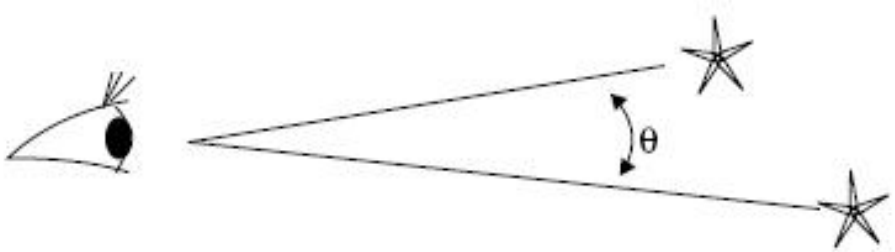
Astronomical Techniques I

Lecture 3

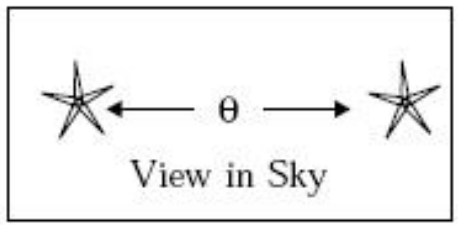
Yogesh Wadadekar

Jan-Feb 2015

Universe is a 2D surface!



Cross Section View



Smallest measurable angular separations (arcsec)

Optical	10^{-3}	best
Radio	10^{-6}	Space Very-Long Baseline Interferometry (VLBI))
X-ray	2	limited by spacecraft
γ-ray	3600	limited by properties of γ-ray detectors

How far would a 2 rupee coin ($\sim$ 2 cm diameter) be if it subtends an angle of 1 milliarcsec?

Smallest measurable angular separations (arcsec)

Optical	10^{-3}	best
Radio	10^{-6}	Space Very-Long Baseline Interferometry (VLBI))
X-ray	2	limited by spacecraft
γ-ray	3600	limited by properties of γ-ray detectors

How far would a 2 rupee coin ($\sim$ 2 cm diameter) be if it subtends an angle of 1 milliarcsec?

$2 \times 10^5 \times 2 \times 10^3 / 10^5 = 4000$ km.

Angular separation between 2 coordinates on the sky

$$z_1 = \sin \delta_1 \quad (1)$$

$$y_1 = \cos \delta_1 \cos \alpha_1 \quad (2)$$

$$x_1 = \cos \delta_1 \sin \alpha_1 \quad (3)$$

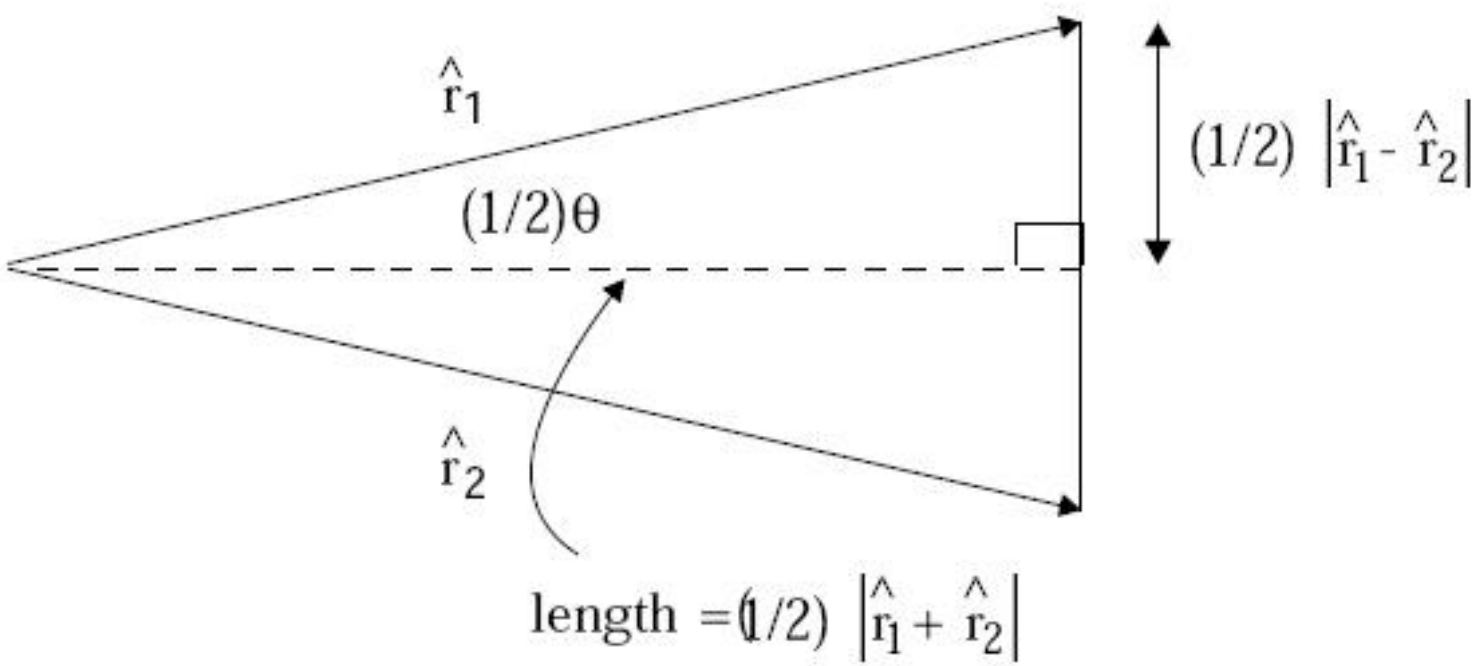
where α and δ represent RA and Dec respectively.

Angular separation between 2 coordinates on the sky

$$z_1 = \sin\delta_1 \quad (1)$$
$$y_1 = \cos\delta_1 \cos\alpha_1 \quad (2)$$
$$x_1 = \cos\delta_1 \sin\alpha_1 \quad (3)$$

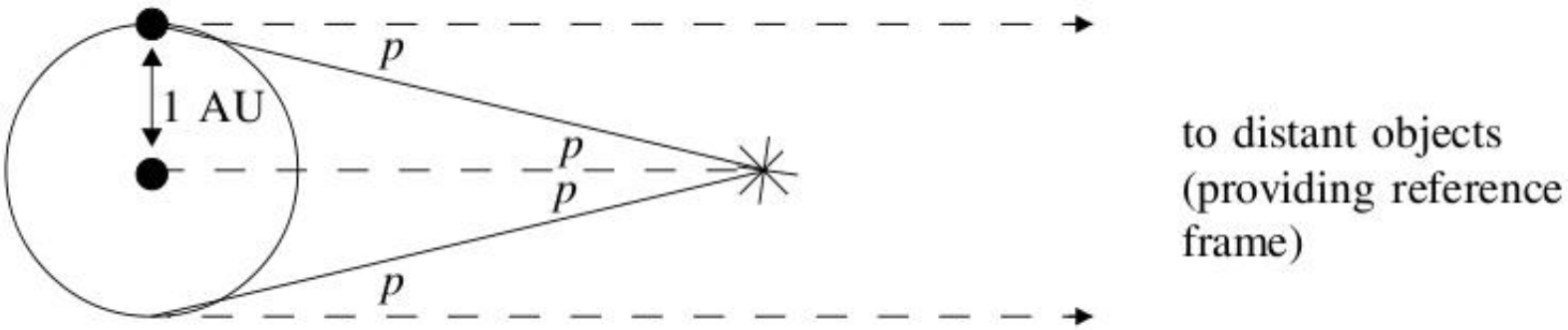
where α and δ represent RA and Dec respectively. For unit vectors $\hat{r}_1$ and $\hat{r}_2$, $\cos\theta = \hat{r}_1 \cdot \hat{r}_2$
$\cos\theta = \sin\delta_1 \sin\delta_2 + \cos\delta_1 cos\delta_2 \cos(\alpha_1 - \alpha_2)$
Will this formula work on a computer for small angular separations θ?

