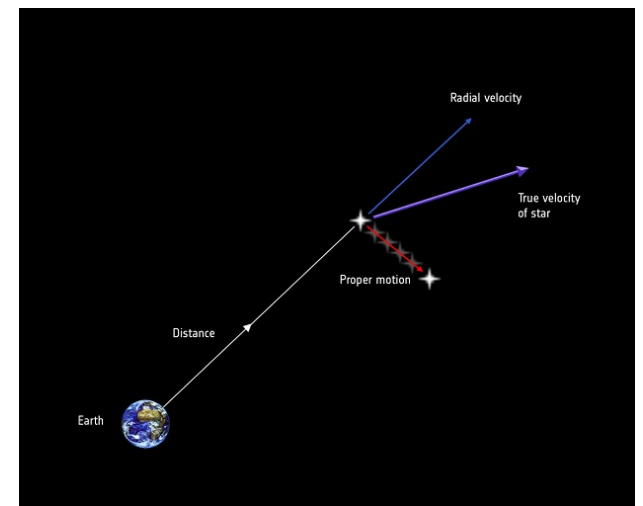
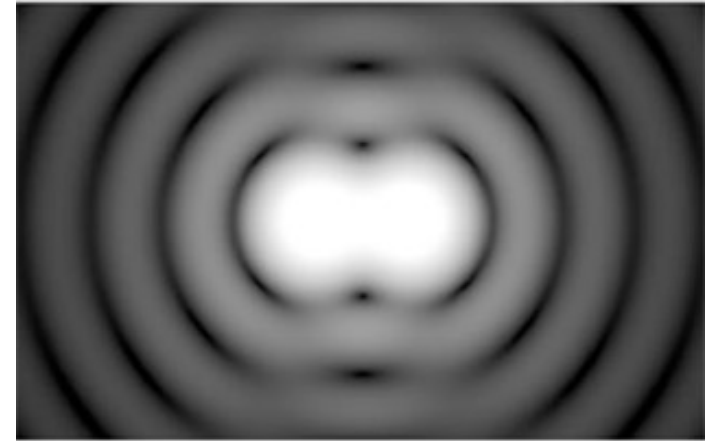


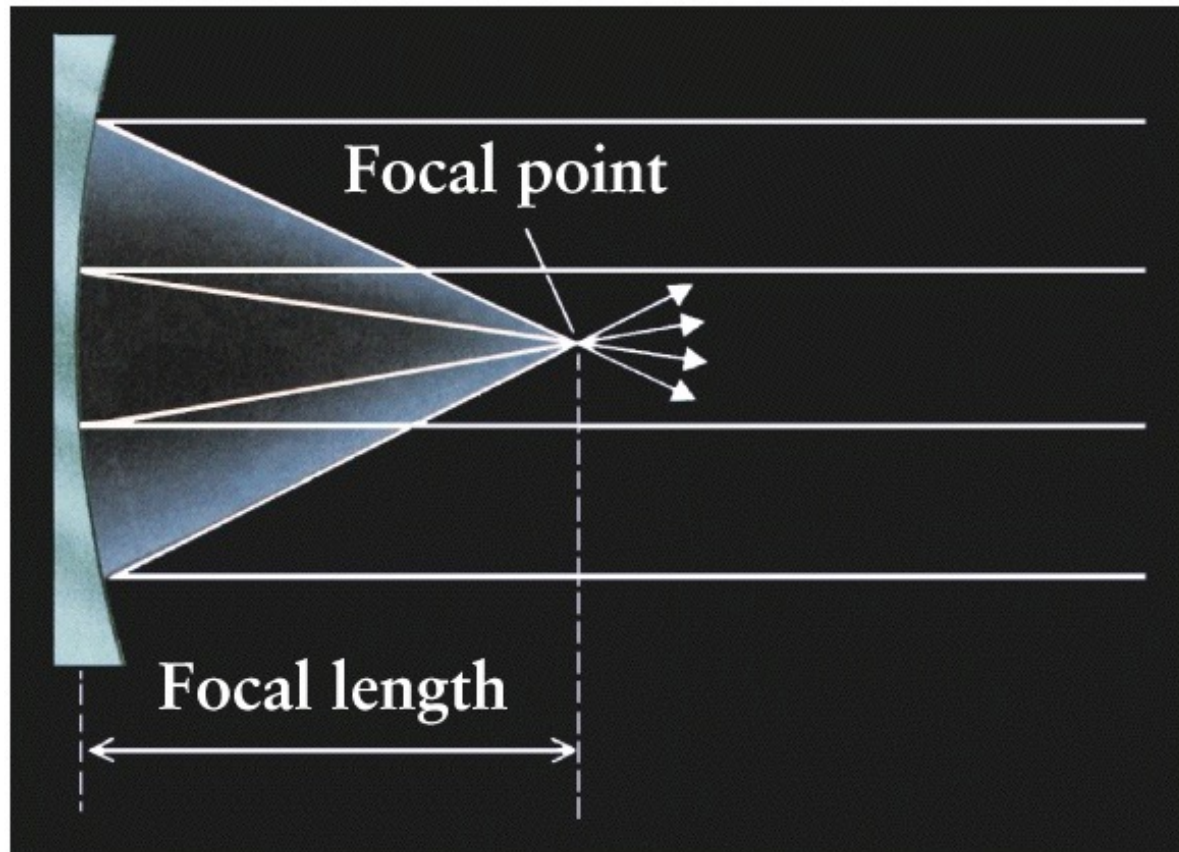
Telescopes and Angles

- Angular Resolution
- Angular Size
- Stellar Parallax
- Proper Motion
- Radial Motion

