Visions of the Multiverse

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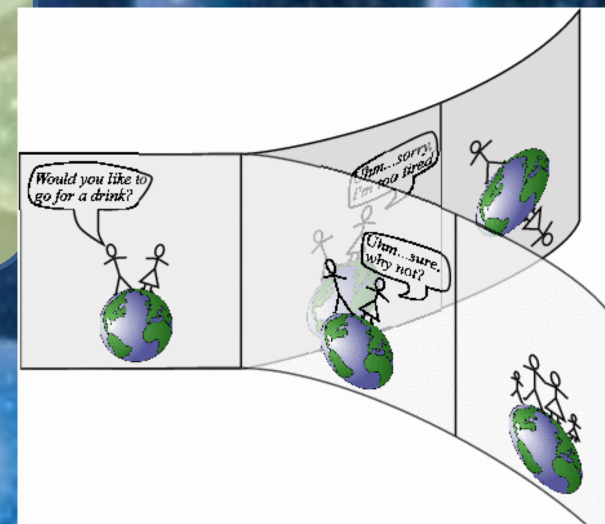
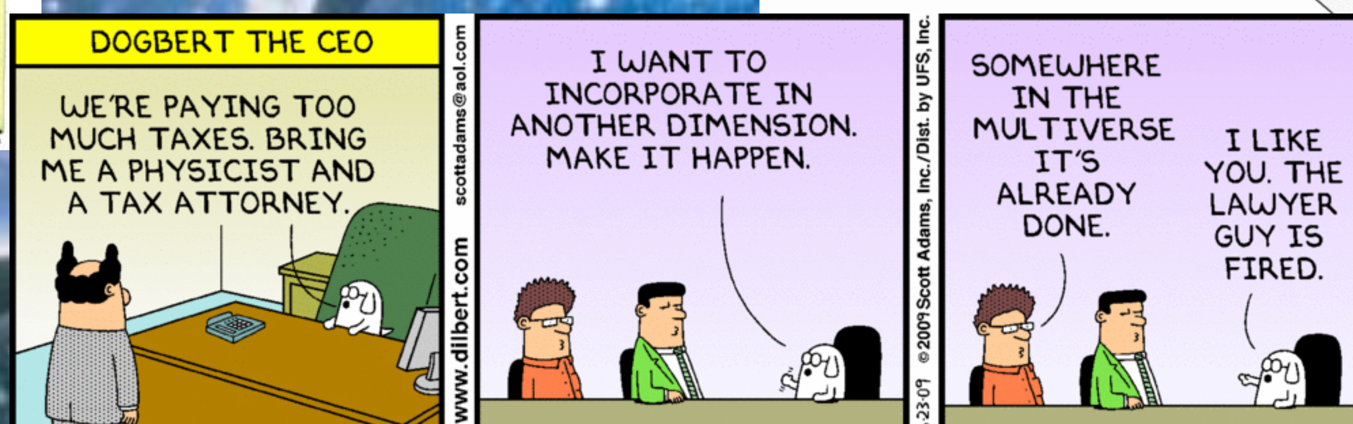
P102 summary

April 23, 2014

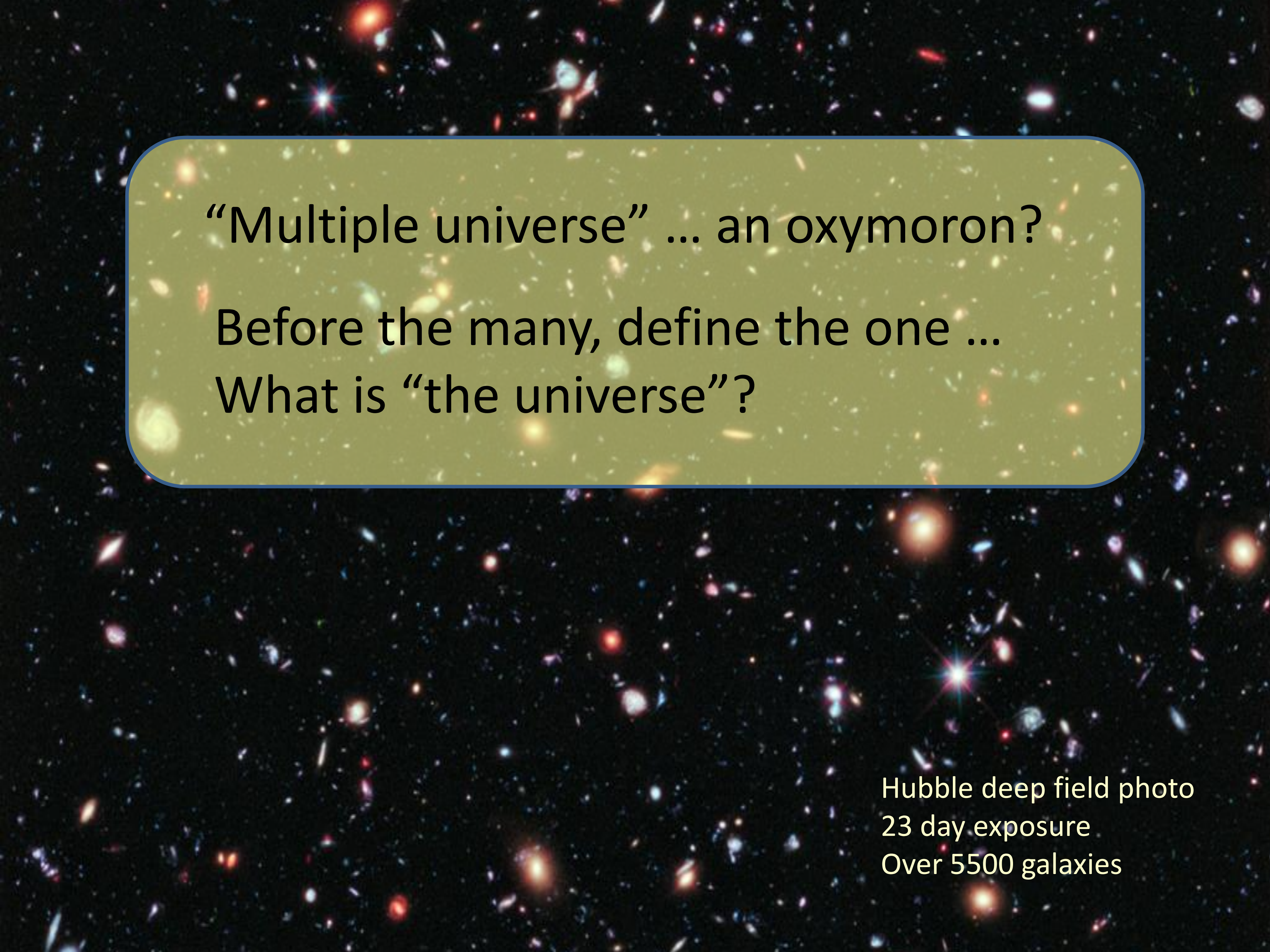




J. Baum/SPL, from nature .com

"Multiple universe" … an oxymoron?

Before the many, define the one …
What is "the universe"?



Hubble deep field photo
23 day exposure
Over 5500 galaxies

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Universe

From Wikipedia, the free encyclopedia

For other uses, see Universe (disambiguation).

The **Universe** is commonly defined as the totality of existence,[1][2][3][4] including planets, stars, galaxies, the contents of intergalactic space, and all matter and energy.[5][6] Similar terms include the *cosmos*, the *world* and *nature*.

The observable universe is about 46 billion light years in radius.[7] Scientific observation of the Universe has led to inferences of its earlier stages. These observations suggest that the Universe has been governed by the same physical laws and constants throughout most of

Dictionary.com universe

u·ni·verse [yoo-nuh-vurs] ? Show IPA

noun

1. the totality of known or supposed objects and phenomena throughout space; the cosmos; macrocosm.
2. the whole world, especially with reference to humanity: *a truth known throughout the universe.*
3. a world or sphere in which something exists or prevails: *his private universe.*

The universe (my working definition):

Everything that exists or could ever exist, in principle, in our experience. ("Our experience" includes things inferred by instrumentation.)

Everything to which we are causally connected, now or in the future.

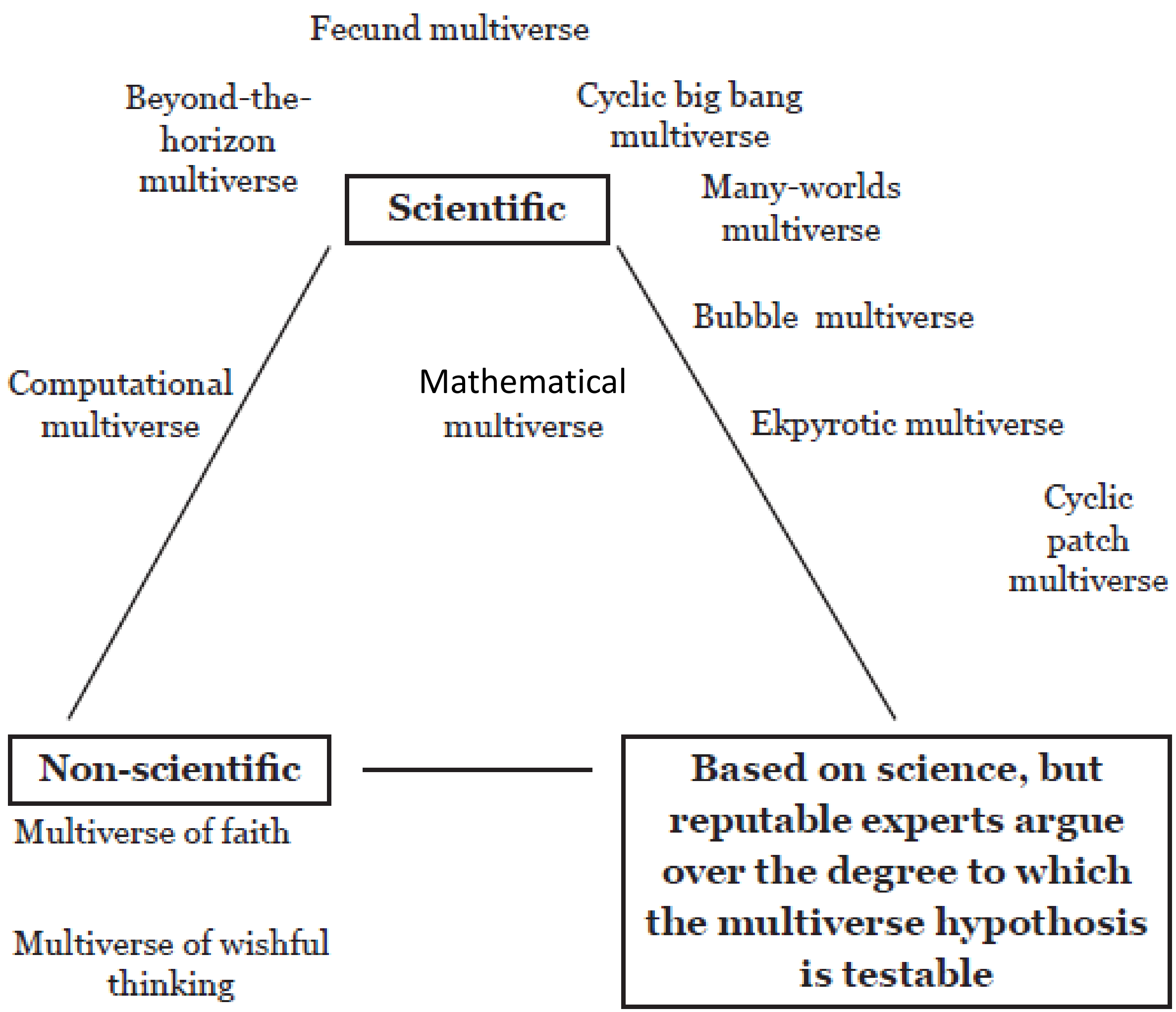


Figure 1.1: Relative degrees to which different multiverse concepts are scientific.

