Characterization and calibrations of VIS cameras for space applications – JANUS and HYPSOS systems

Livio Agostini - 35th Cycle

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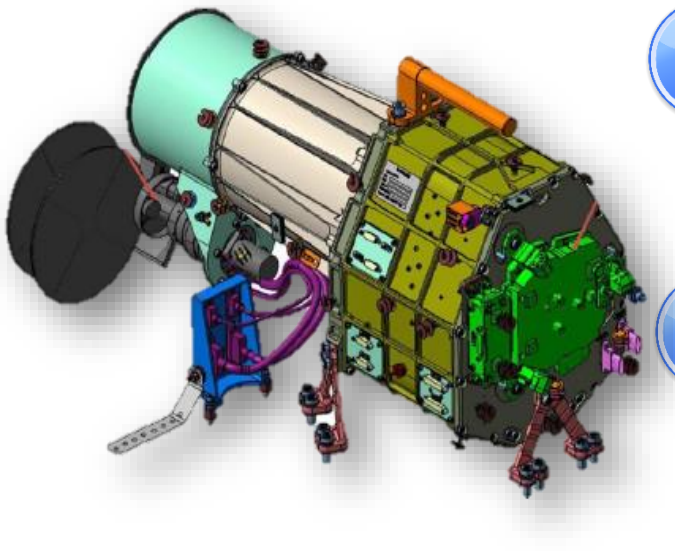
Co-supervisors: Dr. Alice Lucchetti, Prof. Giampiero Naletto

Admission to second year - 10/09/2020

JANUS
(Jovis, Amorum Ac Natorum Undique Scrutator)



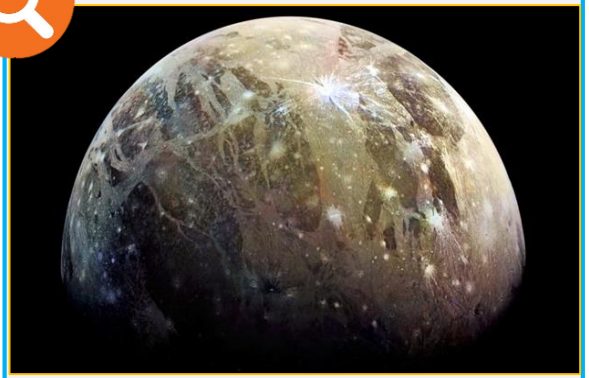
GENERAL INFORMATIONS

PI : *Prof. P. Palumbo (University Parthenope)*
Deputy-PI: *Dr. G. Cremonese (INAF – OAPD)*
Prime Contractor: *Leonardo SpA*

MAIN FACTS

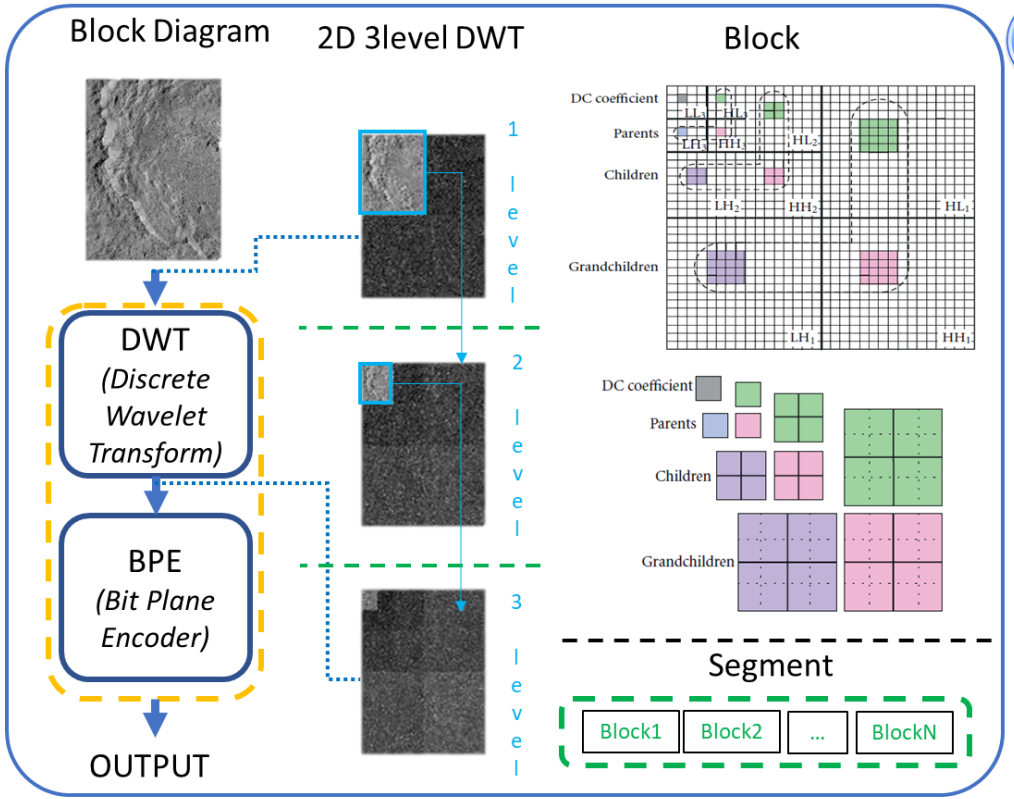
- On board of ESA JUICE mission
- Launch date: May/June 2022
- 7 years of cruise, 3.5 years of mission
- High resolution camera with modified Ritchie-Chretien design. 5/10 m/pix @ 500km
- Optical Head + PEU + MEU
- Multispectral capabilities