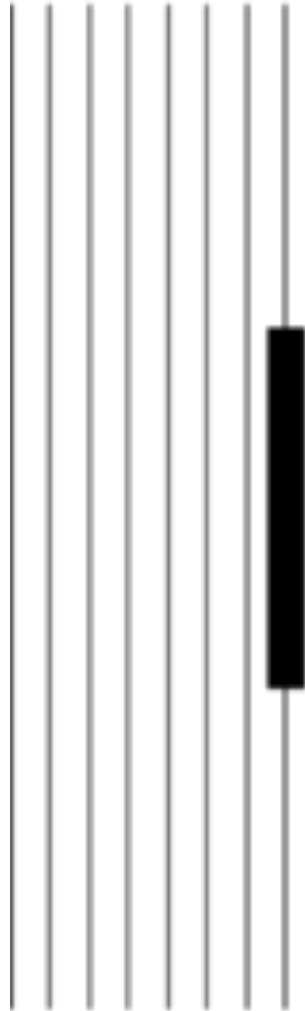


Reflecting Telescopes

- Most large telescopes use reflection

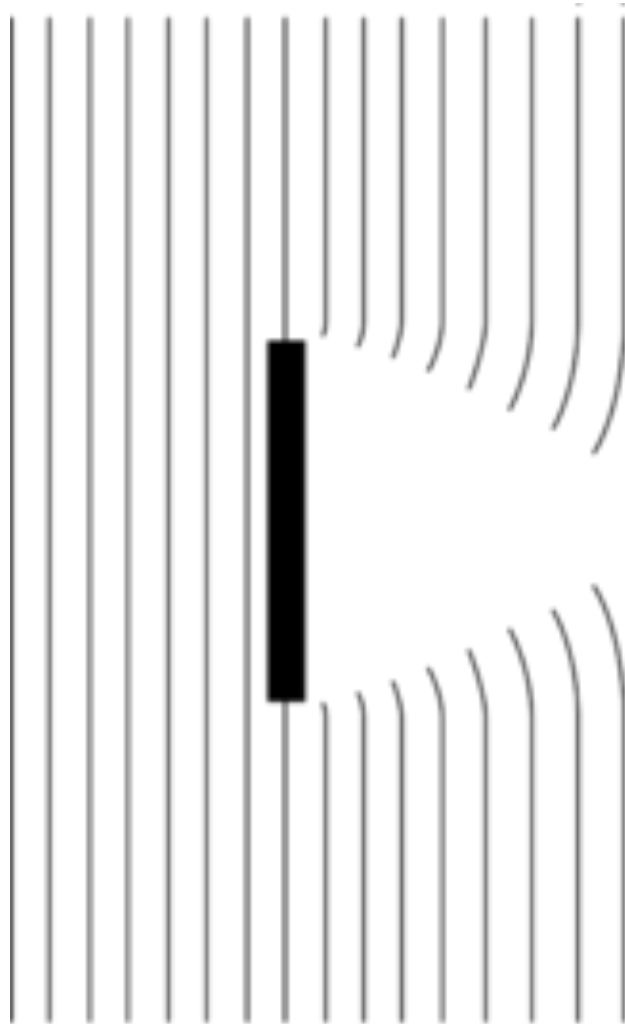


What happens to the light waves after passing the obstacle?