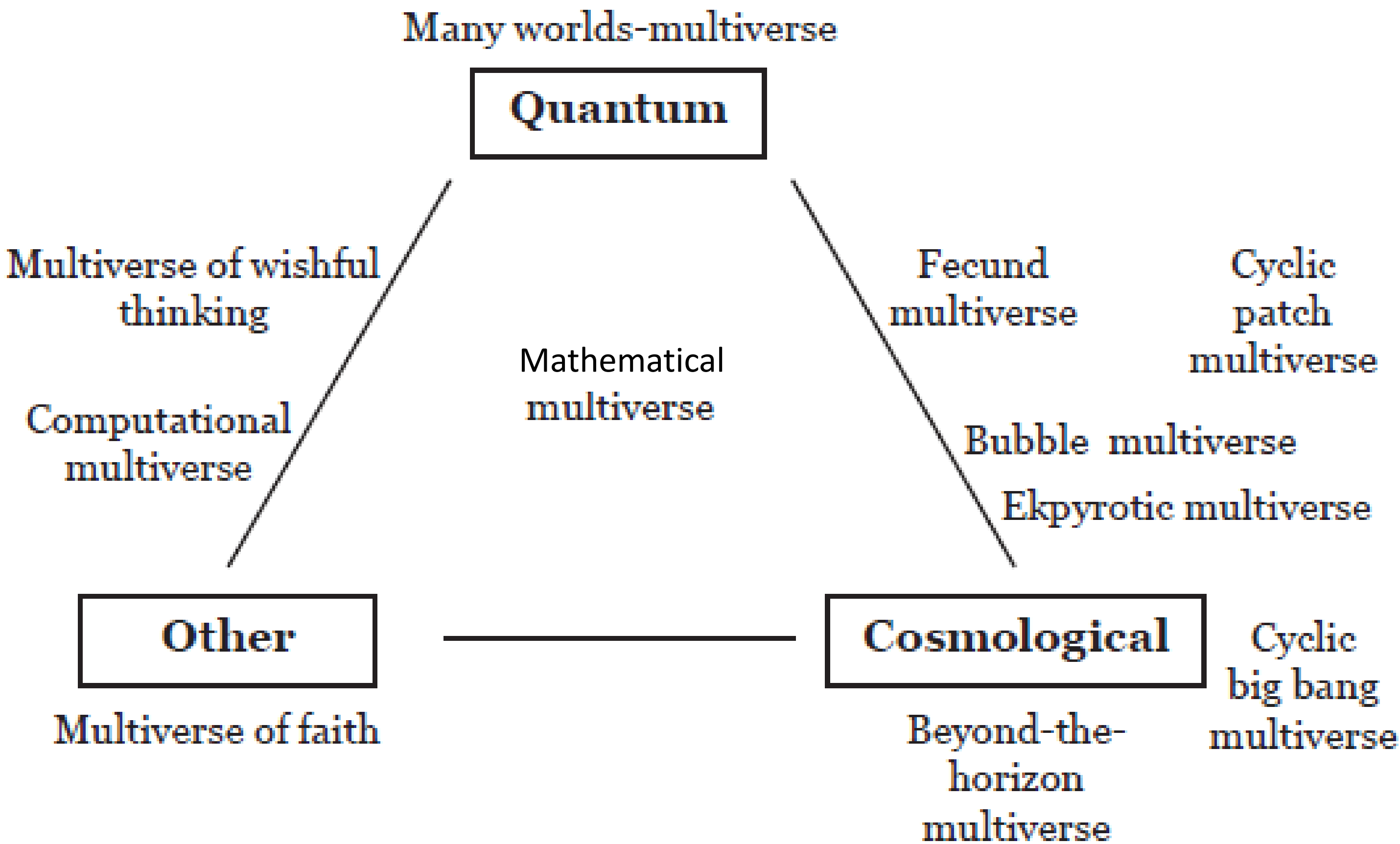
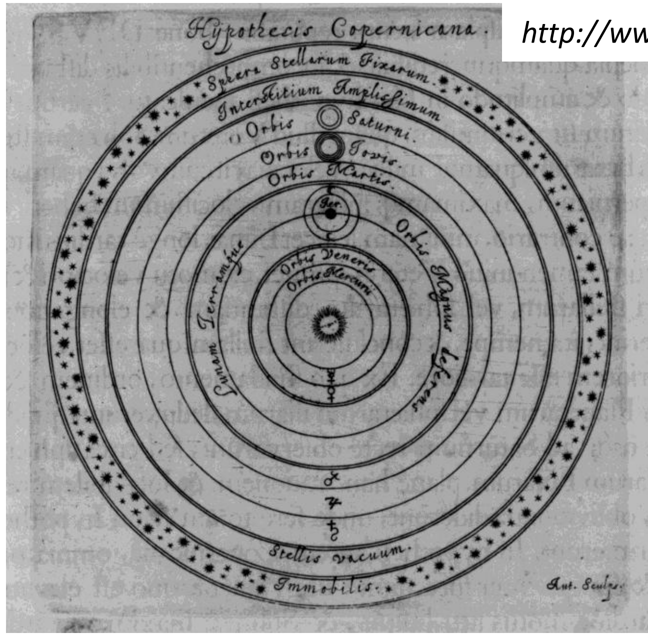


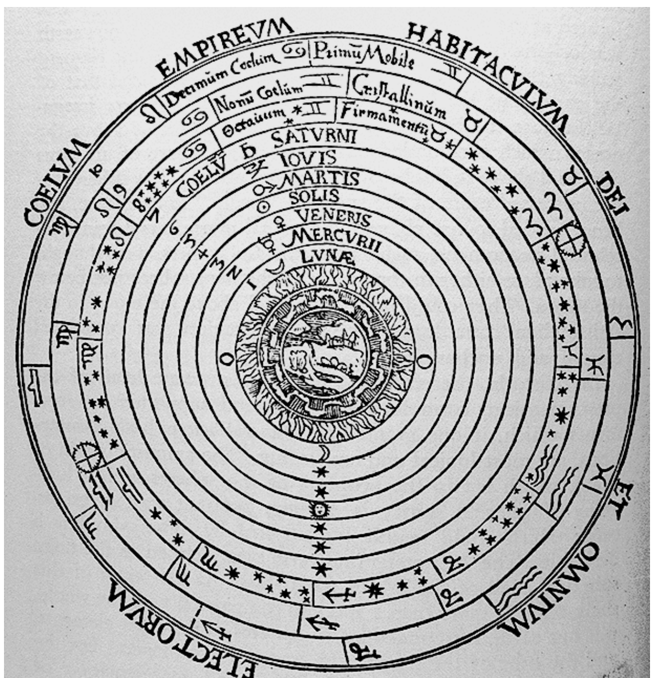
Figure 1.2: Relative degree of quantum versus cosmological character for different multiverse concepts.

Cosmology for non-cosmologists

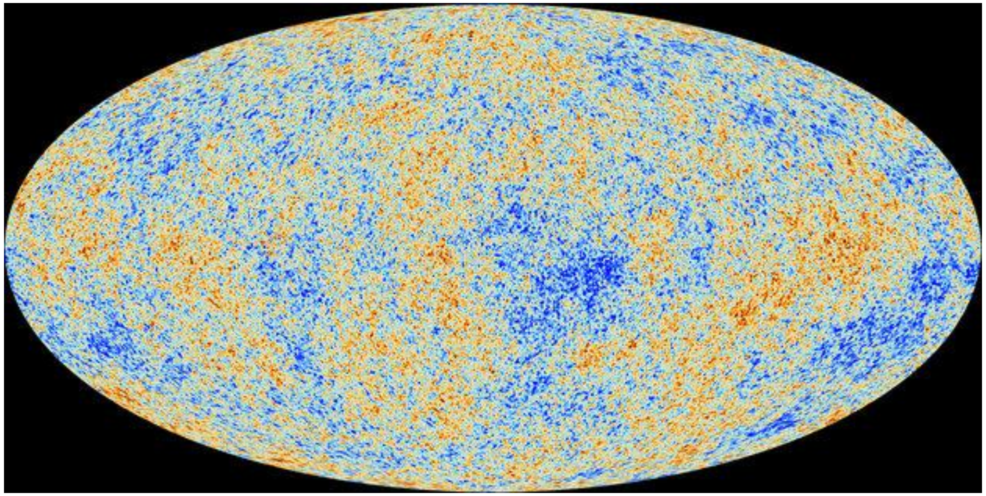


http://www.hps.cam.ac.uk/starry/copercosmol.html

Representation of Copernicus' Cosmos taken from Johannes Hevelius' *Selenographia*.



The Christian Aristotelian cosmos, engraving from Peter Apian's Cosmographia.



CMB, from ESA's Planck mission website

Vesto Slipher (1875-1969) Lowell Observatory
discovers a strange thing in 1912 …

Most nearby galaxies are moving away from us

Made use of the Doppler shift in atomic spectra

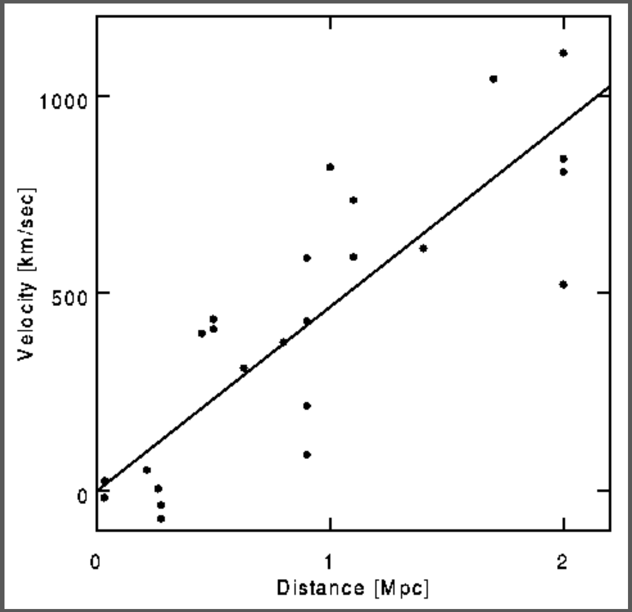
Hubble

Edwin Hubble (1889-1953) and Milton Humason (1891-1972) at Mount Wilson Observatory combine Hubble's distance measurements (Cephied variable stars) with Slipher's reshift information and discover …

Humason (from AIP)

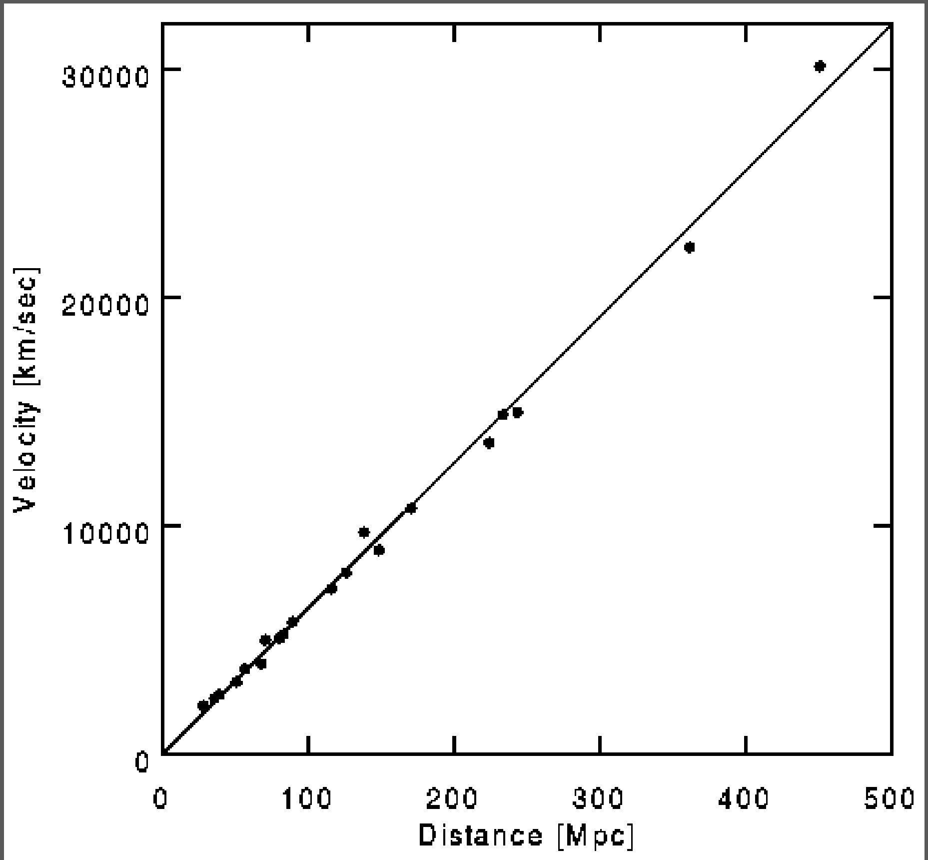
Galaxies that are further away are moving away from us faster

Hubble's Law V=Hd



Welcome to the "expanding universe"!!