For small angular separations...



$$\tan(\theta/2) = |\hat{r}_1 - \hat{r}_2|/|\hat{r}_1 + \hat{r}_2|$$

Parallax second (parsec)

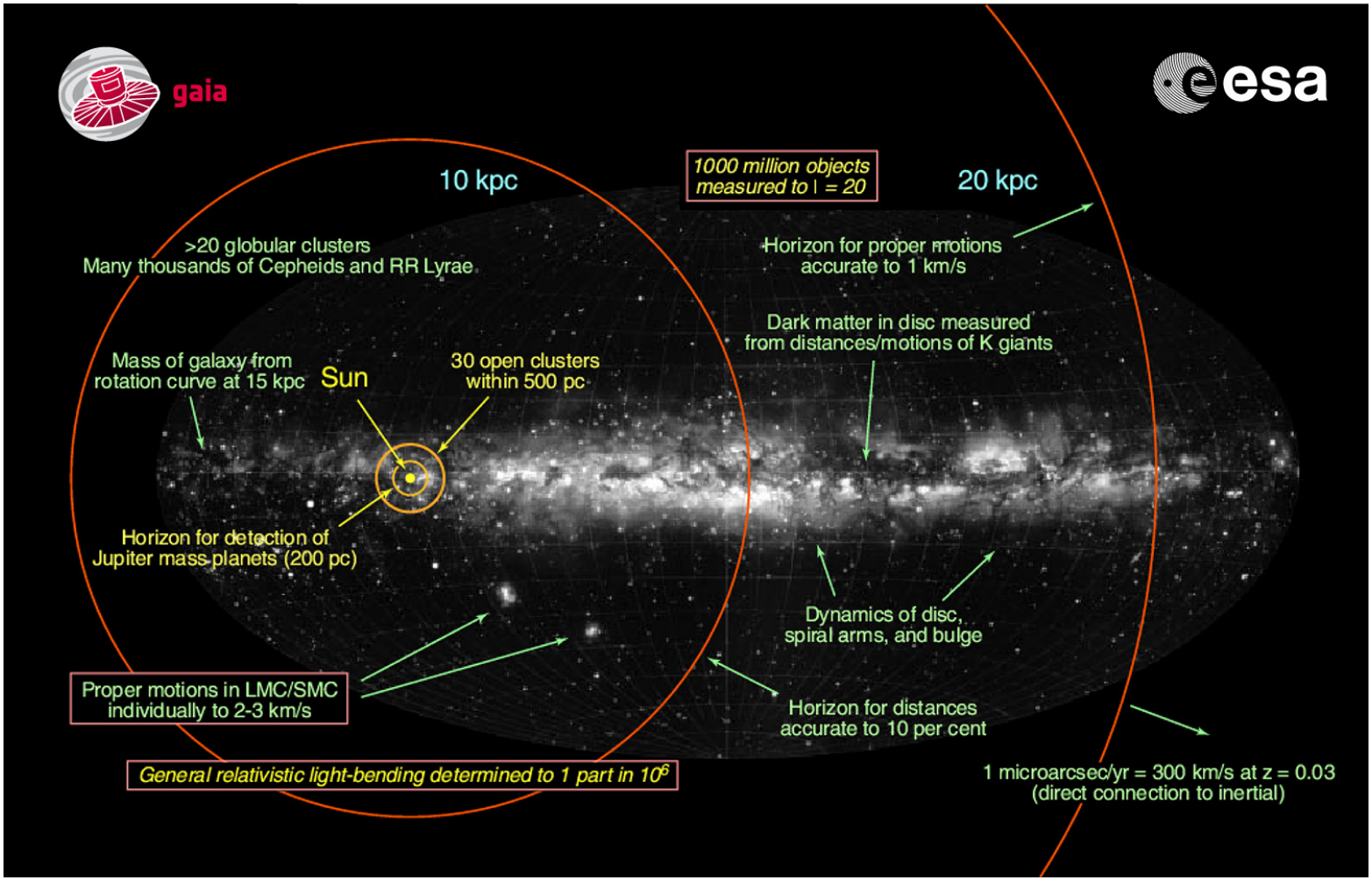


If $p = 1$ arcsec, distance to the star is one parsec. How much is a parsec in AU units? The nearest star is 1.3 parsec away. If the earth-sun distance were 1 meter, how far away is the nearest star? The galactic center is 8 kpc away. How far is that?

Hipparchos and Gaia

Between 1989 and 1993, the Hipparcos satellite, launched by the European Space Agency (ESA), measured parallaxes for about 100,000 stars with an astrometric precision of about 0.97 milliarcseconds, and obtained accurate measurements for stellar distances of stars up to 1,000 pc away.
ESA's Gaia satellite, launched in 2013, is intended to measure one billion stellar distances to within 20 microarcseconds, producing errors of 10% in measurements as far as the Galactic Center, about 8,000 pc away.

Gaia


gaia
esa
10 kpc
1000 million objects
measured to I = 20
20 kpc
>20 globular clusters
Many thousands of Cepheids and RR Lyrae
Horizon for proper motions
accurate to 1 km/s
Dark matter in disc measured
from distances/motions of K giants
Mass of galaxy from
rotation curve at 15 kpc
Sun
30 open clusters
within 500 pc
Horizon for detection of
Jupiter mass planets (200 pc)
Dynamics of disc,
spiral arms, and bulge
Proper motions in LMC/SMC
individually to 2-3 km/s
Horizon for distances
accurate to 10 per cent
General relativistic light-bending determined to 1 part in 10^6
1 microarcsec/yr = 300 km/s at z = 0.03
(direct connection to inertial)

Solid angle

is the area on the unit sphere that an object covers. Since a unit sphere has an area of 4π, there are 4π steradian on the sky.
How many square degrees are there in the sky?

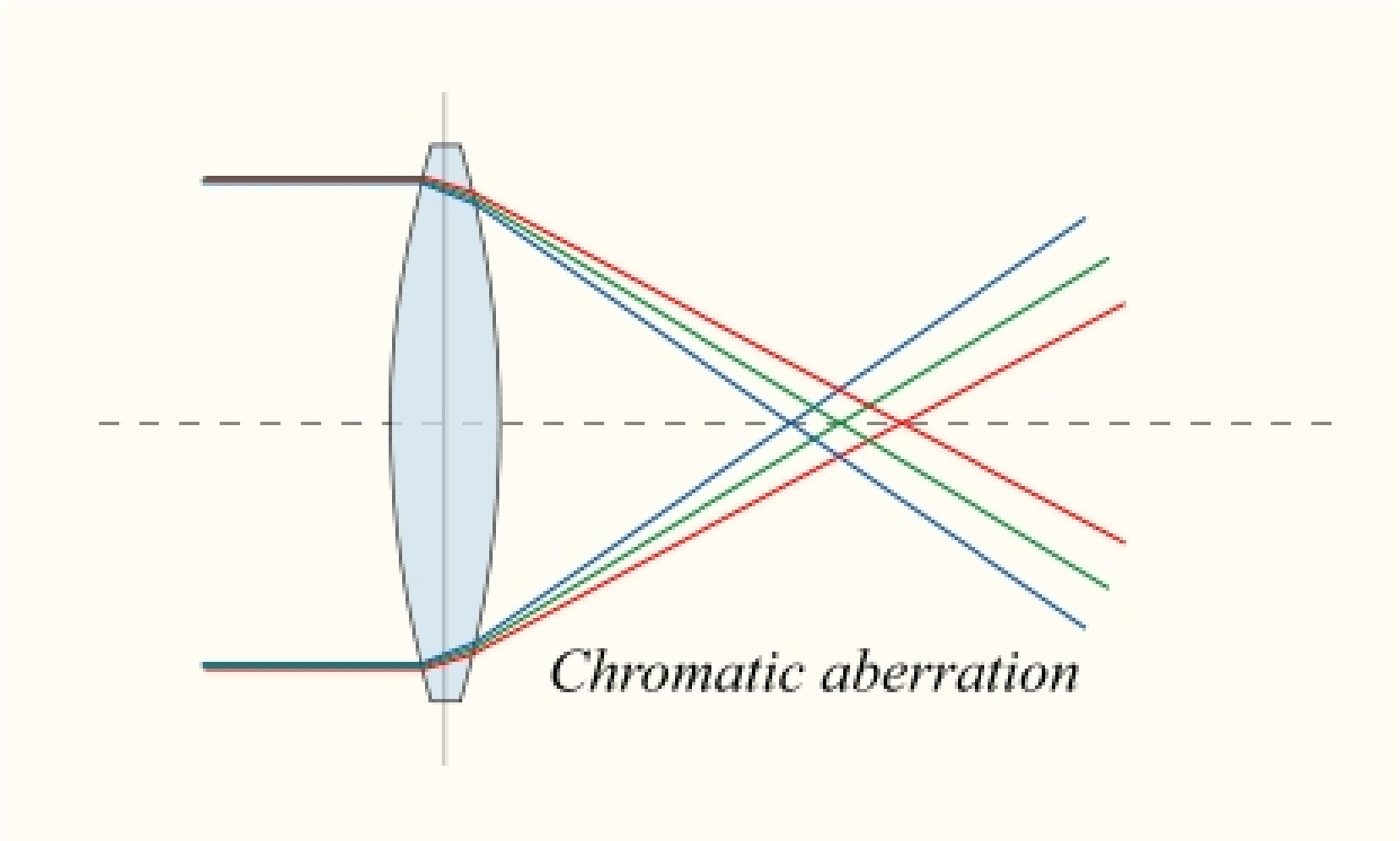
Solid angle

is the area on the unit sphere that an object covers. Since a unit sphere has an area of 4π, there are 4π steradian on the sky.

