

# 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 ?

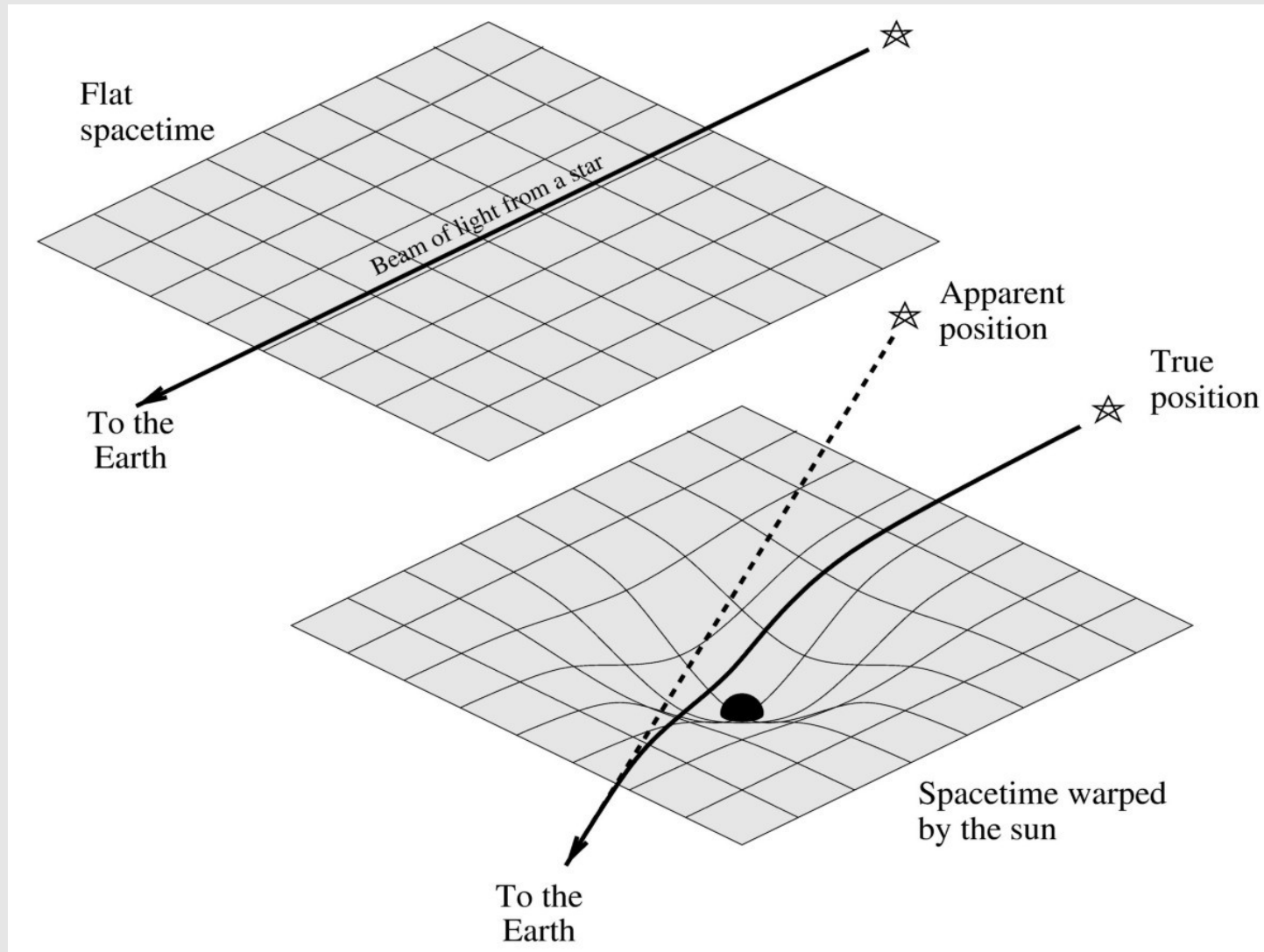
## Big AI has a great idea!!!

