Mclean seminar sec.3.2.3-3.3.2

2024/05/17

M1 Kensho Tanaka

3.2.3 Reflecting telescopes; the parabolic dish

a lens

- must have a good surface finish.
- must be transparent.
- must be free from internal flaws.

a miiror

- only needs to have a good surface finish.

3.2.3 Reflecting telescopes; the parabolic dish

a lens

- the effect of surface bump is only (n-1)d =0.5d (for n = 1.5) in transmission.

a miiror

- a surface deviation d is doubled to 2d in the wavefront.

- **mirrors have to be polished better in order not to disturb the wavefront.**
- This is not a limitation today.
  - average dump is smaller than 0.12mm to 85km.(Subaru telescope)

3.2.3 Reflecting telescopes; the parabolic dish

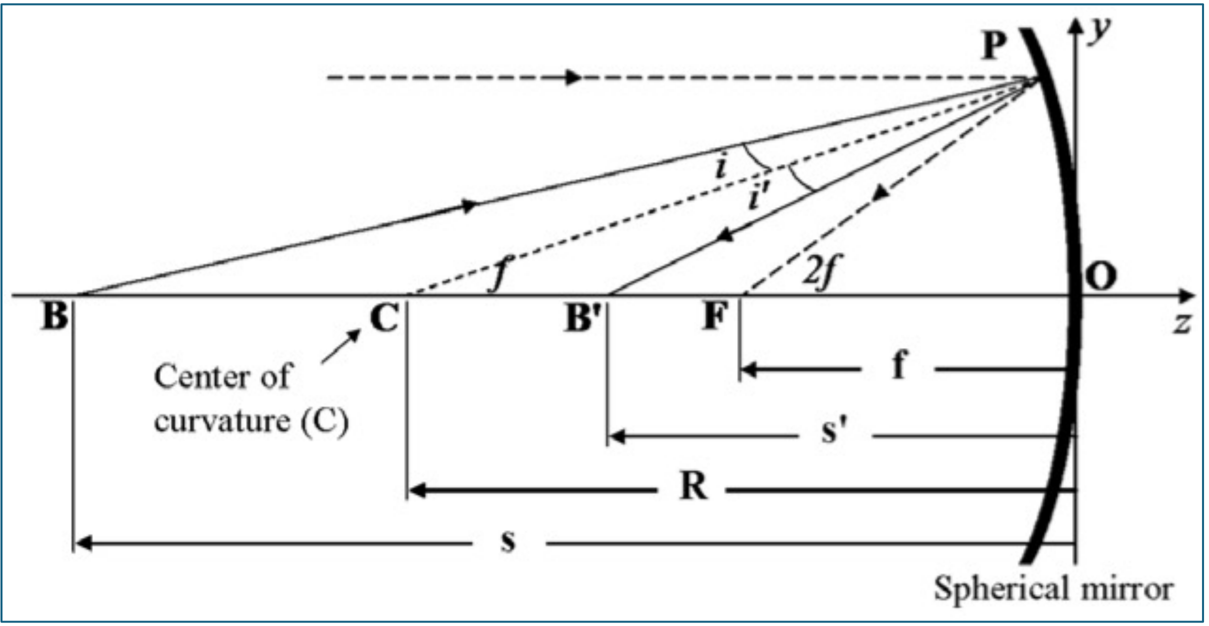
a lens

- suffers chromatic aberration because of the dependence of refractive index on wavelength.
- to reduce this effect, multiple lenses are needed. But that means more light loss.

a miiror

- is achromatic
- some metallic coatings absorb in the UV. (Sec12.1)

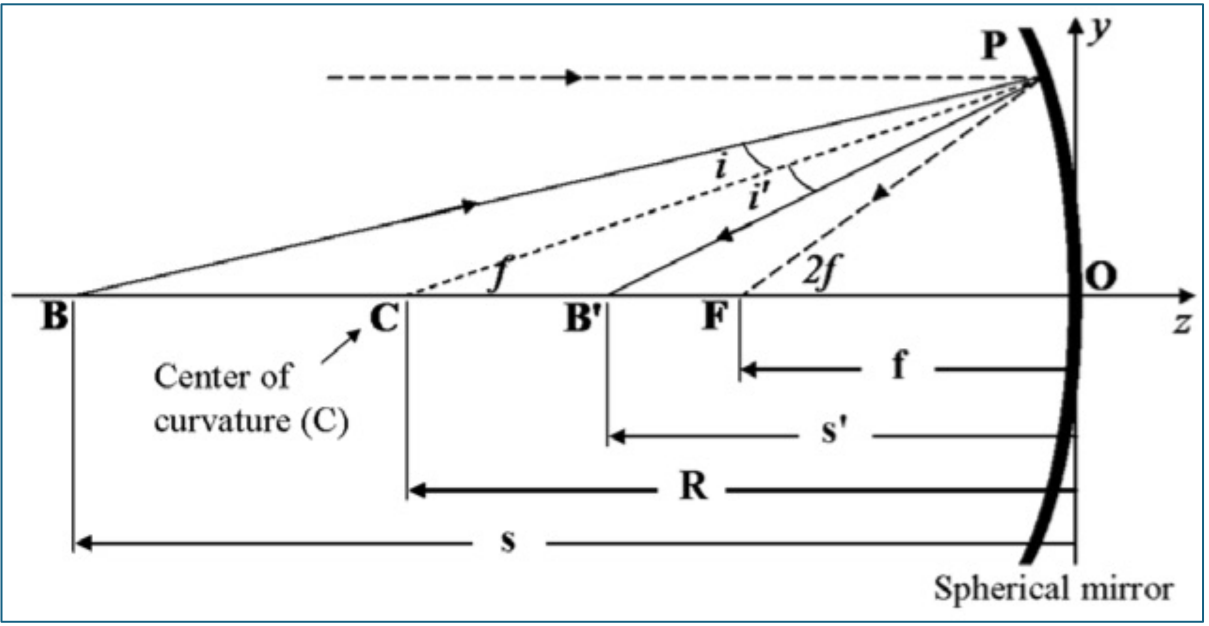
3.2.3 Reflecting telescopes; the parabolic dish



- Today, all large astronomical telescopes are “reflectors” and use curved mirrors to achieve light collection and focus.

- spherical aberration exists.
  - the focus points depend on how far away from the center on the mirror the light enters.

3.2.3 Reflecting telescopes; the parabolic dish



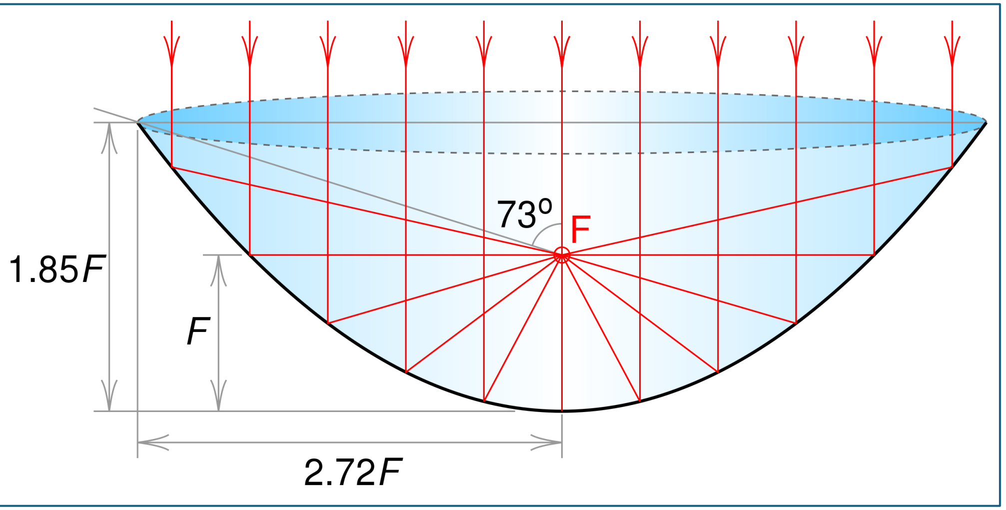
- At the paraxial focus point the image is blurred.

