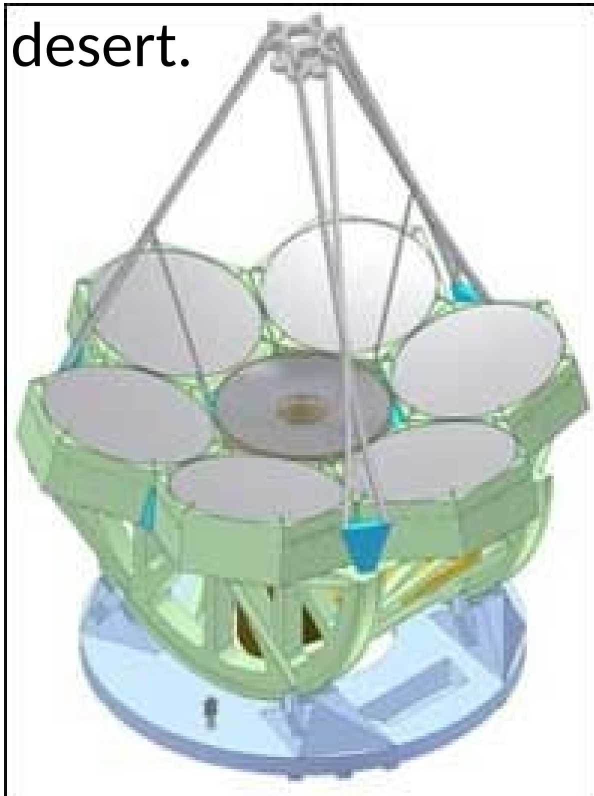
The GMT Consortium Large Earth Finder

Sagi Ben-Ami
Smithsonian Astrophysical Observatory

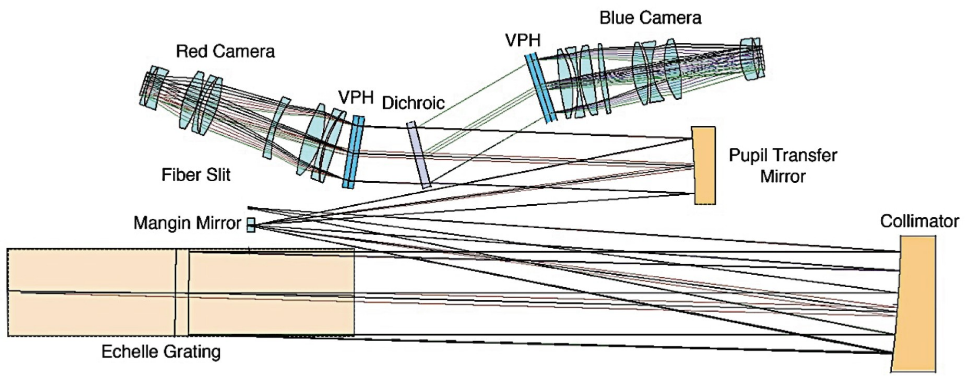
The Giant Magellan Telescope

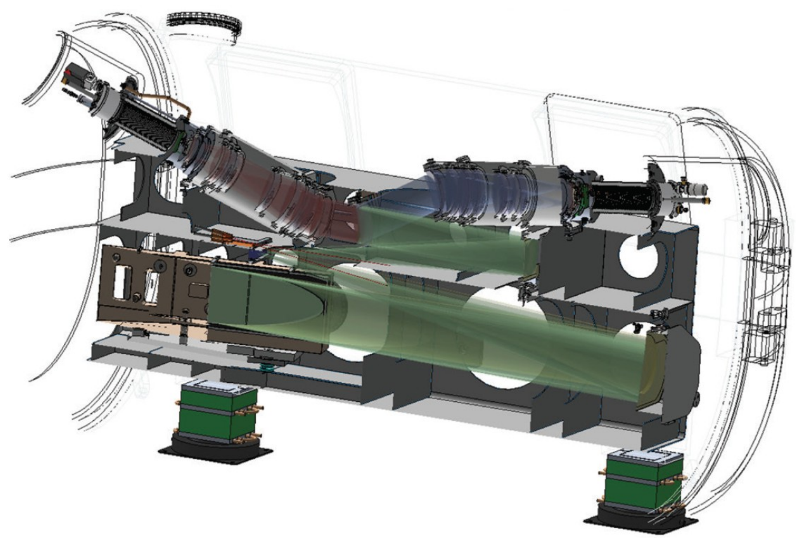
- The GMT is one of the three next generation optical telescope.
- Segmented Gregorian design (six off axis and one on axis 8.4m mirrors) with an effective aperture of 25.4m diameter.
- F/8.2 with a FoV of 24’. Plate Scale of 1’’ mm^{-1}.
- Site: Cerro Las Campanas in Chile’s Atacama desert.



The GMT Consortium Large Earth Finder

- The GMT Consortium Large Earth Finder (G-Clef) is a general purpose visible echelle spectrograph that offers precision radial velocity capabilities.

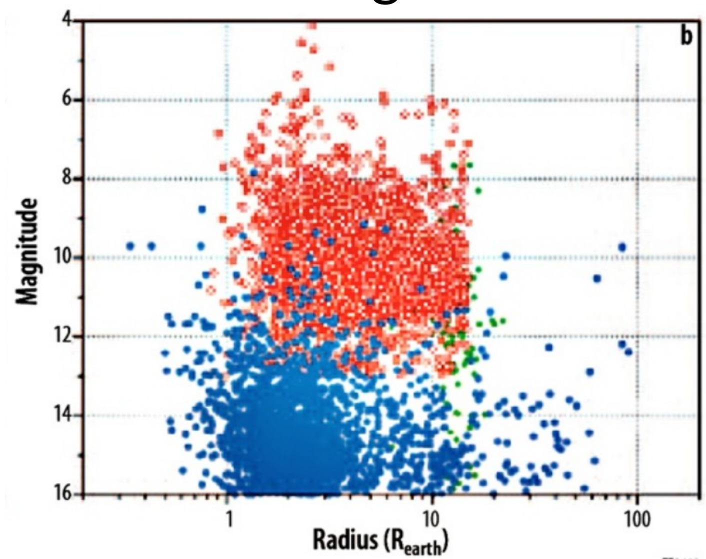




- G-Clef was chosen as the 1st light instrument for the GMT.

