Title: Testing time asymmetry in the early universe

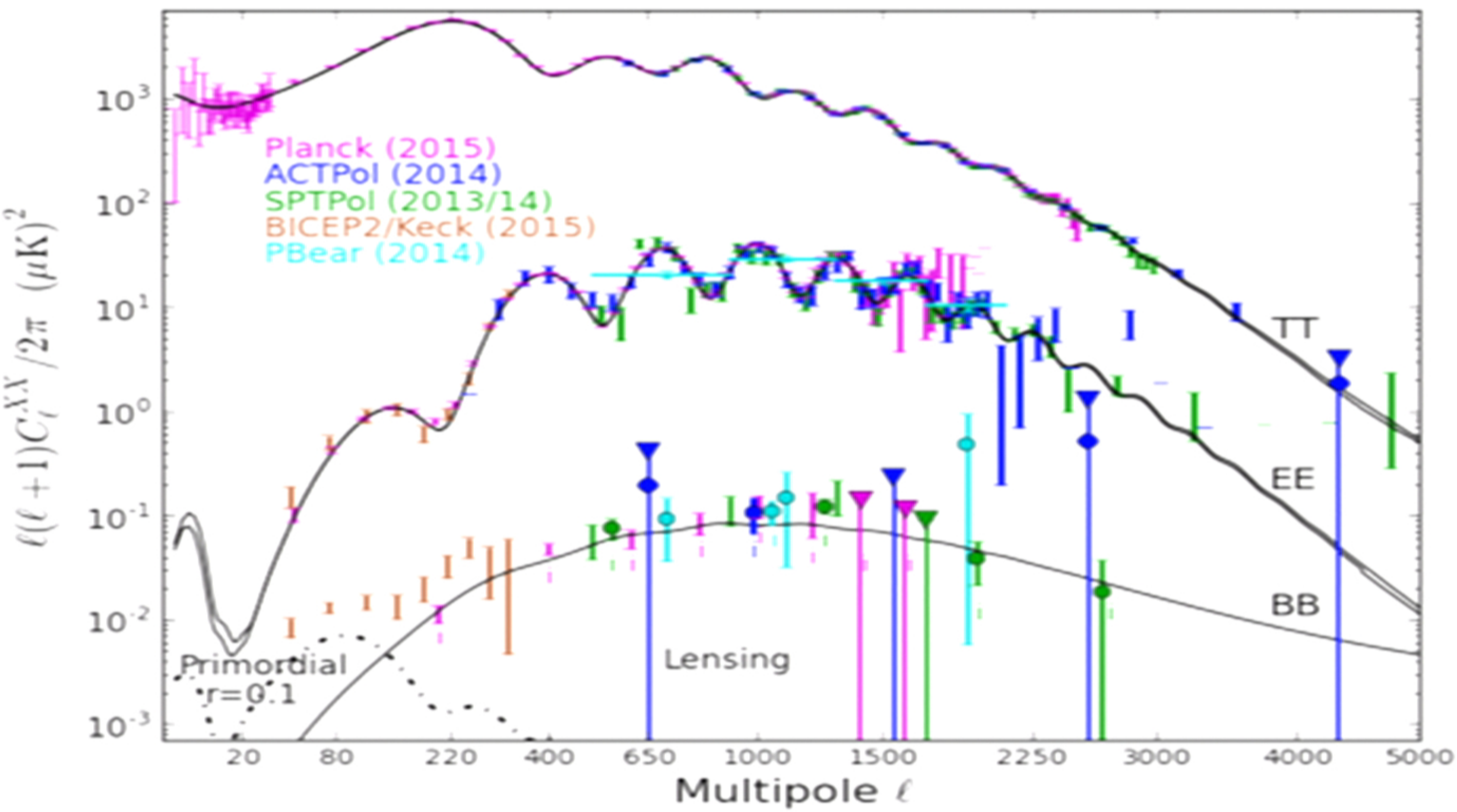
Date: Jun 28, 2016 10:00 AM

URL: http://pirsa.org/16060111

Abstract:


Brian Keating
UC San Diego
Testing Fundamental
Physics with the CMB
ALMA

Confirming Experiment by Theory



BICEP2
March 2014

Broad frequency coverage and resolution are required to detect and remove foregrounds

L. Page

Weak on Time

Any theory consistent with quantum mechanics and special relativity allows the direction of time to be reversed ....”

Weak on Time

"The standard model of particle physics is almost time-reversible but not fully so. (There is one mostly inconsequential aspect of the weak nuclear interaction that does not reverse.)...

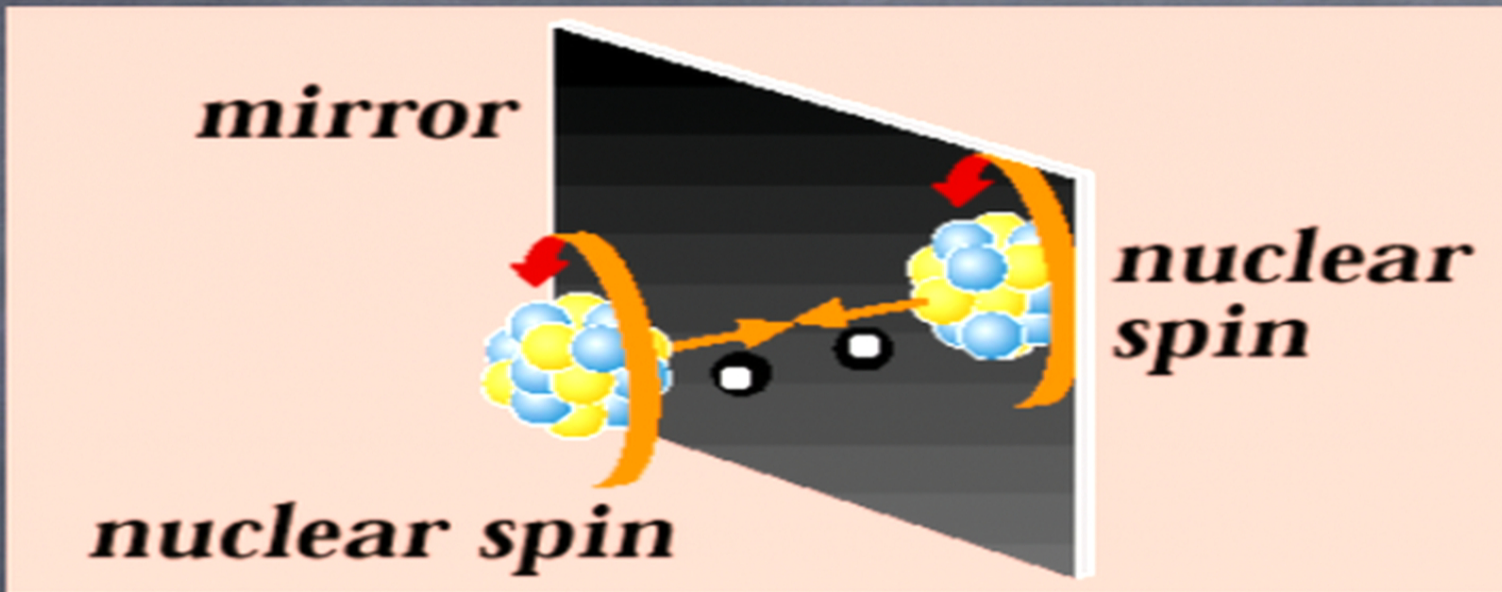
Any theory consistent with quantum mechanics and special relativity allows the direction of time to be reversed ...."

Feynman's Alien!

Suppose we are in contact with an alien species, but only by text message.

Starting with a universal language,then progressing to physics & chemistry, we could make a common language and two-way communication.

Feynman's answer: Try Symmetry!



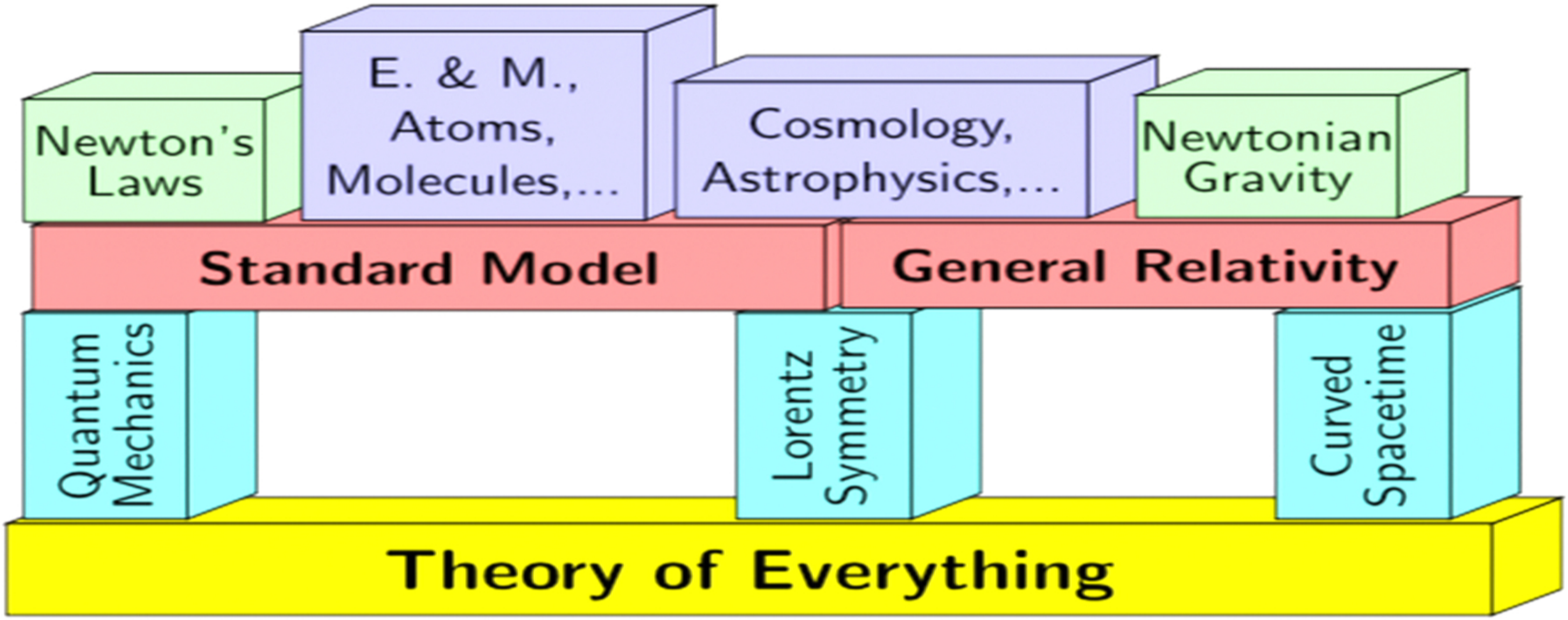
The direction of the emitted electron (arrow) reverses on mirror reflection, but the direction of rotation (angular momentum) is not changed. CP violated.

