In-flight calibration and performance verification of the Metis and STC instruments

Chiara Casini - 36th Cycle

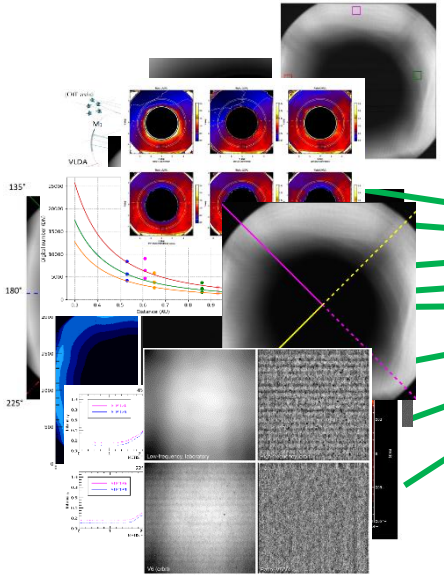
MEETING FOR THE ADMISSION TO THE THIRD YEAR

05-06/09/2022

Scientific Images Calibrations

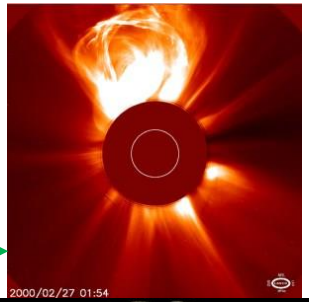
SCIENCE???

NO



My work

SCIENCE???



YES

My PhD activity serves to acquire a deep and detailed knowledge of the Metis and STC instruments in one of the most critical and important phase of a space mission: it's essential to obtain scientific useful images.

https://www.researchgate.net/publication/321358296 Calibration Projection and Final Image Products of MESSENGER's Mercury Dual Imaging System/figures

Metis of Solar Orbiter

Launch 09/02/2020 | **06/2020** | **11/2021** | **01/2026** | **2030**

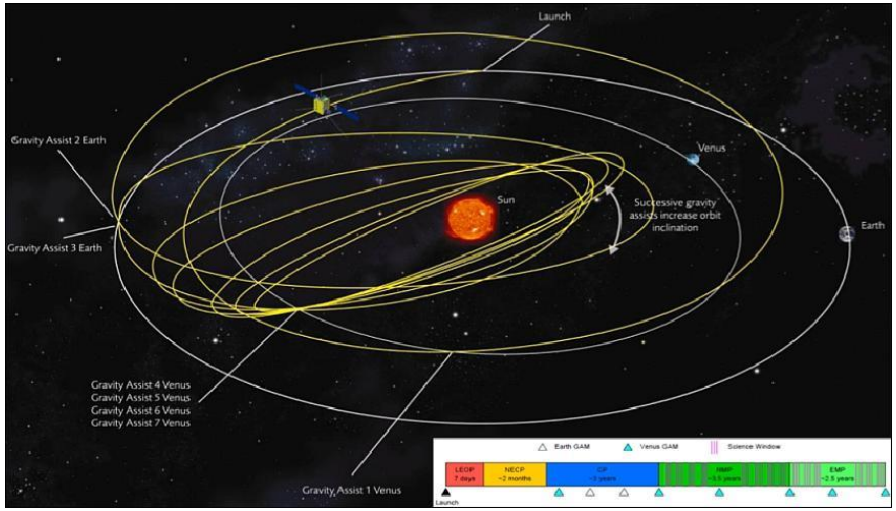
Mission phases

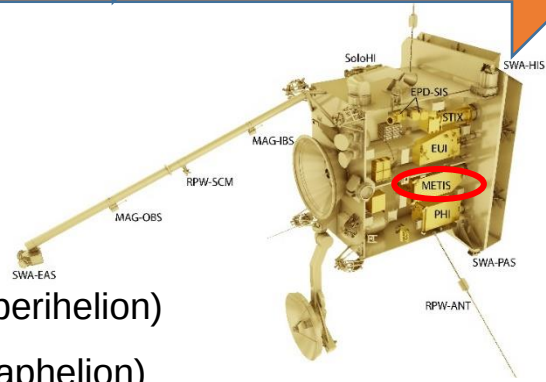
Commisioning

Cruise

Nominal

Extended mission time





ORBIT:

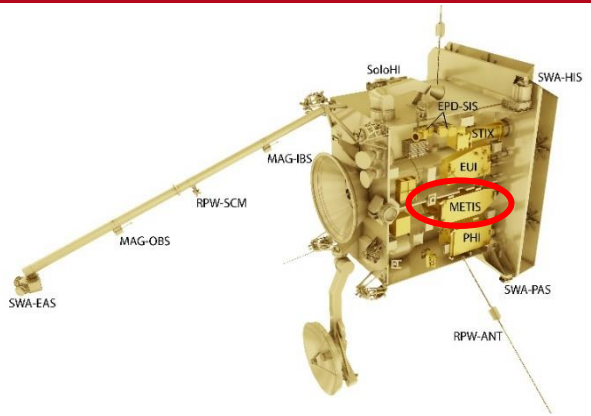
0.28 – 0.32 AU (perihelion)

0.74 -- 0.91 AU (aphelion)

