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Space Volcano Observatory (SVO) : A metric resolution system on-board a micro / mini - satellite

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ABSTRACT

1500 volcanoes on the Earth are potentially active, one third of them have been active during this century and about 70 are presently erupting. At the beginning of the third millenium, 10% of the world population will be living in areas directly threatened by volcanoes, without considering the effects of eruptions on climate or air-trafic for example. The understanding of volcanic eruptions, a major challenge in geoscience, demands continuous monitoring of active volcanoes.

The only way to provide global, continuous, real time and all-weather information on volcanoes is to set up a Space Volcano Observatory closely connected to the ground observatories. Spaceborne observations are mandatory and implement the ground ones as well as airborne ones that can be implemented on a limited set of volcanoes.

SVO goal is to monitor both the deformations and the changes in thermal radiance at optical wavelengths from high temperature surfaces of the active volcanic zones. For that, we propose to map at high resolution (1 to 1,5 m pixel size) the topography (stereoscopic observation) and the thermal anomalies (pixel-integrated temperatures above 450°C) of active volcanic areas in a size of 6 x 6 km to 12 x 12 km, large enough for monitoring most of the target features. A return time of 1 to 3 days will allow to get a monitoring useful for hazard mitigation.

The paper will present the concept of the optical payload, compatible with a micro/mini satellite (mass in the range 100 – 400 kg), budget for the use of Proteus platform in the case of minisatellite approach will be given and also in the case of CNES microsat platform family.

This kind of design could be used for other applications like high resolution imagery on a limited zone for military purpose, GIS, evolution cadaster …

1. INTRODUCTION

The European Space Agency (ESA) issued the 13th July 1998 the call from the Earth Explorer Opportunity Mission (EEOM).

The Space Volcano Observatory (SVO) proposal, submitted to ESA the 1st December 1998, has been prepared by the Institut de Physique du Globe de Paris (IPGP) and the Institut Géographique National (IGN) with the help of Alcatel Space.

The EEOM initiative is associated with the 2 boundary conditions:

- the total cost for the full realisation of any selected mission must not exceed an absolute financial ceiling of 80 Meuros (1998 prices), including satellite, launcher, ground segment

- it must be feasible to launch any selected mission by the Year 2002.

After the presentation of SVO proposal based on the Proteus platform for mini-satellite, impact on the use of CNES microsat platform will be analysed.

2. SCIENTIFIC JUSTIFICATION

1500 volcanoes on the Earth are potentially active, 500 of them have been active during this century and about 70 are presently erupting. At the beginning of the third millennium, ten percent of the world population will be living in areas directly threatened by volcanoes (see Table 1), without considering the effects of eruptions on climate or air-traffic for example. About 30.000 people have died from volcanic eruptions in the pass 50 years, and billions of Euros of damage has been incurred. Significant advances in eruption prediction and forecasting have been made in recent years, party as the result of studies of the major volcanic eruption at Mount St. Helens (USA) in 1980, Nevado del Ruiz (Colombia) in 1985, Pinatubo (Philippines) in 1991 and Unzen (Japan) in 1991. Over the same period significant progresses have been achieved in understanding of how volcanoes work, especially on a few volcanoes where a particular effort has been made (Decade volcano program) following the recommendations of the IAVCEI. This is the case for Etna, Vesuvius, Vulano (Italy), Santorini (Greece), Teide (Spain), Furnas (Portugal), Sakurajima (Japan), Merapi (Indonesia), Popocatepetl (Mexico), but many other volcanoes are not sufficiently monitored and a catastrophe like that of Nevado del Ruiz could occur again, especially in the Andes. The understanding of volcanic eruptions, a major challenge for the geoscience community, demands continuous monitoring of active volcanoes. With the growth in world population – especially around volcanoes – and the increasing cost and sophistication of the engineering structures and technical installations, there is an increasing need to forecast catastrophic events and to mitigate their damaging effects. Presently, in spite of the efforts of many countries, only a few volcanoes are monitored by modern observatories. Even in the best equipped of them, real time data acquisition on the very active parts of the edifices during crisis in still a very difficult and risky task. The only way to provide global, continuous, real time and all weather information on volcanoes is to set up a Space Volcano Observatory (SVO) closely connected to the ground ones. Spaceborne observations are mandatory and complement ground measurements as well as airborne measurements by airplanes, helicopters, drones, or balloons. While satellite observations can provide temporally continuous high resolution imagery, airborne measurements (that have become very effective in the last years) provide very high spatial resolution at specific points in time, and ground based methods typically provide high precision measurements at specific locations, limited by logistics and accessibility. The SVO project is designed to largely improve the understanding of the volcanic activity and to provide significant advances for the mitigation of volcanic hazards. Among the different geophysical parameters used for understanding and forecasting the evolution of an active, the deformations and the thermal changes are of primary interest. These parameters can be highly dynamic before and during paroxysms. The SVO team proposes the realisation of a satellite capable of measuring with a high resolution and a frequent sampling rate the topographic and thermal changes of the most central parts of the volcanoes.

