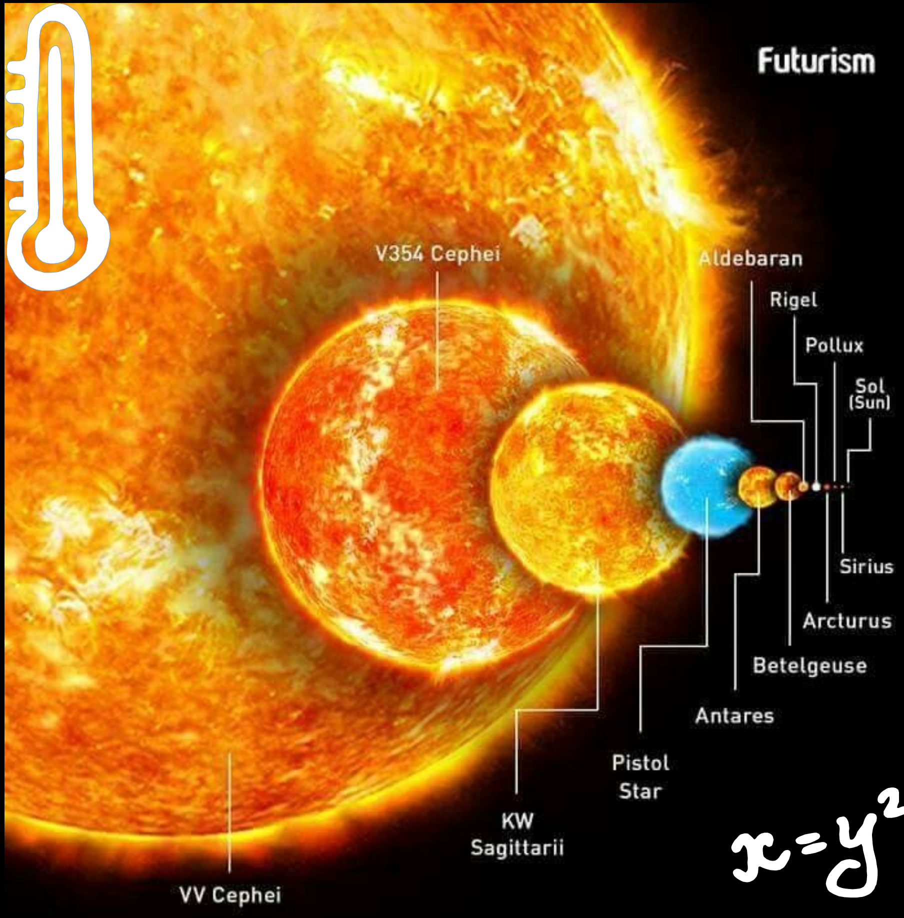
Astronomical Measurements

(Day 02)



$x=y^2$

Today

1. Quantities to be measured
2. Electromagnetic spectrum
3. Earth’s atmosphere
4. ~~Other carriers of information~~

Observational astrophysics

1. Measure properties from astronomical sources

2. Estimate the errors of the measurements (stochastic and systematic)

3. Use the measurement(s) to estimate other physical parameters

4. Compare observations with astrophysical models and theories

Observational astrophysics

1. Measure properties from astronomical sources

2. Estimate the errors of the measurements (stochastic and systematic)

→ Most of our time on these

3. Use the measurement(s) to estimate other physical parameters

→ Some discussion about this

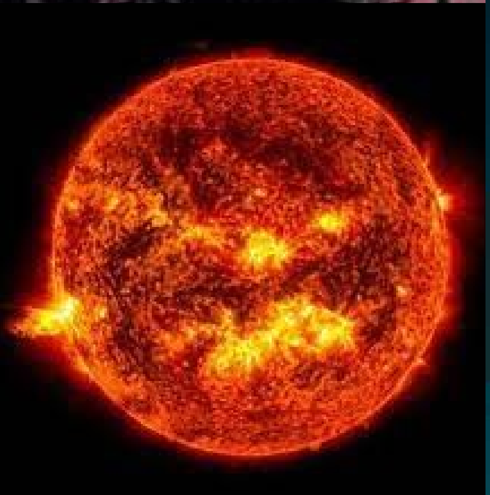
4. Compare observations with astrophysical models and theories

→ This is for you

What do we see, if we look to the sky?

What do we see, if we look to the sky?



What do we see, if we look to the sky?

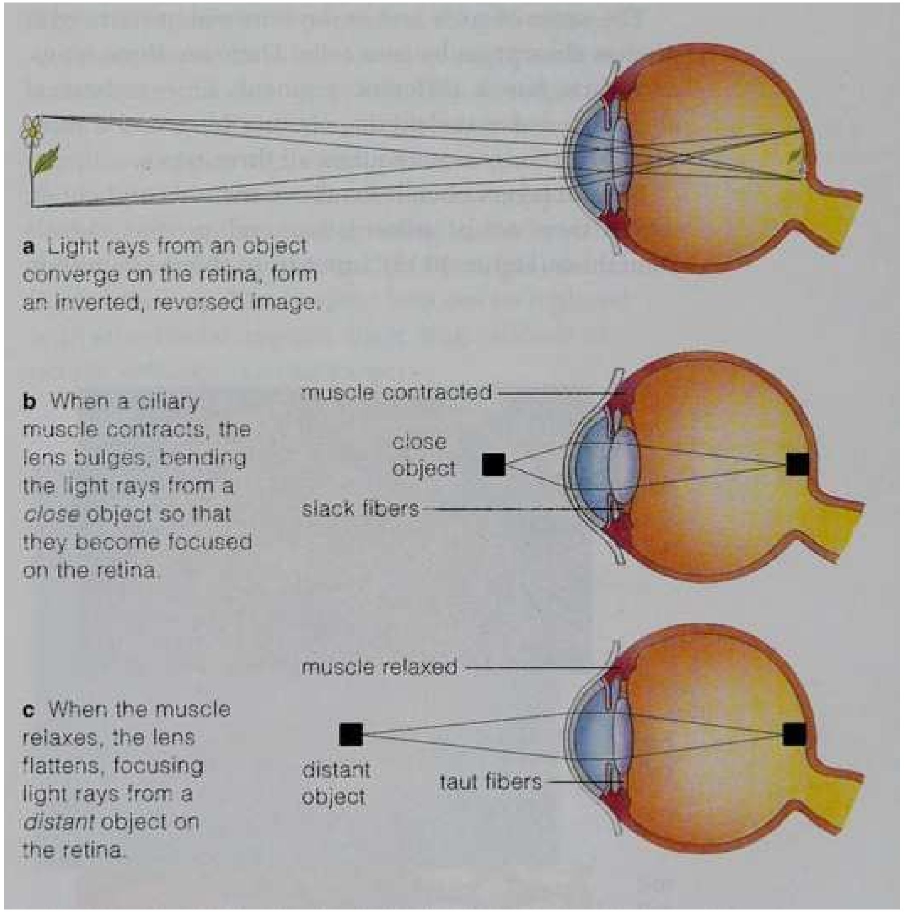
What would you like to measure, from those objects?

- Position of the source, i.e. two coordinates of the position projected on the celestial sphere;
- Distance to the source, i.e. the third spatial coordinate of the source;
- Size and shape of the source (in case it can be resolved);
- Motion (projected) on the sky (the proper motion);
- Motion along the line of sight (the radial velocity);
- (Projected) Rotation and orientation;
- Flux (i.e. a measurement of the rate with which energy travels through a surface. We will cover what astronomers mean by that below);
- Spectral energy distribution (energy as a function of frequency or wavelength);
- Polarization;
- Acceleration (in certain cases);
- The time variability of (some? of) the previous quantities.

Observing in the visible

Human eye: the first astronomical instrument

- Defines the visible spectrum (~380-700 nm)
- Region of strongest output from the Sun
- With naked eye observations, ancient civilizations:
  discovered 5 planets, defined constellations, distinguished the zodiacal belt (the region within which the Sun, Moon and planets move), observed eclipses, observed comets, catalogued the visible stars, observed novae,…
- Interpretation of the observations was of course limited



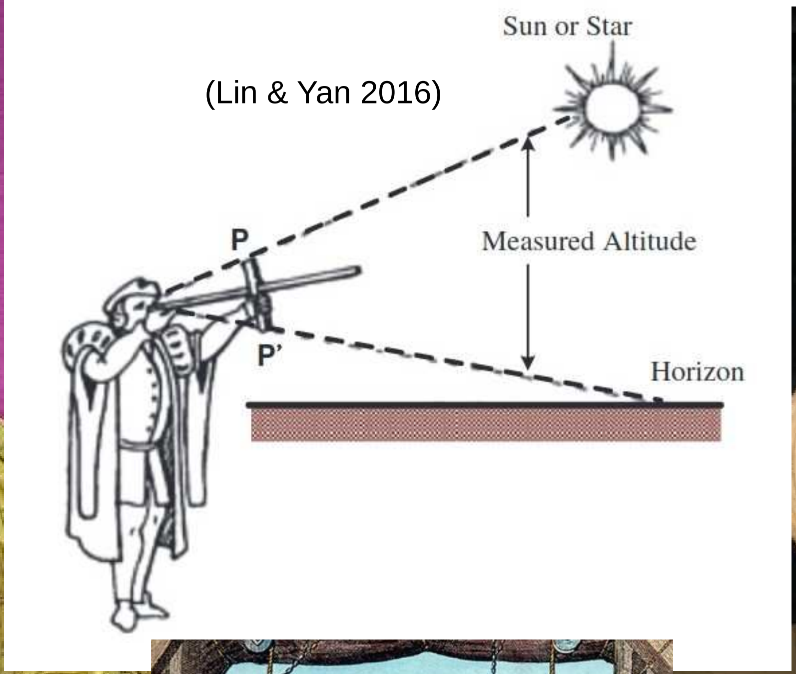
(Starr 2006)

Before the telescope

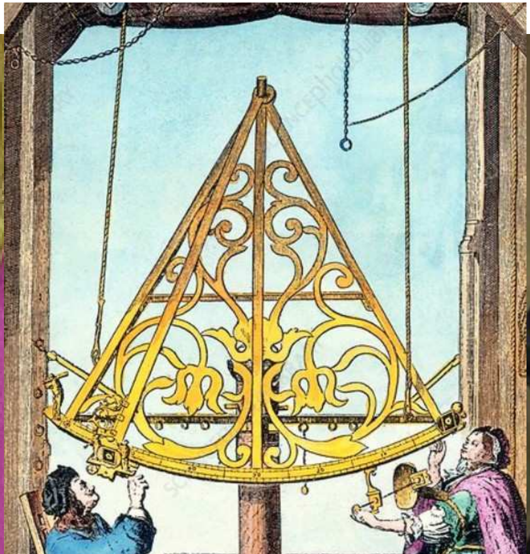
Ancient instruments: used for measurements, calculations, and demonstrations

- Cross staff (Jacob's staff): for angles
- Armillary sphere: model of the celestial sphere, usable for observations
- Astrolabe: a projection of the celestial sphere onto a plane (finding the position of stars, time of celestial events)
- Quadrant and Sextant: (1/4 or 1/6 of a circle) measure altitude above the horizon and angular distance between stars

(Tycho Brahe and a mural quadrant)

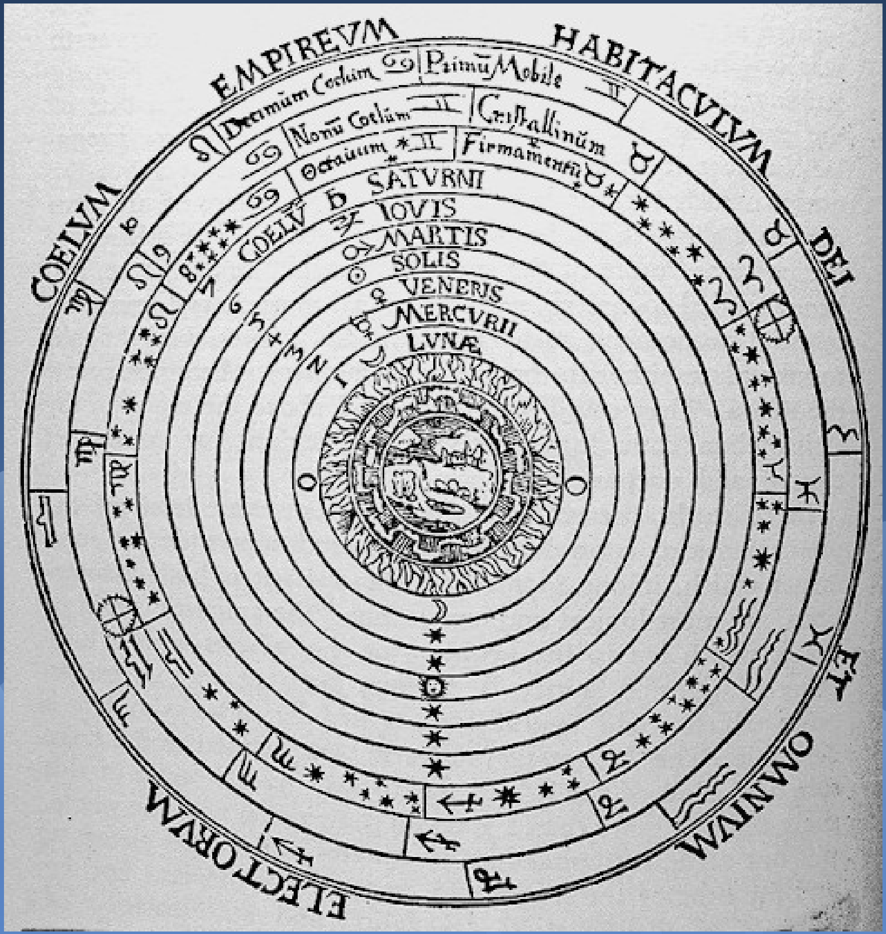


(Lin & Yan 2016)



Ptolemy's Almagest (~ 150 A.D.)

- 13 books on the stars and planets (see Peters & Knobel 1915; Toomer 1984)
- Earliest surviving stellar catalogue (1022 stars; mostly from Hipparchus)
- With positions (ecliptic coordinates) and magnitudes
- Refers to and uses the work of Hipparchus



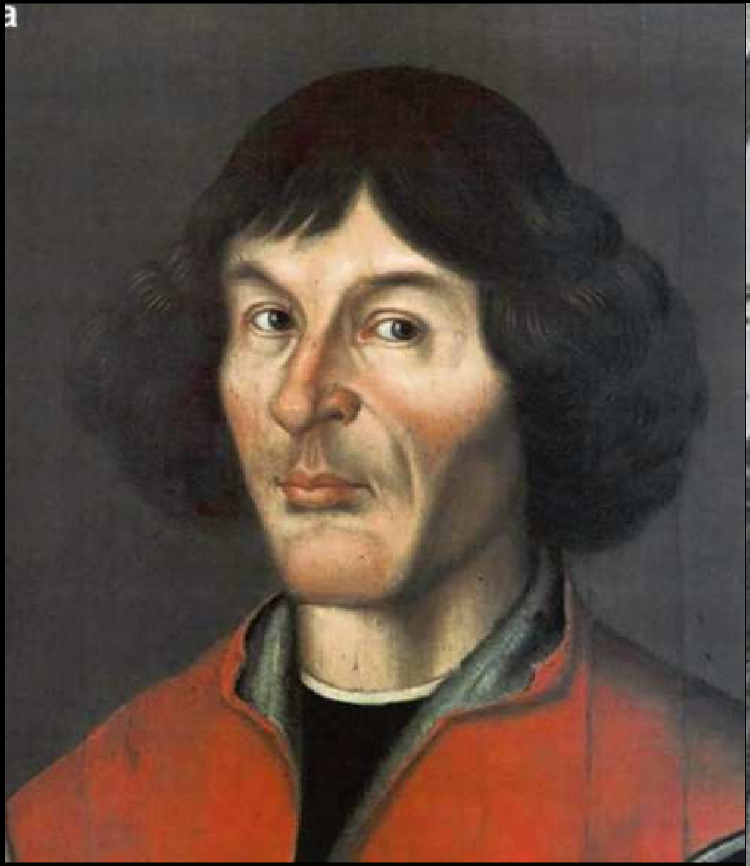
Positions and motions

Measurements and mathematical descriptions of the sky: important breakthroughs before the telescope

- Astrometry: measurement of positions on the sky of stars and other celestial objects
- Hipparchus: precession of Earth's rotation axis
- Nicolaus Copernicus (1473-1543): planetary motions in a heliocentric system: not more accurate, but more elegant and simple (see Evans 1998)
- Tycho Brahe (1546-1601): improved instruments and measurements
- Johannes Kepler (1571-1630): used Brahe's data, Mars in particular, to derive the three laws of planetary motion

(Evans 1998)

All before the telescope



Nicolaus Copernicus

Tycho Brahe

Johannes Kepler

Stellar brightness

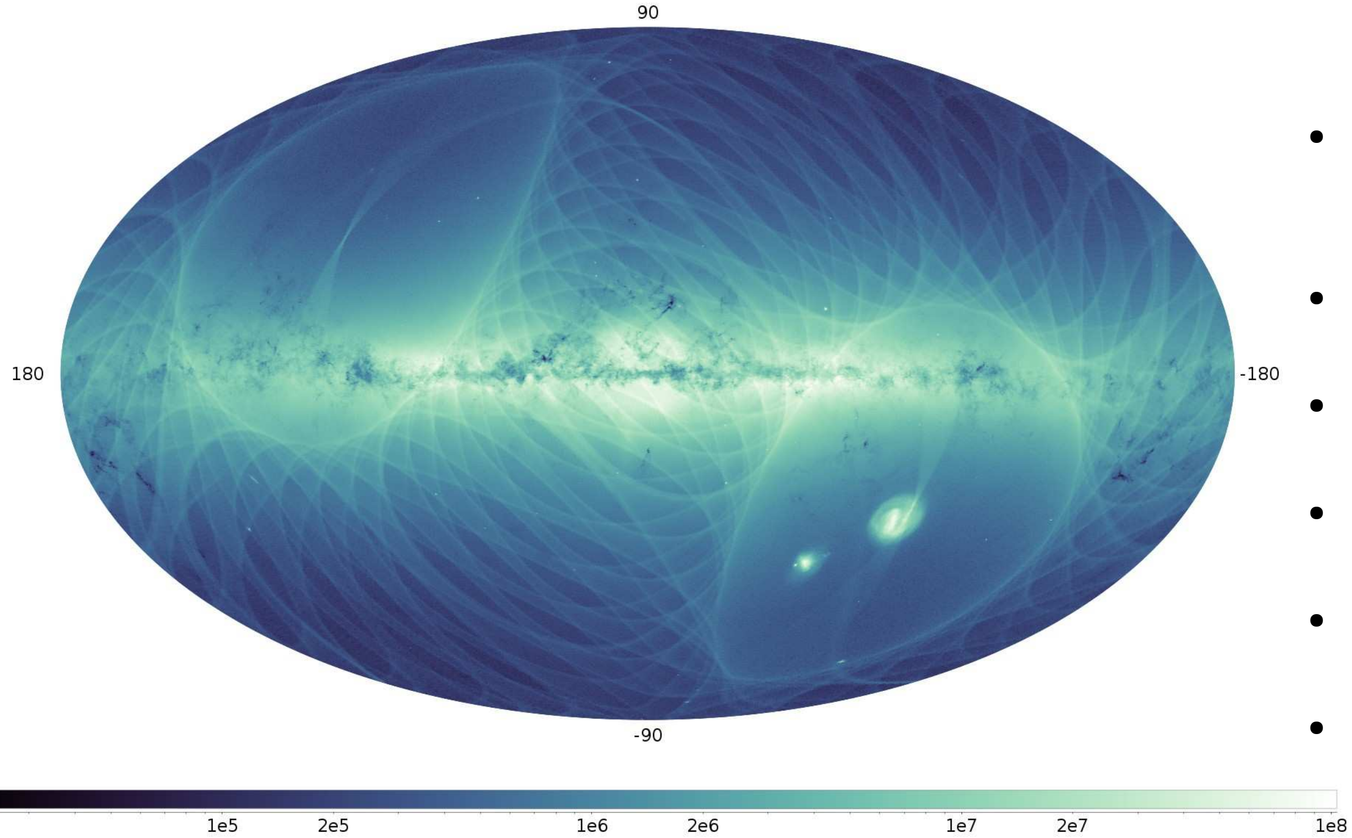
Magnitudes: ranking of stars in terms of brightness (by eye) attributed to Hipparchus

- Connected to the apparent flux
- Magnitude 1 to 6, brightest to faintest. Δ of 5 mags = factor 100 in brightness
- The eye response is ~logarithmic (see Weber-Fechner laws of psychophysics)
- Al Sufi: ~1000 stars in 964 (Schaefer 2013)
- Tycho Brahe: ~1000 stars in 1598 (Verbunt & van Gent 2010a)
- Johannes Hevelius: ~1500 stars in 1690 (Verbunt & van Gent 2010a)

(Farnese Atlas)

(Stellar catalogue of Hipparchus – Schaefer 2005)

Gaia stellar catalogue



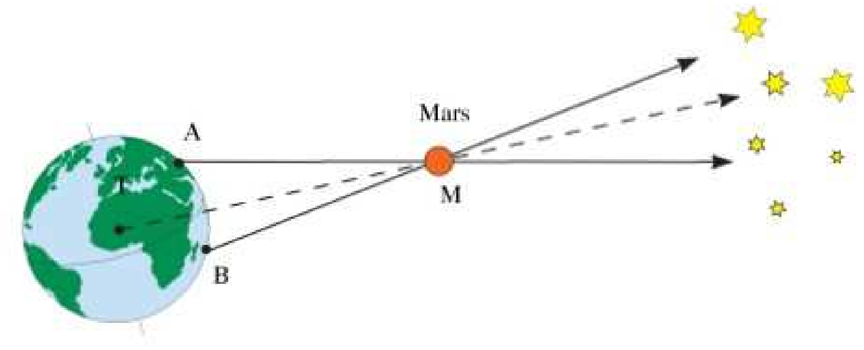
Gaia DR4 sky map in preparation. In galactic coordinates, illustrating the density of measurements processed by the source cross-match (Credit: Gaia; 03.03.2021)

- Gaia EDR3 (Gaia collaboration 2021):
- 1 811 709 771 stellar positions
- 1 806 254 432 w/ G magnitudes
- 1 542 033 472 w/ BP
- 1 554 997 939 w/ RP
- 1 540 770 489 w/ (BP-RP)