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

$$G_{\mu\nu} - (\Lambda g_{\mu\nu}) = -8\pi G T_{\mu\nu}$$

$\Lambda$  = 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

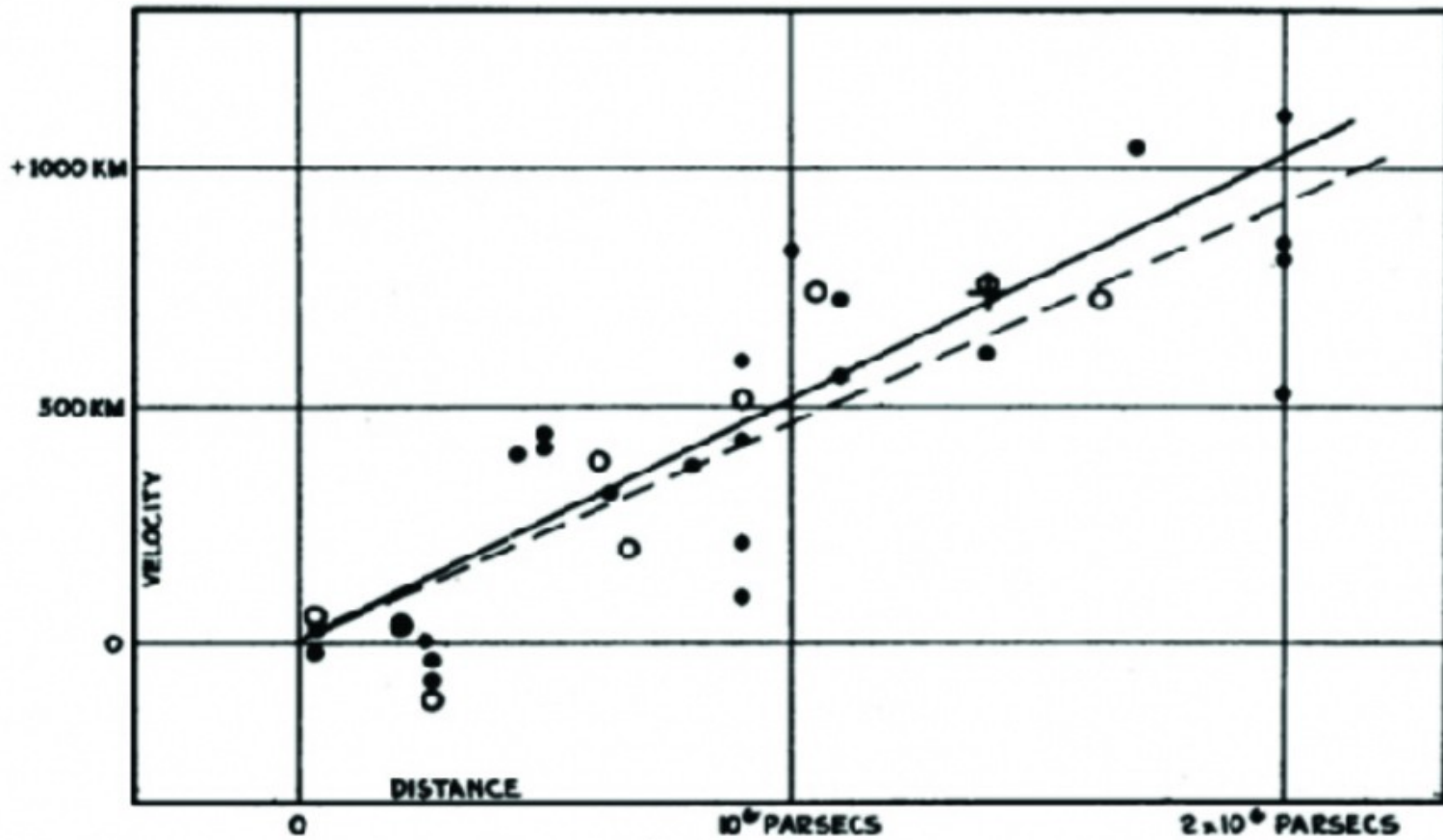


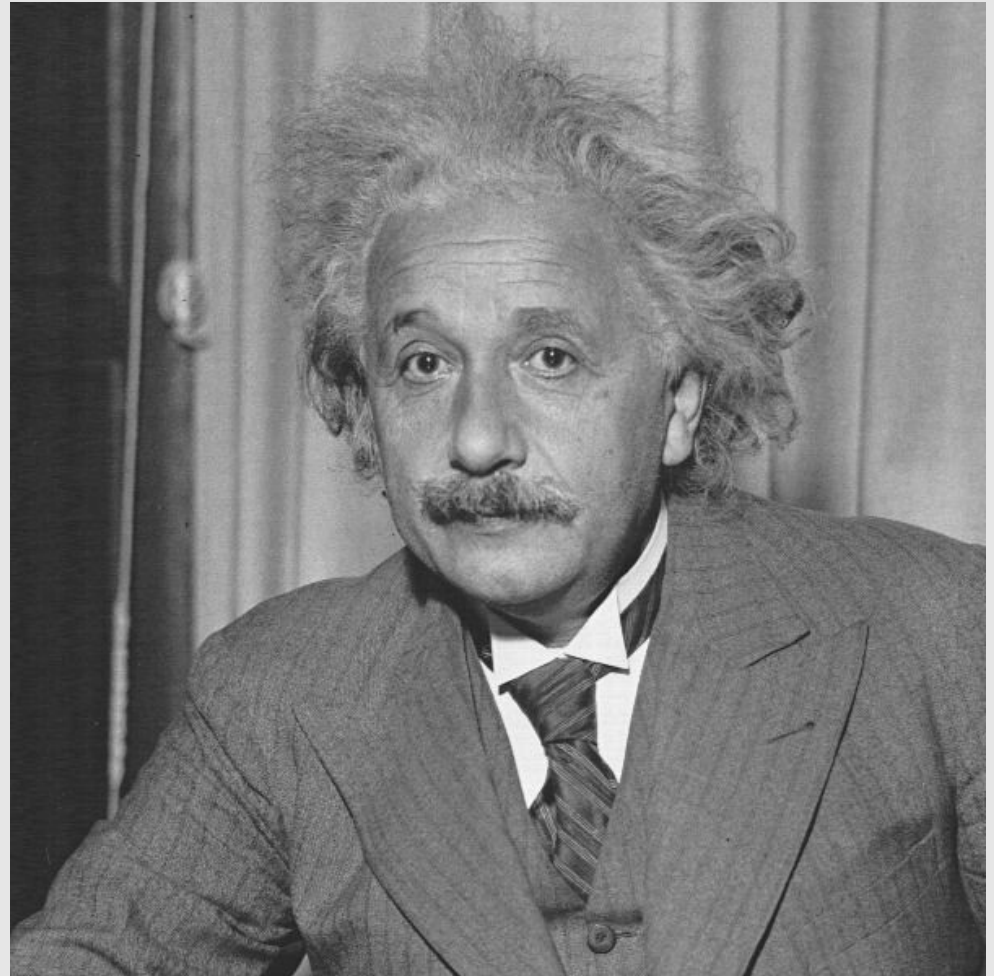
FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

