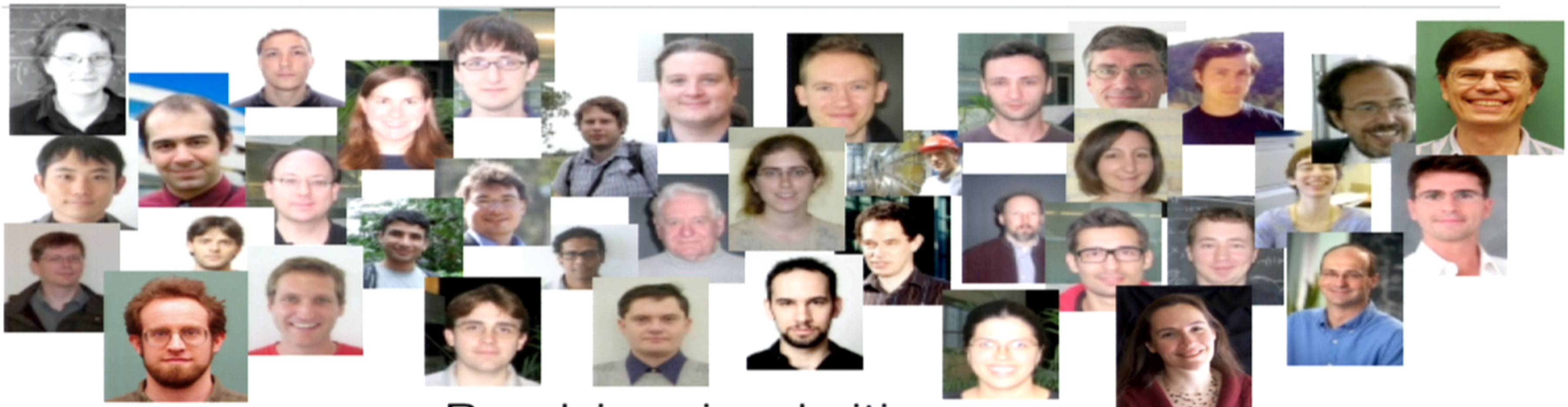
Title: 12/13 PSI Researcher Presentation

Date: Oct 24, 2012 03:30 PM

URL: http://pirsa.org/12100050

Abstract:

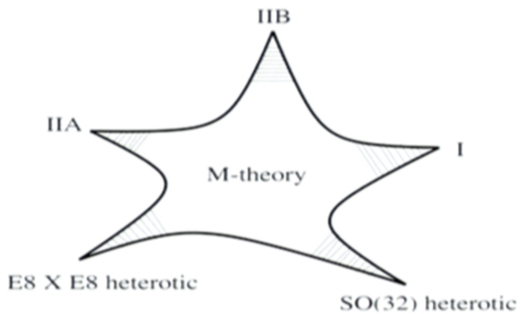
Cosmology at York U and Perimeter Institute

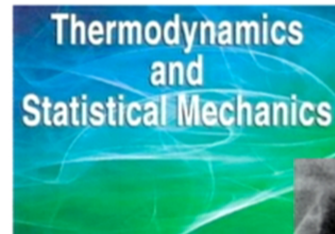


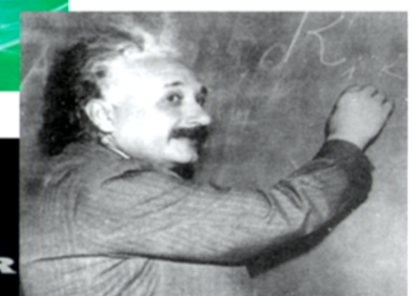
String cosmology
Resolving singularities
Inflationary cosmology
Gravitational waves
Quantum cosmology
Holographic cosmology
Cosmology of BSM physics
Baryogenesis
Black holes
Cyclic universes
Numerical relativity
Galaxy formation
Particle astrophysics
Dark energy
Cosmic strings
Dark matter
Eternal inflation
CMB

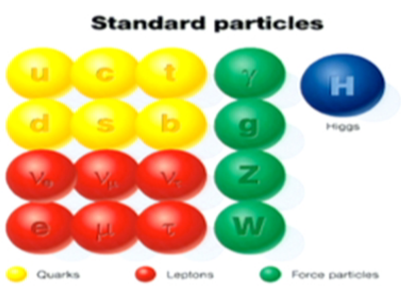
Theoretical cosmology

- Understanding what the fundamental laws of nature predict for the structure, contents, and evolution of the universe.

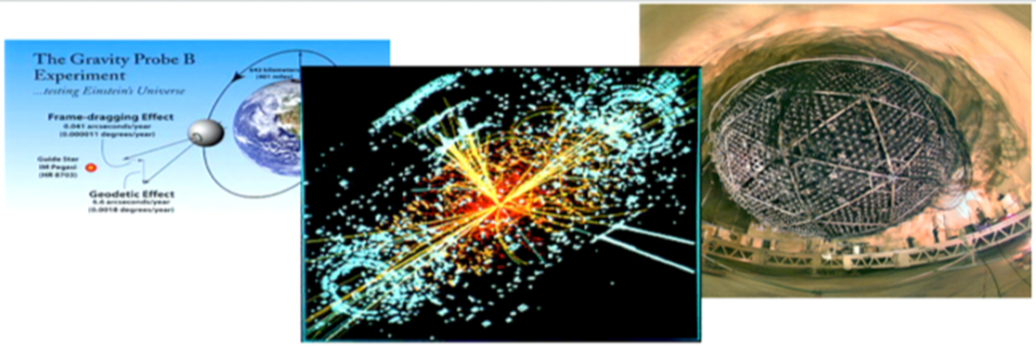








Observational cosmology

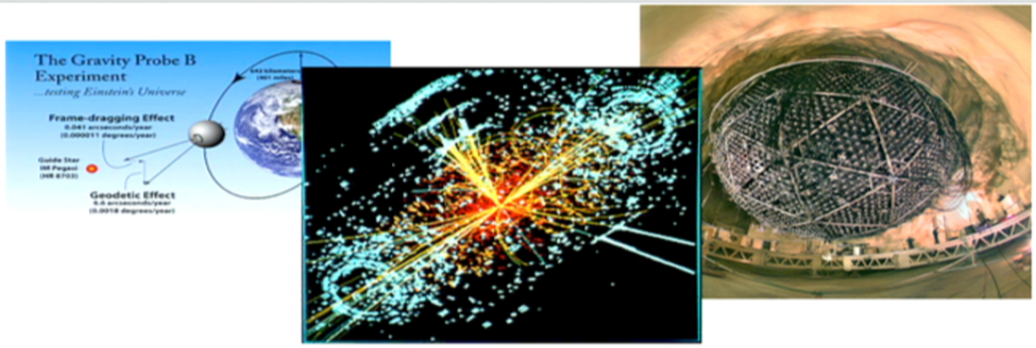


Laboratory experiments inform our theories.

Many theories cannot be tested by any practical experiment.

The promise of cosmology: test physics at extremely high and extremely low energies.

Observational cosmology



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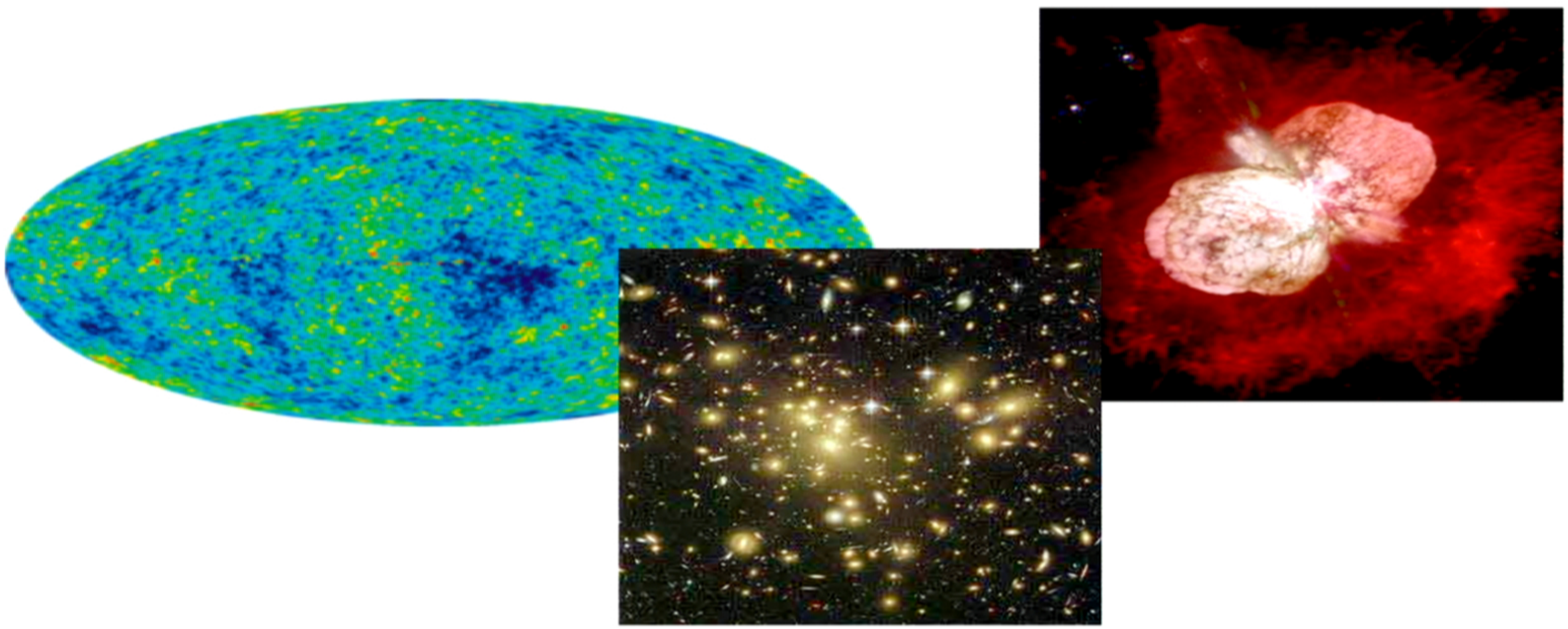
Observational cosmology

- Testing fundamental theories using limited and imperfect records of the past.