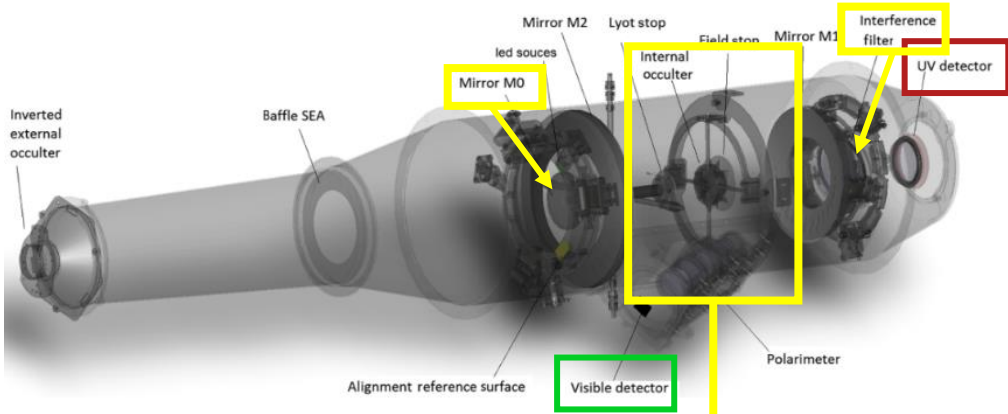
Out-of-ecliptic view:
Multiple gravity assists with Venus to increase inclination out of the ecliptic to :
>24° (nominal mission);
>34° (extended mission)

Antonucci, E. et al. Metis: the Solar Orbiter visible light and ultraviolet coronal imager

Metis of Solar Orbiter



1024 x 1024 pixels



2048 x 2048 pixels

Full Imaging of the corona (1.7 - 9 $R_{\odot}$):

- UV (121.6±10 nm)
- visible light (580-640nm) in total and polarized brightness

Spatial resolution and detector exposure time can change based on the science goal.

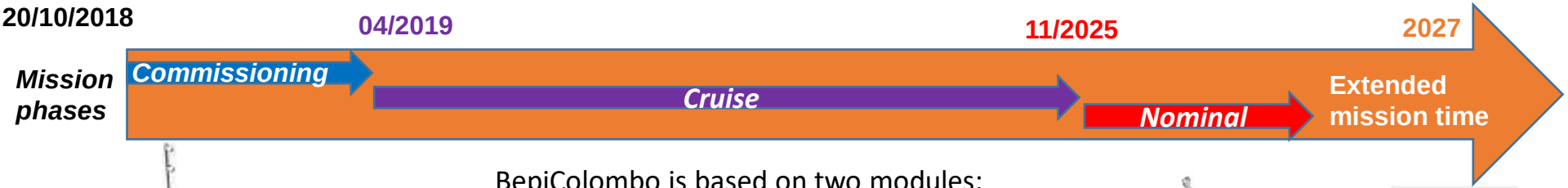
The Internal Occulter (IO) is extremely important to minimize the straylight.

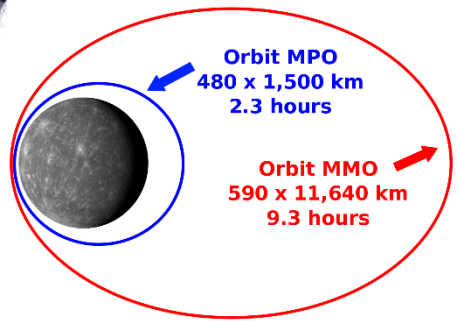
Antonucci, E. et al. Metis: the Solar Orbiter visible light and ultraviolet coronal imager

STC of BepiColombo

Launch BepiColombo

20/10/2018





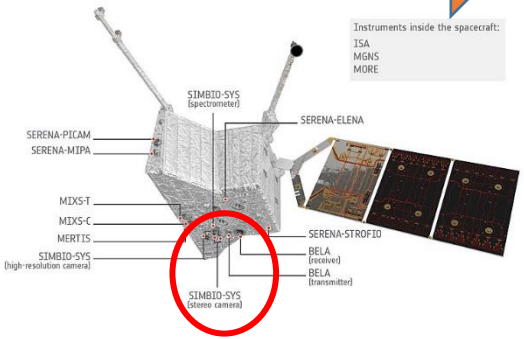
BepiColombo is based on two modules:

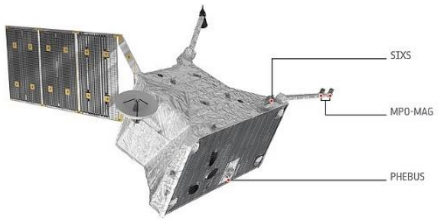
- **Mercury Magnetospheric Orbiter** (MMO) realized by the JAXA (Japanese space agency)
- **Mercury Planetary Orbiter** (MPO) realized by the ESA.

MPO study: surface, exosphere and internal composition of the planet.

- ✓ Periherm and apoherm [480 km, 1500 km].
- ✓ Orbital period of 2.3 hours.

MPO accommodates 11 instruments including SIMBIO-SYS where STC is included.





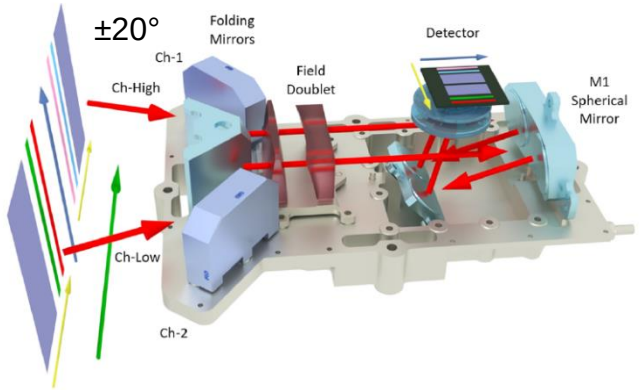
G. Cremonese et al. SIMBIO-SYS: Scientific Cameras and Spectrometer for the BepiColombo Mission

STC of BepiColombo

SIMBIO-SYS is composed by:

- **HRIC** (High Resolution Channel) the goal is the characterization of special surface targets with high resolution:
  - **400-900 nm** spectral range
  - **6m/px** Spatial resolution (at the best)
- **VIHI** (Visible Infrared Hyperspectral Imaging): the goal is to map the planet in order to provide the global mineralogical composition of the surface:
  - **400-2000 nm** spectral range.
  - **120 m/px – 480 m/px** spatial resolution
- **STC** (STereo Channel) is a double wide angle camera:
  - **410-930 nm** spectral range (2 panchromatics filters and 4 broad-band filters)
  - Total FoV **5.38° x 3.2°** (5.38° x 2.31° - 5.38° x 0.38°)
  - **58 m/px** spatial resolution (at best)

STC main scientific objective is the global mapping of the entire surface of Mercury in 3D.