The limited factor for Earth remote sensing in visible wavelength is the cloud cover. The SVO team used the data base of the International Satellite Climatology Project (ISCCP) to determine the percentage of visibility on the volcanoes listed in Table 1, and analysed a time series of 8 years of daily data (1986 to 1993). The percentage of visibility depends on the location of the volcano on the Earth and on its elevation. The highest volcanoes are visible more often in average. The long term percentage varies from 33 % to 70 % of visibility. This value is expected to be significant on all volcanoes located in continental areas or with high elevation, whereas it may be somewhat overestimated for volcanoes of low elevation with oceanic climate conditions. This because the grid size of the ISCCP catalog (0.5°) may include data over sea generally less cloudy. Volcanic plumes make sometimes the observation more difficult, but largely depends on the type of activity of each particular volcano and can also be considered as useful parameter for the SVO mission. The global average of visibility for a panel of the 47 most dangerous volcanoes is 55 %. On some volcanoes, additional data confirm the validity of our result. For example, on Piton de la Fournaise, five years of continuous range measurements over the summit crater using an automated Electronic Distance Meter (EDM) with distances ranging between 1600 m and 3200 m indicates 55 % of visibility (65 % from the ISCCP data). The analysis of more local and more frequent data available for a 4 months period (01/12/92 – 28/02/93) on three Philippine volcanoes located in a relatively cloudy area with respect to the global average (Mayon, Pinatubo, Taal) indicate that the clouds are less frequent in the morning than in the afternoon. Our analysis need to be refined, but it seems that the more favorable time window for day time observations will be between 10:00 and 12:00 local time. This constraint will be used for the definition of satellite phasing. In consequence, the night time passes would occur between 22:00 and 24:00 local time. Although the band of the planned CCD camera is limited to 0.4 µm – 1 µm, and thus also covers the near IR, it has to be noted that the cloud cover are significantly more transparent in the range 0.8 µm – 1 µm than in the pure visible band. This will enhance the capability of night observation in case of thin cloud cover or thin volcano plume.

3. SCIENTIFIC OBJECTIVES

Scientific objectives are detailed in reference document [3]. SVO will give information on :

a. Volcano monitoring (the most important)

- Our goal is to monitor both the morphological change and changes in the pattern of thermal radiance of active volcanic zones (area where the magma reaches the surfaces : lava lakes, lava domes, lava flows, eruptive vents).

b. Landslide monitoring

- Hundred of active landslides exist around the world, several of them presenting a direct or indirect risk for inhabited areas and infrastructures.

c. Mudflows

- In volcanic area, the risk of landslides of mud flows is higher because the terrain made by recent volcanic deposits is generally not consolidated, in 1995Nevado del Ruiz killed 20 000 people.

d. Faults mapping and earthquakes study

- SVO could obtain detailed images of fault traces, area stuck by a large earthquake, and also for guiding emergency and rescue operations as well as post-seismic scientific studies.

