Fine-tuning

carbon to stars to galaxies to the entire universe

Joseph Silk
Gresham College
December 6, 2017

Examples of fine-tuning

- Carbon
- Stars
- Galaxies
- Inflation

What is the border between cosmology and philosophy?

As viewed by a room full of philosophers

Prior: *some swans are white, some are black, some are black and white.*

Data: *at least one swan has a black side*

would their progeniture be asymmetrically left or right?

As viewed by a room full of physicists

Swan negritude is truly rare

Why? the greatest problem in biophysics

PHILOSOPHERS

The ontology and epistemology of swan asymmetry launched a new field of philosophy: post-modernist empiricism in the multiverse

PHYSICISTS

Physics and Astronomy persuaded the funding agencies to launch major research initiatives in biophysics and exoplanets on black swan origin

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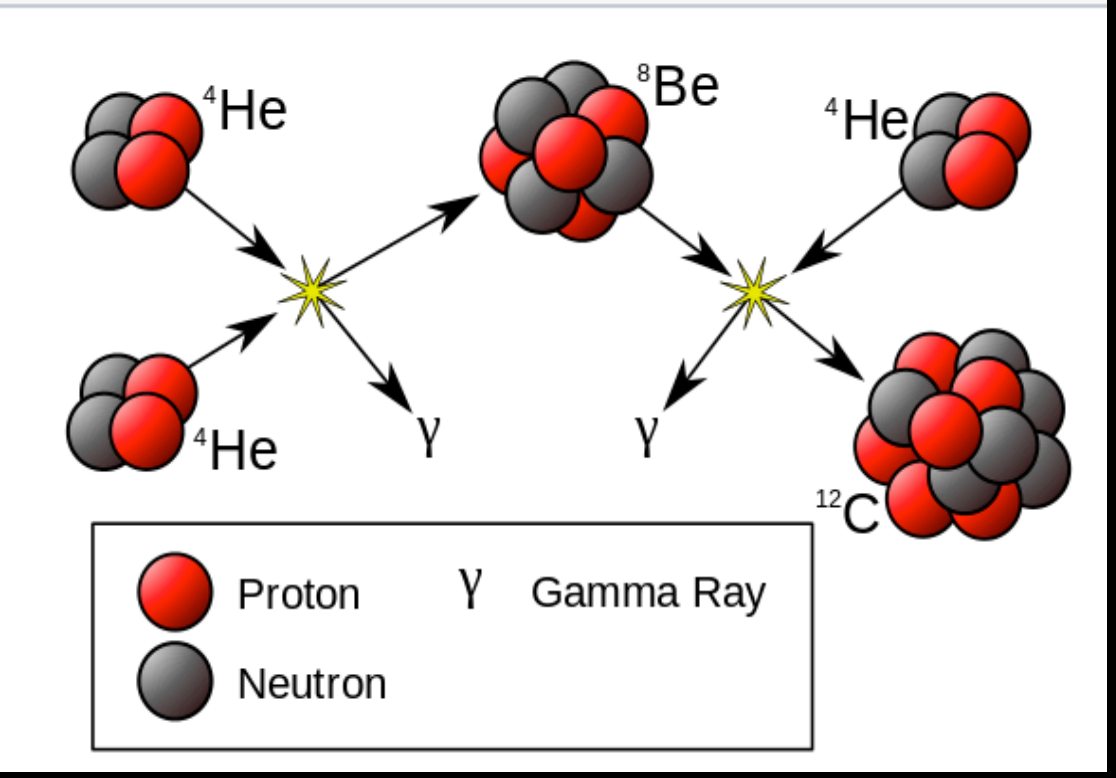
Things are the way they are because they were the way they were

Fred Hoyle 1915-2001

Founder of the

Steady State Universe



Carbon is very abundant

but

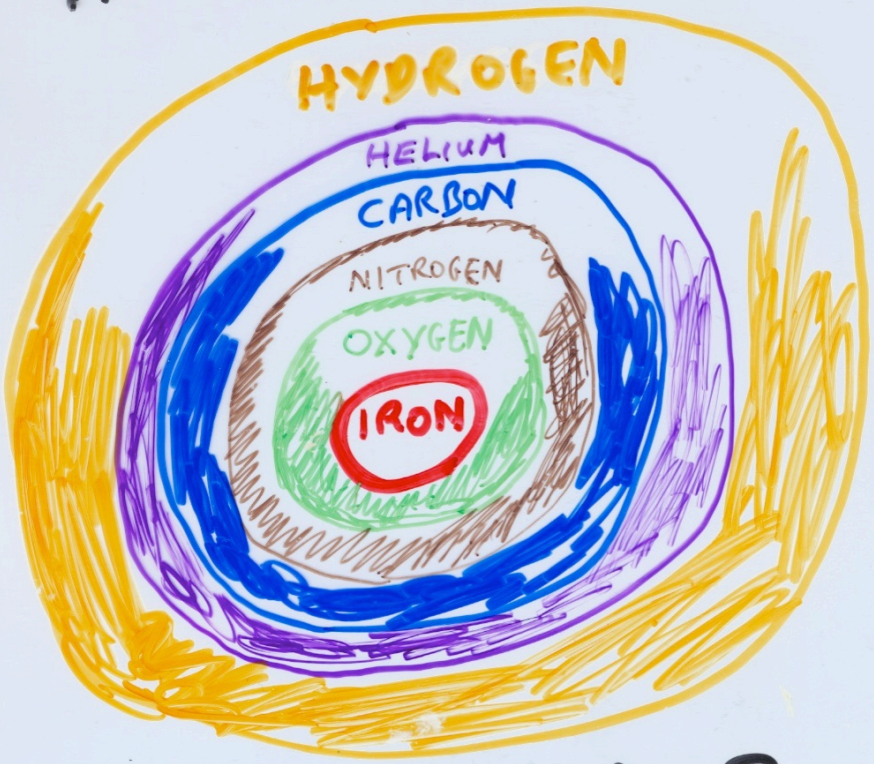
Beryllium + Helium have too much energy to form Carbon

Fred Hoyle prediced a resonance at 7.68 MeV in the Carbon nucleus (1954)

3 years later it was measured

One of the most amazing predictions in physics!

