Conceptual Physics

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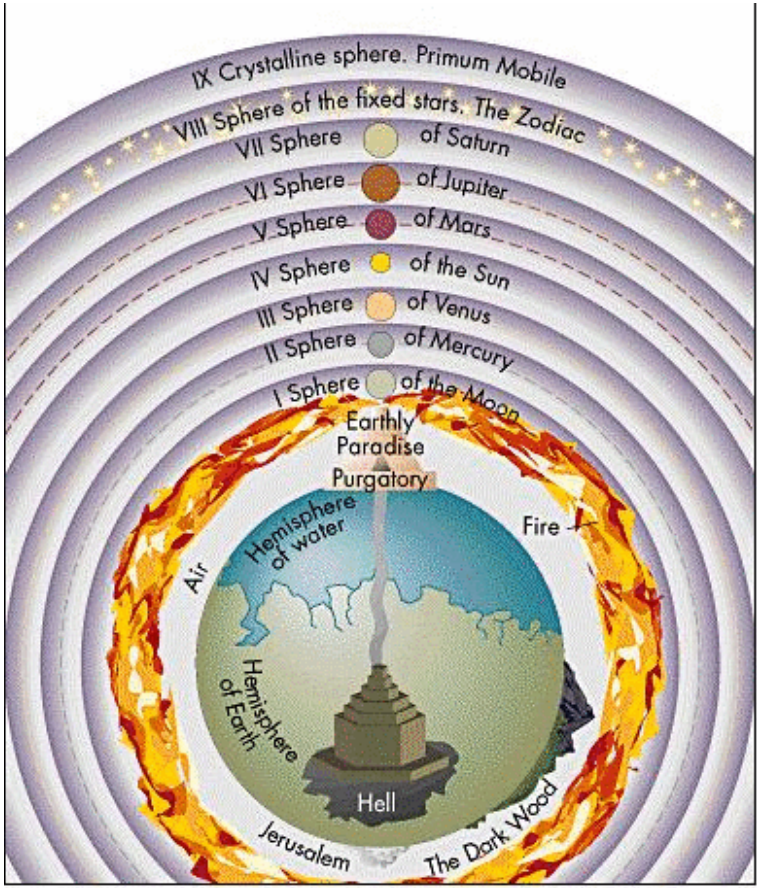
Night sky provides a strong impression of a changeless universe

- ✧ Clouds drift across the Moon ☞ on longer times Moon itself grows and shrinks
- ✧ Moon and planets move against the background of stars
- ✧ These are merely local phenomena caused by motions within our solar system
- ✧ Far beyond planets ☞ stars appear motionless

According to ancient cosmological belief ☞ stars
except for a few that appeared to move (the planets)
where fixed on sphere beyond last planet



The universe was self contained
and we (here on Earth) were at its center

Our view of universe dramatically changed after Galileo's telescopic observations: we no longer place ourselves at the center and we view the universe as vastly larger

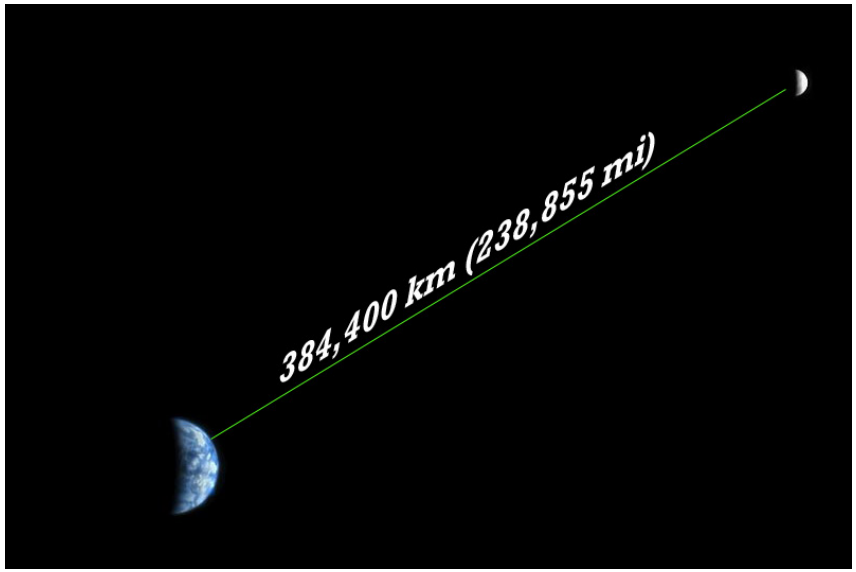
Distances involved are so large that we specify them in terms of the time it takes the light to travel a given distance

