

Phys 2310 Mon. Oct. 16, 2017

Today's Topics

- **Finish Chapter 34: Geometric Optics**
- **Homework this Week**

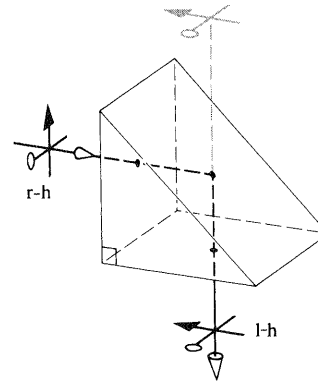
Homework this Week (HW #10)

Homework this week due Mon., Oct. 23:

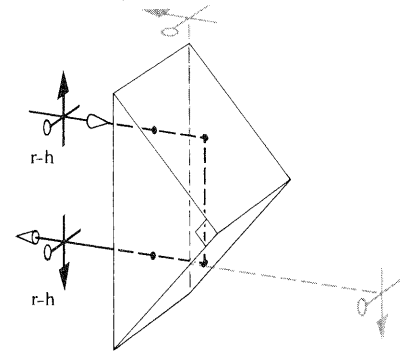
**Chapter 34: #47, 57, 59, 60, 61, 62, 63, 67,
73**

Supplementary: Reflecting Prisms

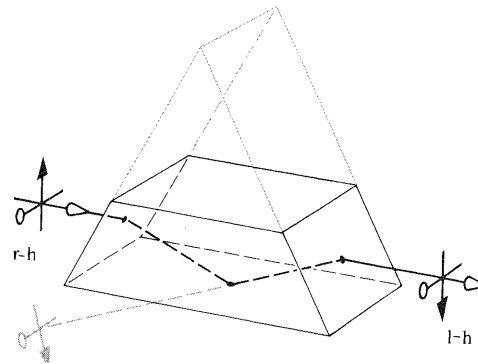
- Prisms can be used to modify the path of light, not just disperse it.
 - Done via reflection (total internal or with silvered surfaces)
- Right Angle Prism
 - Deviates light by 90°
- Porro Prism
 - Right angle shape but deviates light by 180°
- Dove Prism
 - Used to rotate light beam
- Penta Prism
 - Used to invert light beam or image



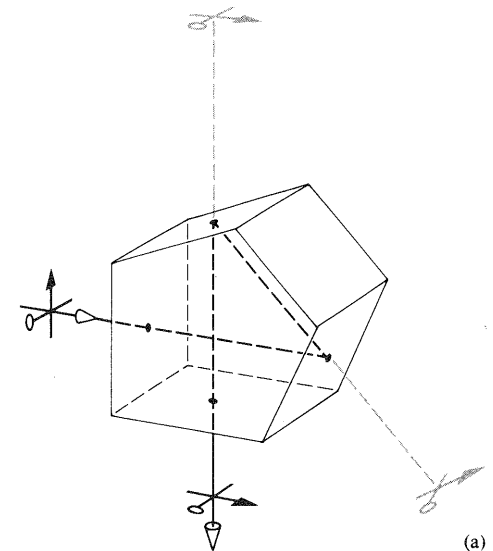
Right Angle



Porro



Dove



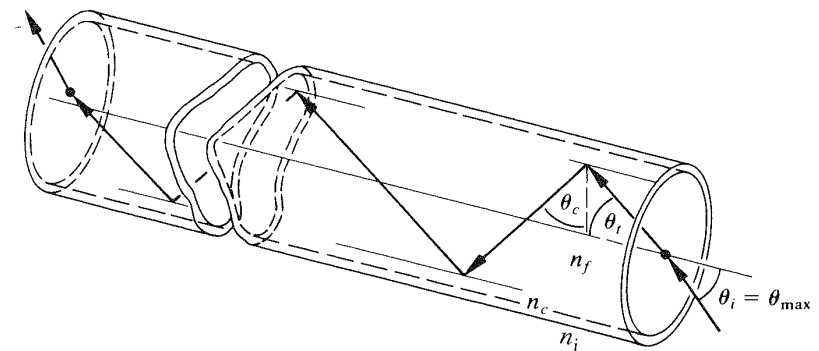
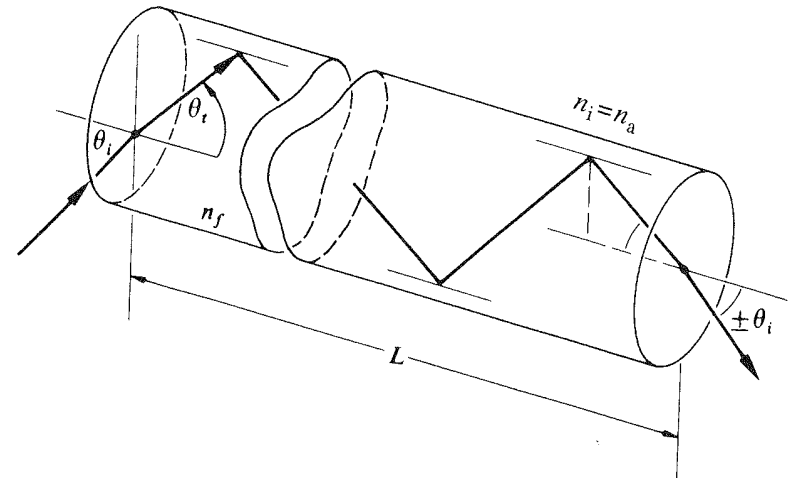
Penta

Supplementary: Optical Fibers

- **Optical fibers are extremely useful in optical systems for directing light along a complex path to a particular point. In telecommunications this allows the transmission of information by fast optical switching of solid-state lasers.**
- **Low index outside creates total internal reflection if light enters at less than the critical angle (see text):**

Numerical Aperture:

$$NA = \sin \theta_{\max} = \frac{1}{n_i} (n_f^2 - n_c^2)^{1/2}$$



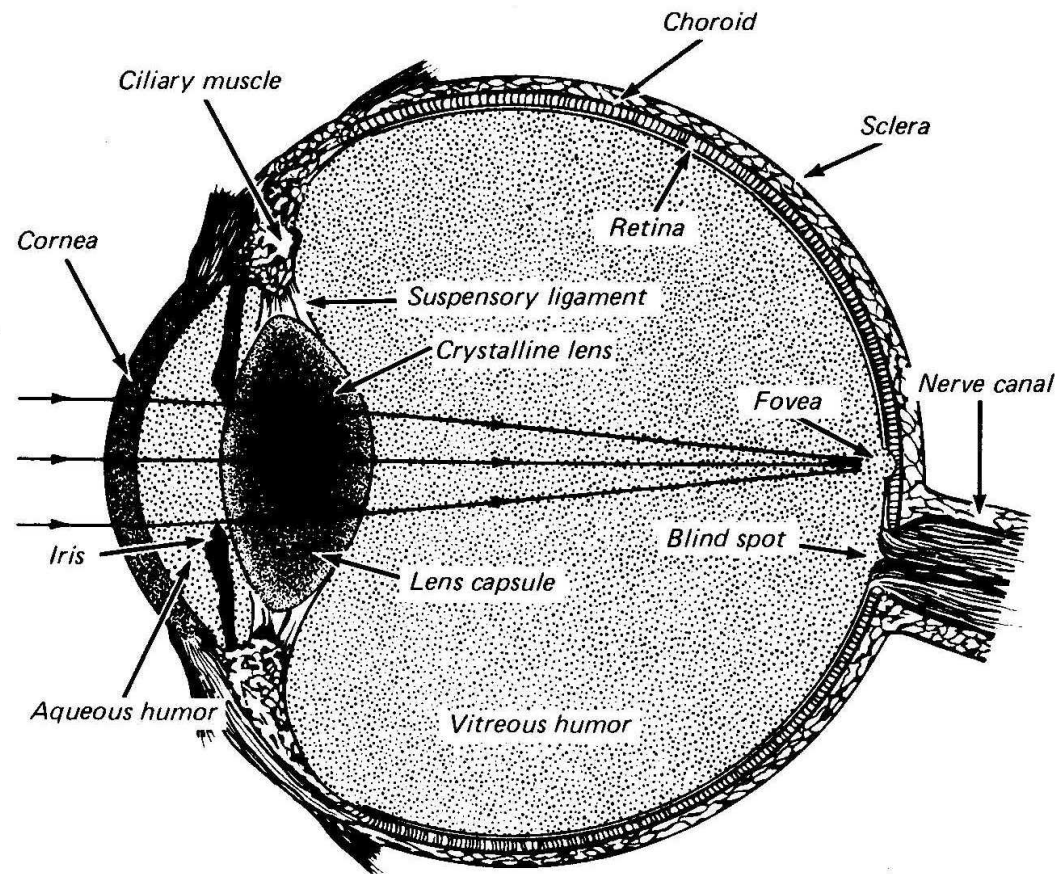
Modern fibers are often made of gradient index material so the pulses are not spread by the range of OPL.

Supplementary: Fiber Optics

- Note: time for light rays to traverse a fiber depends on which path they take.
 - The more reflections the longer the OPL.
 - Result is that a sharp pulse of light (telecom. bit) will spread
 - Gradient index fibers (continuous radial index gradient) can confine rays to center region
 - OPL differences much smaller
- Fiber transmission is not perfect so absorption limits length
 - New exotic fibers (Erbium-doped) can actually lase to boost signal power.

