Astronomy Lab

A) Observation and Classification of Astronomical Objects

B) Atmospheric Refraction

Supervisor: Markus Mugrauer

Last Update: April 2026

1 Introduction

1.1 Constellations and Star Names

Constellations provide a rough guide to orientation in the sky. Even in ancient times, groups of fixed stars that are close together in the celestial sphere were grouped together to form constellations. The stars in a constellation may be far apart in space. In 1925, the boundaries of the constellations were defined by international agreement using sections of right ascension and declination circles. In total, the sky is completely covered by 88 constellations officially recognized by the International Astronomical Union (IAU). Many of the constellation names used today originate from Greek mythology (heroes and mythical creatures).

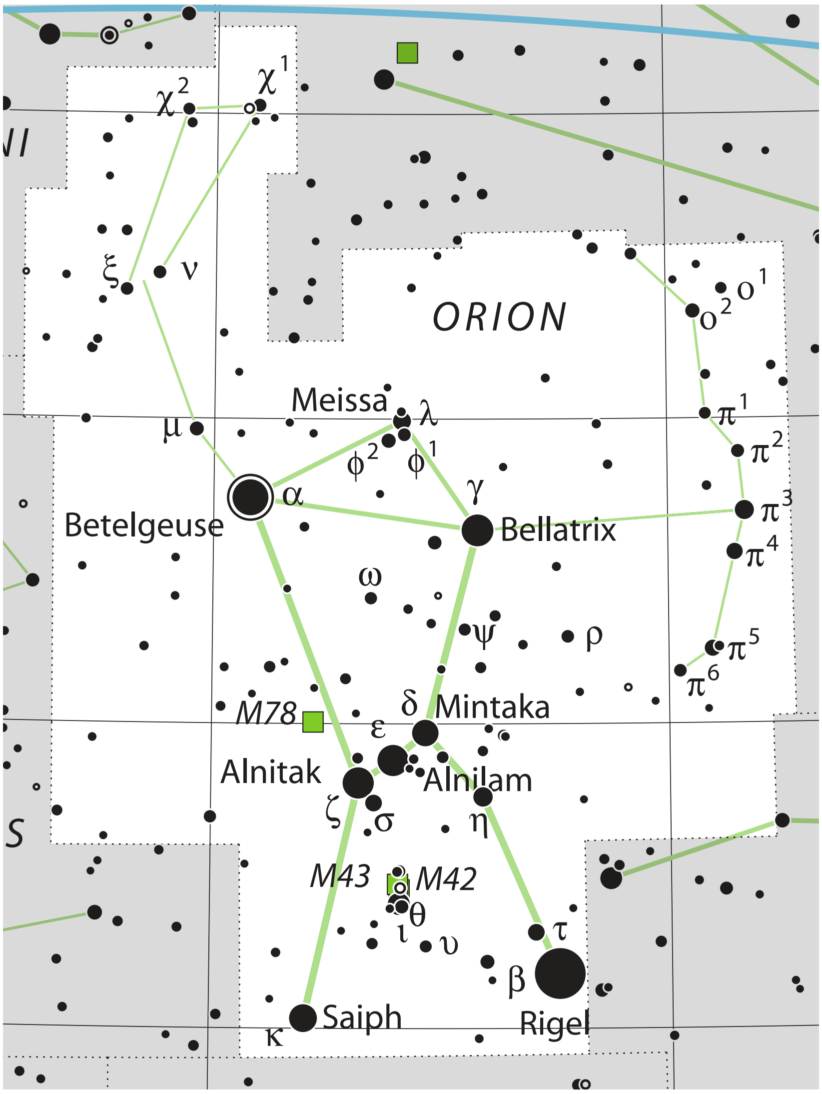


Figure 1: Star map of the constellation Orion.

Figure 2: Section of the sky around the constellation Southern Cross.
Photo: M. Mugrauer

In addition, constellations were invented by navigators and cartographers of the sky, such as Johann Bayer (1572-1625), Johannes Hevelius (1611-1687), and Nicolas Louis de Lacaille (1713-1762). Lacaille added 14 constellations (auxiliary devices of science and art), and the remaining gaps in the southern sky were then filled with constellations invented by other astronomers. Some constellations were later abolished, e.g., Argo Navis (ship) → Carina (ship's keel), Vela (sail), Puppis (aft deck of the ship).

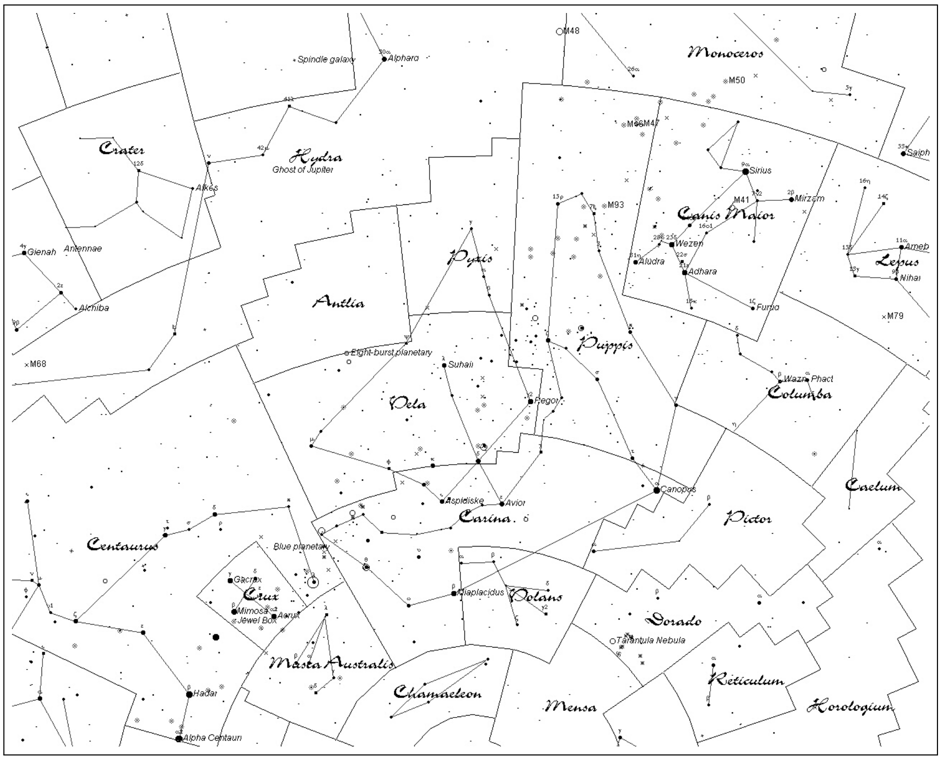


Figure 3: The ancient constellation Argo Navis.