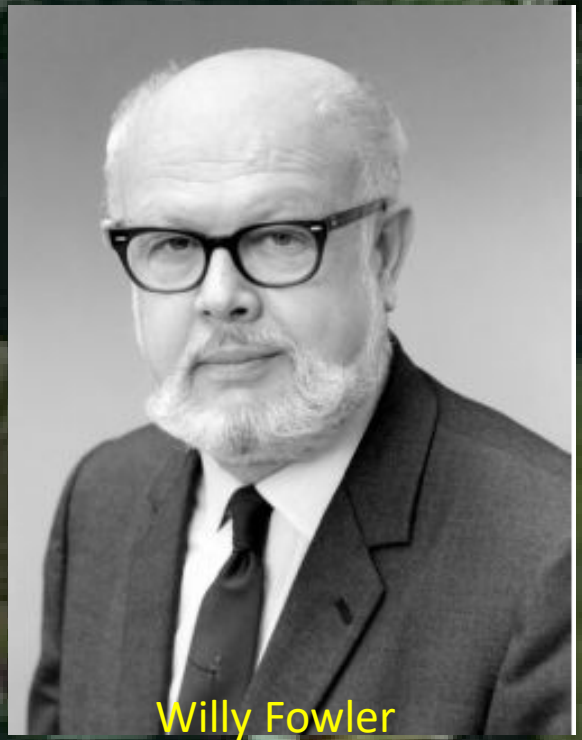
A MASSIVE STAR EVOLVES



AND EXPLODES

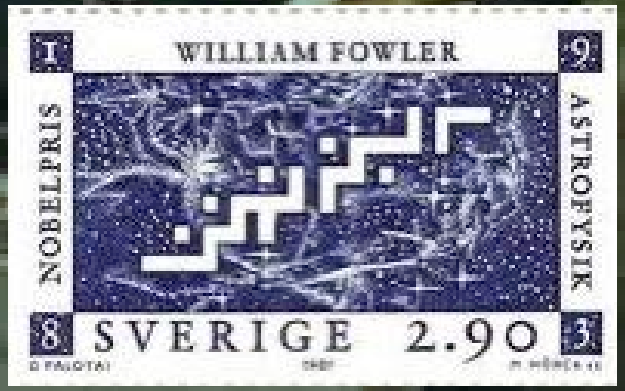
FROM ITS ASHES OUR SOLAR SYSTEM FORMED

Geoff and
Margaret Burbidge



Willy Fowler

Fred Hoyle



Burbidge, Burbidge, Fowler, Hoyle

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The elements were cooked together from elementary particles in less time than it takes to cook a dish of duck and roast potatoes

