GIGS: A high-resolution Germanium Immersion Grating Spectrograph for 3-8 μm in a single observation

Matt Richter, UC Davis

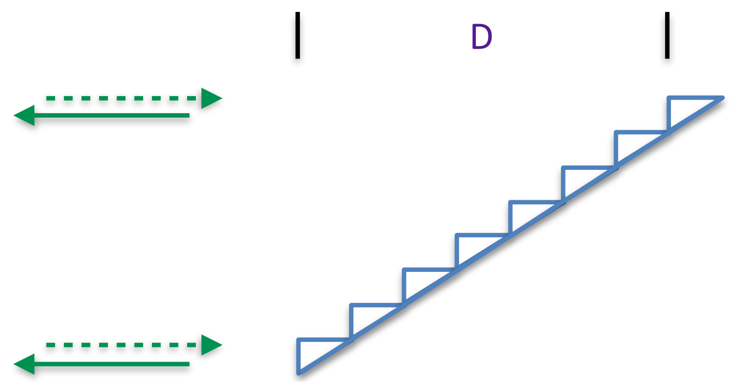
Outline

- Reflection gratings for high resolution in the IR
- Immersion gratings
  - silicon
  - germanium
- Motivation for a germanium immersion grating instrument
- Potential application to SOFIA

Grating resolving power

- **Theoretical maximum resolving power for a diffraction grating is the optical path difference (in waves) between first and last groove.**

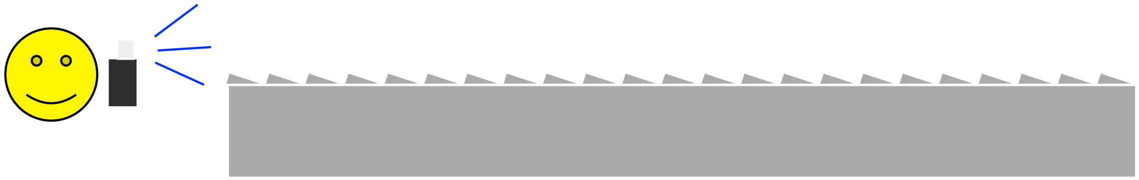
$$R = \frac{\lambda}{\Delta\lambda} = 2 * \frac{D}{\lambda}$$



- **Slit width will reduce resolving power**
- **Beam shape reduces delivered resolving power (Erickson and Rabanus, 2000)**

Large gratings for IR

- At longer wavelengths, larger gratings are required for high resolution
  - TEXES & EXES: 36-40” long
    - R~100,000 at 10 microns



Large gratings for IR

- **At longer wavelengths, larger gratings are required for high resolution**
  - **TEXES & EXES: 36-40” long**
    - **R~100,000 at 10 μm**
  - **AIRES: 42” long**
    - **R~70,000 at 20 μm**
    - **R~5000 at 200 μm**

Figure 4. The AIRES echelle. Reflections are seen from both facets.

From Erickson et al (2007)

Immersion gratings

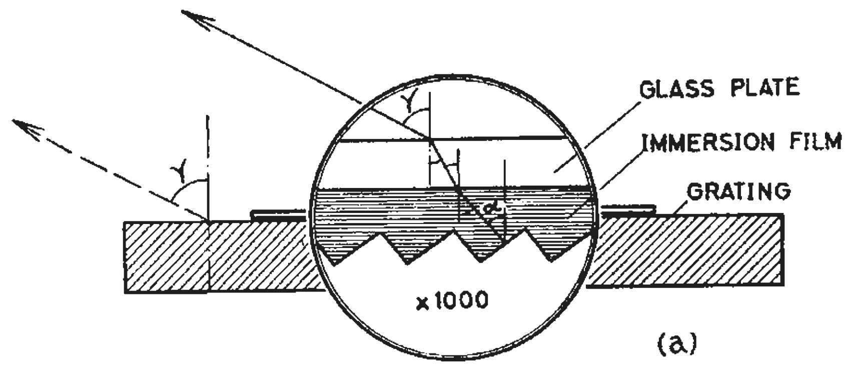
- **Recognized in 1950s that the resolving power of a grating would increase by immersing the grating in a high index medium**

Diffraction Gratings in Immersion

AT the London Optical Conference in 1950, it was suggested[1] that the resolving power R of diffraction gratings might be increased by immersing the grating in a medium of high refracting index μ_i. Thus:

$$R = \frac{2\ W \sin\alpha}{\lambda} \cdot \mu_i, \qquad (1)$$

where W is the ruled width of the grating and where α applies for the case of autocollimation of incidence and diffraction. This idea, which is a strict parallel

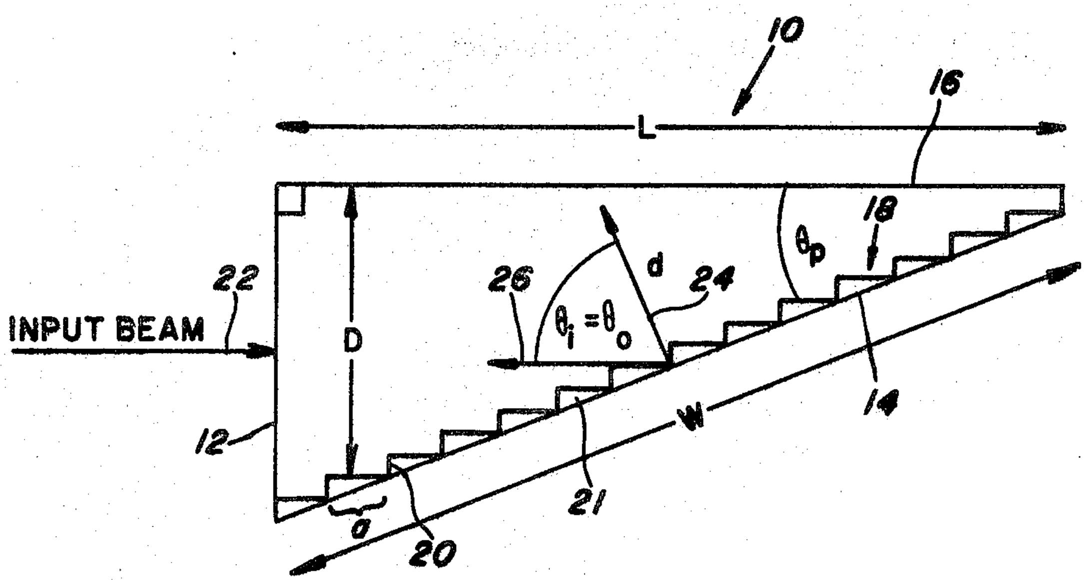


(a)

