hi

Day 27, 04.25.2019

Cosmology 5

April 2019

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
31	1	2 lecture	3	4 lecture	5 HW9 due	6 HW10
7	8	9 lecture	10	11 lecture	12 project day 2 HW10 due	13 HW11
14	15	16 lecture	17	18 lecture	19	20 HW12 MA & paper (look in notes for MA set)
21 HW11 due	22	23 lecture	24	25 lecture	26 Honors data upload HW12 MA due	27 2nd Midterm ← ...
28 2nd Midterm MasteringAstronomy Friday midnight through Tuesday midnight ... →	29	30	1	2	3 FINAL EXAM 07:45!!!!! HW12 paper due	4

Week 15 last, Higgs Boson, the Big Bang is properly named, and the Flatness of the world

TUESDAY, April 23	**Higgs Boson and mass**
Required Readings:	Chapter 12 in PCC
	TOE chapter 9
	Chapter 17 in PCC
Recommended Readings:	
Additional content:	primitiveDiagrams_0 (13m), primitiveDiagrams_1 (4m), primitiveDiagram_2 (9m) in:
Tasks:	3 movies on how to make Feynman Diagrams
Homework available:	
Homework due:	
anything posted?	slides
THURSDAY, April 25	**The Big Bang, for real and the geometry of the universe**
Required Readings:	CP Section 22.1-22.4, 23.1-23.4
Recommended Readings:	
Additional content:	
Tasks:	
Homework available:	Midterm 2: **available Friday, April 26 midnight and closes Monday, April 29 midnight**
Homework due:	HW12: Friday, April 26, the MasteringAstronomy part
	MW12: Friday, May 3, the paper part
anything posted?	slides

housekeeping 1/3

I believe that all LON-CAPA inputs are now done.

Second Midterm:

- *available Friday, midnight. due Tuesday, midnight*
- *MasteringAstronomy*
- *Special Relativity through today*

Final Exam Day (May 3, **07:45**, here):

Poster session: I’ll bring bagels and cream cheese

- *poster proponents get points for their work product*
- *viewers get points for asking good questions*

Feynman Diagram Project: read the packet!

- *see blog or pick it up*

You’ll turn in a bunch of stuff:

- *HW12 paper*
- *FD project results*
- *Course review*
- *Honors Project paper*

The blog has a number of links to last-weeky things

housekeeping 2/3

7 posters, right?

1. *We are **Mark Bassett and David Weinstein**, and we will make a poster on the discovery of Helium.*
2. *We are **Jiaxuan Xiong and Yifei Zhang**, and we will make a poster on the first observation of a Black Hole in Cygnus X.*
3. *We are **Kayla Wells and Clea Derozier**, and we will make a poster on the discovery of Cosmic Rays by Hess.*
4. *We are **Monica Judd and Brendan Jenkins** and we will be making a poster on the discovery of the Neutron by Chadwick*
5. *We are **Lauren Chapman and Madison Crosser**, and we will make a poster on The Discovery of a Neutrino by Reines and Cowan.*
6. *I am **Myrna Kada**, and I will make a poster on The Discovery of the Weak Neutral Currents at CERN.*
7. *We are **Evan Smith and Charles Keranen**, and we will make a display about The Discovery of the Longest Redshift Object, GRB 090423.*

housekeeping 3/3

you know the drill:

To: RAYMOND L BROCK

From: sirs@msu.edu

Student Instruction Rating System (SIRS Online) collects student feedback on courses and instruction at MSU. Student Instructional Rating System (SIRS Online) forms will be available for your students to submit feedback during the dates indicated:

ISP 220 001: 4/15/2019 - 5/15/2019
ISP 220 002: 4/15/2019 - 5/15/2019

Direct students to https://sirsonline.msu.edu.

Students are required to complete the SIRS Online form OR indicate within that form that they decline to participate. Otherwise, final grades (for courses using SIRS Online) will be sequestered for seven days following the course grade submission deadline for this semester.

SIRS Online rating summaries are available to instructors and department chairs after 5/15/2019 at https://sirsonline.msu.edu. Instructors should provide copies of the rating summaries to graduate assistants who assisted in teaching their course(s). Rating information collected by SIRS Online is reported in summary form only and cannot be linked to individual student responses. Student anonymity is carefully protected.

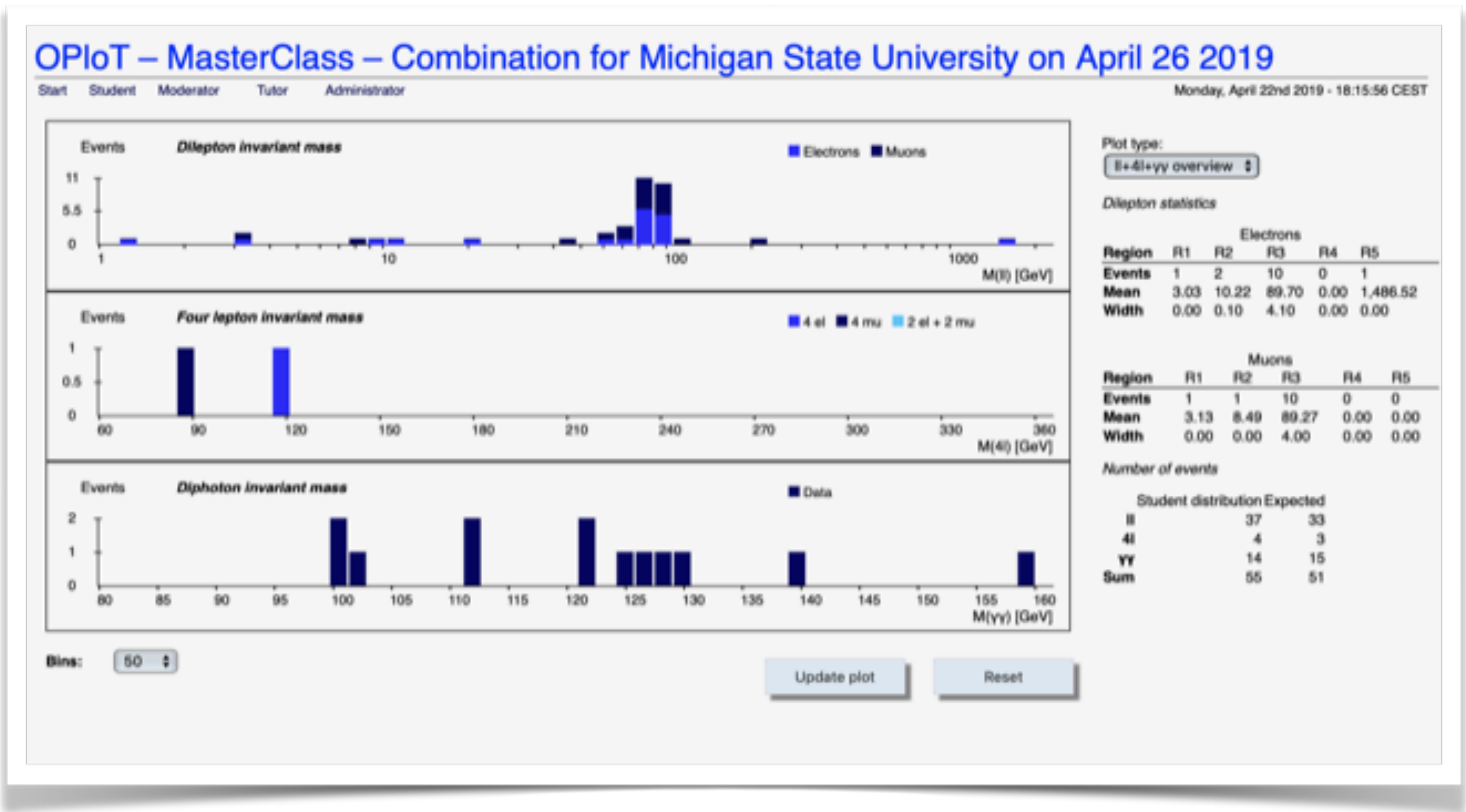
If you have any questions, please contact Michelle Carlson, (mcarlson@msu.edu, (517)432-5936).

I had a section 2

Thanks, Benjamin!

Benjamin got uploading Hypatia data to work fine.

Thanks!



go there

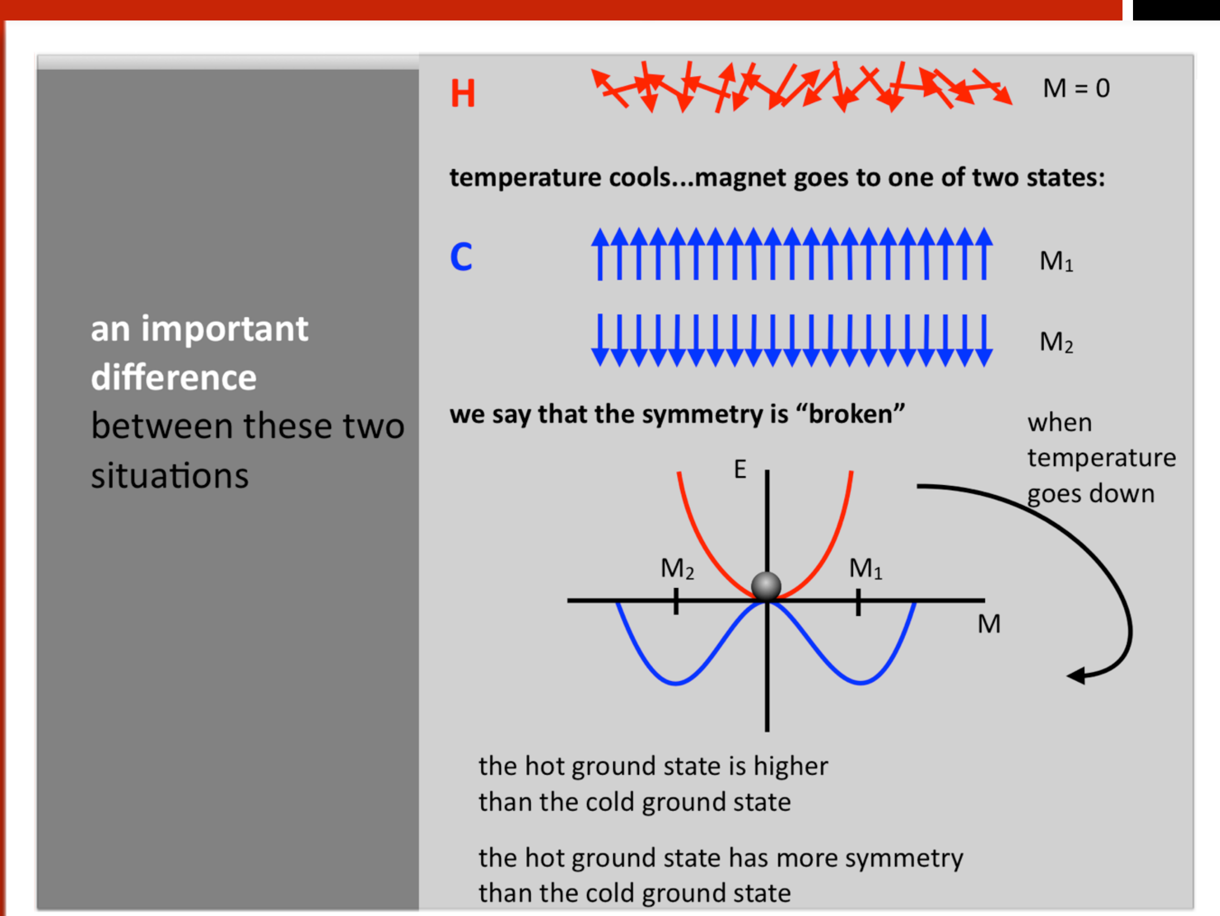
https://qstbb.pa.msu.edu/storage/QS&BB2019/Homework_Projects/honors_project_2019/UploadInstructions/

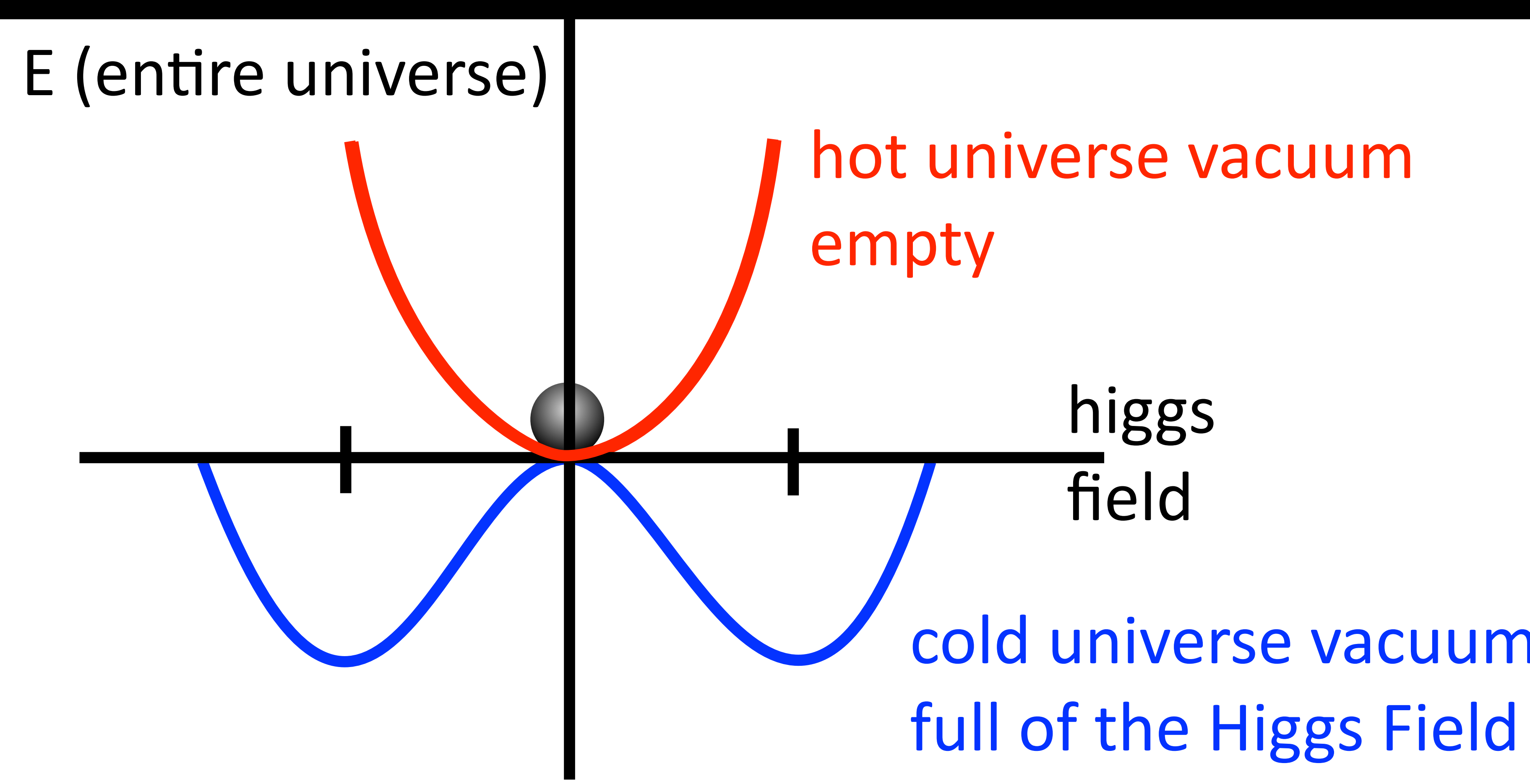
KEEP
CALM
AND
LET’S
REVIEW

from a hot phase in the universe

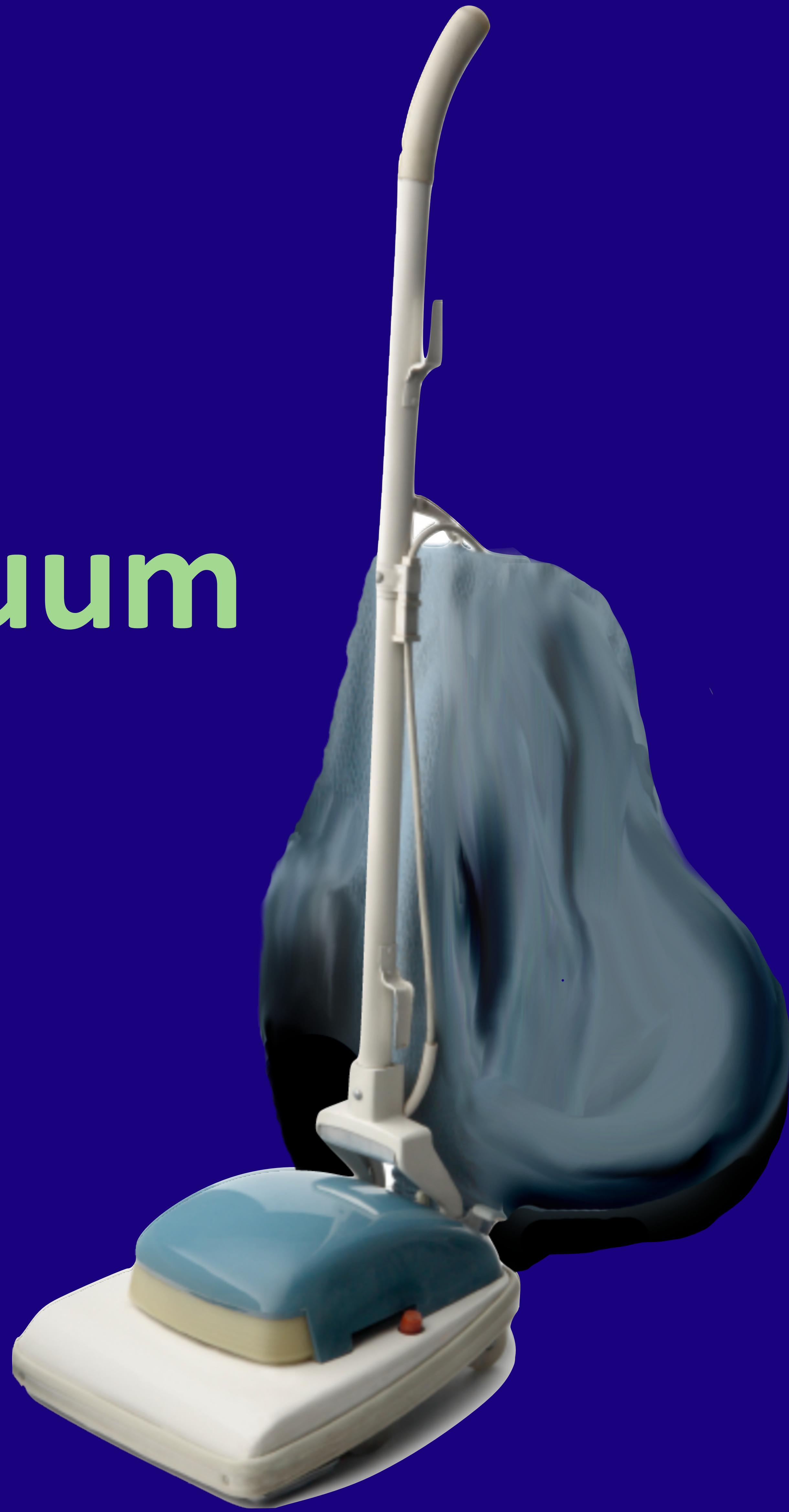
cool it all at once

@ 10^{-12} seconds after the BB





vacuum



had only zero-average-value fields

now it's full of a finite average value Higgs Field

mass

was born

in the Higgs Field

definite predictions

of Weinberg's model

0. The weak and electromagnetic interactions are two aspects of the same force

1. The W Boson should exist

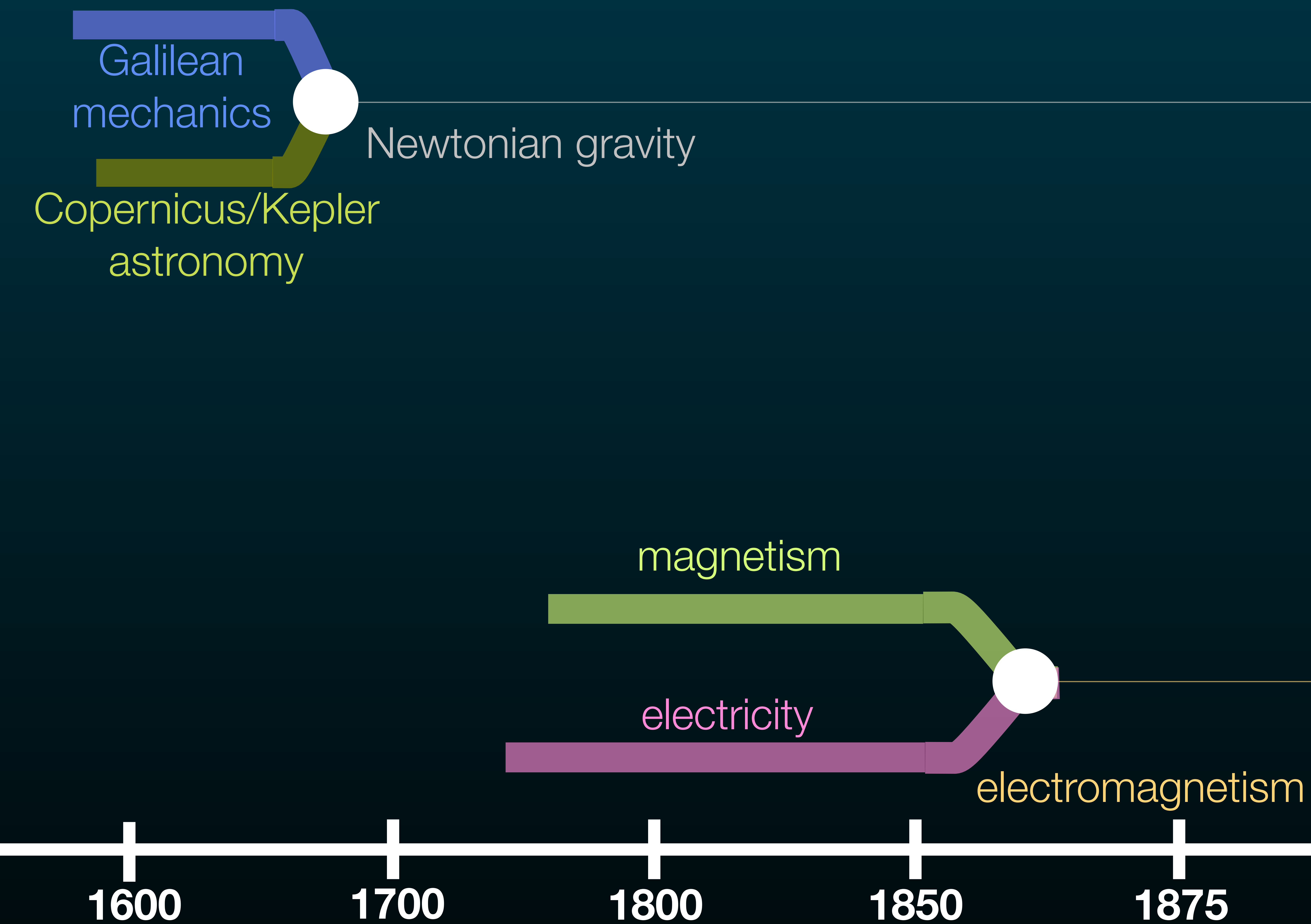
2. An additional "Z Boson" should exist

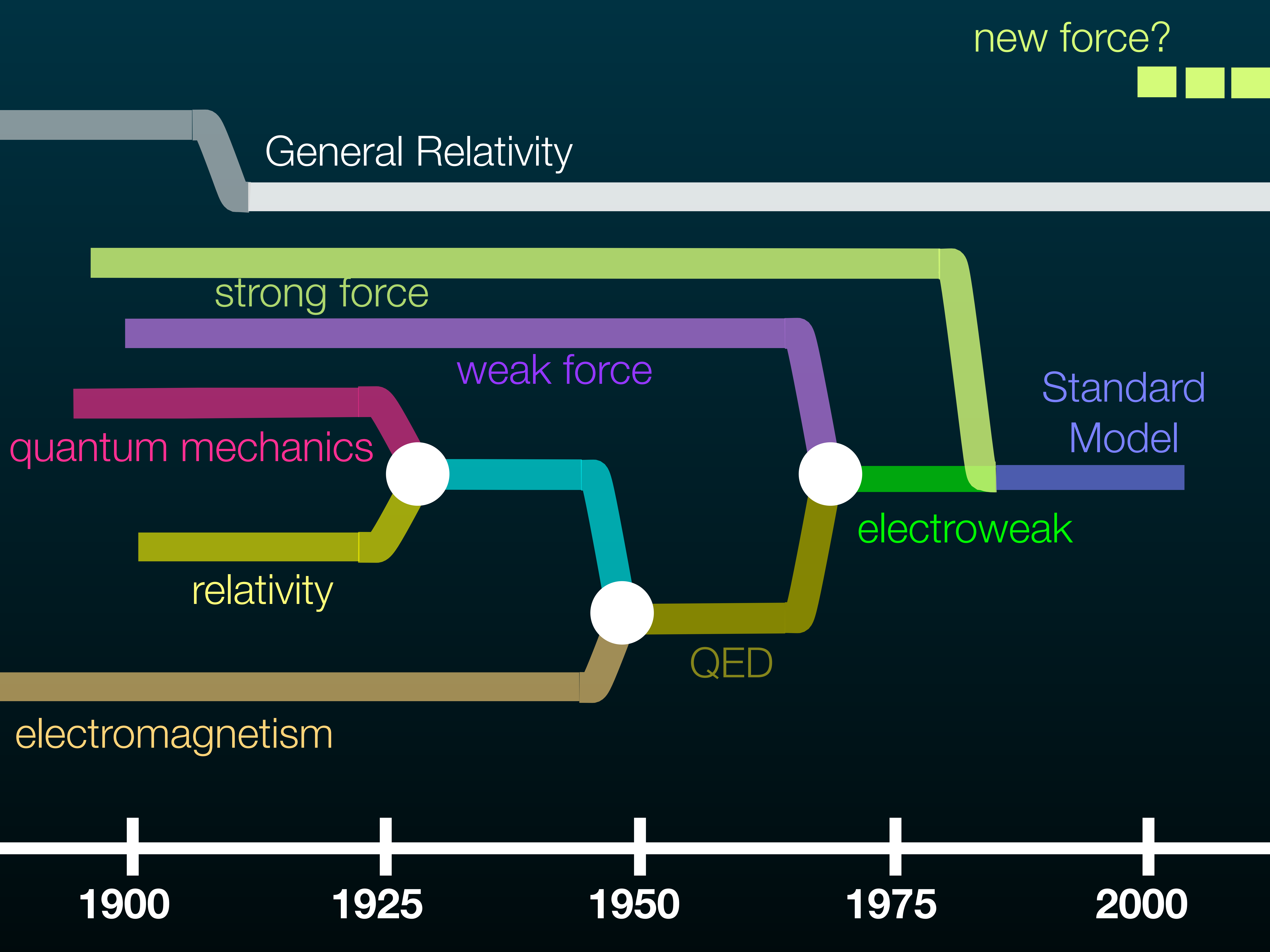
   Many physics reactions relate M_W to M_Z

3. This Z Boson and the γ are intimately related

   any reaction with a photon, must also happen with a Z^0

4. The Higgs Boson should exist


Galilean mechanics
Newtonian gravity
Copernicus/Kepler astronomy
magnetism
electricity
electromagnetism
1600
1700
1800
1850
1875


new force?
General Relativity
strong force
weak force
Standard
Model
quantum mechanics
electroweak
relativity
QED
electromagnetism
1900
1925
1950
1975
2000

hi, again, again

still Day 27, 04.25.2019

Cosmology 5

10^{-32} s

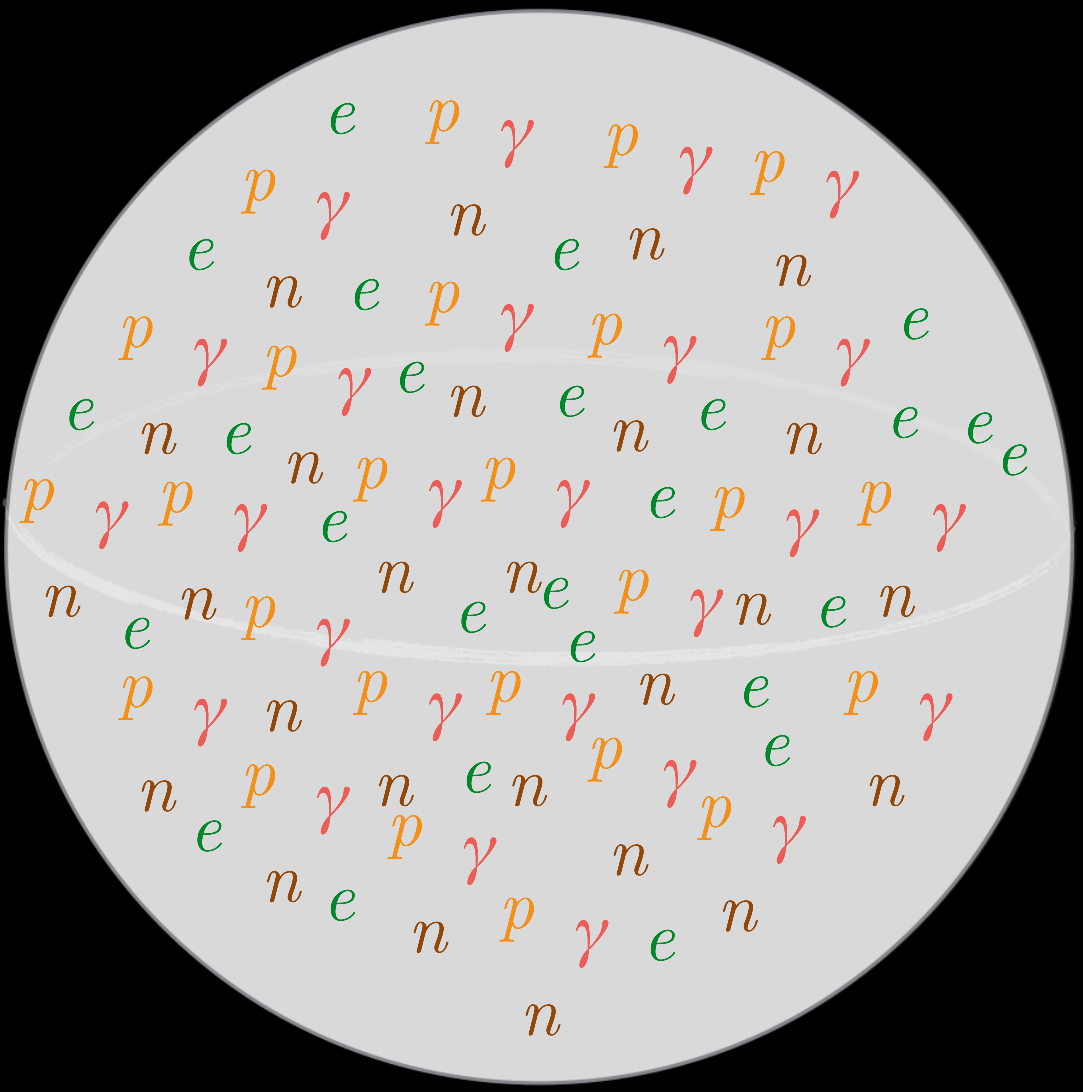
0.5m

$10^{24°}$

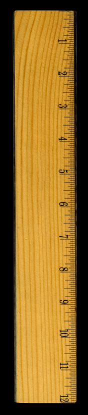
10^{-12} s

10^{10} m

$10^{17°}$

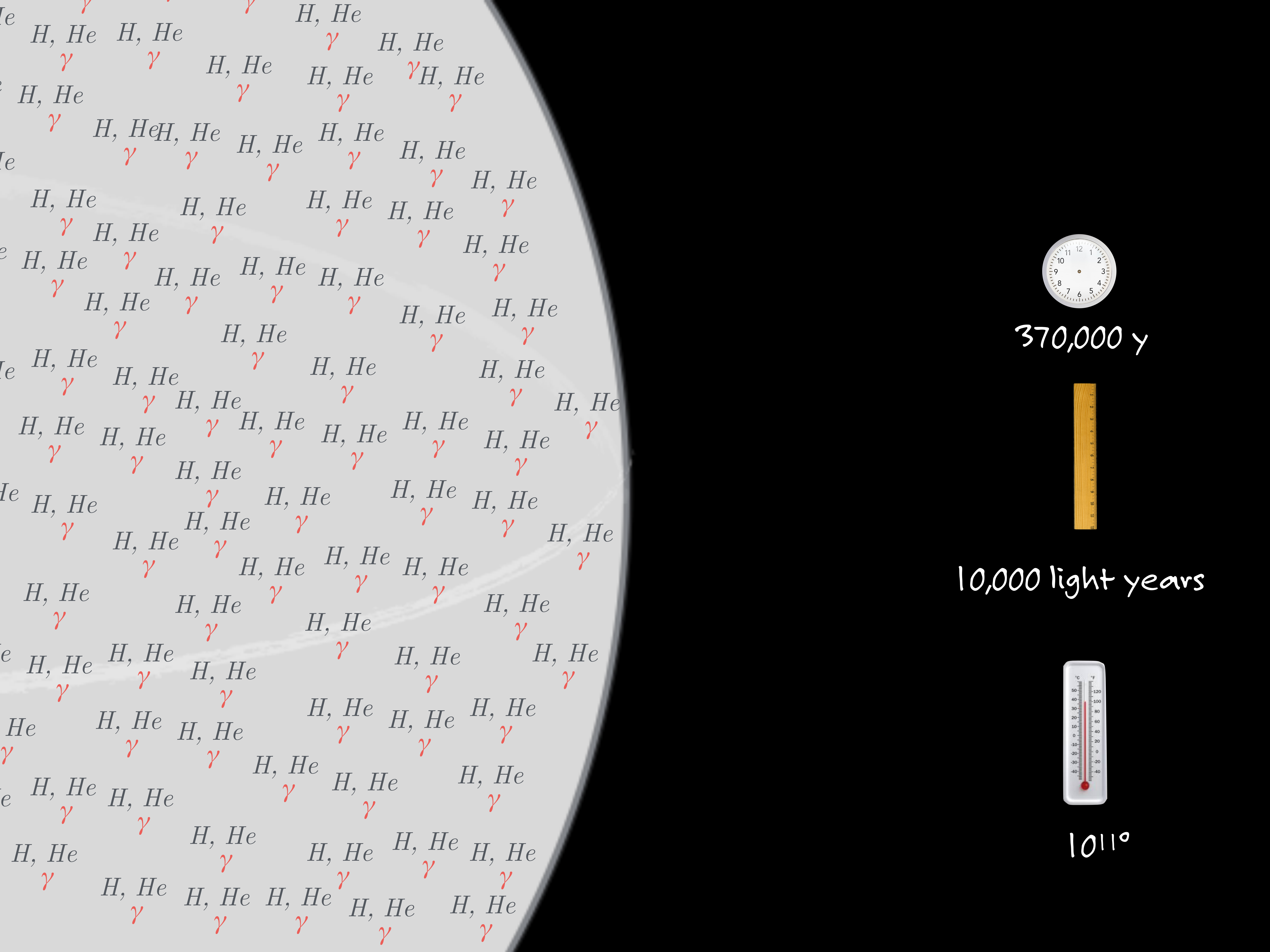


10^{-6} s



10^{12} m

10^{13}°


H, He
γ
370,000 y
10,000 light years
1011°


13,800,000,000 y
46,000,000,000 light years
3°

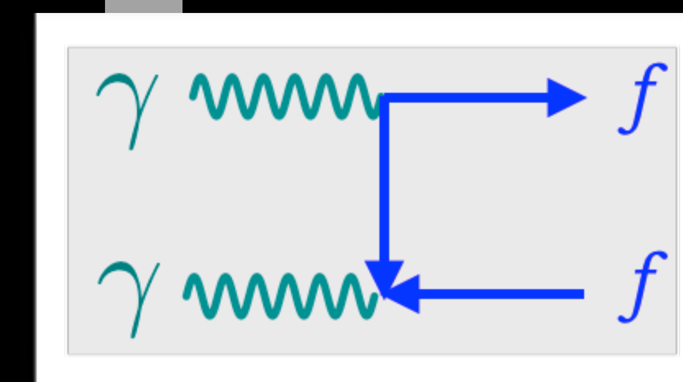
elementary particle epoch

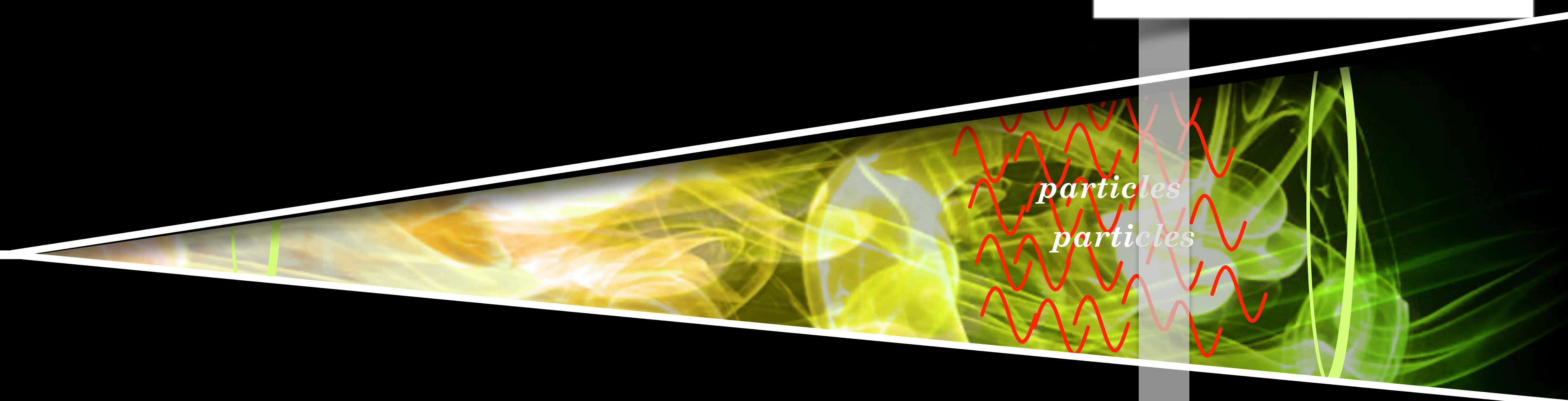
Electroweak Phase Transition

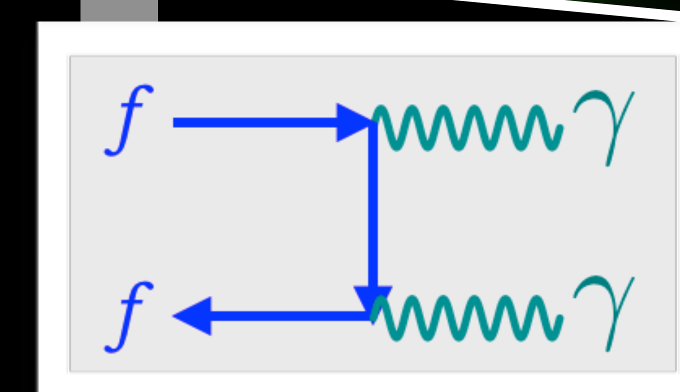
"Quantum Foam"

?

