Appendix A: Astronomical Formulae

Introduction

Magnification

The magnification of an astronomical telescope changes with the eyepiece used. It is calculated by dividing the focal length of the telescope (usually marked on the optical tube) by the focal length of the eyepiece (both in millimeters). Thus:

$$\frac{\text{Telescope focal length}}{\text{Eyepiece focal length}} = \text{Magnification}$$

For example, a telescope with a 1200-mm focal length using a 12-mm ocular is operating at 100× magnification (1200/12 = 100).

Focal Ratio (f/stop)

The focal ratio, or f/stop, of any lens system (including telescopes) is computed by dividing the focal length by the clear aperture (usually expressed in millimeters). In other words, the focal ratio is the ratio of the focal length and clear aperture. Thus,

$$\frac{\text{Telescope focal length}}{\text{Clear aperture}} = \text{Focal ratio}$$

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For example, a telescope with a focal length of 1200 mm and a 150 mm (6″) clear aperture has a focal ratio of f/8 (1200/150 = 8).

True Field of View

There are two ways to calculate the true field of view (FOV) in degrees of a telescope and eyepiece combination. An easy method to use is to divide the apparent field of view (AFOV) of the ocular by the magnification of the system. The AFOV for almost all eyepieces is provided by the manufacturer and is easy to derive the magnification of any telescope/ocular combination. Thus,

$$\frac{\text{AFOV}}{\text{Magnification}} = \text{FOV}\left(\text{field of view}\right)$$

For example, a 30-mm Plossl eyepiece generally has an AFOV of 52°. Used in a telescope with a 1200-mm prime focal length, the magnification is 40×. The true field of view is therefore 1.30° (52/40 = 1.3).

Power per Inch

This is good to know because it is a truism among amateur astronomers that the power per inch (PPI) figure of a telescope and ocular should not exceed 50 PPI in excellent seeing conditions. In average seeing conditions, I figure about 30 PPI as a practical maximum.

PPI can be calculated by dividing the magnification of the telescope and eyepiece combination by the telescope's clear aperture in inches (1 in. = approximately 25 mm). Thus,

$$\frac{\text{Magnification}}{\text{Aperture}}\left(\text{IN}\right) = \text{PPI}\left(\text{power per inch}\right)$$

For example, a 150-mm clear aperture is approximately 6″, so such a telescope operating at 120× magnification is at 25 PPI (120/6 = 20).

Exit Pupil

The exit pupil is the diameter of the "light pencil" that emerges from the eye-piece. The pupil of fully dark-adapted human eye can dilate to about 7-mm diameter, so an exit pupil in excess of 7 mm is passing more light than the eye can accept. On the other hand, as the exit pupil decreases below 7 mm, lack of light becomes the basic limiting factor to what you can see at night. Exit pupils of less than about 0.5 mm are so small and pass so little light to the eye that they are functionally useless. Actually, I like exit pupils of at least 1.0 mm for decent viewing.

Exit pupil can be calculated by dividing the telescope's clear aperture (in millimeters) by the magnification produced by the ocular in use. Thus,

$$\frac{\text{Aperture}}{\text{Magnification}} = \text{Exit pupil}$$

For example, our 150-mm (f/8) clear aperture telescope with a 10-mm ocular is operating at 120× magnification and therefore has a 1.25 mm exit pupil (150/120 = 1.25).

Another way to calculate exit pupil is to divide the eyepiece focal length in millimeters by the telescope's focal ratio (f/stop).

$$\frac{\text{Ocular focal length}}{\text{Telescope focal ratio}} = \text{Exit pupil}$$

Thus, a 10-mm ocular in our f/8 (150-mm clear aperture and 1200-mm focal length) telescope has a 1.25-mm exit pupil (10/8 = 1.25). Either formula results in the same answer.