G-CLEF: Science Cases

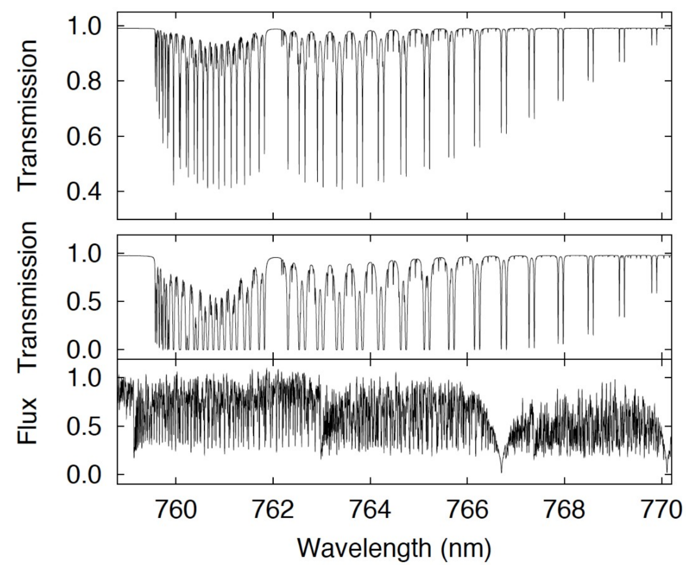
- Weighing planets in the TESS Catalogue.



Planet	a (AU)	Reflex Velocity (m/sec)				
		G2V	M0V	M2V	M4V	M6V
Jupiter (318 M_{Earth})	0.1	89.8	116	136	201	284
Jupiter (318M_{Earth})	1.0	28.4	36.7	42.9	63.6	89.9
Jupiter (318 M_{Earth})	5.0	12.7	16.4	19.1	28.4	40.2
Neptune (17 M_{Earth})	0.1	4.8	6.2	7.2	10.8	15.2
Neptune (17 M_{Earth})	1.0	1.5	2.0	2.3	3.4	4.8
Super Earth (5 M_{Earth})	0.1	1.4	1.8	2.1	3.1	4.4
Super Earth (5 M_{Earth})	1.0	0.45	0.57	0.67	1.0	1.4
Earth	0.1	0.28	0.37	0.43	0.68	0.89
Earth	1.0	0.09	0.12	0.13	0.20	0.28
Mars (0.11 M_{Earth})	0.1	0.03	0.04	0.05	0.07	0.09
Mars (0.11 M_{Earth})	1.0	0.009	0.012	0.014	0.021	0.030

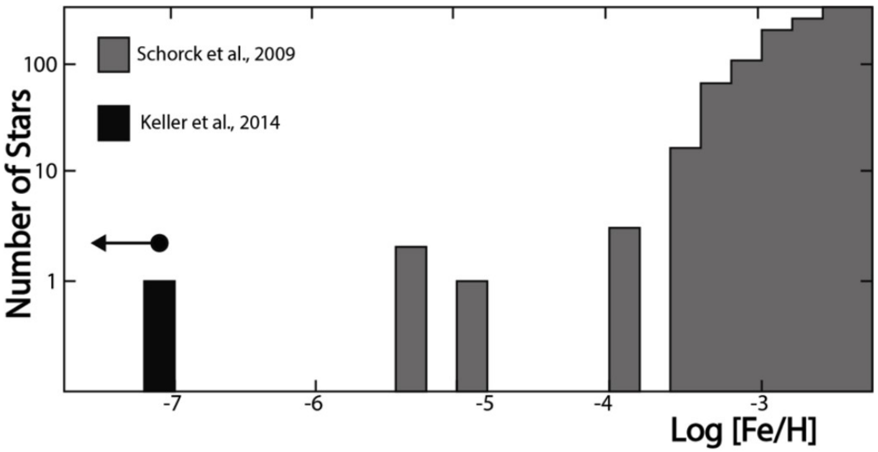
- O_2 in the transmission spectra of exoplanets:

A-Band absorption features between 7600-7700Å .



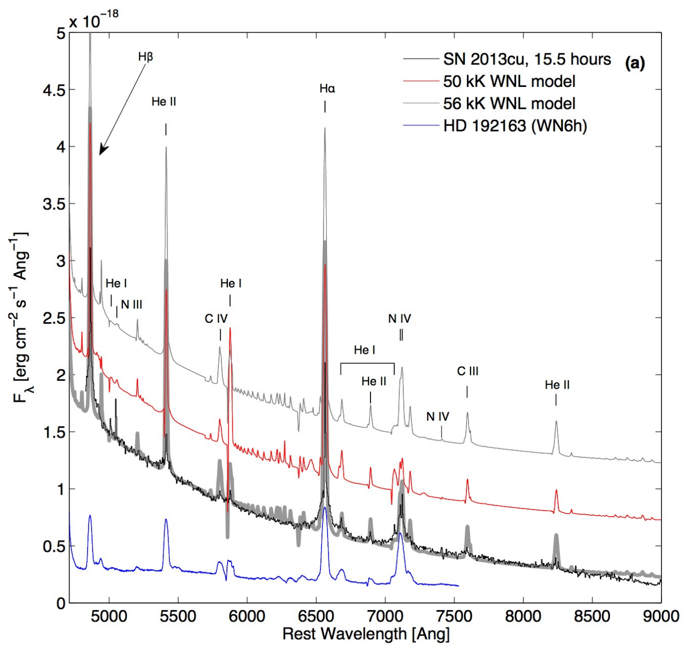
G-CLEF: Science Cases

- Near-field cosmology: Characterization of metal poor stars – the fossils of structure formation at the earliest phase after the big bang.



- Flash Spectroscopy of SNe:

  Direct measurements of CSM composition, unique properties of the progenitor.



Science Requirements

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

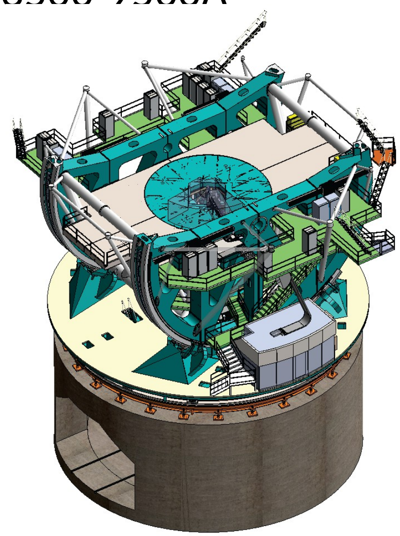
- Long term wavelength scale stability
- Very high resolution
- High S/N
- Instrument Changeover Speed

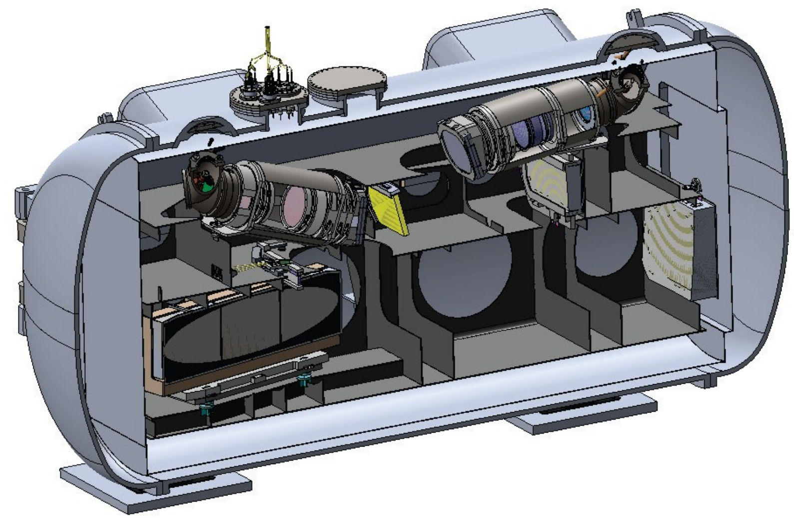
Detailed Chemical Composition Beyond the Local Group

