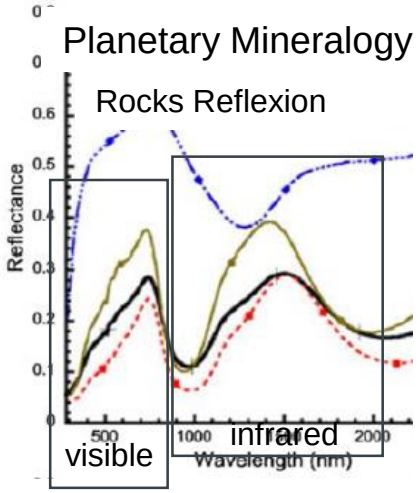
IR bandwidth link.
SWIR Acquisition and
Tracking Camera

Earth Observation

Better Flora
segregation

Planetary Mineralogy

Rocks Reflexion



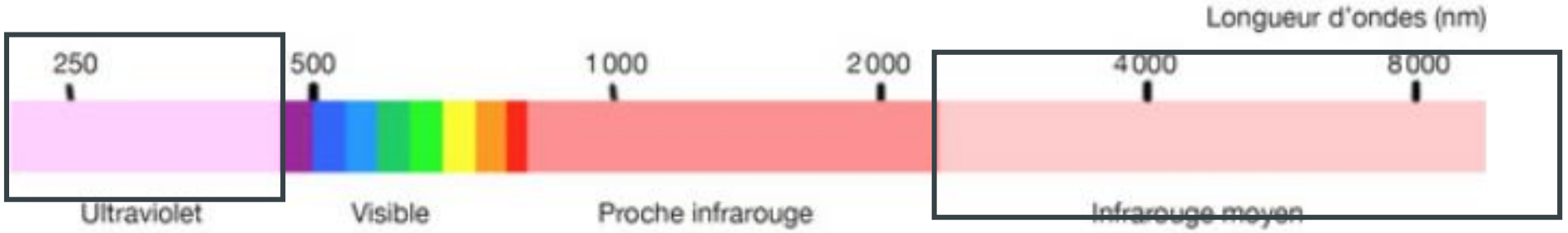
Better ground segregation

Defense

Night Glow

Space Cameras : Multiple Applications

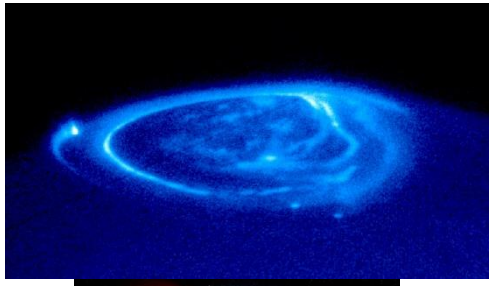
UV/IR Imaging

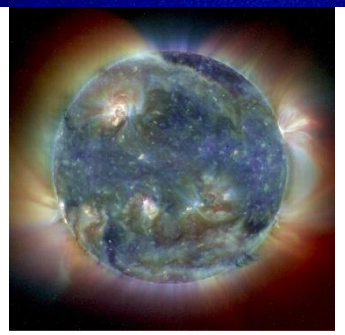


UV Bandwidth

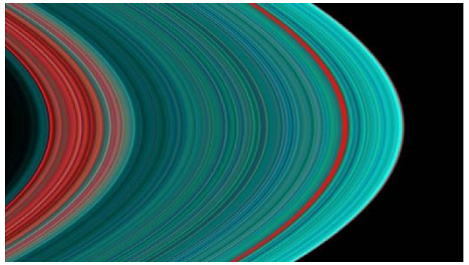
IR Bandwidth

Earth/Planetary observation
Sun observation



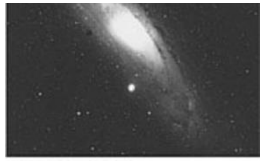


Spectrography



Multispectral imaging

IR Astrophotography

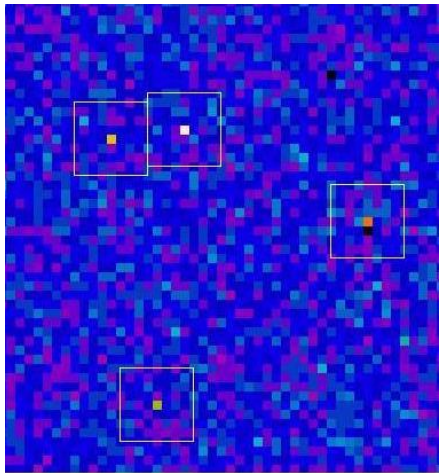


M31 in the visible.

