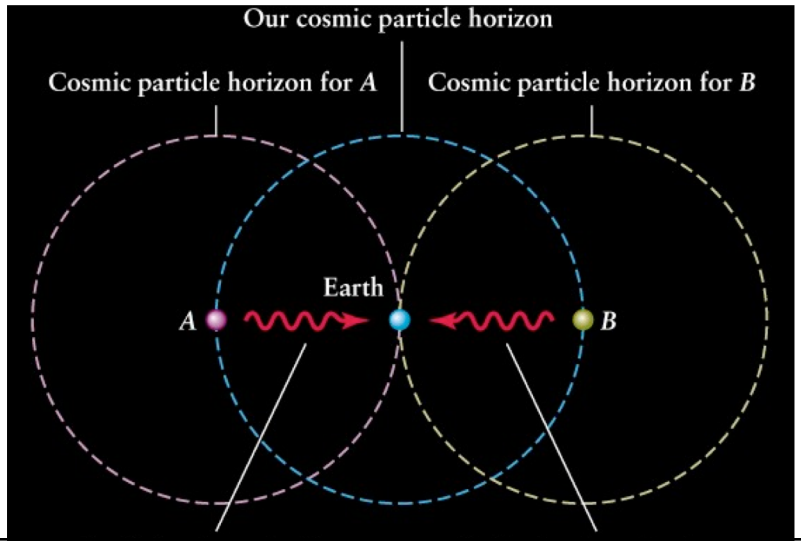
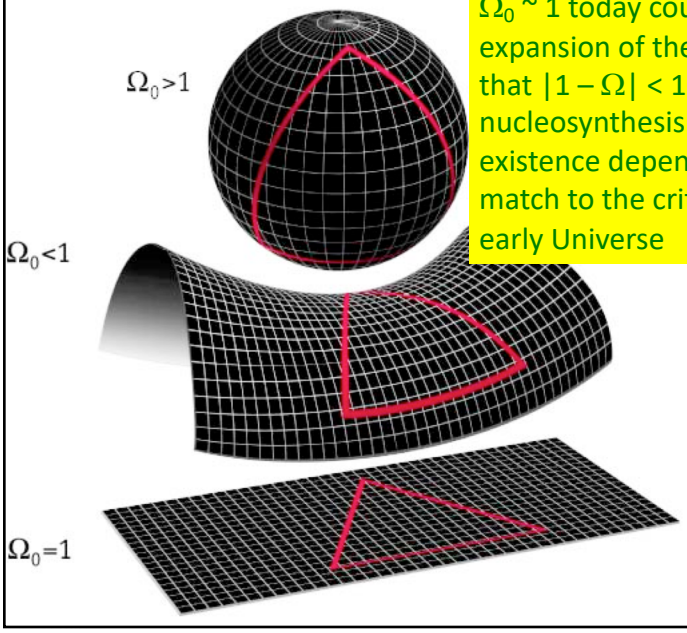
The Horizon Problem (or causality problem)

Antipodal points in the CMB are separated by ~ 1.96 $r_{horizon}$.
Why then is the temperature of the CMB constant to ~ 10^{-5} K?