Hulthen and Neuhaus (1954)

Immersion gratings

- Recognized in 1950s that the resolving power of a grating would increase by immersing the grating in a high index medium
- 1984, Sica patented idea of using prism with grating formed on a reflective surface



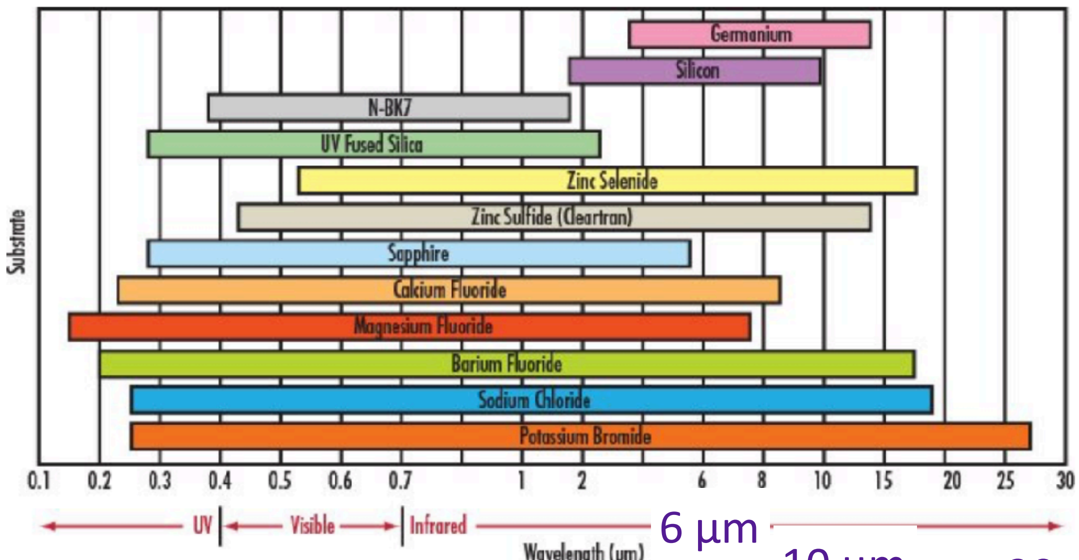
Sica, Jr. 1984, US Patent #4475792

Ames Research Center

Immersion gratings

UC DAVIS PHYSICS

- **Recognized in 1950s that the resolving power of a grating would increase by immersing the grating in a high index medium**
- **1984, Sica patented idea of using prism with grating formed on a reflective surface**
- **Many crystals are transmissive in the IR**



6 µm

10 µm

30 µm

Figure 1: *Transmission regions for Edmund Optics® window substrates.*

Germanium (*n* = 4)

Silicon (*n* = 3.5)

Zinc Selenide (*n* = 2.4)

Potassium Bromide (*n* = 1.5)

From Edmund Optics website

Silicon Immersion gratings

- Jaffe group at UT long history
  - chemical etching of Si

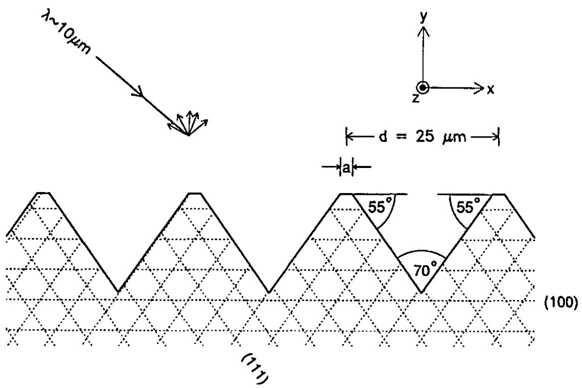


Fig. 1. Groove profile of an etched grating. The angles between the crystal lattice planes (indicated by the dotted lines) determine the blaze angle (55°) and the groove apex angle (70°). Our sample grating has a groove spacing d of 25 μm. The width a of the flat groove tops (2.4 μm in our case) depends on the details of the fabrication process.

