Varying c, cosmic structure and the quest for quantum gravity

João Magueijo
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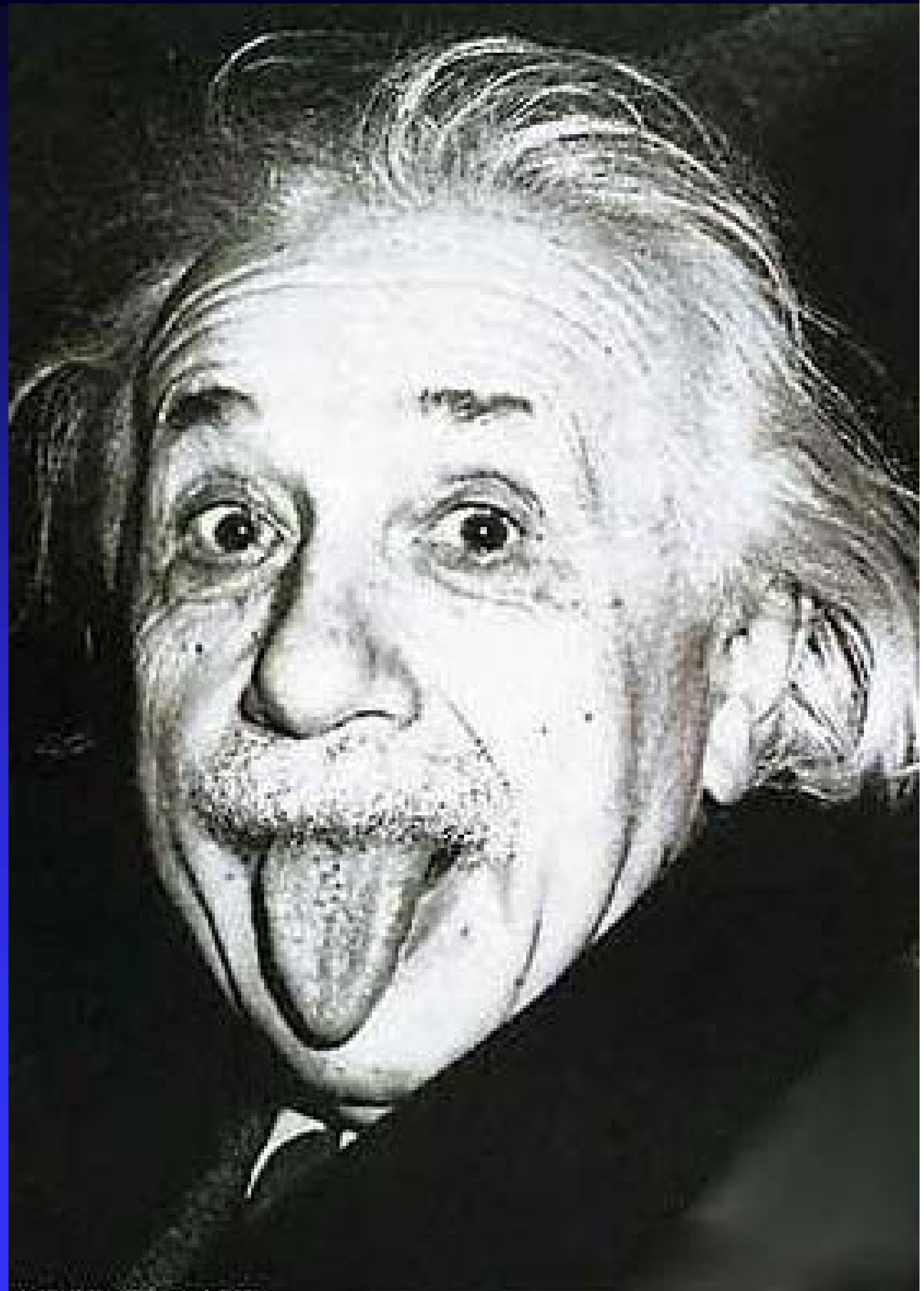
Imperial College, London

THE THEORY OF RELATIVITY

THE SPEED OF LIGHT

C

IS CONSTANT



How can the speed of light be the same for everyone?

- Space and time cannot be the same for everyone
- Time dilates for moving observers
- Moving objects shrink

Time dilation

Length contraction

The speed of light is a speed limit

This cartoon turns into the major scaffolding of modern physics

- The Principle of (Local) Lorentz Invariance
- The Principle of General Covariance

- BREAK IT AT YOUR PERIL

We face two major outstanding problems in “fundamental” physics:

- 1. The problem of the origin of the cosmic structure
- 2. The problem of quantum gravity

- Inflation? String theory?
- Something more radical?