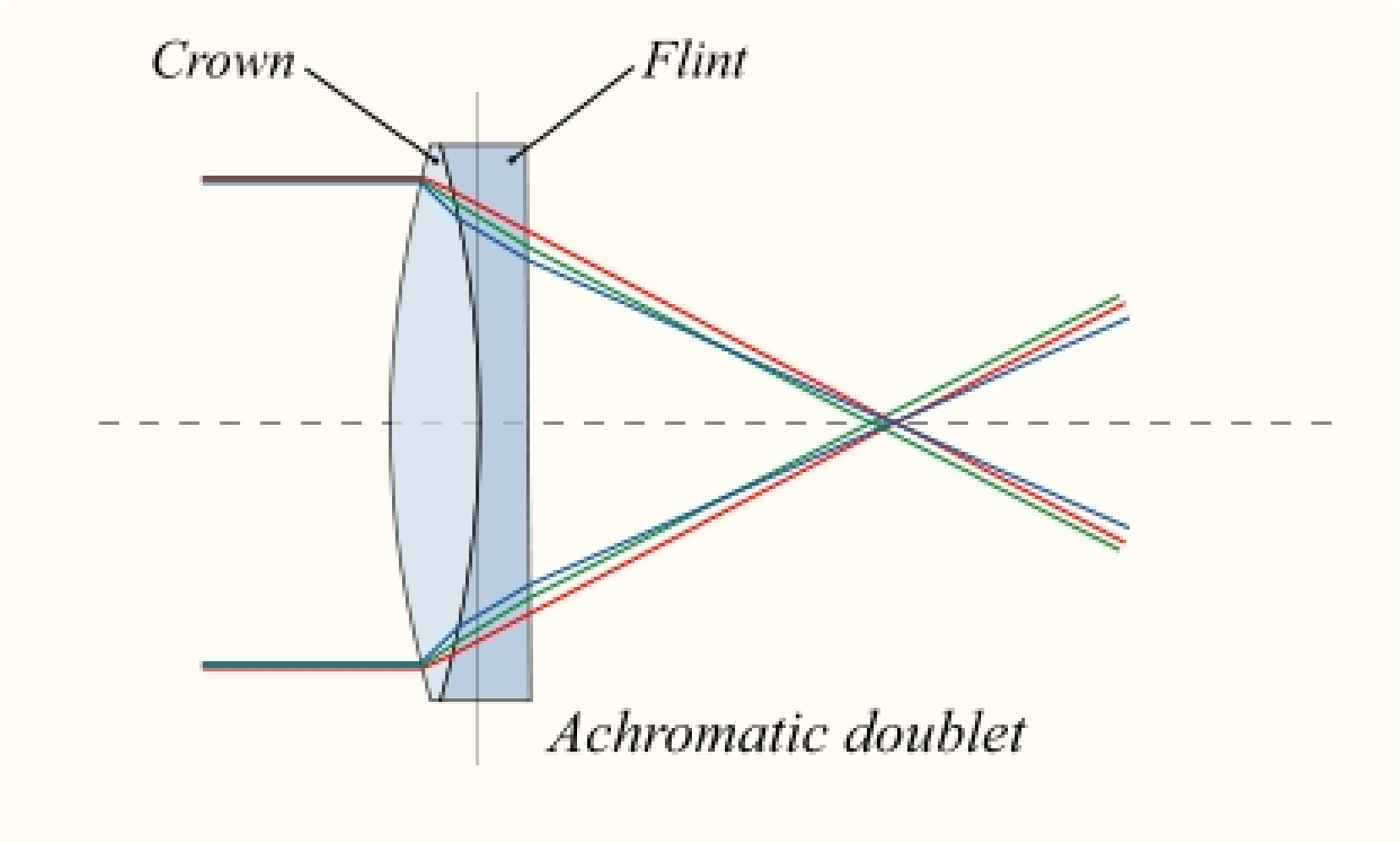
How many square degrees are there in the sky?

