

JACIE 2015 Session #6 – Tampa, May 5-7 2015

# PLEIADES SATELLITES IMAGE QUALITY IN-ORBIT CALIBRATION AND ASSESSMENT

LAURENT LEBÈGUE, DANIEL GRESLOU, GWENDOLINE BLANCHET,  
FRANÇOISE DELUSSY, SÉBASTIEN FOUREST, VINCENT MARTIN,  
CHRISTOPHE LATRY, PHILIPPE KUBIK, JEAN-MARC DELVIT, CÉCILE DECHOZ,  
VIRGINIE AMBERG



# SUMMARY

- Introduction to PLEIADES-HR
- Acquisitions capabilities
- The Image Quality Commissioning



# PLEIADES PROGRAM CONTEXT

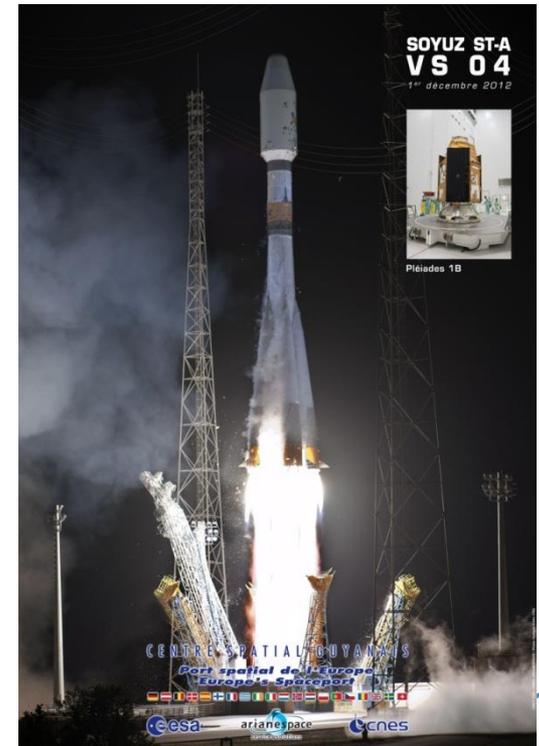
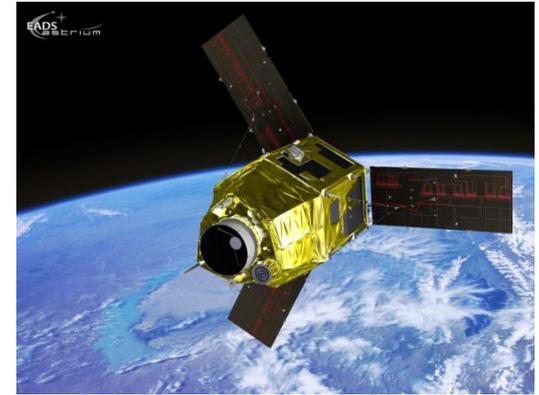
**Pleiades is a Dual, High Resolution, Optical Earth Observation System**

**The program is developed by CNES in cooperation with**

- Spain Instituto Nacional de Técnica Aeroespacial y Dirección General de Armamento y Material
- Sweden Swedish National Space Board
- Belgium Federal Office for Space Policy
- Austria Österreichische Forschungsförderungs-gesellschaft

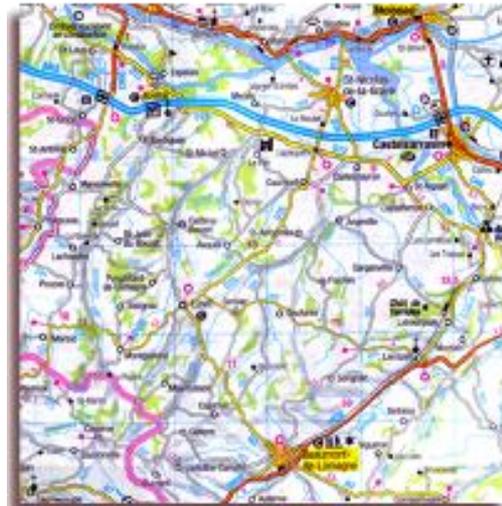
**Pleiades 1A launched December 17<sup>th</sup>, 2011**

**Pleiades 1B launched December 2<sup>nd</sup>, 2012**



# MAIN MISSIONS

- Defense
- Civil security
- Cartography
- Geophysics risks

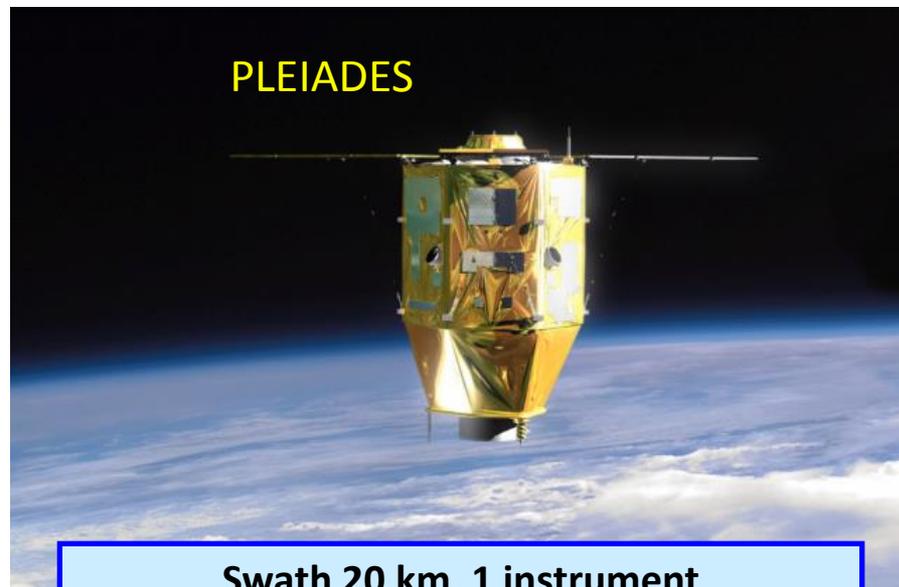


- Hydrology
- Renewable resources
- Geology
- Marine environment

# FROM SPOT TO PLEIADES

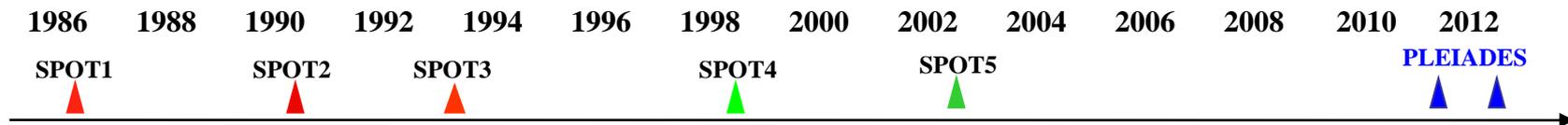


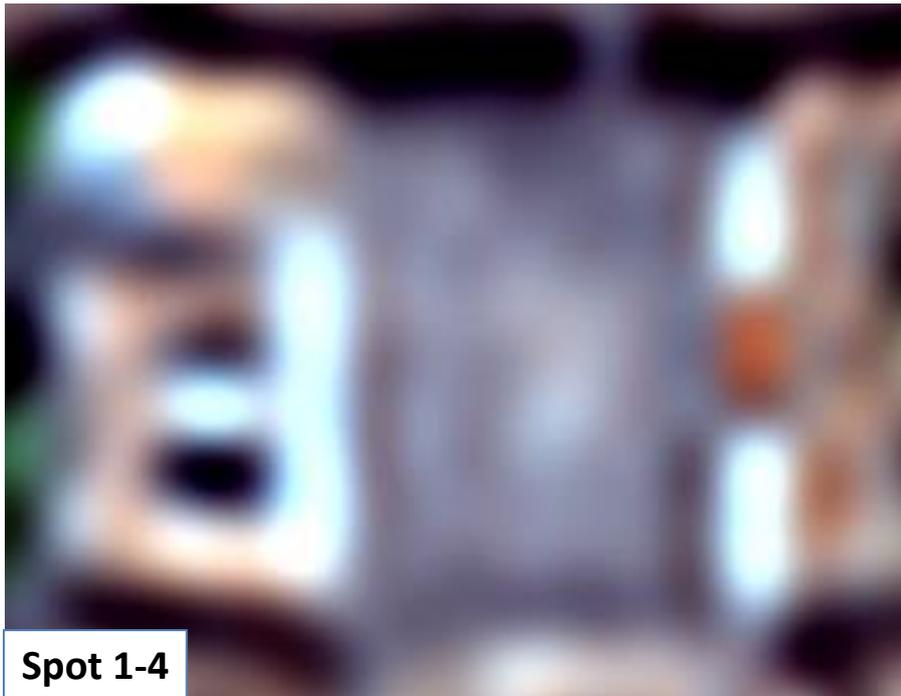
PLEIADES



Swath 60 km , 2 instruments  
East/West tilt +/- 27°  
SPOT 1- 4 : 10m PA, 20m XS  
SPOT 5 : 3.5m PA, 10m XS

Swath 20 km, 1 instrument  
Agile satellite  
70 cm PA, 2.80 XS





Spot 1-4



Spot 5



Pleiades

# PLEIADES

## MAIN MISSION REQUIREMENTS

### Image characteristics

- 0.7 m Pan resolution at nadir
- four XS bands (blue, green, red, near IR) with 2.8 m resolution at nadir
- 20 km swath at nadir
- data coded on 12 bits
- product is resampled @ 0.5m to improve robustness to ground processing
- Localization performance requirement : 12 m CE90