Distances and sizes

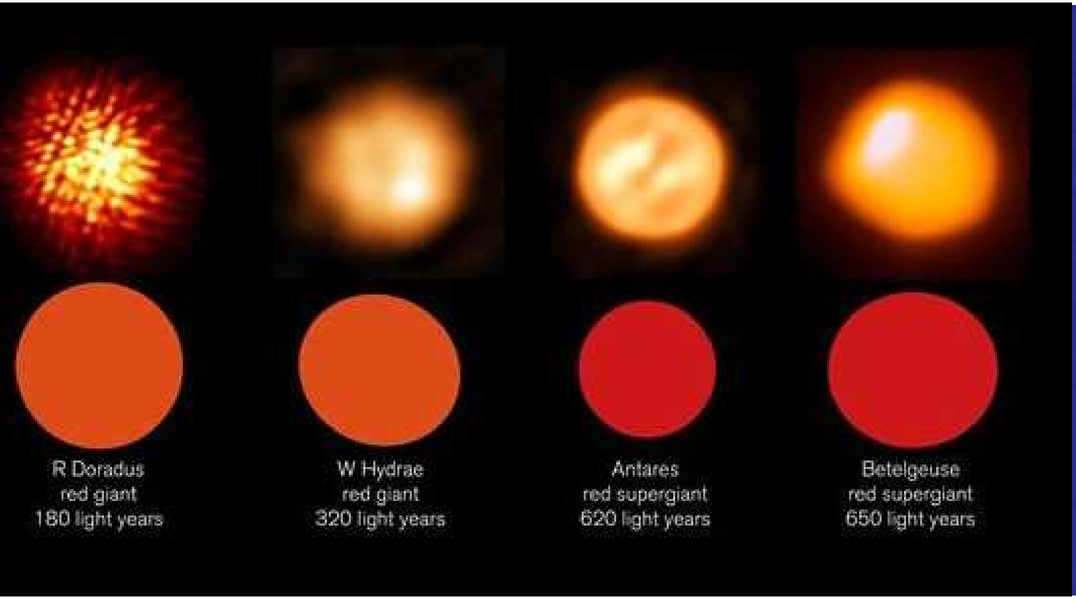
How far away? The Moon, the Sun, the planets, comets, stars

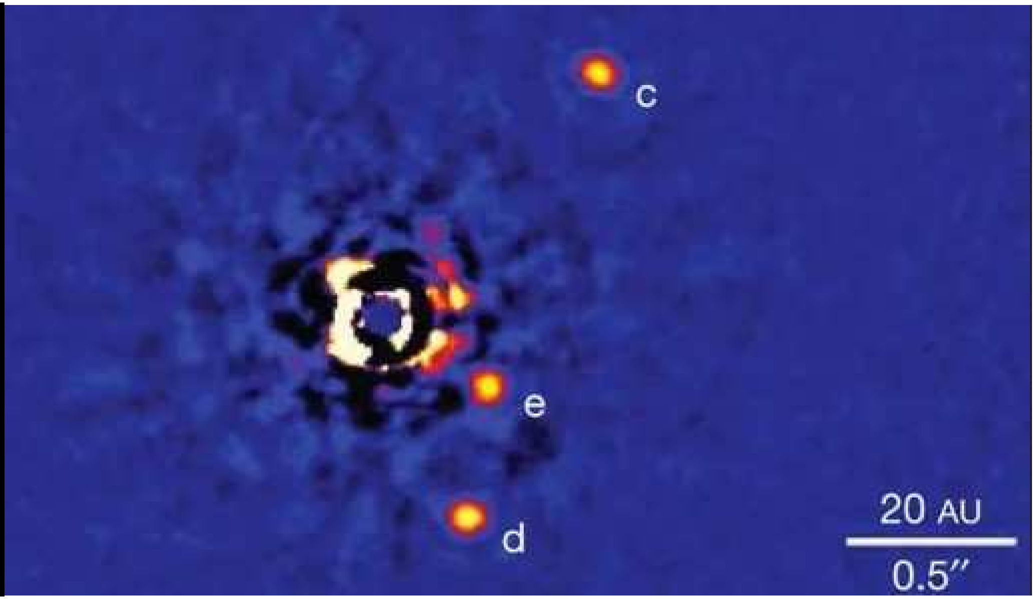
- Diurnal parallax – distance to the Moon
- Timing a lunar eclipse (Aristarchus of Samos)
- Moon diameter Ptolemy (by an accidental interplay of inaccuracies; Neugebauer 1975)
- But the same method gave distance and size of the Sun in error by a factor 1/20.
- Corrected only in 1672 by John Flamsteed
- SN1572 – no parallax detected comparing observations by Tycho Brahe (Denmark) and Jeronimo Munoz (Spain)



(Credit: ESO)

Sizes of stars and images of exoplanets





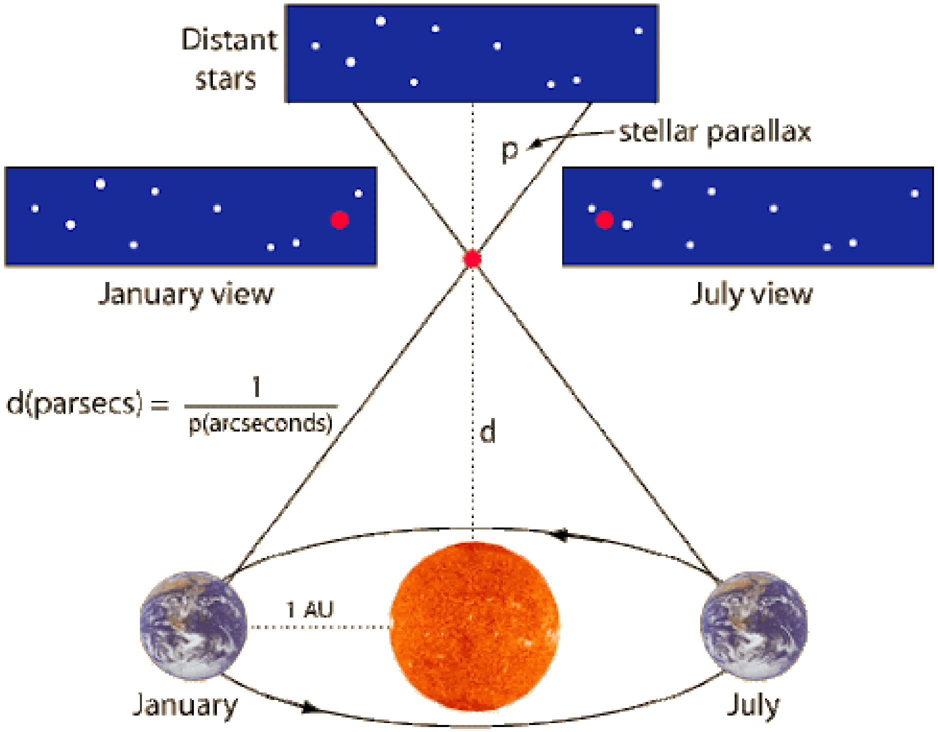
ESO/K. Ohnaka (Antares);
Alma (ESO/NAOJ/NRAO)/E. O'Gorman/P. Kervella (Betelgeuse);
ESO (R Doradus);
Alma (ESO/NAOJ/NRAO)/W. Vlemmings (W Hydrae)

HR8799 direct imaging planet detections
Credit: Marois et al (2010)

Stellar parallaxes

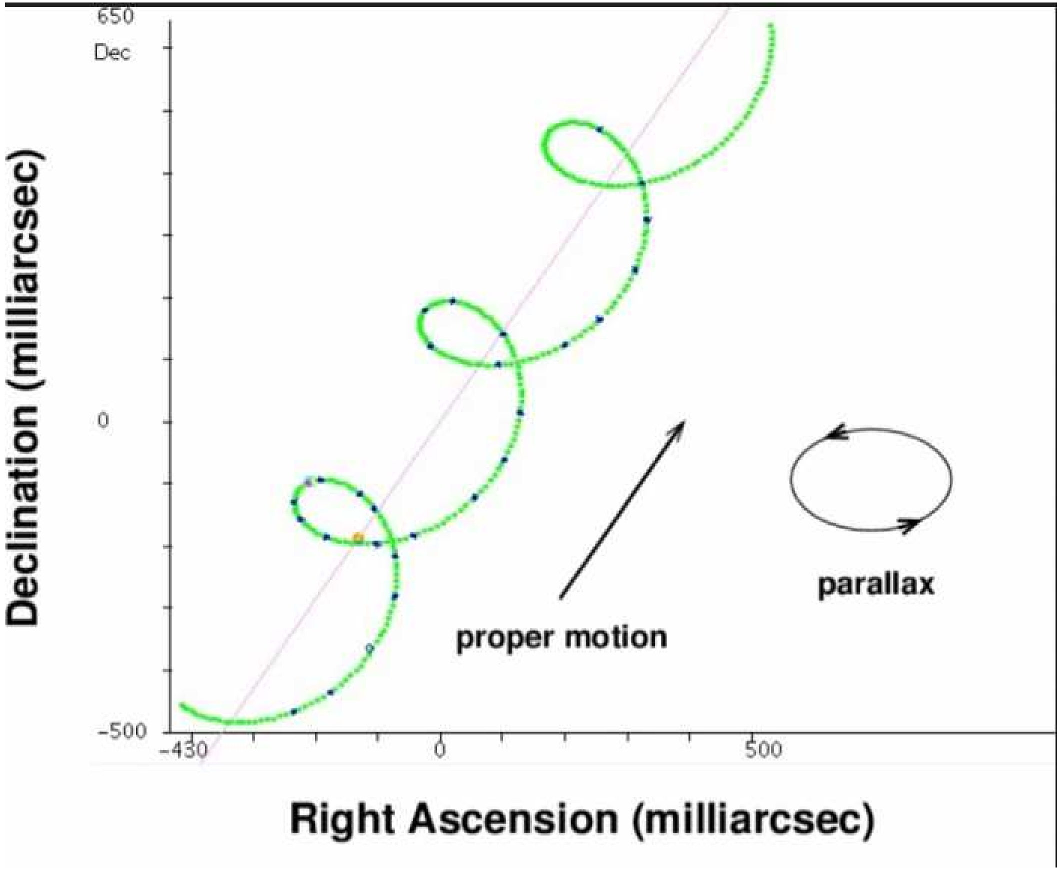
Annual parallax: a nearby object moves against the background of more distant objects

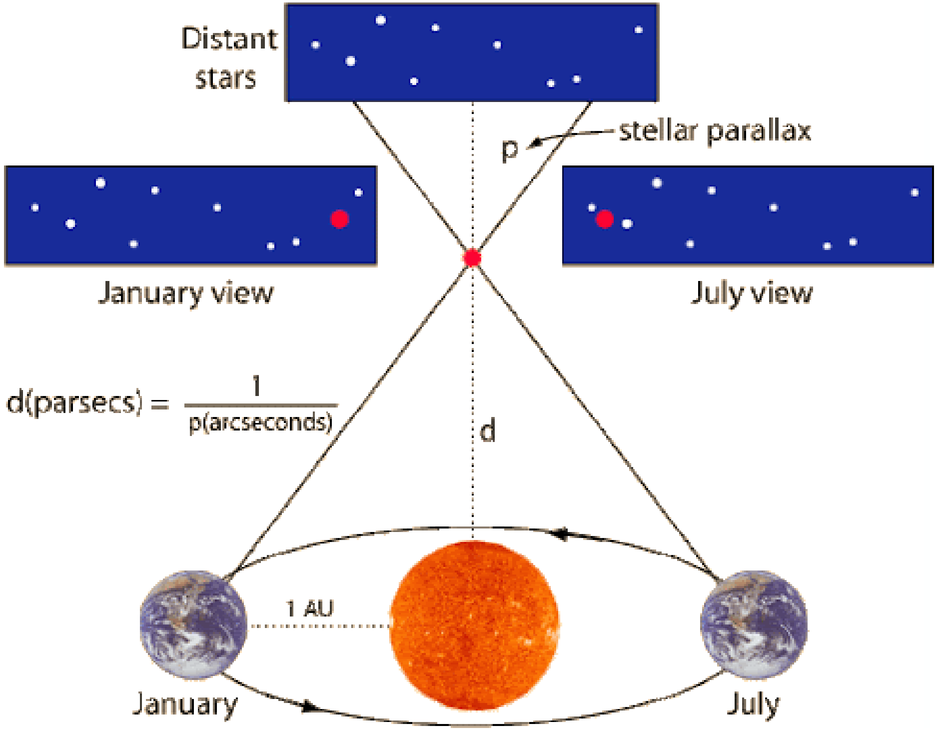
- Edmund Halley (1713): three stars changed position since the ancient Greeks
- Stars 20 000 to 30 000 times as distant as the Sun
- James Bradley (1748): 400 000 times (and discovered astronomical aberration and nutation in the process)
- Only by 1840, three astronomers independently measured stellar parallaxes: Friedrich Bessel, Wilhelm Struve and Thomas Henderson for 61 Cyg, Vega, and alpha Cen



(Credit: Hyperphysics, Georgia State University)

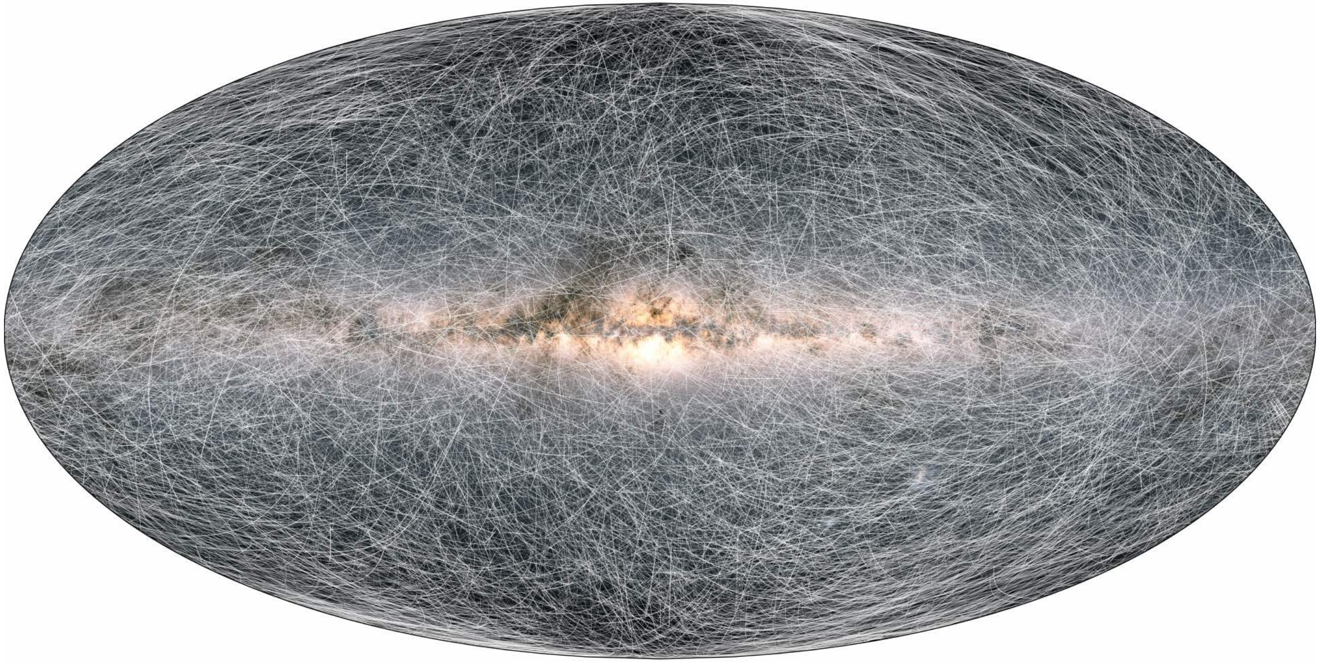
Parallaxes and proper motions





(Credit: Hyperphysics, Georgia State University)

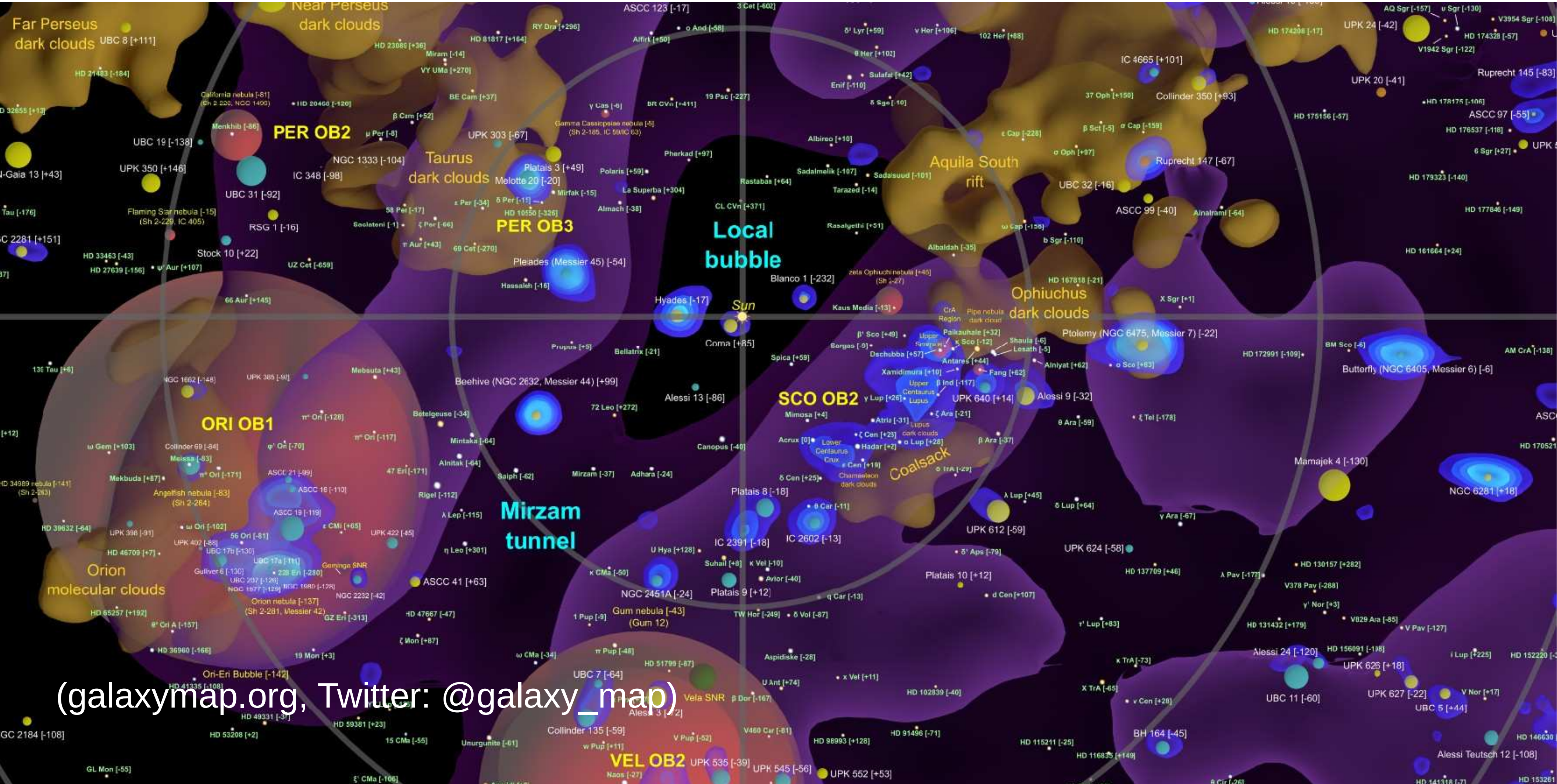
Gaia proper motions and distances



The trails on this image show the displacement of stars on the sky 400 thousand years into the future. Credit: ESA/Gaia/DPAC

- Gaia EDR3 (Gaia collaboration 2021):
- 1 467 744 818 sources with parallax and proper motion to reveal their distances and motions.
- Not against background stars, but distant quasars

Galaxy map



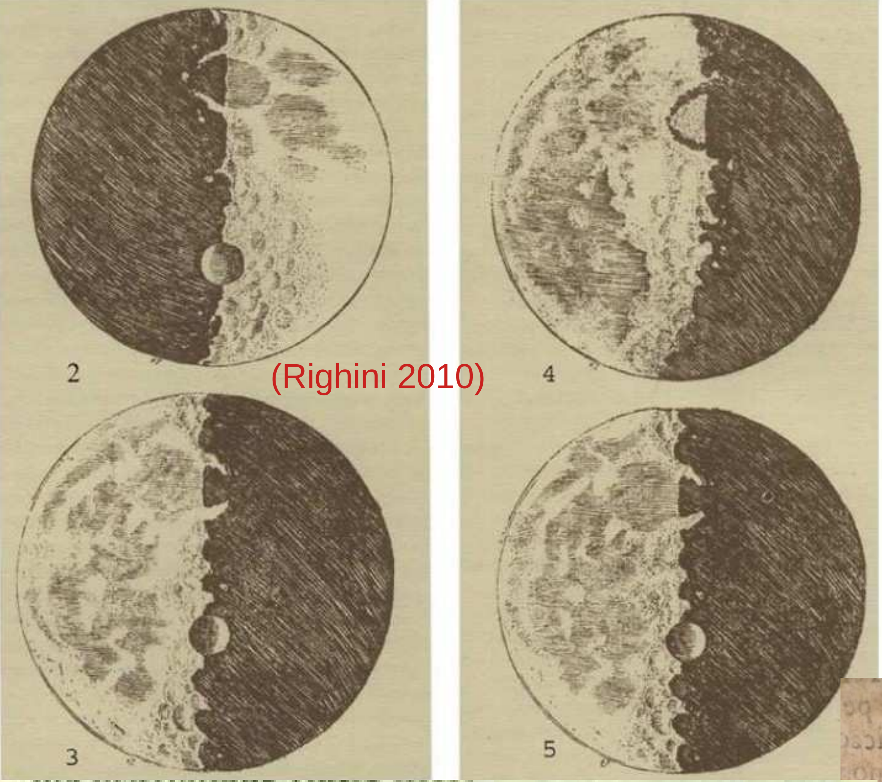
(galaxymap.org, Twitter: @galaxy_map)

Invention of the telescope

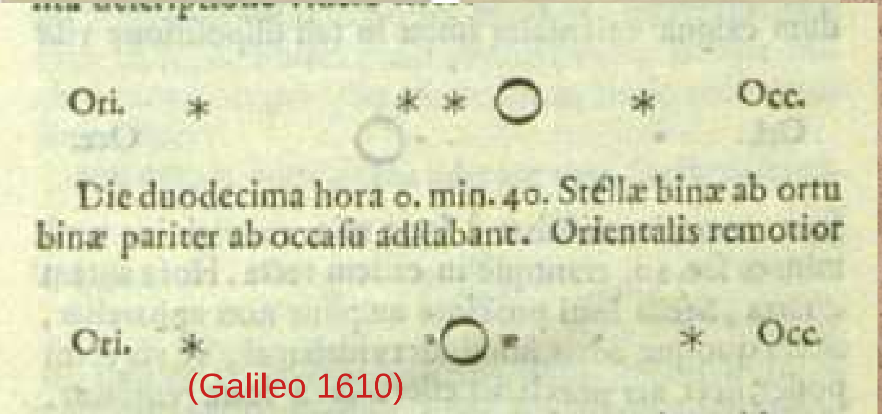
Optical telescope:

- Effectively enlarges the eye. Fainter objects can be seen, and magnification helps in discerning details
- Invented in the Netherlands; by whom, it is disputed (patent application by Hans Lipperhey 1608; given to Jacob Metius)
- Galileo Galilei: first systematic study of the sky with a telescope in 1609 (10 months between hearing about the telescope and publishing Sidereus Nuncius)
- Diameter of the objective 38mm; magnification 10x; but images of low quality

- The Moon is not a smooth sphere
- Jupiter had its own moons (not all the sky objects were orbiting the Earth)
- Venus had phases (only explained in a heliocentric model)
- Saw the rings of Saturn (but did not recognize them as such)
- Found new stars in the sky
- See Van Helden (1989)



(Righini 2010)

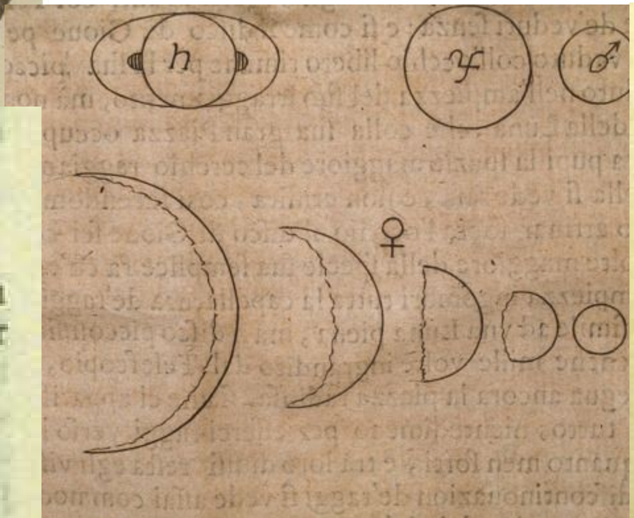


Ori. * * * ◯ * Occ.