Within a constellation, stars are designated by small Greek letters according to their brightness up to approximately the 4th magnitude (according to J. Bayer). Fainter stars are designated by small Latin letters or numbers (according to F. Flamsteed [1646-1719]). The complete designation of a star is then composed of the Greek or Latin letter or a number, followed by the genitive of the Latin constellation name or its abbreviation, e.g. α Lyrae = α Lyr, γ Leonis = γ Leo, 32 Ursae Majoris = 32 UMa. Even today, proper names, often of Arabic origin, are still commonly used for the brightest stars.

1.2 Catalogs of astronomical objects

Star catalogs list these stars, but also fainter ones. They are named with the abbreviation of the catalog and a number.

Table 1: Common Star Catalogs

Name	Abbre-viation	Limit [mag]	Number of Stars	Equin-ox
Bonner Durchmusterung	BD	9.5	$3.2 \cdot 10^5$	1855
Henry-Draper-Katalog	HD	9.0	$2.2 \cdot 10^5$	1900
Positions & Proper Motions Star Catalogue Heidelberg	PPM	12.0	$1.8 \cdot 10^5$	2000
Smithonian Astrophysical Observatory Catalogue	SAO	12.2	$2.6 \cdot 10^5$	1950
Hipparcos Input Catalogue	HIC	12.5	$1.1 \cdot 10^5$	2000
The Hipparcos & Tycho Catalogues	HIP	11.5	10^6	1991.25
The 2 Micron All Sky Catalogue	2MASS	15.8	$4.7 \cdot 10^8$	2000
Gaia DR3 Catalogue	Gaia DR3	21.0	$1.8 \cdot 10^9$	2016

Thus, one and the same star can be designated by different names, e.g., Vega = α Lyrae = α Lyr = BD+38° 3238 = HD 172167 = ($\alpha_{2000} = 18^h\ 36^m\ 56^s$; $\delta_{2000} = +38°\ 47'\ 01''$). Other celestial objects, such as star clusters, gas nebulae, galaxies, radio, X-ray, or infrared objects, are designated in a similar manner. The brighter objects, which appear as nebulae when observed with smaller telescopes, are still often designated by their number in older "nebula" catalogs in conjunction with the catalog abbreviation, regardless of their physical nature. The different object designations, together with further properties of the objects, are available online in the `SIMBAD`[1] database.

Table 2: Common Nebula Catalogs

Name	Abbreviation	Number of Objects
Messier-Catalog	M	103
New General Catalogue of Nebulae & Clusters of Stars	NGC	7840
Index Catalog	IC	5386

Examples: Orion Nebula = M 42 = NGC 1976 (gas nebula), Crab Nebula = M 1 = NGC 1952 (supernova remnant), Praesepe = M 44 = NGC 2632 (open star cluster), Andromeda Nebula = M 31 = NGC 224 (galaxy)

[1] `https://simbad.u-strasbg.fr/simbad/`

1.3 Star Maps

In conjunction with star catalogs, star charts are often published as pictorial representations of parts of the celestial sphere, which are often compiled into star atlases. Among other things, they are used for orientation in the sky, to better locate objects whose coordinates are given, or to plot newly discovered and moving objects, such as comets and planetoids. Like the catalogs, the maps always refer to a specific reference equinox. This must be taken into account when coordinates are taken from catalogs or when objects are newly plotted on the maps.

Table 3: Selected Star Maps and Sky Atlases

Name	Limit [mag]	Equinox
Bonner Durchmusterung	9.5	1855
Atlas Coeli	7.8	1950
Sternatlas (1975.0)	6.0	1975
Atlas Stellarum	14.5	1950
POSS-1	21.0	1950
POSS-2	21.0	2000
2MASS	15.0	2000
PanSTARRS (PS1)	22.0	2000

Online, the sky atlases can be displayed using the `Aladin Sky Atlas`[2] program and combined with catalogs from the `VizieR`[3] astronomical database.

1.4 Rotating Star Maps

Rotating star maps are useful for quickly orienting yourself in the night sky. They basically consist of a round base sheet with two scales attached to the edge, one for setting the observation date and the other for reading the right ascension, as well as a cover sheet with an elliptical cutout. This reveals the part of the sky that is visible from a given location, as shown on the base sheet, and which is above the horizon at a specific time. There is a scale on the cover sheet for setting the time. In addition, the cover sheet generally also contains scales for reading the altitude and azimuth of the stars, and the base sheet contains a scale for reading the declination.

With a rotating star map as an analog calculator, a series of simple tasks (with low accuracy) can be solved within its area of validity (specified geographical latitude, and equinox):

[2] `https://aladin.cds.unistra.fr/`
[3] `https://vizier.cds.unistra.fr/`

1. Determination of the section of the sky that is above the horizon at a specific time (CET): The section of the cover sheet then shows the part of the sky that is above the horizon when the true local time is set on the base sheet above the observation date, i.e., the time taking into account the difference between the geographical longitudes of the reference meridian for CET ($\lambda = 15°$) and the observation location, expressed in time units, is set on the cover sheet.

2. Determination of the sidereal time for a specific time in CET: As in 1., the true local time must be set above the observation date. At the hour angle 12 h (south direction) on the cover sheet, the sidereal time is read on the right ascension scale of the base sheet.

3. Determination of the rising and setting times of celestial bodies: The location of the celestial body is aligned with the east or west edge of the section on the cover sheet. The time of rising or setting can then be read above the desired date.

4. Determination of star coordinates in the equatorial or horizontal system: The right ascension and declination of an object can be determined using the coordinate grid on the base sheet; the azimuth and altitude can be read directly from the coordinate grid on the cover plate after setting the observation time.