- Slit Length for MOS

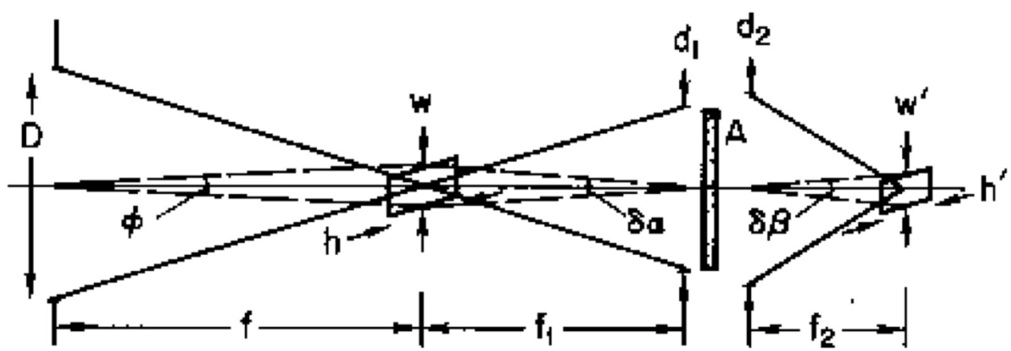
So how do we achieve all of these ?

- A fiber-fed high dispersion spectrograph thermally stabilized deployed at a gravity invariant location.
- Pass band: 3500-9500Å





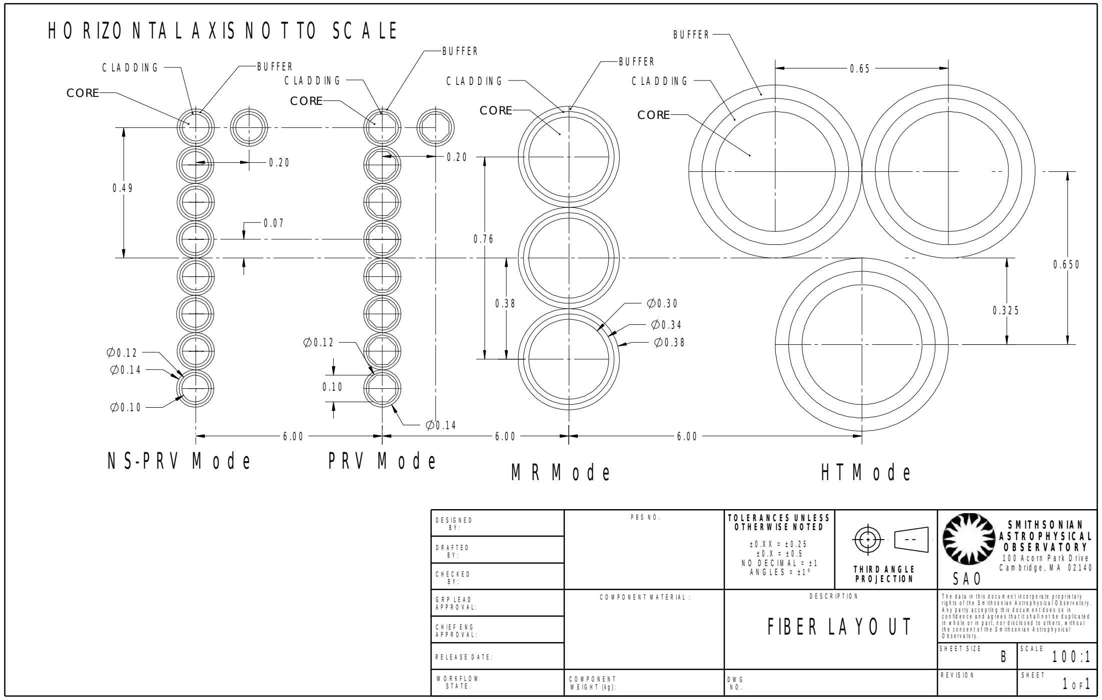
- Different resolution is achieved by feeding the spectrograph with fibers of different core diameters.

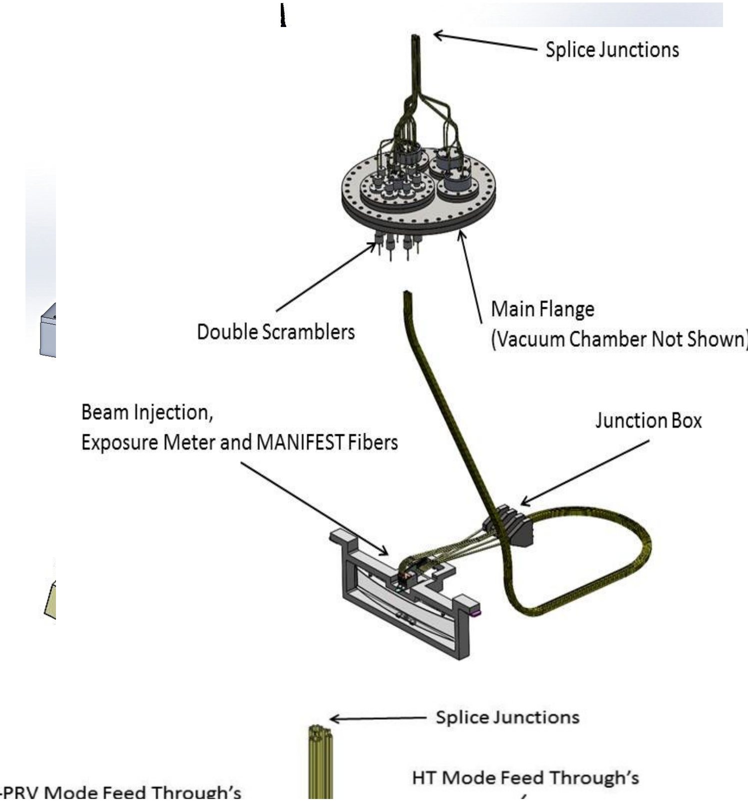


Comments
recision Radial Velocity, Pupil Sliced x 7
Pupil Sliced x 7
Through MANIFEST, Multiplex = 40