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

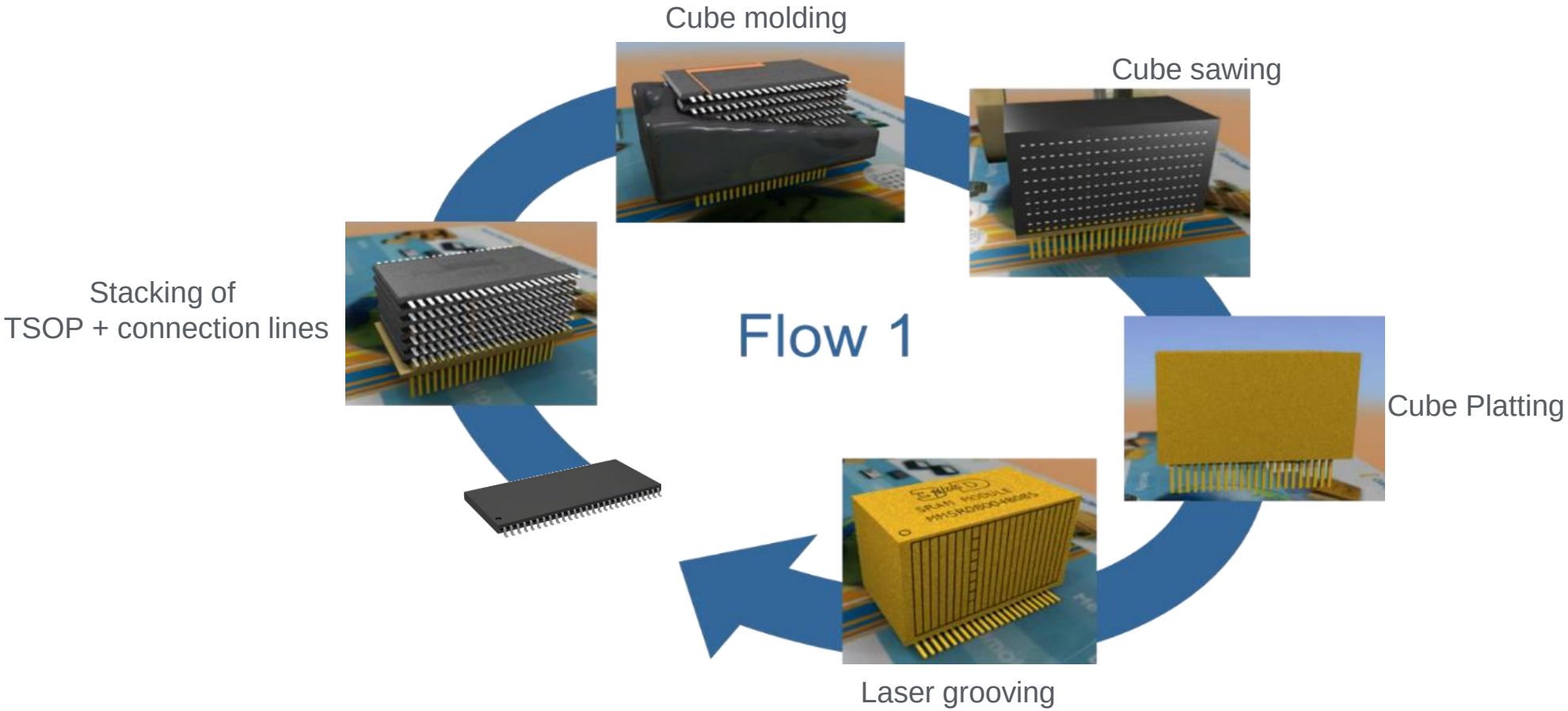
3D PLUS Company

Headquarters
Paris area, France

- **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**

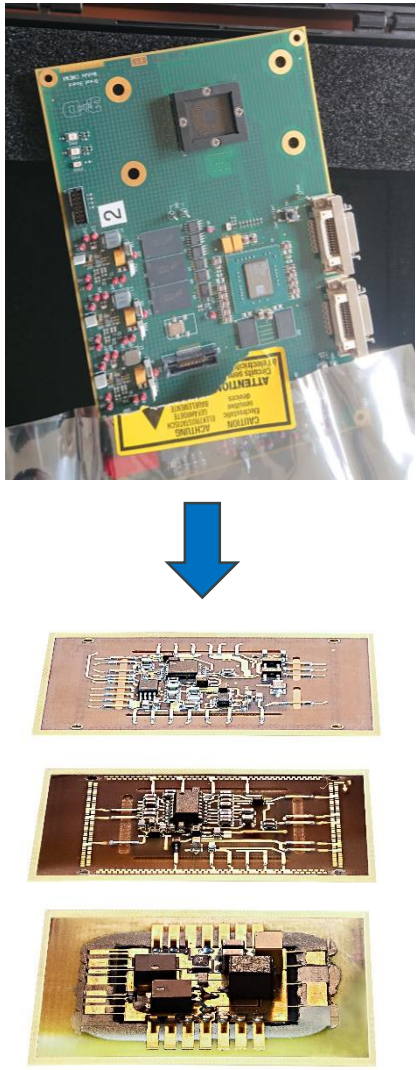
3D PLUS Stacking Core Technology

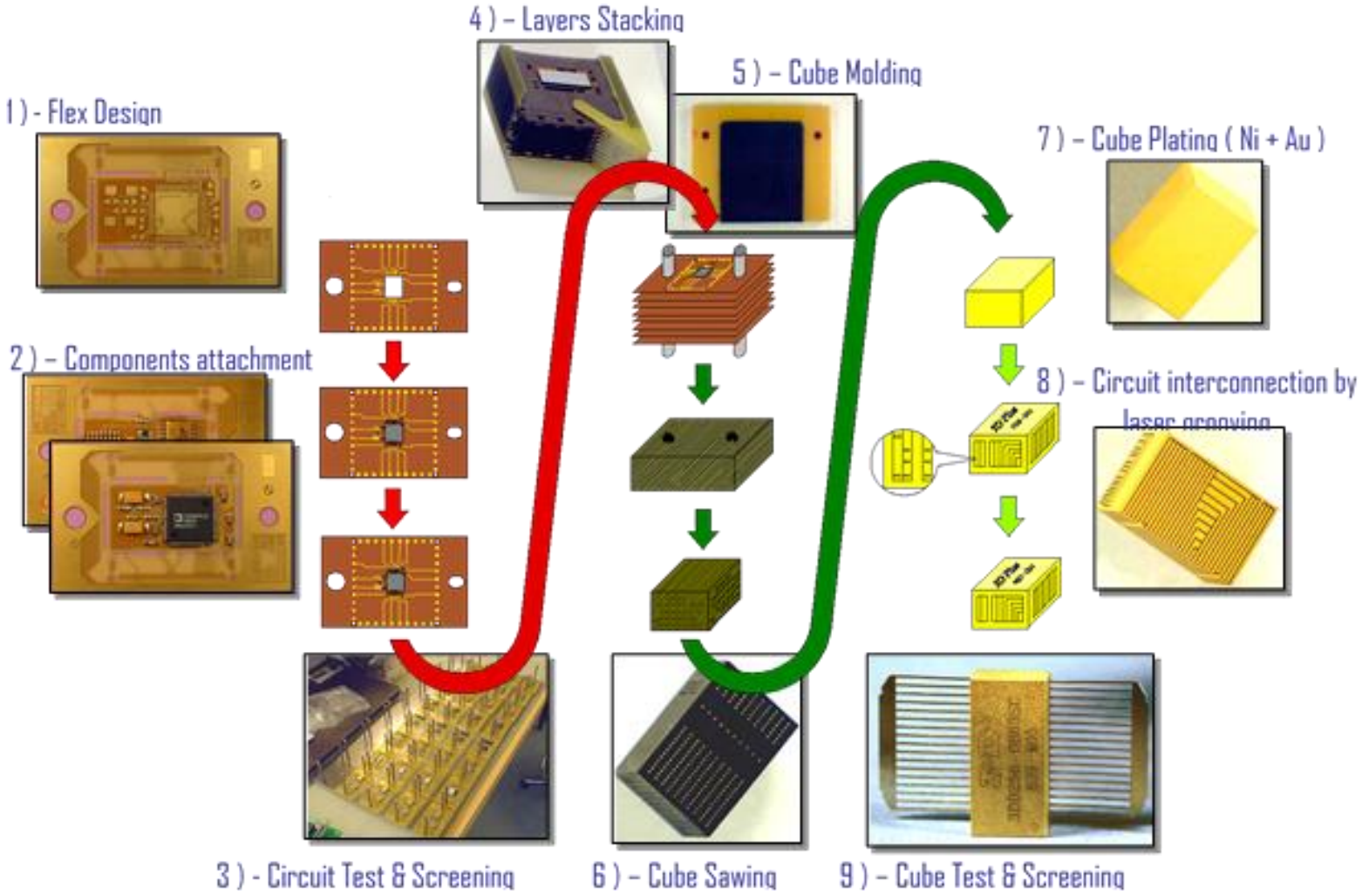
Flow 1 : 3D PLUS Historical Stacking Process



3D PLUS Stacking Core Technology

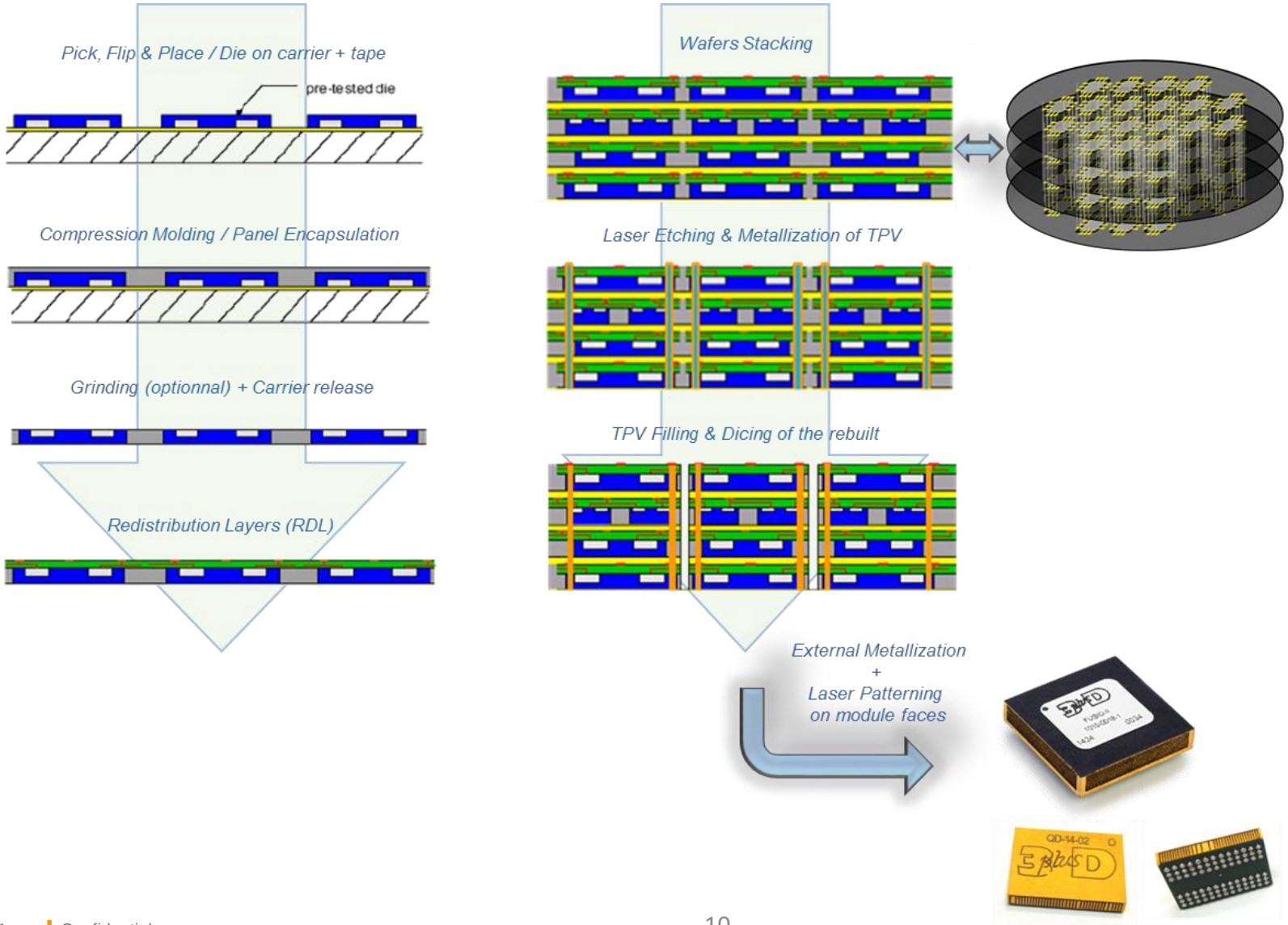
Flow 2 : 3D PLUS System-in-Package





3D PLUS Stacking Core Technology

Flow 3 WDoD™ : 3D PLUS High density Stacking process

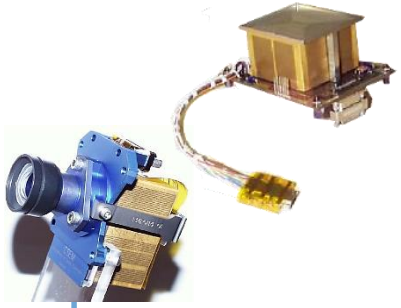


3D PLUS Cameras : Heritage

18 years of experience of supplying space qualified camera heads