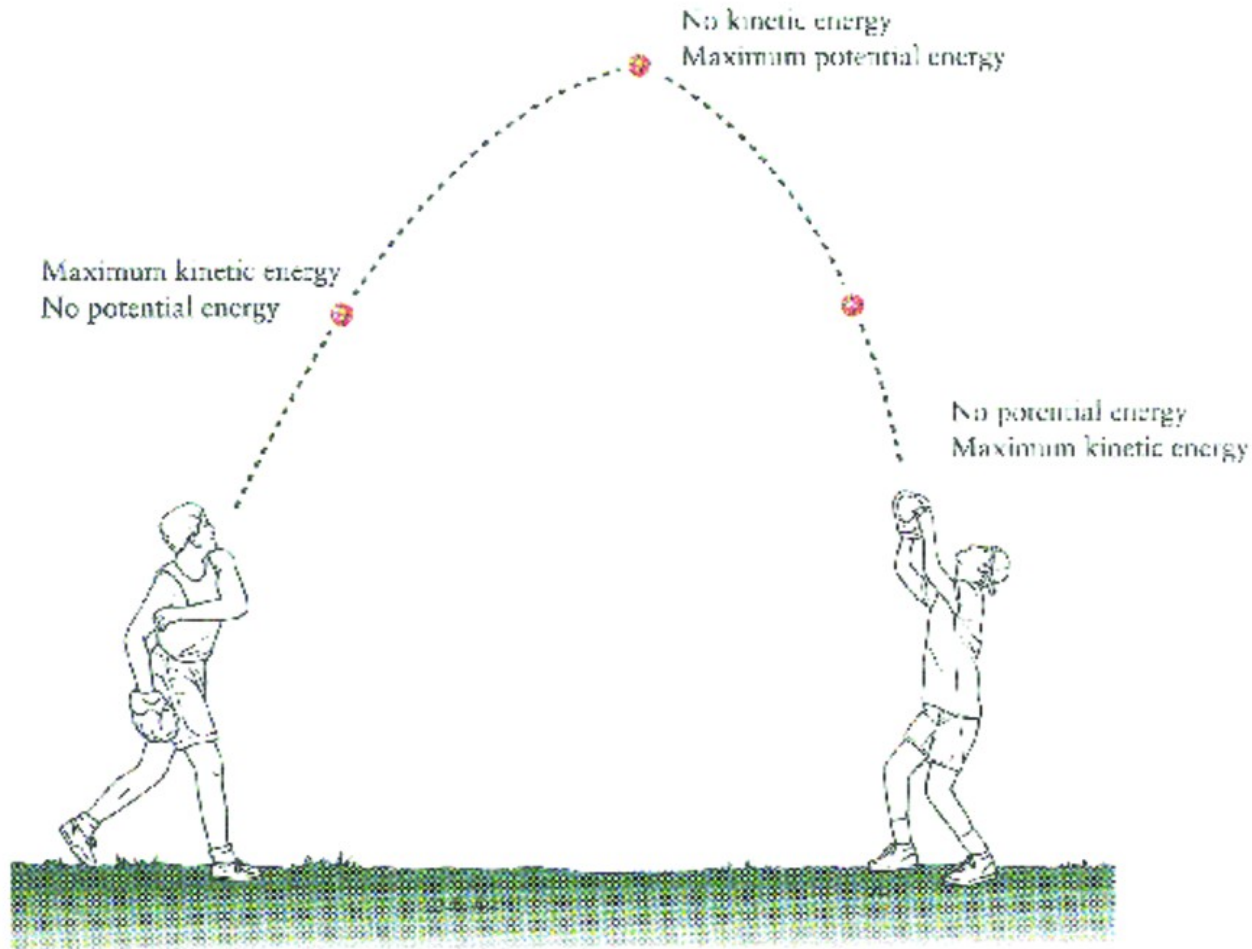


## “The Worst Mistake of My Life.”

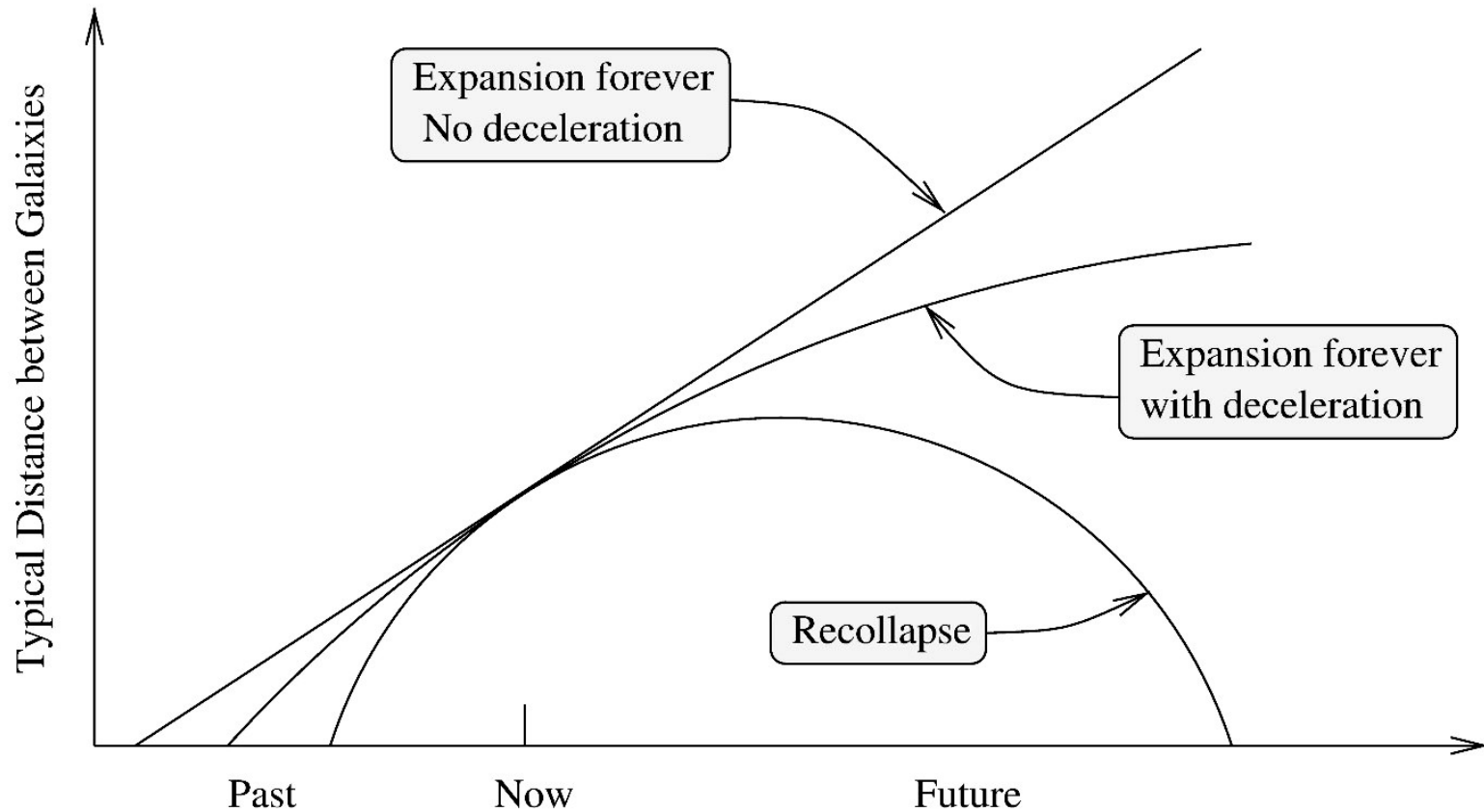
- 1) The original version of Einstein's equations of general relativity demanded that the universe expand or contract.
- 2) In those days (1917) the universe was thought to be static, so Einstein added an extra term to the equations so they gave a static universe.
- 3) Ten years later the expansion of the universe was discovered and the extra term was removed.



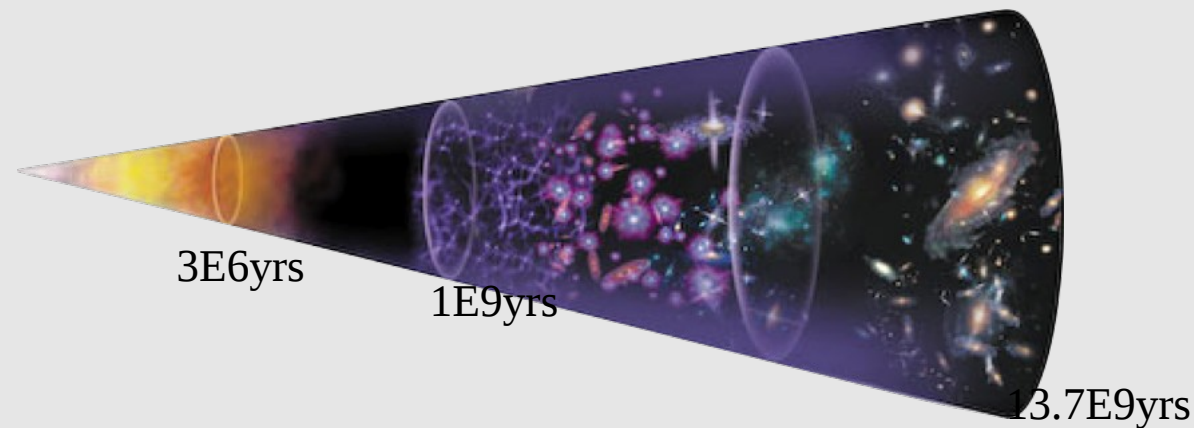
# What is the Past and Future of the Universe ?



# The Newtonian View of the Expansion of the Universe



# • Evolution of the Universe

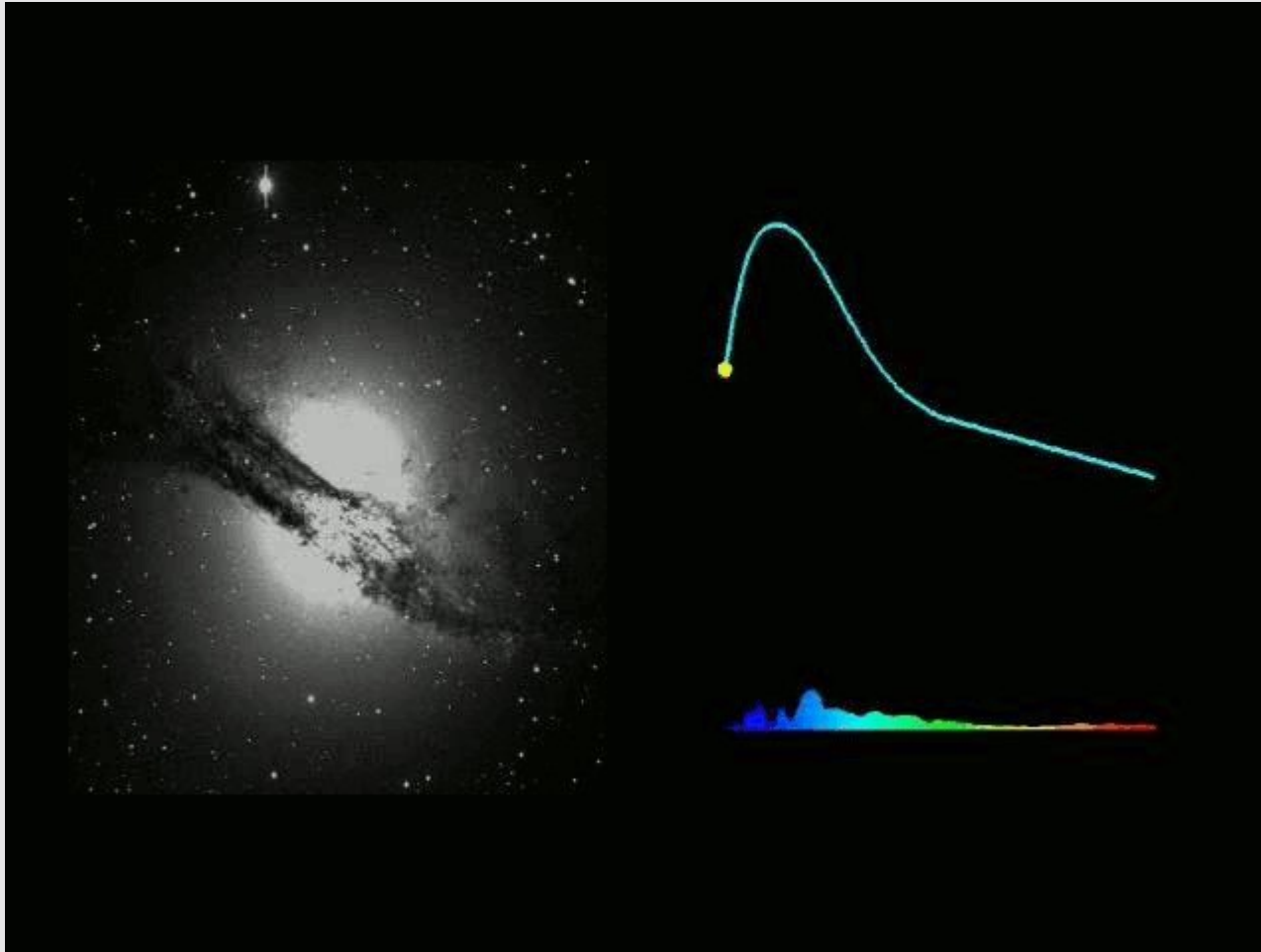


- $T \sim 10^{15} K, t \sim 10^{-12}$  sec: Primordial soup of fundamental particles.
- $T \sim 10^{13} K, t \sim 10^{-6}$  sec: Protons and neutrons form.
- $T \sim 10^{10} K, t \sim 3$  min: Nucleosynthesis: nuclei form.
- $T \sim 3000 K, t \sim 300,000$  years: Atoms form.
- $T \sim 10 K, t \sim 10^9$  years: Galaxies form.
- $T \sim 3 K, t \sim 10^{10}$  years: Today.