George Gamow 1904-1968

RALPH ALPHER
GEORGE GAMOW
ROBERT HERMANN

predicted origin of light elements
& fossil radiation

The Origin of Chemical Elements

R. A. ALPHER*
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland

AND

H. BETHE
Cornell University, Ithaca, New York

AND

G. GAMOW
The George Washington University, Washington, D. C.

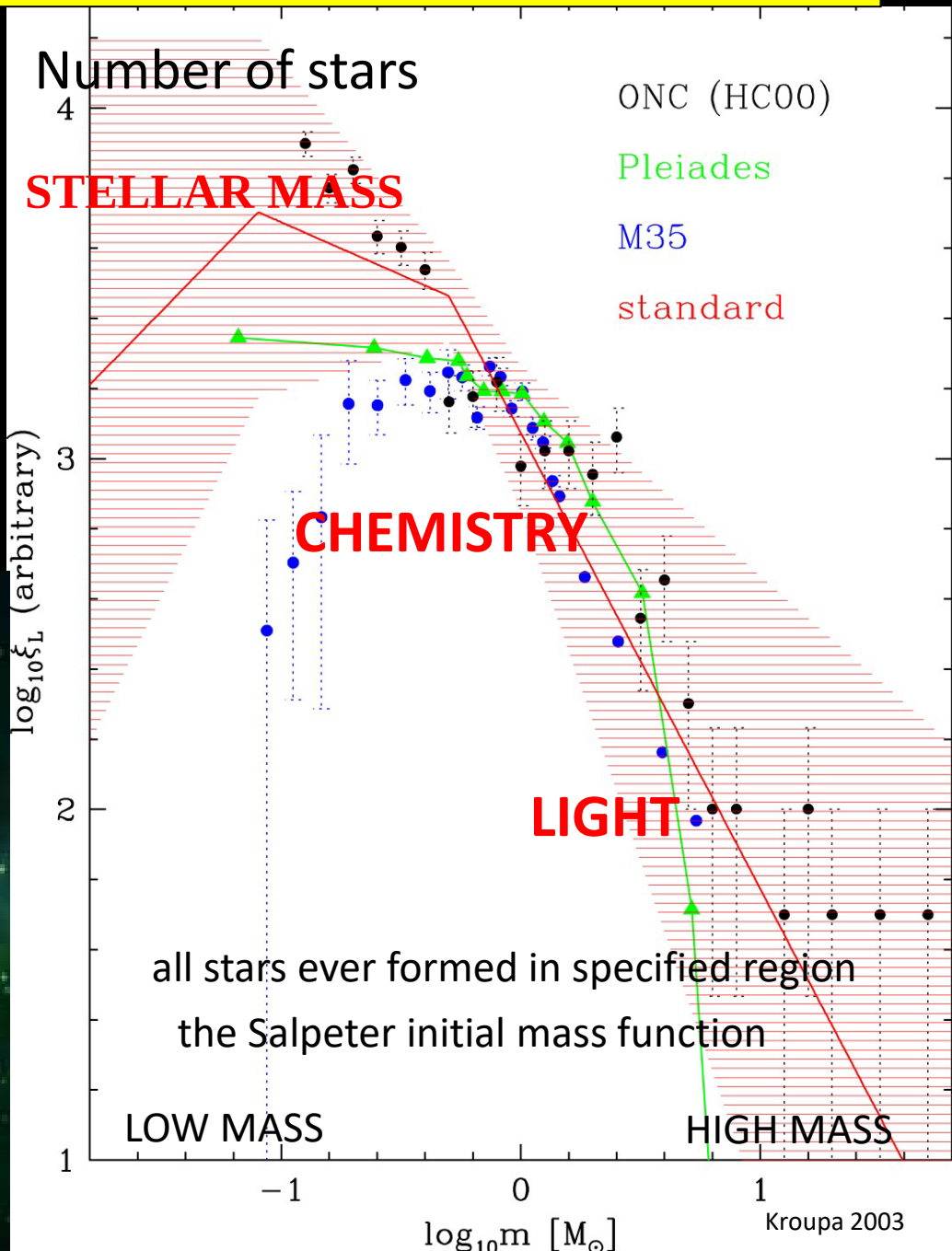
February 18, 1948

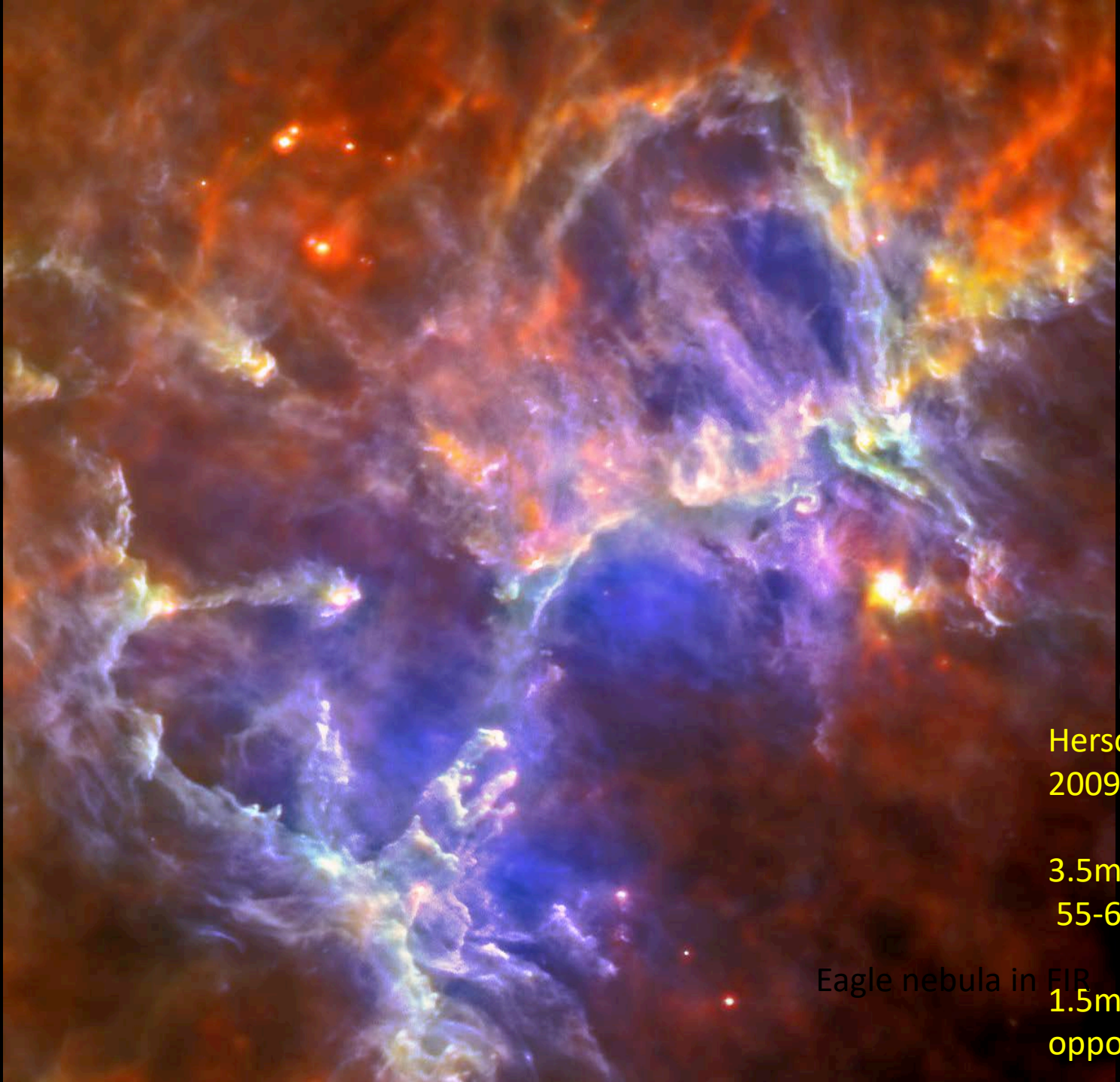
half an hour of creation...

The birth function of stars

Ann Arbor,
Michigan
1953

The mass distribution of stars at birth: account for lifetimes





Herschel Space Telescope
2009-2013

3.5m diameter
55-672 μm (FIR)

Eagle nebula in FIR

1.5million km from earth,
opposite sun

if the matter was evenly disposed throughout an infinite space, it could never convene into one mass; but some of it would convene into one mass and some into another, so as to make an infinite number of great masses, scattered at great distances from one to another throughout all that infinite space.
And thus might the sun and fixed stars be formed…

if the sun at rest were an opaque body like the planets or the planets lucid bodies like the sun, how he alone should be changed into a shining body whilst all they continue opaque, or all they be changed into opaque ones whilst he remains unchanged, I do not think explicable by mere natural causes…

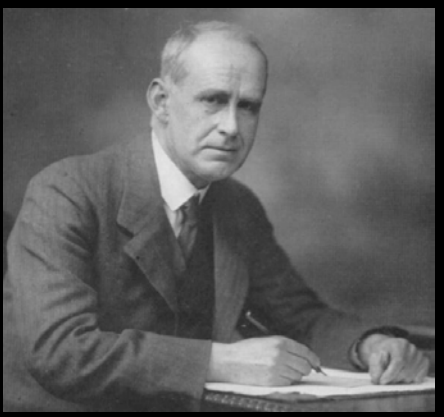
Isaac Newton, letter to Richard Bentley, December 10, 1692

I

we have found that as Newton first conjectured…. All celestial bodies originate by a process of fragmentation of nebulae out of chaos, of stars out of nebulae, of planets out of stars and satellites out of planets.

James Jeans 1902

$R_{jeans} = v_{sound}\, t_{free\ fall}$



We can imagine a physicist on a cloud-bound planet who has never heard tell of the stars, calculating …a series of globes of gas of various sizes, as a tussle between radiation pressure and gas pressure. The contest is overwhelmingly one-sided except between 10^{33} and 10^{35} grams, where we may expect something interesting to happen. What 'happens' is the stars.

Arthur Eddington, 1926

What determines the mass of a star?

A struggle between gravity versus (electromagnetic) pressure

one number: controls the masses of stars,
its all fundamental constants,

$$\alpha_g \equiv G m_p^{\,2} e^{-2} \approx 3.10^{-37}$$

so small because gravity is really weak, but adds up,
electron and proton charges cancel

There are 3 important stellar masses

the most massive star….the Eddington mass about 100 M_{sun}

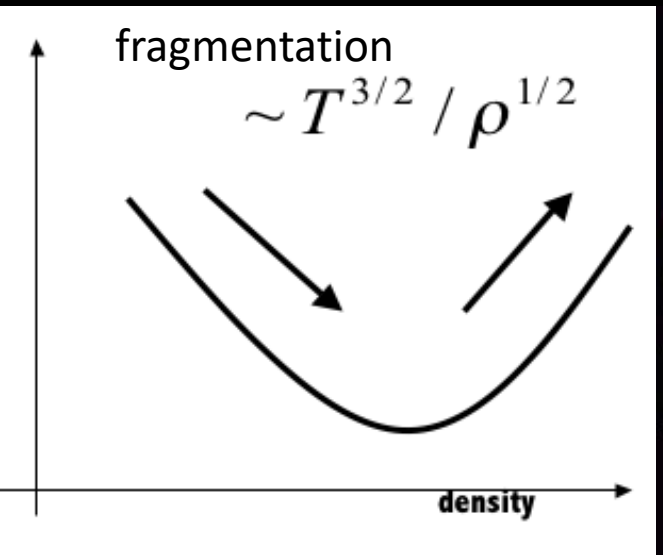
the smallest star that burns hydrogen…0.08 M_{sun} a brown dwarf

