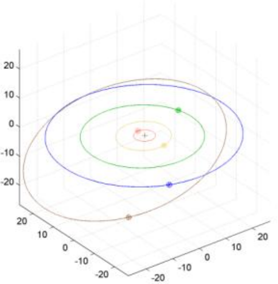
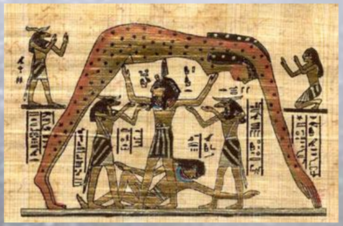
Cosmology

- **Age of the Universe**
  - Future?
  - The cosmic calendar
  - Age of the Earth
  - Red shift
- **Structure and evolution of stars**
- **Relativity**
  - Special Relativity
  - Ideas of General Relativity
    - Gravitational lensing
    - Precession of Mercury
- **Exotic case studies**
  - Neutron stars
  - Black holes, quasars
- **Planets & moons**
  - Detecting planets orbiting other stars
  - The Solar System
    - The Earth
- **A human history of cosmology**
- **Gravity**
  - Newton/Kepler
  - Einstein
  - Computer Simulation
- **Size of the Universe**
  - Measurement
    - Parallax
    - Luminosity
  - Earth
    Solar System
    Galaxy ...

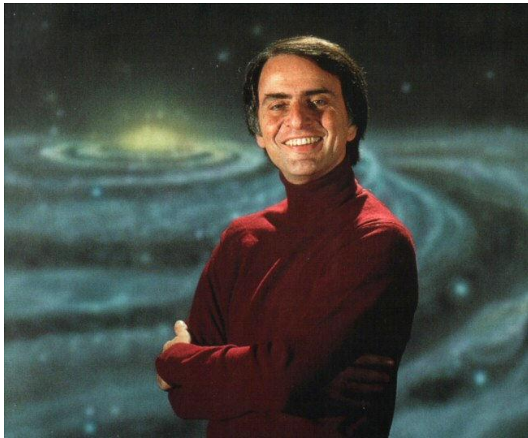




The Cosmos is all that is or ever was or ever will be.

In the last few millennia we have made the most astonishing and unexpected discoveries about the Cosmos and our place within it, explorations that are exhilarating to consider. They remind us that humans have evolved to wonder, that understanding is a joy, that knowledge is prerequisite to survival.

I believe our future depends on how well we know this Cosmos in which we float like a mote of dust in the morning sky.



Carl Sagan (1934-1996)
Cosmos pp20

How big is the Universe?
How far away are the stars?
How can we measure these things?

Physical stats of the Universe

Diameter: 93 billion light years

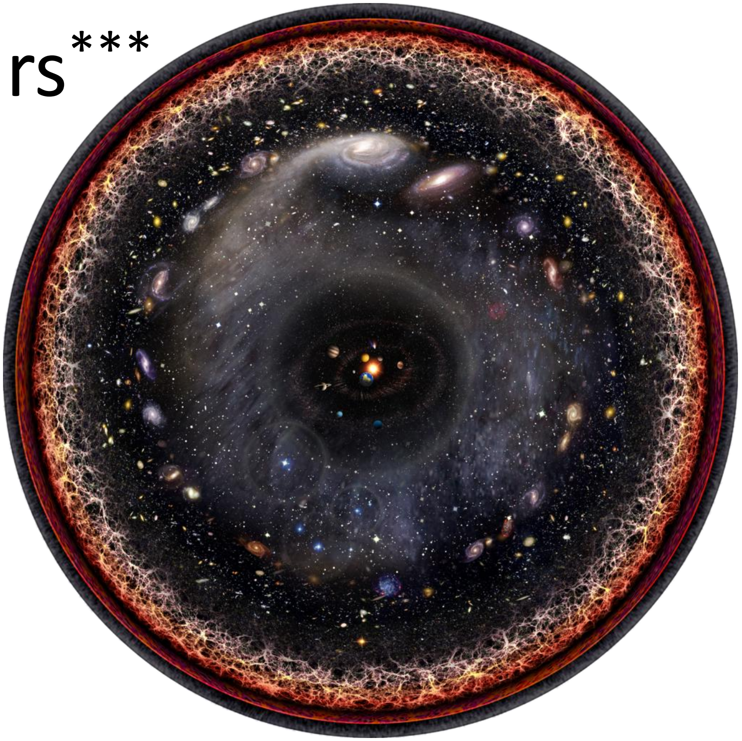
Volume: 4 x 10^{83} litres

Mass: 10^{53} kg*

Density: 9.9 x 10^{-30} gcm^{-3} **

Age: 13.8 billion years***

Temperature: 2.73K



*Ordinary matter: 4.9%

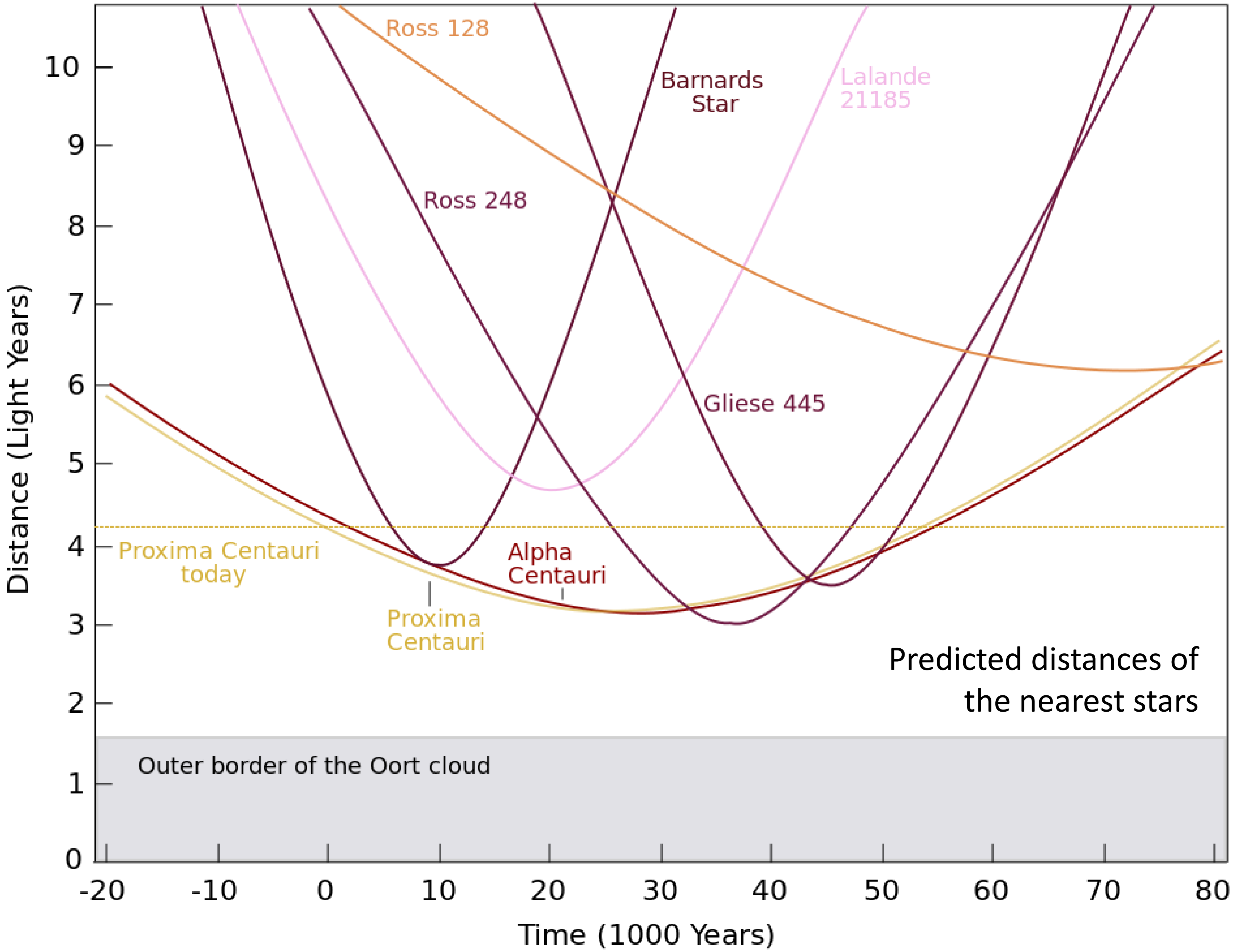
Dark matter: 26.8%

Dark energy: 68.3%

*** The Earth is 4.54 ± 0.05 billion years old

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

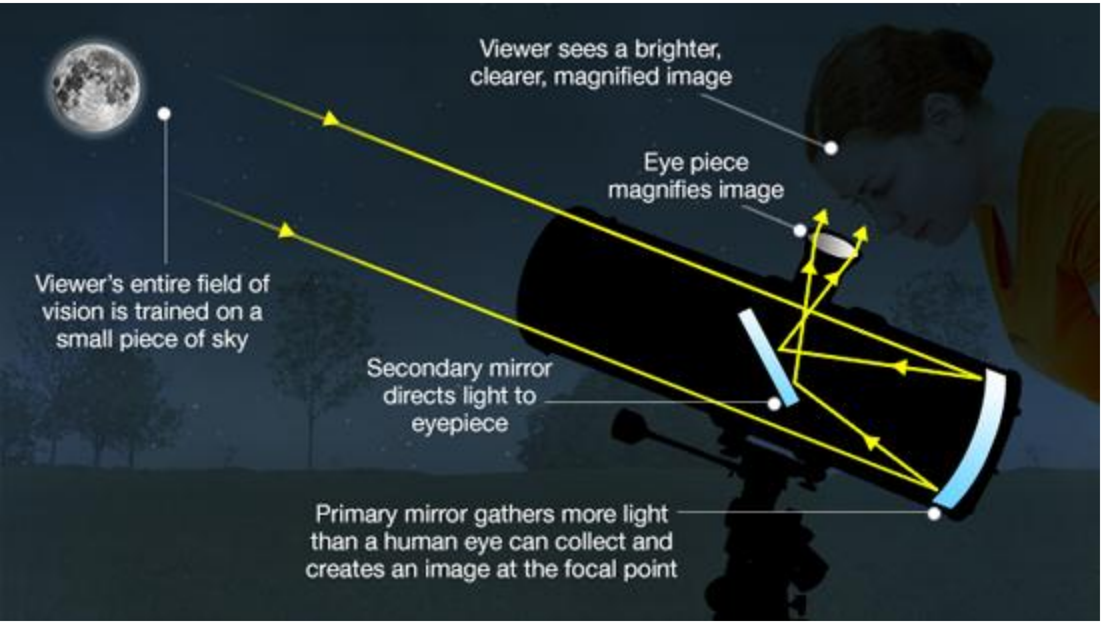
*6 protons per cubic metre

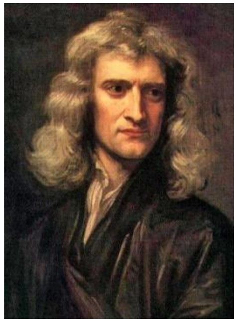


Predicted distances of the nearest stars

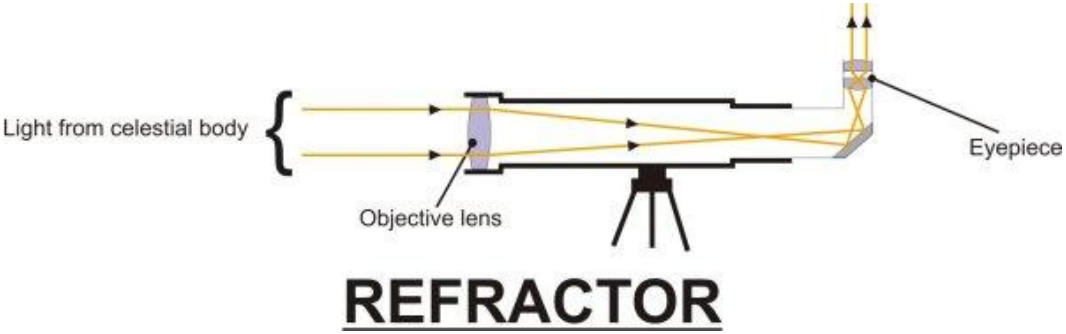
Observational tools for viewing the Cosmos

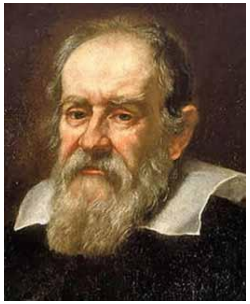
Telescopes: **reflecting** and **refracting**





Isaac Newton
(1642-1727)





Galileo
1564-1642

Angular resolution of a telescope

Angular resolution in radians

Wavelength of light

$$\boxed{\Delta\theta \approx \frac{\lambda}{D}}$$

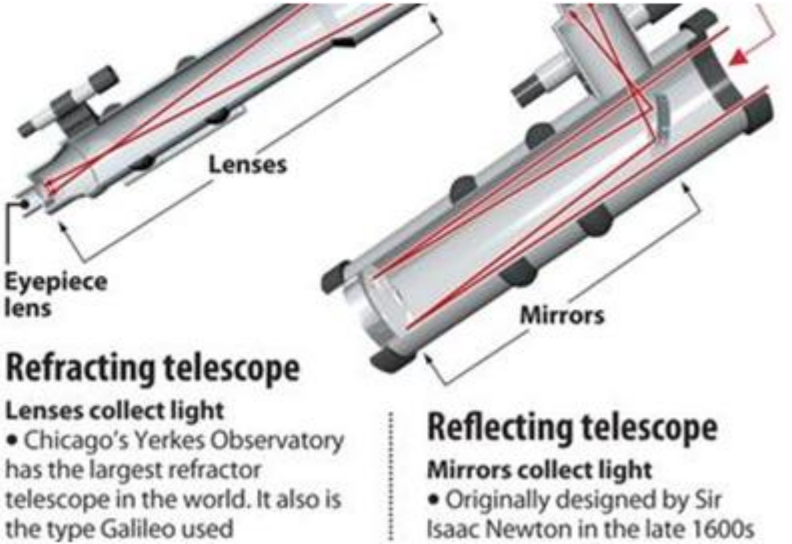
Diameter of telescope aperture

The **Gran Telescopio Canarias** (meaning "Canaries Great Telescope"), also known as GranTeCan or GTC, is a 10.4 m (410 in) reflecting telescope undertaking commissioning observations at the Roque de los Muchachos Observatory on the island of La Palma, in the Canary Islands in Spain, as of July 2009.

$\lambda \approx 10^{-7}\,\mathrm{m}$ visible light

$$\Delta\theta \approx \frac{10^{-7}}{10.4} = 9.6\times10^{-9}\ \text{radians}$$

$$\Delta\theta = 0.00198\ \text{arc seconds}$$



Refracting telescope

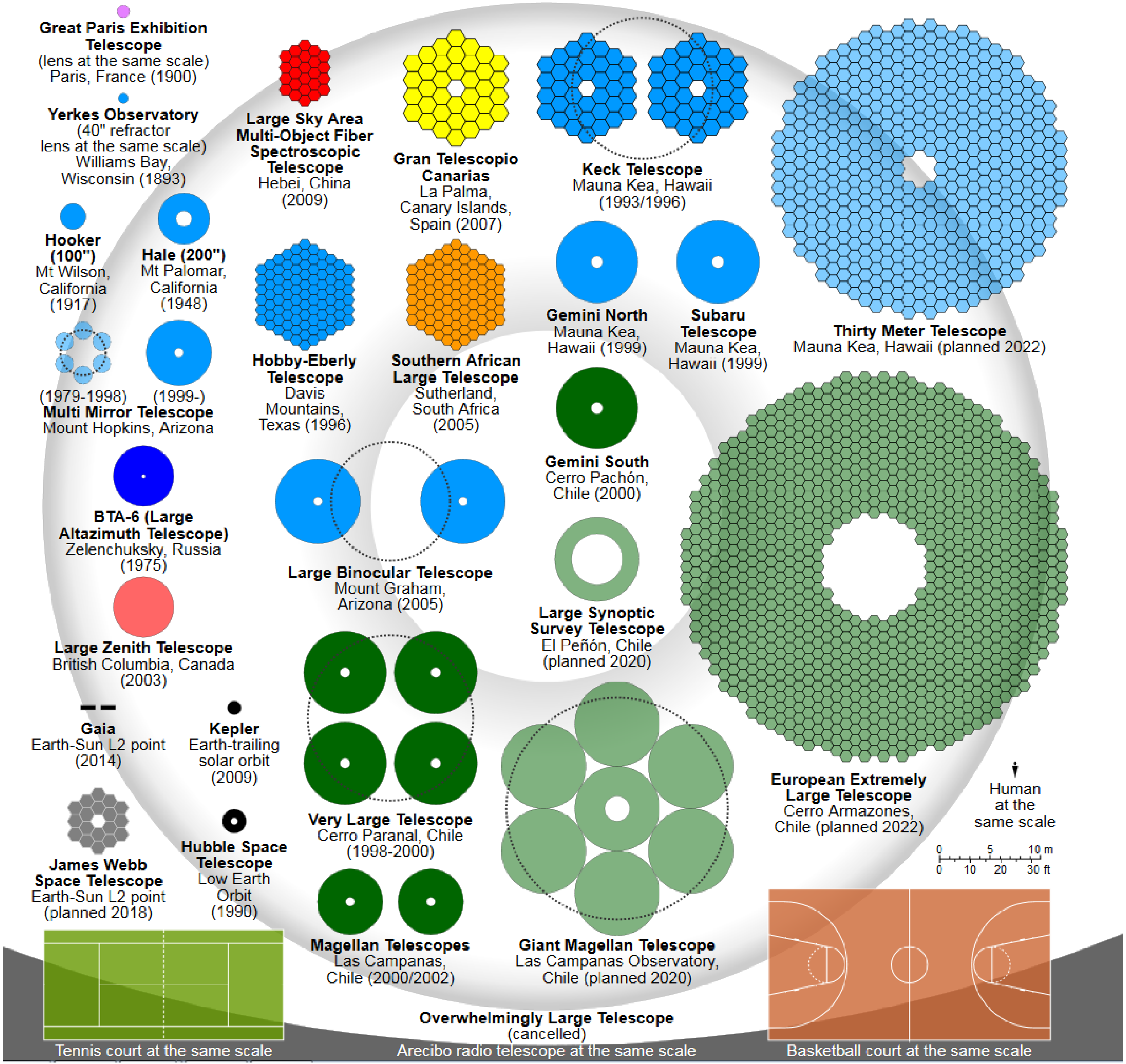
Lenses collect light

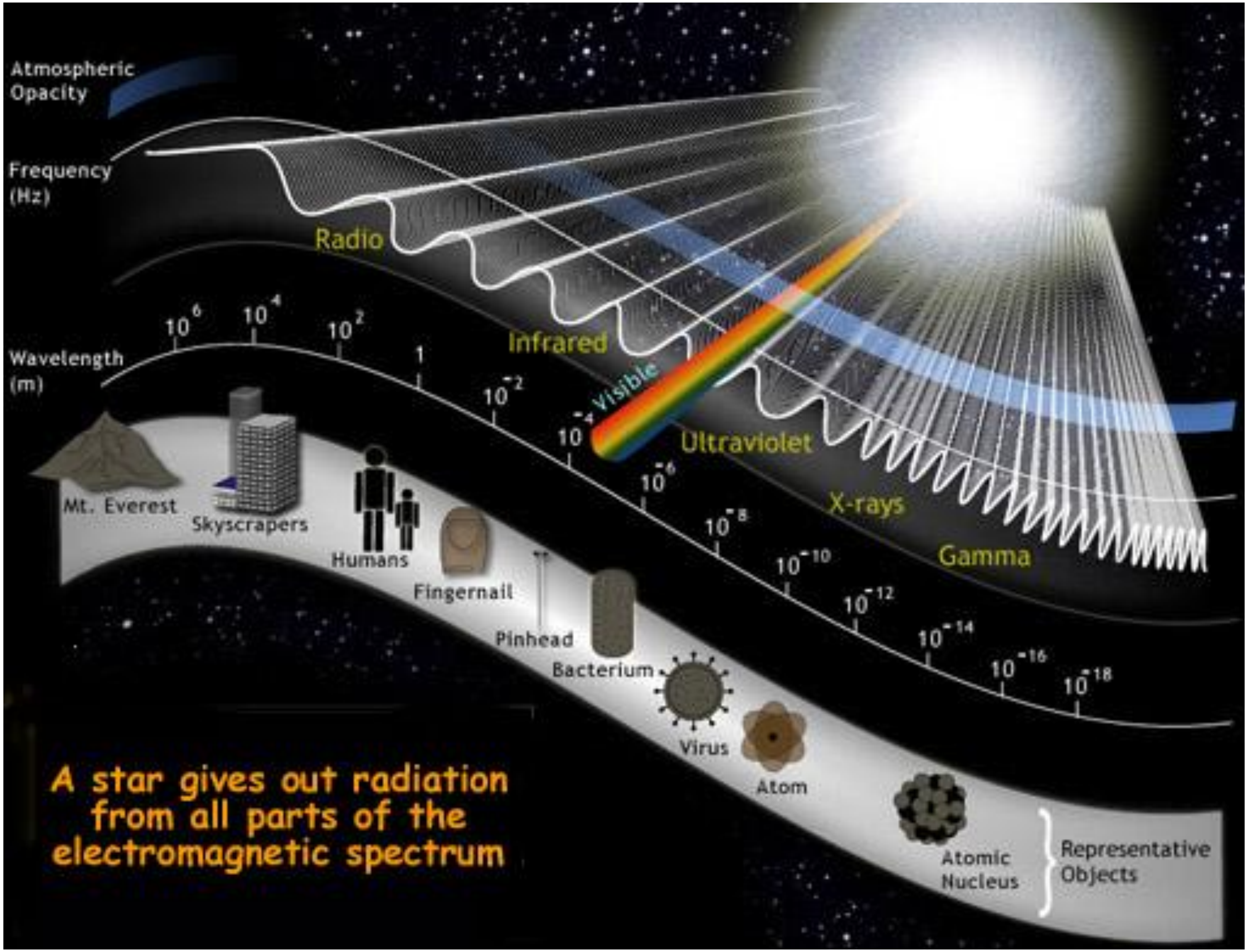
- Chicago's Yerkes Observatory has the largest refractor telescope in the world. It also is the type Galileo used

Reflecting telescope

Mirrors collect light

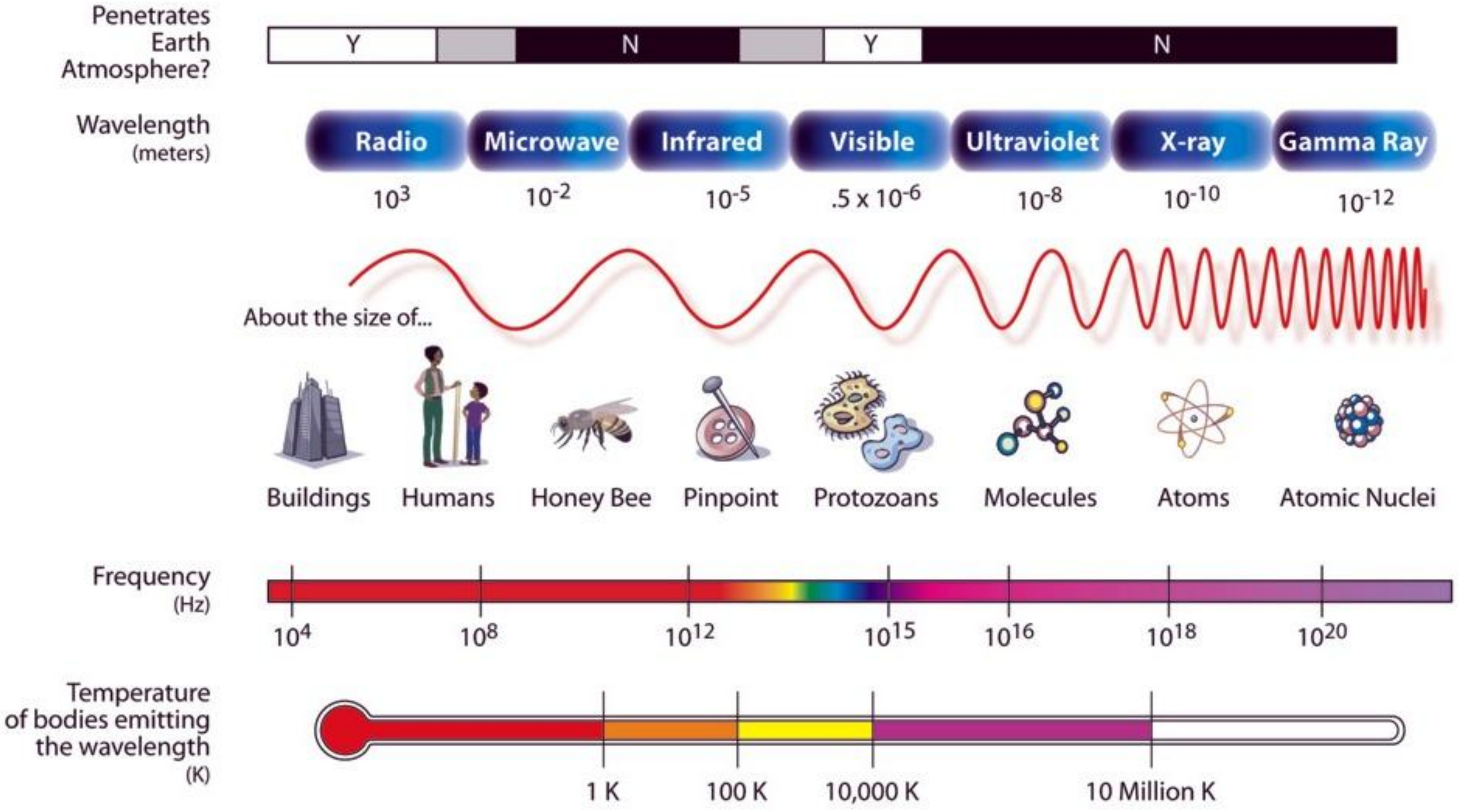
- Originally designed by Sir Isaac Newton in the late 1600s


Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor
lens at the same scale)
Williams Bay,
Wisconsin (1893)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China
(2009)
Gran Telescopio Canarias
La Palma,
Canary Islands,
Spain (2007)
Keck Telescope
Mauna Kea, Hawaii
(1993/1996)
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022)
Hooker (100")
Mt Wilson,
California
(1917)
Hale (200")
Mt Palomar,
California
(1948)
Hobby-Eberly Telescope
Davis
Mountains,
Texas (1996)
Southern African Large Telescope
Sutherland,
South Africa
(2005)
Gemini North
Mauna Kea,
Hawaii (1999)
Subaru Telescope
Mauna Kea,
Hawaii (1999)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
Gemini South
Cerro Pachón,
Chile (2000)
BTA-6 (Large Altazimuth Telescope)
Zelenchuksky, Russia
(1975)
Large Binocular Telescope
Mount Graham,
Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile
(planned 2020)
Large Zenith Telescope
British Columbia, Canada
(2003)
Gaia
Earth-Sun L2 point
(2014)
Kepler
Earth-trailing
solar orbit
(2009)
Very Large Telescope
Cerro Paranal, Chile
(1998-2000)
European Extremely Large Telescope
Cerro Armazones,
Chile (planned 2022)
Human
at the
same scale
0 5 10 m
0 10 20 30 ft
James Webb Space Telescope
Earth-Sun L2 point
(planned 2018)
Hubble Space Telescope
Low Earth
Orbit
(1990)
Magellan Telescopes
Las Campanas,
Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory,
Chile (planned 2020)
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale



A star gives out radiation from all parts of the electromagnetic spectrum

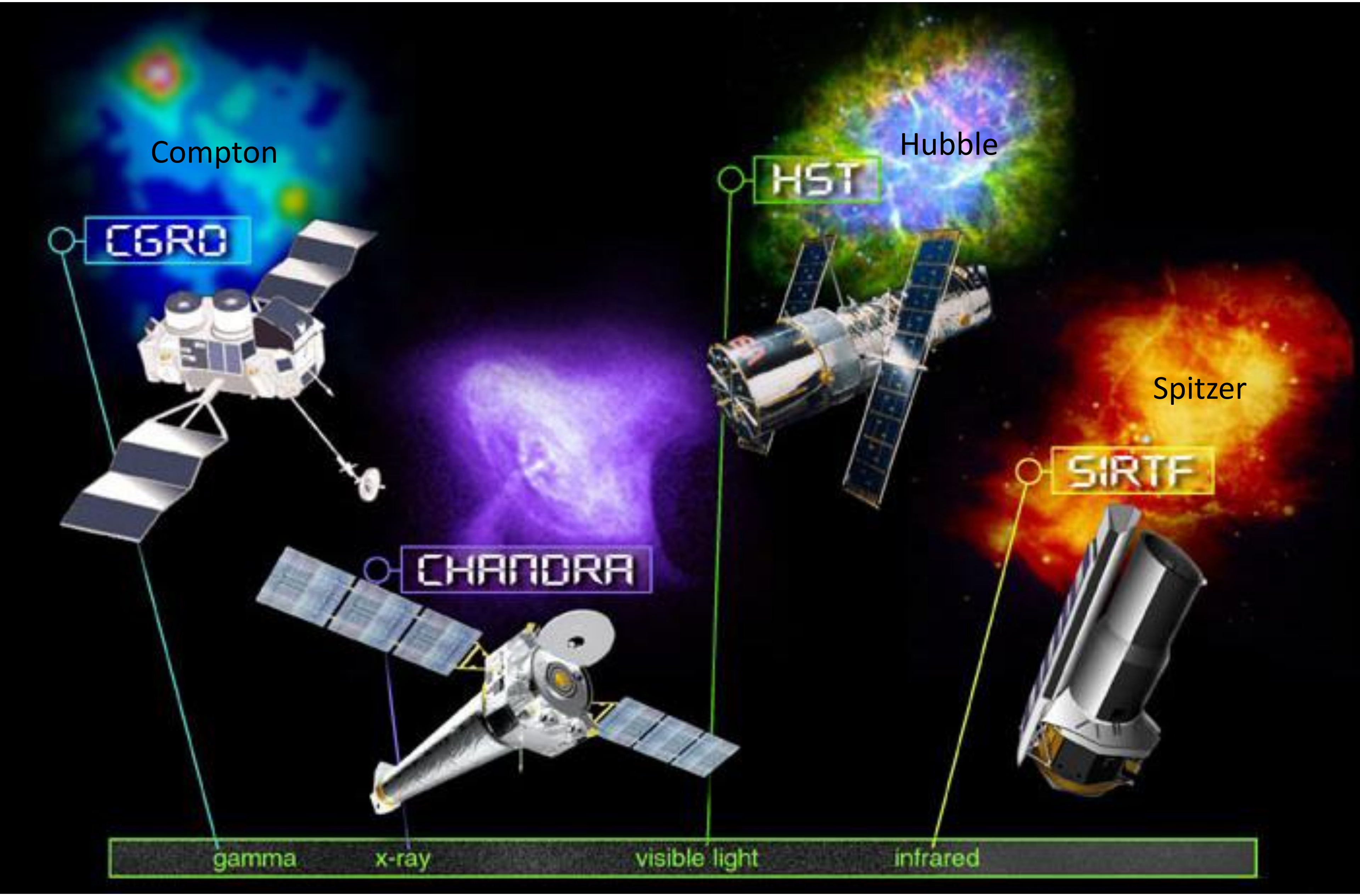
THE ELECTROMAGNETIC SPECTRUM



Convert wavelength into frequency using $c = f\lambda$

$$c = 2.998 \times 10^8 \, \mathrm{ms}^{-1}$$

NASA space telescopes

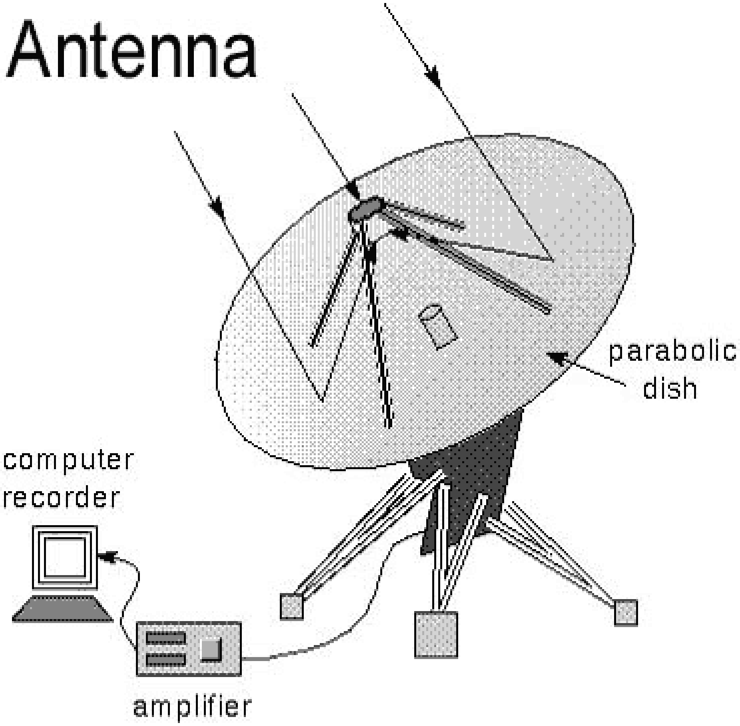


The Hubble space telescope

SETI INSTITUTE

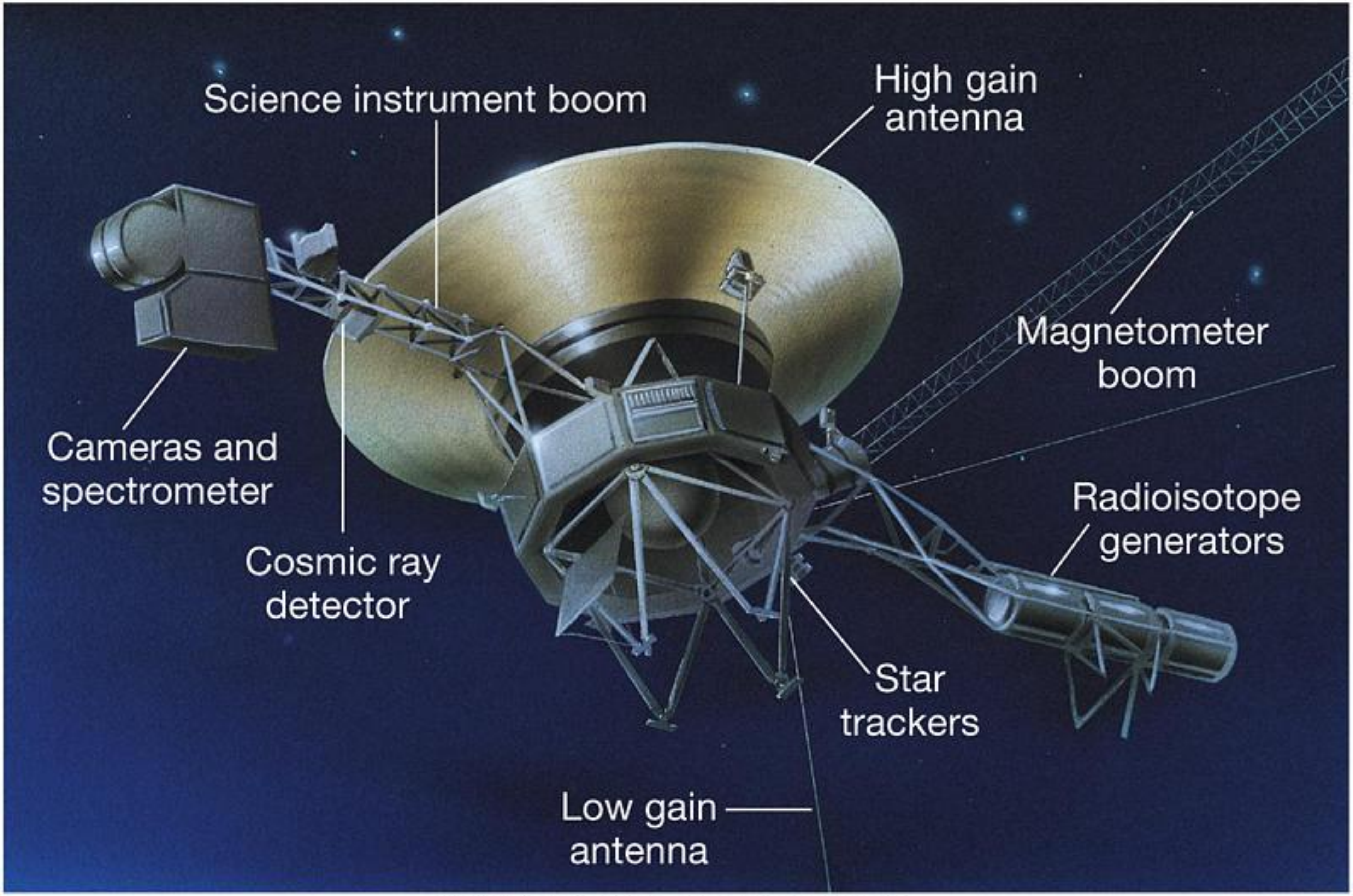
Radio astronomy

Antenna



A radio telescope reflects radio waves to a focus at the antenna.

Observations from beyond the Earth .... **Voyager 1 & 2 (1977 -)**



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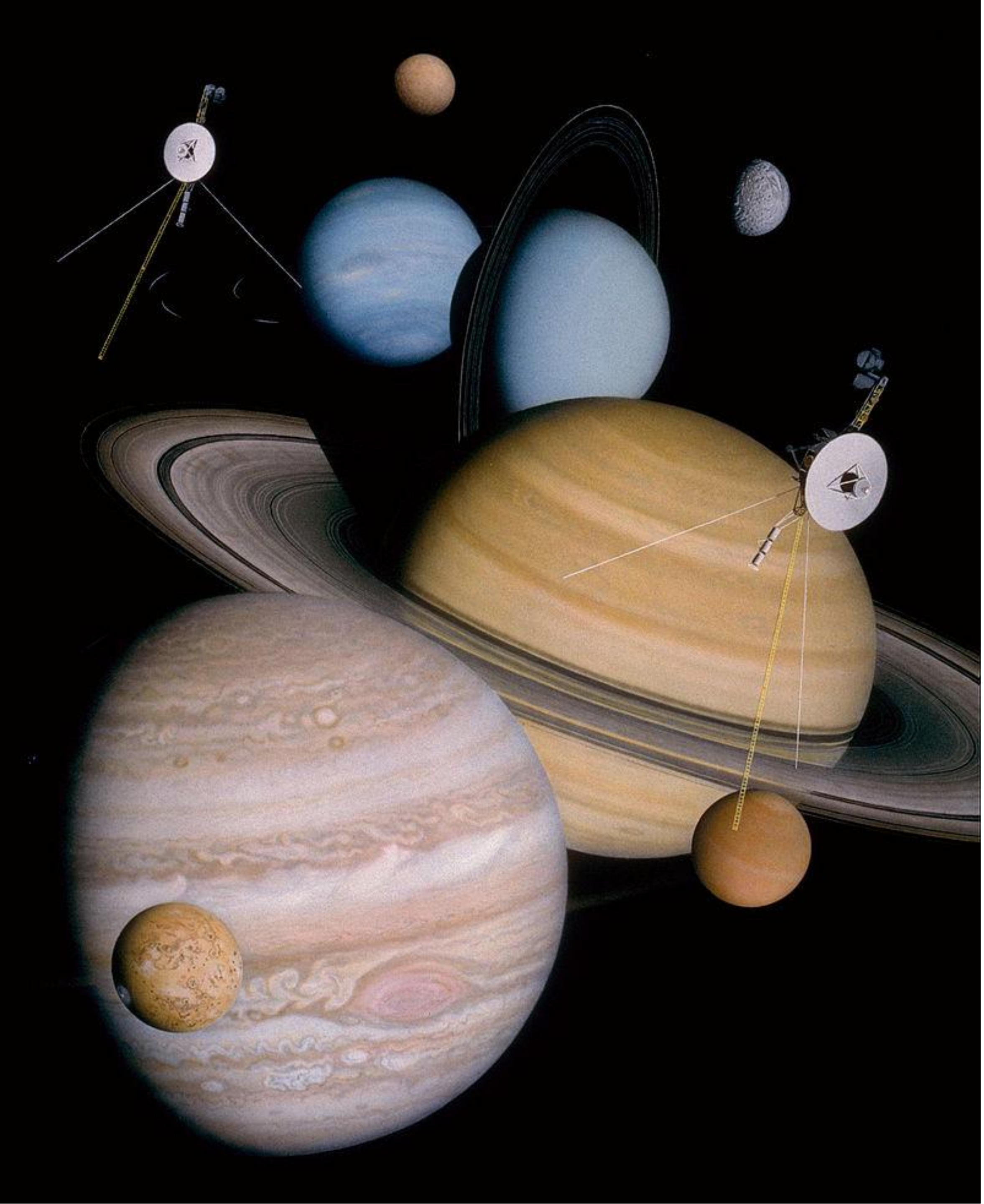
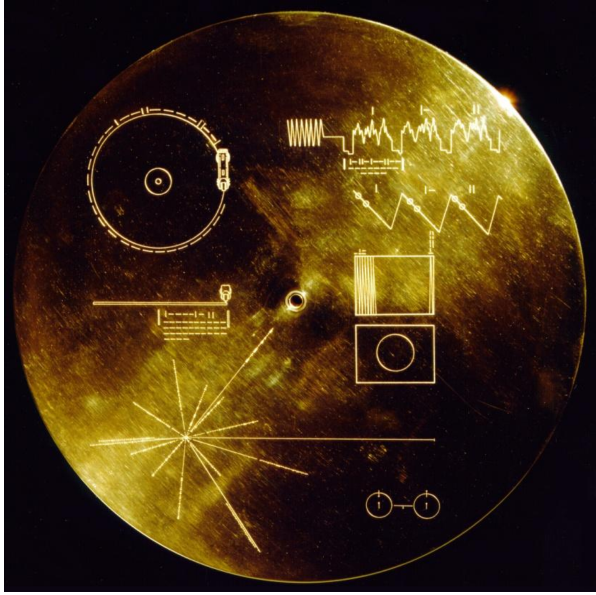
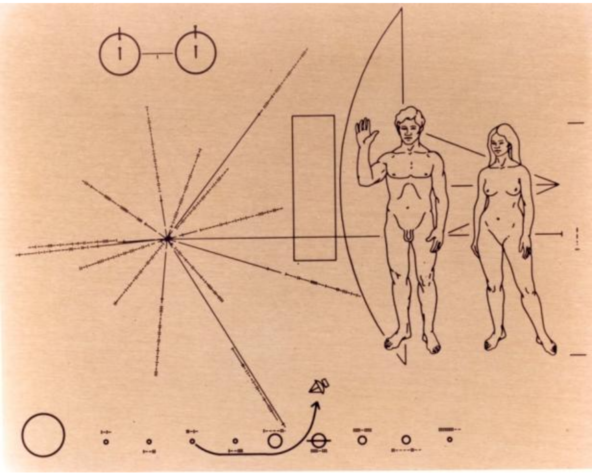
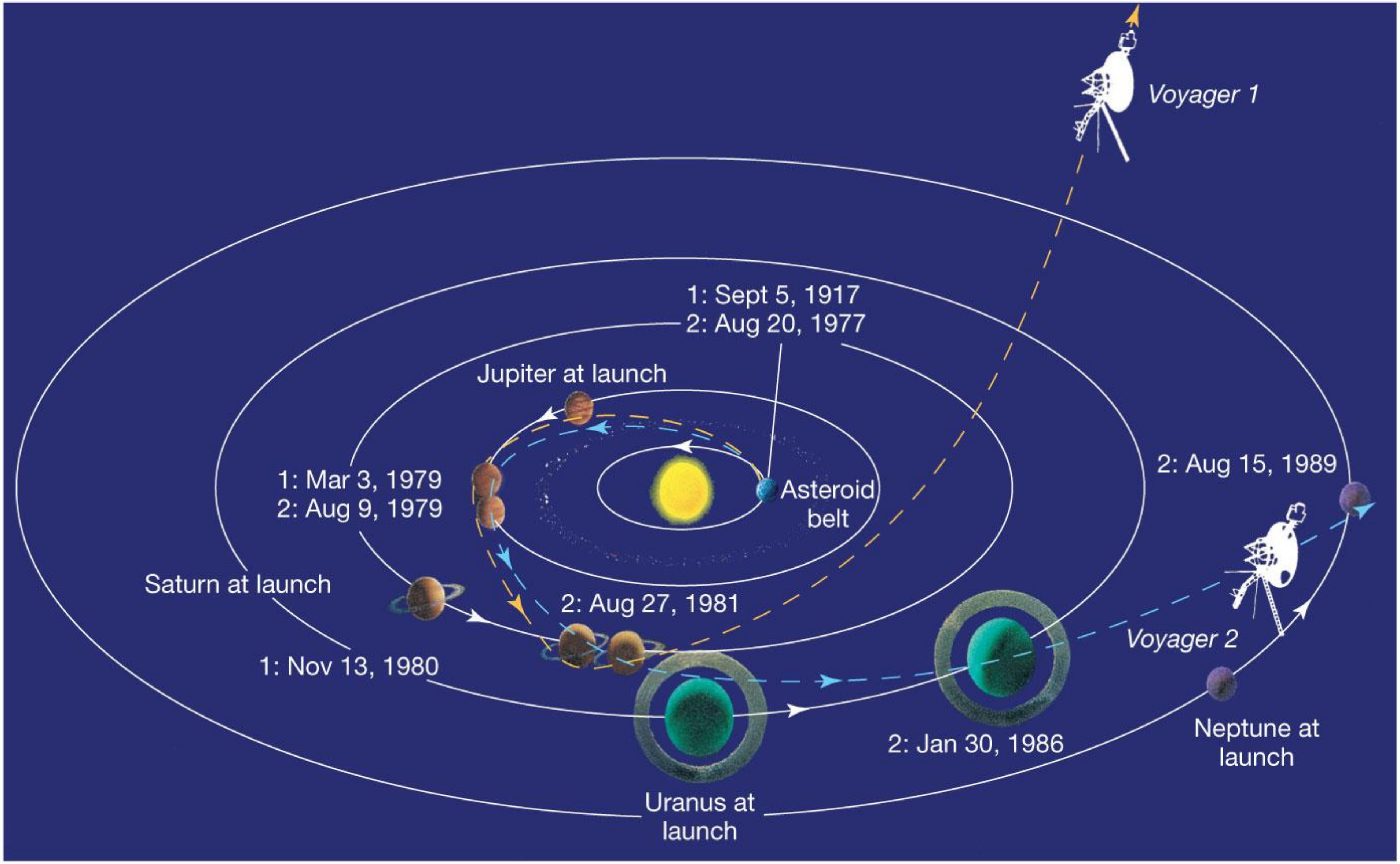






Greetings from Earth!



