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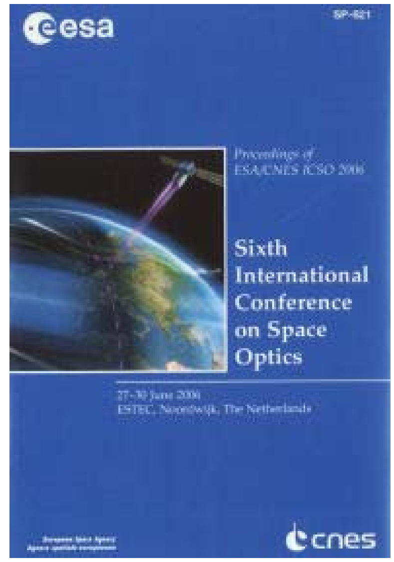


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# OCAPI : A MULTIDIRECTIONAL MULTICHANNEL POLARIZING IMAGER

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## ABSTRACT

OCAPI (Optical Carbonaceous and anthropogenic Aerosols Pathfinder Instrument) is an imager dedicated to the observation of the spectral, directional and polarized signatures of the solar radiance reflected by the Earth-Atmosphere system. The measurements are used to study air quality and pollution by tracking aerosol quantity, types and circulation at various scales in the visible range. The main characteristics of OCAPI are a 110° along track and cross track field of view, eight polarized channels distributed between 320 and 2130 nm. The resolution is 4 x 4 km2 in the visible and the shortwave infrared (SWIR) range, and 10 x 10 km2 in the UV. The instrumental concept is derived from POLDER and PARASOL with additional channels in the UV and SWIR to better determine aerosol properties and constrain Earth surface and cloud contributions in the detected signal. It is based on three wide field-of-view telecentric optics (UV, Visible and SWIR), a rotating wheel bearing spectral and polarized filters and two dimensional detector arrays at the focal plane of the optics. The instrument requirements, concept and budgets are presented

## ACRONYMS

OCAPI : Optical Carbonaceous and anthropogenic Aerosols Pathfinder Instrument

TRAQ : TRopospheric composition and Air Quality

TROPOMI : Tropospheric OMI Instrument

SIFTI : Static Infrared Fourier Transform Interferometer

POLDER : Polarization and Directionality of the Earth's Reflectance

PARASOL : Polarization and Anisotropy of Reflectance for Atmospheric Sciences coupled with Observations from a Lidar

MODIS : Moderate Resolution Imaging Spectro-radiometer

## 1. INTRODUCTION

OCAPI is one of the three instruments of the TRAQ mission. TRAQ was elaborated in response to the Second Call for Earth Explorer Core Mission Ideas released by ESA on March 2005.
This mission is fully dedicated to air quality and science issues related to tropospheric composition and global change. Three objectives are addressed :

- Velocity of air quality changing on a global and regional scale ;
- Strength and distribution of the sources and sinks of trace gases and aerosols influencing air quality ;
- Role of tropospheric composition of global change.

For that, high quality, high spatial and temporal resolved information on tropospheric composition with small ground footprints and global coverage are required.
This is achieved by an optimal synergy between three complementary instruments: a UV-VIS-NIR grating imaging spectrometer (TROPOMI), an infrared (SWIR-TIR) Fourier transform interferometer (SIFTI) and a multi-viewing polarization-resolving imaging radiometer (OCAPI). The OCAPI's capabilities will give information on tropospheric aerosols, which will be simultaneous and co-located with trace gas concentration obtained from TROPOMI and SIFTI.
Furthermore, a new optimized orbit offering a near global coverage and a unique diurnal time sampling with up to 5 daytime observations over Europe and other mid-latitude regions is proposed
The OCAPI's scientific requirements were defined by LOA. ASTRIUM was in charge of the instrument study. CNES managed optimization between instrument definition and requirements.

