

Engineering an highly segmented, very wide-field spectrograph

R. Ragazzoni^{*a}, A. Fontana^b, D. Maccagni^c, A. Baruffolo^a, A.G. Bianco^c, A. diPaola^b, J. Farinato^a,
G. Gentile^a, E. Giallongo^b, F. Pedichini^b, R. Speziali^b, V. Testa^b

^aINAF – Astronomical Observatory of Padova, vic. Osservatorio 5, I-35122 Padova (Italy);

^bINAF – Astronomical Observatory of Roma – via Frascati 33, I-00040 Roma (Italy);

^cINAF – Istituto di Fisica Cosmica – via E. Bassini 15, I-20133 Milano (Italy)

ABSTRACT

The concept of segmenting the focal plane of an existing 8m class telescope in order to fill it with an array of several fast cameras has been developed further and in this work the status of an engineering program aimed to produce a design qualified for the construction, and to assess its cost estimates is presented. The original concept of just having simple cameras with all identical optical components other than a pupil plane corrector to remove the fixed aberrations at the off-axis field of a telescope has been extended to introduce a spectroscopic capability and to assess a trade-off between a very large number (of the order of thousand) of cameras with a small single Field of View with a smaller number of cameras able to compensate the aberration on a much larger Field of View with a combination of different optical elements and different ways to mount and align them.

The scientific target of a few thousands multi-slit spectra over a Field of View of a few square degrees, combined with the ambition to mount this on an existing 8m class telescope makes the scientific rationale of such an instrument a very interesting one. In the paper we describe the different options for a possible optical design, the trade off between variations on the theme of the large segmentation and we describe briefly the way this kind of instrument can handle a multi-slit configuration. Finally, the feasibility of the components and a brief description of how the cost analysis is being performed are given. Perspectives on the construction of this spectrograph are given as well.

Keywords: wide field astronomy, segmented optics, focal reducer

1. INTRODUCTION

The concept of segmenting the focal plane of a relatively large telescope in a number of smaller areas where, possibly, the correction can be achieved in a simpler manner, has been introduced time ago [1] and it has been [2,3,4] further exploited recently. What does “simpler” means is of course a matter of which kind of merit function you want to use for such a judgment. The first obvious consideration is that a camera covering a smaller Field of View is, within conformity of any other parameter, physically much smaller. This is of course compensate by the larger amount of camera and in fact the paved silicon surface, for example, is at first order, an invariant. This statement cannot be extended, however, to other issues, for example to the optical elements. Remaining just confined to glass volume, for instance, the effect of segmenting into smaller camera is much more subtle than what one could think. The thickness of smaller lenses is not linear with the size and, anyway, there is a non linear factor given from the practicality of making lenses thickness smaller than a certain given amount. Polishing of the optics is another parameter that cannot be handled in a superficial manner. While the surface polished can follow some simple rules, although with some limitation again, the difficulty of providing a large number of optics is modulated by the way the generation of the optical elements is achieved. A Computer Controlled Machine can change tools and shape to which to aim in a straightforward manner while in other cases a setup for the machine is required making the case for a lot of strictly identical lenses an ideal one. Even when some approximations can be done there are still the need to work out the extreme cases in which one could fall into. For example because of vignetting in the entrance field lenses of each camera the silicon area covered by each camera is slightly larger than what is supposed to be by a mere subdivision into equal parts. There is in fact a little augmentation of the detector area to take into account for this effect. Given that one have to choose a CCD for all or most of all the cameras one has to tune this to the largest vignetting available making the more extremely highly segmented case leading

*roberto.ragazzoni@oapd.inaf.it; phone +39-049-8293517; fax +39-049-8293518

to a much larger silicon area than a conventional camera. We found some solutions apparently practically viable in which the vignetting amount of a size comparable (or in some cases even larger) then the Field of View of a single unit.