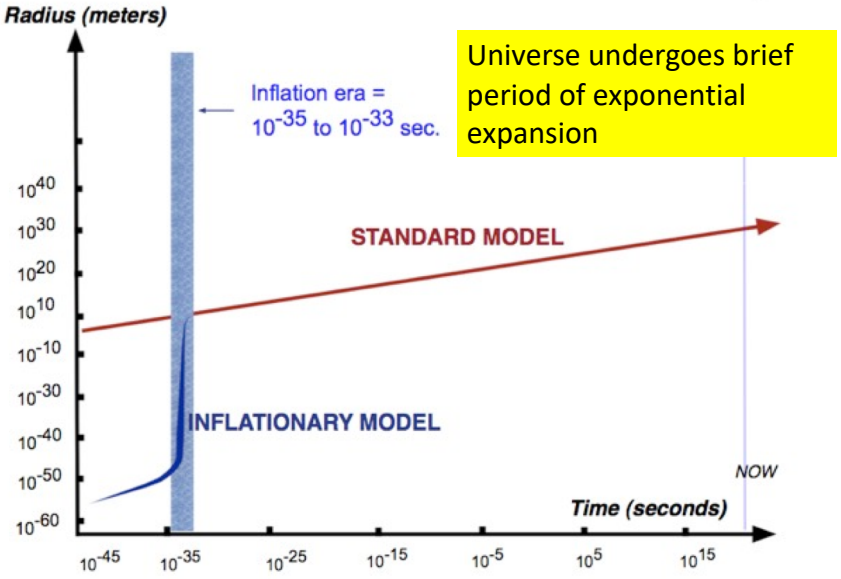


The Flatness Problem (or fine tuning problem)

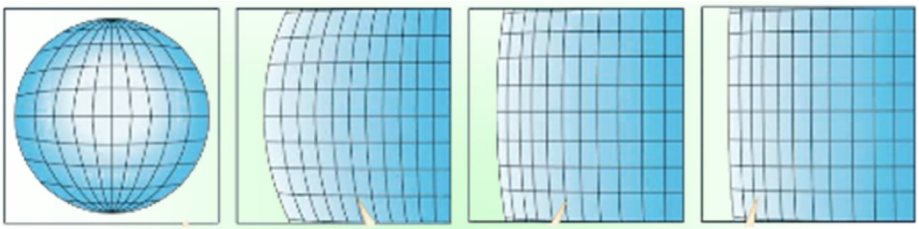


Ω_0 ~ 1 today coupled with expansion of the Universe implies that $|1 - \Omega| < 10^{-14}$ when BB nucleosynthesis occurred. Our existence depends on a very close match to the critical density in the early Universe

Theory of Cosmic Inflation



How Inflation Solves the Flatness Problem



As the universe expands manyfold, and the region within our horizon gets to be a smaller and smaller fraction of the whole Universe, the surface becomes flat over the region we can examine -- the observable Universe.

It is thought that the *a* expanded by a factor of $>10^{50}$.

Cosmic Inflation Summary

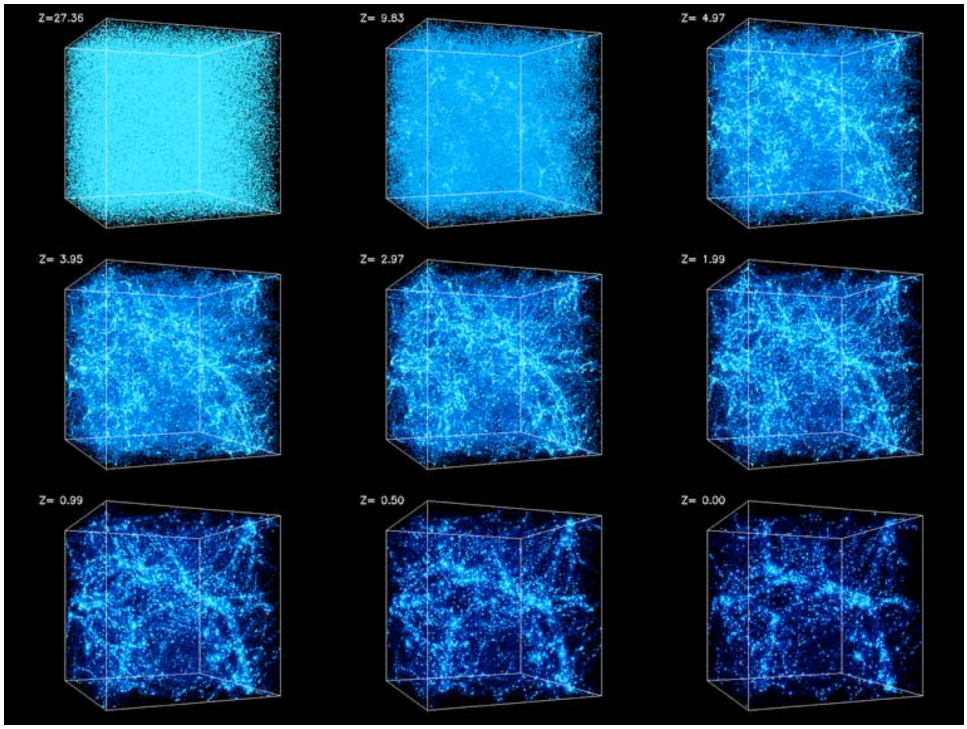
Standard Big Bang theory has problems with tuning and causality
Inflation (exponential expansion) solves these problems:

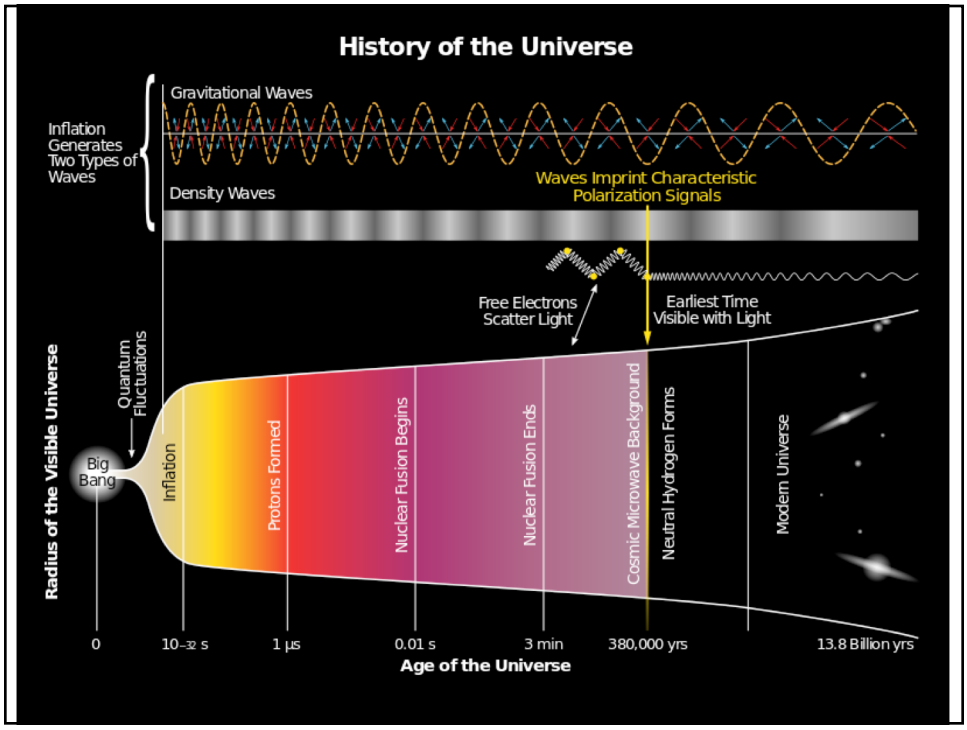
- Causality solved by observable Universe having grown rapidly from a small region that ***was*** in causal contact before inflation
- Fine tuning problems solved by the diluting effect of inflation

Inflation naturally explains origin of large scale structure:

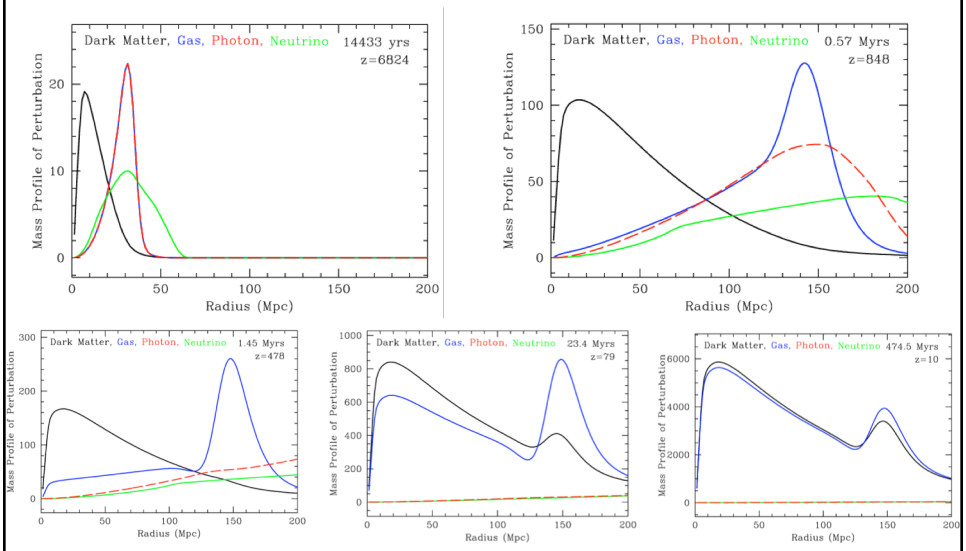
- Early Universe has quantum fluctuations both in space-time itself and in the density of fields in space. Inflation expands these fluctuation in size, moving them out of causal contact with each other. Thus, large scale anisotropies are "frozen in" from which structure can form.

