MMIRS Technical Memorandum

MMIRS Calibration System Design Concept

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Updates:

estimated: Aug 1 2007 – v1.0
detailed mechanical design, exact cost estimate and schedule

15 July 2007 - draft
1^{st} draft version: concept and part identification, rough cost estimate

1. Introduction

In this document a calibration system is proposed and described for the MMIRS instrument. The calibration unit would be part of MMIRS, attached to the outside of the MOS section in front of the corrector assembly. Therefore no telescope facility is required for calibration, and the same calibration system would be used at both telescopes (MMT and Magellan).

This memorandum briefly summarizes the optical and mechanical requirements (section 2), then a short description of the design evolution is given (section 3). In section 4 we describe in detail the optical, mechanical and electrical design of the proposed calibration system. Section 5 gives a list of parts and estimated cost of items, than a preliminary schedule (section 6) is sketched. Finally we list the open issues, not detailed design problems (section 7).

2. Requirements

2.1. Optical guide lines

The following requirements were the basic guide-lines for the optical design:

a. provide even illumination of an incandescent source over the detector area (18×18 mm) for flat-fielding, without any small scale variation or structure (slow, large scale variations – if not time dependent – are allowed, as can be subtracted during data reduction)

b. provide even illumantion of an emission-line source the detector area (18×18 mm) for wavelength solution determination. Even illumination is not as critical as for flat-fielding, however to ensure self-consistency between the solutions of different objects high level of uniformity is desired.

c. provide enough flux for both type of light sources (mentioned above) to maintain reasonably short exposure times for calibration frames

d. mimic the telescope's f/5 beam as close as possible, in order to maintain similar angle of incidence at detector as stellar-source liht rays. This is crutial in order to effectively remove fringing from images

e. do not interfere with scientific light path, e.g. scientific imaging or spectroscopy is not affected by any vignetting etc. caused by any component of the calibration system

f. make sure origianl baffle system is working for the calibration light path as well, and if not additional baffles must be designed but with e) kept in mind

2.2. Mechanical guide lines

The following requirements were the basic guide-lines for the mechanical design:

a. must be part of instrument, so calibration system would be given (and the same) for both telescopes

b. must fit within the opening of the primary mirror cell

c. instrument with cal. system mounted must fit underneath the telescope while (while instrument sitting on its cart and rolled under telescope for mounting)

d. serve as cover for optics in the calibration setup, or have an independently controlled but integrated optical cover assembly

e. work dependably under any gravitational load, as being part of instrument and mounted on rotator the gravitational field is changing

f. any mechanical malfunction must not endanger the corrector optics

Among all these the very limited space constraints were mainly driving the design.

2.3. Electrical guide lines

The following requirements were the basic guide-lines for the electrical design:

a. as cal. system is not accesible when instrument is mounted, spare light/power sources must be built in and switching should be automatic/possible from outer/software controll interface

b. must generate minimal heat, as enclosed in a small and sort-of closed volume within the optical light path internal seeing can be disturbed by heat generated in the calibration system

c. provide reasonably short setup time for cal. light injection

d. as non-imaging optics high level of absolute accuracy in moving stages is not required

e. adjustable flux of light sources, as the J, H and K band response of the instrument can be significantly different (mainly for flat field source)

f. any electrical malfunction must not endanger the corrector optics (CaF_2 element is sensitive for heat load possibly coming from overheated incand lamp)

3. Design Concept Evolution

3.1. Solutions for Similar Problems in Other Instrument

As an obvious analogous problem, the Hectospec/Hectochelle calibration system at the MMT was examined.

The Hectospec solution is tied to the telescope chamber, and would require similar installations/modifications to the Magellan dome as it was done for MMT. This is rejected by our guide lines.

The Hectochelle option, ThAr lamps mounted in front of the secondary (within the optical shadow of the secondary), is also rejected as beeing an IR instrument the entire secondary is masked by the Lyot stop.

The Flamingos II instrument for the Gemini telescope has the advantage of using the GCAL unit, the Gemini Facility Calibration Unit. This is a very nice overall solution for calibrating any instrument of a given telescope using a common system, however our part-of-the-instrument guideline also rejects this option. Not to mention the level of complication/cost of such system. However, it is worth to note that future telescope designs would benefit a lot from such pre-thinking and design of a facility calibration unit. They also claim a very high throughput (real advantage for high-resolution spectroscopic applications using faint ThAr lamps).

An other example we had closer look is the Hydra fiber-feed MOS calibration system, which deployes a removable diffuser screen in front of the focal plane, illuminated by instrument-mounted ("internal") light sources. This solution can be intagrated, part of the instrument, however in bvery tight volumes the even illumination can be a real challenge.

