Dark Energy & other Flaws of the Universe

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Questions:

- What is the structure of 'Space and the Universe' ?

- How was the 'Past' and the 'Future' ?

- Why does the Universe looks like it does,

or does is look like it does because we are looking?

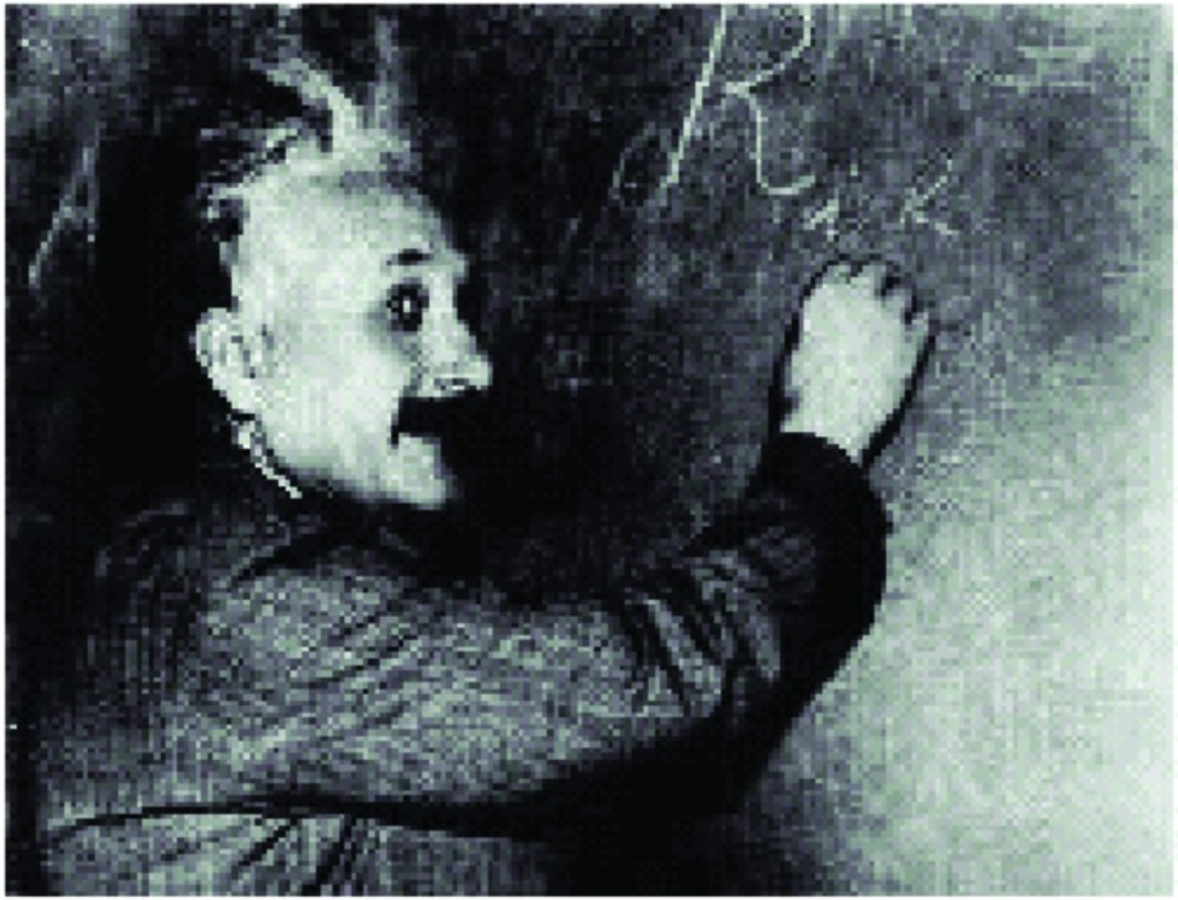
- Is our Universe unique ?

What is Space, Time and Gravitation ?

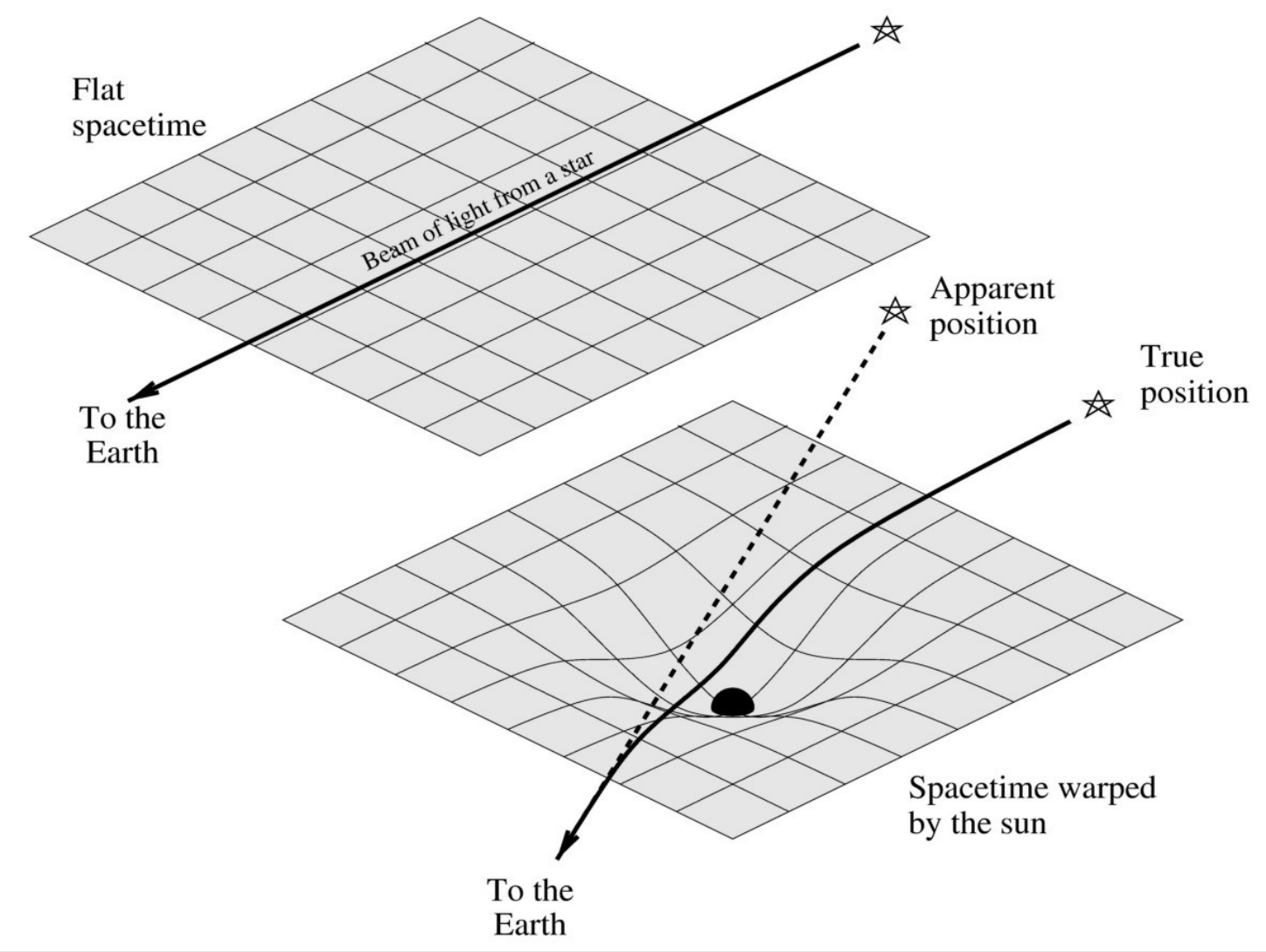
Big Al has a great idea!!!

In 1915 Albert Einstein proposed his theory of gravity.

He believed that space and time were parts of one spacetime continuum.



The Rubber Sheet Picture of Gravity



Einstein had the same problem Newton had!

- The bending of light was confirmed.
- But, why don't things fall into a heap in the middle?
- So, when everything else fails, add a fudge factor!

Einstein's New Equations

$$G\mu\nu - (\Lambda g\mu\nu) = -8\pi G T\mu\nu$$

Λ = Cosmological Constant

(to resist collapse)

Prediction ➔ A stable (eternal) Universe

A Priest is called in!

Prediction ➔ An Expanding Universe

Belgian Astrophysicist Abbey Georges LeMaitre finds a new solution to Einstein's equation without Lambda

His solution shows an expanding Universe with a definite beginning!

