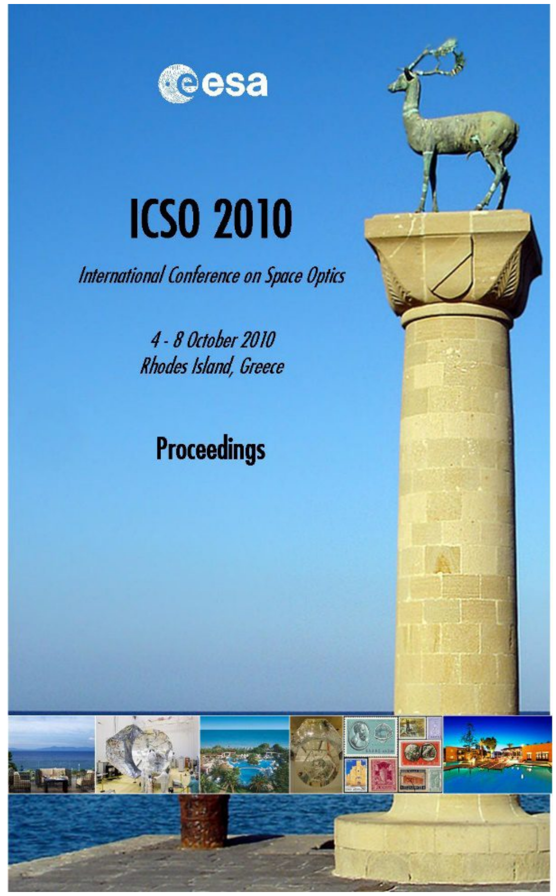
# International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010

*Edited by Errico Armandillo, Bruno Cugny, and Nikos Karafolas*




## *Geo-oculus: high resolution multi-spectral earth imaging mission from geostationary orbit*

*L. Vaillon, U. Schull, T. Knigge, C. Bevillon*

International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny, Nikos Karafolas, Proc. of SPIE Vol. 10565, 105651V · © 2010 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2309216

# GEO-OCULUS: HIGH RESOLUTION MULTI-SPECTRAL EARTH IMAGING MISSION FROM GEOSTATIONARY ORBIT

L. Vaillon[1], U. Schull[2], T. Knigge[2], C. Bevillon[1]
[1]*EADS Astrium Satellites, France,* [2]*EADS Astrium Satellites, Germany*

Geo-Oculus is a GEO-based Earth observation mission studied by Astrium for ESA in 2008-2009 to complement the Sentinel missions, the space component of the GMES (Global Monitoring for Environment & Security). Indeed Earth imaging from geostationary orbit offers new functionalities not covered by existing LEO observation missions, like real-time monitoring and fast revisit capability of any location within the huge area in visibility of the satellite. This high revisit capability is exploited by the Meteosat meteorological satellites, but with a spatial resolution (500 m nadir for the third generation) far from most of GMES needs (10 to 100 m). To reach such ground resolution from GEO orbit with adequate image quality, large aperture instruments (> 1 m) and high pointing stability (<< 1 µrad) are required, which are the major challenges of such missions.

To address the requirements from the GMES user community, the Geo-Oculus mission is a combination of routine observations (daily systematic coverage of European coastal waters) with "on-demand" observation for event monitoring (e.g. disasters, fires and oil slicks). The instrument is a large aperture imaging telescope (1.5 m diameter) offering a nadir spatial sampling of 10.5 m (21 m worst case over Europe, below 52.5°N) in a PAN visible channel used for disaster monitoring. The 22 multi-spectral channels have resolutions over Europe ranging from 40 m in UV/VNIR (0.3 to 1 µm) to 750 m in TIR (10-12 µm).