- The diameter of the blur is

$$\beta = \frac{206265}{128F^3} arcsec \quad (F = f/D)$$

- $F = 15, \beta = 0.48 arcsec$
  - comparable with seeing
- $F = 3, \beta = 1\ arcmin$

3.2.3 Reflecting telescopes; the parabolic dish



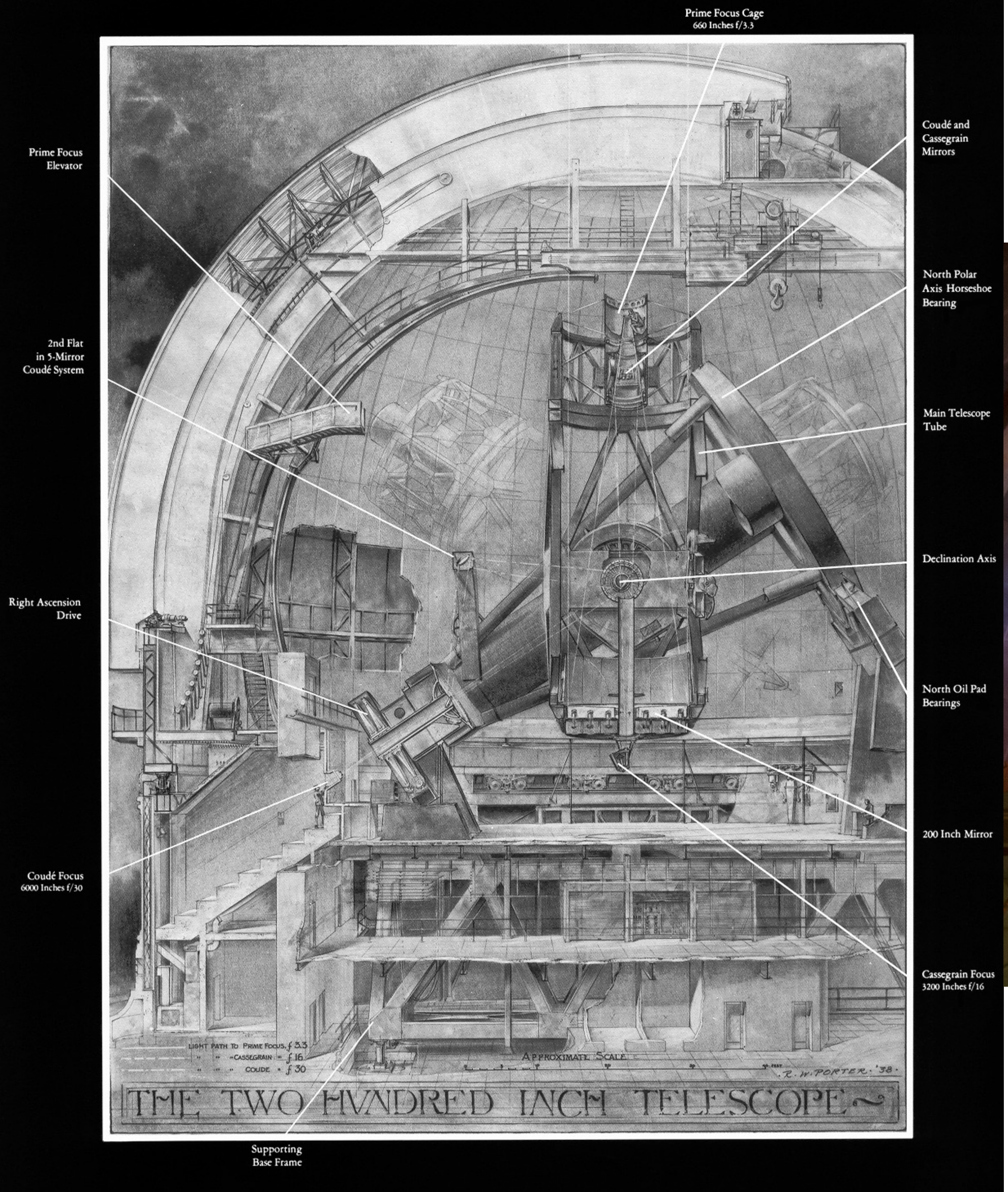
(https://ja.wikipedia.org/wiki/%E6%94%BE%E7%89%A9%E9%9D%A2%E9%8F%A1)

- **a spherical-shaped mirror** is not the correct shape to compensate for the change of angle.
- **a conic section** (ellipse, parabola, hyperbola) will solve this problem.
  - any ray starting at one focus will form a perfect point image at the other. > **“stigmatism”**
- In the case of **the parabola**, rays from that focus are parallel to the axis and all such rays meet at the other focus.

3.2.3 Reflecting telescopes; the parabolic dish

- **A single mirror telescope**
  - With some additional optics, many professional telescopes use the “prime” focus of the primary mirror for direct imaging.
  - 5m Hale on Mt. Palomar
  - Subaru 8.2m Telescope with large CCD camera
    - it needs “corrector” lens system in front of CCD

5m Hale on Mt. Palomar

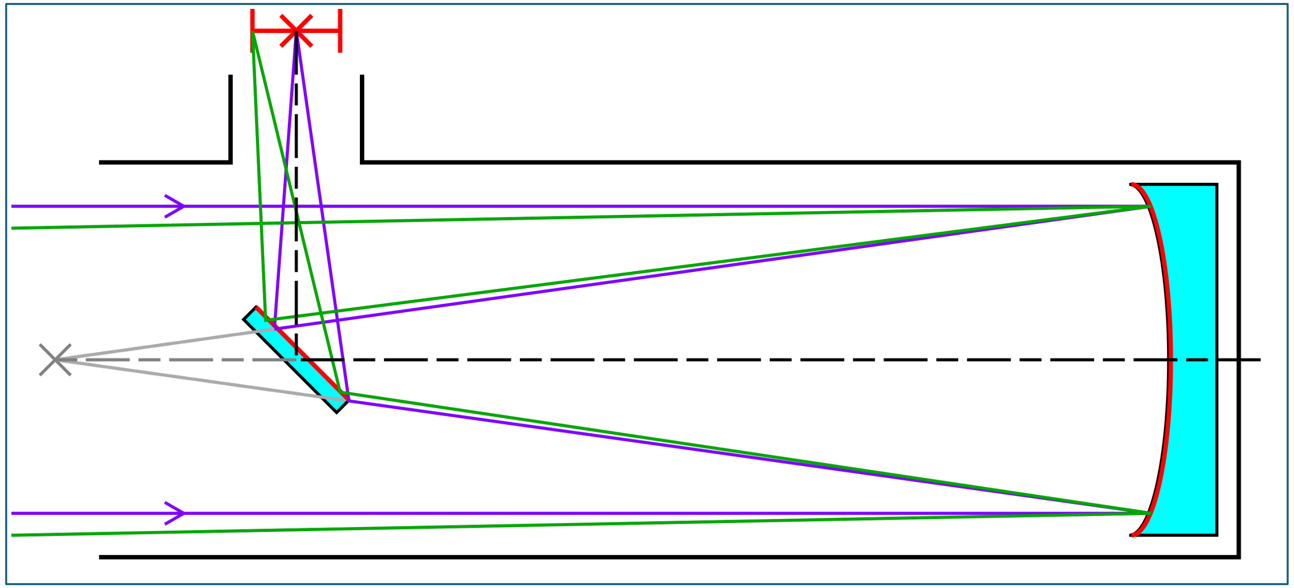


(Palomar/Caltech)

(Palomar/Caltech/Caltech Archives)

3.2.3 Reflecting telescopes; the parabolic dish

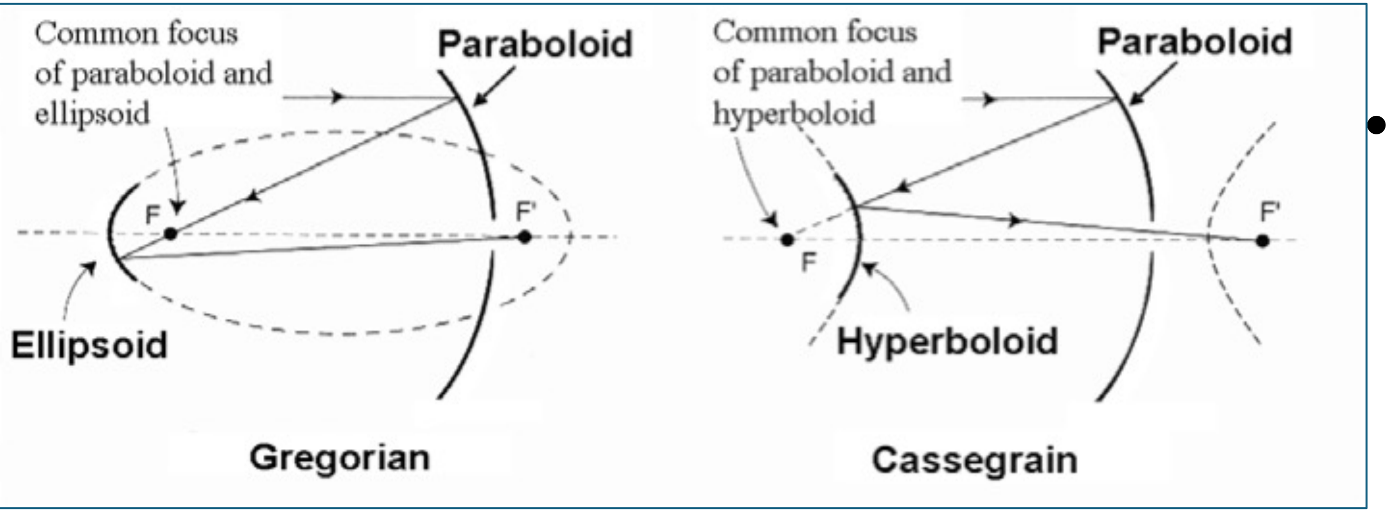
Newtonian design



(https://en.wikipedia.org/wiki/Newtonian_telescope)

- **two-mirror telescopes**
  - the “secondary” mirror can have a variety of surface shapes.
  - the plane mirror is at 45° to deflect the beam through a right angle and out the side of the tube.
  - the secondary mirror can be also perpendicular to the beam to send it back to the primary.

