Title: Searching for Other Universes

Date: Jul 14, 2014 07:00 PM

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Abstract: Centuries of astronomy and cosmology have led to an ever-larger picture of our â€˜universeâ€™ â€” everything that we can observe. For just as long, there have been speculations that there are other regions beyond what is currently observable, each with diverse histories and properties, and all inhabiting a â€˜Multiverseâ€™. A nexus of ideas from cosmology, quantum gravity, and string theory lead to the prediction that we inhabit one of the most interesting sorts of Multiverses one could imagine: one that arises as a natural consequence of compelling explanations for other physics, and one that at least in principle can be tested with observations. In this talk, I will outline these ideas, and discuss the first observational tests of the Multiverse using data from the Wilkinson Microwave Anisotropy Probe.

Searching for Other Universes

ISSYP 2014

Matthew C. Johnson
York University and Perimeter Institute

The Universe

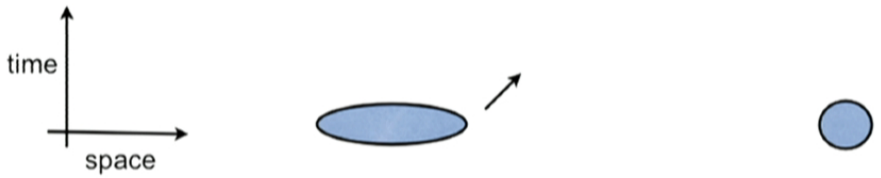
Everything.

The Local Universe

Everything that we can interact with.

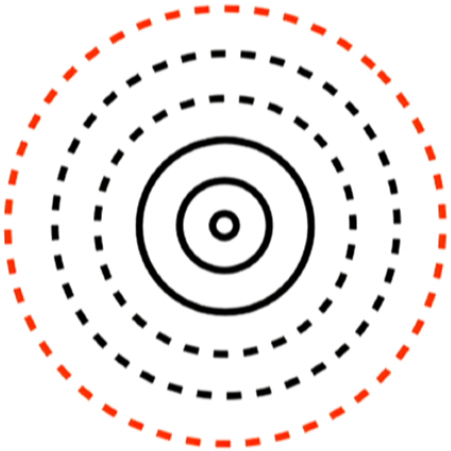
Far Out = Far Back in Time

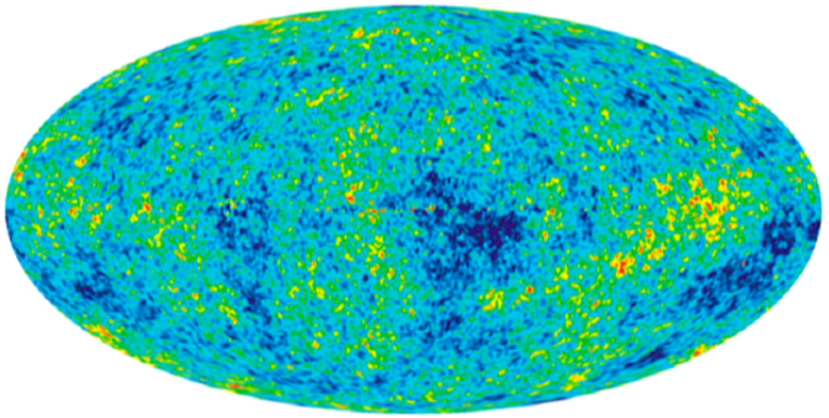
Light has a constant speed.
Looking out is looking back in time.



The Observable Universe

Everything that we observe.





Cosmic Microwave Background (CMB) radiation

- The radiation released when neutral atoms were formed.

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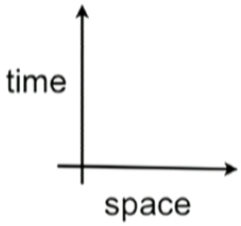
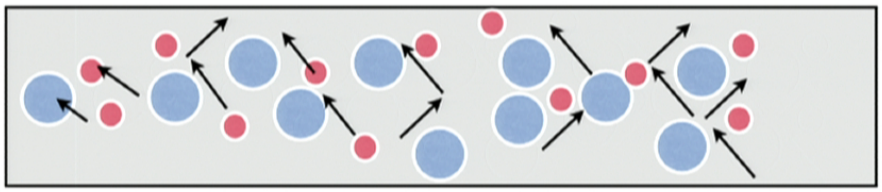


opaque



What is our best model?

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

(a time, not a place)

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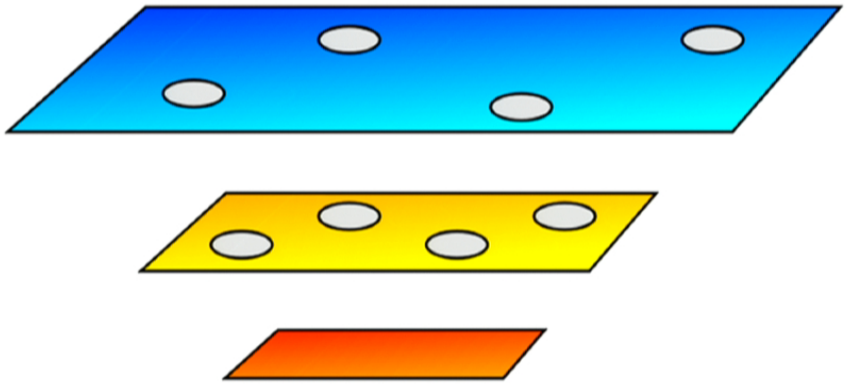
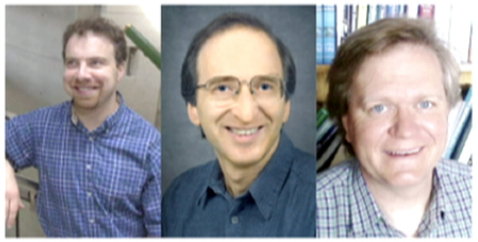
The expansion of the Universe is accelerating!





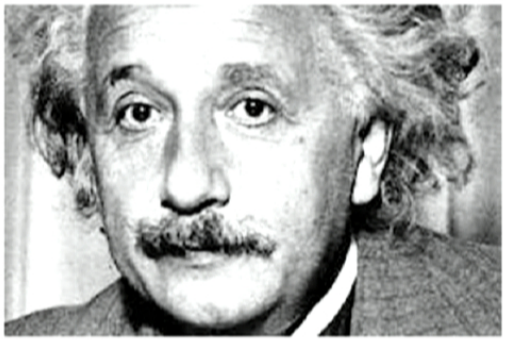
Nobel Prize 2011!

