Volume

1

INTRODUCTION TO ASTRONOMY

Astronomical Coordinates, Distances and Magnitudes

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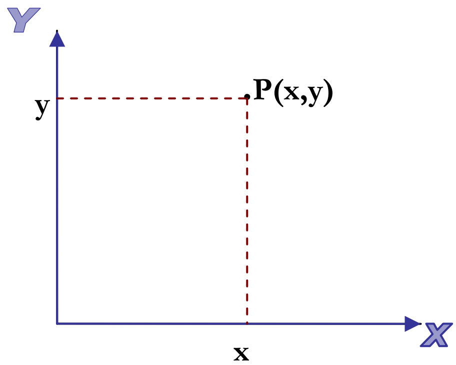
1

Reference Systems

Cartesian and Spherical Polar Systems of Reference

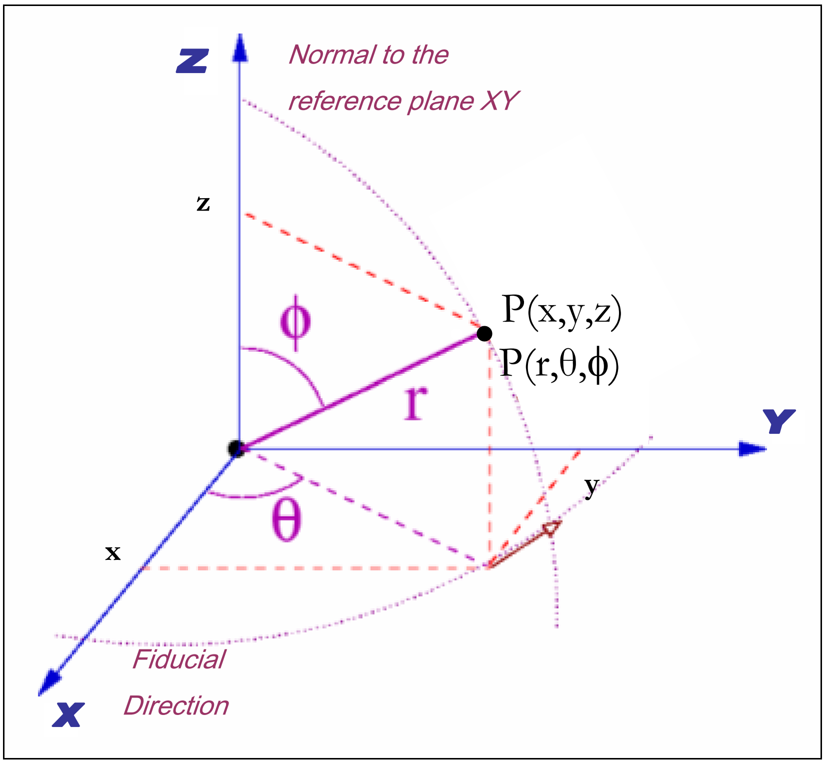
In order to locate the position of a point or to determine distances between points, it is necessary to define a Reference System (RS). Maps are the most common examples.

The two-dimensional Cartesian RS is the first defined in Spanish Schools. Two perpendicular axes, XY, and a unit of length are defined. The coordinates of any point are obtained by projecting the position of the point on the axes.



The 2D Cartesian System is the easiest to introduce and can be naturally extended into 3D with axes XYZ. The definition of coordinates through normal projections is easy: besides, each of the coordinates gives information about the ***distance*** *to the corresponding axis. For this reason, this reference system is not suitable for defining the location of objects without knowing their distance to the centre of the RS; this is the case of most of the astronomical sources.*

Polar Reference Systems (RSs) are the most natural systems to define the position of a point located at an unknown distance. These are natural systems used since childhood to point towards something; the easiest version is to use the ground as a reference plane and mark the location of an object by its "elevation" above that plane and the angle between the line-of-sight to the object and some fiducial direction as, for instance, the corner of the room or the tower of the church. The abstraction of this natural SR is named the *Spherical Polar System.* The position of a point is given by three coordinates: two angles (ϕ,θ) and a distance (r) as shown in the figure. The geographical (geographical latitude and longitude) and the astronomical RSs are Spherical Polar systems. The differences between the various astronomical RSs are marked by the spatial orientation of the reference plane (or the direction perpendicular to it also as polar axis in the astronomical context) and the orientation of the fiducial direction in the reference plane.



The relationship between the Cartesian and the Spherical Polar coordinates is derived from the figure:

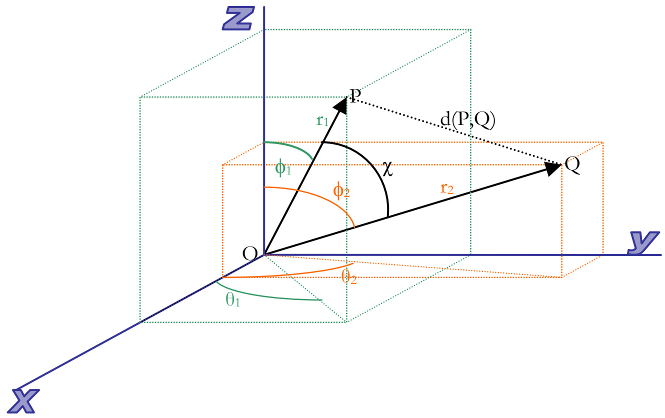
$$x = r \sin\phi \cos\theta$$
$$y = r \sin\phi \sin\theta$$
$$z = r \cos\phi$$

Once the spherical polar coordinates of two points are known $P(r_1, \theta_1, \phi_1)$ y $Q(r_2, \theta_2, \phi_2)$ the distance between them can be calculated by:

– Transforming Spherical to Cartesian coordinates and using the expression :

$$d(P,Q) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

– Using the cosine formula of plane trigonometry and applying it to the triangle OPQ [1]



The main astronomical RSs are classified by:

– *the fundamental plane* in: alt-azimutals, equatorials, ecliptics...

– *the location of the centre* in: topocentrics, geocentrics, heliocentrics, baricentrics...

Fundamental Planes

Fundamental planes are defined as follows:

Celestial Horizon: plane perpendicular to direction of the Earth gravity field[2] at the location of the observer.

Celestial Equator:: plane perpendicular to the axis of rotation of the Earth.

Ecliptic: plane which contains the orbit of the Earth around the Sun..

