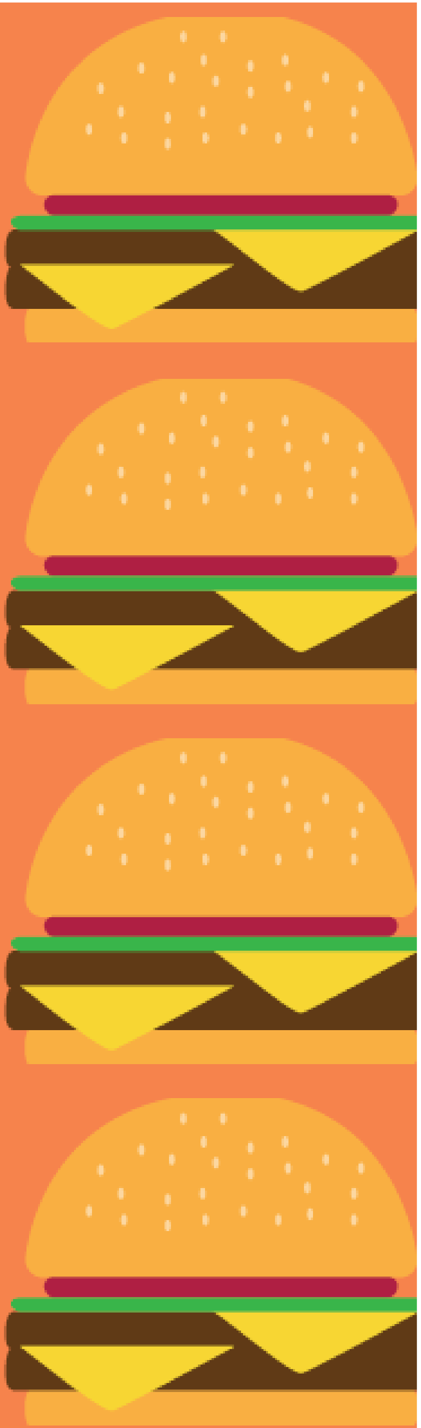
PHYSICS DEPARTMENT SHOWCASE



RESEARCH TALKS, SOCIALIZING, AND FOOD!

Join us for talks on current research opportunities and the state of the department, followed by a BBQ social (with veggie options!). Meet the different clubs and committees that make up our department.

FRIDAY, SEPT. 27, 3:30-6PM

3:30PM: SNACKS IN THE LOBBY
4PM: TALKS IN THE LECTURE HALL
5PM: BBQ ON SMALL LAWN

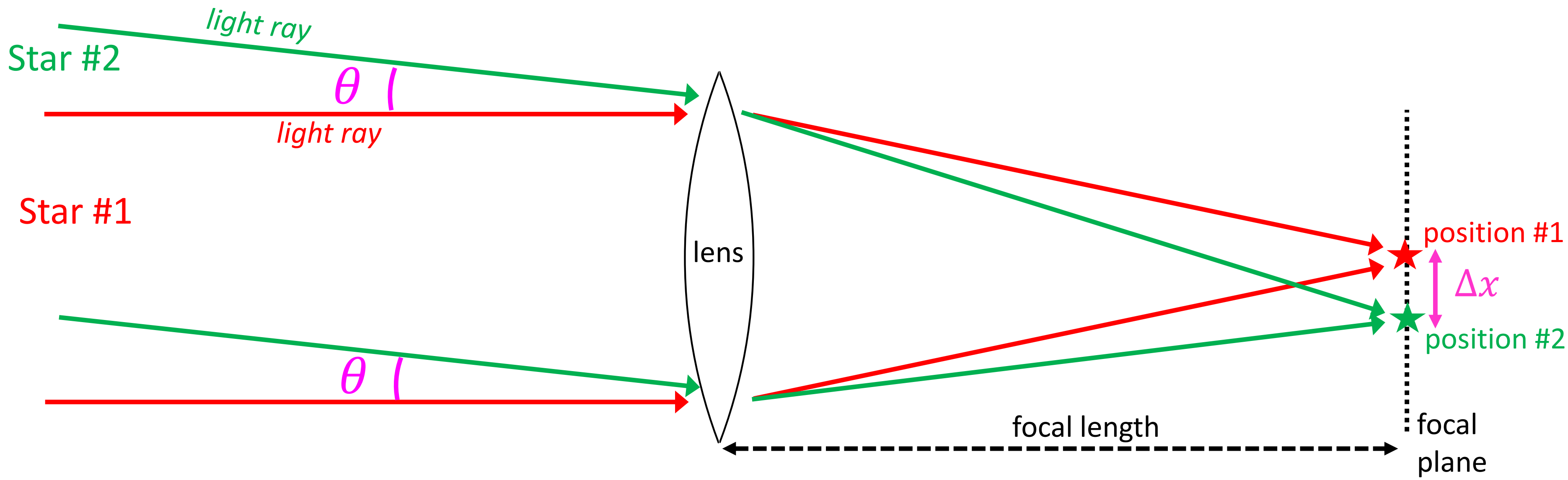
Today's Topics

Wednesday, September 27, 2019 (Week 4, lecture 12) – Chapter 6.

1. Reflecting Telescope
2. Resolving power
3. Adaptive Optics

Stellar Imaging Basics: Lens

Basic idea: You want to convert a light ray **angle** from a star into a **position**.



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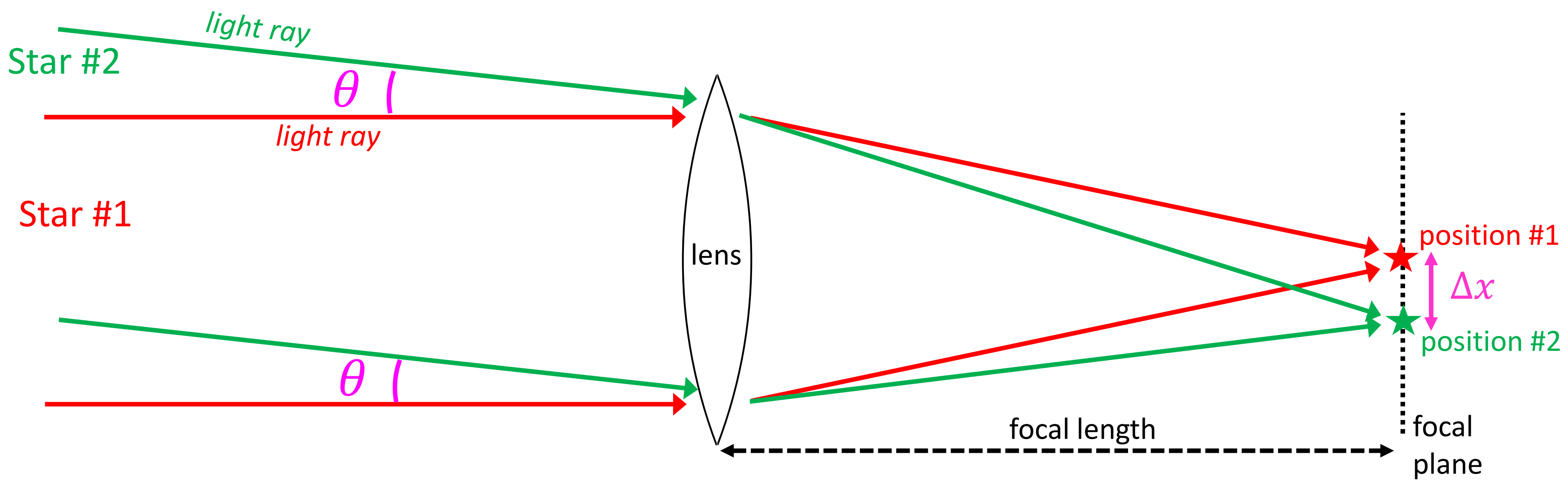

- Bigger lens collects more light.
  → You can see dimmer stars and further away stars.
- Magnification = Δx gets bigger (for a given θ).
  → You can distinguish between two very close feature.
- Lens subtly distort the image.
  → chromatic aberrations, glass defects, large lens sag.