The nucleus in front of the mirror represents the actual direction while its mirror image isn't found in nature. Experiments can distinguish between the object and its mirror image. But violate CP and T (CPT):

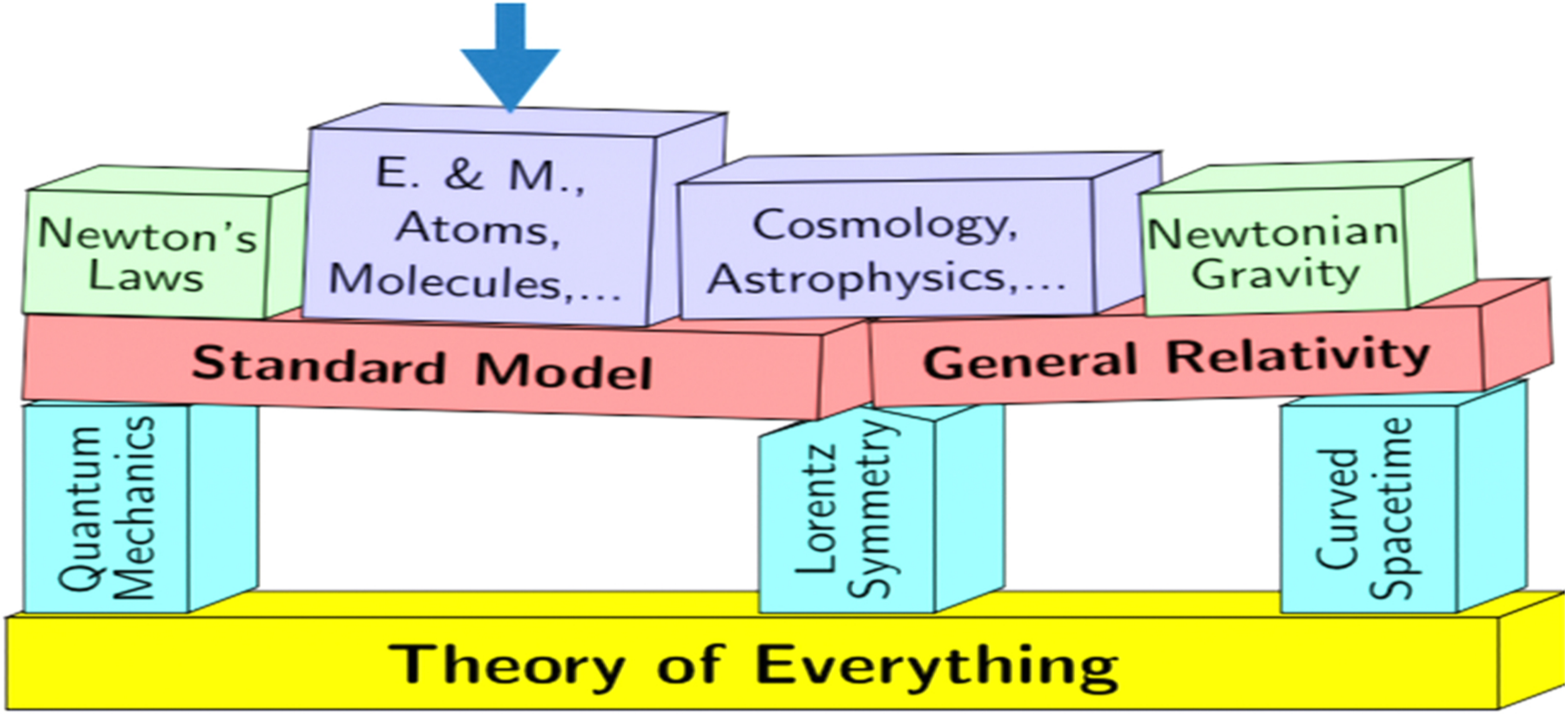
Don't shake hands with a lefty!

https://en.wikipedia.org/wiki/CPT_symmetry

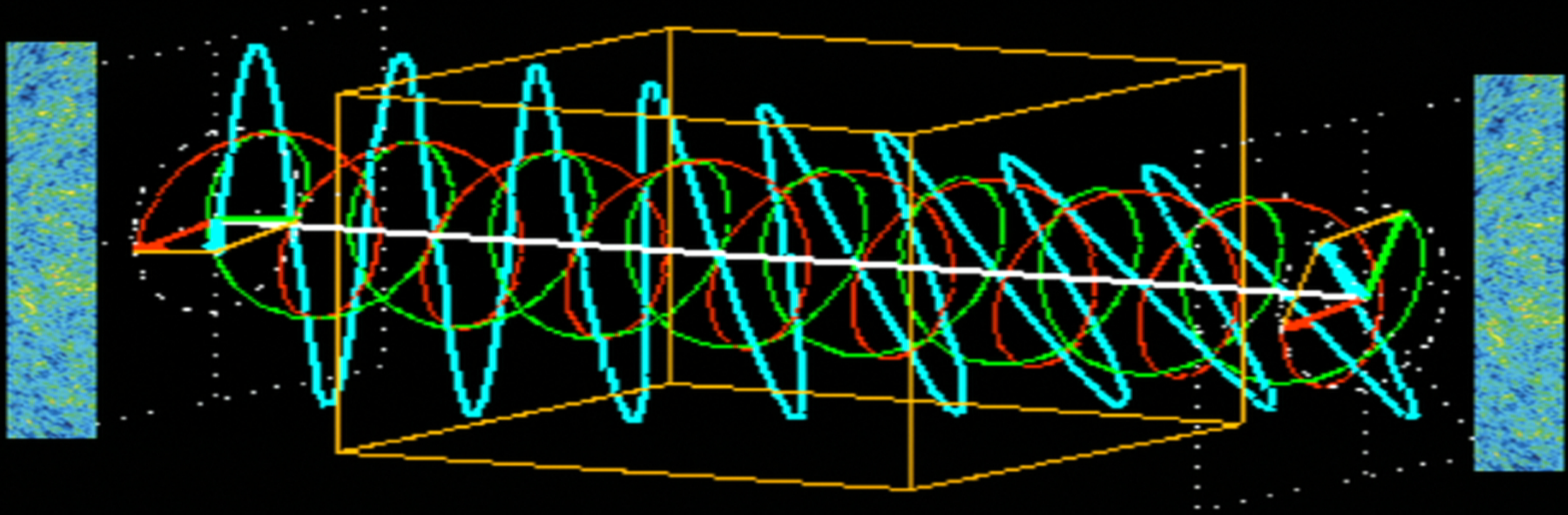
A consequence of this derivation is that a violation of CPT automatically indicates a Lorentz violation.


E. & M., Atoms, Molecules,...
Newton's Laws
Cosmology, Astrophysics,...
Newtonian Gravity
Standard Model
General Relativity
Quantum Mechanics
Lorentz Symmetry
Curved Spacetime
Theory of Everything

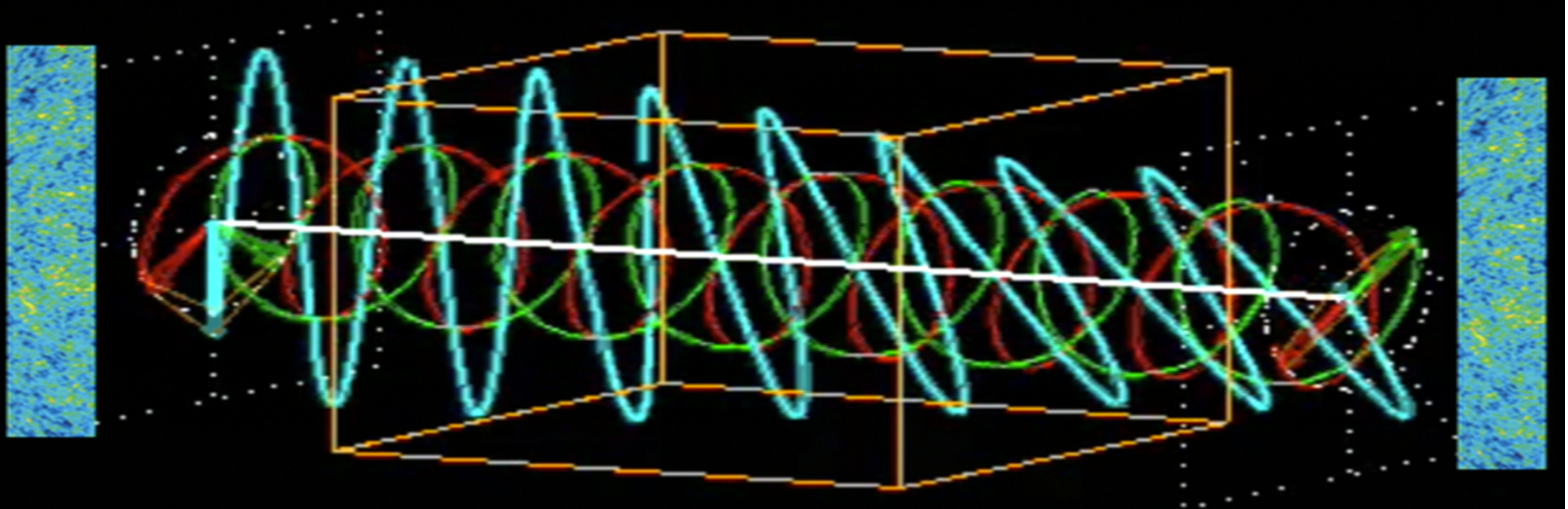
Can we test Lorentz Invariance with the CMB?



Cosmic Birefringence



Cosmic Birefringence



Look for a preferred direction in space!

How? Add a Chern-Simons Interaction to E&M

$$\mathcal{L}_{\rm EM} = -\frac{1}{4}F_{\nu\lambda}F^{\nu\lambda}$$

$$\mathcal{L}_{\rm CS} = -\frac{1}{2}p_\alpha A_\beta \tilde{F}^{\alpha\beta}$$

$$\begin{aligned} \vec{\nabla}\cdot\vec{E} &= 4\pi\rho - \vec{p}\cdot\vec{B} \\ -\partial_t\vec{E} + \vec{\nabla}\times\vec{B} &= 4\pi J - p_0\vec{B} + p\times\vec{E} \\ \vec{\nabla}\cdot\vec{B} &= 0 \\ \partial_t\vec{B} + \vec{\nabla}\times\vec{E} &= 0. \end{aligned}$$

Carroll, Field, Jackiw 1990

$$\omega = ck \quad \rightarrow \quad \omega = \begin{cases} ck & \text{LCP} \\ c(1-\epsilon)k & \text{RCP} \end{cases}$$

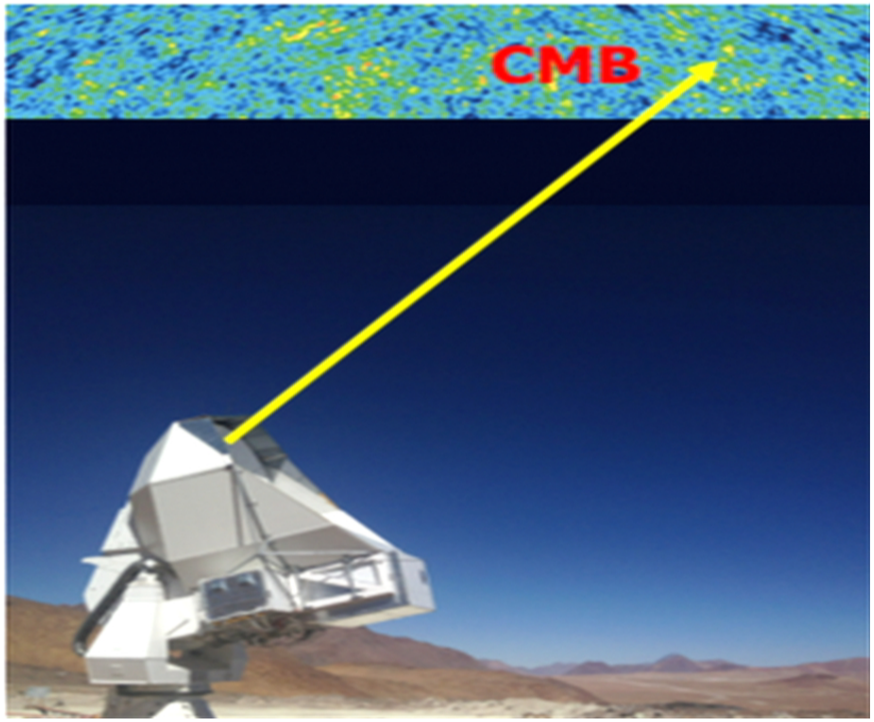
- Violates Lorentz Invariance & parity symmetry in EM.
- Rotates the polarization plane of photons.

