Preliminary optical design for Plures and Rosetta

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ABSTRACT

Some, preliminary, optical design for three wide field cameras are briefly reported for the space missions Plures and Rosetta. Plures is a proposal to the European Space Agency (ESA) for a wide field telescope able to detect Supernovae explosions with a time resolution of the order of a fraction of a minute. After the Supernova detection the telescope should switch to a narrow, single–object mode in order to probe the event in a photometric and spectroscopic mode. Plures should continuosly monitor the Virgo cluster with a field of view of the order of 100 squared degrees. Rosetta is a cornerstone mission of ESA for the approaching of a cometary body, after the fly–by with two asteroids. In the approach phase Rosetta should orbit around the comet. Two cameras will map and probe the surface of the comet nucleus. For the three optics all reflective, unobstructed solutions are presented.

1. INTRODUCTION

In this paper three different optical solutions are presented, in order to fullfill the requirements for the main optics of Plures[1], a concept proposed to the European Space Agency (ESA) by CISAS in the framework of the Horizon 2000 Plus program and for the two scientific cameras for the interplanetary mission Rosetta[2] (a cornerstone of ESA). Tab.1 gives the main requirements of the three designs.

In spite of the considerable difference between size, scientific requirements and field of view of the three cameras, the same approach has been used for their optical design. Being the UV coverage a key factor an all–reflective solution is mandatory. The required field of view and optical quality prevent the use of any two mirrors Schwarzschild solution[3]. Correction of the off–axis performances via some refractive device (correcting plate, Mangin mirror, etc.) has been ruled out, at least in this preliminary phase.

Unobstructed solutions are better from the point of view of the attainable contrast, a desirable feature, especially for the Rosetta cameras. For the very wide field of view of Plures and the Wide Angle Camera of Rosetta the adoption of an unobstructed solution is, moreover, a good choice in order to avoid vignetting.

In order to keep the number of reflections to a minimum, three mirrors solutions have been explored. The adoption of off–axis sections of optical solutions with revolution simmetry having a common optical axis enables the use optics of relatively easy manufacturing.

In the following sections details about the cameras are given.

Mission	Camera	Aperture	Field of View	F/number	Quality
Rosetta	Narrow Angle Camera (NAC)	80 mm	$1.2^0 \times 1.2^0$	7	Diffraction limit
	Wide Angle Camera (WAC)	30 mm	$18^0 \times 18^0$	3	Pixel–limited[a]
Plures	Main Optics	500 mm class	$10^0 \times 10^0$	2 ... 5[b]	Few arcsec

[a] The pixel is a $12\mu m \times 12\mu m$ one.

[b] Depending on the adopted detector size.

Table 1: The first–order optical performances for the three optics discussed in the text.

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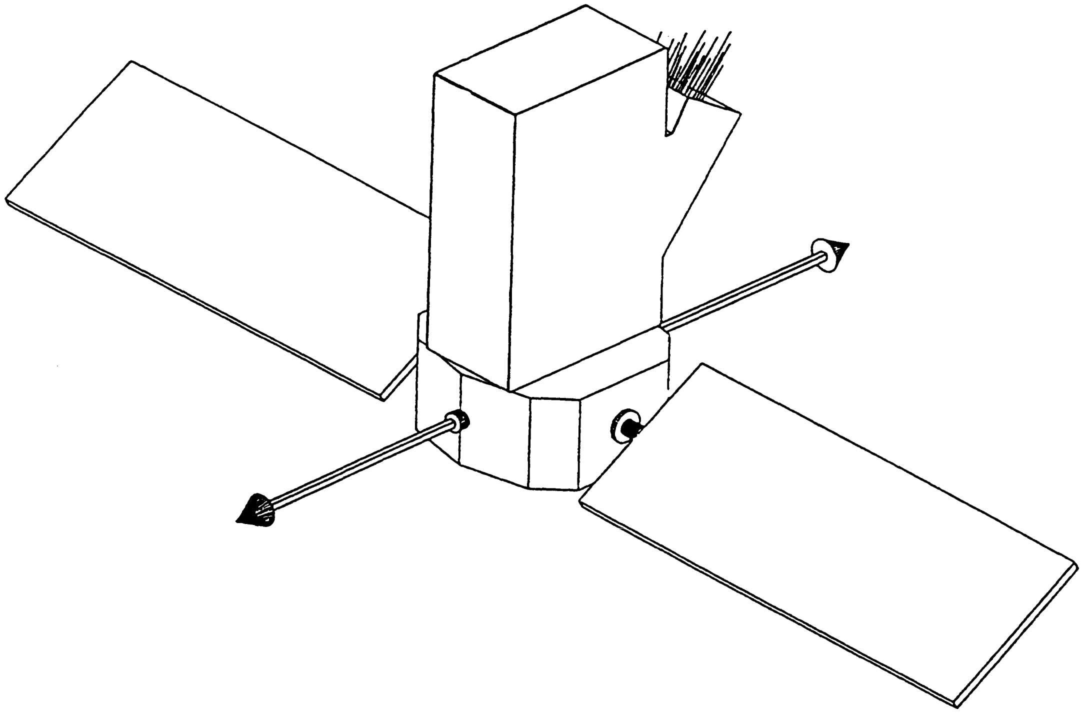