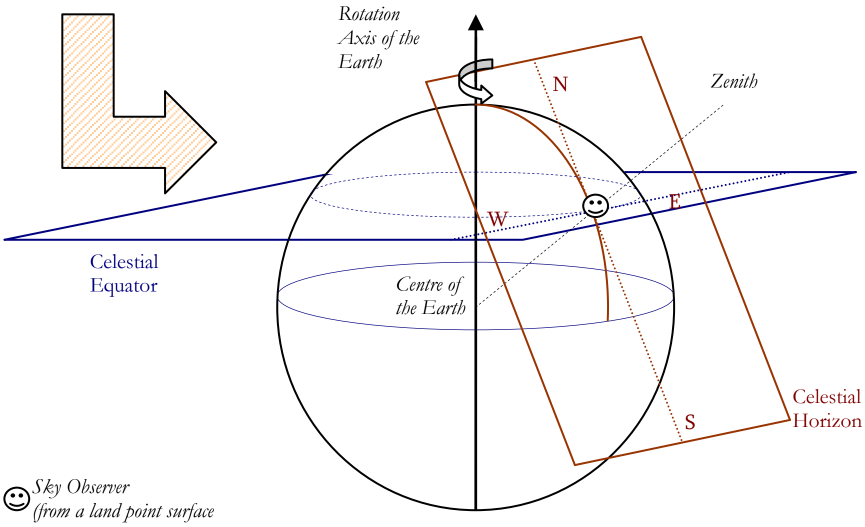
The Celestial Horizon depends on the location of the observer on the Earth's surface, and roughly coincides with the plane tangent to the figure of the Earth[3] at the

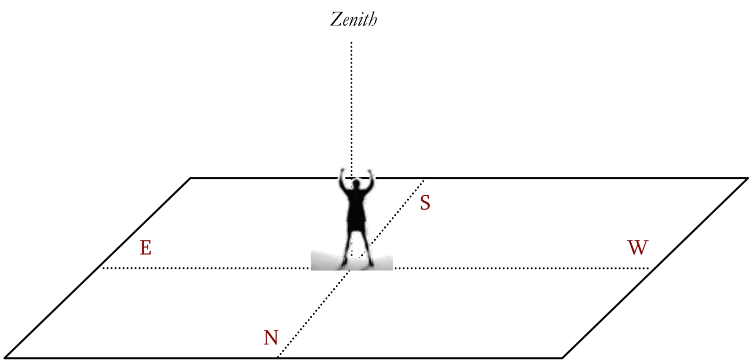
[1] Note that application of this formula requires the angle between $\mathbf{r_1}$ and $\mathbf{r_2}$ **to be calculated,** χ**,** this can be shown to be, $\cos\chi = \cos\phi_1\,\cos\phi_2 + \sin\phi_1\,\sin\phi_2\,\cos(\theta_2 - \theta_1)$, from spherical trigonometry.

[2] This direction is often marked with a plumb and it is also known as the plumb line or the astronomical vertical.

[3] The figure of the Earth is close to an ellipsoid of revolution.

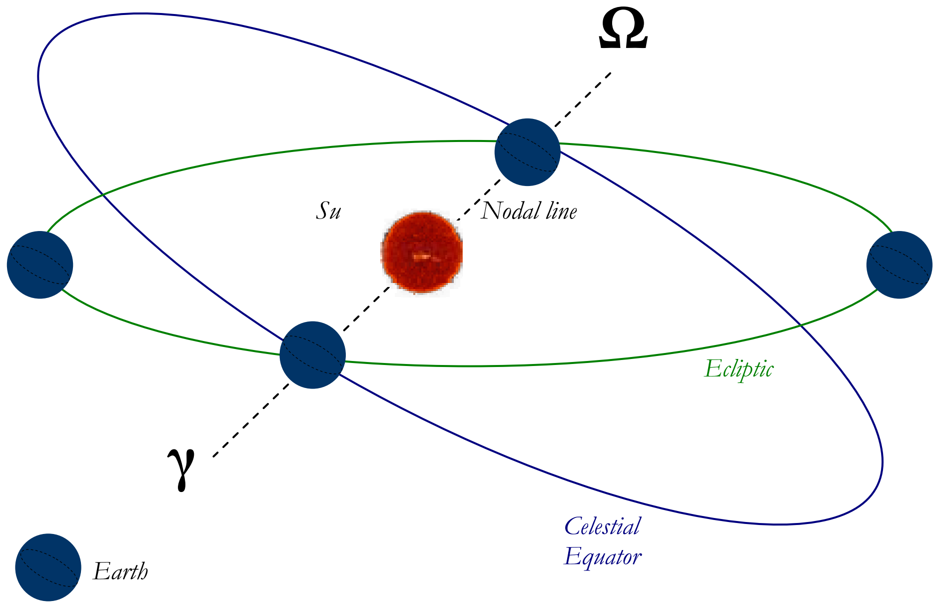
observer location. The four cardinal points (North-South-East-West) are defined by the projection on the *Horizon* of the local "parallel" and "meridian" as shown in the figure:





All RSs using the celestial horizon or the zenith to define either the reference plane or the fiducial direction on that plane, are tight to the surface of the Earth, and thus, rotate with it. The apparent motion of the Sun during the day and the stars during the night (east to west) just indicates that we, as observers of the sky, are bound to the surface of a rotating body: the Earth. The "true" motions of the stars are not appreciable at first sight.

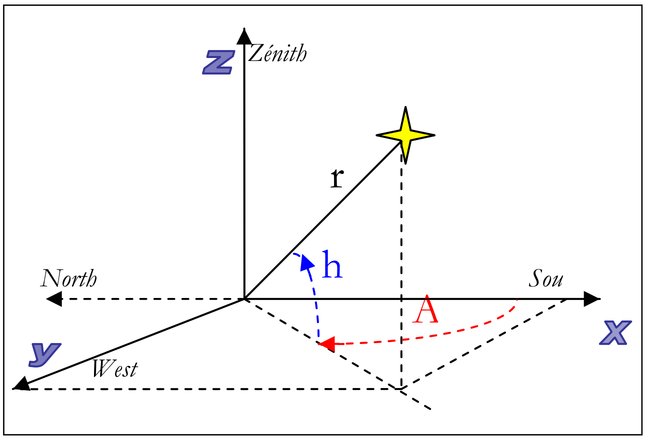
Thus, it is necessary to define a *non-rotating* SR to assign coordinates to the astronomical bodies that can be used for their identification. A new reference plane is introduced for this purpose: the ecliptic plane. The intersection between the ecliptic and the celestial equator defines a straight line which is used as a *fiducial* direction in the non-rotating SRs. This straight line is named the *nodal line* and points in two well known directions in space: the Aries (γ) and Libra (Ω)[4] constellations, marking the equinoxes.



