Spartan Infrared Camera

High Resolution Imaging for the SOAR Telescope

www.pa.msu.edu/~loh/SpartanIRCamera

Ed Loh, Physics & Astronomy
Michigan State University, East Lansing, MI Loh@pa.msu.edu

- Imaging at 1-2.5μm with tip-tilt correction for atmospheric turbulence
  - –High angular resolution: FWHM expected to be less than 0.25 arcsec
  - –Significant fraction of the light is in the diffraction limited part of stellar image @ H & K
- Instrument Design
  - –Aluminum mirrors
  - –Symmetry ⇒ stiffness
  - –Alignment of optics with metrology
  - –Novel thermal reflector
  - –Electronics
- Test of Image Quality in Laboratory

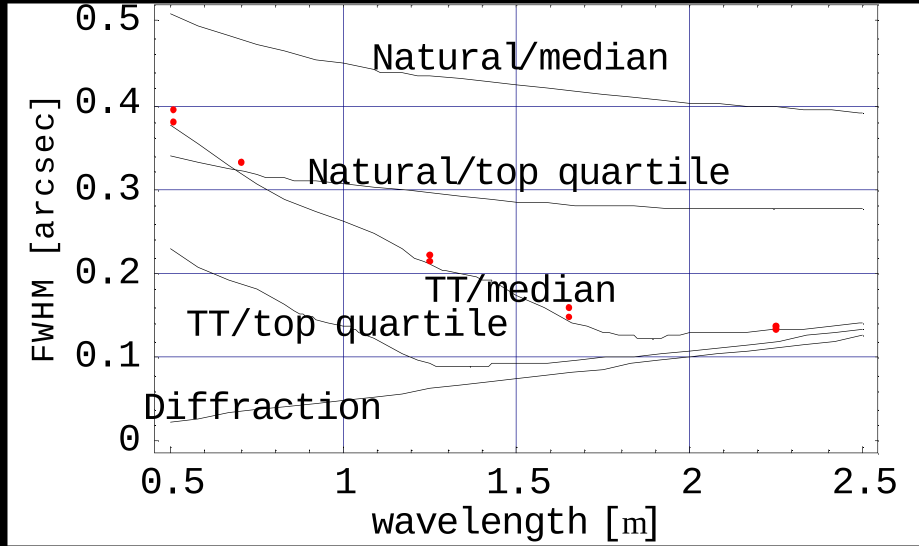
We thank Michigan State University, SOAR Telescope, National Council for Scientific and Technological Development of Brazil (CNPq), State of São Paulo Research Foundation (FAPESP), & US National Science Foundation for funding the Spartan Camera.

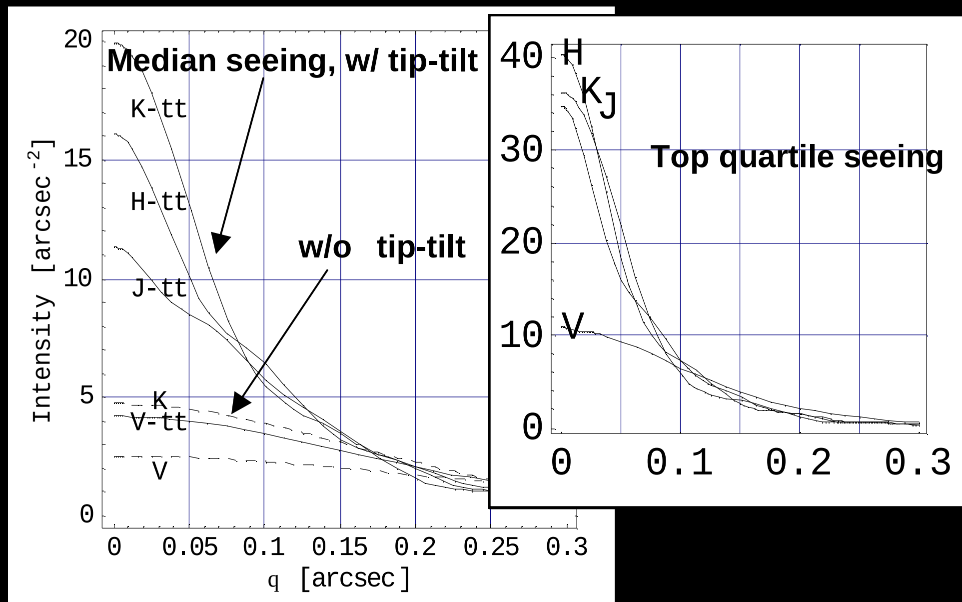
Science Objective: High Resolution Imaging

- Prediction for tip-tilt correction of atmospheric turbulence
  - @ 500nm, r_0=20cm (median seeing) & 30cm (top 25%)
- Observing with tip-tilt
  - Point-spread function has spike of diffraction width & broad wings
  - Spike has substantial amount of light in H & K bands.
    - » Strehl≡(amplitude in diffraction core)/ideal

