Astrophysics

Content: 2+2, 2×13×90 = 2 340 minutes = 39 hours
Tutor: Martin Žáček zacekm@fel.cvut.cz department of Physics, room 49

On-line informations:

http://fyzika.feld.cvut.cz/~zacek/ … *this presentation*

Many years (20?) teaching astrophysics (Prof. Petr Kulhanek), many texts and other materials but mostly in Czech (for example electronic journal Aldebaran Bulletin).

2011 … first year of teaching Astrophysics in English

2012-16 …

2017 … about 6 students, lextures on Thursday 11:00 lecture and 12:45 exercise

https://www.fel.cvut.cz/cz/education/bk/predmety/12/77/p12773704.html ... AE0B02ASF
https://www.fel.cvut.cz/cz/education/bk/predmety/12/78/p12784304.html ... AE0M02ASF

Syllabus

Classes:

Astronomy & astrophysics

1. Astrophysics, history and its place in context of natural sciences.
2. Foundations of astronomy, history, its methods, instruments.
3. Solar system, inner and outer planets, Astronomical coordinates.

Physics of stars

4. Statistics of stars, HR diagram. The star formation and evolution. Hyashi line.
5. Final evolutionary stages. White dwarfs, neutron stars, black holes.
6. Variable stars. Cepheids. Novae and supernovae stars. Binary systems.
7. Other galactic and extragalactic objects, nebulae, star clusters, galaxies.

Cosmology

8. Principle of special and general theory of relativity. Relativistic experiments.
9. Cosmology. The Universe evolution, cosmological principle. Friedman models.
10. Supernovae Ia, cosmological parameters of the Universe, dark matter and dark energy.
11. Elementary particles, fundamental forces, quantum field theory, Feynman diagrams.
12. The origin of the Universe. Quark-gluon plasma. Nucleosynthesis. Microwave background radiation.
13. Cosmology with the inflationary phase, long-scale structure of the Universe.
14. Reserve

Syllabus

Practices:

Astronomy & astrophysics

1. **Astronomic scales, lenghts and magnitude (Pogson) scale.**
2. **Kepler's and Newtonian laws. Newton gravitation law.**
   Energy and momentum conservation.
3. **Astronomical coordinates, measuring time and space.**

Physics of stars

4. **Numerical solution of the ordinary differential equations. Star equilibrium model.**
5. **White dwarfs, neutron stars and black holes, diameter, density.**
6. **Law's of the electromagnetic radiation.**
7. **Types of rotation, rotation motions. Rotation of liquids, vortices.**

Cosmology

8. **Measuring time and space, Lorentz transformation, metrics, metric tensor.**
9. **Hubble constant, age of the Universe.**
10. **Gravitational red shift, time dilatation.**
11. **Elementary particles, Feynman diagrams construction.**
12. **Calculation of the expansion function for different types of matter.**
13. **Cosmological red shift.**
14. **Final test, graded assessment.**

1. Astronomy & astrophysics

What is the difference between astronomy and astrophysics?

Astrophysics:

The application of physics to an understanding of the workings of everything in the Universe, including (but not exclusively) stars, and of the Universe itself. Astrophysics began in the 19 century with the application of spectroscopy to the stars, which led to the measurements of their temperature and composition. Astrophysicists are able to study matter in the Universe under extreme conditions (of temperature, pressure and density). that cannot be achieved in laboratories on Earth.

Astronomy:

Everything others, today mostly the experimantal (observational) astronomy.

1. Astronomy & astrophysics

First astrophysicist:

Sir Arthur Eddington (1882 – 1944)

Eddington was an English theoretical astronomer who carried out the crucial test of Albert Einstein's general theory of relativity, developed the application of physics to an understanding of the structure of stars and was a great popularizer of science in the 1920s and 1930s. Earlier Eddington had studied proper motion of stars. After that, he went on to aplly the laws of physics to the conditions that opperate inside stars, explaining their overall appearance in therms of the known laws relating temperature, pressure, density.

1905 … graduated at the Cambridge university
1912 … leader of the expedition to Brasil (Sun eclipse)
1914 … Director of the Cambridge Observatories
1919 … two expedition
(test deflection of light predicted by Albert Einstein)
1926 … published book The Internal Constitution of the Stars

more information: *http://en.wikipedia.org/wiki/Arthur_Eddington*

Units in astronomy - lenght

Light year (l. y.):

A unit of distance often used by science fiction writers and occasionally by astronomers.

One light year is the distance that light travelling at a speed of 299 792 458 metres per second can travel in 1 year.

Other derived units: light day, light hours and light seconds.

1 l. y. = 9.46×1012 km, nearest star Proxima Centauri … 4.22 l. y.

Astronomical unit (AU):

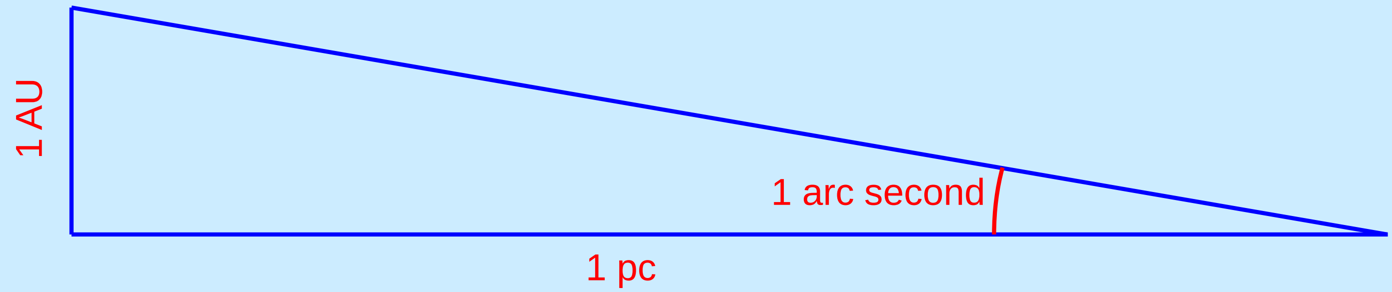
A measure of distance defined as the average distance between the Sun and the Earth over one orbit (one year). 1AU is equal to 149,597,870 km (=499.005 light seconds).

Parsec:

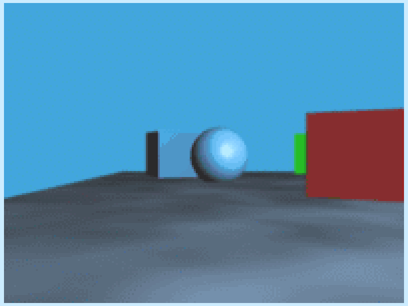
A measure of distance used by astronomers, equal to 3.2616 l. y.

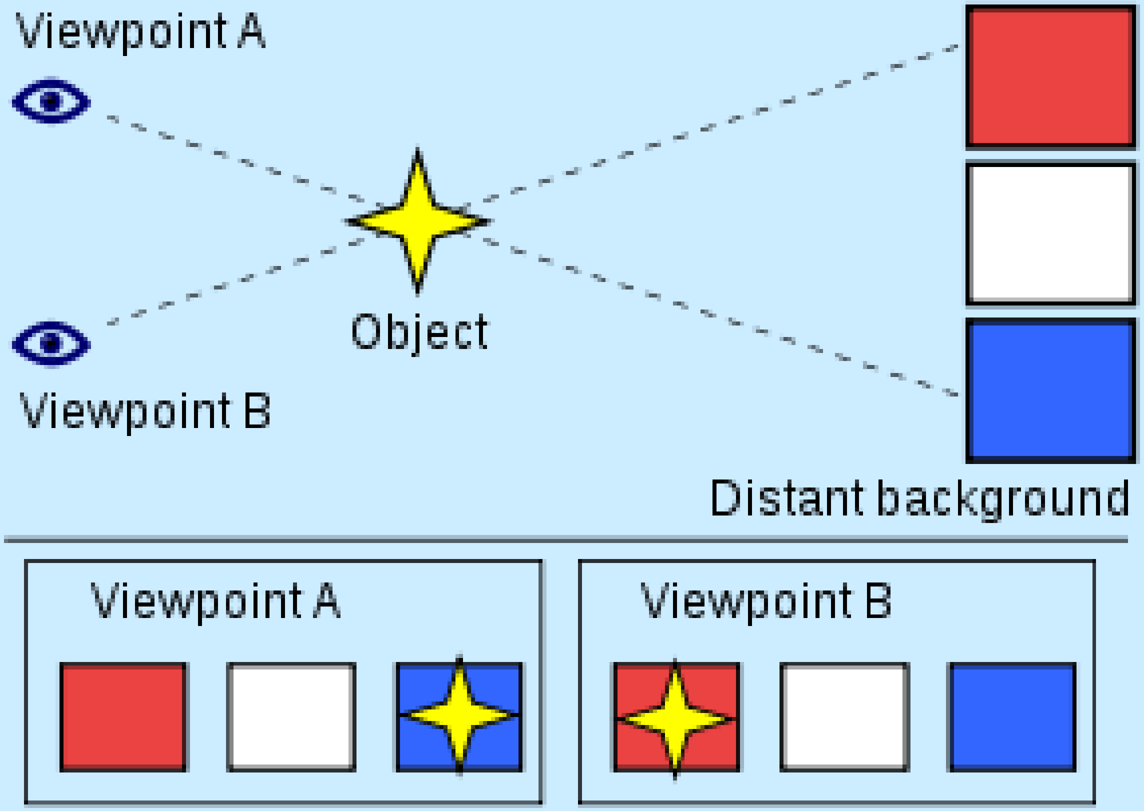
A parsec is the distance from which the Earth and the Sun appear to be separated by angle of 1 arc second.

Derived units: kpc, Mpc.