## 2. REQUIREMENTS

OCAPI aims at retrieving aerosols parameters required for air quality monitoring and to correct the products retrieved in the UV-VIS and SWIR for the impact of aerosols. The technique is a heritage of the POLDER

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and PARASOL missions which showed convincingly that aerosols belonging to the accumulation mode can be characterized over lands using polarization and multidirectional reflectance measured in selected visible channels at 443 nm, 490 nm, 670 nm and 865 nm. Lessons learned from MODIS show that SWIR channels at 1650 and 2130 nm are very useful to subtract the background signal in the aerosols retrieval. To get accurate information on aerosols, they have to be distinguished from semi-transparent clouds. This justifies the presence of channels dedicated to cloud characterization like the 1370 nm channel.
Compared to PARASOL, OCAPI needs a higher spatial resolution of 4 km instead of 6 km, allowing for more cloud free scenes, more precise retrieval of aerosol properties and identification of polluting aerosol. Furthermore a larger field of view is expected : +/- 55° along and cross track instead of respectively +/- 51° and +/- 42° for PARASOL.
An option consisting in the implementation of a 320 nm UV channel with a lower resolution (10 km) has been studied. The objective was the detection of ozone. At the end, it was integrated in the TROPOMI mission.
The baseline for the spacecraft design of the TRAQ mission was to use a mini-satellite platform. Thus, OCAPI should stay a little instrument with reduced interface allocations.
All these elements lead to the following requirements and allocations :

| Central wavelength (nm) /(P= polarisation ) | Bandwith (nm) |
|---|---|
| 320 P (option) | 10 |
| 443 | 20 |
| 490 P | 20 |
| 670 P | 20 |
| 865 P | 40 |
| 1370 | 40 |
| 1650 P | 40 |
| 2130 P | 40 |

| | |
|---|---|
| Field of view | 110°min along track and cross-track |
| Resolution (Nadir) | VIS and SWIR : 4 x 4 km2,<br>UV : 10 x 10 km2 |
| Directionality | 14 min successive view of a surface target |
| SNR | 200 at 10% ground reflectance and sun at zenith |
| Mass | 40 kg max |
| Power | 50 W max |
| Volume | 0.6 x 0.6 x 0.3 m3 max |
| Mean data rate | 5 Mbps max |

The considered altitude is 700 km.

## 3. INSTRUMENT CONCEPT

The instrumental concept derived from POLDER/PARASOL (Fig. 1) is based on three wide field-of-view telecentric optics (UV, Visible and SWIR), a rotating wheel bearing spectral and polarized filters displayed on two sectors (external one for SWIR and UV, internal one for Visible), and two-dimensional detector arrays at the focal plane of the optics. The 110° along-track by 110° cross-track instantaneous field of view intercepts a 2D Earth scene that is imaged on the 500 x 500 pixels detection arrays in the Visible and SWIR, and on the 200 x 200 pixels detection array in the UV. Considering that OCAPI is at a 700 km altitude, this produces a swath width of 2000 km (2300 km once projected on Earth). The size of a ground pixel at nadir is 4 km x 4 km (6.3 km x 6.3 Km at 55° because of Earth distortion) for Visible and SWIR channels, and 10 km x 10 km for UV channels.

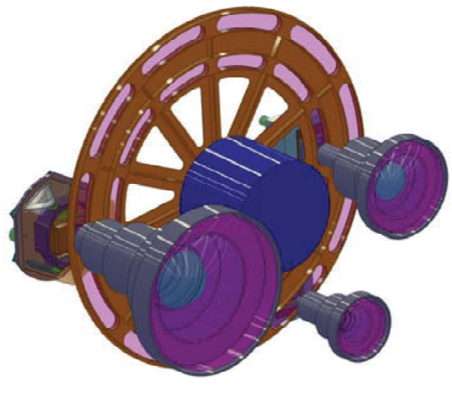

**Fig. 1** : OCAPI instrument concept. There are three wide field-of-view optics sharing the same filter wheel. SWIR optics is the largest one, and UV the smallest

Multi-angle viewing is achieved by along-track migration at the satellite velocity. Thus, during a single orbit, the same target can be observed under 15 viewing angles due to the large field of view along track and the observation frequency (one image every 20 s) (see Fig. 2).