Adam Riess, Saul Perlmutter, Brian Schmidt

What is our best model?

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

- The properties of expansion in a homogeneous and isotropic universe are determined by what the Universe contains.



General Relativity

What is our best model?

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$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Spacetime curvature

Matter & energy

What is our best model?

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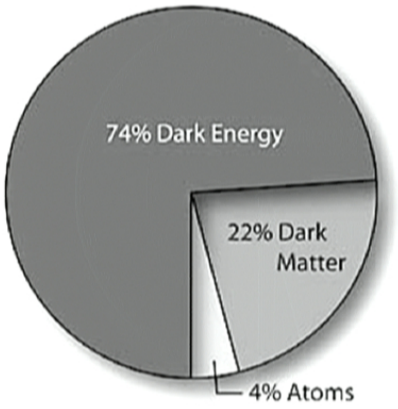

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ΛCDM

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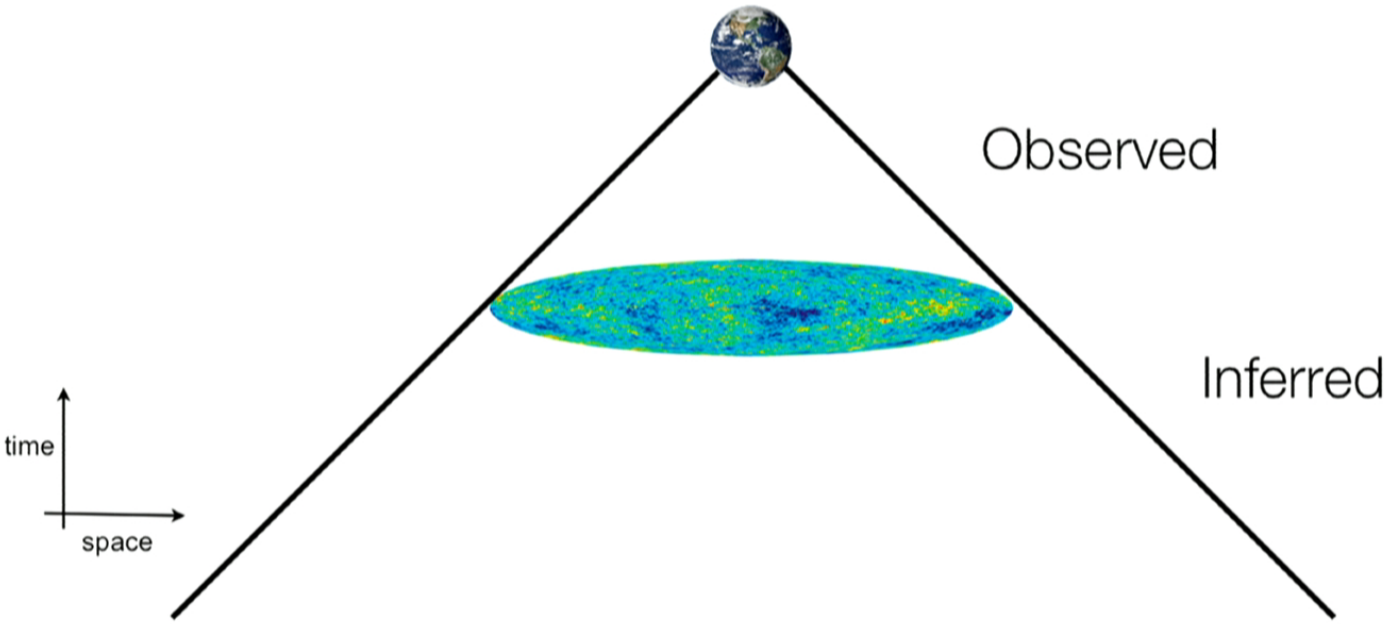
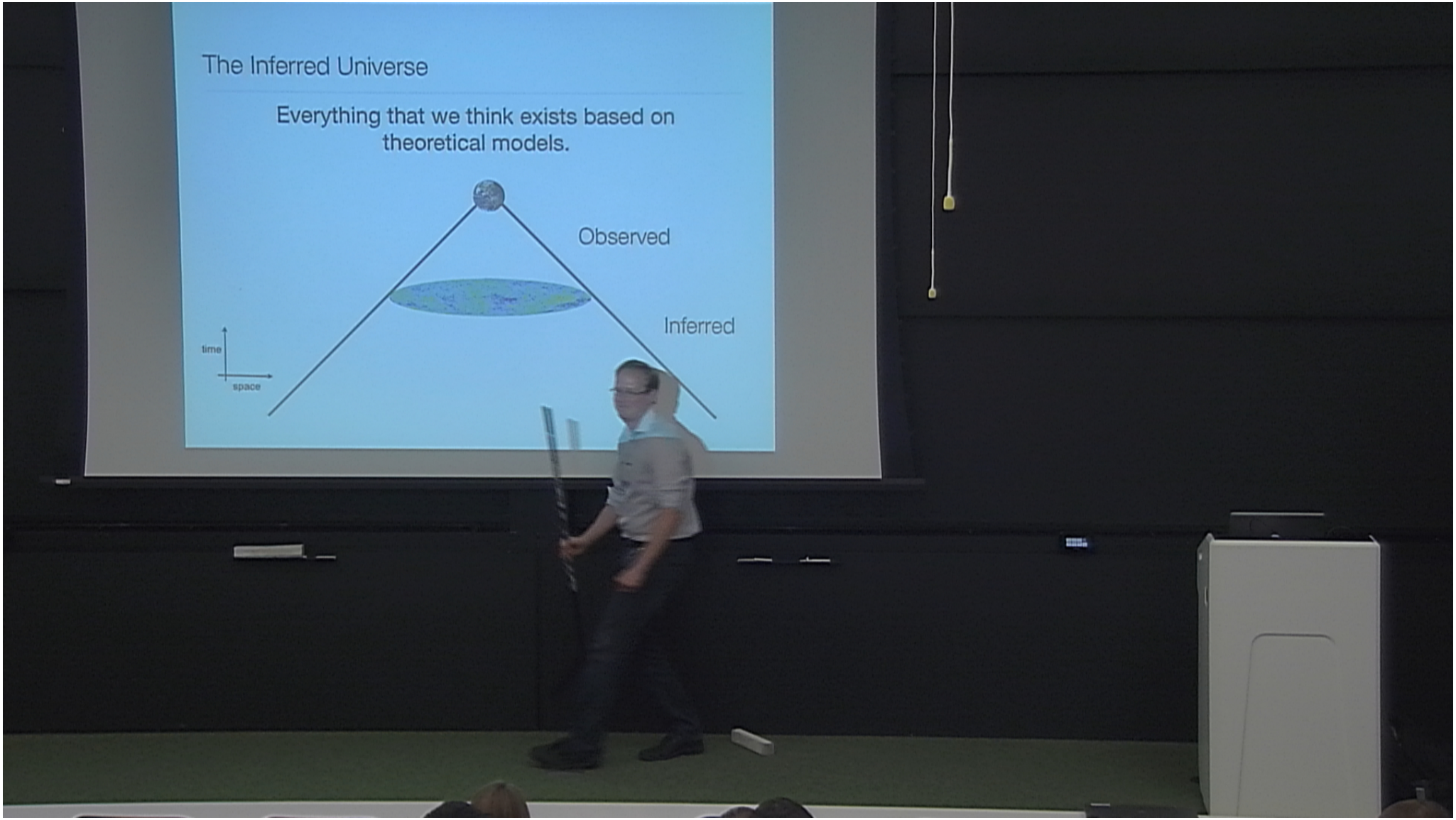
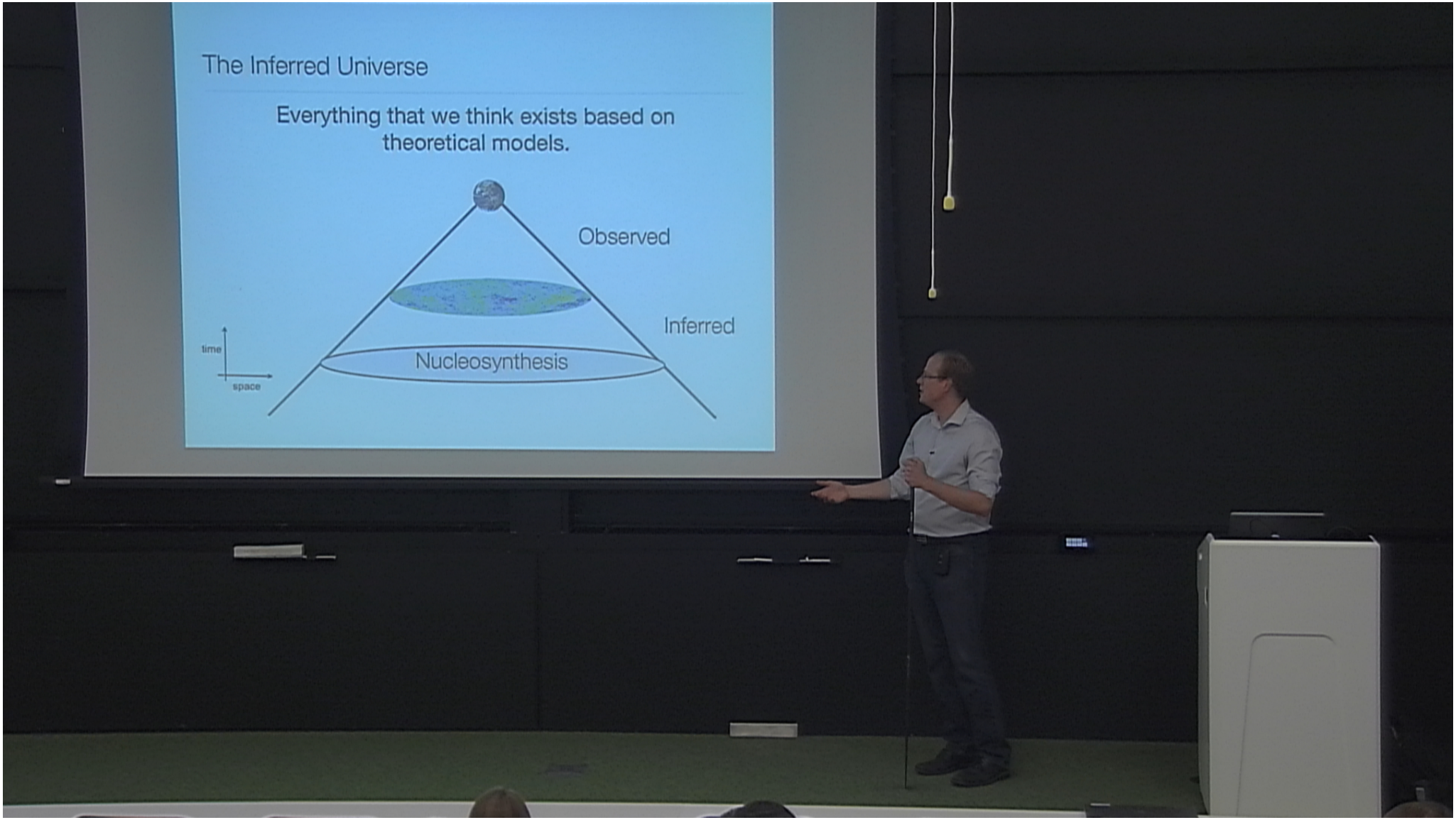
$$\Lambda CDM$$

The Inferred Universe

Everything that we think exists based on theoretical models.




