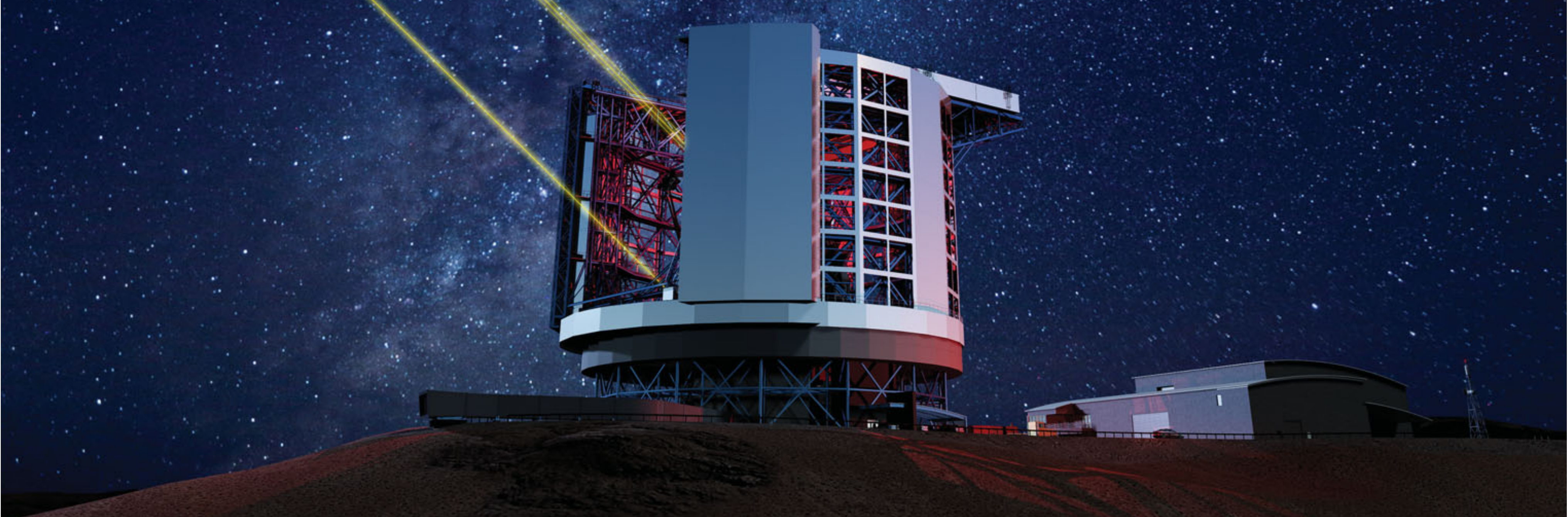
GMT in the Context of ELTs:

Challenges and Solutions in Building the Next Generation of Telescopes

- GMACS
- GCLEF (cross dispersion)
- GMTNIRS (cross dispersion)



Goals for today:

How do the Giant Segmented Mirror Telescopes address the challenges associated with:

– Large optics

– Large structures

– *Instruments*

- What drives the size of instruments?
- How do telescope designs affect them?

- [Adaptive Optics — Wednesday]

Topics:

- What do telescopes do and how?
  - Mirrors & Structures
  - Telescope optics 101
  - Strategies of the 3 GSMTs
    - Optical Configurations
    - Segments — Small
    - Structures
- What do instruments do and how?
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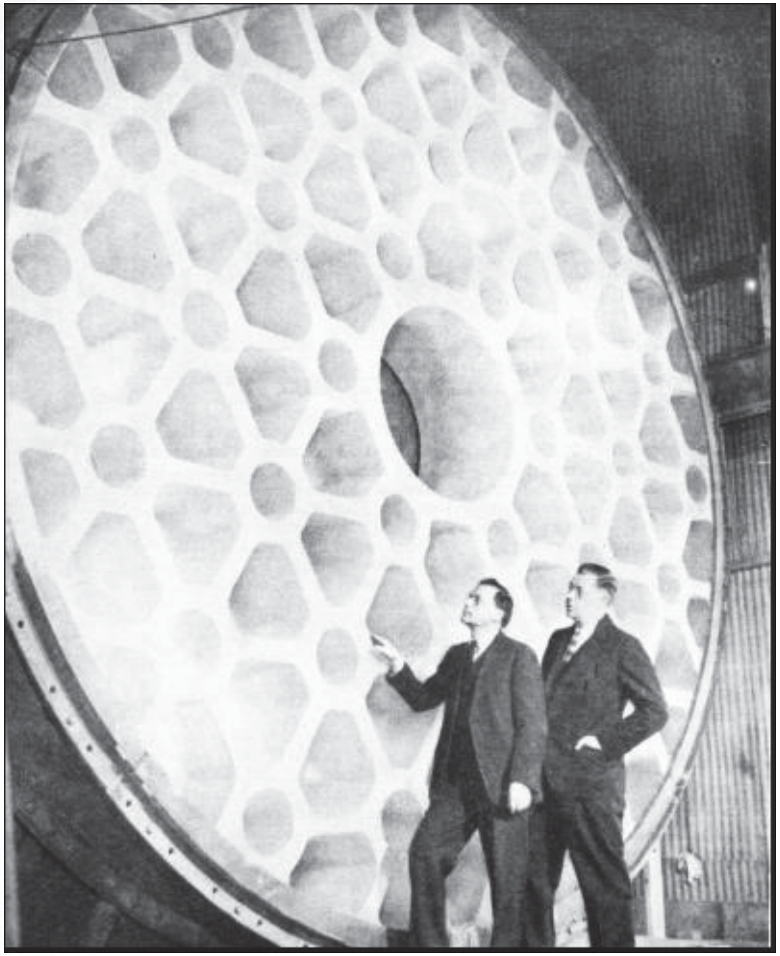
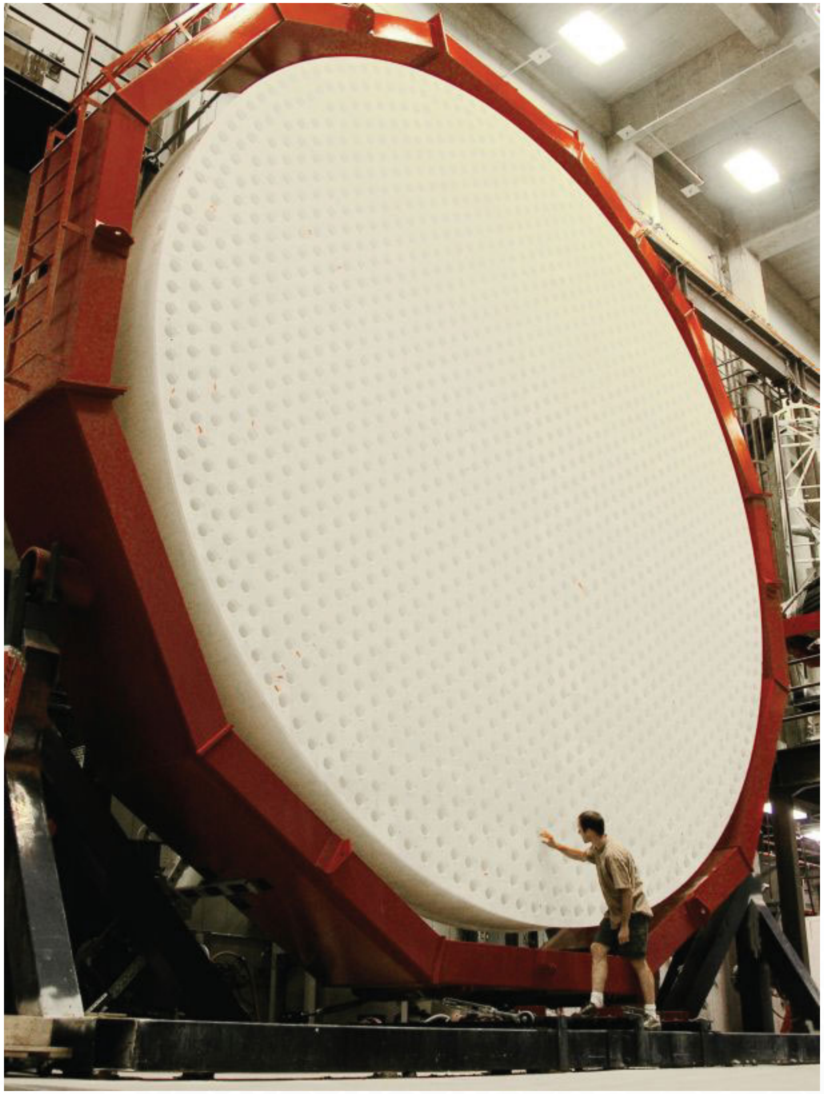
Mirrors: collect light and focus light



Palomar 200-inch (5-meter)



One 8.4-meter GMT Segment

Mirrors:

- **Collect light**
  - 8.4 m is the limit of monolithic mirrors → next generation must be segmented
    - Harder and harder to: cast them that big, polish them, and TEST them.
  - Secondary mirrors are getting BIG! (3m ... Too big to make them Adaptive!)
- **Make sharp images** (diffraction limit scales as $1/D$)
  - Diffraction limited image quality → figure errors must be < $\lambda/20$ rms
    - For $\lambda \sim 1\mu m$: RMS < 0.05μm or 50nm (diameter of hair ~100,000 nm)
    - For $\lambda \sim 0.5\mu m$ (5000Å): RMS < 0.025μm or 25nm
  - Figure accuracy & alignment requirements → need "active optics" support

Structures:

- **Telescope structures (telescope mount + pier)**
  - **Support the optics — hold them in the right shape without breaking them**
  - **Protect the optics (earthquakes!)**
  - **Point the optics — move quickly, accurately, smoothly**
  - **Be stable — reject vibrations and wind shake**
  - **Be stiff — don't flex under changes in gravity**

- All structural issues get harder with D:
  - Mass $\propto D^3$ (volume)
  - Wind loads $\propto D^2$ (cross sectional area)
  - Stiffness $\propto D$ ($k=dF/dx$, axial or shear loads)
  - Deflections $\propto D^2$ (gravity)
  - Natural frequencies $\propto D^{-1}$ (as in $\omega=[k/m]^{1/2}$)
  - Stresses $\propto D$ (gravity loads)

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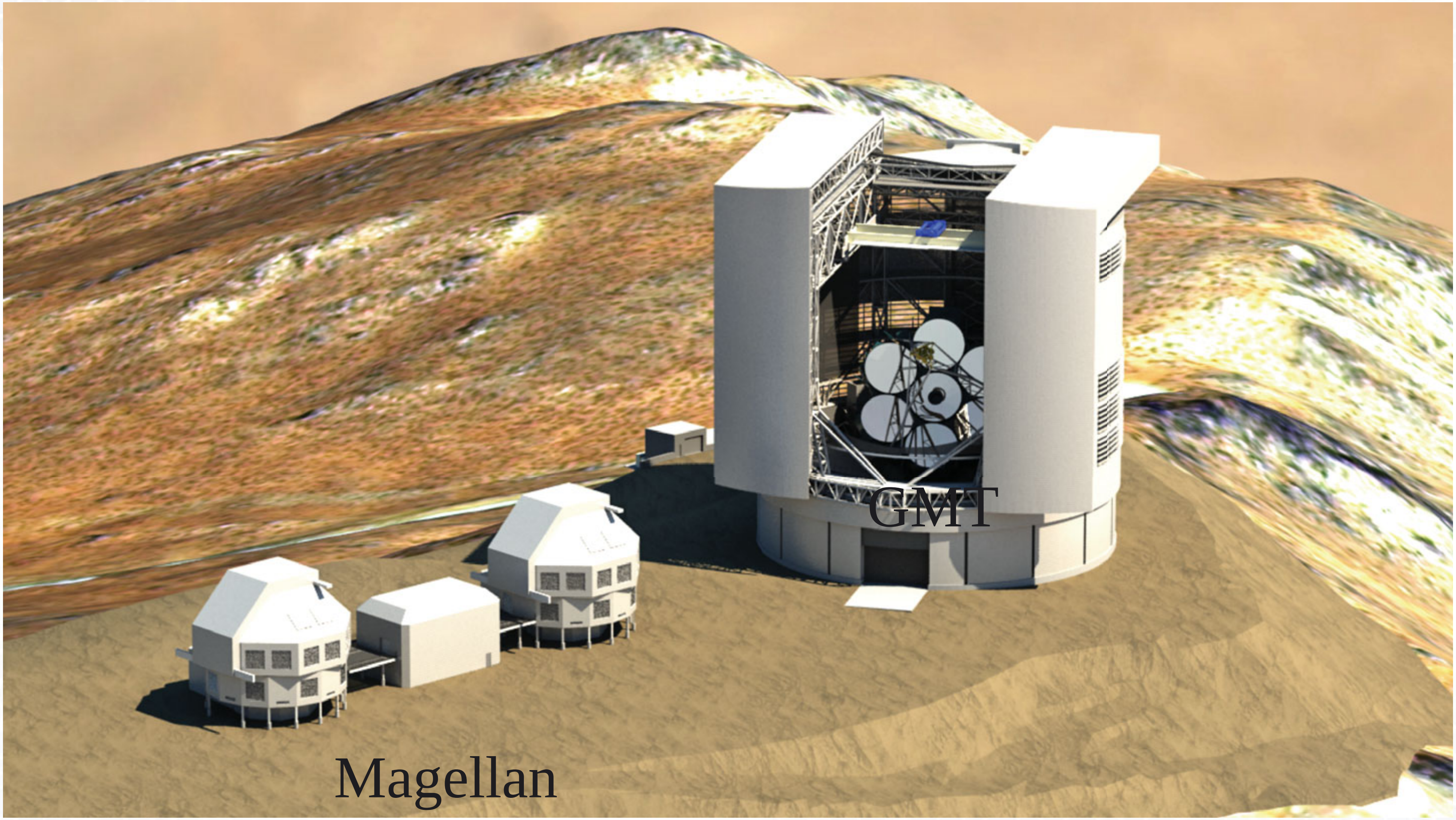
→ Telescopes primary mirrors must get FASTER, more ASPHERIC to keep the structures reasonable and costs down.

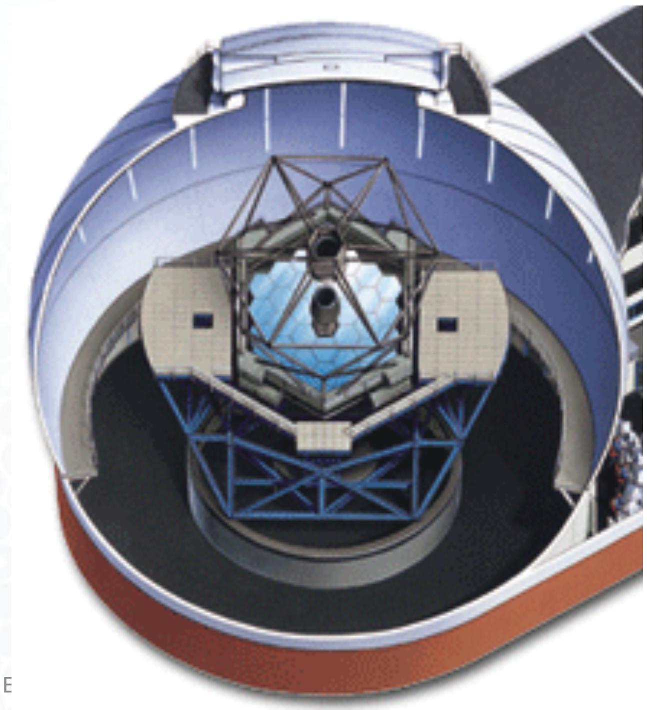
→ Structures must get stiffer, stronger

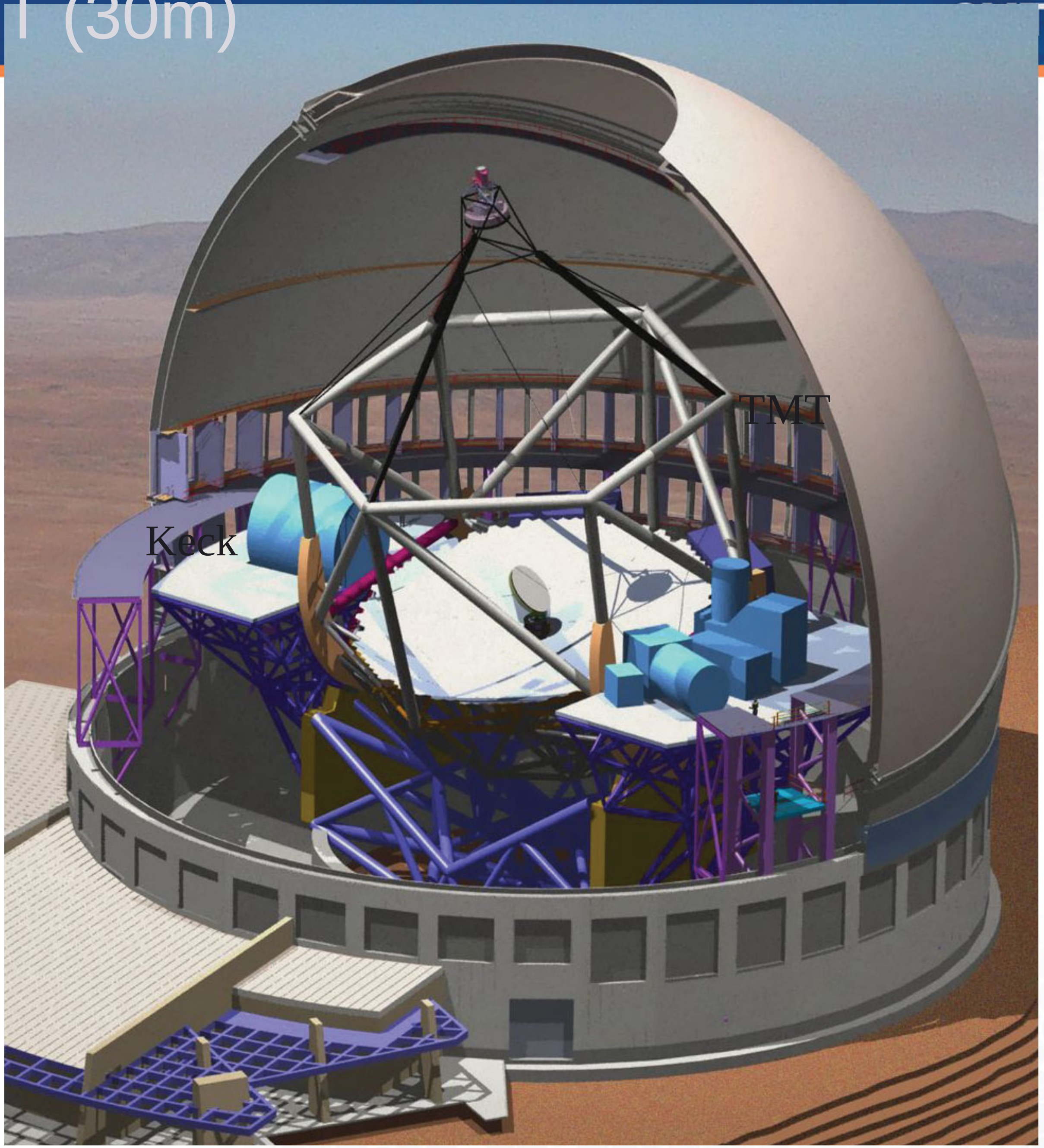
→ Designs must get more compact.

Visual impression:
Magellan (6.5 m) vs GMT (25.4m)



Visual impression:
Keck (10m) vs TMT (30m)





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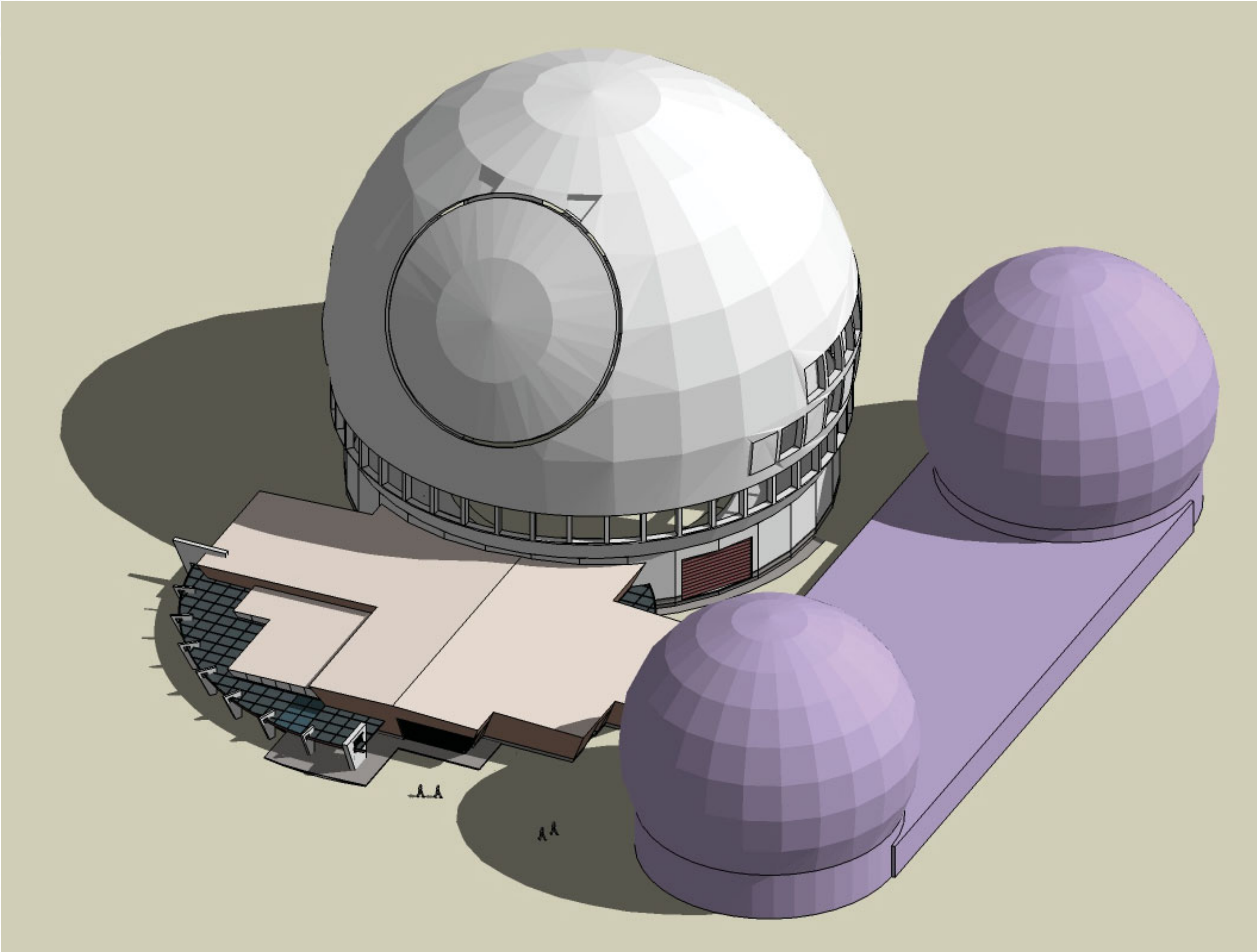
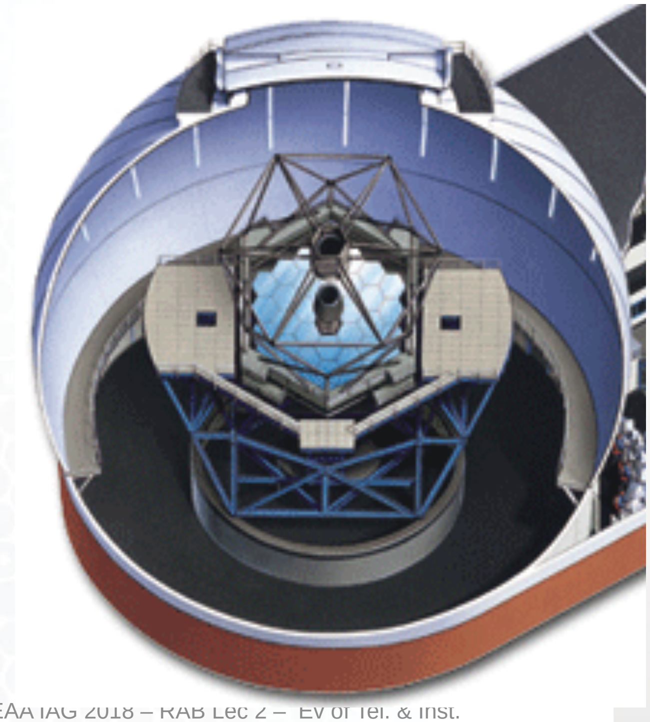
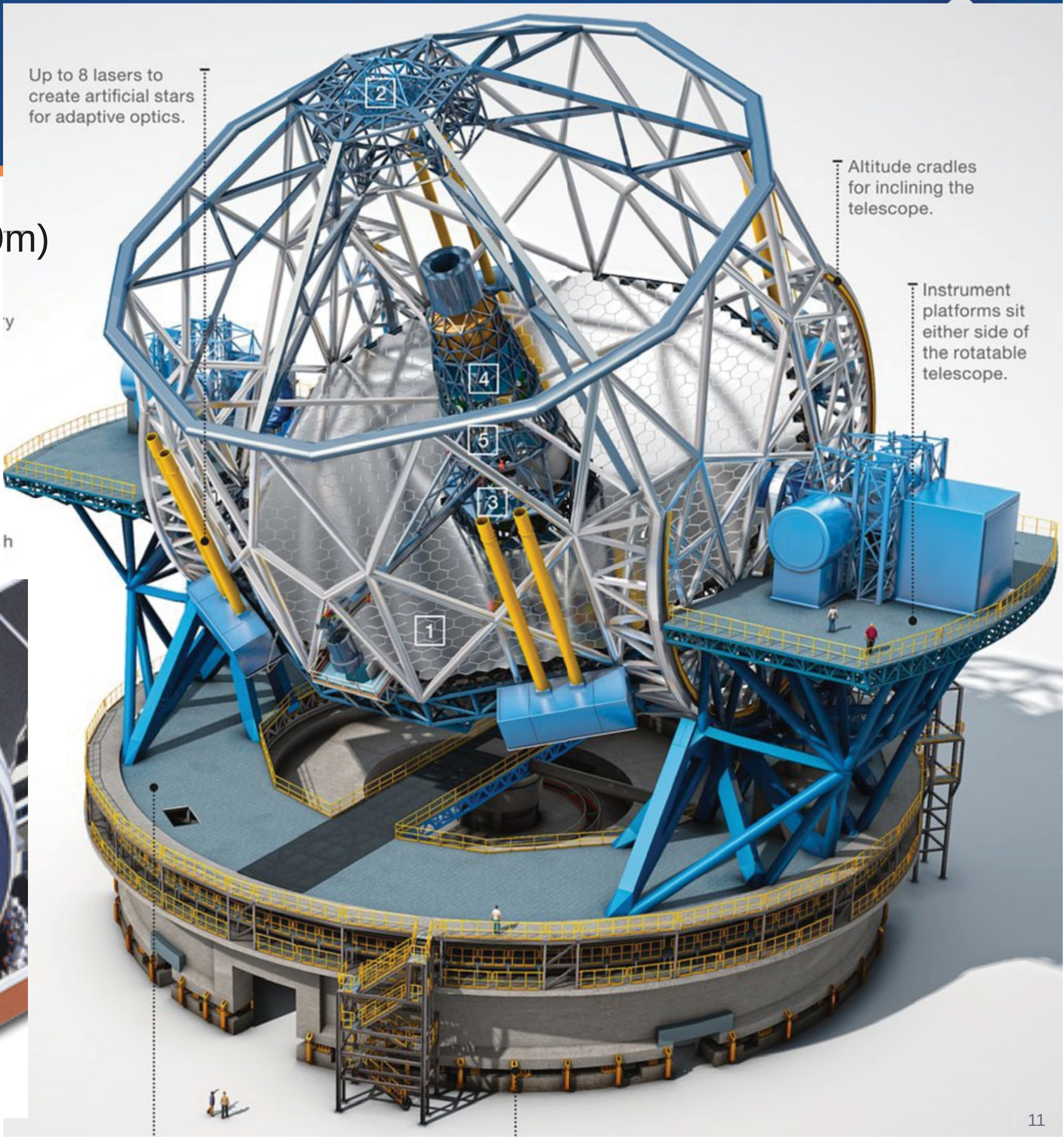


Visual impression:

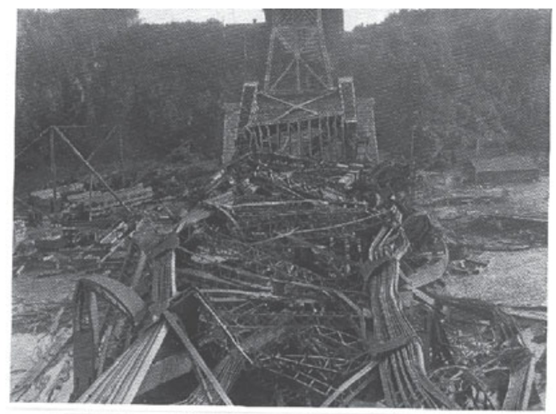
Keck (10m) vs E-ELT(39m)

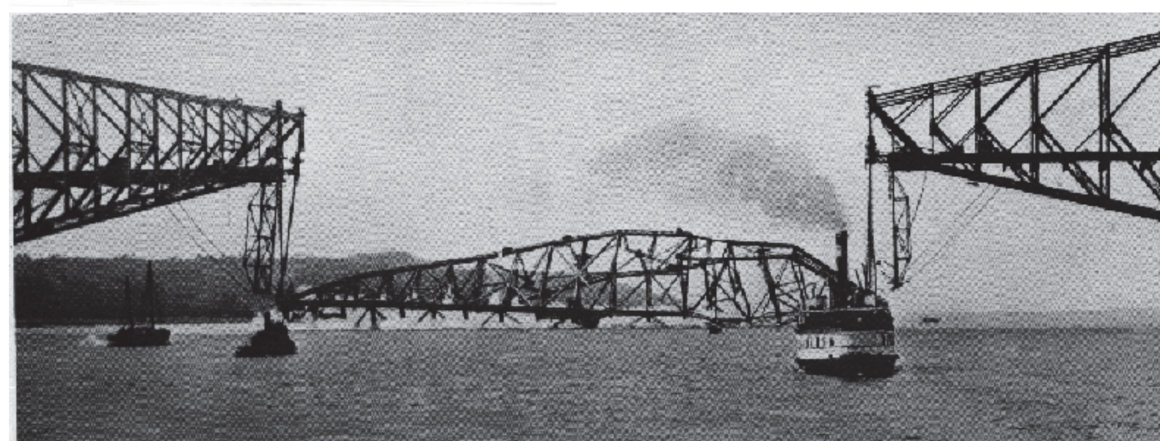




How hard can a large structure be?

- Bridges
  - Kinzua Viaduct 1887 600m steel, collapsed
  - Quebec Bridge 1917 600m steel, collapsed
  - Golden Gate Bridge 1937 30x2000m steel
  - Tacoma Narrows Bridge 1940 1800m steel, collapsed

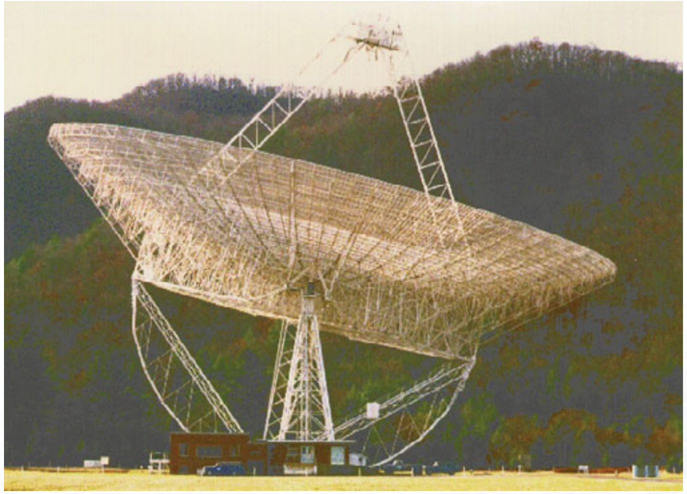




How hard can a large MOVING structure be?

Radio Telescopes

Arecibo	1963	300m	fixed dish
Green Bank	1962	91m	collapsed 1988
~~Sugar Grove~~	~~1965~~	~~200m~~	~~steerable~~ (canceled)
Effelsberg	1970	100m	fully steerable
Green Bank	2000	100m	fully steerable



Topics:

- What do telescopes do and how?
  - Mirrors (collect and focus light)
  - Structures (point and follow targets, support optics)
  - Telescope optics 101
  - Strategies of the 3 GSMTs
    - Optical Configurations
    - Segments — Small
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- What do instruments do and how?
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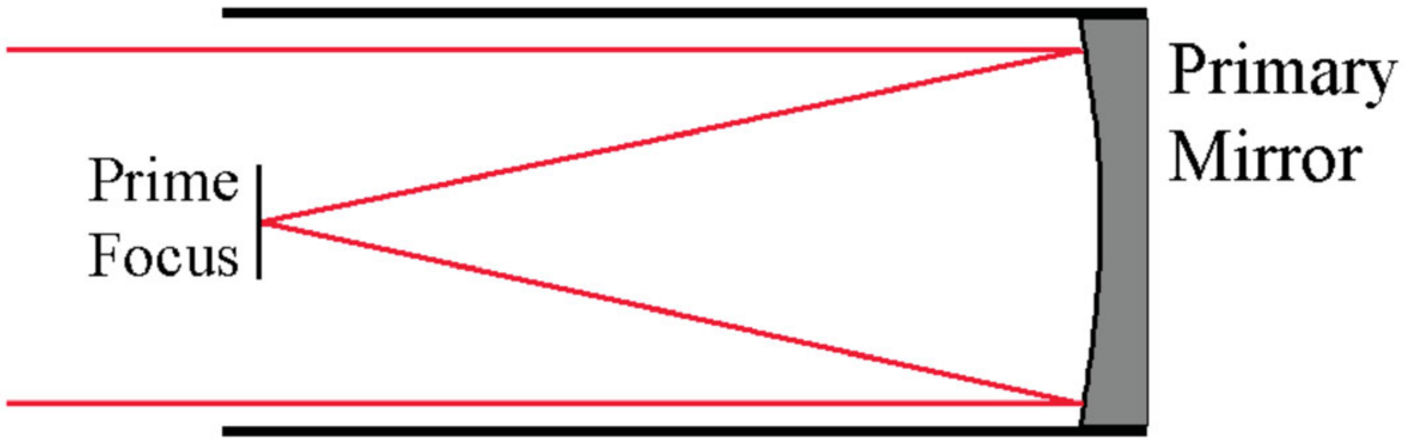
Geometrical optics (ray tracing) 101

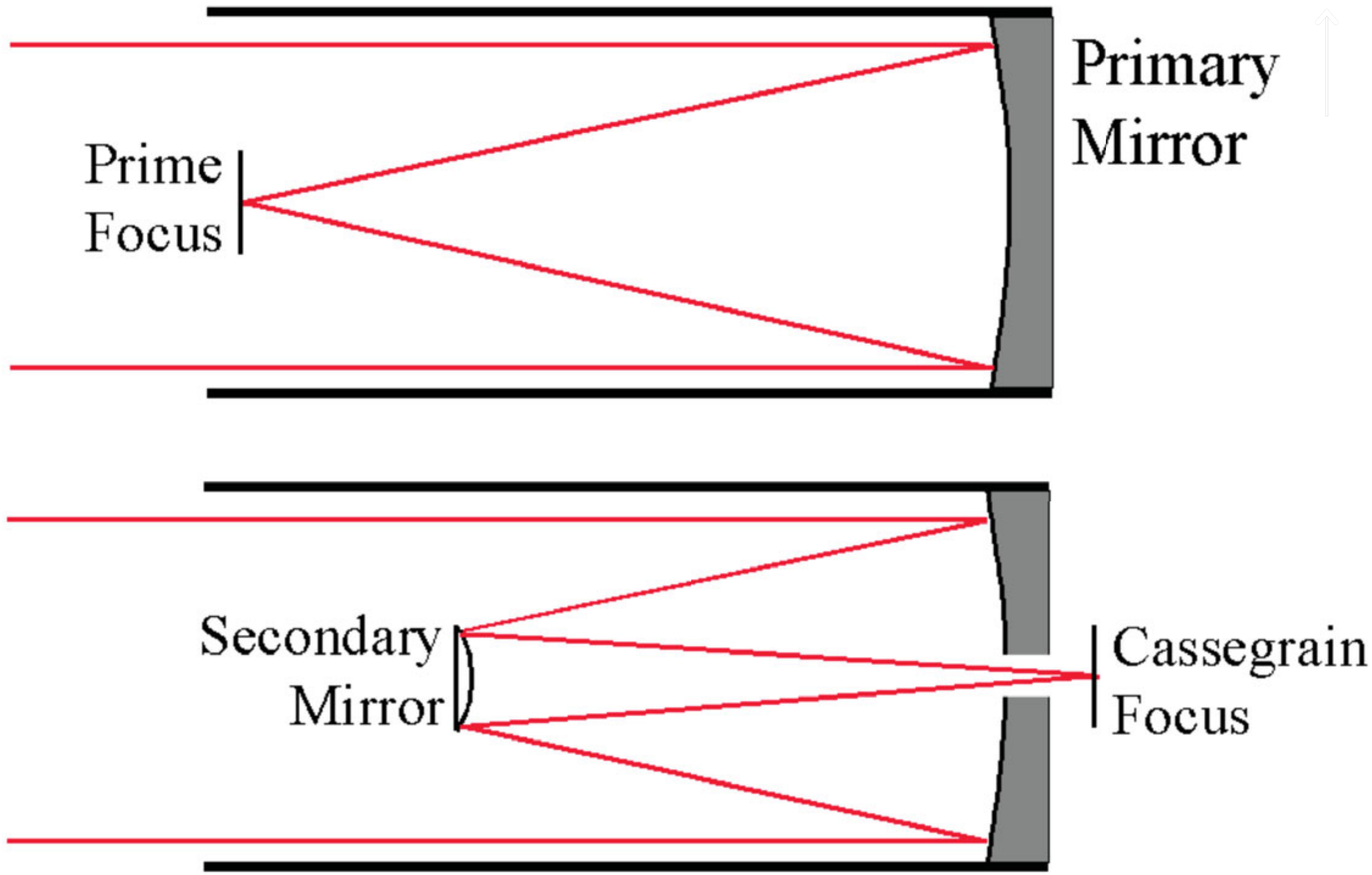
GMT



- PRIMARY MIRROR: must get faster, more curved (smaller F/#)

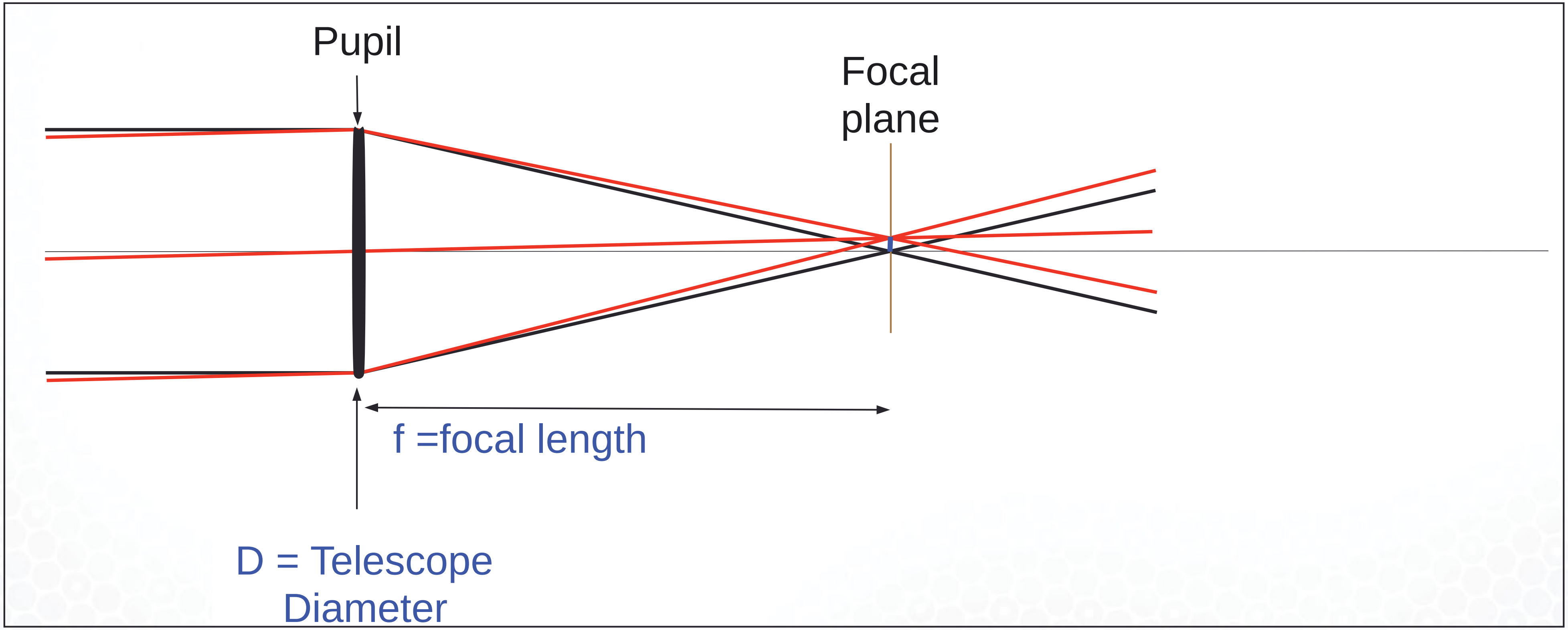
- FINAL F/# is determined by where you want the focal plane (as long as M1 and M2 together make good images

Geometrical optics (ray tracing) 101



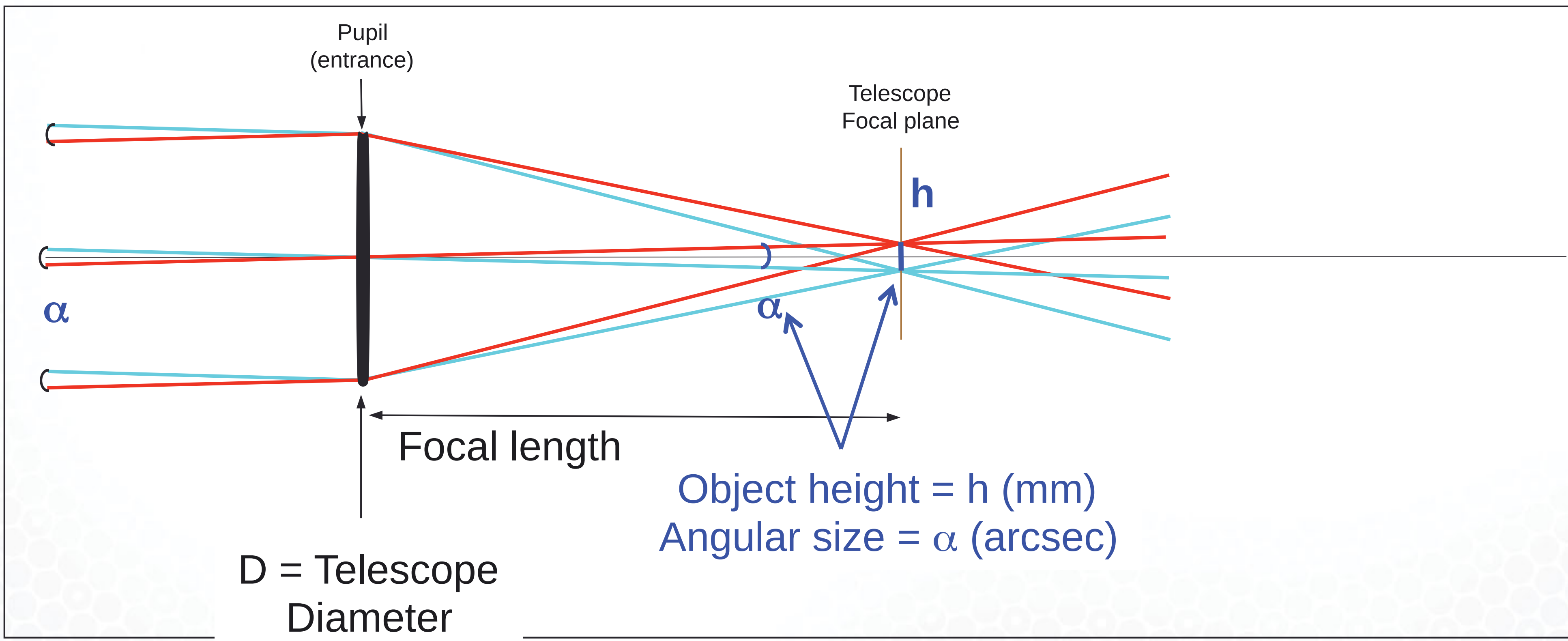
Basic Telescope Parameters

- F/# = (focal length) / (pupil diameter) = f / D



Basic Telescope Parameters

- F/# = (focal length) / (pupil diameter) = f / D
- $\alpha \approx$ image size (or FOV)



Basic Telescope Parameters

- F/# = (focal length) / (pupil diameter) = f / D
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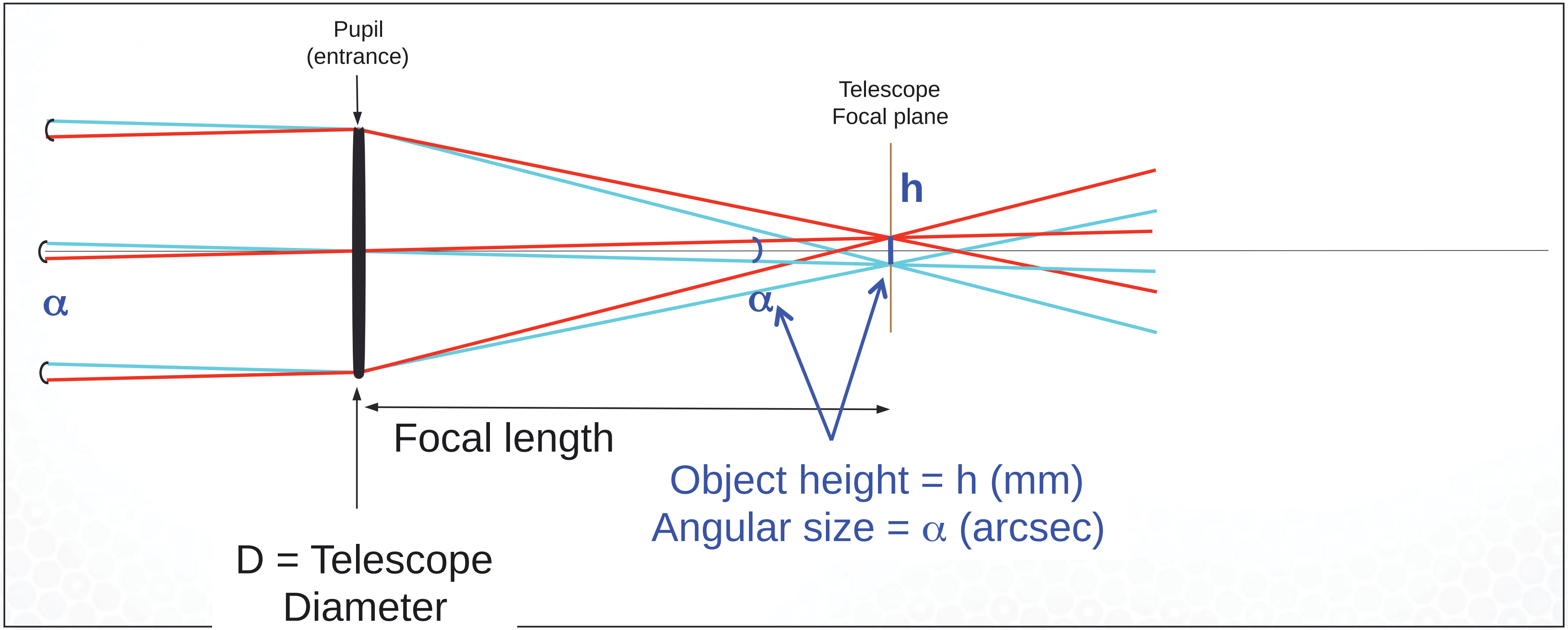
- Focal plane scale (mm/asec): $\sin 1'' = \dfrac{h}{D_{tel} \times F/\#_{tel}}$