3.2.3 Reflecting telescopes; the parabolic dish



- Many large reflecting telescopes are of the Cassegrain design and contain a central hole in the primary mirror.
- Image quality is limited by the off-axis effect called "coma" in which images become more and more comet-like with small tails.
- Gregorian has more field curvature than the classical Cassegrain.

3.2.3 Reflecting telescopes; the parabolic dish

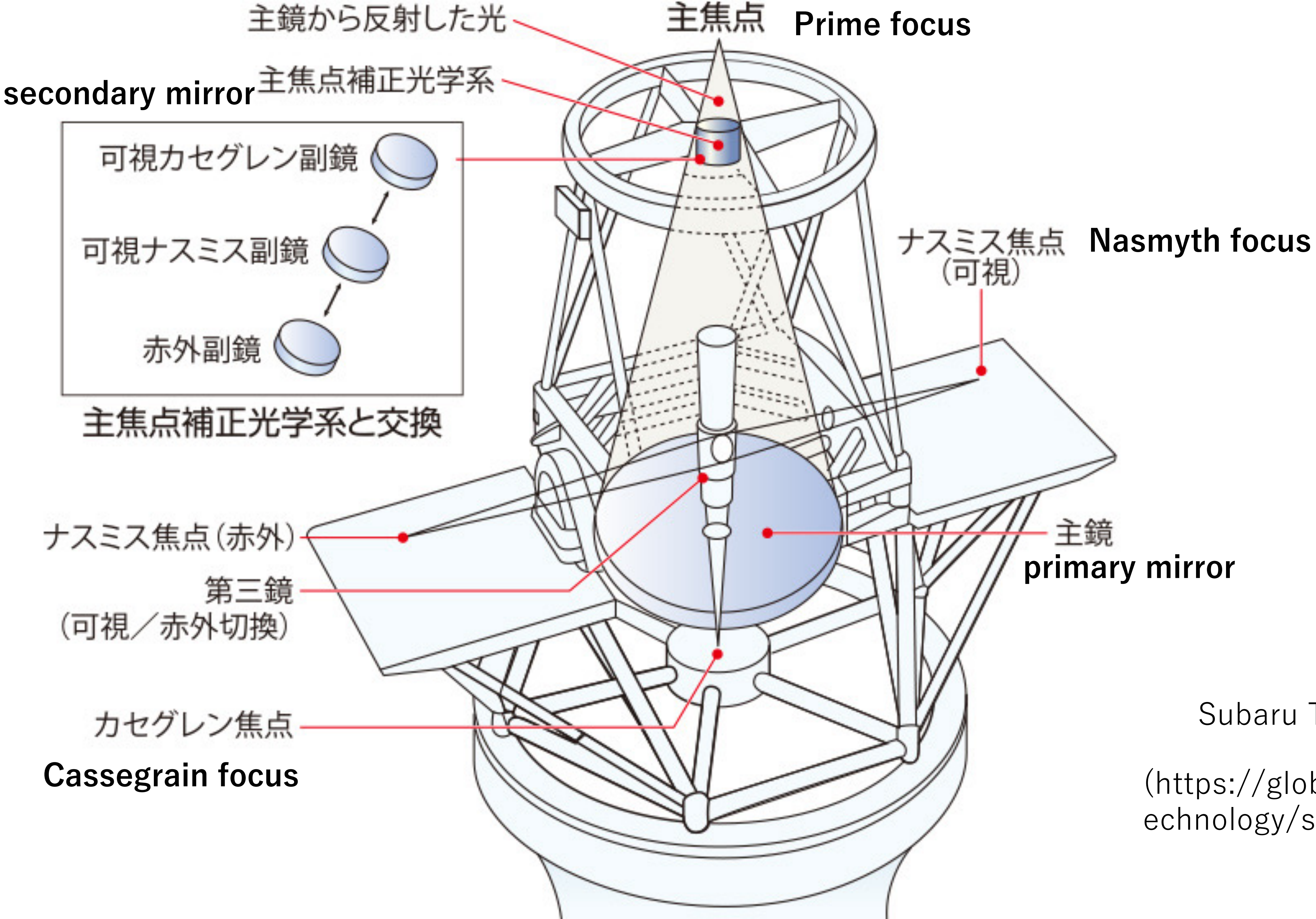
- **Ritchey-Chrétien (or RC) design**
  - both the primary and secondary mirrors are hyperbolic surfaces.
  - Invented by American astronomer George Willis Ritchey (1864-1945) and French astronomer Henri Chrétien (1879-1956)
  - eliminates the effect of coma and thus gives good performance over a larger FoV.

- **Ritchey-Chrétien design telescope**
  - 0.5m Ritchey-Chrétien Telescope(or RCT) first built in 1927
  - 2.54m Hooker Telescope
  - Palomar 5.08m Telescope
  - twin 10 m Keck Telescopes
  - four 8.2 m VLTs
  - twin 8 m Gemini telescopes
  - 8.2 m Subaru
  - 10.4 m GTC
  - The Hubble Space Telescope

3.2.3 Reflecting telescopes; the parabolic dish

- **a third or "teriary" mirror** can be located to direct the light along an axis of rotation of the telescope.
  - it is used in order to make the final focus unmovable, independent of where the telescope is pointing.

  - For an equatorial mount : **coudé focus**
    - a change of secondary mirror is required with the coudé arrangement.
    - that leads a very focal length.
  - For altitude-azimuth mounts : **Nasmyth focus**
    - it does not require a change of secondary mirror.
    - the image scale is the same as at the Cassegrain focus.

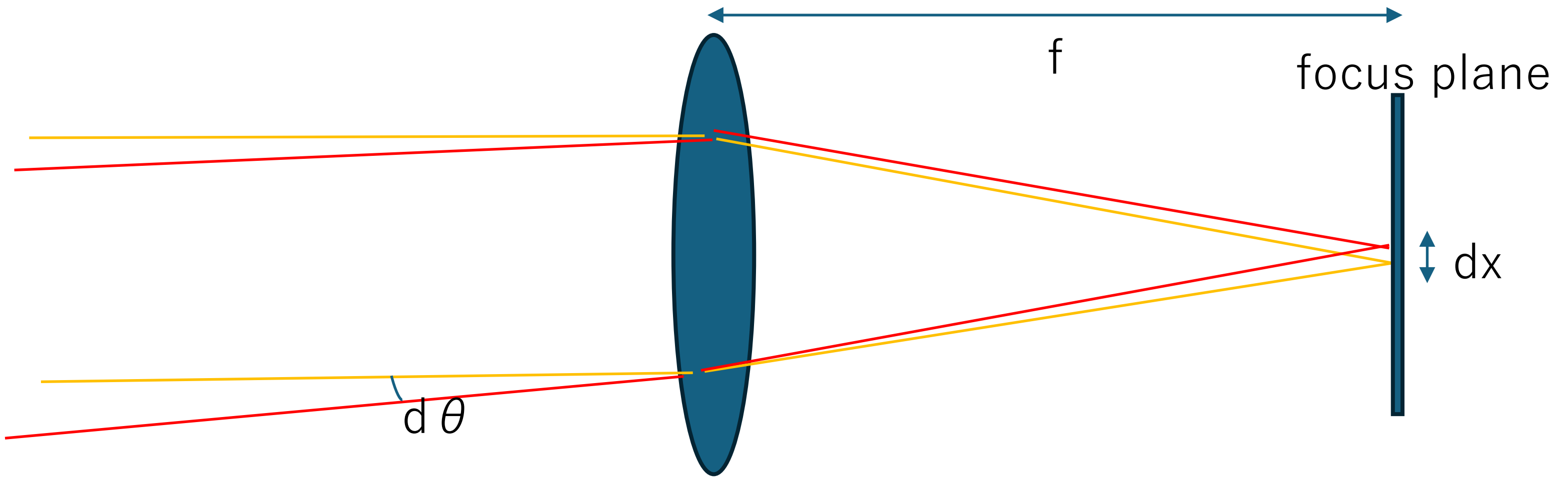


Subaru Telescope

(https://global.canon/ja/technology/support30.html)

3.2.3 Reflecting telescopes; the parabolic dish

- **plate scale**
  - it measures the number of seconds of arc on the sky corresponding to 1mm at the focus of the telescope.
  - the longer the focal length (f), the smaller the number of seconds of arc per millimeter and the greater the magnification.