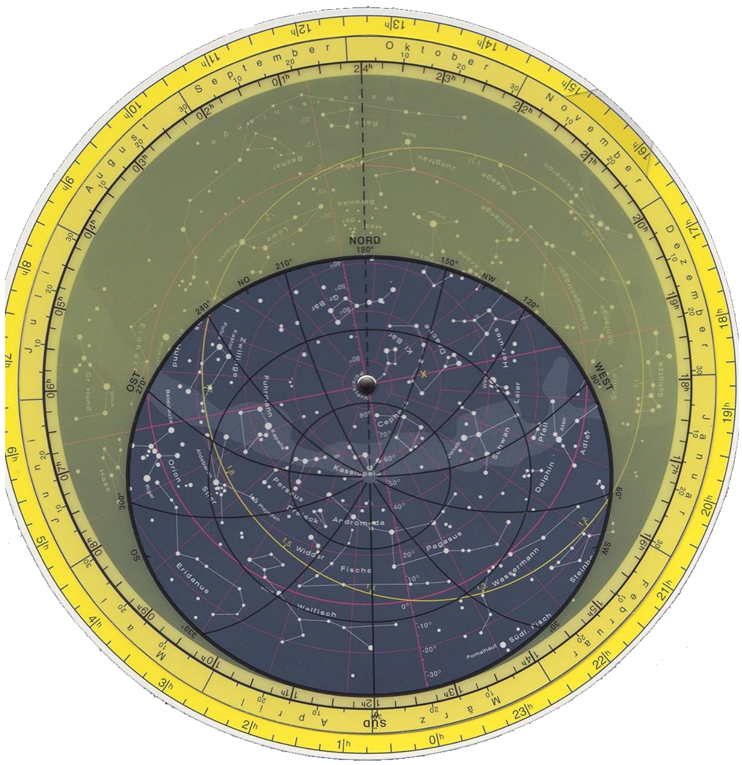


Figure 4: The rotating star map used in this experiment.

1.5 PC Programs for Displaying the Sky

Astronomical visualization programs are available for computers. They usually allow equatorial and horizontal coordinates to be displayed in various projections, free choice of observation location and time, display of object types such as stars, planets, moon, sun, star clusters, and galaxies, as well as constellations and constellation boundaries. They also feature editing and printing options and offer upgrade options for controlling smaller telescopes.

1.6 Almanacs

Almanacs are astronomical calendars that contain pre-calculated celestial coordinates (ephemerides) for an entire year. For the sun and planets, the locations are generally given for each day, for the moon for each hour, and for fixed stars for intervals of 10 days. In addition, almanacs contain numerous other details, e.g., about eclipses, star occultations, or satellite locations. In addition to information about the movements of the bodies in the planetary system, almanacs also contain lists of astronomical objects in the fixed star sky that can be observed. These usually include double stars, variable stars of various types, open and globular star clusters, gas nebulae, and galaxies.

2 Astronomical Coordinate Systems

The precise position of an object in the sky can be specified using coordinates in various coordinate systems.

2.1 Horizontal Coordinate System

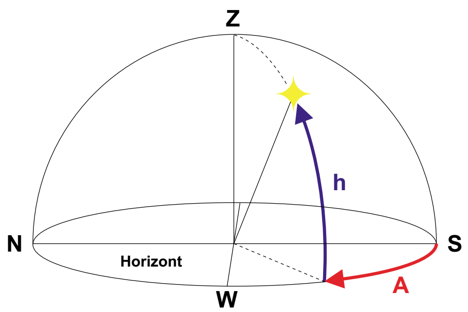


Figure 5: Horizontal System

A: Azimuth or azimuth angle

This is the angle between the great circle passing through the points (N, Z, S) (meridian) and the great circle passing through the object and Z, measured from south in westerly direction$[0° \leq A < 360°[$.

h: Altitude

This is the angle between the object and the horizon and is measured from $-90°$ (nadir) to $0°$ (horizon) to $+90°$ (zenith).

Advantage: Easy to specify the position of an object.

Disadvantage: Coordinates are time-dependent due to the Earth's rotation and can change significantly even within short periods of time (stars move across the sky from east to west $\Rightarrow$ Earth rotates from west to east).

2.2 Equatorial Coordinate System

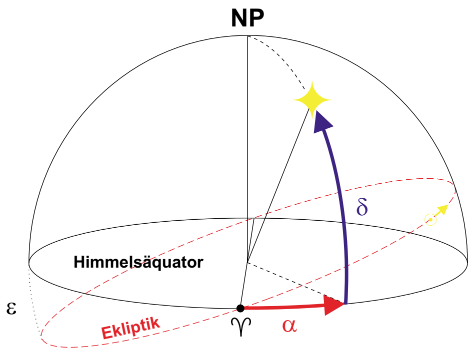


Figure 6: Equatorial System

α: Right Ascension

This is the angle between the object and the vernal equinox ♈ measured in easterly direction $[0^h \leq \alpha < 24^h[$

δ: Declination

This is the angle between the object and the celestial equator, measured in northerly direction from the south celestial pole (SP) at $\delta = -90\,°$ to the north celestial pole (NP) at $\delta = +90\,°$

The vernal equinox ♈ (Aries point) is the intersection of the celestial equator with the annual path of the Sun in the sky, the ecliptic, at which the Sun crosses the celestial equator from south to north on its path. At the beginning of spring (21 March), the sun is at the vernal equinox ($\alpha = 0^h$), then moves eastward along the ecliptic to the northern summer solstice ($\alpha = 6^h$), which it reaches on 21 June. It then descends southward again and reaches the autumnal equinox ♎ ($\alpha = 12^h$) on 23 September. On 21 December, the sun reaches its northern winter solstice ($\alpha = 18^h$).

The ecliptic is nothing more than the intersection of the Earth's orbital plane with the equatorial coordinate system. Since the Earth's axis of rotation is inclined by $\varepsilon = 23.5\,°$ to the perpendicular to its orbital plane around the Sun, the celestial equator and the ecliptic are also tilted by this angle relative to each other.