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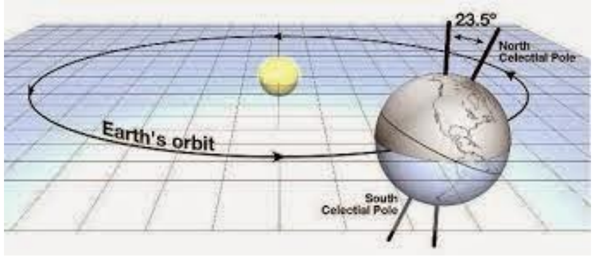
Astronomical length scales

Astronomical Unit (approximately the Earth-Sun distance)



$$\boxed{1\text{AU} = 1.496 \text{ x } 10^{11} \text{ m}}$$

Light-year

$$c = 2.998 \times 10^{8}\,\text{ms}^{-1}$$

$$t_{year} \approx 365 \times 24 \times 3600 = 3.15 \times 10^{7}\,\text{s}$$

$$t_{year} \approx \pi \times 10^{7}\,\text{s}$$

$$1\text{ly} = ct_{year} = \boxed{9.461 \times 10^{15}\,\text{m}}$$

calculated from more precise light speeds and year durations

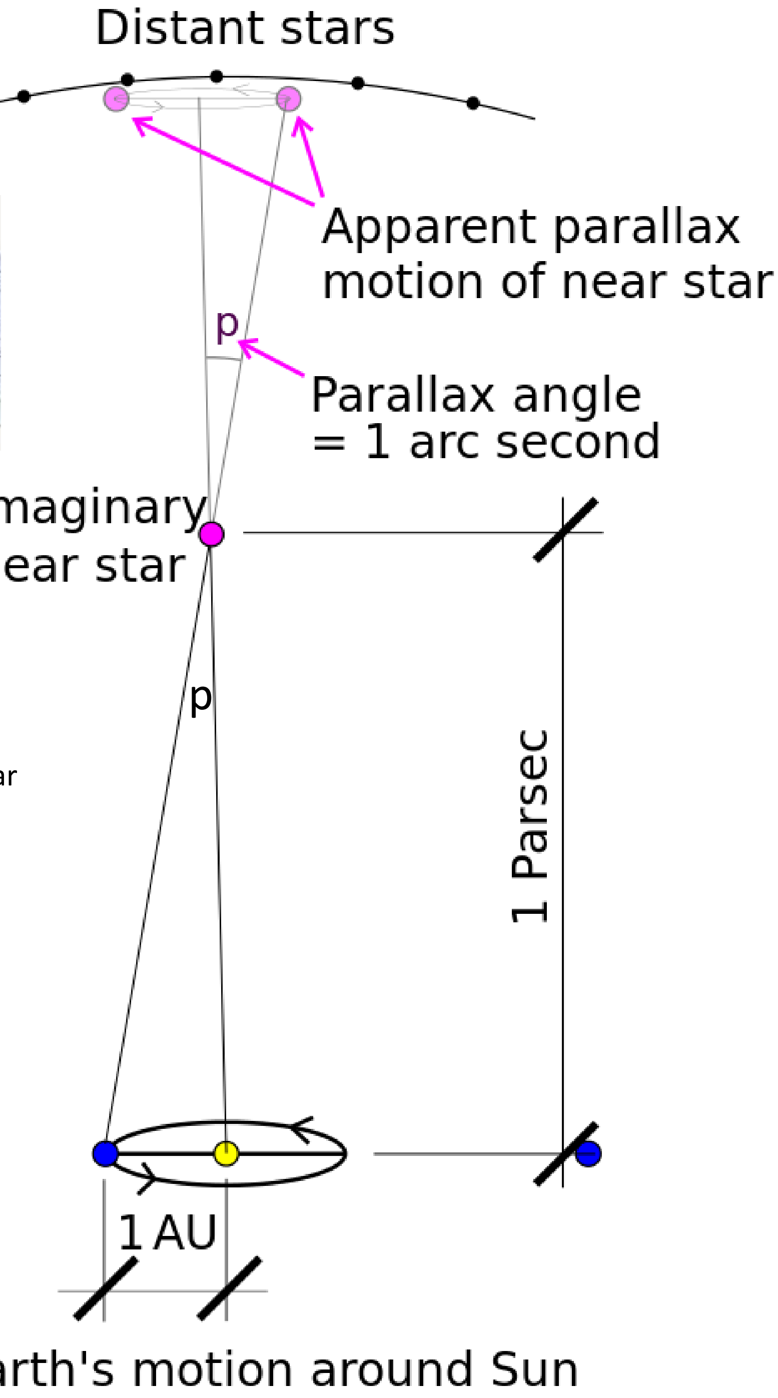
60 arc minutes = 1 degree
60 arc seconds = 1 arc minute

Parsec

$$1\text{AU} = 1\text{pc} \times \tan\left(\frac{1^{\circ}}{60 \times 60}\right)$$

$$1\text{pc} = 2.063 \times 10^{5}\,\text{AU}$$

$$\boxed{1\text{pc} = 3.086 \times 10^{16}\,\text{m}}$$

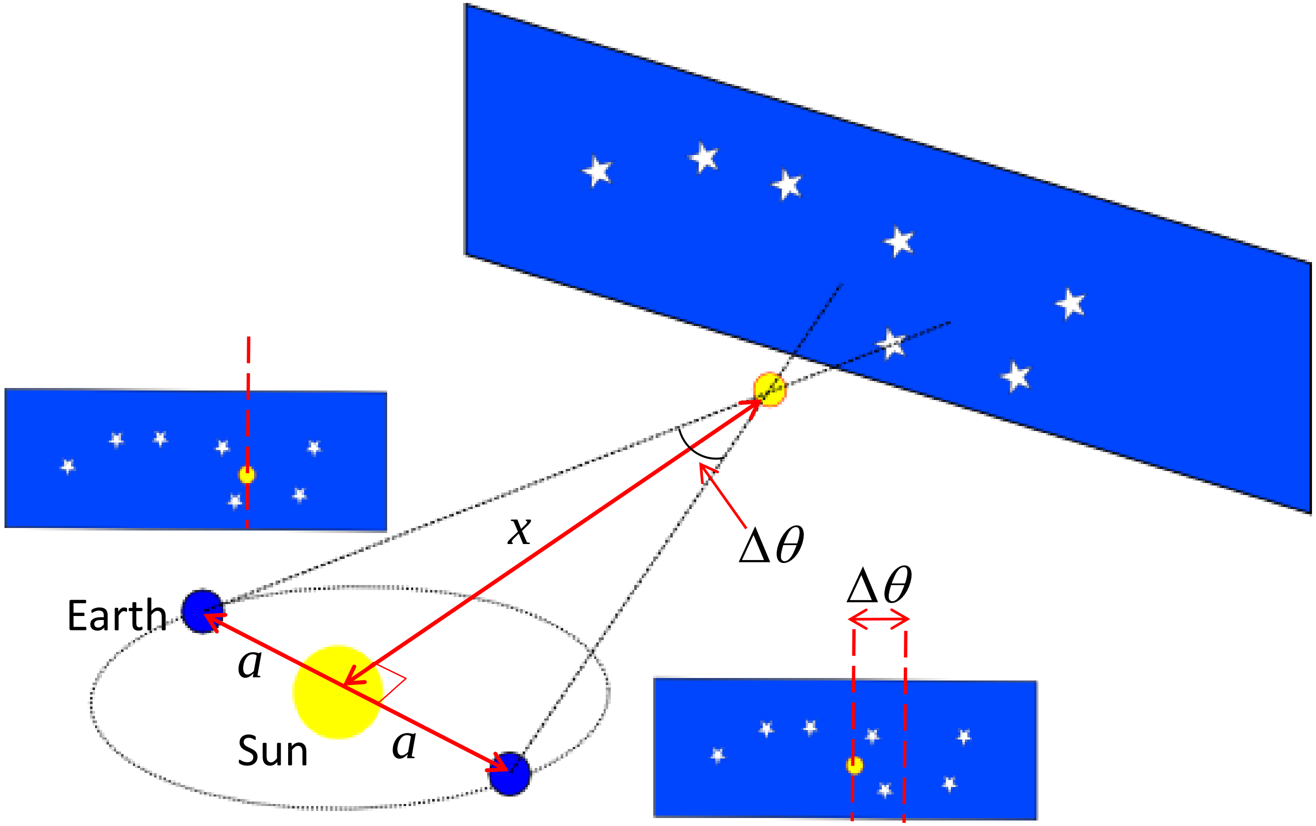


Measuring distance *x* of stars via **Parallax**

Caution! Parallax is often stated as $\Delta\theta/2$

Record the angular change $\Delta\theta$ in the position of a star over the course of a year, i.e. as the Earth orbits the Sun

This assumes the stars are fixed relative to the Earth over this timescale!



a = 1AU = 1.496×10^{11} m

$$\tan\tfrac{1}{2}\Delta\theta = \frac{a}{x}$$

$$\boxed{x = \frac{a}{\tan\tfrac{1}{2}\Delta\theta}}$$

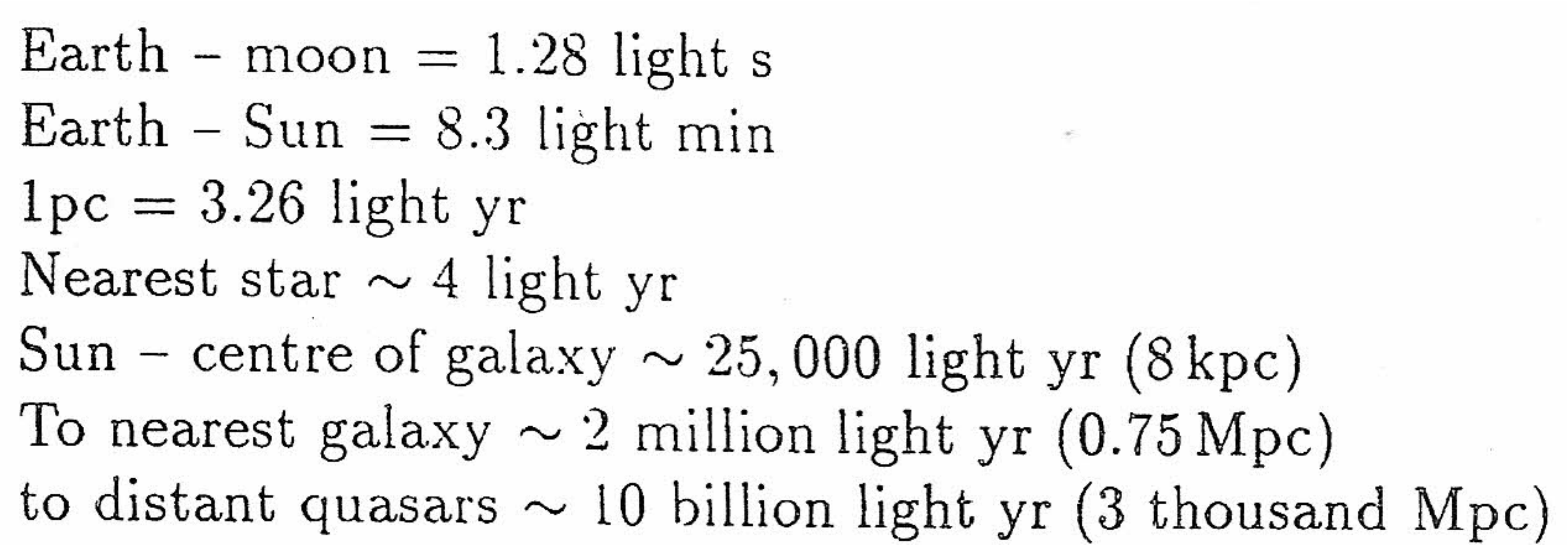
The parallax of our nearest star outside of the solar system (Proxima Centauri) is $\Delta\theta = 1.53626$ arc-seconds

$$\Delta\theta = \frac{1.53626^{\circ}}{3600} \qquad \therefore x = \frac{1}{\tan\tfrac{1}{2}\Delta\theta} = \boxed{268{,}529\text{AU}}$$

$$x = \boxed{4.02 \times 10^{16}\,\text{m}}$$

$$x = \frac{4.02 \times 10^{16}}{9.461 \times 10^{15}} = \boxed{4.25 \text{ light-years}}$$

Summary of astronomical distances



Earth – moon = 1.28 light s

Earth – Sun = 8.3 light min

1pc = 3.26 light yr

Nearest star $\sim$ 4 light yr

Sun – centre of galaxy $\sim$ 25,000 light yr (8 kpc)

To nearest galaxy $\sim$ 2 million light yr (0.75 Mpc)

to distant quasars $\sim$ 10 billion light yr (3 thousand Mpc)

1 AU = 1.496×10^{11} m

1 light year = 9.461×10^{15} m

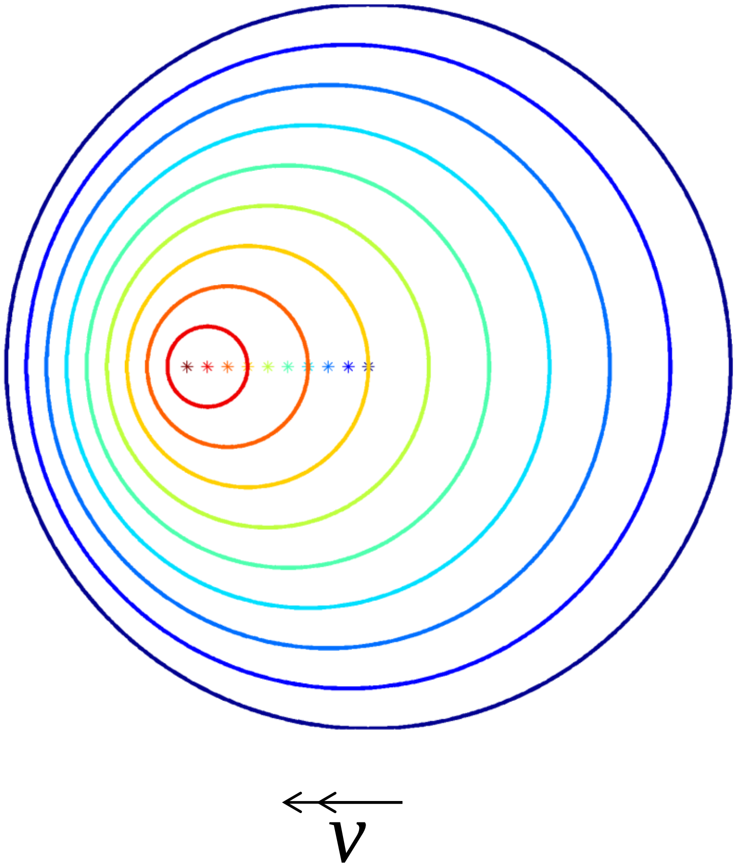
1 parsec = 3.086×10^{16} m

1Mpc = 10^{6} parsecs = 3.086×10^{22} m

Doppler shift method for measuring radial velocity

$$\boxed{c = f\lambda}$$

If an object emitting radiation at frequency *f* moves radially towards an observer at velocity *v*, the observer will measure a *slightly higher frequency* of radiation as the emitted waves 'bunch up'.



Velocity of emitter towards observer

Frequency of emitted radiation

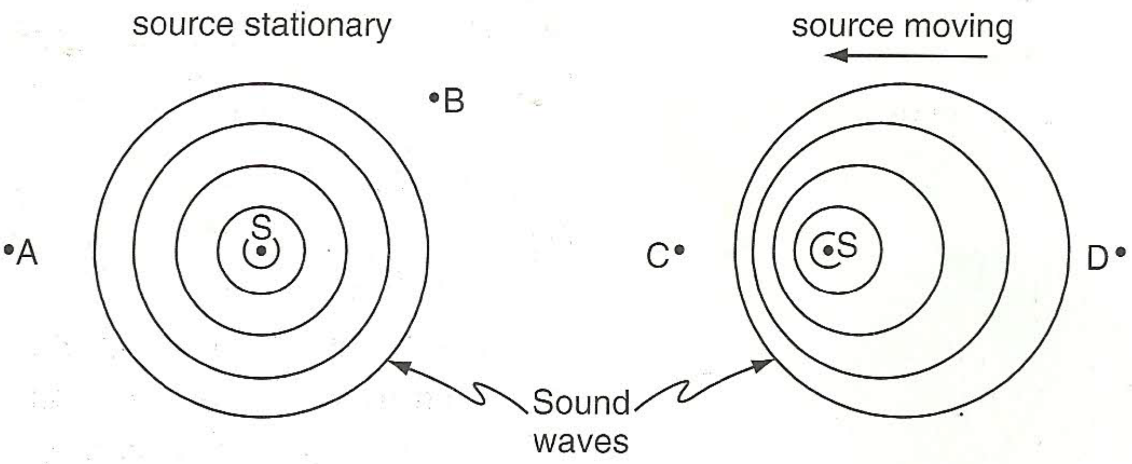
frequency change

$$\boxed{\Delta f = \frac{v}{c} f}$$

Speed of radiation

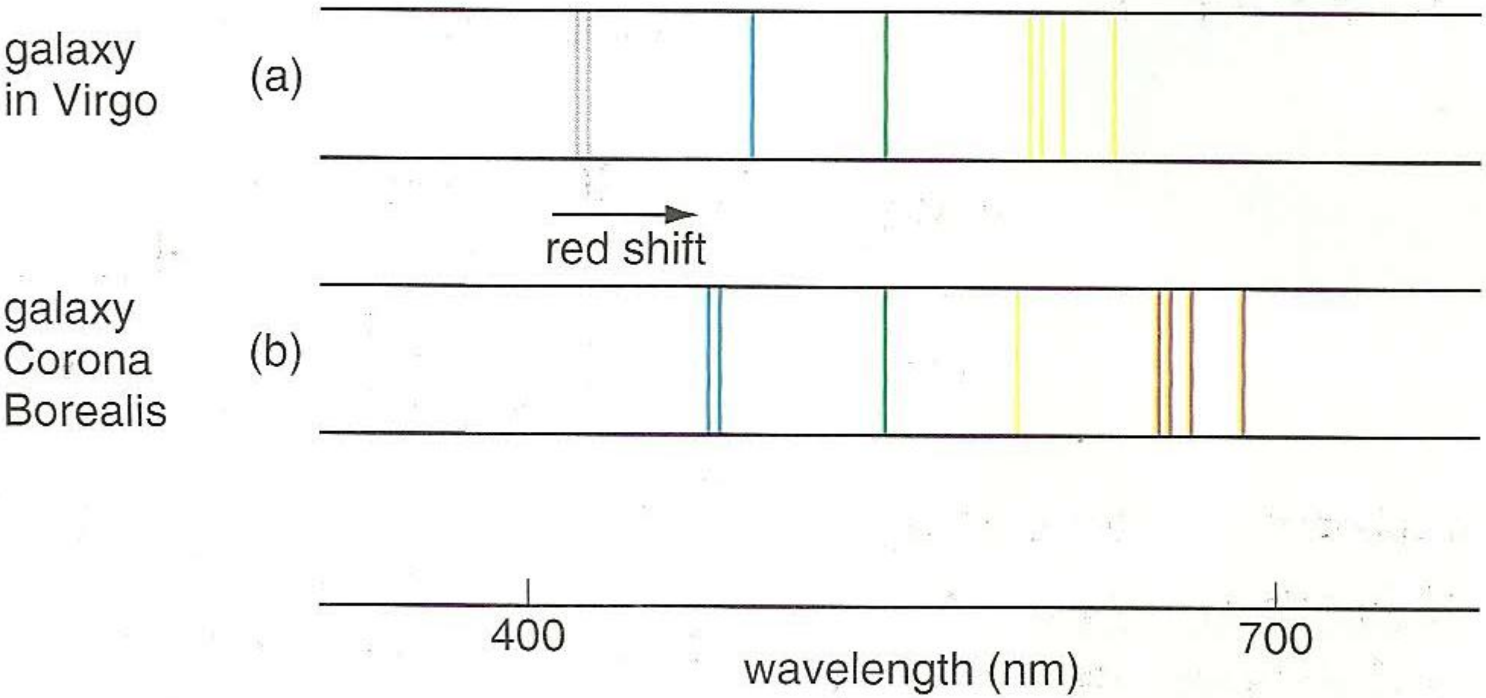
Note this formula is 'Classical'. It is valid when v << c, otherwise a relativistic version must be used

Christian Doppler
1803-1953

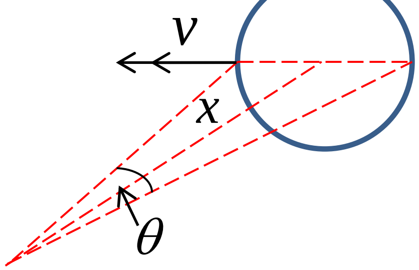


Redshift *z* is the fractional change in wavelength of light due to the doppler effect

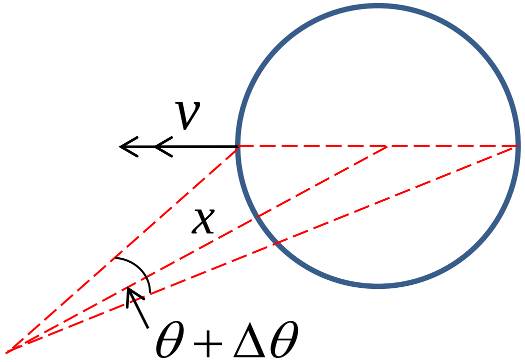
$$z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emmitted}}}{\lambda_{\text{emmitted}}}$$



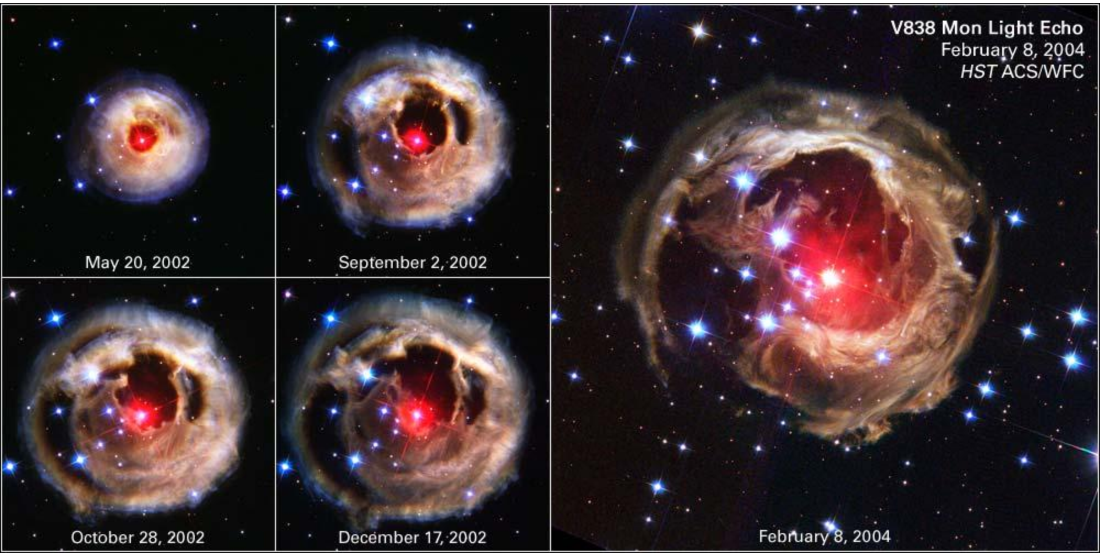
Using **radial velocity** calculation (via Doppler shift) to calculate distances of stars

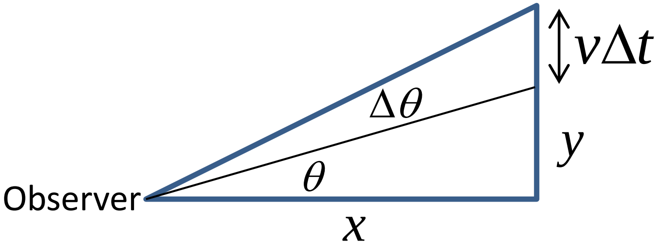


Radially expanding gas cloud at time _t_



Radially expanding gas cloud at time _t_ + Δ_t_





$$y = x\tan\theta$$

$$\tan(\theta+\Delta\theta) = \frac{v\Delta t + y}{x}$$

$$x = \frac{v\Delta t + x\tan\theta}{\tan(\theta+\Delta\theta)}$$

$$x\left(\tan(\theta+\Delta\theta) - \tan\theta\right) = v\Delta t$$

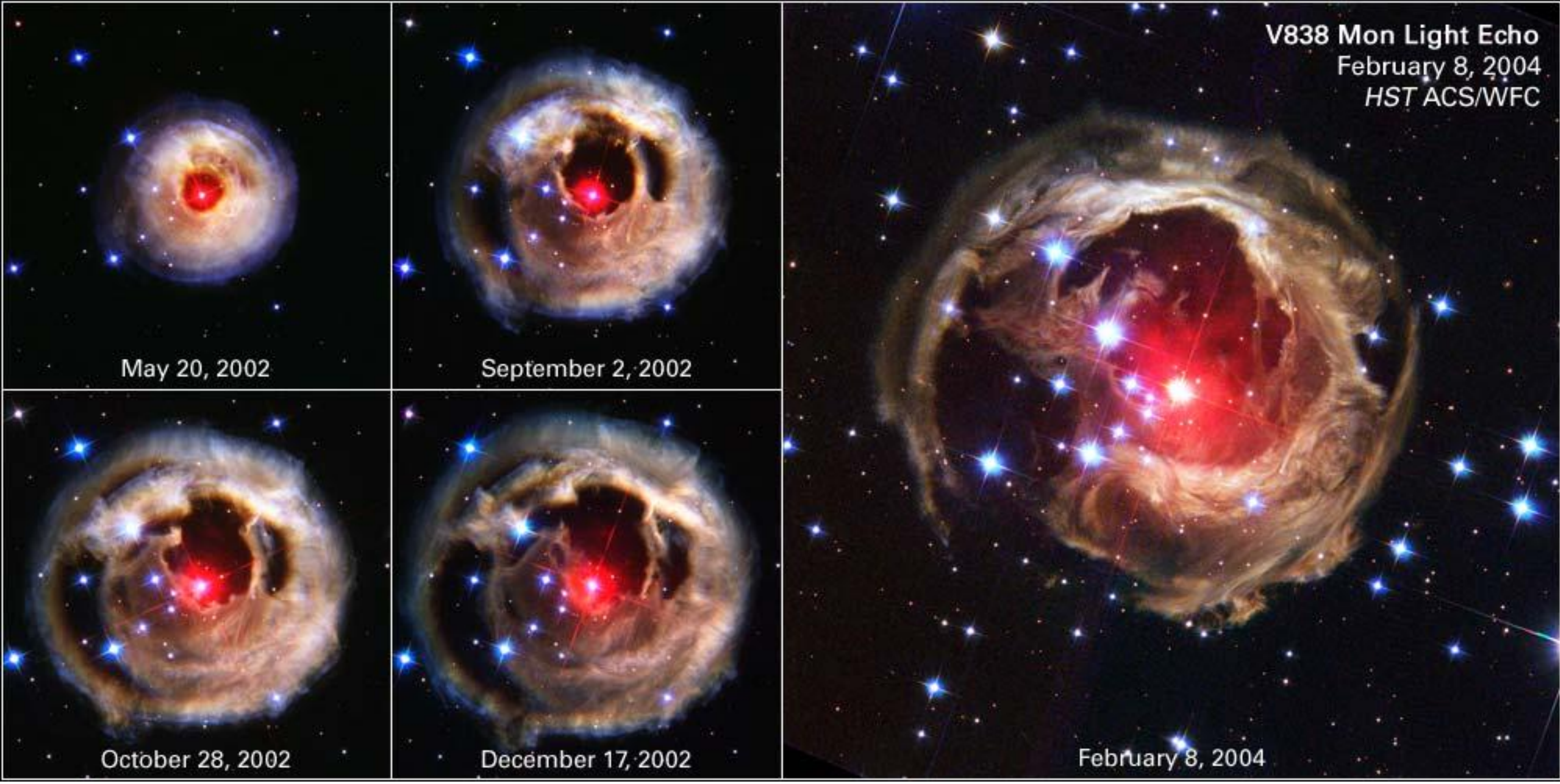
$$x = \frac{v\Delta t}{\tan(\theta+\Delta\theta) - \tan\theta}$$

$$\boxed{x \approx \frac{v\Delta t}{\Delta\theta}}$$

*Measure _v_ from Doppler shift of spectrum

*Measure angular change $\Delta\theta$ between observations

*Hence obtain distance of star at centre of expanding gas cloud



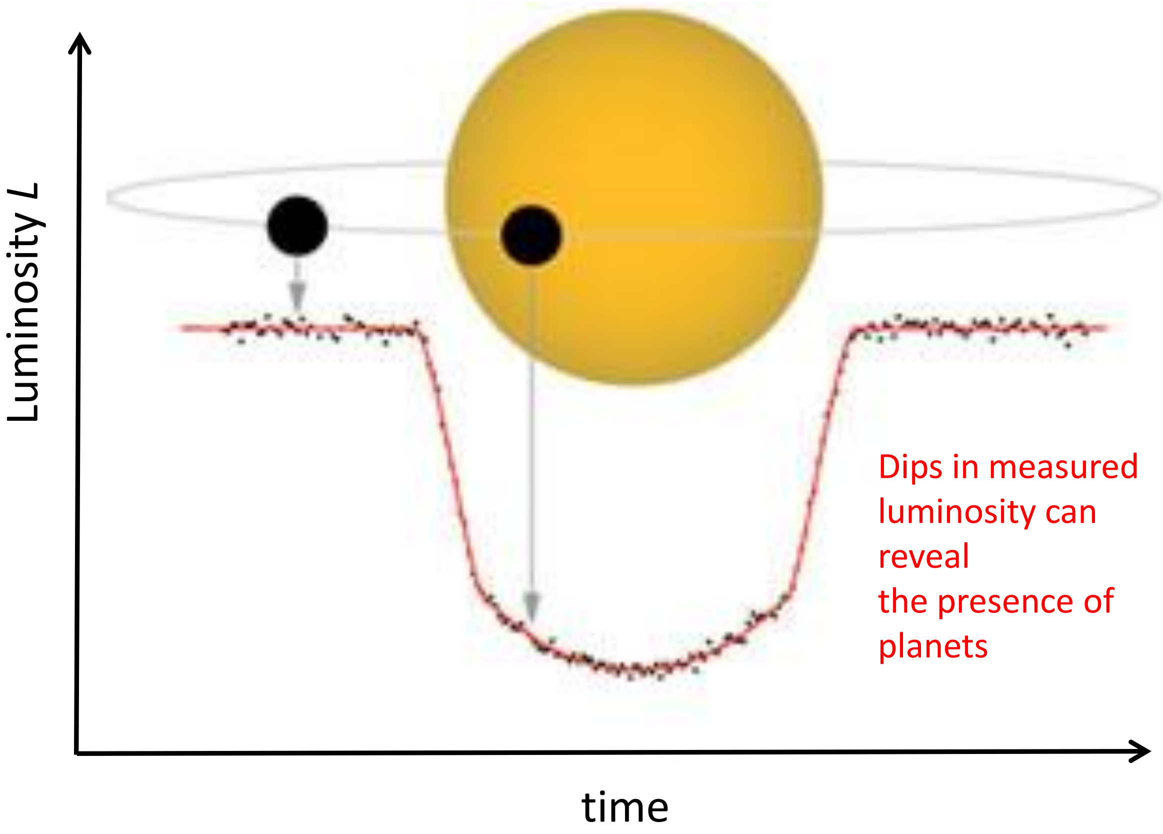
*Measure *v* from Doppler shift of spectrum
*Measure angular change $\Delta\theta$ between observations
*Hence obtain distance of star at centre of expanding gas cloud

$$\Delta f = \frac{v}{c} f$$

$$x \approx \frac{v\Delta t}{\Delta\theta}$$

The key challenge here is to work out what the **emission frequency f** should be, in order to work out the doppler shift

Luminosity method for measuring distances, and detecting planets!



Dips in measured luminosity can reveal the presence of planets

Luminosity L is the light power generated by a star

$$\boxed{B = \frac{L}{4\pi x^2}}$$

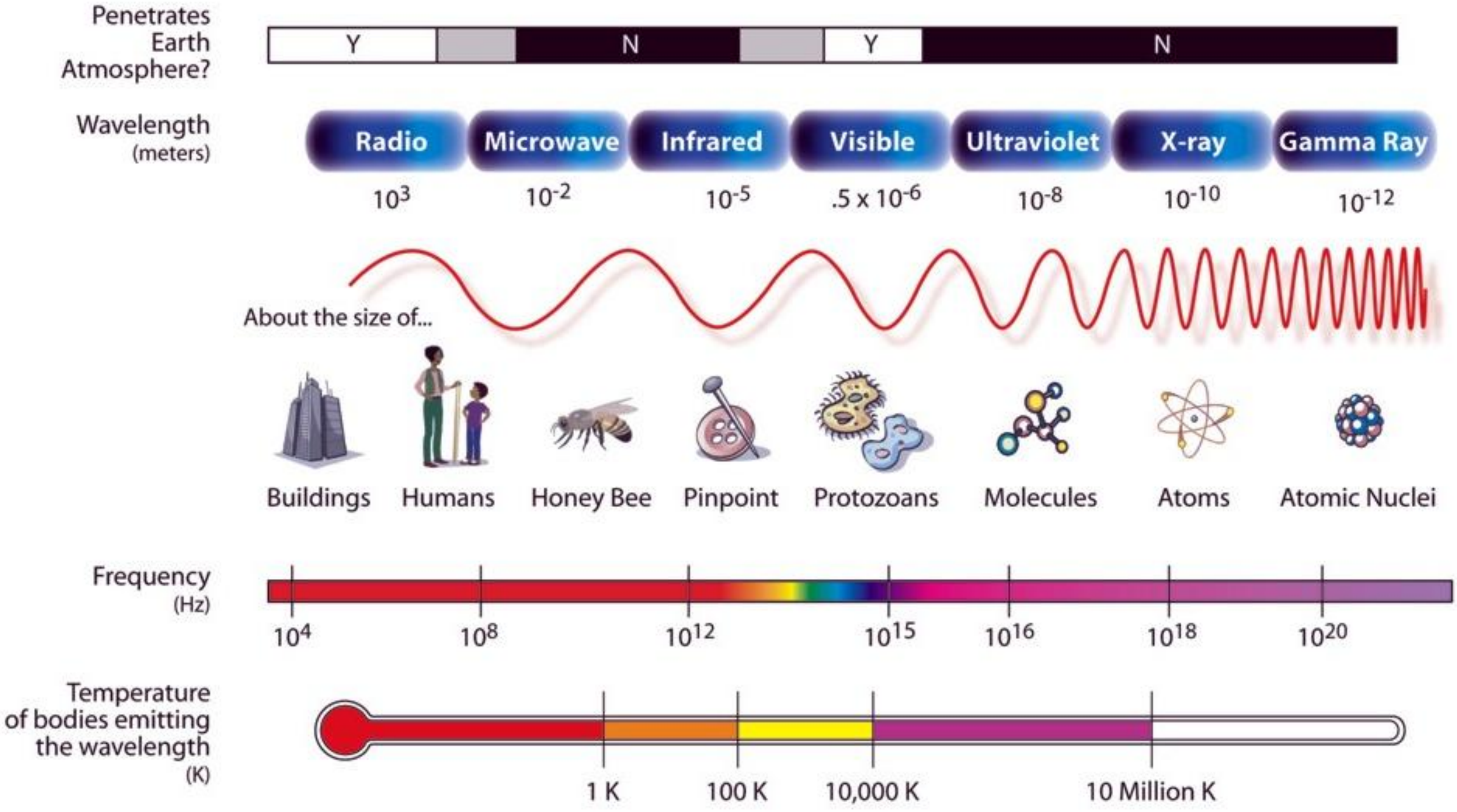
If the star is a distance *x* away then the ‘brightness’ *B* (defined as the power per unit area) is *L* divided by the area of a sphere of radius *x*

If we know the luminosity of a certain type of star (indicated by its *spectrum*) then we can use the measured brightness to work out how far away it is.

$$\boxed{L_{\odot} = 3.846 \times 10^{26}\,\mathrm{W}}$$

Current luminosity of our Sun

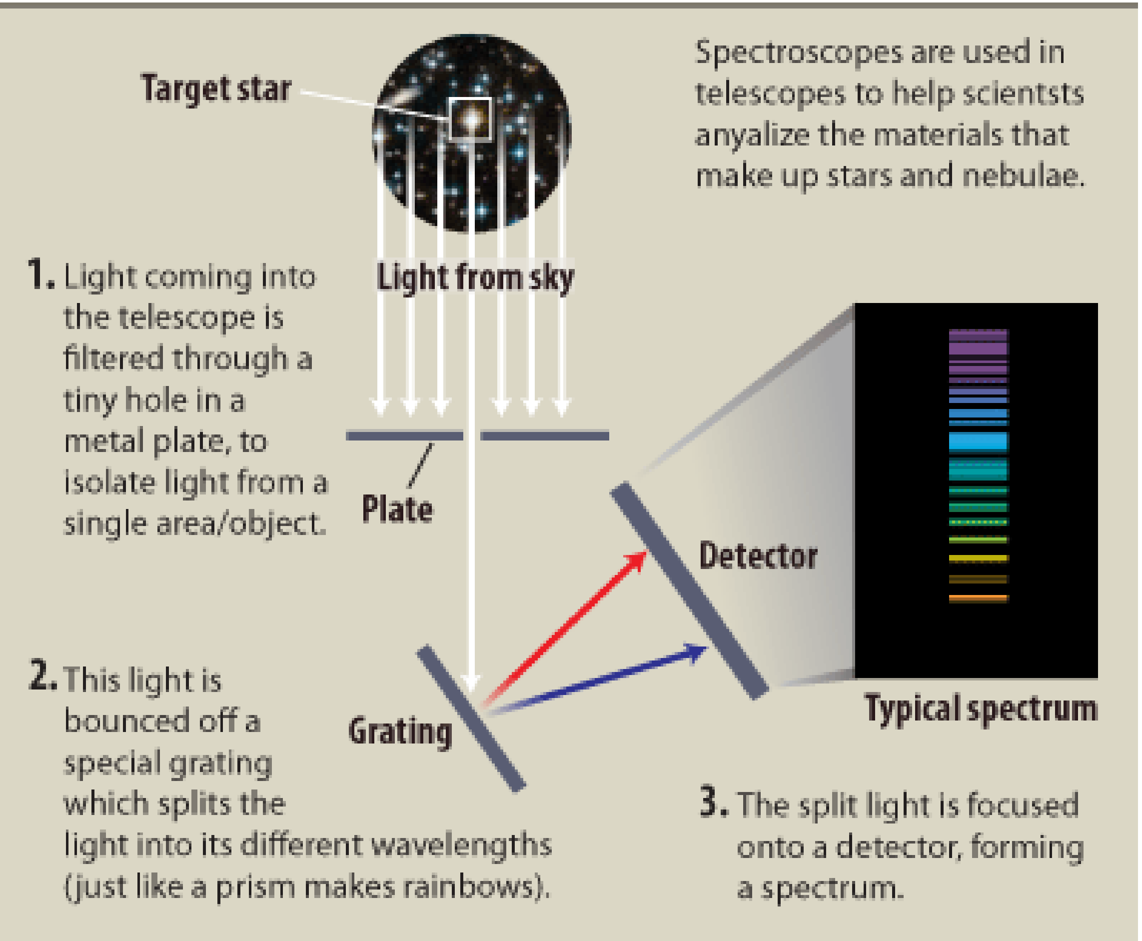
THE ELECTROMAGNETIC SPECTRUM



Convert wavelength into frequency using $c = f\lambda$

$$c = 2.998\times10^{8}\,\mathrm{ms}^{-1}$$

How a Spectroscope Works

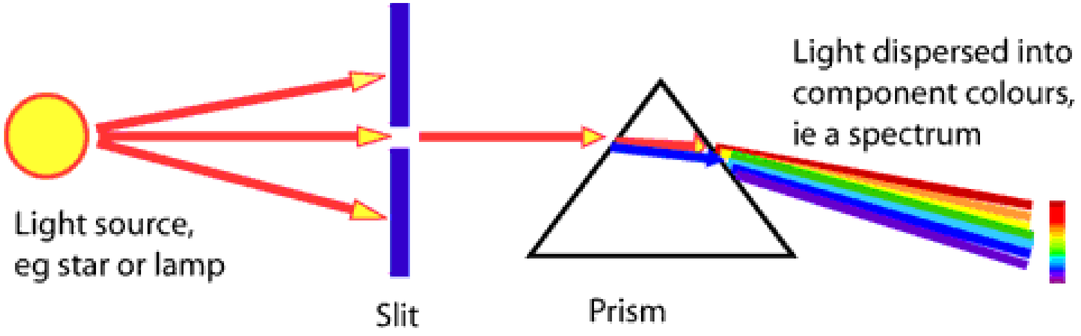


Spectroscopes are used in telescopes to help scientsts anyalize the materials that make up stars and nebulae.

1. Light coming into the telescope is filtered through a tiny hole in a metal plate, to isolate light from a single area/object.

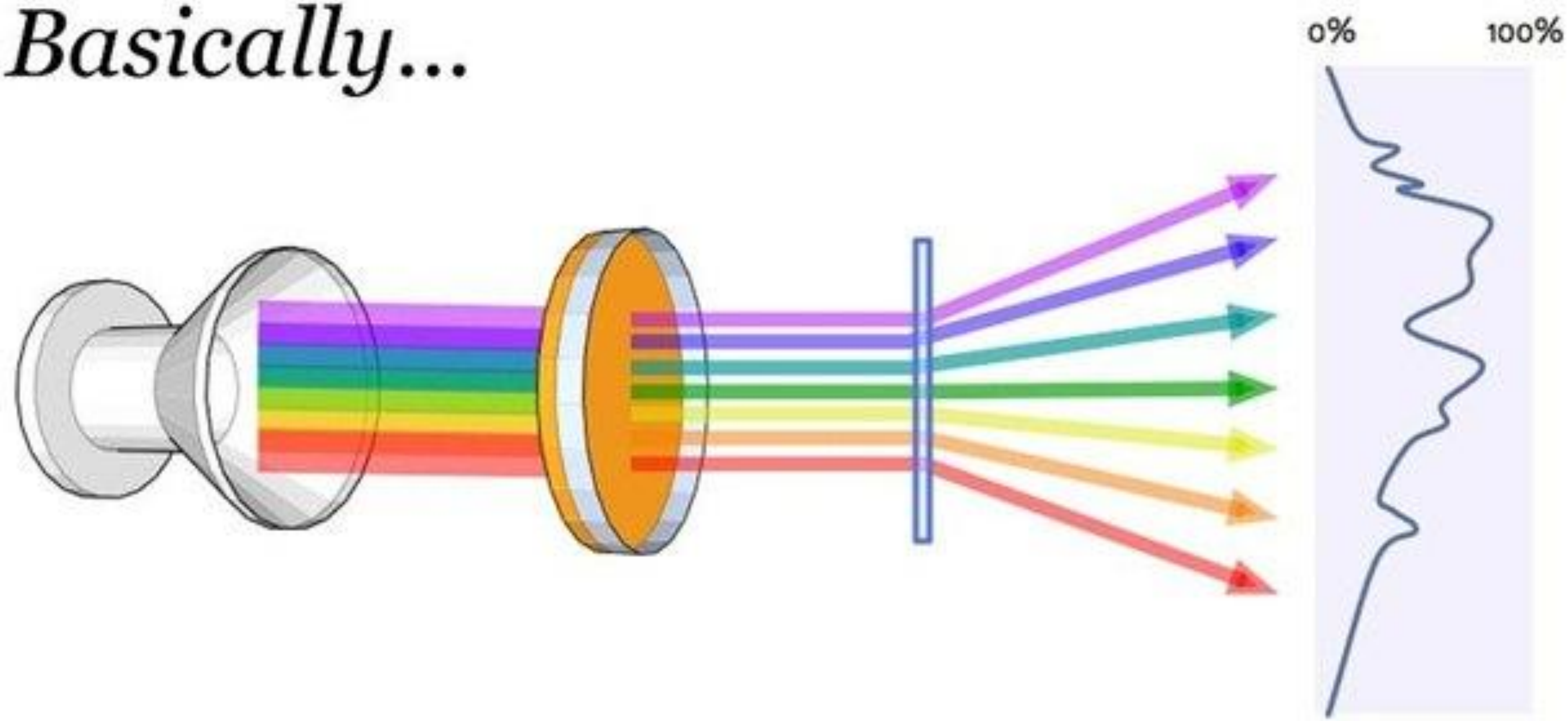
2. This light is bounced off a special grating which splits the light into its different wavelengths (just like a prism makes rainbows).

3. The split light is focused onto a detector, forming a spectrum.



Dispersion of light through a prism

Basically...



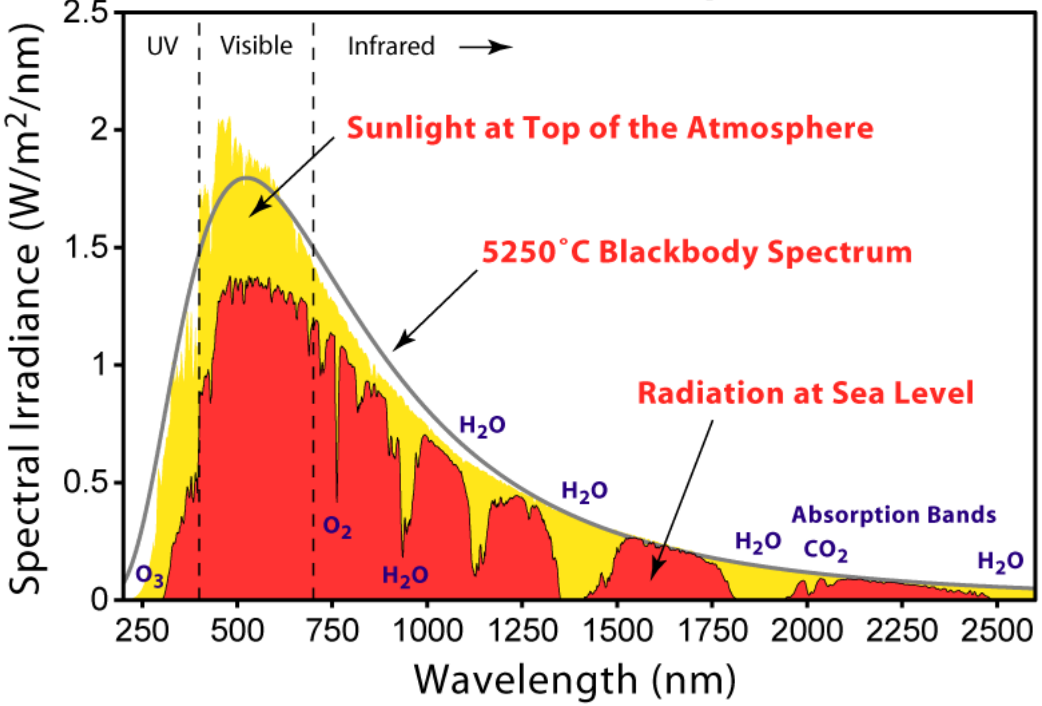
1. A broad-spectrum light (halogen, incandescent) is shone through a sample

2. Some colors are absorbed more than others depending on its composition

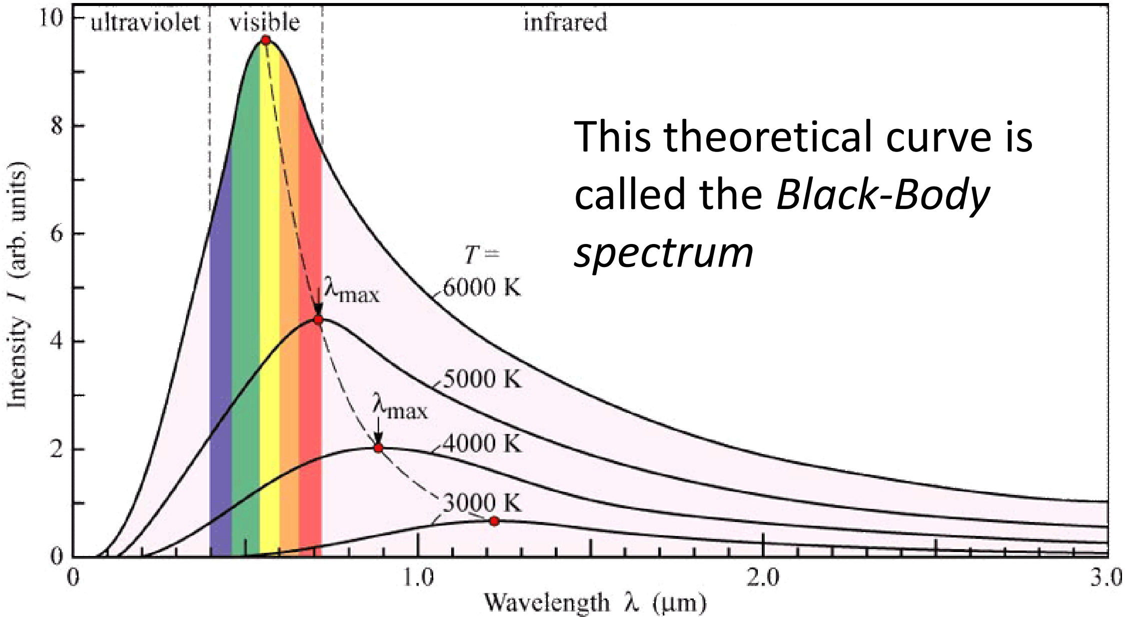
3. Diffraction grating splits light into colors so they can be measured separately

4. A webcam measures each color and graphs their intensities. This is compared to known samples.

Solar Radiation Spectrum



Note solar energy is absorbed in atmosphere by oxygen, water vapour, carbon dioxide etc. Hence *dips* in the solar spectra at sea level.