Alt-Azimutal Reference System

The XY plane is the celestial horizon at the observer location and the polar axis (axis Z) points to the zenith. On the XY plane, the fiducial direction points to the south and the angles are measured from south to west. The alt-azimutal coordinates are two angles: Azimut (A) and Height (h). The relation between Cartesian and the alt-azimutal coordinates is:

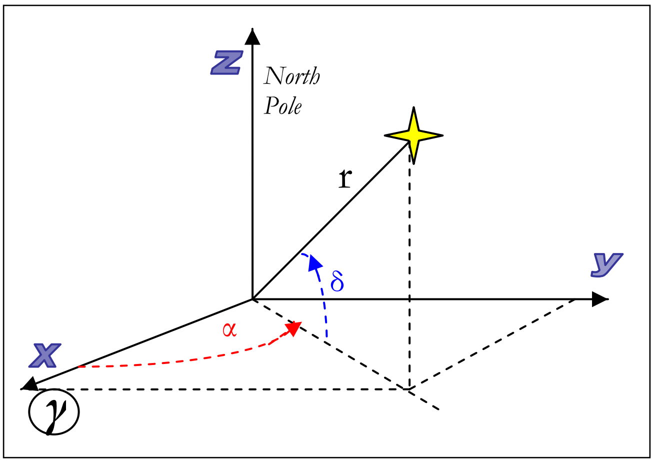
[4] In reality, neither the equator nor the ecliptic are fixed. The axis of rotation of the Earth changes direction in space due to the internal structure of the Earth and the gravitational interaction with the Sun, the Moon and other bodies in the Solar system. The orbit of the Earth is also slightly variable because of the action of other bodies in the Solar system. This problem is solved by determining the date or *epoch* to which the ecliptic and the equator used correspond.



$$x = r \cos h \cos A$$
$$y = r \cos h \sin A$$
$$z = r \sin h$$

(Absolute) Equatorial Reference System

The plane XY is the celestial equator (the plane parallel to the equator of the Earth passing through the observer location), and the polar axis (axis Z) points to the North celestial Pole. The fiducial direction in the XY plane is marked by γ and angles are measured in the sense of Earth rotation (towards the East). The absolute equatorial astronomic coordinates are: Right Ascension(α) and Declination(δ). The relationship between the Cartesian coordinates and the equatorial coordinates is:



$$x = r \cos\delta \cos\alpha$$
$$y = r \cos\delta \sin\alpha$$
$$z = r \sin\delta$$

The Absolute Equatorial system is used, by default, to search and identify the astronomical sources. For instance, all exoplanetary systems in Appendix 1 are identified by one pair (α, δ) and one epoch[5], which fixes the orientation of the equinox. These coordinates are used in the application "*The smart space traveller*" to represent the location of the known planetary systems.

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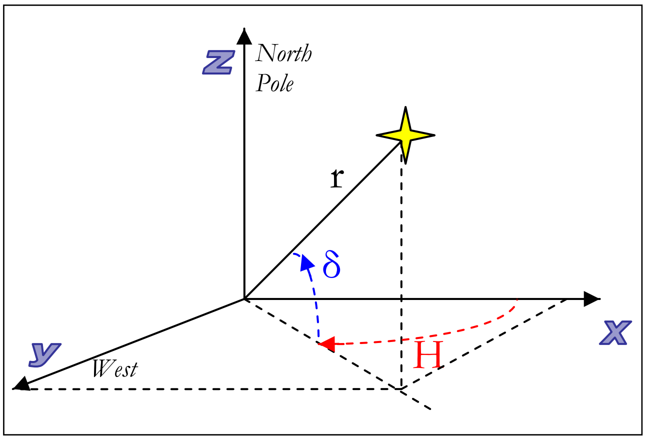
[5] The epoch is defined by its Julian date. Standard epochs were 1950.0 and 2000.0; the decimals indicate the fraction of the year passed since the beginning of the years of reference 1950 or 2000..

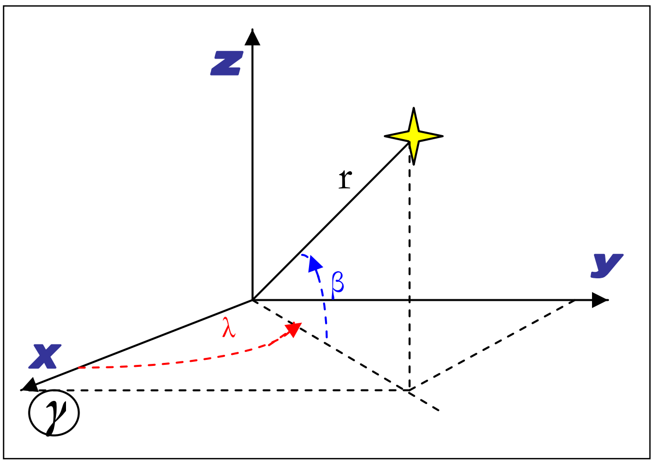
Notice that the alt-azimutal system is the simplest for an observer situated on Earth (that is, in rotation) while the (absolute) equatorial system is the most suitable to render the coordinates of the astronomical sources; and an additional system is defined in between the two[6] that has a fundamental plane, the celestial equator but uses as fiducial direction the "projection of the south" as marked in the figure and, henceforth, it is tight to the Earth rotation.. The angles are measured from the X axis X, in a counter Earth rotation direction (i.e., following the apparent movement of the stars from east to west). The ("hour") equatorial astronomic coordinates of a star in this system are: Hour Angle (H) and Declination(δ). The relationship between the Cartesian coordinates and the ("hour") Equatorial coordinates is:



$$x = r \cos\delta \cos H$$
$$y = r \cos\delta \sin H$$
$$z = r \sin\delta$$

Ecliptic System of Reference

Plane XY coincides with the ecliptic: the plane containing the orbit of the Earth around the Sun. The polar axis (axis Z) points to the north pole of the ecliptic. On this plane XY, the angles are measured from a point γ toward the East (in the direction of the Earth rotation and orbital motion). The ecliptic astronomical coordinates are given by two angles: Ecliptic Longitude (λ) and Ecliptic Latitude. The relationship between the Cartesian and ecliptic coordinates is:



$$x = r \cos\beta \cos\lambda$$
$$y = r \cos\beta \sin\lambda$$
$$z = r \sin\beta$$

[6] In the Spanish tradition this system is named: "Sistema Ecuatorial Horario" or "Hour-angle based equatorial system"

This RS is useful to follow the apparent motion of the Sun (due to the Earth orbital motion) and the planets and asteroids (since their orbital planes are very close to the ecliptic). This system is used in the application *"The Solar sailing Ship"*.