### Revisit Capability

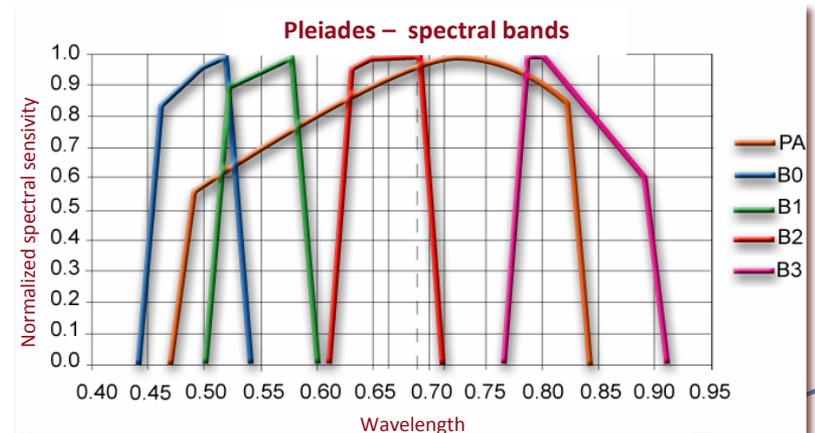
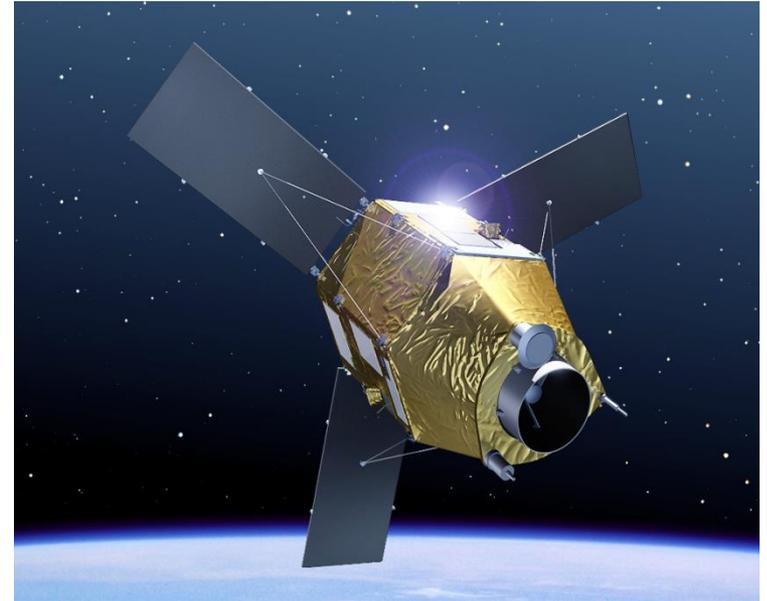
- Daily accessibility to any point on the globe (with 2 satellites)

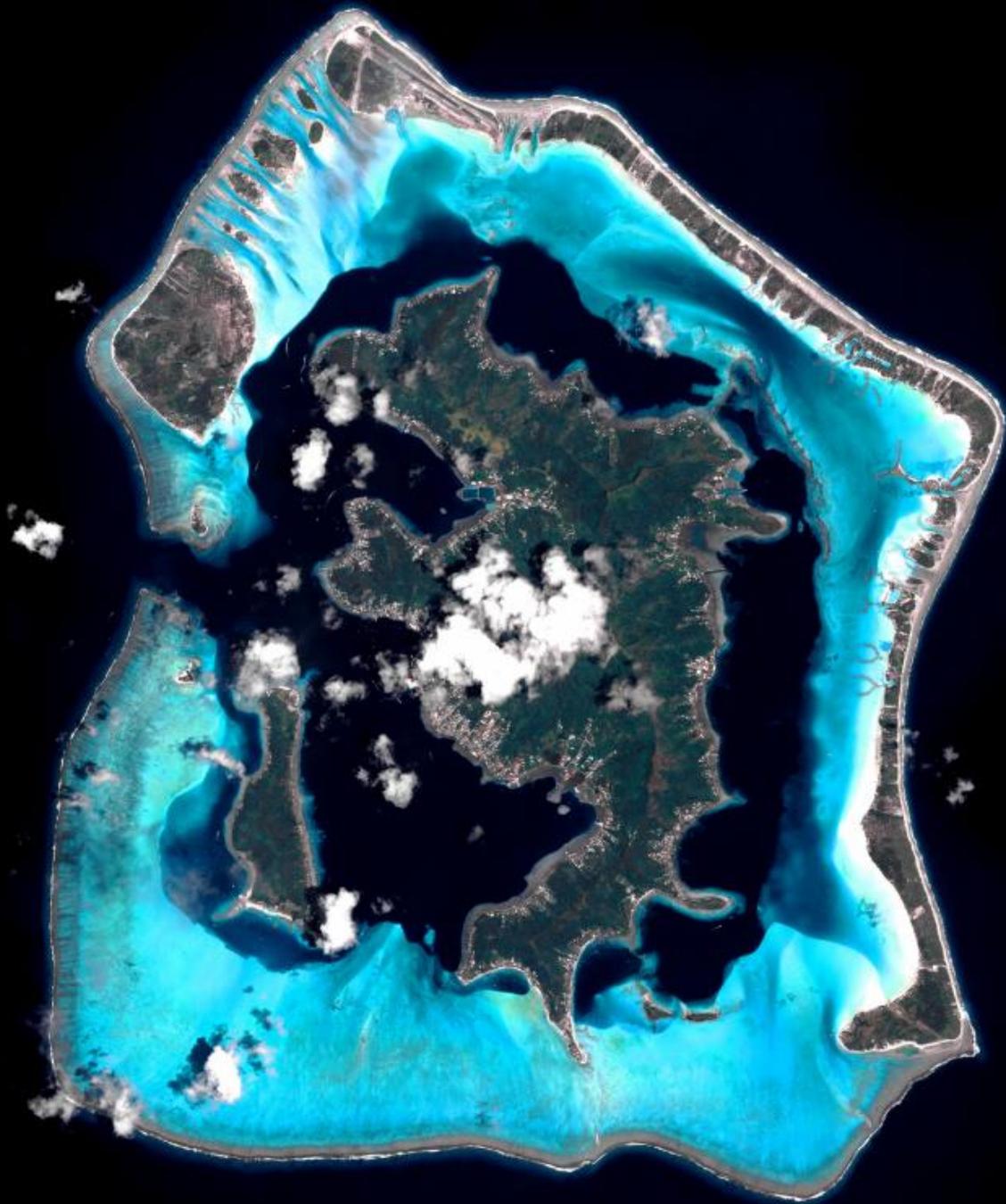
### Improved access image delay

- Better than 24 hours between image request and image delivery in nominal mode
- and even better, 1 hour, with Direct Tasking ...

### Large coverage capability

- In average 350 segments per satellite and per day with only Kiruna and Toulouse ground stations
- and even better with Regional Image Receiving Stations ...









# PLEIADES SATELLITE

## A new concept compared to Spot

A small and very agile satellite to improve operational capability and minimize the conflicts between users

## Designed for an high agility

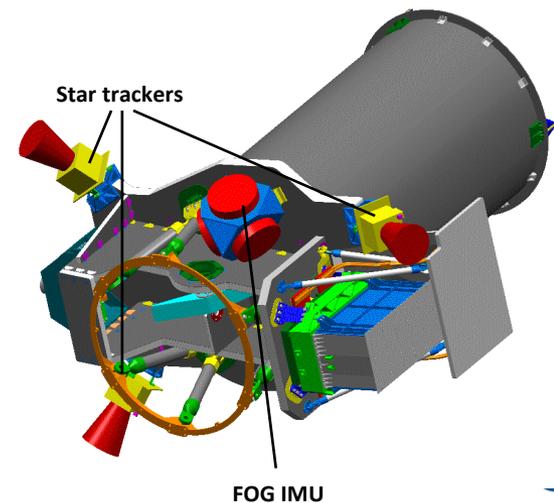
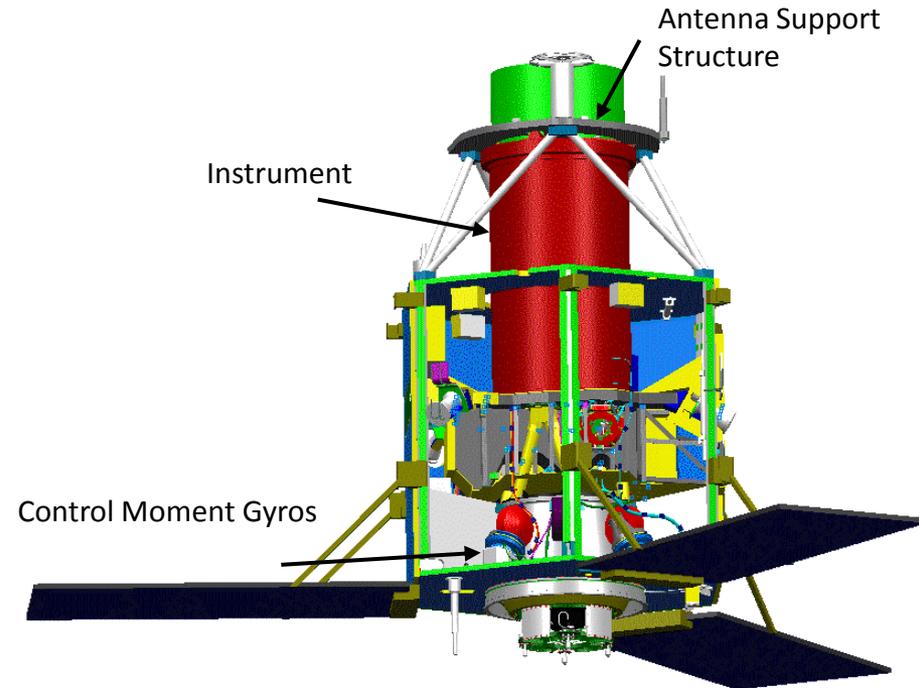
Compact <1000 kg satellite with low inertia

