Class 4

Sun & Coordinate Systems

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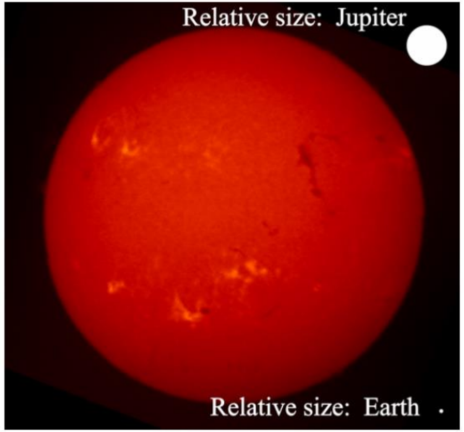
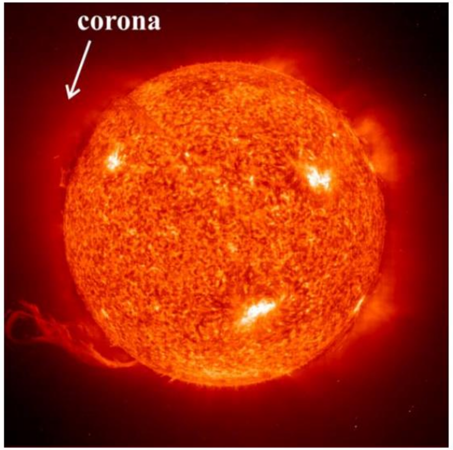
Variable Sun





- The sun is the source of the solar wind.
- **Coronal mass ejections** are large pieces of solar matter ejected from the solar surface. They produce **large non-recurrent geomagnetic storms** when they impinge on the magnetosphere.

Corona

- A corona (Latin for 'crown', in turn derived from Ancient Greek κορώνη, korṓnē, 'garland, wreath') is an aura of plasma that surrounds the Sun and other stars. (https://en.wikipedia.org/wiki/Stellar_corona)
- The Sun’s corona is the outermost part of the Sun’s atmosphere. The corona is usually hidden by the bright light of the Sun's surface. That makes it difficult to see without using special instruments. However, the corona can be viewed during a total solar eclipse.

Image of the solar corona during a total solar eclipse on Monday, August 21, 2017 above Madras, Oregon. Credit: NASA/Aubrey Gemignani

Variable Sun

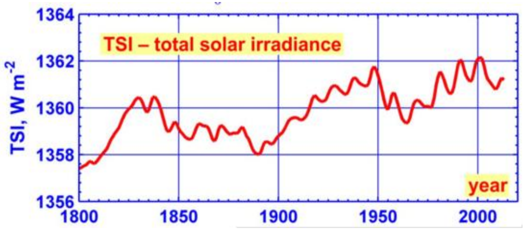
- Solar flares eject large fluxes of energetic particles, mostly protons (energies = many megaelectronvolt = MeV).
- These energetic particles are capable of penetrating spacecraft walls and damaging electronic components.
- Large fluxes of energetic particles may be lethal for humans.
- The Earth's magnetic field protects spacecraft at low earth orbit (LEO) from the damaging effects of extraterrestrial energetic particles. However, these particles pose problems for manned space flight to the Moon, Mars, and other planets.

Electronvolt (eV)

- Amount of kinetic energy gained by a single electron accelerating from rest through an electric potential difference (Voltage) of one volt in vacuum.
- When used as a unit of energy, the numerical value of 1 eV in joules (symbol J) is equivalent to the numerical value of the charge of an electron in coulombs (symbol C).
- It has a value of one volt, 1 J/C, multiplied by the electron's elementary charge e, $\sim 1.6 \times 10^{-19}$ C. Therefore, one electronvolt is equal to $\sim 1.6 \times 10^{-19}$ J.
- The electronvolt, as opposed to the volt, is not an SI unit. The electronvolt (eV) is a unit of energy whereas the volt (V) is the derived SI unit of electric potential. The SI unit for energy is the joule (J).