$$dx = f\ tan d\theta$$

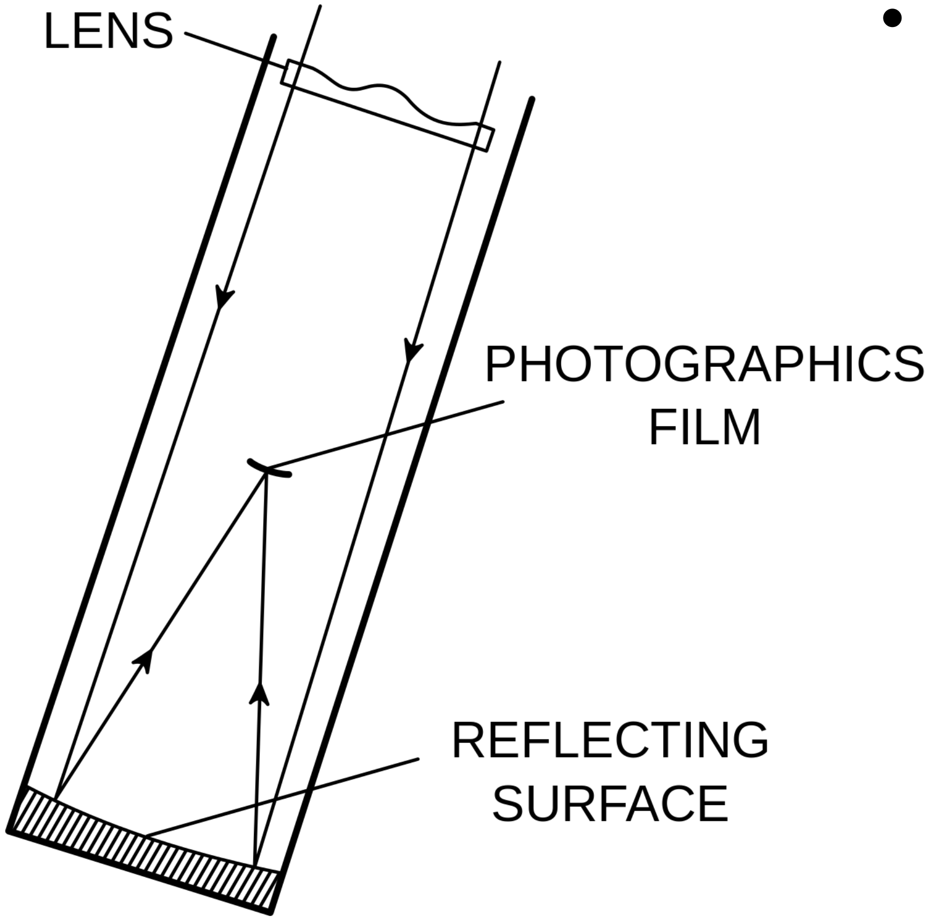
$$dx \approx f d\theta$$

plate scale(”/mm) $= \frac{d\theta}{dx} = \frac{206265}{f}\ arcsec$

3.2.3 Reflecting telescopes; the parabolic dish

- **plate scale example**
  - f = 10m
  - 20.6265”/mm
  - 0.206”/pix, if the pixel scale of CCD is 0.01mm
  - ~4.85 pixels per arcsecond
  - in case of the prime focus, the shortest f, and plate scale is largest.
- **f number (F = f/D)**
  - small focal ratios (like f/1) mean large angles and more light and hence, a photographic exposure would take less time, it would be “faster”.
  - the shorter the telescope for a given diameter.
  - ➢the smaller the dome or enclosure is.
  - ➢modern telescopes tend to employ very fast primary mirrors to minimize the size and expense of the dome.

3.2.4 Corrector s and hybrid telescopes



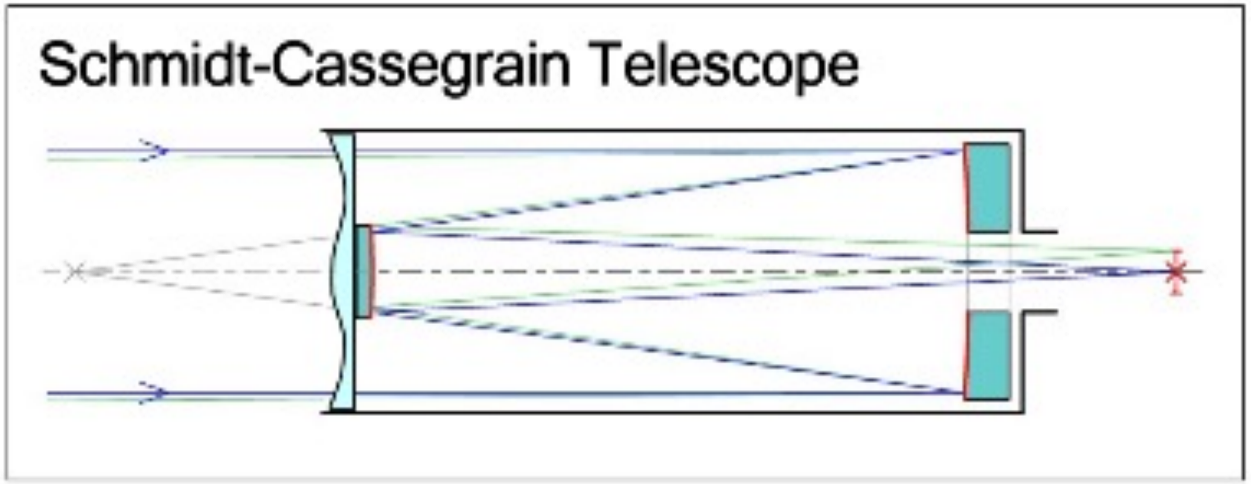
(https://ja.wikipedia.org/wiki/シュミット望遠鏡)

- Schmidt telescope
  - a primary mirror has **a spherical surface**.
  - A thin refracting **"corrector plate"** with a complex shape is placed at the entrance tube of the telescope to **correct the spherical aberration** of the spherical primary mirror.
  - In this case, the focal surface is significantly curved and lies inside the telescope tube between the corrector plate and the primary mirror.
  - The corrector lens limits the size of Schmidt telescope, the largest is 1.34m

3.2.4 Correctors and hybrid telescopes

- Schmidt-Cassegrain telescope
- Maksutov-Cassegrain telescope
  - The Maksutov is similar except that the corrector plate is replaced with a more easily polished spherical correcting lens and the secondary mirror is an aluminized reflective patch on the inner surface of the lens.

鏡筒



for small telescopes ranging from 10-35cm

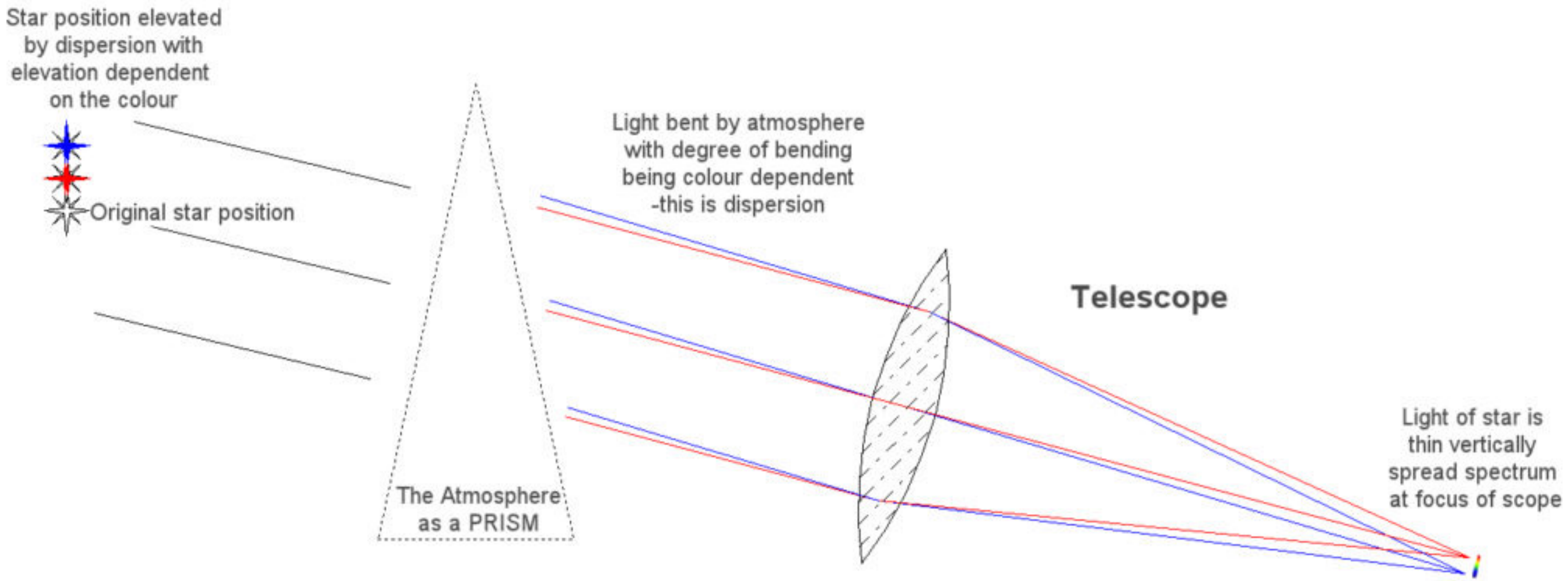
(https://telescopicwatch.com/telescope-comparisons/schmidt-cassegrain-vs-maksutov-cassegrain/)

