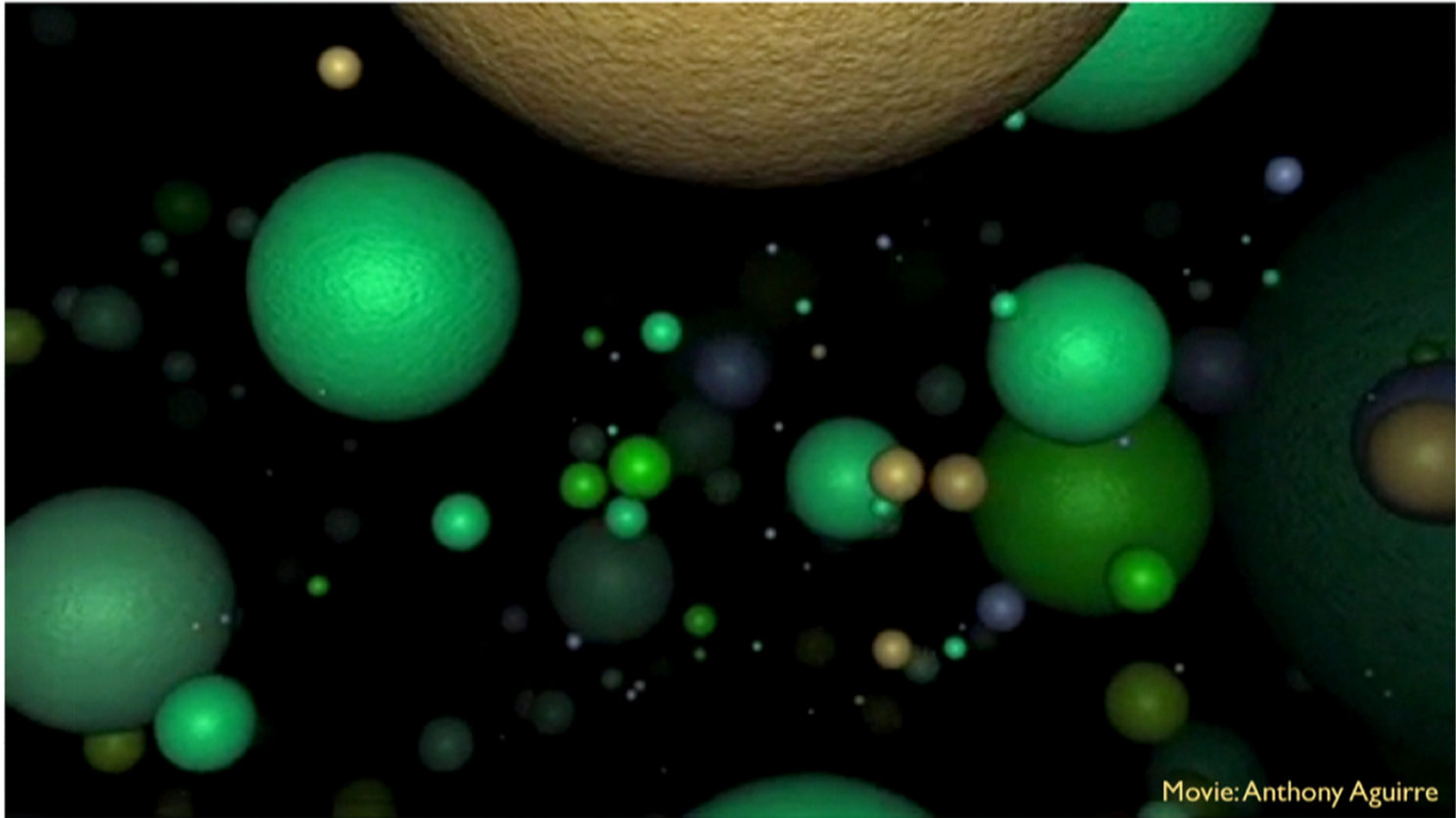


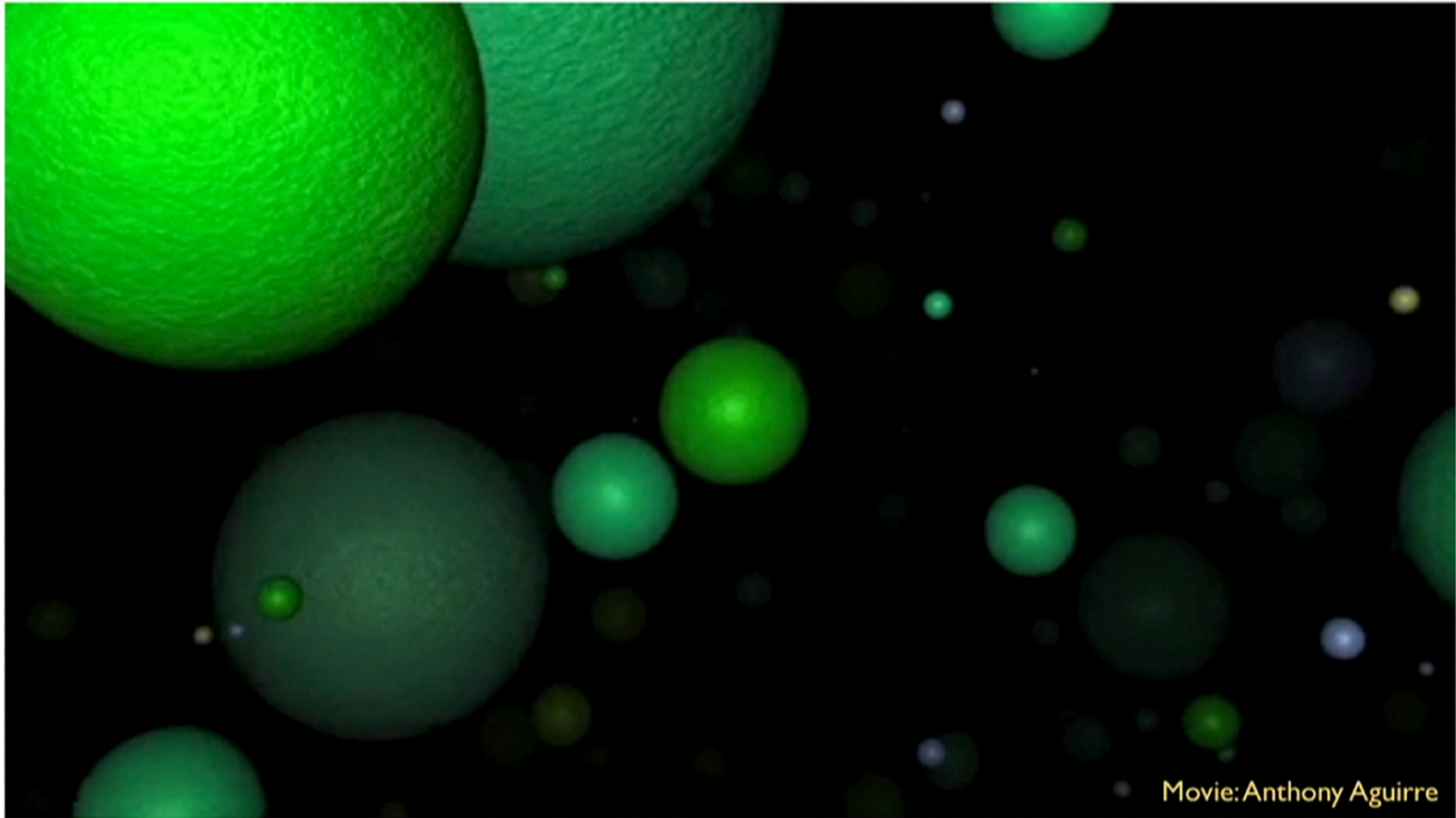
Title: EinsteinPlus 2014 - Cosmology Keynote