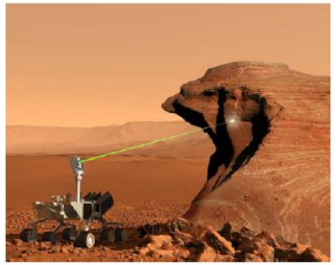
SMART-1, Moon Mission, ESA

MARS EXPRESS, Mars Mission, ESA

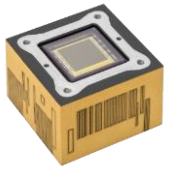


PROBA 2, Earth Observation, ESA

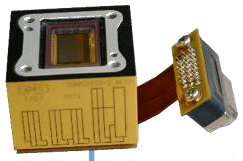
MSL / CURIOSITY, Mars mission, NASA



MARS 2020 / PERSEVERANCE, NASA



OneWeb, constellation, USA



2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

ROSETTA / PHILAE, Deep space mission, ESA

CAMISRA, Science Camera, ISRO

SENTINEL 1A, GMES, ESA

EYESAT, CubeSat, CNES

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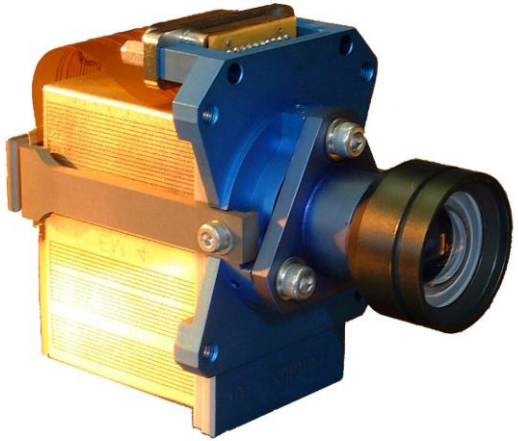
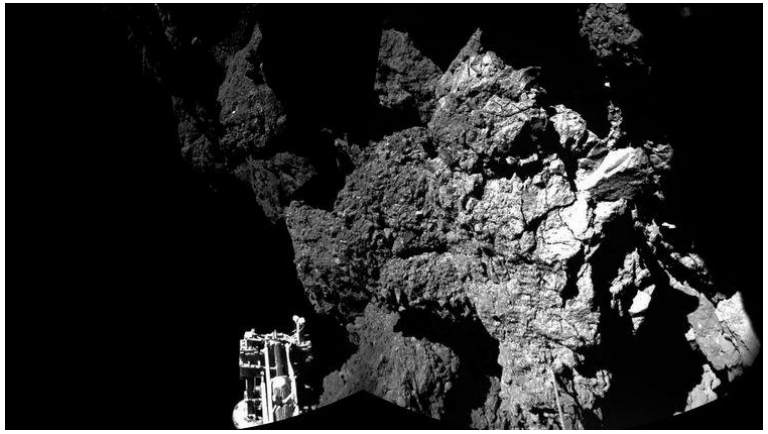
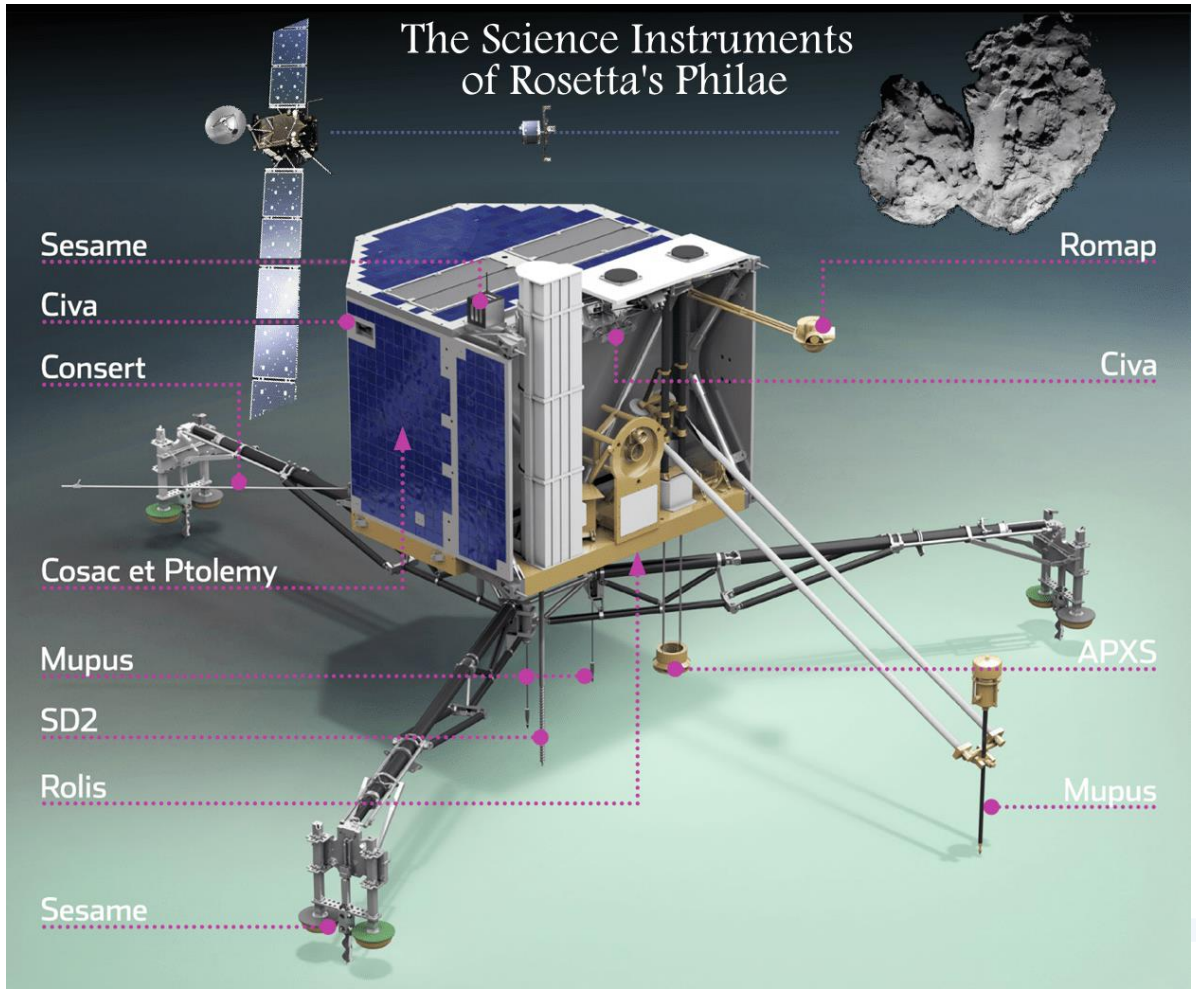
3D PLUS Cameras : The beginning