# Some 80 years later: A Big Surprise:

Type Ia Supernovae as 'quasi'-standard Candles

(Phillips & Co. 1989ff)



(Animation from Saul's Webpage)



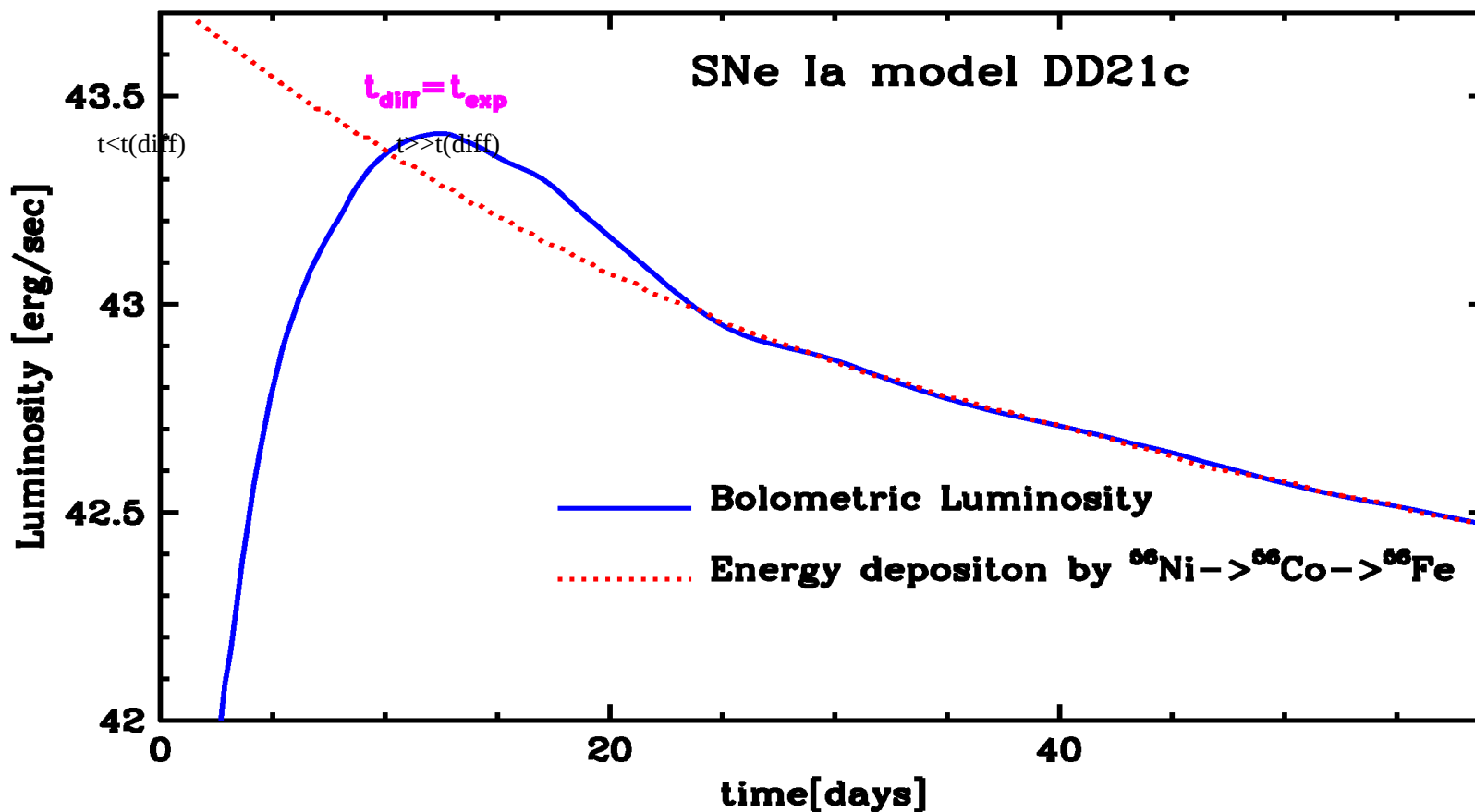
# The Brightness Decline Relation: Light Curves in a Nutshell

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

Optical Luminosity:

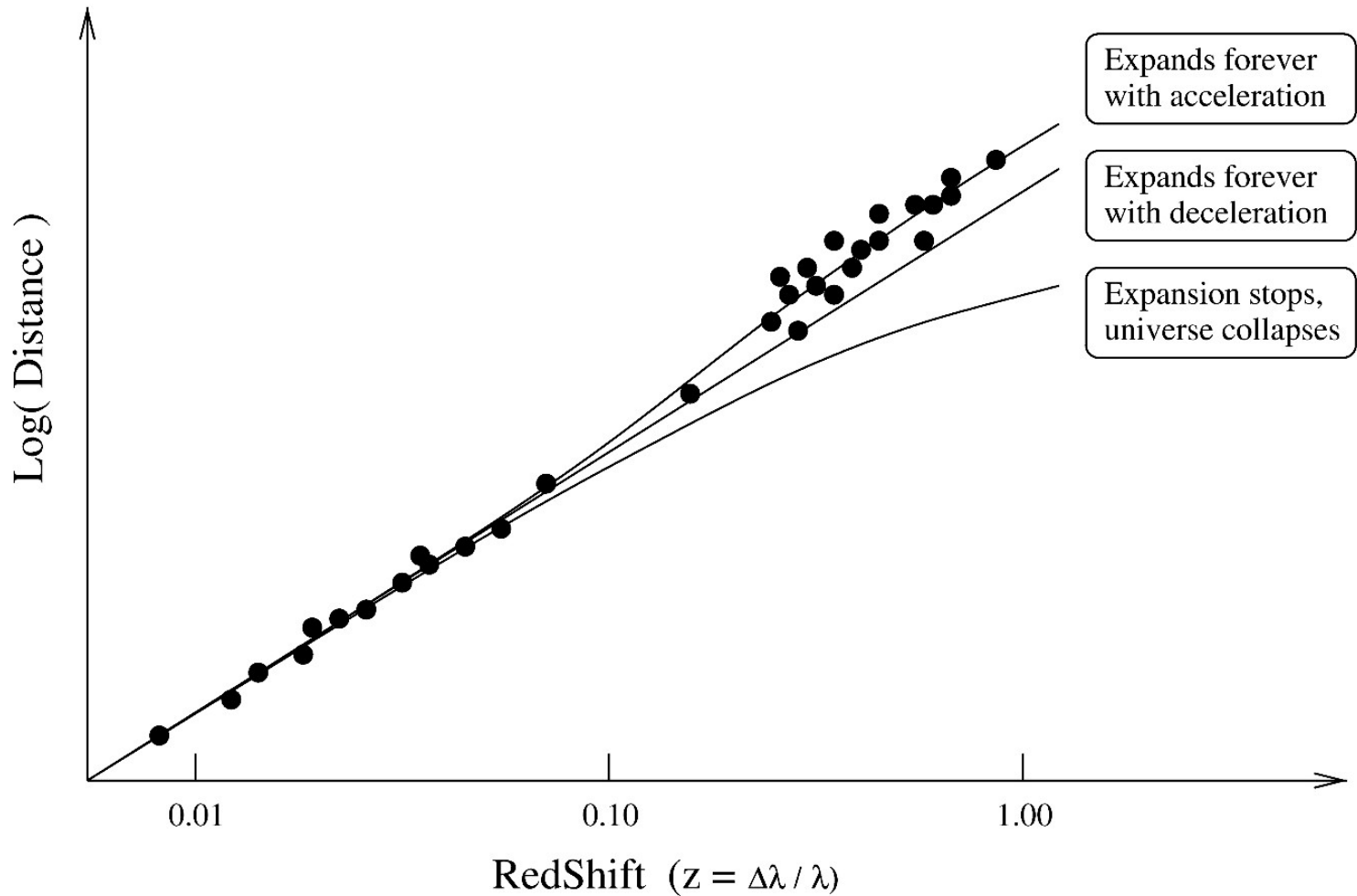
Deposition of hard photos/positrons + diffusion of low energy photons + geometrical dilution by expansion