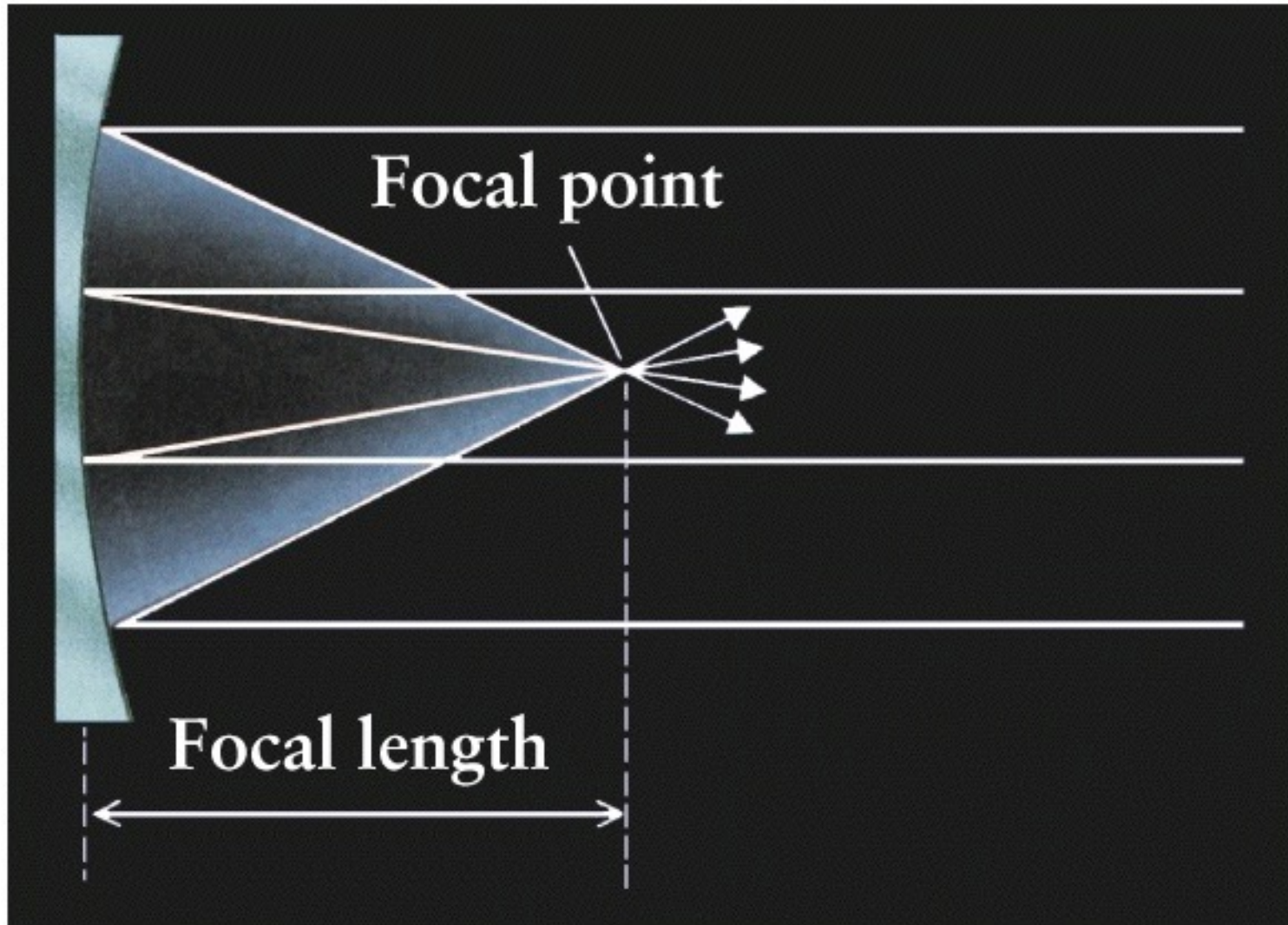


- A. Reflection
- B. Refraction
- C. Diffraction
- D. Nothing

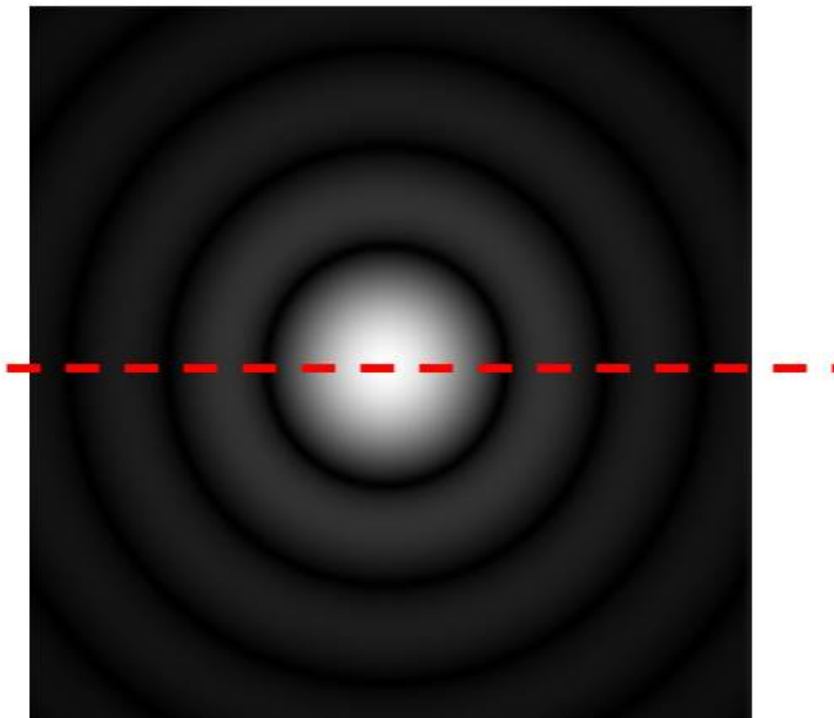
What happens to the light waves after passing the obstacle?



Telescopes suffer from diffraction

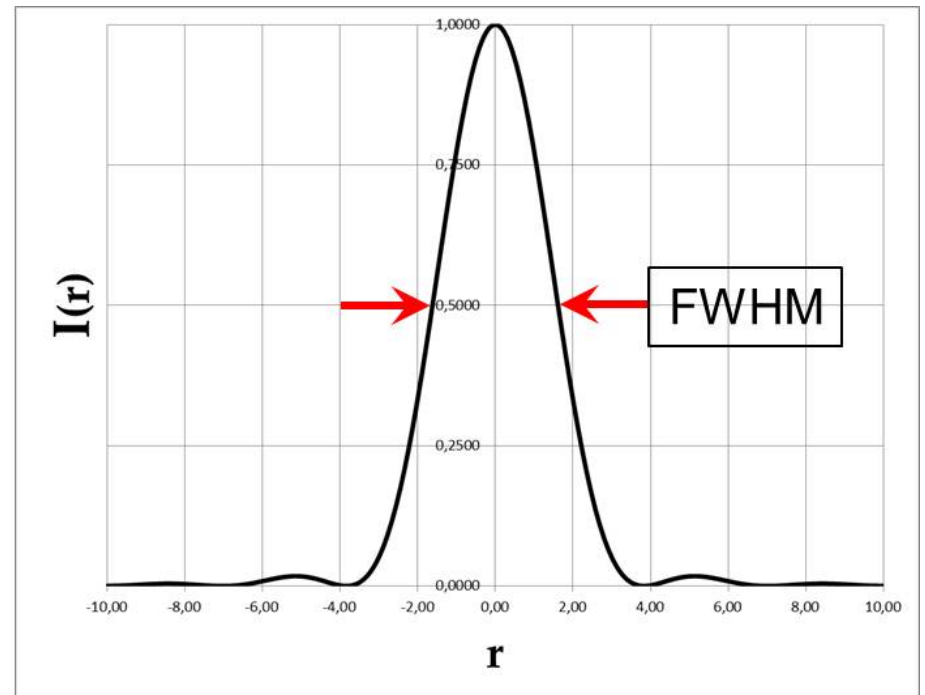


Diffraction Pattern



Point-Spread-Function (PSF)