3.1.1. Wavelength Calibration Methods, Sources

Besides the obvious and common flat-fielding requirements of imaging, the spectroscopic mode of MMIRS also requires a definition for a pixel position–wavelength solution. The atmosphere can serve in the NIR bands (J, H and K) as a reference, as night sky lines (non-thermal atmospheric lines: air glow; atmospheric molecular absorption lines – for λ>2 μm also in emission) clealry show up on longer exposure time integrations. However short exposures (e.g. standard star observations) require an artifical calibration source. The following web-site has some useful information on NIR calibration methods and techniques, as it was one of the main topics of an ESO Instrument Calibration Workshop held in Garching, Germany, January 2007: http://www.eso.org/sci/meetings/cal07/index.html

As artifical sources the ones below were explored by others, with the listed main properties/problems/advantages found (from H.U. Kaeufl's presentation, see link above):

source	*λ – range [nm]*	*brightness*	*line-density*	*operational constraints*	*absolute precision*
OH-airglow	950 – 2000	acceptable	marginal	needs tel. @ night	~20m/s (tbc)
atmospheric absorption lines	950 – 1900	na	marginal to acceptable	not for long-slit mode	~15-20m/s (tbc)
	1900 – 5200	acceptable – good	acceptable to good	needs tel. @ night	~ 15-20ms (tbc)
gas cell absorption (std)	2000 - 5200	acceptable – good	good to very good	cumbersome operations	< 1m/s v **absolute (!)**
gas discharge lamps	950 – 2500	very good	inappropriate	none	< 10 m/s
hollow cathode lamps	950 – 2500	marginal	good to very good	illumination compromises	< 10 m/s (c.f. P 17)

Table 1 – ***Properties of NIR wavelength calibrator sources***

As mentioned, atmospheric lines could be used with MMIRS in certain exposures.

The gas cell absorption solution has the advantage that once the flat field illumination is eveloped, it can be just inserted into the light path. However N_2O and OCS mixture would be ideal for the 1-2.5 micron bandwith, chemical stability is still to be proven, as well as leakage and pressure/thermal stability issues have to be addressed. Also, for the relatively low resolution of MMIRS the line density is too high.

The ThAr/hollow cathode lamp solution could be a god one, with appropriate line density and stability, but the intensity lewel is very low (see Hectochelle experiences). Still, proper illumination is required, and the diffusing options detailed below all sacrifice too big amount of the already low intensity.

The only applicable artifical source we left with is the gas discharge lamps, especially the Ar filled lamps. See figures below for the lines and relative intensities (source: GCAL web page, http://www.gemini.edu/sciops/instruments/gcal/gcalIndex.html)

