CUSTOM MADE CAMERAS

FOR DEEP SPACE NAVIGATION AND LONG-RANGE DETECTION

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ASIC/FPGA development

SODERN

2023, MARCH

SODERN: WORLD LEADER in SPACE OPTRONICS

SPACE CAMERAS

STAR TRACKERS
(Space, day, military)

Located South of Paris, with 450 employees
83 M€ Revenue in 2021

World wide company with 50% of export sales

NEUTRONIC

SPACE CAMERAS

Auricam

- Surveillance & Detection
- Monitoring
- Rendez-Vous
- Exploration & Science

FOV 35°/60°
Mass <450g
Low Power <2W
7/15 year lifetime

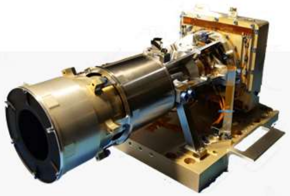
Aramis

Software for:

- Rendez-Vous
- Relative Navigation
- Final approach
- Lateral sensor

VIS & Infrared
Non-cooperative navigation
6°of Freedom
Long-range detection

Custom Made



- Highly complex environments missions (scientific, military and commercial)
- Example: JUICE mission, ERO mission

SPACE CAMERAS

Custom Made

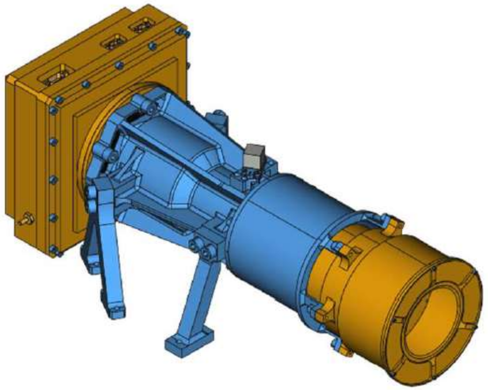
- Highly complex environments missions (scientific, military and commercial)
- Example: JUICE mission, ERO mission

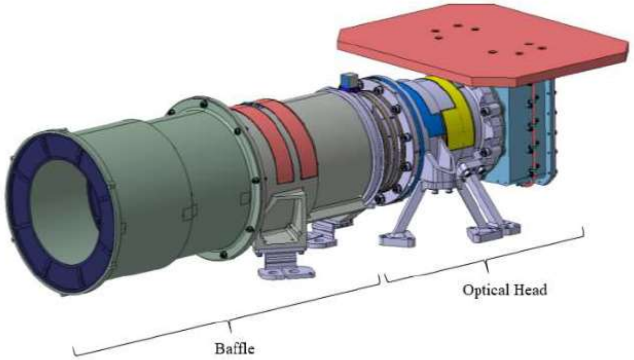
« NAVCAM JUICE»
Navigation Camera

« NAC ERO»
Narrow Angle Camera

CUSTOM MADE CAMERAS

« NAVCAM JUICE »
Navigation Camera



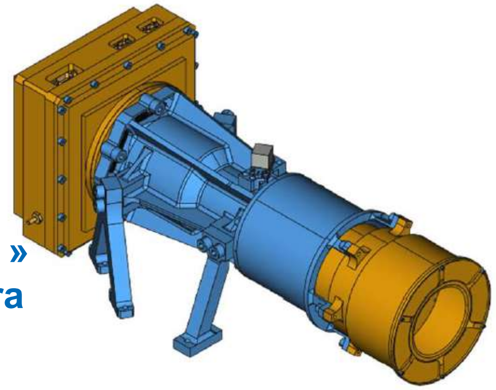


« NAC ERO »
Narrow Angle Camera

NAVCAM JUICE : Flight Models (FM) already delivered. Launch very soon !

NAC ERO : Engineering Model (EM) in progress. FPGA already tested !

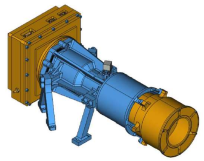
CUSTOM MADE CAMERAS



« NAVCAM JUICE »
Navigation Camera

NAVCAM JUICE Cameras

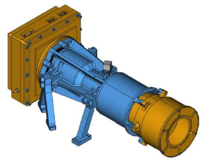
« NAVCAM JUICE » NAVIGATION CAMERA



- **Embedded on the Jupiter Icy Moon Explorer (JUICE) (ESA mission)**
- **NAVCAM JUICE : a key instrument for the spacecraft navigation**
- **Measure the position of the moons and the stars in its field of view**
- **The combination of these two measurements gives the accurate position of each of Jupiter icy moons**