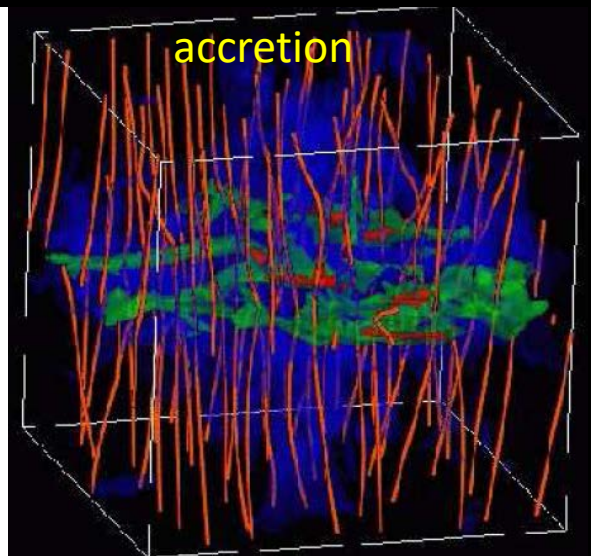
A dead star or white dwarf…1.7 M_{sun}

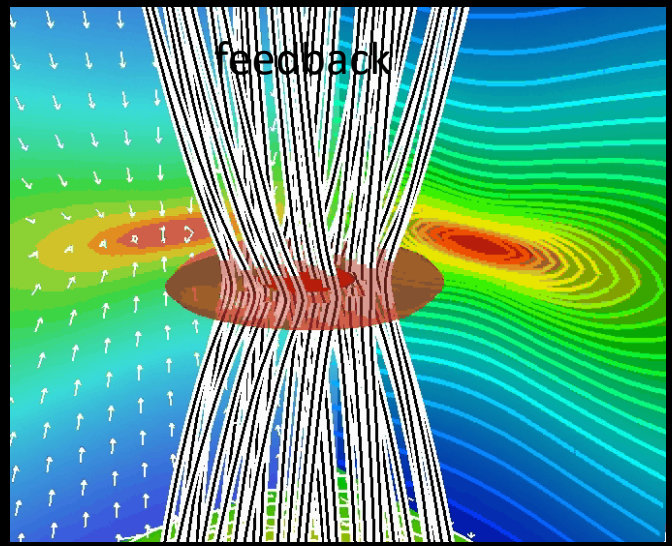
G is Newton's constant, m_p is the mass of a proton, m_e is the mass of an electron

Interstellar clouds fragment

- typical fragment mass $\approx \alpha_g^{-3/2} \alpha m_p \approx 0.01 M_{sun}$
- continuing ***accretion*** of gas
- stopped by ***feedback***

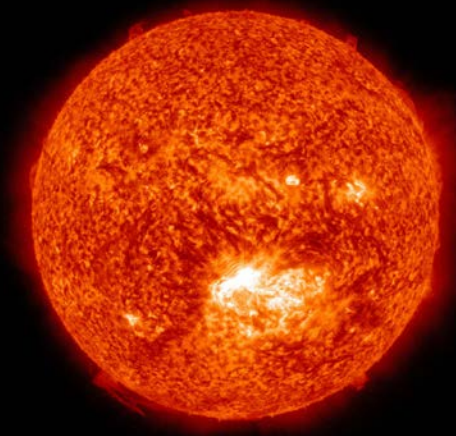






The lifetime of a star depends mostly on its mass

A great discovery of 20th century: the sun is a fusion reactor



Energy radiated is proportional to: M^3

Lifetime of a star is proportional to $1/M^2$

The sun will live for ten billion years…..
but a $100M_{sun}$ star only lives a million years!

10^6 years is a mere instant in the lifetime of the Milky Way, so we should see many dying stars!

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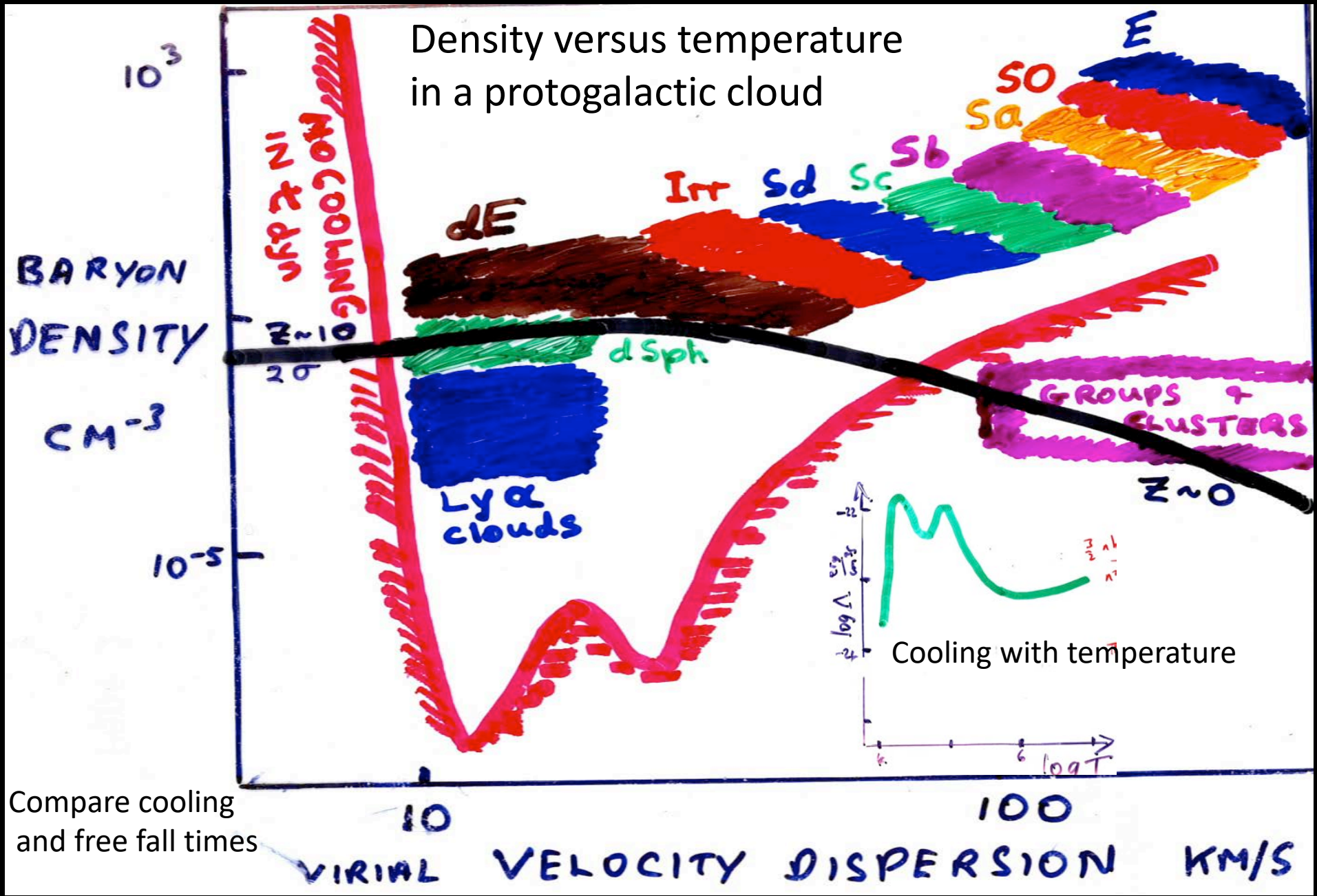
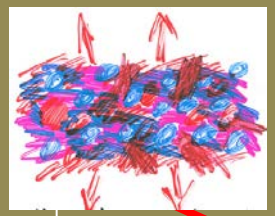
tussle between cooling and gravity



