The GMT-Consortium Large Earth Finder (G-CLEF): A Versatile, Optical Echelle Spectrograph for the GMT

Andrew Szentgyorgyi

Presentation to ExoPAG

Reno / 14 Oct 2012

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The G-CLEF Science Team

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G-CLEF has been selected for first light at the GMT

Talk Outline

1. Introduction to/Status of the Giant Magellan Telescope
2. Science Drivers for G-CLEF
3. System Description of G-CLEF
4. Can We Detect Exoearths?

The GMT Concept

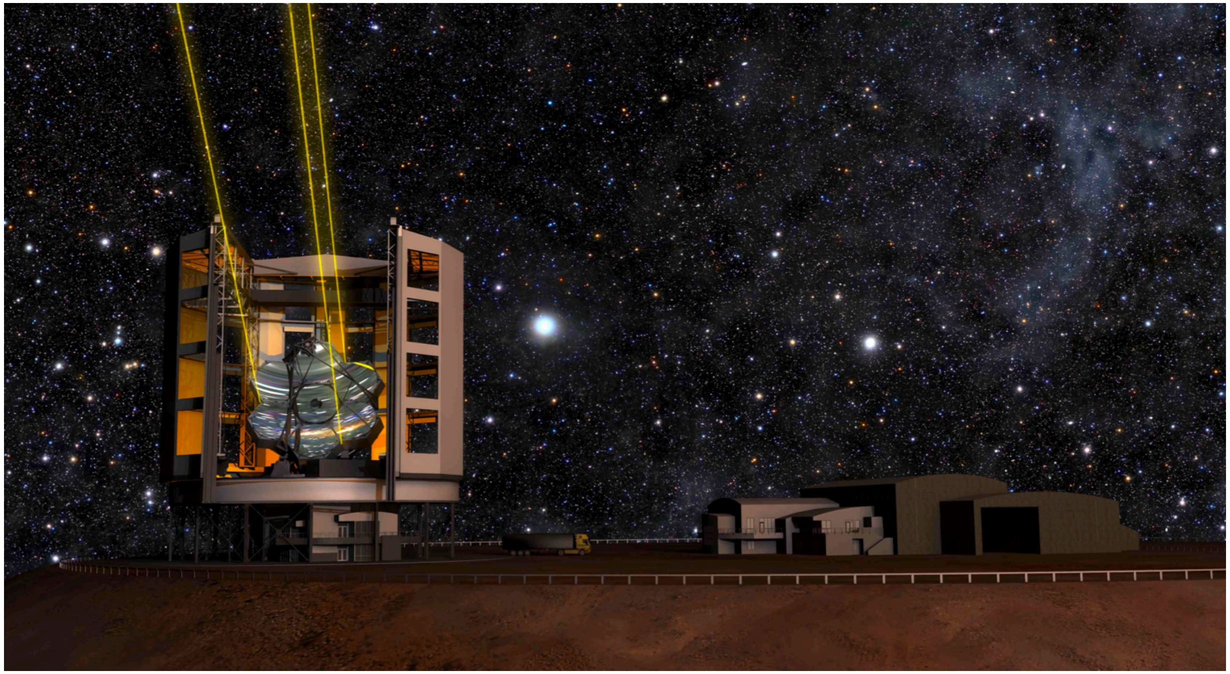
Giant-Segmented Mirror Telescope

7 x 8.4m primary mirror segments

380 square meters of collecting area
(22-m equivalent diameter)

f/0.7 primary focal ratio

Gregorian optical design
segmented secondary



Construction is underway, first blast (of 72*)*

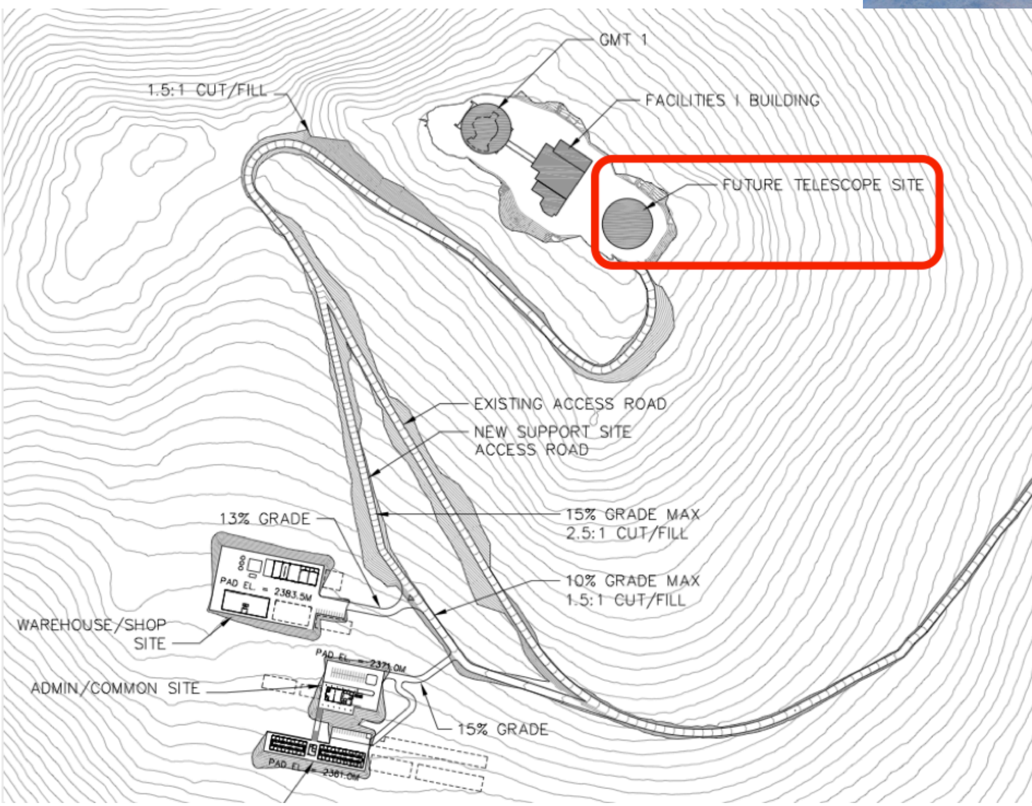
Cerro Las Campanas, March 23, 2012

After 17 blasts …

May 17, 2012

GMT Site, Late July, 2012

There is room for GMT2



Also: First Off-Axis Primary Mirror is Very, Very Close to Completion

Boundary Conditions/Guiding Principles for The G-CLEF Concept

- Only instruments that will close scientific thresholds are interesting for the GMT
  - Instruments that only provide incremental improvements in capability and performance are not interesting.
- An inefficient instrument wastes a large aperture
- Alignment with the top investigations listed in the Decadal Survey is critical.

Science Working Group

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The CoDR Science Case for G-CLEF

1. Planetary science
    a. Detection and characterization of exoplanets
    b. Ultra-high precision abundances in solar analogs›› and twins
2. Stellar science
    a. Asteroseismology
    b. Hot subdwarfs and substellar companions
    c. Chemical abundances in stars
    d. Isotopic ratios in metal-poor stars
    e. Age dating the oldest stars
3. Galactic and Local Group science
    a. Globular clusters
    b. Chemical Abundances in the Inner Galaxy
    c. Galactic structure
    d. Metallicities and chemical abundances of stars in dwarf galaxies
    e. Velocity dispersions and dark matter profiles
    f. Massive stars in the Magellanic Clouds
4. Extragalactic science, cosmology & fundamental physics
    a. Dissecting galaxies with supergiants
    b. Probing the cosmic dawn
    c. Probing the nature of the first stars with high redshift protogalaxies
    d. Gamma-ray bursts
    e. Fundamental constants

A stand-alone document
65 pages long

Abundance studies across the Local Group and Beyond
Detection, census of the most metal poor stars

- *Extended blue response*
- *High resolution*

Gamma ray burst science / ISM at very high Z
Studies of IGM at high Z
Constancy of α & μ over cosmological time scales

