INNOVATIVE COMPACT FOCAL PLANE ARRAY FOR WIDE FIELD VIS AND IR ORBITING TELESCOPES

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The future generation of high angular resolution space telescopes will require breakthrough technologies to combine large diameters and large focal plane arrays with compactness and lightweight mirrors and structures. Considering the allocated volume medium-size launchers, short focal lengths are mandatory, implying complex optical relays to obtain diffraction limited images on large focal planes.

In this paper we present preliminary studies to obtain compact focal plane arrays (FPA) for earth observations on low earth orbits at high angular resolution. Based on the principle of image slicers, we present an optical concept to arrange a 1D FPA into a 2D FPA, allowing the use of 2D detector matrices. This solution is particularly attractive for IR imaging requiring a cryostat, which volume could be considerably reduced as well as the relay optics complexity.

Enabling the use of 2D matrices for such an application offers new possibilities. Recent developments on curved FPA allows optimization without concerns on the field curvature. This innovative approach also reduces the complexity of the telescope optical combination, specifically for fast telescopes. This paper will describe the concept and optical design of an F/5 - 1.5m telescope equipped with such a FPA, the performances and the impact on the system with a comparison with an equivalent 1.5m wide field Korsch telescope.

I. SEGMENTATION OF LINEAR FOCAL PLANES

The size of a focal plane for low earth orbit imaging satellites is constrained by the size of the field and the required sampling. The combined needs for high angular resolution over a wide field of view of future imaging systems using the TDI push broom technology leads to prohibitive size of these 1D focal planes arrays (FPA), exceeding a 1 meter length. A direct consequence of this focal plane size is the volume and size of the optics relay transferring the field. The optical quality over the field is required to be homogeneous and high, leading to large freeform optics, which manufacturing is complex, but also which alignment is tight and which stability and position tolerance is a challenge. These constraints lead to an increase in mass, volume and cost of the systems.

The slicer principle classically used in integral field spectroscopy aims at providing slices of an image at the entrance slit of a spectrograph. It basically transforms a 2D image into a 1D format, by use of a specific slicing components and a re-imaging system made of several small focusing mirrors. This principle can be inversed (see Fig. 1) and applied to a linear FPA as used for Earth observation telescopes, in order to segment it and replace the different parts of the image on a 2D FPA. For instance, a 1D push-broom FPA made of 40 lines of 100,000 pixels, divided in 50 segments of 2k pixels, can be arranged into a 2k x 2k 2D matrix.

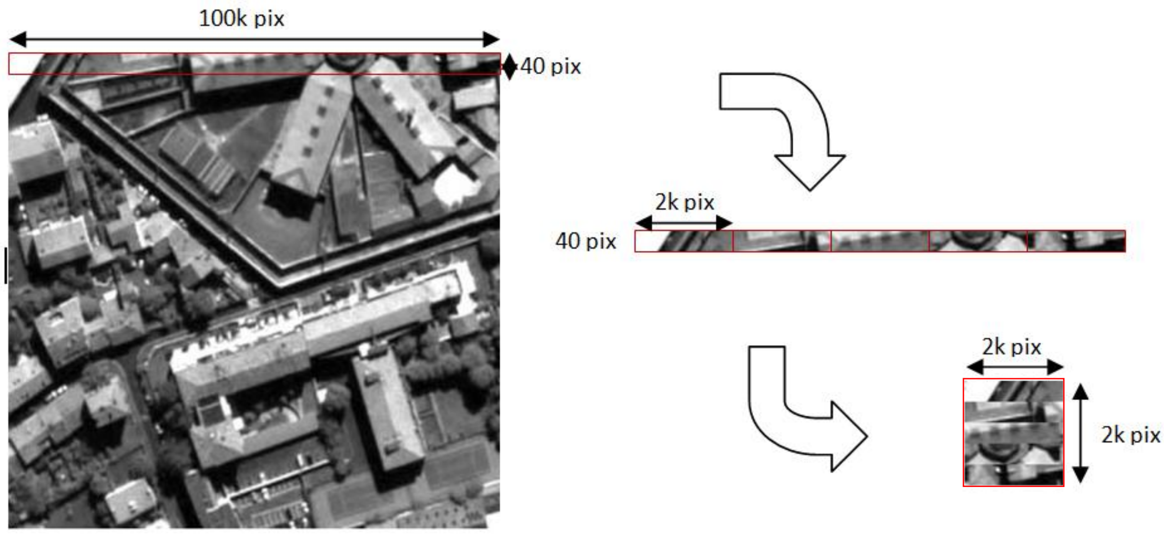

Fig. 1 schematic of reimaging a linear field over a 2D matrix

The slicing and re-arrangement of the image can be done early in the optical train. The direct consequence is that the following transfer optics will benefit of this configuration. The gain obtained in terms of volume could lead in a significant reduction of the overall mass of the system, and furthermore a strong reduction of the cryostats complexity for infrared focal plane instrumentation.