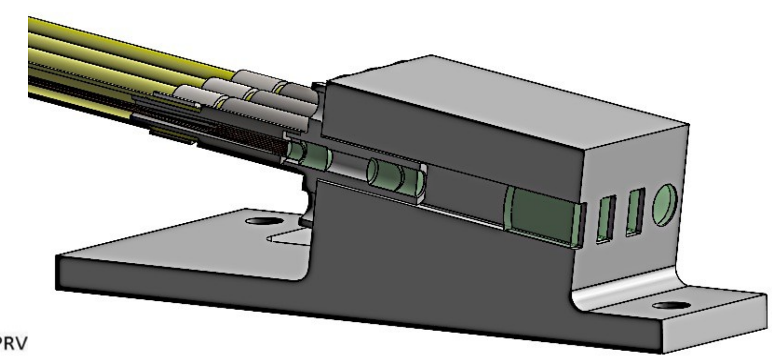
$$\delta\lambda = P\omega'$$

Optical Path: Fiber Run





(Scrambler)

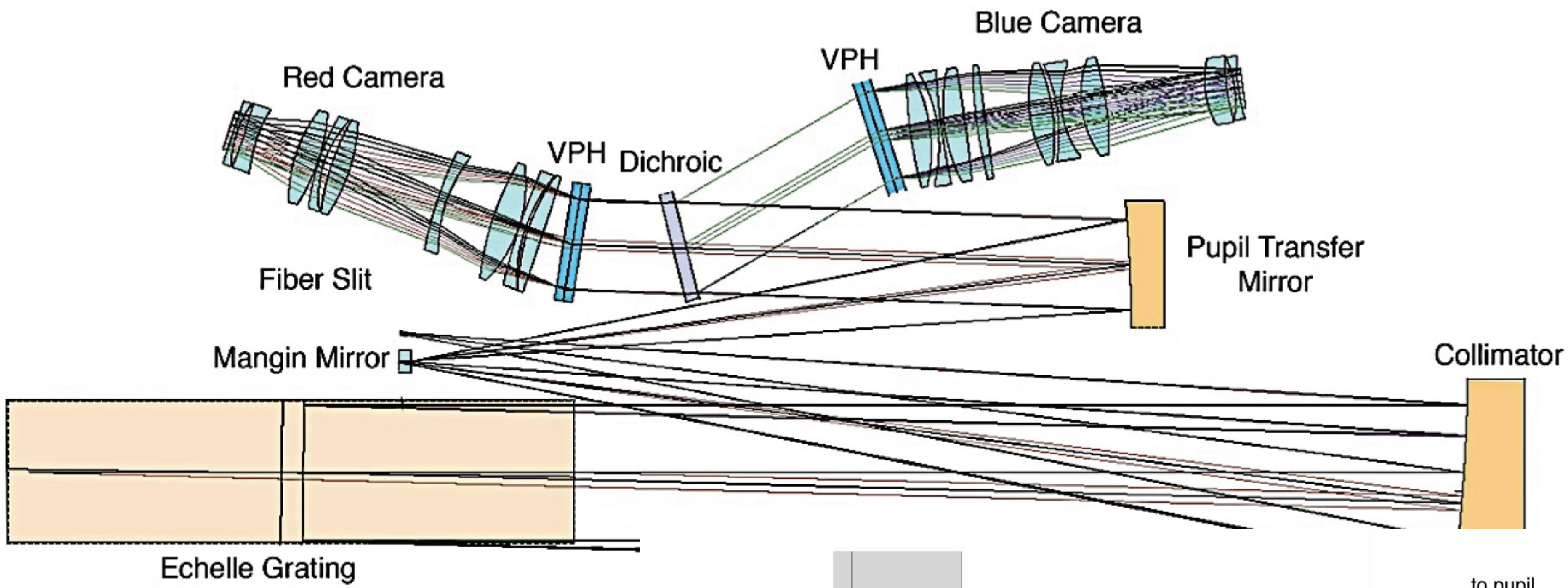


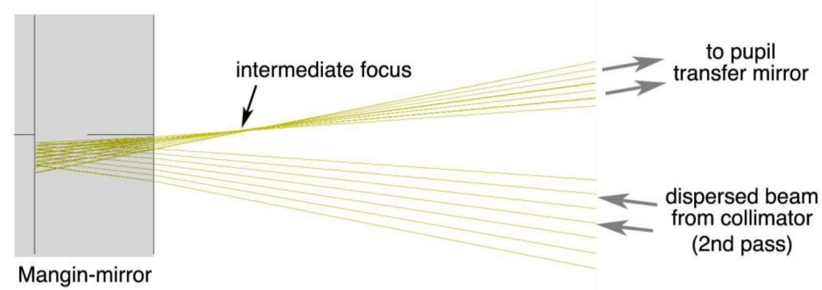
Spectrograph F/# converters

PRV

(Exposure Meter)

Spectrograph Optical Design

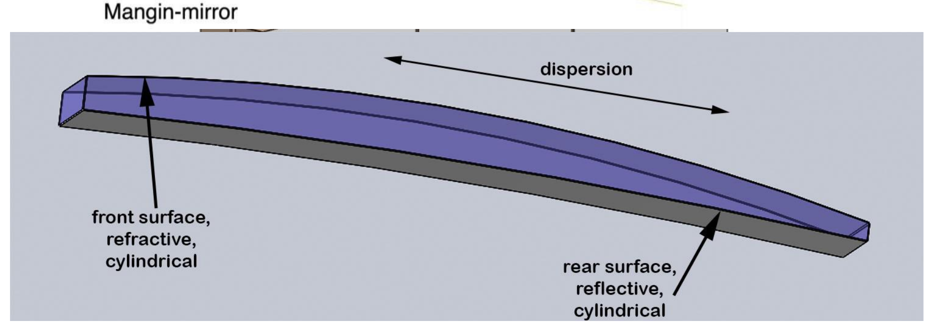




Grating: A mosaic of three 300x400mm R4 operating at a quasi-Littrow configuration.

