Astro 426/526

Fall 2019

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Lecture 5: Telescope Design

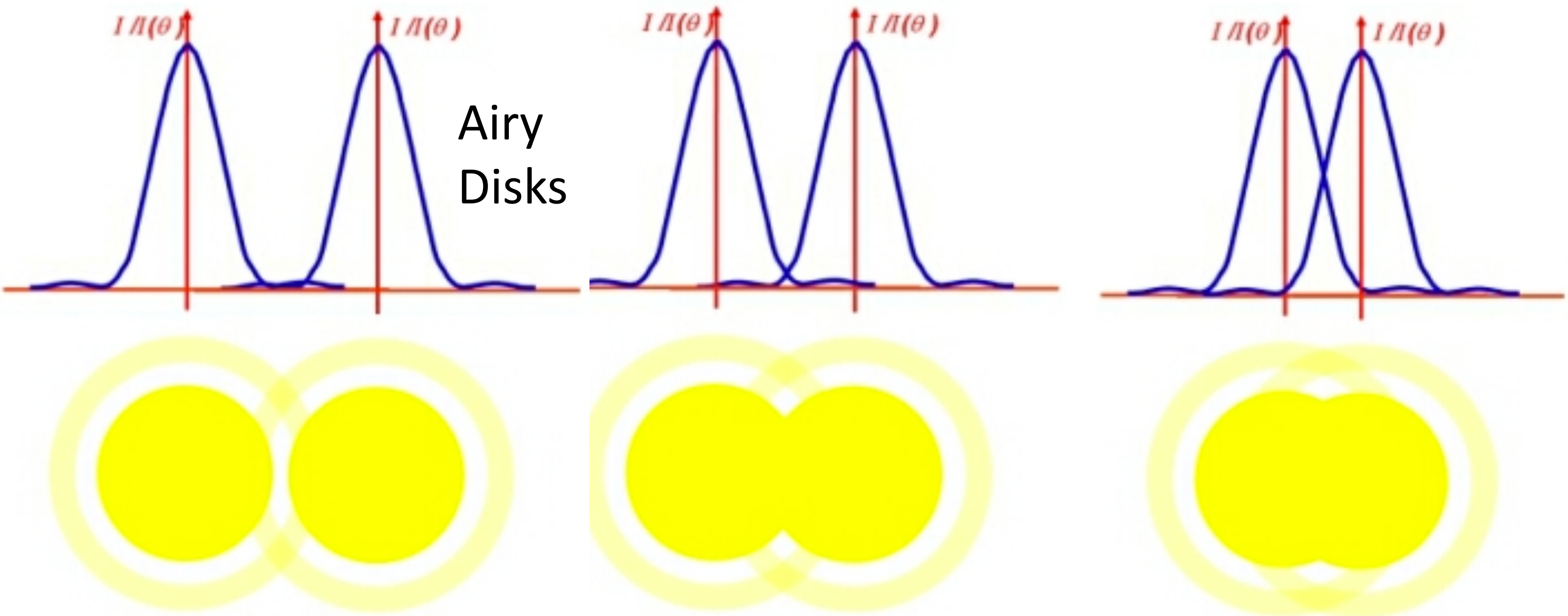
Reminder from last week

- Fundamental limits in (classical) optics come from thermodynamics and the wave nature of light
  - Brightness is conserved
  - Diffraction limits the resolution, which depends on the size of the aperture
  - Etendue/throughput/AΩ is conserved, and also depends on size of aperture

Telescope Design

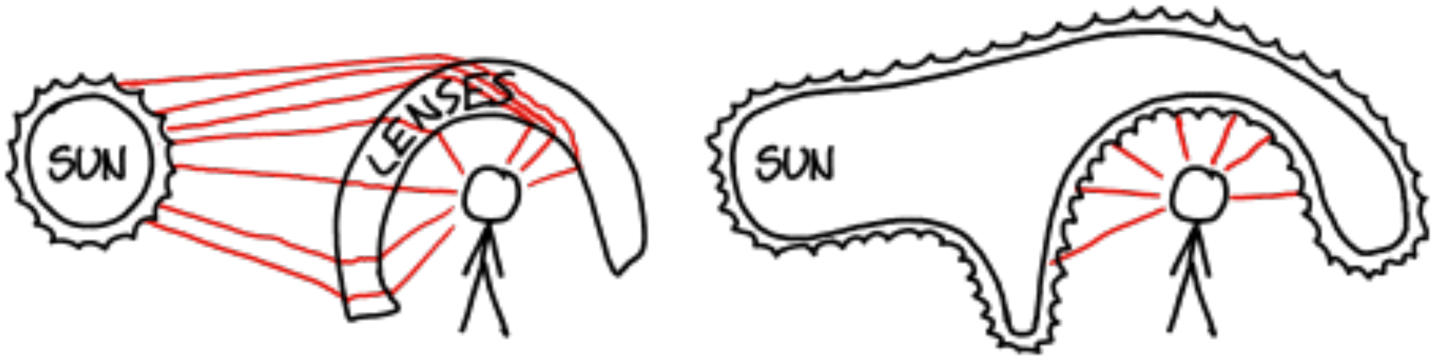
- Build the largest telescope you can afford
- Provide diffraction-limited images over as large of an area as we can cover with detectors
- Design it to be efficient
- Shield the signal from unwanted contamination
- Adjust the final beam to match the signal optimally onto detectors