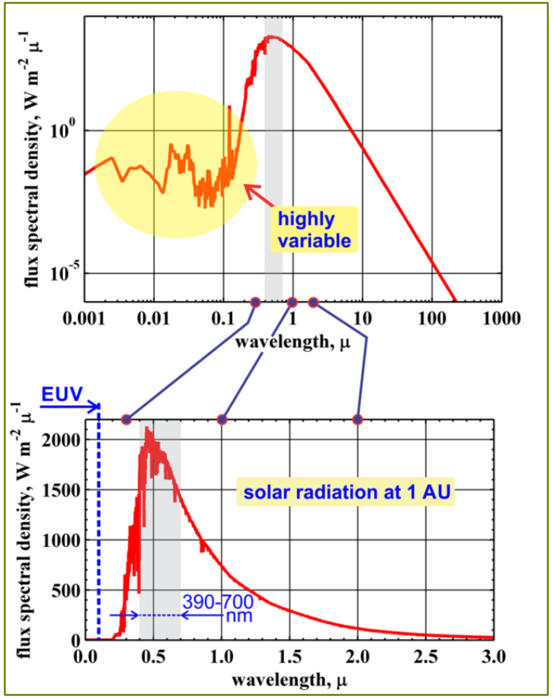
Sun's Electromagnetic Radiation Output

- Spectral distribution of the solar electromagnetic radiation peaks in the visible wavelength range.
- The total radiation flux is almost constant, however the short-wavelength radiation (extreme ultraviolet EUV, X-ray) changes substantially with time.
- The short-wavelength part solar radiation is especially important for processes in the upper atmosphere of the Earth.



Solar "constant"

$$F_S = \int_0^\infty f(\lambda)\,d\lambda = 1360-1362\ \mathrm{W/m^2}$$



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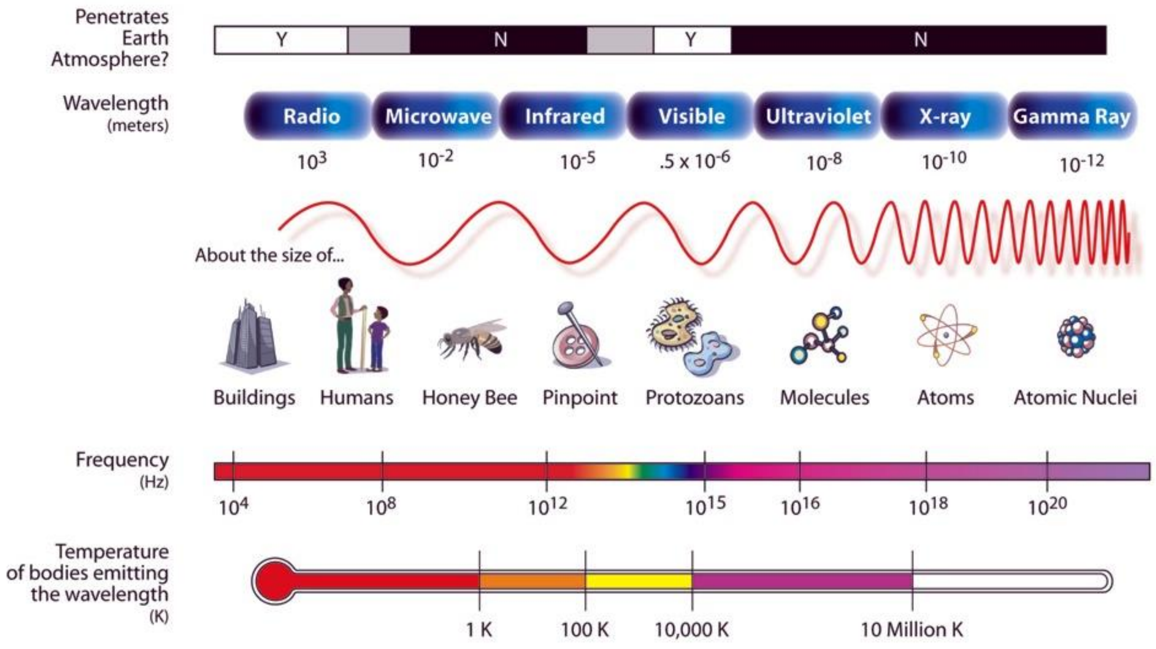
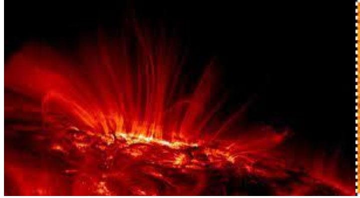
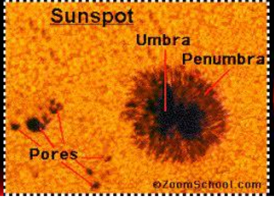
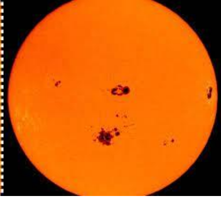
Recall: Electromagnetic Spectrum