## I. MISSION DESIGN

### A. *Mission objectives*

The Geo-Oculus mission objectives have been derived from a comprehensive review for user requirements, potential applications and the related product requirements. The scope of this survey covers the political framework in terms of ongoing or future European initiatives, especially the GMES initiative, as well as international treaties and European and national directives, policies and protocols. Potential synergies with European and international Earth observation systems and missions, like the Sentinels, GEOSS and EPS were identified and considered for the identification of suitable applications for Geo-Oculus. The Geo-Oculus mission objectives (see Fig. 1) selected in consultation with ESA are the following:

- Disaster Monitoring (floods, large landslides, storms), for which the main requirements are high spatial resolution (10-20 m) in broad visible range and short acquisition delay/ timeliness (<1 h);
- Fire Monitoring, to provide on demand infrared observations for fire fighting and allow mitigation organisation with very short delay (10 min.), thus requiring high satellite agility;
- Marine applications, focused on Algal Bloom Detection/Monitoring and Water Quality Monitoring with respect to European Regulation. In addition, secondary mission objectives have been defined, Oil Slick Environmental Information and Erosion / Sediment Transport on the European Shoreline Monitoring. Such sea surface observations require multi-spectral data with medium resolution (100 to 1000 m) but high signal-to-noise ratio (up to 1500).

| | Primary Mission Objectives | | | | Secondary Mission Objectives | |
|---|---|---|---|---|---|---|
| **Application** | **Mission 1: Disaster Monitoring** | **Mission 2: Fire Monitoring** | **Mission 3: Algal Bloom Detection / Monitoring** | **Mission 4: Water Quality Monitoring wrt. European Regulation** | **Mission 5: Oil Slick Environmental Information** | **Mission 6: Erosion / Sediment Transport on the European Shoreline Monitoring** |
| Type of service | on demand | on demand | routine / on demand | routine | on demand | on demand |
| Service regions | Europe | all European fire endangered areas up to 45° N | all European waters | all European waters | all European waters | European coastal waters |
| Product Image Size | 150 x 150 km² | 100 x 100 km² | 100 x 100 km² | 100 x 100 km² | 100 x 100 km² | 100 x 100 km² |
| Service period | all year | summer-early fall | all year | all year | all year | all year |
| Daily service period (solar zenith angle, time span) | <80° | 24 hours (sun avoidance ok) | <60° | <60° | <60° | <60° |
| Effective Revisit Time | 1 hour | 10 minutes | 1 day | 1 day | 1 hour | on request |
| Timeliness | 1 hour | 15 minutes | 1 hour | 1 day | 1 hour | 1 hour |
| Acquisition Delay | 1 hour | 10 minutes | 3 hours | 3 hours | 1 hour | 1 hour |
| Spatial Sampling Distance (products) | 10m | 250 m | 100 m | 100 m | 25 m | as high as possible |

**Fig. 1.** Geo-Oculus mission objectives

### *B. Mission scenario*

Step and stare observation with large matrix detectors is preferred to scanning concepts, due to greatly improved flexibility in terms of integration time for each application and the maximization of observed area. In particular, the possibility for real-time commanding allows for the optimization of mission planning vs. cloud cover. Indeed, thanks to its geostationary orbit, Geo-Oculus has the capability to access every spot within its footprint at the time the spot becomes cloud free. Analysis of the cloudiness over Europe showed that the achievable ground coverage with Geo-Oculus (~40 m GSD (Ground Sampling Distance) over Europe) is ~2.5 times more than Sentinel 3 at 300 m GSD (see Fig. 2).

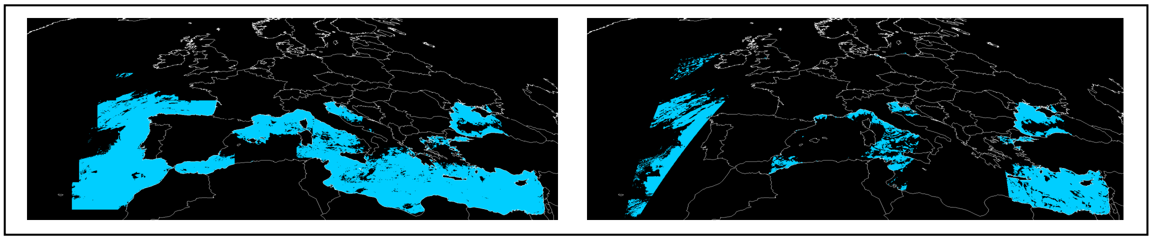


**Fig. 2.** Ground coverage within one day for Geo-Oculus (left) and LEO (Sentinel 3, right) are highlighted blue

The selected mission scenario (see Fig. 3) is the result of a compromise between systematic coverage of European coastlines (about 65 images every day) for marine applications and parallel emergency missions for fire monitoring (10 min revisit time), disaster and oil slick monitoring (60 min revisit time).