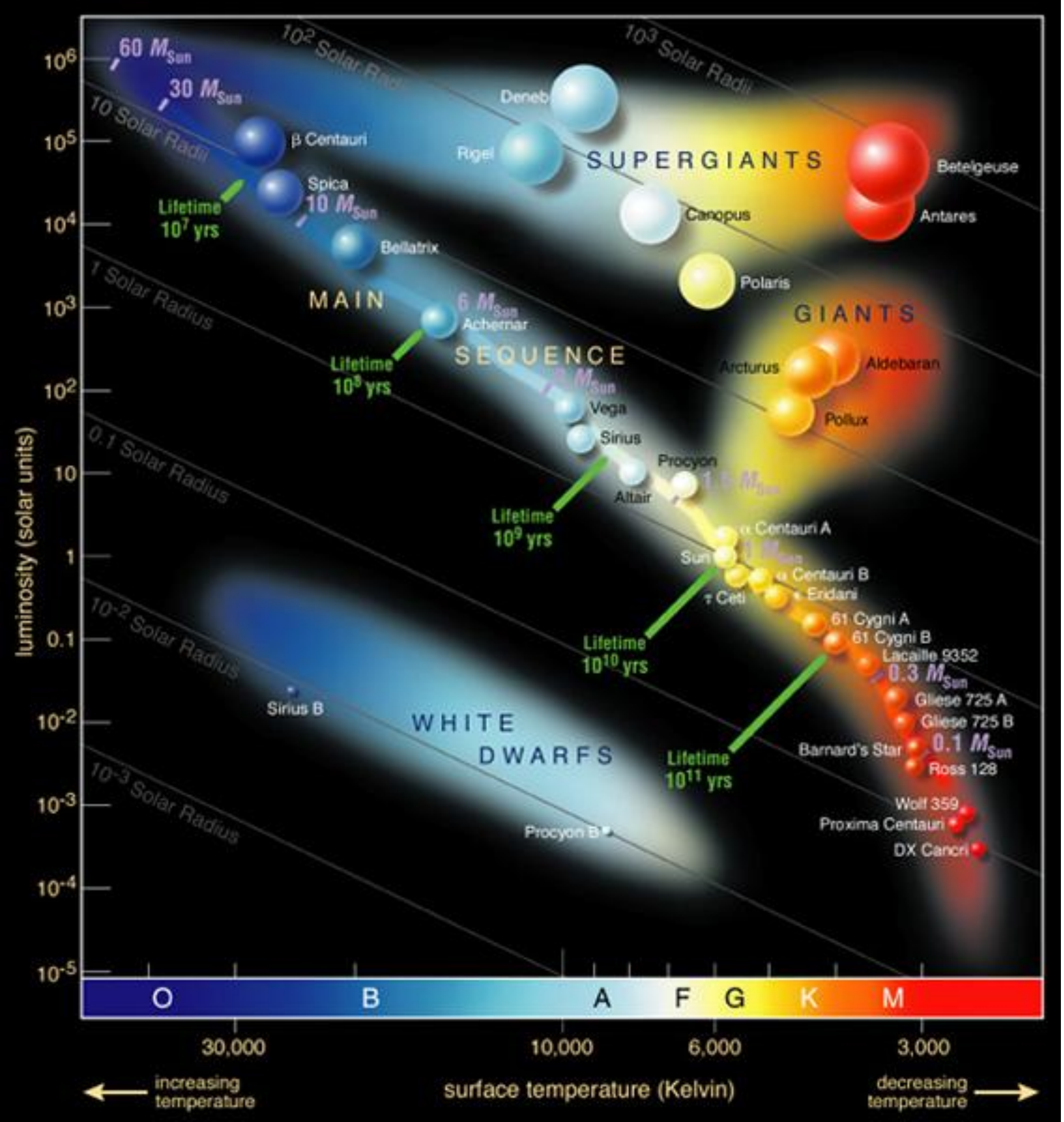
This theoretical curve is called the *Black-Body spectrum*

Measure **surface temperature** of a star from the spectral shape

(i.e. brightness at different wavelengths)

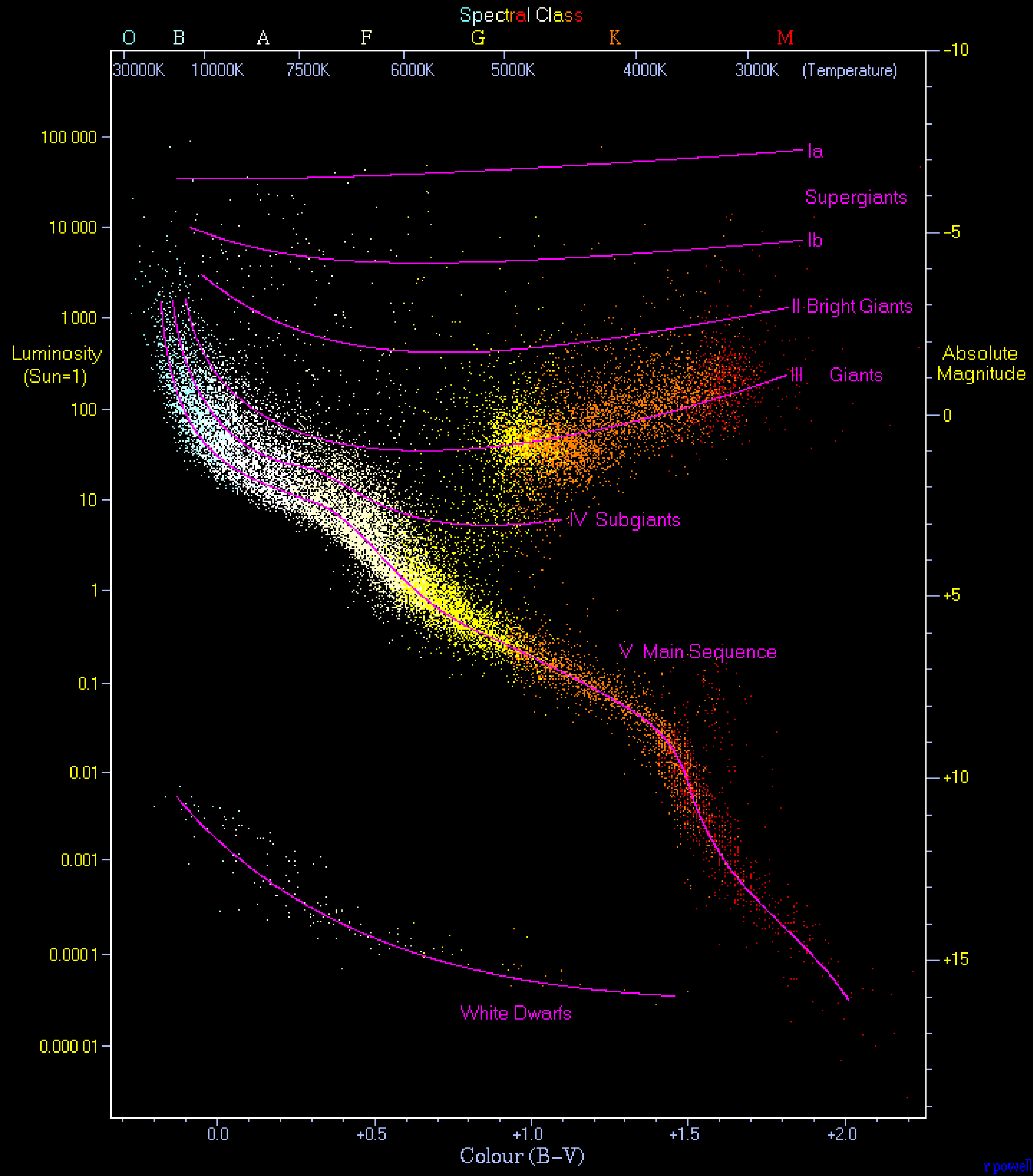
Convert wavelength into frequency using

$$c = f\lambda$$



Hertzsprung-Russell diagram

1910 by Ejnar Hertzsprung and Henry Norris Russell

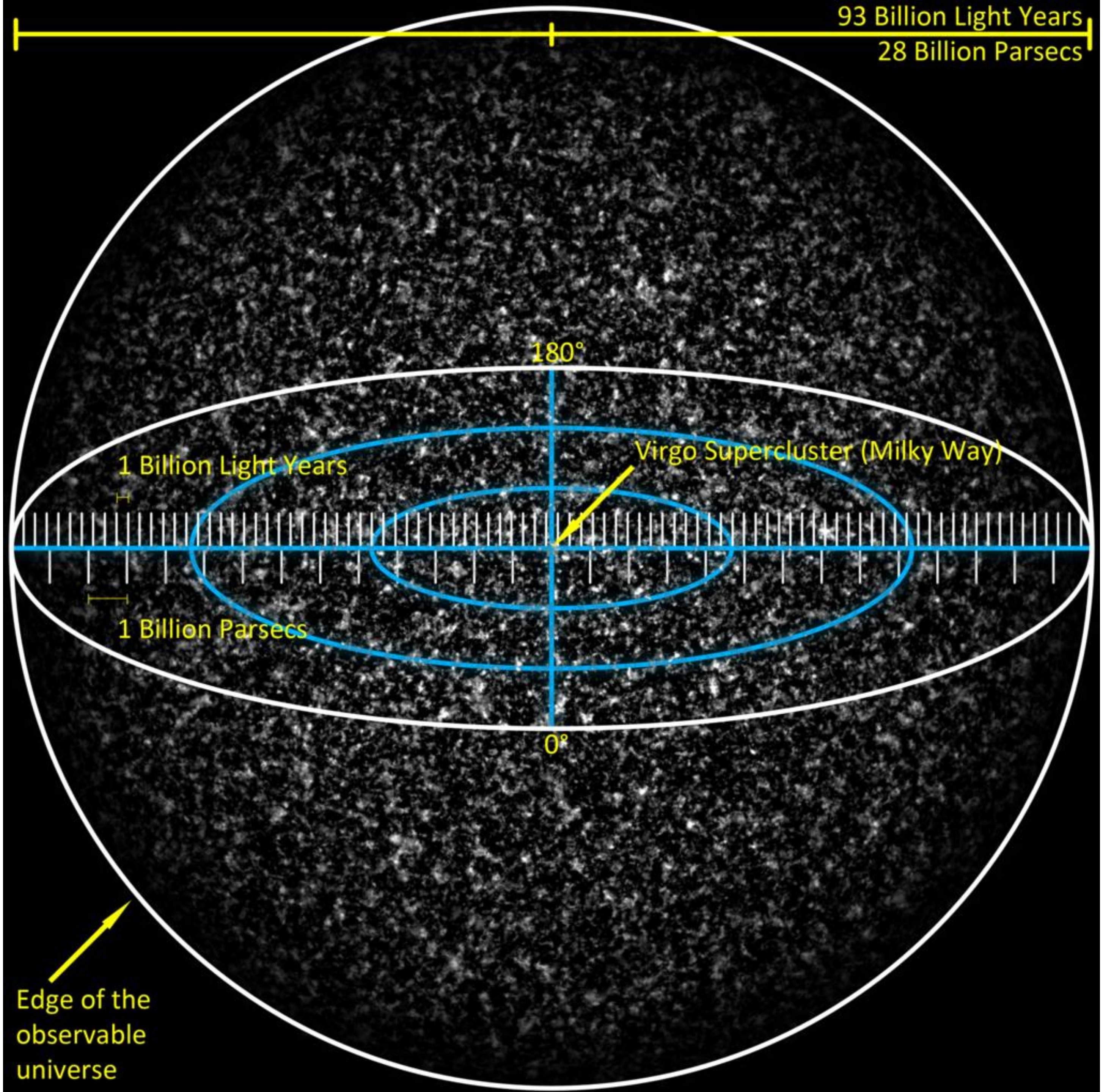


Hertzsprung–Russell diagram with 22,000 stars plotted from the Hipparcos Catalogue and 1,000 from the Gliese Catalogue of nearby stars.

Stars tend to fall only into certain regions of the diagram. The most prominent is the diagonal, going from the upper-left (hot and bright) to the lower-right (cooler and less bright), called the **main sequence**.

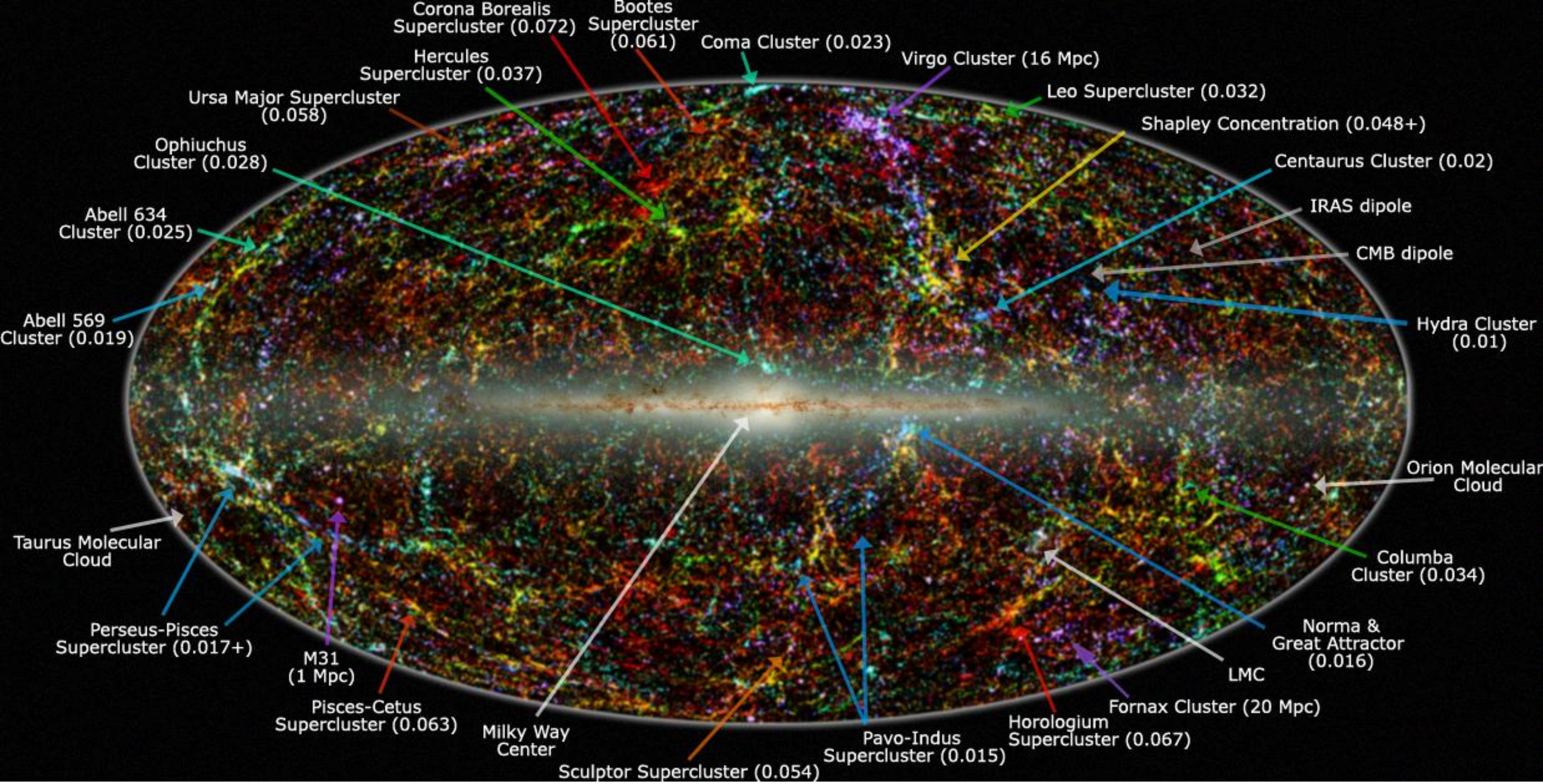
In the lower-left is where **white dwarfs** are found, and above the main sequence are the **subgiants**, **giants** and **supergiants**.

The Sun is found on the main sequence at luminosity 1 (absolute magnitude 4.8) and B−V colour index 0.66 (temperature 5780 K, spectral type G2V).


93 Billion Light Years
28 Billion Parsecs
180°
1 Billion Light Years
Virgo Supercluster (Milky Way)
1 Billion Parsecs
0°
Edge of the observable universe

NASA; ESA; G. Illingworth, D. Magee, and P. Oesch, University of California, Santa Cruz; R. Bouwens, Leiden University; and the HUDF09 Team

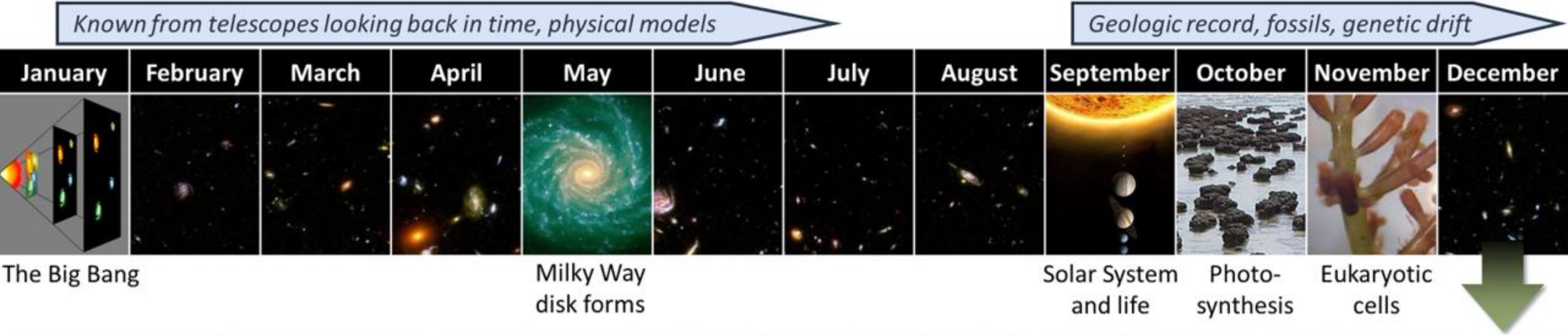
The Hubble eXtreme Deep Field (XDF) was completed in September 2012 and shows the farthest galaxies ever photographed. Except for the few stars in the foreground (which are bright and easily recognizable because only they have diffraction spikes), every speck of light in the photo is an individual galaxy, some of them as old as 13.2 billion years; the observable universe is estimated to contain more than 200 billion galaxies.



Panoramic view of the entire near-infrared sky reveals the distribution of galaxies beyond the Milky Way. The image is derived from the **2MASS Extended Source Catalogue** (XSC)—more than 1.5 million galaxies, and the Point Source Catalogue (PSC)--nearly 0.5 billion Milky Way stars. The galaxies are colour coded by redshift (numbers in parentheses). Blue/purple are the nearest sources ($z < 0.01$); green are at moderate distances ($0.01 < z < 0.04$) and red are the most distant sources that 2MASS resolves ($0.04 < z < 0.1$). The map is projected with an equal area Aitoff in the Galactic system (Milky Way at centre).

IPAC/Caltech, by Thomas Jarrett - "Large Scale Structure in the Local Universe: The 2MASS Galaxy Catalog", Jarrett, T.H. 2004, PASA, 21, 396

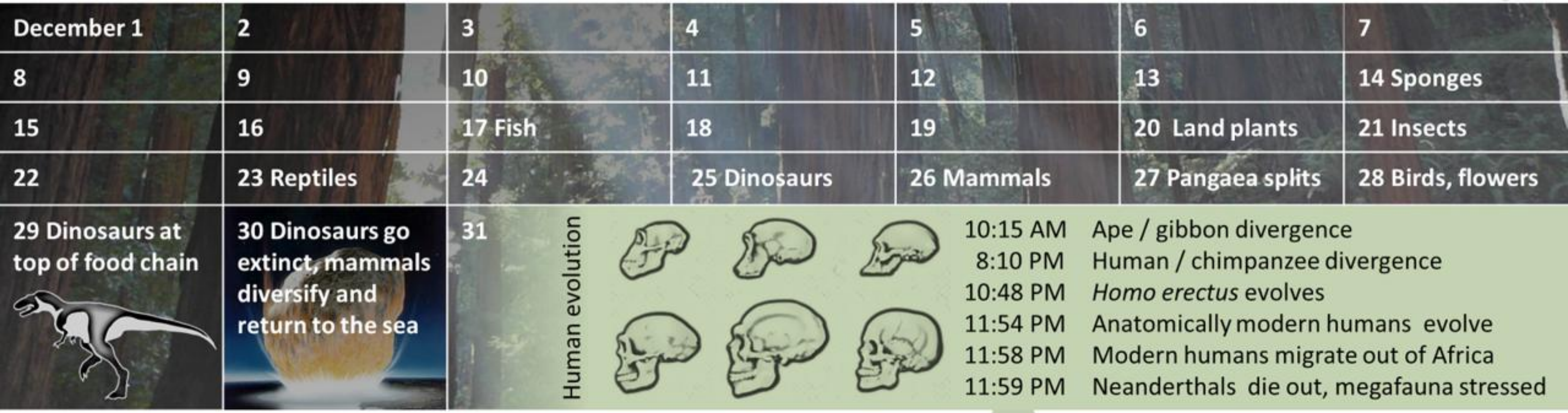
How old is the Universe? Does it have a beginning, and an end?



Known from telescopes looking back in time, physical models

Geologic record, fossils, genetic drift

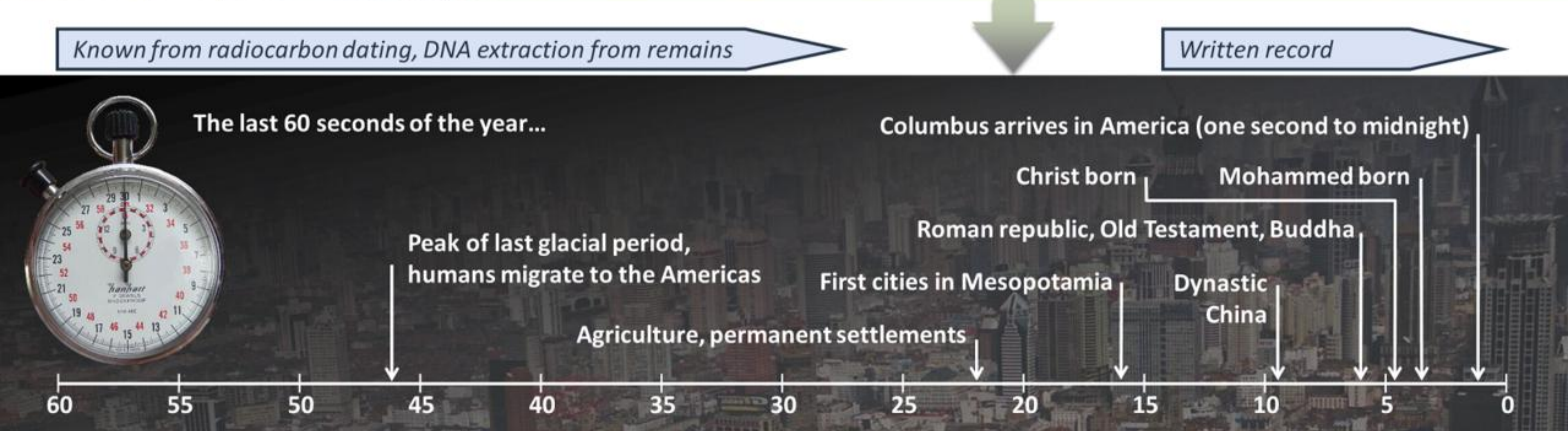
January	February	March	April	May	June	July	August	September	October	November	December
The Big Bang				Milky Way disk forms				Solar System and life	Photo-synthesis	Eukaryotic cells	



December 1	2	3	4	5	6	7
8	9	10	11	12	13	14 Sponges
15	16	17 Fish	18	19	20 Land plants	21 Insects
22	23 Reptiles	24	25 Dinosaurs	26 Mammals	27 Pangaea splits	28 Birds, flowers
29 Dinosaurs at top of food chain	30 Dinosaurs go extinct, mammals diversify and return to the sea	31				

Human evolution

10:15 AM	Ape / gibbon divergence
8:10 PM	Human / chimpanzee divergence
10:48 PM	*Homo erectus* evolves
11:54 PM	Anatomically modern humans evolve
11:58 PM	Modern humans migrate out of Africa
11:59 PM	Neanderthals die out, megafauna stressed



Known from radiocarbon dating, DNA extraction from remains

Written record

The last 60 seconds of the year…

Peak of last glacial period, humans migrate to the Americas

Agriculture, permanent settlements

First cities in Mesopotamia

Dynastic China

Roman republic, Old Testament, Buddha

Christ born

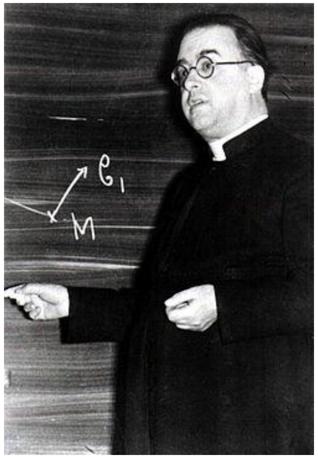
Mohammed born

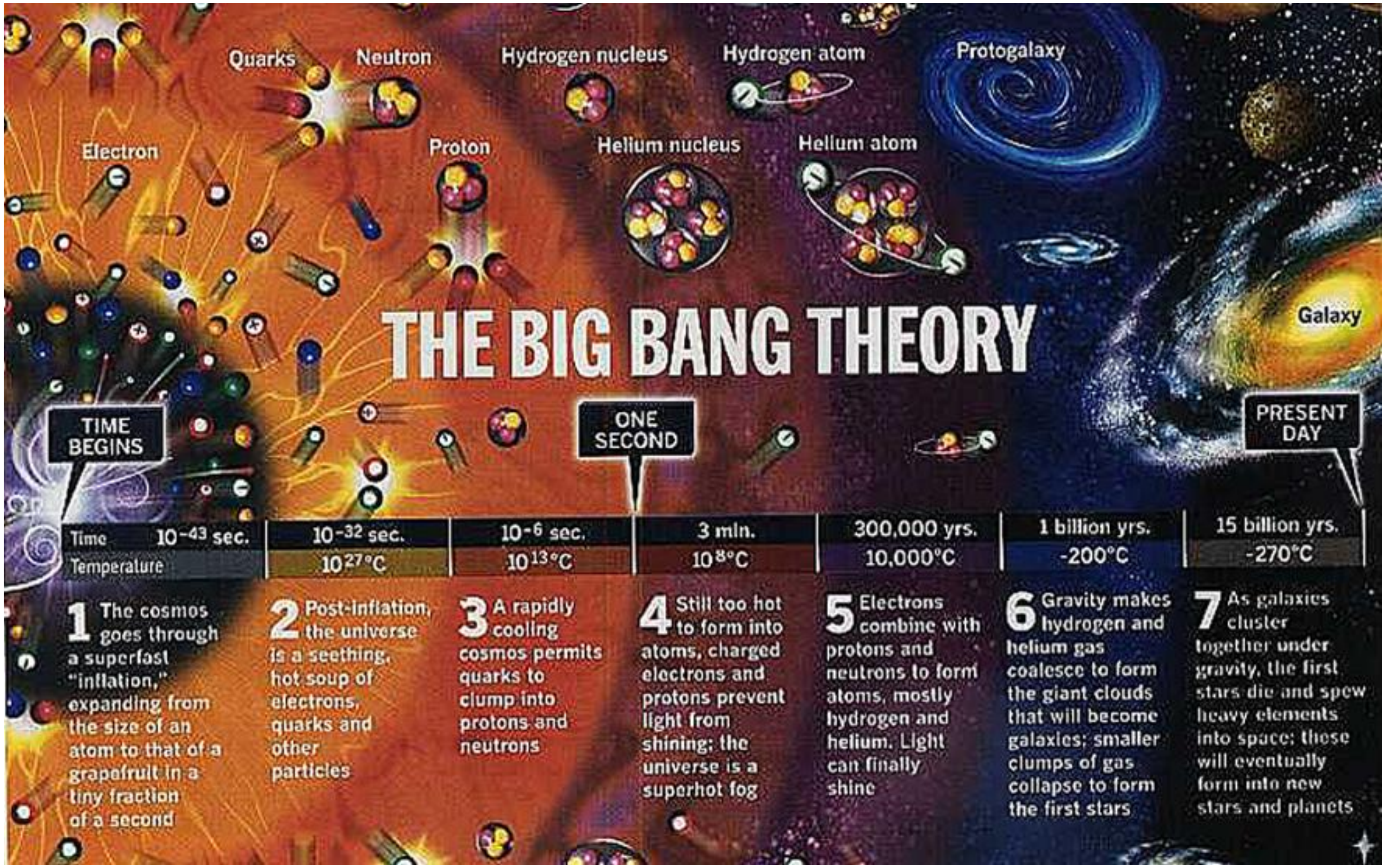
Columbus arrives in America (one second to midnight)

How old is the Universe?

13.8 billion years

George Lemaitre (1894-1966) proposed what is now termed the **Big Bang theory** of the Universe i.e. an expansion from a *singularity*





Time	10^{-43} sec.	10^{-32} sec.	10^{-6} sec.	3 min.	300,000 yrs.	1 billion yrs.	15 billion yrs.
Temperature		10^{27}°C	10^{13}°C	10^{8}°C	10,000°C	-200°C	-270°C

1 The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second

2 Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles

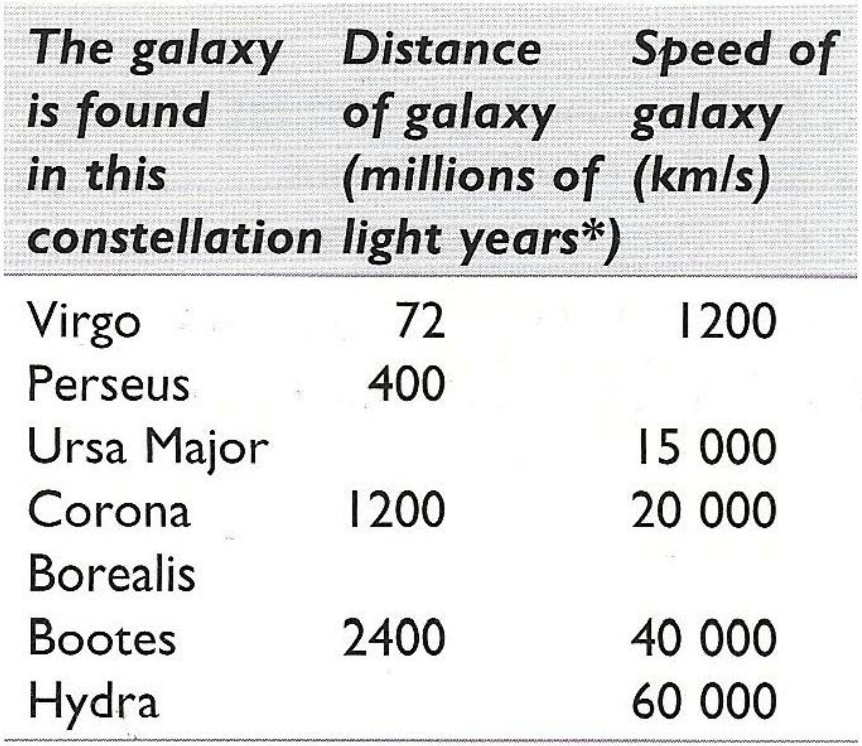
3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons

4 Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog

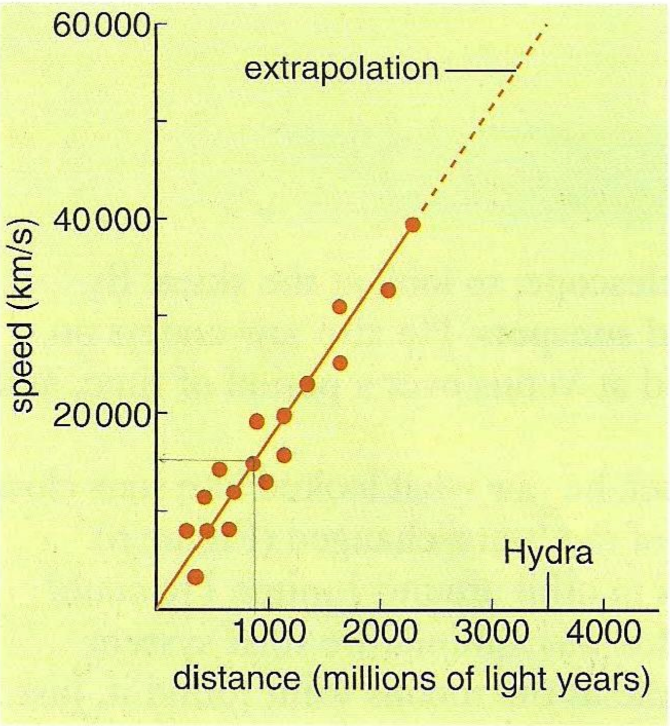
5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine

6 Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars

7 As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets



The galaxy is found in this constellation	Distance of galaxy (millions of light years*)	Speed of galaxy (km/s)
Virgo	72	1200
Perseus	400	
Ursa Major		15 000
Corona Borealis	1200	20 000
Bootes	2400	40 000
Hydra		60 000



Edwin Hubble
(1889-1953)

Hubble found that the majority of galaxies were *moving away from each other.* The resulting doppler shift would be towards the *red* end of the spectrum. The line of best fit to the speed vs distance graph gives an idea of the age of the universe

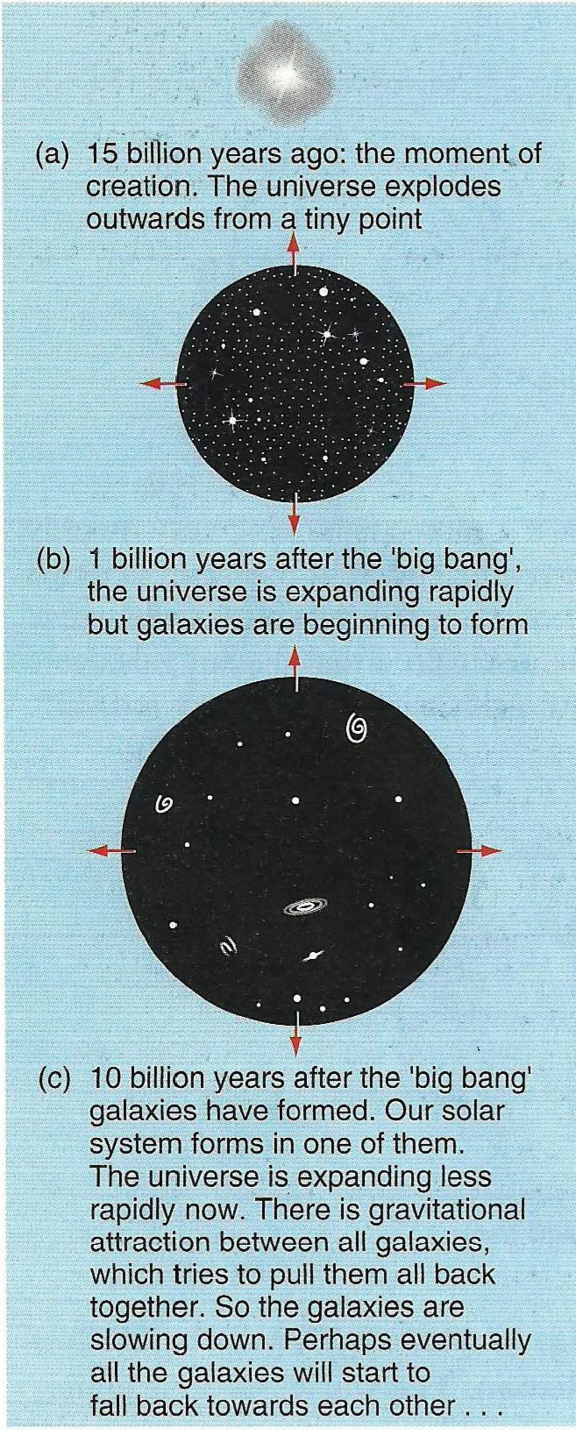
$$t \approx \frac{2300 \times 10^{6} \times 9.46 \times 10^{15}\,\mathrm{m}}{40{,}000 \times 10^{3}\,\mathrm{ms^{-1}}}$$

$$t \approx 5.4 \times 10^{17}\,\mathrm{s}$$

$$t \approx 17.2\,\text{billion years}$$

If one accounts for relativistic effects, inflation etc

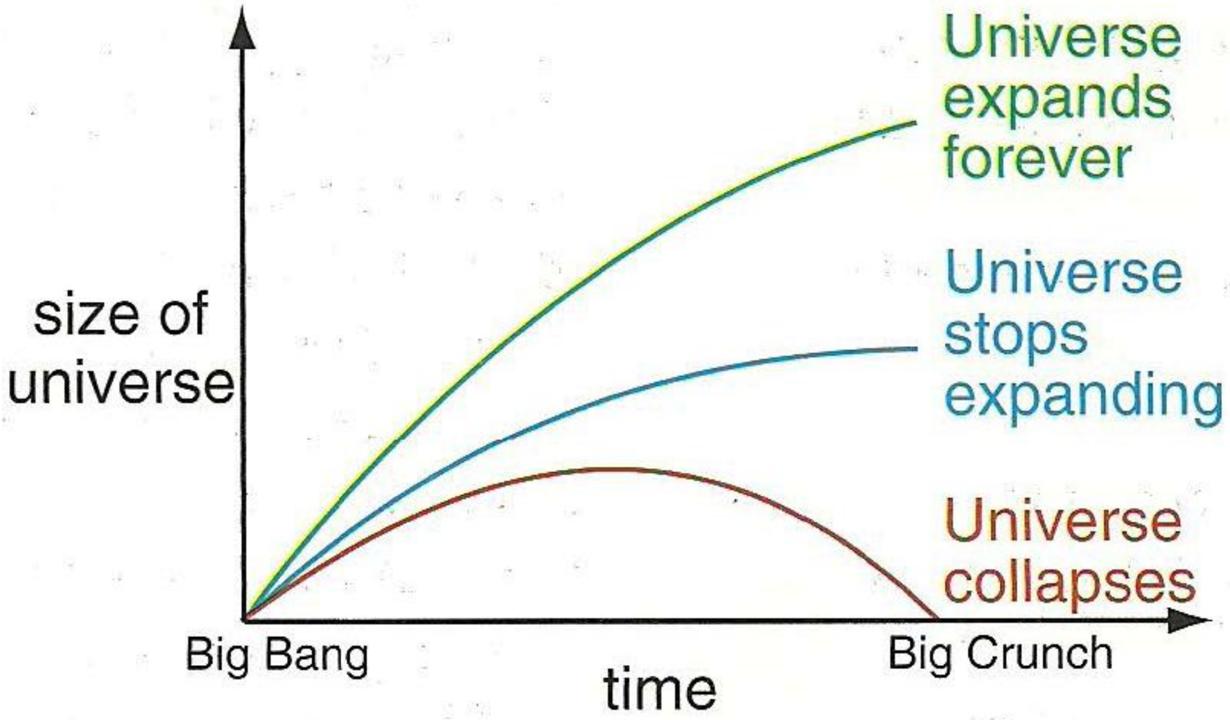
t = 13.8 billion years



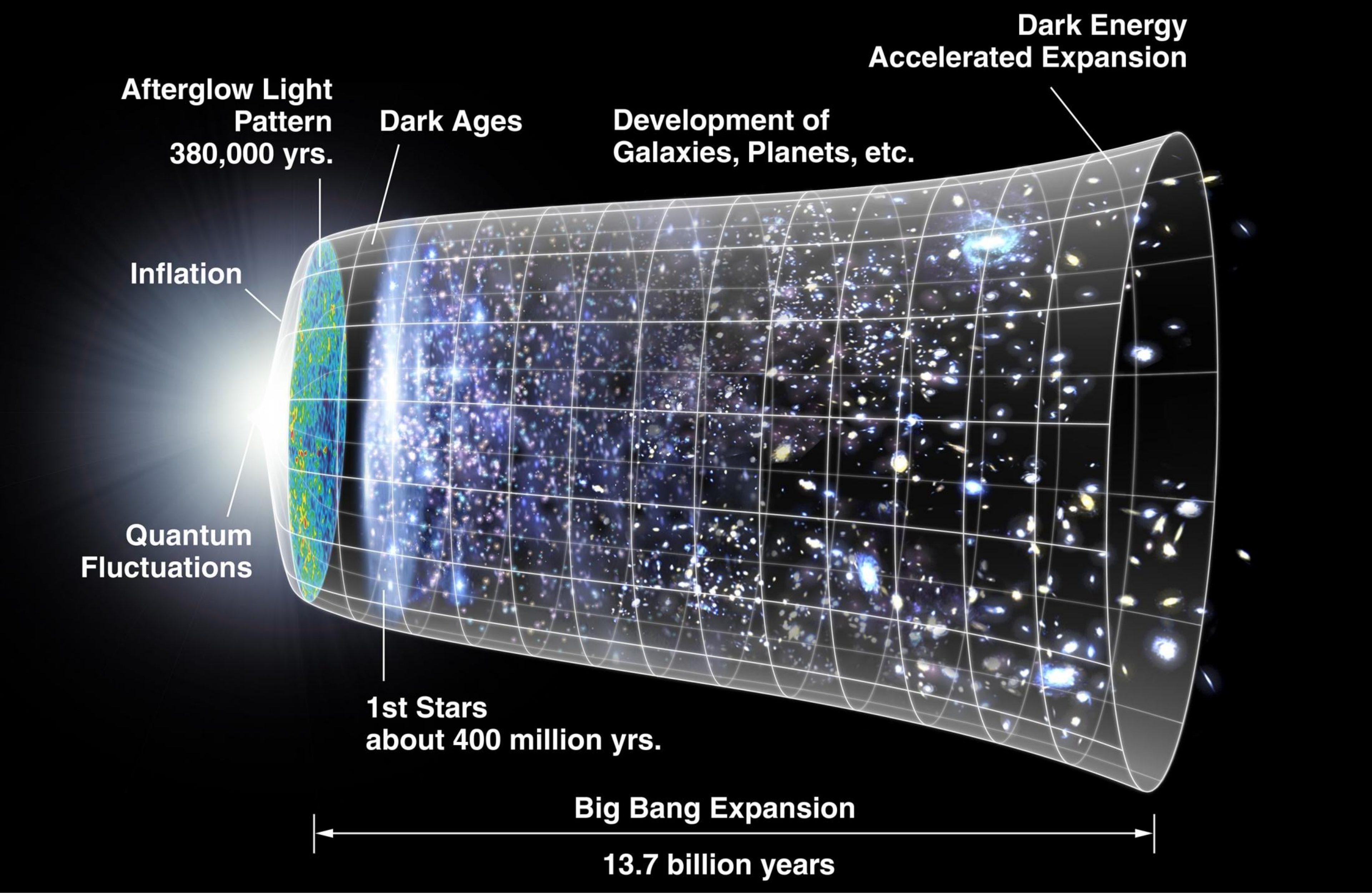
(a) 15 billion years ago: the moment of creation. The universe explodes outwards from a tiny point

(b) 1 billion years after the 'big bang', the universe is expanding rapidly but galaxies are beginning to form

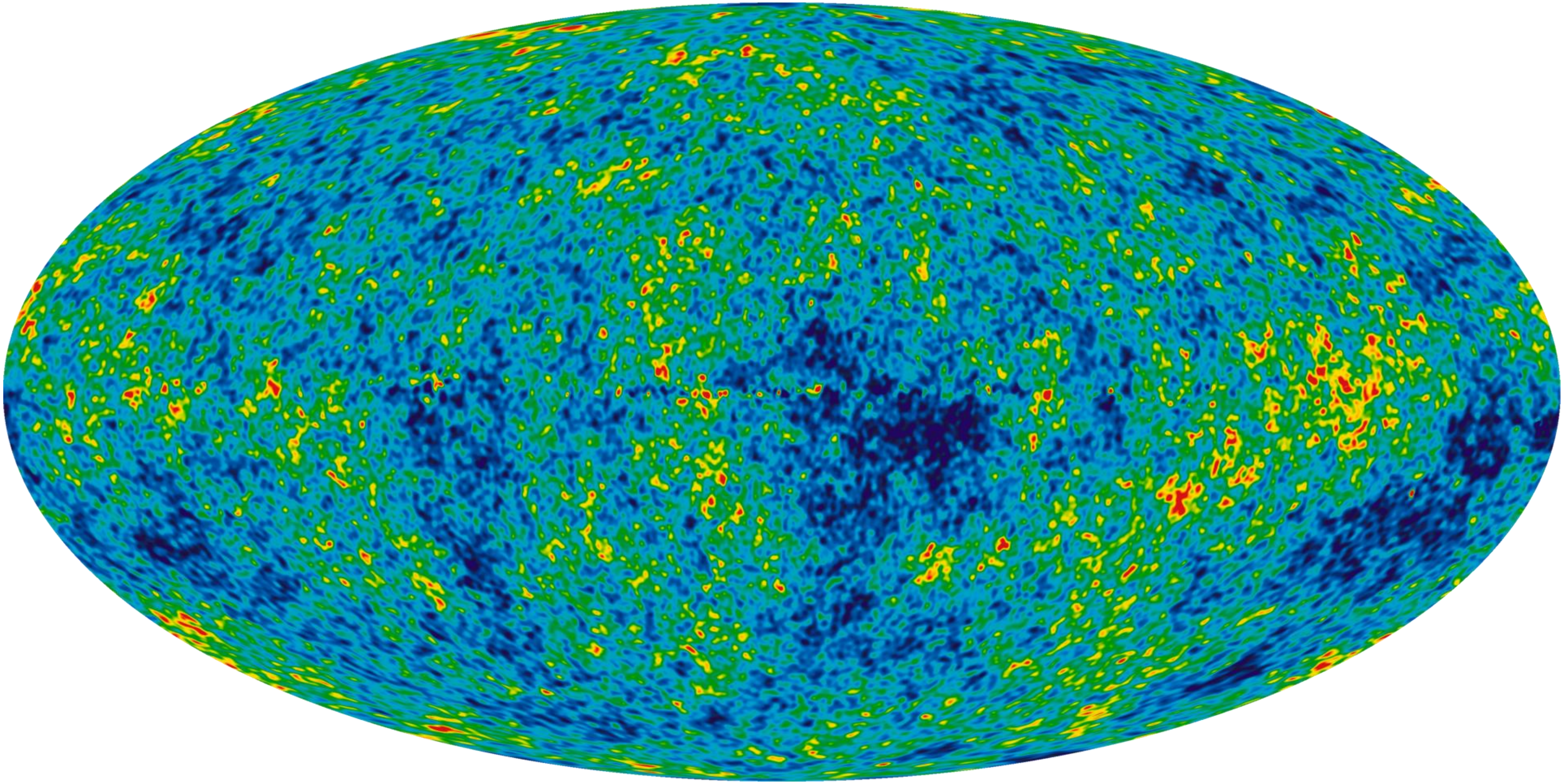
(c) 10 billion years after the 'big bang' galaxies have formed. Our solar system forms in one of them. The universe is expanding less rapidly now. There is gravitational attraction between all galaxies, which tries to pull them all back together. So the galaxies are slowing down. Perhaps eventually all the galaxies will start to fall back towards each other . . .



Does the universe expand forever? Or does it gradually slow down, or does it contract?



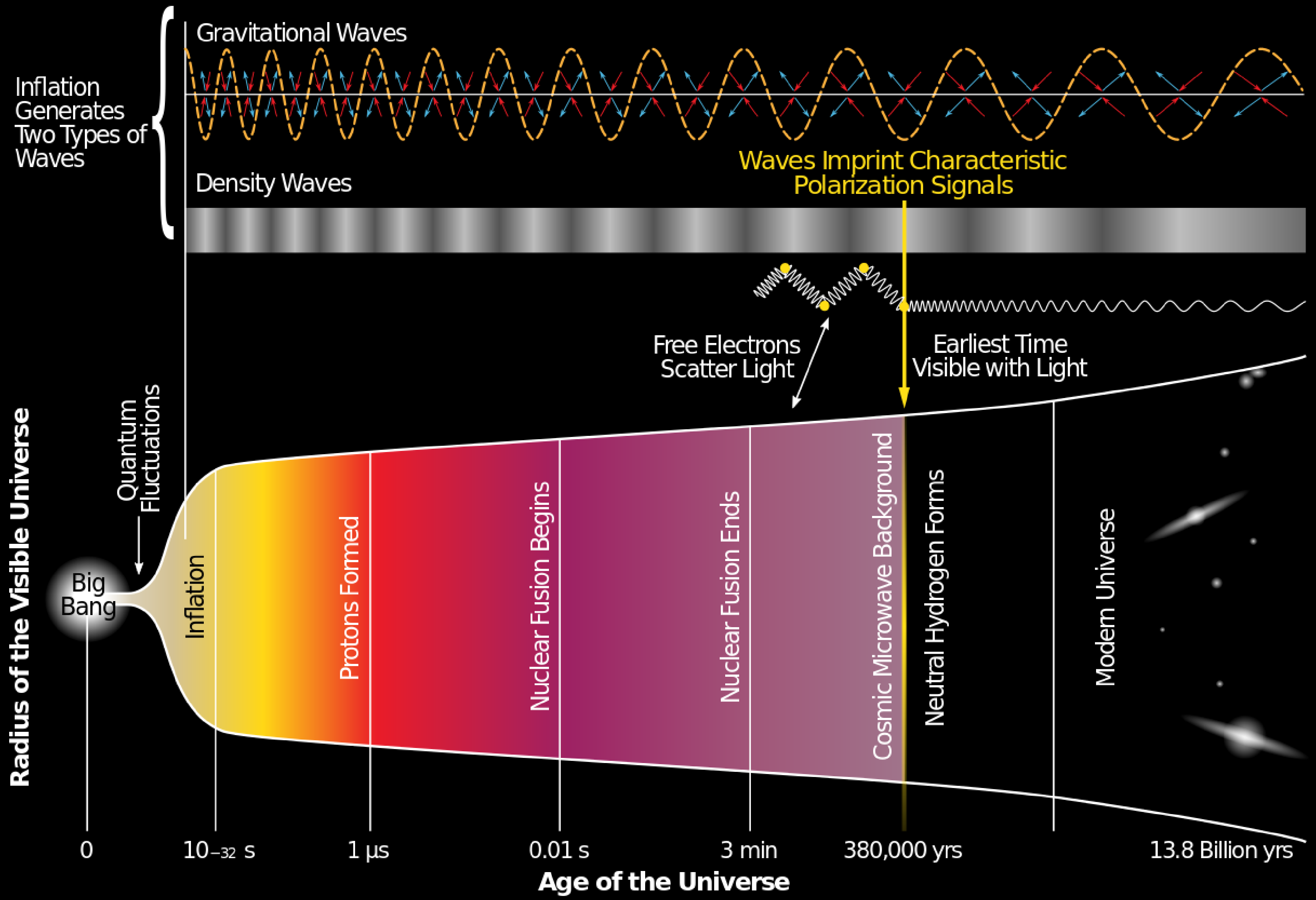
NASA/WMAP Science Team - Original version: NASA; modified by Ryan Kaldari

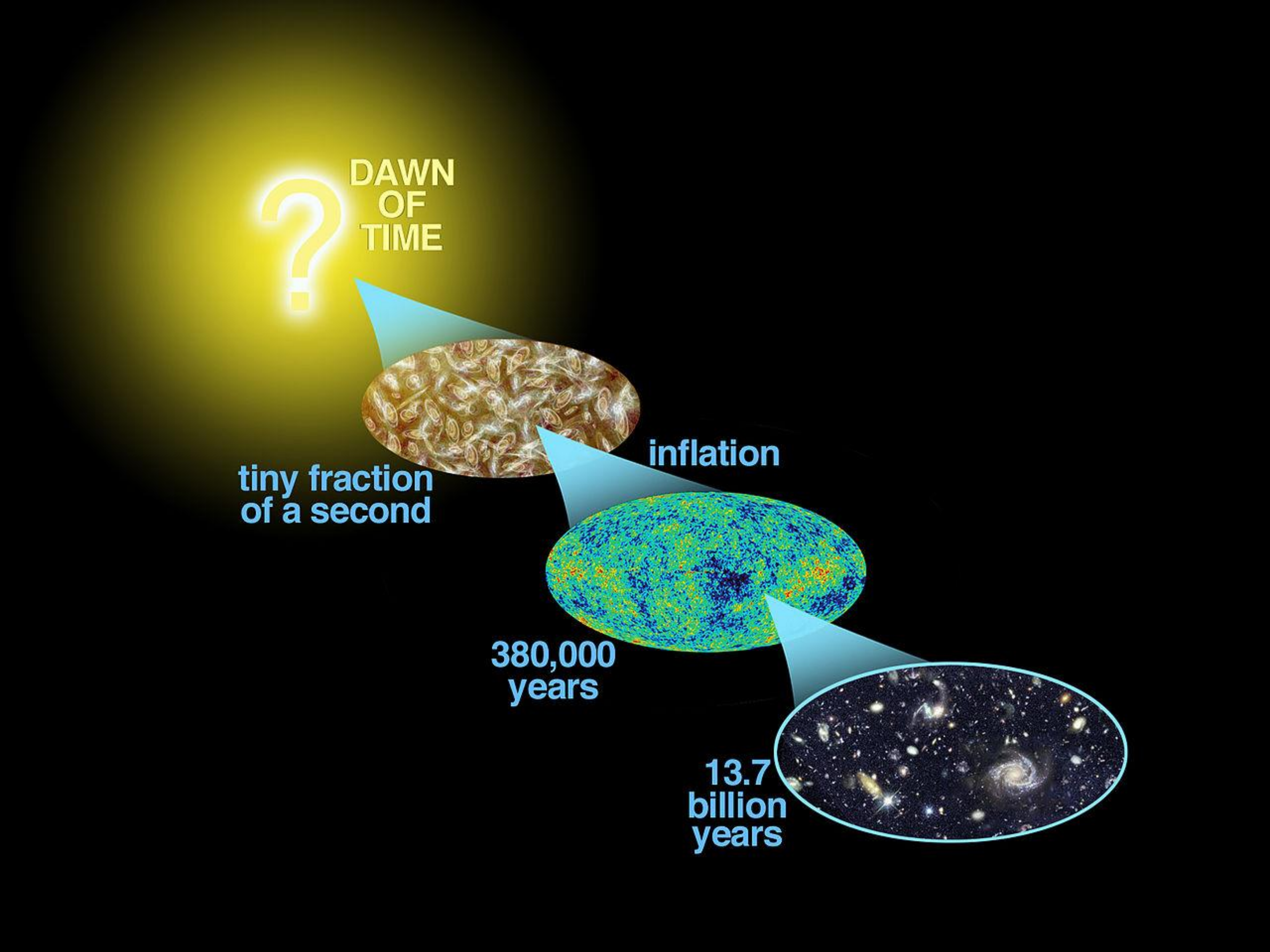


Nine Year Microwave Sky . The detailed, all-sky picture of the infant universe created from nine years of WMAP data. The image reveals 13.77 billion year old temperature fluctuations (shown as colour differences) that correspond to the seeds that grew to become the galaxies. The signal from our galaxy was subtracted using the multi-frequency data. This image shows a temperature range of ± 200 μK.