More  $^{56}\text{Ni}$   $\rightarrow$  Higher luminosity & temperature  $\rightarrow$  larger opacity  $\rightarrow$  longer diffusion time scales



# The Hubble Diagram for Type Ia Supernovae

The distances to the supernovae are measured from their brightness

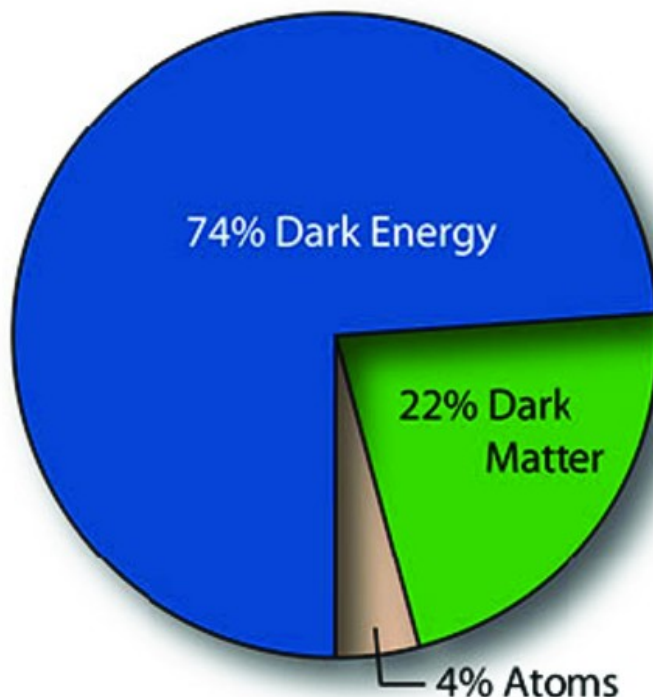


Nobel Price 2011: Perlmutter, Riess & Schmidt

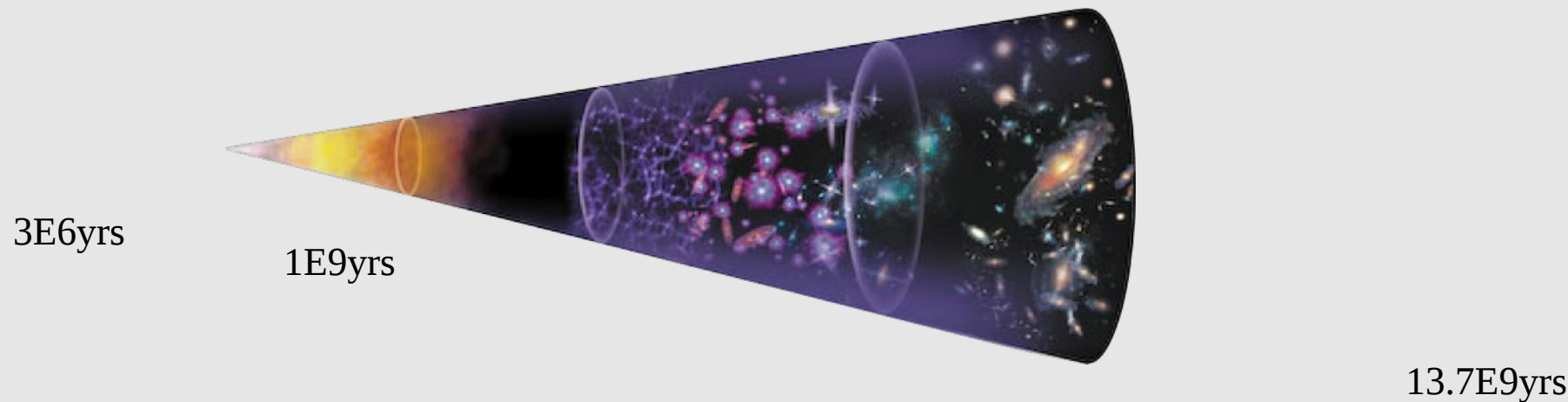


# The $\Lambda$ CDM (Consensus) Model

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



# • Evolution of the Universe

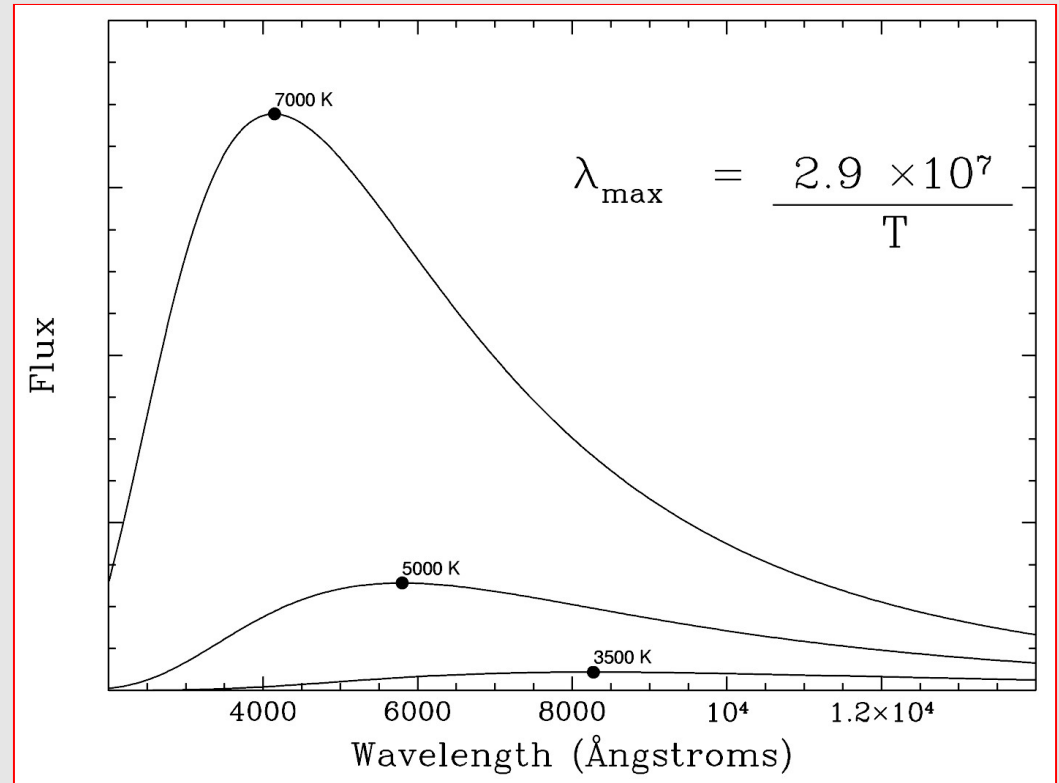


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# The Light Produced by the Big Bang. I.

- 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...