Band	Strehl Top 25%	Strehl Median
K	0.50	0.28
H	0.30	0.12
J	0.15	0.05

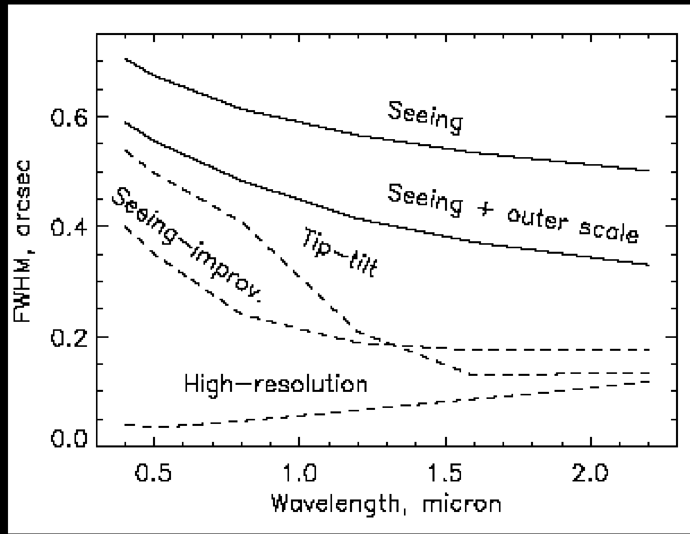
  - For optimal estimate of flux of point sources, tip-tilt gets 0.4 mag deeper or takes ½ observing time.
- For 1hr exposure, mJ=24.6, mH=23.1, mK=23.2.
  - 5σ; aperture for max S/N; median seeing; 10C; ε=0.1; MKO filters.

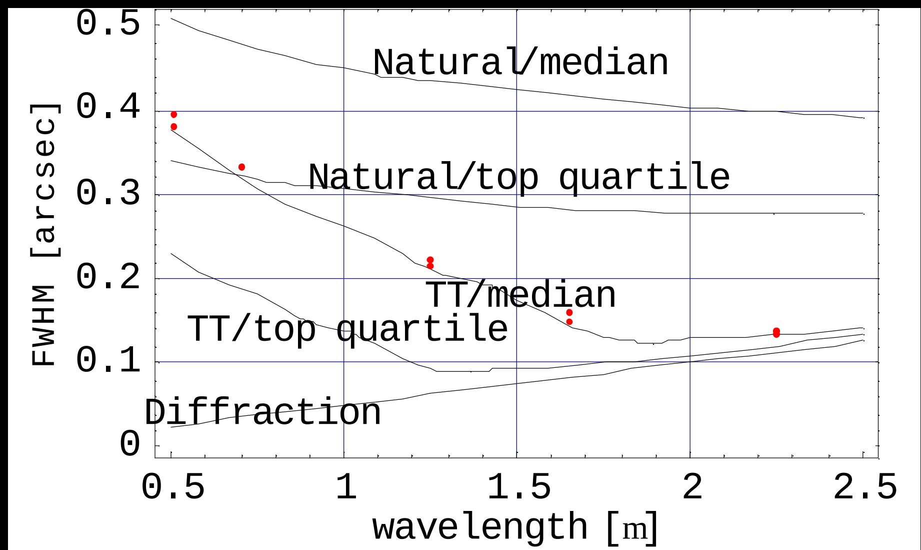




Turbulence with finite scale

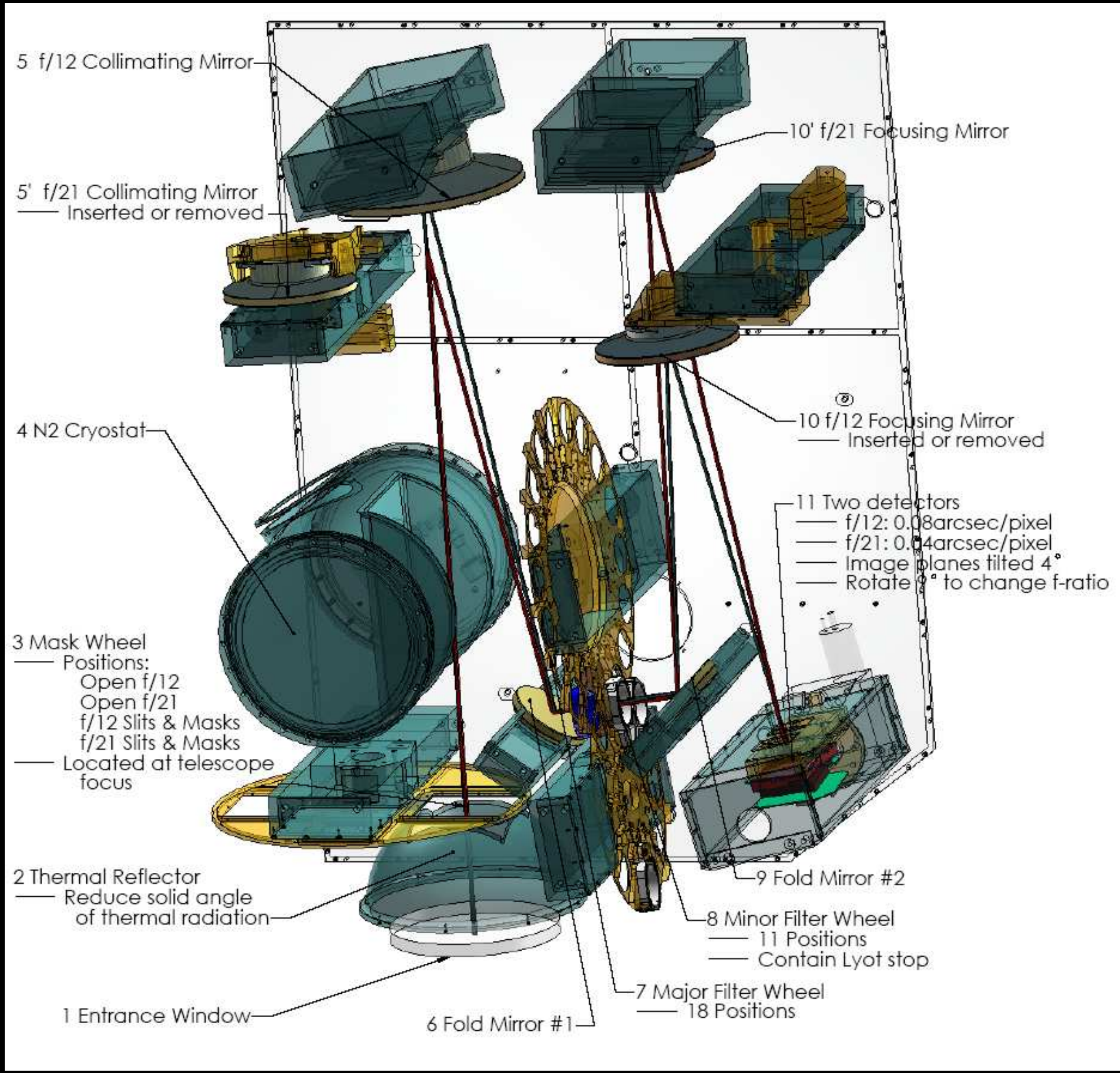
- Model with turbulence cut off at 25m (Tokovinin 2003, “SOAR AO CoDR, Appendix A.”)
  - r0=15cm & 25cm. (Same seeing; reduced image motion)
- Substantial improvement with tip-tilt