- light second ☞ $1\ \text{ls} = 1\ \text{s}\ \ 3 \times 10^8\ \text{m/s} = 3 \times 10^8 \text{m} = 300,000\ \text{km}$
- light minute ☞ $1\ \text{lm} = 18 \times 10^6\ \text{km}$
- light year ☞ $1\ \text{ly} = 2.998 \times 10^8\ \text{m/s} \cdot 3.156 \times 10^7\ \text{s/yr}$
  $= 9.46 \times 10^{15}\ \text{m} \approx 10^{13}\ \text{km}$

How long would it take the space shuttle to go 1 ly?

Shuttle orbits Earth @ 18,000 mph ☞ it would need $37,200$ yr

- For specifying distances to Sun and Moon we usually use km

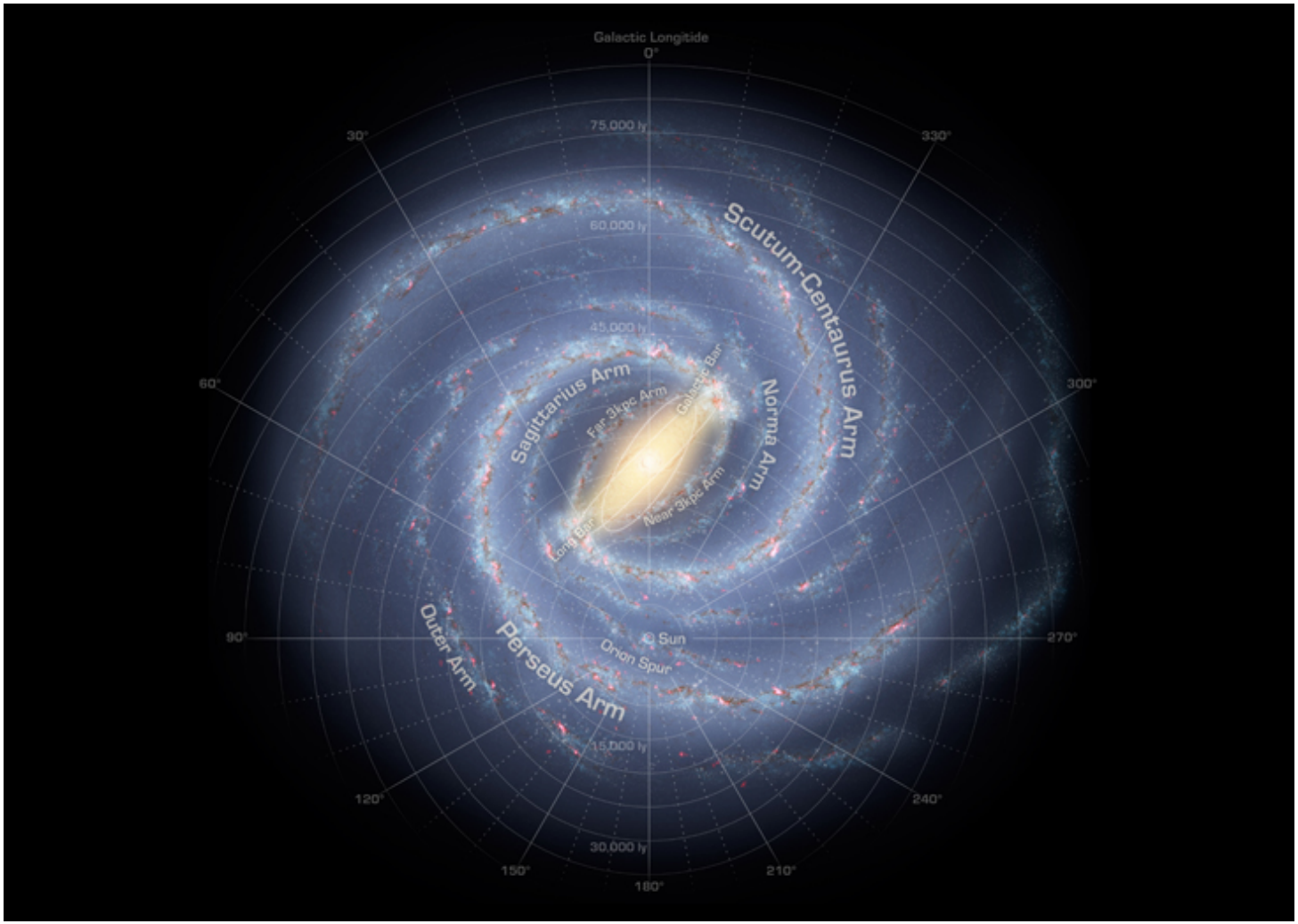


  but we could specify them in terms of light
- Earth-Moon distance is 384,000 km ☞ 1.28 ls.
- Earth-Sun distance is 150,000,000 km ☞ 8.3 lm
- Far out in the solar system
  Pluto is about 6×10^9 km from the Sun ☞ 6×10^{-4} ly
- Nearest star to us ☞ Proxima Centauri is about 4.3 ly away
- Nearest star is 10,000 times farther from us
  than outer reach of solar system

- On clear moonless nights thousands of stars with varying degrees of brightness can be seen ☞ as well as the long cloudy strip known as Milky Way
- Galileo first observed with his telescope that Milky Way is comprised of countless numbers of individual stars
- Half century later (about 1750) Thomas Wright suggested that Milky Way was a flat disc of stars extending to great distances in a plane which we call Galaxy (Greek for “milky way”)

Milky Way over Quiver Tree Forest in southern Namibia

- Galaxy has diameter $\sim 100,000$ ly and thickness $\sim 2,000\ ly$
- It has a bulging central "nucleus" and spiral arms
- Our Sun is located half way from the Galactic center to the edge



some $26,000$ ly from the center

- Sun orbits Galactic center about once every 250 million years
- its speed is

$$v = \frac{2\pi \quad 26,000 \times 10^{13}\ \text{km}}{2.5 \times 10^{8}\ \text{yr}\ 3.156 \times 10^{7}\ \text{s/yr}} = 200\ \text{km/s}$$

- Total mass of all stars can be estimated using orbital data of Sun
- Assume most of the mass is concentrated near center of Galaxy
- Sun and solar system (of total mass m)
  move in circular orbit around Galaxy center (of total mass M)
- Apply Newton's laws