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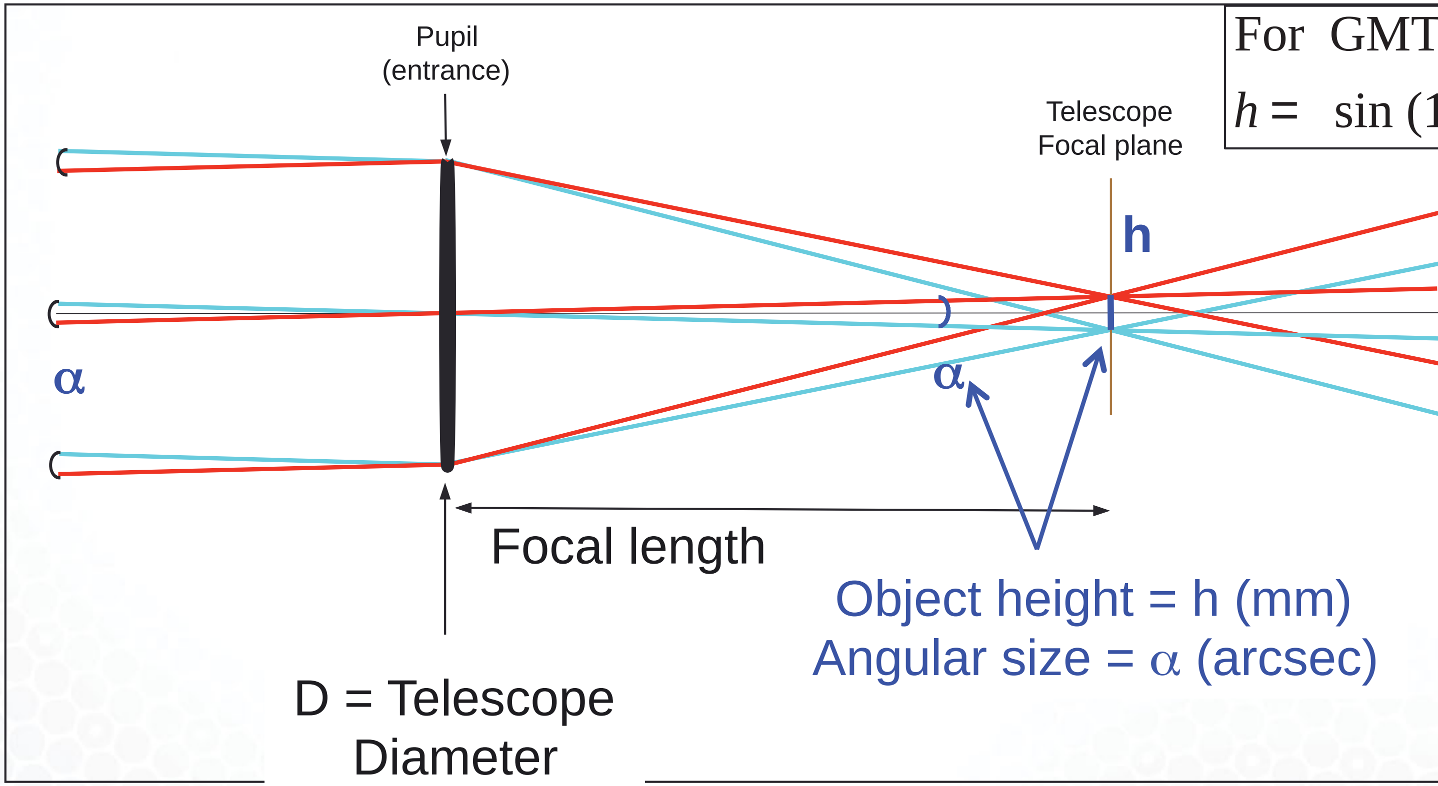
For GMT (F/8.2)

$$h = \sin(1'') \times 25\text{m} \times 8.2 = 1.0 \text{ mm}$$



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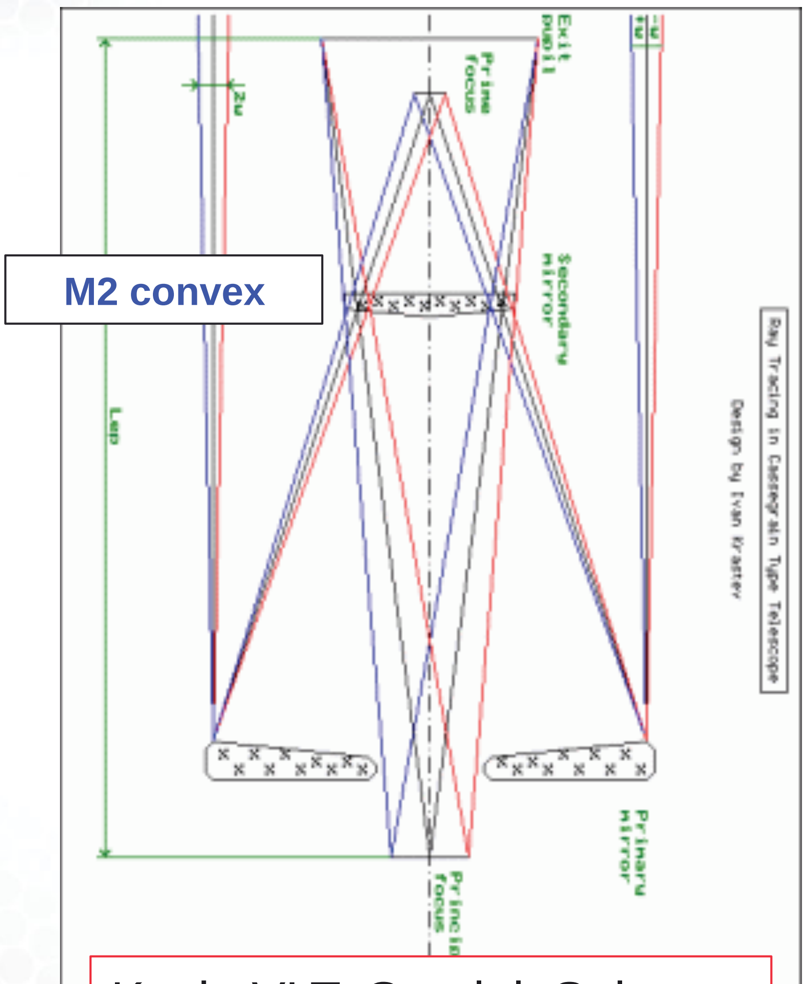
Strategies of the GSMTs:

- Focal ratios:
  - Faster primary mirrors: Smaller domes are cheaper!   — All
  - Faster overall: trying to keep smaller plate scale — GMT, yes. Others?
- Optical configurations:
  - no low order aberrations
  - GMT: Aplanatic Gregorian…
  - TMT: Ritchey-Cretchien…
  - E-ELT: 3-mirror anastigmat + 2 folding mirrors

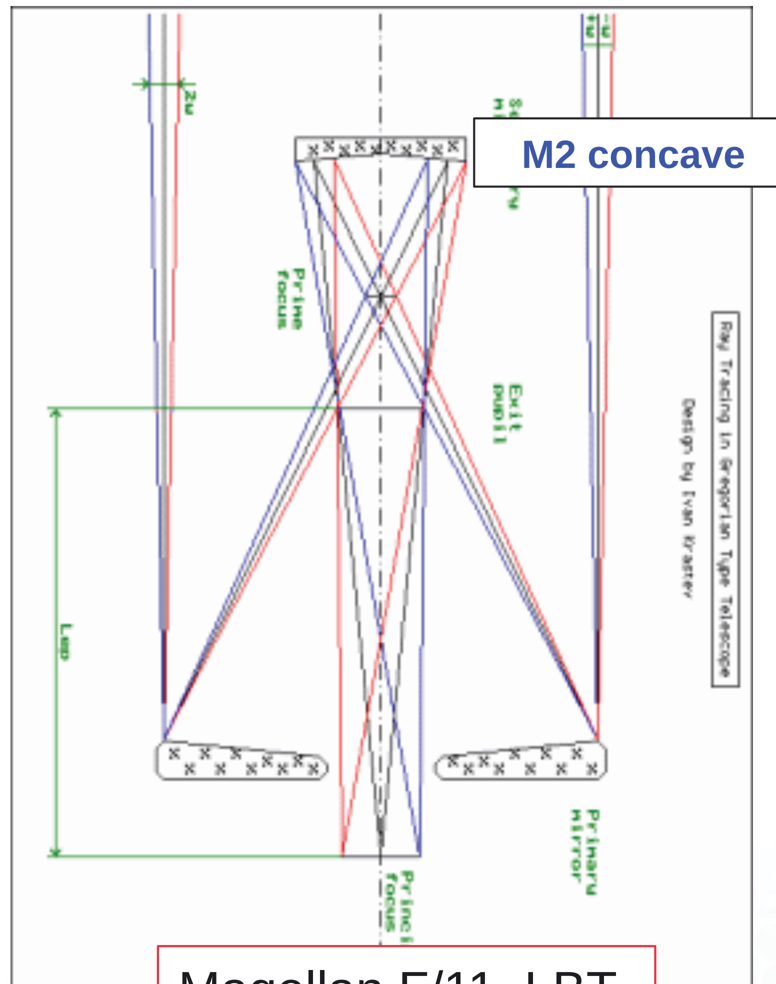
Telescope configurations:

Ritchey-Crétchien



Keck, VLT, Gemini, Subaru, MMT, most 4 m,…

Aplanatic Gregorian

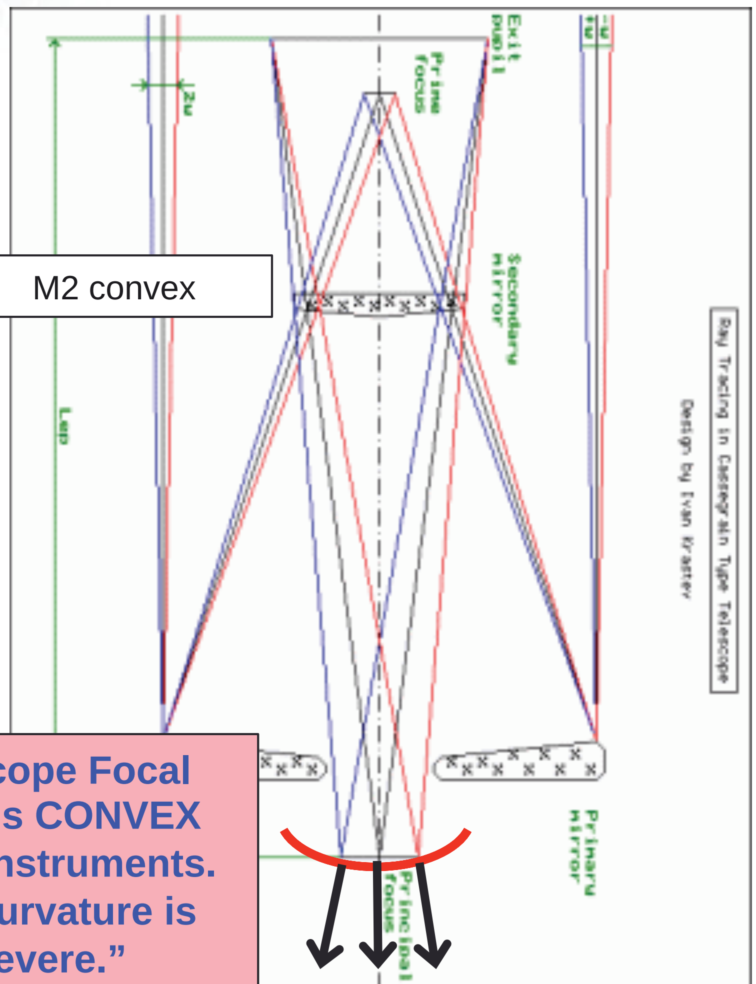


Magellan F/11, LBT

Telescope configurations:

GMT

Ritchey-Crétchien

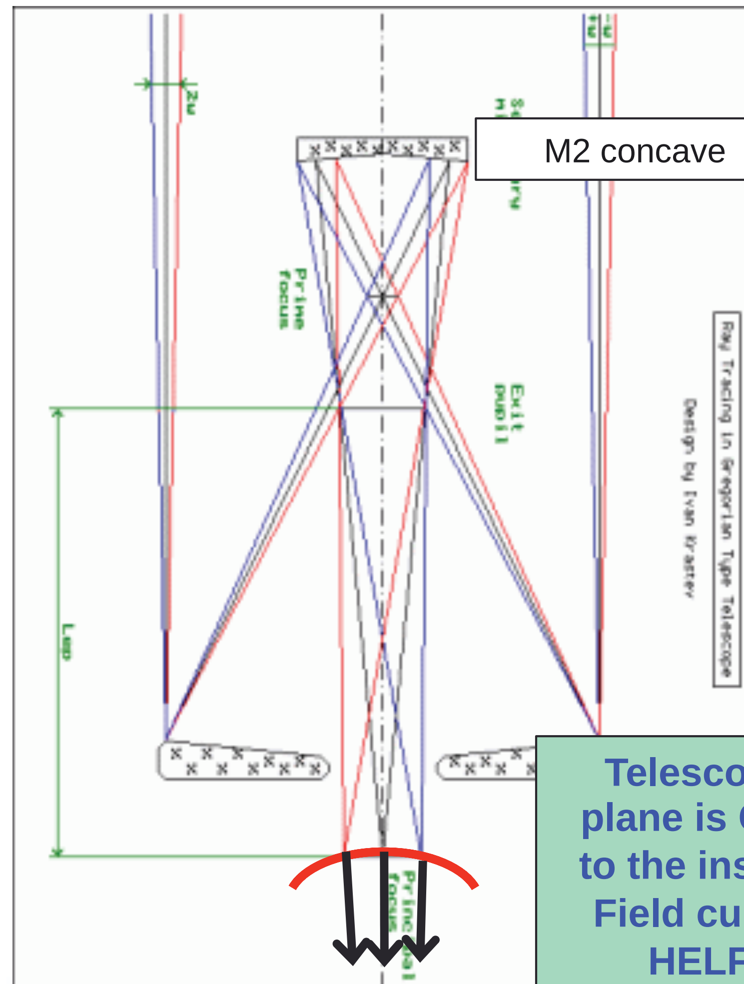


M2 convex

Telescope Focal plane is CONVEX to the instruments. field curvature is “severe.”

Focal Plane

Aplanatic Gregorian:



M2 concave

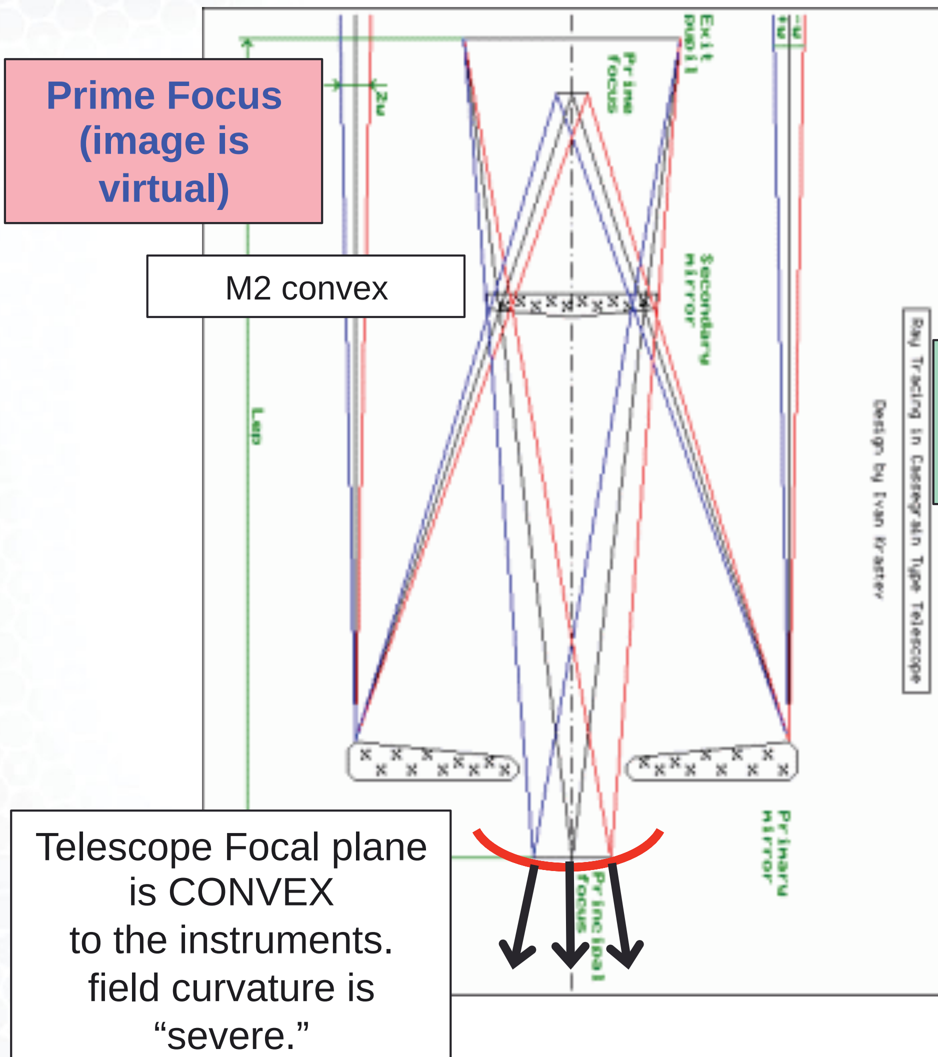
Telescope Focal plane is CONCAVE to the instruments. Field curvature is HELFPFUL. Wider field of view.

Focal Plane

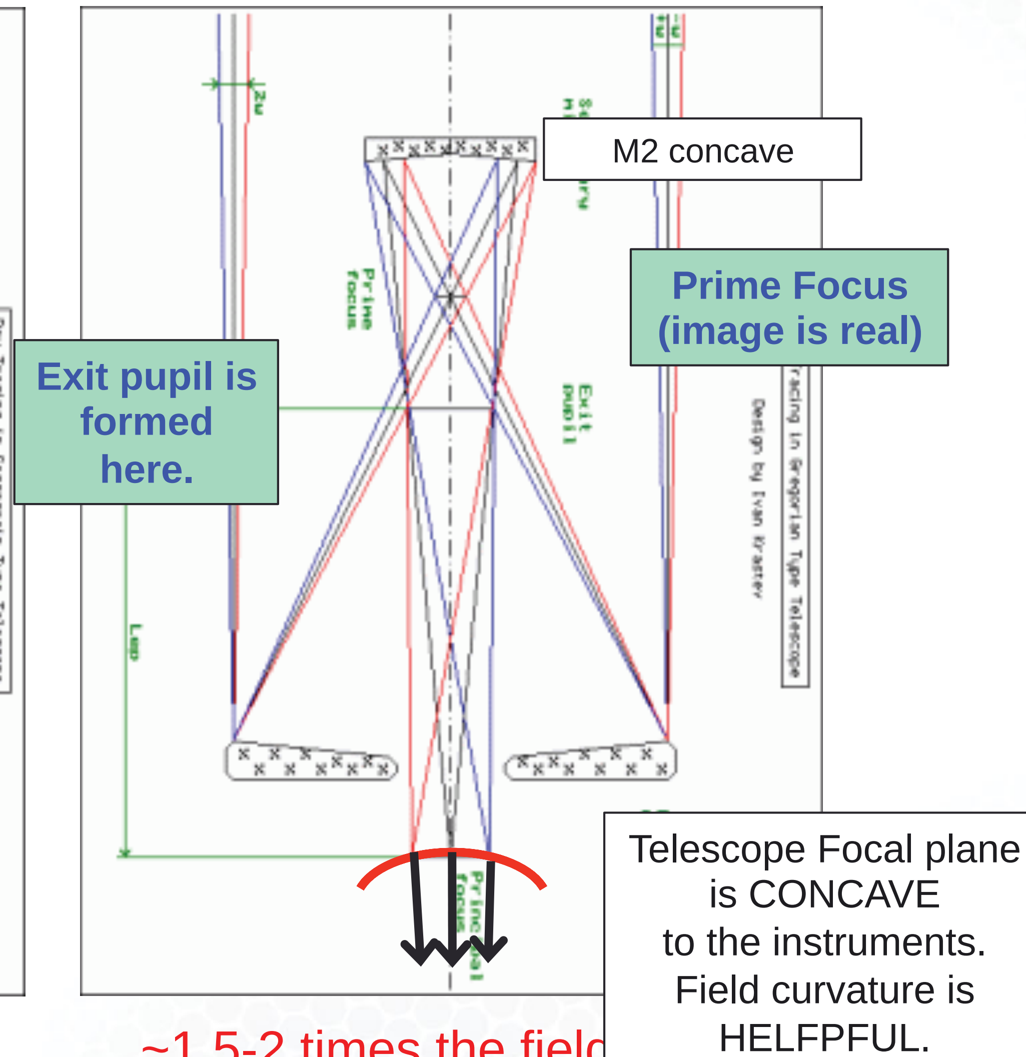
WFOS / MOBIE for TMT — Feedin

Telescope configurations:

Ritchey-Crétchien



Aplanatic Gregorian



~1.5-2 times the fiel

Telescope configurations: 3 mirror anastigmat.

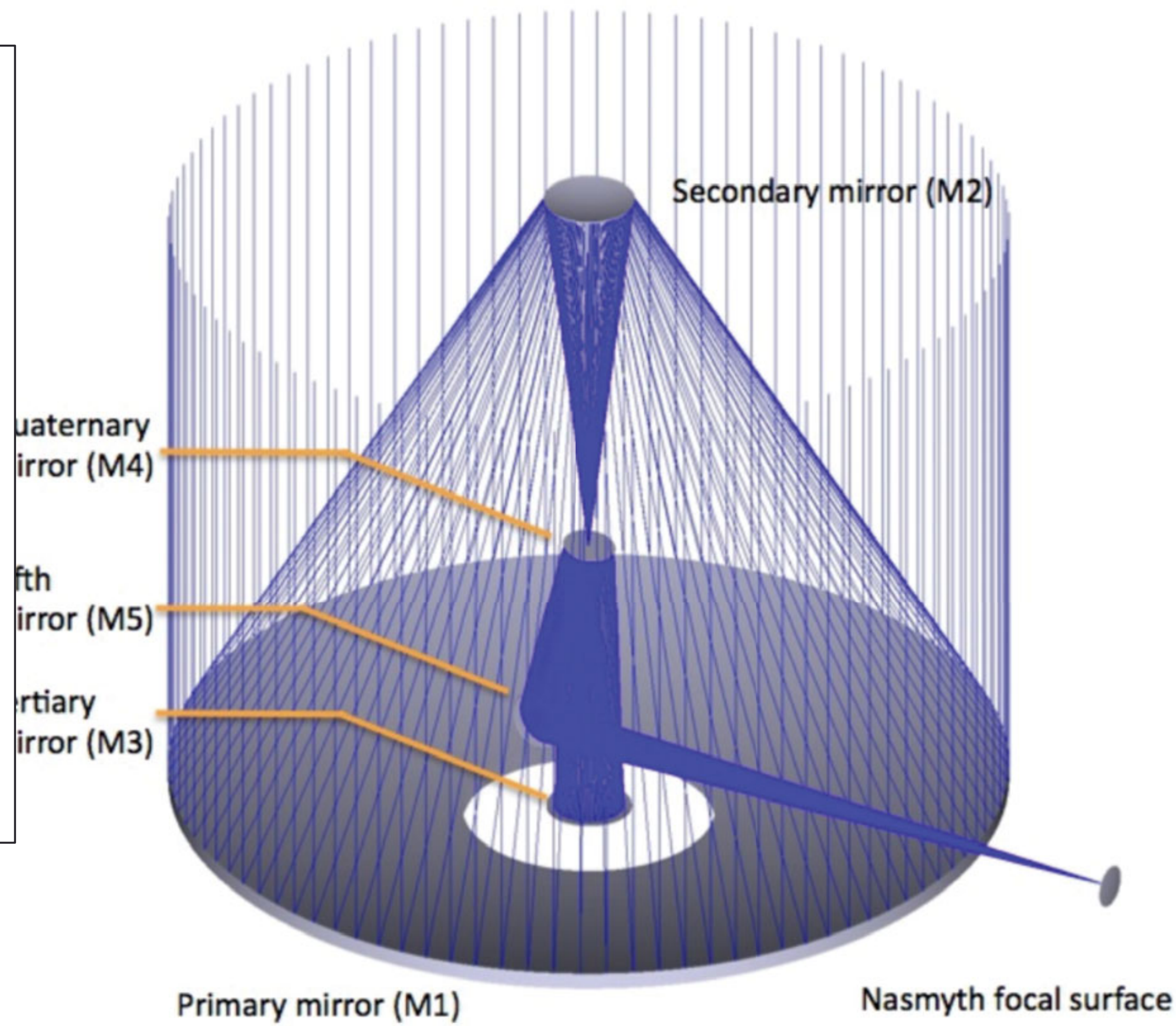
GMT

Pros:

- Very big
- Best diffraction limit (D =39m)
- Good image quality

Cons:

- Complexity (alignment)
- Thermal background (high contrast imaging, IR sensitivity)



igure 1. Nasmyth configuration

Strategies of the GSMTs:

- Focal ratios:
  - F/# of primary: small (keeps dome smaller)
  - F/# overall: 8 (instruments behind primary) vs 16/17 (instruments at nasmyth)
- Optical configurations:
  - GMT: ASM at M2, 2 warm mirrors thermal backgrounds
  - TMT: No ASM, post-focal AO system (2 warm mirrors + 10 reflections in AO system)
  - E-ELT: ASM at M4, 5 warm mirrors

	GMT	TMT	ELT
Configuration	Gregorian	Ritchey-Creitchen	3-mirror anast.+2 fold
Diameter	25.4m (22)	30 m	39 m
F/#	8.2	16	17.5
Plate scale	1.0	2.2	3.3
FOV	20’ (10’)	10’	10’

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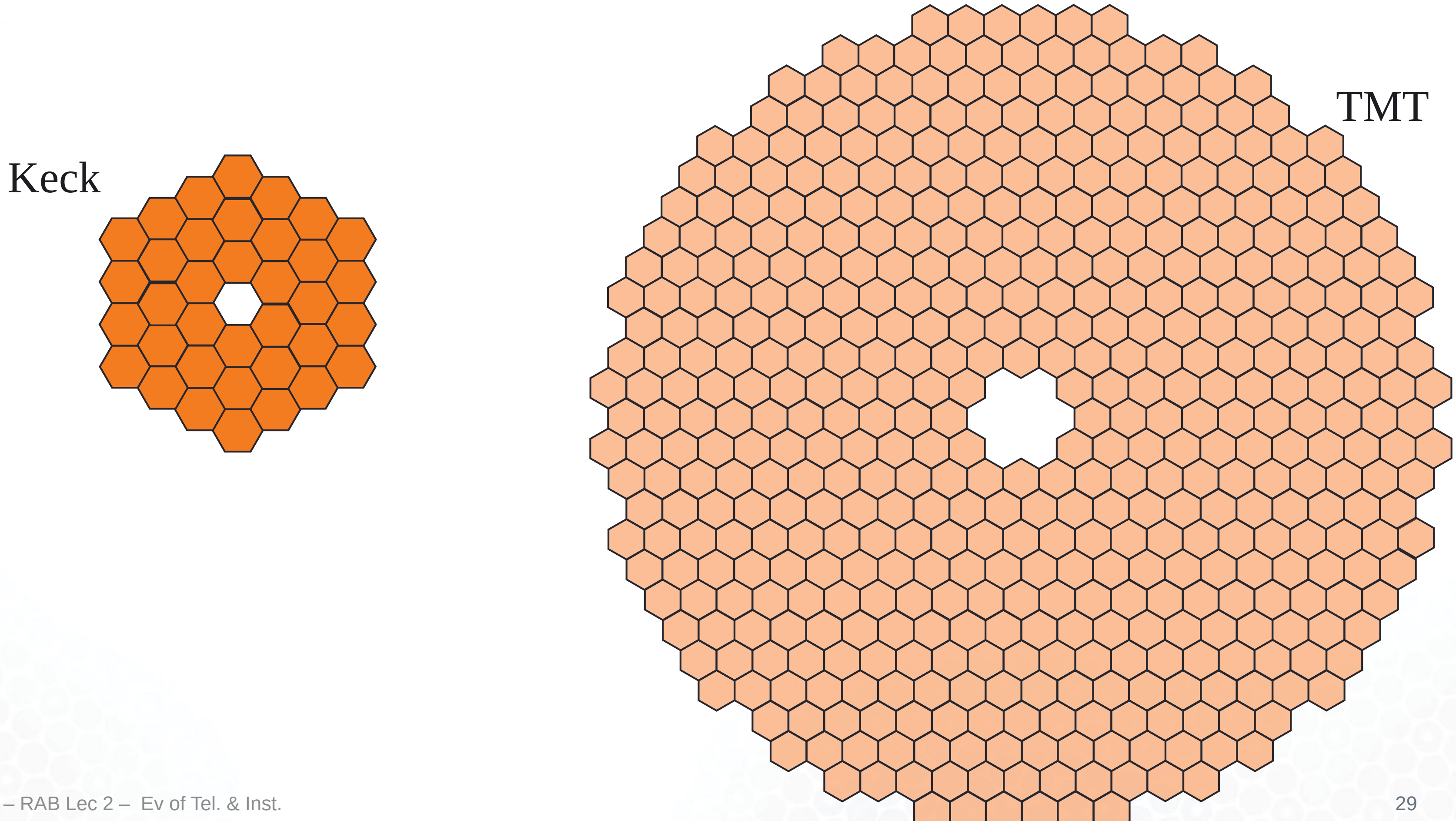
Segment fabrication: small segments

- Total number of segments: 492 for TMT (36 for Keck)
- Total number of prescriptions: 11 (3 for Keck)



Segment Fabrication

- Casting, figuring, and testing
  - Stressed mirror polishing
  - relatively proven, but more aspheric segments are harder.

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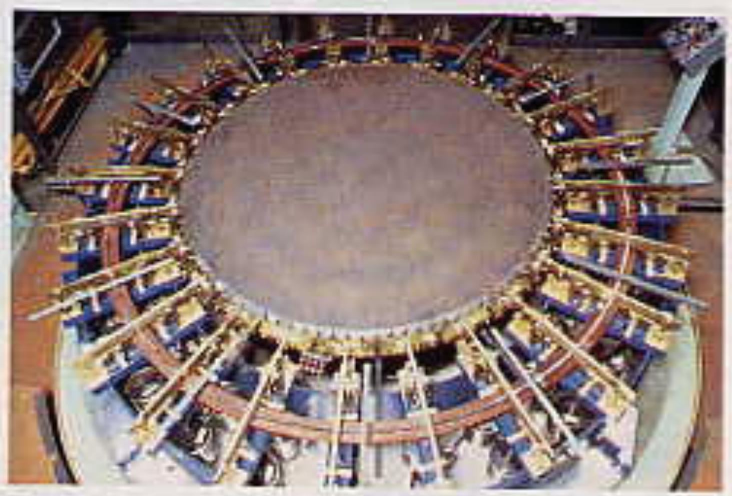

Figure 4. To create the off-axis, parabolic shapes of the Keck mirror segments, a technique called stressed mirror polishing was developed. Lever arms are attached to the perimeter of a mirror blank; weights attached to the levers then produce calculated bulges in the surface of the glass that are removed by polishing a spherical impression into the surface. When the weights are released, the glass relaxes into the calculated nonspherical shape.

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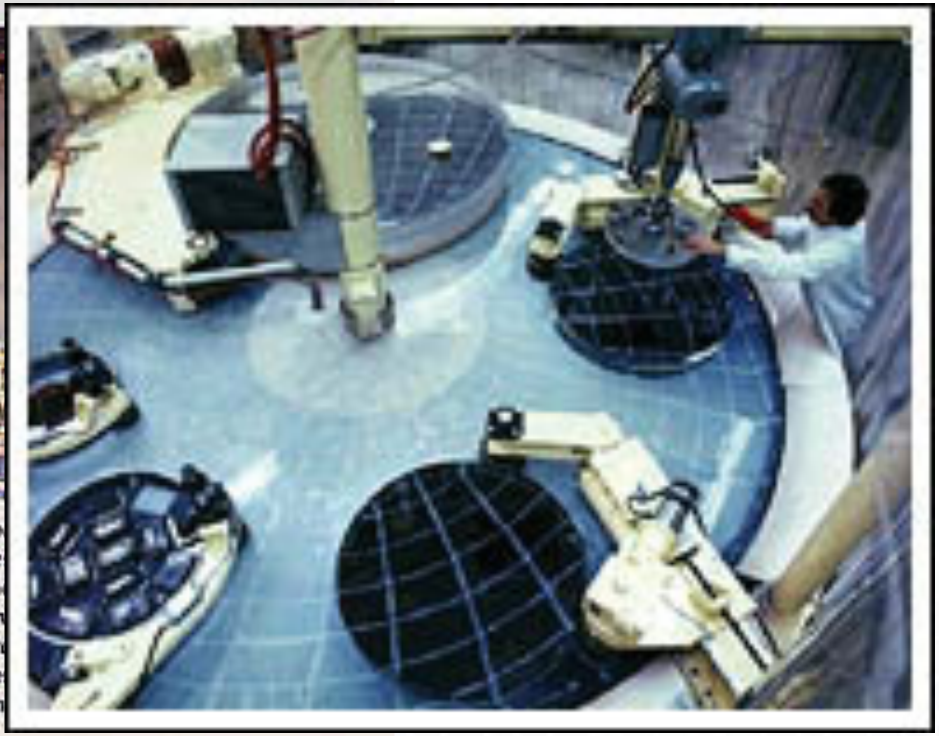
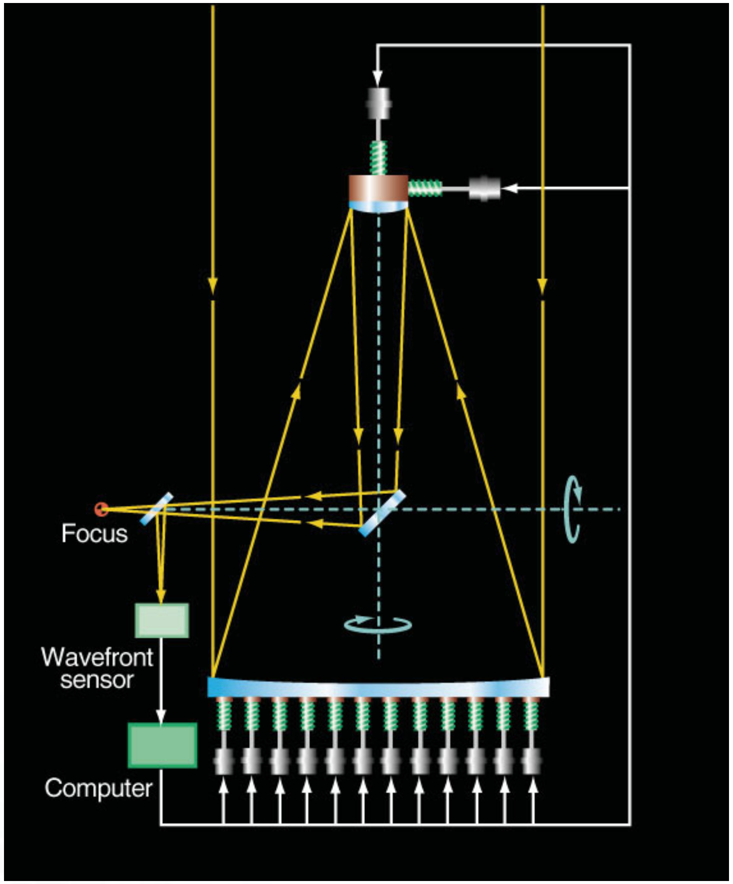


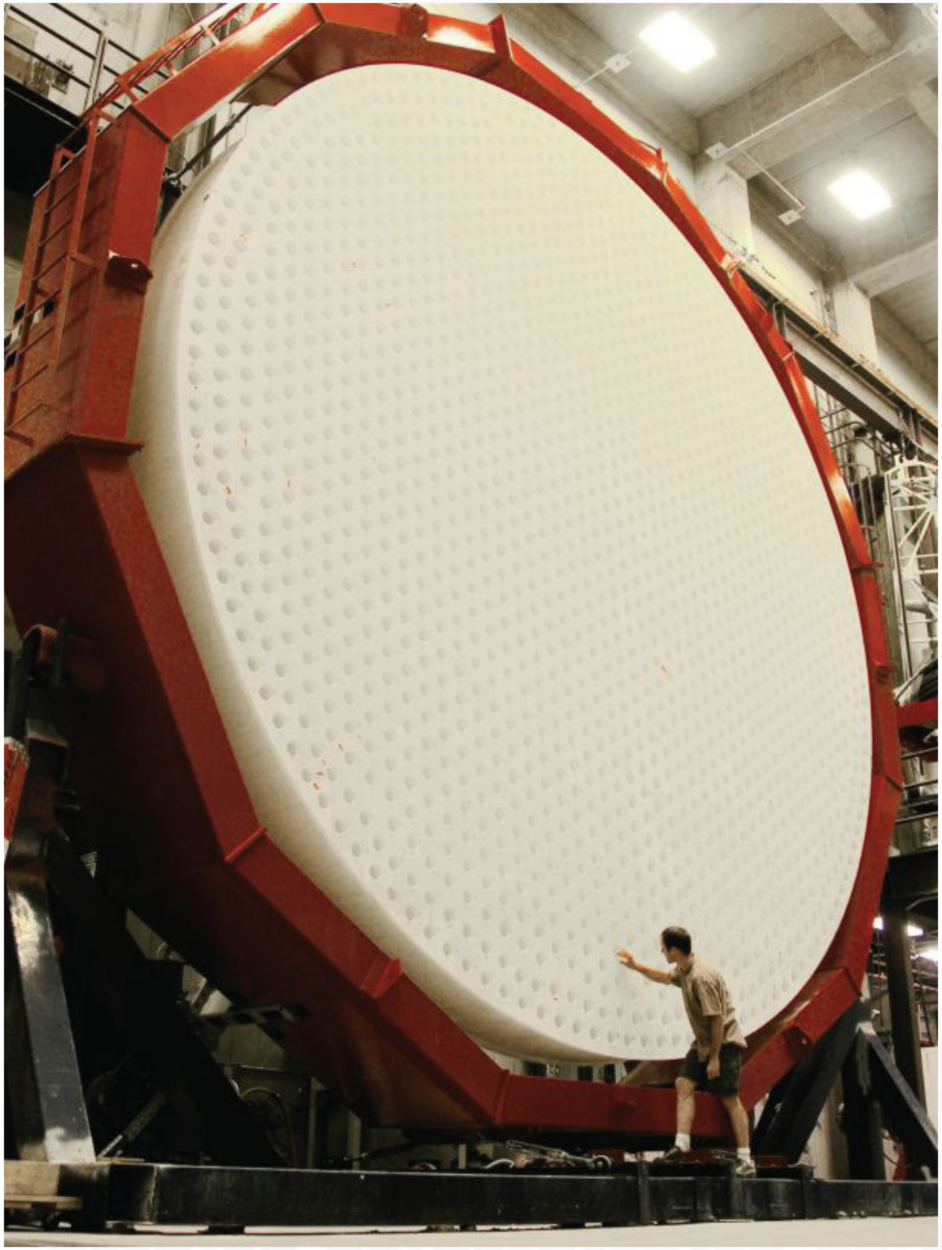
Supporting M1 in telescope: "active" optics

GMT

- 1977: John Hardy, "Active Optics: A New Technology for the Control of Light"



Active Optics block diagram
Credit: ESO



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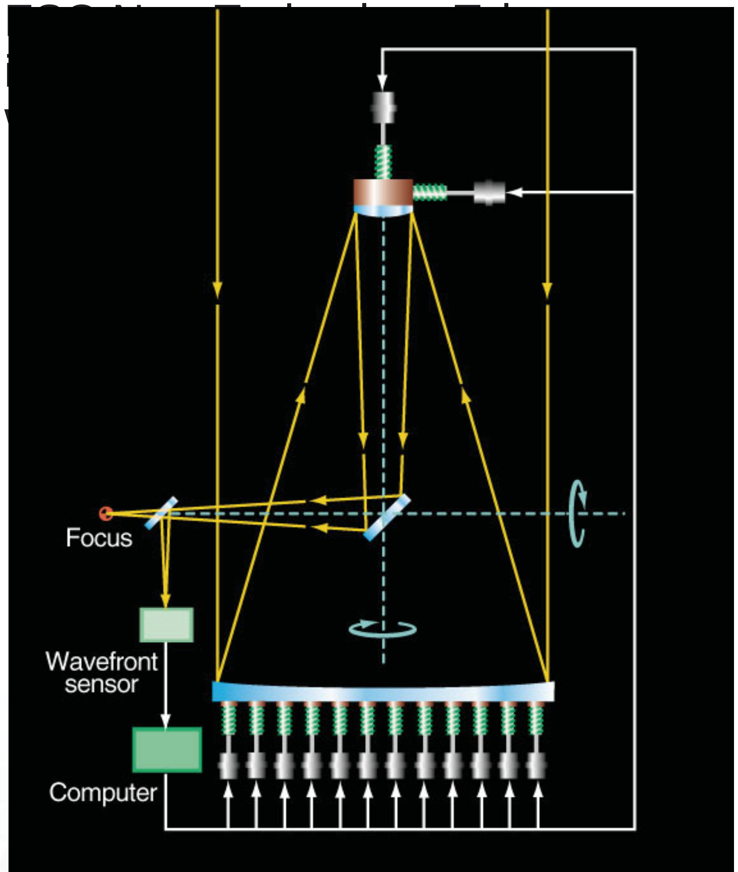

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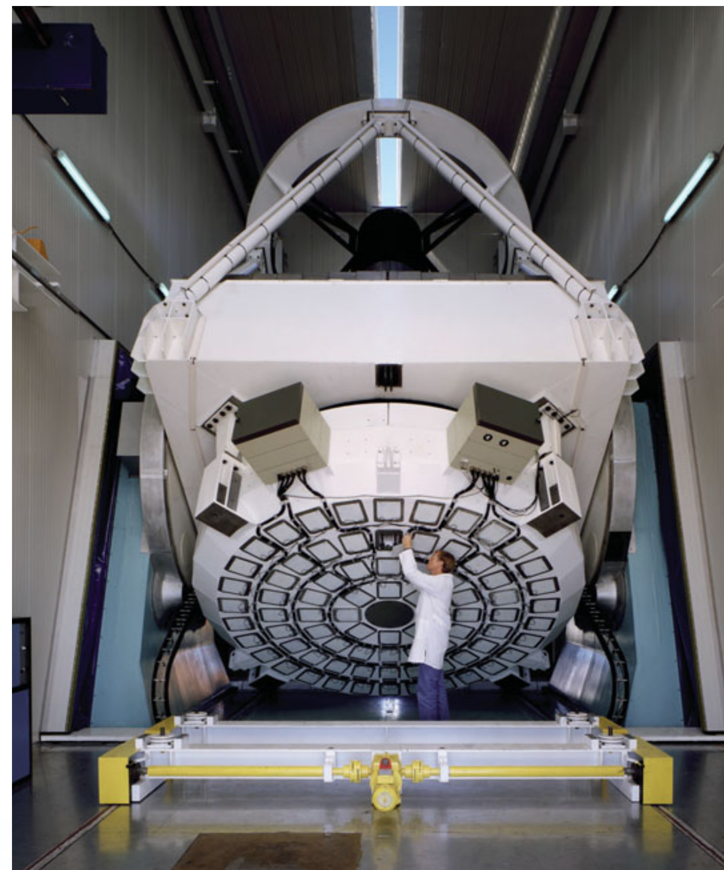
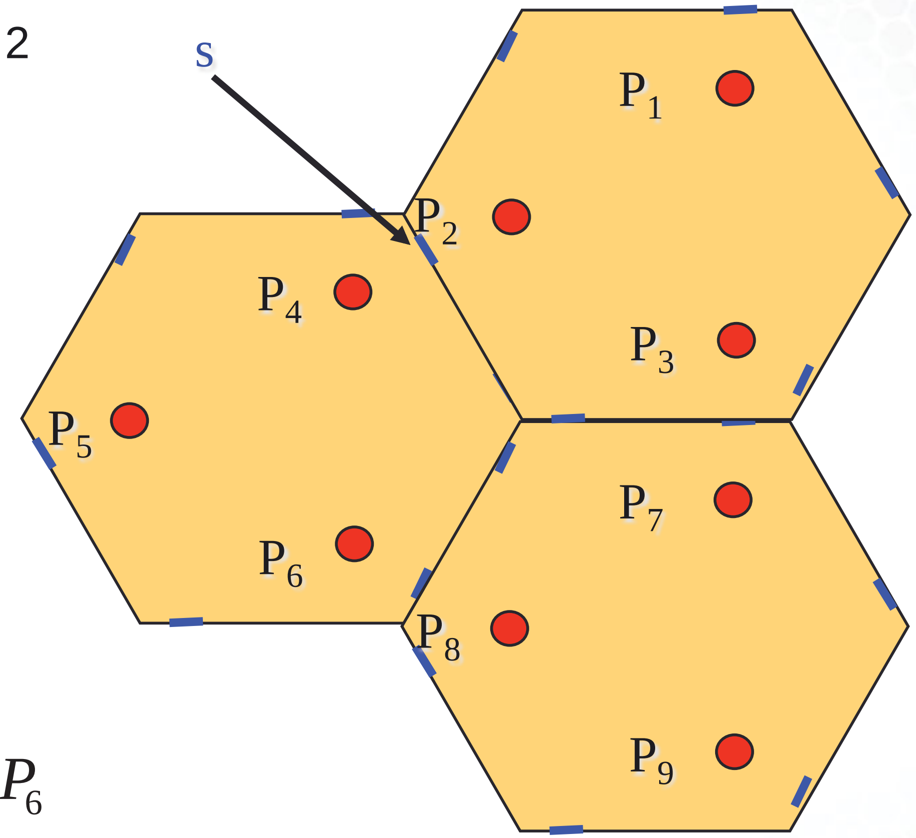
- ESO New Technology Telescope inaugurated in 1990 (Raymond Wilson, Kavli Prize 2010)



3.56 m New Technology Telescope
Credit: ESO

Active optics: figure control and alignment

- Principle of active control with edge sensors:
  - Sensor signal depends only on the motion of 2 neighboring segments. Offsets are ~linear
- Sensors need to be cheap (2772 vs 168) and not interlocking!
- Actuators need to be cheap (1476 vs 108)



Actuator (piston)

Sensor (measures height difference)

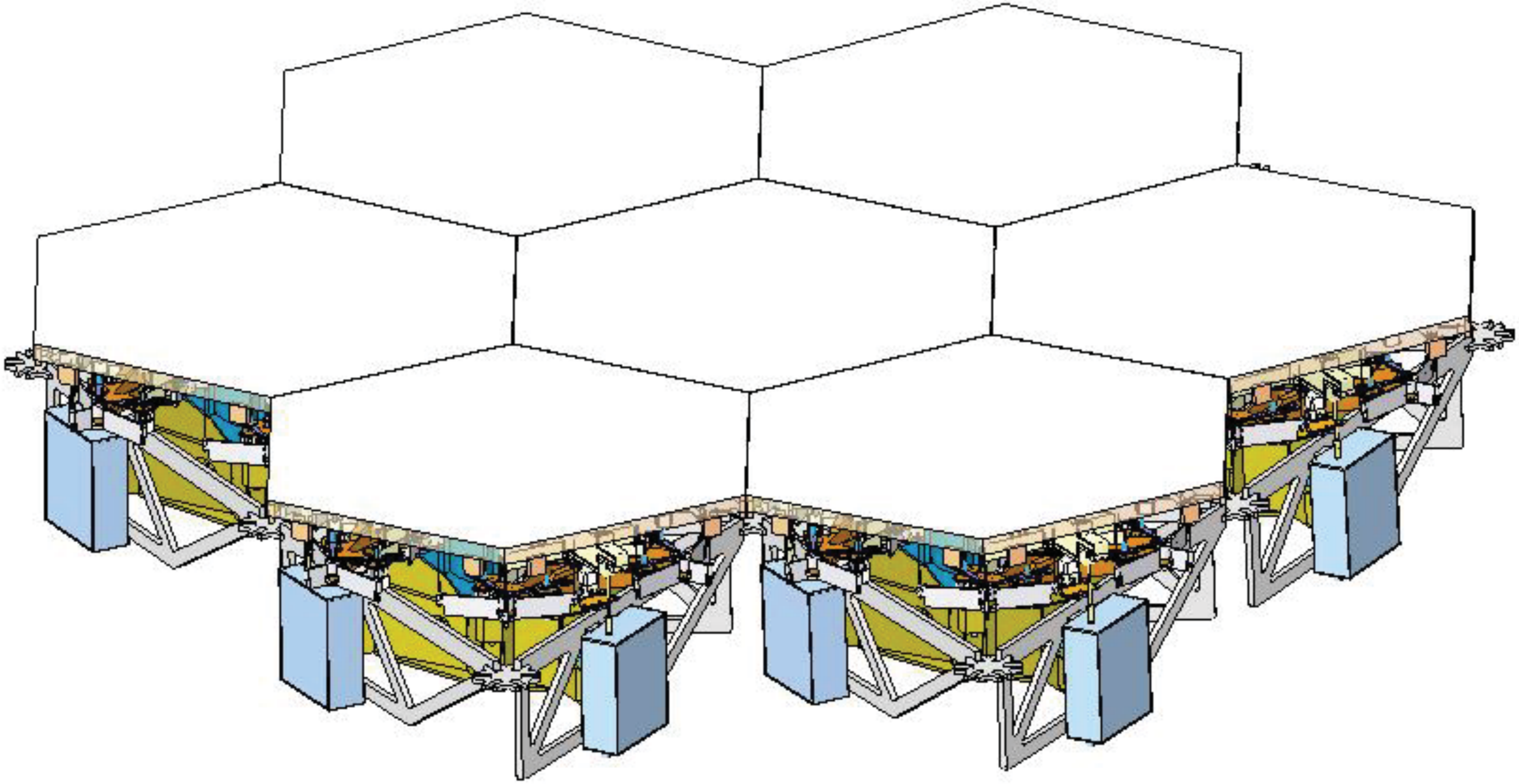
$$s = a_1P_1 + a_2P_2 + a_3P_3 + a_4P_4 + a_5P_5 + a_6P_6$$

a = constant coefficients (depend only on geometry)

Credit: J. Nelson

Active optics: figure control and alignment

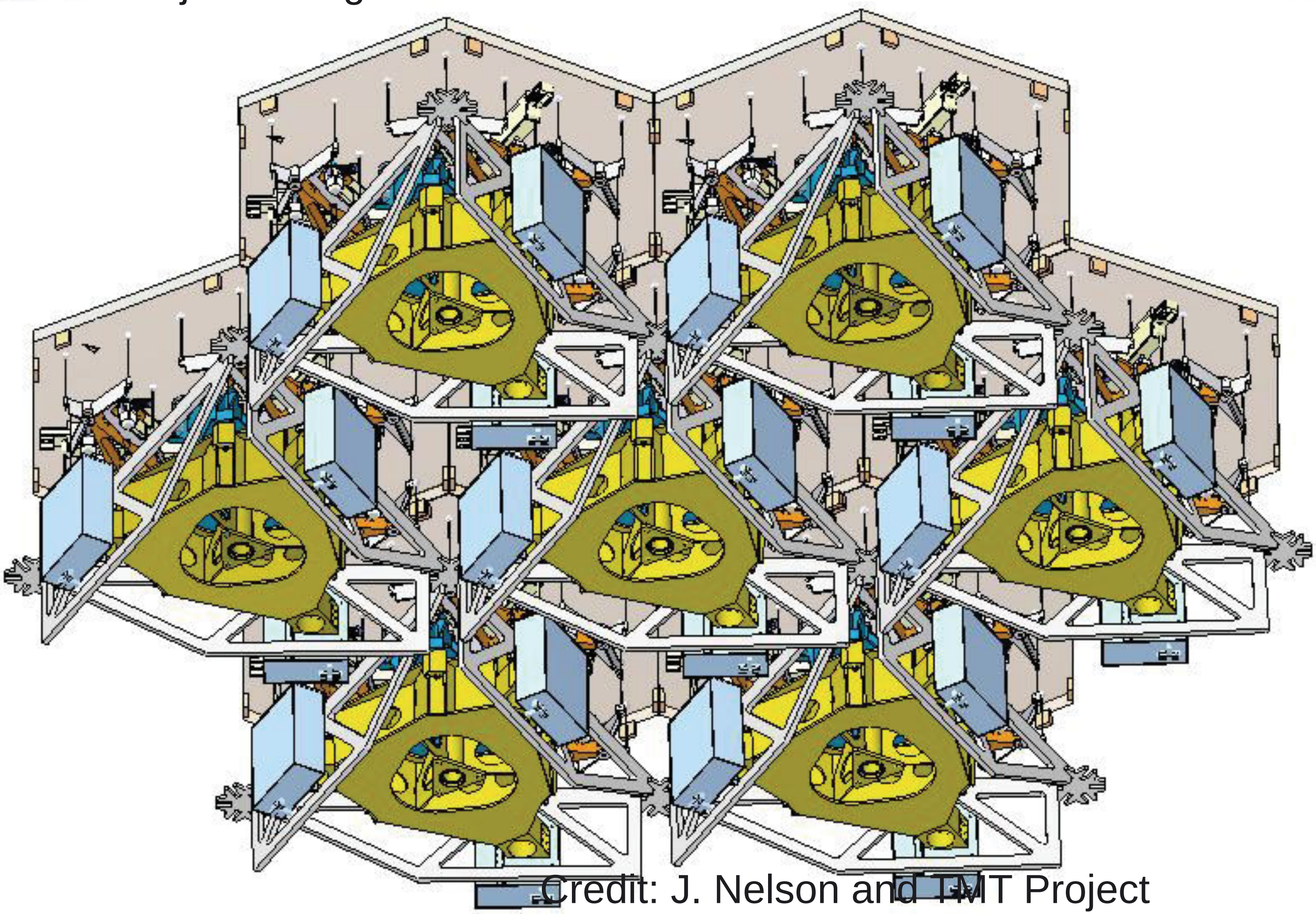
View of 7 adjacent segments -- Top view.