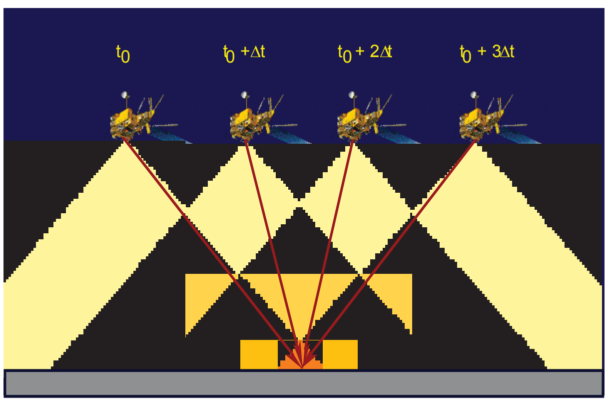


**Fig. 2** : Principle of directional signature measurement. As the satellite goes along its orbital path, a surface target is within the instrument FOV for about 5 mn. During that time, the radiometer makes about 15 acquisitions and the target reflectance is measured under different geometries.

The selected spectral bands were presented in the previous section. Most of these channels are polarized (P in the table), which means that the measurement is obtained with three successive acquisitions with similar spectral filters in addition to polarizers oriented at 0°, 60° and 120°. For the UV channel at 0.32 um it has been shown that two polarization orientations are enough for the retrieval process.

Taking into account optical glass and detector available properties, the channels are gathered into three cameras, two with silicon detector arrays (UV and Visible) and one with MCT (Mercury Cadmium Telluride) detector array (SWIR). For the aim of intercalibration between the cameras, an additional channel at 0.865 um is included in the SWIR camera (MCT sensitivity covers this wavelength).

A very important issue in order to minimize the overall dimensions, mass and power of the instrument is that only one filter wheel is used for the three cameras. Accounting for the dark signal references, there are 11 channels on the external sector (8 SWIR, 2 UV, a common dark) and also 11 channels on the internal sector (10 VIS, dark). The dark signal references allow to calibrate the overall signal offset at each wheel rotation, and thus to minimize the stability requirements impacting on the radiometric image quality, e.g. the detector thermal stability.

The dynamic range is adjusted for a maximum reflectance of 1, with sun at nadir (bright clouds). The POLDER experience in the Visible and Near Infrared spectral range has shown that larger radiances were limited to the particular case of a specular reflectance over small lakes and rivers (the ocean surface is rougher even if resolved at 4 km, which yields a lower and more diffuse glint). The exposure time and the video electronics gain can be changed in flight with respect to observed reflectances and ground calibration.

Basically, OCAPI has two nominal operation modes: the “Imaging” mode (IMAG) and the “Stand By” mode (STBY). The instrument will be set in the Imaging mode on the illuminated part of the orbit corresponding to solar zenith angle less than 75°. The IMAG and STBY modes are performed alternatively during a nominal operation sequence, and then repeated on the successive orbital cycles.
The imaging mode consists in image cycles repeated all along each orbit. As shown in Fig. 3, an image cycle is constituted by an image sequence followed by a time interval during which no image is acquired. The image cycle duration (20s) is four times the image sequence duration of 5s corresponding to one turn of the wheel. For the VIS camera, an image sequence is constituted of 11 successive images. For the SWIR and UV cameras sharing the same filter wheel sector and the same dark signal reference, an image sequence consists in 9 and 3 images respectively.

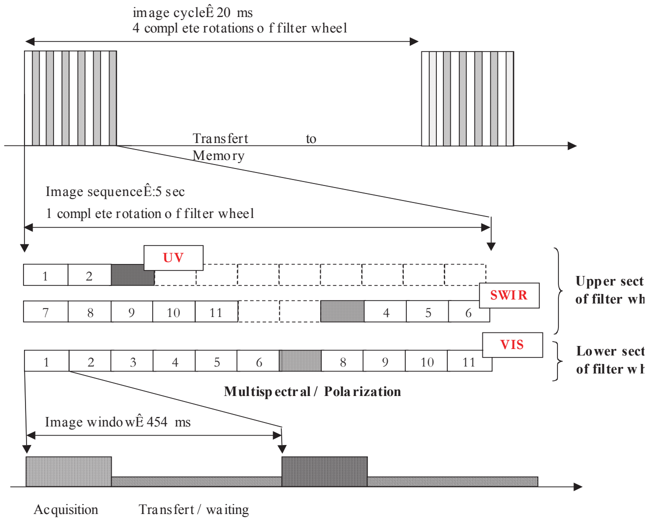


**Fig. 3** : Imaging sequence

OCAPI calibration plan is derived from the POLDER and PARASOL experiment return. The instrument is designed to be very stable. Therefore, the instrument can be calibrated using various techniques, and there is no need for on-board calibration equipment. The SWIR radiometric calibration could be obtained by observation of selected ground scenes or by intercalibration with SIFTI, which uses a sun calibration system.