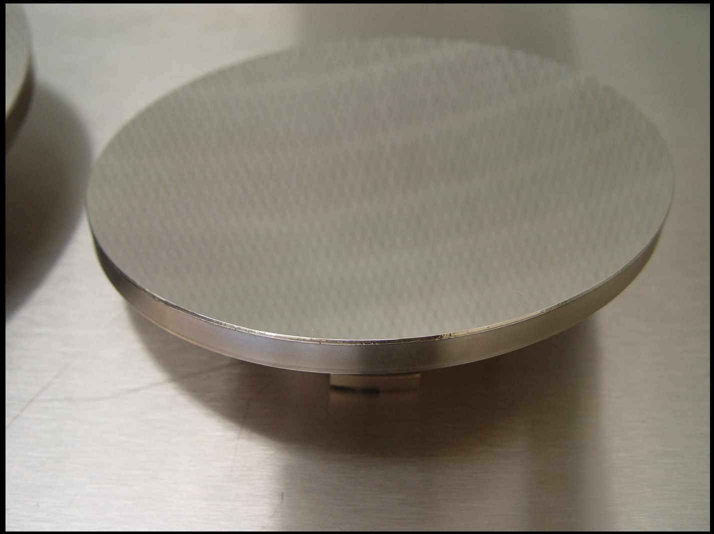
Modes

- J, H, & K spectral bands 1-2.4μ
- Rockwell HgCdTe 2048x2048 detectors
  - Two initially
  - Four in a year (B Barbuy & S Viegas)
- Modes
  - Wide-field imaging at f/12
  - Diffraction-limited imaging at f/21
  - Grism spectroscopy; resolution 200. (possible upgrade)
  - Coronagraphic mask (possible upgrade)
  - Polarimetry (upgrade, Magalhães)
- Filters
  - J, H, K
  - Others can be added. Need $.



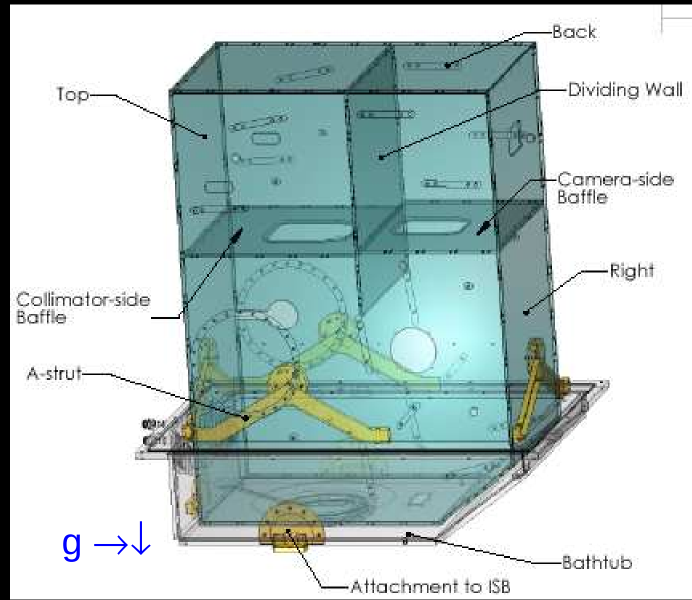
Aluminum Mirrors

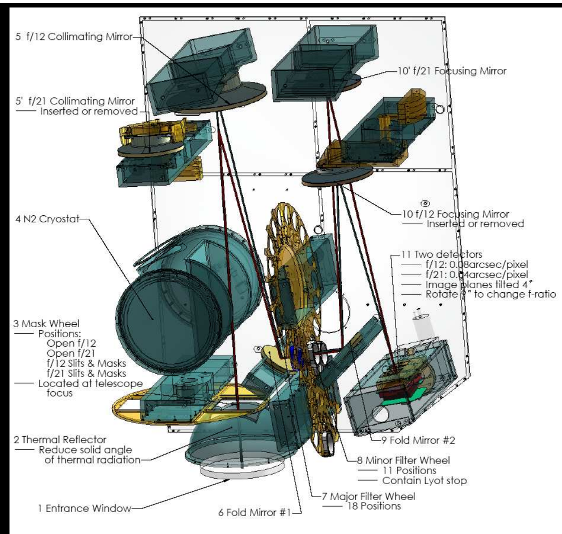
- Advantages for aluminum
  - Mirror can be installed by metrology of mirror pads.
    - » Mirror fabricated, polished, & tested while bolted to master jig.
    - » Mirror surface & mounting pads located by interferometry
  - Focus is athermal, since mirror & COB are both aluminum
    - » Install & test at 300K; run at 77K.
- Details
  - Surface accuracy 50nm (PV) ⇒ Strehl of 4 mirrors is 0.991 @1200nm.
  - Axsys Technologies, Rochester Hills, MI
  - Computer-generated hologram
    - » Makes reflected wave from off-axis asphere into a sphere
    - » Creates alignment for master jig & interferometer
  - Diamond-turned surface; nickel coated; polished; Ag with SiO_2 coating. 99% reflectivity.