3.2.5 Telescope mounts

- Because the rotation of the Earth on its axis causes the daily rising and setting of the stars, all telescopes require **a means to continually update the direction in which they are pointing.**
- The sidereal rate is 15.041 arcsec/second
- The main problem
  - alignment of the rotation axes
  - mechanical flexure of the telescope structure
  - cyclic errors in the gear trains
  - atmospheric refraction (which depends on wavelength, pressure, and temperature)
- These effects are removed or minimized by a computer model of the telescope derived from hundreds of pointing measurements spread over the sky.

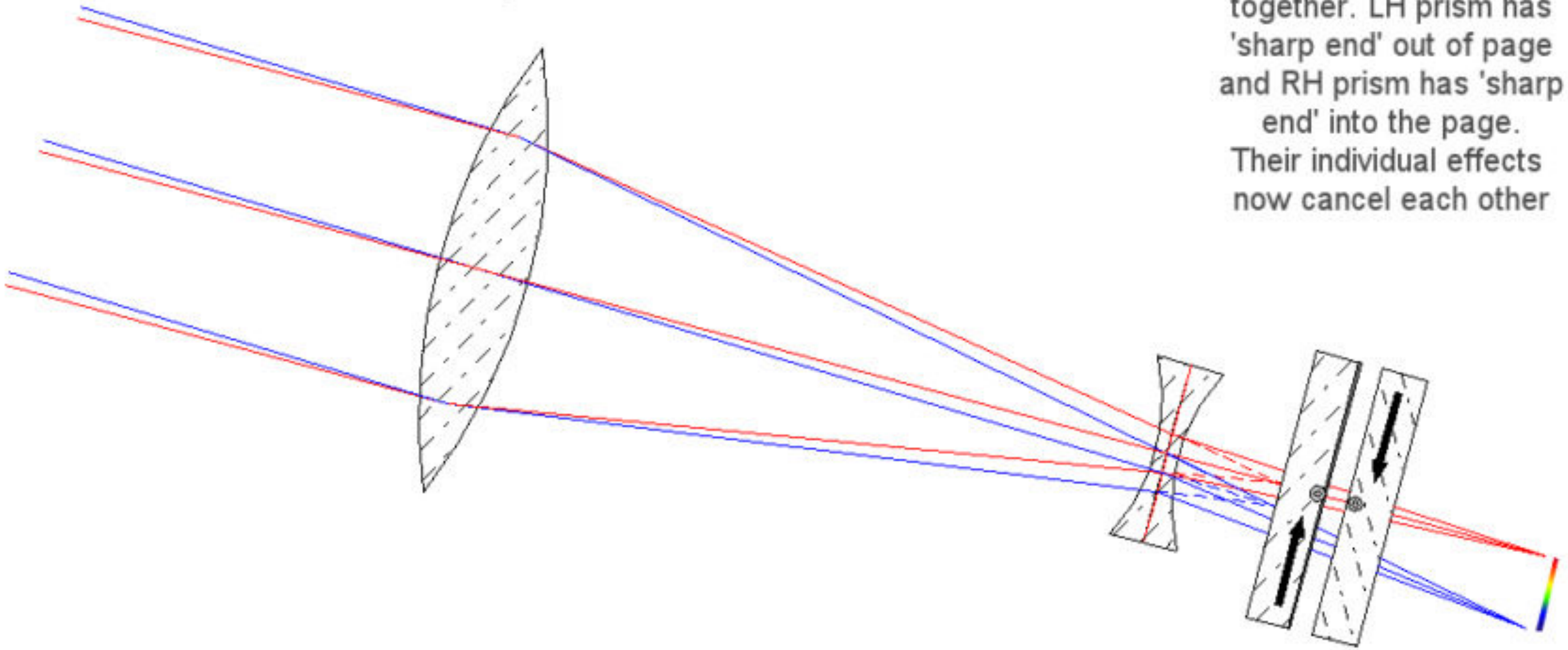
3.2.5 Telescope mounts

- For the correction of the wavelength dependence in the refractive index of air
- **ADC (Atmospheric Dispersion Compensator)**
  - a pair of counter-rotating matched, compound prisms composed of two materials with different dispersive properties.
  - The pair are arranged to give zero angular deviation at a selected wavelength, and their relative rotation provides the required color compensation.

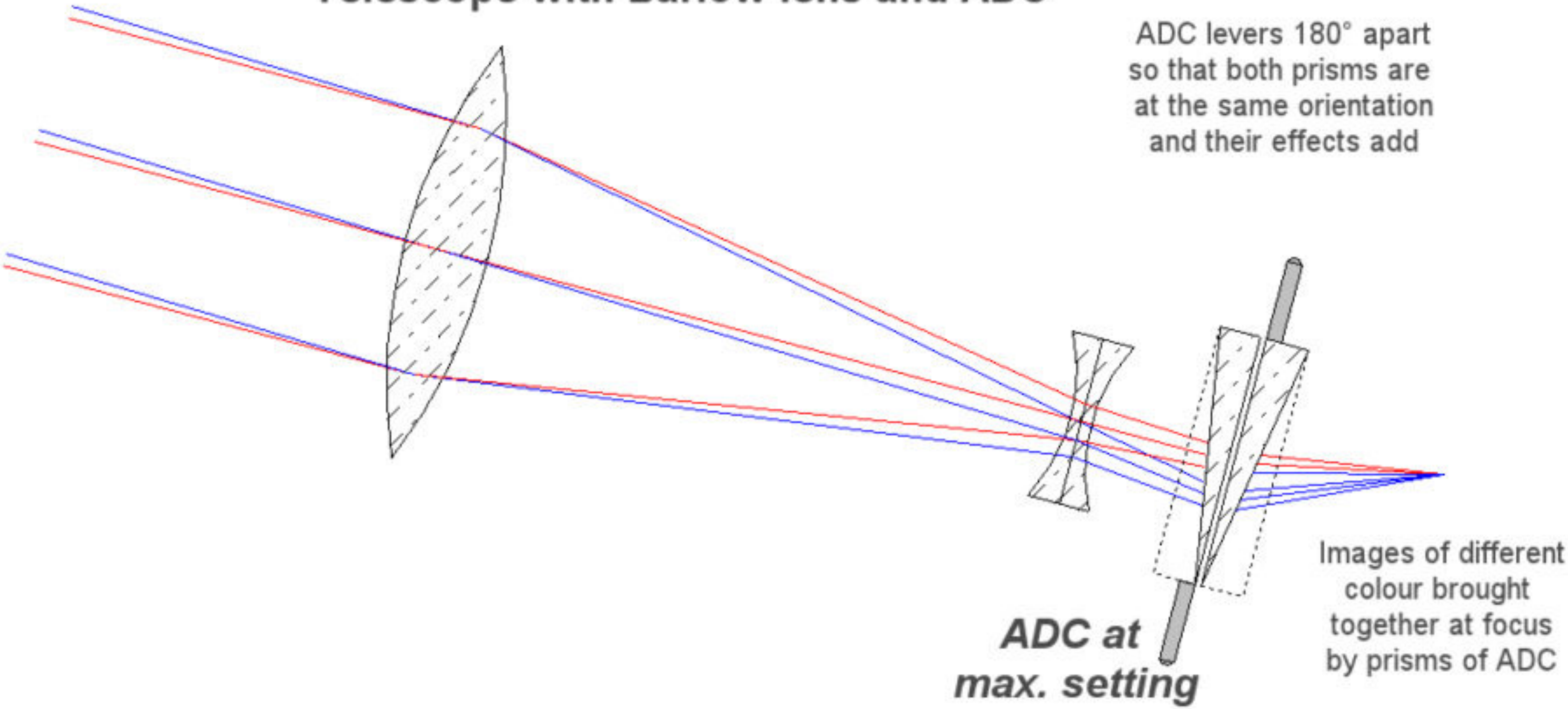


(https://skyinspector.co.uk/atm-dispersion-corrector-adc/)