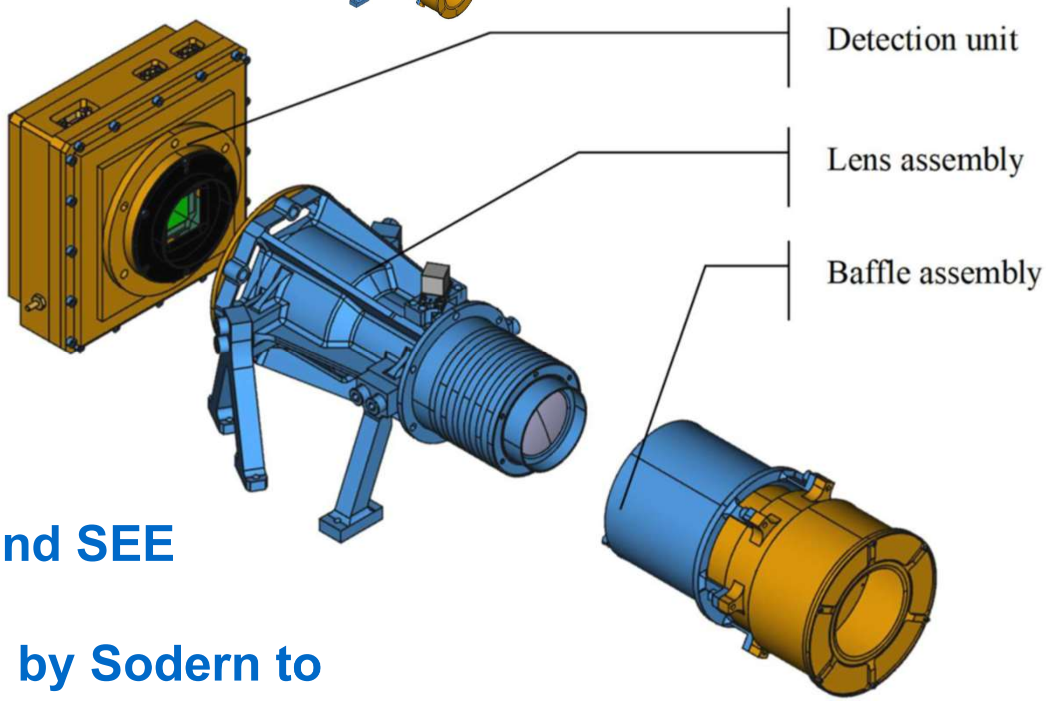
above that primary mission, NAVCAM is also used by the spacecraft attitude control during close fly-bys in order to improve the spacecraft absolute pointing performance.

« NAVCAM JUICE » NAVIGATION CAMERA



3 main subassemblies:

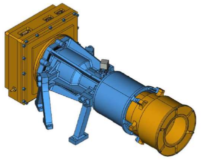
- ❑ Detection unit
- ❑ Lens
- ❑ Baffle



Made to withstands Jovian environment (Proton, heavy ion, high electron fluxes)

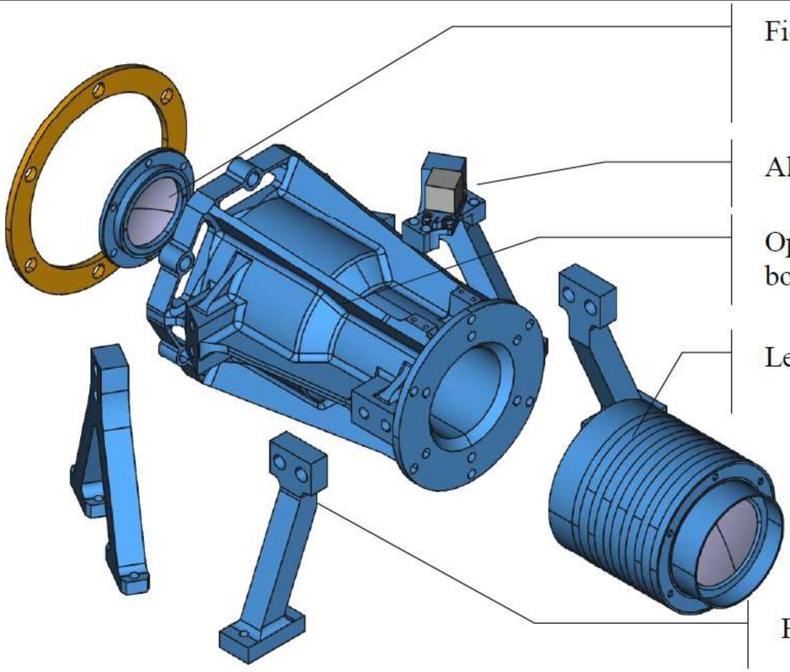
- ❑ Radiation hardened boards (100 Krad and SEE mitigation inside)
- ❑ Radhard glasses (specially developped by Sodern to minimize performance degradation)
- ❑ Optics with high mounting precision and stability
- ❑ Baffle with high performance of StrayLight rejection

« NAVCAM JUICE » NAVIGATION CAMERA



Lens Assembly features:

- Field of View = 4°
- Pupil diameter = 80mm
- Magnitude (star detection) = 8.8



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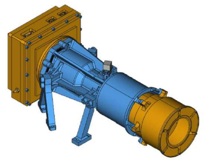
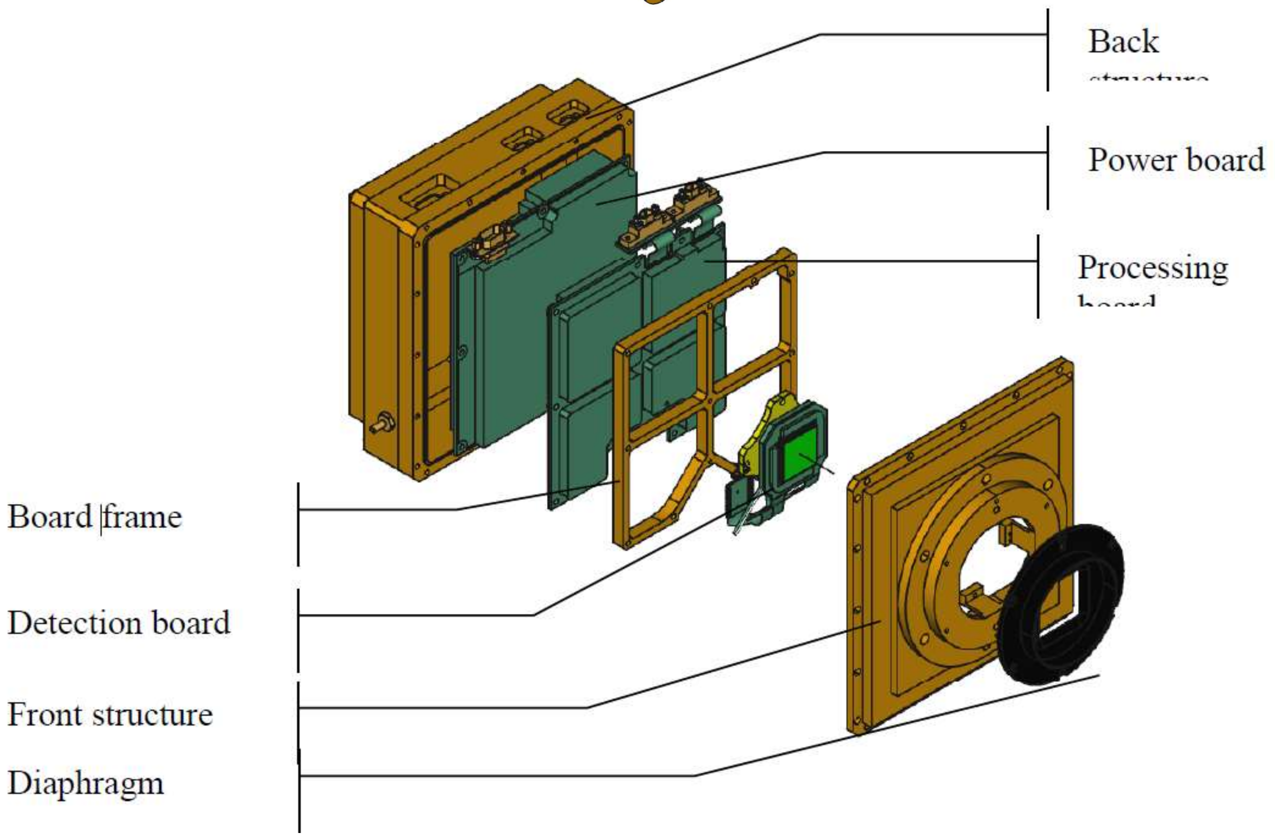


Detection Unit features:

- 3x electronics boards
  (power board, detection board, processing board)

- HAS2 sensor (1Mpixels)
- Thermo Electrical Cooler (TEC)
- 1 Gb SDRAM
- 16 Mb MRAM
- RTAX2000S FPGA



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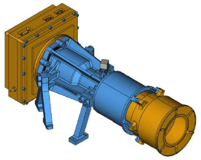


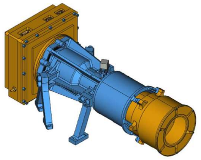
FPGA design features:

- redundant Spacewire RMAP (20 Mbps)
- SDRAM and MRAM controller
- HAS2 Sensor controller (with scalable signals)
- Servo control loop for sensor temperature regulation
- Image processing (radiometric and geometric corrections)

MRAM content: FPN (1 Million parameters) + additional parameters + microcode
SDRAM : area for image acquisition and image summation
20 MHz Oscillator