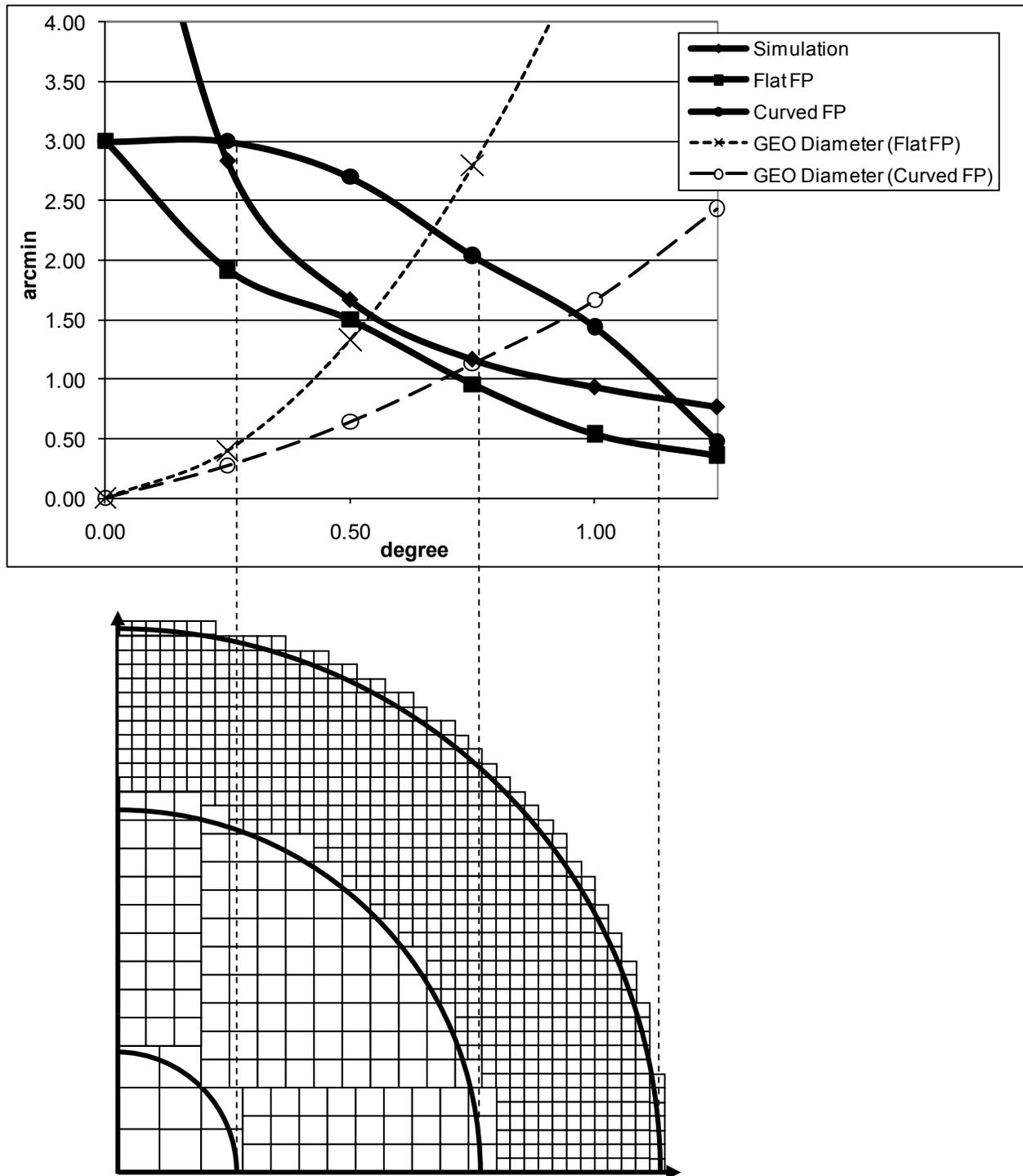


Figure 1 Assuming uniform correction over a single camera one could be tempted to modify the size of the single camera accordingly to the off-axis distance; moreover the size of the spot in the field lens will increase accordingly requiring the detector of each camera to be larger in order to comply with the requested segmentation..