- *Extended red response*

Detection, census & characterization of exoearths by PRV

- *Long term wavelength scale stability*
- *Very high resolution*
- *High S/N*

Detailed Chemical Composition Beyond the Local Group

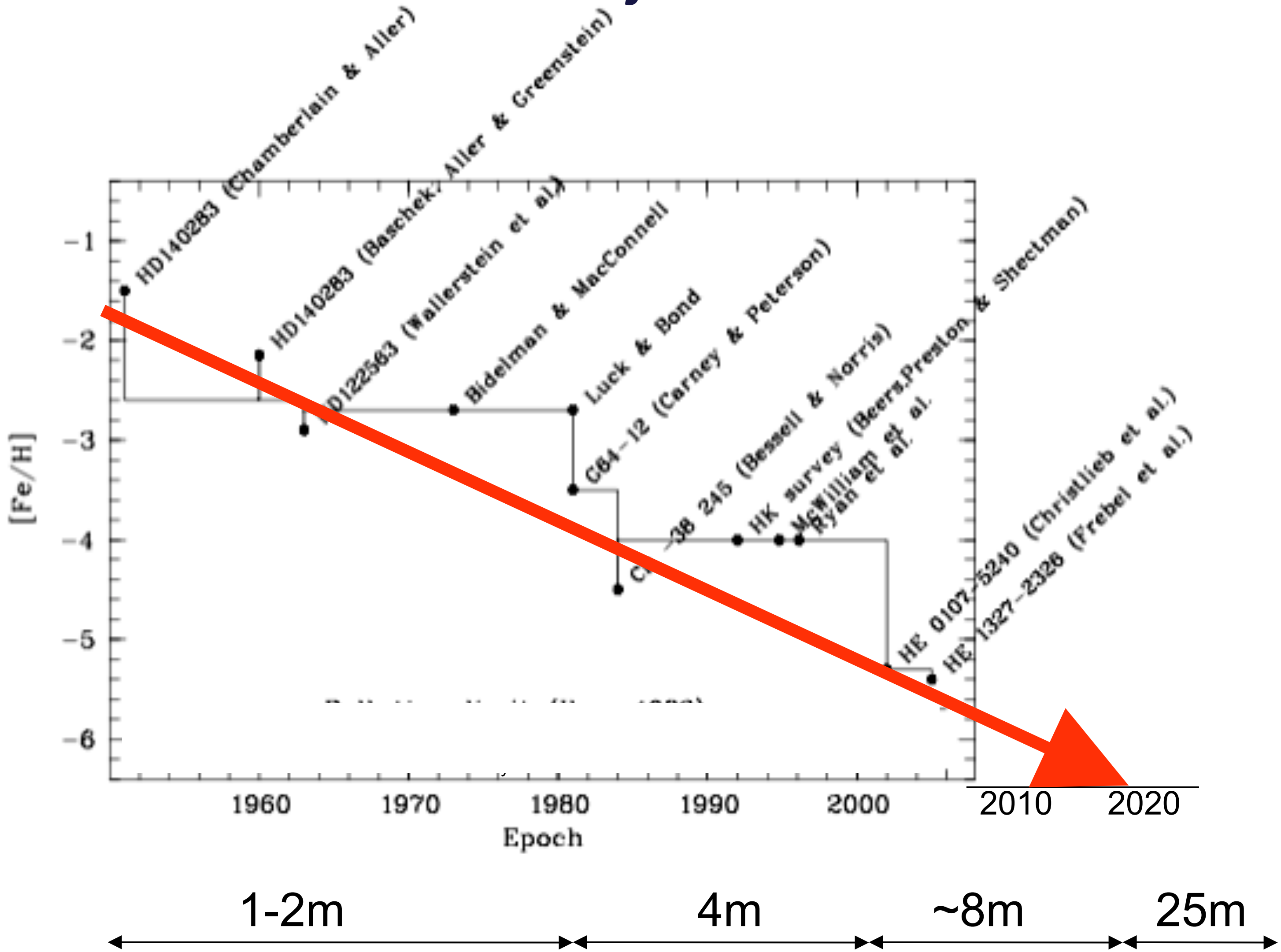
- *Slit Length for MOS*

Gamma Burst Science, High Z IGM & ISM

- *Instrument Changeover Speed*

Science Flowdown to Instrument Requirements

The Power of GMT and G-CLEF for Discovery and Characterization of Metal-Poor Stars



G-CLEF Parameters

Parameter	Value	Parameter	Value
Modes	HT, PA, PRV & MOS	Cameras	Red & Blue
Res	25k, 40k & 100k	Input f/#	f/8
Peak Efficiency	>35%	Camera Beam Diameter	200mm
Passband	3500Å-9500Å	Derotation?	No
Calibration	Contin., ThAr, I_2, Ultrastable Etalon	ADC?	Yes
Apertures	25.4m & 7 x 8.4m	Band Limiting Filters?	Yes
Grating	300mm x 1200mm, R4		

Feed	Resolution	Fiber Dia. (μ)	Fiber Dia. (arcsec)	Comments
HT	25000	1220	1.2	
PA	40000	711	0.7	
PRV	120000	230	0.7	Pupil Sliced & Scrambled
MOS	40000	711	0.7	

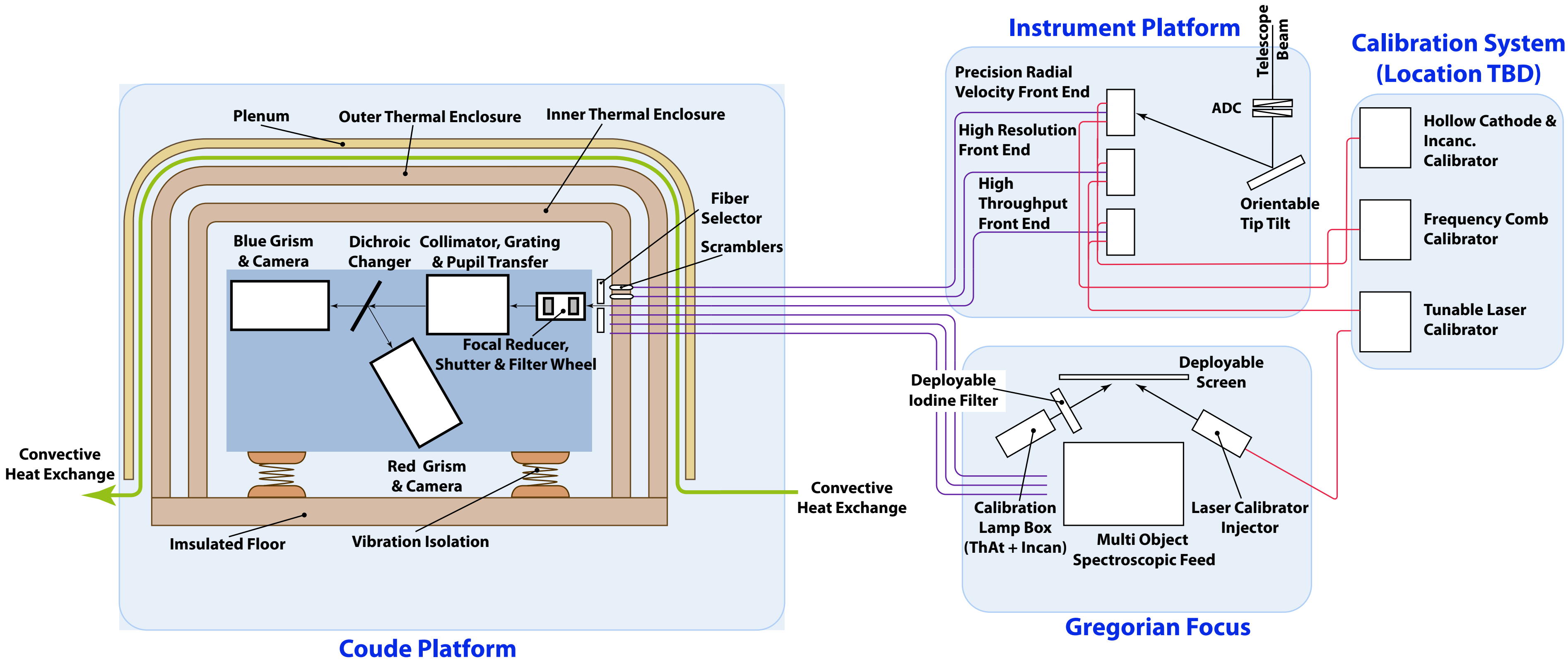
Thermal and Mechanical Stability Requirements to Anchor the Wavelength Scale for PRV

Extremely high thermal and mechanical stability requirements drive design to:

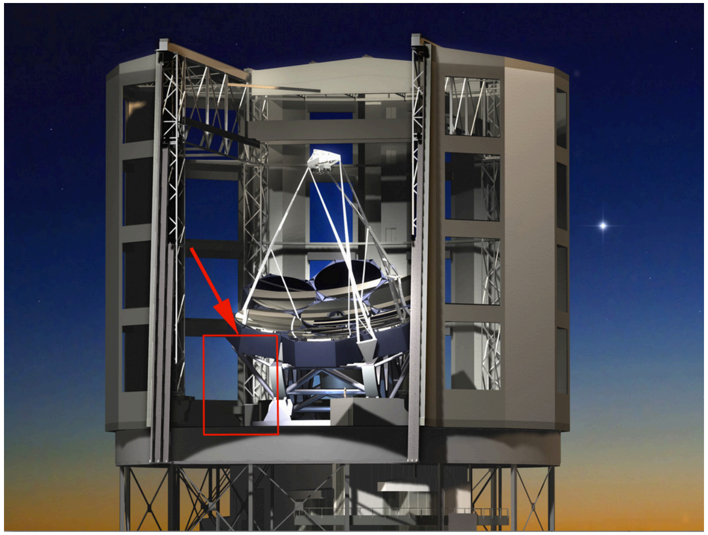
- Vacuum enclosure for thermal isolation
- Gravity invariant mounting
- Fiber feed for thermal isolation
- Elimination of heat sources on or near spectrograph