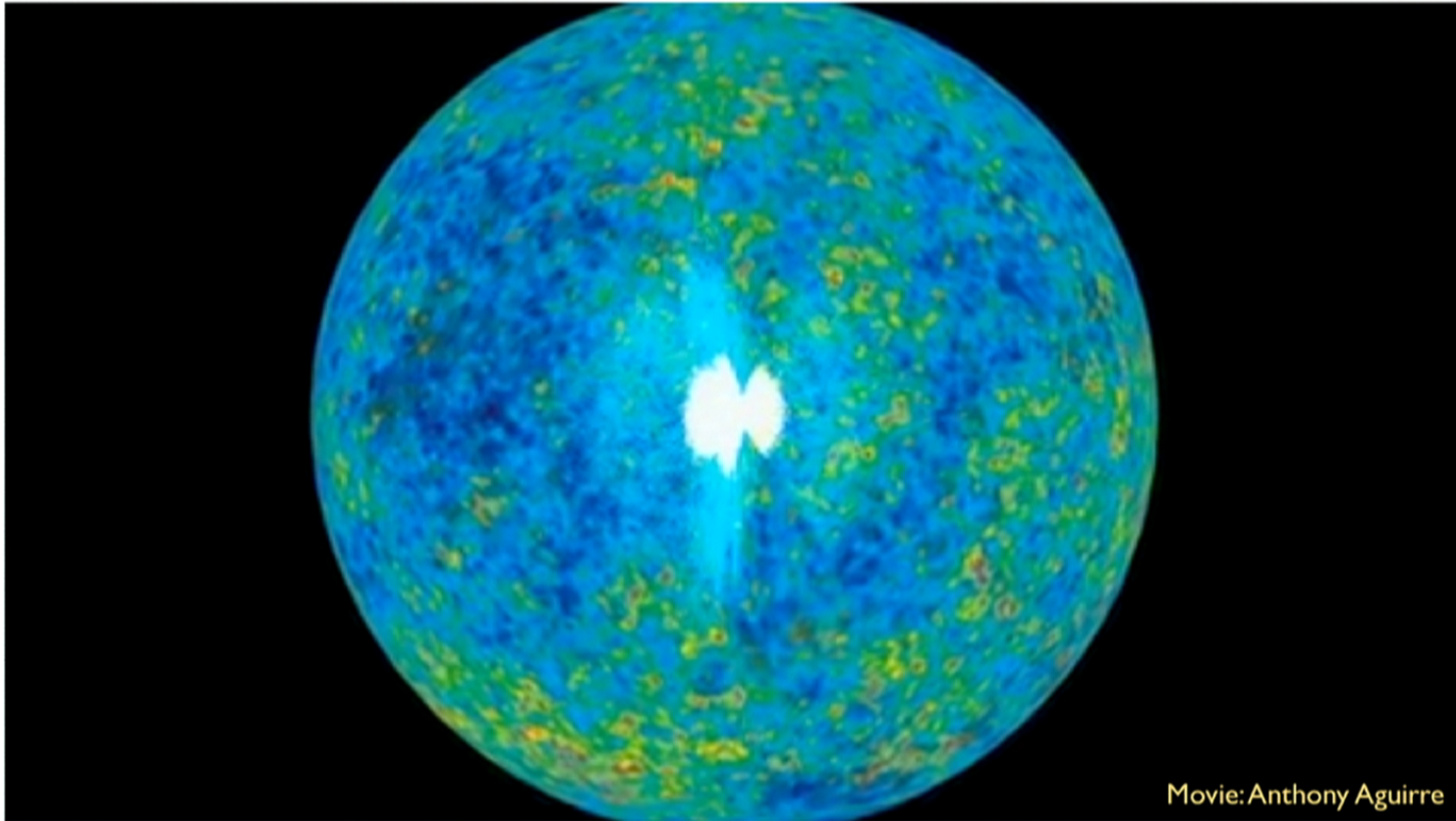
Date: Jul 08, 2014 10:30 AM

URL: <http://pirsa.org/14070020>

Abstract:







Movie: Anthony Aguirre



# The Local Universe

---

Everything that we can interact with.



# The Local Universe

---

Everything that we can interact with.



# The Observable Universe

---

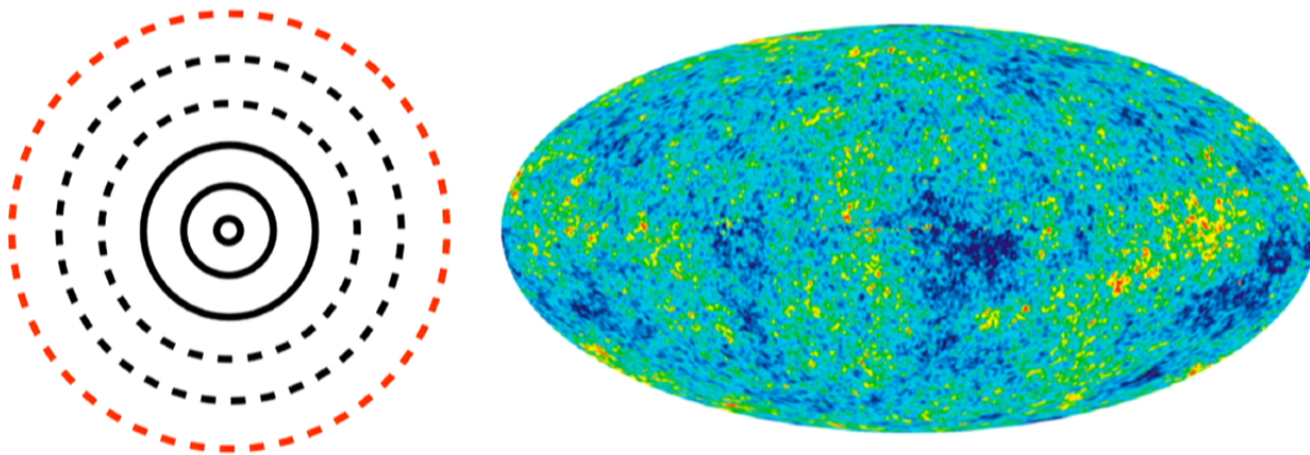
Everything that we observe.



# The Observable Universe

---

Everything that we observe.



