Astr 2310 Thurs. March 3, 2016
Today's Topics

- **Chapter 6: Telescopes and Detectors**
  - **Optical Telescopes**
    - **Simple Optics and Image Formation**
    - **Resolution and Magnification**
  - **Invisible Astronomy**
    - **Ground-based Radio Astronomy**
    - **Ground-based Infrared Astronomy**
    - **Space-based Ultraviolet and X-ray Astronomy**
  - **Detectors and Imaging Processing**
    - **Photography**
    - **Charge-Coupled Devices (CCDs)**
    - **Signal-to-Noise and Background**
  - **Spectroscopy**
    - **Grating Spectrographs**
  - **Next Generation Telescopes**
    - **Hubble Space Telescope (HST)**
    - **James Webb Space Telescope (JWST)**
    - **Next Generation Ground-based Telescopes**

Chapter 6 Homework

Chapter 6: #1, 2, 3, 4, 6

- Due Thursday March 31

Optical Telescopes - I

- **Telescope Optics**
  - **Powers of a Telescope:**
    - **Light Gathering Power: Bigger Telescopes Collect More Light (see fainter things):**

      LGP ~ D^2

    - **Angular magnification**

      A telescope satisfies the thin lens equation with the object at infinity. Thus the imageis formed at the focal length of the telescope. The scale is given by the arc-length formula:

      $s = f\theta$ where f is the focal length (mm) and s is a linear scale (eg., mm).

      Thus, the angular magnification is given by the focal length and 1/f gives the "plate scale" (radians/mm). This is commonly expressed in arcsec/mm in which case:

      θ/s (arcsec/mm) = 206265/f (mm)

    - **Minimum resolution angle:**

      Diffraction from a circular aperture limits the angular resolution of the telescope:

      $\theta_{min} = 206265\ \lambda/D$

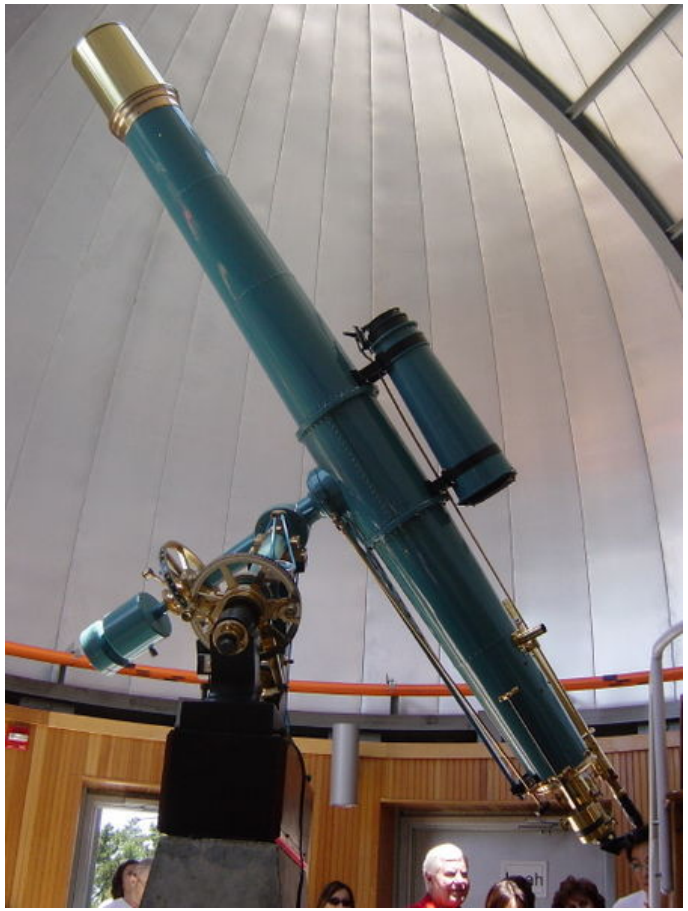
Optical Telescopes - II

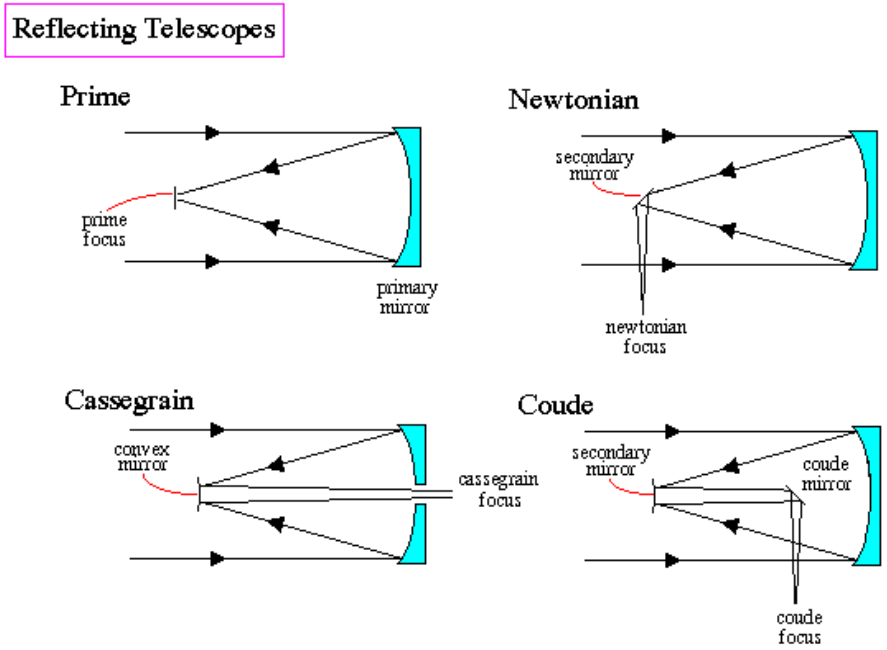
- **Refracting Telescopes**

  The refracting telescope forms an image using a lens. Inexpensive telescopes but research refractors are of historical interest only.

- **Reflecting Telescopes**

  All modern research telescopes use a mirror to collect light. Several different types (see figure