- All forms of EM radiation are the same, but they seem very different because of the very different scales involved.
- Radiation can pass around objects which are much smaller than the wavelength.







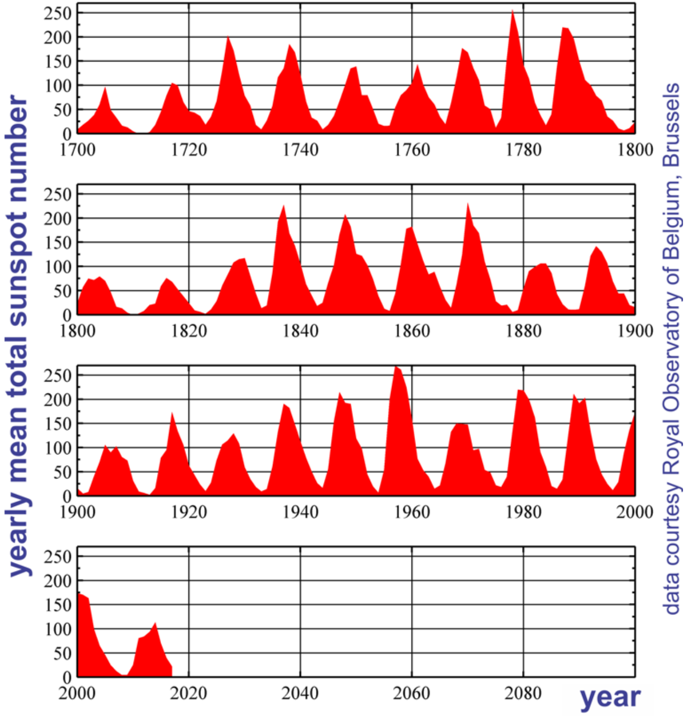
Sunspot

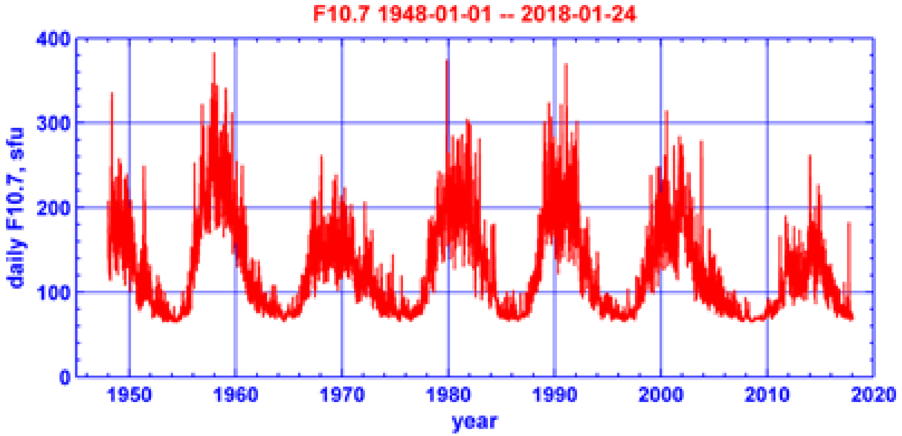
- Sunspots are temporary phenomena on the Sun's photosphere that appear as spots darker than the surrounding areas.
- They are regions of reduced surface temperature caused by concentrations of magnetic field flux that inhibit convection.
- Sunspots usually appear in pairs of opposite magnetic polarity. Their number varies according to the approximately 11-year solar cycle.
- Individual sunspots or groups of sunspots may last anywhere from a few days to a few months, but eventually decay.
- Sunspots expand and contract as they move across the surface of the Sun, with diameters ranging from 16 km (10 mi) to 160,000 km (100,000 mi).
- Larger sunspots can be visible from Earth without the aid of a telescope.
- They may travel at relative speeds, or proper motions, of a few hundred meters per second when they first emerge.

Yearly Mean Sunspot Numbers

- Solar spots served for several hundred years as an indicator of solar activity.