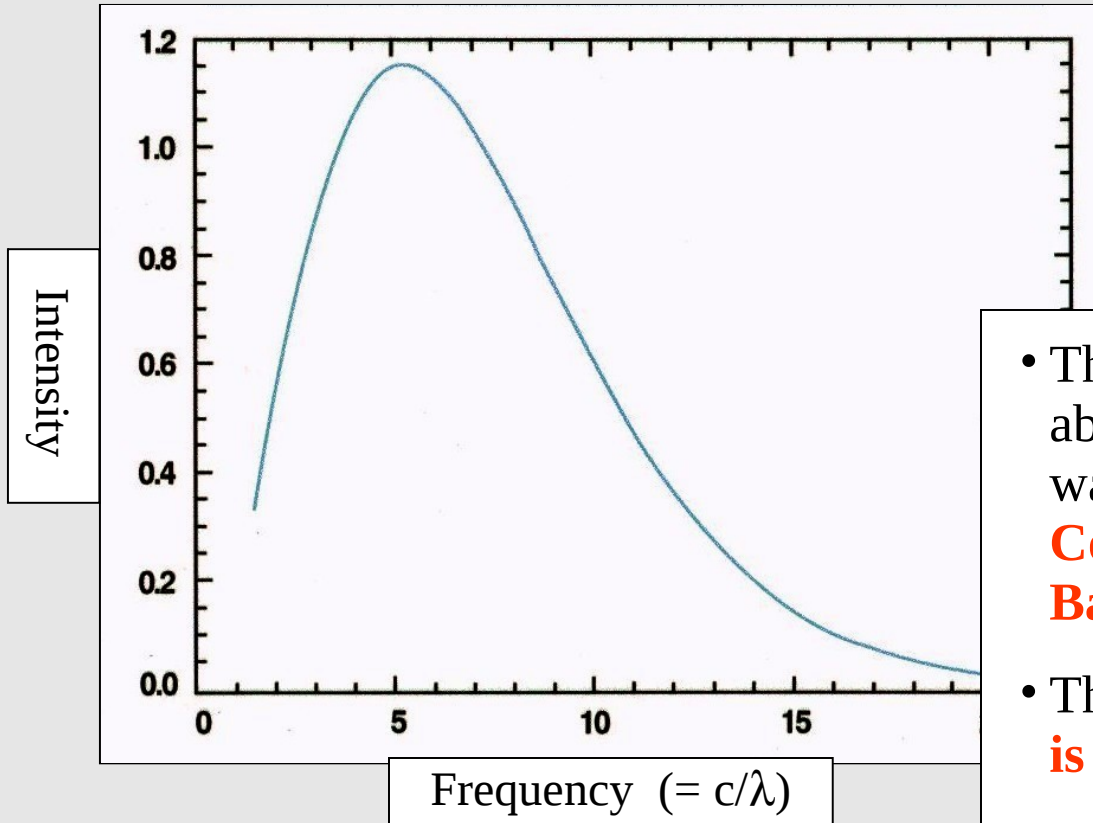


Arno Penzias

Robert Wilson

1978 Nobel Laureates in Physics

# The Cosmic Microwave Background

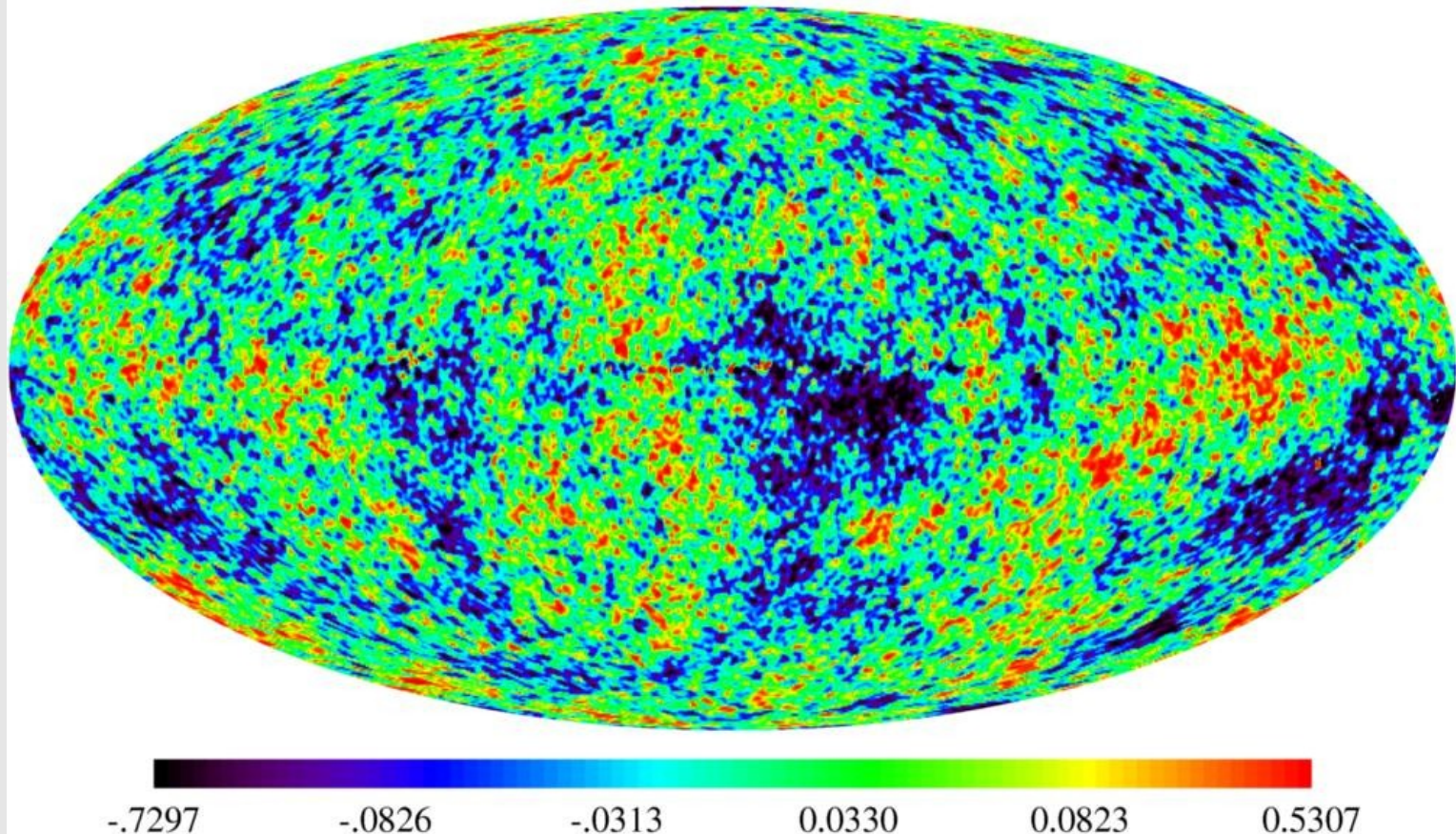


- The peak of the spectrum is at about 1 mm. These are microwaves so the light is called the **Cosmic Microwave Background, or CMB**.
- The corresponding **temperature is 2.7**
- The spectrum is not measurably different from a **black body spectrum**.

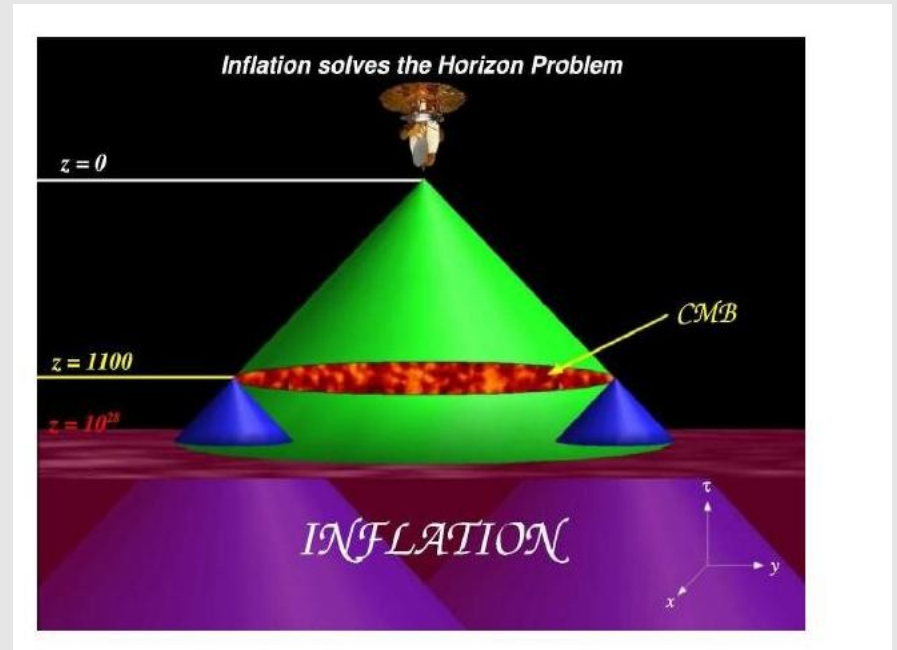
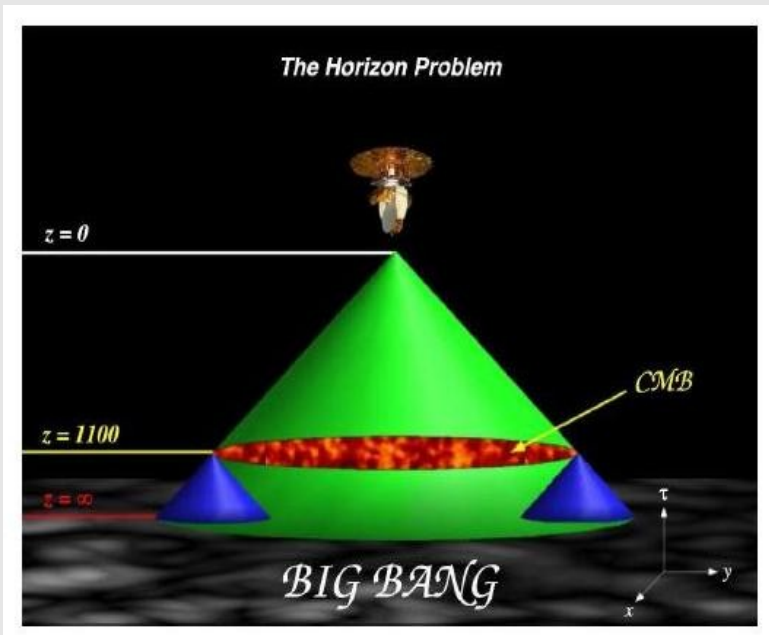
# Fluctuations in the MWB

Does this look totally random to you?