Rosetta / Philae : the first Camera

- **Electronics design : IAS**
- **Packaging Technology : 3D PLUS**



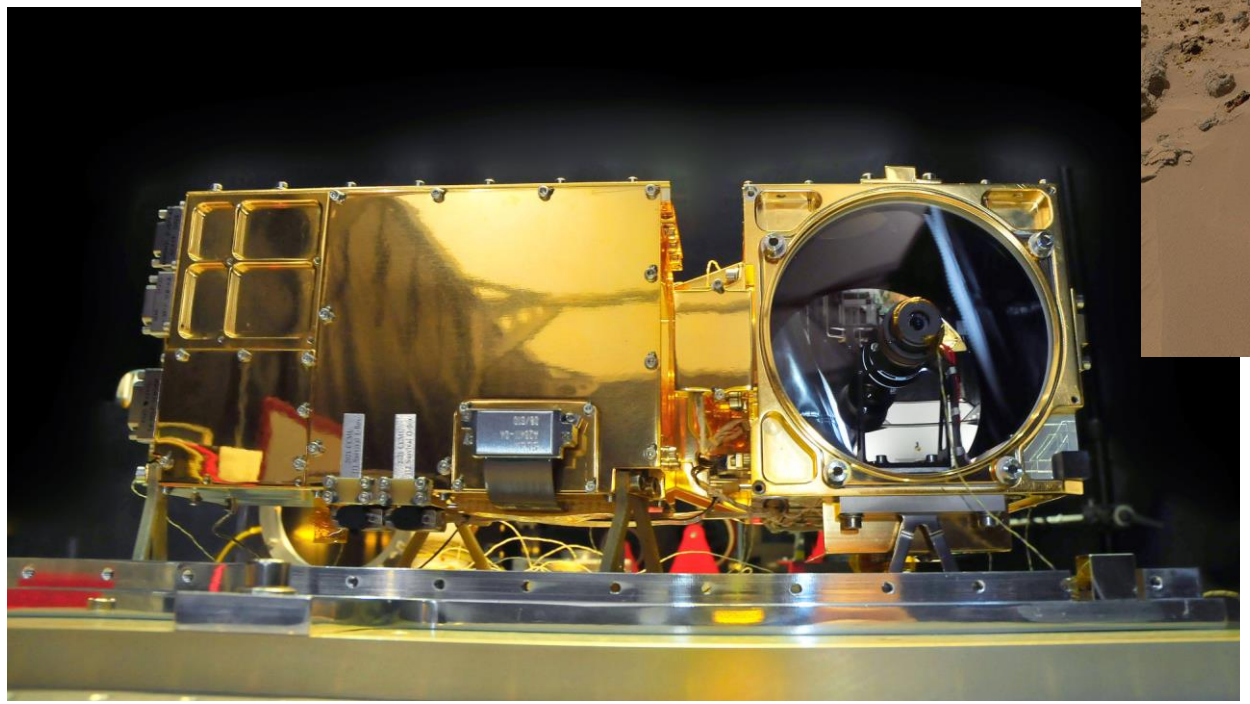


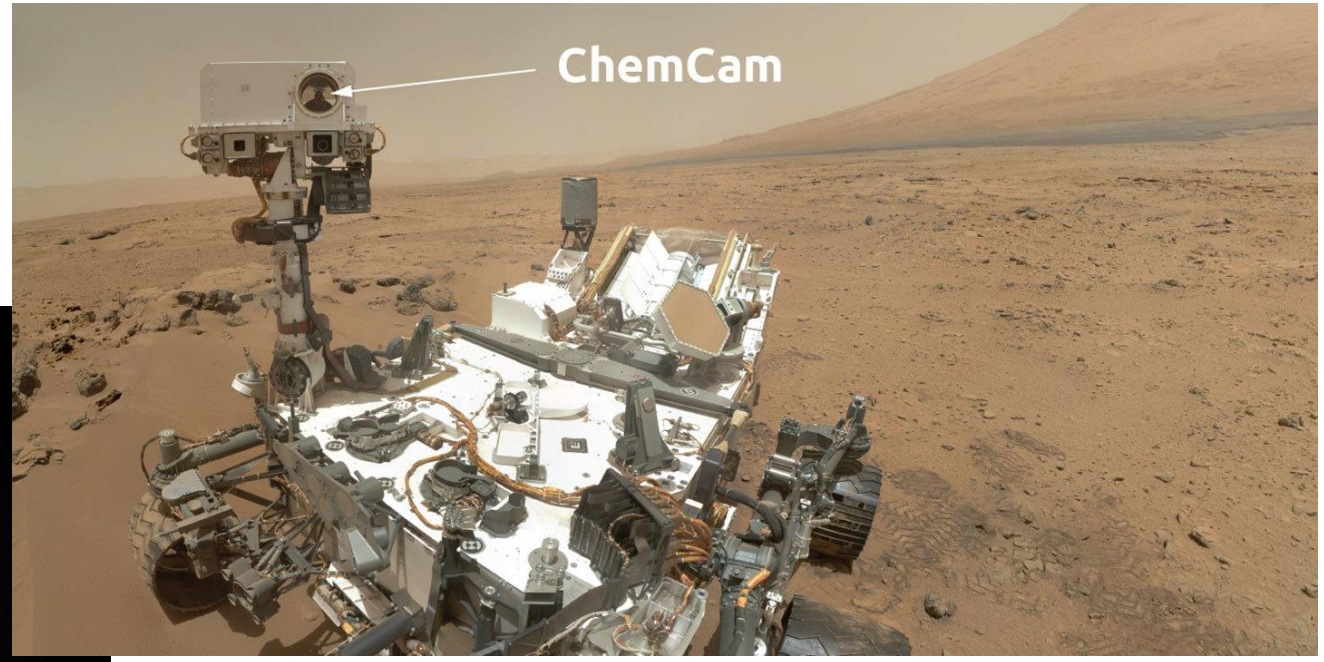


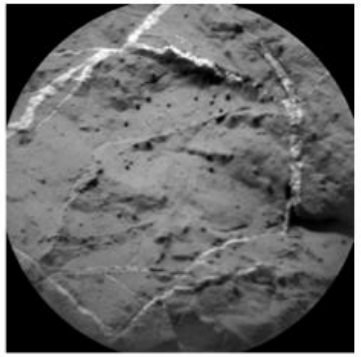
3D PLUS Cameras : The beginning

Rosetta / Philae : the first Camera

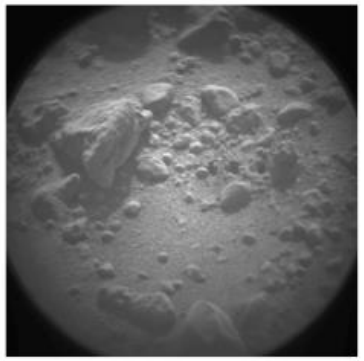
- **Spare used on Curiosity's ChemCam instrument**







ChemCam monochrome images



3D PLUS Cameras : A generic product

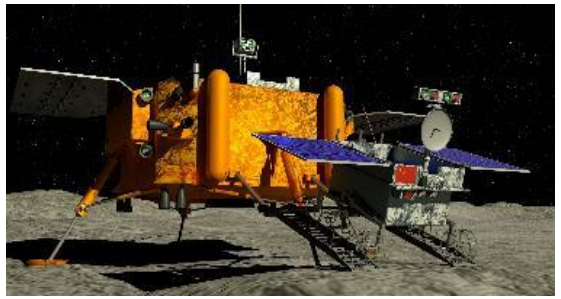
Aiming to answer to the growing needs for Imaging in Space Applications