Figure 1: Plures spacecraft layout.

2. PLURES

Plures (see Fig.1) is a wide field ($10^0 \times 10^0$), UV (125–300 nm), reflective only, 500 mm class telescope, equipped with a large size detector, able to monitor the nearby cluster of galaxyes in Virgo, for the search of Supernova (SN) explosions. The optics must be able to switch rapidly to a narrow field mode in order to perform photometry and medium resolution spectroscopy on the detected events.

Plures is a double acronyms: it stays for PayLoad for Ultraviolet research on Early Supernovae and for PLUto and CeRES, two mithological names linked to the Virgo's one.

According to the most recent determinations of the frequency of SNe in external galaxies[4,5], Plures should be able to detect 2–3 SNe per year catching them shortly after the emergence of the shock wave to the photosphere. The choice of the UV band is due to the fact that most of the energy in this very early phase of a SN explosion lie in this spectrum range[6]. To date, never a SN was observed so early and much has still to be learned in relation to energy production and transport in SNe, ionization of the circumstellar material, etc. The sharp time resolution (of the order of the fraction of a minute) should also allow to check for the possible coincidence with gravitational waves experiments[7] and time delay in the neutrino detection[8]. The adoption of a photon counting detector allows for the coherent summation of the short exposures taken during the search mode. In this way images of the Virgo cluster with equivalent exposure times of the order of several months should be obtained. Another *by–product* of such a mission is given by the possibility to perform an all–sky UV survey in the 2 or 3 months around the conjunction of the Sun in the foreground of the Virgo cluster.

The optical scheme adopted for Plures (see Fig.2) is derived from a solution found in the literature[9]. In that solution a very large secondary mirror and a refractive correcting plate close to the detector have been removed through a careful optimization process. In the referenced optical scheme, in fact, the secondary mirror has been placed very close to the foci of the primary mirror. A slight power in the small secondary mirror will translates into a very large tertiary one. In our deisgn, however, the secondary mirror is placed far enough from the foci of the primary mirror to allow for the positioning of the pupil input on it (in the referenced design the pupil input was placed by a diaphgram before the primary mirror). In this way the relative size of the tertiary mirror can be conveniently relaxed.

It is interesting to note that the center of the field of view covered by the detector is not aligned with the optical