Mangin Fold Mirror to correct cylindrical field curvature

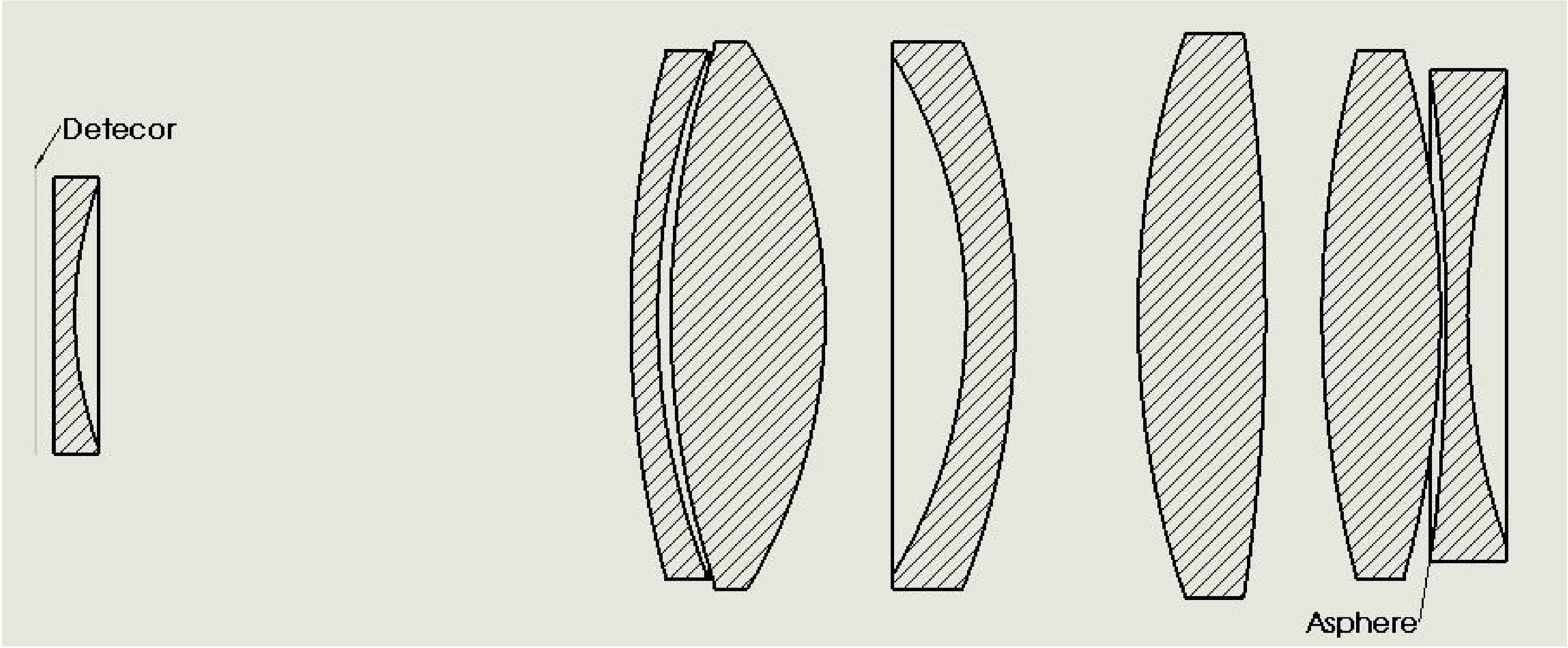
$$\Re = \frac{\lambda}{\delta\lambda} = \frac{\delta A}{r\phi}\frac{d_1}{D}$$



G-Clef Red Camera

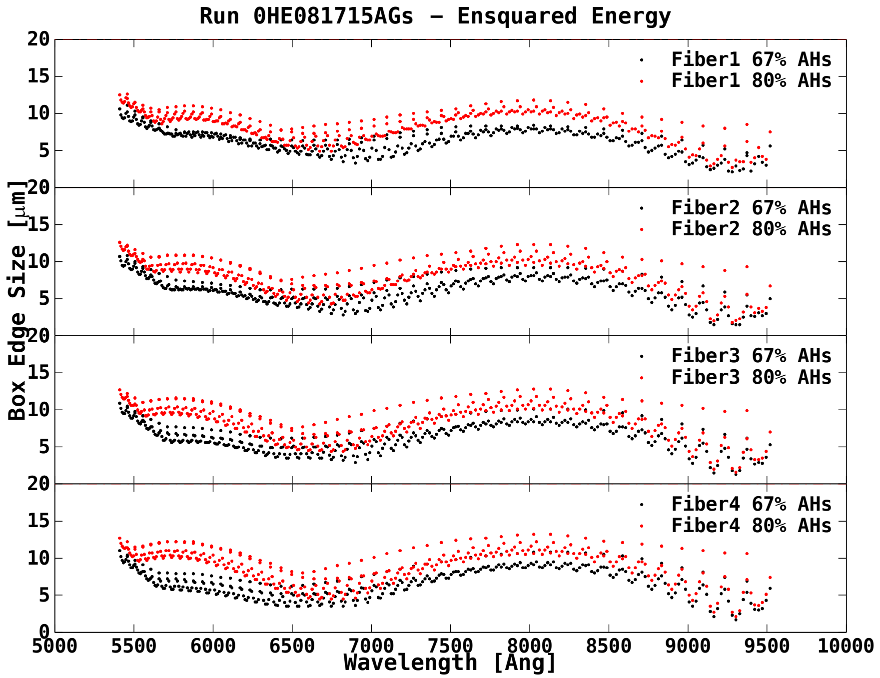
- The re-designed red camera is a 7-element camera with one aspheric surface on the back surface of the 1st lens (Glass substrate).
- Power is mainly due to CaF_2 positive lenses, with *i*-line negative and meniscus lenses to control chromatic aberrations.

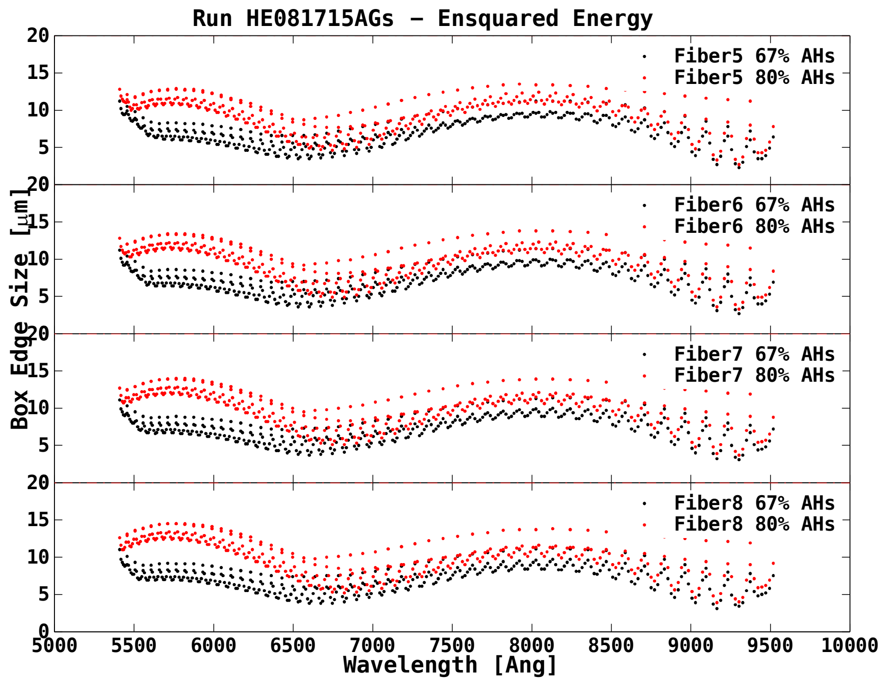
Passband	5400-9520Å (Orders 65-113)
Focal Length	450mm
Beam Diameter	250mm
FoV	7.7°
Testable in collimated light (air-space).	Yes



Red Camera: PRV Ensquared Energy

- Center-to-center distance between fibers in pseudo-slit increased to 170µm.
- 80% Ensquared energy below 18µm (Nyquist for STA 9µm pixels) across the entire echellogram.

