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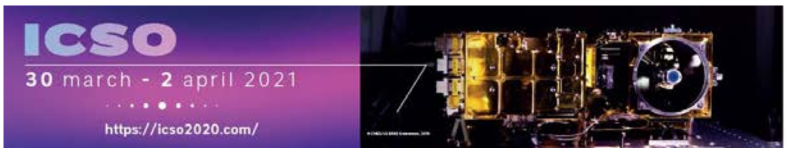

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The Fisheye of the Comet Interceptor's EnVisS Camera

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ABSTRACT

Entire Visible Sky (EnVisS) camera is one of the payload proposed for the ESA selected F-Class mission Comet Interceptor. The main aim of the mission is the study of a dynamic new comet, or an interstellar object, entering the inner solar system for the first time. The Comet Interceptor mission is conceived to be composed of three spacecraft: a parent spacecraft A and two, spacecraft B1 and B2, dedicated to a close and risky fly-by. EnVisS will be mounted on spacecraft B2, which is foreseen to be spin-stabilized. The EnVisS camera is designed to capture the entire sky in some visible wavelength bands while the spacecraft pass through the comet's coma. EnVisS optical head is composed of a fisheye lens with a field of view of 180° x 40° coupled with an imaging detector equipped with both band-pass and polarimetric filters. The design of fisheye lenses requires to take into account some issues typical of very wide-angle lenses. The fundamental origin of the optical problems resides on the entrance pupil shift at large angle, where the paraxial approximation is no more valid: chief rays angles on the object side are not preserved passing through the optics preceding the aperture stop (fore-optics). This effect produces an anamorphic deformation of the image on the focal plane, i.e. the focal length is changing along the elevation angles. Tracing the rays appropriately requires some effort by the designer. It has to be considered that distortion, including anamorphism, is an aberration that does not affect the quality of a point source image, thus it can be present also in well corrected lenses. In this paper the optical design of the fisheye lens, that will be mounted on the EnVisS camera for the ESA F-class "Comet Interceptor" mission, will be presented together with the initial optical requirements and the final expected optical performances.

Keywords: fisheye lenses, wide angle lenses, lens mapping function, astronomical imaging.

1. INTRODUCTION

The Comet Interceptor mission aims to encounter and explore an object entering the inner Solar System for the first time, or, possibly, an interstellar object originating at another star [1][2]. Due to the extremely high orbital eccentricities of either type of target, Comet Interceptor will perform a flyby of the ancient object. Nevertheless, the mission is scientifically compelling and combines the first exploration of a new type of target with unique measurements, within the constraints of the F class missions. The Comet Interceptor mission involve separate spacecraft elements working together to ensure a low-risk, bountiful, interdisciplinary scientific return through unprecedented multi-point measurements. Multiple viewing positions will greatly increase the 3D information provided on the nucleus and its jets/coma. Similarly, in situ observations of the cometary environment also benefit from multiple sampling paths. The multiple mission elements can sample gas composition and density, dust flux, and interaction between the plasma and solar wind, to build up a 3D 'snapshot' of the region around the target. One spacecraft, named spacecraft A, will make remote and in situ observations of the target from afar, to protect it from the dust environment of an active comet, and act as the primary communications hub with Earth for all other mission elements. Two other spacecraft, B1 and B2, will be deployed to venture closer to the target, carrying complementary instrument payloads, to build up a 3D view of the comet. This approach will also enable a combination of a low-risk and guaranteed baseline science return from the more distant spacecraft A with higher-risk but high-gain sampling of the inner coma by the releasable probes, which do not necessarily need to survive the full encounter for mission success. EnVisS camera will penetrate inside the coma and will acquire very large field of view images while the hosting spacecraft B2 will rotate.