2. LOOKING GLOBALLY TO THE OPTIMUM SEGMENTATION

In an effort to reach an engineered version of the optomechanical design for such a kind of camera one is faced with a number of troubles. While making an end-to-end design and simulation (see for example an outcome of a preliminary engineering effort in [6]) is a conservative approach some separation of the problems into different category is required in order to converge toward a sound solution. From the pure optical design viewpoint a decision that divide the design into two large and different categories is represented by the position where the correction is applied inside each single camera. In its original format in fact the idea was to apply this correction in the pupil plane. This allows, in principle, for making the whole optical design perfectly identical but the pupil plane corrector. Let's now skip the problems to be faced for the actual manufacturing of the pupil plane corrector and concentrate on the subtle effects of this choice. The very first consideration is that one is forced to divide the Field of View into small areas such that the variations in the quality across the smaller FoV does not manifest themselves larger than a given specification (that is typically of the order of a fraction of the achievable seeing, so something in the ballpark of 0.1 to 0.5 arcsec, generally speaking). Simple raytracing allows for defining such a size and it is straightforward to see that under a number of reasonable circumstances this figure will become larger getting away from the optical axis of the telescope. Also, this number depends upon the intermediate focal ratio but, in practice, given the mechanical constraint of where a secondary mirror can be realistically mounted and where the camera can be conveniently located we figured out that, given a certain existing 8m class telescope, the secondary mirror choice does not offers too much degrees of freedom. Computing this size gives, for a certain full Field of View, the physical size of each small camera and its overall number. This increase dramatically toward larger Field of View as the optical quality degrades typically with a power of two to three while the area under considerations of course change quadratically, leading to a large power of 4 to 5 for the exponent of a relationship number of cameras versus full FoV. Moreover one is to be faced with the problem just sketched in the introduction of the vignetting. The field lens, in fact, is looking at a severely aberrated entrance image, especially toward the outer edges of the full FoV. This will means that starlight coming from some objects will be "split" into more than a camera. In order to avoid to loose light one have to recover this by oversizing the physical size of the detector. In reality also the optical design, to some extent, have to consider this reimaging. This also makes the preliminary optical design (we means here a first order conceptual design of the single cameras) a little trickier than expected. In fact clearly the field lens is unchanged but the rays crossing the pupil will arrive also from areas of the Field of View outside of the nominal size of the lenslet array and, especially on the side to reimage into the detector, this poses extra constraints into the optical design. This is not only true for just to convey with off-axis optical aberrations but also to match the maximum physical size allowed. In fact the whole small camera has to comply with the maximum physical size given by the "shadow" of each lenslet array. The shape of the lenses in order to match this, also, drift from rectangular in the entrance field lens, to circular in the pupil plane, to a rounded square in any reimaged plane. The reason why the reimaged plane is not square as the entrance one is again given by the vignetting problem mentioned above. One can see from Fig.1 that the size of the entrance optical quality can becomes comparable to the size of the entrance field. This will makes the shape of the reimaged plane very roundish and the requirements in terms of covered silicon size enlarging, in the limit case by a factor two in size and four in surface. As this is generally speaking unacceptable as the cost of the detector surface is a significant fraction of a camera the size of the entrance lens could be changed accordingly to their distance from the axis as is depicted in the bottom part of Fig.1 Another possibility is of course to break the assumption that the correction is achieved in an uniform manner, that is on the pupil, over the whole small camera. Breaking this condition leads unvariably to the matter of leaving the option for mass production of optics. This is, however, only partially true. In the original concept in fact, the correction (or at least the vast part of it) is to be achieved in the first collimator and pupil corrector. This is because the design involves a second camera with, in-between, some field selectors (moving slits or other kind of devices with a similar purpose) that should remain, at first order, in mass production also in this second case. Another possibility is to split the correction places into two areas where one can introduce variable correctors. However, this will makes the design with even extra constraints for such a limited number of cameras that we believe it is not viable. Making a realistic subdivision of the full Field of View one can recognize that in fact the overlal number of actually different cameras is not so large. Let's take the subdivisions depicted in Fig.2. Avoiding to place the center of a camera just on the center of the full Field of View but just on a corner one can see that a four-fold symmetry can be further augmented to an almost 8th one for most of the cameras. In other words the camera on the diagonal have to be duplicated four times while the one on the small part of the so-defined "octant" can be replicated exactly for eight times each. This makes the full number of completely independent cameras dropping to about sixteen. The detailed comparison of the number of different camera is shown in Fig.3. The way the correction is

achieved, moreover, is likely to be very similar for cameras that are, in their intimate details, slightly different one from each other, as, basically, the optical recipe for a certain distance from the optical axis will be substantially closer for similar values of such a parameter, maybe just changing the orientation of the square covered Field of View. One can speculate, at this level of the optical design, that this can be, partially, achieved by using spherical optical components mounted in a tilted and/or decentered fashion. Also one should recall that local curvatures of the focal plane can be handled to a large extent by a local tilting of the detector.