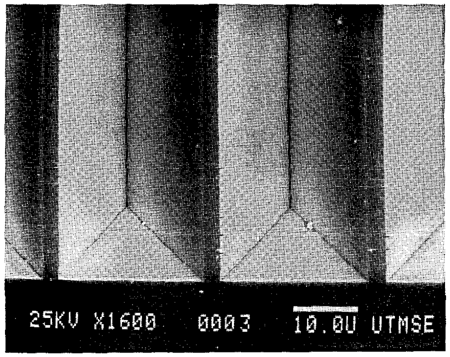
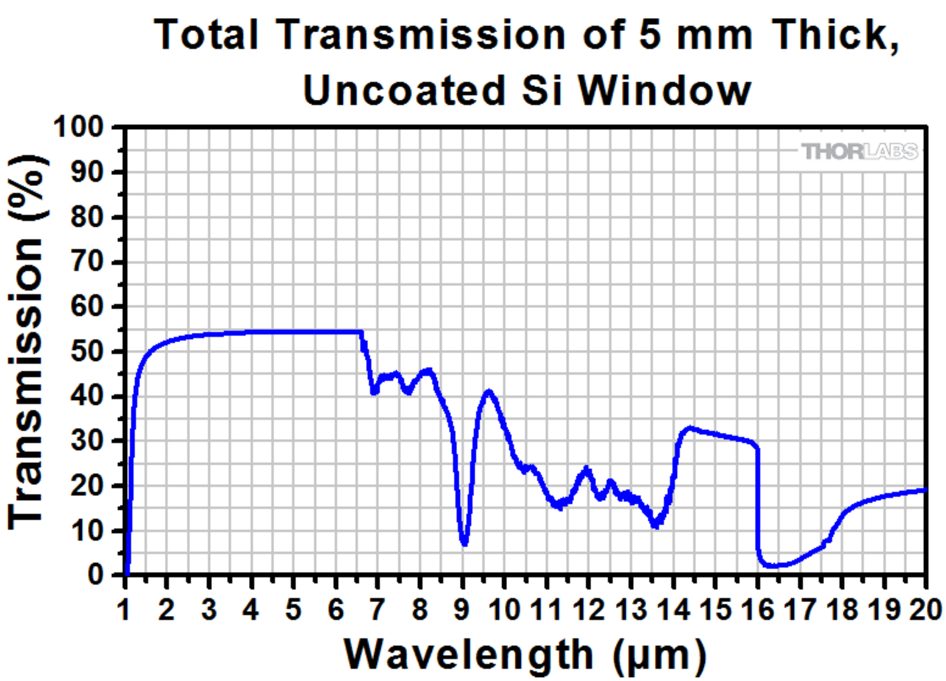


Fig. 2. SEM of a sample grating etched into silicon. The micrograph shows the bottom end of two grooves at a magnification of 1600×. The three wide, dark, vertical stripes are the residual flats between grooves. The groove bottoms are very sharp straight lines showing the excellent surface quality of the etched groove walls. The horizontal lines are artifacts produced by a scanning instability of the SEM.

Graf et al 1994

Silicon Immersion gratings

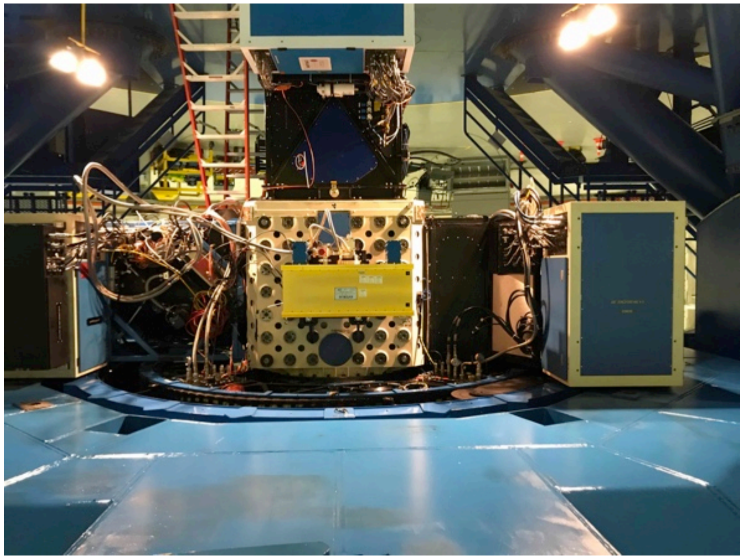
- **Jaffe group at UT long history**
- **Si has transmission good to ~6 microns and *n* = 3.5**



From ThorLabs website

Silicon Immersion gratings

- Jaffe group at UT long history
- Si has transmission good to ~6 microns and *n* = 3.5
- Si immersion gratings used in iSHELL at IRTF and IGRINS at Gemini, DCT, and others

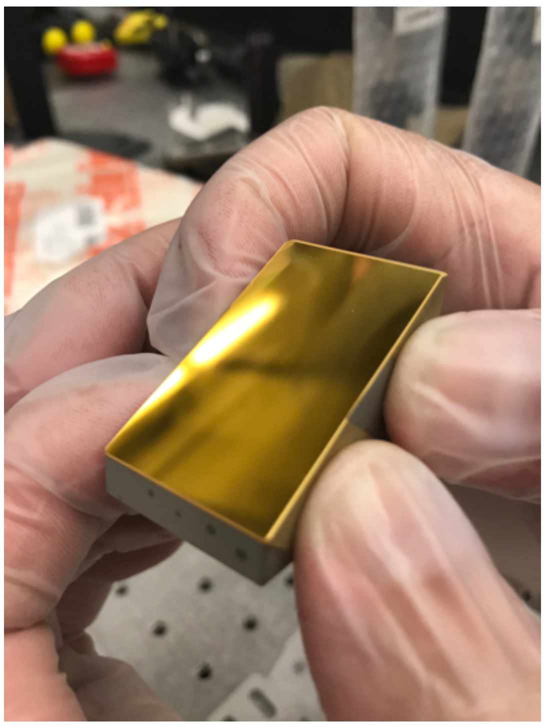


IGRINS on the Gemini
South Telescope in Chile

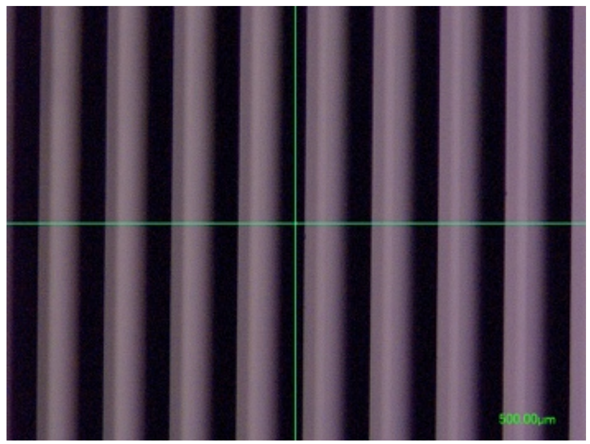
iSHELL on the NASA
Infrared Telescope (IRTF)