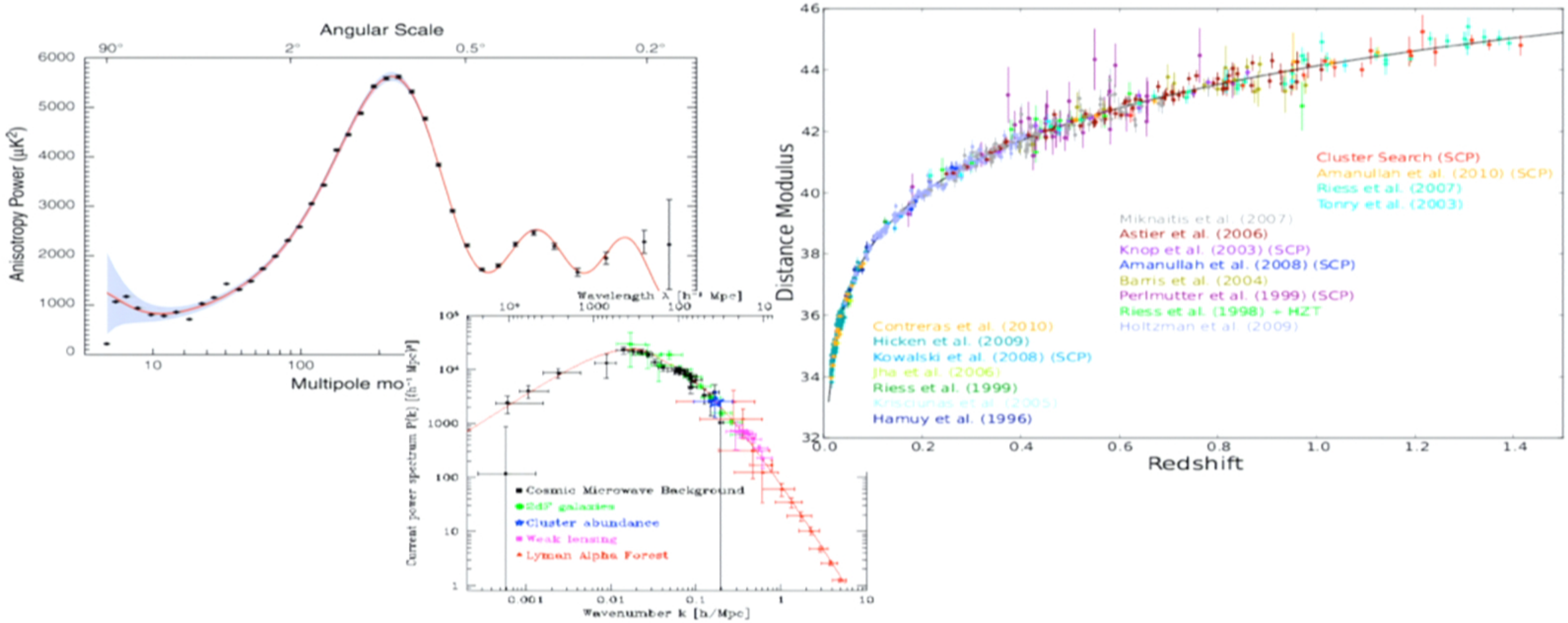


Observational cosmology

- Testing fundamental theories using limited and imperfect records of the past.

Observational cosmology

- This program has been amazingly successful!



Modern cosmology

- Cosmology is a data driven field!
- Surprises: dark energy, dark matter....
- New datasets are on the way:

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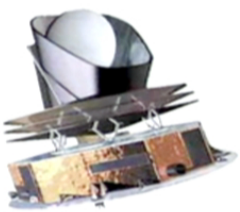
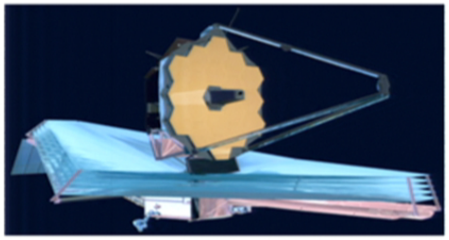
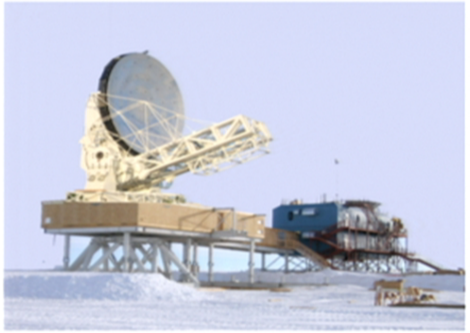

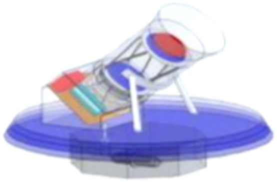

The promise of cosmology

String theory	CMB
Particle physics	Large scale structure
Gravity	Supernovae
……..	………

The nature of: quantum gravity, dark matter, dark energy, particle physics, gravity….

Standard big bang cosmology

- ``Our whole universe was in a hot dense state, then nearly 14 billion years ago expansion started….." (The big bang theory)

Standard big bang cosmology

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13.7 Billion Years: the present.

9.1 Billion Years: our sun ignites.

100 million years galaxies and first stars form.

380,000 years: neutral atoms form.

1 second: atomic nuclei form.

10^{-6} seconds: protons and neutrons form.

?Big Bang?

Standard big bang cosmology

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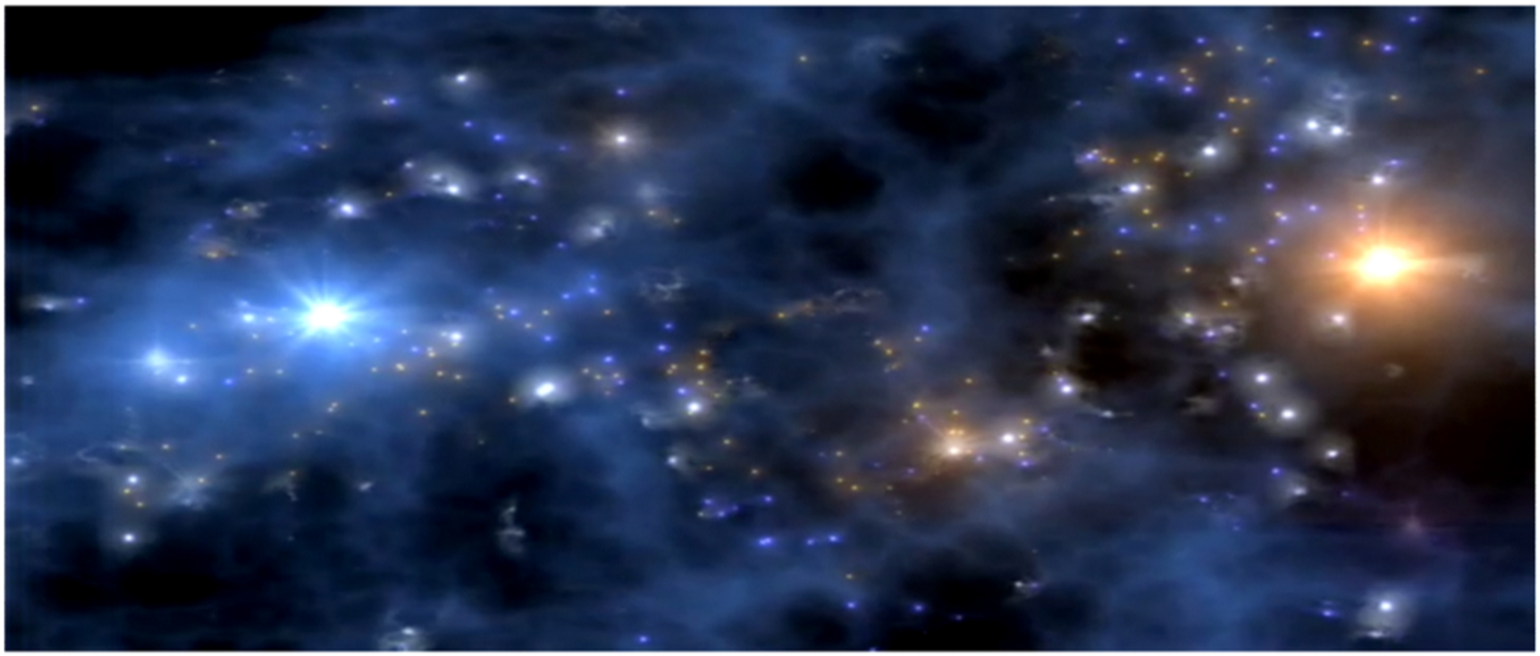

Cosmic Microwave Background (CMB) radiation

- The radiation released when neutral atoms were formed.
- A basic prediction of the standard big bang cosmology.

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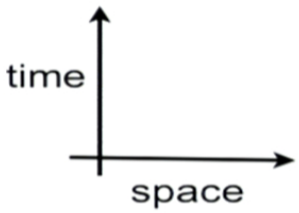
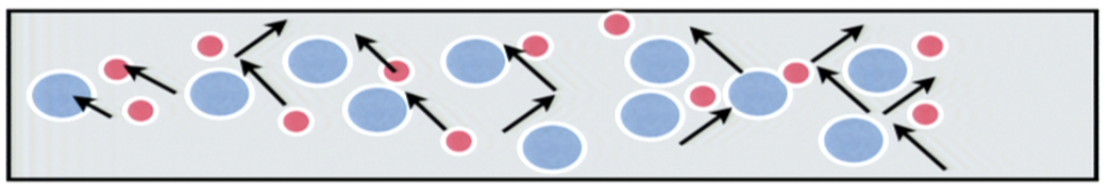