4. THE SVO CONCEPT

So, an ideal space monitoring system for volcanoes would include sensors allowing in continuous and real time:

a. High resolution monitoring of topographic changes (lava dome growth, determination of volume of eruptive products like lava flows, pyroclastic deposits, lahar deposits, volcanic landslides, plinian and strombolian deposits, …). A resolution around 1 m would be ideal for greatly increase the knowledge in this field.

b. High resolution monitoring of ground deformations due to the magma movement beneath the Earth surface in the plumbing systems of the volcanoes (e.g. due to the pressure and/or volume variations in magmatic chambers or reservoirs, dike emplacements, etc.). Vertical resolution in the order of 1 cm, relevant to a pixel in the order of 1 m^2, is enough for several applications and it would fruitfully integrate ground measurements nowadays carried out with geodetic techniques (e.g. GPS, leveling, EDM). However, sometimes very large deformations (in the order of several ten of centimeters) occur on volcanoes, for instance, close to the magma injected fractures or near to very active faults. Those very large deformation also often correspond to the most violent events.

c. Thermal monitoring (1 m resolution mapping and monitoring of the magmatic bodies, 5 m resolution mapping and monitoring of the geothermal areas on volcanoes, 30 m resolution mapping and monitoring of the low energy thermal anomalies, temperature profiles above the volcano and in the volcanic plumes, …).

d. Gas release analysis and monitoring (H_2O, CO_2, SO_2, …).

e. Particle release analysis and monitoring.

Some of the above tasks are already partly covered with existing satellites, but others (the first task for example) are missing from the present space possibilities.

In the framework of this proposal to ESA, the SVO team had proposed to develop a new satellite dedicated the high resolution imagery of the most active areas of volcanoes (craters, lava flows and lava lakes, lava domes). The system will monitor the subtle changes of the volcano shape through a simple comparison of DEM realised at each passage ; it is expected to greatly enhance the observations capabilities corresponding to the first three elements listed above. The high resolution topographic mapping (first task) will authorise a step forward both in volcano monitoring and in volcanological science, and it is our first priority. The second and third tasks (deformation monitoring, thermal monitoring) are already partly covered by other satellite techniques but not at the proposed high resolution. Improvement in the mapping of anomalies is thus expected. The proposed system will monitor thermal changes of high temperature areas (in night time). The ground resolution will be 1.5 m, the dynamic range 12 bits (11 useful bits), and the footprint for one single image 6 km x 6 km.

The system proposed here has a 3 days repeat time only (at equator, at higher latitudes the repeat time will be 2 or 1 day) its characteristics are unique and would already constitute a significant step forward in high resolution volcano monitoring from space, its mission duration is 2/3 years.

None of the presently existing or planned satellite system meet those requirements that are mandatory for an effective monitoring of small, hot and highly dynamic sources of the volcano phenomena.

Despite their limitations, these systems have proved to be useful for the air traffic alert during eruptions (in the case of meteorological satellites), for the detection and mapping of thermal anomalies (LANDSAT TM, ATSR, SPOT 4), for the detection of the volcanoes and to the high dynamic character of volcanic activity, these systems can rarely be used as an operational contributor to effective volcano monitoring that requires a daily updating of the information.

The goals of SVO are not compatible with commercial satellite imagery for several reasons: repeatability largely depending on the other requests and probably larger than a few days, no real time data download, cost. In addition, these satellite do not have the capability of single pass stereo imagery, and one stereo couple would imply data acquisitions separated by several days, thus less or no coherence on deforming areas : this would also greatly reduce the interest for volcano monitoring. In the development of the SVO mission particular attention will be given to the ground segment that is a fundamental elements when quick delivery of validated information is requested.