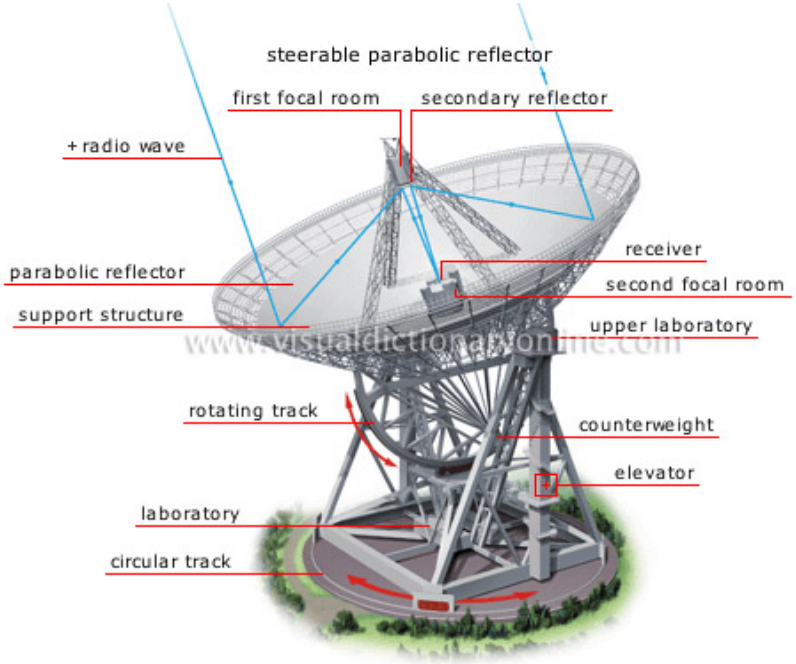


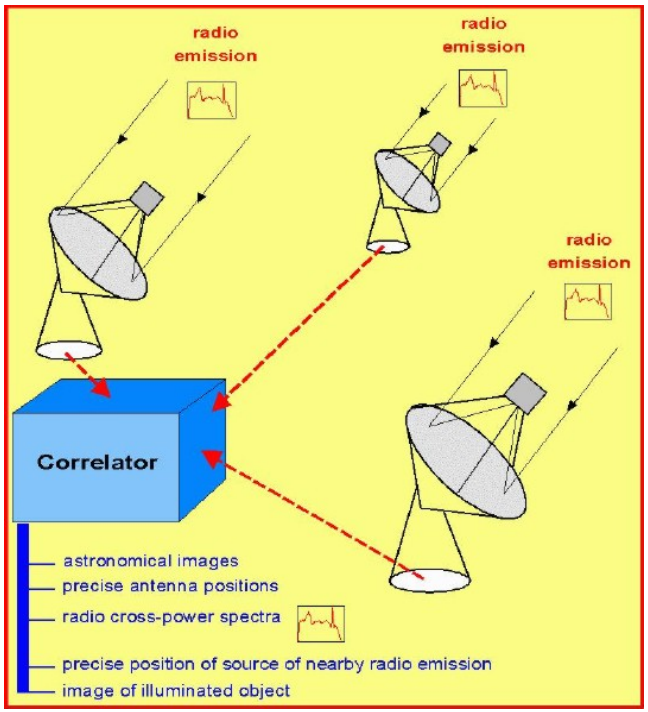


Invisible Astronomy

- **Ground-based Radio Astronomy**
  - **Radio atm. window allows ground-based radio astronomy**
    - **Radio technology is well-developed**
    - **Diffraction limit of largest radio telescopes is huge**
      - **Consider a 300-meter dish at λ = 10 cm**

        $\theta_{min} = \lambda/D = 0{,}1/300 = 3.33 \times 10^{-4}$ radian = 1 arcmin
    - **Radio Interferometry (aperture synthesis)**
      - **Use signal delay between multiple telescopes to simulate a bigger aperture**