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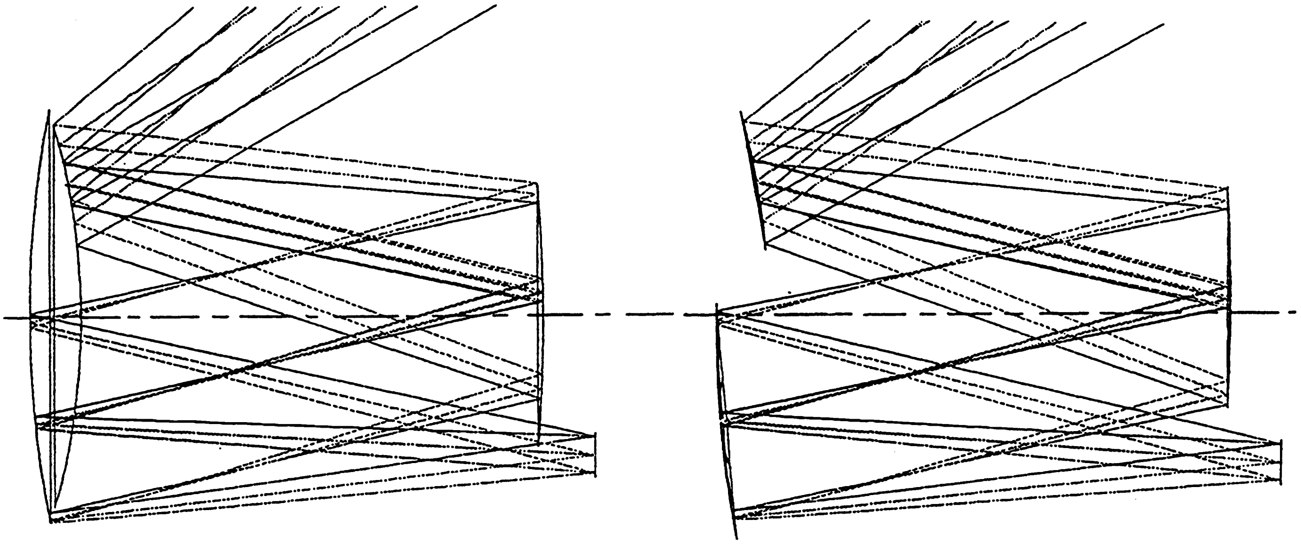

Figure 2: *Left*: the optical layout of Plures showing the three optical surfaces around the common axis; *Right*: the same optical design with the off-axis mirrors cutted out; note the pupil input located at the secondary mirror.

axis of the telescope. In fact this design is derived by a common axis of revolution telescope with an obstruction larger than the unity. For this reason only off-axis rays can be effective.

It is interesting to point out that scanty literature can be found on this class of solutions, probably due to this reason. Such useless telescopes (if used at full aperture) become however very interesting using off-axis section. The performances of this solution are reported in the left of Fig.3. In the filter wheel a section of an hyperbolical surface is alway able to conjugate a point on the focal plane with the entrance of a photometer and/or a small spectrograph. The blurring of the image is usually amplified by this operation, but optimizing the position and the conical costant of this relay mirror, it is possible to give performances very close to the diffraction ones. It is recalled that in the photometric and spectroscopic mode the target is an unresolved object and no field of view other than that required for the acquisition is necessary.

A mechanical arrangement of the optics inside the spacecraft is shown in the right panel of Fig.3

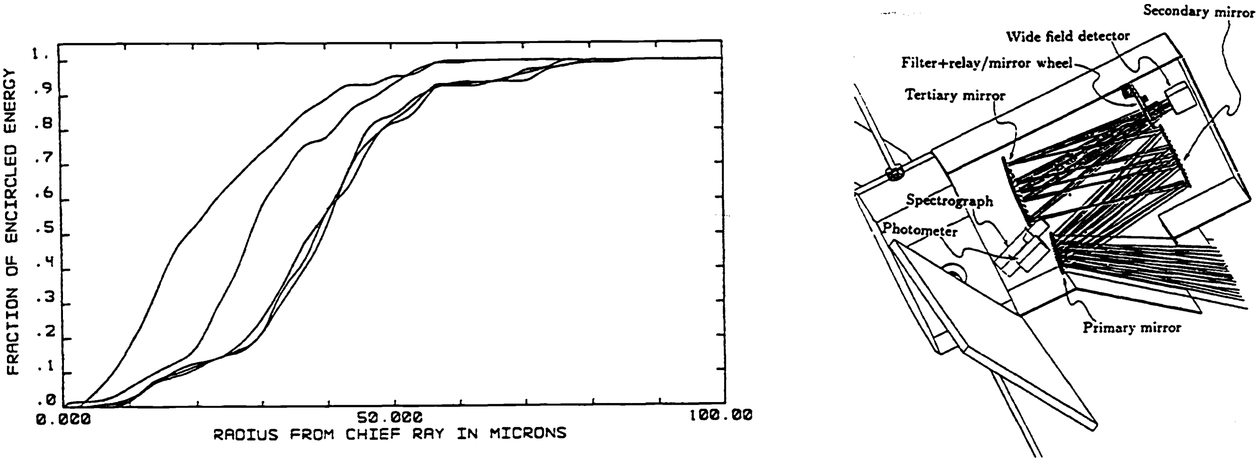

Figure 3: *Left*: the Geometric Encircled Energy plotted for various points on the Field of View; *Right*: A sketch of the internal mechanical arrangement for Plures; note the relay mirror on the filter wheel. During the Supernova probing, this mirror is placed in the optical path and the beam is refocussed to the photometer and the spectrograph, usually in *stand-by* mode.

