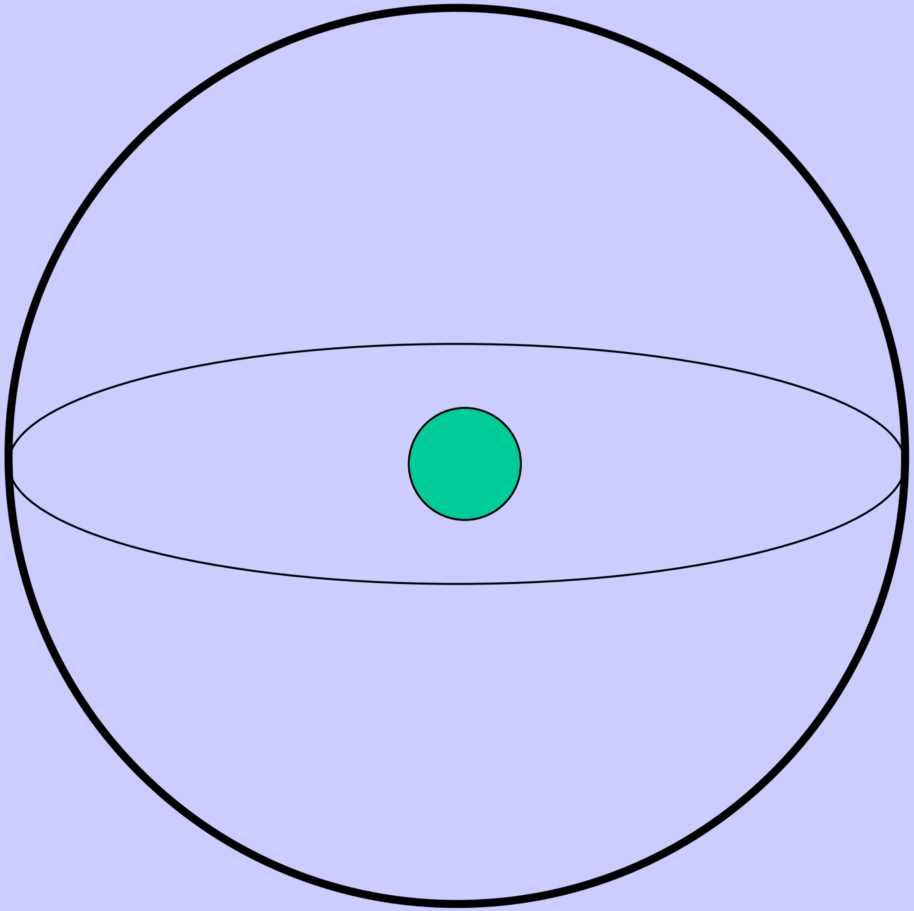
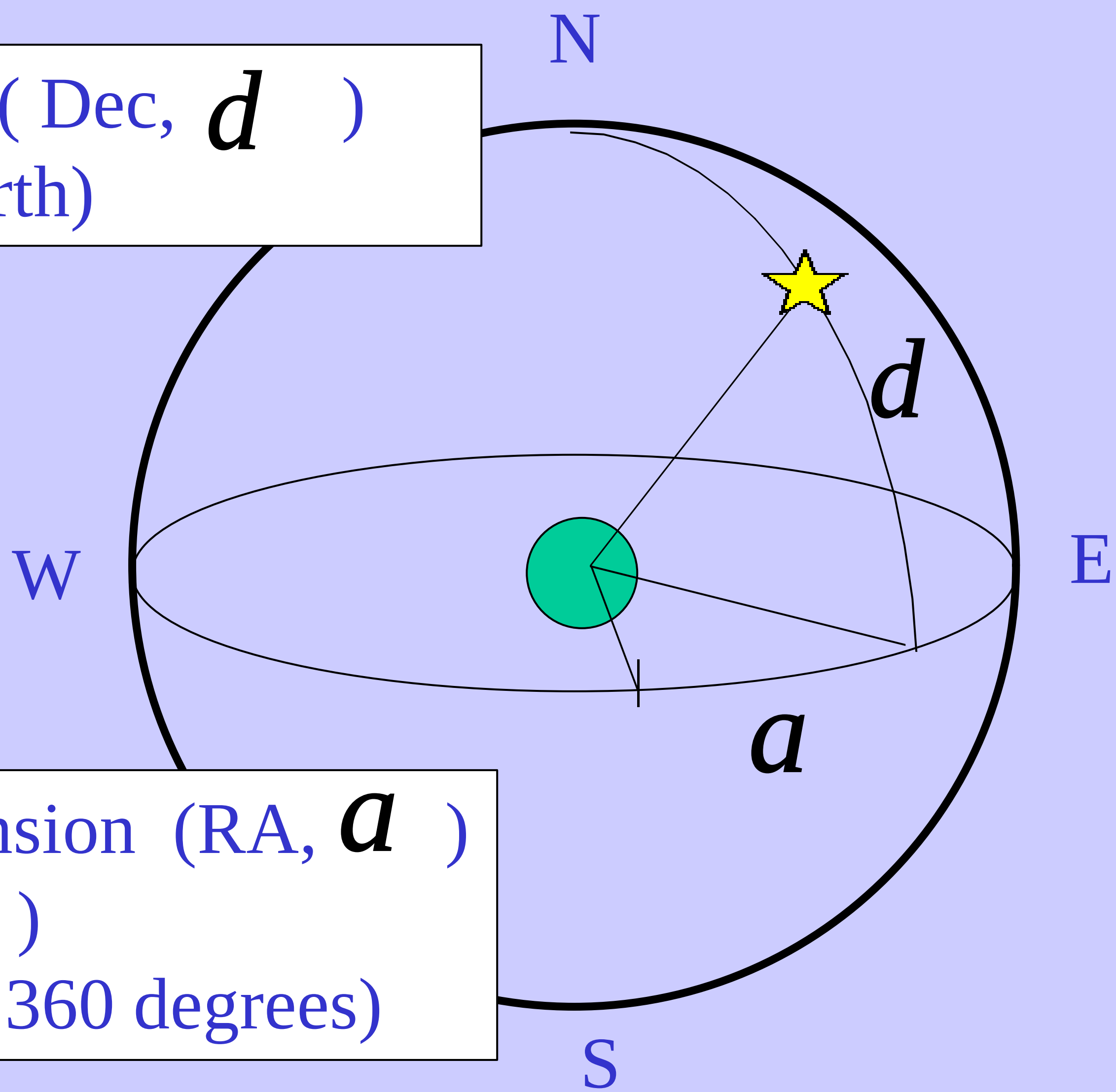
5. ***<u>THE MOTIONS OF STARS IN SPACE</u>***

