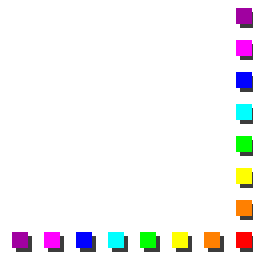


Telescopes

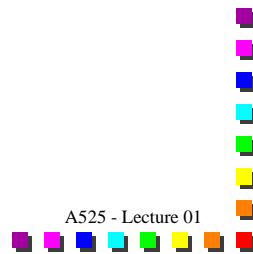
Astronomy 525

Lecture 01



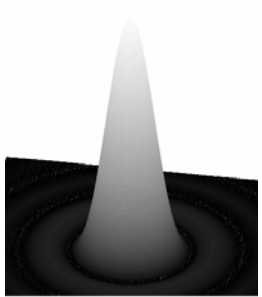
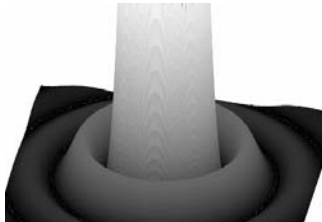
Outline

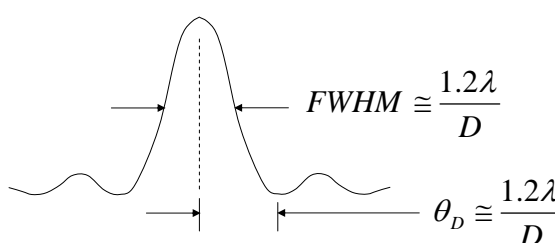
- Perfect Telescope
 - Diffraction-limited performance
- Plate scale
- The HST blunder
- Simple optics
- Telescope design
- Types of telescopes



The Perfect Telescope

- Collects photons with 100% transmission
 - No obscurations
 - Zero thermal emission and zero scattered light
- No geometrical aberrations
 - Diffraction-limited performance

