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NSI- Astronomy Technology Program

Technical Note:
Subaru concentric corrector and four barrel GLAO imager Optical Design Concept

Project: Subaru GLAO

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1. Overview:

This document describes an optical design concept for a Subaru GLAO system consisting of an adaptive secondary mirror, concentric corrector and a 4-barrel IR imaging system feed by the concentric corrector.

The concentric corrector provides a universal 22.8' diameter field of view (at f/12.4) with residual optical design aberrations less than 66mas. This corrector is designed to feed multi-barrel optical systems without pupil miss-match.

The imager design concept is a 4-barrel imaging system feed by this corrector with each barrel having a 4kx4k H4RG detector covering a 6.8' x 6.8' field of view (0.1"/pixel sampling). The total imager field of view is 185 square arc minutes.

The concentric corrector provides a useful function of correcting the residual aberration of the telescope at an intermediate focus giving a well-corrected field for the wave front sensors. The corrector can be used to feed instruments other than the 4-barrel IR imager providing a universal GLAO focus station.

This document is a preliminary design concept intended to explore potential optical designs concepts for the Subaru GLAO system.

2. Adaptive Secondary mirror and Concentric Corrector System:

The proposed GLAO system provides a very wide field that is difficult to economically utilize because of the large optics required if the light is brought back to the Cassegrain foci location (currently at 3 meters back focal distance). With an f/12.4 focal ratio the 22.8' field is 0.64m in diameter. For such a field the imager optics will be very large and likely outside the largest diameter which critical materials such as CaF2 (~420mm) are available. If a shorter focal ratio is used the focal surface can be made smaller but a larger adaptive secondary mirror is required unless the focus is moved closer to the secondary. The proposed system has an adaptive secondary mirror 1.26m in diameter. This is in the range of current adaptive secondary mirror manufacturing technology. The concentric corrector allows a multi-barrel approach to be used for the imager reducing the size of the imager optics. Though the corrector optics are large the material is infrasil-302 and is available in the required sizes.

Initial specifications:
Focal ratio: f/12.4 was selected, as this close to the value that gives a reasonable sized adaptive secondary mirror the fits current manufacturing capabilities and is the same as one of the current focal stations used at Subaru.

Entrance Pupil: An entrance pupil located at the secondary mirror was selected; this advantageous for reducing the sky background but comes as a cost of a reduced light gathering for the telescope. The entrance pupil diameter for the 8.3m Subaru telescope is 7.75m, a 12% loss of light gathering. The design can easily be changed to a pupil at the primary with a slightly larger adaptive secondary mirror to regain this lost light. Because the imagers have well corrected internal stops this option should be considered, but this is a topic of for a future study.

Field of View: The 22.8' field of view is based on the space needed to fit the four 6.8' fields with sufficient space, a gap of ~70mm between fields, for the opto-mechanics of each of the individual barrels.

Exit Pupil: The exit pupil of the 'concentric corrector' is to be at the centre of curvature of the focal surface.

Field Curvature: A convex focal surface curvature is selected. This results in the instruments diverging from each other. This implies a Ritchey Chretien (convex) secondary.

Image Quality: A criteria of degrading the median corrected image quality by less than 10%, with goal of less than 5% is selected as a starting point for image quality. The median corrected image quality is assumed to be 0.2", this implies corrector optical image qualities of 0.09" with a goal of 0.06"

Wavelength Range: 0.8um to 2.5um (z through K band), refocusing between bands may be considered but is undesirable. Image quality at 589nm (the Laser guide star wavelength) should also be well corrected and have good transmission.