opaque



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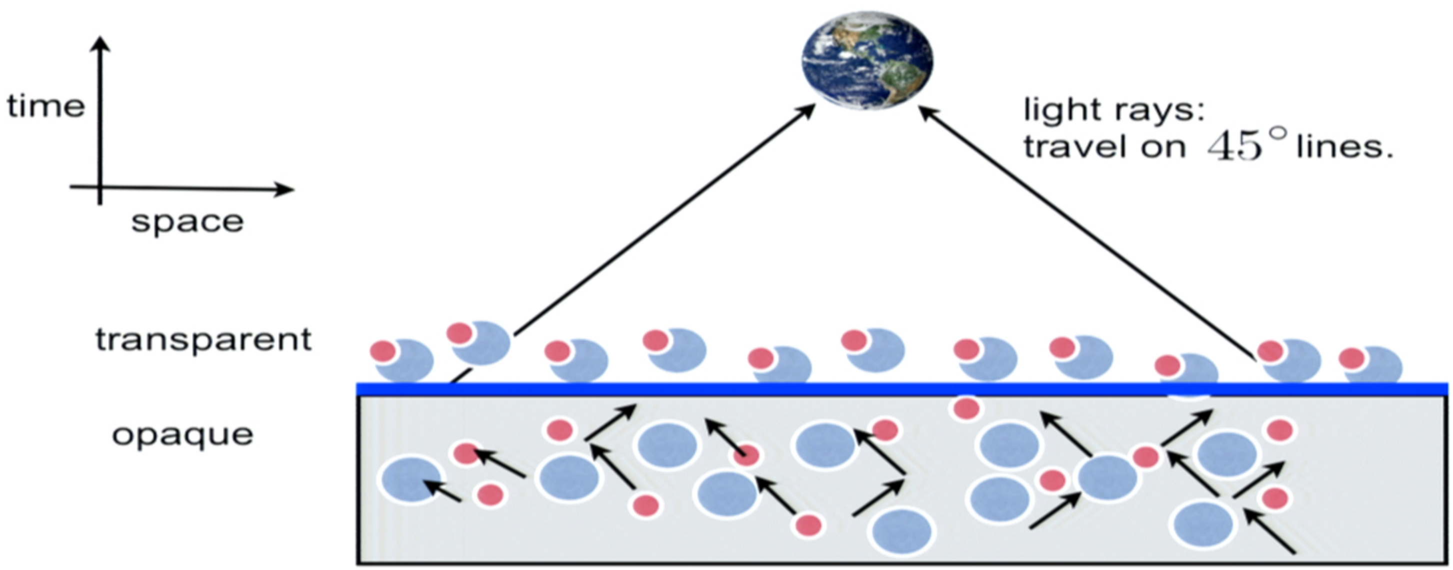

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- The CMB circa 1965 (Penzias and Wilson). Nobel!

The first observational confirmation of the standard big bang cosmology

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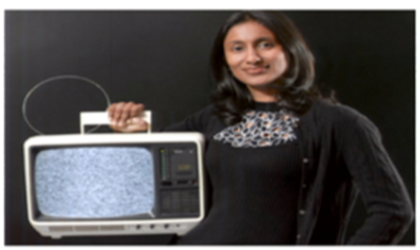
The CMB has the same intensity in every direction on the sky!

⟶ The universe is very nearly isotropic!



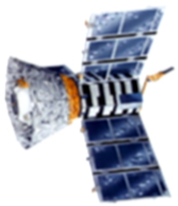
Dr. H. Peiris with the ``LTI" (Low Tech Instrument)

CMB is responsible for ~1% of the fuzz.

Cosmic Microwave Background (CMB) radiation

- The era of precision cosmology:

COBE



CMB is universe's most perfect blackbody

$$T = 2.73^\circ \ \mathrm{K}$$

Temperature anisotropies $\frac{\Delta T}{T} \simeq 10^{-5}$

Cosmic Microwave Background (CMB) radiation

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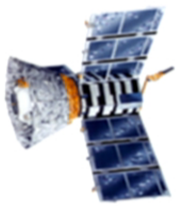

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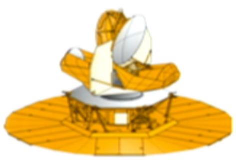
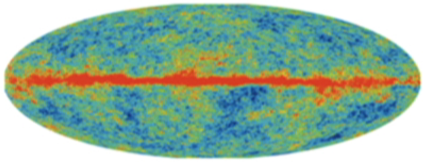
WMAP





precision measurement of the statistics of fluctuations

Cosmic Microwave Background (CMB) radiation

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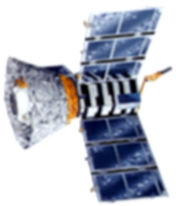

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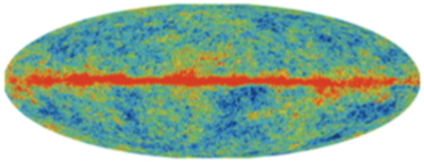
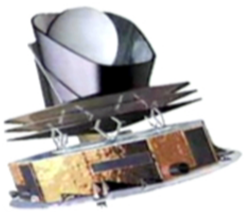


precision measurement of the statistics of fluctuations

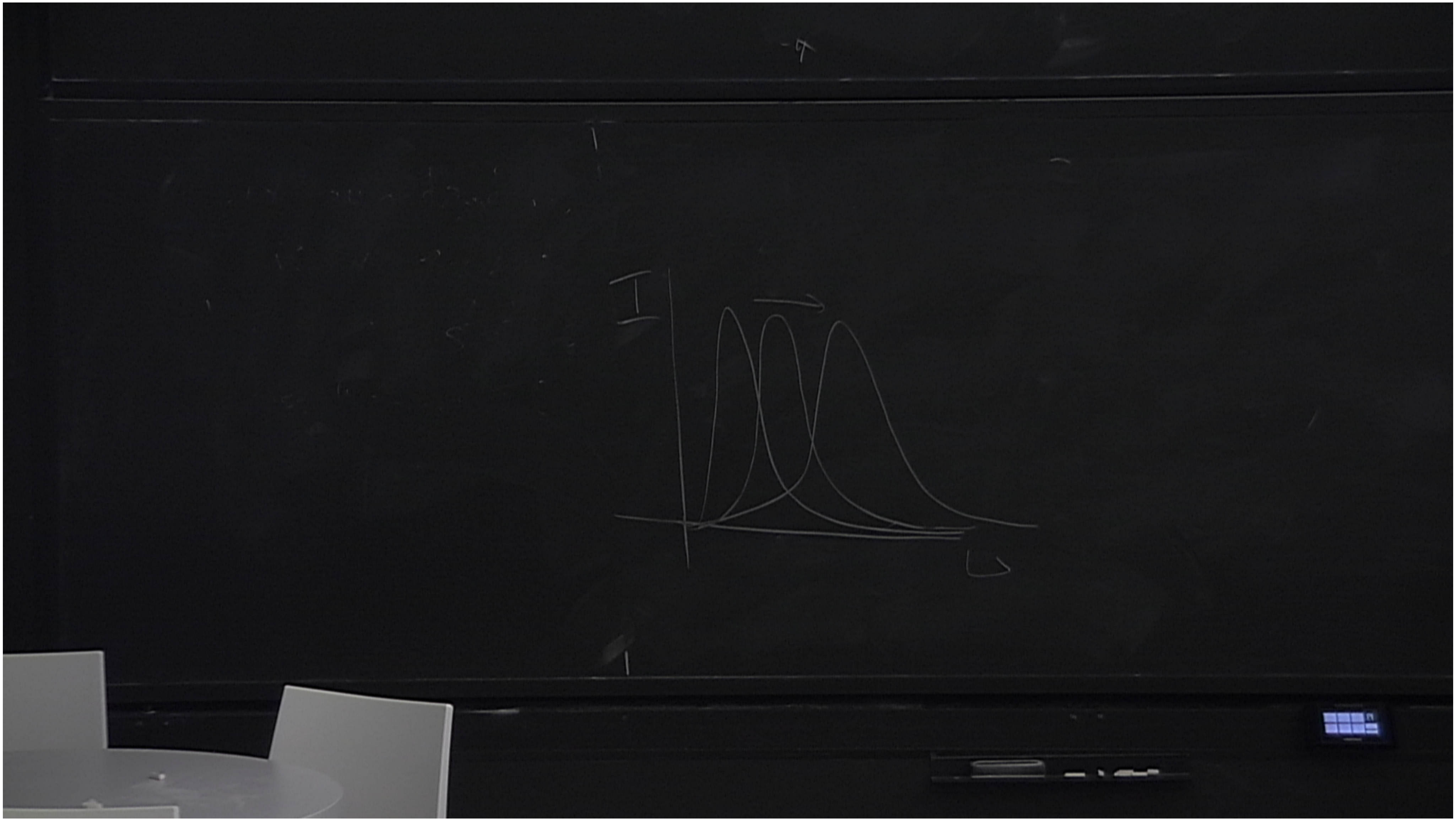
Planck



Intensity & polarization

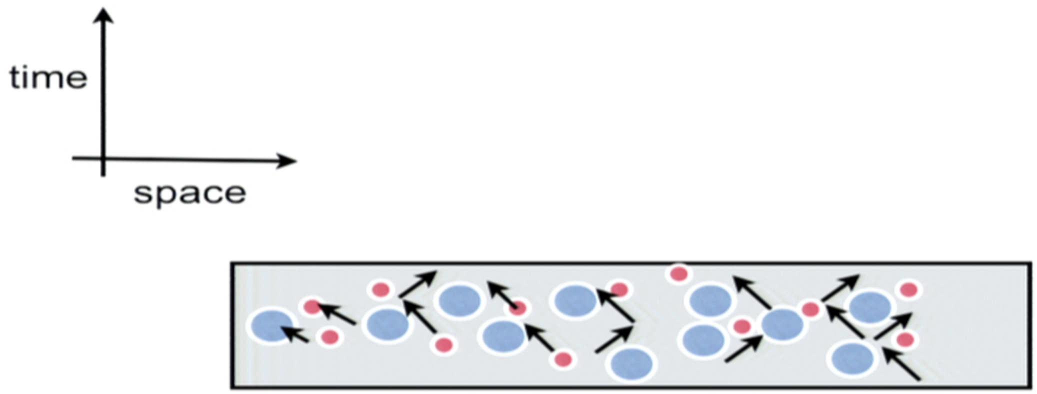
?exciting hints of new physics?

Data is in hand, we'll see in 2013!