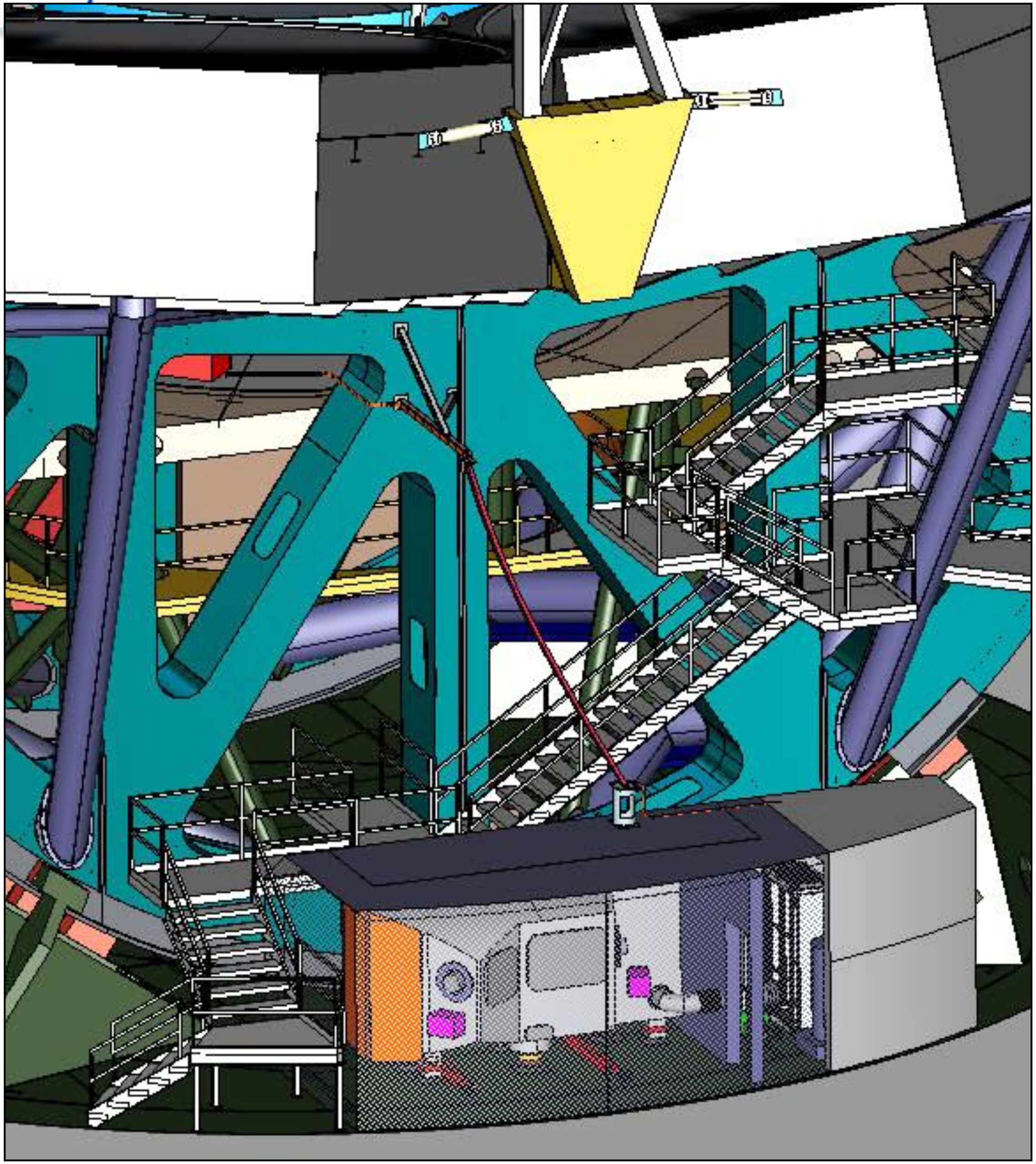
Pressure stabilization required to fix the ambient index of refraction

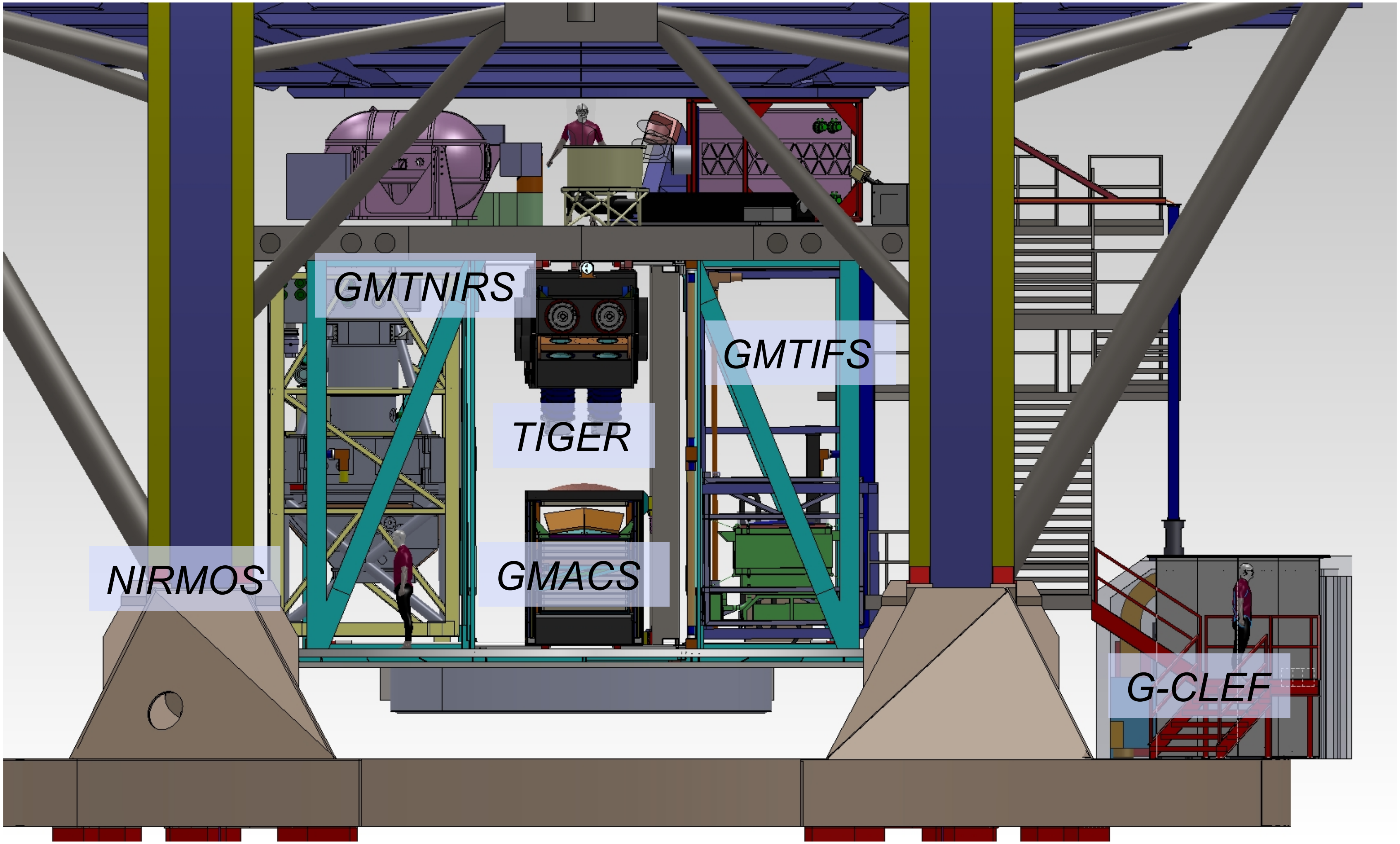
G-CLEF System Diagram



G-CLEF Mounting on the GMT Azimuth Platform and Fiber Run






GMTNIRS
GMTIFS
TIGER
NIRMOS
GMACS
G-CLEF

The design challenge: echelle resolution

- Echelle resolution is purely function of ratio of spectrograph beam size to telescope beam size