Optical Design:
The centric corrector optical design is show in Figures 1 and 2 and the image quality in Figure 3. The design consists of a two-element corrector, all spherical surfaces, with an adaptive secondary mirror. The corrector eliminates the field dependent astigmatism in the Ritchey Chretien optical system and images the exit pupil to the centre of curvature of the focal surface. The 'centric' exit pupil allows multiple copies of the same instrument to be arranged on the focal surface. As each instrument is place on the focal surface, normal to the curved focal surface, the instrument looks back to the common exit pupil at the centre of curvature of the focal surface. Thus, the instruments are all identical and do not require non-symmetric optics to work at an off field location.
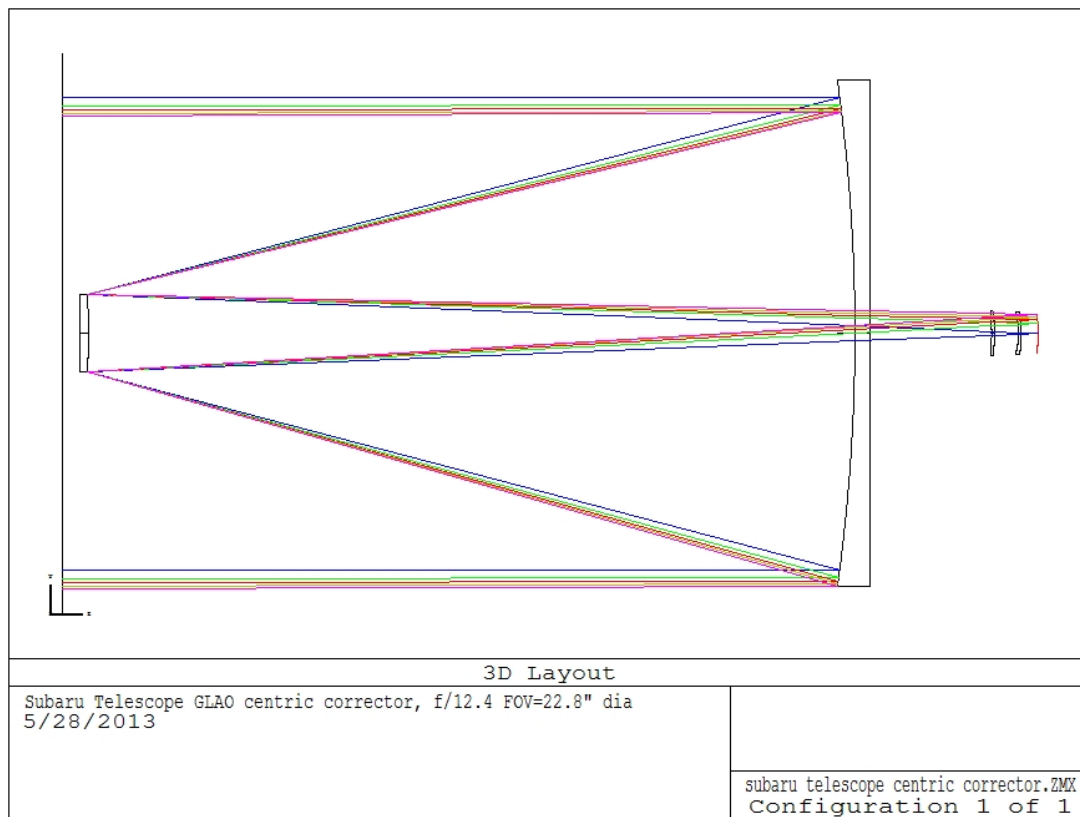


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                          3D Layout
 Subaru Telescope GLAO centric corrector, f/12.4 FOV=22.8" dia
 5/28/2013

                                    subaru telescope centric corrector.ZMX
                                    Configuration 1 of 1
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Figure 1: GLAO centric corrector on telescope

Only two elements are required rather than the typical 3 elements in a Wynne type corrector because the corrector does not flatten the field curvature of the system as is normally done. The net positive petzval sum of the Ritchey Chretien optical system is an advantage because this produces a convex focal surface (as