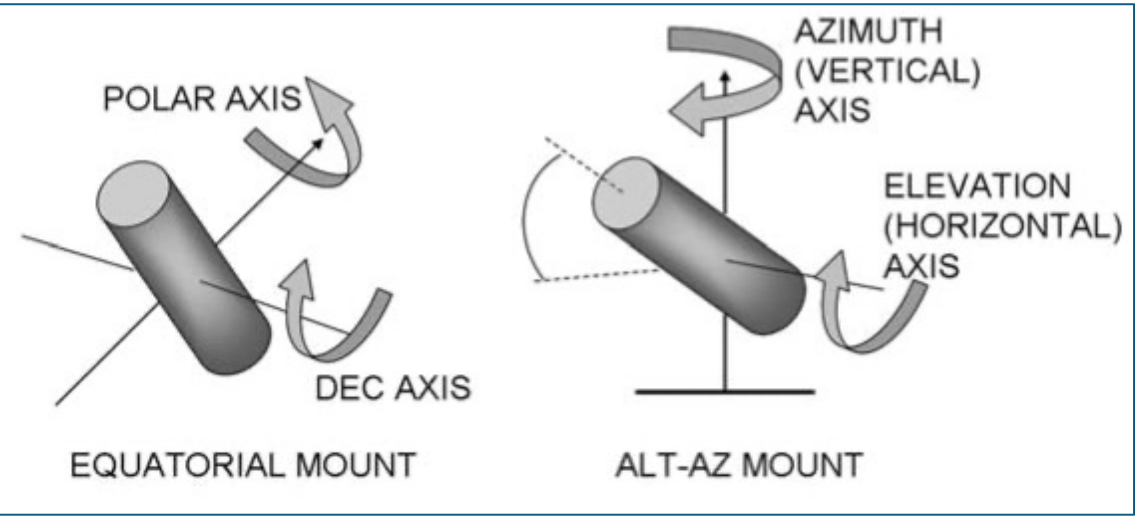
Telescope with Barlow lens and ADC



Telescope with Barlow lens and ADC

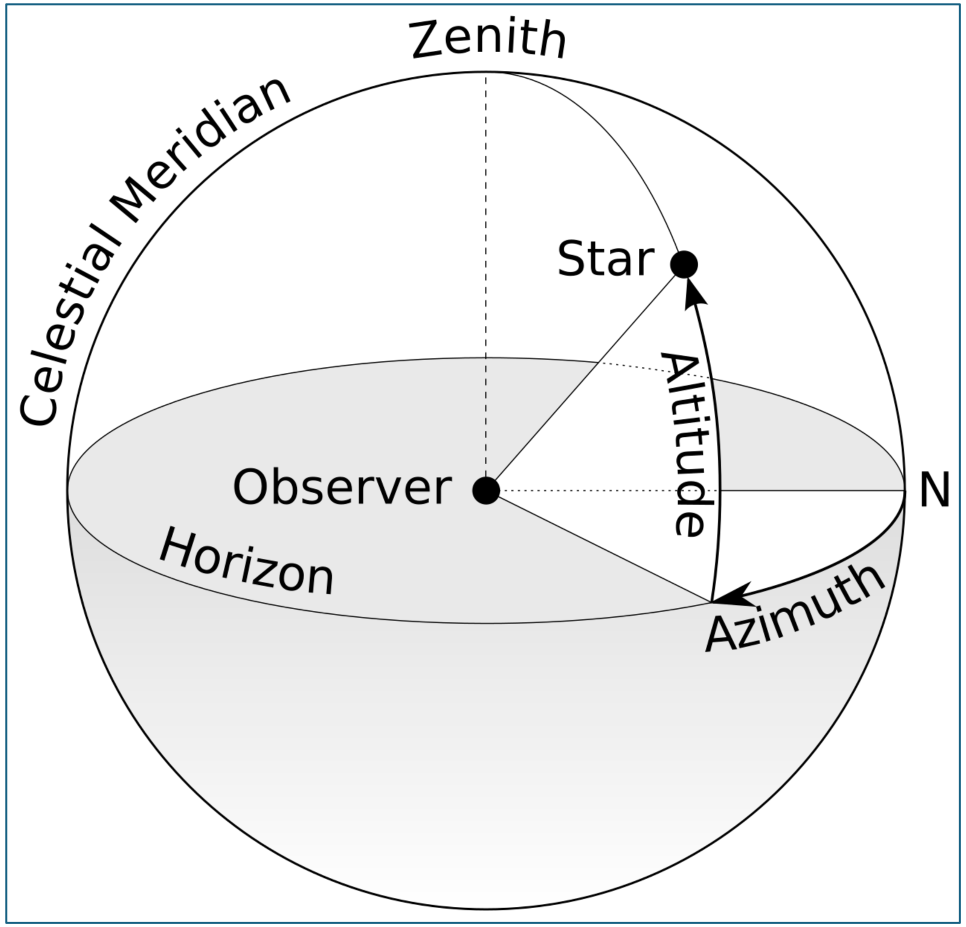


3.2.5 Telescope mounts



- **Equatorial mount**
  - **the polar axis** : turned continuously to track the star along the earth axis
  - **the declination axis** : moves at the right angles to the first
  - the image at the telescope focus maintains the same orientation at all times.
- **Altitude-Azimuth mount**
  - **Azimuth axis**
  - **Elevation axis**
  - the rate of rotation varies with the position of the object in the sky.
  - the image at the focus rotates with time; this is called **field rotation**.

3.2.5 Telescope mounts



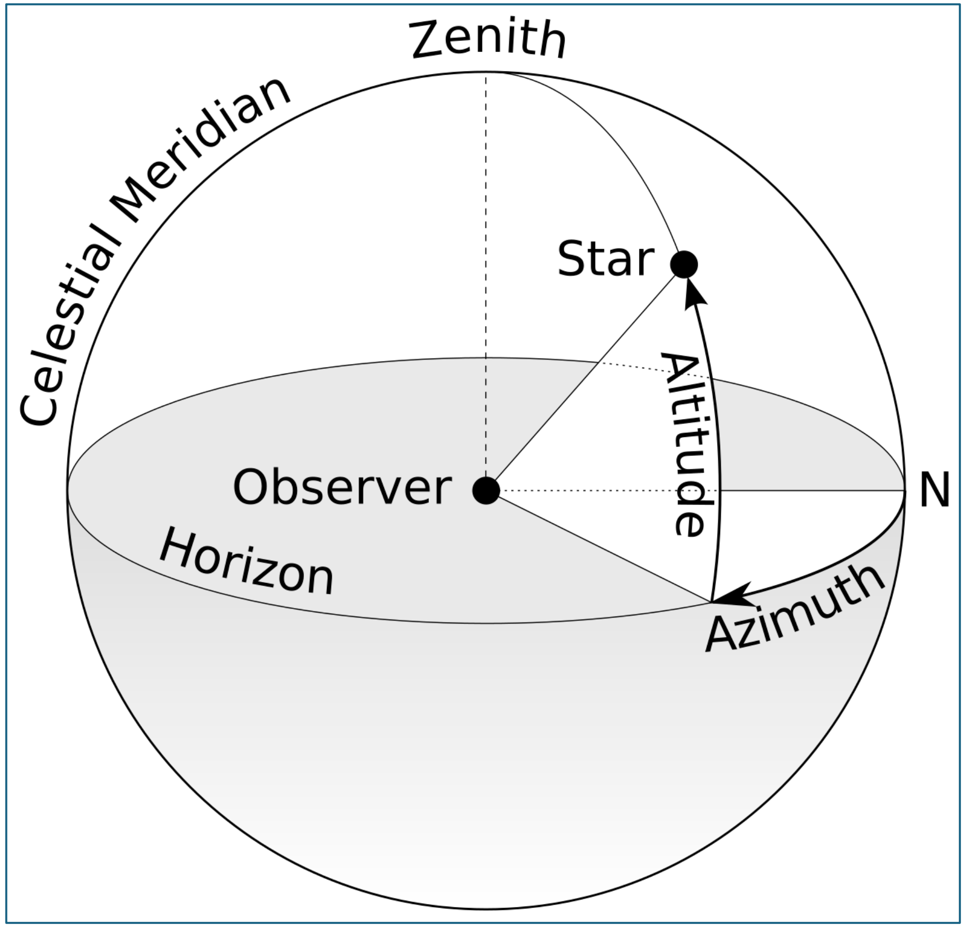
(https://en.wikipedia.org/wiki/Azimuth)

- **Altitude-Azimuth mount**
  - field rotation

$$\omega = \Omega\, cosA \frac{cos\phi}{sinz}$$

  - ω : the field rotation rate (rad/second)
  - Ω : the sidereal rate (7.2925 x10^-5 radians/s)
  - ϕ: the latitude of the telescope
  - A : azimuth (方位角)
  - z : zenith distance