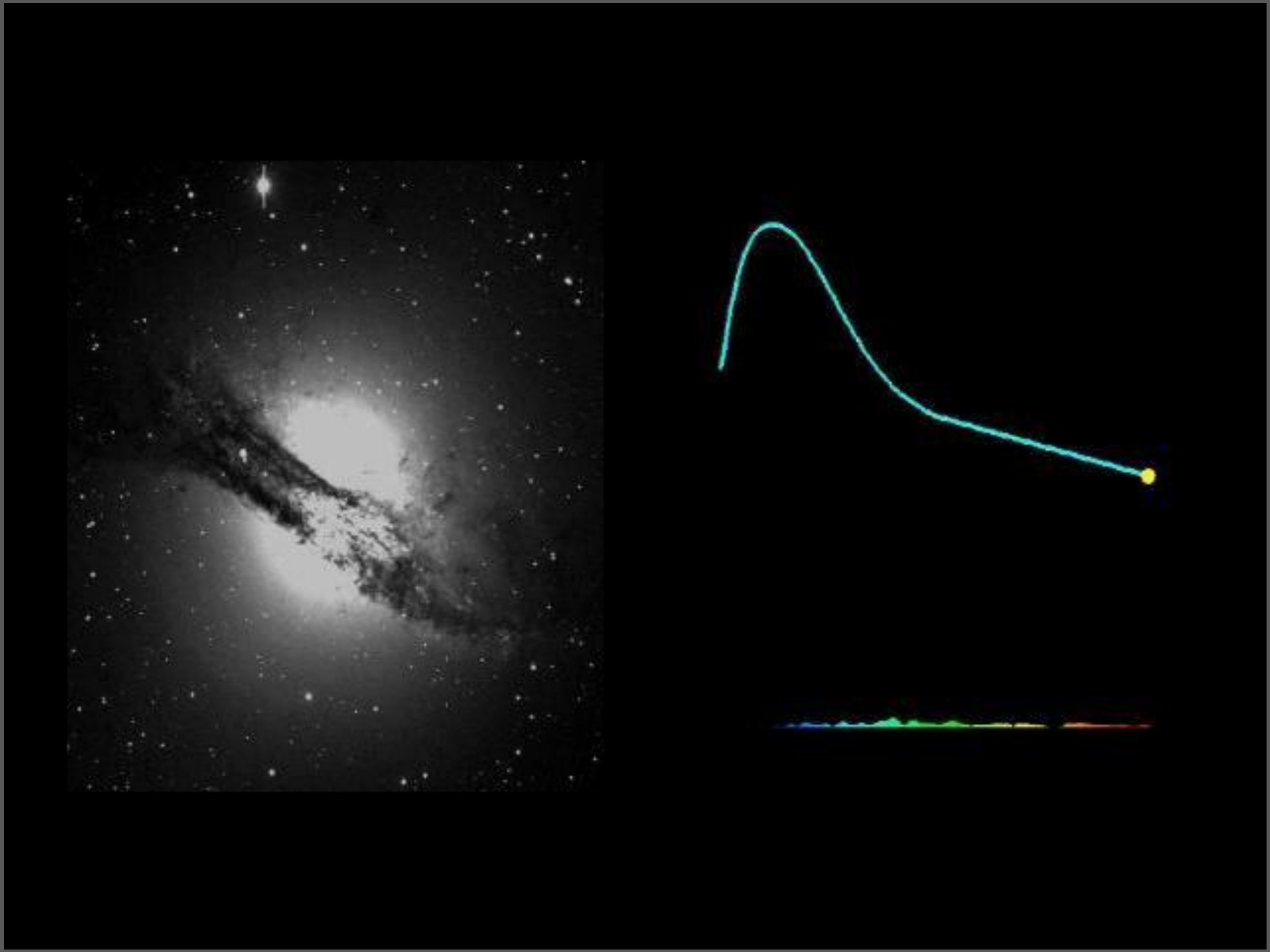
extrapolate back in time find the age of the universe → 13.7 billion years.



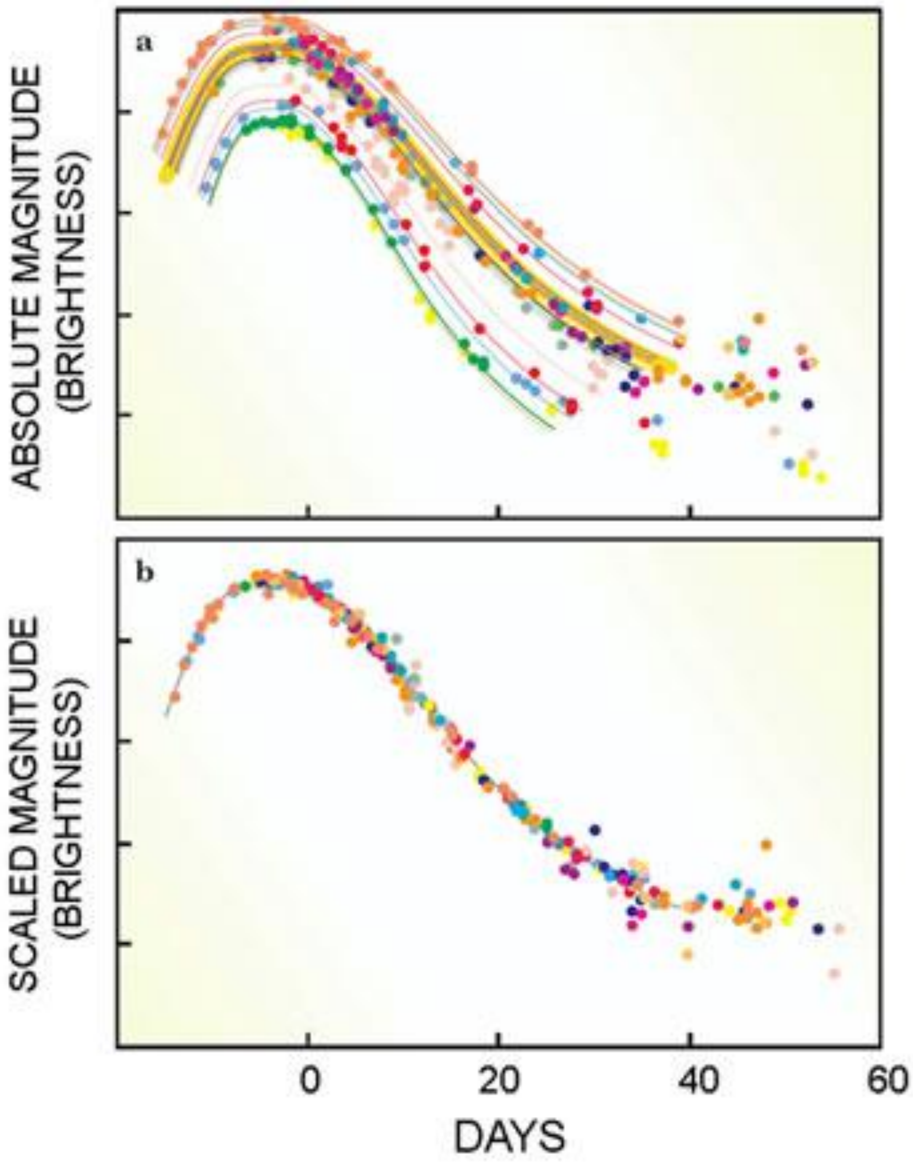
Type Ia SNe from Riess, Press and Kirshner (1996)

Light travels 1 Mpc in 3 million years

Type 1A supernovas – Use as "standard candle" to gauge distance to distant objects

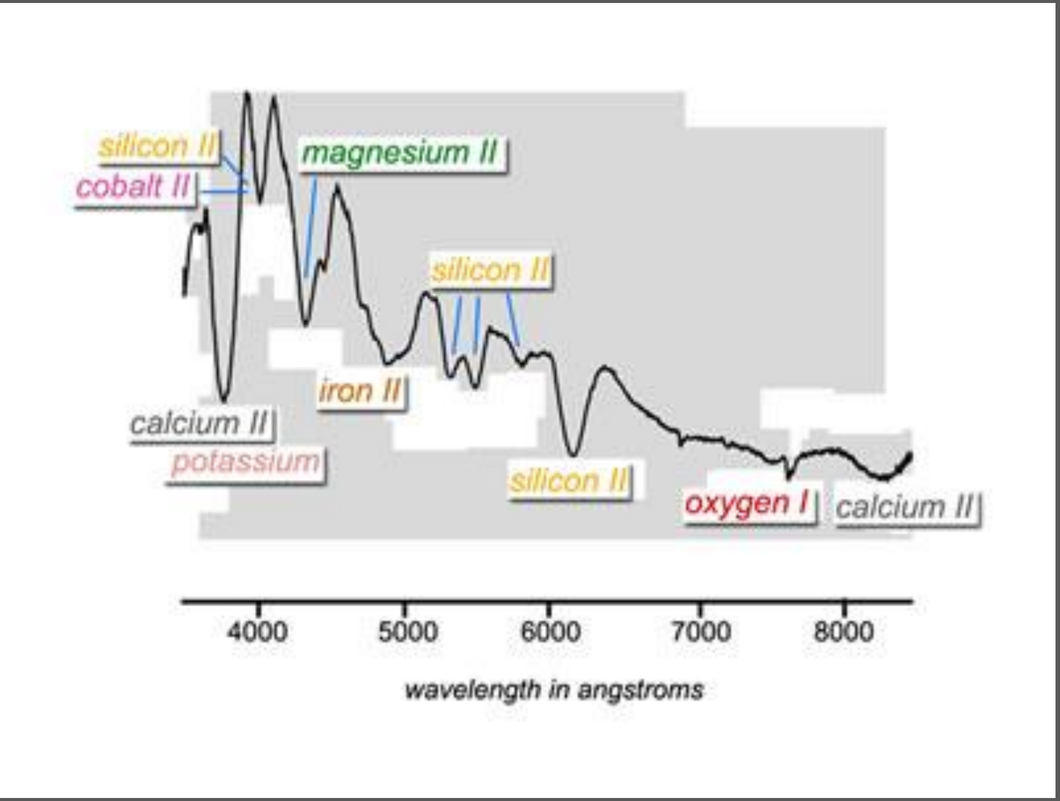


Energy produced in a short period is roughly that produced by the sun (at current energy output) in about 10 billion years.

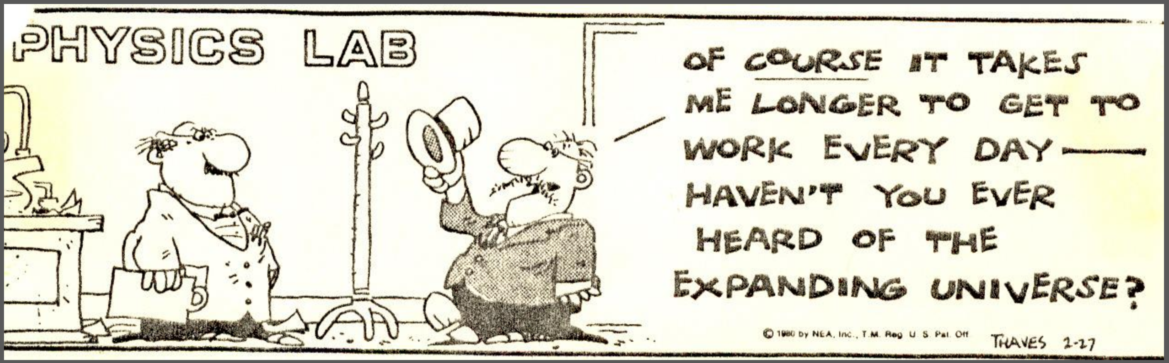


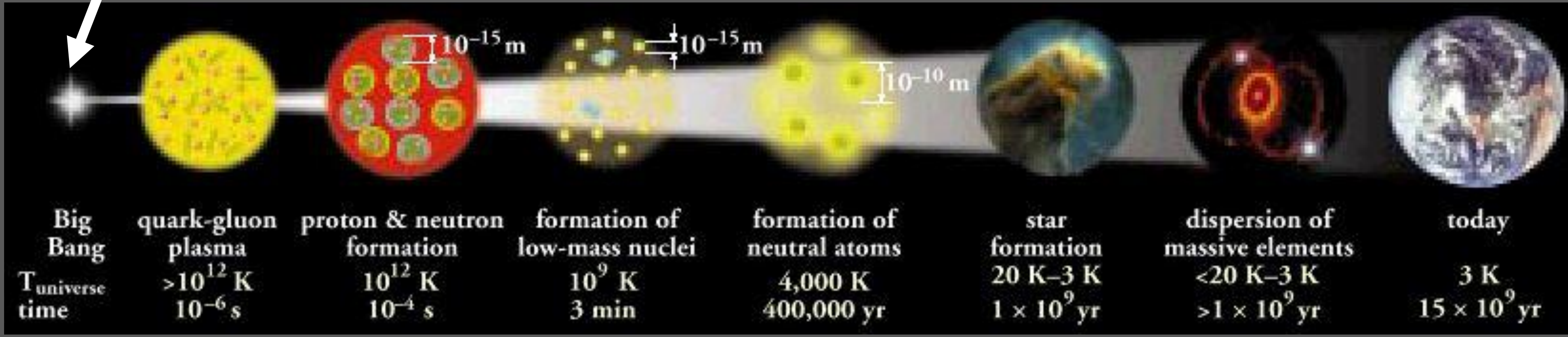
a
ABSOLUTE MAGNITUDE (BRIGHTNESS)
b
SCALED MAGNITUDE (BRIGHTNESS)
0
20
40
60
DAYS

Spectral lines (atomic absorption) can provide classification information for the type of supernova and allow for recession velocity determination using the relativistic Doppler effect (frequency shift of the light)