Die duodecima hora o. min. 40. Stellæ binæ ab ortu binæ pariter ab occasu adstabant. Orientalis remotior

Ori. * ◯ * Occ.

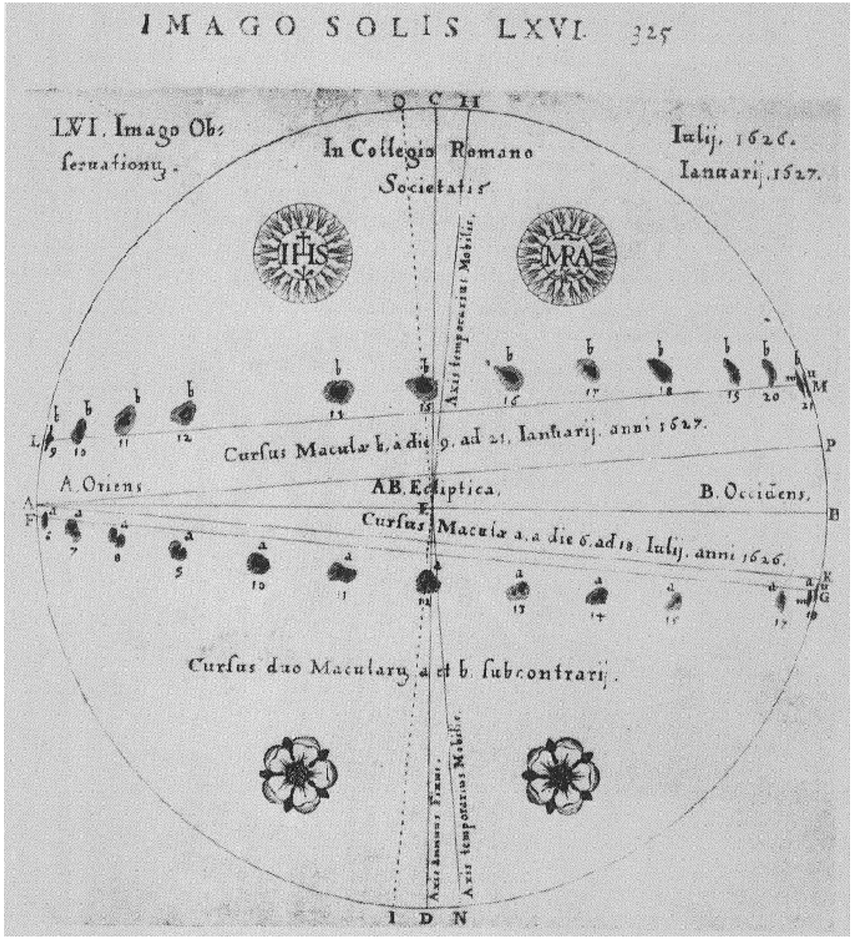
(Galileo 1610)



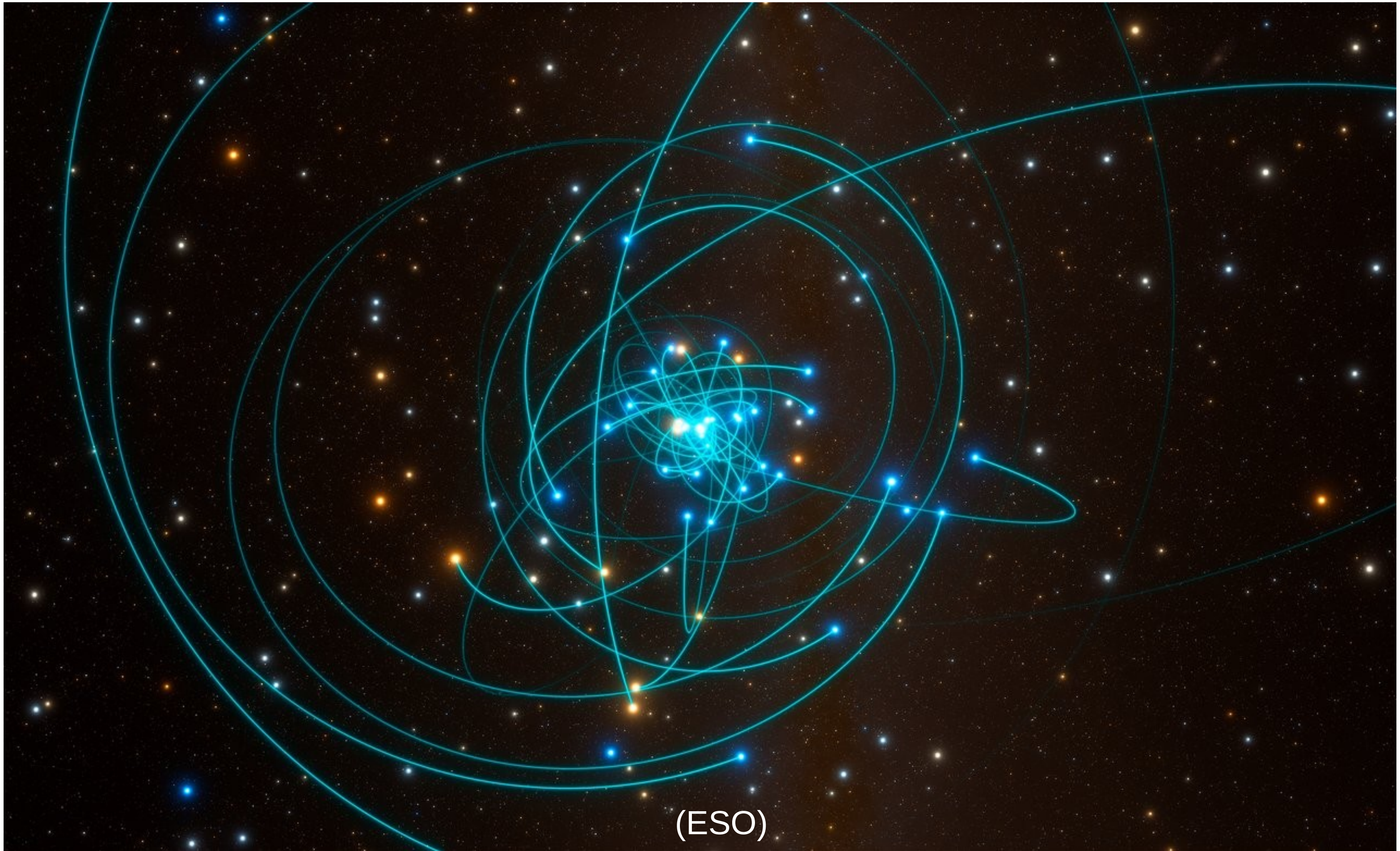
Solar rotation

Sunspots observations: there is evidence (also in myths) of observations in antiquity (see Vaquero & Vazquez 2009)

- With the telescope: Thomas Harriot (1610), Johannes Fabricius (1611), Christoph Scheiner (1611), Galileo (1611). Period of 26 days.
- Galileo: sunspots are on (or close) to the Sun; and the Sun rotates (1612)
- Scheiner: Inclination of the Sun’s rotation axis (~7 deg; 1626-1630)
- With some evidence that the solar rotation rate accelerated within 15deg of the equator (Herr 1978) just before the Maunder minimum



Acceleration

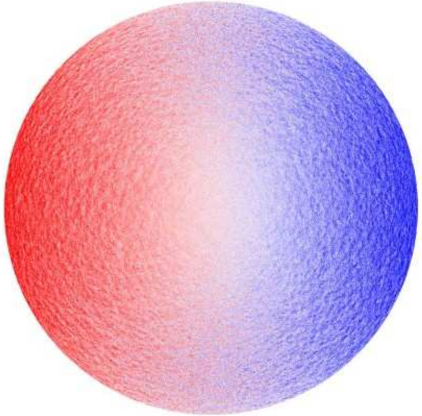


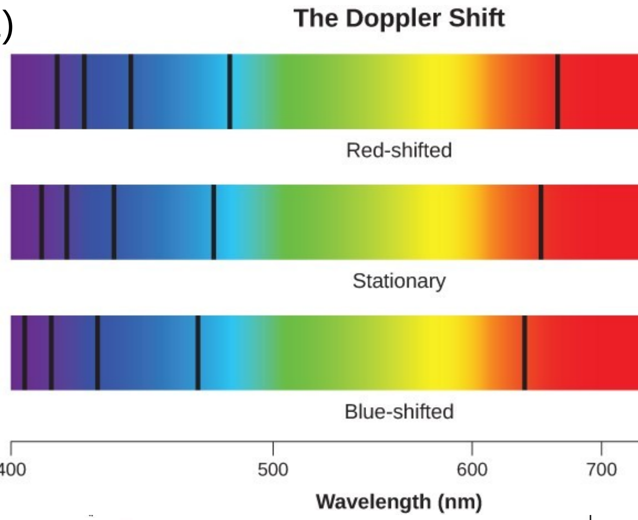
Stellar rotation

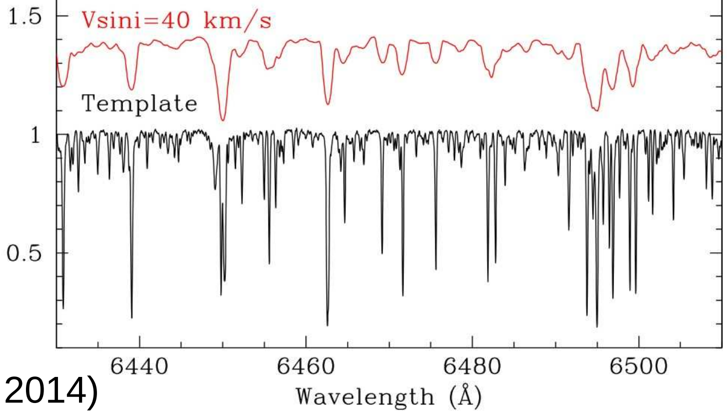
Stars with spots: Ismael Boulliaud suggested that the variability of some stars could be related to spots and rotation (1667)

- Hermann Vogel, doppler shift of solar rotation (1871)
- William de Wiveleslie Abney suggested the use of the width of spectral lines (Abney 1877)
- Frank Schlesinger showed evidence of rotation in δ Lirae (Schlesinger 1910)
- Otto Struve (1929-1934) measured the projected rotational velocity (Struve 1930)

(Kashyap & Hanasoge 2021)







(Casares & Jonker 2014)

Photography

Integration time can increase: for the human eye ~30 ms (or ~250ms if adapted to the dark). With a film > 1h.

- Thomas Wedgwood: Sun images using silver nitrate (~1800)
- Louis Daguerre: the "daguerreotype" process (~1837)
- William Herschel calls it photography ("writing with light", 1839)
- Unsuccessful daguerreotype of the Moon (Daguerre, ~1839)
- John William Draper, first daguerreotype of the Moon (~1840); 20min exposure
- 1850: First daguerreotype of a star (Vega) by John Adams Whipple and William Cranch Bond; 38 cm Harvard refractor (100 s).
- 1858: George Philips Bond, magnitude of stars can be derived from astronomical photographs (stellar photometry).

(Daguerreotype taken in 1851 by John Adams Whipple)

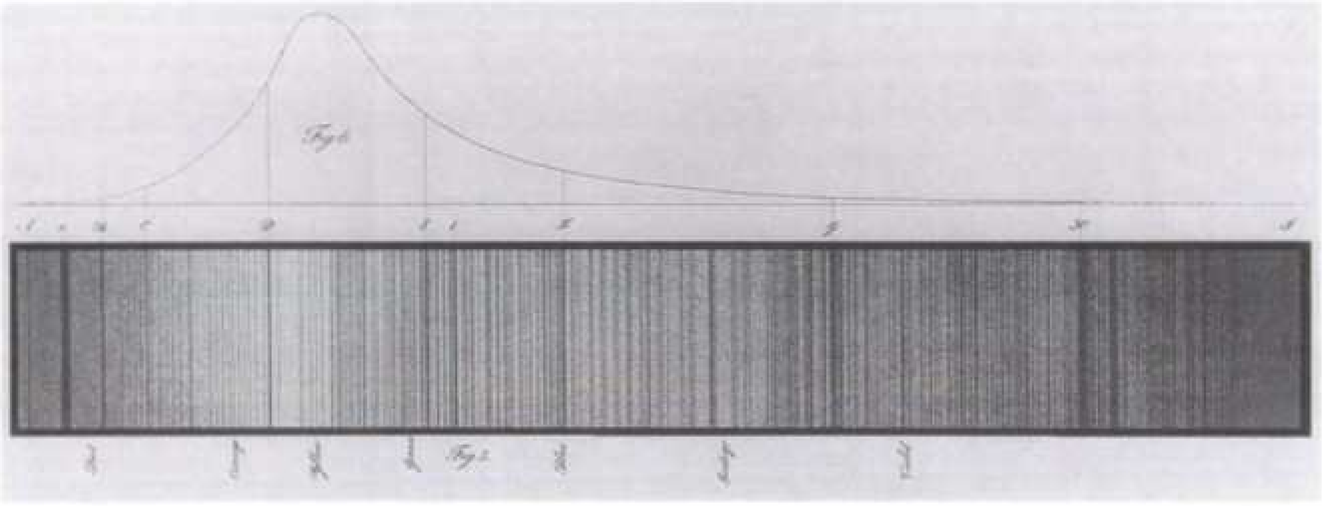
Photography

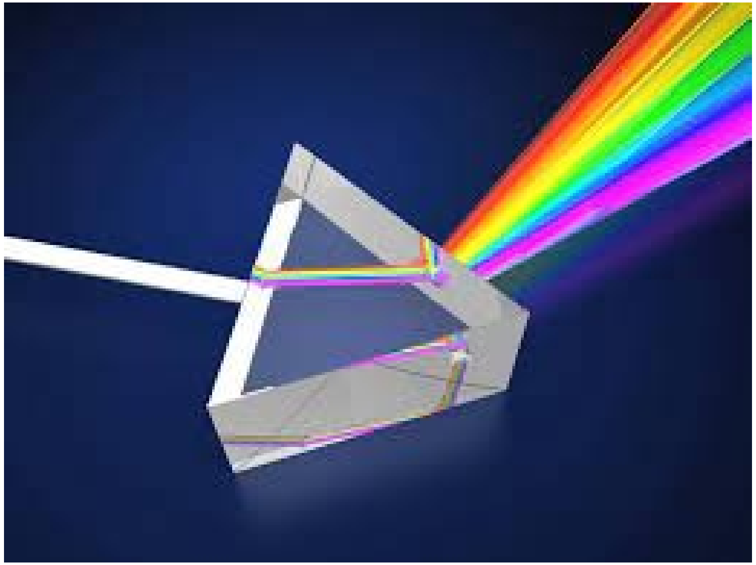
Credits: NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team

Spectroscopy

Fraunhofer lines: By ~1817, Joseph von Fraunhofer catalogued ~600 dark lines in the solar spectrum.

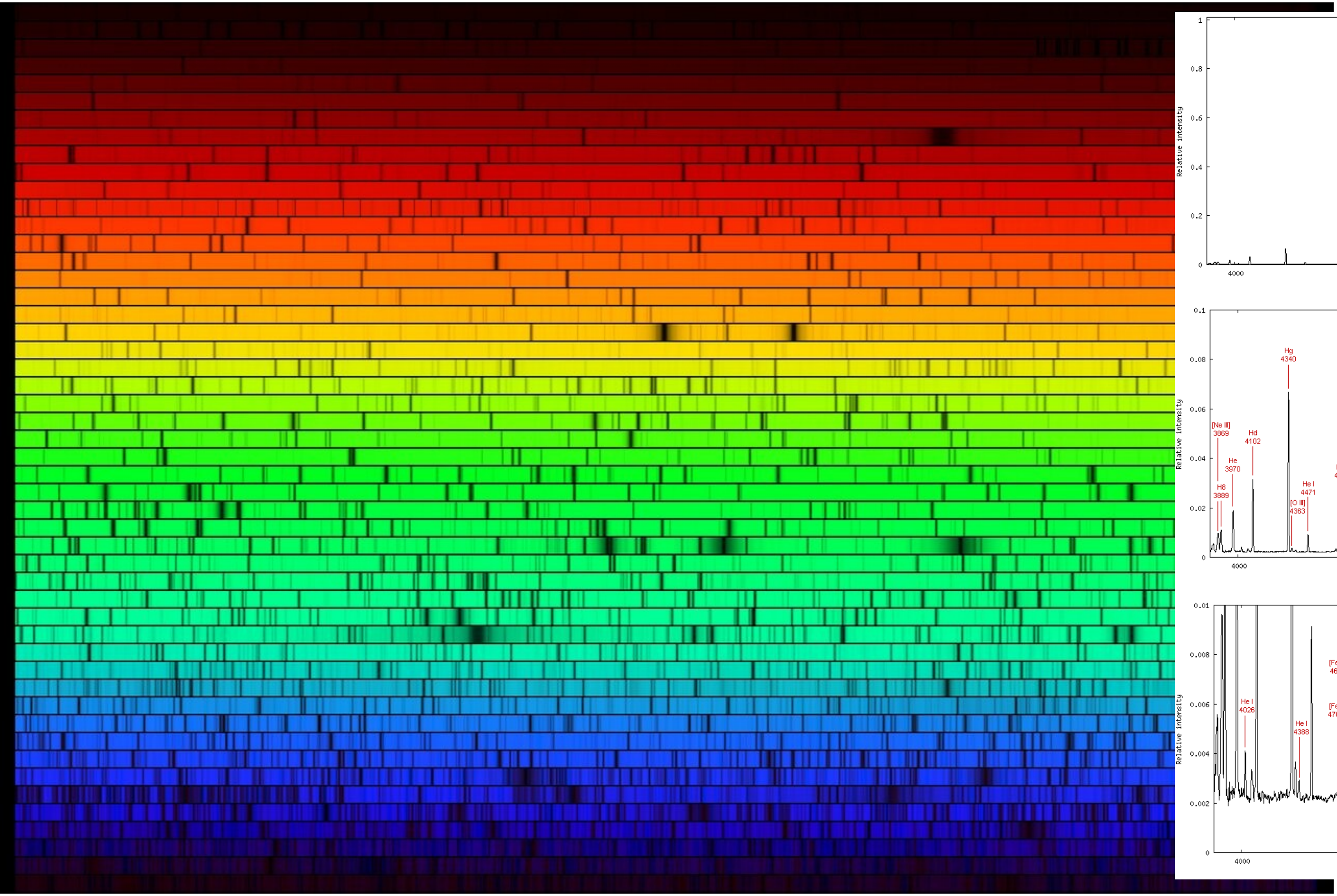
- Lines first seen by William Hyde Wollaston (Wollaston 1802)
- 1864, William Huggins: emission lines in the spectra of nebulae. 1868: line of sight velocity from the spectrum doppler shift.
- 1872: Henry Draper records the spectrum of Vega.



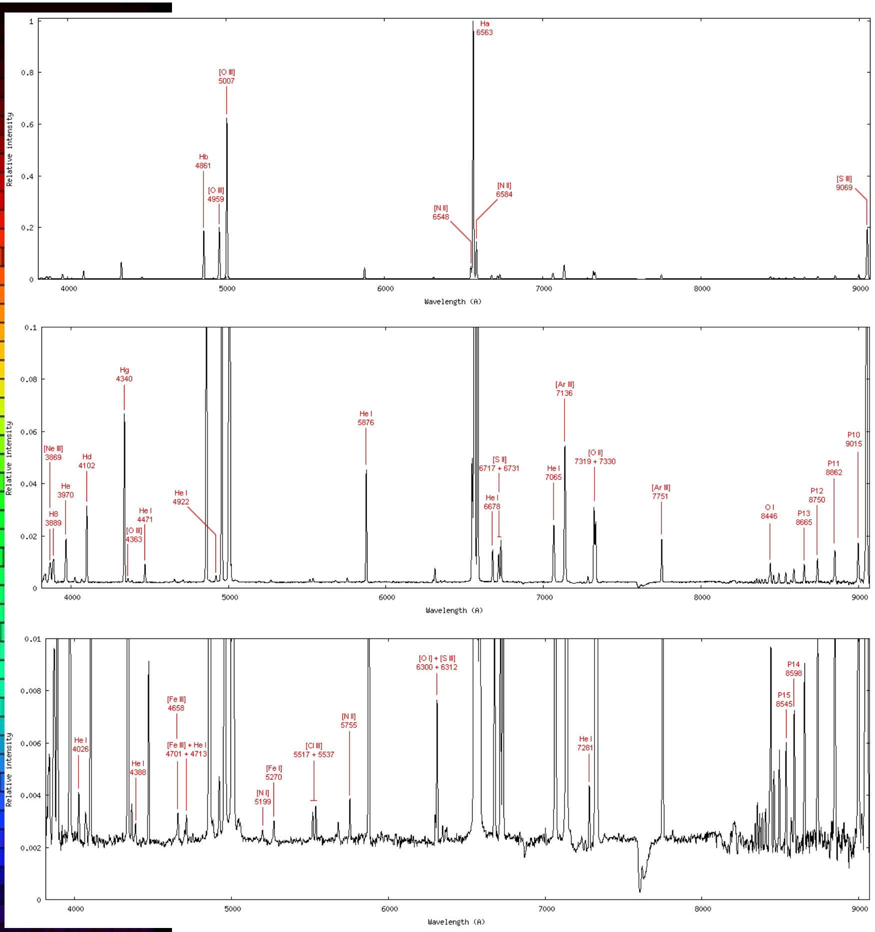


(Solar spectrum by Fraunhofer, 1817; Fig. 3.1 Brand 1995)

Spectroscopy



(Credit: N.A.Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF)

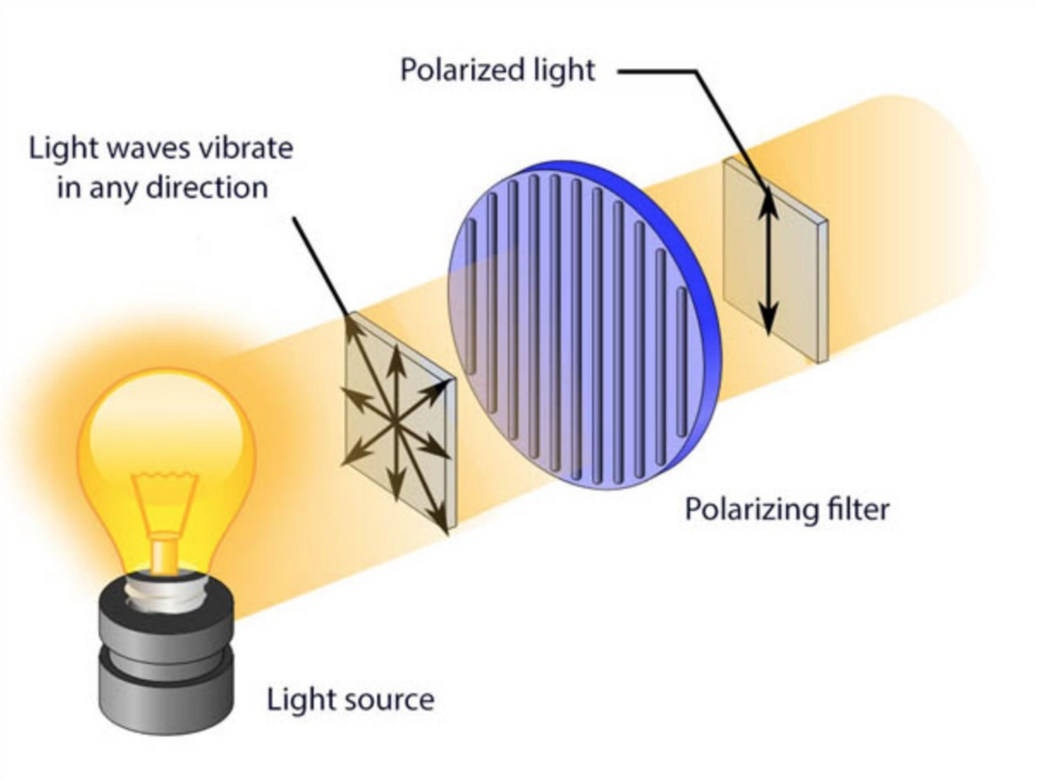


(Christian Buil: www.astrosurf.com)

Polarimetry

Double refraction: Erasmus Bartholin (1669) discovers that calcite ($CaCO_3$) refracts light in two beams (by polarization).

