"Instead of studying for finals, what about just going to the Bahamas and catching some rays? Maybe you'll flunk, but you might have flunked anyway; that's my point."

Jack handy

Check your blackboard grades. After Wednesday, they are considered accurate. Lab grades are provided by lab instructors, not me.

Group Project 2 and HW4 solutions are posted on the course web page.

Total in-class points: 690
Lab points: 230
Total Course Points: 920
A: 920-824, B:823-732, C:731-639

We will NOT MEET during our final time. I will be available on **zoom** during test time **(Wednesday, May 8 11am-1pm)**, in case you wish to take the test in a 'live' setting.

Test 3 and the Comprehensive Final will be on blackboard.

Tests will be timed: Test 3 has 60 minutes, Comprehensive Final has 120 minutes.

Tests will be available May 1 until May 8 @1pm

Big Bang predictions which have been observed

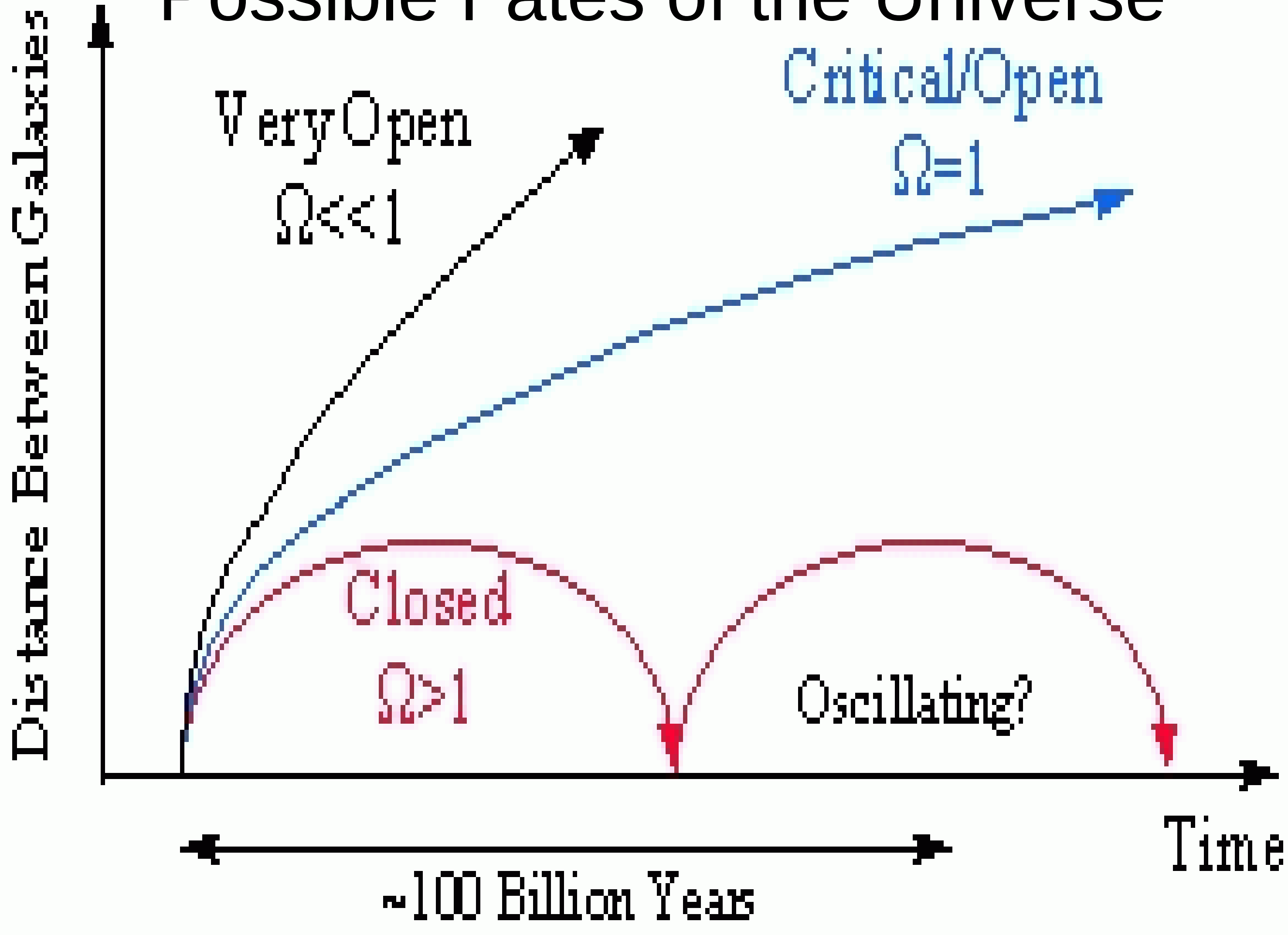
1) Expanding Universe

2) Nucleosynthesis: 75%H, 25% He, no ‘metals’ (Pop III stars)

3) The cosmic microwave background (CMB). The ‘bang’ of the big bang which occurred at recombination.

4) Tiny variations in the CMB: to make galaxies & galaxy clusters.

Possible Fates of the Universe



$\Omega = \rho/\rho_{crit}$ = the actual density over the critical density.

Closed, open, or critical?

Now that we know the 'magic number,' how can we tell if we have enough mass to close the Universe?

This image was taken with the Hubble Space Telescope. The exposure time was 11.3 days in the constellation of Fornax.

Calculating the Density of the Universe!

1) Count the number of galaxies in the image.
2) Multiply by the number of images it would take to cover the entire sky.
This gives the total number of galaxies in the Universe (about 100 Billion!)
3) Multiply by the average mass of a galaxy.
This gives the total mass of the Universe.
4) Divide by the volume of the Universe (assume a size based on its age).
This gives the density of the Universe.
5) Divide by the critical density to find out if it's open, closed, or critical.

Density of the Universe!

From the Hubble deep fields:

Ω=0.26!

According to this calculation, the Universe will

e x p a n d f o r e v e r

Fate of the Open Universe

What happens to the Universe as it ages?

Fate of the Open Universe

The Universe continues to expand forever.

Summary:

Stars form from remaining gas in galaxies.

Eventually star formation will stop.

Galaxies dissolve into free-floating stars

Stars dissolve into fundamental particles

Black holes evaporate

Universe is dark, non-interacting fundamental particles and low, low, low energy photons.

Possible Fate #1: Open Universe

Eventually the gas is used up and no new stars will form.

At 1 trillion (10^{12}) years after the big bang, all stars have reached their end products, leaving only white dwarfs, neutron stars and black holes.

1000000000000 years

Possible Fate #1: Open Universe

At 10^{18} (1 million trillion) years after the big bang, Galaxies dissolve. Interactions between dead stars fling some out into the inter-galactic space. Over time, this removes the dead stars from the galaxies.

1000000000000000000 years

Possible Fate #1: Open Universe

At 10^{45} years after the big bang, protons are decaying. When the protons go, so do the neutrons. White dwarfs and neutron stars turn into a cloud of electrons, positrons, and photons.

100000000000000000000000000000000000000000
0000 years

Possible Fate #1: Open Universe

At 10^{65} years after the big bang: Stellar mass black holes evaporate.

100000000000000000000000000000000000000000000000000000000000000000 years

Possible Fate #1: Open Universe

At 10^{100} years after the big bang; supermassive black holes evaporate. The Universe consists of nothing but neutrinos, electrons, positrons and photons, so spread out that nothing interacts.

The Universe continues to expand and cool forever.