Rigid satellite with fixed solar array

Attitude control system with powerful CMG actuators

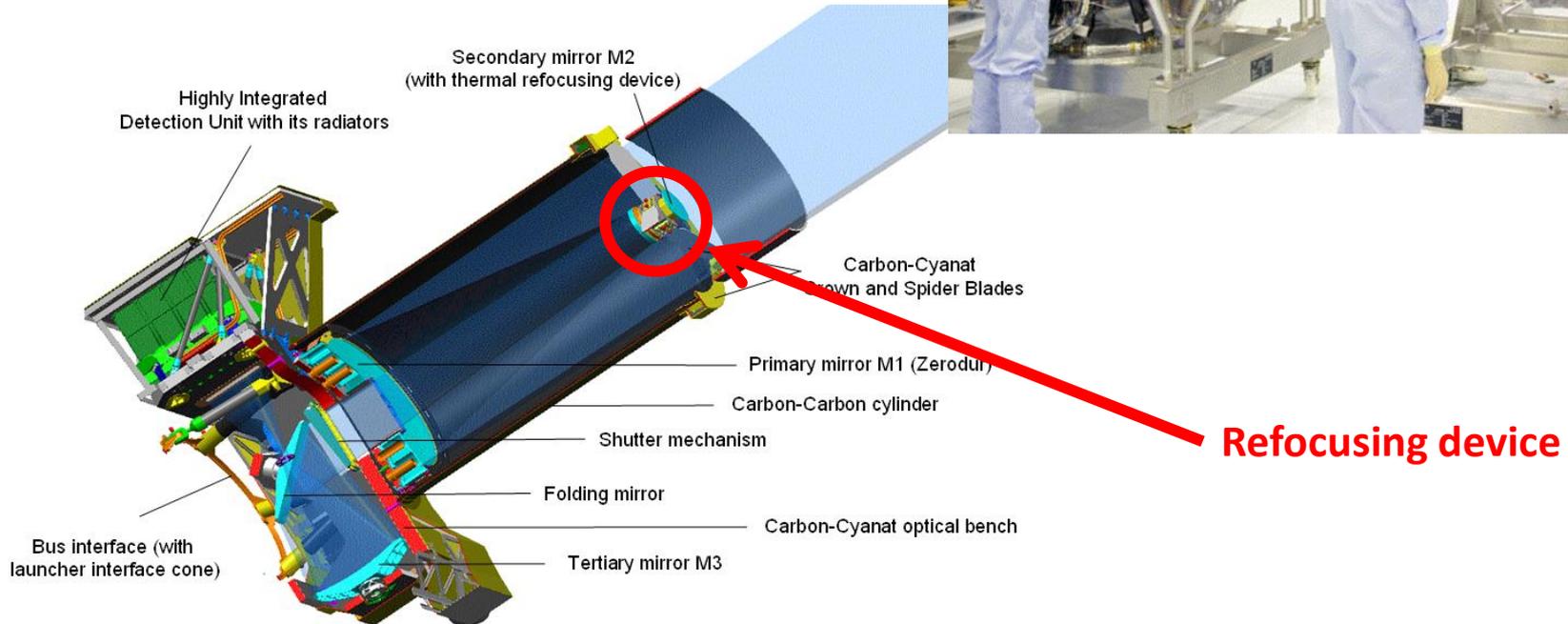
## Designed for an high image quality

High stability instrument with high precision sensor heads mounted on the optical bench for maximum geometrical quality accuracy (star trackers, Inertial Measurement Unit (FOG))



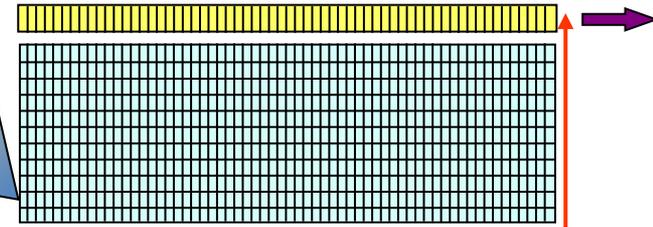
# PLÉIADES INSTRUMENT

Korsch type telescope  
focal length = 13 m  
input diameter = 65 cm

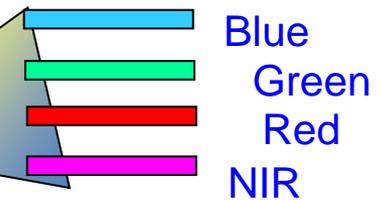
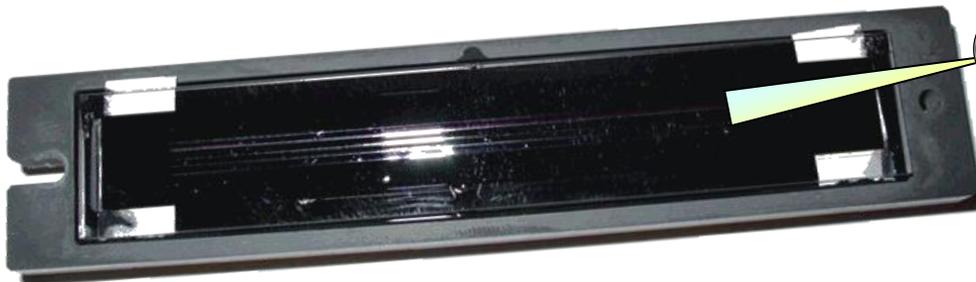


# ARRAYS ON PLÉIADES

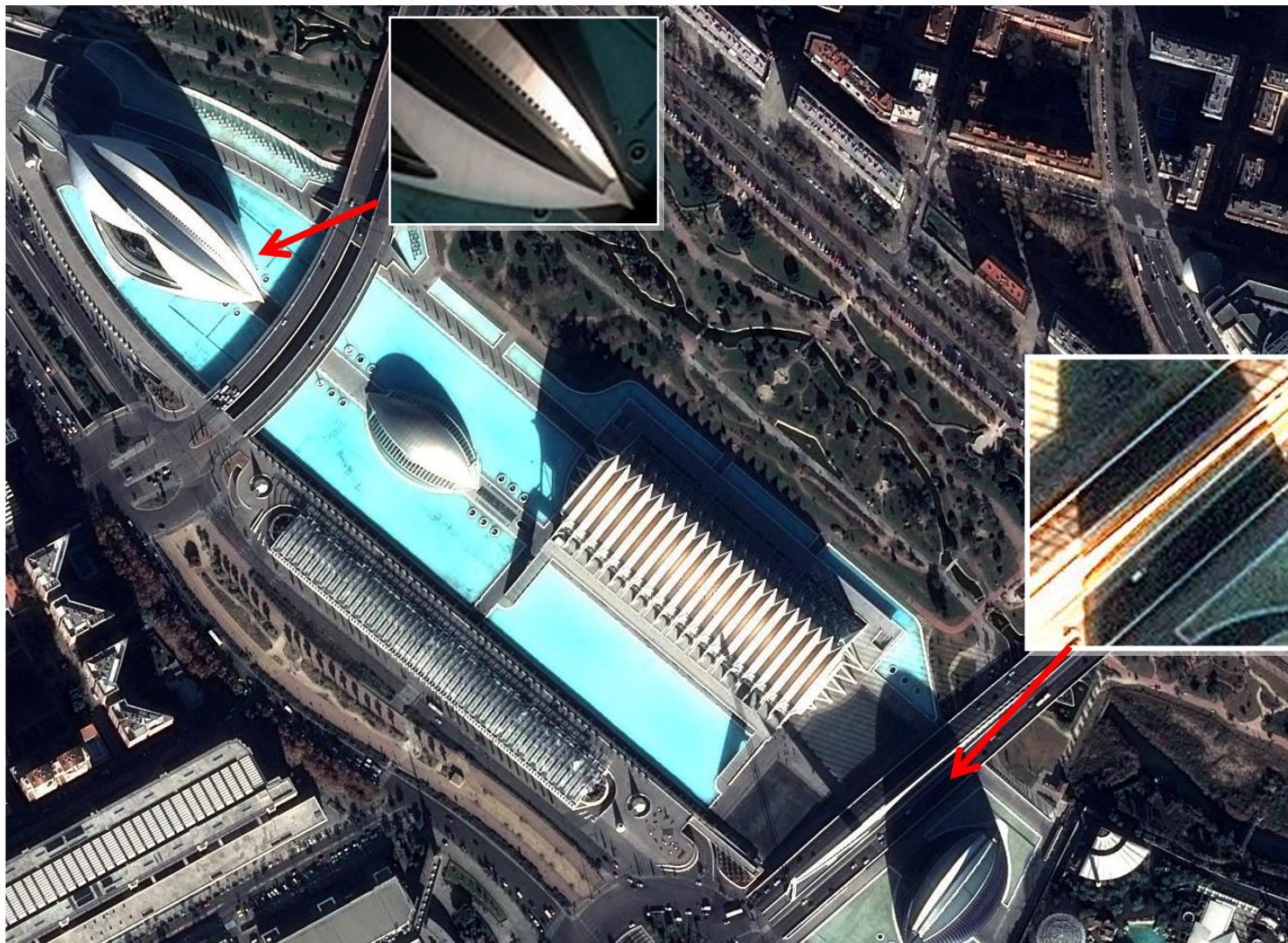
5 x TDI PA: 6000 columns x 20 lines, 13  $\mu\text{m}$