- ~1672, Christian Huygens attempts to explain double refraction with wave theory of light
- ~1808, Étienne-Louis Malus finds that reflection can polarize the light
- Polarization can happen by absorption, reflection or scattering
- Chandrasekhar (1946): Thomson scattering should polarize the radiation of early-type stars
- William Hiltner (1949) and John Hall (1949): ISM polarizes stellar light
- Polarization by magnetic fields or scattering by dust grains



(Credit: Sky & Telescope)

Polarimetry

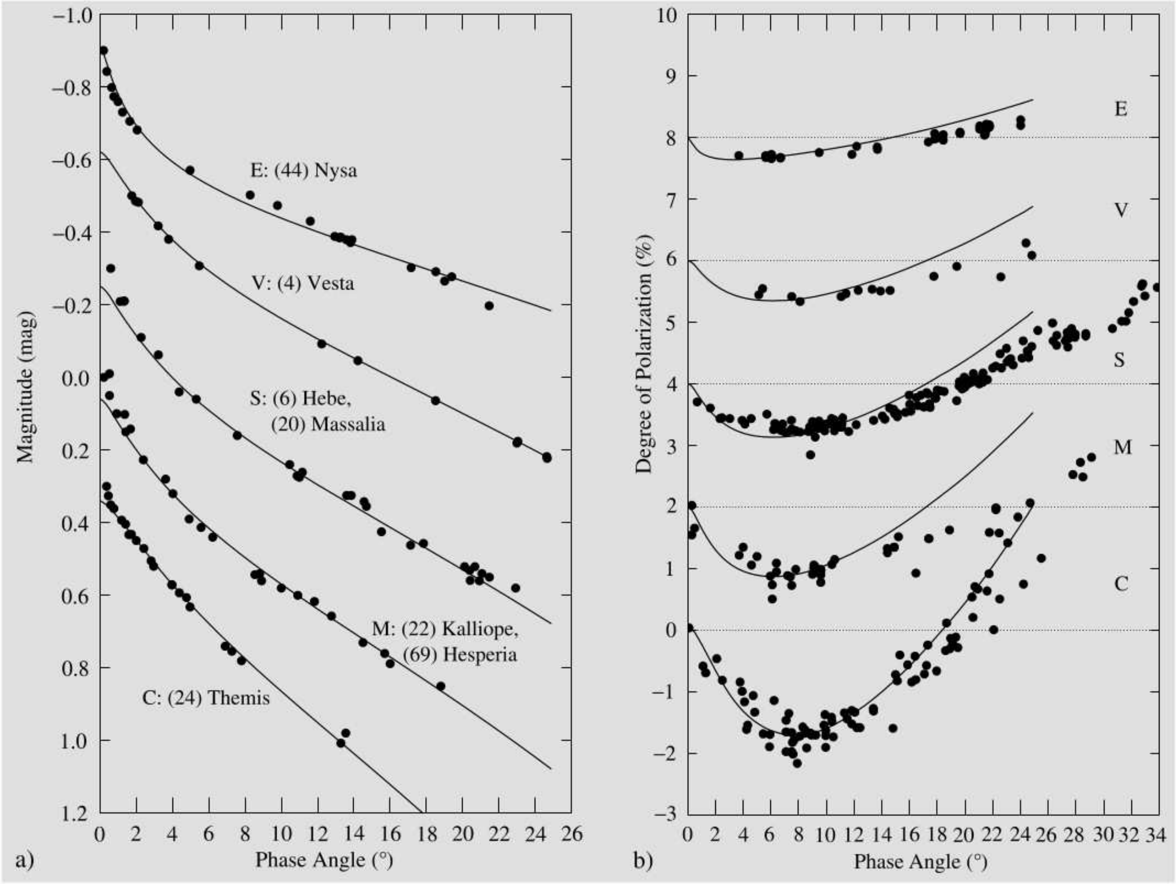


Fig. 7.22 The phase curves and polarisation of different types of asteroids. The asteroid characteristics are discussed in more detail in Sect. 8.11. (From Muinonen *et al.*, *Asteroid photometric and polarimetric phase effects*, in Bottke, Binzel, Cellino, Paolizhi (Eds.) *Asteroids III*, University of Arizona Press, Tucson)

(Credit: Fundamental Astronomy, Karttunen et al. 2003)

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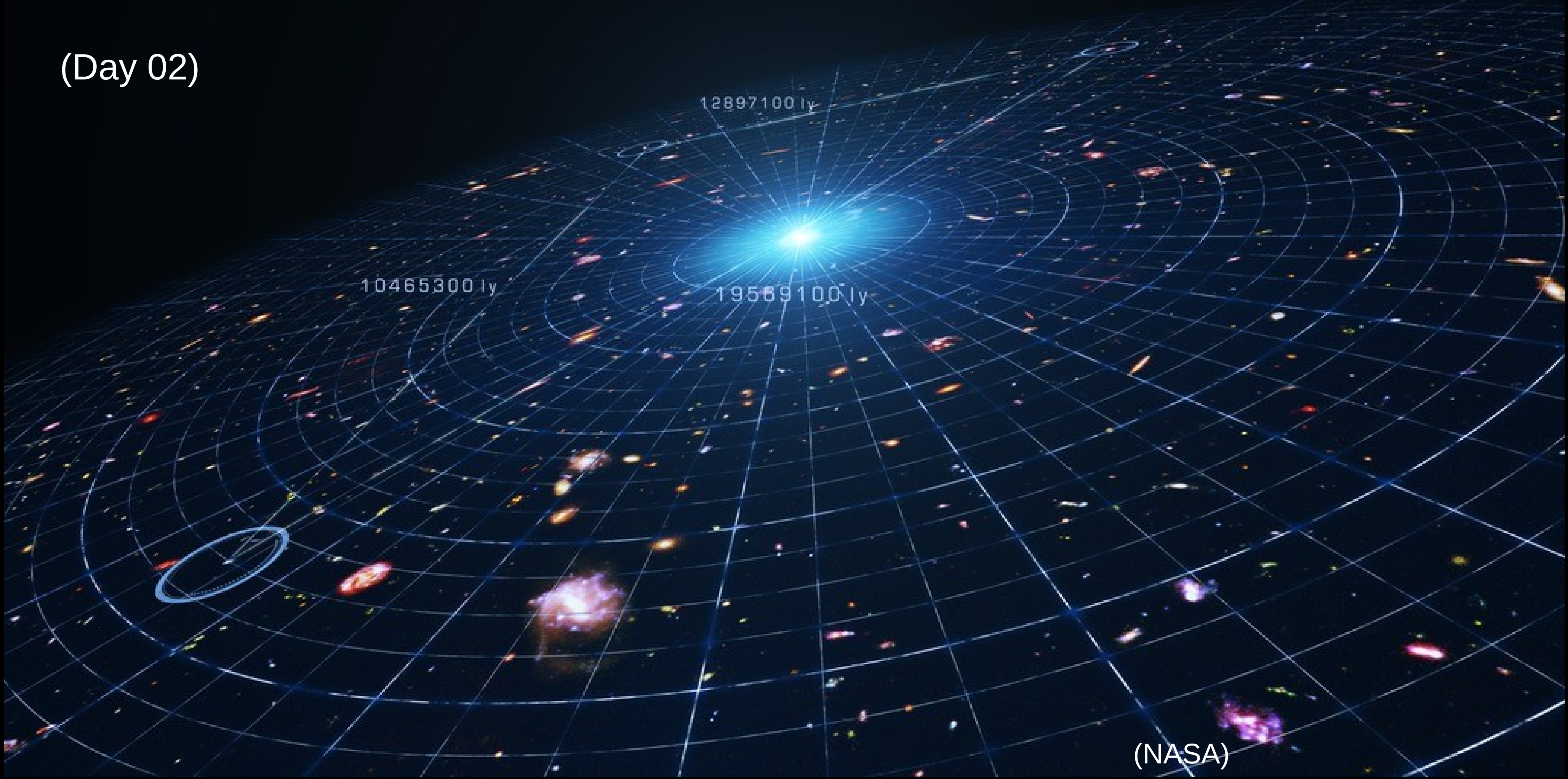
Information from the Universe

(Day 02)



(NASA)

Information from the Universe

1. Electromagnetic radiation

2. Cosmic rays

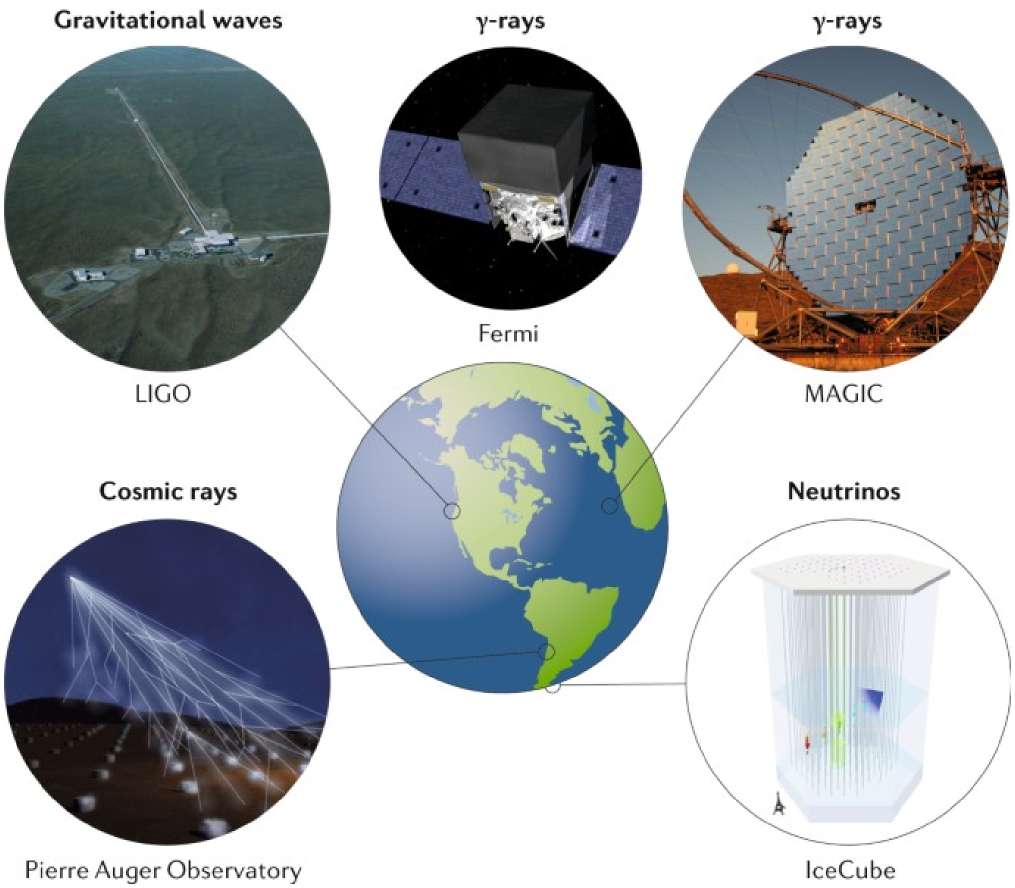
3. Neutrinos

4. Meteorites

5. Gravitational waves

6. Solar wind

7. Samples from solar system objects (in-situ or returned)



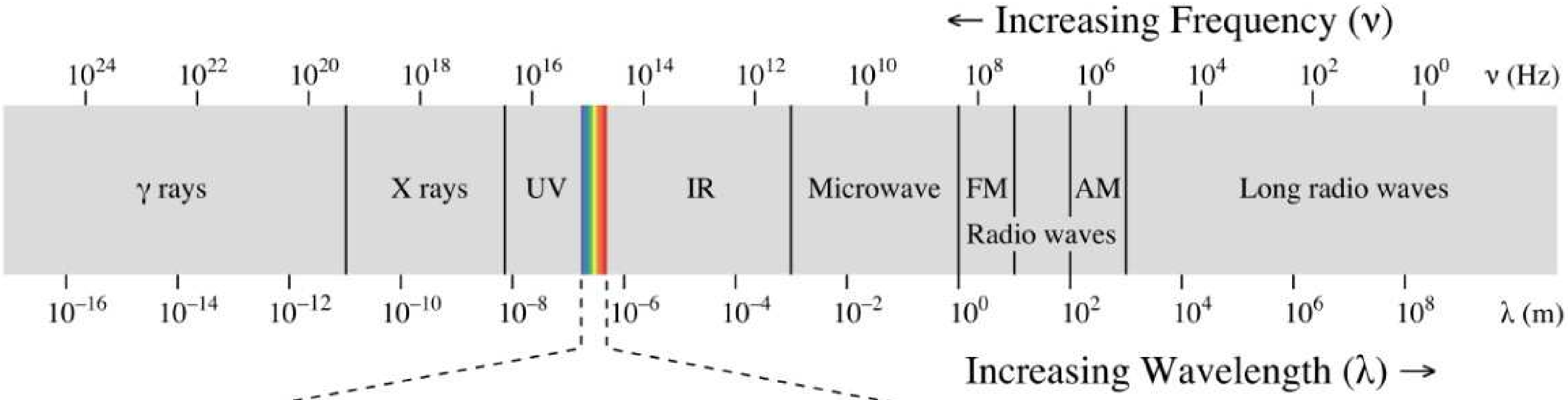
(Nature)

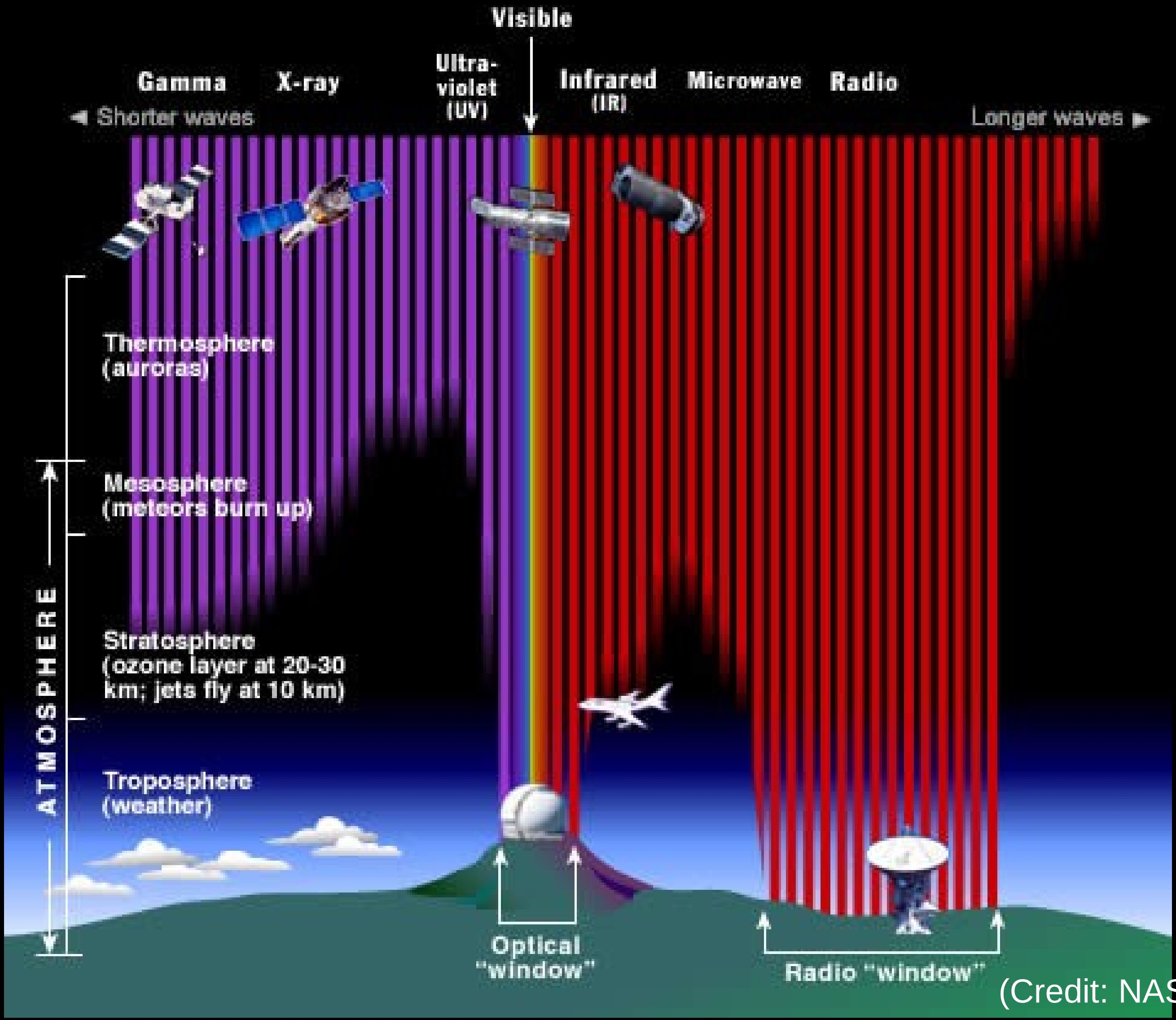
Electromagnetic radiation

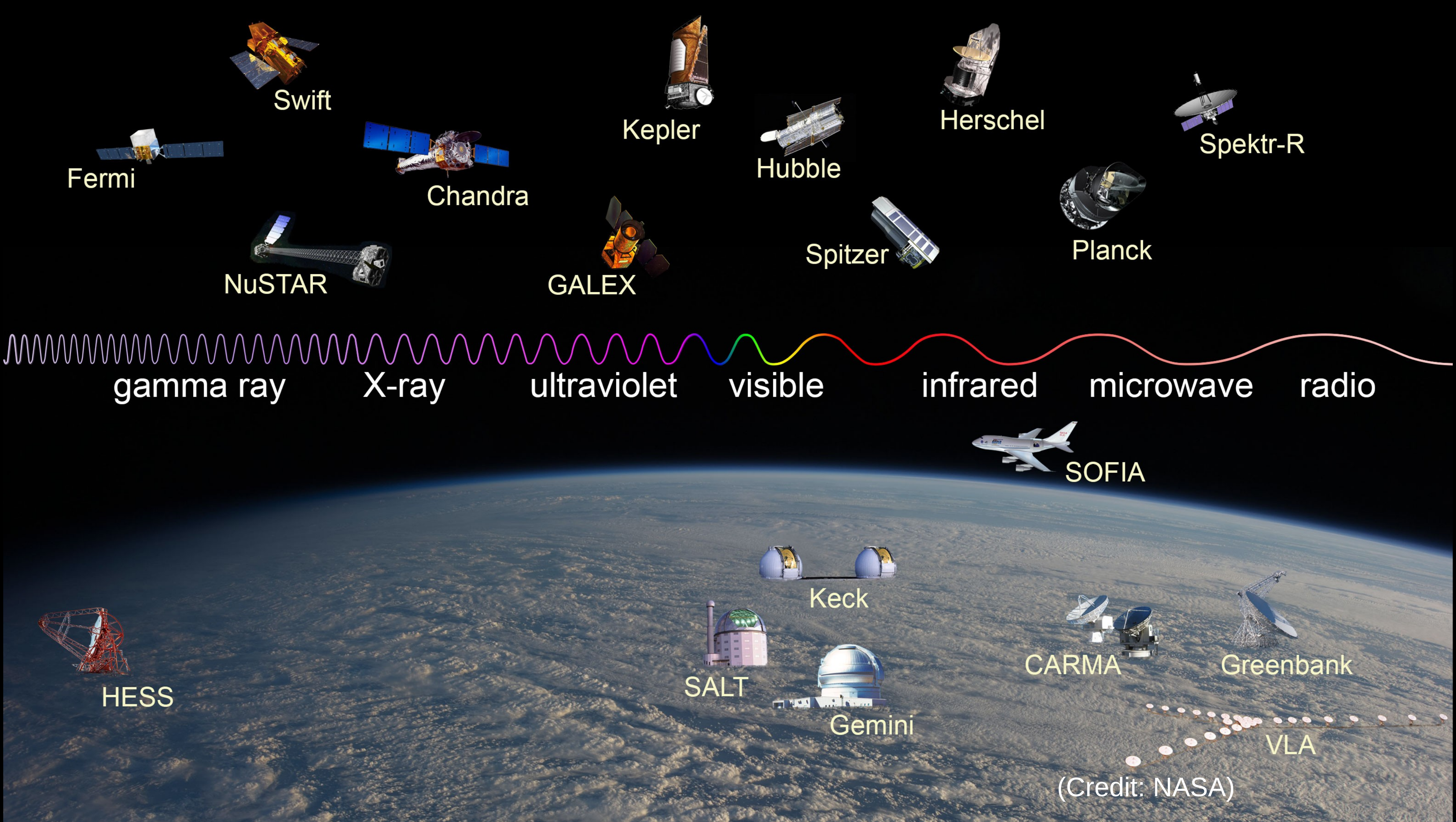
Electromagnetic waves, travelling through space, carrying energy