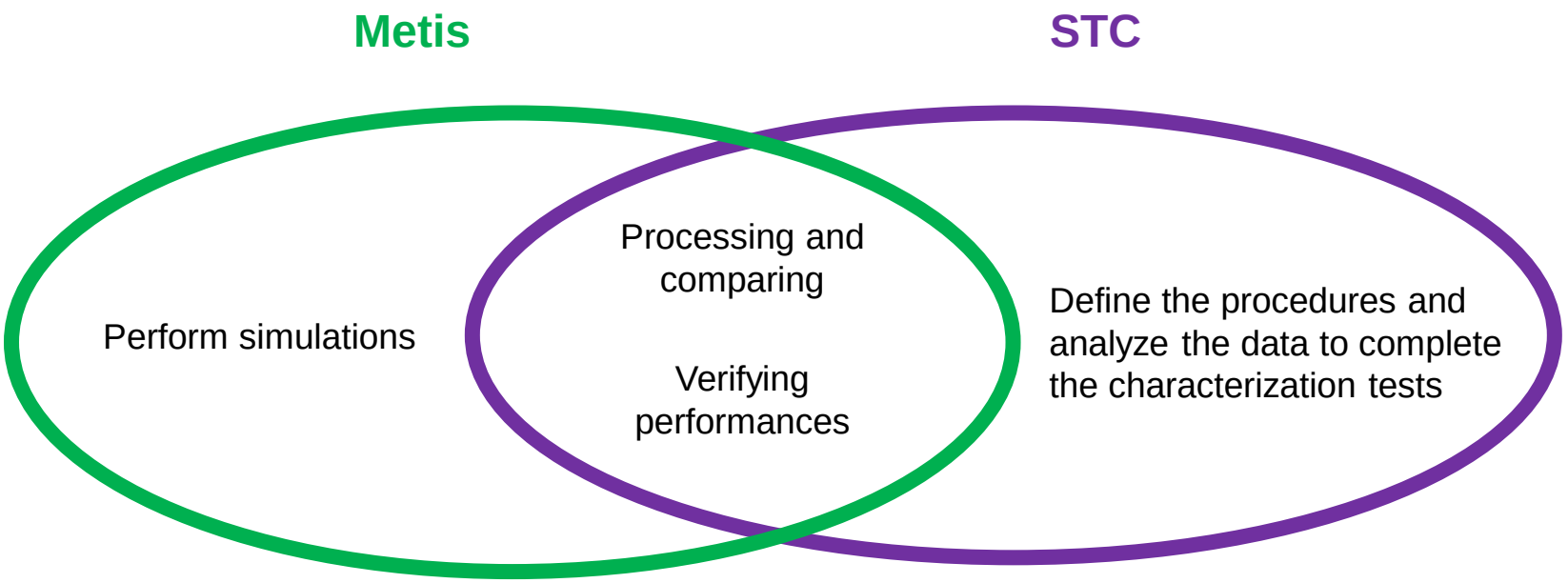
The STC camera is able to reach the goal thanks to the two sub-channels: High (H) and Low (L).

- a front unit, which consists of two independent fore-optics modules, one for each subchannel;
- a common telescope unit (off-axis modified Schmidt)

G. Cremonese et al. SIMBIO-SYS: Scientific Cameras and Spectrometer for the BepiColombo Mission

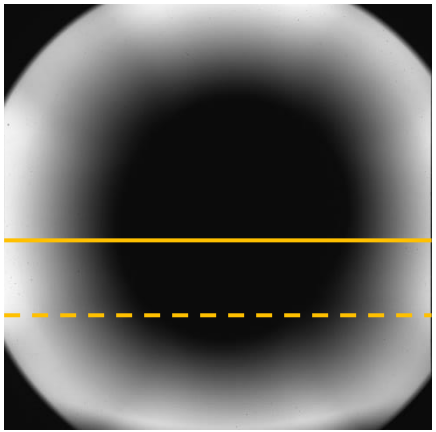
Map of my PhD work

Calibration

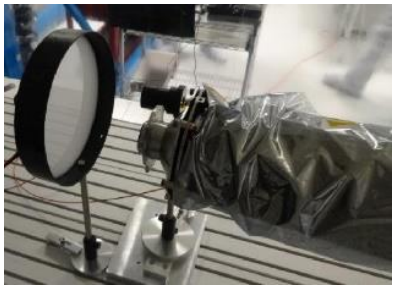


PROCESSED AND COMPARED

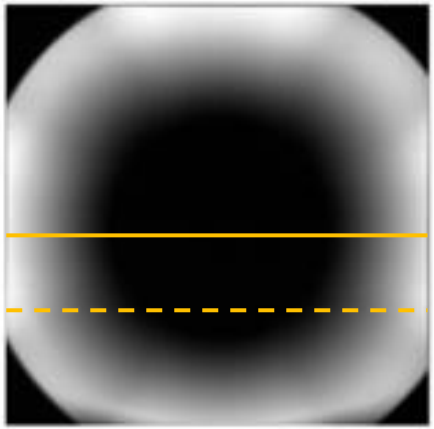
On-ground



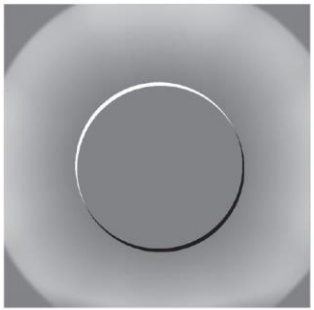
t_{exp}=100s

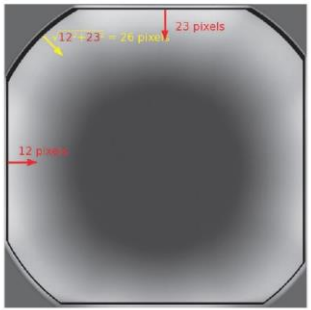


In-flight (reconstructed)