- A typical solar cycle lasts 11 years with solar activity passing through a solar maximum and solar minimum.
- The short-wavelength radiation (extreme ultraviolet EUV and X-rays) from the sun varies much more than visible radiation.
- The variation in the upper atmosphere and ionosphere is closely related to the solar EUV radiation.
- Since EUV does not penetrate to the ground, a correlation with the (proxy) 10.7 cm radiation is used.
- **The mean solar daily flux at the wavelength λ=10.7 cm is used as an indicator for the solar EUV radiation reaching the top of the earth's atmosphere.**

Yearly Mean Total Sunspot Number





Mean solar daily flux at the wavelength λ=10.7 cm

Solar min: 1996–1998, 2007–2009, 2018-2020
Solar max: 2001–2003, 2012–2014, 2023-2025

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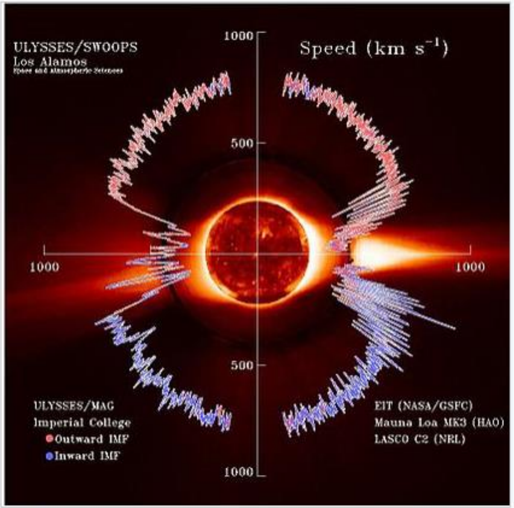
Solar Wind

- The solar wind is a stream of charged particles released from the upper atmosphere of the Sun, called the corona. This plasma mostly consists of electrons, protons and alpha particles with kinetic energy between 0.5 and 10 keV.
- At a distance of more than a few solar radii from the Sun, the solar wind reaches speeds of 250–750 km/s and is supersonic, meaning it moves faster than the speed of the fast magnetosonic wave.