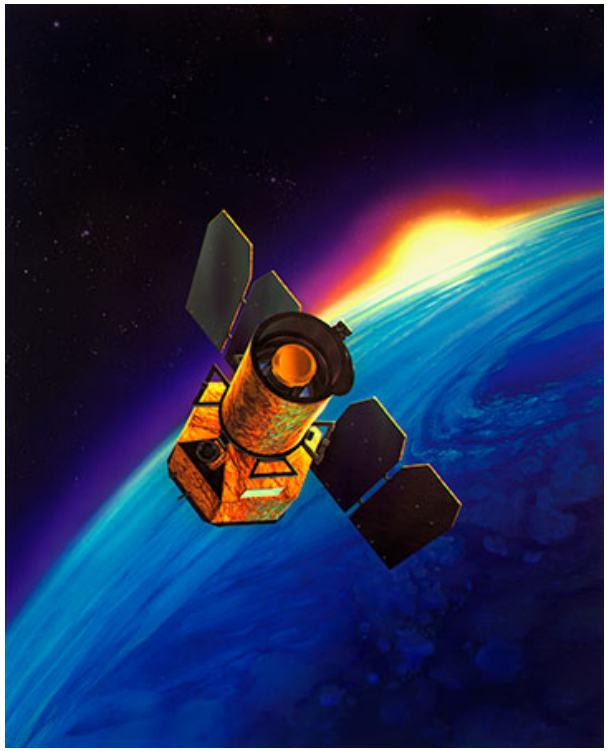


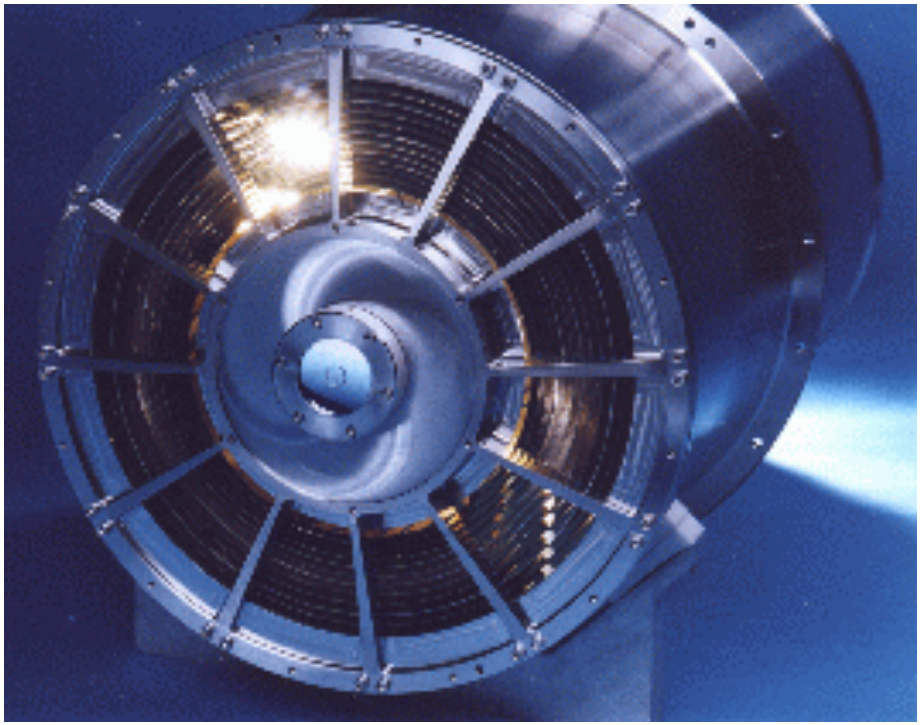
Ground-based and Space-based Infrared Astronomy

- **Infrared Windows (between the water absorption bands) allows ground-based infrared astronomy**
  - **Lower extinction in the infrared**
    - **Star forming regions**
    - **Center of the Galaxy**
  - **Cool stars and dust**
  - **Redshift of distant objects in the expanding universe**
    - **Visible light redshifted into infrared**
- **Longer Wavelength Infrared must be Observed from Space**

Space-based Ultraviolet and X-ray Astronomy

- Earth's atmosphere absorbs ultraviolet and x-ray photons
  - Ultraviolet telescopes use conventional technology (e.g., GALAX)
    - Hottest stars emit in UV
    - Accreting gas within interacting binary stars
    - Quasars and other active galactic nuclei
    - X-ray telescopes require grazing incidence reflecting optics
  - X-ray telescopes require grazing incidence reflecting optics to focus light (grazing light doesn't penetrate the mirror)





Detectors and Image Processing

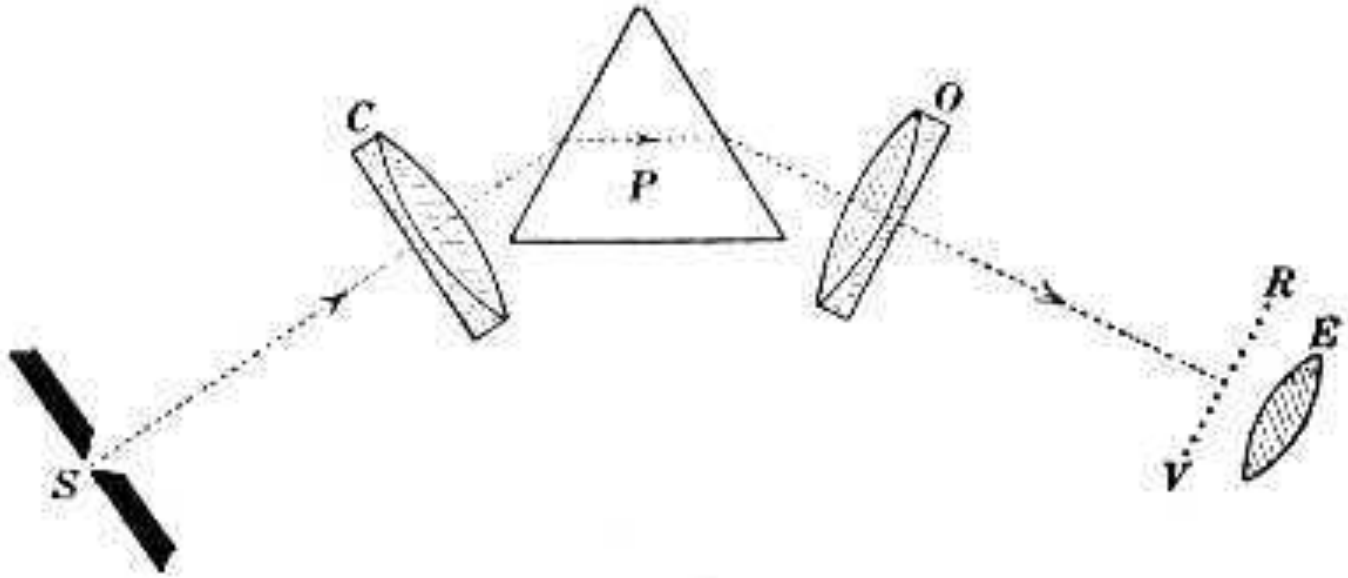
- **Photography**
  - In the old days, astronomical data was recorded on photographic film
    - Film could be digitized for computer analysis
    - Film has a low quantum (detection) efficiency (~2%)
    - Can't be reused and must be developed.
    - Wavelength response different depending treatment
- **Digital Detectors**
  - All modern detectors are digital
  - Charged Coupled Detectors (CCDs) most common
    - Grid of electrodes create potential wells in Silicon
    - Electrons created by photons collected into "pixels"
    - Electrodes manipulated to transport the charge to an external readout amplifier
    - Signal digitized and stored on computer as a digital image.
    - Sizes range from 4 to 16 megapixels or more with mosaics