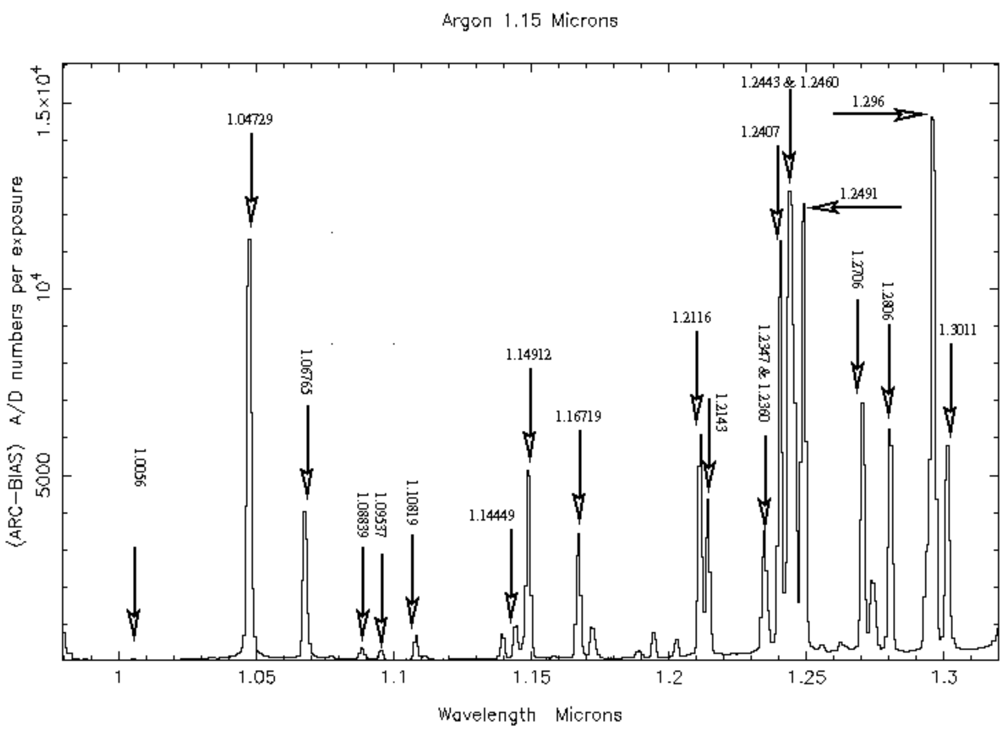
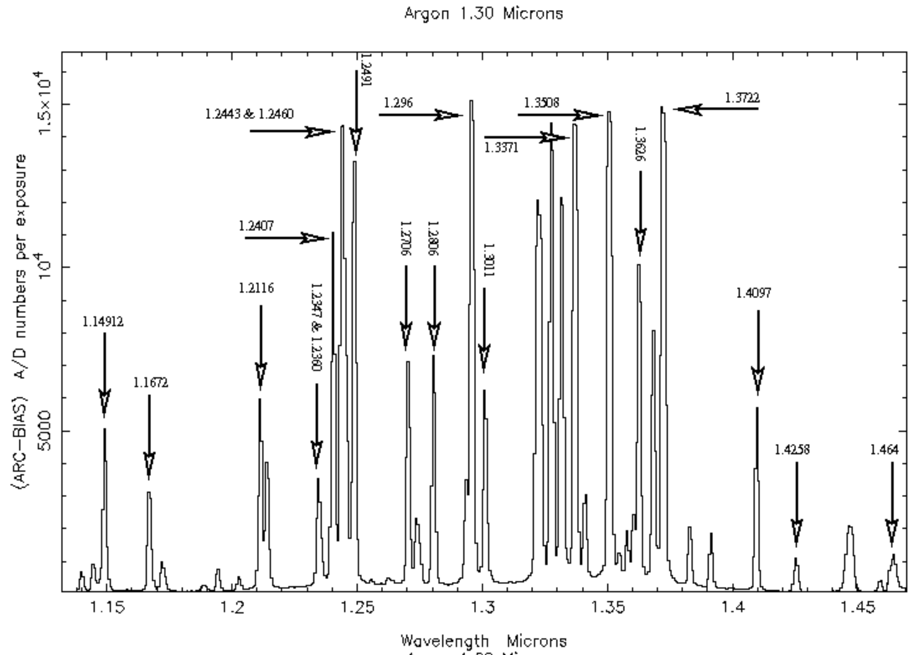
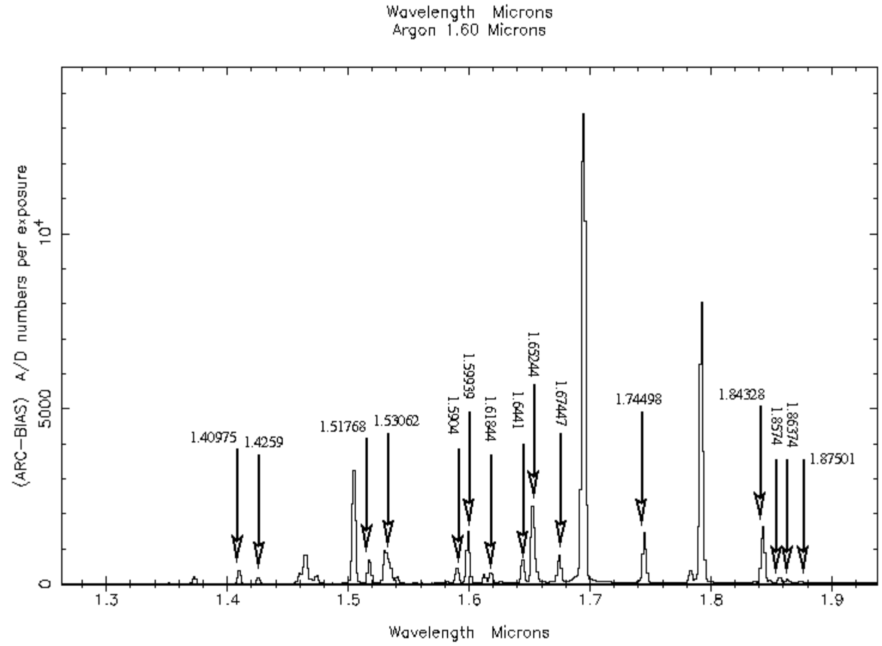


Figure 1 a,b,c and d – ***Lines of an Ar pen ray lamp***


Argon 1.30 Microns
(ARC-BIAS) A/D numbers per exposure
Wavelength Microns
1.14912
1.1672
1.2116
1.2347 & 1.2360
1.2407
1.2443 & 1.2460
1.2491
1.2706
1.2806
1.296
1.3011
1.3371
1.3508
1.3626
1.3722
1.4097
1.4258
1.464