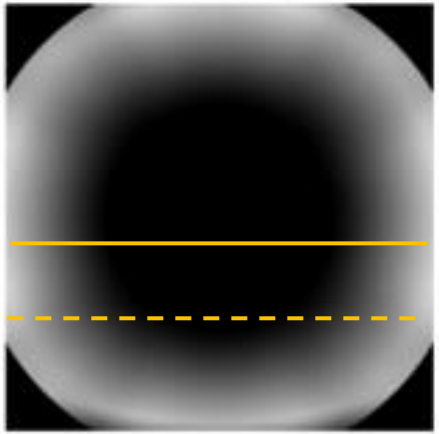


The centre of the image is changed because we move the IO to minimize the straylight

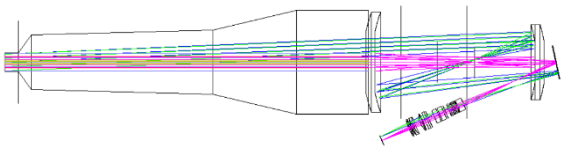




Simulated



Raytracing simulation of Metis

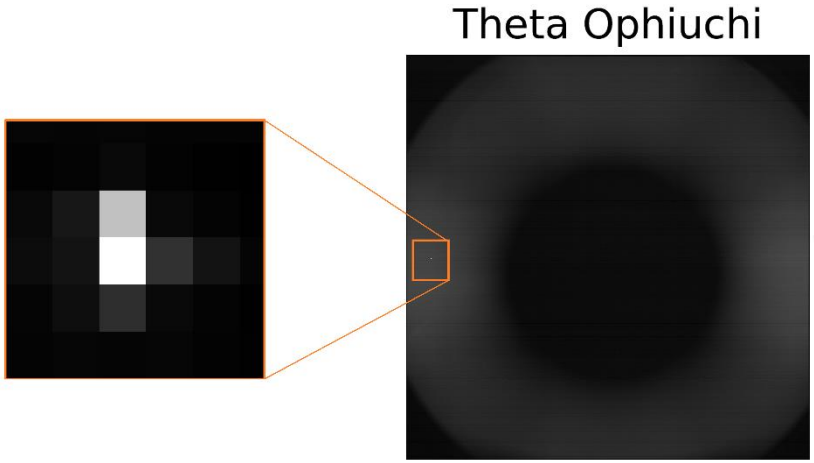


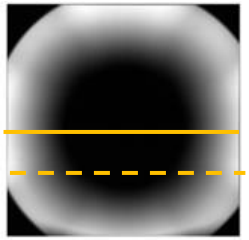
A. Liberatore et al., “In-flight calibration of Metis coronagraph on board of Solar Orbiter”, Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020, 118525B (2021)

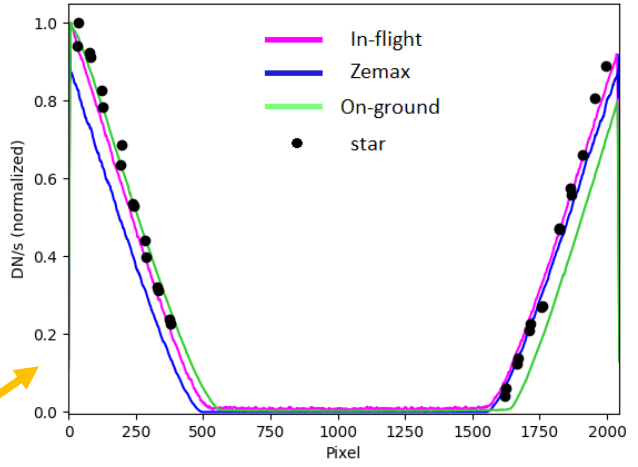
PROCESSED AND COMPARED

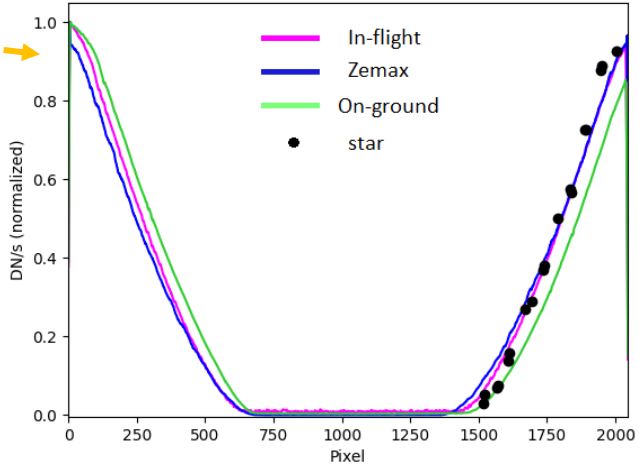
Theta Ophiuchi passed twice in front of Metis:

- STP 140 March 2021 (0,72 AU) - *row <u>1017</u>*
- STP 182 December 2021 (1,01 AU) - *row <u>615</u>*