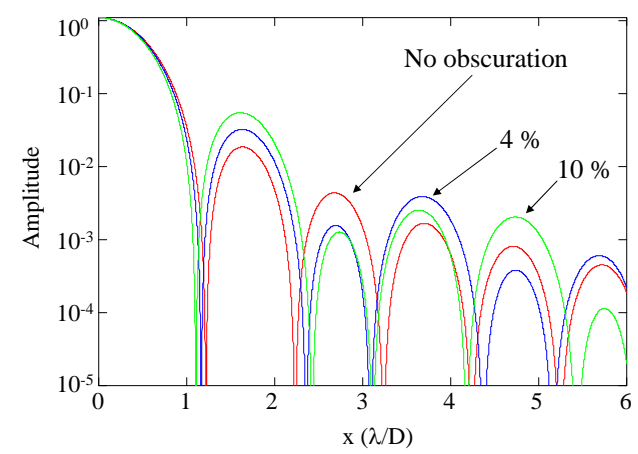


$$FWHM \cong \frac{1.2\lambda}{D}$$

$$\theta_D \cong \frac{1.2\lambda}{D}$$

Telescopes 3 A525 - Lecture 01

Diffraction PSF



Amplitude

$x (\lambda/D)$

No obscuration
4 %
10 %

Obscuration is by area

Telescopes 4 A525 - Lecture 01

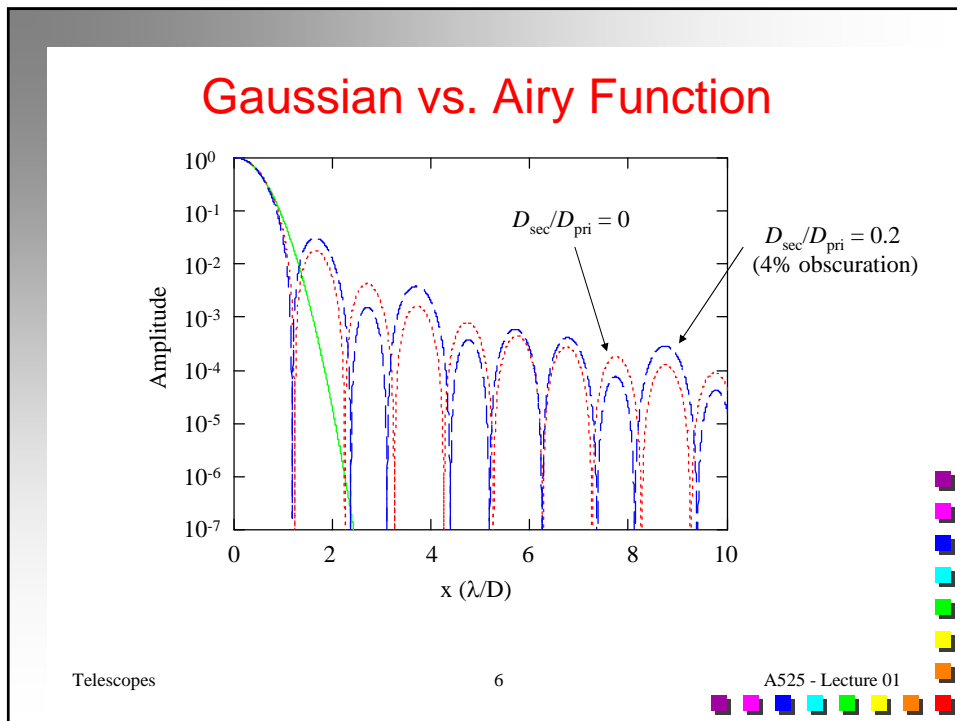
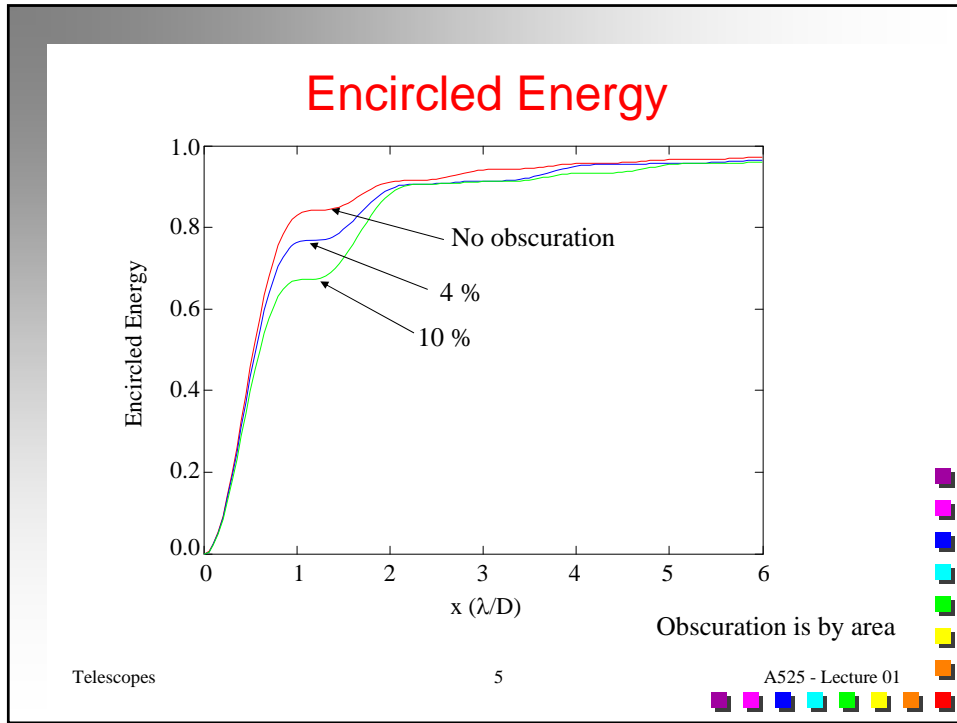
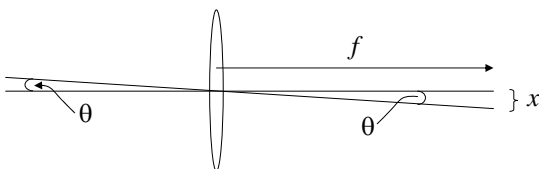


Plate Scale



$f = \text{focal length}$
 $f\# = f/D$

$$f\# = \frac{\text{effective focal length}}{\text{primary diameter}} \quad x = \theta f = \theta D f\#$$