SCIENTIFICAL OBJECTIVES



- study of magmatic, tectonic and impact features of surfaces (icy moons)
- cryovolcanism
- constrain surfaces composition
- Ganymede rotation and libration
- jovian system object observation
- investigation of Io's tidal heating
- Jupiter troposphere: clouds, vortices and lighting
- stratospheric variations
- aurora activity
- plumes, torus and exosphere

Compression factor for JANUS



GENERAL INFORMATIONS

JANUS will use a Wavelet compression scheme based on the CCSDS 122.0-B-1 algorithm. The compressor is made by two main stages:

- DWT – that performs a decorrelation of the image according to a 3-levels 2D Discrete Wavelet Transform that is, each low-pass (LL) coefficients matrix is the new input for a 2D DWT. The image is then decomposed in a hierarchical way in low and high frequencies versions of the original image. The DWT output is called *coefficient*. Each portion of the image is decomposed in 64 coefficients, the DC referring to the lowest frequency plus 63 coefficients of higher frequency.
- BPE - that encodes the coefficients of the DWT output according to a bit-plane scheme

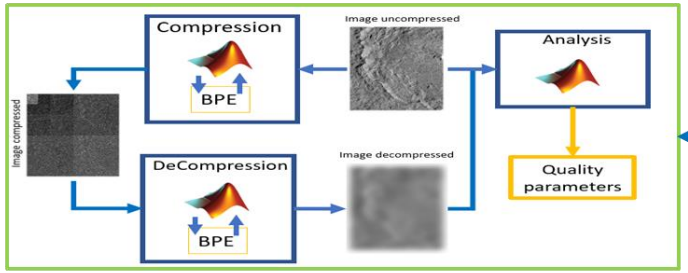
Determine the best CR (Compression Ratio) for JANUS. This implies a trade-off between quality and data volume

METHODS

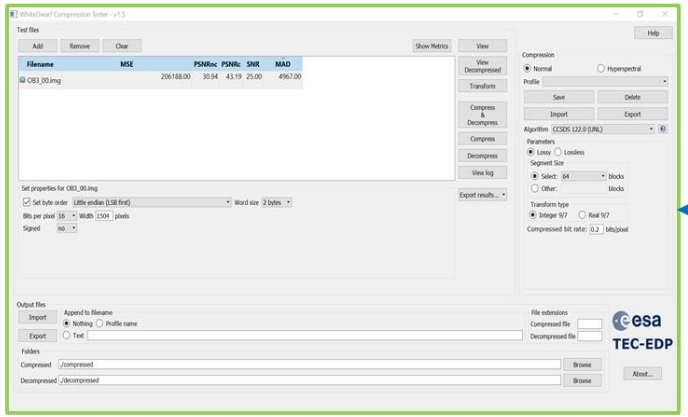
The evaluation includes two approaches:

- Objective metrics
- Subjective metrics

Compression factor for JANUS



Block diagram of the preliminary simulation strategy



The ESA WhiteDwarf program

INSTRUMENTS

Several software implementations of the CCSDS compression scheme are available online (such as the BPE project from University of Nebraska Lincoln and the ESA's WhiteDwarf executable). These programs allow to evaluate the performance of the compressor at different:

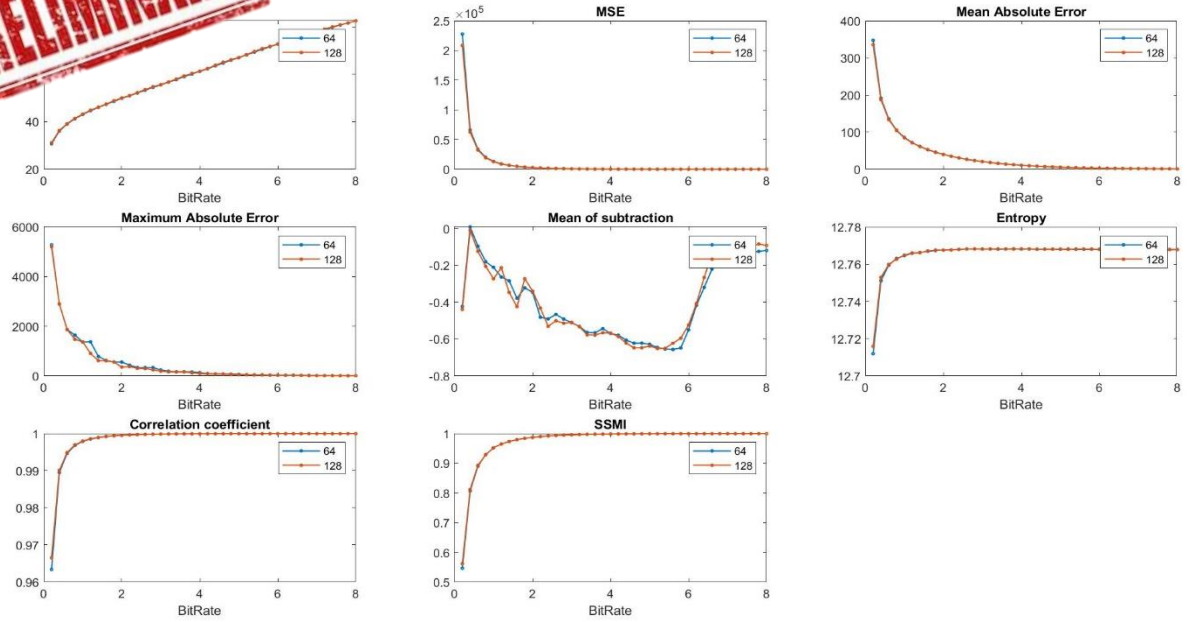
- Compression ratios
- Number of blocks in segment

The DWT type has been set to the JANUS's one (the algorithm has two different types of DWT : float and integer)

- For the preliminary test an image of 1504x1504 pixels (figure on the left) has been compressed/decompressed with different compression ratios and number of blocks in segment
- This preliminary work allows the team to plan a strategy, targets and working flow when the effective JANUS compressor simulator will be available. The short term objective is also accelerate the following analysis, gaining experience on the compressor.

Compression factor for JANUS

PRELIMINARY



Different objective distortion index as function of bit rate (compression ratios from 2 to 80). In blue simulations with 64 blocks in a segment, in red simulations with 128 blocks in a segment