From leica-microsystems.com



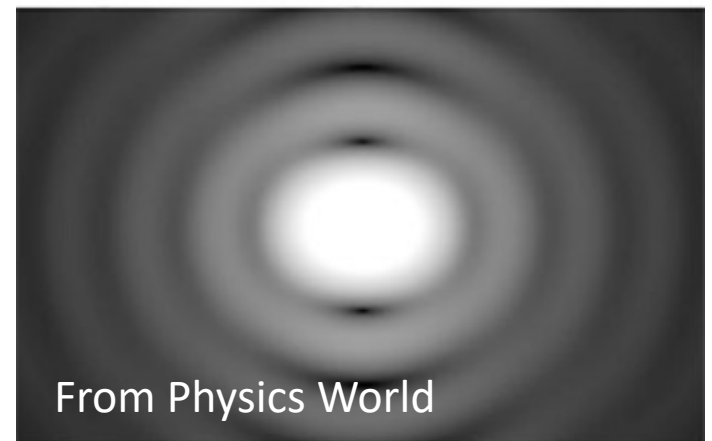
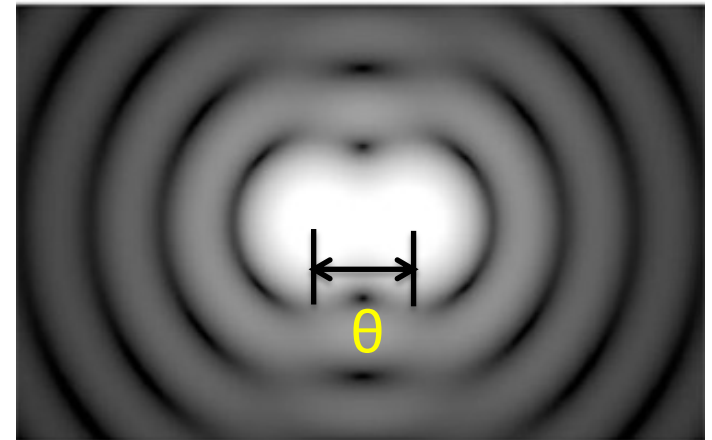
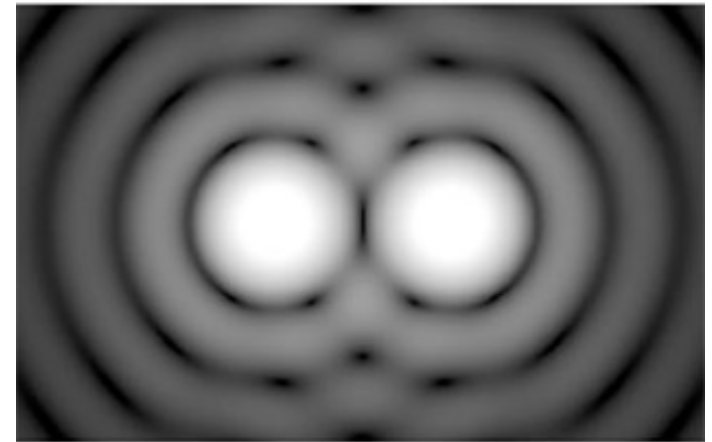
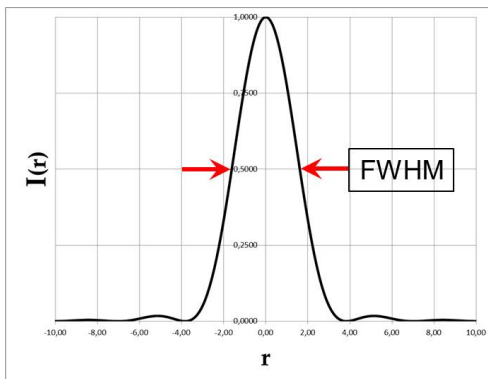
Measured by
Full-Width-Half-Maximum

Diffraction Limit to Angular Resolution

If two stars are closer than

$$\theta = \frac{1.2\lambda}{D} \text{ radians}$$

they are said to be unresolved



From Physics World

Arcseconds

- Radians are not a convenient unit for the small angles in astronomy so we use arcseconds. There are 60 arcseconds (") in an arcminute (') and 60 arcminutes in a degree (°).
- How many arcseconds are in one radian?

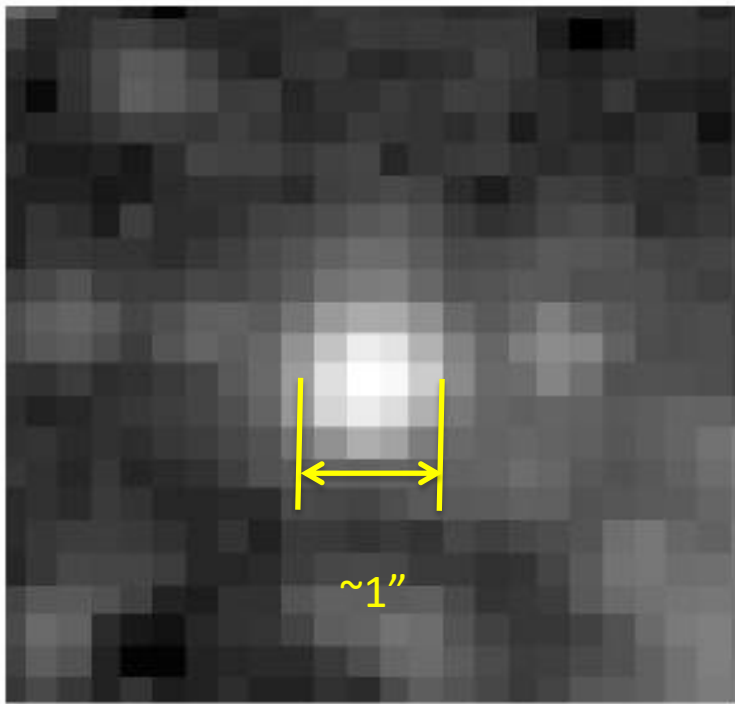
$$2\pi \text{ radians} = 360 \times 60 \times 60 \text{ arcseconds}$$