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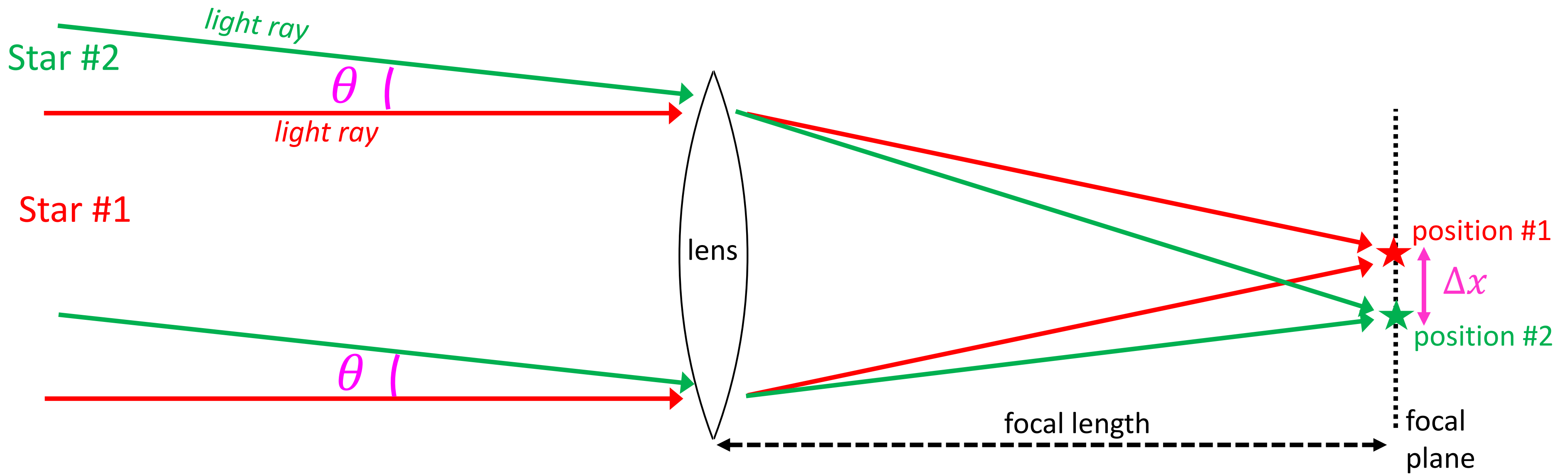

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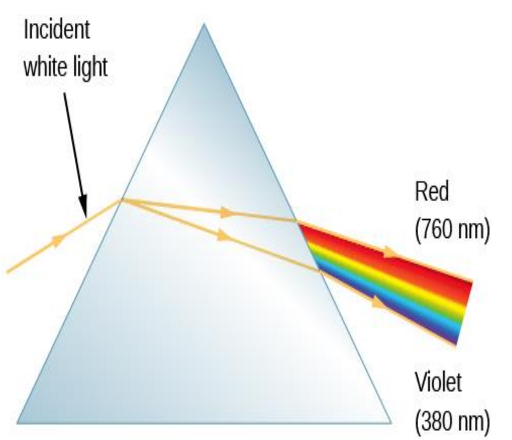
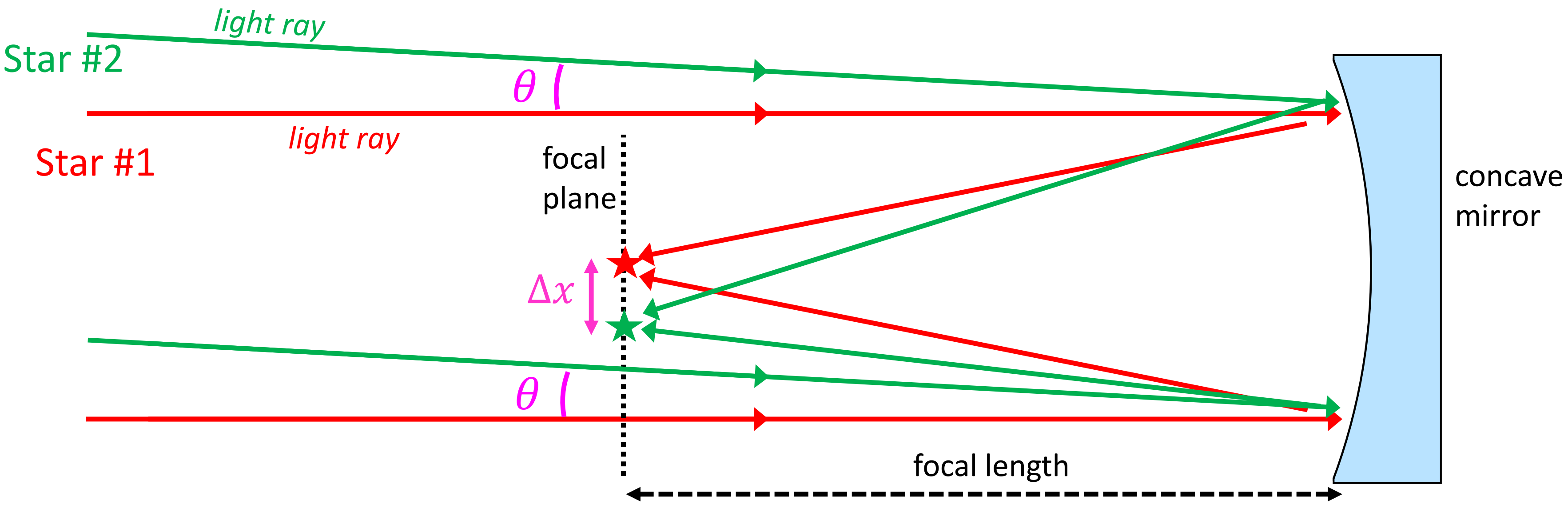


Stellar Imaging Basics: Mirrors

Same basic idea: Convert a light ray **angle** from a star into a **position**.