presumed that processes are in equilibrium

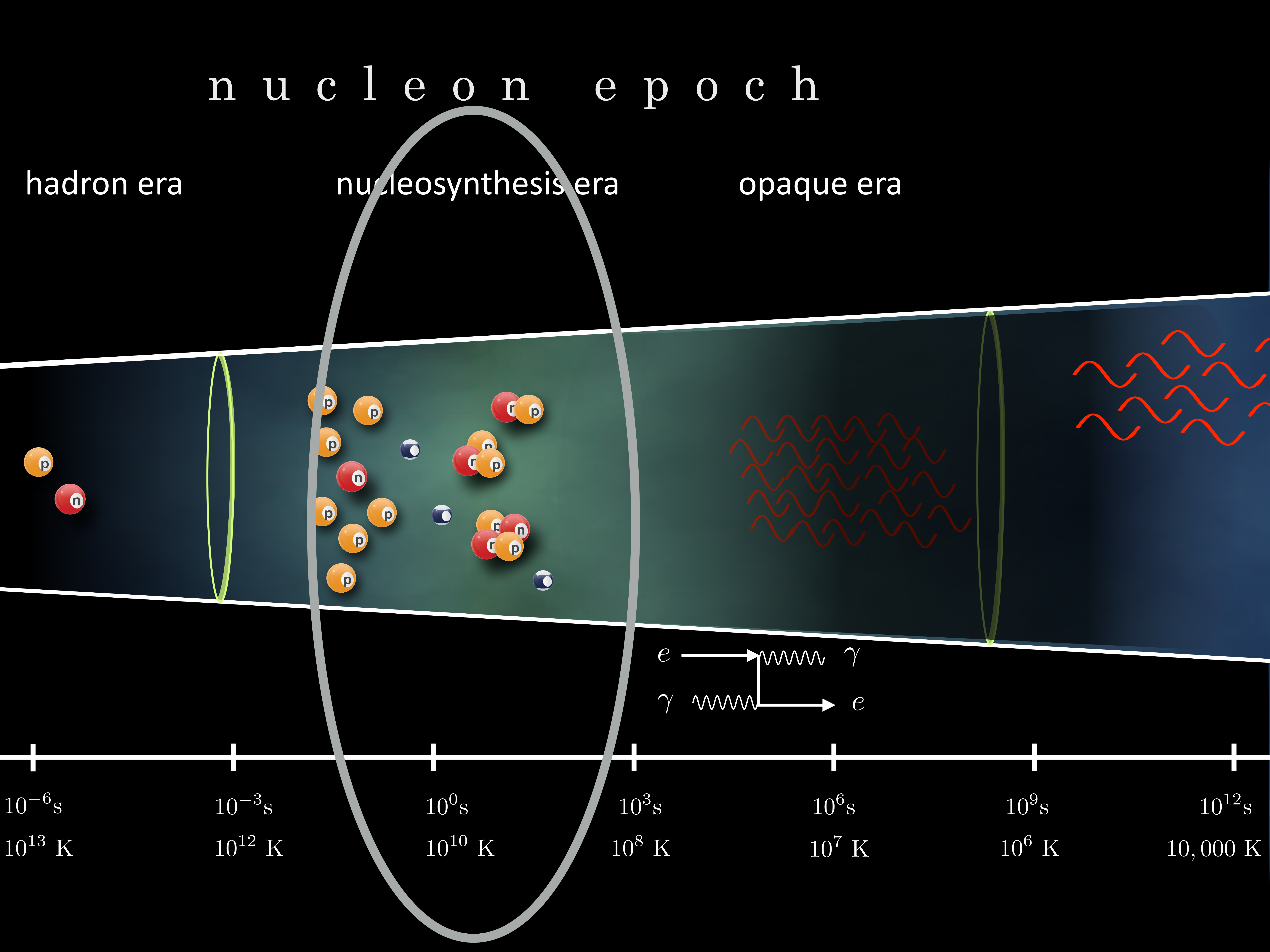




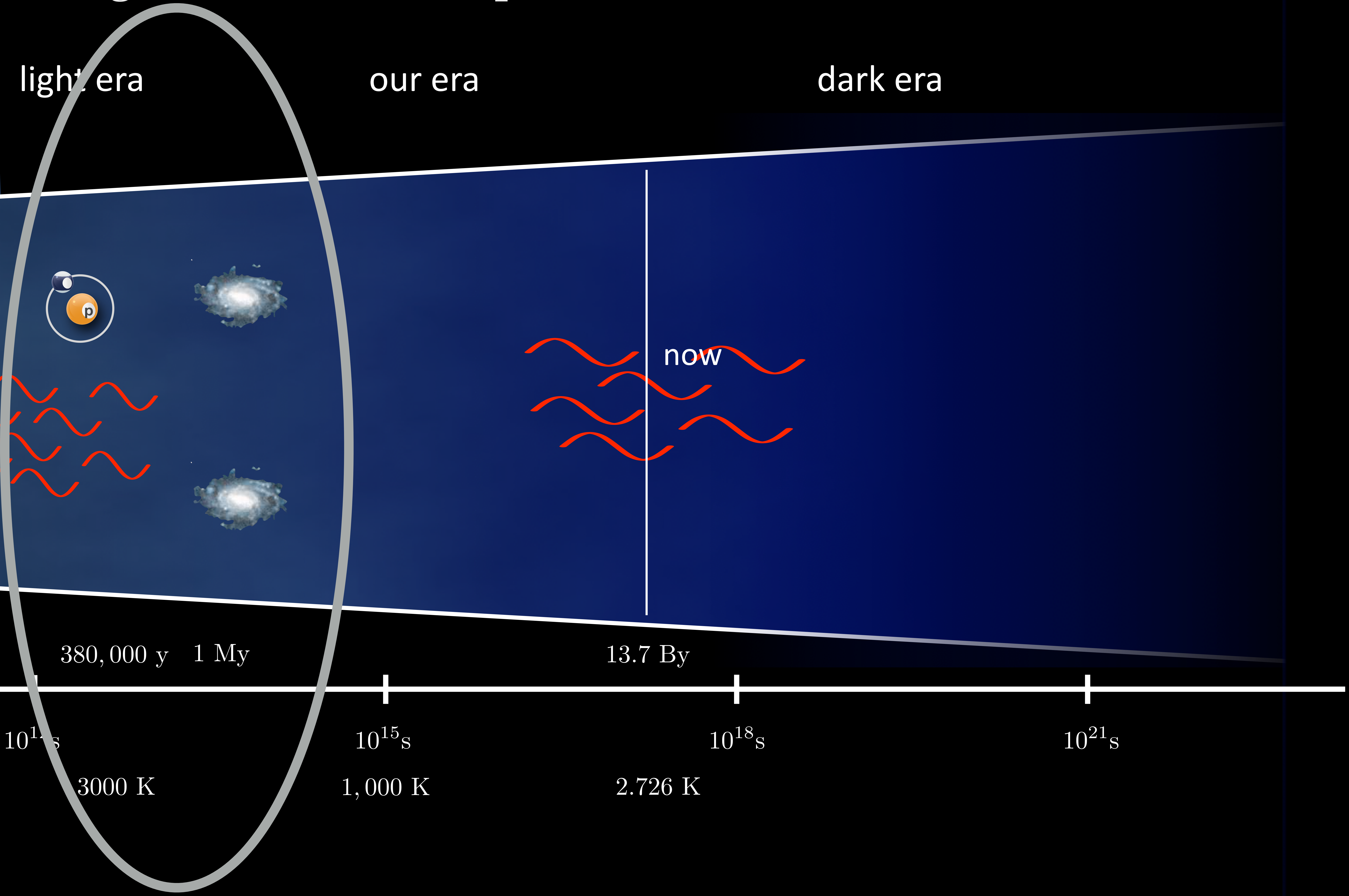


10^{-42}s 10^{-39}s 10^{-36}s 10^{-33}s 10^{-30}s 10^{-27}s 10^{-24}s 10^{-21}s 10^{-18}s 10^{-15}s 10^{-12}s 10^{-9}s 10^{-6}s

10^{22} K 10^{21} K 10^{18} K 10^{15} K


nucleon epoch
hadron era
nucleosynthesis era
opaque era
p
n
e
γ
γ
e
10^{-6}s
10^{13} K
10^{-3}s
10^{12} K
10^{0}s
10^{10} K
10^{3}s
10^{8} K
10^{6}s
10^{7} K
10^{9}s
10^{6} K
10^{12}s
$10{,}000$ K

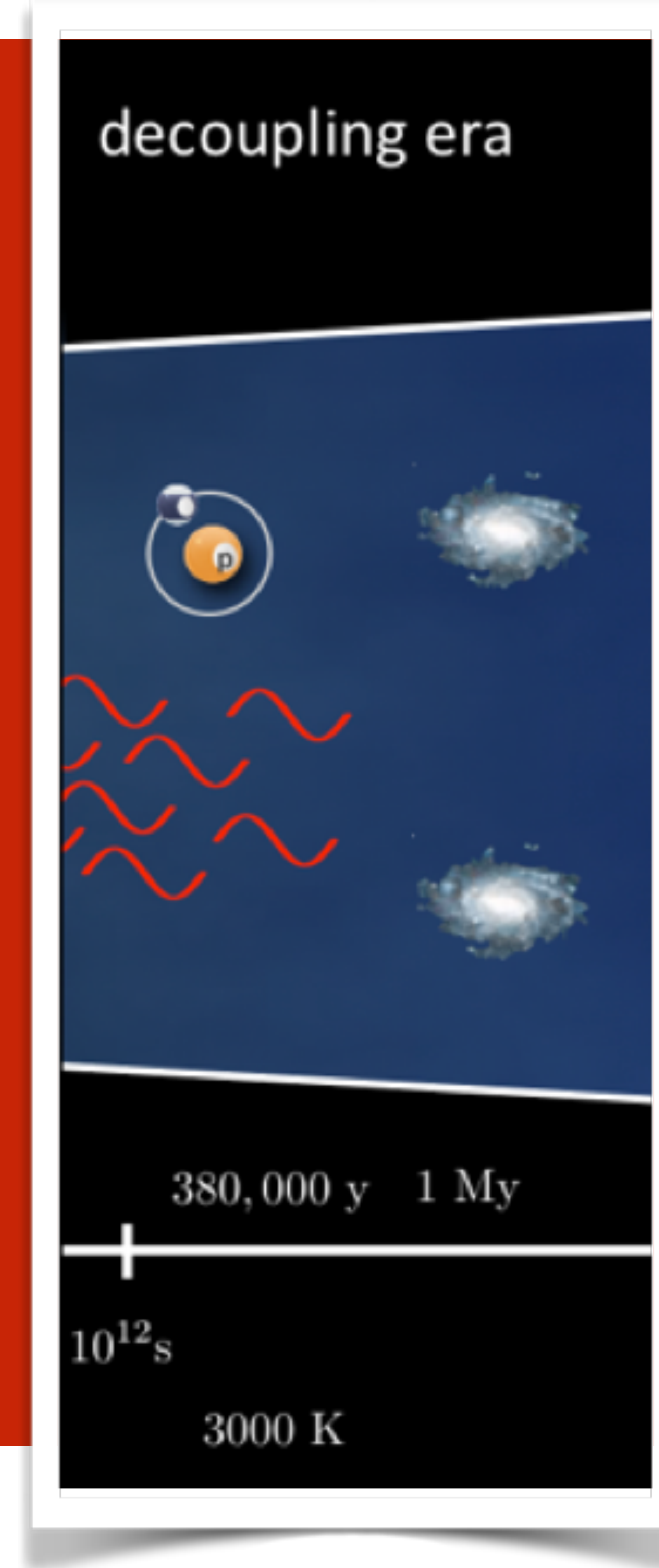
galactic epoch



3 minutes

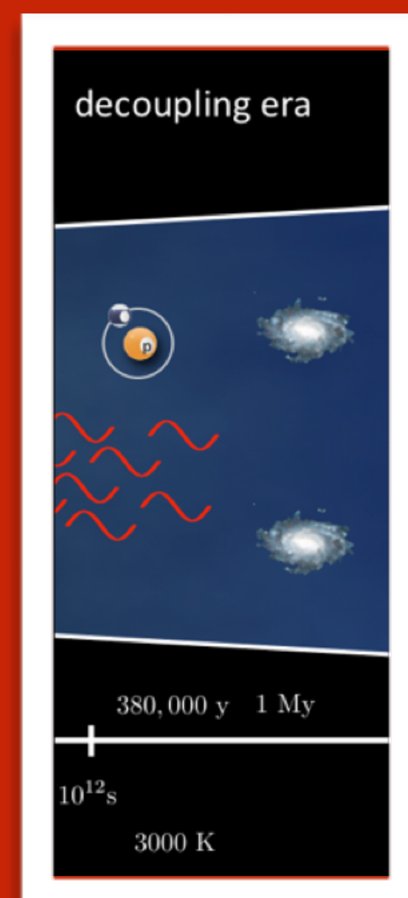
370,000 years

(all within the first 15 fake-minutes on my calendar)



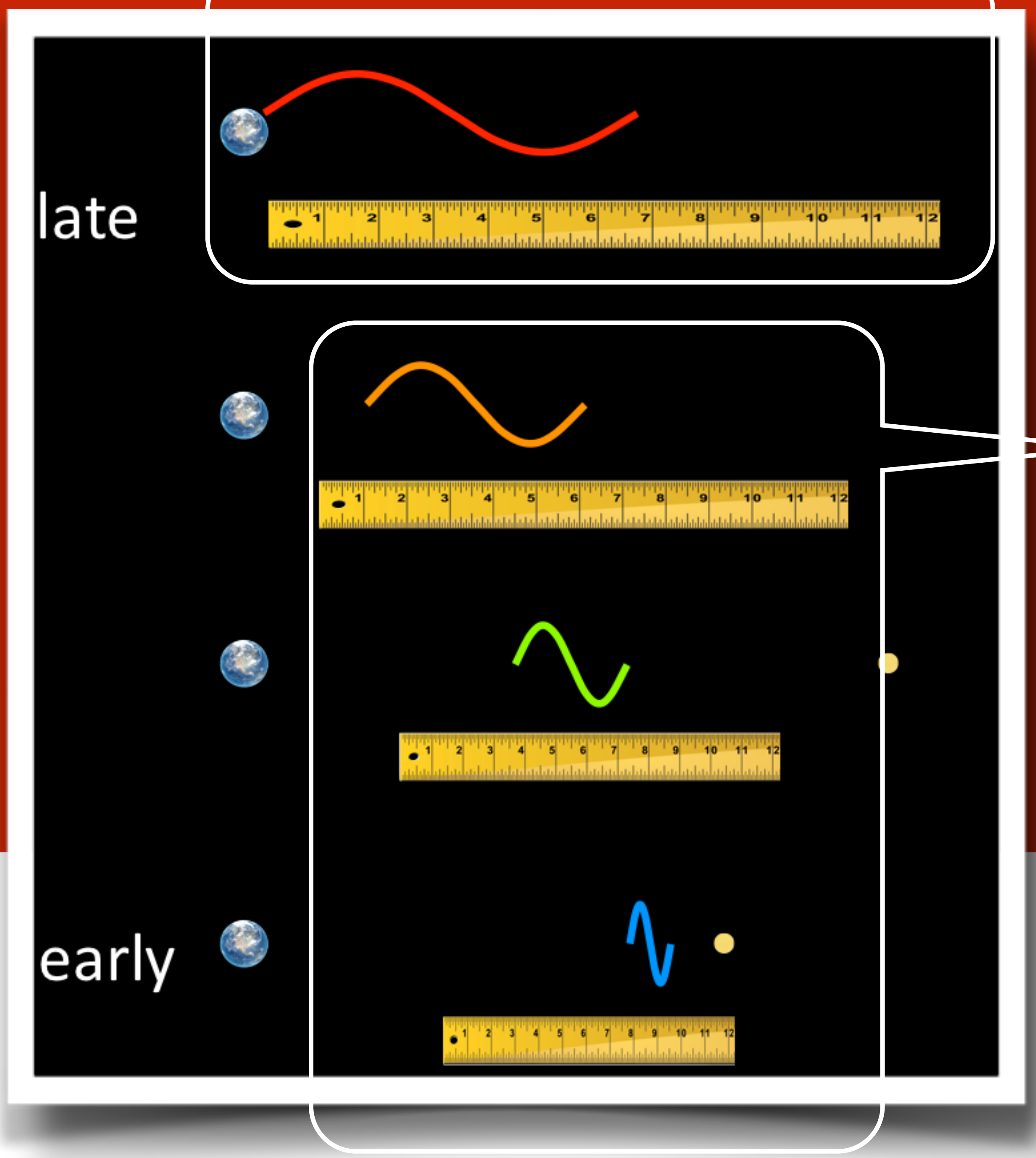
the Cosmic Microwave Background, CMB

about 370,000 y after BB



at some point, they are too low in energy to make new particles...they just hang around.
about 70,000 years after BB

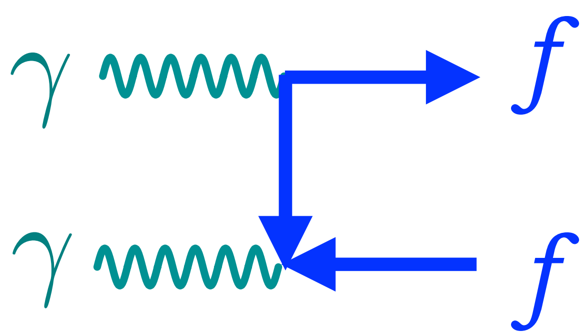
remember



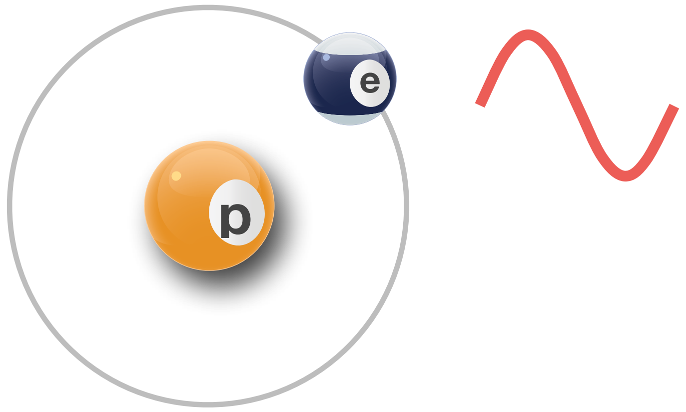
many high energy photons: create new particles, ionize atoms, disintegrate nuclei

primordial photon mischief

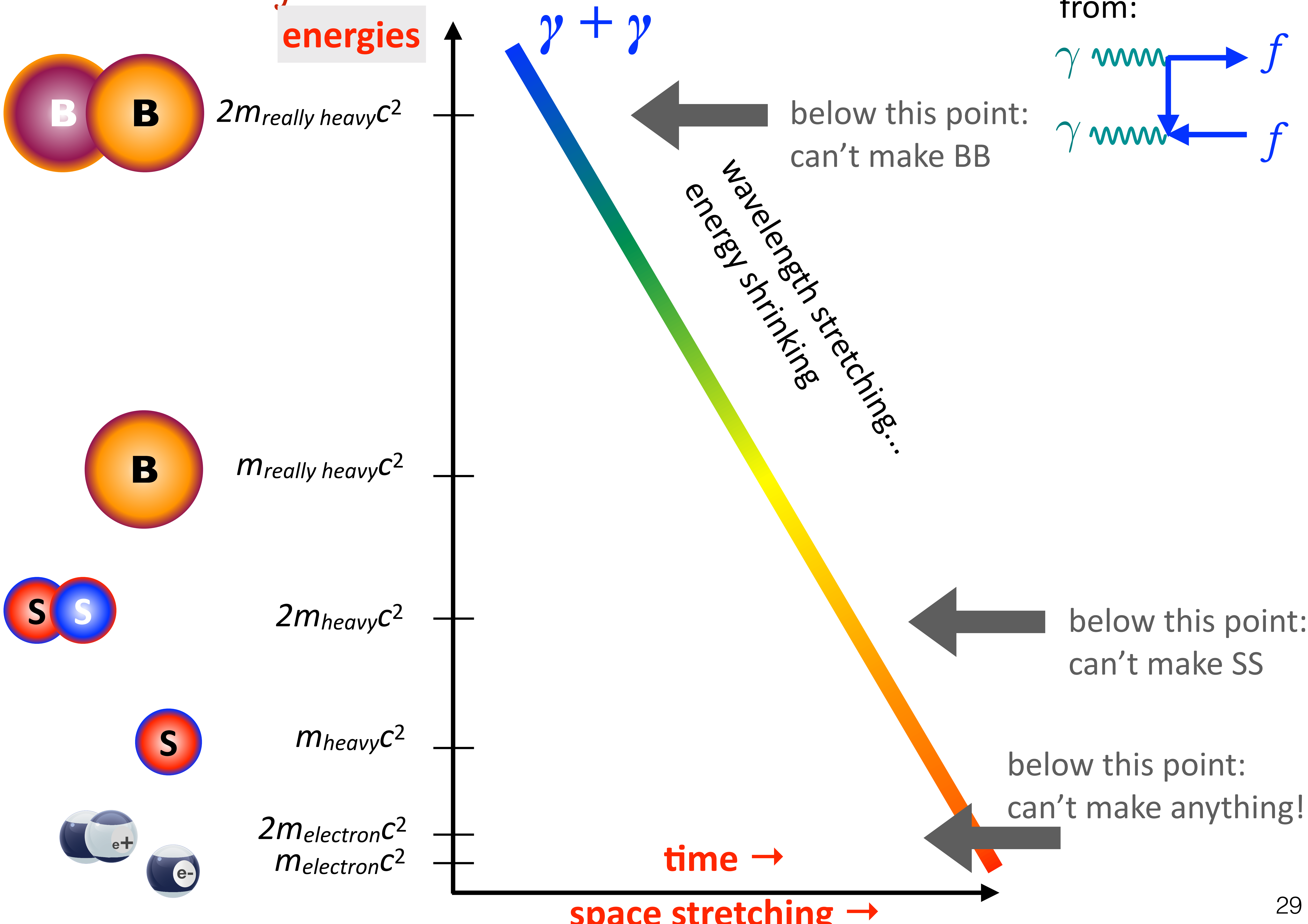
annihilate into fermion-antifermion pairs



ionize early atoms



heavy species "freeze out": pairs cannot be created any more



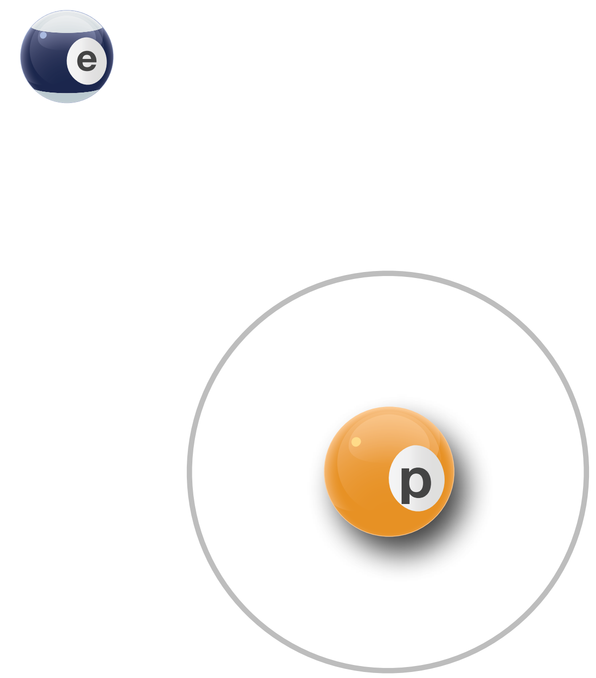
there is a magic point

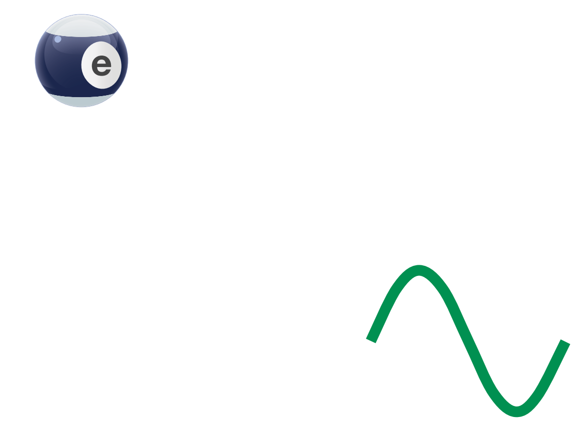
at which atoms can start to form

"recombination"

which is an odd name, since there wasn't a "combination" yet!

After protons, neutrons, and electrons are stable...

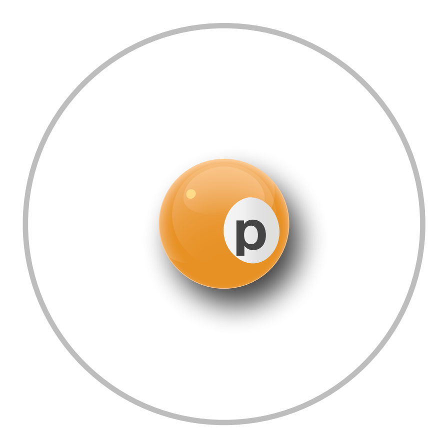




left-over photons ionize the baby Hydrogen atoms

The Universe consists of: a **plasma**...charged particles, unbound...freely moving around. Opaque.

At one point...about 10^{12-13} s - 370,000 y:



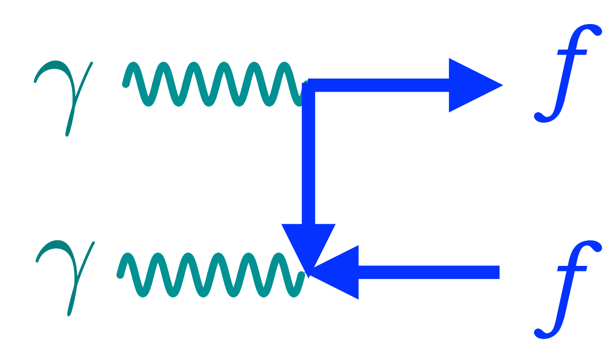
Bingo.
We have H atoms (and He)

the photons don't have 13.6 eV of energy

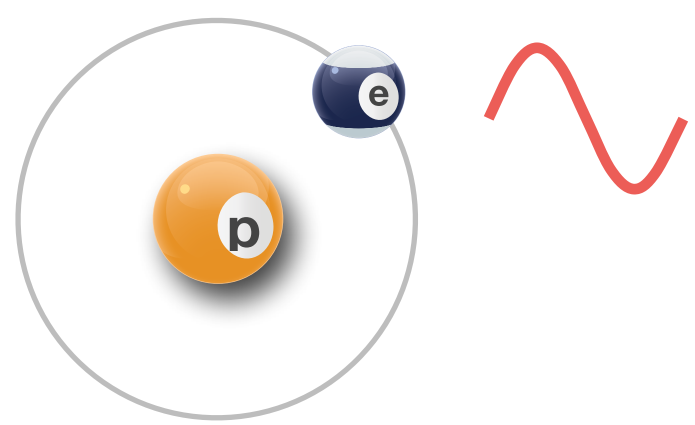
The Cosmic Microwave Background

primordial photon mischief

annihilate into fermion-antifermion pairs

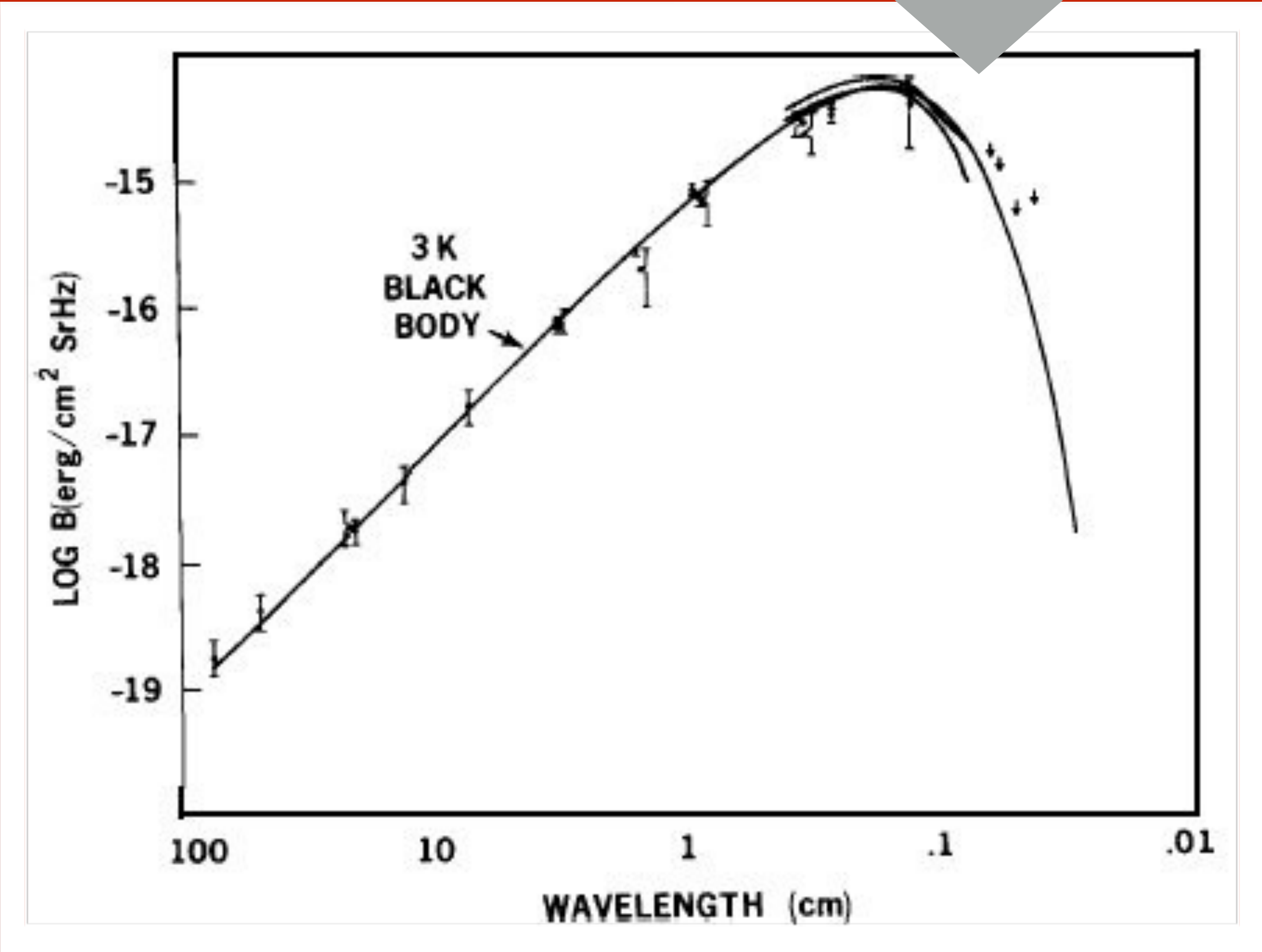


ionize early atoms



then, they're done and hang around about 1mm, microwaves

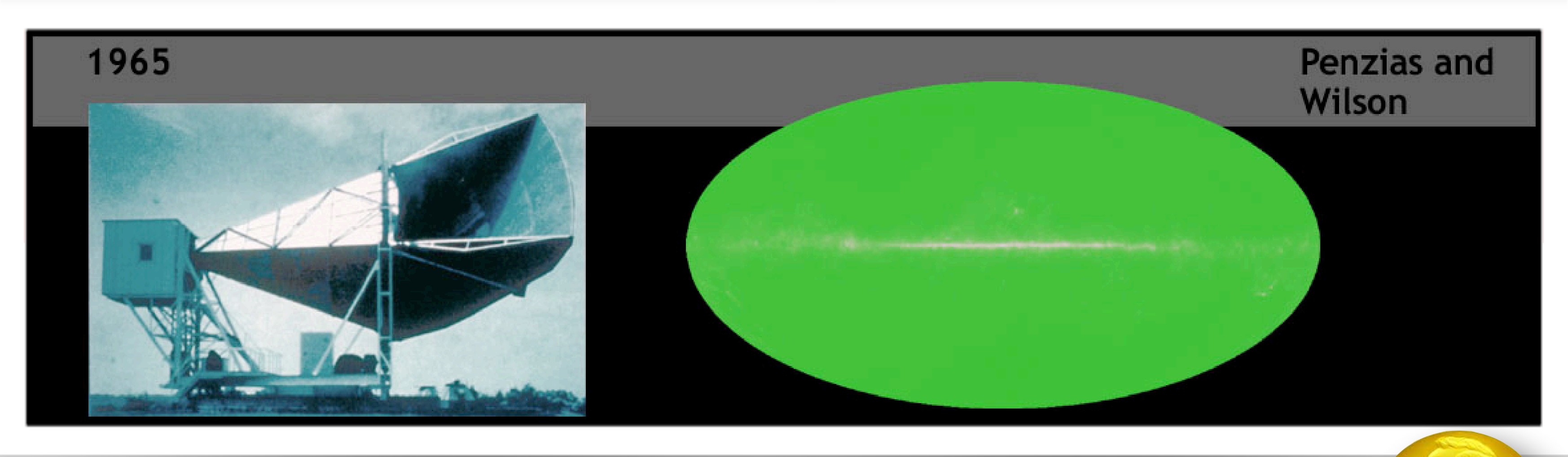
balloons to get above atmosphere to measure infrared wavelengths



a blackbody spectrum

of ~3K above absolute zero

the peak is limited by the atmosphere

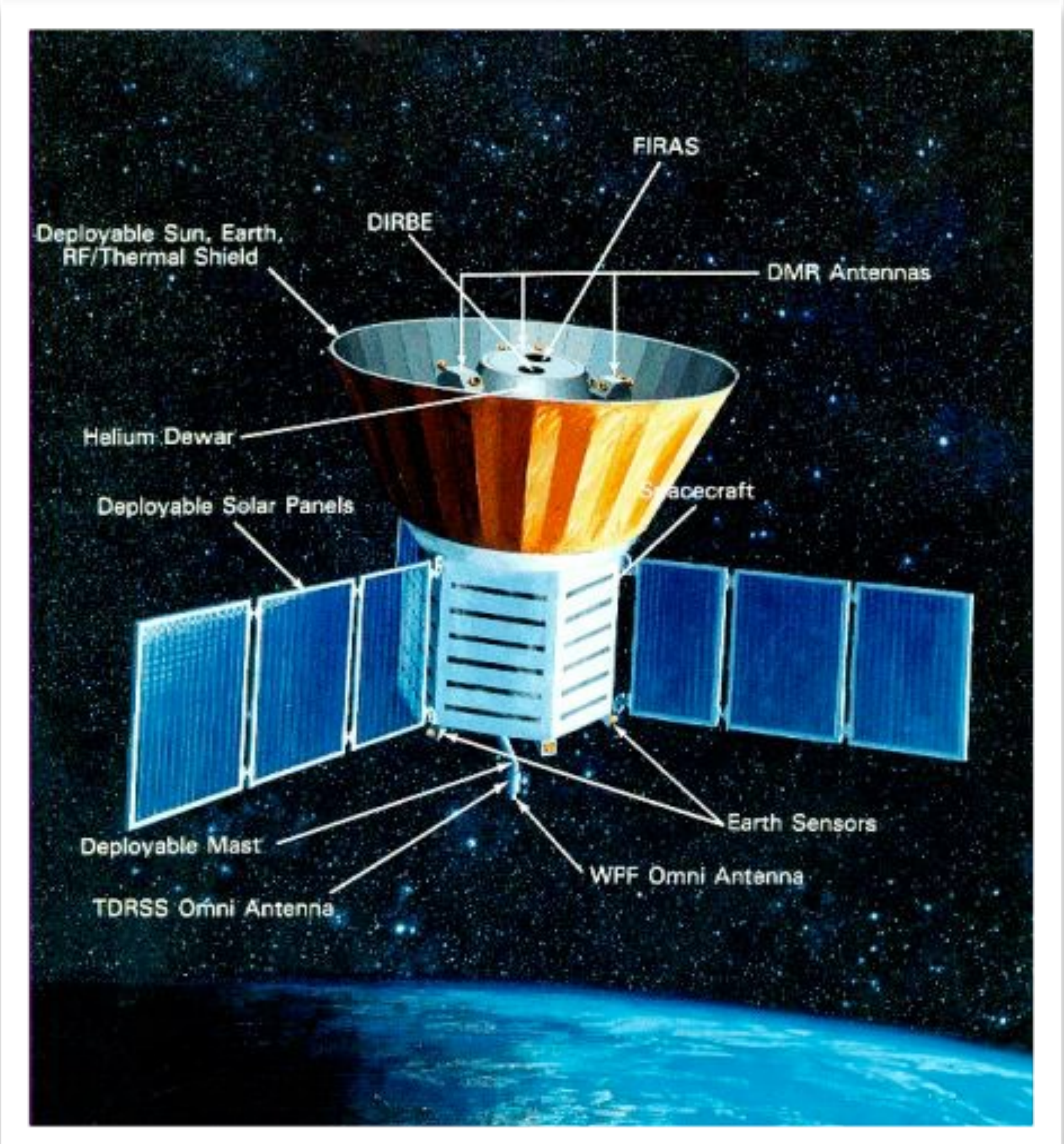


Robert Wilson Anro Penzias, 1978

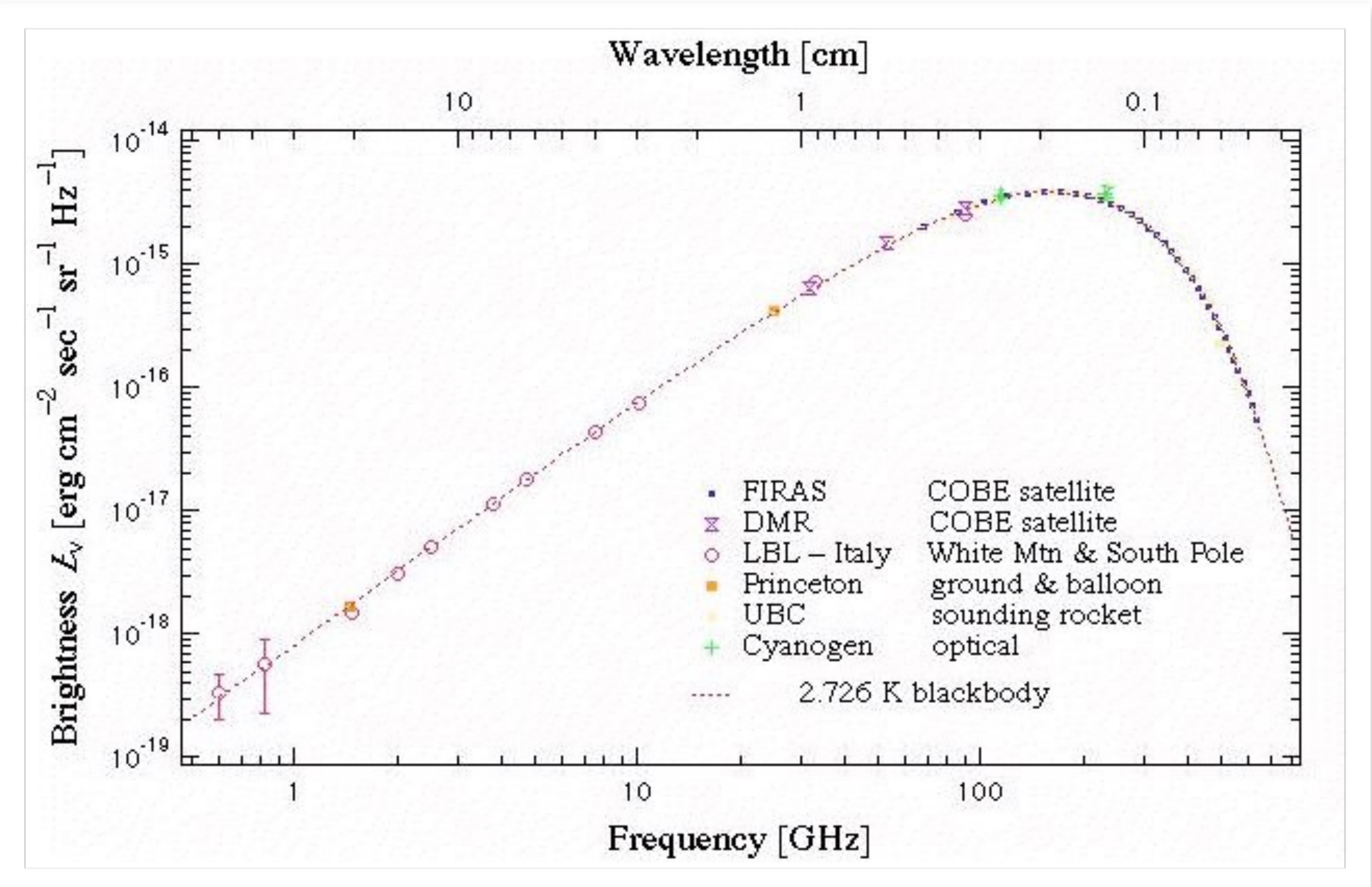
The Cosmic Background Explorer (COBE)

mission launched in 1989 to measure the CBM

COBE measured E&M radiation as a function of frequency outside of the earth's atmosphere



showing precisely the blackbody spectrum for a temperature of 2.726K



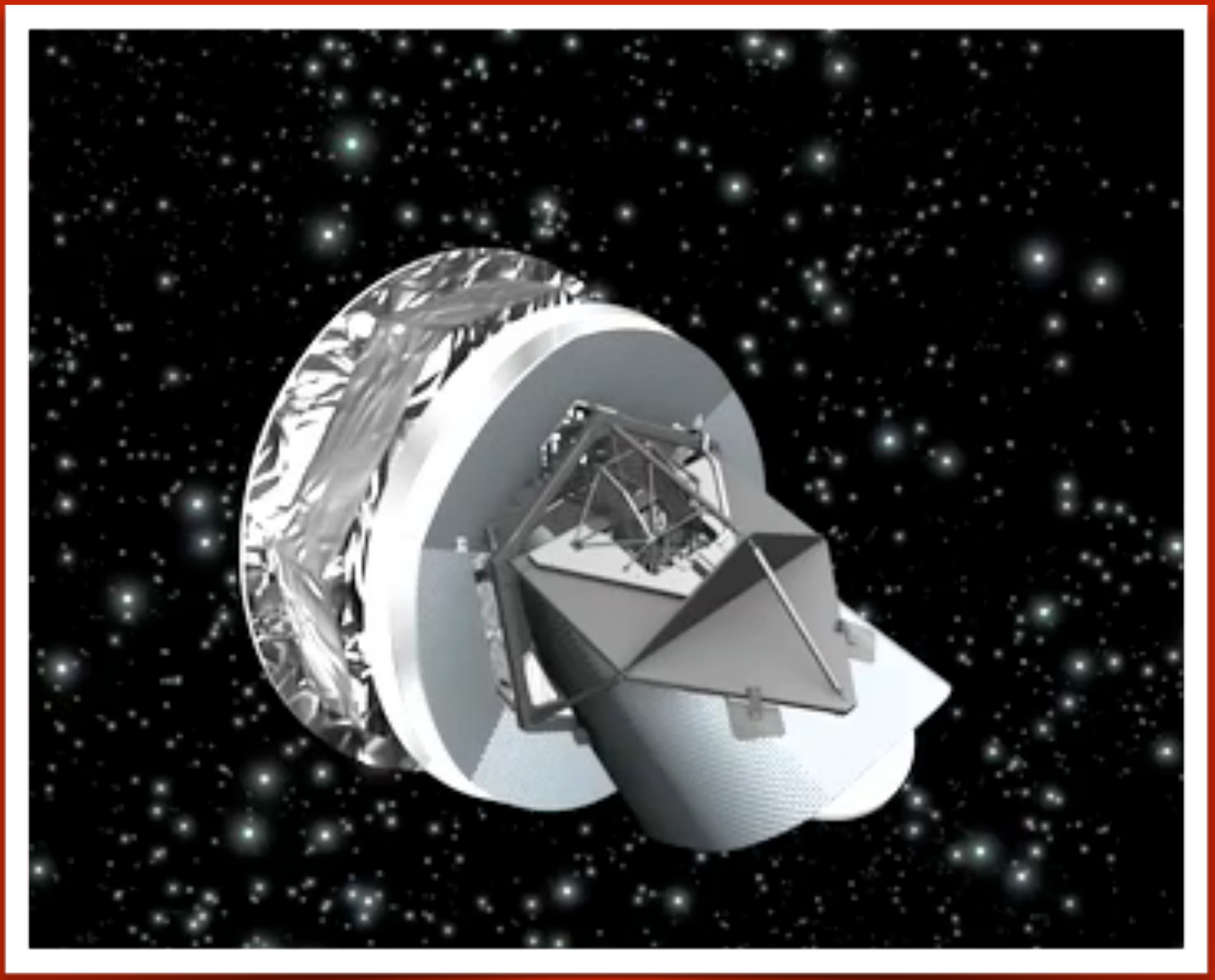
But they went further

and mapped the “sky” in various wavelengths — temperatures

and built “false-color” thermo-maps — pioneered a Method

This is the newest one, launched 2009

European Space Agency (ESA) “Planck” observatory…gives you the idea



gotten
better
and
better

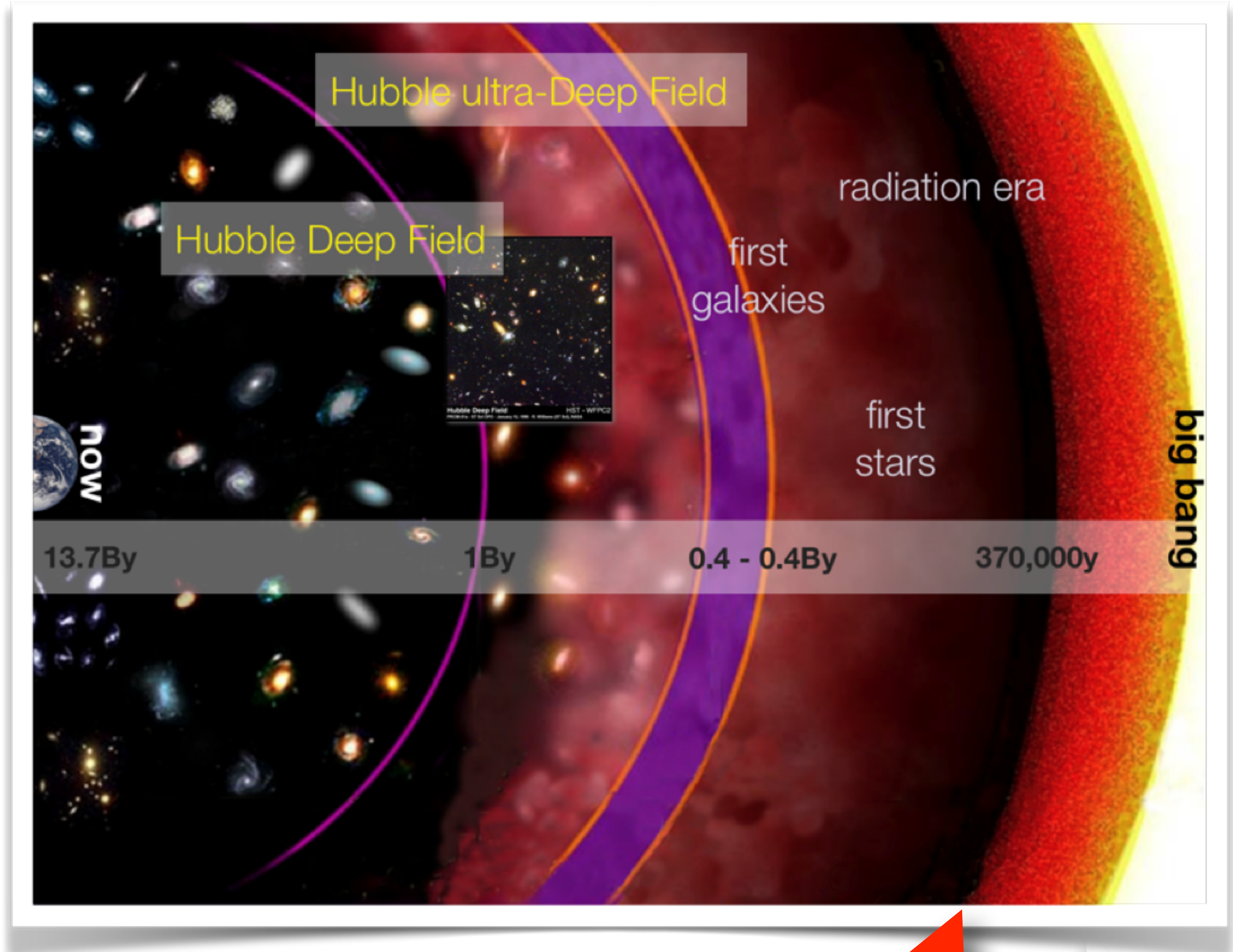
An all-sky image (like a Mercator projection) of the sky…

this is very convincing

Heck. This is amazing!