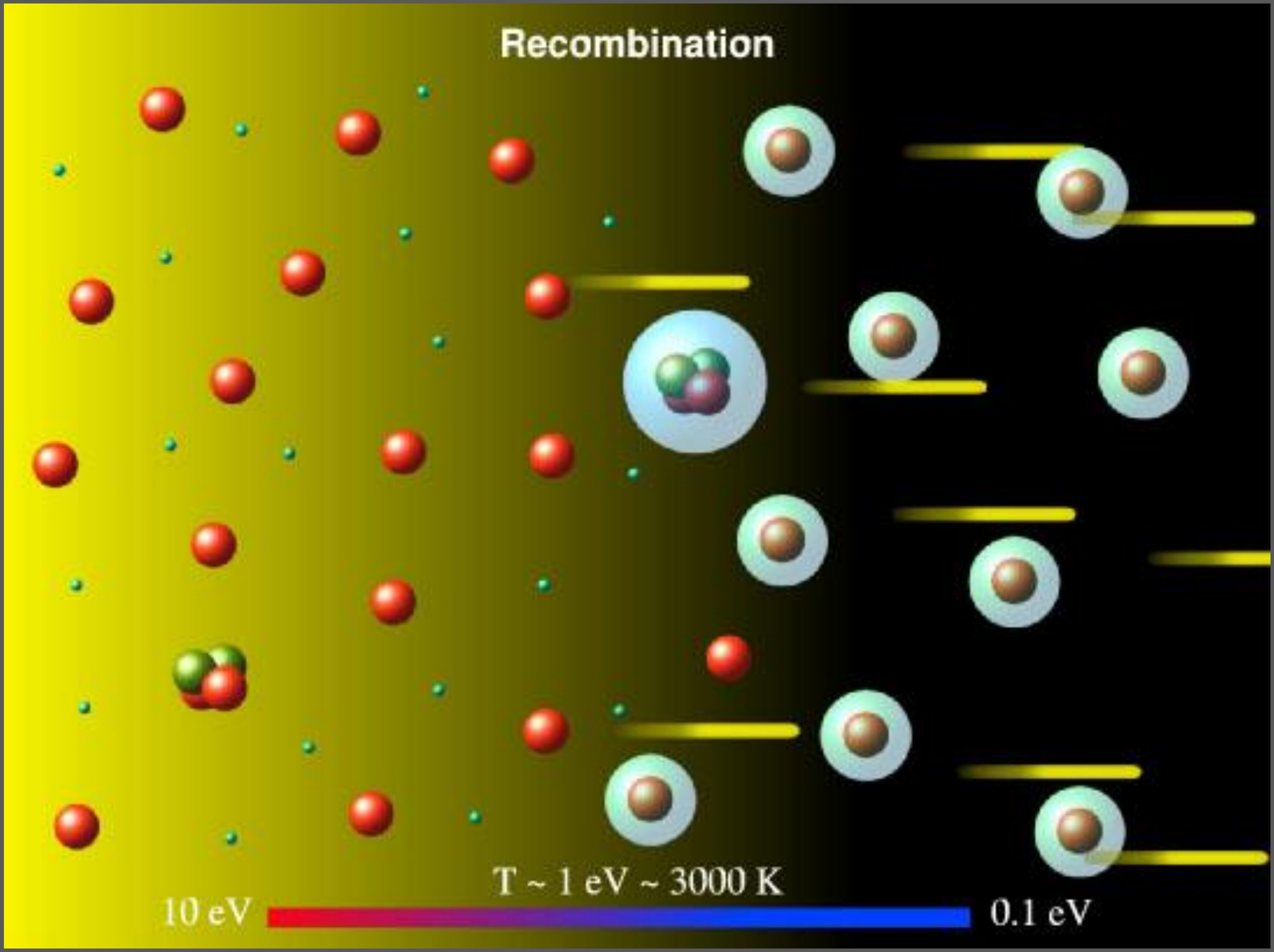


Beasts dwell here





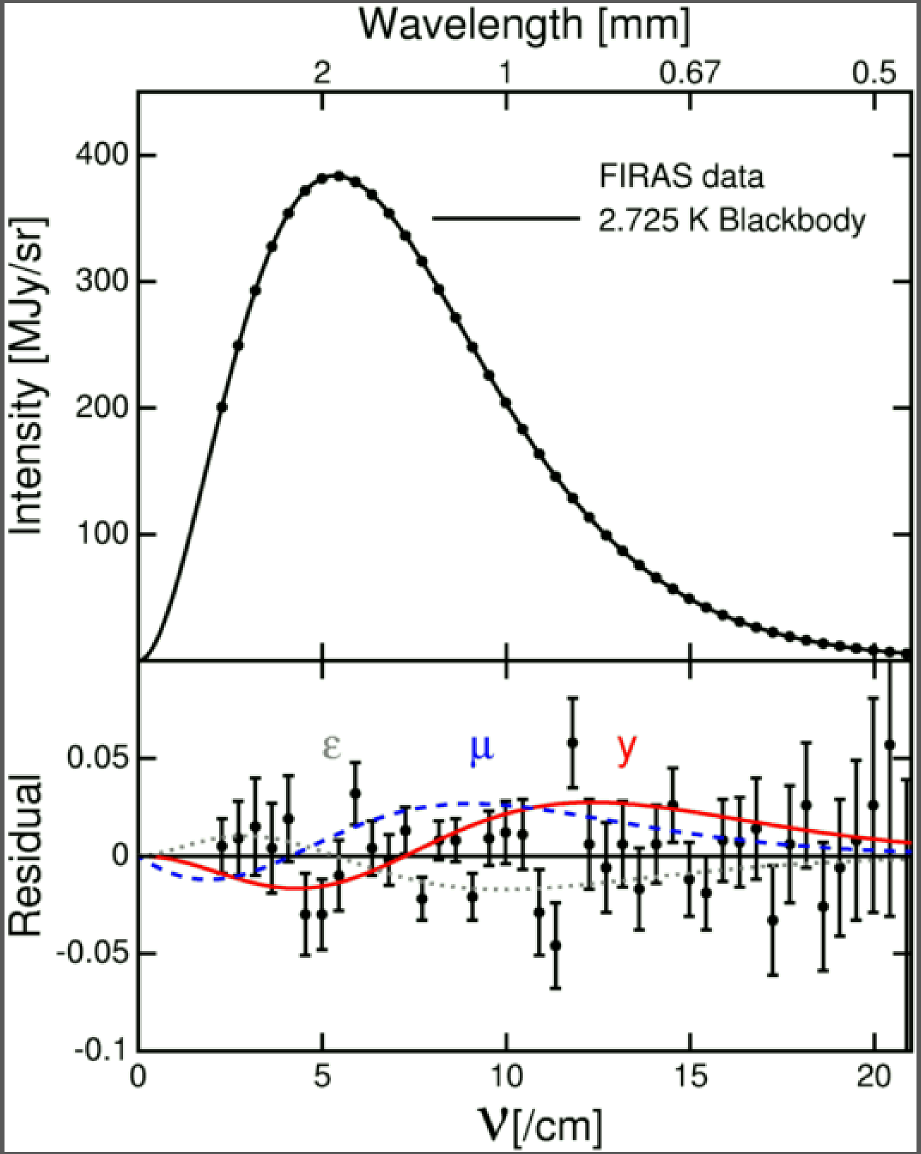
TIME



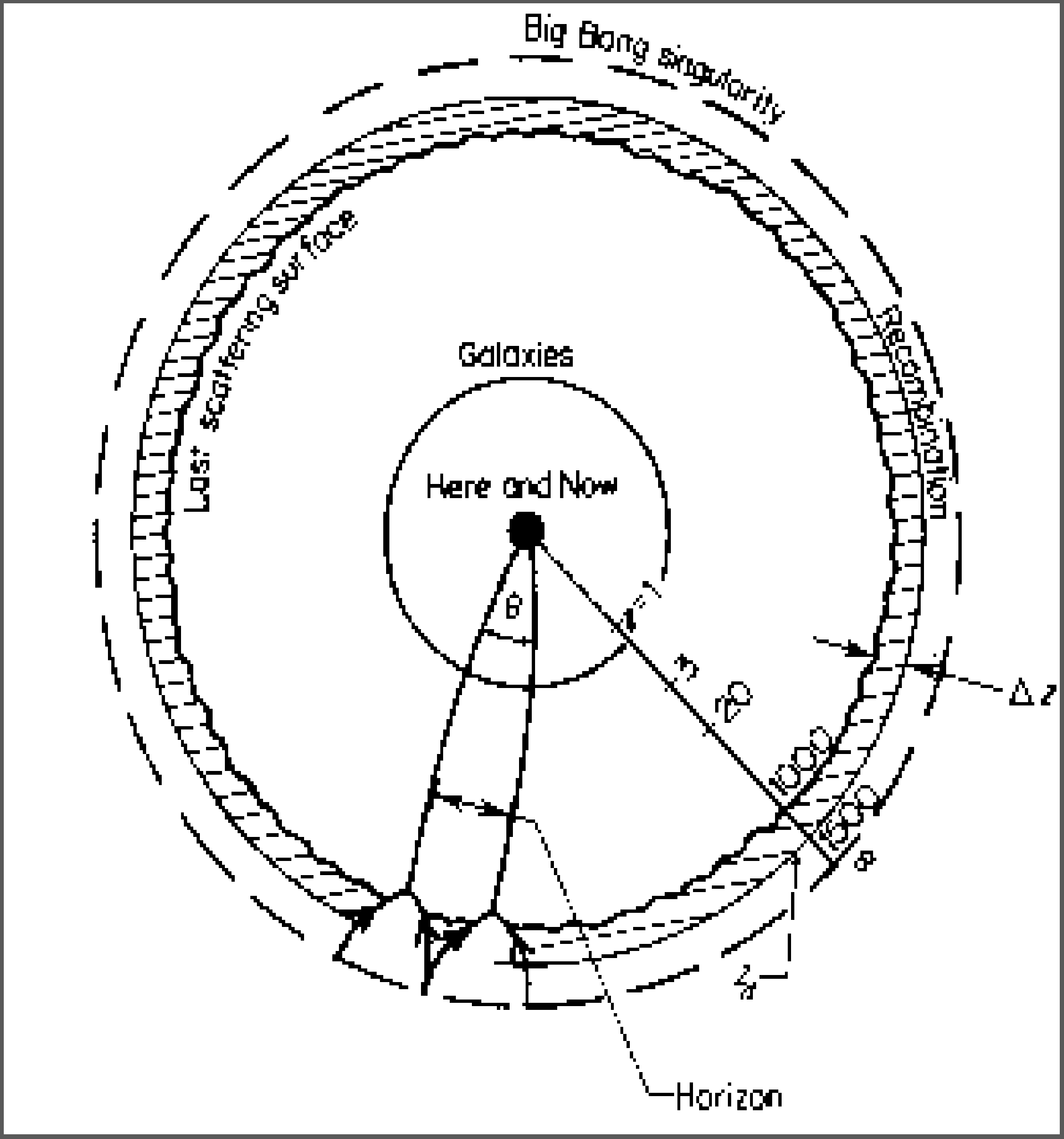
From http://ned.ipac.caltech.edu/level5/Sept02/Kinney/Kinney3.html