Edwin Hubble (1889 – 1953)

Hubble's Law

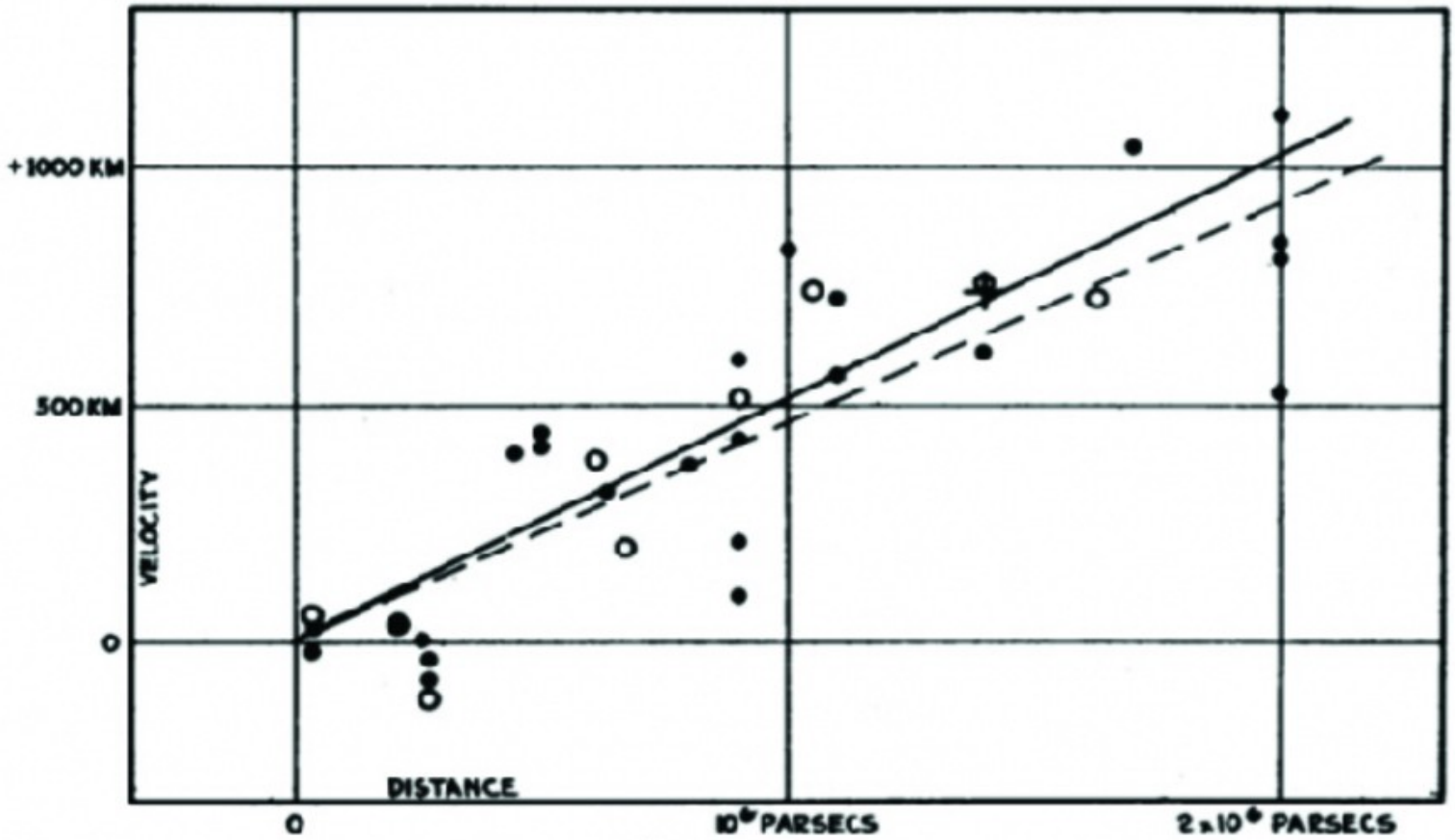


FIGURE 1

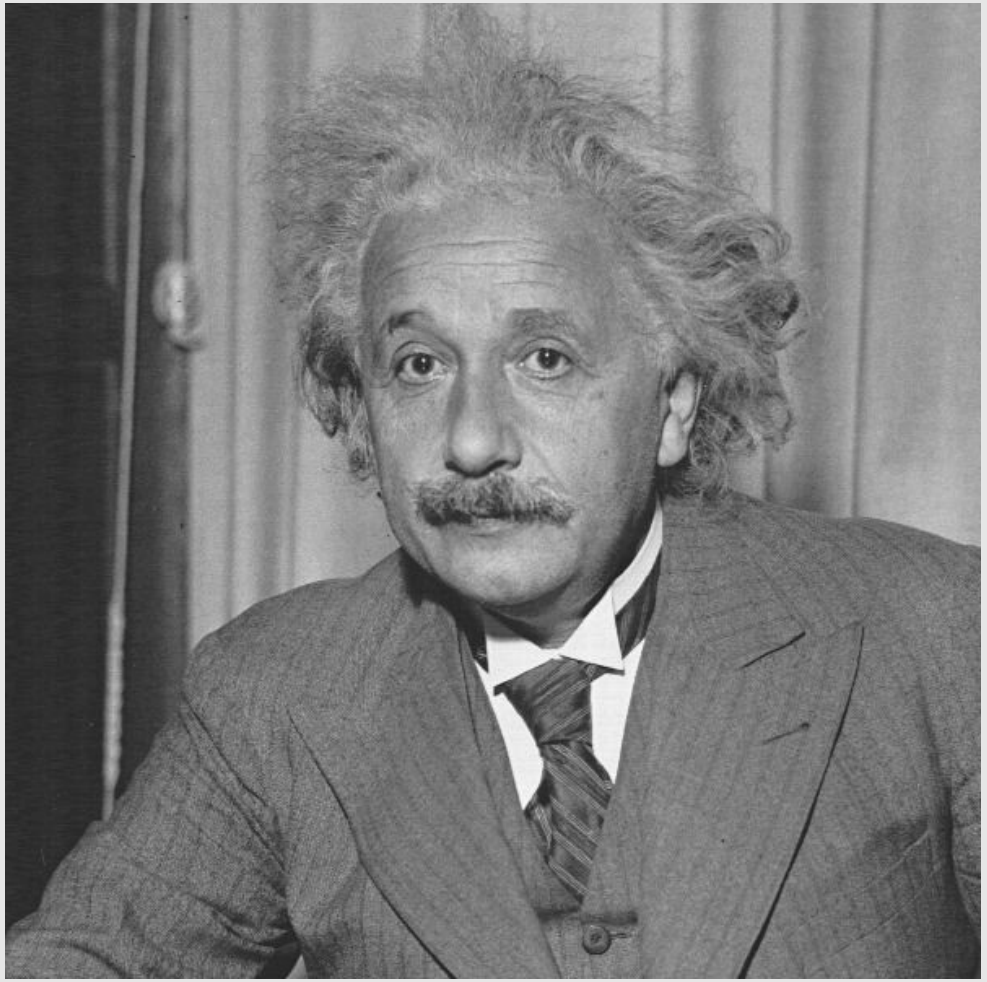
Velocity-Distance Relation among Extra-Galactic Nebulae.

“The Worst Mistake of My Life.” (Part 1)

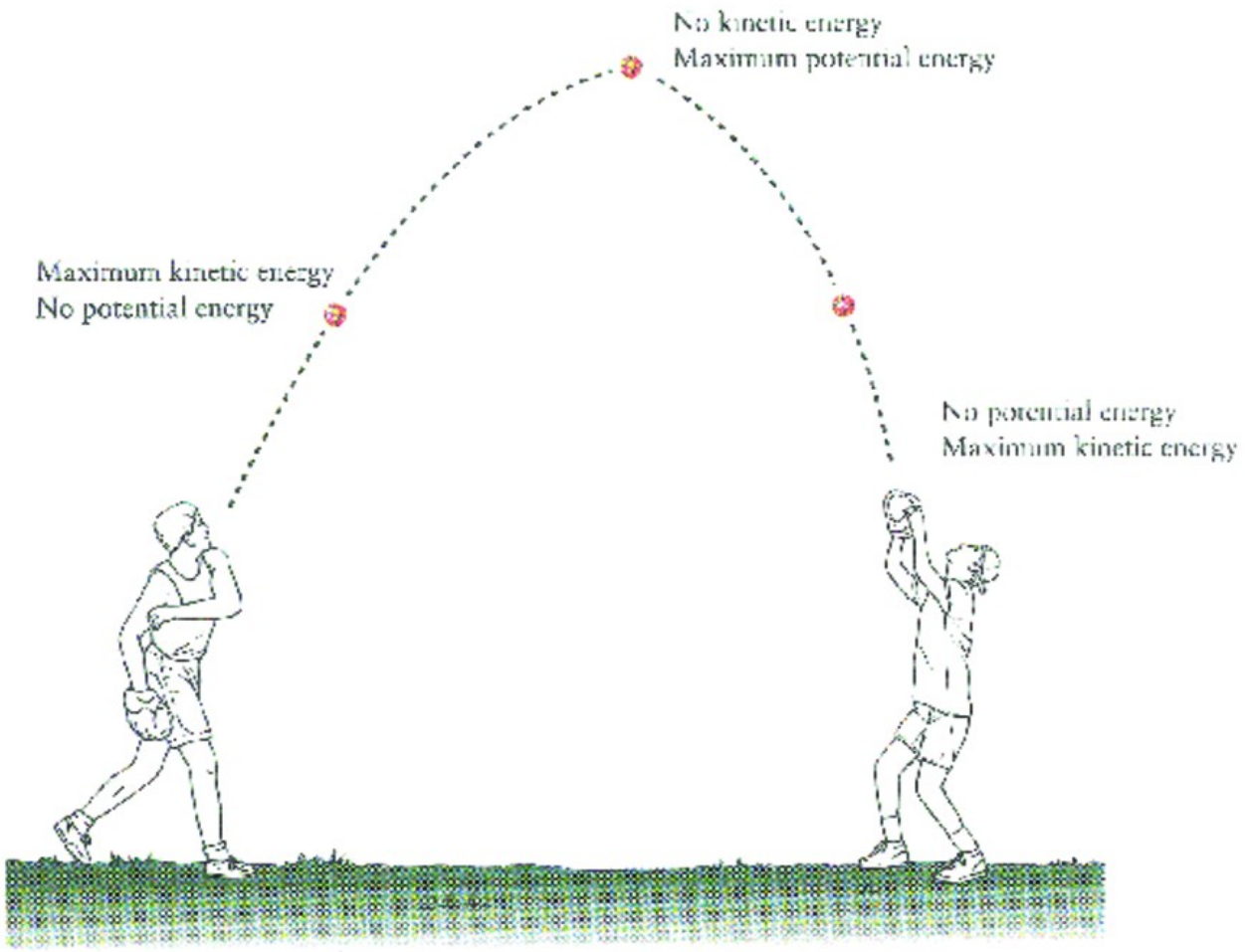
1) The original version of Einstein’s equations of general relativity demanded that the universe expand or contract.