The FPGA design uses 62% of R-Cells, 75% of C-Cells and 80% of RAM blocks

« NAVCAM JUICE » NAVIGATION CAMERA

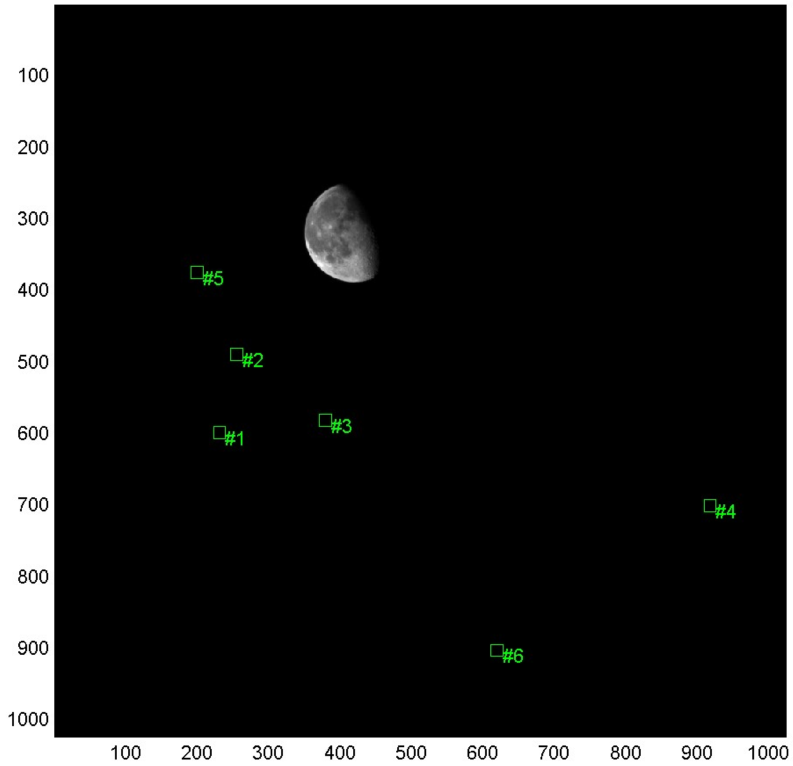


Operating modes inside the FPGA:

- ❑ IMAGING mode
- ❑ STAR CENTROIDING mode

IMAGING mode used to acquire the moon lamb:

- ❑ 1 window with scalable size (rectangular)
- ❑ scalable exposure time
- ❑ FPN correction



STAR CENTROINDING mode to acquire the stars and deliver the centroid of the stars :

- ❑ Multi-windows in multi-frames acquisition operation
- ❑ electron filtering
- ❑ frame summation
- ❑ FPN correction + radiometric correction + lens geometric corrections

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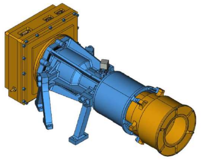


Why choosing the RTAX2000S for the mission ?

1 - Business

- device price
- development price (experience shorting the electronic board dev time)
- risk mitigation (experience in power consumption and frequency performance)

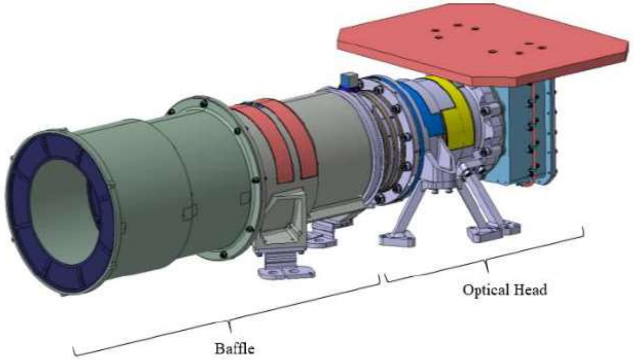
2- Radhard environment (Proton, Heavy ions, Electrons)

- Anti-fuse technology with 100 Krad TID
- SEE tolerance

3- Low frame rate of images

- One image every few seconds
- Allow to slow down the processing and save FPGA cell resources !