II. RELIABILITY, MANUFACTURING

Two main methods and generally used for slicers manufacturing, depending on the optical quality requirements: diamond machining for standard quality, or classical polishing for high performance imaging systems. Tab. 1 compares the results given by these methods. The polishing method recently benefits from improvements in order to manage the pseudo mass production aspects for the MUSE/VLT instrument, for which more than 1000 components have been provided in two years by the French society Winlight Optics[1].

Tab.1 Comparison of surface qualities obtained with two manufacturing methods.

	Diamond machining	**Polishing**
Surface quality	λ/20 RMS	λ/100 RMS
Roughness	5-10nm RMS	0.3-0.4nm RMS
Edges misfigure	20-50µm	<5µm
Tilt errors	<30’’	<15’’

III. TECHNOLOGICAL READINESS LEVEL

The MUSE instrument [2] recently installed on the Very Large Telescope (VLT) is equipped with 24 integral field spectrographs (IFS). On each of them are placed 48 slices and 48 focusing mirrors, each slice being 33.4mm x 0.925mm. Fig. 2 shows a module made of 4 slicers and their associated focusing mirrors, integrated and aligned. These very simple devices are suitable for space applications.

Since 10 years, space R&T projects on image slicers demonstrated the space qualification up to TRL5. These activities were undertaken in the frame of the SNAP/JDEM (pre-EUCLID, [3]) project or in the frame of NIRSpec, for which the entrance field is sliced, re-oriented and placed at a fixed position in the same plane of the entrance field to get a compact system, easy to assemble. A slicer demonstrator was realized under ESA contract in 2004 for a TRL6 qualification in 2006 (see Fig. 3).