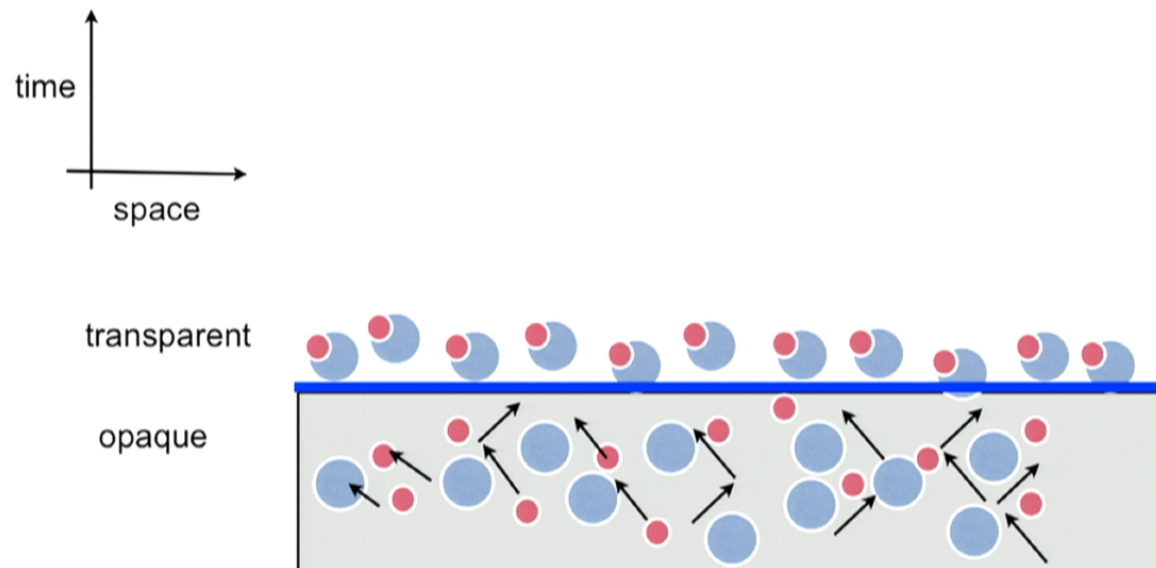
## Cosmic Microwave Background (CMB) radiation

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- The radiation released when neutral atoms were formed.

## Cosmic Microwave Background (CMB) radiation

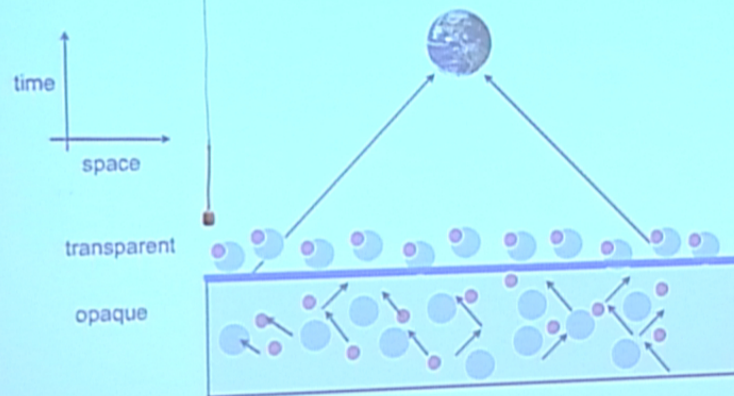
- The radiation released when neutral atoms were formed.





## Cosmic Microwave Background (CMB) radiation

- The radiation released when neutral atoms were formed.







# The Inferred Universe

---

Everything that we think exists based on  
theoretical models.

## 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)





What is our best model?

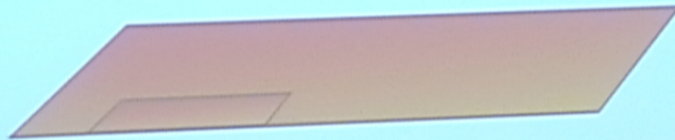
- “Our whole universe was in a hot dense state, then nearly 14 billion years ago expansion started.....” (The big bang theory)

The Big Bang

(a time, not a place)

What is our best model?

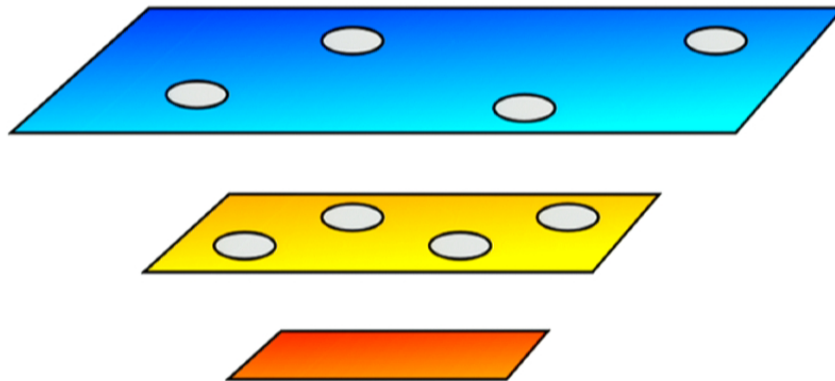
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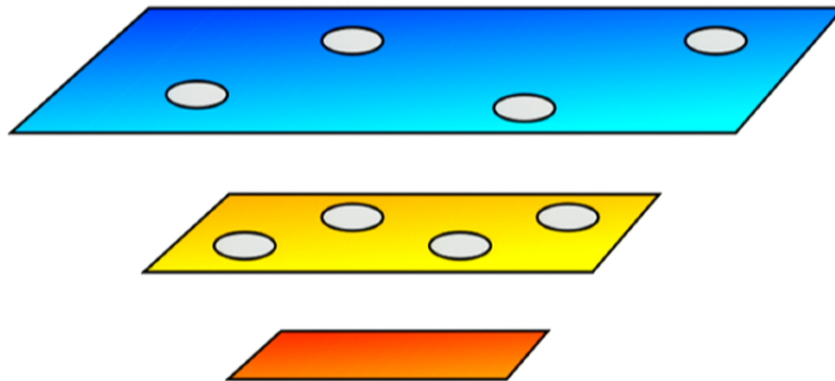
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## What is our best model?