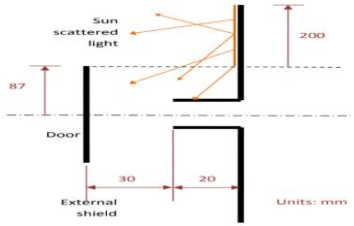




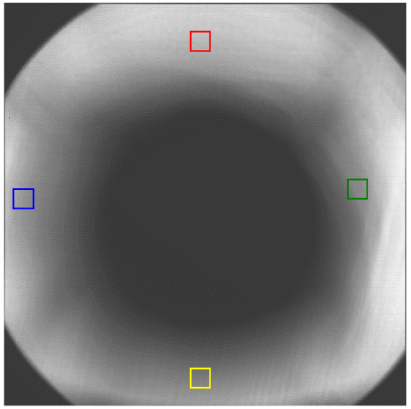


VERIFIED PERFORMANCES (METIS)

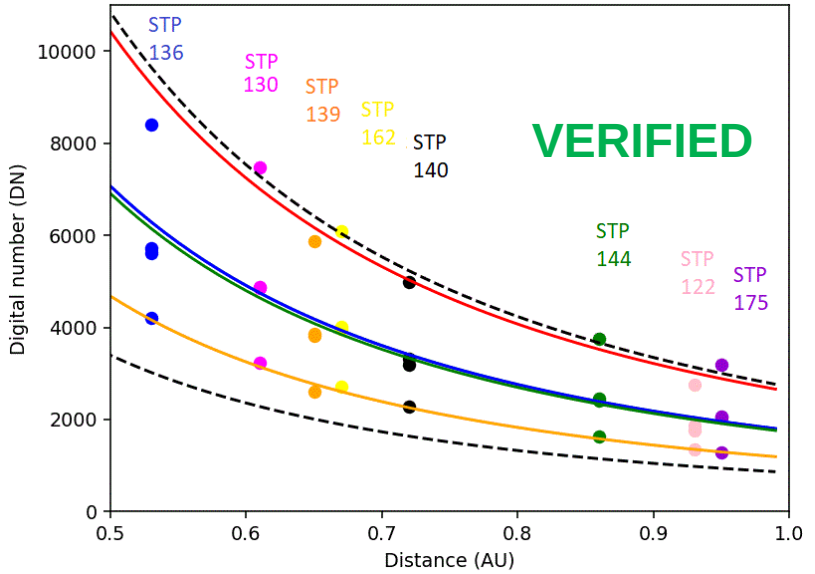
Verification of non degradation: 8 images at 8 different Astronomical distances



The light of the sun is reflected by the shield and, a portion is reflected towards the door.



Boxes of 100 x 100 pixels in the visible channel 4 fitting curves.



$\alpha\ 1/r^2$

- we can use the retro-reflection of the door to estimate the optical elements possible degradation
- we can predict the effects of the possible degradation on the door images via ray tracing simulations .

VERIFIED PERFORMANCES (STC)

Dark current acquisitions campaign:

- the acquisition of a set of 10 dark-current images
- for a specific Integration Time (IT)
- with a specific Repetition Time (RT)

STC detector composed by:

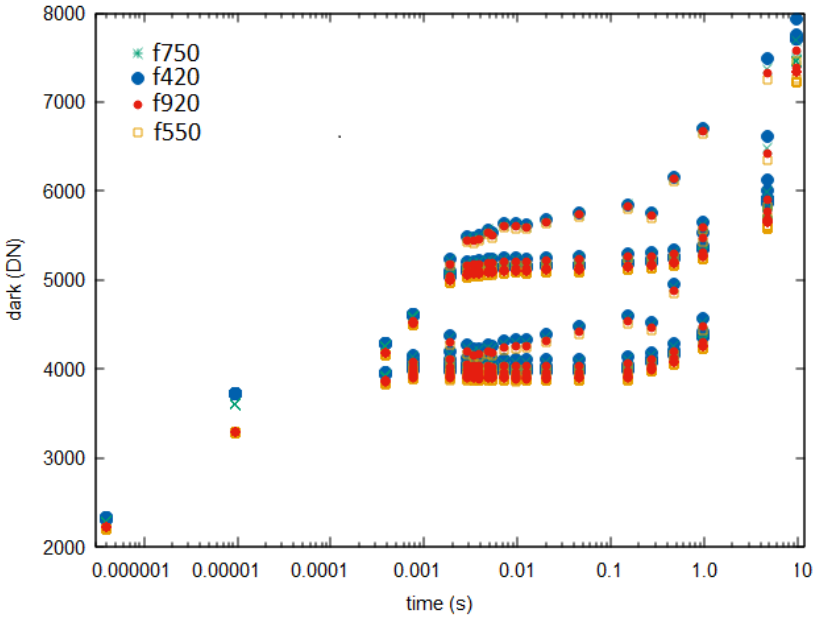
- 2 Panchromatic (PanL and PanH)
- 4 colored filters (f750, f420, f920 and f550)

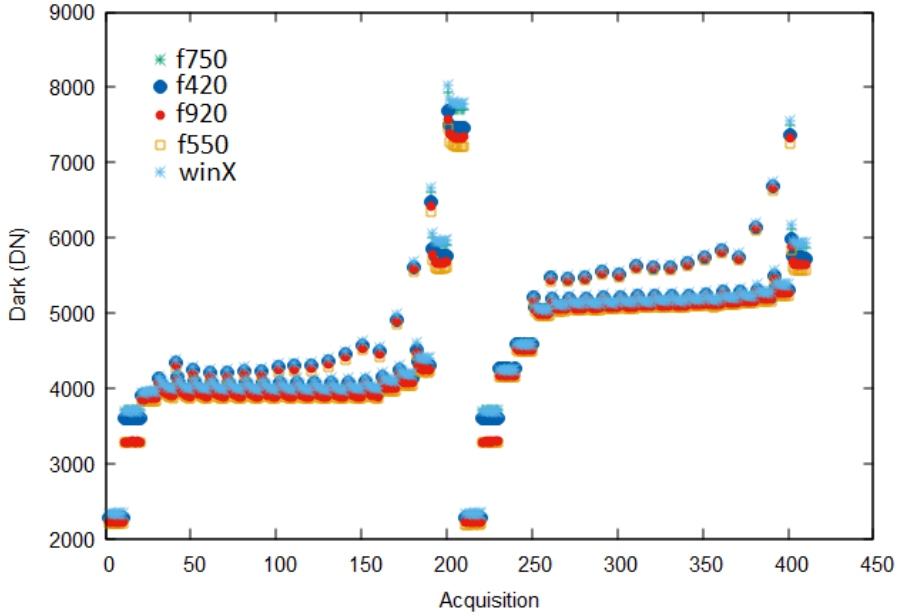
Start-End Rows			Vert Dim
2016	576px (strip 9)	1471px (strip 22)	
	F920		64px
1953 1808			
	F550		64px
1745 1610			
	PANL		384px
1227 820			
	PANH		384px
437 303			
192:319 (strips 3,4)	F420		64px
163 240 WinX 100 95			
	F750		64px
(0,0) 32	896px		