$(180/\pi)^2 \times 4 \times \pi = 41253$

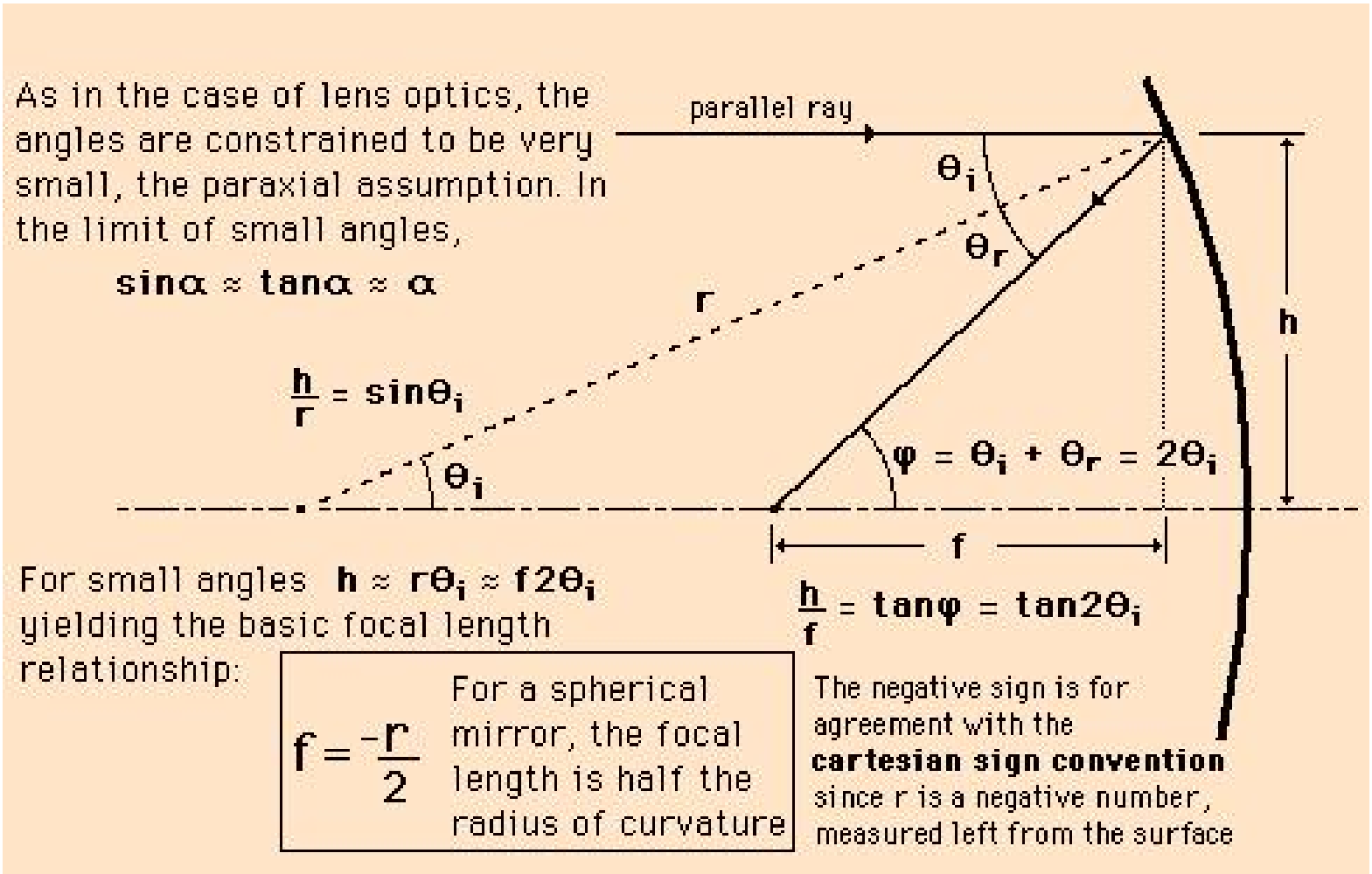
Chromatic Aberration



Chromatic Aberration - the solution



Spherical Aberration



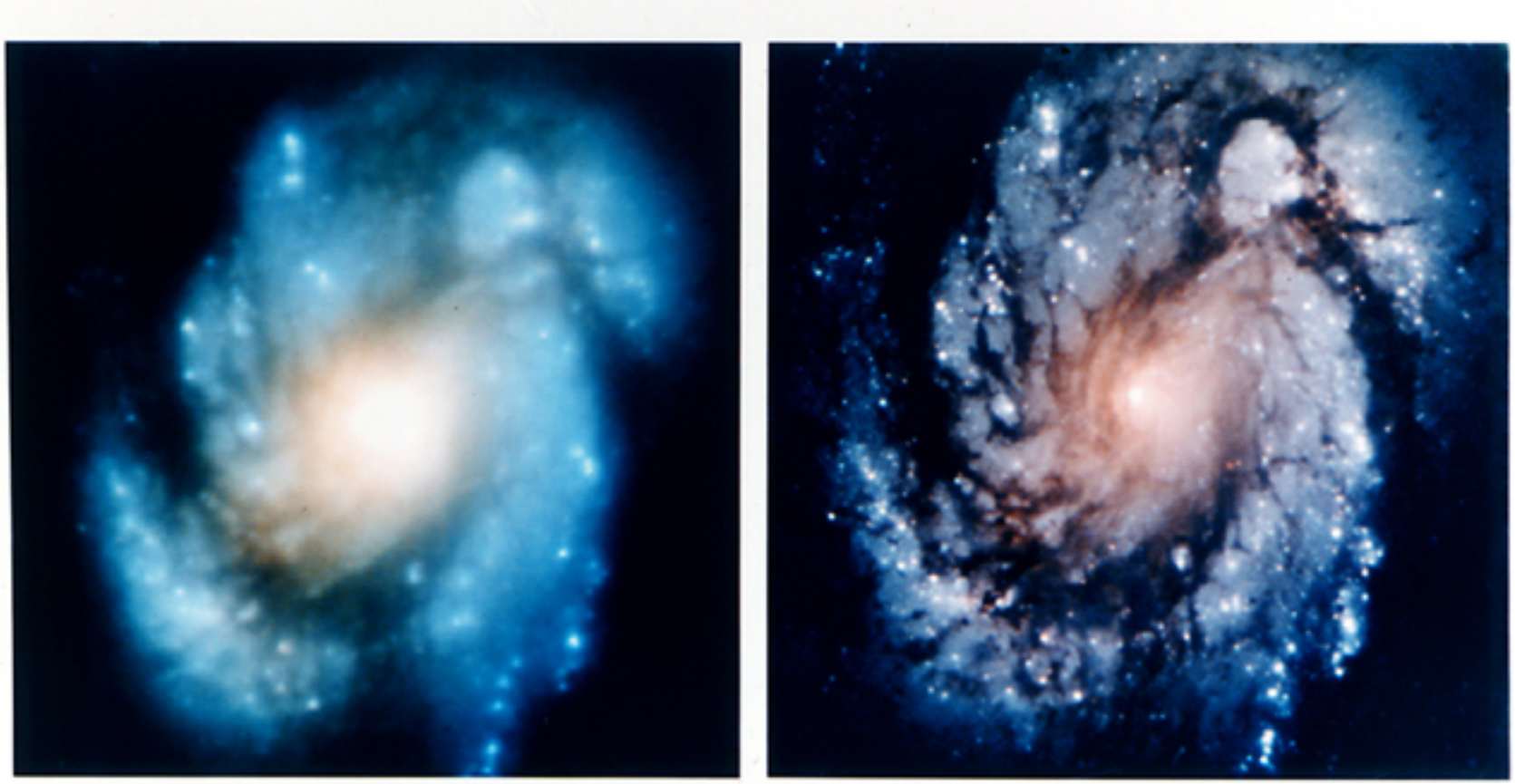
Solution - use a parabolic mirror

Spherical Aberration - the ultimate example

Cause of the problem with Hubble optics

- the main null corrector had one of its lenses sitting in a groove 1.3 mm away from where it needed to be. precision but poor accuracy.
- there were two other null correctors of lower precision that showed that spherical aberration was present. These readings were ignored.
- there had been a lot of bad blood between NASA and Perkins-Elmer due to cost and schedule overruns by the company.