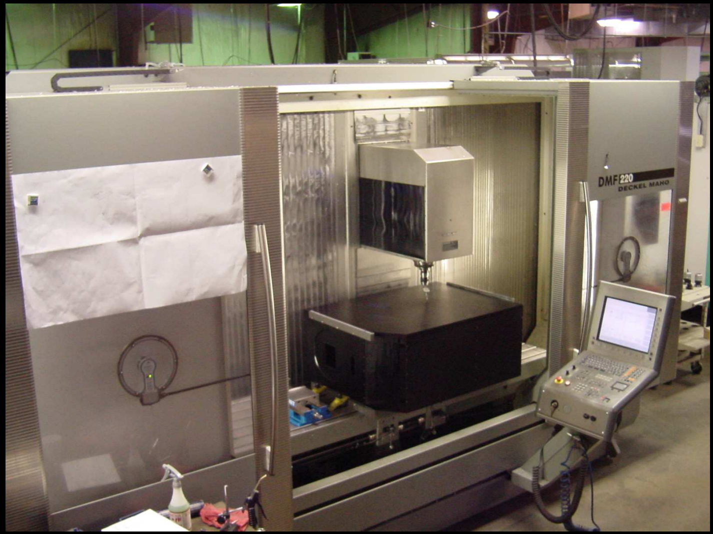
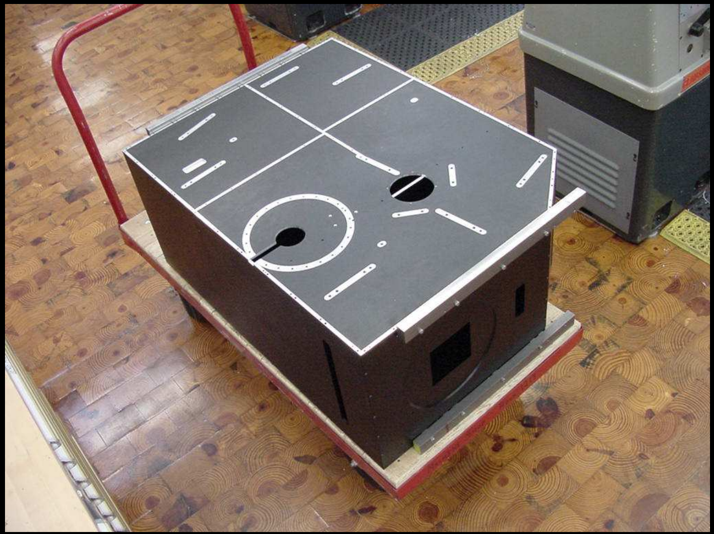
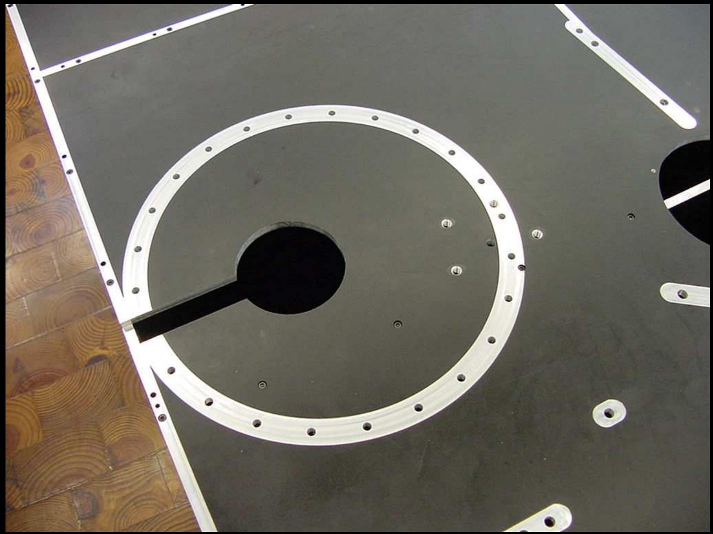
Symmetrical Design

- Boresight requirement: Detector & tip-tilt sensor maintain alignment as Nasmyth port turns
  - 0.04” in sky
  - 5μrad for mirrors inside instrument
- Symmetry eliminates torques
- Cryo-optical box (COB) has two plates & optics are mounted on posts centered between plates
  - Gravity is parallel to plates of COB
  - No torque parallel to plates