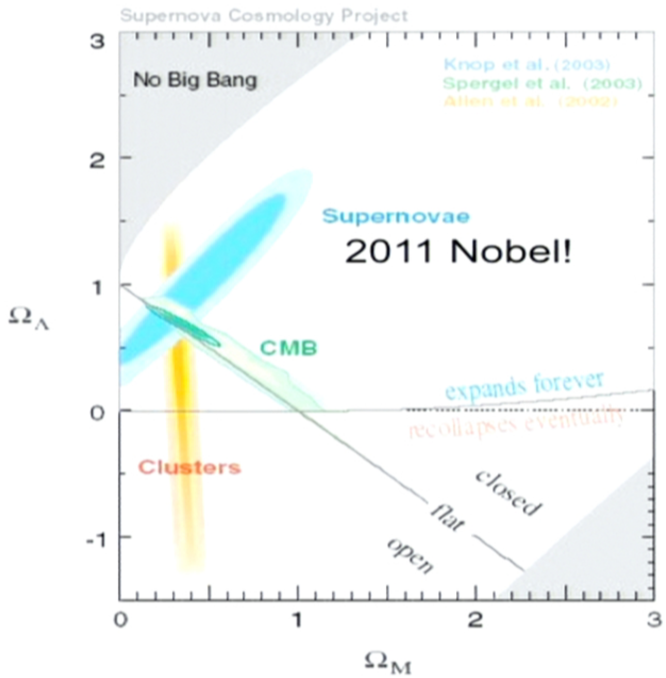
Cosmic Microwave Background (CMB) radiation

- Temperature anisotropies encode density perturbations.

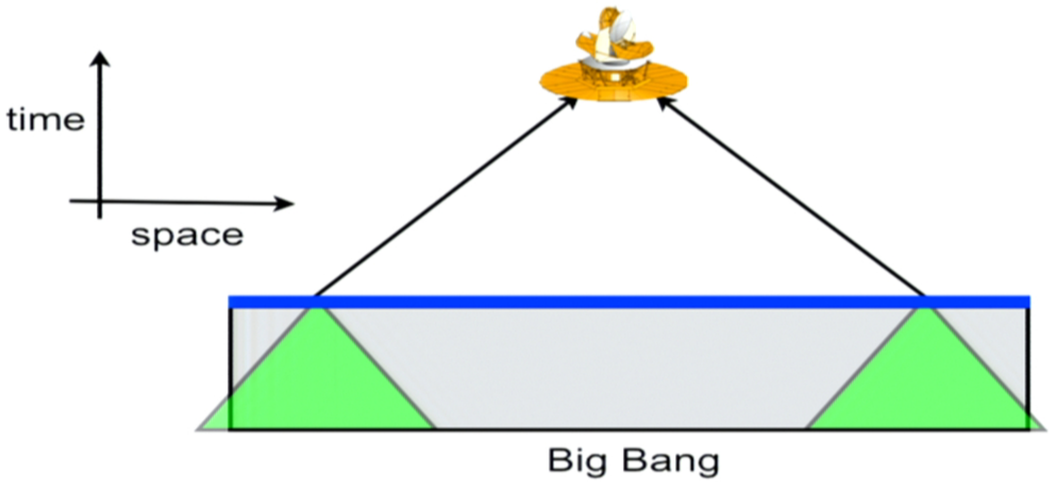


What we know

- CMB + supernovae + LSS : concordance cosmology.



Initial conditions: Inflation



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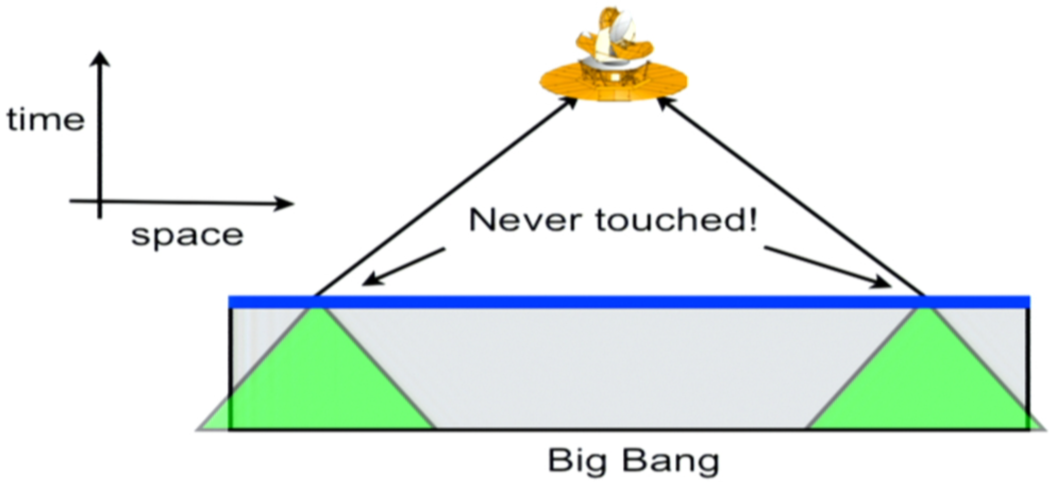
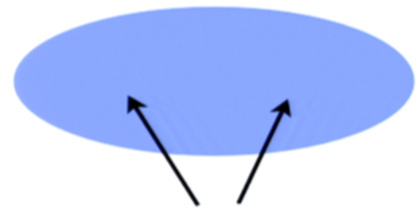


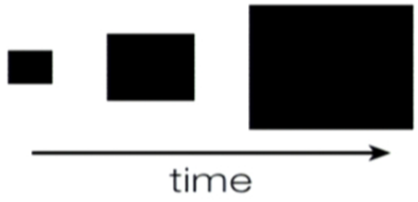


Inflation

- What causes inflation?

  Need something that dilutes very slowly, or not at all.

  Acts like a fluid with negative pressure.



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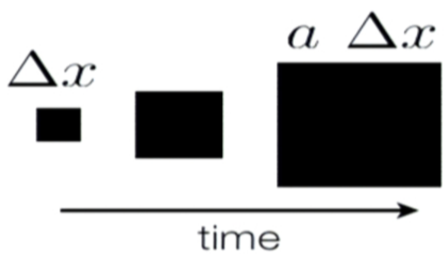

$$a \propto \exp\left[\sqrt{\frac{8\pi G_N}{3}\rho}\;\; t\right]$$

$$\rho \simeq 10^{85}\ \mathrm{kg/m^3}$$

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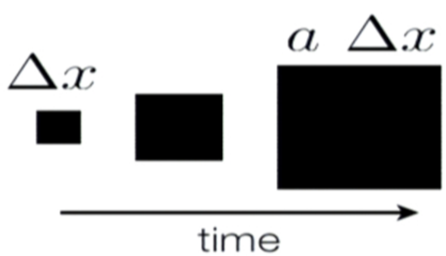

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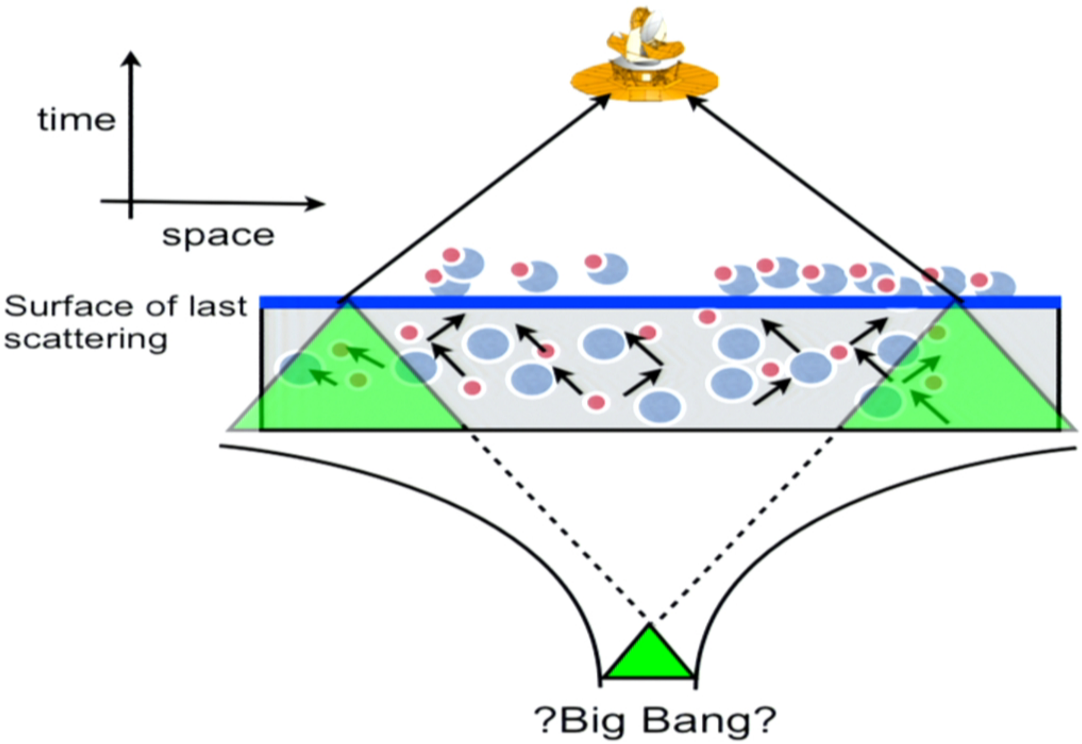
Perfect candidate: potential energy of a scalar field!

Initial conditions: Inflation



Quantum fluctuations in the inflaton provide the initial perturbations.

Testing Inflation

- The power spectrum of fluctuations: $P(k) = Ak^{n_s - 1}$

  $A = (2.42 \pm .11) \times 10^{-9}$ $\quad n_s = .968 \pm .012$ (WMAP)

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- The energy scale of inflation: primordial gravitational waves

$$E \leq 10^{16}\mathrm{GeV} \qquad \text{(WMAP)}$$

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- Gaussianity of fluctuations: $\Phi(\mathbf{x}) = \phi_G(\mathbf{x}) + f_{\mathrm{NL}}\phi_G^2(\mathbf{x})$

  $f_{\mathrm{NL}}^{\mathrm{local}} = 32 \pm 21$ $\Delta f_{\mathrm{NL}}^{\mathrm{local}} \simeq 4$

  WMAP Planck

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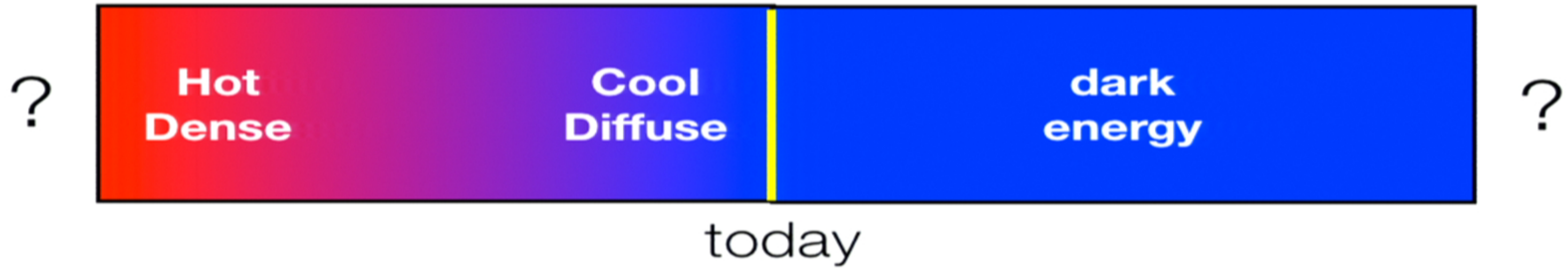
  $\Delta f_{\mathrm{NL}}^{\mathrm{local}} \simeq 4$ Planck

- How much inflation: spatial curvature.