WMAP 5 year ILC



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



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

The sun shines with a power of  $3.85 \times 10^{33}$  erg/s =  $3.85 \times 10^{26}$  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:  ${}^1\text{H}$ , some  ${}^4\text{He}$



Step 2:

- available: p, some d,  ${}^4\text{He}$



Step 3:

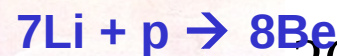
- available: p, some  ${}^3\text{He}$ ,  ${}^4\text{He}$   
little d (rapid destruction)



Step 4:

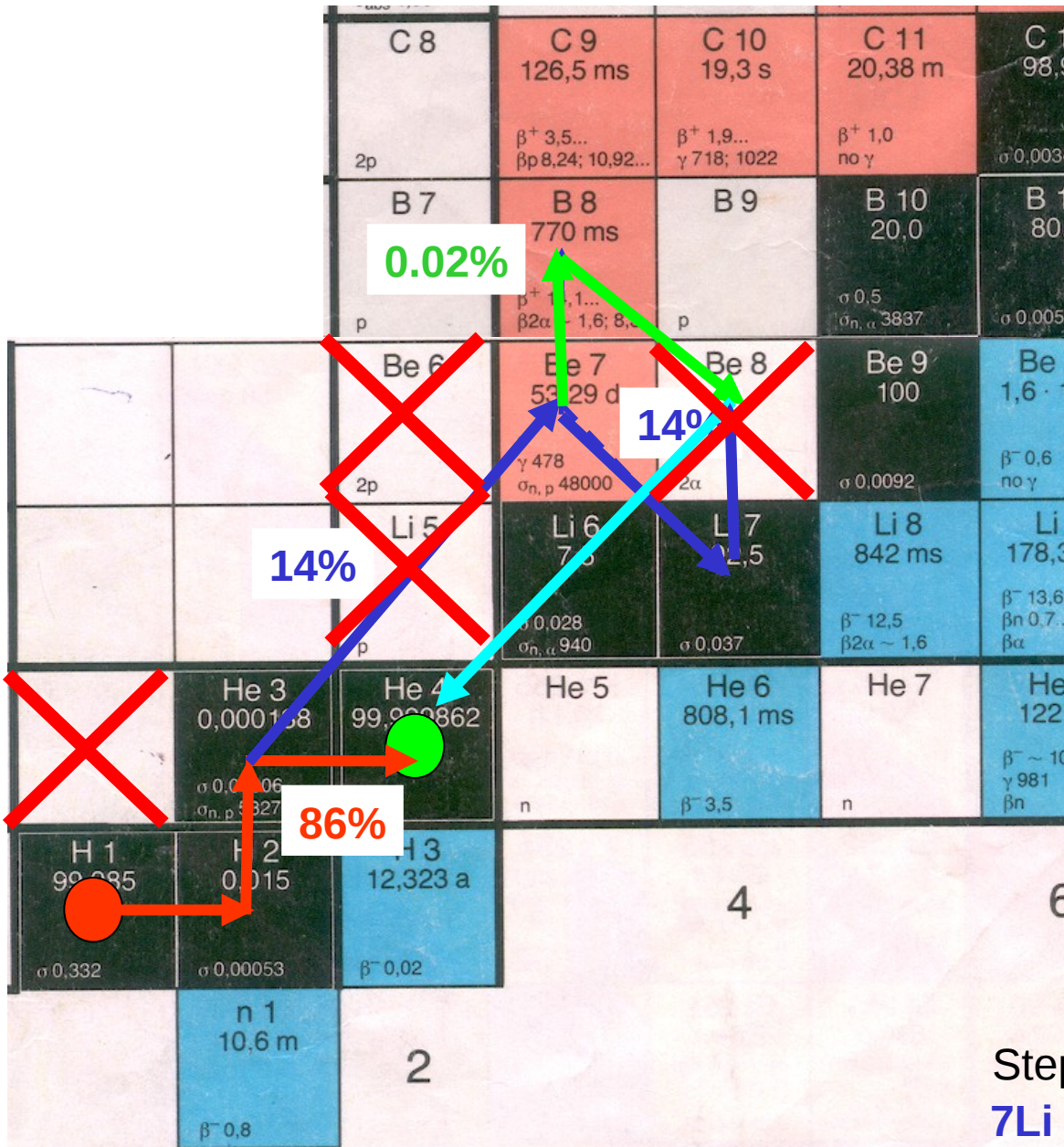


Step 5:



26

} 2 x 4He



# When stars run out of Hydrogen, they burn Helium

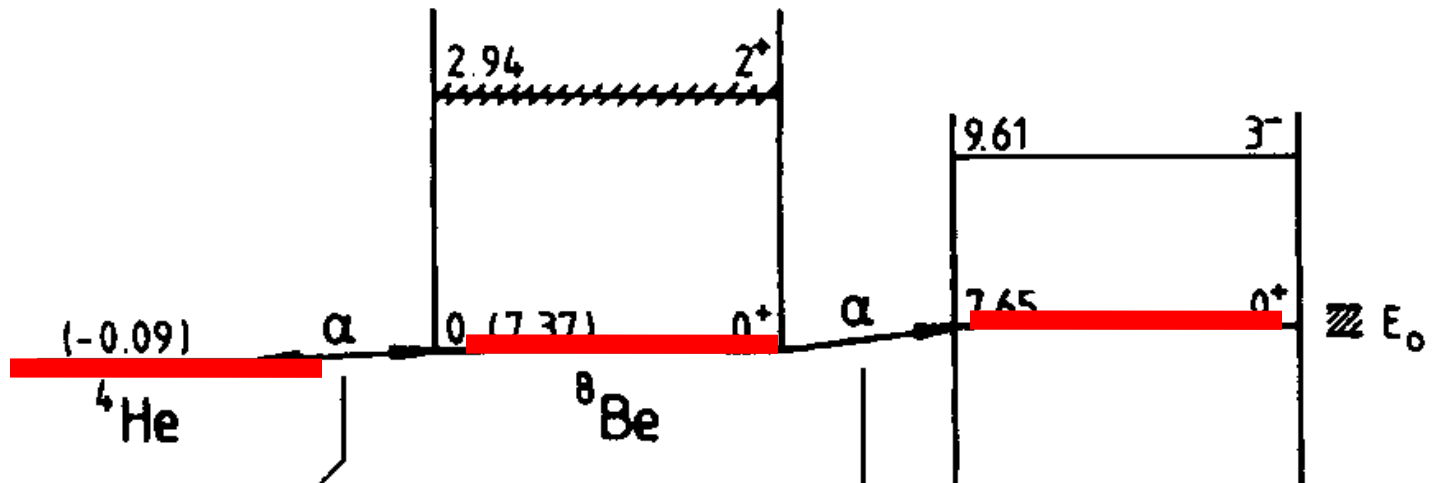
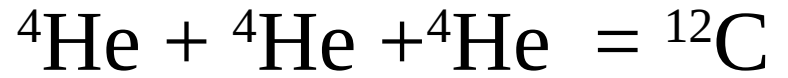
	C 8	C 9 126,5 ms	C 10 19,3 s	C 11 20,38 m	C 12 98,90	C 13 1,10
2p		$\beta^+$ 3,5... $\beta p$ 8,24; 10,92...	$\beta^+$ 1,9... $\gamma$ 718; 1022	$\beta^+$ 1,0 no $\gamma$	$\sigma$ 0,0034	$\sigma$ 0,0009
	B 7	B 8 770 ms	B 9	B 10 20,0	B 11 80,0	B 12 20,20 ms
p		$\beta^+$ 14,1... $\beta 2\alpha \sim 1,6; 8,3$	p	$\sigma$ 0,5 $\sigma_{n,\alpha}$ 3837	$\sigma$ 0,0055	$\beta^-$ 13,4... $\gamma$ 4439... $\beta\alpha$ 0,2...
	Be 6	Be 7 53,29 d	<del>Be 8</del>	Be 9 100	Be 10 $1,6 \cdot 10^6$ a	Be 11 13,8
2p		$\epsilon$ $\gamma$ 478 $\sigma_{n,p}$ 48000	$2\alpha$	$\sigma$ 0,0092	$\beta^-$ 0,6 no $\gamma$	$\beta^-$ 11,5... $\gamma$ 2125... $\beta\alpha$ 0,77...
	Li 5	Li 6 7,5	Li 7 92,5	Li 8 842 ms	Li 9 178,3 ms	Li 10 1,38
p		$\sigma$ 0,028 $\sigma_{n,\alpha}$ 940	$\sigma$ 0,037	$\beta^-$ 12,5 $\beta 2\alpha \sim 1,6$	$\beta^-$ 13,6... $\beta n$ 0,7... $\beta\alpha$	n
	He 3 0,000138	He 4 99,999862	He 5	He 6 808,1 ms	He 7	He 8 122 ms
	$\sigma$ 0,00006 $\sigma_{n,p}$ 5327	n	n	$\beta^-$ 3,5	n	$\beta^- \sim 10...$ $\gamma$ 981 $\beta n$
	H 1 99,985	H 2 0,015	H 3 12,323 a	4	6	
	$\sigma$ 0,332	$\sigma$ 0,00053	$\beta^-$ 0,02			
		n 1 10,6 m	2			
		$\beta^-$ 0,8				