## 4. INSTRUMENT CHARACTERISTICS

OCAPI is composed of three sub-assemblies:

- The opto-mechanical assembly (OMA).
- The video electronic unit (VEU)
- The service electronic unit (SEU)

For the TRAQ mission, because of accommodation constraints on the spacecraft, these three sub-assemblies were split.

**Opto-mechanical assembly**
The opto-mechanical assembly (see Fig. 4) gathers in the same structure: the three objectives, the filters fitted on the two-sectors rotating wheel, the three detection units (detector, related thermal control and proximity electronics), the rotating wheel with its motor and ball bearings, and the wheel turn sensor. The main structure of the opto-mechanical assembly is designed to provide the required mechanical and thermal stability for each of these components, and also the required interfaces for the external baffles and radiators.

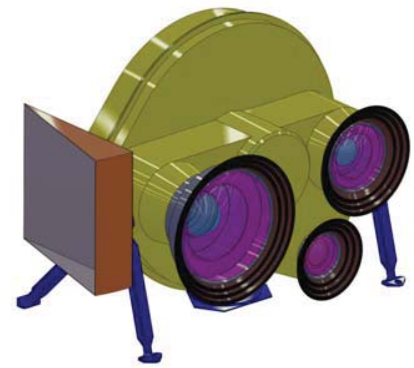

**Fig. 4** : The Opto-mechanical Assembly gathering the objectives, the filter wheel and the detection units. On the left there is the SWIR radiator and its earth shield

The three objectives are telecentric wide field-of-view lens assemblies. The first lens is made of silica in order to resist to space radiation. The second one is a sphero-parabolic lens which corrects the distortion and compensates the pupil size in the field of view. The remaining lenses focalize the image on the detector and correct the optical defaults of the objective as aberrations or chromatism.
Assuming a 22.5 µm pixel size for visible and UV channels and a 30 µm pixel size for SWIR, the focal length of the objectives are 3.93 mm for the visible objective, 1.57 mm for the UV objective and 5.25 mm for the SWIR objective. Since the optical principle is the same for each objective, the dimensions are roughly proportional to the focal, as reflected in Fig. 1. Aperture of the objectives is F/4.8, which is a good compromise with regards to radiometric resolution, diffraction effect and aberrations correction in the field. The field of view is larger than 110° along and cross track
The optical combination for the visible (see Fig. 5) is nearly the same as the Polder/Parasol one (f=3.5mm, F/4.8), and the glasses are the same. For the UV and SWIR, optical combination with the required performances (85 % min transmission,+/- 30 µm max distortion for all channels) have been found .

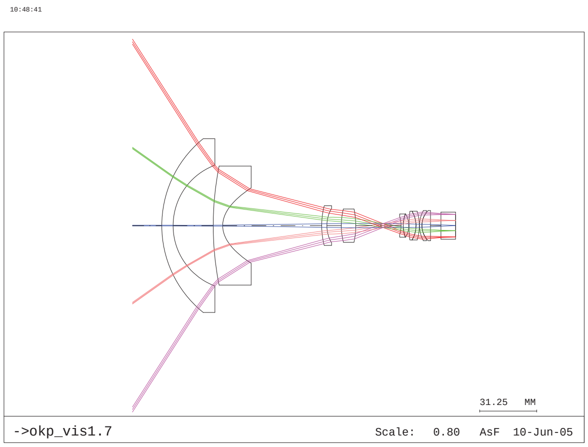


**Fig. 5** : Optical design for the visible channels set

The telecentric optics provides near-perpendicular incidence of the optical rays on the filters reducing the spectral shift in the field of view. Furthermore, the interference filters use Ion Assisted Deposit (IAD) technology as on PARASOL, in order to ensure no spectral variation between air (on-ground) and vacuum (in-flight).