NASA / WMAP Science Team WMAP # 121238 Image Caption 9 year WMAP image of background cosmic radiation (2012)

History of the Universe





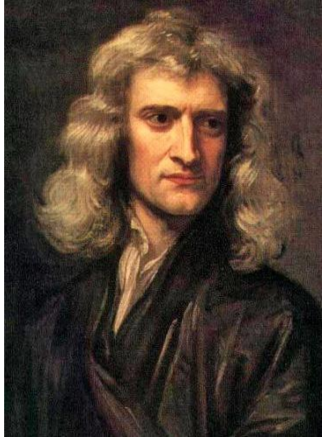
DAWN
OF
TIME

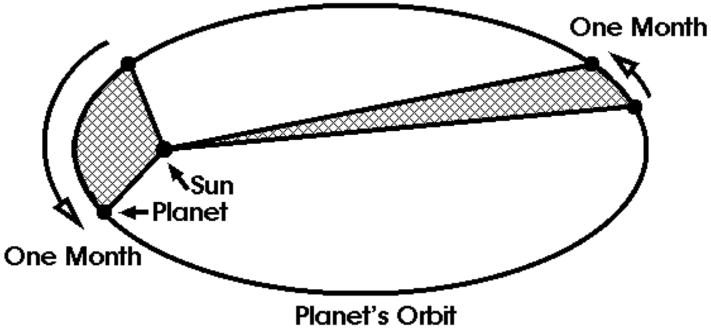
tiny fraction
of a second

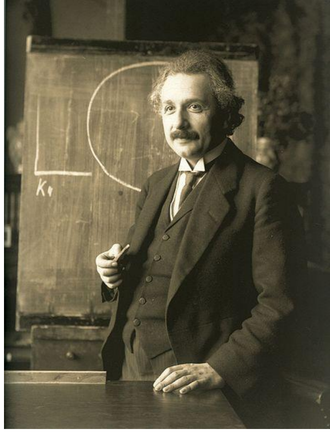
inflation

380,000
years

13.7
billion
years



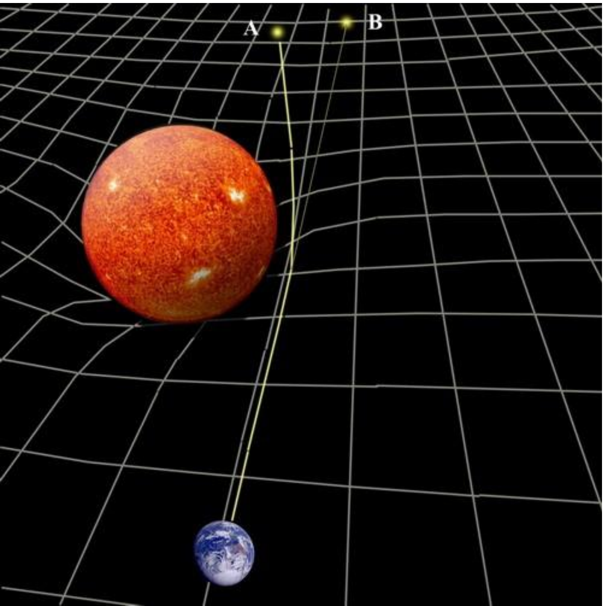


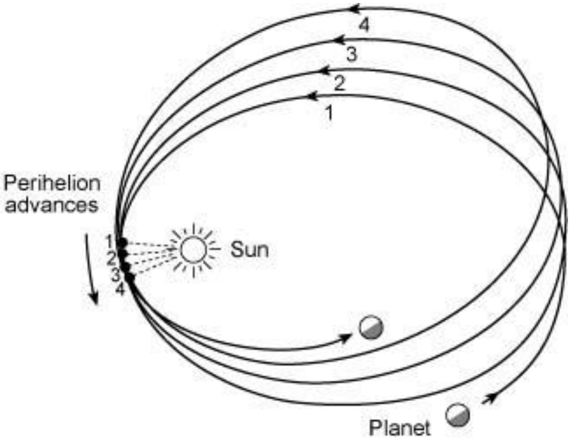


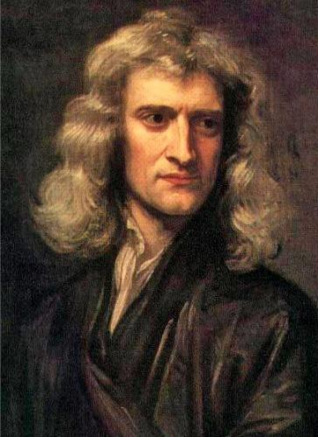
$$F = \frac{GMM_{\odot}}{r^2}$$

Gravity

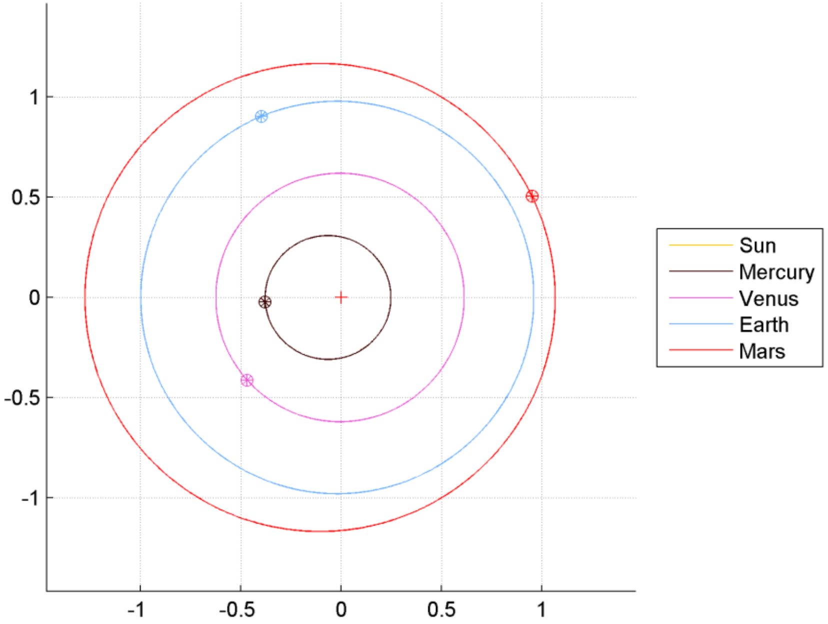
$$P^2 = \frac{4\pi^2}{G\left(M + M_{\odot}\right)} a^3$$







Isaac Newton (1642-1727) developed a mathematical model of Gravity which predicted the elliptical orbits proposed by Kepler

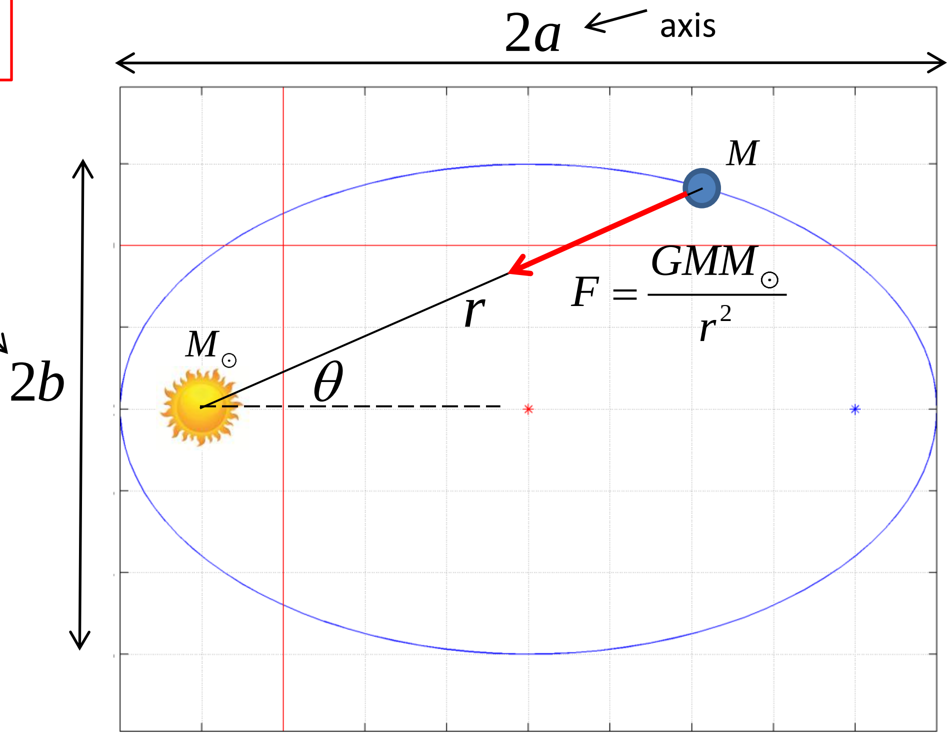


Planet and Solar masses

Force of gravity

$$F = \frac{GMM_{\odot}}{r^2}$$

$$G = 6.67 \times 10^{-11}\,\mathrm{m^3kg^{-1}s^{-2}}$$



Semi-major axis

Semi-minor axis

$$r = \frac{a\left(1-\varepsilon^2\right)}{1+\varepsilon\cos\theta}$$

Polar equation of ellipse

$$\varepsilon = \sqrt{1-\frac{b^2}{a^2}}$$

Eccentricity of ellipse

$$P^2 = \frac{4\pi^2}{G(M+M_{\odot})}a^3$$

Orbital period *P*

Kepler's three laws are:

1. *The orbit of every planet in the solar system is an ellipse with the Sun at one of the two foci.*
2. *A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.*
3. *The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.*

The wording of Kepler's laws implies a specific application to the solar system. However, the laws are more generally applicable to any system of two masses whose mutual attraction is an inverse-square law.

$$r = \frac{a\left(1-\varepsilon^2\right)}{1+\varepsilon\cos\theta}$$

Polar equation of ellipse

$$\varepsilon = \sqrt{1-\frac{b^2}{a^2}}$$

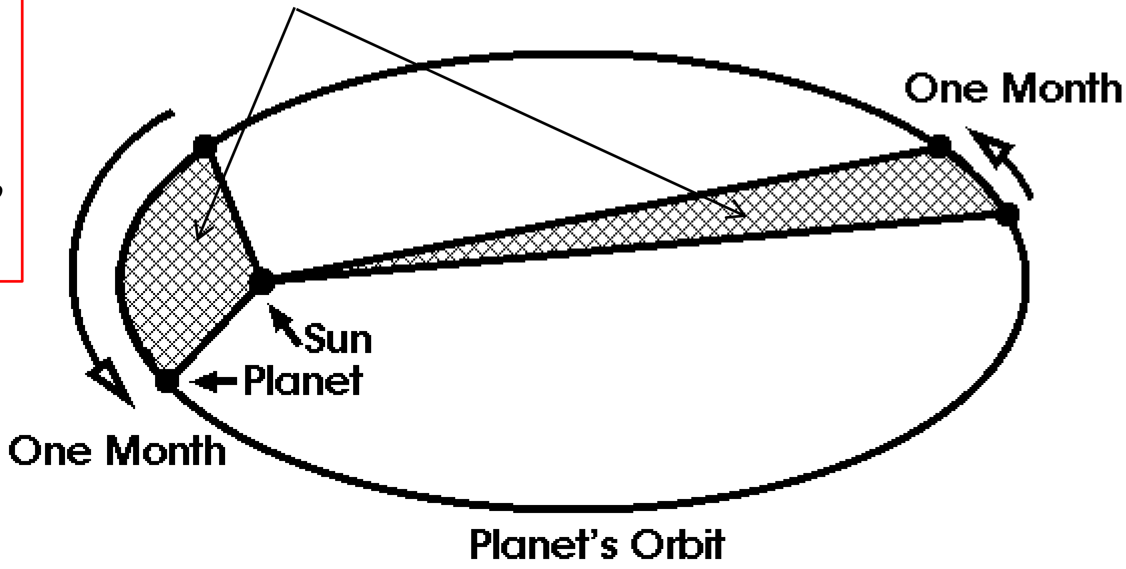
Eccentricity of ellipse

$$P^2 = \frac{4\pi^2}{G(M+M_\odot)}a^3$$

Orbital period *P*

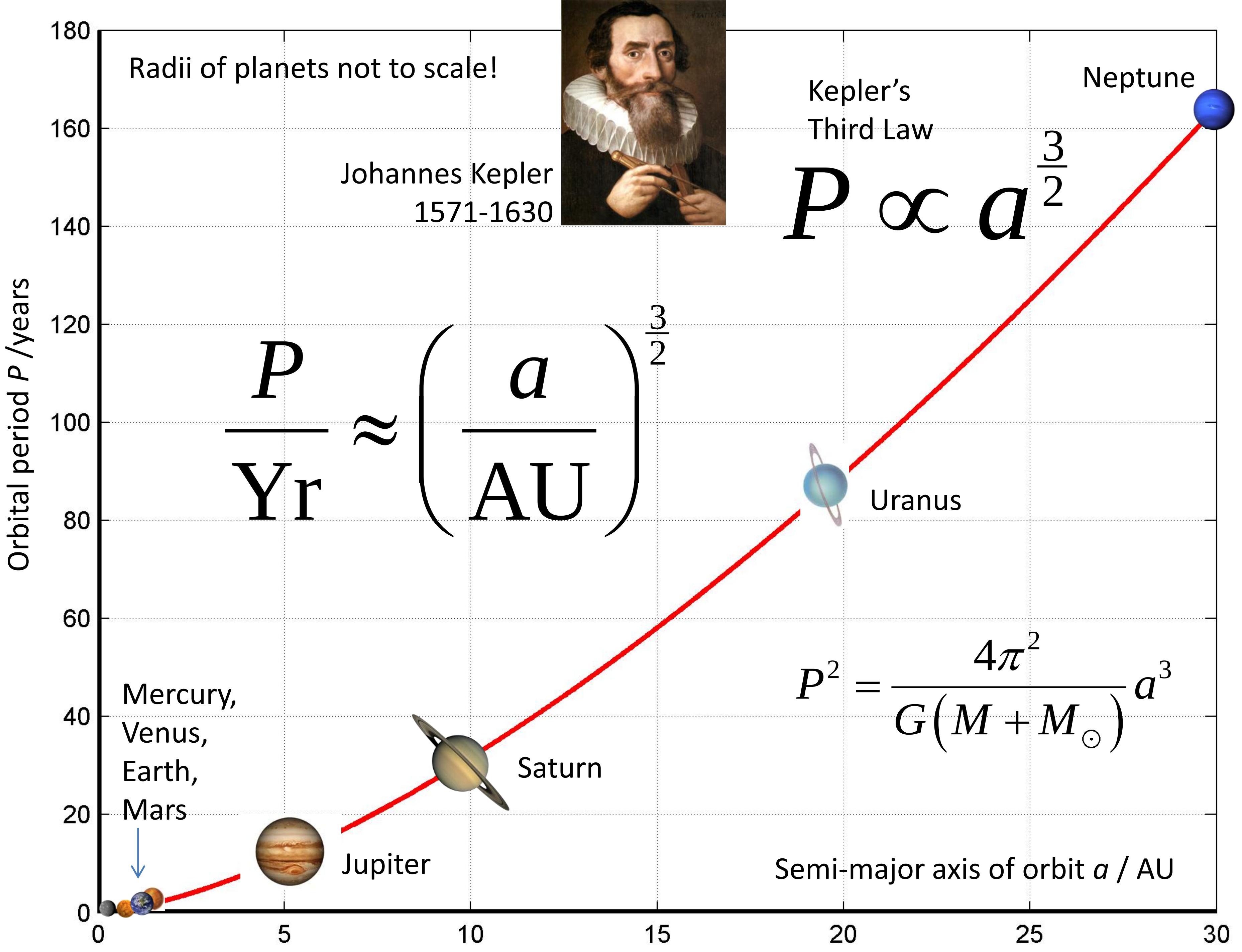
$$\frac{dA}{dt} = \tfrac{1}{2}\sqrt{G(M+M_\odot)\left(1-\varepsilon^2\right)a}$$

This is a constant



Equal areas swept out in equal times

Johannes Kepler
1571-1630



Radii of planets not to scale!

Johannes Kepler
1571-1630

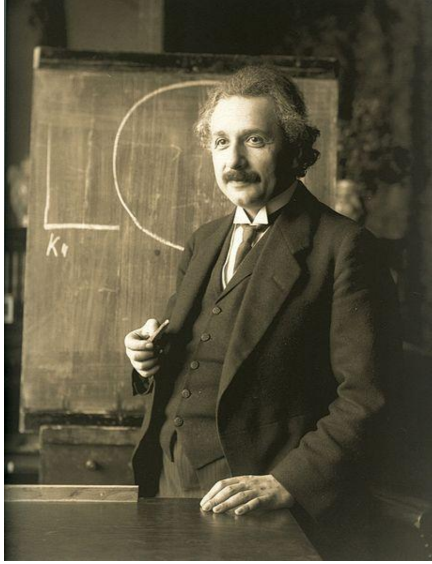
Kepler's
Third Law

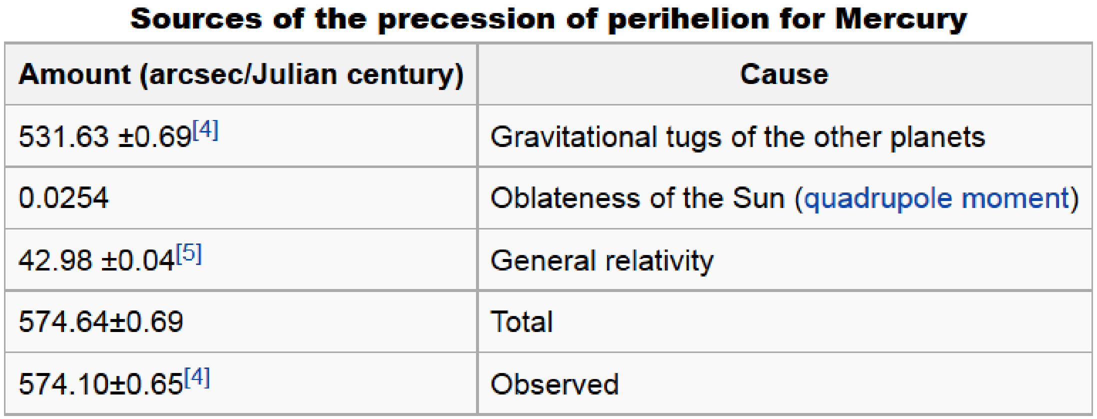
$$P \propto a^{\frac{3}{2}}$$

$$\frac{P}{\mathrm{Yr}} \approx \left(\frac{a}{\mathrm{AU}}\right)^{\frac{3}{2}}$$

$$P^2 = \frac{4\pi^2}{G\left(M + M_\odot\right)} a^3$$

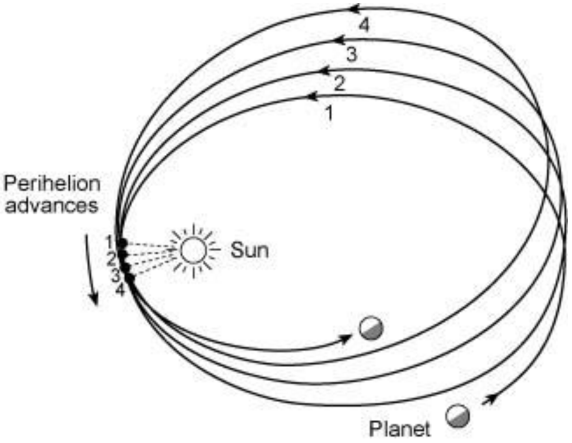
Albert Einstein (1879-1955) proposed a radical new theory of gravity, General Relativity, in which both space & time (‘*spacetime*’) are *curved* by the presence of mass. This helped to explain *anomalies* in the Newtonian model such as the *precession of the orbit Mercury* and the amount that light is bent by massive objects (*Gravitational lensing*). Note General Relativity predicts the *same* planetary dynamics as Newton’s model when gravity is fairly weak. i.e. Newton’s model can be thought of as an *approximation*.

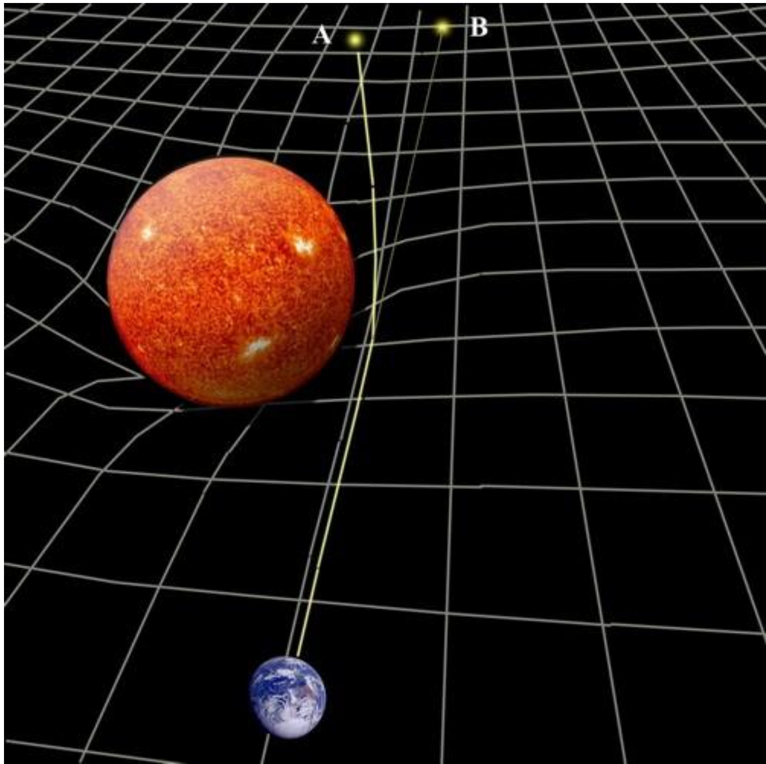




Sources of the precession of perihelion for Mercury

Amount (arcsec/Julian century)	Cause
531.63 ±0.69[4]	Gravitational tugs of the other planets
0.0254	Oblateness of the Sun (quadrupole moment)
42.98 ±0.04[5]	General relativity
574.64±0.69	Total
574.10±0.65[4]	Observed





Escape velocity

To escape the gravity of a spherical astronomical body of mass *M* and radius *R* the total energy of the system must be positive at an infinite distance from the body.

In other words, it will have some kinetic energy and will never be gravitationally attracted back towards the body.

For a mass *m* blasting off with velocity *v*, it will escape the gravitational influence of *M* if:

$$\tfrac{1}{2}mv^2 - \frac{GMm}{R} > 0$$

$$\therefore \quad \boxed{v > \sqrt{\frac{2GM}{R}}}$$

For Earth, the escape velocity is:

$$v_{escape} = \sqrt{\frac{2GM}{R}}$$

$$v_{escape} = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{6.38 \times 10^{6}}} \approx \boxed{11.2\,\mathrm{kms}^{-1}}$$

It is interesting to work out the radius of a star of mass *M* such that the escape velocity exceeds that of the speed of light. Since this is not possible, the star becomes a ***Black Hole***.

This inequality defines the maximum radius of a Black Hole, which is called the ***Schwarzschild radius***. This is the *event horizon*, or 'point of no return' from the centre of a Black Hole.

For the Sun to become a Black Hole ($M = 2 \times 10^{30}$ kg, $R = 6.96 \times 10^{8}$ m) its radius would have to **shrink to less than 2.97 km.**

This is a mindblowing density of 1.8×10^{19} kgm^{-3} !

$$\sqrt{\frac{2GM}{R}} > c$$

$$\frac{2GM}{R} > c^2$$

$$\boxed{R < \frac{2GM}{c^2}}$$

$$\rho_{\text{Black hole}} > \frac{M}{\tfrac{4}{3}\pi\left(\dfrac{2GM}{c^2}\right)^3}$$

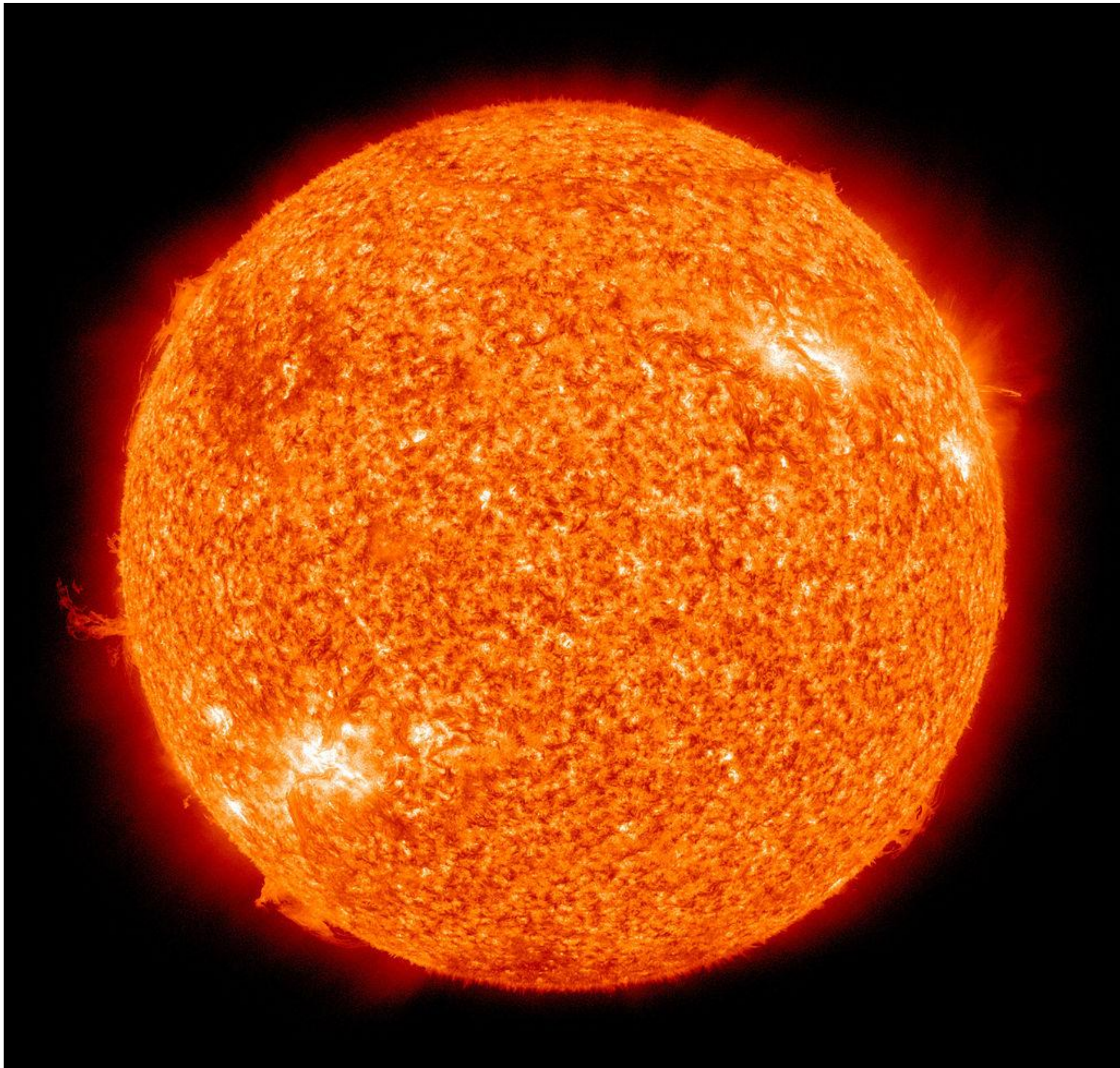
$$\boxed{\rho_{\text{Black hole}} > \frac{3c^6}{32\pi G^3 M^2}}$$

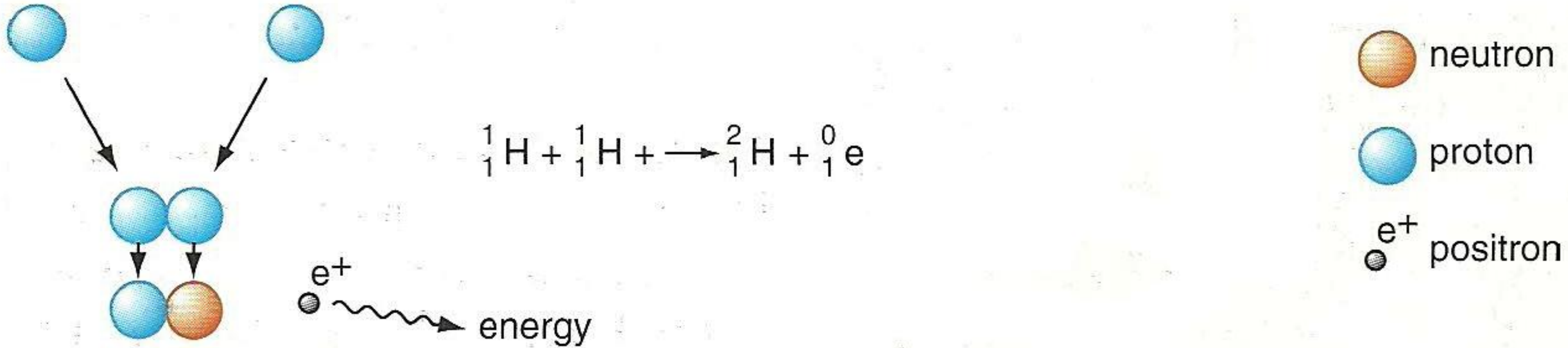
Stars & Galaxies

A star is a luminous sphere of plasma held together by its own gravity.

The nearest star to Earth is the Sun.

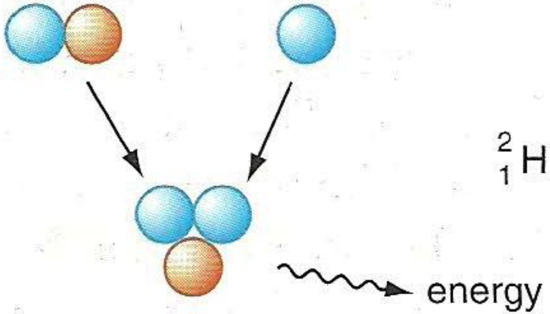
For at least a portion of its life, a star shines due to **thermonuclear fusion** of hydrogen into helium in its core, releasing energy that traverses the star's interior and then radiates into outer space.





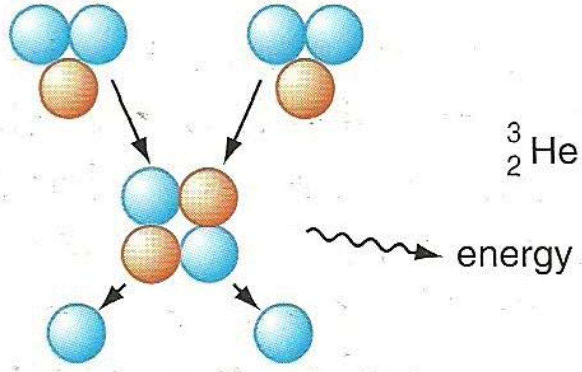
$${}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} + \longrightarrow {}^{2}_{1}\mathrm{H} + {}^{0}_{1}\mathrm{e}$$

Stage 1 2 protons fuse to make deuterium, with the release of a positron and energy
A positron is a positively charged electron. The energy is carried away by a γ-ray



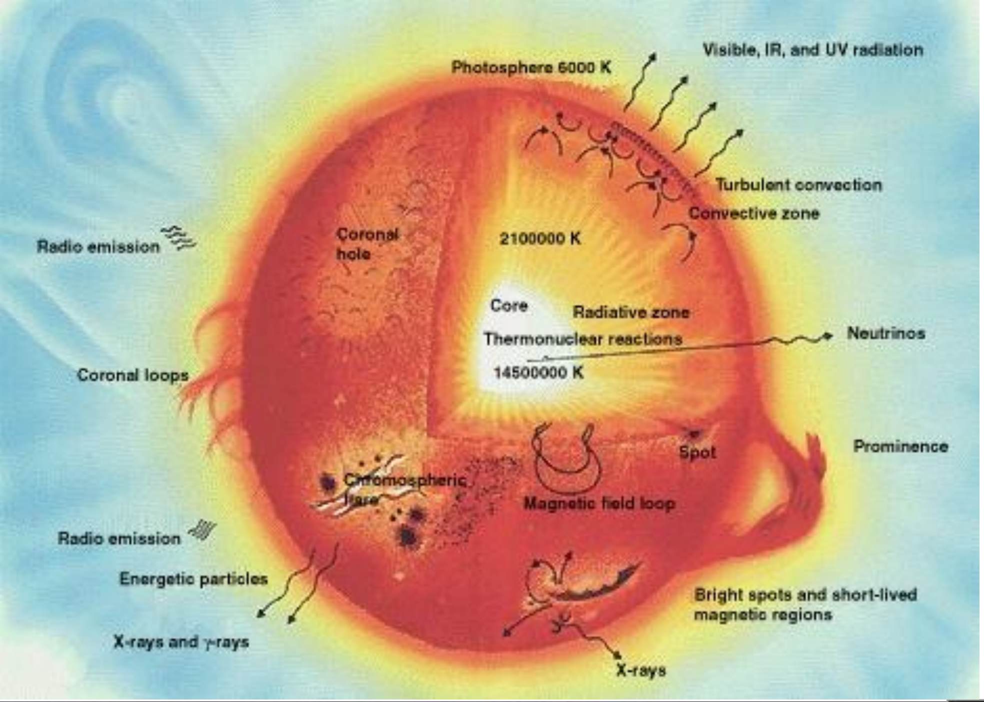
$${}^{2}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} + \longrightarrow {}^{3}_{2}\mathrm{He}$$

Stage 2 Deuterium fuses with a proton to form Helium-3, with a further release of energy



$${}^{3}_{2}\mathrm{He} + {}^{3}_{2}\mathrm{He} + \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H}$$

Stage 3 The process is completed when two Helium-3 nuclei fuse to make Helium-4



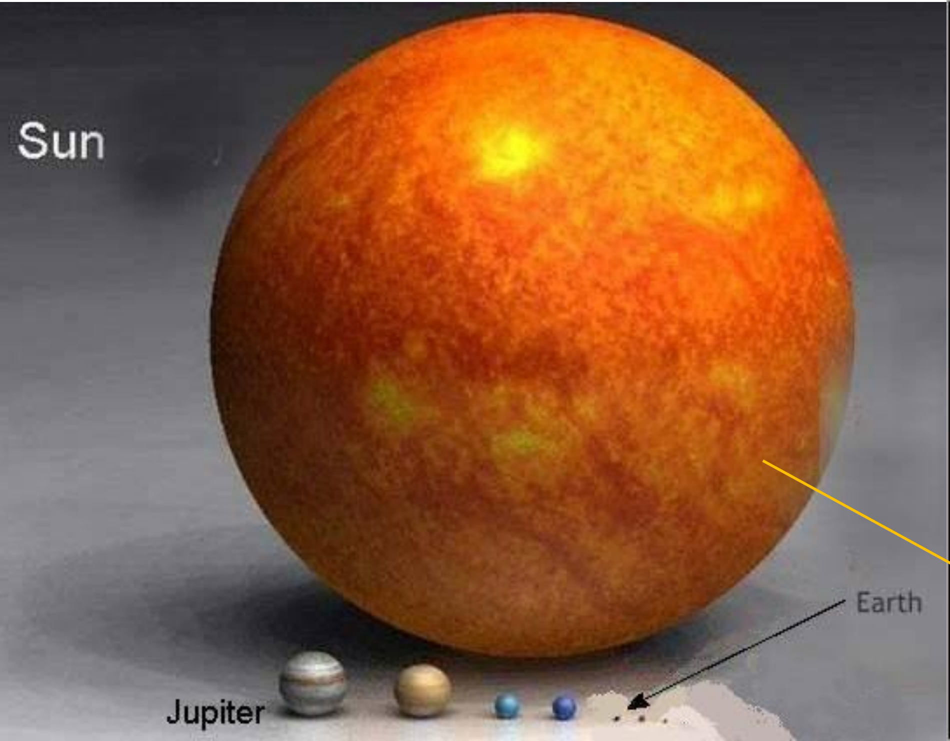
Stars vary in radius, mass and surface temperature (which is related to their luminosity)

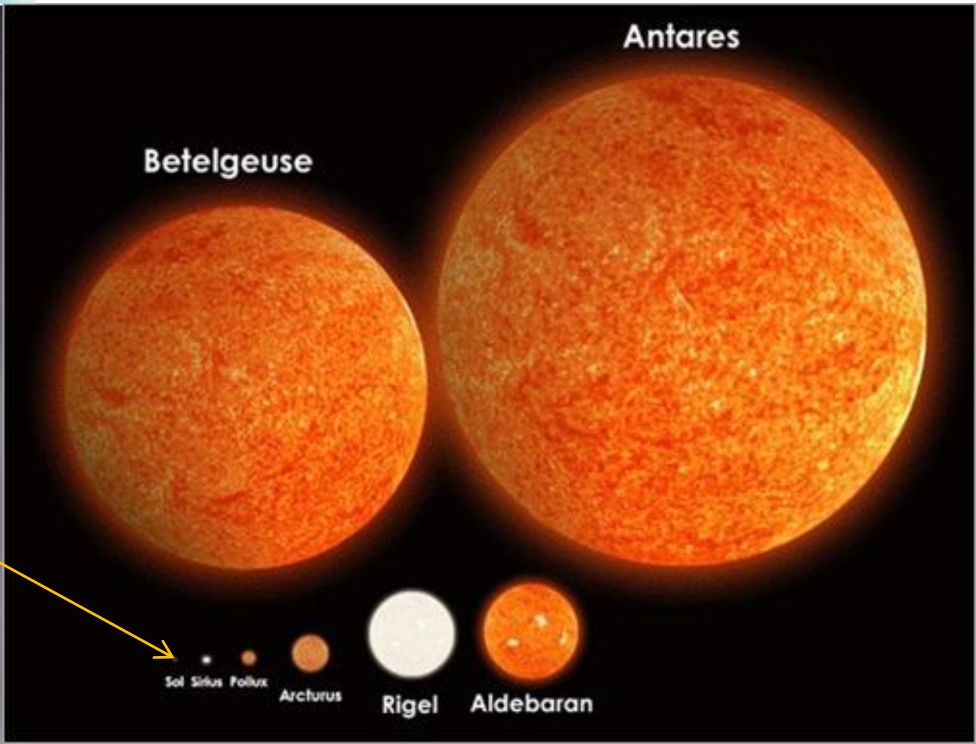
Stefan-Boltzmann law:

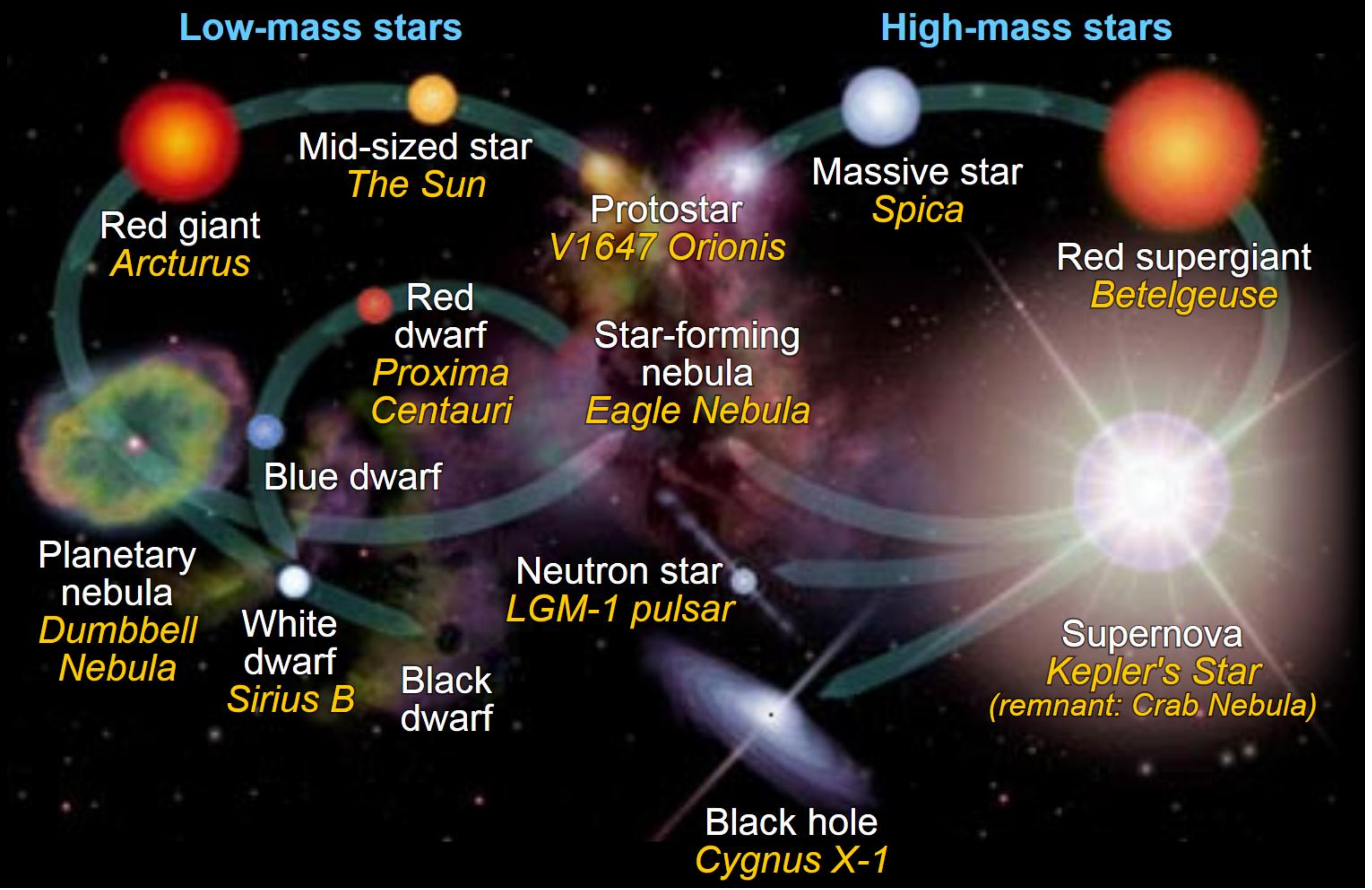
$$L \propto T^4$$

Total power radiated (all frequencies)

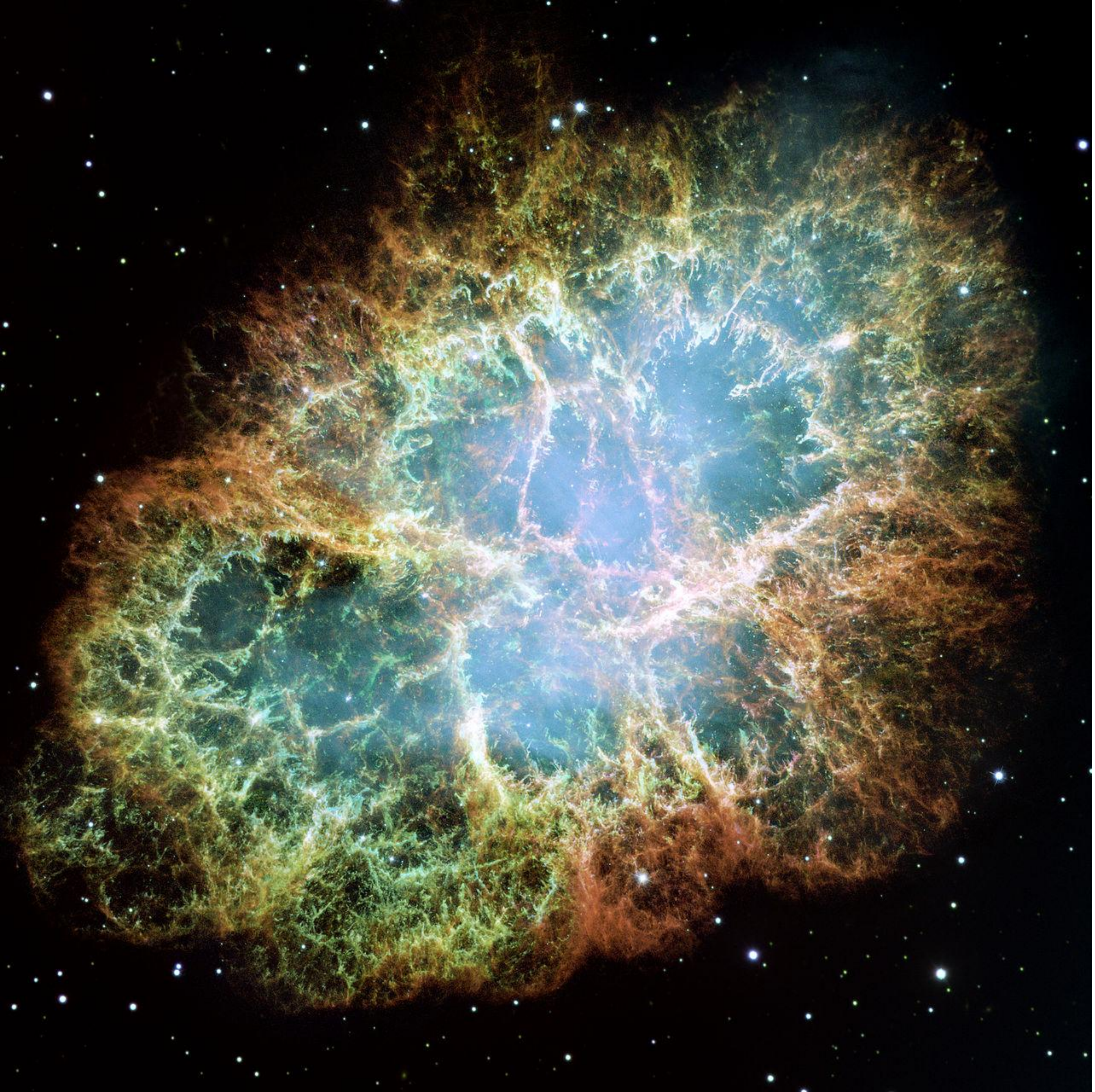
Surface temperature /Kelvin





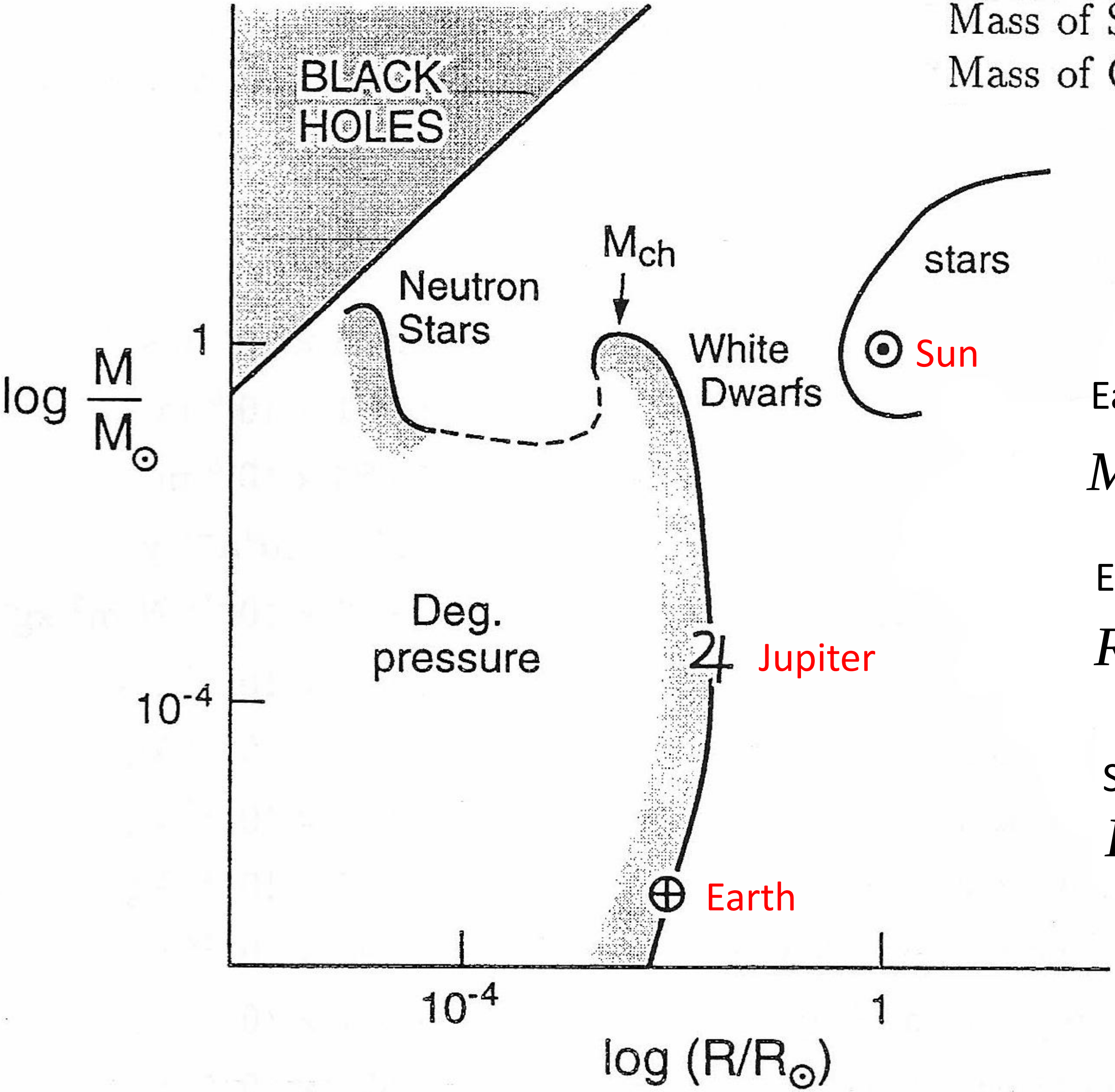


The lifecycle of a star – much of what happens depends upon its *mass*



The Crab Nebula, remnants of a supernova that was first observed around 1050 AD

Mass of Sun $= 2 \times 10^{30}\,\mathrm{kg} = M_\odot$
Mass of Galaxy $\sim 10^{11} - 10^{12}\,M_\odot$



Mass-radius diagram for objects of planetary and stellar mass.