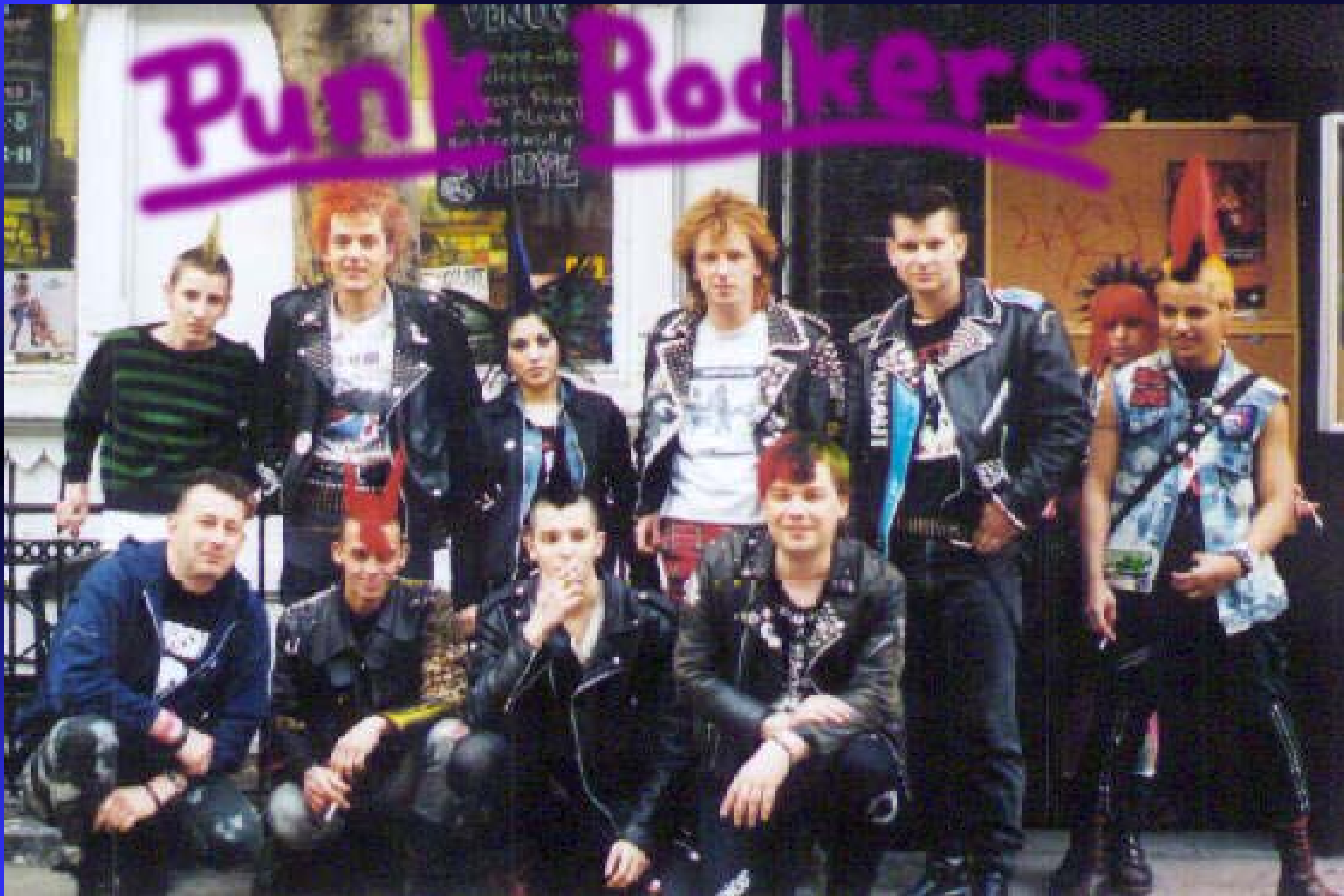
Radical solutions: why not?

- Because quite often they are worse than the conventional ones!

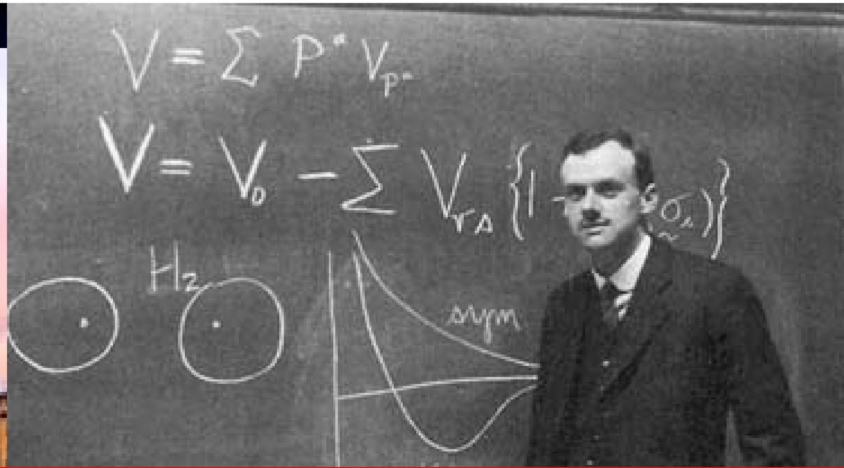
The danger is that we are potentially wrecking the whole building

Bandwagon science

The dangers of bandwagon science

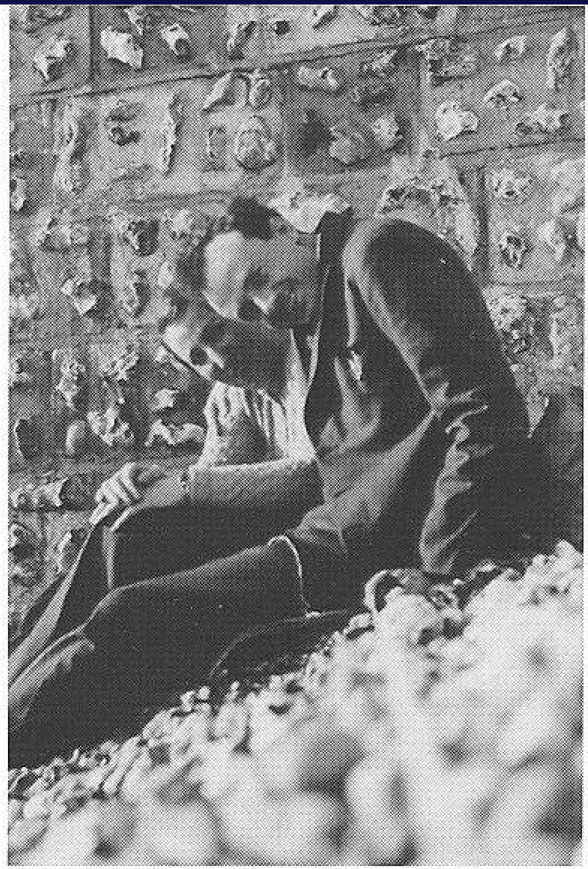

Punk Rockers


Budweiser Budvar
BUDWEISER



One field of work in which there has been too much speculation is cosmology. There are very few hard facts to go on, but theoretical workers have been busy constructing various models for the universe, based on any assumptions that they fancy. These models are probably all wrong. It is usually assumed that the laws of nature have always been the same as they are now. There is no justification for this. The laws may be changing, and in particular quantities which are considered to be constants of nature may be varying with cosmological time. Such variations would completely upset the model makers.

Paul Dirac



Dirac and Manci on their honeymoon, Brighton, January 1937

"Look what happens to people when they get married"
(Niels Bohr)

Why do constants of nature take their values?

$$\alpha = \frac{e^2}{\hbar c} \approx \frac{1}{137}$$

E

it is

$$\approx \frac{9}{8\pi^4}\left[\frac{\pi^5}{2^4 5!}\right]^{1/4}$$

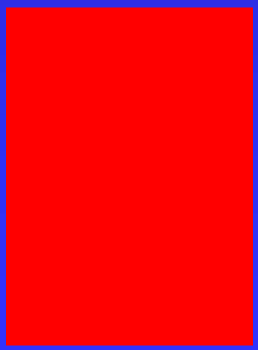
“Varying constant” theories

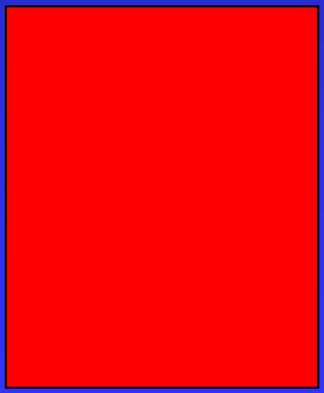
G

Brans-Dicke (1961)

e

Bekenstein (1982)