Parallax




Viewpoint A
Object
Viewpoint B
Distant background
Viewpoint A
Viewpoint B


AC MILLIVOLTMETER
1 CHANNEL
AC VOLTS
RANGE

Parallax in astronomy

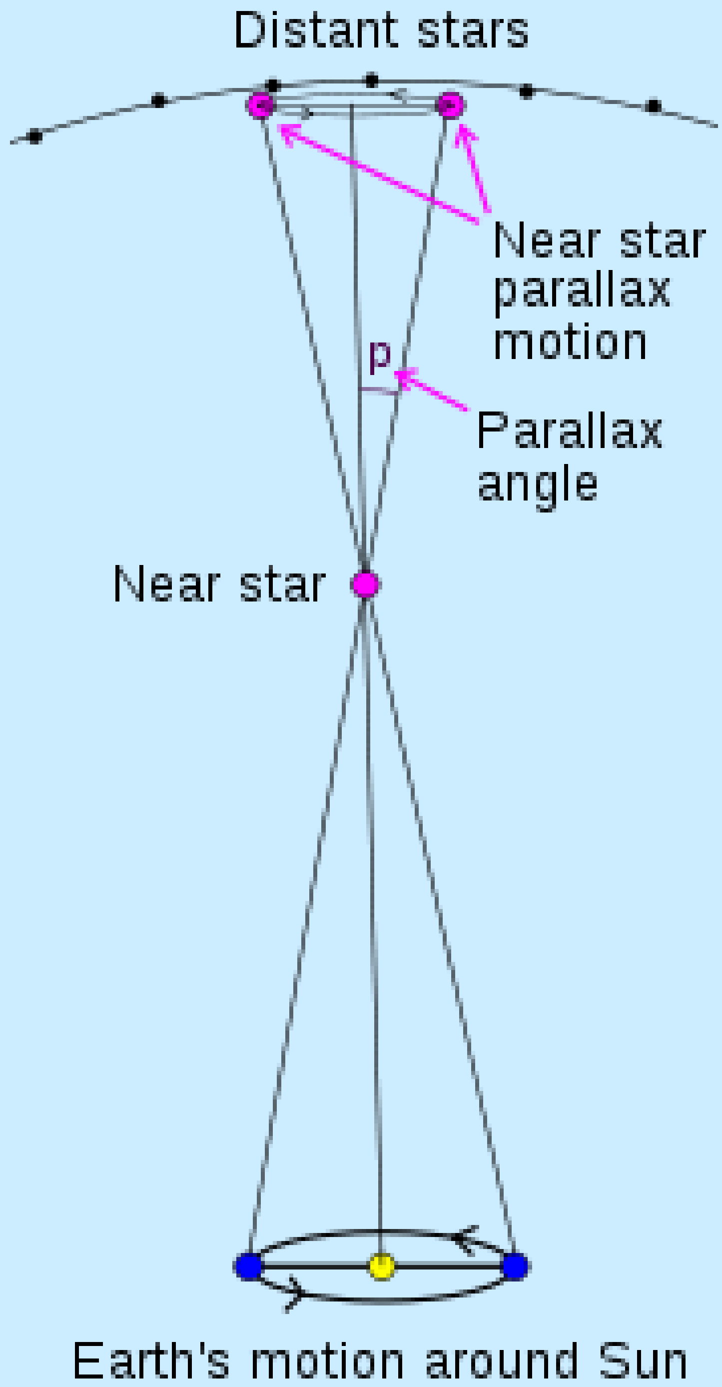
-Stars

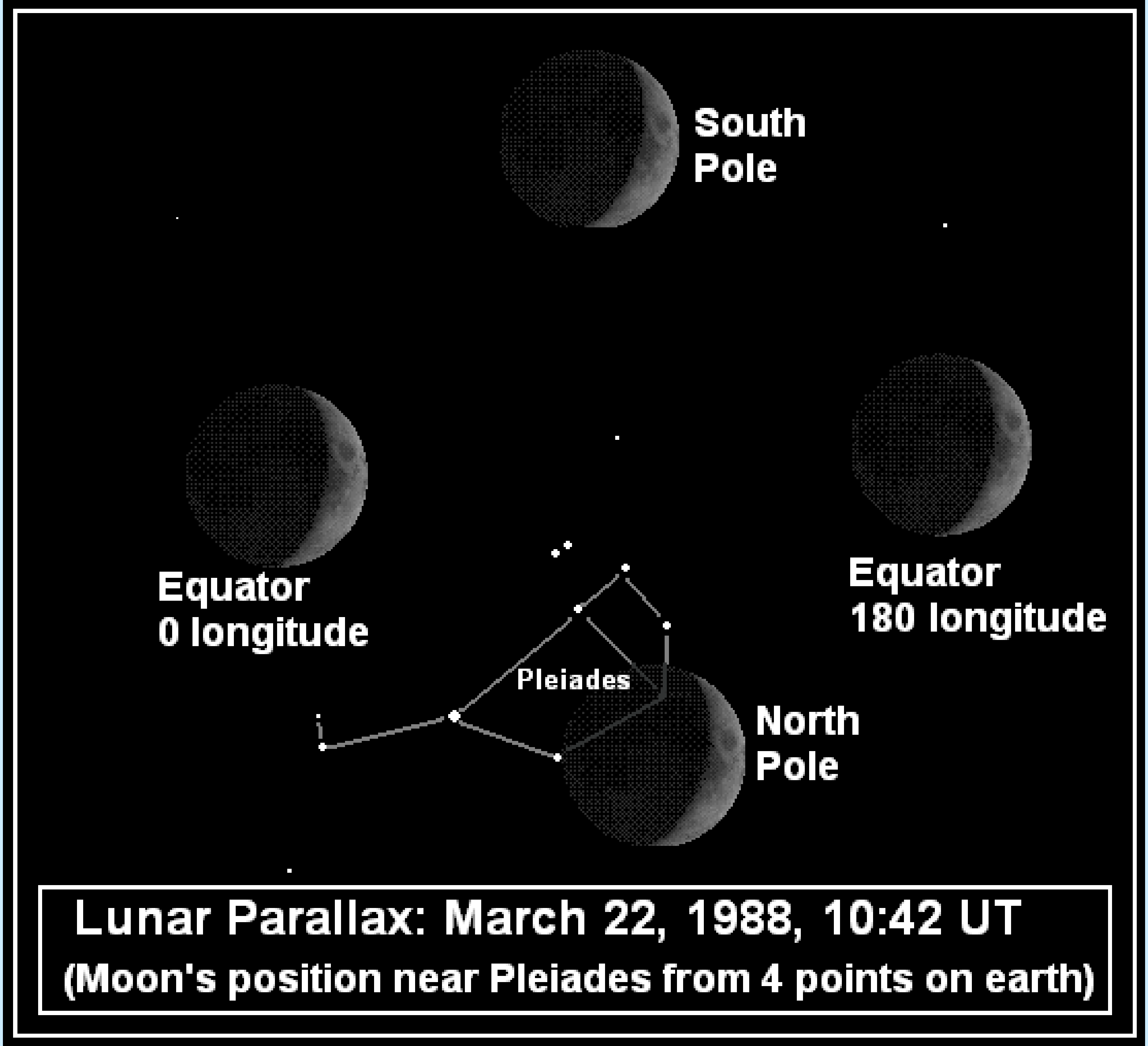
-Planets

-Mond

Calculation of parallax:

$$\pi('') = \frac{1}{r(\text{pc})}$$




South
Pole
Equator
0 longitude
Equator
180 longitude
Pleiades
North
Pole
Lunar Parallax: March 22, 1988, 10:42 UT
(Moon's position near Pleiades from 4 points on earth)

Units in astronomy - brightness

Historical background:

- *Hipparchus* (190-127 bc) - Greek astronomer, beginnig of scientific astronomy, he developed spherical trigonometry and was able to calculate Sun eclips, first star catalog, roughly 800 of stars devided to 6 groups according to their brightness.
- Hipparchus ranked stars in a scale 'first magnitude', for the brightest star he knew, to 'sixth magnitude', for those that can just be seen by the unaided human eye.
- 19th century: scientificaly exact brightness scale based on the well defined quantity.

Magnitude scale

Also known as Pogson scale. Scale used by astronomers as a measure of the brightnesses of astronomical objects. The original magnitude scale was based on how bright object look to the human eye; historically first scale was made from Hiparchos (6 values of brightness). In the middle of the 19th century, however, it became appreciated that the way the human eye works is not linear, but follows a logarithmic rule. So a star of the first magnitude is much more than six times brighter than a star of the sixth magnitude.

In 1856 the English astronomer Norman Pogson (1829-91) proposed that, in order to achieve to precise scale that matches the traditional scale based on human vision, in absolute terms a difference of 5 magnitude should corresponds to a factor 100 difference in brightness. In other words, a difference of 1 magnitude corresponds to a difference in brightness of 2.512 times (because 2.5125 = 100).

A star that is 2 magnitude brighter than another is 2.5122 times brighter, and so on.
This is the scale used by astronomers today, with the actual brightness measured by light-detecting machines, no longer estimated by eye. Because of the way Hipparchus defined the original magnitude scale, the dimmer a star is, the greater is its magnitude on the Pogson scale. And because brighter stars than Hipparchus considered have to be accounted for, negative numbers have to be used as well.

Magnitudes are measured in different wavelength bands (in different colours) or over the entire electromagnetic spectrum (the bolometric magnitude).

Magnitude scale

Apparent magnitude (*m*):

The brightness of a star, measured on a standard magnitude scale, as it appears from Earth. Because stars are at different distances from us, and objects that are the same brightness will look fainter if they are further away, the apparent magnitude cannot be used on its own to tell us how bright a star really is.

Absolute magnitude (M):

The apparent magnitude that a star or other bright object would have if it were at a distance of exactly 10 parsecs from the observer.

$$m = -2.5 \log \frac{I}{I_0} \qquad \Delta m = m_2 - m_1 = -2.5 \log \frac{I_2}{I_1}$$

$$M = m - 5 \log r + 5$$

Magnitude scale - differences

A Magnitude Difference of:	Equals a Brightness Ratio of:
0.0	1.0
0.2	1.2
1.0	2.5
1.51	4.0
2.0	6.3
2.5	10.0
4.0	40.0
5.0	100.0
7.5	1000.0
10.0	10,000.0

$$\Delta m = m_2 - m_1 = -2.5 \log \frac{I_2}{I_1}$$

$$10^{\frac{m_1 - m_2}{2.5}} = \frac{I_2}{I_1}$$

$$\left(\sqrt[5]{100}\right)^{m_1 - m_2} = \frac{I_2}{I_1}$$

$$2.512^{m_1 - m_2} = \frac{I_2}{I_1}$$

Apparent magnitude – bright objects

App. mag.	Celestial object
–38.00	Rigel as seen from 1 astronomical unit, It is seen as a large very bright bluish scorching ball of 35° apparent diameter
–30.30	Sirius as seen from 1 astronomical unit
–29.30	Sun as seen from Mercury at perihelion
–26.74	**Sun**[4] (398,359 times brighter than mean full moon)
–23.00	Sun as seen from Jupiter at aphelion
–18.20	Sun as seen from Pluto at aphelion
–12.92	Maximum brightness of Full **Moon** (mean is –12.74)[3]
–6.00	The **Crab Supernova** (SN 1054) of AD 1054 (6500 light years away)[6]
–5.9	International Space Station (when the ISS is at its perigee and fully lit by the sun)[7]
–4.89	Maximum brightness of **Venus[8]** when illuminated as a crescent
–4.00	Faintest objects observable during the day with naked eye when Sun is high
–3.82	Minimum brightness of Venus when it is on the far side of the Sun
–2.94	Maximum brightness of **Jupiter[9]**
–2.91	Maximum brightness of **Mars[10]**
–2.50	Minimum brightness of Moon when near the sun (New Moon)
–1.61	Minimum brightness of Jupiter
–1.47	**Brightest star** (except for the sun) at visible wavelengths: Sirius[11]
–0.83	Eta Carinae apparent brightness as a supernova impostor in April 1843
–0.72	**Second-brightest star**: Canopus[12]
–0.49	Maximum brightness of Saturn at opposition and when the rings are full open (2003, 2018)
–0.27	The total magnitude for the Alpha Centauri AB star system, (Third-brightest star to the naked eye)
–0.04	Fourth-brightest star to the naked eye Arcturus[13]
−0.01	Fourth-brightest individual star visible telescopically in the sky Alpha Centauri A