Compare cooling and free fall times

FROM LINEAR TO NONLINEAR

$$t_{cool} \sim \frac{nkT}{\Lambda(T)n^2}$$



$$M_{cooled-baryons} \sim \alpha_g^{-2}\alpha^3\left(\frac{m_p}{m_e}\right)\left(\frac{t_{cool}}{t_{dyn}}\right)T^{1+2\beta}$$

theory (CDM-motivated)

Φ(L/M)

galaxy number

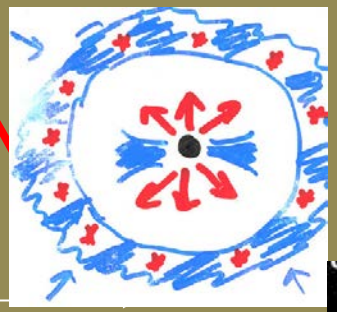
observations

Model matches data at one point!

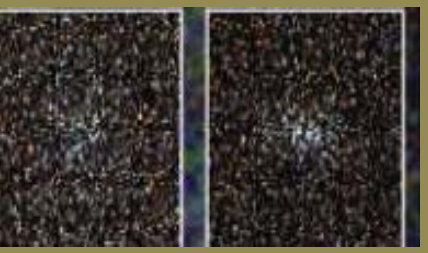
$$L_* \sim 3\times10^{10} L_{sun}$$

$$L_h \sim 10^{12} M_{sun}$$

$$t_{dyn} \sim \frac{1}{\sqrt{Gm_p n}}$$



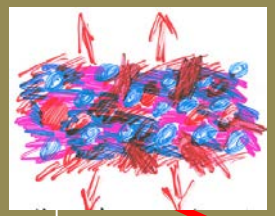
axy luminosity/mass



SuperNovae

ActiveGalacticNuclei

Typical mass of a galaxy



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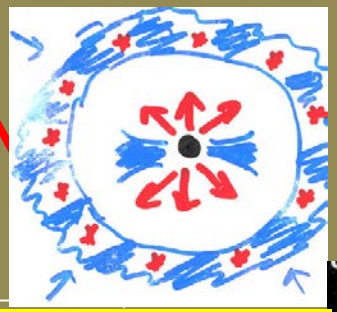
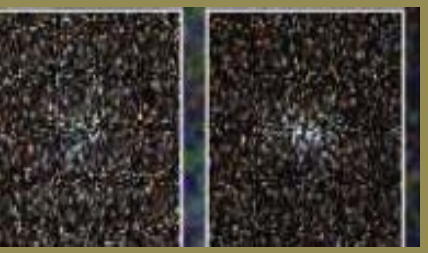


luminosity / mass



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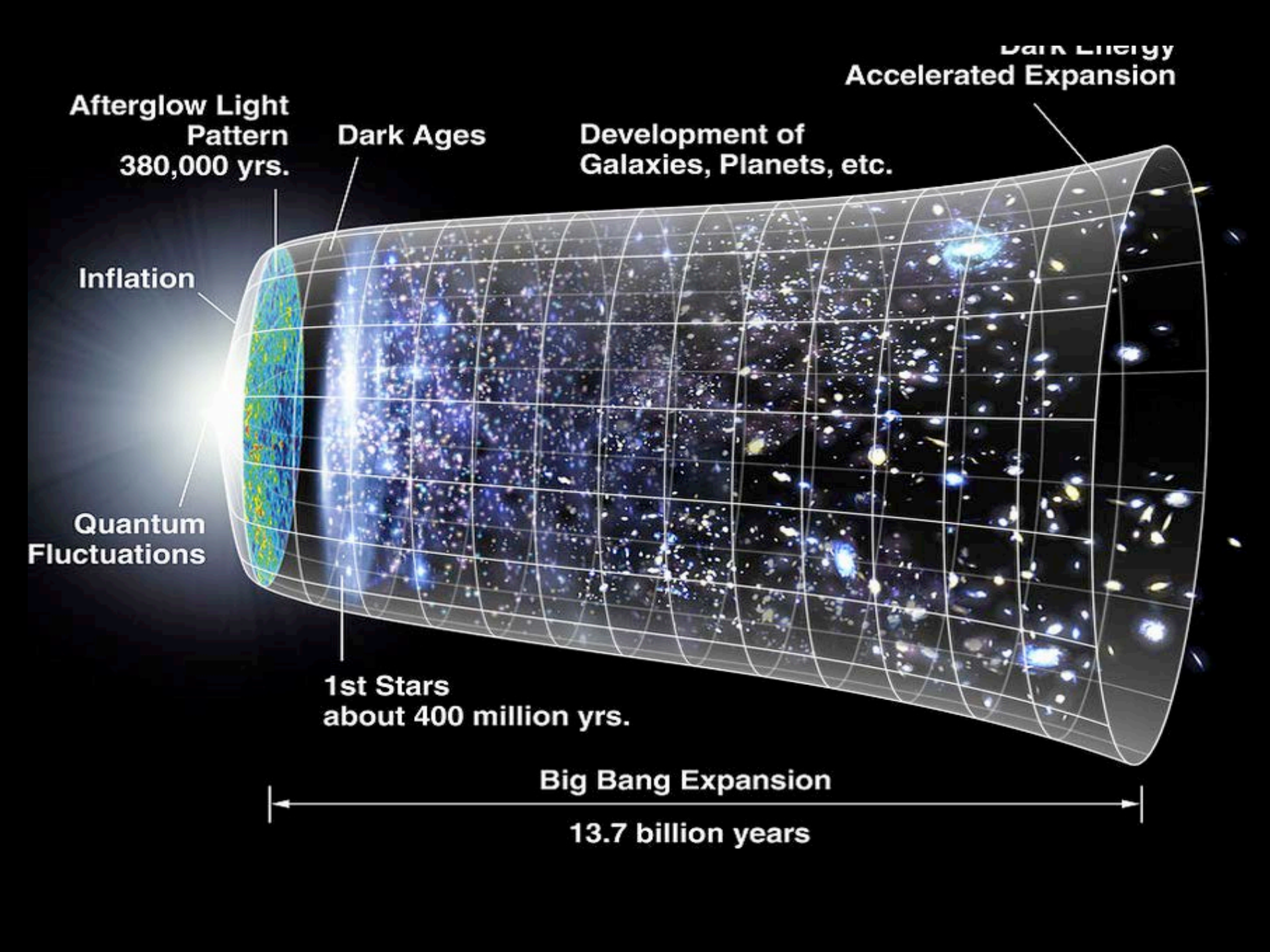
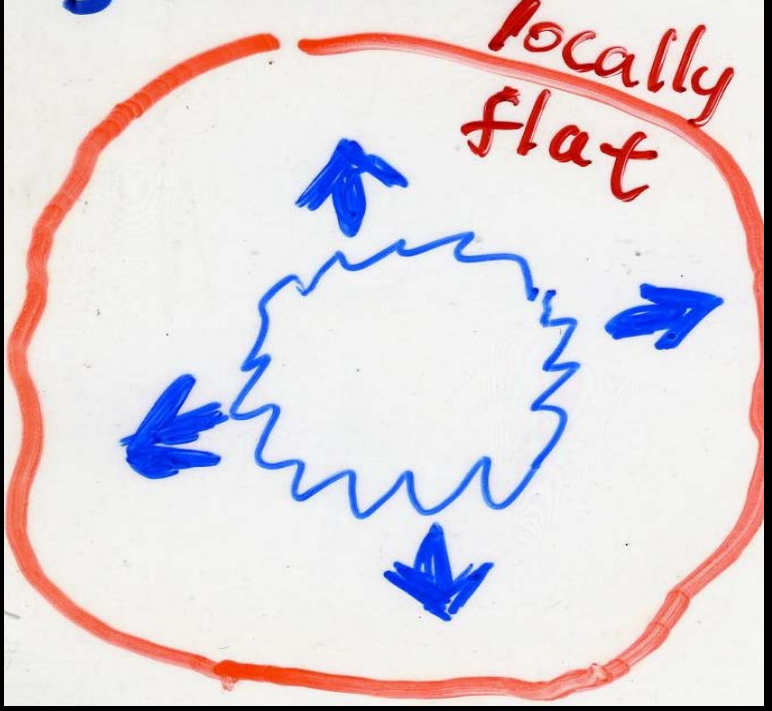