The Inferred Universe
Everything that we think exists based on theoretical models.
Observed
Inferred
time
space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Observed
Inferred
Nucleosynthesis
time
space

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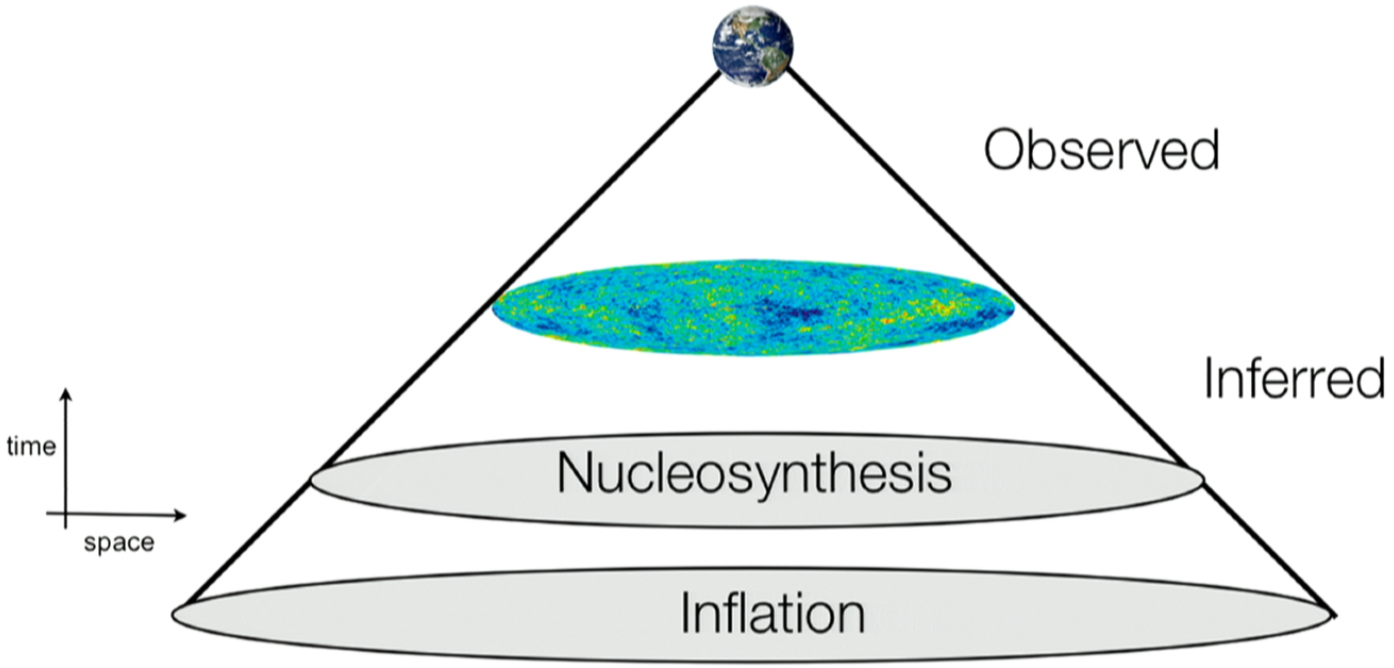

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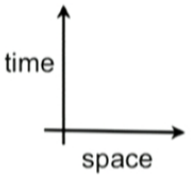
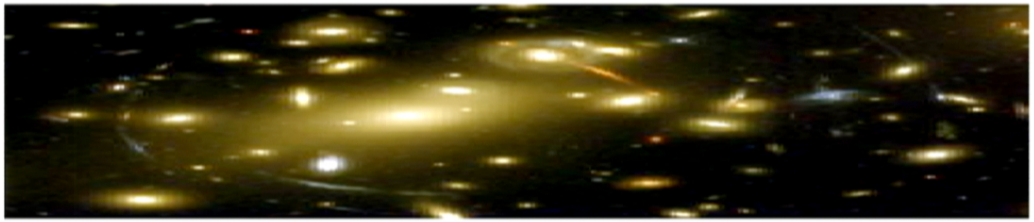


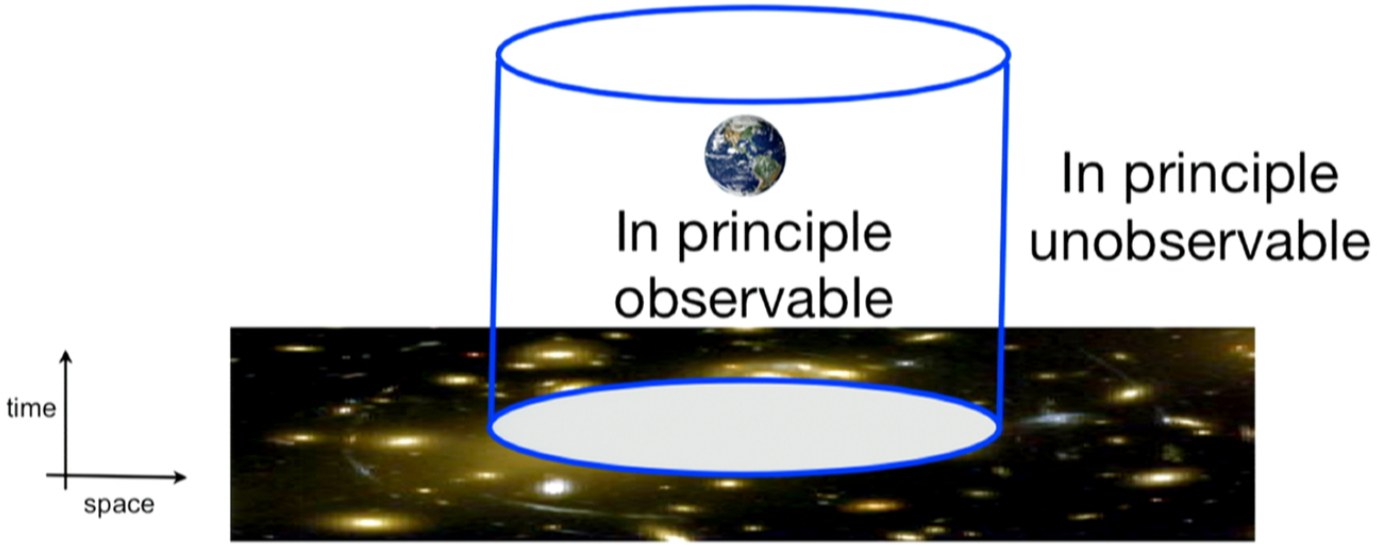



Λ

The Inferred Universe

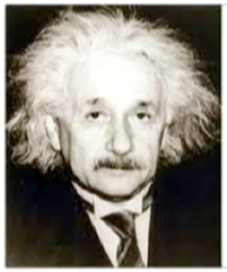
Everything that we think exists based on what we observe and theoretical models.

This is all we will ever see!



What is dark energy?