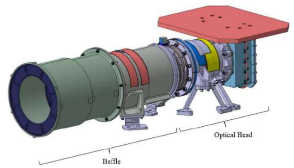
CUSTOM MADE CAMERAS



« NAC ERO »
Narrow Angle Camera

NAC ERO

« NAC ERO » NARROW ANGLE CAMERA

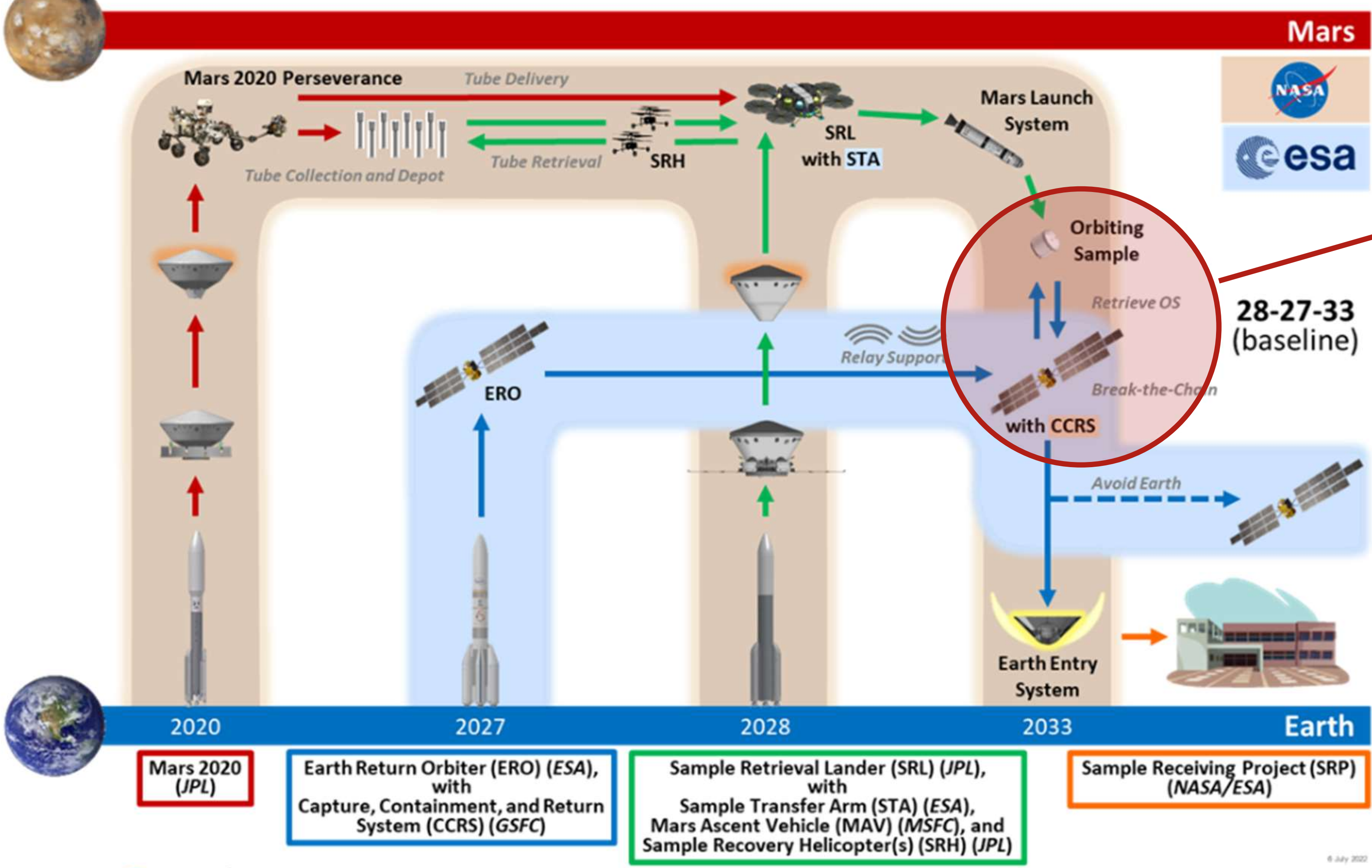


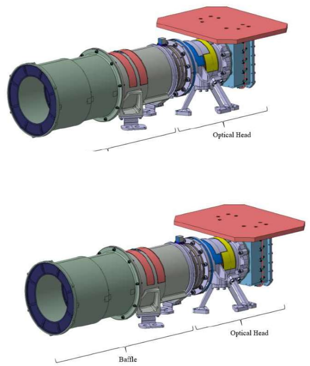
- Will be embedded on Mars Sample Return – Earth Return Orbiter (MSR-ERO) (ESA/NASA joint Mars Sample Return Campaign)

- aims to return soil and atmospheric samples from the Mars surface to Earth by 2031

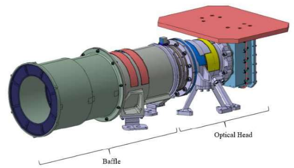
- NAC : a key instrument for the rendezvous between the spacecraft and the OS (Orbital Sample) in the orbit of Mars

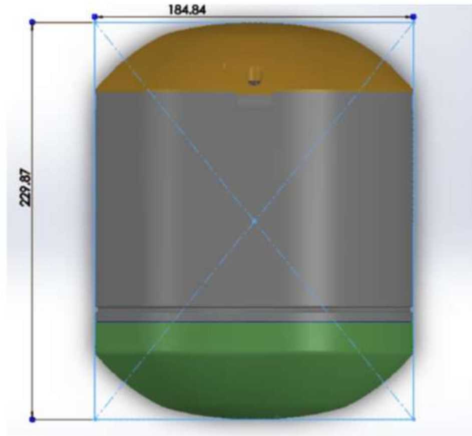
OVERVIEW OF THE MARS SAMPLE RETURN PROGRAM