POLARBEAR & the Simons Array

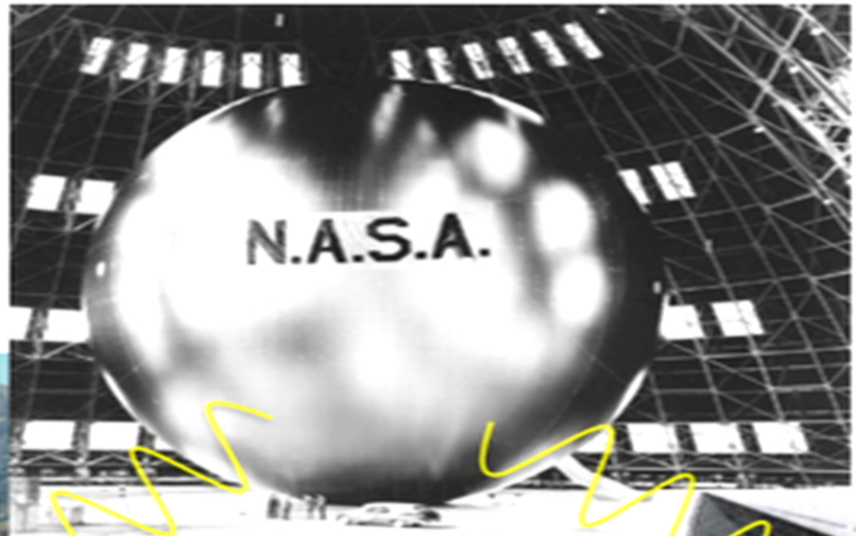
- Low pressure
- Very dry (usually) all year
- Good weather (almost) all year

Low atmospheric noise

- ~1 hour drive from San Pedro de Atacama (nearest town)
- Observe throughout the year (as well as day & night)
- Very low (statistical noise) detectors
- But systematic errors are paramount!

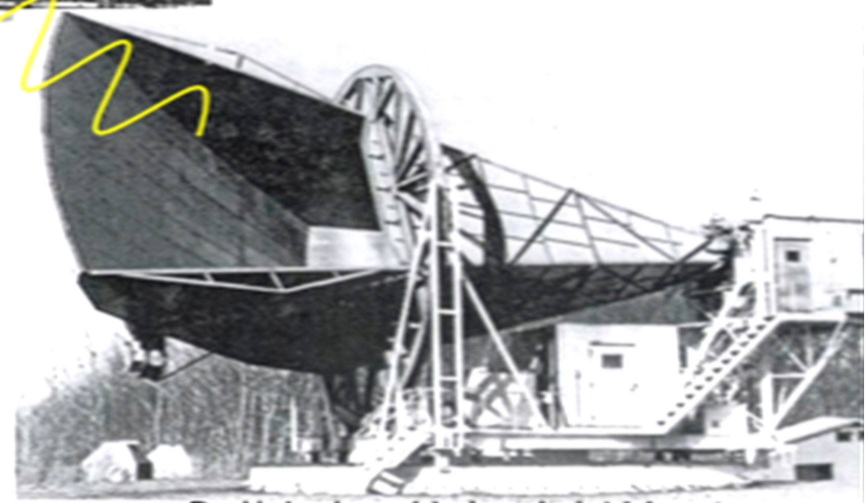


Calibration matters!



Low noise Maser amplifier coupled to a horn reflector antenna

JPL, Pasadena CA



Bell Labs, Holmdel NJ

The internet....circa 1960

TABLE II — SOURCES OF SYSTEM TEMPERATURE

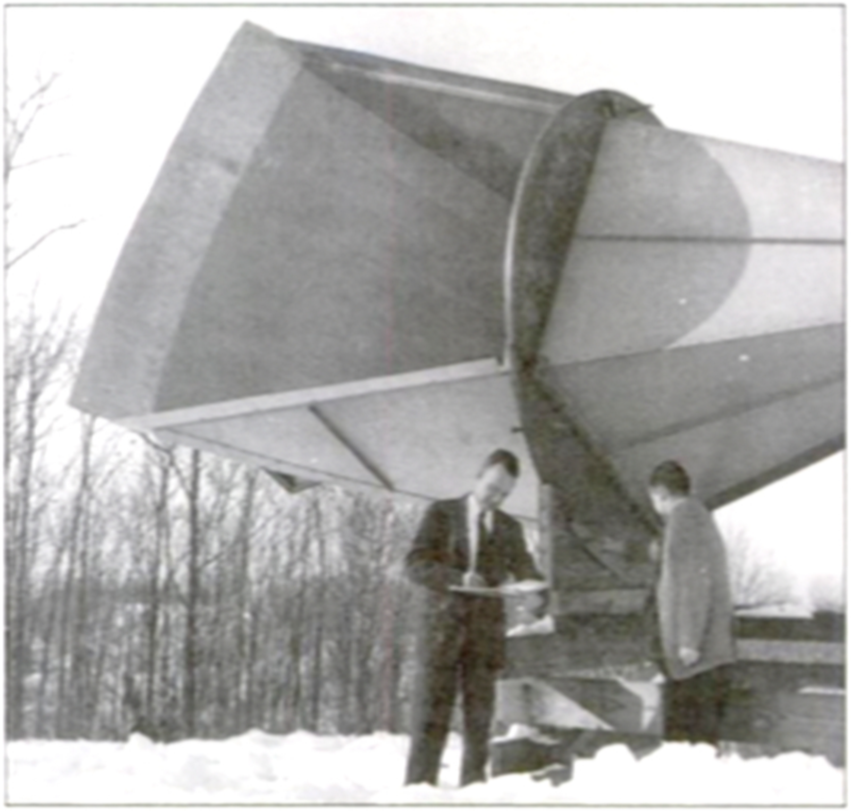
Source	Temperature
Sky (at zenith)	2.30 ± 0.20°K
Horn antenna	2.00 ± 1.00°K
Waveguide (counter-clockwise channel)	7.00 ± 0.65°K
Maser assembly	7.00 ± 1.00°K
Converter	0.60 ± 0.15°K
Predicted total system temperature	18.90 ± 3.00°K

the temperature was found to vary a few degrees from day to day, but the lowest temperature was consistently 22.2 ± 2.2°K. By realistically assuming that all sources were then contributing their fair share (as is also tacitly assumed in Table II) it is possible to improve the over-all accuracy. The actual system temperature must be in the overlap region of the measured results and the total results of Table II, namely between 20 and 21.9°K. The most likely minimum system temperature was therefore

$$T_{system} = 21 \pm 1°K.^*$$

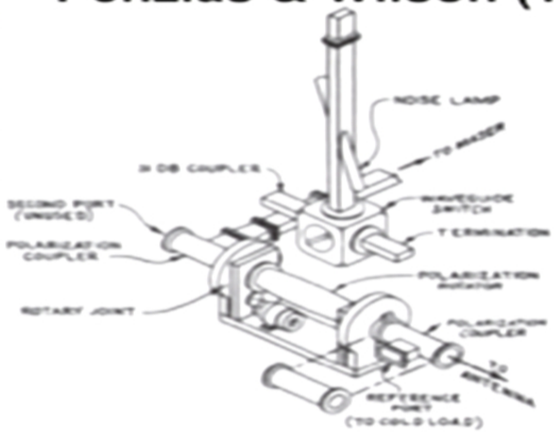
The inference from this result is that the "+" temperature possibilities of Table II must predominate.

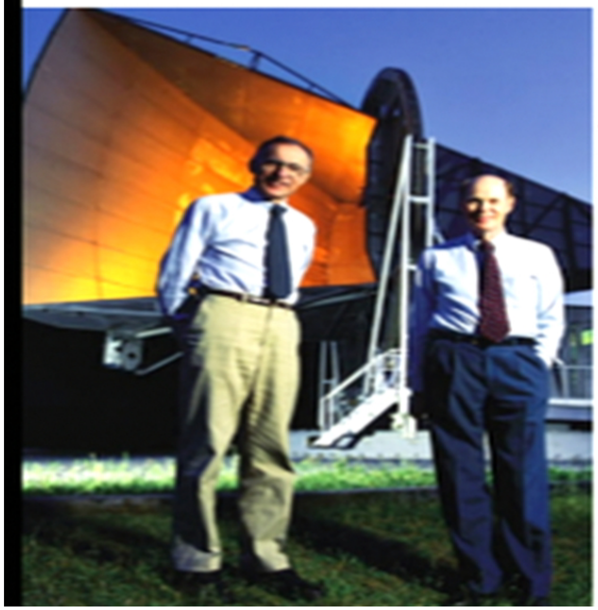
Ed Ohm (1961)



Edward Ohm (right) at the 20-foot horn antenna at Holmdel, New Jersey. He had noticed as early as 1961 that the horn was registering more static than expected when pointed at the sky but had not realized its significance.

Penzias & Wilson (1965)





A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE
AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and free from seasonal variations (July, 1964–April, 1965). A possible explanation for the observed excess noise temperature is the one given by Dicke, Peebles, Roll, and Wilkinson (1965) in a companion letter in this issue.

The total antenna temperature measured at the zenith is 6.7° K of which 2.3° K is due to atmospheric absorption. The calculated contribution due to ohmic losses in the antenna and back-lobe response is 0.9° K.

The radiometer used in this investigation has been described elsewhere (Penzias and Wilson 1965). It employs a traveling-wave maser, a low-loss (0.027-db) comparison switch, and a liquid helium–cooled reference termination (Penzias 1965). Measurements were made by switching manually between the antenna input and the reference termination. The antenna, reference termination, and radiometer were well matched so that a round-trip return loss of more than 55 db existed throughout the measurement; thus errors in the measurement of the effective temperature due to impedance mismatch can be neglected. The estimated error in the measured value of the total antenna temperature is 0.3° K and comes largely from uncertainty in the absolute calibration of the reference termination.

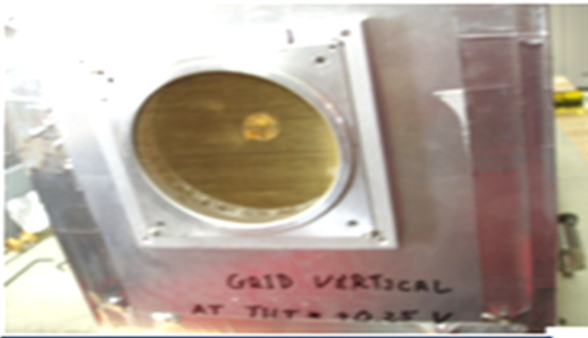
The contribution to the antenna temperature due to atmospheric absorption was obtained by recording the variation in antenna temperature with elevation angle and employing the secant law. The result, 2.3° ± 0.3° K, is in good agreement with published values (Hogg 1959; DeGrasse, Hogg, Ohm, and Scovil 1959; Ohm 1961).