$$\frac{GMm}{r^2} = m\frac{v^2}{r}$$

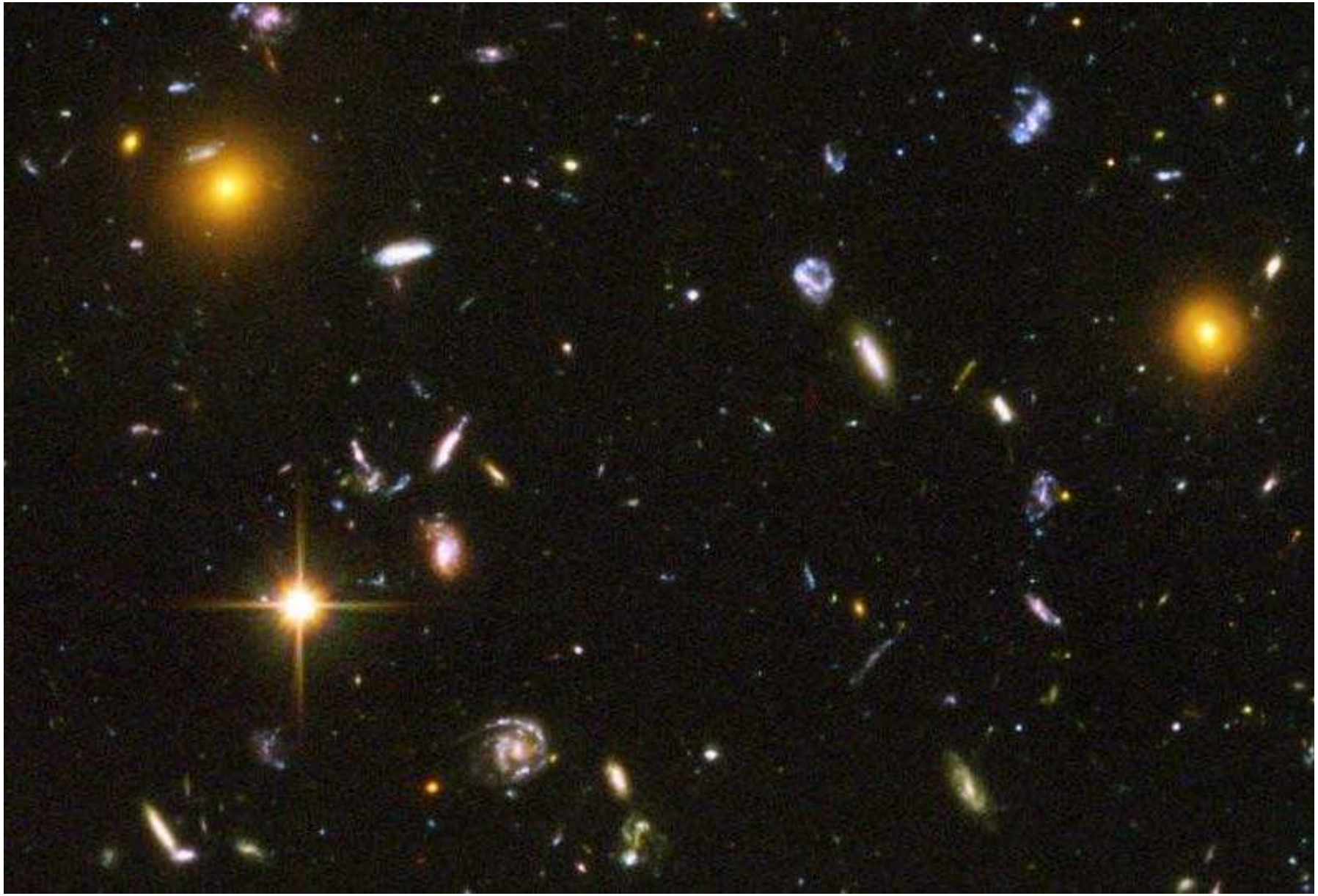
$$G = 6.674 \times 10^{-11}\ \text{N}\,\text{m}^2\,\text{kg}^{-2}$$

$$M = \frac{r\,v^2}{G} \approx 2 \times 10^{41}\ \text{kg}$$

- Assuming all stars in Galaxy are similar to Sun ($M_\odot \approx 2 \times 10^{30}$ kg) we conclude that there are roughly 10^{11} stars in the Galaxy

- In addition to stars we can see with telescope
  many faint cloudy patches that were once called “nebulae”
- Those in the constellations of Andromeda and Orion
  can actually be discerned with naked eye on clear night
- At first it was not universally accepted
  that these objects were extragalactic
- Very large telescopes constructed in XX century
  resolved individual stars within these extragalactic objects
  that also contain spiral arms
- It became logical that nebulae must be galaxies similar to ours
- Distance to nearest spiral galaxy ☞ Andromeda over 2 million ly
  a distance 20 times greater than the diameter of our Galaxy
- Today it is thought there are $\sim 4 \times 10^{10}$ galaxies
  that is as many galaxies as there are stars in the Galaxy