Resolving limit (Rayleigh Criterion)



http://astronomy.swin.edu.au/cosmos/R/Rayleigh+Criterion

Conversation of brightness



An Ideal Telescope

- An ideal telescope would still have diffraction-limited resolution
- At best, it re-creates the surface brightness that it is imaging

A simple telescope

- See lecture notes

Practical Limitations

- For many situations, optics behave far from ideal
- **Aberrations** are introduced by these nonideal elements
- Telescope designs are often based on minimizing the kinds of aberrations that matter the most for that specific measurement
- Adding more elements can counteract some kinds of aberrations, but leads to more cost and complexity

Geometric optics

- Wavelength of light must be short compared to the dimensions of the optical elements
- Use Snell's Law/Fermat's Principle for refraction and reflection
- Everything is well behaved and easy to describe within the **paraxial region** – where the small angle approximation is accurate (also known as the **first-order region** – where these first-order approximations are accurate)
- Within this region, imaging quality is ideal

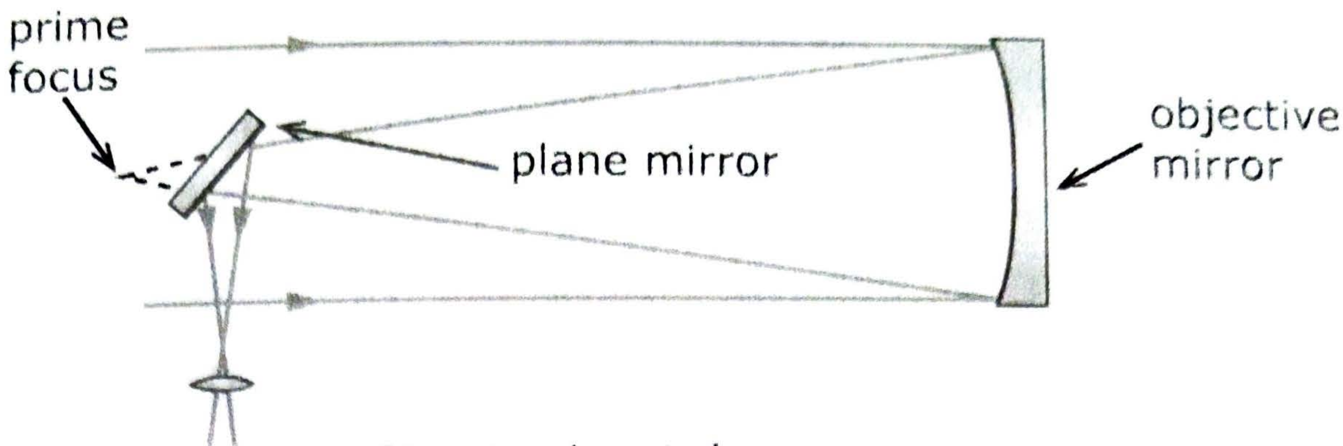
Basic optical telescope types

- Reflecting telescopes are commonly used because they are **achromatic**
- The primary element collecting light is a **reflector** (lenses may still be necessary elsewhere)
- The basic telescope types have a **paraboloidal primary mirror** to collect and focus light, and some sort **of secondary mirror** (sometimes called m1, m2)
- Prime-focus telescope is simplest design, and has only a primary mirror (Figure 2.1 from text)