- For Palomar: $f/16$ with 5 m primary

$$x = \frac{1''}{206265''/\text{rad}} 16 \cdot 5 \times 10^3 \text{ mm} = 0.388 \text{ mm}$$

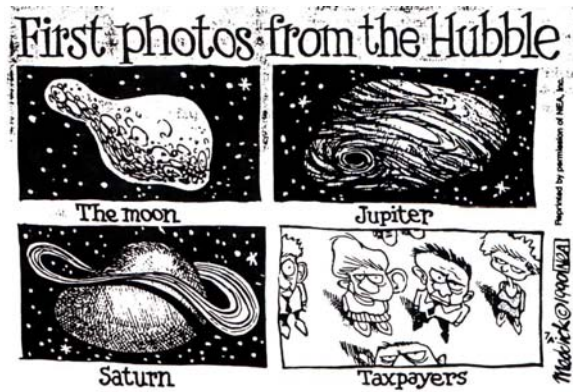
$$\Rightarrow 1'' \leftrightarrow 0.388 \text{ mm}$$

$$\Rightarrow \text{Plate scale} = 2.57''/\text{mm} \text{ in telescope focal plane}$$
 [Often reimaged to match detector pixel size.]

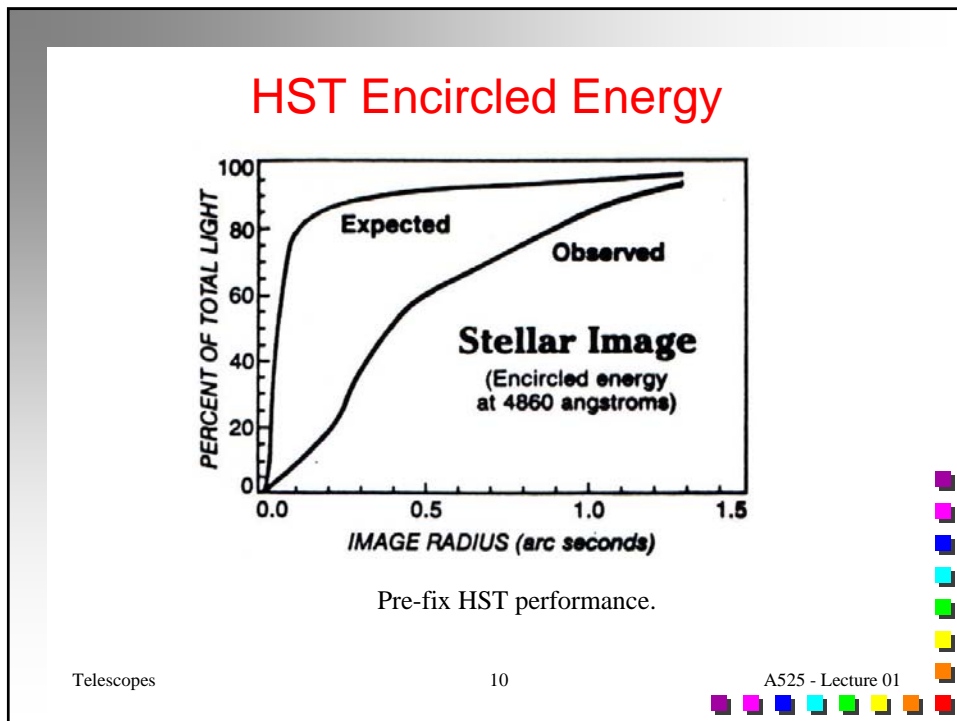
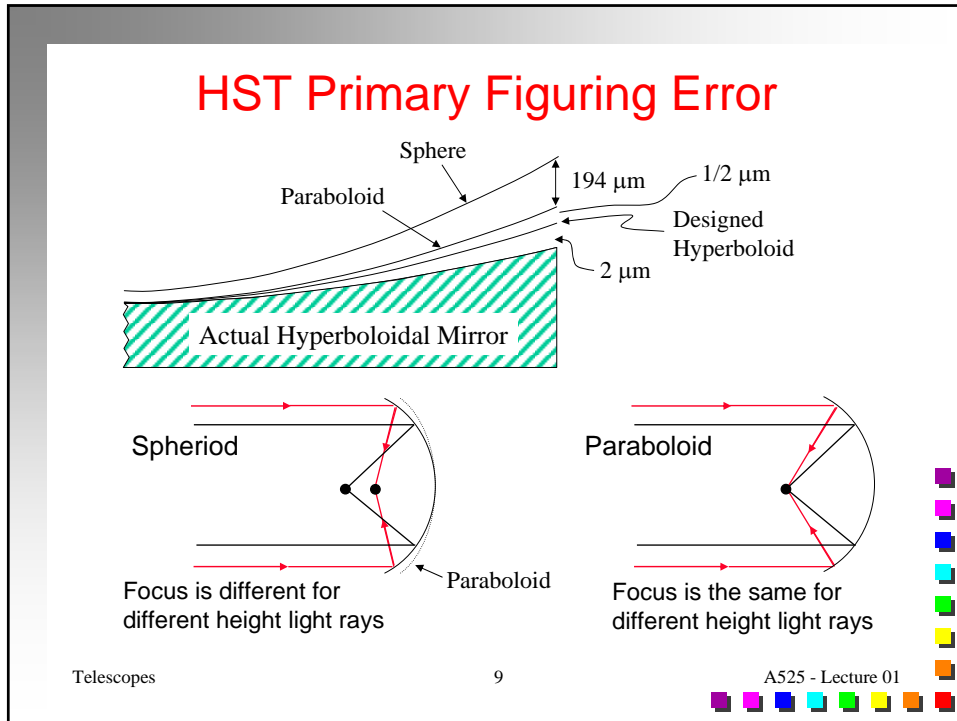
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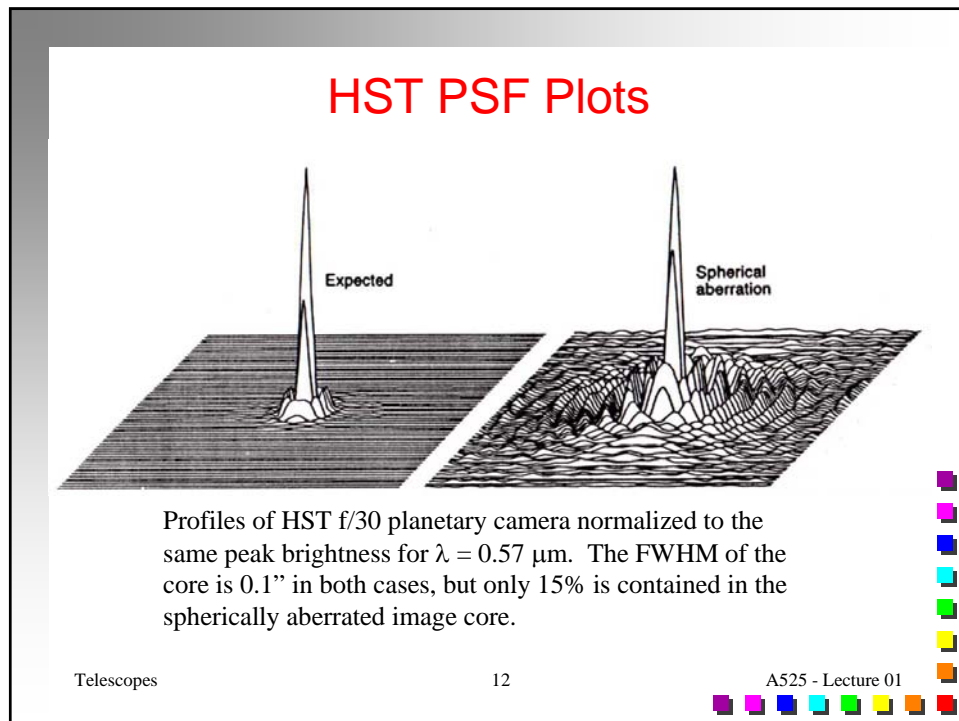
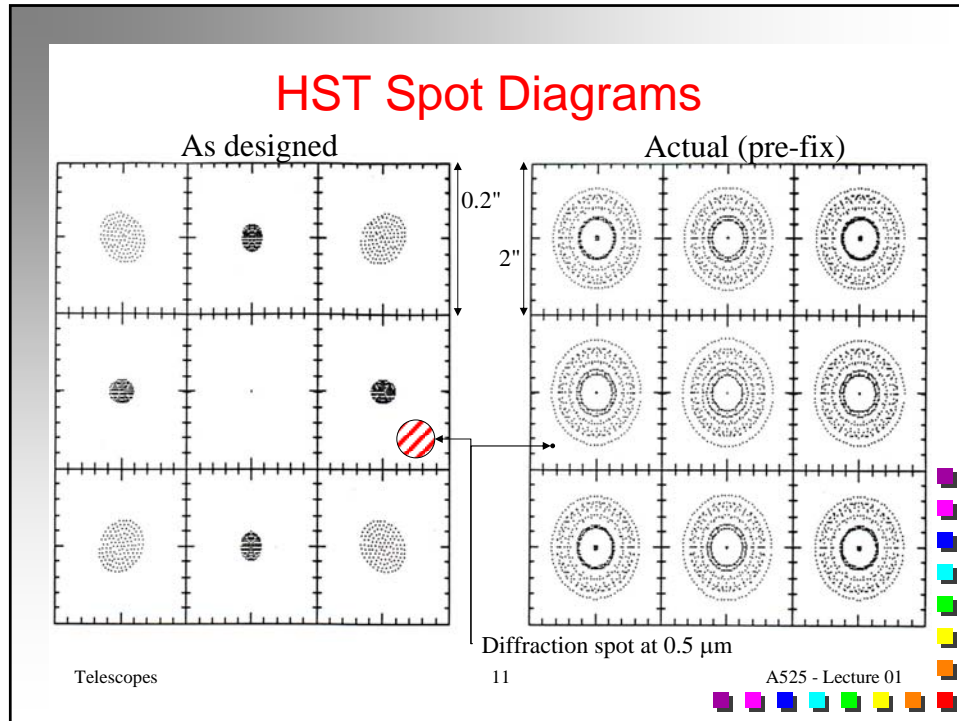
When telescopes go bad