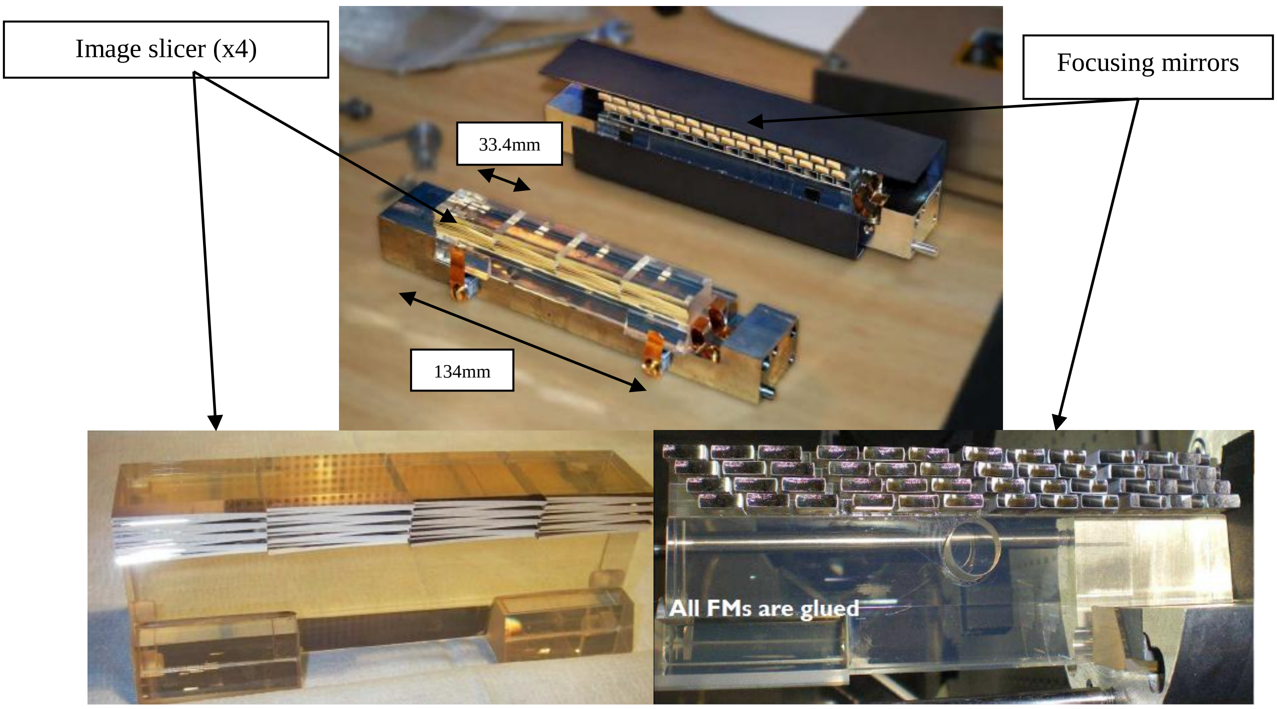

Fig. 2 A MUSE/VLT module made of four slicers and their associated focusing mirrors. (Credit ESO/CRAL/Winlight, Bacon et al 2012)

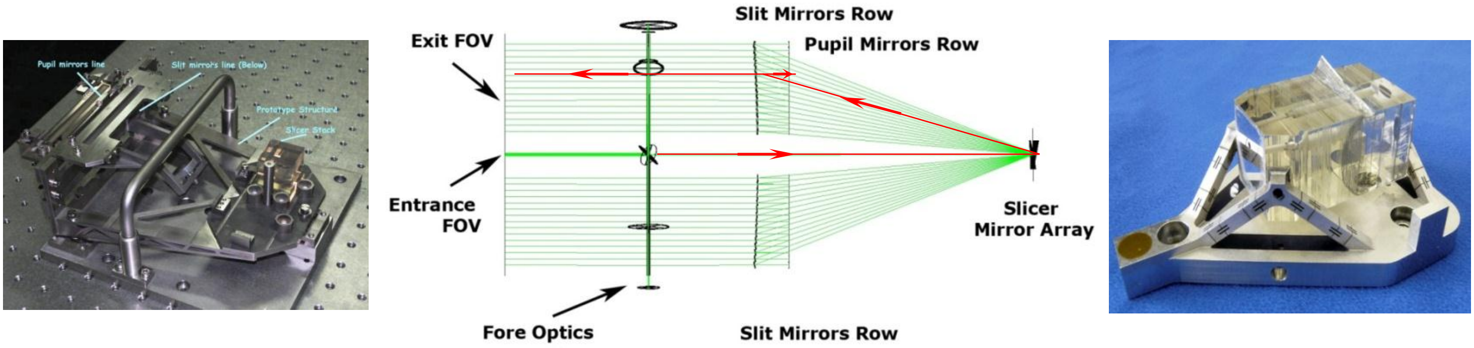

Fig.3 ESA prototype (2004, right) and qualification demonstrator (2006, left). Middle: optical design proposed for the NIRSpec instrument, managing tight positioning requirements.

IV. PRELIMINARY DESIGN

A specific Zemax module has been developed at LAM in order to directly optimize the design regarding manufacturing possibilities. This development was undertaken in partnership with Winlight Optics, with a shared patent CNRS/Winlight.

A preliminary design has been performed, based on a 1.5m Korsch Telescope at F/5, including a pupil relay for active optics purposes (Laslandes et al 2013 [4]). The field segmentation occurs after this relay (see Fig.4).

On the preliminary design, the image is segmented and sent to the slicer. An additional optical relay could be added in order to re-image this slicer on a flat detector to reduce the incoming angles and keep a constant magnification over the field. The overlap is necessary as on actual designs in order to adjust the different parts (see Fig. 5).

For low earth orbit (LEO) earth observation applications, the frame rate of current 2D detectors is not fitting the requirements. To overcome this issue, an interesting solution is to place classical 1D detectors in place of the slicer. The imaging system can adapt the angles in order to manage the volume of 1D detectors and place them one below the other, with specific angles for each of them. This solution has the advantage to avoid the optical relay and uses only existing qualified technologies