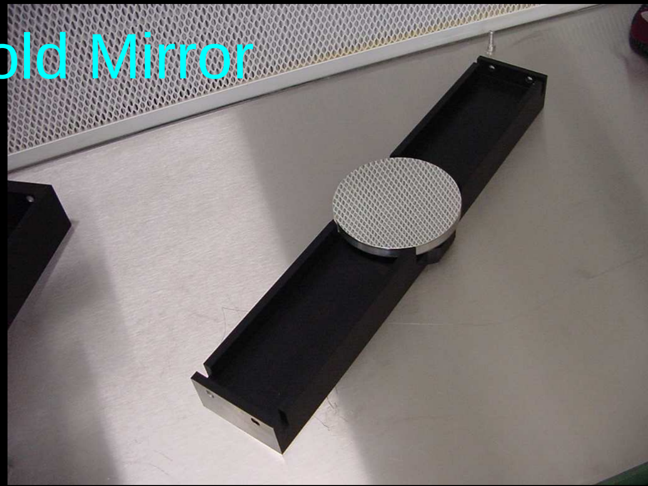


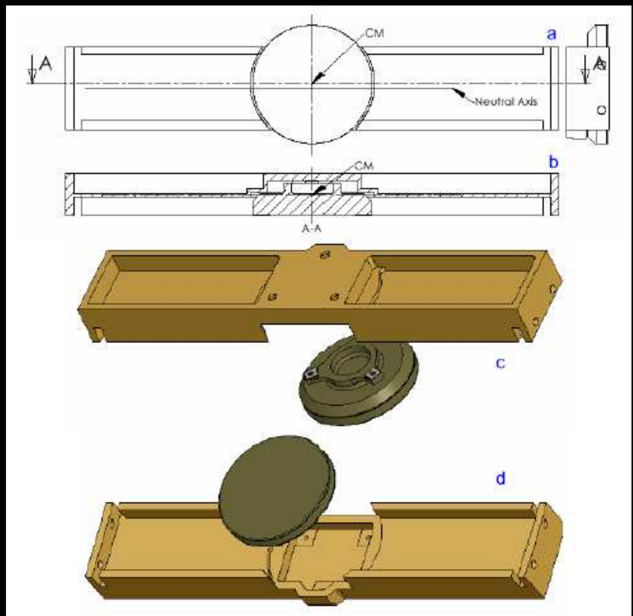
Machining the Cryo-optical Box

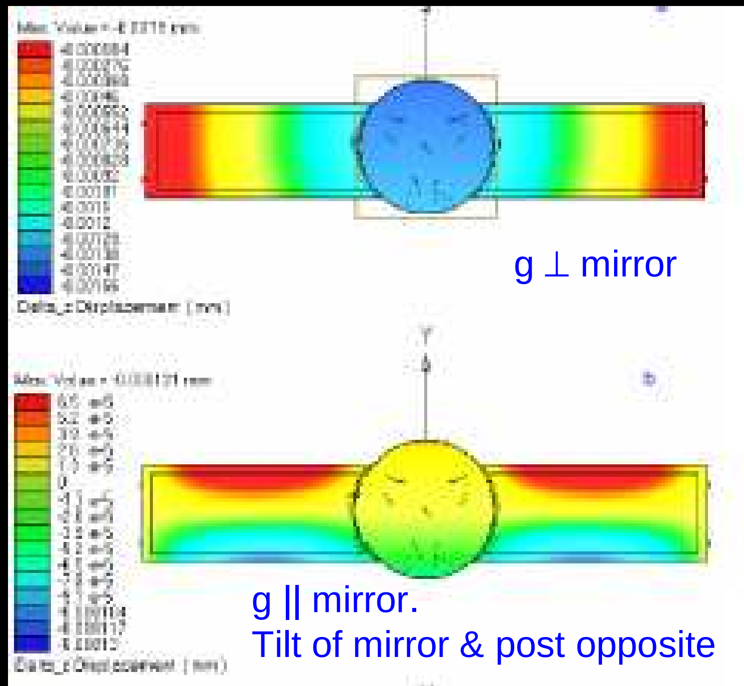





Post for Fold Mirror

- Posts designed to eliminate torque parallel to mirror surface
  - Put CM on neutral axis