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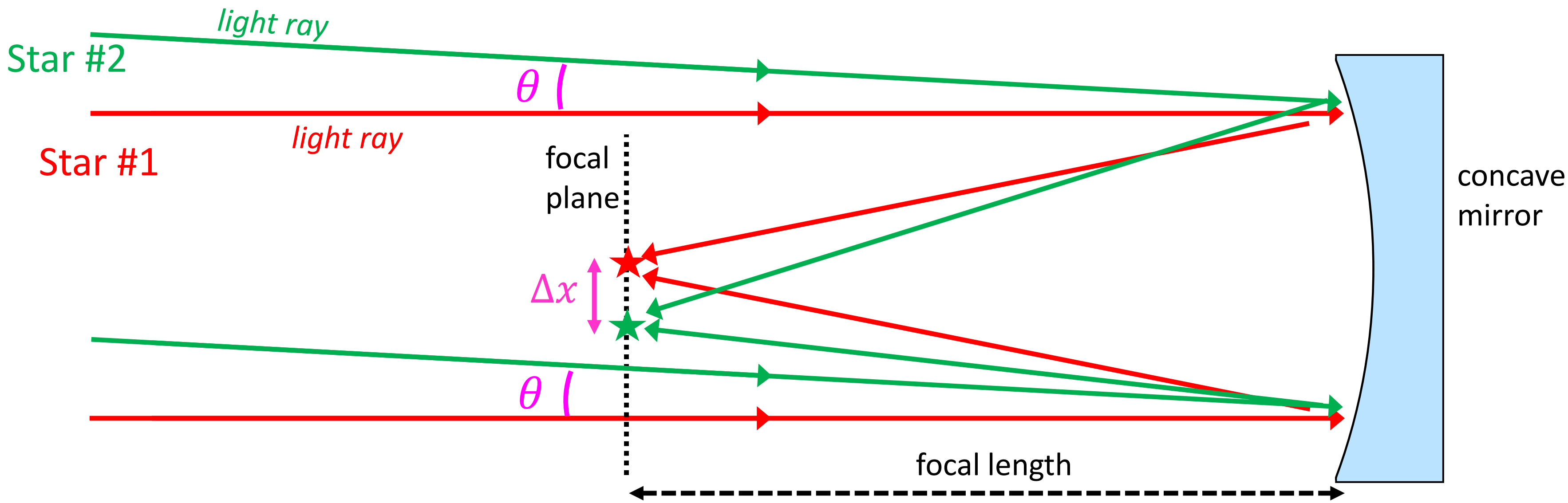
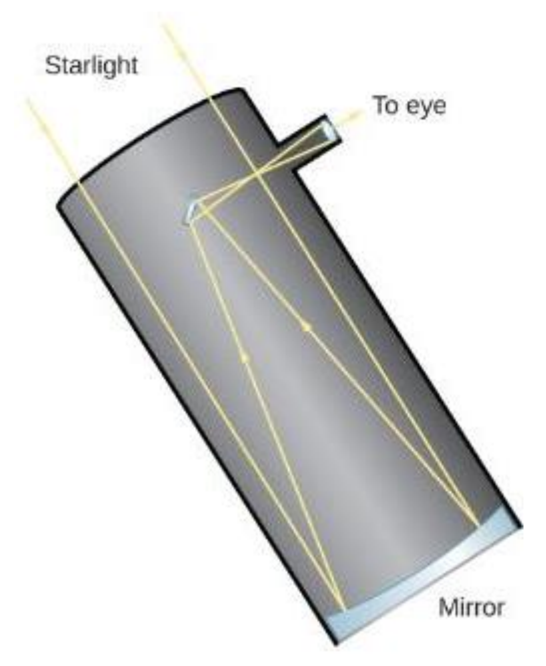


- Bigger mirror collects more light.
  → You can see dimmer stars and further away stars.
- Magnification = Δx gets bigger (for a given θ).
  → You can distinguish between two very close feature.
- Mirrors can provide near zero distortion.
  → no chromatic aberrations, no glass defects, much less large mirror sag.

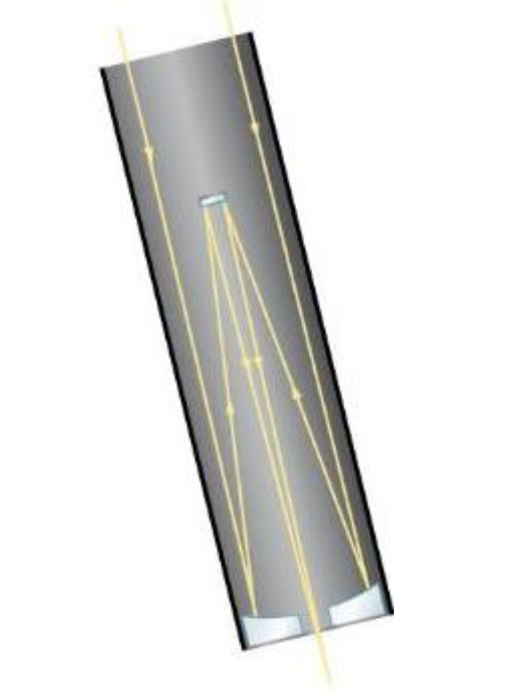
Reflecting Telescope

A **large curved mirror** collects the light and then focuses it onto a secondary smaller mirror.

→ invented by Isaac Newton.
→ Parabolic curved mirror is ideal.



Newtonian Reflector



Cassegrain Reflector

[OpenStax: Astronomy]

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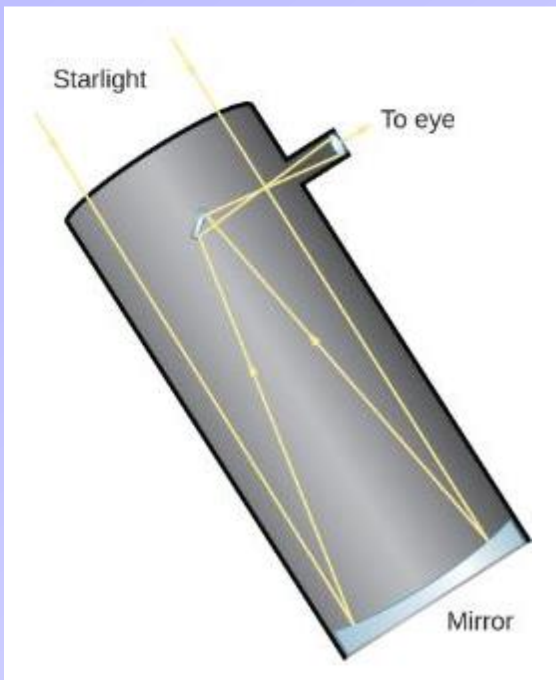

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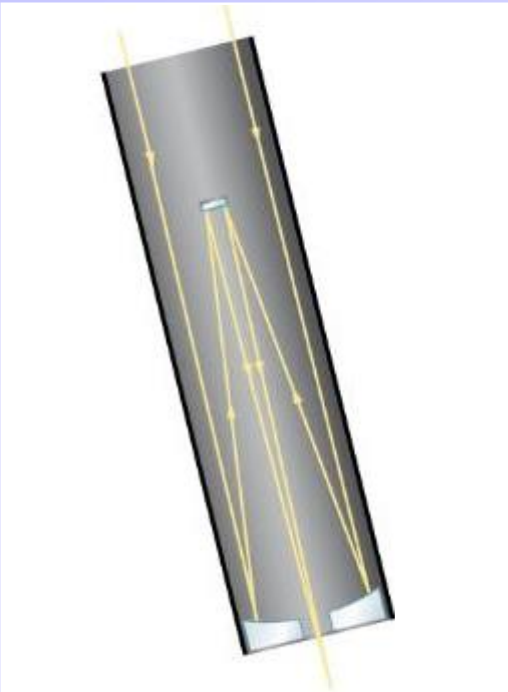

Cassegrain Reflector

Benefits

- No chromatic aberrations.
- Glass defects do not matter.
- Large mirror can be supported across its entirety.
  → Sag is less of problem.

Drawbacks

- Open to air: more cleaning.
- Secondary mirror and support structure introduce diffraction effects from their shadows.