3.2.5 Telescope mounts



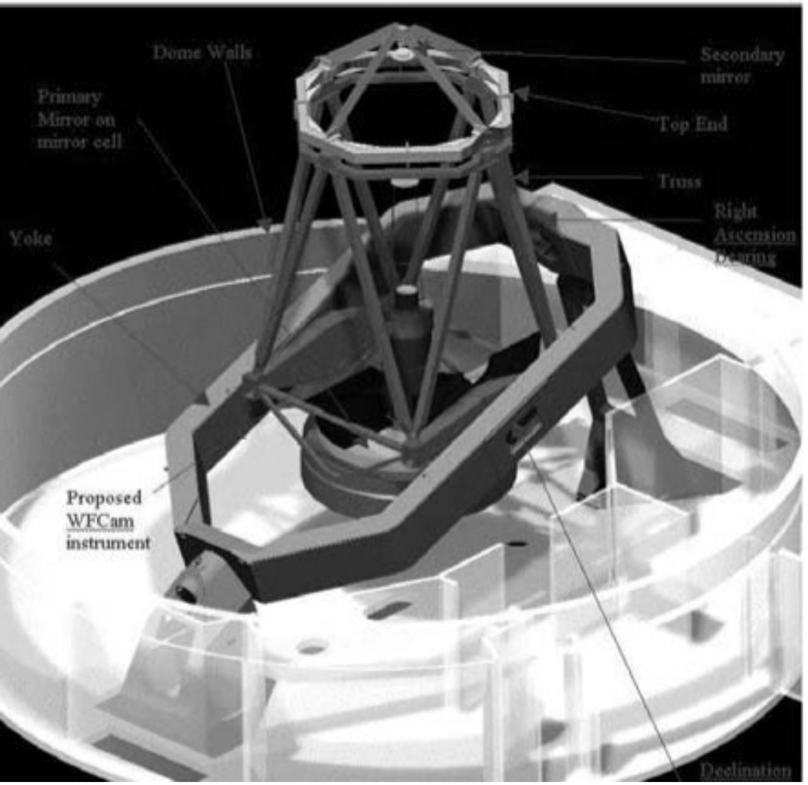
(https://en.wikipedia.org/wiki/Azimuth)

- **Altitude-Azimuth mount**
  - field rotation

$$\omega = \Omega \cos A \frac{\cos\phi}{\sin z}$$

  - z gets close to 0° , ω becomes extremely large.
  - > the dead zone of a few degrees near the zenith
  - Field rotation can be compensated by counter-rotating the entire instrument at available rate, or rotating an optical compensator such as a K-mirror.

3.2.5 Telescope mounts



- **Altitude-Azimuth mount**
  - Despite these complications most modern telescopes are built this way because **it aids the mechanical design and reduces the total weight and load on the bearings**.

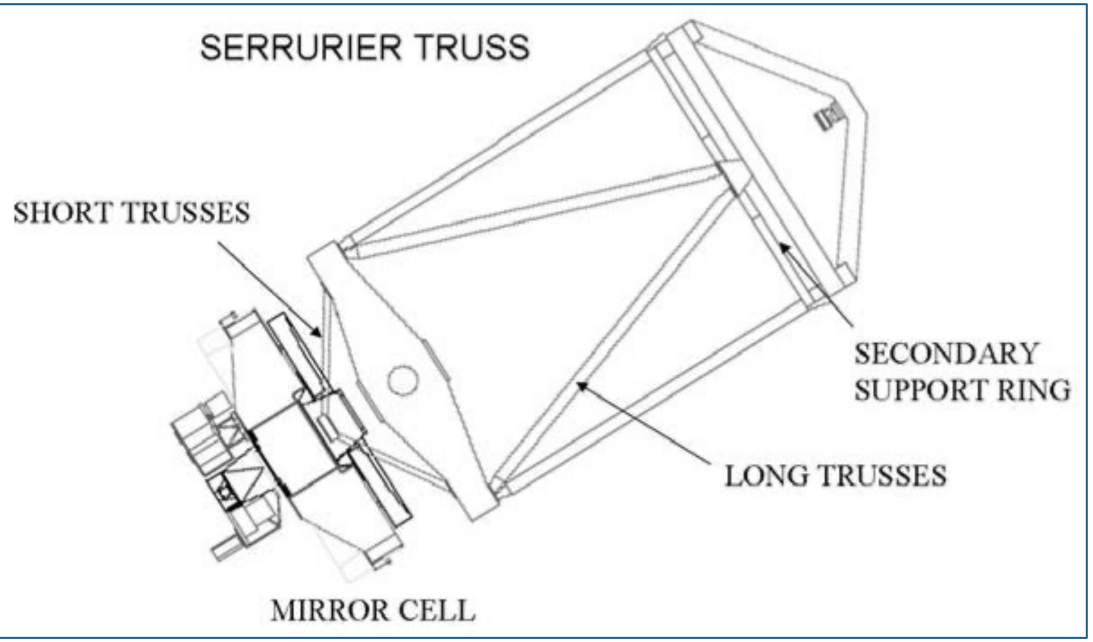
left : an equatorial mount telescope, the English yoke of the 3.8 m U.K. Infrared Telescope (UKIRT)
right: an altitude-azimuth, he 3.5 m WIYN (Wisconsin-Indiana-Yale and NOAO) telescope

3.2.5 Telescope mounts

(https://web.archive.org/web/20081101052950/http://www.nofs.navy.mil/about_NOFS/telescopes/fastt.html)

- **Transit telescope**
  - the telescope is fixed to point only in the plane of the north-south meridian line.
  - it can select any point from zenith to horizon, and the stars are allowed to drift across the field of view
  - Flagstaff Astrometric Scanning Transit Telescope (FASTT) at the U.S. Naval Observatory in Arizona

3.2.5 Telescope mounts



（the3.8mUKIRT)

- **The best way to support the mirrors of the telescope**
  - an open steel framework known as a truss, which is a structure with one or more triangular units constructed with straight slender members whose ends are connected at joints.

  - **the Serrurier truss**
  - developed by engineer Mark U. Serrurier (c. 1905-1988) in 1935
  - Two sets of opposing trusses support the primary and secondary mirrors before and after the declination (or elevation) pivot axis.
  - Each truss has an equal amount of flexure (bending under its own weight) such that the primary and secondary mirrors move, but **remain in planes parallel to each other and therefore maintain their collimation** (alignment of their optical axes).

3.3 Automated Telescopes and Remote Sensing

- **3.3.1 Remote sensing**
- **3.3.2 Automated imaging telescope**
- 3.3.3 Survey Telescope

3.3.1 Remote sensing

- Global high-speed telecommunications means that remote observing at ground- based telescopes, in a manner analogous to remote observing using space facilities, is now practical.
- The first demonstration is Royal Observatory Edinburgh (U.K.) in the early 1980s
  - using satellite telephone links, the U.K. Infrared Telescope in Hawaii and an infrared photometer were controlled and data returned to Edinburgh.
  - the data rate was very slow.
- From then, remote sensing technology has been advanced.
  - partly because the rate of growth of digital communications technology has kept up with the bit rate from imaging technology.
  - astronomers in California can operate instruments on the Keck telescopes in Hawaii from one of several remote observing sites.

3.3.1 Remote sensing

- **Remote "eaves-dropping" observing**
  - distant participants can take part in the observing session by viewing computer displays of the instrument status in real time and giving advice by means of a video-link.
  - The actual observing is performed by **a qualified team-member on site**.

- **"service" observing**
  - those proposing the experiment are not expected to send a representative, nor are they expected to eaves-drop.
  - The observations are carried out by a qualified staff scientist and the data are transferred to a digital storage medium in a standard form and then mailed to the team.

3.3.1 Remote sensing

- **The next step in remote sensing is “queue scheduling”**
  - in a manner similar to radio telescopes.
- **Examples**
  - poor seeing

    > spectroscopy for relativity bright objects
  - excellent seeing and dark Moon

    >a faint object spectrograph or imager
  - marked improvement in the dryness of the night

    >use a long-wavelength infrared instrument.

- There is the issue of rapid response to supernovae or GRB.

3.3.2 Automated imaging telescopes

- There are now a number of sites where **computers and weather-monitoring equipment make the decision to open the observatory and begin a pre-programmed set of observations.**

- Progress in this area began with projects like GNAT (Global Network of Automated Telescopes) in the early 1990s (Crawford and Craine, 1994; Craine et al., 2007).

- Now, however, CCDs have led to Automated Imaging Telescopes (AITs). GNAT, a non-profit organization, is adopting the Moving Object and Transient Event Search System (MOTESS) of robotic imaging telescopes and deploying dozens of them around the world.

3.3.2 Automated imaging telescopes

- "MicroObservatory"
  - pioneered in the 1990s by a group at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.
  - consists of a network of **five automated telescopes** with CCD cameras **that can be controlled over the Internet**
  - Users are responsible for taking their own images by pointing and focusing the robotic telescopes, determining exposure times, and selecting filters.
  - Each telescope is ~1m (40 inches) high and portable (135lb), employing the Maksutov design, with a 15.2 cm (6-inch) spherical primary mirror and a 13.3 cm (5.25-inch) corrector.