viewed from the instrument). With the convex focal surface the instruments diverge from each other, allowing more space for the optics and the mechanics.
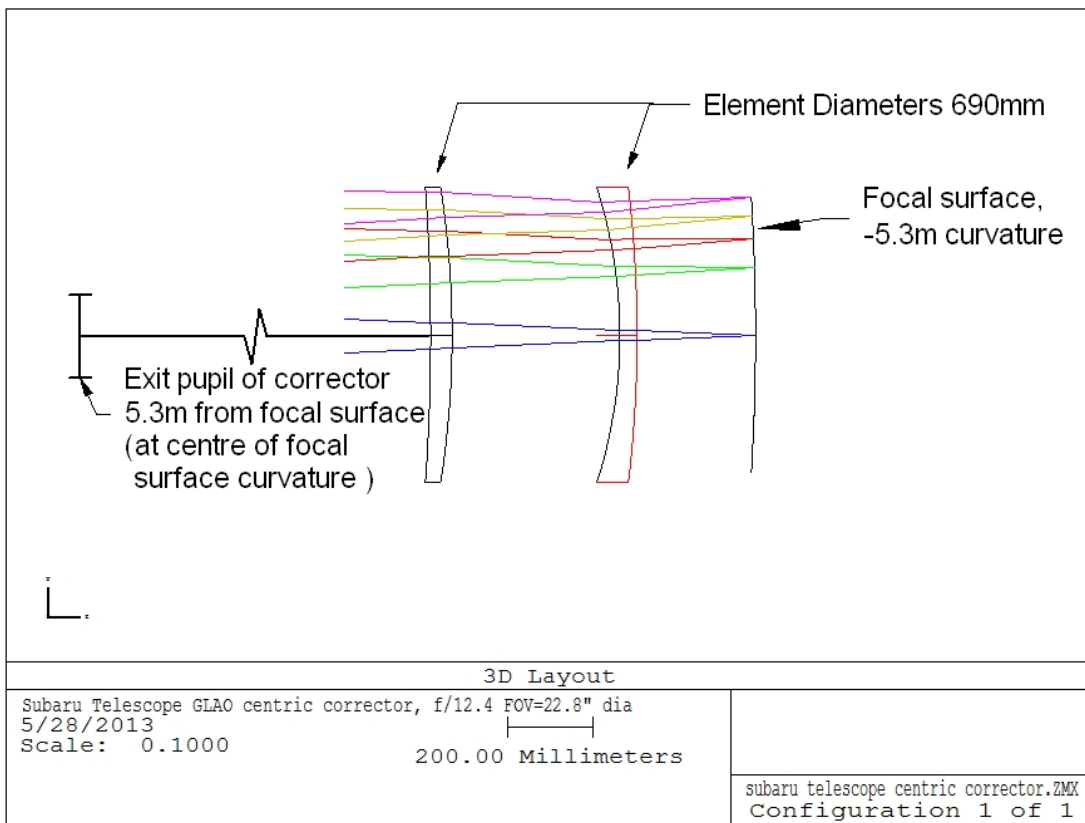

Figure 2: Detail of Centric Corrector

The corrector is zero optical power. With zero power the corrector introduces no colour to the system even though only one glass type is used. Infrasil 302 was selected for the glass type rather than nBK7 or fused silica because of the requirement of good transmission in K band. Infrasil is available in the required sizes for the element. Heraeus quotes a maximum diameter of 690mm for Infrasil 302 in the data sheet and it has been confirmed directly with Heraeus than a 690mm diameter x 100mm thickness 82kg blank can be produced (they can even produce slightly larger blanks if needed).

The image quality of the concentric corrector is a RMS spot diameter < 66mas over the 22.8" FOV. The 'spot' diagram for corrector is shown in figure 3. The box width in the spot diagram is 0.21" and the plate scale is 2.14"/mm. These aberrations are the optical design residuals; i.e. the aberrations in Zemax for the perfect system without manufacturing and alignment errors. The optical design residuals meet the goal for image quality of < 5% degradation of the 0.2" mean corrected image quality. Image quality of the fabricated system will be worse than the optical design residual. Typical systems are about 50% worse than the optical design residuals. Image degradation between 5% and 10% of the 0.2" mean seeing is reasonable to expect for the fabricated corrector. The optical

design residual can be improved with the introduction of aspheric surface on the corrector if needed.