5 x 4-colors XS : 1500 columns, 52  $\mu\text{m}$



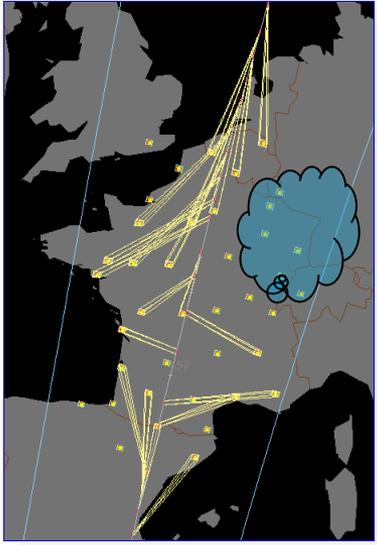
# 12 BITS PIXELS DYNAMIC



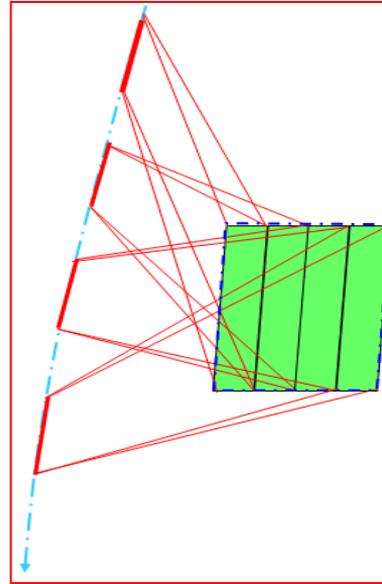
Anti-blooming  
device



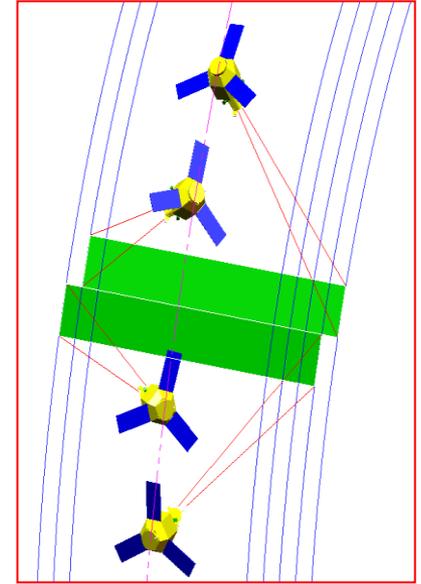
# ACQUISITIONS CAPABILITIES



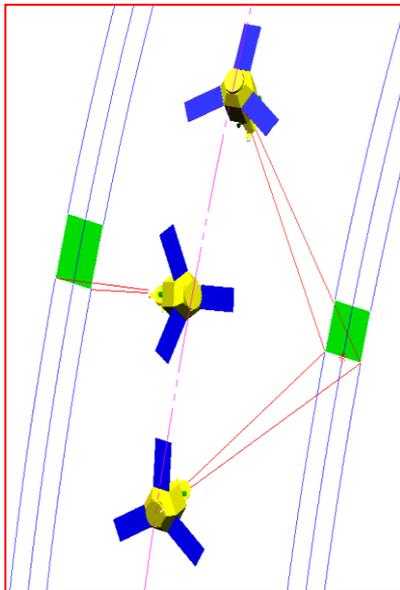
Nebulosity optimization



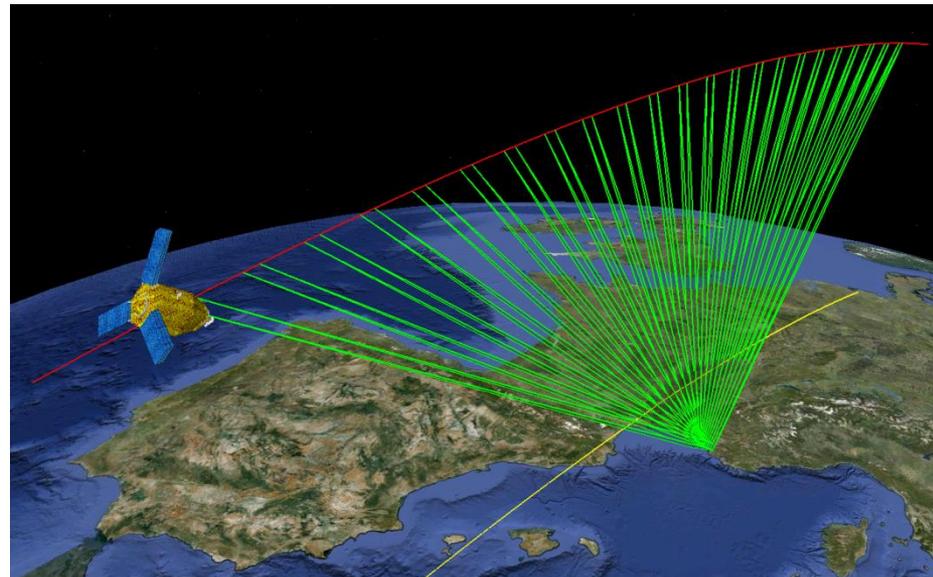
Mosaics



Ortho-track



Depointing, stereo, tri-stereo, ...



Persistent vision



Melbourne



Rio Airport

# ONE EXAMPLE OF RESOLUTION AND AGILITY

Three pictures on Mecca "tower clock" acquired by Pléiades 1B every 90sec in a single pass to see 3 faces of the building and the minutes needle moving !





## THE IMAGE QUALITY COMMISSIONING

### Main goals

- Calibration of onboard and ground image radiometric and geometric models parameters (in-orbit evolutions and sometimes many approximations from ground measures)
- Image Quality performances assessment (MTF, SNR, location, planimetry, registration, ...) and comparison to requirement and pre-flight budgets.
- Ground processing algorithms parameters tuning.
- Characterization and correction (if possible) of potential anomalies.

About 30 people have worked during 2x6 months at the Image Calibration Center (ICC) at CNES. Main results are obtained in 2 months...

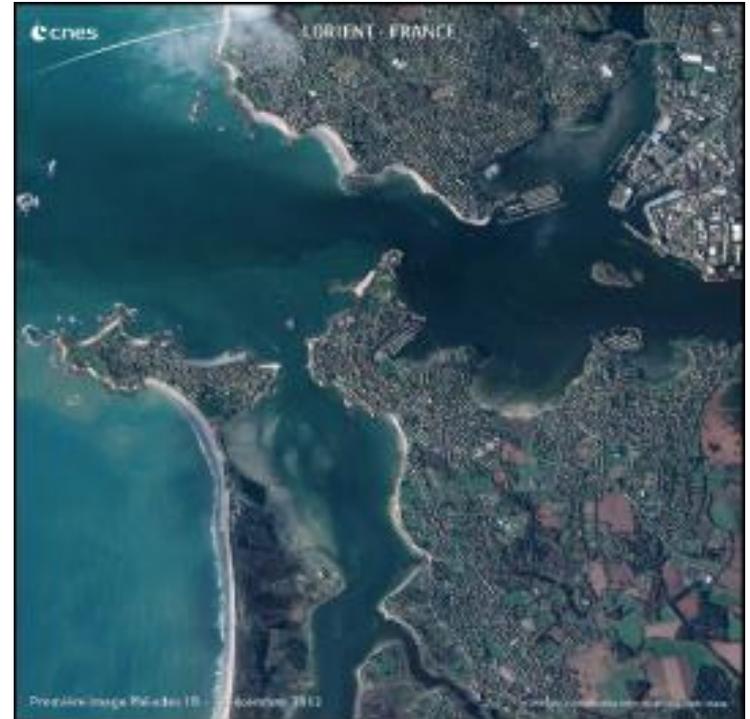
Acquisitions of sites dedicated to Image Quality thanks to innovating guidance taking benefit from agility.



# FIRST IMAGE PRODUCED 3 DAYS AFTER LAUNCH

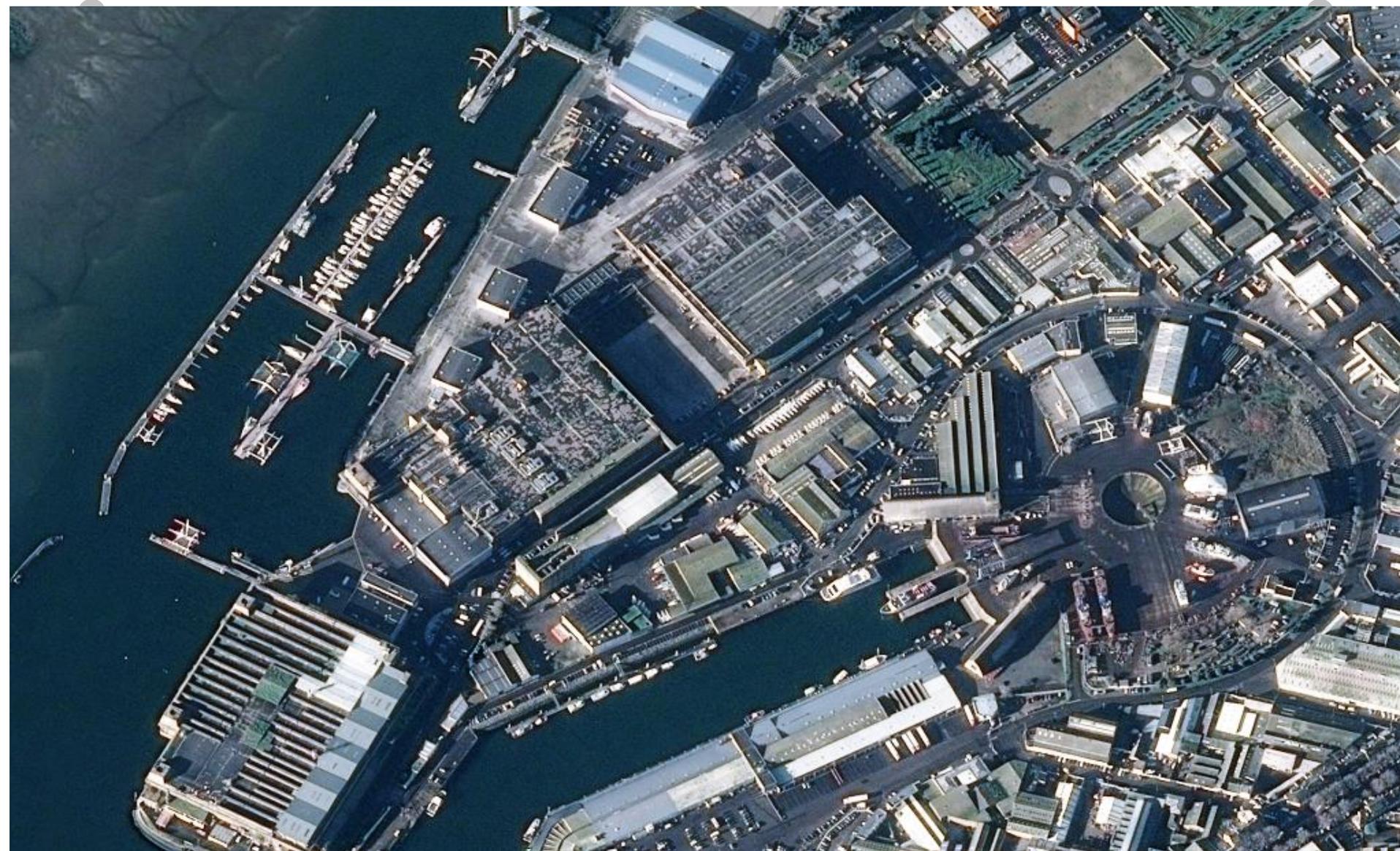


Pleiades 1A  
Paris, France, 12/20/2011  
24 h between acquisition and  
production



Pleiades 1B  
Lorient, France, 12/05/2012  
10 h between acquisition and  
production

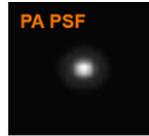
# PLEIADES 1B FIRST IMAGE : LORIENT, FRANCE, 12/05/2012



# THE IMAGE QUALITY COMMISSIONING ACTIVITIES

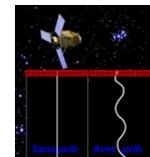
## Radiometric activities

- Refocusing
- Absolute Calibration
- Inter-detector normalization
- Restoration & PAN-Sharpening
- Resolution assessment (MTF + SNR)

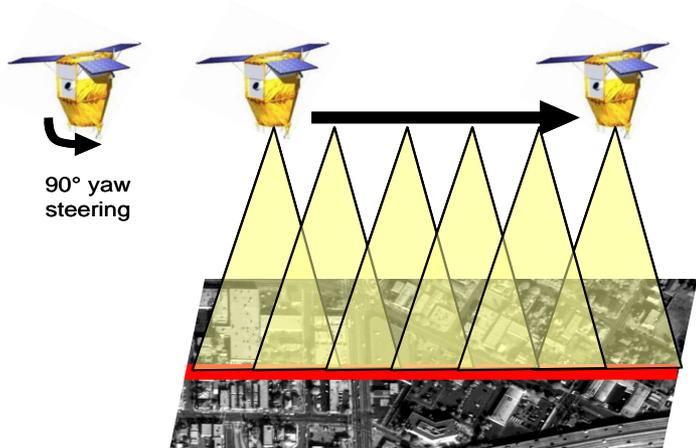


## Geometric activities

- Location (biases calibration and performance assessment)
- Focal plane cartography (absolute and relative for registration)
- Dynamic stability (micro-vibrations, drifts, ...)
- Performance assessment (planimetry, altimetry, 3D rendering)