- HST: \$1.5 billion and the optics were wrong!
- Very bad PR for NASA and Astronomy



Telescopes A525 - Lecture 01





Optics

- Motivation
- Thin lens
- Telescopes
 - Mixing conic sections

Telescopes

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Motivation

- Why should we know about optics?
- User viewpoint (observer)
 - You will get better results if you know how your experiment works and what its limitations are.
- Builder's viewpoint (experimenter)
 - If you have someone design a system and build it for you, there is little incentive for them to keep it simple (and cheap).
- Pragmatists viewpoint (wage earner)
 - You can make more money!

Telescopes

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Thin Lens Equations

- Thin Lens Formula:

$$\frac{1}{q} - \frac{1}{p} = \frac{1}{f}$$

f = focal length
 p = image distance (neg. when to left of lens)
 q = object distance (pos. when to right of lens)
- Newton's Formula:

$$x \cdot y = f^2$$

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Thin Lens Equations (cont'd)

- Lensmaker's Formula:

$$\frac{1}{f} = (n - 1) \left[\frac{1}{r_1} - \frac{1}{r_2} \right]$$

n = refractive index
 r_1, r_2 = radii of curvature

$(\Rightarrow r > 0$
 $) \Rightarrow r < 0$

For a

- convex lens: $r_1 > 0, r_2 < 0 \Rightarrow f > 0$
- concave lens: $r_1 < 0, r_2 > 0 \Rightarrow f < 0$

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Telescopes

- Refractors
 - Chromatic aberration
 - Must be internally flaw free
 - Must support from the side
- Reflectors (astronomers choice)
 - Typically have central obscuration
 - Have spiders to support secondary (diffraction spikes)



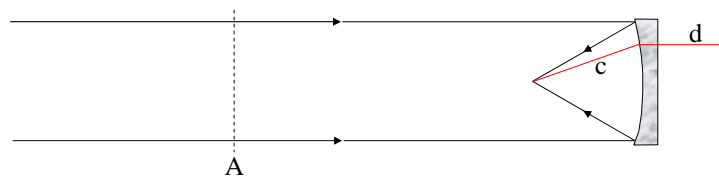
Telescopes

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The Parabolic Mirror

- Consider light from a very distant spot on the optical axis



- A parallel wavefront passes A in phase. We want it to arrive at the focus still in phase. Therefore, all paths from A to the focus must be the same length.
- A parabola is the locus of points equidistant from a point and a line. Therefore, $c = d$ and the distance from A to the focus is a constant.