RdV, Navigation & Docking, Startracking

Satellite monitoring

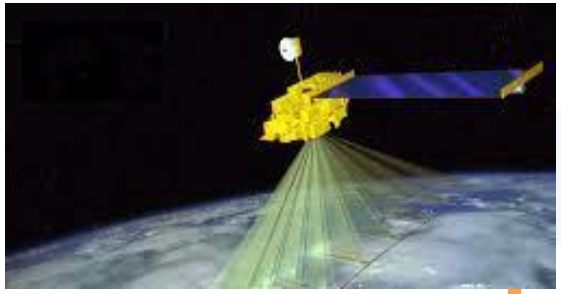
Earth wide-angle observation

Rover navigation, Payload monitoring



Imaging of extraterrestrial soil

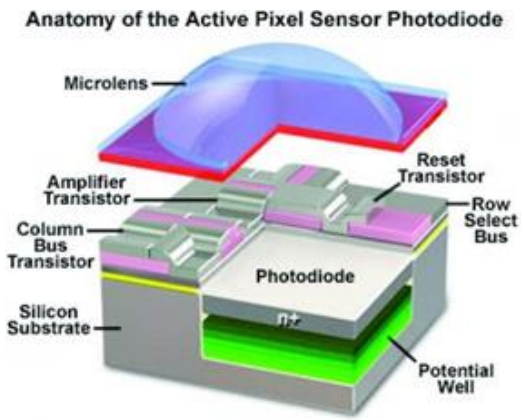
Athmospheric aerosol measurements



3D PLUS Camera : A fruitful collaboration

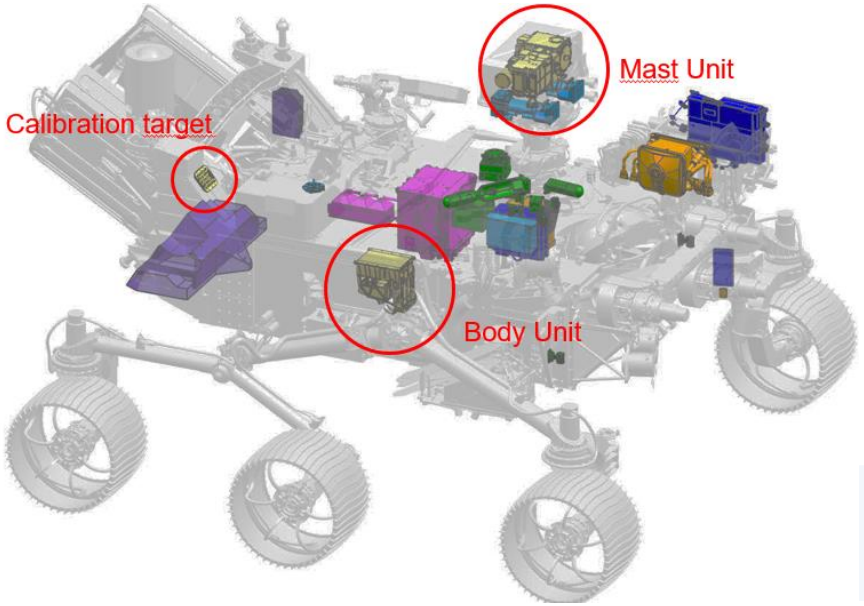
A development in collaboration with the Centre National d'Etudes Spatiales (CNES)

- **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

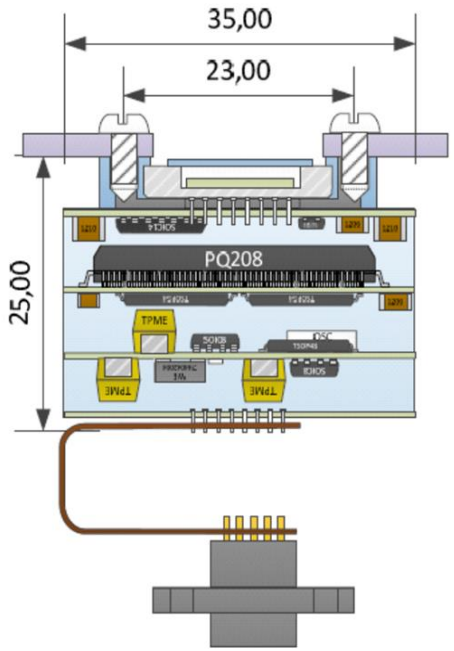


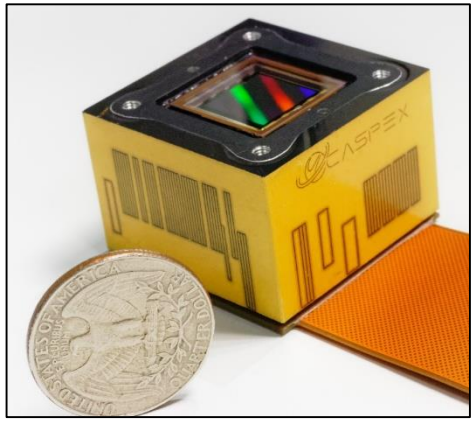
Project : Mars 2020's SuperCam Instrument

3D PLUS Cameras : the first catalog Space Camera

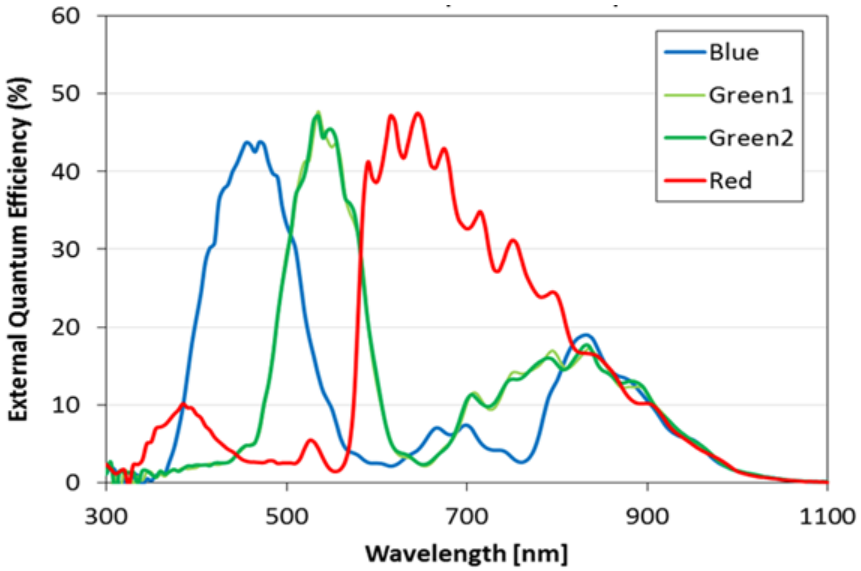
Characteristics of the Space Camera

- **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 > 62MeV.cm²/mg
  - Highly miniaturized :
    - 62g
    - 35x35x23 mm³





CASPEX Microcamera



3D PLUS Cameras : the first catalog Space Camera

Specific Qualification Process

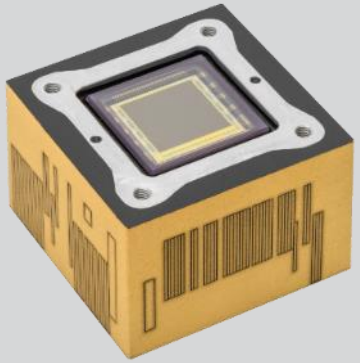
- **Sensor qualification :**
  - Components screening
  - Specific qualification of samples
    - Moisture testing
    - Vibrations and shock
    - Thermal cycling
    - On/Off
- **Components Qualification**
  - 3D PLUS Expertise
- **Camera Qualification :**
  - Destructive Physical Analysis
  - Life Test
  - Thermal Cycles
  - Humidity
  - Mission Specific Cycles
  - Radiation Testing

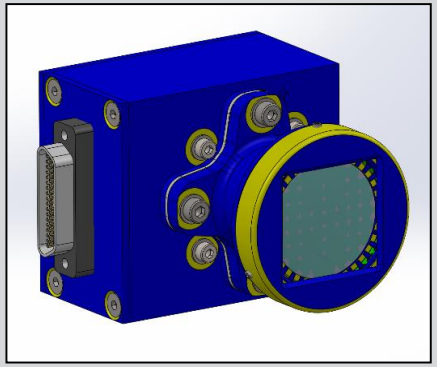
3D PLUS Cameras : the first catalog Space Camera

Multiple configurations and options development

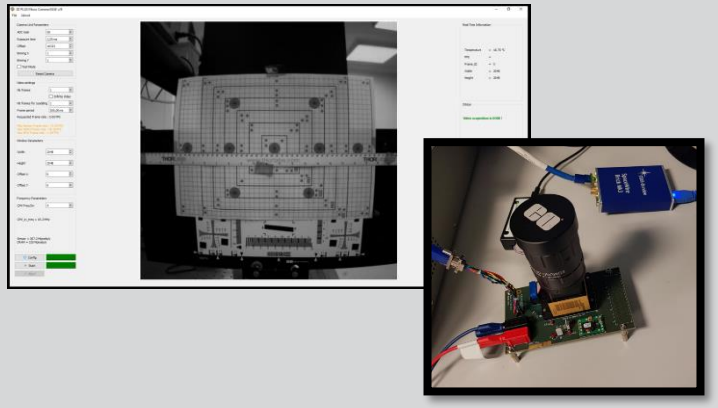
Electrical interfaces solutions

Space Grade Objectives solutions





Mechanical Interfaces/enclosures solutions

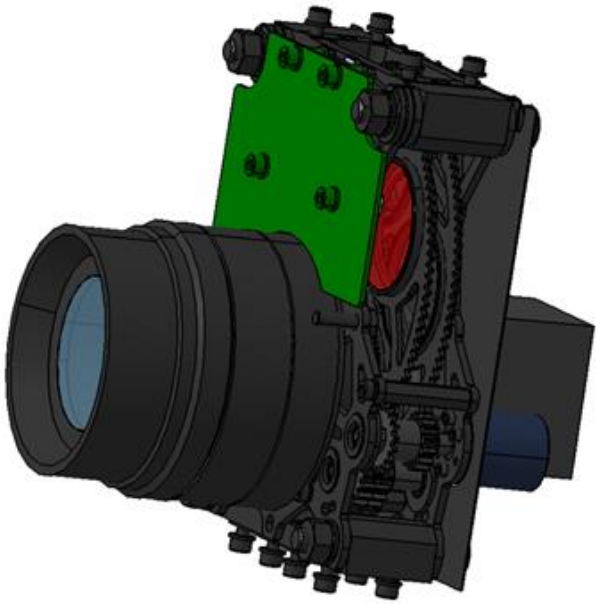


Firmware and development options, Test equipment

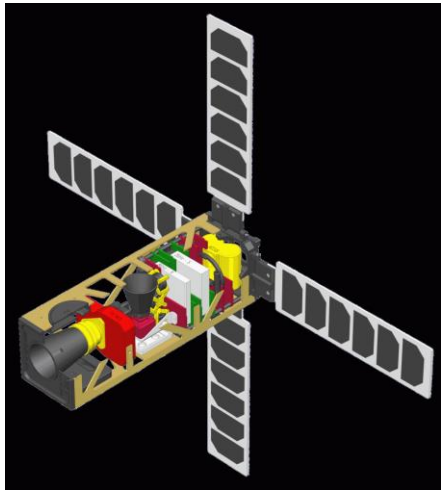
3D PLUS Cameras : First Flight Heritage !