Deep field of view as seen by Hubble Space Telescope

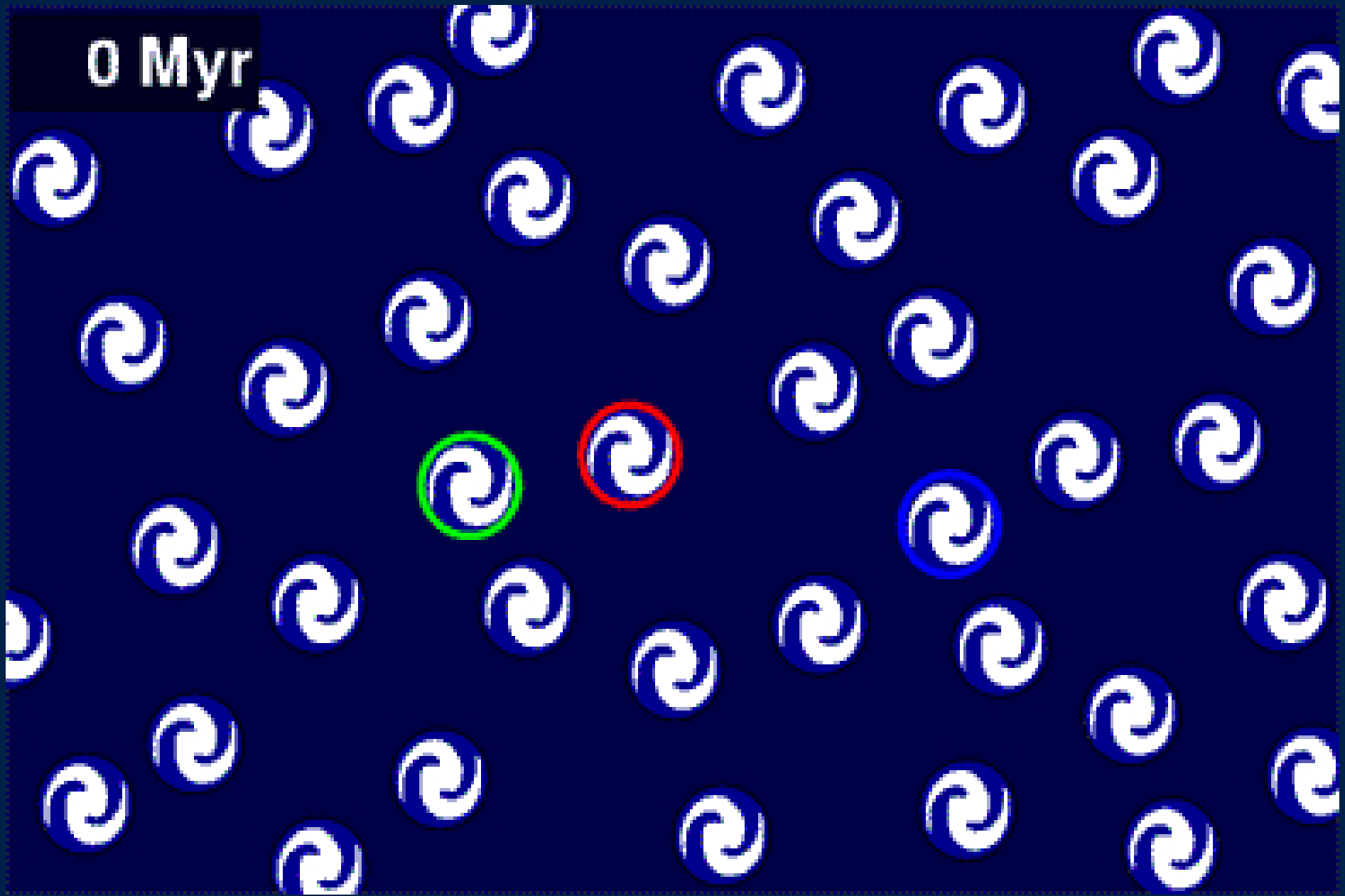


Hubble's law of cosmic expansion

- In late 1920's ☞ Hubble discovered that
  spectral lines of galaxies were shifted towards red
  by an amount proportional to their distances
- If redshift is due to Doppler effect
  this means galaxies move away from each other
  with velocities proportional to their separations
- This what we expect according to simplest possible picture
  of flow of matter in expanding universe
- Observer at any point in universe
  will observe distant galaxies receding from him/her
  with radial velocities proportional to their distance from observer

$$V = H_0 \times d$$

- Hubble constant ☞ $H_0 \approx 22.4\ \mathrm{km/s}$ per million light years


0 Myr

- All organisms living on Earth
  require C-based chemistry in liquid water
- According to hot Big Bang model ☞ life (as we know it)
  could not have appeared earlier than $t \sim 10\,\mathrm{Myr}$ after the Bang
  'cause Universe was bathed in thermal radiation background
  above boiling temperature of liquid water
- After $10 \lesssim t/\mathrm{Myr} \lesssim 17$ Universe cooled down
  to habitable comfortable temperatures ☞ $273 \lesssim T/\mathrm{K} \lesssim 373$
- Each star is surrounded by an habitable zone
  defined as the orbital range around star
  within which surface liquid water could be sustained
- Since water is essential for life as we know it
  search for biosignature gases naturally focuses on planets
  located in habitable zone of their host stars

- Total energy flux $\mathscr{F}$ (energy per unit area per unit time) passing through a region can be related to effective temperature T

$$\mathscr{F} = \sigma_{\rm SB}\, T^4$$

Stefan-Boltzmann constant ☞ $\sigma_{\rm SB} \approx 5.67 \times 10^{-8}\ \mathrm{W\,m^{-2}\,{}^{\circ}K^{-4}}$