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

The Observable Universe is nearly homogeneous and isotropic.



Nobel Prize 1978!

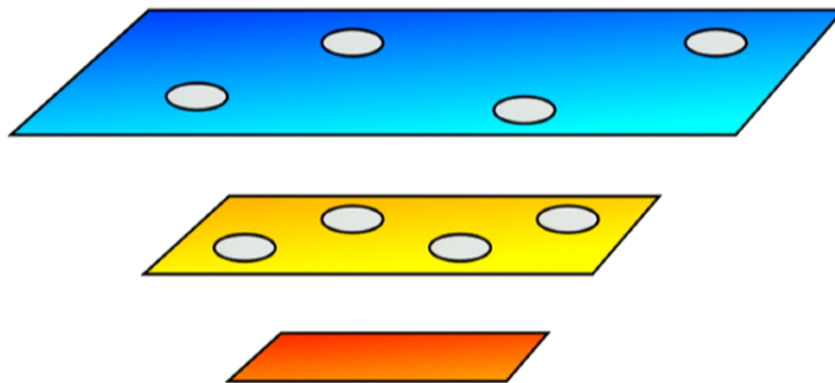
Arno Penzias and Robert Wilson



## 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 Observable Universe is statistically homogeneous and isotropic.



$1/1000000$

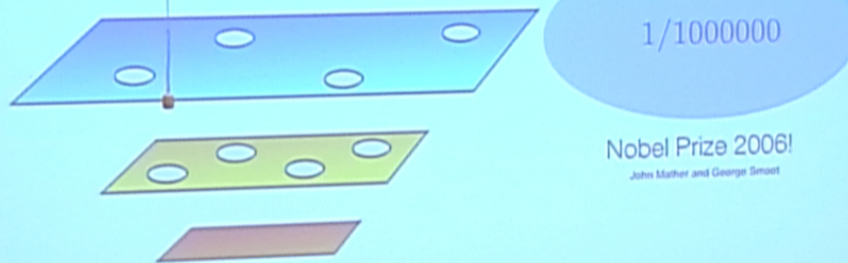
Nobel Prize 2006!

John Mather and George Smoot

What is our best model?

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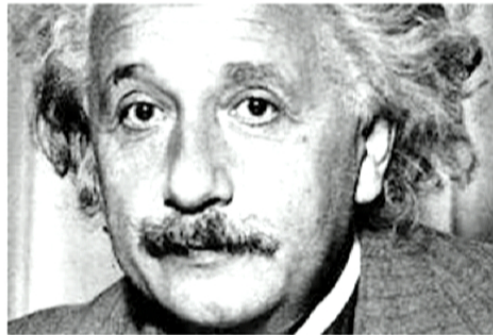
The Observable Universe is statistically homogeneous and isotropic.



## 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



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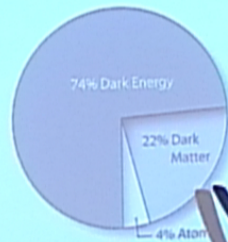
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$\Lambda$ CDM