Resolution

The resolution of a telescope must be considered. In terms of ideal "seeing" conditions, the following formula applies:

$$\text{Resolution} = \frac{116}{D}$$

$$D = \text{diameter of telescope in mm}$$

Example: a 254-mm telescope (10″)

$$\text{Resolution} = \frac{116}{\text{mm}254}$$

$$\text{Resolution} = 0.457(0.5)\text{seconds}$$

How faint an object can your telescope see:

$$m = 2.7 + 5\log D$$

$$D = \text{Objective lens diameter}$$

where m is the limiting magnitude, for example, a 10″ telescope:

$$m = 2.7 + 5\log(254\,\text{mm})$$

$$m = 14.7$$

The faintest object a 10″ telescope can see (depending on seeing conditions) is a visual magnitude of 14.7 (Pluto has a magnitude of around 13.8).

Appendix B: Glossary

Airy Disk The best focused spot of light that can be created by a perfect lens system, assuming a circular aperture and limited by light diffraction.

Altazimuth A telescope mounting that allows motion of the telescope about a vertical axis (in azimuth) and a horizontal axis (in altitude).

Antireflection Coating (AR) Coating is a type of optical coating applied to the surface of lenses and other optical devices to reduce reflection.

Astigmatism An optical system with astigmatism is one where rays that propagate in two perpendicular planes have different foci.

Autoguider An electronic device that makes use of a CCD camera to detect guiding errors and makes automatic corrections to the telescope's drive system in order for it to track accurately.

Autotracking The ability of a Dobsonian mount to track celestial objects as they move across the night sky.

Barlow Lens It is named after Peter Barlow and is a diverging lens which, used in series with other optics in an optical system, increases the effective focal length of an optical system as perceived by all components after it is in the system.

Central Obstruction It is usually defined as a telescope's secondary mirror, for example, in a Newtonian telescope's optical system that acts as a central obstruction in the telescope's light path.

Collimation Refers to all the optical elements in an instrument being on their designed optical axis. It also refers to the process of adjusting an optical instrument so that all its elements are on that designed axes (in line and parallel). With regard to a telescope, the term refers to the fact that the optical axes of each optical component should all be centered and paralleled, so that collimated light emerges from the eyepiece.

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Coma In optics (especially telescopes), the *coma* (aka comatic aberration) in an optical system refers to aberration inherent to certain optical designs or due to imperfection in the lens or other components which results in off-axis point sources such as stars appearing distorted, appearing to have a tail (coma) like a comet.

Conical Mirror A cone-shaped mirror that can be mounted more easily and cools down faster than conventional "cylindrical" mirrors.

Dawes Limit A formula to express the maximum resolving power of a microscope or telescope.

Depth of Focus A lens optics concept that measures the tolerance of placement of the image plane (the film plane in a camera) in relation to the lens.

Declination (Dec) An axis of rotation on an Altazimuth telescope mount that is perpendicular to the polar axis and allows the telescope to be pointed at objects of different declinations.

Dielectric Coatings These consist of layers of dielectric materials (i.e., not metals, which are used in mirrors for consumer goods) and are designed to achieve the highest possible reflectance, usually at specific wavelengths.

Diffraction The bending of light waves around the edge of an obstacle. When light strikes an opaque body, for instance, a shadow forms on the side of the body that is shielded from the light source. Ordinarily light travels in straight lines through a uniform, transparent medium, but those light waves that just pass the edges of the opaque body are bent, or deflected.

Diffraction Limited The minimum angular separation of two sources that can be distinguished by a telescope depends on the wavelength of the light being observed and the diameter of the telescope. This angle is called the diffraction limit.

Dispersion For a refracting, transparent substance, such as a prism of glass, the dispersion is characterized by the variation of refractive index with change in wavelength of the radiation.

ED Short for extra low dispersion, usually referring to glass that focuses red, green, and blue light more tightly than a regular crown flint objective and resulting in better color correction.

Equatorial Mount A mount for instruments that follows the rotation of the sky (celestial sphere) by having one rotational axis parallel to the Earth's axis of rotation. This type of mount is used for astronomical telescopes.

Extrafocal The focus is outside of the focal plane.

Eye Relief For an optical instrument (such as a telescope, a microscope, or binoculars), it is the distance from the last surface of an eyepiece at which the user's eye can obtain the full viewing angle.

Focal Length The focal length of an optical system is a measure of how strongly the system converges or diverges light. For an optical system in air, it is the distance over which initially collimated rays are brought to a focus.

