Schmidt-Cassegrain Telescope

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The University's first modern, computerised, and motorised astronomical telescope originally installed in the Cromwell Tower Observatory at King's College in 2002 is a 10" f/10 Meade LX200 EMC Telescope. Commonly referred to as the 'Meade Classic' telescope more recently, it uses widely adopted Schmidt-Cassegrain optics. In order to understand how a Schmidt-Cassegrain telescope works, this document provides some essential backgrounds in imaging using parabolic reflectors and Schmidt cameras leading on to the principles of Schmidt-Cassegrain telescopes.

1. Parabolic reflectors

A parabolic reflector is a curved reflective surface shaped like a paraboloid that is used to collect or project rays of radiation or waves such as light. The unique shape allows it to either concentrate incoming parallel rays onto a single focal point (Fig.1) or take radiation from a source placed at that focus and project it outward as a strong, parallel beam (Fig.2).

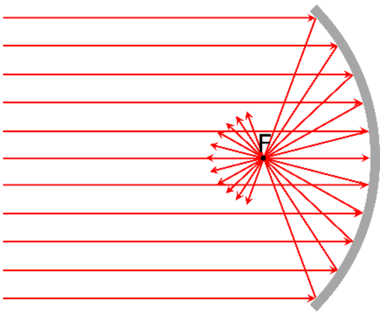

Fig.1 Parabolic reflector with incoming rays

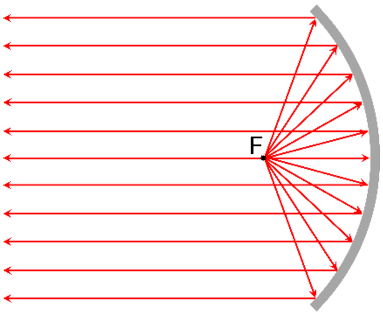

Fig.2 Parabolic reflector with outgoing rays

Parabolic reflectors are widely used across various applications such as the following. In telecommunications, satellite dishes and radar antennas use them to receive or transmit radio signals over long distances (Fig.3). In lighting, flashlights and car headlights use this shape to create a highly directed and adjustable beam of light. In astronomy, telescopes with parabolic reflectors are called reflecting telescopes or reflectors used to gather light from celestial objects including distant stars and galaxes (Fig.4).

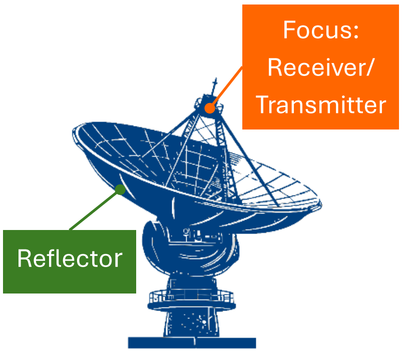

Fig.3 Parabolic antenna for satellite communications

The dimensionless ratio of focal length f to aperture D, $N = f/D$, is called focal ratio and is often denoted by f/N (Fig.4). For example, the University's 10" Meade telescope has an aperture of 10" with a focal length of 2540 mm = 100" and so its focal ratio is f/10. A smaller focal ratio up to f/5 yields brighter optical images and less exposure time and hence faster to take photograph with. A focal ratio within the range f/6 – f/9 is regarded as medium, whereas f/10 or higher is considered as slow.

Fig.4 Imaging an object using a parabolic reflector

The angular resolution of an imaging device is the minimum angular separation of two distant point locations that can be distinguished. For a camera or telescope using a parabolic reflator of diameter D as aperture, the angular resolution is set by diffraction limit $\theta = 1.22\,\lambda/D$ (rad) in terms of the wavelength λ of the light (Fig.5). This θ is given by the angular radius of the Airy disc of the image from the central brightness (centre of image) to the first ring of darkness (Fig.5) on the screen/sensor plate where the image is formed.