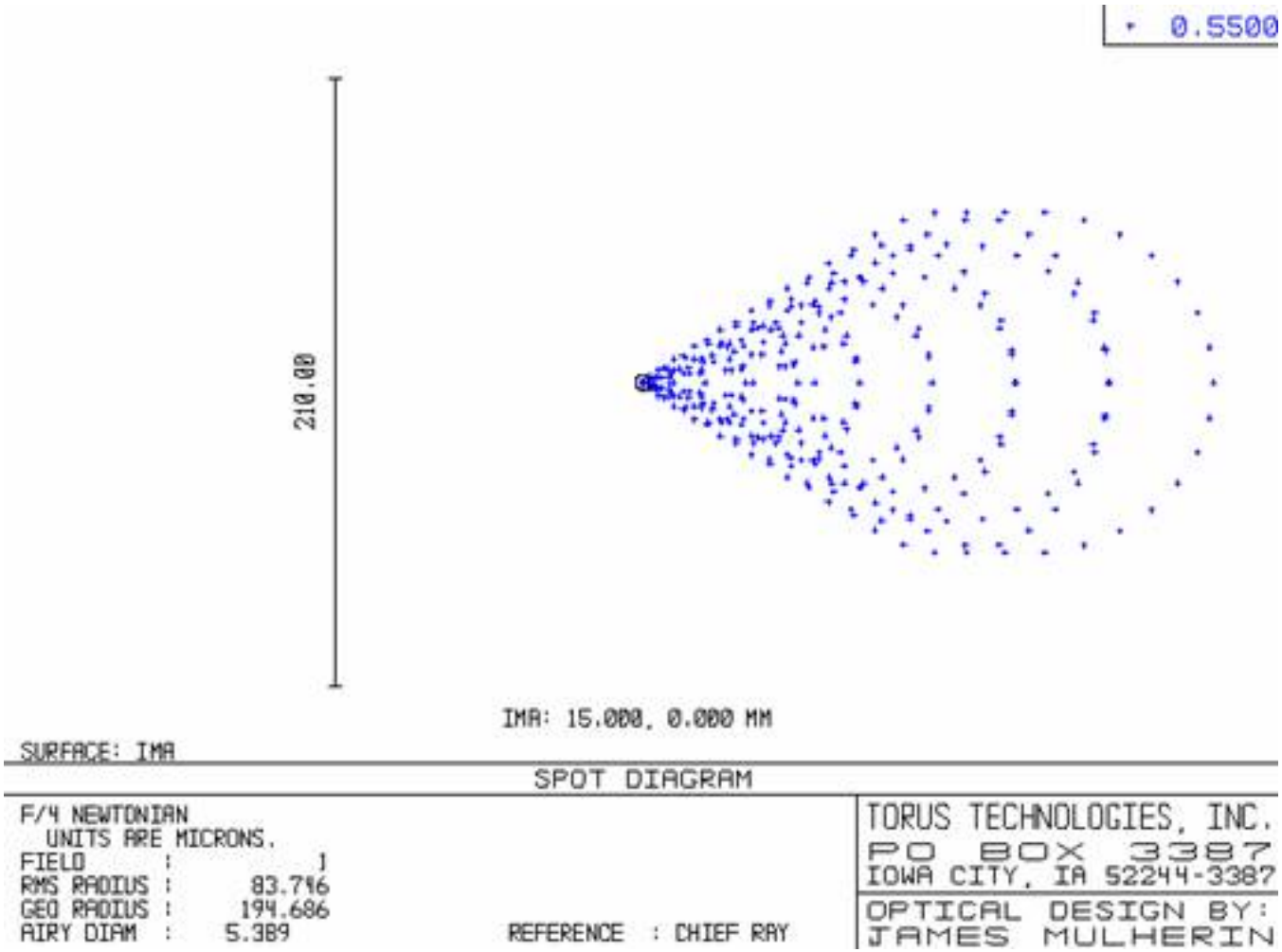
M100 before and after COSTAR



Wide Field Planetary Camera 1

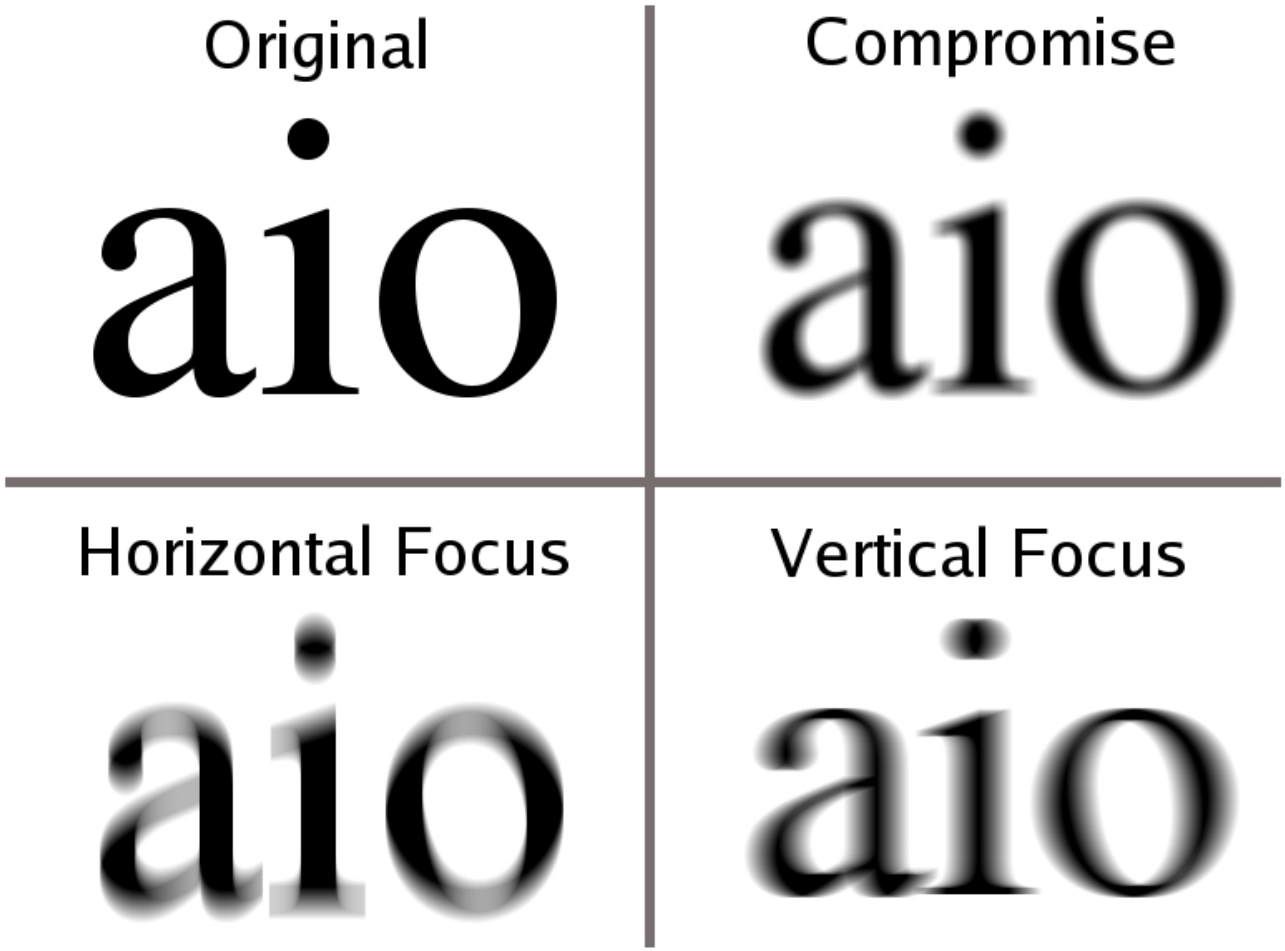
Wide Field Planetary Camera 2

Coma or comatic aberration - inherent to parabolic telescopes

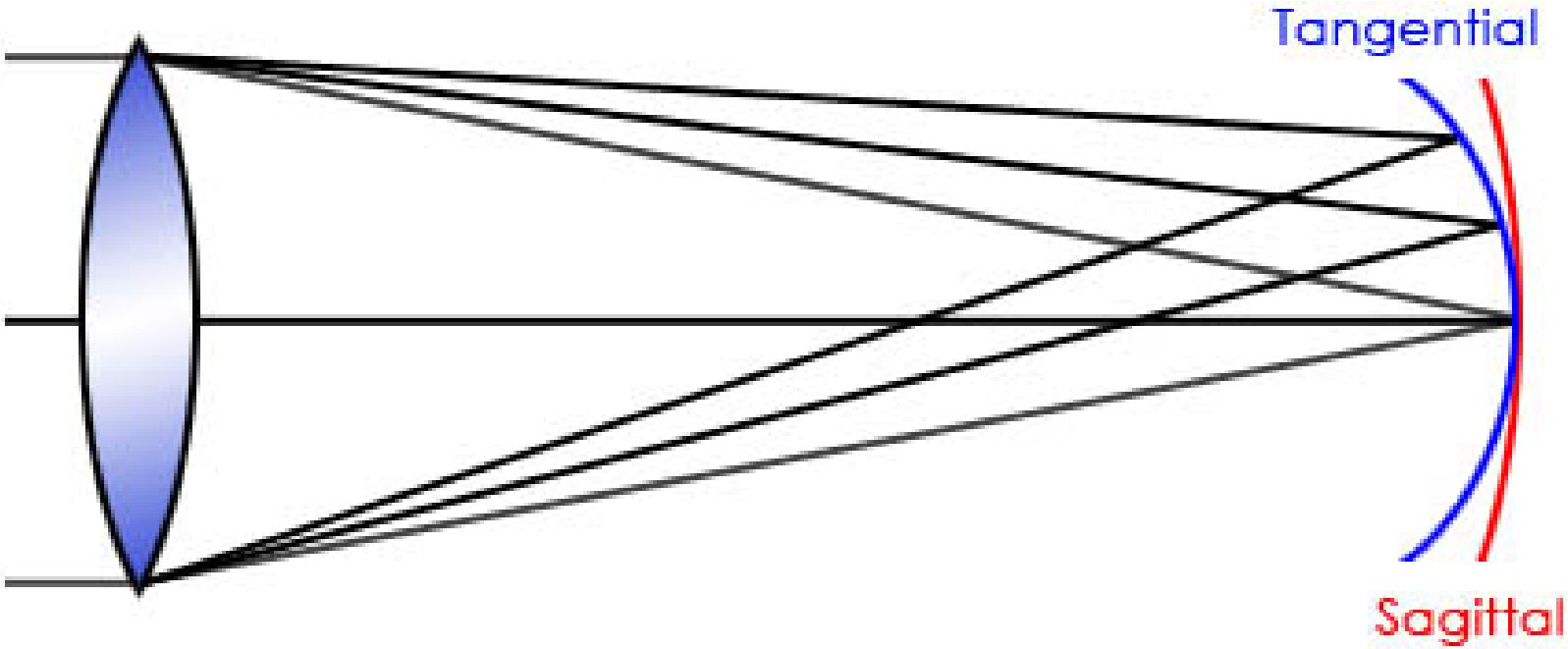


show video

Astigmatism



Astigmatism focal surfaces



Two distinct focal surfaces exist in the presence of astigmatism, a tangential focal surface and sagittal focal surface