Supplementary: Optical Instruments

- Human Eye



Supplementary: Optical Instruments

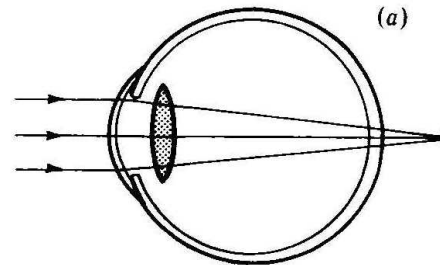
• Vision Correction

- Farsighted means the eye's lens focuses light too far (behind the retina)

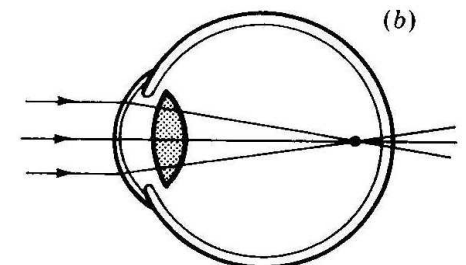
- Correction made via a positive lens

- Nearsighted means the eye's lens focuses light too close (in front of the retina)

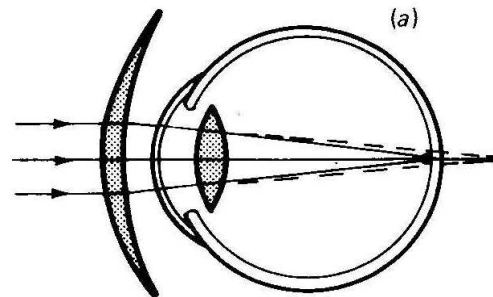
- Correction made through a negative lens



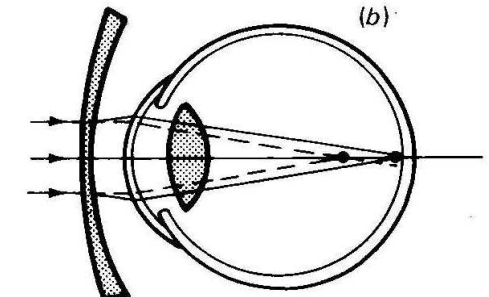
Hypermetropia, farsighted



Myopia, nearsighted



Farsighted eye corrected

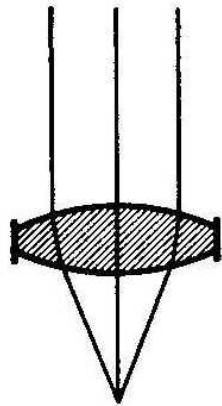


Nearsighted eye corrected

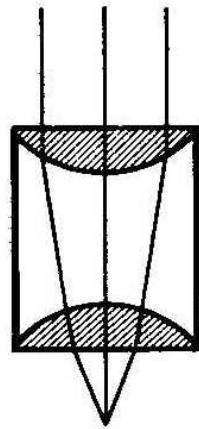
Supplementary: Optical Instruments

- Magnifying Glass

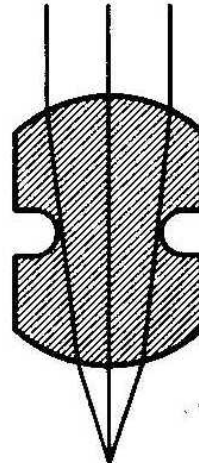
- Used to magnify and image and produce parallel (collimated) beam for easy focusing with the eye
- Complexity (expense) depends on need
 - Higher precision need requires more lenses to reduce aberrations



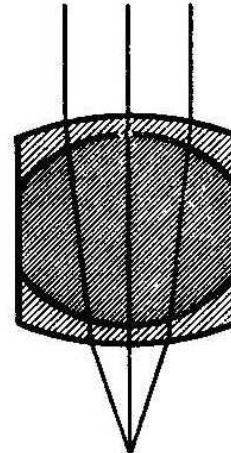
Double convex



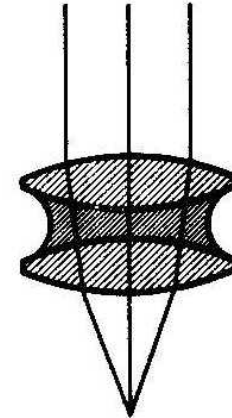
Doublet



Coddington



Hastings triplet



Achromat

Chapter 34: Optical instruments

- **More on Magnifiers**

- **Minimum focus for the eye is about 25cm (near point).**
- **Note that the magnification of a magnifying glass depends on the angular magnification: $M_\theta = \theta/\theta'$. From (b):**

$$\frac{1}{s} + \frac{1}{-25} = \frac{1}{f} \text{ or :}$$

$$\frac{1}{s} = \frac{25 + f}{25f} \text{ and}$$

$$\tan \theta = \frac{y}{25} \text{ and } \tan \theta' = \frac{y}{s} = y \frac{25 + f}{25f}$$

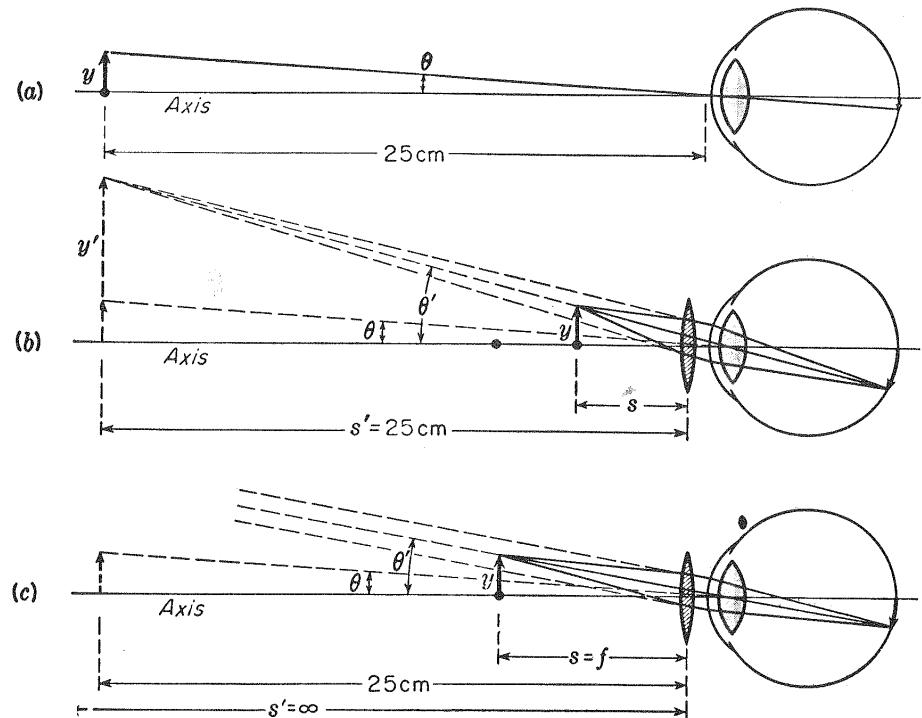
But for small angles $\tan \theta \cong \theta$ so the magnification is :

$$M_\theta = \frac{\theta'}{\theta} = \frac{25}{f} + 1$$

When the object is at the focal length ($s = f$):

$$\theta = \frac{y}{25} \text{ and } \theta' = \frac{y}{f} \text{ and :}$$

$$M_\theta = \frac{\theta'}{\theta} = \frac{25}{f}$$



Chapter 34: Optical Instruments

- **Eyepieces**

- **Used in conjunction with another instrument**
 - **Magnifies image**
 - **Produces collimated beam**
- **Similar to magnifiers but we also require the exit beam (exit pupil) to be smaller than the iris of the eye ($\sim 7 - 8$ mm)**

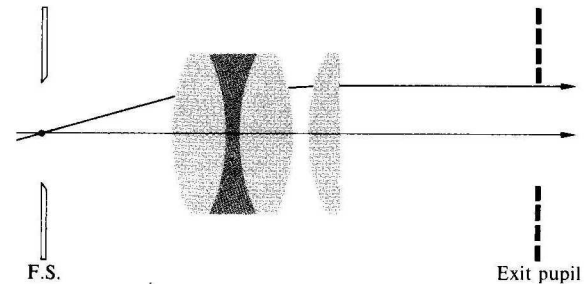


Figure 5.96 The orthoscopic eyepiece.

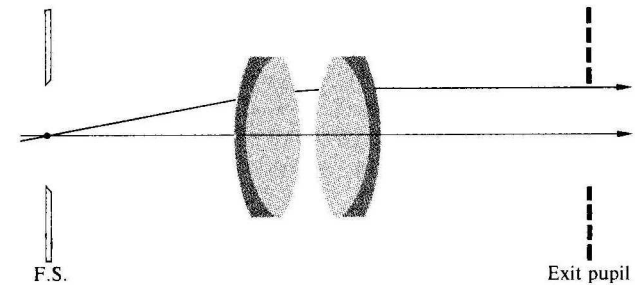


Figure 5.97 The symmetrical (Plössl) eyepiece.