The Celestial Sphere

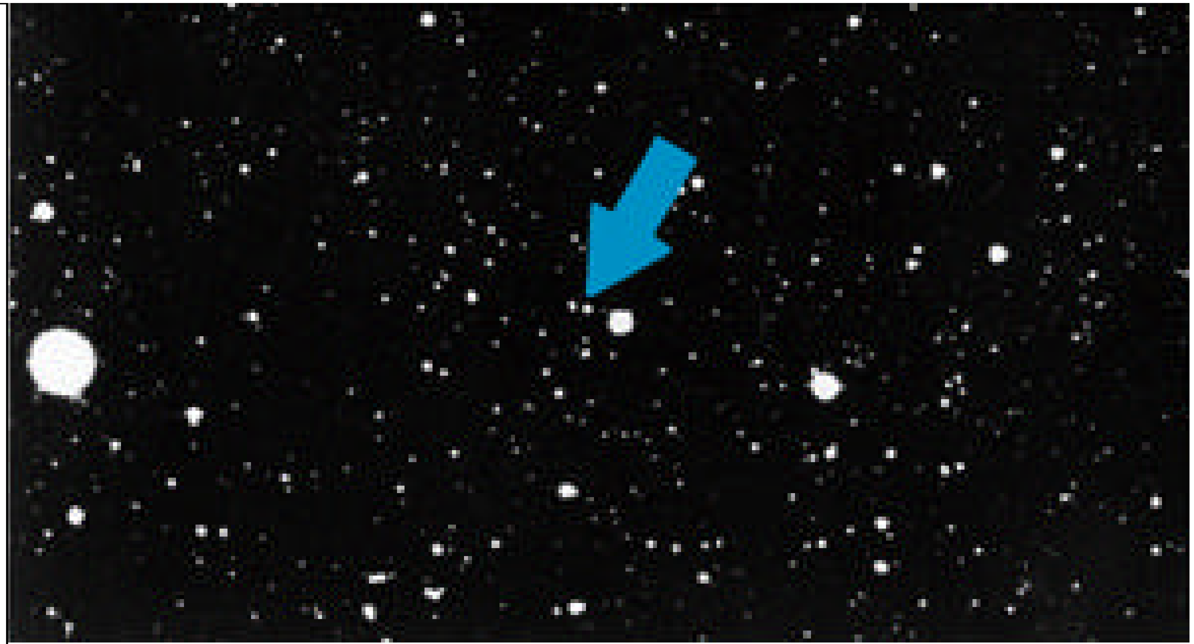


Star Coordinates

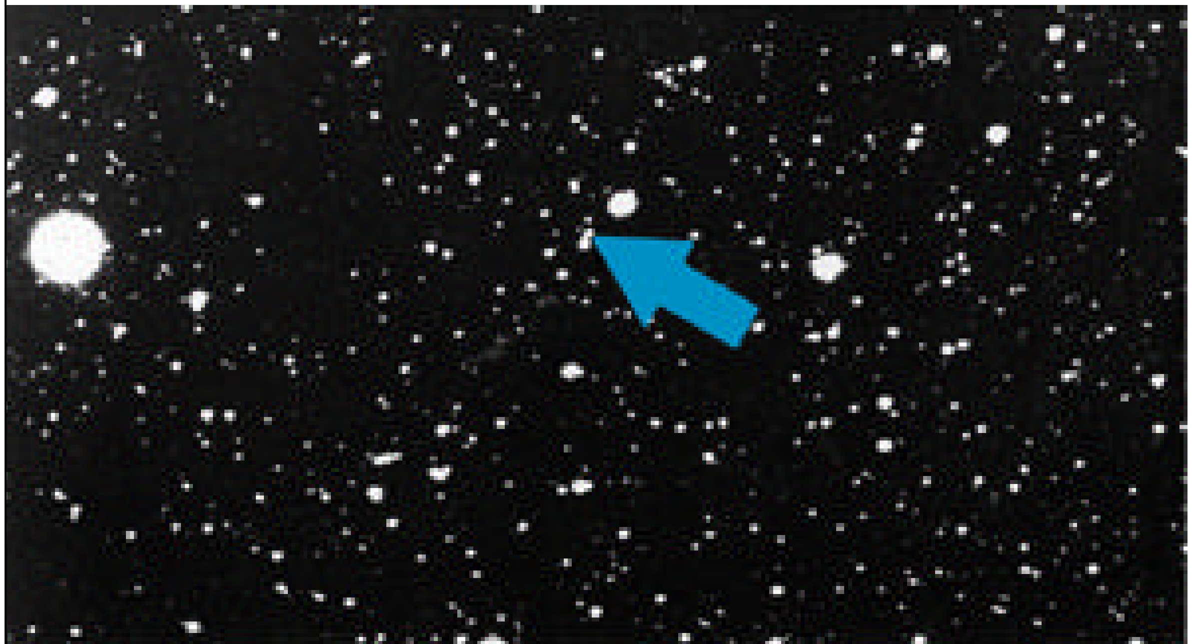
Declination (Dec, *d*)
(Degrees North)



Right Ascension (RA, *a*)
(Hours East)
(24 hours = 360 degrees)