- Luminosity (energy per unit time) of star is L and flux at distance r from the star are related by

$$\mathscr{F} = \frac{L}{4\pi r^2}$$

because area of sphere of radius r is $A = 4\pi r^2$ and flux is luminosity divided by area

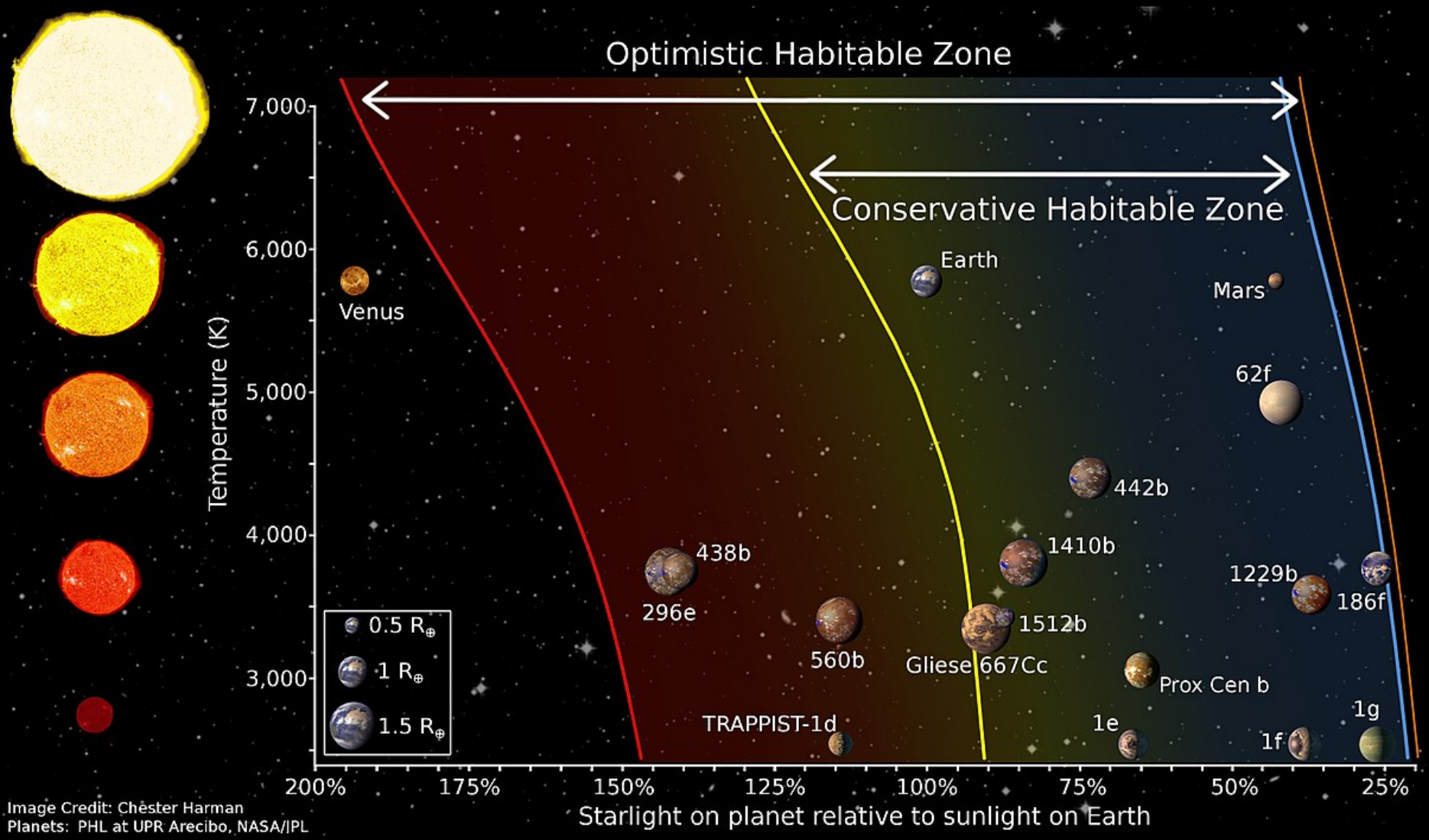