EyeSat's IRIS Instrument : Launched in December 2019

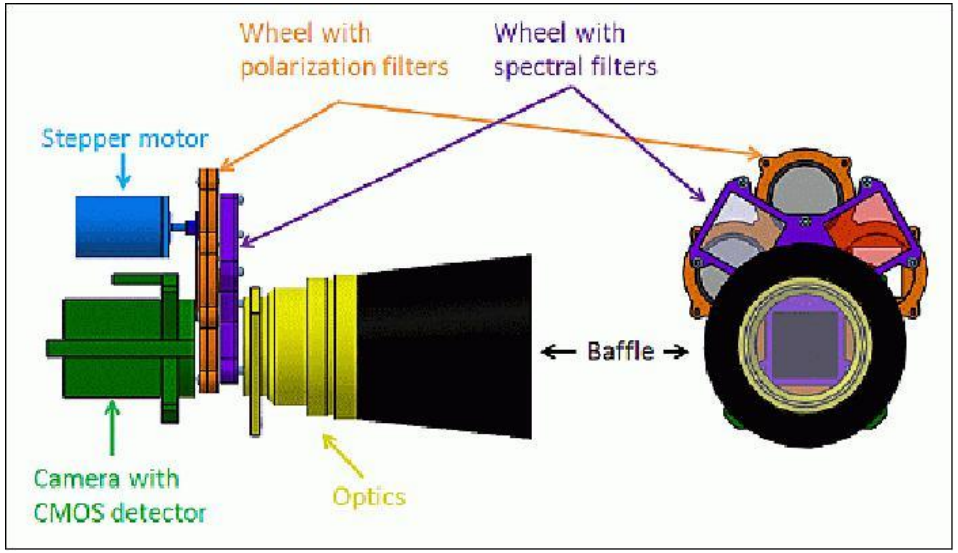
- **Nano-Sat 3U**
- **Applications :**
  - Zodiacal Light Analysis
  - Milky Way Imaging



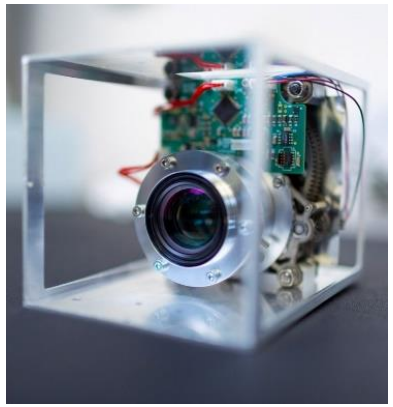
Camera IRIS

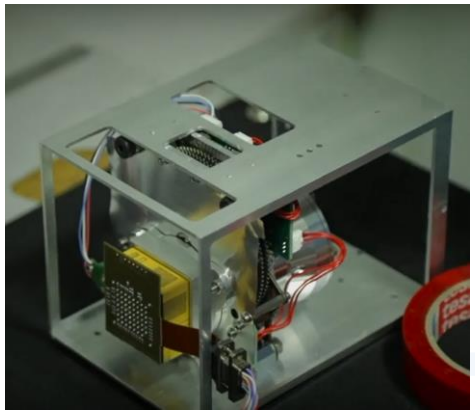


EyeSat nanosatellite 3D Model (*)



IRIS instrument schematic view of the camera (*)





IRIS instrument integrating 3D PLUS 4Mpx CMOS Camera Head (*)

(*) Credits images : EyeSat Team

3D PLUS Cameras : Parallel Camera Development

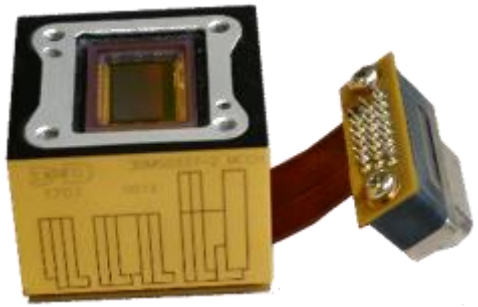
SODERN's AURIGA Star Tracker : OneWeb Constellation

- **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

sodern
arianegroup



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)

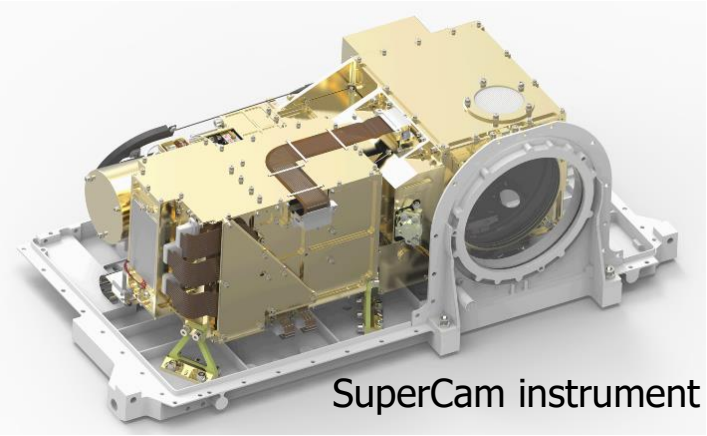
Jet Propulsion Laboratory
California Institute of Technology

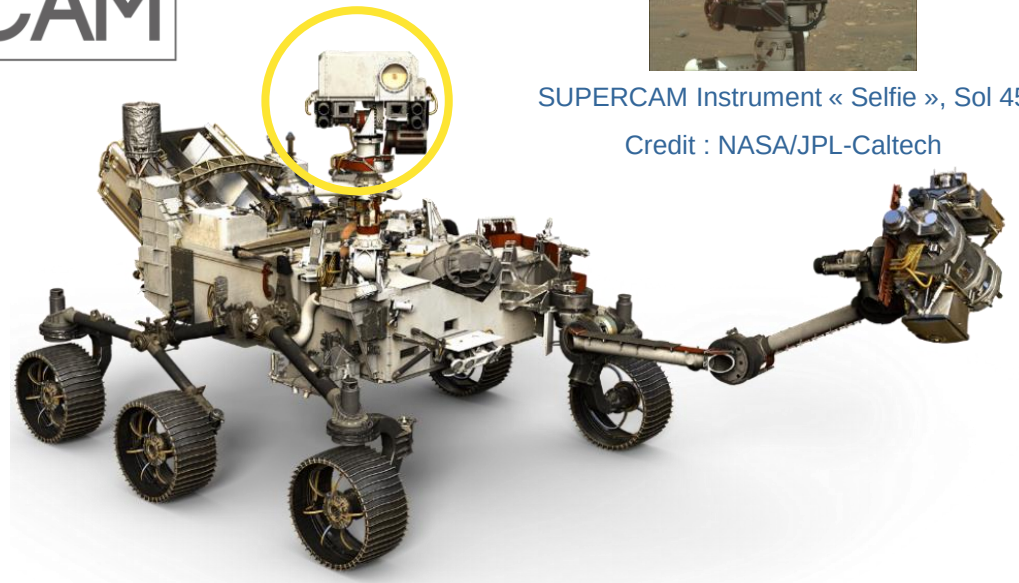
MARS 2020 SUPER CAM

SUPERCAM Instrument « Selfie », Sol 45

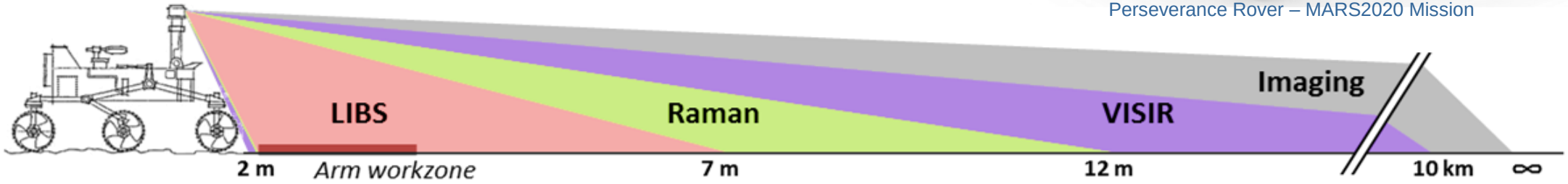
Credit : NASA/JPL-Caltech

- **Landed in March 2021**





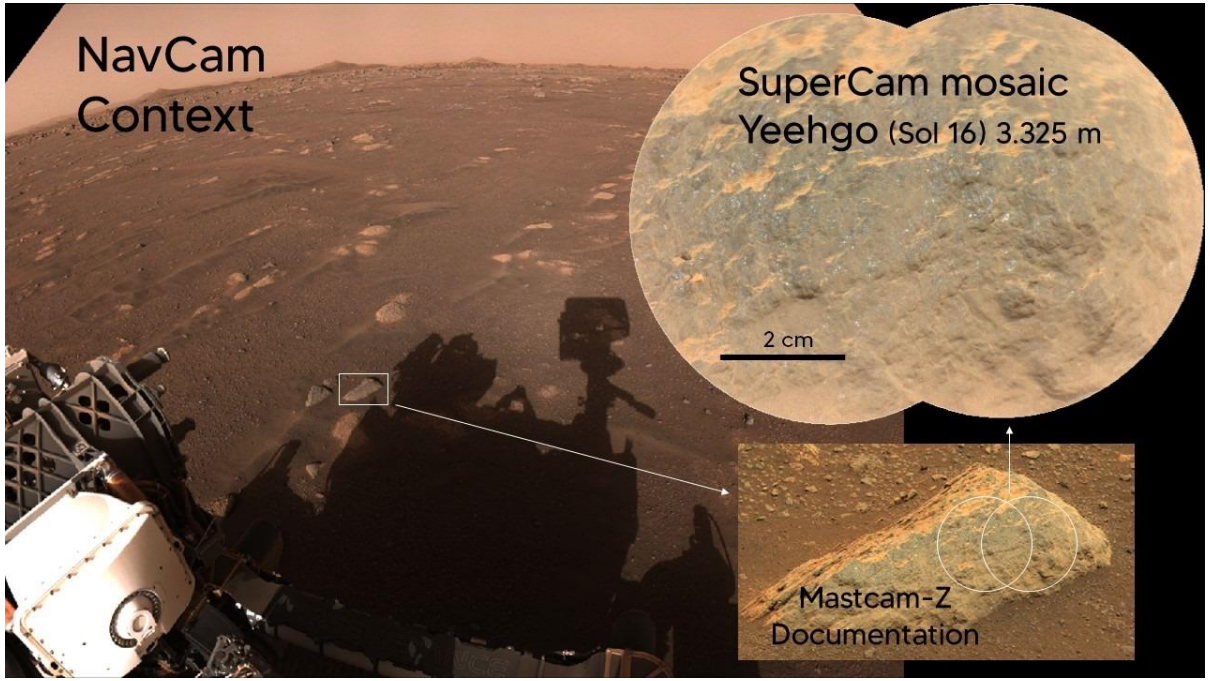
Perseverance Rover – MARS2020 Mission



3D PLUS Cameras : The Mars 2020 mission

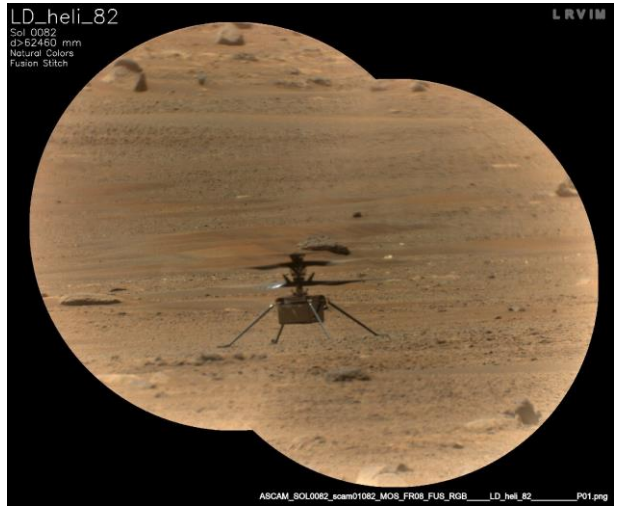
3D PLUS Camera on Mars

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



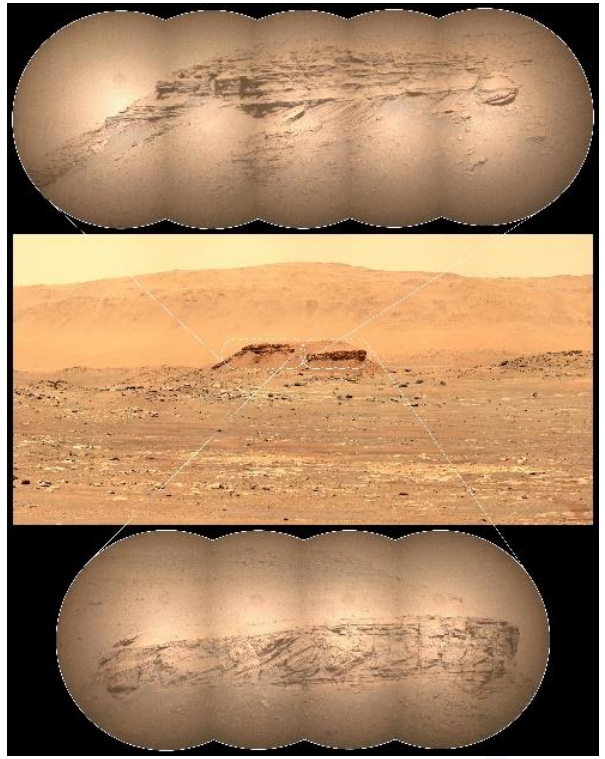
Yeehgo rock target, sol 16;