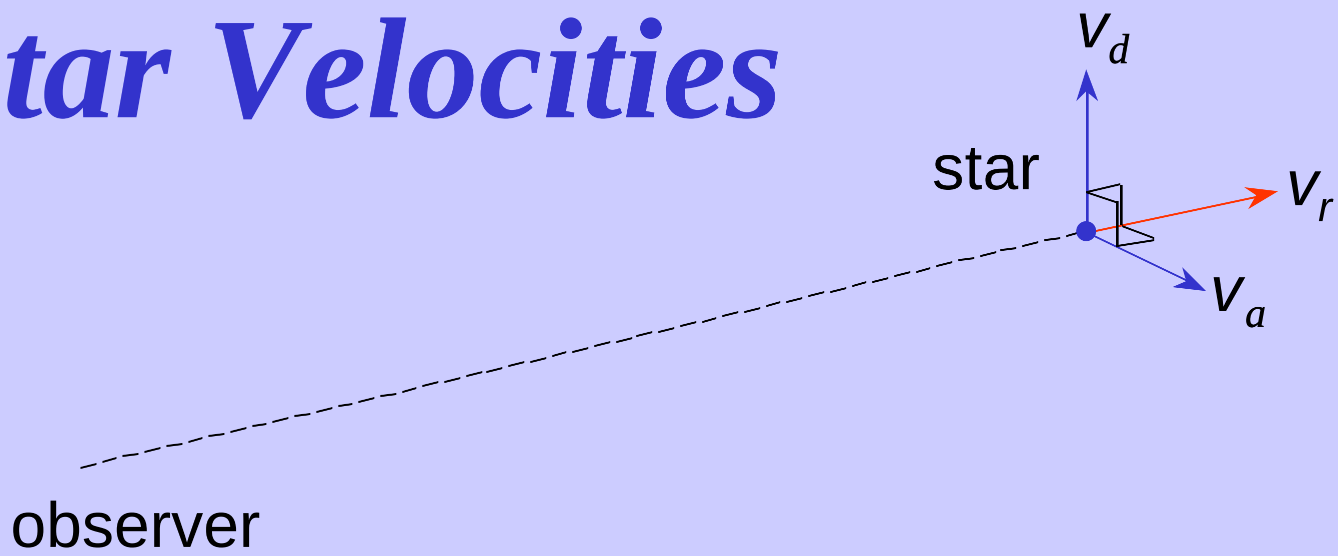


May 30, 1916



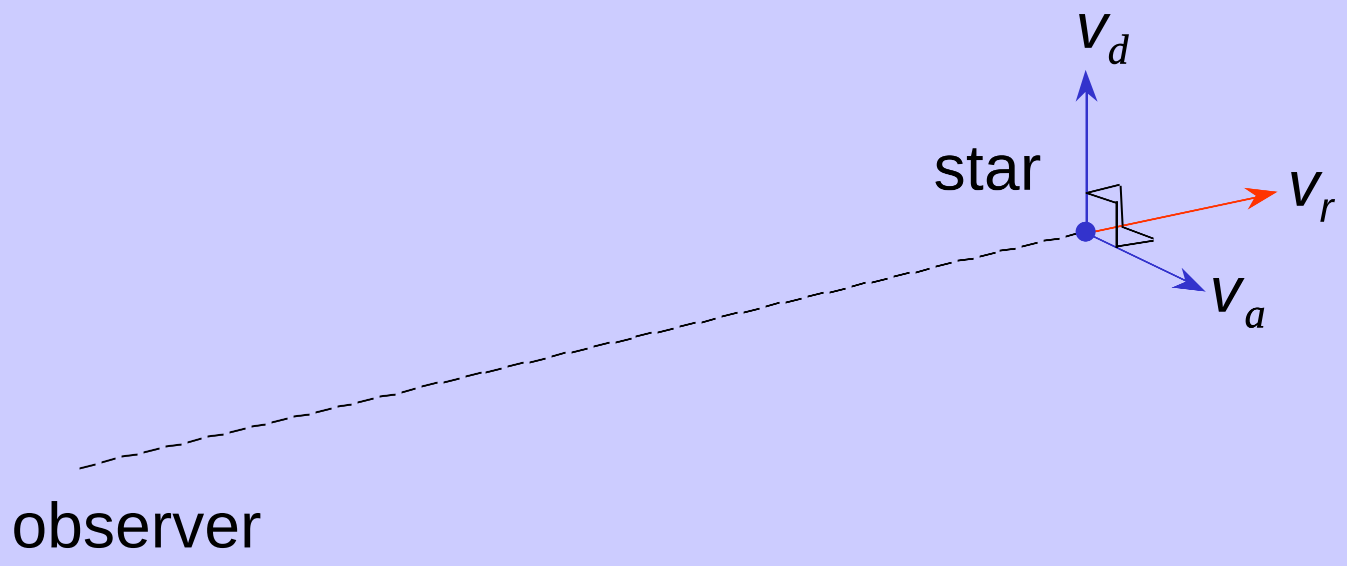
August 24, 1894

Star Velocities



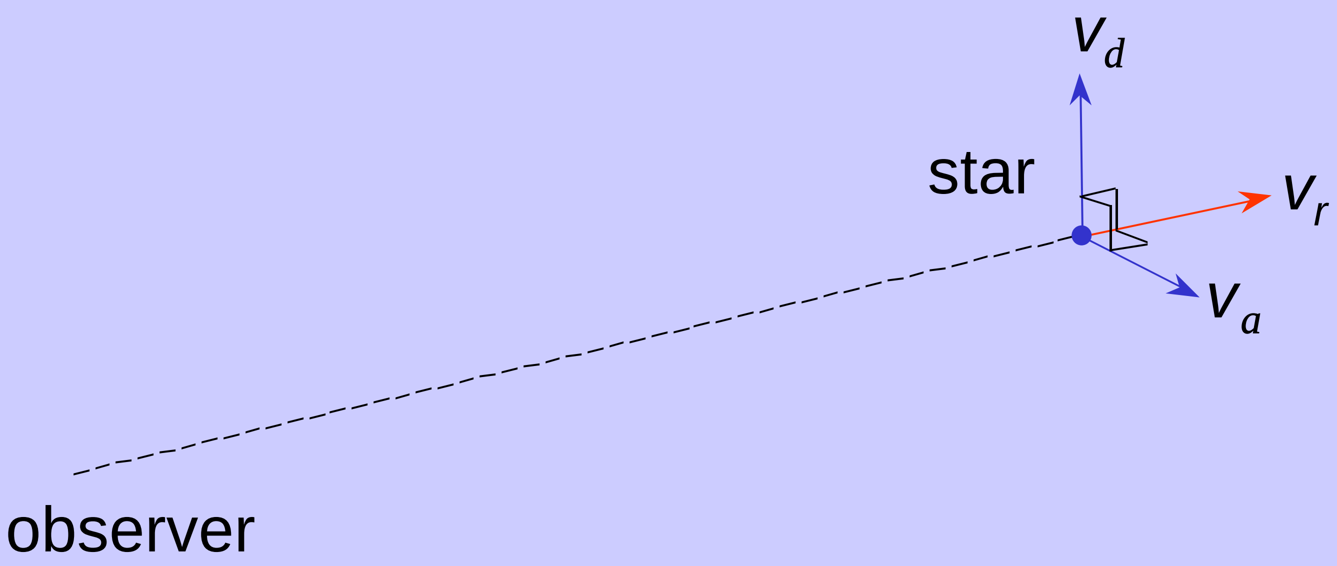
3 velocity components

(mutually perpendicular)



- in line-of-sight (radial direction)

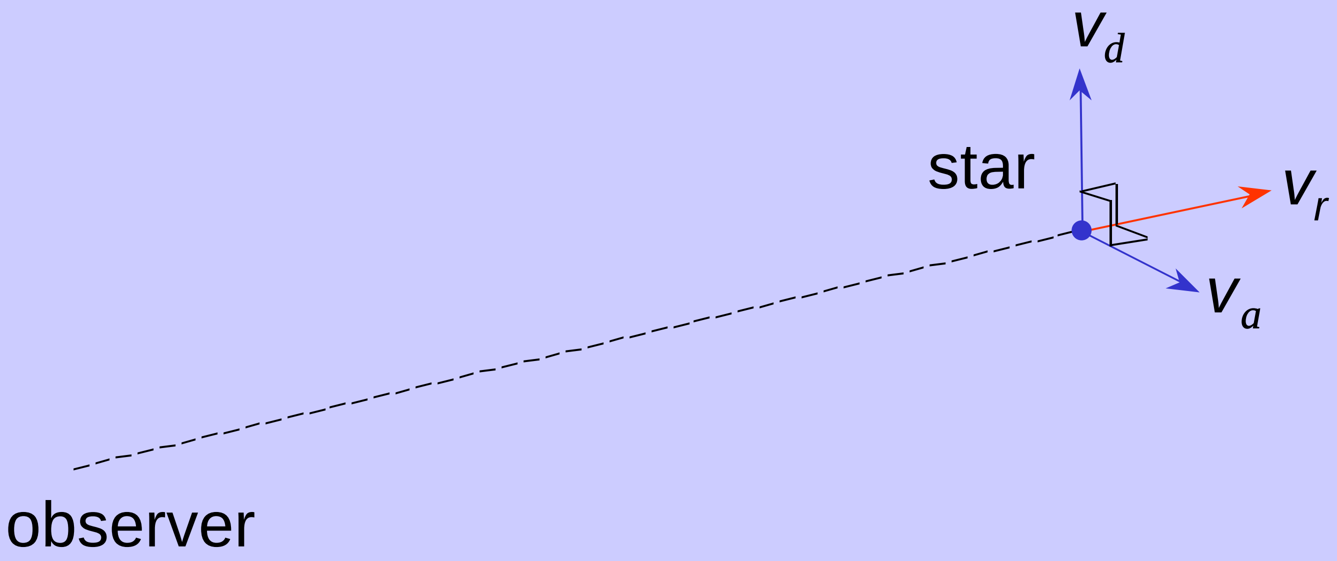
RADIAL VELOCITY v_r (km s^{-1})



- 2 components perpendicular to the line of sight

TRANSVERSE VELOCITY v_t (km s^{-1})

$$V_t = \sqrt{V_a^2 + V_d^2}$$



v_α and v_δ are the components of v_t in the directions of increasing RIGHT ASCENSION (α) and DECLINATION (δ) on the sky.