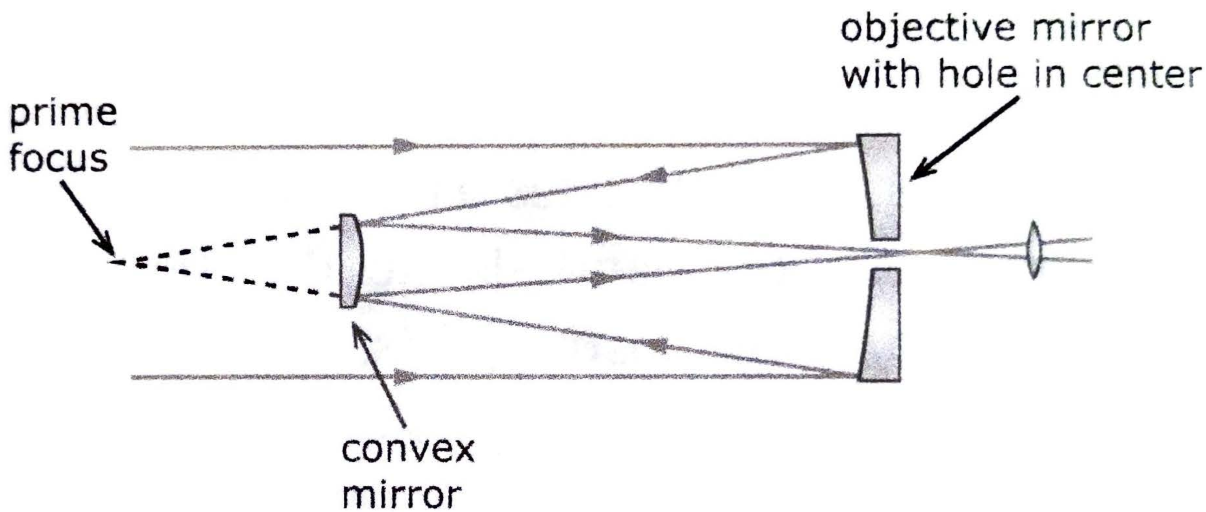
Basic reflecting telescope types

- See lecture notes

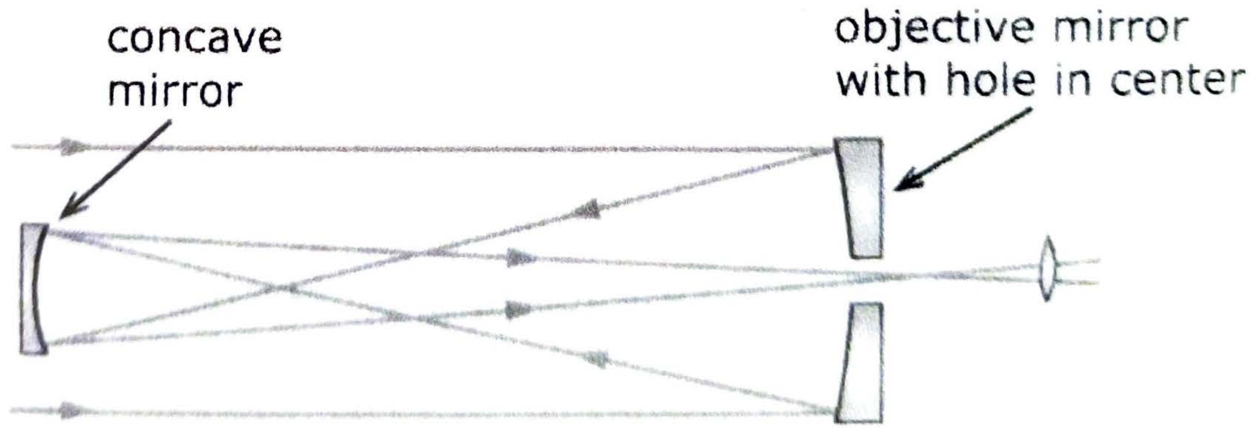
2.2 Telescope design



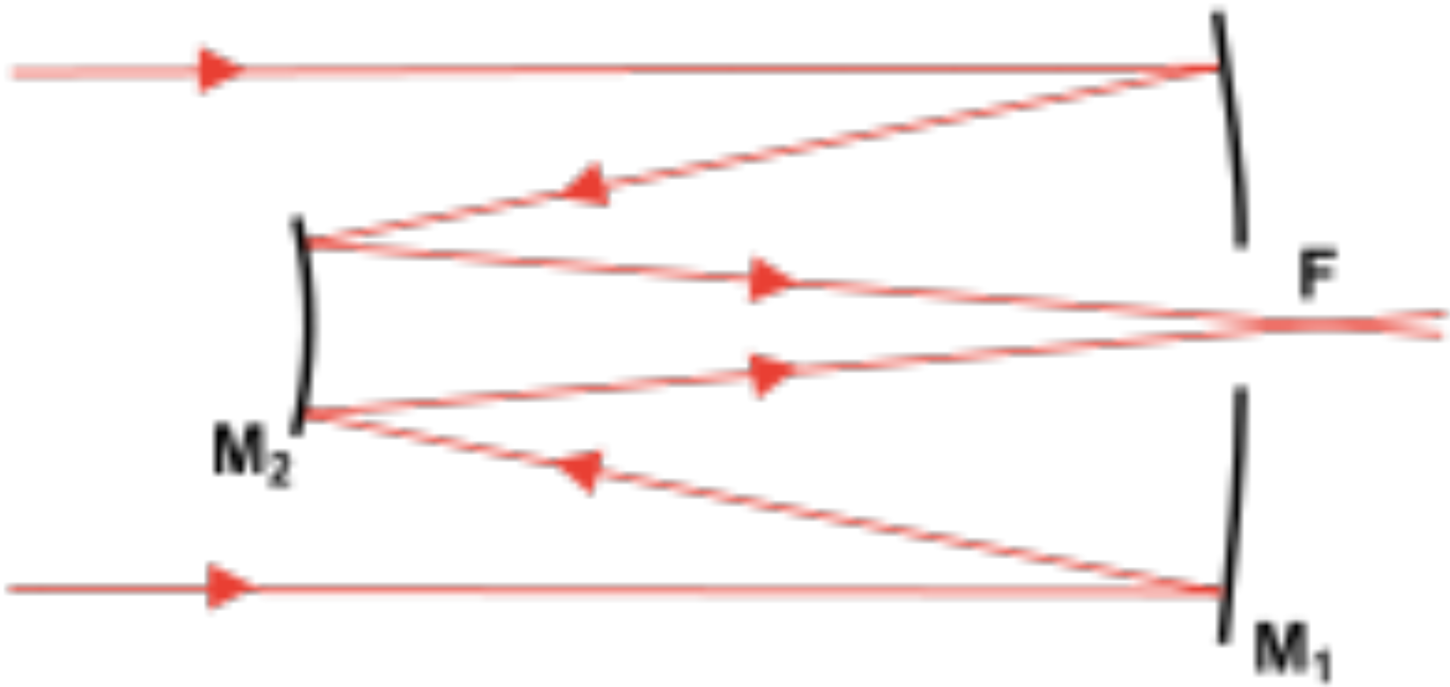
Newtonian telescope



Cassegrain telescope



Gregorian telescope



Ritchey-Chrétien

Telescope mounts

- Historically, telescopes were often on an equatorial mount
  - One axis is aligned with a celestial pole, making it much easier to track celestial objects
  - Amateur telescopes still commonly use this kind
- Modern telescopes are typically on a computer-controlled altitude-azimuth (alt-az) mount