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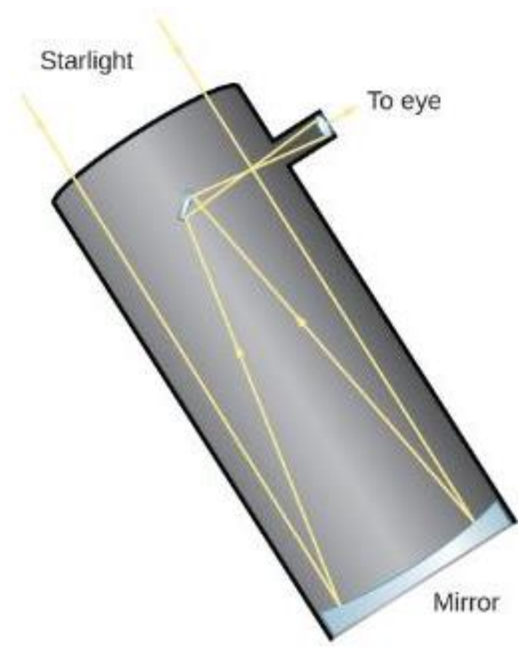

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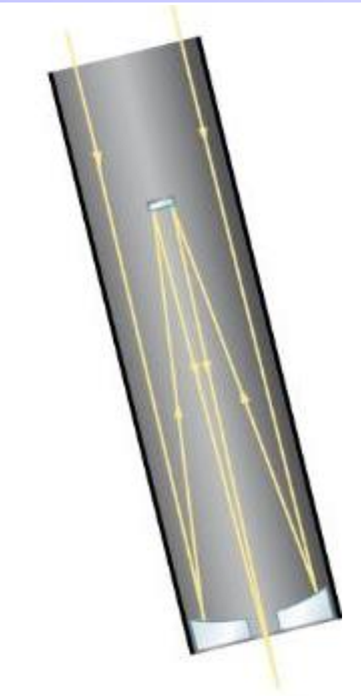

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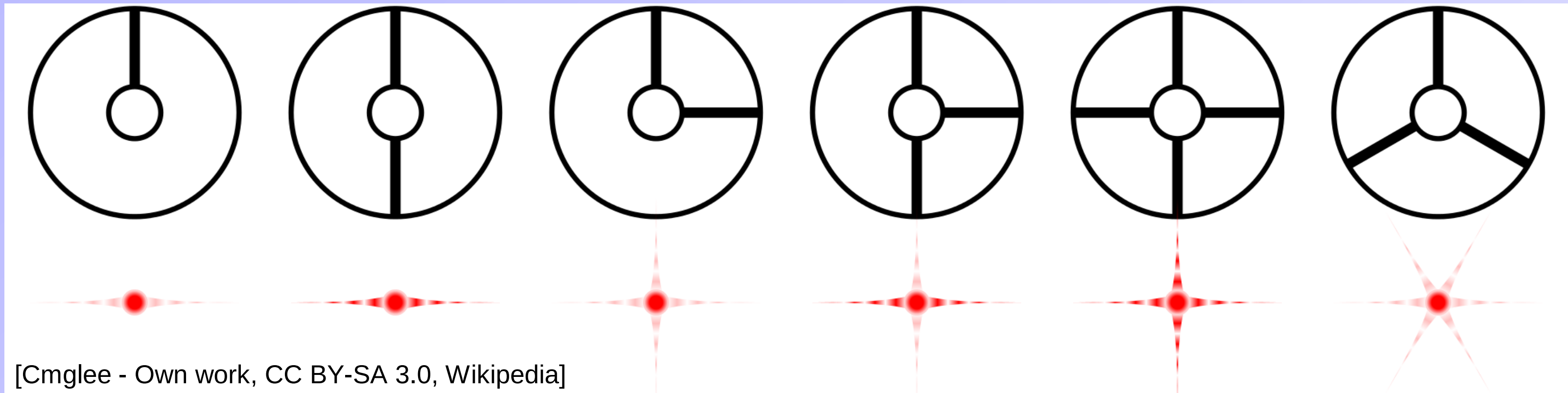
Almost all scientific telescopes are reflectors.

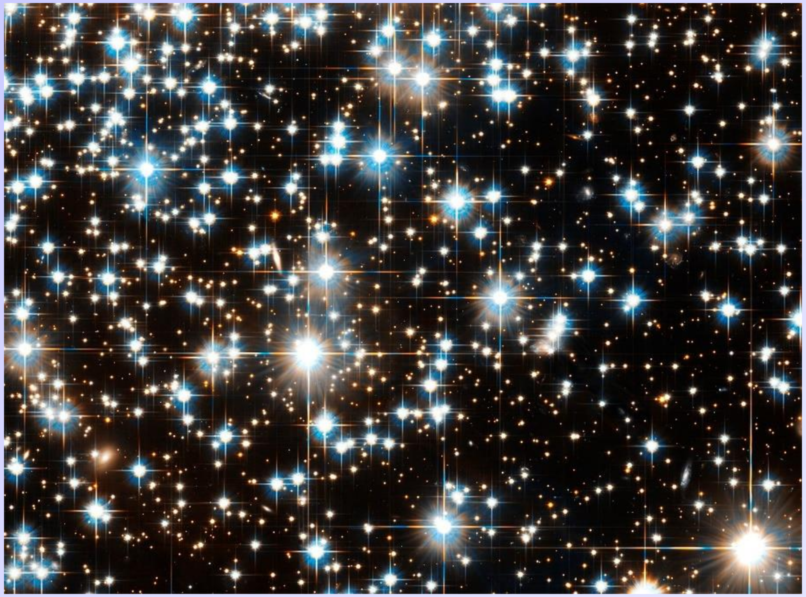
[OpenStax: Astronomy]

Star Spikes

Shadow from support structure for secondary mirror generates “star spikes”.



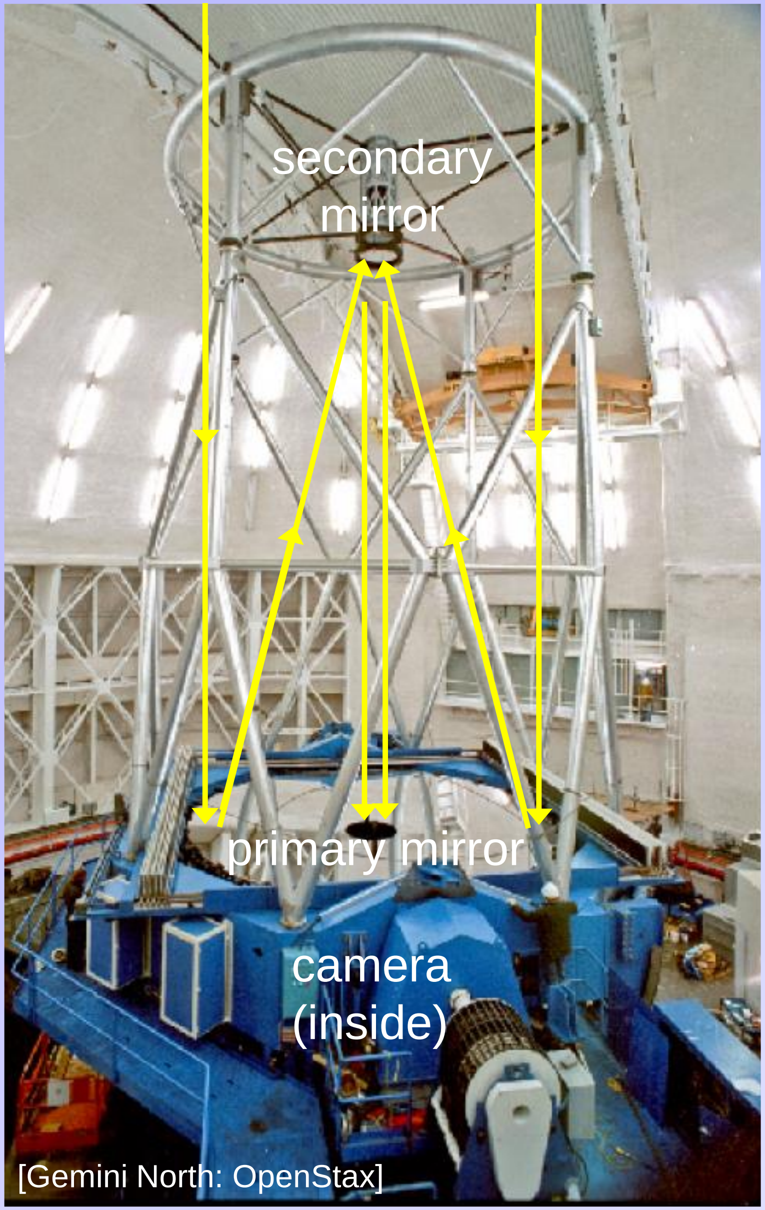
[Cmglee - Own work, CC BY-SA 3.0, Wikipedia]