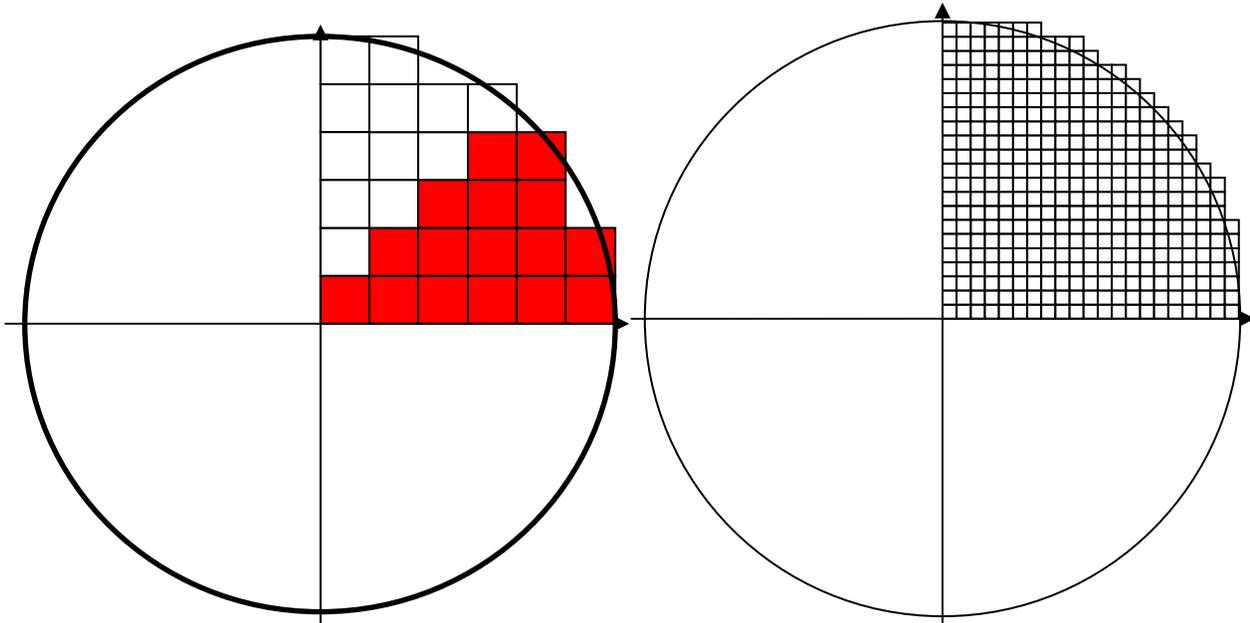


Figure 2. In contrast with a large segmentation (right side) a moderate one (as depicted in the left side of this representative image) will exhibit a much smaller number of cameras. However these are likely to be different each one from any other. Choosing a simple symmetry, however, this last statement can be greatly edulcorated.

While the above mentioned consideration involves uniquely optical design issues a number of other trouble and related cures, can be identified. The most obvious one is that in order to keep the same multiplexing the way that the slits are introduced in the intermediate focal plane has to be modified accordingly. In the original scenario, in fact, one could imagine some metallic strips entering the focal plane through some little guides with actuators placed on the back of the detector volume. This would allow for a relative freedom in the choice of the actuator technology and also to the possibility to “pack” them along the optical axis rather than in the footprint, or shadow, of the field lens of each small camera.

A more milder segmentation, furthermore, could take back into the discussion realm the option of the changeable masks. This option would be rather unpractical for the “one thousand” class of number of cameras design originally depicted but it could become reasonable, although challenging, for an option with a total number of larger cameras of the order of less than one hundred. A robotized system to deploy some (likely flexible) masks into position is not completely crazy and would allow for solving any problems in terms of multiplexing. Also, multislits can be made in a multiple fashion in a fixed or variable way (with some limitations) by allowing pairs of metallic slides to slide one over each other, although this would also impose some constraints in the focal ratio illuminating them (in order to limit the

effects of the different plane where the slits would occur) and, also, would limit the maximum product of the resolution power by the spectral coverage. Mixed solutions, of course, would be always possible.