- Quick estimate of T at given r from

$$\sigma_{\rm SB}\, T^4 = \mathscr{F} = \frac{L}{4\pi r^2}$$

For solar system ☞ $\sigma_{\rm SB}$, 4π, $L_\odot$ are constants

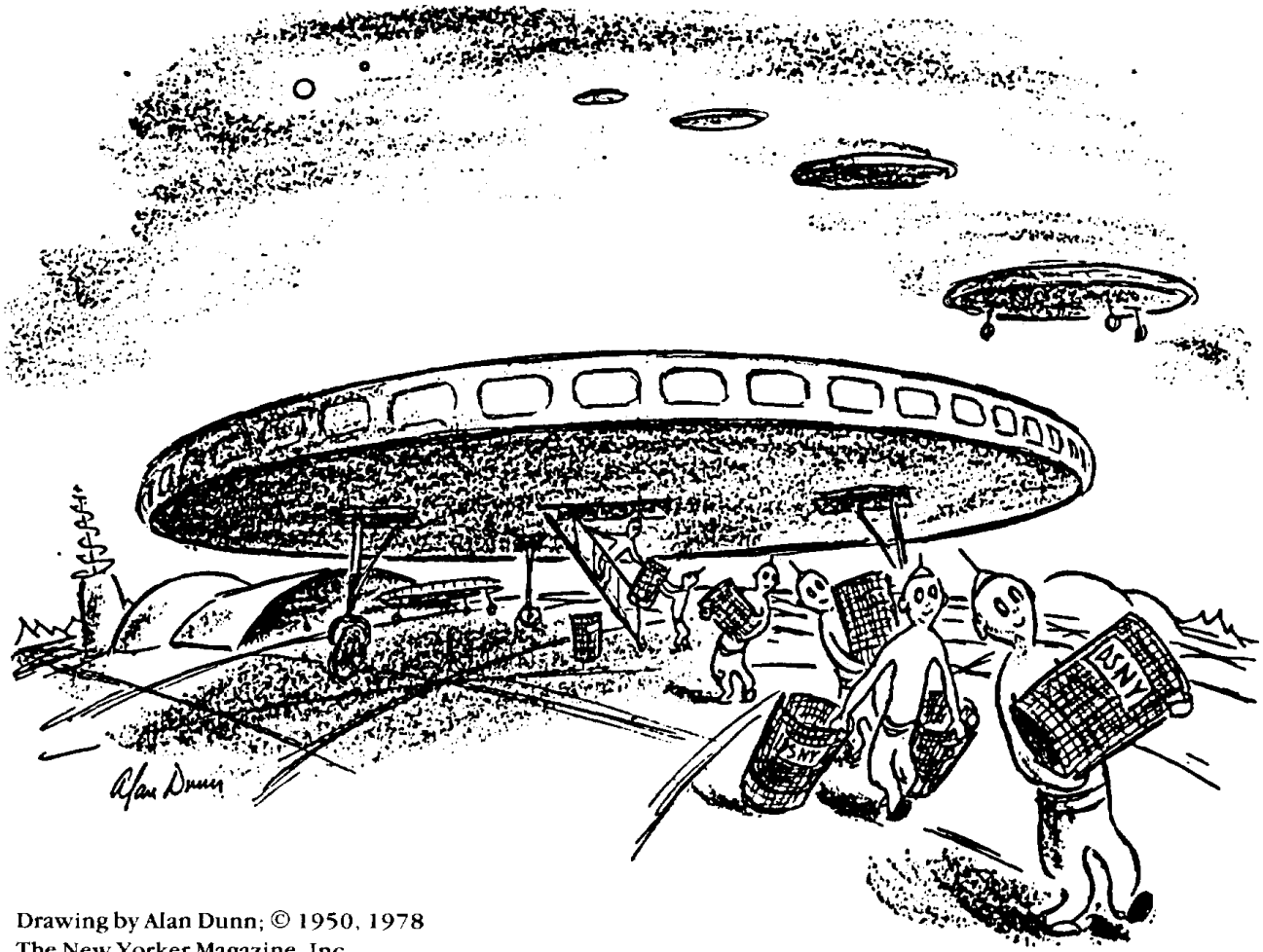
$$T^4 \propto \frac{1}{r^2} \Rightarrow T \propto r^{-1/2}$$