Star Spikes from a Hubble Space Telescope image (NGC 6397).

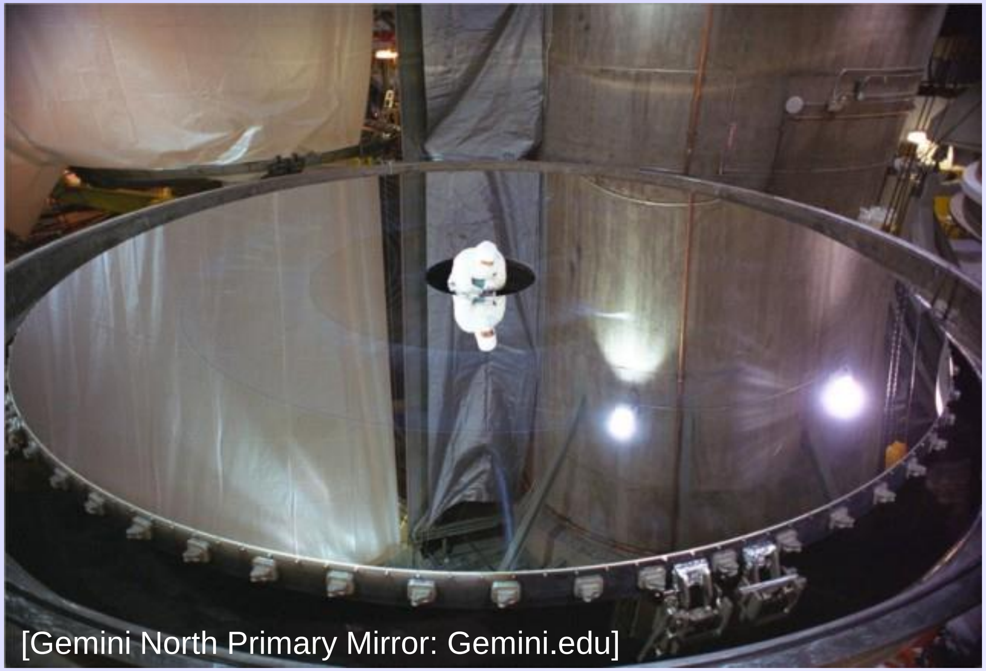
[NASA, ESA, and H. Richer (University of British Columbia), Wikipedia]

Single Mirror Telescopes



The Gemini telescopes are some of the largest single mirror telescopes.

- → 8.1 m (26 ft) primary mirror.
- → 1 m secondary mirror.
- → Locations: Hawaii & Chile

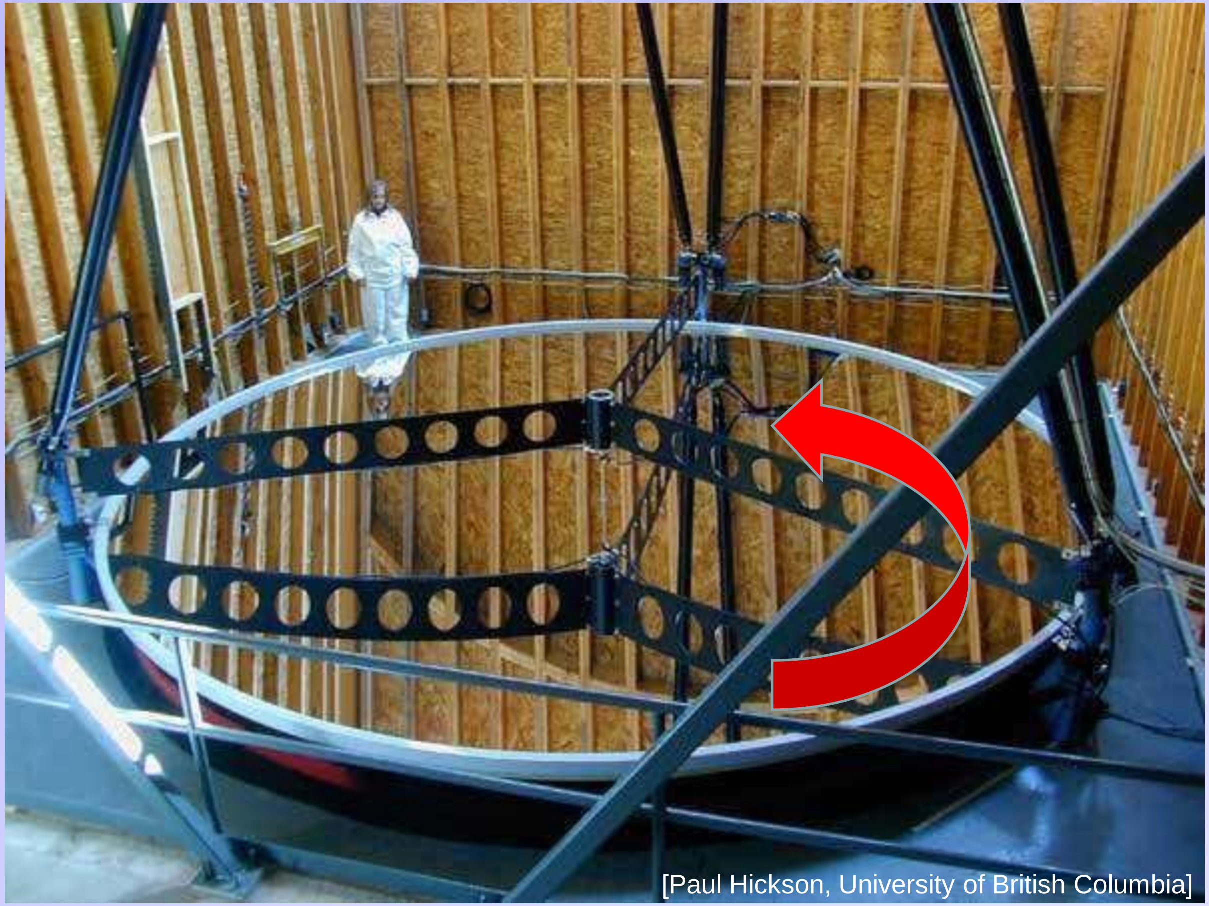


Liquid Mirrors

Fact: A rotating liquid has a parabolic surface (under gravity).

→ exactly the surface needed for a telescope.

→ Rotating liquid mercury makes an excellent mirror.