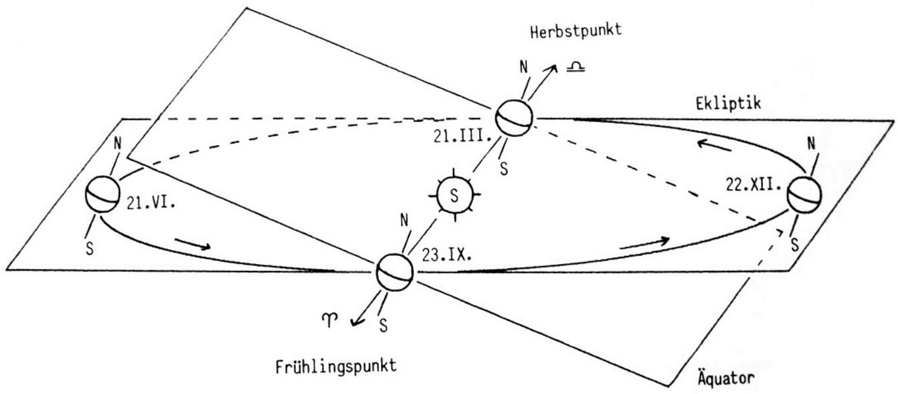


Figure 7: Annual movement of the Earth in the solar system.

2.3 Transformation of Coordinate Systems

The spherical triangle between the celestial north pole, the zenith, and the object is called the **astronomical triangle**.

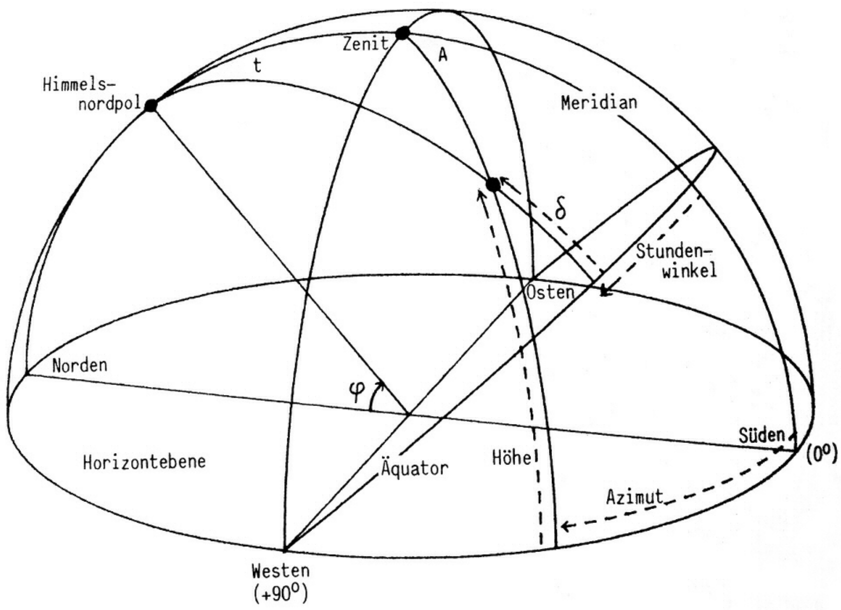


Figure 8: Graphical relationship between the equatorial and horizontal coordinate systems.

Applying the sine rule in the spherical triangle yields:

$$\boxed{\cos h \cdot \sin A = \cos \delta \cdot \sin t}$$

Applying the cosine rules in the spherical triangle yields:

$$\boxed{\sin h = \sin \varphi \cdot \sin \delta + \cos \varphi \cdot \cos \delta \cdot \cos t}$$

$$\boxed{\sin \delta = \sin h \cdot \sin \varphi - \cos h \cdot \cos \varphi \cdot \cos A}$$

with the hour angle t of an object: $\boxed{t = \Theta - \alpha}$

Θ indicates the right ascension value that is currently on the meridian and is an important quantity for the observing astronomer, referred to as the **sidereal time**. Like solar time, sidereal time runs from 0 to 24 hours, but it is based on the Earth's rotation time, which is $23^h 56^m 4^s$.

The local sidereal time (LMST) at the time of observation in Jena and thus also the hour angle of an object can be determined using the sidereal time table below.

Sternzeittabelle für Jena um 0 UT

Datum			LMST		Datum			LMST	
dd	mm	yyyy	hh	mm	dd	mm	yyyy	hh	mm
01	04	2026	13	24	01	05	2026	15	22
02	04	2026	13	28	02	05	2026	15	26
03	04	2026	13	32	03	05	2026	15	30
04	04	2026	13	36	04	05	2026	15	34
05	04	2026	13	40	05	05	2026	15	38
06	04	2026	13	44	06	05	2026	15	42
07	04	2026	13	48	07	05	2026	15	46
08	04	2026	13	51	08	05	2026	15	50
09	04	2026	13	55	09	05	2026	15	54
10	04	2026	13	59	10	05	2026	15	58
11	04	2026	14	03	11	05	2026	16	02
12	04	2026	14	07	12	05	2026	16	06
13	04	2026	14	11	13	05	2026	16	09
14	04	2026	14	15	14	05	2026	16	13
15	04	2026	14	19	15	05	2026	16	17
16	04	2026	14	23	16	05	2026	16	21
17	04	2026	14	27	17	05	2026	16	25
18	04	2026	14	31	18	05	2026	16	29
19	04	2026	14	35	19	05	2026	16	33
20	04	2026	14	39	20	05	2026	16	37
21	04	2026	14	43	21	05	2026	16	41
22	04	2026	14	47	22	05	2026	16	45
23	04	2026	14	51	23	05	2026	16	49
24	04	2026	14	55	24	05	2026	16	53
25	04	2026	14	58	25	05	2026	16	57
26	04	2026	15	02	26	05	2026	17	01
27	04	2026	15	06	27	05	2026	17	05
28	04	2026	15	10	28	05	2026	17	09
29	04	2026	15	14	29	05	2026	17	13
30	04	2026	15	18	30	05	2026	17	16

Figure 9: Local sidereal time for Jena at 0 UT.

3 Optical Properties of Telescopes

Telescopes collect light from the objects being observed and project it onto the receiver or the entrance aperture of an accessory device. The detection, measurement, and analysis of radiation coming from a celestial body are carried out with the aid of various receivers (e.g., the eye, photographic plate, secondary electron multiplier, CCD-detector) and often in combination with additional devices (e.g., spectrograph, polarimeter). The most important optical properties of telescopes are considered below.