« NAC ERO » NARROW ANGLE CAMERA





Canister storing the samples from Mars, about the size of a soccer ball

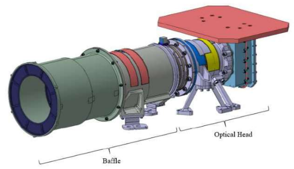
It is painted white to maximize the albedo

It is completely passive (no RF beacon, no light emitter)

It will be launched in orbit with poor precision

“OS”
Orbital Sample

« NAC ERO » NARROW ANGLE CAMERA



First step : OS long range detection
(IMAGING mode)

Range : [3 000 km ; 70 km]

OS magnitude: up to 12,6 (very faint object)

Mars at 12,5° of the line of sight

The Cameras provide the images with the OS. Images are downloaded to earth and processed on earth.

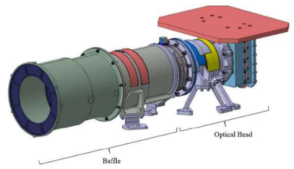
Second step : OS Rendezvous
(TARGET CENTROIDING mode)

Range : [70km ; 400m]

The Cameras detect and compute the OS centroid. They guides the Spacecraft for the orbit-matching with the OS.

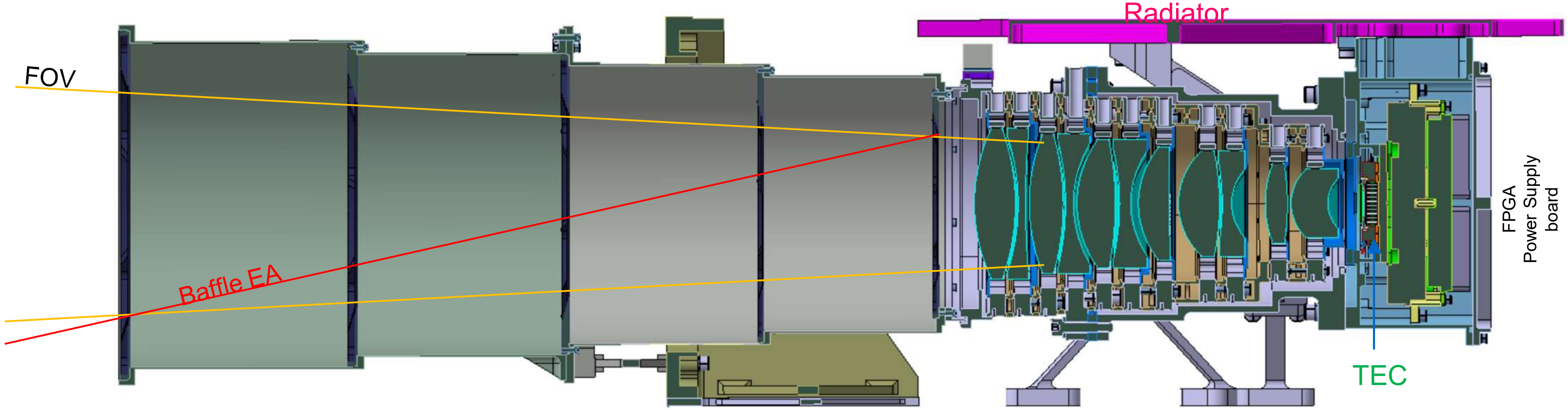
Last step : OS Capture
Range [400m ; 0]
Performed by others instruments (LIDAR)

« NAC ERO » NARROW ANGLE CAMERA



Features:

- SNR >3 | FOV= 4,5° | Baffle EA = 14° | Pupil = Ø80mm | 14,5 kg | Pmax< 12W
- Ultra Stable Optical Mount inherited from S5 UV-VI Spectrometer
- Accurate thermal control to minimize impact of dark signal & defect pixels
- Sensor cooled down to -15°C to achieve SNR performance



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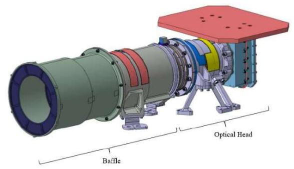

- NAC reuses major elements of Sodern star tracker (power supply, detection module). Optical Module & baffle are specific developments.
- All sources of noise are characterized: fixed pattern noise, photo response non uniformity, dark signal, distortion, chromatism
- A calibration will be performed once the camera will be around Mars, for detection of defective pixels (spikes)