SUMMARY OF THIS CHAPTER

Astronomic coordinates are spherical polar coordinates: the location of an astronomical source is marked by two angles because distance is frequently unknown.

Four fundamental systems are used:

Name	*Fundamental Plane*	*Bound to Earth rotation*	*Coordinates*
Alt-Azimutal	*Horizon*	*Yes*	*Height (h)* *Azimut (A)*
Equatorial (absolute)	*Celestial Equator*	*No*	*Declination (δ)* *Right Ascension (a)*
Equatorial (hour-angle)	*Celestial Equator*	*Yes*	*Declinación (δ)* *Hour Angle (H)*
Ecliptic	*Ecliptic*	*No*	*Ecl. Longitude (λ)* *Ecl. Latitude. (β)*

Distances between the stars are calculated in a simple manner, transforming these coordinates into Cartesian coordinates and using the formula:

$$d(P,Q)=\sqrt{(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2}$$

Chapter

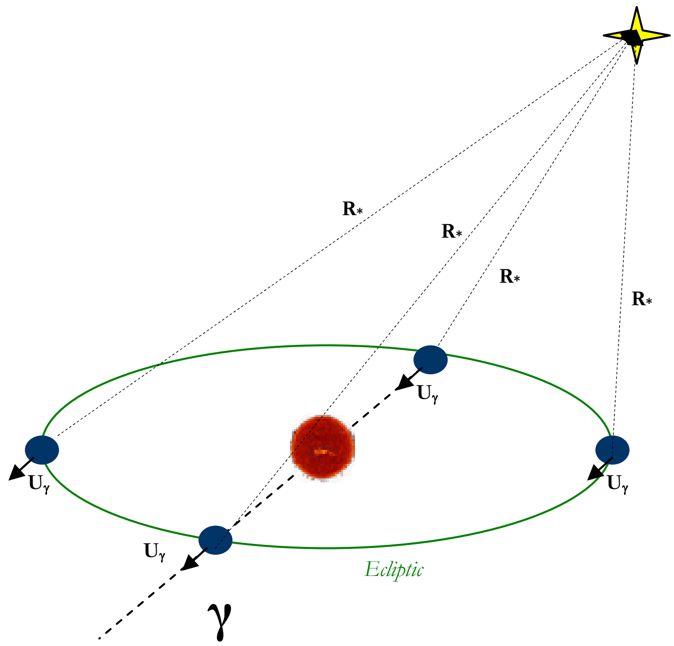
2

Distances and Magnitudes

The basic unit of distance in Astronomy is the Astronomical Unit (AU) or semi-major axis of the orbit of the Earth: an ellipse with eccentricity 0.0167. This distance corresponds to:

$$1\ \mathrm{AU} = 1.49 \cdot 10^{13}\ \mathrm{cm}$$

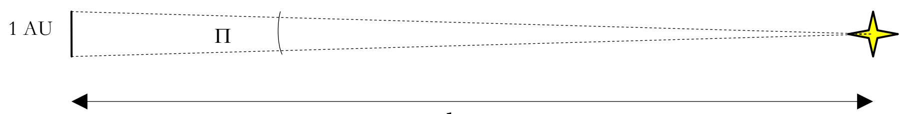
The basis of the measurement of distances of the stars is the parallax[7], as indicated in the figure:



Let us use **γ** as fiducial direction as indicated by the unit vector **Uγ** in the figure, the projection of the stellar radio-vector in this direction changes as the Earth moves in its orbit. This projection also depends on the distance to the star: it is very large for nearby sources (like the one in the figure) and tiny for very distant objects and thus can be used to determine distances. This method is limited by the accuracy of the

[7] This method is analogous to that used by our brain to infer distances to objects using as reference two simultaneous observations with two detectors slightly separated one from the other: the eyes.

measurement of the angles. For many years, this limit has been around 1" (or 0.º0002777 or 4.84814 $\cdot 10^{-6}$ rad). This led to the definition of a new unit of distance: the *Parsec* (pc), which is the distance at which "the parallax" is 1" . Graphically, the parallax of a star Π is,



As distances to stars are far greater than the distance to the Sun (1 AU), the segment drawn in the figure is practically equal to the arc subtended by the angle Π on a circumference of radio d,

$$1 \text{ AU} = \Pi \, d$$

if Π is given in arcseconds,

$$d = 3.07 \cdot 10^{18} \text{ cm} / \Pi (")$$

Therefore, if Π (") = 1", the distance, d, to the star is $3.07 \cdot 10^{18}$ cm. This distance is named parsec (pc), so

$$1 \text{ pc} = 3.07 \cdot 10^{18} \text{ cm} = 2.06 \cdot 10^{5} \text{ AU}$$

Usually, distances to stars are given either in parsecs or by providing the parallax directly. The unit "light-year" is not frequently used. The relationship between light-years and parsec is:

1 light-year = c*(1 year) = ($3 \cdot 10^{10}$ cm/s) (365.25*24*3600 s) = $9.3 \cdot 10^{17}$ cm = 0.30 pc

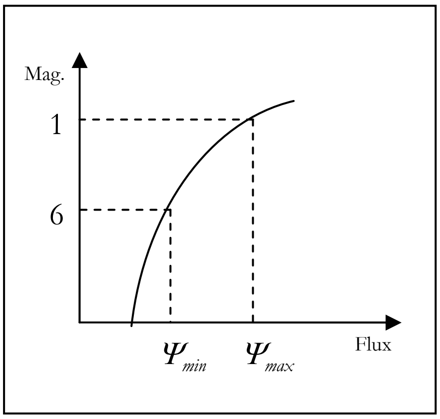
Stars seen in the sky with the naked eye are at distances of between 1 pc and 2,000 pc (for example, Deneb, α-Cygnus is around 450 pc from the Earth)

Astronomical Magnitudes

99.9% of the information about stars is obtained from the energy that they radiate. Stars emit electromagnetic radiation and this radiation carries information about their structure, composition, velocity, etc. Most of this information is obtained through the analysis of the energy distribution, i.e., the flux of radiation from the star detected on Earth at each wavelength. The flux is defined as the amount of energy received per unit of surface (normal to the direction of propagation) and per unit of time.