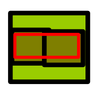
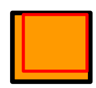
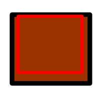
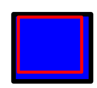
| Missions: | Disaster | Fire | Oil Slick / Erosion | Marine |
|---|---|---|---|---|
| Observation times | Daytime | 24 h | Daytime | Daytime |
| Observation cycle (min) | 60 | 10 | 60 | 540 |
| Product FoV (km E/W x km N/S, at SSP) | 300x141 | 285 x 285 | 285 x 285 | 285 x 285 |
| Image FoV (km E/W x km N/S, at SSP) | 157x157<br>0.25° x 0.25° | 300 x 300<br>0.48° x 0.48° | 300 x 300<br>0.48° x 0.48° | 300 x 300<br>0.48° x 0.48° |
| APE (orbit + attitude) | +/- 7.5 km | | | |
| PDE (mosaic imaging) | 700m | - | - | - |
| Number of images per product | 3 | 1 | 1 | 1 |
| FoV at nadir |  |  |  |  |

**Fig. 3.** Baseline parameters for Geo-Oculus mission scenarios

### *C. Overall spacecraft design*

The spacecraft is composed of a large instrument (1.5 meter aperture diameter), further described in the following, which is mounted on the nadir side of a service module derived from conventional telecom platform (see Fig. 4). The challenging pointing requirements (100 µrad absolute and <1 µrad stability over 100 msec) imposed by image quality are met thanks to high-end AOCS sensors, i.e. Astro APS star tracker hybridised with Astrix 200 Fibre Optics Gyroscopes (radiation-hardened version of gyroscopes used on accurate LEO observation missions), and actuators with low micro-vibration signature (magnetic bearing wheels).

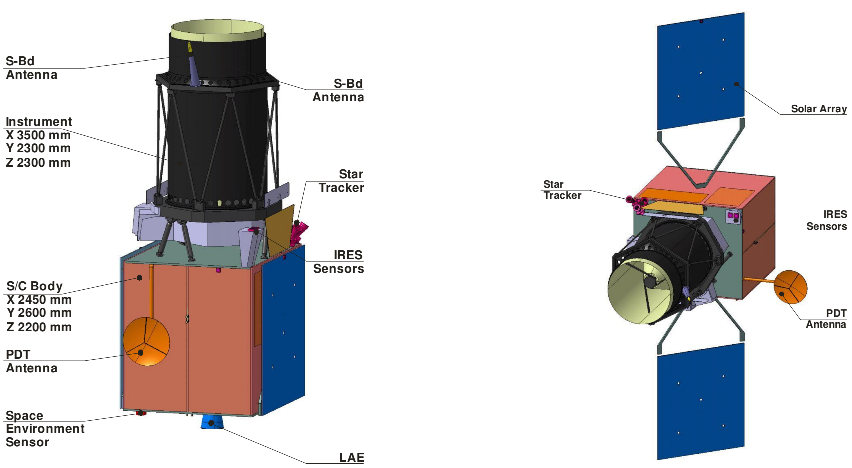



**Fig. 4. Geo-Oculus spacecraft configuration (left: stowed, right: deployed)**

## II. INSTRUMENT DESIGN

### *A. Imaging capability*

In order to support Fire Monitoring & Marine applications, the instrument provides simultaneous imaging of Earth scenes on four multi-spectral focal planes (UV-blue, Red-NIR, MWIR and TIR) with a ground FoV (Field of View) of 300x300 km (0.48x0.48 deg). In Fig. 5, for some channels, subscript "a" refers to Fire Monitoring mission while "b" refers to Marine application and corresponds to different radiometric requirements. The worst case VNIR (Visible & Near Infra-Red) resolution (at 52.5 °N corresponding to a viewing zenith angle of 60 deg) is 40 m for fire & disaster monitoring. It is degraded by a factor of two for marine applications (80 m) because pixel binning is necessary to meet the challenging SNR (Signal-to-Noise Ratio) requirements of these applications.