Cosmological Constant



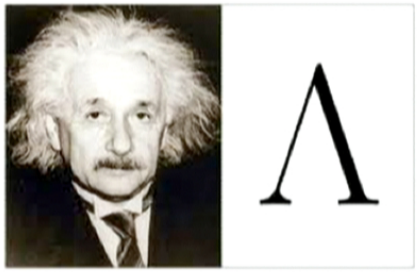
Λ

Prediction from
Quantum Field Theory

(zero-point energy)

What is dark energy?

Cosmological Constant



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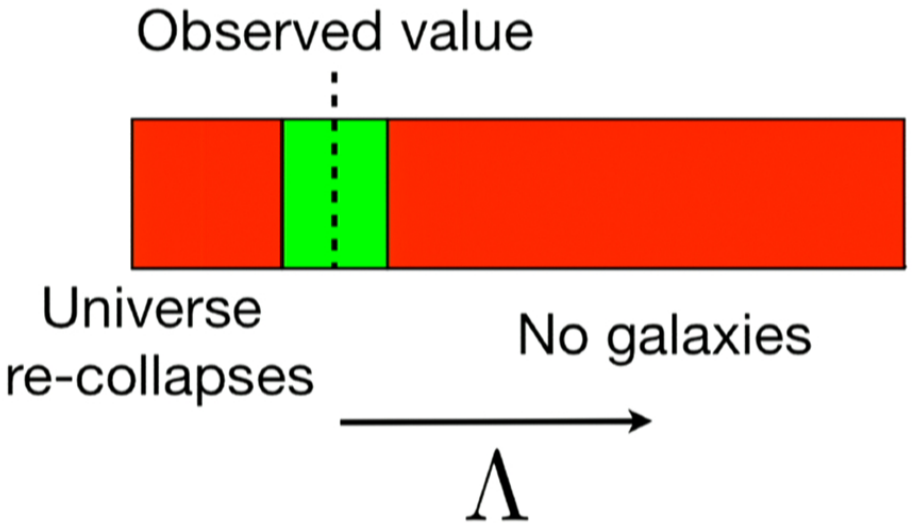
Weinberg's Prediction of Λ

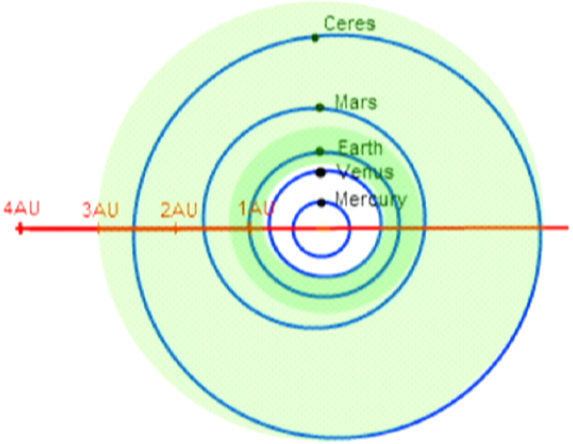
What if the cosmological constant varies between Observable Universes?

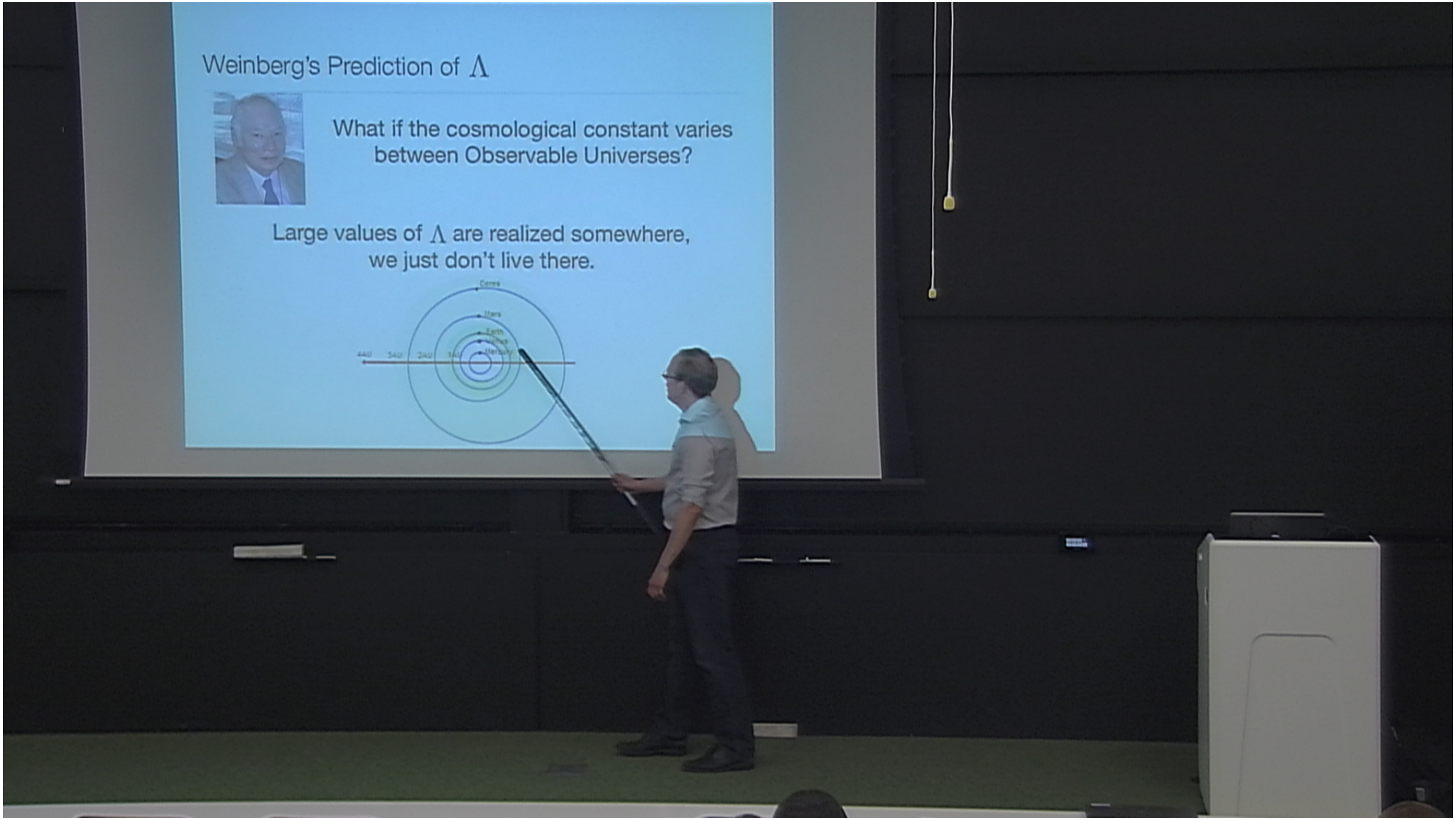


Weinberg's Prediction of Λ

What if the cosmological constant varies between Observable Universes?