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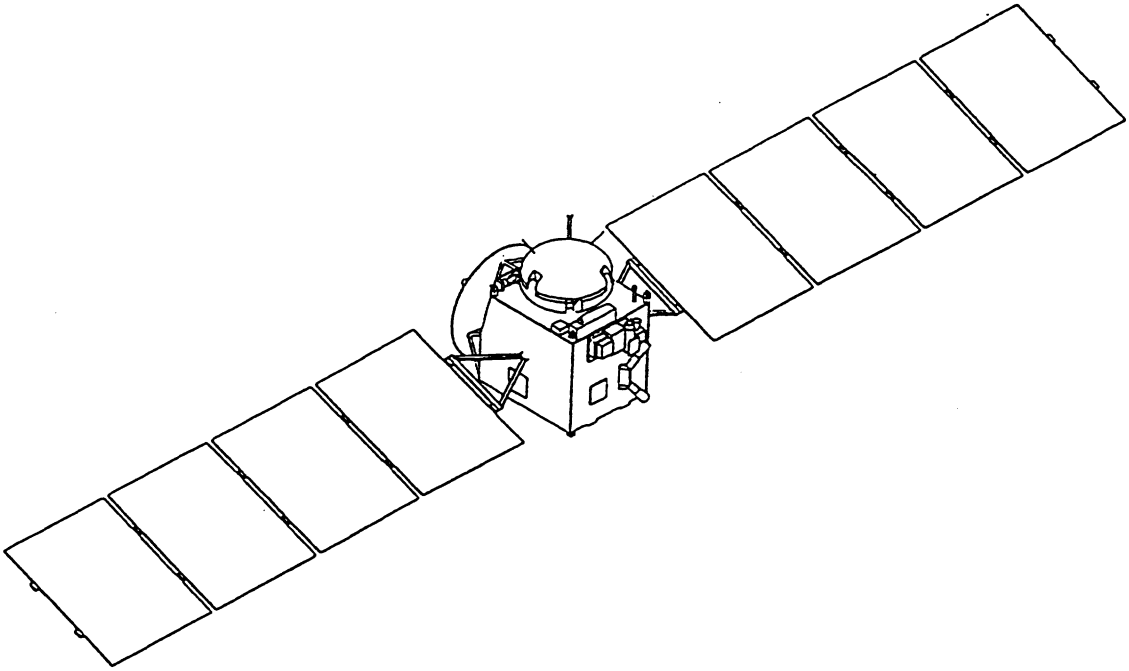

Figure 4: The Rosetta spacecraft layout, as reported in Ref.2.

3. ROSETTA

Rosetta (see Fig.4) is a cornerstone mission of ESA for the extended study of a cometary body. After an interplanetary flight, gravitationally assisted by one or more *swing-by* where two *fly-by* with asteroids are planned, it will reach a comet with a very low relative velocity. In this way it will be possible to navigate around the comet nucleus with the closest distance as small as a few Km. A careful mapping of the cometary body will allow, apart the exceptional scientific value of such observations, to establish a feasible site to launch at least one surface package that should land on the comet and perform *in-situ* analysis.

The mapping and the observation of interesting features is a task demanded to two cameras. The first one is the Narrow Angle Camera (NAC) that should allow a resolution of some cm on the comet surface, and a Wide Angle Camera (WAC) that should monitor most of the surface of the comet for the detection of transient phenomena like jets.

3.1 Narrow Angle Camera (NAC)

The optical scheme of the NAC (see Fig.5) was derived from an off-axis portion of a very fast wide field optical solution found in the literature[10]. In the original solution the first and tertiary mirror have to be made on the same spherical substrate. Adopting an off-axis section of this solution the mechanical advantages deriving from the choice of the same substrate are lost and a *true* three mirrors solution has been optimized.