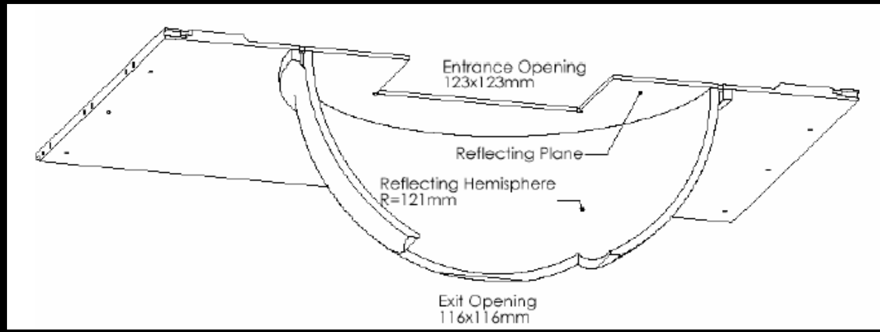


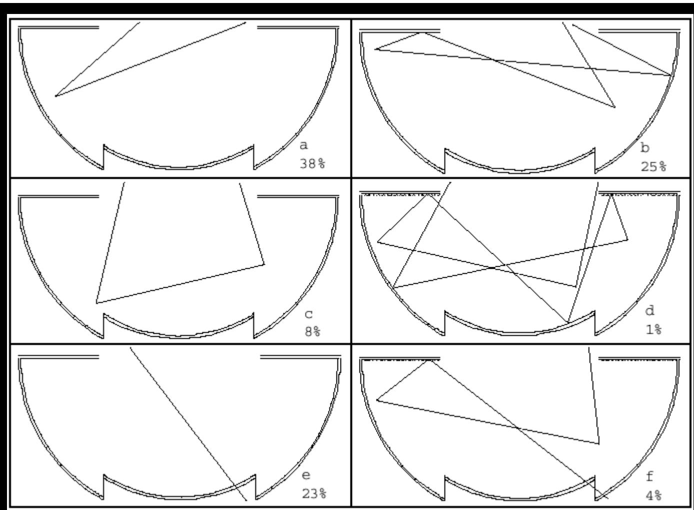


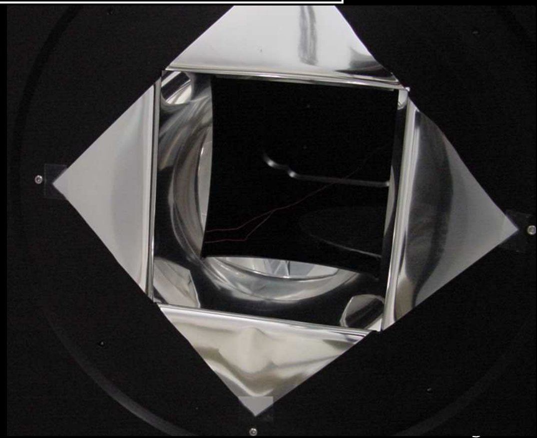


Thermal Reflector

- Thermal radiation in the 120x120mm opening is 4.7W. Thermal load is 4.1 W for all else.
- Thermal reflector is a plane & hemisphere. Cases:
  - Hemisphere reflects radiation back directly for 38% of rays
  - Hemisphere & plane make a corner reflector to reflect radiation back (25%)
  - Radiation enters entrance aperture (23%)
  - Radiation is absorbed in thermal reflector
- Fabrication
  - Hemisphere is polished Al
  - Plane covered with aluminized mylar
- Thermal reflector reduces load by 0.34.
- Total heat load of 1000x700x400mm cryogenic box is designed to be 6W. (3L/day of N2)
  - Currently, we measure 10W. Possible loads are vent holes in thermal blanket and taping together of innermost and outermost layers of blanket.

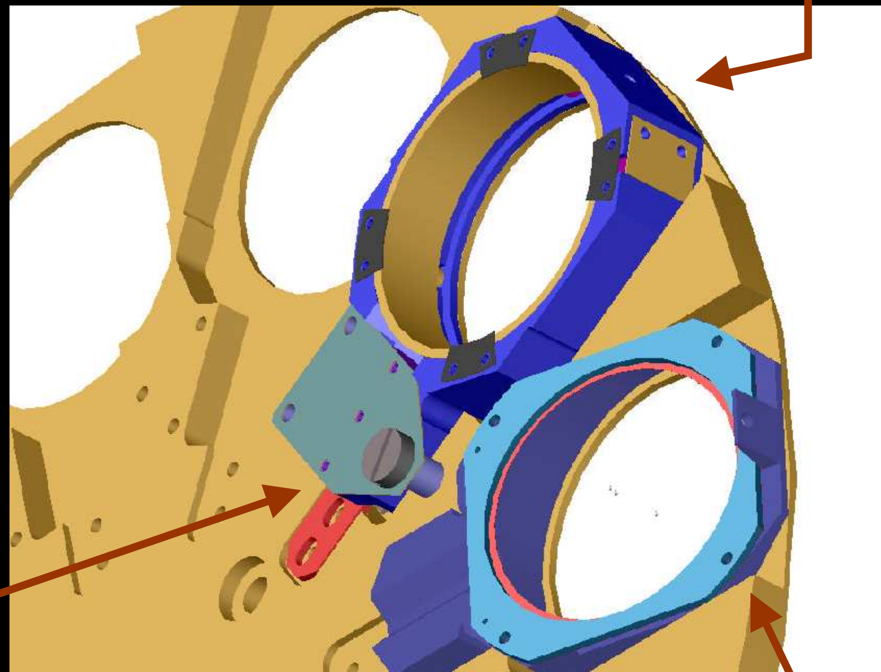






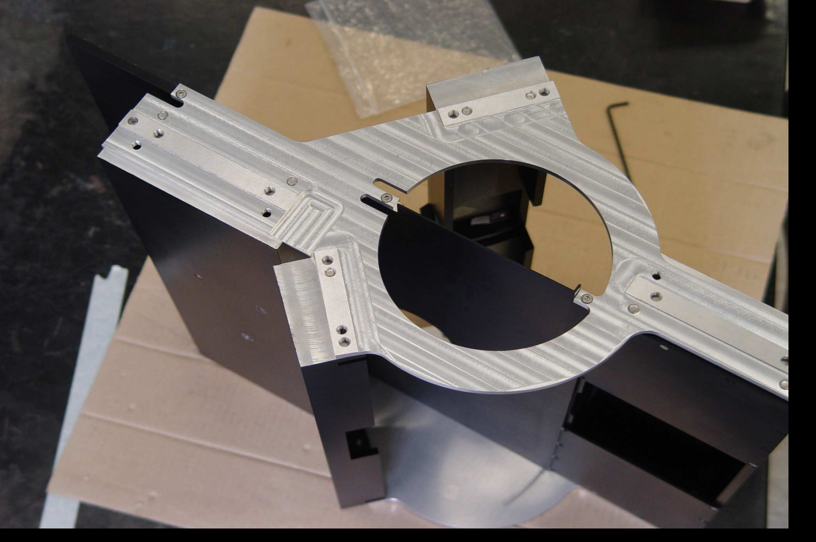
Filter wheels

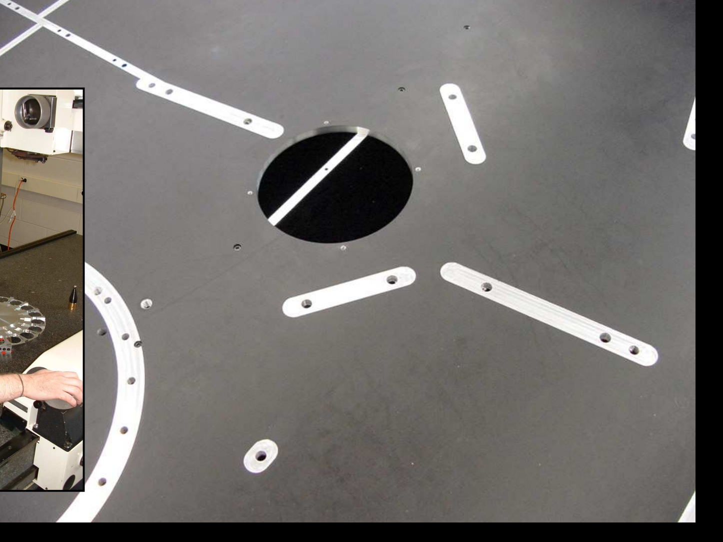
- Designed by René Laporte
- Filters can be inserted through port in vacuum enclosure.
  - Warm-up required. Disassembly of optics not required
- Positions
  - 18 on filter wheel #1
  - 11 on wheel #2