Some kind of inflation appears to be required but the exact inflationary model not decided yet…

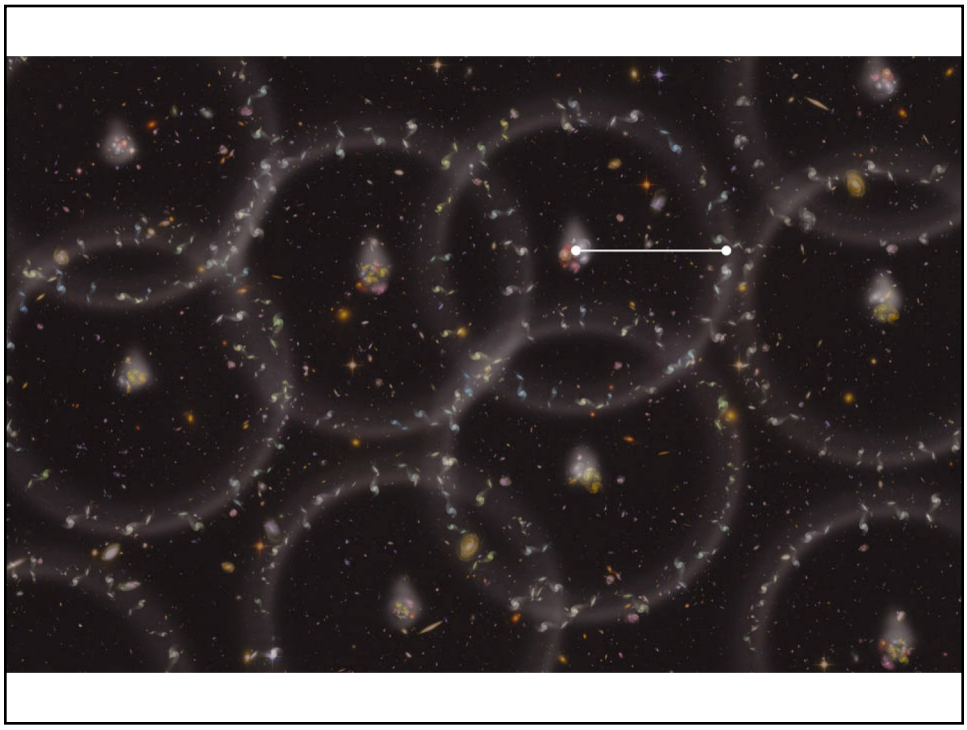




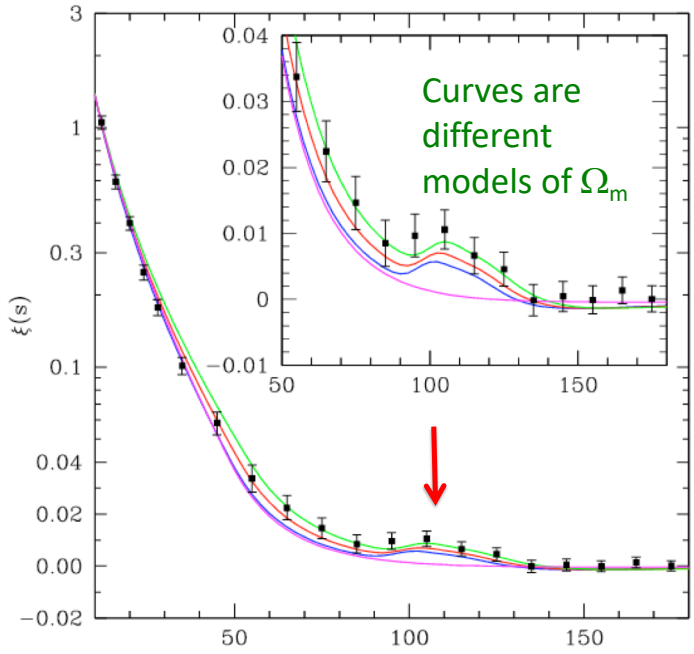
BAO: Baryonic Acoustic Oscillations