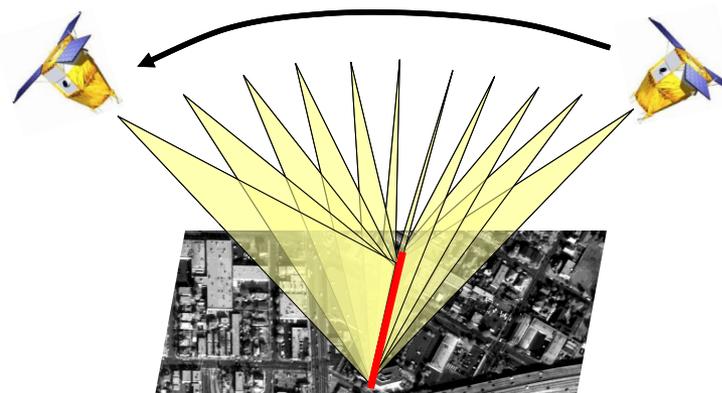


# DEDICATED GUIDANCE TO EARTH TARGETS...

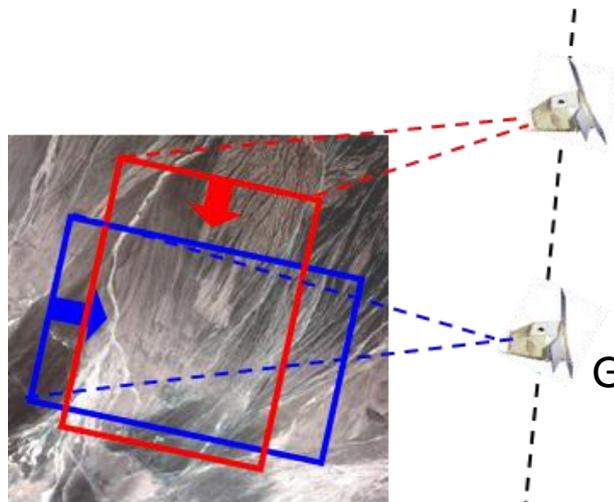


90° yaw steering

AMETHIST for inter-detector normalization

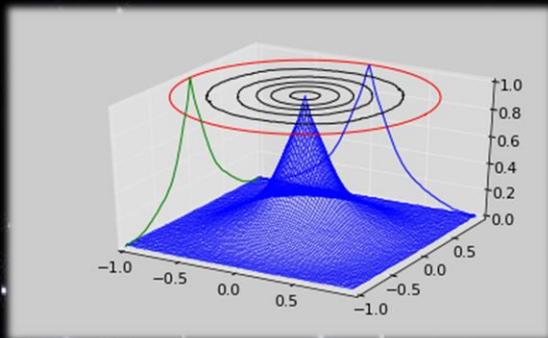


Steady-Mode for Radiometric SNR assessment

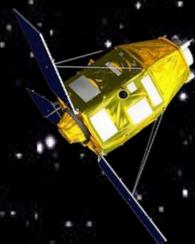


Geometric auto-calibration for focal plane cartography

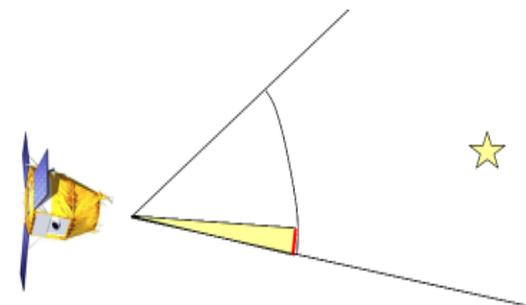
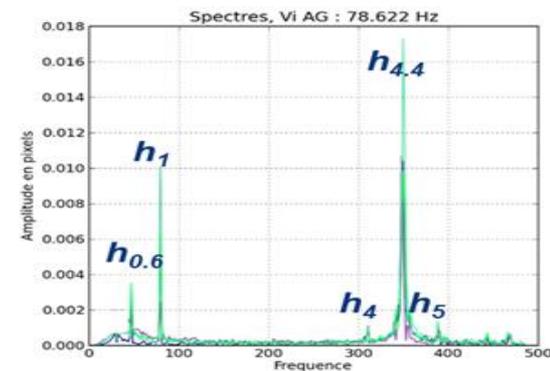
# ...AND TO CELESTIAL BODIES



Refocusing and MTF assessment



Radiometric absolute calibration



Line of sight dynamic stability

# RAW IMAGE UNFOCUSED



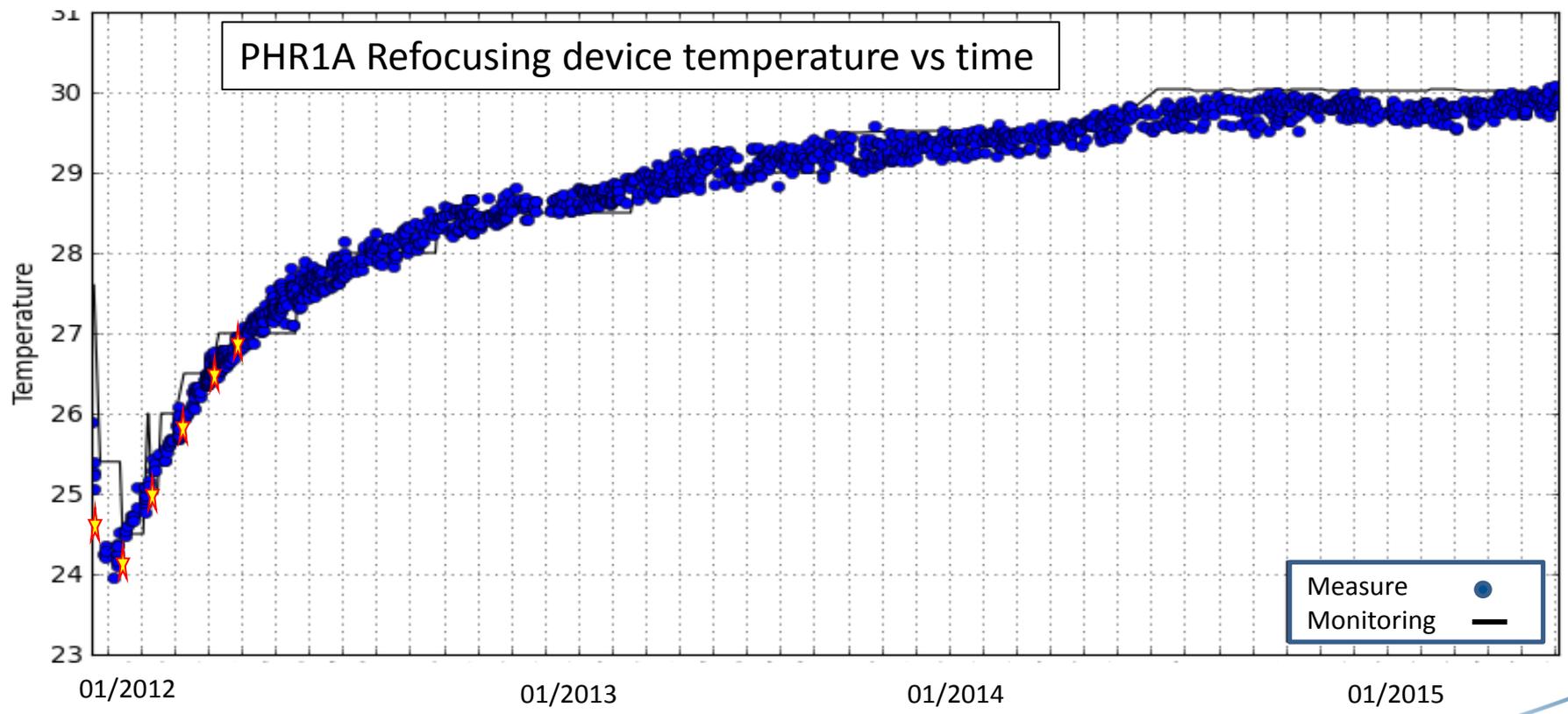
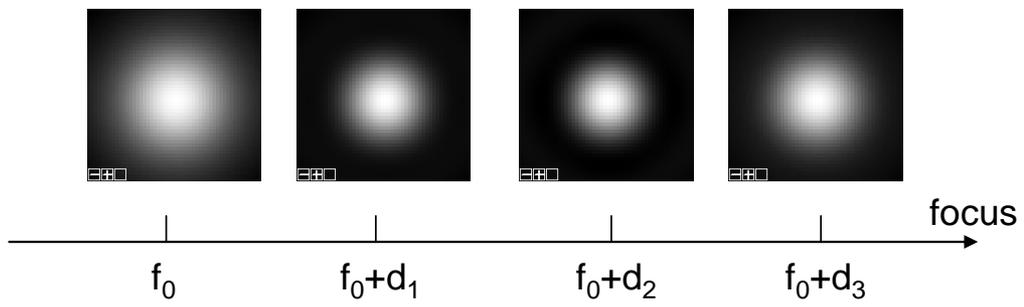
# RAW IMAGE WELL FOCUSED