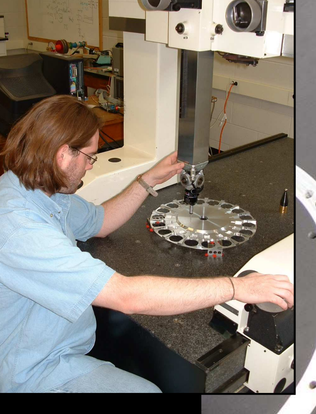


Alignment with Metrology

- Problems with optical alignment
  - Many degrees of freedom: Two off-axis aspherical mirrors, two fold mirrors
  - Adjustments have thermal problems
- Align with metrology
  - Require 0.1 mm & 0.15 mrad precision.
  - Coordinate-measuring machine has 6µm accuracy over 1000x700x400mm volume
  - Mirrors fabricated with accurately placed pads.
  - Shim is between cryo-optical box (COB) & post for optic. Shim allows x-y motion, machined for z. Shim pinned to COB.
- Method proven by sharpness of images (See Image Test)



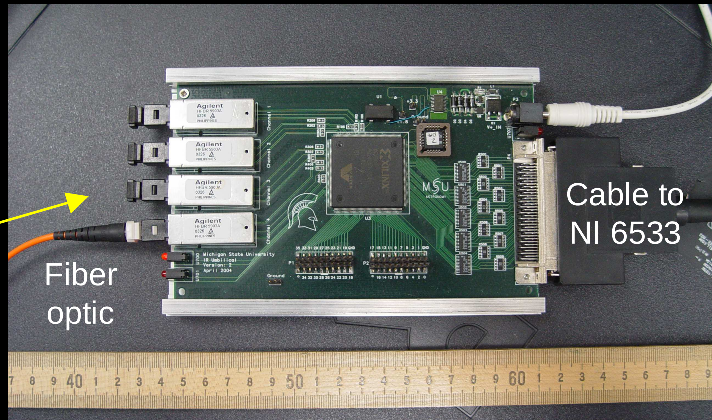


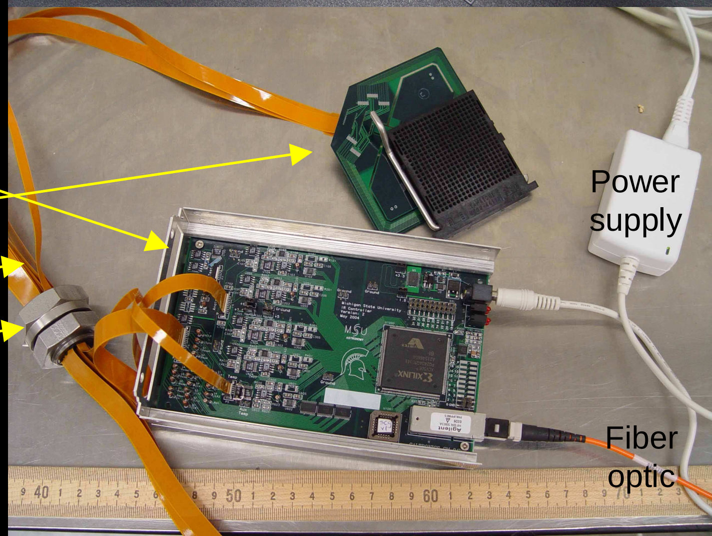


Spartan Infrared Camera

Electronics

- Use NI I/O card, which has LabView driver
- Four custom cards
  - Umbilical board for serializing/deserializing. One for 4 detectors
  - Controller board to control & read detector. One 3U (160x100-mm) board per detector. 1.5 Watts. Also reads 4 temperature sensing diodes
  - Detector board for thermal isolation
  - Flexible cable between controller & detector. Potted to vacuum bulkhead. Thermal isolation. Microstrip ⇒ very clean signal path.
- Read time: 8s for 16Mpixels (4 quadrants of 4 detectors in parallel)