2) In those days (1917) the universe was thought to be static, so Einstein added an extra term to the equations so they gave a static universe.

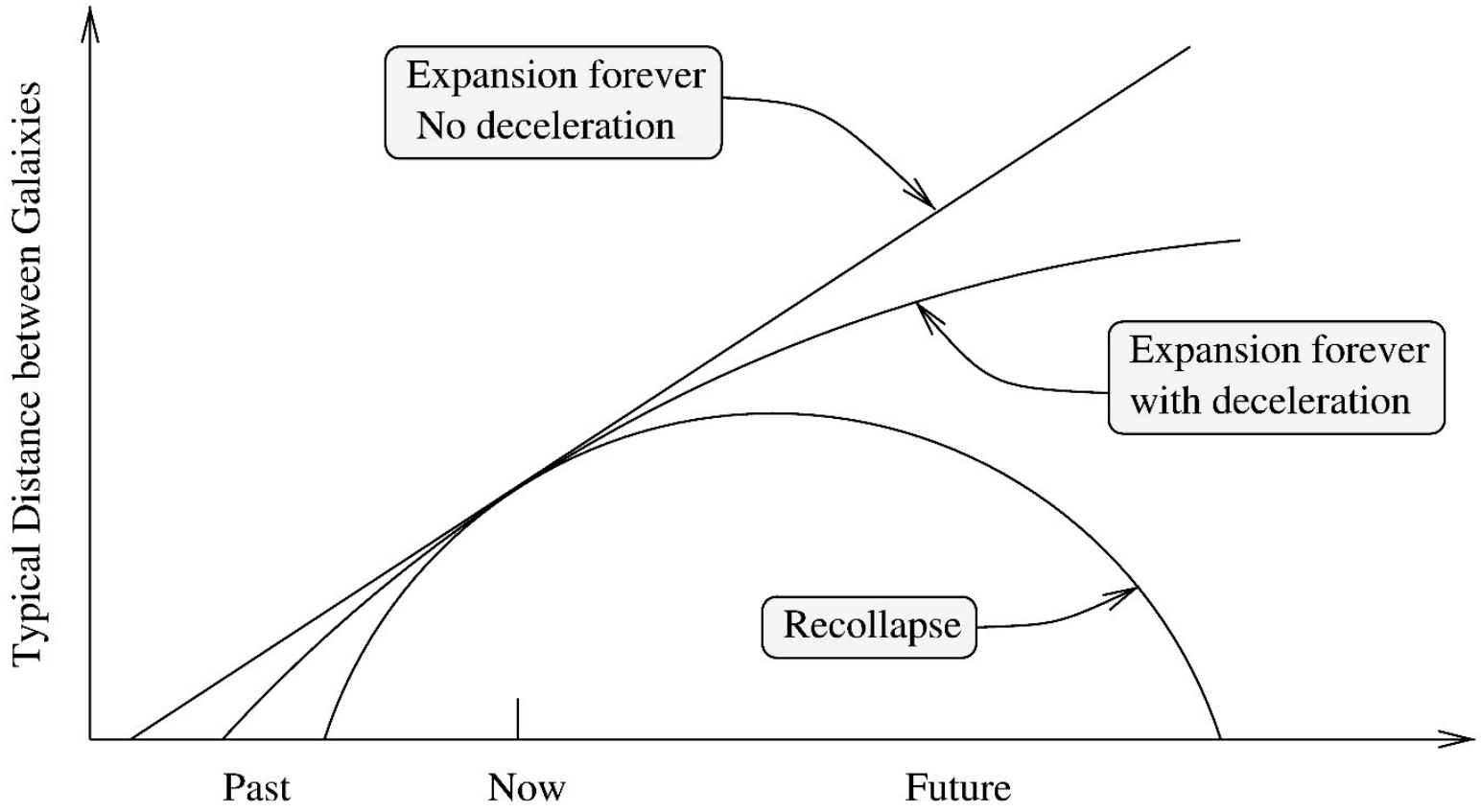
3) Ten years later the expansion of the universe was discovered and the extra term was removed.



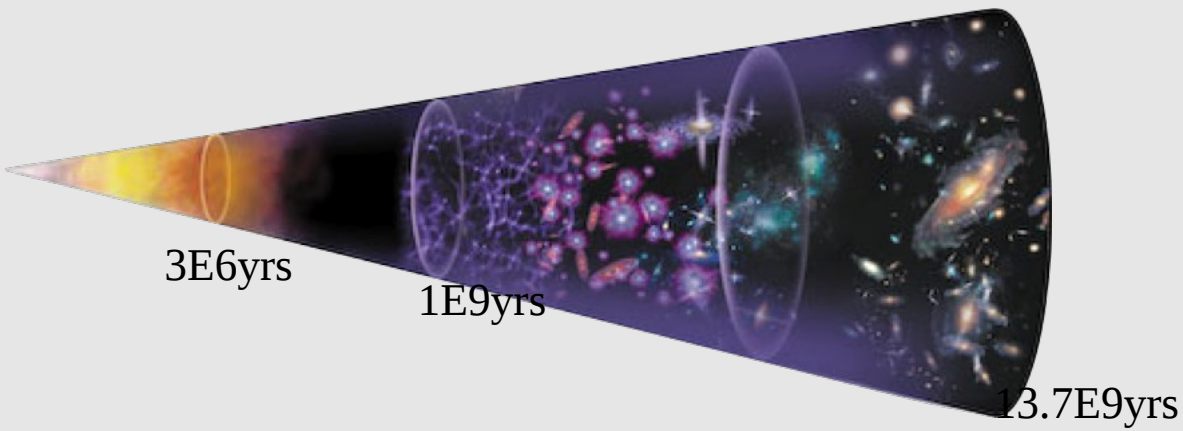
What is the Past and Future of the Universe ?



The Newtonian View of the Expansion of the Universe



- Evolution of the Universe



- $T \sim 10^{15}\ K, t \sim 10^{-12}$ sec: Primordial soup of fundamental part
- $T \sim 10^{13}\ K, t \sim 10^{-6}$ sec: Protons and neutrons form.
- $T \sim 10^{10}\ K, t \sim 3$ min: Nucleosynthesis: nuclei form.
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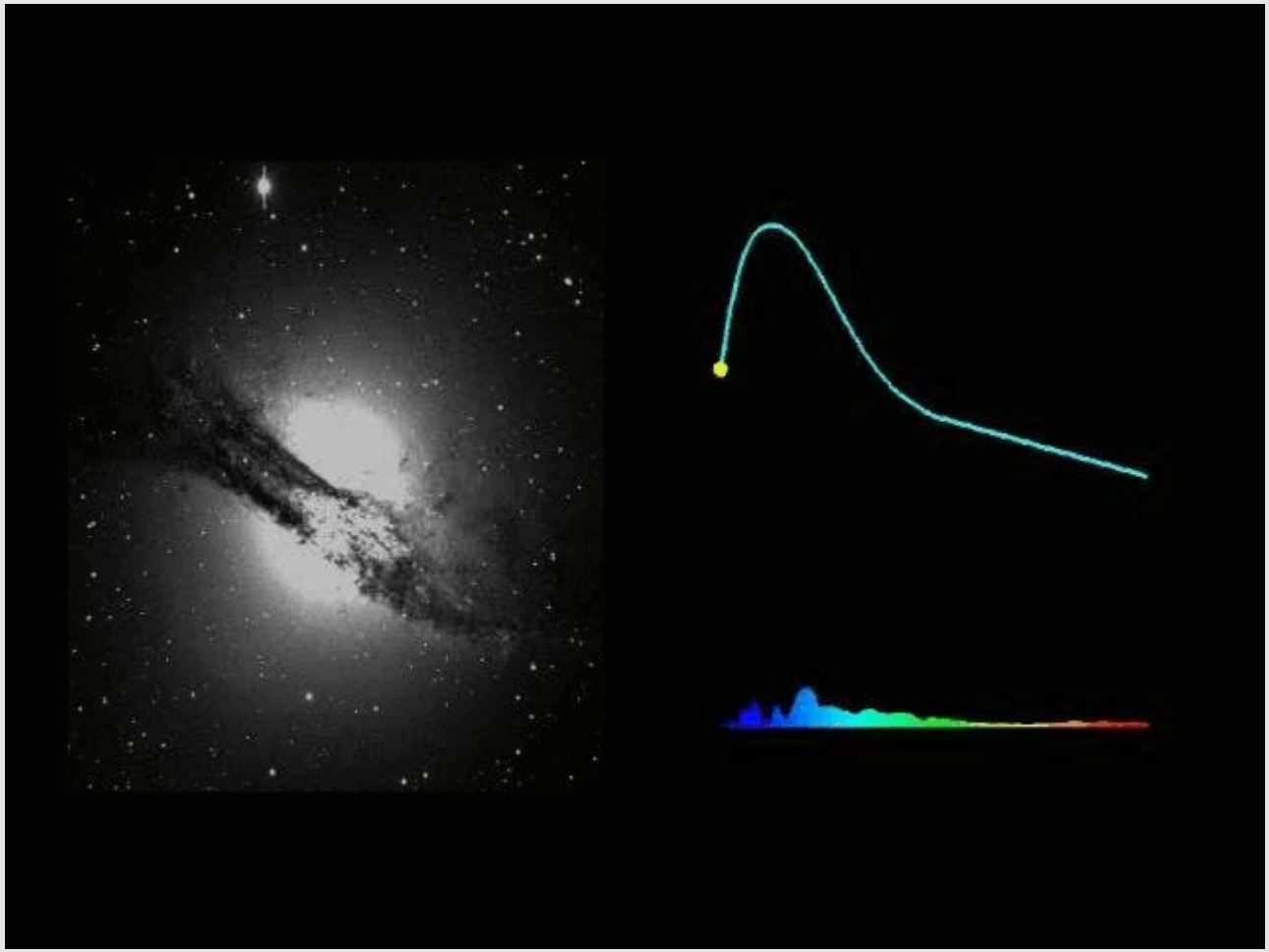
Some 80 years later: A Big Surprise:

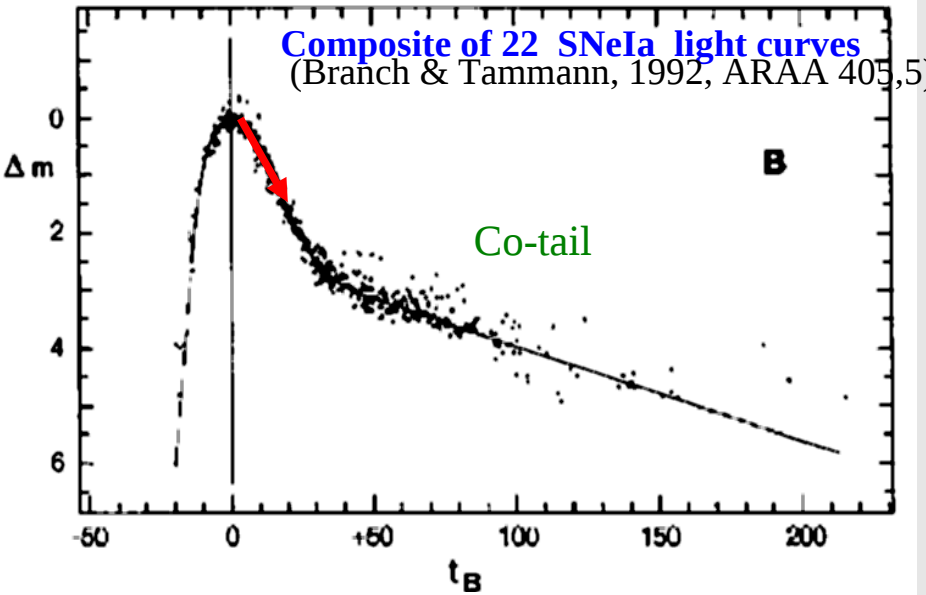
Type Ia Supernovae as 'quasi'-standard Candles

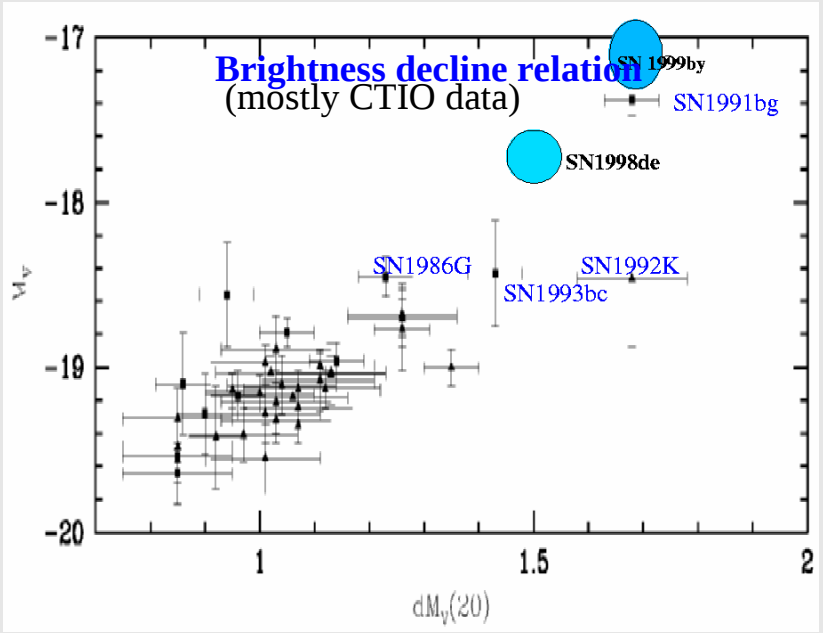
(Phillips & Co. 1989ff)

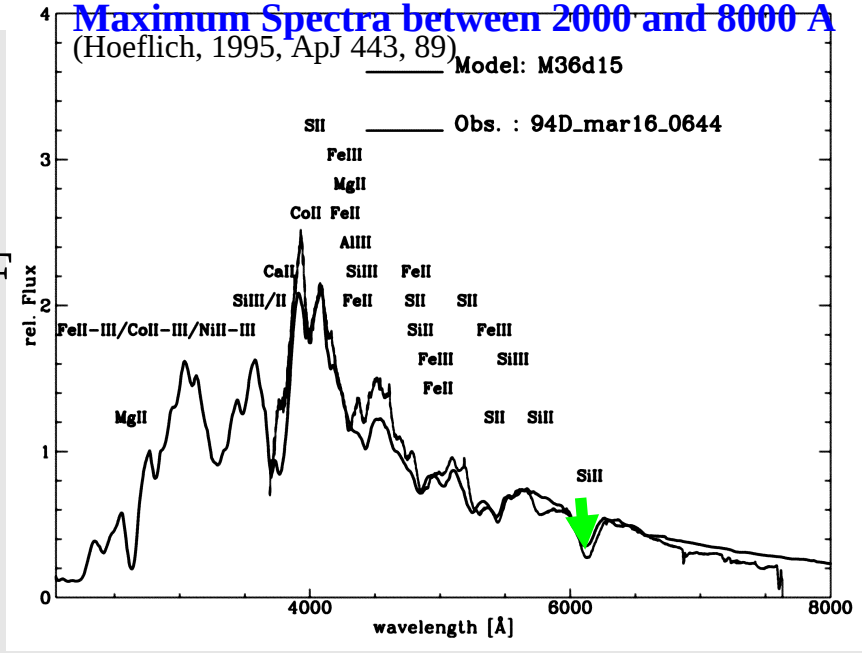


(Animation from Saul's Webpage)

Observables in Type Ia Supernovae







- LC s are rather similar
- decline rate is related to brightness (cosmology!!!)

- spectra are governed by Doppler shifted lines (10000km/sec) of products of explosive C/O/Si burning

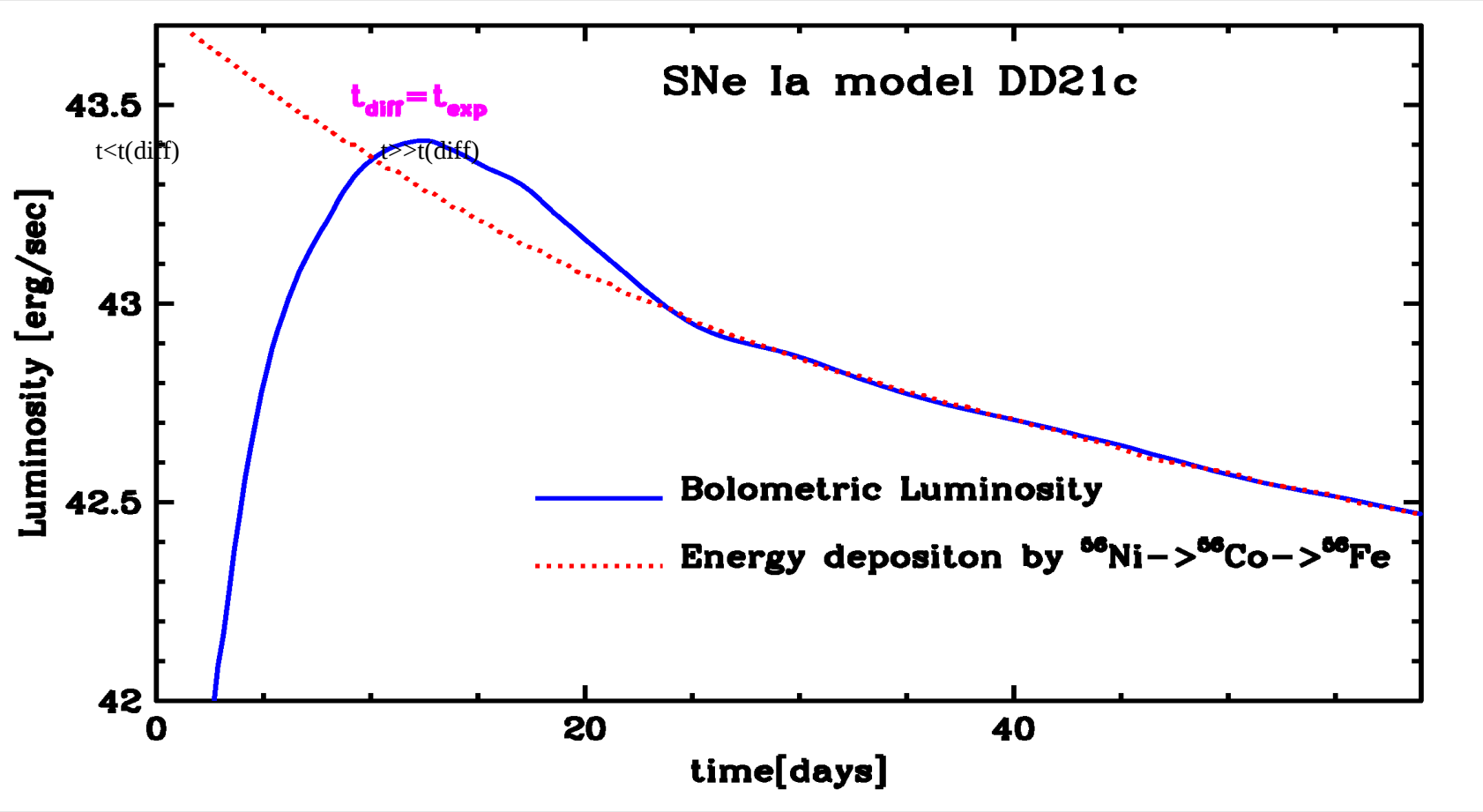
PROBLEM: Are subluminous and normal bright SN in the same class?