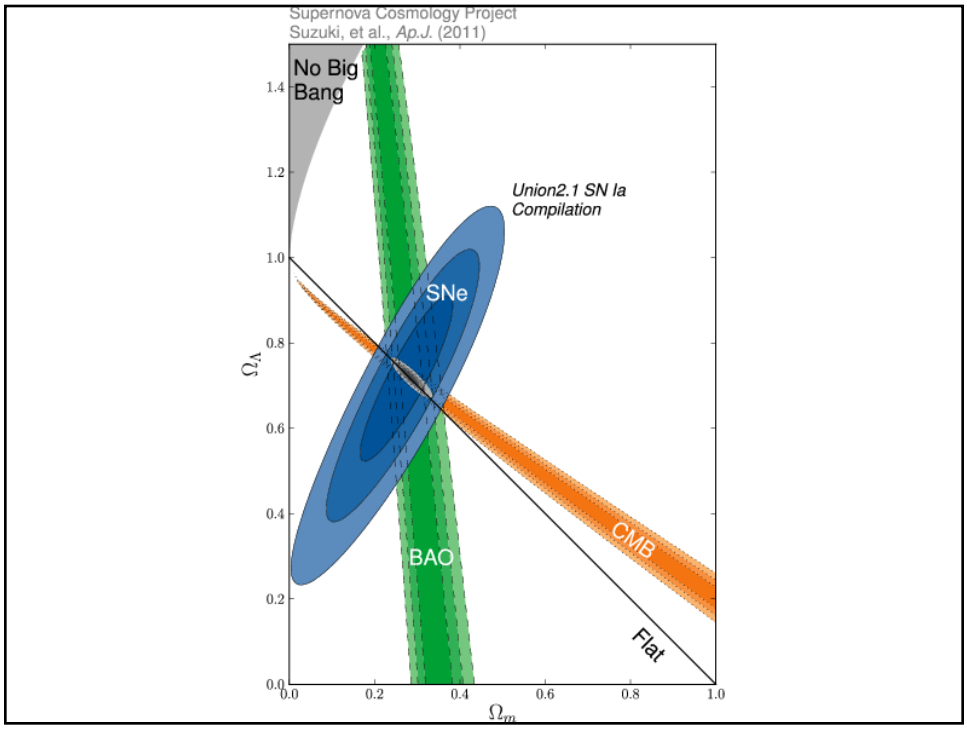
Predict an overdensity in baryons (traced by galaxies) ~ 150 Mpc at the scale set by the distance that the baryon-photon acoustic wave could have traveled before CMB recombination