Earth mass

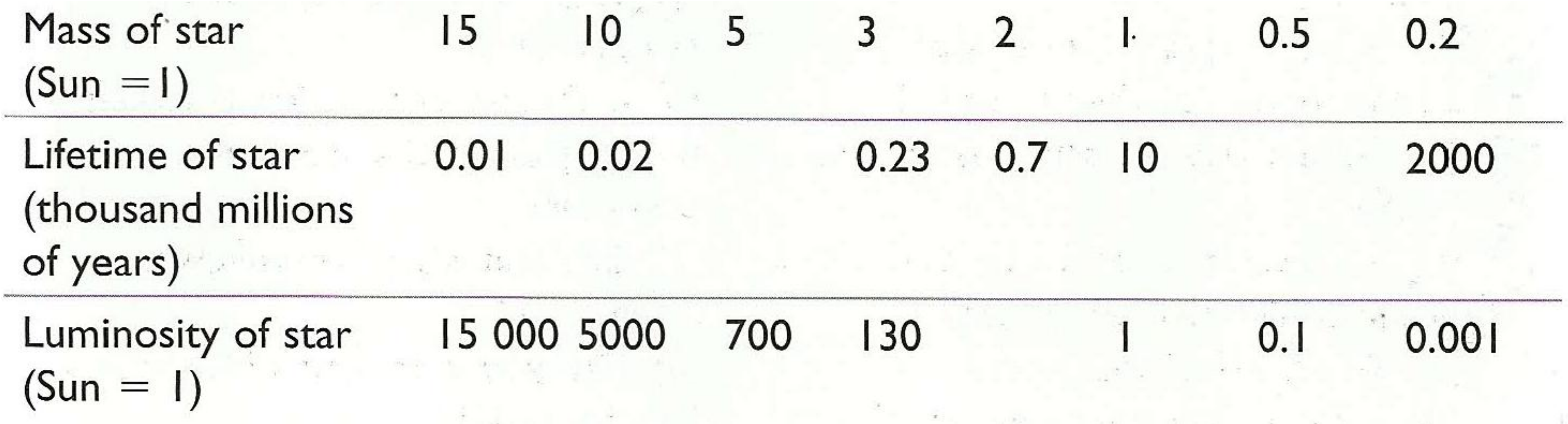
$$M_\oplus = 5.972 \times 10^{24}\,\mathrm{kg}$$

Earth radius

$$R_\oplus = 6.371 \times 10^{6}\,\mathrm{m}$$

Solar radius

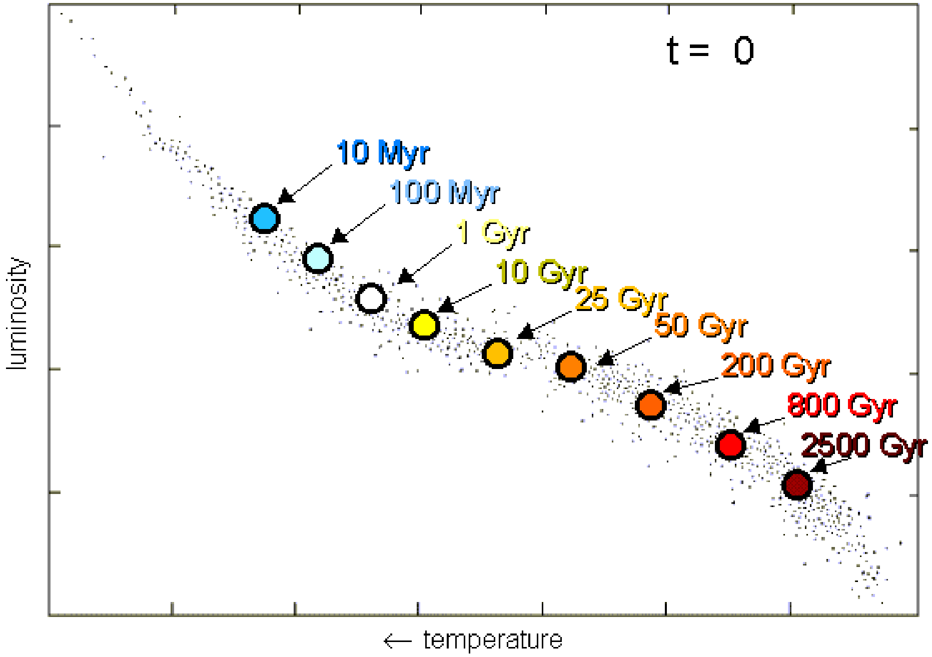
$$R_\odot \approx 110 R_\oplus$$

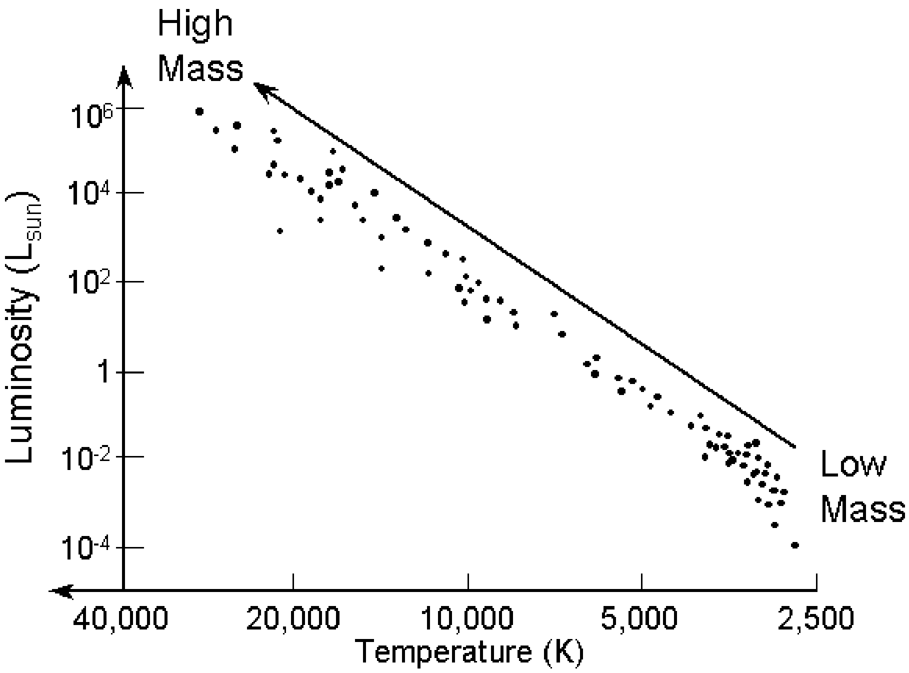


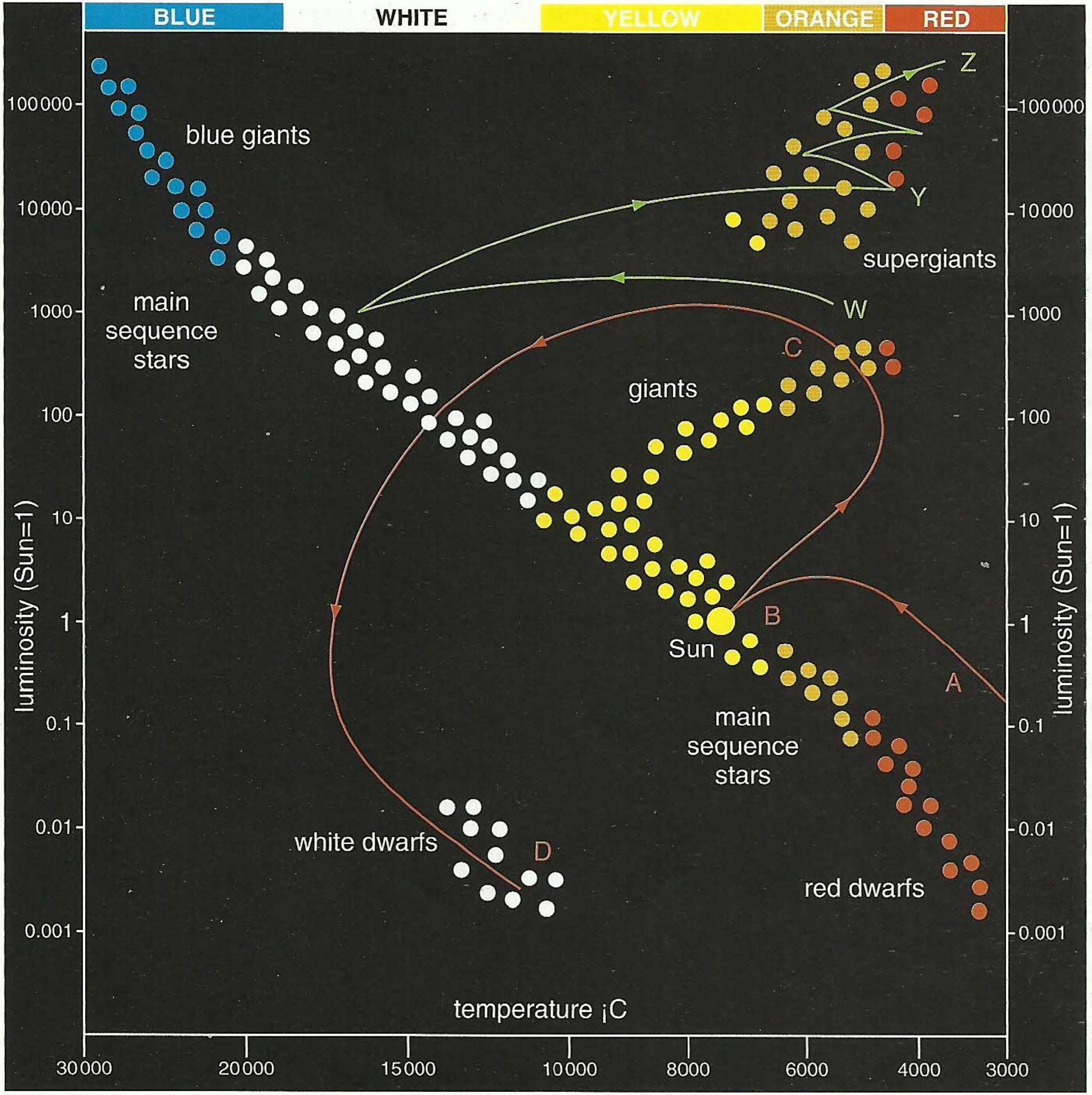
Mass of star (Sun = 1)	15	10	5	3	2	1	0.5	0.2
Lifetime of star (thousand millions of years)	0.01	0.02		0.23	0.7	10		2000
Luminosity of star (Sun = 1)	15 000	5000	700	130		1	0.1	0.001

For **main sequence** stars:

$$t_{lifetime} \approx 10^{10}\ \text{years} \times \left(\frac{M_{\odot}}{M} \right)^{\frac{5}{2}}$$







Hertzsprung-Russell diagram

1910 by Ejnar Hertzsprung and Henry Norris Russell

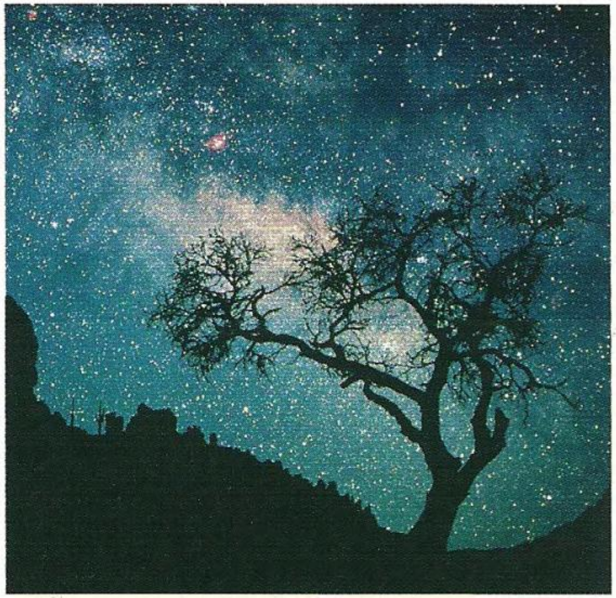
Colliding spiral galaxies

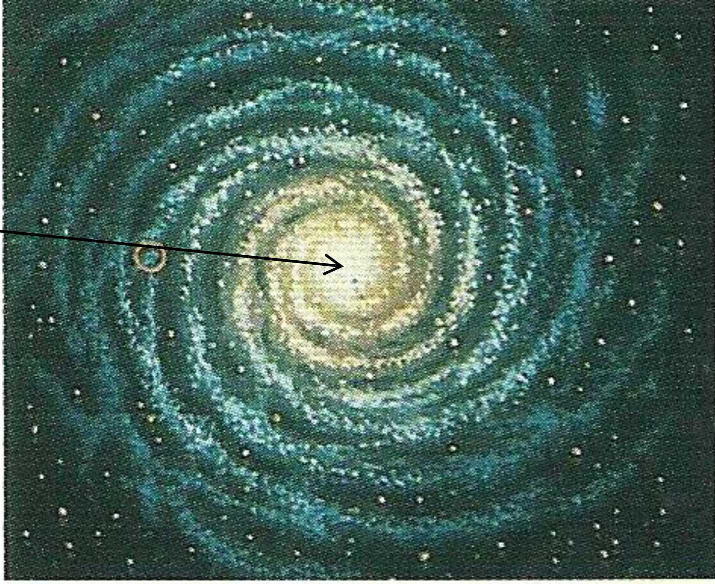
NGC 4414, a typical spiral galaxy in the constellation Coma Berenices, is about 55,000 light-years in diameter and approximately 60 million light-years away from Earth.

Galaxies are gravitationally bound systems of stars, gas, dust, planets and dark matter

Galaxies range from a few thousand stars to over 10^{14} stars

There are approximately 170 billion galaxies in the observable universe!

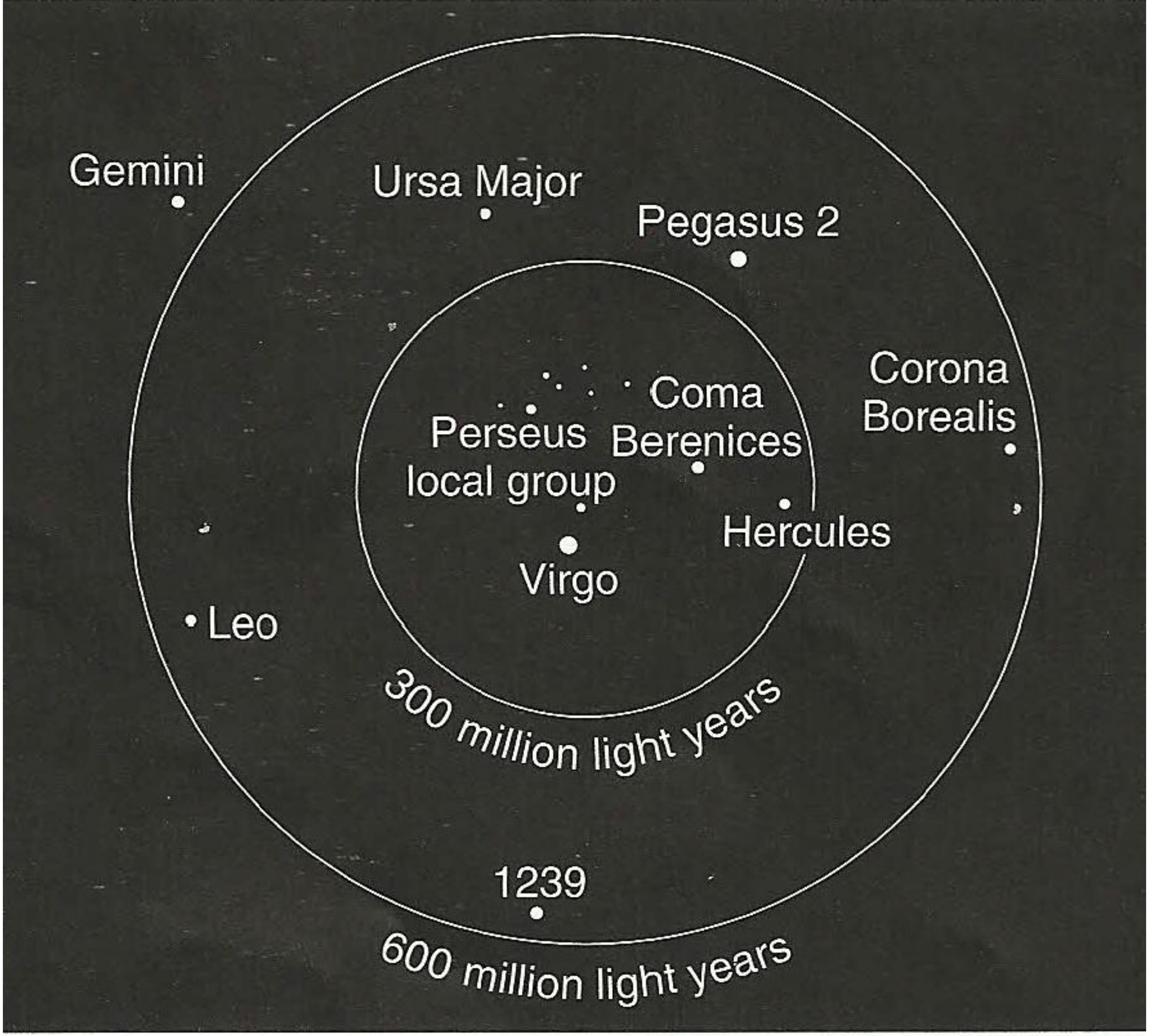


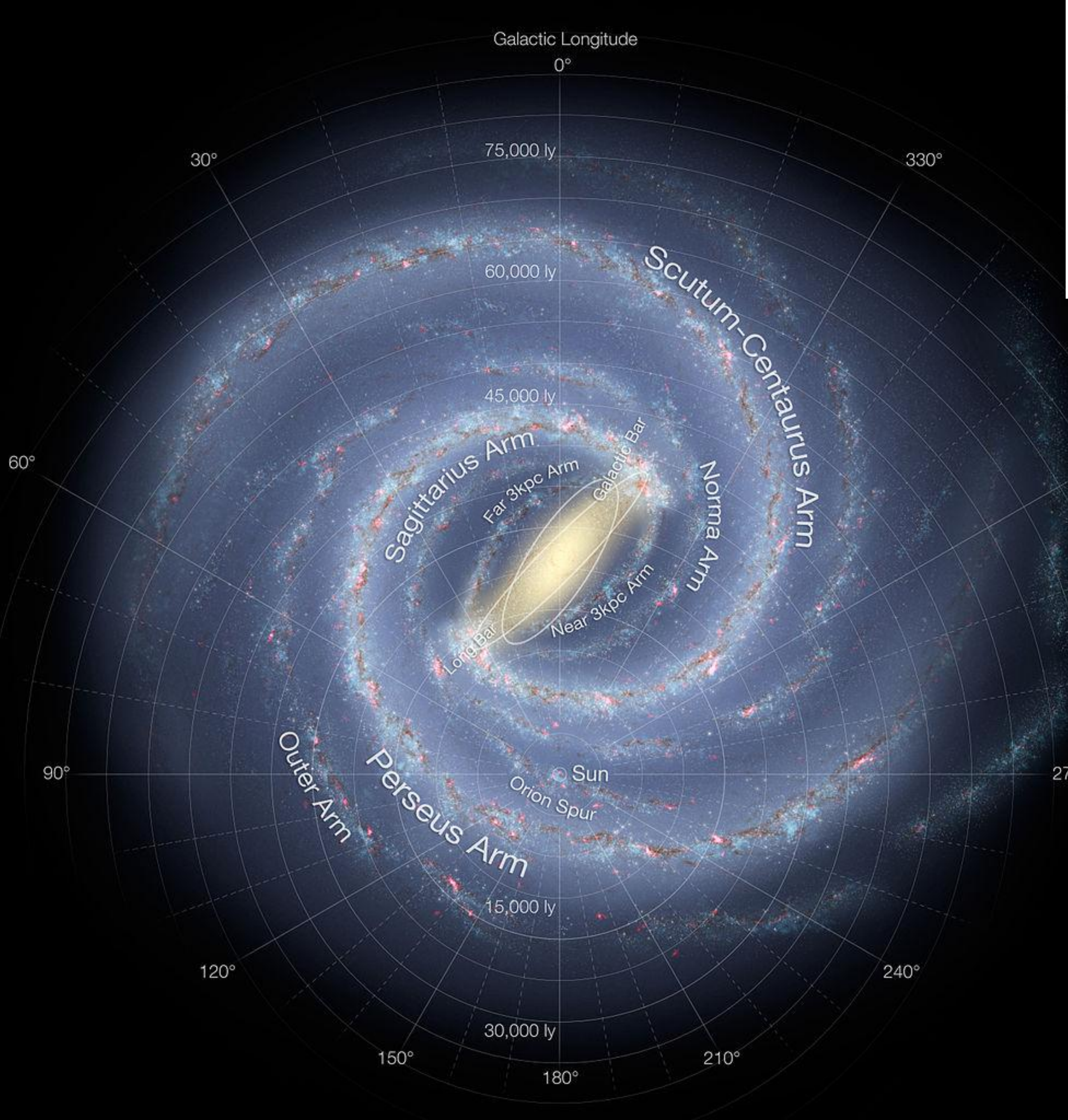


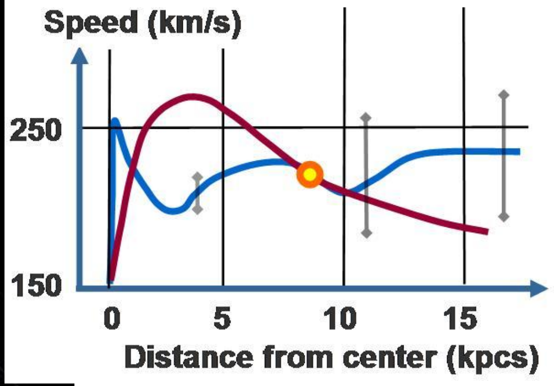
Centre is a bright radio source (Sagittarius A*, which is likely to be a supermassive black hole)

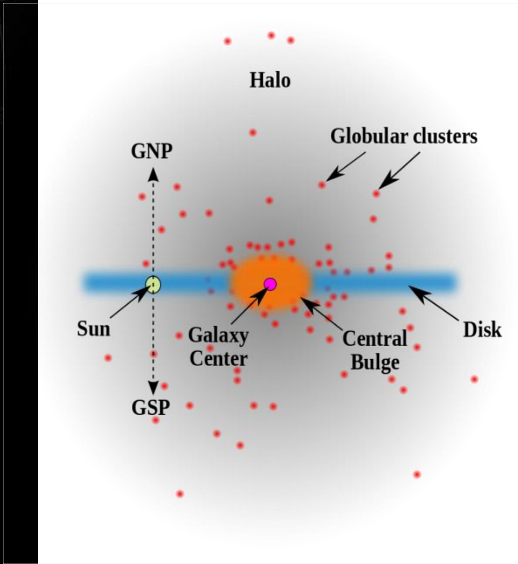
The Milky Way

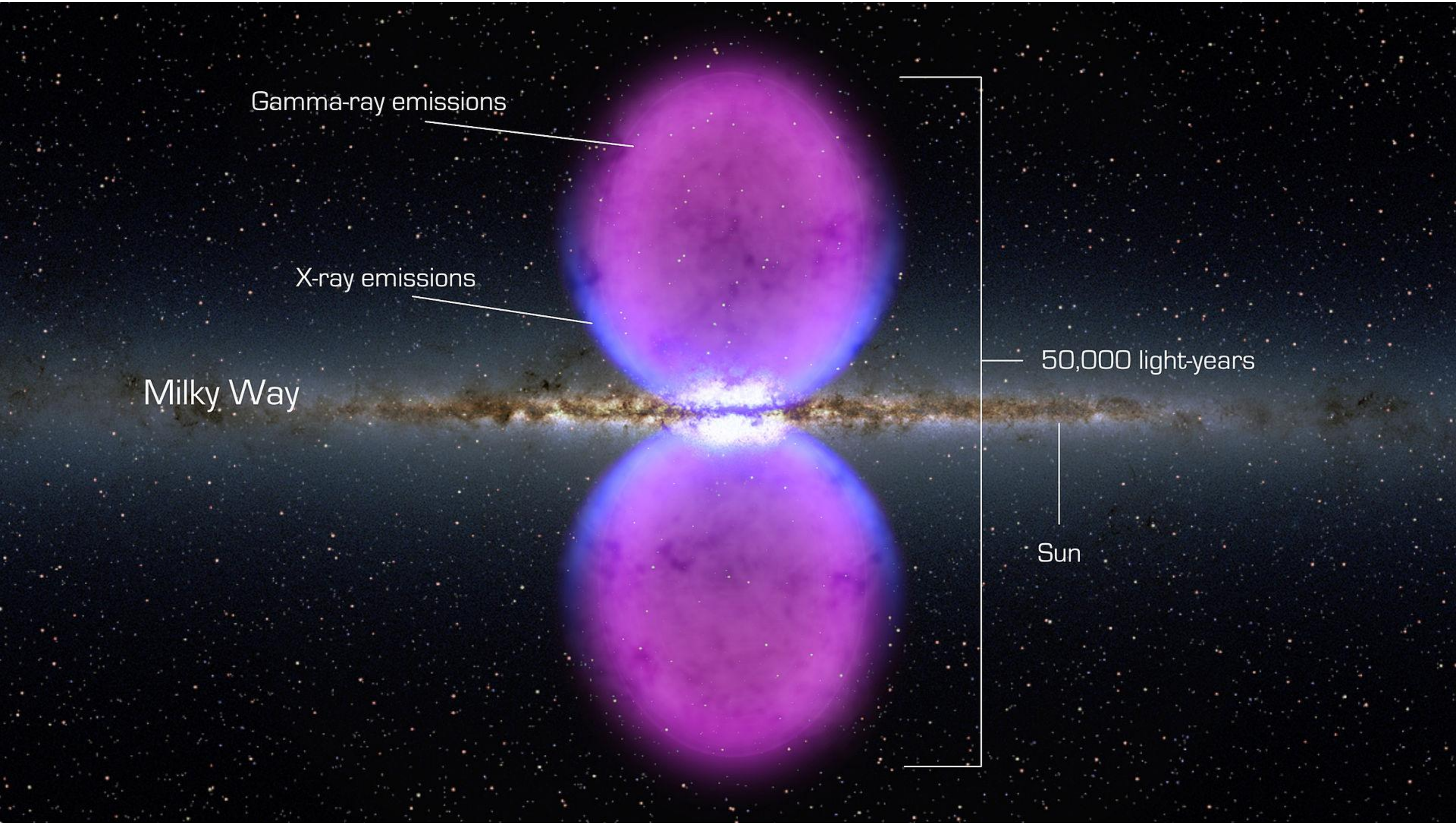
200-400 billion stars. Its mass is between 0.8 and 1.5 x 10^{12} solar masses.
100,000-120,000 light years diameter
Rotation period about 300 million light years


Gemini
Ursa Major
Pegasus 2
Corona Borealis
Coma Berenices
Perseus local group
Hercules
Virgo
Leo
300 million light years
1239
600 million light years


Galactic Longitude
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
180°
75,000 ly
60,000 ly
45,000 ly
15,000 ly
30,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
Sun
Orion Spur
Outer Arm
Perseus Arm

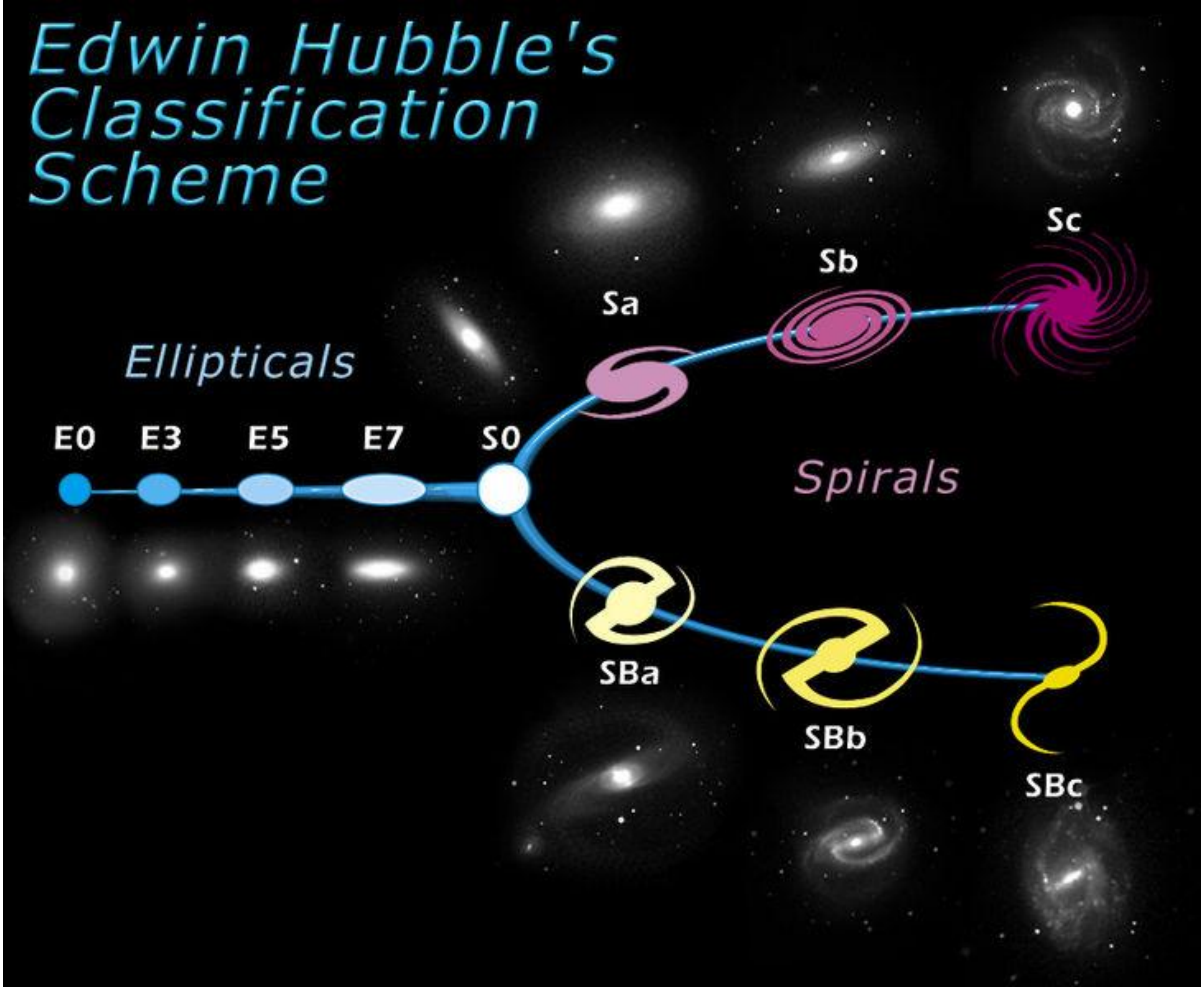

Speed (km/s)
250
150
0
5
10
15
Distance from center (kpcs)


Halo
Globular clusters
GNP
GSP
Sun
Galaxy Center
Central Bulge
Disk


Gamma-ray emissions
X-ray emissions
Milky Way
50,000 light-years
Sun

Andromeda Galaxy — NASA, Hubble Telescope

Edwin Hubble's Classification Scheme

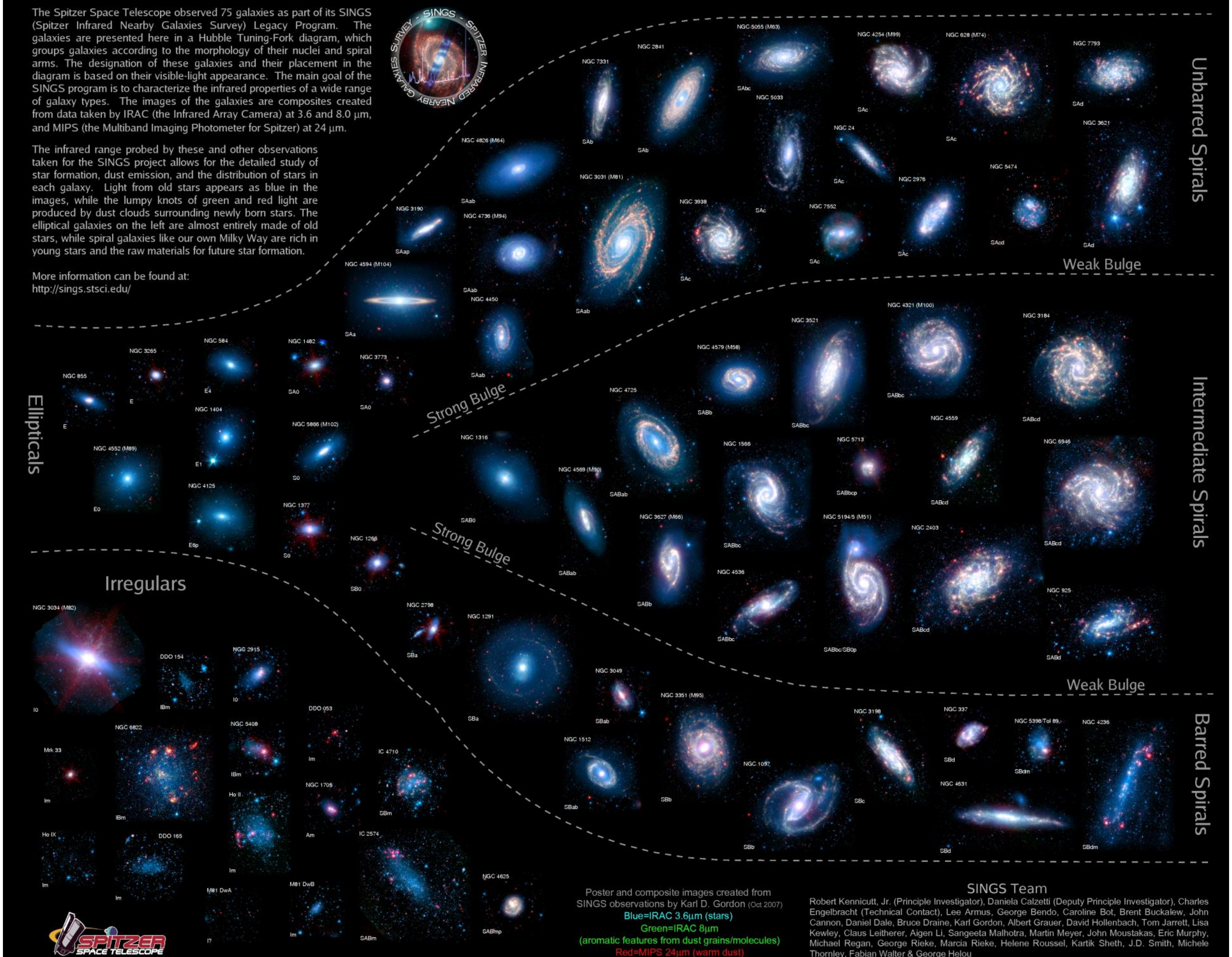


The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 µm, and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 µm.

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:
http://sings.stsci.edu/

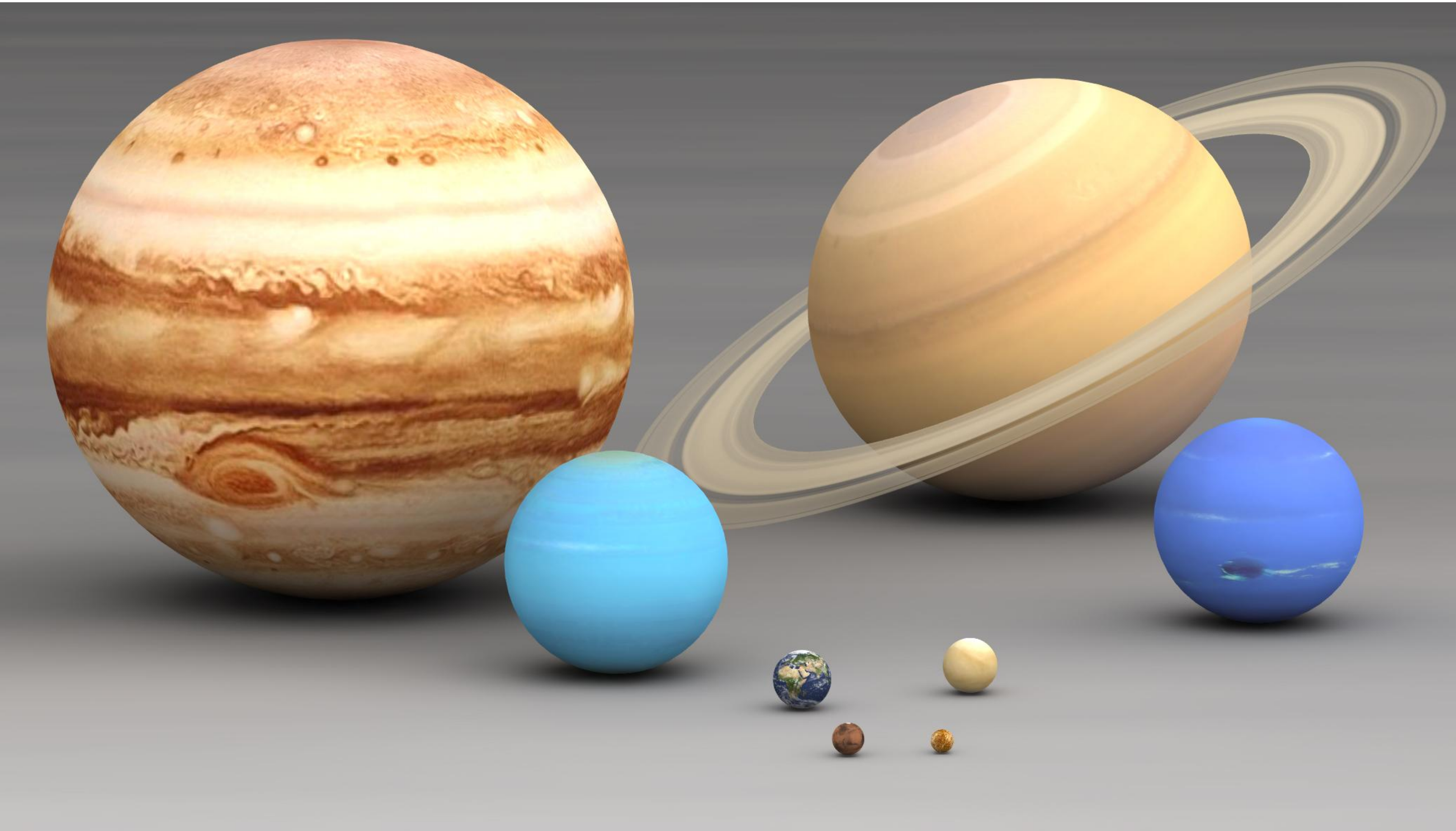


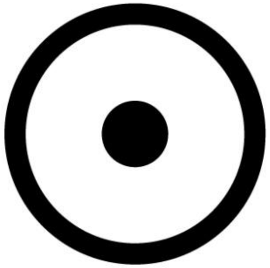
Poster and composite images created from SINGS observations by Karl D. Gordon (Oct 2007)
Blue=IRAC 3.6µm (stars)
Green=IRAC 8µm
(aromatic features from dust grains/molecules)
Red=MIPS 24µm (warm dust)

SINGS Team

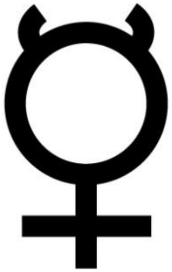
Robert Kennicutt, Jr. (Principle Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kartik Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Helou

The Solar System

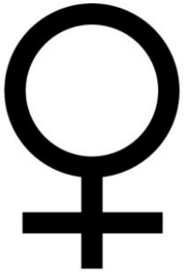




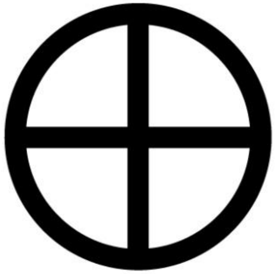
Sun



Mercury

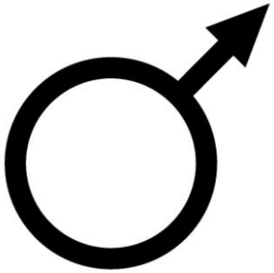


Venus



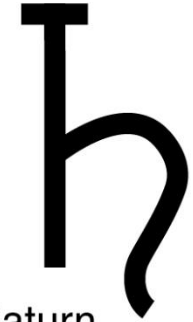
Earth

Moon

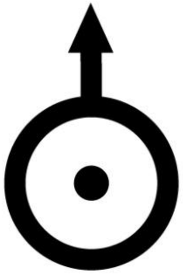


Mars

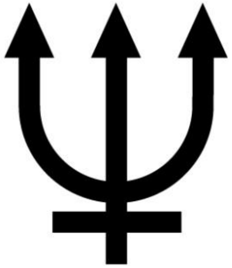
Jupiter



Saturn

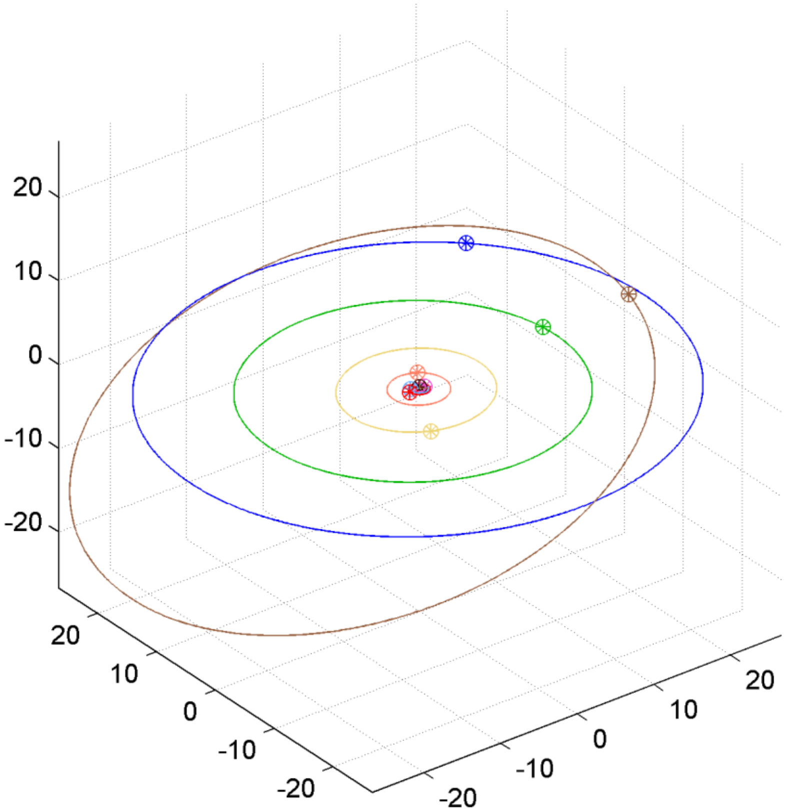


Uranus



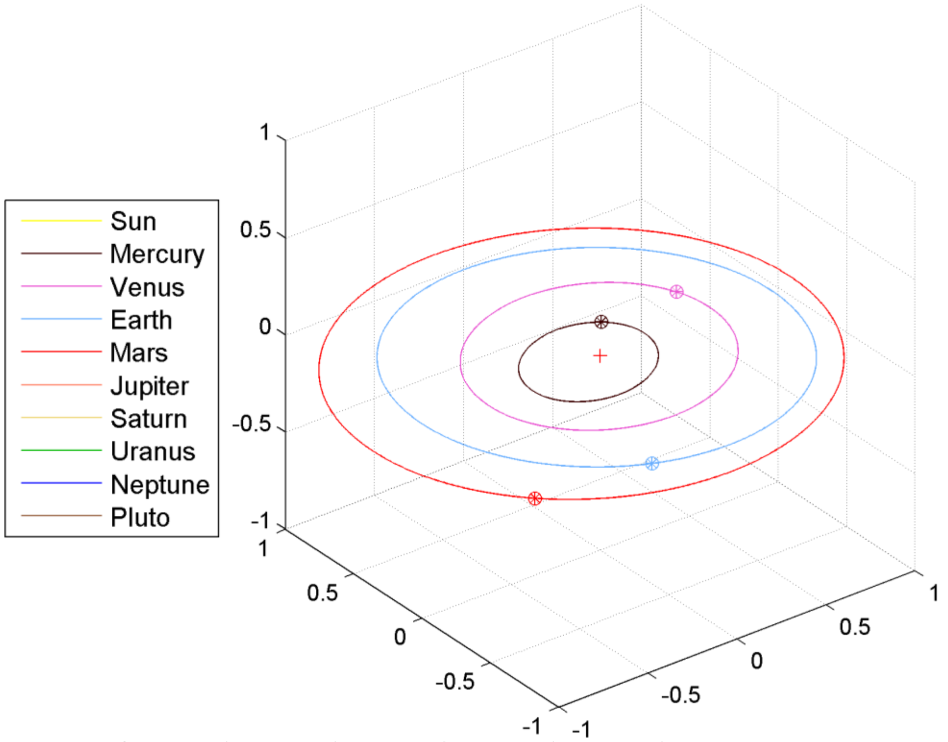
Neptune

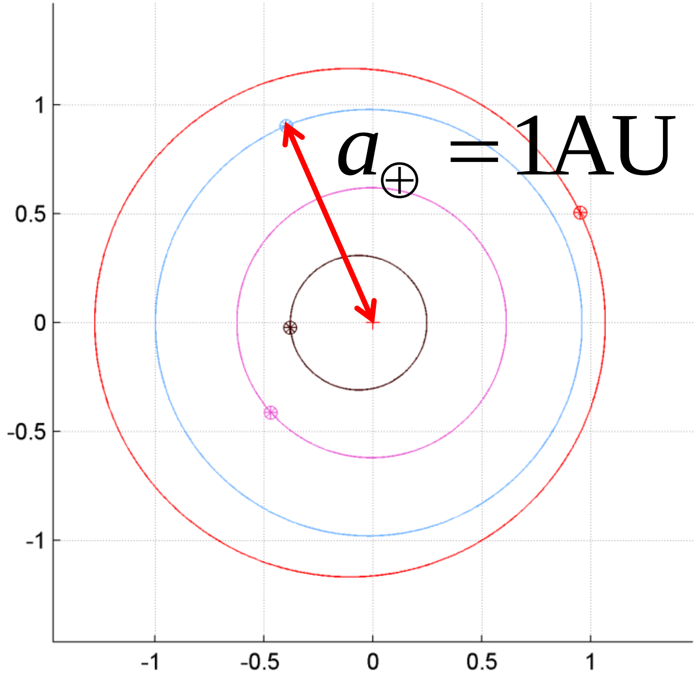
Pluto



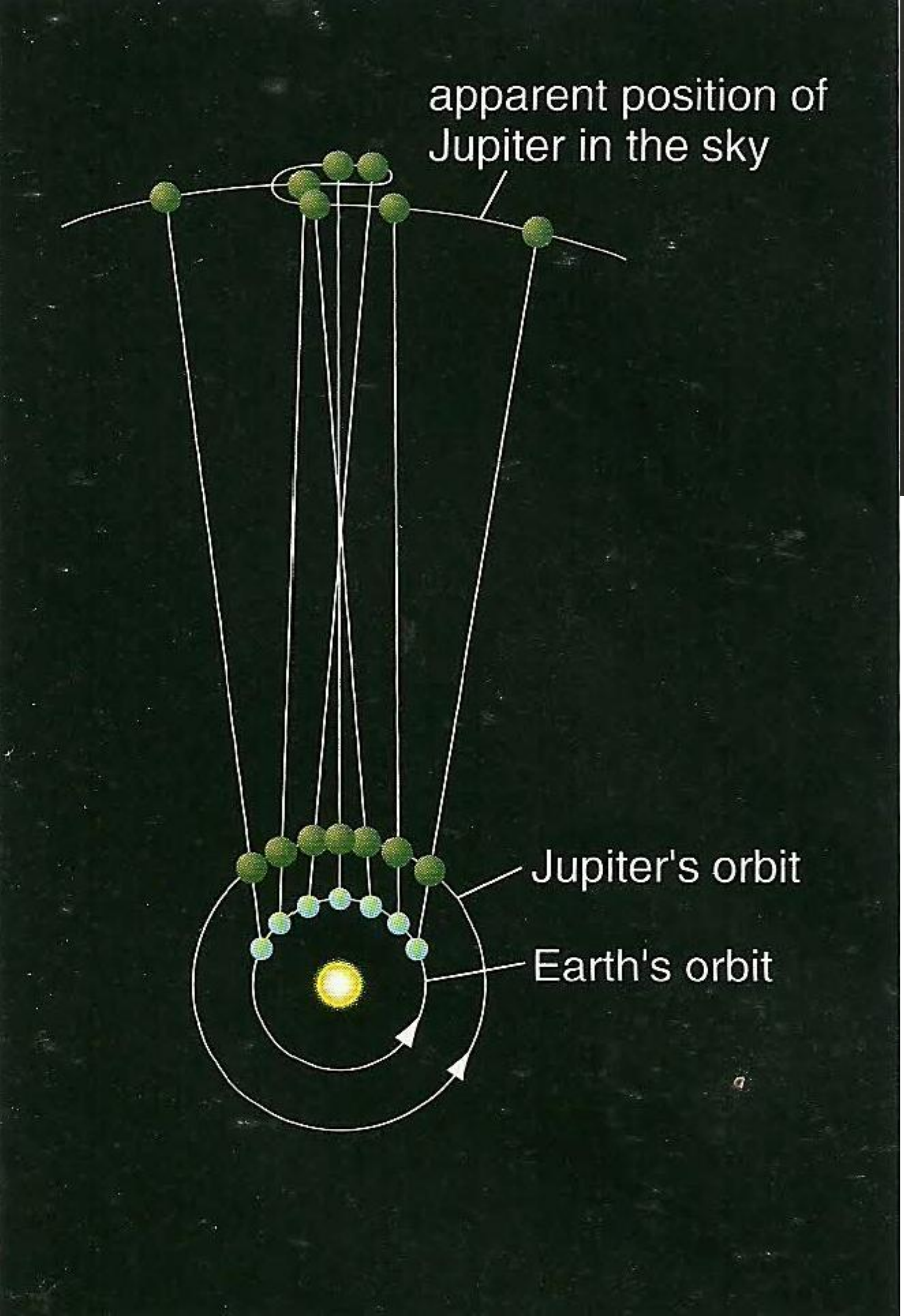
Scale in astronomical units AU

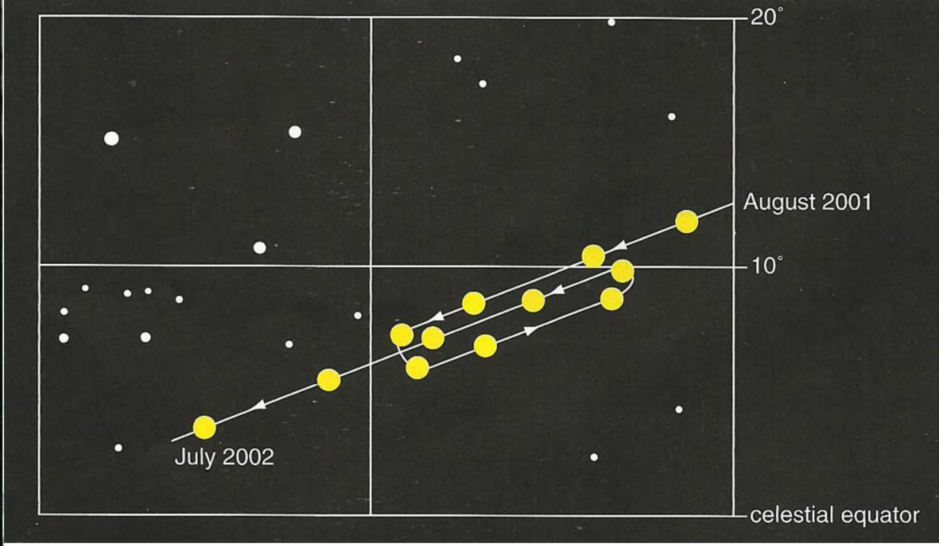
$$\boxed{1\mathrm{AU} = 1.496 \times 10^{11}\,\mathrm{m}}$$





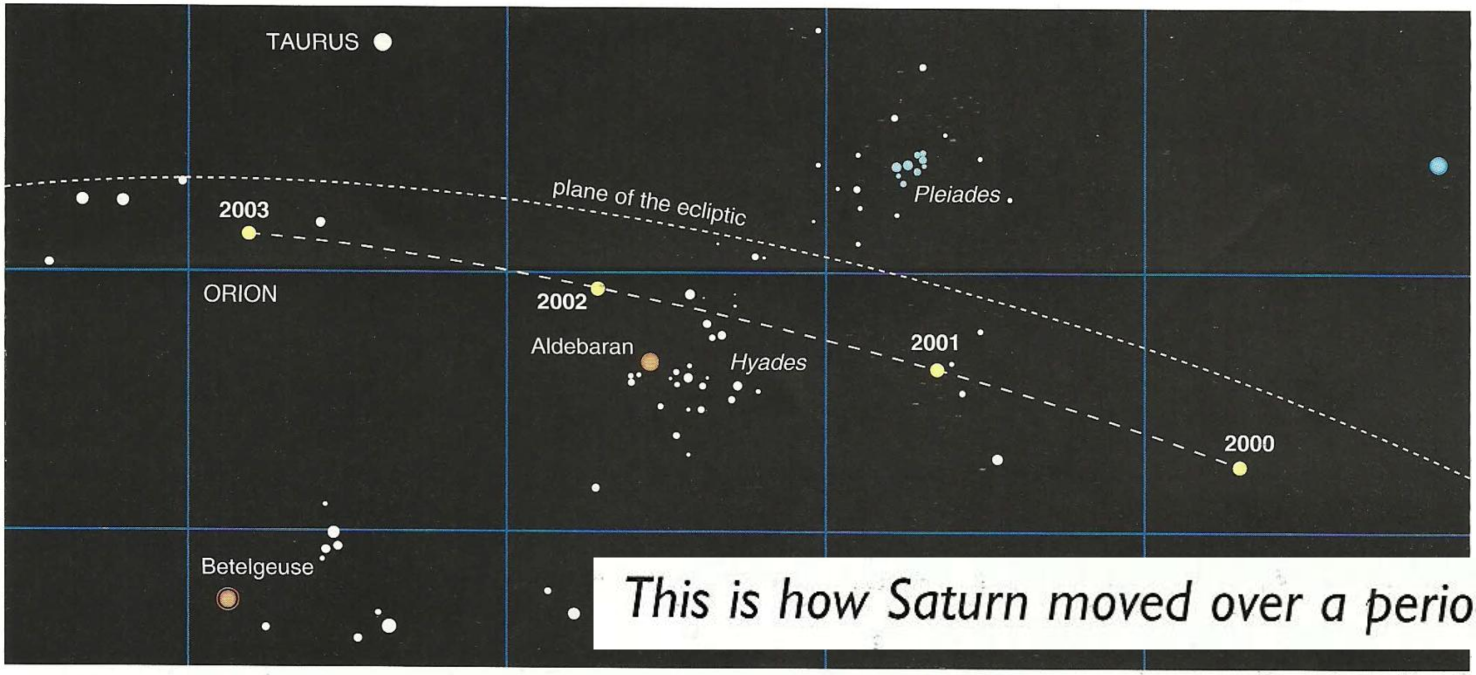
$$a_{\oplus} = 1\mathrm{AU}$$



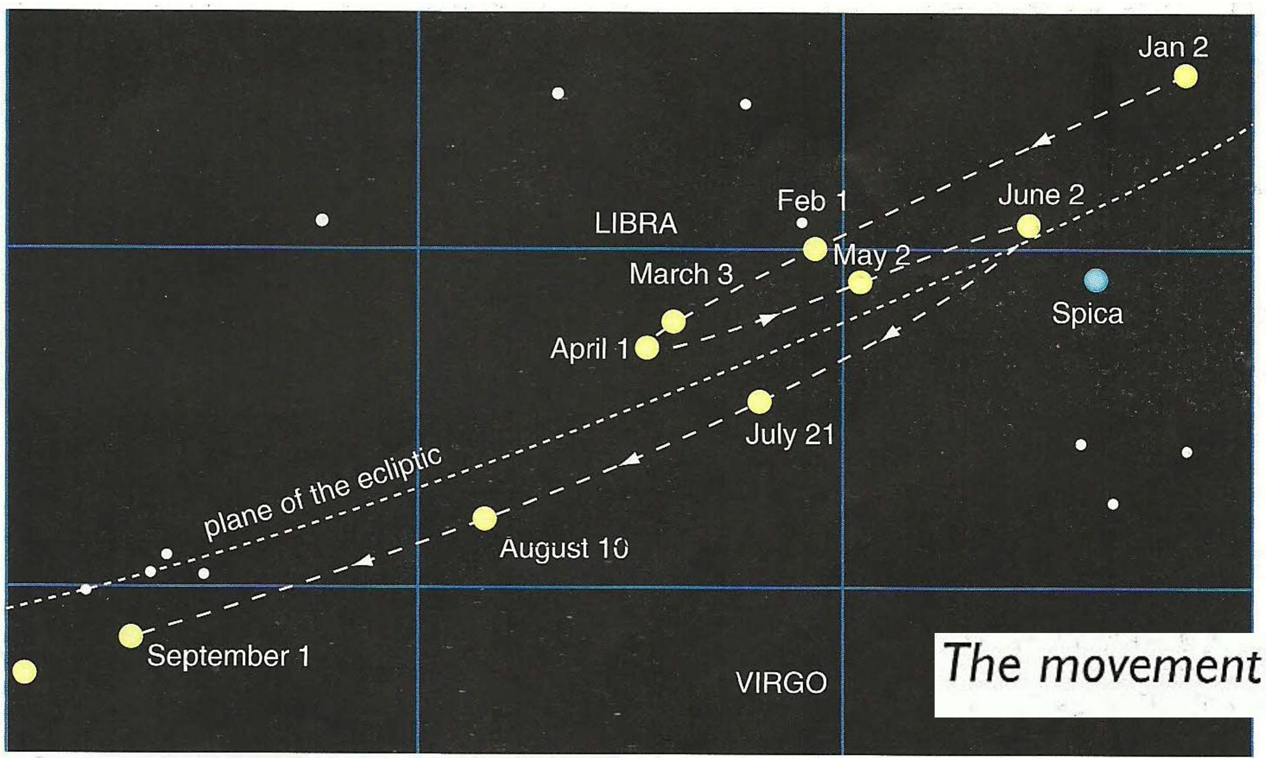


Since the Earth is also orbiting the Sun the positions of the planets as observed from Earth appear to make complex motions across the sky as viewed over any nights.