Credit: J. Nelson and TMT Project

Active optics: figure control and alignment

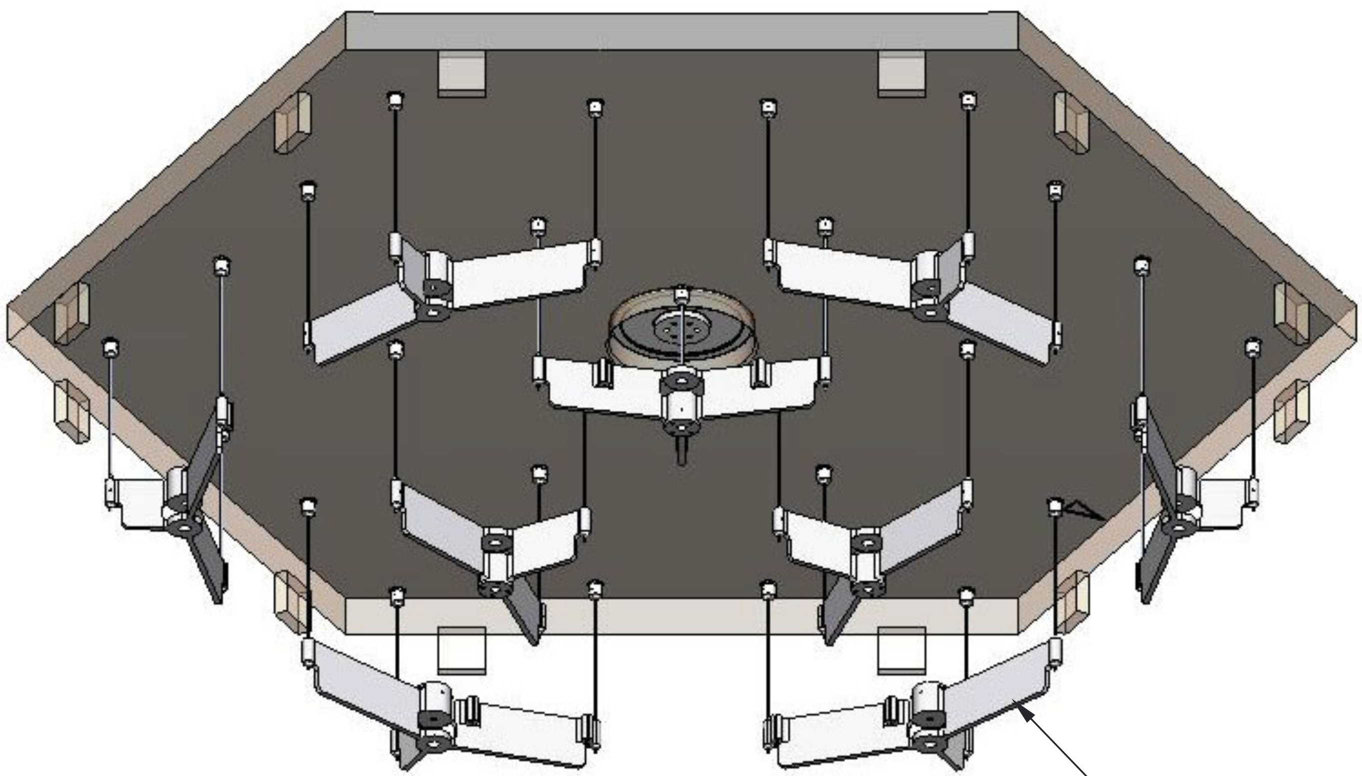
View of 7 adjacent segments -- Bottom view.



Credit: J. Nelson and TMT Project

Active optics: figure control and alignment

Small Whiffletree Triangles Attached



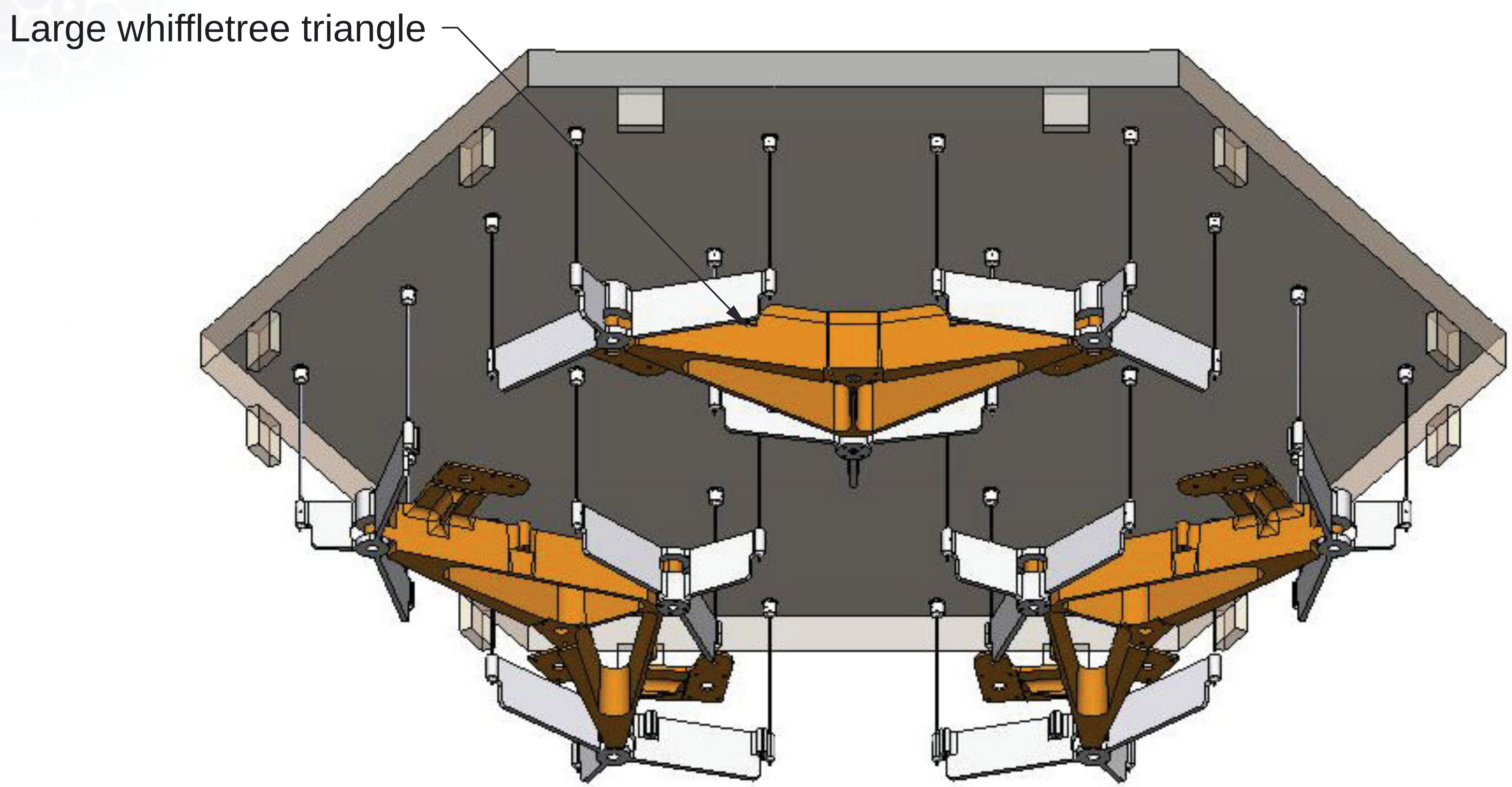
Small whiffletree triangle
- 3 inner
- 6 outer

Note: Does not represent assembly sequence

Credit: J. Nelson and TMT Project

Active optics: figure control and alignment

Large whiffletree triangles attached

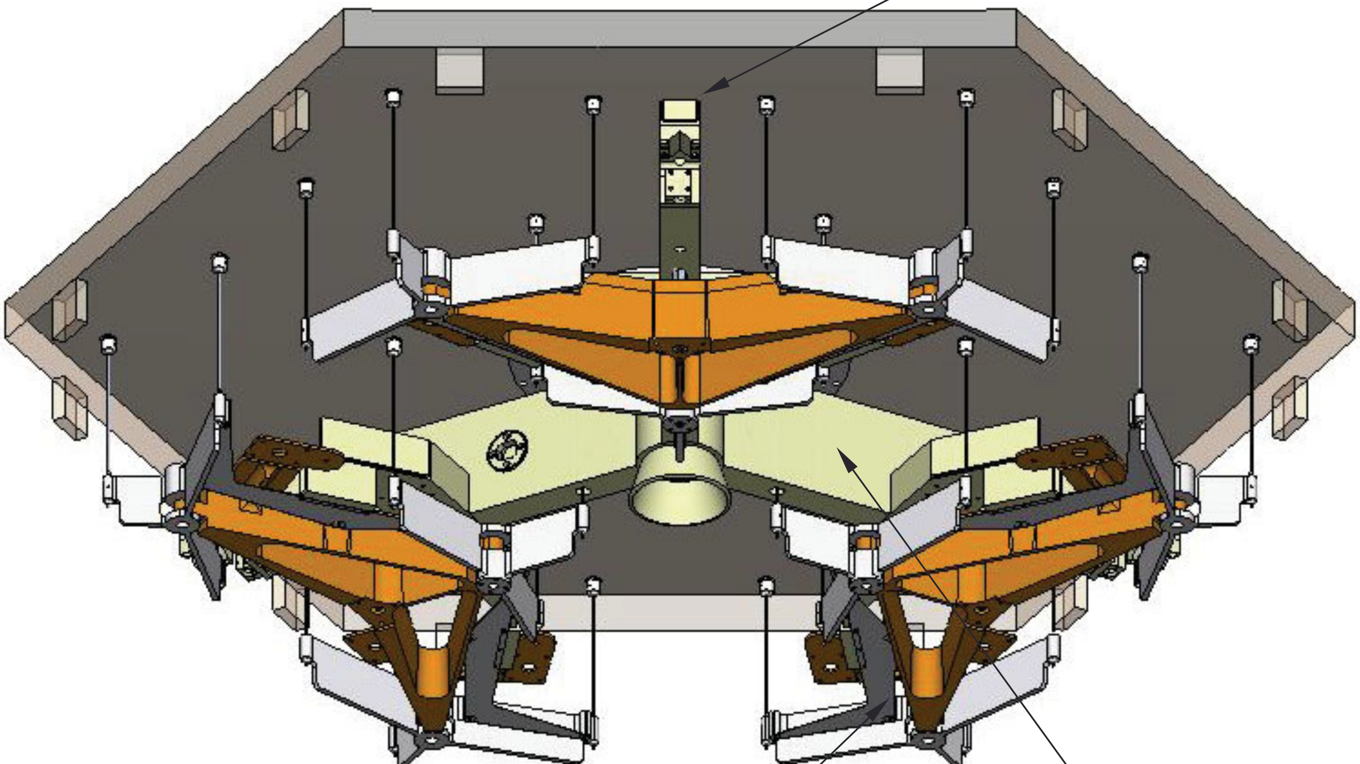


Note: Does not represent assembly sequence

Credit: J. Nelson and TMT Project

Active optics: figure control and alignment

Moving frame attached



Note: Does not represent assembly sequence

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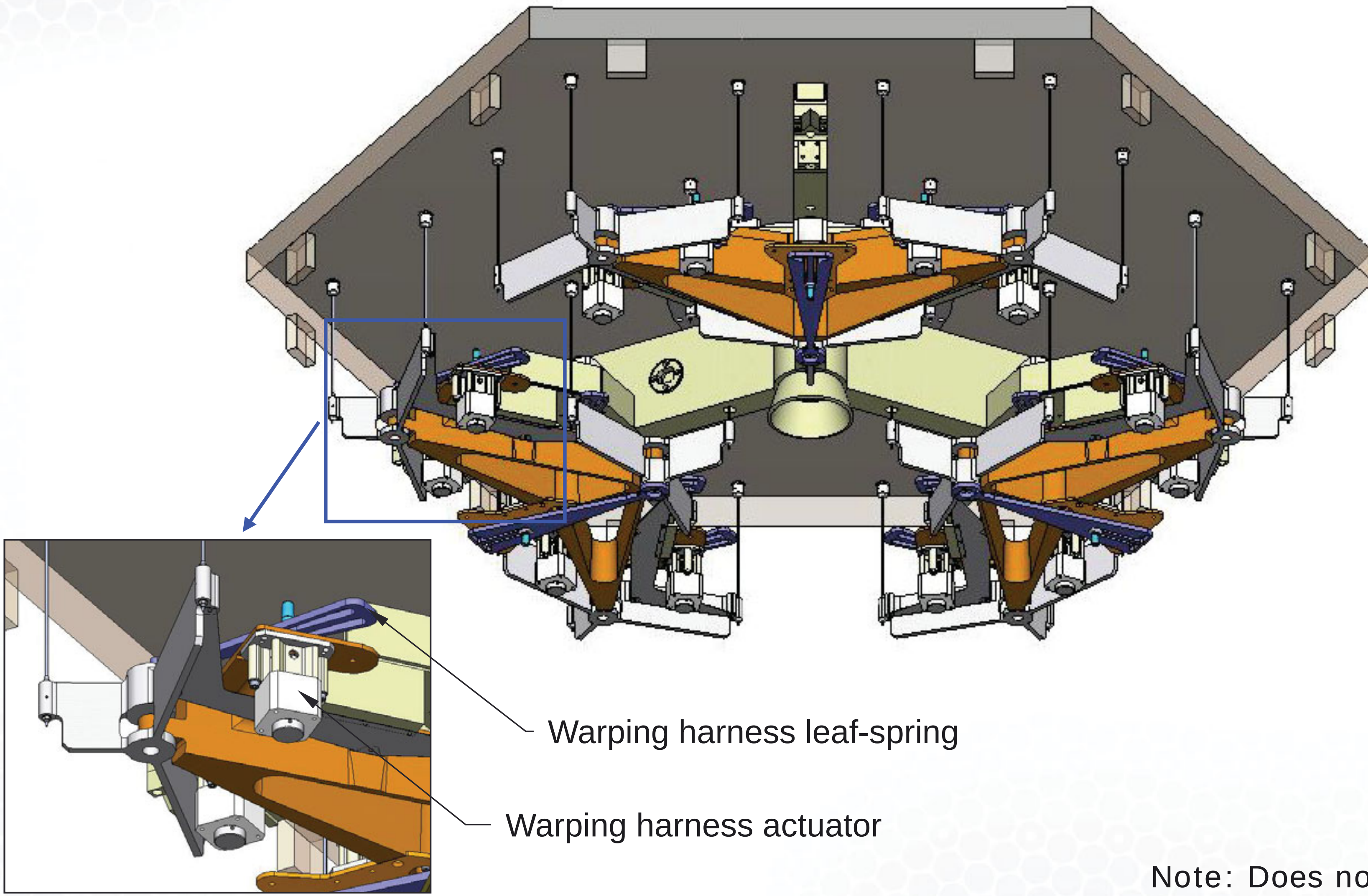
Active optics: figure control and alignment

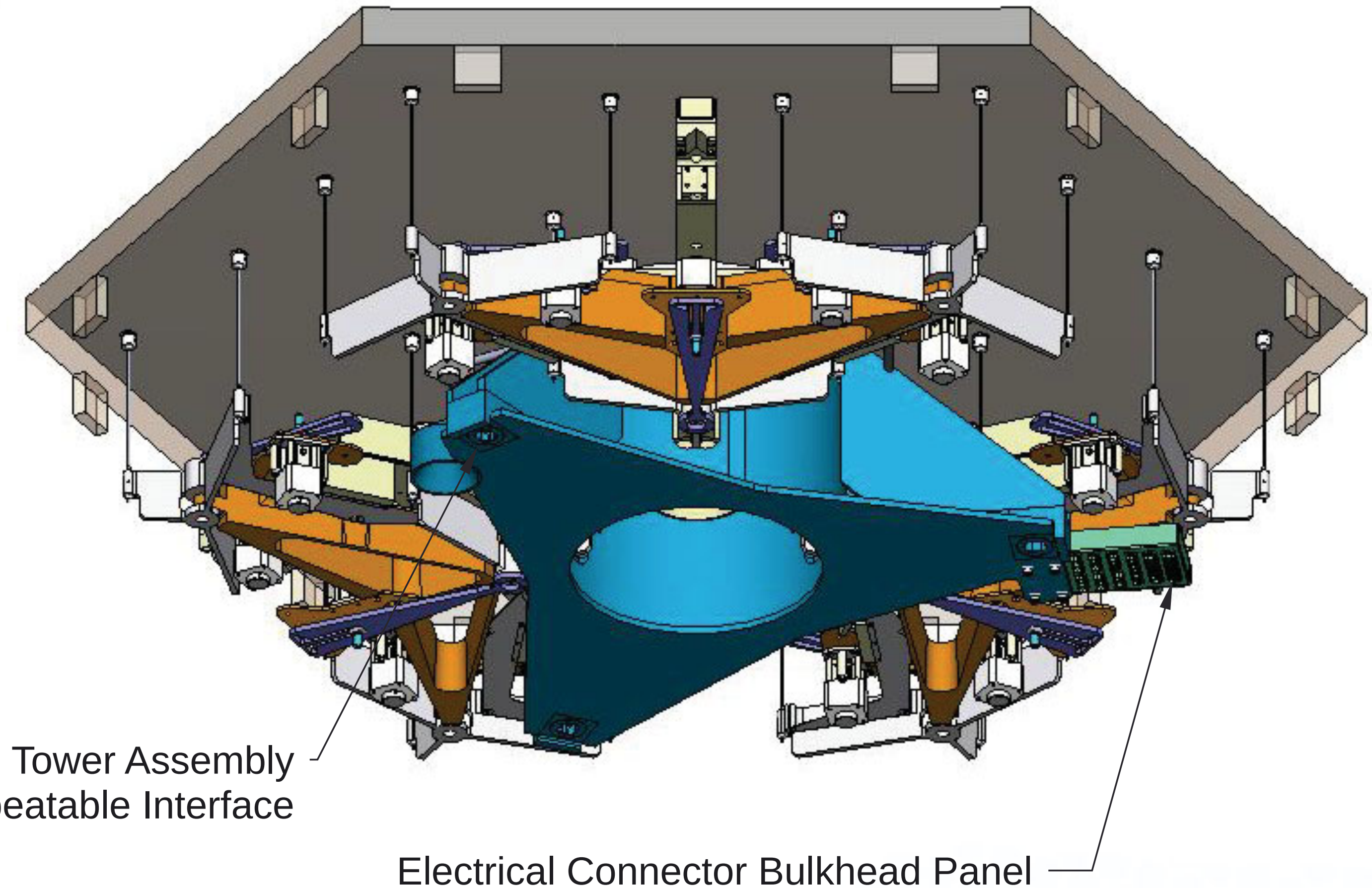
Warping harness added



Note: Does not represent assembly sequence

Active optics: figure control and alignment

Tower & locks installed



Note: Does not represent
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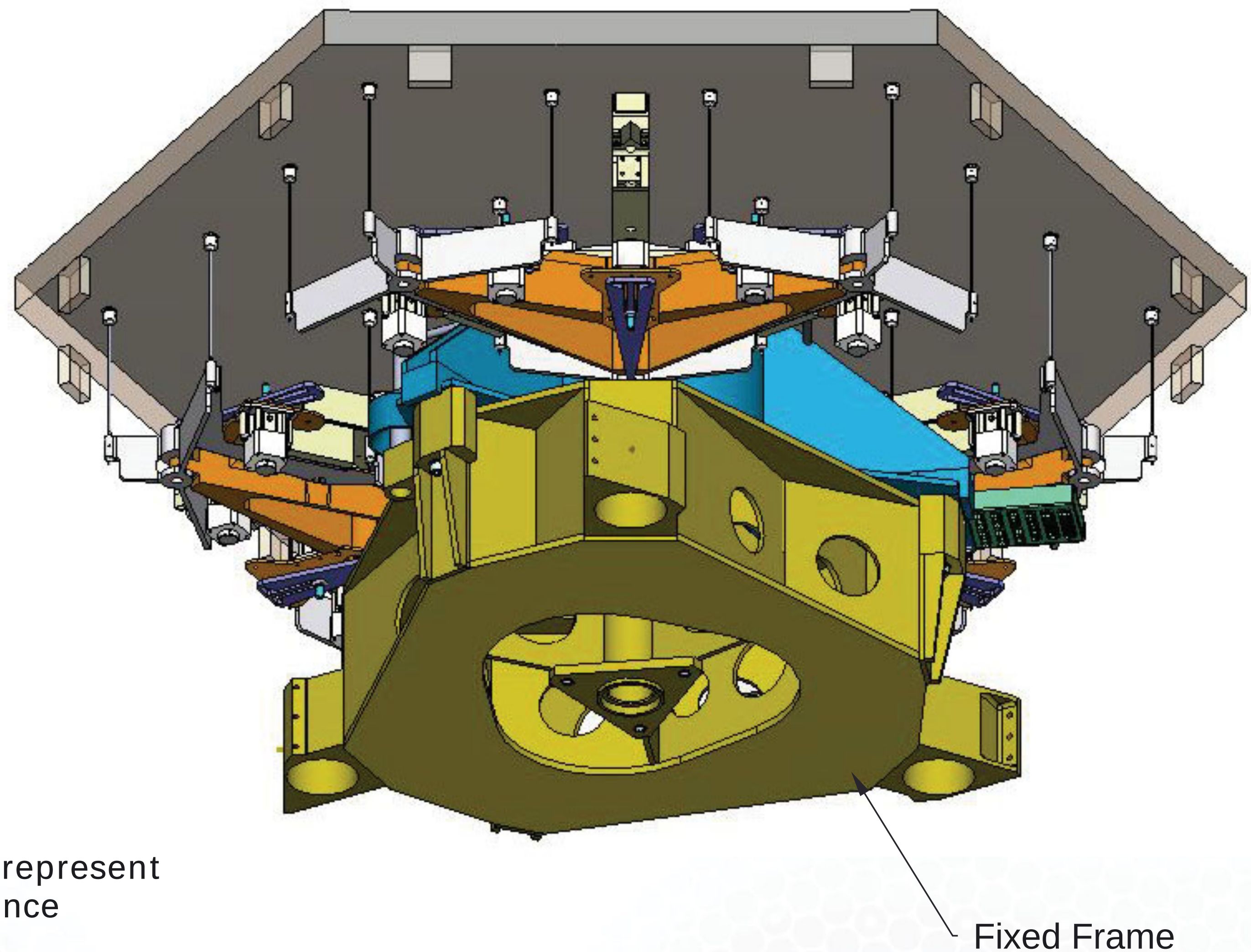
Active optics: figure control and alignment

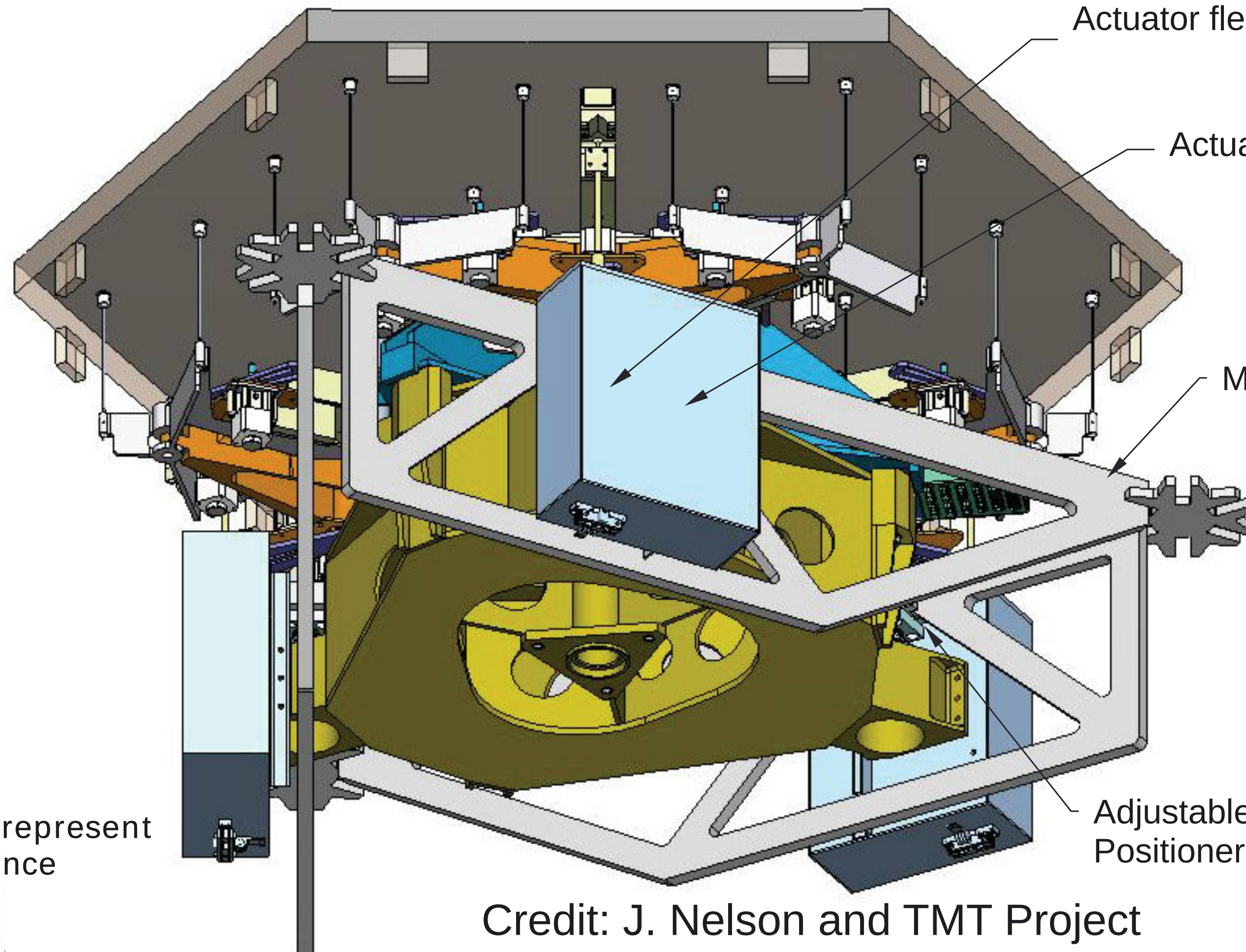
Fixed frame included



Note: Does not represent assembly sequence

Active optics: figure control and alignment

Installed on mirror cell



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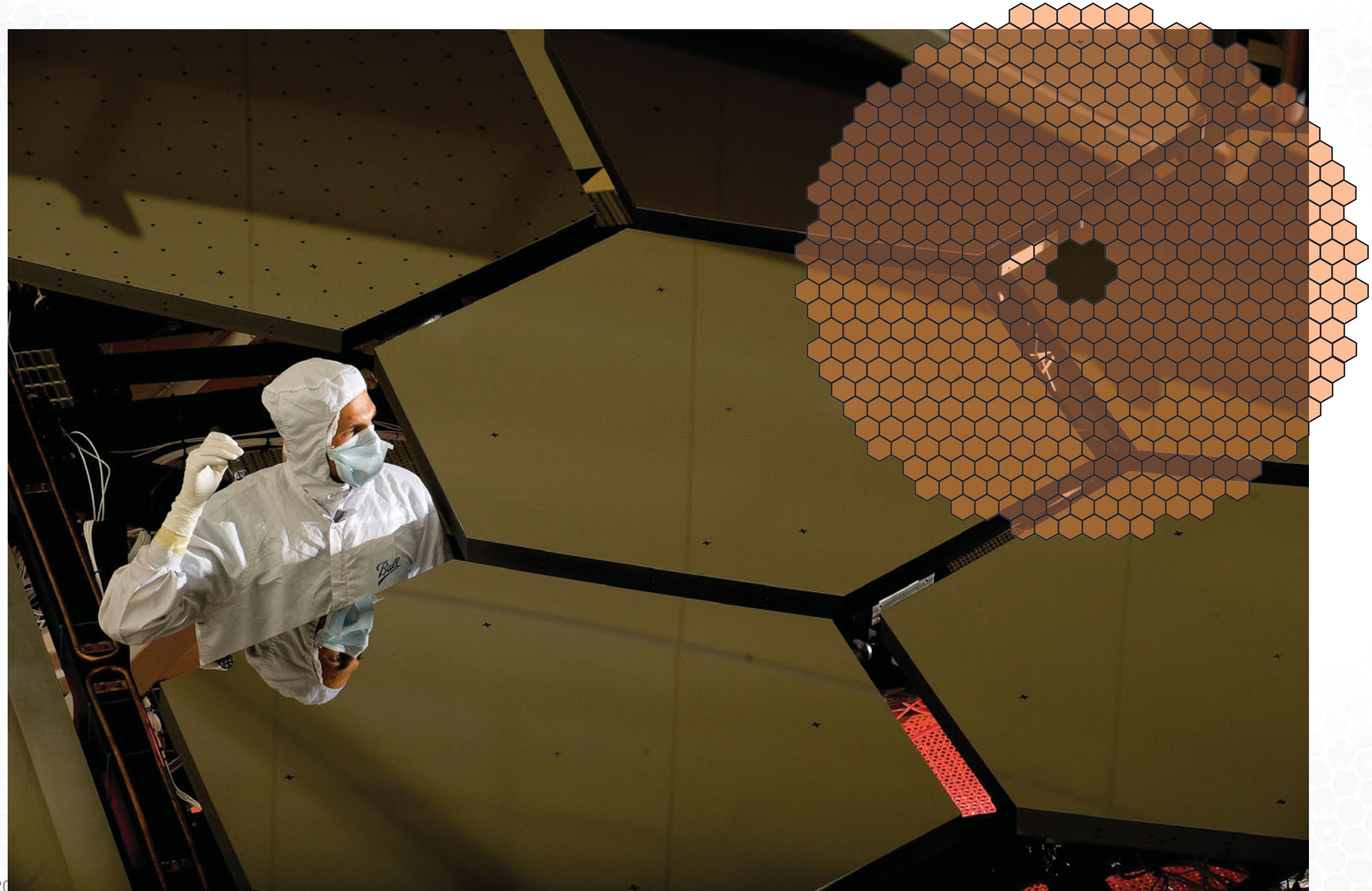
Small (~1m) segment pros/cons:

- Challenges:
  - Figure:
    - High curvature
    - 11 (TMT) and 12 (ELT) different prescriptions for the segments
    - Fragile, flexible mirrors: mirror figure created ”on the telescope”
  - Maintenance: coating has to happen ~daily (10’s of segments per week)
  - Adaptive optics:
    - Pupil is messy for AO (edges scatter light) — bad for high contrast imaging.
    - M2 is very big (3m diameter) and it can’t be a deformable mirror!
- Benefits:
  - Easy to test, known process to make (slow, difficult, but known)
  - Known alignment process on the telescopea (in theory, “just a big matrix inversion”)

Pupil for AO – edges scatter, gaps are warm



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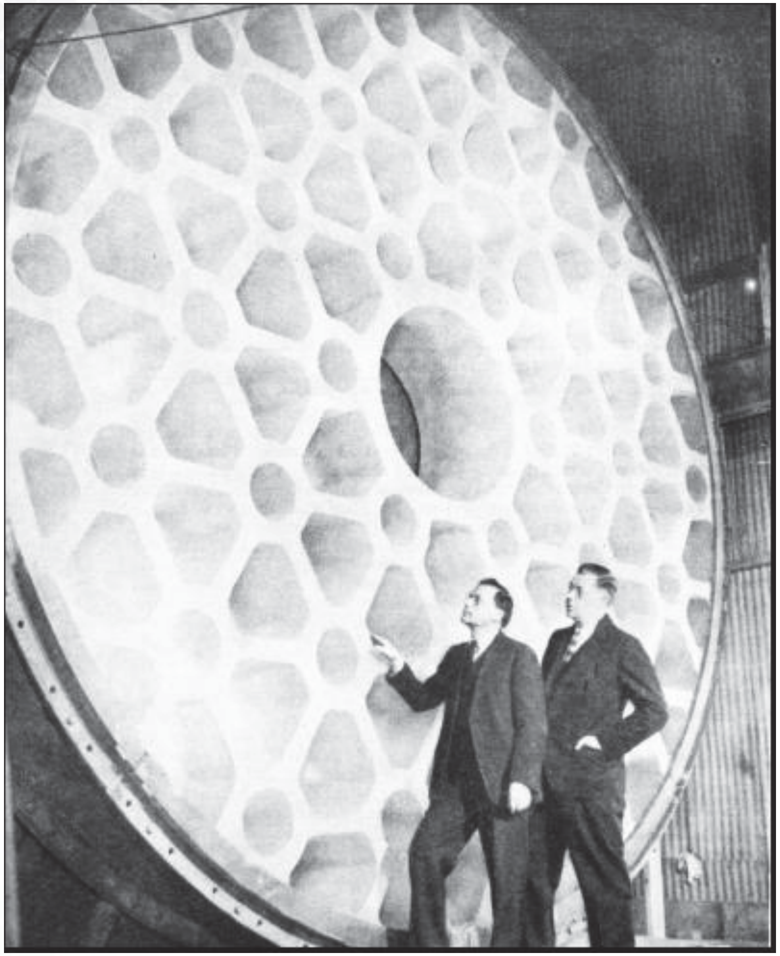
    - High curvature
    - 11 (TMT) and 12 (ELT) different prescriptions for the segments
    - Fragile, flexible mirrors: mirror figure created ”on the telescope”
  - Maintenance: coating has to happen ~daily (10’s of segments per week)
  - Adaptive optics:
    - Pupil is messy for AO (edges scatter light) — bad for high contrast imaging.
    - M2 is very big (3m diameter) and it can’t be a deformable mirror!
- Benefits:
  - Easy to test, known process to make (slow, difficult, but known)
  - Known alignment process on the telescopea (in theory, “just a big matrix inversion”)

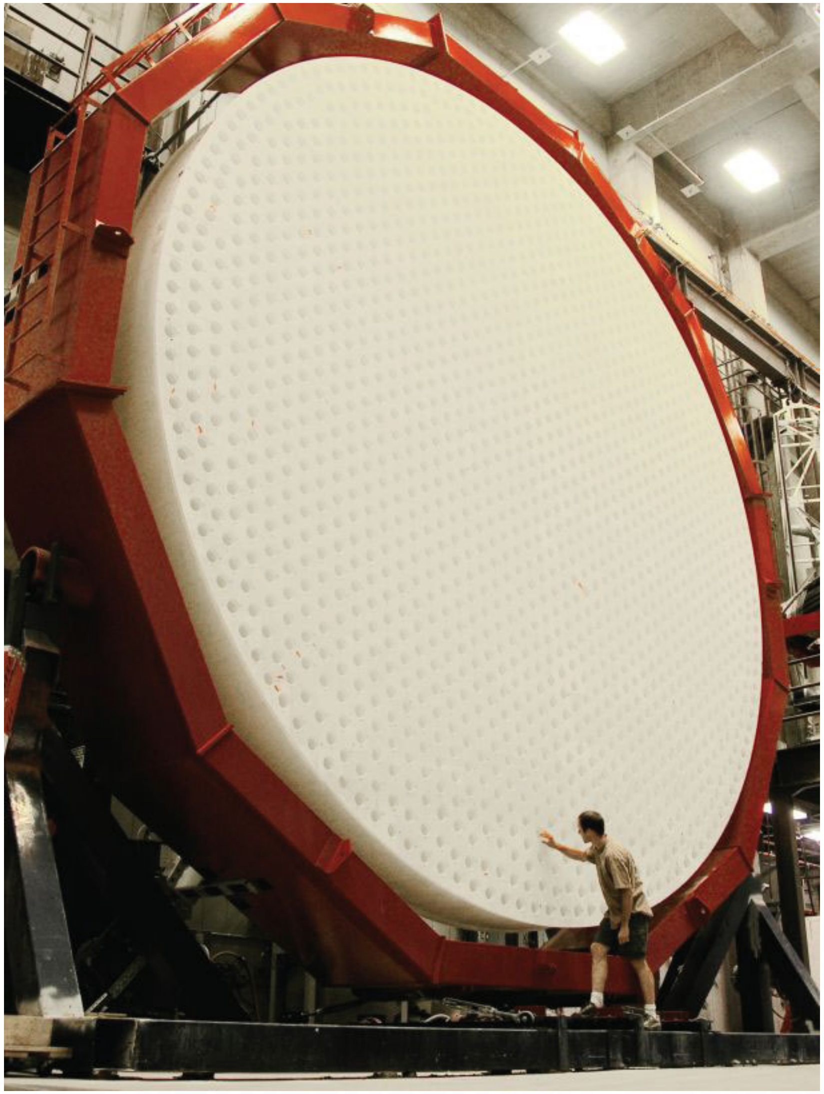
Topics:

- What do telescopes do and how?
  - Mirrors & Structures
  - Telescope optics 101
  - Strategies of the 3 GSMTs
    - Optical Configurations
    - Segments — Large
    - Structures
- What do instruments do and how?
  - Instruments optics 101
  - Basic scaling relations for spectrographs.
  - Limitations for large spectrographs
  - Strategies for GSMTs
- GSMT Comparison

GMT: Largest possible segments.



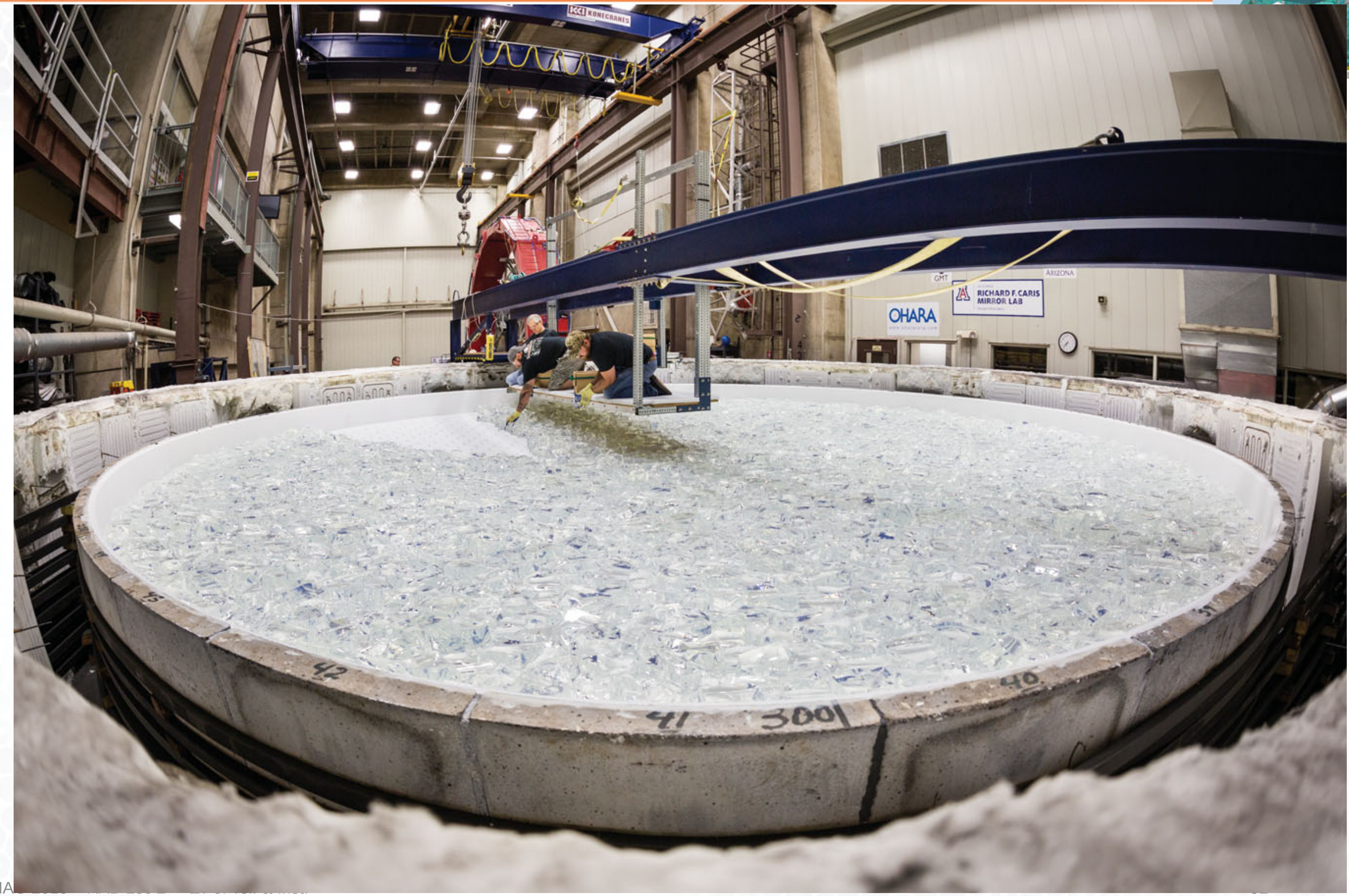
Palomar 200-inch (5-meter)



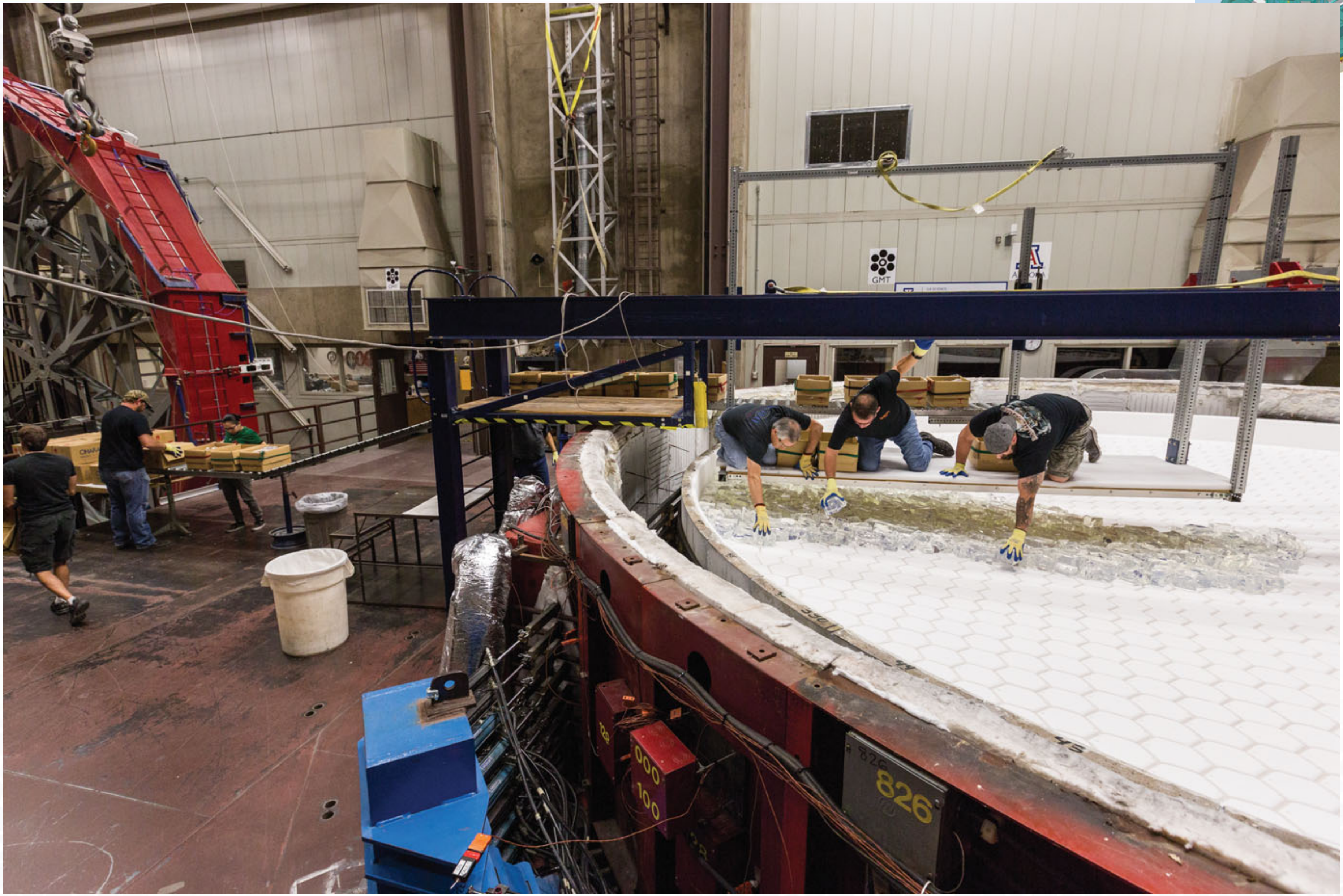
One 8.4-meter GMT Segment

Mirrors are made in the Caris Mirror Lab at UA

Segment Fabrication: make mold, lay glass

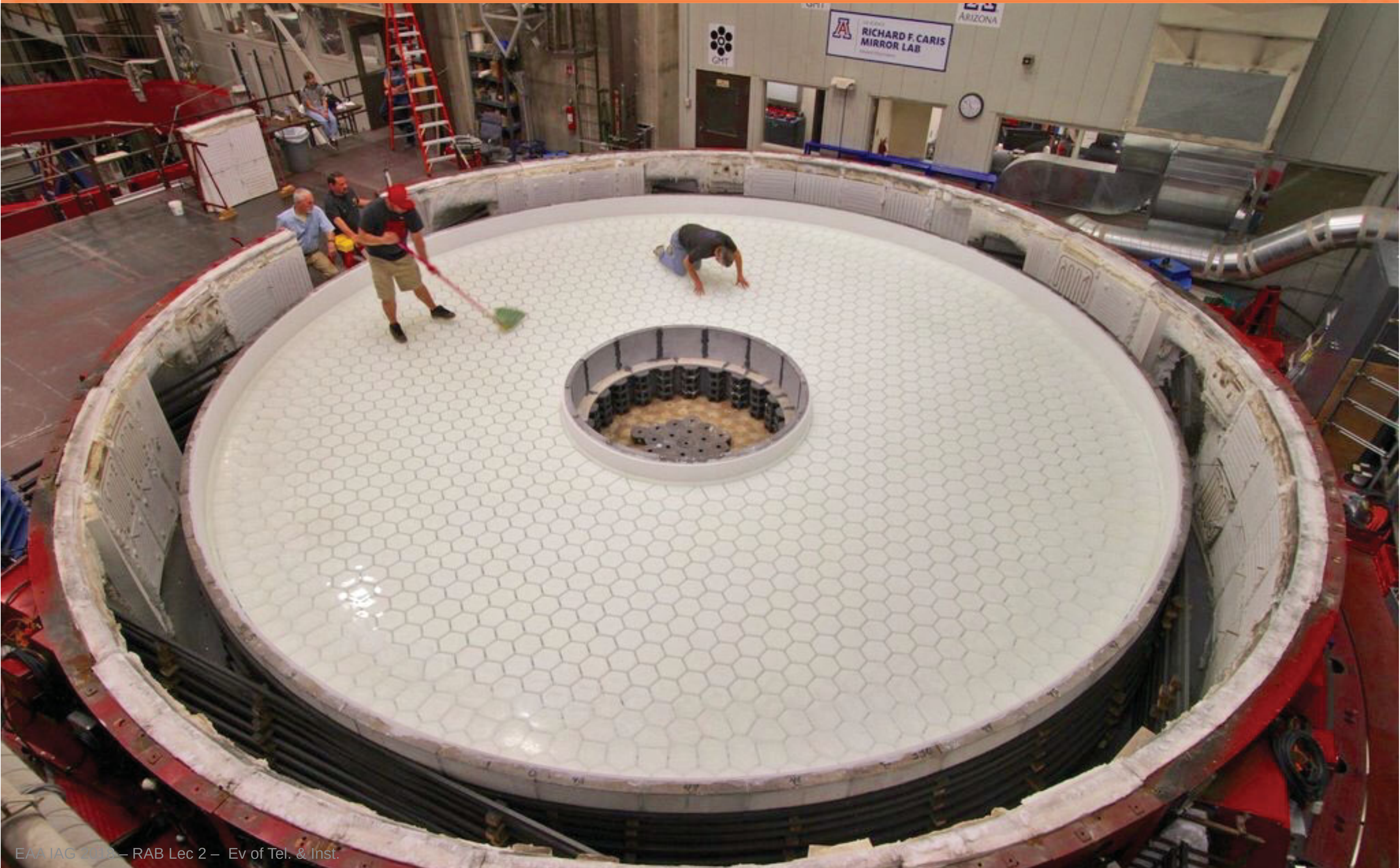


Segment Fabrication: make mold, lay glass



Segment Fabrication: spin cast in oven

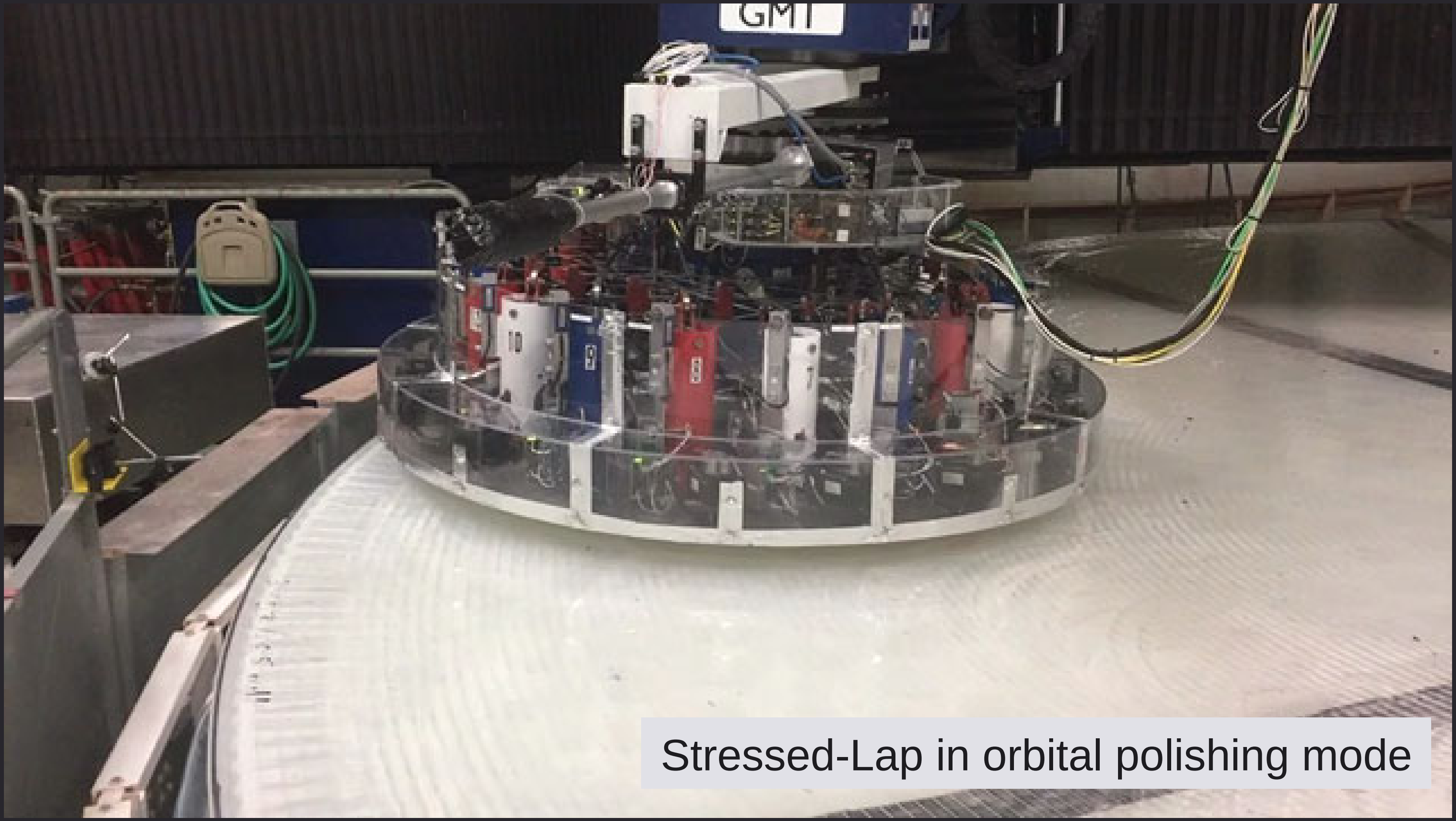
Mirror Segment 4 (center segment)