5. MISSION OVERVIEW

The SVO mission is intended primarily for near continuous monitoring of deformation and the thermal changes in the most active areas on volcanoes (lava domes, lava lakes, active craters, eruptive vents, lava flows). These areas are generally not accessible to ground based techniques. To avoid competing science, only the instruments necessary for the volcano monitoring purpose will be implemented on the satellite. The satellite has to be on a helio-synchronous circular orbit of 685 km altitude which has to be determined with precision in respect of an optimal access criterion to targeted areas. There is no dependence to other missions, but the SVO mission will be complementary to the future SAR interferometry missions. It will have links with several programs of meteorological observation from LEO and GEO orbit on the Earth that are already used for the large scale observation of volcanoes. The SVO mission will also have some links with the Volcano Ash Advisory Program (VAAP) that is a structure supported by the International Civil Aviation Organisation (ICAO) for the monitoring of volcanic ash plumes and aircraft safety. Nine Volcano Ash Advisory Centers (VAAC) are already operational: Toulouse (France), Buenos Aires (Argentina), Darwin (Australia), London (UK), Montreal (Canada), Tokyo (Japan), Anchorage (USA), Washington (USA), Wellington (NZ).

The use of one satellite is not optimal for hazard mitigation, but will be enough in many cases. For scientific purpose, one satellite observing two/three years will bring a unique set of data at high spatial resolution, high temporal sampling rate on the volcanoes. One very valuable aspect will be the global character of the mission that will provide topographic data on many volcanoes, a very important data set for the subsequent missions. The proposed width of the area to be observed is 6 km x 6 km. Such an area corresponds in general to the active and most dangerous part of the volcanoes has often an extension of a few hundred of meters to a few kilometers. Even if the effects of the eruptions create a risk at much larger distances, this is the area where most of the precursory phenomena occur and this is the area more difficult and risky to monitor with ground based methods. Image capture will be done without long storage on board and will be based on the direct reception of images by ground stations located where the need is real (volcanological observatories may hosts data receiving stations). This strategy permits to minimise the delay for accessing the data, that is fundamental for a system dedicated to risk mitigation. It will also allow to lower the weight and cost of the satellite. Finally, it will also enhance the scientific collaboration between European and non EC researchers. The cost of some direct reception stations may be supported by bilateral or multilateral scientific agreements. This mission will contribute to the advancement of European Earth Observation capabilities.

The scientific objectives implicate the following tasks:

a. To be able to capture, in the day time part of the satellite track, a maximum stereo set of 3 images of volcano summits, to build accurate, reliable and very frequent DEMs of volcanoes in activity (aim: daily or a maximum of two to three days coverage).

b. To be able to capture, in the night time part of the satellite track, a monocular view of an active volcano to map (essentially in close infrared wavelengths) hot surfaces whose pixel integrated black body temperature exceeds about 450° C, and thus lava flows and active terminal domes on volcanoes, this with an analysis sharpness of about 4.5 meters at nadir. No temperature measurement will be possible because the targets are expected to be thermally heterogeneous even within a single pixel, and with only a single, panchromatic, band it will not be possible to determine the size of sub-pixel radiant surface. The aim is only to detect and to map hot areas and their evolutions.

c. To be able to carry out relative localisation of night and day images, with an accuracy of about 5 meters (by use of projectors installed in the field, or by the use of natural lights that could be geo-referenced in urban or inhabited areas).

d. To be able to ensure the following observational tasks:

- daily coverage of 30 targets (volcanoes with the highest level of risk)
- weekly coverage of 40 other targets (other volcanoes with on-going eruption of in a presumed unrest phase)
- annual coverage of the 500 volcanoes known as active in recent history.