$$1 \text{ radian} = \frac{360}{2\pi} \times 60 \times 60 \text{ arcseconds}$$

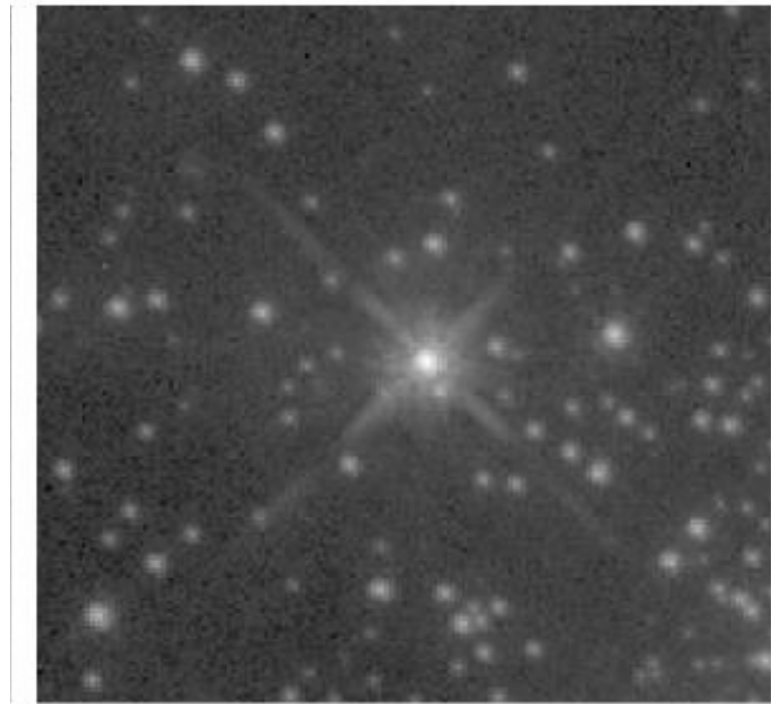
$$1 \text{ radian} = 206265 \text{ arcseconds}$$

Atmospheric 'Seeing'

- The atmosphere blurs optical images to around 1 arcsecond in size

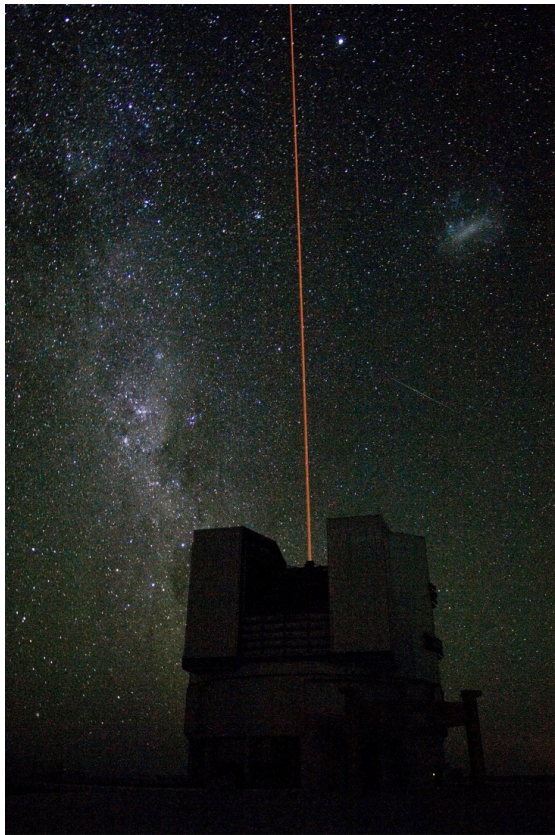


Ground-based telescope image

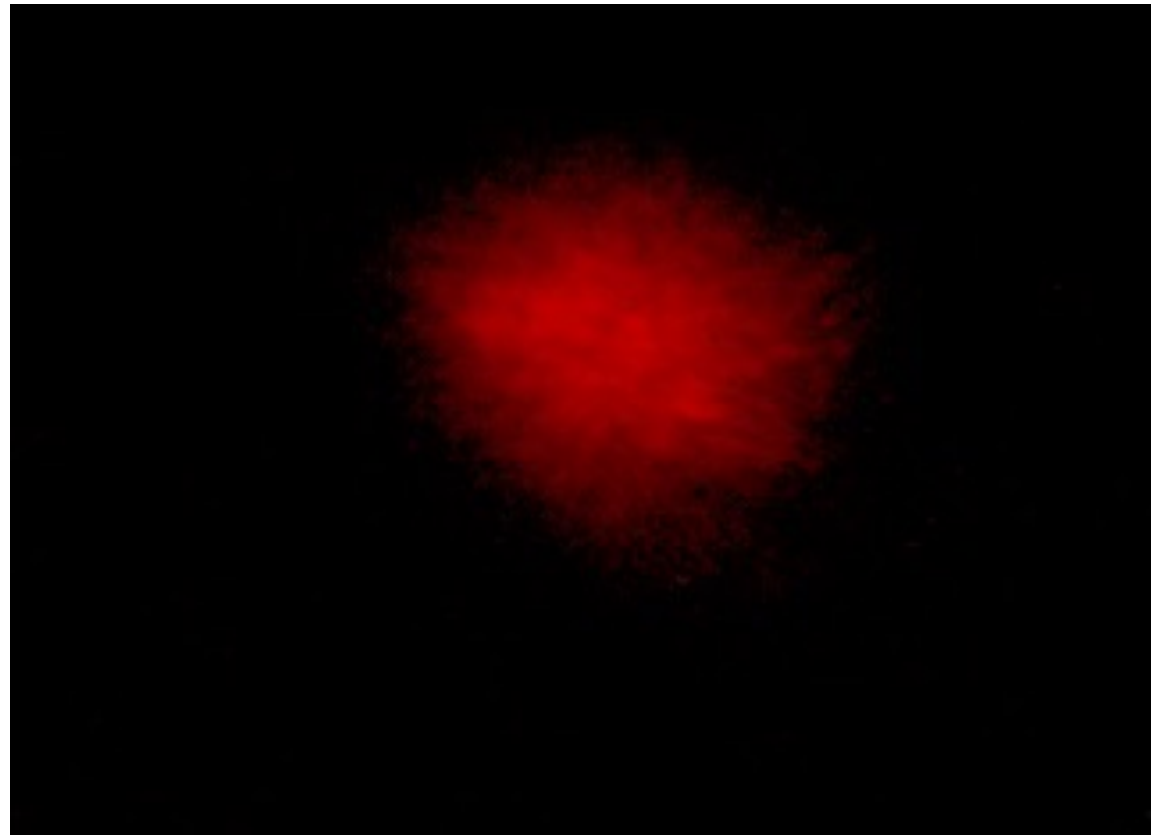


Space-based telescope image (HST)