The maximum angular resolution R is the corresponding Dawes' limit given by $R = \theta = 1.22\,\lambda/D$ (rad) specified at a blue light wavelength $\lambda = 460$nm. It is conveniently expressed as $R = 4.56/D$ with D in inches and R in arcseconds. This means the University's 10" Meade telescope has a (maximum) angular resolution of 0.46 arcsec

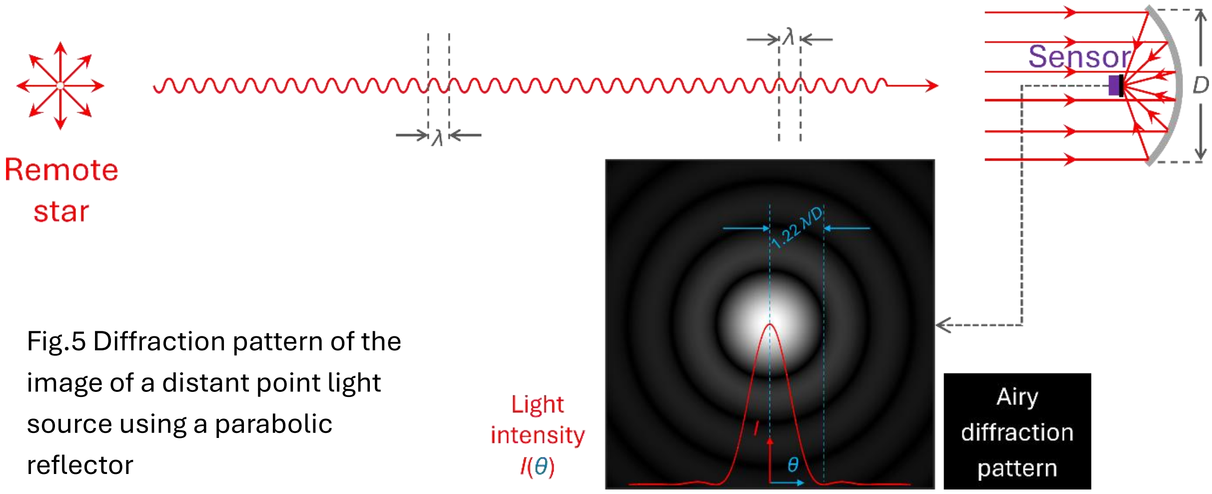

Fig.5 Diffraction pattern of the image of a distant point light source using a parabolic reflector

The practical maximum magnification M_{max} for a telescope is generally $M_{\text{max}} = 50\,D$ (D in inches). If the optical image is viewed using an eyepiece with a focal length of f_{E}, then the optical magnification is given by the ration $M = f/\,f_{\text{E}}$ up to M_{max} approximately. If the optical image is 'snapped' by a camera sensor, then the following qualities are more used than the conventional optical magnification:

$$\text{Field of View (FOV) (deg)} = \frac{57.3 \times \text{sensor size (mm)}}{f\ \text{(mm)}}$$

$$\text{Pixel scale or FOV per pixel (arcsec/px)} = \frac{206.265 \times \text{pixel size } (\mu\text{m})}{f\ \text{(mm)}}$$

2. Schmidt cameras

Spherical reflectors is a curved reflective surface having a spherical shape. Similar to a parabolic reflector, it can also be used to collect or project rays of radiation or waves. Unlike a parabolic reflector, it does not have a well-defined focal point and so focusing is not perfect (Fig.6). The corresponding off-axis distortion of imaging forming is called spherical aberration. Nonetheless, because the manufacture of spherical reflectors is less expensive, they could substitute parabolic reflectors for nondemanding purposes.

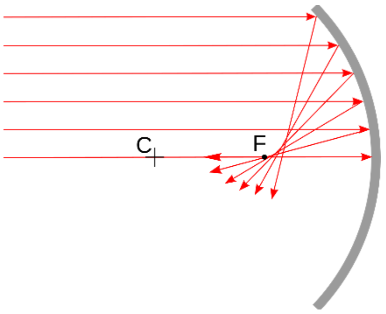

Fig.6 Spherical reflector with incoming rays, with C as the centre of curvature and F as the approximate focus.

In 1930, Bernhard Schmidt introduced a lens with a nonuniform thickness called the Schmidt corrector plate to be placed at the centre of curvature so that the refracted incoming light beam will be focused by a spherical reflector as if by a parabolic reflector, with the aperture given by the diameter of the corrector plate (Fig.7). The resulting imaging device is called the Schmidt camera or Schmidt telescope.

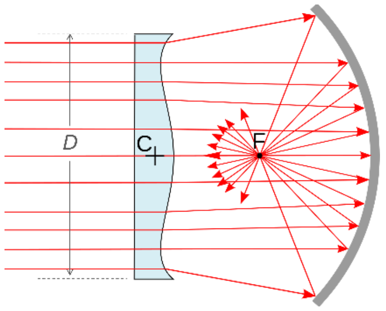

Fig.7 Spherical reflector with a Schmidt corrector plate with an exaggerated thickness profile.