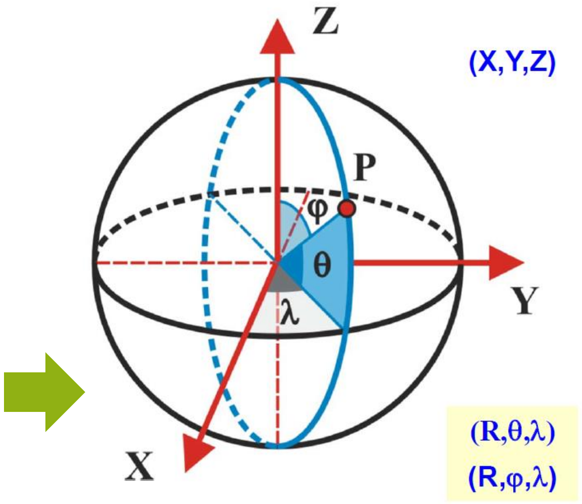
Ulysses' observations of solar wind speed as a function of helio latitude during solar minimum. Slow wind (≈400 km/s) is confined to the equatorial regions, while fast wind (≈750 km/s) is seen over the poles.[1] Red/blue colors show inward/outward polarities of the heliospheric magnetic field.

Solar Wind

- Expansion of the solar corona gives rise to the solar wind, which is a highly supersonic flow of plasma.
- Solar Wind consists mostly of protons (**$H+$**) and electrons with a small addition (about 5%) of alpha-particles (**He^{2+}** ions) and a very small presence of highly ionized ions of other elements.
- Solar wind accelerates within 0.2 AU from the Sun, and it propagates with a near constant speed of about V_{SW} = 300–800 km/s.
- The solar wind number density is inversely proportional to the square of the distance from the Sun; it is approximately **$n_{SW} = 5\ cm^{-3}$** (five protons and five electrons per cubic centimeter) at 1 AU.

Coordinate Systems

- Coordinate systems play an exceptionally important role in exploration of space. They provide the means to describe complicated motions of celestial bodies and spacecraft.
- The most commonly used coordinate system in science and engineering is the rectangular **Cartesian coordinate system** formed by three orthogonal (perpendicular to each other) vectors x,y,z.
- The coordinate system that is used most often in space (and in astronomy as well) is the **spherical coordinate system**.
- In the spherical coordinate system, one describes the position of a point by a distance from the center of coordinates and two angles between the direction to the point and two coordinate-system-specific **reference vectors**.



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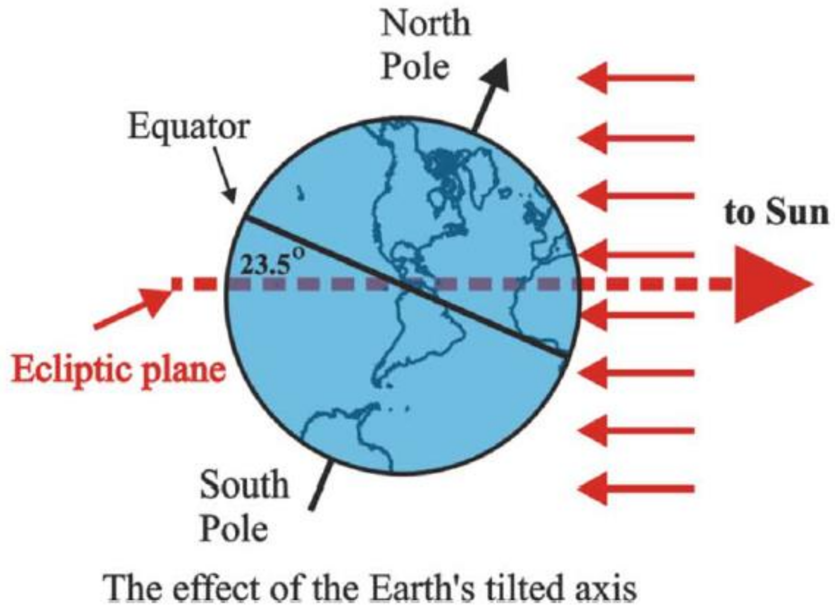
Coordinate Systems: Center