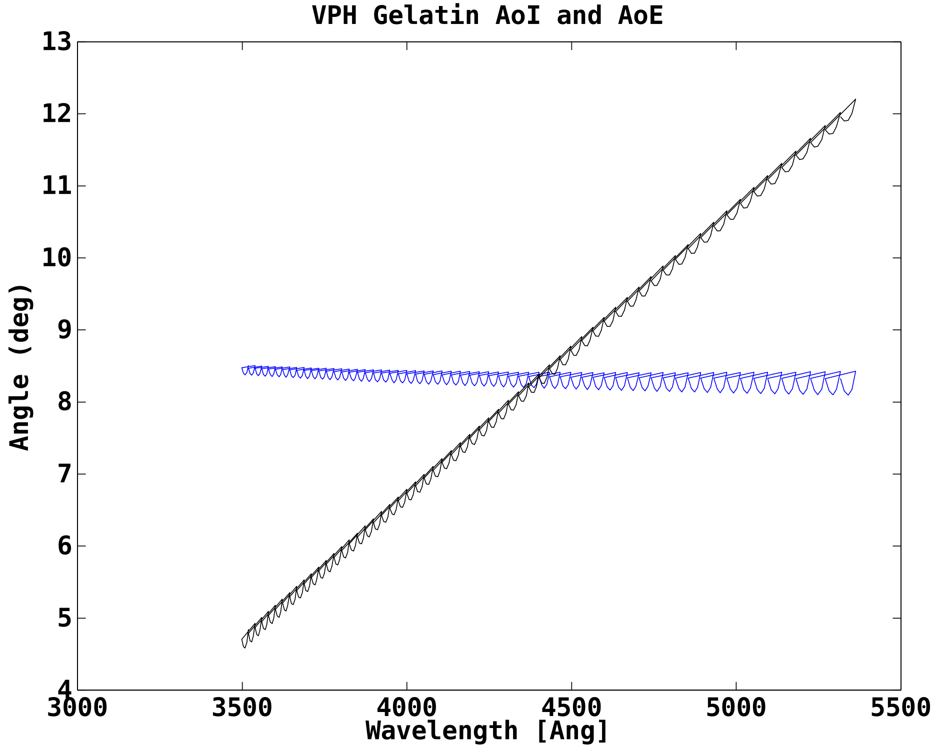


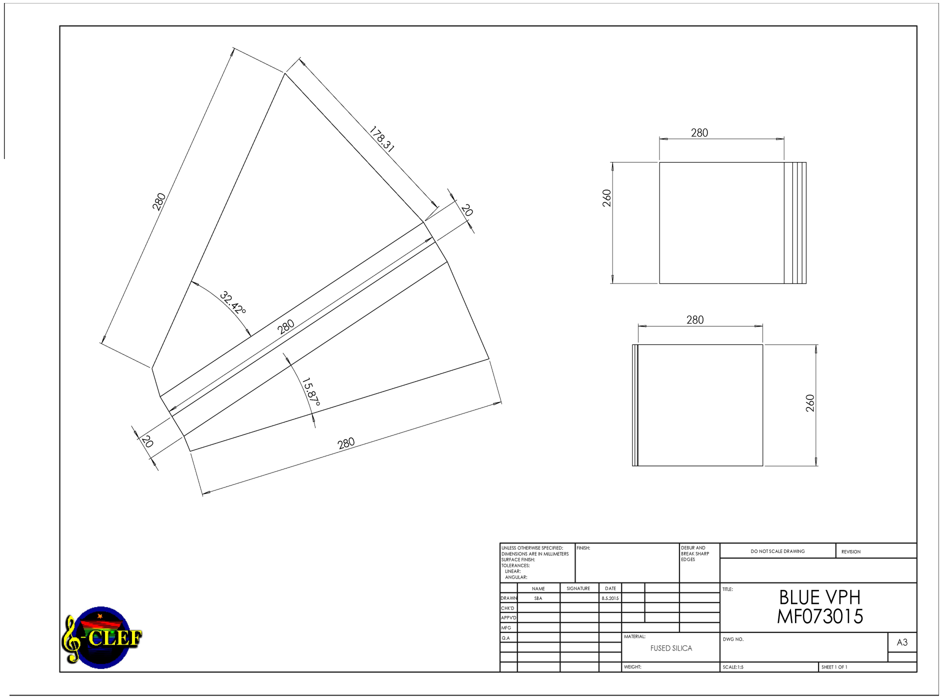


X-dispersers: VPH Gratings

- VPH Grating: A modulation in the index of refraction induced by holographic exposure of dichromatic gelatin.
- Higher efficiency than common ruled gratings.

Blue X-disperser:
A VPH-Prism.

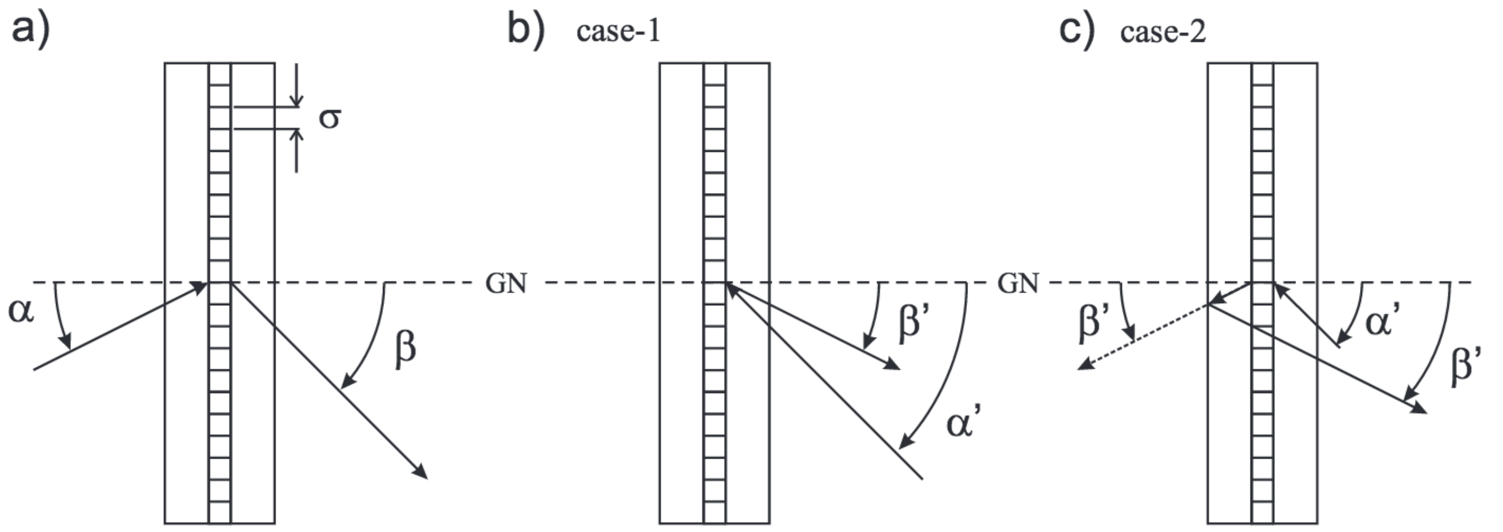




VPH Ghosts Mitigation: Tilted Fringes

- Narcissistic Ghosts: Scattering from Gelatin-Glass interface after reflection from the detector $m = 1;\ m' = 0$.
- Littrow ghost: Recombination of cross dispersed orders by the VPH $\Delta m = 0$.