Since the corrector plate lenses can be made using the inexpensive moulding process, Schmidt cameras achieve a high quality-to-cost ratio. However, the presence of typically a glass lens as the front corrector means the resulting Catadioptric optics is not immune from chromatic aberration and has a lower infrared sensitivity. However, Schmidt telescopes still outperform refracting telescopes with respect to these two aspects due to their use of relatively thin corrector lenses.

Compared with imaging devices using simple spherical reflectors, Schmidt cameras are free of spherical aberration that limits the off-axis resolution making them suitable for astronomical surveys and deep-sky imaging.

3. Schmidt-Cassegrain telescopes

Schmidt-Cassegrain telescopes (SCT) are Schmidt cameras with an additional co-axial, convex secondary mirror with the Cassegrain design. This allows SCTs to have a longer focal lengths and hence a higher magnification compared to Schmidt cameras. Depending on the location of the front corrector, there are two types of SCT: In the non-compact type (Fig.8), the corrector plate remains at or near the centre of curvature (C_P) of the primary mirror as in standard Schmidt cameras (Fig.7). It requires a longer optional tube but offers better correction of aberrations and overall optical performance. In the compact form, the corrector plate is located near the focus of the primary mirror (F_P) which has the advantage of using significantly shorter optical tubes for given apertures and focal lengths (Fig.9). This means that compact SCTs are more portable and can save considerably installation space in an observatory. The world's largest SCT, the James Gregory Telescope, located at the University of St Andrews in Scotland is a non-compact SCT. Many commercially available SCTs are of the compact form, including the University's 10" Meade telescope.

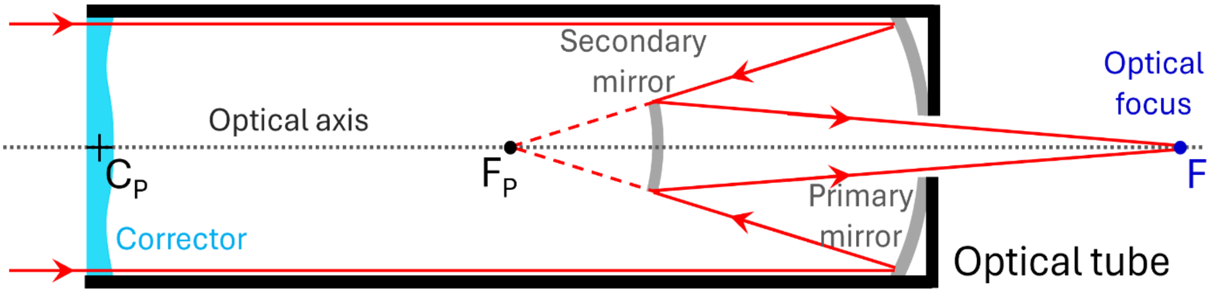

Fig.8 Schmidt-Cassegrain telescope: non-compact type

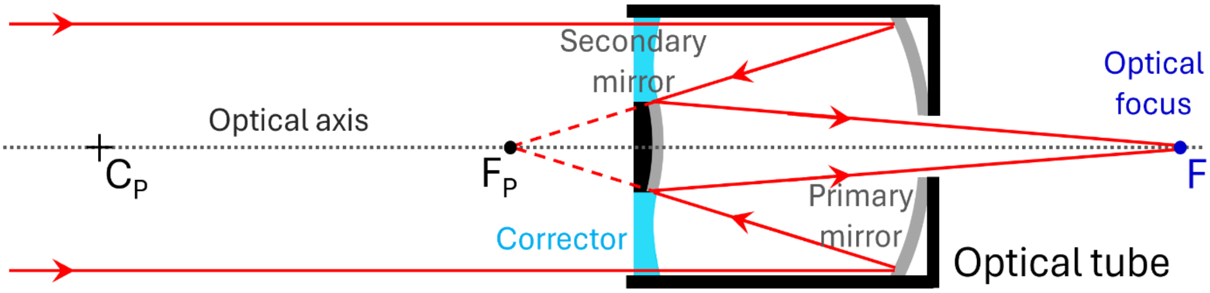

Fig.9 Schmidt-Cassegrain telescope: compact type