Penzias and Wilson and the antenna used to first detect the CMB

From http://aether.lbl.gov/cmb.html

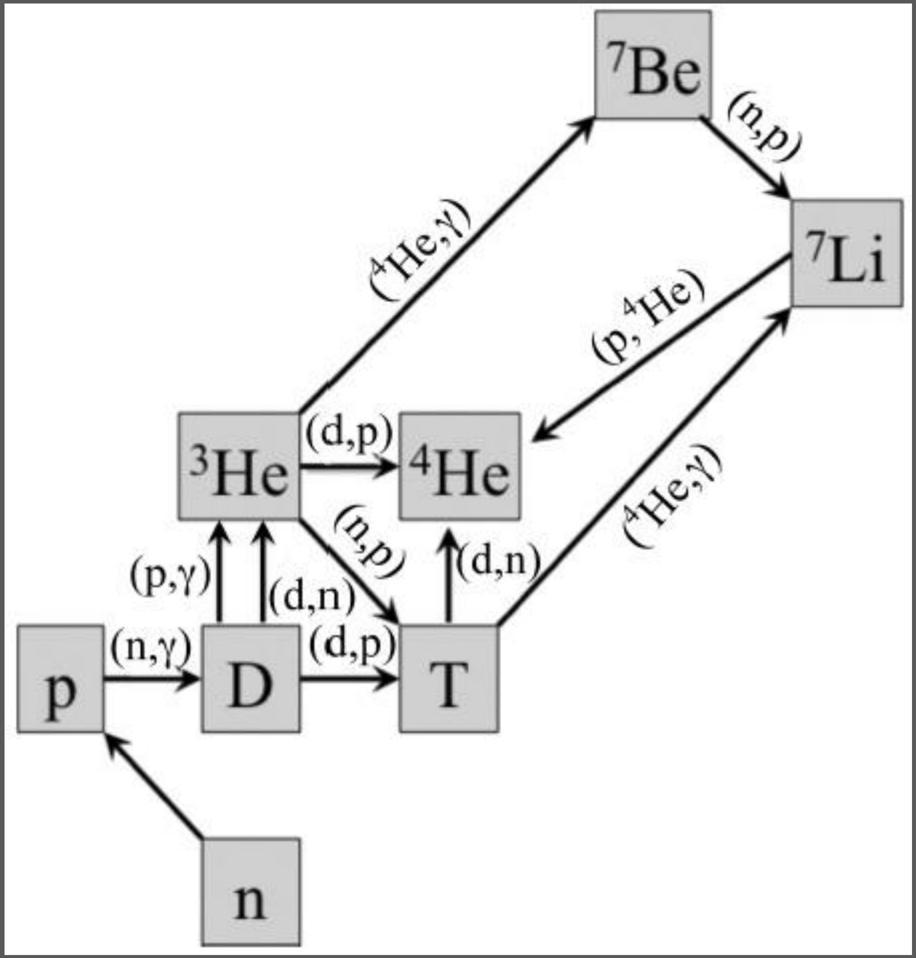


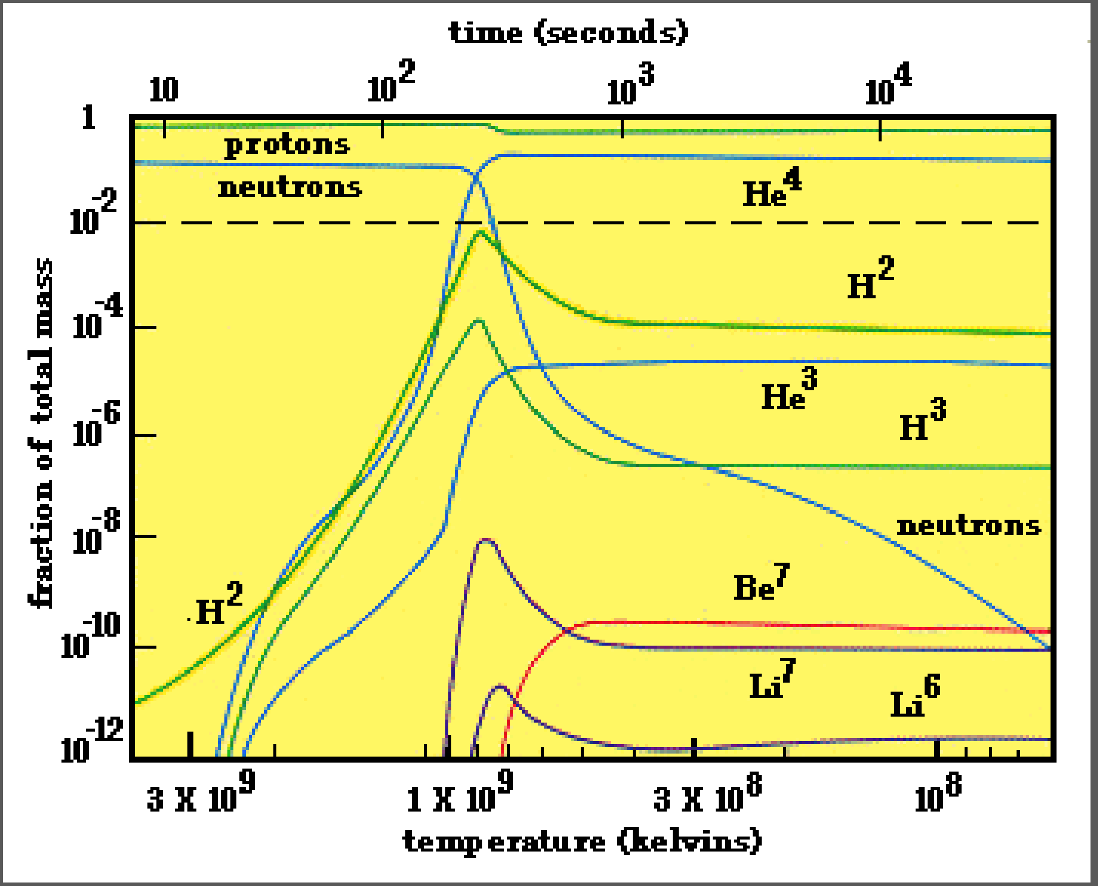
From http://www.astro.ucla.edu/~wright/CMB.html



From http://aether.lbl.gov/cmb.html

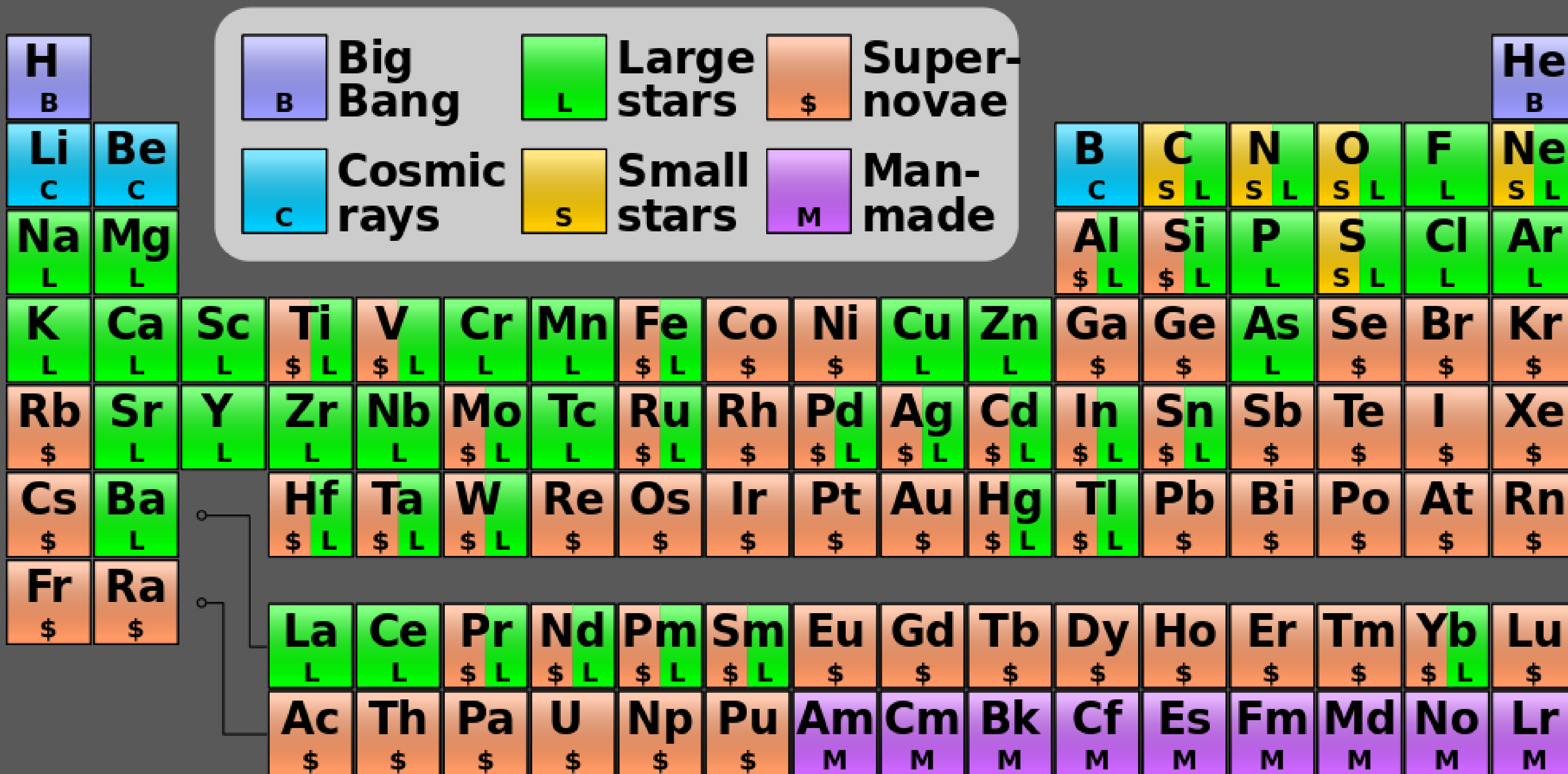
Big bang nucleosynthesis



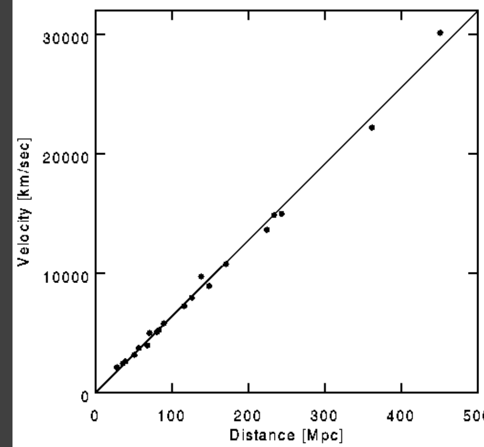


time (seconds)
10
10^2
10^3
10^4
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
fraction of total mass
protons
neutrons
He^4
H^2
He^3
H^3
neutrons
Be^7
H^2
Li^7
Li^6
3 X 10^9
1 X 10^9
3 X 10^8
10^8
temperature (kelvins)

Origin of elements

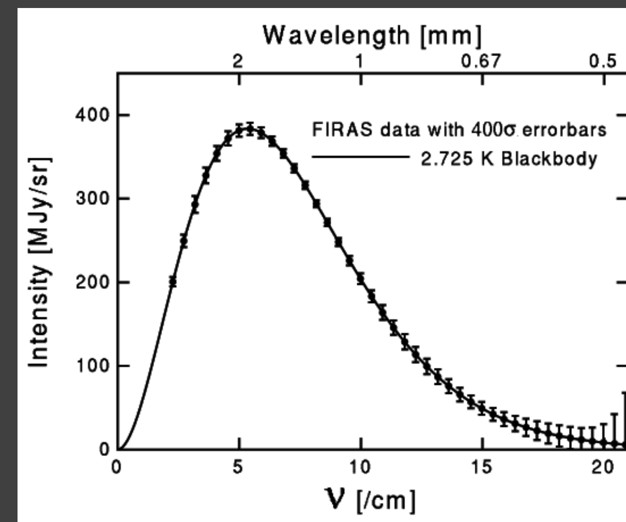


- Expansion of space

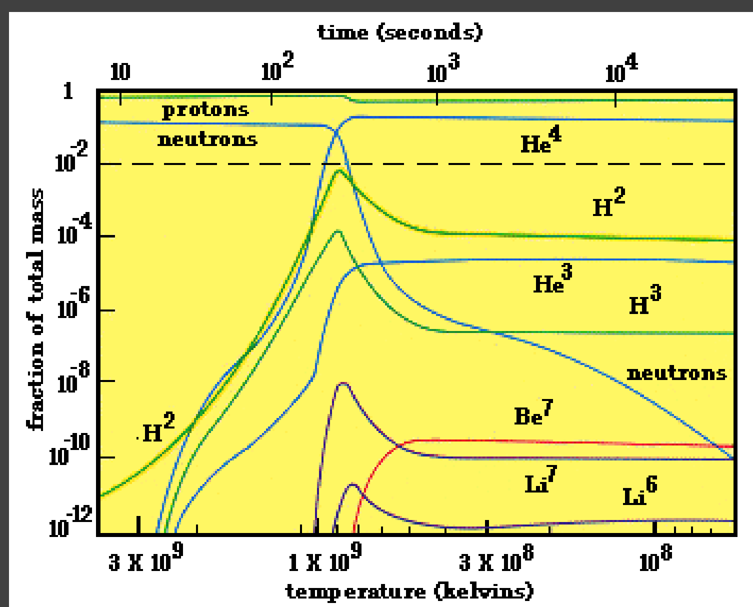


- Cosmic microwave background

Penzias and Wilson, 1964



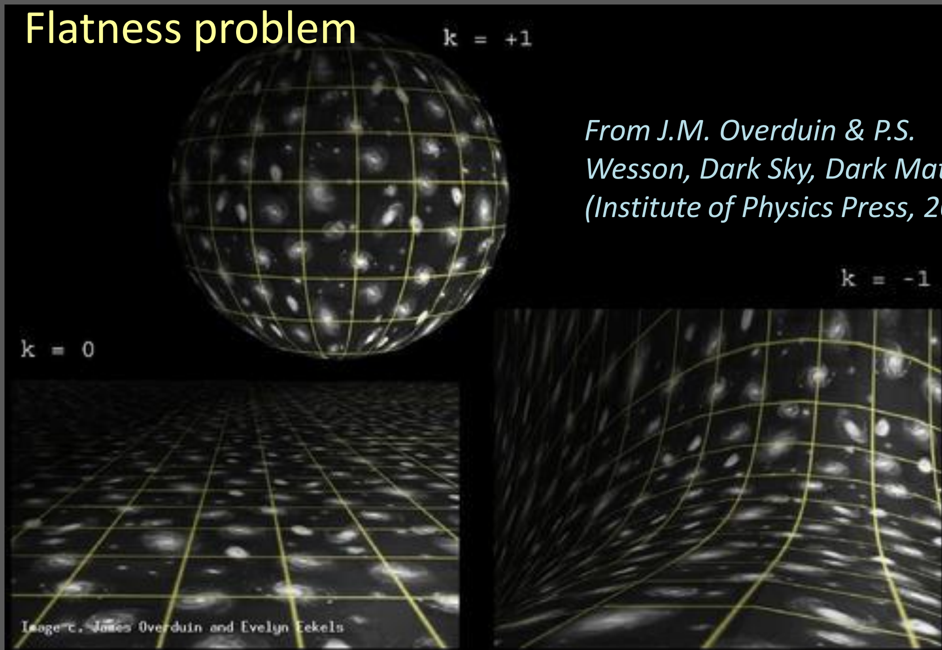
- Nucleosynthesis



The big bang HAD to happen

The hot big bang?
What utter nonsense!