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

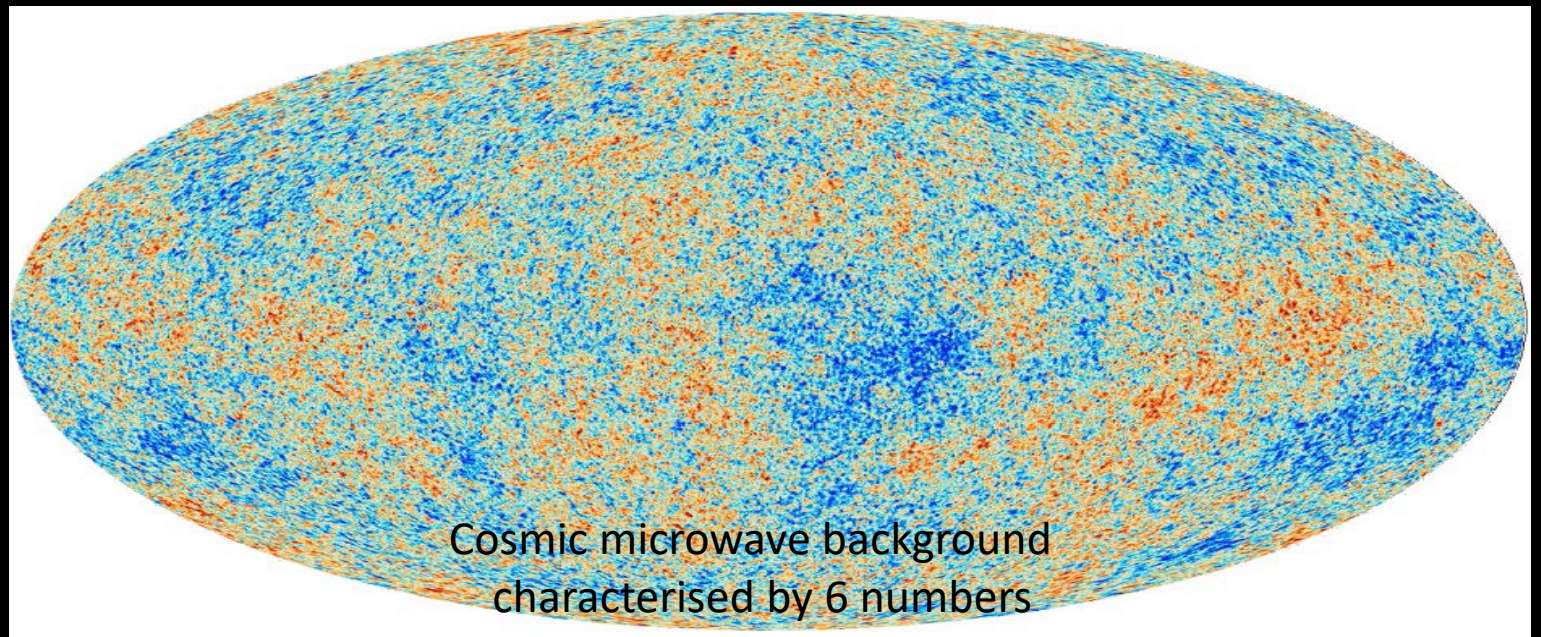


inflationary cosmology makes 3 predictions:

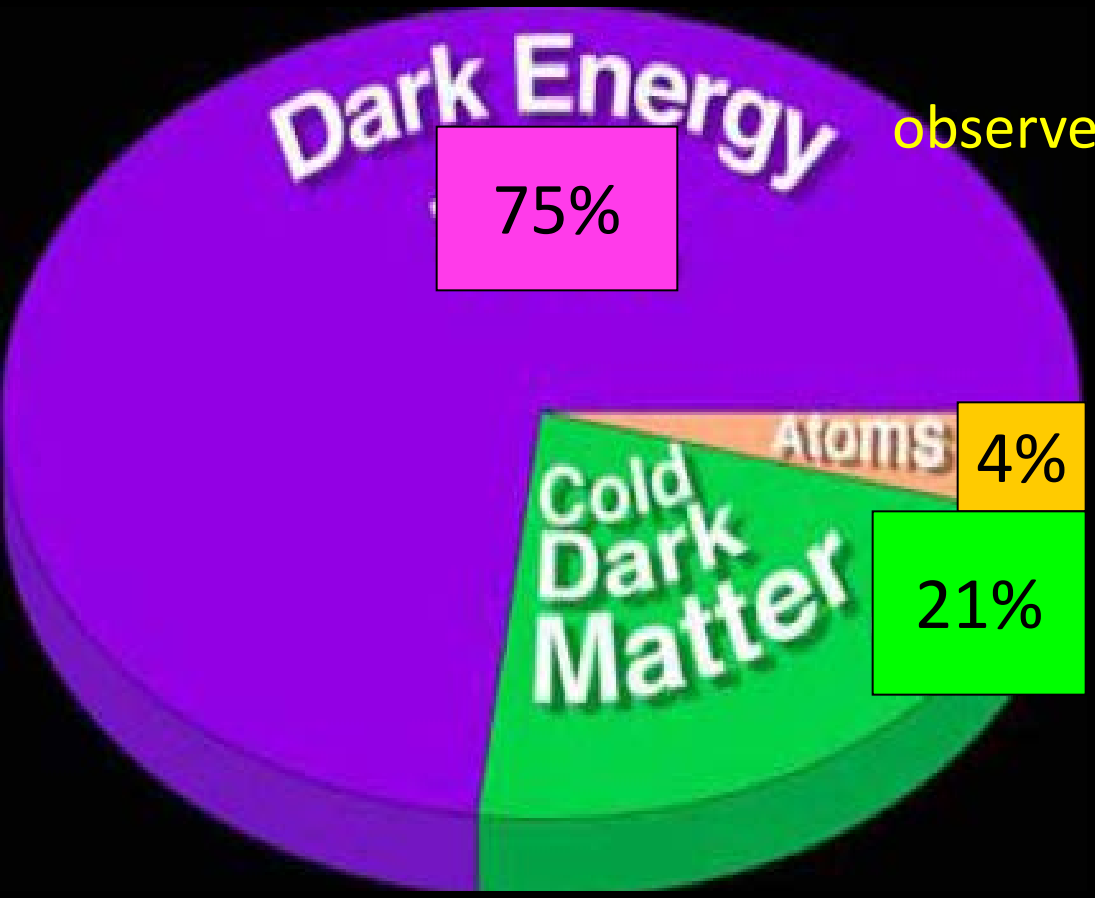
1. flatness of space
2. size of the universe
3. density fluctuations