The Brightness Decline Relation:Light Curves in a Nutshell

Energy Input: Radioactive Decay $^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$
Products: X- and Gamma-ray photos + positrons

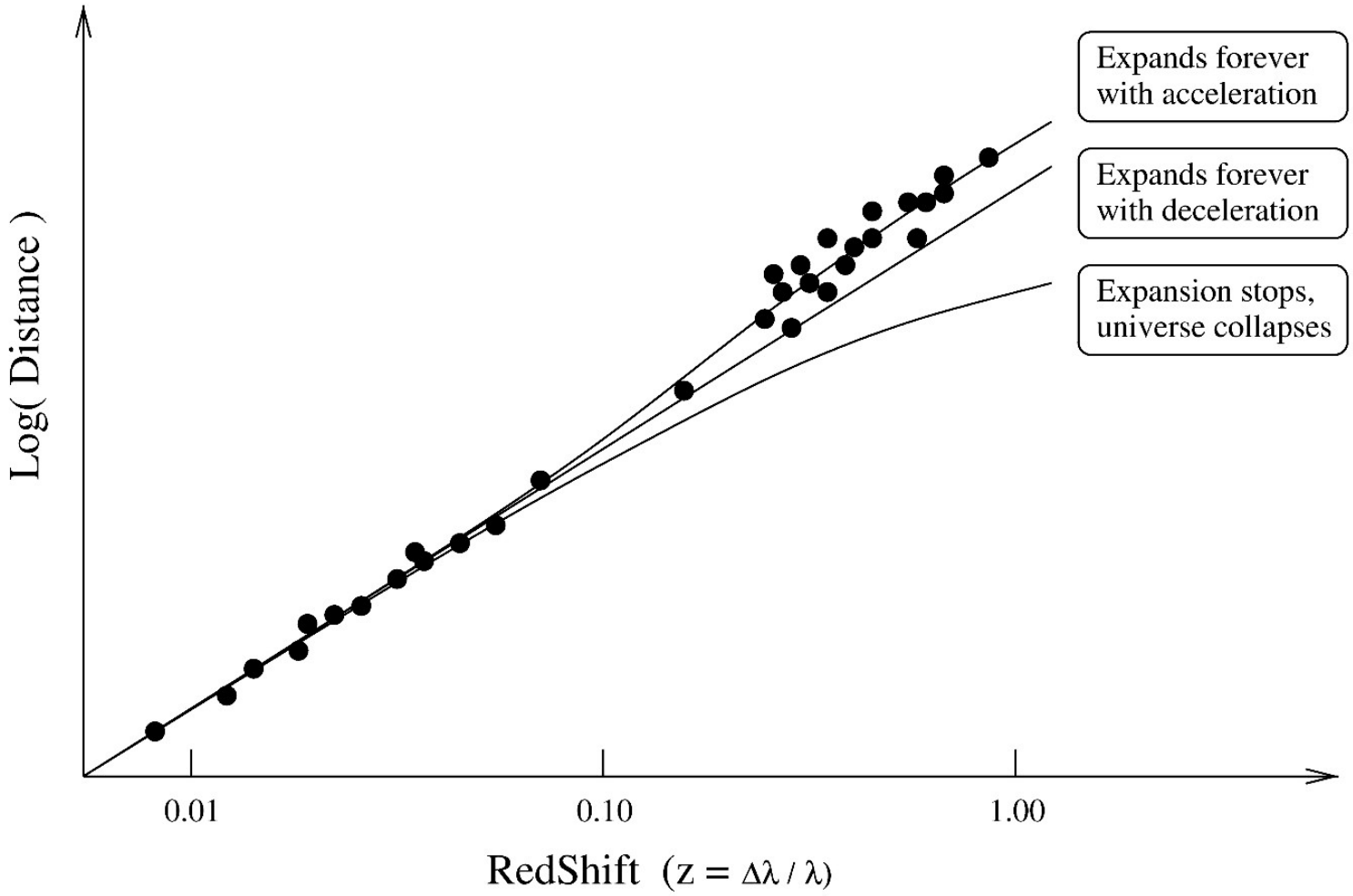
Optical Luminosity:
Deposition of hard photos/positrons + diffusion of low energy photons + geometrical dilution by expansion

More ^{56}Ni → Higher luminosity & temperature → larger opacity → longer diffusion time scales



The Hubble Diagram for Type Ia Supernovae

The distances to the supernovae are measured from their brightness



Nobel Price 2011: Perlmutter, Riess & Schmidt

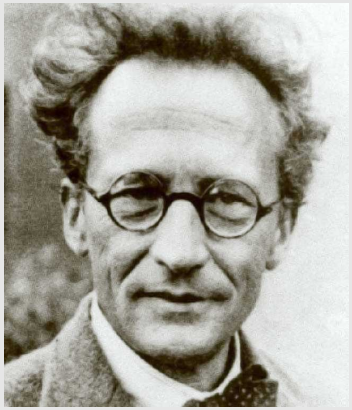
“The Worst Mistake of My Life.” (Part 2/post)

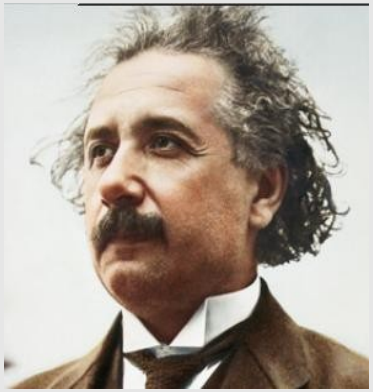
Exchange between **Einstein & Schroedinger (1917ff)** (from Harvey, astro-ph Nov 12, 2012)

1) *Schroedinger* suggests that a cosmological constant cannot be dismissed in an expanding universe and the GR-equations have still a solution.

2) Einstein responds: “*This means, one not only has to start from the existence of a non-observable, dominant negative energy density in the interstellar space but also has to postulate a hypothetical law about space time distribution of this mass density.*”

Convinced all, and the dialogue was forgotten for some 80 years.





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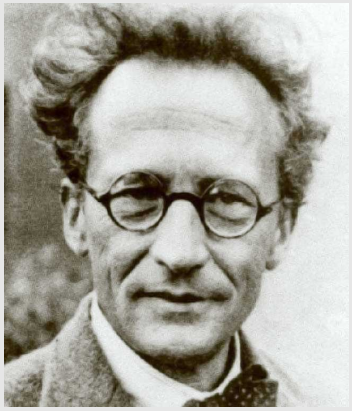
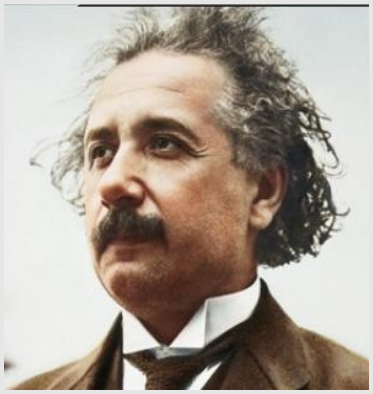
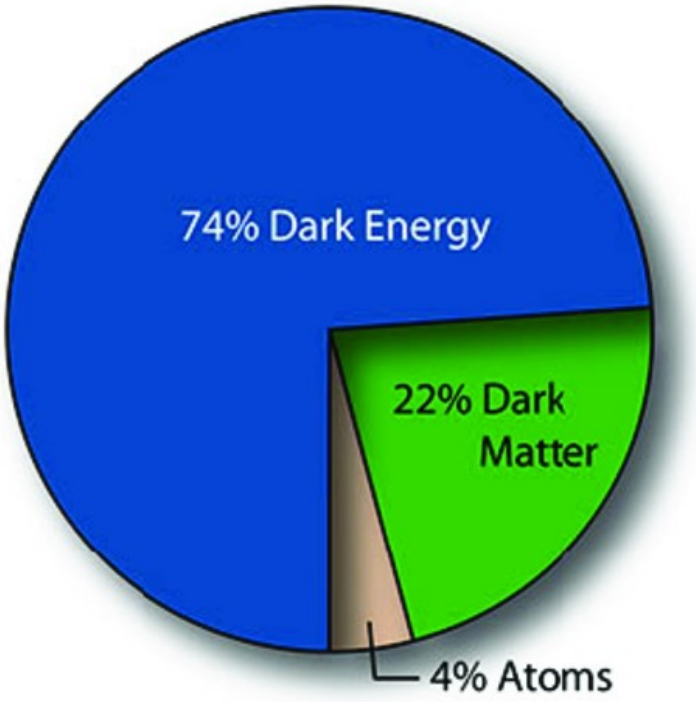




Epilog: Nobel Price for Physics 2011

The ΛCDM (Consensus) Model

- Universe is geometrically “flat”
- Universe is 13.7 Bilion years old
- Normal matter makes up ~4%
- Dark matter makes up ~23%
- Dark Energy makes up ~73%