We can see the left-over, cooled radiation from the BB

everywhere in the cosmos at the same temperature



opaque

can't "see" any further back than this

now we know that the universe had a beginning

Stars are finite in number, and finite in lifetime - they have not been shining forever

you can comfirm that tonight.

the initial hot radiation...now cool and measured to be uniform

and everywhere

It’s smooth...

universe is isotropic and homogeneous

That’s good!

It’s smooth...

universe is isotropic and homogeneous

That’s bad! We’re here! Our Stuff is here!

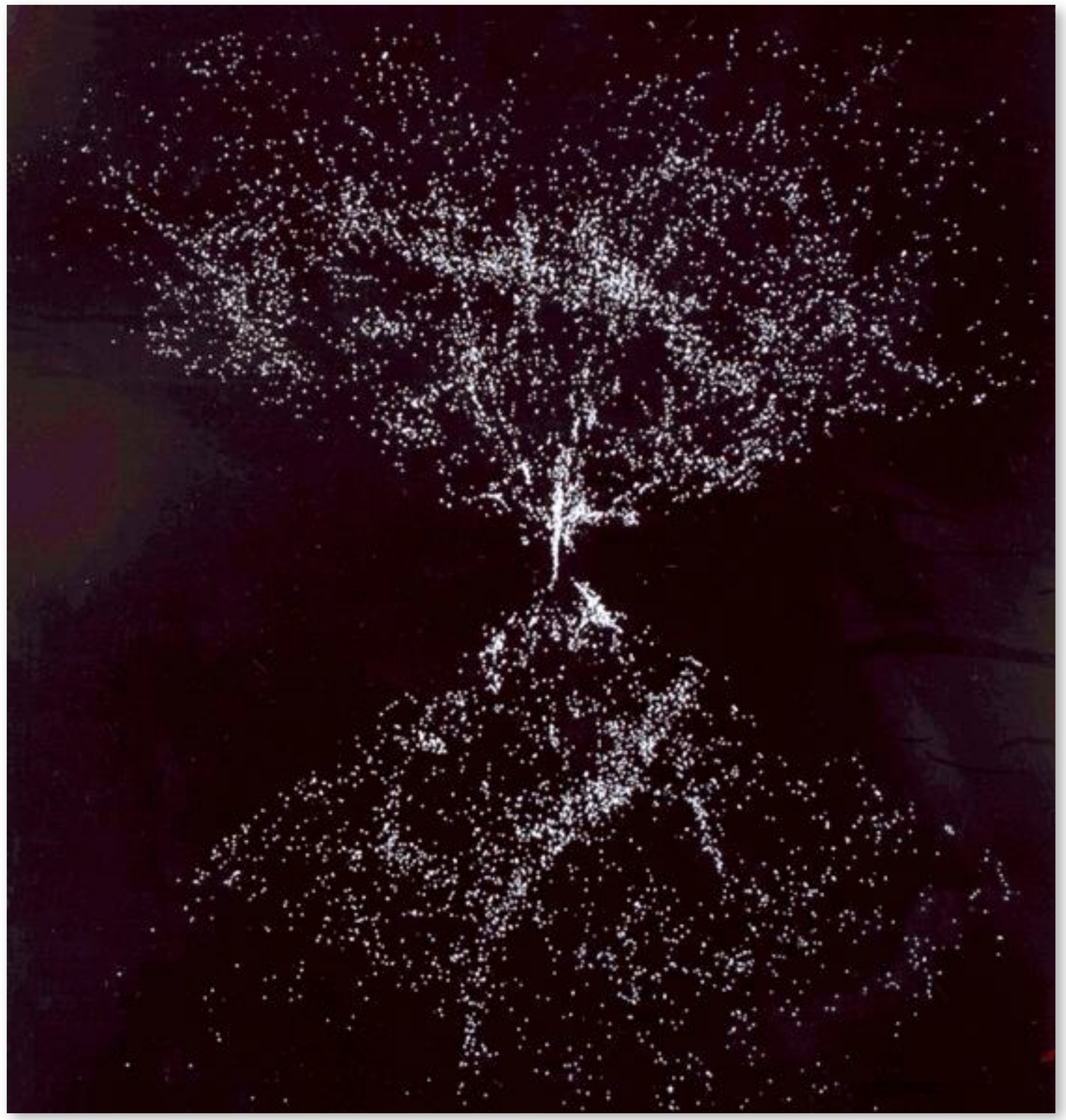
stay tuned.

There *is* structure in the universe

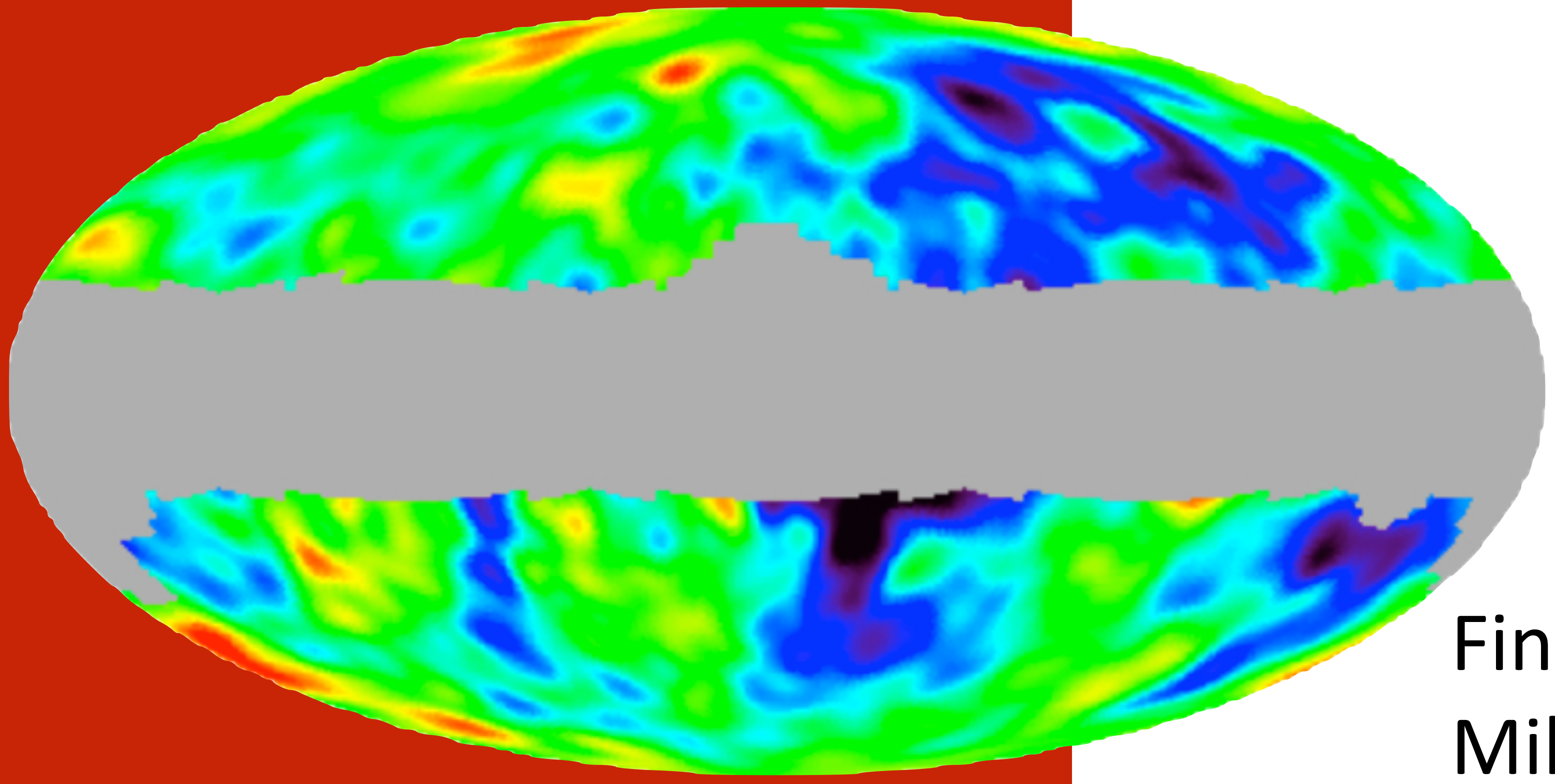
galaxies

planets

you, me



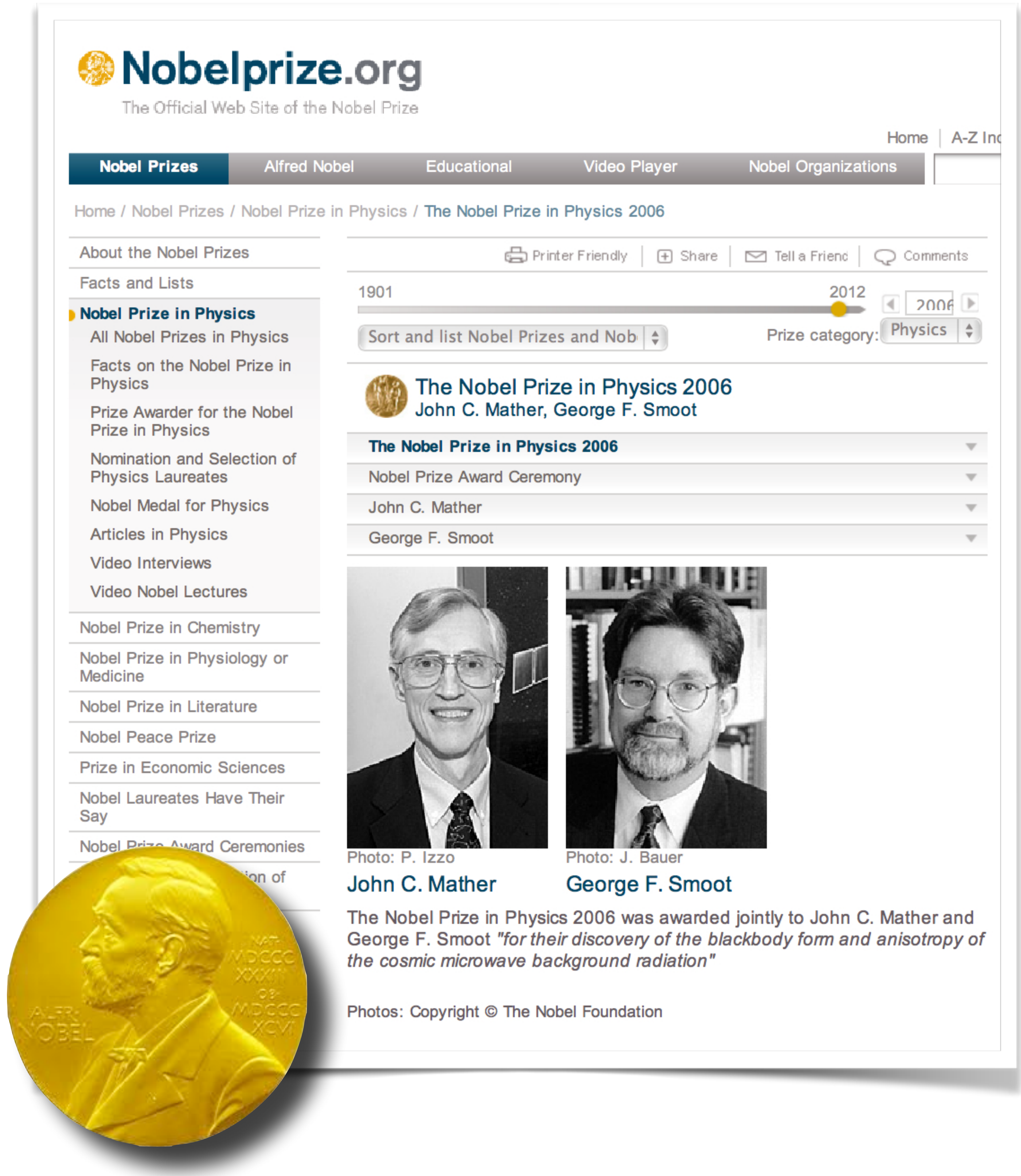
And, that's true. There is non-random structure: These filament-like strands are combinations of 11,000 galaxies (MW at the center).



Final 4 year exposure of COBE with a model of the Milky Way microwaves subtracted

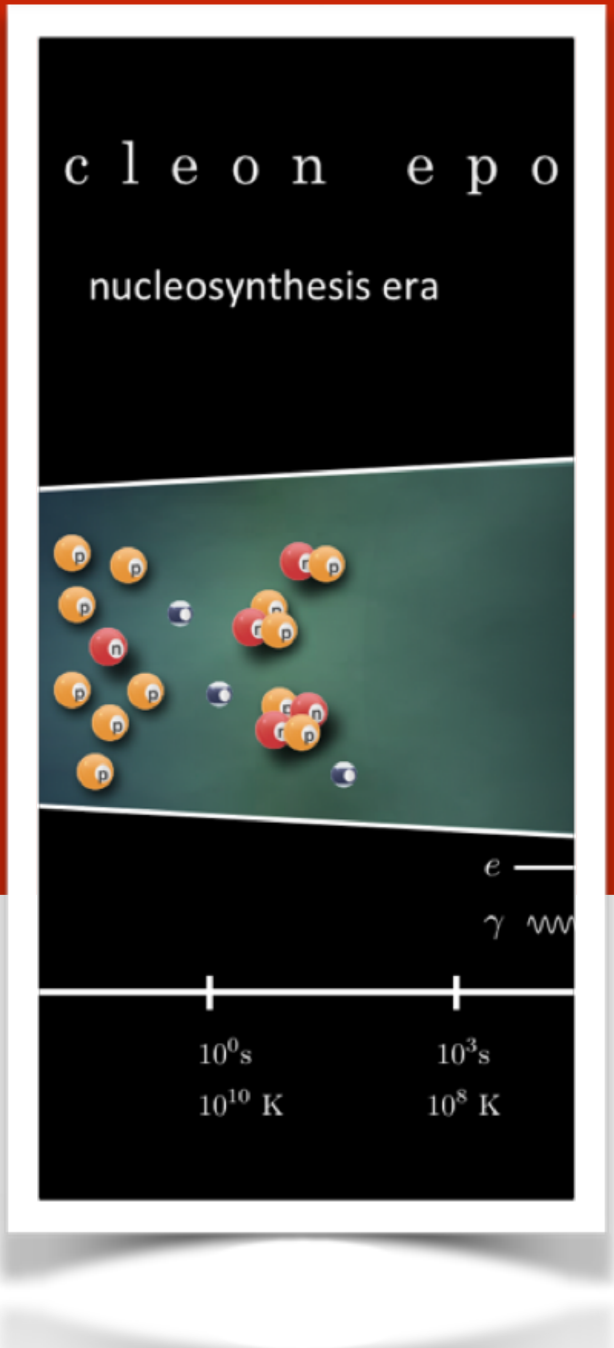
John Mather and George Smoot

COBE principals



Helium.

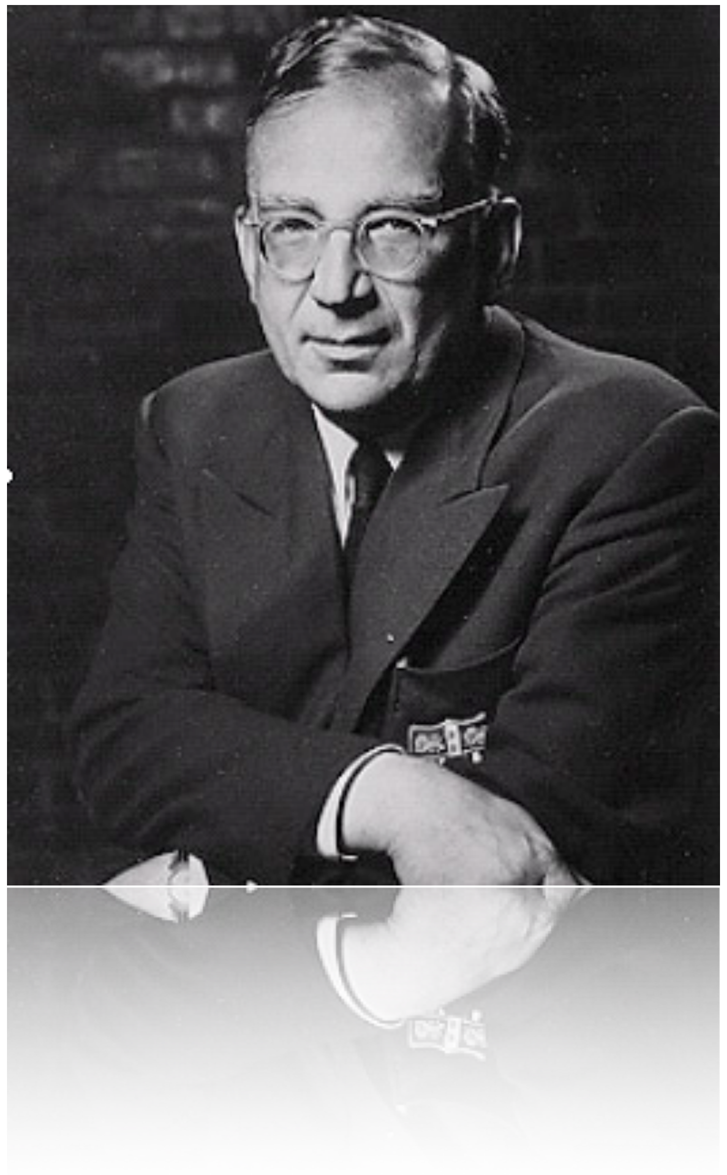
about 3 minutes after BB



George Gamow

tried to make the Big Bang make elements

failed for all but H, its isotopes, and He



Remember the isotopes:

H 1 proton

D 1 proton + 1 neutron
Deuterium

^{3}He 2 protons + 1 neutron
“Helium three”

^{4}He 2 protons + 2 neutrons
“Helium four” - regular He
very tightly bound together

‘‘primordial Helium’’ and Deuterium

Accounting for the Big Bang production of light elements by mass-fractions:

H ~ 73%

He ~ 24% → cannot have come from stars

D ~0.01% cannot have come from stars

equal in all directions

data

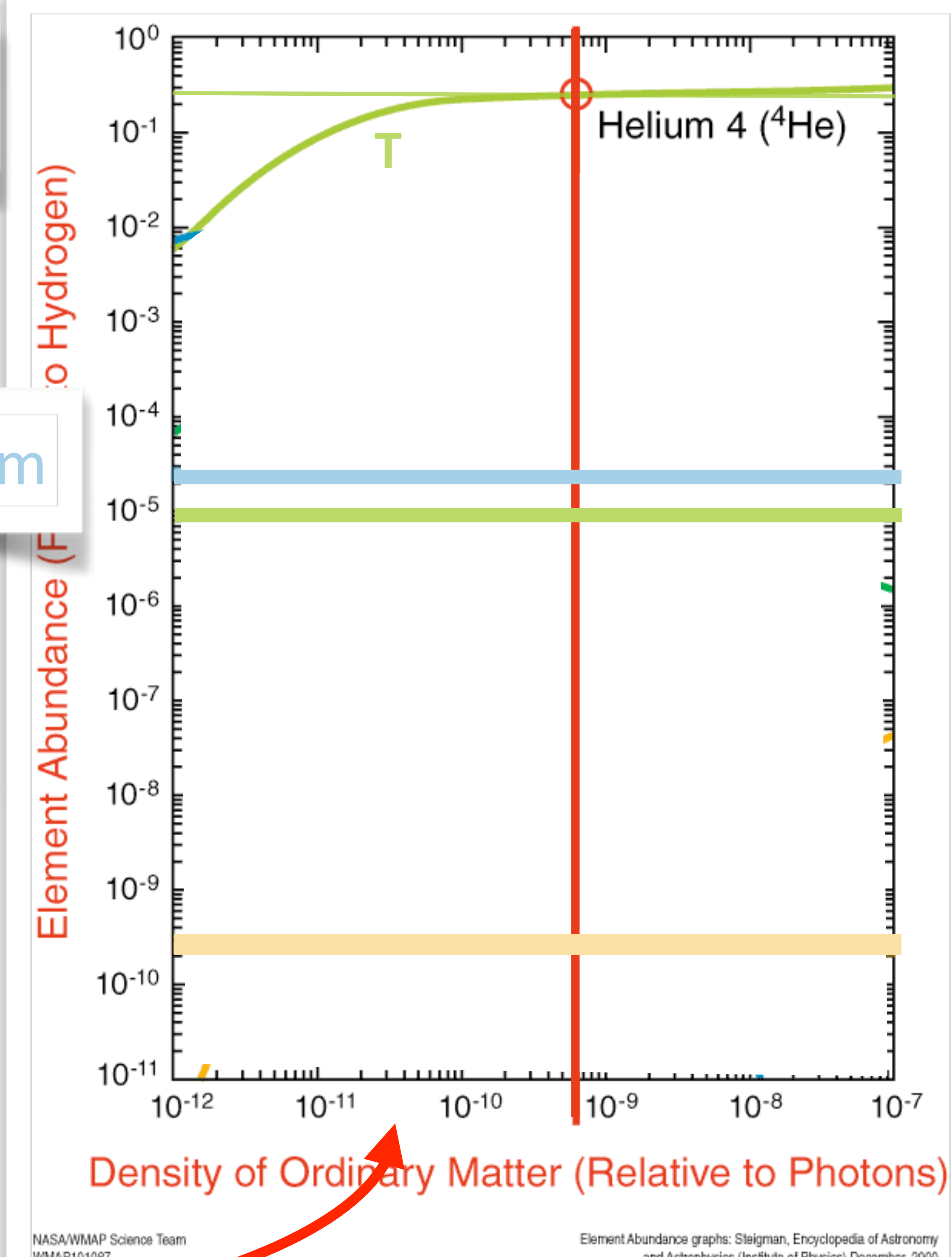
Theory Predictions

data, ^{4}He

data, Deuterium

data, ^{3}He

data, Li



essentially: $\frac{\#\ \text{baryons}}{\#\ \text{photons}}$

The Hot Big Bang Model is very highly and precisely confirmed.

From 10^{-10} seconds after the BB

our understanding of the Universe is standard physics particle: **the universe**

symbol:    $

charge: 0

mass: 6×10^{51} kg, size? ~46 BLy

spin: ?

category: the one we've got

How old is the Universe?

We're sure of that: 13.799 ±0.021 B years

How big is the Universe?

Thaaaat's a toughy: multiple answers depending on how you interpret it!

You could say "13.799 Light Years" in radius.

From this way of thinking:

How far away is the boat? OA? ...like the 13.799 B years number.

so. about the universe

How old is the universe?

We're sure of that: 13.82 ±0.050 B years

How big is the universe?

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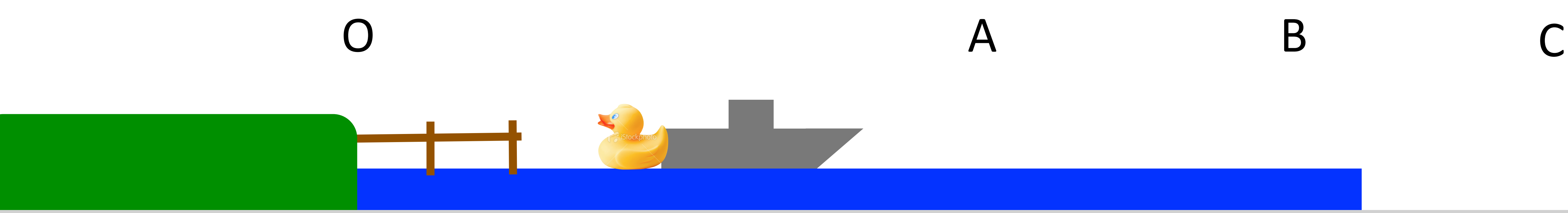

How far away is the boat? OA? ...like the 13.82 B years number.

OB? ...you know that the boat is at B when ducky comes home.

so. about the universe

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We’re sure of that: 13.799 ±0.050 B years

How big is the universe?

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From this way of thinking:

How far away is the boat? OA? ...like the 13.82 B years number.

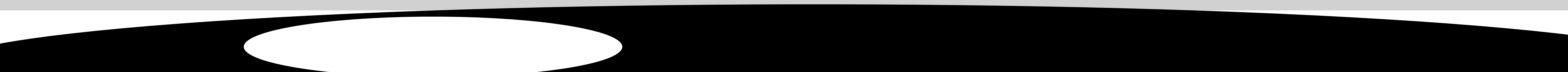
OB? ...you know that the boat is at B when ducky comes home.

If the ocean stretches over time...you might even say that it’s OC away.

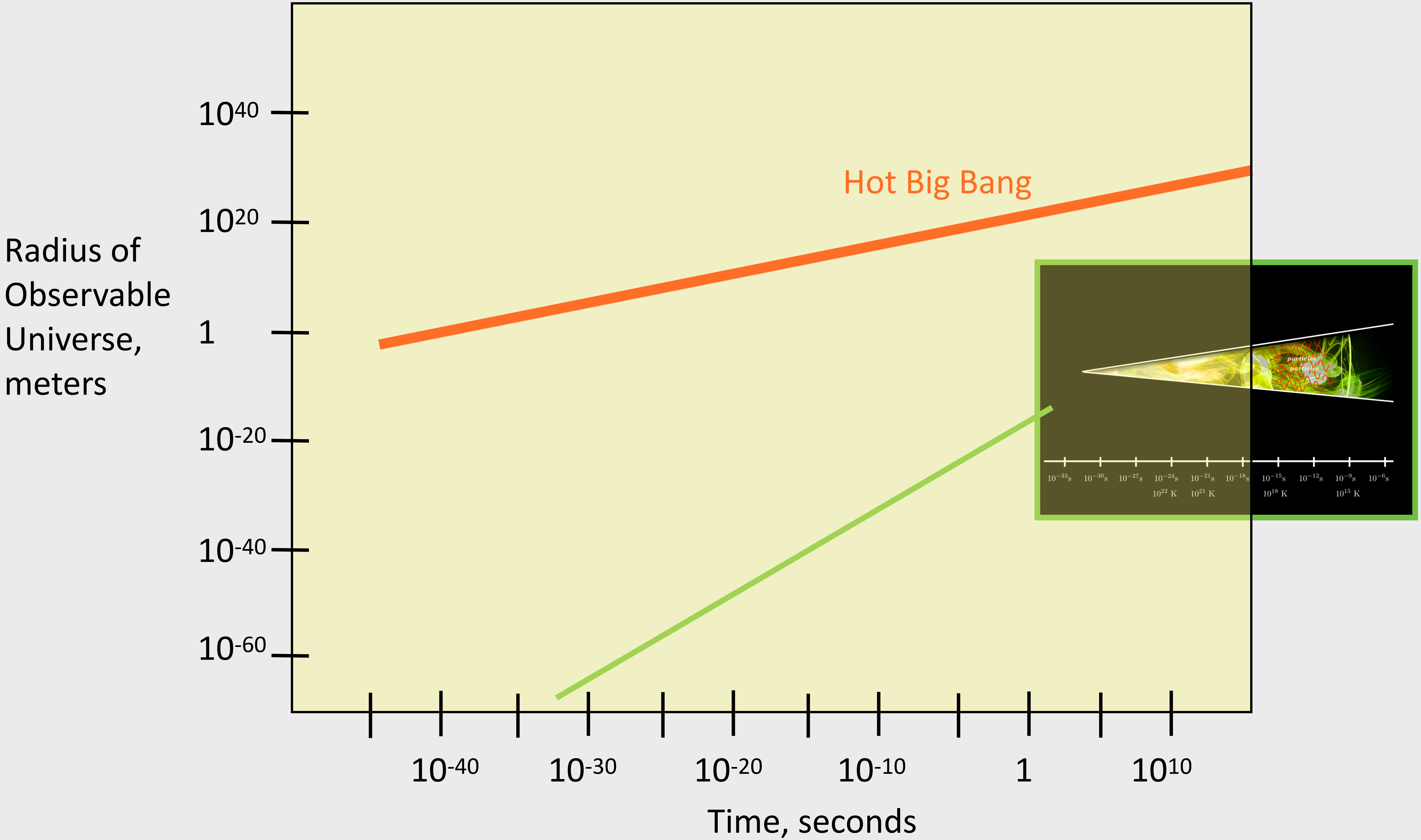
In these “co-moving coordinates”...the universe is about 46 BLy big.

I tend towards this one.

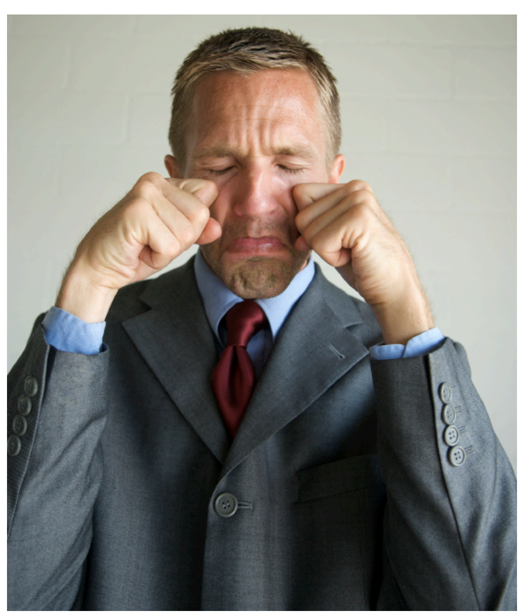
our observable patch might be only a small part of a larger universe



Size of the Observable Universe?



4 problems



1. The Horizon Problem (or: Smoothness Problem)

2. The Flatness Problem (or: Fine Tuning Problem ~ the Age problem)

3. The Structure Problem

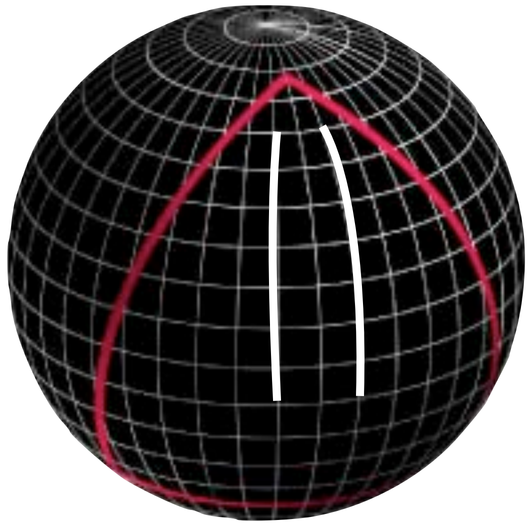
4. The Antimatter Problem (or the Baryon Problem)

want to know the curvature of the Universe

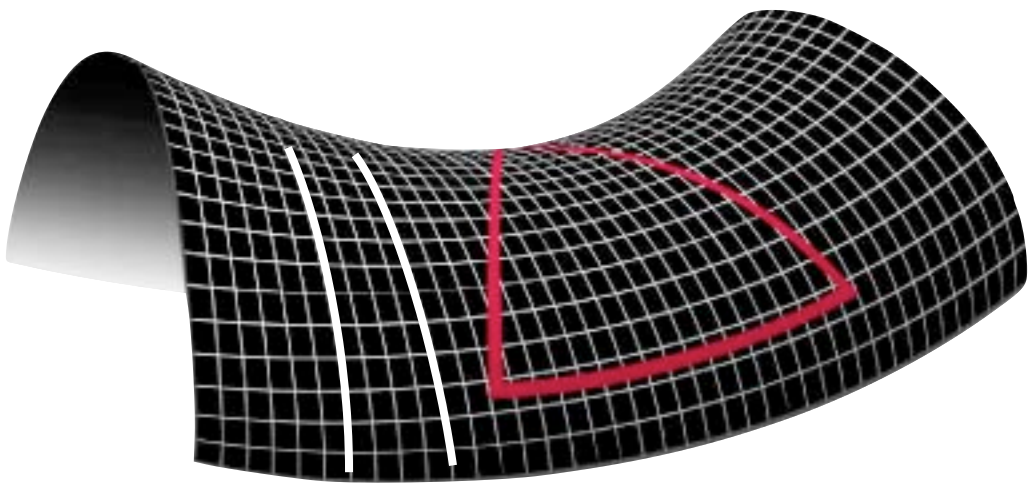
linked to the fate of the Universe

as well as its origins

curvature, “k” – hypervolumes

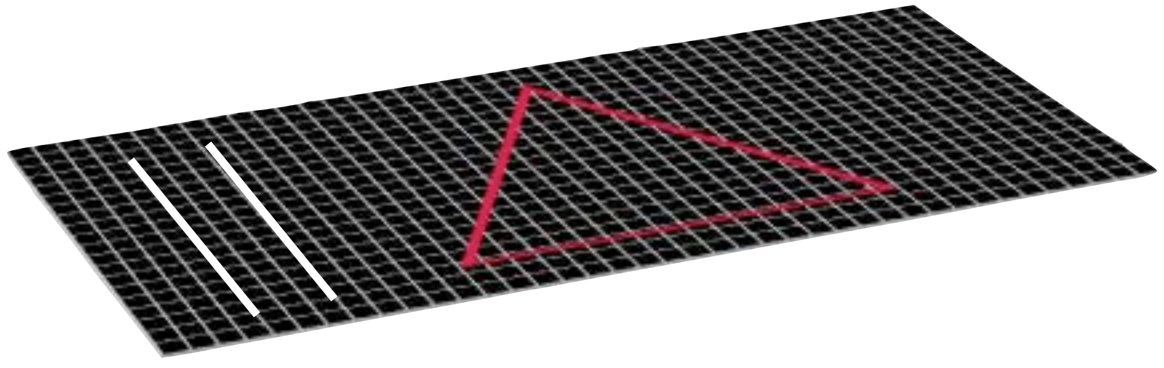


$k = +1$,
positive curvature
finite, unbounded



$k = -1$, negative
curvature
infinite, unbounded

$k = 0$, no curvature
infinite, unbounded



These 3 are the only geometries that can be homogeneous and isotropic

curvature of the universe

will be formed by the distribution of mass, energy, and pressure

curvature, k

would depend on:

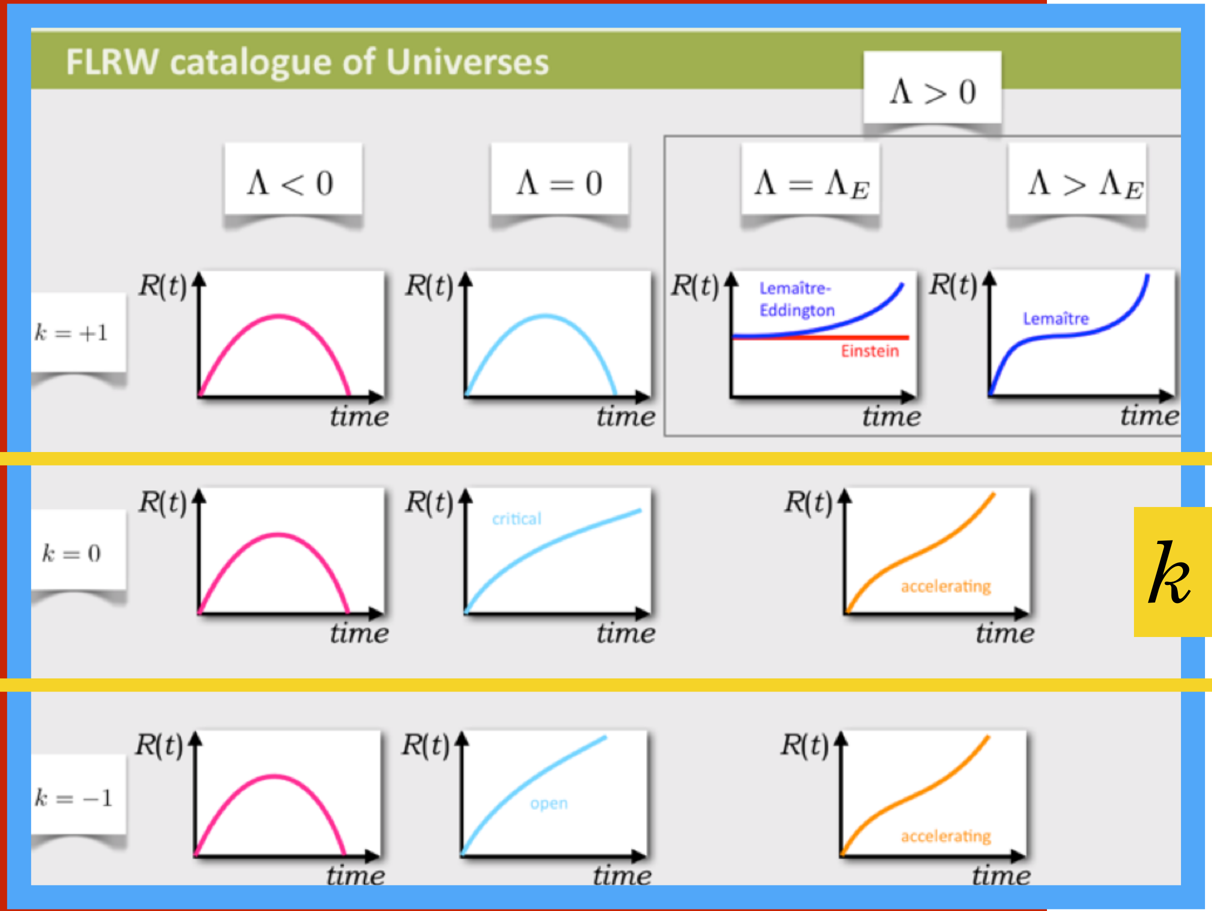
Hubble Constant, H

Mass density, ρ

Like Goldilocks:

if H and ρ are just right...

the universe will be flat



$k = 0$ ....would mean flat.

from Friedman Equation

gathering constants...

define the "density parameter:

$$\boxed{\Omega_m(t) = \frac{\rho}{\rho_c}}$$ Density parameter for matter

ρ_c "Critical density" for FLAT

$\rho_c \sim 10^{-26}\ \mathrm{kg\ m^{-3}}$

about 5 Hydrogen atoms/m^3

$$k = CH^2(\Omega_m - 1)$$

Want flat? $k = 0$

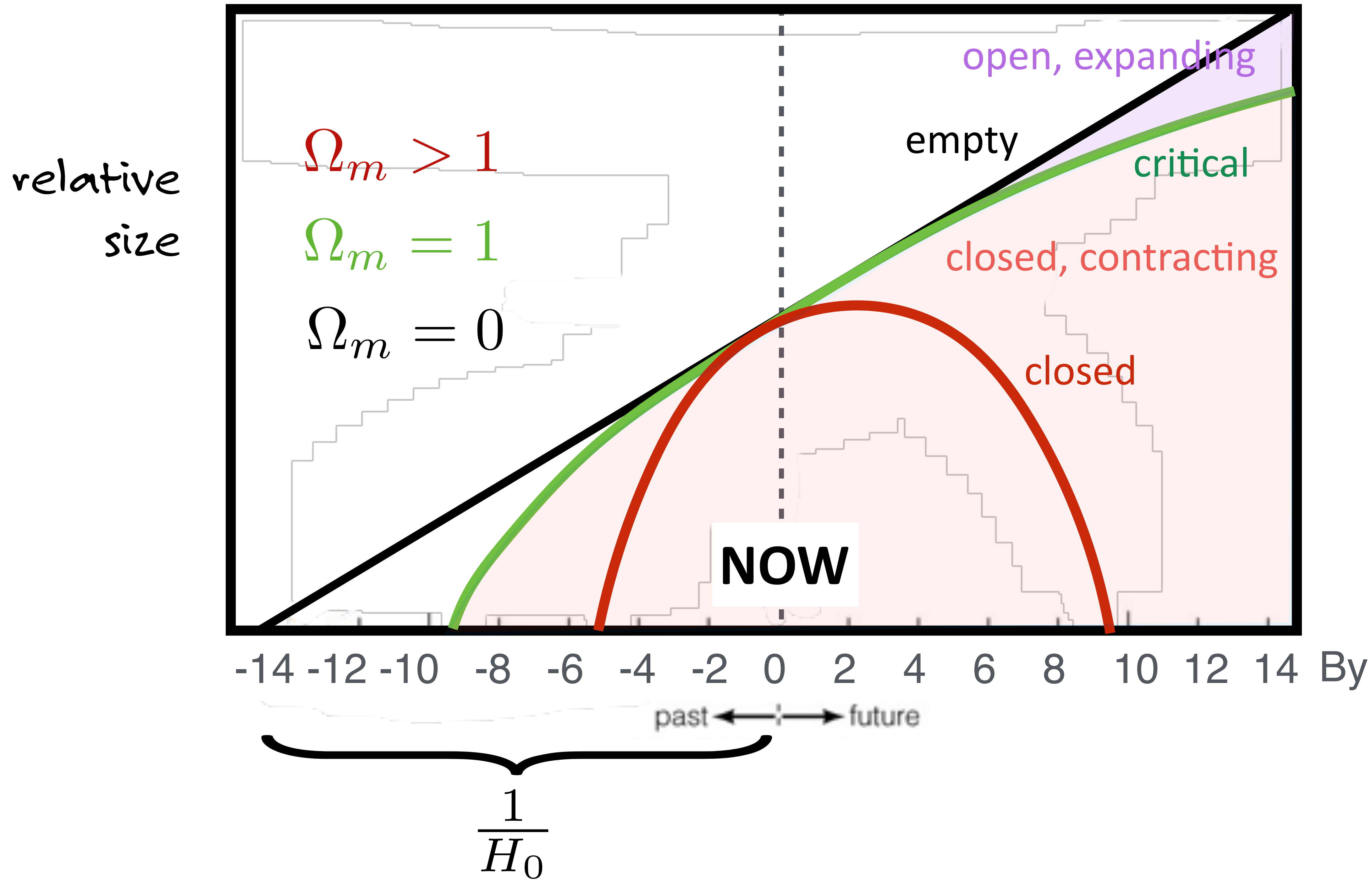
$\Omega_m(t) = 1$ is the boundary between flat and either closed or open geometries.