Mirror Segment 4: rear surface polishing

Mirrors Polished Using Active Lap

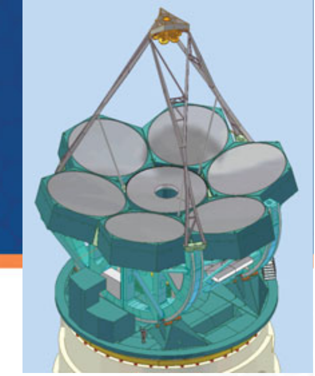
Segment 2 on the Large Polishing Machine



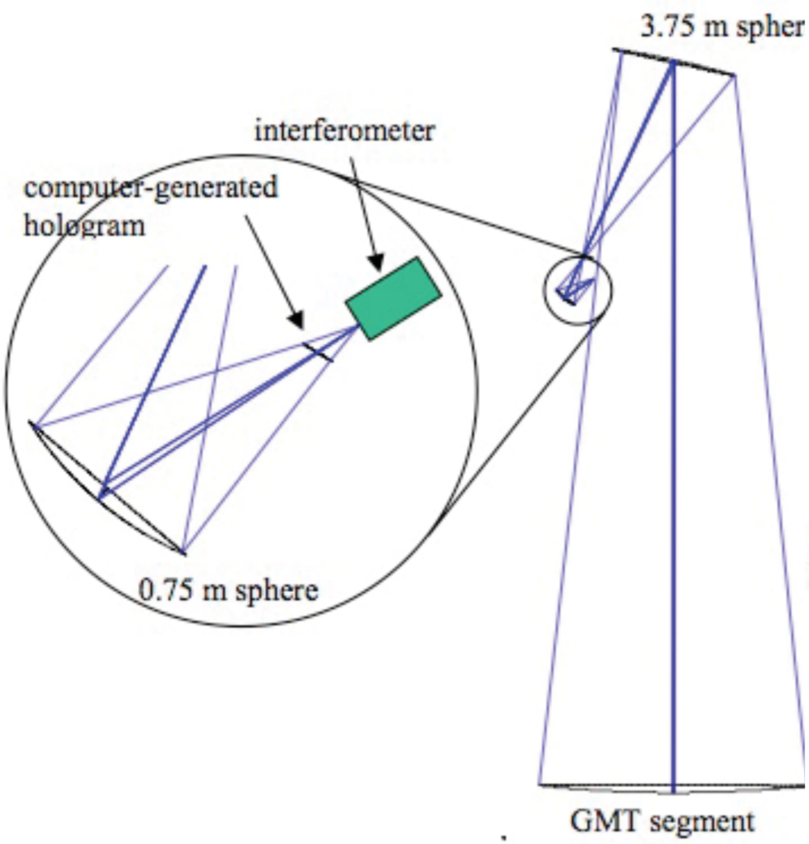
Stressed-Lap in orbital polishing mode

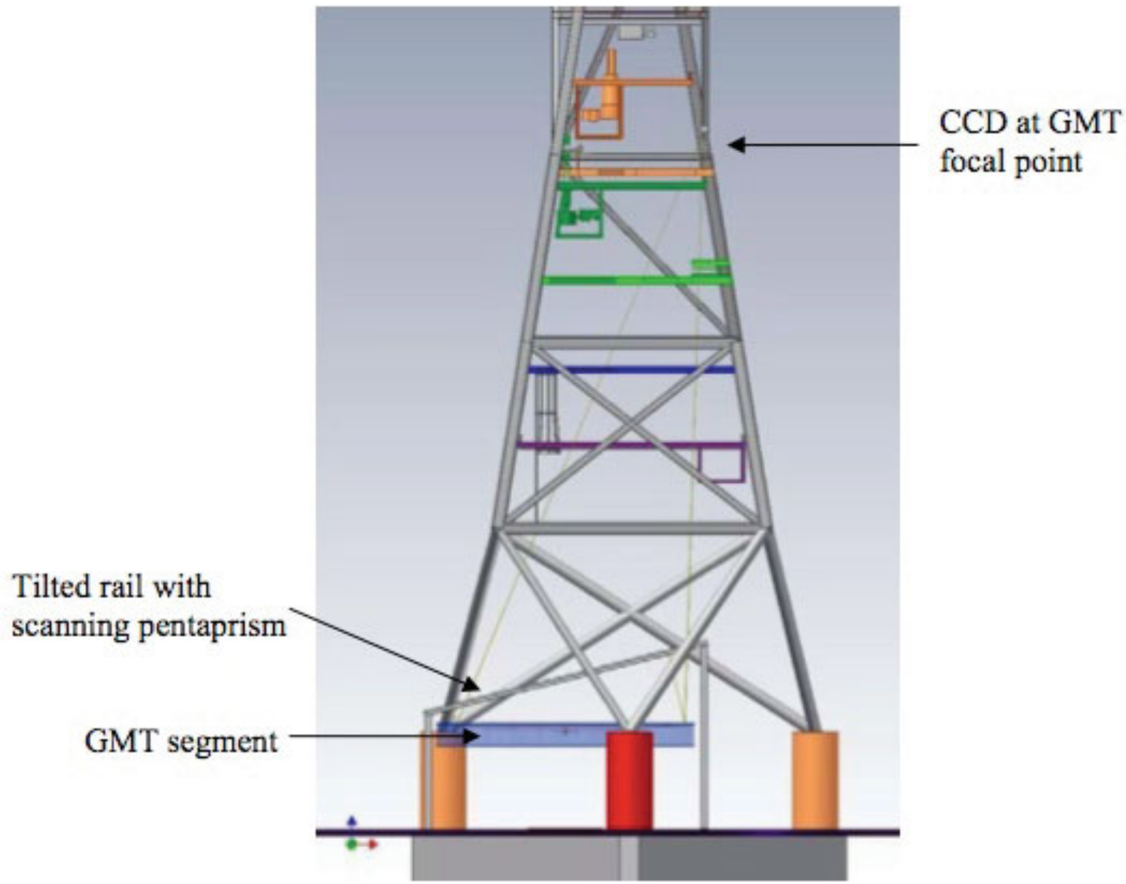
Mirrors are made in the Caris Mirror Lab at UA

Optical testing: required a new test tower

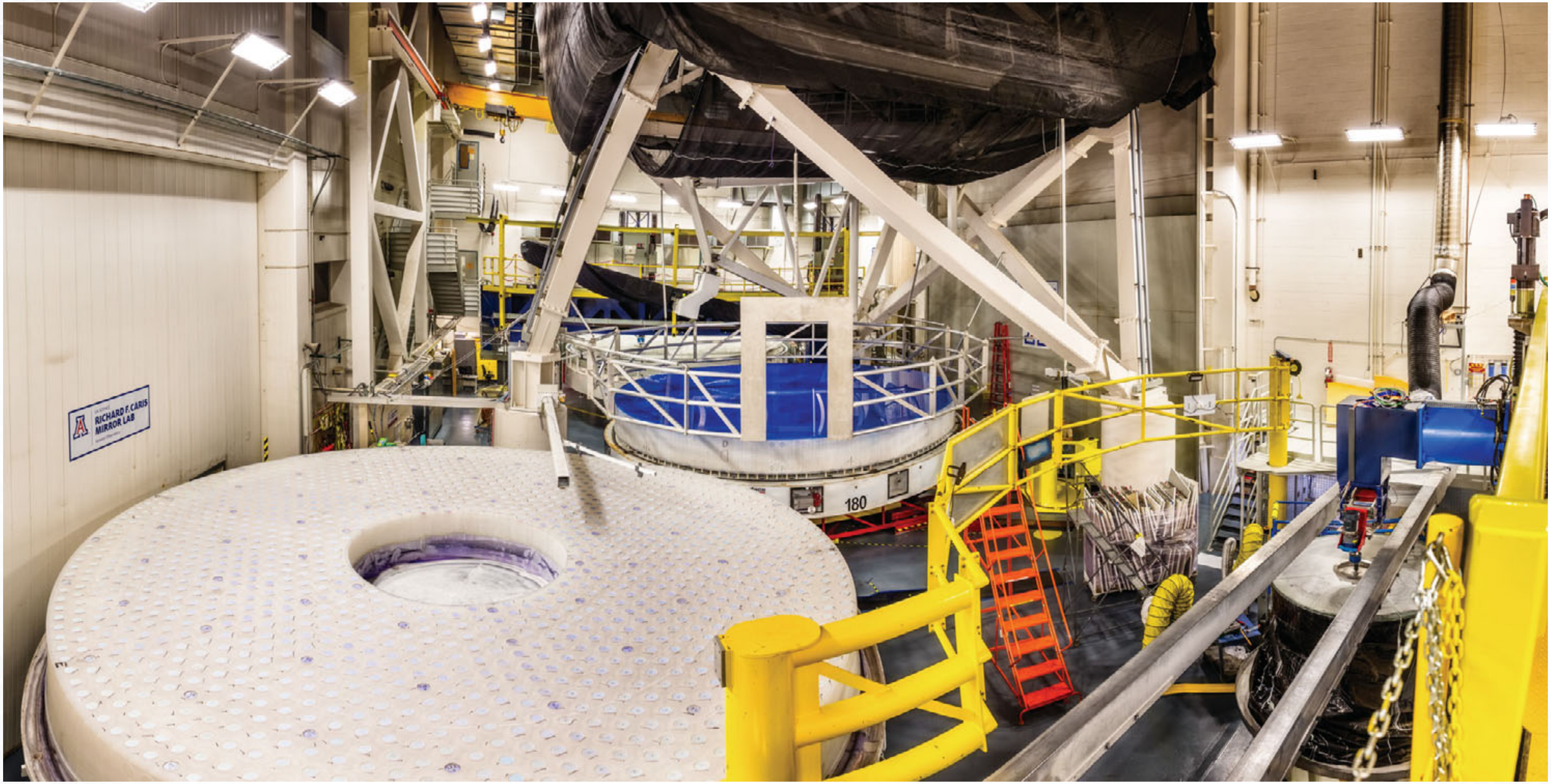


- On-axis segment ~easy.
- Off-axis segments harder — but DONE and GOOD!





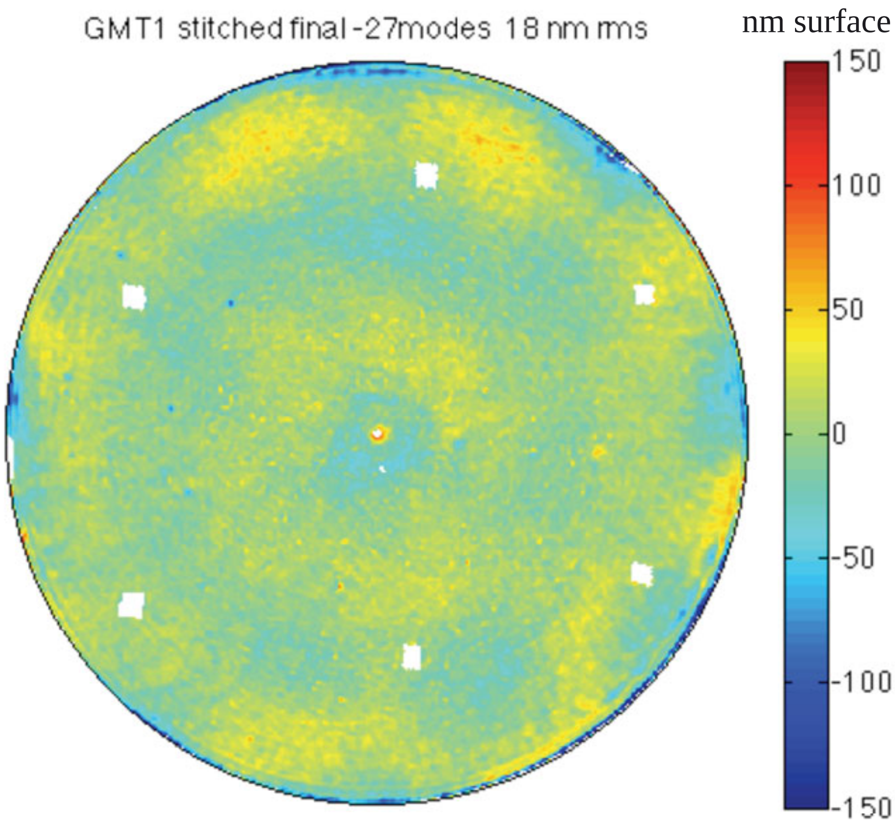
Mirror status: Segment 1 — done in 2012



Mirror status: Segment 1 — done in 2012

- < 20 nm rms surface error (in it's cell with active optics support)
- 3 completely independent metrology tests confirm figure

to parent axis

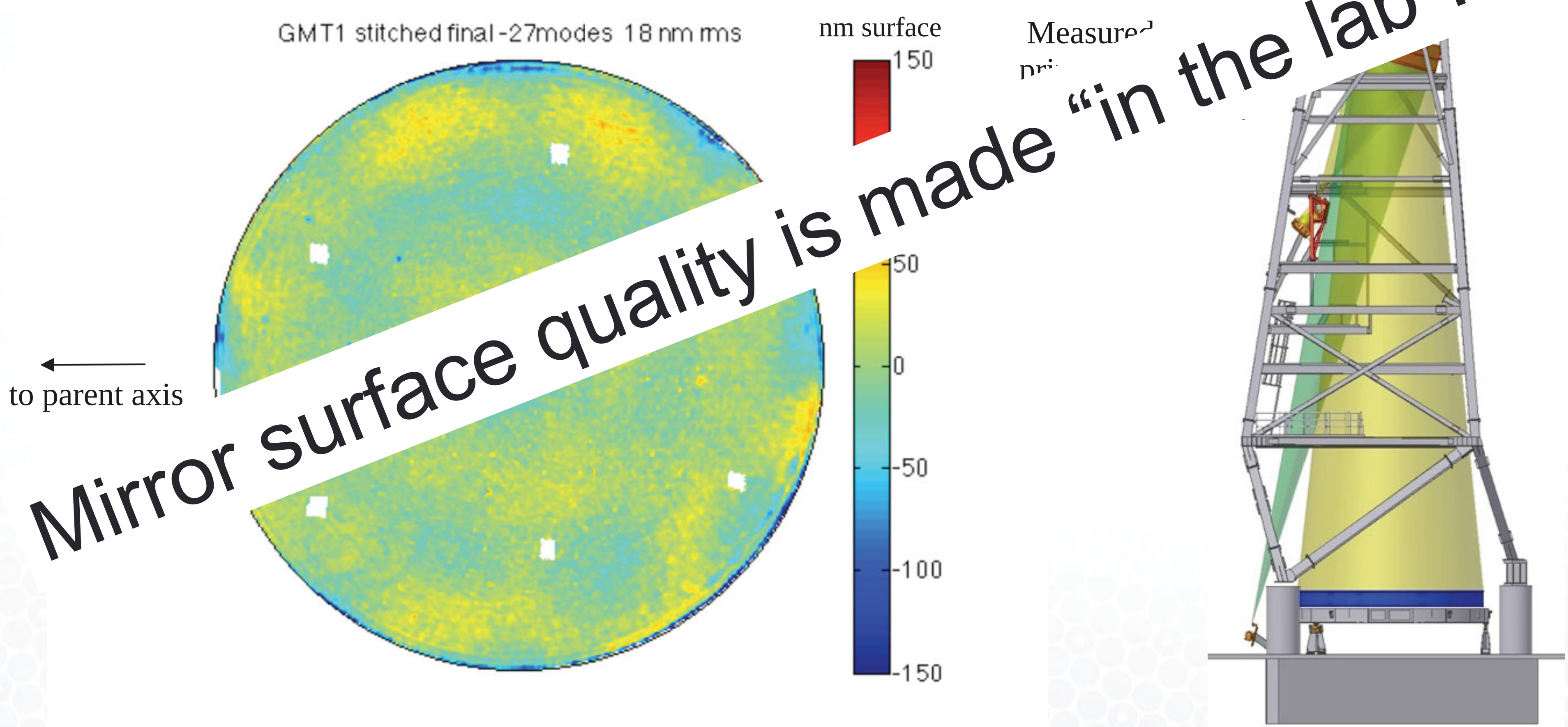


Measured with the principal test on the 28m test tower

Mirror status: Segment 1 — done in 2012

GMT

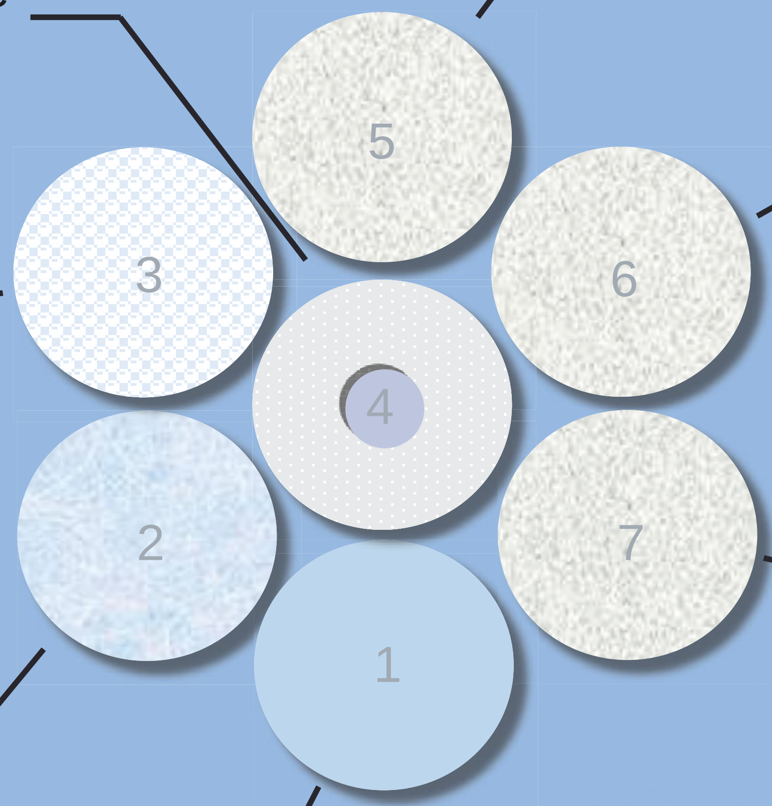
- < 20 nm rms surface error (in it's cell with active optics support)
- 3 completely independent metrology tests confirm figure



Mirror surface quality is made "in the lab".

Primary Mirror Production

GMT

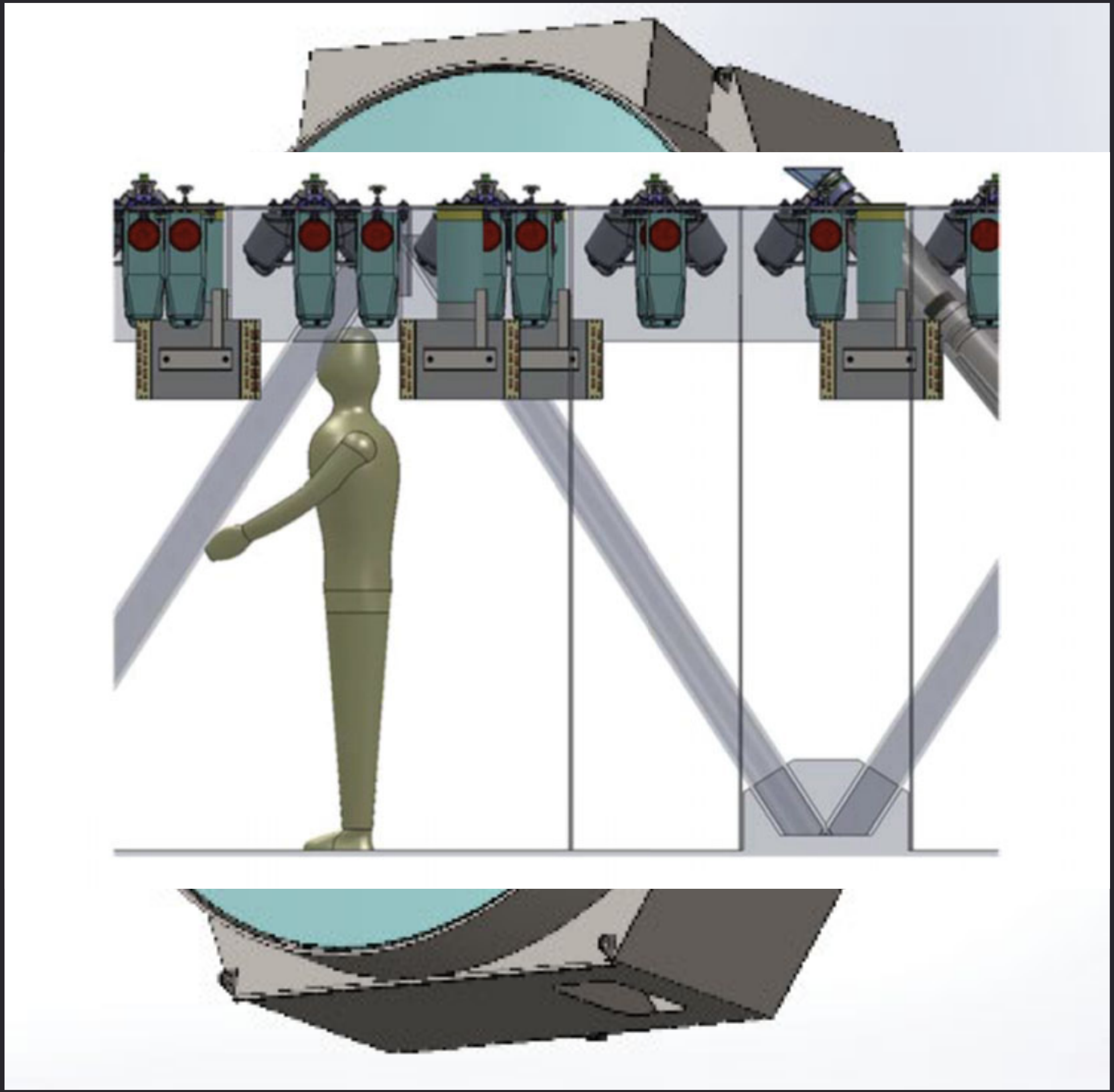


OHARA Ohara Corporation

UA SCIENCE RICHARD F. CARIS MIRROR LAB Steward Observatory

Primary Mirror Segment Support & Control

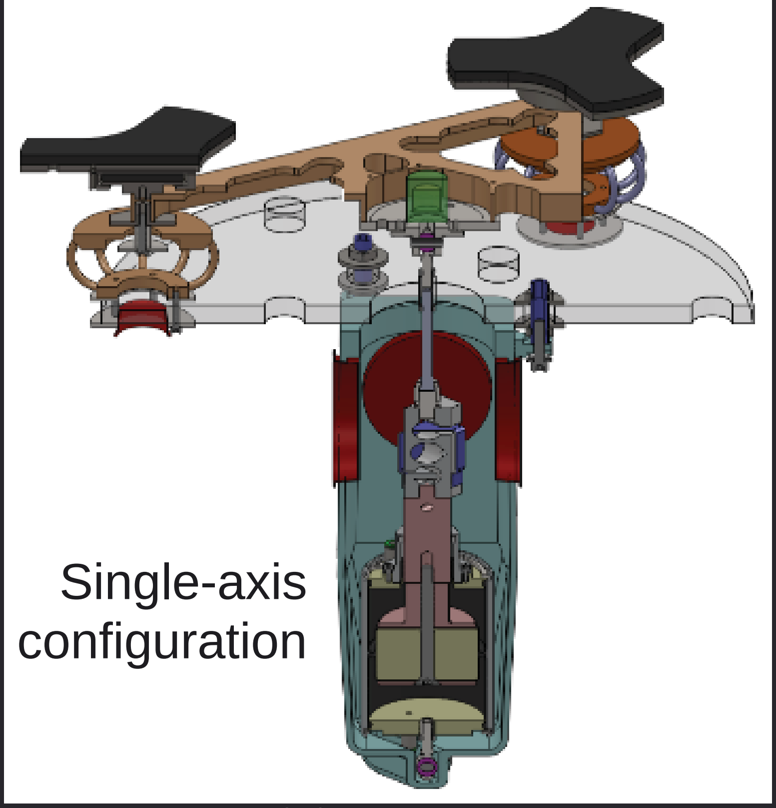
- Primary mirror segments contained in mirror cells
- 17 tons of glass
- 23 tons of steel
- 10 meters wide
- 3.2 meters high

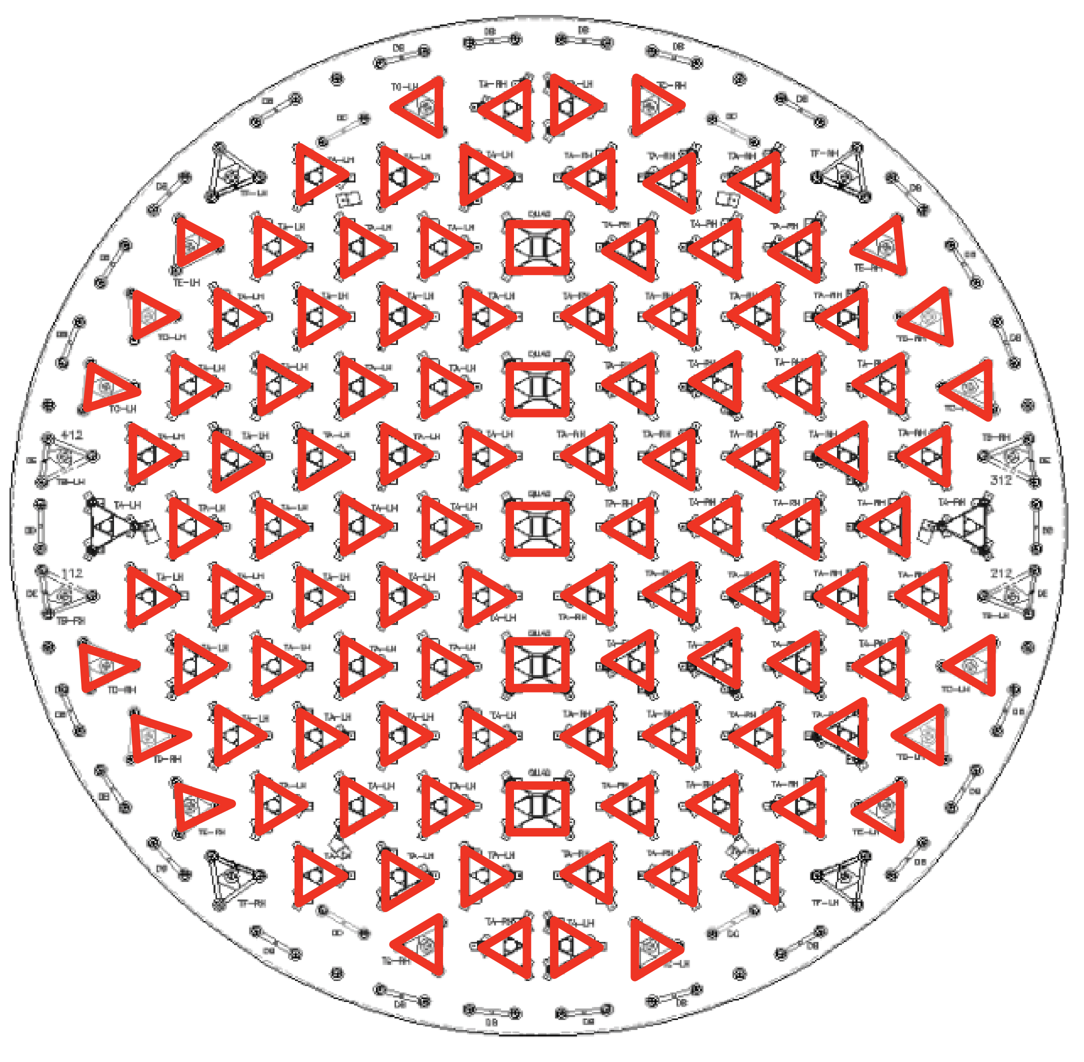


Primary Mirror Segment Support

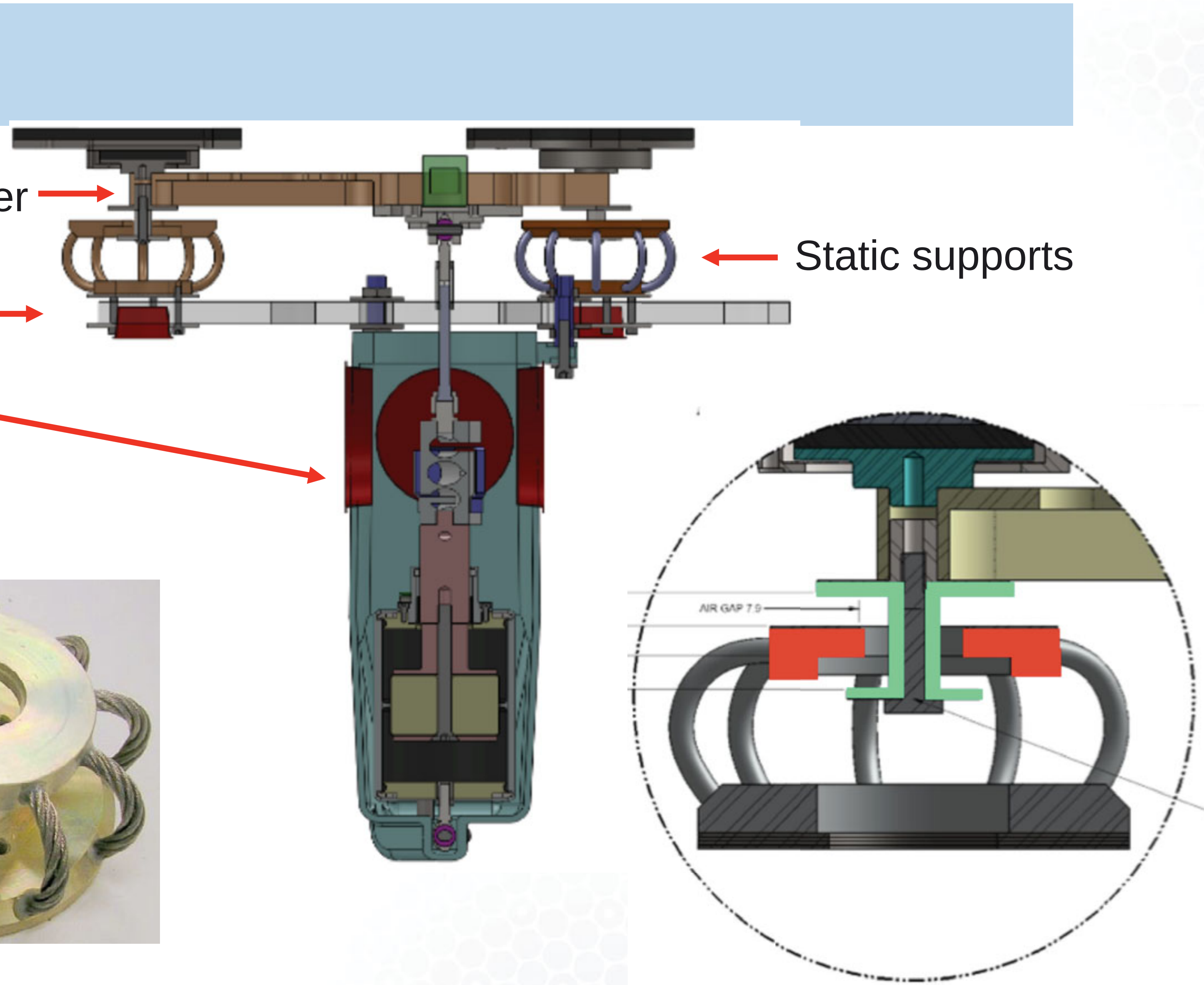
GMT

- Mirror segments supported on 165 pneumatic force actuators





Primary Mirror Segment Support



Static support

Topics:

- What do telescopes do and how?
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    - Segments
    - Structures
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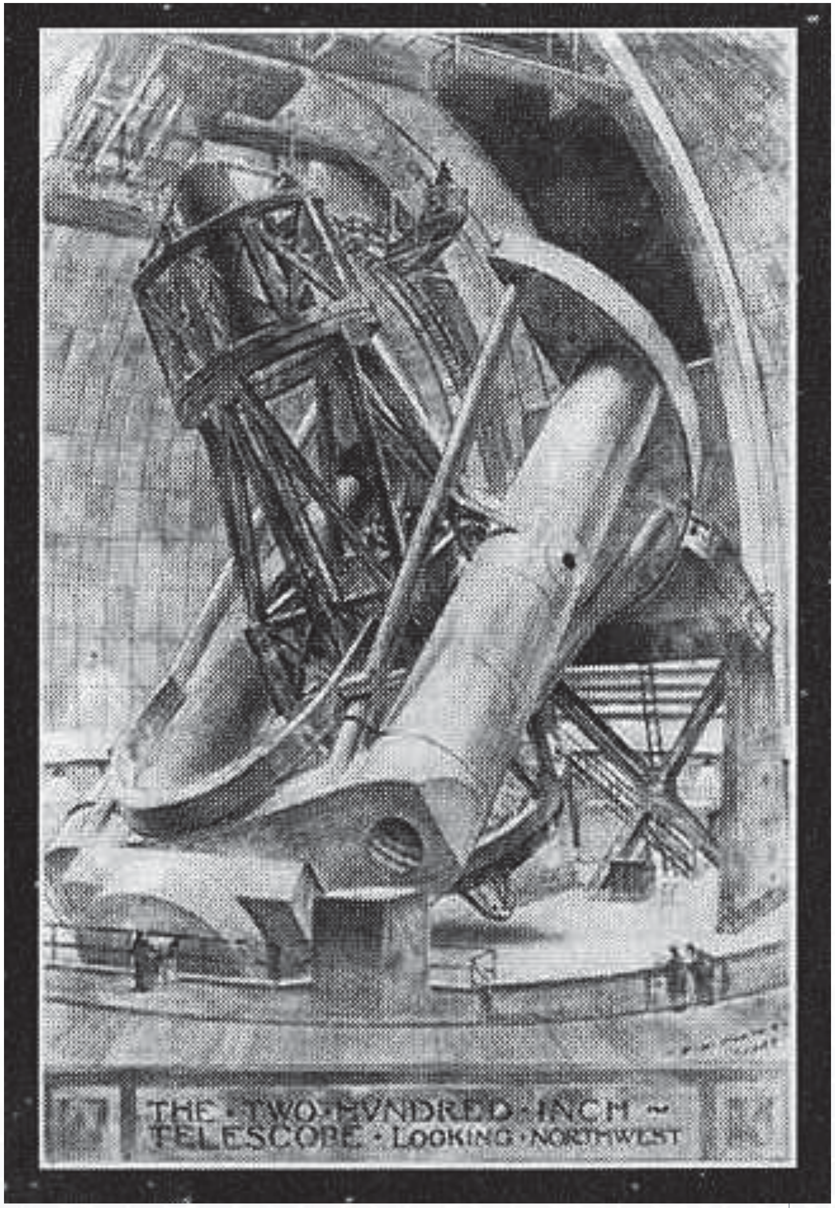
  - Limitations for large spectrographs
  - Strategies for GSMTs
- GSMT Comparison

Structures: made smaller by faster mirrors!

GMT

- Optical Telescopes
  - Mt Wilson 1918 2.5 m
  - Palomar 1948 5 m

Old style:
Equatorial (5m)



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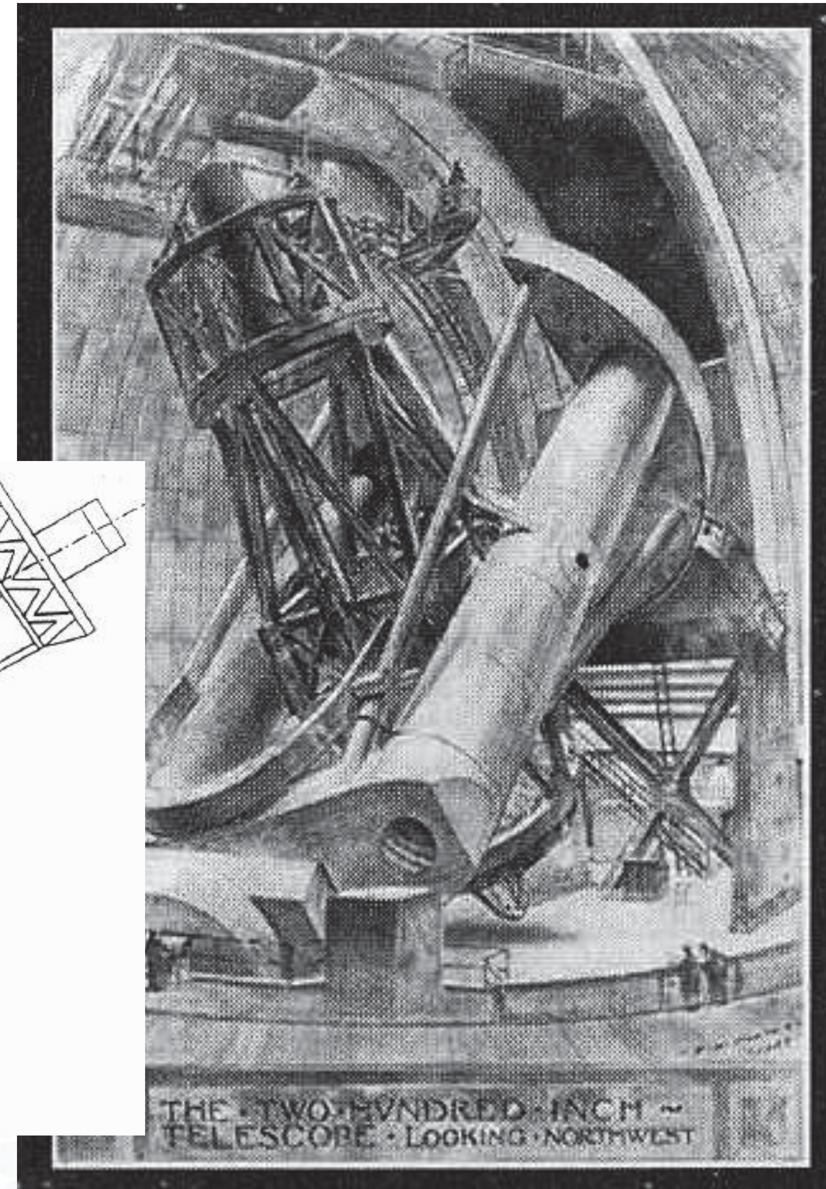
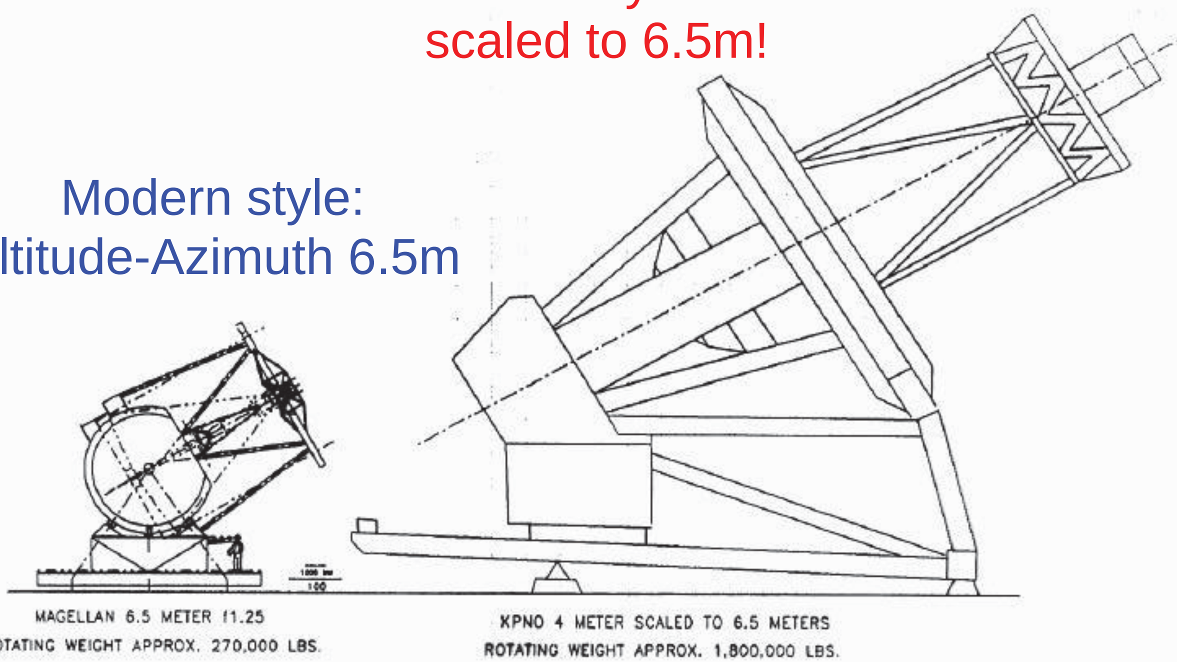


Old-style:
scaled to 6.5m!

Modern style:
Altitude-Azimuth 6.5m



(Credit: S.Shectman, Magellan)

Modern Alt-Az mounts

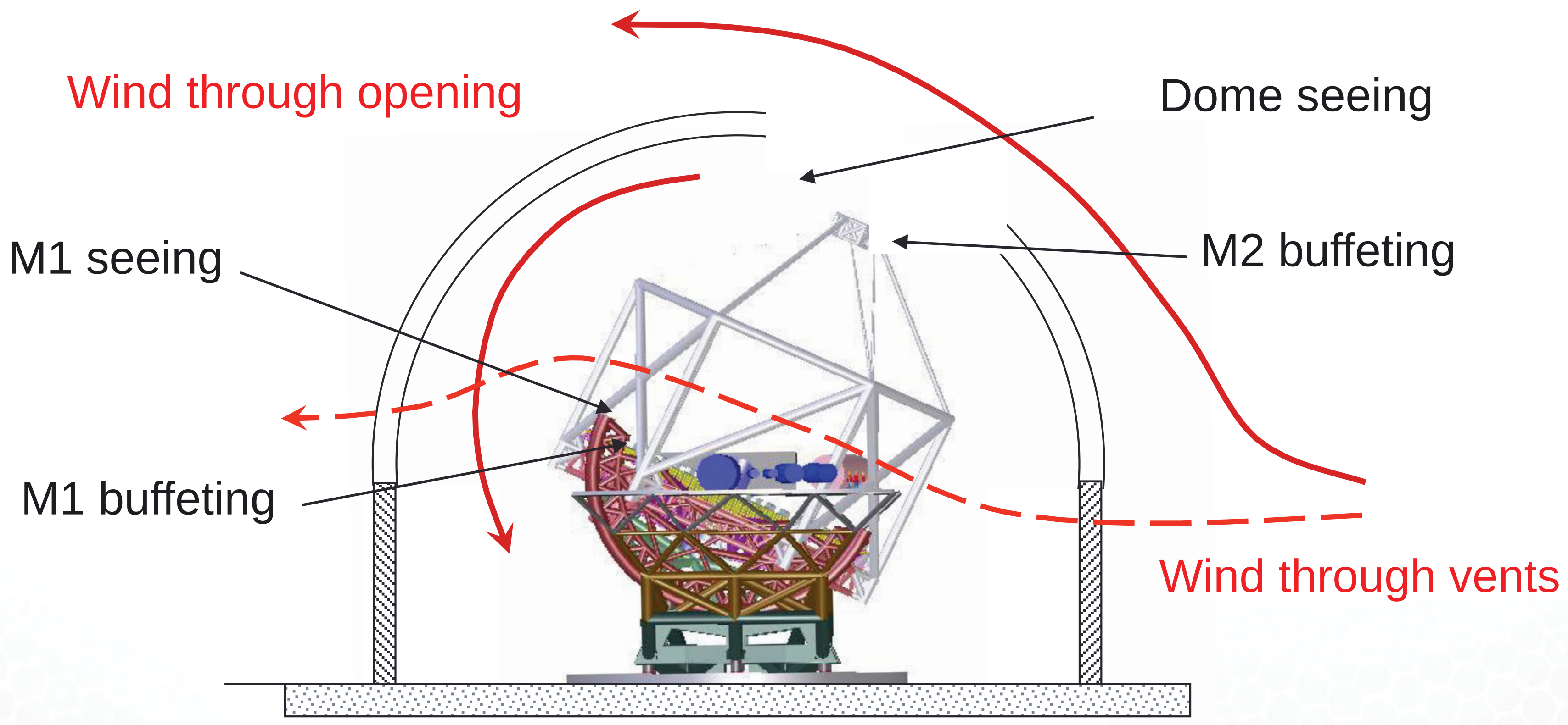
GTC	2010	11 m
Keck x2	1995	10 m
Gemini x2	1999	8 m
VLT x4	2000	8 m
Subaru	1999	8 m
Magellan x2	2001	6.5 m

Desktop model of GMT

(Credit: Keck Obs.)

