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Reflective Schmidt Designs for Extended Object Detection in Space Astronomy – Active Optics Methods

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Abstract: Fast reflective Schmidts allow accurate imaging of 3° diagonal sky fields over extended spectral ranges from far-uv to infrared. For space astronomy we present 50cm aperture designs, 3- and 4-reflection, as fast as $f/2$, for extended object detection. Active optics methods are presented to obtain accurately the free-form aspheric mirror.

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Keywords: Schmidt systems, optical design, astronomical optics, active optics, elasticity, deformable mirrors

1. Introduction

Multi-wavelength detection of *extended objects* in space astronomy – with narrow-band filters centred from far-ultraviolet to infrared – requires wide-field achromatic optical systems with high throughput. This leads to consider exclusively catoptric systems. The image detection being planned by *drift-scan integration* technique the sky projection of the field of view must be realized *distortion-free* by the optical system. The optical design requires avoiding or minimizing the obstruction of optical beams caused by telescope mirrors as well as to avoid spiders in the beam. The basic features of MESSIER Microsatellite Project¹⁾ are currently a 50cm aperture telescope at $f/2$ with 6 narrow-band filters discreetly centred over a spectral range from 200 to 1000nm. The requested field of view (FoV) is $2.5 \times 1.5^\circ$, i.e. 3° diagonal, and an angular resolution of 1-2arcsec.

Three-mirror anastigmat (TMA) centred systems shows a central obstruction somewhat larger than 25% in energy which is not suitable. TMA systems designed off-axis fully avoid central obstruction but leads to highly aspheric free-form mirrors which are difficult to manufacture without high frequency errors. Assuming that a small central obstruction, say 4-5% in energy, is tolerable, folded reflective Schmidt systems – developed hereafter – are interesting systems because requiring only one aspherical mirror which can be easily manufactured by active optics process.

2. Folded reflective Schmidt systems

Curved detector are currently built in many laboratories, so one can now use them as detector directly imaged at the natural curved FoV of a Schmidt telescope, i.e. without requiring a three-lens corrector. This allows to fully benefit of the distortion free advantage provided by these systems.

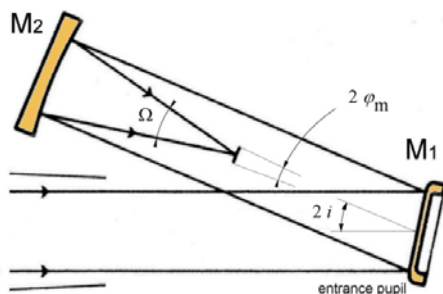


Fig. 1. Reflective Schmidt basic parameters Ω , i , ϕ_m

In a two-mirror reflective Schmidt the centre of curvature of spherical concave mirror M_2 – of radius R – is located at the vertex of aspheric mirror M_1 . The focal length of the system is $f = R/2$. Mirror M_1 defines the entrance pupil. We assume that the principal incident beam on M_1 is cylindrical of diameter d , and denote $\Omega = f / D$ the telescope f-ratio. Given an inclination of angle i of M_1 and a maximum semi-field angle ϕ_m (Fig.1), the angular resolution is predicted from analysis by relationship^{2,3)}

$$d = 0.012 \phi_m [(3i / 2) + \phi_m] / \Omega^3. \quad (1)$$

Dominating residual aberration is 5th-order astigmatism – *Astm5*. Optimizations carried out below with Zemax code are in agreement with Eq.(1) which applies to an optical surface of M_1 mirror generated by *homothetic ellipses* and where the elliptical *null-power zone* is $(3/2)^{1/2} = 1.224\dots$ times larger than that of the *full-aperture contour*.^{2,3)} This result was used by S.-g. Wang, D.-q. Su et al.⁴⁾ for the optical design of giant reflective Schmidt LAMOST. The optical shape of mirror M_1 is optimized in the form of a power series³⁾ $Z = \sum A_{2n} (x^2 \cos^2 i + y^2)^n$ with $n = 1, 2$ and 3. One investigates below two folded systems that allow the detector to be mounted outside the telescope. These systems present a central obstruction lower than 5% in energy and do not need any spider into the beams. The curvature of the *anastigmatic field* is $P_z = 1/f = 2/R$.

2.1. DESIGN 1 – Three-reflection simply folded system : The addition of a holed folding flat mirror between M_1 and M_2 gives free access to the detector and renders the instrument more compact. However for a $2.5 \times 1.5^\circ$ FoV at $f/2$ the incident angle at M_1 is at least $i = 12^\circ$ (Fig.2).

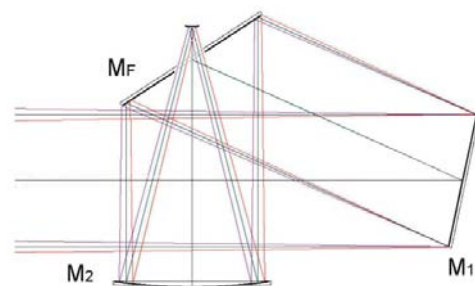


Fig.2. DESIGN 1: Three-reflection reflective Schmidt. 50cm aperture. Parameters $\Omega=2$, $\phi_{mx}=0.75^\circ$ in the plane of this figure, $\phi_{my}=1.25^\circ$, $i=12^\circ$. Ray tracing optimization led to *Astm5* blur residual $< 8.8\mu\text{m}$ RMS in diameter, i.e. 1.8 arcsec resolution

2.2. DESIGN 2 - Four-reflection double-folded system with three mirrors: This design allows reducing the incident angle to minimum (Fig.3). The incident beam is first reflected by a flat mirror M_F , then by the aspheric elliptic bi-symmetric M_1 mirror. The beams returns to the same M_F mirror which reflect them on M_2 . The focal surface is projected through a hole of M_F which provides the clearance for detector. This design (Fig.4) provides a better resolving power than Design1 because the incidence angle i of the chief ray is reduced from 12° to 9° .