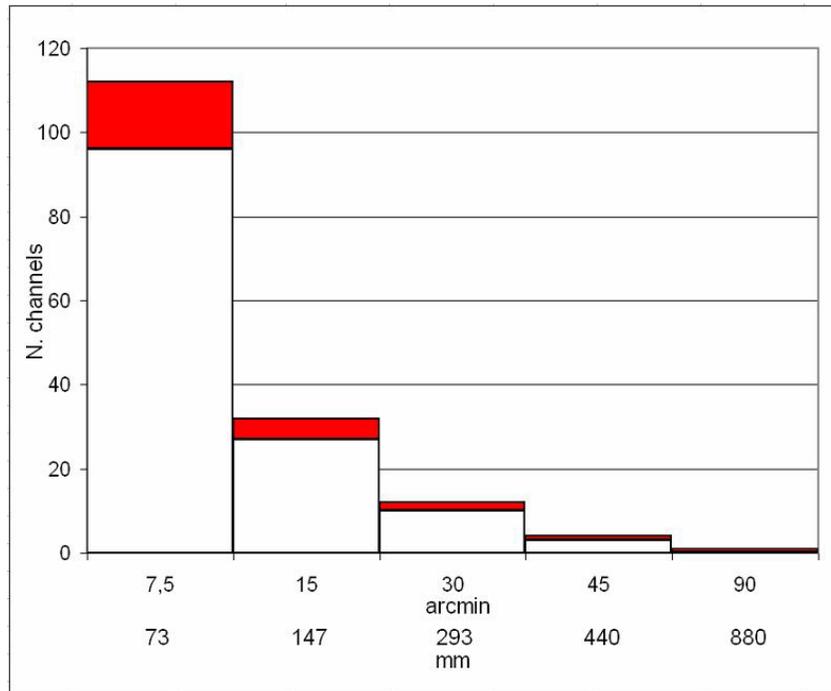


Figure 3 Number of small cameras and of actual different channels for various radius of the full covered Field of View. The largest figure amounting to about 1.5 degrees.

Another issue of interest once an optomechanical design is tentatively finalized is the way lenses are kept in order to comply with different thermal behavior of glasses and metal. This could insert a dark zone between adjacent cameras. This however can be slightly ameliorated by both placing the field lenses into a slightly defocused region (a solution, however, that is equivalent to introduce some further vignetting) or to keep the lens from the inner parts, and assuming the rays are bent enough not to cover the part of the lens where the holder is acting. Clearly, as this would require extra machining on such a lens, points toward a field lens that is mass produced, thinking the degrees of freedom for the optical designer. Other issues that are here just mention are:

- The impact of the electronics “cost” in economical as well as practical matters, like weight, volume, thermal dissipation and so on;
- The ability to insert filters and different kind of dispersing elements are to be traded off between the larger available volume, the larger physical size of such elements and the (slightly) enlarged requirements in terms of quality or optical performances (as they are now covering a larger Field of View);
- The serviceability of such modules. Initially it was conceived to build up cameras into limited groups, but this option is probably to be dropped to a one-to-one module to cameras.
- The possibility to use cooling systems more effective than just Peltier cooling, as it was originally envisaged;
- The delivery time of the optics and the different ways of testing these as the correction of the field depending aberrations are now “spreaded” over several optical elements while initially one could conceive to align and test each single camera without pupil corrector in a uniform manner;
- The control software has to control a smaller number of cameras but with more parameters each, as well as for the data reduction software.

3. CONCLUSIONS

Progressing in the optomechanical design of this kind of camera we found that the extreme segmentation we originally conceived is carrying a number of drawbacks that, although circumventable, exhibits some degree of nuisance. We are now working onto receding toward a segmentation that, still being two order of magnitude larger than any existing wide field device in astronomical use, is one order of magnitude smaller than the initial concept. While an almost full and detailed optical design has been carried out for the 1000 cameras concept we are now working on defining the conceptual, first order, guidelines and will proceed to a detailed optomechanical design. Such exercise will make the right perspective to decide which of the two options, or where in between to target, is to be selected.

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