Challenges: Structural — WIND

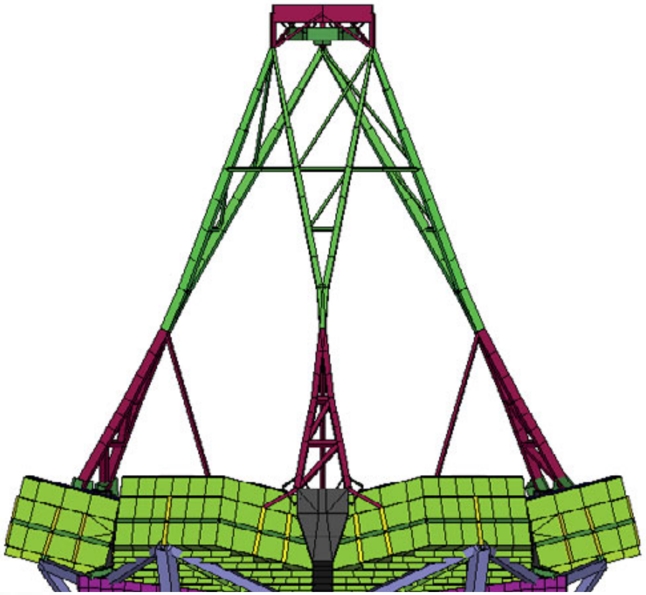
- Wind disturbance rejection
  - Dynamic response analysis of vibrational modes: used to refine design
    - Structure filters out power on small scales (wind disturbance)

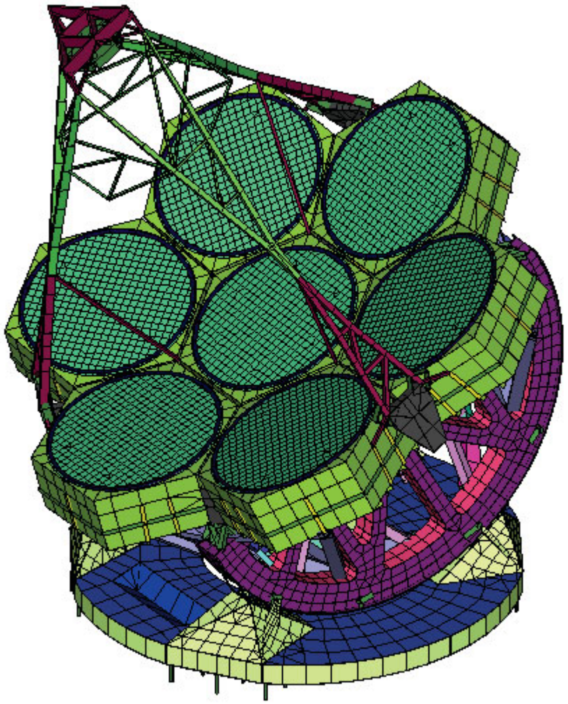


Artistic credit: J. Nelson

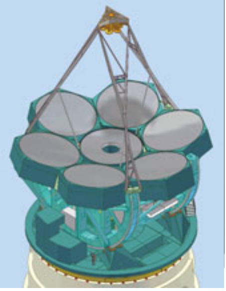
Challenges: Structural — WIND

- Wind disturbance rejection
  - Dynamic response analysis of vibrational modes: used to refine design
    - Structure filters out power on small scales (wind disturbance)
    - Secondary mirror (light, high frequency): actively controlled (hexapod)



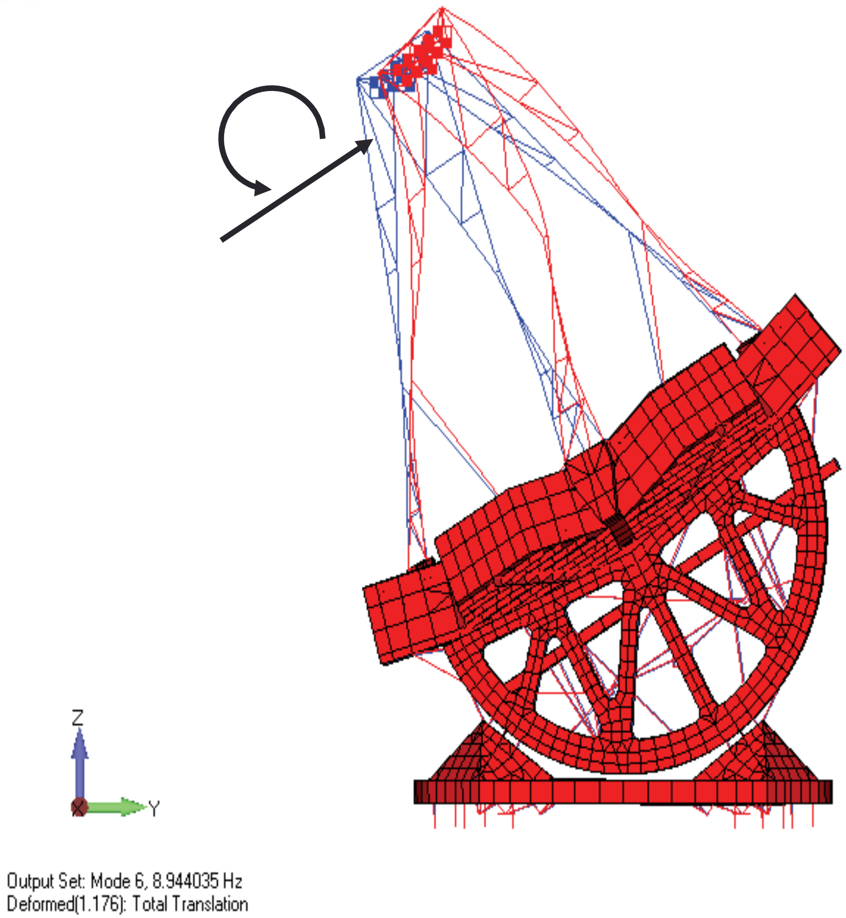


Challenges: Structural — dynamic response

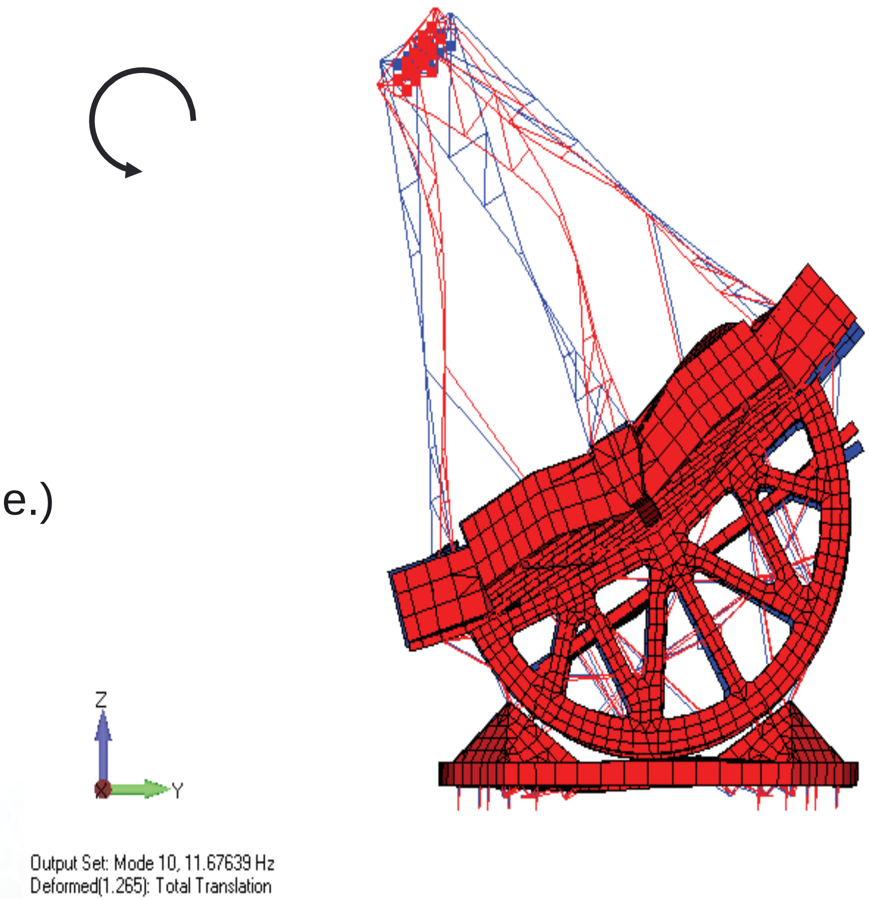


Note: motion of image = 2x [angle of Secondary Mirror]

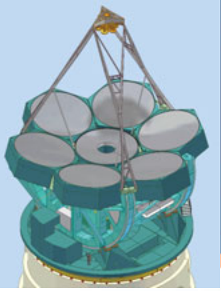
2nd fore-aft mode (9 Hz) | 3rd fore-aft mode (10 Hz)



(Not to scale.)



Modeling by S. Gunnels and Simpson, Gumpertz,& Heger for GMT



Challenges: Structural — dynamic response

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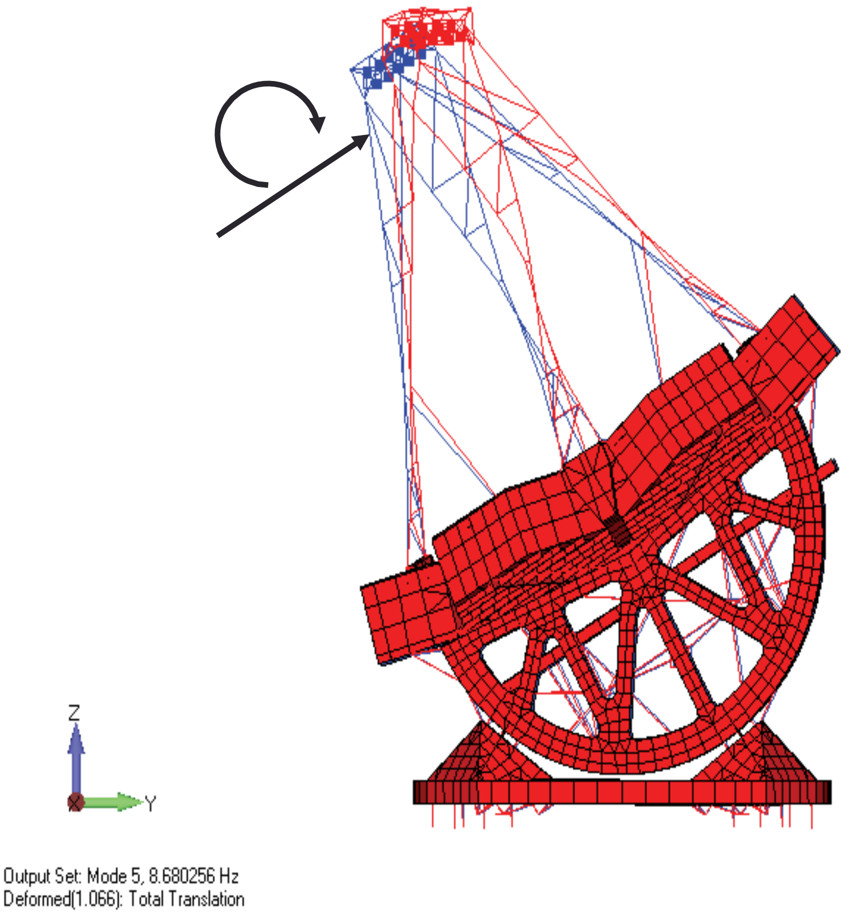
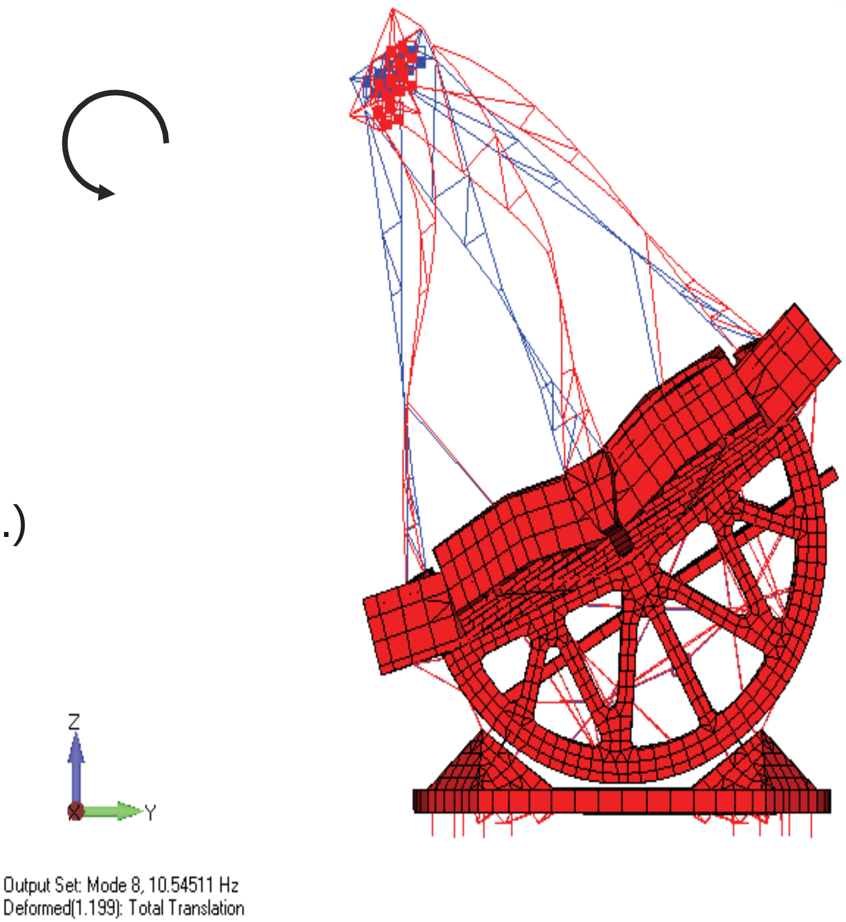
2^{nd} fore-aft mode (9 Hz)



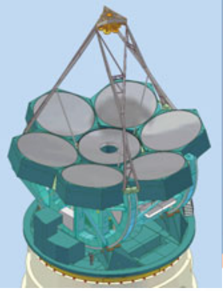
(Not to scale.)

3^{rd} fore-aft mode (10 Hz)



Modeling by S. Gunnels and Simpson, Gumpertz,& Heger for GMT

Challenges: Structural — dynamic response



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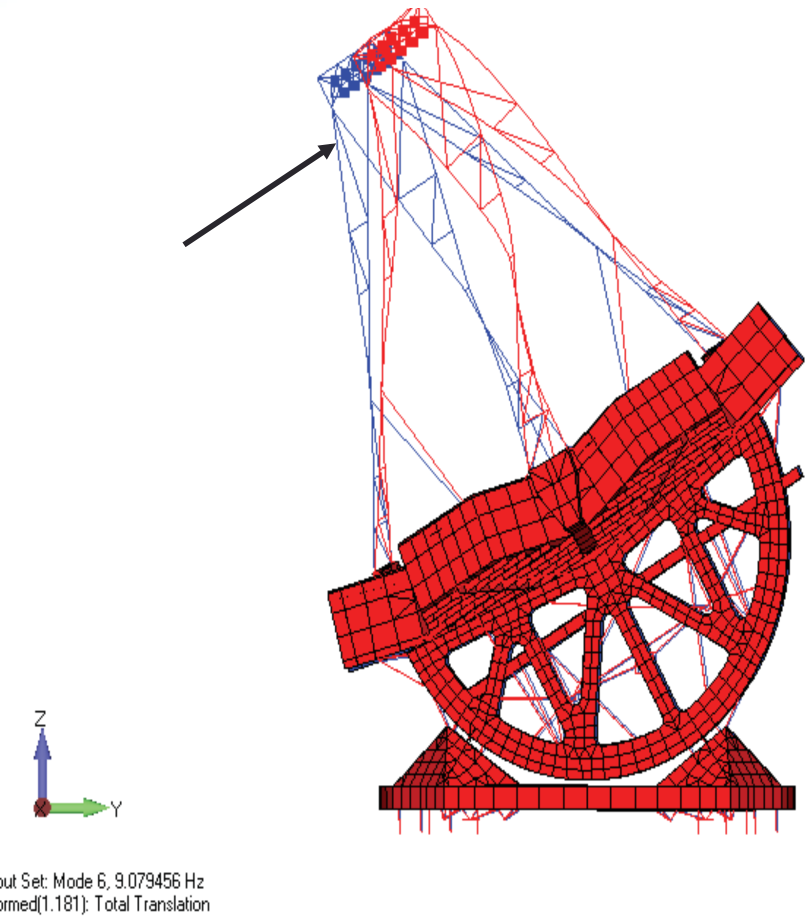
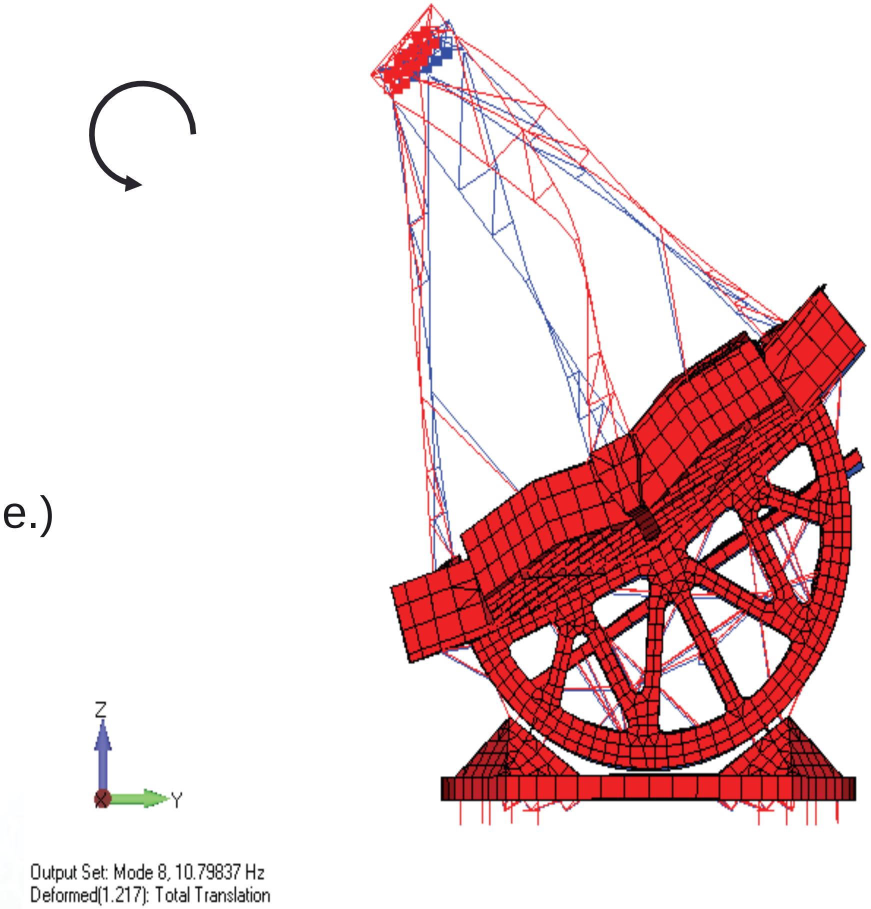


(Not to scale.)

3rd fore-aft mode (10 Hz)



Modeling by S. Gunnels and Simpson, Gumpertz,& Heger for GMT

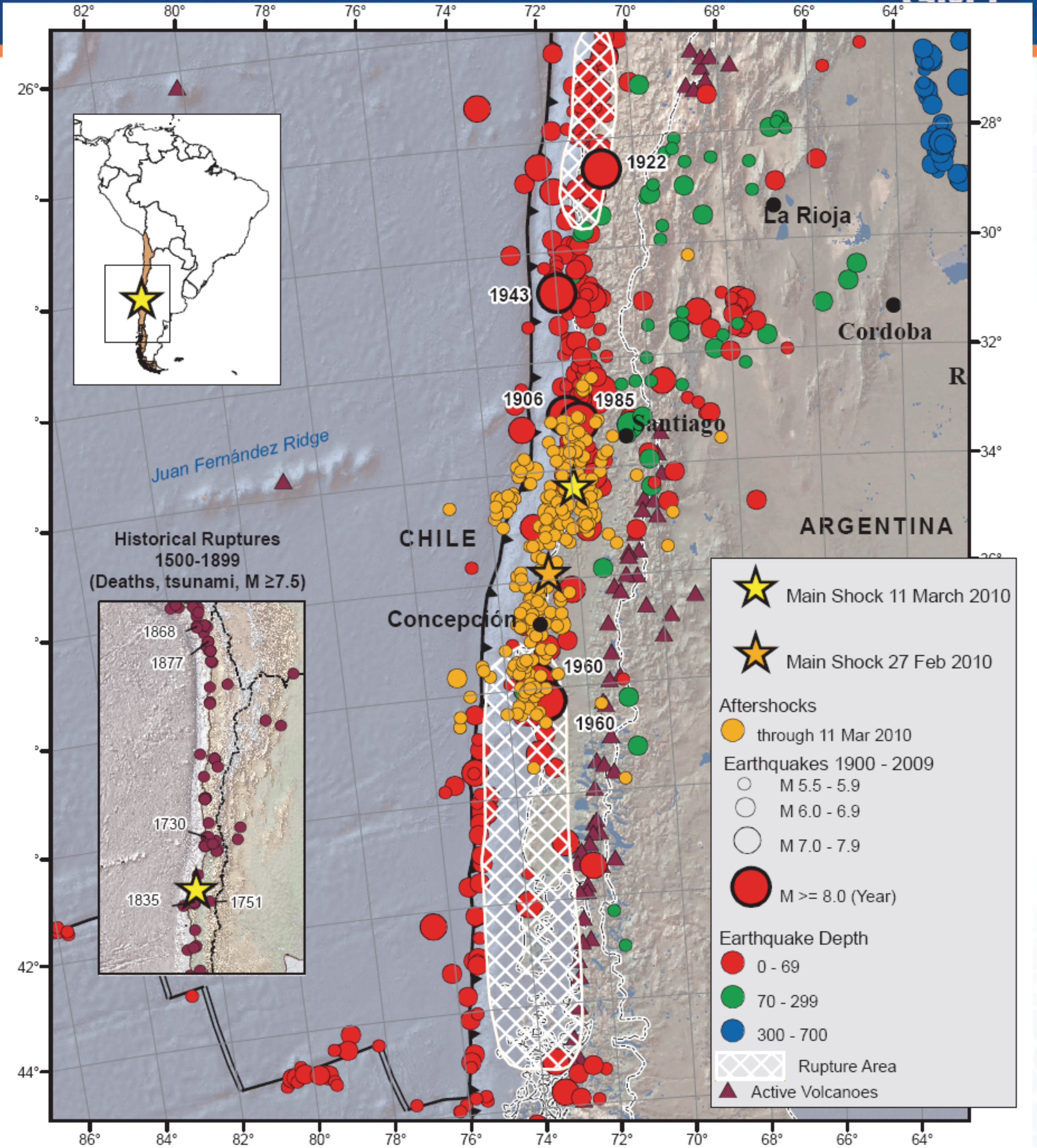
Earthquake Country!

Historical data:

- Magnitude > 8
- Return on ~ 40 year intervals

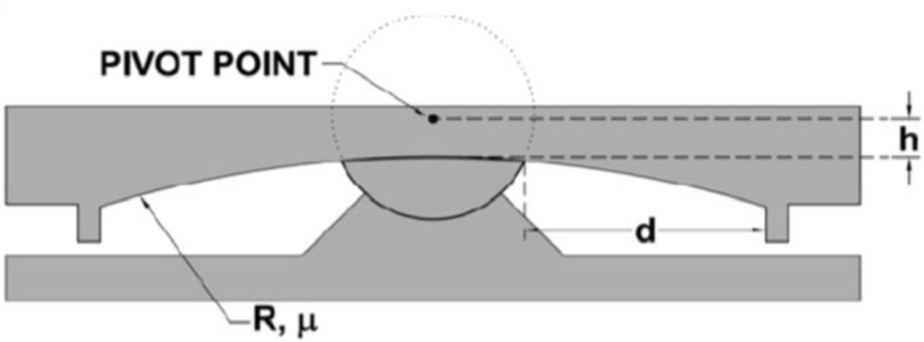
Strategy:

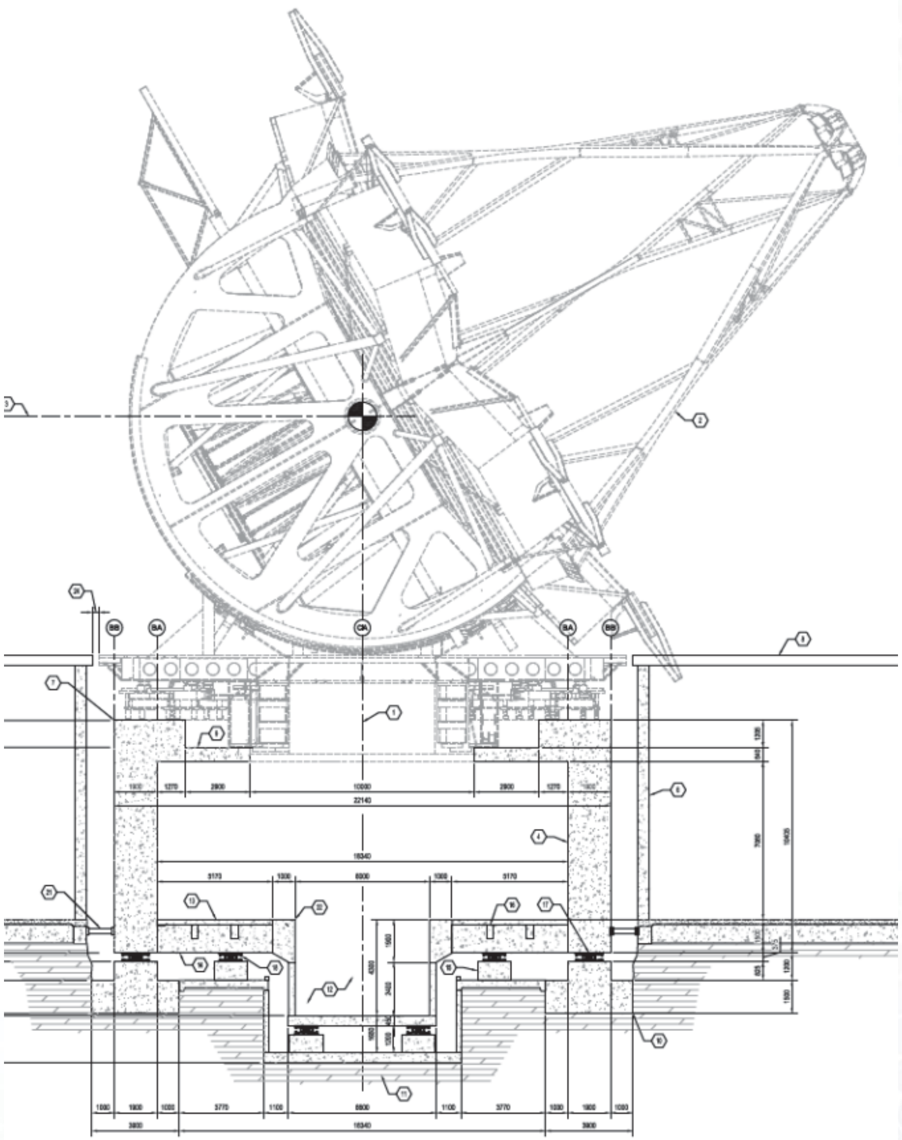
Design for maximum “survival” level event for an earthquake that occurs on ~1,500 year intervals



Seismic Base Isolation: using single friction pendulums

- 24 isolators in concrete ring wall
- Permits ± 0.5 meter relative motion





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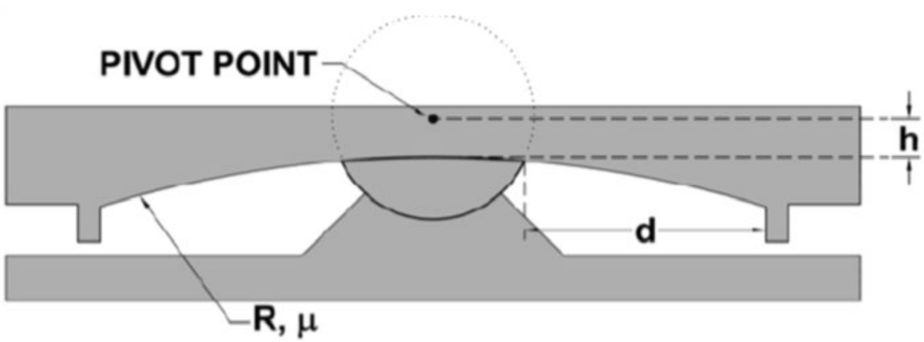
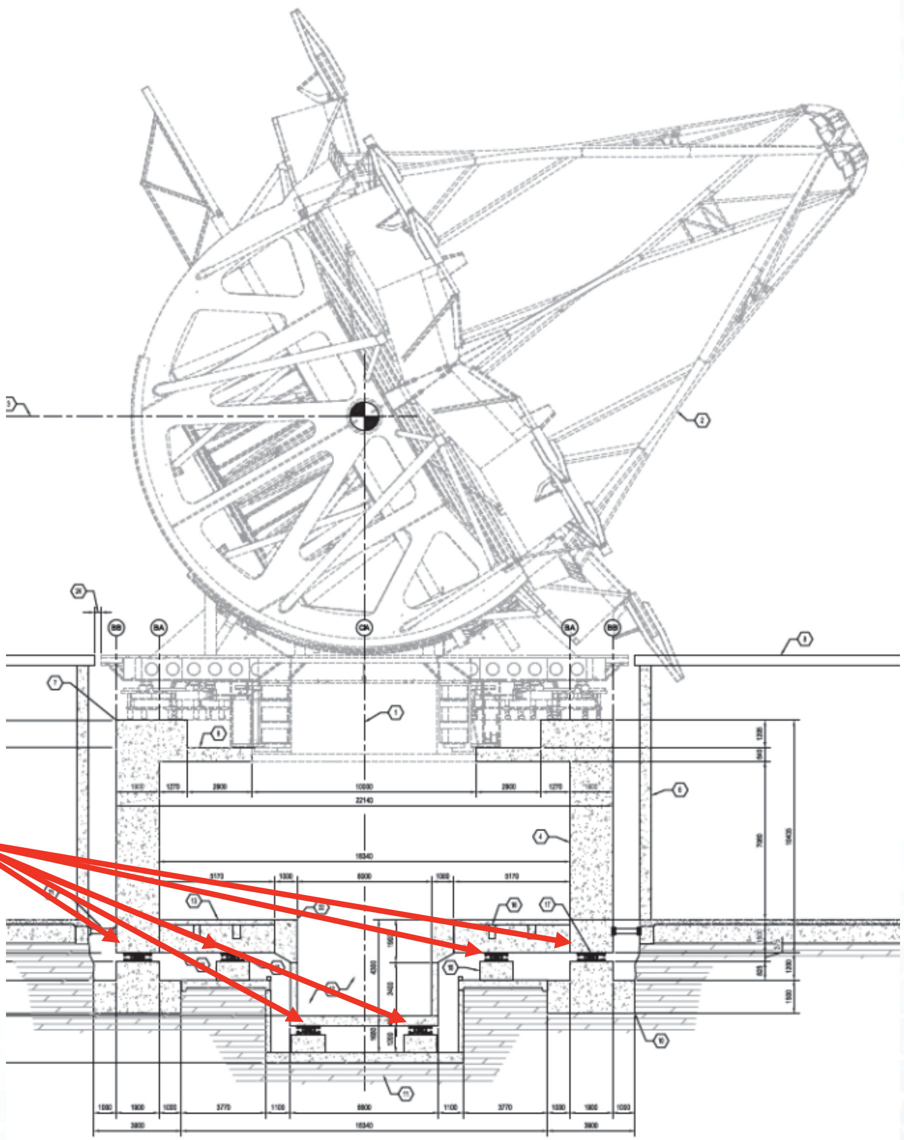
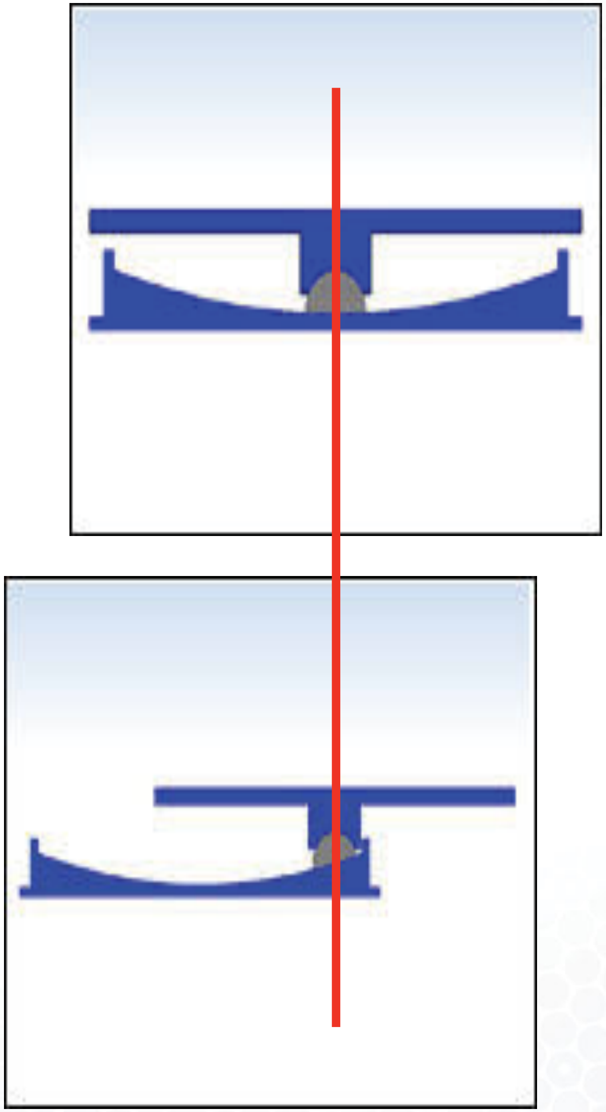




Seismic Base Isolation: using single friction pendulums

- 24 isolators in concrete ring wall
- Permits ± 0.5 meter relative motion
- Standard in construction industry:
  - Pasadena City Hall, Burbank airport parking structure!



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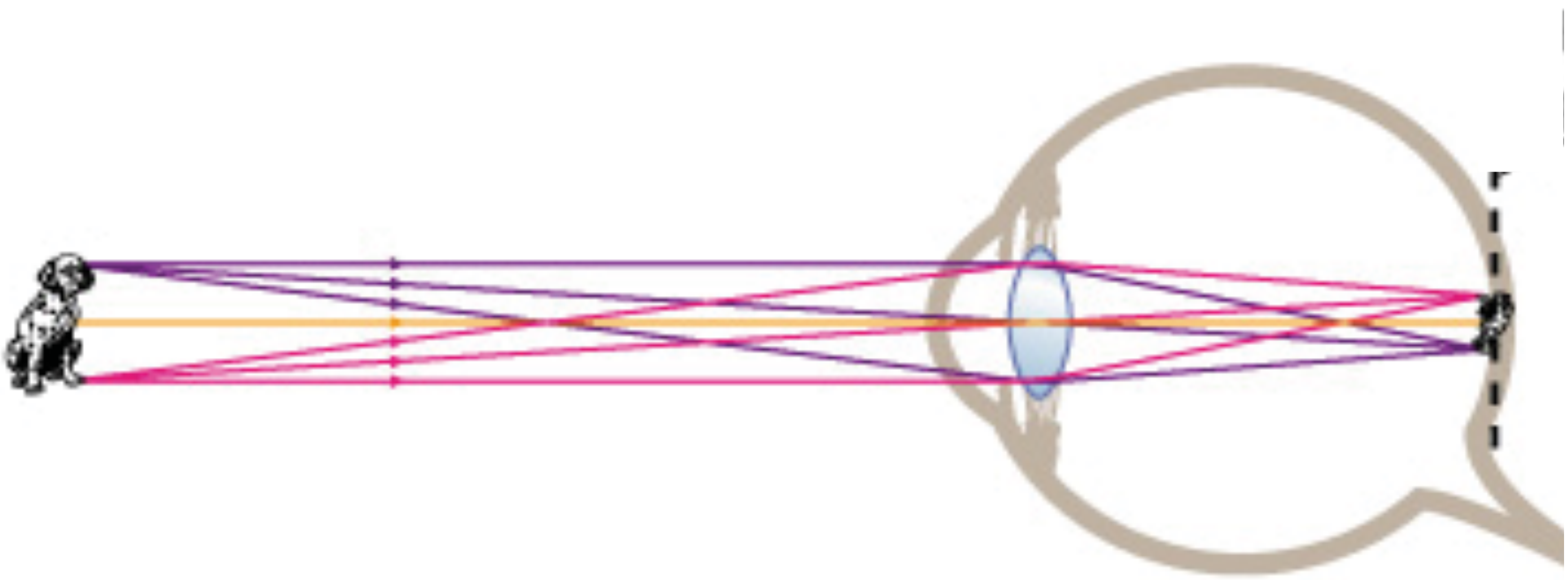
- GSMT Comparison

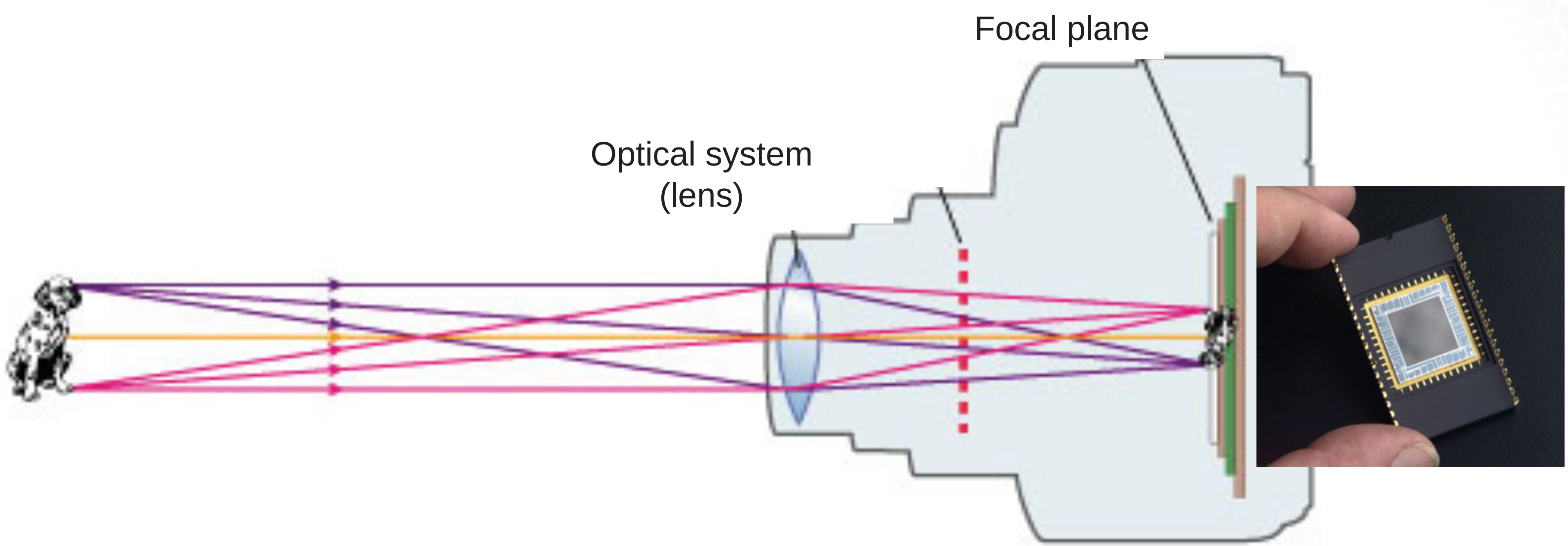
What telescopes do: collect light, form image

What is the instrument's job?



Your eye makes an image of an object at any distance on your retina.

What is the instrument's job?



A camera makes an image of an object at any distance on a CCD.

Instrument's job: re-image to a smaller scale

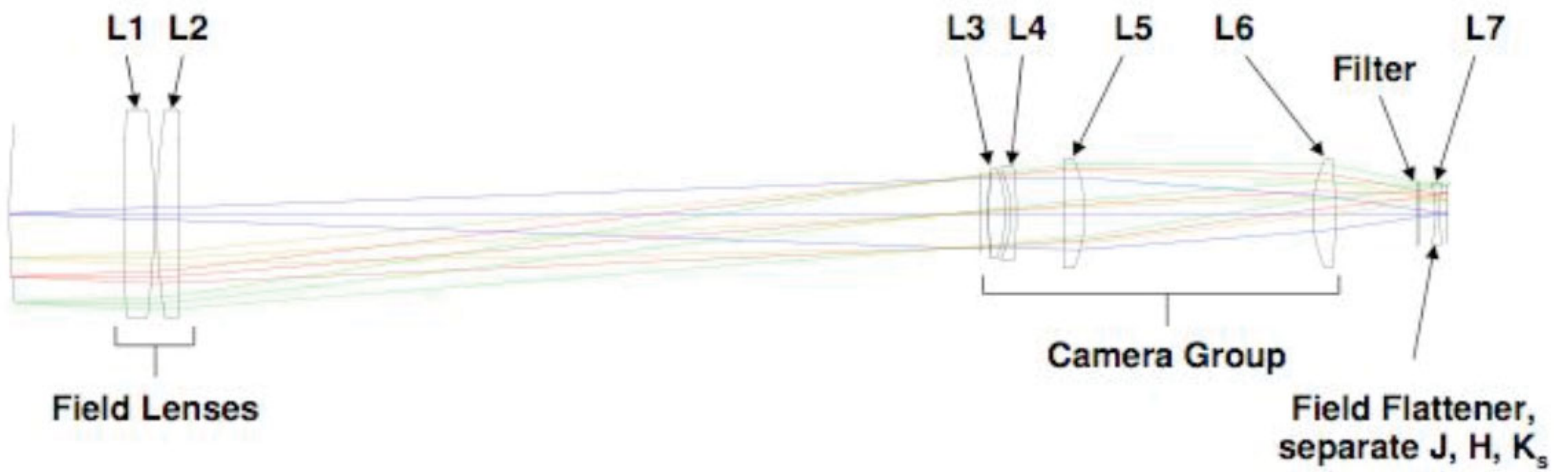
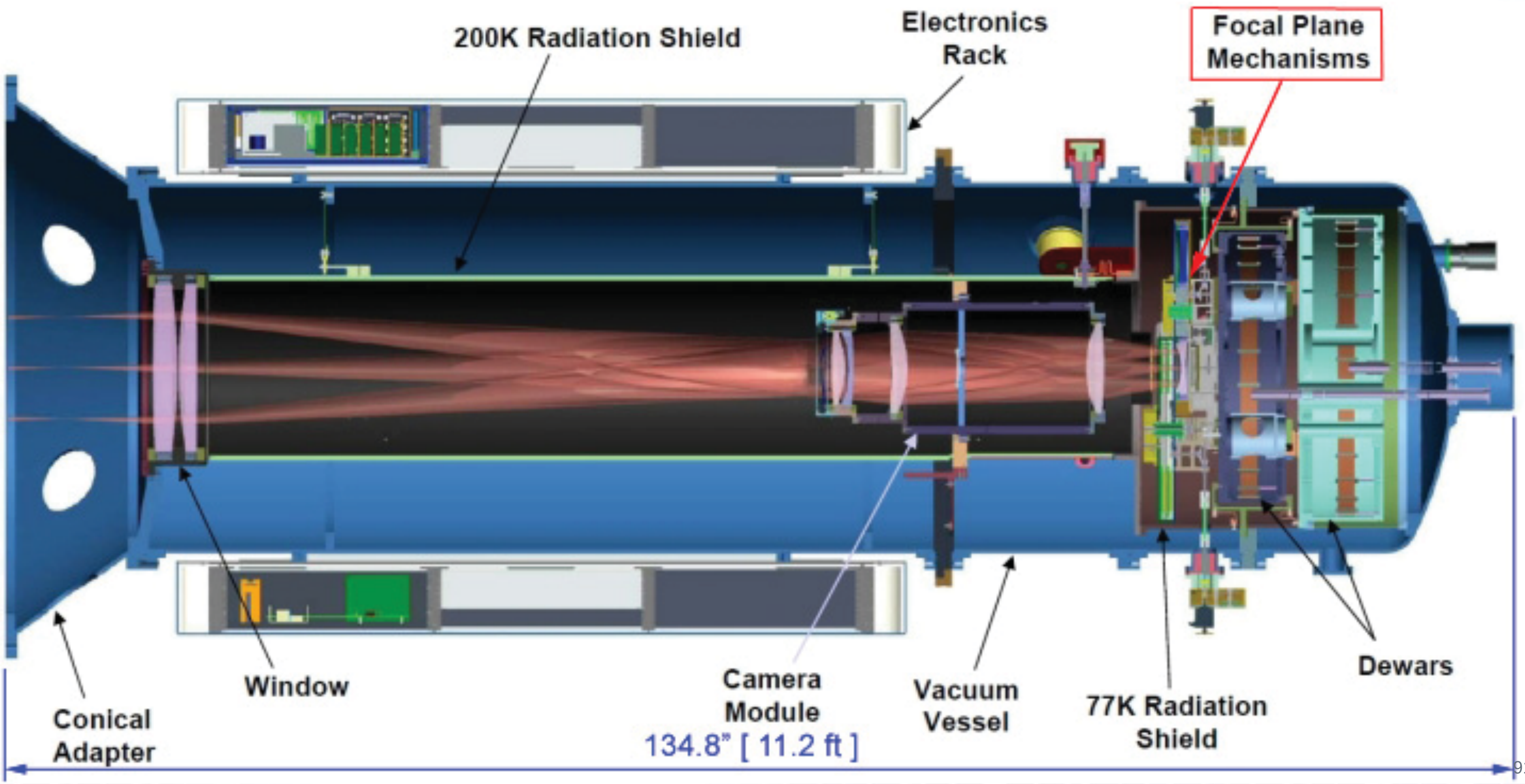


Figure 3. FourStar optical design.