  $\Omega_k = -.0043 \pm .0049$ WMAP

  $\Delta\Omega_k = .0016$ Planck + SDSSIII

Dark energy

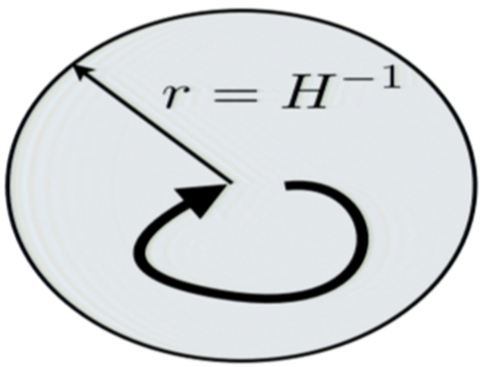


- What is dark energy?

De Sitter space

- A spacetime with only a cosmological constant.
- There is an event horizon, just as for a black hole.

$$ds^2 = -\left(1 - H^2 r^2\right) dt^2 + \frac{dr^2}{\left(1 - H^2 r^2\right)} + r^2 \left(d\theta^2 + \sin^2\theta d\phi^2\right)$$



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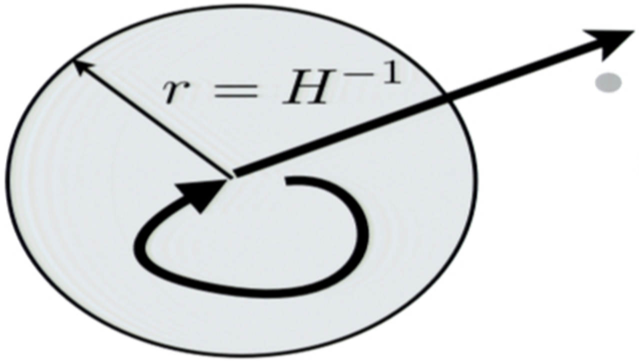
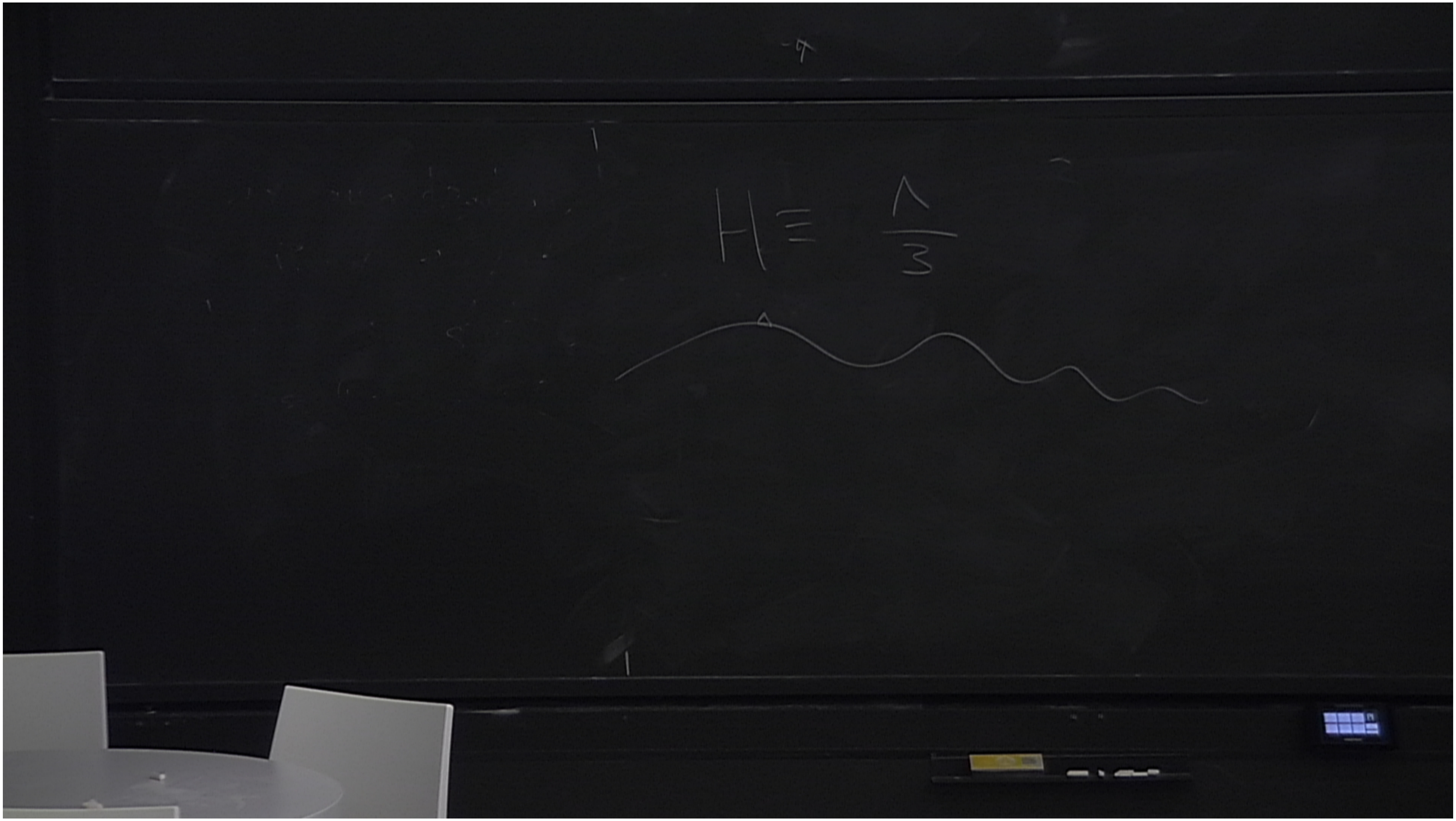


- Once you cross $r = H^{-1}$, there is no coming back.


$H \equiv \frac{\Lambda}{3}$

De Sitter space

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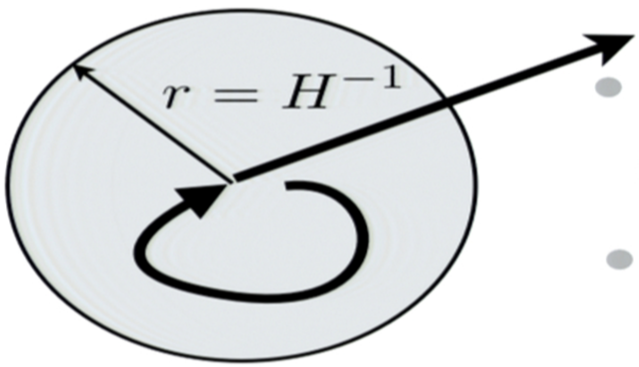
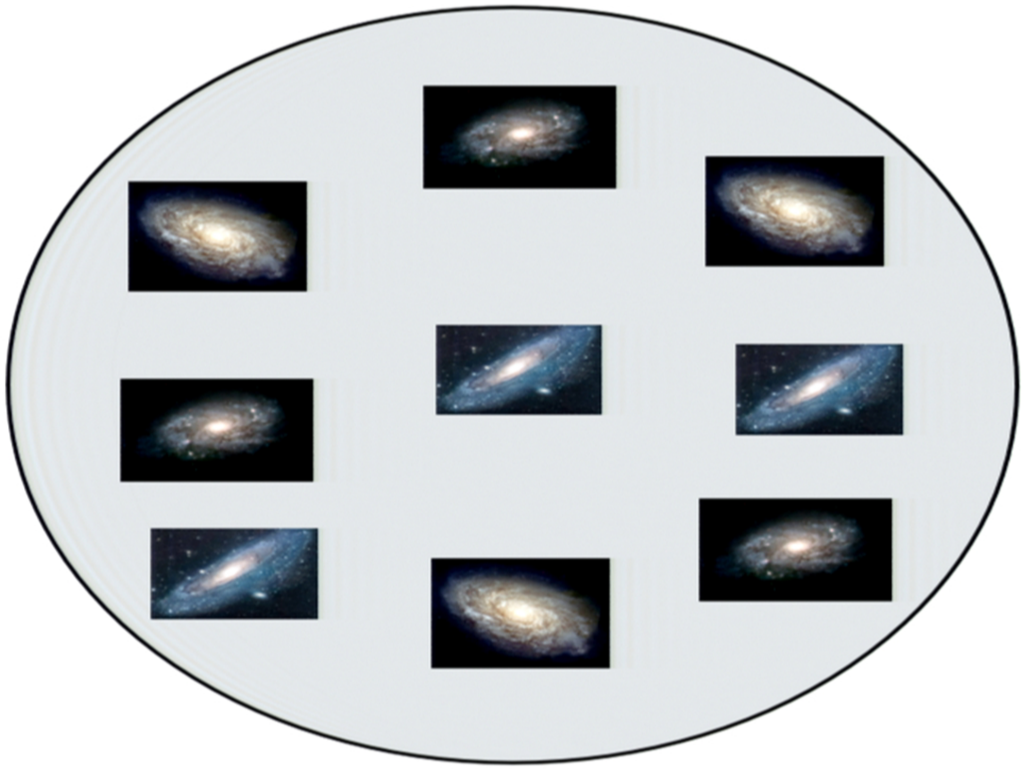