Flatness problem

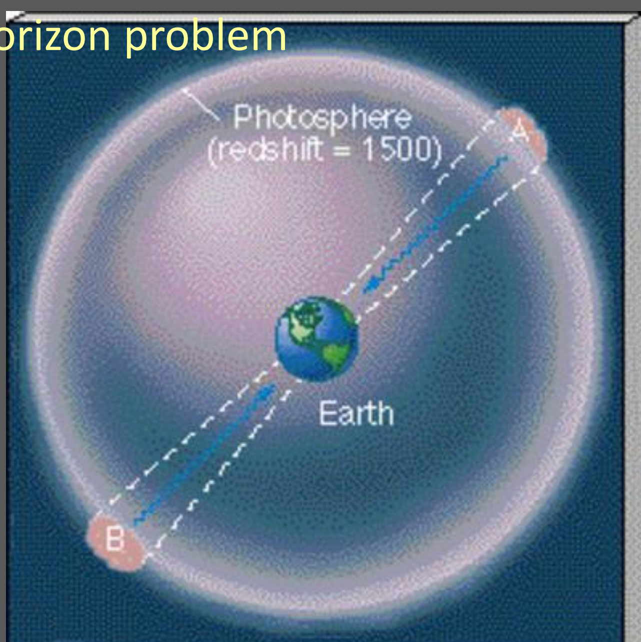


From J.M. Overduin & P.S. Wesson, Dark Sky, Dark Matter (Institute of Physics Press, 2003)]

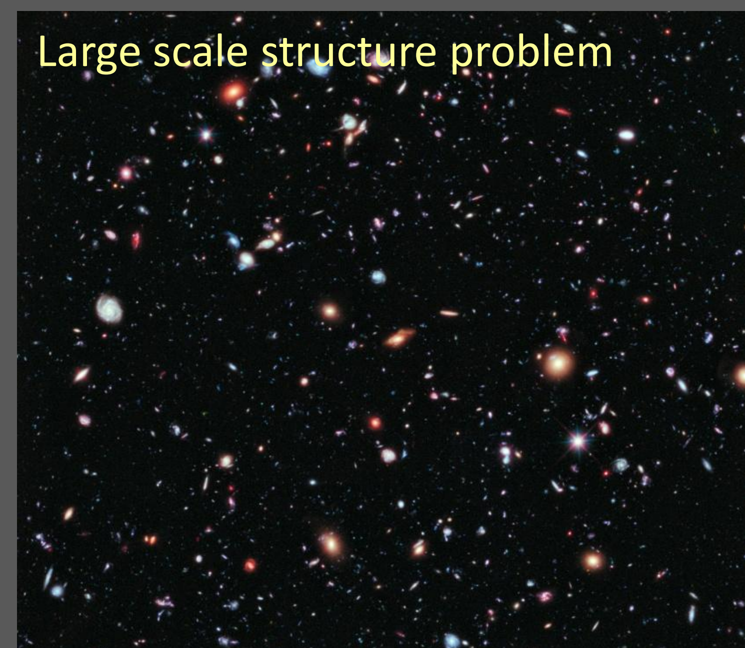
Magnetic monopole problem

Singularity problem

Horizon problem



Large scale structure problem

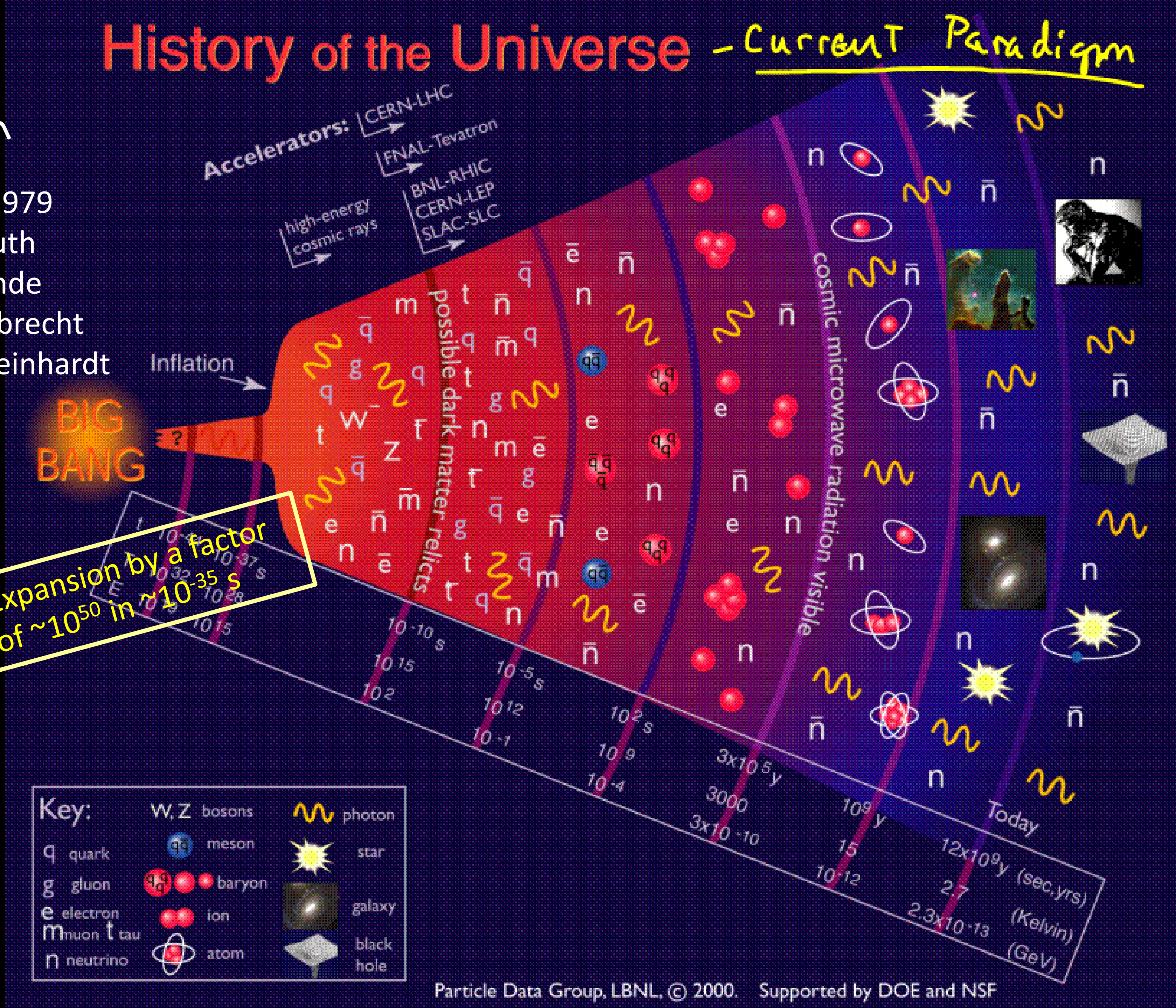


Geometry of the universe is ~ flat

http://www.youtube.com/watch?v=x8pupNMn5nI

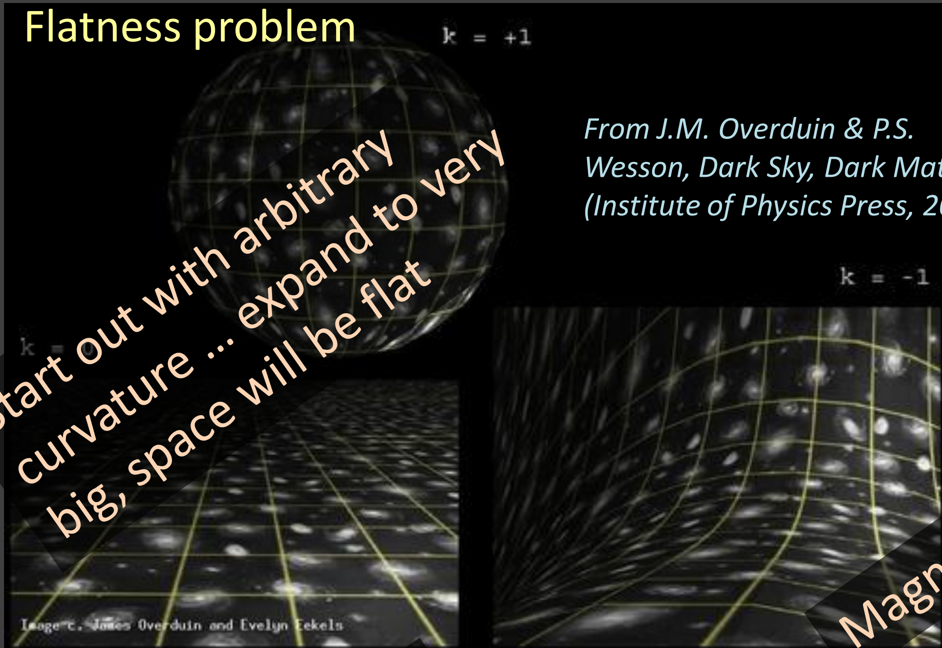
Cosmic inflation

~1979
Guth
Linde
Albrecht
Steinhardt



bang?
nonsense!

Flatness problem



From J.M. Overduin & P.S. Wesson, Dark Sky, Dark Matter (Institute of Physics Press, 2003)

Start out with arbitrary curvature … expand to very big, space will be flat

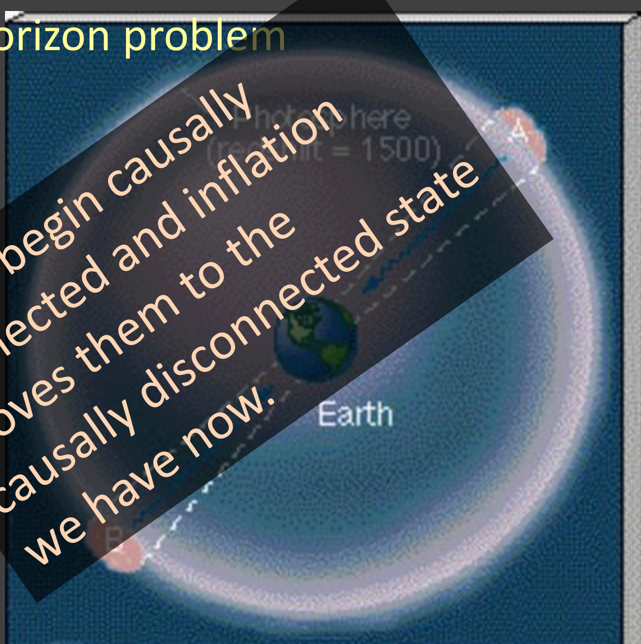
Magnetic monopole problem

Magnetic monopole density → 0

Singularity problem

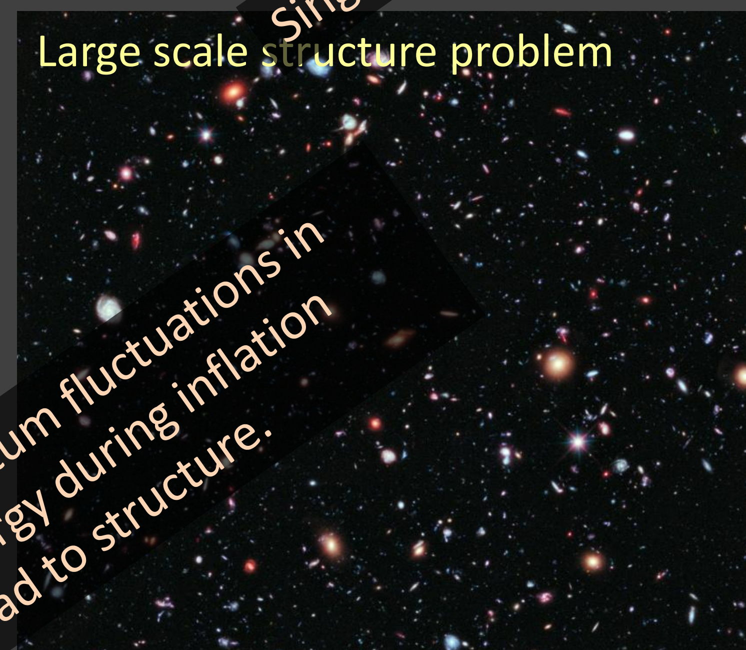
Singularity not necessary.

Horizon problem



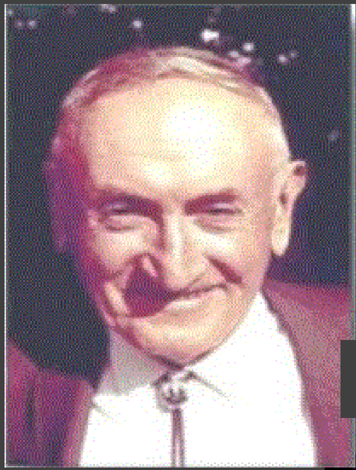
Points begin causally connected and inflation moves them to the causally disconnected state we have now.

Large scale structure problem



Quantum fluctuations in energy during inflation lead to structure.