Our cameras make an image of an object at a FIXED distance. (re-imaging)

IR re-imager on Magellan: 4-Star



E

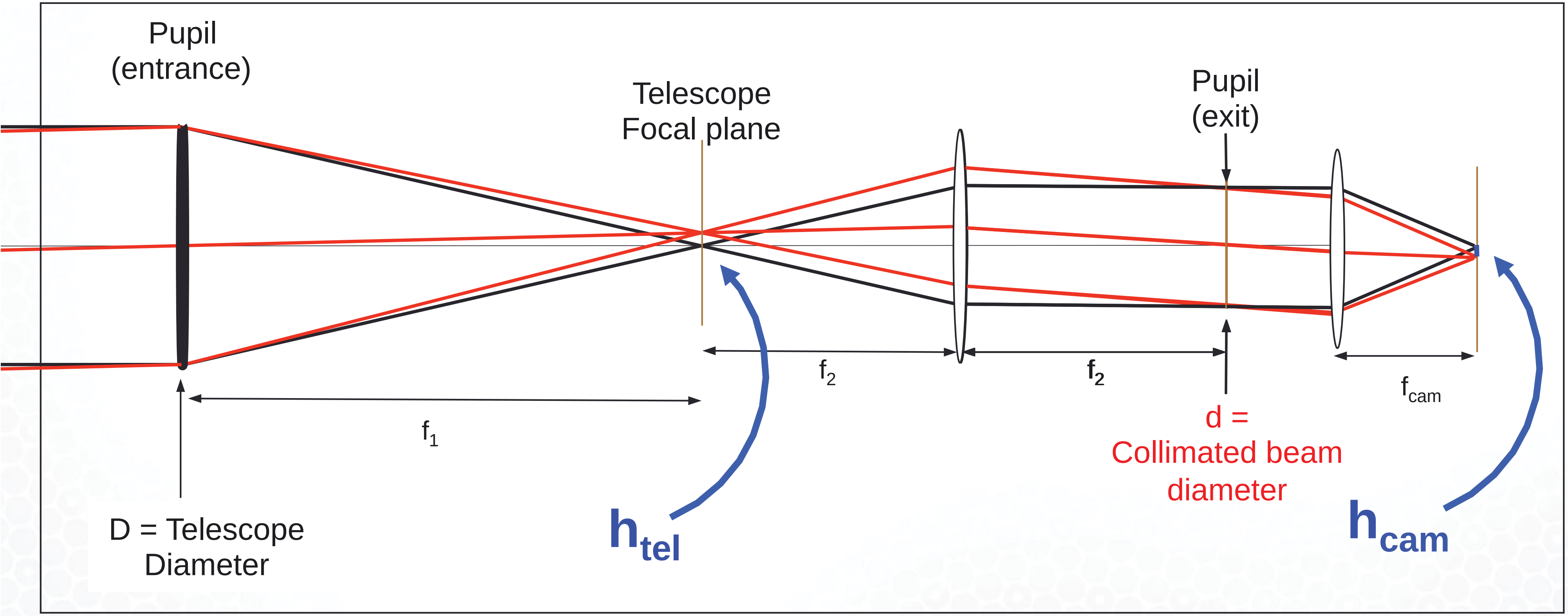
IR re-imager on Magellan: 4-Star

Telescope + instrument (re-imager)

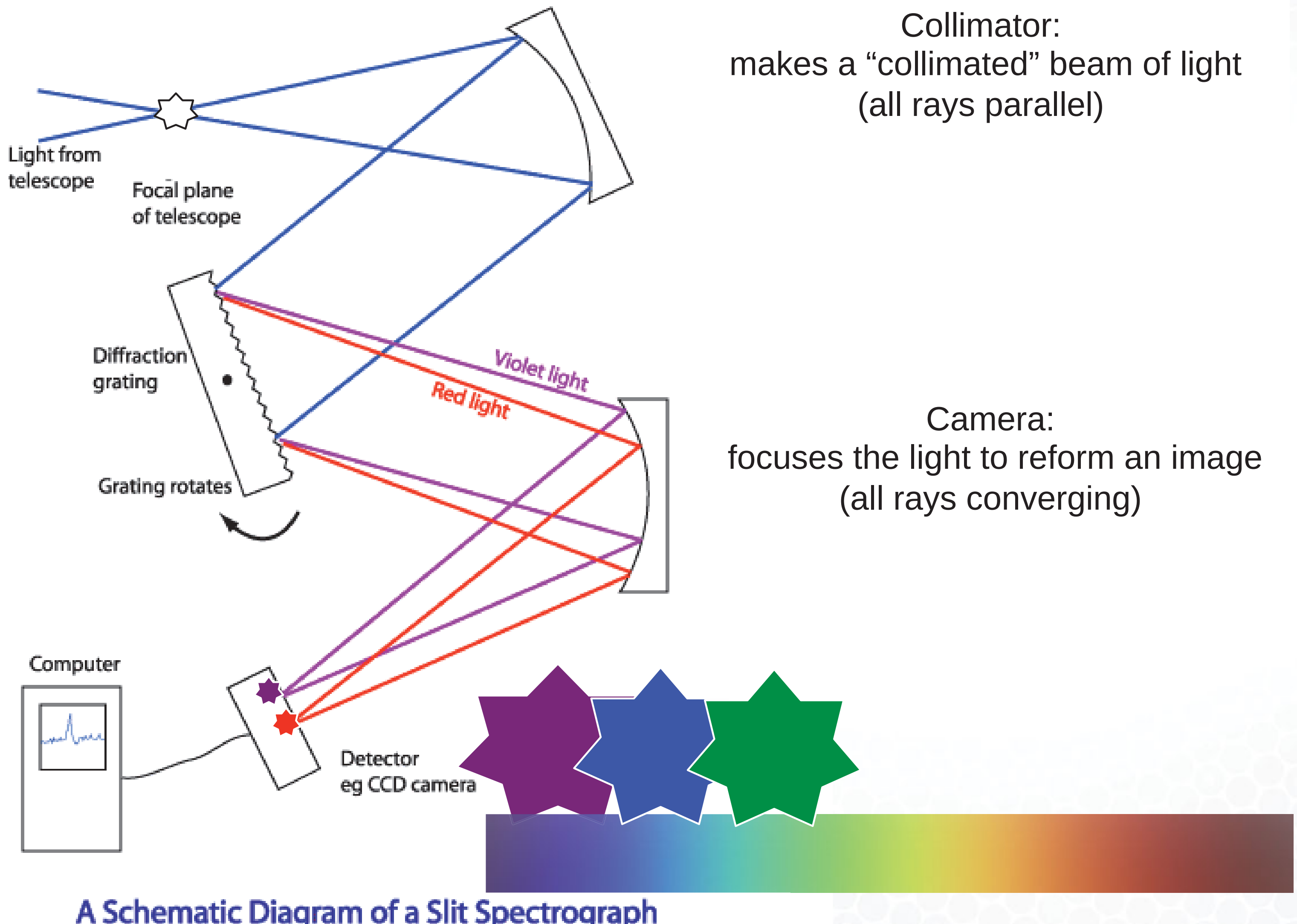
$h_{cam} = f_2 / f_1 \quad h_{tel}$

GMT: $h_{cam} = 1.5 / 8.2 \quad h_{tel}$

$h_{cam} \sim 0.2 \quad h_{tel}$



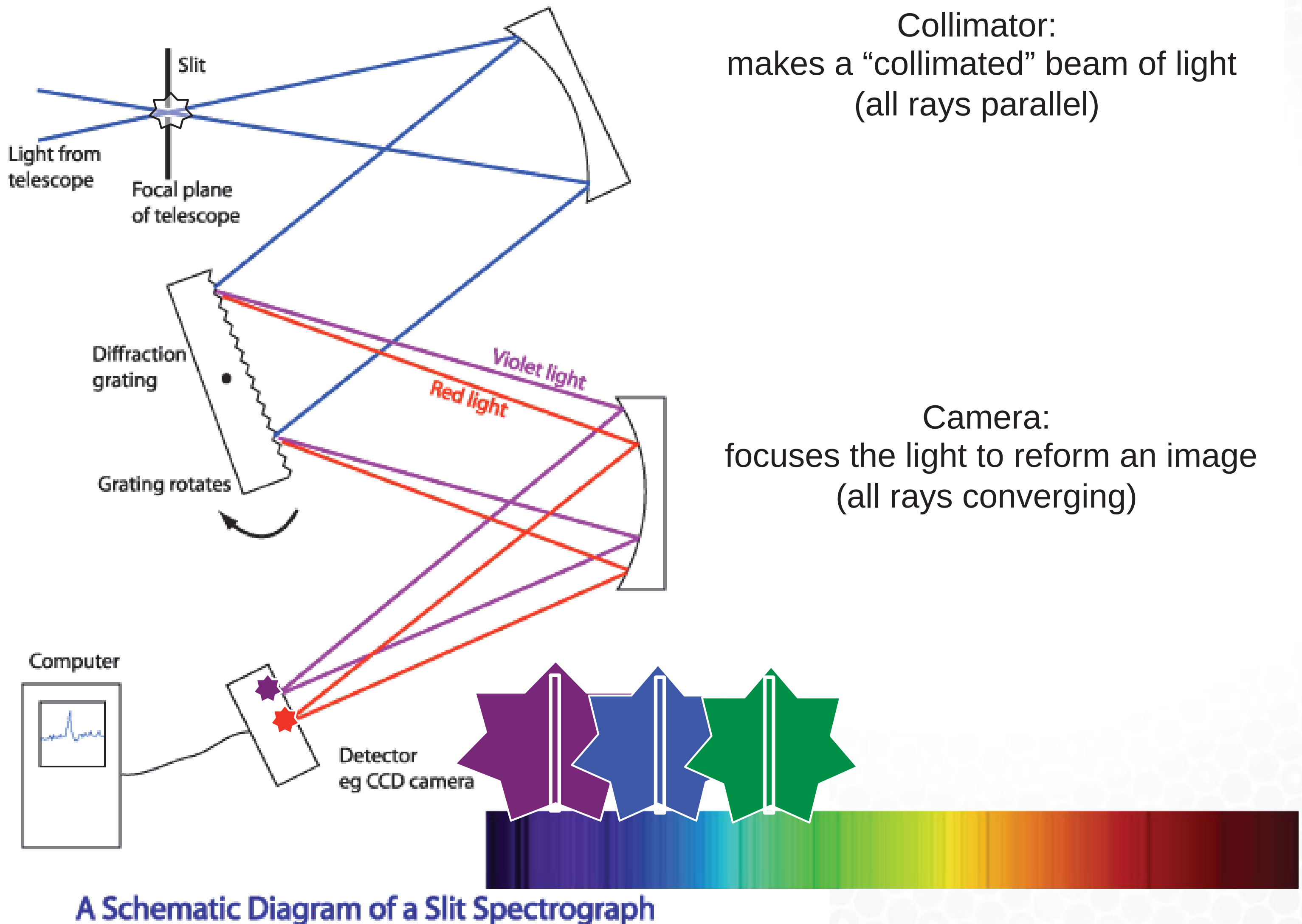
Simple spectrograph: add grating …



Collimator:
makes a "collimated" beam of light
(all rays parallel)

Camera:
focuses the light to reform an image
(all rays converging)

Simple spectrograph: add grating .. And a slit



Collimator:
makes a “collimated” beam of light
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Camera:
focuses the light to reform an image
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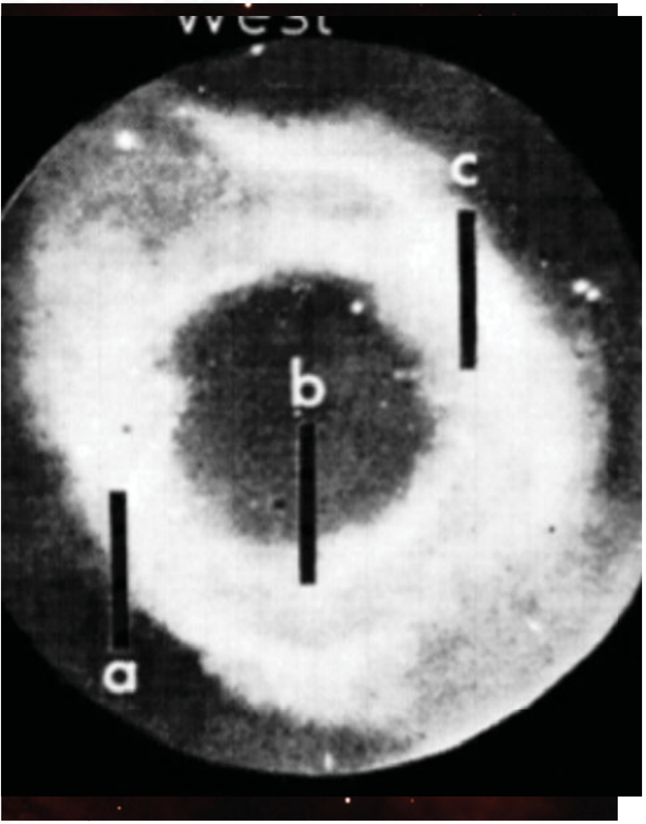
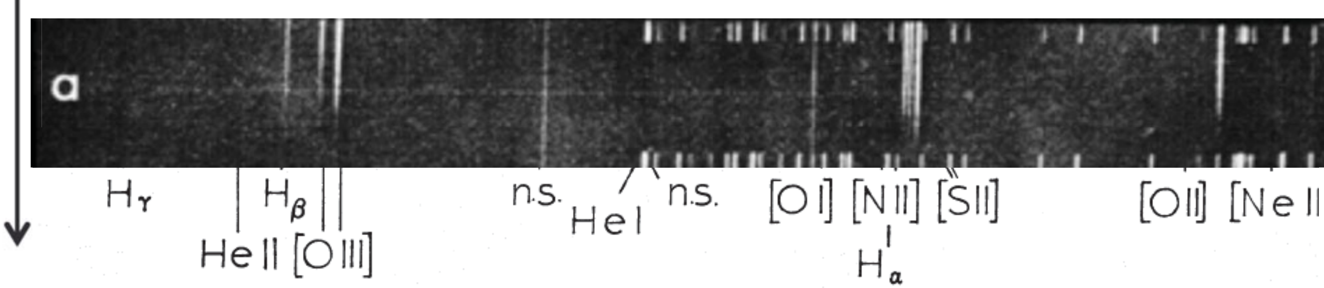
Instruments do science: spectroscopy



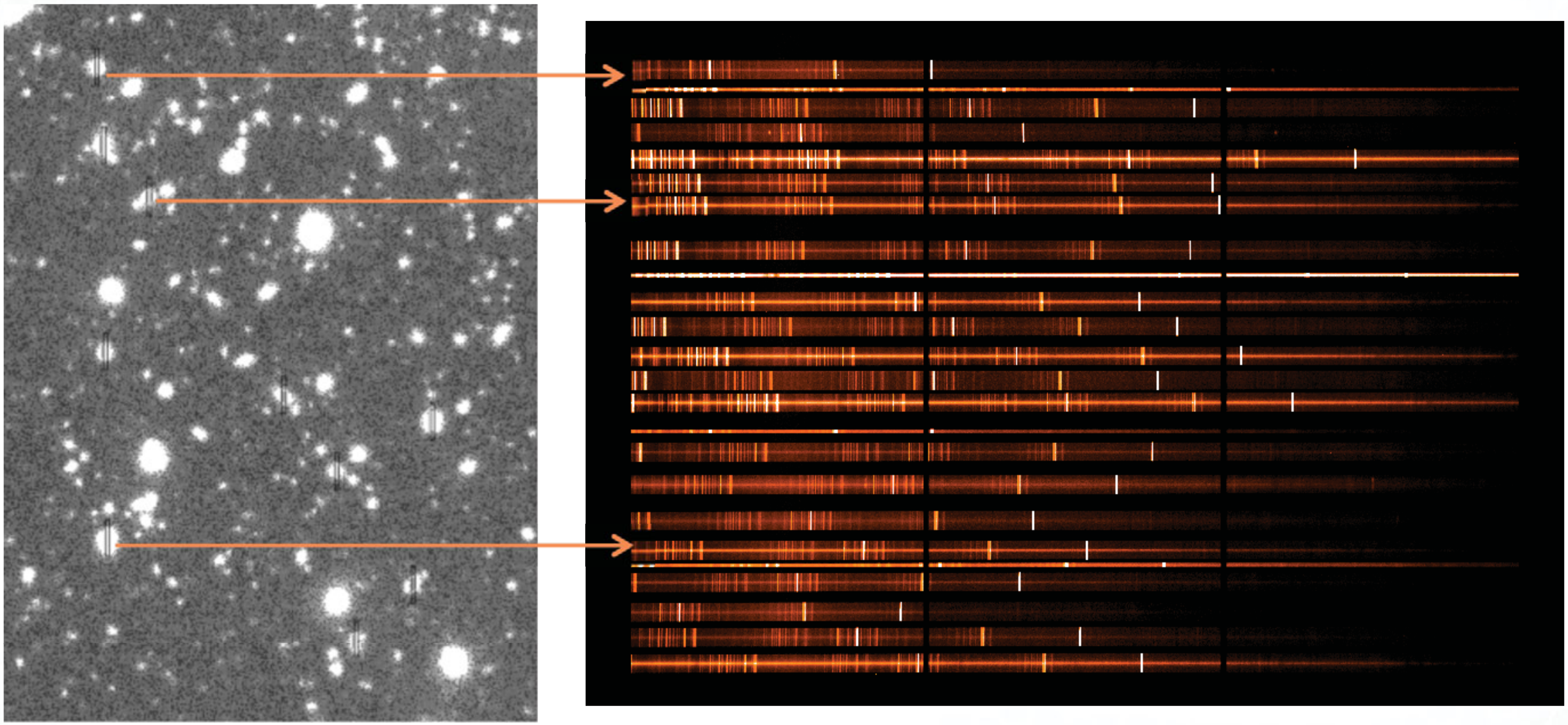
Location
on the sky



Brightness of the sources at different colors (wavelengths)

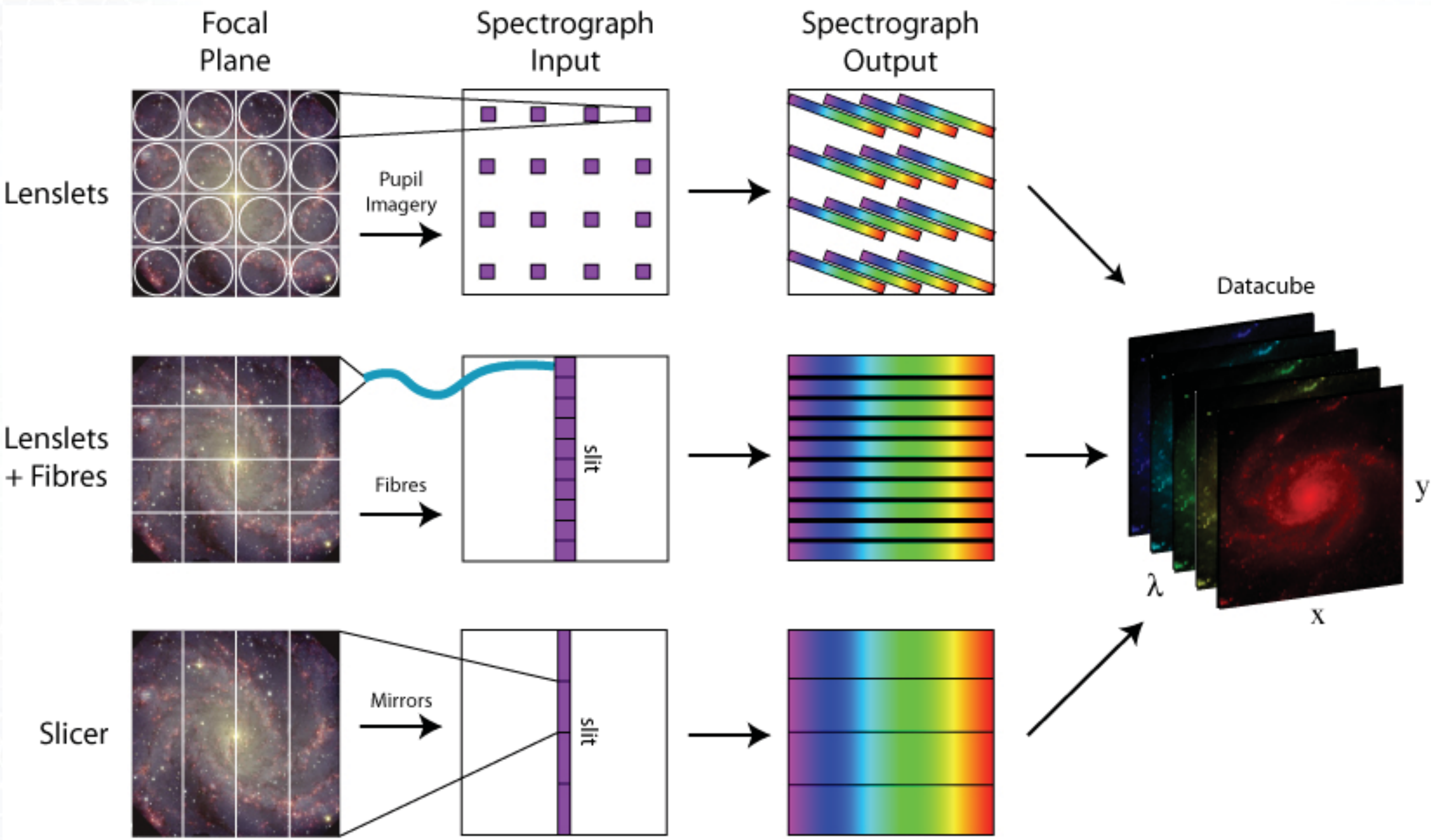
A spectrum is worth a million pictures.

Instruments do science: multi-object spectroscopy

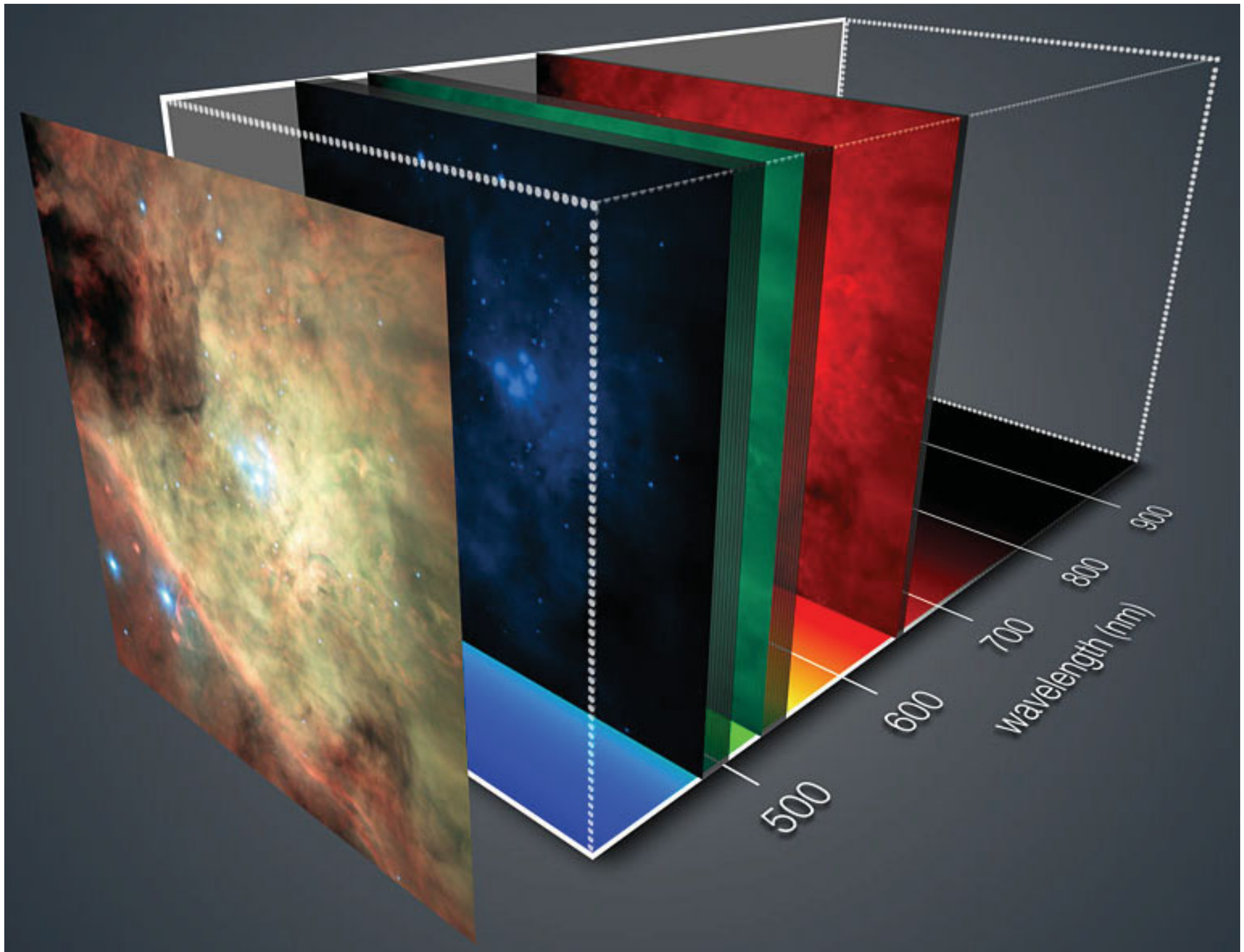


~100x increase in efficiency: study ~100 objects at once.

Instruments do science: integral field unit (IFU) spectroscopy

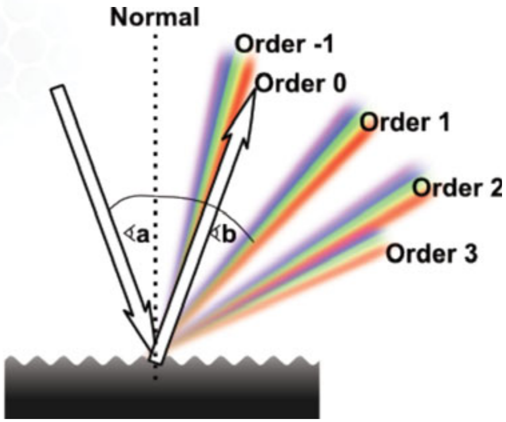


Instruments do science: integral field unit (IFU) spectroscopy

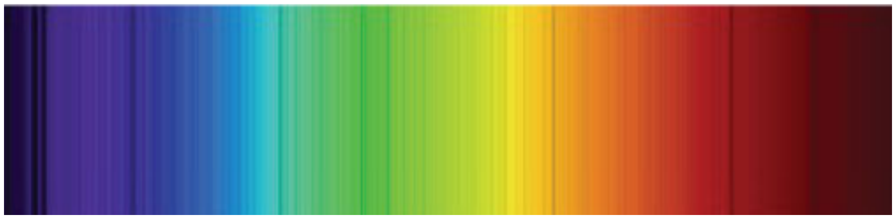


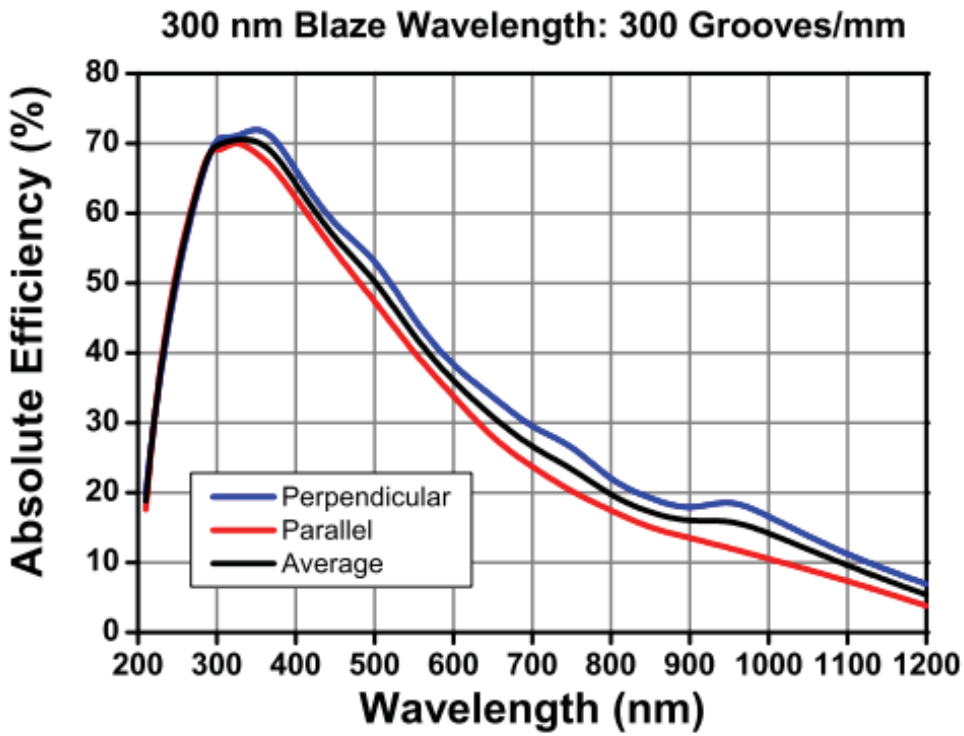
~100x increase in efficiency: study an object in much more detail.

Dispersion elements: Standard Grating



high groove density, low order numbers

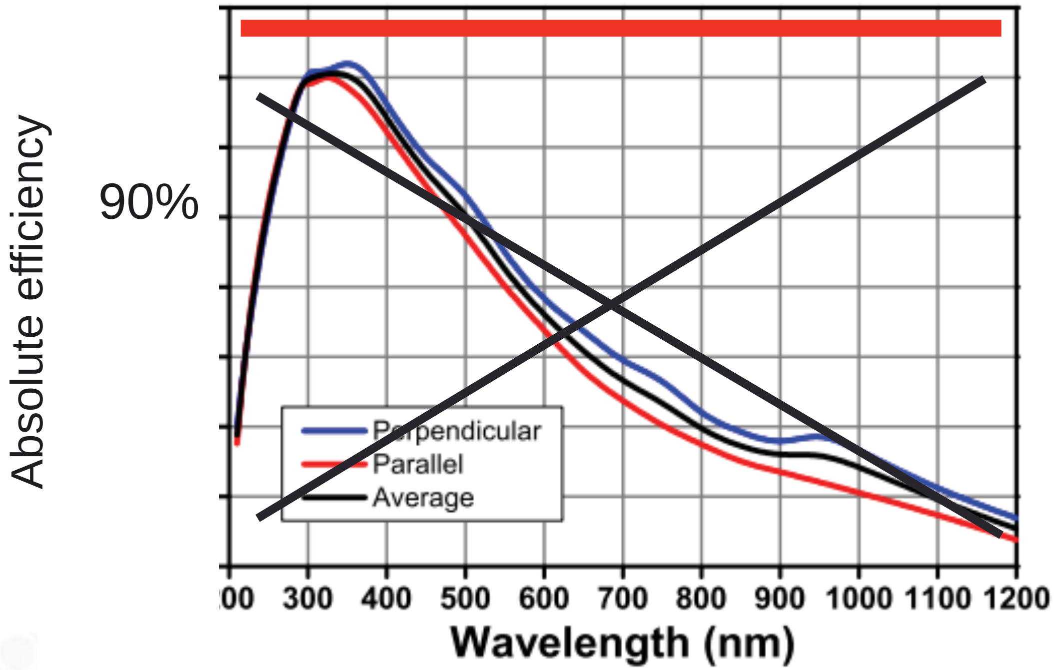




Good: high dispersion

Bad: lower throughput

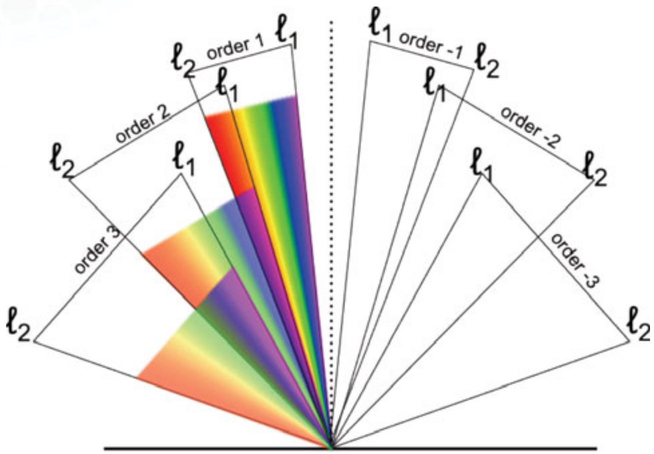
Dispersion elements: Prisms (glass or ZnSe)



Bad: low dispersion

Good: high throughput

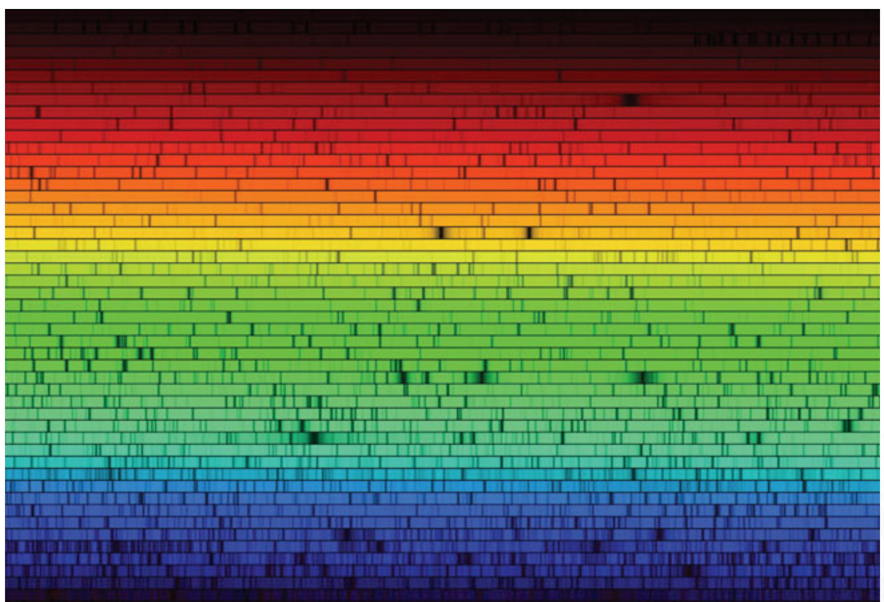
Dispersion elements: Echelle grating



Low groove density, high order numbers

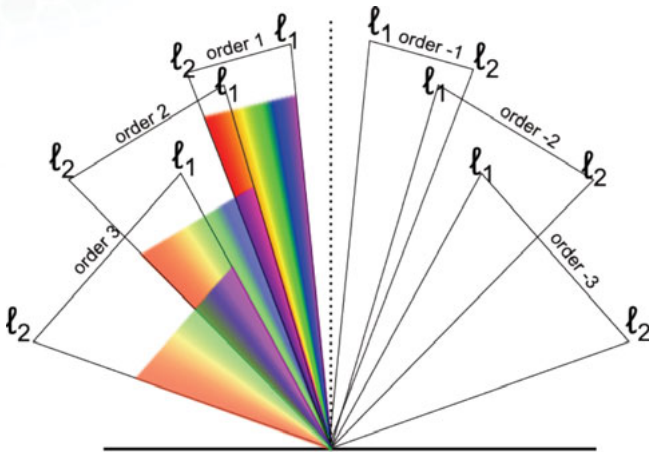
Good: VERY high dispersion

Good: higher throughput



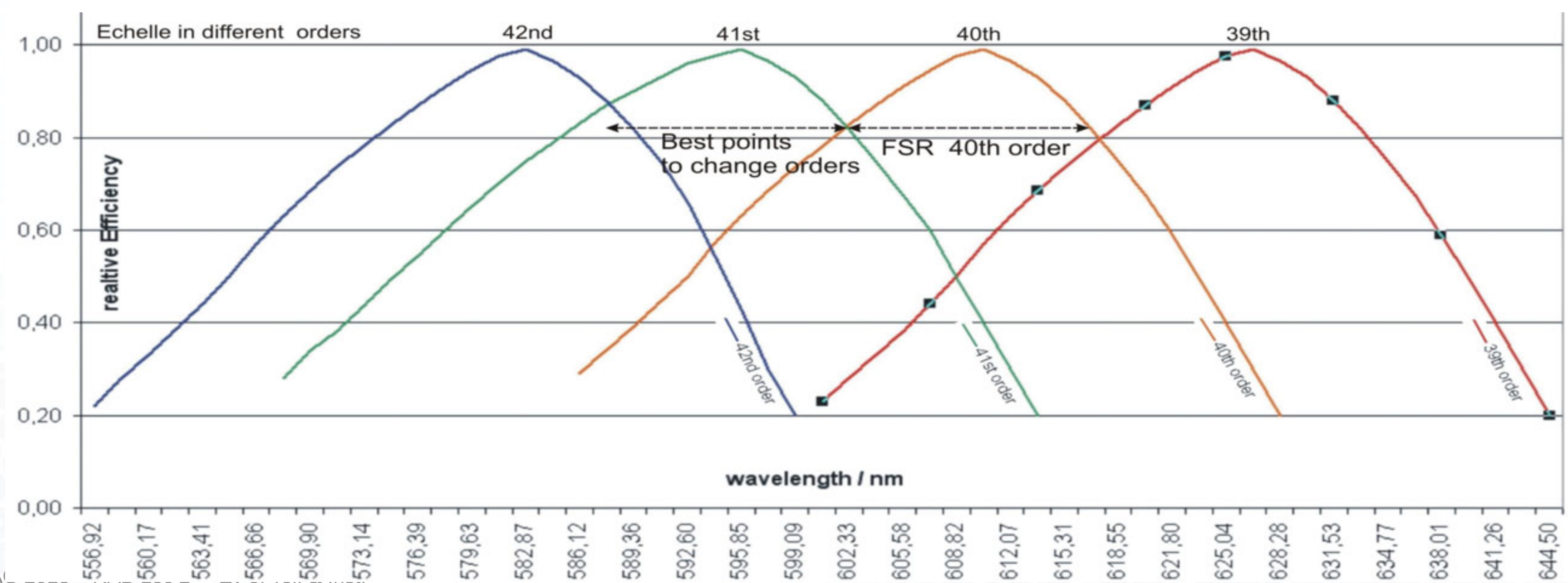
Dispersion elements: Echelle grating

Low groove density, high order numbers



Good: VERY high dispersion

Good: higher throughput



Topics:

- What do telescopes do and how?
  - Mirrors & Structures
  - Telescope optics 101
  - Strategies of the 3 GSMTs
    - Optical Configurations
    - Segments
    - Structures
- What do instruments do and how?
  - Instruments optics 101
  - Basic scaling relations for spectrographs.
  - Limitations for large spectrographs
  - Strategies for GSMTs
- GSMT Comparison

Spectrograph scaling relations:

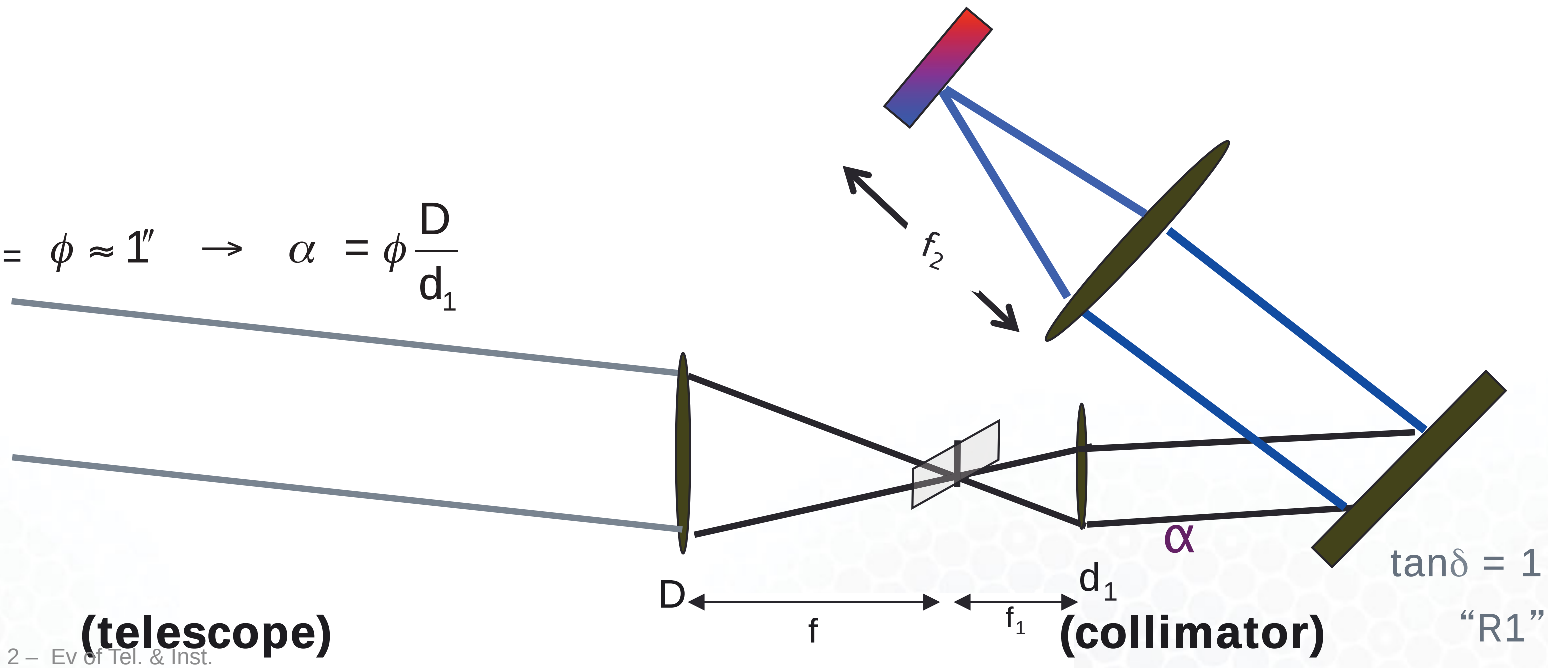
Resolving power: $\Delta\lambda/\lambda$ resolving power from the grating

(groves, blaze, beam width)

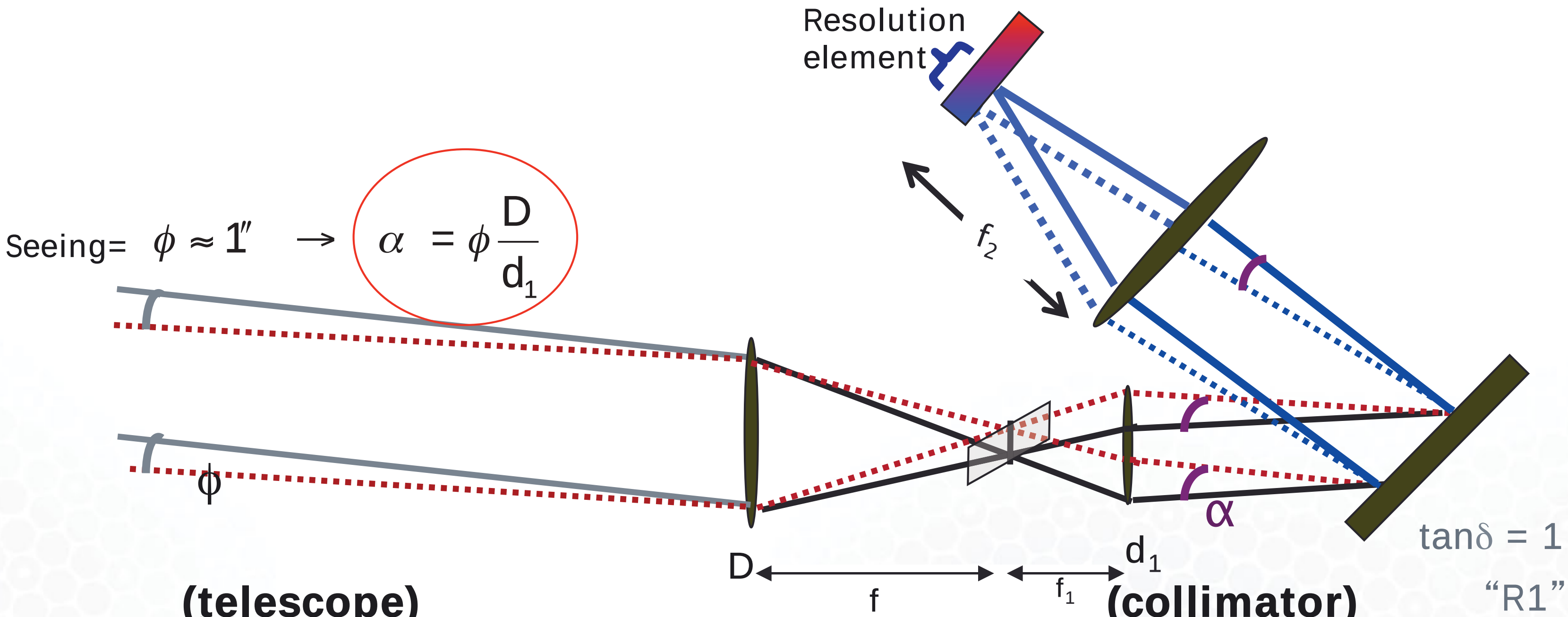
Showing here: proportionality to emphasize the performance

of the grating on your telescope

Seeing= $\phi \approx 1''$ $\rightarrow$ $\alpha = \phi \dfrac{D}{d_1}$



Spectrograph scaling relations:



Spectrograph scaling relations:

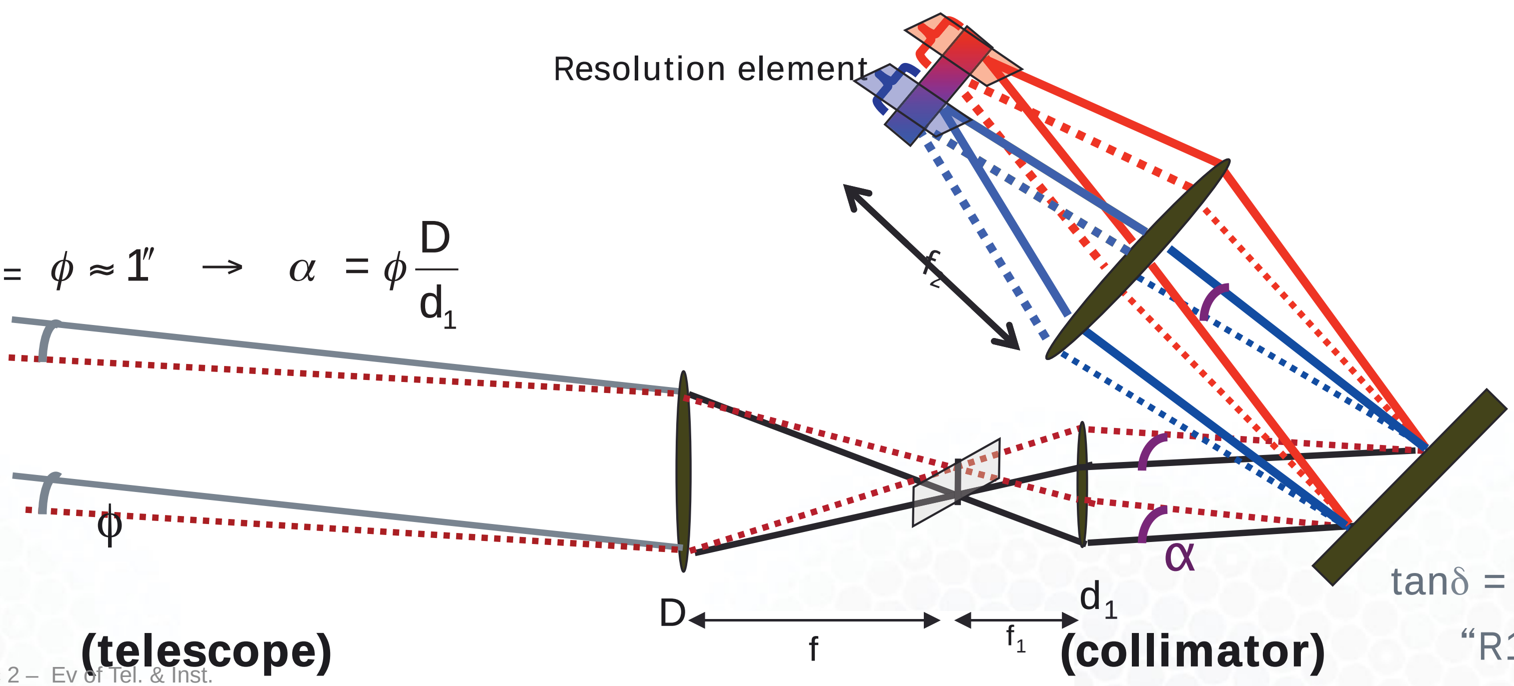
$$R = \frac{\lambda}{\delta\lambda} = 2\frac{\tan\delta}{\phi}\frac{d}{D}$$

d/D = diameter of beam : telescope

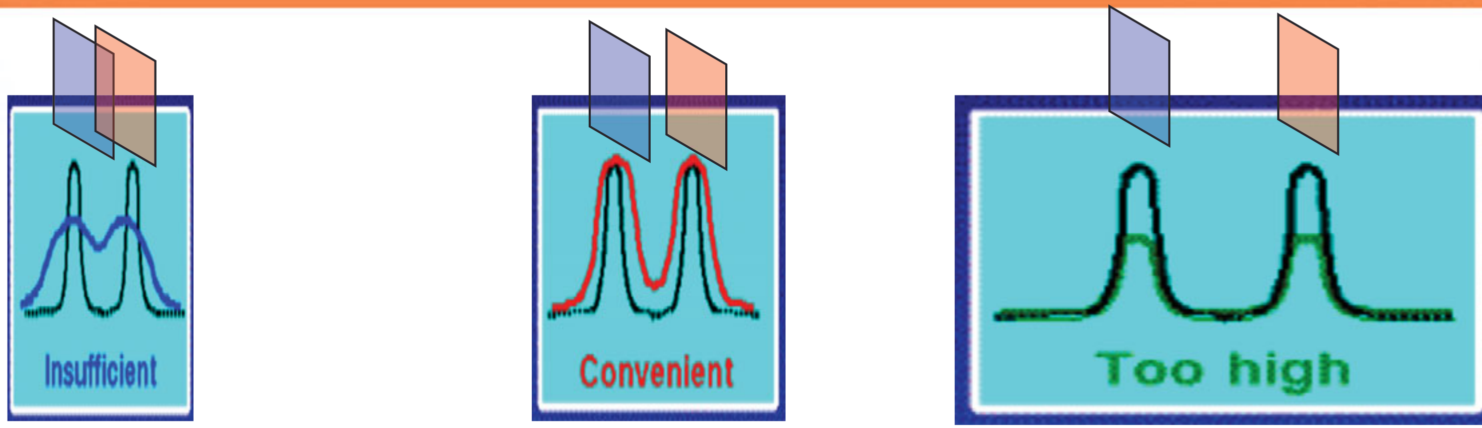
δ = blaze angle (& grating length)

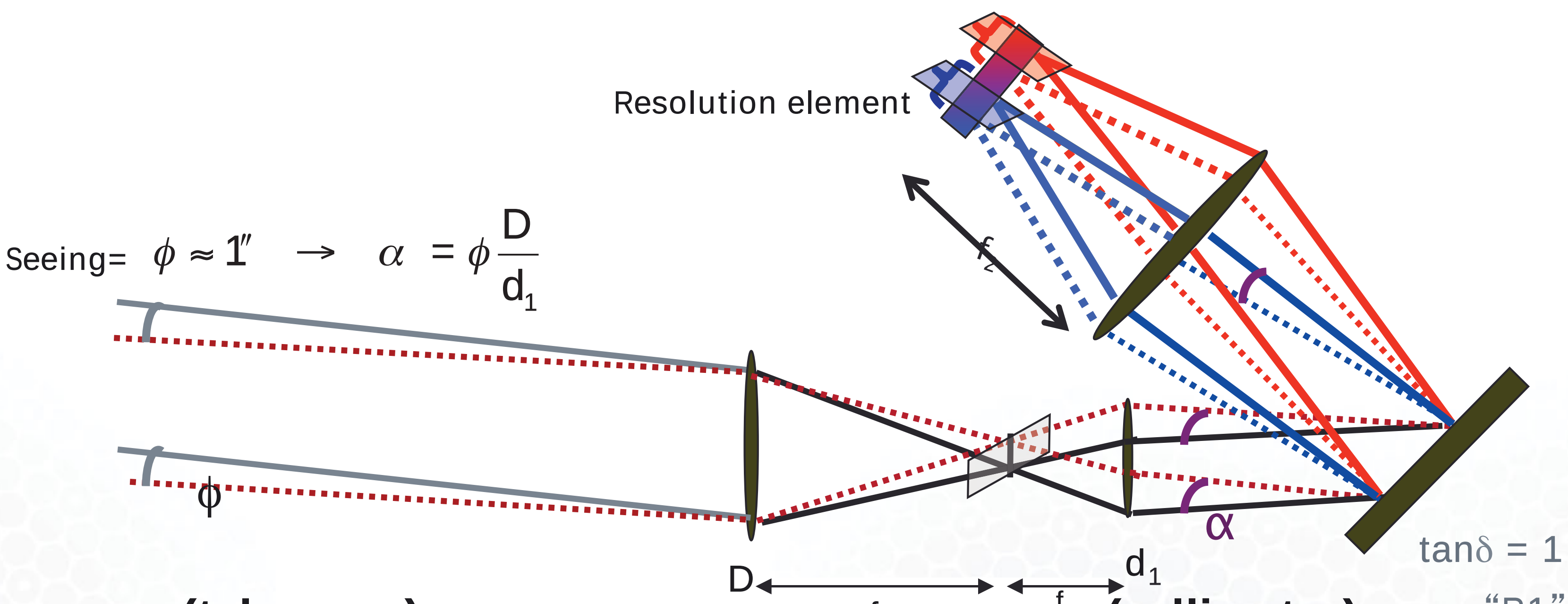
ϕ = slit width ~ seeing psf ~ 1 arcsecond

Seeing= $\phi \approx 1'' \rightarrow \alpha = \phi \frac{D}{d_1}$



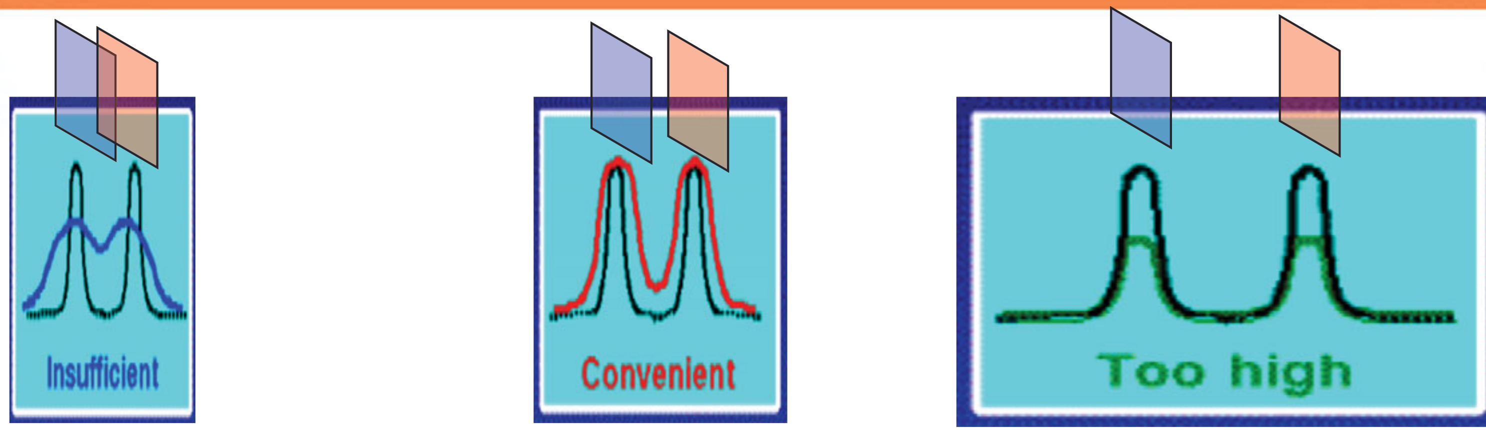
Spectrograph scaling relations:



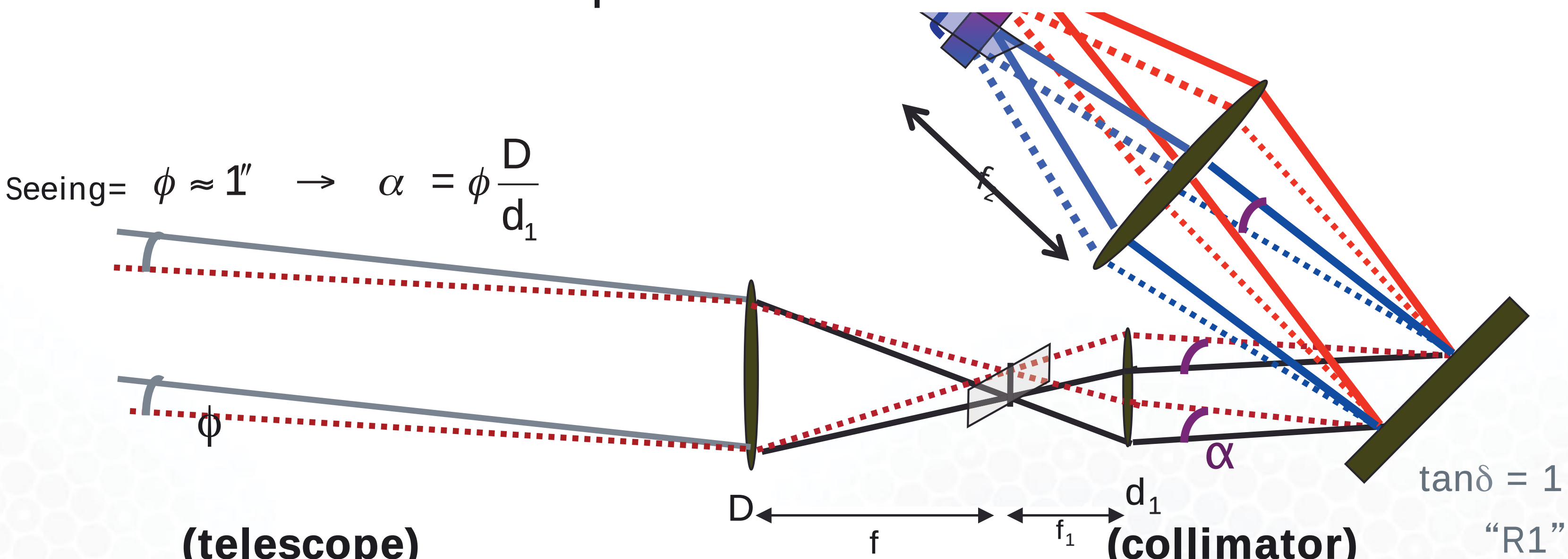


WFOS / MOBIE for TMT — Feedin

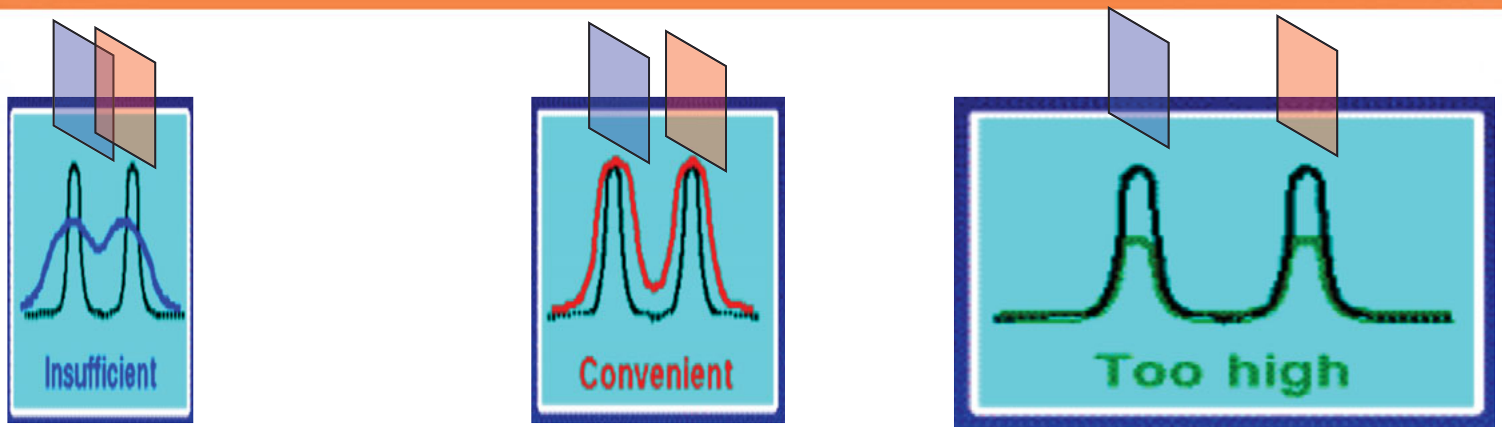
Spectrograph scaling relations:



Is there enough dispersion to separate the [slit images] at the desired spectral resolution?