Large Zenith Telescope: 6 m diameter.

Benefits:

- About 1/10th the cost of a solid mirror.
- Much lighter than a solid mirror.
- Good for star surveys.

Downsides

- Telescope must be pointed vertically upwards.
- Limited star tracking.
- Mercury is toxic.

Segmented Telescopes

Problem: A single mirror larger than 8 m will experience significant sag issues.

Solution: Segment the mirror into smaller sections for easier support.

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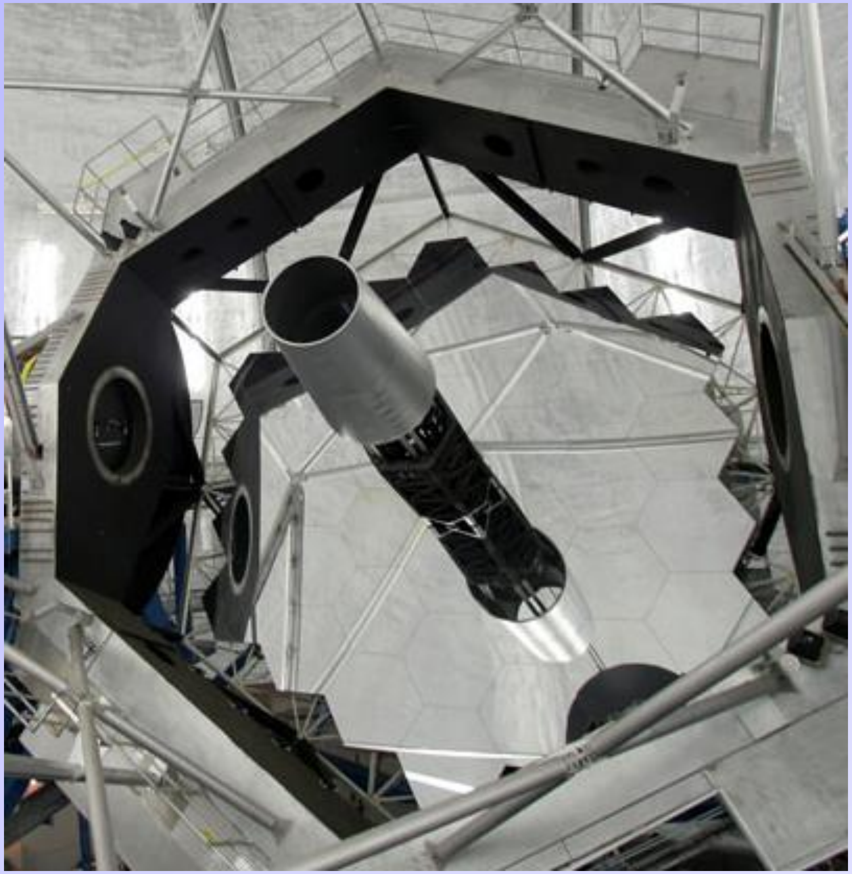
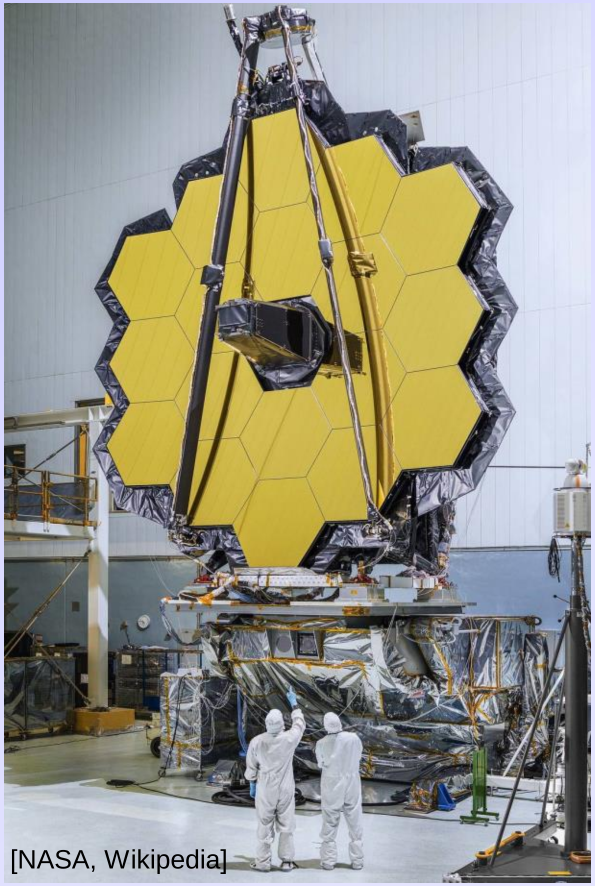


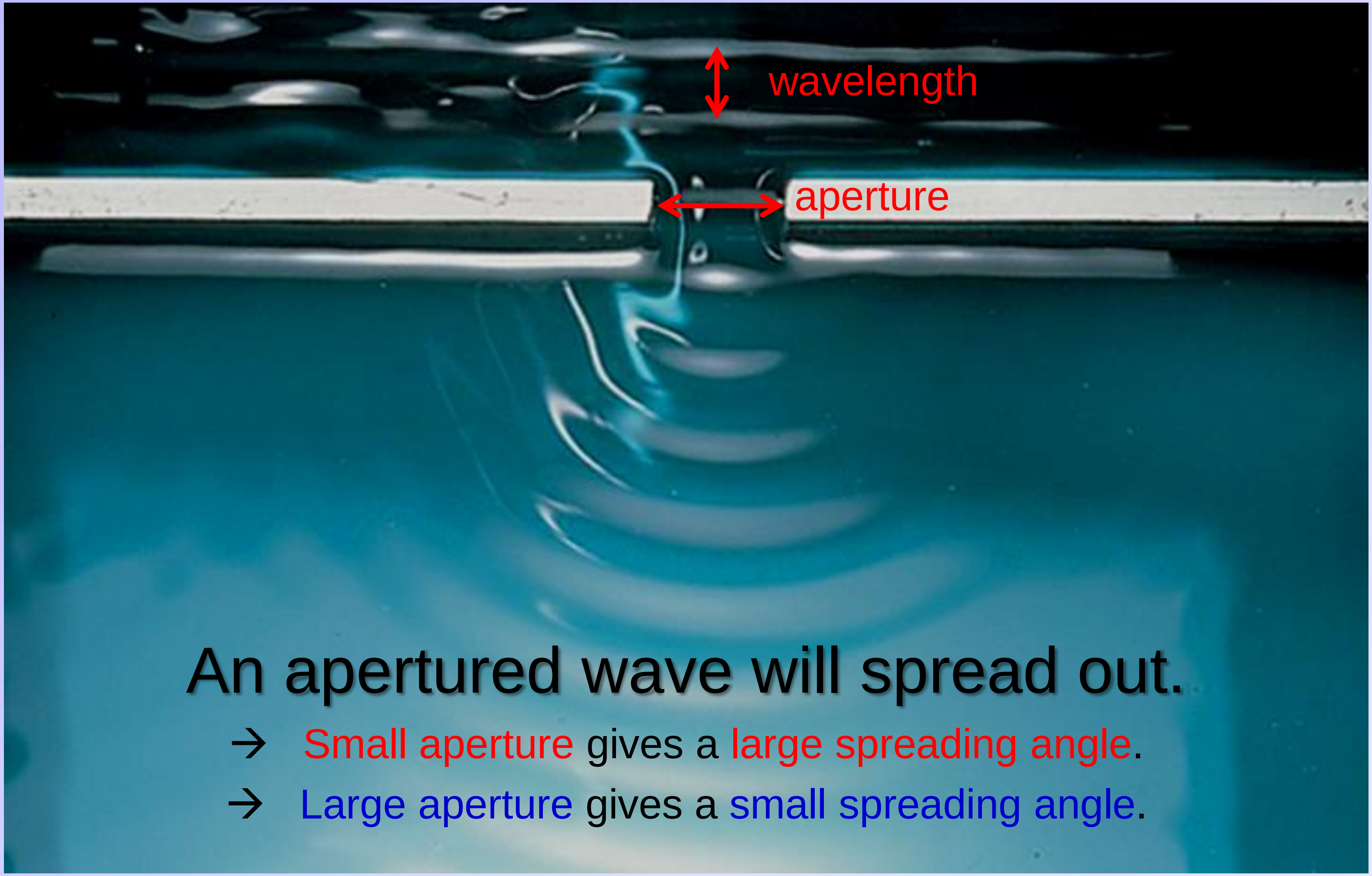
36-segment mirror of the Keck telescope (Hawaii)