Germanium Immersion gratings

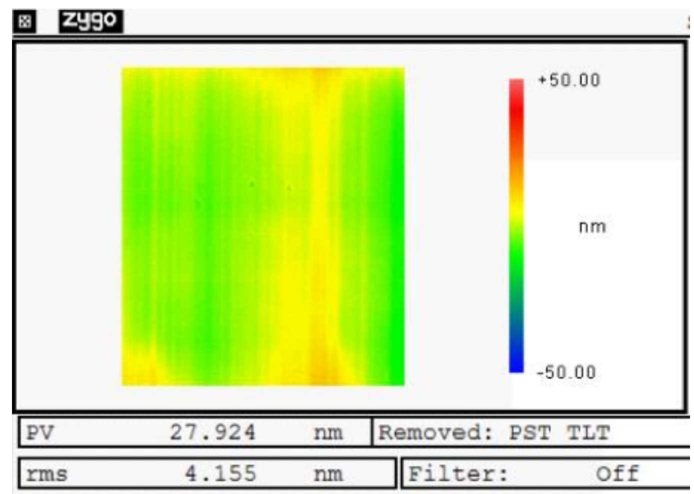
- **LLNL (Kuzmenko) and Canon, Inc (Sukegawa) machine grooves with diamond tool**



Gold coated Ge immersion grating from Canon



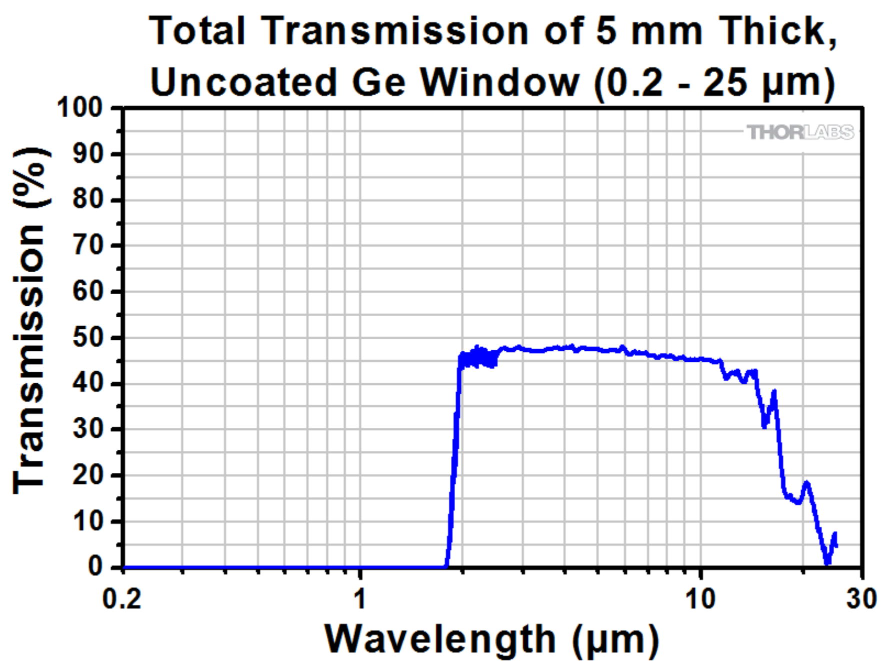
325x photo of Ge grating groves



ZYGO results from Canon grating

Germanium Immersion gratings

- LLNL (Kuzmenko) and Canon, Inc (Sukegawa) machine grooves with diamond tool
- Ge has good transmission from 2 to 12 microns and *n* = 4
  - illuminated beam area for given R is 16x smaller