# WELL FOCUSED RESTORED IMAGE

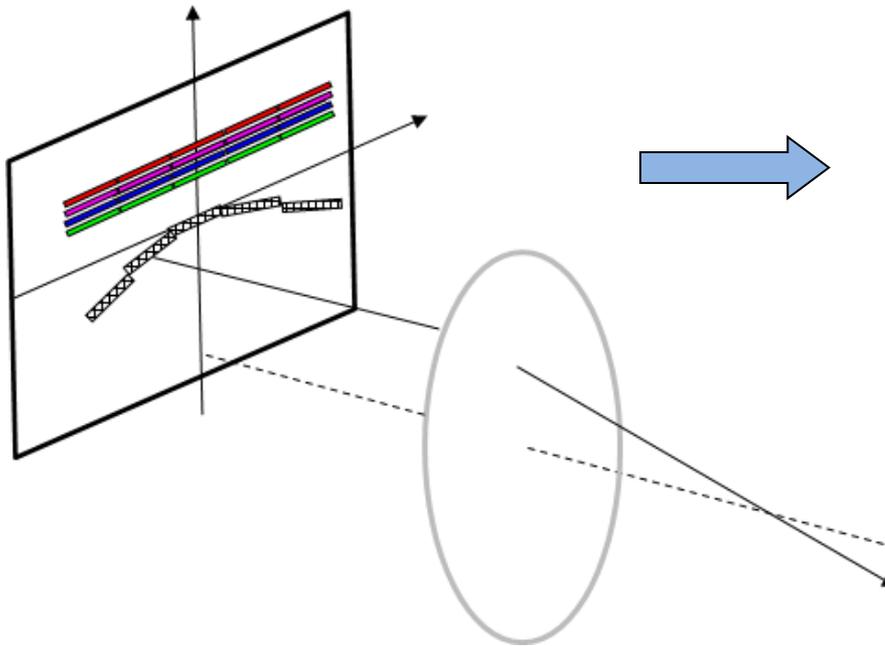


# Best focus monitoring

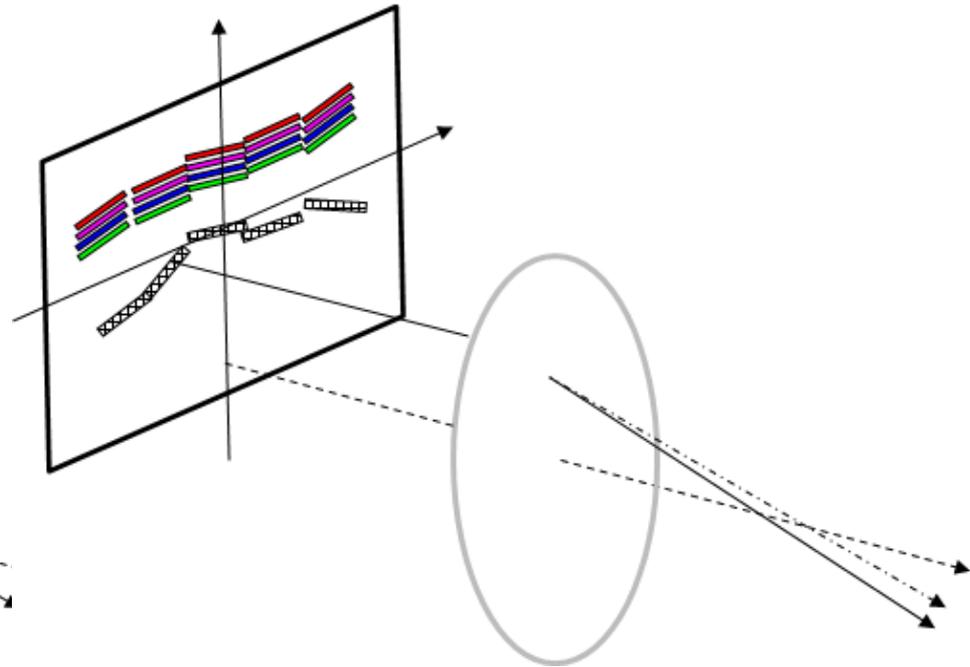


# FOCAL PLANE CARTOGRAPHY CALIBRATION

*Ground model*



*In-orbit model*



*Geometric model enhancement: arrays alignments, tilts, magnification, ...*

# PA+XS PAN-SHARPENING REQUIRES AN ACCURATE SPECTRAL BANDS REGISTRATION



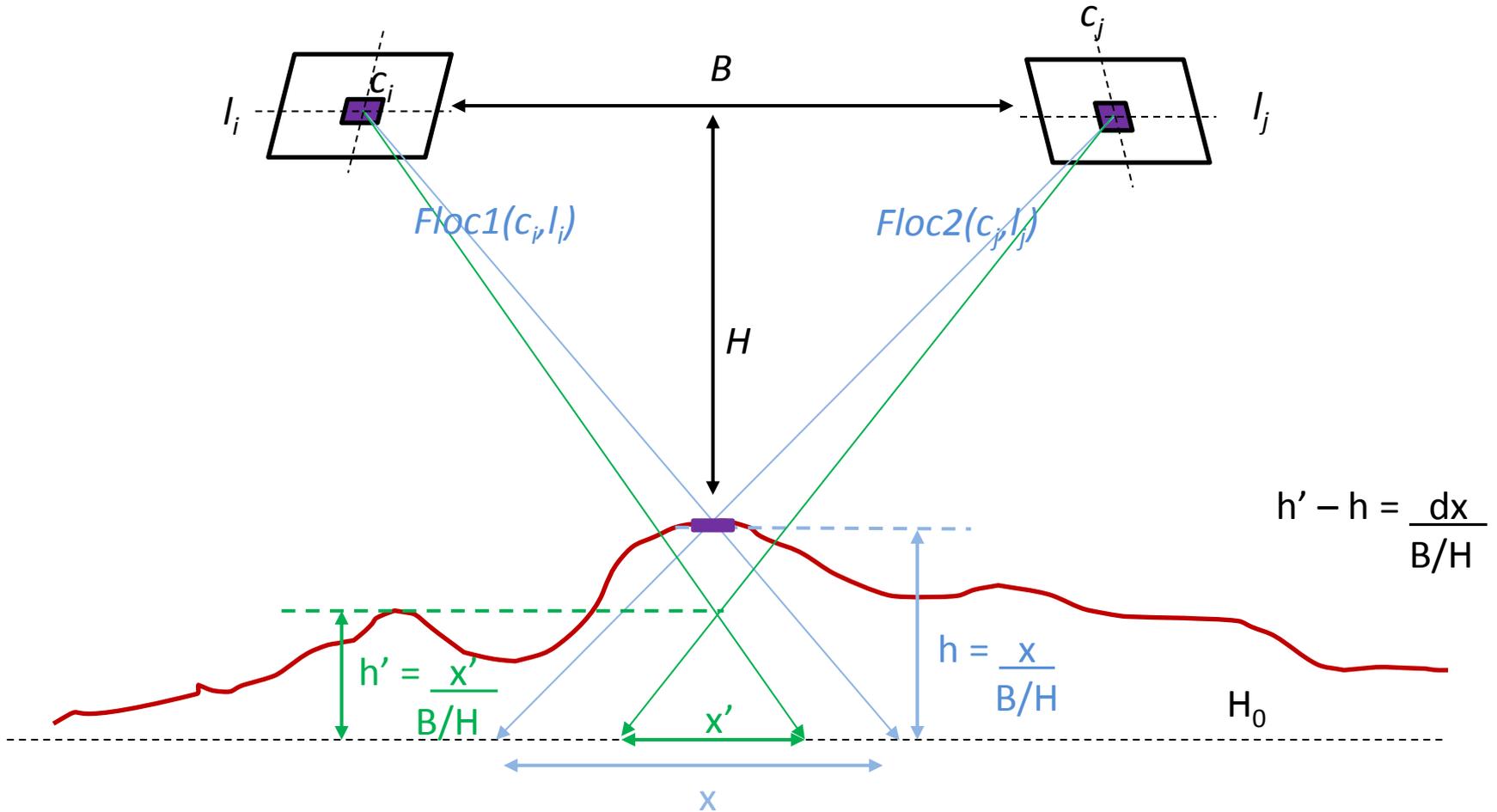
**SPECTRAL BANDS REGISTRATION = ACCURATE RELATIVE FOCAL PLANE  
CARTOGRAPHY (PIXELS VIEWING DIRECTION)  
~0,2 PIXELS ACCURACY**



**SPECTRAL BANDS REGISTRATION = ACCURATE RELATIVE FOCAL PLANE  
CARTOGRAPHY (PIXELS VIEWING DIRECTION)  
~0,2 PIXELS ACCURACY**



# ABSOLUTE FOCAL PLANE CARTOGRAPHY : IMPACT ON STEREO RESTITUTION

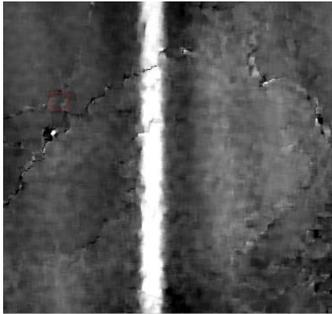


# FOCAL PLANE ABSOLUTE CARTOGRAPHY CALIBRATION ~0,2 PIXELS ACCURACY

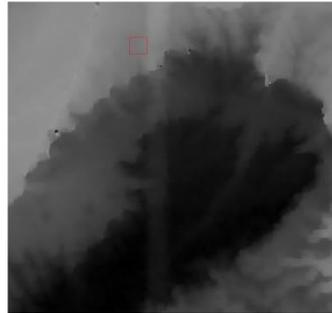
Example over Monument Valley (B/H 0,09)

A one pixel ( $dx=70$  cm) viewing directions relative error gives a 7,77 m altitude restoration error for a B/H=0.09 !

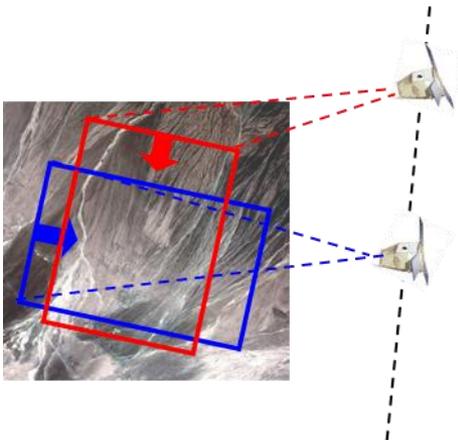
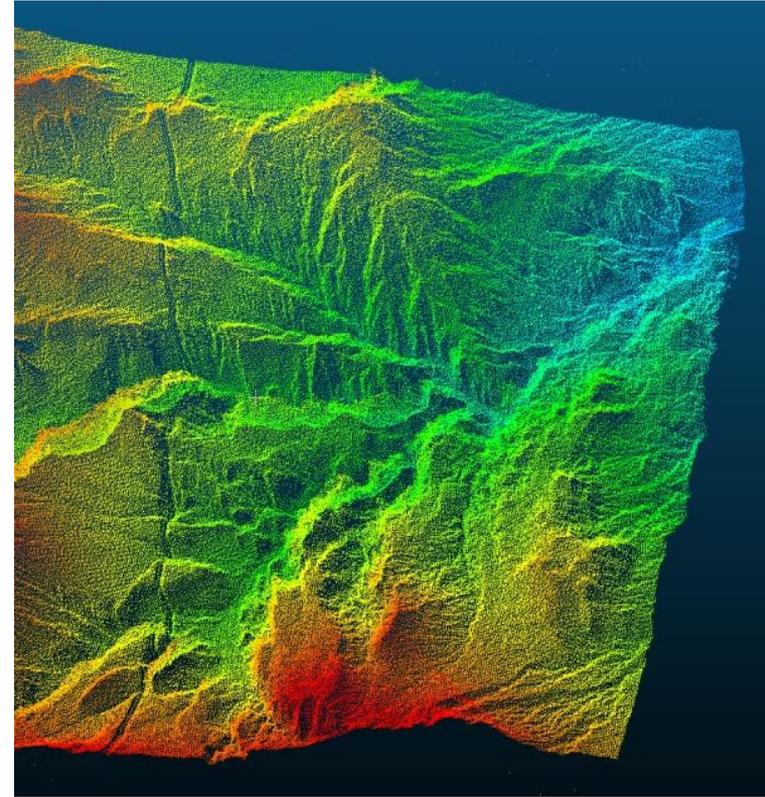
Column shift