6. OBSERVATION GEOMETRY

The observations will be performed in along track stereoscopy, with a lateral aiming capability of 40°. The images will be acquired by sets of three: one at the closest point of the spot, one before and one after, separated from 10° - 15° from the direction of the first image. Large stereo angle will require more time for stereo data acquisition along the track, thus less time for data downloading to the receiving station and less observable targets on one pass. If stereo angle larger than 15° are necessary, they will be obtained by using different passes on the same track. The acquired area will be 6 km x 6 km at the nadir, with one large spectral band (0.4 µm to 1 µm) only. One satellite alone will allow for the observation in the worst case of one given spot every 3 days, in stereoscopy and in near-IR night acquisition as well. Every 15 days a scene will be accessible with the optical axis closer than 10° from the nadir, providing the best quality possible of the DEM. In each orbit, considering the dead times requested for aiming the platform, a maximum number of three spots will be acquired on day time, and the same for night time as well. The following numbers characterise the acquisition time and the minimal geometrical separation of two consecutive targets to be observed during a given pass:

- duration of one stereo scene acquisition (with images taken at ± 15° angles), according to the speed of mirror rotation and satellite velocity: 43 s

minimum distance between two targets when stereo scenes are acquired: 250 km.

- A daily survey of several volcanoes located close one to the others is not compatible with the stereo imagery

- when stereo imagery is not mandatory, a group of close volcanoes can be monitored on a daily basis, the capability decreasing from the case of ~ N/S orientation to the case of ~ E/W orientation.

The geometric calibration will be performed in flight and without special equipment, as a result of the automatic correlation of several sets of 3 images in good geometric configuration (areas close to the nadir of the satellite, chosen in mountainous areas of Europe). Radiometric calibration will be performed on homogeneous places, from time to time, in order to check the sensitivity evolution of the CCD pixels.

7. THE SVO SATELLITE

In view, to reduce cost and to give confidence on schedule, the SVO satellite is based on existing technologies:

- French PROTEUS platform, develop by CNES and ALCATEL in partnership

- CCD area array detector use on the Camera Numerique of IGN

- telescope in Carbon/Carbon material and Zerodur mirrors developed in the frame of an ESA development contract

- depointing mechanisms identical to SPOT/HRV camera.

7.1. Proteus platform

The first use of this platform is the NASA – CNES JASON 1 satellite with a launch in 2001.

This platform allow the use of a payload in the range 300 kg – 250 W.

The platform AOCS gives the needed ± 40° across track depointing, and for the 3 views stereo observation of a target, the platform will be in inertial pointing with no actuation of Solar Array during this sequence.

On the upper face of the platform, the payload is fixed and includes:
- the instrument associated with a signal processing box (buffers and image compression around 1/1.5 typically)

- a L-Band telemetry (3 Mbits/s) working only with the local reception stations (direct visibility).

The platform have enough power autonomy for acquisition and transmission to the local ground station of one image in the shadow zone.

Figure 1 presents the SVO satellite.

7.2. SVO instrument

The instrument includes:

- a flat depointing mirror
- a telescope
- a focal plane assembly with a CCD matrix
- a video chain.

The depointing mirror uses a mechanism simular to the HRV instrument (which gives a depointing of 27° in less than 10 seconds) and allows the along track depointing for stereo observations.

The camera is built around a 4096 x 4096 Kodak CCD matrix (KAF-16800), with pixel size 9 µm x 9µm. The maximum electron capacity per pixel is 80 000 and the noise current is 20 electrons/pixel/second at a temperature of 20° (very low). The environmental conditions around volcanoes are such that it is advisable, even if not fully compulsory, to use matrix with an anti-blooming capability. In some sites close to the sea or with a lake, the water surface will be close enough for the Sun specular reflection to make the camera impossible to use. Such a situation will not be very frequent. Kodak company is ready to provide the matrix with an anti-blooming, which will result in a sensitivity loss, but not at a prohibitive level (around 30 %). No spectral filtering will be performed to limit the sensitivity in the IR band. The CCD matrix will be used in the TDI mode.

The relatively small size of the Kodak CCD (37 x 37 mm) would allow to use a small mechanical slitter based on the TRACE experiment. The duration of exposure will be adjusted to the number of TDI stage.

For day time observation, the spatial sampling is 1.5 m and the number of TDI stage is the range 10 – 20.