The back focus of the image surface from the primary mirror is 3m. This is the same as the current f/12.4 focal station on Subaru.
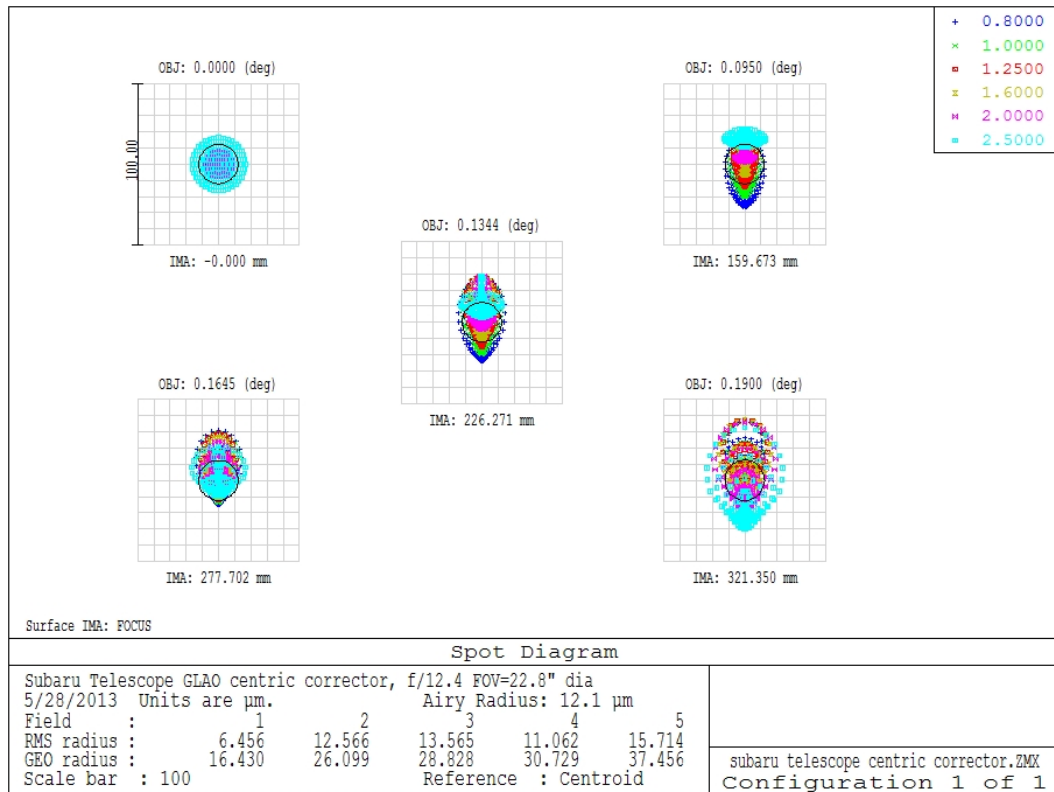

Figure 3: image quality of concentric corrector (Image at intermediate f/12.4 focus after corrector)

3. 4-Barrel Imaging System

The imagers are derived from the CFHT WIRCAM instrument design. The sampling is 0.1" per a 15um pixel corresponding to critical sampling at the median GLAO corrected seeing of 0.2". Critical sampling at the median seeing gives a larger field but the system will be under sampled at the times of best seeing. The larger 15um H4RG-15 pixels were selected over the 10um H4RG-10 pixels to give the camera a slower focal ratio. The camera focal ratio with the 15um H4RG is a modest f/4 rather than f/2.7 required for the 10um pixels. With the slower focal ratio the camera design is simpler and opto-mechanical stability is much less stringent. This is at the cost of slightly larger camera optics, which will be paid back by the relaxed fabrication and stability tolerances.