- Once you cross $r = H^{-1}$, there is no coming back.
- Signals redshift:

$$\frac{f_{\rm rec}}{f_{\rm emit}} = \left(1 - H^2 r_{emit}^2\right)^{1/2}$$

Our future



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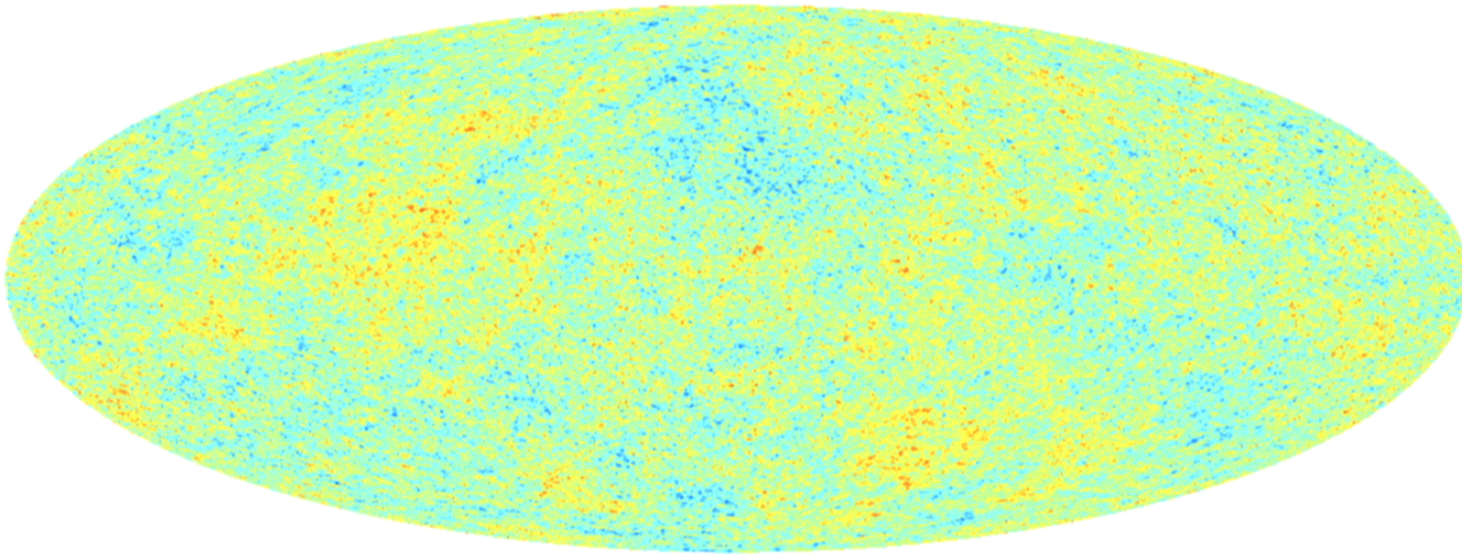

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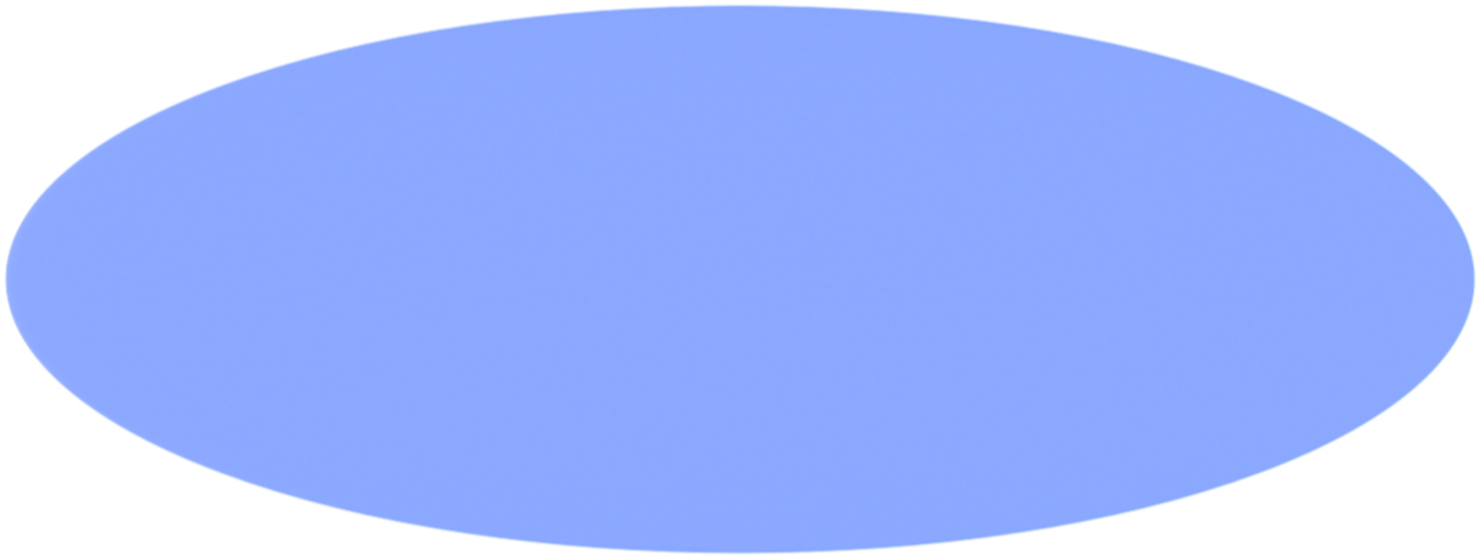


Testing dark energy

- Dark energy density:

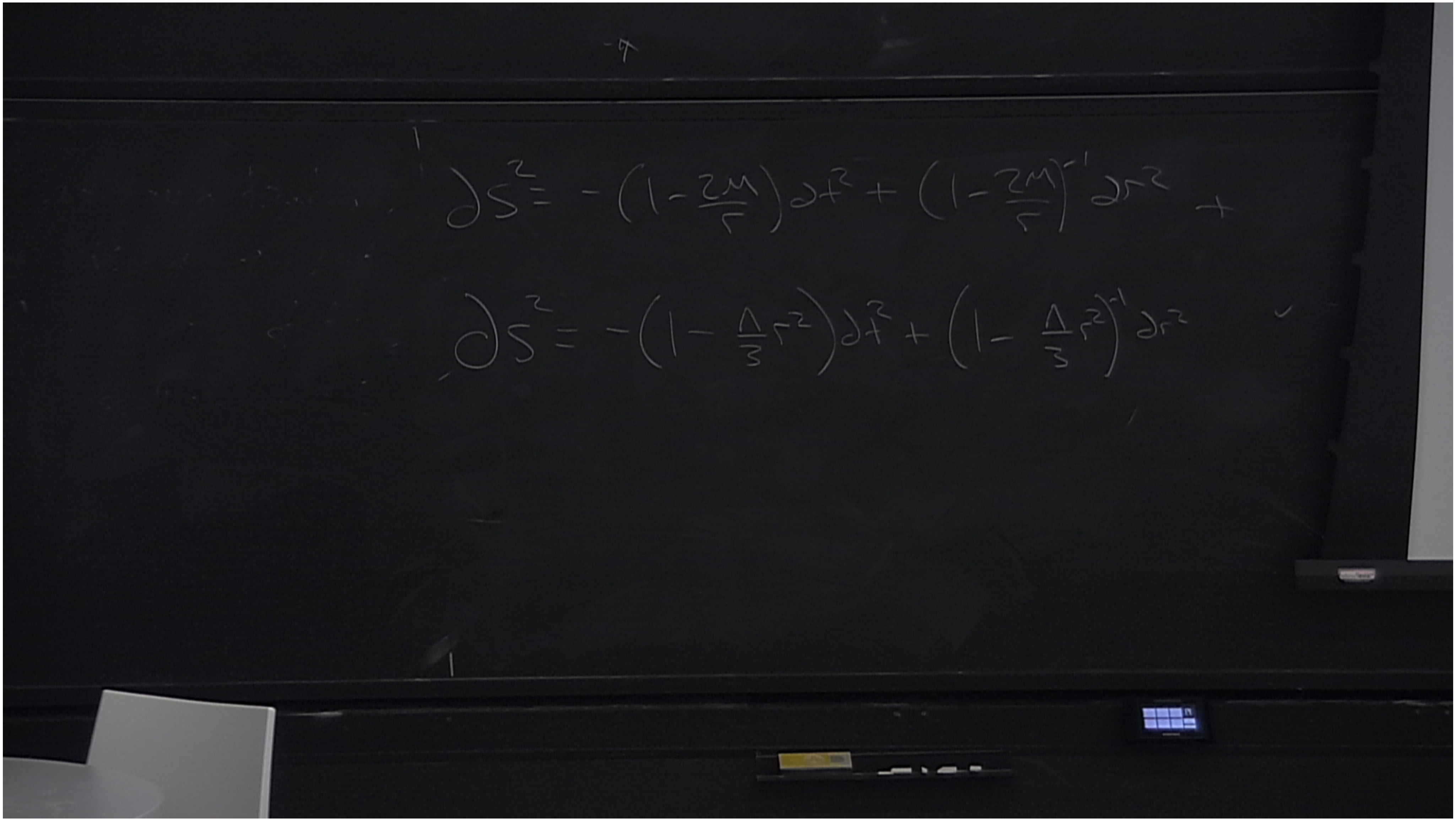
$$\Omega_\Lambda = .727 \pm .030$$

WMAP

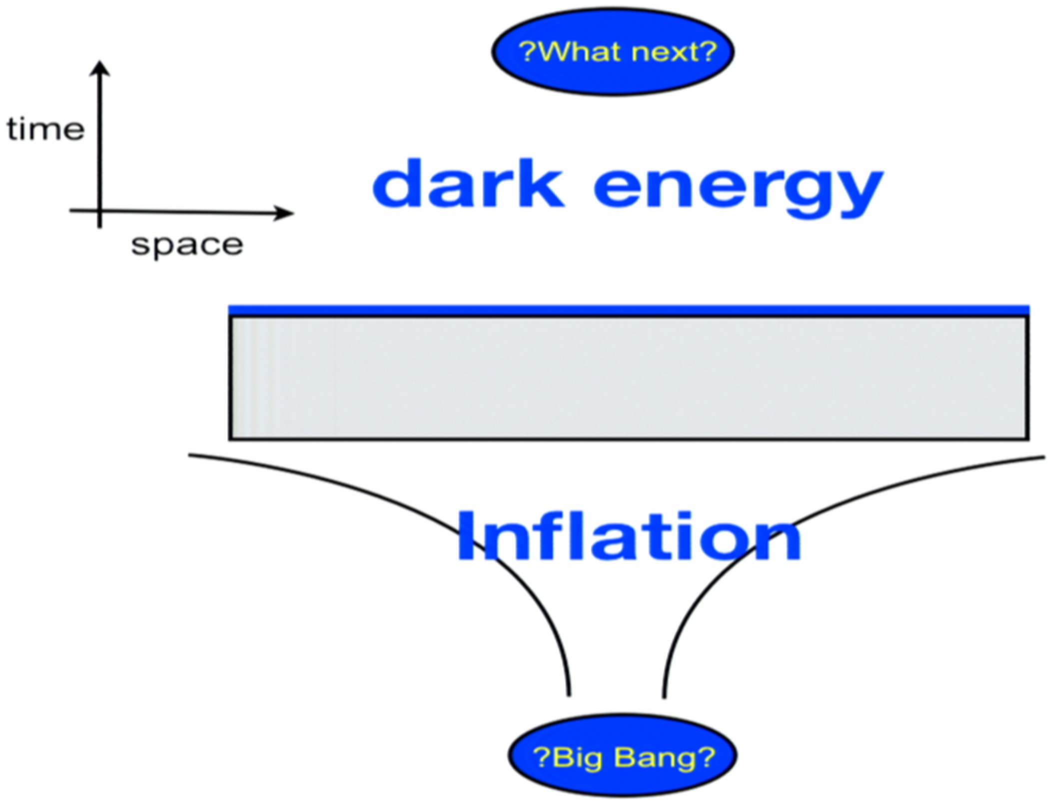
- Dark energy equation of state: is the density constant?

$$w = -1.1 \pm .14 \qquad \Delta w = .06$$

WMAP — Planck + SN


$ds^2 = -\left(1-\frac{2M}{r}\right)dt^2 + \left(1-\frac{2M}{r}\right)^{-1}dr^2 +$
$ds^2 = -\left(1-\frac{\Lambda}{3}r^2\right)dt^2 + \left(1-\frac{\Lambda}{3}r^2\right)^{-1}dr^2$

Accelerated expansion



- Strong evidence for at least two epochs of accelerated expansion.

The big questions

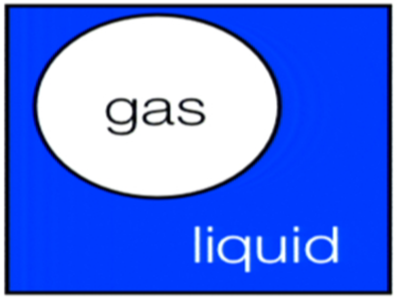
- Evidence for accelerated expansion has lead us to ask some truly fundamental questions!

My research

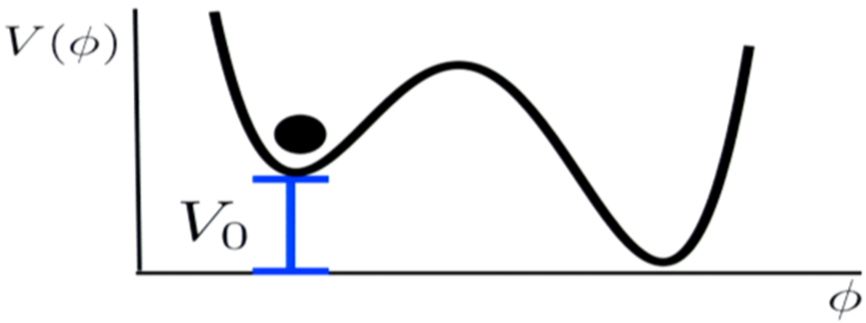
- Beginnings and endings: initial conditions for inflation, future evolution of our universe.
- Fundamental theoretical models of inflation and dark energy.
- The role of extra spatial dimensions in cosmology.
- Identifying new imprints of fundamental physics on cosmology.
- Analysis of CMB data.
- Theory of de Sitter space.

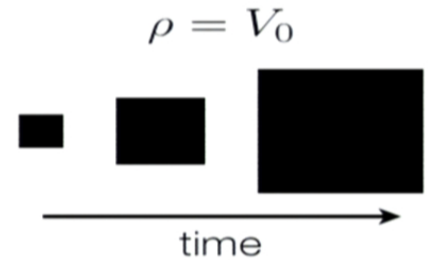
Cosmic phase transitions

Liquid water goes to steam by the formation of bubbles.



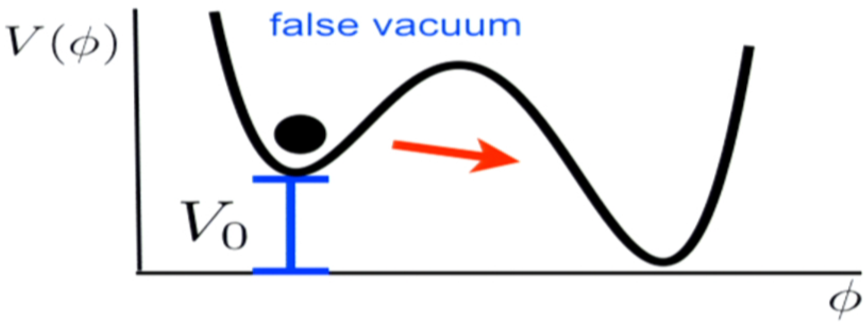
When accelerated expansion ends locally





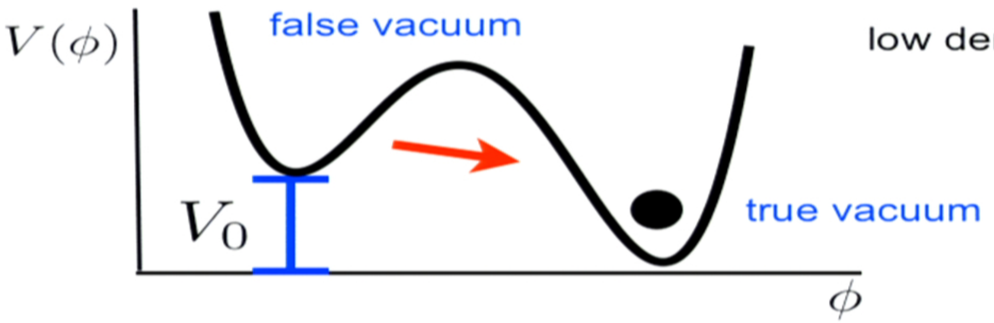
Classically, the universe undergoes accelerated expansion forever.

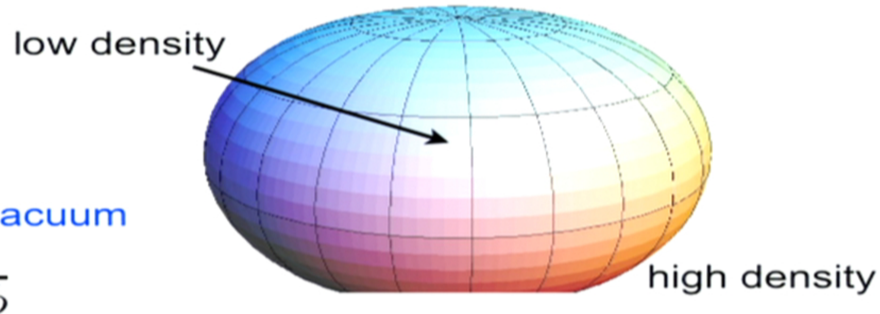
When accelerated expansion ends locally



Quantum mechanically, the field tunnels through the barrier!

When accelerated expansion ends locally





Quantum mechanically, the field tunnels through the barrier!

- Doesn't happen everywhere, only inside bubbles.
- The probability per unit time per unit volume to form a bubble:

$$\lambda = Ae^{-S_E}$$

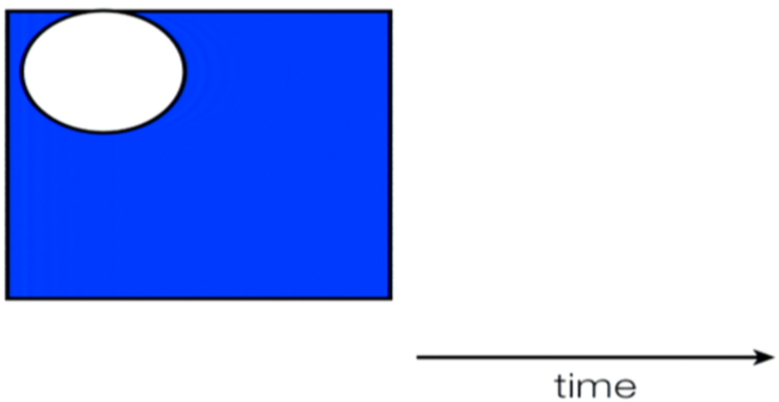
$$S_E \propto \frac{\sigma^4}{\Delta V^3}$$ (surface tension) (energy difference)

Typically, the probability is quite small.

Coleman
Coleman & de Luccia

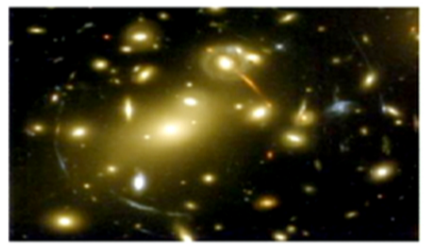
Does the accelerated expansion ever end?

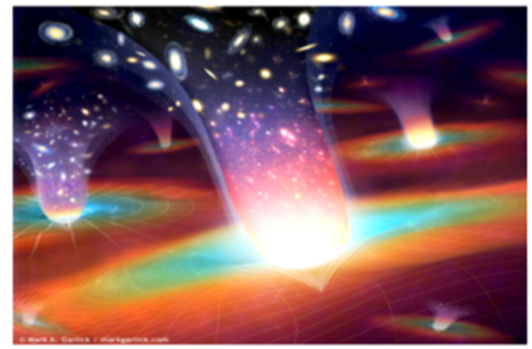
- In a static or decelerating universe:



Eternal Inflation

- Eternal inflation: the Universe is infinitely big!