In addition, the Disaster Monitoring application requires a visible PAN (Panchromatic) focal plane with higher resolution (10.5 m nadir, 21 m over Europe) and reduced FoV (157x157 km, i.e. 0.25x0.25 deg) imposed by the use of the same detector array as the UV-blue & Red-NIR channels.

| Channel ID | Center wavelength (nm) | Bandwidth (nm) | Focal planes |
|---|---|---|---|
| UV1 | 318 | 10 | UV-blue |
| UV2 | 350 | 10 | |
| VNIR1 | 412 | 10 | |
| VNIR2 | 443 | 10 | |
| VNIR3 | 490 | 10 | |
| VNIR4 | 510 | 10 | |
| VNIR5 | 555 | 10 | |
| VNIR7 | 655 | 155 | PAN |
| VNIR6 | 620 | 10 | Red-NIR |
| VNIR8a | 665 | 10 | |
| VNIR8b | 665 | 10 | |
| VNIR9 | 681 | 8 | |
| VNIR10 | 709 | 10 | |
| VNIR11 | 753 | 8 | |
| VNIR12 | 779 | 15 | |
| VNIR13a | 865 | 20 | |
| VNIR13b | 865 | 20 | |
| VNIR14 | 885 | 10 | |
| VNIR15 | 900 | 10 | |
| VNIR16 | 1040 | 40 | |
| SWIR | 1375 | 50 | SWIR MWIR |
| MWIRa | 3700 | 390 | |
| MWIRb | 3700 | 390 | |
| TIR1a | 10850 | 900 | TIR |
| TIR1b | 10850 | 900 | |
| TIR2a | 12000 | 1000 | |
| TIR2b | 12000 | 1000 | |

| | Channels | Number of channels | GSD (m) at 52.5°N | FOV (km) |
|---|---|---|---|---|
| Disaster Monitoring | PAN | 1 | 21.0 | 157x157 |
| | UV-blue | 4 | 40 | 300x300 |
| | Red-NIR | 8 | 40 | |
| Fire Monitoring | Red-NIR | 2 | 40 | 300x300 |
| | SW/MW IR | 2 | 300 | |
| | TIR | 2 | 750 | |
| Marine Applications | UV-blue | 7 | 80 | 300x300 |
| | Red-NIR | 10 | 80 | |
| | SW/MW IR | 2 | 300 | |
| | TIR | 2 | 750 | |

**Fig. 5.** Summary of Geo-Oculus spectral channels and imaging capability

### *B. Optical design*

The instrument is based on a 1.5 m diameter Korsch telescope (the same size as Aeolus/Aladin instrument), as presented in Fig. 6. The diameter is driven by the high resolution PAN channel. The four multi-spectral focal planes are separated by a set of dichroïc plates. For each focal plane, a filter wheel selects the narrow channels in each band. Cold stops are required in front of the IR (Infra-Red) focal planes which need to be controlled at low temperatures (130 K for MWIR and 50 K for TIR). The PAN channel is separated in the field from the multi-spectral channels using the off-axis Korsch optical combination