SIMBIO-SYS: Scientific Cameras and Spectrometer for the BepiColombo Mission, G. Cremones Space Sci Rev (2020) 216:75 https://doi.org/10.1007/s11214-020-00704-8e

VERIFIED PERFORMANCES (STC)

Mean value of the dark signal intensities acquired through the filter f750, f420, f920 and f550 at different exposure time.





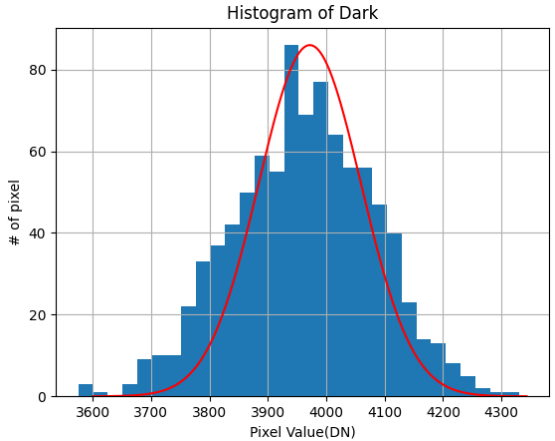
One possible solution is considering a small window named windows-x (WINX). It is a out-of-filter window, which is a region on the detector of dimension 64x128px sitting in the unilluminated part of the detector

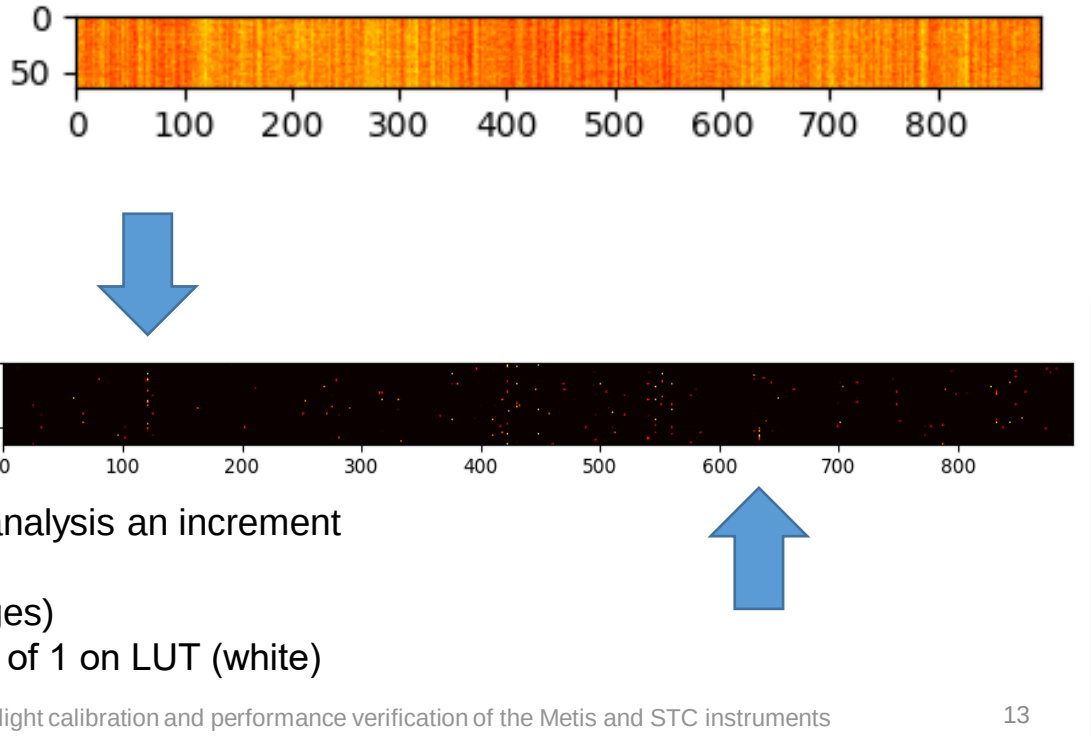
VERIFIED PERFORMANCES (STC)

The thresholds for designating a pixel as “bad” were set to 3σ above or below the mean as appropriate.

Therefore, I calculate for every image its histogram.