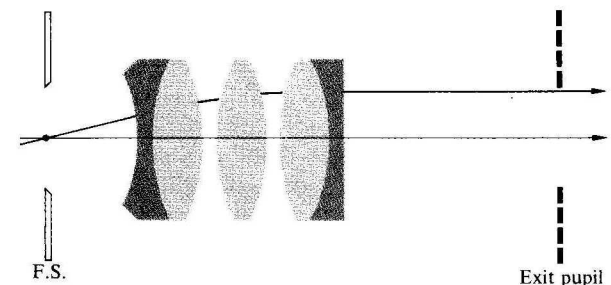
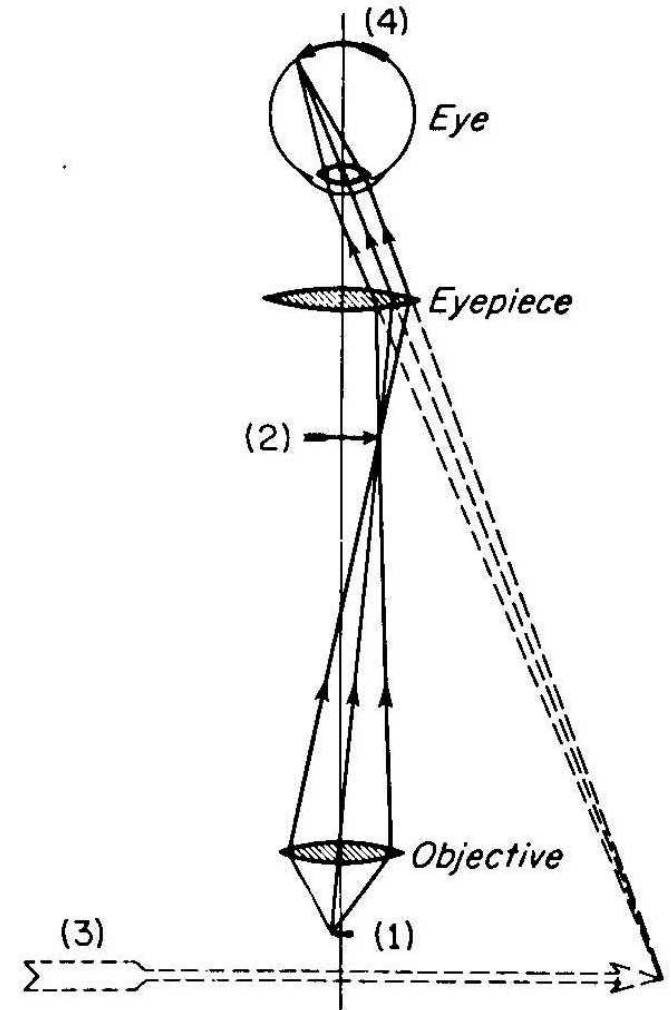


Figure 5.98 The Erfle eyepiece.

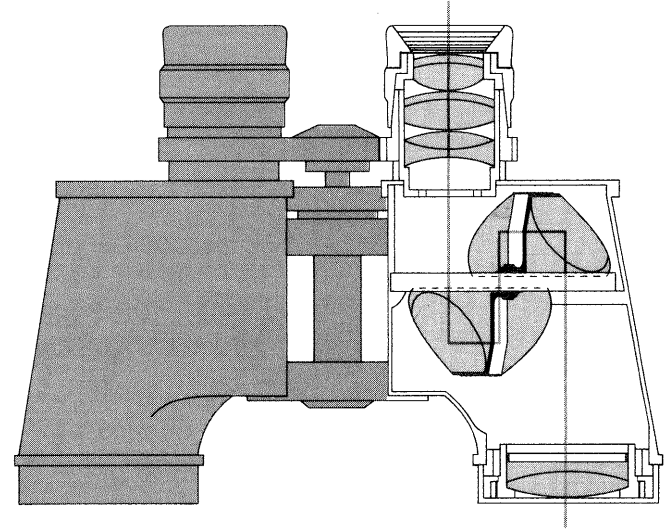
Chapter 34: Optical Instruments

- Microscope
 - Objective placed close to subject (object distance \sim focal length)
 - Large image distance plus eyepiece greatly magnifies the subject
 - Note that the eyepiece produces a collimated (parallel) beam so eye can view subject



Supplementary: Optical Instruments

- Binoculars
 - Consists of a two-lens objective
 - Forms the image
 - Second lens reduces chromatic (color) aberration.
 - An eyepiece
 - Acts as a magnifier to view and enlarge the image
 - Two Porro prisms
 - Four reflections to shorten the binoculars
 - Four reflections to invert (revert) the image



Supplementary: Optical Instruments

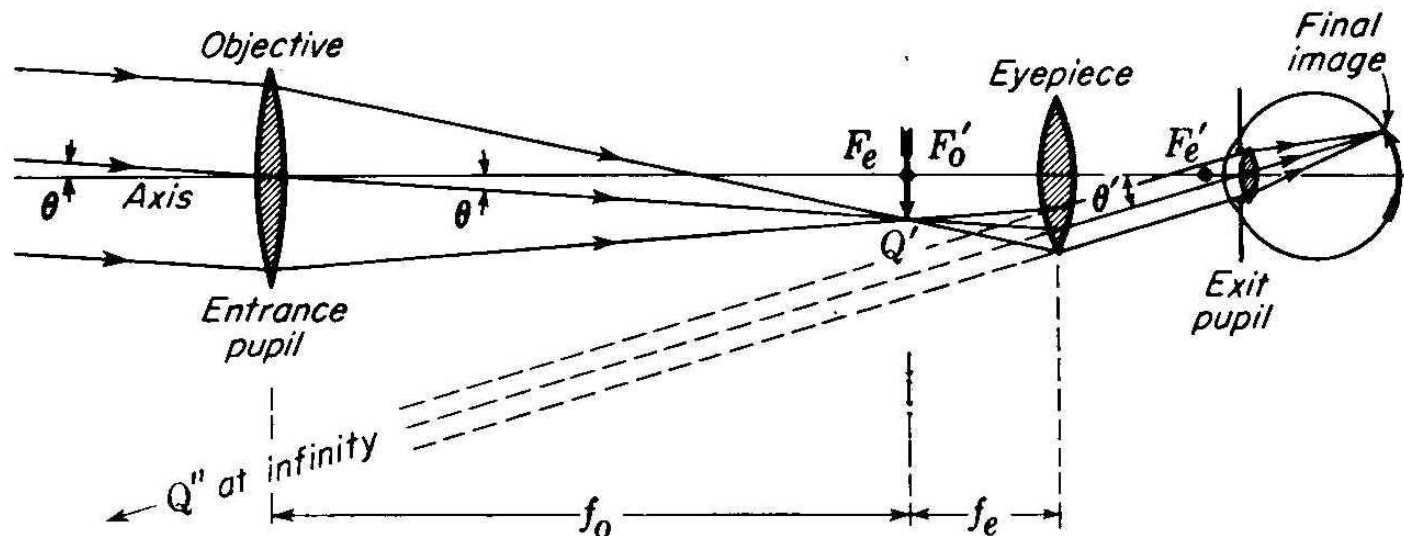
- Telescope:

- First (objective) lens form image at Q'
- Eyepiece acts as a magnifier to magnify the image and collimate the light
 - Diameter of beam = exit pupil and can't be larger than eye's iris ($\sim 7 - 8\text{mm}$)

Magnification of objective and eyepiece = $\frac{-s_i}{s_o}$ so compute for both. Then $M_T = M_O \times M_e$

If the object is at infinity or unknown distance use angular magnification: $y_o = f_o \theta_o$ and $y_e = f_e \theta_e$

and since $y_o = y_e$ (Q') we have $M_\theta = \frac{\theta_e}{\theta_o} = \frac{f_o}{f_e}$

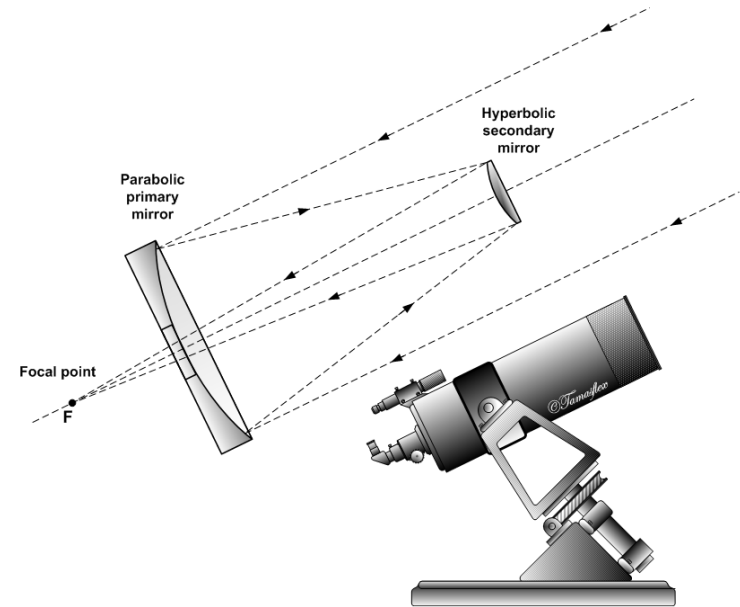


Supplementary: Optical Instruments

- **Cassegrain Telescope**
 - **Common, Two-mirror Telescope**
 - **Concave Primary Mirror (parabola or hyperbola: positive f.l.)**
 - **Convex Secondary Mirror (hyperbola: negative f.l.)**
 - **Advantage is that f_{eff} is longer than telescope since secondary increases f.l. of system.**