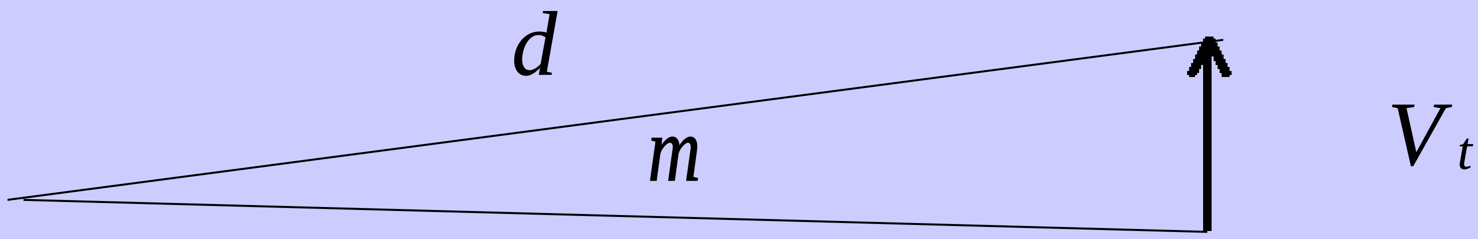
- v_r - from Doppler shift of spectral lines
- v_α, v_δ - projected onto the sky
  - we can measure only angular changes over time, called PROPER MOTION
    . μ (arcsec yr^{-1})
  - Two components of μ are
    $\mu_\alpha \cos \delta$, μ_δ
  - (see handout …)

Proper Motions tiny

Speeds of stars orbiting the Galaxy

$v \sim 250$ km s^{-1}

- but distances are in parsecs - 1 pc = 3×10^{13} km
- thus proper motions μ are small (< 0.1 arcsec yr^{-1})



small angle

$$V_t = m\ d$$

$$= \frac{m\ (\mathrm{arcsec\ yr^{-1}}) \times d\ (\mathrm{pc})}{206{,}265\ (\mathrm{arcsec/radian})} \times \left(\frac{3\times10^{15}\ \mathrm{km\ pc^{-1}}}{3\times10^{7}\ \mathrm{s\ yr^{-1}}} \right)$$

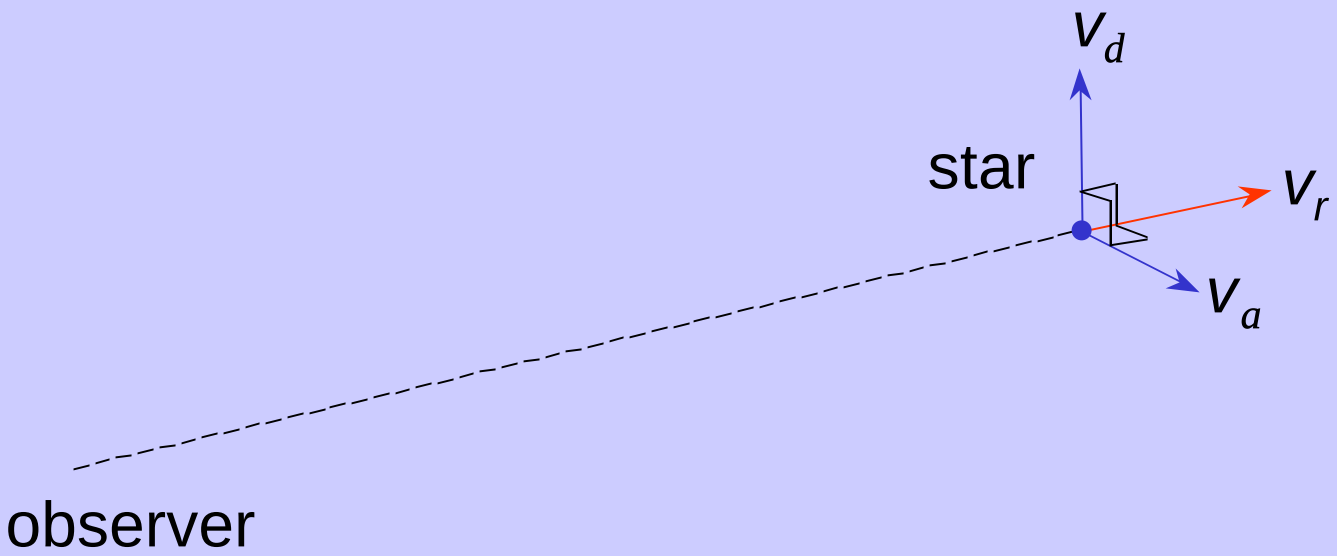
- Fast caclulation:

$$V_t = 4.74 \mu d$$

- ONLY for V_t in km s^{-1},

  μ in arcsec yr^{-1},

  d in parsecs



- <u>SPACE MOTION</u> = velocity vector

speed $$V = \sqrt{V_r^{\,2} + V_t^{\,2}}$$

+ direction specified by v_α, v_δ, v_r

Astrometry Satellites

- ***HIPPARCOS*** (1997)
- Accurate parallax and proper motion for bright stars (V < 9)

$$10^{-3}\ \text{arcsec yr}^{-1}$$

- stars to 200 pc
- ***GAIA*** planned ESA (2012 ...)
- parallax 10^{-5} arcsec
- proper motion $10^{-6}\ \text{arcsec yr}^{-1}$
- distances and motions
  . of stars throughout the Galaxy

Star Cluster at the Galactic Centre

VLT (Very Large Telescope)

D=8m, one of 4, in Chile.