10000000000000000000000000000000000000
00000000000000000000000000000000000000
0000000000000000000000000 years

Possible Fate #1: Open Universe

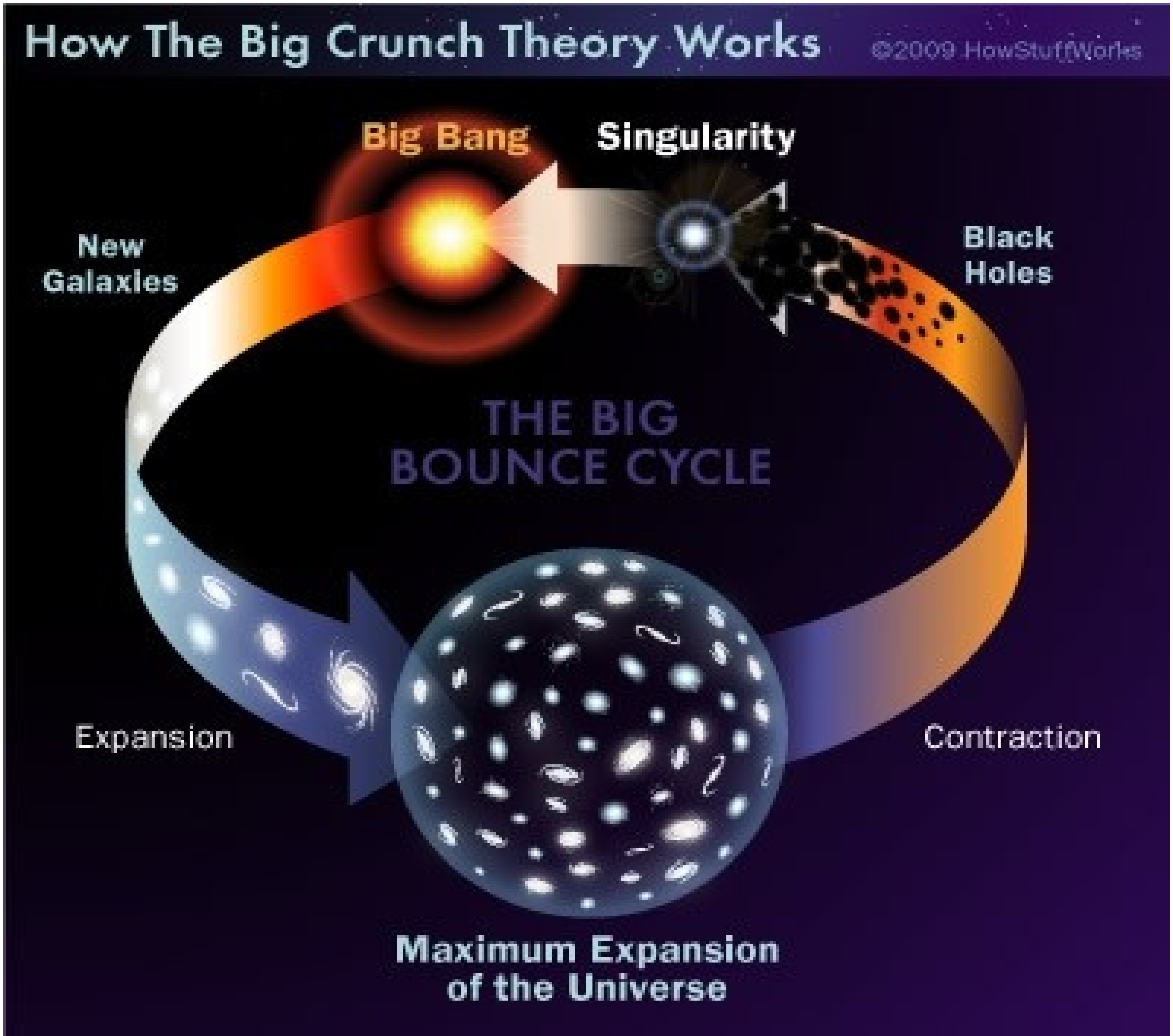
This is called the cold, dark death. (Cheery, isn't it?)

10000000000000000000000000000000000000000
0000000000000000000000000000000000000000
000000000000000000000000000 years

Possible Fate #2: critical case

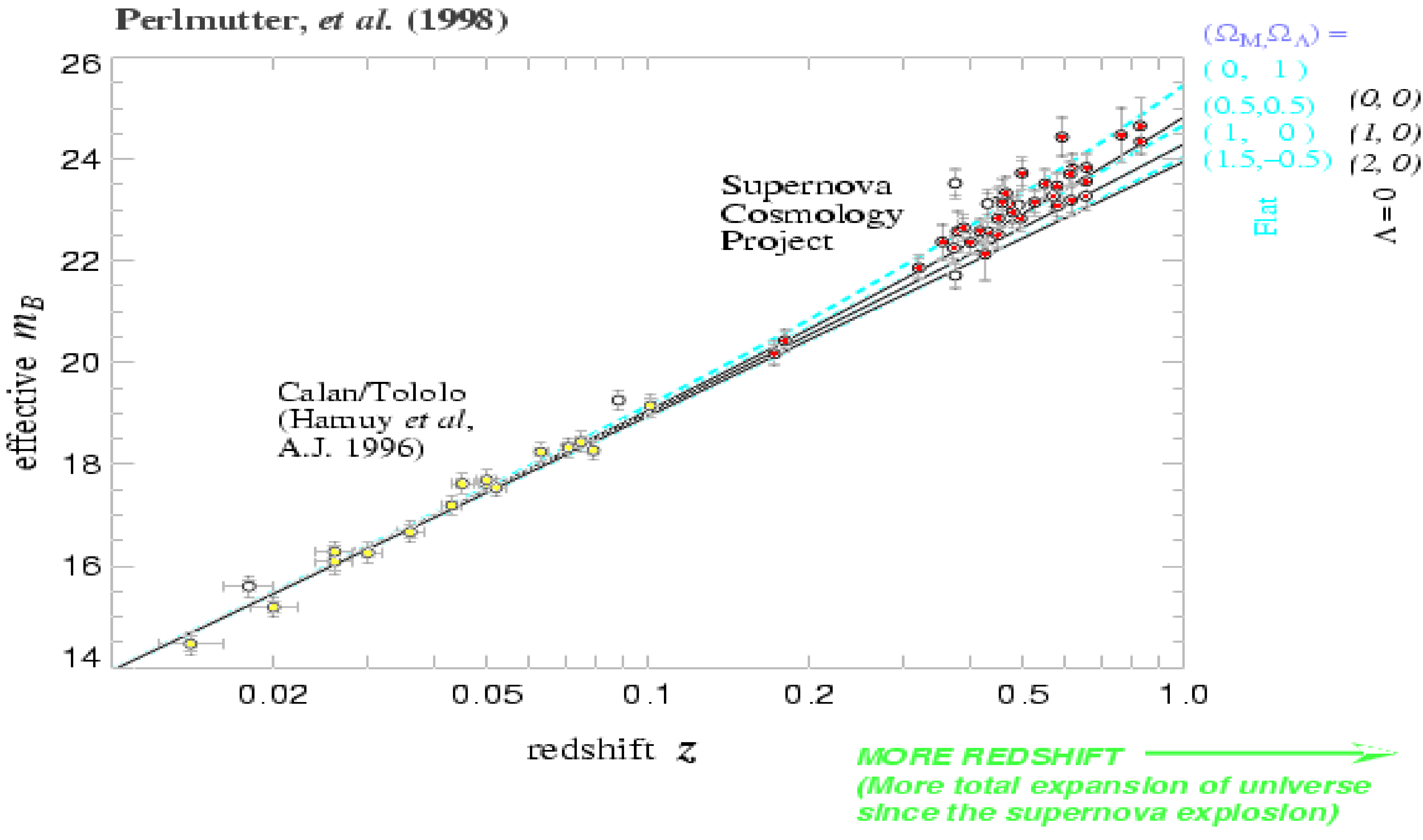
In this case, the fate is the same as in Fate #1. The Universe eventually dies a cold death.