$$\sin\beta' = \frac{\Delta m \lambda}{\sigma \cos\gamma} + \sin\alpha$$



Tilted Fringes

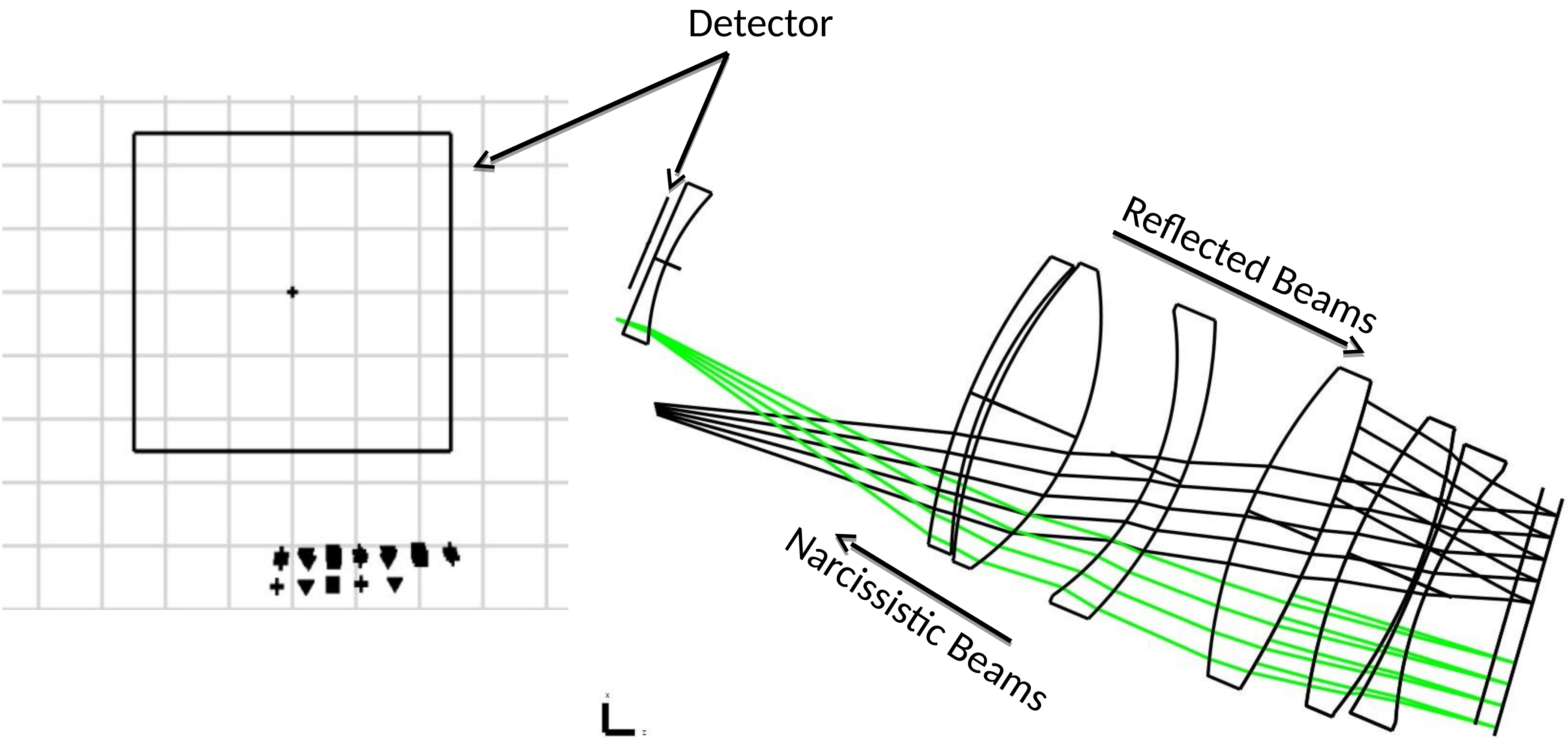
- By introducing a tilt to the imprinted fringes, we move the operation wavelength away from the Littrow configuration.
- The tilt should be large enough so that the ghosts are moved away from the detector.

$$\sin\beta_B = n_2 \sin\left[\arcsin\left(\frac{\sin\alpha}{n_2}\right) - 2\phi\right]$$