Infrared light

(to see through the intervening dust)

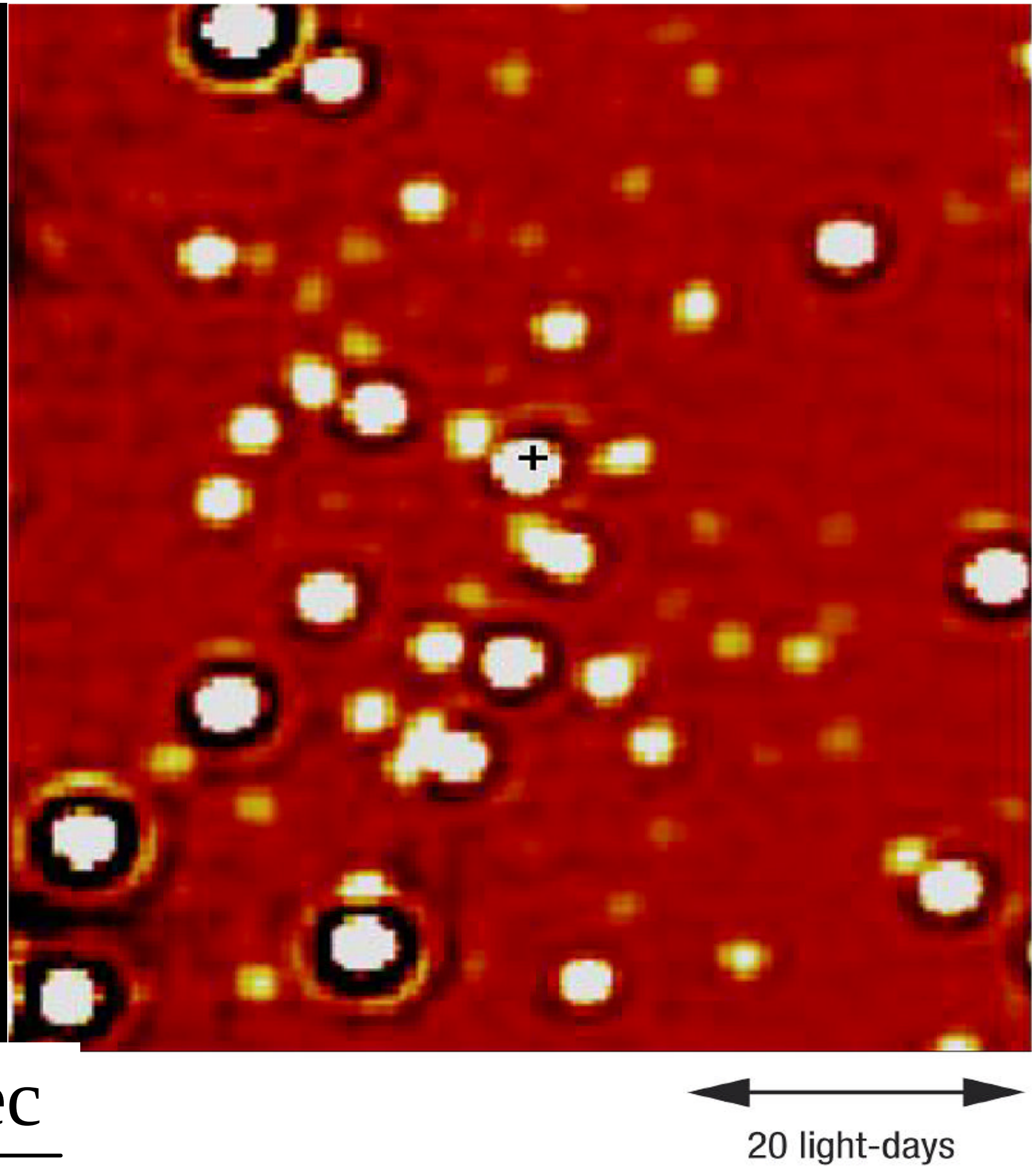
The Centre of the Milky Way
(VLT YEPUN + NACO)

ESO PR Photo 23a/02 (9 October 2002)

Stars orbiting the Black Hole

Adaptive Optics

(corrects for seeing)



The Centre of the Milky Way (detail)
(VLT YEPUN + NACO)