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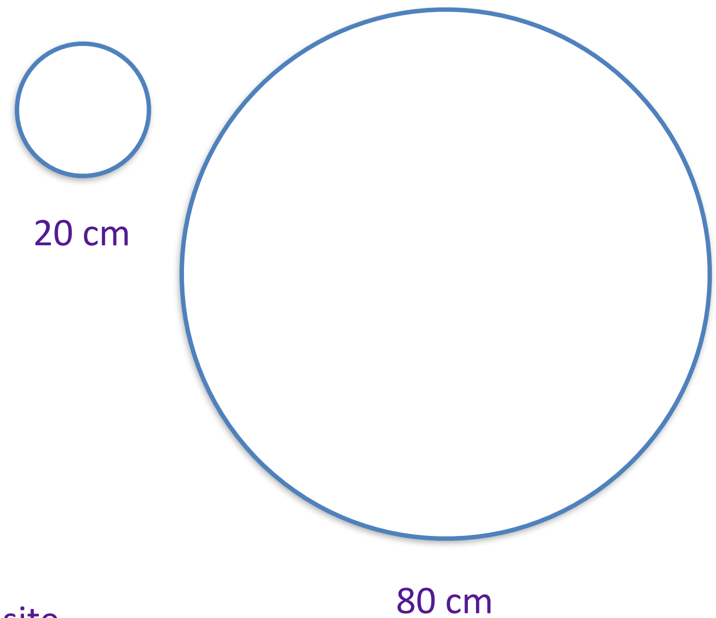
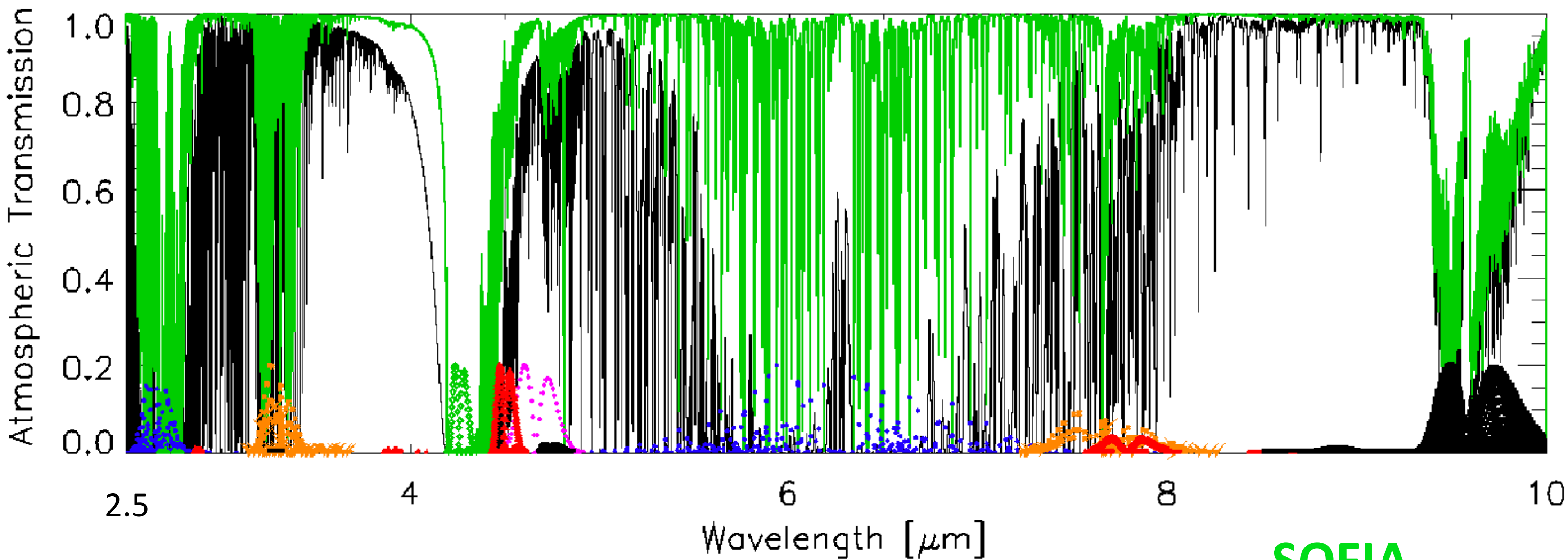


Atmospheric transmission



SOFIA

Mauna Kea

Important molecules: H_20, CO_2, CO, CH_4, N_2O, O_3

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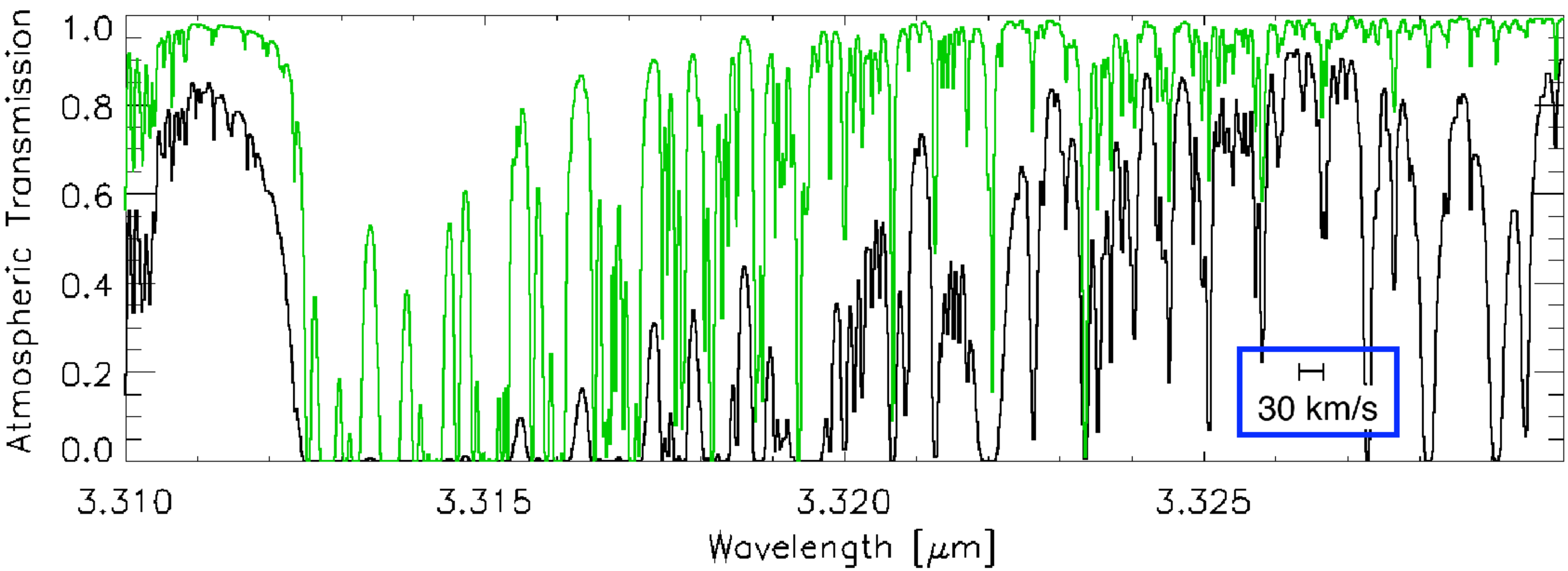

