A New Infrared Camera Optical Design

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Abstract: We have designed a novel all-reflective optical system for an infrared camera. The camera gives a flat 5 arcminute field with a final focal ratio of f/2.5 when used at the f/15 focus of the Anglo-Australian Telescope (AAT). A 70mm diameter Fabry-Perot filter can be accommodated in a collimated beam, thereby giving narrow-band imaging capability. The design could readily be adapted to other telescopes and focal ratios. Its advantages are no chromatic aberration, no vignetting, no ghost images, low light-loss and excellent image quality.

1. Introduction

Astronomical cameras typically have some refracting optics, due to the difficulty of designing reflecting systems without introducing vignetting. In the near-infrared, the cost of suitable lens material is a large fraction of the cost of the instrument, and the high refractive indices can result in substantial light loss at the interfaces unless multi-layer anti-reflection coatings are used as in FAST (Krabbe *et al.* 1991). Other successful systems (e.g., IRCAM (McLean 1987) and IRIS (Gillingham and Lankshear 1990)) use a combination of reflecting and refracting optics. In the mid-IR a camera has been built (Gezari *et al.* 1989) with off-axis reflecting optics, although with only a small (15 arcsec) field of view.

In an attempt to circumvent the problems of refractive systems we have investigated a number of all-reflective (excluding filters and windows) systems, and have arrived at an interesting design that we propose to construct.

2. The Design Goals

Our design goals for the camera optics were as follows:

(a) low focal ratio: f/2.5, chosen to give a wide field of view (4.8 x 3.7 arcmins using a Mitsubishi PtSi detector, with 26 × 20 μm pixels) and a well sampled image (~ 0.5 arcsecs/pixel) on the AAT,
(b) wide spectral coverage: from 1.4 to 3.4 μm, with no chromatic aberration over the width of a band (J, H, or K),
(c) high image quality: spot sizes smaller than 25 μm over the full field of view,
(d) high throughput,
(e) flat image field and
(f) unobscured optical path.

Generally speaking, it is not difficult to design a lens system to have simultaneously a large, flat, field of view, low focal ratio, and high image quality. The problem is eliminating chromatic aberration and achieving a high throughput with the limited range of (expensive) optical materials suitable for the near-infrared. An all-reflective system has the advantage of no chromatic aberration, but usually has the disadvantage of vignetting. We have designed a new off-axis mirror imaging system that overcomes the vignetting problem.

3. Optical Layout

Figures 1 and 2 shows the optical layout of the camera. The light from the telescope forms an image at the telescope focal plane, shown at the top of Figure 1. A flat mirror directs the light to a collimating mirror which produces parallel light for the Fabry-Perot interferometer. The collimator also produces an image of the telescope's pupil (the primary mirror) at the entrance aperture of the camera, thereby eliminating stray infrared radiation coming from outside the field of view. The Fabry-Perot etalon is placed just in front of the camera aperture in order to minimise the required diameter (70mm in this design) and to maximise its etendue (throughput). The outer surfaces of the Fabry-Perot are wedge-shaped to reduce ghost images.

After passing through the Fabry-Perot, the light encounters an off-axis three-mirror imaging system (Figure 2), producing a re-imaged focal plane on the detector, with a scale one-sixth that of the original f/15 focus (i.e., the final focal ratio is f/2.5). A flat mirror M4 is used to fold the optical axis for convenience prior to passing through one of several 2% filters used to remove unwanted orders transmitted by the Fabry-Perot.

All the optical components after the Fabry-Perot are cooled to solid nitrogen temperatures to reduce thermal emission. The detector is also cooled, to reduce its dark-current.

The design process for our off-axis three-mirror system can be considered in three steps.

First, a preliminary configuration of an on-axis three mirror system was designed using geometrical image formulae to satisfy the f/ratio requirements of the camera. This system

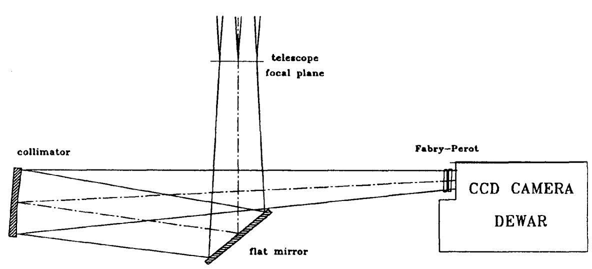

Figure 1 — Collimating optics and Fabry-Perot.

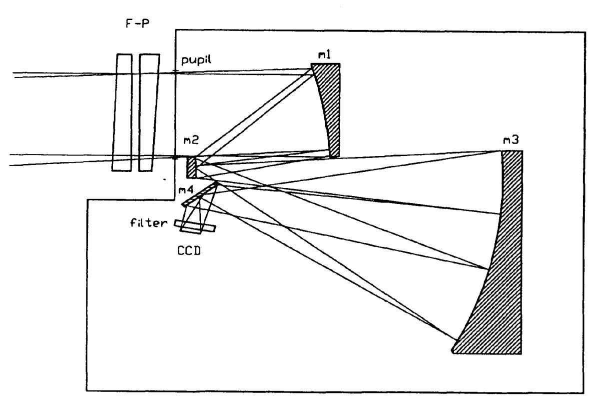

Figure 2 — Optical configuration of the camera.