Argon 1.60 Microns
(ARC-BIAS) A/D numbers per exposure
Wavelength Microns
1.40975
1.4259
1.51768
1.53062
1.5904
1.59939
1.61844
1.6441
1.65244
1.67447
1.74498
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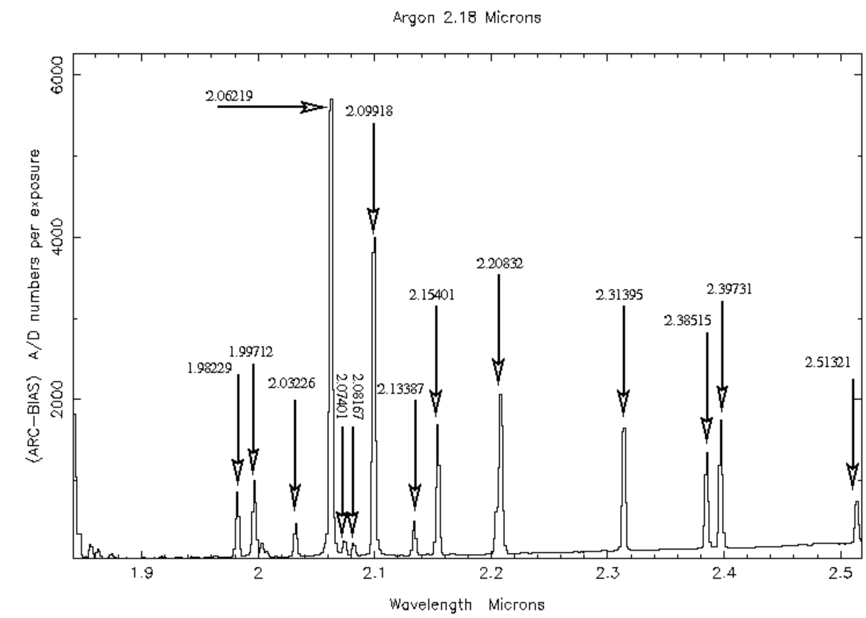
1.86374
1.87501



3.2. *Absolute Real Time Solution or Flexure Tracking*

We briefly examined the possibility not to use a real-time calibrator (gas discharge lamp), but rather use a simpler "tracking" system. In this scenario the pixel-to-wavelength mapping would have been done based on one or more long exposure time image showing the atmospheric features, also registered by the tracking system. Then short integrations could be calibrated by interpolating/predicting the wavelength solution based on shifts registered by the tracking system. Such tracking could be done by a NIR laser line, by placing a standard calibration mark (small slit aperture) in very slit mask (e.g. in one of the corners), and illuminating it with an internal source. A laser diode could be placed locally above the slit mask wheel, or the light could be guided there by relay/projection optics. However, single line (single wavelength) solutions assume a pure linear shift in the wavelength solutions, any nonlinear effects would require more tracking points/wavelengths.

Even the Flamingos I experience was that wavelength calibration frames could be just taken a day after in the same telescope/instrument position (e.g. virtually "tracking" the flexures this way), there are several problems with developing and relying on such tracking system. (Operating the source at cryogenic temperatures; adding the source/projection system to the almost all built MOS section; asuming linear shifts of the wavelength mapping in the simplest solution; etc.) So, we soon rejected this option.

3.3. *Examined Possibilities*

Due to tight space constraints first a possible internal illumination system was explored, than we moved to the outside of the MOS cell.

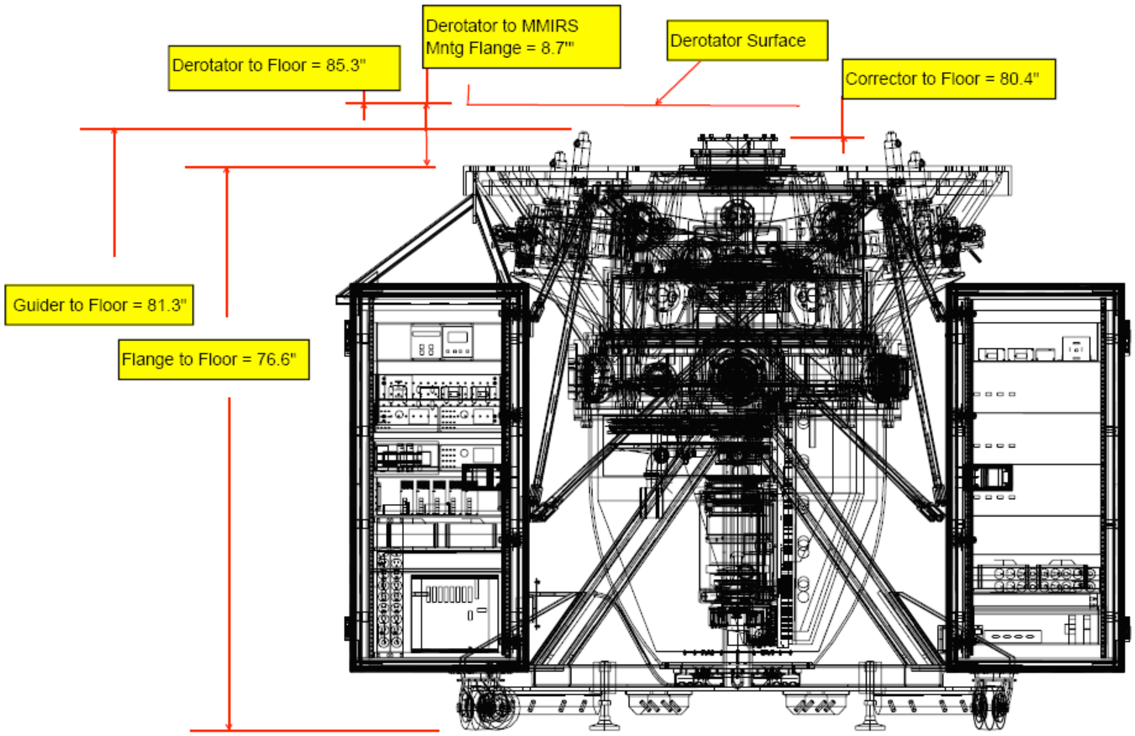


Figure 2 – *Clearence requirements for MMIRS at the MMT*

3.3.1. Pull-over Diffuser Screen

3.3.2. Internal Sources

3.3.3. External Sources

3.3.4. Integrating Sphere Solutions

4. Review of Selected Design

The best design concept we could come up with, as an after-design add-on calibration system for MMIRS, is the following:

Both flat-fielding and wavelength-calibrating light sources are diffused by the same integrating sphere. The exit pupil of the sphere is conjugated to the Lyot stop of MMIRS optical train by a NIR Fresnel lens, mounted right in front of the correcotor assembly. The spehere is located outside of the main optical axis, in a permanent location, and the calibration light is projected into MMIRS by the means of a deployable fold mirror. The Fresnel lens and the flat mirror are mounted on a linear, ballscrew-driven stage, actuated by the standard MMIRS Phytron stepper drive assembly.

4.1. Optical Layout

The figure below gives the optical layout in a linearized view, using sequential ray tracing and paraxial Fresnel-lens approximation of Zemax.

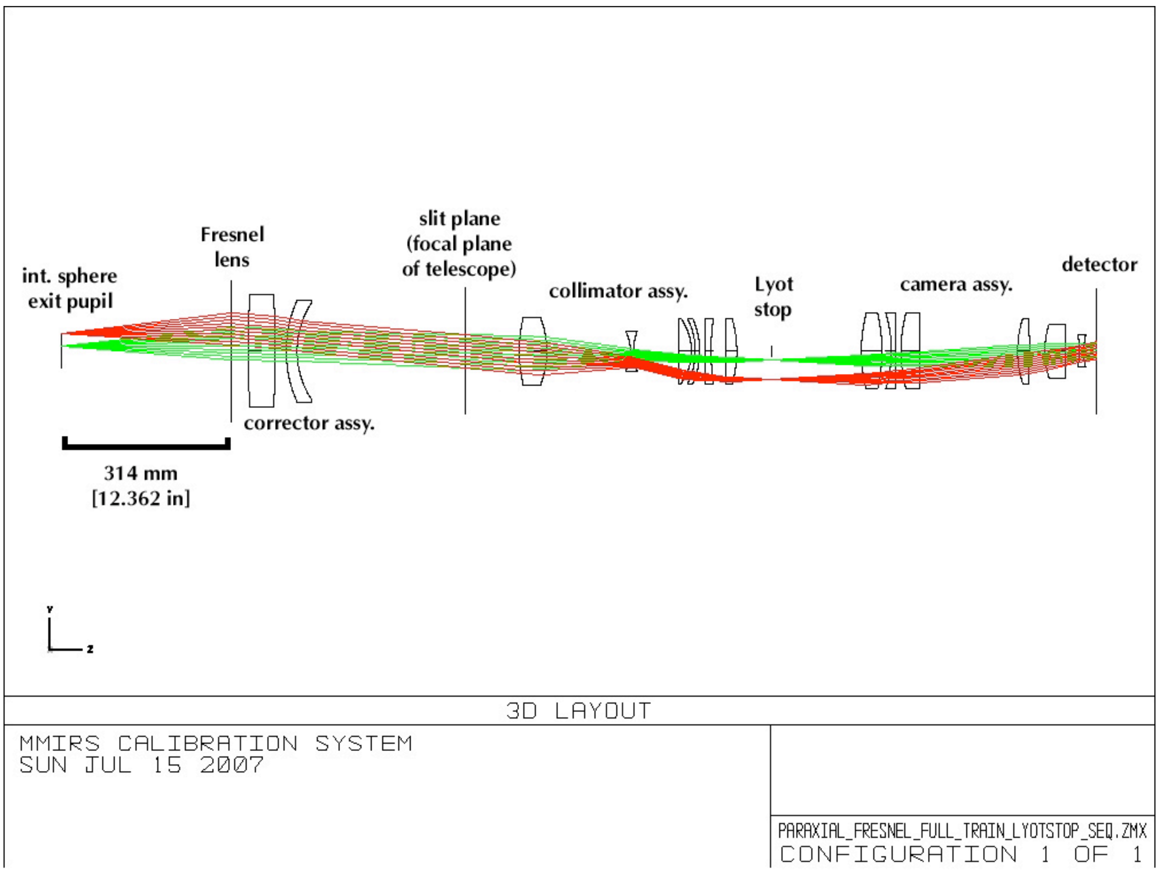


Figure 3 – ***Linearized optical layout of the calibration light path***

The exit pupil of the sphere is conjugated to the Lyot stop of MMIRS by the Fresnel lens deployed in front of the corrector assembly. The focal length of the fresnel lens is choosen that the sphere can be placed (via a fold mirror) outside of the MMIRSoptical axis.