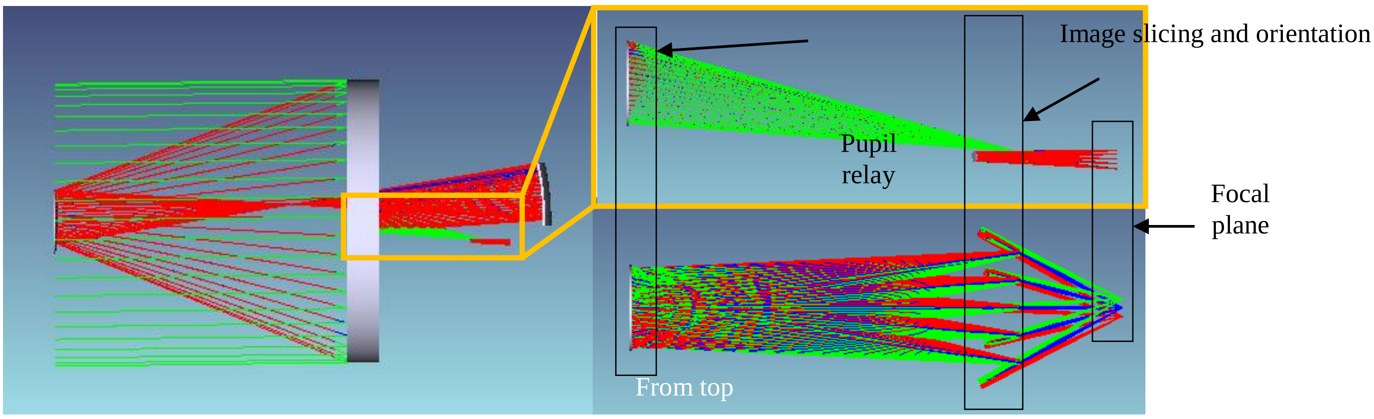

Fig. 4 Preliminary design of a Korsch F/5 telescope, with a 1.5m.

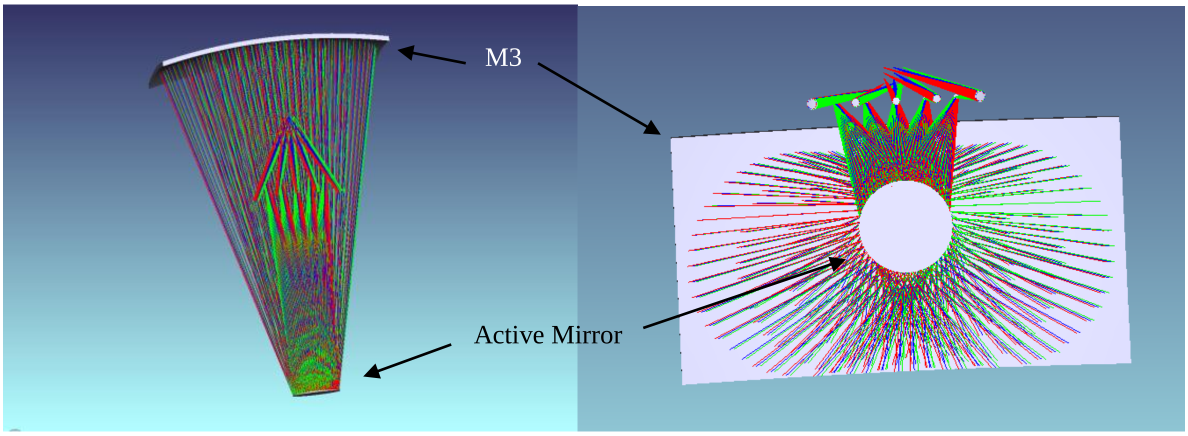

Fig. 5 View of the focal plane module, including the tertiary mirror. The pupil relay can be used for active correction of the wave front.

V. CONCLUSIONS-DISCUSSION

The principle presented in this paper is based on the segmentation of linear FPA to re-arrange the image in a compact way. 1D space qualified detectors can be used in the focal plane, but in a configuration one below the other, instead of a linear placement. The focusing mirrors allow for magnification (typically a factor of 5), that means the intermediate focal plane (the one to be segmented) can have a size 5 time smaller than the physical focal plane.

Such a system allows a reduction of mass and volume of space FPA, and only uses well qualified technologies. This volume reduction present an advantage for infrared instrumentation, as the size of the cryostats can strongly be reduced. In addition, the AIT time will benefit of the simplification of the system.

Several points must be addressed in order to pursue this study. The reduction of the intermediate FPA implies the use of a faster telescope. A direct consequence is the sensitivity to optical alignment. A tolerancing study must be performed with well-chosen parameters corresponding to Korsch designs currently proposed for earth observation satellites.

A global system study must be performed in order to evaluate the impact on the global telescope as well as the risk induced. Additional improvements can be proposed, such as the development of curved space detectors. Their use will drastically reduce the complexity of fast telescope, by simplifying the optical relays. Such a technology is not developed in Europe and must be launch in a very near future.

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