$$\Delta\beta = \left|\alpha - \beta_B\right|$$

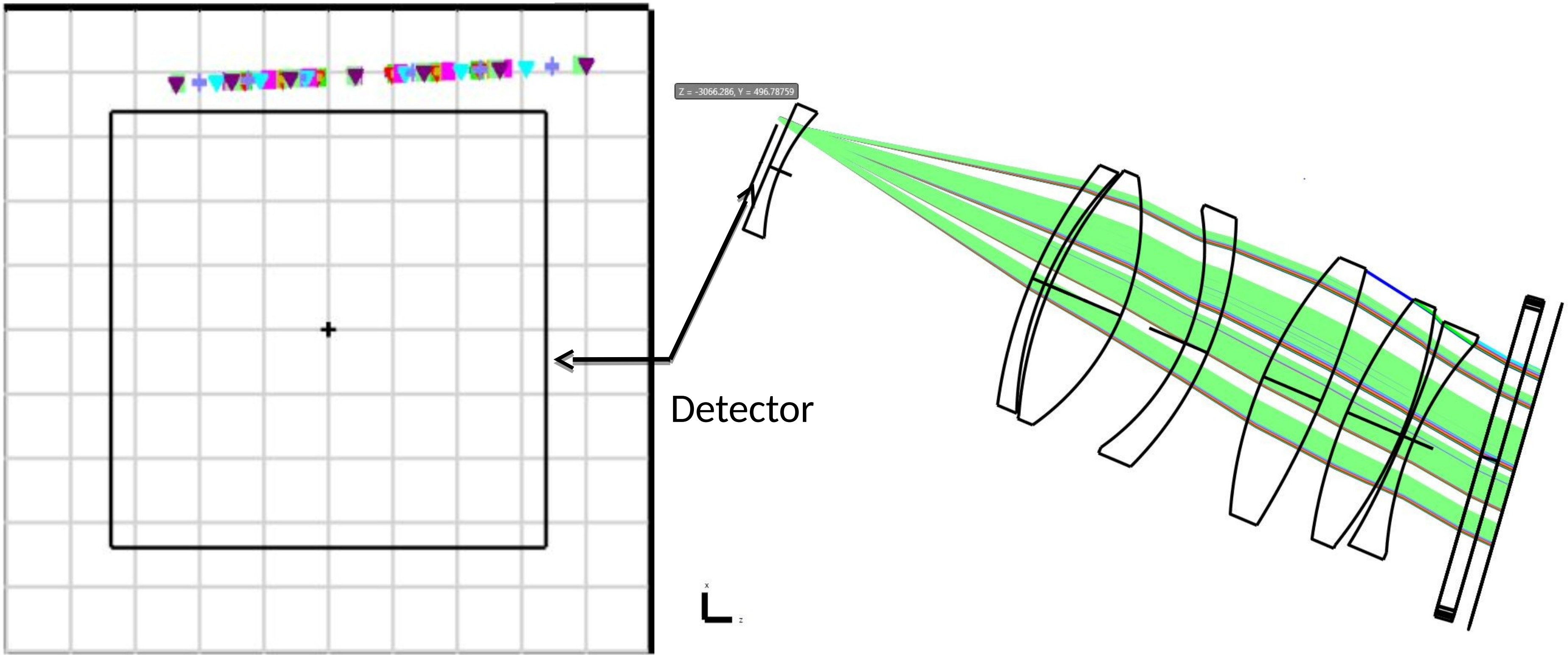
Narcissistic Ghost

- The increased VPH-camera angle deflects ghost beams to higher angles.



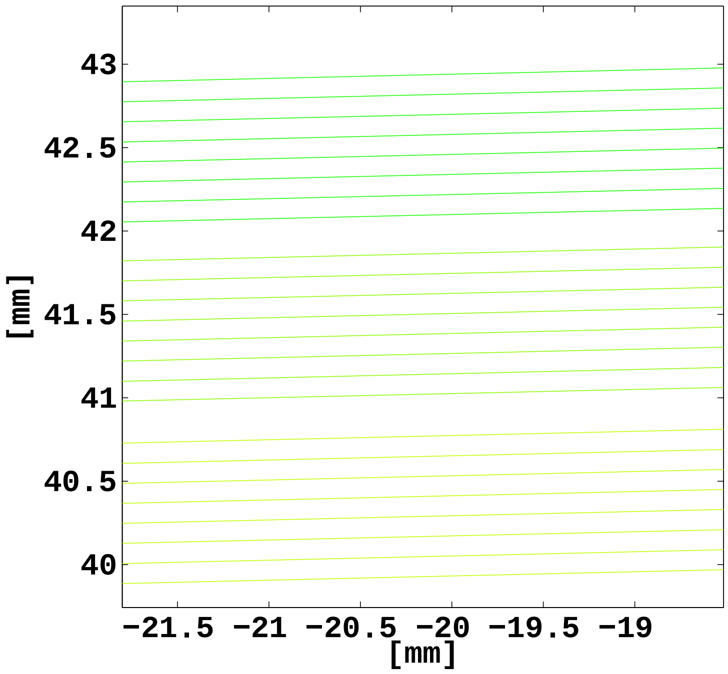
Littrow Ghost

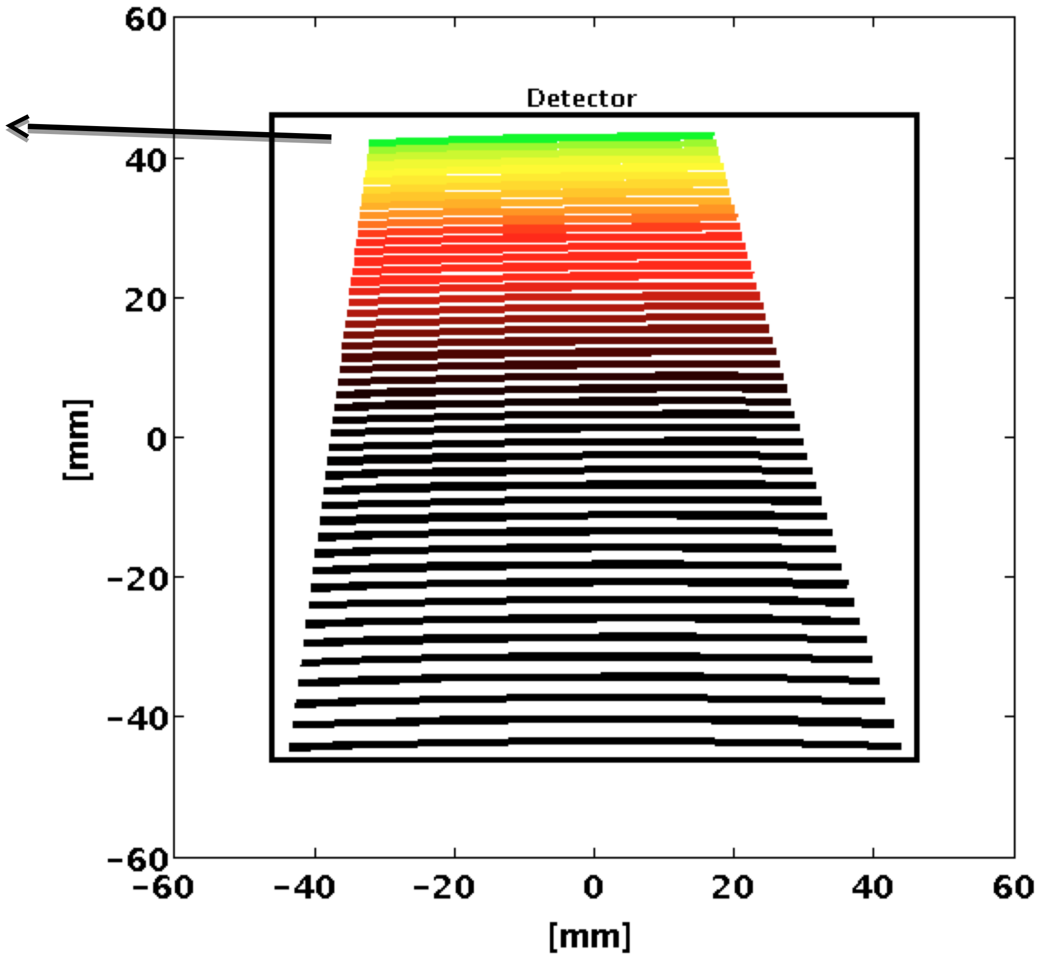
- Tilted fringes ensure that we no longer operate in Littrow configuration, and so the recombined rays miss the detector after recombination.



Red Arm Echellogram

- Entire Echellogram fits well onto the detector (92.4×92.2mm), with at least 1mm for alignment in each direction.





Blue Arm Echellogram

- Entire Echellogram fits well onto the detector (92.4×92.2mm), with at least 0.5mm for alignment in each direction.