All of these concepts (radiative flux, electromagnetic waves, wavelength) were defined much later than when stars were first observed by human beings and Astronomy was born. In Ancient Greece, the flux from stars was "determined" in astronomical magnitudes[8]; this name derives from Hipparcos who classified the stars in 6 types of magnitudes according to their brightness. The most brilliant stars in the night sky were classified as first magnitude stars while the weakest, that could be barely observed with the naked eye, were classified as sixth magnitude stars (for example, the two weakest stars of the Pleiades).

Therefore, to determine the relation between astronomical magnitudes (m) and the flux (Ψ), one must take into account the response of the human eye to the radiation. The human eye has a logarithmic response and works between two thresholds: the low threshold, Ψ_{min} (no radiation is detected below it) and the high threshold, Ψ_{max} (above it eyes are dazzled); roughly $\Psi_{max}=100\Psi_{min}$.



Therefore,

[1] $m = k\ log(\Psi)+C$

[2] $1 = k log(\Psi_{max}),\ \ 6=k log(\Psi_{min})$

accordingly, $k=-2.5$, and

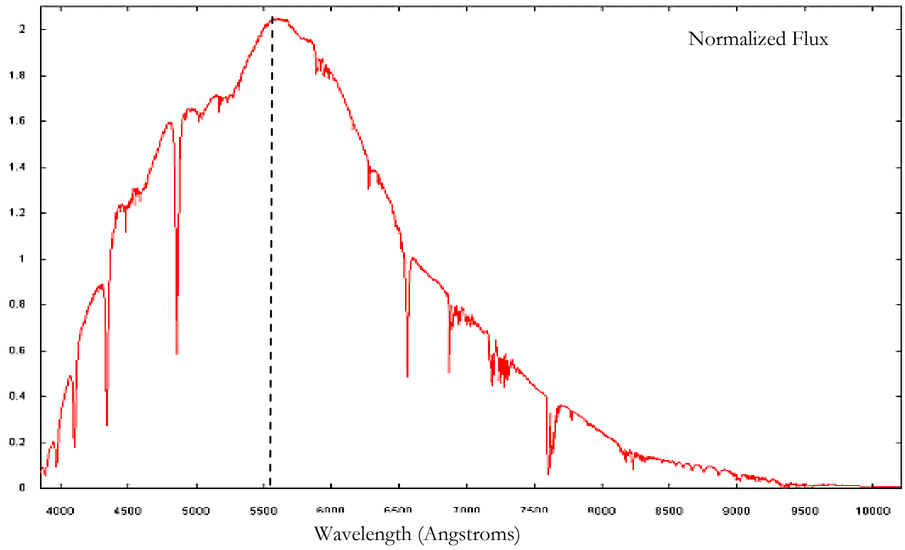
$m = -2.5\ log\ (\Psi) + C$, or,

$m_1\text{-}m_2 = -2.5\ log\ (\Psi_1/\ \Psi_2)$

"C" is fixed with the flux of the star Vega (α Lyrae), so that,

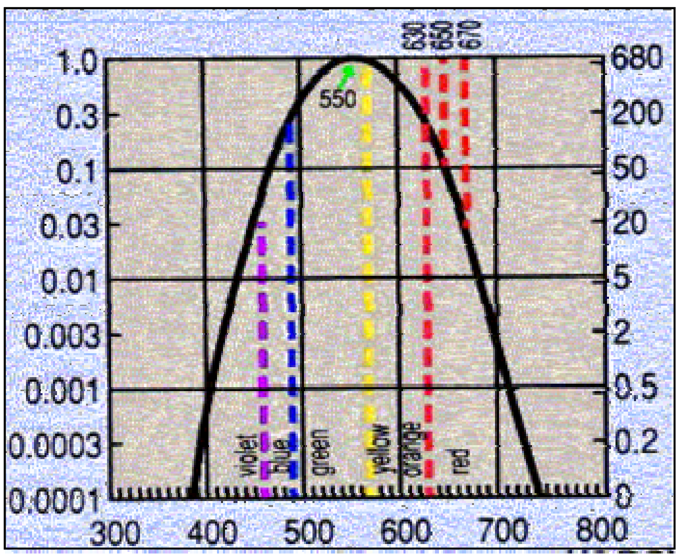
$$m(\alpha\ \text{Lyrae}) = 0\ \text{, or, }\ C = 2.5\ log\ (\Psi\ (\alpha\ \text{Lyrae}))$$

[8] The use of the term "astronomical magnitude" may lead to confusion, as it does not represent a generic physical magnitude, rather a very specific magnitude: flux of energy.



The energy distribution of α Lyrae is represented in the figure[9]. To determine the value of the constant *C*, it is necessary to integrate the product of the distribution of energy of Vega with the response of the human eye. The human eye detects (and the brain interprets) radiation between two wavelengths: from some 3900Å to 7500Å. The brain codifies the radiation received at 3900Å as colour violet, and that received at 7500Å as red; the rest of the rainbow colours are between these two limits.

Sensitivity of the human eye



Wavelength in Angstroms/10

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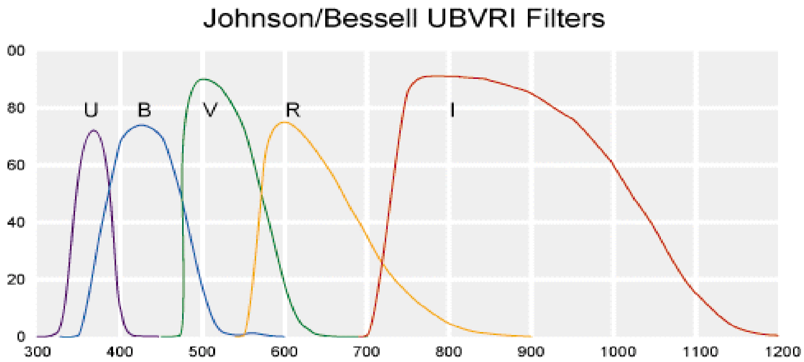
[9] Vega flux is $3.44 \cdot 10^{-9}$ erg/s/cm^2/Å at 5556 Å, the peak of the energy distribution (1 Å or Angstrom=10^{-8} cm)

In addition to these "visual" magnitudes, the same scaling has been applied to other more specific astronomical measurements intended to determine the "colours" of the stars. The most widely used is the Johnson System that makes use of 5 filters: U,B,V,R and I, which are represented in the figure,



Wavelength in Angstroms/10

Percentage of incident flux transmitted by the filter versus wavelength.