SOFIA

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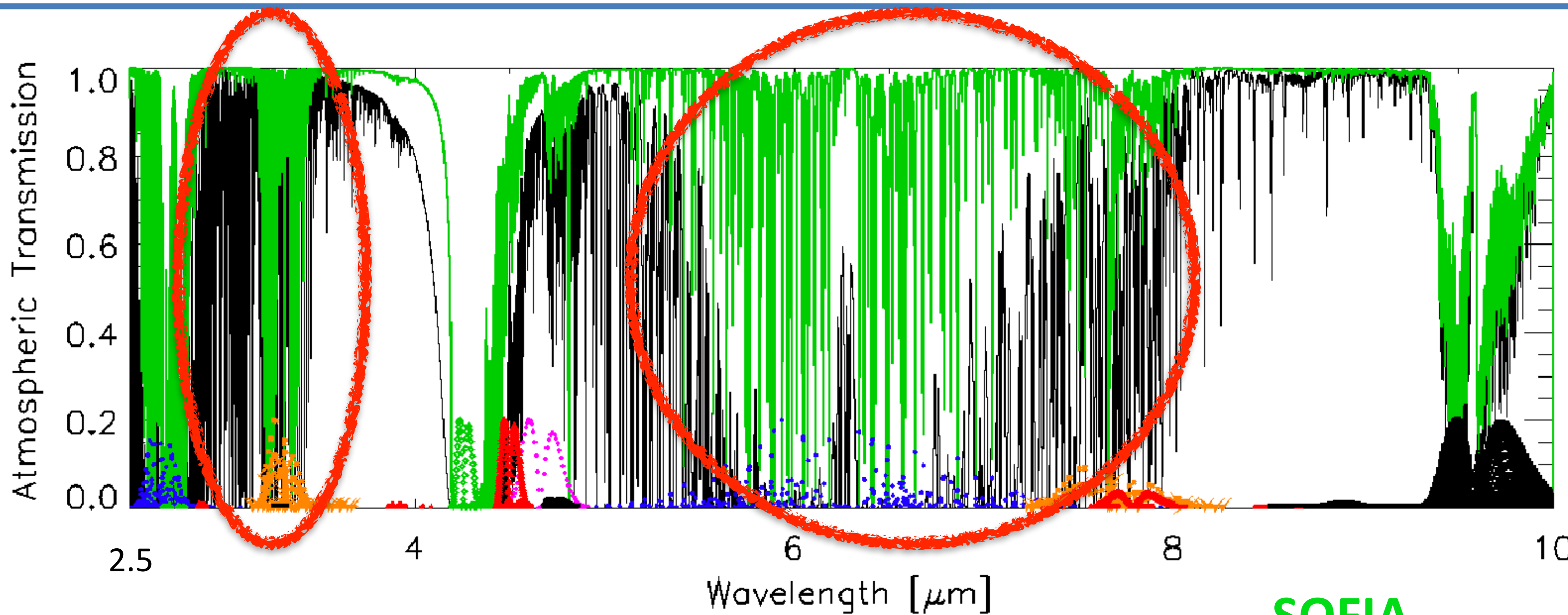
Atmospheric transmission



SOFIA

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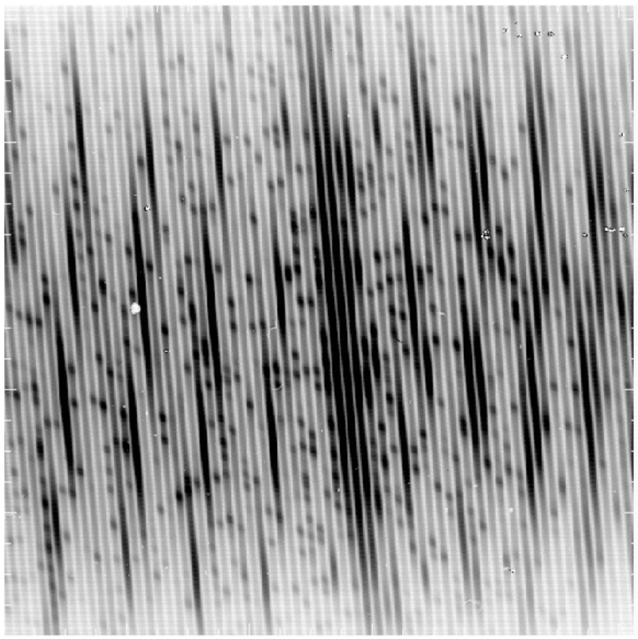
Wavelength vs spatial coverage

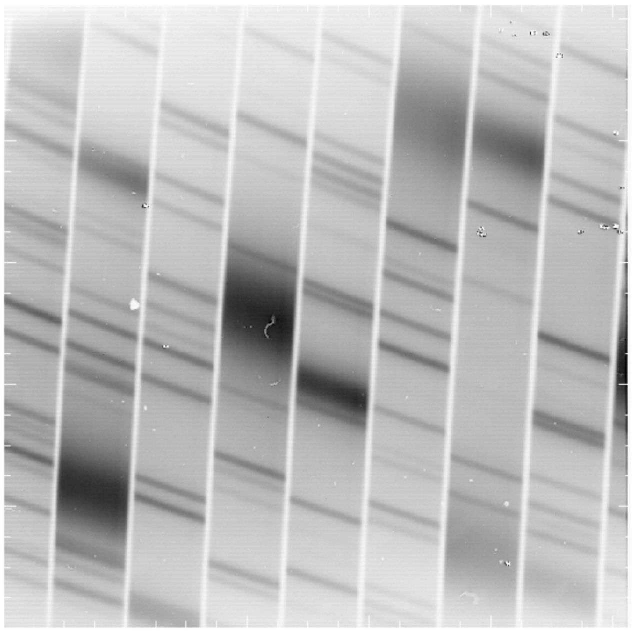
- **Focal plane area is limited**
- **Tradeoff between wavelength coverage and spatial coverage in a single exposure**