Focal Point The point where a light cone converges is called the primary mirror's focal point.

Focal Ratio The numerical value of the relative aperture. If the relative aperture is f8, 8 is the f-number and it indicates that the focal length of the lens is 8 times the size of the lens aperture.

Fresnel Lens Series of concentric rings, each consisting of a thin part of a simple lens, assembled on a flat surface.

Gamma Stretch Gamma refers to the degree of contrast between the midlevel gray values of a raster dataset. Gamma does not affect the black or white values in a raster dataset, only the middle values. By applying a gamma correction, you can control the overall brightness of a raster dataset. Additionally, gamma changes not only the brightness but also the ratios of red to green to blue.

GOTO Represents a type of electronic telescope drive that can automatically go to a selected celestial object on demand.

Interpupillary Distance (IPD) The distance between the center of the pupils of the human eye. Average interpupillary distance is 65 mm.

Intrafocal The focus is inside the focal plane.

Lazy Susan Bearing A circular revolving frame that rotates with the use of ball bearings; sometimes used in Altazimuth telescope mounts.

Magnification A measure of the ability of a lens or other optical instrument to magnify, expressed as the ratio of the size of the image to that of the object.

Multicoated Refers to lens elements of optical system with many layers of lens coating (of transparent dielectric material) to increase transmission of light and reduce reflection.

Parabolic Mirror A cone-shaped concave mirror with a rounded-off tip, whose cross section is shaped like the tip of a parabola.

Peak-to-Valley Wavelength A term describing how sounds and light waves are measured. The peak of a wave is known as the peak, while the low dip of the wave is known as the valley. Wavelength is determined by measuring the distance between each crest.

Rayleigh Criterion or Resolving Power A criterion for how finely a set of optics may be able to distinguish the location of objects which are near each other.

Right Ascension (RA) The arc of the celestial equator measured eastward from the vernal equinox to the foot of the great circle passing through the celestial poles and a given point on the celestial sphere, expressed in degrees or hours. Right ascension is the celestial equivalent of terrestrial longitude. Both right ascension and longitude measure an angle that increases toward the east as measured from a zero point on an equator, which, by convention, is the first point of Aries.

Ronchi Test In optical testing, a Ronchi test is a method of determining the surface shape (figure) of a mirror used in telescopes and other optical devices.

Sagitta In optics is where it is used to find the depth of a spherical mirror or lens.

Secondary Mirror A secondary mirror (or secondary) is the second deflecting or focusing mirror element in a reflecting telescope.

Seeing Disk Diameter The point spread function diameter (seeing disk diameter or "seeing") is a reference to the best possible angular resolution which can be achieved by an optical telescope in a long photographic exposure and corresponds to the diameter of the fuzzy blob seen when observing a point-like star through the atmosphere.

Sled Focuser The sled-type focuser enables the whole secondary mirror together with eyepiece to move closer or further away from the primary to achieve focus instead of the usual way of racking the eyepiece in and out.

Spherical Aberration An optical effect observed in an optical device (lens, mirror, etc.) that occurs due to the increased refraction of light rays when they strike a lens or a reflection of light rays when they strike a mirror near its edge, in comparison with those that strike nearer the center.

Spherical Mirror A mirror whose surface is curved liked a sphere and is usually found in smaller telescopes with and f/10 focal ratio or higher.

Strehl Ratio A measure of optical quality that measures how much an optic deviates from perfection. A Strehl ratio of 1.0 is the best one can attain.

Truss Tube A type of round tube design used primarily on Dobsonian telescopes that uses trusses (lightweight poles) to secure and maintain the optical components in precise alignment.

Turned Down Edge An aberration that occurs when the edge does not end abruptly but curls over gradually, starting from about 80% of the way out from the center of the mirror.

Vignetting A condition caused by any portion of an incoming light column (or the resulting light cone) failing to reach the focal plane. The primary causes of vignetting are obstructions blocking the light's path or light missing a reflecting surface.

Zonal Errors Localized defects that arise during the initial figuring and polishing of optical mirrors.

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