- In a vacuum, EM waves travel with the speed of light
- Frequency of oscillation or wavelength
- Can also be treated as photons of a given energy ($E = h\nu$)
- Source of most astronomical information

	Wavelength	Frequenzy
Red	~ 625 – 740 nm	~ 480 – 405 THz
Orange	~ 590 – 625 nm	~ 510 – 480 THz
Yellow	~ 565 – 590 nm	~ 530 – 510 THz
Green	~ 520 – 565 nm	~ 580 – 530 THz
Blue	~ 445 – 520 nm	~ 675 – 580 THz
Indigo	~ 425 – 445 nm	~ 700 – 675 THz
Violet	~ 380 – 425 nm	~ 790 – 700 THz

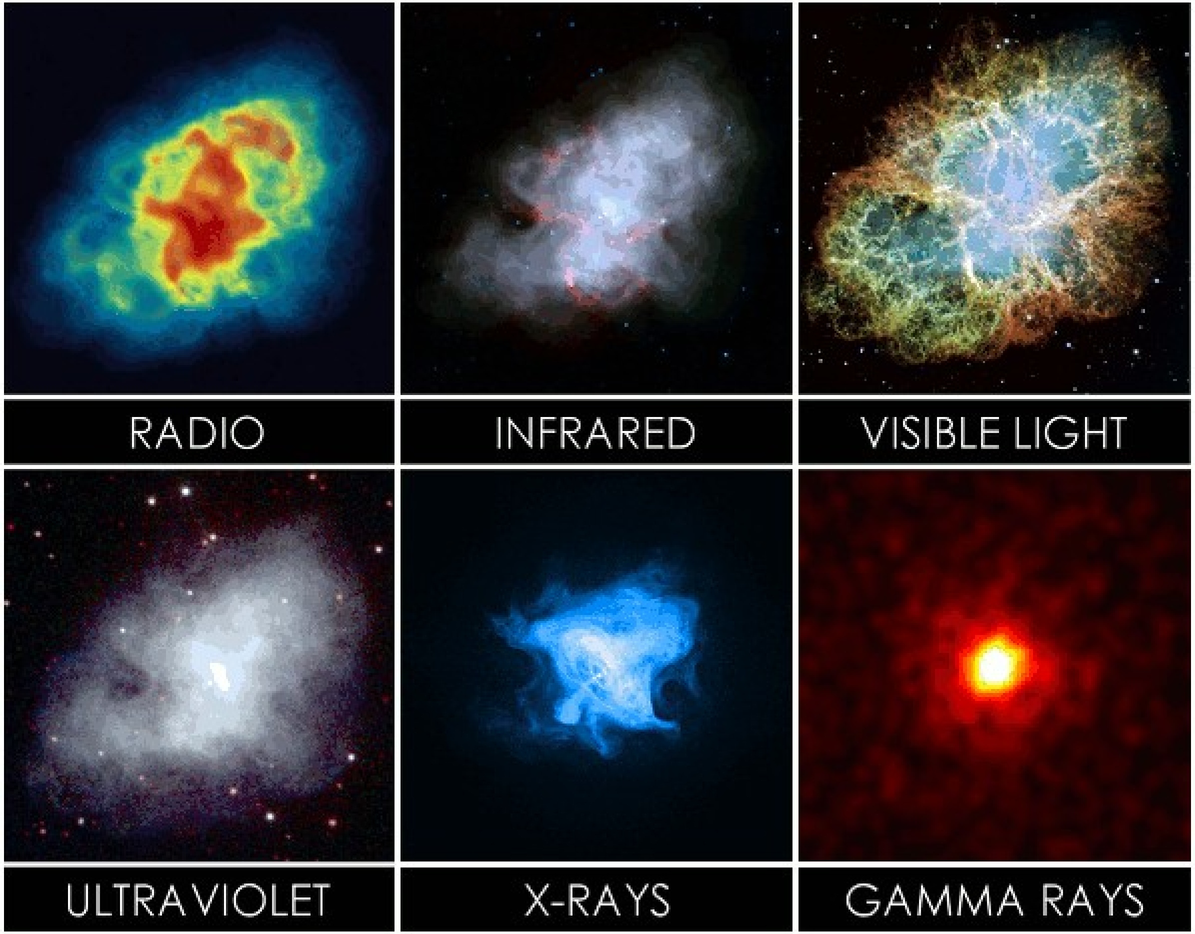



Visible
Gamma
X-ray
Ultra-
violet
(UV)
Infrared
(IR)
Microwave
Radio
Shorter waves
Longer waves
Thermosphere
(auroras)
Mesosphere
(meteors burn up)
Stratosphere
(ozone layer at 20-30
km; jets fly at 10 km)
Troposphere
(weather)
ATMOSPHERE
Optical
"window"
Radio "window"
(Credit: NASA)


Swift
Fermi
Chandra
NuSTAR
GALEX
Kepler
Hubble
Spitzer
Herschel
Planck
Spektr-R
gamma ray
X-ray
ultraviolet
visible
infrared
microwave
radio
SOFIA
Keck
SALT
Gemini
HESS
CARMA
Greenbank
VLA
(Credit: NASA)

Why bother with multi-wavelength?

- Different processes have different dominant energy scale
- The physics we can learn is thus different
- Higher temperature, shorter wavelength
- But not all electromagnetic radiation is from thermal emission



(Crab Nebulae)

What do we measure?

Flux: energy travelling through a surface per unit area, per unit time (integrated in a certain passband) – (W m^{-2})

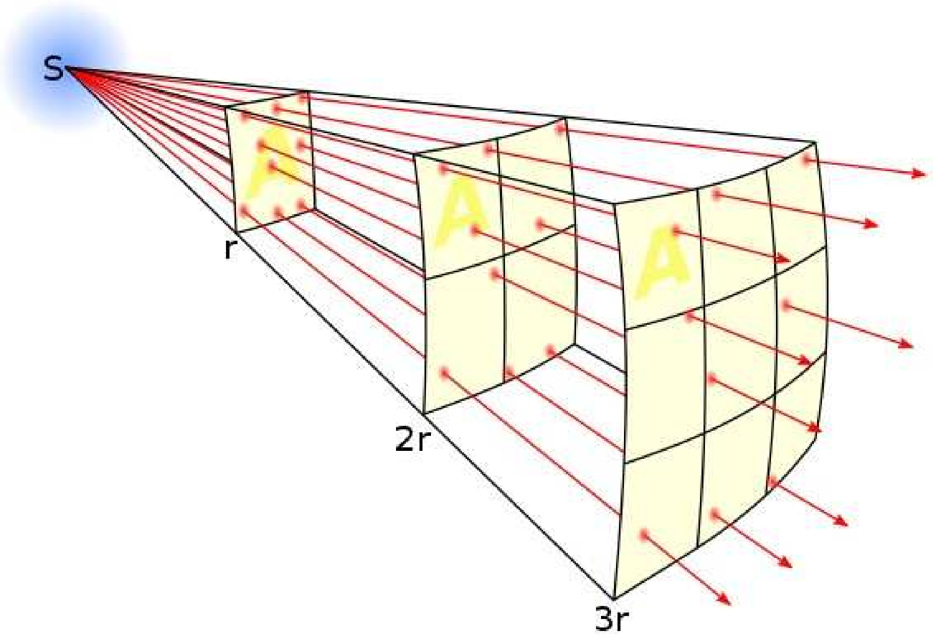
- From a distance source, diluted by the inverse square law

- If luminosity is the power output (in W) of a source (e.g. star), the flux at its surface is:

$$L = F_{\rm emitted}\ 4\pi\, R^2,$$

- and what was measured:

$$L = F_{\rm measured}\ 4\pi\, d^2.$$

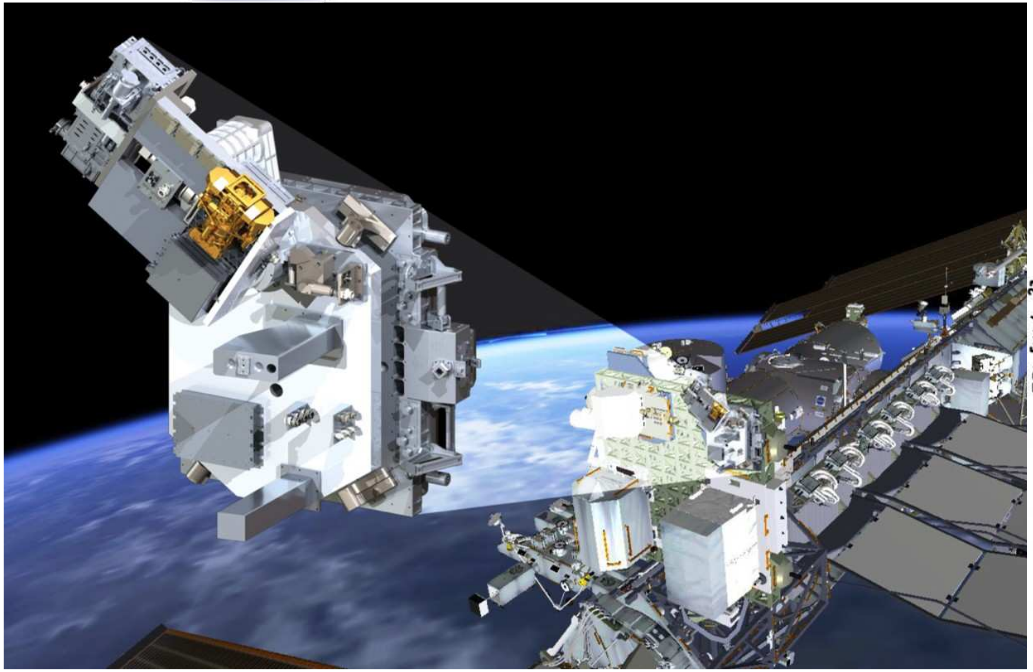


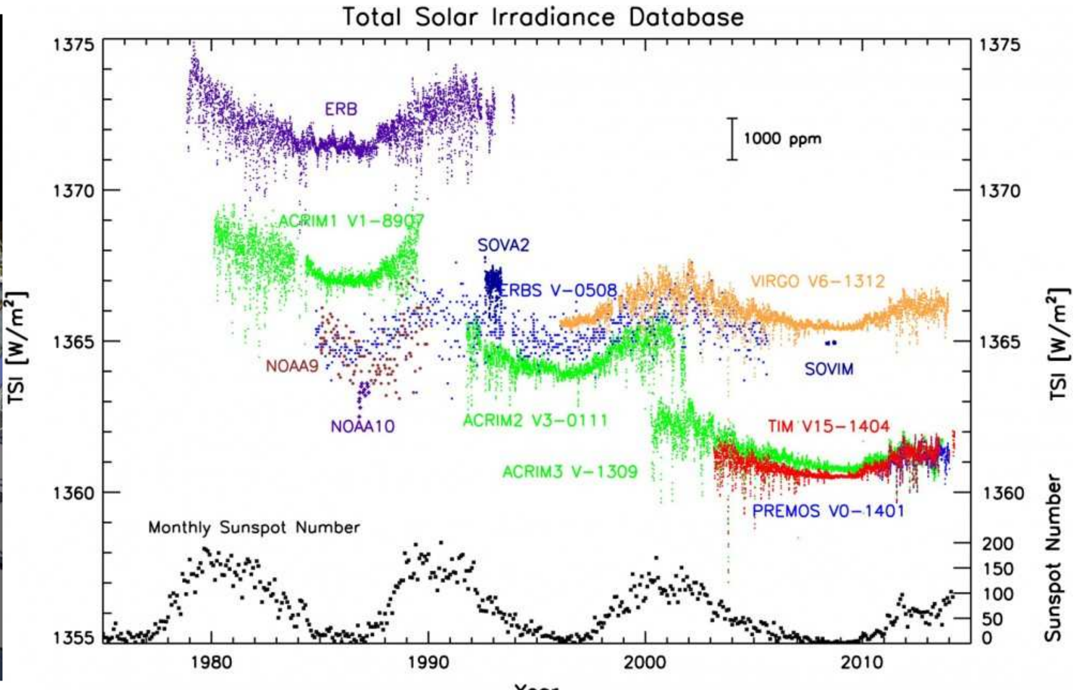
$$F_{\rm measured} = (\frac{R}{d})^2\, F_{\rm emitted}$$

$$F_{\rm measured} = \frac{1}{4}\,\alpha^2\, F_{\rm emitted}$$

Total solar irradiance

- TSIS-1 with Total Irradiance Monitor & Spectral Irradiance Monitor (200-2400nm, 96% of TSI)
- TIM – cavity radiometer absorbs 99.99% of the light



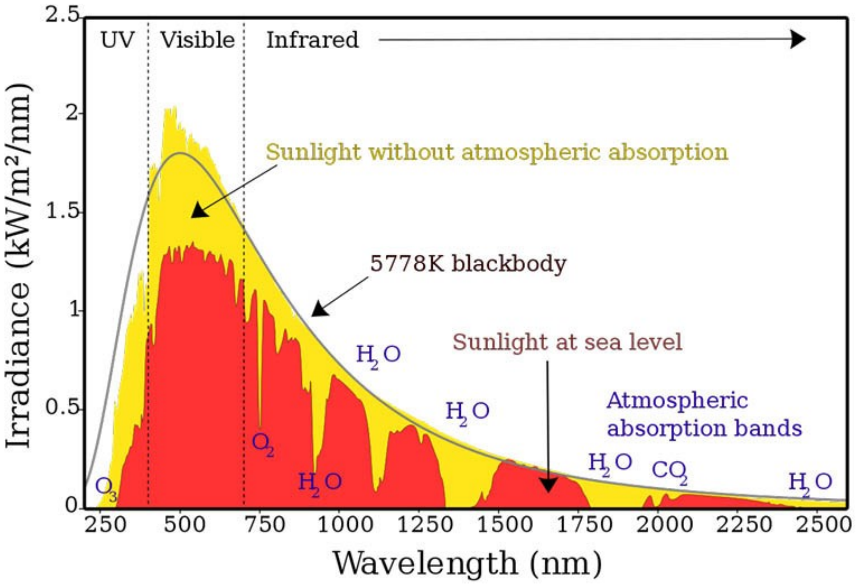


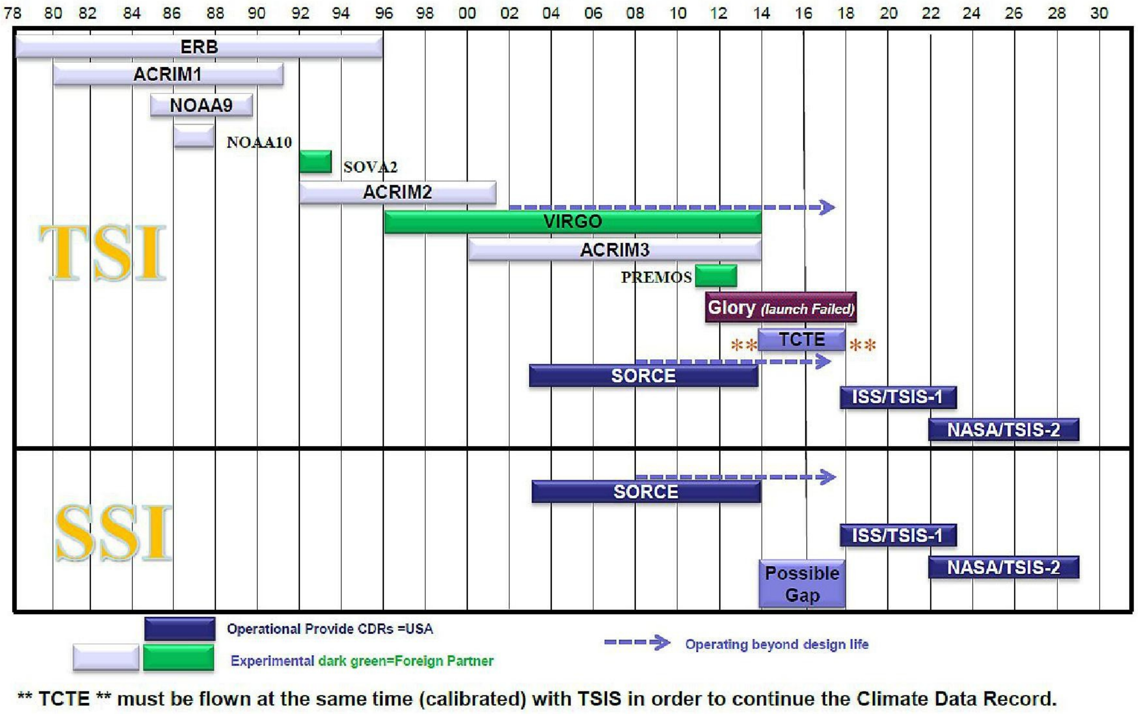
Flux density

Flux density: energy travelling through a surface per unit area, per unit time, per unit frequency (or wavelength)

(W m^{-2} Hz^{-1} or W m^{-3})

- Also called spectral irradiance





Flux and intensity

Specific intensity: flux density per unit solid angle (W m^{-2} Hz^{-1} sr^{-1})

$$\mathrm{d}E_\nu = I_\nu \cos\theta \,\mathrm{d}A\,\mathrm{d}\omega\,\mathrm{d}\nu\,\mathrm{d}t\,,$$

- Independent of distance
- If the source is resolved

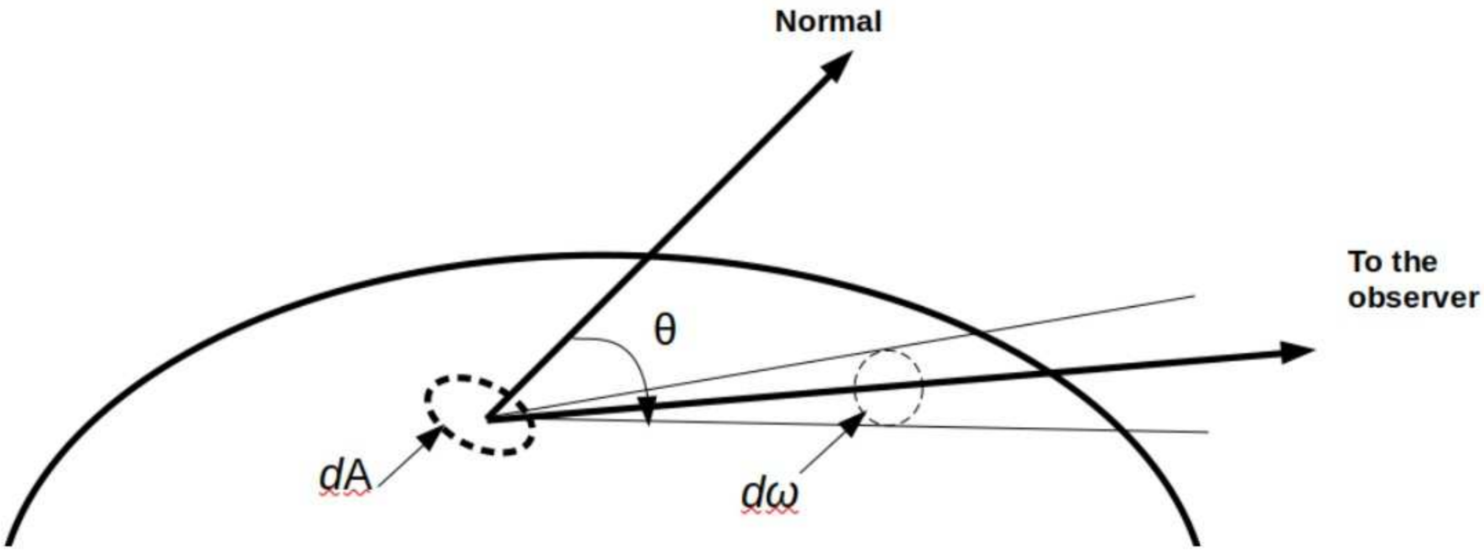
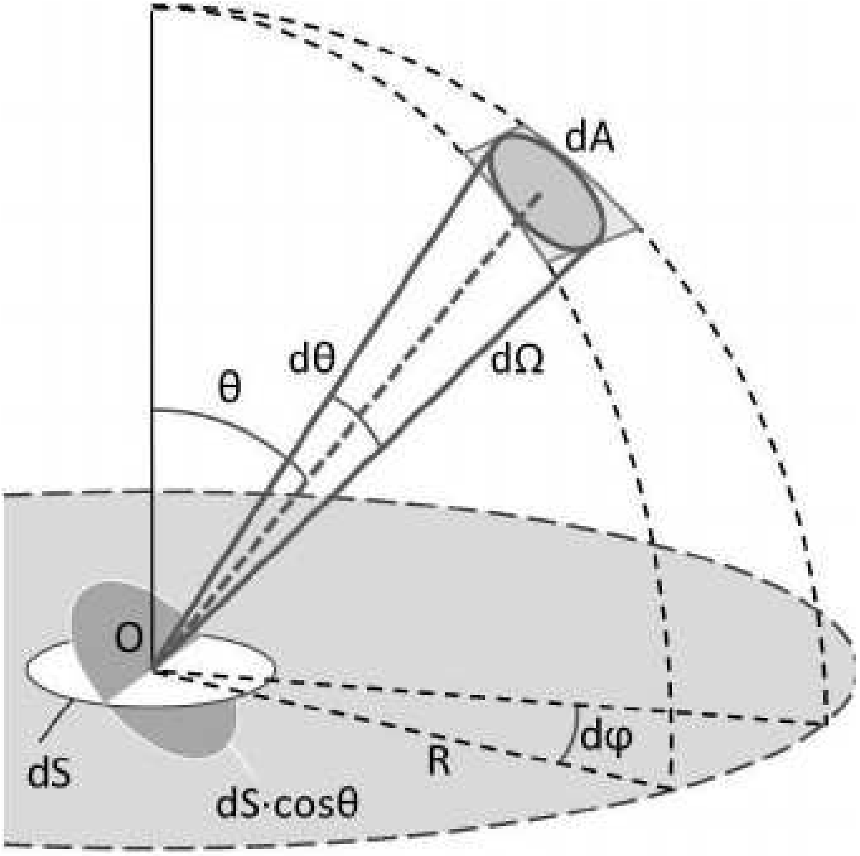
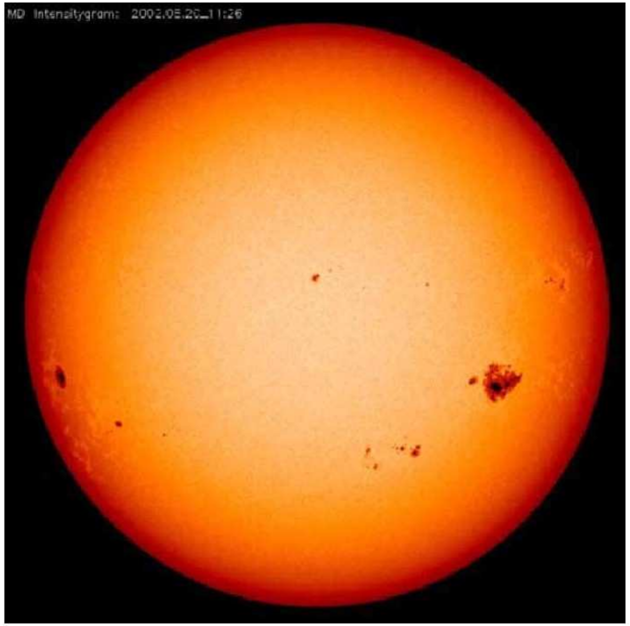


Figure 2: The geometry needed for the definition of specific intensity.