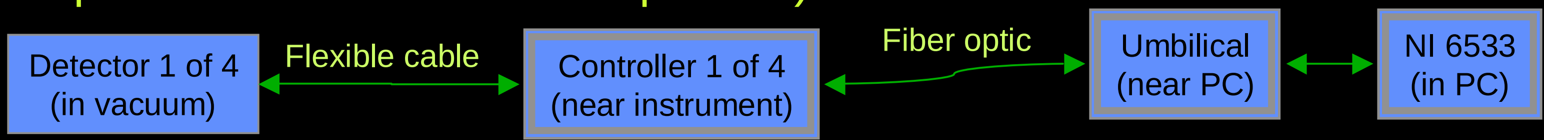
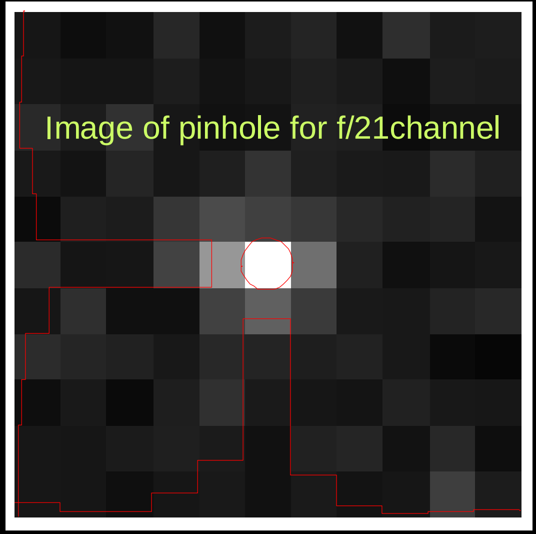
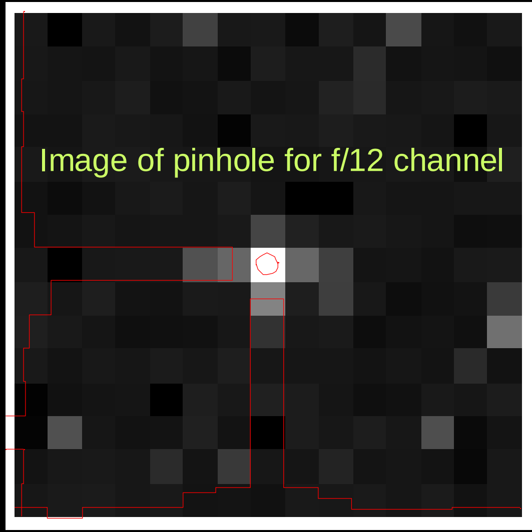


Image quality of the instrument

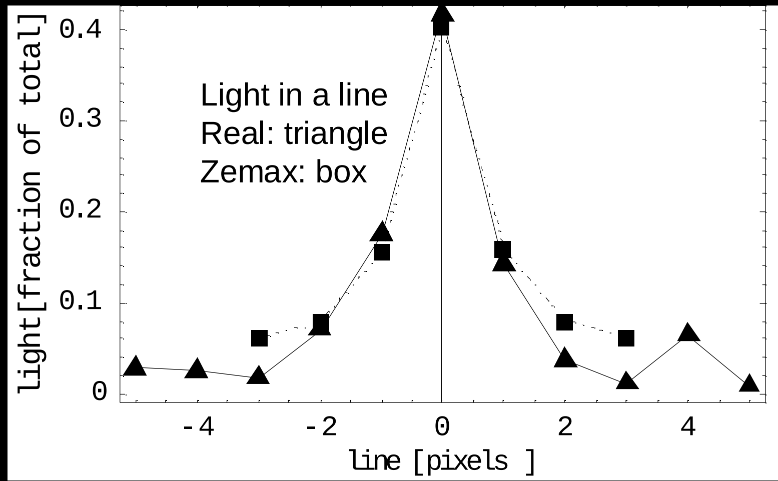
- Test
  - Test at room temperature with visible light. (Instrument uses mirrors and one glass optic with no power.)
    - **Test can reveal problems easily, since phase errors at 632nm are double those in J band.**
  - Laser (632nm) illuminates an 8-μm pinhole placed on the mask wheel (at the telescope focus). Diffraction due to the small pinhole fills the pupil with a slight apodization.
  - Finite pinhole (circle in the pictures) causes some light to spill into adjacent pixels.
  - Radius of first dark diffraction ring
    - **0.44 & 0.84 pixel for 632nm & J band for f/21**
    - **0.25 & 0.48 pixel for 632nm & J band for f/12**

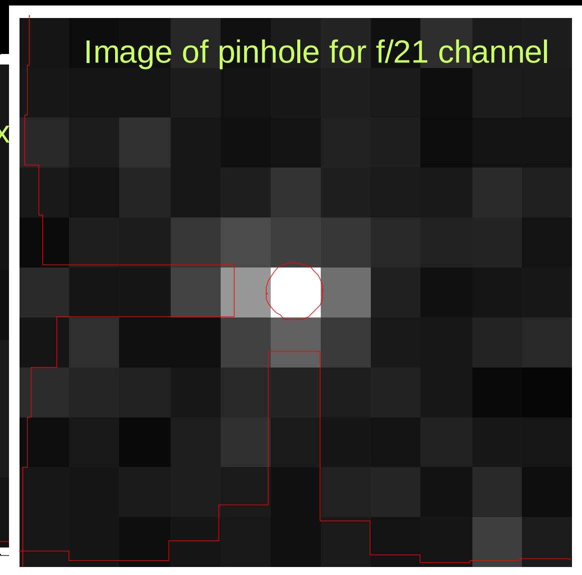




Results of test for image quality

- Comparison with image generated from the optical design by Zemax. Results presented for f/21.
  - Actual & theoretical images agree in the central 3x3 pixels.
  - Actual image has <u>more</u> light in the central pixel and <u>less</u> light at R=2 pixels. Disagreement may be due to
    - » **Zemax limit on picture size. With small number of pixels, light cannot diffract to large radii.**
    - » **Slightly apodized beam**
- Images are sharp for both high-resolution (f/21) and wide-field (f/
  channels even at visible wavelengths.





The Team

- Members & responsibilities
  - J Biel (technician), electronics
  - J Chen (gs) & N Verhanovits (gs, now at Fasco Motors), software
  - D Baker (ug & technician), B Hanold (ug), B Lien (gs) & E Samet (ug), testing, metrology
  - D Circle, D Keesaer (MC Molds), R Laporte (INPE), & O Loh (Johns Hopkins), mechanical
  - M Davis (gs, now at SWRI), optics
  - MSU Phys-Ast shop & McMolds, mechanical fabrication
  - E Loh