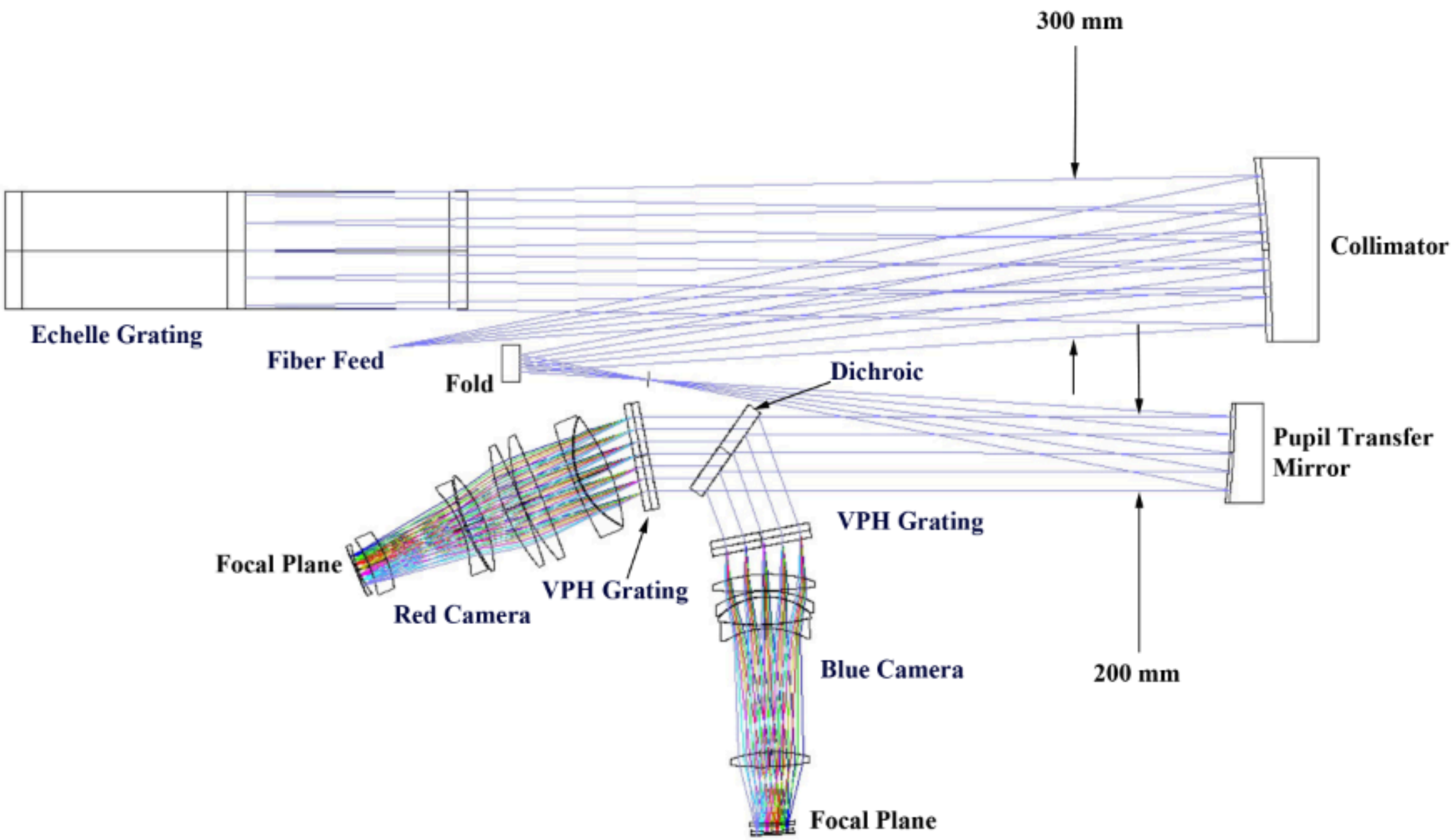
$$R = 2 \cdot Tan(\theta_D) \cdot \frac{1}{\omega} \cdot \frac{\phi_B}{\phi_T}$$

- R = Resolution, ΘD = Diffraction Angle, ω = Slit width (“), ϕ’s are beam and telescope primary diameters

R > 100,000 needed for PRV

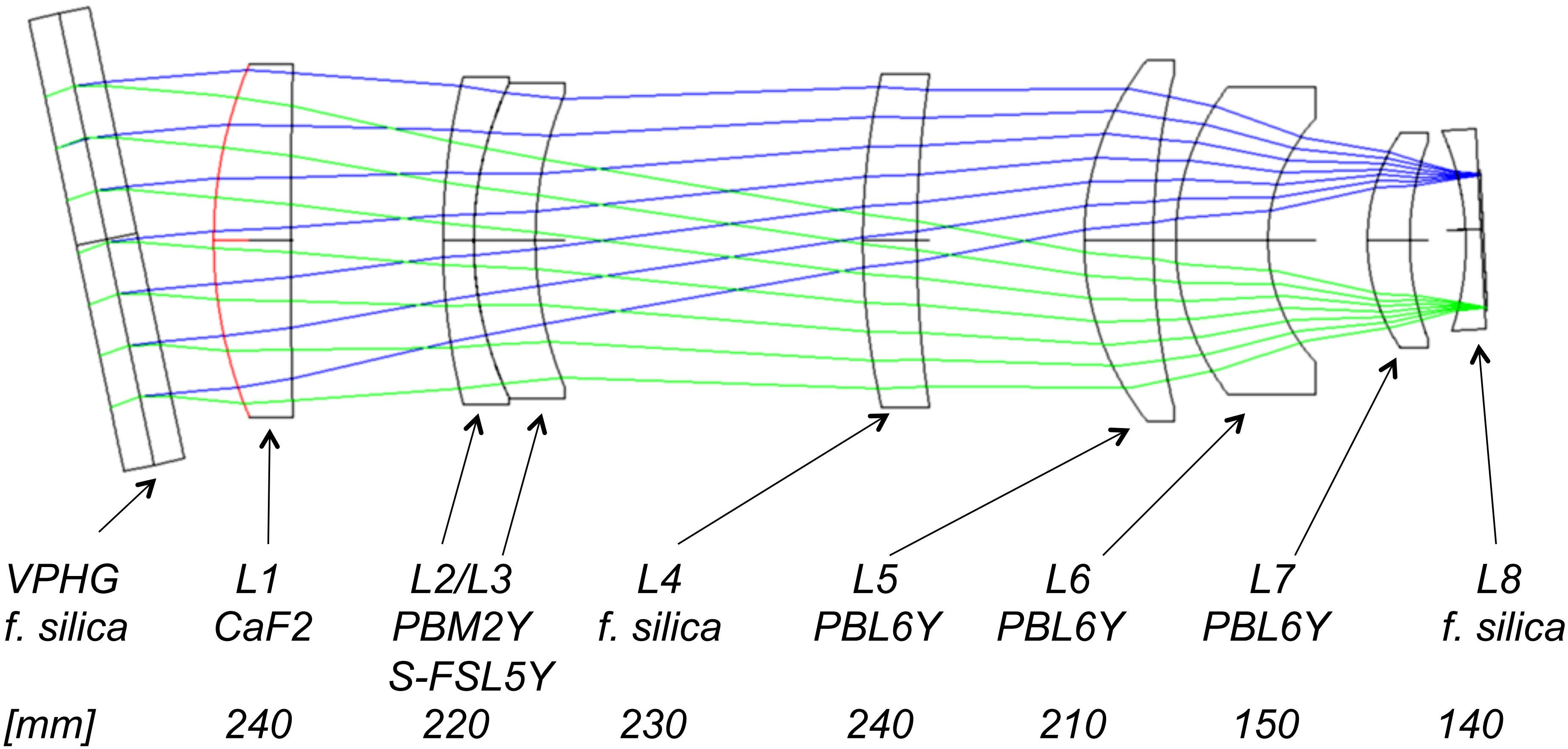
- Today $\varphi_T = 8$, $\varphi_B \sim .25$
- In ELT era $\varphi_T > 25$, but $\varphi_B \sim .25$
- **Optical glass φ < .3**

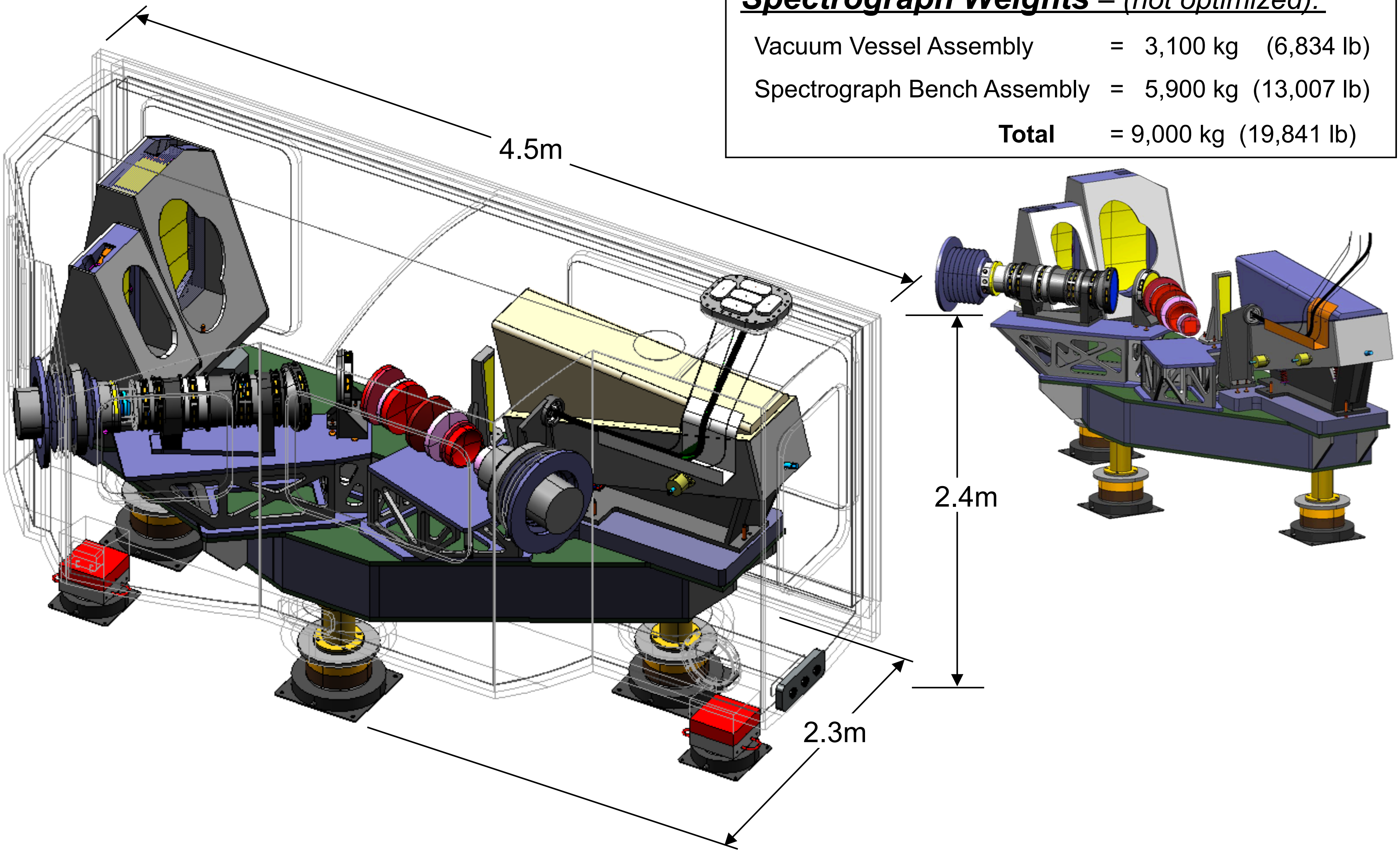
Asymmetric White Pupil Configuration Reduces Requirements for Lens Substrate Diameter