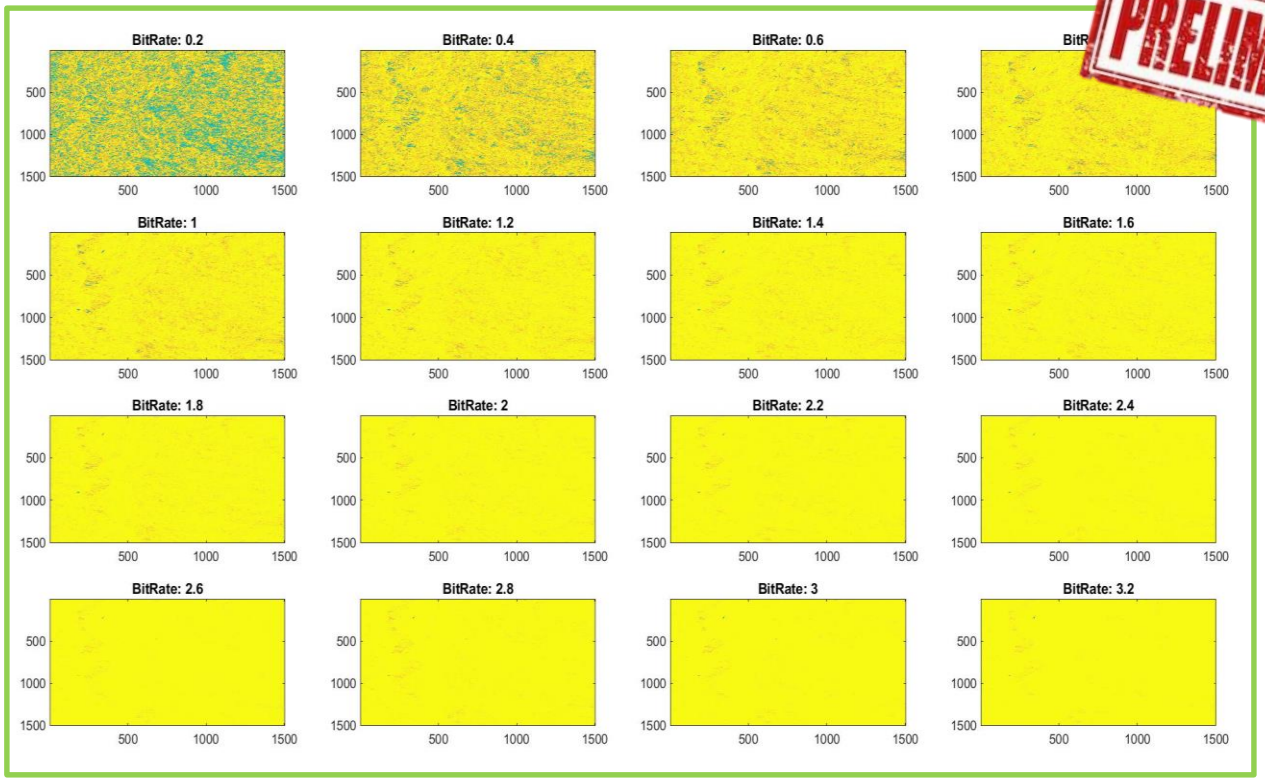
CONVERSION

$$BitRate \approx \frac{2^{bit}}{Compression\ ratio}$$

PERFORMANCE METRICS

- $MSE = \sum_{i=1}^{N}\sum_{j=1}^{M}\frac{1}{MN}\left(IM_{orig} - IM_{decomp}\right)^2$
- $PSNR = 10\log_{10}\frac{\left(2^{bit}-1\right)^2}{MSE}$
- $MAE = mean\left(\left|IM_{orig} - IM_{decomp}\right|\right)$
- $MxAE = max\left(\left|IM_{orig} - IM_{decomp}\right|\right)$
- $Mean\Delta = mean\left(IM_{orig} - IM_{decomp}\right)$
- $Entropy = -\sum P \cdot \log_2 P$

Compression factor for JANUS



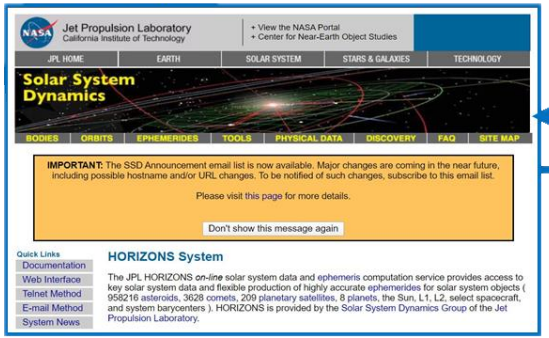
For example, the SSIM (the structural similarity index for measuring the image quality) can be considered in between an objective index and a subjective one.