Adaptive Optics

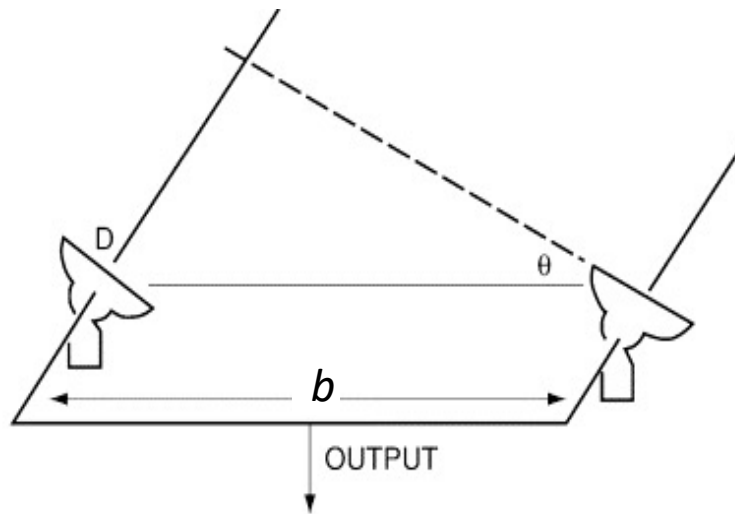


First Light of the VLT Laser Guide Star

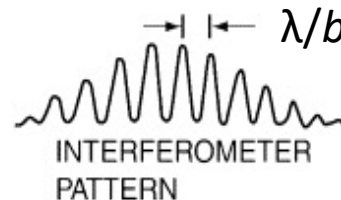
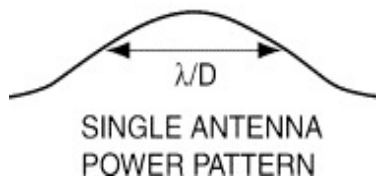


Interferometer Arrays

- Increase resolution at long wavelengths using pairs of telescopes separated by baseline, b



$$\theta \approx \frac{\lambda}{b} \text{ radians}$$



Discussion

- What would change about an array of telescopes if you increased the size of the individual telescopes, D , but kept the baseline, b , the same?

Angular Size of an Object

- The angular size of an object of size l and distance d is

$$\theta = \frac{l}{d} \text{ radians}$$

$$= 206265 \frac{l}{d} \text{ arcseconds}$$

- How do we find the distance d ?

Parallax

- Parallax is the apparent change in the position of an object due to a change in viewpoint