2. ENVISS IMAGES ACQUISITION MODE

The EnVisS optics [3][4] is composed of a fisheye lens, able to sample a 360°×180° field of view (FOV). The image is projected into the focal plane, where a 2k×2k image sensor is placed (top-right panel of figure 1). The potential full FOV of the fisheye is represented by the gray circle in figure 1, but only a rectangular subarea of it is recorded (red rectangle in the figure 1). This recorded strip, as projected in the sky, is shown in the left panels of the figure 1. While the red strip is acquired, the probe hosting the EnVisS optics is moving (with a velocity V) and rotating (with an angular velocity ω). Then acquisitions start at a given t0 (ACQ1 at the top left panel in the figure 1). Successive acquisitions are then done at different time, where the probe has moved and rotated (e. g. ACQ2, ACQ3 etc.). Once the probe has completed the full rotation a strip is recorded with the same orientation as the first (ACQ 'n'). The line of sight (LOS) of each pixel is the different at each acquisition and care should be taken during image mosaicking and the data analysis.

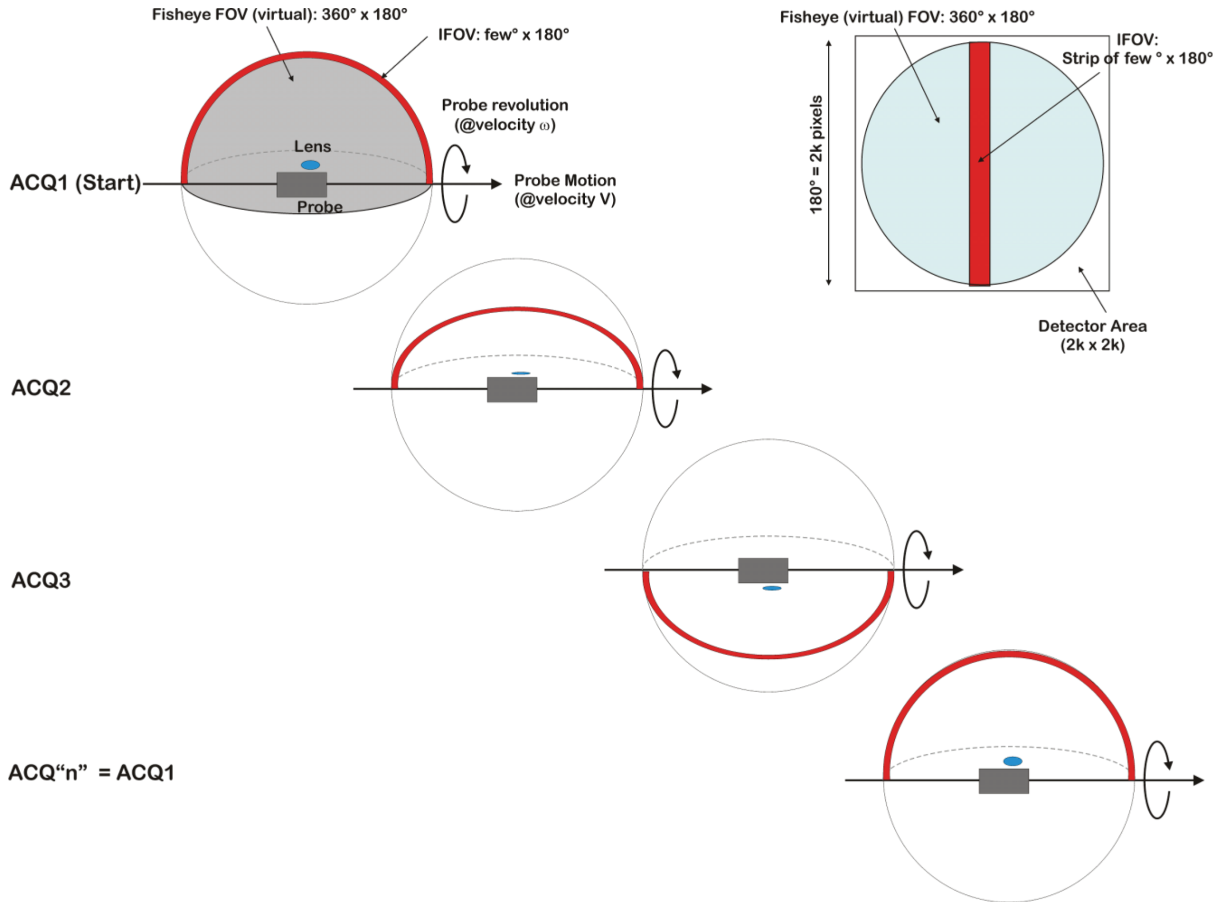

Figure 1. How the EnVisS fisheye operates during the data acquisition.