Solid angle





$$d\Omega = \frac{dA}{R^2} = \frac{Rd\theta\ R\sin\theta d\varphi}{R^2}$$

$$d\Omega = \sin\theta\ d\theta\ d\varphi$$

Magnitude and surface brightness

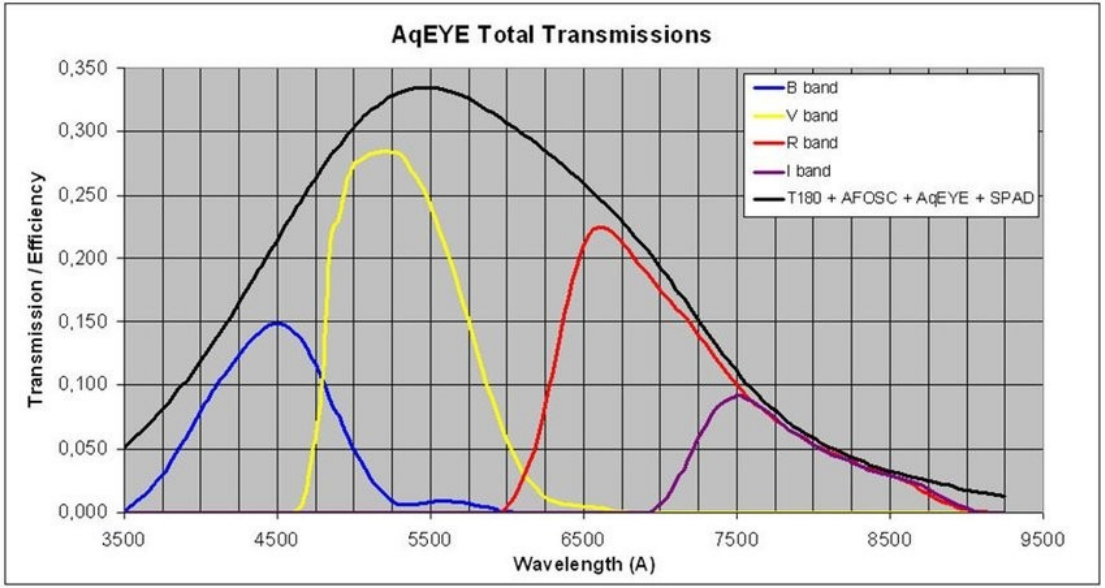
Apparent magnitude is related to the flux:

$$(m_1 - m_2) = -2.5\log_{10}(\frac{F_1}{F_2})$$

Surface brightness is related to the intensity:

$$(\mu_1 - \mu_2) = -2.5\log_{10}(\frac{I_1}{I_2})$$

(in mag/arcsec^2)



Flux = <I> * Ω

$$m = -2.5\log_{10} F + \text{const} = -2.5\log_{10}\langle I\rangle\Omega + \text{const}$$

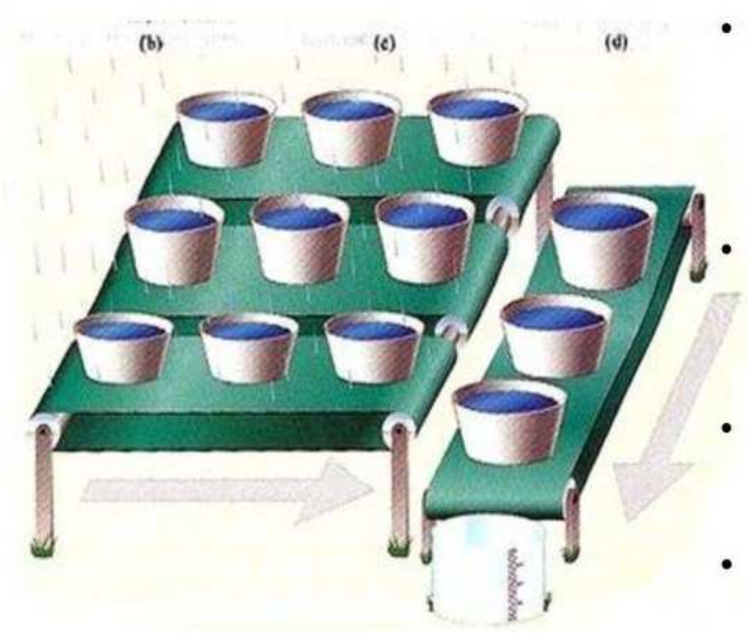
$$= \langle\mu\rangle - 2.5\log_{10}\Omega$$

Instrumental and physical units

- We measure **"counts"** integrated during a certain time
- Weighted by the telescope + instrument + detector + atmosphere sensitivity/transmission.

- The measurement then needs to be "calibrated"; all those effects corrected and converted to physical units

- That's where you need a standard source, of known flux, to model all effects



- Rain = Photons
- Water = Charge (photon strikes silicon semiconductor surface and knocks an electron loose by the photoelectric effect)
- Buckets = pixels (electrons accumulate in "potential wells;" depth represents how much charge each pixel can hold)
- The charge in each line of pixels is shifted to the readout register
- The charge in each pixel is counted

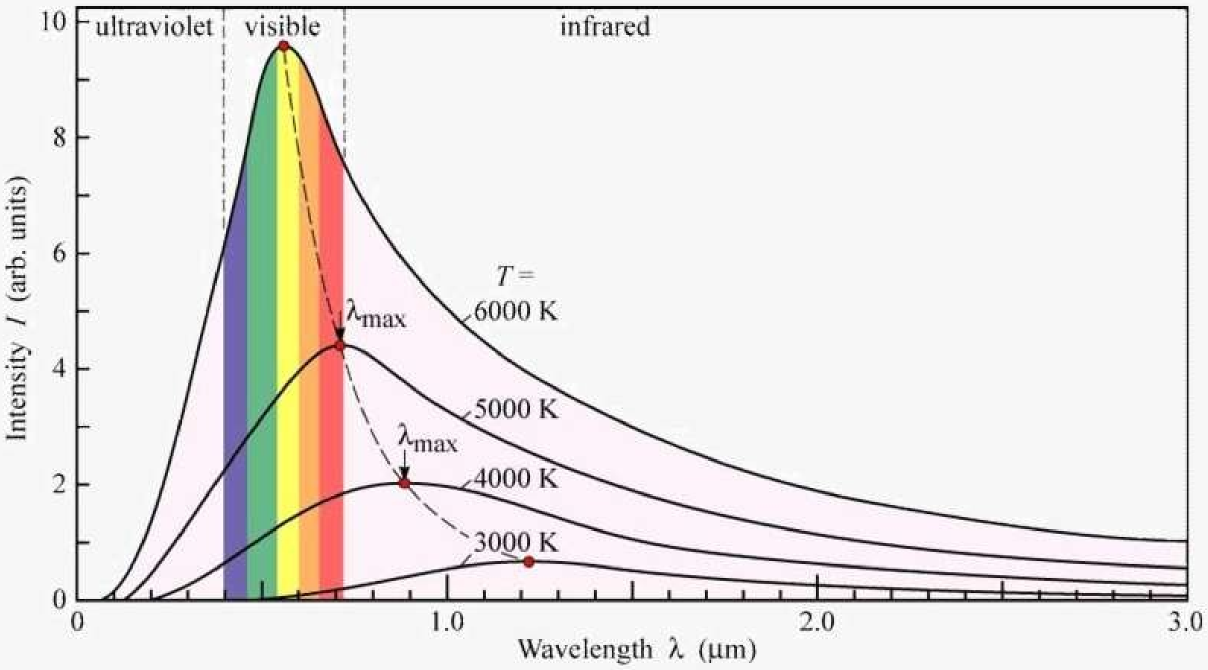
Black body radiation

Steffan-Boltzmann law: $F = \sigma\ T^4,$

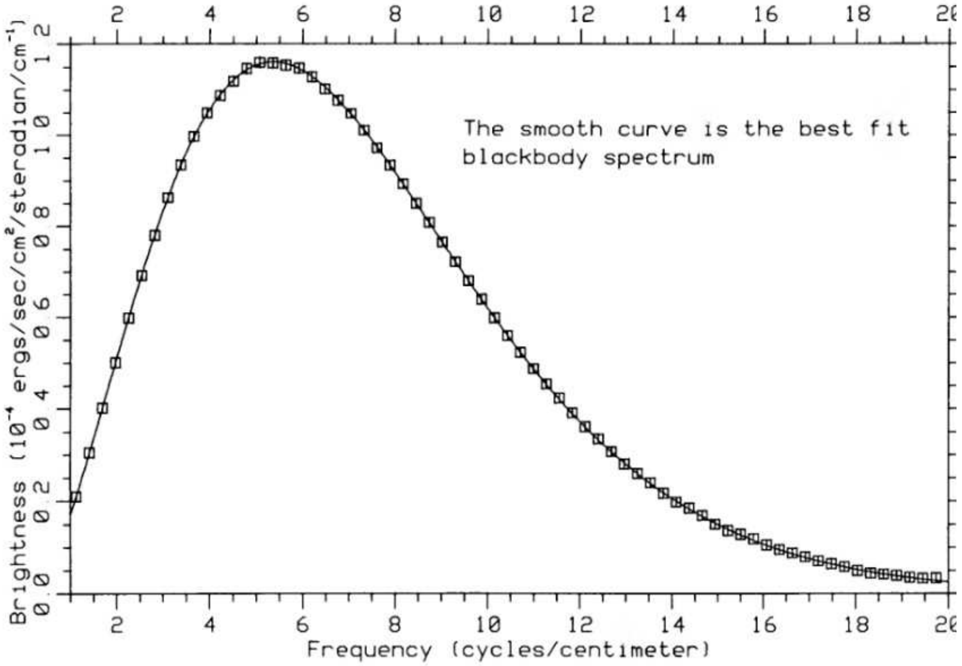
Planck's law:

$$I_\nu = B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{\exp\left(\frac{h\nu}{kT}\right) - 1}$$

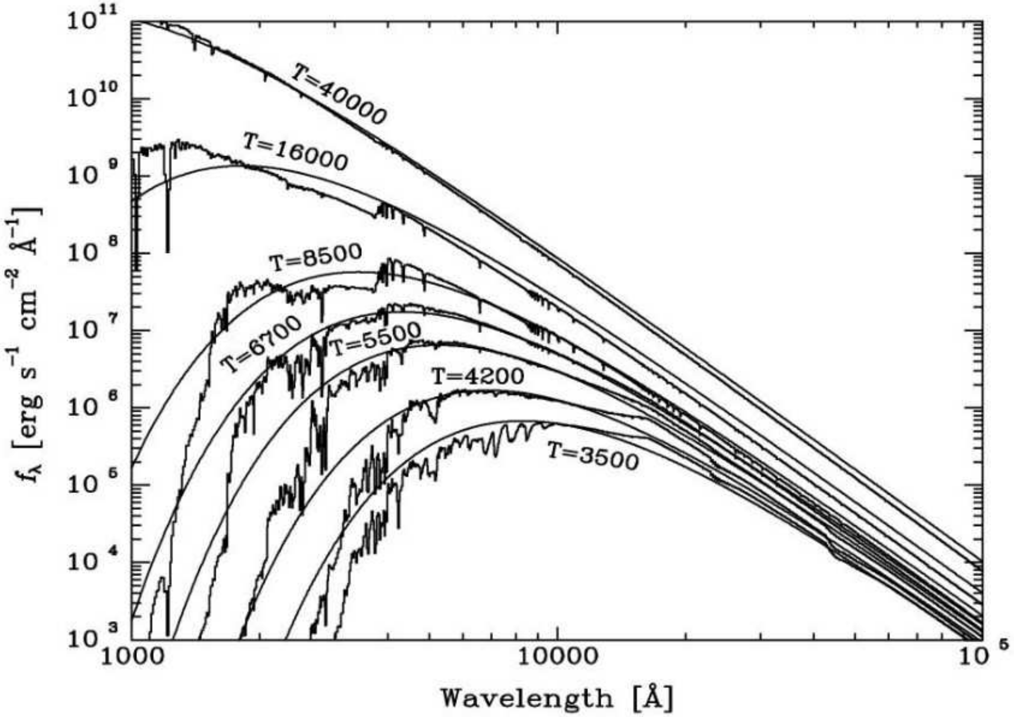
$$I_\lambda = B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{\exp\left(\frac{hc}{\lambda kT}\right) - 1}$$



Black body radiation



(CMB COBE data)



Other sources of EM radiation

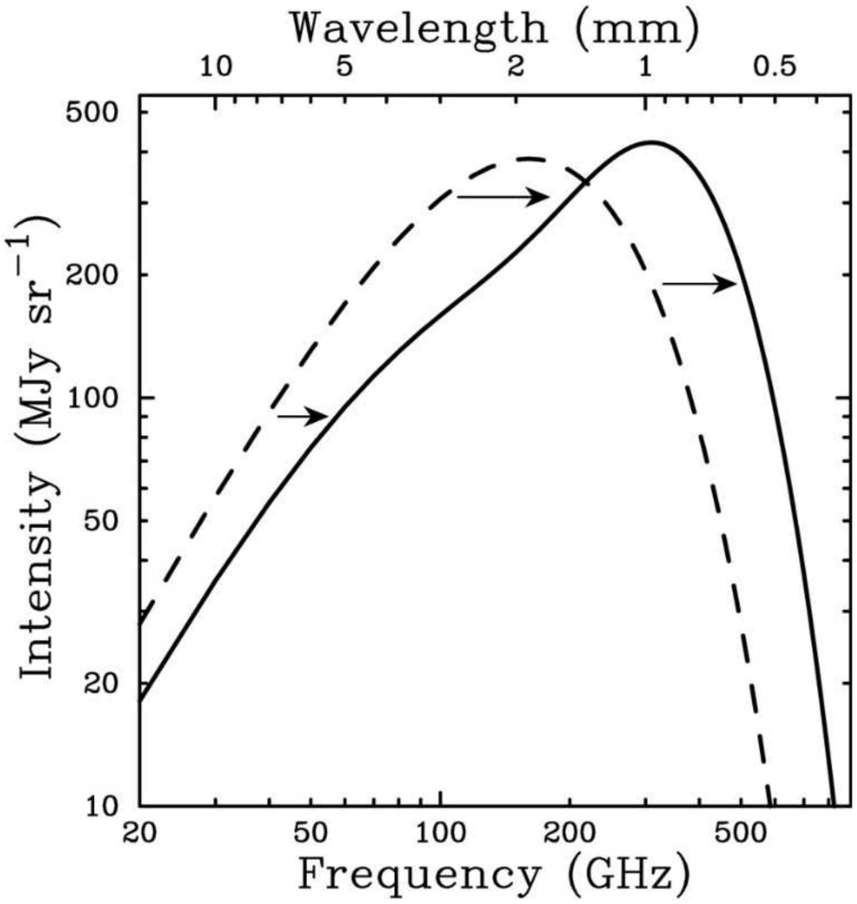
- **Bremsstrahlung**: radiation emitted by a charged particle under influence of the electric field of another charged particle
- Cooling of the intracluster medium, radio emission in HII regions and planetary nebulae

- **Thermal bremsstrahlung**: when the velocity distribution is thermal

- **Synchrotron radiation**: radiation emitted by charged particles suffering acceleration by a magnetic field, when the velocity of the particles is relativistic
- Radio, optical, and/or X-rays

- **Inverse Compton scattering**: photons gain energy in the scattering with electrons

- **Line emission:** from ionized gas and/or collisional excitation



Earth’s atmosphere

(Credit: NASA; from ISS point of view)

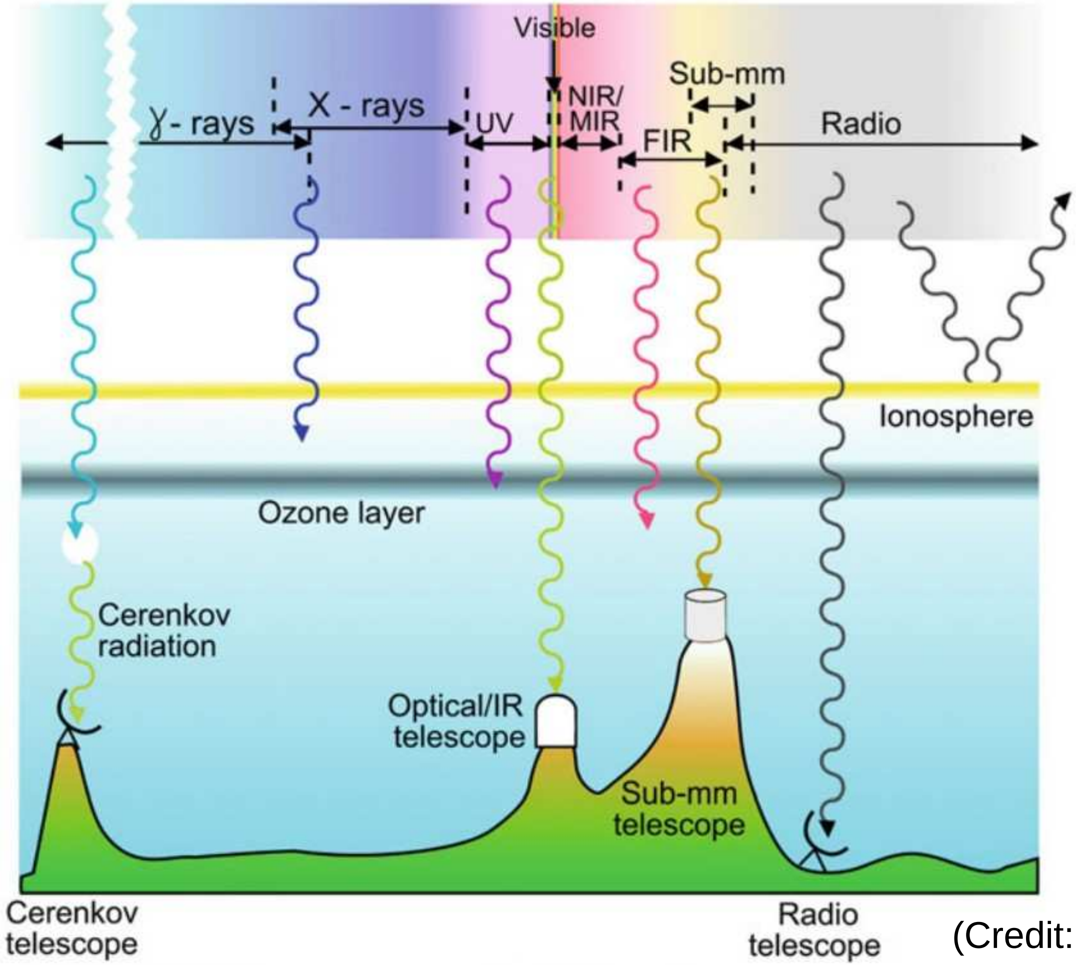
Observing from the ground

The atmosphere only transmits certain wavelengths

- Absorption and scattering
- Refraction (alters apparent position of the source)
- Emission (lines and continuum background)
- Turbulence (degrades the image quality)
- Ionosphere (limits low frequency radio observations)

(Credit: ESO)

Observing from the ground



(Credit: Lawrence 2013)

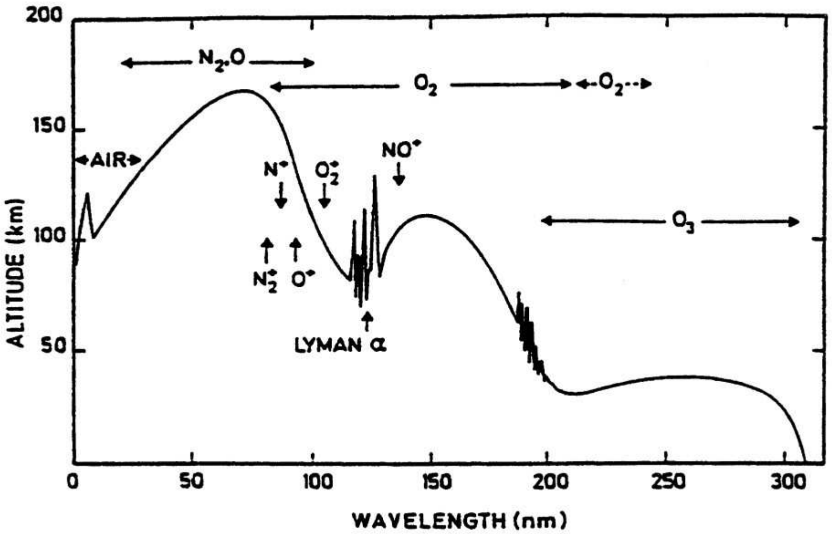
Atmospheric conditions in your proposal

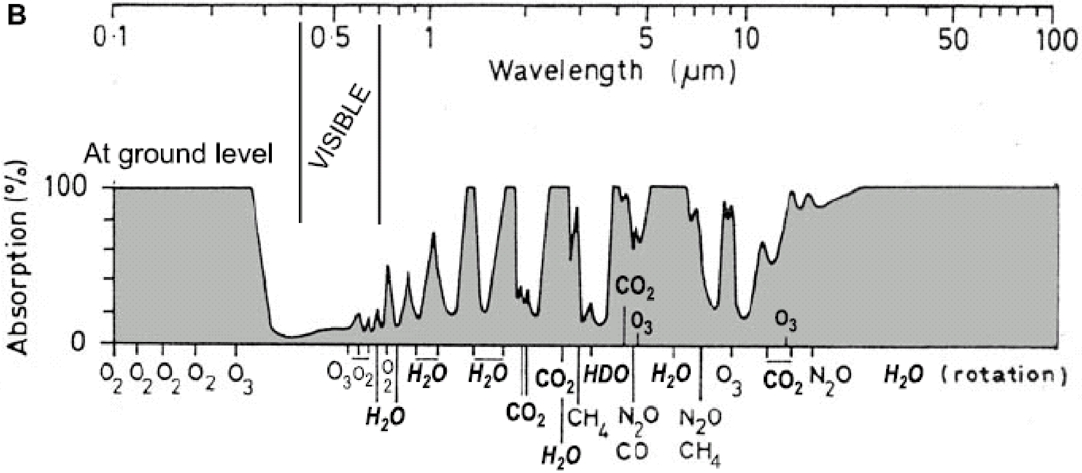
RUNS

Run	Period	Instrument	Tel. Setup	Constraints
001 • Run 1	109	UVES	UT2	FLI: 50% • Turb.: 85% • pwv: 30.0mm • Sky: Clear