The layout of the images is shown in Figures 4, 5, and 6. The cameras are within a volume of 2.1m in length and 0.8 in diameter. A window has been put at the entrance to the cameras, with the intention of the cameras being enclosed in the Dewar with the corrector and wave front sensors outside the Dewar. The cameras have been designed with a sharp pupil image.
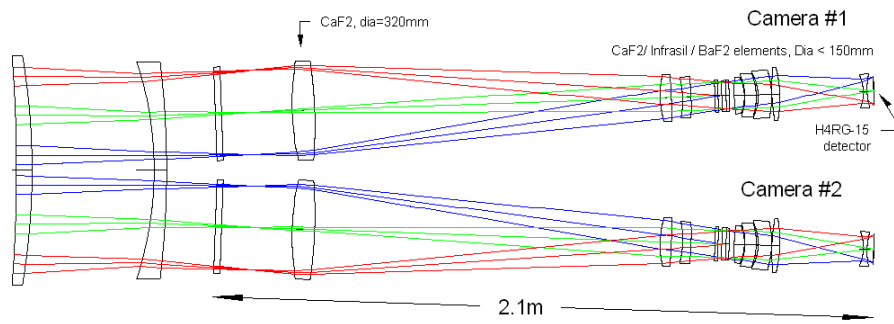
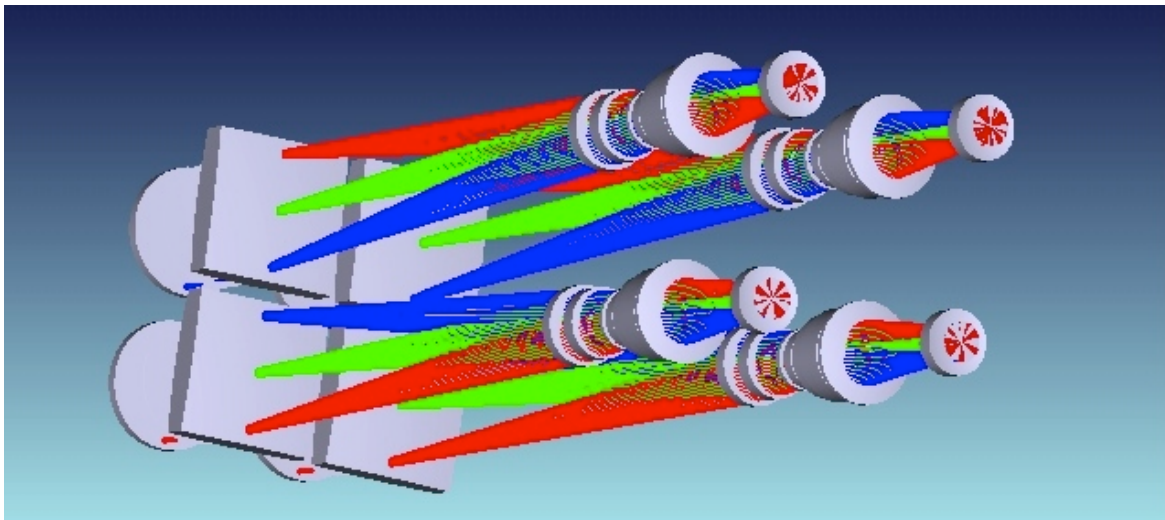**Figure 4: Layout showing two of the imager cameras**

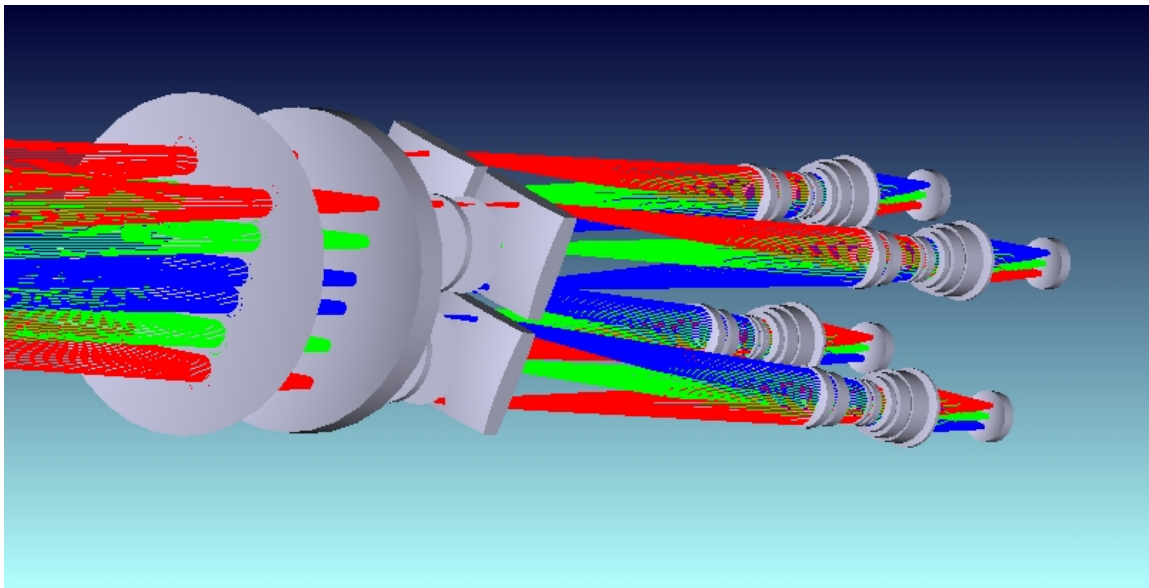**Figure 5: Layout of the 4 cameras viewed from back**

Figure 6: Layout of the 4 cameras with corrector viewed from front

It may be possible to rely on a cold stop at the camera pupil and move the telescope stop from the secondary to the primary and still have good background suppression with a net gain in telescope aperture. There is a filter included in the design located just after the stop as in WIRCAM.