http://en.wikipedia.org/wiki/Apparent_magnitude

Apparent magnitude – faint objects

App. mag.	Celestial object
+0.03	Vega, which was originally chosen as a definition of the zero point[14]
+0.50	Sun as seen from Alpha Centauri
1.47	Minimum brightness of Saturn
1.84	Minimum brightness of Mars
3.3	The SN 1987A supernova in the Large Magellanic Cloud 160,000 light-years away,
3 to 4	Faintest stars visible in an urban neighborhood with naked eye
3.44	The well known **Andromeda Galaxy** (M31)[15]
4.38	Maximum brightness of Ganymede[16] (moon of Jupiter and the largest moon in the solar system)
4.50	M41, an open cluster that may have been seen by Aristotle[17]
5.14	Maximum brightness of **brightest asteroid** Vesta
5.32	Maximum brightness of Uranus[18]
5.95	Minimum brightness of Uranus
7 to 8	**Extreme naked eye limit** with class 1 Bortle Dark-Sky Scale, the darkest skies available on Earth[23]
7.72	The star HD 85828[24] is the faintest star known to be observed with the naked eye[25]
7.78	Maximum brightness of Neptune[26]
8.02	Minimum brightness of Neptune
9.50	Faintest objects visible using common 7x50 binoculars under typical conditions
12.00	Sun as seen from Rigel
12.91	**Brightest quasar** 3C 273 (luminosity distance of 2.4 giga-light years)
13.65	Maximum brightness of Pluto[31] (725 times fainter than magnitude 6.5 naked eye skies)
22.91	Maximum brightness of Pluto's moon Hydra
23.38	Maximum brightness of Pluto's moon Nix
24.80	Amateur picture with greatest magnitude: quasar CFHQS J1641 +3755[36][37]
27.00	Faintest objects observable in visible light with **8m ground-based telescopes**
28.20	Halley's Comet in 2003 when it was 28AU from the Sun[40]
29.30	Sun as seen from Andromeda Galaxy
31.50	Faintest objects observable in visible light with **Hubble Space Telescope**
36.00	Faintest objects observable in visible light with E-ELT

http://en.wikipedia.org/wiki/Apparent_magnitude

Time in astronomy

Atomic clock

- General name for any variety of timekeeping devices which are based on regular vibrations associated with atoms. **The first atomic clock** was developed in 1948 by the US National Bureau of Standards, and was based on measurements of the vibrations of atoms of nitrogen oscillating back and forth in ammonia molecules, at a rate of 23,870 vibrations per second. It is also known as an ammonia clock.
- **The standard form of atomic clock today** is based on caesium atoms. The spectrum of caesium includes a feature corresponding to radiation with a very precise frequency, 9,192,631,770 cycles per second. One second is now define as the time it takes for that many oscillations of the radiation associated with this feature in the spectrum of caesium. This kind of atomic clock is also known as a caesium clock; it is accurate to one part in 10^{13} or 1 second in 316,000 years.
- **Even more accurate clocks** have been developed using radiation from hydrogen atoms. They are known as hydrogen maser clocks, and one of these instruments, as the US Naval Research Laboratory in Washington, DC, is estimated to be accurate to within 1 second in 1,7 million years. In principle, clocks of this kind could be made accurate to one second in 300 million years.

FOCS 1, a continuous cold caesium fountain atomic clock in Switzerland, started operating in 2004 at an uncertainty of one second in 30 million years.

The master atomic clock ensemble at the U.S. Naval Observatory in Washington D.C., which provides the time standard for the U.S. Department of Defense.

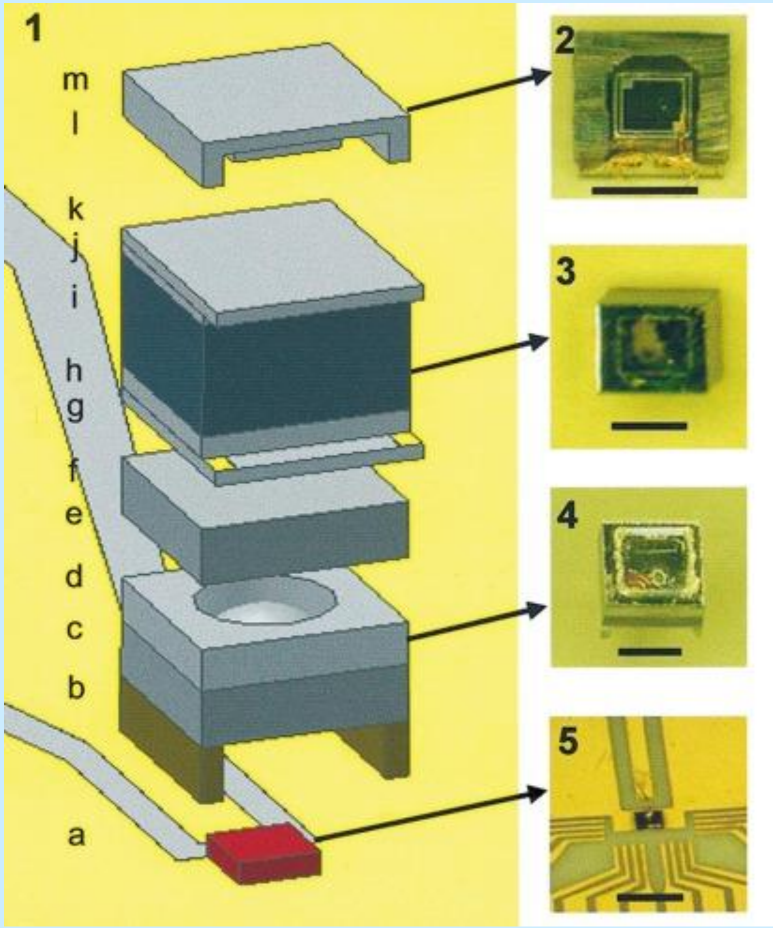
First Atomic Clock Wristwatch (HP 5071A Cesium Beam Primary Frequency Reference, Batteries are included, they last about 45 minutes but are rechargeable).

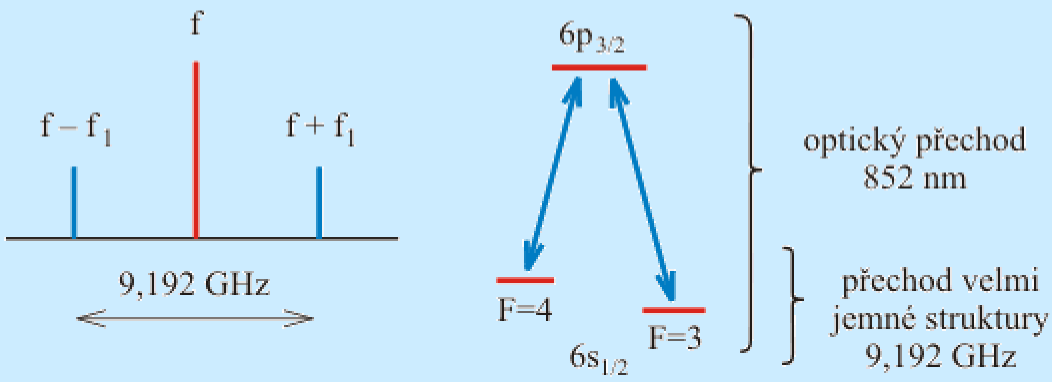
- http://en.wikipedia.org/wiki/Atomic_clock
- http://www.leapsecond.com/

Smalest atomic clock

Smalest atomic clock

Based on structures that are the size of a grain of rice (V < 10 mm^3) and could run on a AA battery (dissipate less than 75 mW). Chip-scale atomic clocks, for example, are stable enough that they neither gain nor lose more than ten millionths of a second over the course of one day





More info:
http://www.nist.gov/public_affairs/releases/miniclock.cfm
http://tf.nist.gov/general/pdf/1945.pdf
http://www.aldebaran.cz/bulletin/2004_43_nah.html

Time scales

Atomic Time

- is measured in seconds from 1 January 1958 (that is from astronomical moment of midnight, Greenwich Mean Time, on the night of 31 December 1957/1 January 1958.

International Atomic Time (TAI)

- IAT or, from the French, TAI) Standard international time system based on atomic time and maintained by the Bureau International de l'Heure in Paris.

Universal Time (UT)

- Essentially the same, for everyday purposes, as Greenwich Mean Time. UT is actually calculated from sidereal time, and is the basis for civil timekeeping. **Coordinated Universal Time (UTC)** is the time used for broadcast time signals, and is kept in step with International Atomic Time by introducing occasional 'leap seconds' into the broadcast time signals.