This scenario is furthermore complicated by the fact that the fisheye optical axis is not orthogonal to the probe motion direction (as depicted in the figure 1), but it is tilted by some degrees. Moreover, due to the very wide FOV of the fisheye, the pixel plate scale (°/px) is not uniform along the 180° FOV, i.e. the central (axial) pixel sample the sky with a different angular resolution with respect to the other pixels. The maximum deviation will appear at the edges of the FOV, i.e. the lens horizon (±90°, pixel#1 and pixel#2048).

3. ENVISS SKY MAPPING FUNCTION

In order to settle the optical distortion problem, we decide to design a fisheye with an equidistant projection function (also called F-Theta lens). Referring to the figure 2, R is the radial distance of a chief ray of a given field from the optical axis (ψ being its angular coordinate) and Z is the angular field distance from the zenith. There are many ways in which the field (Z angles) may be mapped onto the focal plane, i.e. $R=R(Z)$. A "perfect" undistorted map of the object space is one where $\psi=Z$, i.e. $R=f{\cdot}tan(Z)$ with f being the lens focal length. Every point in the space is mapped maintaining the same angular distribution into the focal plane and object straight lines remain straight (distortion free) in the image. This function is known as *perspective projection* and has no meaning for wide zenith angles, because the focal plane would be infinitely wide and the entrance pupil (the pin-hole) would be completely obscured at $Z=90°$. In order to have a wide-angle lens useful for any application, some image distortion has to be introduced. *Equidistant* (also called F-Theta or linear scaled) projection has the form $R=f{\cdot}Z$. The equidistant function maintains angular distances. In this kind of projection each pixel samples the same angular portion of the sky. For the EnVisS case, due to the FOV of 180° and a detector with 2k pixels, a plate scale of approximately 0.09°/px is obtained. In a F-Theta lens this scale is uniform along the whole FOV.

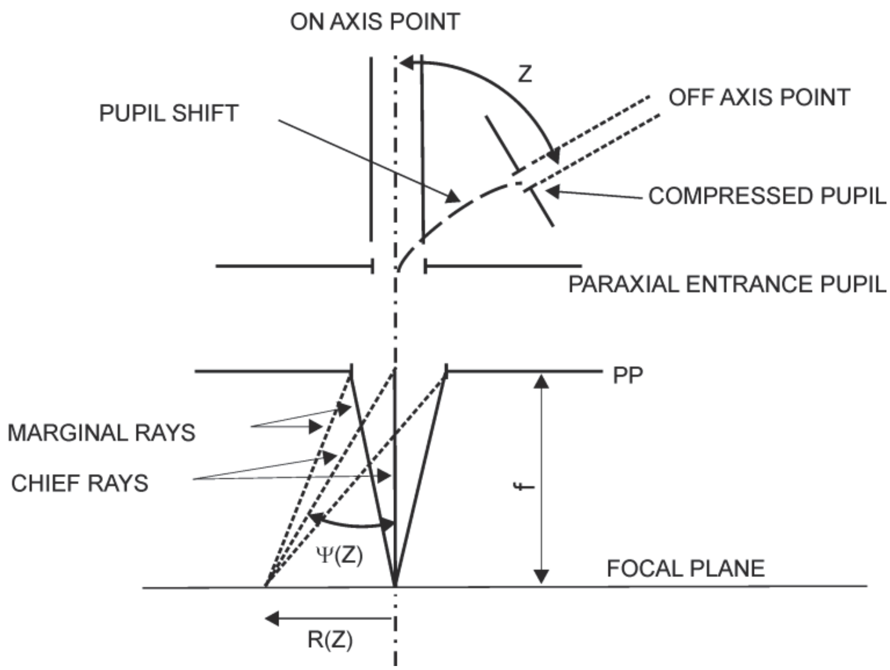

Figure 2. Scheme on how the sky mapping function of a wide-angle lens works.