For night time observation, detection of hot lava is not compatible with 1.5 spatial sampling; a pixel agglomeration give a spatial sampling of 4.5 m and need a number of TDI stage around 100. This important value of TDI stage need good knowledge of instrument axis versus PROTEUS star sensor axis (periodic calibration campaign).

The telescope optics, in order to overcome the diffraction limits, will need to be at least 35 cm in diameter (entrance pupil). The requested focal length for 1.5 m ground pixel size is 4.1 meters, which means an aperture ratio of f/12 (for a 685 km). This corresponds to an instantaneous FOV (IFOV) of about 2.2 µrad (0.5 arcsec). Analysing various telescopes suitable of fulfilling the above requirements, the minimum achievable mass of the camera including the optics, shutter unit and the FPA with read out electronics and the interface to an (external) image data buffer (but excluding the front end scanning mirror) could amount to about 8 to 10 kg only if a compact optical and mechanical configuration is chosen. The optical design require a Ritchey-Chretien telescope with lens correctors near the focal plane.

SVO telescope require a highly stable structure, and we propose the reuse of a design which has been developed and successfully qualified through mechanical and thermal tests (see figure 2). A coefficient of thermal expansion better than 10^{-7}/C has been achieved on the quasi-isotropic C/C structure about 20° C temperature variation has been requested to observe 1 µm defocusing.

8. GROUND SEGMENT

12 to 16 receiving stations are necessary to ensure suitable coverage of the most active volcanic areas worldwide. The receiving stations will be installed in major volcanological observatories (see table below). The images and products will be added to a central database via Internet. Assuming 12 ground stations, and 37 full scenes per day, the total amount of data is about 2.2 Gbytes/day. A package of software will be provided together with the receiving stations in order to allow a real time processing of the data for DEM production. A master station will be operated in one control center in Europe. This center will be responsible for the precise orbit and ephemeris calculation and for the observation schedule. This center will be linked to a control center in charge of the data uplink for satellite maintenance and programmation.

The visibility zone, with a limit elevation angle of 20° and an altitude of 685 km for the satellite, has a radius around 1470 km. In the case of Indonesia for example, it means that a station in Yogjakarta may allow the observation of all active volcanoes of the country.

If possible, reception stations should be designed without requirement of a directive antenna so as to limit their cost.

In the reception stations will be installed a software allowing DEM computations using the stereoscopic images, an image processing software allowing to use the precise GPS orbits (downloaded from IGS web sites), the star images and the DEM of the zone so as to provide a correct superposition of day and night images in the same reference frame.

9. SVO MISSION ON-BOARD A MICRO-SATELLITE

The original 1998 SVO mission use a Proteus platform for minisatellite in view to respect stringent schedule :

- the platform will be flight proven (launch of Jason 1 in 2001)
- relaxation of mass and power budget for the payload (Proteus Platform is oversized for SVO payload).

Since the proposal, the french space agency CNES is developing a new platform for micro-satellite. The first observation mission will be Picard (permanent measurement of sun diameter), Alcatel has studied, in 1999, a carbon-carbon telescope compatible with this kind of µsatellite platform.

Architecture of such telescope (see figure 3) is very similar of SVO Telescope and give confidence on use of µsatellite :

- Telescope architecture is optimized for CNES µsat platform (size 0.6 m x 0.3 m x 0.3 m) and for cost reduction
- the detection uses area array CCD with a mechanical shutter
- the mechanical shutter is mechanically decoupled from the stable structure between the 2 mirrors telescope and the focal plane.

For the future SVO mission, instead a 4 K x 4 K CCD array, we can envisage a 8 K x 8 K CCD aray in view to have a better spatial sampling or to increase the TFOV.

For stereo mapping, we cannot use a depointing mechanism, the platform AOCS has to manage the needed set of 3 images of volcano summits.