That is easier said than done !

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

Nature needs to collide **three** Helium-nuclei within

**$10^{-15}$  seconds !**



We got lucky !!!  
**Nature chose** to put a  
 Resonant state in  ${}^{12}\text{C}$  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.

# Fundamental laws of a German tribe near Colon (as formulated by a brewery and translated by Ingo Wiedenhoefer)

## Das kölsche Grundgesetz



### Artikel 1

*”et es wie et es”*

Et es wie et es.

The laws of nature are as they are.

### Artikel 2

*“et kütt wie et kütt”*

Habe keine Angst vor der Zukunft.

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

### Artikel 3

Et hätt noch immer jot jegange.

Immer noch Vergangenheit.

### Artikel 3

*“et hätt noch emmer jot jegange.”*

### Artikel 4

*It always went well (not the end of the physics)*

Jammere den Dingen nicht nach.

### Artikel 5

Et blieb nix wie et wor.

Sei offen für Neuerungen.

### Artikel 6

Kenne mer nit, bruche mer nit,

foit domet.

Sei kritisch, wenn Neuerungen.

### Artikel 7

Wat wellste maache?

Füge dich in dein Schicksal.

### Artikel 8

Achte auf deine Gesundheit.

### Artikel 9

Wat soll der Quatsch?

Stelle immer erst die Universallfrage.

### Artikel 10

Drink doch ene met.

Komme dem Gebot der  
Gastfreundschaft nach.

### Artikel 11

Do laachste dich kapott.

Bewahre dir deine gesunde  
Einstellung zum Humor.

### Artikel 12

Lass dich nicht verbiegen.

Gaffel. Besonders Kölsch.

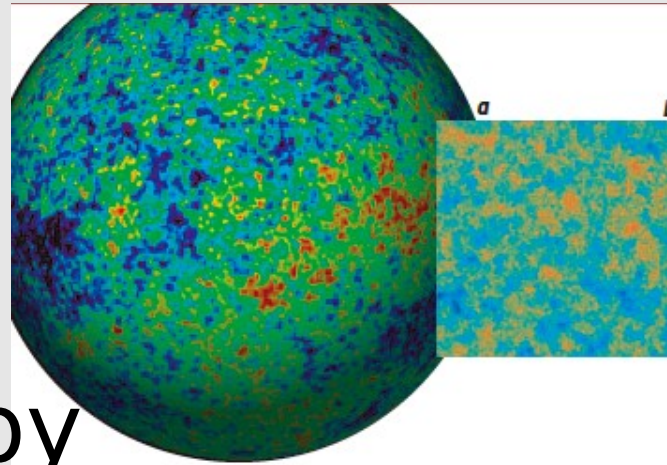




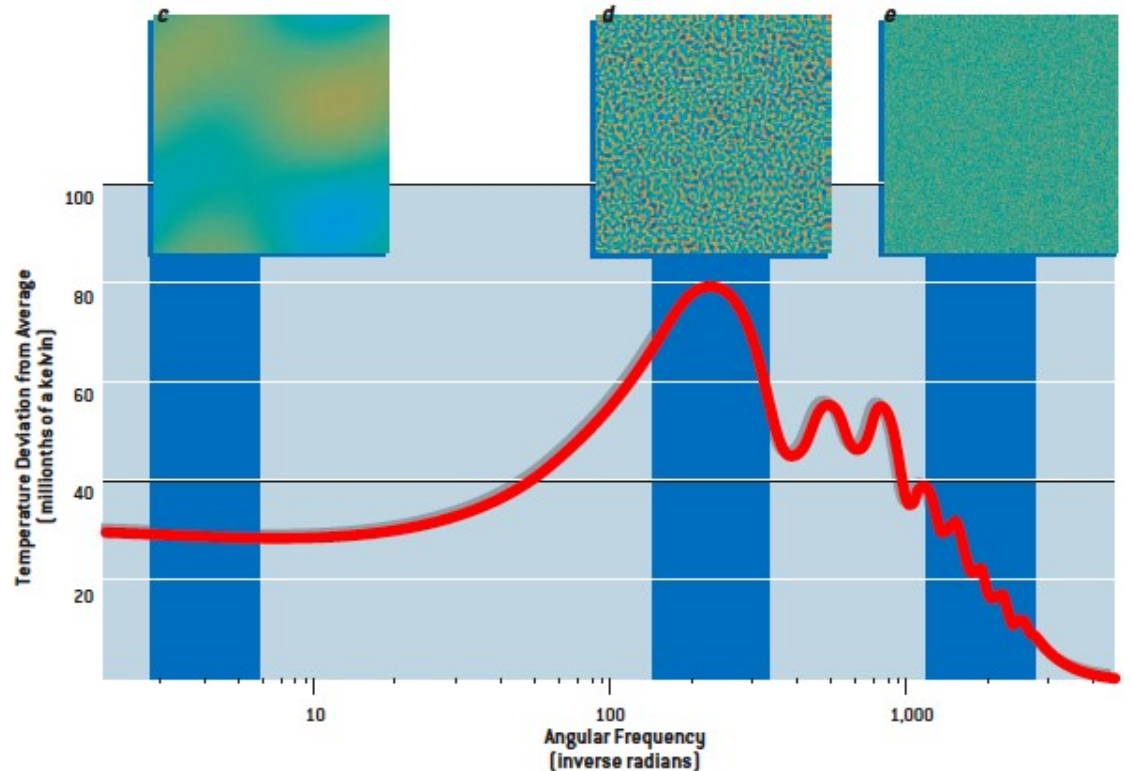
## The “Unwanted” Relics Problem

- In GUT theories, when  $SU(5)$  symmetry breaks down into a subgroup like  $SU(3) \times SU(2)_L \times U(1)$ , there inevitably arise highly stable particles that have the characteristics of magnetic monopoles with a mass  $\sim 10^{16}$  GeV.
- Calculations show that the monopole density is far above critical density and would close the Universe—what prevented this?

Build up a power spectrum by averaging over  $m$ -modes. (large uncertainties for low- $l$  modes)



OBSERVATIONS OF THE CMB provide a map of temperature variations across the whole sky (a). When researchers analyze portions of that map (b), they use band filters to show how the temperature of the radiation varies at different scales. The variations are barely noticeable at large scales corresponding to regions that stretch about 30 degrees across the sky (c) and at small scales corresponding to regions about a tenth of a degree across (e). But the temperature differences are quite distinct for regions about one degree across (d). This first peak in the power spectrum (graph at bottom) reveals the compressions and rarefactions caused by the fundamental wave of the early universe; the subsequent peaks show the effects of the overtones.



# How the Distances between Galaxies (or Anything Else) Increase in an Expanding Universe