Row shift



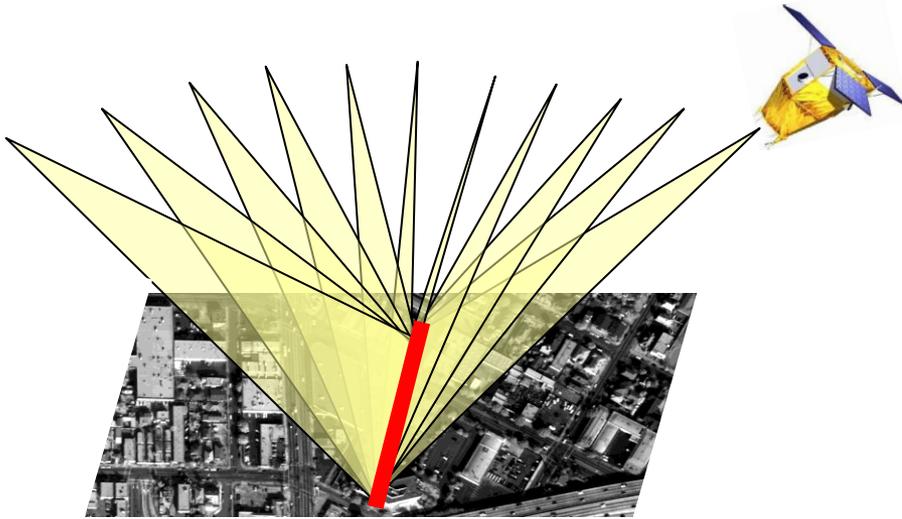
Strip width  
~50 pixels



Geometric auto-calibration enhance absolute cartography accuracy to 0,2 pixel

# SIGNAL-TO-NOISE RATIO ASSESSMENT

## Steady-mode

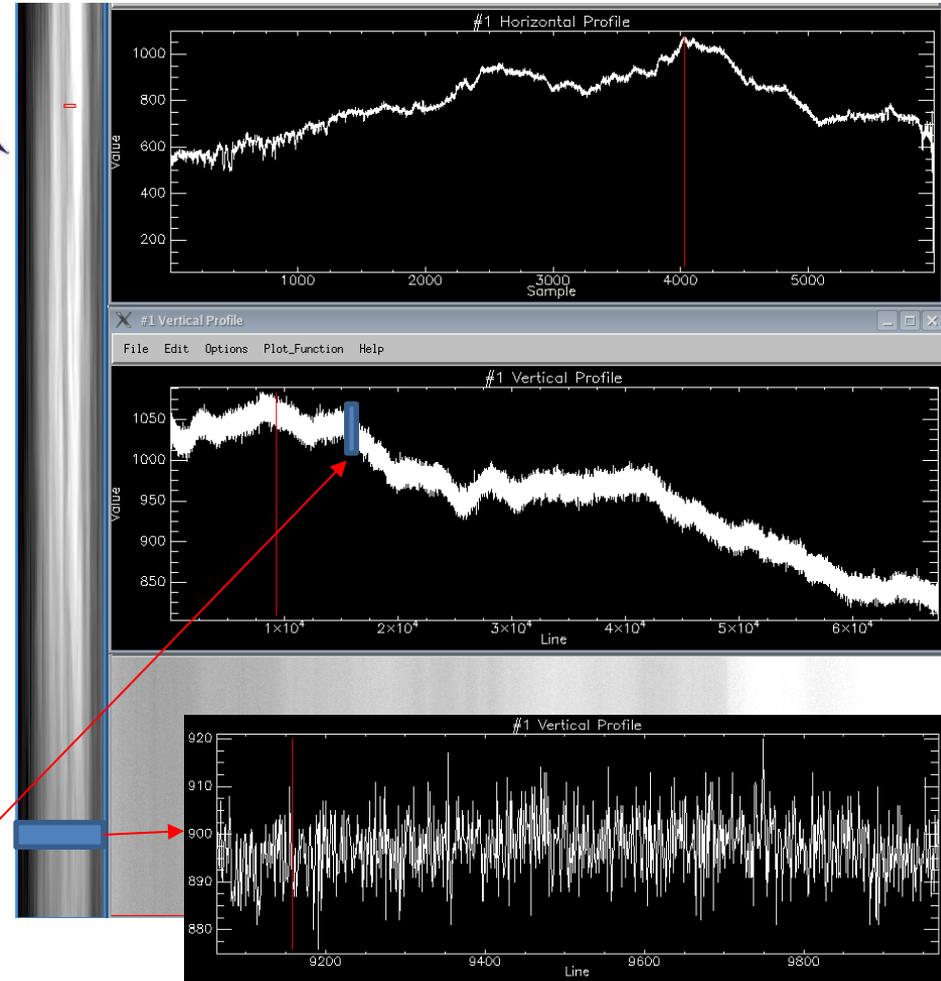


### Acquisition duration

- a few seconds
- about 60000 rows

### Relative line-of-sight good stability

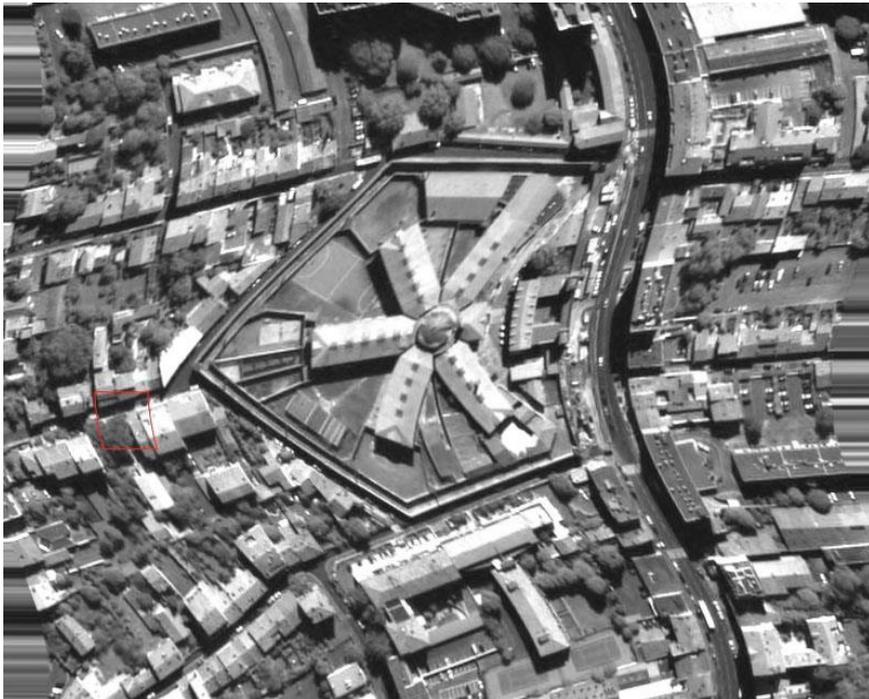
- use of 1000 rows



Vertical profile of 1 column for 1000 rows

# IN-FLIGHT MICROVIBRATIONS ASSESSMENT

## Potential geometric effects on images

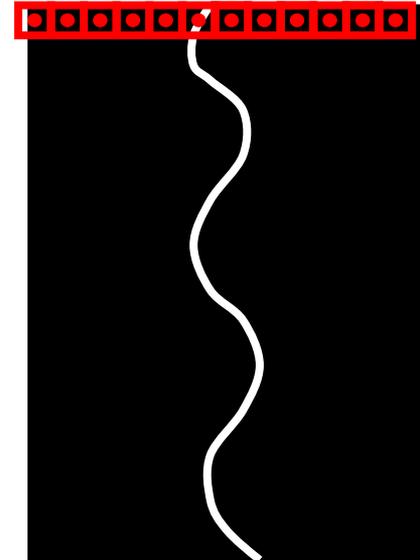
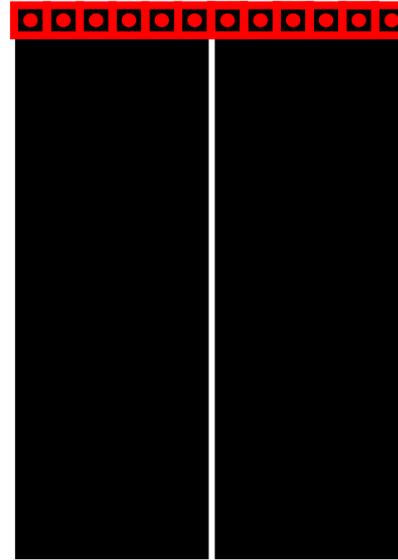
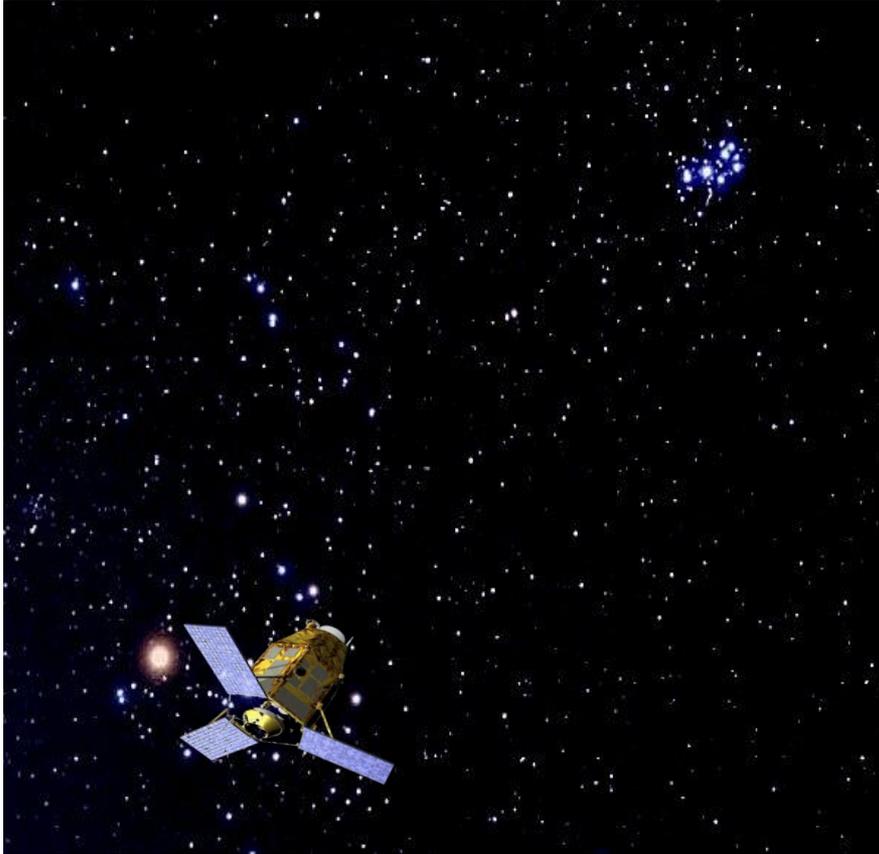