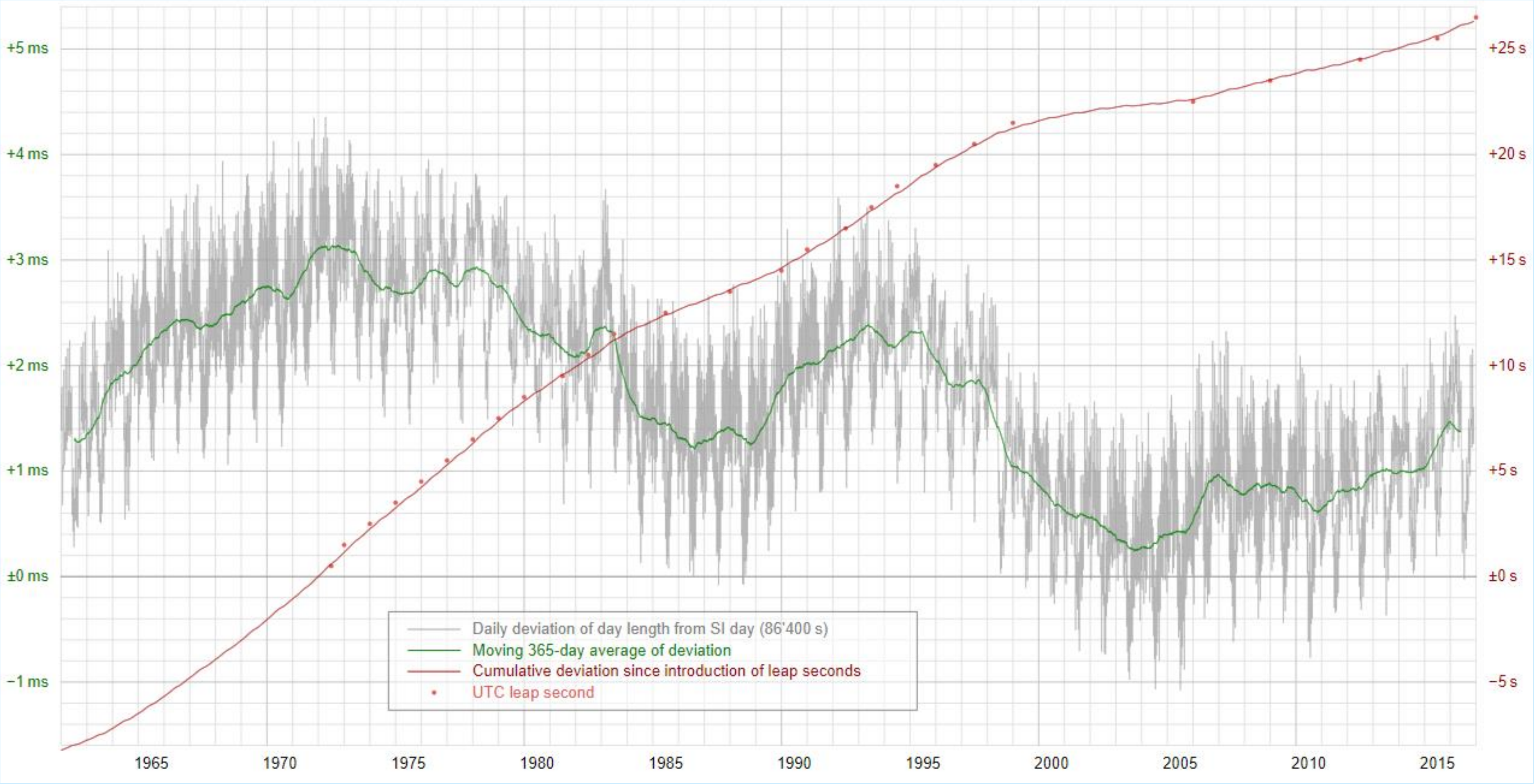
UT1

- is the principal form of Universal Time. While conceptually it is mean solar time at 0° longitude, precise measurements of the Sun are difficult. Hence, it is computed from observations of distant quasars using long baseline interferometry, laser ranging of the Moon and artificial satellites as well the determination of GPS satellite orbits. UT1 is the same everywhere on Earth, and is proportional to the rotation angle of the Earth with respect to distant quasars, specifically, the International Celestial Reference Frame (ICRF), neglecting some small adjustments.

Today: TAI - UTC = 37 seconds,
last leap second was on 31. December 2016.

More info:
http://en.wikipedia.org/wiki/International_Atomic_Time
http://www.leapsecond.com/java/gpsclock.htm
http://en.wikipedia.org/wiki/Leap_second

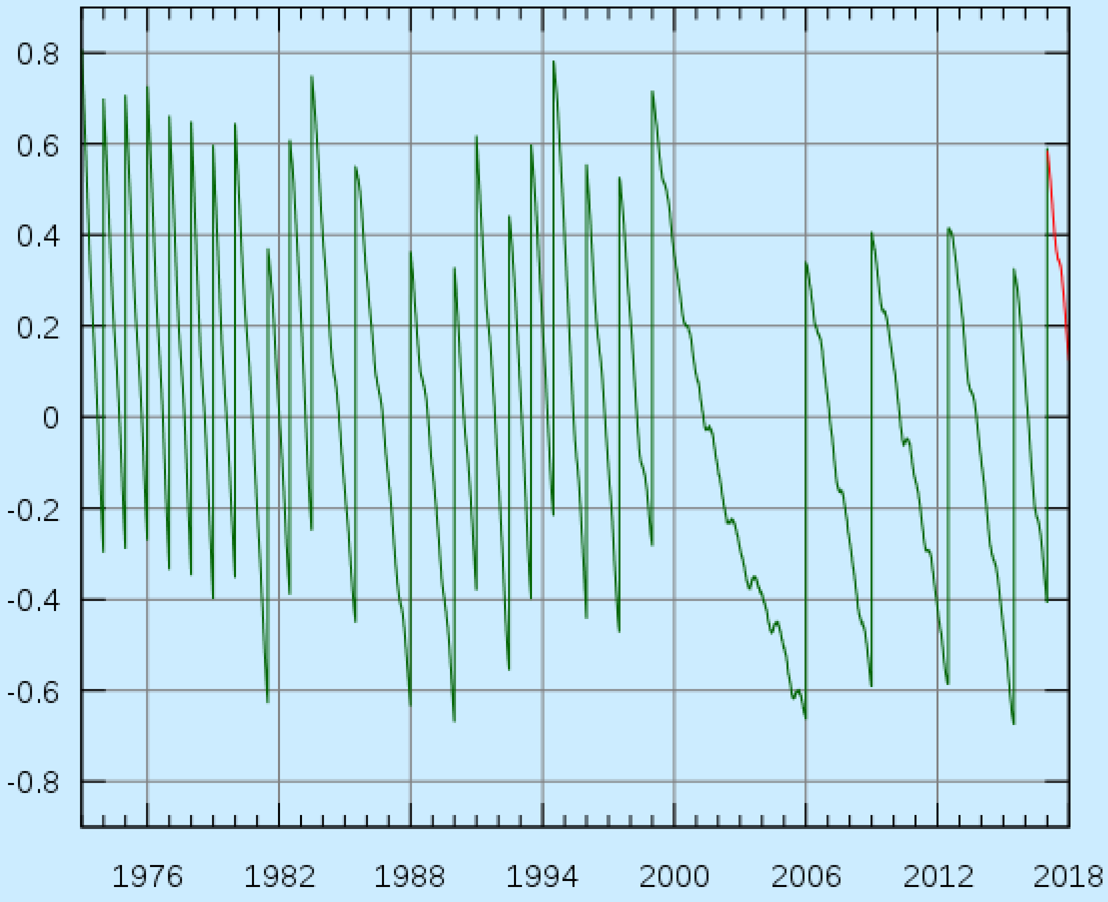
Time scales – length of days



Actual rotational period varies on unpredictable factors such as tectonic motion and has to be observed, rather than computed.

http://en.wikipedia.org/wiki/Leap_seconds

Time scales – UT1 & UTC

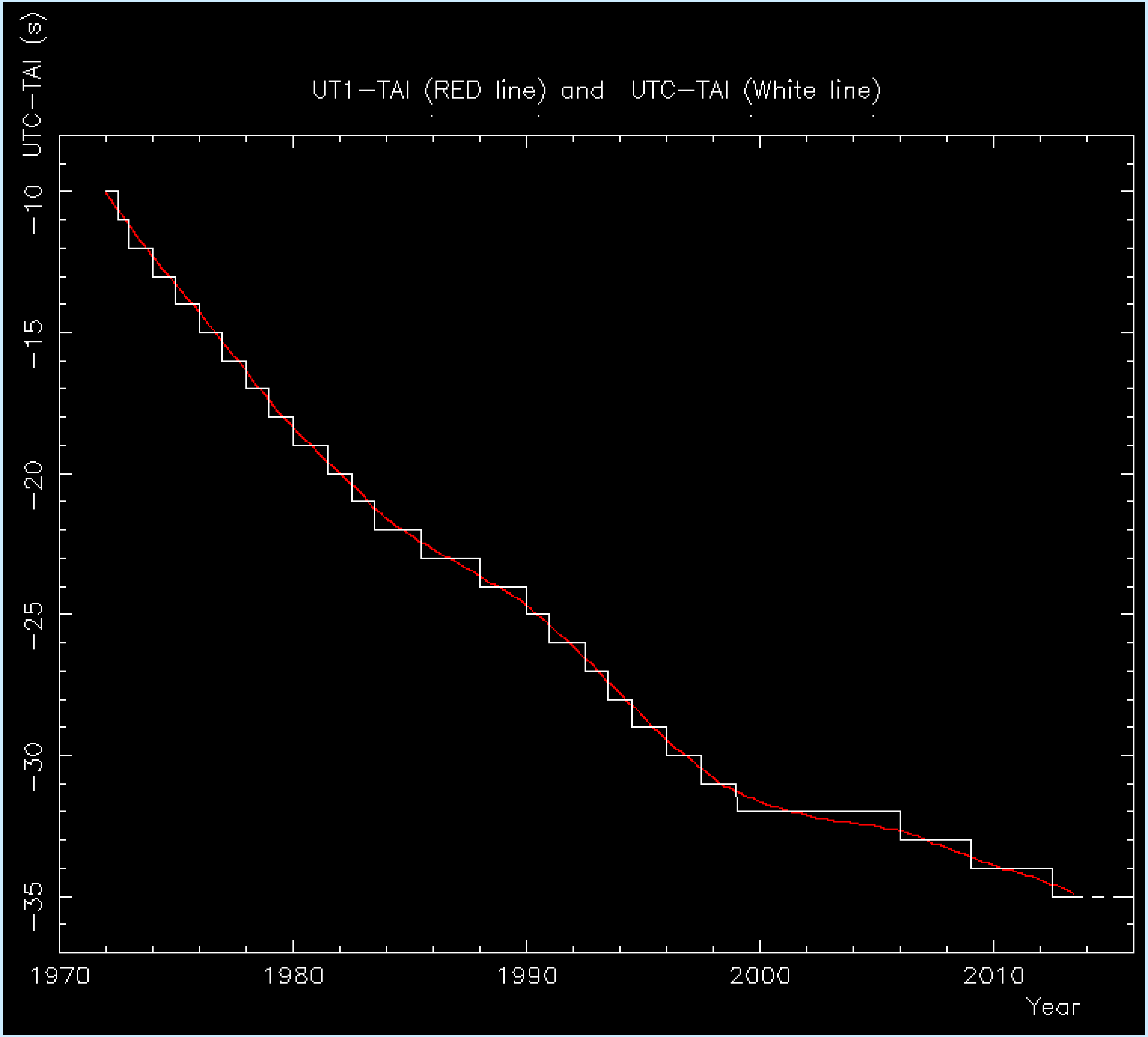


Plot showing the difference UT1 − UTC in seconds. Vertical segments correspond to leap seconds. Red part of graph was prediction.

|UTC − UT1| < 1 second

As with TAI, UTC is only known with the highest precision in retrospect. The International Bureau of Weights and Measures (BIPM) publishes monthly tables of differences between canonical TAI/UTC and TAI/UTC as estimated in real time by participating laboratories.

http://en.wikipedia.org/wiki/Coordinated_Universal_Time



http://hpiers.obspm.fr/eop-pc/

Synodic – sidereal day

Sidereal day (=stellar day)
day measured in terms of the rotation of the Earth compared with the fixed stars.
Sidereal day =23h 56m 4.090 530 832 88s, 0.997 269 566 329 08 mean solar days.