Varying c theories

c(x,t)

- Covariant and Lorentz invariant
  [Moffat,Magueijo, etc, etc]
- Bimetric theories [Moffat, Clayton, Drummond, etc, etc]
- Preferred frame [Albrecht, Magueijo,Barrow,etc,etc]

c(E)

- Deformed dispersion relations

  [Amelino-Camelia, Mavromatos, Magueijo & Smolin, etc, etc]

Bimetric theories

A metric for gravity (Einstein frame):

$$g_{\mu\nu} \xrightarrow{gravity} S = \int dx^4 \sqrt{-g}\, R$$

A metric for matter (matter frame):

$$\hat{g}_{\mu\nu} \xrightarrow{matter} S_m = \int dx^4 \sqrt{-\hat{g}}\, L(\hat{g}_{\mu\nu}, \Psi, etc)$$

Bimetric VSL: a rather conservative thing to do…

- If the two metrics are conformal, we have a varying-G (Brans-Dicke) theory

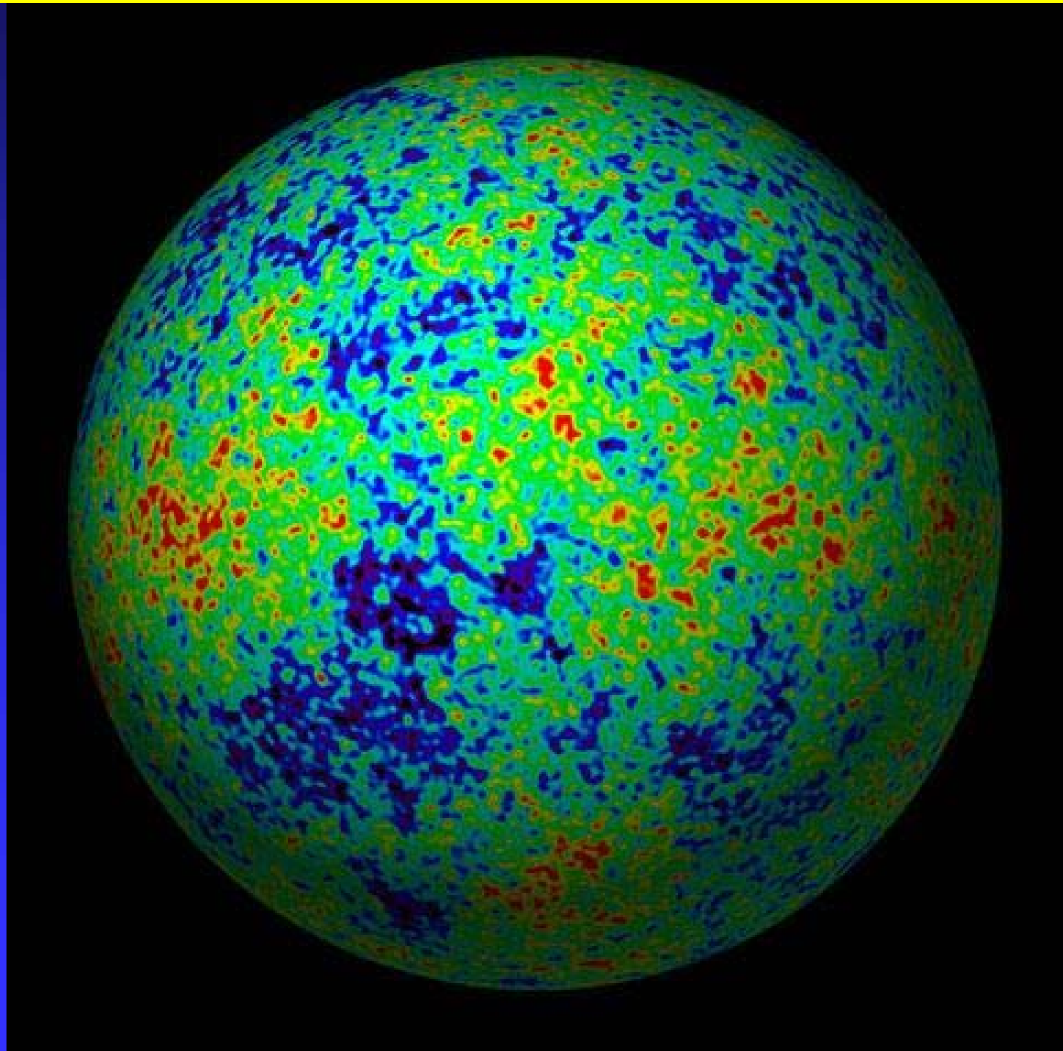
$$\hat{g}_{\mu\nu} = e^{\phi} g_{\mu\nu}$$

- If they are disformal we have a VSL theory

$$\hat{g}_{\mu\nu} = g_{\mu\nu} + B\partial_\mu\phi\partial_\nu\phi$$

- The speed of light differs from the speed of gravity (larger if B>0, with $+---$)