4. ENVISS OPTICAL DESIGN

The ray trace layout of the fisheye lens for EnVisS is shown in the next figure 3 (A.S. label shows the diaphragm position). The design is based on a COTS monochrome image sensor 3DCM734-1 by 3D plus with a resolution of $2k^2$ pixels and a 5.5 µm squared pixel size. This has led to a fisheye focal length of 3.3 mm working at a relative aperture F/3. The total track of the lens is 110 mm, while the frontal lens is 70 mm in diameter. Care has been taken in selecting the lens glasses of the first two lenses to be made of a radiation tolerant glass (Schott K5G20). Optical performance, in terms of polychromatic (500–770 nm) spot size dimension, is shown in figure 4. The chief ray angles of incidence on the focal plane assembly are maintained within 4° along the whole field in order to keep the design as close as possible to a telecentric condition.

The F-theta condition is shown in figure 5, with a maximum distortion of about 0.5% compared to an equidistant projection function. This shows the deviation from a uniform plate scale, which mean value is 0.09 °/px.

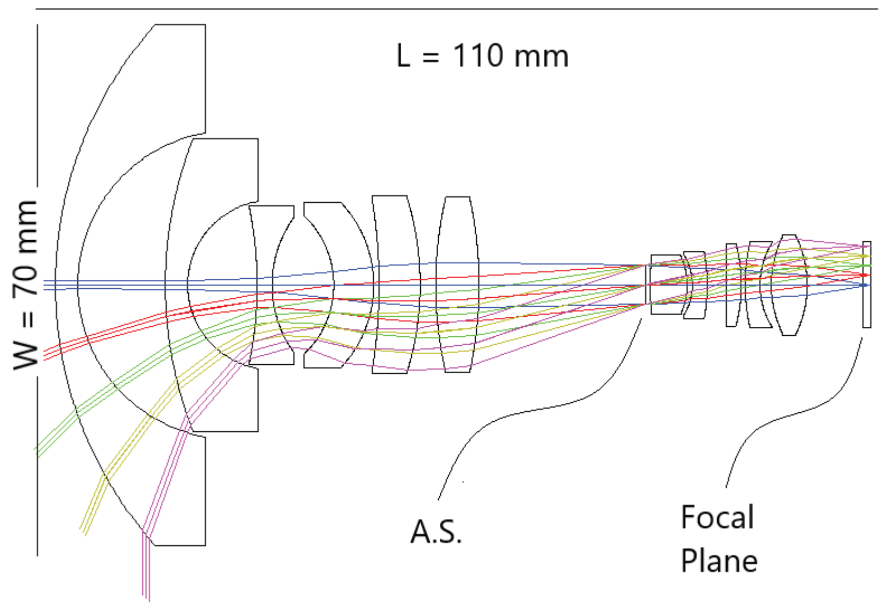

Figure 3. Optical layout of the fisheye lens.