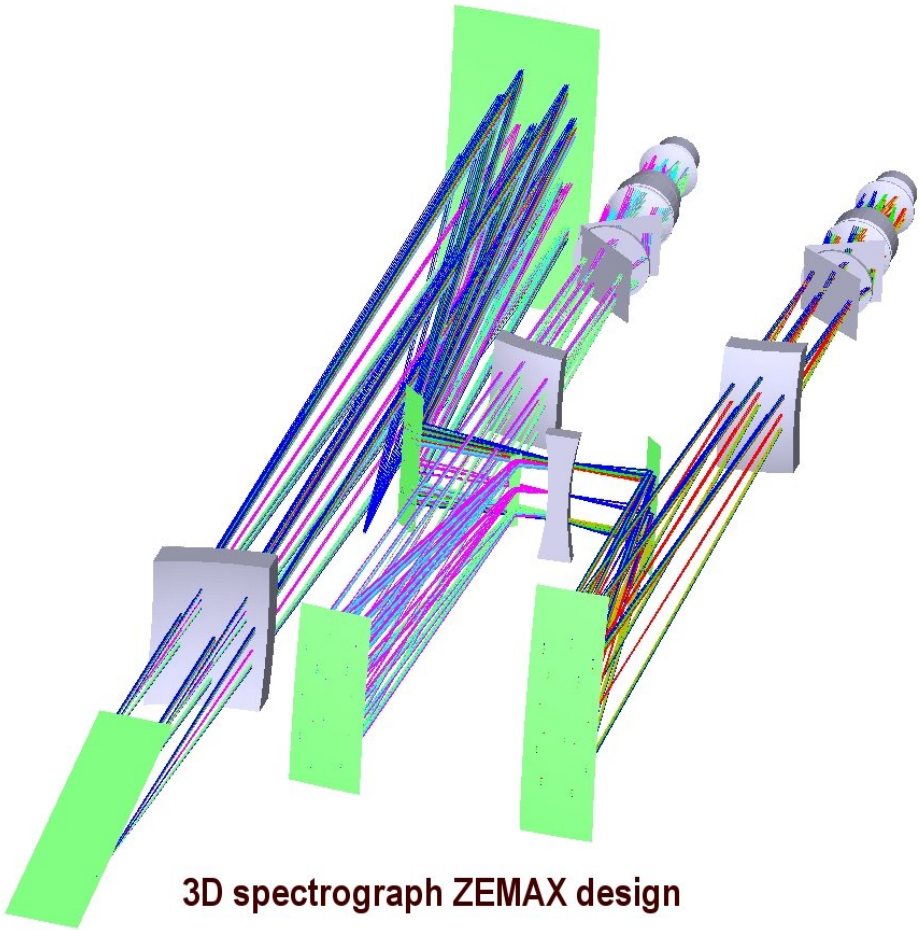
Geometrical optics

is the branch of optics where $\lambda \to 0$. In this approximation optical laws may be formulated using the formalism of geometry. One can then speak of a pencil of light rays that have a sharp edge (except for diffraction which affects a region of about a wavelength at the edge of the pencil).