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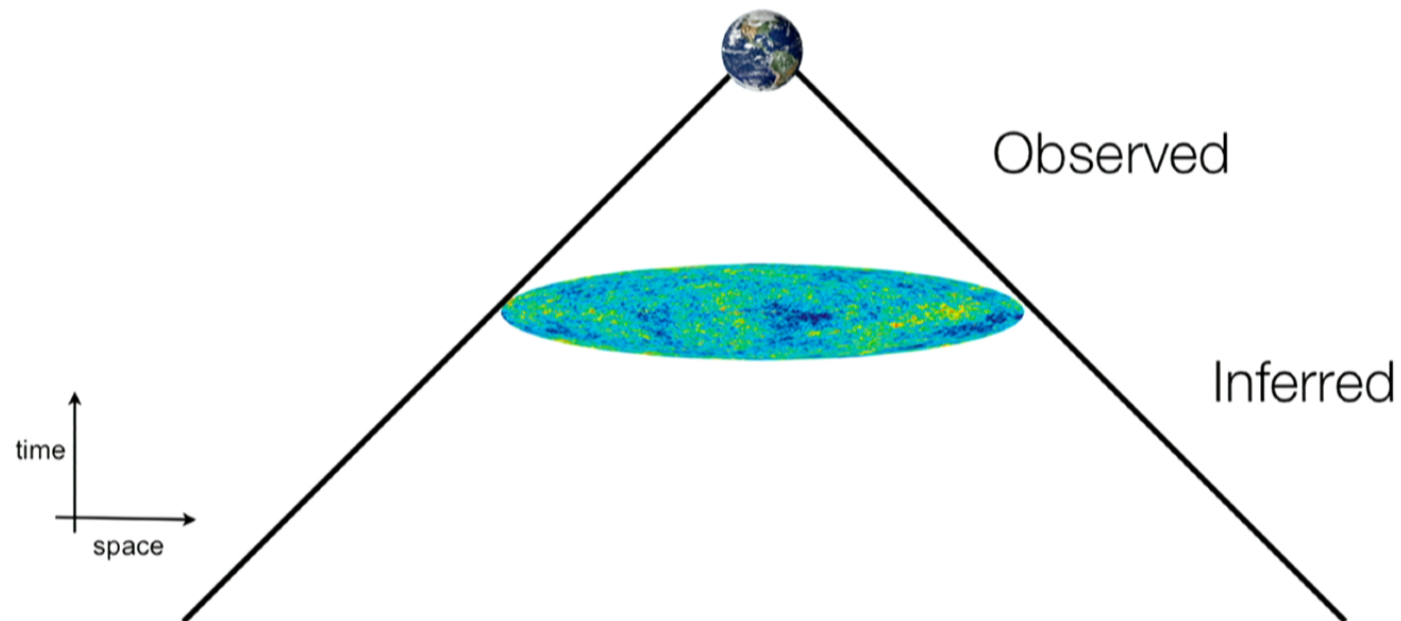
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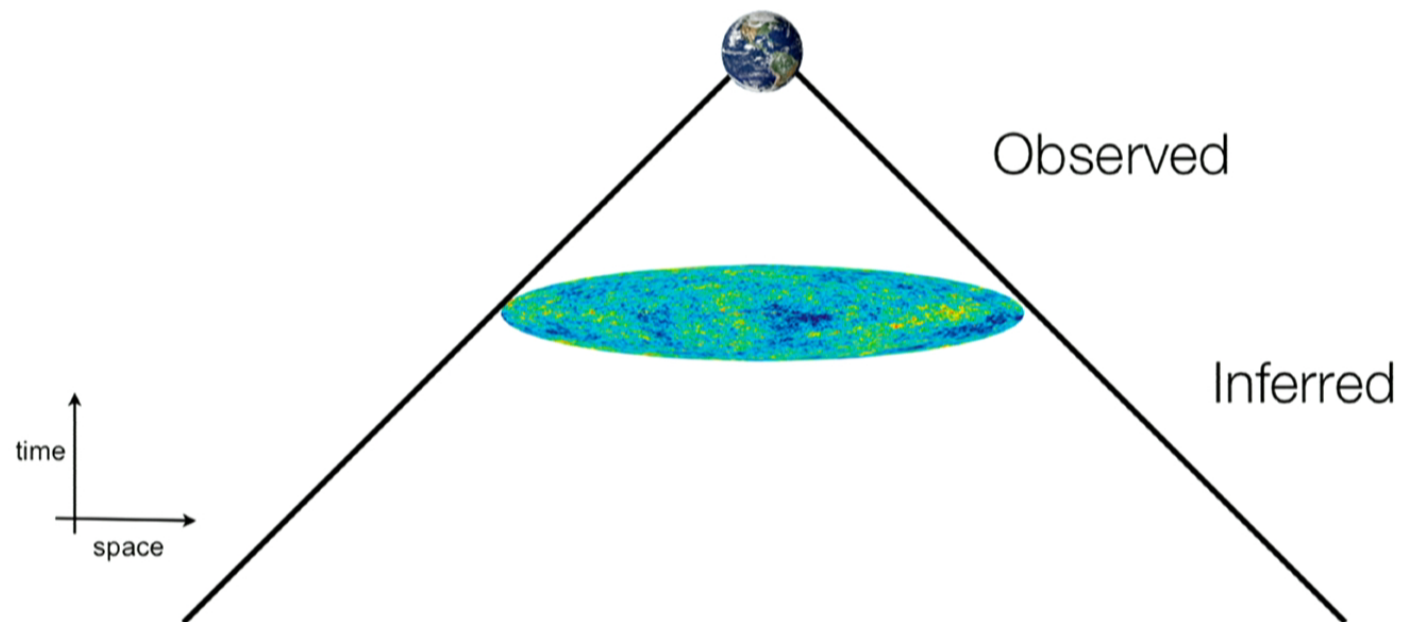
# The Inferred Universe

Everything that we think exists based on theoretical models.