Reducing beam size increases included angles ➜ more challenging optical design

Blue Camera Design

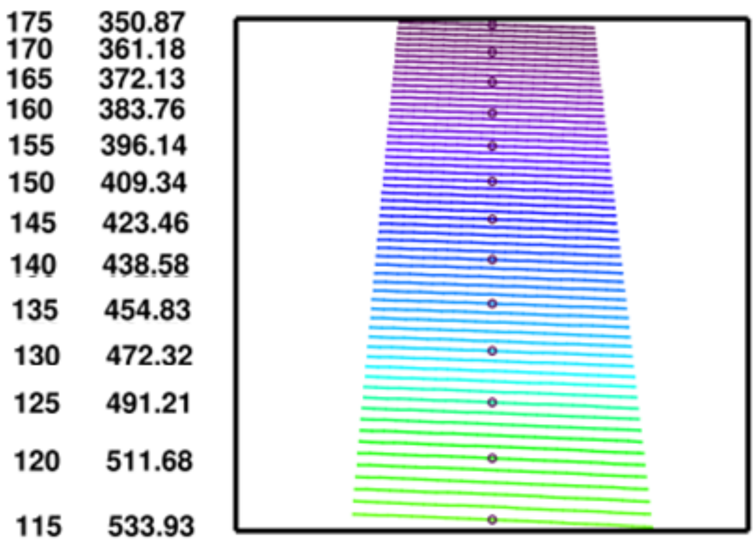




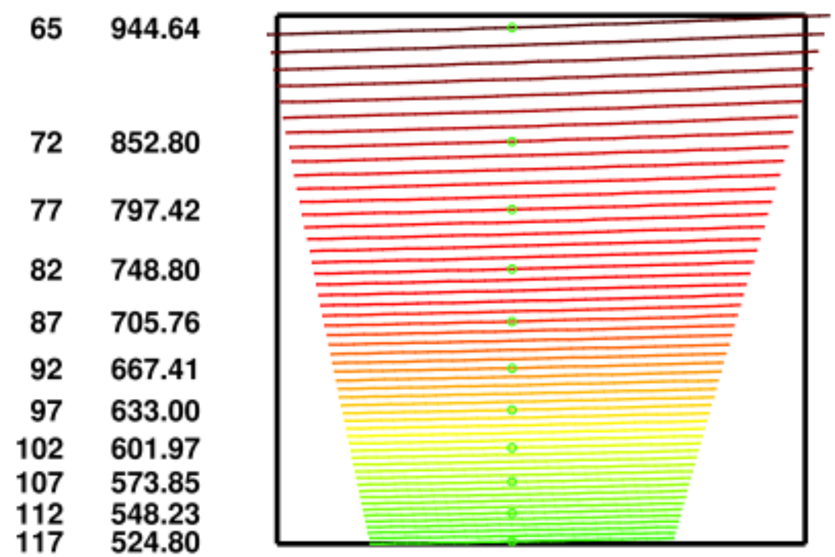
Spectrograph Weights – _(not optimized):_

Vacuum Vessel Assembly	= 3,100 kg	(6,834 lb)
Spectrograph Bench Assembly	= 5,900 kg	(13,007 lb)
Total	= 9,000 kg	(19,841 lb)