$$f_{\text{eff}} = \frac{f_1 \cdot f_2}{f_1 + f_2 - d}$$

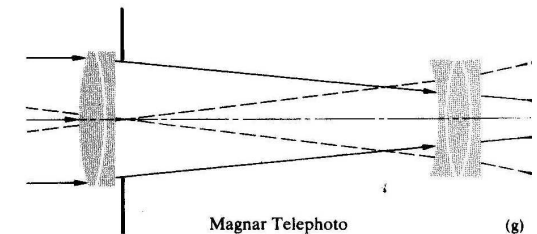
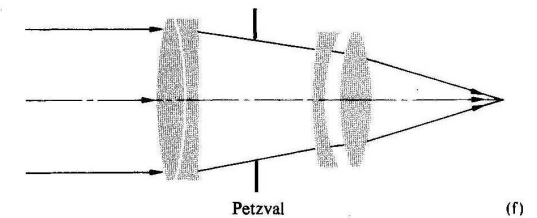
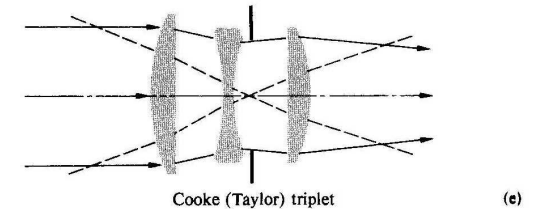
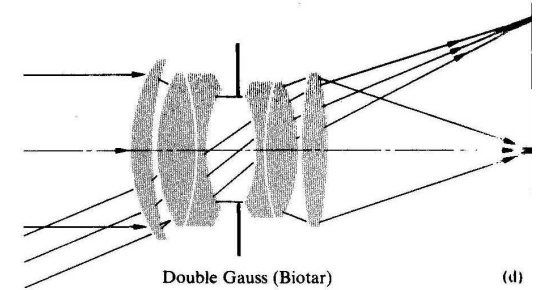
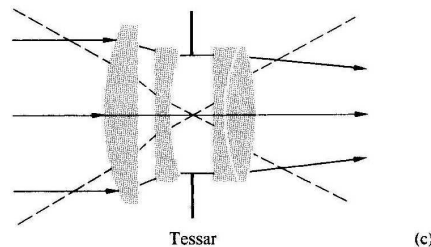
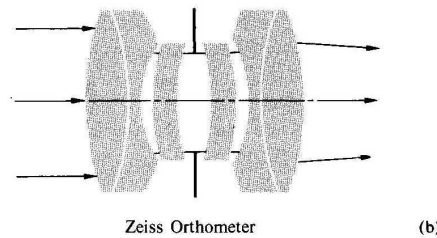
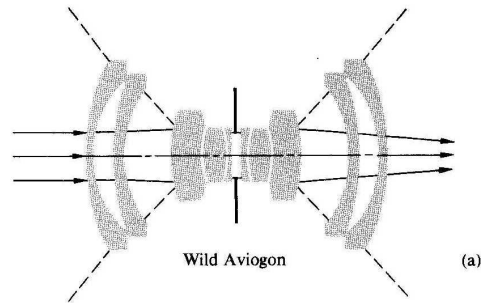
where f_1 is the focal length of the primary, f_2 is the focal length of the secondary (negative), and d is their separation.



Supplementary: Optical Instruments

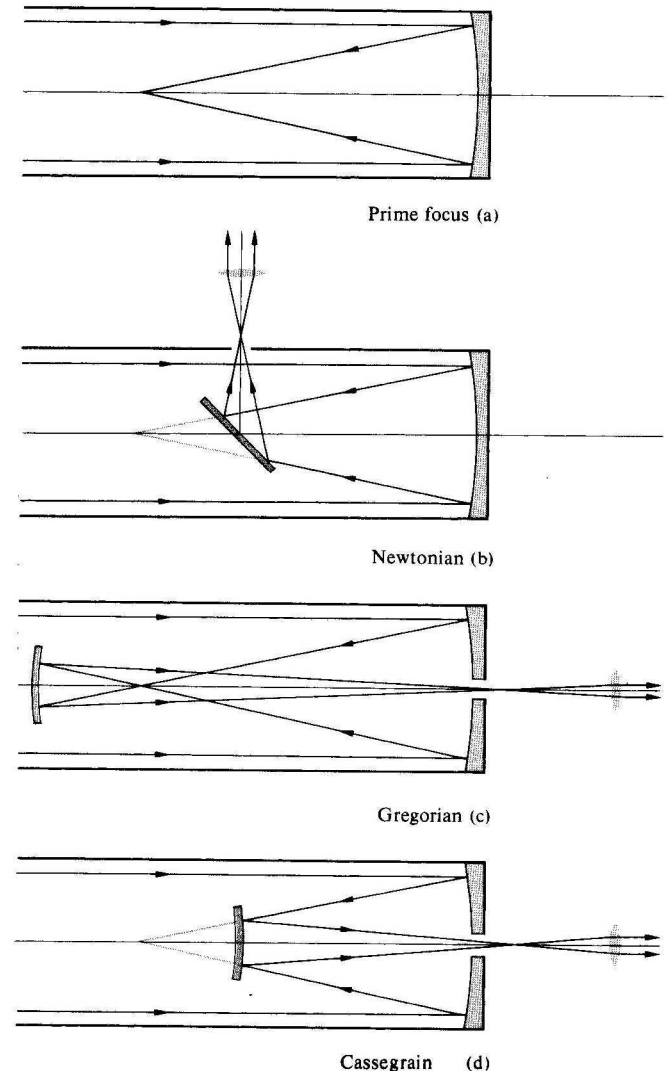
• Camera Lens

- Designed to image onto flat film or digital detector
- Design trade-offs include speed ($f\#$), image quality, field of view, and complexity
- Some lenses work best at mag. ~ 1 (copy lenses)
- Some lenses designed for objects close to infinity



Supplementary: Optical Instruments

- Reflecting Telescopes
 - All modern telescopes use mirrors instead of lenses
 - Big lenses too expensive
 - Need for edge support limits size to ~ 1m diameter
 - Various designs depending on need
 - Prime focus: camera at focus
 - Newtonian: bent light path allows for viewing
 - Cassegrain: convex second mirror magnifies and forms image at rear where complex and heavy instruments can be
 - Gregorian: Longer system, better images than Cassegrain but seldom used.



Supplementary: Optical Instruments

- **Hubble Space Telescope**
 - About the size of WIRO (UW's telescope) but in space so 1000X more expensive
 - Extremely well made optics since above the atmospheric turbulence
 - Contains suite of instruments for imaging and spectroscopy
 - **Diffraction limits angular resolution: $\theta_{\min} = 1.22 \lambda/D$**
- **Similar to Military satellites (KH-11Keyhole)**

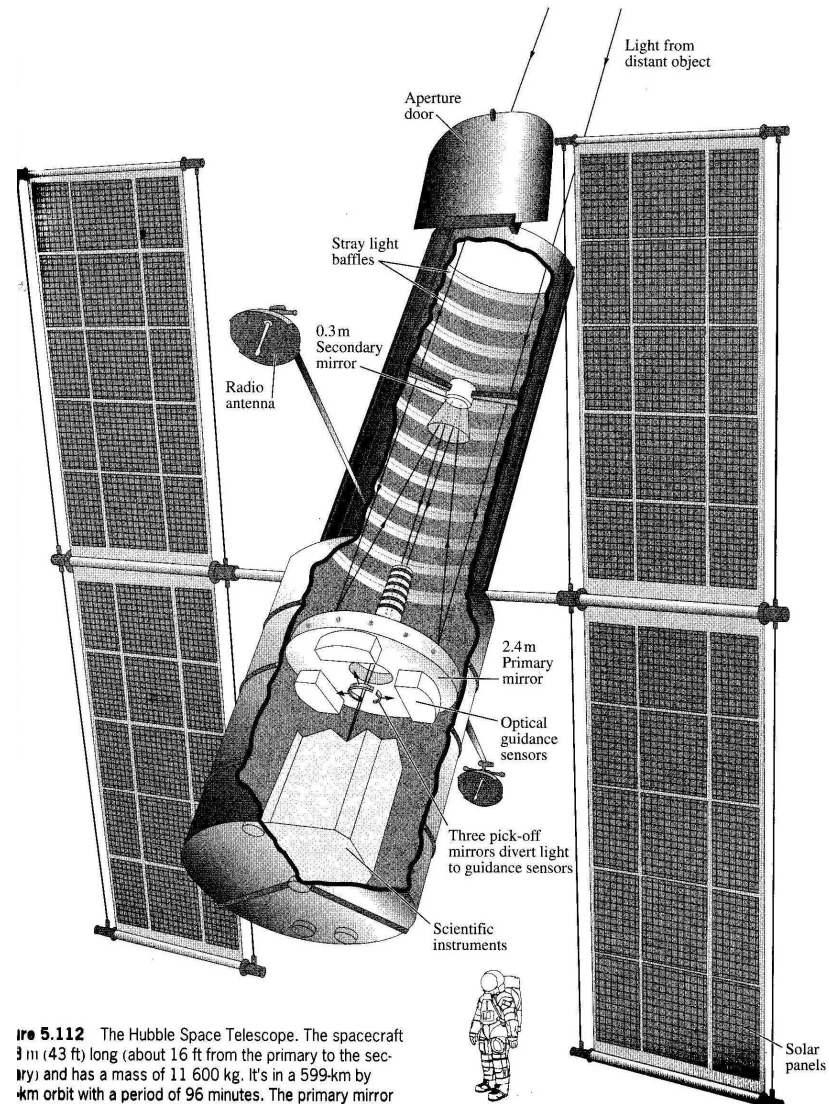


FIG 5.112 The Hubble Space Telescope. The spacecraft 33 m (43 ft) long (about 16 ft from the primary to the secondary) and has a mass of 11 600 kg. It's in a 599-km by 400-km orbit with a period of 96 minutes. The primary mirror

Supplementary: Optical Instruments

- **Hexagon: KH-9 spy satellite uses Cassegrain telescope and big reels of film. Canisters ejected and recovered via parachute and plane. Resolution less than 1 foot. KH-11 is better and uses digital detectors. NROL-36 is latest.**