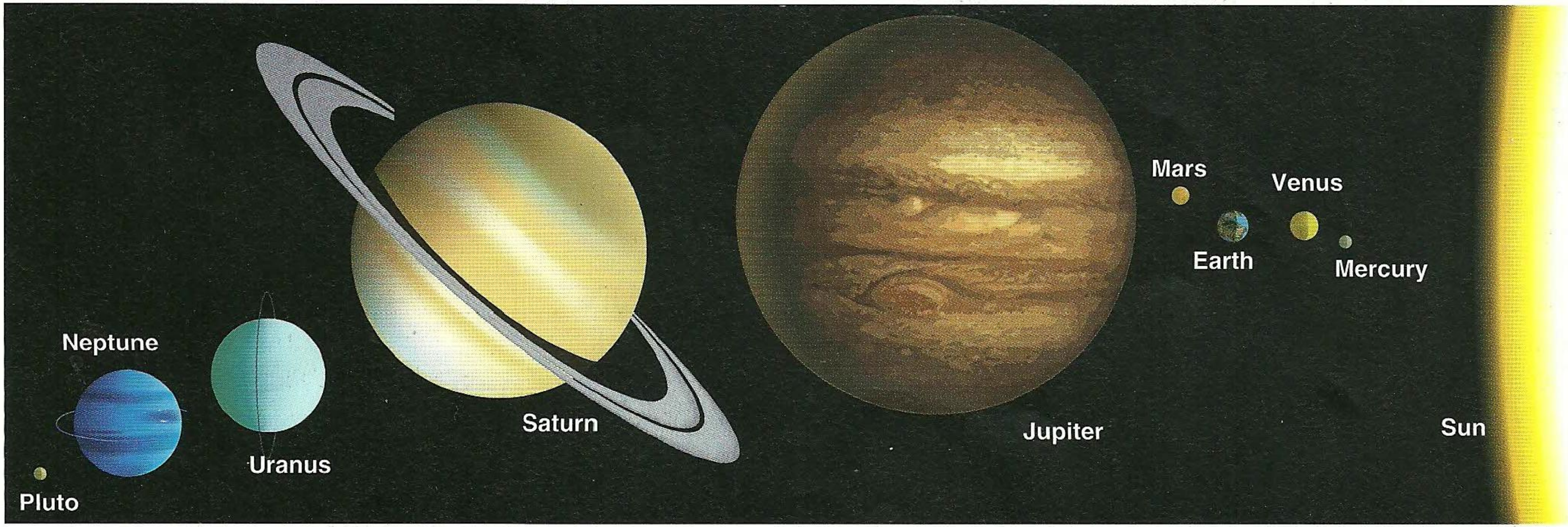
This is why a heliocentric model is *much easier to understand* than one based upon a fixed Earth (geocentric)



This is how Saturn moved over a period of 4 years



The movement of Mars during 1999



Planet	***Diameter of planet***	***Average distance of planet from the Sun***	***Time taken to go round the Sun***	***Number of moons***	***Average temperature on sunny side***
Mercury	4900 km	58 million km	88 days	0	350°C
Venus	12 000 km	108 million km	225 days	0	480°C
Earth	12 800 km	150 million km	365¼ days	1	20°C
Mars	6800 km	228 million km	687 days	2	0°C
Jupiter	143 000 km	780 million km	12 years	14	−150°C
Saturn	120 000 km	1430 million km	29 years	24	−190°C
Uranus	52 000 km	2800 million km	84 years	15	−220°C
Neptune	49 000 km	4500 million km	165 years	3	−240°C
Pluto	3000 km	5900 million km	248 years	1	−240°C

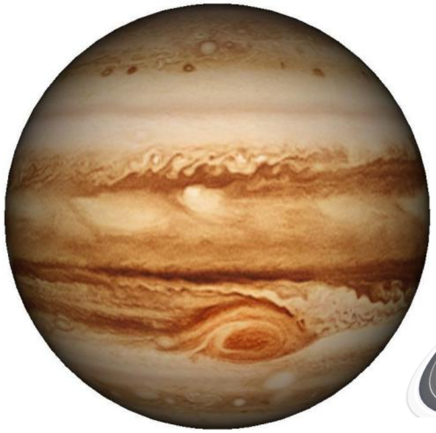
Object	$M/M_\oplus$	a /AU	$R/R_\oplus$	T_{rot} / days	P /Yr
Sun	332,837	-	109.123	-	-
Mercury	0.055	0.387	0.383	58.646	0.241
Venus†	0.815	0.723	0.949	243.018	0.615
Earth	1.000	1.000	1.000	0.997	1.000
Mars	0.107	1.523	0.533	1.026	1.881
Jupiter	317.85	5.202	11.209	0.413	11.861
Saturn	95.159	9.576	9.449	0.444	29.628
Uranus†	14.500	19.293	4.007	0.718	84.747
Neptune	17.204	30.246	3.883	0.671	166.344
Pluto†	0.003	39.509	0.187	6.387	248.348

Venus, Uranus and Pluto rotate clockwise about their internal axis
All other planets rotate anti-clockwise

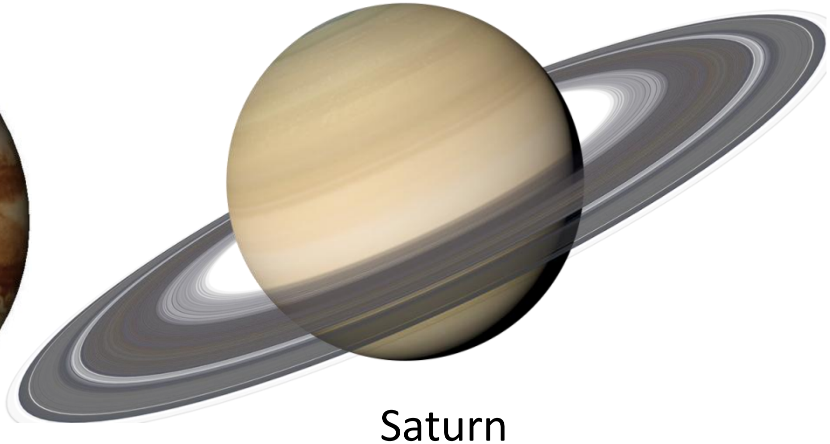
Earth parameters

$$M_\oplus = 5.972 \times 10^{24}\,\mathrm{kg}$$

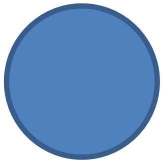
$$R_\oplus = 6.371 \times 10^{6}\,\mathrm{m}$$



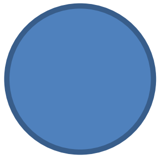
Jupiter



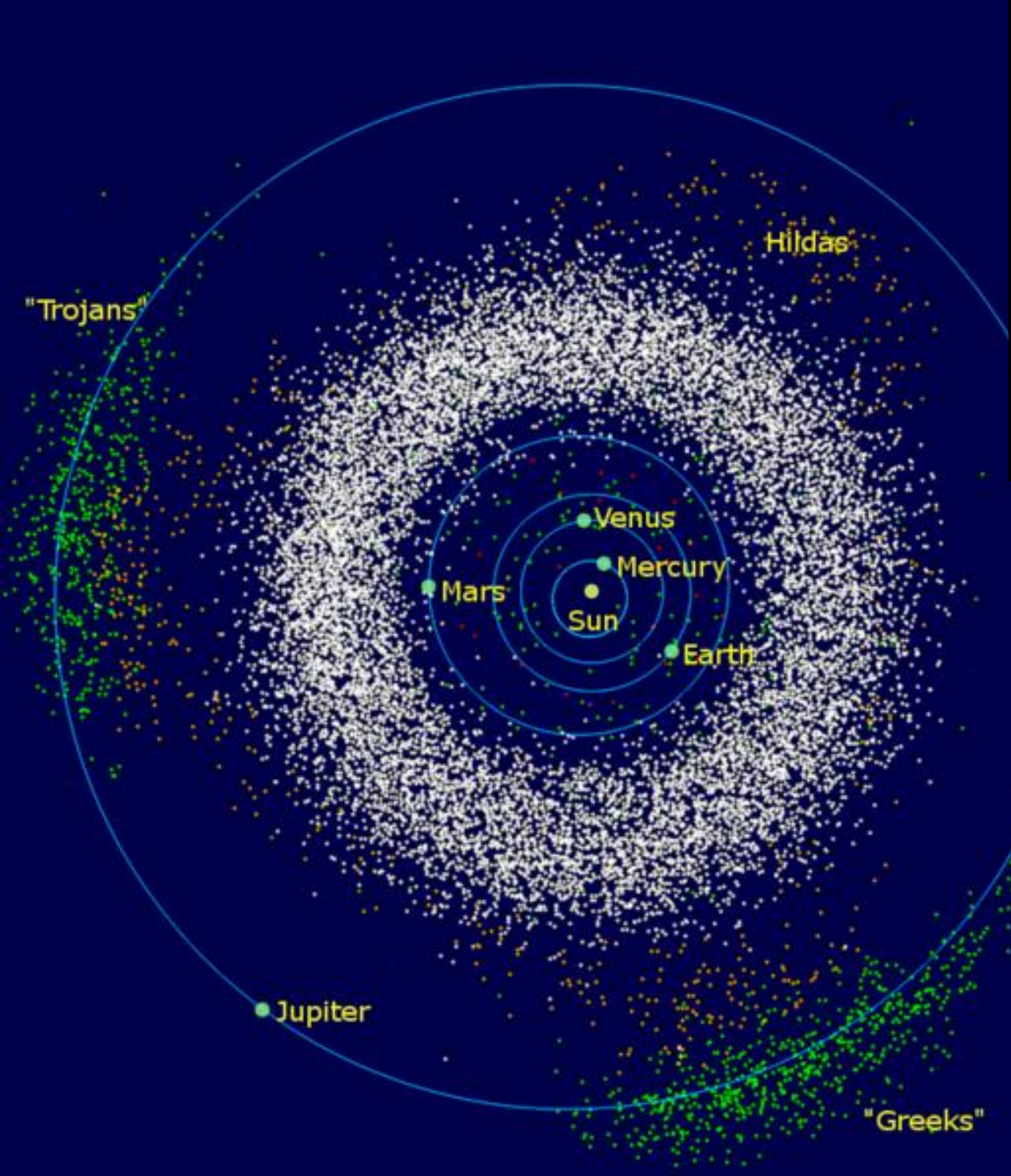
Saturn

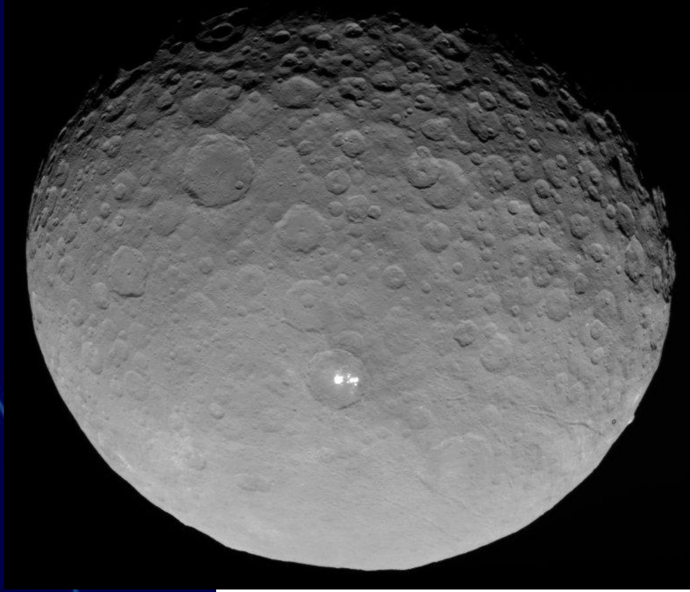


Uranus



Neptune

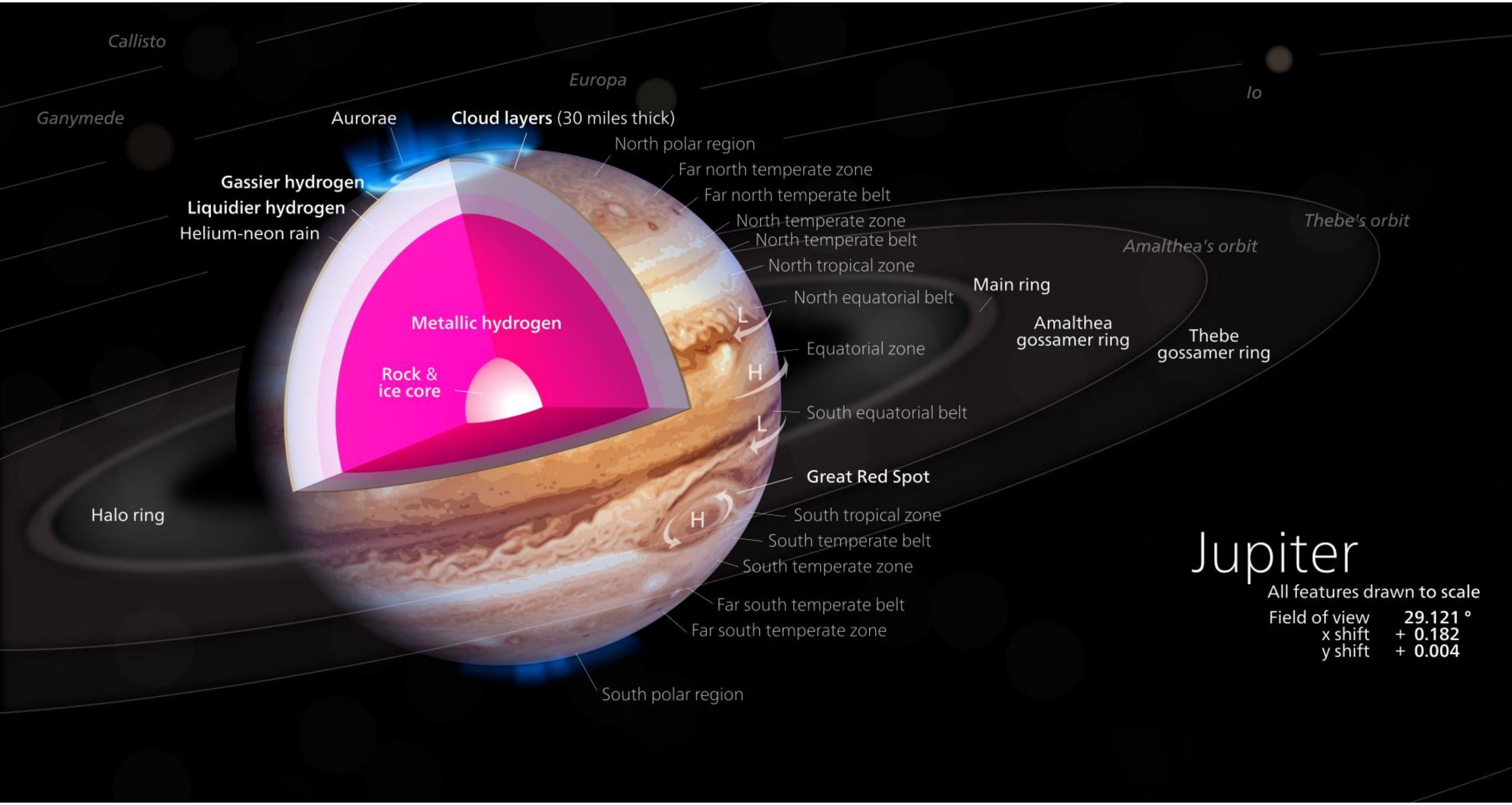


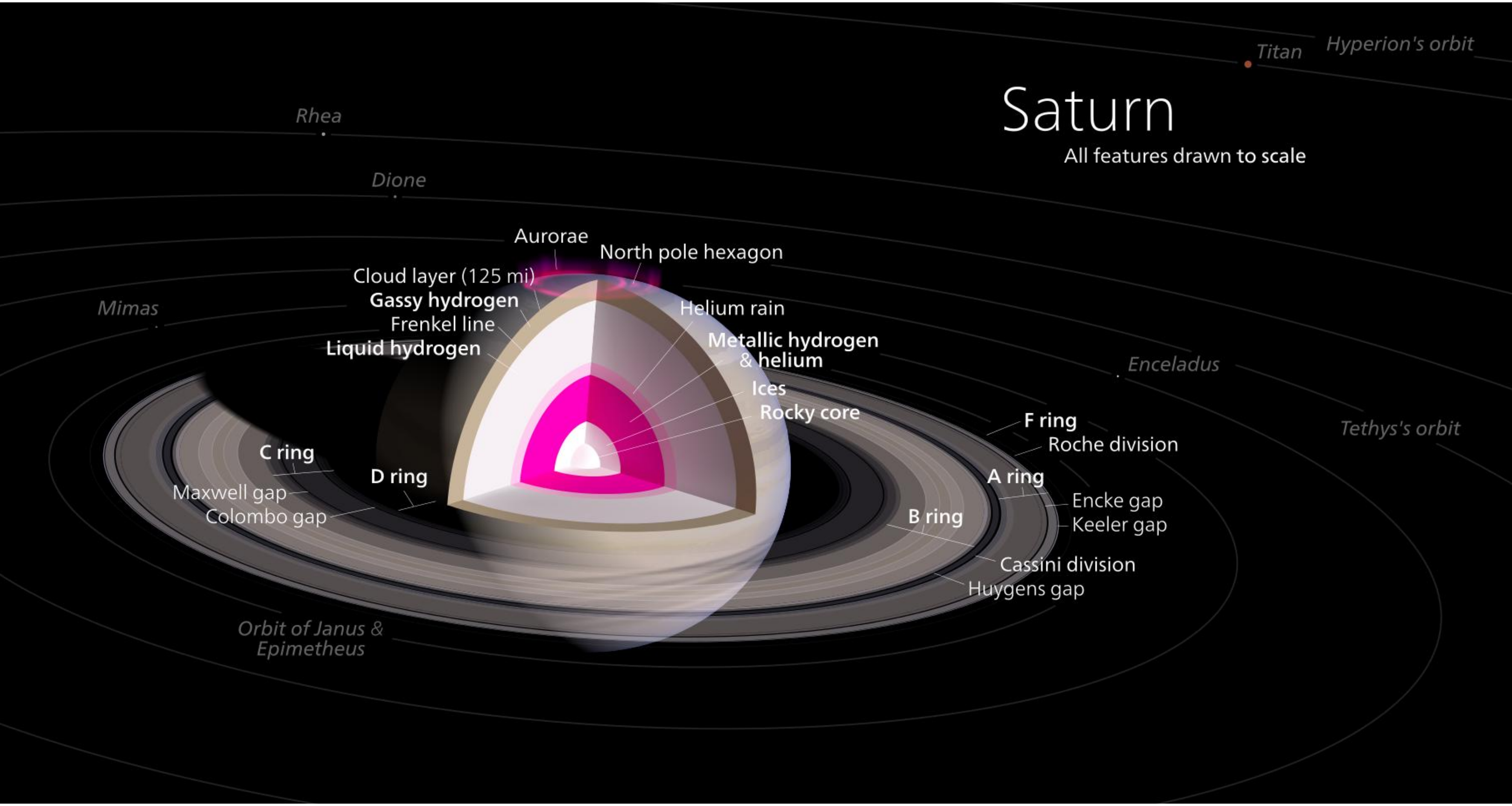


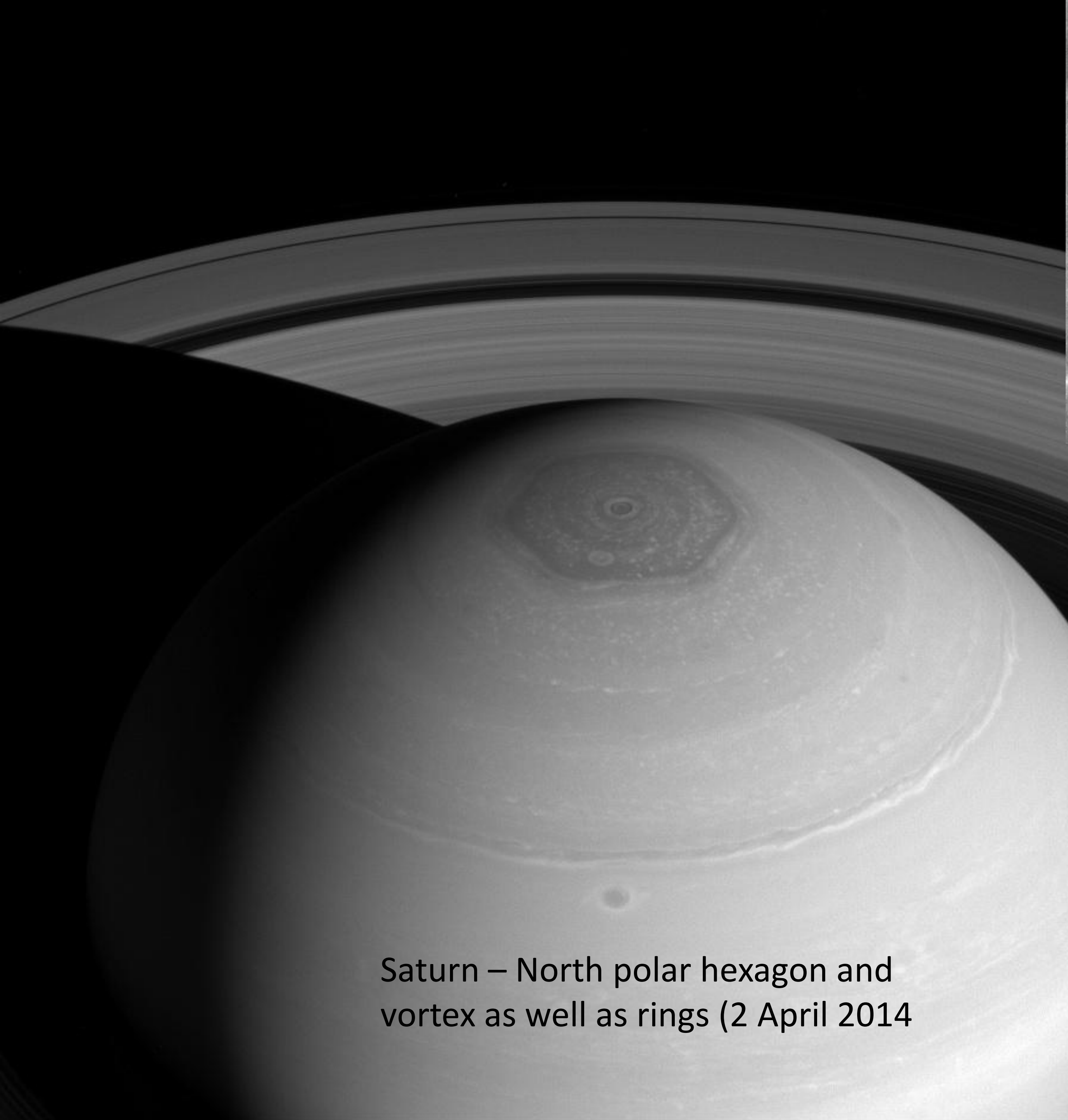
Dwarf planet
Ceres within the
Asteroid belt

Radius
476 km

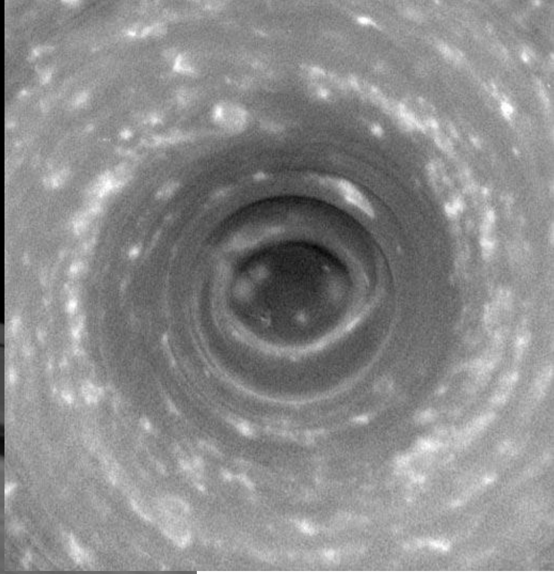
Mass
0.00015 Earths
(9.43×10^{20} kg)


Callisto
Europa
Io
Ganymede
Aurorae
Cloud layers (30 miles thick)
North polar region
Far north temperate zone
Far north temperate belt
Gassier hydrogen
Liquidier hydrogen
Helium-neon rain
North temperate zone
North temperate belt
North tropical zone
Thebe's orbit
Amalthea's orbit
Main ring
North equatorial belt
Metallic hydrogen
Amalthea
gossamer ring
Thebe
gossamer ring
Equatorial zone
Rock &
ice core
L
H
L
H
South equatorial belt
Great Red Spot
Halo ring
South tropical zone
South temperate belt
South temperate zone
Far south temperate belt
Far south temperate zone
South polar region
Jupiter
All features drawn to scale
Field of view 29.121 °
x shift + 0.182
y shift + 0.004


Saturn
All features drawn to scale
Titan
Hyperion's orbit
Rhea
Dione
Aurorae
North pole hexagon
Cloud layer (125 mi)
Gassy hydrogen
Mimas
Frenkel line
Liquid hydrogen
Helium rain
Metallic hydrogen & helium
Ices
Rocky core
Enceladus
Tethys's orbit
F ring
Roche division
C ring
D ring
A ring
Maxwell gap
Colombo gap
Encke gap
Keeler gap
B ring
Cassini division
Huygens gap
Orbit of Janus & Epimetheus

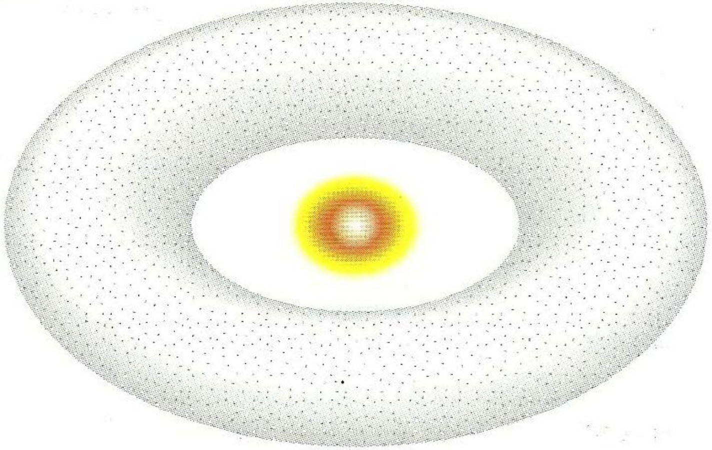


Saturn – North polar hexagon and vortex as well as rings (2 April 2014

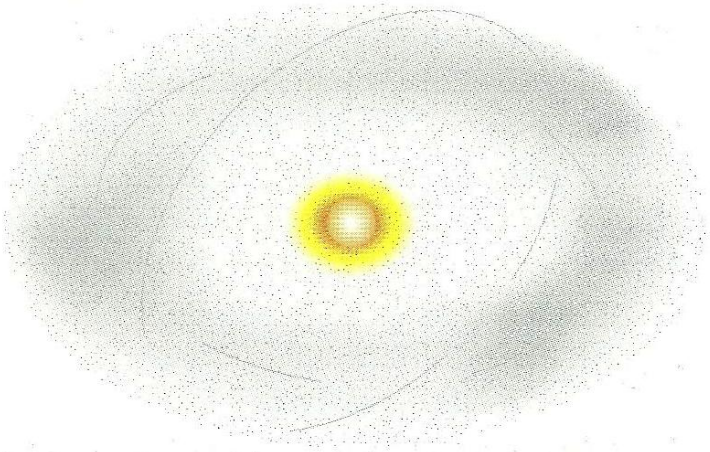


South Pole Saturnian ‘hurricane’

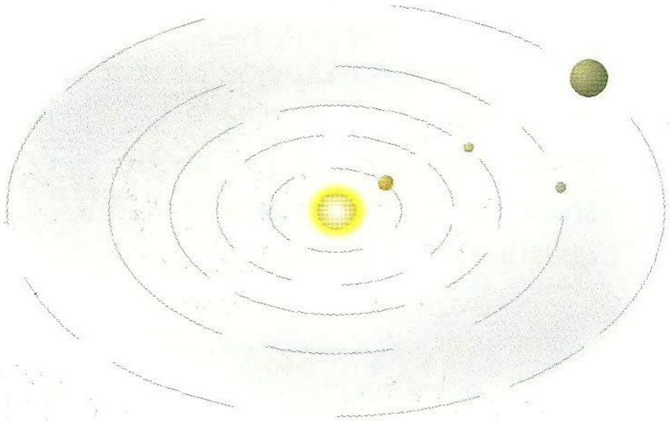
Formation of the solar system



1 4500 million years ago a shock wave, in a spiral arm of our galaxy, triggered the collapse of a gas cloud. This developed into a doughnut shape, which flattened out



2 Enough hydrogen gathered in the centre for fusion to start in the Sun. Solid particles began to strike each other and stick together

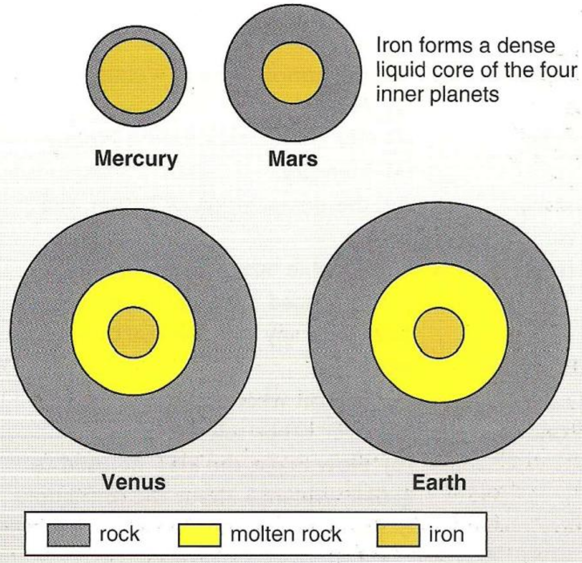


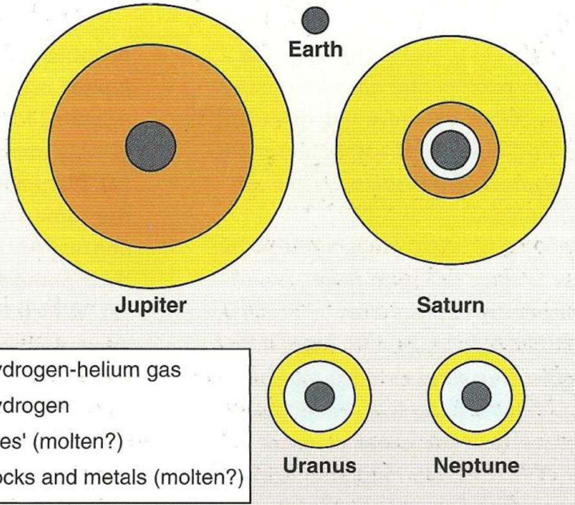
3 Eventually, as the small particles continued to coalesce, just a few large planets and moons were left. Most of the gas and dust in the solar system became attached to a planet, or was removed by a strong solar wind. After millions of years, the gravitational attraction between the planets tended to pull their orbits into the same plane.

Planet	*Mass relative to Earth*	*Radius (Earth = 1)*	*Relative density (water = 1)*	*Distance from Sun in AU†*	*% Rocks*	*% Ice*	*% Gas*	*Main gases in atmosphere*
Mercury	0.06	0.38	5.4	0.39	nearly all	–	–	none
Venus	0.82	0.95	5.2	0.72	nearly all	–	some in atmosphere	CO_2
Earth	1	1	5.5	1	nearly all	water in oceans, ice at poles	some in atmosphere	N_2, O_2
Mars	0.11	0.53	3.9	1.5	nearly all	ice at poles	some in atmosphere	CO_2
Jupiter	318	11.2	1.3	5.2		10% rock/ice	90%	H_2, He
Saturn	95	9.4	0.7	9.5		30% rock/ice	70%	H_2, He
Uranus	14.6	4.1	1.2	19.1		70% rock/ice	30%	H_2, He, CH_4
Neptune	17.2	3.9	1.7	30.1		70% rock/ice	30%	H_2, He, CH_4
Pluto	0.1?	0.4?	?	39.4		mostly rock/ice	?	none?

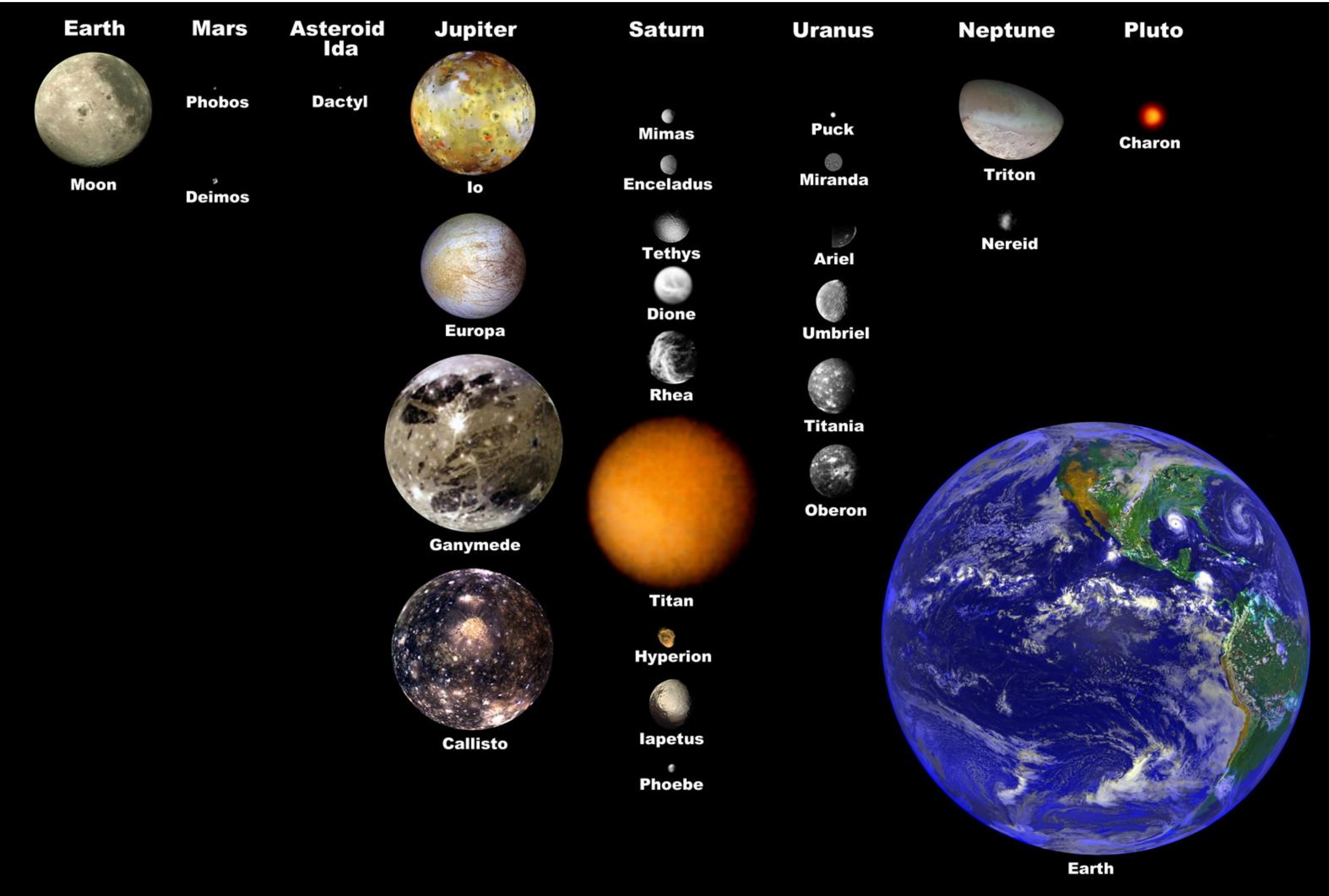
Table 1

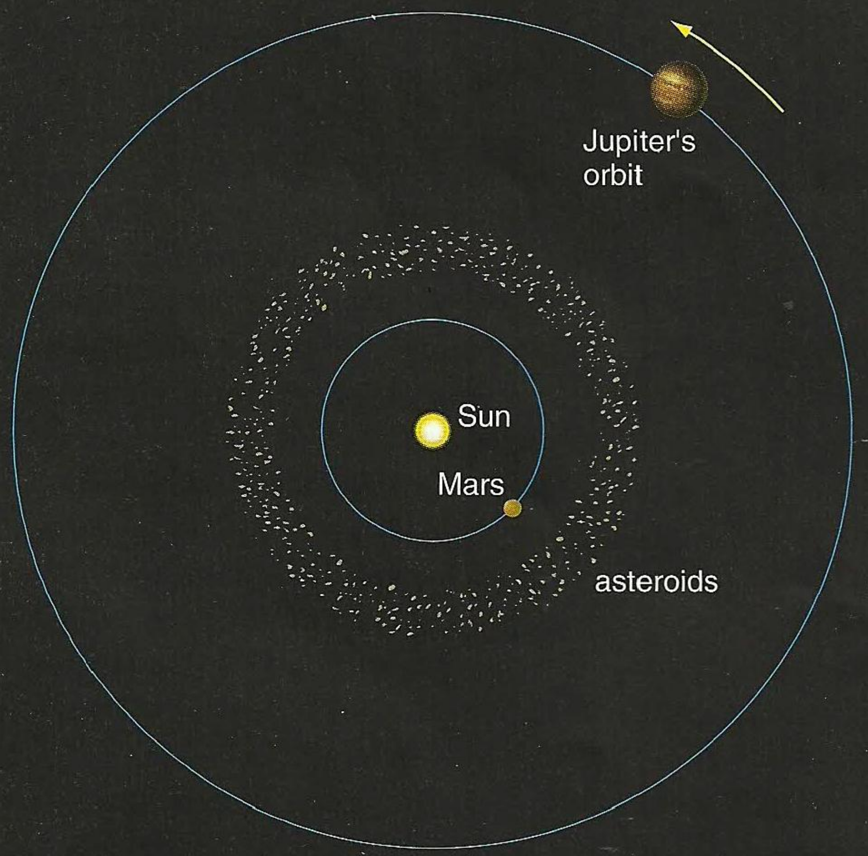
† 1 Astronomical Unit of AU is the average Earth–Sun distance.
O_2 oxygen, N_2 nitrogen, CH_4 methane, CO_2 carbon dioxide.

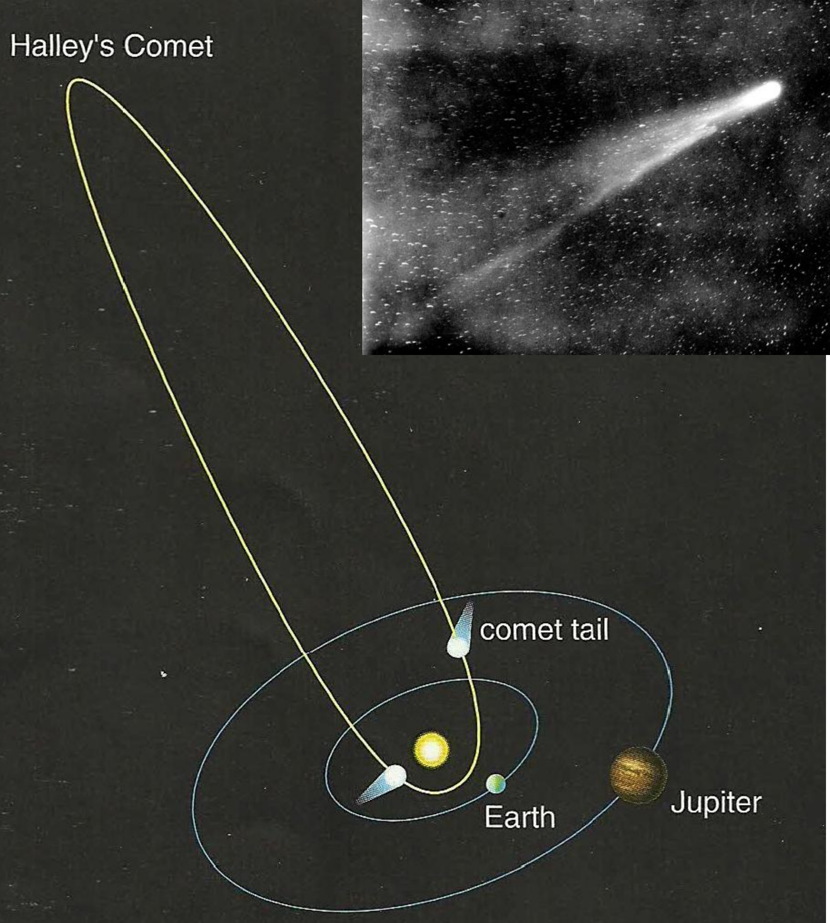


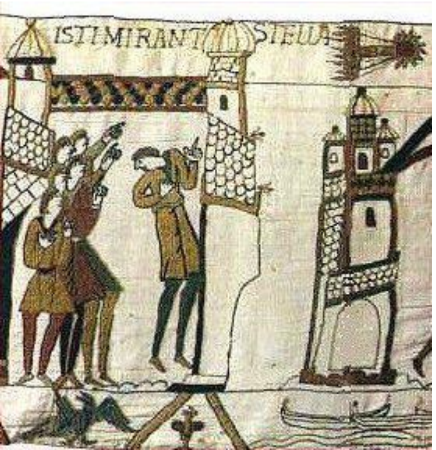


Moons


Earth
Mars
Asteroid Ida
Jupiter
Saturn
Uranus
Neptune
Pluto
Moon
Phobos
Deimos
Dactyl
Io
Europa
Ganymede
Callisto
Mimas
Enceladus
Tethys
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
Puck
Miranda
Ariel
Umbriel
Titania
Oberon
Triton
Nereid
Charon
Earth

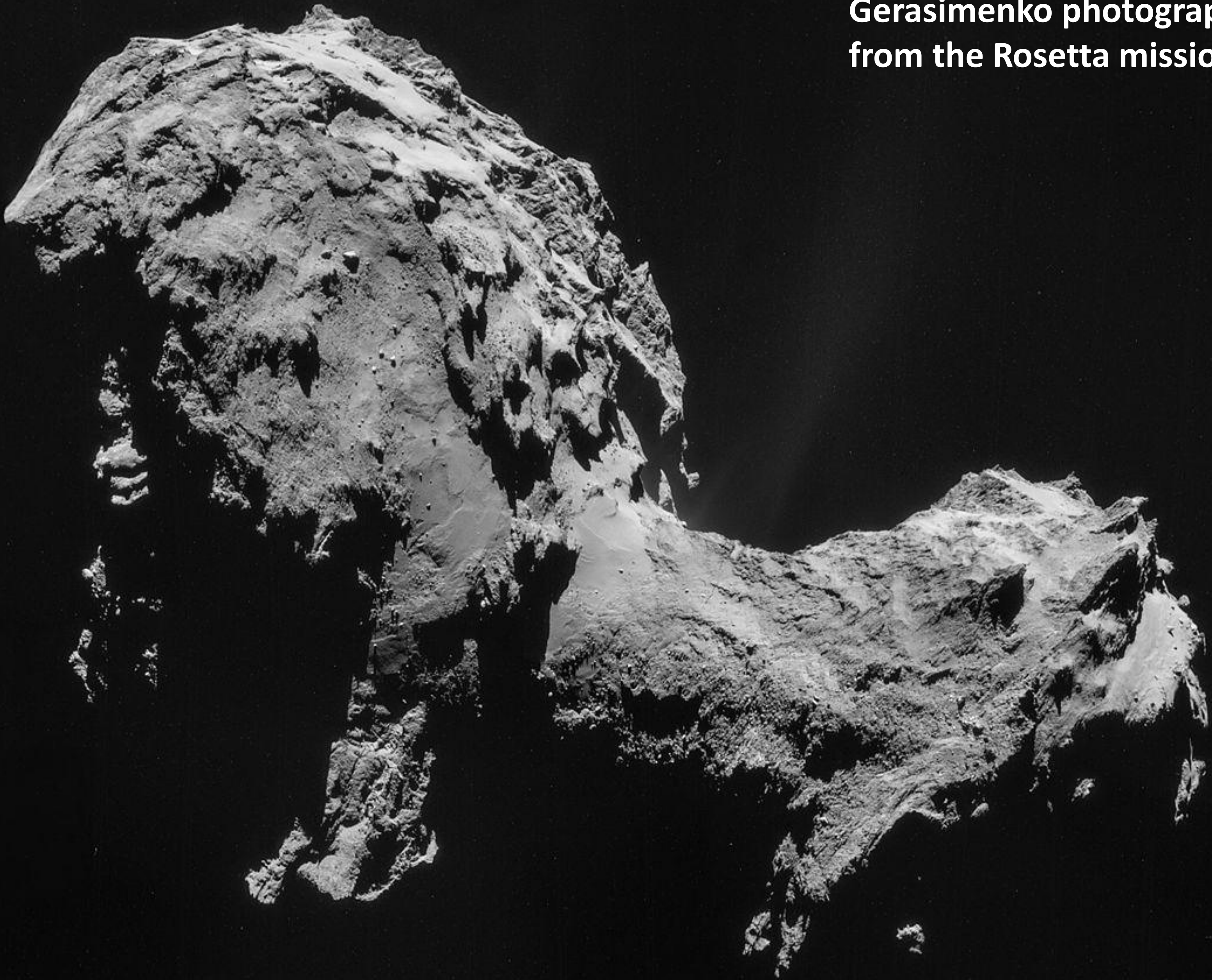




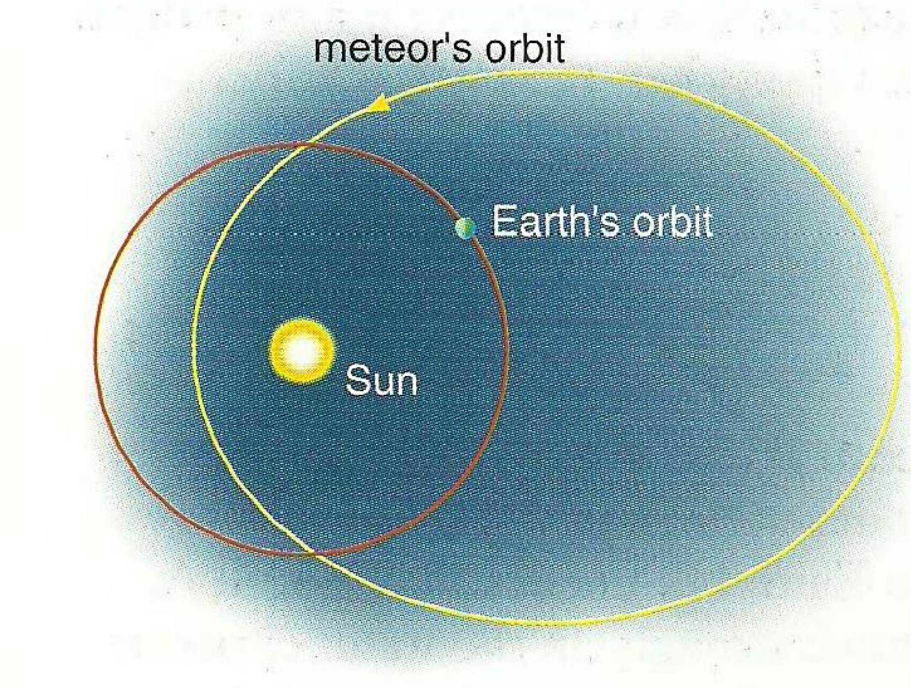


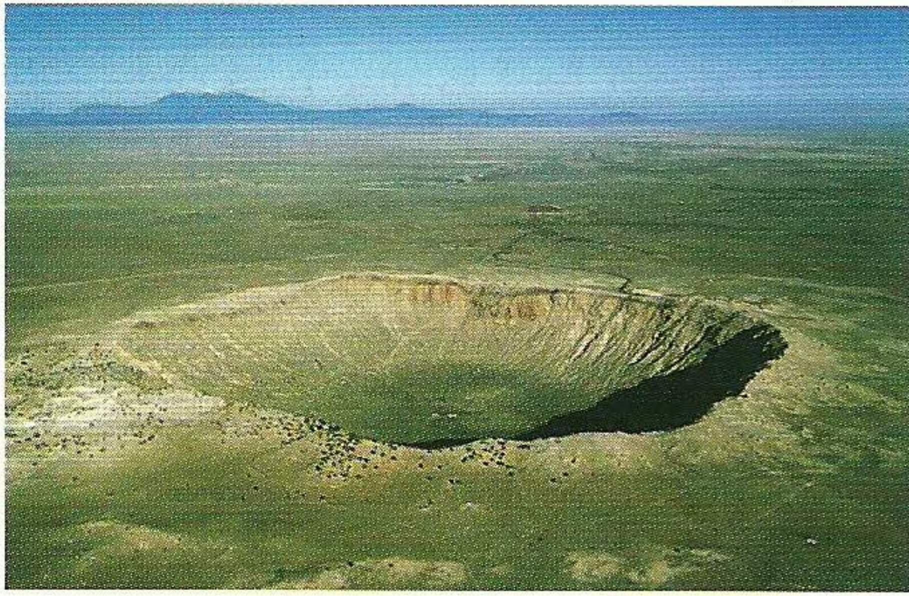

Hale Bop 1997


1577



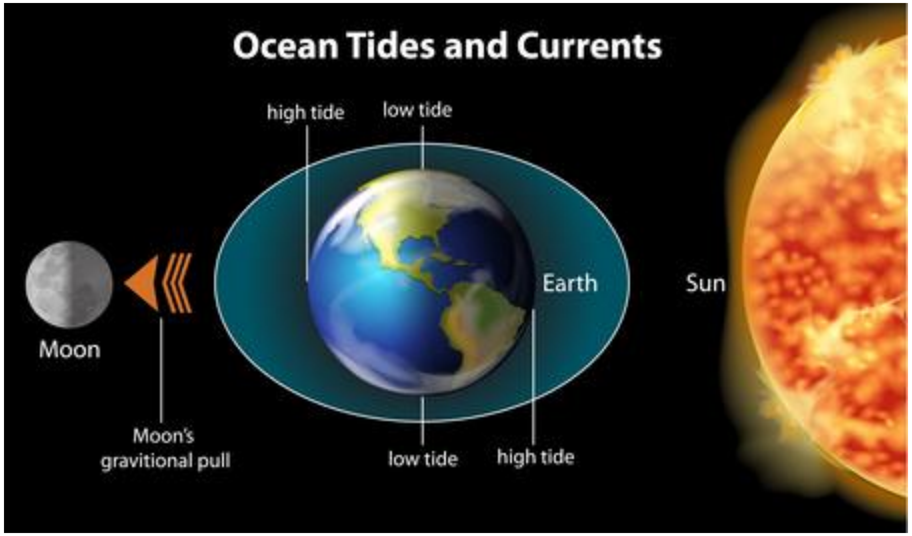
Comet 67P/Churyumov–Gerasimenko photographed from the Rosetta mission 2014