3.1 Diffraction at the Objective

In simple terms, the objective of a telescope can be thought of as a single slit,

whose diffraction pattern is given by: $\boxed{I(x) = I_0 \left(\frac{\sin x}{x}\right)^2}$ with $\boxed{x = \pi \frac{D}{\lambda} \sin\alpha}$

With the maximum path difference Δs for light rays arriving at the slit at an angle α: $\Delta s = D \cdot \sin\alpha$ and the condition for diffraction minima: $\Delta s = n \cdot \lambda$ with $n \in \mathbb{N}$.

$\Rightarrow$ Condition for diffraction minima: $D \cdot \sin\alpha = n \cdot \lambda$ with $n \in \mathbb{N}$

$\Rightarrow \alpha = n \cdot \frac{\lambda}{D}$ (small angle approximation) with the first minimum at: $\tilde{\alpha} = \frac{\lambda}{D}$

The calculation with a circular aperture as objective yields the Airy function:

$\boxed{I(x) = 4I_0 \left(\frac{J_1(x)}{x}\right)^2}$ Bessel function: $\boxed{J_1(x) = \sum_{k=0}^{\infty} \frac{(-1)^k}{k!(k+1)!} \left(\frac{x}{2}\right)^{2k+1}}$

$\Rightarrow$ Diffraction pattern $\hat{=}$ Airy disk

The first minimum here is at $x = \pi \cdot \frac{D}{\lambda} \cdot \sin\alpha_m = 3.8317$ and for small angles

$\Rightarrow \tilde{\alpha} = \frac{3.8317}{\pi} \cdot \frac{\lambda}{D} = 1.22\frac{\lambda}{D}$ (in radians)

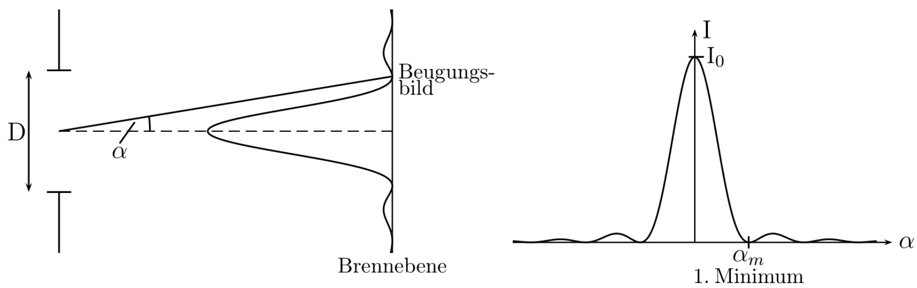


Figure 10: Diffraction at the objective of a telescope.

3.2 Angular Resolution

The angular Resolution refers to the smallest angular distance between two point light sources at which they can still be perceived separately. Due to the diffraction of light at the objective of the telescope (entrance pupil), a point light source is imaged as a diffraction pattern (central disk with concentric rings of decreasing brightness). Diffraction theory provides the following for the radius $\tilde{\alpha}$ of the first dark ring in radians:

$$\boxed{\tilde{\alpha} = 1.22 \cdot \frac{\lambda}{D}} \qquad \text{(Rayleigh criterion)}$$

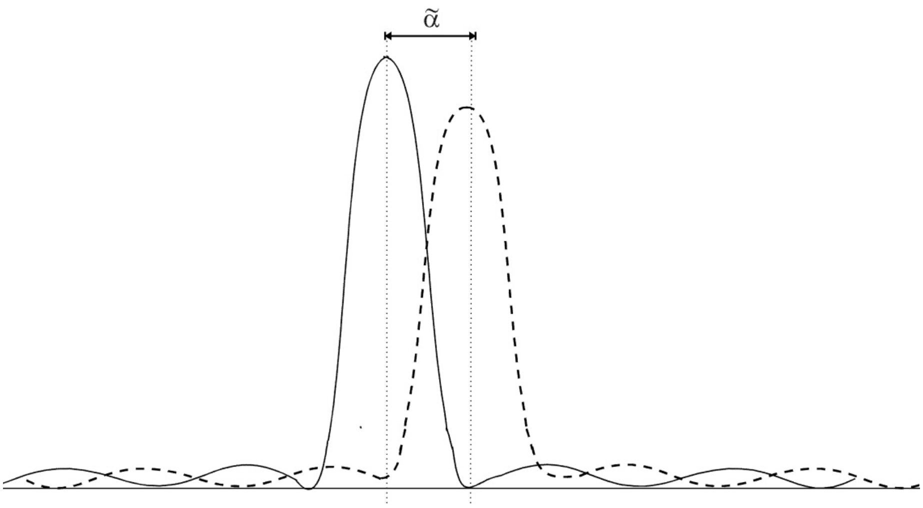


Figure 11: The Rayleigh criterion.

However, closely separated stars can already be distinguished when the maximum brightness of one is approximately at the edge of the diffraction disk of the other star. The theoretical resolving power of a telescope is therefore defined as the angular distance in radians:

$$\boxed{\tilde{\alpha}_{\text{Limit}} = \lambda/D}$$

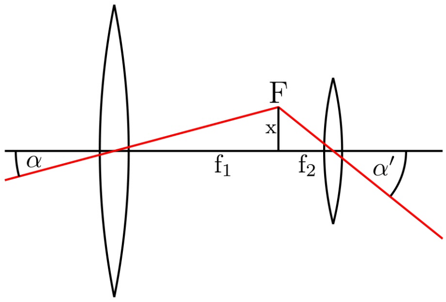
For $\lambda = 560\,\text{nm}$, which corresponds to the maximum sensitivity of the eye, the rule of thumb is:

$$\boxed{\tilde{\alpha}_{\text{Limit}} = 115/D[\text{mm}]} \qquad \text{(theoretical angular resolution)}$$

The definition of the theoretical angular resolution of a telescope given here only takes into account the effects caused by spreading a point source of light into a diffraction disk due to light diffraction at the entrance pupil of the telescope. In astronomical telescopes with a free aperture $D \gtrsim 150\,\text{mm}$, however, the angular resolution is largely determined by directional scintillation caused by turbulent elements in the atmosphere with variable refractive indices, which are subject to strong weather-related fluctuations. The actual resolving power of a telescope can therefore vary from night to night. It can be determined, for example, by observing binary stars with different angular separations. Large ground-based telescopes therefore do not offer any gain in angular resolution without additional aids, but they do offer a gain in the amount of light collected and available for measurements.