A shorter distance means that more light can be captured by the Fresnel lens, so shorter exposure timescan be applied. However, we have to make sure that in the folded light path photons can only enter the MMIRS optical train reflected from the fold. So some baffleing is necessary betwwen the fold and the sphere, which initiates a bit longer off-axis distance.

Another trade-off in setting the distance is the size of the exit port on the sphere. While a 178 mm focal length Fresnel can result a 1.5 inch opening (while maintaining the unvignetted illumination of the 70x70 mm focal plane of the telescope; therefore the full 50 mm radius aperture of the Lyot stop; and so the full 36x36 mm detector array), it would put the sphere too close to the optical axis and proper baffleing could not be constructed.

Also, a short focal length Fresnel lens makes the focal plane of the telescope (slit plane) conjugate to the back of the selected integrating sphere (6 in "Spectralon" sphere by Labsphere). That means any small-scale structure of the sphere illumination would be directly transferred to the detector, and that is not acceptable.

Using a 318 mm focal length lens the exit pupil of the sphere would be 314 mm before the Fresnel lens, latter placed ~1.5 inches from the first surface of the corrector. This assures a conjugate relation between the Lyot-stop and the sphere exit, and a way out-of-focus (a non-conjugate) realtion in terms of the slit plane and the internal surface of the sphere.

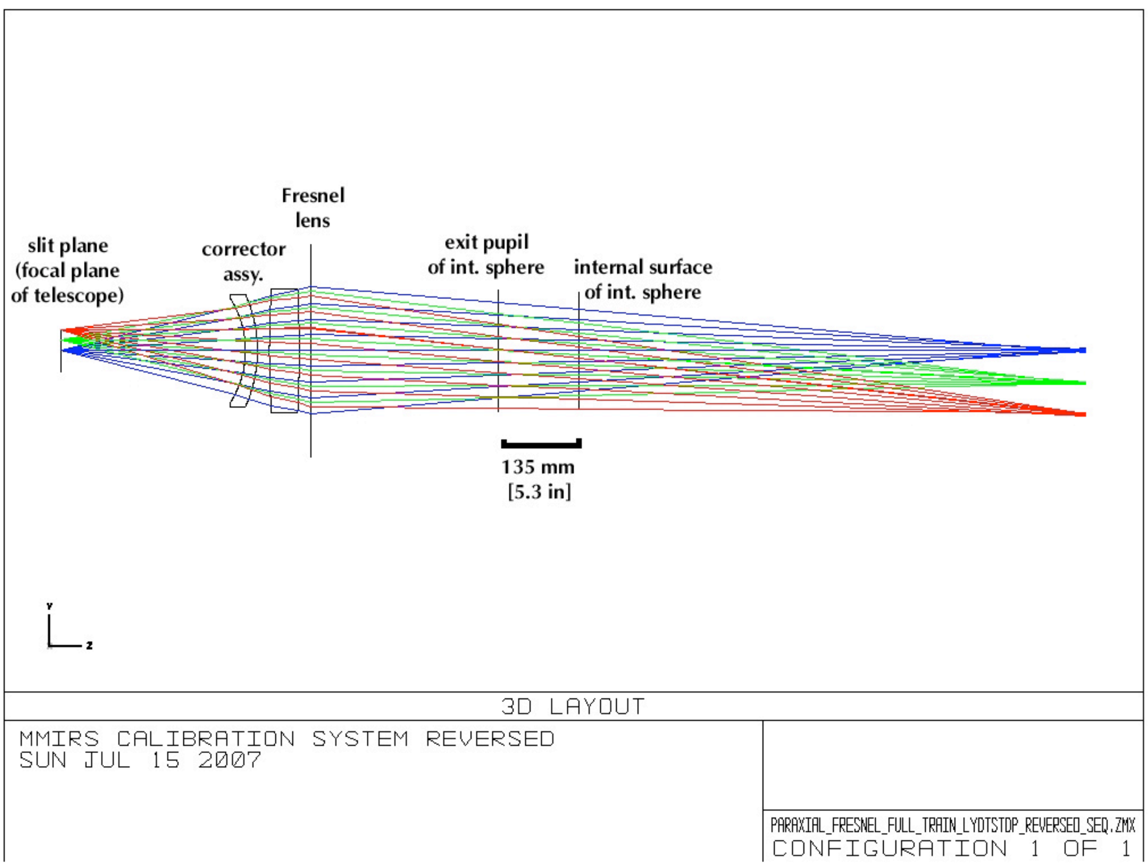


Figure 4 – ***Conjugate-plane check for the 318 mm focal length Fresnel lens***

The choice of Fresnel Technologies #33 lens (f=318 mm, clear aperture of 267 mm) is favorable in terms of the off-axis distance (see figure of non-sequential Zemax model below), however the exit pupil diameter of the sphere is increased to ~63 mm (2.5 inches) for proper illumination of the MMIRS aperture stop. By chance, it coincides with the standard exit port diameter of the selected integrating sphere. As the other ports (illumnation ports) are 25.4 mm (1 inch) in diameter, the port fraction is just above 7%. This is a bit above the rule of the thumb 5% limit, but using the highest reflectance Spectralon material, the output intensity should be still high and uniform enough.