For the number of TDI stage needed for radiometric image quality, we could envisage different solutions (choice to be done after system trade-off) :

- classical TDI at CCD level
- mechanical displacement of focal plane assembly at the same velocity than the Earth image in the focal plane
- suppression of image displacement in focal plane by use of mechanism which changes the place of an optical component
- suppression of image displacement in focal plane by a specific rotation of platform given by the AOCS.

10. CONCLUSION

SVO could be a future system for volcanoes survey.

Selection of area array CCD, like for airbone application, allow use of classic mini/micro satellite platform for metric IFOV (relaxation of AOCS specifications) and give a "low cost - low risks" solution but with a limited production in term of square km.

The SVO concept could be used for other applications like high resolution imagery on a limited zone for military purpose, GIS evolution cadaster, …

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4. Picard Telescope – Revue fin d'études phase O/A. Document ASPI-99-PSF-187 – November 3, 1999.

Tectonic Zone	Volcano	Altitude (m)	Country	Last strong event	Population within 20 km around volcano (millions)	Percentage of year without clouds *
Central America	Popocatepetl	5465	Mexico	23/09/98	> 1 (Mexico City)	56
South East Asia	Merapi	2911	Indonesia	Since 1992	> 1 (Jogyakarta)	47
South America	Guagua Pichincha	4784	Ecuador	07/10/98	> 1 (Quito)	39
Europe	Etna	3350	Italy	Since 1995	0.5 (Catania)	69
South America	Fuego	3763	Guatemala	19/11/98	0.5 (Antigua)	61
Africa	Nyamuragira	3058	Congo-K	27/10/98	0.5 (Goma)	33
Central America	Cerro Negro	675	Nicaragua	06/11/98	0.3 (Telica)	57
South East Asia	Rabaul	688	New Guinea	28/05/97	0.1 (Rabaul)	35
Indian Ocean	Fournaise (Piton)	2631	France	09/03/98	0.05	65
South East Asia	Peuet Sague	2780	Indonesia	27/04/98	0.05	27
Central America	Rincon de la Vieja	1916	Costa Rica	16/02/98	0.05	51
Central America	Arenal	1657	Costa Rica	05/05/98	0.05	48
North America	Yellowstone	2805	USA	09/01/98	0.05	40

* data source ISCCP

Table 1 – Active volcanoes and population around volcano

FIGURE 1 - SVO SATELLITE

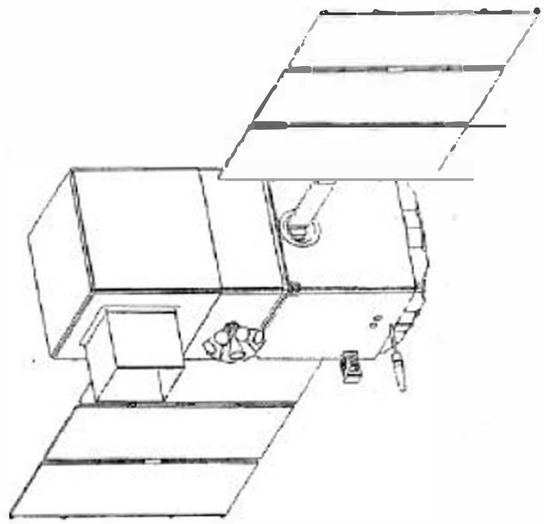
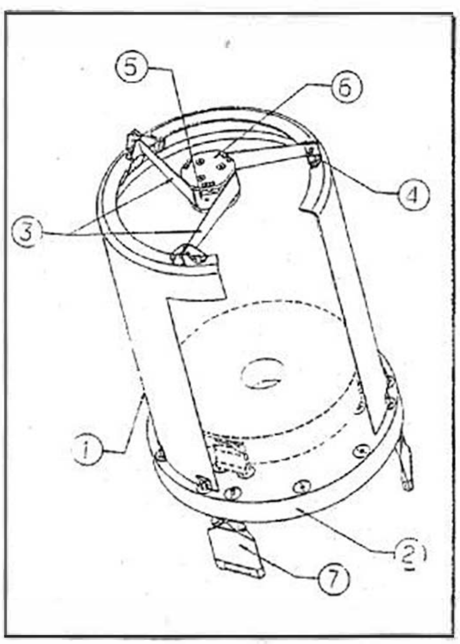
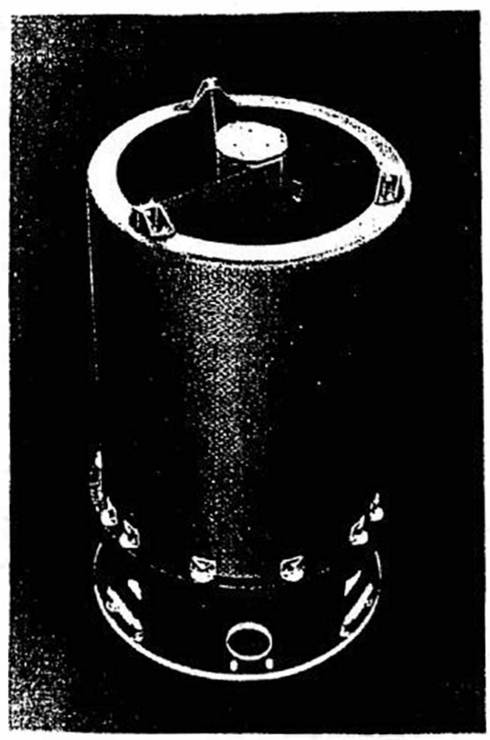