For Normally (Gaussian) distributed data only 0.3% of the pixels values would lie outside the mean ±3σ range





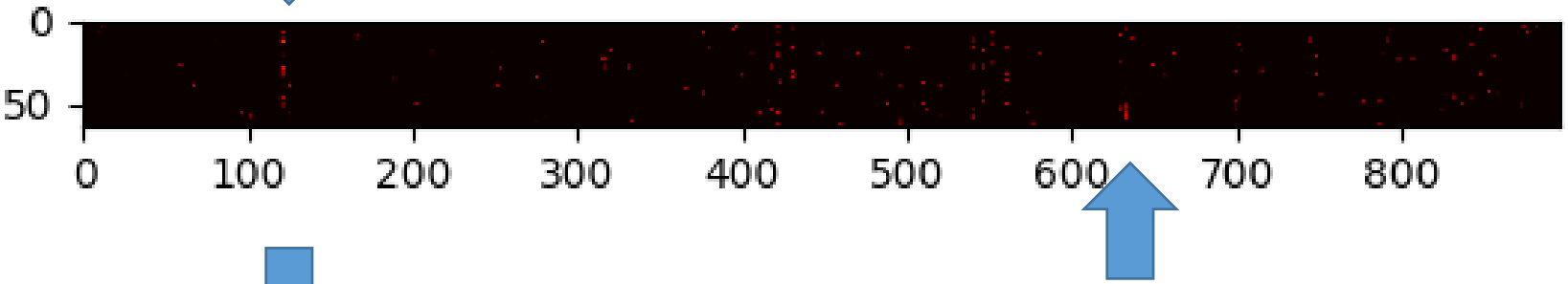
Take all value beyond **mean ± 3σ**

- Lookup table (LUT): on each image analysis an increment of 1 on bad pixel coordinates
- Divide for the 10 (number of the images)

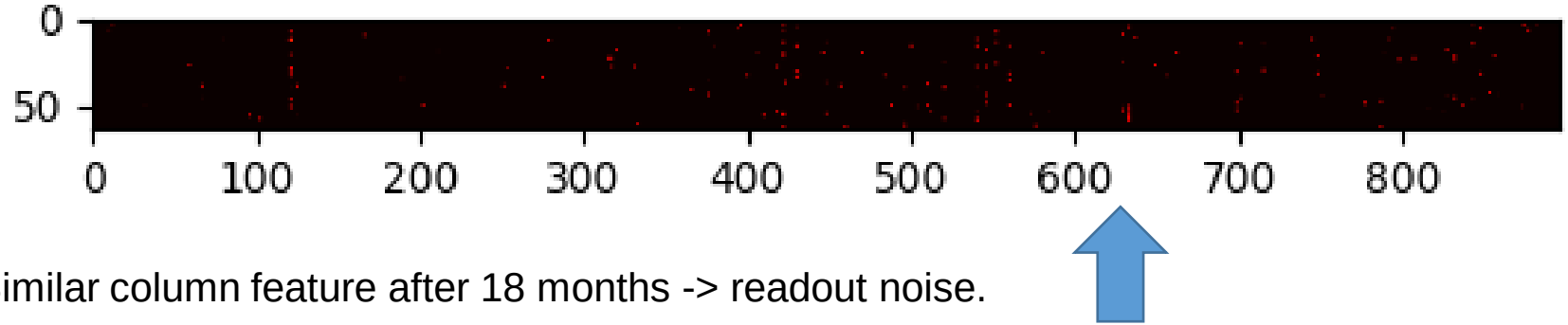
→ bad pixel on all images has the value of 1 on LUT (white)

PROCESSED AND COMPARED (STC)

ICO 1 (**07-06-2019**) t_{exp}=0,00528 s

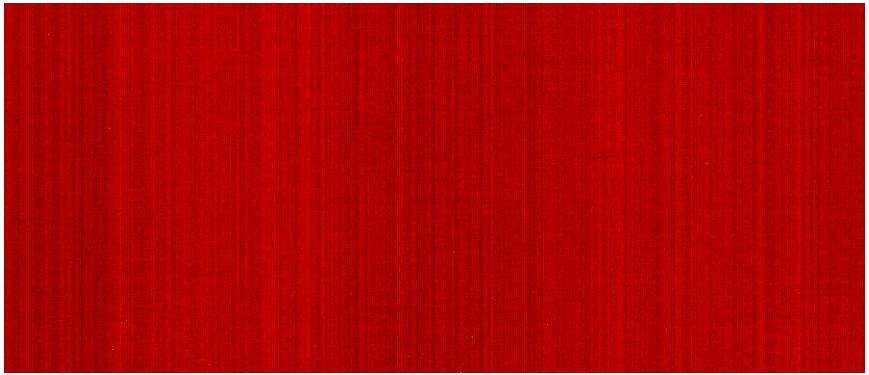


ICO 4 (**14-12-2020**) t_{exp}= 0,005299 s

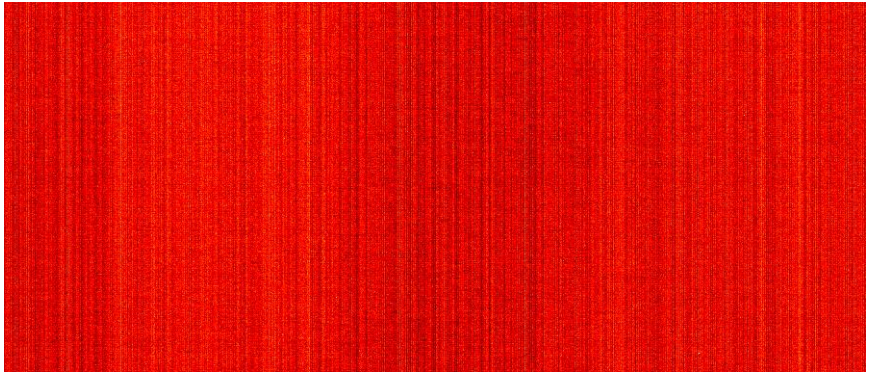


Similar column feature after 18 months -> readout noise.