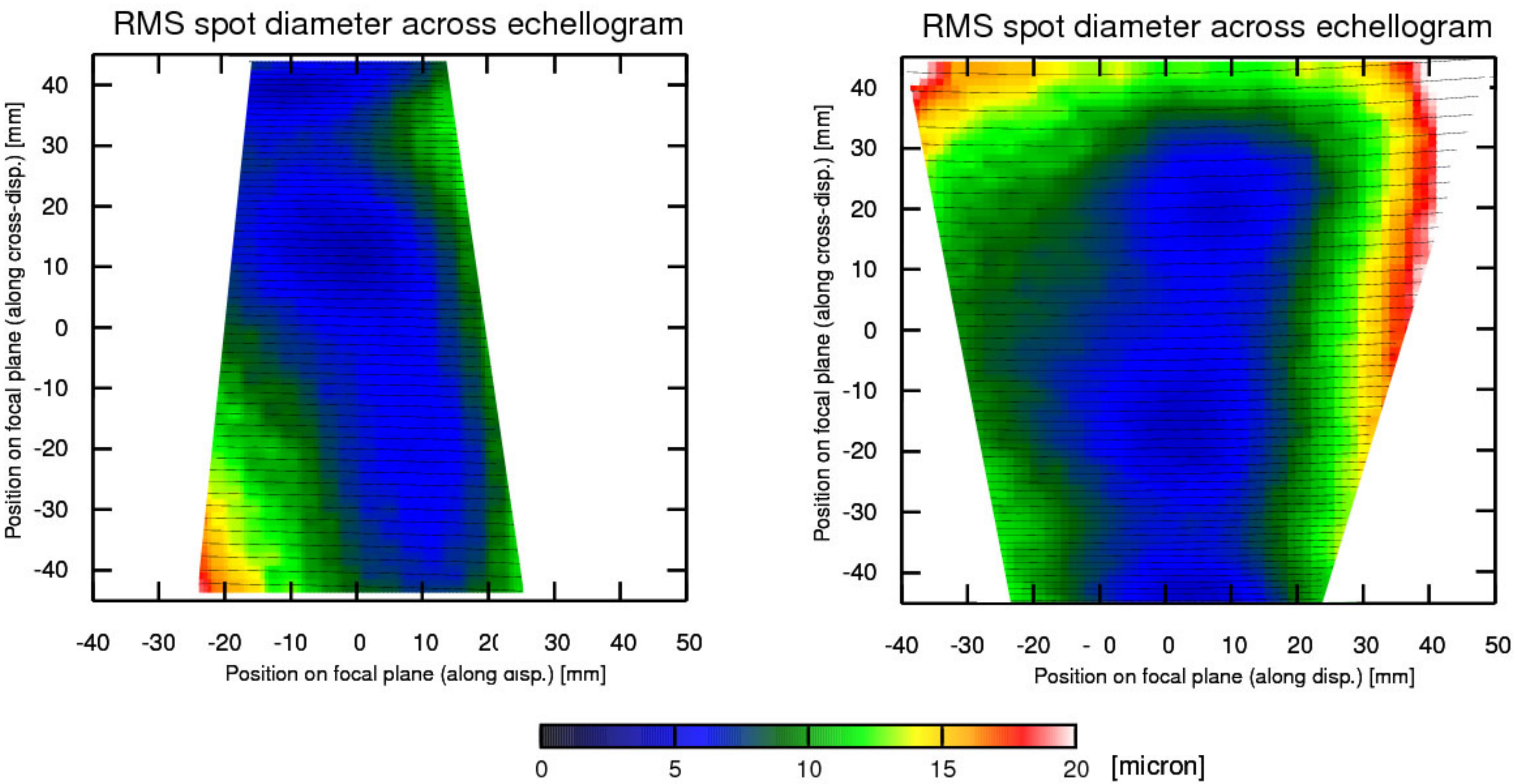
Echellogram format on 4k x 4k CCD



blue echellogram



red echellogram



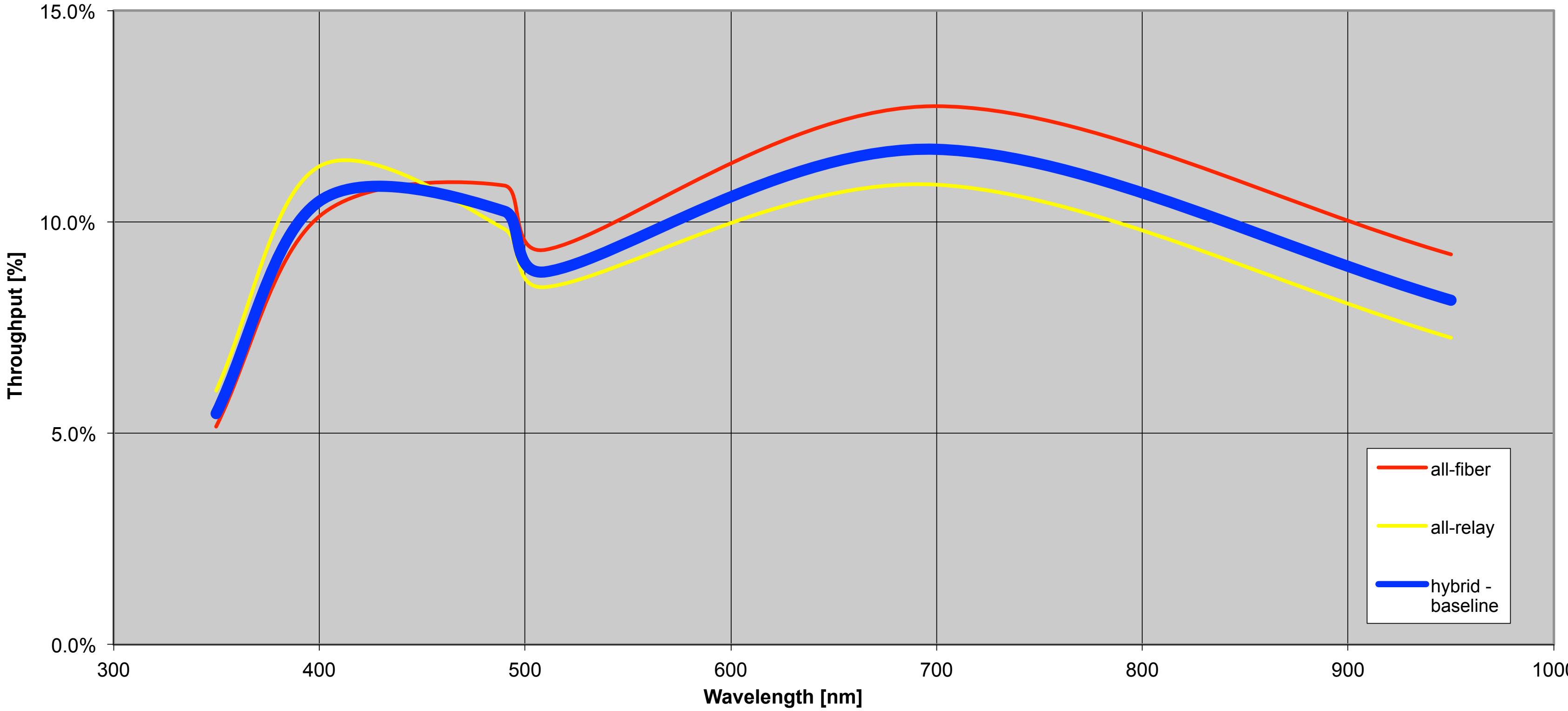
the cameras provide excellent image quality at f/2.5 over the entire detector

the RMS spot size diameters are within 1x1 pixel area for both the red and blue arms

Total System Efficiency

Everything is included except atmosphere:

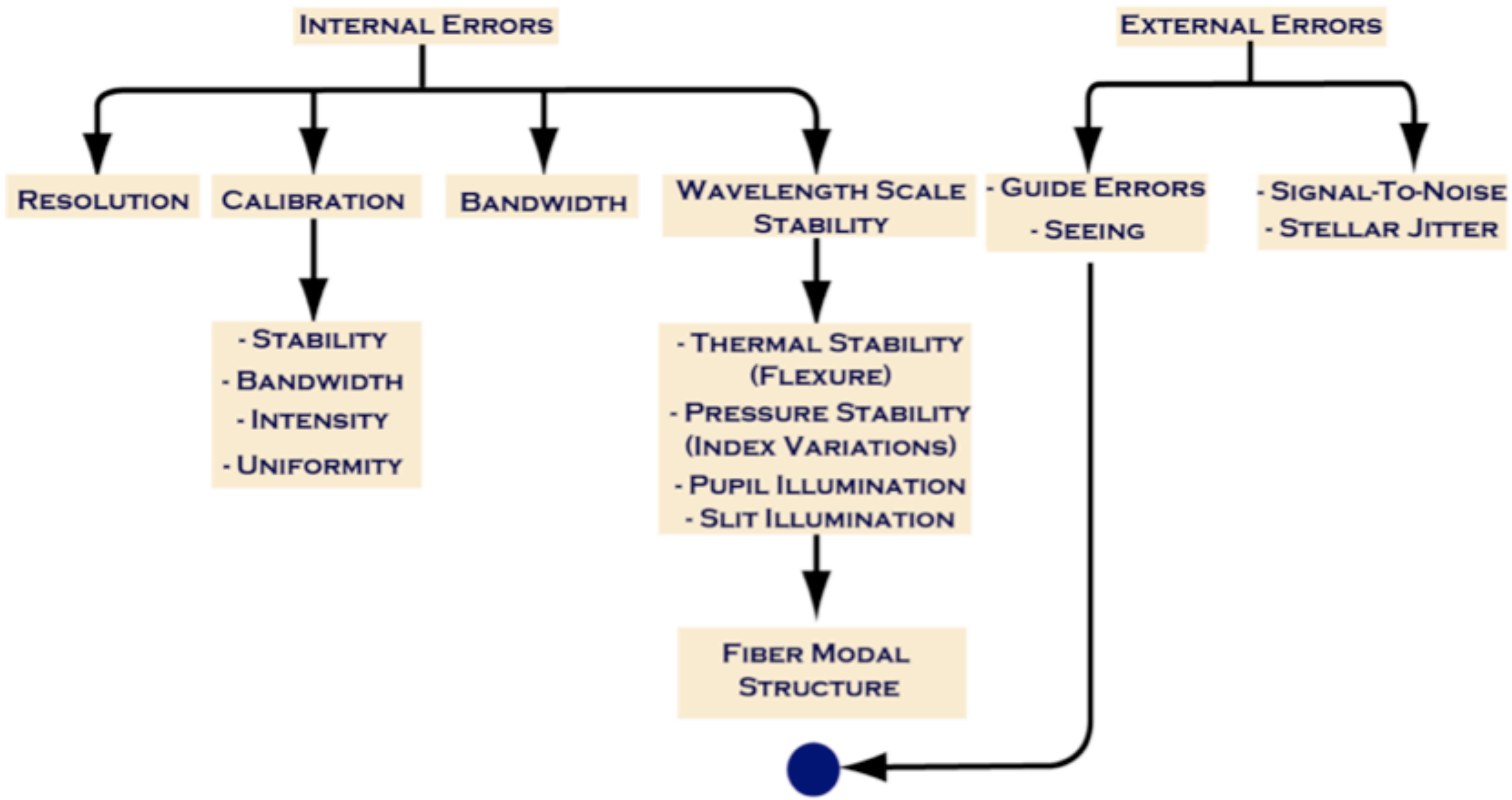
- telescope
- front end optics (tertiary, relay optics, ADC)
- fiber system (Fresnel losses, slit losses, FRD losses, internal transmission)
- spectrograph (f-ratio conversion, gratings, optics, detector)



Requirements for Exoearth Mass Measurements

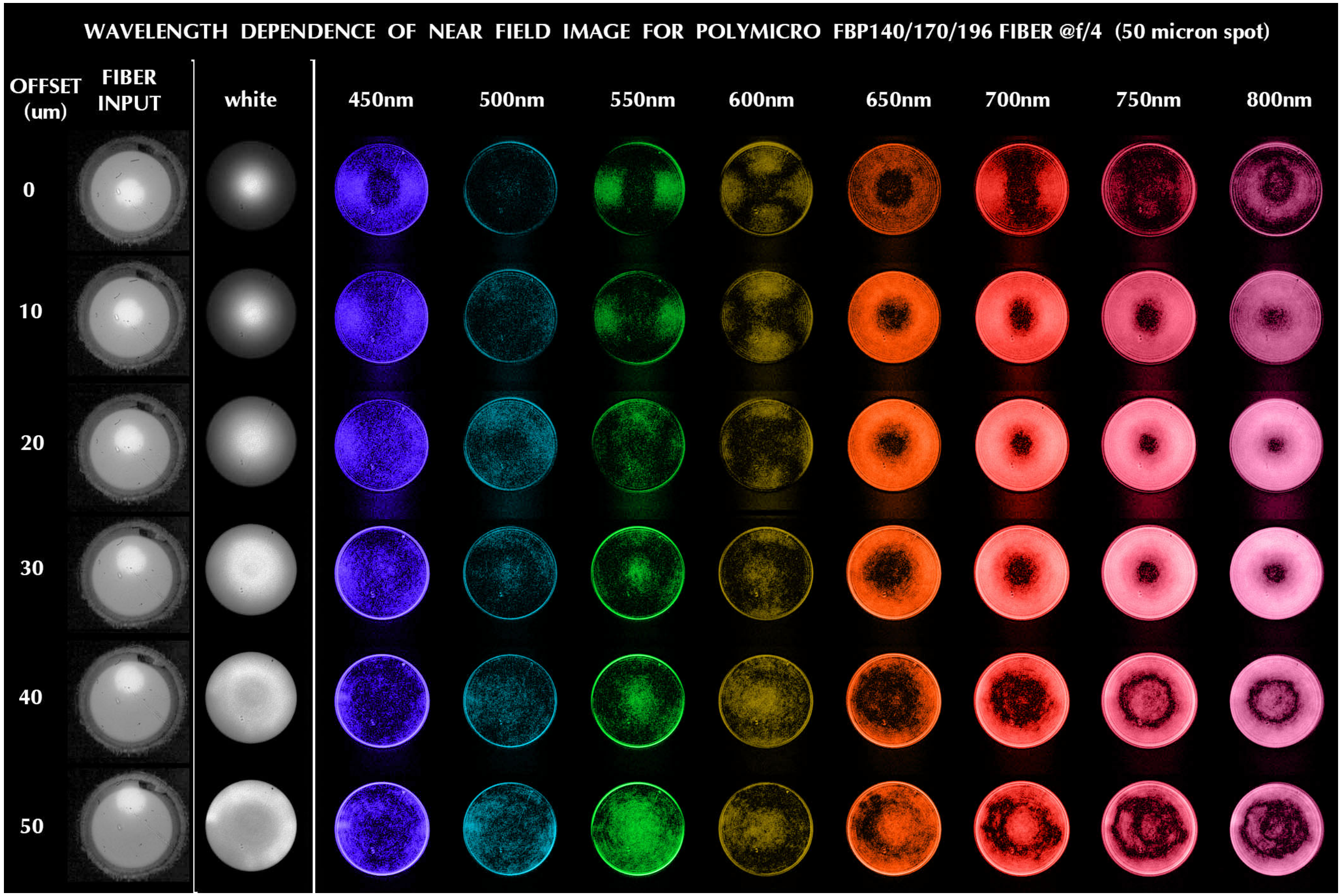
- The ability to detect planets transits of exoearths and measure the reflex motion of their host stars on year-to-multiyear timescales
- Detect the presence of earth mass planets
  - Earth-sun reflex (K) ~ 10 cm/sec
  - State of the art is ~ 0.6 m/s
  - Finding earth analogues requires at least 5-6x better precision
- Many lessons have been learned from HARPS example, but improvements in calibration, guiding, stability, mode scrambling & signal-to-noise are needed.
- **Is it possible?**