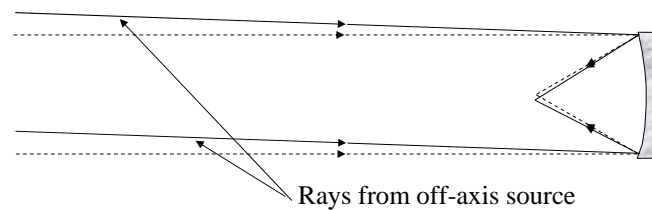
Telescopes

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Parabolic Mirror (cont'd)

- A parabola will form a perfect (geometric) image at the focus.
- NOTE: This is only for rays parallel to the axis. Off-axis rays will not be as good.



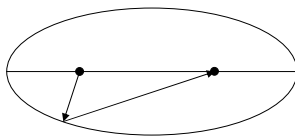
Telescopes

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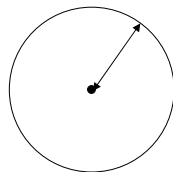
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Other Conics

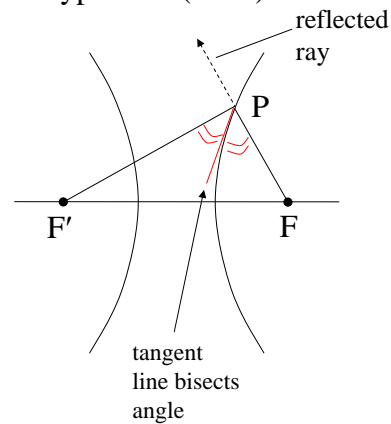
- Ellipse ($e < 1$):



- Sphere ($e = 0$):



- Hyperbola ($e > 1$):



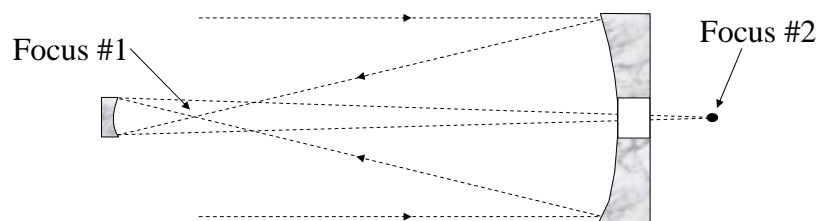
Telescopes

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Gregorian Telescope

- Conic sections produce perfect (geometric) images and can be strung together to form complex systems.



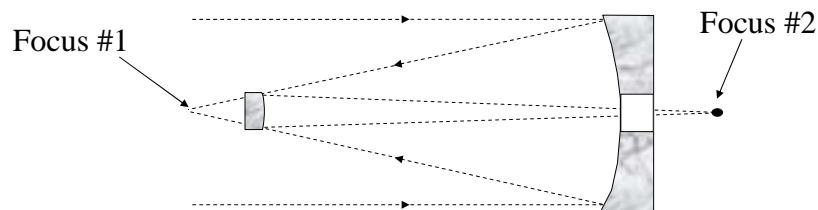
- **Parabolic primary** produces a perfect image at #1.
- **Ellipsoidal secondary** transfers a perfect image to #2.
- An erect image is produced.

Telescopes

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Cassegrain Telescope



- **Parabolic primary** produces a perfect image at #1.
- **Hyperbolic secondary** relays the virtual image at #1 to a real image at #2.
- Greater compactness than Gregorian telescope.
- But - hyperbolic secondary is hard to make and off-axis performance is not terribly good.

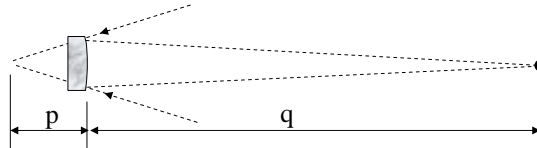
Telescopes

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Designing a Cassegrain Telescope

- Start by picking the aperture and final focal length.
 - This gives f-ratio (f#) and plate scale
 - The final focal length is $f_p m$ where m = magnification produced by the secondary. f_p is the primary focal length. $m = 1$ for flat.