# The Inferred Universe

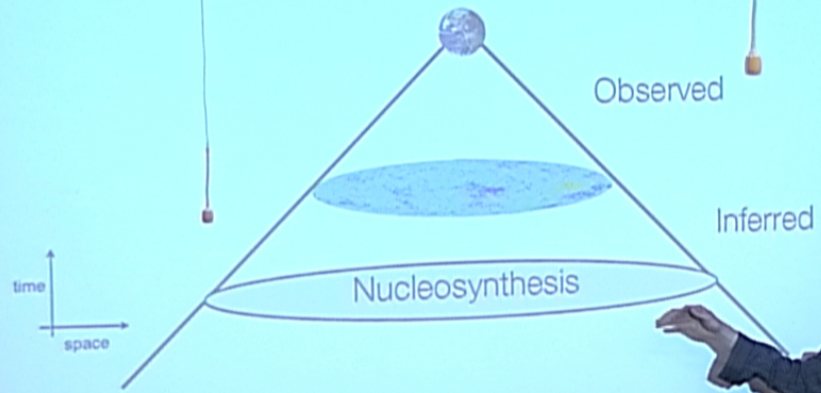
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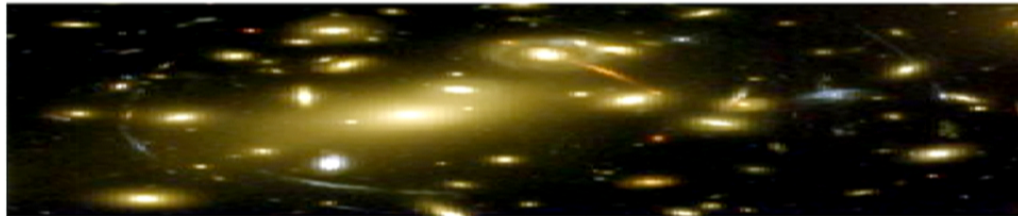
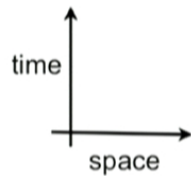




# The Inferred Universe

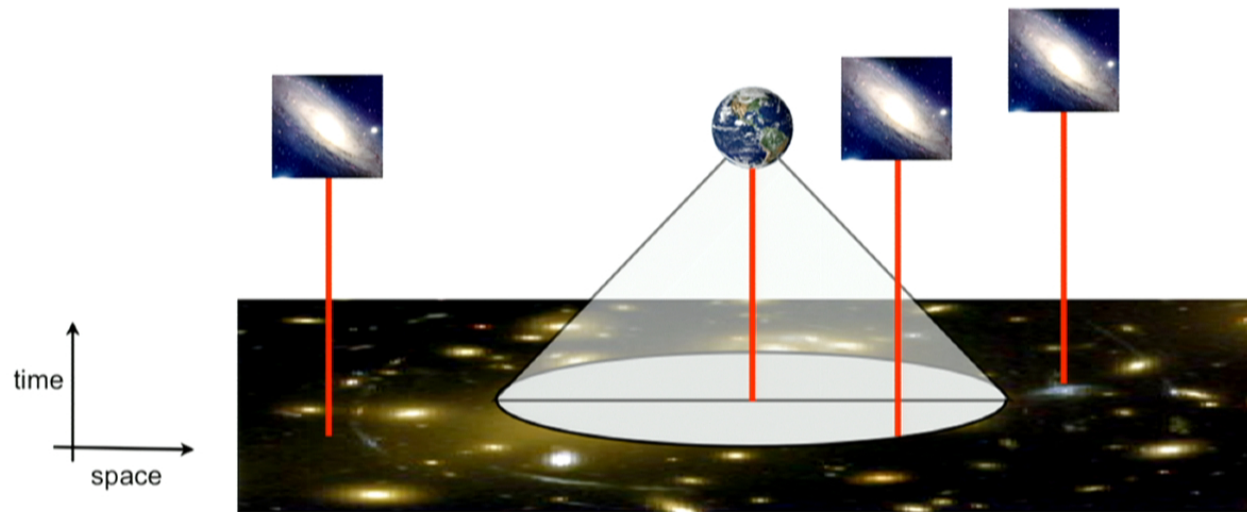
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# The Inferred Universe

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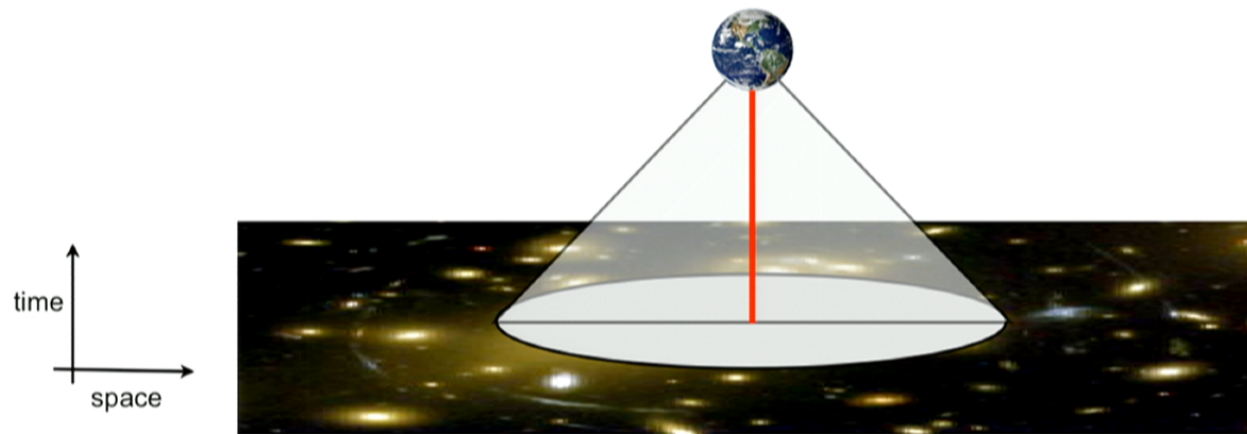