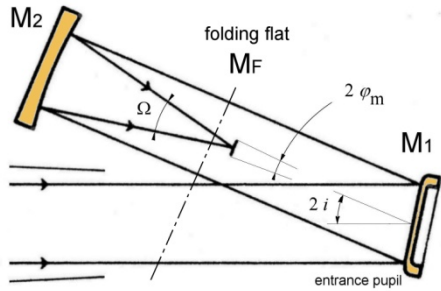


Fig.3. M_F flat-mirror folding both the incident and reflected beams at M_1 allows minimizing the deviation angle $2i$

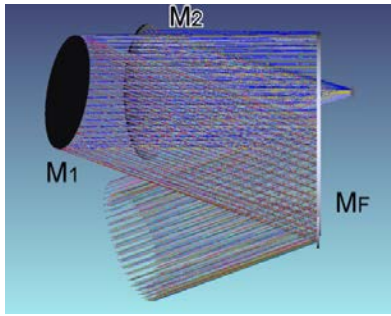


Fig.4. DESIGN 2 : Four-reflection three-mirror Schmidt. 50cm aperture. Virtual view of Design 2. Parameters : $\Omega=2$, $\varphi_{mx}=0.75^\circ$ in the plane of this figure, $\varphi_{my}=1.25^\circ$, $i=9^\circ$. Ray tracing optimization led to $Astm5$ blur residual $< 6.4\mu m$ RMS in diameter, i.e. 1.3 arcsec resolution

3. Active Optics aspherization of M_1 mirror

The two designs above use an aspheric mirror M_1 , a spherical mirror M_2 and flat holed mirror M_F . Mirror M_1 is bi-axisymmetric and generated by homothetic ellipses (Fig.5).

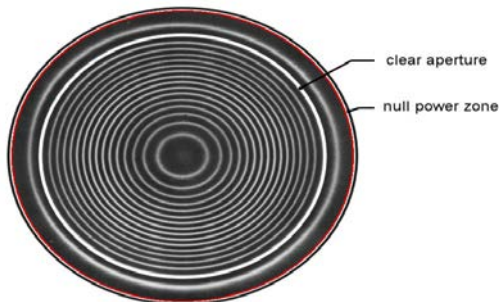


Fig.5. Isolevel lines of M_1 optical surface generated by homothetic ellipses. The best optical performance is achieved when the sizes of elliptic clear aperture and elliptic null-power zone (outside) are set in the ratio $\sqrt{3/2}$.

Ratio $\sqrt{3/2}$ ensures the *algebraic balance of local curvatures along the principal meridian directions*.^{2,3)}

One has found possible to practice the aspherization by stress surfacing with a full aperture rigid flat lap.⁵⁾ The elastic design uses an elliptical contour semi-built-in in a *closed biplate form*.³⁾ The plate is submitted to a partial vacuum – generating a uniform load q back to the mirror surface – during grinding and polishing. One solved the bi-laplacian Poisson equation³⁾

$$\nabla^4 z \equiv \partial^4 z / \partial x^4 + 2 \partial^4 z / \partial x^2 \partial y^2 + \partial^4 z / \partial y^4 = q/D, \quad (2)$$

where D is the rigidity. The boundary conditions at the contour of the biplate (Fig.6) are such that the tangential bending moments generated by uniform load allow the clear aperture contour *to rotate tangentially of a controlled amount distribution* with respect to above algebraic balance law.

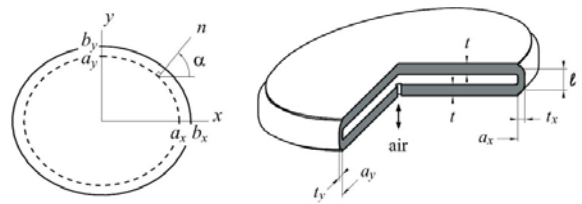


Fig.6. Elasticity design of M_1 mirror as a *closed biplate form*³⁾ made of two identical vase forms in vitro-ceram material linked together with epoxy. Radial thickness of the cylinder contour is optimized to achieve the required slope along clear aperture perimeter (*dotted line*)

Relationships between the axial thickness t of one of a plate, axial length l of the built-in outer cylinder, semi-axes a_x and a_y of elliptic clear aperture, and radial thicknesses t_x and t_y of outer cylinder have been established for satisfying above boundary conditions.³⁾

4. Conclusions

The two proposed 3^o diagonal-field designs require making only one aspheric mirror. This mirror could be obtained by spherical figuring via active optics methods requiring only a *single actuator* – uniform load – which would avoid high spatial frequency or ripple errors. Study also granted by ANR-OASIX #12-JS05-0004.

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