Relational equations:

$$m = \frac{q}{p} \quad e_s = \frac{m+1}{m-1} \quad f_s = \left[\frac{1}{p} - \frac{1}{q} \right]^{-1} \quad r_s = 2f_s$$

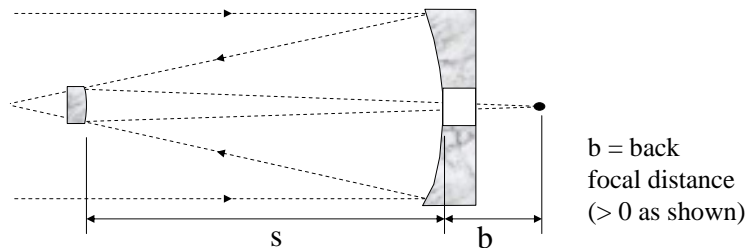
$p, q > 0$ (convex)

Telescopes

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Designing a Cassegrain (cont'd)



$$q = s + b \quad \& \quad m = \frac{q}{p} \quad \Rightarrow \quad s = \frac{mf_p - b}{m + 1}$$

$$p = f_p - s$$

- Effective focal length = focal length of telescope

$$f_{eff} = f_p m$$

Telescopes

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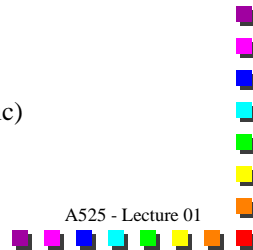
Other Telescope designs

- **Dall-Kirkham:**
 - Make secondary mirror a sphere
 - Adjust “figure” of primary to compensate (remove spherical aberration)
 - Bad off-axis performance
- **Ritchey-Chrétien Telescope**
 - Design used for all large telescopes
 - Reduce off-axis aberrations by
 - Slightly flattening primary (hyperbolic)
 - slightly flattening rim of secondary (hyperbolic)

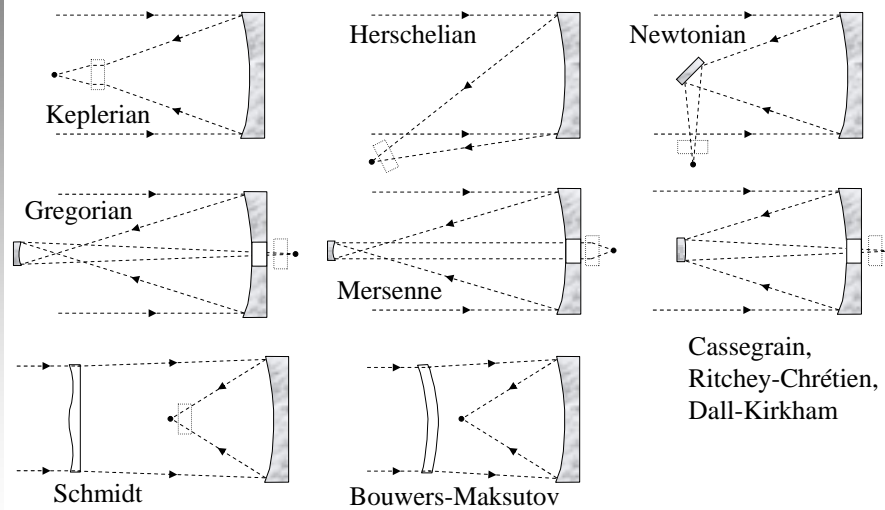
Telescopes

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Schematics of Telescopes



Telescopes

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Telescope Types

Type	Primary Optics	Secondary Optic
Keplerian	Sphere or parabola	None
Herschelian	Off-axis parabola	None
Newtonian	Parabola	Diagonal Flat
Gregorian	Parabola	Ellipse
Mersenne	Parabola	Parabola
Cassegrain	Parabola	Hyperbola
Ritchey-Chrétien	Modified parabola	Modified hyperbola
Dall-Kirkham	Ellipse	Sphere
Schmidt	Aspheric refractor	Sphere
Bouwers-Maksutov	Refractive meniscus	Sphere

Telescopes

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