For the visible range, the nominal choice is a back illuminated charged coupled device (CCD) with a minimum of 500x500 pixels detection array, a 22.5 µm pixel size and a memory zone which provide high spectral quantum efficiency, including in the UV range. So the visible and UV cameras can use the same detector. A reduced zone (200x200 pixels) of the detection array will be used in the UV camera. The ratio between integration time and transfer time from the imaging to the memory zone is kept around 50, as for Parasol to limit the smearing contribution (the pollution from the scene during the line transfer). As for Parasol, the detector thermal control around 20° C is performed with Peltier elements. Depending on the sensitivity to protons, this temperature could be lowered.

For the SWIR it is proposed to develop a 500 x 500 pixels Infrared complementary metal oxide semiconductor (IRCMOS) array with a 30µm pixel size. In order to minimize cost, risk and schedule, this device will only use existing technological bricks. As example the pixel size is 30 um in order to use validated CTIA (Capacitance TransImpedance Amplifier) injection stage. 0.5 µm CMOS process will be used for Read Out Integrated Circuit (ROIC) manufacturing. Thanks to the 15x15 mm2 sensitive area size, no butting is required. The analogue (on chip read-out chain, output stages...) and digital (serial register, row and column scanners...) peripheral blocks will only be slightly modified. In order to meet the specified signal-to-noise ratio and dynamic range, the charge handling capacity requirement is in the order of 1 million charges, which is well within the ROIC state of the art. Thanks to the CMOS reading principle, there is no smearing effect in the SWIR. From dark current evaluation and radiometric analysis it is derived that the operating temperature should be around 200 K, with a stability of 100mK during 5s (interval between two dark reference measurements).
The SWIR detector cooling is realized by conductive connection to a radiated area (0.05 m2) installed on the anti-sun face of OCAPI. In fact, due to the selected “drifting” orbit, the sun is turning around the instrument: a spacecraft yaw flip is performed every 40 days to avoid radiator sun illumination. And also a protective cover is necessary in order to avoid Earth albedo illumination.

**Video Electronic Unit**
This unit manages the interfaces with the proximity electronics of each detector and digitalizes the analogical signals on 12 bits, which is transmitted to the payload data handling and memory unit. Integration start and end signals are delivered to the detectors in synchronization with the filter wheel rotation using the information delivered by the wheel turn sensor. This unit needs to be fixed closed to the opto-mechanical assembly to avoid signal alteration.

**Service Electronic Unit**
The Service Electronic Unit includes power converters, filter wheel mechanism electronic, overall and detector thermal control electronic. It could be placed far away from the two others modules.

## 5. INSTRUMENT BUDGETS

**Signal to noise ratio**
The requirement is a signal to noise ratio of 200 for each channel when the instrument receives the radiance corresponding to a ground reflectance of 10% and the Sun at the zenith. Accounting for the mission parameters, the characteristics of the detectors and the optics, and the required signal to noise ratio, the minimum integration time for the most critical visible channel has been evaluated to 5ms. This is well below the available integration time, as derived from the filter wheel geometry and velocity. In fact the integration is selected to minimize the smearing effect, typically 150 ms. In order to avoid saturation when looking to the maximum specified radiance, neutral optical densities are mounted on top of each filter/polarizer assembly.
For the UV channels, the required integration time to meet signal to noise requirement is about 90 ms, which stays acceptable with regards to the filter wheel characteristics. And for the SWIR the required integration time is about 15 ms. Due to the CMOS

reading process which avoids smearing effects, it will be not necessary to increased the integration time for the SWIR.

**Mass, power, volume and data rate budget**

- The OCAPI's total mass is evaluated at 30.2Kg including 20% contingency.
- The power consumption is 32W.
- The external dimensions of the three sub-assemblies are the followings : opto-mechanical assembly (OMA). 400x520x360 mm3, video electronic unit (VEU) 230x180x310 mm3, service electronic unit (SEU) 230x180x155 mm3.
- The data rate is computed with the image sequence presented in the OCAPI concept description (Fig. 3). It includes the instrument housekeeping data required by the image processing (15 % of the useful data rate). The mean data rate in imaging mode is 3.5 Mbps.

## 6. CONCLUSION

A compact instrument dedicated to aerosols study with enhanced capabilities comparing to POLDER/ PARASOL has been designed. The OCAPI's budgets and characteristics are well consistent with the requirements and allocations.
The overall OCAPI design takes experience of the previous POLDER and PARASOL development. The only identified new development concerns the SWIR detector array, for which risk is minimized by using existing and validated technological bricks.