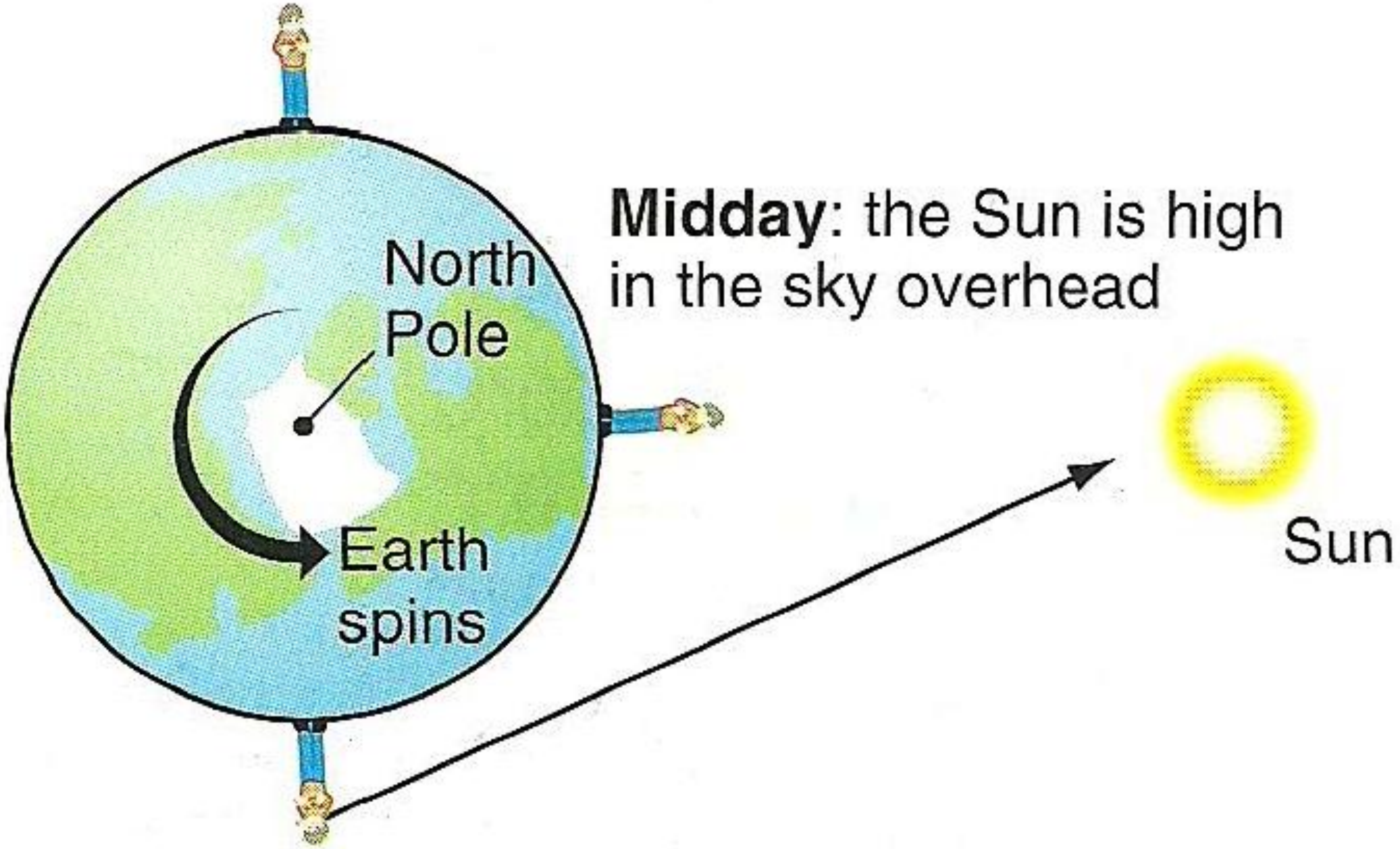




This crater in the Arizona desert is thought to have been formed by a meteor impact about 20 000 years ago. It is 200 m deep and 800 m wide.

Earth seasons & tides

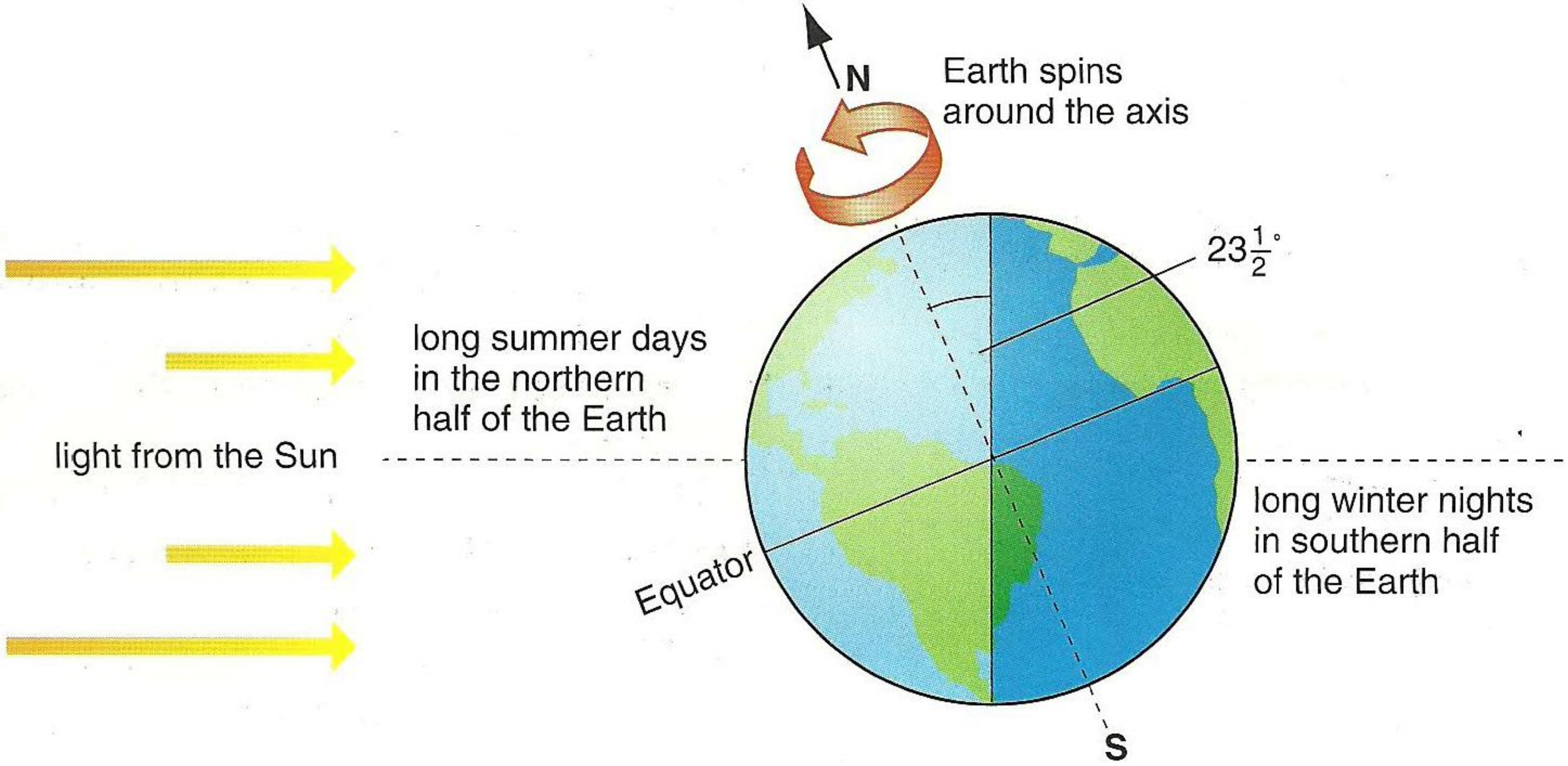


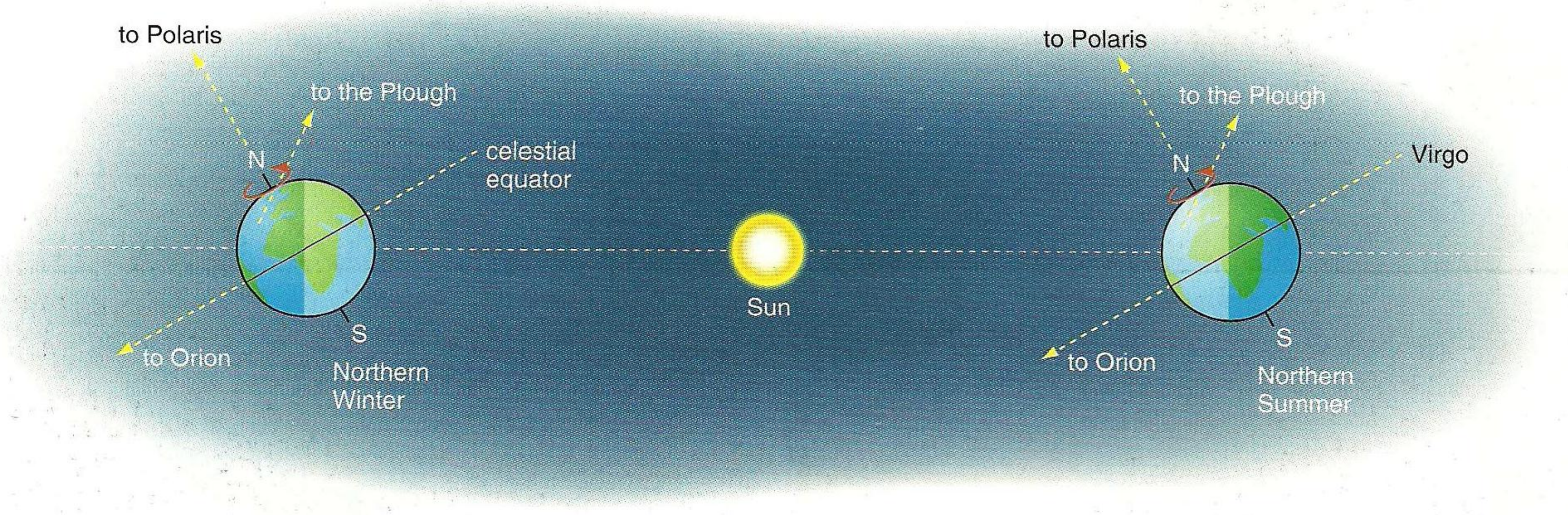


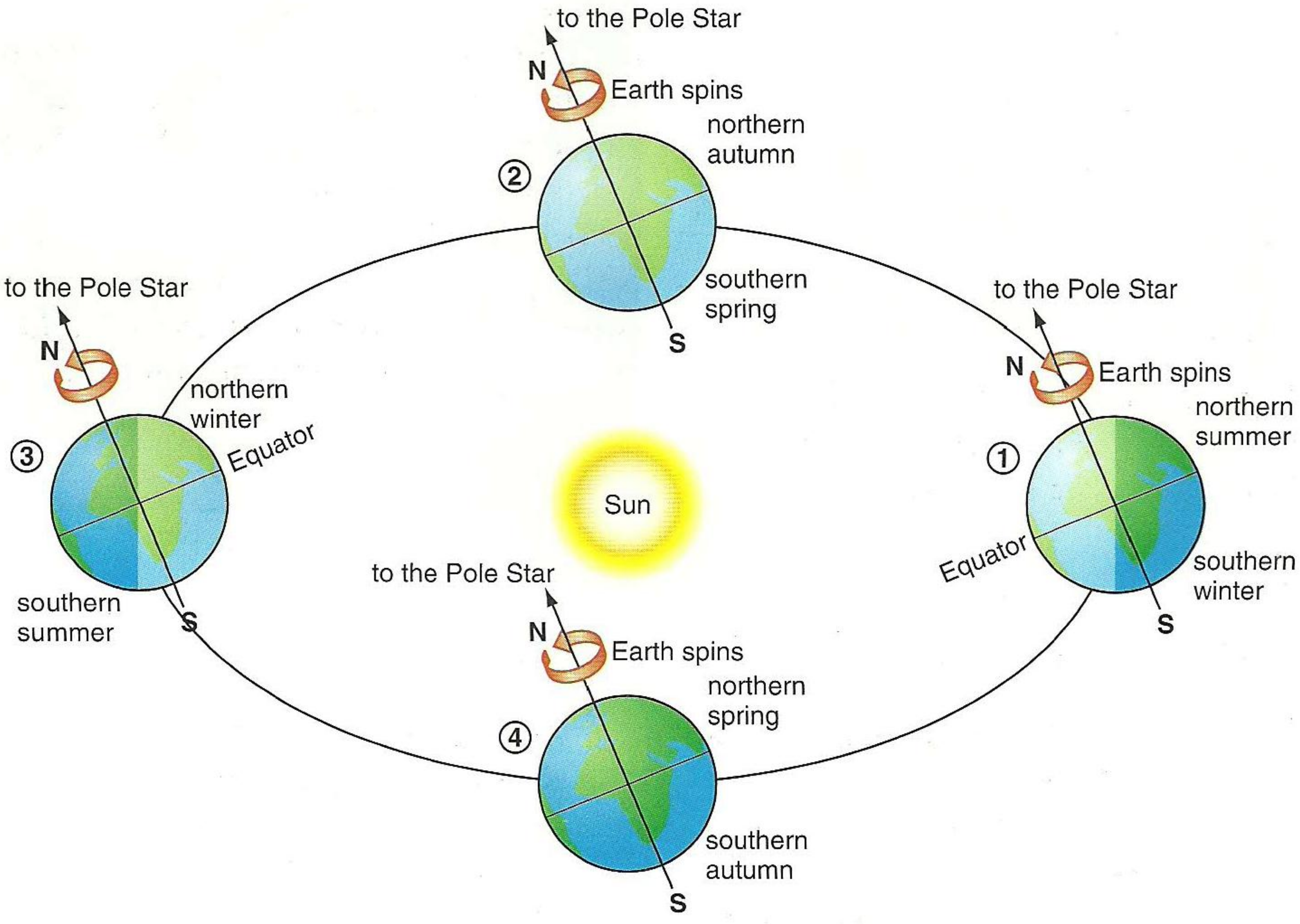
Evening: the Sun is setting over the horizon

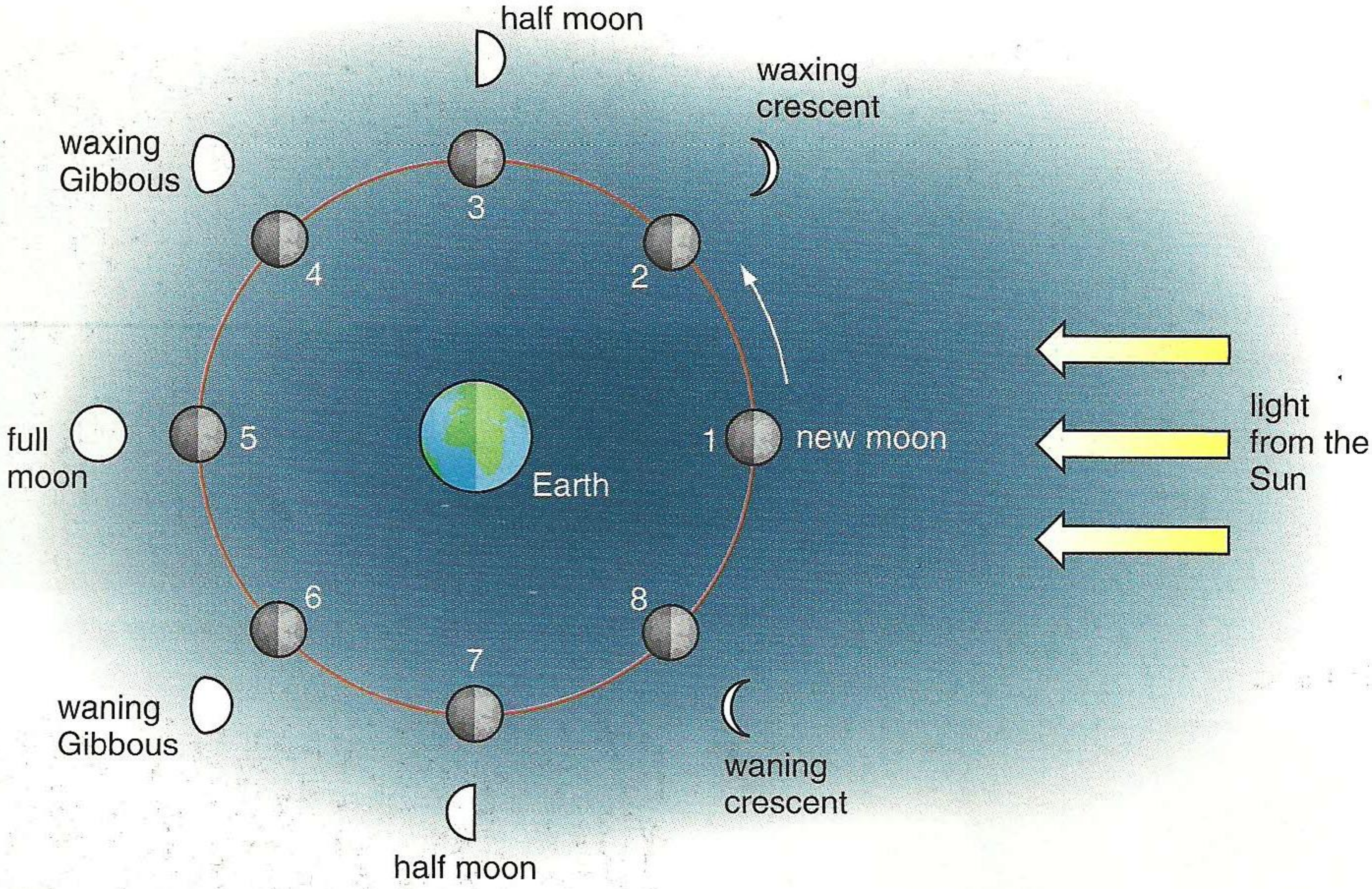
Midday: the Sun is high in the sky overhead

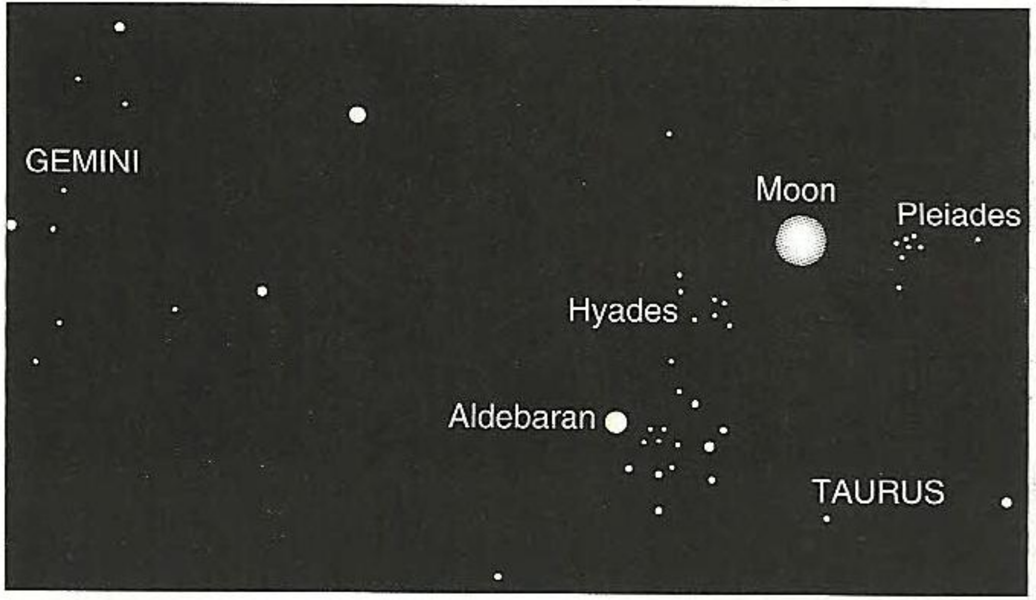
Morning: the Sun rises and is seen low down close to the ground


N
Earth spins
around the axis
$23\frac{1}{2}°$
long summer days
in the northern
half of the Earth
light from the Sun
long winter nights
in southern half
of the Earth
Equator
S

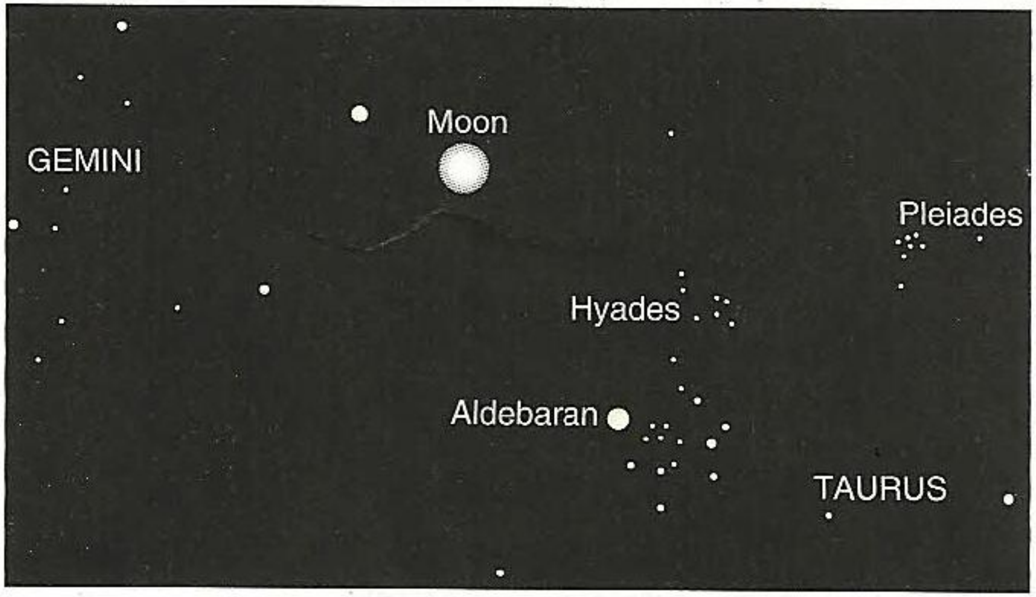

to Polaris
to the Plough
N
celestial
equator
S
to Orion
Northern
Winter
Sun
to Polaris
to the Plough
N
Virgo
S
to Orion
Northern
Summer

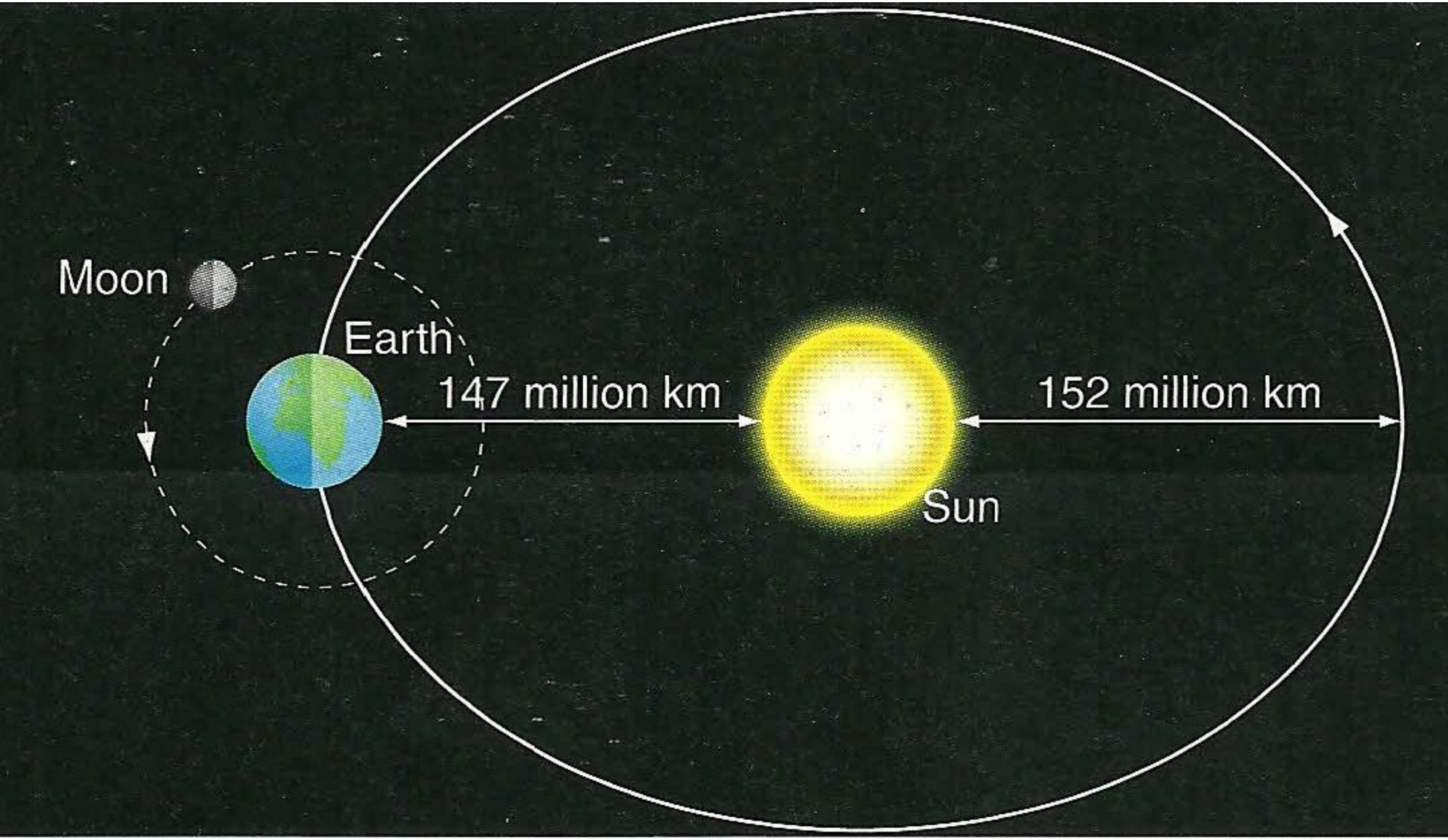

to the Pole Star
N
Earth spins
northern autumn
②
southern spring
S
to the Pole Star
N
northern winter
Equator
③
southern summer
S
Sun
to the Pole Star
N
Earth spins
northern summer
①
Equator
southern winter
S
to the Pole Star
N
Earth spins
northern spring
④
southern autumn
S

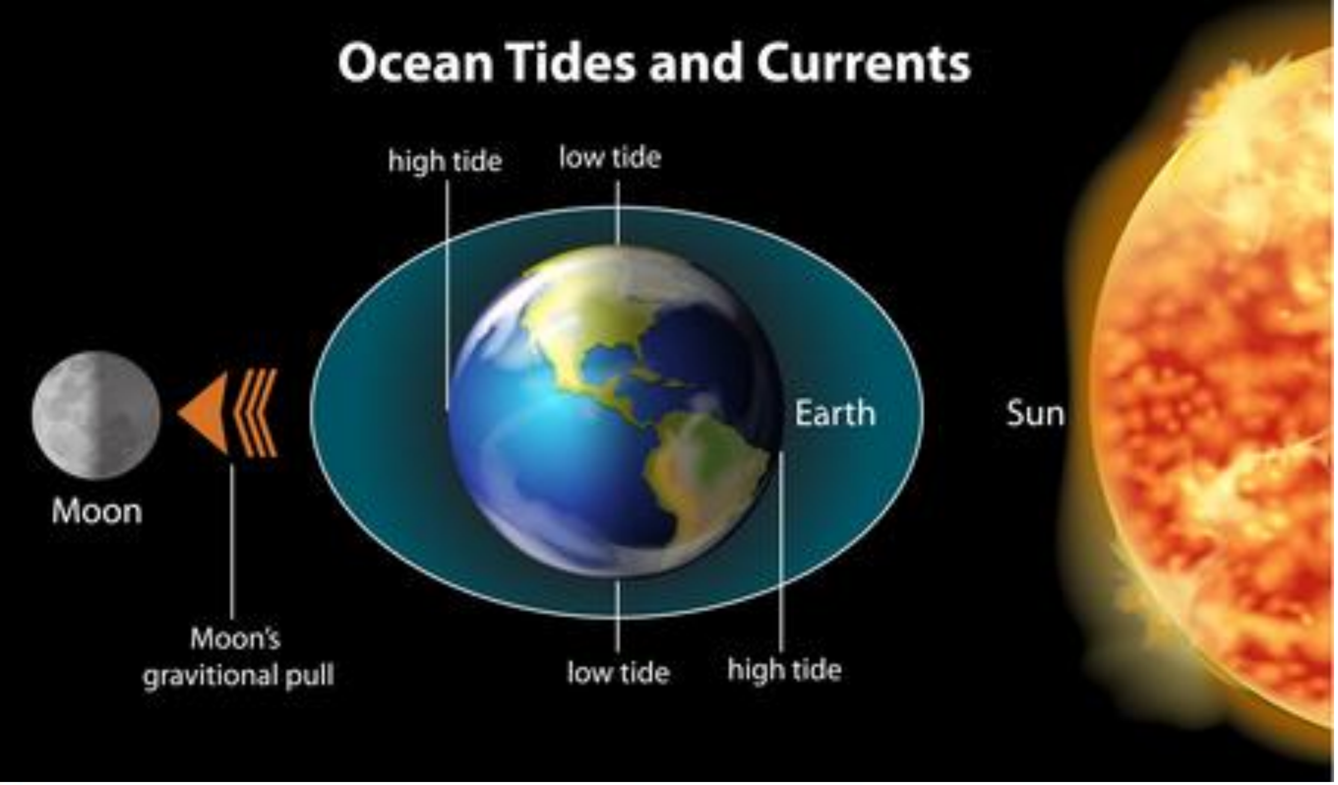

half moon
waxing crescent
waxing Gibbous
3
4
2
full moon
5
Earth
1
new moon
light from the Sun
6
8
7
waning Gibbous
waning crescent
half moon

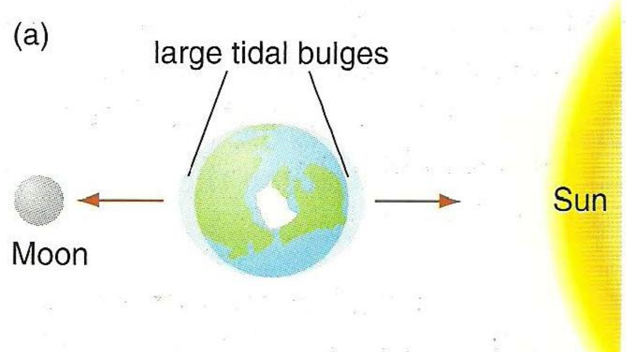


Change of position of the Moon against background constellations over the course of one day

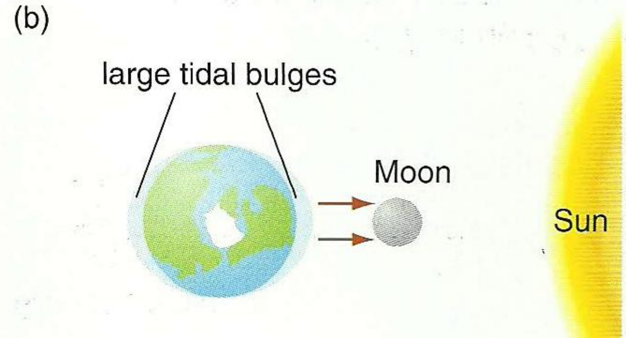



Moon
Earth
147 million km
152 million km
Sun

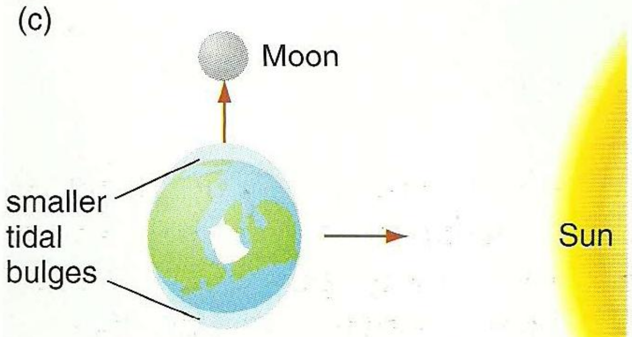

Ocean Tides and Currents
high tide
low tide
Moon
Earth
Sun
Moon's gravitional pull
low tide
high tide



Spring Tide: Full Moon



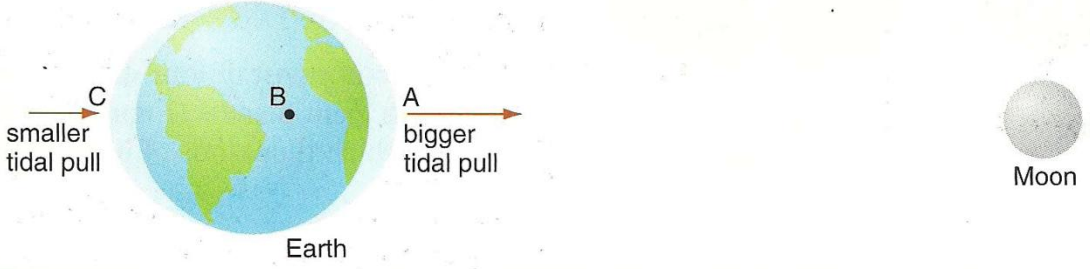
Spring Tide: New Moon

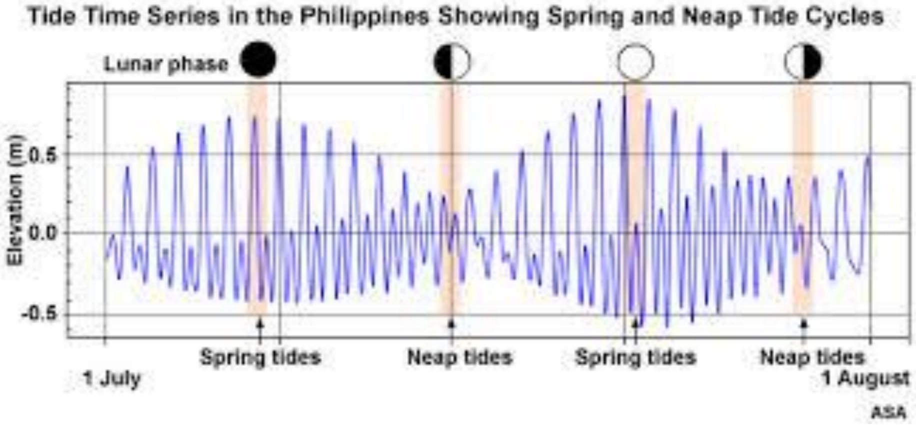


Neap Tide

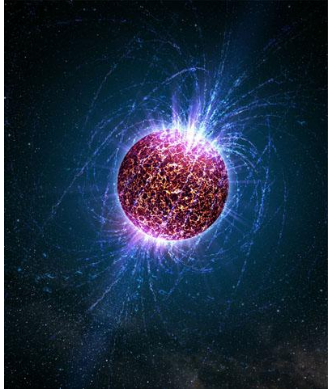
The gravitational pull of the Moon on the ocean causes our **tides**. We get two high tides a day. The Earth-Moon system rotates about a centre of gravity (or **barycentre**) at B (Figure 4). This is inside the Earth but not at its centre. At A, there is a high tide because the Moon pulls more strongly on the water closer to it. At C there is also a high tide. At C the Moon pulls the water less strongly. As the water rotates around B it piles up; this is because the Moon's pull is not strong enough to keep it in a smaller circular path.

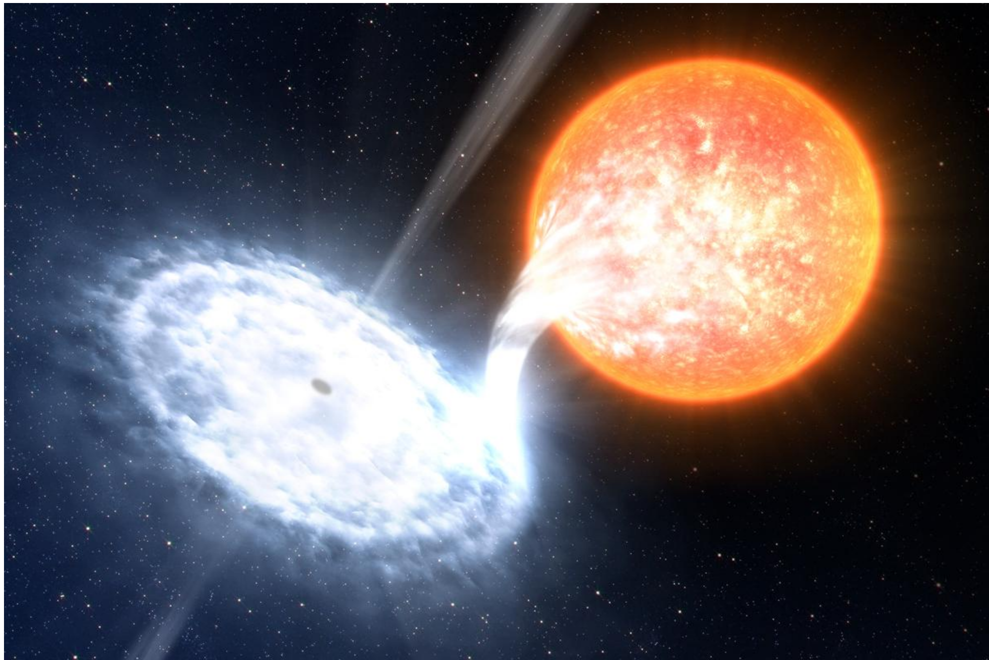
The Sun also exerts a tidal pull on our seas, but about half as much as the Moon. Twice a month, the Sun and Moon line up to produce a large tidal pull. We then get **spring tides**. When the Sun and Moon pull at right-angles to each other, the high tides are smaller, These are called **neap tides** (Figure 5). Other factors, such as strong winds, also affect the height of tides.





Exotic objects: Strange planets, Neutron Stars, Quasars, Supernovae, Black Holes

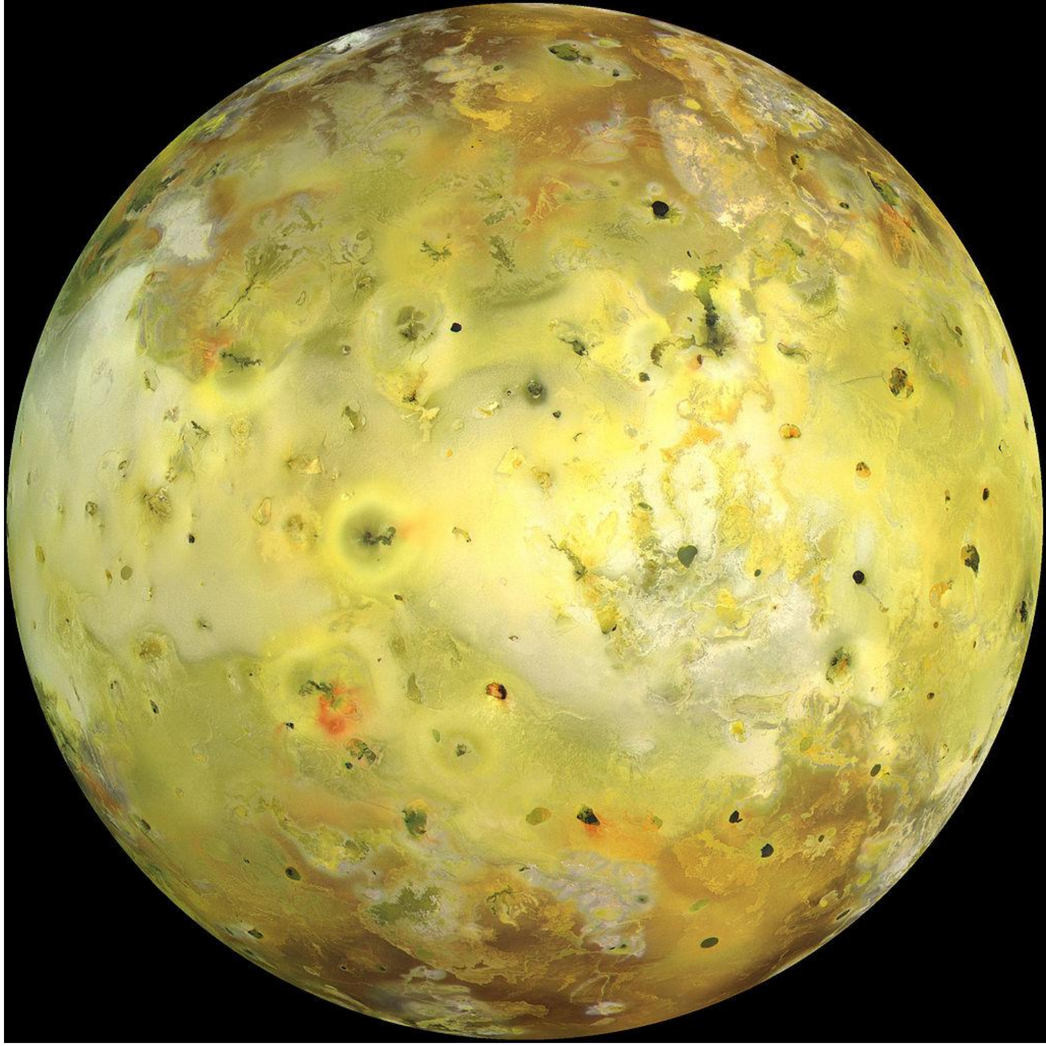


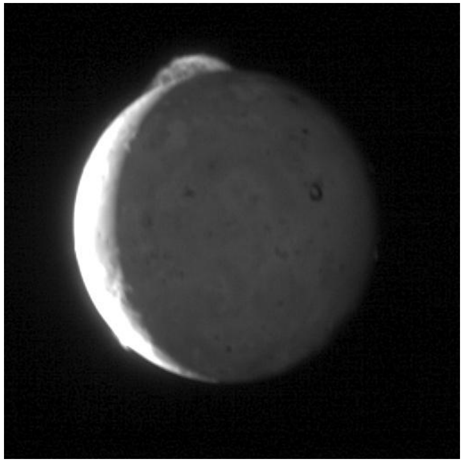


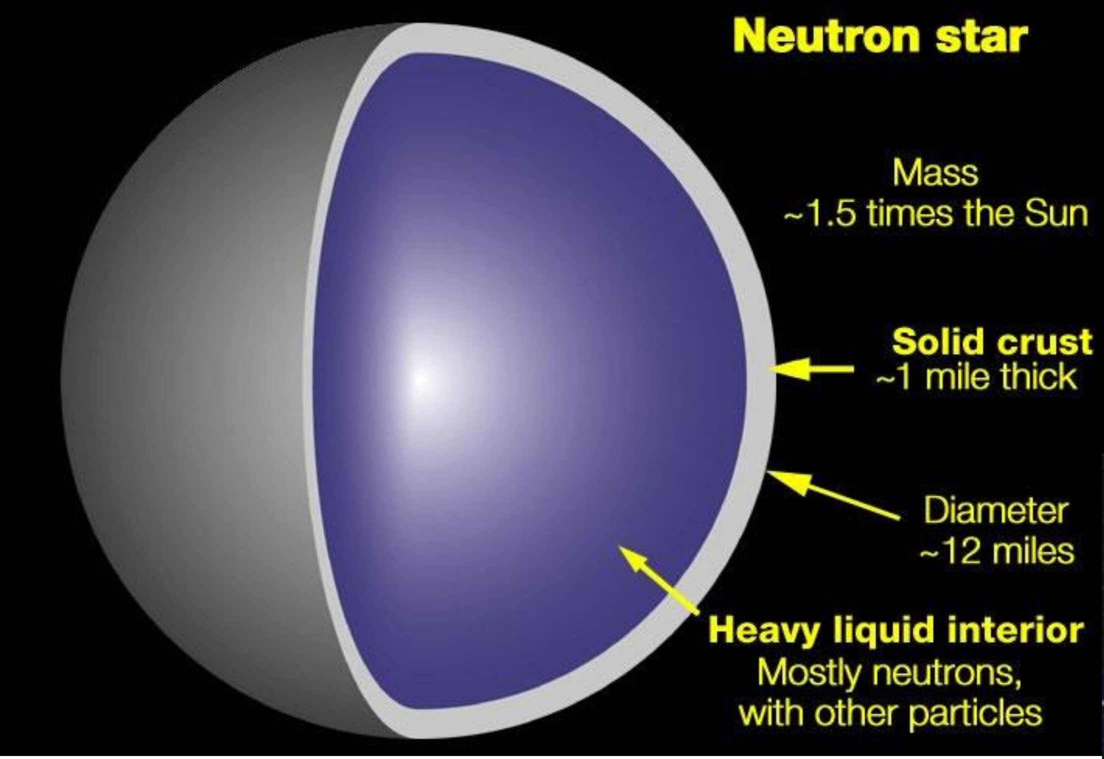
Io – a moon of Jupiter

With over 400 active volcanoes, Io is the most geologically active object in the Solar System. This extreme geologic activity is the result of tidal heating from friction generated within Io's interior as it is pulled between Jupiter and the other Galilean satellites—Europa, Ganymede and Callisto.