It is based on the idea that the human vision is highly trained to identify the structures in an image.

The index performs a sort of normalization on the luminance and contrast in order to highligh the structures.

JUICE/JANUS Target of opportunity

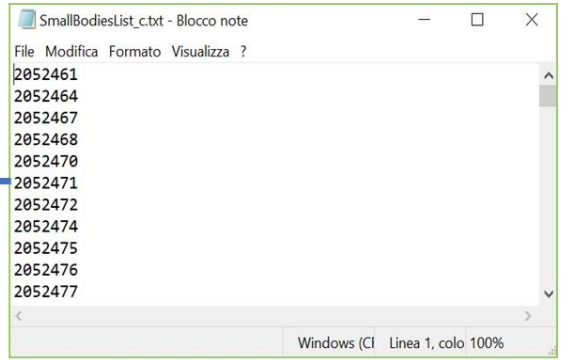
HORIZONS System



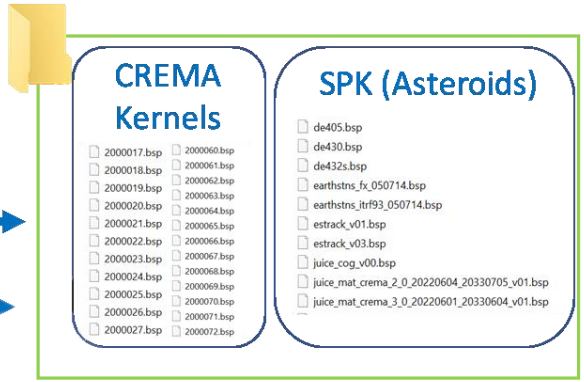
ESA website

smb_spk

HorizonsDownload3.py

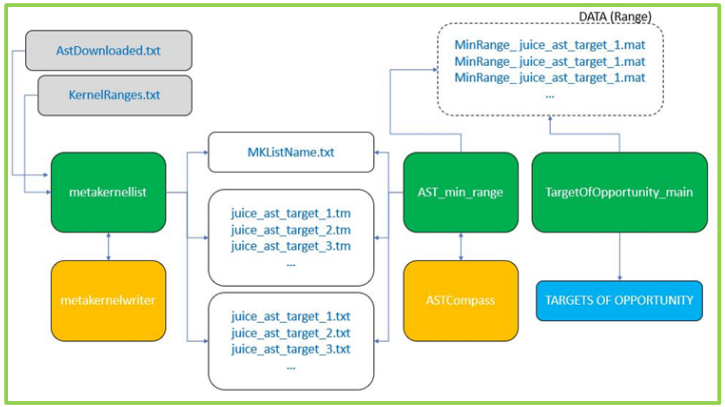


ftp



JUICE/JANUS Target of opportunity
Automatic Asteroids Search Toolkit

Algorithm

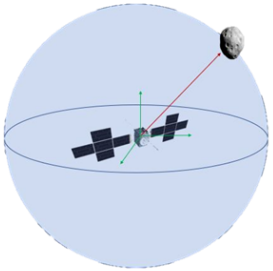


Programs

SPICE

FORMULAS

$$R = \sqrt{x^2 + y^2 + z^2}$$



$$Proj = \frac{Diam_{ast}}{H} f$$

$$H = \min(R)$$

$$PixFrac = \frac{Proj}{Pixel}$$

CAPABILITIES

- Semi-automated Metakernel generation
- Minimum distance calculation
- Pixel fraction calculation

PRO

- Modular approach (possibility to add new instruments)
- Precise results (due to the SPICE kernels)

CONTRA

- Slow analysis (brute force analysis with very large dataset downloading needed)

JUICE/JANUS Target of opportunity

Preliminary results

SPKEZR parameters	
Frame	ECLIPJ2000
Aberration	LT+S
Observer	JUICE
Date Start	2024 dec 12 00:00:00 UTC
Date End	2029 dec 12 00:00:00 UTC
Time resolution	1 hour