Ultimately, main contributor to noise is Straylight from Mars & Sun

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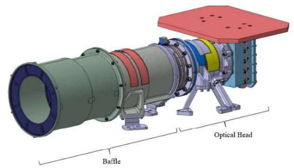
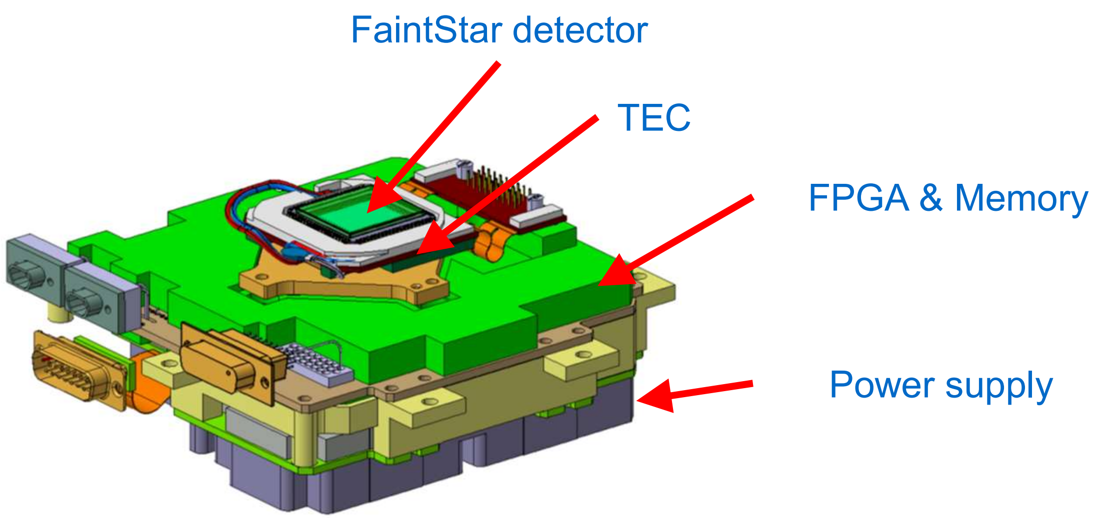


Detection Unit features:

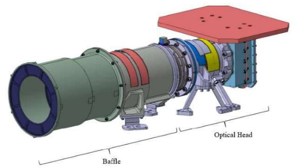
- 3x electronics boards (power board, detection board, processing board)

- FaintStar sensor (1Mpixels)
- Thermo Electrical Cooler (TEC)
- 1 Gb SDRAM
- ProASIC3L FPGA (RT3PE3000L)



3 stacked electronics boards

« NAC ERO » NARROW ANGLE CAMERA



FPGA design features:

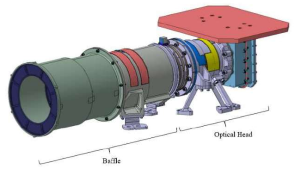
- redundant Spacewire RMAP (10 Mbps in Rx , 80 Mbps in Tx)
- SDRAM controller
- sensor controller (parameters handling + Spacewire interface)
- servo control loop for sensor temperature regulation
- image processing
- full L-TMR inside / Safe FSM / all RAM blocks with EDAC protection / Scrubbing for all memories with long time data retention

SDRAM :

- area to store up to 20 images in a single acquisition (one burst)
- EDAC protection of each pixel in the images

80 MHz oscillator

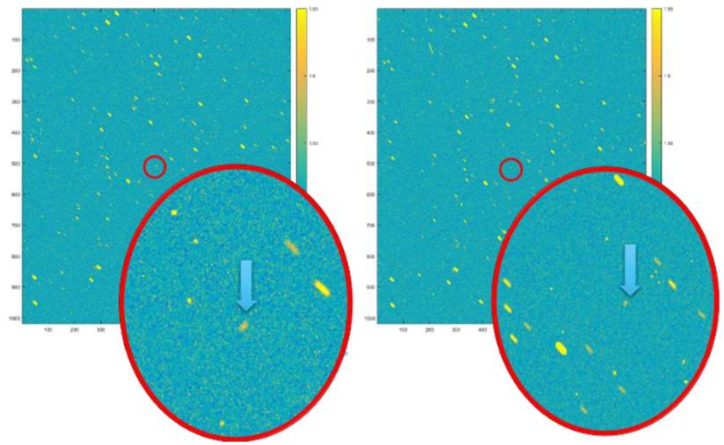
« NAC ERO » NARROW ANGLE CAMERA



Operating modes inside the FPGA:
- ❑ IMAGING mode
- ❑ TARGET CENTROIDING mode

IMAGING mode, in range [3000km-70km]:
- ❑ 1 to 20 full frames (1020x1020 pixels per frame)
- ❑ scalable exposure time

TARGET CENTROINDING in range [70km-400m]:
- ❑ 2 full frames
- ❑ scalable window selection (up to full frame)
- ❑ star masking (up to 640 scalable windows)
- ❑ Thresholding
- ❑ Electron filtering
- ❑ Centroid computation with quality index