Pan-Starrs Camera

Largest mosaic under development is the 1.4 G pixel Pan-Starrs Camera

Spectroscopy (conceptual)

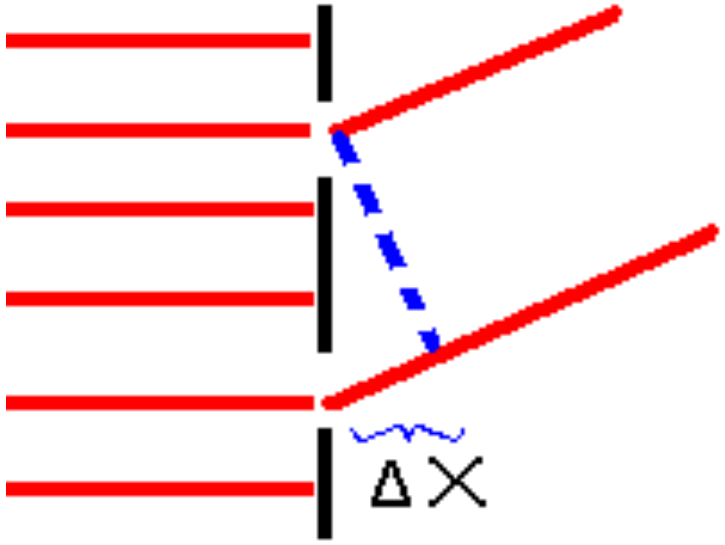
- **Prism Spectrograph**
  - **Dispersion of light by a prism can be used to make a low resolution spectrometer**
  - **Slit isolates region of telescope's image**
  - **First lens makes light parallel (collimated)**
  - **Prism disperses light by color (refraction changes angle according to wavelength)**
  - **Second lens images slit onto a focal plane but at different positions according to wavelength (a spectrum)**