Possible Fate #3: Closed Universe



But there's a surprise!

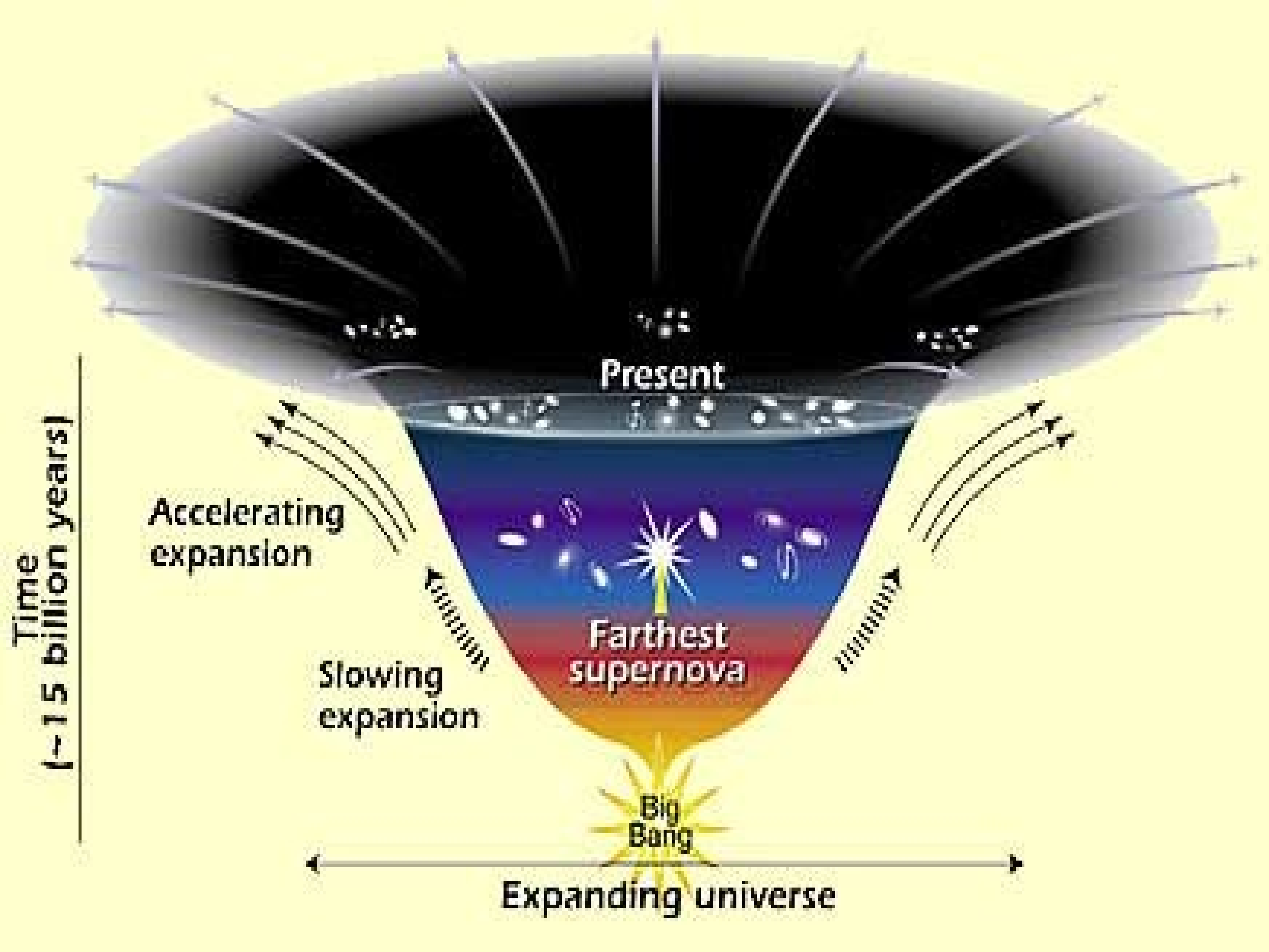
In the 1990s, using Type I supernova, astronomers have learned that the Universe is actually *accelerating* rather than slowing down.



Dark Energy Ω_Λ

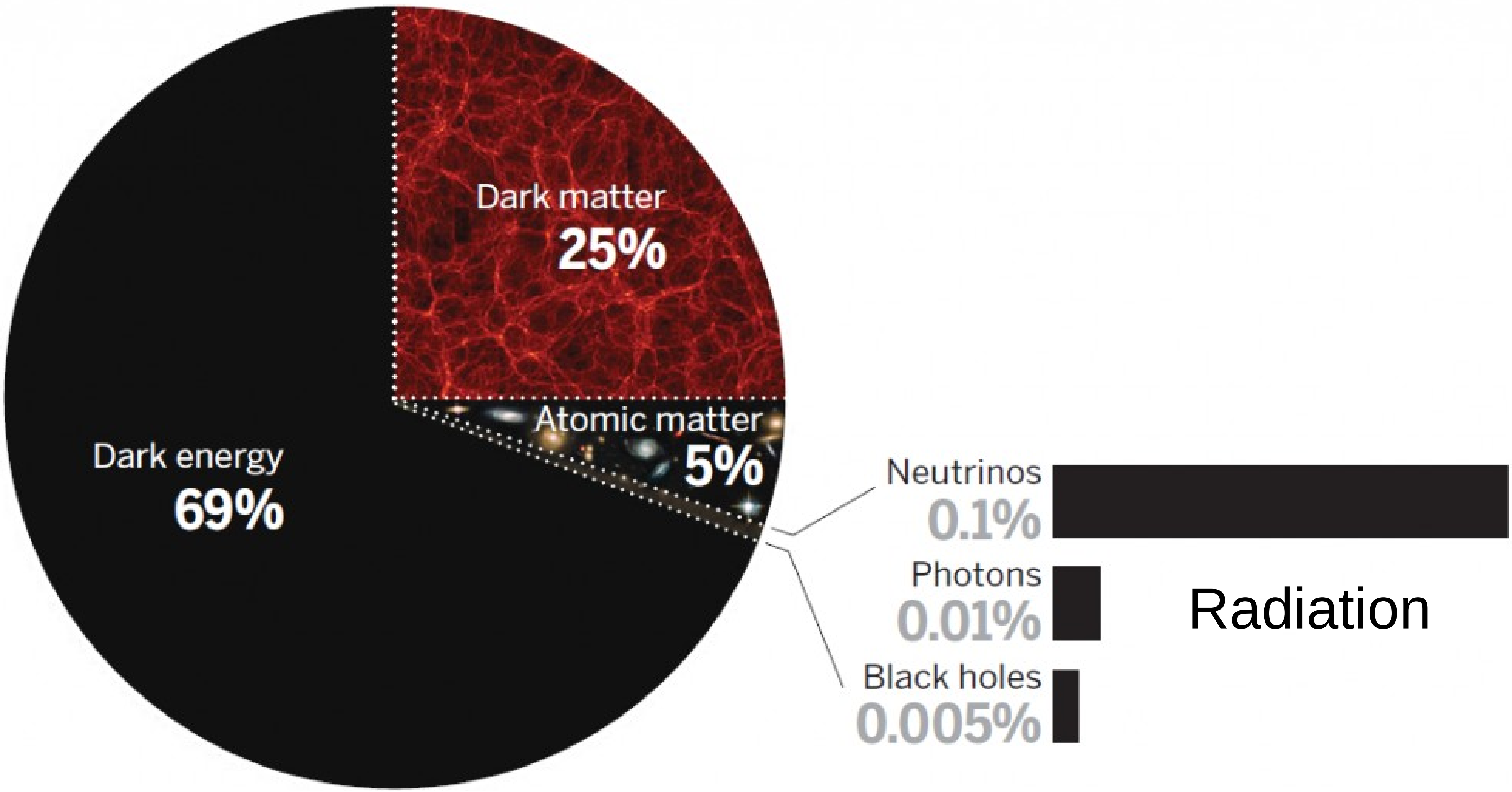
A new force that is causing the Universe to expand quicker as it grows in size.