Images with microvibrations



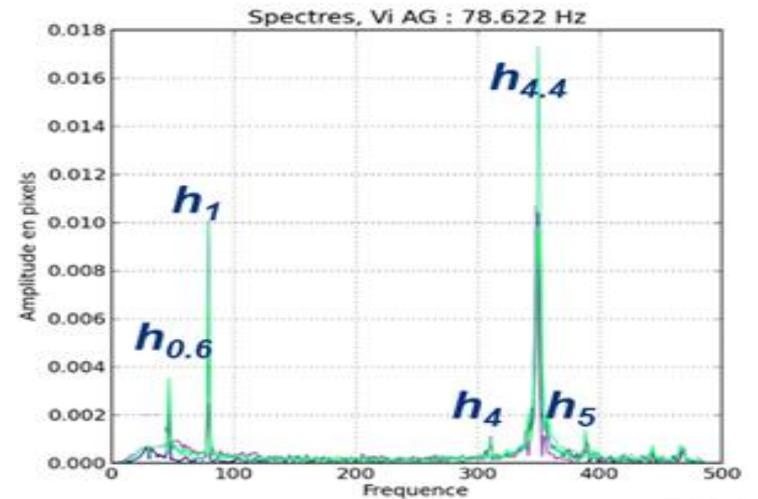
Images without microvibrations

# STARACQ ACQUISITIONS



*Without  $\mu vib$*

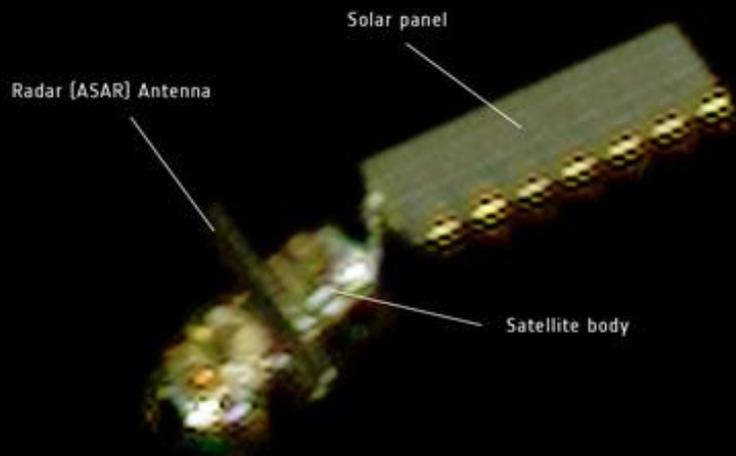
*With  $\mu vib$*



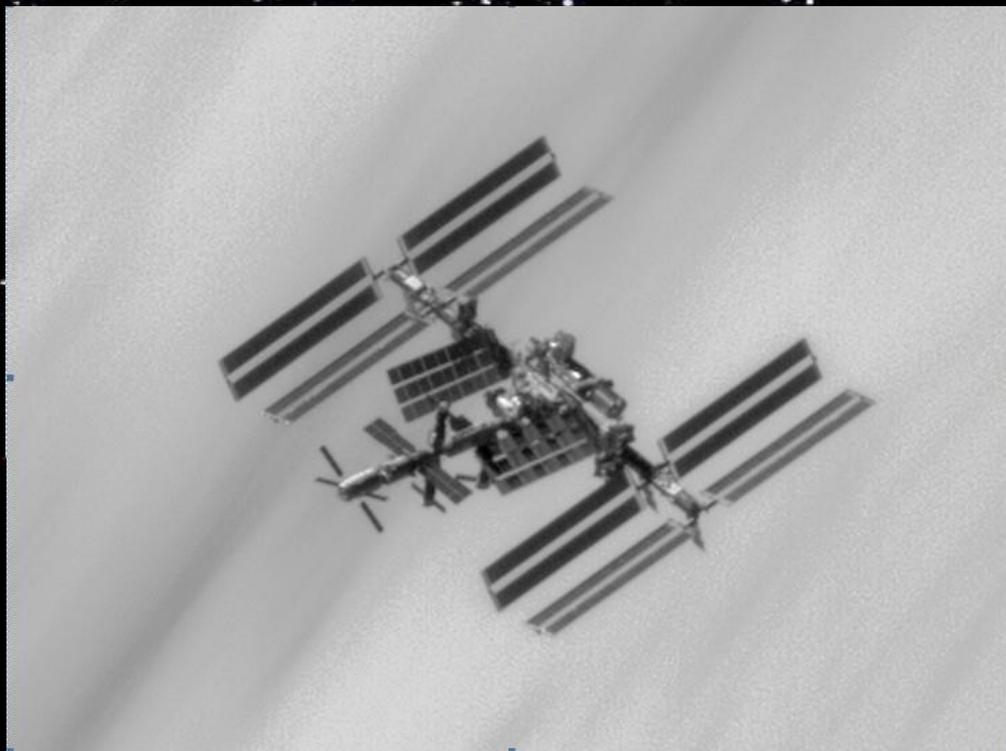
# THE OPPORTUNITY TO IMAGE SOME OTHER ORBITING OBJECTS...



Jupiter and its satellites



Envisat



ISS and ATV

# MAIN PERFORMANCE

## Excellent performance on both satellites

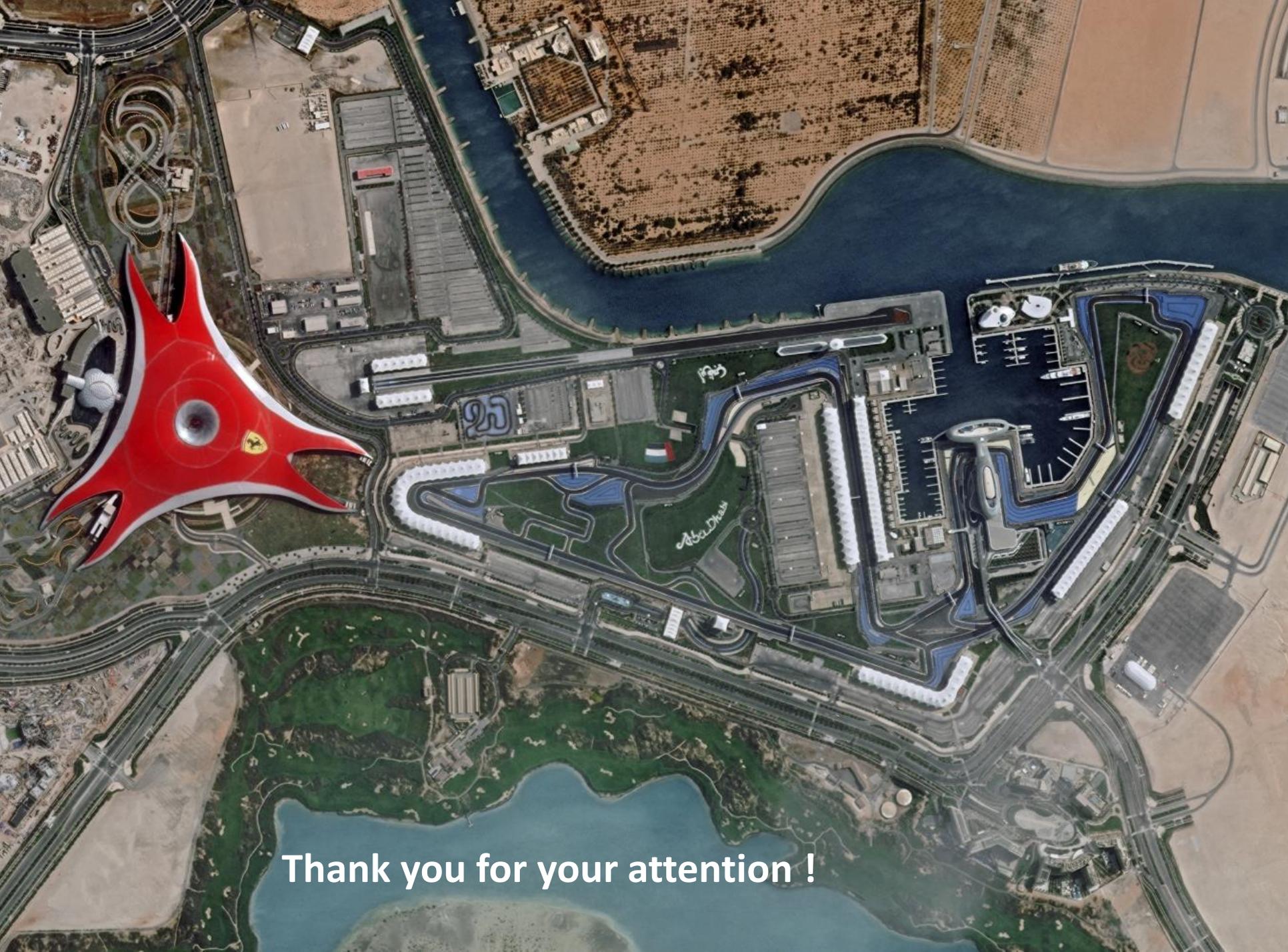
- All requirements are fulfilled with a comfortable margin (confirmed by respectively three and two years of in-flight monitoring on PHR-1A and PHR-1B)
- Very similar performance between 1A and 1B (coherent constellation)

| Image Quality criteria  |             | Performance |
|---|-------------|-------------|
| Location CE90 (with accurate attitude and for depointing < 30°) | All bands   | 6.5 m       |
| PAN/XS registration in XS pixels (90%)                          | PA/XS       | 0.20        |
| XS/XS registration in XS pixels (90%)                           | XS          | 0.18        |
| Planimetry in PAN pixels (90%)                                  | All bands   | 0.20        |
| Altimetry for a stereo pair with a b/h of 0.15 (RMS)            | PA          | 1 m         |
| Absolute calibration accuracy                                   | All bands   | <3 %        |
| Multi-temporal calibration accuracy                             | All bands   | 1%          |
| Inter-Pleiades accuracy   | All bands   | 2%          |
| MTF @ Nyquist   | PA          | 0.15        |
|   | XS (X axis) | 0.31        |
|   | XS (Y axis) | 0.26        |
| SNR @ L2  | PA          | 156         |
|   | B0/B1/B2    | 158         |
|   | B3          | 190         |









Thank you for your attention !

All you ever wanted  
to know about  
**satellite imagery** !

Contact : [laurent.lebegue@cnes.fr](mailto:laurent.lebegue@cnes.fr)