~60 orders
~2" long slit

EXES cross-dispersed data emphasizing wavelength coverage

7 orders
~20" long slit



EXES cross-dispersed data emphasizing slit length

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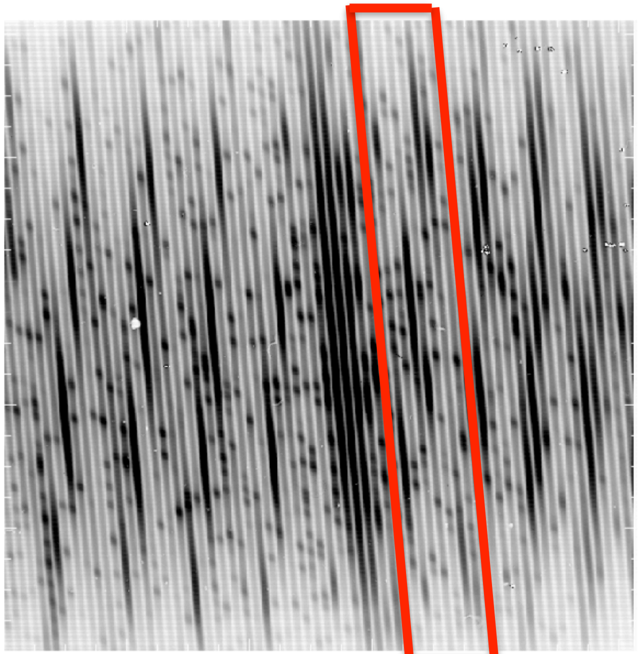

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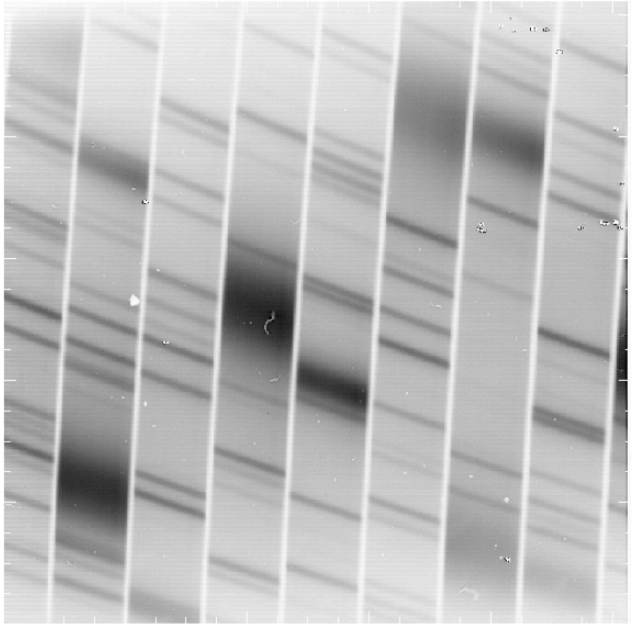


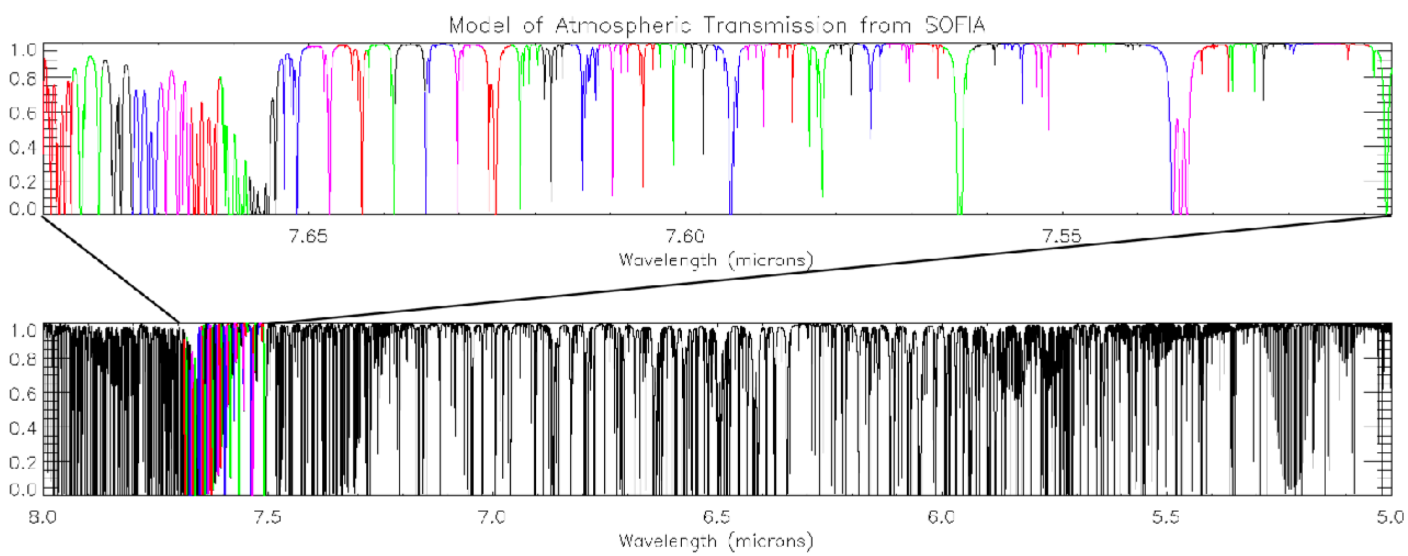
EXES cross-dispersed data emphasizing slit length