It seems to be caused by a lack of matter.

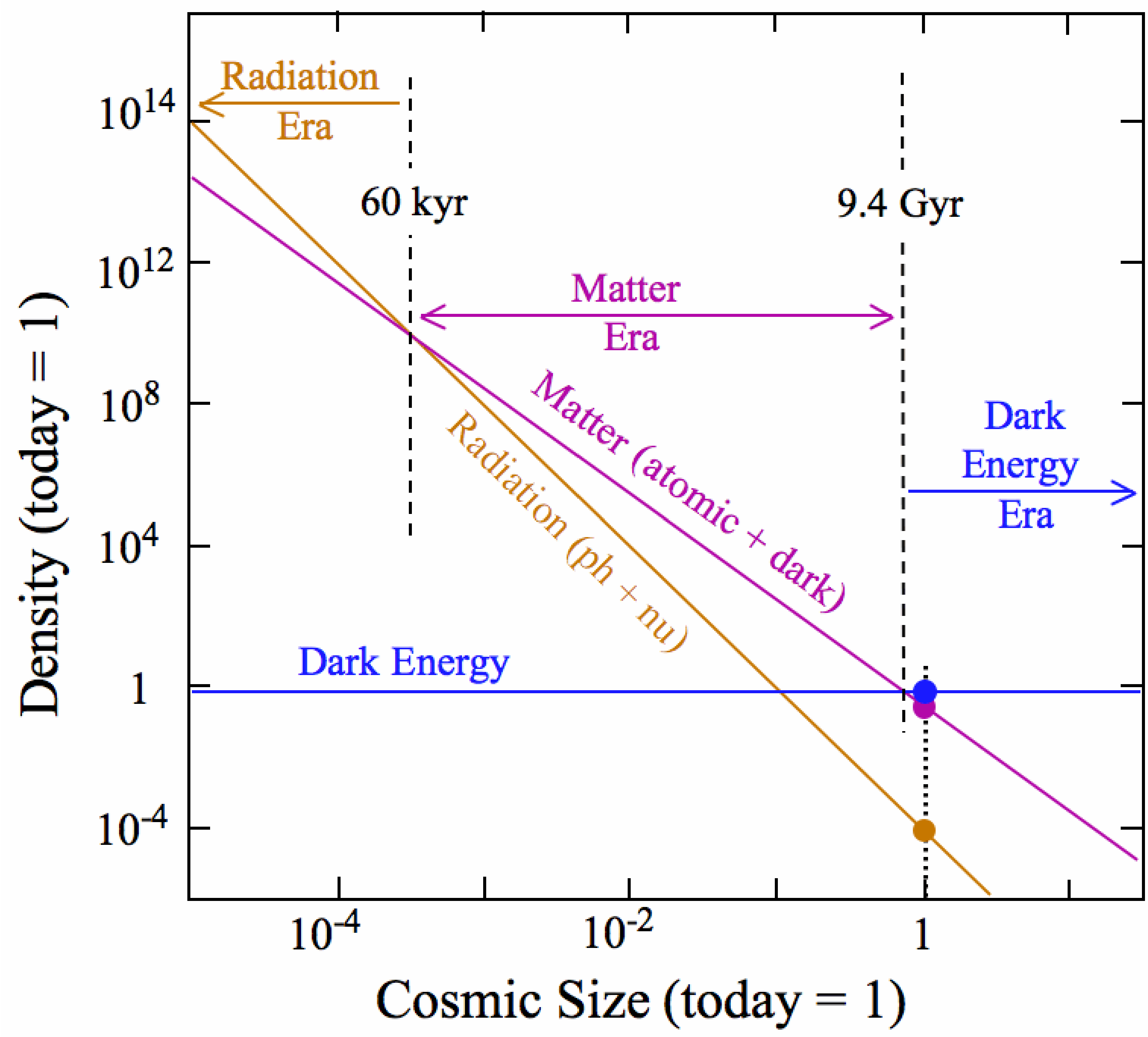

Present
Accelerating
expansion
Farthest
supernova
Slowing
expansion
Time
(~ 15 billion years)
Big
Bang
Expanding universe

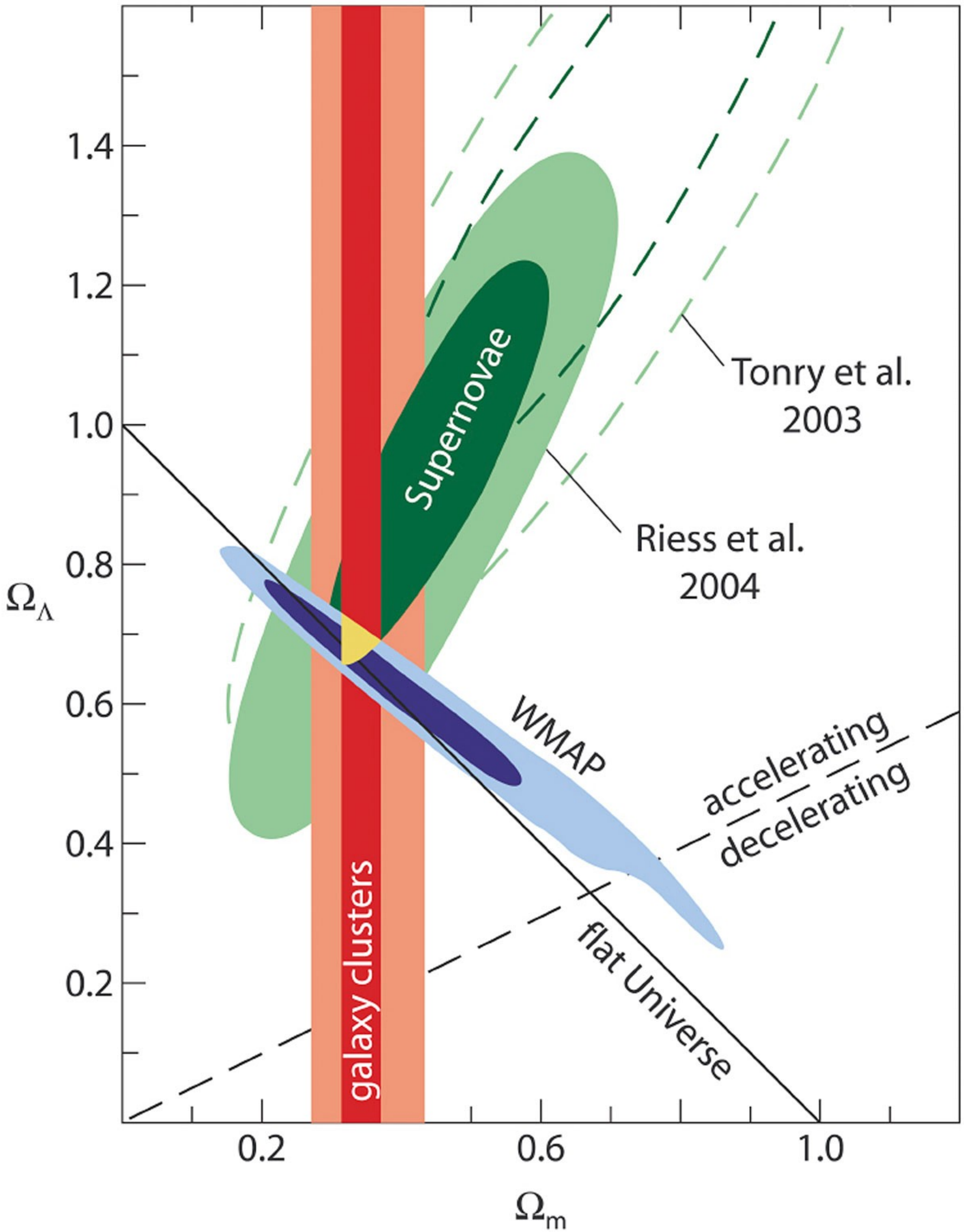
The multiple components that compose our universe

Current composition (as the fractions evolve with time)



As the Universe expands, it changes





Results of all these (and more) measurements!