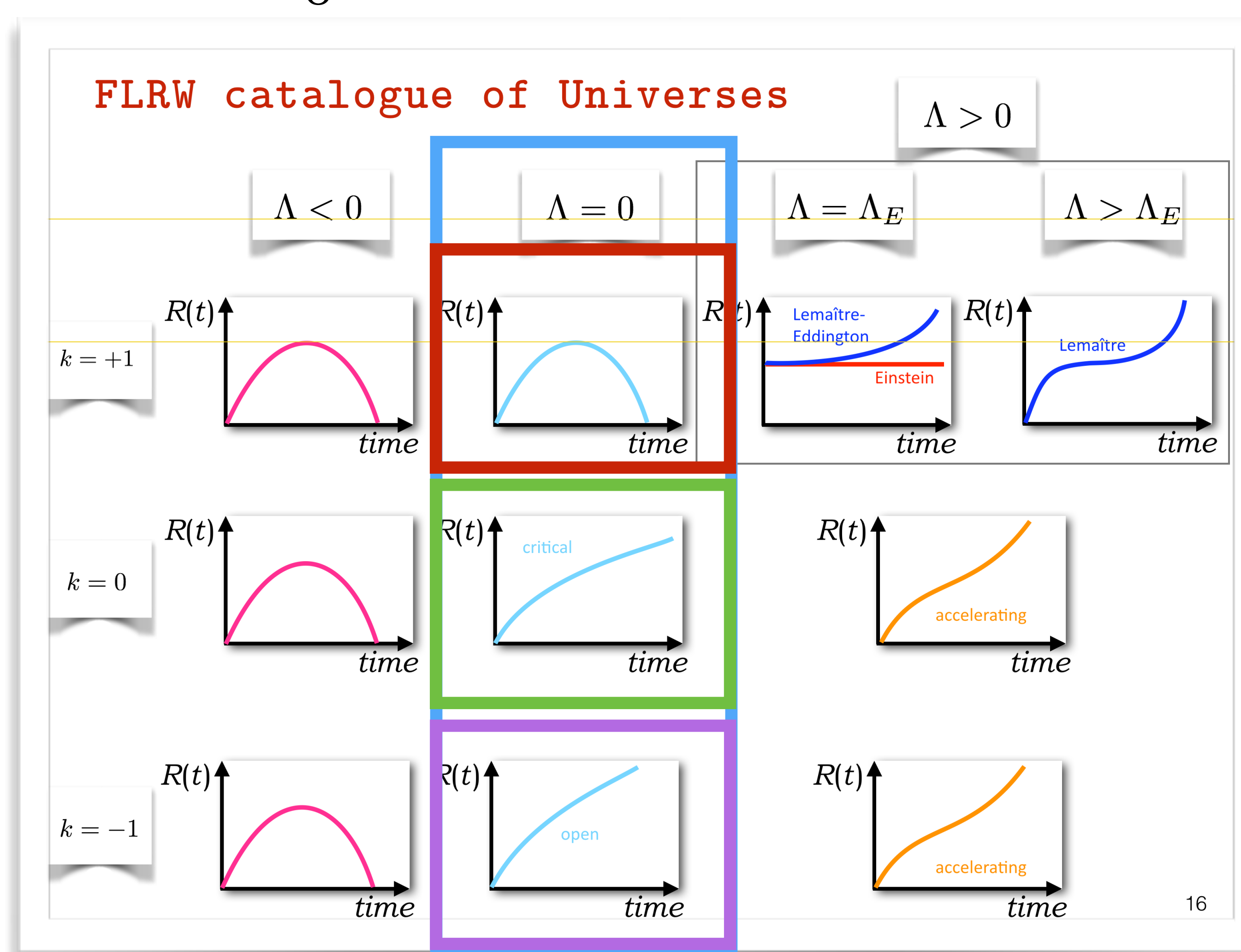
Competition

$$k = CH^2(\Omega_m - 1)$$

Between expansion (Hubble Parameter)

Gravitation (Density)





what can be measured?

many quantities

1. **Hubble Constant**
   from velocities of far-away galaxies

2. **large-scale densities**
   motions of galaxies
   the Cosmic Microwave Background, CMB

3. **“baryon densities”**
   survey of stuff that shines...mostly Hydrogen
   from the CMB

problem #1

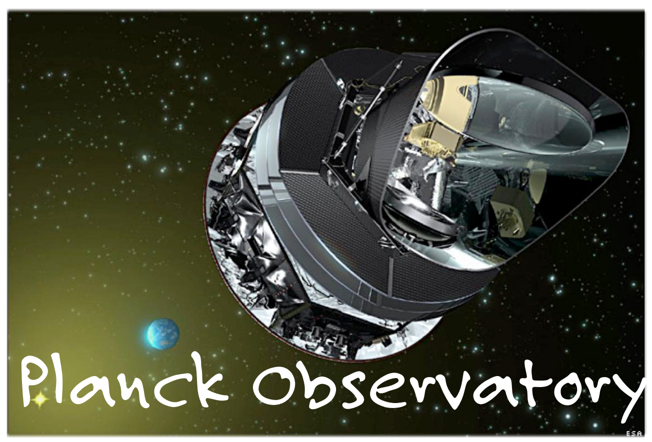
the flatness problem.

the master formula relating curvature to "stuff" $k = CH^2(\Omega_m - 1)$

closed

flat which implies $k =$ so: $\Omega_m(t)$ better be $=$

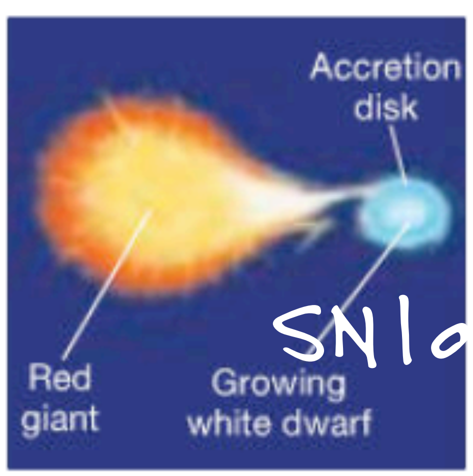
open



$\Omega_m(t) =$ so $k =$ >0 / 0 / <0 which implies closed / flat / open

$\Omega_{\rm DM}(t) =$ $\Omega_{\rm b}(t) =$

$(\Omega_{\rm b} + \Omega_{\rm DM} =$ $)$

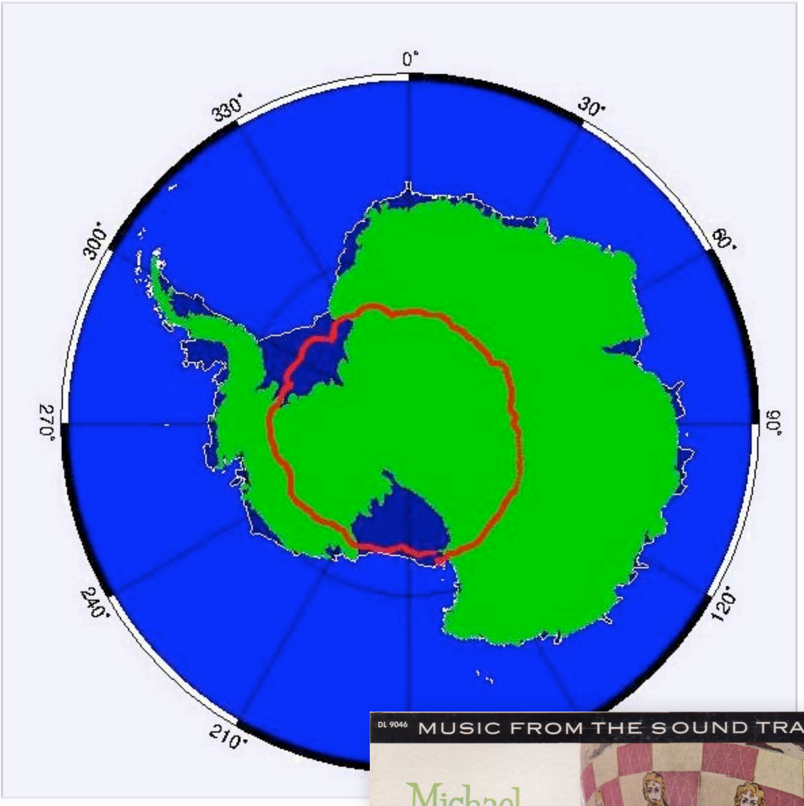


$\Omega_\Lambda(t) =$

---

now: $(\Omega_m + \Omega_\Lambda - 1) =$ which implies closed / flat / open

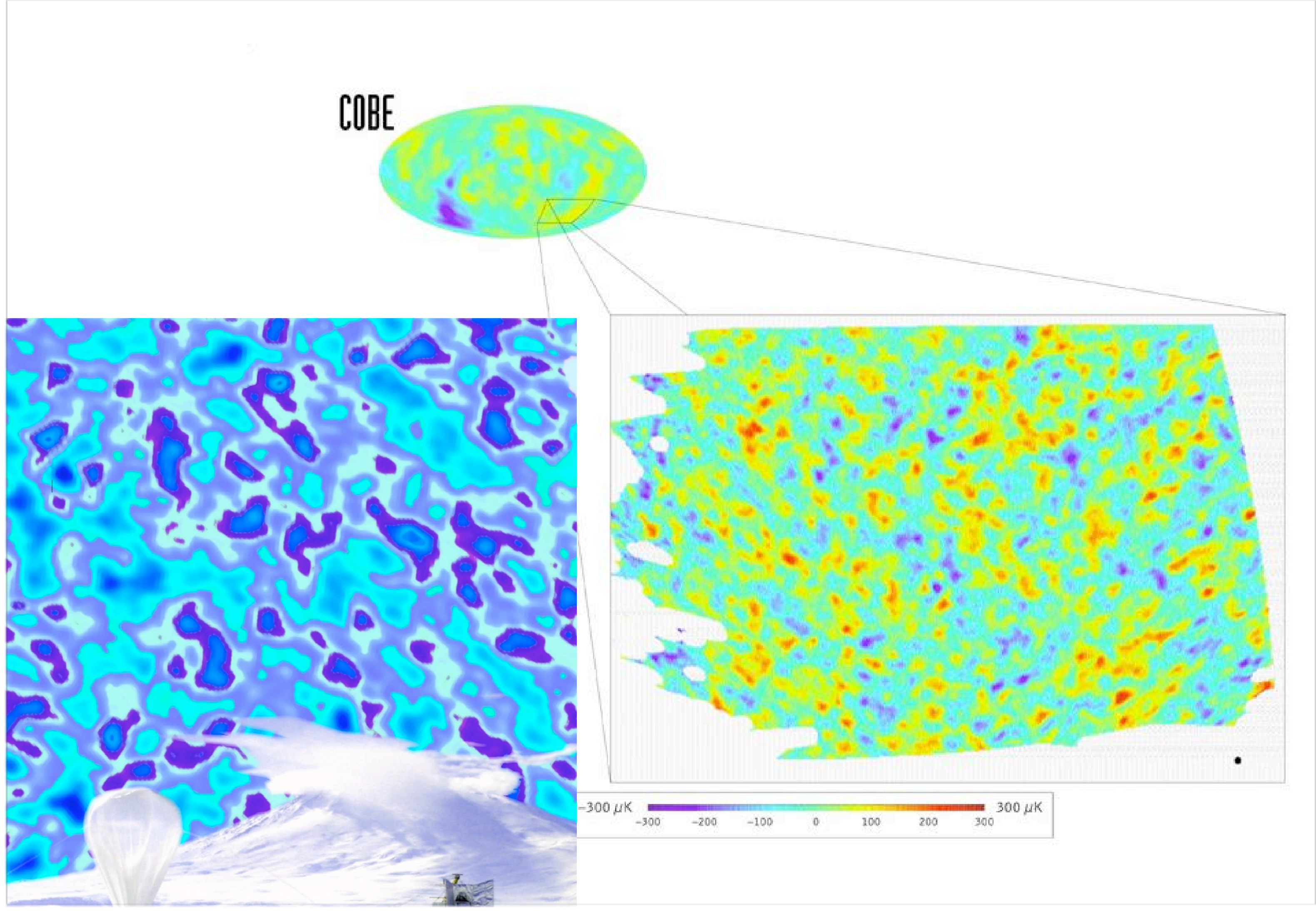
CMB, 1997-2003



Around the world in 7-10 days...from Antarctica

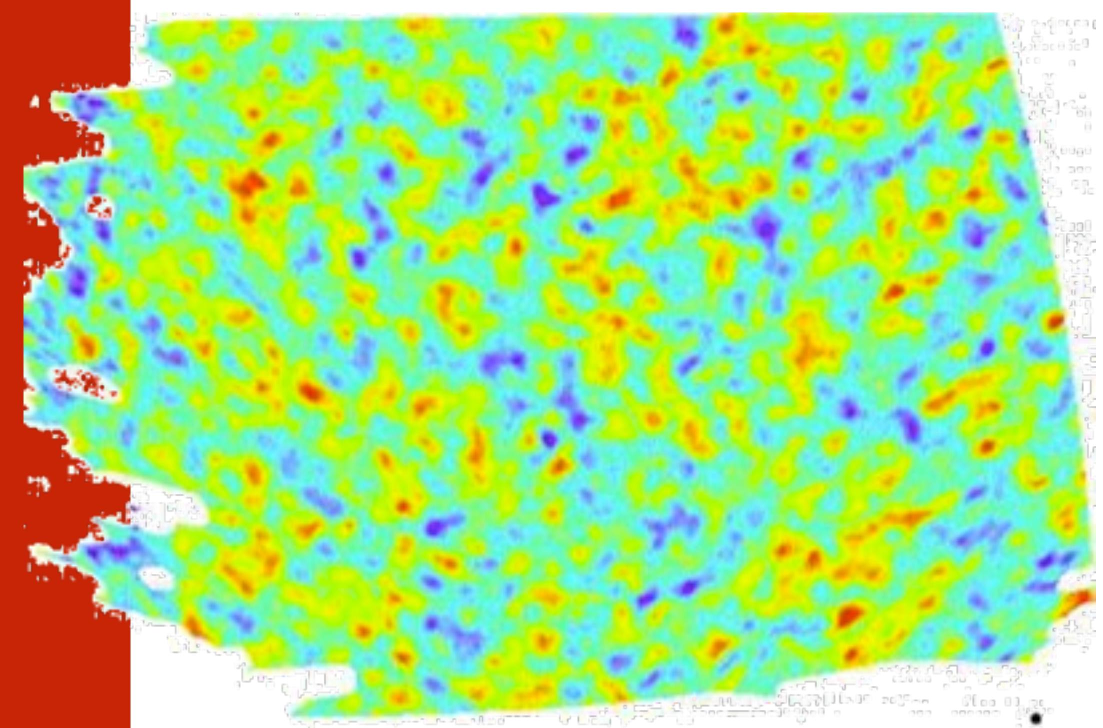
Balloon **O**bservations **O**f **M**illimetric **E**xtragalactic **R**adiation **AN**isotropy and **G**eophysics...

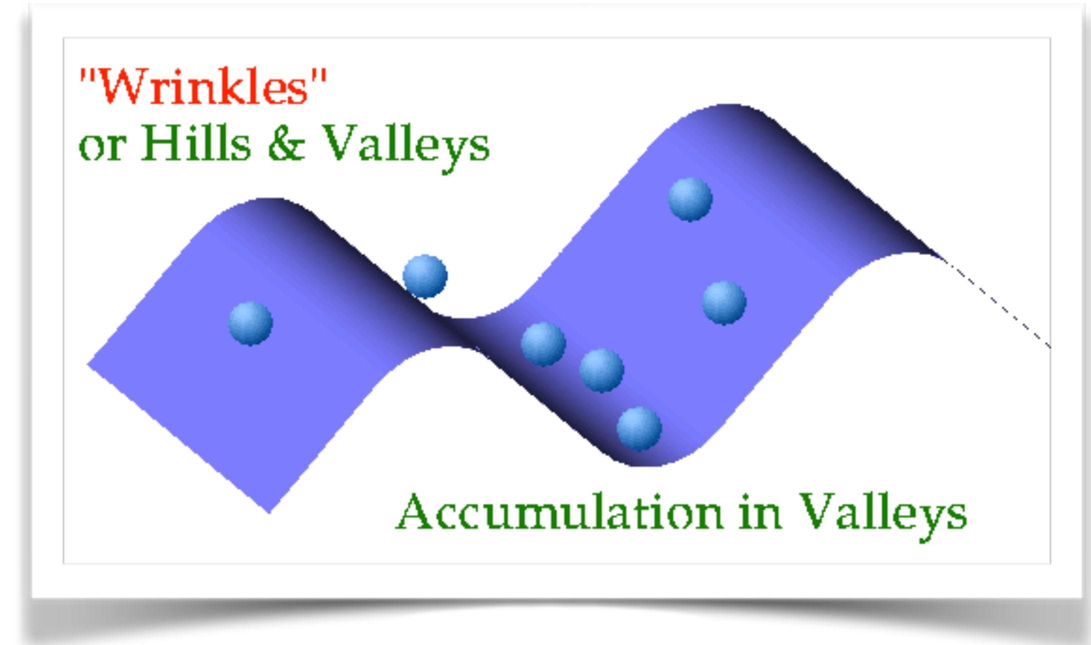
BOOMERANG



could distinguish about 0.3°

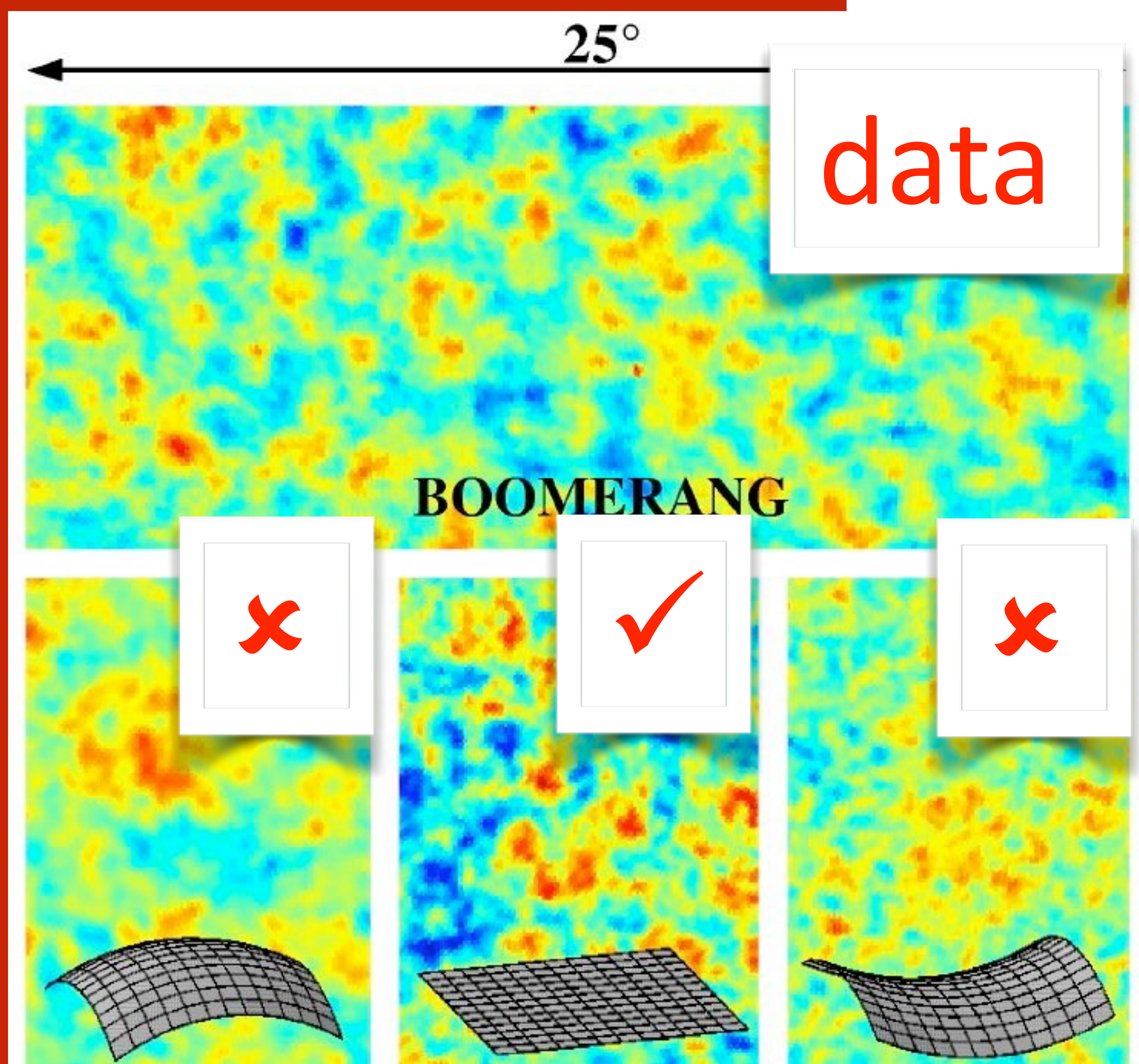
the temperature fluctutation pattern is a measurement of curvature

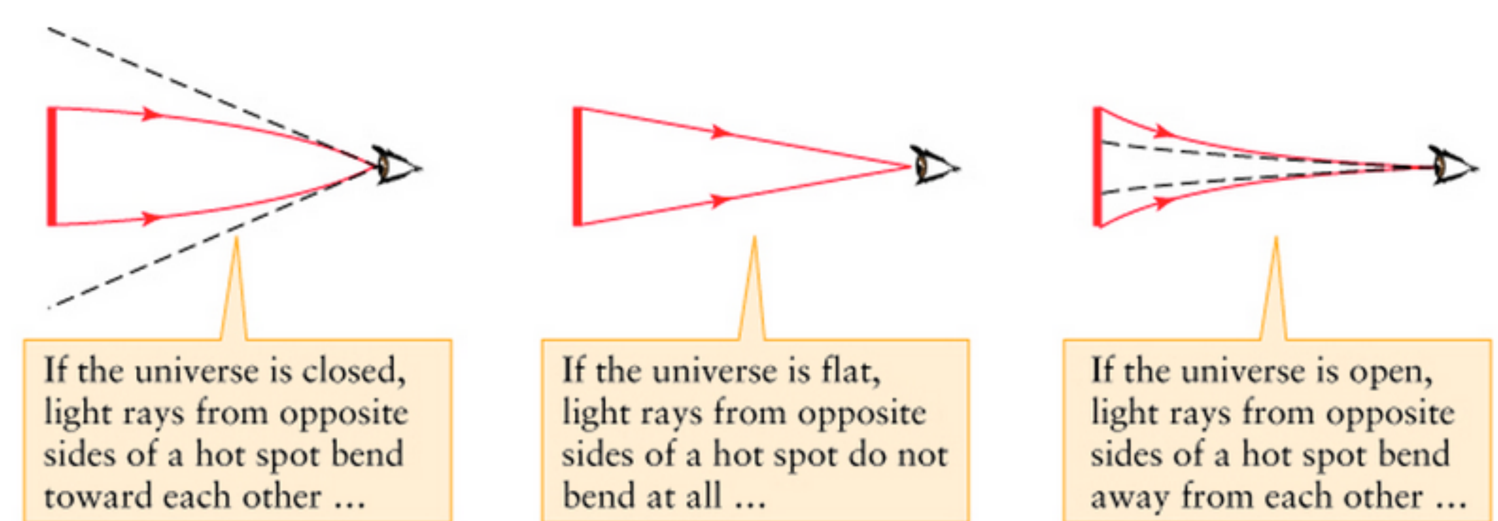




“high” temperature means high density regions
“low” temperature means low density regions

Red = Hotter than average by 300 microKelvin.
Blue = Cooler than average by 300 microKelvin.

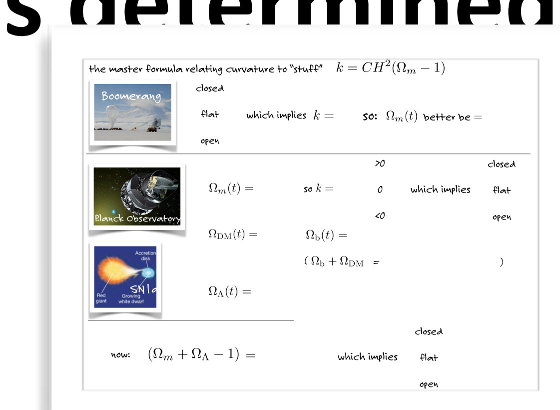




Can be modeled for that moment of last scattering...

The result? **A flat geometry was determined,**

So we’d better have: $\Omega_m(t) = 1$



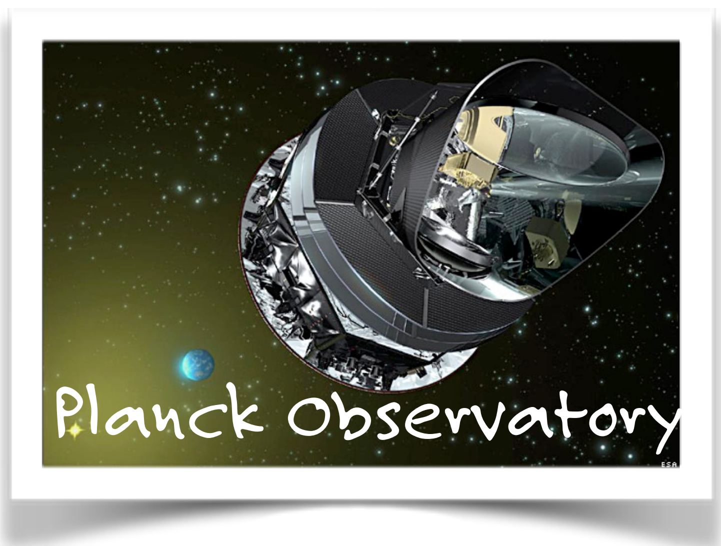
the master formula relating curvature to "stuff" $k = CH^2(\Omega_m - 1)$

closed

flat

open

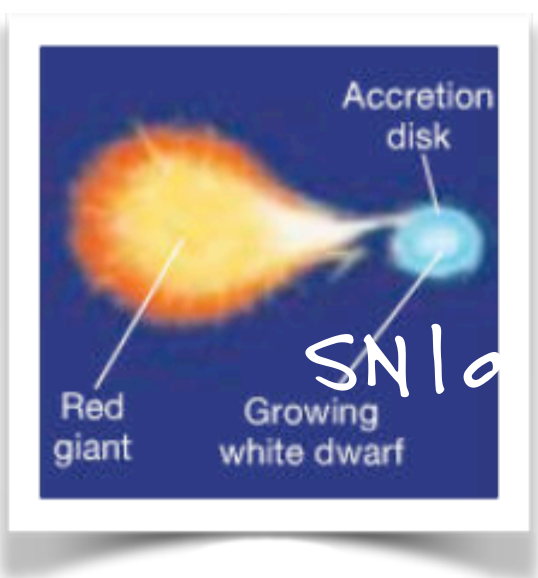
which implies $k = 0$ so: $\Omega_m(t)$ better be $= 1$



$\Omega_m(t) =$ so $k =$ >0 / 0 / <0 which implies closed / flat / open

$\Omega_{\mathrm{DM}}(t) =$ $\Omega_{\mathrm{b}}(t) =$

$(\Omega_{\mathrm{b}} + \Omega_{\mathrm{DM}} = \quad)$

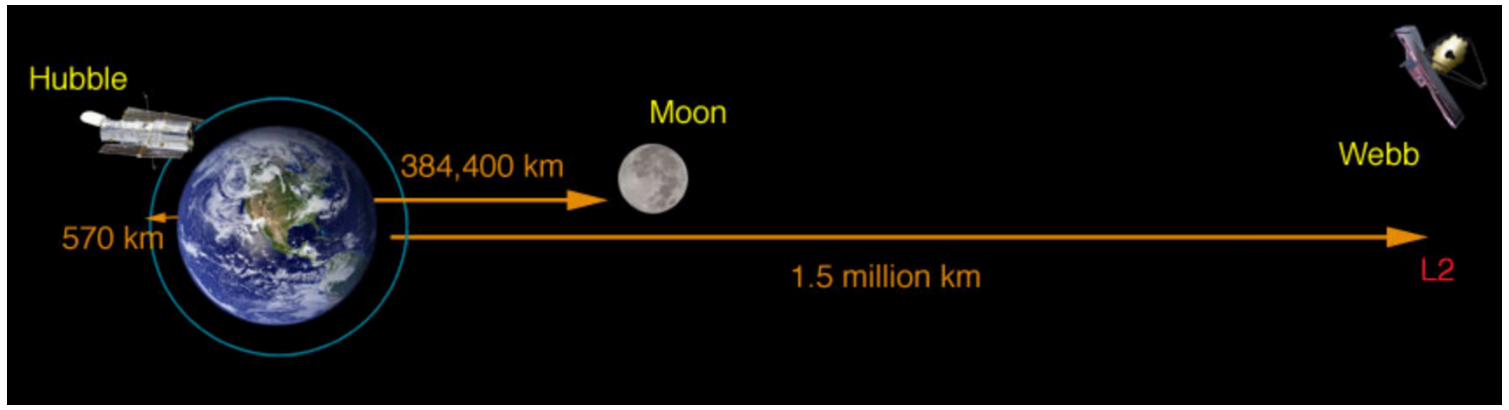


$\Omega_\Lambda(t) =$

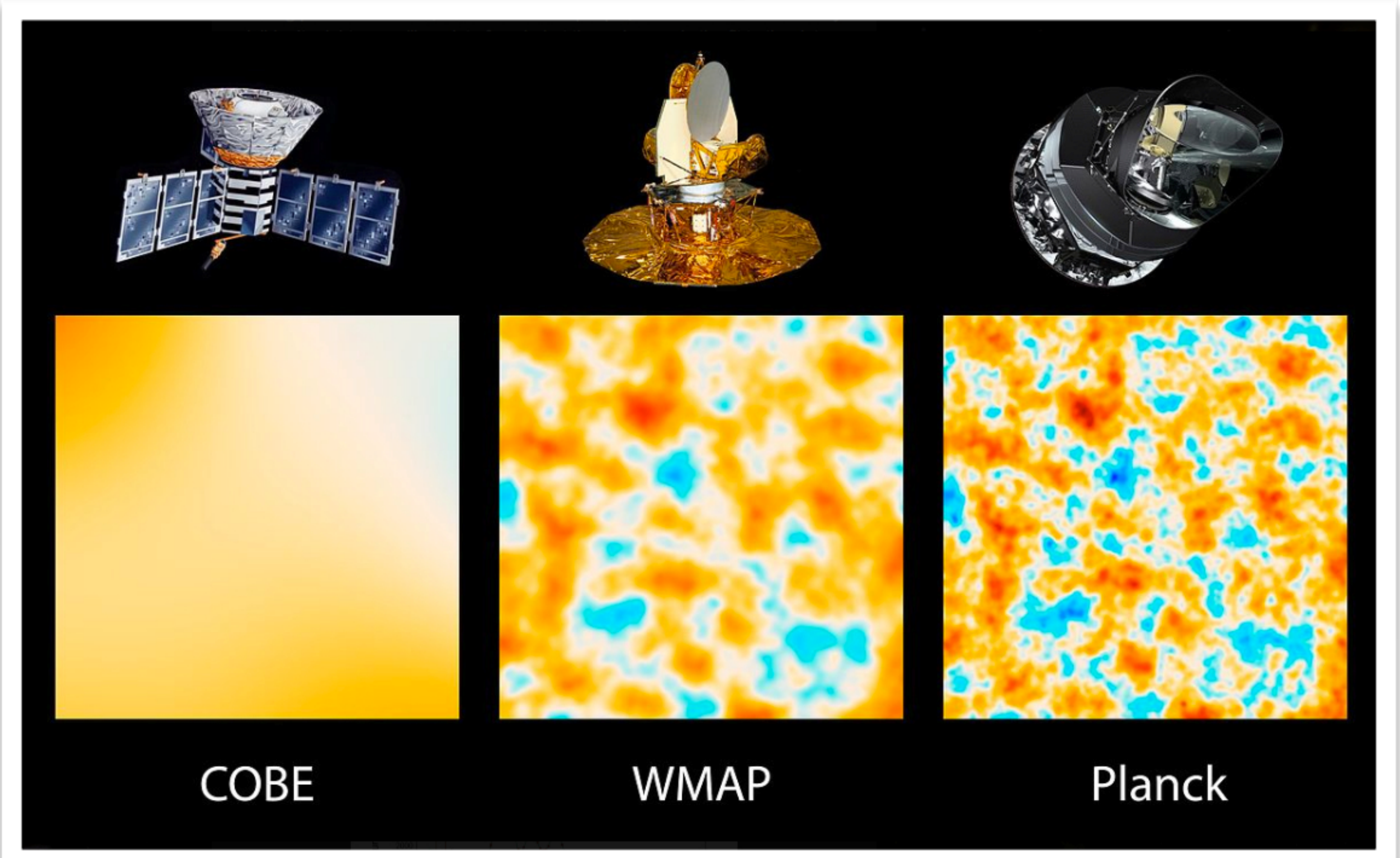
now: $(\Omega_m + \Omega_\Lambda - 1) =$ which implies closed / flat / open

This measurement has evolved

Cosmology is actually now a precision science.

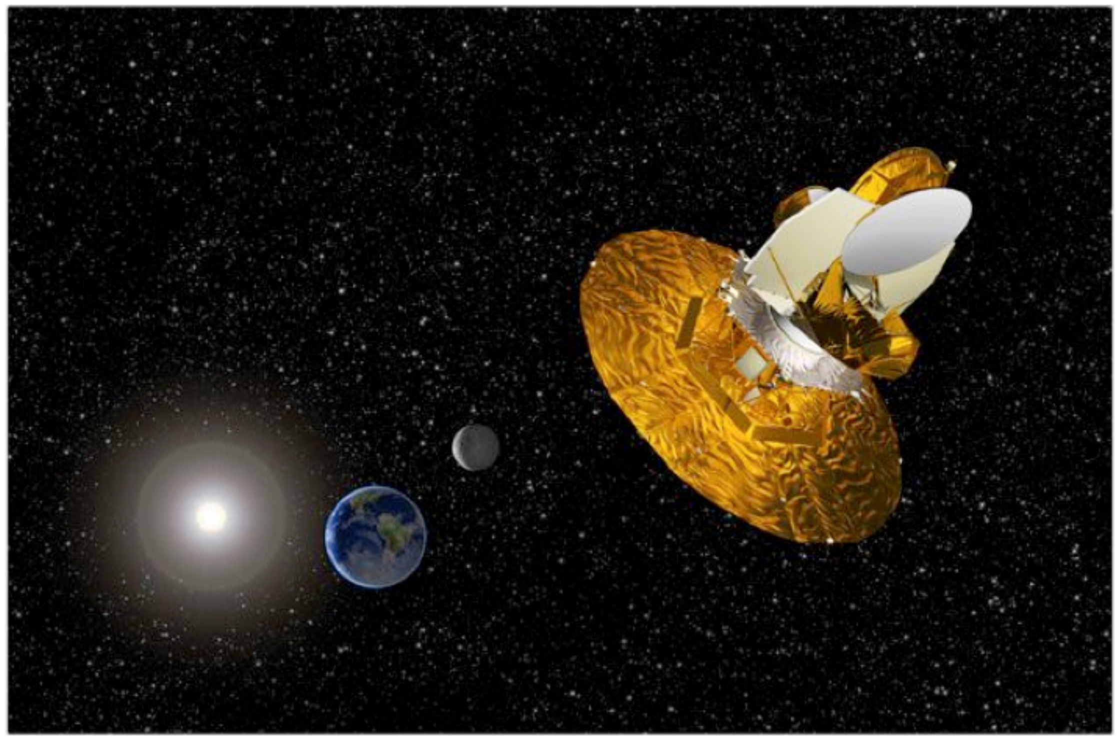


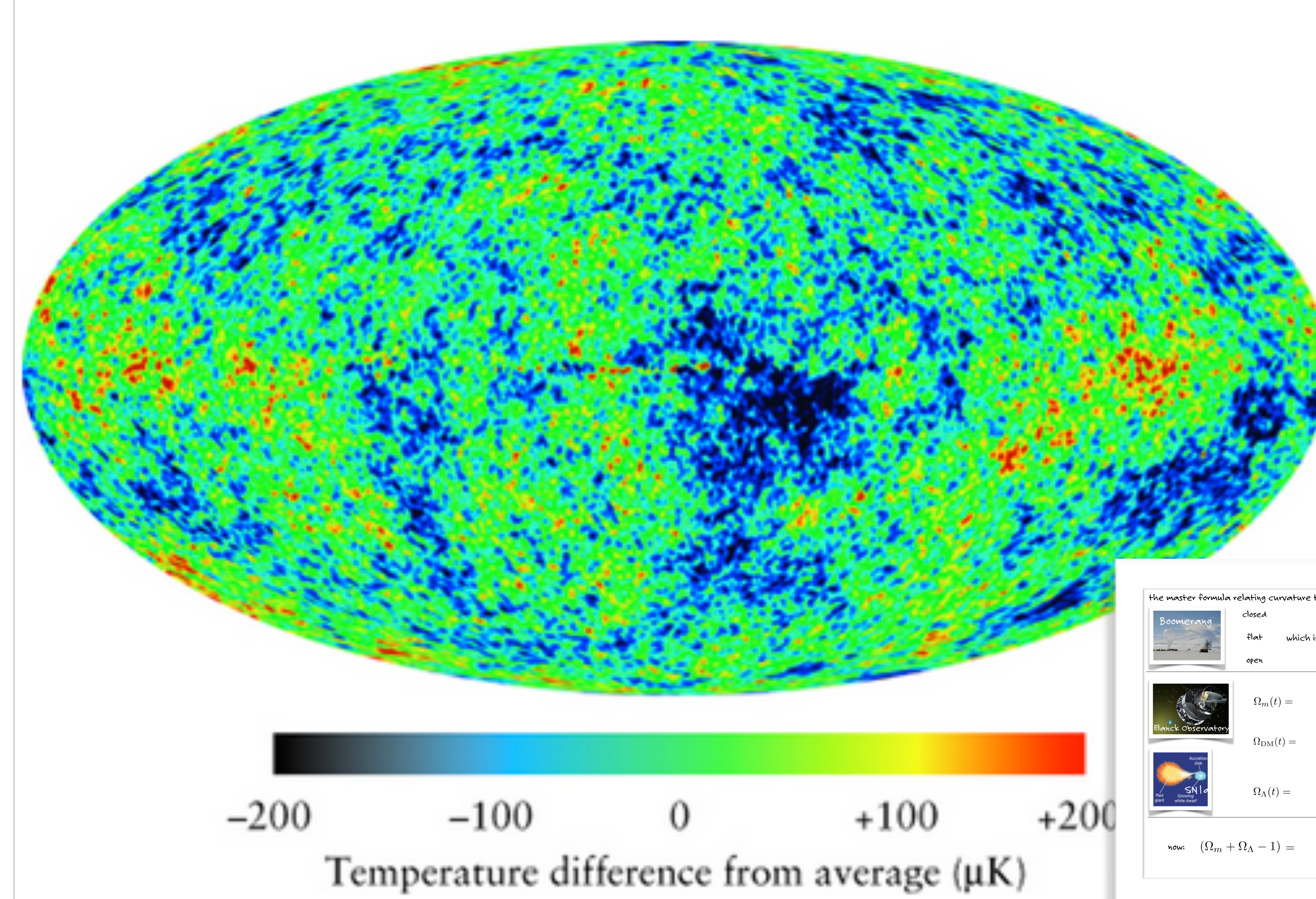
1989 to 1993 | 2001 to 2010 | 2009 to 2013

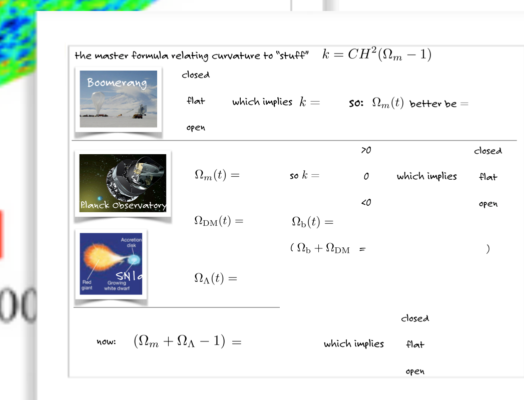


COBE's resolution was 7 degrees.