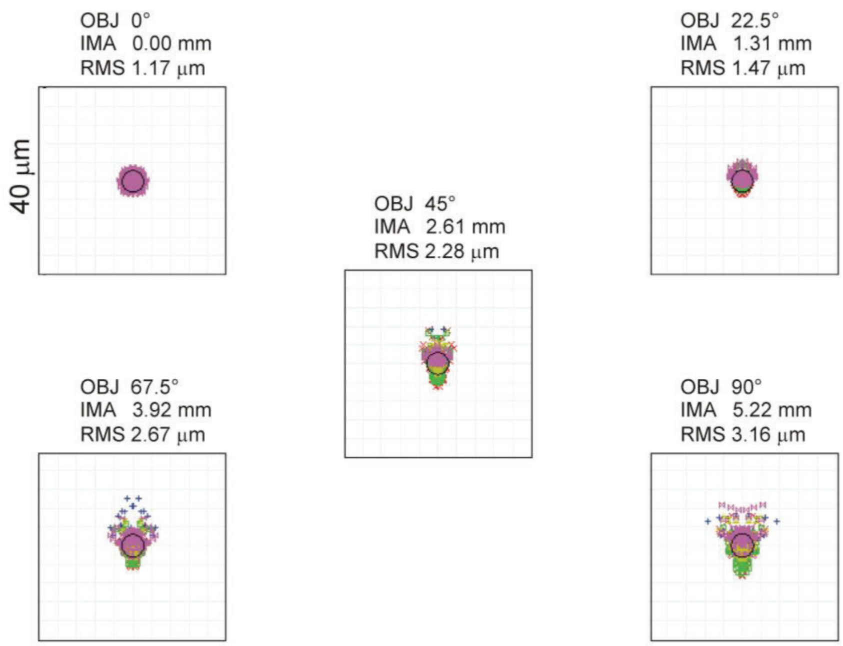

Figure 4. Polychromatic spot size in the range 500–770 nm.

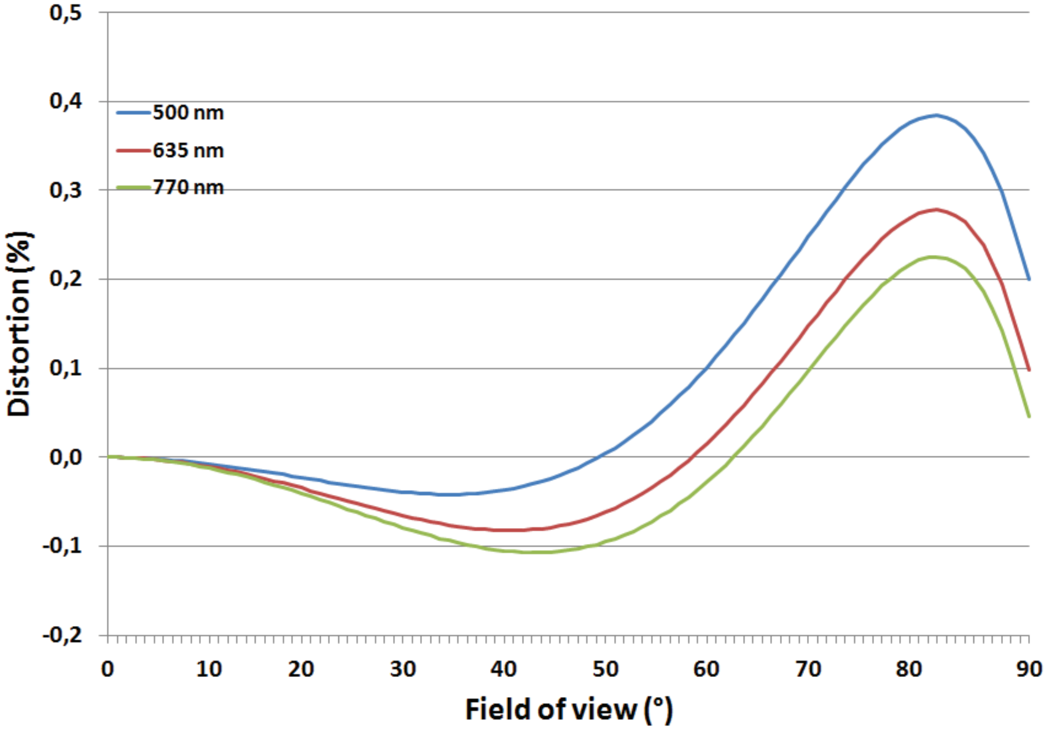

Figure 5. Distortion deviation from the F-theta condition.

5. CONCLUSION

A telecentric F-theta fisheye lens for the EnVisS instrument to be mounted on the ESA Comet Interceptor mission has been designed. Ray tracing shows the optical quality is quite pixel limited along the whole field of view and in the wavelengths range 500–770 nm. The maximum deviation from the telecentric condition is about 4° for the marginal field (FOV=90°) chief ray. Deviation from the equidistant projection function is less than 0.5%, showing that the lens works in a F-theta condition.

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