Synodic day (=solar day)
is the period of time it takes for a planet to rotate once in relation to the Sun.

Mean solar time
conceptually is the hour angle of the fictitious mean Sun. Currently (2009) this is realized with the UT1 time scale, which is constructed mathematically from very long baseline interferometry observations of the diurnal motions of radio sources located in other galaxies, and other observations.

There are many of other time scales but for us not so important or obsolete:

UT0, UT2, UT1R etc. … (other variants of Universal Time)
Ephemeris time (ET) … obsolete, to the 1970,

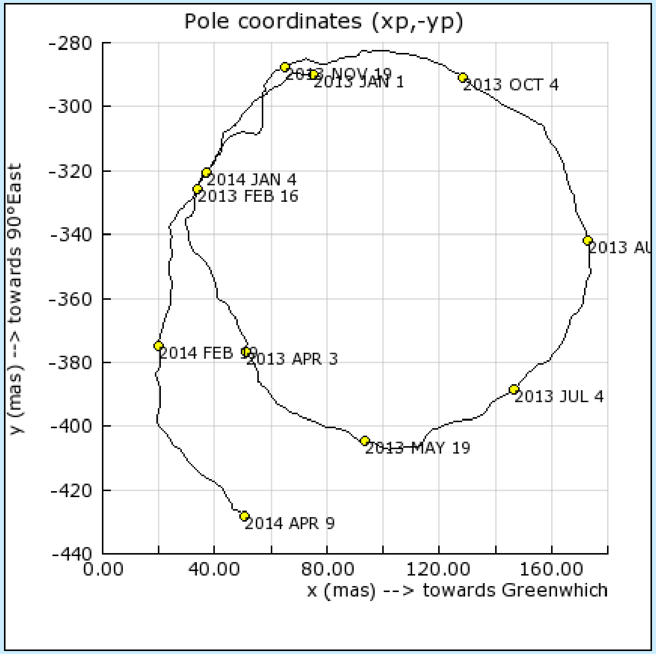
Animated explanation of synodial-siderial day difference
https://www.youtube.com/watch?v=lwVf-AvD8ds

http://en.wikipedia.org/wiki/Ephemeris_time
http://en.wikipedia.org/wiki/Earth_rotation
http://en.wikipedia.org/wiki/Synodic_day
https://en.wikipedia.org/wiki/Sidereal_time

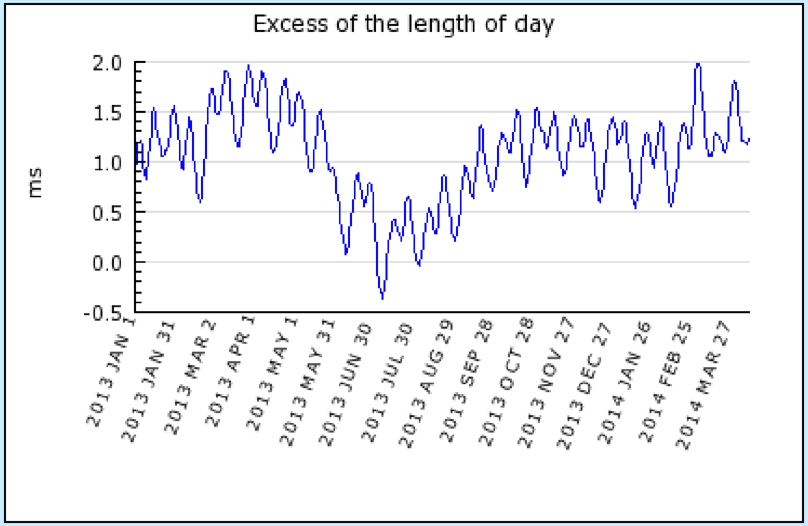
Earth rotation & axis orientation

Earth rotation & axis orientation is determined from the observations of a given astro-geodetic technique VLBI, LLR, SLR, GPS, DORIS) by various organisations all over the world.

Polar motion over recent year



Length of day, 0 = 24 hour day



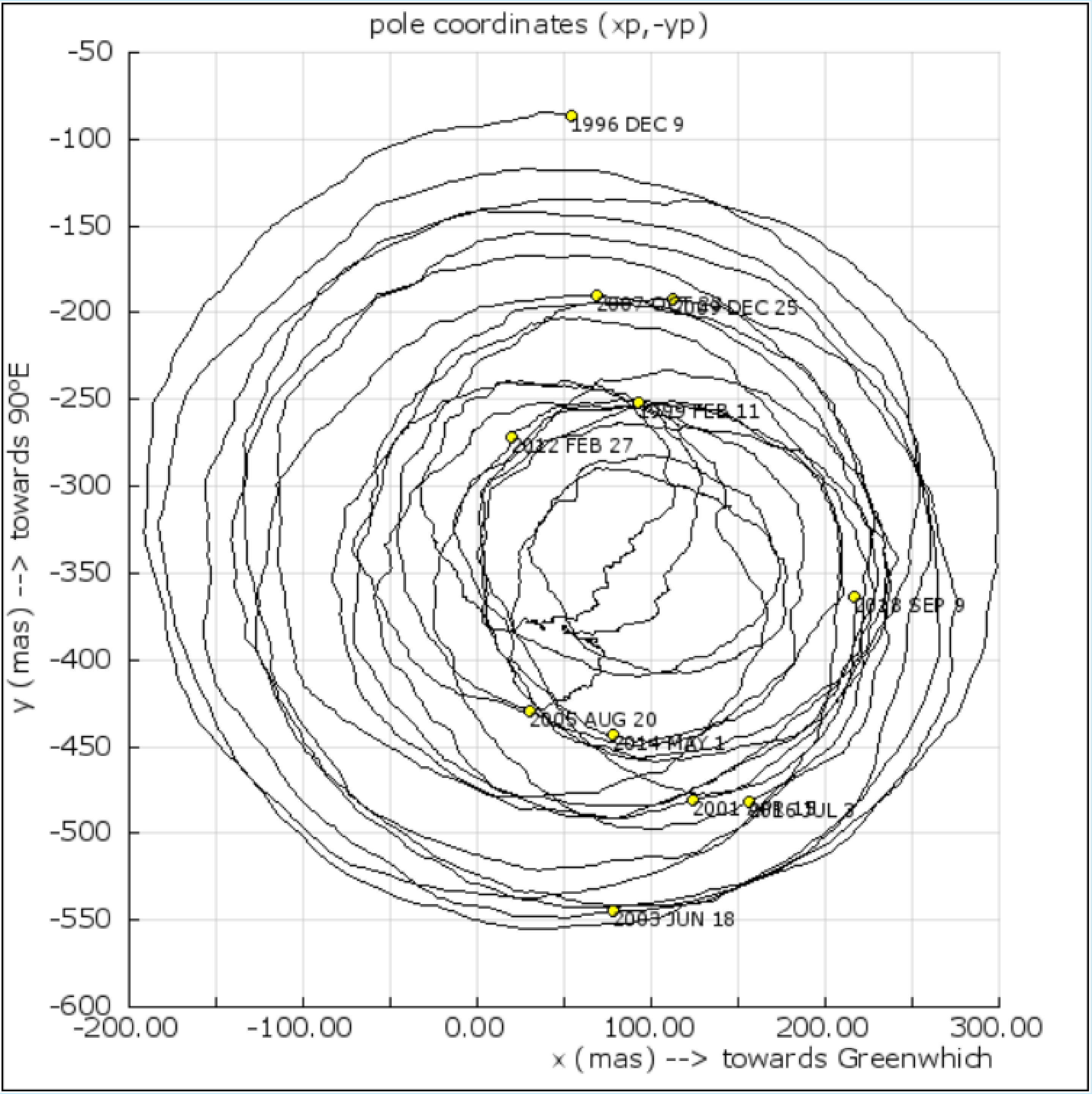
LATEST EARTH ORIENTATION PARAMETERS

http://hpiers.obspm.fr/eop-pc/index.php?index=realtime&lang=en

Today (2018.03.12) the latest values for polar motion and UT1 are:

x= 11.52 mas y= 363.86 mas and UT1-UTC= 155.705 ms.

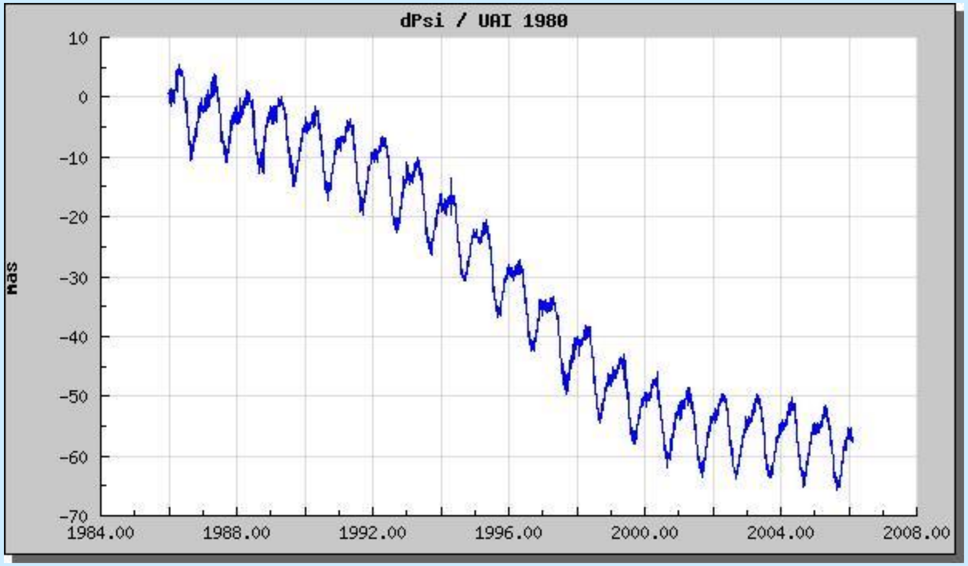
http://hpiers.obspm.fr/eop-pc/
http://en.wikipedia.org/wiki/Earth_rotation
https://en.wikipedia.org/wiki/Precession
https://en.wikipedia.org/wiki/Nutation