3.3 Magnification

When observing visually, the magnification V of the telescope is important. This refers to the ratio of the size of the viewing angles with (α') and without a telescope (α) to a distant object. For small angles, the following applies:



From geometry, it follows that:

$x = \mathrm{f}_1 \cdot \tan\alpha = \mathrm{f}_2 \cdot \tan\alpha' \Rightarrow$

Magnification:

$$V = \frac{\alpha'}{\alpha} \approx \frac{\tan\alpha'}{\tan\alpha} = \frac{\mathrm{f}_1}{\mathrm{f}_2} = \frac{f_{\text{Telescope}}}{f_{\text{Eyepiece}}}$$

Optimal Magnification:
$1 \cdot A_{\text{Eye}} = V_{\text{optimal}} \cdot A$

$A_{\text{Eye}} \approx 2'$, and $A = 1.22 \cdot \frac{\lambda}{D}$ yield at $\lambda = 560\,\text{nm}$:

Optimal Magnification: $$V_{\text{optimal}} = \frac{A_{\text{Eye}}}{A} \approx D[\text{mm}]$$

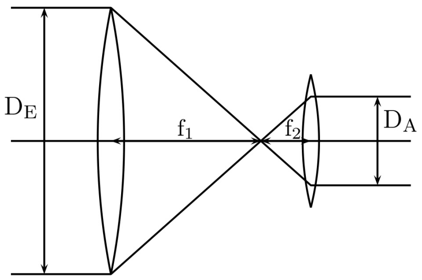
Maximal useful Magnification:
The angular resolution of the telescope is theoretically optimally discernible to the observer if the following applies: $2 \cdot A_{\text{Eye}} = V_{max} \cdot A \Rightarrow$

Maximal useful Magnification: $$V_{max} = 2 \cdot \frac{A_{\text{eye}}}{A} \approx 2 \cdot D[\text{mm}]$$

Minimal useful Magnification:
The maximum pupil diameter of the eye is approximately 6 mm. $\Rightarrow$
$D_A \leqq D_{\text{Eye}}$, otherwise loss of light! $\Rightarrow D_A = \frac{D}{V} \leqq D_{\text{Eye}} \Rightarrow V \geqq \frac{D}{D_{\text{Eye}}} \Rightarrow$

Minimal useful Magnification: $$V_{min} = \frac{D}{D_{\text{Eye}}} \approx \frac{D[\text{mm}]}{6}$$

3.4 Exit Pupil



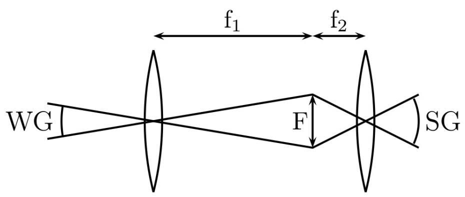
D_E - Entrance Pupil ($D_E = D$)
D_A - Exit Pupil
$\frac{D_E}{f_1} = \frac{D_A}{f_2} \Rightarrow D_A = \frac{f_2}{f_1} D \Rightarrow$

Exit Pupil: $\boxed{D_A = \frac{D}{V}}$

The magnification is therefore equal to the ratio of the size of the entrance pupil D to that of the exit pupil D_A. The exit pupil must not be larger than the pupil diameter of the observer, otherwise light will be lost.

3.5 Field of View Diameter

For visual observation, the field of view diameter of the eyepiece is important, as this defines which objects can still be observed completely in the sky.



- The true field of view WG is the angular diameter of the circular section of the sky that can be viewed with an eyepiece on a telescope.
- The apparent field of view SG of an eyepiece is the angular diameter at which the circular field of view of the eyepiece appears to the observer.

$$\boxed{WG = 2\arctan\frac{F}{2f_1} \quad SG = 2\arctan\frac{F}{2f_2}}$$ (true & apparent field of view)

The true field of view diameter of an eyepiece WG can be determined from measurements of the transit time Δt of a star with declination δ through the field of view of the eyepiece (drift method):

$$\boxed{WG = k_1 \cdot k_2 \cdot cos(\delta) \cdot \Delta t}$$ (true field of view of an eyepiece)

with $k_1 = 360°/24\text{h} = 15°/\text{h} = 15''/\text{s}$.

When measuring the field of view diameter of an eyepiece, one must make sure that the star drifts centrally through the field of view of the eyepiece.

3.6 Limiting magnitude

In visual observations, the apparent brightness of the faintest stars that are just barely visible is referred to as the limiting magnitude. The boost of limiting magnitude $\Delta m = m_{\text{telescope}} - m_{\text{eye}}$ (in mag) when observing point sources of light with a telescope is calculated from the objective aperture D and the diameter D_{eye} of the pupil of the eye based on the relationship between the ratio of radiation fluxes and astronomical magnitudes:

$$\boxed{\Delta m = -5 \cdot \log(D_{\text{Auge}}/D_{\text{Teleskop}})} \qquad \text{(Boost of Limiting Magnitude)}$$

The limiting magnitude of the observer m_{eye} and thus also the limiting magnitude of the stars that can still be detected with a telescope $m_{\text{telescope}}$ can be determined by observing the polar sequence. To do this, once the eyes have fully adapted to the darkness, one observe the constellation Ursa Minoris and identify the faintest stars in it that are still visible to the naked eye.

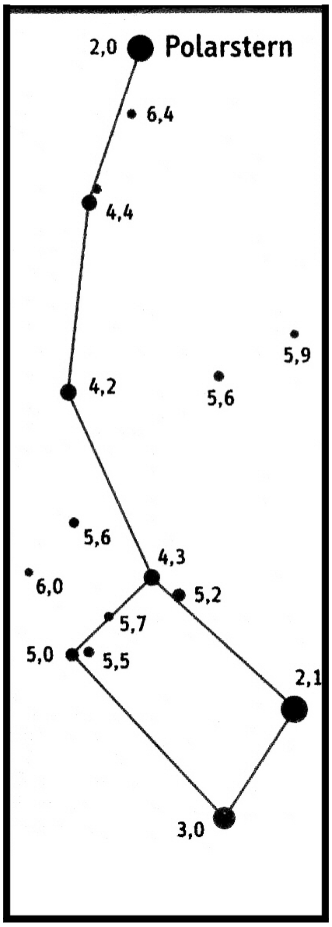


Figure 12: Star map of the polar sequence with the brightest stars in the constellation Ursa Minoris. The apparent magnitudes of the stars are given in magnitudes.