Large values of Λ are realized somewhere, we just don't live there.




Weinberg's Prediction of Λ
What if the cosmological constant varies between Observable Universes?
Large values of Λ are realized somewhere, we just don't live there.
Ceres
Mars
Earth
Mercury
4AU
3AU
2AU
1AU

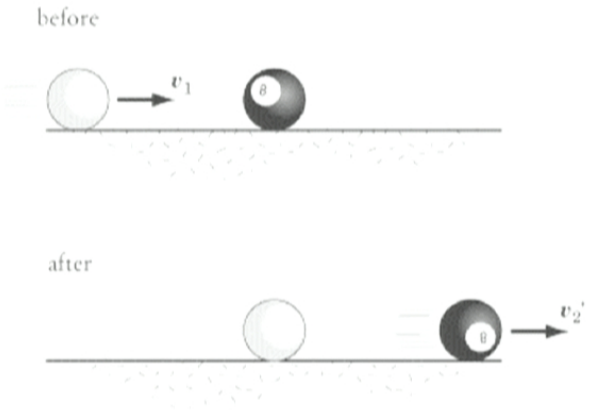
Weinberg's Prediction of Λ

What if the cosmological constant varies between Observable Universes?

Large values of Λ are realized somewhere, we just don't live there.

Is there a Multiverse where the cosmological constant can take many values?

String Theory



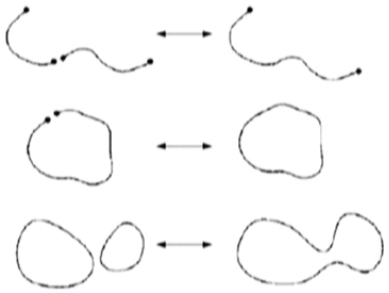
Nearly all of modern physics: point particles.

This worked until.....

String Theory

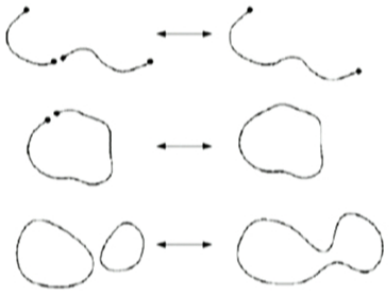
(Graviton: particle associated with gravity)

String Theory



- String theory: A good theory of quantum gravity!
- Unifies all forces and fundamental particles!
- This only works if there are 9 dimensions of space!

String Theory



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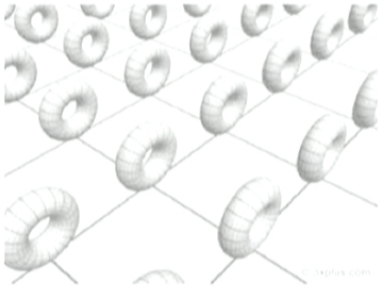


The solution: make the extra dimensions small!

String Theory

- To keep the extra dimensions small, need to add energy.

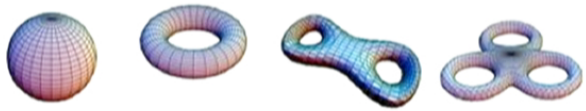
Λ : energy stored in the extra dimensions.

String Theory

- To keep the extra dimensions small, need to add energy.

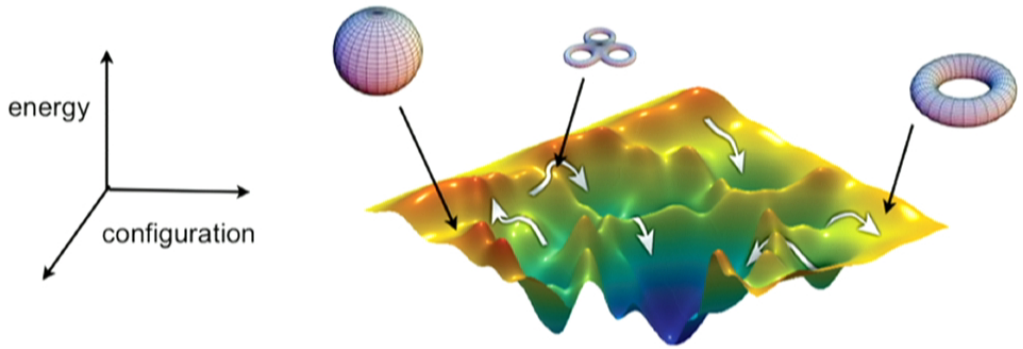
Λ : energy stored in the extra dimensions.

- The extra dimensions can assume many configurations:



Many possible values of Λ!

The String Theory Landscape

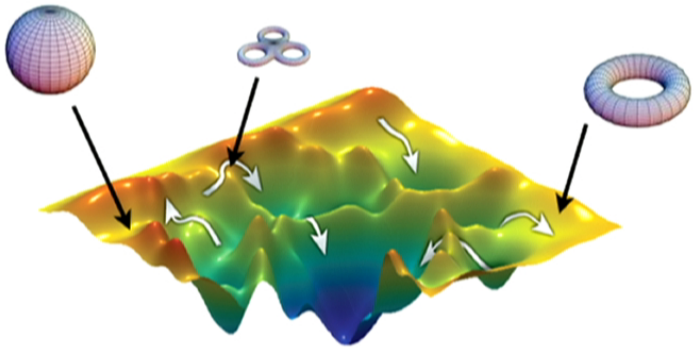


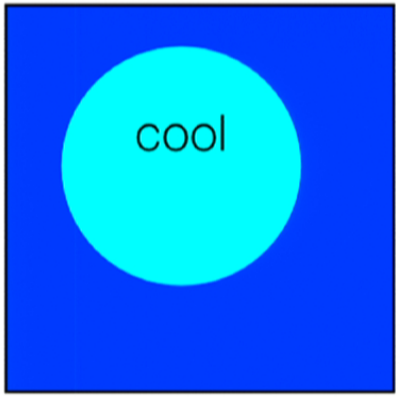
- Configurations can be deformed into one another.
- Can each of these configurations be physically realized?