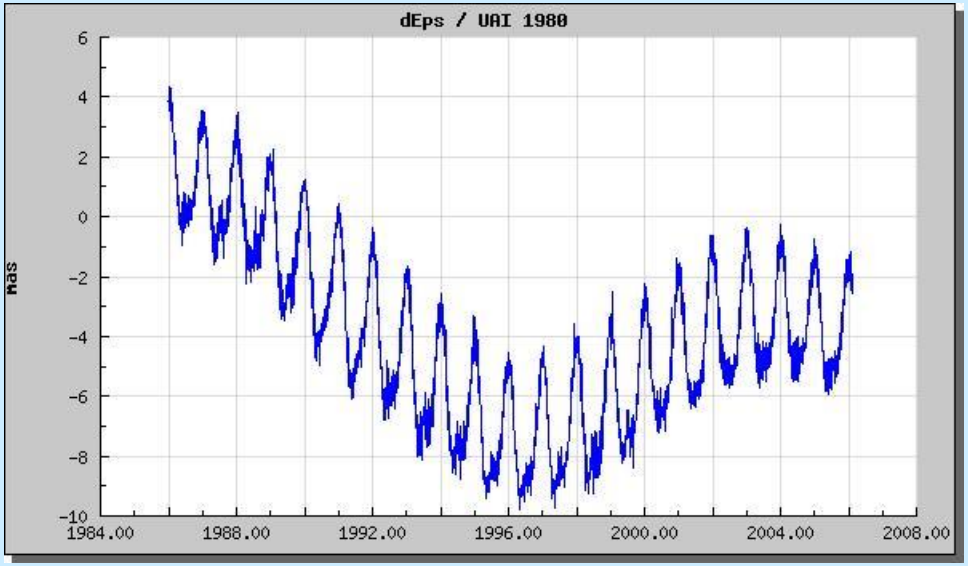


Earth pole movement in last 20 years

http://hpiers.obspm.fr/eop-pc/index.php?index=realtime&lang=en

Earth rotation & axis orientation





CELESTIAL POLE OFFSETS

give the offsets in longitude dPsi and in obliquity dEps of the celestial pole with respect to its position defined by the conventional IAU precession/nutation models. Their accurate determination from VLBI observation started in 1984.

http://hpiers.obspm.fr/eop-pc/

VLBI – Very Long Baseline Interferometry

VLBI − Very Long Baseline Interferometry

- Technique of linking radio telescopes thousand of kilometres apart to form an interferometer.

VLBA − Very Long Baseline Array

- A chain of ten identical radio telescopes (each with aperture of 25 m) from St Croix in north-eastern Canada to Hawaii in the Pacific, which can be combined to act as an interferometer with a baseline 8,000 km long and a resolution of 0.0002 arc seconds. The systém is controled from the home of the Very Large Array in Cocorro, New Mexico.

The Mount Pleasant Radio Telescope is the southern most antenna used in Australia's VLBI network

http://hpiers.obspm.fr/eop-pc/index.php?index=techniques

Objects on the sky

Optical astronomy

Catalogues, coordinates

Visible objects on the sky

- *Stars*
- *Planets*
- *Comets & asteroids*
- *Nebulae & galaxies*

… (only very brief owerview)

Optical astronomy

What is the **optical astronomy**?

Astronomy based on observations made using visible light, essentially the same part of the electromagnetic spectrum that our eyes are sensitive to.

Star catalogues:
Is an astronomical catalogue that lists stars. There are many of star catalogues.
The first catalogue is made by Hipparchus for about 2 200 years. Most modern catalogues are available in electronic format and can be freely downloaded from NASA's Astronomical Data Center.
Hipparcos (an acronym for "**Hi**gh **p**recision **par**allax **co**llecting **s**atellite") was a scientific mission of the European Space Agency (ESA), launched in 1989 and operated between 1989 and 1993. See particulars http://www.cosmos.esa.int/web/hipparcos.

Messier catalogue:
Catalogue of *faint astronomical objects* compiled by Charles Messier in the second half of the 18th century as an adjunct to his interest in comets. The Messier Catalogue is now regarded as his chief scientific legacy. The final version of the catalogue lists 110 objects, many now known to be galaxies (such as M31. the Andromeda galaxy) but there are five mistakes in the catalogue (numbers M40, M47, M48, M91 and M102), so the actual number of objects in it is 105.

Coordinates

Two **equatorial coordinates** (first used in the 2nd century BC by Hipparchus):

Right ascension (Rec, *Φ, α*)
One of two coordinates used in astronomy to define the angular distance of the object eastward from a standard point, known as the vernal equinox - equivalent to celestial longitude. It is measured in hours, minutes and seconds;1h = 15 arc degrees.

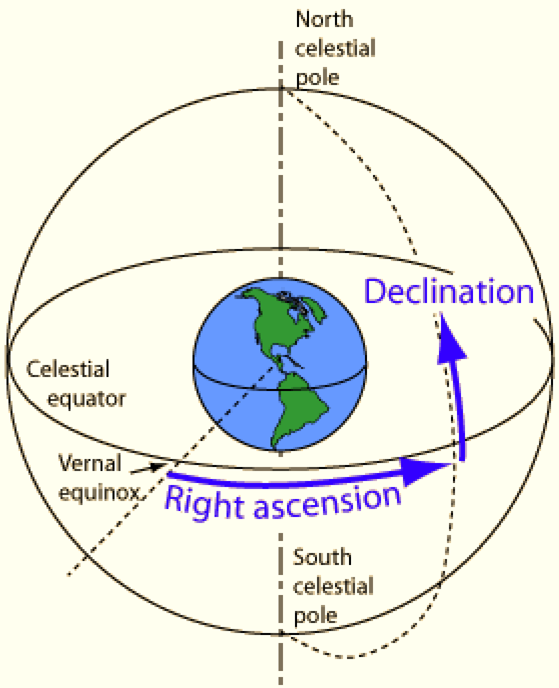
Declination (Dec, *δ, Δ*)
One of two coordinates used in astronomy to define the position of an object on the sky. Declination (dec) is the angular distance of the object north or south of the equator - equivalent to celestial latitude.

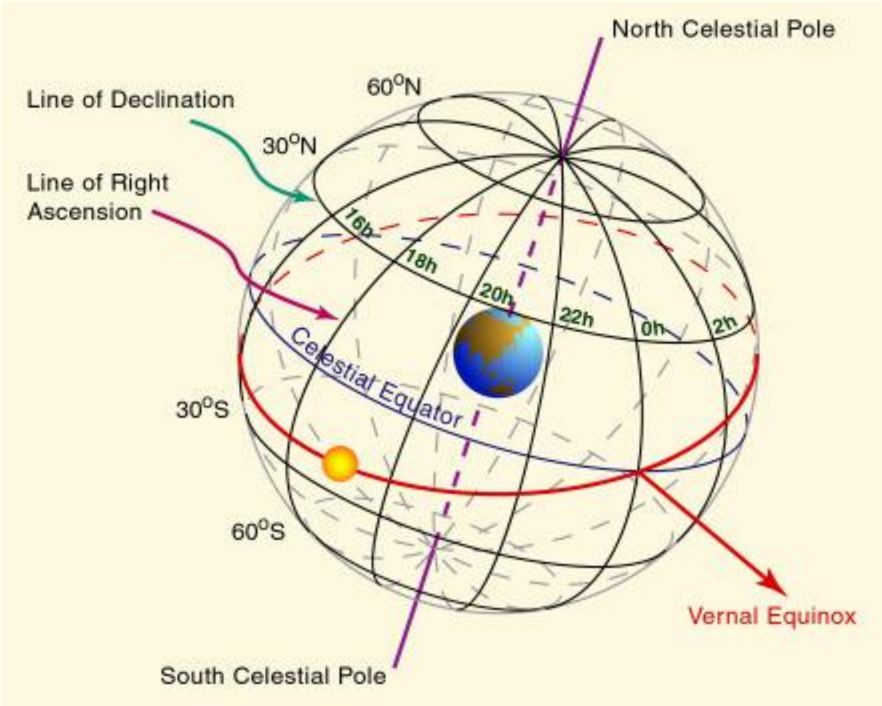
And where is the origin?

Equinox
The moment in the Earth's orbit when the Sun seems to cross the celestial equator, and the day and night are the same length, everywhere in Earth. The spring (or vernal) equinox occurs on 21 March; the autumn equinox occurs on 23 September (the names were given by chauvinistic astronomers in the Northern Hemisphere; the seasons were reversed in the Southern Hemisphere).

Vernal equinox define the origin for equatorial coordinates, for it is $\delta = 0°$, $\Phi = 0h00'00''$.

Coordinates





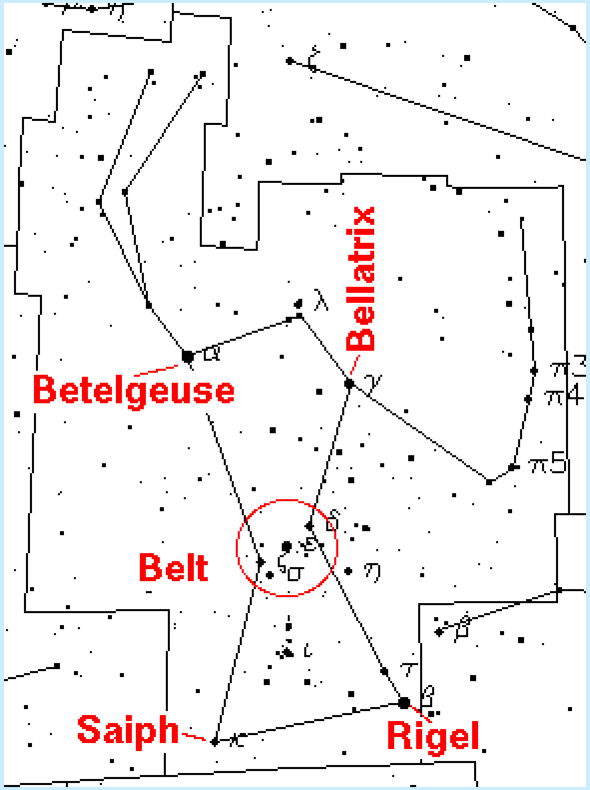
Stars

Proxima Centauri

The closest known star to the Sun, at present at a distance of 1,295 parsecs. Proxima Centauri is a faint dwarf star, with a mass only one-tenth that of the Sun. It is almost certainly physically associated with Alpha Centauri, orbiting that binary star system at a great distance.

Betelgeuse

Bright red star making the shoulder of the constellation Orion (at the top left of the constellation, as viewed from the Northern Hemisphere). Betelgeuse, also known as Alpha Orionis, is a red supergiant at a distance of 200 parsecs. It has diameter 800 times that of the Sun, measured directly by the interferometry.



Interferometry

Technique used primary in radioastronomy but it is also used in optical astronomy. The technique was pioneered by A. A. Michelson and colleagues at the Mount Wilson Observatory in 1920, using two mirrors mounted on a steel beam to deflect light from the same star on to the mirrors mounted on a steel beam to deflect light from the same star on to the main mirror of the 100-inch (254 cm) Hooker telescope. Studies of the interference pattern made by combining the two beams of light made it possible to determine the angular size of the star Betelgeuse as 0.047 arc seconds.