If the sky is observed through one of these filters only the flux transmitted through it will be detected. These allows defining a new set of magnitudes (U,B,V,R,I). Most of the stellar catalogues used for educational purposes indicate the V magnitude of the stars since this is the closest to the eye response (compare with the previous figure).

Absolute Magnitudes

Absolute magnitudes are introduced to take into account the effect of the distance to the stars. The *"apparent magnitudes"* described above are very small (close to 1) if an object is very bright in the night sky however they do not indicate whether the source is very bright or it is very close to us[10].

[10] A very brilliant object located very far away is apparently weaker in the night sky than a weaker but closer object

Absolute magnitudes (M) are defined as the apparent magnitudes of the astronomical sources if they are at 10 parsec from the Earth. The relation between apparent and absolute magnitudes is given:

$$m - M = 5 \log(d) - 5$$

where d is the distance to the star expressed in pc. The second member of this equation is named the "*distance modulus*".

SUMMARY OF THE CHAPTER

The basic units of distance in Astronomy are:

Astronomical Unit (AU) = $1.49\cdot 10^{13}$ *cm*

Parsec (pc) = $3.07\cdot 10^{18}$ *cm*

The distance to a star (in pc) is the same as the inverse of its parallax expressed in arcseconds.

Astronomical magnitudes measure the flux of energy received from the stars. This logarithmic scale is introduced because the first classifications of the stars were made using the human eye as detector.

Vega is the primary star used in the calibration of magnitude systems.

The relationship between apparent magnitudes of two stars is given by:

$$m_1 - m_2 = -2.5 \log (\Psi_1 / \Psi_2)$$

where m_1, m_2 *are the apparent magnitudes of the stars, and* Ψ_1 *and* Ψ_2 *the fluxes of radiation received from them on Earth.*

There are different scales of apparent magnitudes: visual magnitude, the Johnson System, etc…

The absolute magnitude(M) of a star is defined as the apparent magnitude (m) if it were at a distance of 10 pc:

$$m - M = 5 \log(d) - 5$$

where d is the distance to the star in pc.

Chapter 4

Radiation Pressure

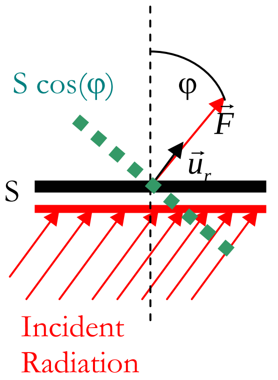
Stars are sources of radiation. Radiation is composed of particles named photons which, on striking a body, push it forwards, i.e. along the path they follow. In the same way that a ball pushes any object it strikes, photons push the material they collide with.

The pressure exerted by radiation on the surface it illuminates depends on the flux of incident radiation, **Ψ**,

$$P_{rad} = \frac{\Psi}{c}$$

and the net force, **F**, exerted by the radiation upon a given flat surface, **S**, is

$$\vec{F} = P_{rad} S \cos\varphi \cdot \vec{u}_r$$



where:

φ: represents the angle between the perpendicular to the surface and the direction of incidence of the radiation.

S cos(φ): the effective surface against radiation.

$\vec{u}_r$: is a unit vector in the direction of incidence.

Application to space missions

The application *"The solar sailing ship"* makes use of the Solar radiation pressure to provide the thrust for space navigation within the Solar System. To calculate the thrust we have used the same formulation and parameters used to compute the effect of solar radiation pressure in the Solar Panels of the Space probes.

Spacecraft carry solar panels that provide electric power to keep the instrumentation inside working . They are particularly sensitive to the effect of radiation pressure given their large surface. As most of the space probes are near the Earth's orbit, the radiation pressure is usually given in terms of the solar flux at the Earth's orbit.

The flux of radiation decreases with the square of the distance to the source[11], thus the solar flux to a distance (r) from the Sun, is:

$$\Psi(r) = \frac{\Gamma_0}{r^2} = \Psi_\oplus \frac{r_\oplus^{\ 2}}{r^2}$$

where, $\Gamma_0 = \Psi_\oplus r_\oplus^{\ 2}$, represents the total energy carried by the solar radiation (e.g., emitted by the Sun) per unit of time, measured from the flux of solar radiation detected in the orbit of the Earth[12], $\Psi_\oplus$.

Then, the force exerted by the solar radiation per unit of mass, $\vec{F}_\Theta$, is:

$$\vec{F}_\Theta = \frac{\Re \cdot S \cdot \cos(\varphi)}{m} P_\oplus \left(\frac{r_\oplus}{r}\right)^2$$

with:

- $\Re$ a constant between 0 and 1 measuring the efficiency of the material to capture solar radiation. $\Re = 1$ indicates that all of the radiation flux is contributing to accelerate the ship.
- ***S cos(φ)*** is the surface of the satellite projected in the direction of incidence.
- ***m*** is the mass of the satellite.
- $P_\oplus$ is the solar pressure in the Earth's orbit.
- $r_\oplus$ is the distance Earth-Sun.
- ***r*** is the distance between the satellite and the Sun..

The term $\left(\frac{r_\oplus}{r}\right)^2$ represents the geometric dilution of solar radiation pressure.

Therefore, for a surface of a given material and satellite mass, the thrust communicated by the solar radiation is constant, unless the orientation of the

[11] Flux is the radiation that passes through the unit of surface in a unit of time. Since the total energy radiated by a star in space is conserved (in the absence of intervening sources or sinks of radiation), the product $4\pi d^2\Psi(d)$ is a constant.: "The integration of all the flux radiated by a star is a constant.". For example, the flux of radiation that arrives from the Sun to the orbit of Mercury is much greater than that which arrives at the Earth's orbit because the Earth is farther away. However, if we drew an imaginary sphere centred in the Sun with a radius of the orbit of Mercury and we multiplied the flux of radiation in the orbit of Mercury by the surface of the sphere, we would obtain the total energy radiated by the Sun per unit of time. The value obtained would be the same if this calculation was repeated at the Earth's orbit because between the Earth and Mercury, there are no clouds that absorb radiation from the Sun.