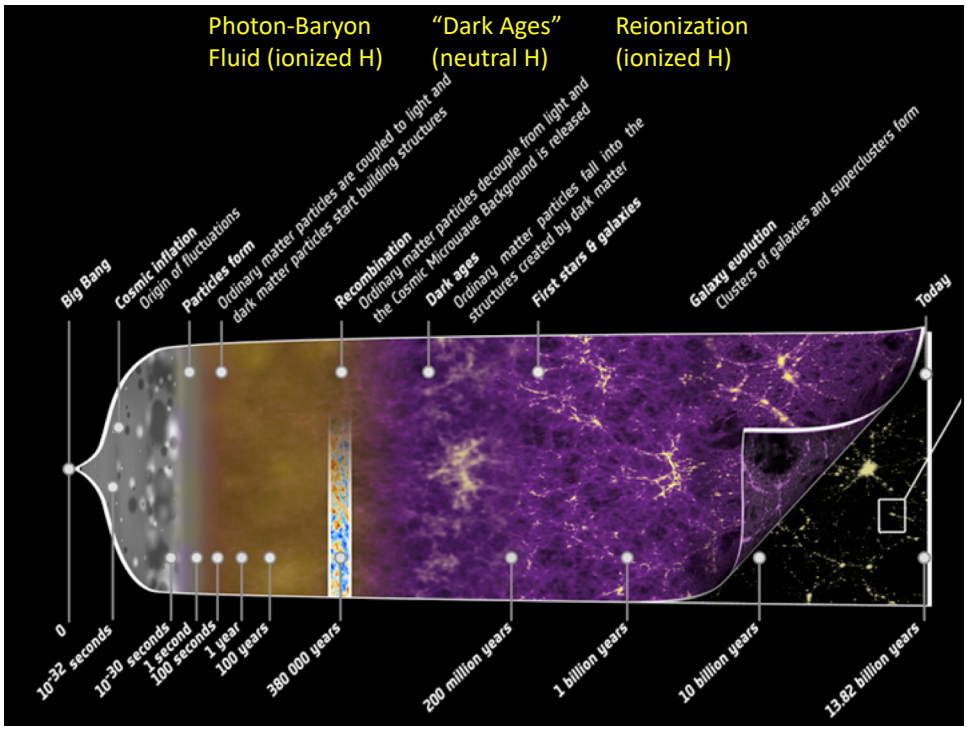


A measure of clustering of SDSS Galaxies

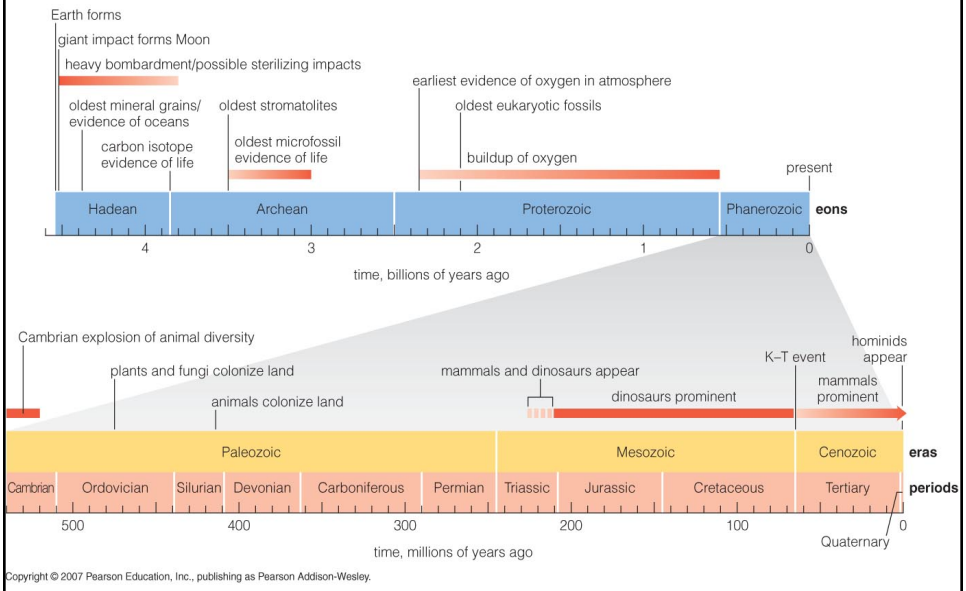


Eisenstein et al. 2005


Supernova Cosmology Project
Suzuki, et al., Ap.J. (2011)
No Big Bang
Union2.1 SN Ia Compilation
SNe
BAO
CMB
Flat
Ω_Λ
Ω_m
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