Cold dark matter

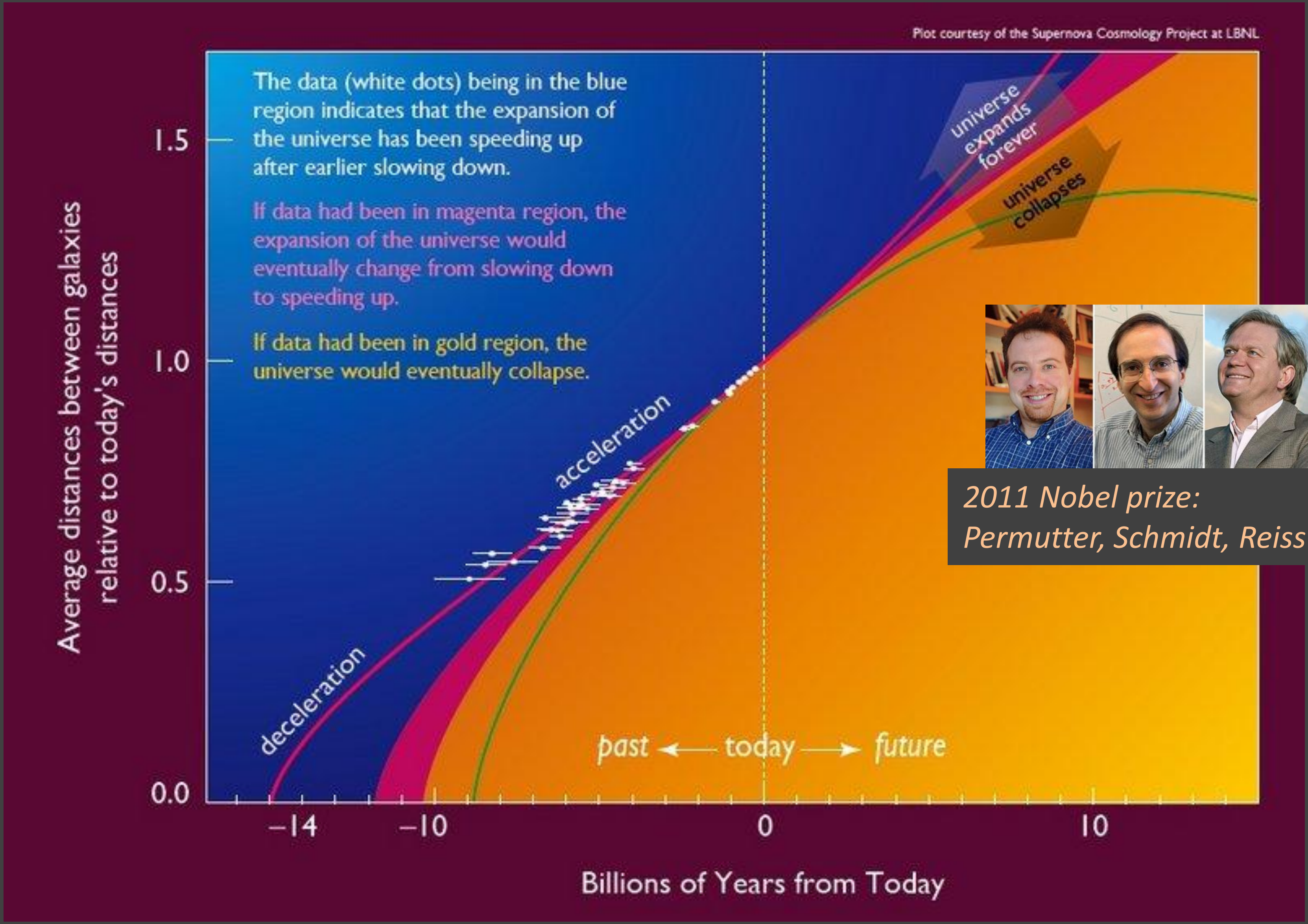


Fritz Zwicky

Bullet cluster

Vera Rubin (published with Kent Ford)

Dark energy

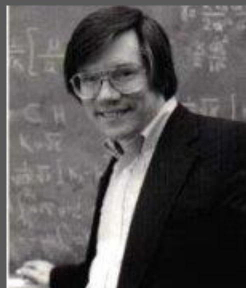


2011 Nobel prize: Permutter, Schmidt, Reiss

“The total energy – matter plus gravitational – remains constant and very small, and could even be exactly zero. … If inflation is right, everything can be created from nothing, or at least from very little. If inflation is right, the universe can properly be called the ultimate free lunch.”

- Alan Guth

SV (5)
Dec 7, 1979



SPECTACULAR REALIZATION:

This kind of supercooling can explain why the universe today is so incredibly flat — and therefore ~~why~~ resolve the fine-tuning paradox pointed out by Bob Dicke in his Einstein day lectures.

Let me first rederive the Dicke paradox.
He relies on the empirical fact the the deacceleration parameter today q_0 is of order 1.

$$q_0 \equiv - \ddot{R} \frac{R}{\dot{R}^2}$$

Use the eqs of motion

$$3\ddot{R} = -4\pi G\,(\rho + 3p)R$$

$$\dot{R}^2 + k = \frac{8\pi G}{3}\rho R^2 ,$$

so

$$\text{~~}q_0 = \frac{\frac{1}{2}(1 + 3p/\rho)}{1 - \frac{3kM_p^2}{8\pi\rho R^2}}\text{~~}$$

$$\frac{k}{R^2} = \frac{8\pi\rho}{3M_p^2} - H^2 \qquad G = \frac{1}{M_p^2}, \quad H = \frac{\dot{R}}{R}$$

$$q_0 = \frac{4\pi}{3M_p^2}(\rho + 3p)\frac{1}{H^2}$$

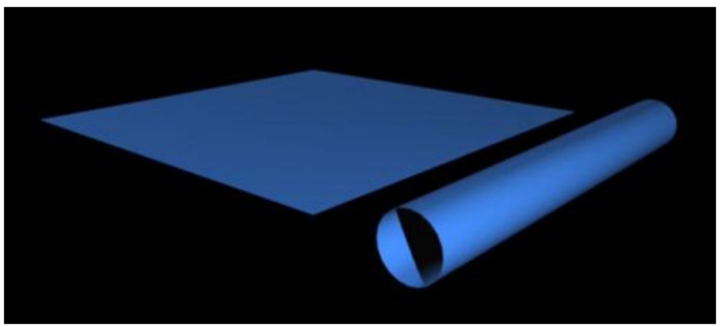
$$\frac{k}{R^2} = \frac{H^2}{(1 + \frac{3p}{\rho})}\left[2q_0 - 1 - \frac{3p}{\rho}\right]$$

Using the above eq, the fact the $\frac{3p}{\rho} \approx 0$ for today's universe, and the fact that $q_0 \sim 1$, one has

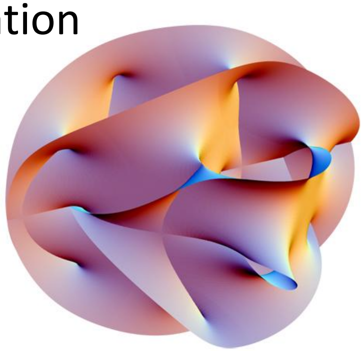
What drives inflation? What is dark energy?

A non-string theorists view of a string theorist’s view of inflation/dark energy

A viable string theory of reality (if such exists) will have to be in 10 dimensions



Compactification



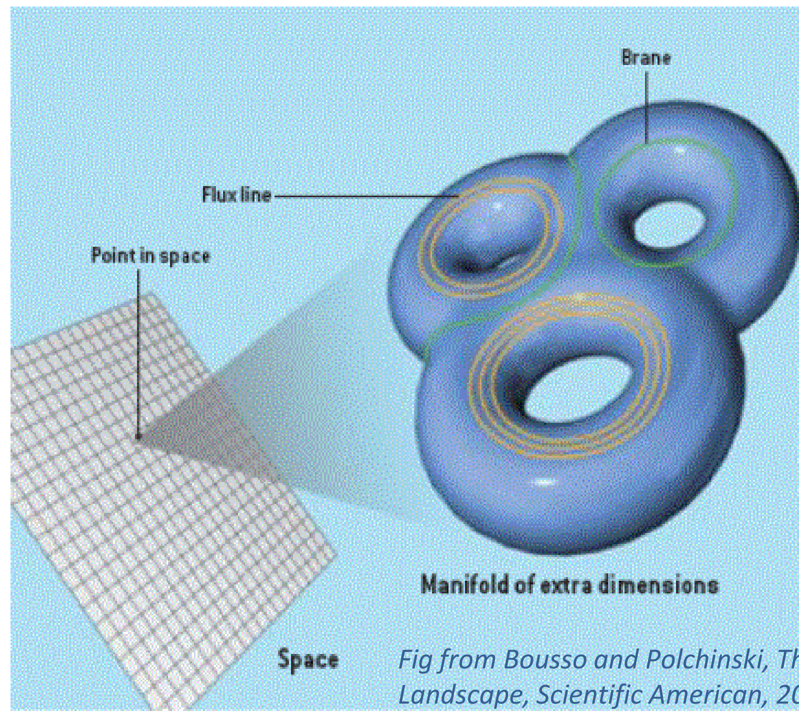
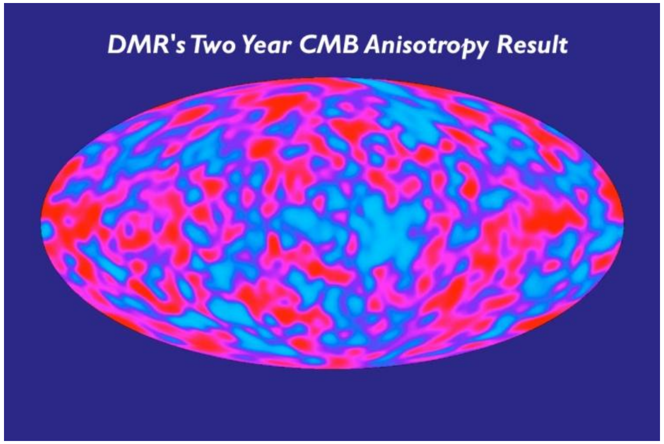


Fig from Bousso and Polchinski, The String Theory Landscape, Scientific American, 2004.

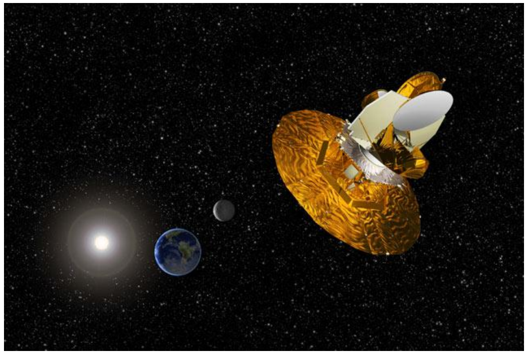
Figs from http://www.learner.org/courses/physics/unit/text.html?unit=4&secNum=4

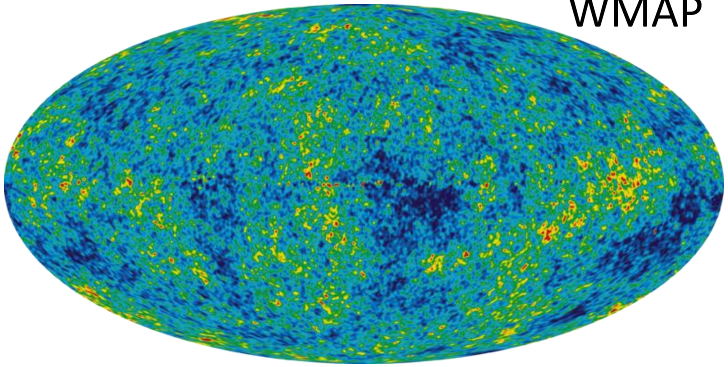
Hot big bang + CDM + DE + inflation
Is this crazy?

Clues from the CMB

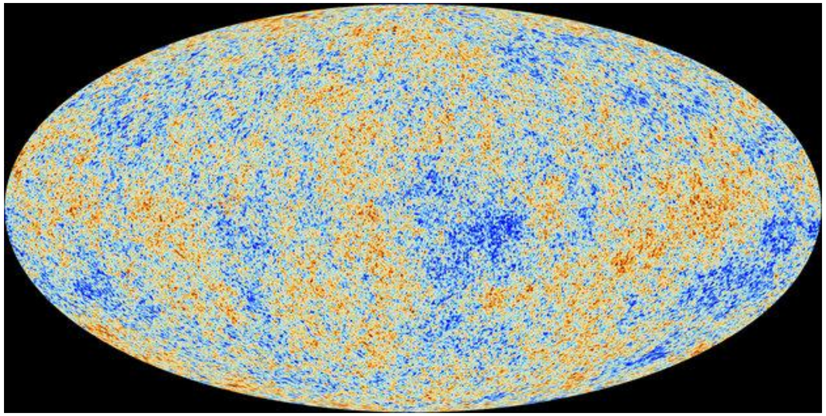


COBE





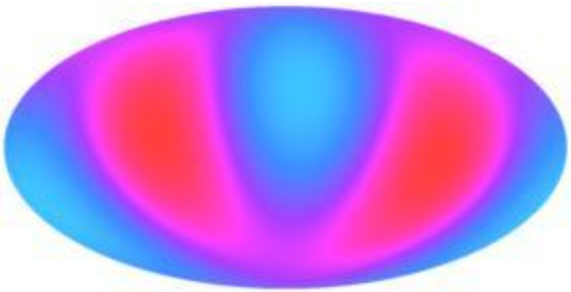
WMAP



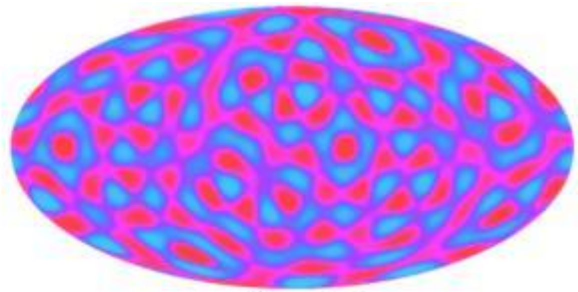
Planck

CMB, from ESA's Planck mission website

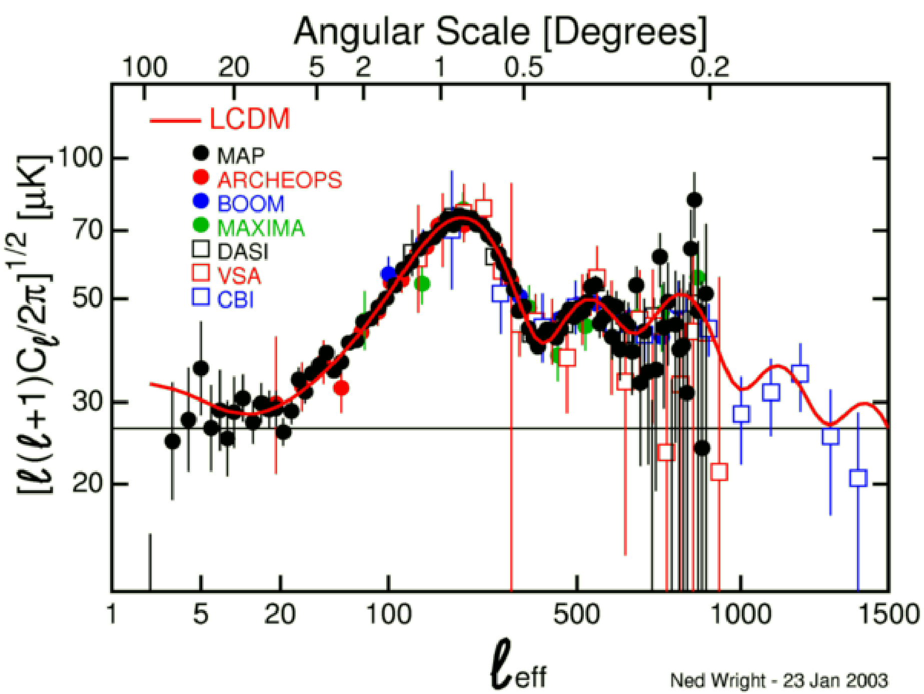
WMAP CMB angular feature size power spectrum – acoustics in the early universe!