Supplementary: Optical Instruments

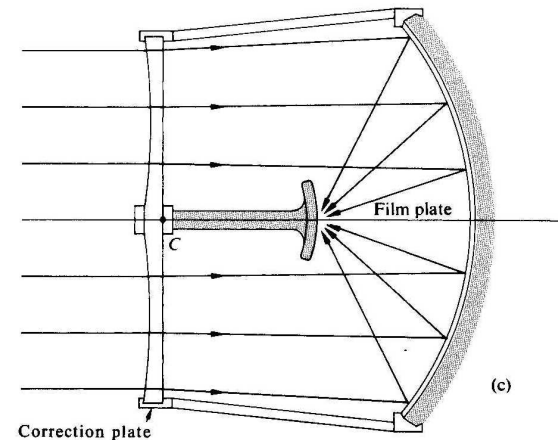
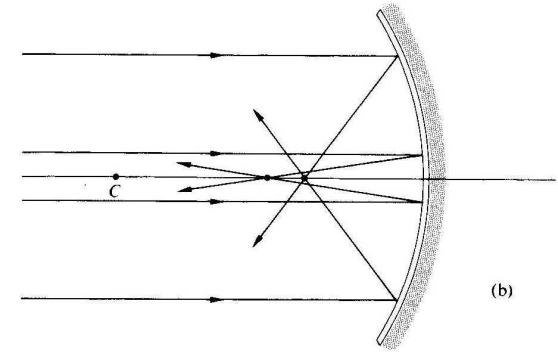
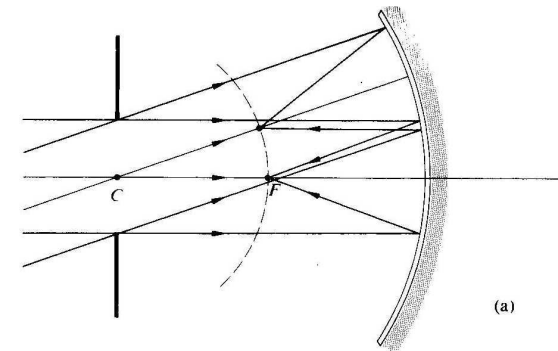
- **KH-7 Declassified Images**
 - Resolution $\sim 10\times$ worse than KH-11
 - KH-12 has Hubble resolution (2.4×10^{-7} radians)



Supplementary: Optical Instruments

- **Schmidt Camera**

- Specialized camera with the best images at the lowest cost
- Found in many scientific instruments, e.g., spectrographs, wide-field cameras
- Aperture stop (a) can limit off-axis rays (see b) and improve image quality but maximum performance requires correction plate (c).
- Disadvantages include:
 - Curved focal plane
 - Interior focus
 - Complex, 4-th order curve on correction plate



Supplementary: Optical Instruments

- Adaptive Optics
 - Earth's atmosphere is highly turbulent (Jet Stream)
 - Causes stars to twinkle
 - Space-based telescopes immune but extremely expensive
 - Fast computers can now sample turbulence and correct it in real-time.
 - Requires complicated and expensive instruments but cheaper than space
 - All the next generations of large telescopes will have adaptive optics

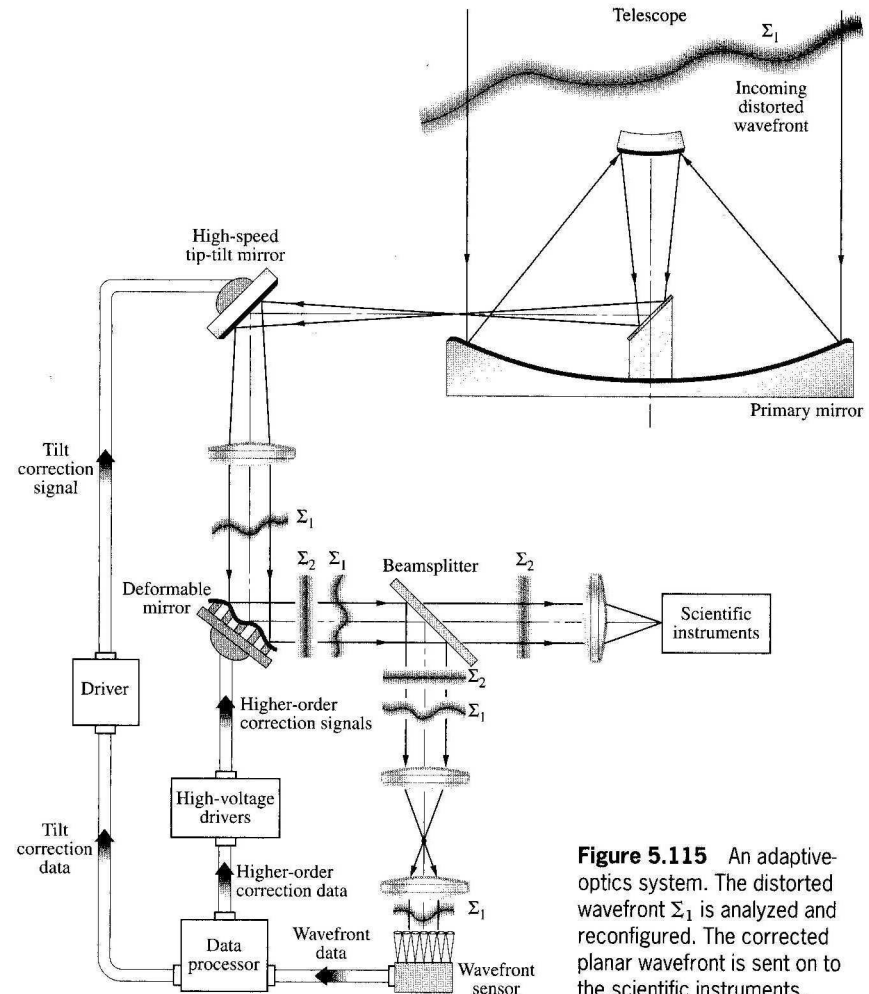
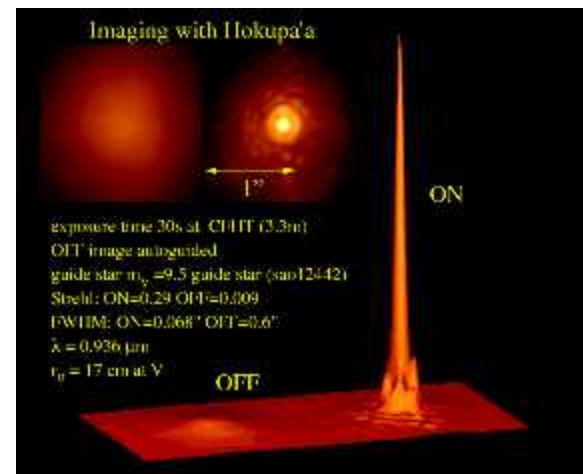


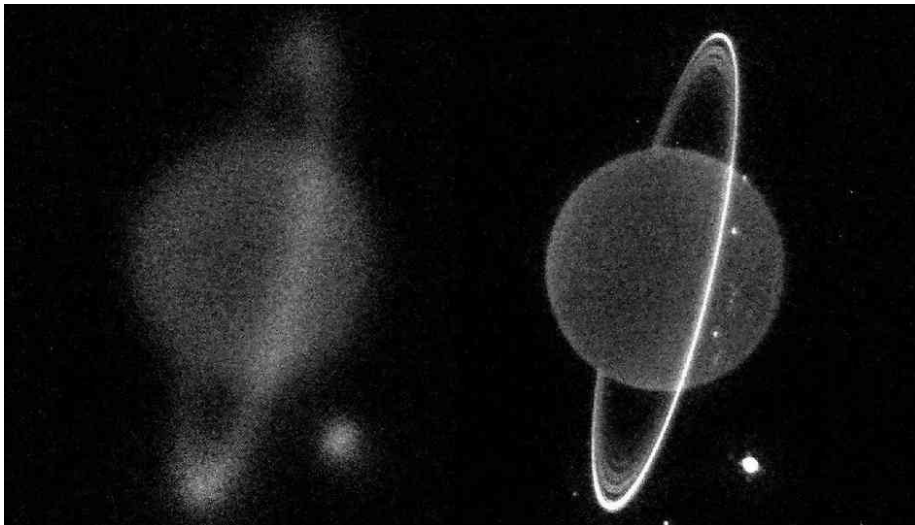
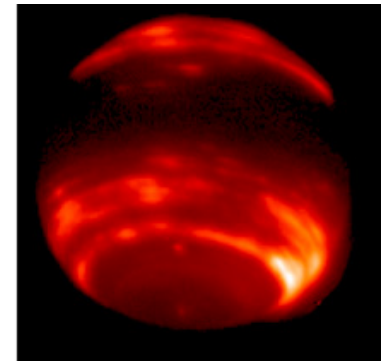
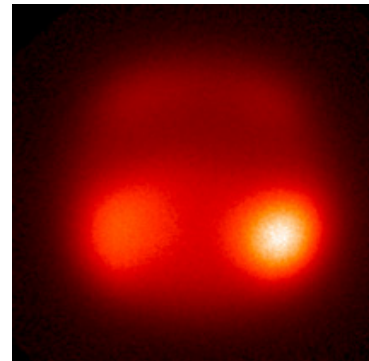
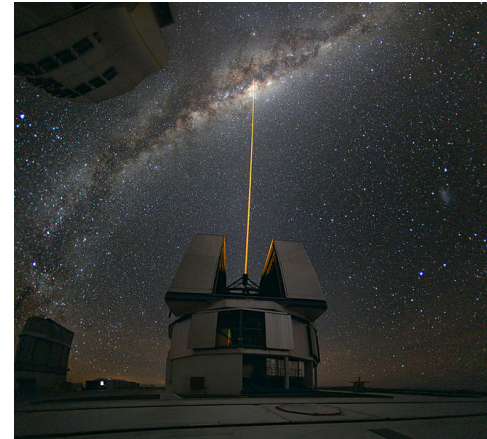
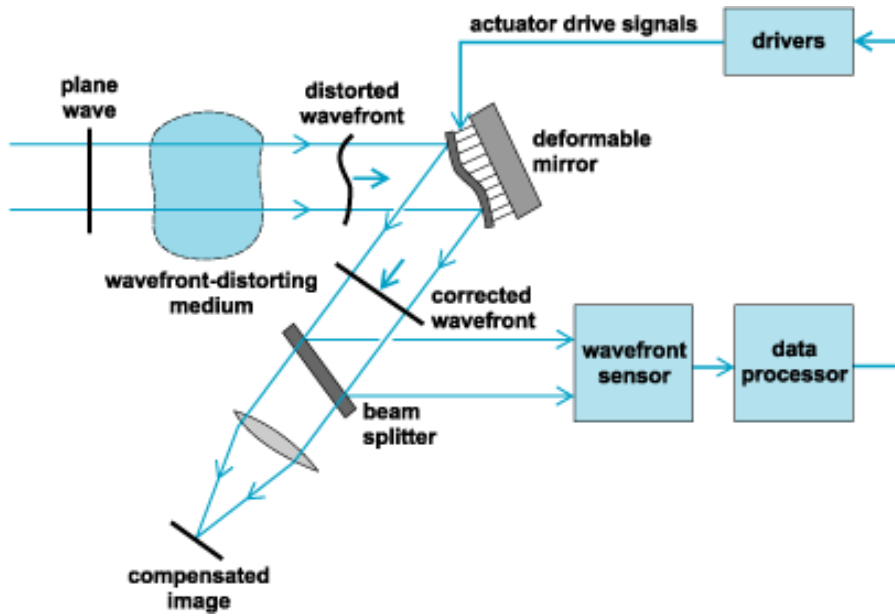
Figure 5.115 An adaptive-optics system. The distorted wavefront Σ_1 is analyzed and reconfigured. The corrected planar wavefront is sent on to the scientific instruments.