Planck's resolution is roughly 1/12 of a degree







WMAP... Wilkinson Microwave Anisotropy Probe

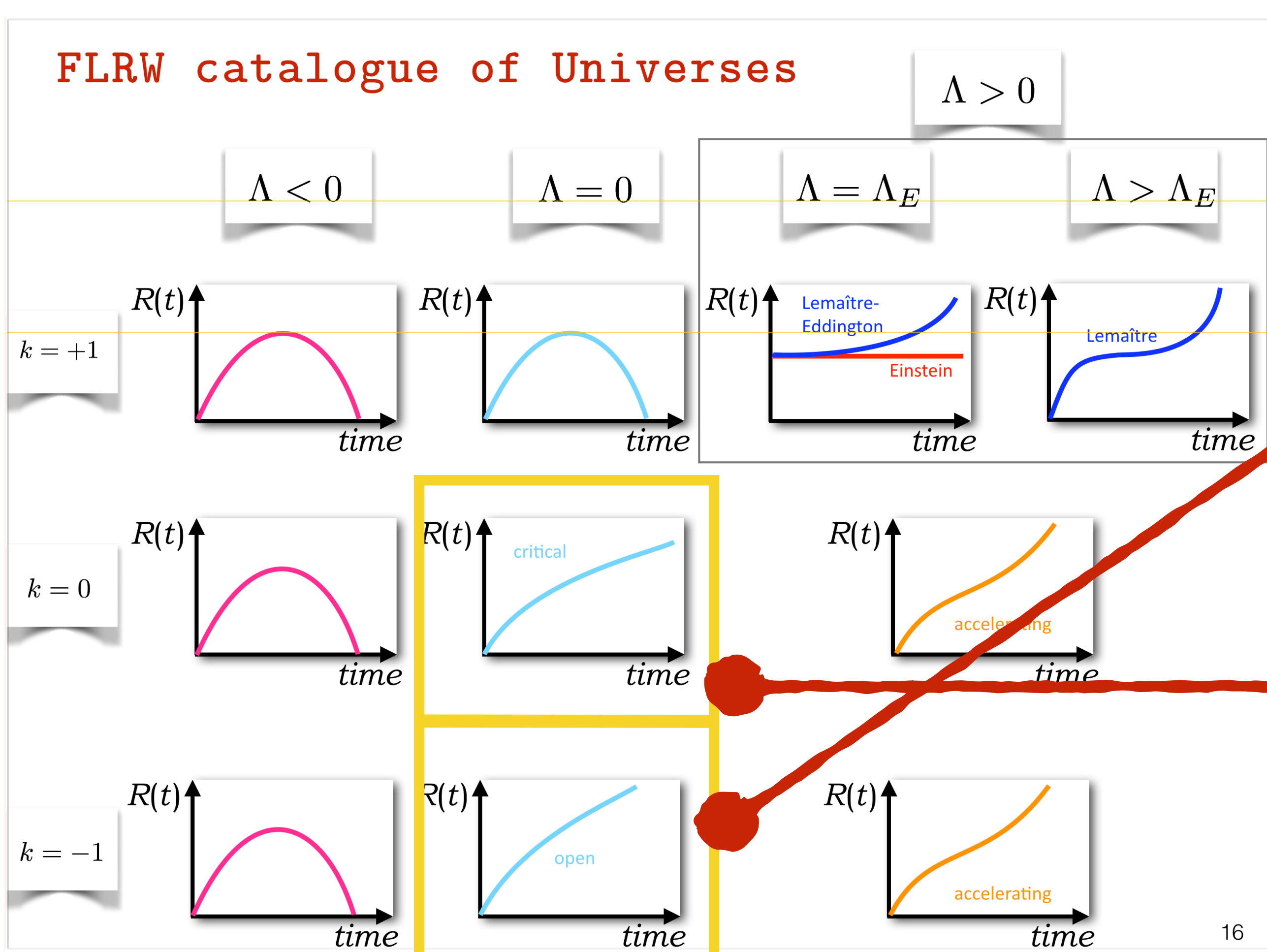
Planck just 2013!

From multiple, different kinds of measurements:

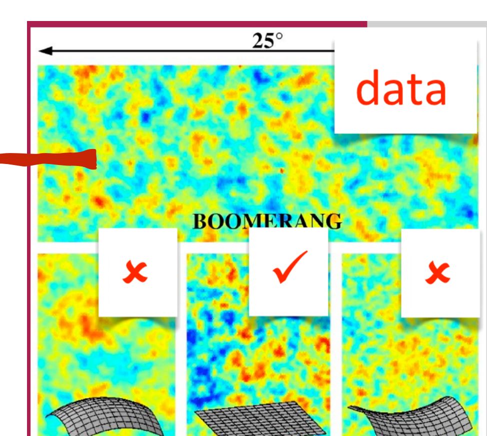
$$\Omega_m(t) = 0.315 \pm 0.007$$

$$\Omega_m(t) \neq 1 \,!$$

$$k = CH^2(\Omega_m - 1)$$ suggests k <1

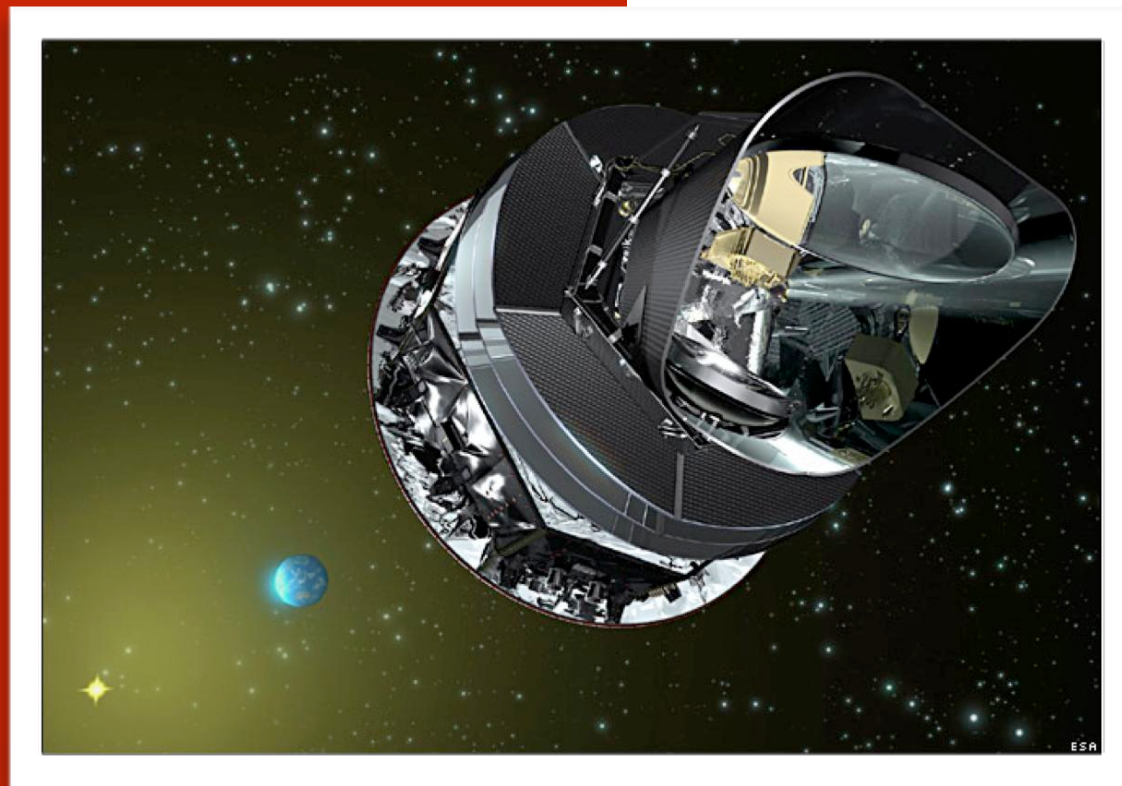


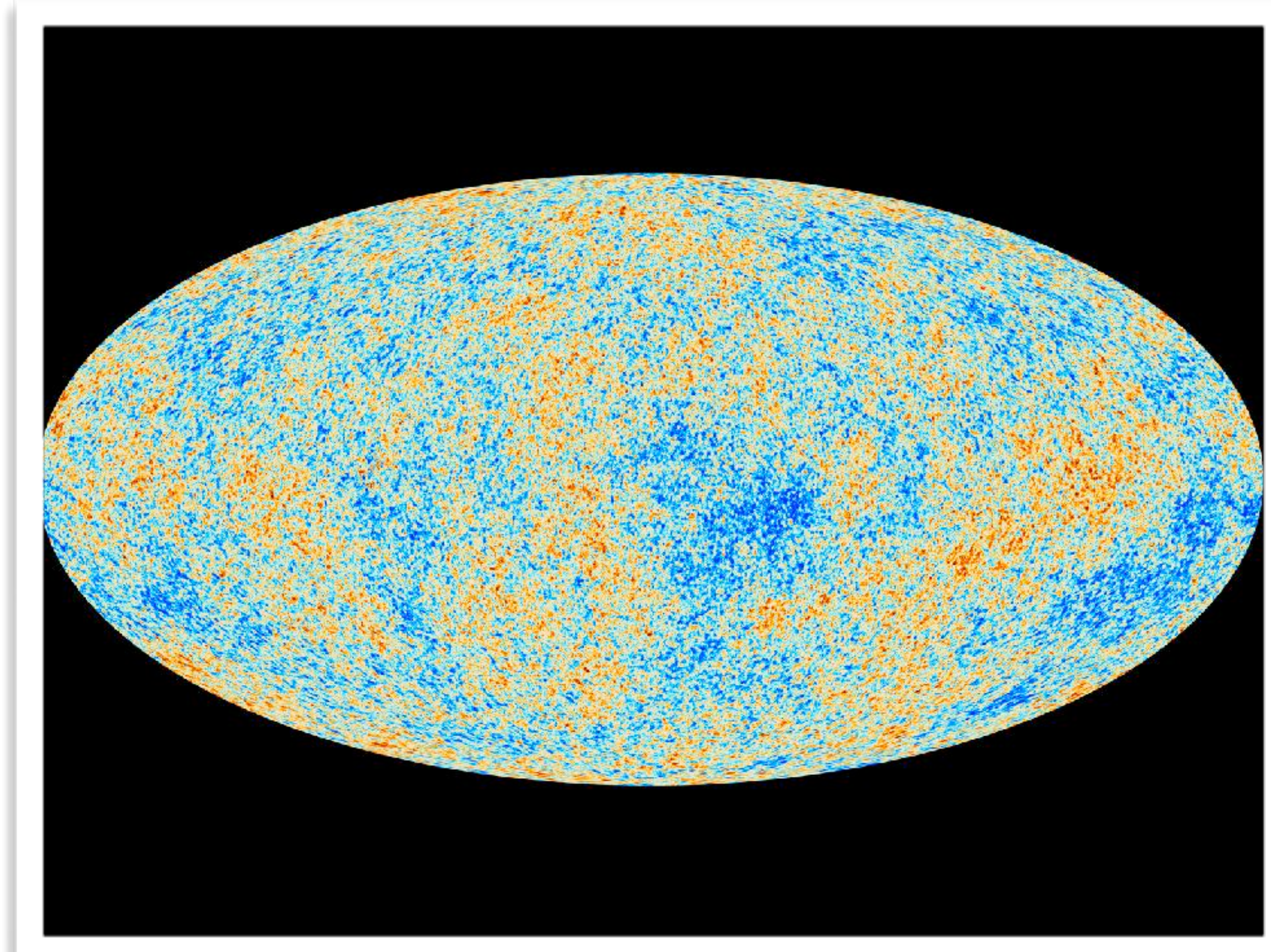
But:



suggested that k = 0

CMB,





now it's really precise

Planck

From multiple, different kinds of measurements:

$$\Omega_m(t) = \boxed{0.308 \pm 0.012}$$

$$\Omega_m(t) \neq 1\,!$$

Further, Dark Matter is part...

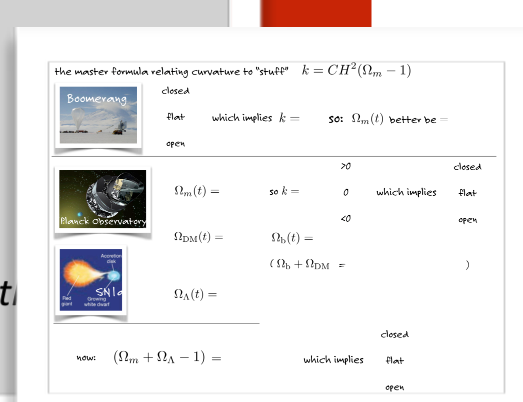
$$\Omega_m(t) = \Omega_{\mathrm{DM}} + \Omega_b$$

From other...multiple, different kinds of measurements: $\Omega_b = \boxed{0.048 \pm 0.0005}$

$$\Omega_{\mathrm{DM}} = \boxed{0.258 \pm 0.004}$$

2. large-scale densities
from motions of galaxies
from the CMB

3. "baryon densities"
survey of stuff that shines...most
from the CMB



everything that shines - Baryons -...4% of the critical density

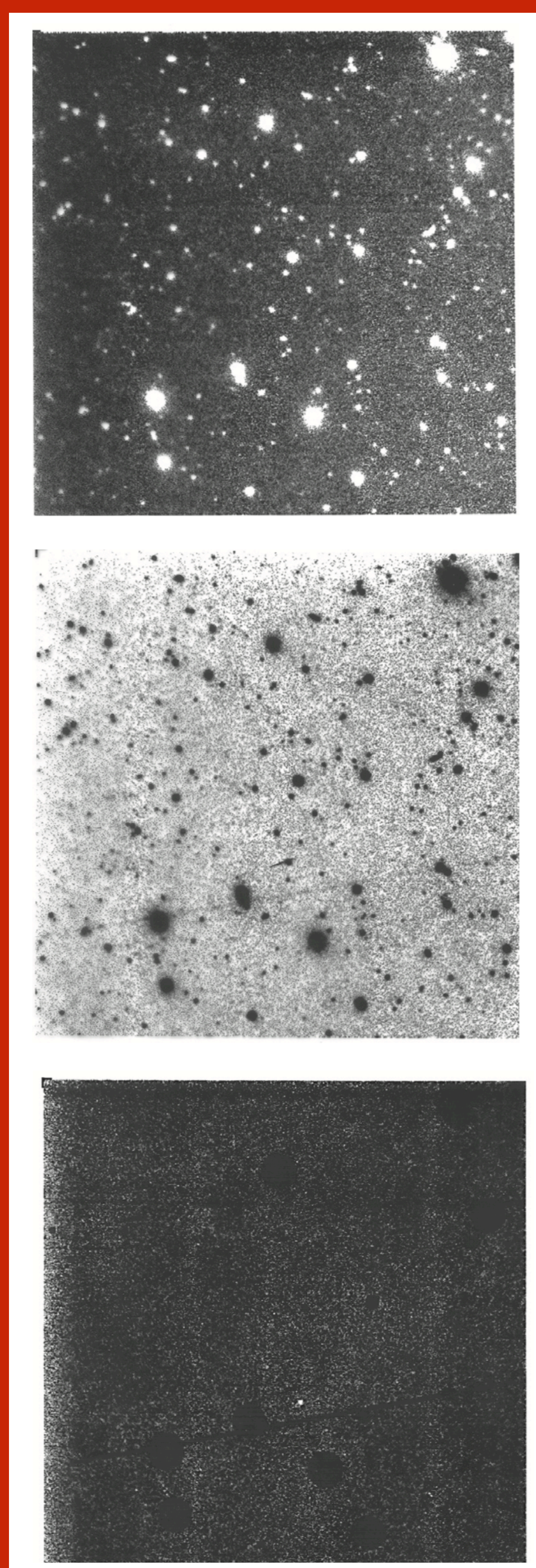
Dark Matter? 30%...

Something missing in order to get to flat at 100%

Boomerang’s flat result

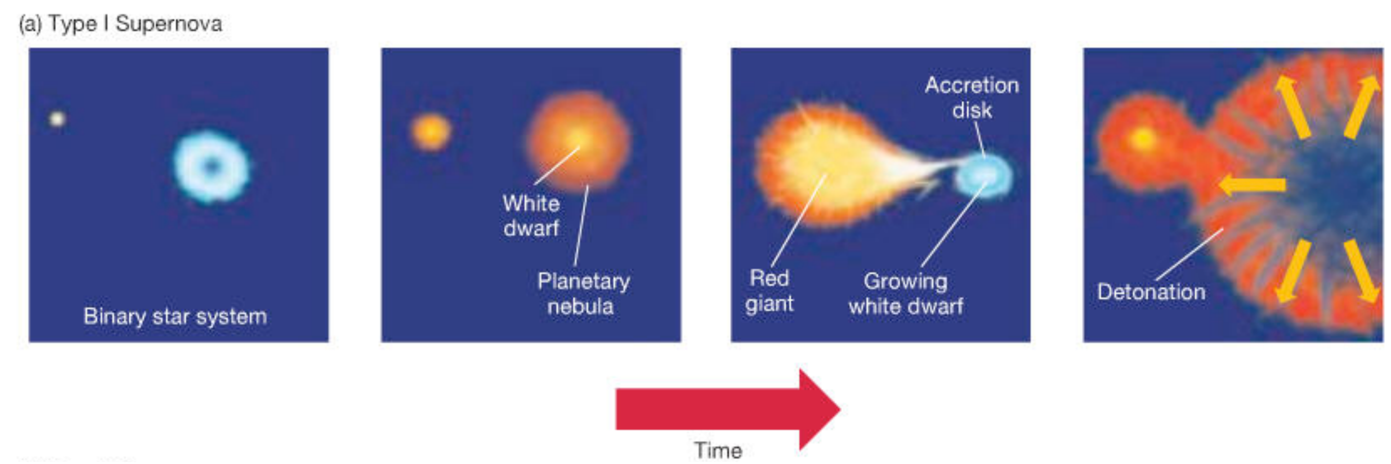
didn’t match the matter-counting results or COBE

by 1998, the Supernova Cosmology Project

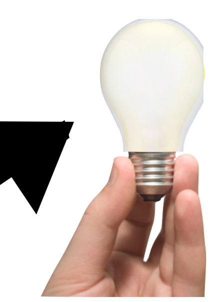


Find and characterize a particular kind of Supernova, called “1a”

1a supernovae are different:
From stars not massive enough by themselves to nova



But in close proximity to another star which it siphons matter from, enough to cause a supernova explosion after all



Remarkably reliable light output.

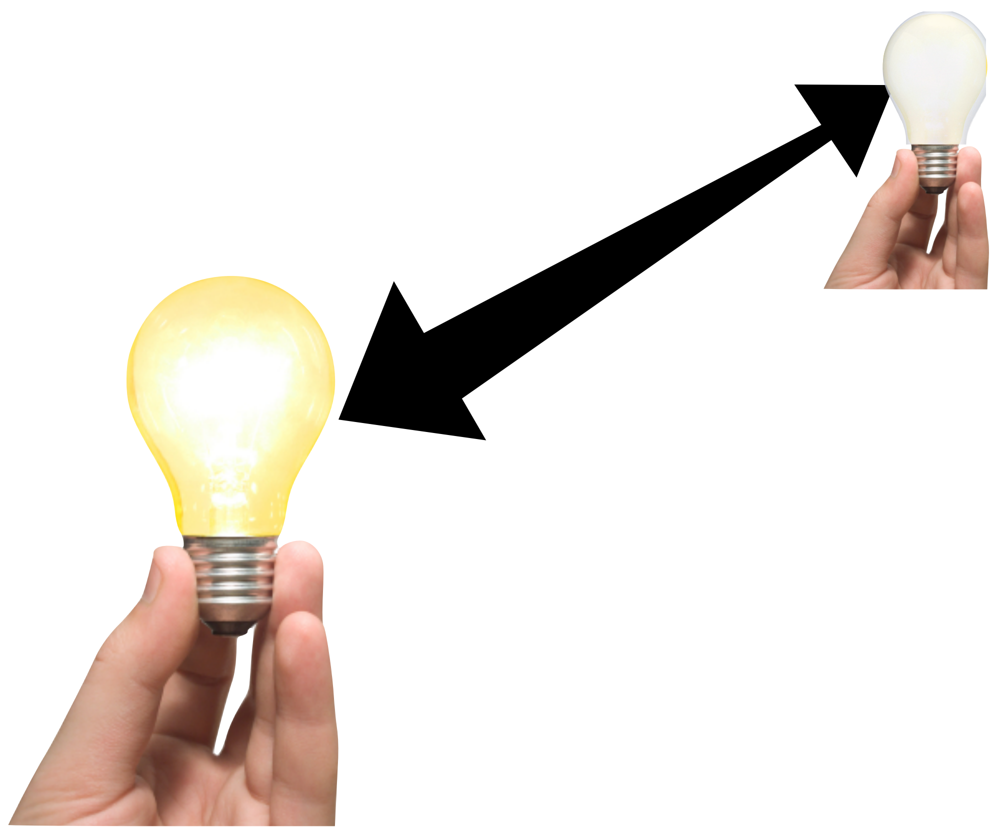
suppose you know how far away an identical bulb is...you could calculate how bright it should appear

so, the game was clear

do the Hubble-thing

use spectra to determine speed, distance

The far-away 1a supernovae appeared to be much too dim for the distances away!



? no...must be further away than expected

they expected to determine how much the expansion of the universe was slowing down.

They ended up showing the opposite!

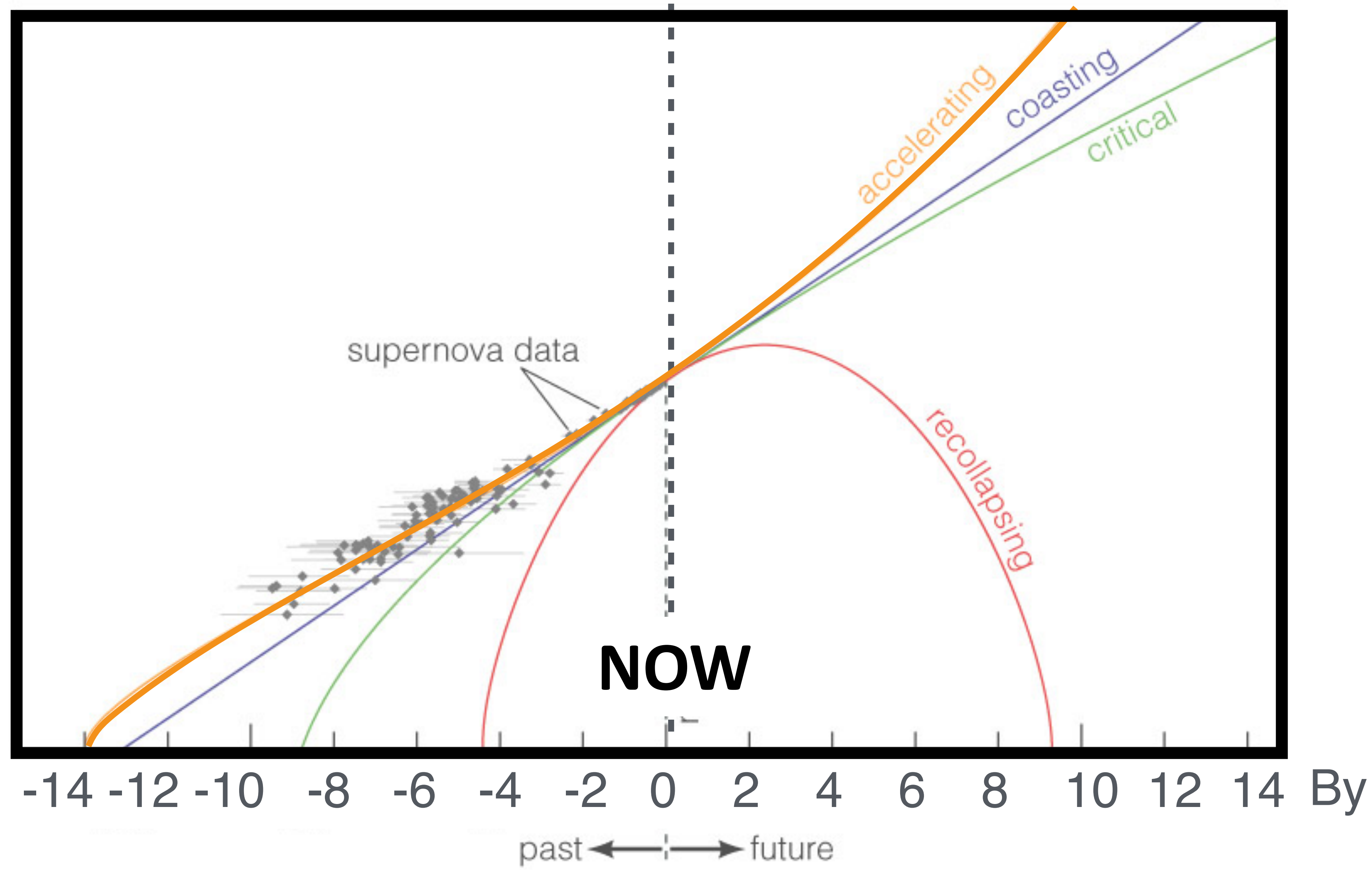
Competition

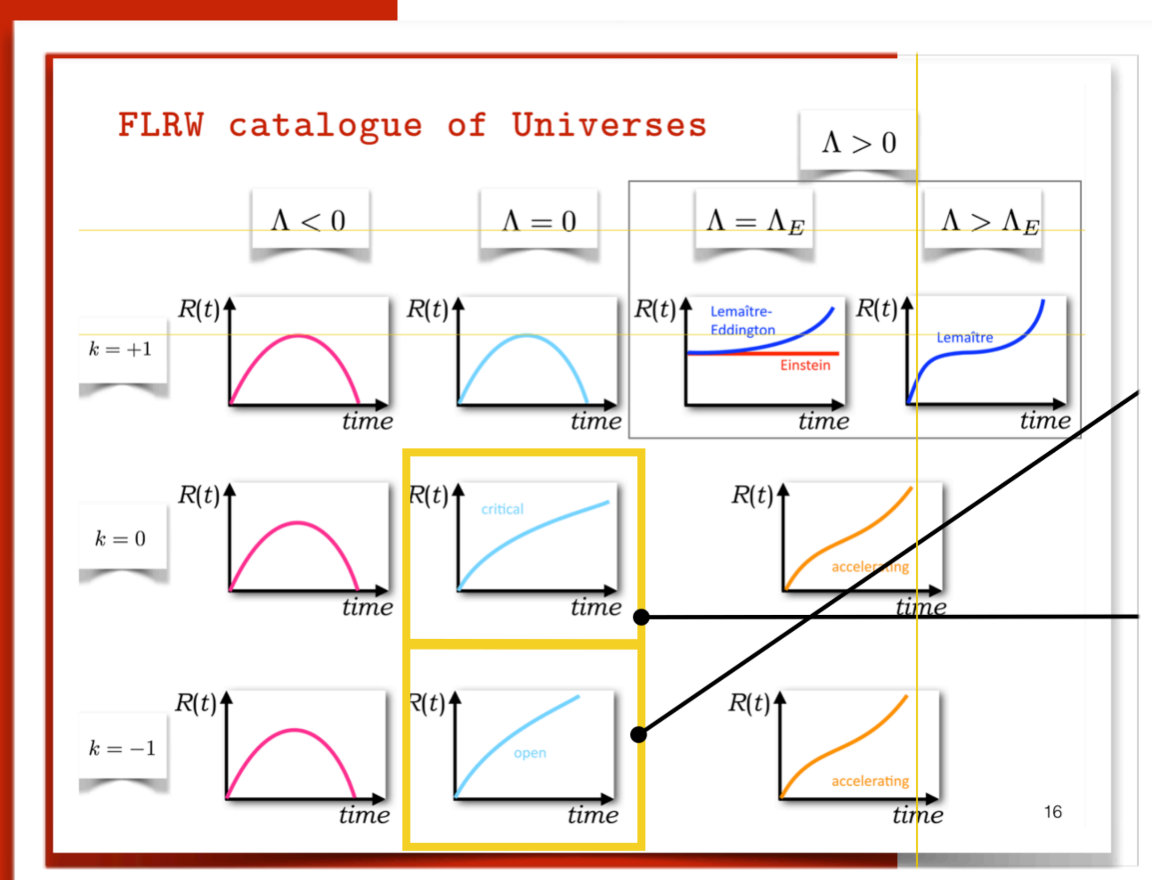
Between expansion (Hubble Parameter)

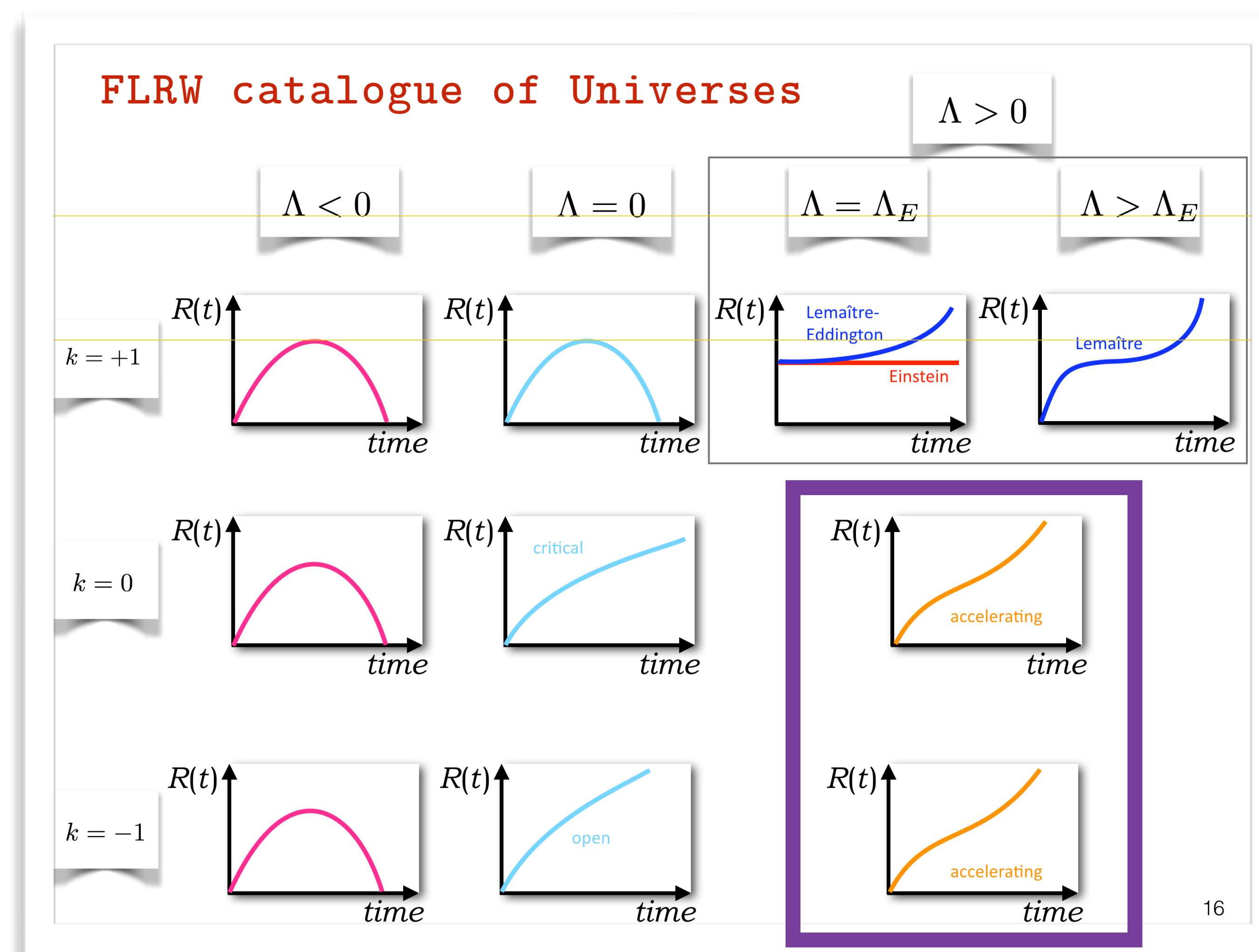
Gravitation (Density)

before, assumed no cosmological constant:

relative size



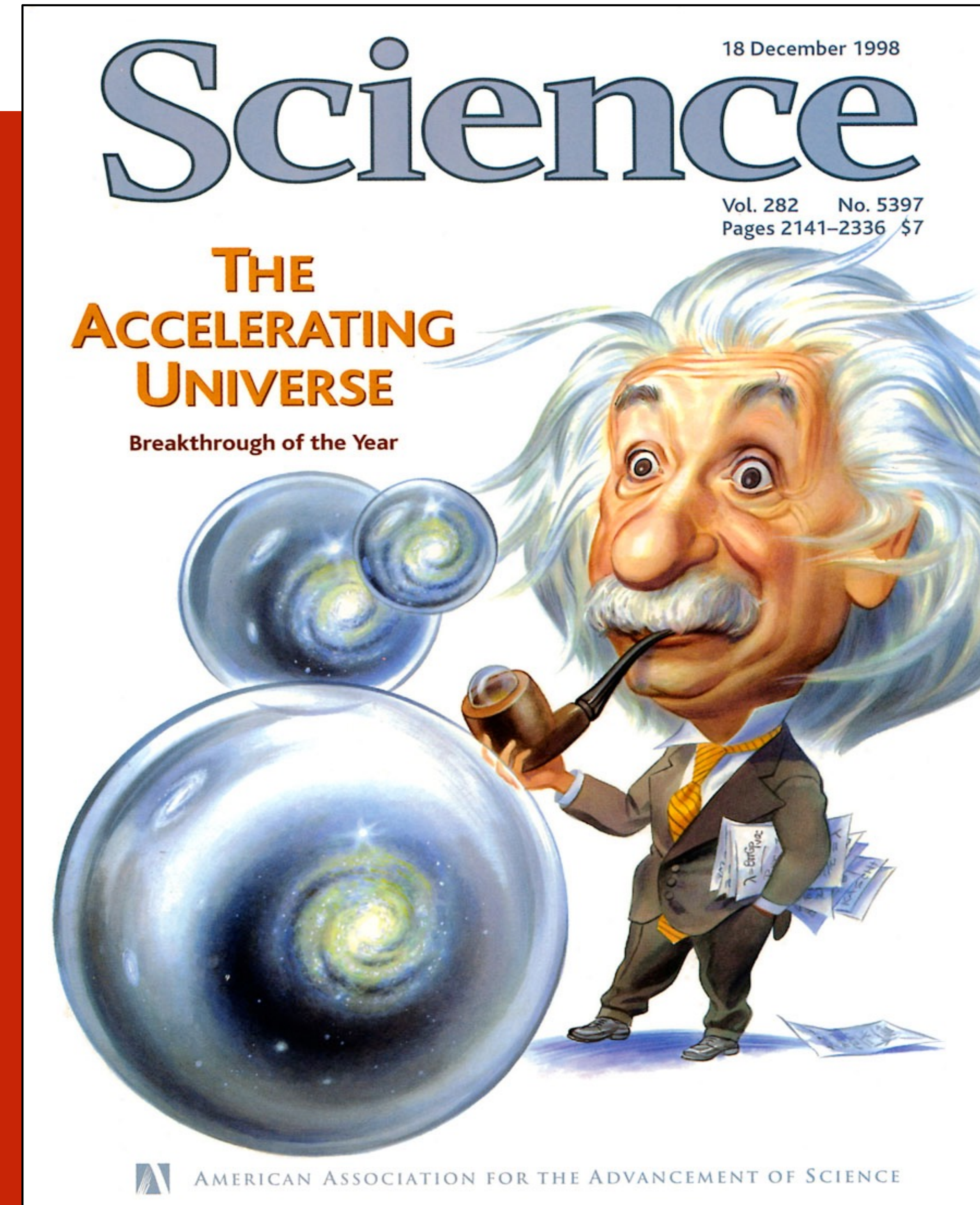




The data require an interpretation

that the Universe's expansion is

Accelerating



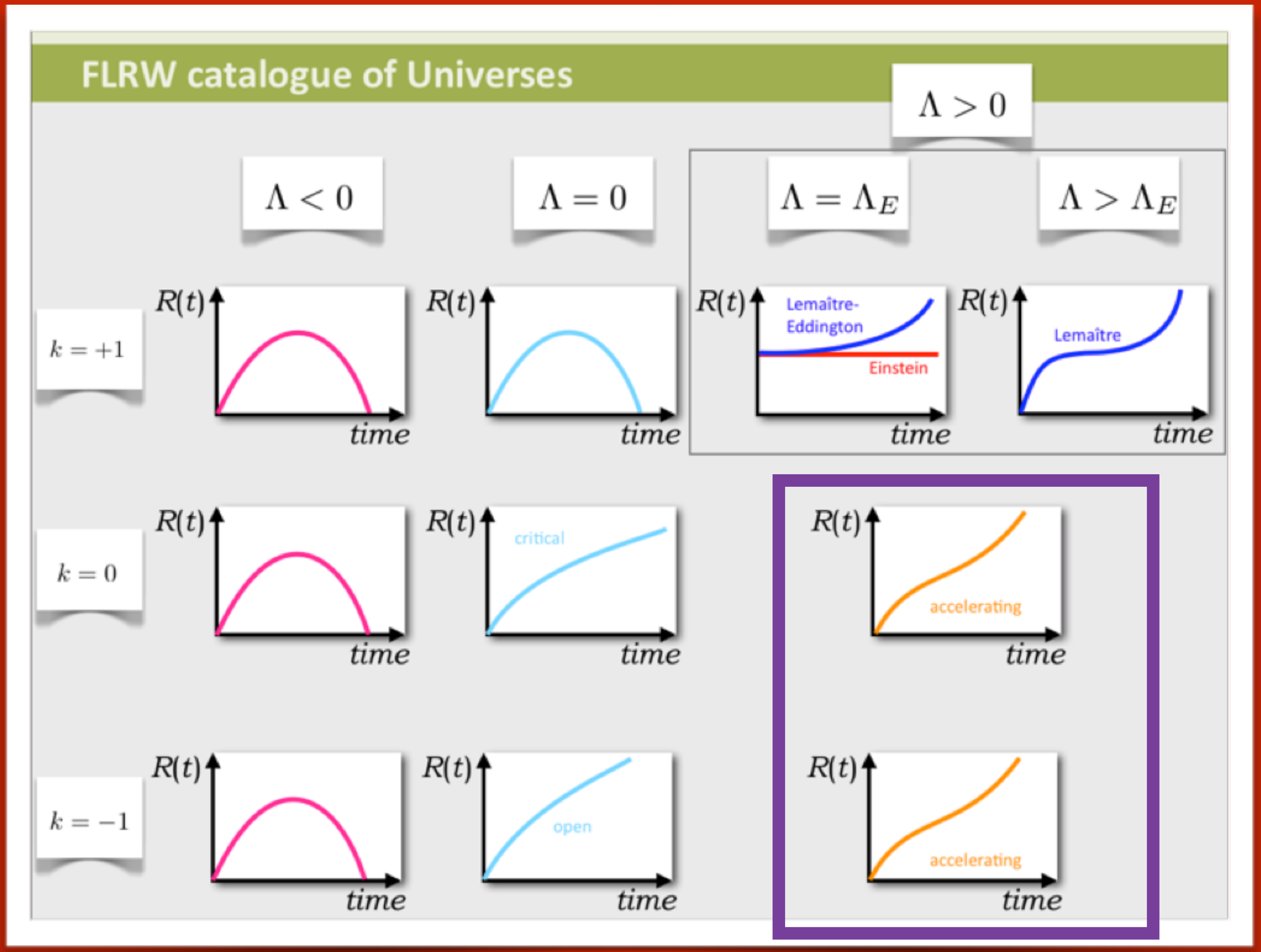
Saul Perlmutter, Brian P. Schmidt and Adam G. Riess, 2011

ONLY ONE WAY TO ACCOMPLISH THAT

within the Friedman equations

the Cosmological Constant

is back



interpreting dark energy

as a vacuum energy:

$$G + \Lambda = T$$

back to the Friedman Equation

with the addition of a Cosmological Constant

one that's different from Einstein's

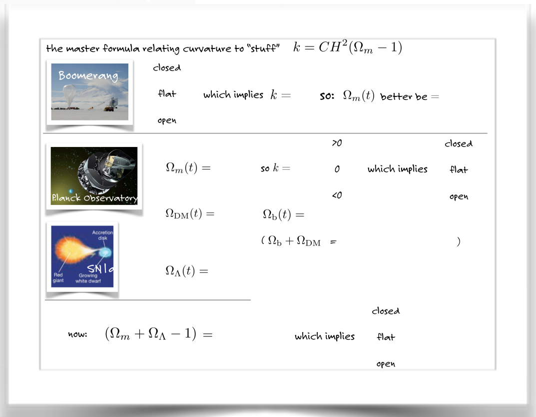
$$k = CH^2(\Omega_m - 1)$$

$$\Omega_m(t) = \frac{\rho}{\rho_c} \quad \text{and} \quad \Omega_\Lambda(t) = \frac{\text{“}\rho_\Lambda\text{”}}{\rho_c}$$

$$k = CH^2(\Omega_m + \Omega_\Lambda - 1)$$

Measure it:

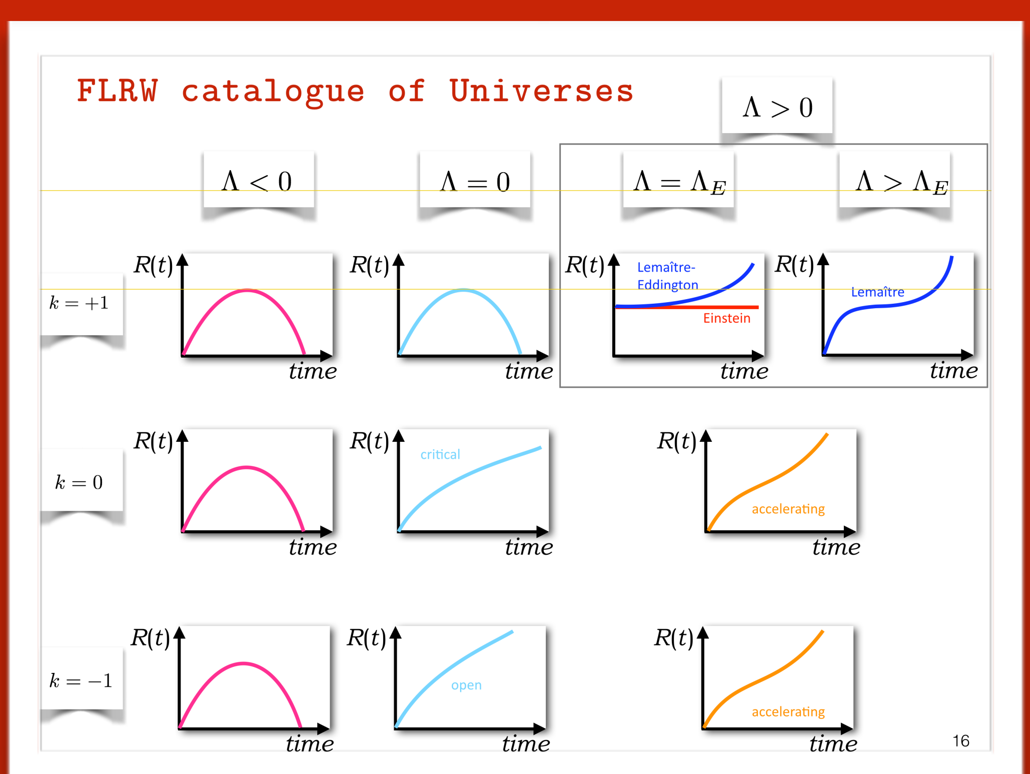
$$\Omega_\Lambda = \boxed{0.692 \pm 0.012}$$



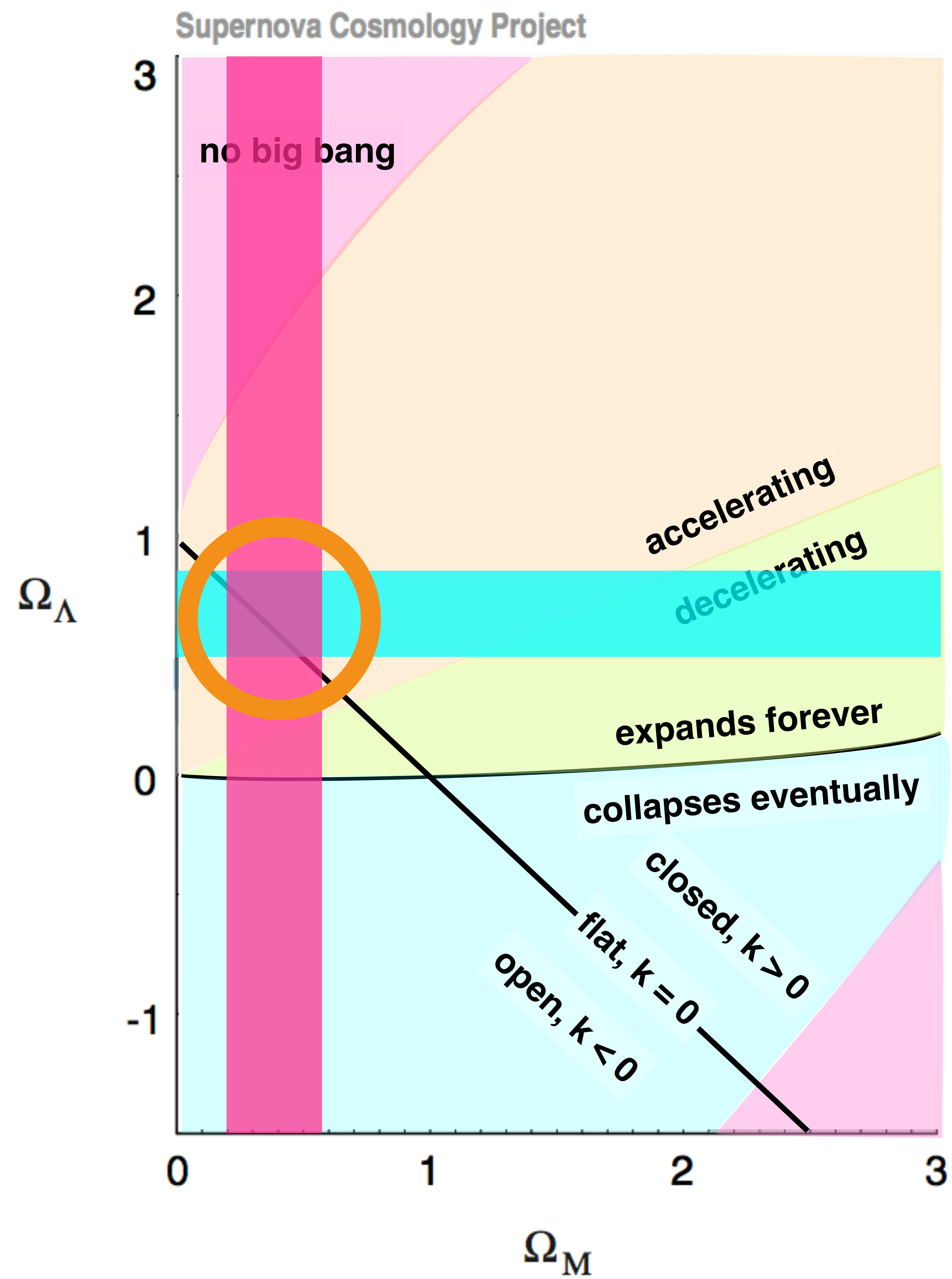
this doesn't say what it is!