Evidence suggests the Universe is flat and will expand forever (accelerating).

Quiz 17, question 1.

Most of the ‘regular’ matter (mass we can see and measure) in our Universe is made of what?

A) H

B) He

C) ‘metals’

D) Dark matter

E) Dark energy

Quiz 17, question 2.

Most of the matter (mass) in our Universe is made of what?

A) H

B) He

C) ‘metals’

D) Dark matter

E) Dark energy

Quiz 17, question 3.

Most of our Universe, in total, is made of what?

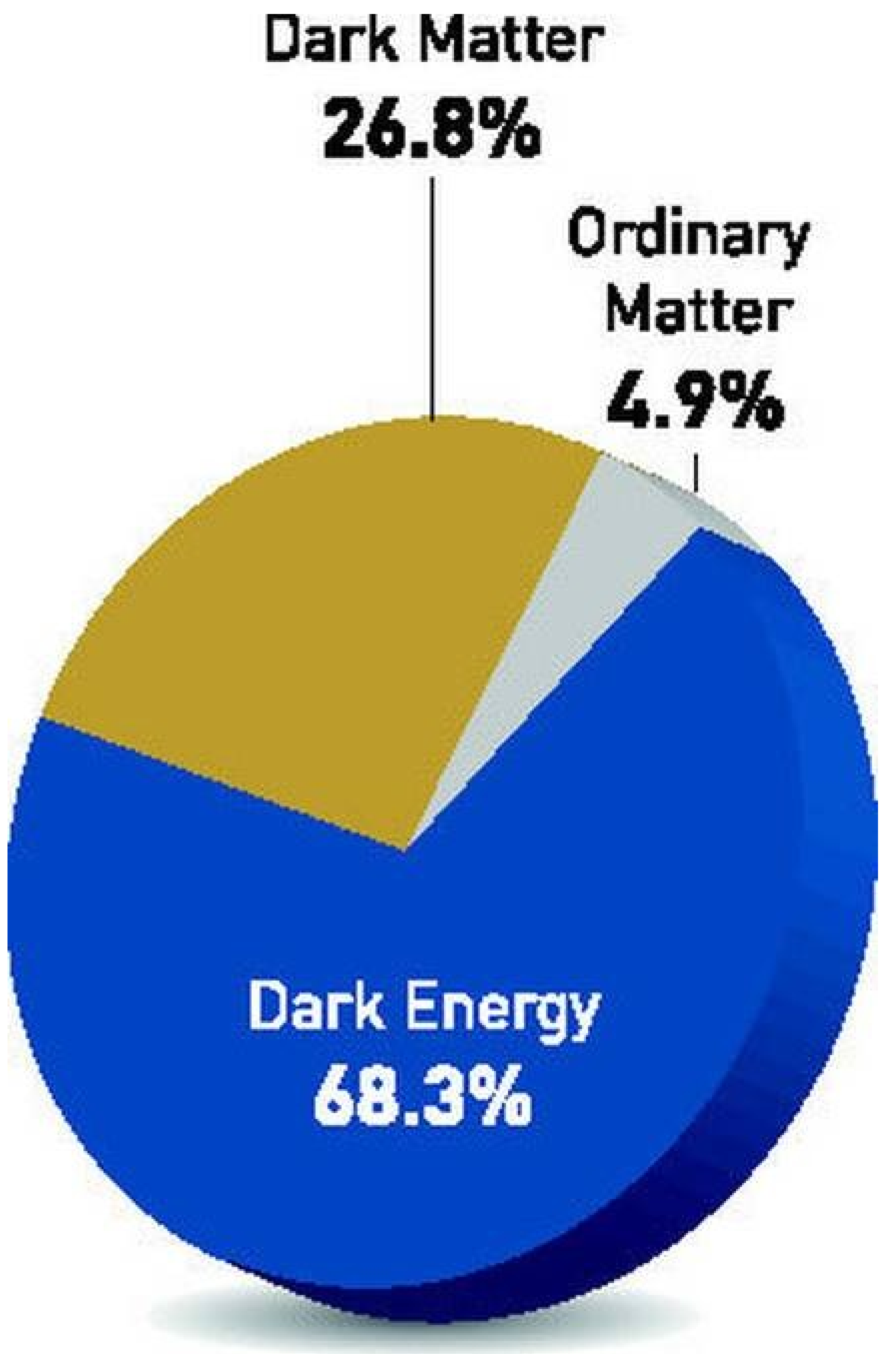
A) H

B) He

C) ‘metals’