The surface brightness S detected by the receiver plays an important role in the measurement of faint light sources. Here, S is proportional to the telescope aperture and inversely proportional to the area of the image of the light source:

$S \propto D^2/l^2$ where l is the diameter of the image of the light source, for which the following applies:

$$l = f_{\text{telescope}} \cdot \tilde{\alpha} \propto f_{\text{telescope}}/D \quad \Rightarrow \quad S \propto \left(\frac{D}{f_{\text{telescope}}}\right)^2 \cdot D^2$$

For an extended light source with an angular diameter α, the following applies:

$$l = f_{\text{telescope}} \cdot \alpha \quad \Rightarrow \quad S \propto \left(\frac{D}{f_{\text{telescope}}}\right)^2$$

To detect faint, extended objects, one therefore needs the largest possible aperture ratio, whereas to detect faint point light sources, one needs the largest possible telescope aperture.

However, the limiting magnitude also depends on the eye's ability to receive radiation, the brightness of the sky background and scattered light in the telescope, turbulence in the Earth's atmosphere (scintillation), and light loss in the Earth's atmosphere and in the telescope. Since these influences are subject to considerable fluctuations, the actual range of a visually used telescope is not a constant value. It can be determined, among other things, by observing a star field for which a brightness scale exists, defined by a sequence of stars of known apparent brightness. The polar sequence is suitable for this, as are star clusters such as the Pleiades or the Praesepe. It should be noted that the eyes have different sensitivities to different wavelengths. In addition, the spectral sensitivity of the eye during night vision differs from that during daytime vision: red objects appear darker at night, while blue objects appear brighter (Purkinje effect). Stars with different spectral flux distributions are therefore perceived as having different brightnesses even if they have the same bolometric brightness. The visual limiting magnitude therefore also depends on the spectral type of the stars being observed.

The human eye adapts from dark to light in just three minutes, but complete dark adaptation takes around an hour. Before determining the limiting magnitude, make sure that no bright light sources are visible. It is best to go into a dark room before observing the polar sequence and wait there for at least 15 minutes before making the observations. The impression of brightness during observation can be increased by not looking directly at objects, but rather looking slightly past them (indirect vision). This is because the density of the rods, which enable vision in low light conditions, is slightly lower in the fovea (towards the optical axis of the eye) than in the peripheral area of the retina. The accuracy that can be achieved when visually comparing the brightness of two light sources depends on their surface area. For extended light sources, an accuracy of ca. ± 0.02 mag can be achieved, and for point light sources, approximately ± 0.2 mag.

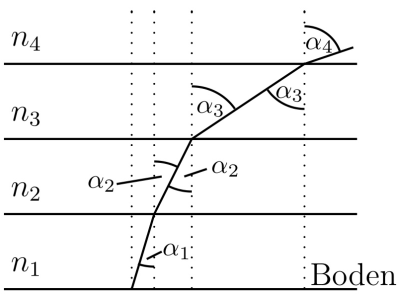
4 Atmospheric Refraction

An electromagnetic wave is refracted at the boundary layer between two media with different refractive indices n. For the angle of incidence α_1 in the medium with refractive index n_1 and the angle of the refracted light beam α_2 in the medium with refractive index n_2, the following applies:

$$\boxed{n_1 \cdot \sin\alpha_1 = n_2 \cdot \sin\alpha_2} \qquad \text{(Snellius equation)}$$

The angles α_i are measured by the light beam in the media relative to the perpendicular to the boundary surface. Since the density of the atmosphere ρ decreases with altitude h according to the barometric formula ($\rho = \rho_0 \cdot e^{-h/H}$), the refractive index of air also decreases with altitude $n\,(\text{ground}) > n\,(\text{space}) = 1 \Rightarrow$ a light ray incident from space is refracted in the atmosphere (refraction).

Calculation of refraction for small zenith angles $z_S \leq 45°$ using the plane-parallel atmospheric model:



$$n_1 \cdot \sin\alpha_1 = n_2 \cdot \sin\alpha_2$$
$$n_2 \cdot \sin\alpha_2 = n_3 \cdot \sin\alpha_3$$
$$n_3 \cdot \sin\alpha_3 = n_4 \cdot \sin\alpha_4$$
$$\vdots$$
$$\Rightarrow n_1 \cdot \sin\alpha_1 = n_\infty \cdot \sin\alpha_\infty = \sin\alpha_\infty$$

α_1: apparent zenith angle z_S
α_∞: true zenith angle z

$\Rightarrow n \cdot \sin z_S = \sin z$ and $z > z_S$

with $z = R + z_S$ and R the angle of refraction or Refraction for short

$\Rightarrow n \cdot \sin z_S = \sin(R + z_S)$

and addition theorems yield: $n \cdot \sin z_S = \sin z_S \cdot \cos R + \cos z_S \cdot \sin R$
if z is small, also R is small $\Rightarrow n \cdot \sin z_S \approx \sin z_S + \cos z_S \cdot R \Rightarrow$

$$\boxed{R = (n-1) \cdot \tan z_S} \qquad \text{(Refraction in radians)}$$

For air, the following applies at air pressure P and temperature T:

$$\boxed{n - 1 = a\,(\lambda) \cdot \frac{P}{T} \cdot \frac{T_0}{P_0}}$$

with the standard conditions: $P_0 = 1013.25\,\text{hPa}$ and $T_0 = 273.15\,\text{K}$

$$\boxed{a\left(\lambda\right) = 2.876 \cdot 10^{-4} + 1.629 \cdot 10^{-6} \cdot \lambda^{-2} + 1.36 \cdot 10^{-8} \cdot \lambda^{-4}} \quad (\lambda \text{ in } \mu\text{m})$$

$a\left(\lambda\right)$ becomes smaller as the wavelength λ increases $\Rightarrow$ refraction R decreases with wavelength $\Rightarrow$ dispersion of the Earth's atmosphere (particularly strong at large zenith angles z).