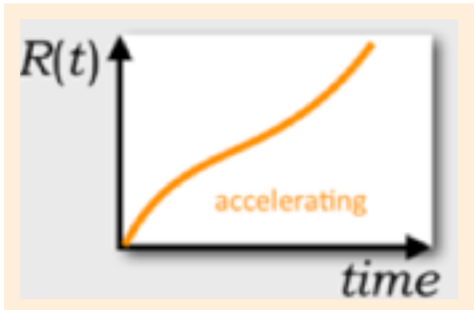
but it is a parameter that can be used to fit observations

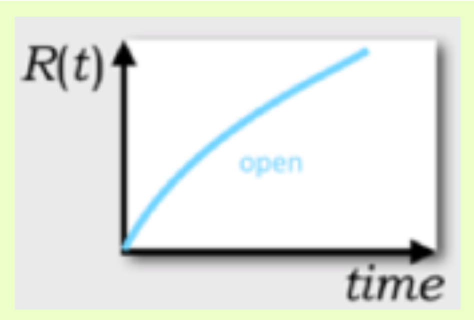
and model universes

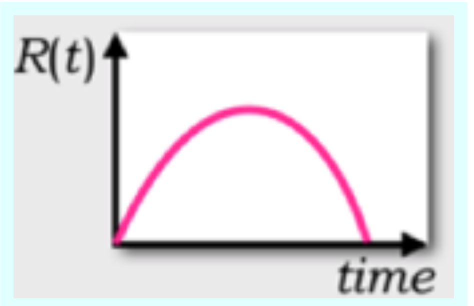


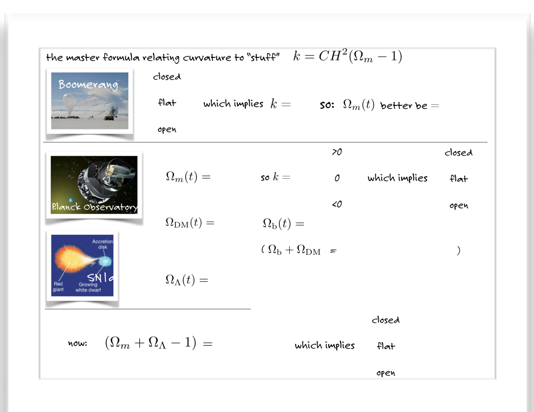
$$k \propto H^2(\Omega_m + \Omega_\Lambda - 1)$$







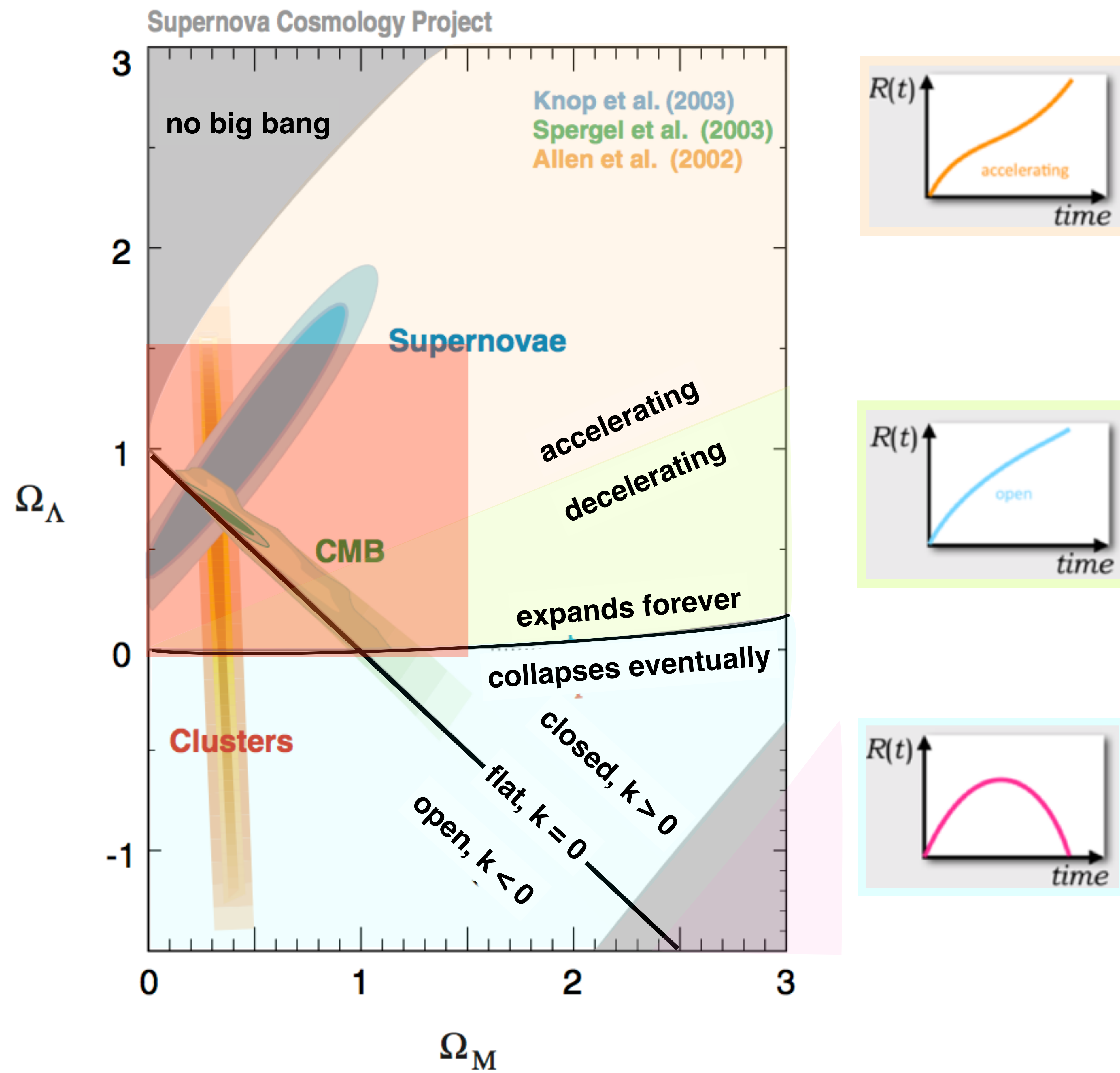




$$\left.\begin{array}{l} \Omega_\Lambda = 0.692 \pm 0.012 \\ \Omega_m = 0.308 \pm 0.012 \end{array}\right\} \sim 1.0!$$

FLAT re-emerges

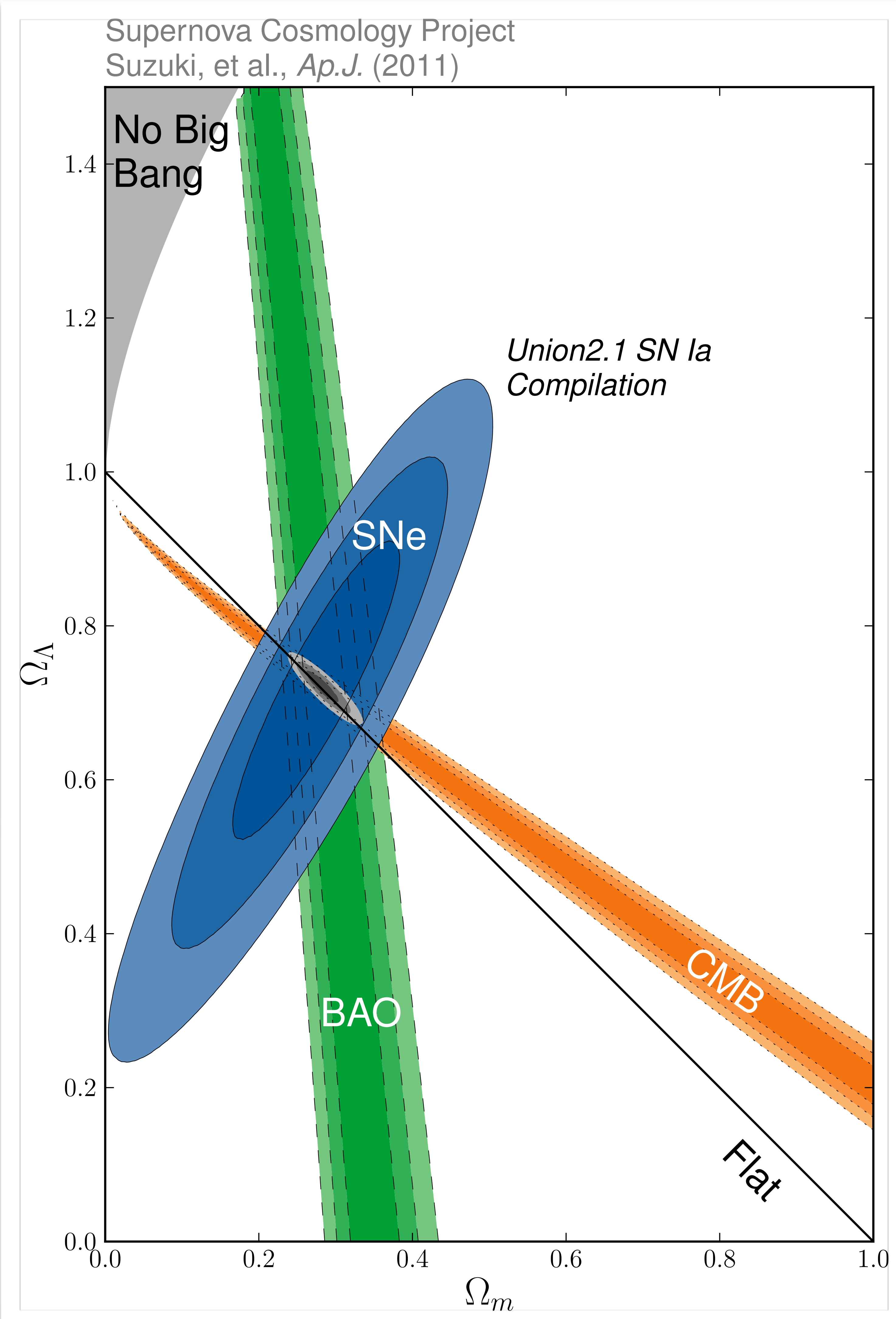
2003



Supernova Cosmology Project
no big bang
Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
Supernovae
accelerating
decelerating
CMB
expands forever
collapses eventually
closed, k > 0
flat, k = 0
open, k < 0
Clusters
Ω_Λ
Ω_M
3
2
1
0
-1
0
1
2
3
R(t)
accelerating
time
R(t)
open
time
R(t)
time

more precise, combined data

2011



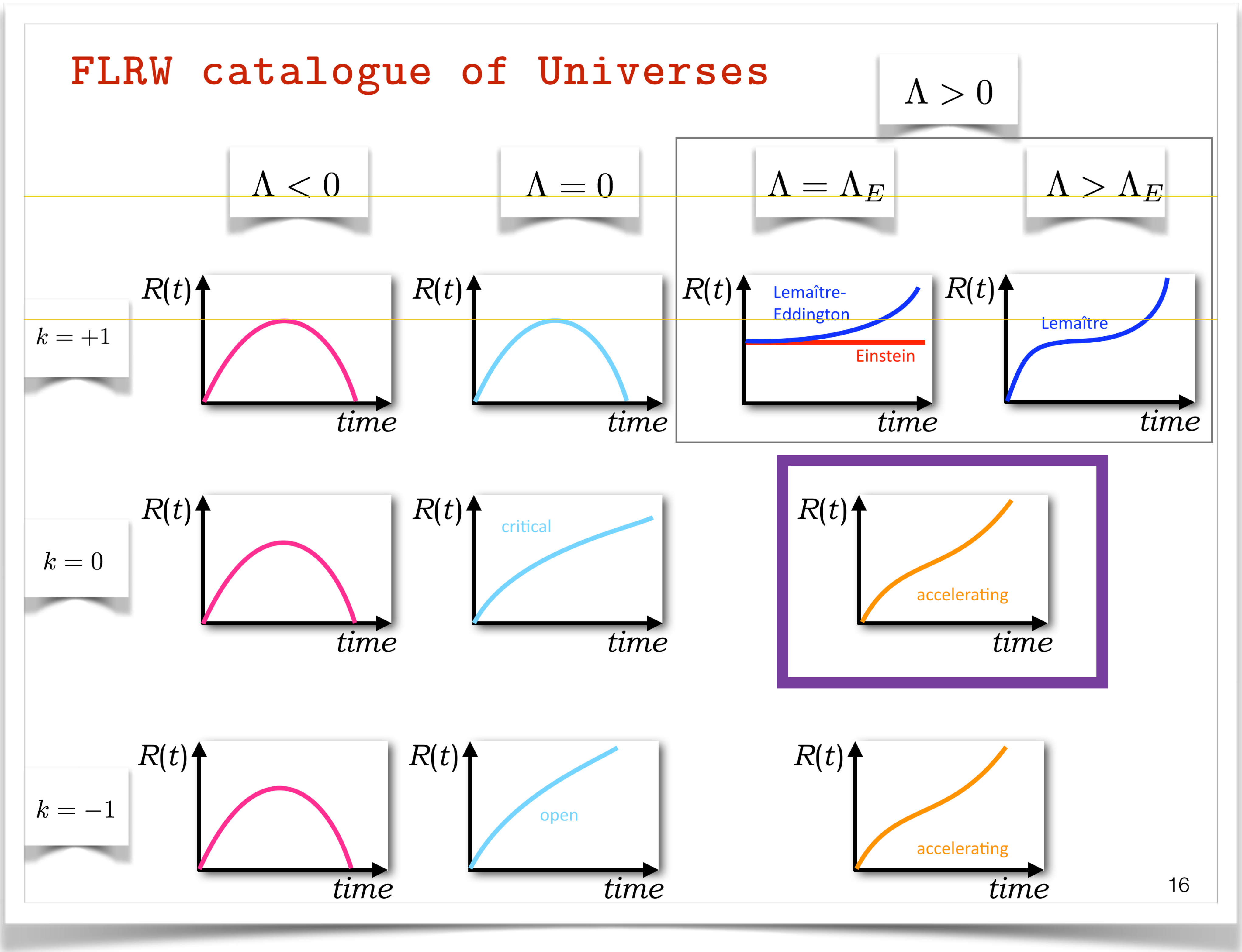
Bingo. Flat.

Didn't have to be this way.

flat

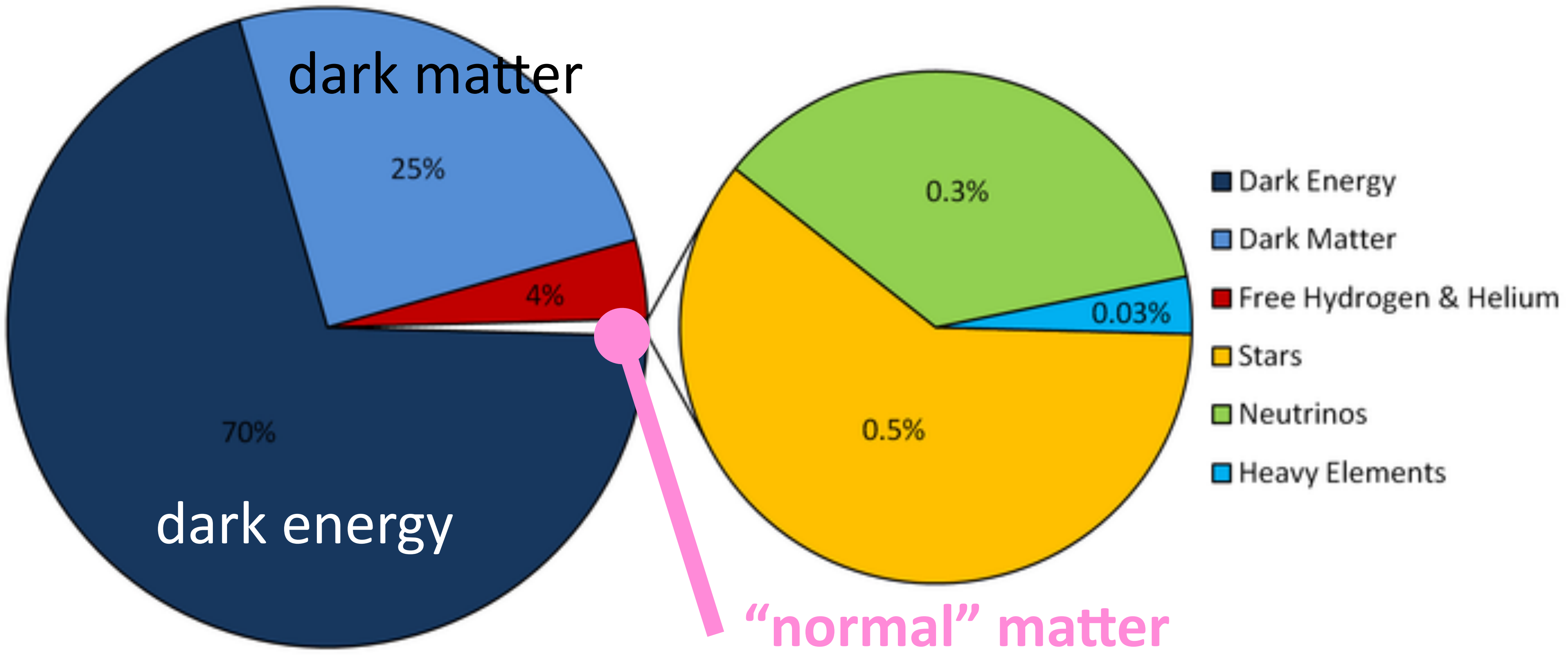
seems to be our universe...

and our bleak fate!



we don't know much!!

This "dark energy" is a huge part of the energy density of the Universe!



interpretation for Λ?

Energy of the vacuum

a negative pressure

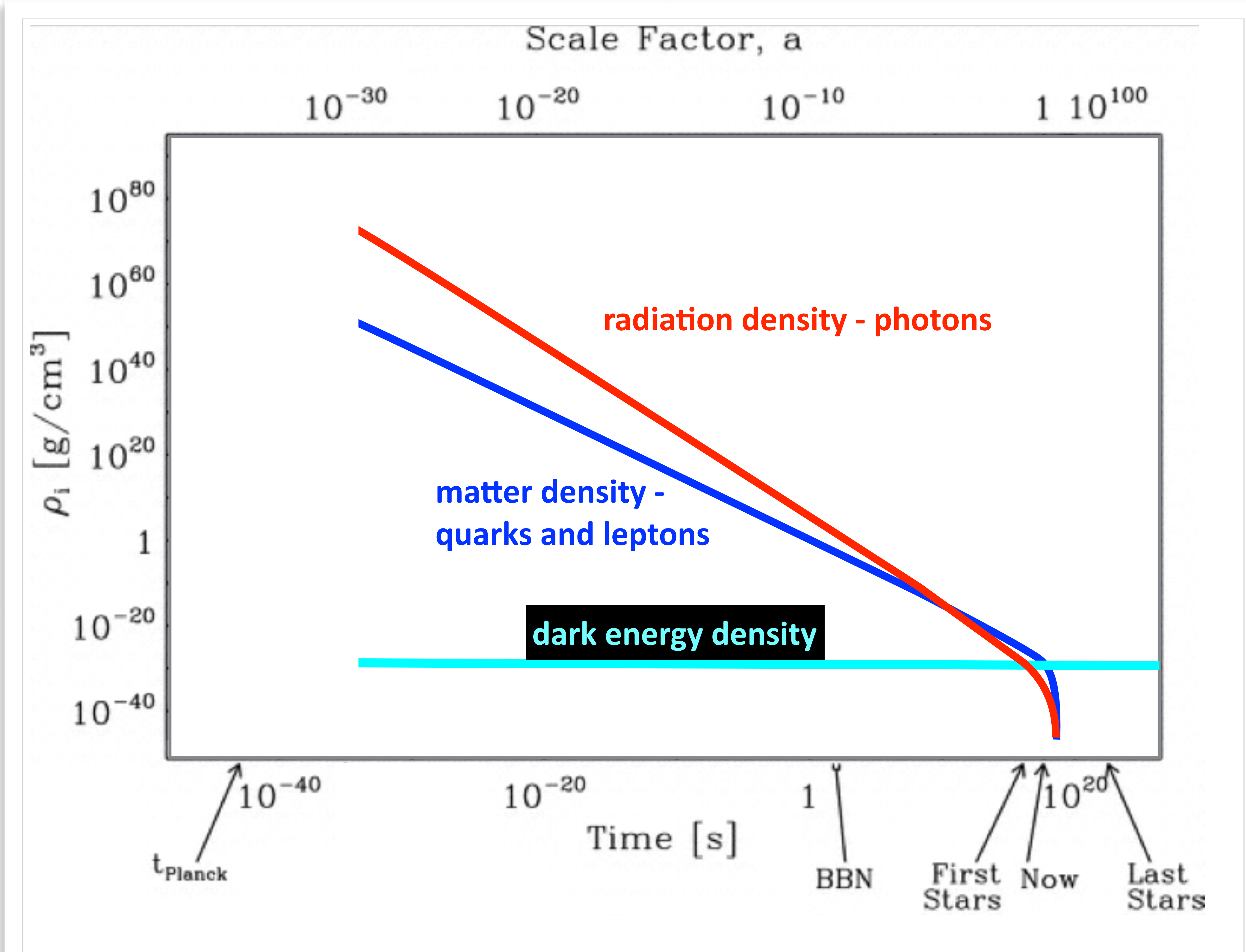
um…

accelerating??

There has to be some "antigravity" kind of force at work to do this

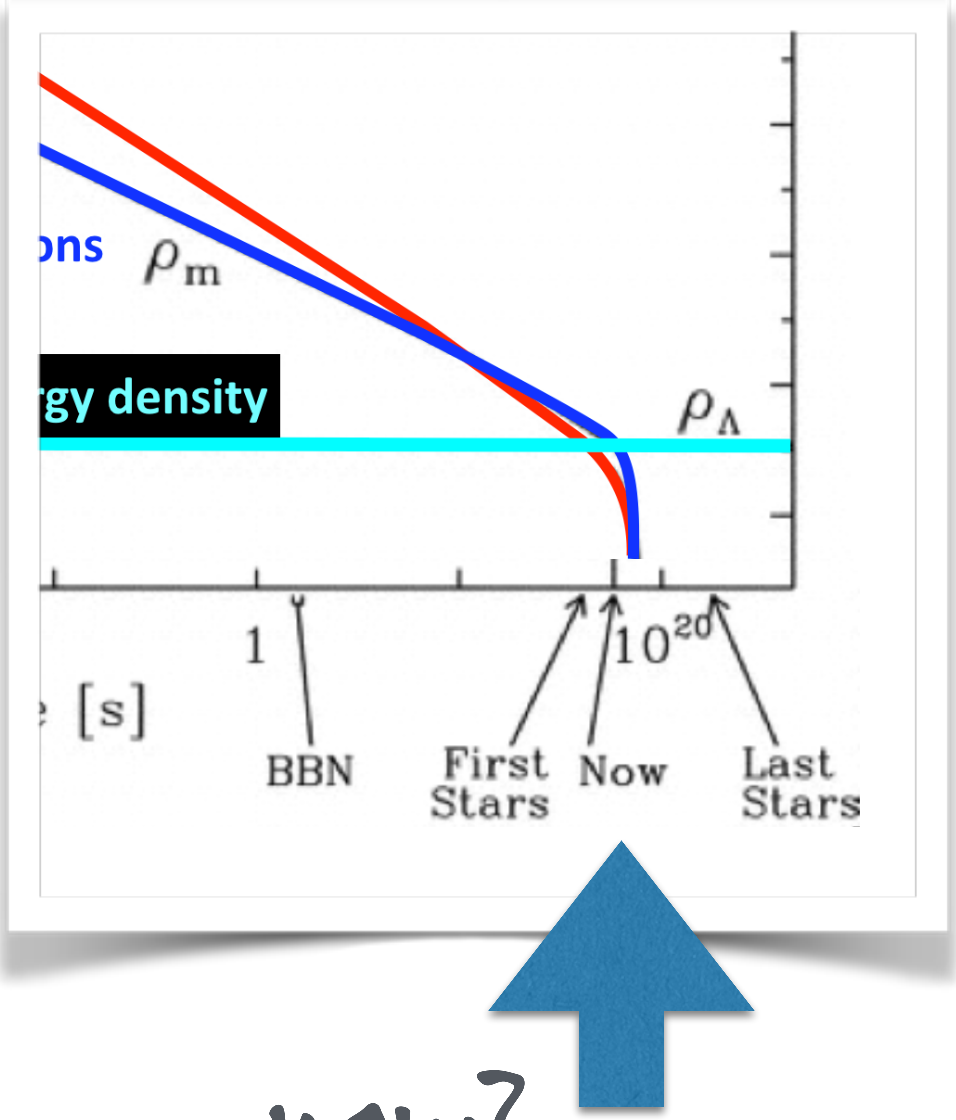
What's more, there has to be a lot of it

we've no real understanding of what DE actually is.



why

now?



ons
ρ_m
rgy density
ρ_Λ
1
10^{20}
[s]
BBN
First Stars
Now
Last Stars

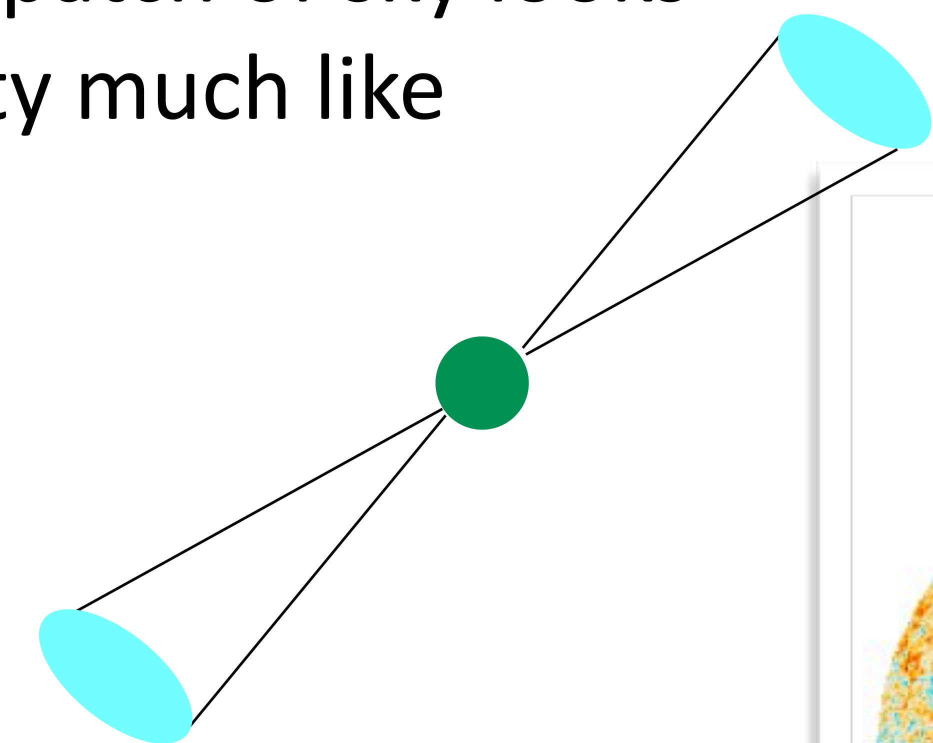
now?

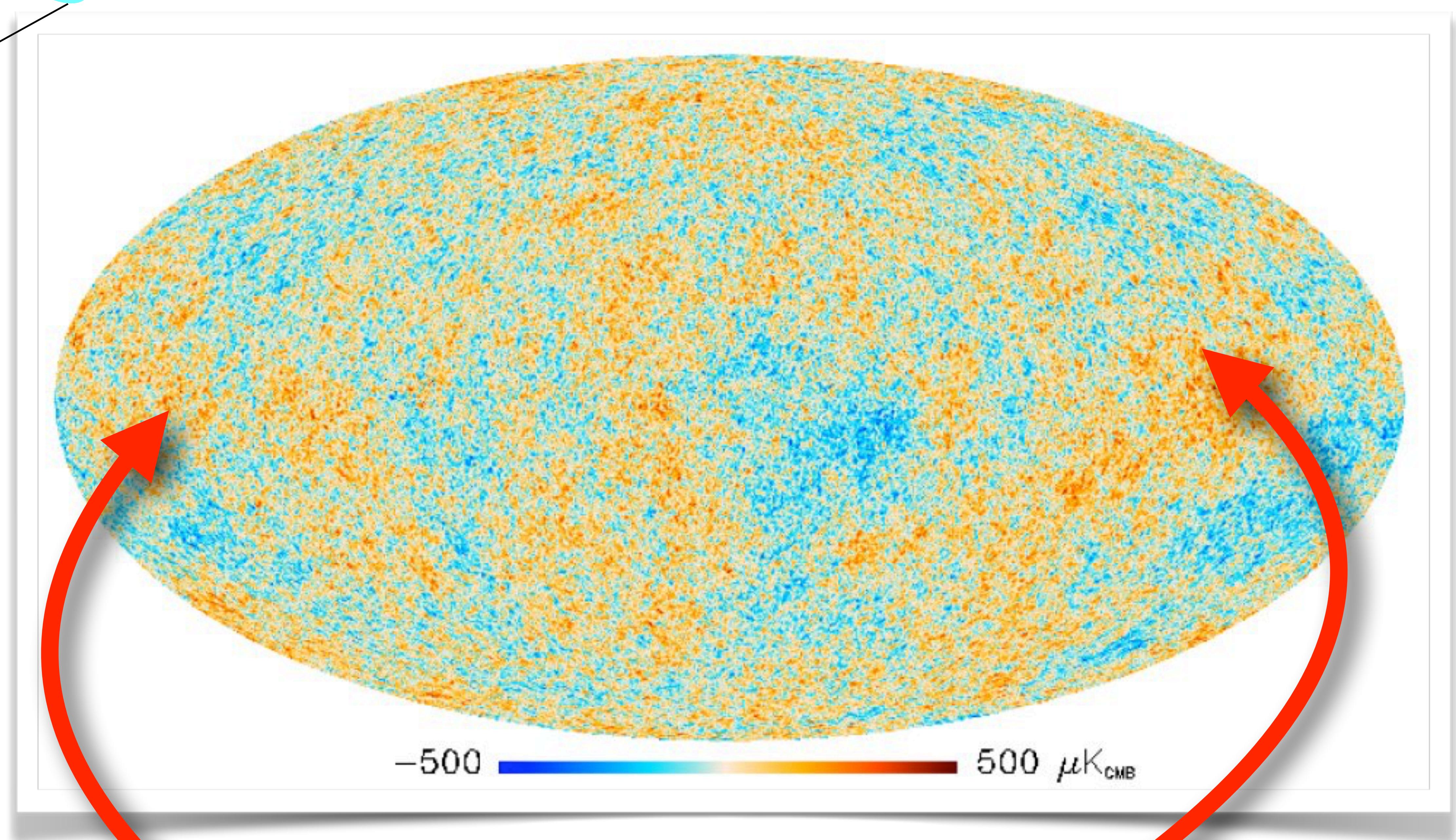
problem #2

the horizon problem.

how could the sky be so uniform?

that patch of sky looks pretty much like





yet the amazing uniformity of the temperatures in the CMB – all over the sky – at recombination...

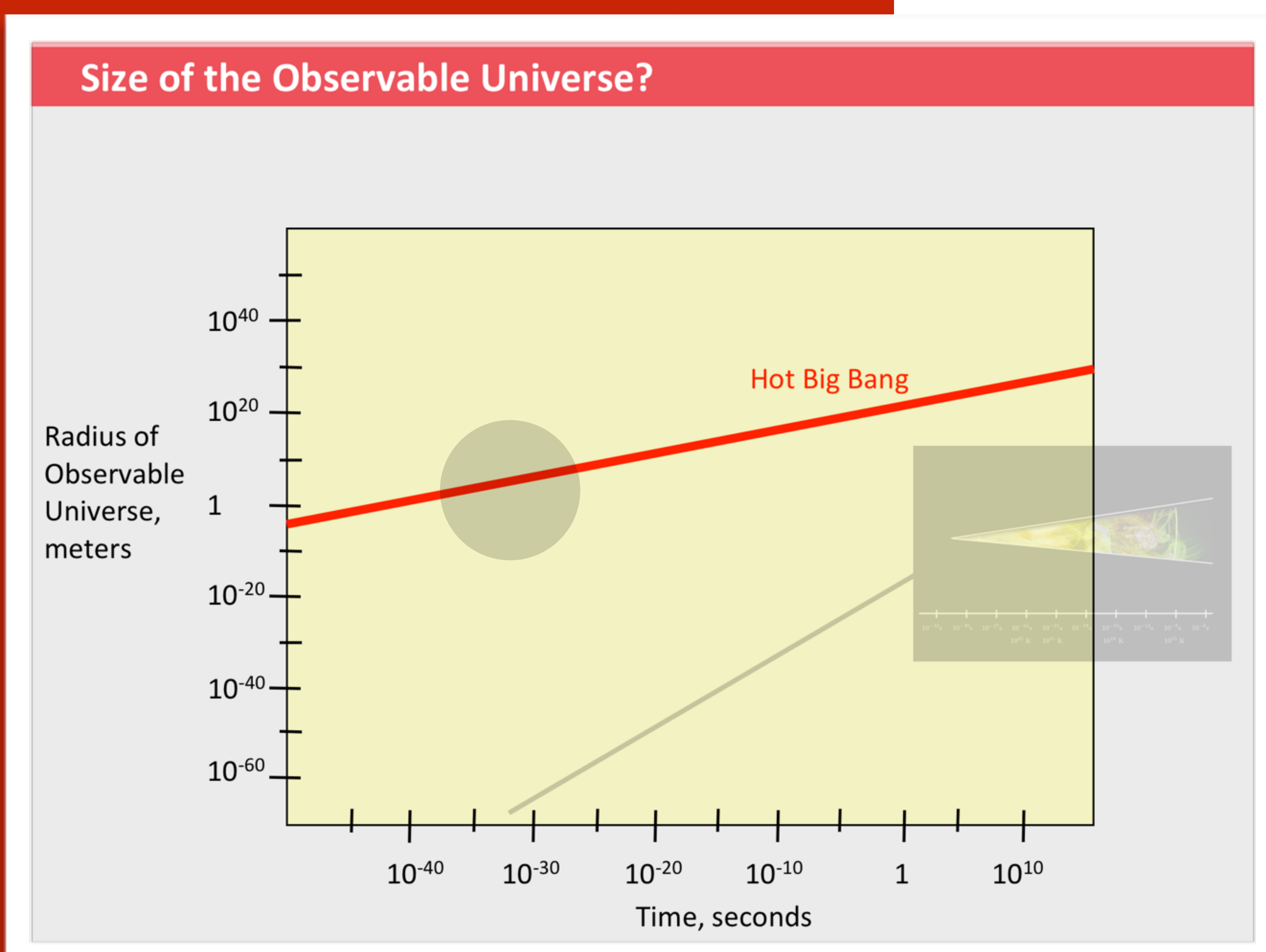
can't have happened causally

when would the two sides ‘‘talk’’?

In the hot big bang scenario...
at about 10^{-32} s, the universe is about a meter in radius

How far could light travel in that time?

$$d(\gamma) = c \times 10^{-32}\mathrm{s}$$
$$= (3 \times 10^{8}\mathrm{m/s}) \times 10^{-32}\mathrm{s}$$



That’s the **Horizon** at that time.

Universe already much bigger than that!