Cosmic Phase Transitions

Liquid water goes to steam by the formation of bubbles.

Cosmic Phase Transitions

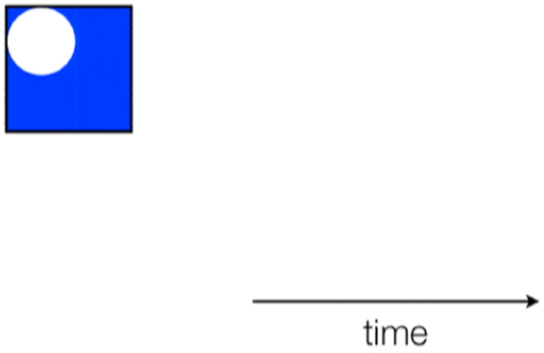




- The configuration of the extra dimensions can undergo phase transitions!
- This means Λ changes as well!
- Our Observable Universe is contained in a bubble.

Cosmic Phase Transitions

- In an accelerating universe:



Observational Tests of Eternal Inflation

- But is eternal inflation experimentally verifiable?

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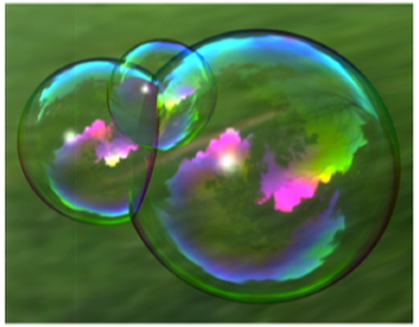
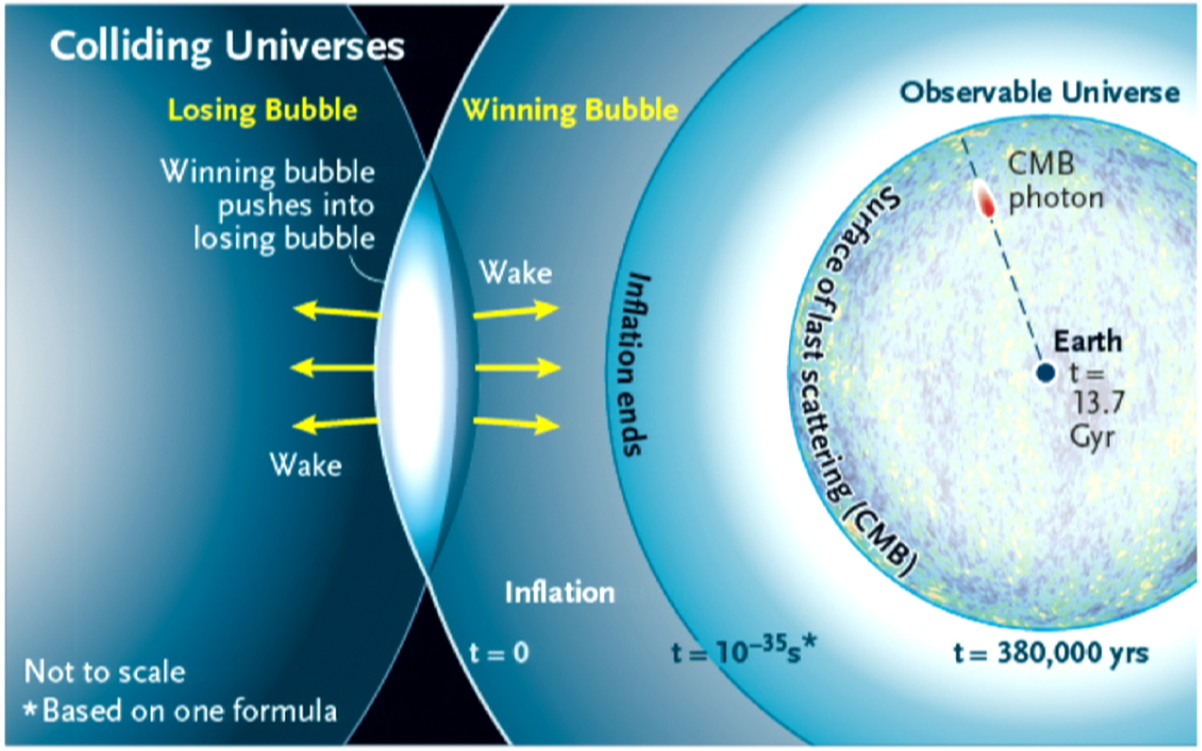
Our bubble does not evolve in complete isolation....



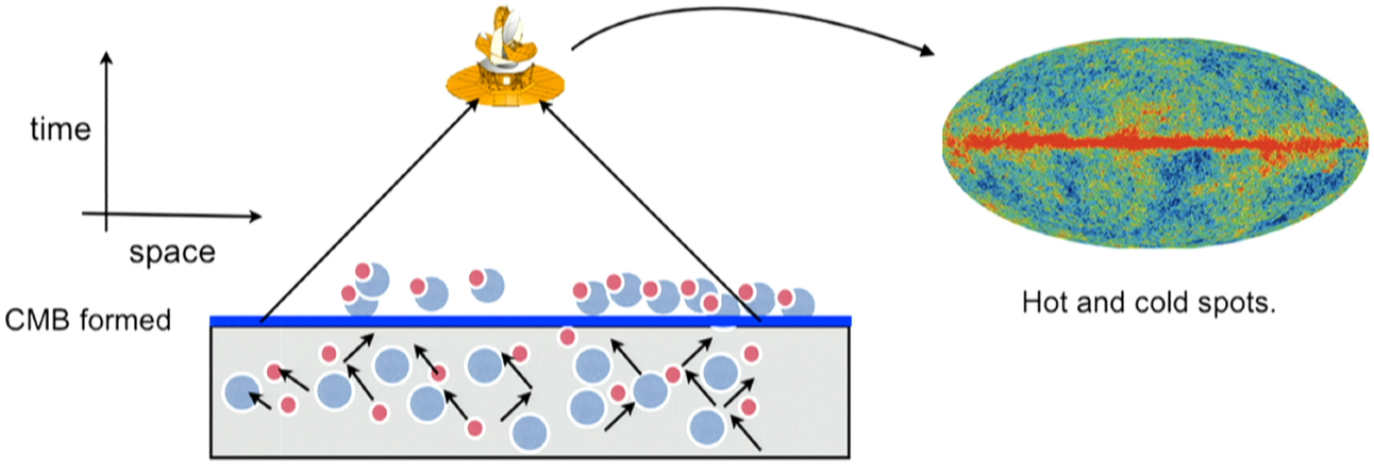
The collision of our bubble with others provides an observational test of the multiverse.