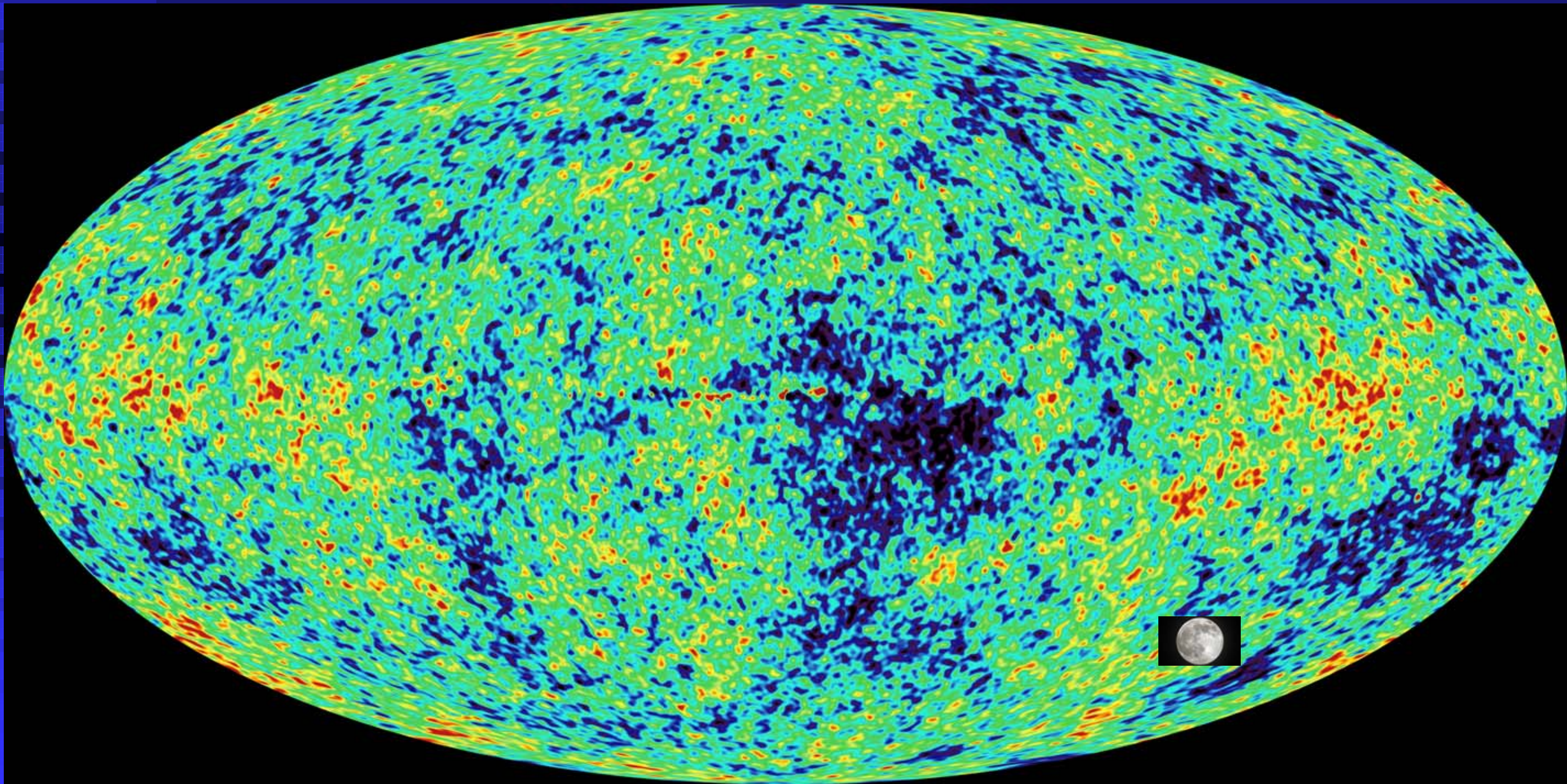
The Universe some 400,000 years after the Big Bang



The Universe is expanding!!!!!!!!

The universe came out of a BIG BANG

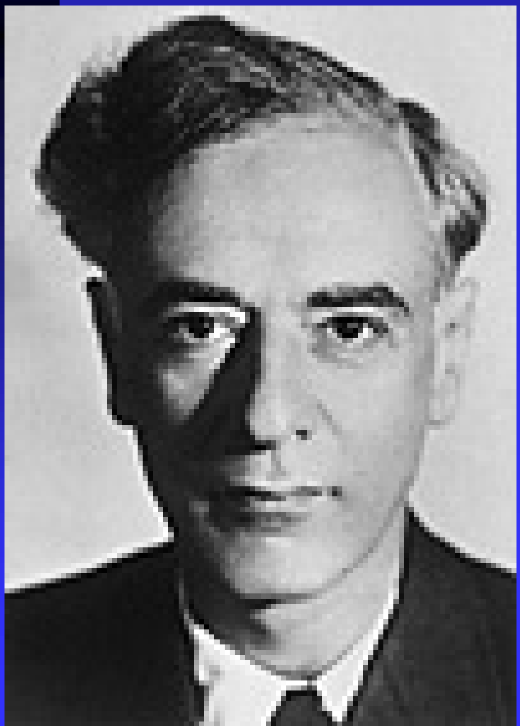
The universe is broken into disconnected “horizons”



The horizon problem

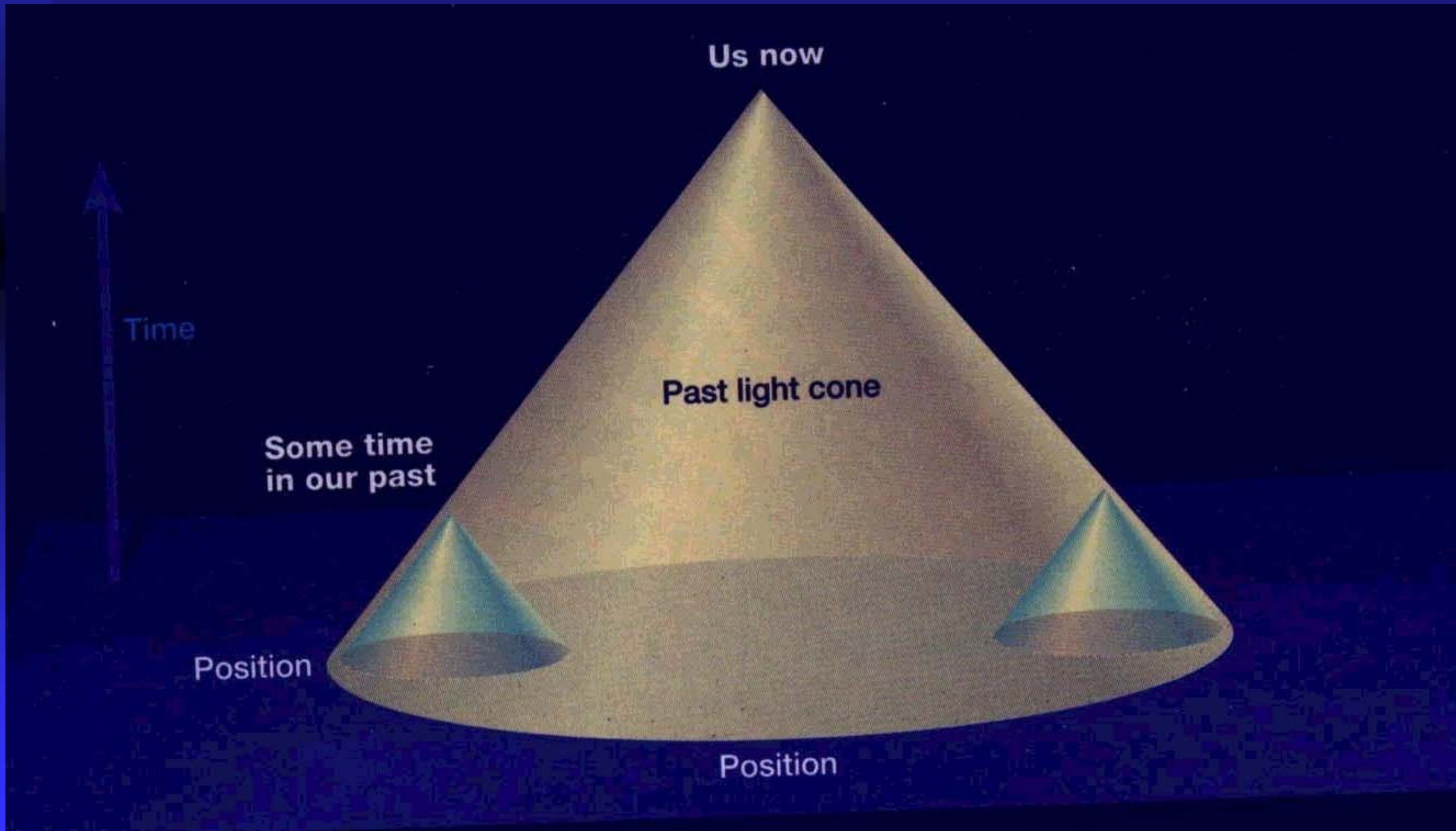
- The universe displays a unity that it has no right to have
- No physical mechanism can explain why the universe looks the same everywhere