Bodies of the Solar System

Main classification (from 26th General Assembly of IAU in 2006):

- **Planets:** in direct orbit of the Sun, spherical shape, gravitationally dominant
- **Dwarf planets:** in direct orbit of the Sun, spherical shape
- **Small Solar System bodies (SSSB)**: every other bodies

Notes:

- **Spherical shape** means here as consequence of hydrostatic equilibrium.
- **Gravitationally dominant** means here that the object cleared the neighborhood.

Other frequently used names:

Minor planets, Planetoids: some of SSSB but not comets (see http://www.minorplanetcenter.net/)
(NEAs, NEO: apollos, athens, amors, asteroid belt, centaurs, trojans, plutoids, …)
Asteroids: small rocky objects of irregular shape, near circular trajectory
Comets: big eccentricity, lump of icy material and dust

Kuiper Belt: see next
Oort Cloud: see next

Bodies of the Solar System

Statistics to the March 2018 (from Wikipedia)

Stars	1 (Sun)
Known planets	8 (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune)
Known dwarf planets https://en.wikipedia.org/wiki/Dwarf_planet	Possibly several hundred, five currently recognized by the IAU (Ceres, Pluto, Haumea, Makemake, Eris)
Known natural satellites	472 (175 planetary 297 minor planetary)
Known minor planets	707,664
Known comets	3,406
Identified rounded satellites	19

https://en.wikipedia.org/wiki/Solar_System https://en.wikipedia.org/wiki/List_of_minor_planets

Asteroid belt, Cuiper delt, Oort cloud

Asteroid belt: The asteroid belt is the circumstellar disc in the Solar System located roughly between the orbits of the planets Mars and Jupiter.

Cupier belt: is a circumstellar disc in the Solar System beyond the planets, extending from the orbit of Neptune (at 30 AU) to approximately 50 AU from the Sun.

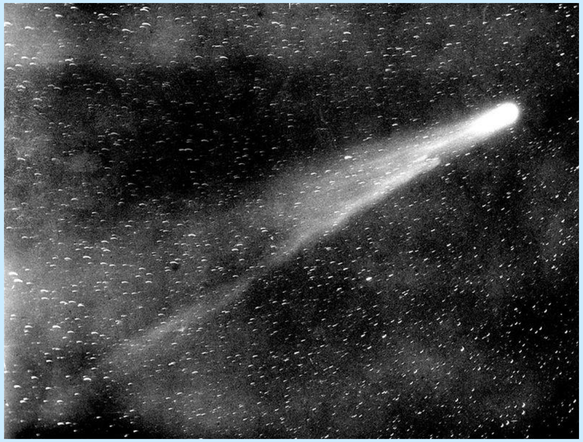
Objects in resonance with Neptune in Cupier belt:
Plutinos … 3:4, 2:3 Cubiwanos … 3:5, 4:7, 1:2   Twotinos … 2:5

Oort Cloud: is a theoretical cloud of predominantly icy planetesimals believed to surround the Sun to as far as somewhere between 50,000 and 200,000 AU (0.8 and 3.2 ly)

See animations of body's of Solar System from
http://www.minorplanetcenter.net/iau/Animations/Animations.html

http://www.minorplanetcenter.net/iau/Animations/Middle_2011.gif
http://www.minorplanetcenter.net/iau/Animations/Inner_2011.gif
http://www.minorplanetcenter.net/iau/Animations/EarthRide2008.gif

Small bodies of Solar System



Halley's Comet (1910), named after the astronomer Edmund Halley for successfully calculating its orbit

243 Ida and its moon Dactyl. Dactyl is the first satellite of an asteroid to be discovered.

Czech observatory specialised to the minor planet’s and comet’s observing: http://www.klet.org/

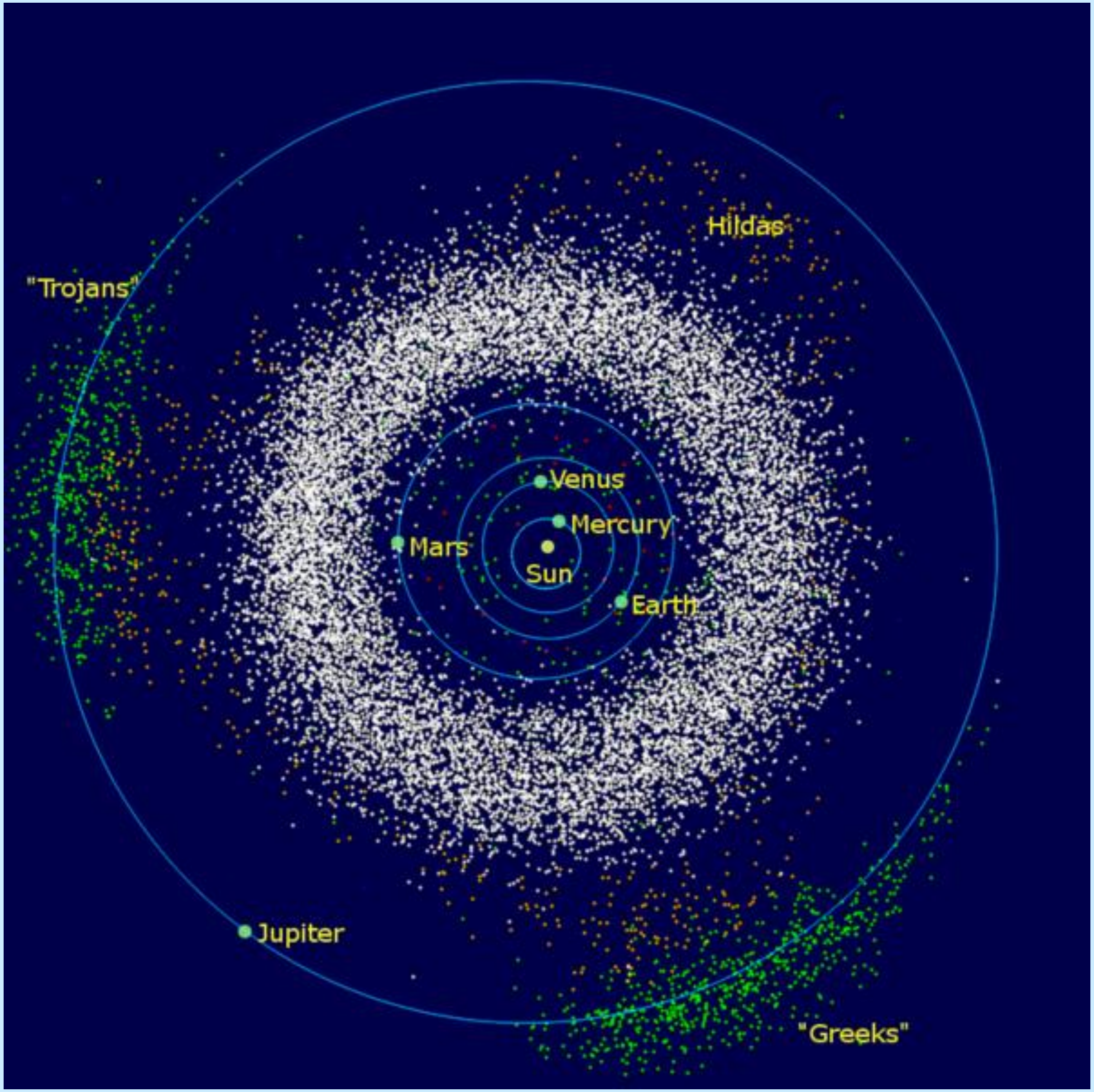
Approximate number of asteroids N larger than diameter D

D	100 m	300 m	500 m	1 km	3 km	5 km	10 km	30 km	50 k m	100 km	200 km	300 km	500 km	900 km
N	~25,000,000	4,000,000	2,000,000	750,000	200,000	90,000	10,000	1100	600	200	30	5	3	1

Asteroids

Asteroids
Rocky object, smaller than a planet, in orbit around the Sun. Most asteroids congregate in orbits between those of Mart and Jupiter, where there are estimated to be a million objects bigger than 1 cm across. The cosmic rubble from the formation of the Solar System, and may represent the kind of material than planets like the Earth formed out of.

1. Ceres (Dwarf planet from 2006)
2. Pallas
3. Juno
4. Vesta
5. Astraea
6. Hebe
7. Iris



Asteroids & comets

Comets

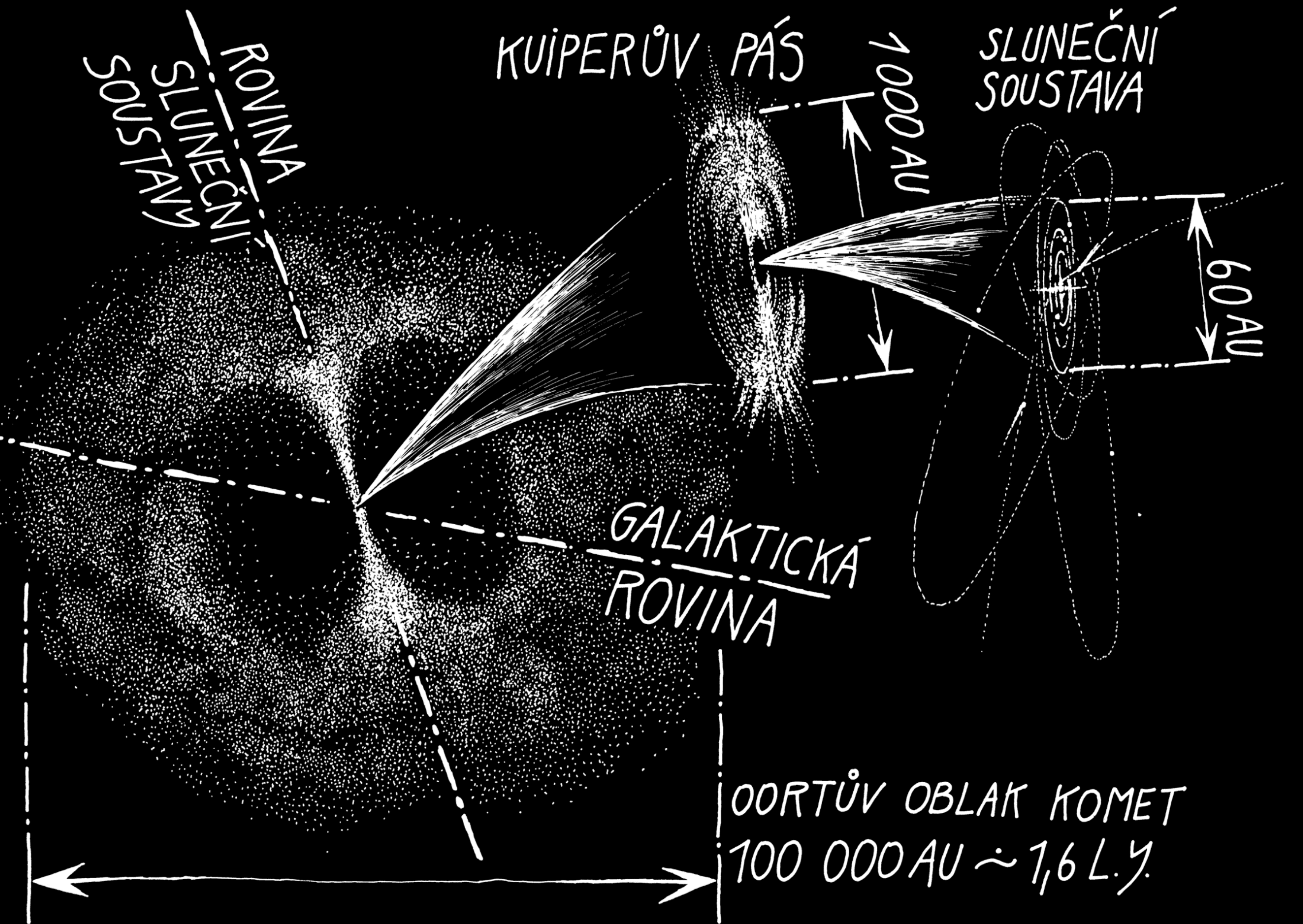
One of the minor constituents of the Solar System, a comet is a lump of icy material and dust (perhaps several lumps moving together), which becomes visible if it approaches the Sun. The heat of the Sun makes material evaporate from the comet, forming a cloudy coma around the Icy nucleus and a streaming tail of tenuous material which always points away from the Sun, because of the pressure of the solar wind. This gives comets their name, from the Greek kometes, meaning a long-haired star. The 'dirty snowball' model was proposed by Fred Whipple in 1949, and has been confirmed by visits of unmanned spaceprobes to comets.