FIGURE 2 - ALCATEL BREADBOARD IN C/C DEVELOPED UNDER ESA CONTRACT
(DIAMETER 30 MM LENGTH - 500 MM)





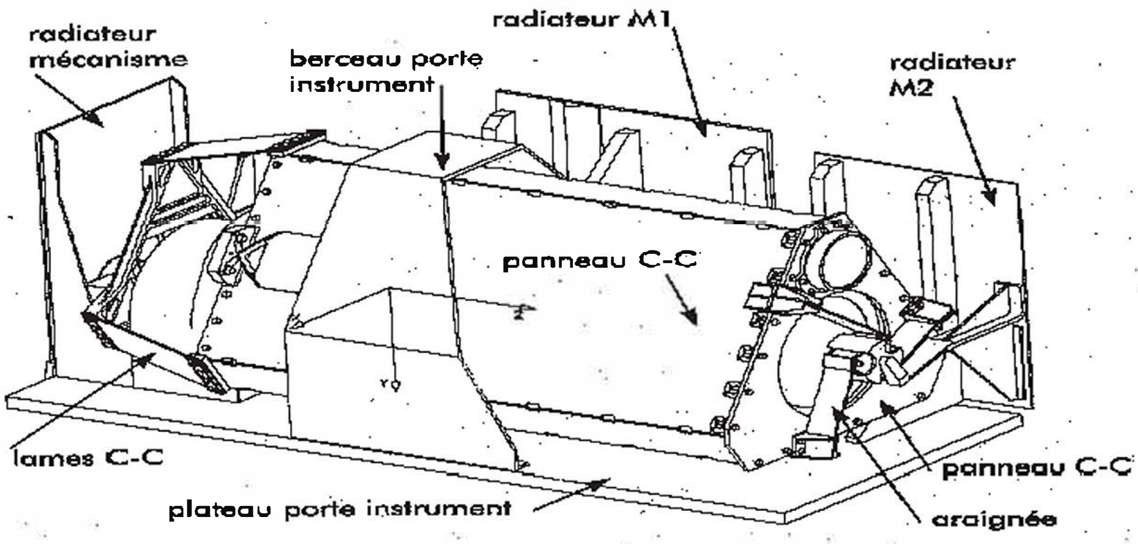


Figure 3 – The Picard Telescope (proposed by Alcatel to CNES and CNRS' Service Aeronomie)