Cosmologists are often wrong but seldom in doubt

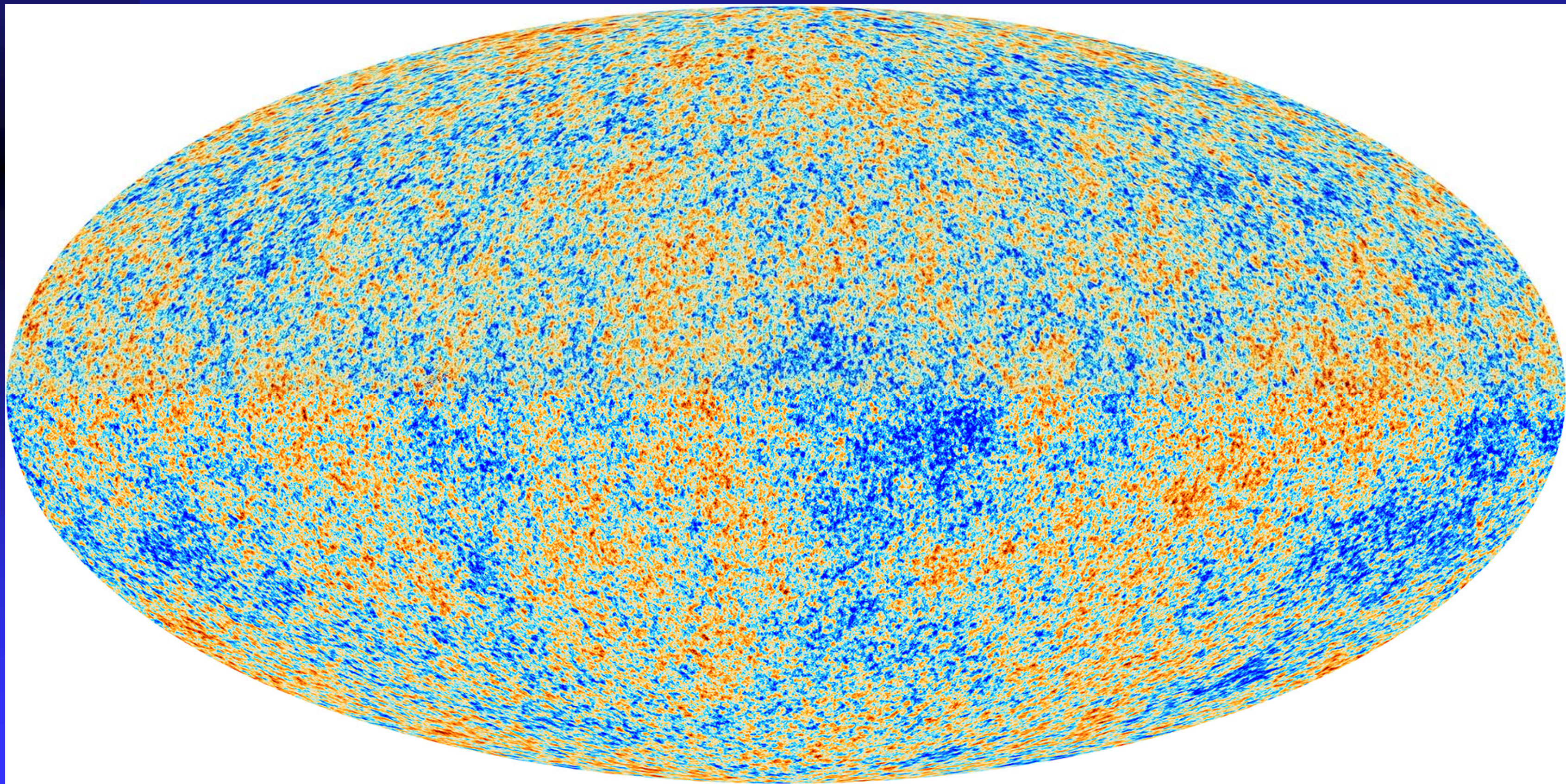


Raise the speed limit

A non-inflationary solution to the horizon problem



But who cares about the horizon problem… Here's the real problem:



The zero-th order "holy grail" of cosmology:

$$k^3|\zeta(k)|^2 = A^2\left(\frac{k}{k_c}\right)^{n_S-1}$$

- Near scale-invariance

$$n_S \sim 1$$

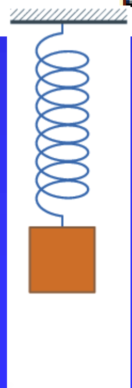
- Amplitude

$$A \sim 10^{-5}$$

How to compute fluctuations:

$$\left\{ \zeta = \frac{v}{z} \qquad z = \frac{a}{c_s} \right\}$$

$$v'' + \left[c_s^2 k^2 - \frac{z''}{z} \right] v = 0$$



I

II

The horizon problem:

- If $c_s = const$
- If $1+3w>0$ (with $w = \frac{p}{\rho}$)

$$v'' + \left[c_s^2 k^2 - \frac{z''}{z} \right] v = 0$$

$$\propto \frac{1}{\eta^2}$$

$$z = \frac{a}{c_s}$$

Dominates
at late times

How inflation solves the problem:

- With $1 + 3w < 0$ $\eta < 0$

$$v'' + \left[c_s^2 k^2 - \frac{z''}{z}\right] v = 0$$

Dominates earlier

Dominates later

$$\propto \frac{1}{\eta^2}$$

- But why do we get scale invariance?