Spectrograph scaling relations:

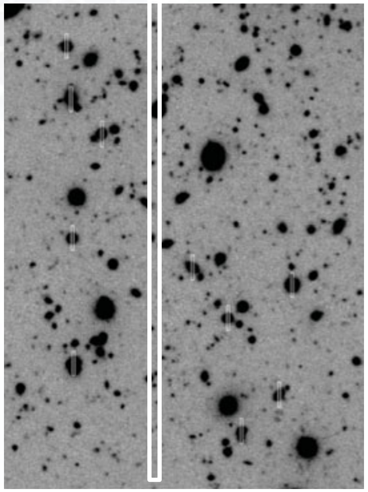


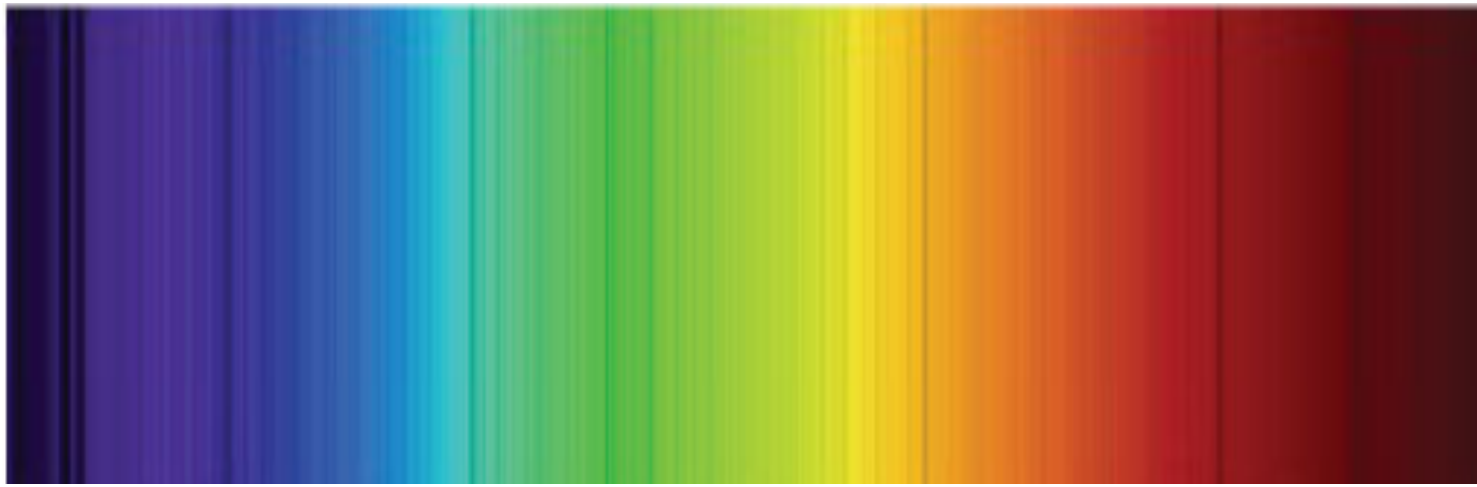
Is there enough dispersion to separate the [slit images] at the desired spectral resolution?

On 8m telescopes: images got better, slits got narrower!

On 30m telescopes: images in optical will not get smaller

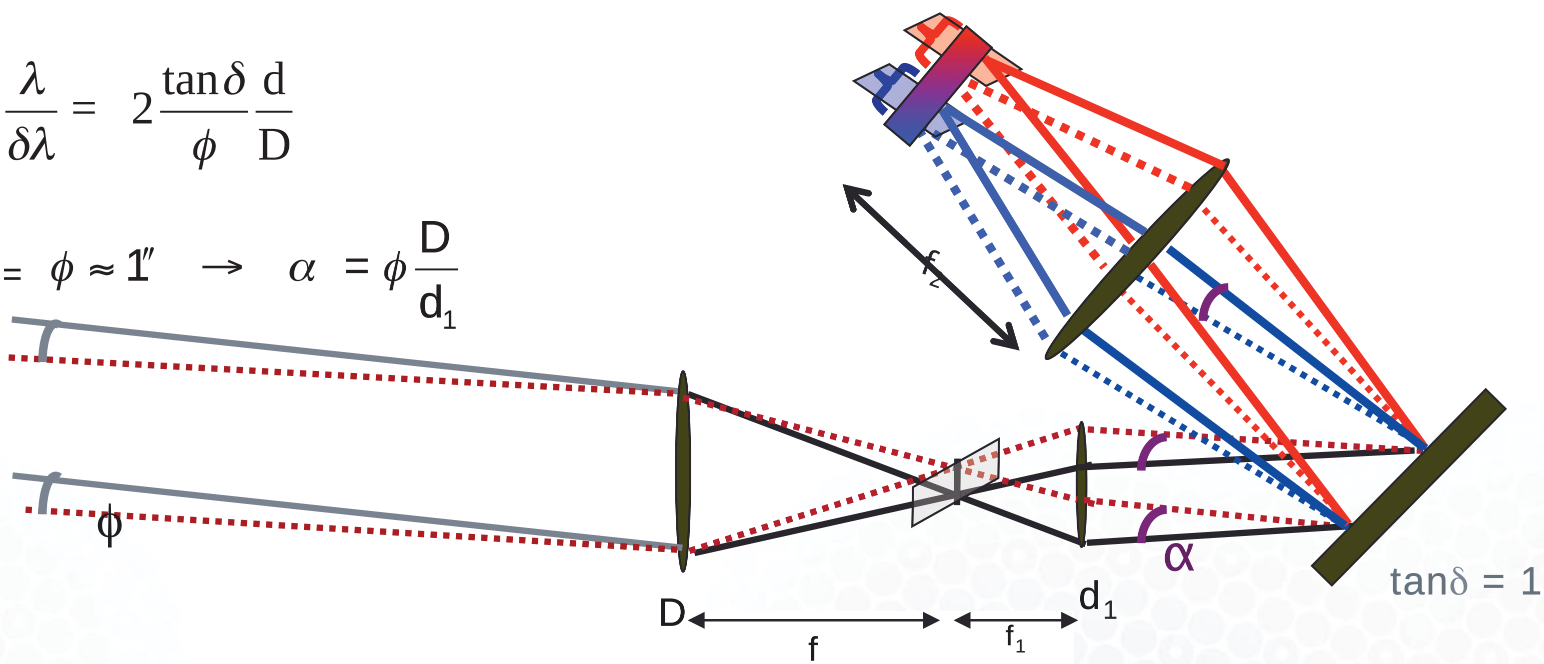
Wide field spectra!



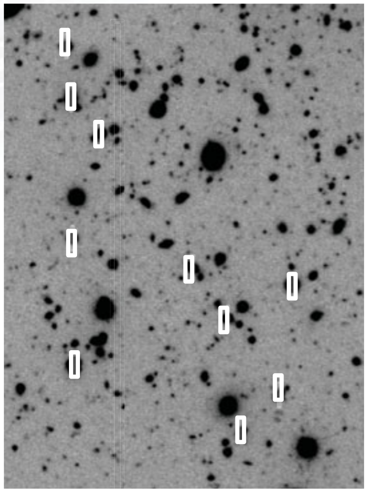


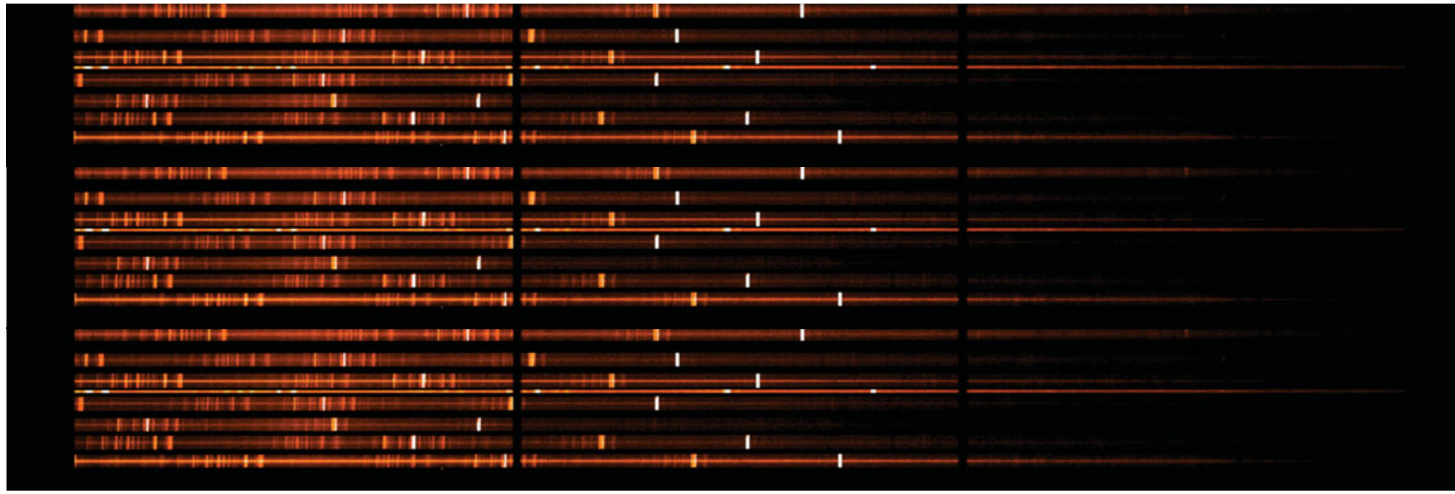
$$R = \frac{\lambda}{\delta\lambda} = 2\frac{\tan\delta}{\phi}\frac{d}{D}$$

Seeing= $\phi \approx 1'' \rightarrow \alpha = \phi\frac{D}{d_1}$



IMACS on Magellan





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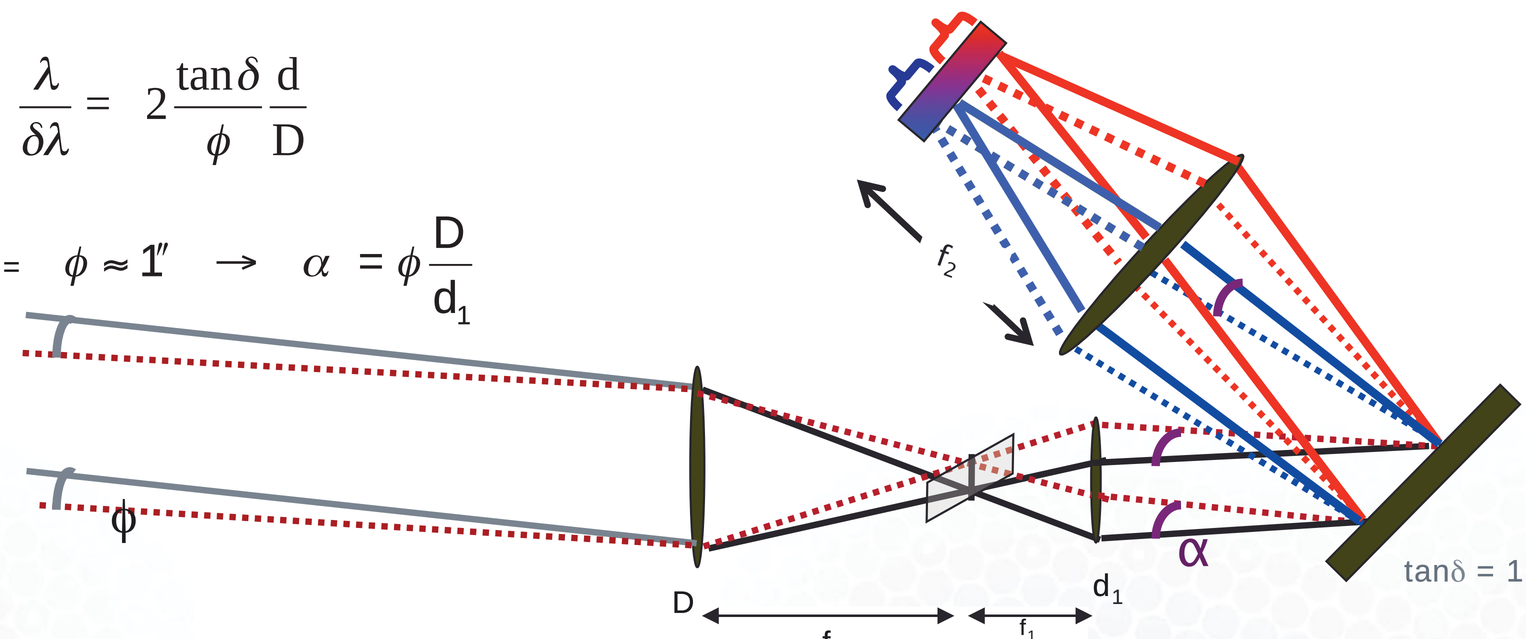
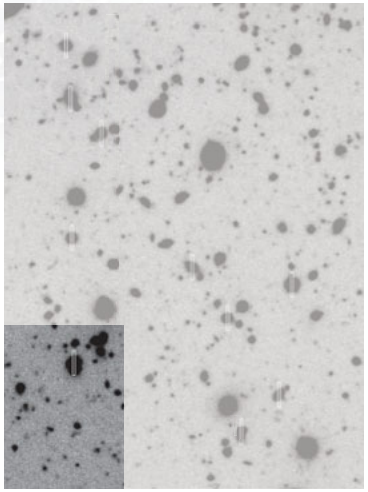
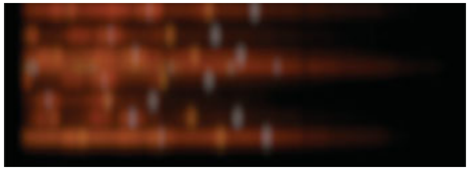


on GMT…



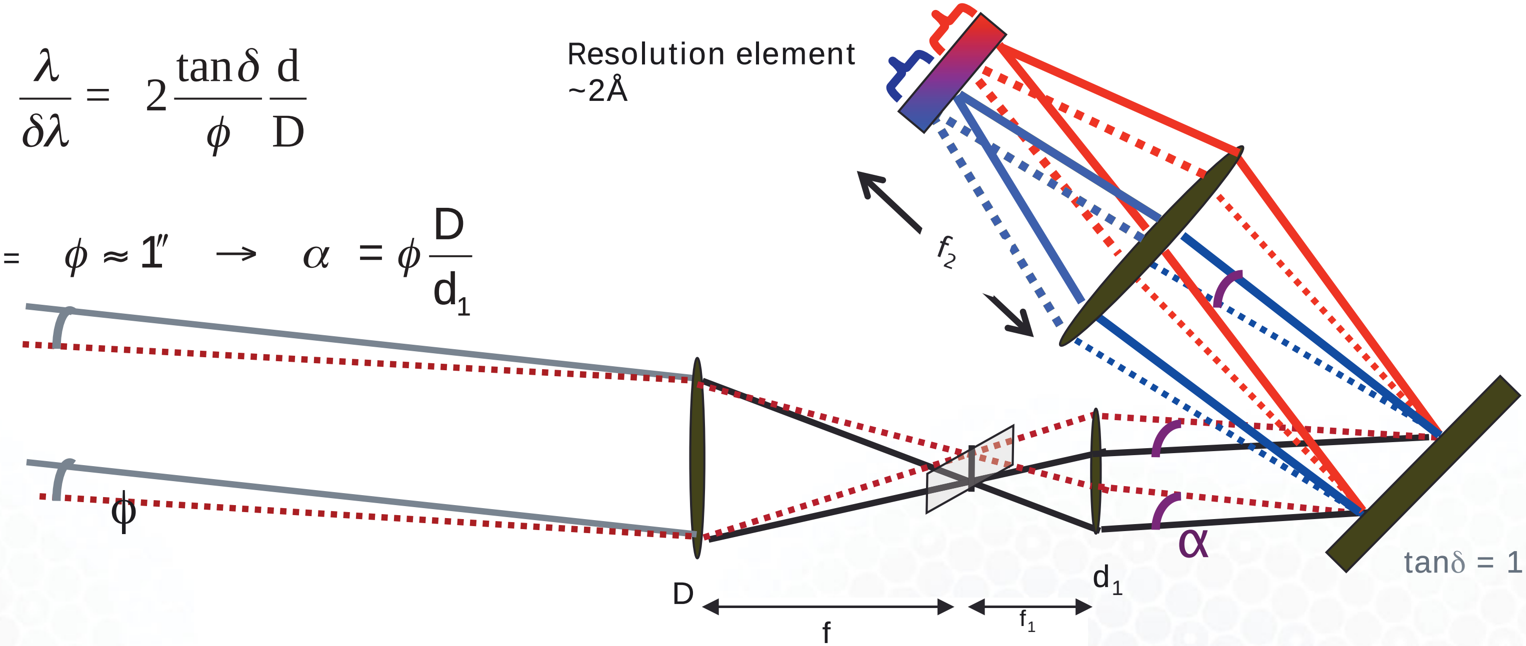


IMACS:

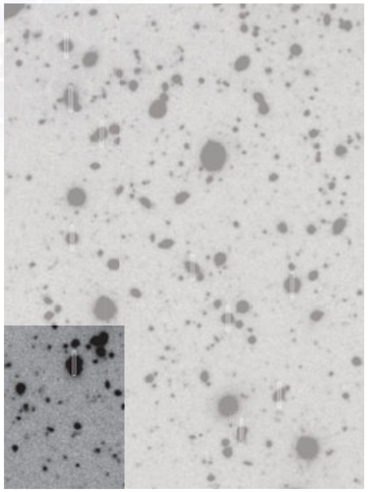
1/3 the field of view
1/3 the resolution over the same wavelength range.

$$R = \frac{\lambda}{\delta\lambda} = 2\frac{\tan\delta}{\phi}\frac{d}{D}$$

Seeing= $\phi \approx 1'' \rightarrow \alpha = \phi\frac{D}{d_1}$

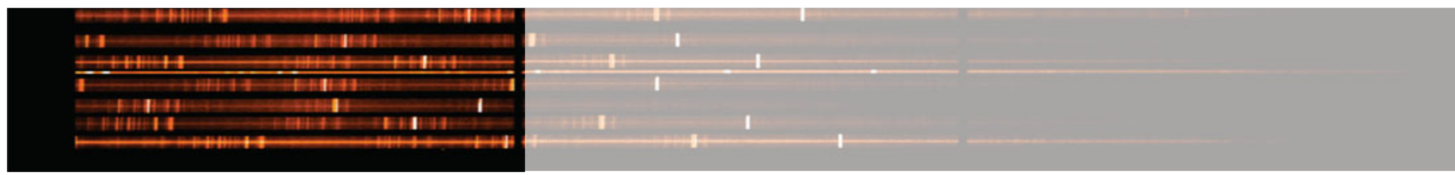


on GMT…



IMACS:

1/3 the field of view
Use a lower density grating to keep same resolution…
But only 1/3 the total wavelength range goes into the camera.



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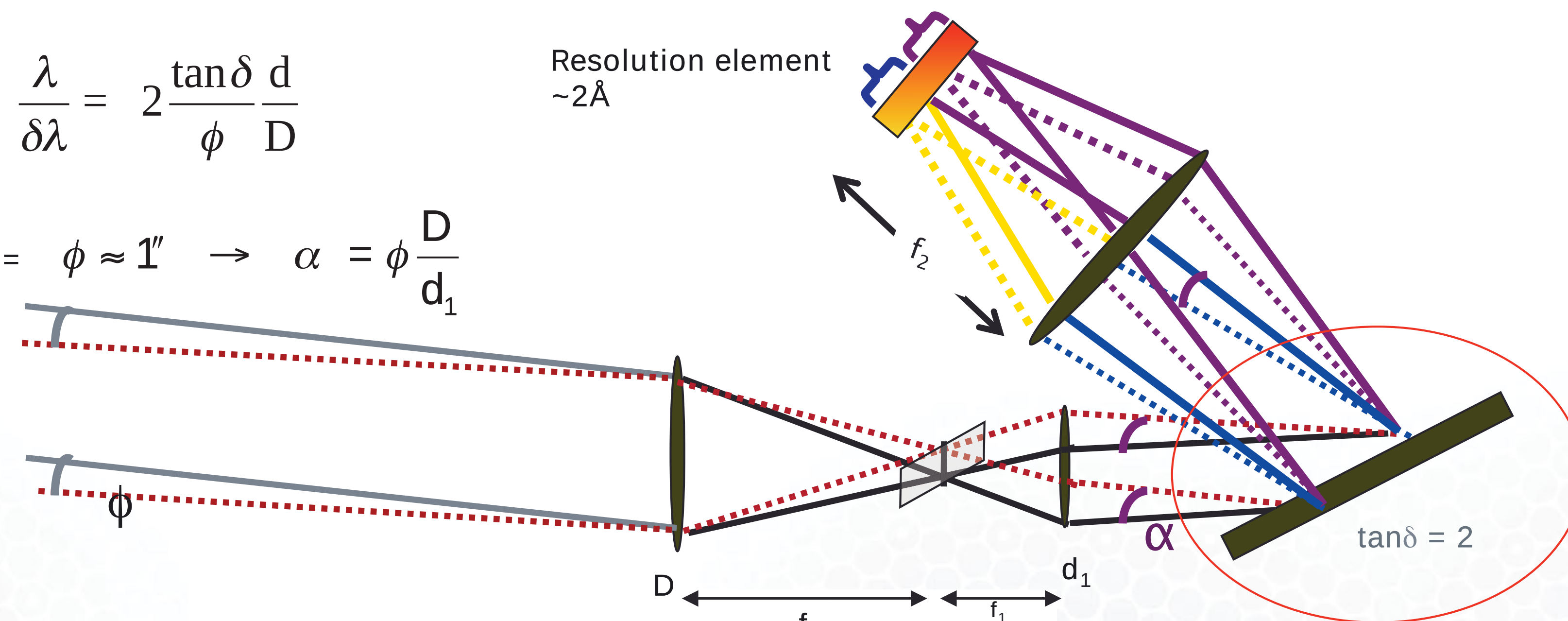
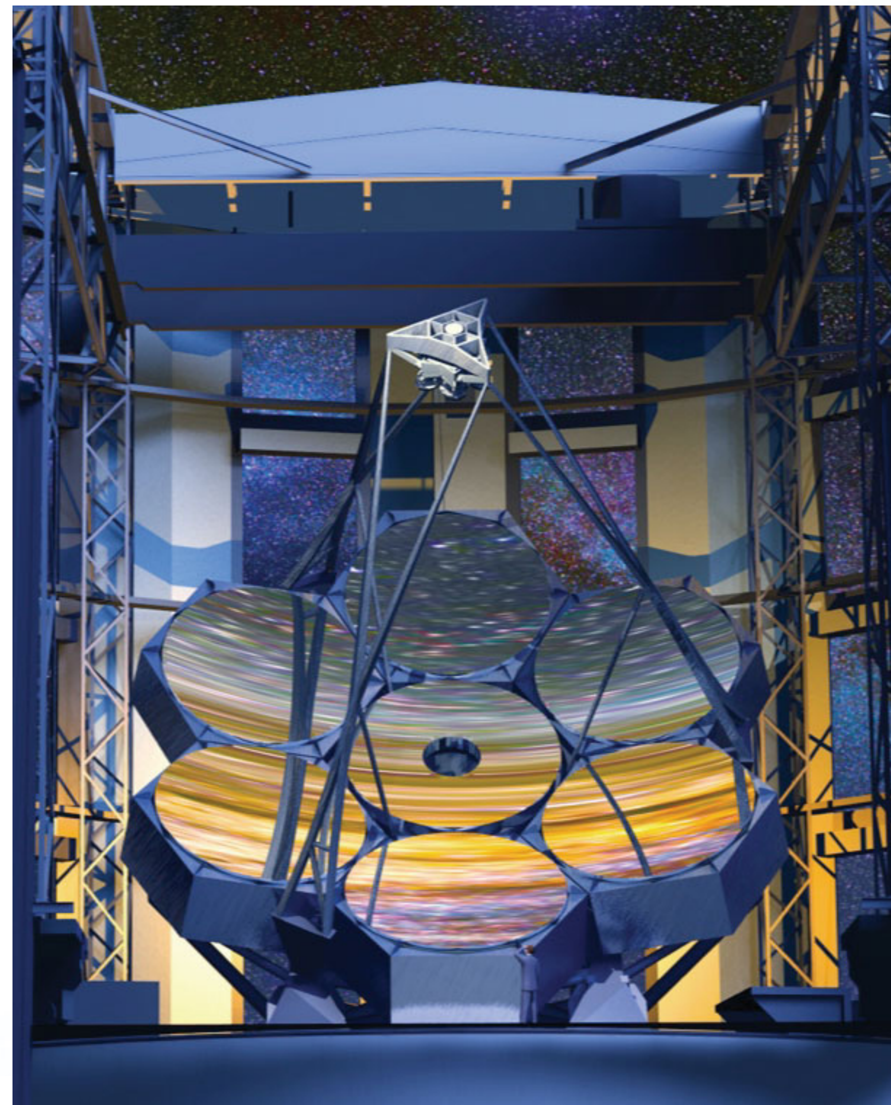


To get the same performance on GMT:

Scale up the collimator to capture the same field of view:

Magellan (D=6.5m, F/#=11)

GMT (D=25m, F/#=8)



To get the same field of view on GMT:

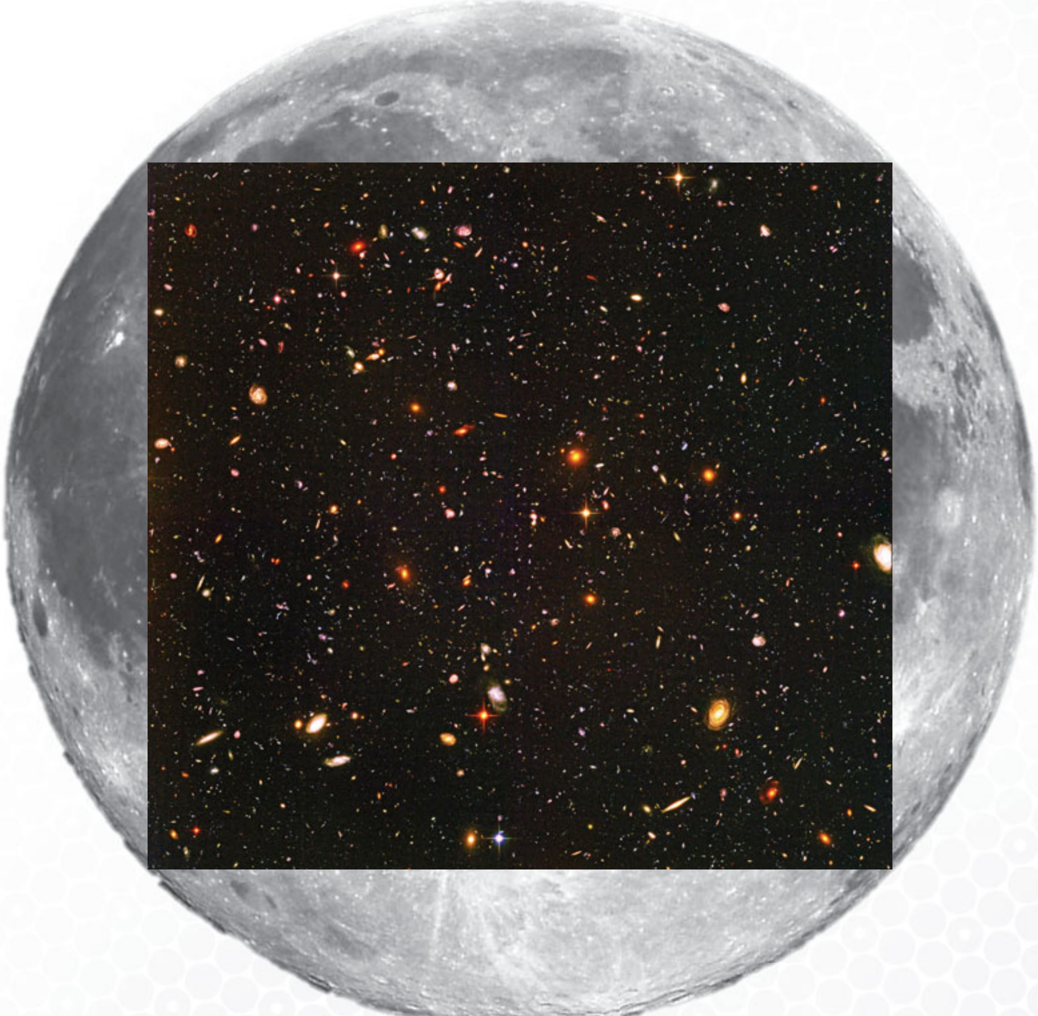
Scale up the collimator to capture the same field of view:

Magellan (D=6.5m, F/#=11)

20 arcmin = 414 mm

GMT (D=25m, F/#=8)

20 arcmin = 1200 mm



To get the same field of view on GMT:

GMT

Scale up the collimator: you can't.

- lenses limit is ~1m

To get the same field of view on GMT:

GMT

Scale up the collimator:

- lenses limit is ~1m (larger mirrors are possible, but need beam folding, alignment hard)

DEIMOS spectrograph for Keck (10 m)

To get the same field of view on GMT:

Scale up the collimator:

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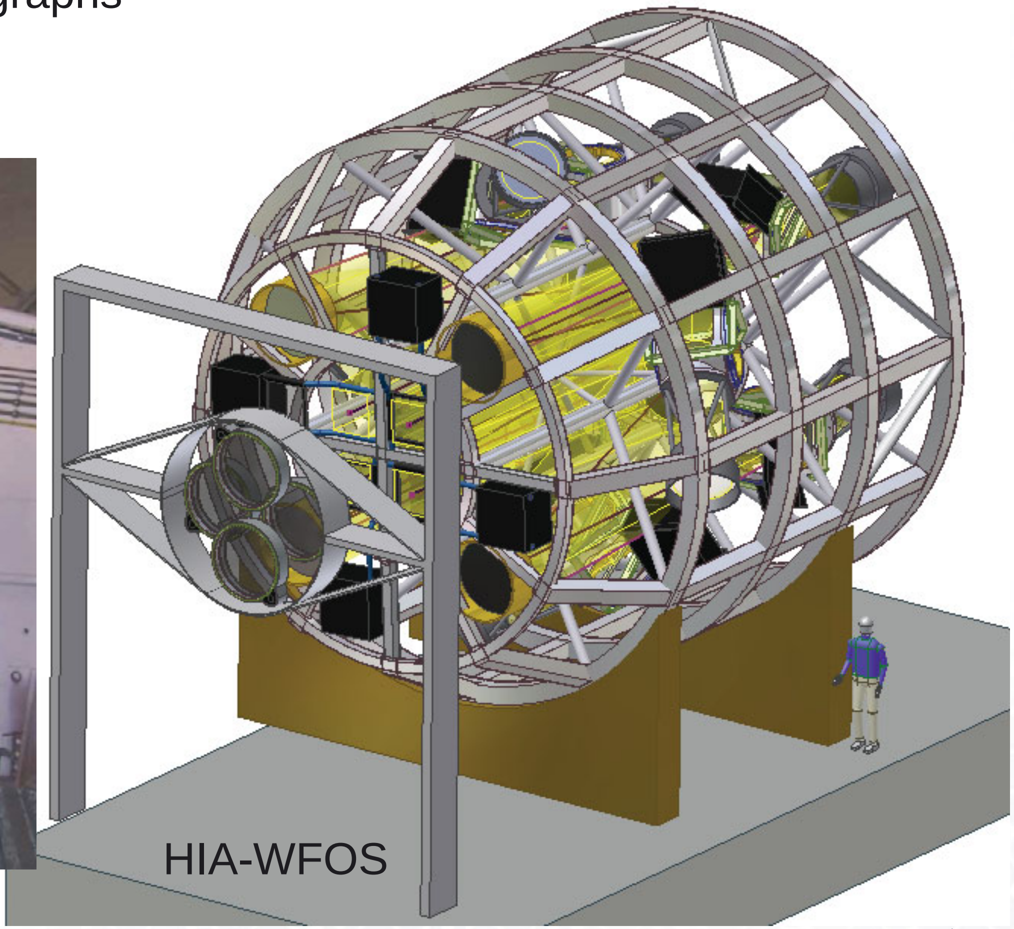
- Larger fields require multi-field spectrographs

DEIMOS spectrograph for Keck (10 m)



HIA-WFOS

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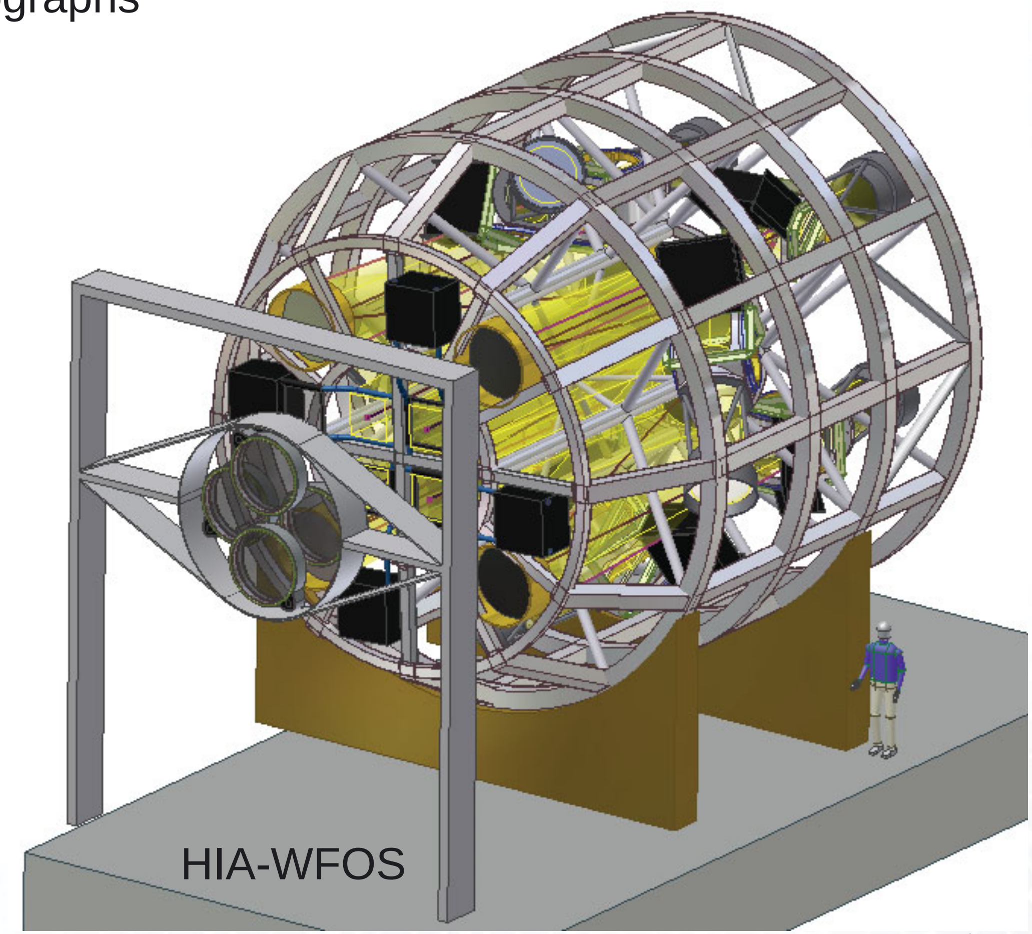
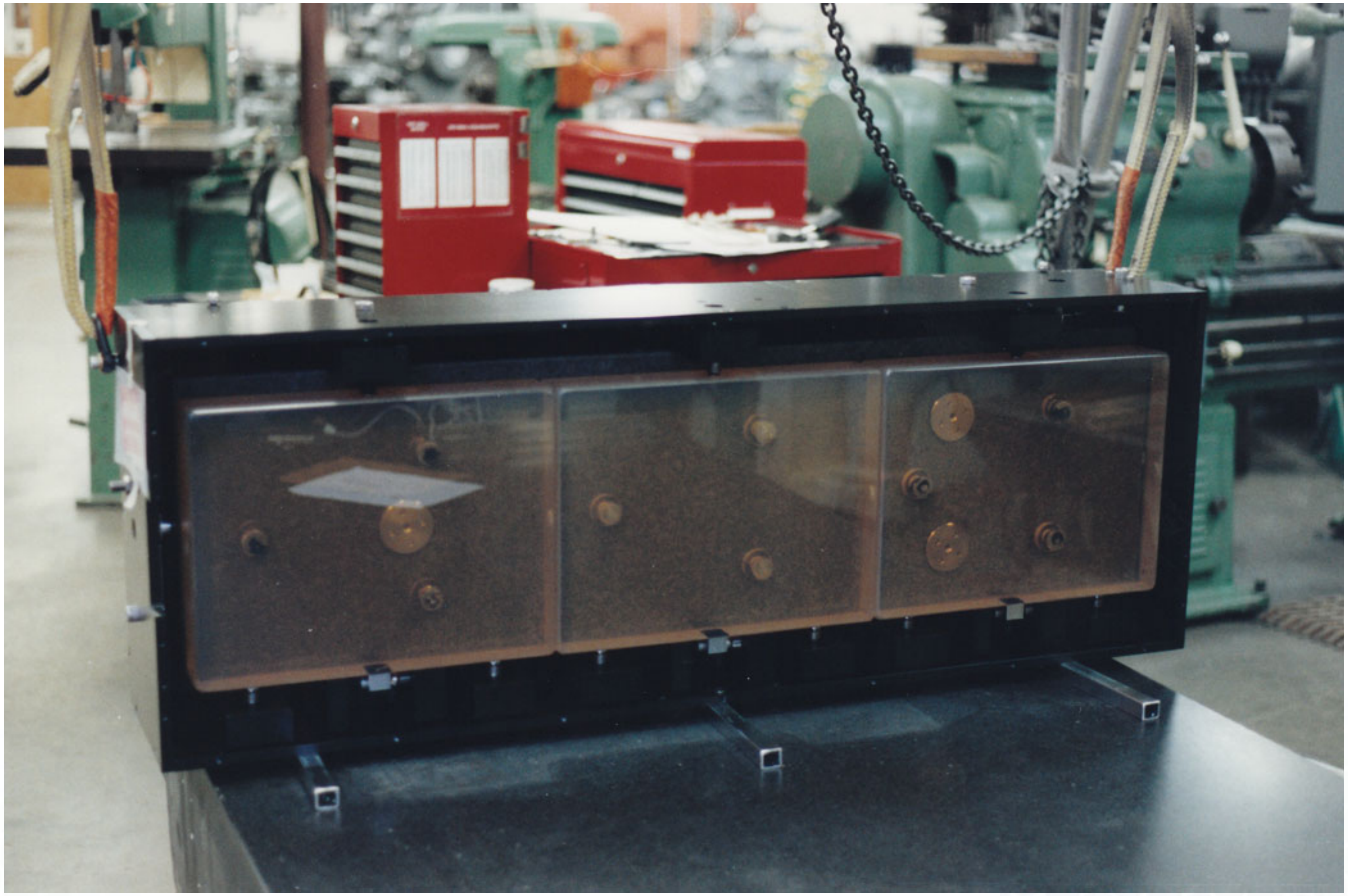


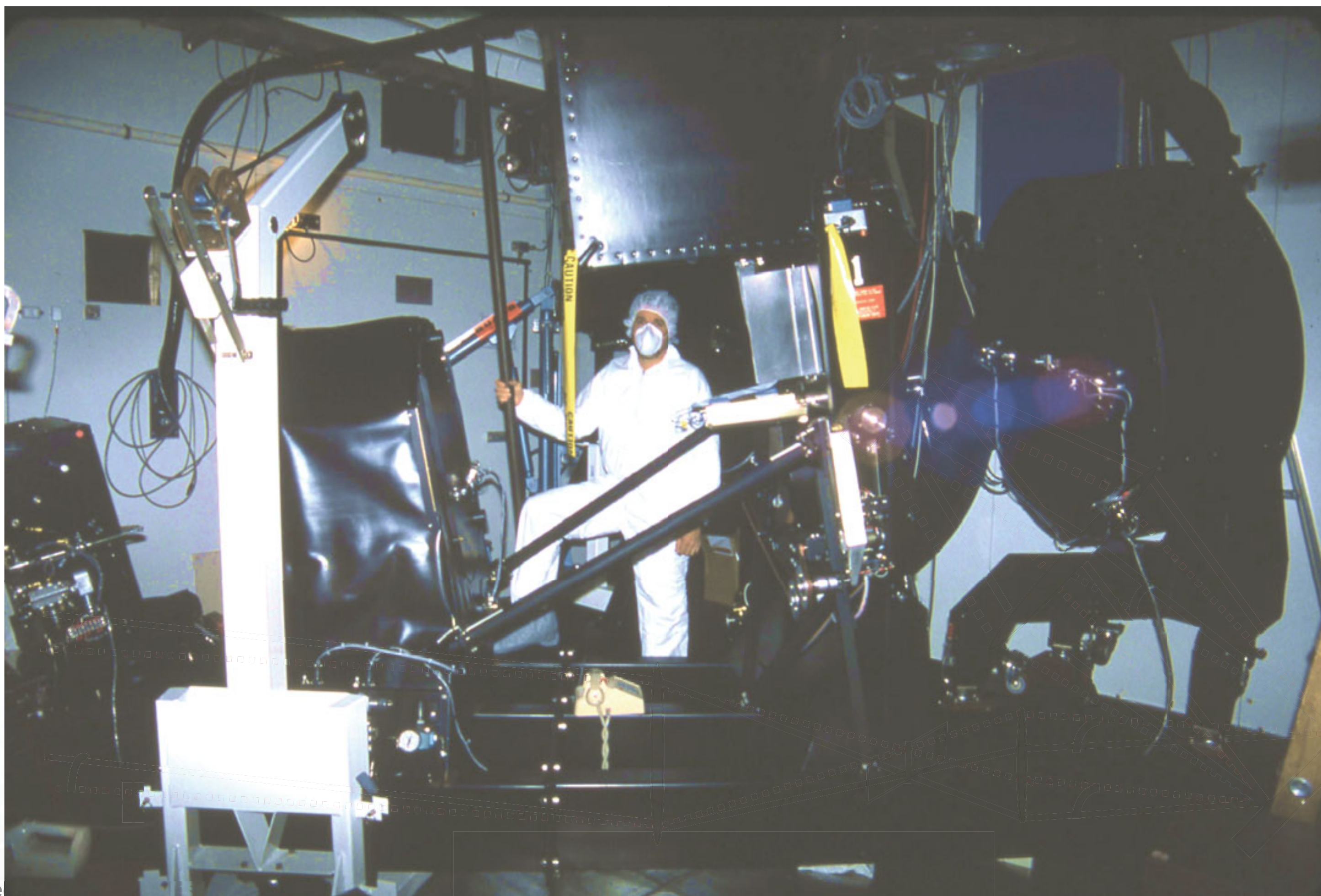
To get the same resolution on GMT:

- Increase the pupil diameter to keep resolution ($R = \frac{\lambda}{\delta\lambda} = 2\frac{\tan\delta}{\phi}\frac{d}{D}$)
  - Largest grating assembly (?) 300x400 x 3



To get the same resolution on GMT:

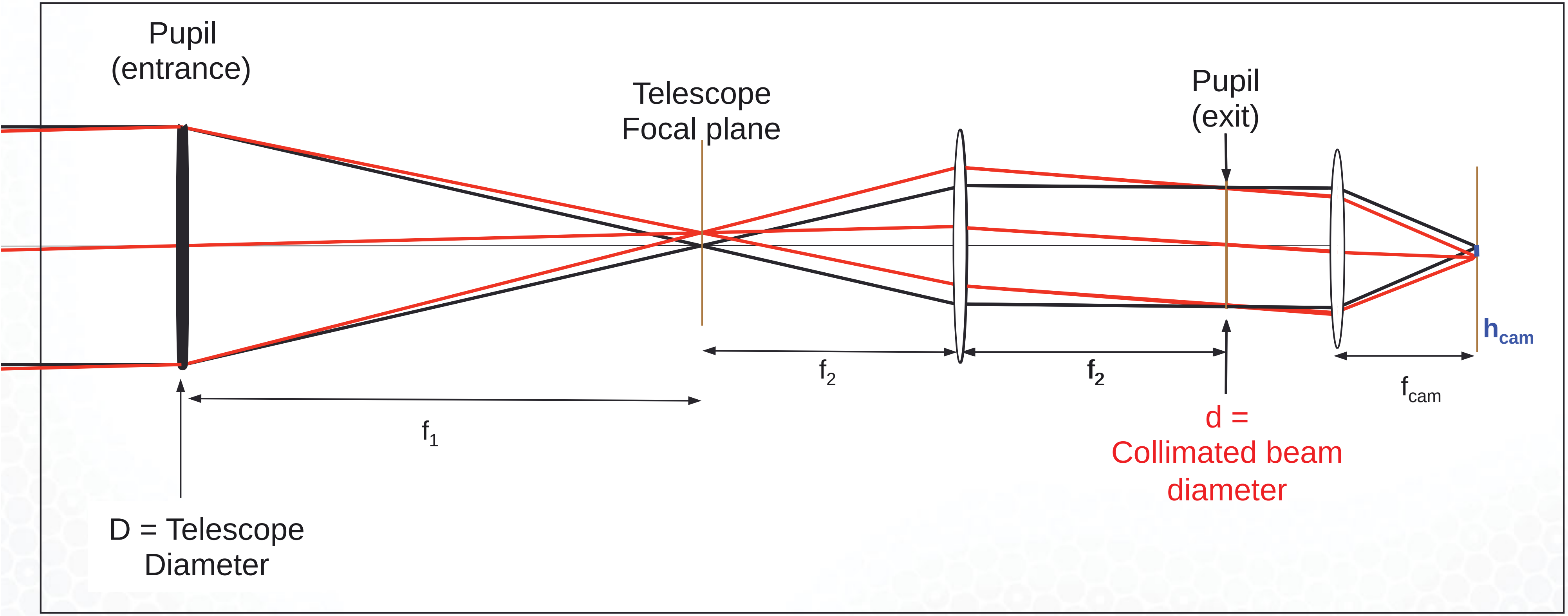
- Increase the pupil diameter to keep resolution ($R = \frac{\lambda}{\delta\lambda} = 2\frac{\tan\delta}{\phi}\frac{d}{D}$)
  - Largest grating assembly (?) 300x400 x 3 … can't get bigger.