The refraction at large zenith angles is calculated using the spherical shell atmosphere model. In this model, the Earth's atmosphere is composed of an infinite number of spherical shells of infinitesimal thickness, resulting in:

$$\boxed{R = K_1 \cdot \tan z_S - K_2 \tan^3 z_S + ...}$$

For $45^\circ < z_S \leq 75^\circ$ under normal conditions in the visible spectral range ($\lambda = 560$ nm), the following applies:

$$\boxed{R = 60.39'' \cdot \tan z_S - 0.07'' \tan^3 z_S}$$

For even greater zenith distances, higher-order series terms must also be taken into account. At the horizon, the following applies in the visible range: $R \approx 0.5^\circ$. By measuring the apparent zenith distance z_S of a celestial body and comparing it with its calculated true zenith distance z at the time of observation, the refraction curve $R(z)$ can be determined.

The altitude of the stars is measured with a theodolite at meridian passage in southerly direction. A theodolite is an instrument for measuring horizontal and vertical angles (if it is suitable for measuring both angles, it is also referred to as a universal instrument). This makes the theodolite ideal for measuring the coordinates of the horizon system (azimuth, altitude). To determine the apparent changes in the zenith distances of points on the apparent celestial sphere caused by refraction, so-called second theodolites are required, which, as their name suggests, have a measuring accuracy of $\pm 1''$. In principle, a theodolite consists of a fixed lower part (essentially: tripod and horizontal circle) and a rotating upper part (essentially: telescope and vertical circle).

5 Experiment Procedure

5.1 North Alignment of the Telementor

To align the hour axis of the parallactic mount of the Telementor telescope parallel to the Earth's axis of rotation (north alignment), the telescope is first focused using the 40 mm Huygens eyepiece. The hour axis of the mount is then roughly aligned to the north and the polar height of the observation site is roughly adjusted. Now the mount is levelled using the bubble level installed on it. In the next step, the hour angle of the North Star (α UMi) is calculated at the time of observation. By loosening the clamp on the hour axis, the hour angle is set and the axis is then clamped again. The declination of Polaris is adjusted by loosening the declination axis clamp and then clamping the axis again. Next, the clamps on the mount's polar height and azimuth axes are loosened and Polaris is centered in the crosshairs of the 40 mm Huygens eyepiece. Once Polaris is in the center of the eyepiece's crosshairs, the two axes of the mount are clamped again. The Telementor mount is now north aligned and nighttime observation can begin.

5.2 Tasks

1. Determine the field of view diameter of all eyepieces with the drift method.
2. Determine the Telementor's angular resolution by observing double stars.
3. Measure the angular distance between two stars using the Telementor.
4. Observe the sun (if possible before sunset), the moon, all planets, and other bright objects visible in the sky.
5. Make drawings of all observed objects and record the most important characteristics of these objects that you recognized during observation with the Telementor.
6. Determine the limiting magnitude m_{eye} by observing the polar sequence and use it to calculate the limiting magnitude $m_{\text{telescope}}$ of the Telementor.

Name	RA	Dec	Epoch	sep	M_1	M_2
	hh mm ss	dd mm ss		$''$	mag	mag
δ Cephei	22 29 10	+58 24 55	2009	40.8	4.2	6.1
β Cygni	19 30 43	+27 57 35	2009	34.6	3.2	4.7
ψ Draconis	17 41 56	+72 08 58	2009	30.0	4.6	5.6
α Ursae Minoris	02 31 47	+89 15 51	2009	18.2	2.1	9.1
ζ Ursae Majoris	13 23 55	+54 55 32	2009	14.3	2.2	3.9
η Cassiopeiae	00 49 05	+57 49 00	2009	13.1	3.5	7.4
γ Andromedae	02 03 54	+42 19 48	2009	9.5	2.3	5.0
ξ Cephei	22 03 47	+64 37 40	2009	7.9	4.5	6.4
γ Arietis	01 53 32	+19 17 39	2010	7.5	4.5	4.6
α Geminorum	07 34 36	+31 53 19	2010	4.7	1.9	3.0
γ Leonis	10 19 58	+19 50 31	2010	4.7	2.4	3.6
ρ Herculis	17 23 41	+37 08 45	2009	4.5	4.5	5.4
ι Trinaguli	02 12 22	+30 18 11	2009	3.8	5.3	6.7
ϵ Draconis	19 48 10	+70 16 05	2007	3.1	4.0	6.9
ϵ^2 Lyrae	18 44 23	+39 36 46	2010	2.4	5.3	5.4
ϵ^1 Lyrae	18 44 20	+39 40 12	2010	2.3	5.2	6.1

Table 4: List of double stars for the determination of the angular resolution.

5.3 Review Questions

1. Use a sketch to explain how the relationship for the true field of view of an eyepiece is derived: $WG = k_1 \cdot k_2 \cdot cos(\delta) \cdot \Delta t$. Then give the numerical value for k_2 to four decimal places.

2. What is the magnification of the eyepieces used with the Telementor?

3. What determines the limiting magnitude of a telescope?

4. How do Huygens eyepieces differ from orthoscopic eyepieces?

5. What is the angular resolution of a telescope and what determines it?

6. Explain the term "optimal magnification" and derive the minimum and maximum useful eyepiece focal length (in mm) for the Telementor.

7. In which constellations are the bright planets at the time of observation?

8. In which constellation are the observation conditions most favorable for an inner or outer planet?

9. What is an open cluster and what is a globular cluster?

10. What is the difference between emission and extragalactic nebulae?

11. What is the "obliquity of the ecliptic"?

12. Why is the south direction preferred for altitude measurement when determining the refraction curve?

13. How do pressure and temperature influence the refraction?

14. Under what conditions does the formula $R = 60.3'' \cdot \tan z_S$ apply?

15. How does the refraction curve affect the time and appearance of sunrise and sunset?

16. How can the phenomenon of the "green flash" of the sun shortly before sunrise or sunset be explained?

5.4 Equipment and Tools

- Telementor (Fraunhofer achromat with $D = 63$ mm, $f/D = 13.\overline{3}$)
- German mount including counterweight, tripod, and storage plate
- 40 mm Huygens eyepiece with crosshairs, 25 mm Huygens eyepiece, and 16 mm orthoscopic eyepiece with rotating crosshairs
- Solar projection screen
- Allen key for adjusting the polar height
- Transport box with carrying straps
- Rotatable star chart

For nighttime observation, in addition to warm clothing, one should also bring a smartphone with a stopwatch and red light app installed.

Figure 13: The Telementor telescope used in this experiment.