How theories with a varying c solve the structure formation problem:

- With $1+3w>0$ but $c_s \propto \eta^{\beta}$ with $\beta < -1$ we still get:

$$v'' + \left[c_s^2 k^2 - \frac{z''}{z} \right] v = 0$$

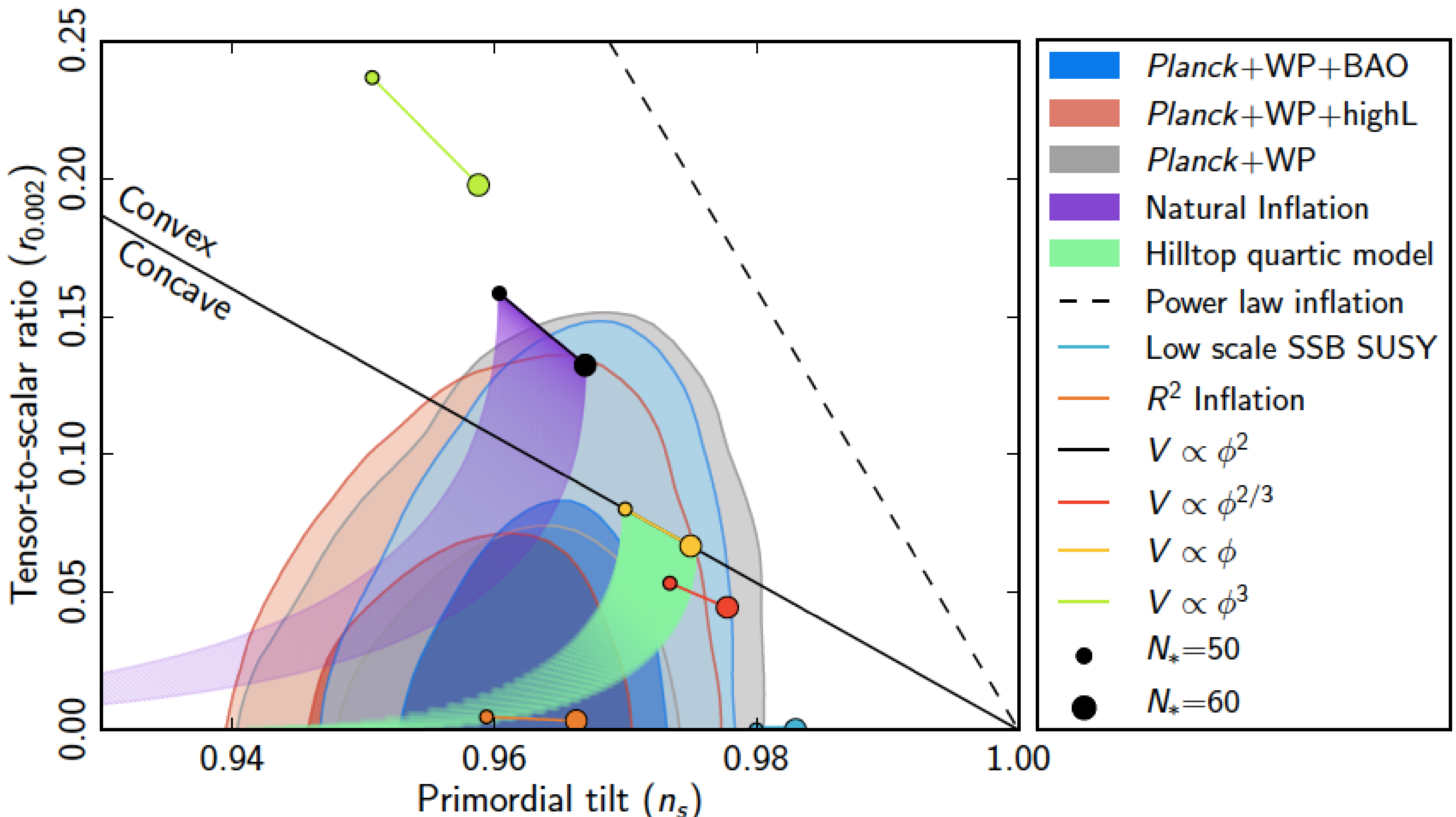
Dominates earlier

Dominates later

$$\propto \frac{1}{\eta^2}$$


WARNING:
Reflections in this mirror may be distorted by socially constructed ideas of 'beauty'