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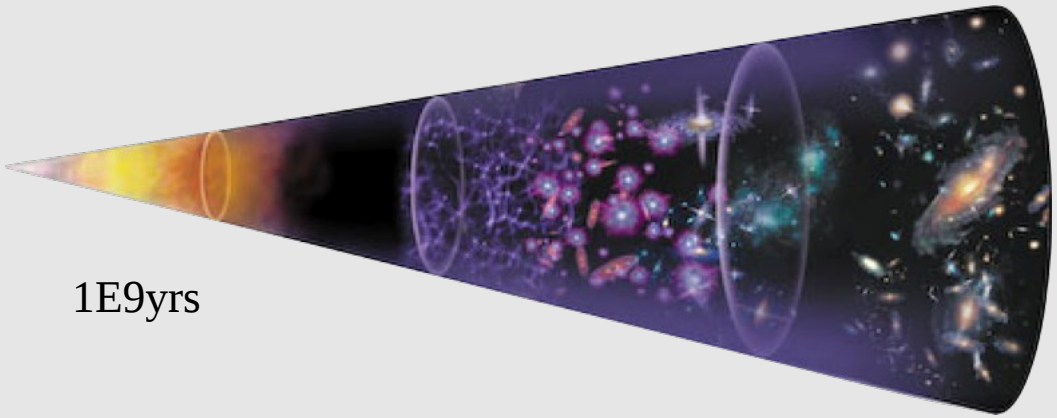

3E6yrs

1E9yrs

13.7E9yrs

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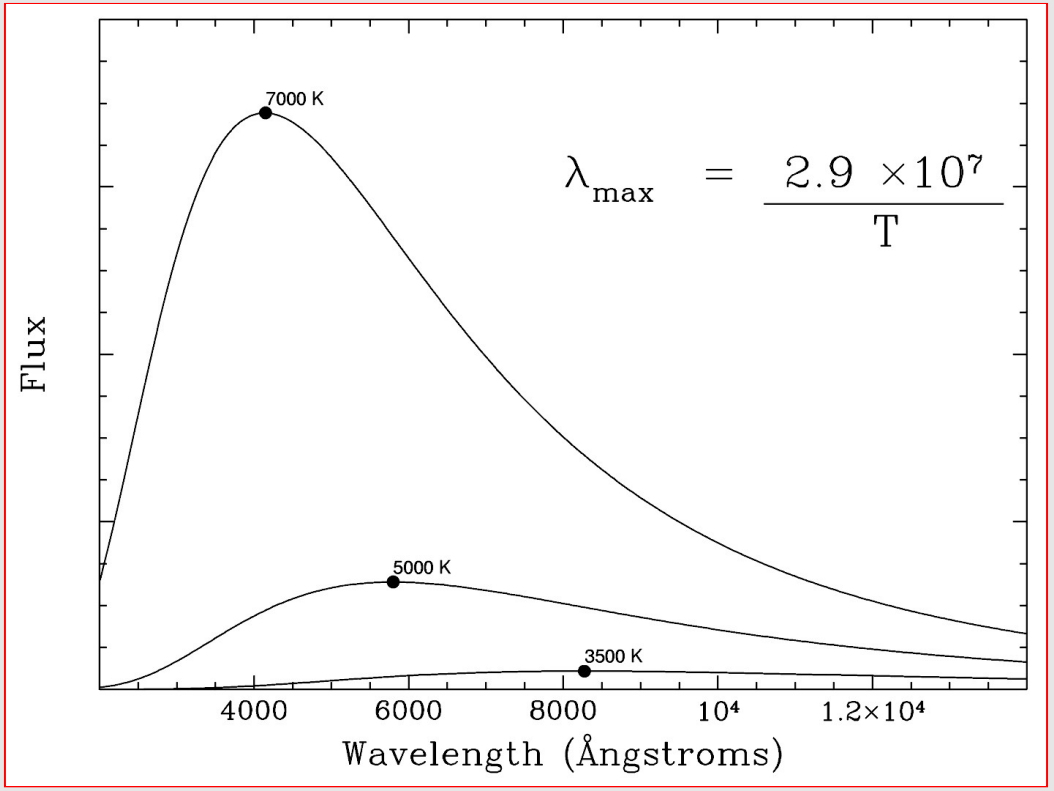
The Light Produced by the Big Bang. I.

•The early universe was hot, dense, and opaque.

• Therefore it was full of black body radiation (Kirchhoff's laws!).



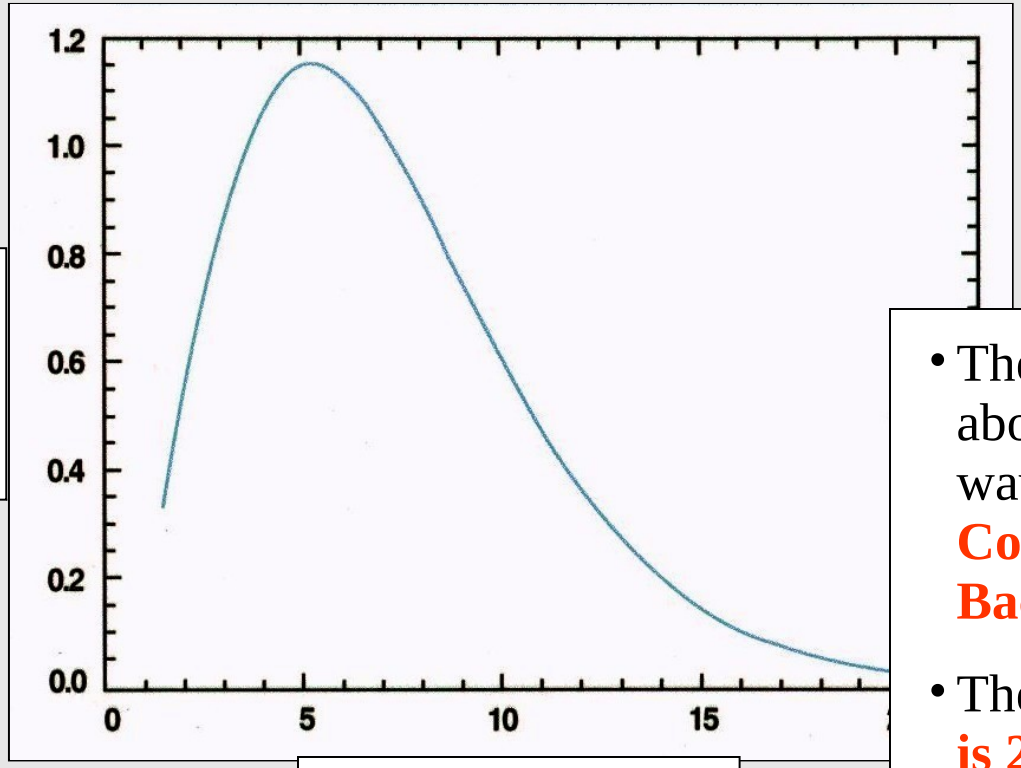
The Big Bang Light Was Discovered in 1965 by…