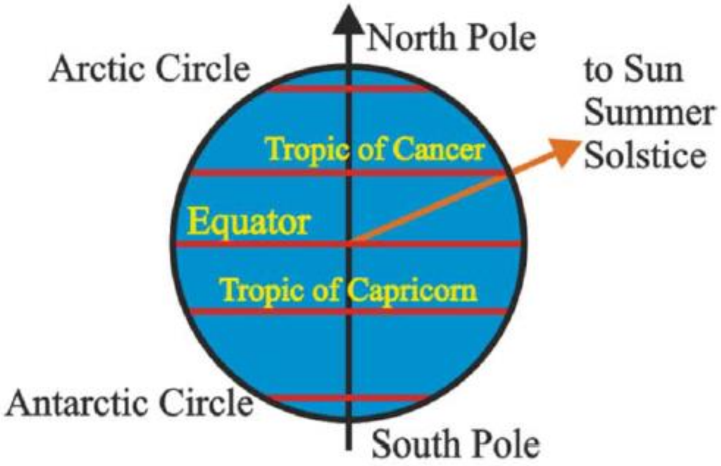
- Depending on application, the center of the coordinate system is selected in such a way as to simplify the description of particle (spacecraft) motion:
  - ✓ geocentric
  - ✓ heliocentric
  - ✓ planetocentric
  - ✓ center of galaxy

Coordinate Systems: Reference vectors

- Reference vector selection determines the fundamental (reference) plane normal to the vector
- Associated with natural phenomena (provided by nature)
  - ✓ rotation of the earth about its axis defines the **equatorial plane**
  - ✓ revolution of the earth around the sun defines the **ecliptic plane**
- assumed fixed in inertial space
  - ✓ in reality, **precession**
- reference vectors are preferred to be perpendicular to each other
  - ✓ how do we define the second vector?

Ecliptic and Equatorial Planes

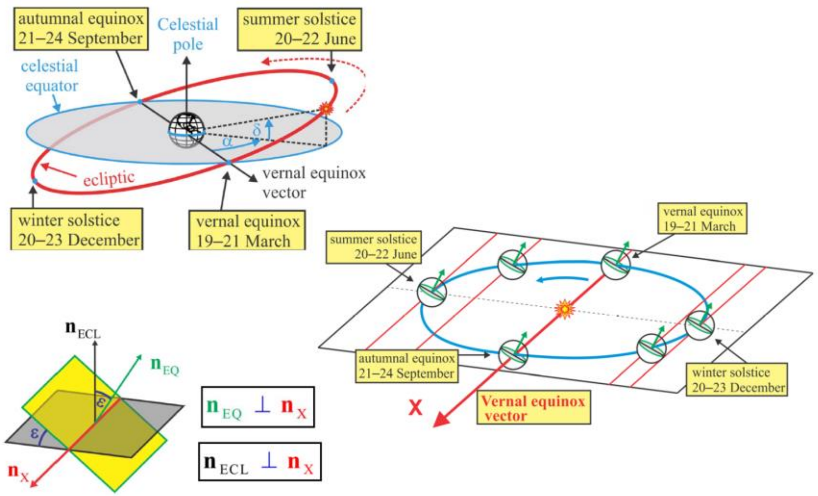




Ecliptic and Equatorial Planes

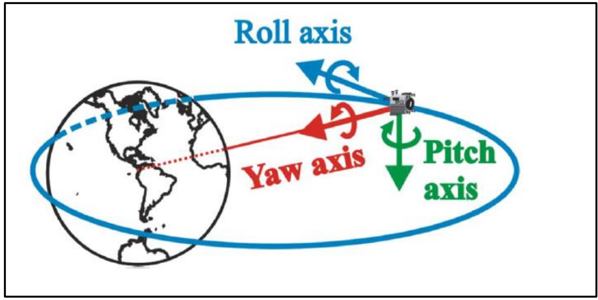
- The plane, which contains the earth's orbit around the sun, is called the **ecliptic plane**. Obviously, the sun is in this plane. The axis of the earth's revolution around the sun (and correspondingly the ecliptic plane) is fixed in inertial space (except for small precession).
- An angle between the orbital plane of a planet and the ecliptic plane is called the **inclination of the orbital plane**. The orbits of the planets are close to the ecliptic plane, except those of Mercury and especially Pluto.
- The Earth rotates about its axis (which defines the South-North direction). This axis of rotation is fixed in inertial space (except for small precession) and its direction does not change as earth moves around the sun.
- The axis of the Earth rotation is not normal to the ecliptic plane; this is the most important factor "responsible" for seasons. The angle between the axis of earth's rotation and the direction perpendicular to the ecliptic plane is **$\varepsilon = 23.44°$ (obliquity of the ecliptic).**