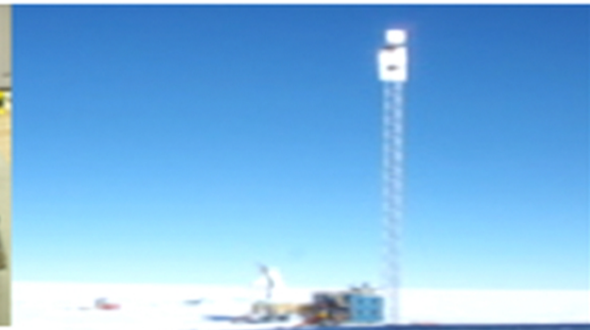
The contribution to the antenna temperature from ohmic losses is computed to be 0.8° ± 0.4° K. In this calculation we have divided the antenna into three parts: (1) two non-uniform tapers approximately 1 m in total length which transform between the 2¼-inch round output waveguide and the 6-inch-square antenna throat opening; (2) a double-choke rotary joint located between these two tapers; (3) the antenna itself. Care was taken to clean and align joints between these parts so that they would not significantly increase the loss in the structure. Appropriate tests were made for leakage and loss in the rotary joint with negative results.

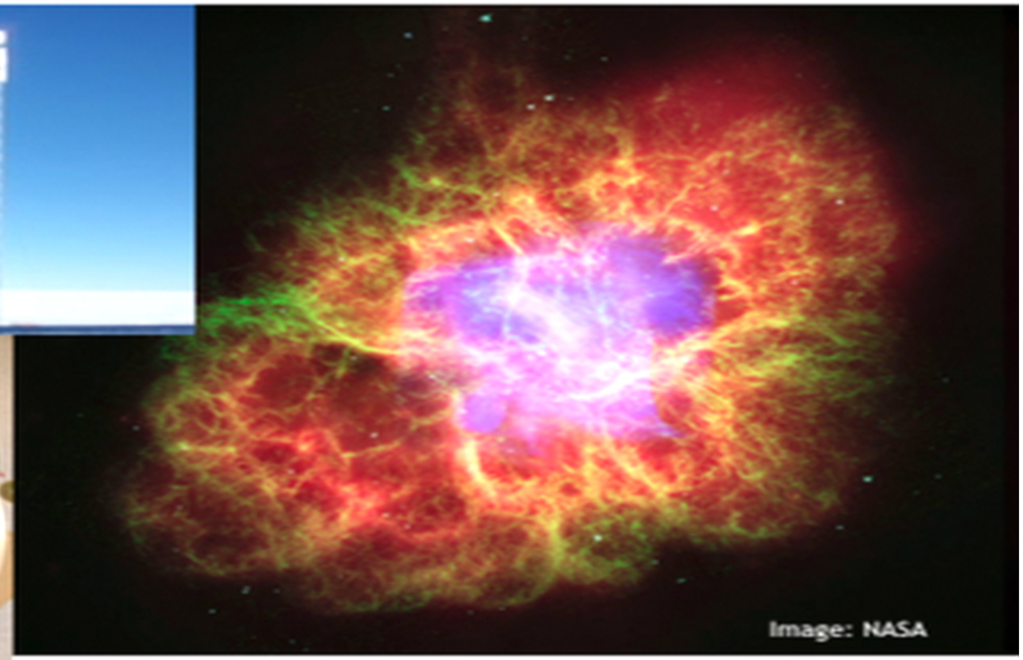
The possibility of losses in the antenna horn due to imperfections in its seams was eliminated by means of a taping test. Taping all the seams in the section near the throat and most of the others with aluminum tape caused no observable change in antenna temperature.

The backlobe response to ground radiation is taken to be less than 0.1° K for two

Calibrating Polarization Orientation: Make a "Standard Stick"







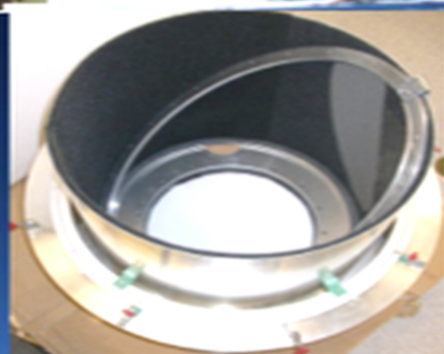
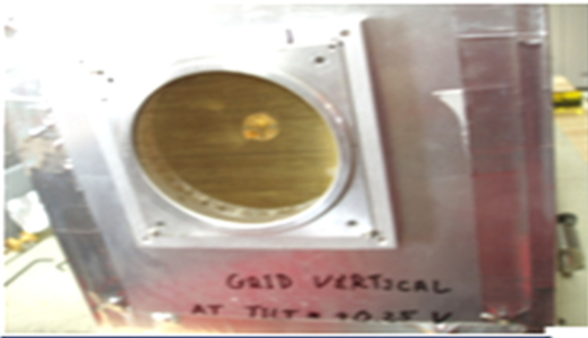
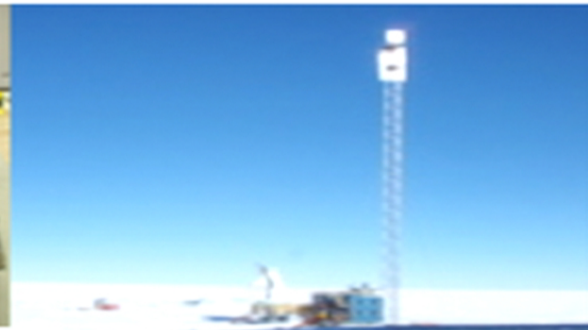


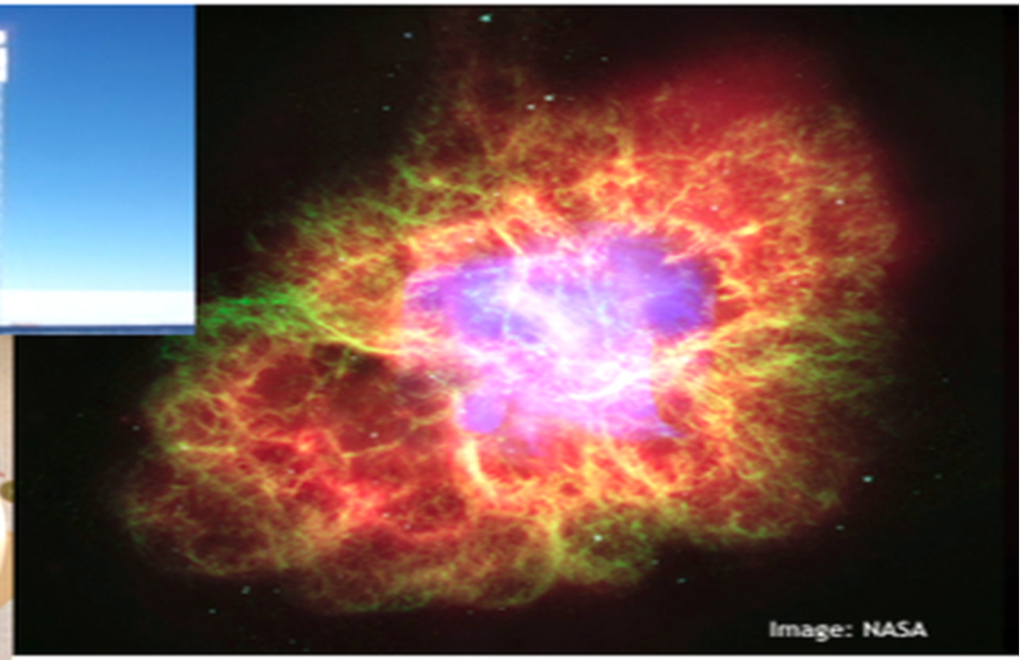
Table 3: Current calibration methods and their precision.

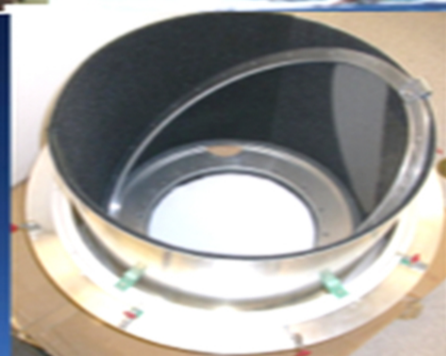
Hardware Method	Precision	Celestial Source	Precision
dielectric sheet	1.3° [12]	Tau A	0.5° [14]
near-field wire grid	1.7° [51]	Cen A	$1.7^{\circ a}$ [58]
as-designed	0.5° [48]		
rotating far-field source	< 1° [50]		

Calibrating Polarization Orientation: Make a "Standard Stick"









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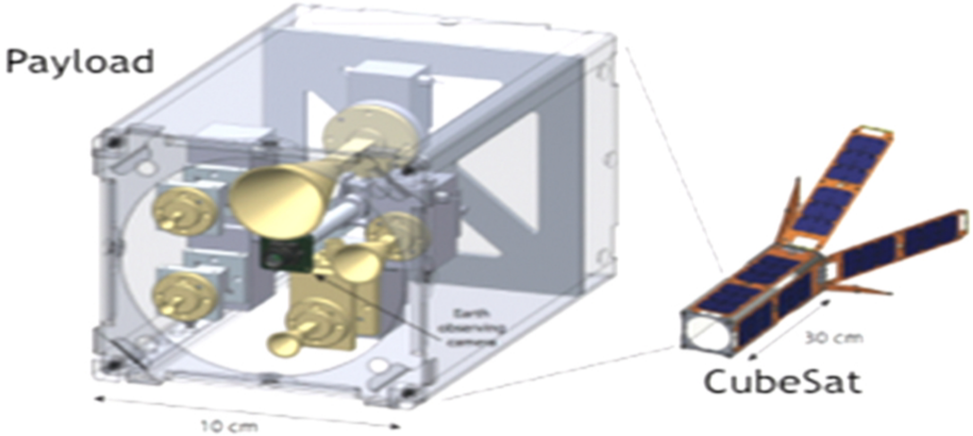
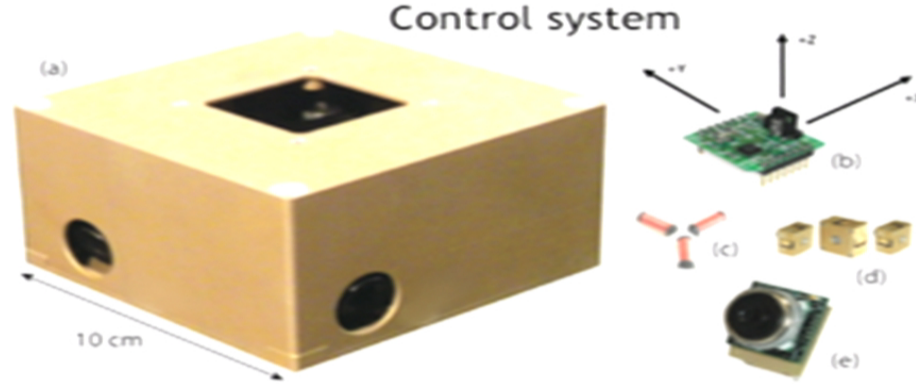
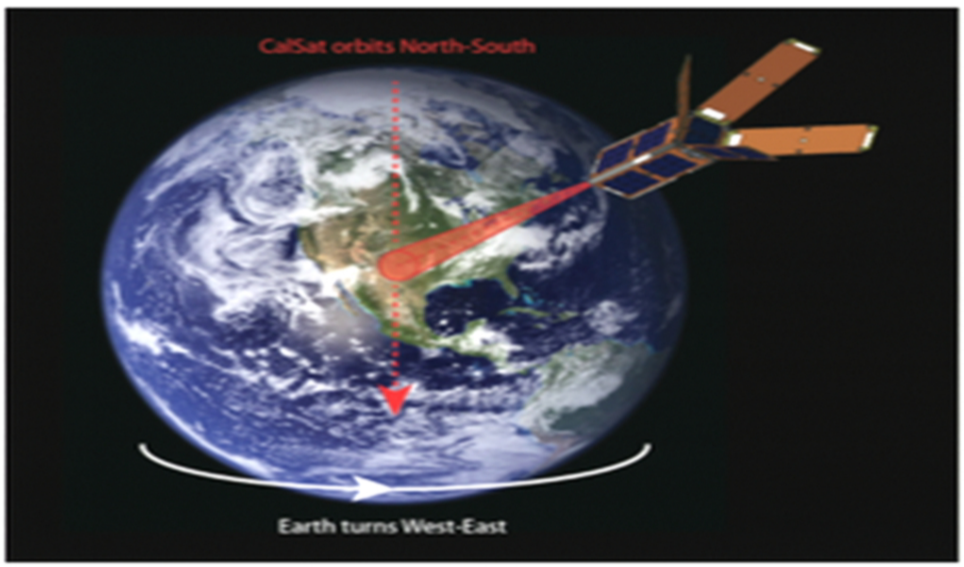
CalSat: Pending NSF MSIP Proposal