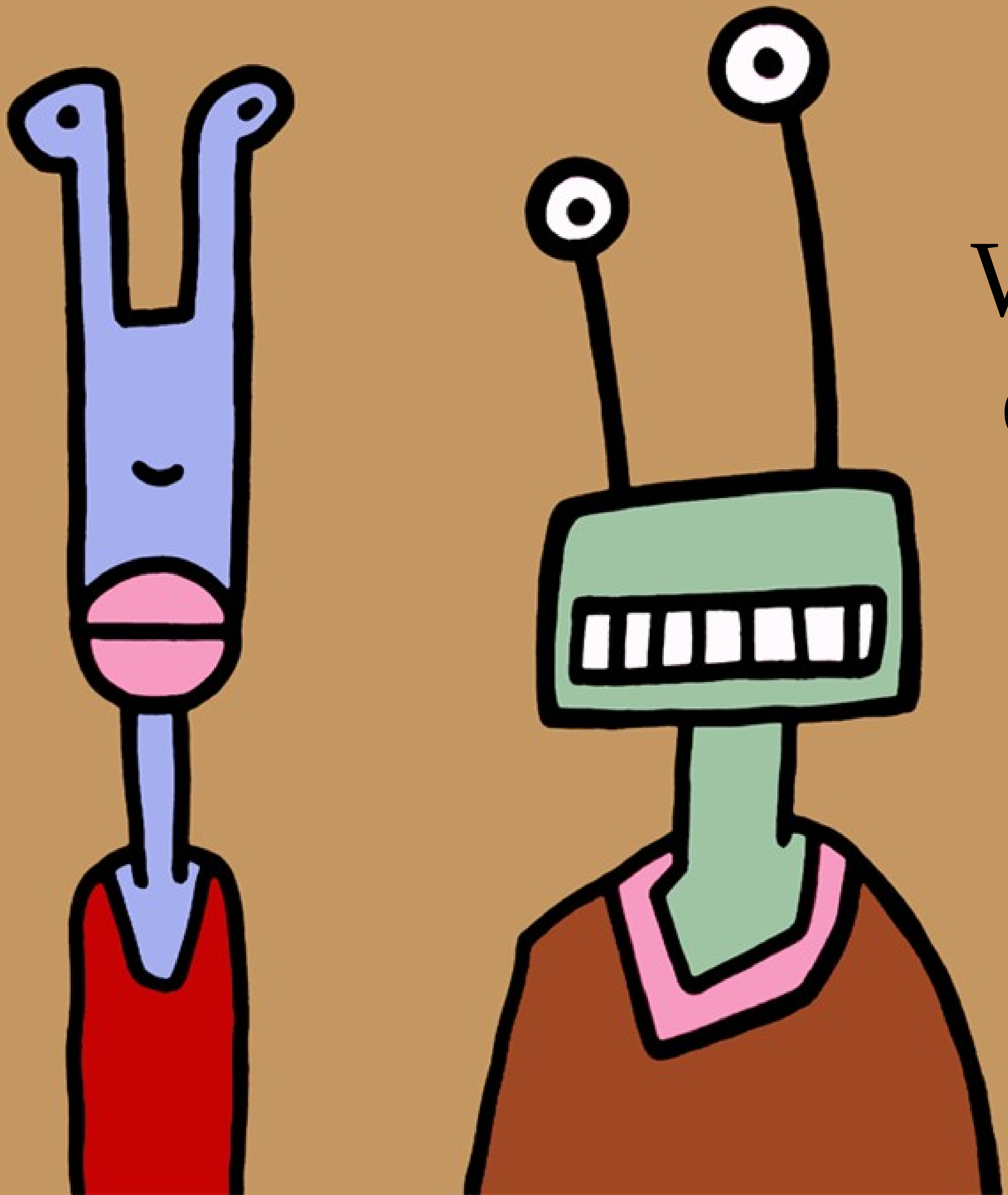
D) Dark matter

E) Dark energy

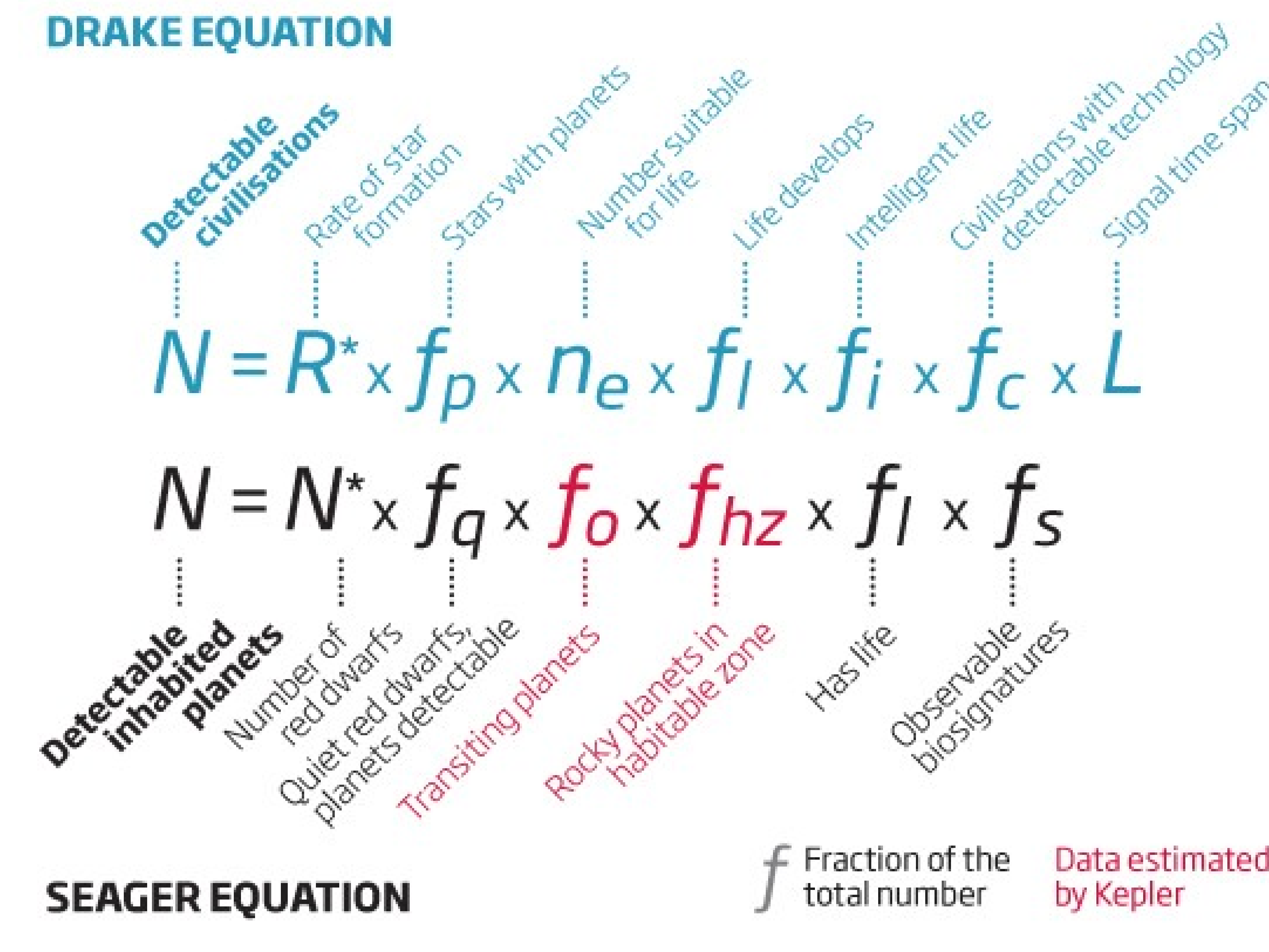


70% H

Life in the Universe



What are the chances that life exists elsewhere?


DRAKE EQUATION
Detectable civilisations
Rate of star formation
Stars with planets
Number suitable for life
Life develops
Intelligent life
Civilisations with detectable technology
Signal time span
$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$
$N = N^* \times f_q \times f_o \times f_{hz} \times f_l \times f_s$
Detectable inhabited planets
Number of red dwarfs
Quiet red dwarfs, planets detectable
Transiting planets
Rocky planets in habitable zone
Has life
Observable biosignatures
SEAGER EQUATION
f Fraction of the total number
Data estimated by Kepler

Summary

We can estimate the likelihood of aliens existing.

- The Drake Equation has us as listeners. The aliens have to (be active participants) make the noise.
- The Seager Equation has us searching. We only have to measure the chemistry of planet atmospheres (currently not possible).

Drake: $N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$

Astronomical factors: R = Rate of star formation. f_s= the fraction of those stars that are like our Sun. f_p=the fraction of Sun-like stars with planets. n_e= the number of planets in the *habitable zone*, where liquid water exists.

Biological factors: f_l=fraction of those planets on which life develops. f_i=fraction of developing life that evolves intelligence.

Sociological factors: f_c=fraction of intelligent life that communicates. L = lifetime of societies that can communicate with us.