Vernal Equinox Vector



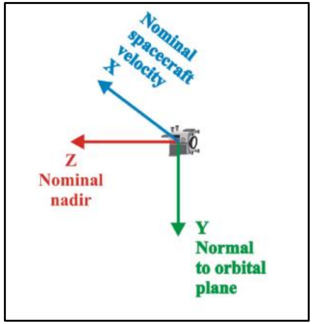
- The vernal equinox is a reference vector to establish longitude in both celestial and ecliptic systems of coordinates.
- There are two equinoxes each year, in the spring and in the fall. At equinox, earth is located at the intersection line of the equatorial and ecliptic planes. The equinox in the spring (around March 21) is called the vernal equinox; the equinox in the fall – the autumnal equinox.
- The direction **from** the center of mass of the Earth to the center of the sun at the vernal equinox is **the reference vector (the vernal equinox vector)** to determine longitude.
- The equinox vector precession rate is ~**0.014 degrees per year.**

Coordinate Systems



Fixed in inertial space	**Pole (Z)**	**X axis**
Celestial (inertial)	Celestial pole	Vernal equinox
Ecliptic	Ecliptic pole	Vernal equinox

Fixed with respect to orbit	Pitch, Roll, and Yaw
Fixed with respect to spacecraft	X, Y, Z



Time

Apparent Solar Time

- One day is determined as an interval between two successive high noons (two successive solar transits across the local meridian). The problem is that all days are slightly different because
  - Earth's orbit around the Sun is not exactly circular
  - Earth rotates about its axis
  - the spin axis is not normal to the ecliptic plane
  - Earth's axis slightly wobbles
- All these effects are small and predictable. So it is possible to build a time scale based on the mean motion of the Earth relative the Sun, **mean solar time**.

Mean solar time

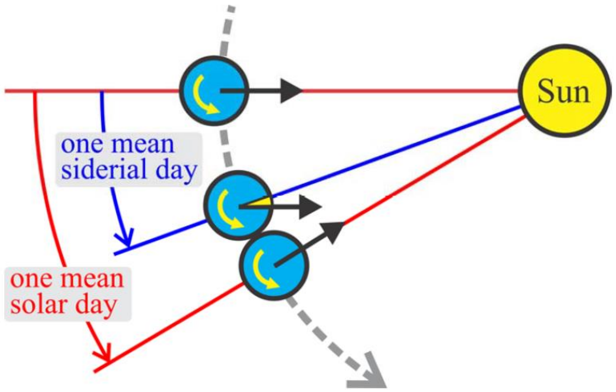
- This is the time that you have on your watch.
- It assumes a circular orbit of the Earth, the spin axis normal to the ecliptic plane, no axis-wobbling, etc.
- A mean solar day is equal to **exactly**

  24 hours = 1440 min = 86,400 sec

Universal Time

- The mean solar time at Greenwich (England) is called the Universal Time (UT).
- Scientific data obtained from spacecraft are very often time-tagged using the UT system.

Sidereal and Solar Time



항성시

- Earth rotation in inertial space (with respect to the stars) determines the sidereal time. One sidereal day is slightly different from the mean solar day.

mean solar day = 1.0027379 mean sidereal day

1 sidereal day = 23 hr 56 min 4.09 sec = 86 164.09 sec

1 mean solar day = 24 hr 00 min 00 sec = 86 400 sec

- spacecraft in geostationary orbit (GEO)

Thank you!