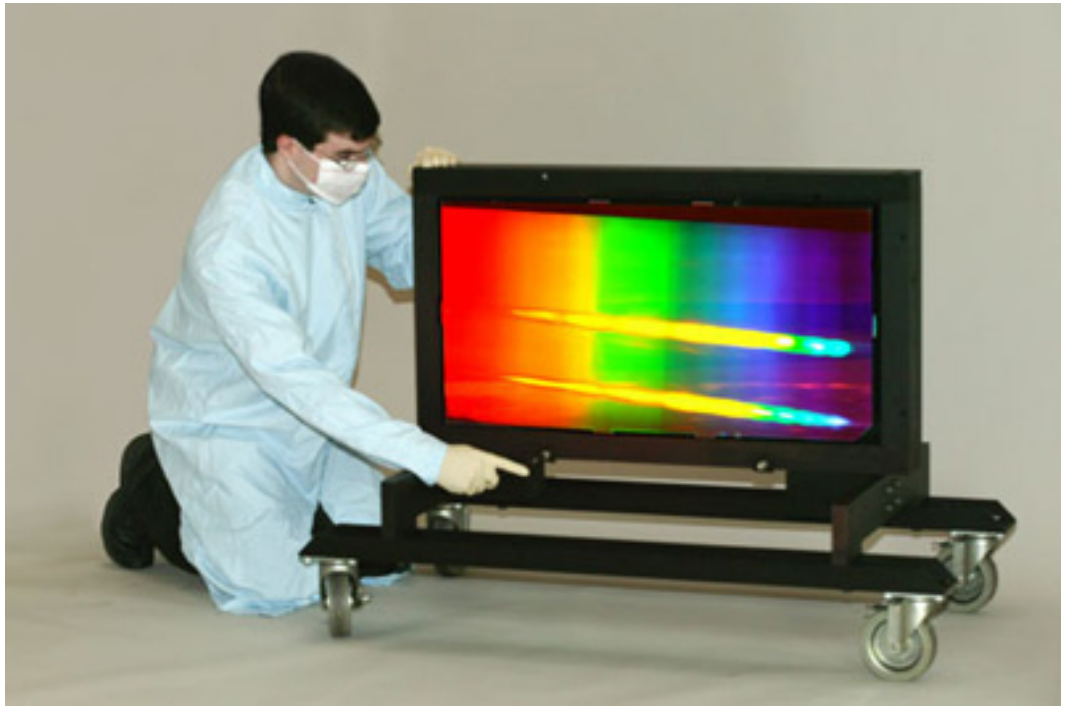


Diffraction Grating

- **Parallel groves act like multiple slits**
  - **Reflected light interferes constructively when path difference is an integer number of wavelengths.**
  - **Parallel light incident on surface reflects and interferes with itself**
    - **Angle of reflected light depends systematically with wavelength**

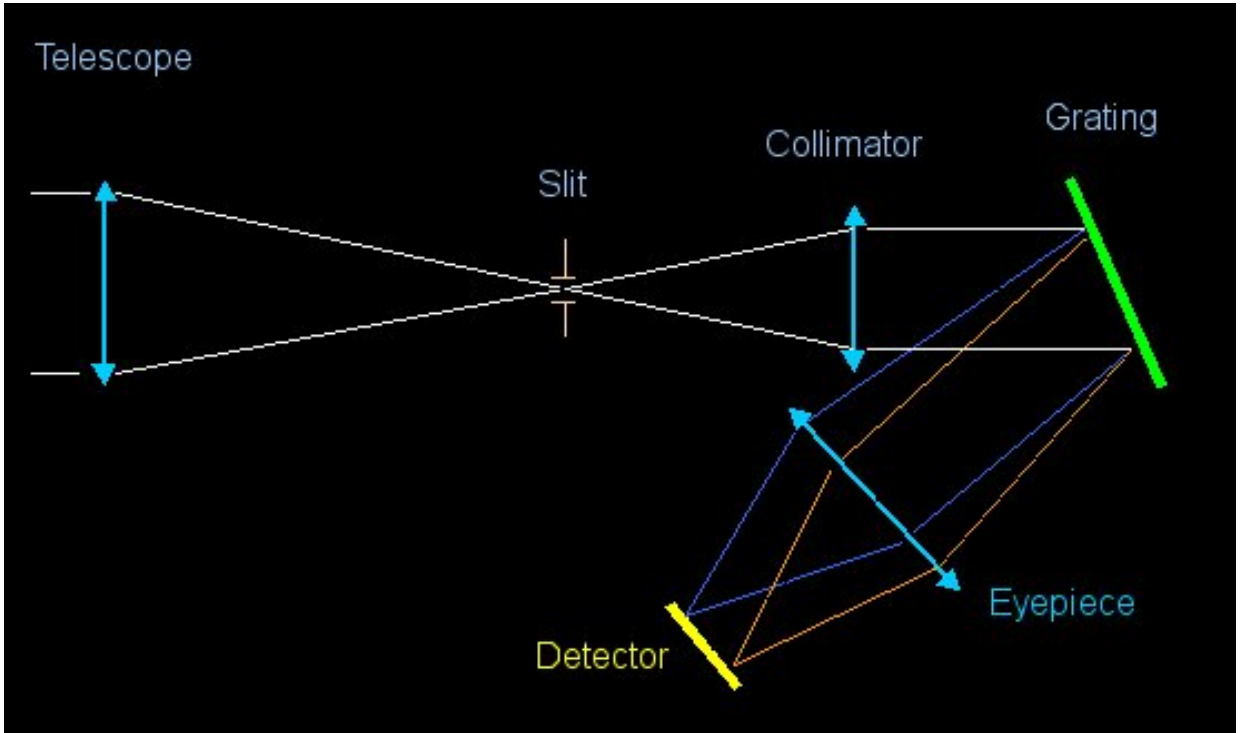
$n\lambda = d \sin\theta$ where n is the order (1, 2, ..), λ is the wavelength, and θ is angle