Basic rules of ray tracing

- rays go through center of lens undeflected
- parallel rays get converged and come together at the focal length

ZEMAX ray trace for a 3D spectrograph



3D spectrograph ZEMAX design

Simplified Prime focus astronomical telescope

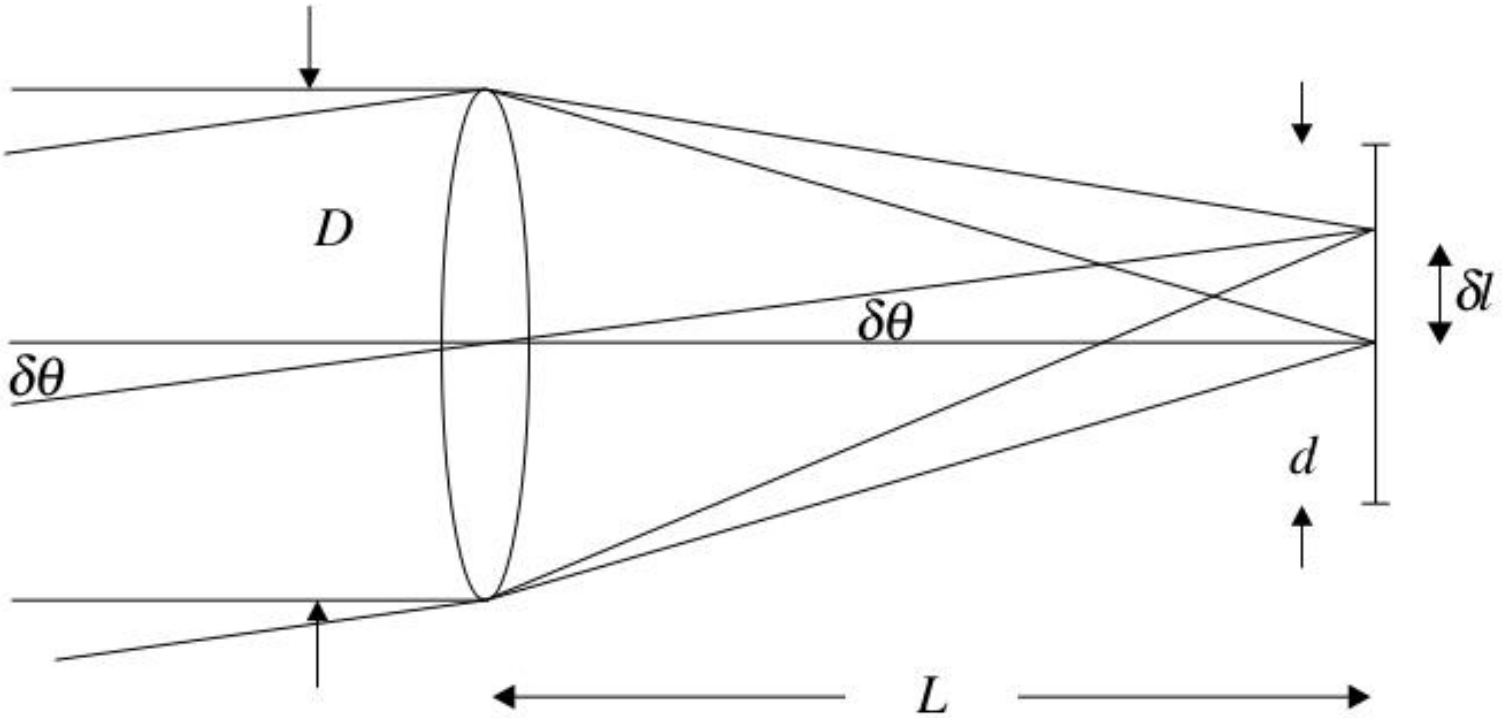
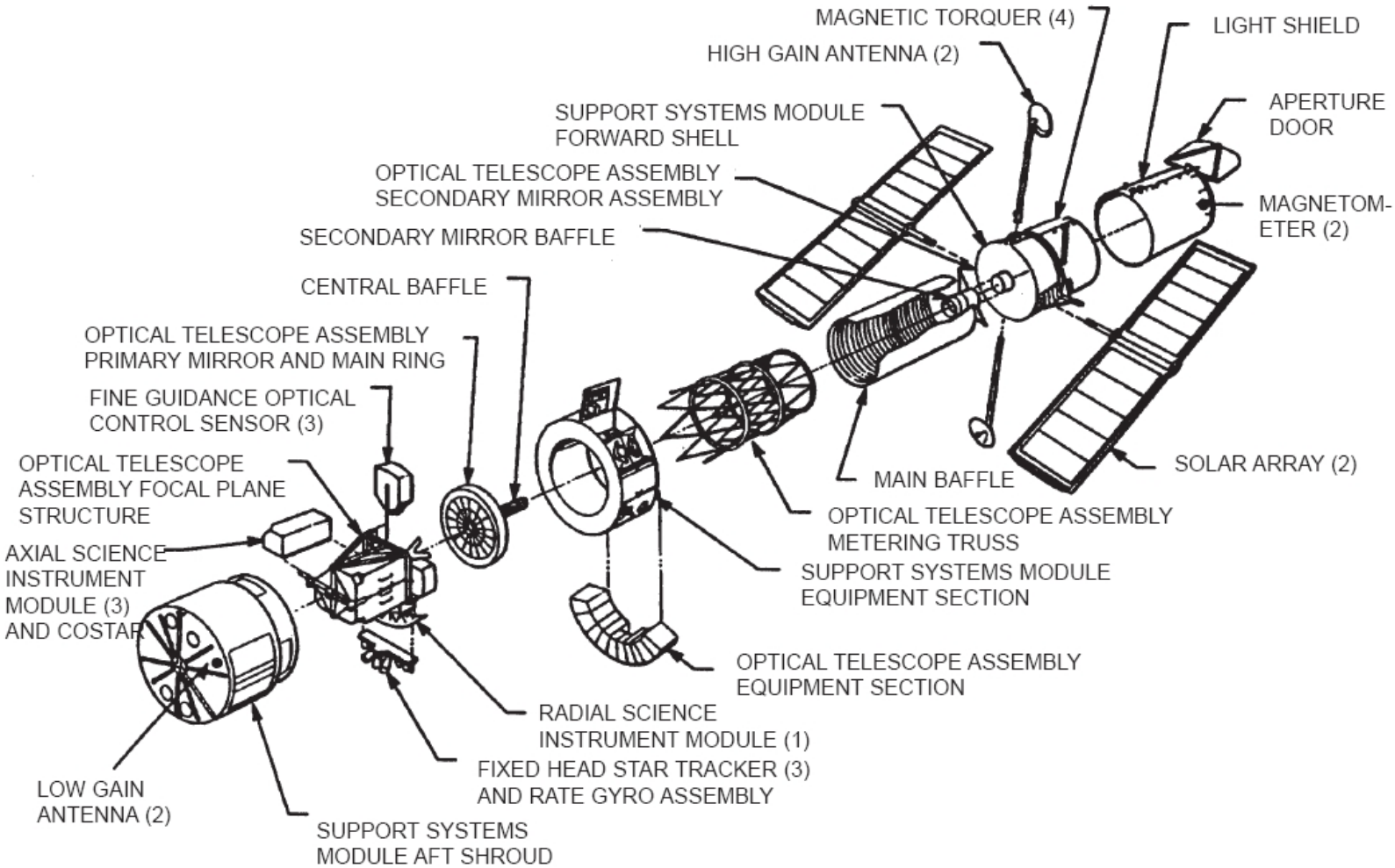
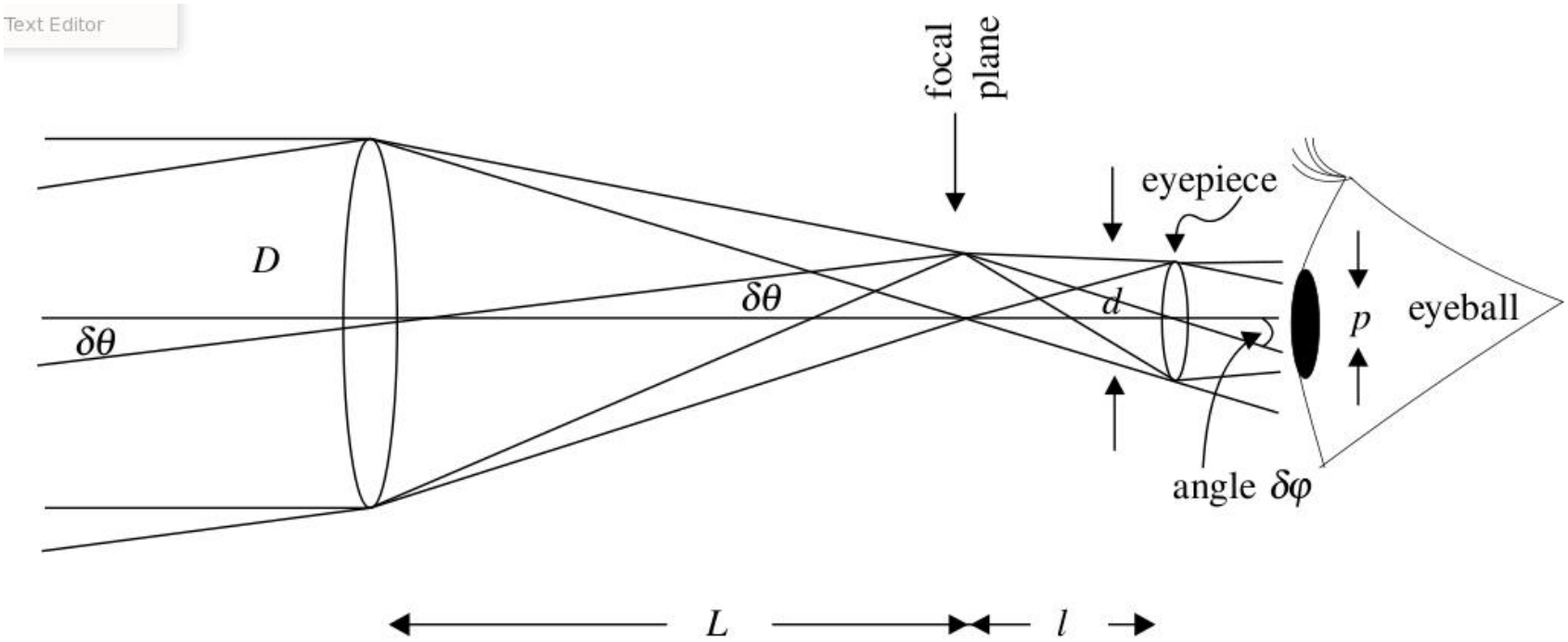