- Operates in the primary CMB bands (47, 80, 140, 249, 309 GHz)
- Commercial microwave components
- Pure polarized signal
- CubeSat platform in Polar low Earth orbit, visible from every observatory
- Star pointing cameras provide 0.05° polarization angle precision
- Use with current and next-gen telescopes like Simons array

PI Brad Johnson, Columbia

Take away

- Fascinating physics beyond “just” the B-modes.
- We will hit a wall beyond which we can’t improve on limits on r.
- No standard polarized candle…must make our own!
- What if we are at the center of a preferred frame, along the radial (time) axis?
- If so, there might be another scalar field with which one could build a second cosmic clock (first being the entropy of the CMB). Two clocks can calibrate a third.

Simons Observatory

Simons Observatory

Time Flow from Linking to Space
(a 4D Hubble-Linked Block Model)

Now, and the Flow of Time (available on arXiv)

Richard Muller,[a] Shaun Maguire[b,c]

[a] *Department of Physics, University of California Berkeley, Berkeley, California 94720, USA*
[b] *Institute for Quantum Information & Matter and Walter Burke Institute for Theoretical Physics, California Institute of Technology, Pasadena, California 91125, USA*
[c] *Department of Mathematics, California Institute of Technology, Pasadena, California 91125, USA*

E-mail: ramuller@lbl.gov, smaguire@caltech.edu

ABSTRACT: The progression of time can be understood by assuming that the Hubble expansion takes place in 4 dimensions rather than in 3. The flow of time consists of the continuous creation of new moments, new *nows*, that accompany the creation of new space. This model suggests a modification to the metric tensor of the vacuum that leads to testable consequences. Two cosmological tests are proposed, but they present both experimental and theoretical problems. A more practical and immediate test is based on a predicted lag in the emergence of gravitational radiation when two black holes merge. In such mergers (as recently observed by the LIGO team), a macroscopic volume (millions of cubic kilometers) of space is created in the region in which the gravitational wave is generated; this one-time creation of new space should be accompanied by the creation of detectable level of new time, resulting in a time delay that could be observed as a growing lag in the emission of the wave as the merger takes place.

KEYWORDS: LIGO, gravitational waves, arrow of time

The progression of time can be understood by assuming that the Hubble expansion takes place in 4 dimensions rather than in 3.

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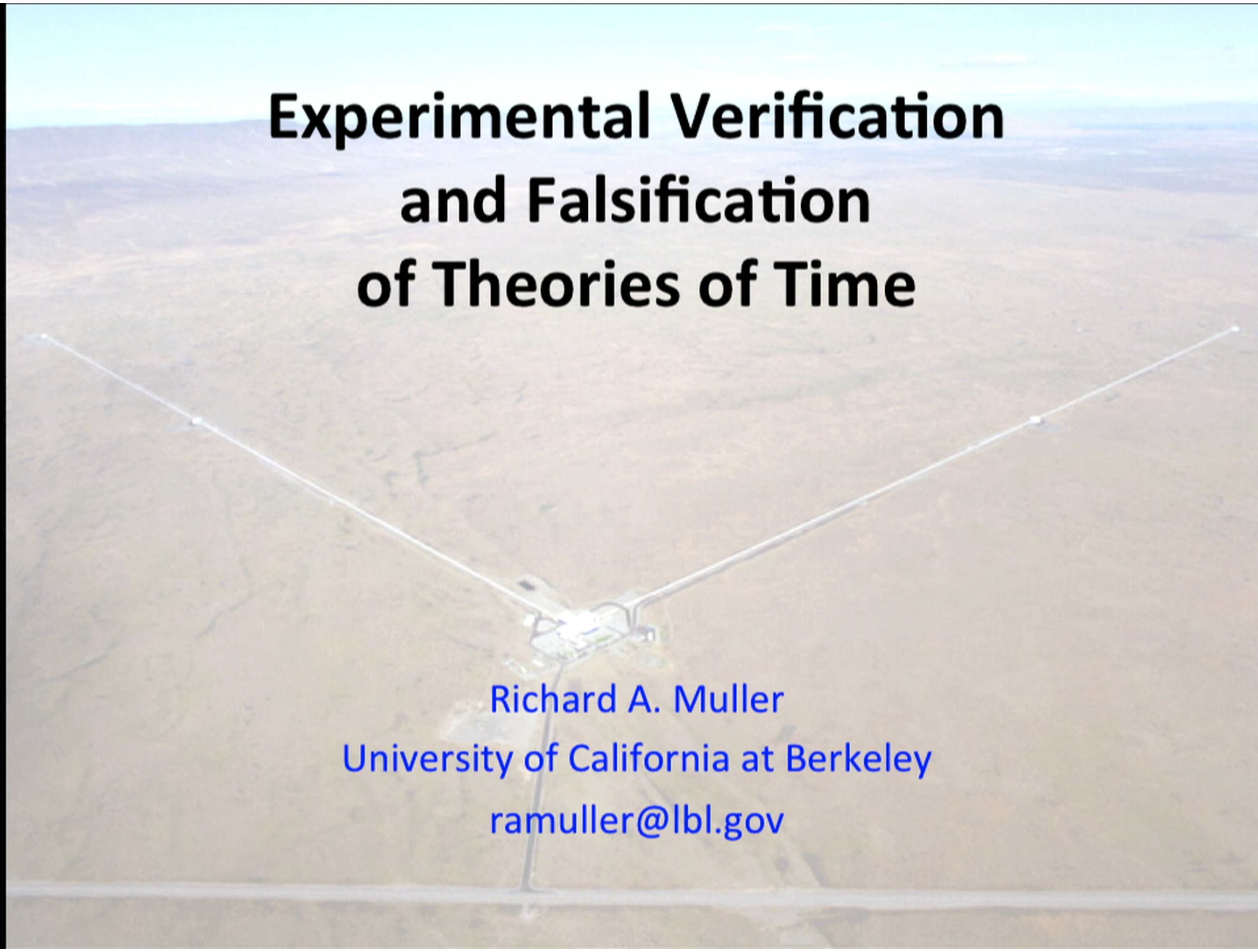
Experimental Verification
and Falsification
of Theories of Time
Richard A. Muller
University of California at Berkeley
ramuller@lbl.gov

My focus: Two Conundrums of Time

- The Flow of Time:

  In any coordinate system, we can stand still in space but not time.

  This is more than a ,minus (–) sign in the metric.

  If we add a second time dimension, would it flow too?

- Now:

  What is the meaning of that special moment we call "now"? We know it is not universal. But it is completely ignored in current physics.

To be worthy of consideration by an experimentalist, a theory must not only be verifiable, but also ***falsifiable***

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(a 4D Hubble-Linked Block Model)

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Keywords: LIGO, gravitational waves, arrow of time

The progression of time can be understood by assuming that the Hubble expansion takes place in 4 dimensions rather than in 3.

The flow of time consists of the continuous creation of new moments, new *nows*, that accompany the creation of new space.

Tests of the *Now* Theory

- **Dark Energy**
  - there will be a new redshift from the acceleration of time
  - part of the dark energy is actually time creation
  - homogeneous FLRW metric: $ds^2 = -dt^2 + a(t)d\Sigma^2$

    makes this difficult (not impossible) to observe

    Compare with advance of perihelion of Mercury

- **Inflationary Era**
  - generation of gravitational waves took place because of inhomogeneities; effects could be detected in 3K polarization (but need to be calculated)

- **LIGO**
  - sudden creation of millions of cubic kilometers of space should be accompanied by a 1-time creation of new time.
  - observable as a *progressive lag* in gravitational wave production

Black Hole Proximate Proper Volume

$$V(R_1, R_2, M) = \int_{R_1}^{R_2} \frac{4\pi r^2}{\sqrt{1 - R_s/r}} dr$$

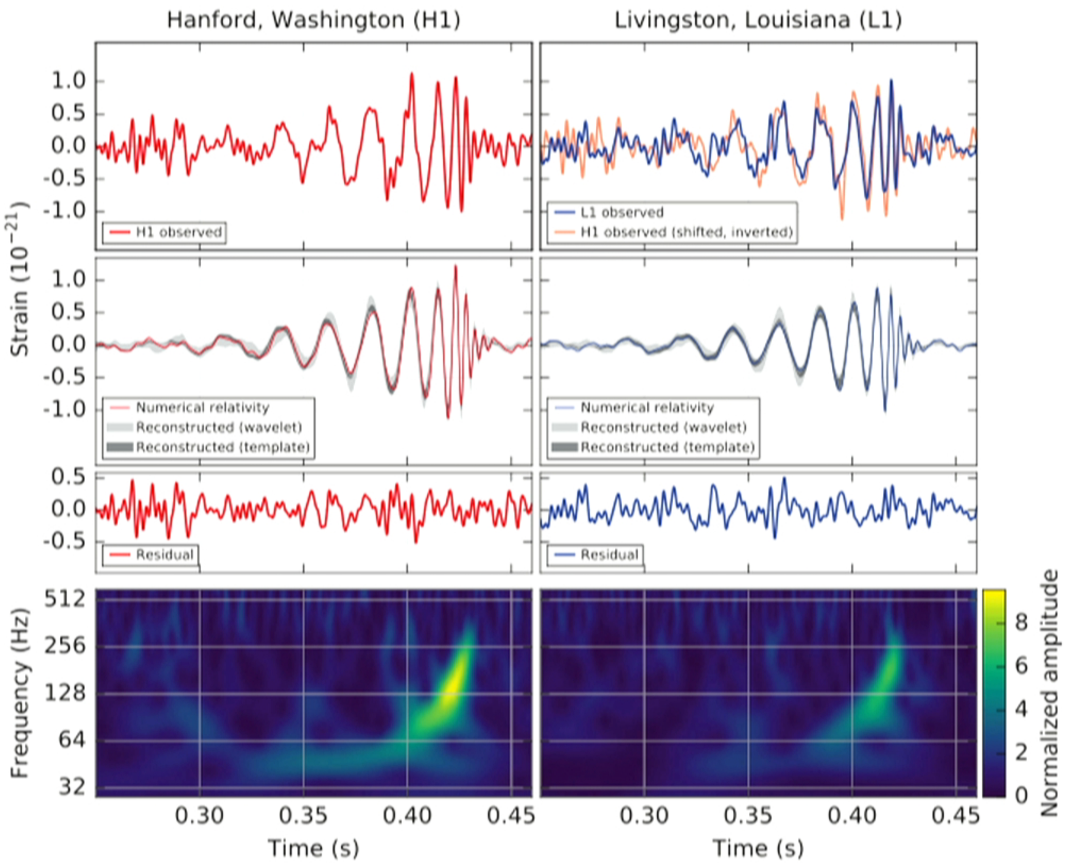
$$\Delta V(R_1, R_2, M) = V(R_1, R_2, M) - V(R_1, R_2, 0)$$

$$\Delta V_{total} = \Delta V(R_1, R_2, 62) - \Delta V(R_1, R_2, 29) - \Delta V(R_1, R_2, 36)$$