[by SiOwl - Own work, CC BY 3.0, Wikipedia]



18-segment mirror of the future James Webb Space Telescope.

Diffraction



An apertured wave will spread out.

→ Small aperture gives a large spreading angle.

→ Large aperture gives a small spreading angle.

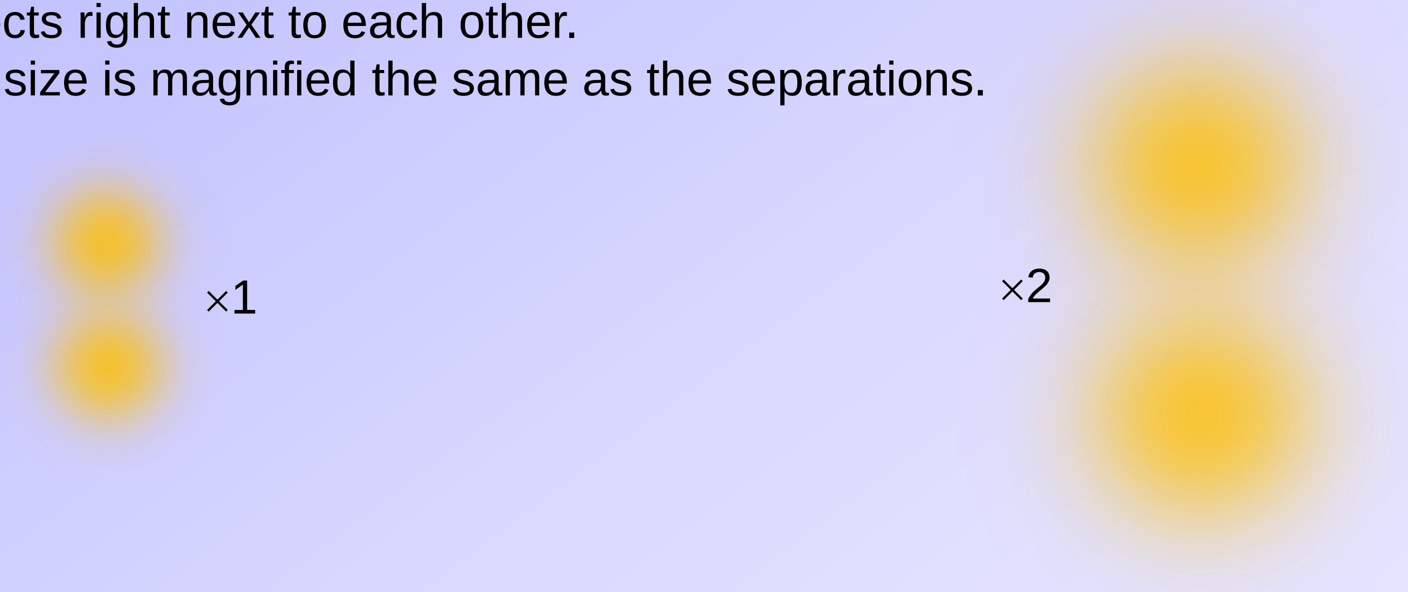
[Source; J. K. Nelson, William & Mary]

Resolving Power

The minimum resolvable angle is fixed by the aperture of the telescope, i.e. the mirror size.

For objects that are really close together, magnifying the image cannot help resolve two objects right next to each other.

→ The spot size is magnified the same as the separations.



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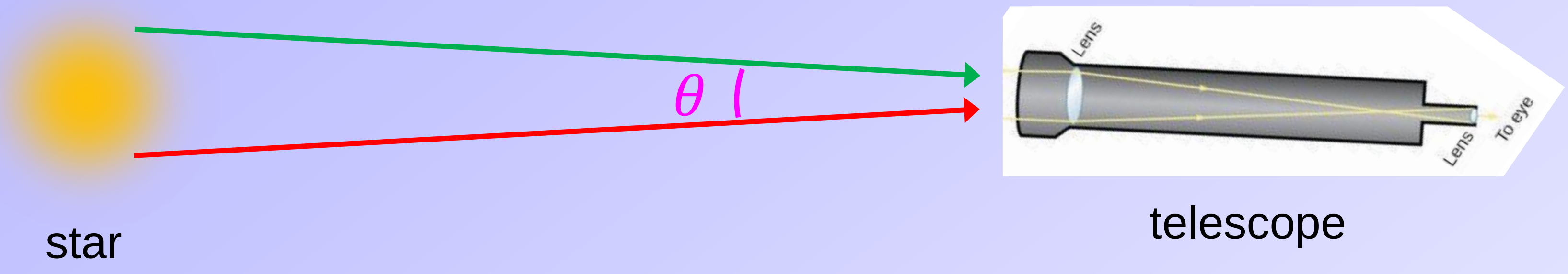
Resolving Power: Rayleigh Criterion

The minimum resolvable angle is fixed by the aperture of the telescope, i.e. the diameter of the primary mirror or lens size.



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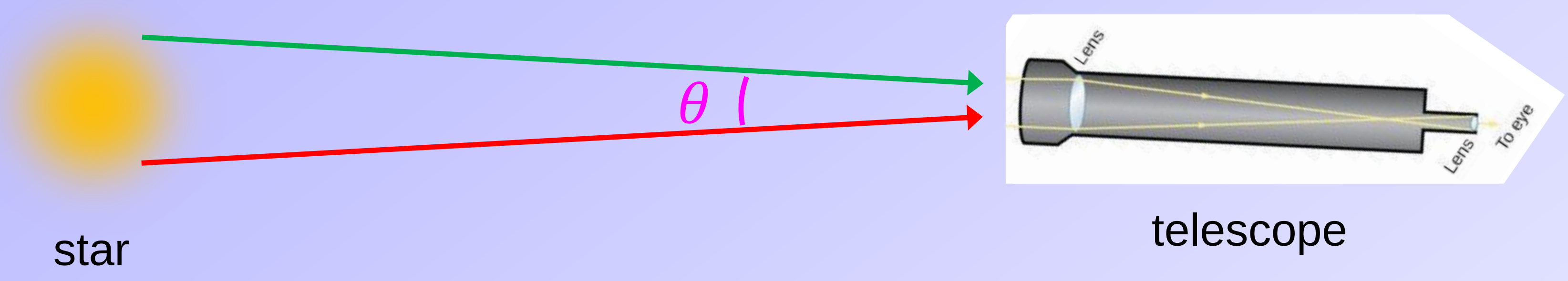