Grating Spectrometer

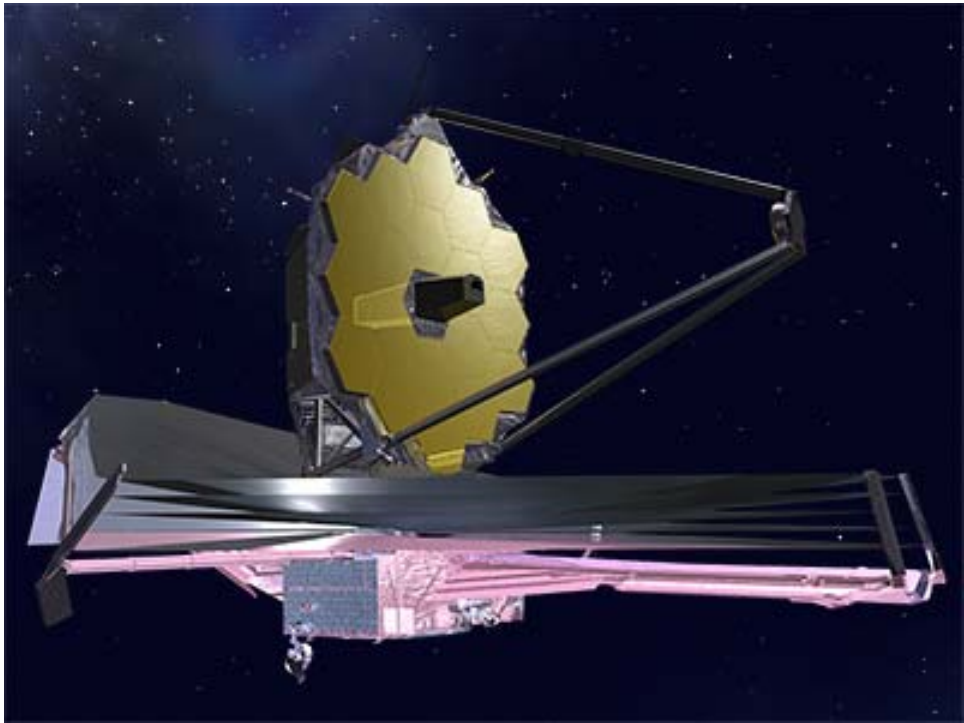
- Grating spectrometers offer more versatility than prism spectrographs and are now standard.
- A sit is used to isolate a position in the telescope's image plane
- A collimating lens is used to form parallel (collimated) light.
- The collimated light reflects from the grating with the angle a function of wavelength
- A camera is used to image the spectrum onto a detector