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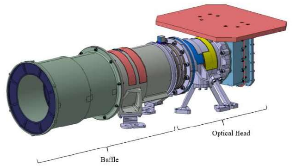
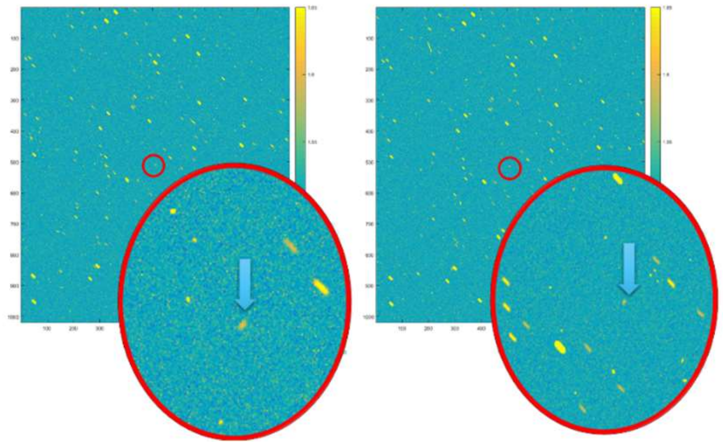


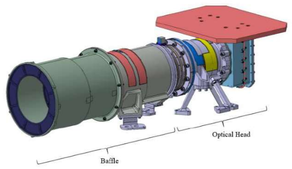
TARGET CENTROINDING in range [70km-400m]:

- Frame rate = 0,5 Hz
- 650 ms sensor exposure + readout
- 1050 ms processing time
- 2 Million pixels (2 images) processed
- Real-time POI matching between 2 images (POI = Pixels of Interest)
- Up to 1 million of POI (=full frame) entering in the computation of the centroid
- One centroid of the OS (Xc,Yc) available every 2 seconds.



The FPGA design uses 44% of Cells and 62% of RAM blocks.

« NAC ERO » NARROW ANGLE CAMERA

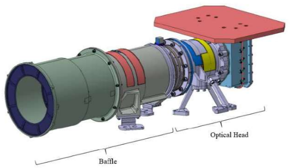


The FPGA is already tested on the Engineering boards (EM) :

- ❑ **burst of 20 images have been tested in IMAGING mode with the Faintstar sensor in the full range of the exposure time.**
- ❑ **representative images have been uploaded inside the SDRAM of the Camera and executed in TARGET CENTROIDING mode.**

Next steps : final assembly of the EM Camera, Flight Models manufacturing and qualification tests.

« NAC ERO » NARROW ANGLE CAMERA



Why choosing the ProAsic3L for the mission ?

1 - Business

- ❑ device price
- ❑ development price (experience shorting the electronic board dev time)
- ❑ risk mitigation (experience in power consumption and frequency performance)

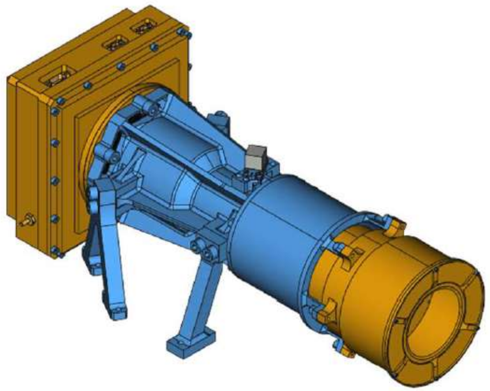
2- Reprogrammability (Flash-based FPGA)

- ❑ to be able to update later the firmware without des-assembling the camera (JTAG programming on the « Test » connector of the Camera)

3- Low frame rate and low power dissipation

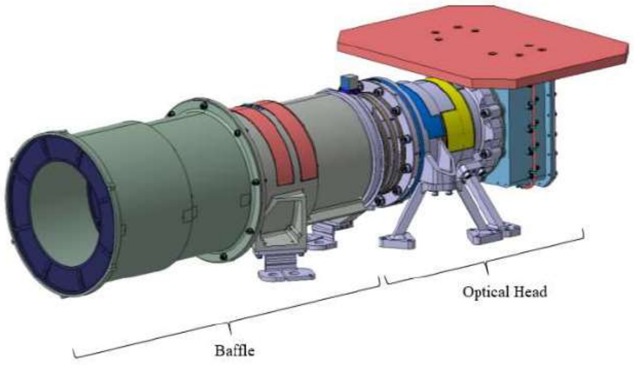
- ❑ one Centroid computation every 2 seconds
- ❑ Main frequency = 20 MHz inside the FPGA; to reduce power dissipation !

CUSTOM MADE CAMERAS



THANK YOU FOR YOUR ATTENTION

Christophe



Acknowledgments

Sodern is under contract with Airbus Defense & Space to design and manufacture the NAC ERO. It is part of the Mars Sample Return mission, a joint ESA/NASA program. ESA leads the Earth Return Orbiter project.

The views expressed in this article can in no way be taken to reflect the official opinion of the European Space Agency.