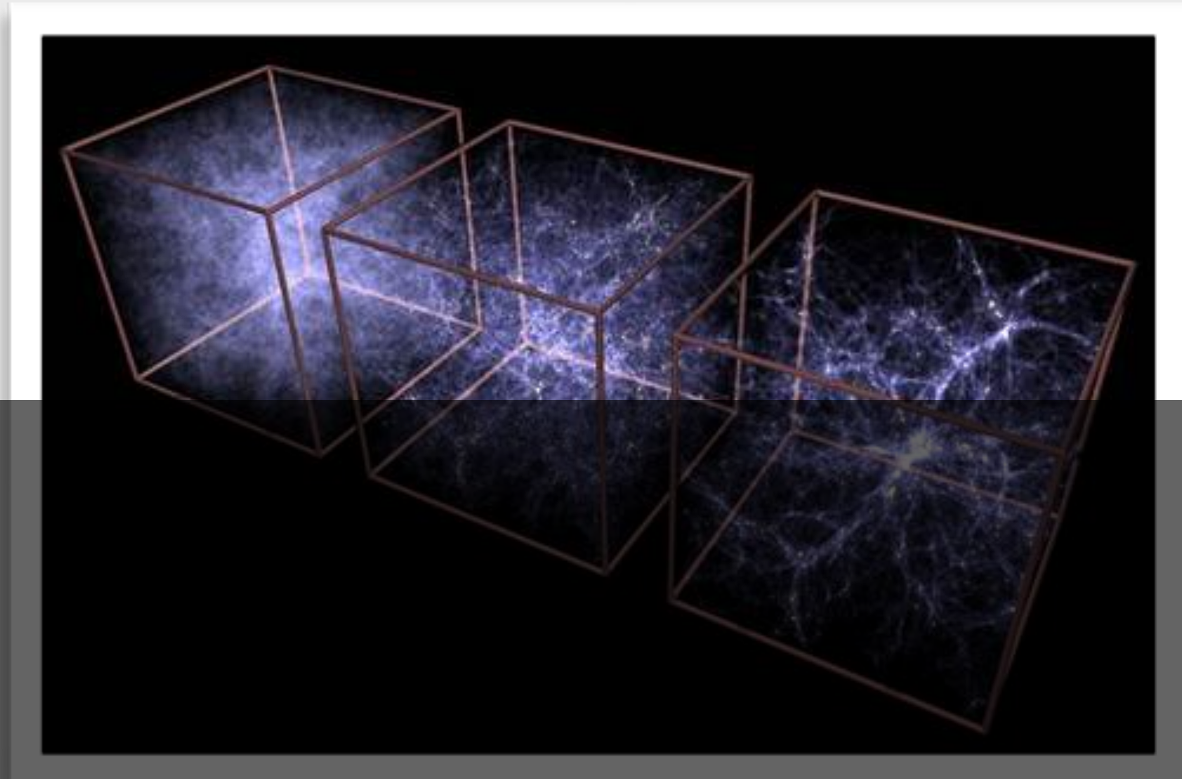
One side could not have affected the other side

problem #3

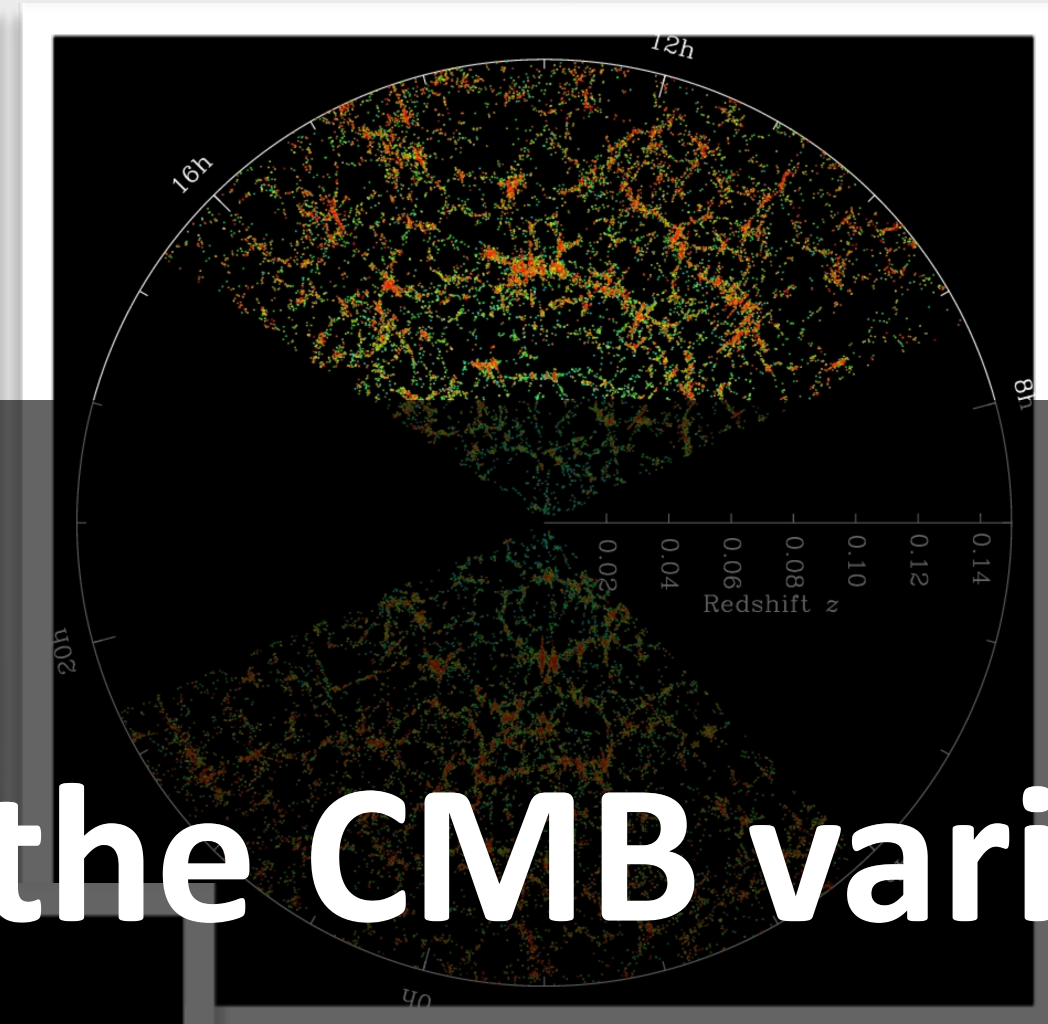
the structure problem.

simulation of galaxy clusters and superclusters is in hand

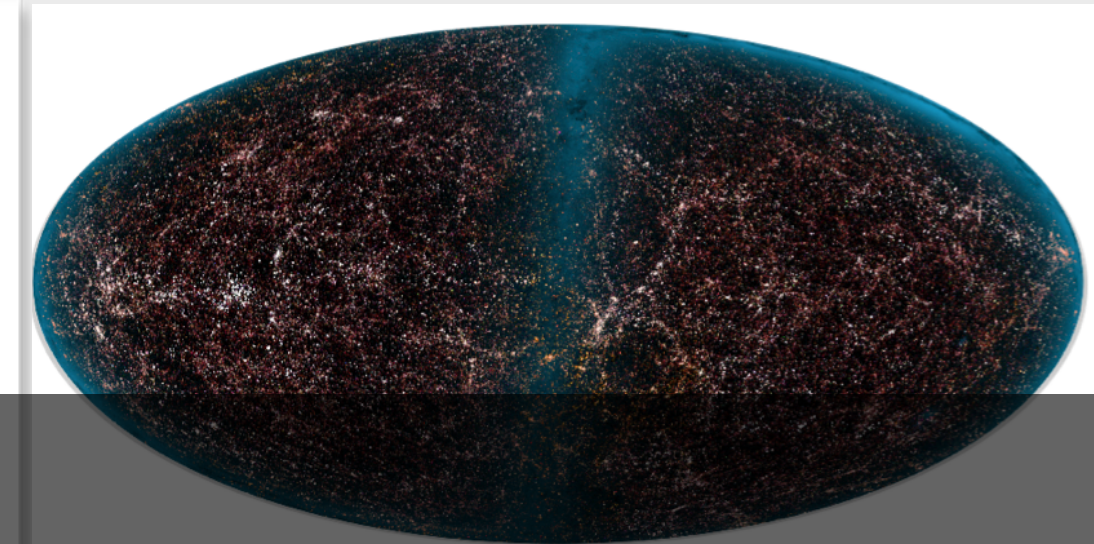
"Millennium Simulation"



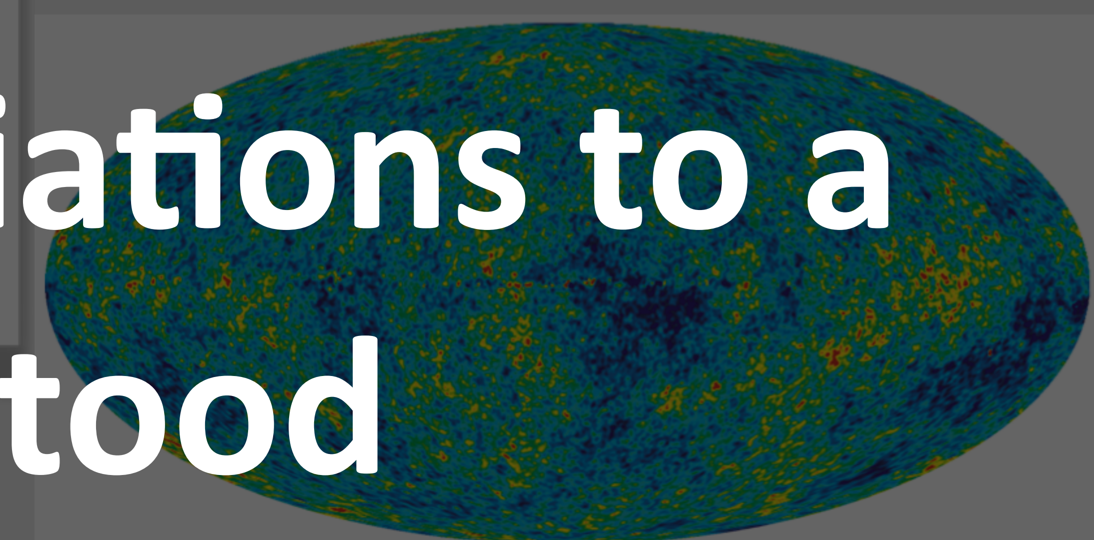
Data: Sloan Digital Sky Survey



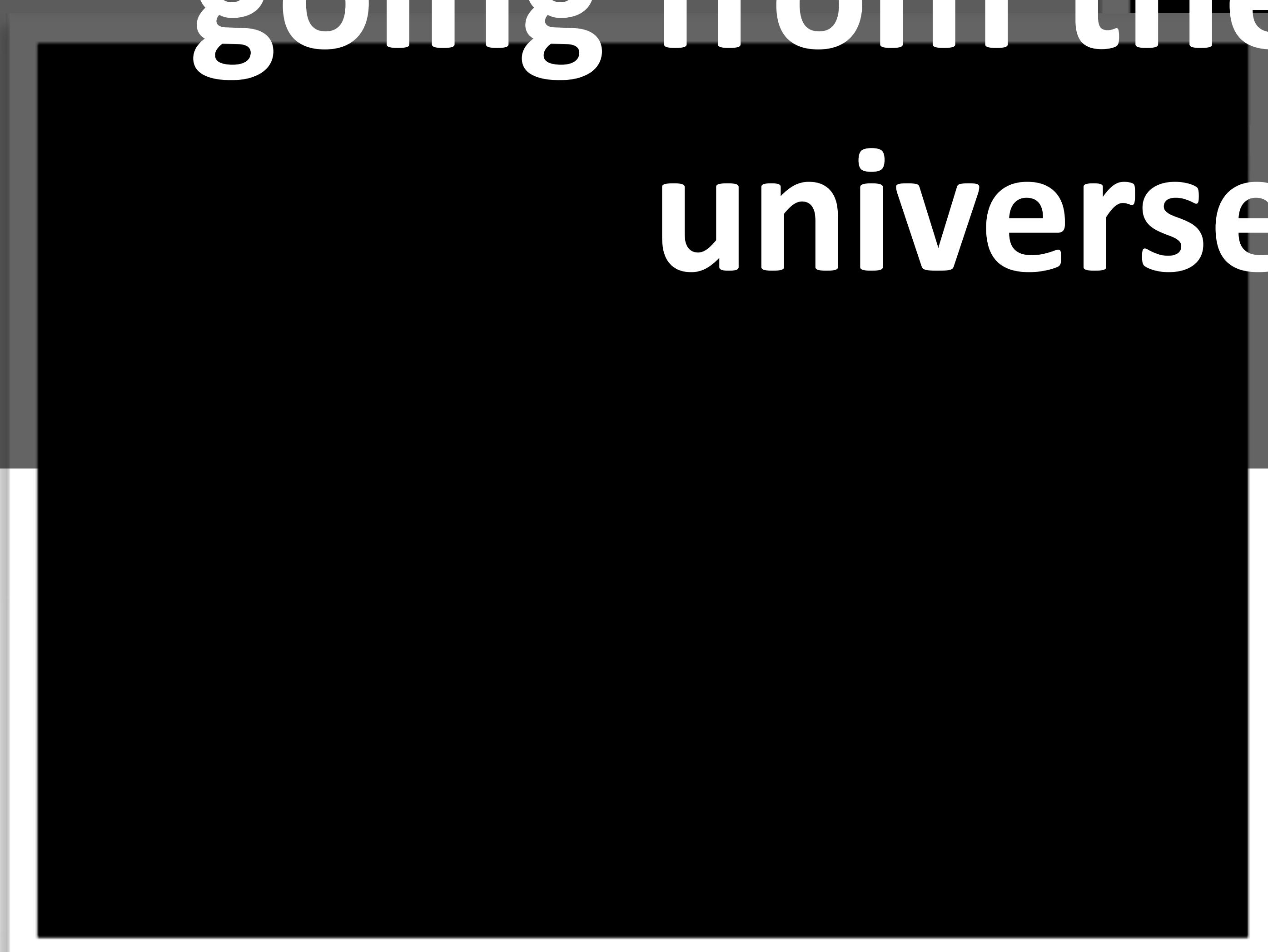
Data: the 2MASS survey



Data: WMAP

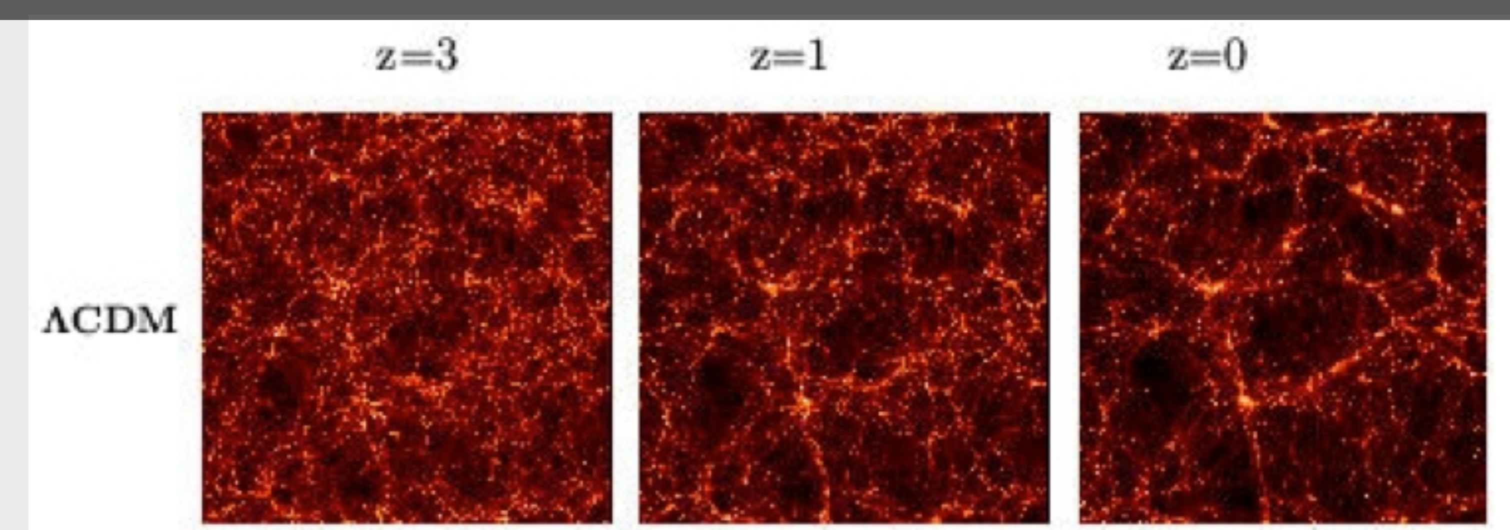


going from the CMB variations to a universe is understood



Bolshoi Simulation compared with Sloan

Simulation: Virgo Collaboration



All use data-based assumptions about Dark Matter and the CMB data as a starting point

the problem is

what’s the source of the CMB structure?

problem #4

the antimatter problem.

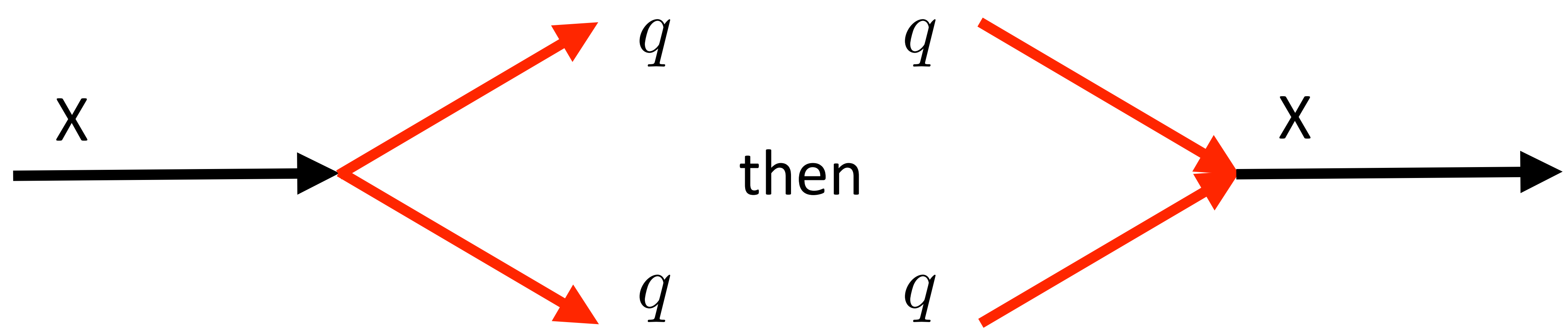
we have only a few ideas about this

all involve **new forces** of nature

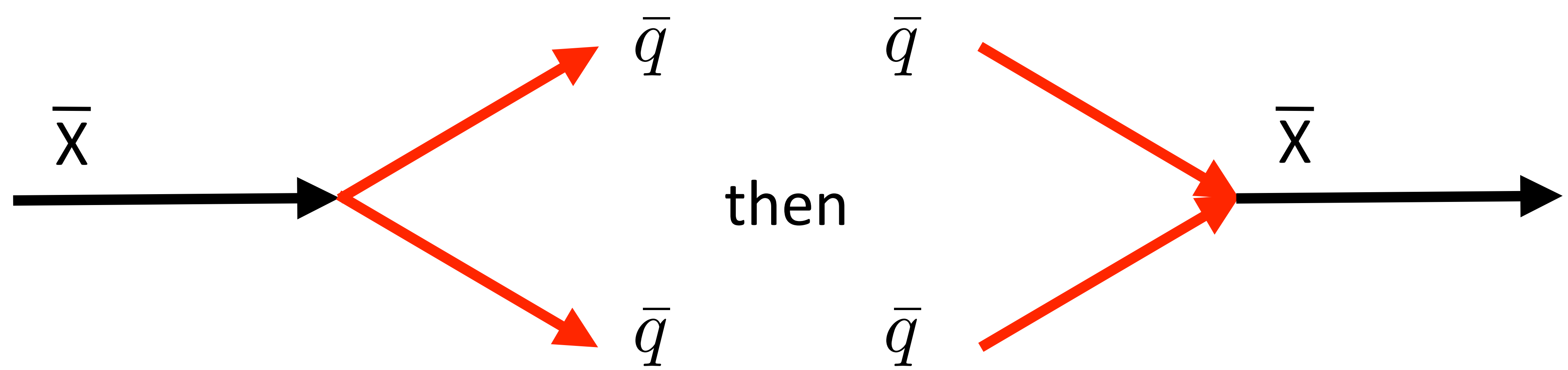
some new particles, X

In the very early universe:

This reaction has to go faster:



than this one:



and X has to be very heavy

A feature of most “Grand Unified Theories” GUTs

And a target of intense experimental searching!

likewise a new force of nature

to provide a quantum for Dark Matter fields

a particle to be found.

BTW:

What Banged?

there is a favored solution to

Horizon, Flatness, Structure...and indirectly, antimatter problems

another phase transition...**the Mother of All Phase Transitions!**

Inflation

supercooling and superheating

taken something out of the microwave and had it explode?

or

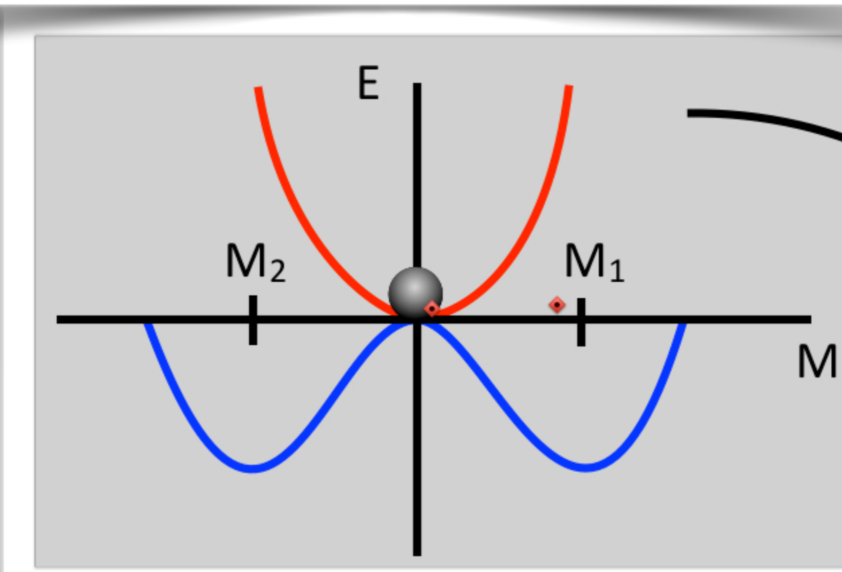
taken a bottle of water out of the freezer and had it suddenly freeze?

Called Superheating and Supercooling...

A substance above its boiling point...and not boiling

or below its freezing point...and not freezing.

like the magnet!
like the Higgs!...but 1st order
gives up energy

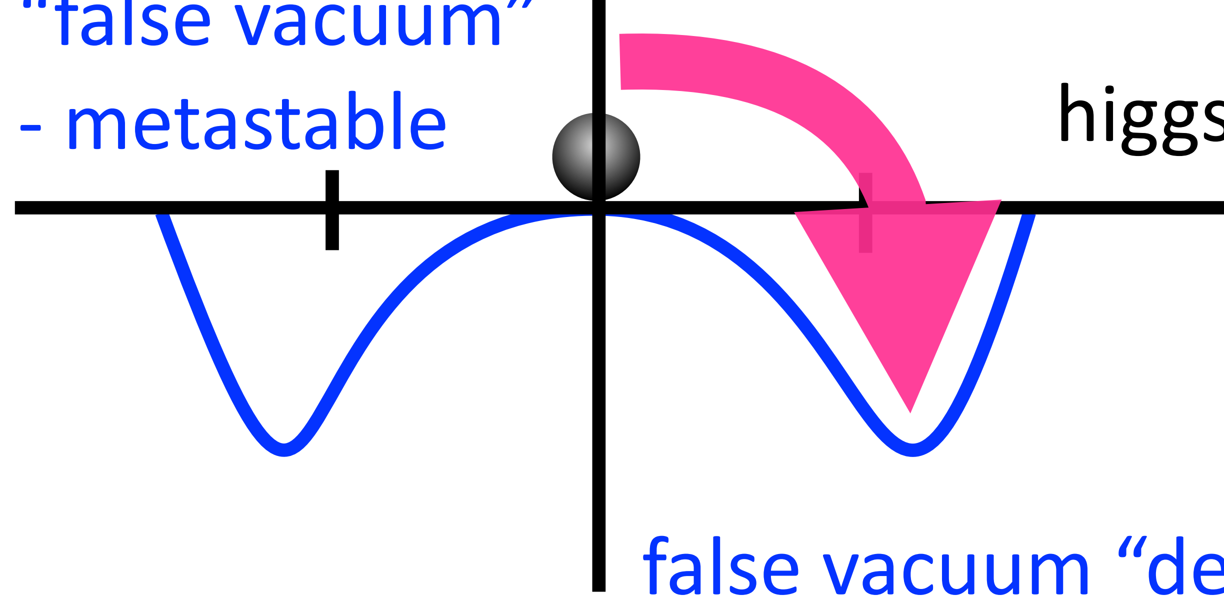


E (entire universe)

period of inflation

0.00000000000000000000000000000000000000001 to
0.000000000000000000000000000000000000001 s

“false vacuum”
- metastable



higgs-like field...the “**Inflaton**”

energy is released --> Λ!

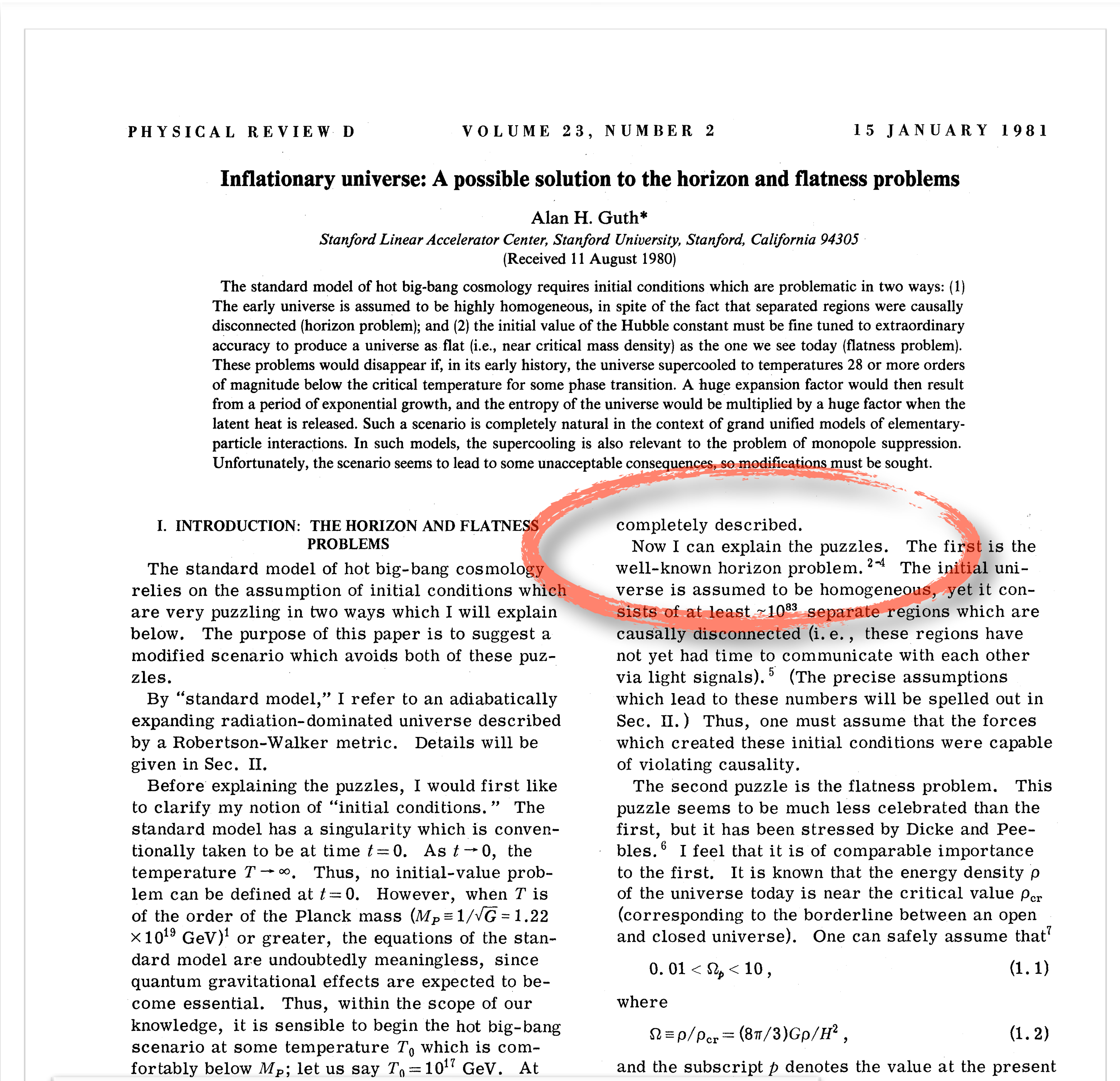
false vacuum “decays” into a cold universe
vacuum full of the Inflaton Field

negative pressure

like anti-gravity

ENORMOUS expansion of the universe

"Inflation"...idea of post doc Alan Guth 1980



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Inflationary universe: A possible solution to the horizon and flatness problems

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(Received 11 August 1980)

The standard model of hot big-bang cosmology requires initial conditions which are problematic in two ways: (1) The early universe is assumed to be highly homogeneous, in spite of the fact that separated regions were causally disconnected (horizon problem); and (2) the initial value of the Hubble constant must be fine tuned to extraordinary accuracy to produce a universe as flat (i.e., near critical mass density) as the one we see today (flatness problem). These problems would disappear if, in its early history, the universe supercooled to temperatures 28 or more orders of magnitude below the critical temperature for some phase transition. A huge expansion factor would then result from a period of exponential growth, and the entropy of the universe would be multiplied by a huge factor when the latent heat is released. Such a scenario is completely natural in the context of grand unified models of elementary-particle interactions. In such models, the supercooling is also relevant to the problem of monopole suppression. Unfortunately, the scenario seems to lead to some unacceptable consequences, so modifications must be sought.

I. INTRODUCTION: THE HORIZON AND FLATNESS PROBLEMS

The standard model of hot big-bang cosmology relies on the assumption of initial conditions which are very puzzling in two ways which I will explain below. The purpose of this paper is to suggest a modified scenario which avoids both of these puzzles.

By "standard model," I refer to an adiabatically expanding radiation-dominated universe described by a Robertson-Walker metric. Details will be given in Sec. II.

Before explaining the puzzles, I would first like to clarify my notion of "initial conditions." The standard model has a singularity which is conventionally taken to be at time $t=0$. As $t \to 0$, the temperature $T \to \infty$. Thus, no initial-value problem can be defined at $t=0$. However, when T is of the order of the Planck mass ($M_P \equiv 1/\sqrt{G} = 1.22 \times 10^{19}$ GeV)[1] or greater, the equations of the standard model are undoubtedly meaningless, since quantum gravitational effects are expected to become essential. Thus, within the scope of our knowledge, it is sensible to begin the hot big-bang scenario at some temperature T_0 which is comfortably below M_P; let us say $T_0 = 10^{17}$ GeV. At

completely described.

Now I can explain the puzzles. The first is the well-known horizon problem.[2-4] The initial universe is assumed to be homogeneous, yet it consists of at least $\sim 10^{83}$ separate regions which are causally disconnected (i.e., these regions have not yet had time to communicate with each other via light signals).[5] (The precise assumptions which lead to these numbers will be spelled out in Sec. II.) Thus, one must assume that the forces which created these initial conditions were capable of violating causality.

The second puzzle is the flatness problem. This puzzle seems to be much less celebrated than the first, but it has been stressed by Dicke and Peebles.[6] I feel that it is of comparable importance to the first. It is known that the energy density ρ of the universe today is near the critical value ρ_{cr} (corresponding to the borderline between an open and closed universe). One can safely assume that[7]

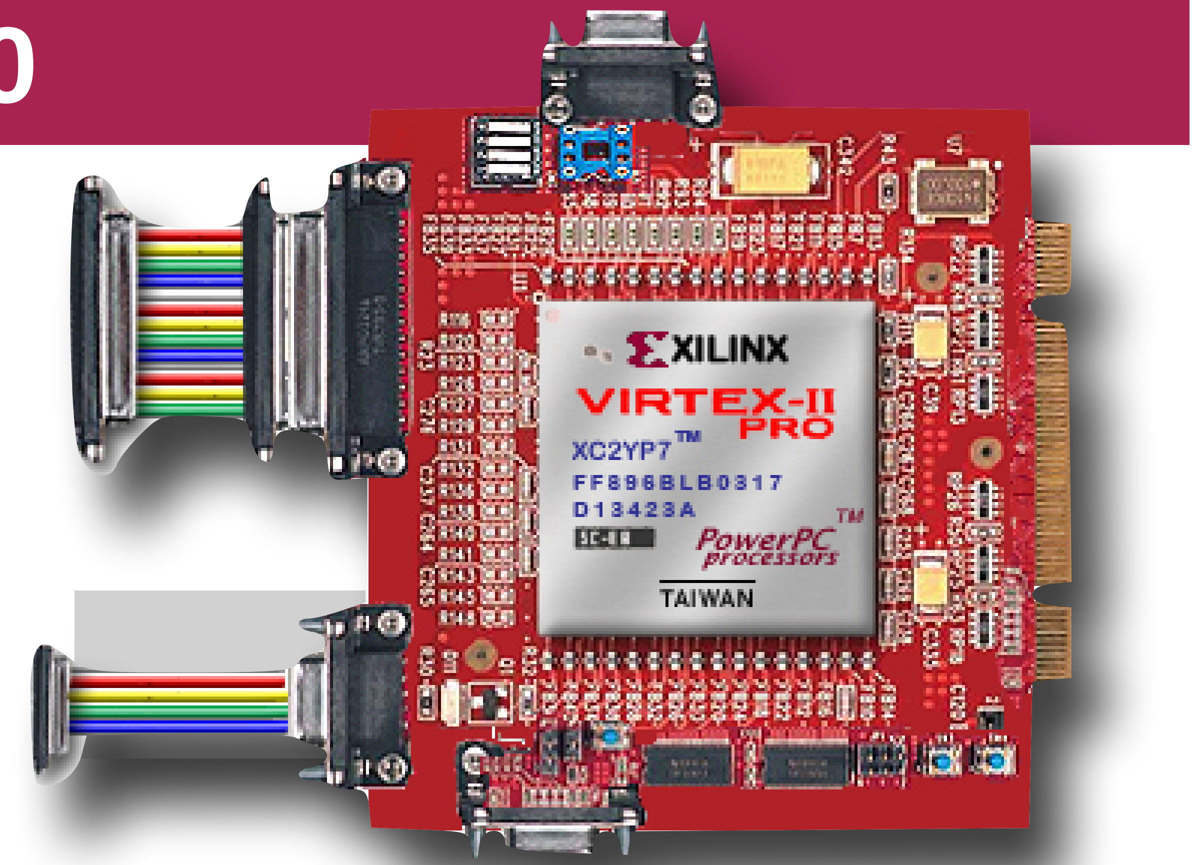
$$0.01 < \Omega_p < 10\,, \qquad (1.1)$$

where

$$\Omega \equiv \rho/\rho_{cr} = (8\pi/3)G\rho/H^2\,, \qquad (1.2)$$

and the subscript p denotes the value at the present

...ounds do not appear at first ...stringent, they, in fact, ...ons. The key point is that ...stable. Furthermore, the ...ppears in the equations for ...niverse is the Planck time, ...A typical closed universe ...size on the order of this ...cal open universe will ...much less than ρ_{cr}. A universe ...years only by extreme fine ...es of ρ and H, so that ρ is ...initial conditions taken at



Expansion is exponential:

Size of observable universe increases by 10^{50} times

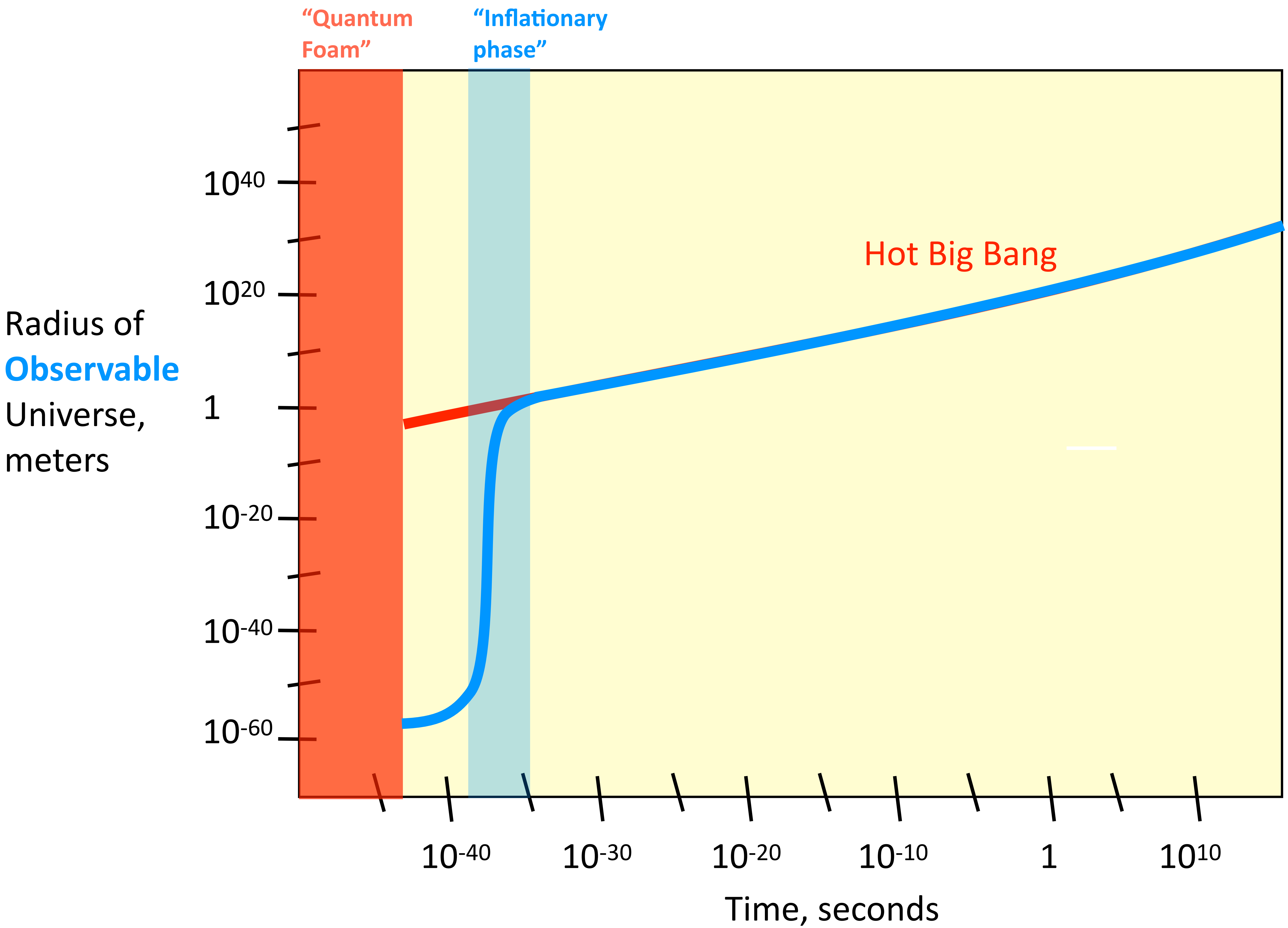
All by considering the universe to have undergone a 1st order phase transition.

What happens to the **Inflaton**?

It decays into the positive energy particles that begin the Hot Big Bang...reheating the universe... in the GUT phase

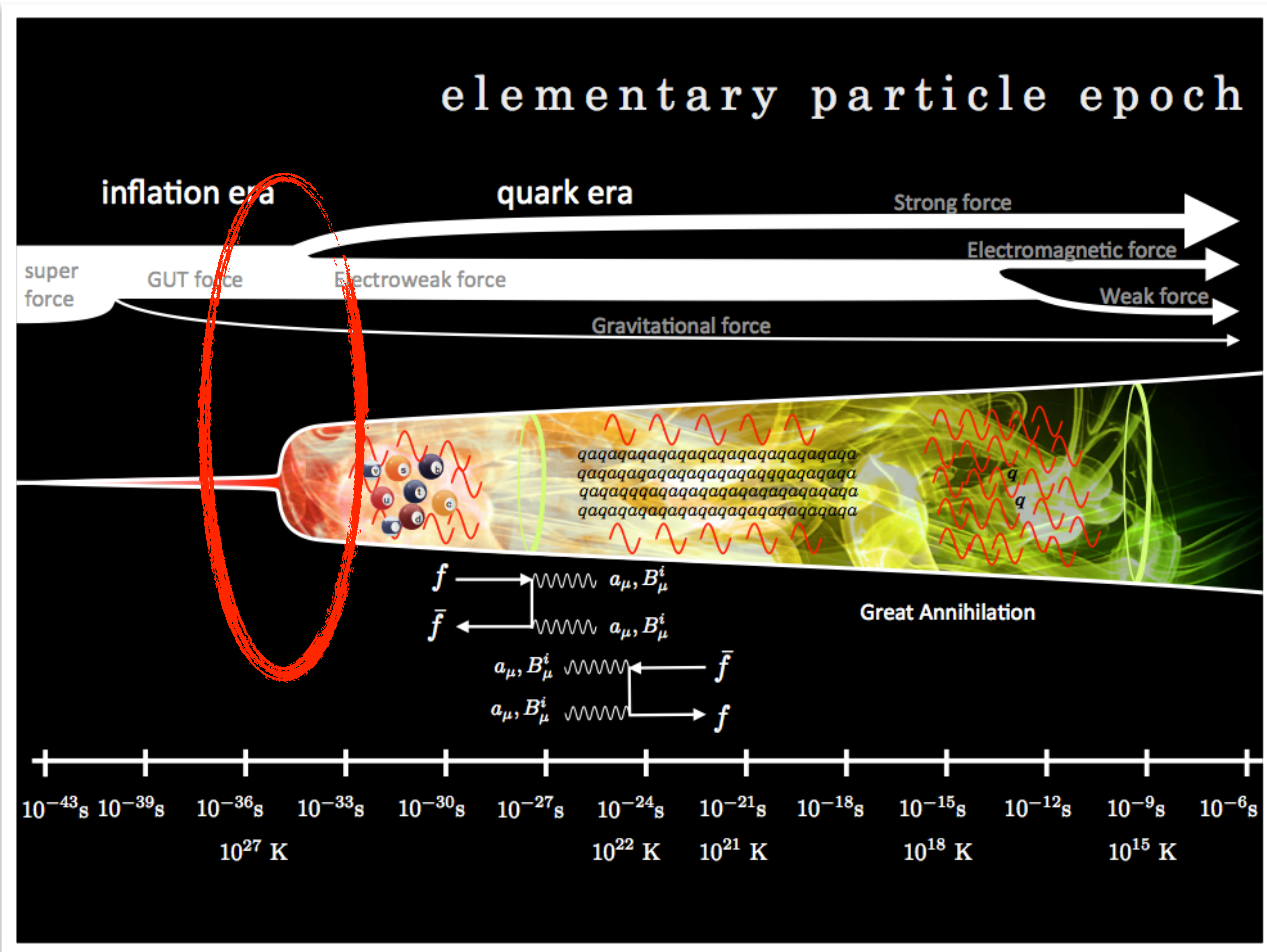
Remember the name: Alan Guth.

Size of the Observable Universe? take 2.



Inflation

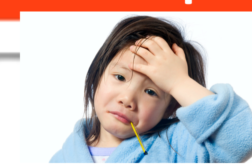
the phase transition that was responsible for separating the strong from the electroweak, fueled the inflationary phase?



‘‘Inflation’’

The whole universe was in “communication” and temperature evened out early.