…the seeds from which galaxies formed

observed!



Cosmic microwave background characterised by 6 numbers



observe a very small density

$$\rho_{vac} \approx 10^{-10}\,\mathrm{eV}^4$$

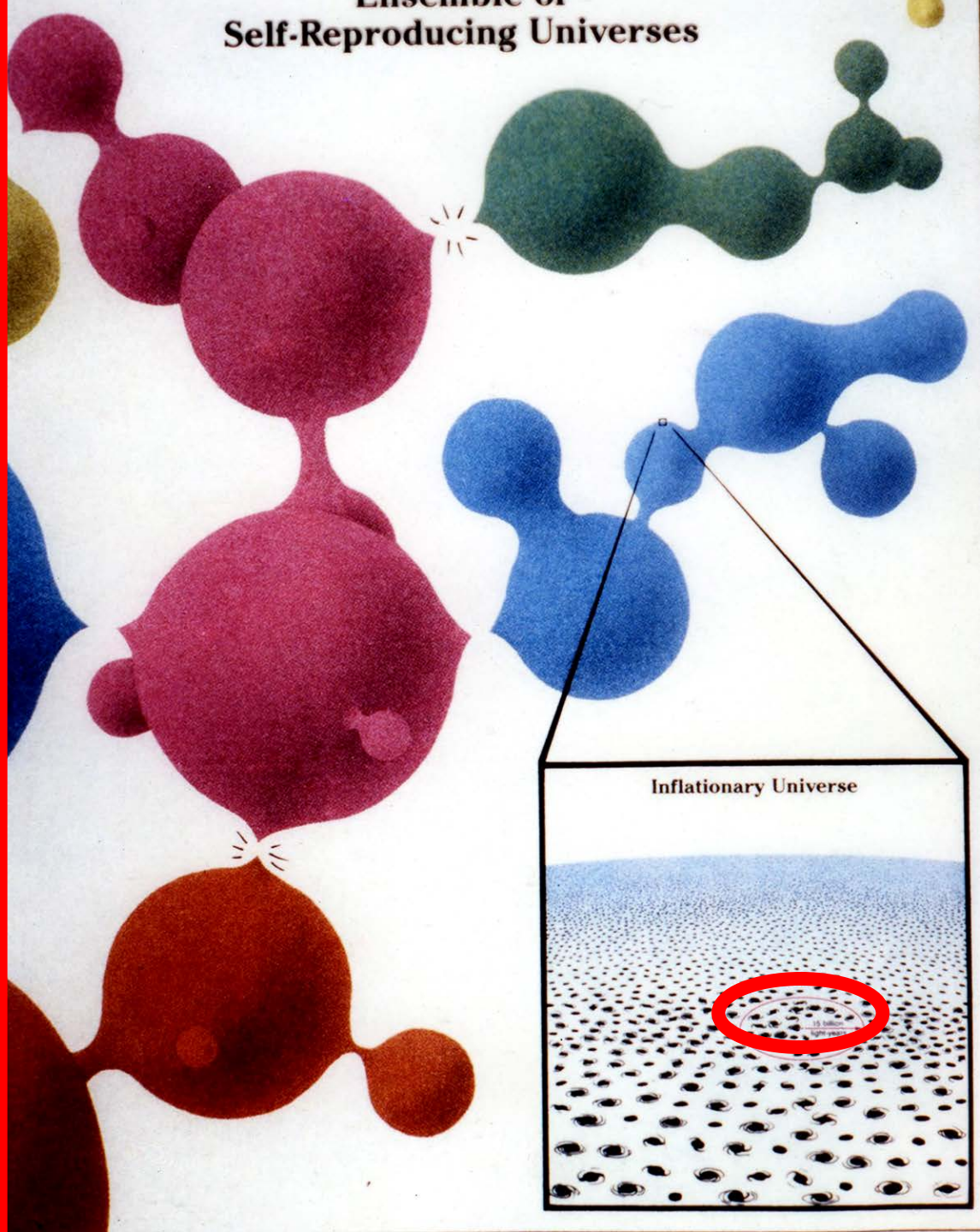
but we predict something big

$$M \sim M_{Planck} = G^{-1/2} = 10^{28}\ \mathrm{eV} \Rightarrow \rho_{vac} \sim 10^{112}\,\mathrm{eV}^4$$

The worst prediction in physics!