The **angular resolution** of a telescope, i.e. <u>resolving power</u>, is given by:

radians

wavelength in meters

SI units: $$\theta_{min} = 1.22\frac{\lambda}{D}$$

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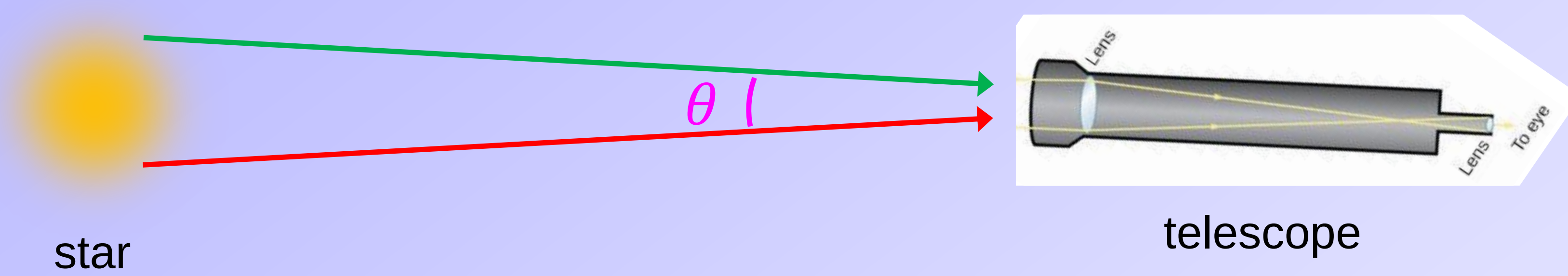

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SI units: $$\theta_{min} = 1.22\frac{\lambda}{D}$$

radians (θ_{min}); wavelength in meters (λ)

More useful units: $$\theta_{min,\,arcsecond} = 0.000252\frac{\lambda_{nm}}{D_m}$$

angular resolution in arcseconds ($\theta_{min,\,arcsecond}$); wavelength in nanometers (λ_{nm}); diameter in meters (D_m)

What's an arcsecond ?

There are "2π" radians in a circle

1 degree = 1/360th of a circle = $1 \times \frac{2\pi}{360} = 0.017453$ rads

1 arcminute = 1/60th of a degree

1 arcsecond = 1/60th of 1 arcminute = 1/3600th of a degree

1 milli-arcsecond = 1 mas = 1/1000th of 1 arcsecond

1 micro-arcsecond = 1 μas = $1/10^6$ of 1 arcsecond

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Examples

Angular size of **Moon** $= 31$ arcminutes $= 31'$ ~ 0.5°

Angular size of **Jupiter** = $30 - 50$ arcseconds $= 30'' - 50''$

Angular size of **Proxima Centauri** = $0.001''$ = 1 mas (nearest star: 4.2 ly)

Angular size of **Betelgeuse** $\simeq 0.05'' = 50$ mas (very large star: 640 ly)

Atmospheric Turbulence

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Atmospheric turbulence limits optical angular resolution to $0.5''$
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Solution #1

- Get rid of atmosphere (mountain tops help).
- Put telescope in space … very expensive, difficult.

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Solution #2

- Adaptive optics

→ Account for atmospheric fluctuations and remove effect from image.

- Keep telescope on ground … less expensive, but challenging.

Adaptive Optics

Basic Idea

- Take a point-like star (very far away) but close to the object you want to image.
- The shape of the “guide star” fluctuates due to atmospheric turbulence.
- **Actively deform your mirror** (slightly) to eliminate shape fluctuations.
  → Guide star becomes a point star now (due to mirror deformation feedback).
  → Often deform the secondary mirror.
- The main object becomes undistorted.

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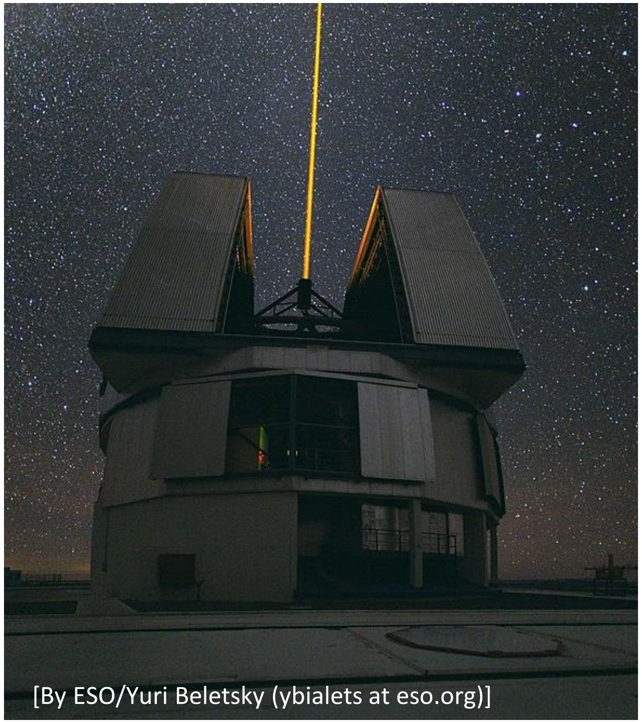
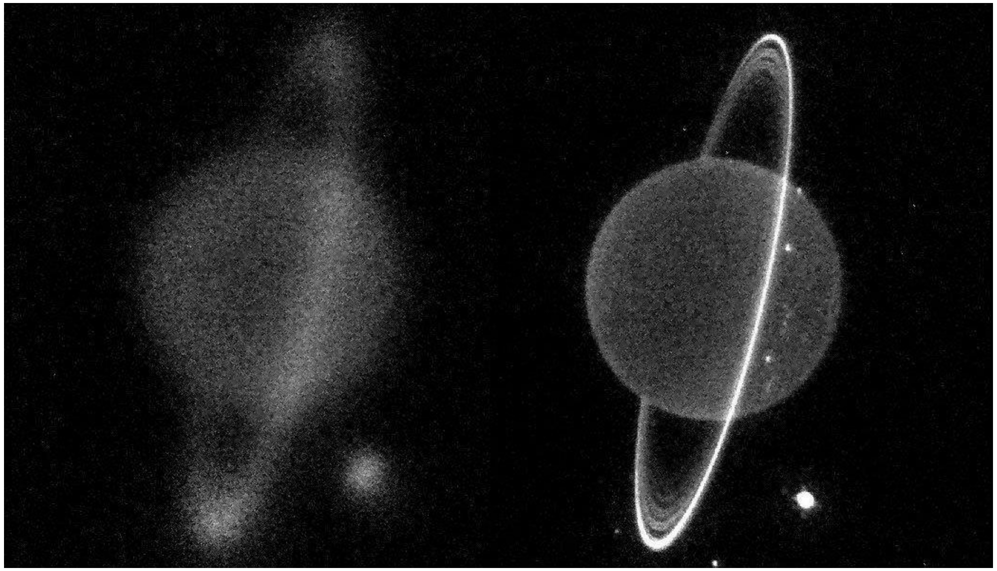
Laser Guide Star

- If there is no nearby point-like star, then a laser can create an **artificial guide star**.
- The laser excites **sodium** atoms in the upper atmosphere (altitude >50 km) to create artificial "star."


[By ESO/Yuri Beletsky (ybialets at eso.org)]

Adaptive Optics Images



[by Heidi B. Hammel and Imke de Pater]

without AO　　　　　with AO