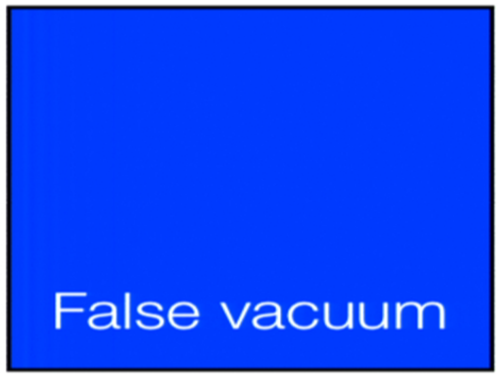
Intrinsically interesting!

Also well-motivated!

Eternal Inflation: is this our universe?

- How does our observable universe fit into this picture?

Vacuum decay could be in our past.

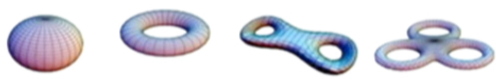


Eternal Inflation: is this our universe?

- How does our observable universe fit into this picture?

  Eternal inflation is nearly inevitable in string theory.

- Extra dimensions are hidden from our view by compactifying them.



The compact space can assume many sizes and shapes.

Eternal Inflation: is this our universe?

- How does our observable universe fit into this picture?

Eternal inflation is nearly inevitable in string theory.

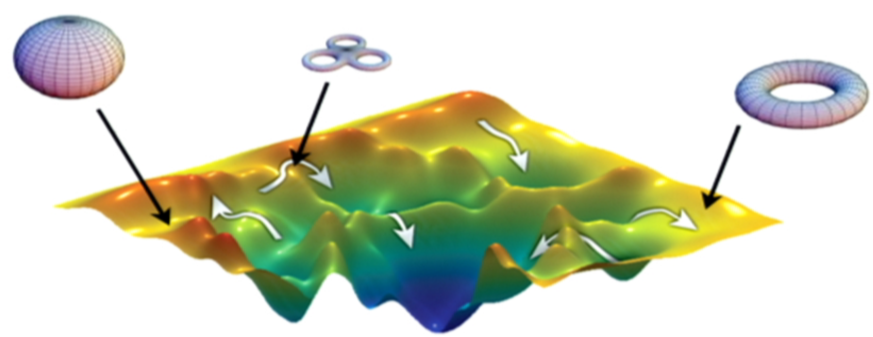
- Extra dimensions are hidden from our view by compactifying them.

The compact space can assume many sizes and shapes.

- Configurations can be deformed into one another at the cost of some energy

Potential ``Landscape"
of string theory

Susskind

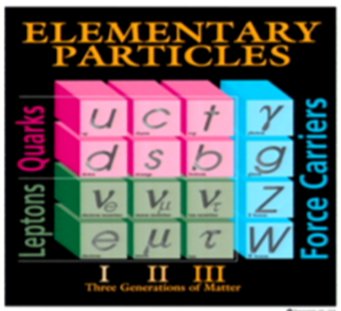


Eternal Inflation: is this our universe?

- How does our observable universe fit into this picture?

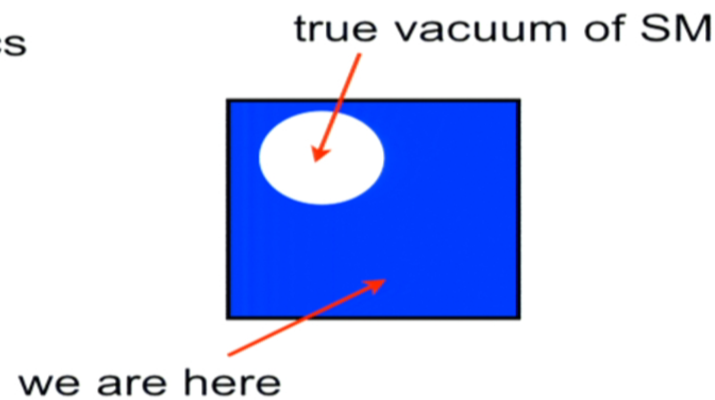
Decay could be in our future.

The standard model of particle physics



+ Higgs Boson

$m_H < 130\ \mathrm{GeV}$



(Don't panic, in this case, we have many years before our vacuum expires.)

Sher
Lindner & Sher
Arkani-Hamed et. al.

latest bound: Elias-Miro et. al.

Really?

- An infinite number of individually infinite universes in an infinite expanding background?

Surely I can't be serious!

- Eternal inflation is a direct consequence of:

non-unique
vacuum state

(possible in standard model)

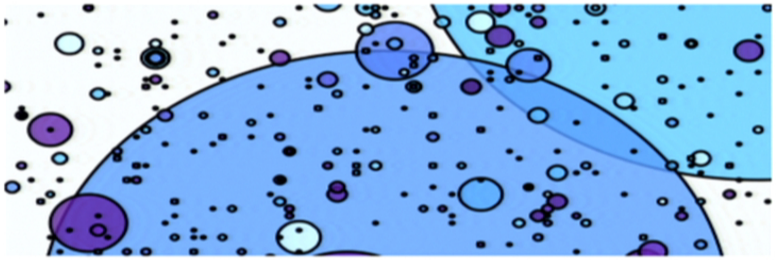
(common in BSM physics)

(inevitable in string theory)

Observational Tests of Eternal Inflation

- Strong theoretical motivation, but is eternal inflation experimentally verifiable?

Our bubble does not evolve in isolation....



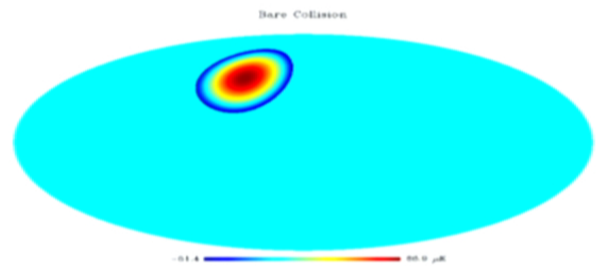
The collision of our bubble with others provides an observational test of eternal inflation.

Aguirre, MCJ, Shomer

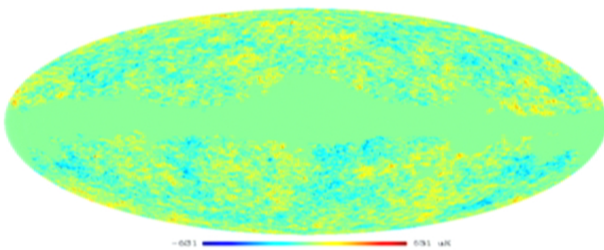
Observational signatures

- Generic signature:

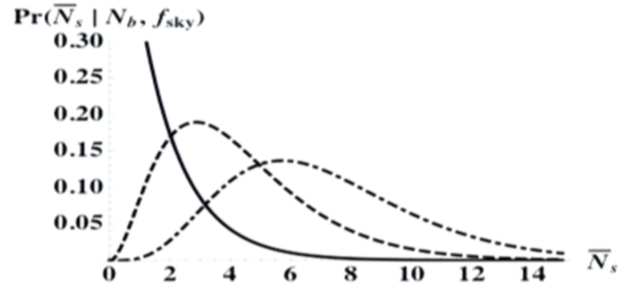
$$\frac{\Delta T(\hat{\mathbf{n}})}{T} \simeq f(\hat{\mathbf{n}}) + \delta_{\Lambda CDM}(\hat{\mathbf{n}})$$



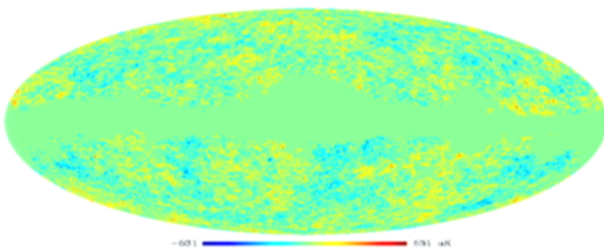
Searching for collisions



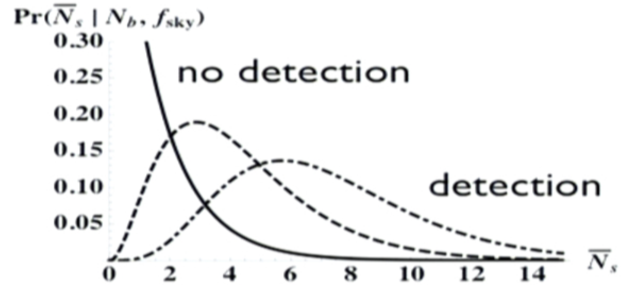
$$Pr(\bar{N}_s|\mathbf{d})$$



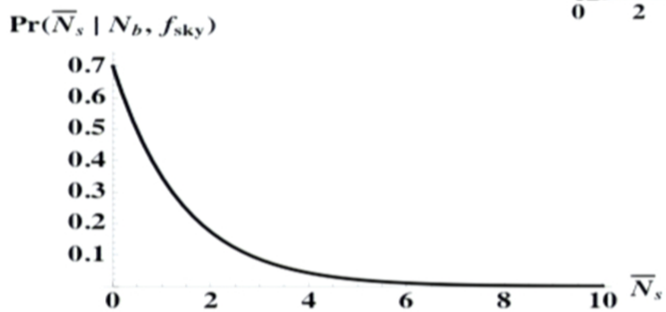
Searching for collisions



$$\longrightarrow Pr(\bar{N}_s|\mathbf{d})$$



WMAP 7



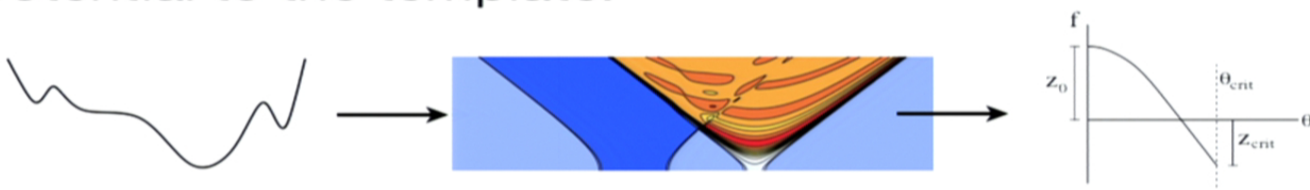
- The posterior is peaked around $\bar{N}_s = 0$

The data does not support the bubble collision hypothesis.

What next?

$$\bar{N}_s < 1.6 \text{ at } 68\% \text{ CL}$$

- What region of theory space have we constrained?
- Numerical simulations are needed to connect the potential to the template!



(Like in inflation: general template for fluctuations needs to be connected to the potential)

Other links between NR and observational cosmology