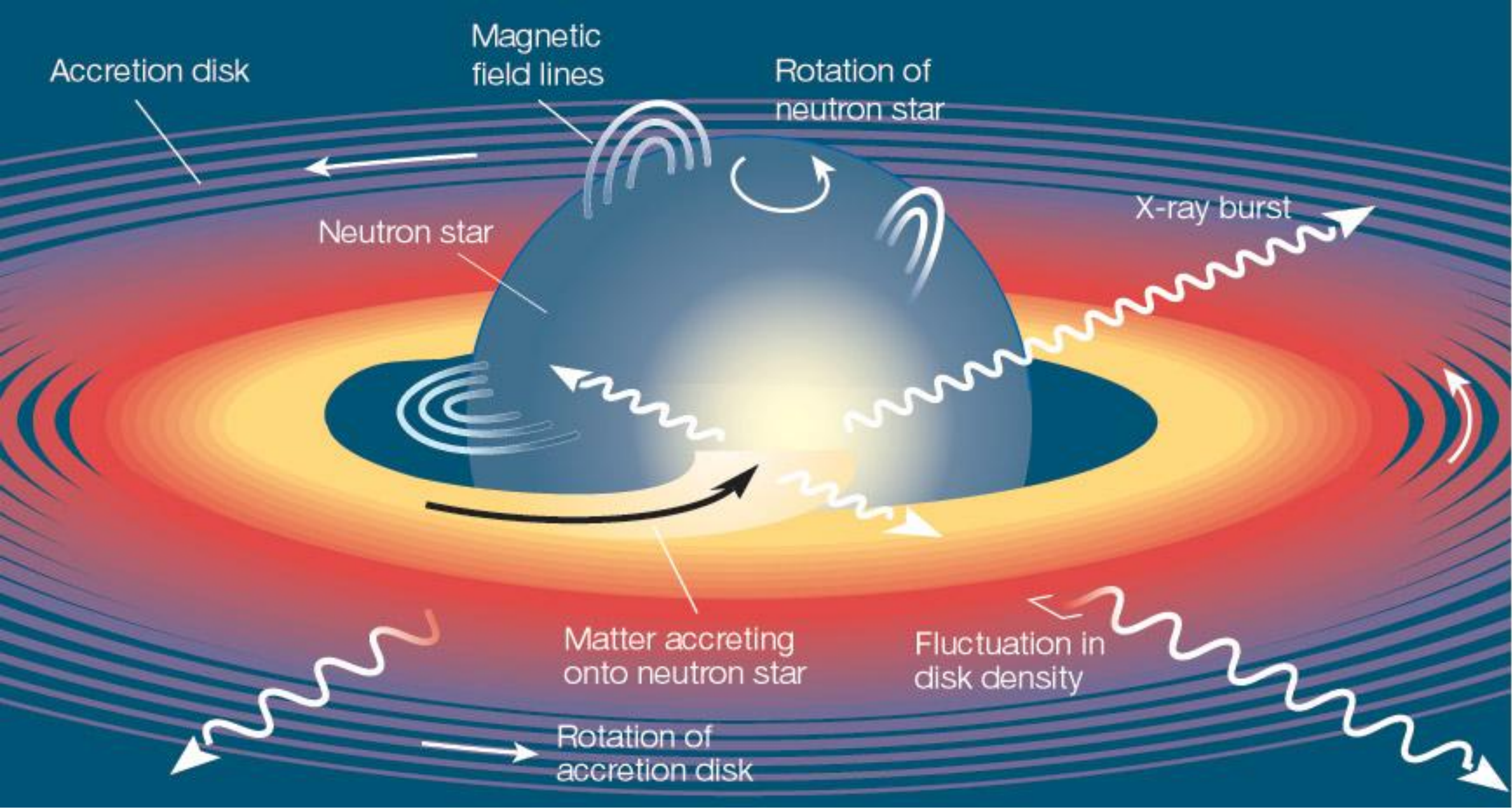
Several volcanoes produce plumes of sulfur and sulfur dioxide that climb as high as 500 km above the surface.

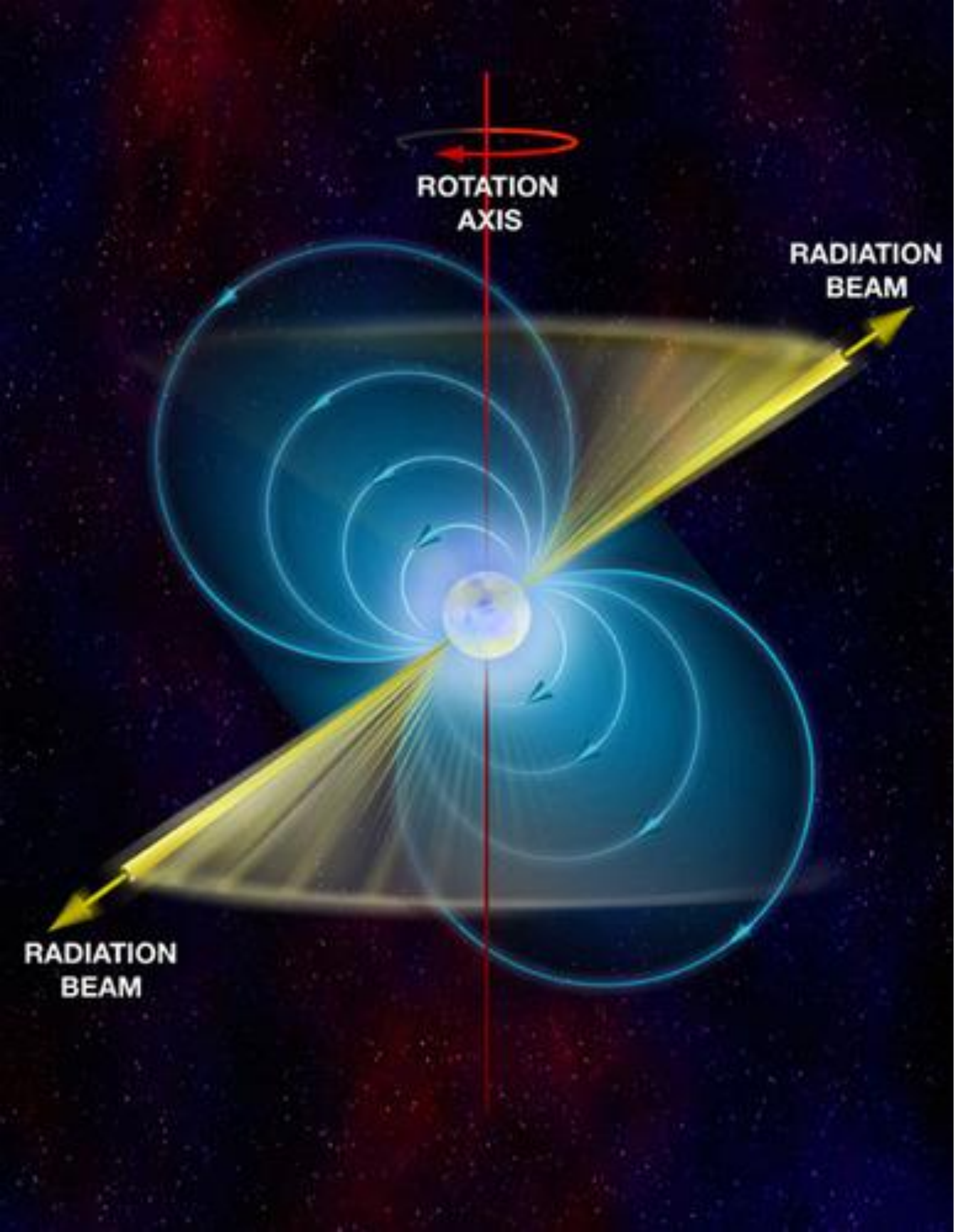


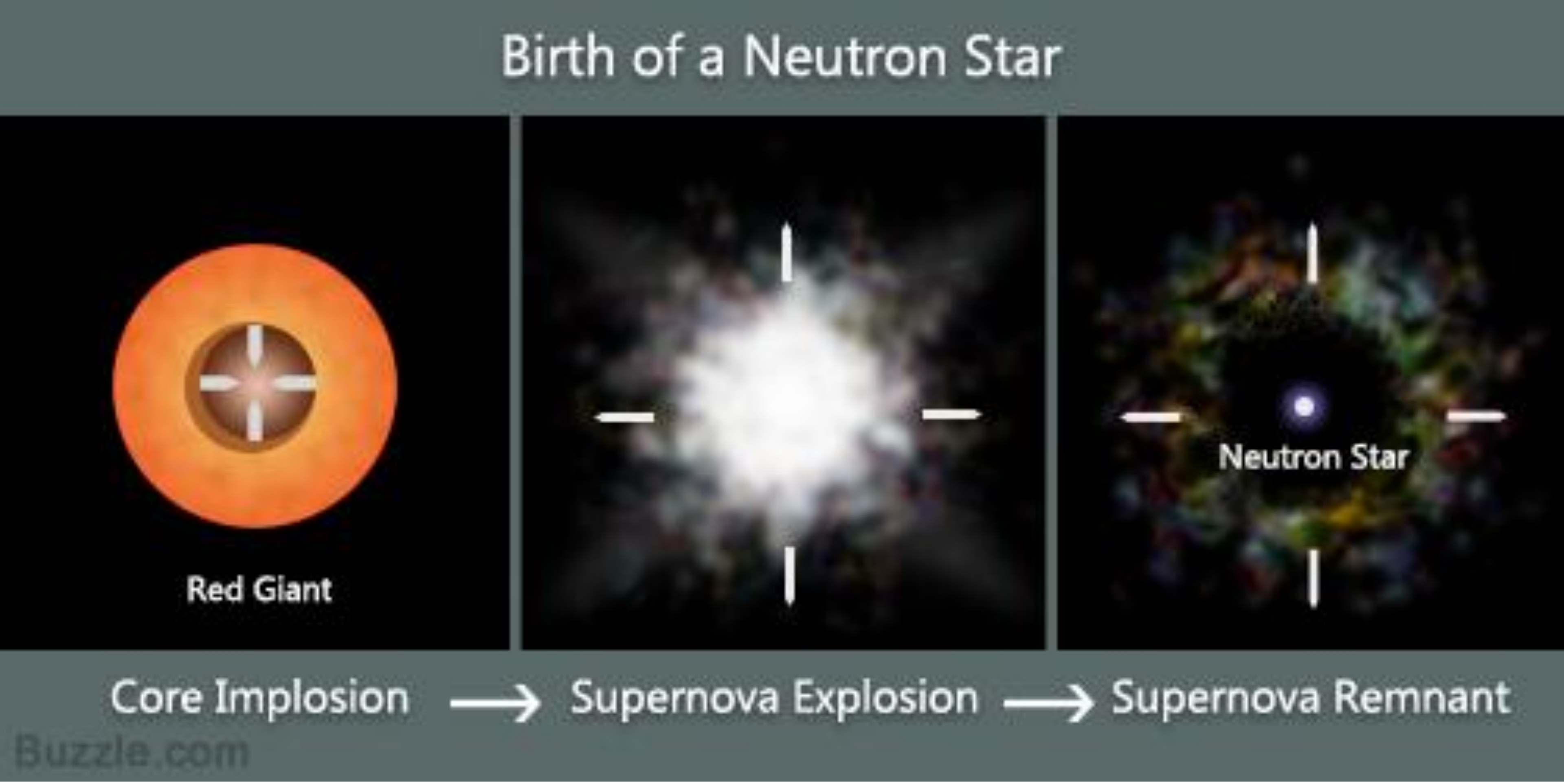



Neutron star
Mass
~1.5 times the Sun
Solid crust
~1 mile thick
Diameter
~12 miles
Heavy liquid interior
Mostly neutrons,
with other particles


Neutron Star
Vancouver
www.kindaroomy.com

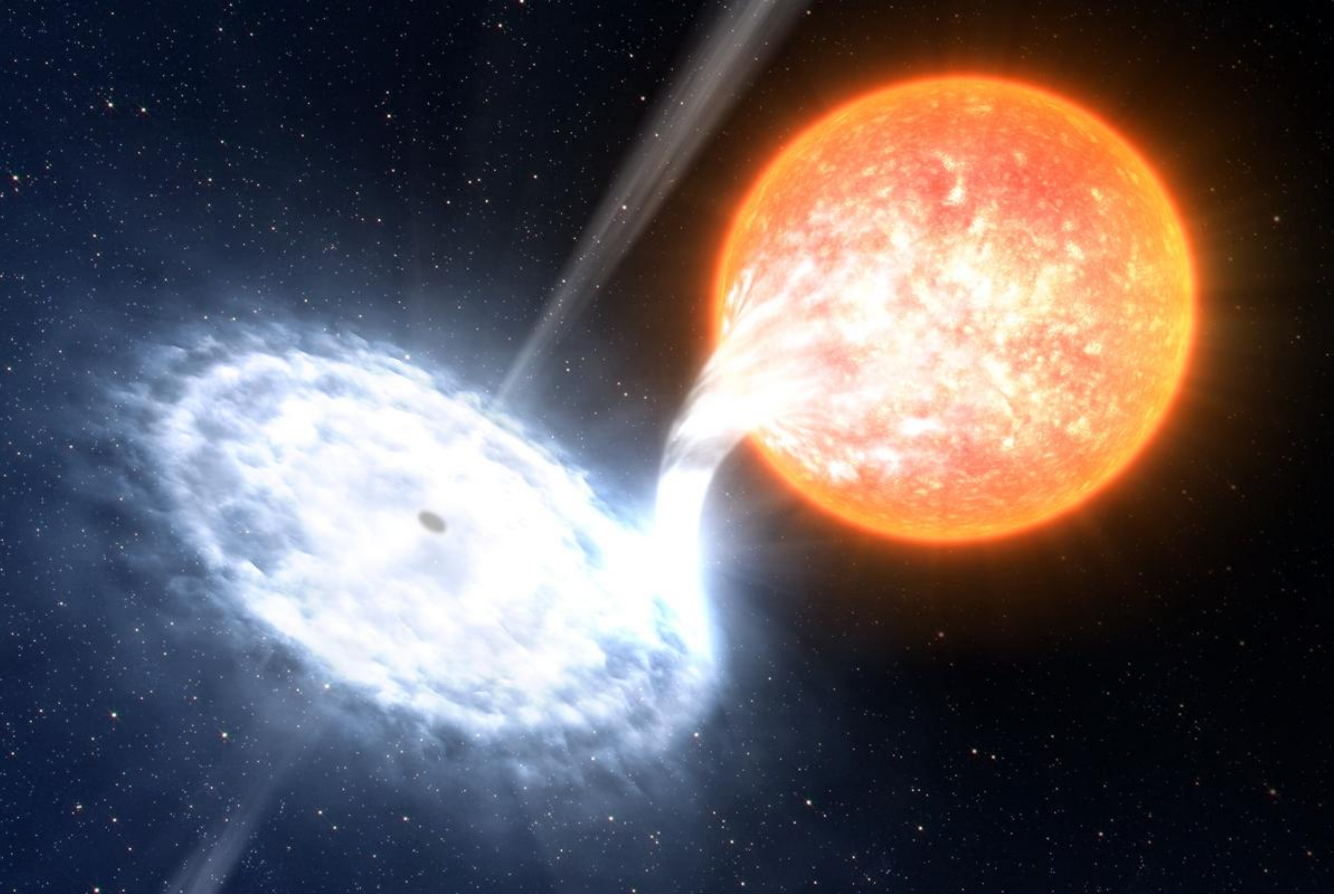

Accretion disk
Magnetic field lines
Rotation of neutron star
Neutron star
X-ray burst
Matter accreting onto neutron star
Fluctuation in disk density
Rotation of accretion disk

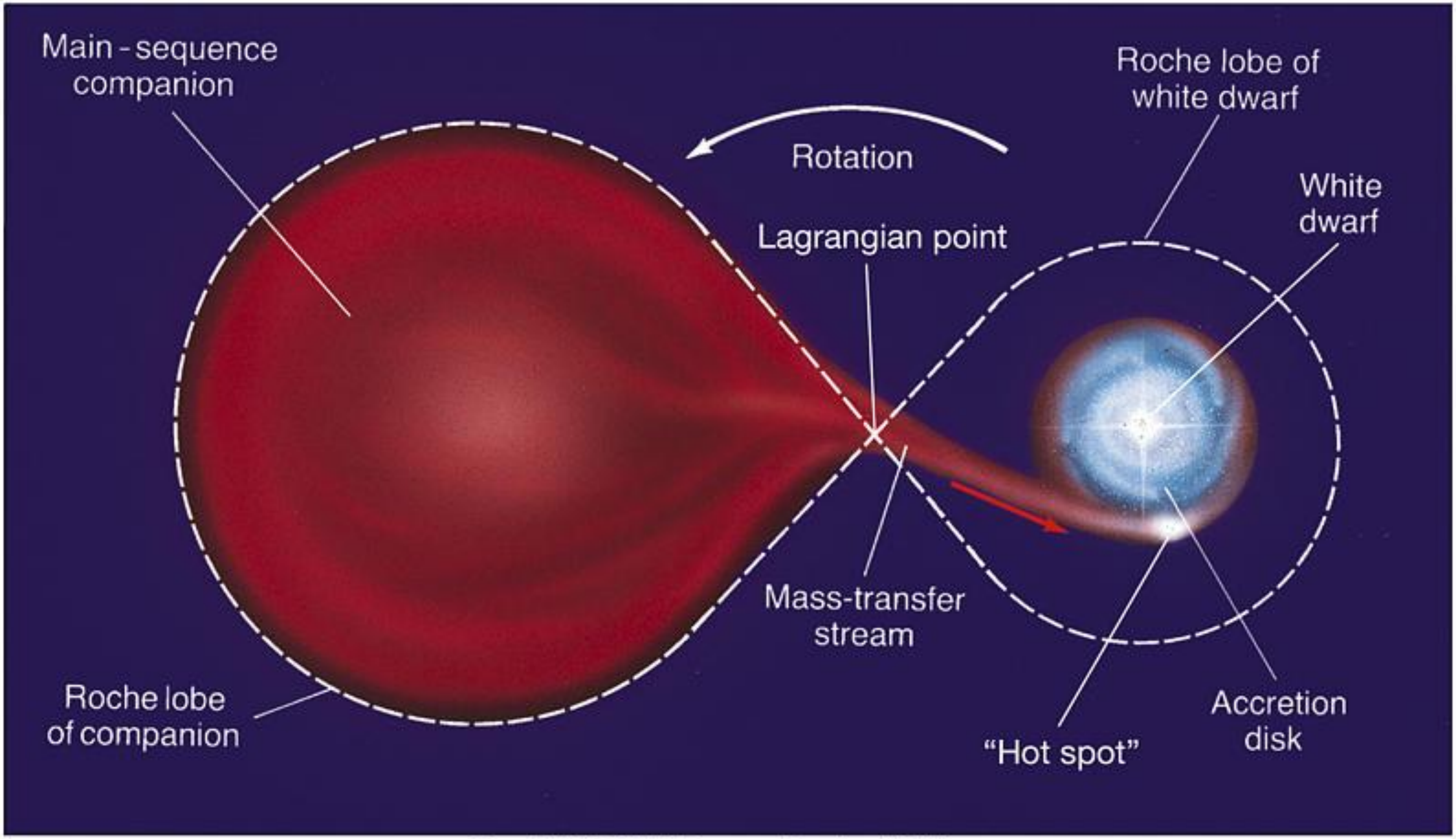

ROTATION AXIS
RADIATION BEAM
RADIATION BEAM



Birth of a Neutron Star

Buzzle.com





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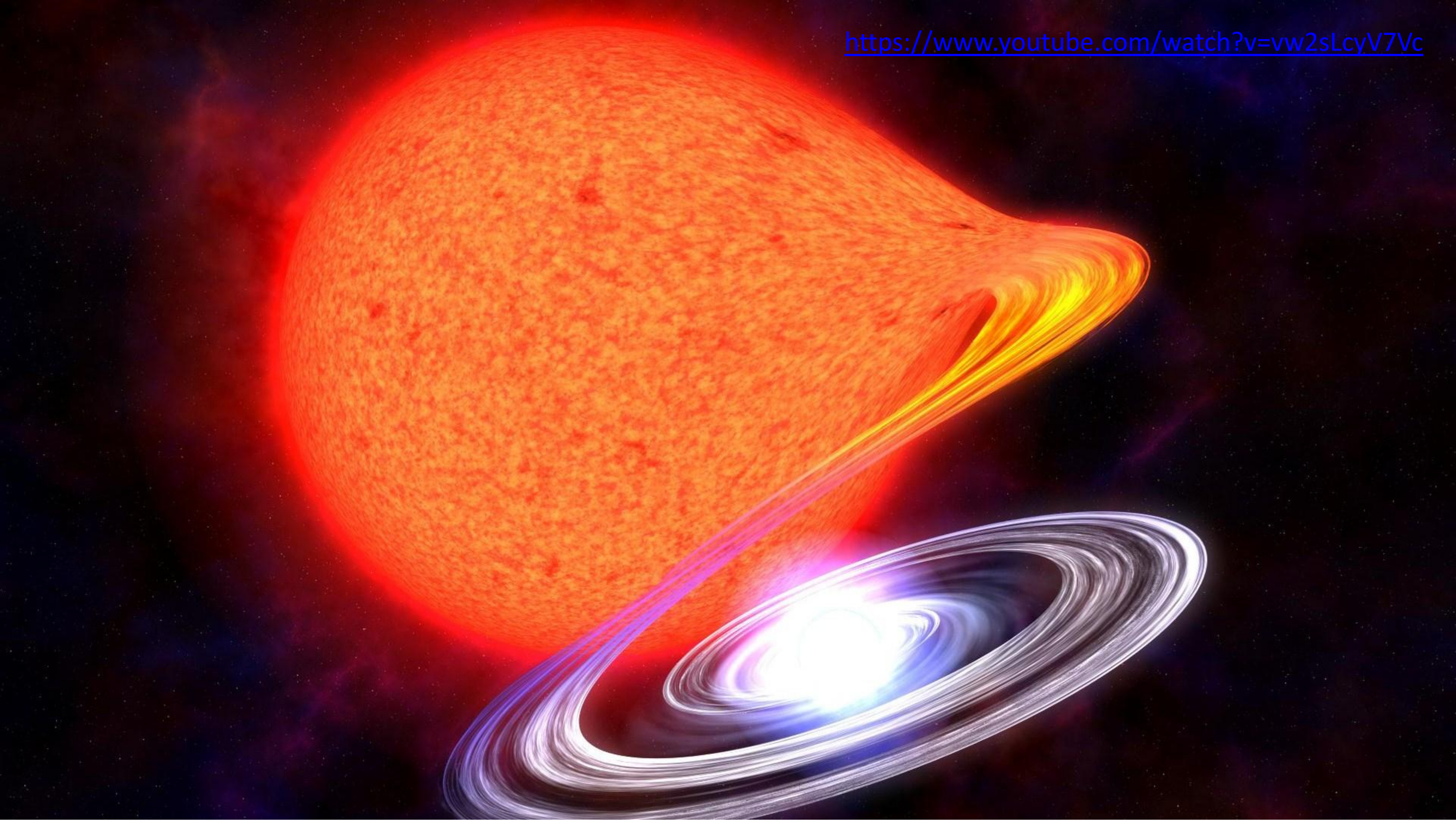
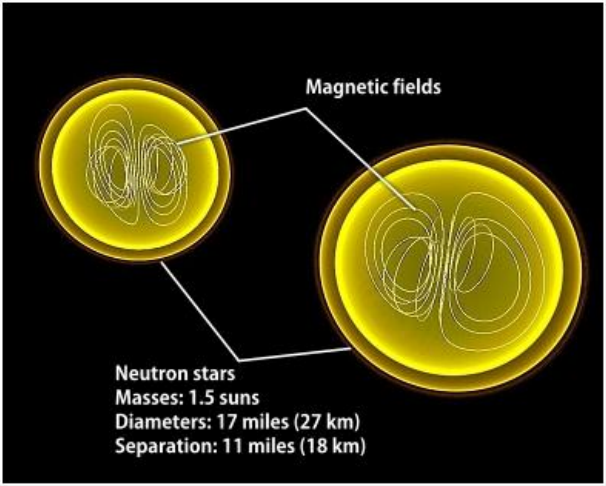


https://www.youtube.com/watch?v=vw2sLcyV7Vc

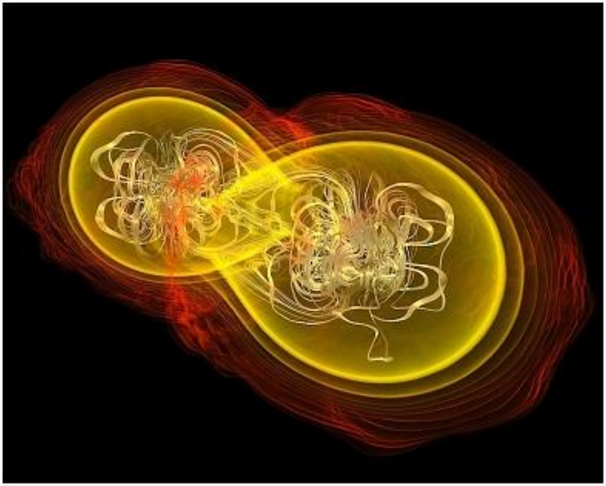
Crashing neutron stars can make gamma-ray burst jets



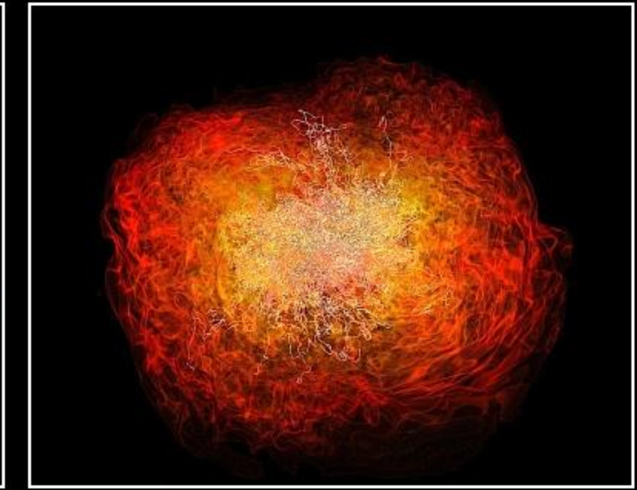
Magnetic fields

Neutron stars
Masses: 1.5 suns
Diameters: 17 miles (27 km)
Separation: 11 miles (18 km)

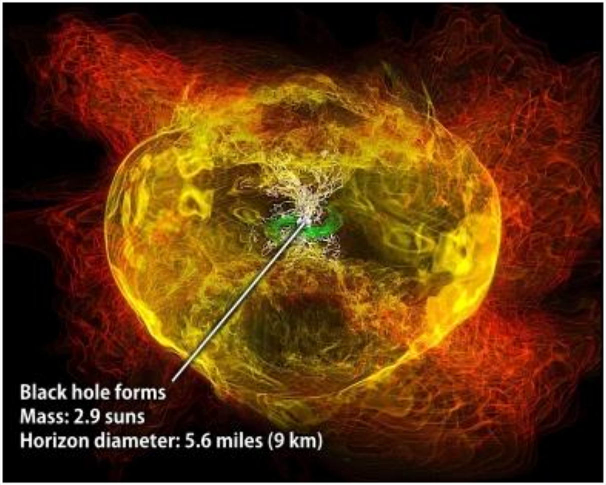
Simulation begins



7.4 milliseconds

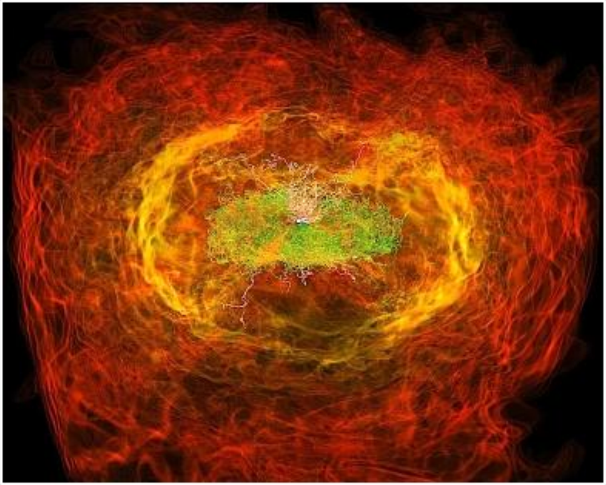


13.8 milliseconds

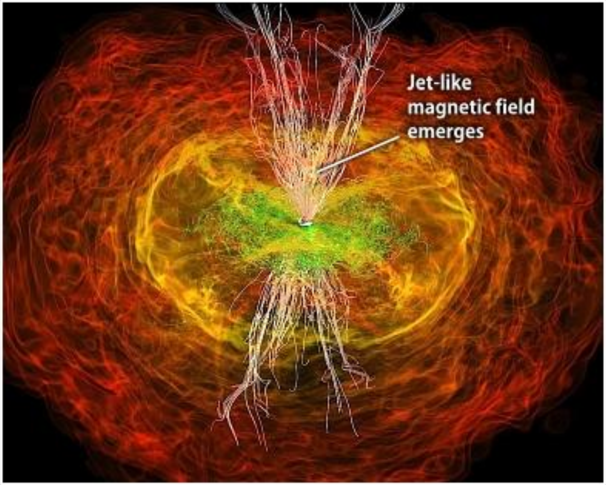


Black hole forms
Mass: 2.9 suns
Horizon diameter: 5.6 miles (9 km)

15.3 milliseconds



21.2 milliseconds



Jet-like
magnetic field
emerges

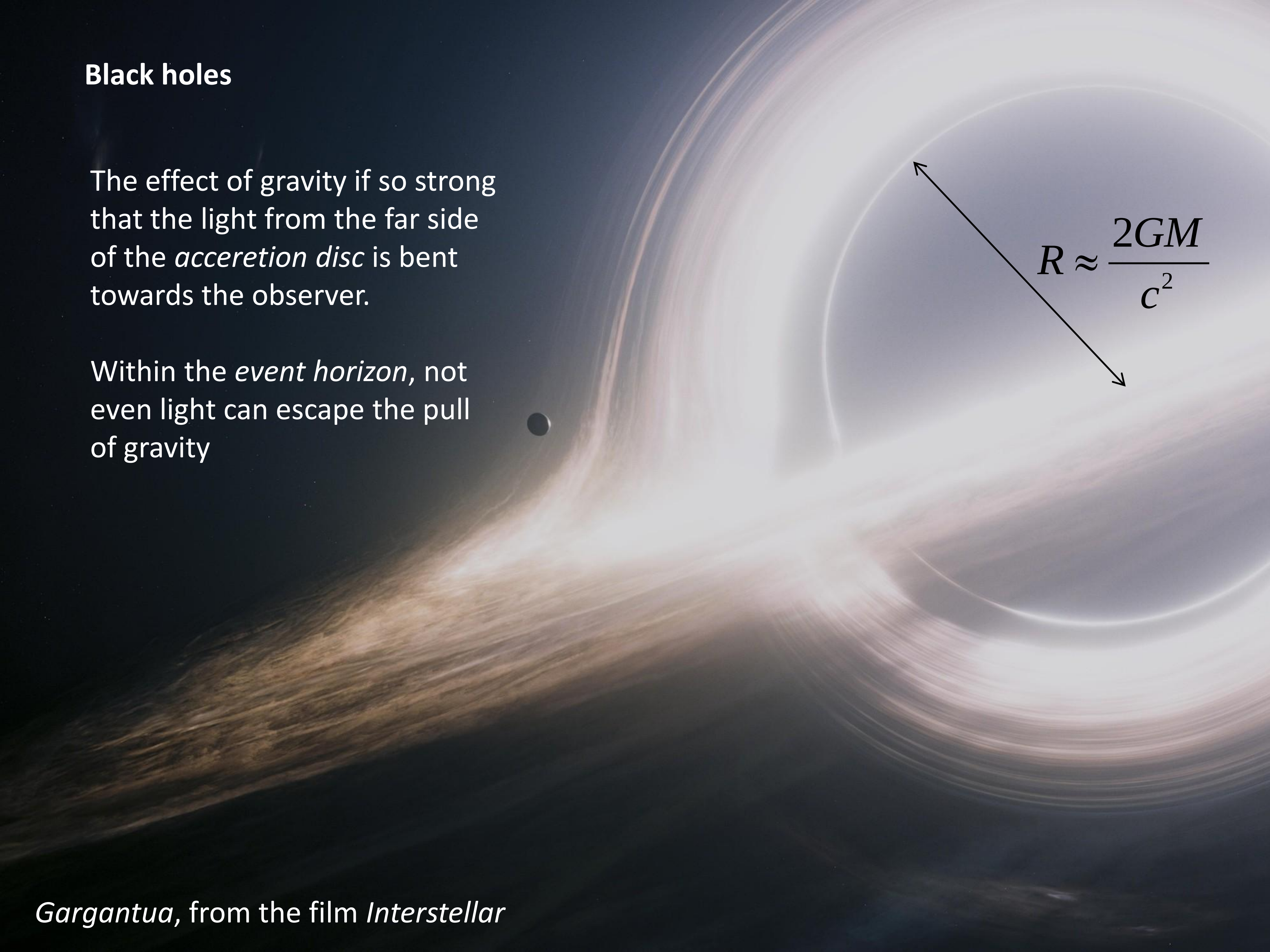
26.5 milliseconds

Credit: NASA/AEI/ZIB/M. Koppitz and L. Rezzolla

Black holes

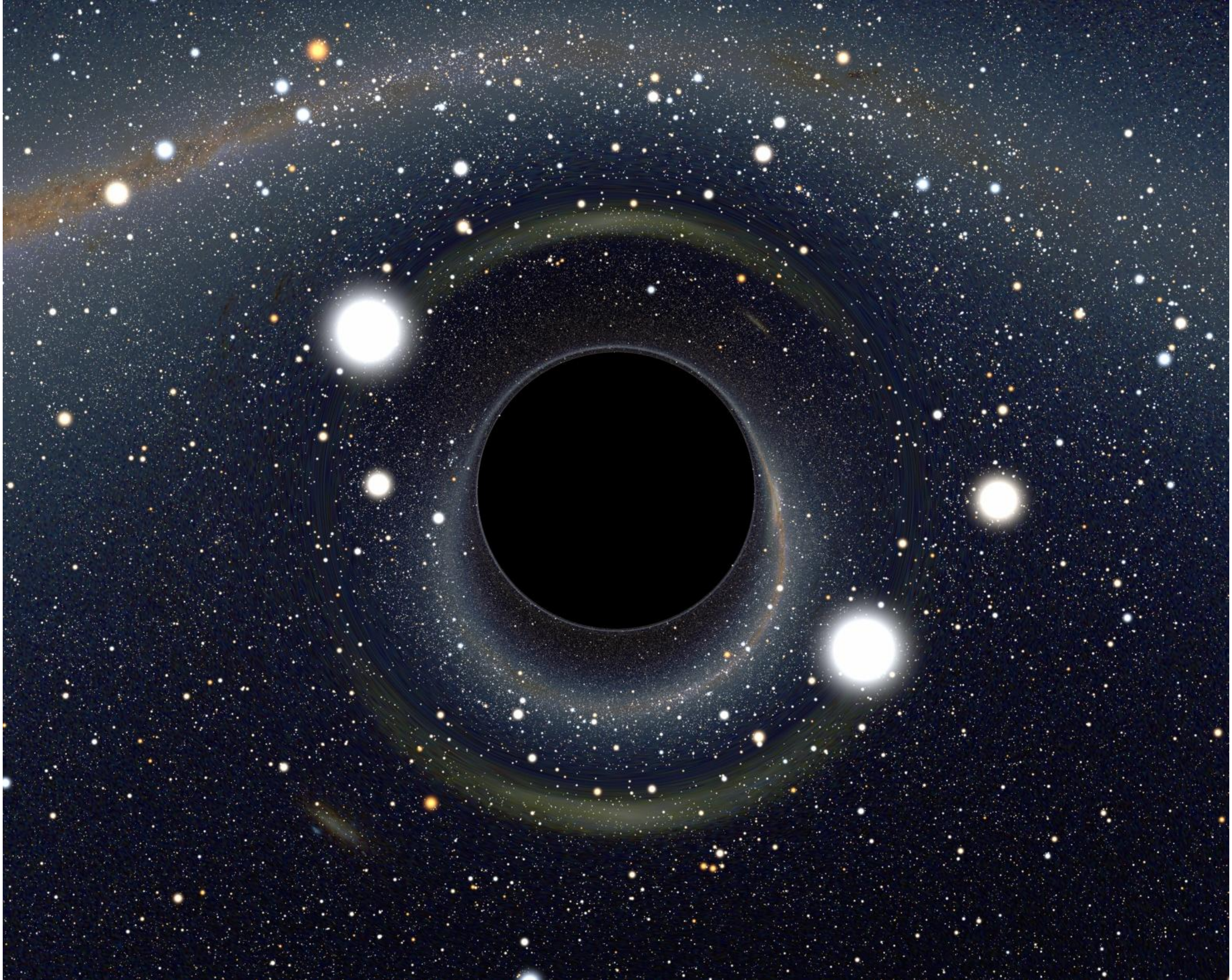
The effect of gravity if so strong that the light from the far side of the *acceretion disc* is bent towards the observer.

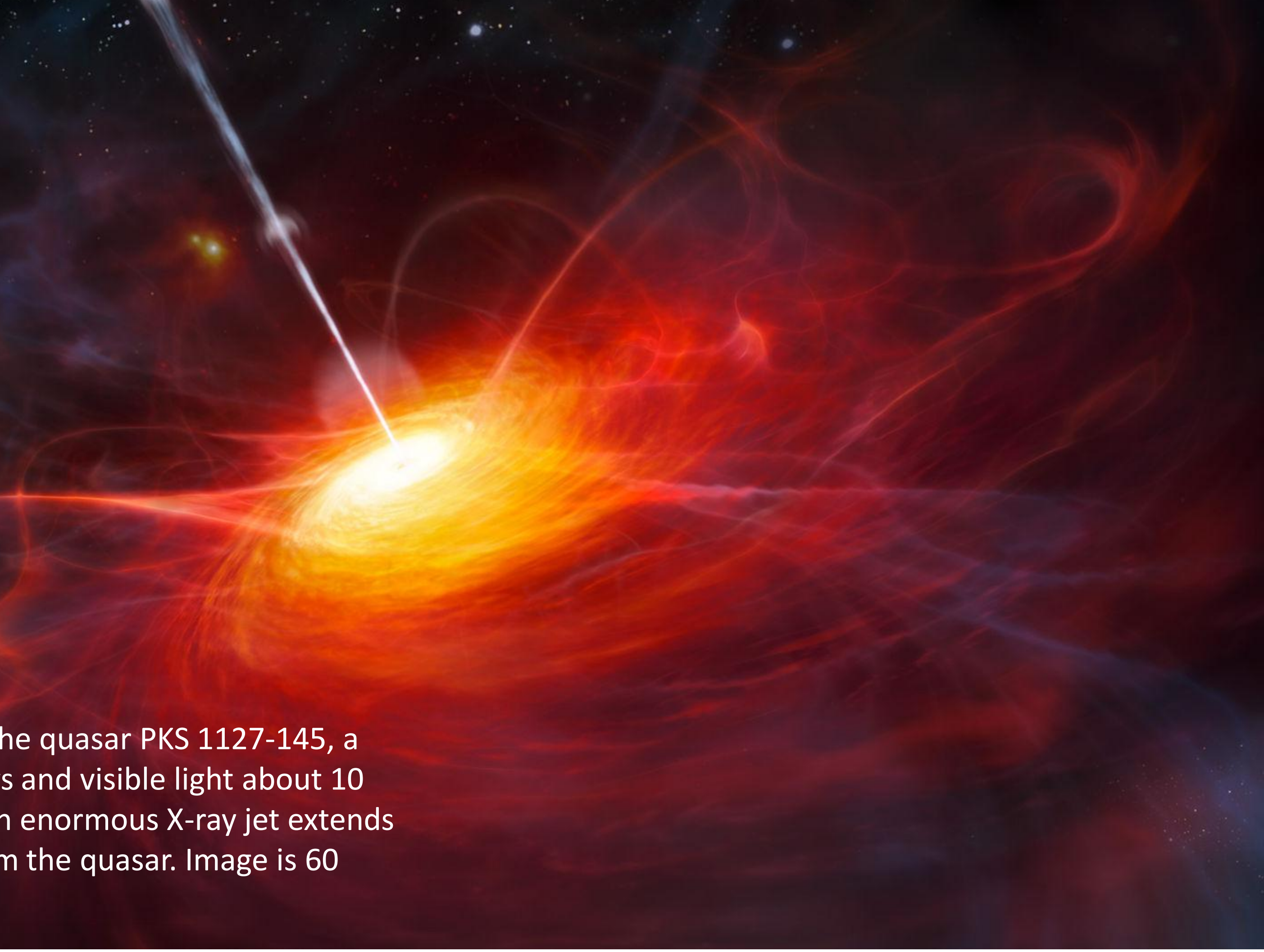
Within the *event horizon*, not even light can escape the pull of gravity

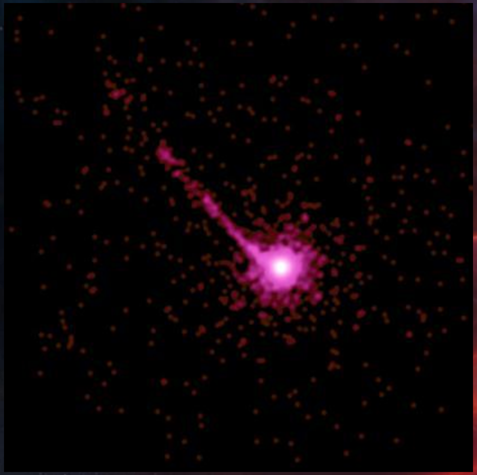


$$R \approx \frac{2GM}{c^2}$$

Gargantua, from the film *Interstellar*







The Chandra X-ray image is of the quasar PKS 1127-145, a highly luminous source of X-rays and visible light about 10 billion light years from Earth. An enormous X-ray jet extends at least a million light years from the quasar. Image is 60 arcsec on a side.

A **quasar** ('quasi-stellar radio source')is a compact region in the centre of a massive galaxy surrounding a central supermassive black hole. Its size is 10–10,000 times the Schwarzschild radius of the black hole. The energy emitted by a quasar derives from mass falling onto the accretion disc around the black hole.

Quasars are extremely luminous and were first identified as being high redshift sources of electromagnetic energy, including radio waves and visible light, that appeared to be similar to stars, rather than extended sources similar to galaxies. Their spectra contain very broad emission lines, unlike any known from stars, hence the name "quasi-stellar". Their luminosity can be 100 times greater than that of the Milky Way.

Nebulae

Photo Credit: *T. Rector (University of Alaska Anchorage)*

A nebula (Latin for "cloud") is an interstellar cloud of dust, hydrogen, helium and other ionized gases.

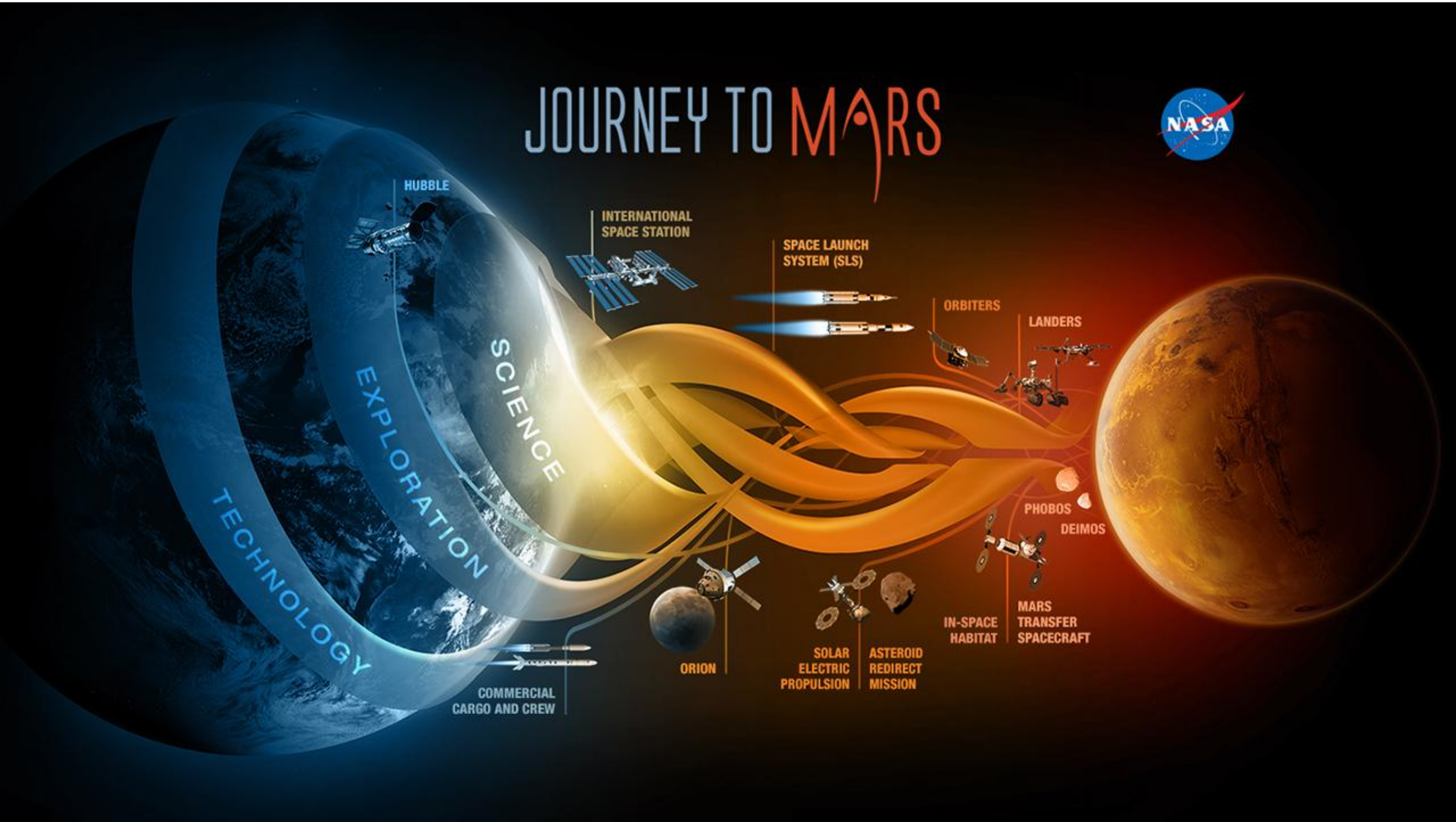
Pillars of Creation
Eagle Nebula
(7000 light years away)

Hubble space telescope, 2014

Horsehead Nebula

Various nebulae, photographed by the Hubble space telescope

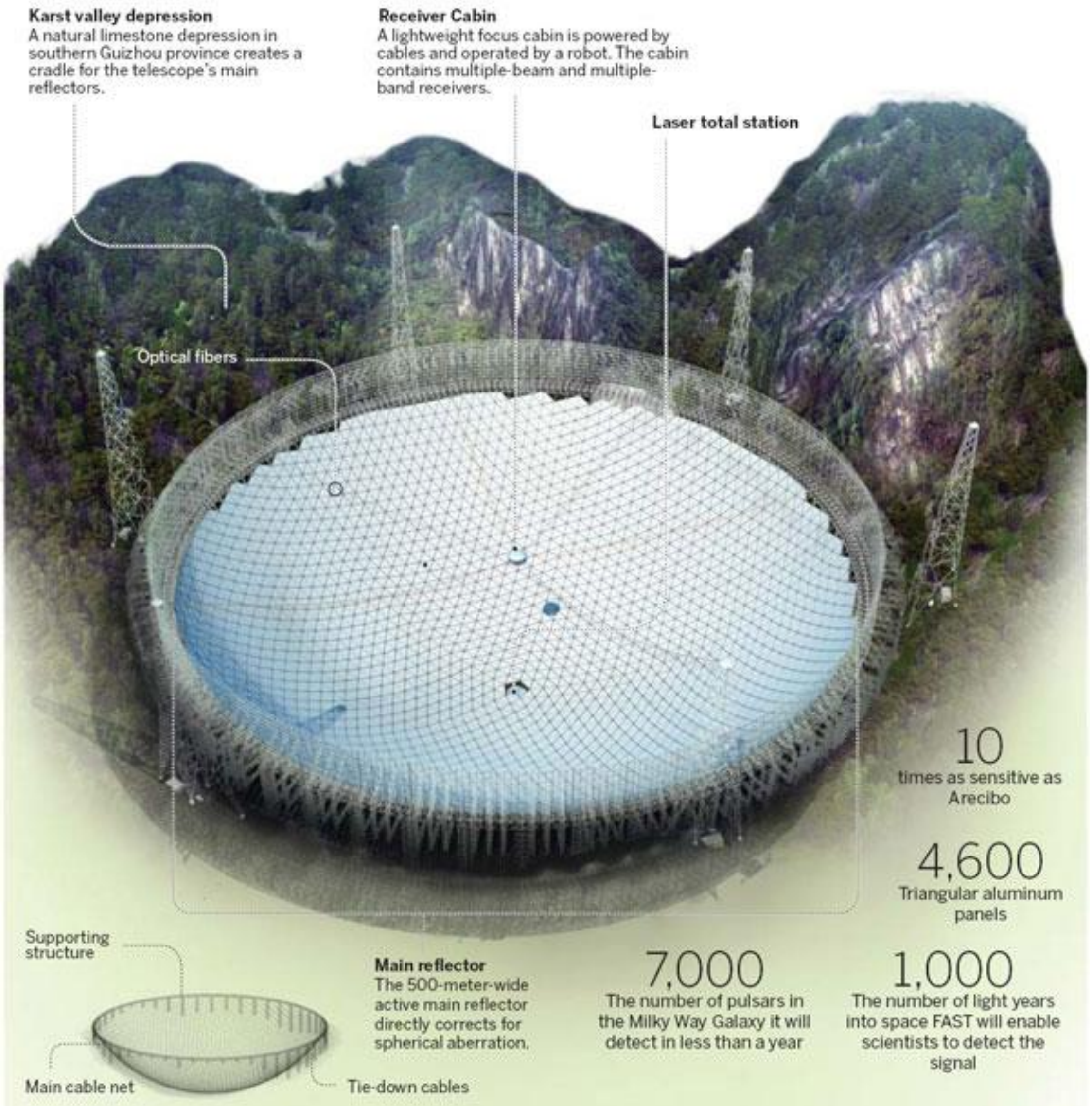
The future of cosmology astronomy & space exploration



A BIG EYE ON THE SKY

500-meter aperture spherical radio telescope (FAST)

- Surveys neutral hydrogen in the Milky way and other galaxies
- Detects new galactic and extragalactic pulsars
- Finds and researches the first shining stars
- Finds out where extraterrestrial life might exist in space
- Detects dark energy and helps us understand the evolution of galaxies



Karst valley depression
A natural limestone depression in southern Guizhou province creates a cradle for the telescope's main reflectors.

Receiver Cabin
A lightweight focus cabin is powered by cables and operated by a robot. The cabin contains multiple-beam and multiple-band receivers.

Laser total station

Main reflector
The 500-meter-wide active main reflector directly corrects for spherical aberration.

10
times as sensitive as Arecibo

4,600
Triangular aluminum panels

7,000
The number of pulsars in the Milky Way Galaxy it will detect in less than a year

1,000
The number of light years into space FAST will enable scientists to detect the signal

Orion: Multi-Purpose Crew Vehicle
The Moon, Asteroids, Mars ....

APOLLO

CREW MODULE DIAMETER:	12.8 FT.
CREW SIZE:	3
SERVICE MODULE DIAMETER:	13 FT.
SERVICE MODULE LENGTH:	24.5 FT.
SERVICE MODULE MASS:	54,000 LBS.
SERVICE MODULE THRUST:	20,500 LBS.
POWER:	BATTERIES, FUEL CELLS
LANDING:	WATER
DOCKING:	LUNAR MODULE
DESTINATION:	SKYLAB, ASTP, MOON

ORION

CREW MODULE DIAMETER:	16.5 FT.
CREW SIZE:	4 (6 TO ISS)
SERVICE MODULE DIAMETER:	16.5 FT.
SERVICE MODULE LENGTH:	15.7 FT.
SERVICE MODULE MASS:	27,500 LBS.
SERVICE MODULE THRUST:	7,500 LBS.
POWER:	SOLAR ARRAYS, BATTERIES
LANDING:	WATER
DOCKING:	MULTI PURPOSE
DESTINATION:	MARS, ASTEROIDS

http://www.nasa.gov/externalflash/orionfirstflight/

References

NASA

esa

European Space Agency

Professor James Schombert
University of Oregon

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