Alternative solutions taken into account were the adoption of an off-axis portion of an all-reflective Schmidt or Baker-Schmidt optics[11,12] but the obtained performances do not look good enough. The adoption *in-toto* of such a class of solutions is feasible but at the expenses of a (noticeable) central obstruction and, in our study, it has been ruled out.

The main drawback of this solution, which gives very good performances (see the left panel of Fig.6), is the very large asphericity of the three surfaces involved. Fitting them with a sphere, the departure reaches for the primary mirror almost $100\mu m$. Even if the feasibility of such mirrors is not out of reality and their relatively small size should

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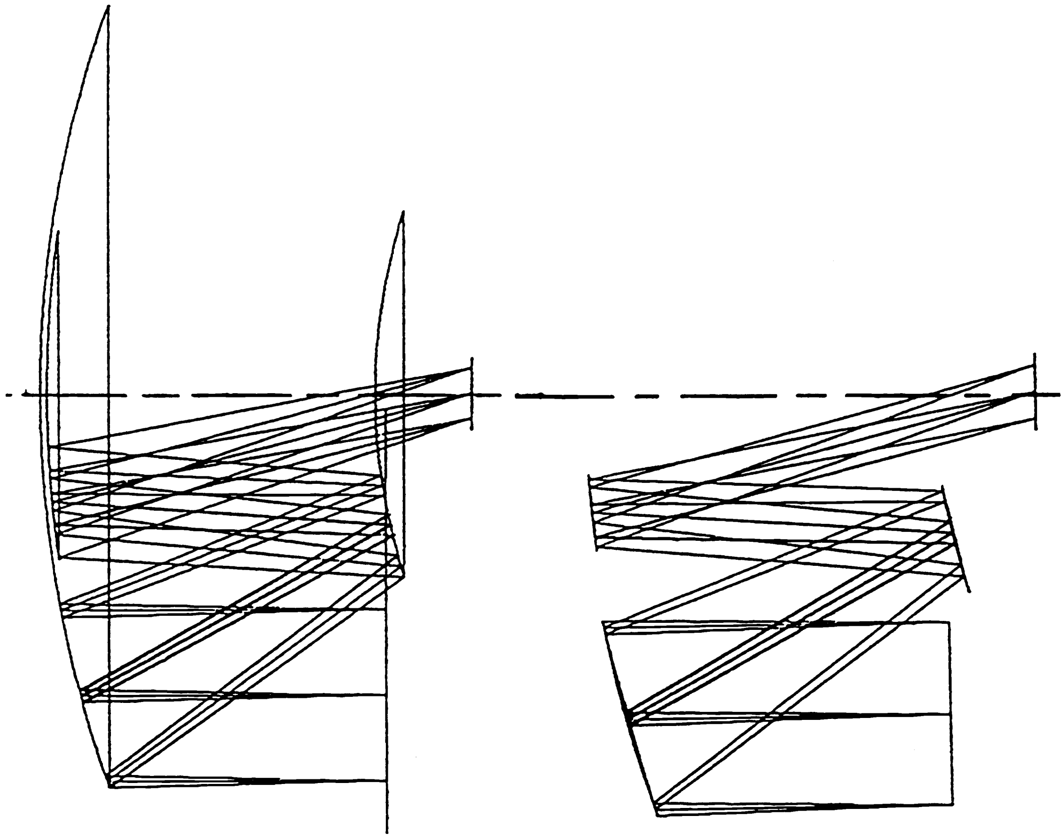

Figure 5: *Left*: the optical layout of the NAC showing the three optical surfaces around the common axis; *Right*: the same optical design with the off–axis mirrors cutted out.