RV Error Contributors



Note: HARPS achieves month-long 9 cm/s stability against ThAr calibrator

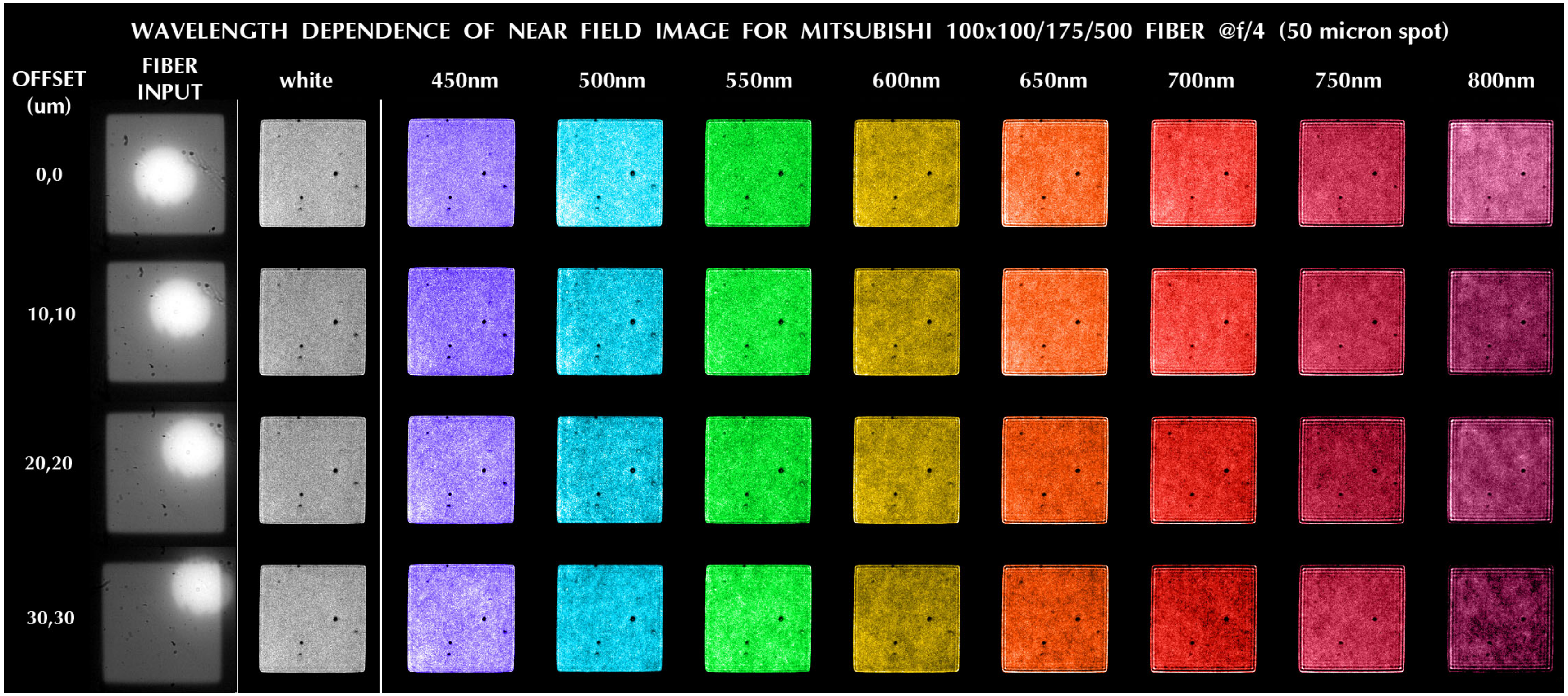
Time-variable slit image structure is produced by seeing and guiding



Gabor Furesz

To date, has been ameliorated with extremely lossy double scramblers, poorly.

New fiber cross section geometries scramble extremely well, with no additional losses



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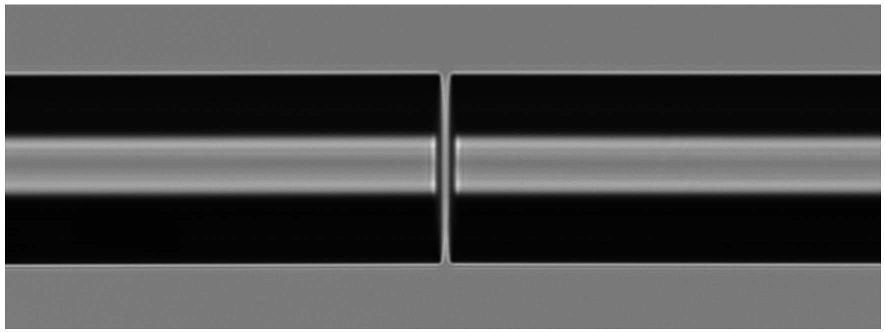
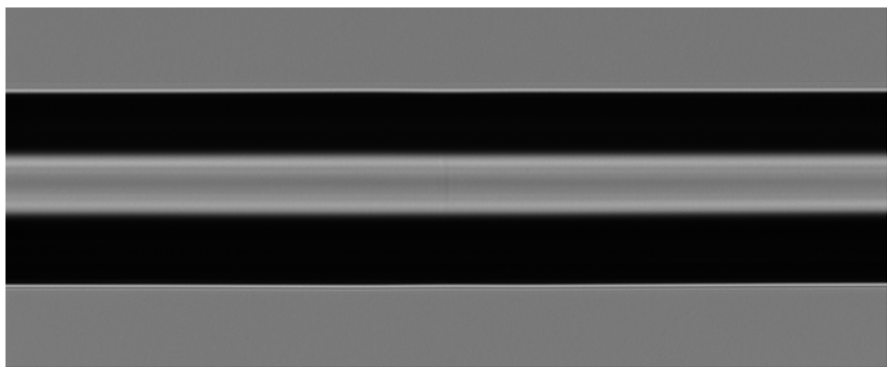
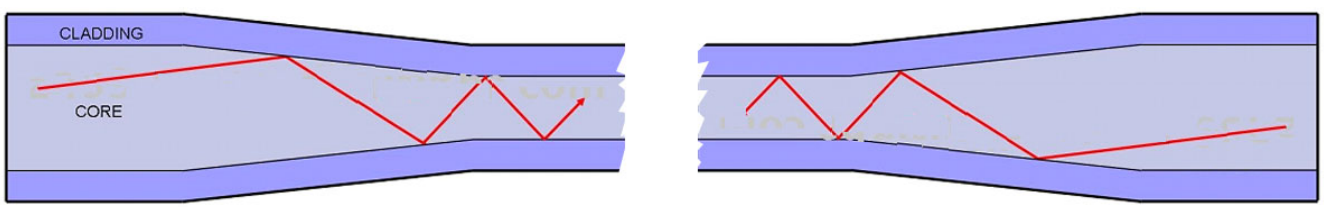
Engineering Optical Fibers for Optimal RV Perforamance





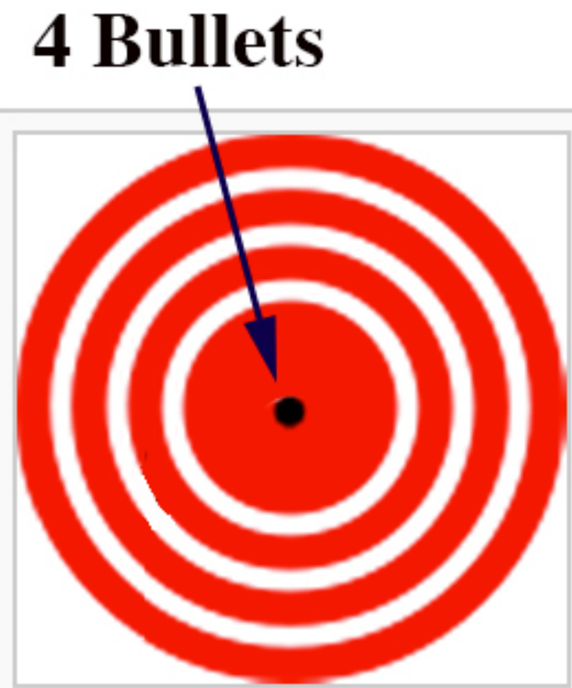


Other considerations for the improvement of RV precision:

- Optical design "secret sauce"
  - Lessons learned from HARPS, UVES, HIRES, MIKE, PFS
- Invar construction
- Superb GMT guides
- Possible use of DM
- Improved thermal control
- Intregrated optical fiber engineering
- &c., &c., &c.