To make sure the detector illumantion is uniform with the calibation system described above, we made a non-sequential Zemax model and performed illumination tests. The layout of the cnfiguration is shown on the following figure:

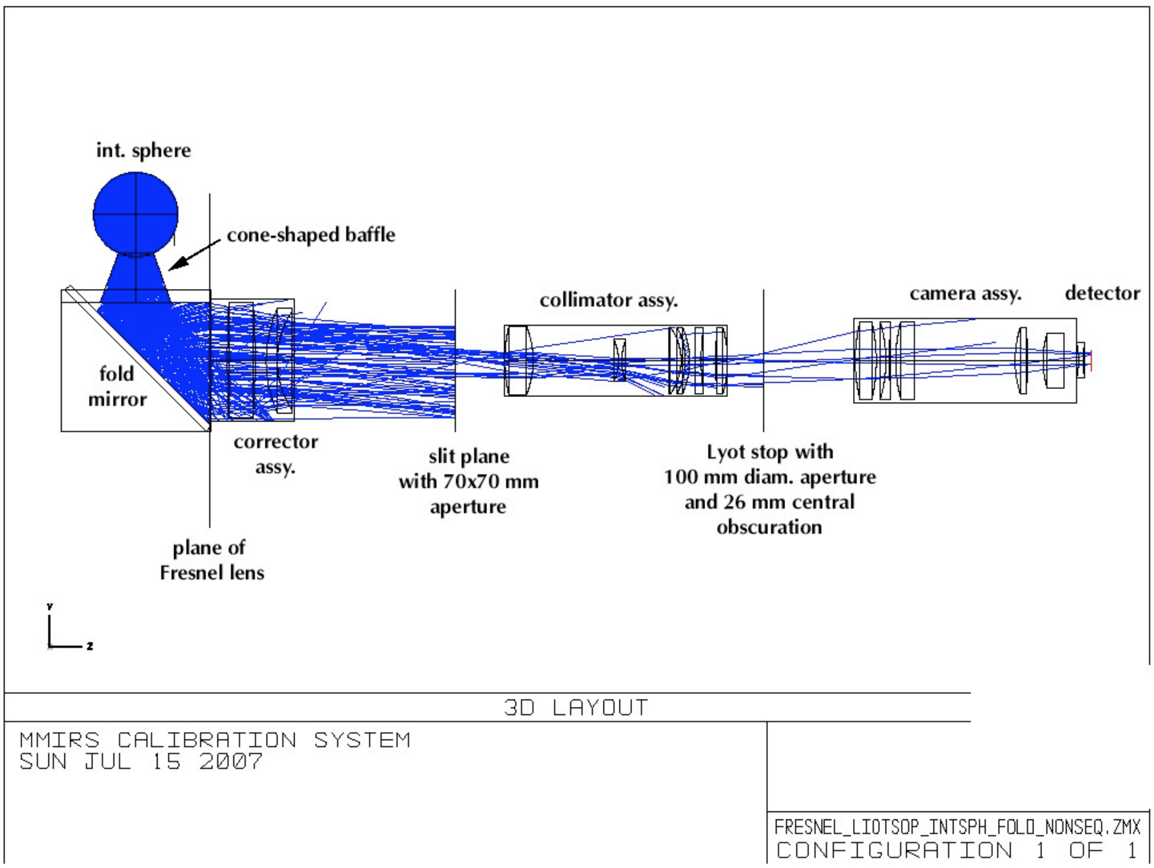


Figure 5 – ***Non-sequential Zemax model of MMIRS calibration system***

There is a 2.5 inch opening on the sphere, which has a Lambertian scattering inner surface. Most of the rays exiting this port are directed towards the fold mirror; the ones exiting at larger angles (and potentially entering the MMIRS optical train directly) are eliminated by an absorbing, cone-shaped baffle. Some rays still can hit the first correcotr lens, but those never make it further than the bezel of that lens. however, this implies that care has to be taken in the mounting/baffleing of the corrector lens.

The folded rays are collected by a 318 mm focal length, 1.6 mm thick Fresnel lens. the slit plane has a square 70x70 mm paerture, representing the 7'x7' FOV of MMIRS. This coresponds to a Lyot stop aperture of 100 mm in diameter, and a 36x36 mm illuminated area at the detector plane. Using the non-sequential ray tracing of Zemax (with 1000 max. segments per ray; 1000 max intersections per ray; 10000 rays per tracing; averaging 1000 traces), we got the following illumination pattern using a 36x36 and a 48x48 mm detector (bith with a 64x64 pixel resolution):