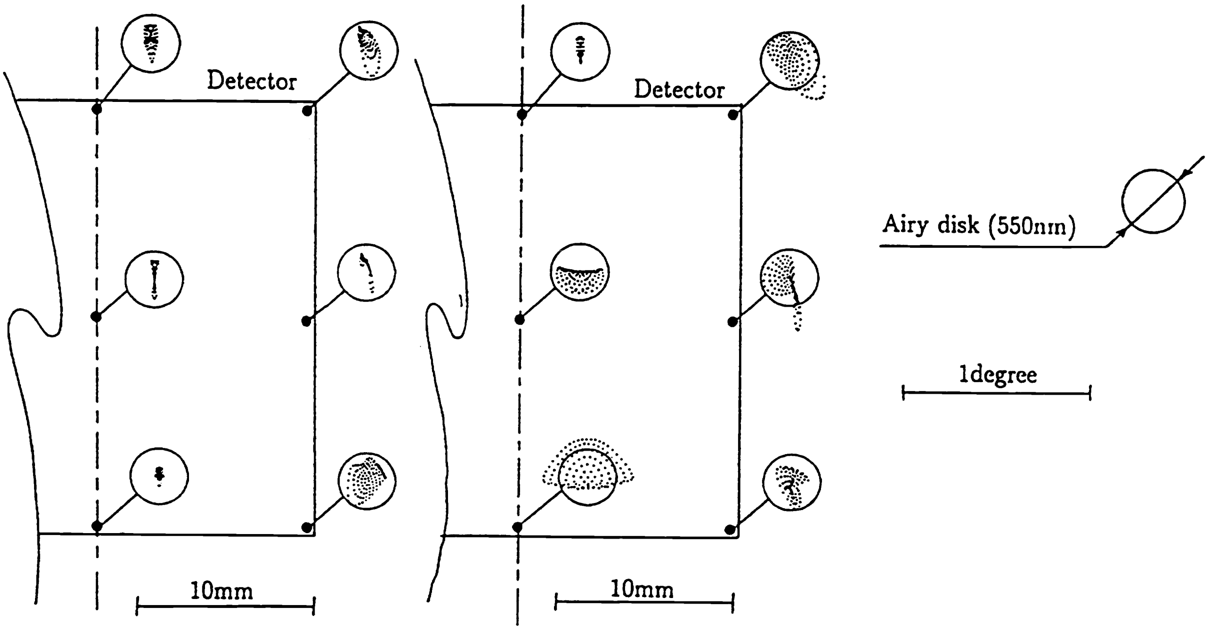

Figure 6: Optical performances for *Left*: a NAC version with all the three mirrors adopting aspheric surfaces up to the 10^{th} term, and *Right*: adopting a slightly hyperbolical tertiary, a slightly aspheric secondary (up to the 6^{th} term) and a full aspheric primary mirror.

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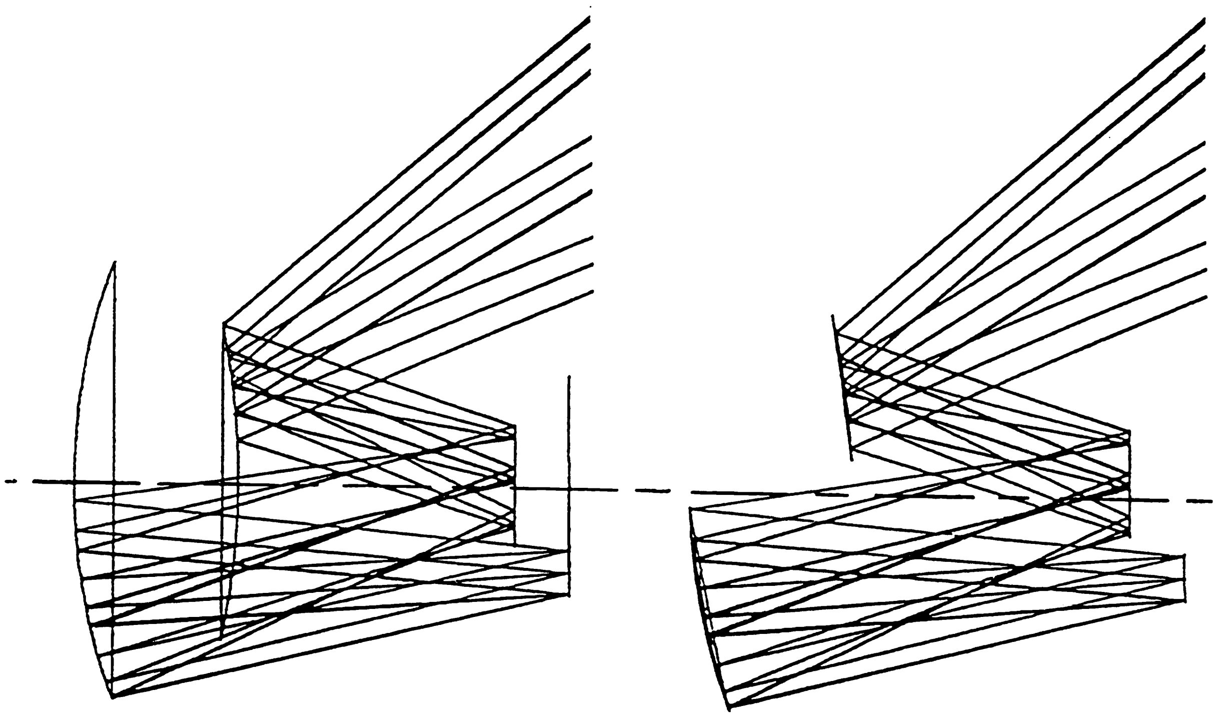