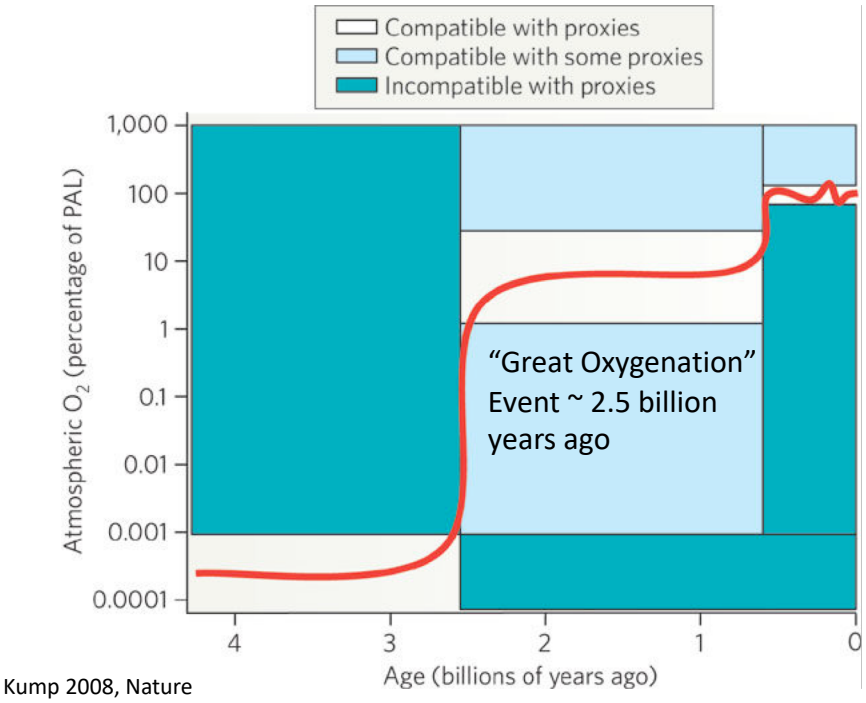

Photon-Baryon Fluid (ionized H)
"Dark Ages" (neutral H)
Reionization (ionized H)
Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
0
10^{-32} seconds
10^{-30} seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years

Evolution of Life on Earth



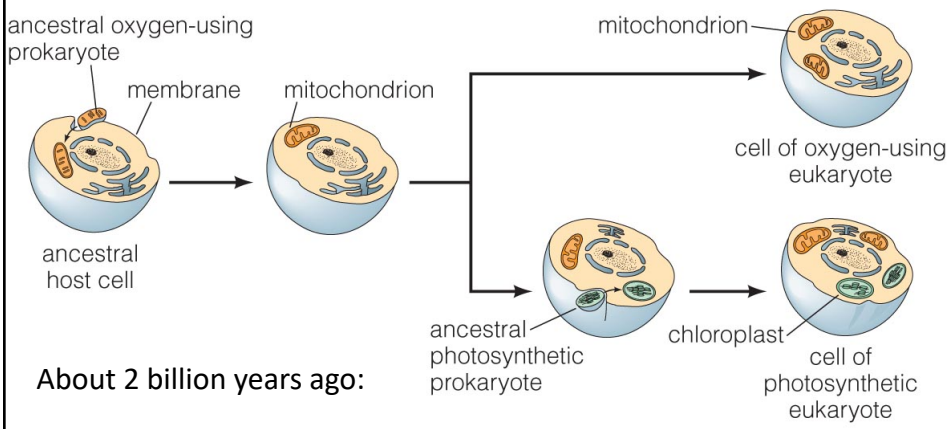
Stromatolites

3.5 billion years ago – evidence from colonies of microbes. Stromatolites are successful forms of life whose descendants still inhabit Earth.