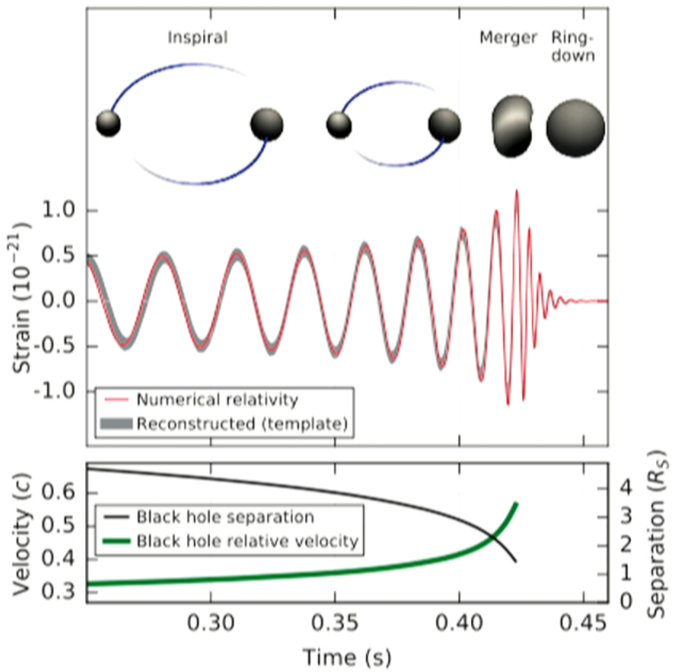
ΔV_{total} = 47 million cubic kilometers

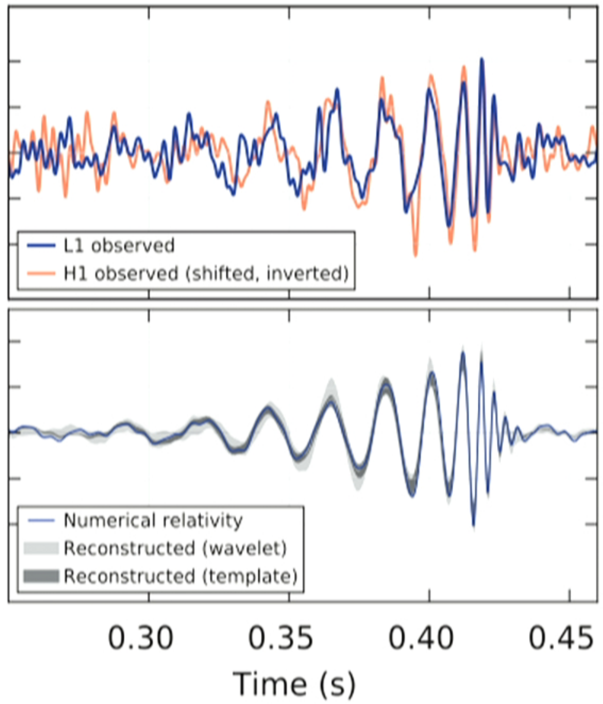
$\Delta t = \sqrt[3]{\Delta V_{total}}/c \approx 0.0012$ seconds