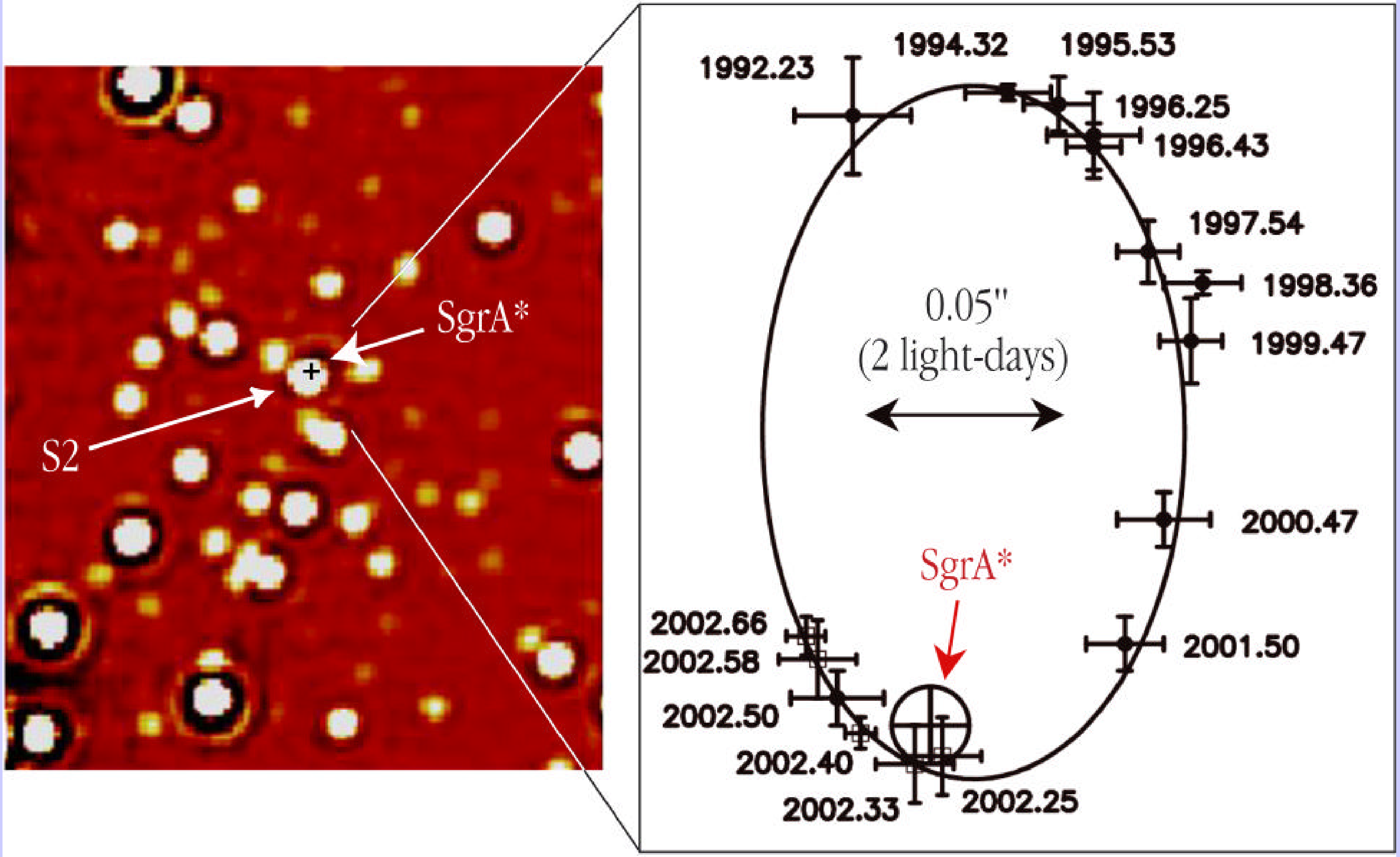
R Photo 23b/02 (9 October 2002)

$$\frac{0.05\ \text{pc}}{8500\ \text{pc}} \times \frac{206265\ \text{arcsec}}{\text{radian}}$$

$$= 1.2\ \text{arcsec}$$

Star Motions at the Galactic Centre

NACO May 2002 | S2 Orbit around SgrA*



The Motion of a Star around the Central Black Hole in the Milky Way

ESO PR Photo 23c/02 (9 October 2002)

Black Hole at the Galactic Centre

- From the proper motions, measure sizes and periods of the star orbits.
- Kepler's law :

$$\frac{M}{M_{\text{sun}}} = \left(\frac{a}{\text{AU}} \right)^3 \left(\frac{P}{\text{yr}} \right)^{-2}$$

- the black hole mass

$$M \approx 3 \times 10^6 \, M_{\text{sun}}$$

THE END