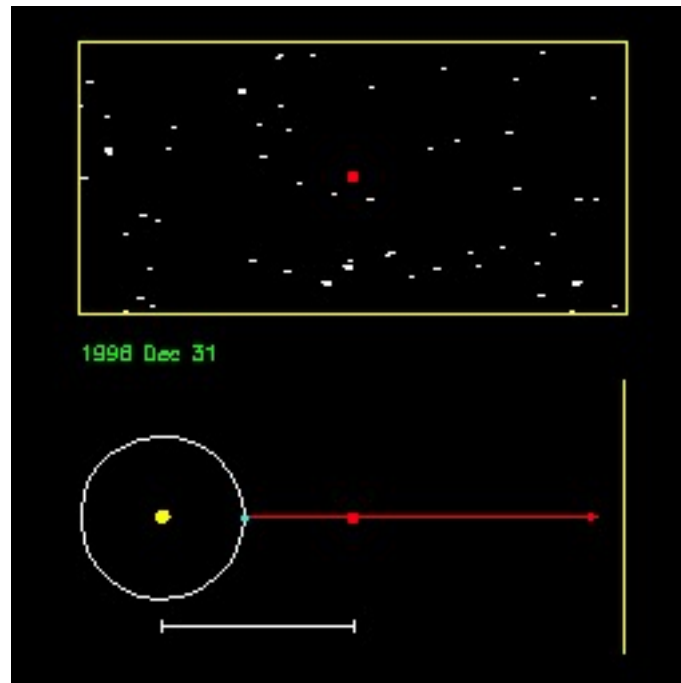
View with left eye



View with right eye

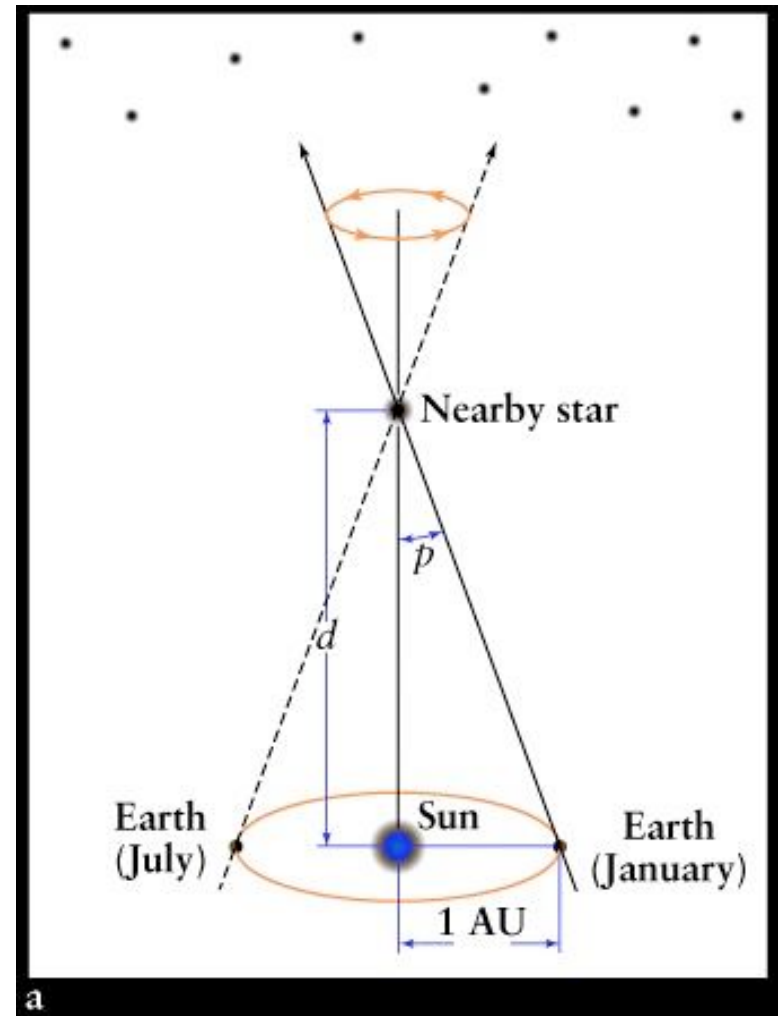
Stellar Parallax

- Nearby stars also appear to move relative to more distant background stars due to the motion of the Earth around the Sun



Trigonometric Parallax Angle

- The trigonometric parallax angle, p , of a star is half the angle through which a star appears to move relative to background stars due to the Earth's motion around the Sun in 6 months



The Parsec

- The unit of distance used in astrophysics is the parsec (pc) – short for parallax arcsecond
- It is defined as the distance (d) of a star that has a trigonometric parallax angle (p) of one arcsecond

Distance

- The distance to a star is

$$d(\text{pc}) = \frac{1}{p(\text{''})}$$

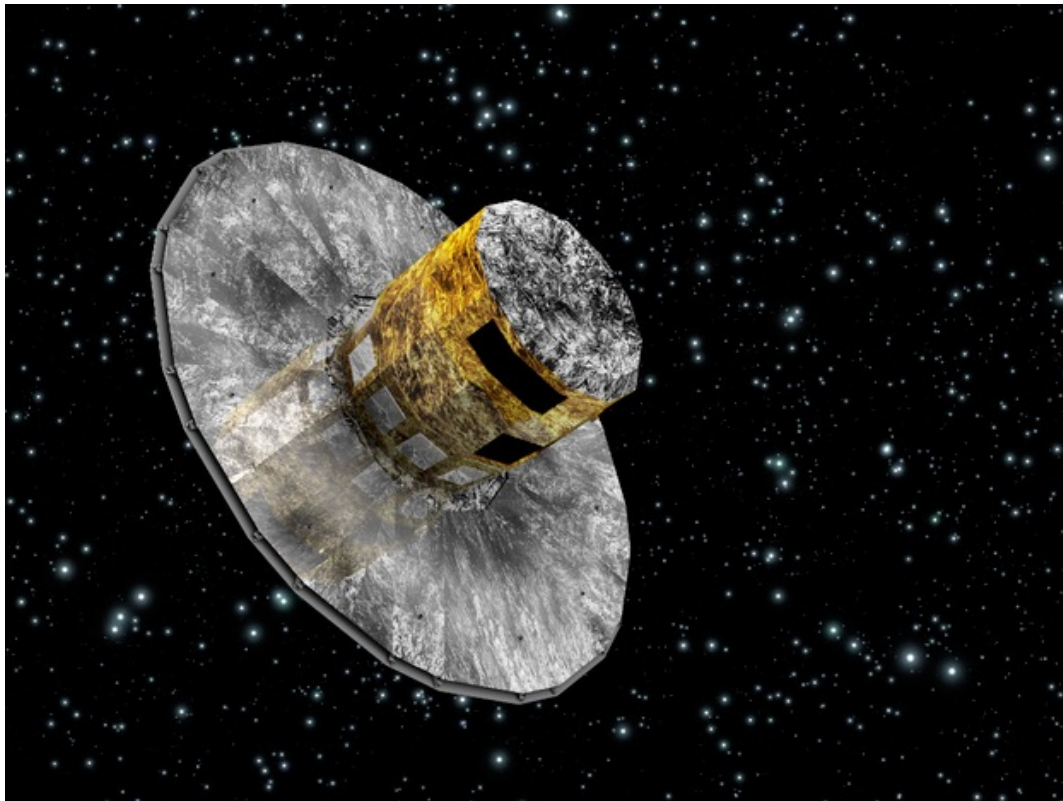
- The parallax of the nearest star at 1.3 pc is therefore 0.77''

Discussion

- Our Galaxy is over 20 kpc across. What accuracy of parallax angle measurement would be needed to measure the distances to stars across the Galaxy? How difficult is that going to be?