Credit : NASA/JPL-Caltech/LANL/CNES/IRAP



RMI in 'Telescope' mode – Ingenuity helicopter from 62m

Credit : NASA/JPL-Caltech/LANL/CNES/IRAP

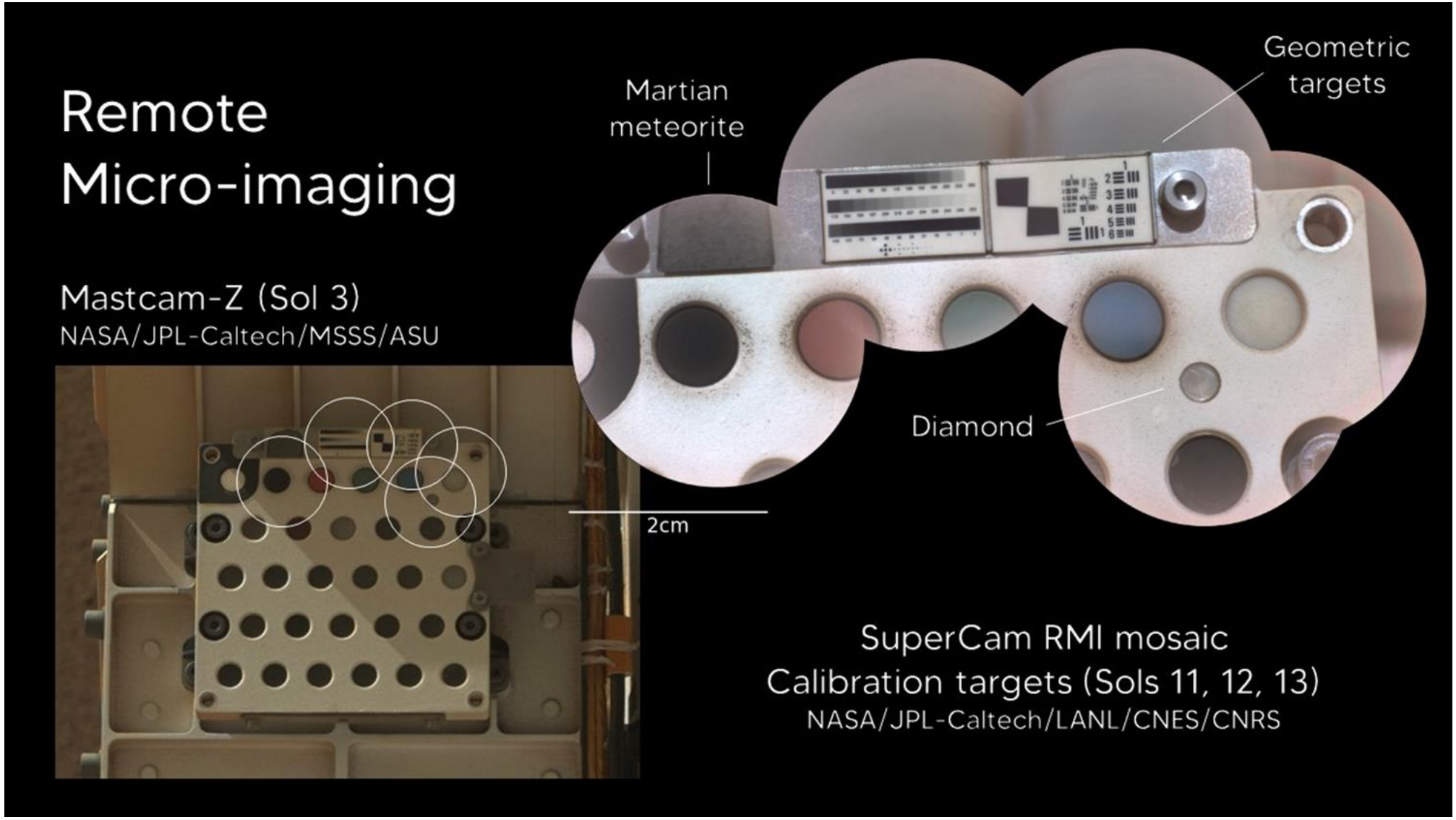


RMI in 'Telescope' mode – Mesa South of Delta – Sol 63

Credit : NASA/JPL-Caltech/LANL/CNES/IRAP

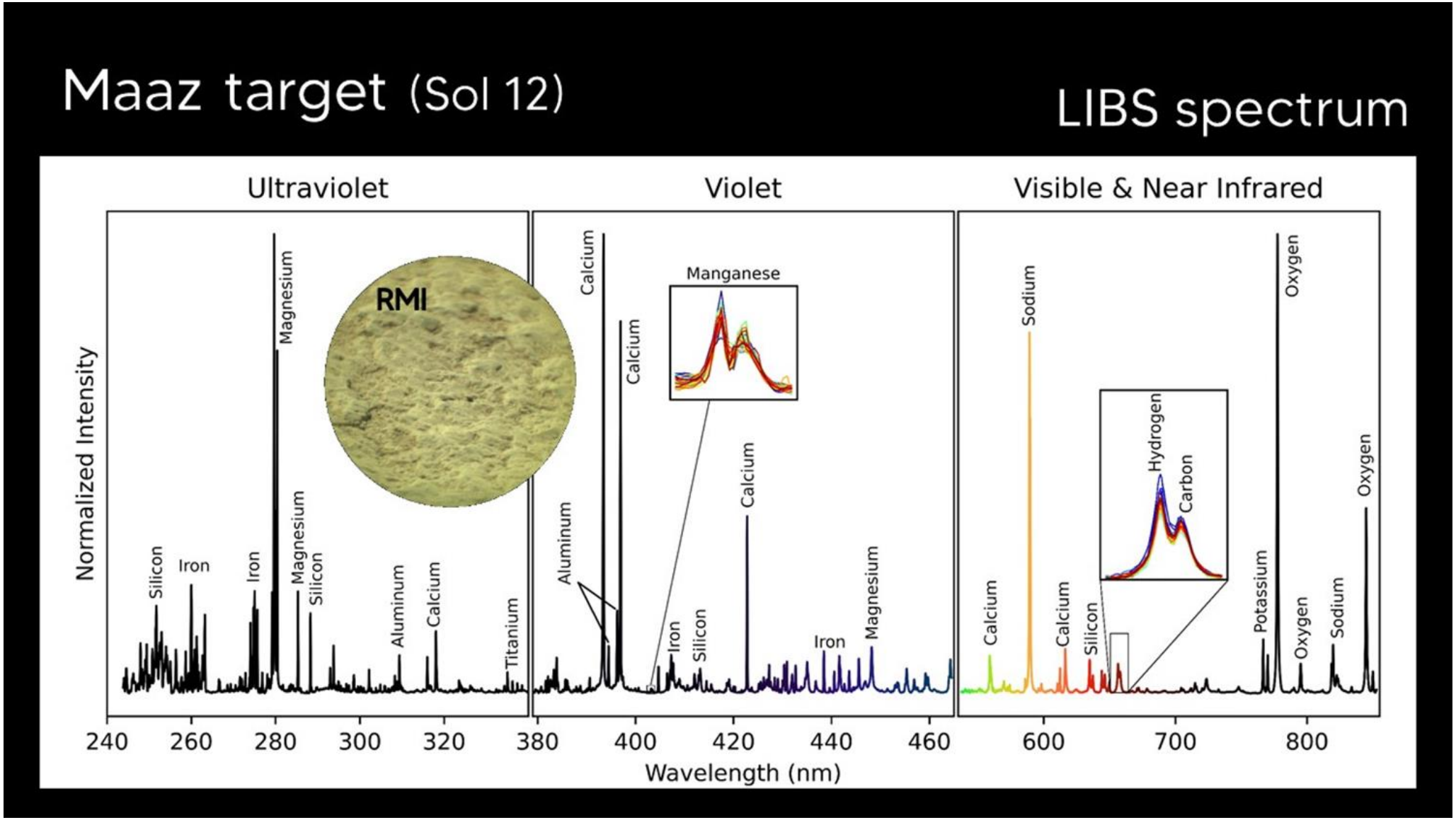
3D PLUS Cameras : The Mars 2020 mission

First images of the RMI



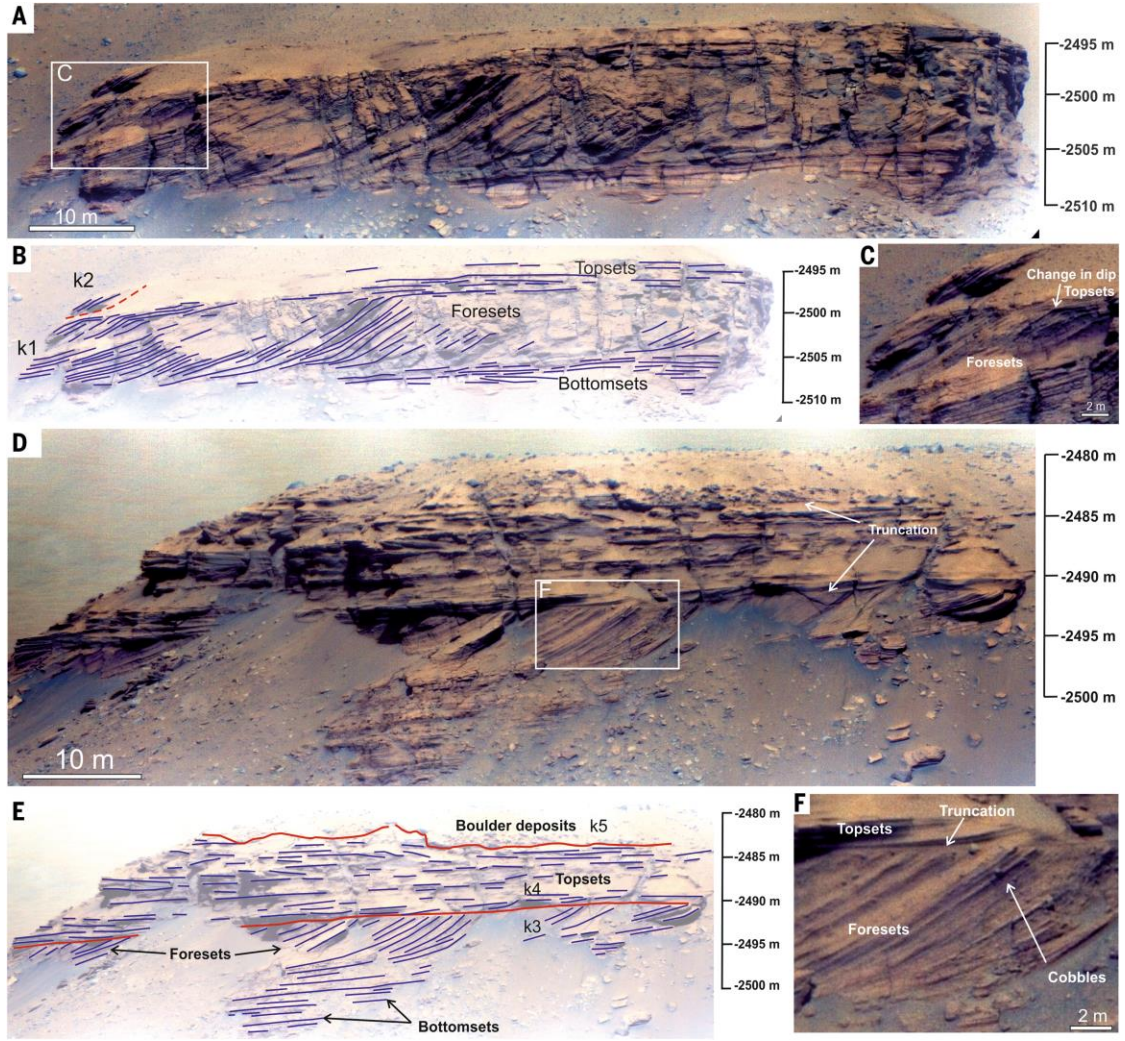
3D PLUS Cameras : The Mars 2020 mission

First images of the RMI

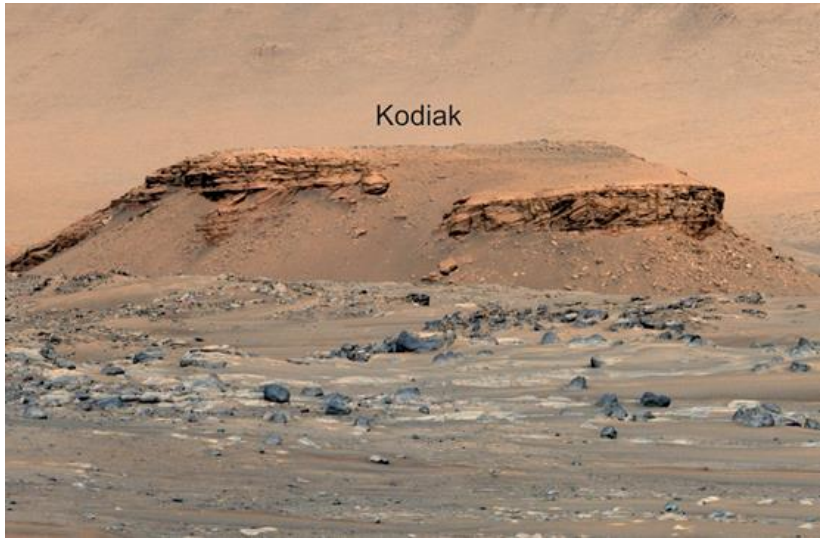


3D PLUS Cameras : The Mars 2020 mission

3D PLUS Camera on Mars : Scientific results



« Perseverance rover reveals ancient delta-lake system and flood deposits at Jezero crater, Mars », N. Mangold *et al.*, Science, october 7th, 2021



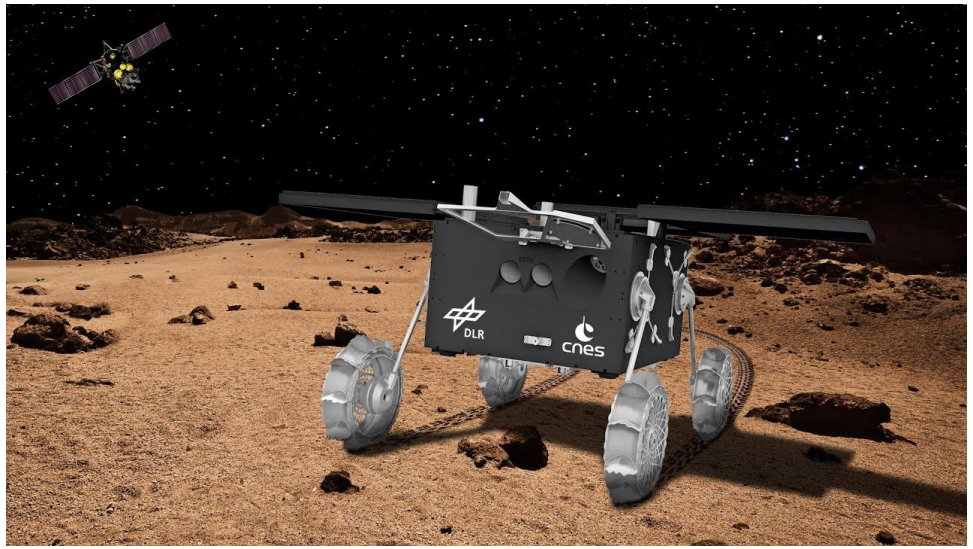
Artist view of how the Jezero crater would have looked like 3 billion years ago

3D PLUS Cameras : Future Missions

Rashid / MMX : CNES Collaborations

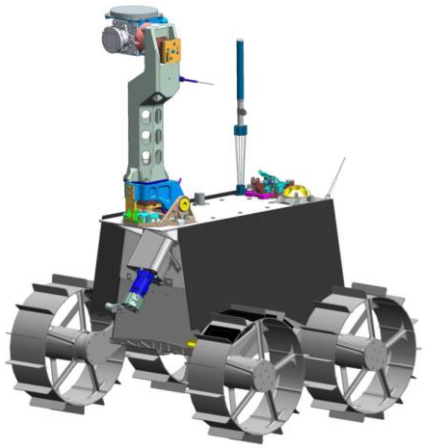
- **On going CNES Collaborations :**
  - ELR Rashid moon rover (with MBRSC) : Moon in 2022
  - Martian Moon eXploration (CNES/DLR/JAXA) : Phobos in 2024

- **Applications**
  - Wheel monitoring
  - Navigation



MMX Martian Moon Rover

Credits : CNES/DLR



ELR Rashid

Credits : MBRSC

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

3D PLUS Cameras : Future Missions

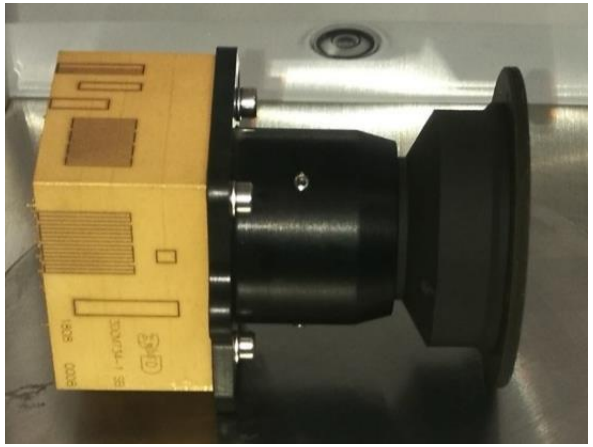
PROSPECT Instrument

- **PROSPECT Instrument / LUNA RESURS**
  - LEONARDO/ROSKOSMOS : Moon 2025
- **ProSEED Drill Monitoring**

LUNA-RESURS lander depiction

Credits : NPO/LAVOCHKIN

PROSPECT Imaging System (EM) with illumination system – Kayser subcontractor for mechanical design and illumination system



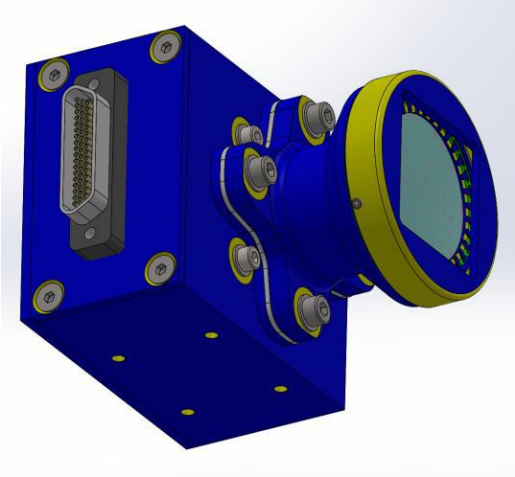
Off-the-shelf objective developed for the PROSPECT instrument