Habitable zone regions



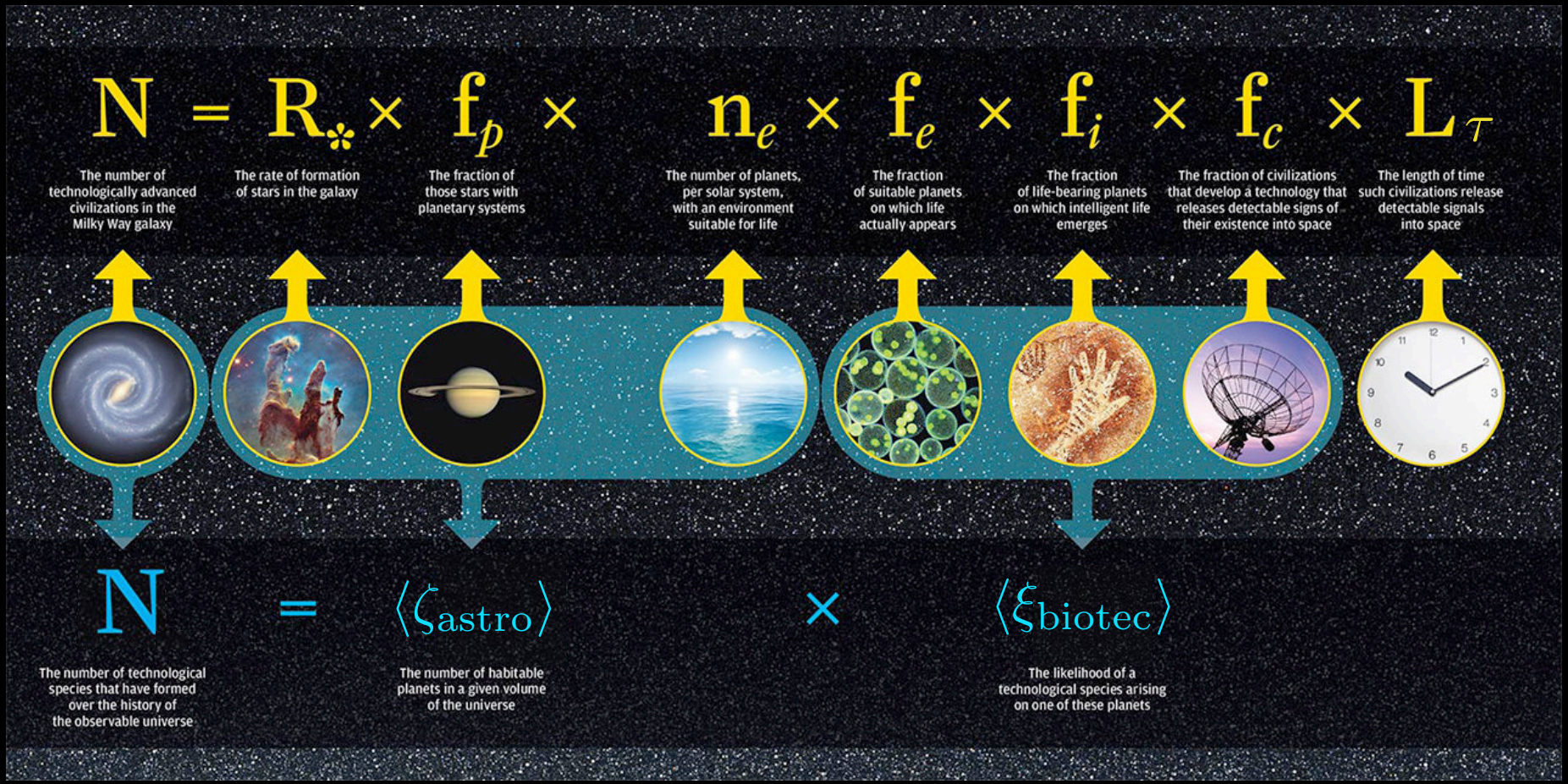
Fermi paradox

Discrepancy between strong likelihood of alien intelligent life
(emerging under a wide variety of assumptions)
and absence of any visible evidence for such emergence



Drawing by Alan Dunn; © 1950, 1978
The New Yorker Magazine, Inc.

Drake's equation



- $\langle \zeta_{\rm astro} \rangle \sim 0.002\ {\rm yr}^{-1}$ and $\xi_{\rm biotec} \leq 1$
- If the communicative phase is smaller than 500 years there would be no paradox