LIGO First Detection



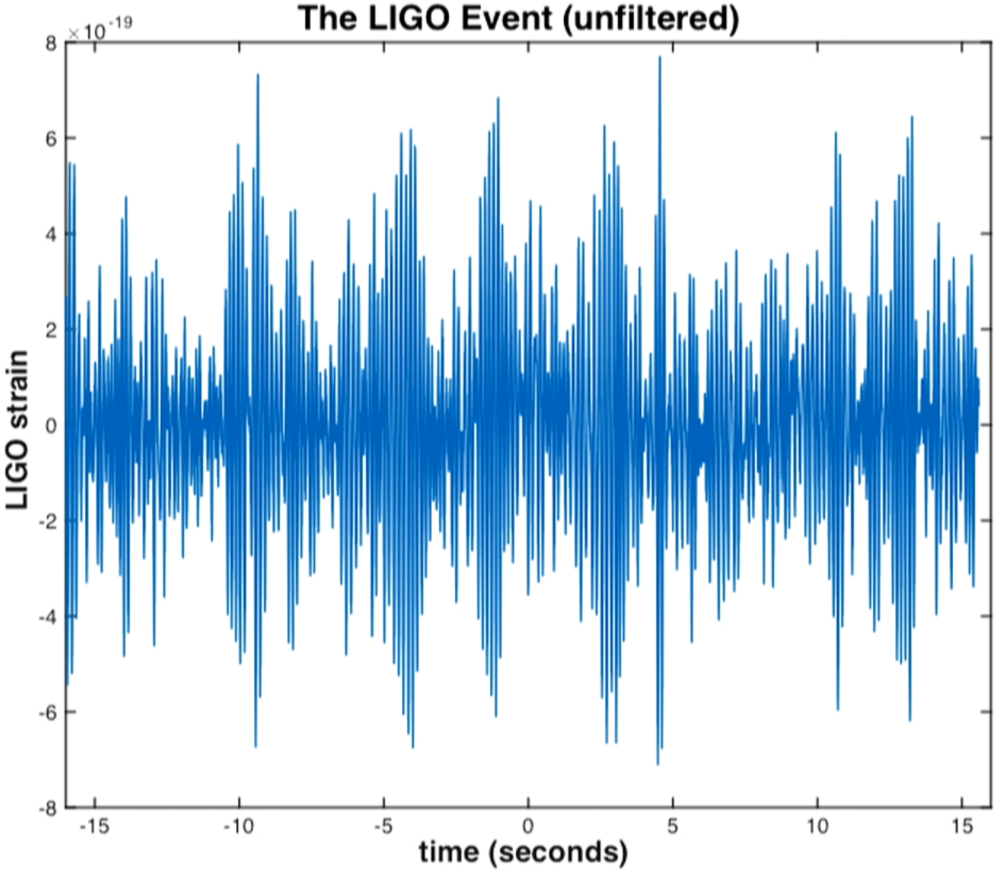
Theory vs Observation

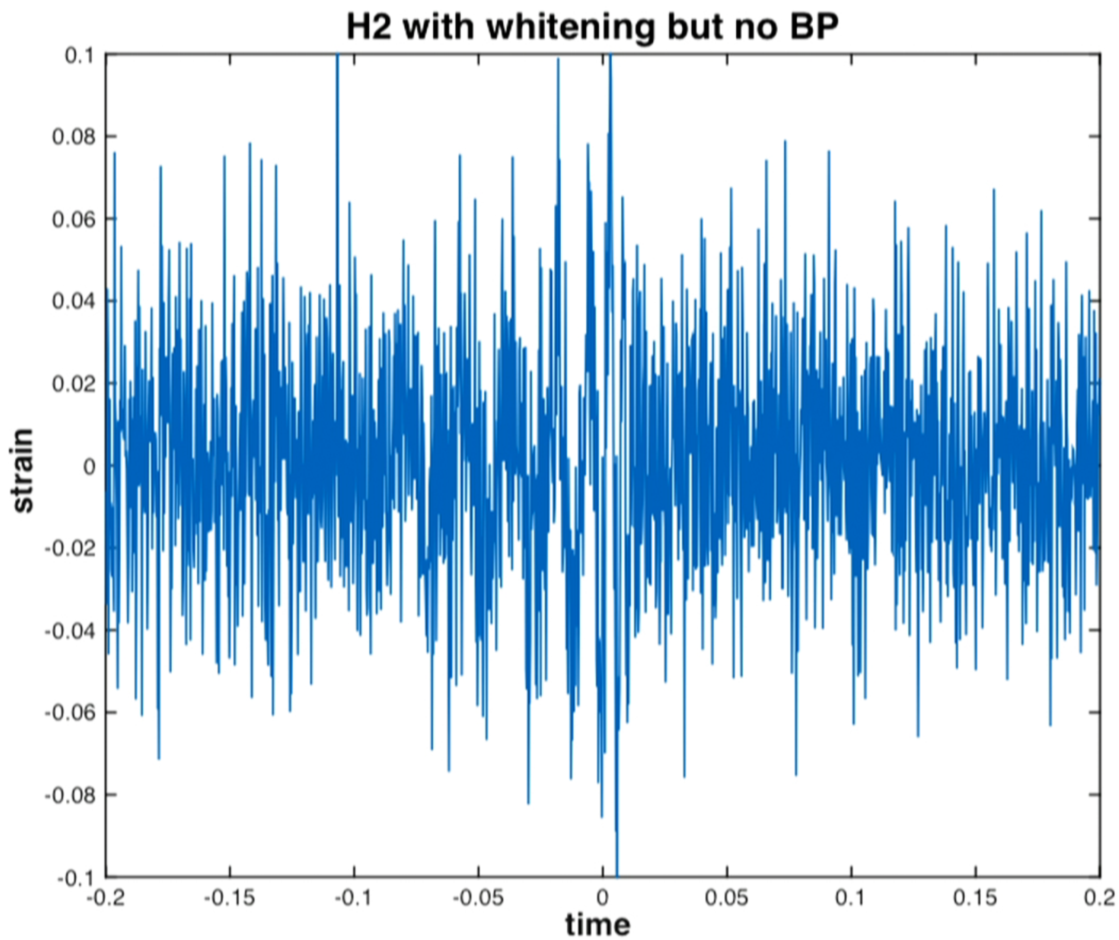


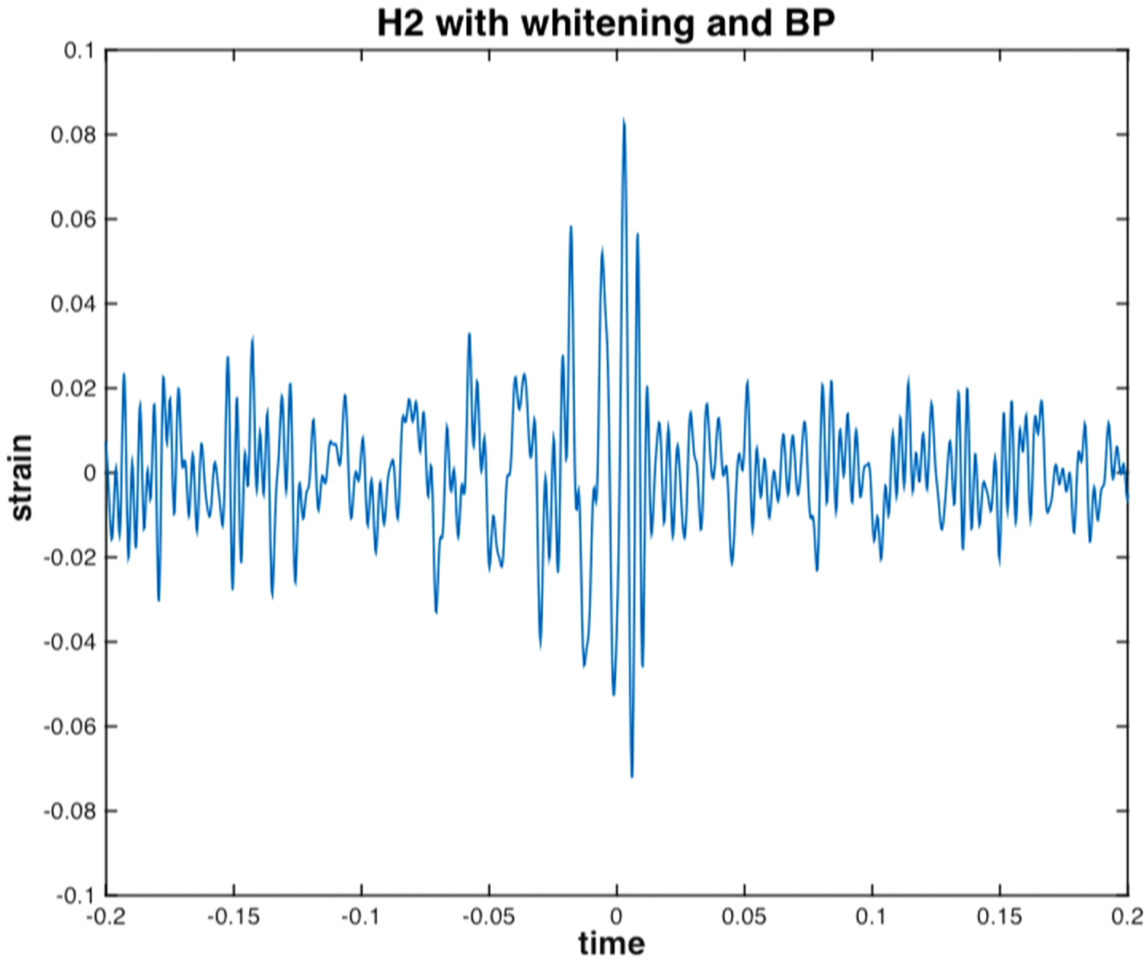


The “chirp” is preceded by many cycles with slowly changing frequeny

LIGO 1st GW observed strain




H2 with whitening but no BP
strain
time
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2



H2 with whitening and BP
strain
time
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
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-0.15
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-0.05
0
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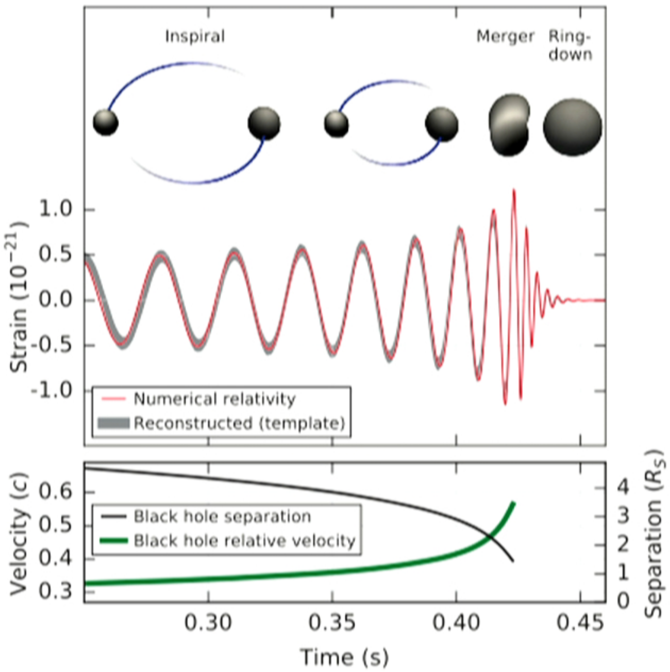
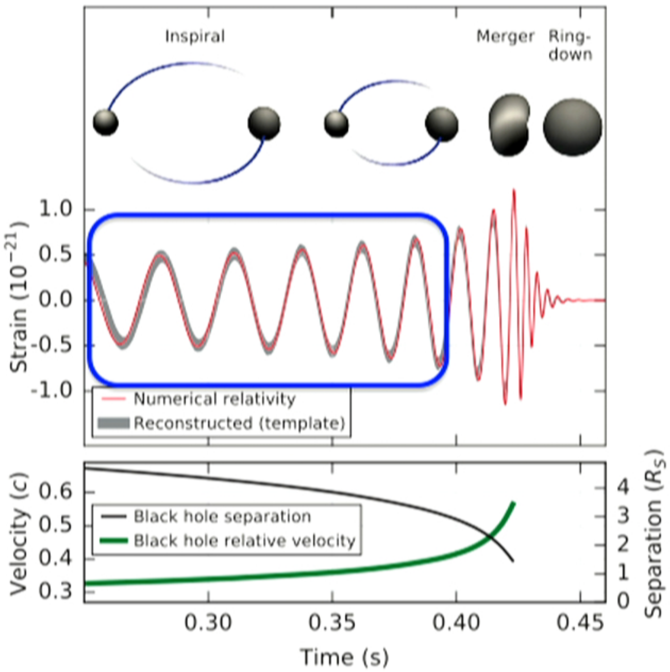
The key is the precursor oscillation



The key is the *precursor* oscillation



Must determine masses, orientation, separations *prior* to the final chirp so there will be no adjustable parameters

To be worthy of consideration by
an experimentalist,
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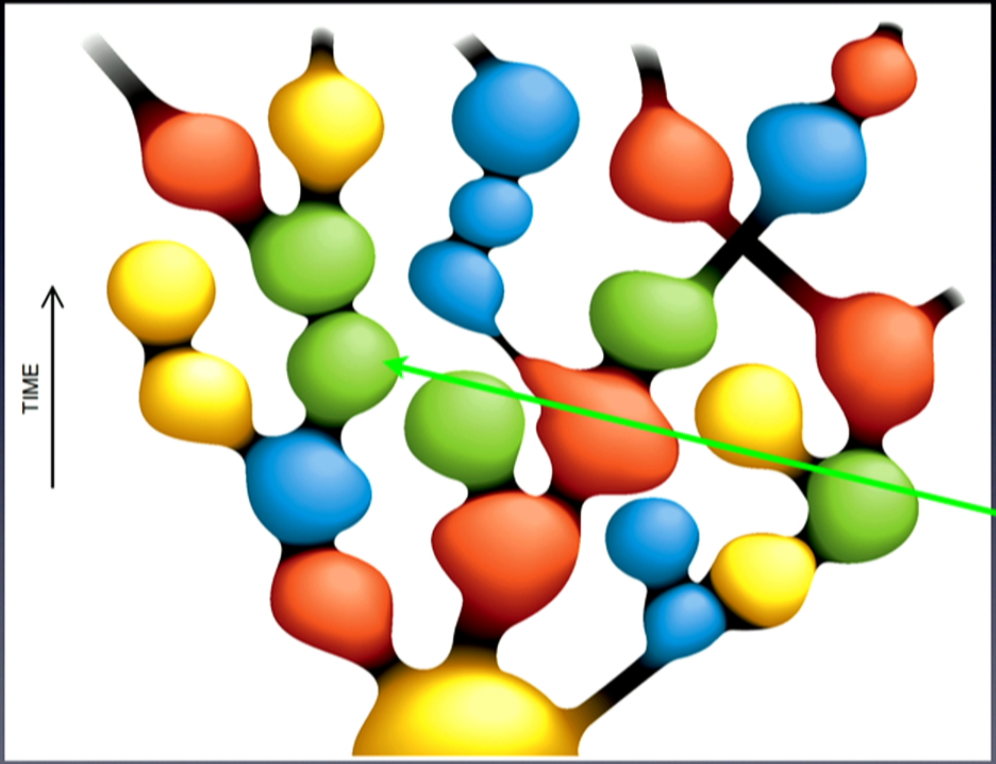
Testing time asymmetry in the early Universe



Andrew Liddle

Time in Cosmology

PI, June 2016

What can the early Universe tell us about time, or time asymmetry?

1. If there is a physical explanation for the `initial′ conditions of the Universe, presumably it takes place in the very early Universe.

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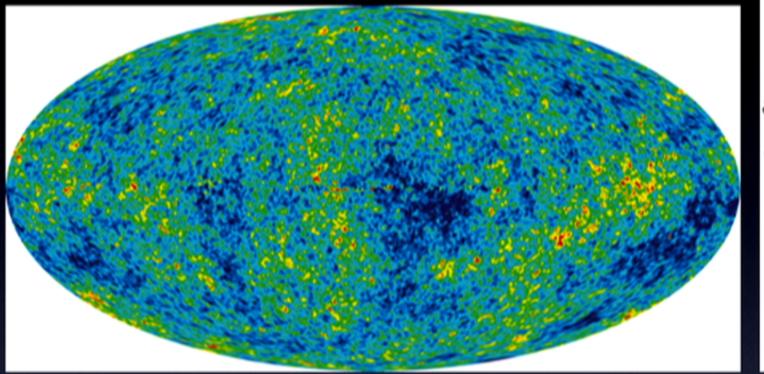
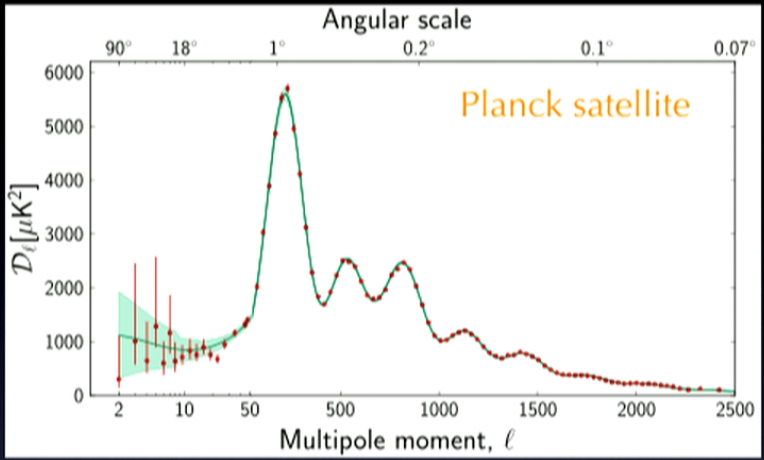
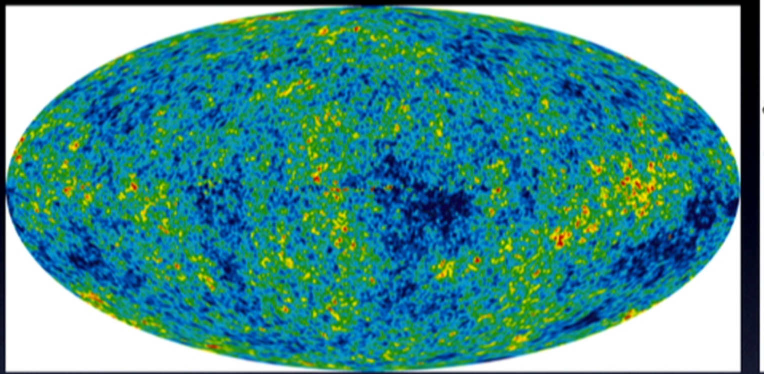
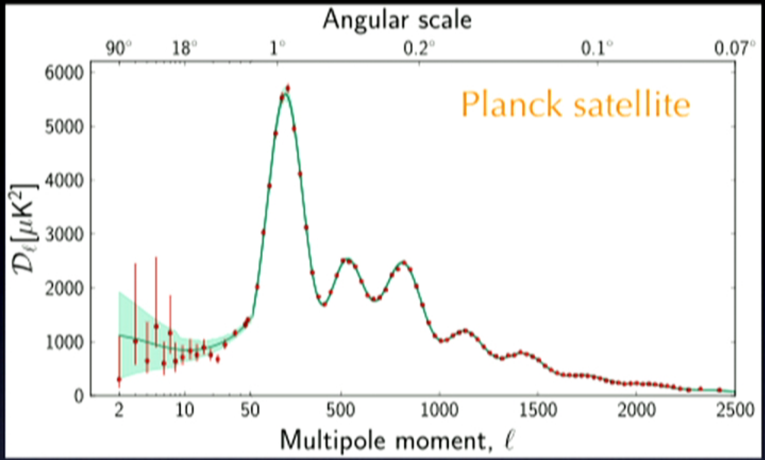




1. If there is a physical explanation for the `initial' conditions of the Universe, presumably it takes place in the very early Universe.