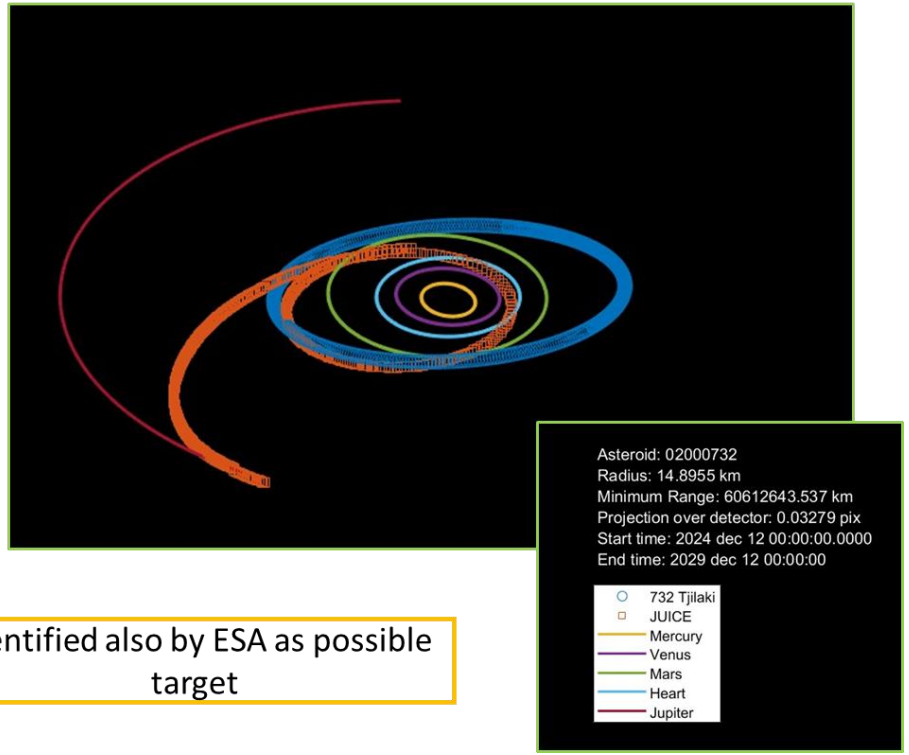
JANUS parameters	
Focal Length	467mm
Pixel	$7\mu m$

Dataset		
Available	Considered	Analized
958216	136213	136213

6 most close

SPICE ID	Name	Pixel Fraction	Diameter [km]	Distance [km]
2004246	Telemann	0.7159	4.81	$4.48 \cdot 10^5$
2000924	Toni	0.5503	85.49	$1.036 \cdot 10^7$
2000001	Ceres	0.5496	939.40	$1.140 \cdot 10^8$
2000202	Chryseis	0.4712	86.15	$1.22 \cdot 10^7$
2000051	Nemausa	0.4251	138.16	$2.17 \cdot 10^7$
2005368	Vitagliano	0.3323	34.81	$6.99 \cdot 10^6$

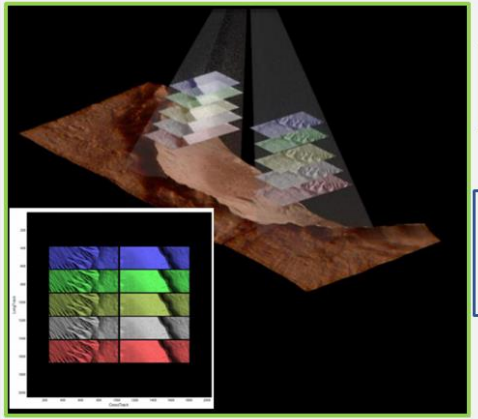
Identified also by ESA as possible target



HYPSOS
HYPerspectral Stereo Observing System

HYPSOS (HYPerspectral Stereo Observing System) is a patented, innovative electro-optics payload, capable of generating hyperspectral maps and Digital Elevation Model (DEM) using only one sensor.

The hyperspectral DTM generated by HYPSOS will include, in a unique dataset, the information on the surface morphology and on its composition. This will avoid the typical problems encountered with the combination of data generated by two different instruments (different calibration; different data production in terms of detector, noise and compression; different observing strategy; different FOV; different spatial and spectral resolutions)..