Supplementary: Optical Instruments

- Examples of Adaptive Optics (AO)
 - Starfire Optical Range (NM)
 - Lasers excite upper atmosphere for monitoring turbulence
 - Used to image satellites, monitor tests
 - AMOS (HI)
 - Similar to Starfire
 - Astronomical Uses
 - Major observatories moving into AO
 - Will be included in all future, large telescopes

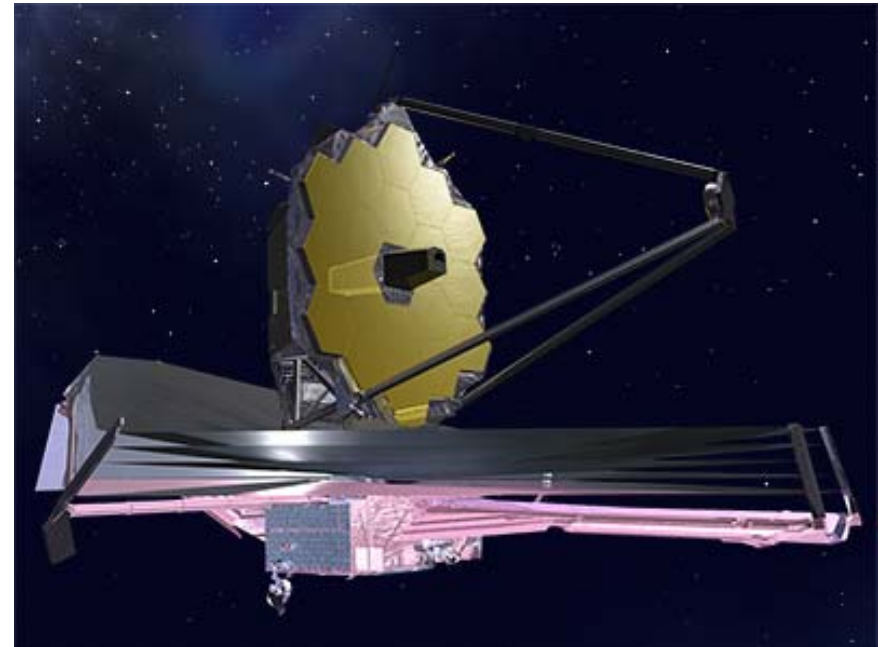
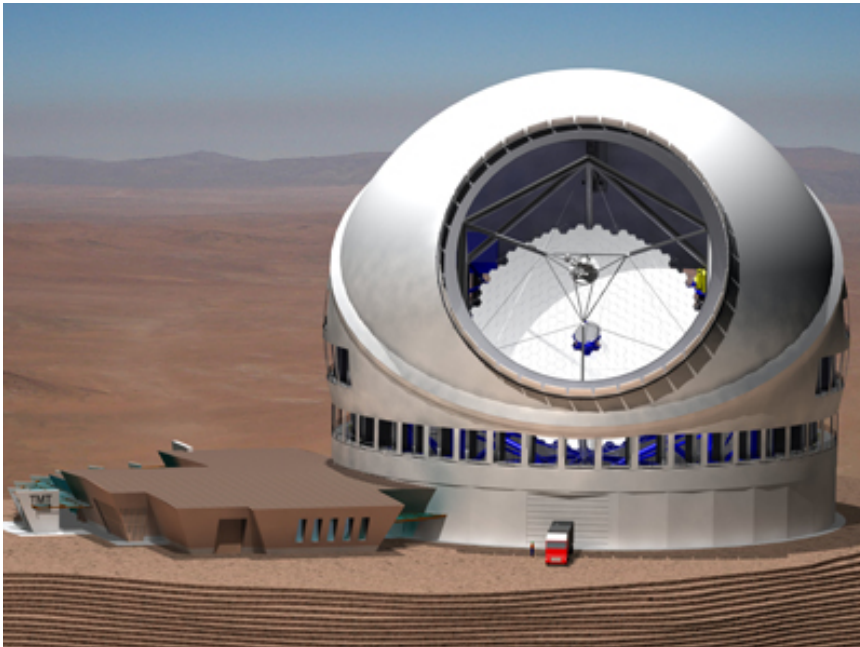


Supplementary: Adaptive Optics Examples



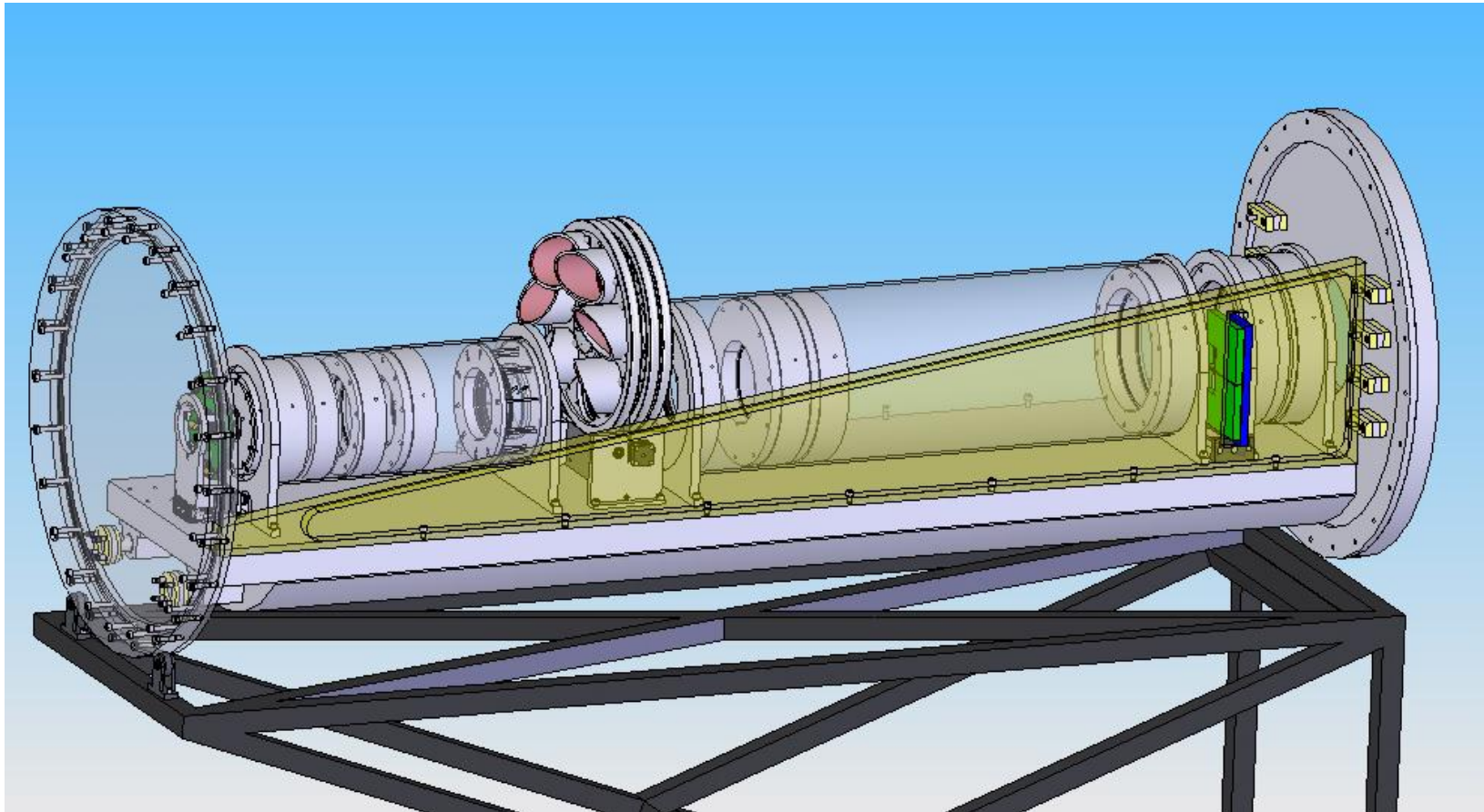
Supplementary: Optical Instruments

- **Examples of Future, Large Telescopes**
 - TMT: Thirty Meter Telescope
 - Giant Magellan
 - James Webb Space Telescope
- **Cost will be ~ \$1B – 5B**
 - Staffing of ~ 200