Kump 2008, Nature

Increase in Cell Complexity



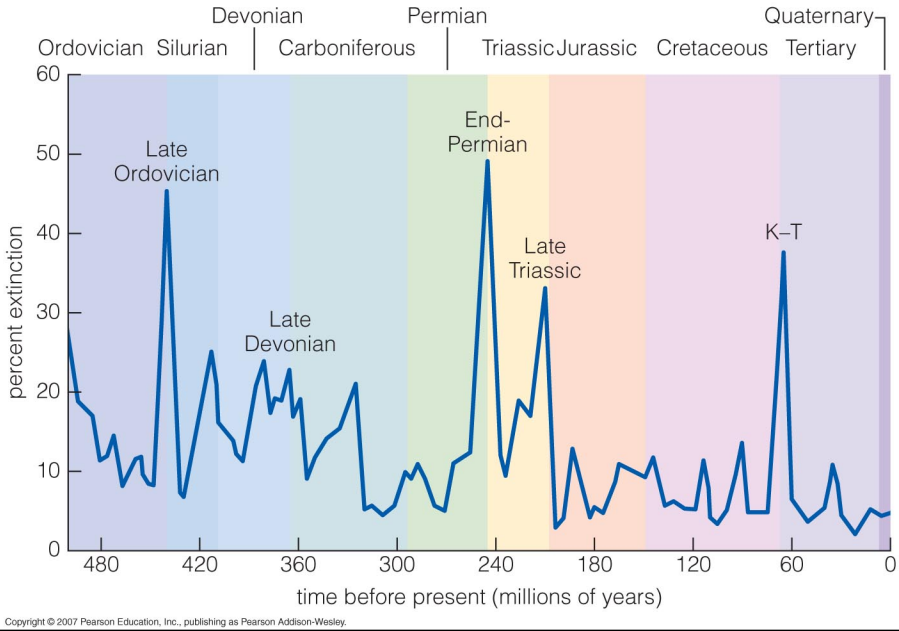
About 2 billion years ago:

b Mitochondria and chloroplasts may have evolved as small prokaryotes invaded a larger host cell, forming a symbiotic relationship.

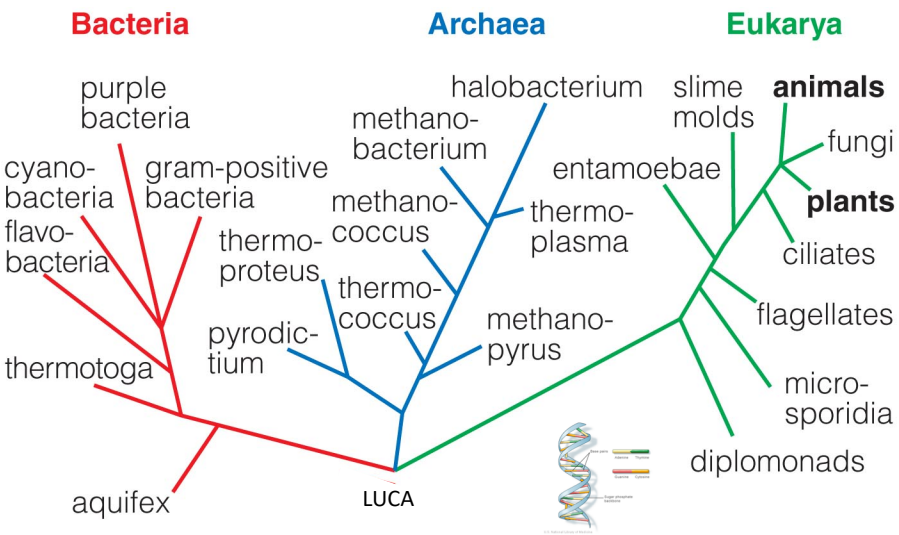
Cambrian Explosion

After 3 billion years of no life form larger than the head of a pin, there is an explosion of diversity in the oceans ~550 My ago – the Cambrian explosion.

Extinction History



The Modern Tree of Life



Maps evolution via the gradual deviation of the base pair sequences in DNA or RNA

Astrobiological Implications

- Earth had life soon after its origin, maybe within 100 million years (definitely by 1 billion years), under extreme conditions.
- Soon after the heavy meteorite bombardment ended, microbes as metabolically complex as now were widespread and abundant.
- So life arose and diversified rapidly, and occupied an amazing array of evolutionary niches.
- Planets with early but short-lived habitable windows (e.g. Mars, Venus) could have been lively.
- Intelligence does not rapidly follow evolution of complex cells (eukaryotes), so microbial life may be abundant while intelligence is rare.