[12] By stereoradian,e.g., divided by 4π

“acting surface” (solar panels, sails...) is changed with respect to the Sun. Thus, $\vec{F}_{P\Theta}$, is usually represented as:

$$\vec{F}_{\Theta} = \frac{\kappa}{r^2} S \cdot \cos(\varphi)$$

with, $\kappa = \frac{R \cdot r_{\oplus}^{2}}{m} P_{\oplus}$

For a 500kg spacecraft,

$$\begin{cases} P_{\oplus} = 5 \cdot 10^{-6} \dfrac{N}{m^2} = 5 \cdot 10^{-5} \dfrac{dinas}{cm^2} \\ R = 1 \\ r_{\oplus} = 1{,}49 \cdot 10^{13}\, cm \\ m = 500Kg = 5 \cdot 10^{5}\, gr \end{cases} \longrightarrow \kappa = 0.224 \cdot 10^{17} \frac{dinas}{g}$$

and the force due to solar radiation pressure is given by:

$$\boxed{\vec{F}_{\Theta} = \frac{0.224 \cdot 10^{17} \cdot S \cdot \cos(\varphi)}{r^2}}$$

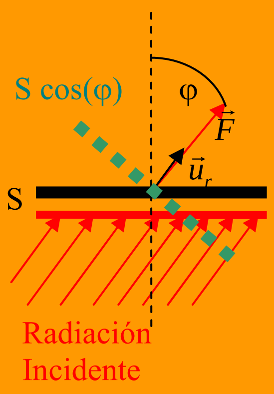
SUMMARY OF THE CHAPTER

1. The pressure of radiation, **P**, is given by:

$$P = \frac{\Psi}{c}$$

where **Ψ** represents the radiation flux and **c** the velocity of light.

2. For space missions the force exerted by solar radiation on a surface S, whose normal makes an angle, φ, with the direction of incidence of the radiation, is given as a function of the solar radiation pressure at the orbit of the Earth and then, applying a geometric dilution factor:



$$\vec{F}_{\Theta} = \frac{\kappa}{r^2} S \cdot \cos(\varphi)$$

$$\text{with,}\quad \kappa = \frac{\Re \cdot r_{\oplus}^{2}}{m} P_{\oplus}$$

- $\Re$ is a constant that depends on the reflectivity of the surface.
- ***S*** is the surface of the satellite.
- ***m*** is the mass of the satellite
- $\mathbf{P}_{\oplus}$ is the solar pressure at the Earth's orbit
- $r_{\oplus}$ is the distance Earth-Sun.
- ***r*** is the distance between the satellite and the Sun.

Appendix

1

Table of Exoplanets:

NAME	**DISTANCE (pc)**	**α(2000.0) (hh mm ss.s)**	**δ(2000.0) (° ‘ “)**
HD 73256	36.52	08 36 23.0	-30 02 15.5
GJ 436	10.23	11 42 11.1	26 42 23.7
55 Cnc	12.53	08 52 37.8	28 19 50.9
HD 63454	35.8	07 39 21.9	-78 16 44.3
HD 83443	43.54	09 37 11.8	-43 16 19.9
HD 46375	33.41	06 33 12.6	05 27 46.5
TrES-1	157 ア 6	19 04 09.8	36 37 57.5
HD 179949	27.05	19 15 33.2	-24 10 45.7
HD 187123	47.91	19 46 58.1	34 25 10.3
Tau Boo(HD 120136)	15.6	13 47 15.7	17 27 24.9
HD 330075	50.20	15 49 37.6	-49 57 48.7
HD 88133	74.46	10 10 07.7	18 11 12.7
HD 2638	53.71	00 29 59.9	-05 45 50.4
BD-10 3166	?	10 58 28.8	-10 46 13.4
HD 75289	28.94	08 47 40.4	-41 44 12.5
HD 209458	47.1	22 03 10.8	18 53 04.0
HD 76700	59.7	08 53 55.5	-66 48 03.6
51 Peg(HD 217014)	15.36	22 57 28.0	20 46 07.8
Ups And(HD 9826)	13.47	01 36 47.8	41 24 38.2
HD 49674	40.73	06 51 30.5	40 52 03.9
HD 68988	58.82	08 18 22.2	61 27 38.6
HD 168746	43.12	18 21 49.8	-11 55 21.7
HD 217107	19.72	22 58 15.5	-02 23 43.9
HD 162020	31.26	17 50 38.4	-40 19 06.1
HD 160691	15.28	17 44 08.7	-51 50 02.6
HD 130322	29.76	14 47 32.7	-00 16 53.3
HD 108147	38.57	12 25 46.3	-64 01 19.5
HD 38529	42.43	05 46 34.9	01 10 05.5
Gl 86(HD 13445)	10.91	02 10 25.9	-50 49 25.4
HD 99492	17.99	11 26 46.3	03 00 22.8
HD 27894	42.37	04 20 47.0	-59 24 39.0
HD 195019	37.36	20 28 18.6	18 46 10.2
HD 6434	40.32	01 04 40.2	-39 29 17.6
HD 192263	19.89	20 13 59.8	-00 52 00.8
Gliese 876	4.70	22 53 16.7	-14 15 49.3
HD 102117	42	11 44 50.5	-58 42 13.4
HD 11964	33.98	01 57 09.6	-10 14 32.7
rho CrB(HD 143761)	17.43	16 01 02.7	33 18 12.6
HD 74156	64.56	08 42 25.1	04 34 41.2