“Evidence” for inflation

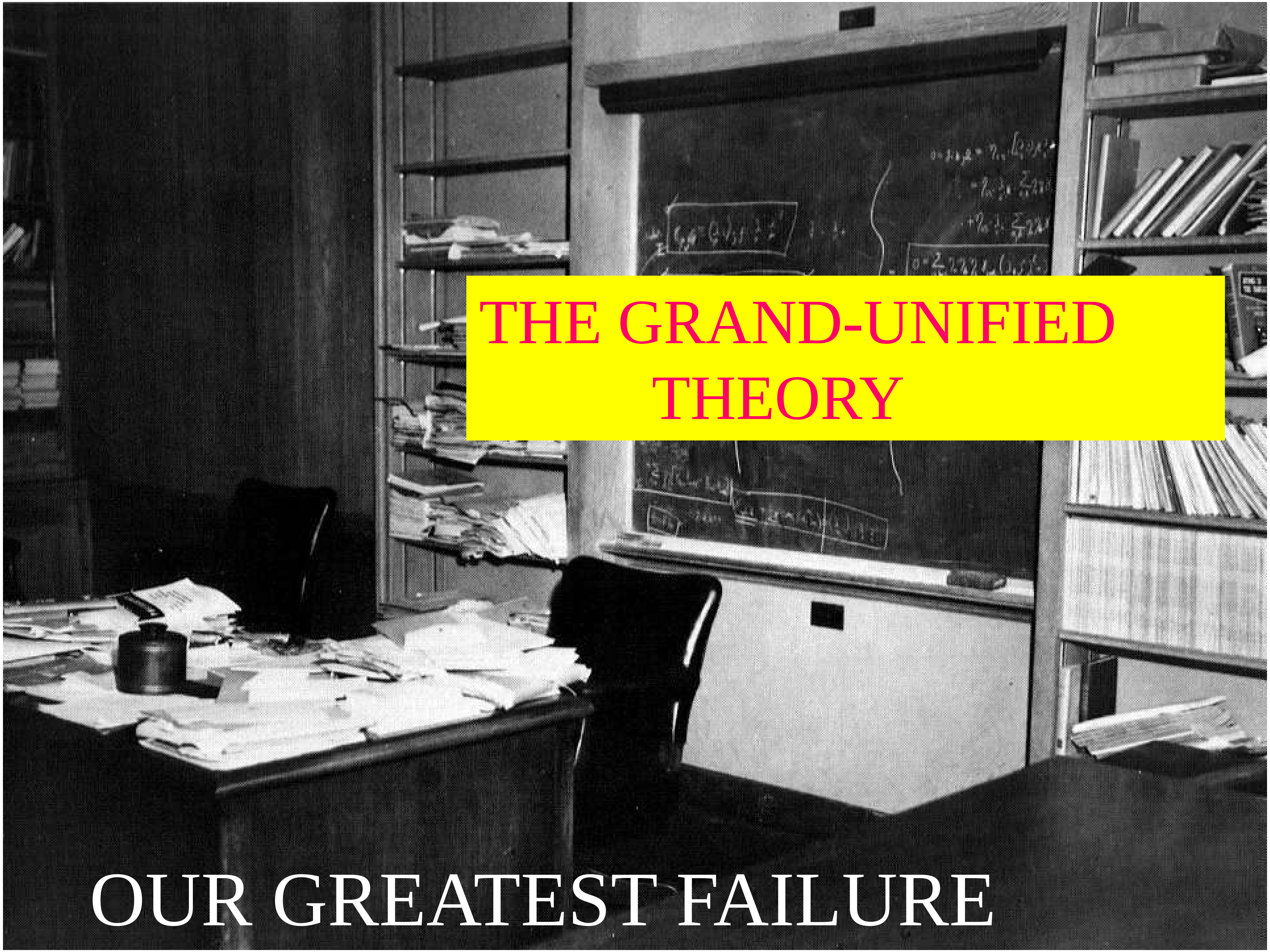


A critique of “evidence for inflation”

- Bayesian evidence is a tool for playing the lottery or investing in the stock market: hedging the bets works!
- It favors non-predictive theories, because you get a power-law fine for spreading your bets, but an exponential one for making a prediction and missing the data.

Science is about falsifiability

- A theory should not only have large evidence, but its evidence should be *exceptional*, given what it would have been had the data been different.
- Not easy to quantify (working in progress, G. Gubitosi, M. Lagos and JM).


THE GRAND-UNIFIED
THEORY
OUR GREATEST FAILURE

Unification requires the quantization of space and time

- Gravity is a property of space and time
- Forces other than gravity are quantized – they come in “atoms” or smallest quantities that cannot be divided any further
- To quantize space and time means to introduced some type of “atoms” of space and time

The Planck Length

The Planck Time

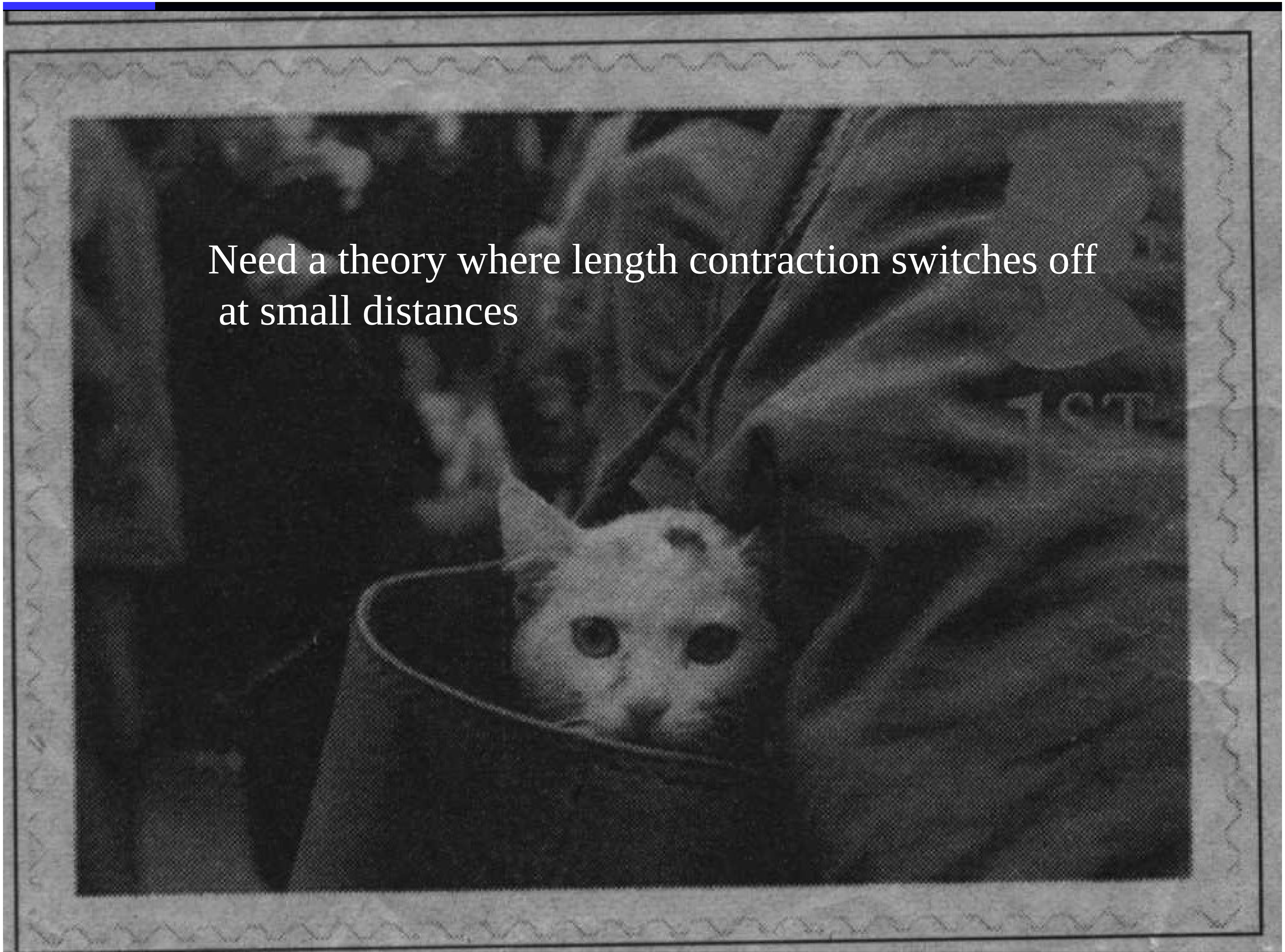
What kind of objects suffer from the effects of "Quantum gravity"?