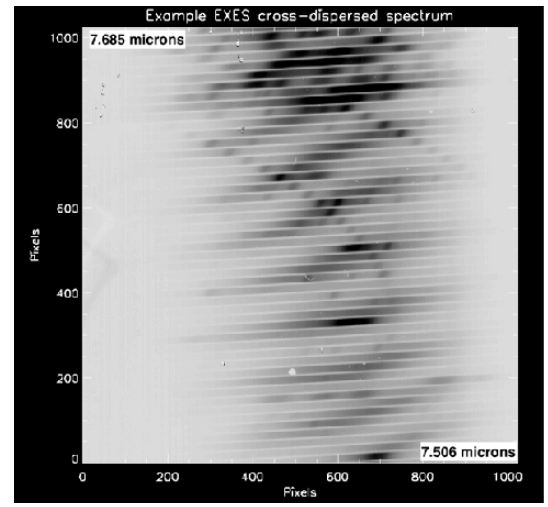
Ames Research Center

Recent EXES spectral surveys

UCDAVIS PHYSICS

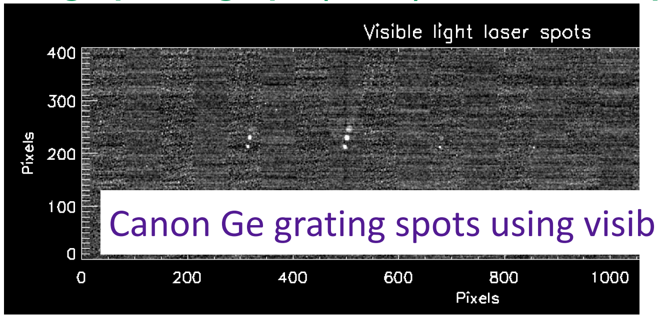
- Number of projects trying to capture large wavelength regions (5-8 μm)
- ~15 settings with minimal overlap
  - each setting takes ≥20 minutes
  - many hours of SOFIA time
- targets are point sources



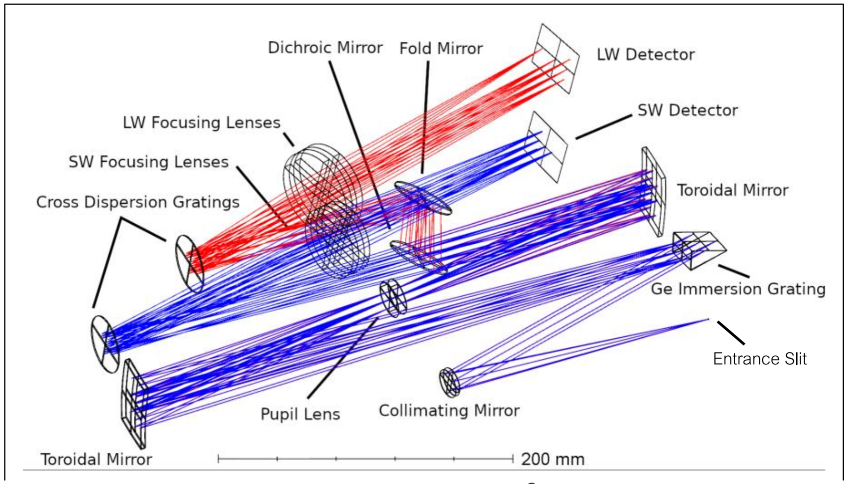


GIGS

- With NASA Ames, working on developing a Germanium Immersion Grating Spectrograph (GIGS) for eventual space mission
  - Work started with Ames CIF award.
  - Awarded an APRA for purchasing gratings and testing in lab
  - submitted a MatISSE to advance to TRL 6
- Features a Germanium immersion grating
- No moving parts
- Optimized for wavelength coverage
  - 3-8 μm in a single shot
    - maybe 2.7ish? Not sure yet
  - 2 arms with dichroic before after primary dispersion
    - R = 25,000 in red arm (5-8 μm)
    - R = 40,000 in blue arm (3-5 μm)
  - 2k by 2k detectors
- Short slit
  - only a few diffraction-limited resolution elements
- Prototype will be built and tested in FLITECAM Dewar



Canon Ge grating spots using visible HeNe



Zemax ray trace of 2 arm GIGS

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GIGS on SOFIA

UCDAVIS PHYSICS

- We have 3 Ge immersion gratings with same parameters
- Would want to have a wider and longer slit for SOFIA
  - reduce wavelength coverage (e.g. 5-8 μm)
    - covers mid-IR region most impacted by telluric H_2O
  - reduce spectral resolution (e.g. R = 10k-20k)
    - still >3x JWST and >5x ISO
- Retain "no-moving parts"
- Try to modify FLITECAM Dewar in a way that preserves certification

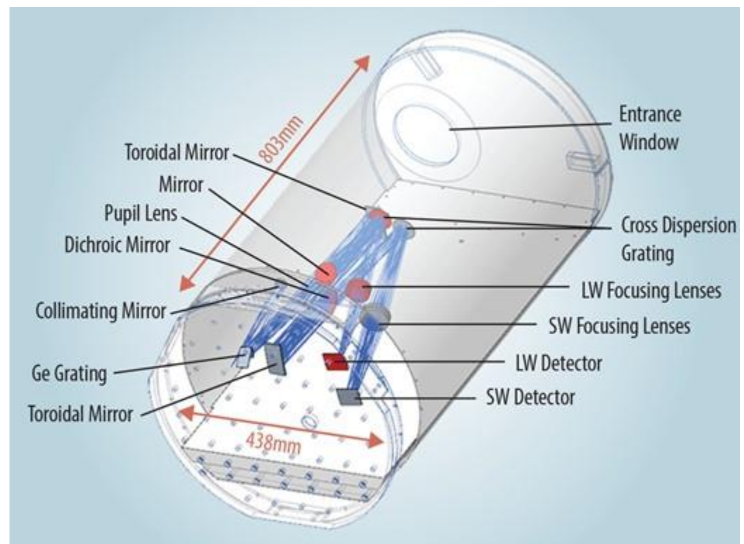

Figure 13 GIGS full optics path inside the FLITECAM dewar