MicroObservatory

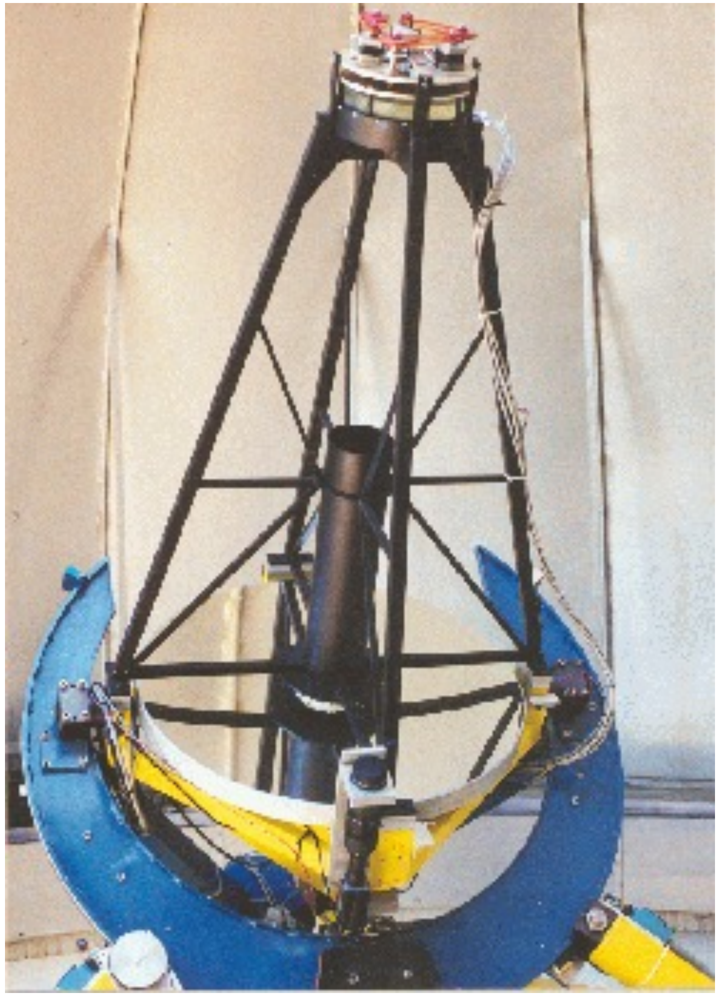
(https://mo-www.cfa.harvard.edu/MicroObservatory/)

3.3.2 Automated imaging telescopes

- **The Berkeley Automatic Imaging Telescope**
  - pioneered by Richmond, Treffers, and Filippenko in 1993
  - was upgraded and moved to the Lick Observatory on Mt. Hamilton
  - known as the **Katzman Automatic Imaging Telescope (KAIT)**

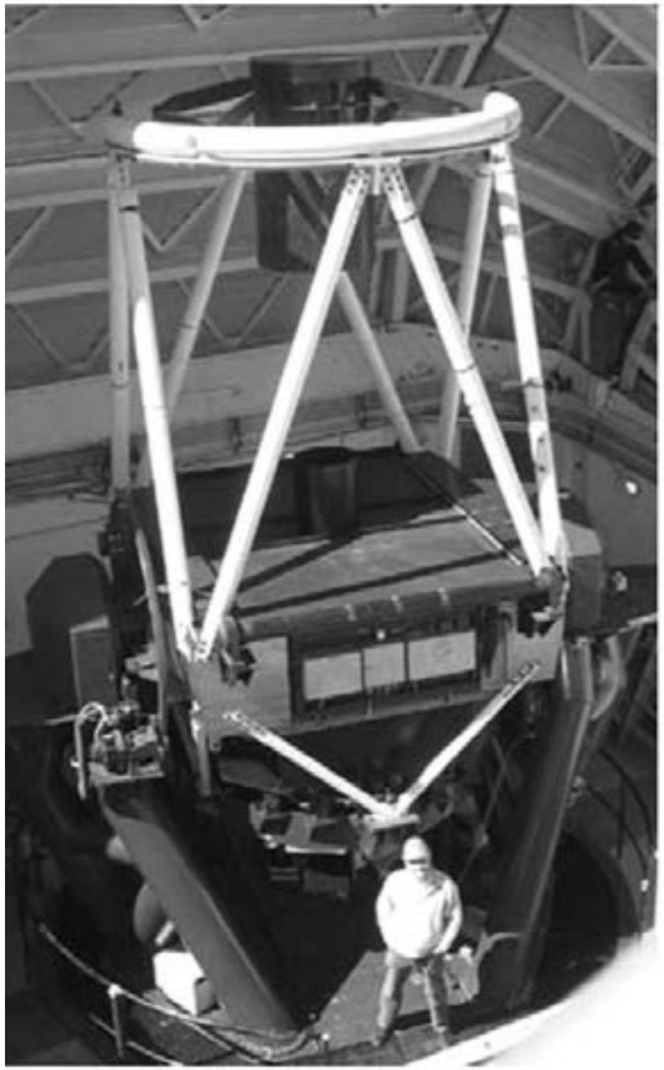
  - 0.75 m (30-inch) fully robotic telescope
  - has found about 50% of all the known nearby supernovae (about 700) in the past decade.
  - has contributed to optical follow-up of gamma-ray bursts

KAIT



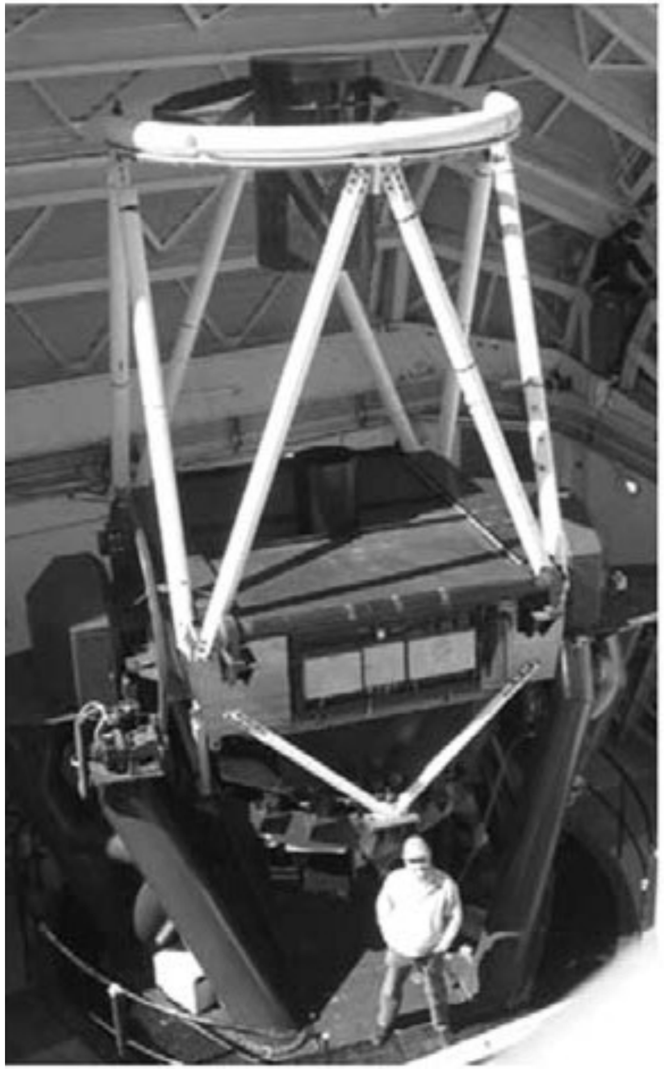
(https://w.astro.berkeley.edu/bait/kait.html)

3.3.2 Automated imaging telescopes



- The Liverpool Telescope(LT)
  - a fully robotic astronomical telescope of larger size, operational in 2003
  - a 2 m RC reflector on an alt-az mount housed in a clam shell enclosure on the summit of Roque de los Muchachos on the Canary Island of La Palma
  - Founded by British astronomer Mike Bode
  - owned and operated by the Astrophysics Research Institute of Liverpool John Moores University,
  - designed and built by Telescope Technologies Limited, a spin-off company of the university.
  - an optical CCD camera with a 4.6 arcmin field of view
  - using a 2Kx2K chip from e2v technologies.

3.3.2 Automated imaging telescopes



- The Liverpool Telescope(LT)
  - This relatively large telescope is **truly robotic in that it is fully autonomous**, using its control system to assess weather conditions, problems, and best observing strategies.
  - Two other robotic telescopes linked with the Liverpool Telescope in a global network for free educational access are those of the Faulkes Telescope Project: one telescope is in Hawaii and the other in Australia.