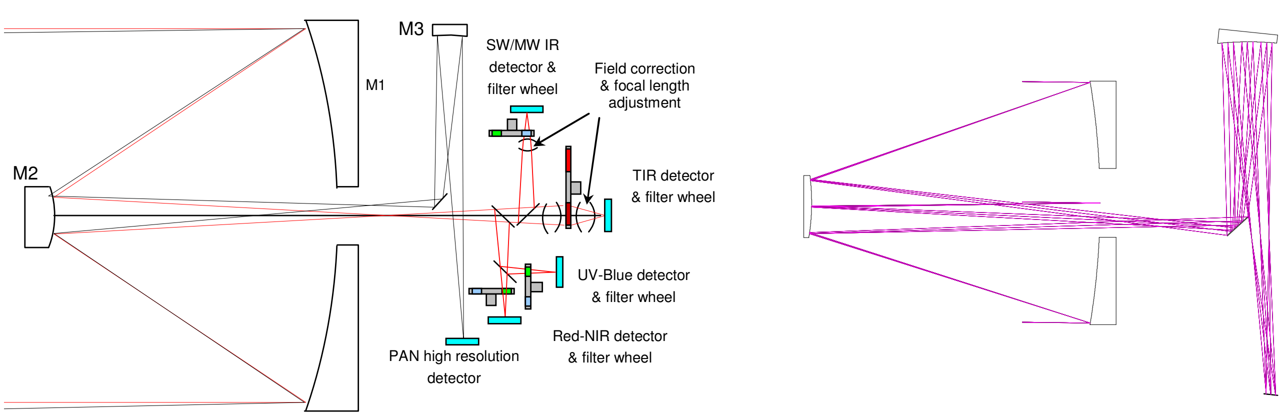



**Fig. 6.** Optical configuration (left: synoptic, right: PAN channel)

### *C. Focal planes & image processing*

Large array detectors are required to cover the wide FoV with the adequate resolution. The Geo-Oculus instrument has been sized based on the space qualified detector technology expected to be available in a typical 5 year time.

For UV and VNIR spectral bands (from 315 to 1040 nm), CMOS technology is preferred to CCD for its ability to build large format arrays, its better immunity to GEO harsh radiation environment and even more because smearing during transfer rules out large space qualified CCD arrays for Earth observation. Thinned backside CMOS technology (already demonstrated in Europe [1]), appropriate anti reflection coating and optimised thickness for active silicon layer are assumed, to improve detection efficiency within the requested spectral range. The largest space qualified CMOS arrays currently available in Europe are in the range of 2 Mpix (e.g. COBRA2M detector developed by Astrium & ISAE/CIMI for the GOCI (GEO Ocean Colour Imager) instrument [2]). 25 Mpixels range space qualified monolithic arrays can be expected within 5 years, provided that necessary pre-developments are initiated. Considering stitching (i.e. gap-less wafer level array assembly) of four such arrays, 100 Mpixels array has been assumed for Geo-Oculus. The array is divided in 4 sub-blocks independently operated (see Fig. 7, left), each featuring 16 video outputs with 20 Mpixels/s data rate, allowing reading the total array in less than 100 msec.

IR detectors are constituted of photo-detectors arrays hybridised on top of a CMOS Read Out Integrated Circuit (ROIC). For SWIR/MWIR band, HgCdTe technology was eventually preferred to QWIP (despite its better yield for large arrays) for its wide-band capability making possible a combined 1.4 µm / 3.7 µm detector. Driven by the minimum pixel pitch reachable thanks to currently available European hybridization technology (about 15 µm), the 30x30 mm² area of the 2k x 2k photo-detector array assumed for Geo-Oculus is larger than today's European state of the art (slightly more than 30 ~~25~~ mm diagonal), but is deemed feasible provided the necessary pre-developments are performed. The associated CMOS ROIC ~~is~~ might also need for stitching of four 1 Mpix sub-arrays, depending on the selected CMOS process. Each sub-block is read out via 4 video outputs with a 10 Mpixels/s output rate (see Fig. 7, centre), so the read out period is 25 ms. The operating temperature of the detector, dictated by the level of dark current, is set to 130K.

For TIR, QWIP technology is preferred for its better yield, uniformity (spatial and spectral) and temporal stability, because HgCdTe metallurgy complexity largely increases with cut-off wavelength. This issue is already tackled by ESA, particularly in the framework of MTG (Meteosat Third Generation) studies, with parallel technological development on HgCdTe and on alternate technology (QWIP). A 25 µm pixel pitch is currently considered. The targeted format of 0.8k x 0.8k pixels has a 28 mm diagonal, slightly larger than the European state of the art (QWIP arrays with about 20 mm diagonal), and seems accessible in Geo-Oculus time frame. The TIR detector architecture is similar to the MWIR one, but simpler thanks to the reduced number of pixels: two 400x800 pixels sub-arrays are read out by two 10 Mpixels/s video outputs (see Fig. 7, right), so the read out period is 16 ms. The detector is operated at 50K to avoid excessive dark current.