$\ell = 2$

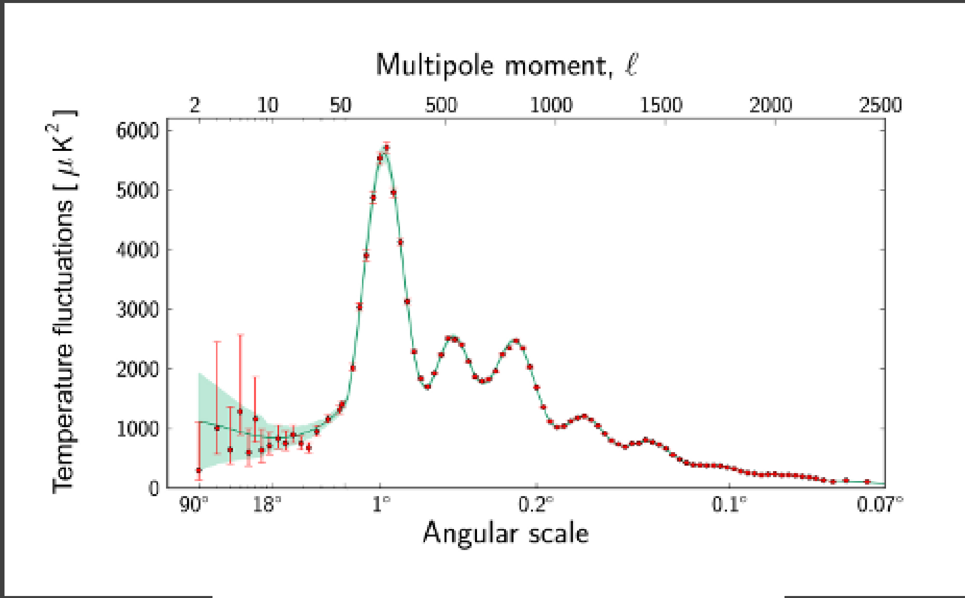


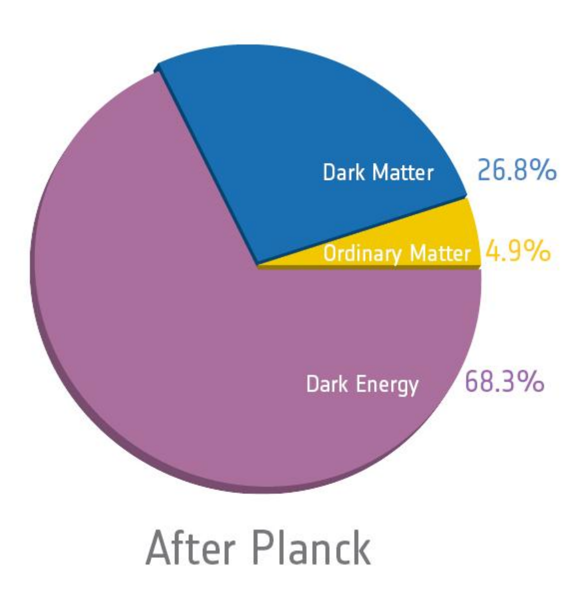
$\ell = 16$



The characteristics of sound waves depend on the medium!

This data is sensitive to amount of
Normal matter, dark matter, dark energy and inflationary model of the early universe





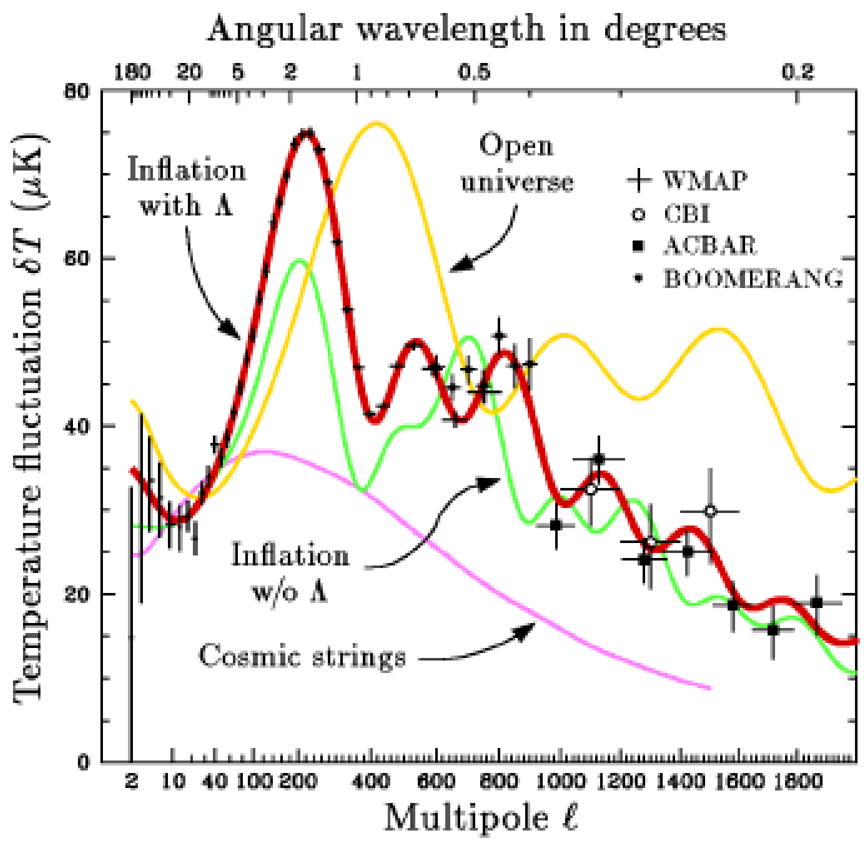
From the Planck collaboration

MIT-CTP#3811 hep-th/0702178

Eternal inflation and its implications‡

Alan H. Guth
Center for Theoretical Physics, Laboratory for Nuclear Science, and Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139

2007



Astronomy & Astrophysics manuscript no. Planck_inflation_driver
March 22, 2013

Planck 2013 results. XXII. Constraints on inflation

Planck Collaboration: P. A. R. Ade[86], N. Aghanim[59], C. Armitage-Caplan[92], M. Arnaud[72], M. Ashdown[69,6], F. Atrio-Barandela[19], J. Aumont[59], C. Baccigalupi[85], A. J. Banday[95,10], R. B. Barreiro[66], J. G. Bartlett[1,67], N. Bartolo[33], E. Battaner[96], K. Benabed[60,94], A. Benoît[57], A. Benoit-Lévy[26,60,94], J.-P. Bernard[10], M. Bersanelli[36,50], P. Bielewicz[95,10,85], J. Bobin[72], J. J. Bock[67,11], A. Bonaldi[68], J. R. Bond[9], J. Borrill[14,89], F. R. Bouchet, M. Bridges, M. Bucher, C. Burigana, R. C. Butler, E. Calabrese, J.-F. Cardoso, A. Catalano

ABSTRACT

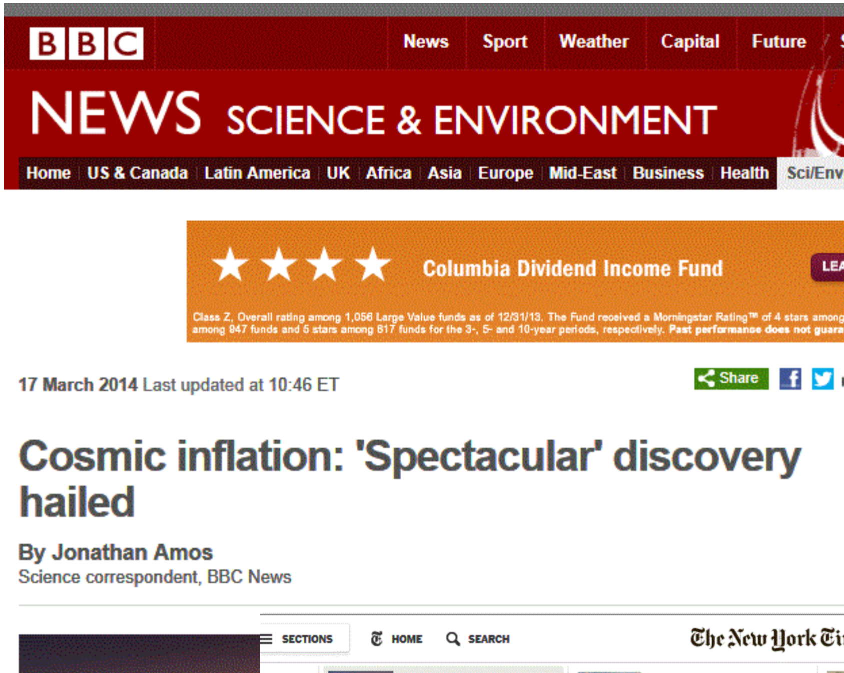
We analyse the implications of the *Planck* data for cosmic inflation. The *Planck* nominal mission temperature anisotropy measurements, combined with the *WMAP* large-angle polarization, constrain the scalar spectral index to $n_s = 0.9603 \pm 0.0073$, ruling out exact scale invariance at over 5σ. *Planck* establishes an upper bound on the tensor-to-scalar ratio at $r < 0.11$ (95% CL). The *Planck* data shrink the space of allowed standard inflationary models, preferring potentials with $V'' < 0$. Exponential potential models, the simplest hybrid inflationary models, and monomial potential models of degree $n \geq 2$ do not provide a good fit to the data. *Planck* does not find statistically significant running of the scalar spectral index

$f_{\rm NL}^{\rm local} = -5/4$. The constraint $0.98 < r_D < 1$ then corresponds to $-1.25 < f_{\rm NL}^{\rm local} < -1.21$. Taking into account the Planck result $f_{\rm NL}^{\rm local} = 2.7 \pm 5.8$ (Planck Collaboration XXIV, 2013), we conclude that the Planck data are consistent with the scenario where the curvaton decays into CDM when it dominates the energy density of the Universe, and its fluctuations are almost entirely converted into adiabatic ones.

11. Conclusions

This paper establishes the status of cosmic inflation in the context of the first release of the *Planck* cosmological results, which includes the temperature data from the first 2.6 sky surveys. CMB polarization as measured by *Planck* will be the subject of a future release. We find that standard slow-roll single field inflation is compatible with the *Planck* data. This result is confirmed by other papers of this series. *Planck* in combination with *WMAP* 9-year large angular scale polarization (WP) yields

Recent result reported by the BICEP2 collaboration



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Cosmic inflation: 'Spectacular' discovery hailed

By Jonathan Amos
Science correspondent, BBC News

theguardian

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Primordial gravitational wave discovery heralds 'whole new era' in physics

Gravitational waves could help unite general relativity and quantum mechanics to reveal a 'theory of everything'

Stuart Clark
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sts detected telltale signs of gravitational waves using the Bicep2 telescope (far the south pole. Photograph: Keith Vanderlinde/NSF

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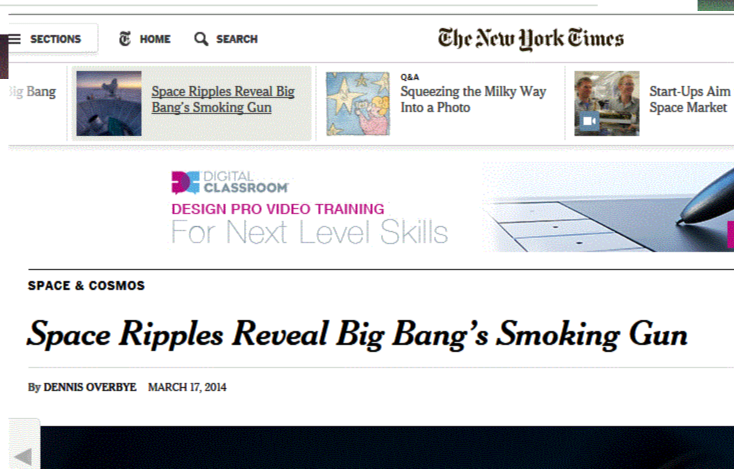

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Space Ripples Reveal Big Bang's Smoking Gun

By DENNIS OVERBYE MARCH 17, 2014