The Seager Equation

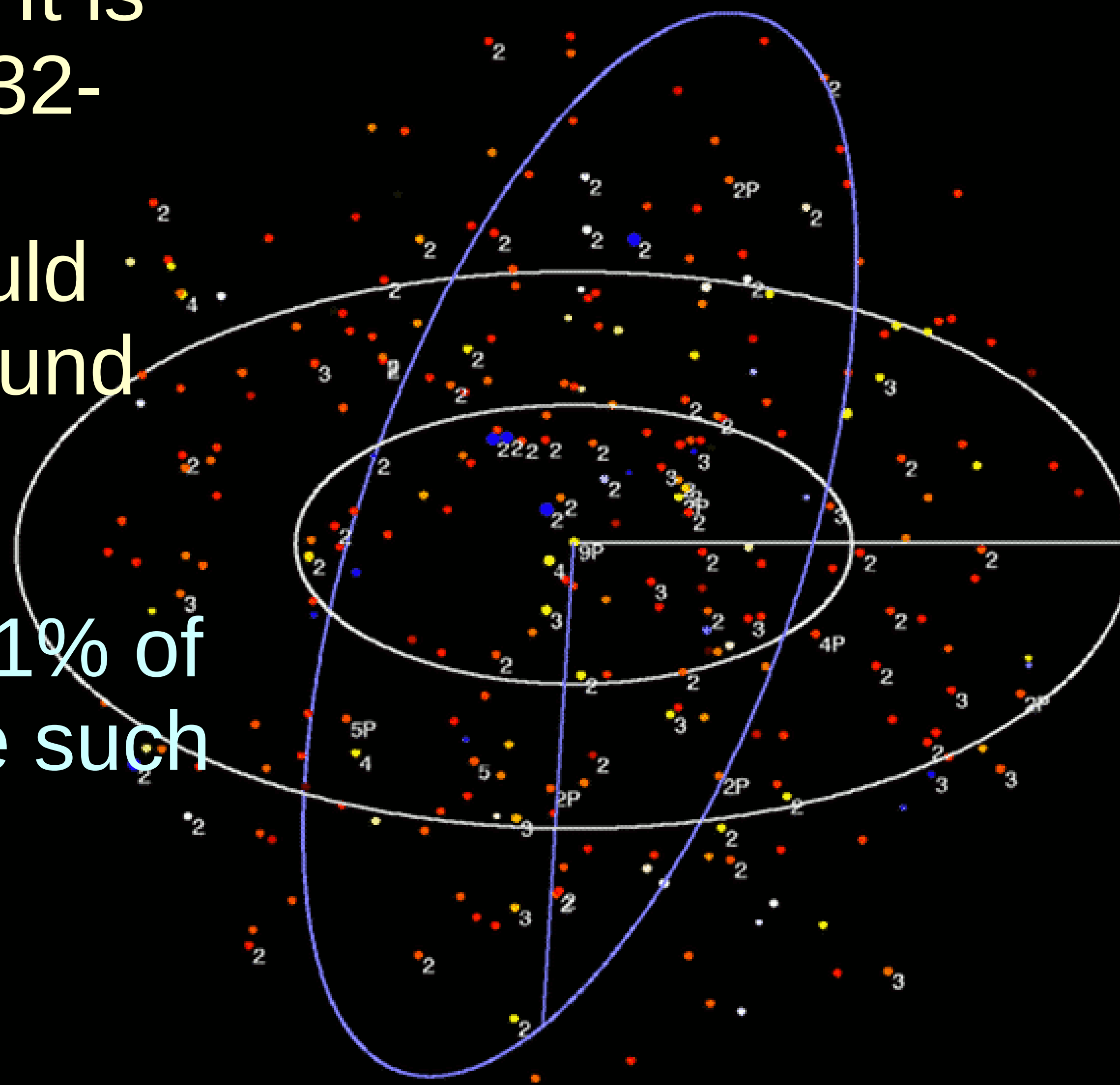
$$N = N_* F_Q F_{HZ} F_o F_L F_S$$

Astronomical factors: N_* = Rate of star formation. f_Q= the fraction of stars that are quiet. f_{HZ}=the fraction of stars with Earth-like planets. F_O= the fraction of planets that can be observed.

Biological factors: f_l=fraction of those planets on which life develops. f_s=fraction of life that produces something detectable.

Within 10pc (33.6ly) there are 259 star systems. It is estimated there are 132-160 Earth-like planets where liquid water could exist: 6-9 of these around Sun-like stars.

It is estimated that ~11% of all Sun-like stars have such planets.

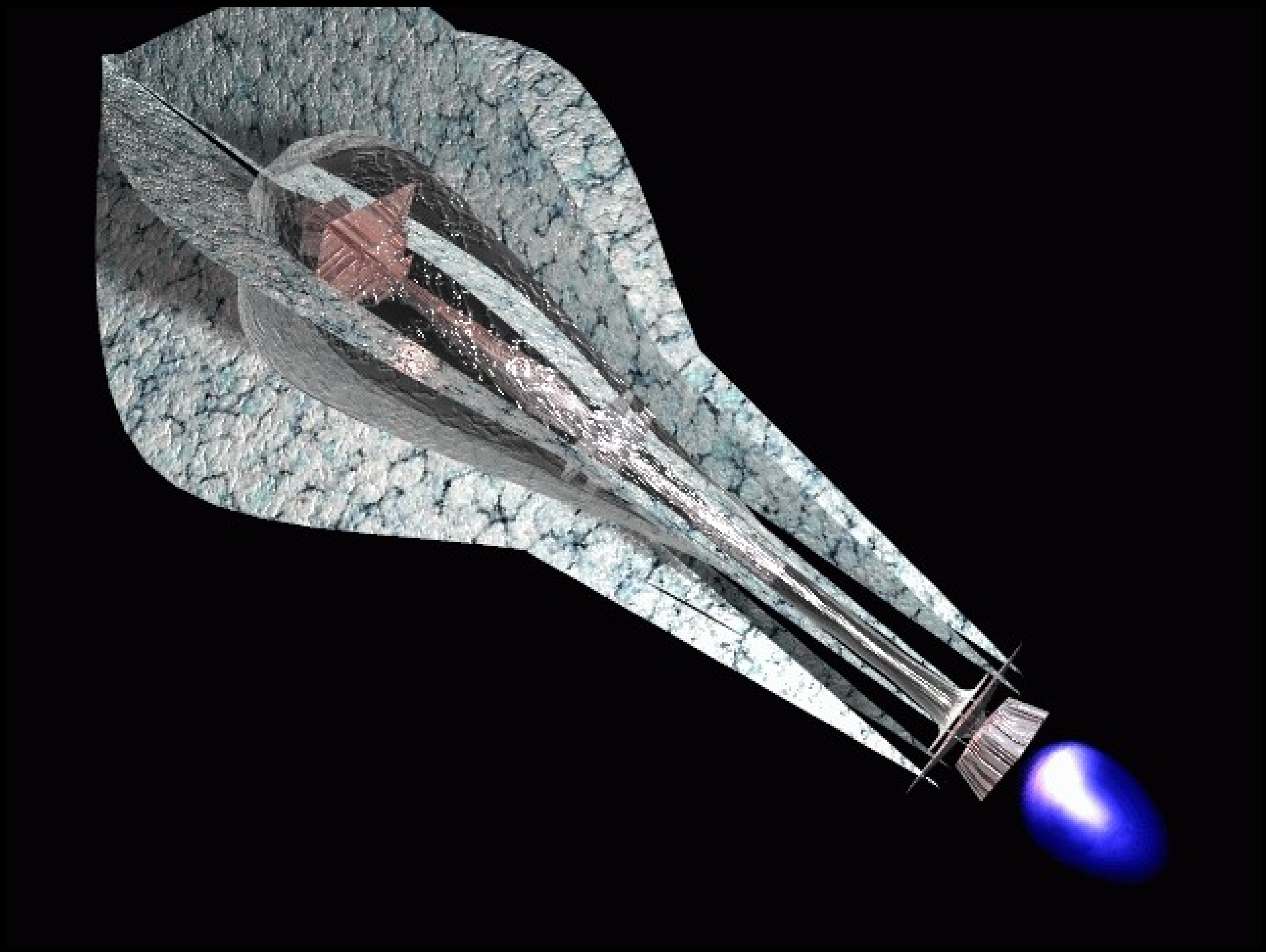


The numbers are staggering!

- Within 10pc there could 160 habitable planets.
- 40-49 Billion habitable planets in our galaxy. Earth is <1/2 the age of our disk.
- 4.2-5.3 Trillion habitable planets in our Universe.

Earth is 1/3 the age of the Universe

The Fermi Paradox: If it's so likely there are aliens, where are they?