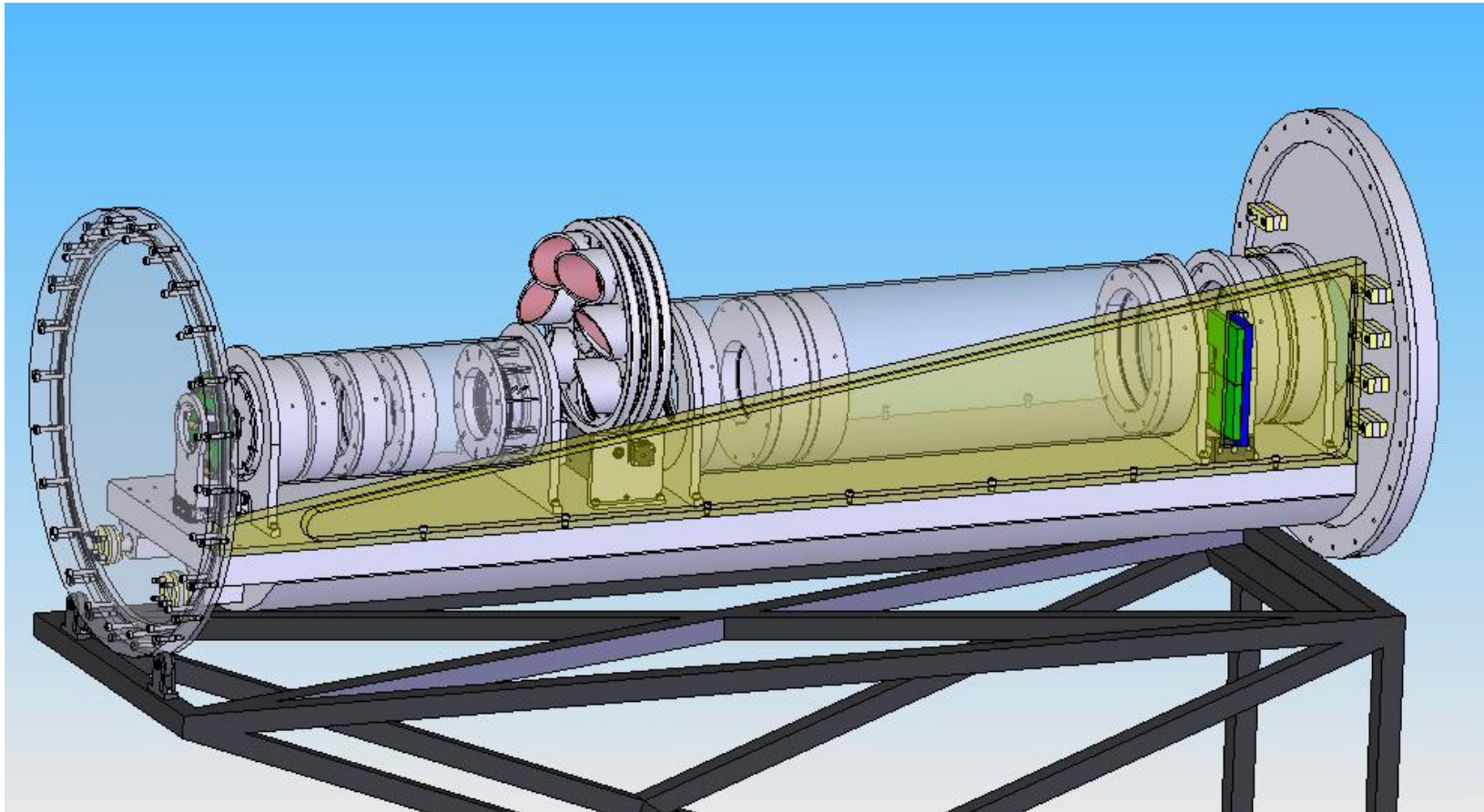
Supplementary: Infrared Instruments

- **Instrumentation for Large Telescopes**
 - Large Imaging Cameras
 - Large Optical and Infrared Spectrographs



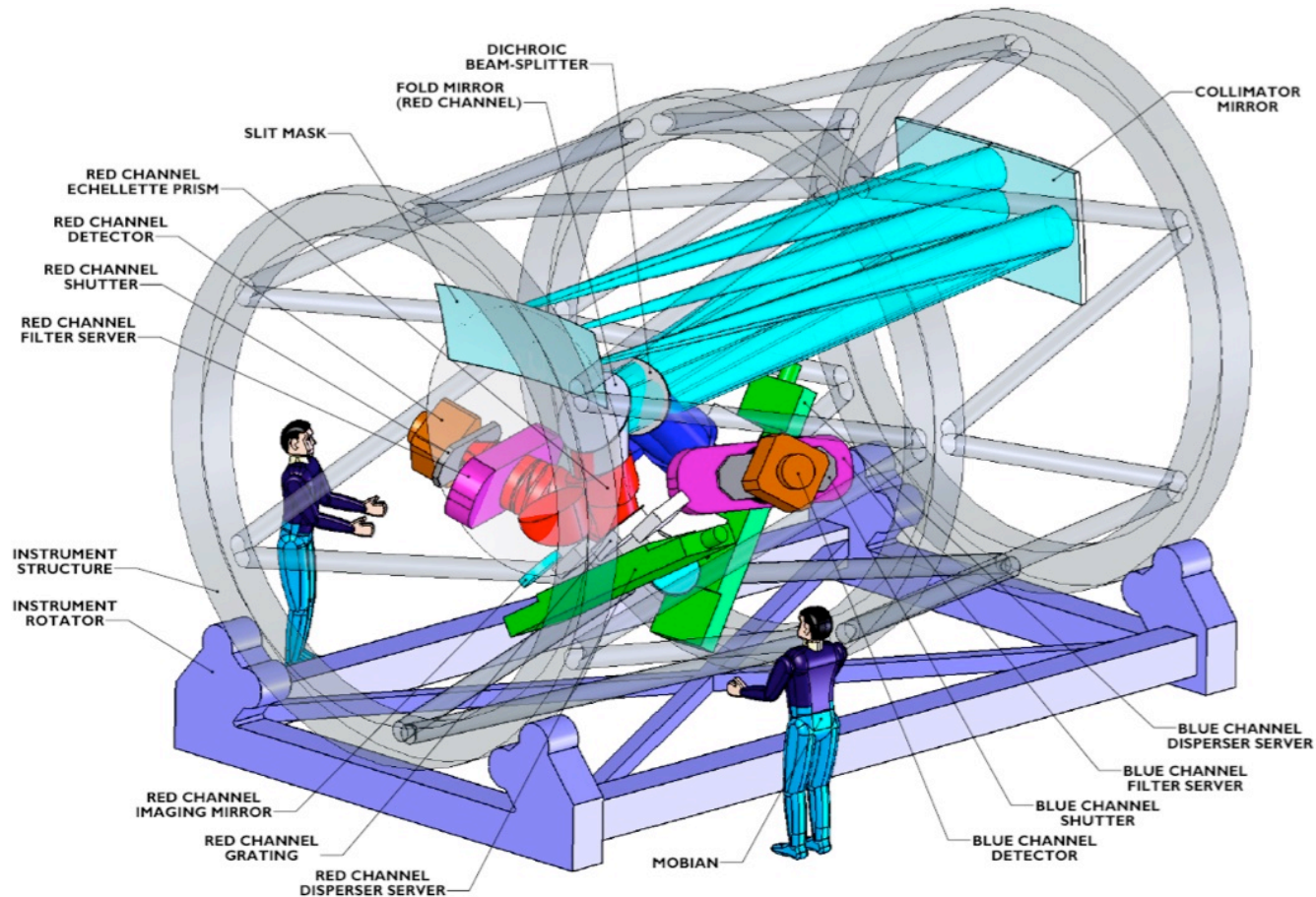
Supplementary: Instruments on TMT

- **NIFAROS**
 - Large Adaptive Optics System
 - Feeds Several Instruments with AO-corrected Beam