For some marine channels with low luminance and high SNR requirements (up to 1500), the long image integration time (up to 2.6 sec) is obtained by post-integration of up to 30 successive sub-images. This processing is performed on-board because raw sub-images would not fit in the available telemetry rate (250 Mbps). The estimated motion of instrument LoS (Line of Sight) between images is compensated to avoid degradation of the image quality. This allows relaxing pointing stability requirements to the capability of high end AOCS performance, avoiding specific LoS stabilization techniques at instrument or platform level. Post-integration with motion compensation is also used for the PAN channel to meet the challenging SNR and image quality requirements.

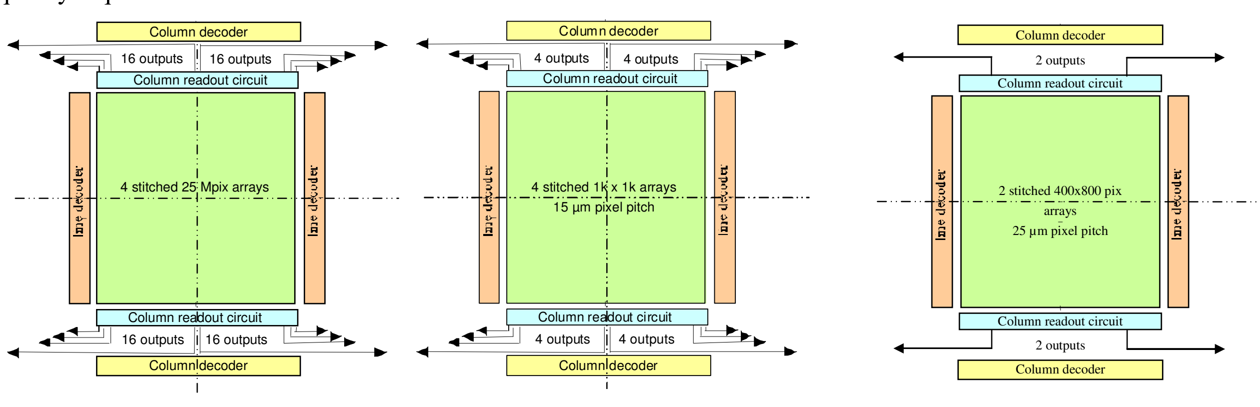



**Fig. 7. Detectors architecture (left: UV-VNIR CMOS, middle SWIR/MWIR HgCdTe, right TIR QWIP)**

*D. Mechanical & thermal architecture*

A full SiC (Silicone Carbide) telescope is preferred to alternate zerodur mirror technology that would result in largely increased mass. Indeed, zerodur density is higher and mirror back lighting is limited in harsh GEO radiation environment (zerodur mirrors bend under radiation). The 1.5 m diameter primary mirror (M1) is made of brazed petals, as successfully demonstrated by Astrium with Aladin and Herschel telescopes. The mono-material telescope design ensures low thermo-elastic sensitivity with minimised gradients thanks to SiC high thermal conductivity and minimum number of interfaces.

The M1 mirror is mounted on the top side of the main interface plate, whereas the bottom face carries all the focal planes and associated optics (see Fig. 8). The secondary mirror (M2) is supported by a spider attached to a hexapod structure which also carries the 2.5m long baffle. This configuration minimises the obscuration and provides a high dimensional stability between the M1 & M2 mirrors, which drives the telescope optical quality. The instrument is interfaced with the platform through a hexapod allowing high mechanical and thermal decoupling with respect to the platform.

Sun illumination of the interior of the telescope, and in particular the M1 mirror, is avoided by a Sun avoidance manoeuvre when the Sun angle reaches 30 deg, i.e. +/-2h around midnight at equinoxes. This interrupts the imaging sequence (anyway limited to IR bands during night time). The telescope is protected against Sun and cold space by the baffle and the focal plane & external structures are isolated thanks to MLI Multi-Layer Insulation). Thermal washers are used to decouple the various assemblies and the whole instrument from the platform. Active thermal control with heaters & thermistors is used to control the telescope temperature in combination with radiative screens on the back of the M1 & M2 mirrors and by direct conductive coupling for other elements.