or Camera

Next Generation Telescopes

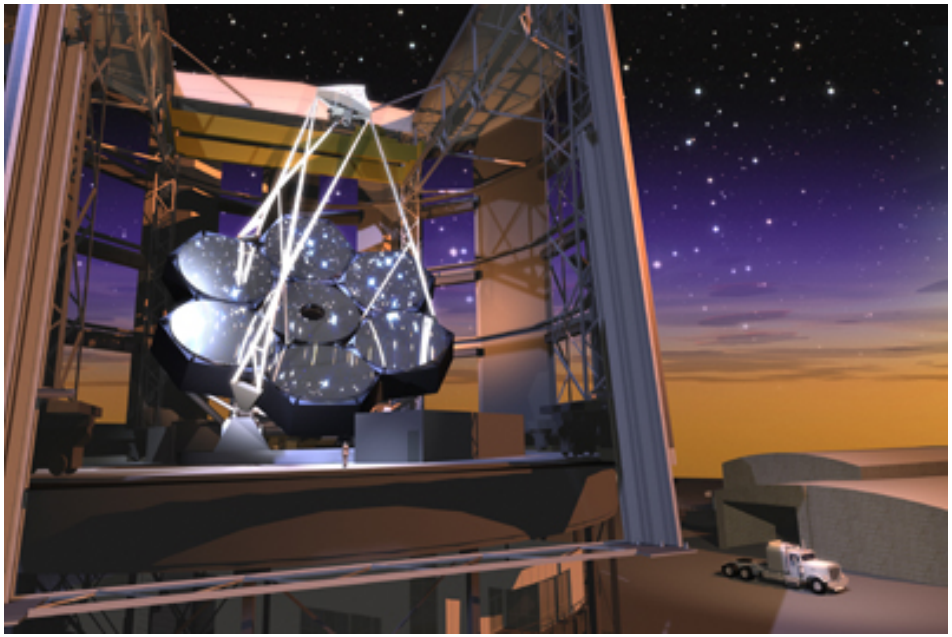
- **Hubble Space Telescope**
  - **Though old, Hubble is the first modern space-based telescope**
- **James Webb Space Telescope**
  - **The next generation of space-based telescopes**
- **Next Generation Ground-based Telescopes**
  - **Ground-based telescopes will use adaptive optics to achieve diffraction limited images**

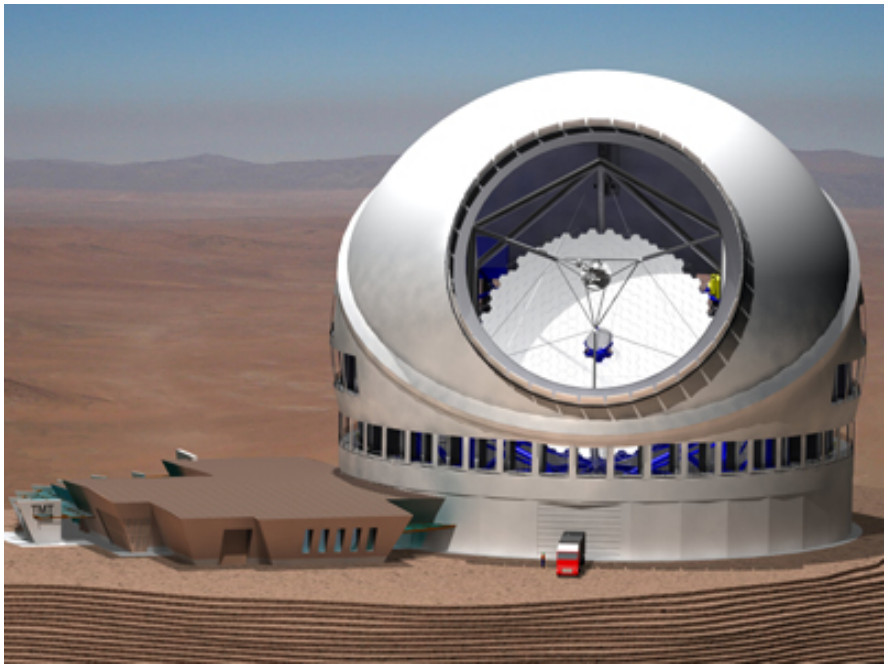


Next Generation Ground-based Telescopes

- **Ground-based telescopes will use adaptive optics to achieve diffraction limited images**
- **Can be much larger than space-based telescopes**

Giant Magellan 24-meter Telescope and the Thirty Meter Telescope





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