L_P

Anything much larger than this is under the rule of classical gravity

Anything smaller than this should know that space has become full of pot holes

length contraction!!!!!!!



Need a theory where length contraction switches off at small distances

Newtonian space-time is recovered when c is taken to infinity

- It looks like we need c to go to infinity as the wavelength becomes the Planck length
- I.e. a theory in which the speed of light is colour dependent.

Varying c theories

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  [Amelino-Camelia, Mavromatos, Magueijo & Smolin, etc, etc]

Scale-invariant fluctuations are associated with the “sweet” DDR:

$$E^2 = p^2(1 + (\lambda p)^4)$$

$$c = \frac{dE}{dp} \rightarrow (\lambda p)^2$$

PLB 736 (2014) [gr-qc]
PRD 88 (2013) 103524
PRD 88 (2013) 041303
PRD 87 (2013) 123532

Emergence of space-time and a 2D fixed point in the UV

- There is mounting evidence for a 2D fixed point in the UV in several quantum gravity approaches.
- This may be encapsulated into deformed dispersion relations (DDRs) in a 4D ordered space-time.
- DDRs may be used to explain primordial fluctuations *directly* (with no inflation).

Will fundamental physics ever meet cosmology?

- The quantum gravity community is either:
  - obsessed with its mathematical navel and treats data and the real world as a venereal disease.
  - or, shows a distinct lack of sociological balls and tries to force contact with mainstream cosmology: i.e. inflation.

A possibility not to be discarded:

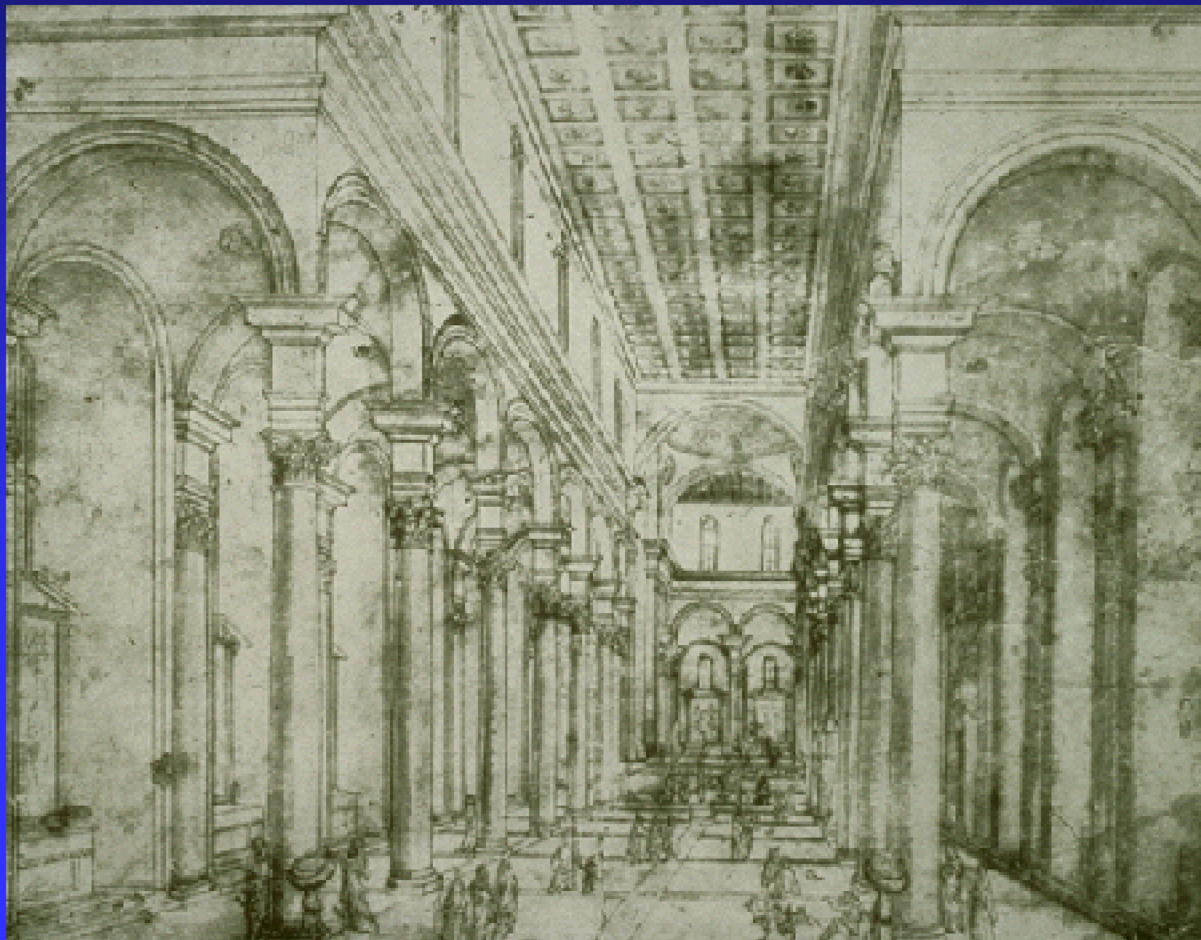
- ALL cosmological models available are not needed.
- Quantum gravity explains what they explain DIRECTLY.
- E.g.: Whatever caused geometrogenesis (a transition to semi-classical space-time) explains the initial value problem of cosmology

My personal view: too many “conjectures” in this type of work

A perspective error… just like Galileo?

Brunelleschi and medieval painting

Brunelleschi



How about gravitational waves?

- In general they could have different DDRs to scalar modes. For example:

$$E^2 = p^2(1 + b^2(\lambda p)^{2\gamma})$$

(and even if gamma is the same, b could be different from 1).

- The UV ratio of the speed of light and the speed of gravity

$$\frac{c_g}{c_m} = b.$$

- The amplitude of the spectrum depends on this:

$$k^3\zeta_S^2 = A_S^2 \sim \left(\frac{L_P}{\lambda}\right)^2$$

$$k^3\zeta_T^2 = A_T^2 \sim \frac{1}{b}\left(\frac{L_P}{\lambda}\right)^2$$

- If you work out all the factors the result is:

$$r = \frac{\mathcal{P}_{\mathrm{T}}}{\mathcal{P}_{\zeta}} = \frac{4}{b}$$

$$\frac{c_g}{c_m} = b.$$