High **accuracy**, but low **precision**.

High **precision**, but low **accuracy**

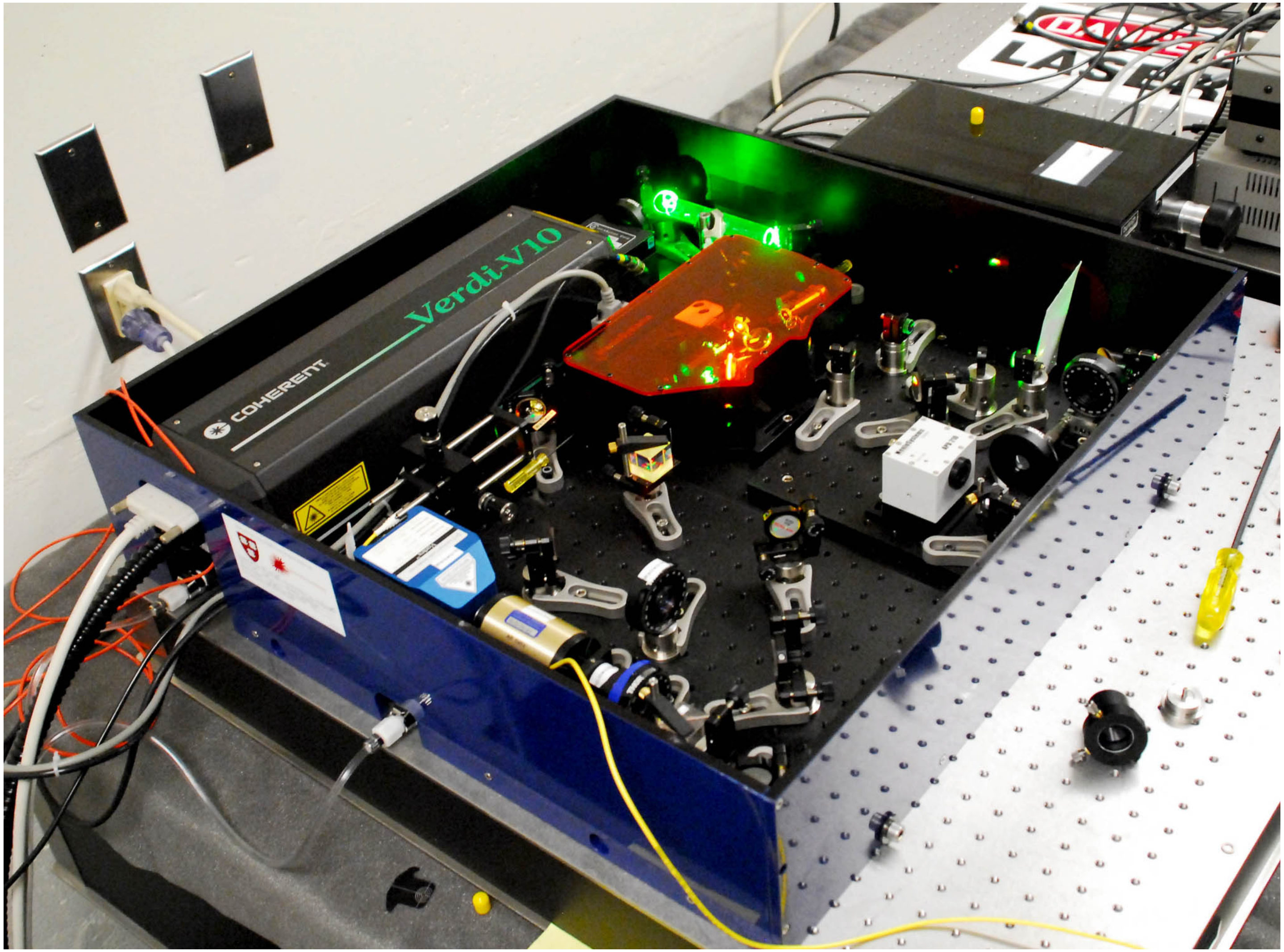


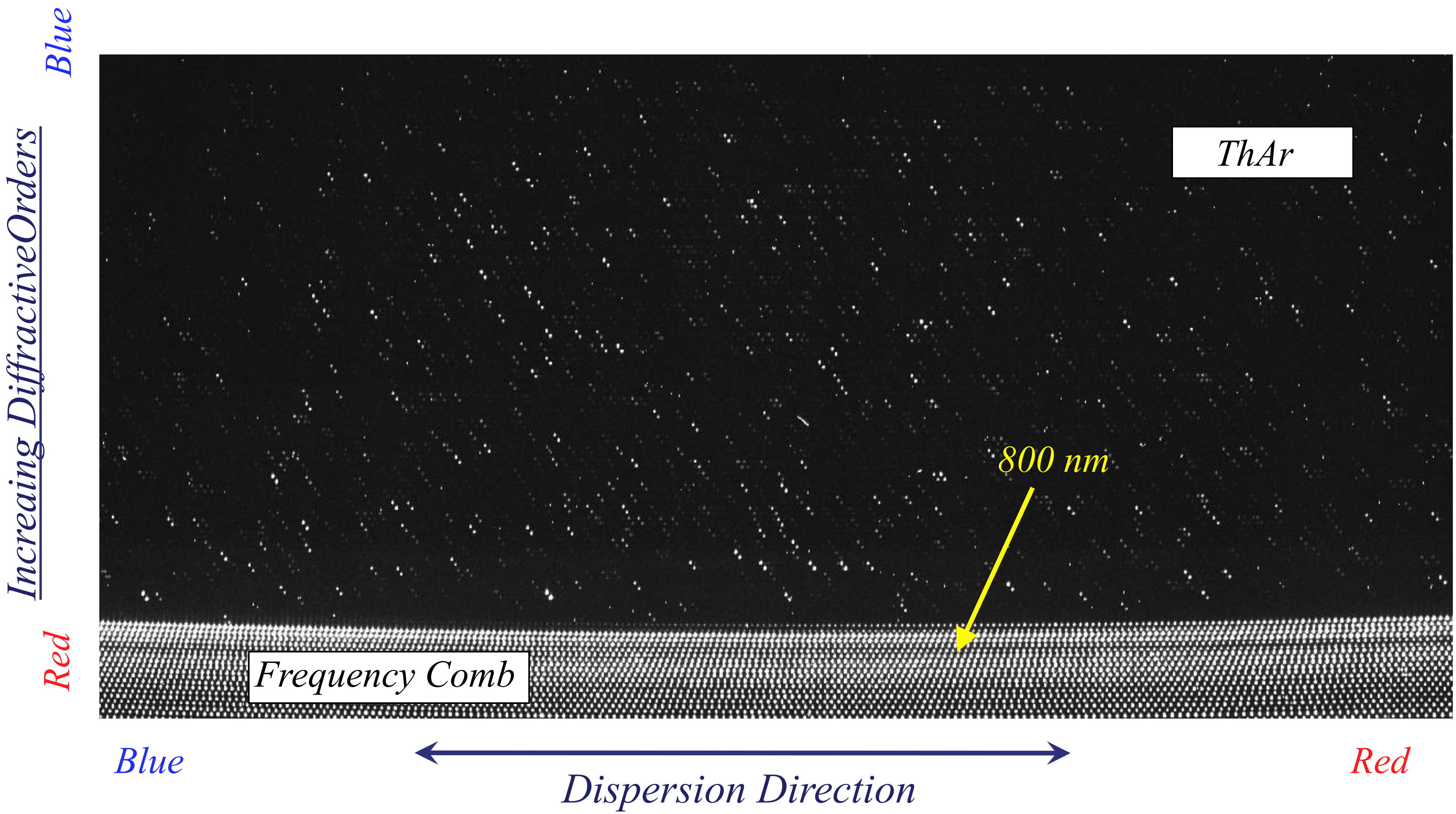
High **precision**, High **accuracy**

It is important to transition from extreme precision to extreme accuracy

- **To work at 10 cm/sec on multiyear time scales**
- **To reduce amount of telescope time required**

Laser frequency combs are accurate calibrators




Blue
Increasing Diffractive Orders
Red
ThAr
800 nm
Frequency Comb
Blue
Red
Dispersion Direction

GMT Instrument Delivery Schedule: When is First Light?