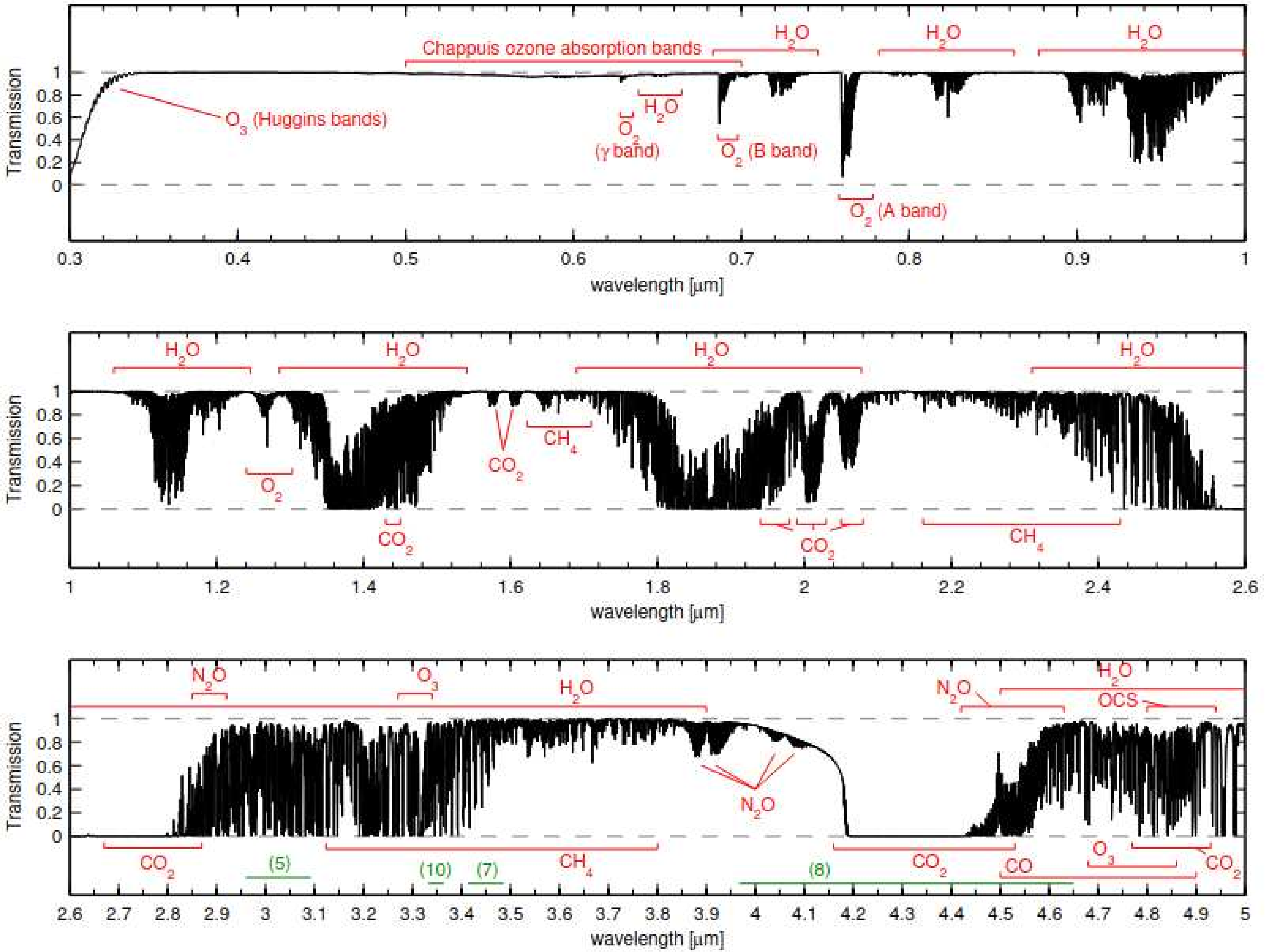
- Fraction of lunar illumination (FLI): fraction of the lunar disk that is illuminated (= 1 for fully illuminated; = 0 also when below horizon)
- Precipitable Water Vapour (PWV): mostly critical for infrared
- Turbulence: seeing is a property of atmospheric turbulence
- Sky Transparency: Photometric (variations under 2%); Clear (Less than 10% of the sky covered in clouds, variations under 10%); Thin cirrus (variations above 10%).

Absorption



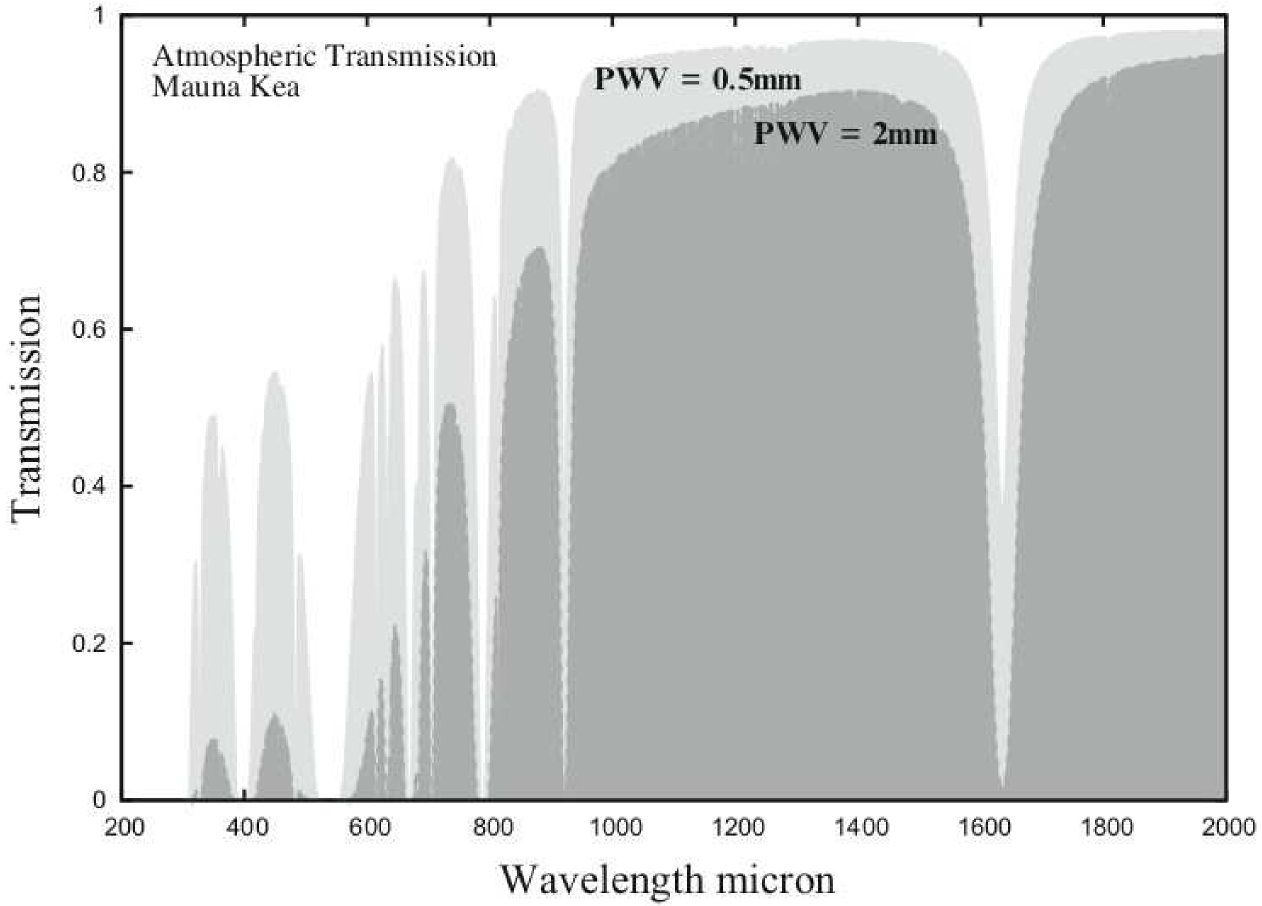


- N_2, O_2, and O_3 block below ~300nm
- 600-1300 nm: H_2O and O_2 important in the near-IR; CO_2 in the IR
- Beyond 1300nm: in some windows light reaches the surface
- 2500nm to 1mm: opaque atmosphere
- Ionosphere blocks beyond ~ 10m



Chappuis ozone absorption bands
H_2O
O_3 (Huggins bands)
O_2
(γ band)
O_2 (B band)
O_2 (A band)
Transmission
wavelength [µm]
O_2
CO_2
CH_4
N_2O
O_3
OCS
CO
(5)
(10)
(7)
(8)

Precipitable Water Vapour



Scattering

- Rayleigh scattering: particles much smaller than wavelength of the radiation

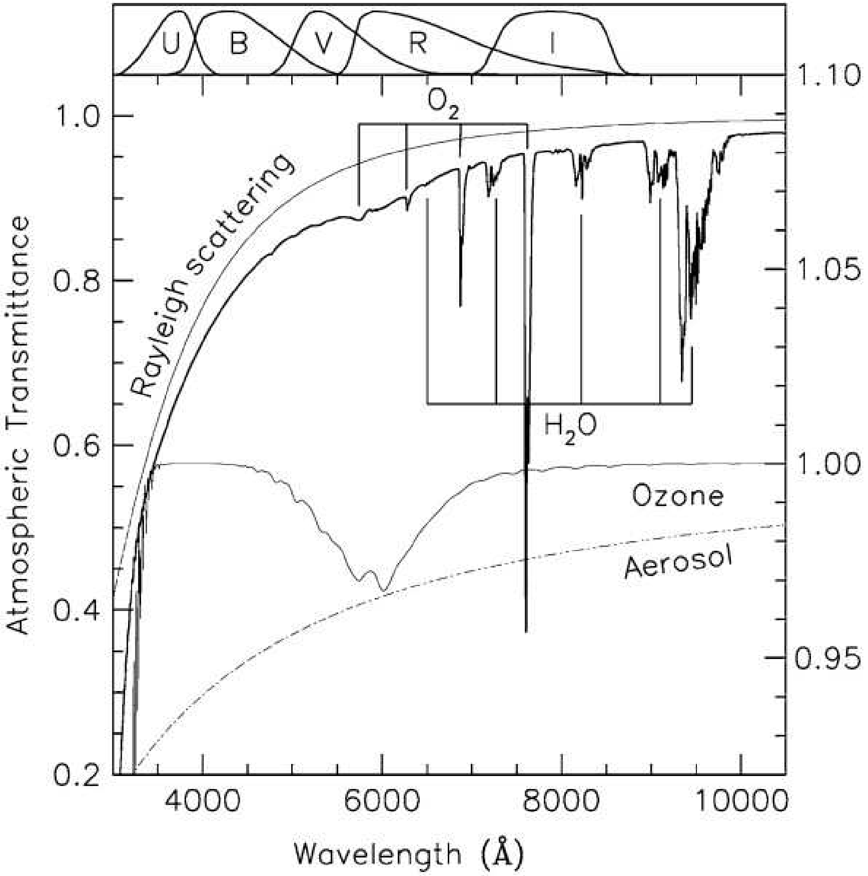
$$\sigma_{\text{Rayleigh}} = \frac{8\pi^3}{3} \frac{(n-1)^2}{\lambda^4 N^2}$$

- Mie scattering: particles have similar or larger size than wavelength of the radiation (also called aerosol scattering)

- Aerosols include: dust, pollen, smoke, water droplets in clouds, volcanic ashes

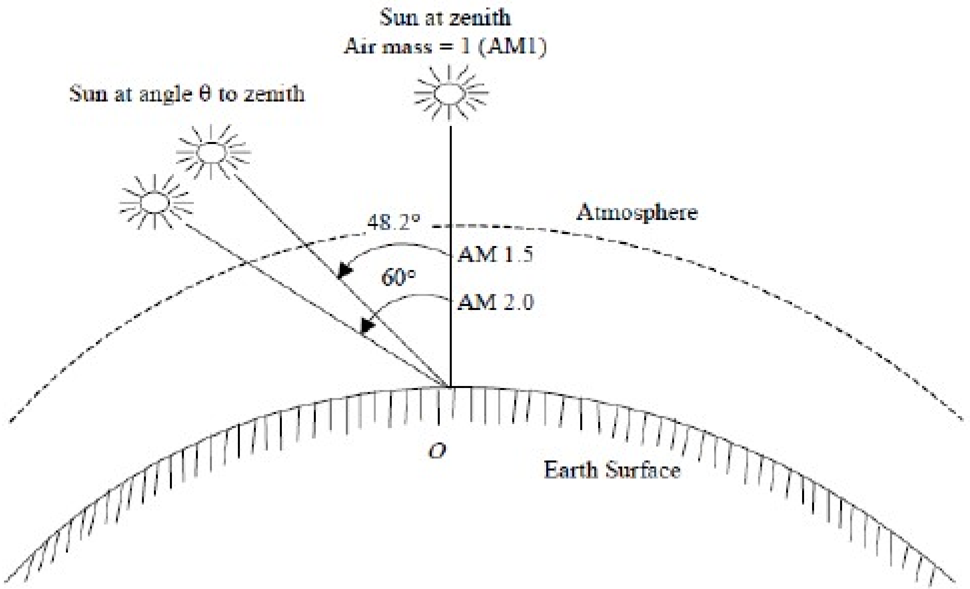
- Blue sky and red sunset: Rayleigh scattering

- White/grey clouds: Mie scattering



Airmass

- **Airmass:** measure of the amount of atmosphere along the line of sight when observing an astronomical source



- Atmospheric extinction can be written as a function of airmass

- Airmass = sec *z*, if *z* not large, or:

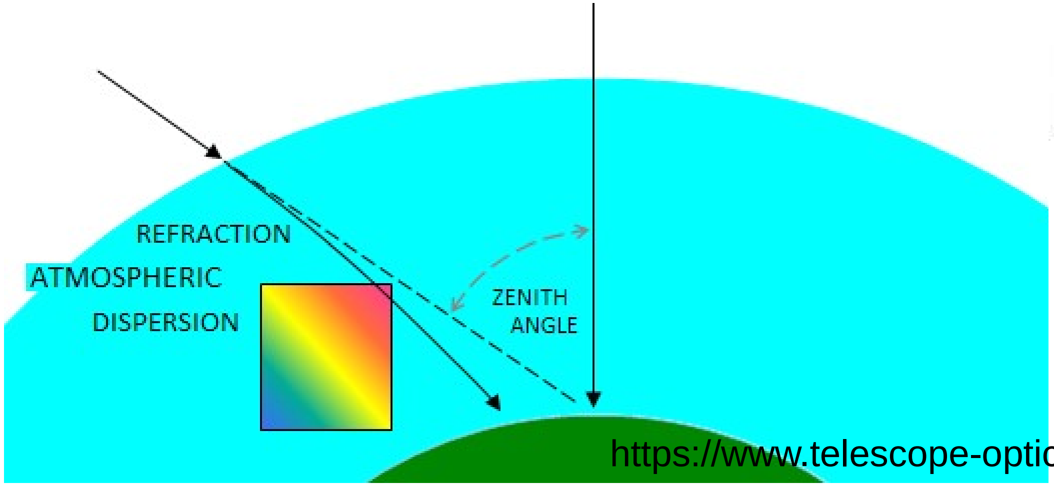
$$X = \sec z - 0.0018167(\sec z - 1) - 0.002875(\sec z - 1)^2 - 0.0008083(\sec z - 1)^3$$

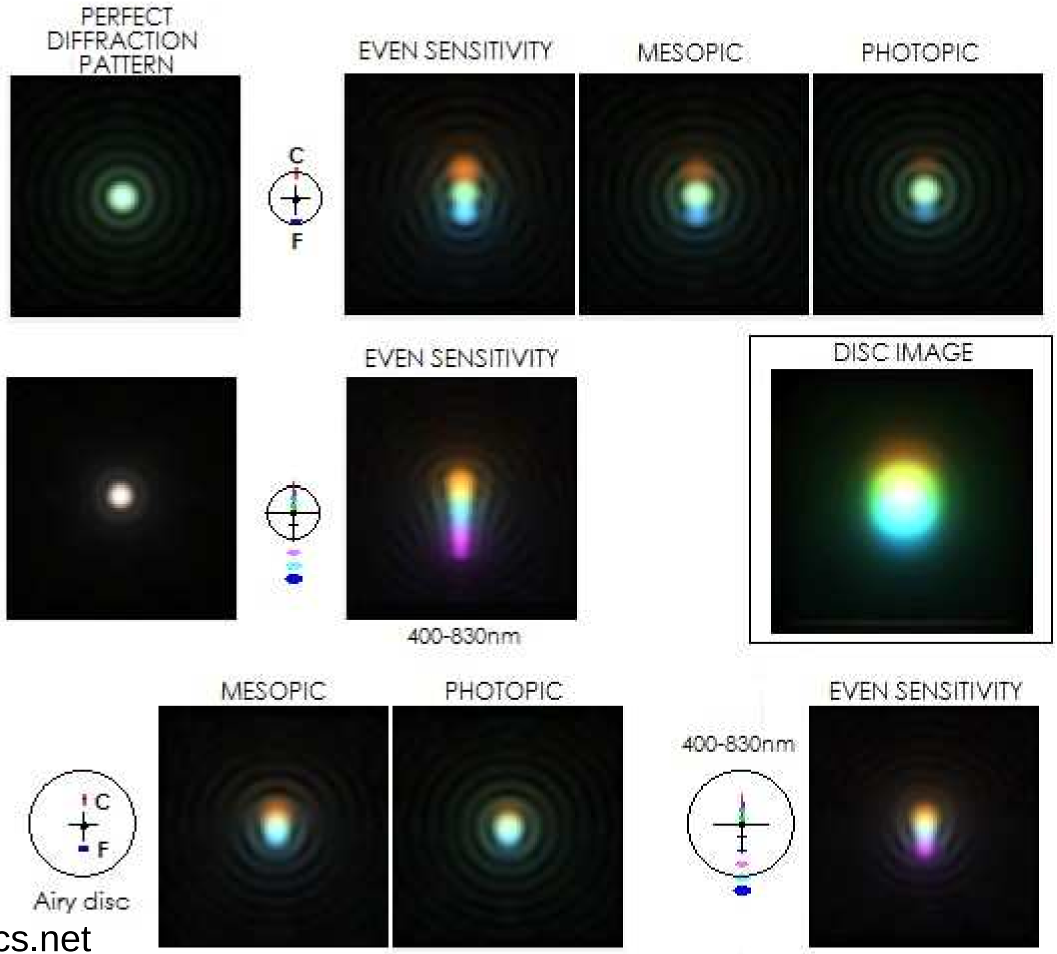
Atmospheric refraction

- **Refraction:** changes the apparent position of the object being observed

- Water vapour can change the refractive index and thus affects refraction

- The refractive index depends on wavelength



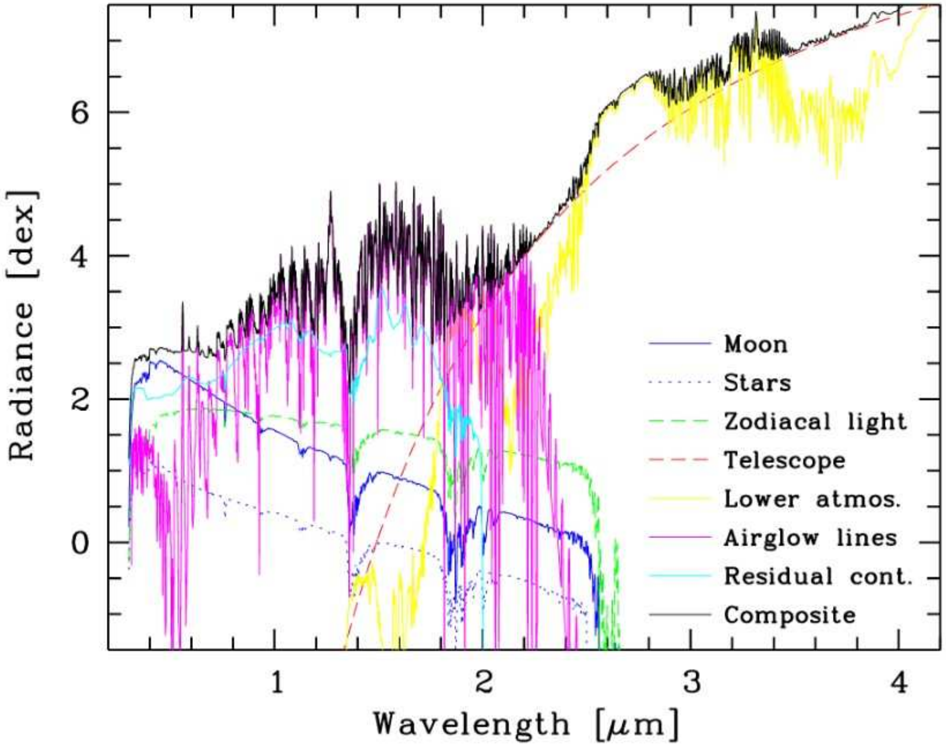


https://www.telescope-optics.net

Night sky brightness

- Night sky is never completely dark, not even from space!

- The Moon is an important source of scattered light



(Noll et al. 2012)

Night sky brightness

- **Airglow:** cosmic rays and sunlight photoionization of gases in the upper atmosphere during daytime

- Emission by recombination

- Green light (~558 nm) from excited oxygen atoms, 90 to 100 km

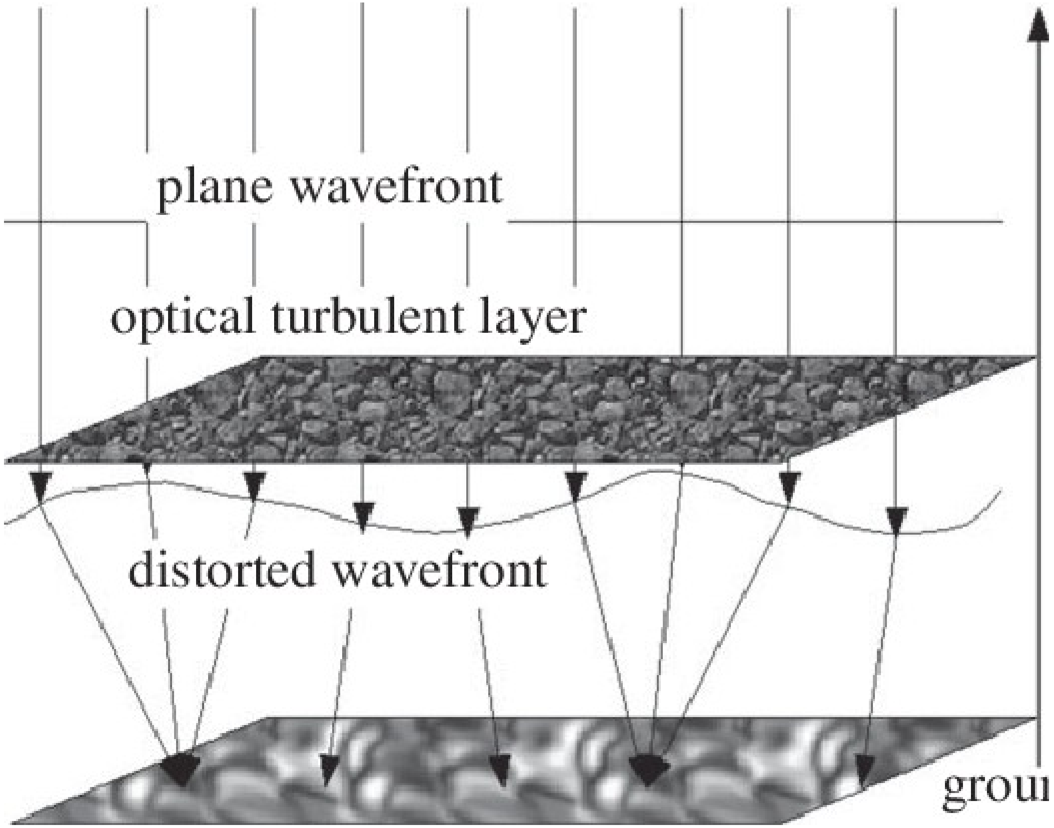
- Blue airglow from excited molecular oxygen (O_2), 95 km

- Red airglow from oxygen atoms at 150 to 300 km.