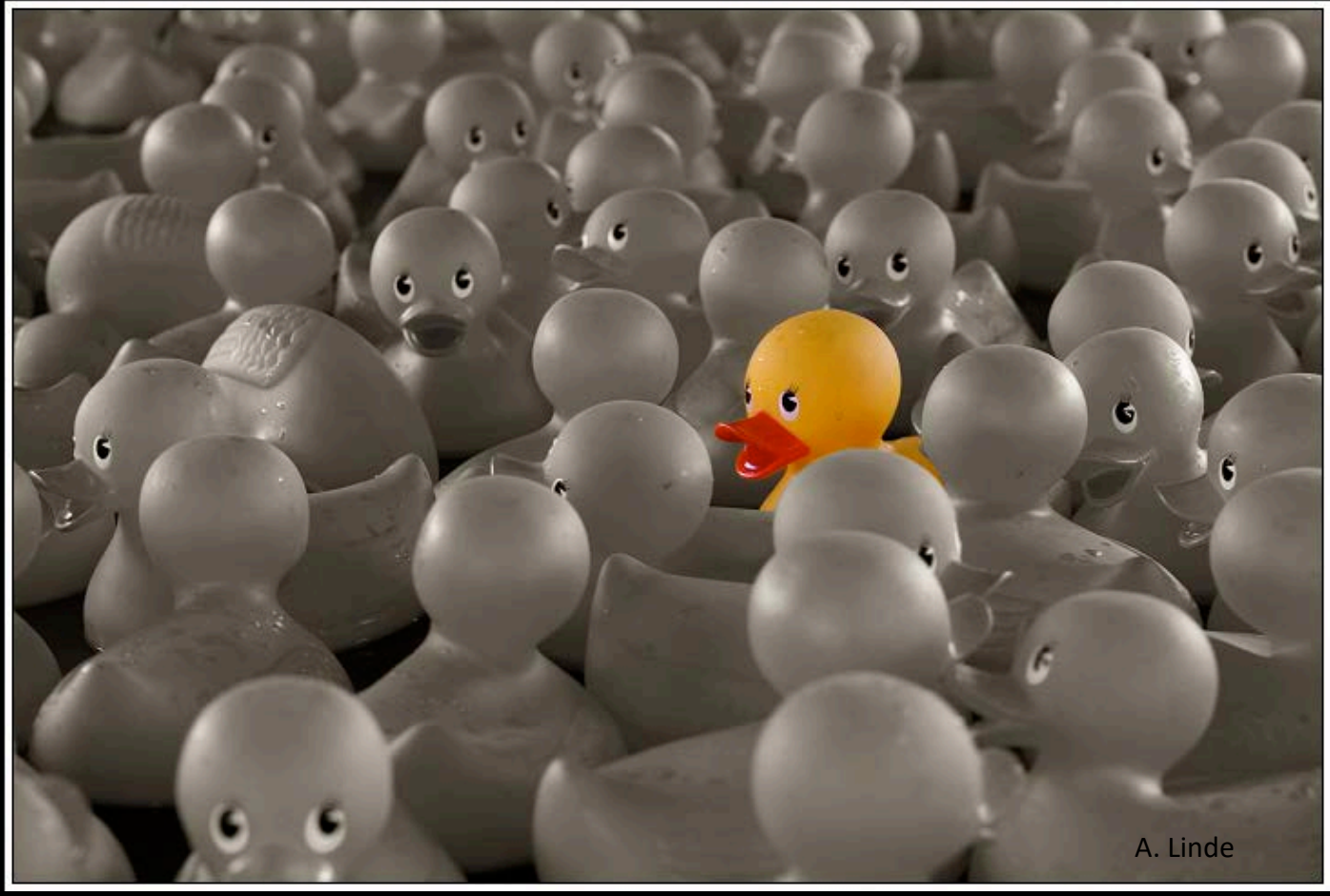
Eternal inflation produces a very large number of inaccessible universes

the multiverse explains why dark energy is so small



We live in one tiny pocket where the value of the cosmological constant is consistent with our kind of life

Leonard Susskind



The multiverse theory can't make any predictions … it can explain anything…

George Ellis

How do we estimate the odds of an infinite multiverse?

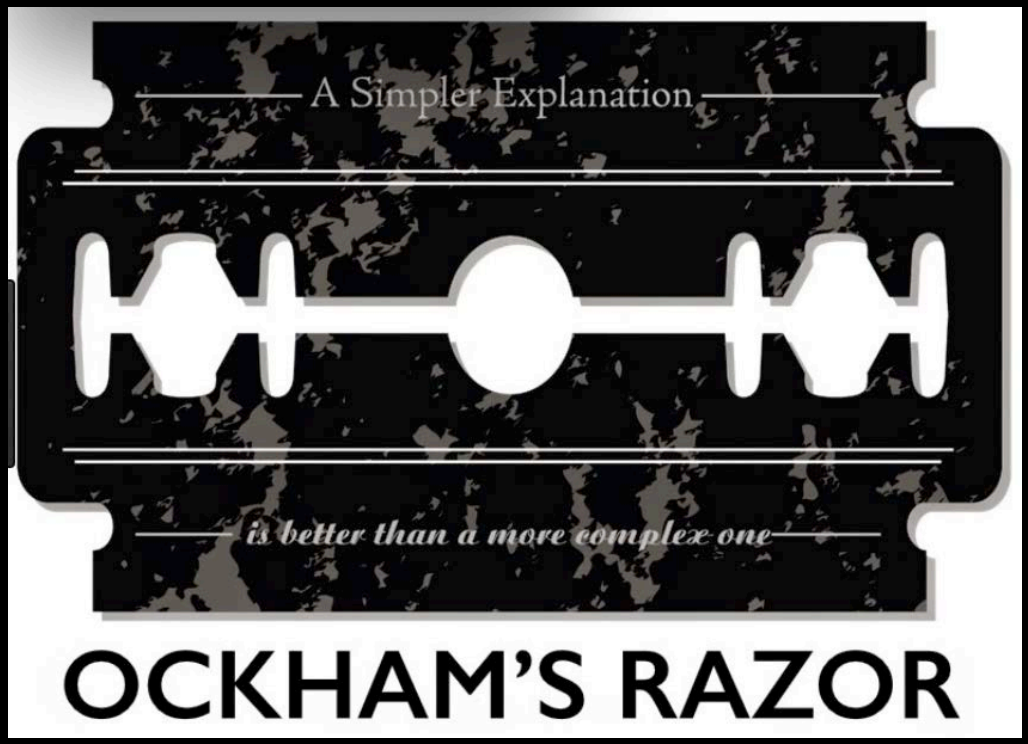
We have absolutely no idea!
Eg in our universe leprechauns are rarer than people
In a multiverse there are infinite numbers of both,
so what's the ratio?

Ockham's razor:
take the parsimonious view,
there is only one universe

William of Ockham
1286-1347

Everything should be kept as
simple as possible, but no simpler
Albert Einstein

Sometimes, Ockham's razor can be useless
eg in long-term weather prediction



it is useful for judging the multiverse but it does open up the issue of intelligent design

if a pocket watch is found on a heath, it is most reasonable to assume that someone dropped it and that it was made by a watchmaker, not by natural forces.

— William Paley 1743-1805

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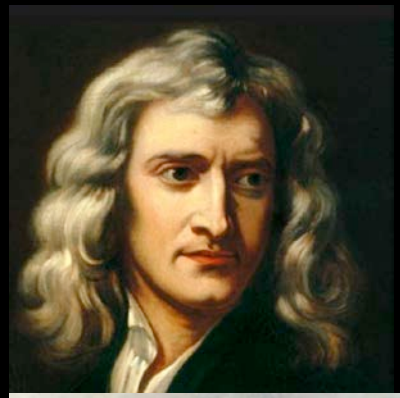
This most beautiful system of the sun, planets and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being.
— Isaac Newton 1643-1727



now that the law of natural selection has been discovered, we can no longer argue that, for instance, the beautiful hinge of a bivalve shell must have been made by an intelligent being, like the hinge of a door by man. There seems to be no more design in the variability of organic beings and in the action of natural selection, than in the course which the wind blows. Everything in nature is the result of fixed laws.
— Charles Darwin 1809-1882

Fine-tuning occurs in forming carbon, stars, galaxies, massive black holes, the beginning of the universe, and even theology perhaps…

its all a matter of local complexity and self-regulation……and physical laws