Figure 7: *Left*: the optical layout of the WAC showing the three optical surfaces around the common axis; *Right*: the same optical design with the off–axis mirrors cutted out; note the location of the pupil input at the secondary mirror and, like for the Plures design, the impossibility for this optical design to observe around the optical axes

allow efficiently recent polishing techniques (like ion–etching), further work has been performed in order to relax the mirror surfaces, at least for some elements. A solution, marginally worse than the diffraction limit for some edge of the detector (see the right panel of Fig.6) has been found. For this optical design, a slightly hyperbolical surface and a slightly aspheric surface have to be used. Asphericity of the primary mirror has been also reduced, even if it remains in the range of several tens of μm.

3.2 Wide Angle Camera (WAC)

The WAC for Rosetta has the largest field of view of the optical design reported in this paper. In spite of this fact, and thanks to the very small entrance aperture (30 mm), it is possible to adopt some optical solutions with mirrors larger than the entrance one. This approach was followed also for the UltraViolet Imager for the ISTP mission[13]: in that case, however, they adopt an external input pupil and aspheric surfaces, like for the Plures and NAC solutions already shown. We have found (see Fig.7) an excellent optical solution adopting only conical surfaces.

The secondary mirror is a highly hyperbolical surface, while the other two optics are off–axis sections of conics. Using a $12\mu m \times 12\mu m$ CCD, 80% of the Geometric Encircled Energy can be obtained in the pixel (see left panel of Fig.8) for any point of the detector with the marginal exception of a corner.

A much better solution can be found slightly asphericizing the primary mirror giving pixel–limited optical performances over the whole detector.

3. CONCLUSIONS

Three all–reflective, unobstructed optical solutions ranging from a few squared degrees to nearly 400 square degrees are briefly reported along with a discussion about how the solutions have been obtained. Further study, especially misalignment tolerances and baffling for rejection of stray–light in the space environment is on the way.

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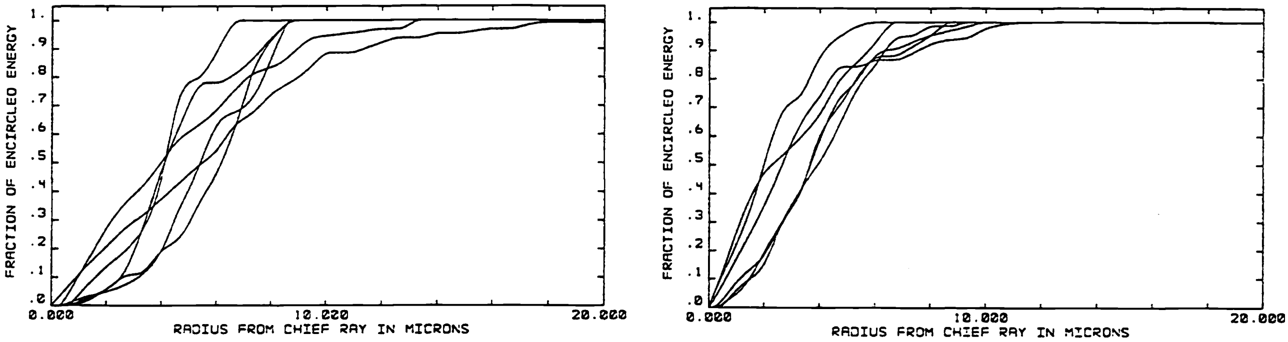

Figure 8: Geometric Encircled Energy for two versions of the WAC, *Left*: a solution with pure conical surfaces and *Right*: with an asphericized primary mirror.

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