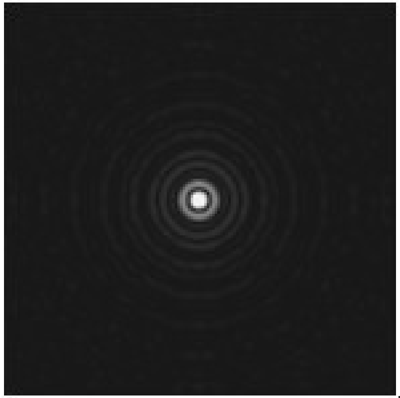
- Yellow light from Na atoms at 92 km.

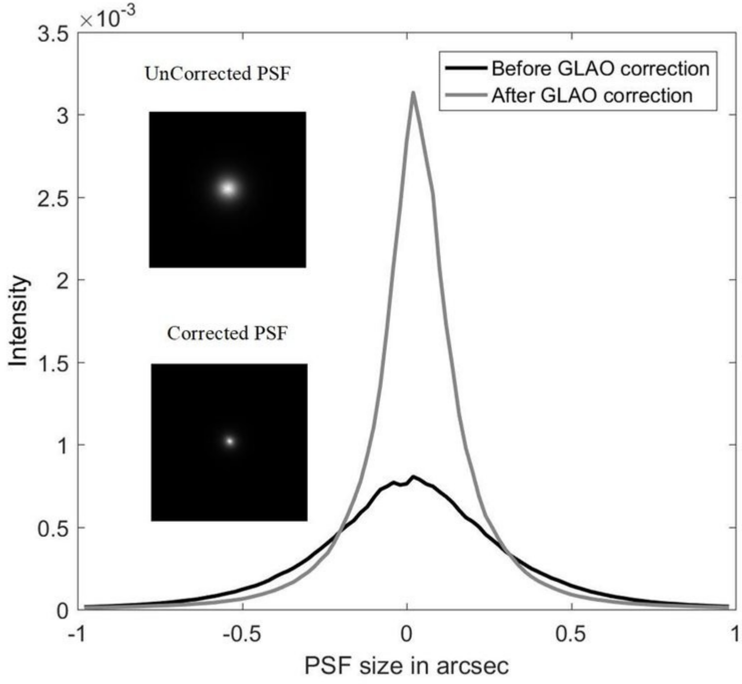
Seeing and scintillation

- The atmosphere is variable, spatially and in time (changes in temperature, density, refraction properties).
- **Seeing:** random variation in the direction of light. Broadens the astronomical image.
- **Scintillation:** random variation in the intensity of the arriving light
- VLT difraction causes a disk of 0.016 arcsec. Median seeing is 0.8 arcsec
- Seeing varies with $\lambda^{-1/5}$

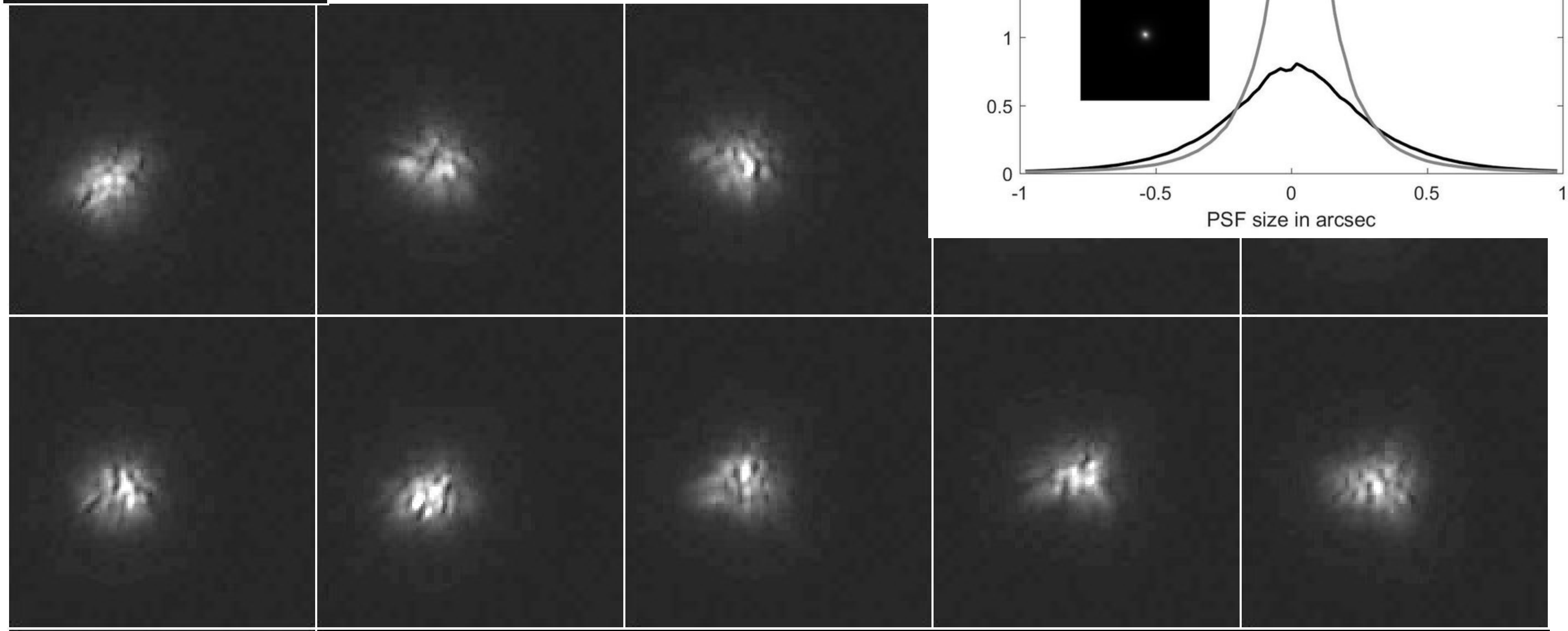


Seeing



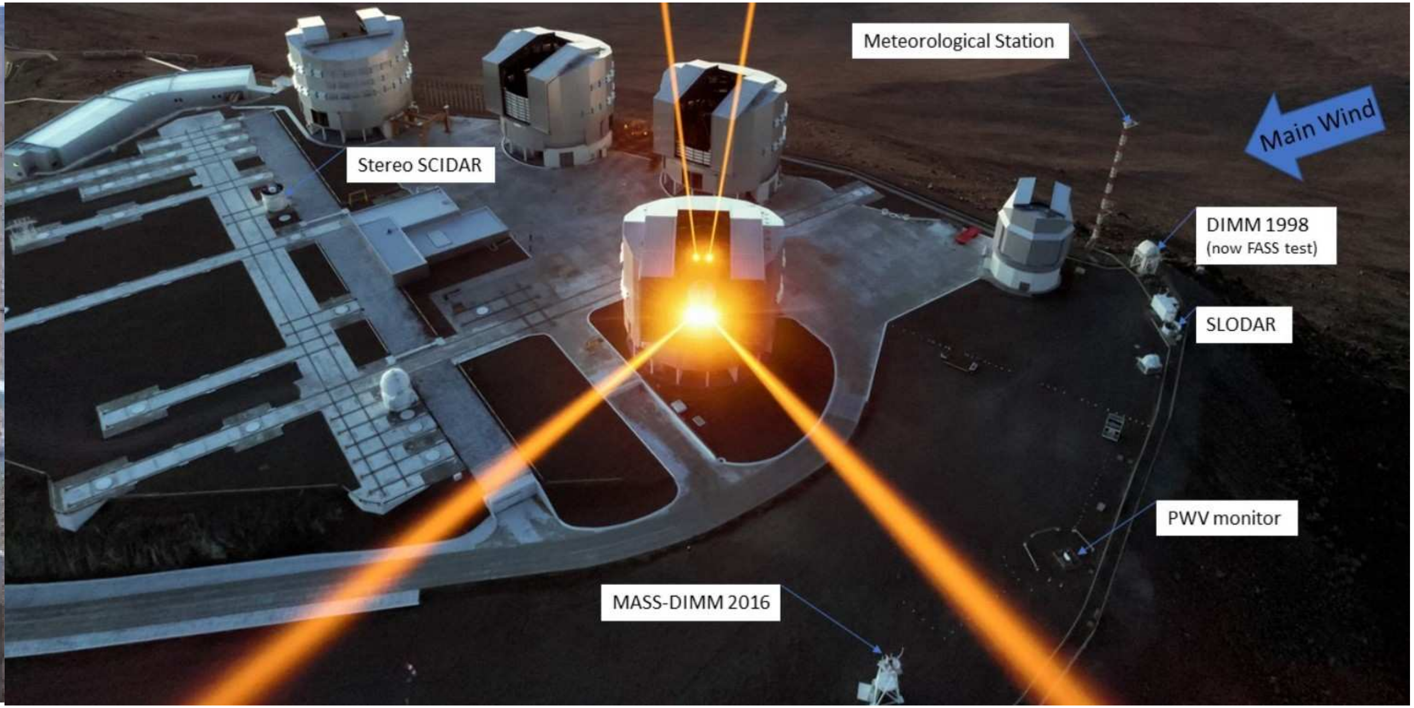


$\times 10^{-3}$
3.5
3
2.5
2
1.5
1
0.5
0
Intensity
UnCorrected PSF
Corrected PSF
Before GLAO correction
After GLAO correction
-1
-0.5
0
0.5
1
PSF size in arcsec

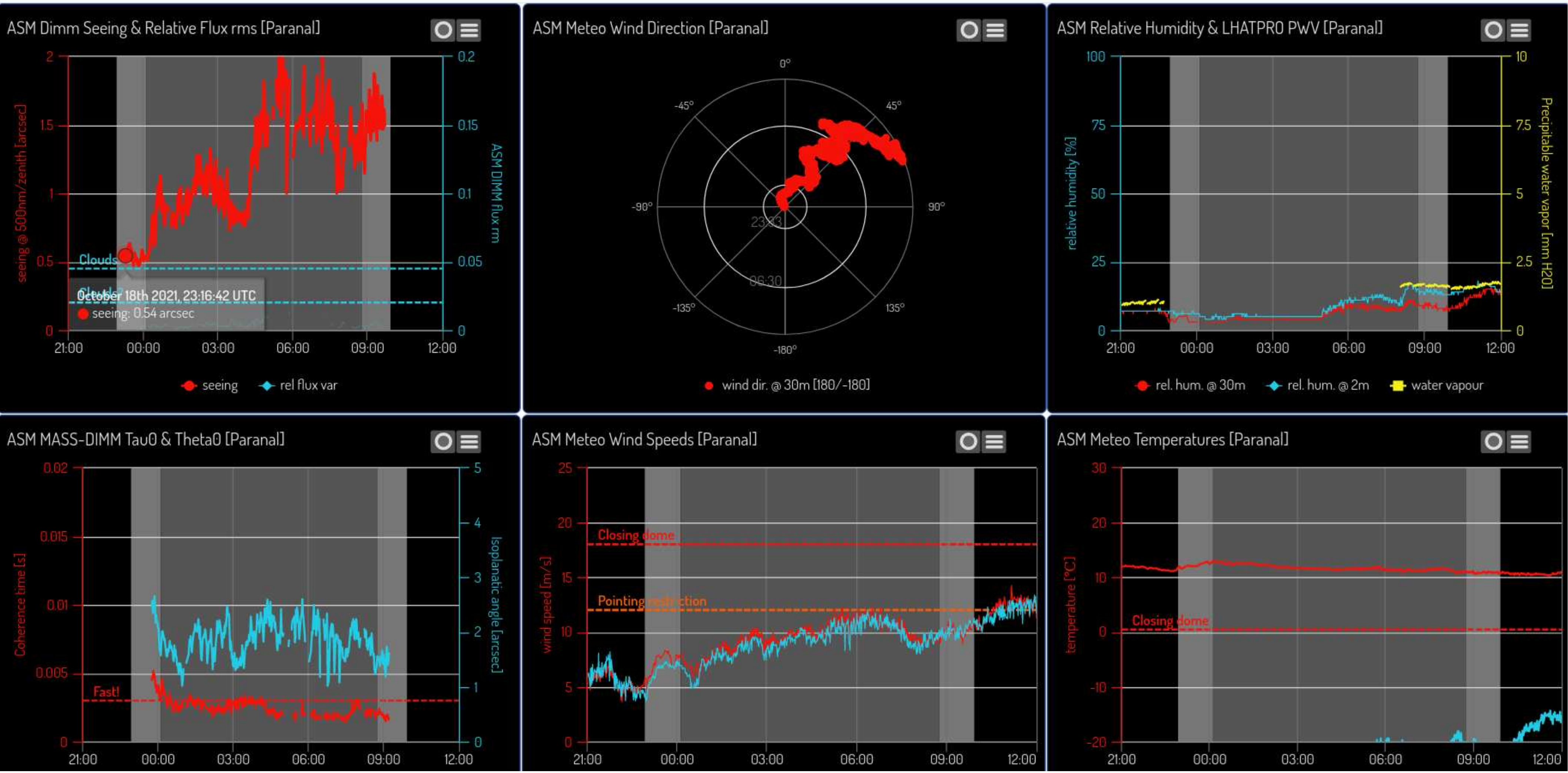


DIMM

- Differential Image Motion Seeing Monitor
- Two apertures monitor same star
- Tracking errors, wind effect, etc, can be corrected



(Credit: ESO)


ASM Dimm Seeing & Relative Flux rms [Paranal]
seeing @ 500nm/zenith [arcsec]
ASM DIMM flux rm
Clouds
October 18th 2021, 23:16:42 UTC
seeing: 0.54 arcsec
seeing
rel flux var
ASM Meteo Wind Direction [Paranal]
wind dir. @ 30m [180/-180]
ASM Relative Humidity & LHATPRO PWV [Paranal]
relative humidity [%]
Precipitable water vapor [mm H20]
rel. hum. @ 30m
rel. hum. @ 2m
water vapour
ASM MASS-DIMM Tau0 & Theta0 [Paranal]
Coherence time [s]
Isoplanatic angle [arcsec]
Fast!
ASM Meteo Wind Speeds [Paranal]
wind speed [m/s]
Closing dome
Pointing restriction
ASM Meteo Temperatures [Paranal]
temperature [°C]
Closing dome

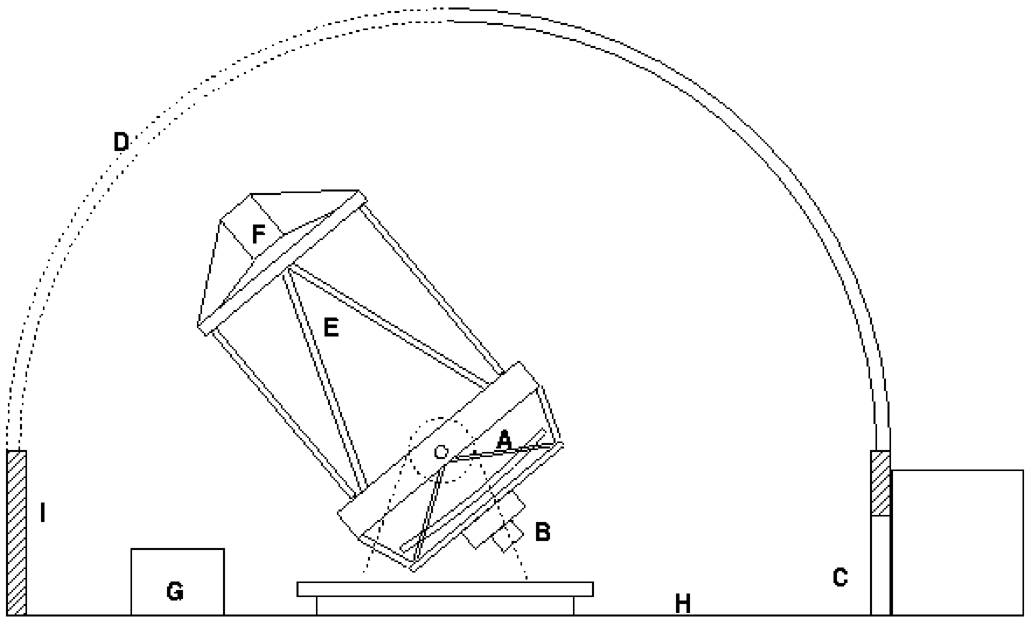
(Credit: ESO)

Dome seeing

- **Convection and turbulence inside the dome**

- A. Primary mirror warmer than the air
- B. Cassegrain instrument behind mirror
- C. Airflow through the entrance door
- D. Turbulence across the enclosure
- E. Convective airflow by the telescope structure
- F. Heat generation by the secondary mirror
- G. Other equipment inside the dome
- H. Enclosure floor
- I. Enclosure and dome walls

- Insulate walls, floor, and equipment. Wind ventilation.



(Credit: ESO)

Observing modes

- **Visitor mode:** you go to observe at a pre-determined date

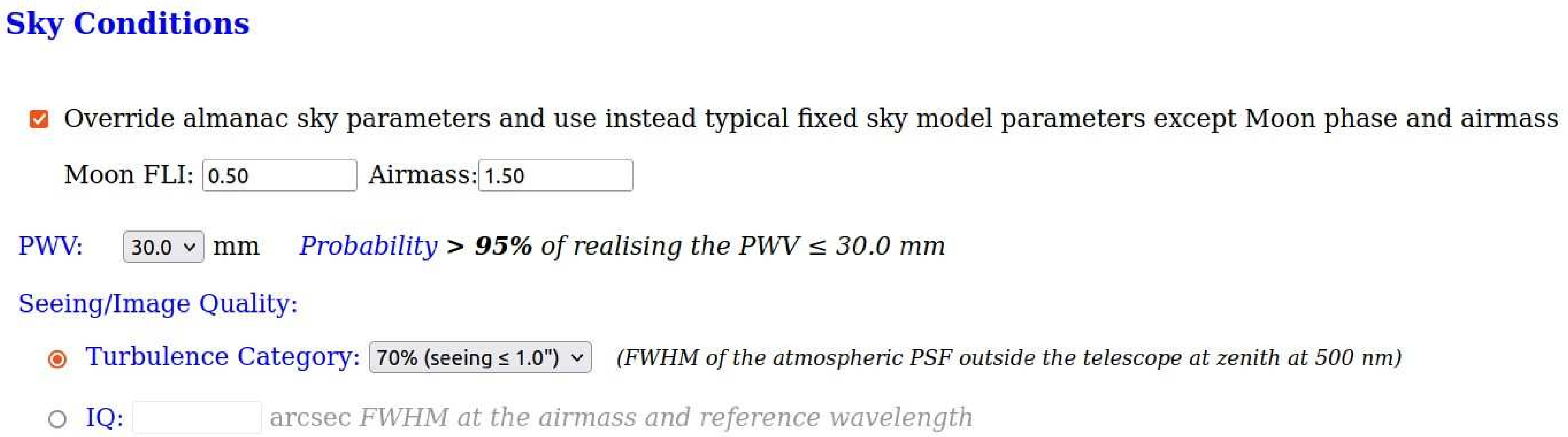
- Great for taking last minute decisions
- Vulnerable to bad weather (or instrument failure, earthquakes?!)

- **Service mode:** you prepare the observations in advance and the observatory staff execute them

- Done only when the conditions are as required
- Subject to the ranking of priorities

Exposure time calculators

- **ETC:** are available for all ESO instruments
- Help to decide the right instrument configuration
- And to estimate the impact of the observing conditions



Choosing observing conditions

- **Best possible conditions ?** – are rare and face strong competition. If you can, do use loose conditions. This can help to make your observations being scheduled (but if you need, do ask for them!!)

- **Moon:** Keep a certain distance, to avoid strong background. Dark time only if sources are faint.

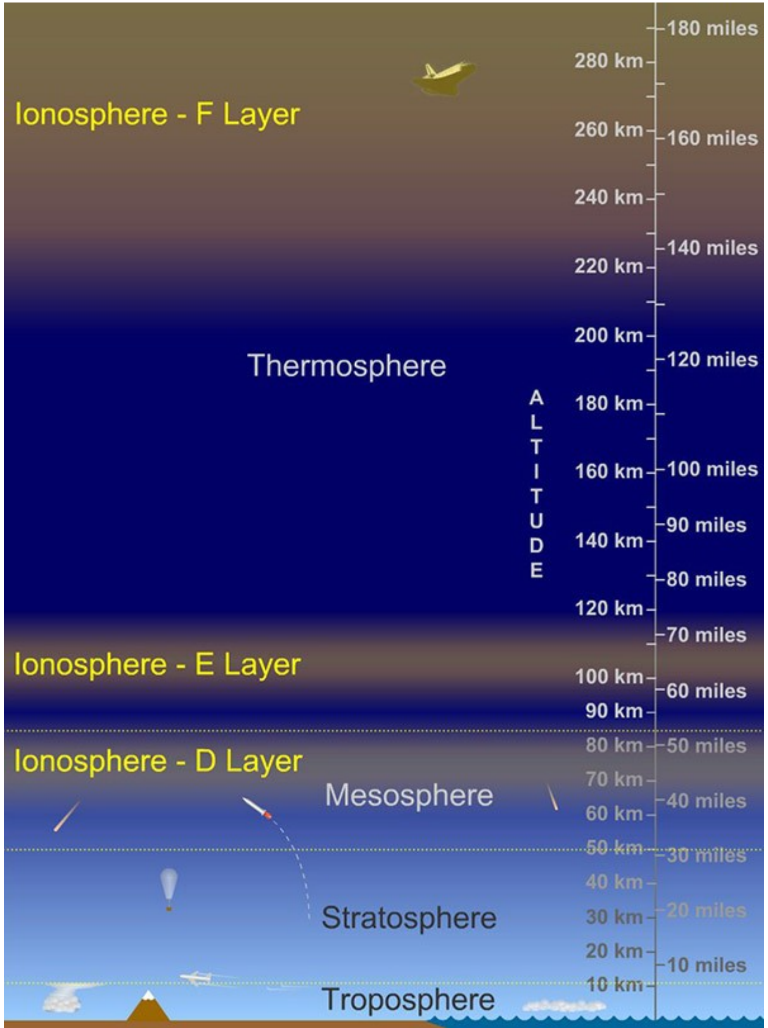
- **Precipitable Water Vapour (PWV):** mostly critical for infrared

- **Seeing:** can affect the final signal-to-noise

- **Sky Transparency:** Photometric only if really doing flux calibration; Thin or thick cirrus usually less requested. **Fillers – any weather condition.**

Ionosphere

- **Ionosphere:** ionized by solar radiation
- D and E layers ionized only during the day
- F layer has the highest electron density
- Cut-off at ~4.5 MHz at night, ~11 MHz during the day
- During the day, at long radio wavelengths, terrestrial radio signals bounce back from the ionosphere (E and D layers), causing background signal



Questions?

(Credit: Shutterstock)