* Observations strongly suggest structures form from super-horizon adiabatic perturbations. Cosmological inflation is a very simple way to generate such perturbations.

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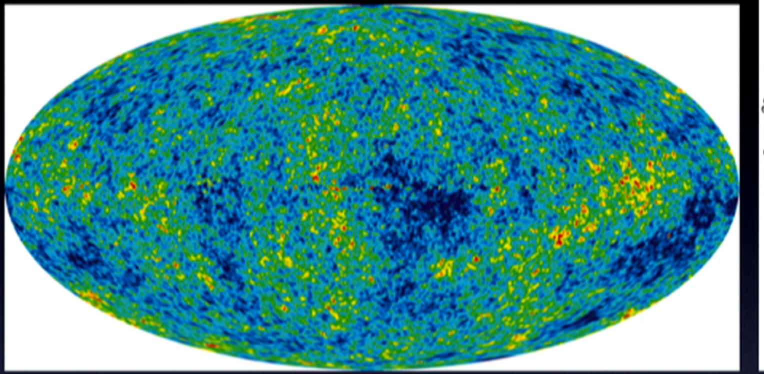

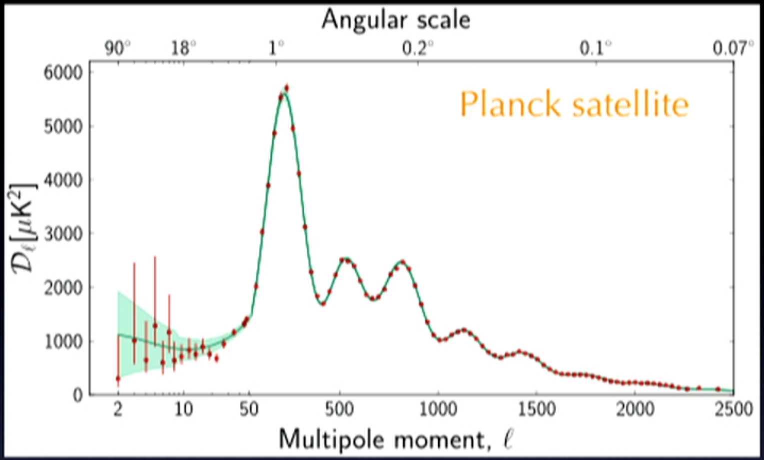

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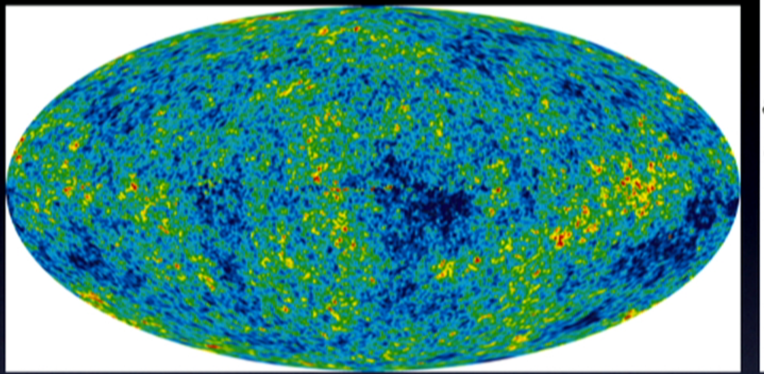

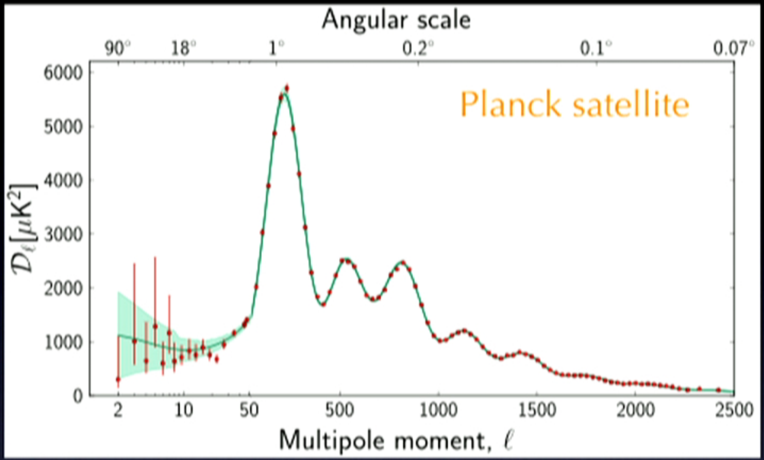

- Observations strongly suggest structures form from super-horizon adiabatic perturbations. Cosmological inflation is a very simple way to generate such perturbations.
- It is also a good way to dramatically lower the entropy density of the Universe, as it gives an enormous expansion at approximately constant total entropy.
- On the other hand, many inflation models have the habit of predicting a multiverse. I like that, but lots of people don't.

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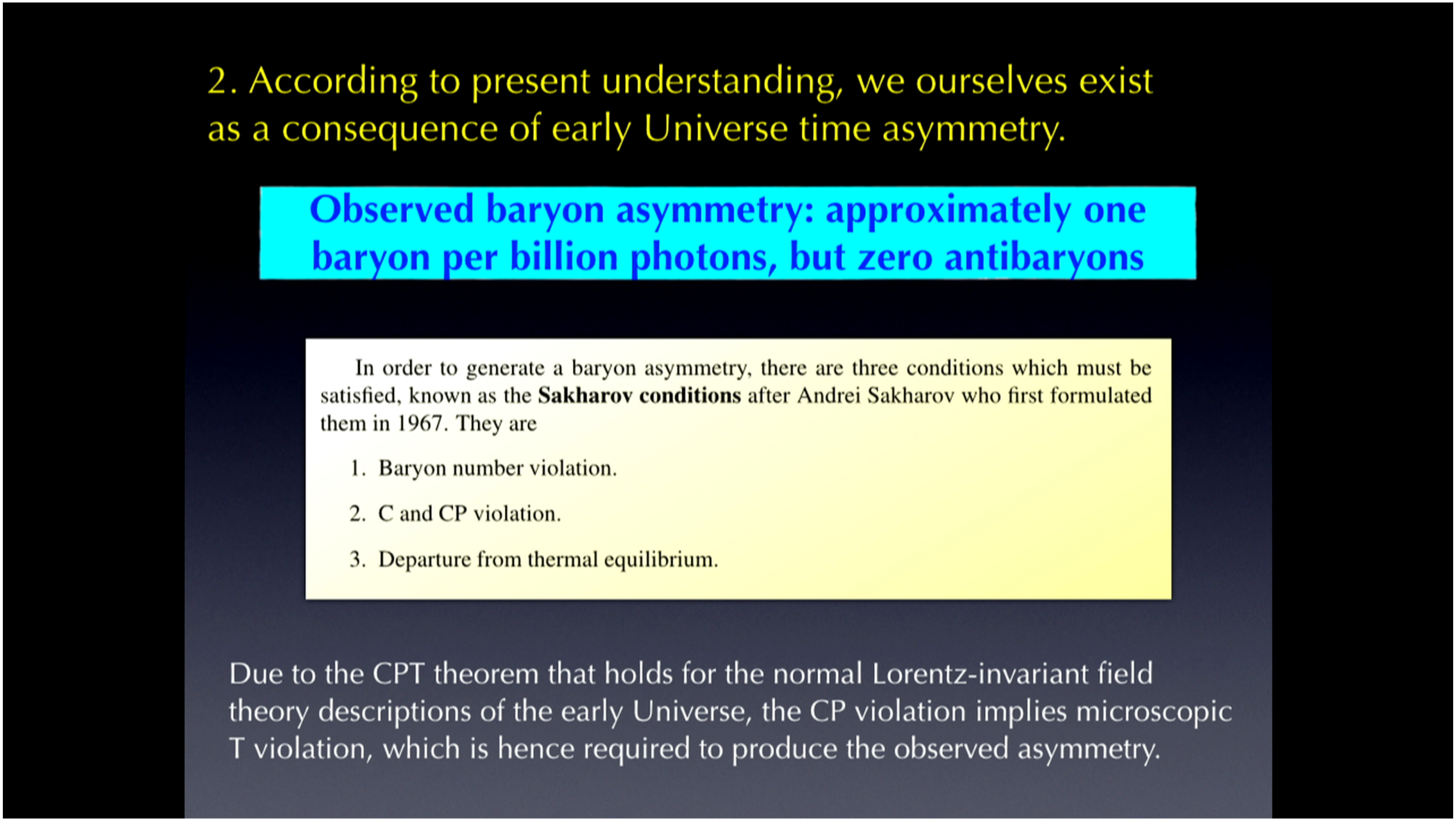
In order to generate a baryon asymmetry, there are three conditions which must be satisfied, known as the **Sakharov conditions** after Andrei Sakharov who first formulated them in 1967. They are

1. Baryon number violation.
2. C and CP violation.
3. Departure from thermal equilibrium.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Due to the CPT theorem that holds for the normal Lorentz-invariant field theory descriptions of the early Universe, the CP violation implies microscopic T violation, which is hence required to produce the observed asymmetry.

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Test case:

Time asymmetric extensions of general relativity,
Marina Cortês, Henrique Gomes and Lee Smolin, arXiv:1503.06085,
Physical Review D92, 043502 (2015)

Cosmological signatures of time-asymmetric gravity,
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This theory adds an extra term to the Hamiltonian formalism of general relativity which is linear in the momentum π conjugate to the metric. This term respects time translations but changes sign under inversions.
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This theory adds an extra term to the Hamiltonian formalism of general relativity which is linear in the momentum π conjugate to the metric. This term respects time translations but changes sign under inversions.
Consequences:

* The Friedmann equation acquires a new term which could, for instance, mimic dark energy or dark radiation.
* Propagation of chiral fermions (eg neutrinos) is modified by a torsion contribution to the connection.

Modified Friedmann equation:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{\Lambda}{3} - \frac{K}{a^2} + \frac{8\pi G\rho_{\rm m0}}{3a^3} + \frac{8\pi G\rho_{\gamma 0}}{3a^4} + \frac{G^2 g^2}{a^2} + \frac{8\pi G n_0 N_{\rm f} k_0}{3a^4} + \frac{16\pi G^2 n_0 N_{\rm f} g(a)}{3a^4}$$

USUAL STUFF

`ASYMMETRIC' DARK ENERGY, RADIATION, ETC

USUAL NEUTRINOS

NEUTRINO TORSION

$g(a)$ is a free function which multiplies the new term in the Hamiltonian

This result suggests strongly that if it is the anthropic principle that accounts for the smallness of the cosmological constant, then we would expect a vacuum energy density $\rho_V \sim (10-100)\rho_{M_0}$, because there is no anthropic reason for it to be any smaller.

Steven Weinberg, 1989, Rev. Mod. Phys.