PI: Dr. G. Cremonese
Contract: ASI-INAF 2018-16-HH.0

Italian patent n.102016000097439, M.Tordi (EIE), G.Cremonese, G.Naletto, C.Re

STEREO capabilities	+	SPECTRAL capabilities	=	NEW Data type
3D	+	1D	=	4D

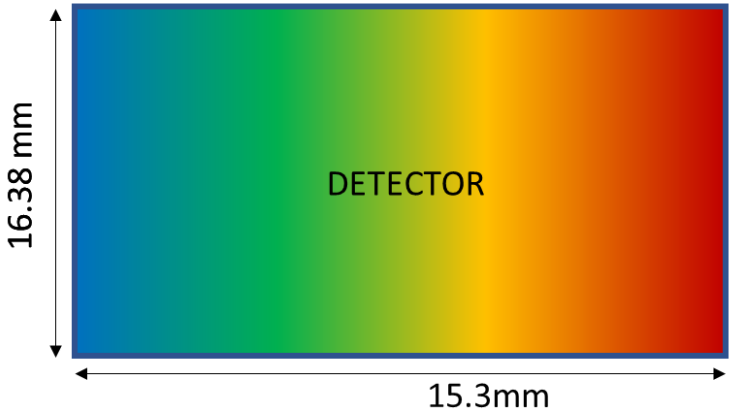
The instrument is able to produce more than 100 stereo pairs on the same detector

HYPSOS
Detector selection

CATALOGUES

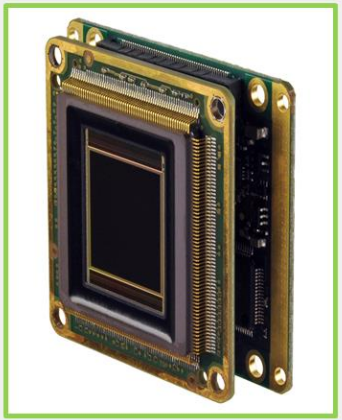
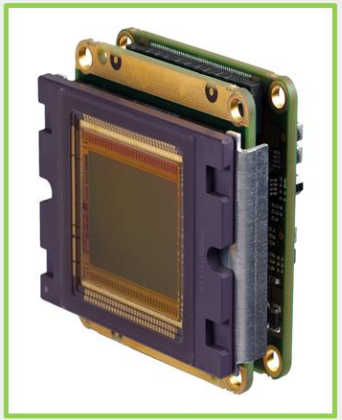
- Hamamatsu
- AlliedVision
- IDS
- XIMEA
- RaptorPhotonics
- TheImagingSource
- ViewWorks
- Pythec
- SpecializedImaging
- Mikrotron
- Atik
- Lumenera
- Alkeria
- ZWO
- Matrix-Vision
- FLIR
- Thorlabs
- Pyxelink
- PCO
- NewImagingTechnologies
- IMPERX
- Crisel-Instruments
- Basler
- Photonfocus
- DPControl
- ImageS -> Teledyne Dalsa
  Teledyne E2V

■ Contacted



MAIN DRIVERS	
Active area	≈20x20 mm^2
Equivalent Pixel size	≈10 µm → ≈25 µm
Housing	Board-level
Chroma	Monochrome
Availability	COTS

HYPSOS
Detector selection

	MATRIX-VISION BF3-5M-0315ZG-100510	PHOTONFOCUS OEM-D2080-160-LC-12	PHOTONFOCUS OEM-D4096-960-LC-10	XIMEA
				NOT AVAILABLE
Technology	CMOS	CMOS	CMOS	CMOS
Image sensor	SONY Pregius IMX342	Photonfocus A2080	CMOS CMV12000	CMOS CMV12000
Pixel size	3.45µm	8µm	5.5µm	5.5µm
Output	Various (USB3)	GigE	GigE	PCIe
Note:	/	/	/	Image sensor detached

HYPSOS
Optical bench

Activities in Luxor laboratory at CNR-IFN:

- Inventory
- Preparation of the optical bench (remotion of previous experiment, storage of components)
- Organization of the workstation

Heritage of materials and techniques from previous space missions: WAC/Rosetta and STC/SIMBIO-SYS:

- Rotational stages & controller
- Source lamp
- PC
- Targets

Thanks for the attention

UNIVERSITÀ
DEGLI STUDI
DI PADOVA