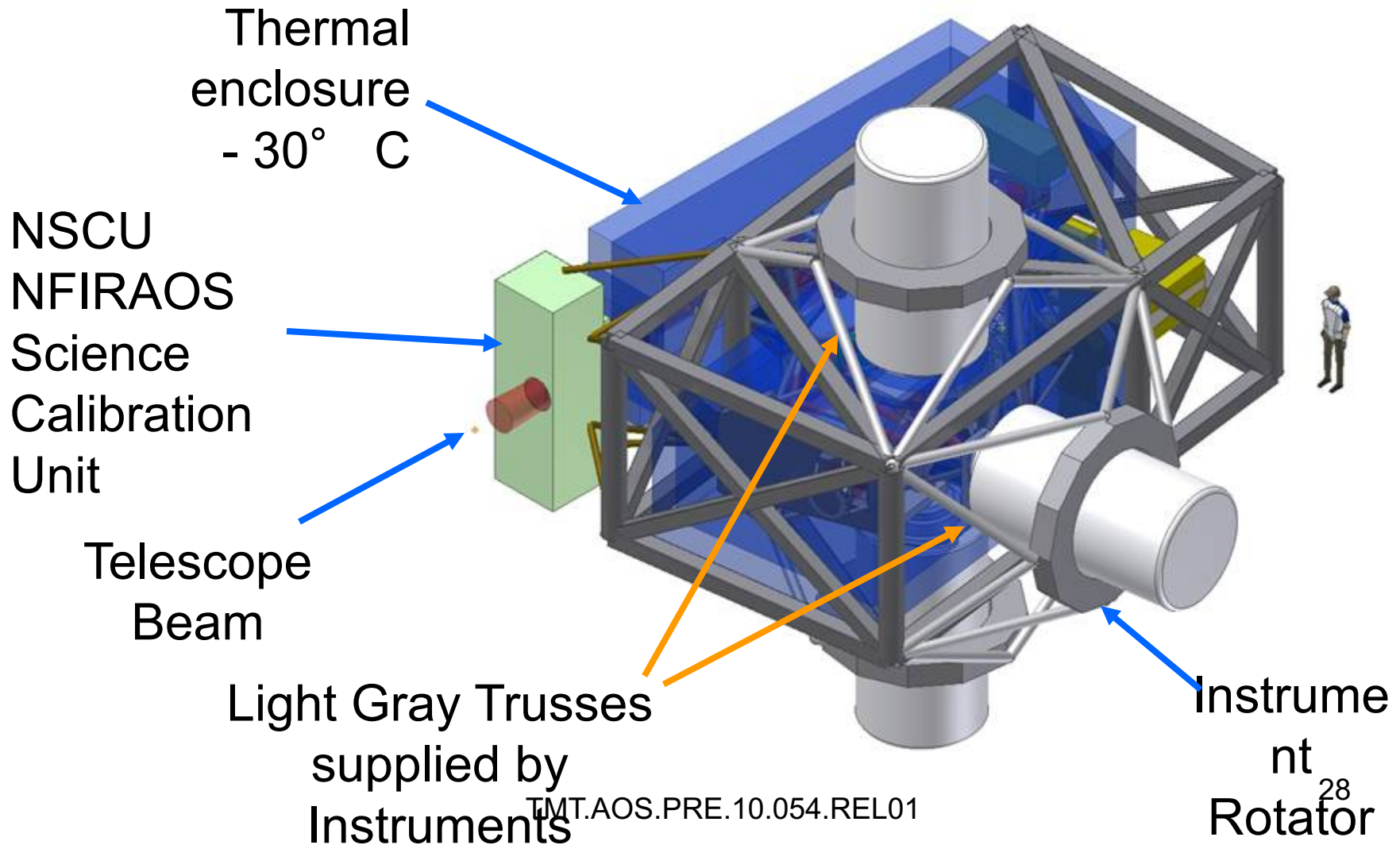
Supplementary: Instruments on TMT

- Instrumentation for TMT
 - WFOS-MOBIE: Wide-Field Optical Spectrograph



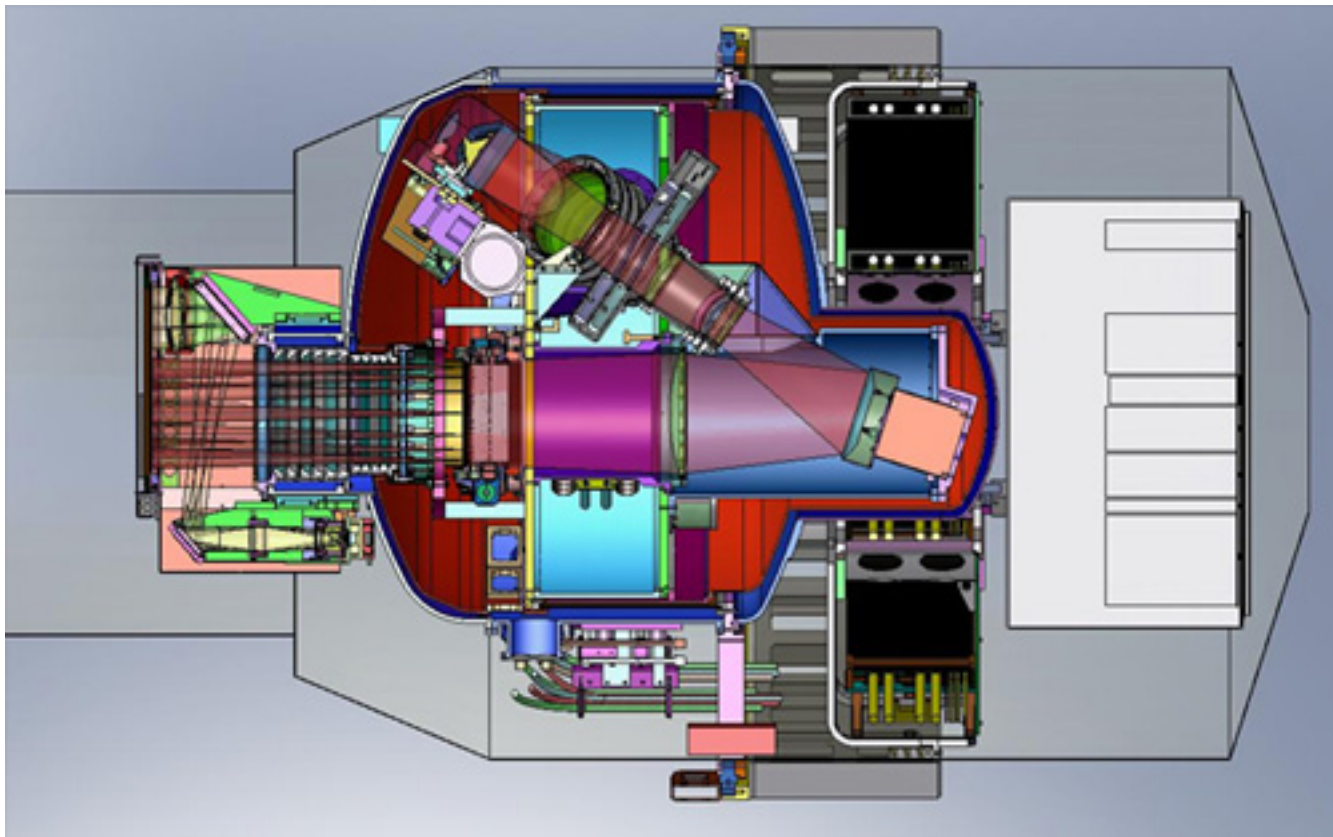
Cooled Enclosure 3

Instruments, and Support Structure



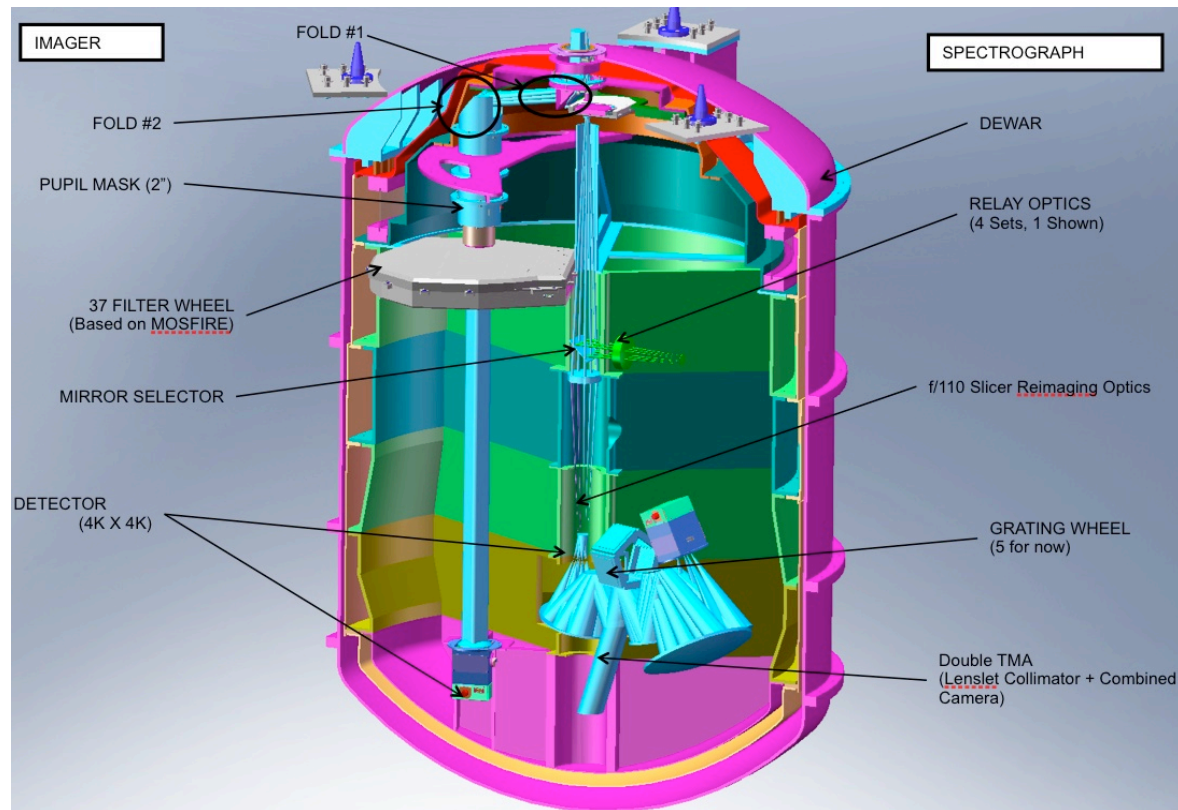
Supplementary: Instruments on TMT

- **Instrumentation for TMT**
 - **IRMS: Infrared Multi-object Spectrograph**



Supplementary: Instruments on TMT

- Instrumentation for TMT
 - IRMS: Infrared Multi-object Spectrograph



Homework this Week (HW #10)

Homework this week due Mon., Oct. 23:

**Chapter 34: #47, 57, 59, 60, 61, 62, 63, 67,
73**

Reading this Week

By Friday:

Finish Ch. 34