The image quality is shown in Figure 7. Spot quality is less than pixels at all points except at the outside corner were the image quality is marginally more at 16um RMS spot diameter. This meets the general rule of thumb of a spot size less than a pixel for an imaging system.
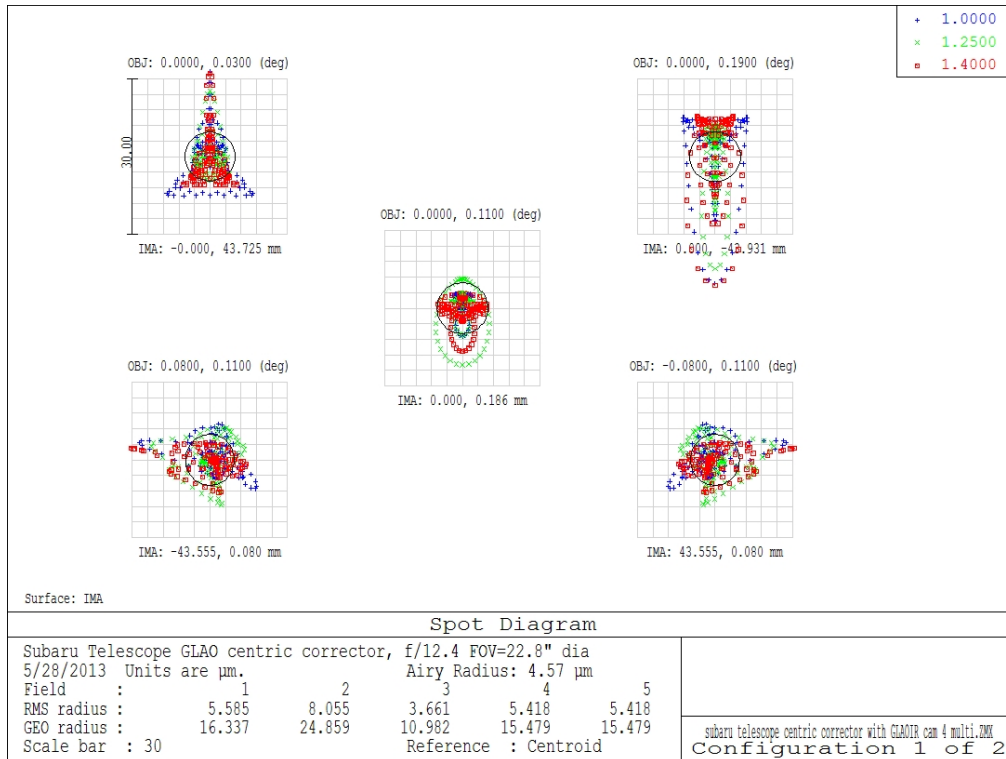

Figure 7: Imager image quality, box is 2 pixel width

4. Summary

The design concept presented solves the problem of large optics by dividing the field into four sub-systems. A concentric corrector is used to feed the sub-systems eliminating the need for non-symmetric optics in the sub-systems. Image quality at this stage of the design process indicates the design is feasible. The imager cameras are based on the CFHT WIRCAM, the cost of WIRCAM was ~4m$, of which ~1.7m$ was detectors. The H4RG-15 detectors are lower cost than the four H2RG detectors used in WIRCAM. The back of the envelope costing for this instrument would be 4m$ for the first camera, and 3m$ for each of the other 3 cameras. The corrector cost is probably the order of 3m$ to 5m$, giving a total cost for the corrector and cameras of ~18m$. The WFS's and adaptive secondary mirror costs are not included, as well as the other related

system costs. This is only a rough order-of-magnitude costing based on historical costing data. As a cautionary note, WIRCAM labour cost are in part subsidized for the CNRS contributions to WIRCAM and it is difficult to determine the full project costs.

The image cameras have an internal stop and are similar in design to a MOS/imager design. The optics for an imager are simpler in that the collimator and camera are designed together with aberrations being passed from one to the other. In a spectrograph the grating aberration greatly reduce the aberrations that can be passed between the collimator and the camera introducing greater complexity for the optical design of MOS systems. This is only a part of the greater cost of MOS systems. Spectrographs required a greater mechanism count with the mask system and require greater stability for accurate sky subtraction and wavelength calibration.