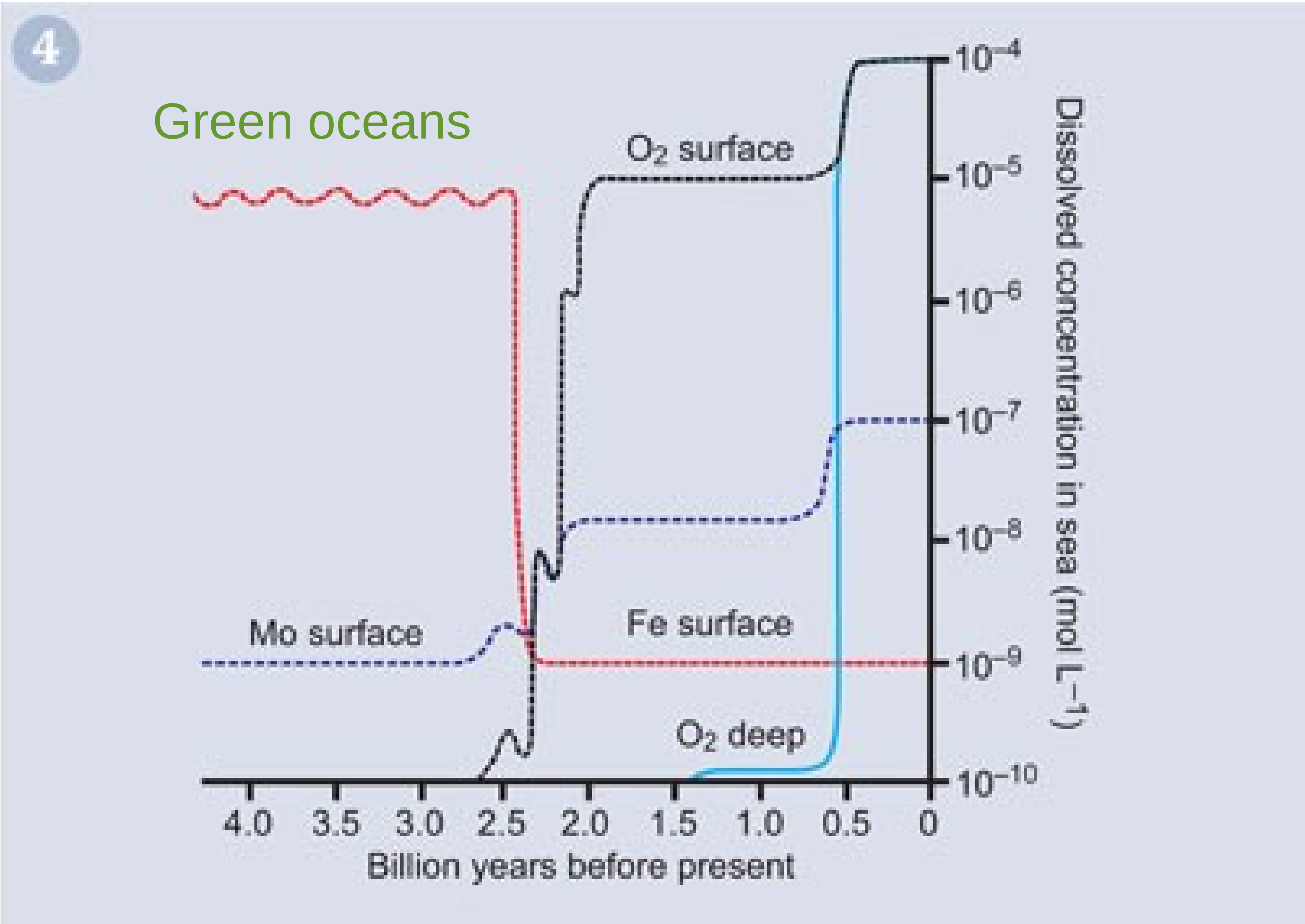


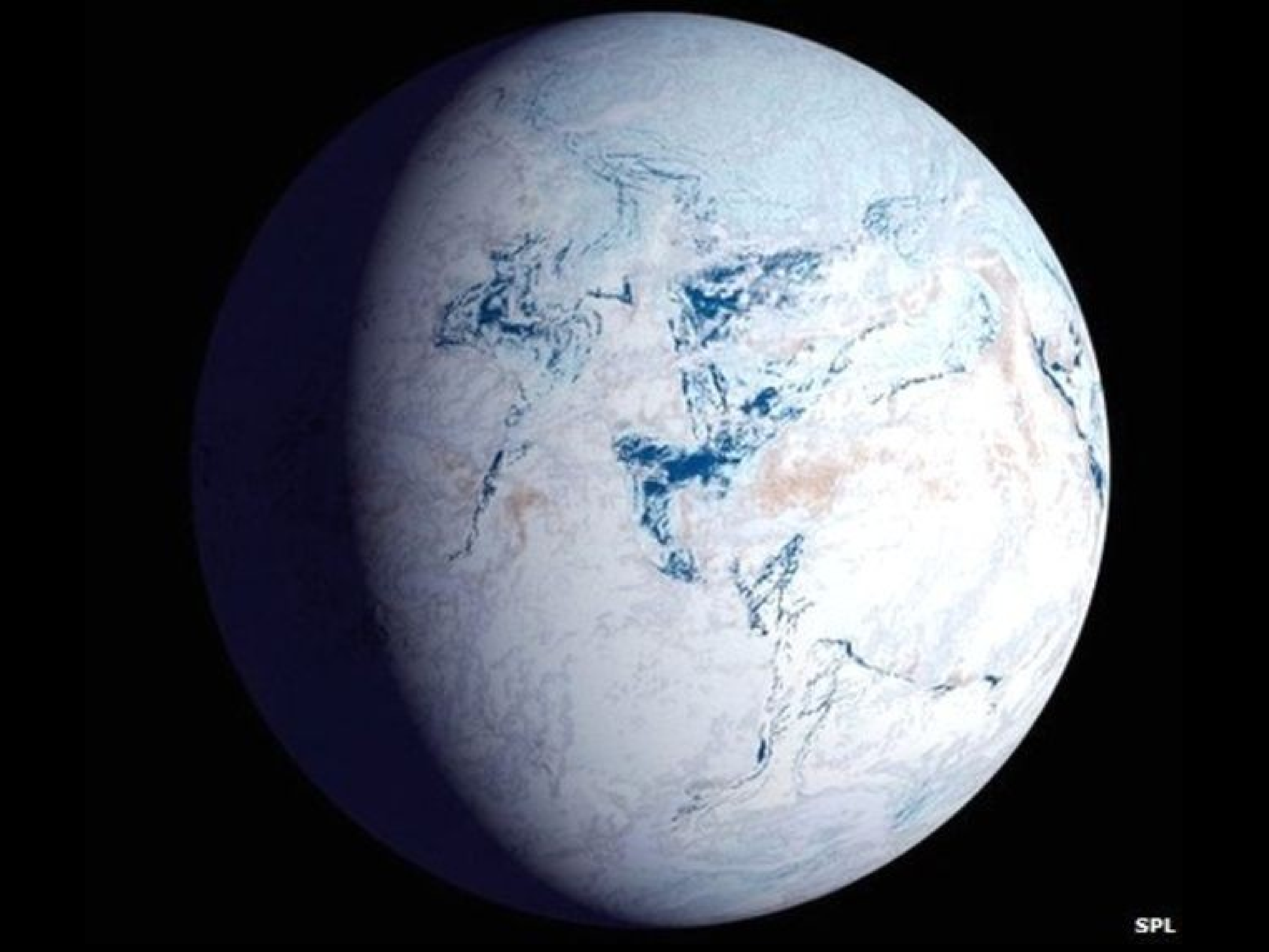
Astrobiology

All known life on Earth requires 6 elements:
H, O, C, N, S, and P

….and time: The Earth formed 4.6 Gyrs ago,
simple life may have started soon thereafter (at least 3.8 Gyrs ago)
Multicellular life only 570 Myrs ago,
Land-based life only 475 Myrs ago (~10% Earth's age).

And oxygen in our atmosphere only ½ that time




SPL

The End

Questions?