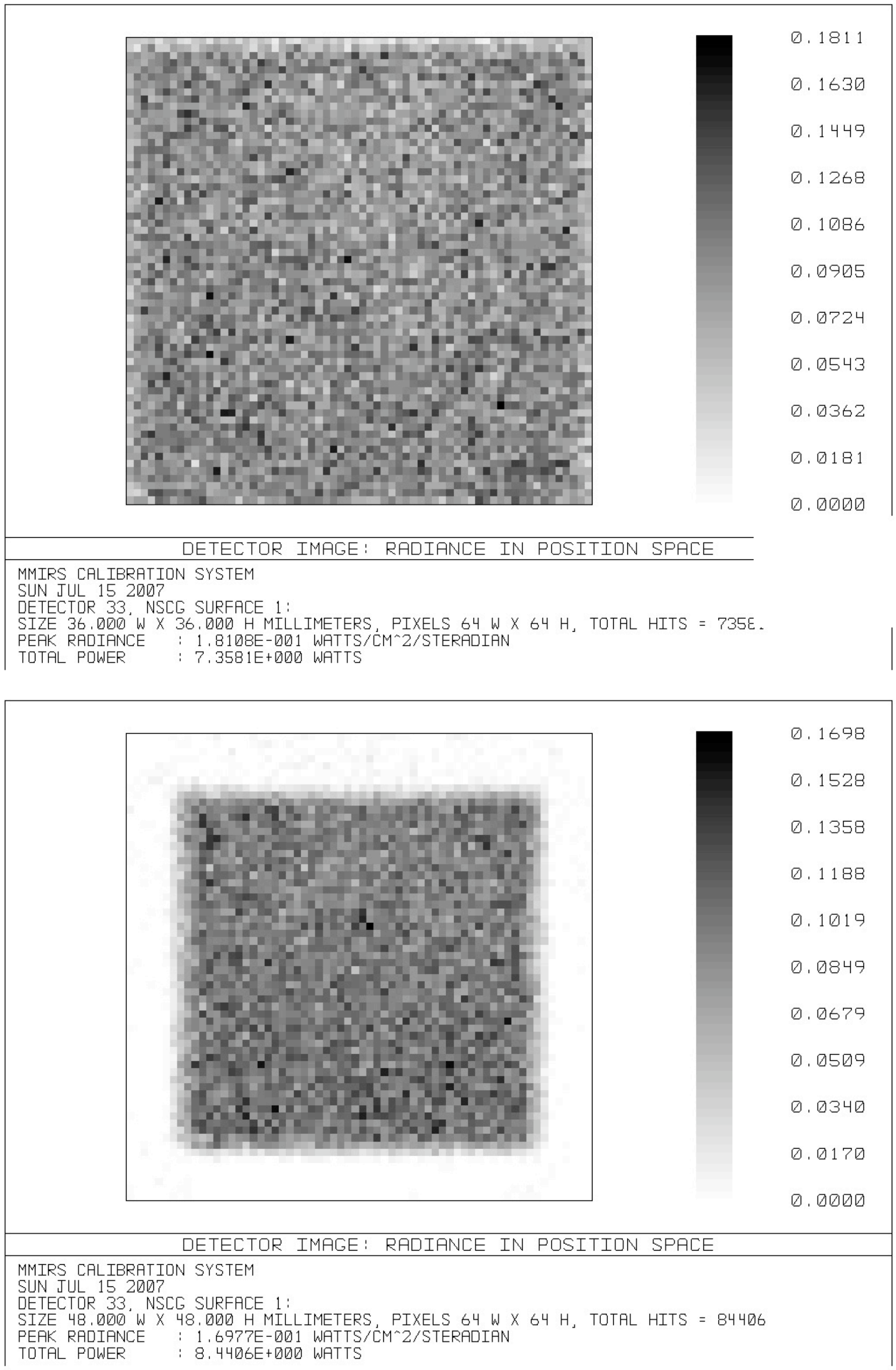


Figure 6 – ***Results of illumination analysis***

4.2. Mechanical layout

same linear drive and guide as for guider stages
torque requirements: 0.007 Nm starting torque; 0.0047 Nm to raise 1 lb against 1 g

4.3. Electronics

same Phytron stepper + gearhead + break as for guider stages
Hall effect limit switches
2 incand lamps
4 pen rays
shutter?

5. Part Identification and Cost Estimate

Table of parts/items to be purchased:

Part	Vendor	Part No.	Quan.	Price (1 pc)	Lead time
Int. sphere	Labsphere	3P-GPS-053-SL / AS-02286-053	1	$1500	?
Fresnel lens	Fresnel Technologies	#33	1	$76	?
Fold mirror	?	?	1	?	?
Incand lamps	?	?	5	?	?
Pen ray lamps	?	?	10	?	?
Linear drive	THK	KR3306A+300LP1-01_0	1	$1217	4-6 weeks
Linear guide	THK	SR25	1	?	?
Stepper	Phytron	ZSS 52.200.2.5-KEB02-GPL52/6.25-SPA	1	$1290	8 weeks

Table of parts to be manufactured:

See mmirs_calsys.mf1 and mf2 files at the MMTI wiki pages under MMIRS/MMIRS Local Archive

Part	Vendor	Mate-rial	Blank size	Draft hours	Machin. hours	Finish	Total cost

6. Schedule

7. Open Issues