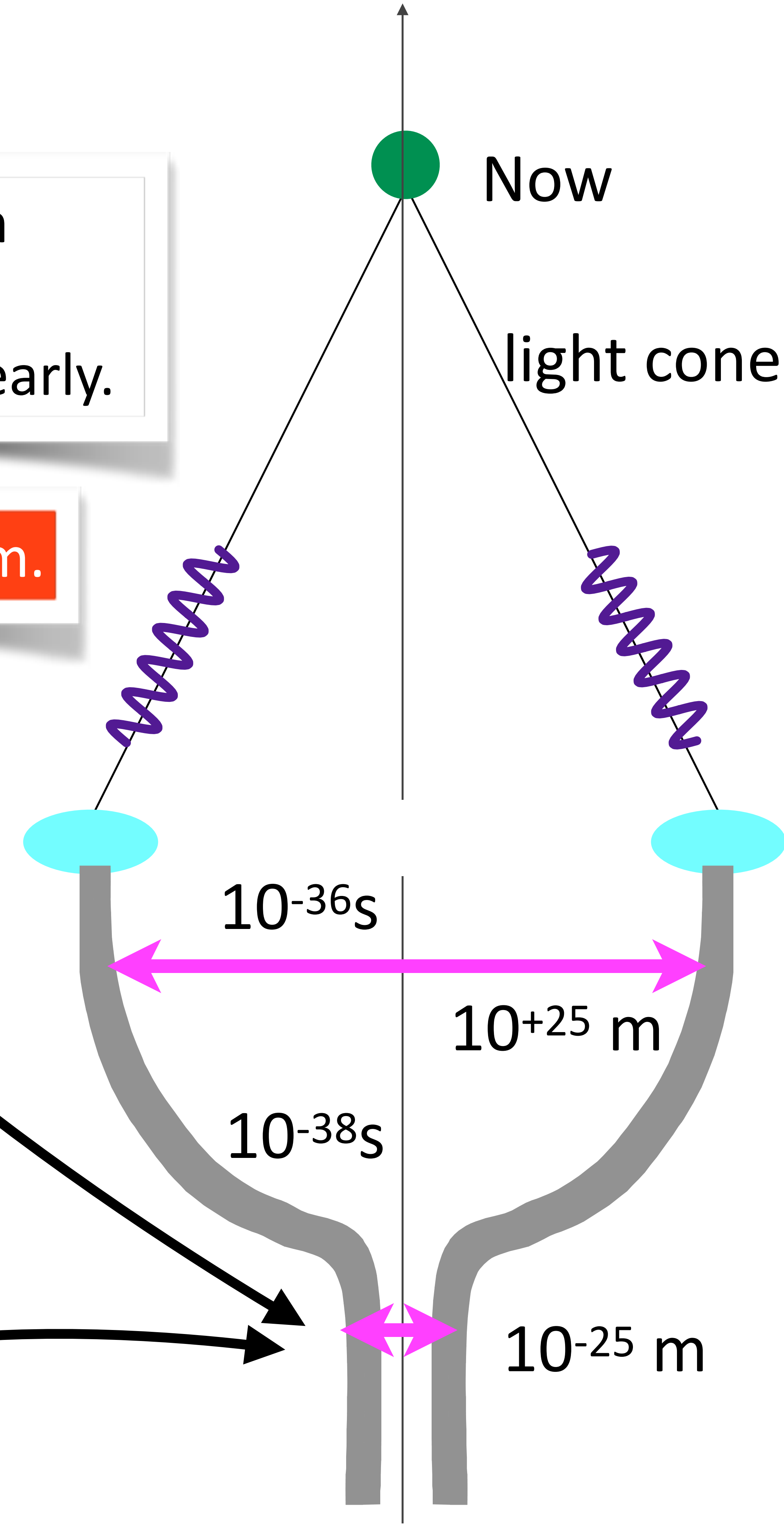
solves the horizon problem.



expands the size of the universe over 50 orders of magnitude

in fraction of a second

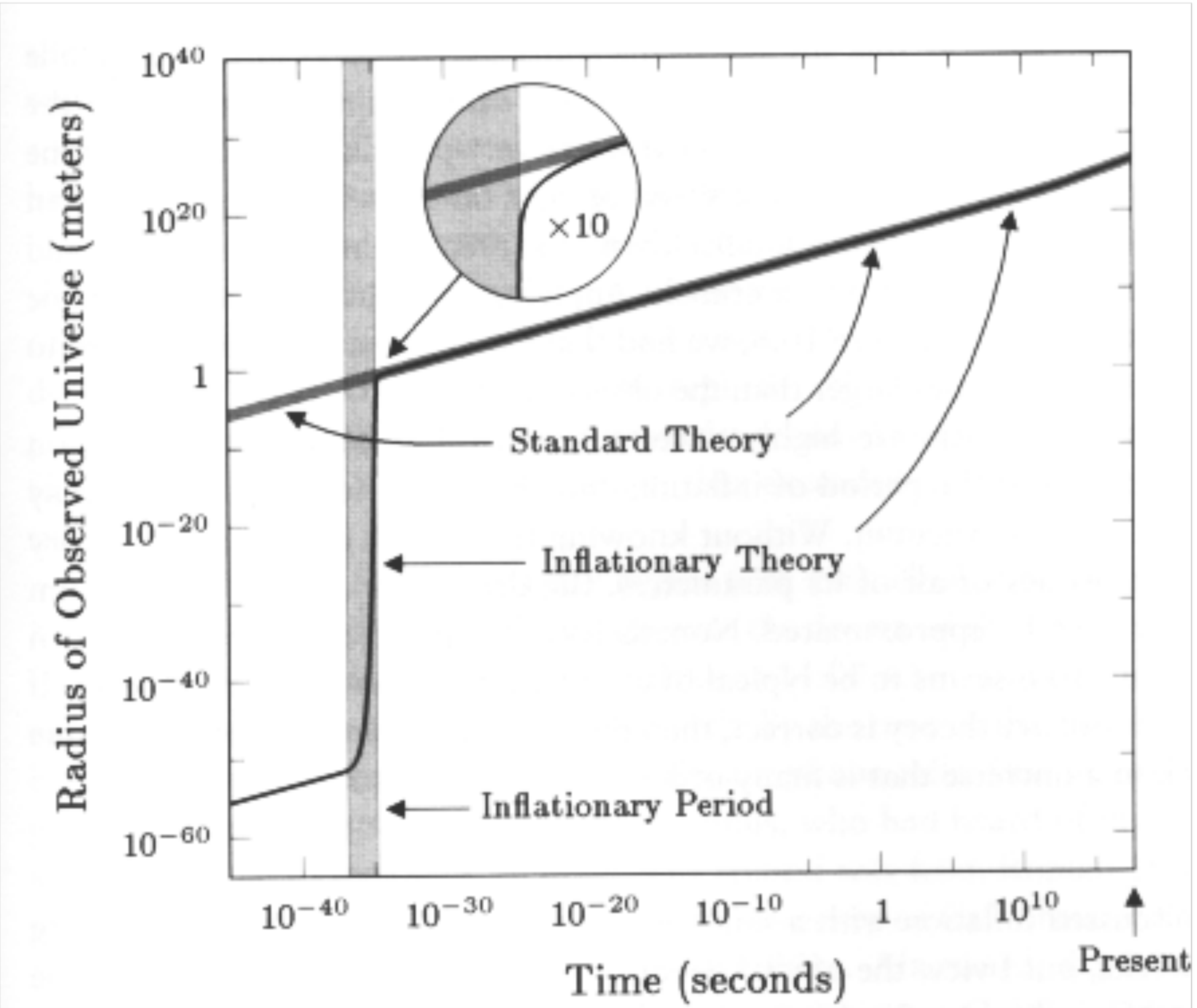
then

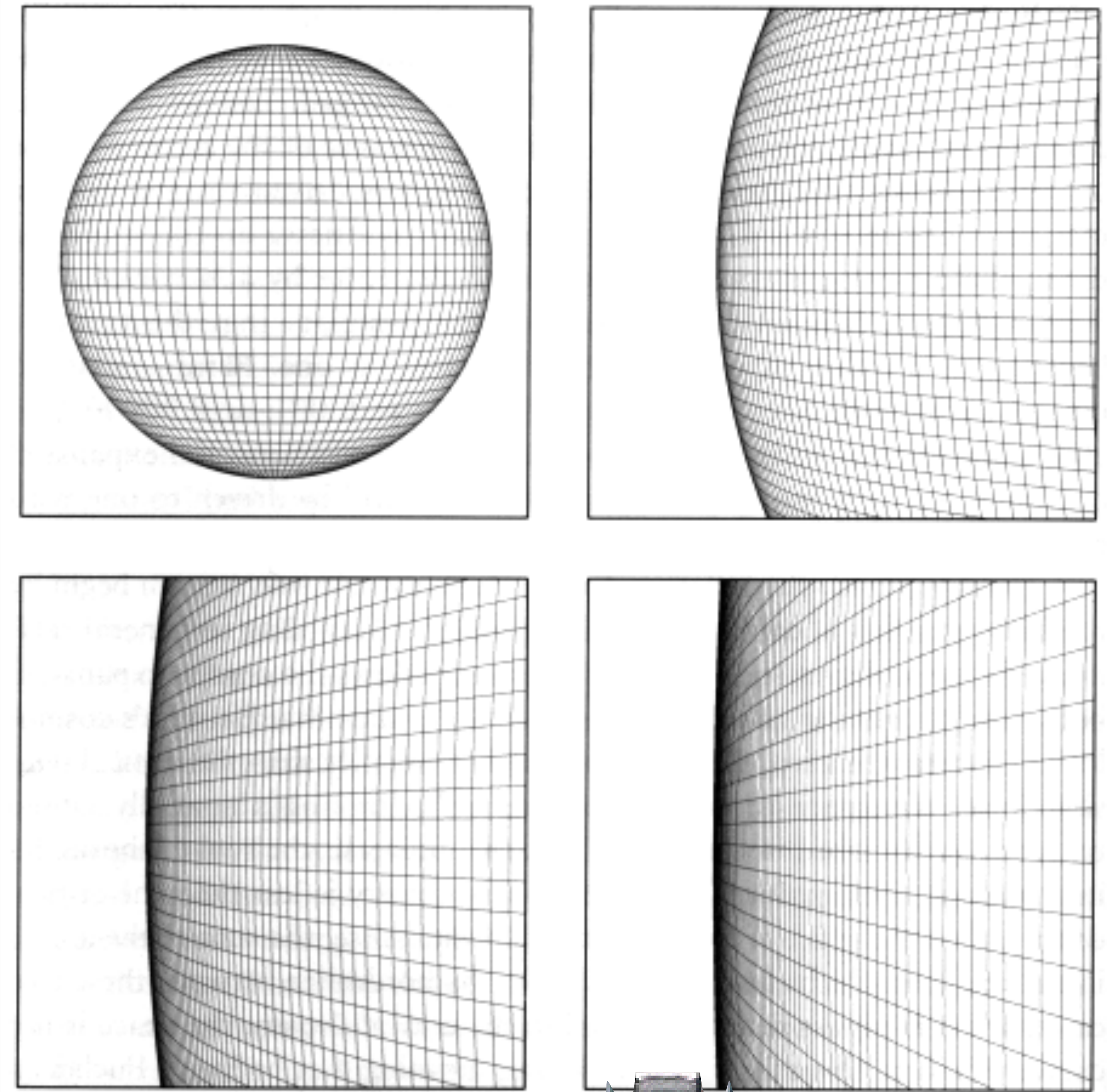


Quantum fluctuations are frozen as they inflate to macroscopic size

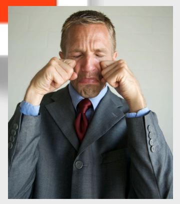
solves the structure problem.

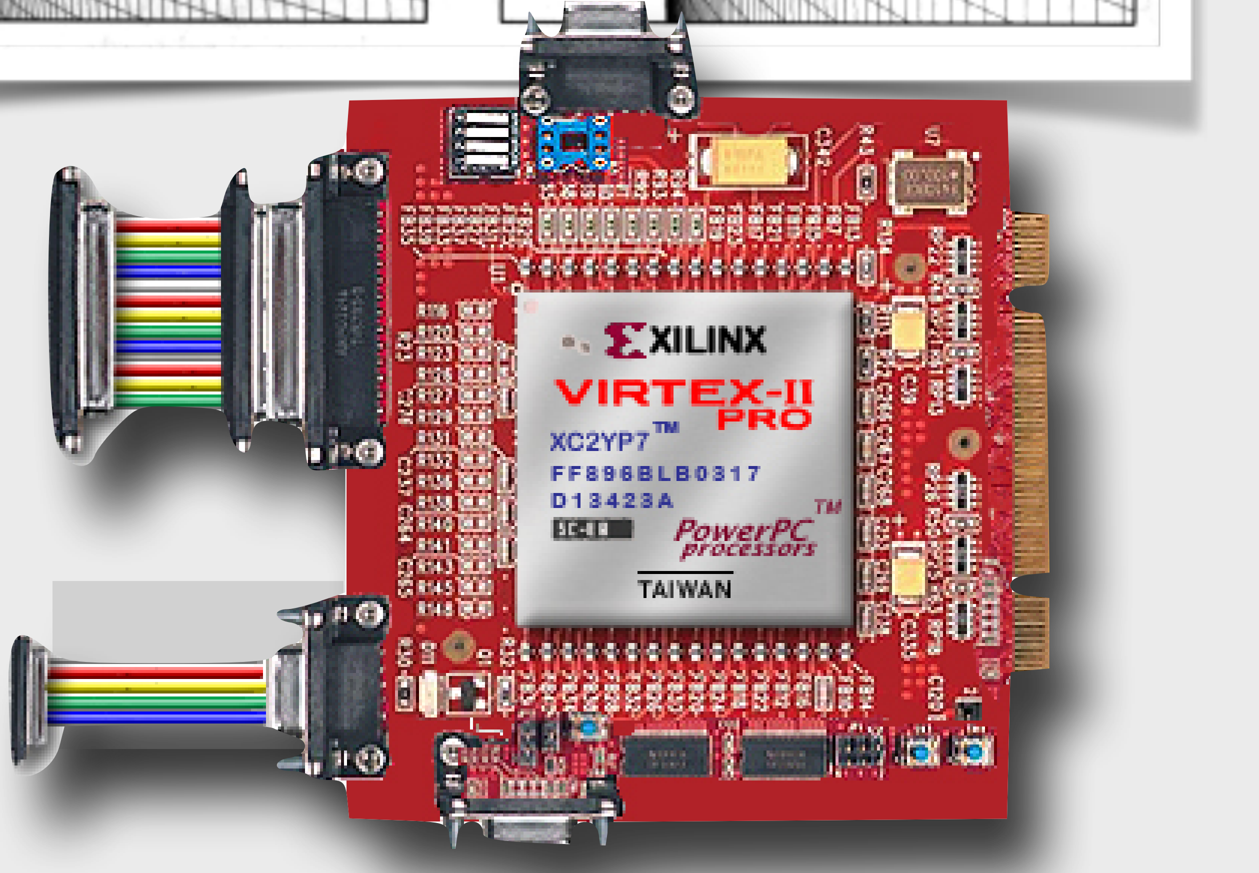
inflated so fast, as to make our neighborhood locally flat to 10^{-50}





solves the flatness problem.





In fact, inflation drives Ω = 1.000000000000000000000000 all of that energy that's given up

during the inflation stage

comes from the vacuum

and creates all matter and energy, leaving negative gravitational energy

the Universe might not have needed anything to start... except nothing

The total energy of the system? Zero.

"Free lunch theorem"

what banged?

nothing.

Inflation even accounts for the "Bang" in Big Bang!

Inflation

Solves all of the problems with the Standard Big Bang model

except the antimatter problem…

but requires GUTS, which usually does solve the antimatter problem

Provides a reason for the “bang”

Uses primordial phase transitions, ala Higgs in particle physics

quantum fluctuations as the means of getting it all started

Of course the issue is: Is Inflation the case?

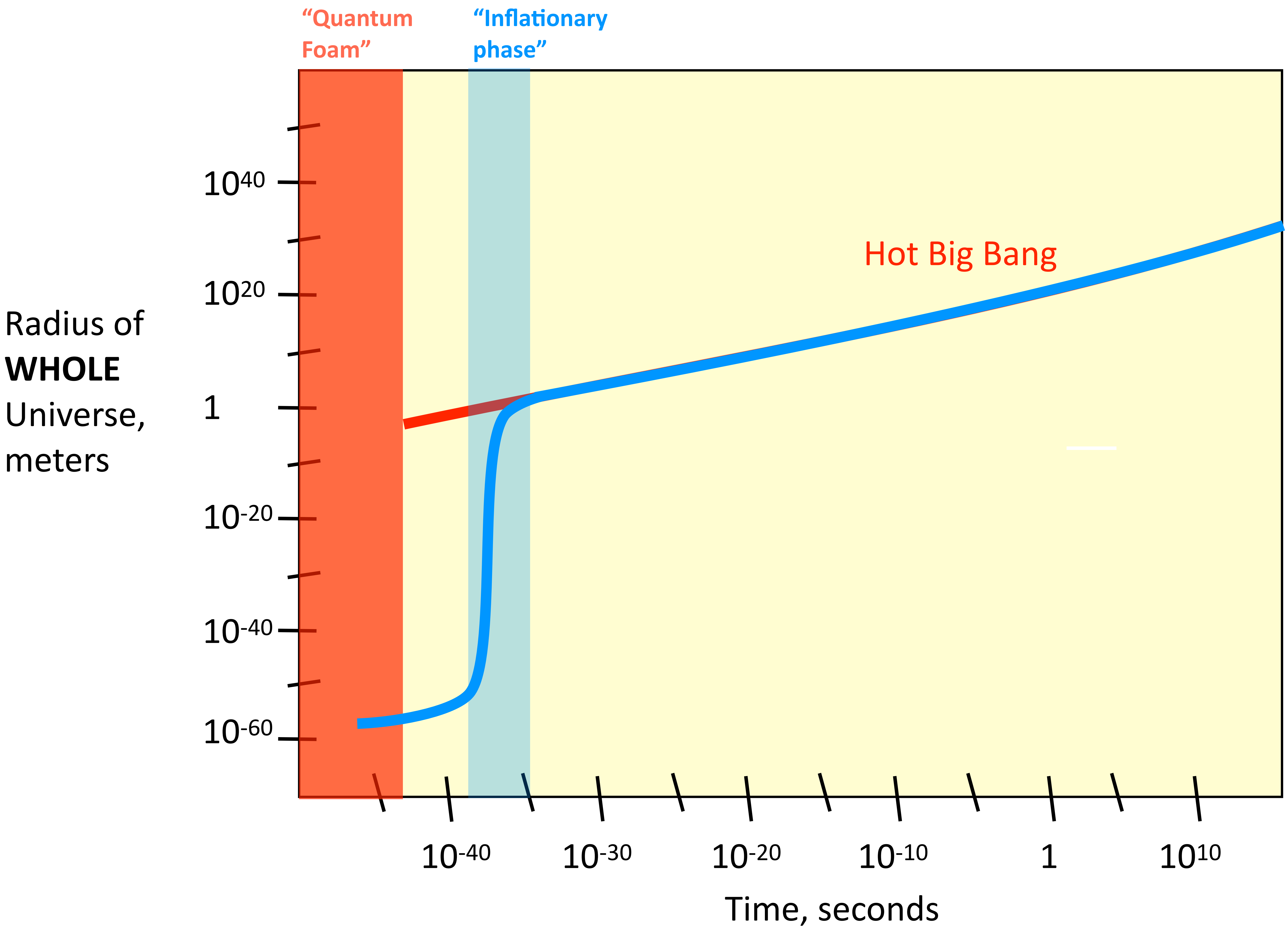
another

blessing-curse thingy

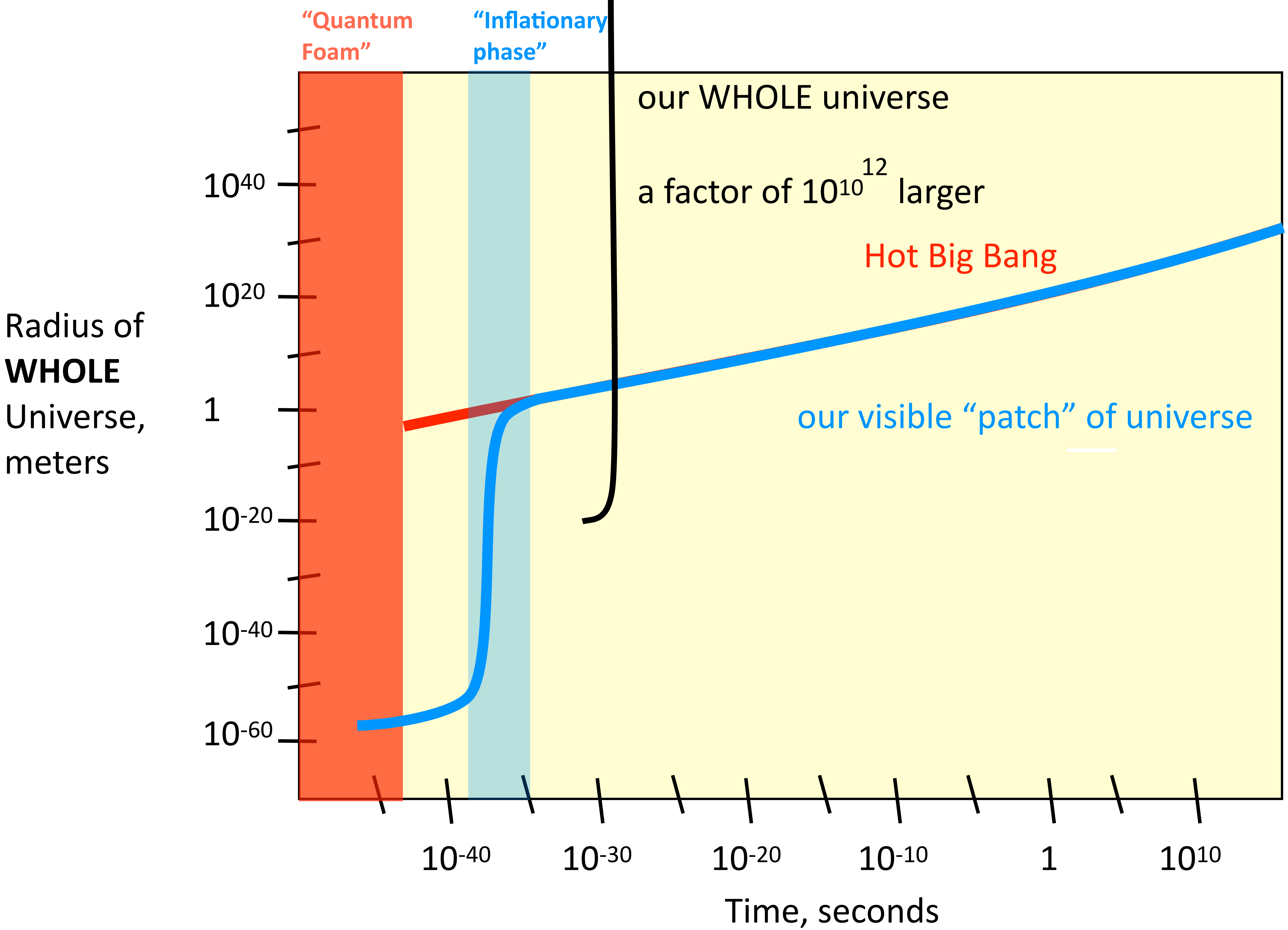
the actual universe must be huge

our visible part a tiny fraction

Size of the **WHOLE** Universe? take 3.



Size of the **WHOLE** Universe? take 3.



`another`

blessing-curse thingy

can’t stop inflation

from happening all the time, randomly, forever

lemons and lemonade

also have particle physics issues:

why are the constants of nature so precise?

and yet so apparently random?

remember string theories?

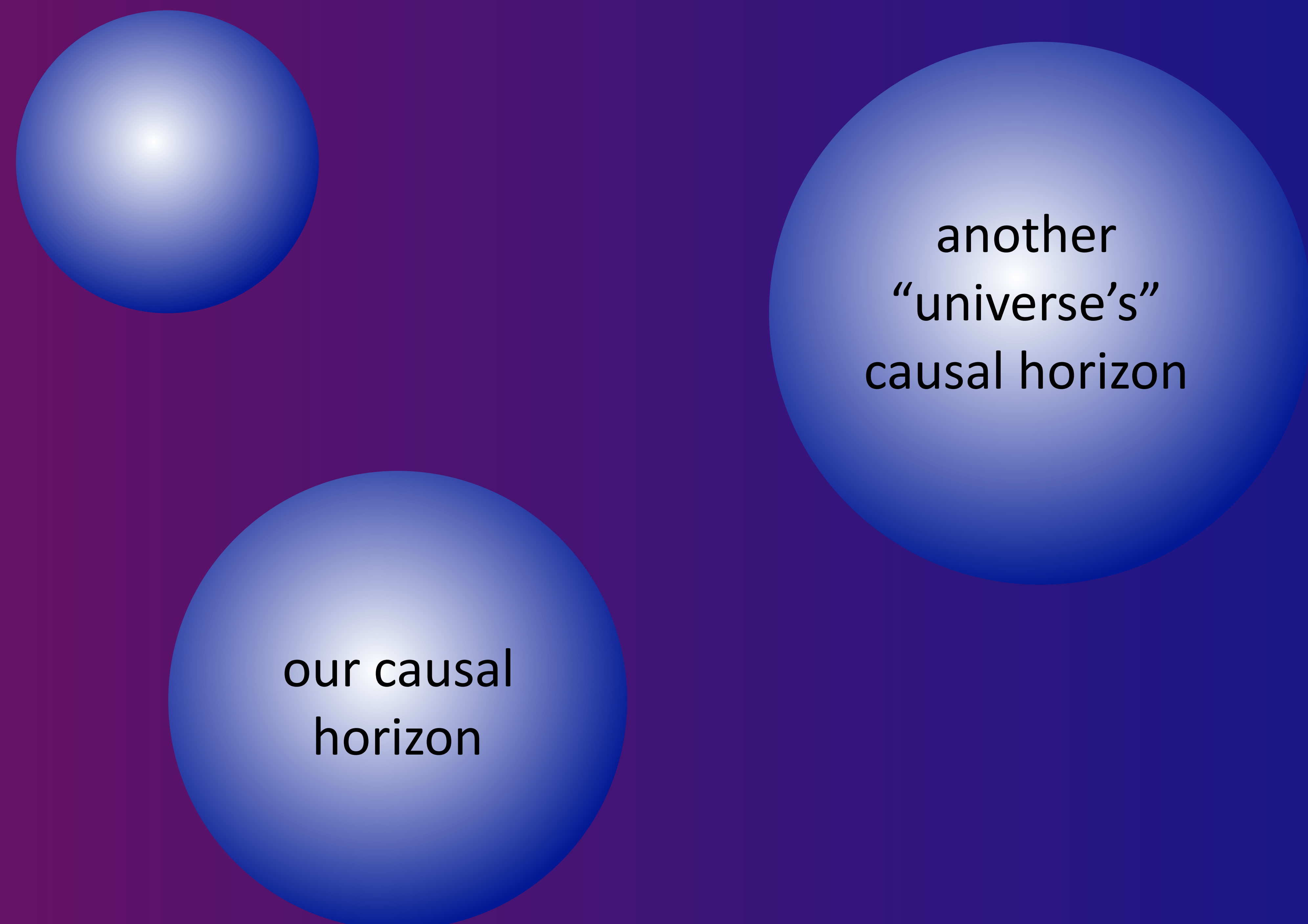
there are conservatively 10^{500} different vacuum solutions

WOO-HOO!

that's good!

for some

The “multiverse idea”

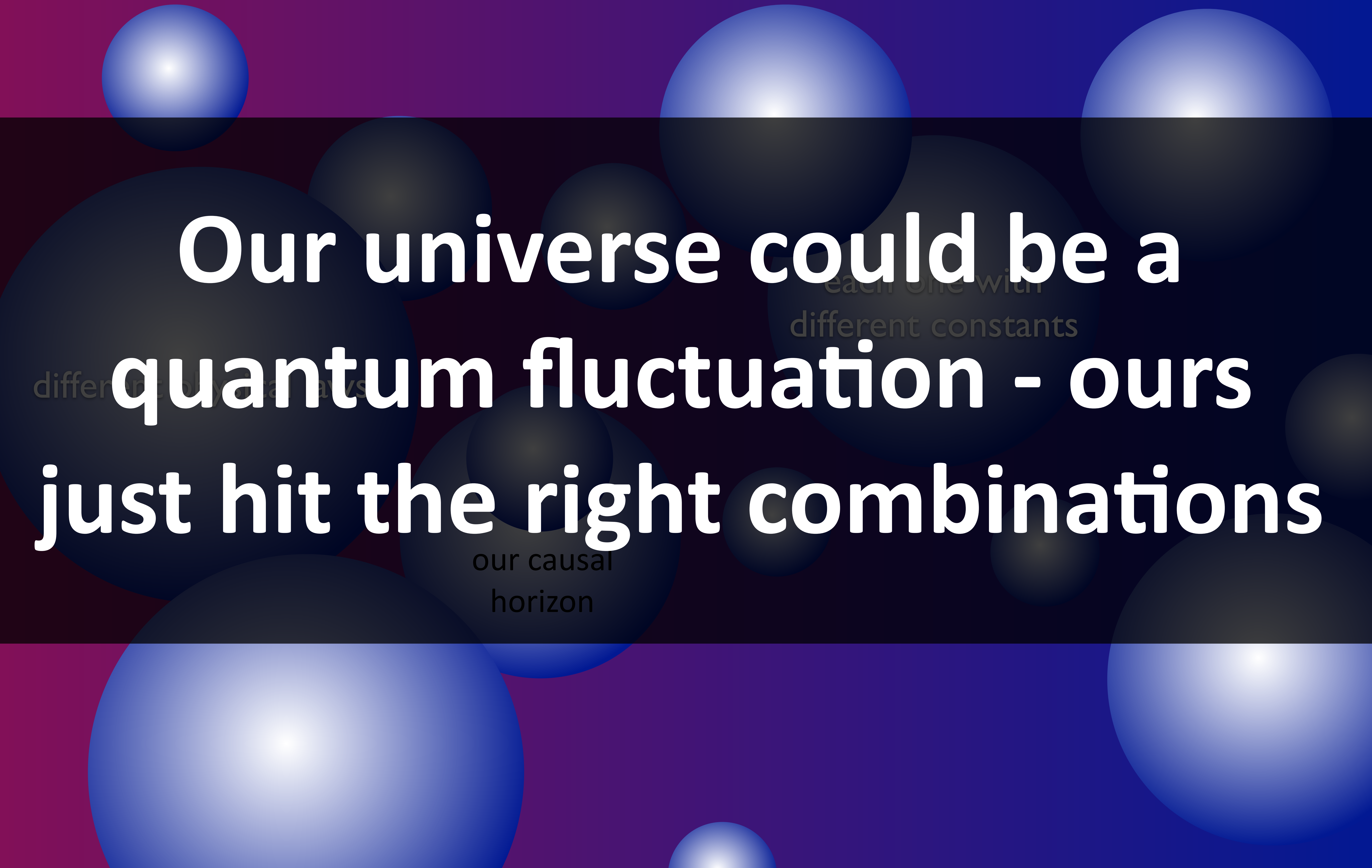


Other “universes” might have different physics
Is this how (not why) our universe supports us...? Could we be a random event?
The enormous number of others would be randomly produced with physics that couldn’t.

inflation is a quantum mechanical theory

quantum mechanically random

Our universe could be a quantum fluctuation - ours just hit the right combinations



Steven Weinberg:

particle: **the universe**

symbol:    $

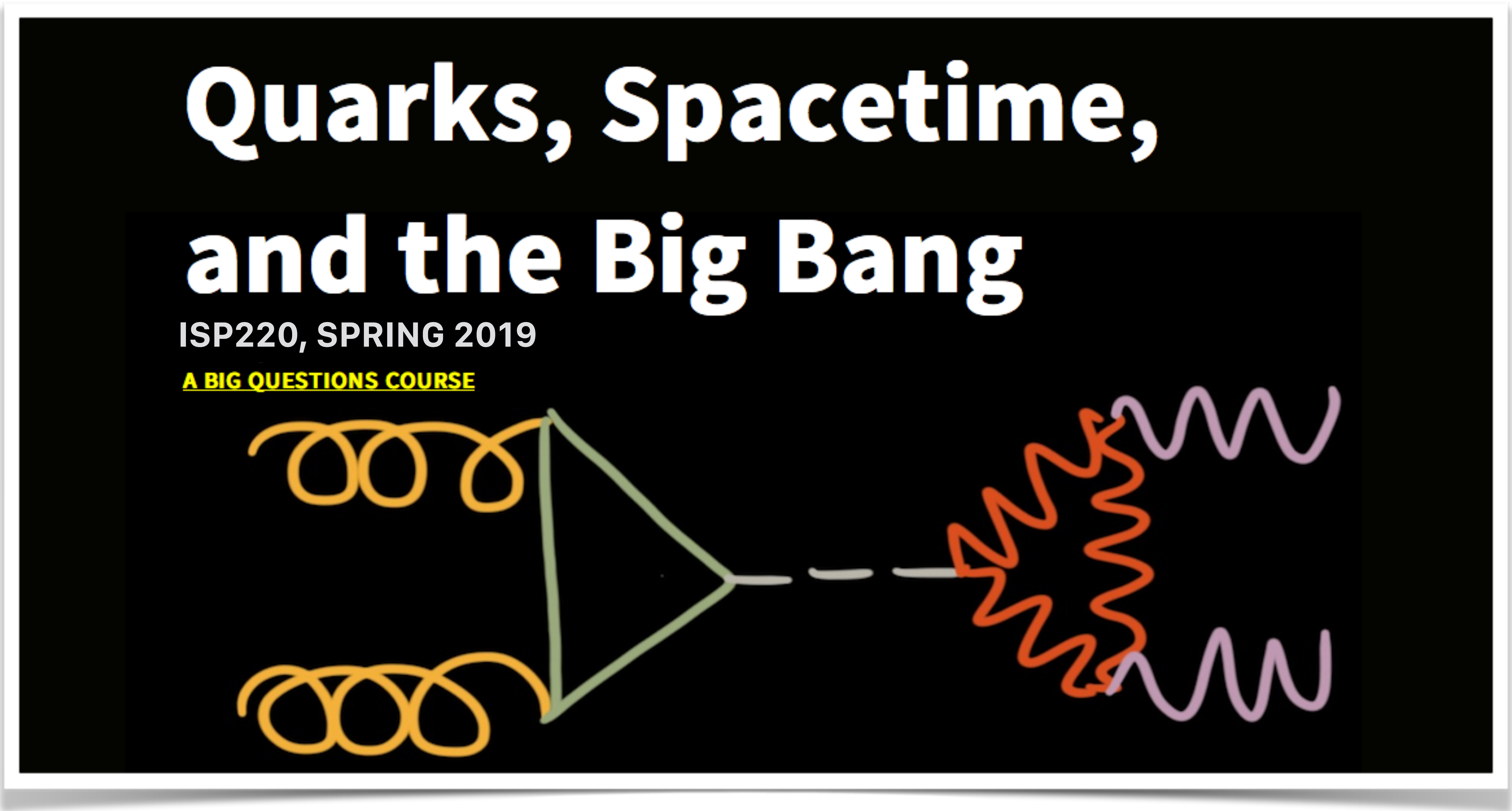
charge: 0

mass: 6×10^{51} kg

spin: ?

category: the one we’ve got

`bye`


Quarks, Spacetime,
and the Big Bang
ISP220, SPRING 2019
A BIG QUESTIONS COURSE

after ISP220 you know a lot now.

our universe continues to surprise.

you’ve seen how the unimaginable

becomes acceptable

scratch any of us hard-boiled physicists

we're pretty impressed with ourselves

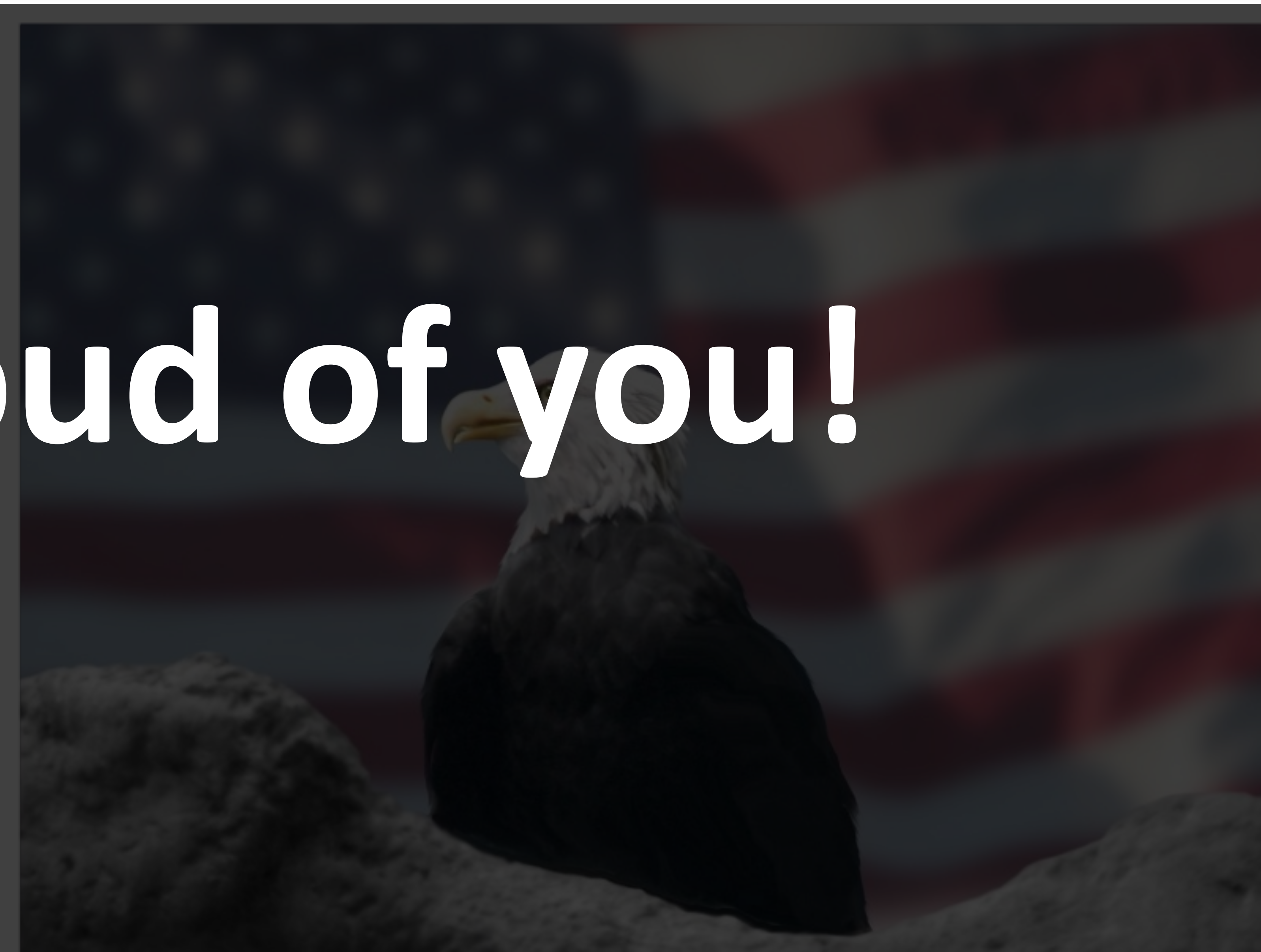
But mostly...we're in awe...every day

how incredibly gorgeous is our Universe

and what a privilege it is to study it.

you’re not physicists, so I know that you’re

brave and fearless to take this course.



I’m proud of you!

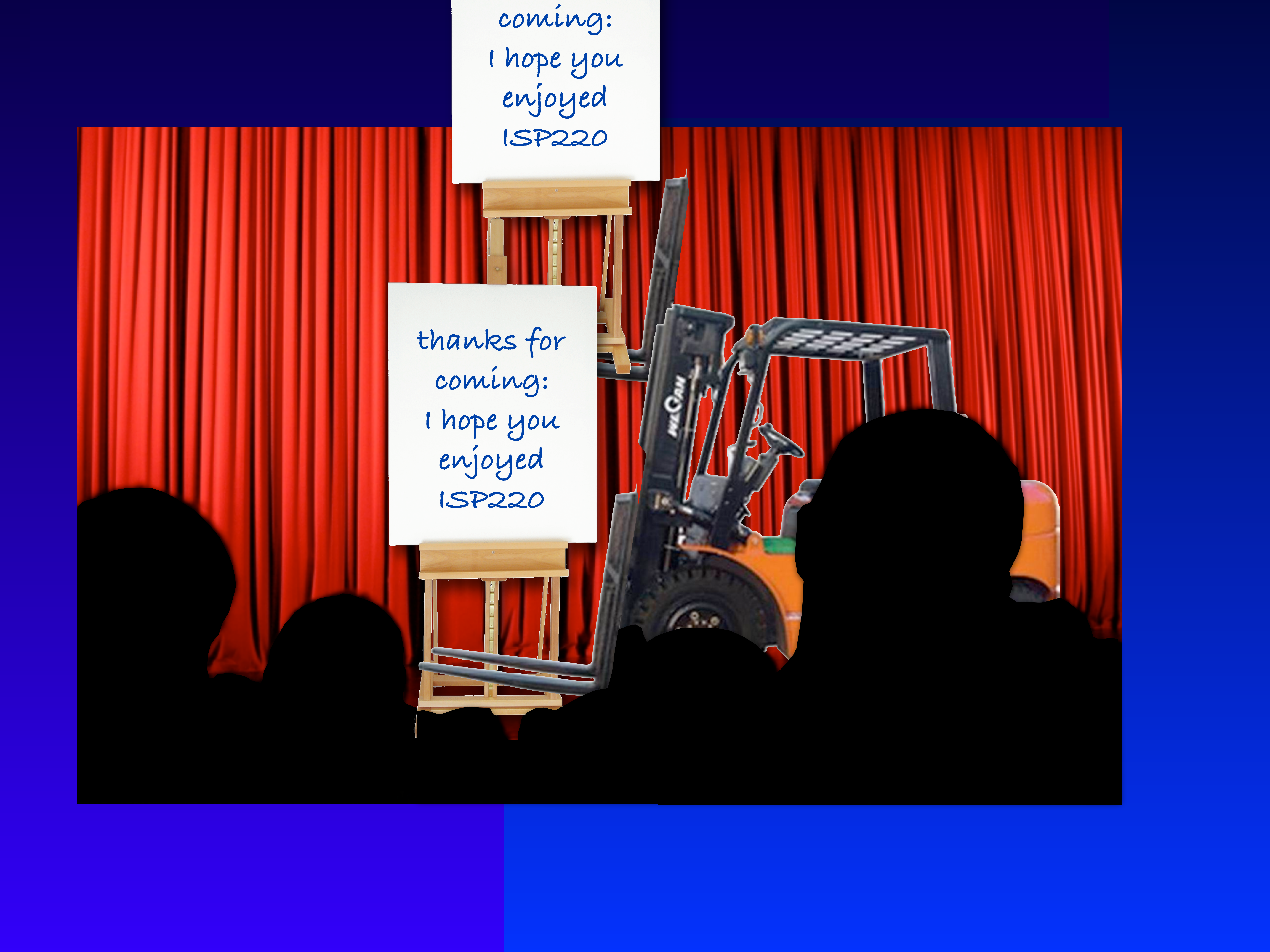
~~here are~~ were my goals

1. to learn some facts and theories about particle physics and cosmology.

2. to learn some tools and apply them in order to understand some experimental and theoretical techniques.

3. To meet some of the historical and contemporary physicists who have made important discoveries in these fields.

...and to immerse you in Science for 4 months.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