3D PLUS Cameras : Future Missions

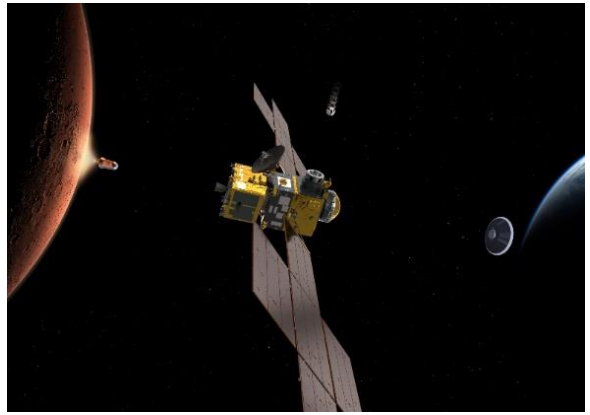
Mars Sample Return Missions

- **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

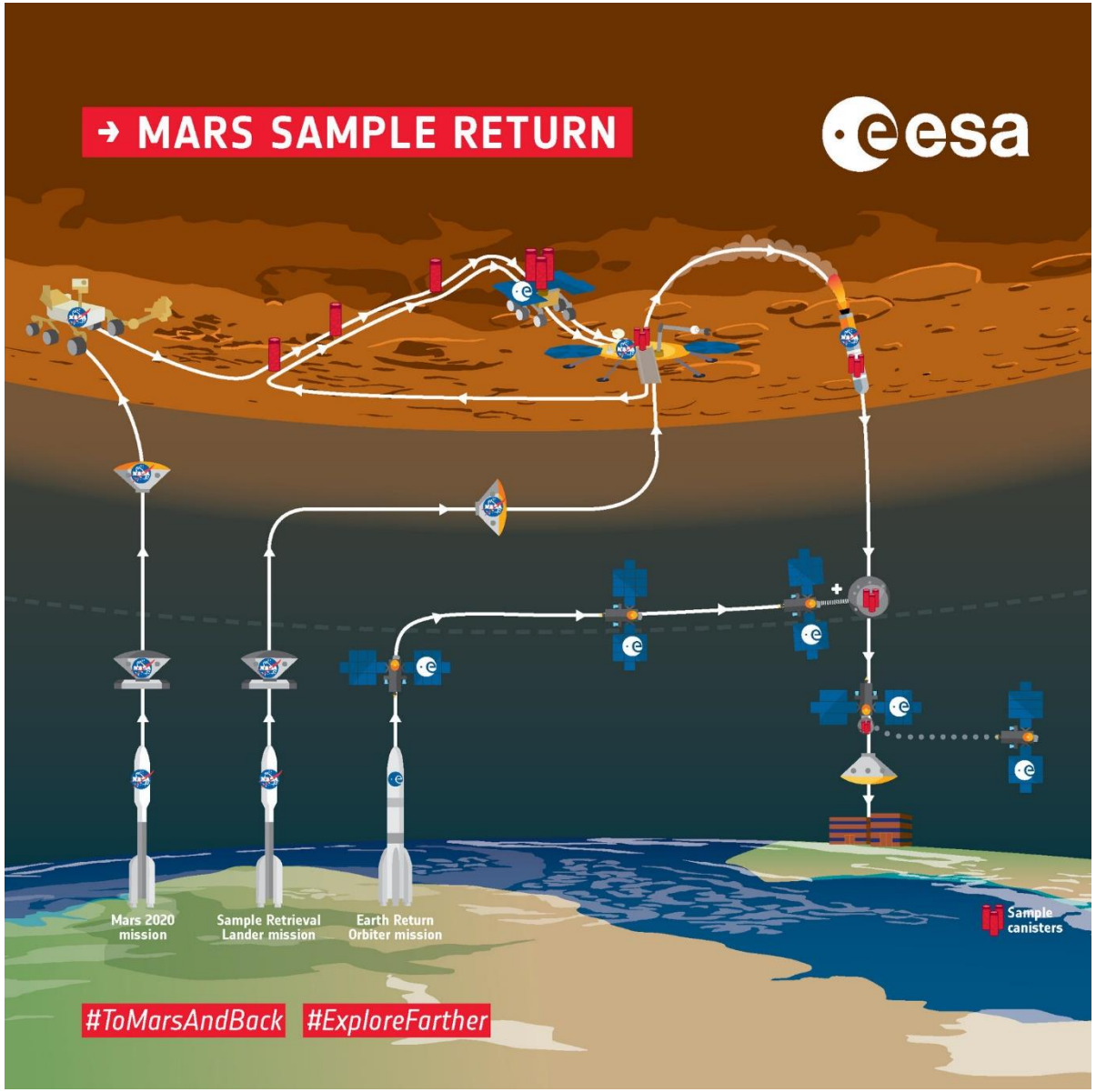


Camera Heads preliminary concept



Earth Return Orbiter spacecraft – artist rendering

Credits : ESA

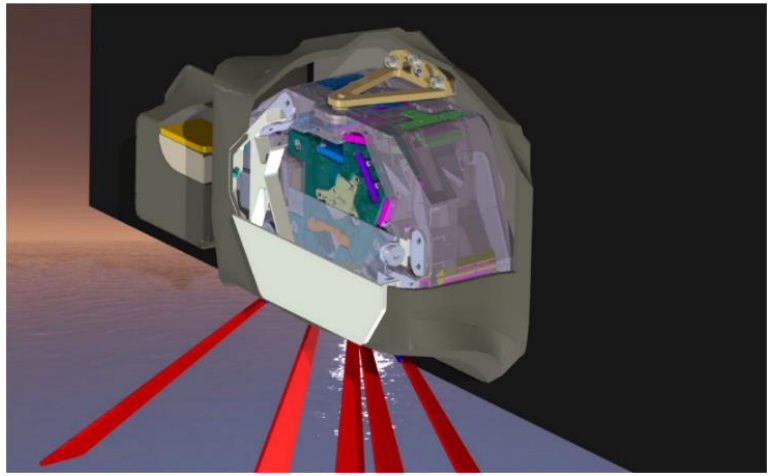


3D PLUS Cameras : Future Missions

SPEXOne Aerosol Polarimeter

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

- **Application :**
  - Aerosol Measurments using a spectro-polarimeter



Rendition of SPEXone instrument

Credits : AIRBUS NL / SRON

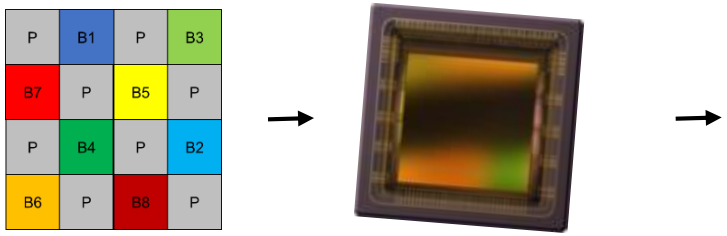
Pace spacecraft – artist rendering

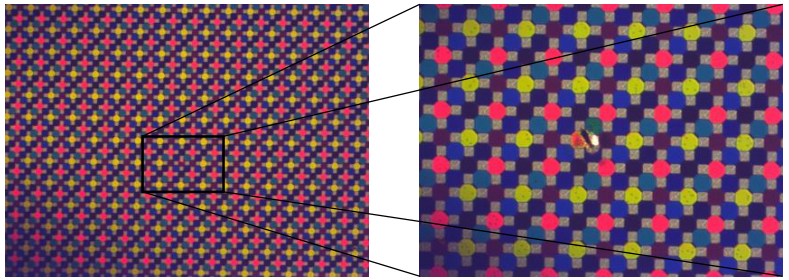
Credits : SRON

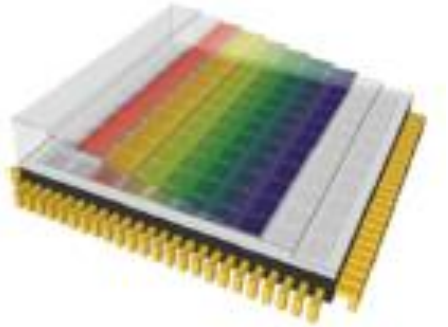
3D PLUS Cameras : Future Developments

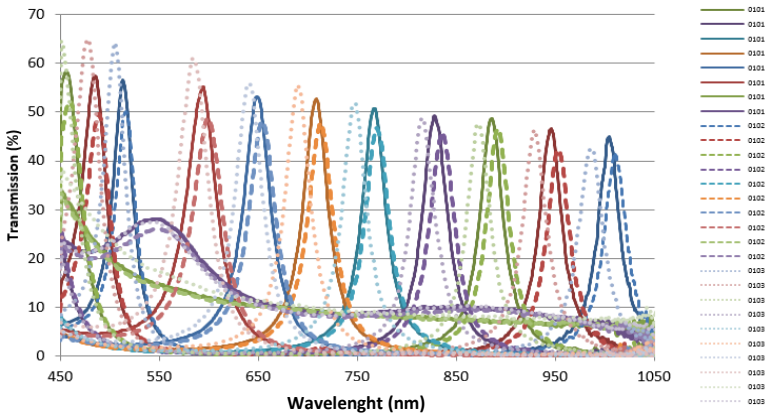
Developments of the Existing Camera

- **Developments of MultiSpectral and Hyperspectral Capabilities**

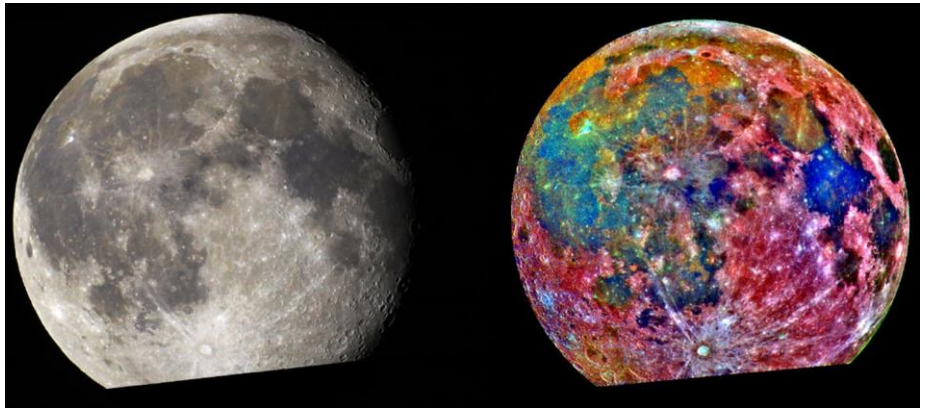








Galileo, 1992



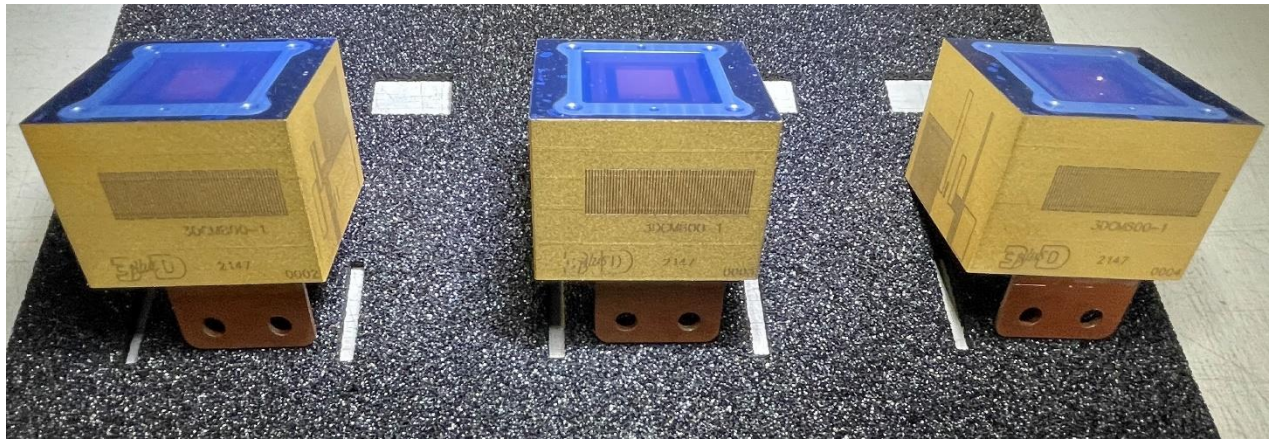
VIS-NIR Lunar image, S. Le Mouélic (LPGN), S. Maurice (IRAP)

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**

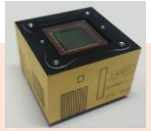
- **Two New Cameras ongoing developments :**
  - 12 Megapixels High Performances Visible Space Camera (3D Prototypes under tests)
  - 1.3 Megapixels SWIR Camera (3D Prototypes soon-to-be manufactured)



New 12 Mpixels HD Space Camera

3D PLUS Cameras : Generic Off-the-shelf Space Cameras

Applications Targets for 3D PLUS Space Cameras

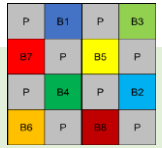


1st Gen → 4 Mpxls

Context imaging for Scientific applications

Plateform/Payload monitoring plate-forme, RDV/Docking Camera, Star Tracker

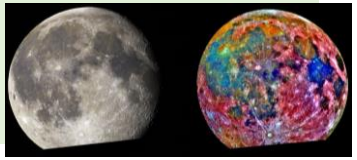
Interest scene detection



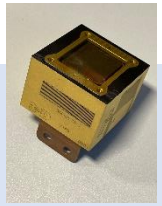
1st Gen Multi/hyperspectral

Spectral Composition and mineralogy

Hyperspectral Camera : Oceans color, Flora, Soil/water quality



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



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

Thanks For Your Attention

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