Telescope parameters

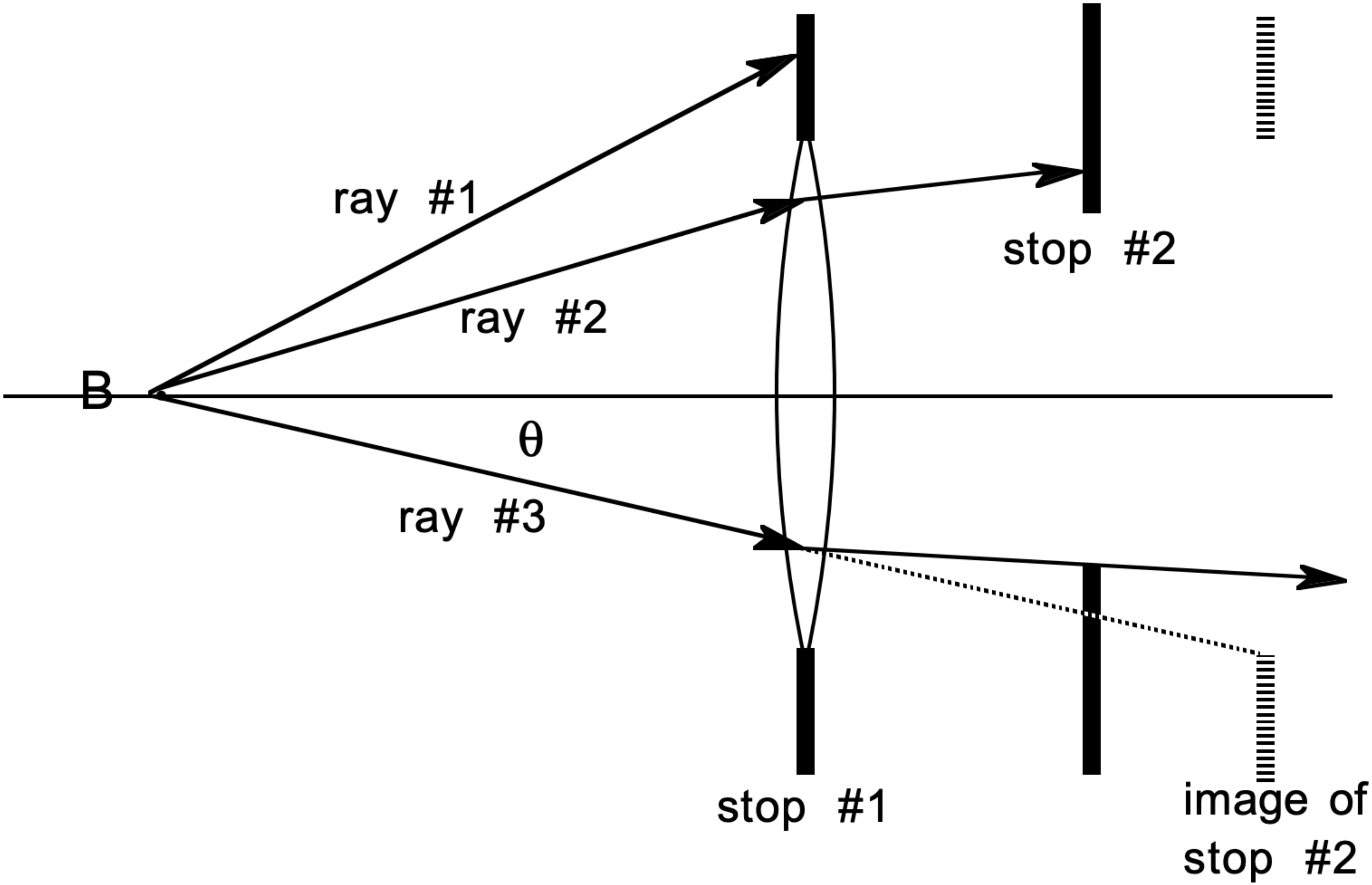
- Focal length **f** – measured by projecting rays from focus back to match the diameter of the aperture
- **f-number** aka f-ratio aka focal ratio F = focal length/aperture
  - $F = f/D$
  - Dimensionless quantity, usually written like “f/10”
  - Energy per unit time onto a single pixel is proportional to $(f/D)^{-2}$
  - Large f-number: “slow”
    - High magnification, but lower brightness (longer exposure time needed)
  - Small f-number: “fast”
    - Shorter exposure time needed
- “effective focal length” = Magnification * f_primary
- For example, a telescope can be spec’d by its primary mirror size, its focal length, and the f-ratio of its secondary

Telescope parameters

- **Plate scale** – how to translate physical units at the focal plane to projected area on the sky
  - How big will this 1 arcmin object appear on my sensor?
  - “Magnification” depends on focal length of primary mirror, and effective focal length of secondary (or eyepiece)
    - For an amateur telescope, $M = f\_primary/f\_eyepiece$
  - $f\_equivalent = M * f\_primary$
  - Probably know f_primary and F_secondary=f_equivalent/D
  - $M = F\_secondary * D / f\_primary$
  - See lecture notes

Telescope Parameters

- **Field of view**: total angle on the sky that can be imaged by the telescope
- **Stop**: a physical mechanism to limit the bundle of light that can pass through
    - **Aperture stop**: limits the incoming bundle of rays
        - E.g. the edge of the primary mirror
    - **Field stop**: Limits the range of angles that the telescope can accept (limits the field of view)
- **Pupil**: an image of the aperture stop (or primary mirror)
    - Entrance pupil: ahead of stop
    - Exit pupil: behind stop



http://www.drdrbill.com/downloads/optics/geometric-optics/Apertures.pdf

Next week

- Homework # 1 is posted on Learn
  - **Due Monday, September 9 at the start of class**
  - Two parts submitted separately
  - **Part 2 must be submitted through Learn**. Why? It will be graded anonymously and checked for plagiarism (compared with internet sources and other student's work). You are encouraged to work together, but write it in your own words.
- Upcoming:
  - Midterm will be on Wednesday, October 2
  - Open book, covering ~ radiometry, telescope design, detectors, and some statistics
    - Ch 1-4 of Measuring the Universe, TBD from Practical Statistics for Astronomers