The temperature of the mirror is very stable during daylight (6h to 18h), when the Sun aspect angle is larger than 90°, i.e. it does not illuminate the inner baffle. This corresponds to the phase of UV-VNIR imaging, where the best accuracy in pointing, defocus and WFE (wave front error) is required. During night time, the illuminated part of the baffle generates a disturbing flux on the mirror, the resulting thermo-elastic deformations which could generate defocus and WFE, are minimised thanks to the high conductivity of the SiC material. Moreover, the response of the mirror to this smoothly-varying flux is quick thanks to the combined effect of the high SiC conductivity and the low mass-to-area ratio of the mirror. Thermo-elastic distortions experienced during the night time are therefore not affecting high resolution daytime imaging performances.

The required radiometric performance implies a stabilised thermal environment for each of the detectors (50 K for TIR, 130 K for MWIR and 20°C for UV & VNIR detectors). While the obvious solutions are passive cooling for UV & VNIR, and active cooling for TIR, the MWIR sensor could be controlled, in principle, with one or the other technique, provided that a sufficient radiating area with full view to cold space can be implemented. This is however not possible for the selected dual wing spacecraft configuration, since solar arrays are in view of possible radiating areas on the north & south walls.

The three UV-VNIR detectors and their proximity electronics are cooled by coupling with a small radiating area (0.06 m²) through conventional heat pipes. IR focal planes are housed in cryostats (single stage for MWIR, two-stage with intermediate enclosure at 150 K for TIR) and cooled by mechanical cryocoolers.

The mass/power budgets for the instrument are 606 kg / 508 W (best estimate plus 20% margin). The power demand is dominated by IR focal planes cooling.

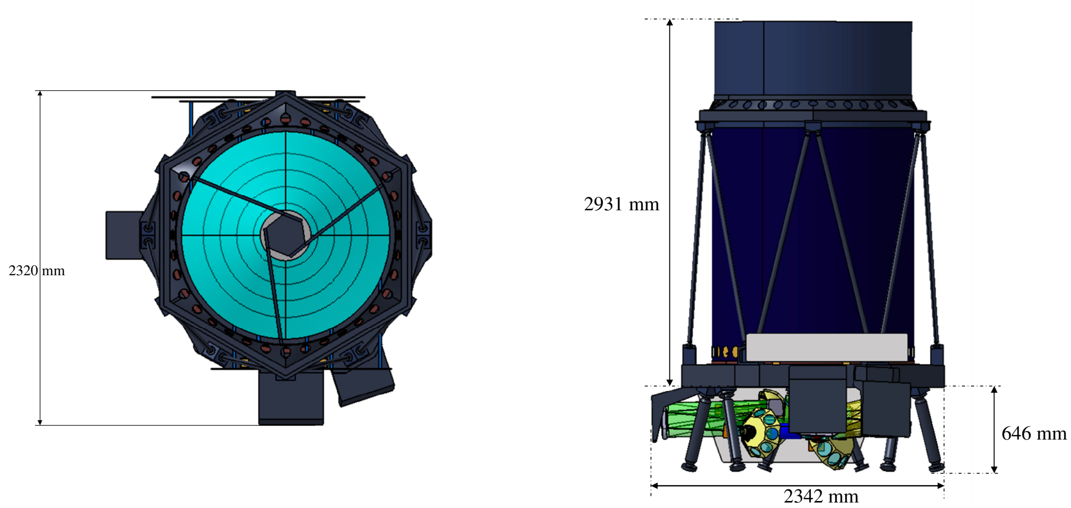



**Fig. 8. Instrument mechanical layout**

### *E. Electrical architecture*

The electrical architecture is the essentially the same for all five focal planes. The focal plane comprises the detector array and the Proximity Electronics Module (PEM) housing all the functions, which require being located close to the detector. The Remote Electronics Module (REM) hosts the other functions specific to each focal plane and provides the interface with the spacecraft data handling system. In order to minimise the power dissipation in the instrument, the REM units are implemented on the platform. All detection chains are connected to a data bus interfacing with the spacecraft data handling system. This modular architecture with an independent detection chain for each focal plane allows design flexibility and ensures robustness to the failure of one chain. Instrument control electronics (for thermal control and activation of calibration devices and filter wheels) can be hosted in one of the REM as depicted in Fig. 9 or in platform electronics.