To get the same resolution on GMT:

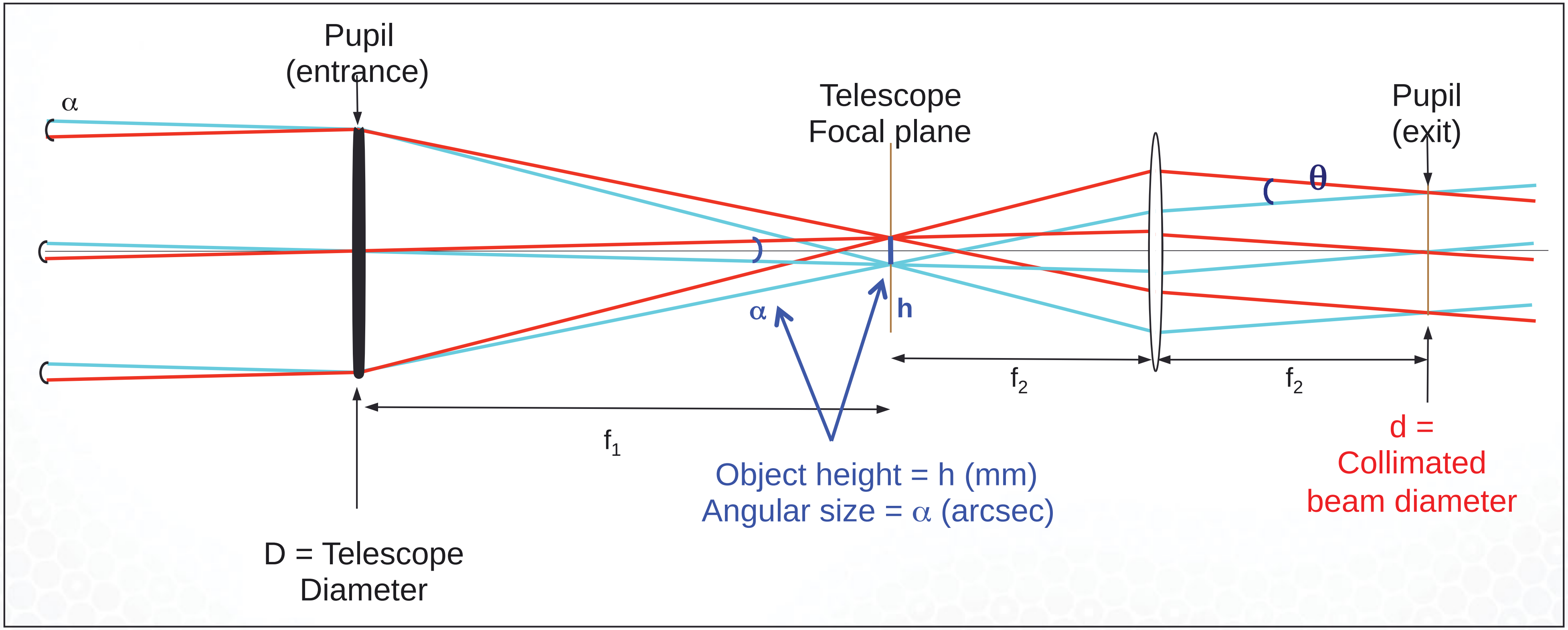
What if you wanted the whole instrument to be smaller?

Can you win by making the pupil smaller, the collimator shorter?



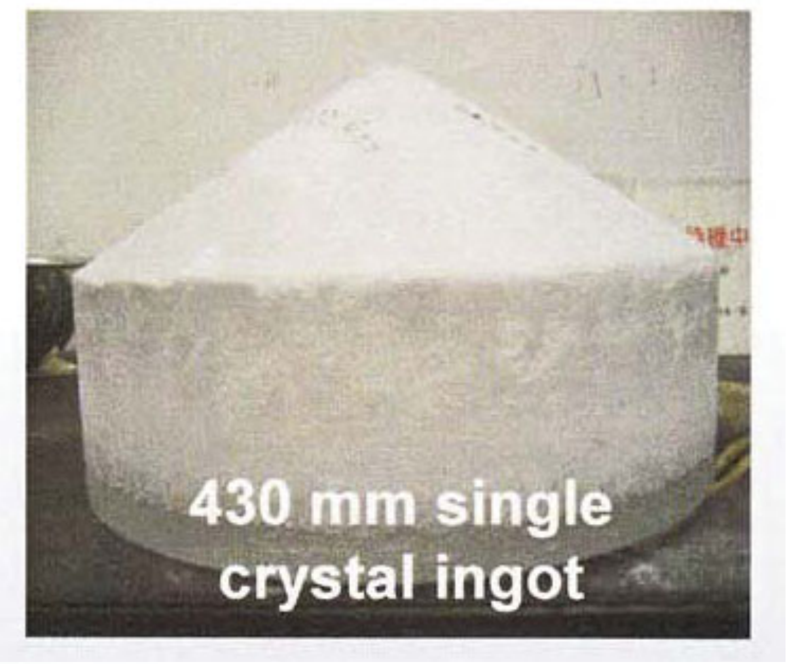
To get the same resolution on GMT:

Angles are magnified at pupil by → $\theta = \alpha \frac{D}{d_1}$

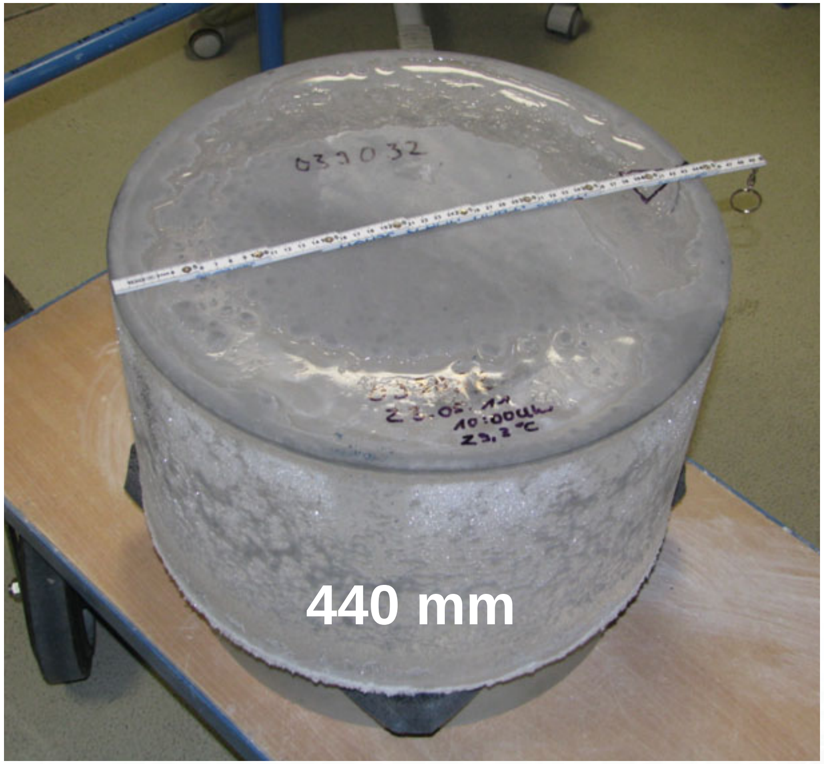


To get the same performance on GMT:

- Increase the camera diameter to catch the beam off the grating:
  - Lens material limit is ~400mm for crystals (CaF_2) and high transmission glasses.



Canon Optron (~1990)



Hellma (~ July 2011)

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  - Mirrors & Structures
  - Telescope optics 101
  - Strategies of the 3 GSMTs
    - Optical Configurations
    - Segments
    - Structures
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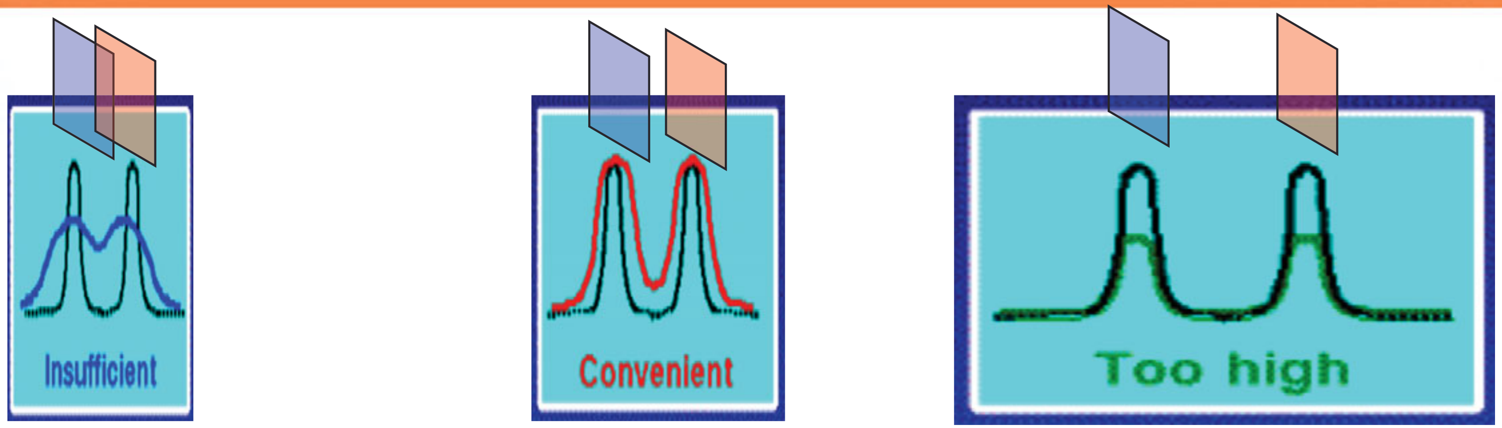
  - Limitations for large spectrographs
  - Strategies for GSMTs

Options for single object (high resolution) spectrograph:

GMT

- The problem: getting resolution
  - R~ d/D (and D has gotten to big for d to keep up)
  - R~ slit width ~ image size — GLAO could help GMT a lot!!
- Solutions:
  - Go for it: — Everyone is going to do this as much as possible.
    - Bigger pupils , ie. Larger gratings: biggest ~ 300mm width (1.2 m length)
    - Requires large cameras ---- biggest is 450
  - Clever optical tricks:
    - Start folding the pupil: white pupil, folded pupil. — G-CLEF does this!
    - Higher dispersion strategies: immersion gratings. — GMTNIRS does this!
    - Split up the telescope pupil — ELT's high resolution spectrograph will do this.
    - Make the problem easier with GLAO — GMT does this over full field,
      E-ELT does this over portions of their field

Make the problem easier:



Is there enough dispersion to separate the [slit images] at the desired spectral resolution?

On 8m telescopes: images got better, slits got narrower!

On 30m telescopes: images in optical will not get smaller…

unless you have full time GLAO!

Options for wide fields of view:

Metric for **wide field** science: $\mathbf{A\varepsilon\Omega/\theta^2}$

- A = Area………………………………………….. YES
- ε = efficiency (0.8 – 0.9 per mirror) ……………… YES, but only to a point!
- Ω = Field of view ………………………………… YES, but only to a point!
- θ = image size (flux concentration) ……………… YES

→ Highest ε will not come with the highest Ω, and vice-versa

Options for wide fields of view:

Multiple fields of view: VERY hard to make work!

- VMOS for VLT* ("never worked well")
- GMACS for GMT (reduced to 1 field)
- OPTIMOS for E-ELT (not moving forward)

- Fibers: increases field of view, maximum throughput 50%
  - EVE for E-ELT (not moving forward)
  - MANIFEST for GMT

$$\boxed{A\varepsilon\Omega/\theta^2}$$

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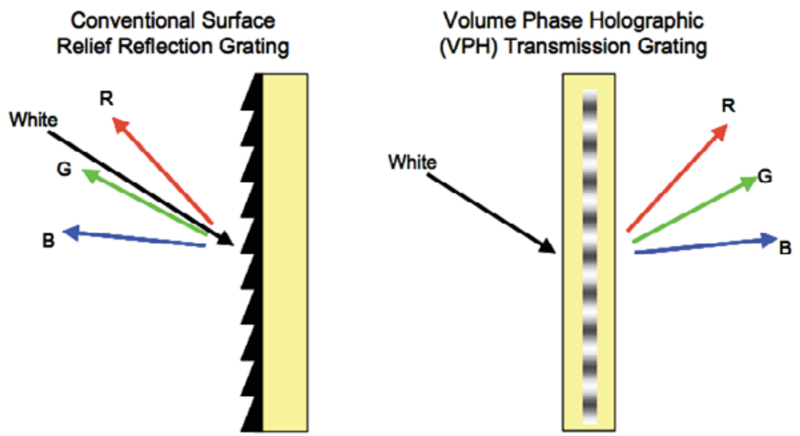
$$\boxed{A\varepsilon\Omega/\theta^2}$$

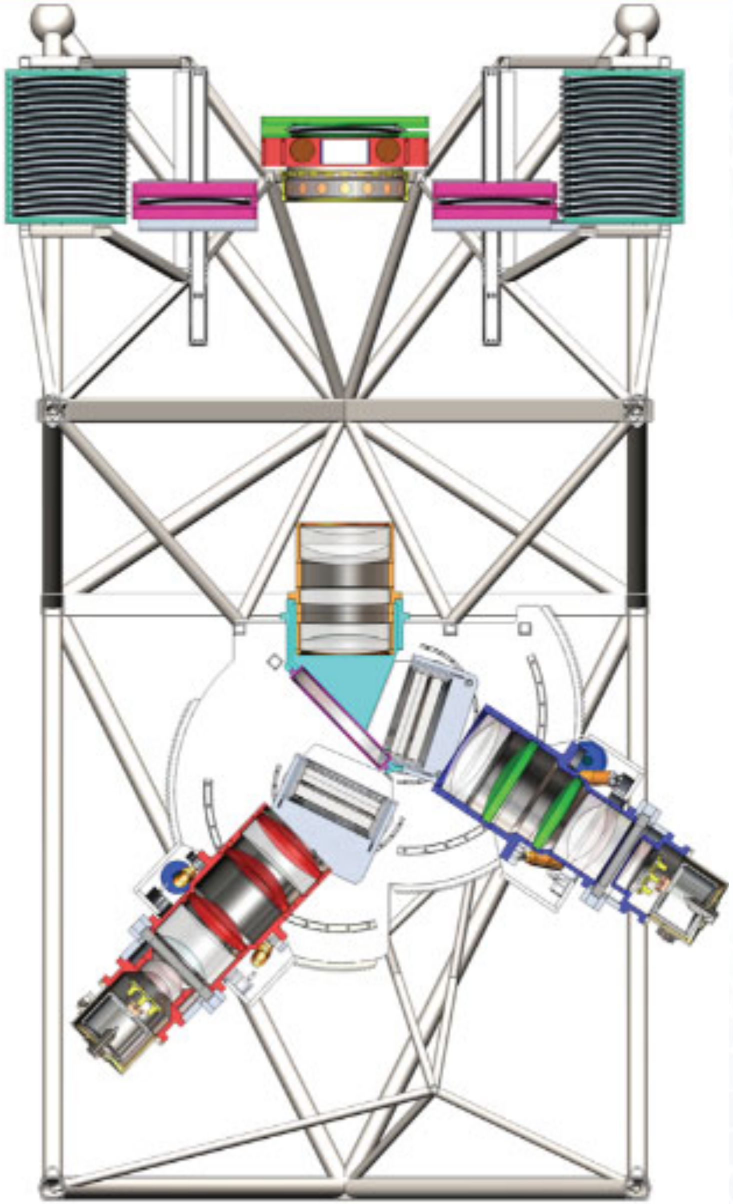
Options for wide fields of view:

VPH gratings: help keep cameras smaller

- several spectrographs in 4-8m telescopes
- GMACS
- GCLEF (cross dispersion)
- GMTNIRS (cross dispersion)

$$\boxed{\mathbf{A\varepsilon\Omega/\theta^2}}$$





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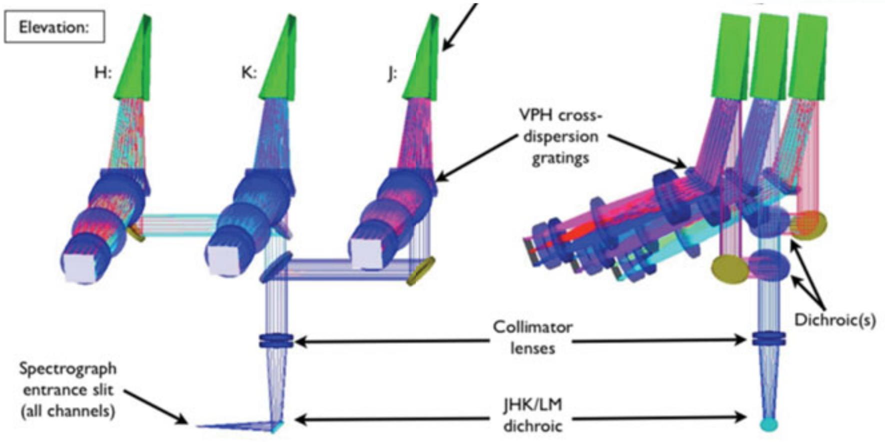
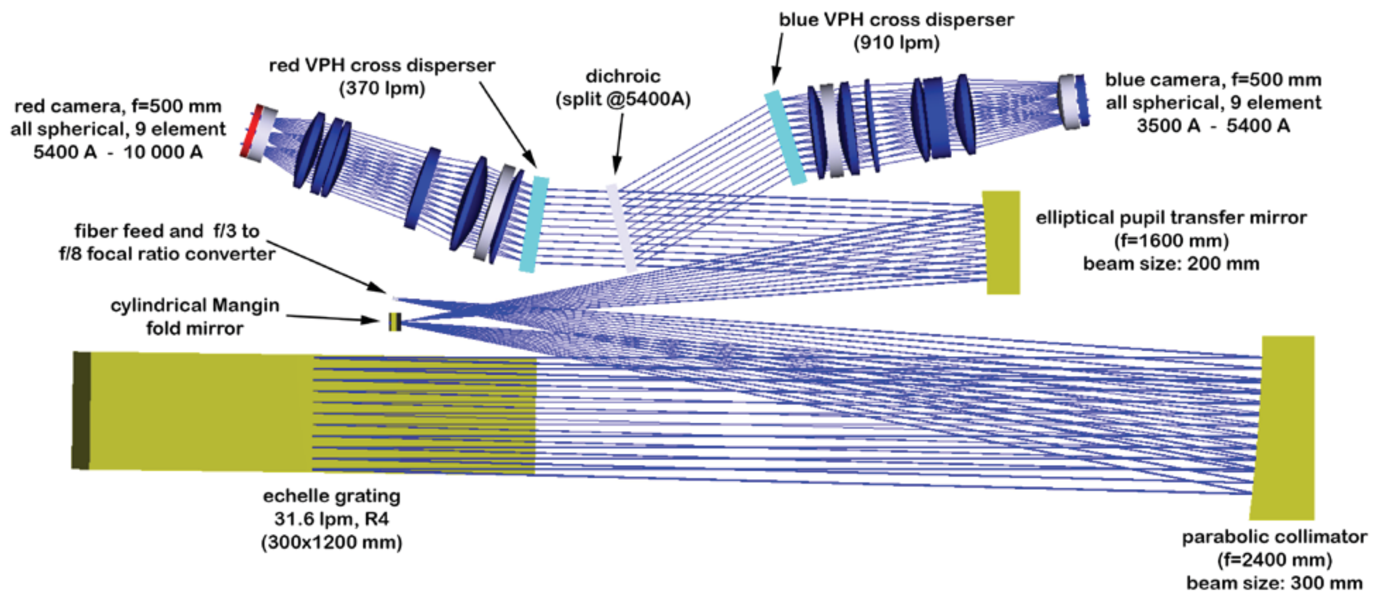


$$\boxed{A\varepsilon\Omega/\theta^2}$$



My conclusions:

- GSMTs:
  - All are challenging, but there are no show-stoppers
  - GMT has some distinct advantages in terms of:
    - $$/ photon
    - Building instruments for wide fields and spectral resolution!
- Instruments: There are solutions for excellent instruments:
  - The instruments don't just "scale up"
  - Best instruments will need to use all the optical tricks.
  - For wide fields of view: Pick one.. High efficiency or largest field of view.
  - Simple telescopes (optical systems) are better for IR and for AO (thermal background)

Extra Slides

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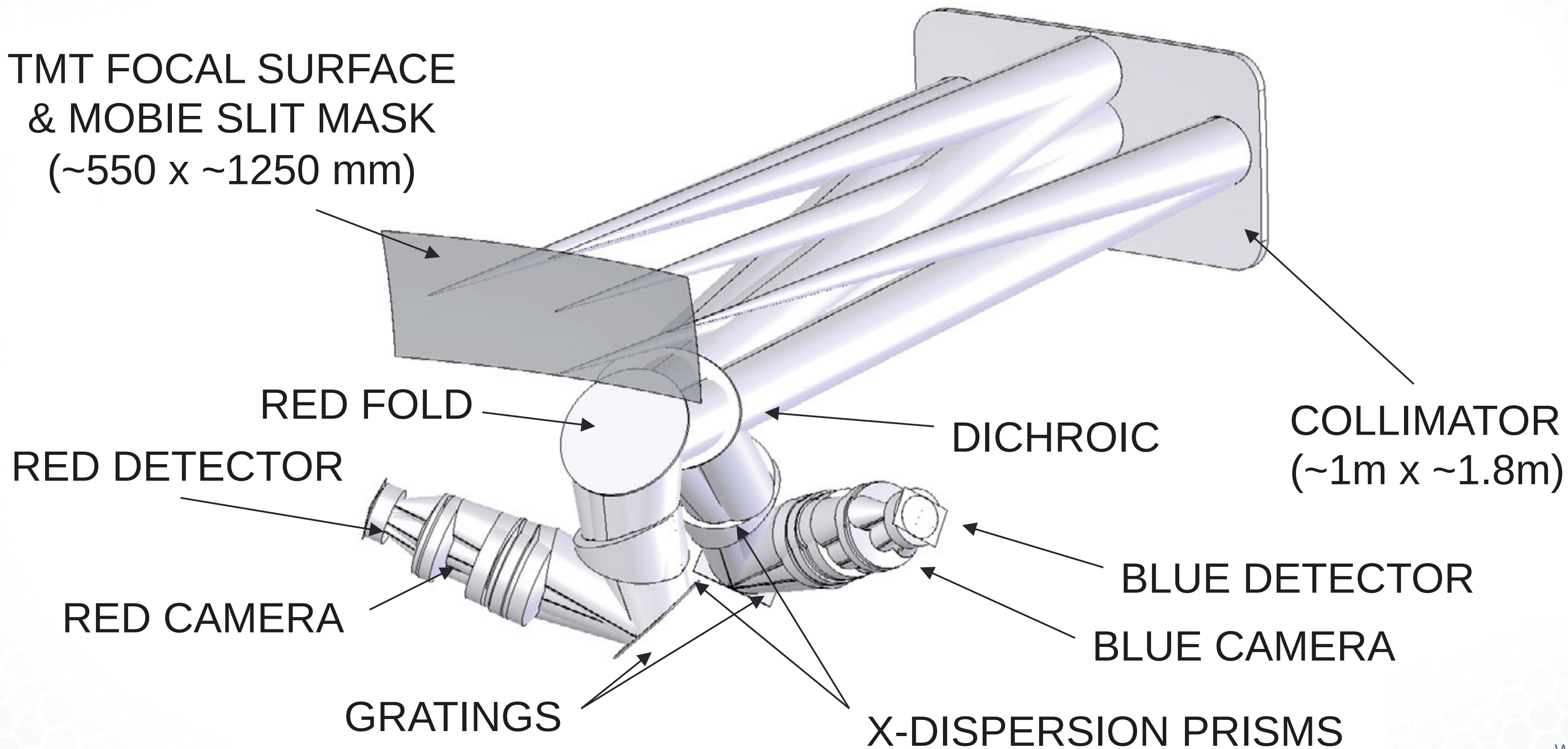
MOBIE Design Concept: Optical Layout

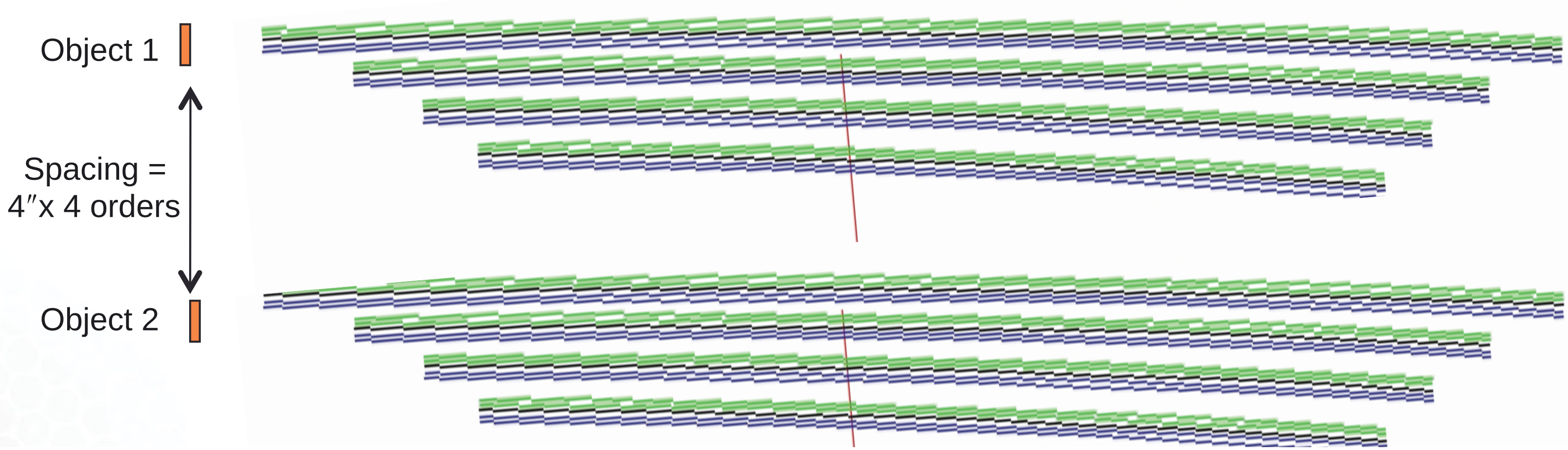


WFOS / MOBIE for TMT — Feedin

Design Concept: performance

Combine the two: Multi-Object, Broadband, Imaging Echellette (MOBIE)

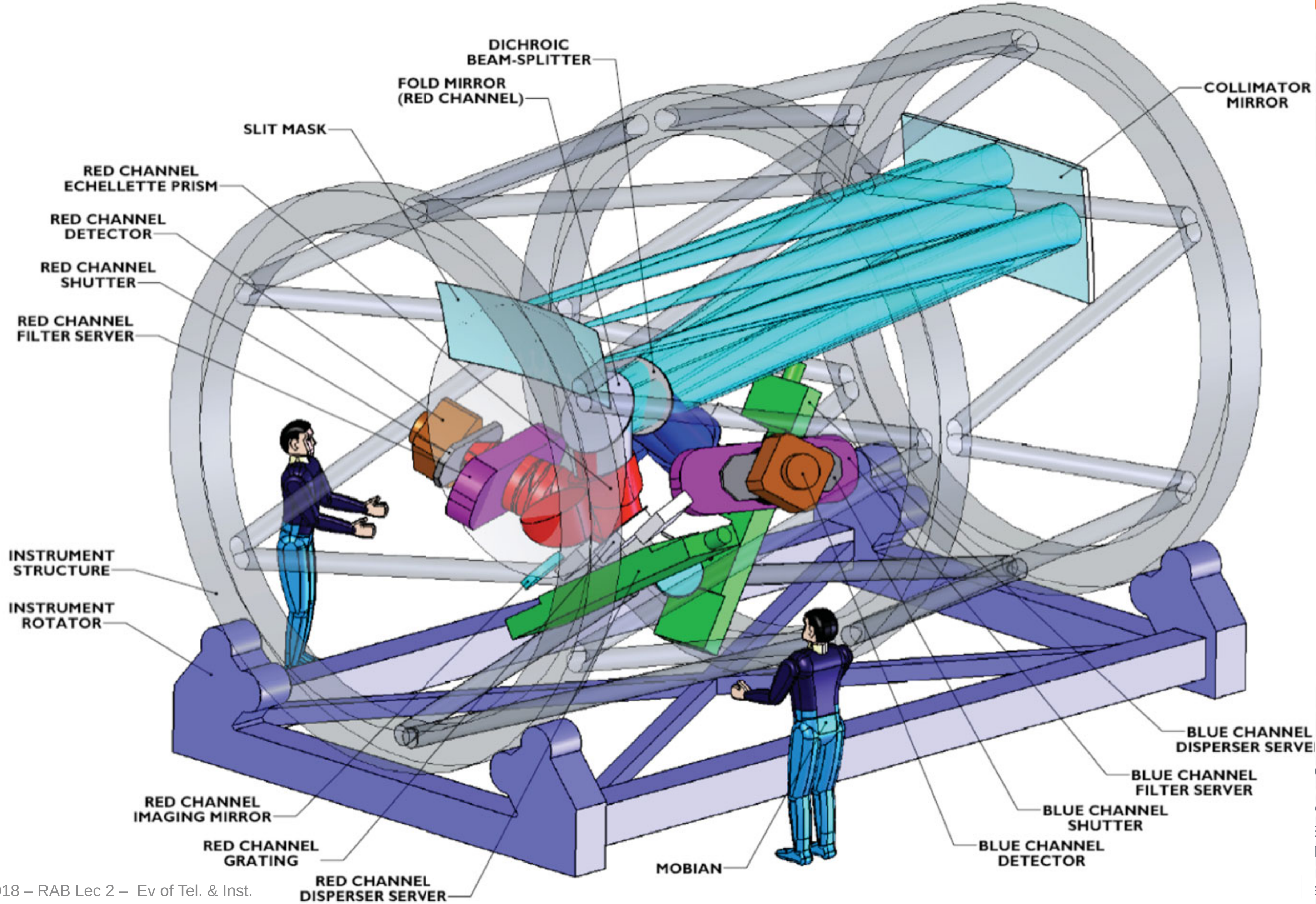
- Extremely flexible: observer chooses
  - # objects
  - Resolution mode: Low — any slit length, 1 order
    Medium — slit length fixed (5″), 1–5 orders available.
    High — slit length fixed (4″), 1–6 orders available.
  - Wavelength coverage: # of orders selected using narrow-band filters



Working example – Multi Object Echellette [prism+grating] in IMACS on Magellan

MOBIE Design Concept: Optical Layout

GMT



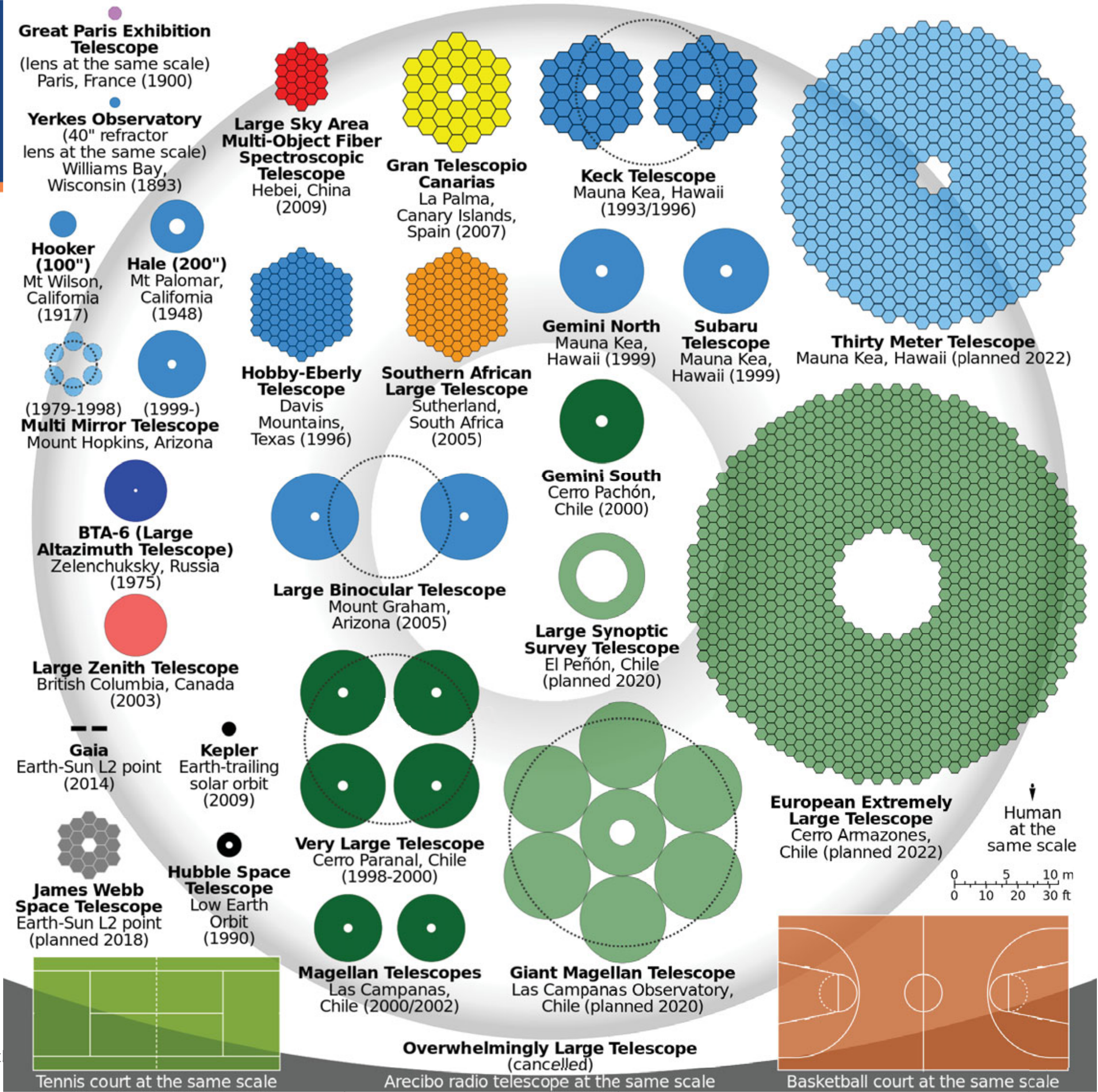
/FOS / 1OBI E for TMT — eedin

Alt-Az:

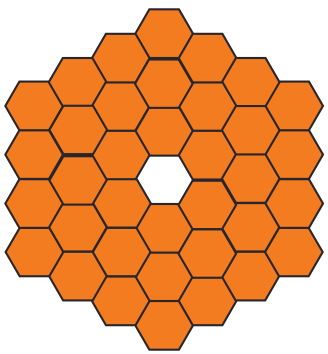
That's a good start.

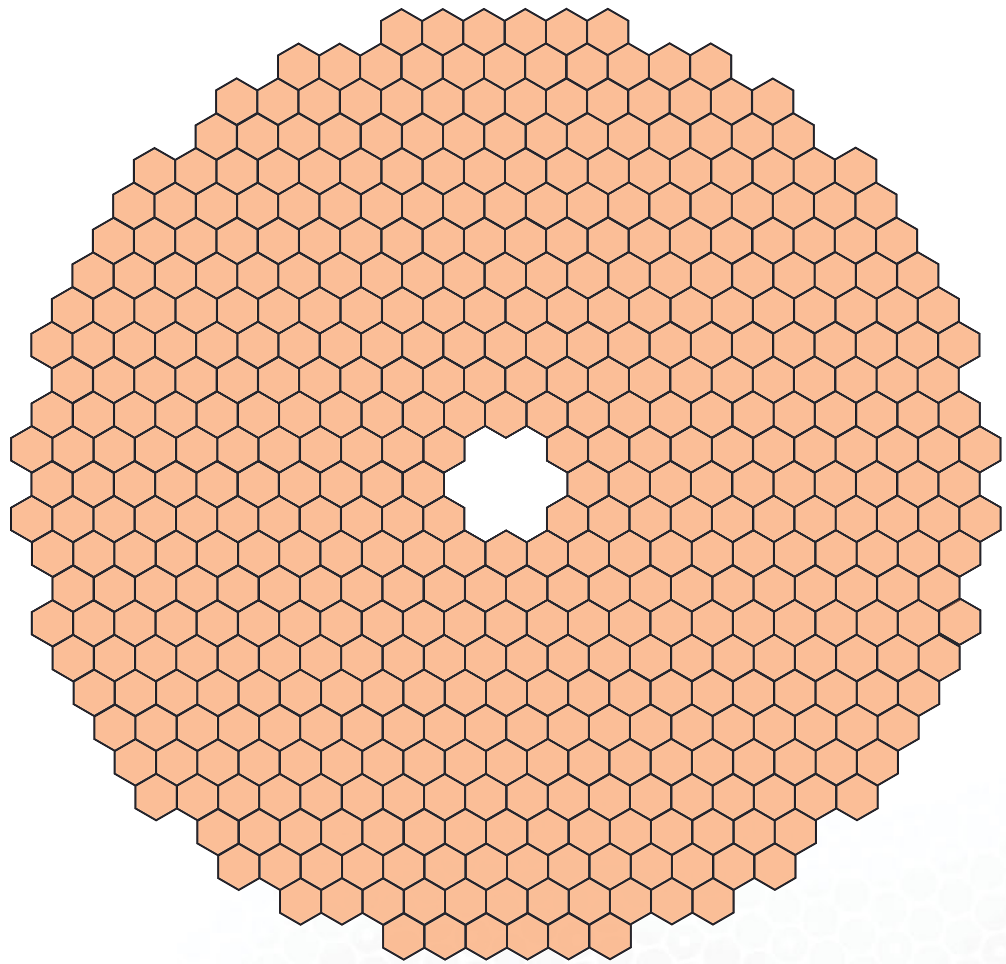
But we are going up a x3-4 from the last generation.

It's serious.



Keck (10m) vs TMT (30m)





MOBIE for TMT: a hybrid approach.

GMT

"Diagnostic" science	"Discovery" science

Examples: targeted studies
- Abund & kinematics of stars (20 Mpc)
- Galactic and Local Group sub/structure

Design priorities:
- Resolution (λ/Δλ): 8,000 – 16,000
- Multiplexing: 10's

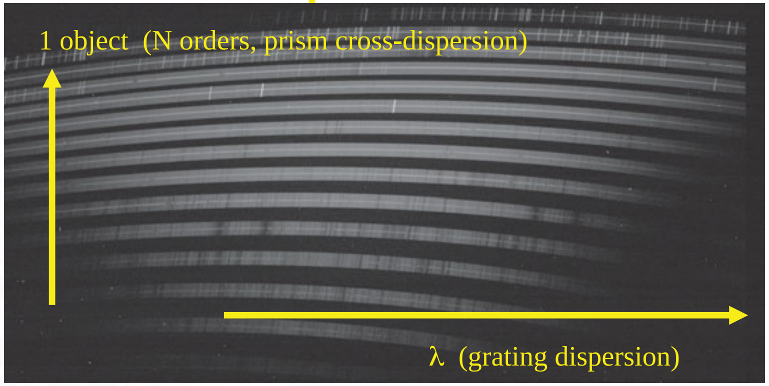
Examples: surveys
- IGM structure and composition at 2<z<6
- stellar pops (chemistry & kinematics z>1.5)

Design priorities:
- Resolution (λ/Δλ): 1,000 – 5,000
- Multiplexing: 100's

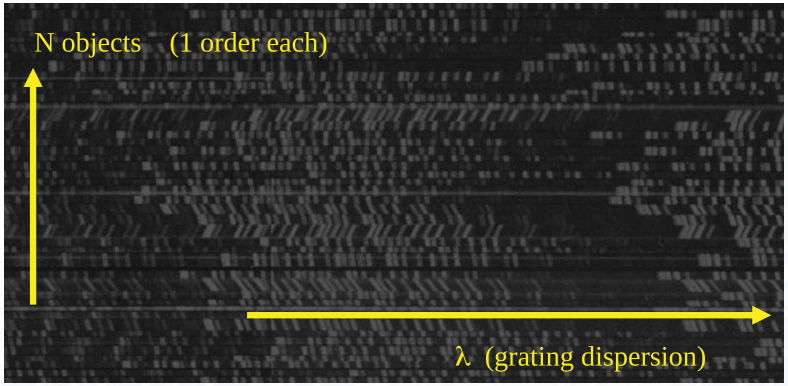
MULTI-ORDER (cross-dispersed) SPECTRA

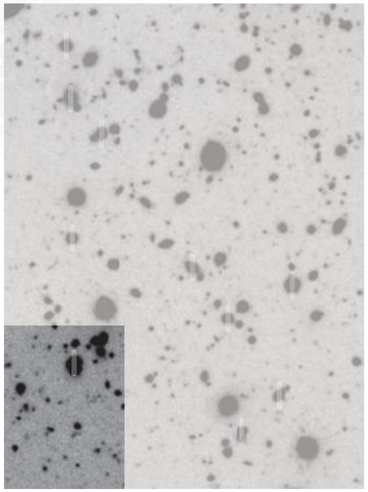
SINGLE ORDER SPECTRA

Echellette spectrographs:
ESI (Keck), MagE (Magellan), XShooter (VLT)



Wide Field Multi-Object spectrographs:
DEIMOS (Keck), VMOS (VLT), IMACS (Magellan)





IMACS:

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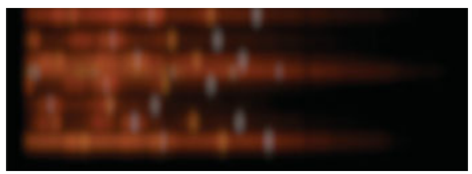

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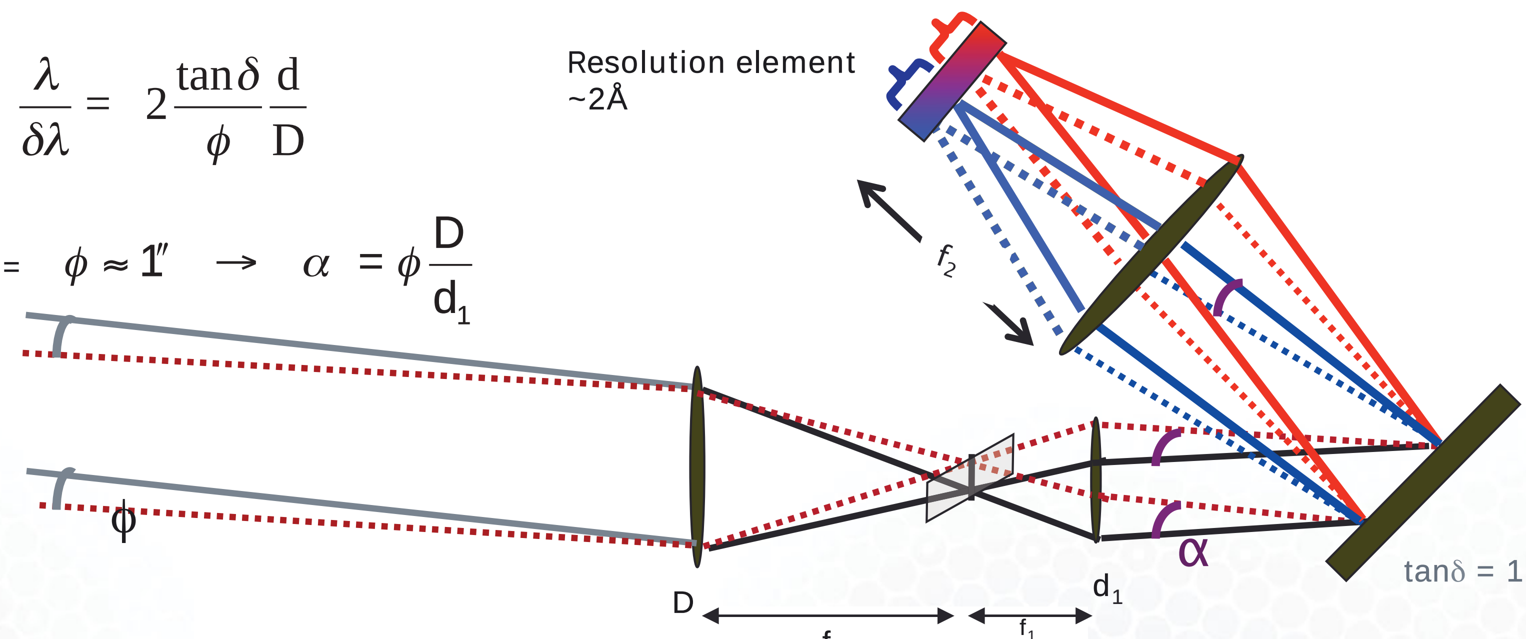
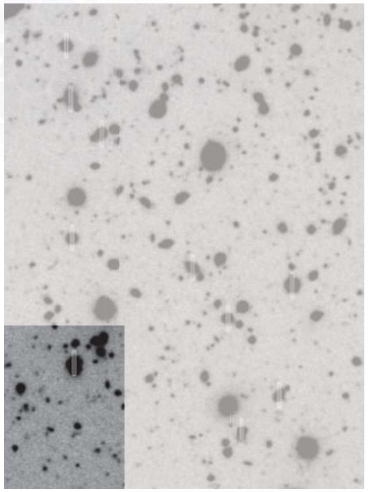
Seeing= $\phi \approx 1'' \quad \rightarrow \quad \alpha = \phi\frac{D}{d_1}$

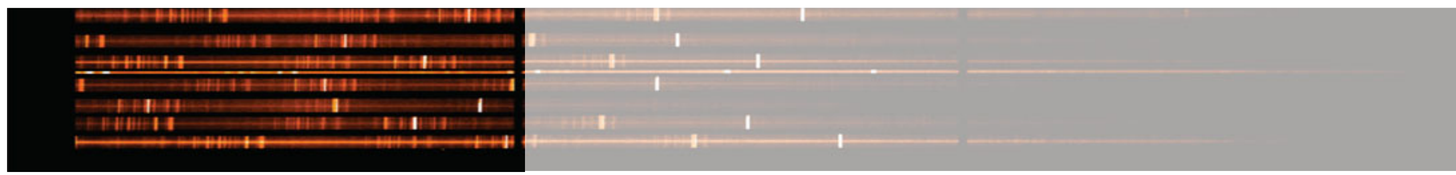


on GMT…



IMACS:

1/3 the field of view
Use a lower density grating to keep same resolution…
But only 1/3 the total wavelength range goes into the camera.



$$R = \frac{\lambda}{\delta\lambda} = 2\frac{\tan\delta}{\phi}\frac{d}{D}$$

Seeing= $\phi \approx 1'' \rightarrow \alpha = \phi\frac{D}{d_1}$