image scale is the ratio of angular distance in the sky to physical distance at the focus, and it depends only on the focal length.
$\delta\theta/\delta I = 1/L$

Unsimplified astronomical telescope

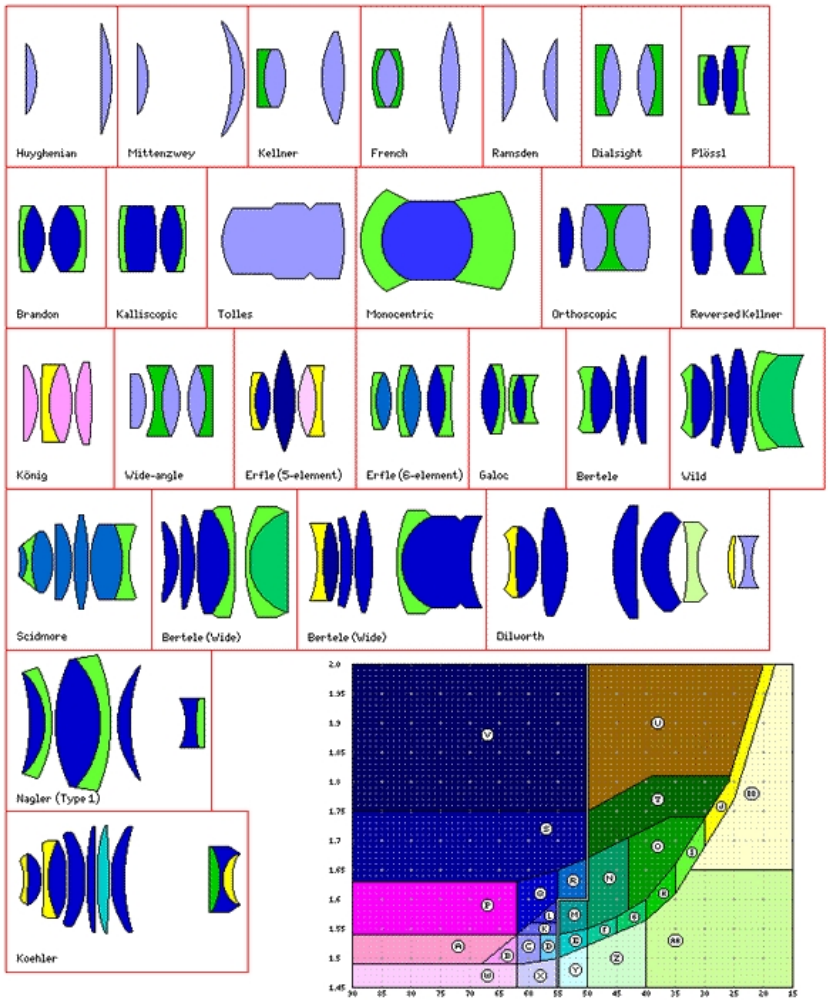


Refractors

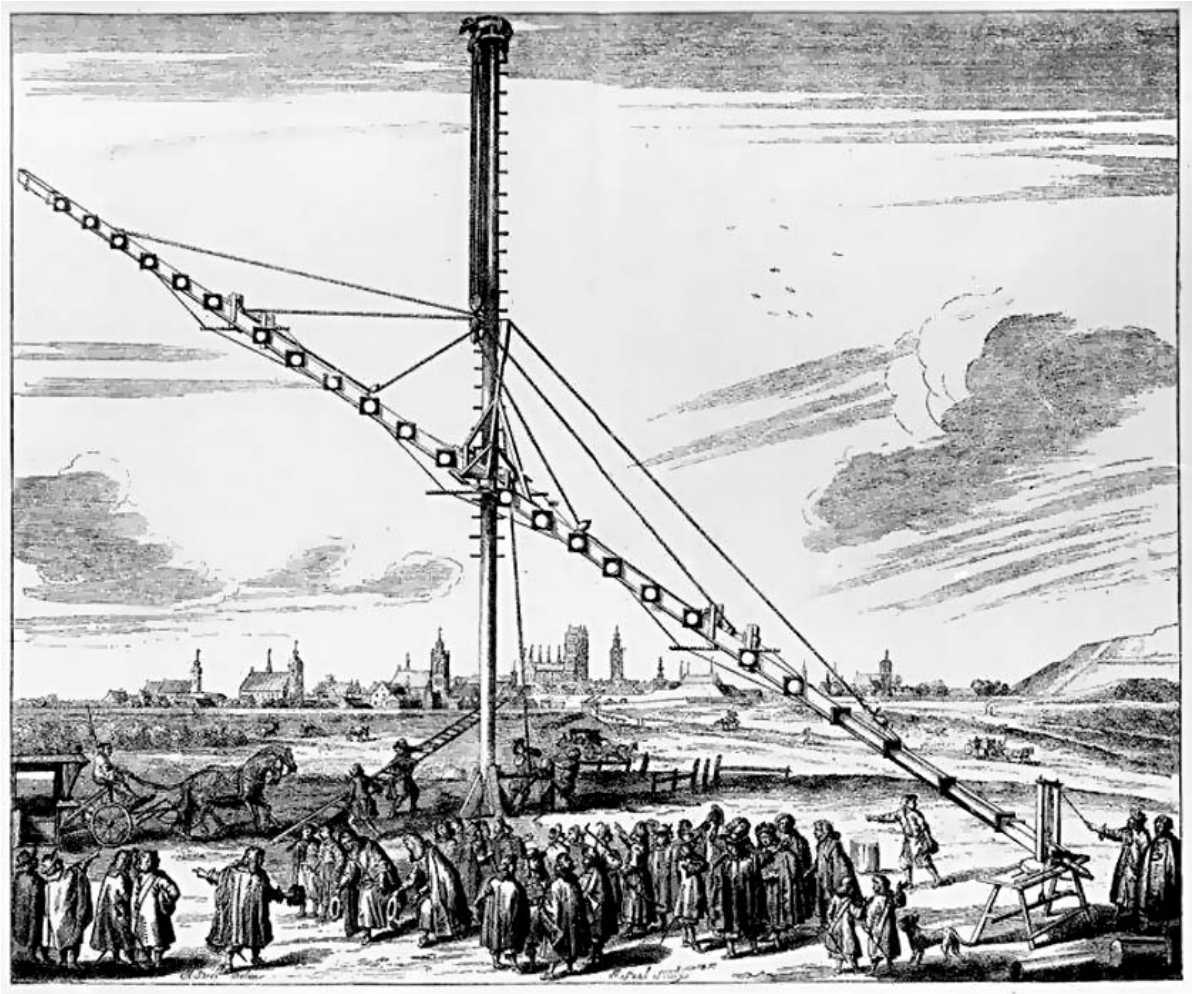


Magnification $M = \delta\phi/\delta\theta = L/l$

Real life eyepiece designs



the fight against chromatic aberration...

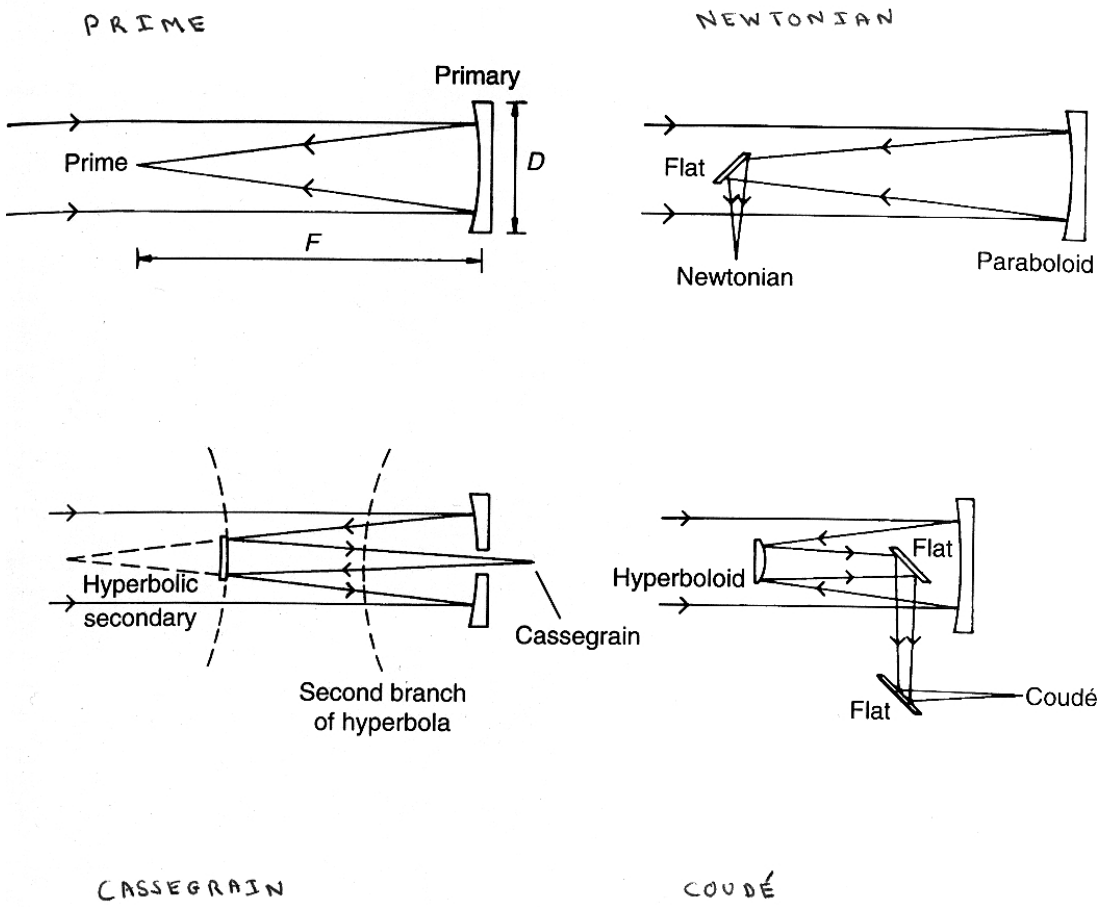


Yerkes - the largest achromatic refractor

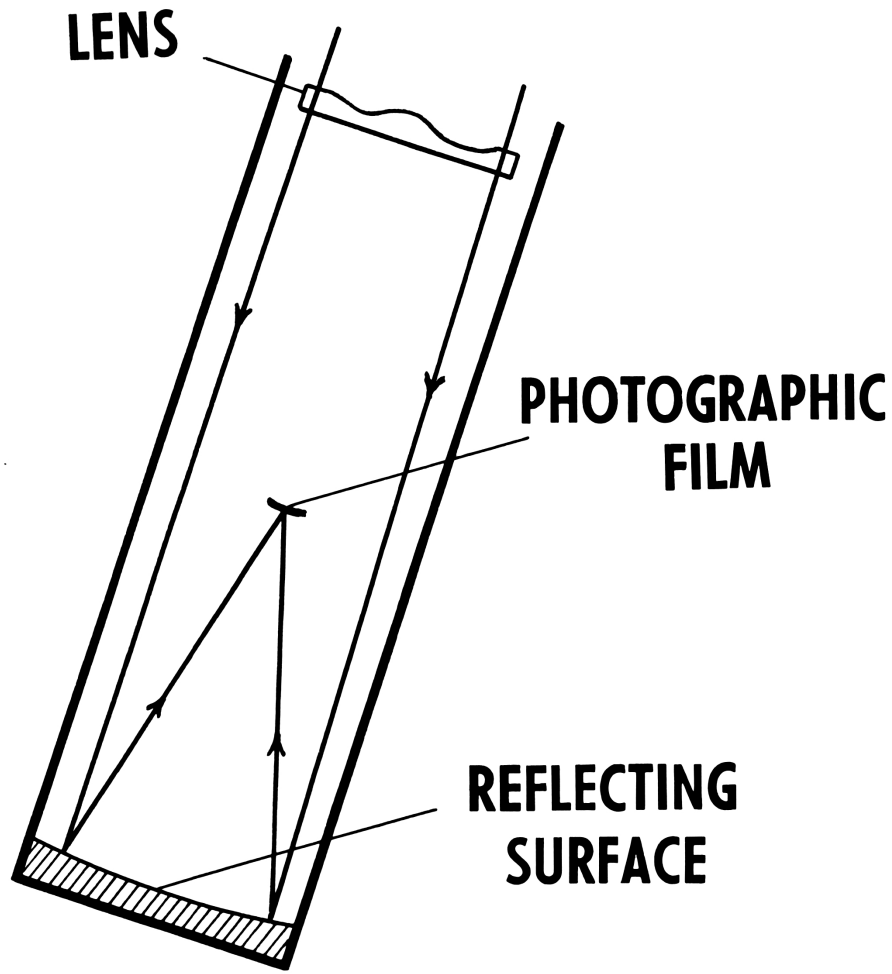
Refractor problem

What is the biggest problem with building extremely large refractors?

Reflector variants



Schmidt camera



Schmidt camera

- easy-to-make spherical primary mirror
- aspherical corrector plate located at center of curvature of primary mirror
- fast focal ratios - wide field of view, ideal for surveys
- low coma and astigmatism
- very strongly curved focal planes
- used in the Hipparcos satelite

48 inch Palomar Schmidt camera

still being used for the Palomar Transient Factory!