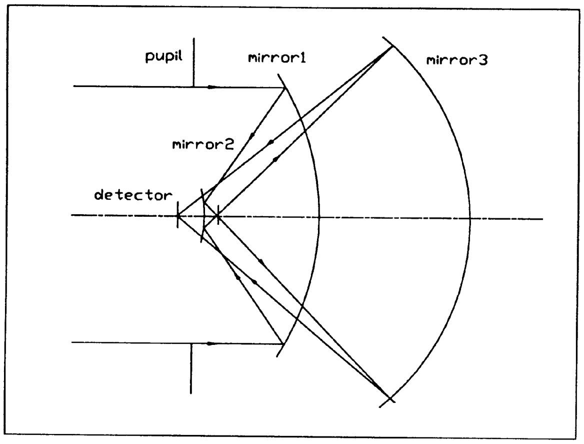

Figure 3 — Preliminary configuration of three mirrors.

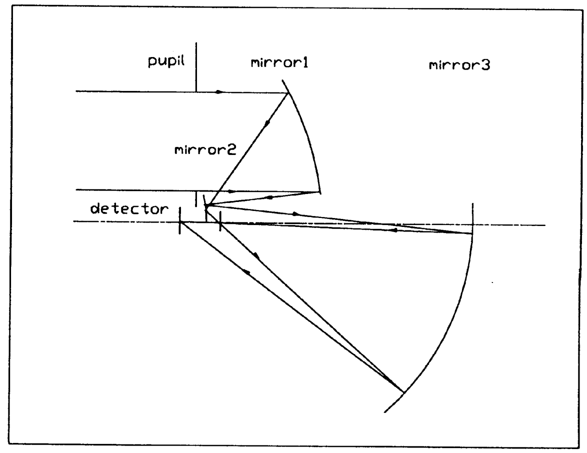

Figure 4 — Off-axis three mirror system.

(shown in Figure 3) has a very low focal ratio of f/0.8 since we will only use about one-third of the aperture for the final design. Mirrors 1 and 2 produce an intermediate reduced image just before mirror 2, where a field stop could be placed. Mirror 3 re-images this intermediate image onto the detector. The distance between mirror 2 and the detector was made as large as possible to allow the insertion of an order-sorting filter.

Secondly, we adopted one-third part of the initial design to produce an off-axis three mirror system, as shown in Figure 4. The design was then optimised using the Kidger Optics design package. Mirrors 1, 2 and 3 were allowed to assume conic shapes, and mirror 3 was given additional fourth and sixth order aspheric deformations in order to flatten the image plane and reduce the system aberrations.

Finally, we modelled the entire optical system, including the primary and secondary mirrors of the AAT and the tilted collimator, and performed an overall optimisation. We were able to successfully remove most of the aberrations introduced by the tilted collimator. Table 1 shows the design parameters, including the primary (surface 1) and secondary (surface 2) mirrors of the AAT (Storey 1981). Note that the design was not finalised when this article went to press, and we expect that small changes to the parameters in Table 1 will be made. Interested people should contact the authors for further information.

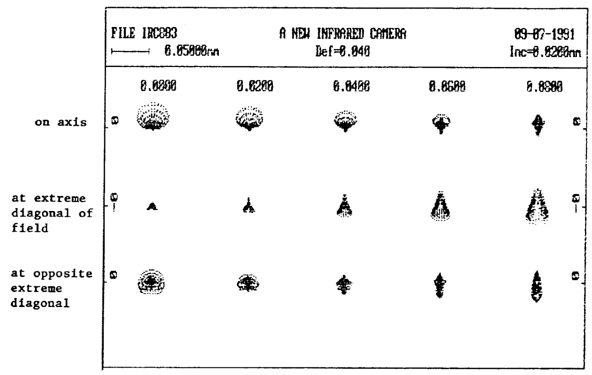

Figure 5 — Spot diagrams.

4. Calculated Imaging Performance

Figure 5 shows the spot diagrams produced by the camera. The five columns in the figure show how the image varies through focus. The three rows show the image quality at the centre, and extreme diagonal edges of the 4.8 × 3.7 arcmin field of view. The bar at the top left of the figure represents a length of 50 μm. The design goal of 25 μm images with a flat field of view has been met.

Table 1. Parameters of the optical system. Please contact the authors for the final specifications.

Surface	Radius Curv. mm	Separation mm	Conic constants	Aspheric coefficients A4	A6
1	-25400.00	0.00	+1.1717	0	0
2	-6722.00	-10077.00	-4.1882	0	0
3	+0.00	+12453.50	+0.0000	0	0
4	-2077.71	+538.89	+0.0000	0	0
5	-289.98	+1237.95	-0.6697	0	0
6	-131.55	-134.05	-13.9878	0	0
7	-228.77	+216.53	-0.0385	+2.53E-10	+6.63E-15
8	+0.00	-252.43	+0.0000	0	0

5. Conclusion and Future Plans

We have presented an unusual optical design for an infrared camera that has no chromatic aberration, no vignetting, high throughput and excellent image quality. We have commenced the detailed mechanical design of the dewar and are seeking advice on manufacturing the camera optics from aluminium using a precision diamond mill. A problem to be resolved is how to mount baffles to prevent stray radiation reaching the detector from unintended reflections. The array detector is in hand, the driving electronics are complete, and we have begun measuring the detector performance in a test dewar.

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