NAME	DISTANCE (pc)	α(2000.0) (hh mm ss.s)	δ(2000.0) (° ‘ “)
HD 37605	42.88	05 40 01.7	06 03 38.1
HD 168443	37.88	18 20 03.9	-09 35 44.6
HD 3651	11.11	00 39 21.8	21 15 01.7
HD 121504	44.37	13 57 17.2	-56 02 24.2
HD 101930	30.49	11 43 30.1	-58 00 24.8
HD 178911 B	46.73	19 09 03.1	34 35 59.5
HD 16141	35.91	02 35 19.9	-03 33 38.2
HD 114762	40.57	13 12 19.7	17 31 01.6
HD 80606	58.38	09 22 37.6	50 36 13.4
70 Vir(HD 117176)	18.11	13 28 25.8	13 46 43.6
HD 216770	37.89	22 55 53.7	-26 39 31.5
HD 52265	28.07	07 00 18.0	-05 22 01.8
HD 34445	45	05 17 41.0	07 21 12.0
HD 208487	44	21 57 19.8	-37 45 49.0
HD 93083	28.9	10 44 20.9	-33 34 37.3
GJ 3021(HD 1237)	17.62	00 16 12.7	-79 51 04.3
HD 37124	33.25	05 37 02.5	20 43 50.8
HD 219449	45.52	23 15 53.5	-09 05 15.9
HD 73526	94.71	08 37 16.5	-41 19 08.8
HD 104985	102.04	12 05 15.1	76 54 20.6
HD 82943	27.46	09 34 50.7	-12 07 46.4
HD 169830	36.32	18 27 49.5	-29 49 00.7
HD 8574	44.15	01 25 12.5	28 34 00.1
HD 202206	46.34	21 14 57.8	-20 47 21.2
HD 89744	38.99	10 22 10.6	41 13 46.3
HD 134987	25.65	15 13 28.7	-25 18 33.6
HD 40979	33.33	06 04 29.9	44 15 37.6
HD 12661	37.16	02 04 34.3	25 24 51.5
HD 150706	27.23	16 31 17.6	79 47 23.2
HD 59686	92.51	07 31 48.4	17 05 09.8
HR 810(HD 17051)	17.24	02 42 33.5	-50 48 01.1
HD 142	25.64	00 06 19.2	-49 04 30.7
HD 92788	32.32	10 42 48.5	-02 11 01.5
HD 28185	39.56	04 26 26.3	-10 33 03.0
HD 196885	33	20 39 51.9	11 14 58.7
HD 142415	34.57	15 57 40.8	-60 12 00.9
HD 177830	59.03	19 05 20.8	25 55 14.4
HD 154857	68.54	17 11 15.7	-56 40 50.9
HD 108874	68.54	12 30 26.9	22 52 47.4
HD 4203	77.82	00 44 41.2	20 26 56.1
HD 128311	16.57	14 36 00.6	09 44 47.5
HD 27442	18.23	04 16 29.0	-59 18 07.8
HD 210277	21.29	22 09 29.9	-07 32 55.2
HD 19994	22.38	03 12 46.4	-01 11 46.0
HD 188015	52.63	19 52 04.5	28 06 01.4
HD 13189	1851.85	02 09 40.2	32 18 59.2
HD 20367	27.13	03 17 40.0	31 07 37.4
HD 114783	20.43	13 12 43.8	-02 15 54.1
HD 147513	12.87	16 24 01.3	-39 11 34.7
HIP 75458(HD 137759)	31.33	15 24 55.8	58 57 57.8

NAME	DISTANCE (pc)	α(2000.0) (hh mm ss.s)	δ(2000.0) (º ‘ “)
HD 65216	35.59	07 53 41.3	-63 38 50.4
HD 183263	52.83	19 28 24.6	08 21 29.0
HD 141937	33.46	15 52 17.5	-18 26 09.8
HD 41004A	43.03	05 59 49.6	-48 14 22.9
HD 47536	121.36	06 37 47.6	-32 20 23.0
HD 23079	34.60	03 39 43.1	-52 54 57.0
16 CygB(HD 186427)	21.41	19 41 52.0	50 31 03.1
HD 4208	32.70	00 44 26.7	-26 30 56.4
HD 114386	28.04	13 10 39.8	-35 03 17.2
HD 45350	48.95	06 28 45.7	38 57 46.7
γCephei(HD 222404)	13.79	23 39 20.8	77 37 56.2
HD 213240	40.75	22 31 00.4	-49 25 59.8
HD 10647	17.35	01 42 29.3	-53 44 27.0
HD 10697	32.56	01 44 55.8	20 04 59.3
47 Uma(HD 95128)	14.08	10 59 28.0	40 25 48.9
HD 190228	62.11	20 03 00.8	28 18 24.7
HD 114729	35	13 12 44.3	-31 52 24.1
HD 111232	28.88	12 48 51.8	-68 25 30.5
HD 2039	90.1	00 24 20.3	-56 39 00.2
HD 136118	52.27	15 18 55.5	-01 35 32.6
HD 50554	31.03	06 54 42.8	24 14 44.0
HD 196050	46.93	20 37 51.7	-60 38 04.1
HD 216437	26.52	22 54 39.5	-70 04 25.4
HD 216435	33.29	22 53 37.3	-48 35 53.8
HD 106252	37.44	12 13 29.5	10 02 29.9
HD 23596	51.98	03 48 00.4	40 31 50.3
14 Her(HD 145675)	18.15	16 10 24.3	43 49 03.5
HD 142022	35.87	16 10 15.0	-84 13 53.8
HD 39091	18.21	05 37 09.9	-80 28 08.8
HD 70642	28.76	08 21 28.1	-39 42 19.5
HD 33636	28.69	05 11 46.4	04 24 12.7
Epsilon Eridani(HD 22049)	3.22	03 32 55.8	-09 27 29.7
HD 117207	33.01	13 29 21.1	-35 34 15.6
HD 30177	54.70	04 41 54.4	-58 01 14.7
HD 50499	47.26	06 52 02.0	-33 54 56.0
HD 89307	30.88	10 18 21.3	12 37 16.0
HD 72659	51.36	08 34 03.2	-01 34 05.6
Gl 777A(HD 190360A)	158.920	20 03 37.4	29 53 48.5
GQ Lup	?	15 49 12.1	-35 39 04.0
2M1207	?	12 07 33.4	-39 32 54.0
AB Pic	45.52	06 19 12.9	-58 03 15.5
OGLE-TR-56	1500	17 56 35.5	-29 32 21.2
OGLE-TR-113	1500	10 52 24.4	-61 26 48.5
OGLE-TR-132	1500	10 50 34.7	-61 57 25.9
OGLE-TR-10	1500	17 51 28.3	-29 52 34.9
OGLE-TR-111	1500	10 53 17.9	-61 24 20.3