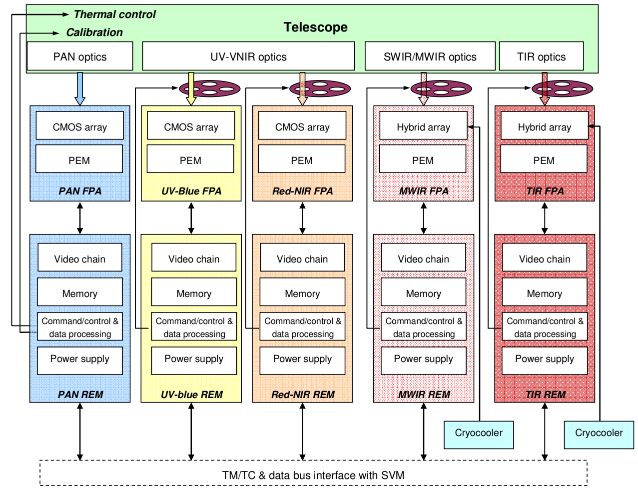



**Fig. 9. Electrical architecture of the instrument**

## III. CONCLUSIONS AND PERSPECTIVES

The Geo-Oculus study allowed defining a GEO-based Earth observation mission providing highly valuable GMES products over Europe, with good complementary to those produced by LEO missions. The fast response and high revisit capability of a GEO observatory is indeed a key asset for "event" monitoring (e.g. disasters, fires, oil slicks …). Moreover, with an optimised observation strategy targeting cloud-free areas, the daily European coverage is improved by a factor of 2.5 as compared to Sentinel LEO system.

The instrument designed to support the identified applications is a large aperture imaging telescope (1.5 m diameter) offering a nadir resolution of 10.5 m (21 m worst case over Europe, below 52.5°N) in a PAN visible channel used for disaster monitoring. The 22 multi-spectral channels have resolution over Europe ranging from 40 m in UV/VNIR (0.3 to 1 µm) to 750 m in TIR (10-12 µm). The resulting instrument is rather complex, with 4 multi-spectral focal planes separated by dichroïc plates and a PAN channel separated in the field.

The study also allowed identifying the key enabling technologies for such an instrument:

- Monolithic SiC telescope, to build large aperture low mass instruments with high dimensional stability in difficult GEO thermal & radiation environment;
- Large array detectors, to allow large FoV and high resolution (e.g. 100 Mpix monolithic CMOS array detector for UV-VNIR, 4 Mpix MWIR hybrid detector). Such detectors exceed current capability but seem accessible within Geo-Oculus development time frame (5 years) with adequate pre-development activities and considering the needs for other short term space missions.
- Image processing techniques to allow long integration time and high image quality with pointing stability requirements on platform accessible with high performance AOCS;

Following the preliminary Geo-Oculus study conducted by Astrium in 2008-2009 for ESA, an assessment study is scheduled in 2011 on the basis of refined user requirements derived from the outcomes of the User Workshop held in April 2010. The successful operation of the GOCI instrument, launched in July 2010 on-board the COMS GEO platform developed by Astrium for Korea, paves the way for future Earth observation from GEO.

## IV. ACKNOWLEDGMENTS

The authors would like to thank J.L. Bézy and M. Aguirre from ESTEC for the fruitful exchanges and valuable advises during the Geo-Oculus study.

## V. REFERENCES

[1] Back-thinned CMOS sensor optimisation, Paul Jerram, David Burt, Neil Guyatt, Vincent Hibon, Joel Vaillant, Yann Henrionb., *SPIE Proceeding 7598*, 2010

[2] COBRA, a space qualified detector family covering the need for many LEO and GEO optical instruments, Michel Bréart de Boisanger, Olivier Saint-Pé, Franck Larnaudie, Saiprasad Guiry, Pierre Magnan & al Neil Guyatt & al, *ICSO 2008 proceedings,* Toulouse 2008