GAIA Satellite

- 5 year mission to measure parallaxes to an accuracy of 25 micro-arcseconds



Parallax motion on the sky exaggerated 100 000 times

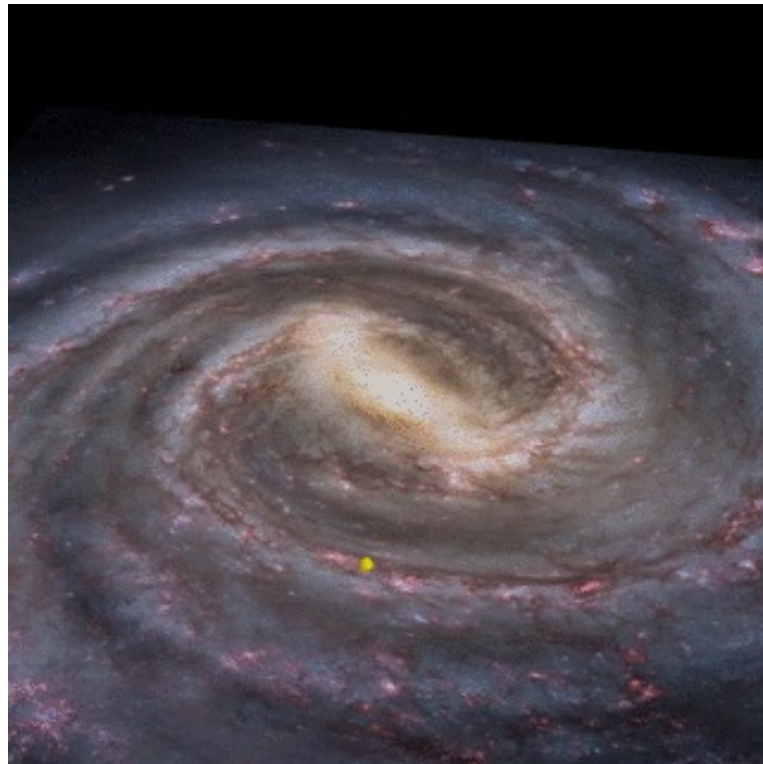
esa



<https://sci.esa.int/web/gaia/-/60233-parallax-and-proper-motion-on-the-sky>

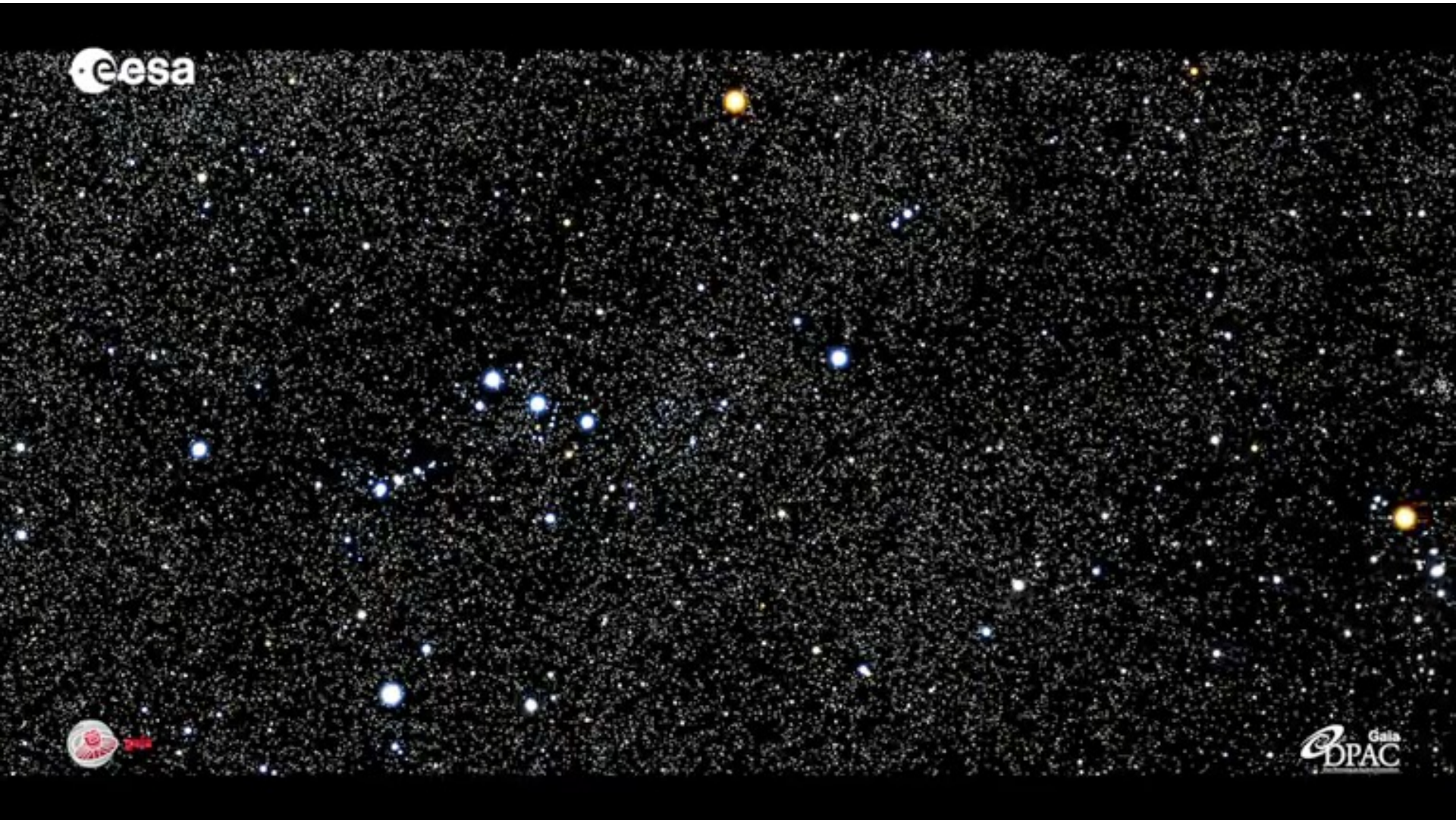
Proper Motion

- Stars also move across the sky due to their true motion – this is proper motion



<https://people.ast.cam.ac.uk/~jls/>

Proper motion of stars in Orion over the next half million years



Radial Velocity

- The radial component of velocity can be found from using the Doppler shift

$$v_r = \frac{\lambda_{obs} - \lambda_0}{\lambda_0} c = \frac{\Delta\lambda}{\lambda} c$$

where λ_{obs} is the observed wavelength and λ_0 is the rest wavelength

Summary

- The angular resolution of telescopes gets better with shorter wavelengths, larger mirrors or arrays of telescopes
- Trigonometric parallax is the only direct way to measure the distance to stars
- Proper motion and radial velocity measurements give the 3D motion of stars