Observational Tests of Eternal Inflation



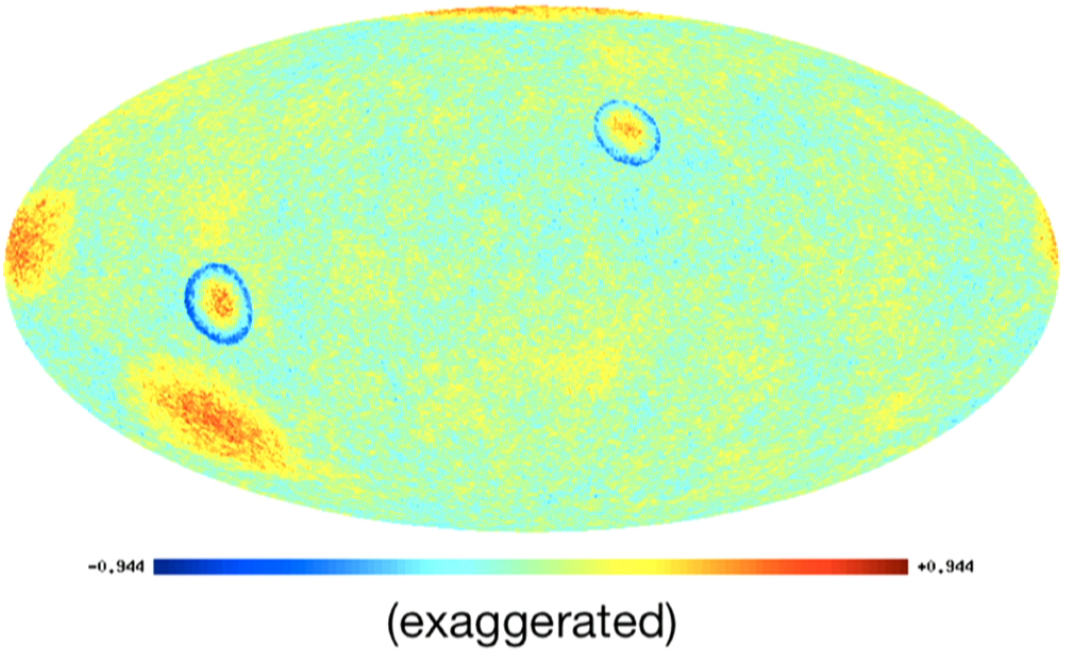
Cosmic Microwave Background (CMB) radiation

- Temperature anisotropies encode density perturbations.



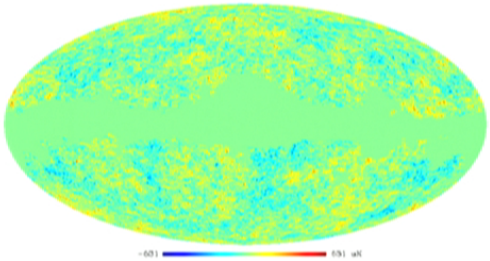
Bubble Collisions

- Bubble collisions induce extra features in the CMB:

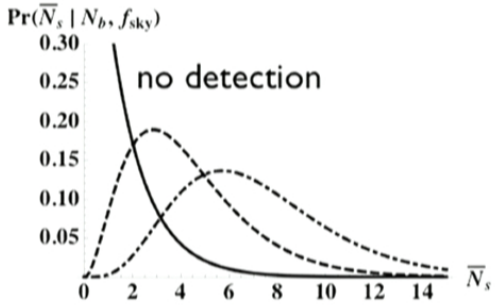


(exaggerated)

Searching for collisions



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



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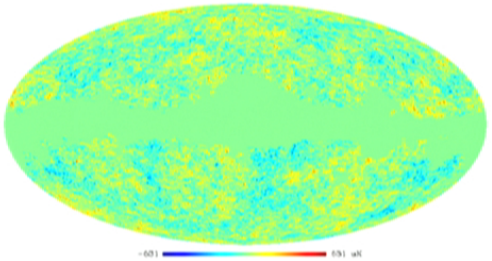

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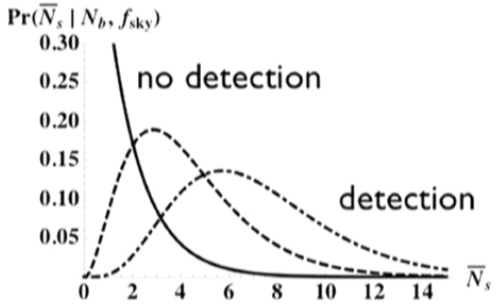

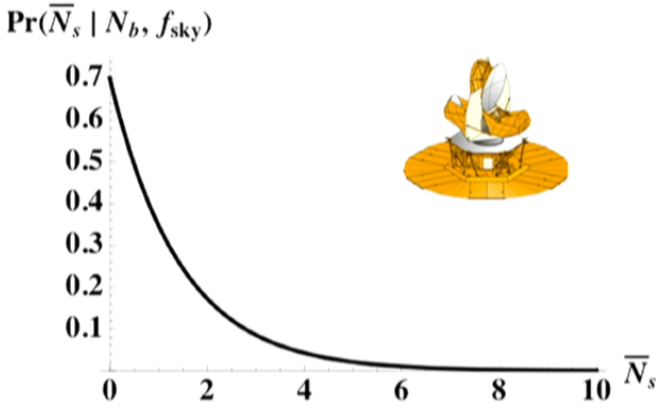

Conclusions

Exciting times for cosmology!