Arno Penzias

Robert Wilson

1978 Nobel Laureates in Physics

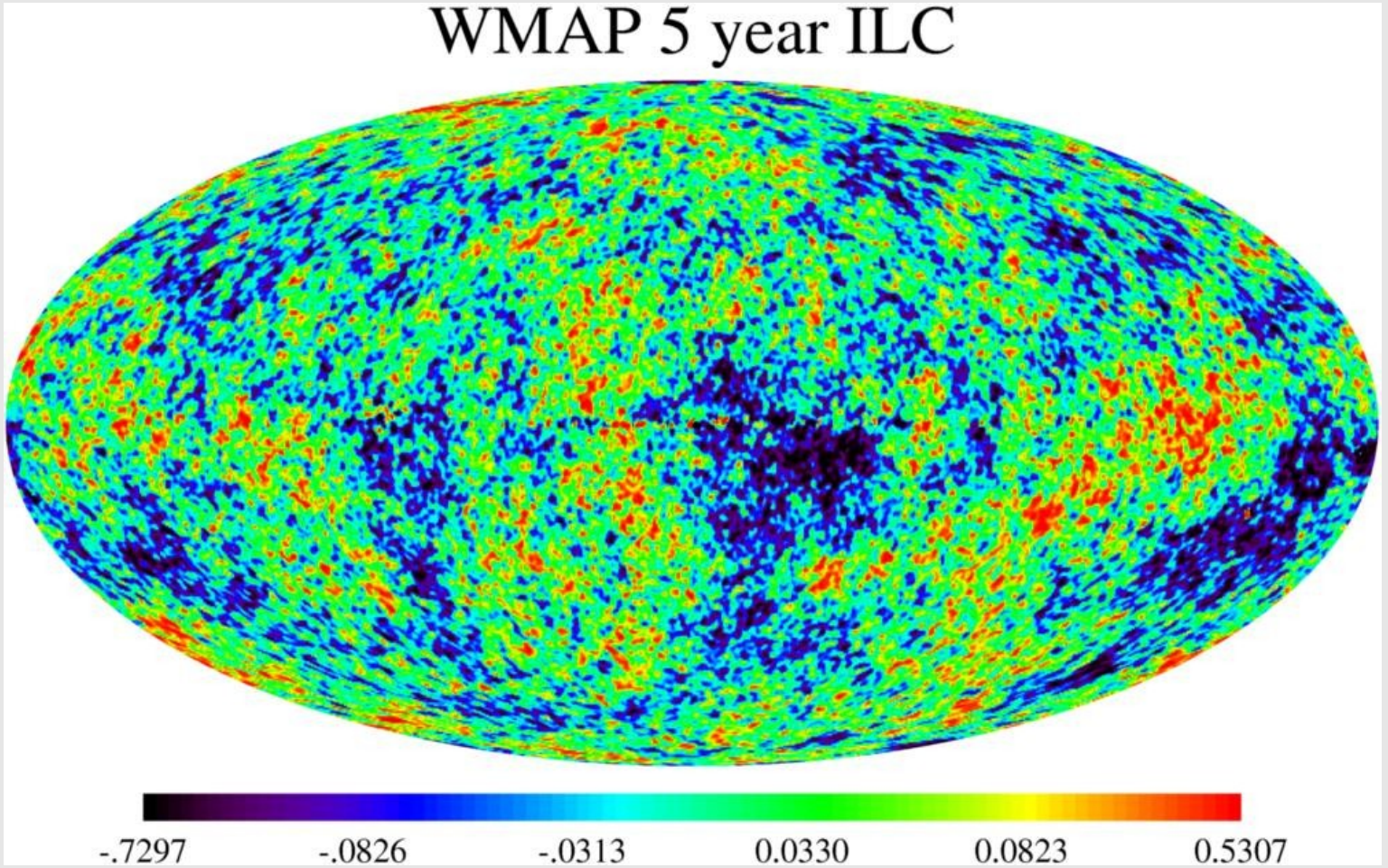
The Cosmic Microwave Background



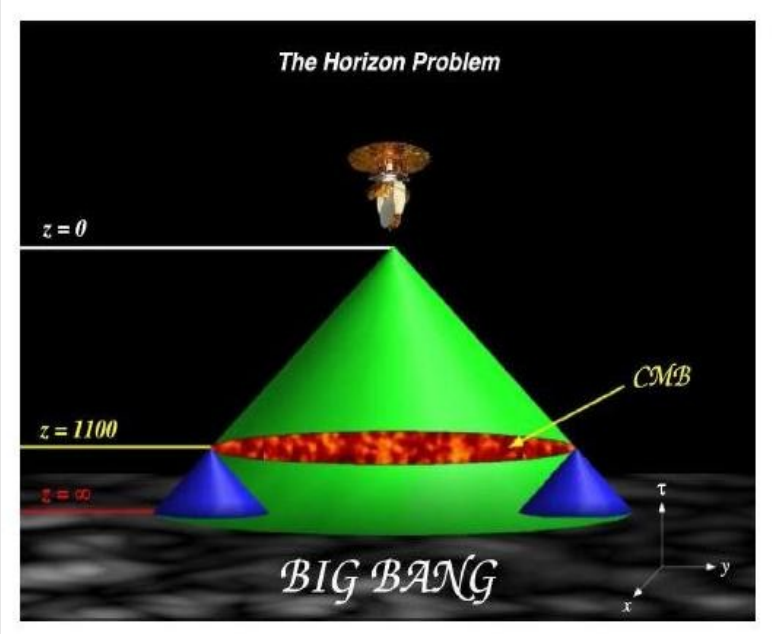
- The peak of the spectrum is at about 1 mm. These are micro-waves so the light is called the **Cosmic Microwave Background, or CMB**.
- The corresponding **temperature is 2.7**
- The spectrum is not measurably different from a **black body spectrum**.

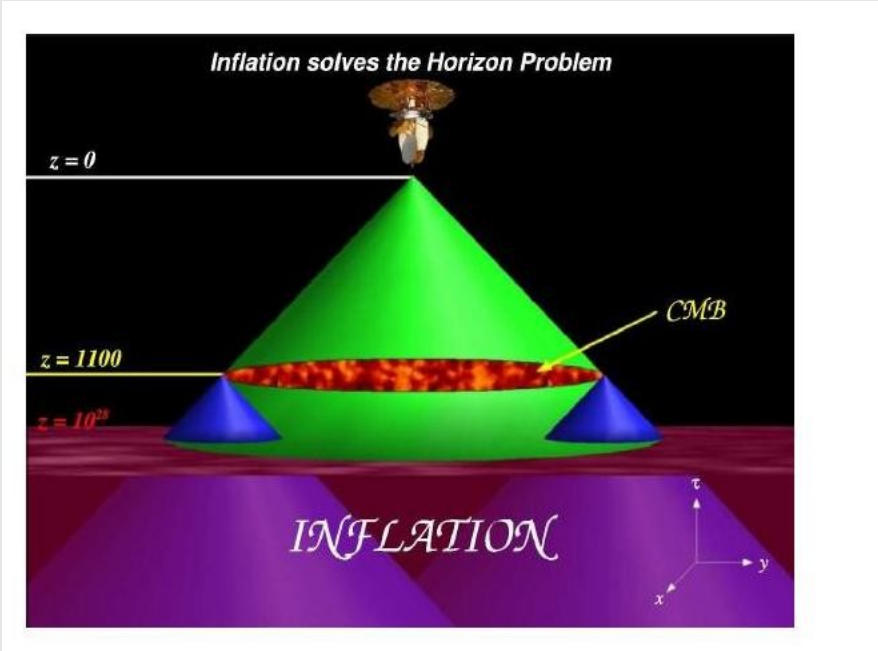
Fluctuations in the MWB

Does this look totally random to you?



Inflation: Why do we need it, or why is the CMB isotropic?





Guth (1981): Expansion to 3 million light years within 1E-35 seconds

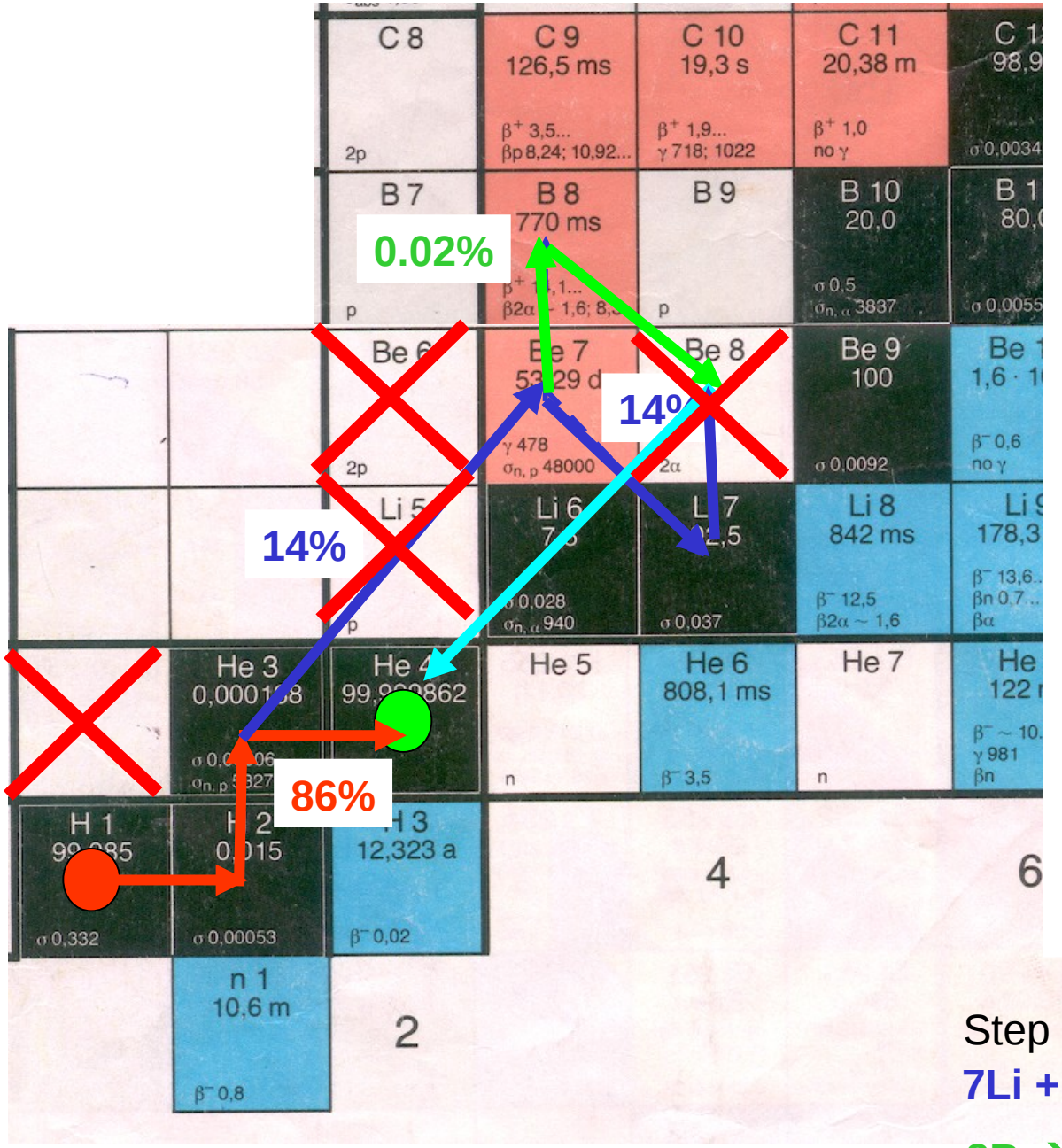
The sun shines with a power of 3.85e33 erg/s = 3.85e26 Watts
It has done so for 4.7 Bio. years (d: Milliarden)

Stars and Star explosions have created the chemical elements our world (and we) are made from

A little “Light Matter”

Only nuclear reactions can convert the chemical elements

- The big bang only created Hydrogen and Helium
- We are made of Hydrogen, Carbon, Oxygen, Calcium, etc.
- The heavier elements (>He) around us were created in stars and star explosions
- Is this just another curious coincidence of the Universe ?



pp-chains: 1H → 4He

Step 1:
- available: ^{1}H, some ^{4}He

$p + p \rightarrow d + e^+ + \nu_e$

Step 2:
- available: p, some d,^{4}He

$d + p \rightarrow {}^3He$

Step 3:
- available: p, some 3He,4He little d (rapid destruction)

86% $^3He + {}^3He \rightarrow 2p + {}^4He$
14% $^3He + {}^4He \rightarrow {}^7Be$

Step 4:

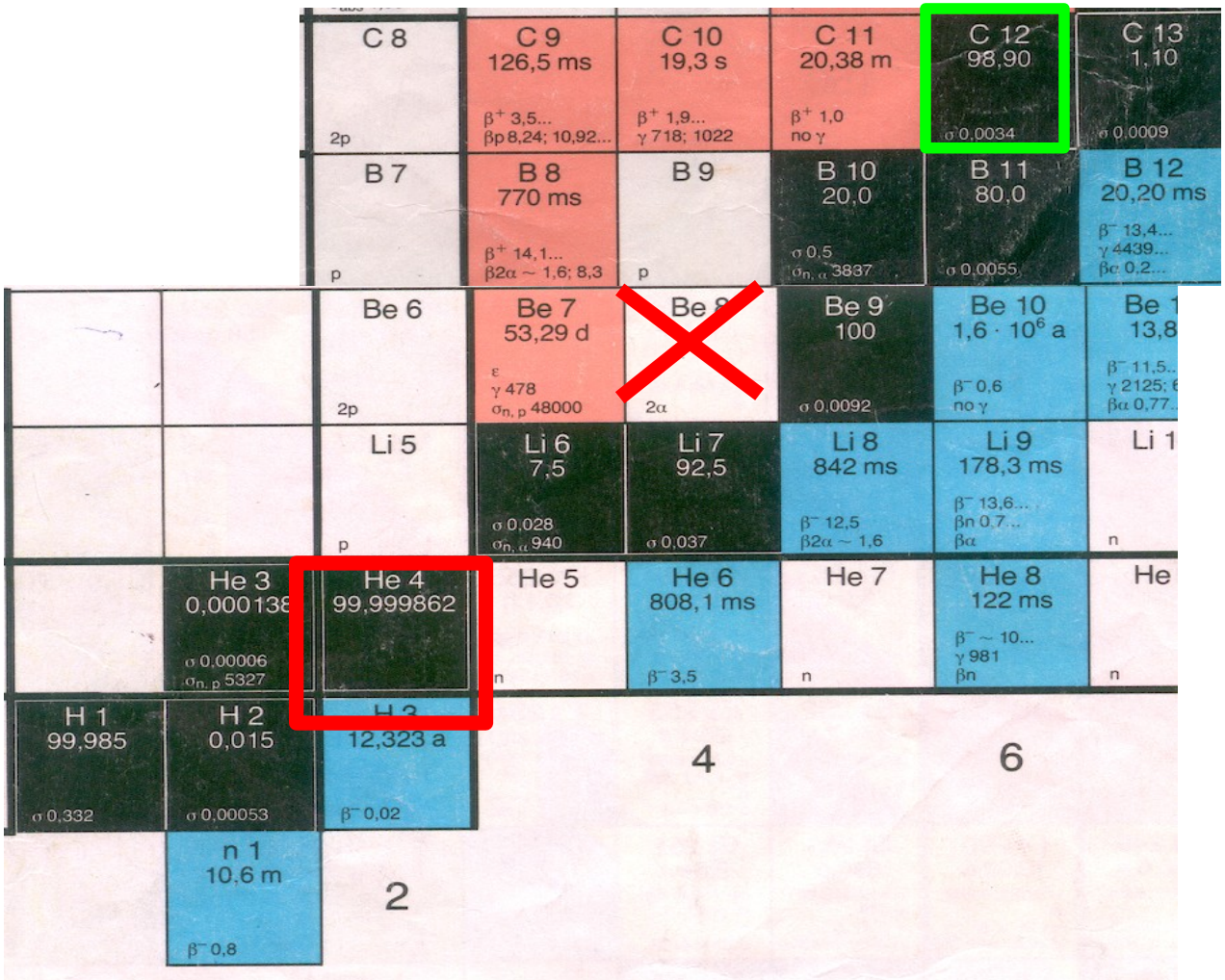
14% $^7Be + e^- \rightarrow {}^7Li + \nu_e$
0.02% $^7Be + p \rightarrow {}^8B$

Step 5:

$^7Li + p \rightarrow {}^8Be$
$^8B \rightarrow e^+ + \nu_e + {}^8Be$

} 2 x ^{4}He

When stars run out of Hydrogen, they burn Helium

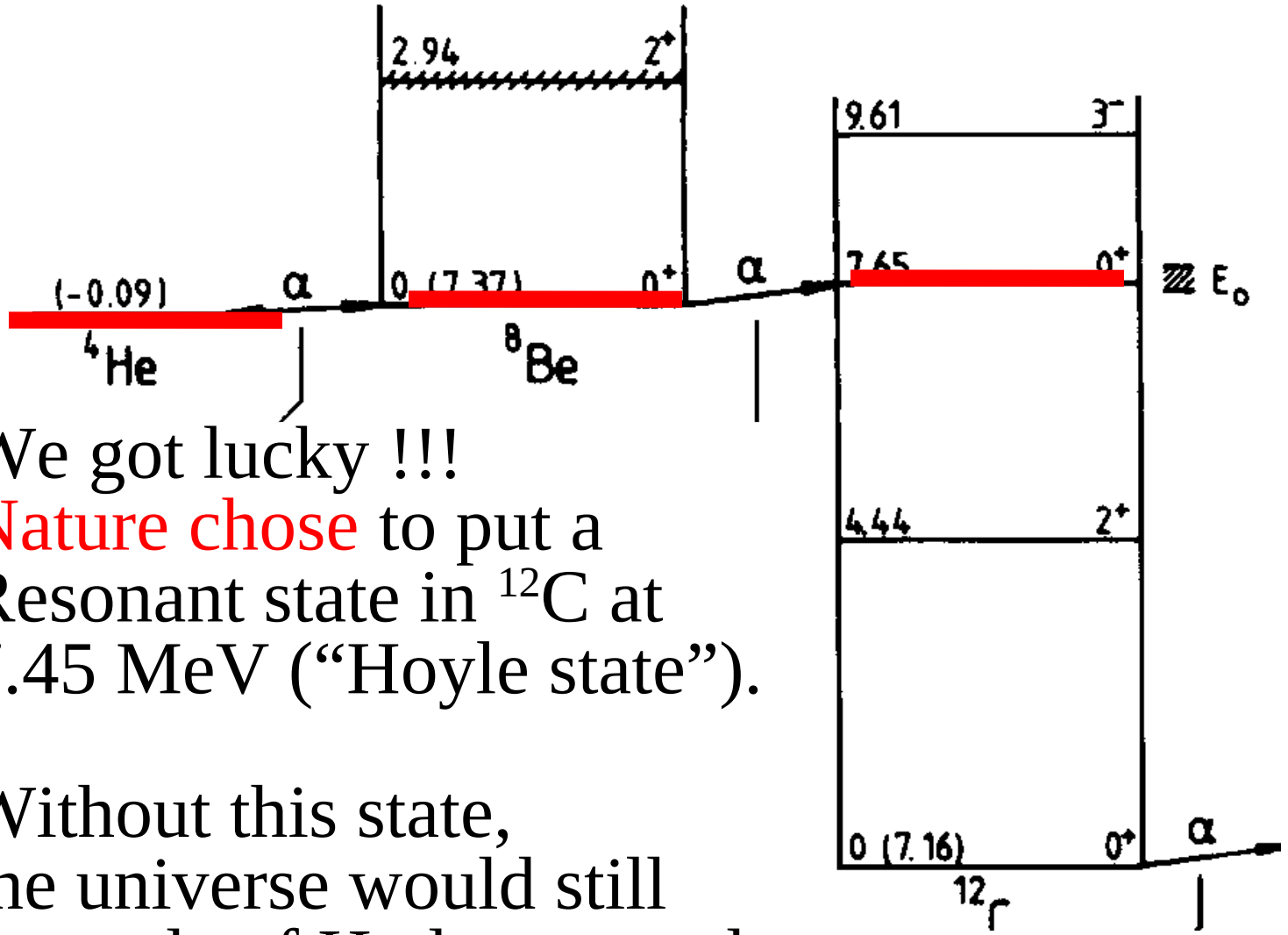


That is easier said than done !

^{12}C can not be made “step by step”.

Nature needs to collide three Helium-nuclei within 10^{-15} seconds !

$^4He + {}^4He + {}^4He = {}^{12}C$



We got lucky !!!
Nature chose to put a Resonant state in ^{12}C at 7.45 MeV (“Hoyle state”).

Without this state, the universe would still be made of Hydrogen and Helium.

Curious Accidents and Coincidences

The isotropic microwave background radiation implies that the universe expanded faster than c very early.

Currently the universe is flat
(Acceleration due dark energy currently balances the deceleration of known matter.)

The universe is made from matter and contains essentially no anti-matter.

Protons can not stick to other protons.

Three Helium nuclei *can* stick together to form Carbon.

The State of the Cosmos

Our current laws of physics break down at the beginning of time.

Still, the laws of physics contain "Constants of Nature", which seem carefully balanced to produce a universe we can live in.

We don't know why, but we keep trying and maybe succeed.

Some of the attempts predict a multitude of "parallel" universes, each with different "Constants of Nature".

The “Anthropic” Principle

The “Constants of Nature” indeed are carefully balanced just to produce a universe we can live in,

because we are alive and measured the Constants of Nature in this universe.

This philosophy would mean that Physics has indeed reached the limits of its own scope; There is no “cause” for the structure of the current universe.

Constitution of a German tribe near Colon

(as formulated by a brewery in Germany)

Das kölsche Grundgesetz

Artikel 1

”et es wie et es”

The laws of nature are as they are.

Artikel 2

“et kütt wie et kütt”

We see the nature as it is because we can observe it

Artikel 3

“et hätt noch emmer jot jegange.”

It always went well (not the end of physics)