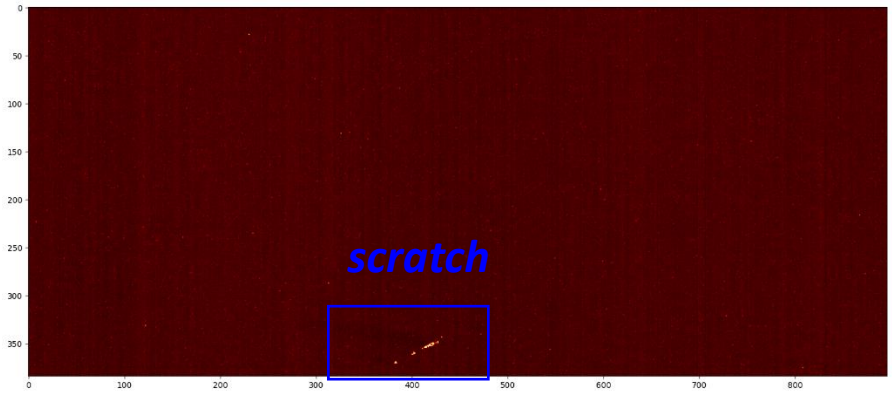
Pan L **Panchromatic** **Pan H**



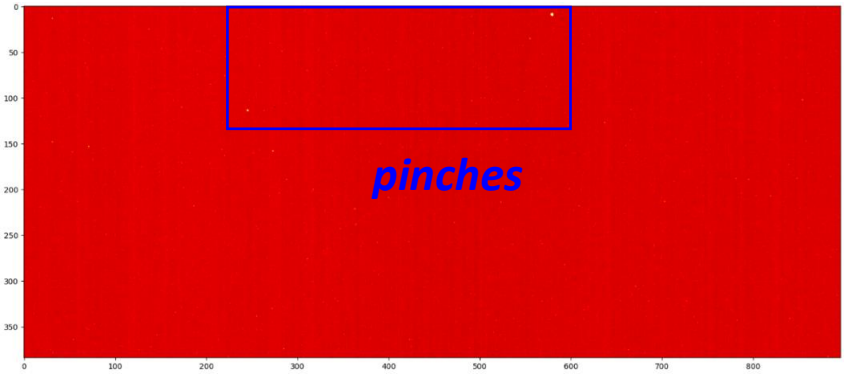
$4 \cdot 10^{-7}$ s



$4 \cdot 10^{-7}$ s



4,8 s

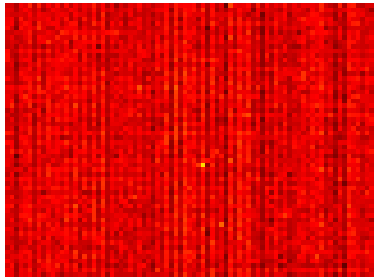


4,8 s

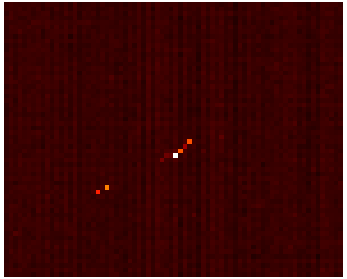
ANALYZE THE DATA TO COMPLETE THE CHARACTERIZATION TEST

Pan L

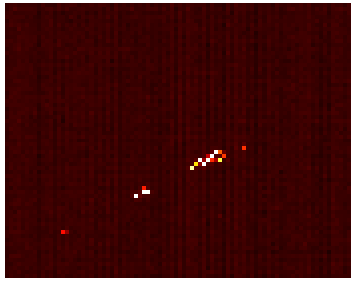
$5{,}76 \cdot 10^{-5}$ s



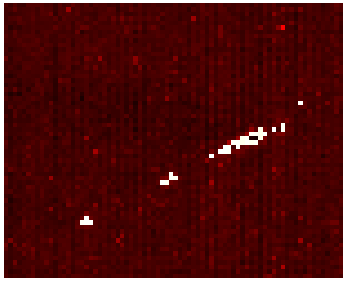
0,0024 s



0,0096 s

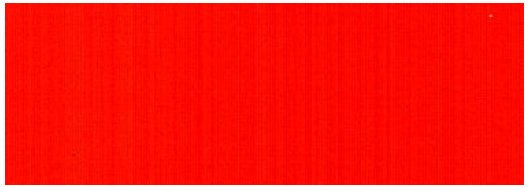


4,8 s



Pan H

0,0024 s



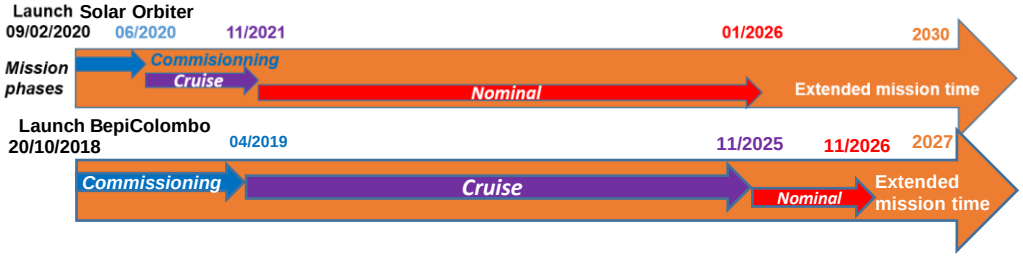
0,03 s

0,27 s

4,8 s

Acquisitions are now taken with the same intervals and times to understand if they are replicable and therefore correctable!

Conclusions



TASK TITLE	% OF TASK COMPLETE	T1			T2			T3			T4			T1			T2			T3			T4			T1			T2			T3			T4		
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Commissioning phase																																					
Review of state of the art of the Metis and STC	100%																																				
Calibration actvities: comparison with on ground results	80%																																				
Optical performances	80%																																				
Cruise Phase																																					
Calibration sequence planning	70%																																				
Performances validation	75%																																				
Straylight	80%																																				
Data Analysis and results																																					
Calibration input for the pipeline	1%																																				
Support to pipeline implementation	1%																																				
Phd Thesis Writing																																					
...	1%																																				

Thanks for the attention

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