Comets are thought to originate in a spherical shell or halo, beyond the orbits of the planets and about halfway to the nearest star (tens of thousands of astronomical units from the Sun). Comets may have been stored in this Oort cloud since the formation of the Solar System; a rival theory suggests that the Oort cloud is renewed by 'new' comets picked up by the Solar System when it passes through giant molecular clouds. The Oort cloud may contain 100 billion comets. From time to time, the gravitational influence of a passing star will disturb the Oort cloud and send comets in towards the Sun, where the gravitational influence of Jupiter and the other giant planets may capture them into relatively short period orbits.

An intermediate ring of comets and other cosmic debris, called the Kuiper Belt, lies beyond the orbits Pluto and Neptune, between about 35 and 1,000 astronomical units from the Sun. It contains perhaps 100 milion comets, some of which may have fed into the belt from the Oort cloud. Whatever their origin, objects in the belt can eventually feed into the planetary part of the Solar System.

The solid nucleus of typical comet is quite small – Halley's Comet, for example, has a nukleus about 15 km by 10 km by 10 km – but the surrounding coma may be hundrets of thousands of kilometres across and the tail may stretch for 100 milion km. The material to make the coma and tail all comes from evaporation of the nucleus, so a comet nucleus gets smaller each time it passes near the Sun, and eventually fades to leave a trail of orbiting dust particles, which cause meteor showers when the Earth runs through the stream.

Comets are arbitrarily divided into two classes, long period and short period (less and more then 200 years period).


ROVINA SLUNEČNÍ SOUSTAVY
KUIPERŮV PÁS
1000 AU
SLUNEČNÍ SOUSTAVA
60 AU
GALAKTICKÁ ROVINA
OORTŮV OBLAK KOMET
100 000 AU ~ 1,6 L.Y.

Nebulae

Old name for any patches of light on the sky. Many of these are now known to be other galaxies, beyond the Milky Way and are sometimes referred to by the old name of external nebulae. The **Andromeda galaxy**, for example, is sometimes called the Andromeda nebula. Other nebulae are now known to be glowing clouds of gas within our own Galaxy, and they are often the sites of star formation. The **Orion nebula** is a classic example of this kind of nebula. The word 'nebula' is simply the Latin form 'cloud'.

Many nebulae are visible to the naked eye, but the invention of the telescope not only revealed many more nebulae than had been seen by the unaided eye, but also showed that many of the clouds are made up of stars too faint and close together to be distinguished by eye. In the first half of the 19th century, many astronomers, notably the Herschels, believed that all nebulae were made up of stars. The development of spectroscopy in the 1860s showed, however, that some nebulae are in fact cloud of gas. At that time it was still not clear whether the nebulae that are composed of stars lie within the Milky Way or beyond it; the question was not finally resolved until the work of Edwin Hubble and his colleagues gave the first good estimates of the distances to several external nebulae in the 1920s.

Within our Galaxy, bright **emission nebulae** are kept warm by the energy radiated by nearby stars, and show up red in astronomical photographs because of the way the starlight is scattered from dust particles in the nebula (this is exactly equivalent to the scattering that makes the sky look blue). Some dark **absorption nebulae** are visible only because they block out the light from more distant stars - they look like dark holes in the bright backdrop of the stars.

Nebulae

Horse head in Orion and surround – all of nebula types

Nebulae – Crab nebula

Crab nebula

The Crab contains something of interest to almost any astrophysicist.

Some facts about Crab nebula:

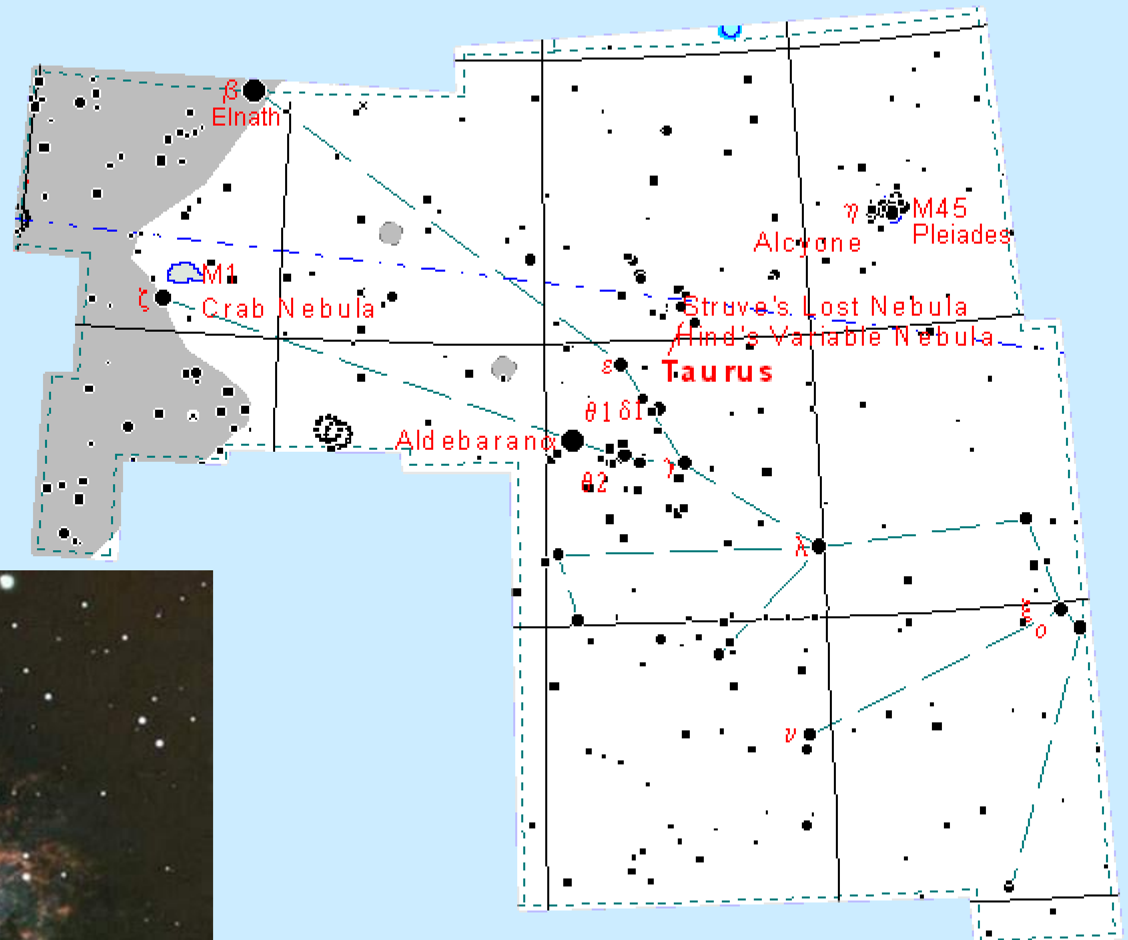
The Crab nebula itself is a glowing cloud of gas and dust in the constellation Taurus
It is about 2 kiloparsecs away from us, also known as Taurus A, M1 and NGC1952.
It has so many names because it appears in almost every observation of the sky at different wavelengths - the Crab was one of the first three radio sources to be identified with known objects, it was second brightest source of gamma rays visible from Earth.

The Crab is the remnant of supernova explosion that was observed by Chinese astronomers in AD 1054, and was temporarily brighter than Venus, being visible in daylight for 23 days.
The cloud of debris produced in that explosion has been expanding ever since, and the materiel in the nebula is still moving outwards at a speed of about 1,500 km per second, telescopically by the English amateur astronomer John Bevis (1693-1771).

The cloud of material contains long, thin filaments that were first observed by Lord Rosse in 1844. His drawings of the filaments in the nebula vaguely resembled the pincers of crab, which is how the Crab nebula got its time.

Nebulae – Crab nebula

Crab nebula:
α = 05h 34.5m,
Δ = +22° 01',
d = 6300 l.y.,
m = 8.4

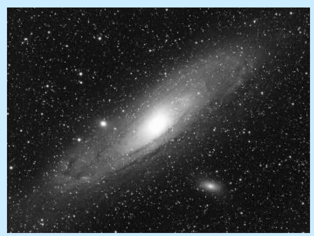


Messier catalogue

M1 Crab nebula:
d = 6300 l.y.,
m = 8.4
supernova remnant

M57 Ring nebula in Lyra
d = 31 600 l.y.,
m = 8.3
planetary nebula

M31 Andromeda galaxy
d = 3 000 000 l.y.,
m = 3.4
galaxy



M92 in Hercules
d = 26 400 l.y.,
m = 6.4
globular cluster

M45 Pleiades
d = 380 l.y.,
m = 1.6
open cluster

http://www.ngc7000.org/ccd/messier.html