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---

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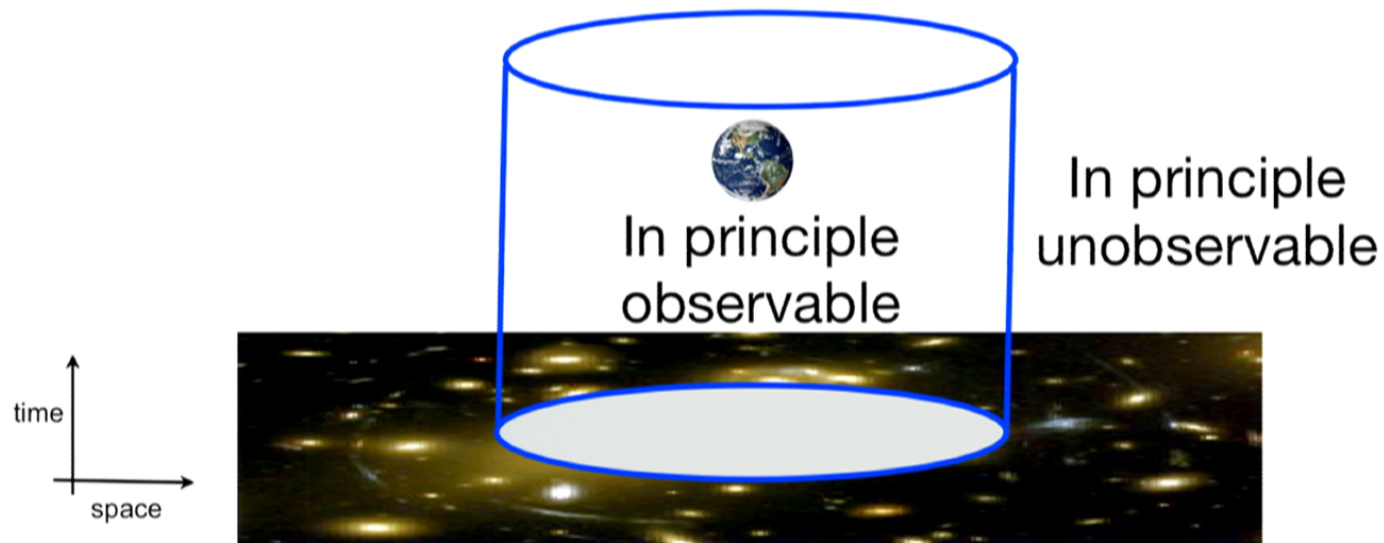
This is all we will ever see!



# The Inferred Universe

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

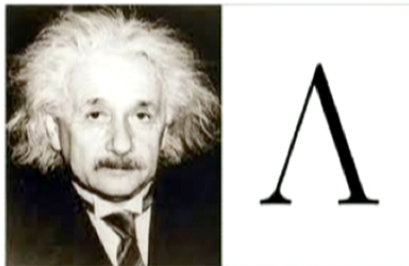
This is all we will ever see!



# What is dark energy?

---

## Cosmological Constant



Prediction from  
Quantum Field Theory  
(zero-point energy)

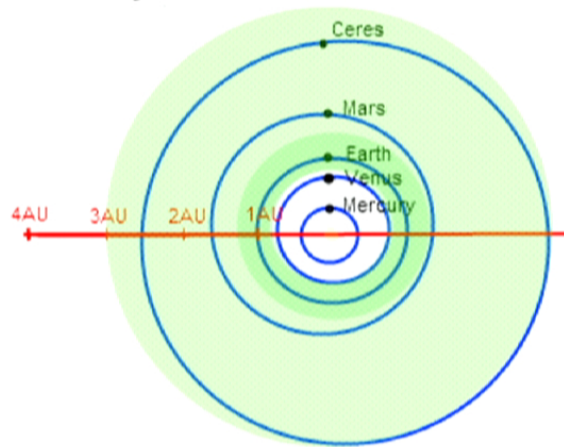


## Weinberg's Prediction of $\Lambda$



What if the cosmological constant varies  
between Observable Universes?

Large values of  $\Lambda$  are realized somewhere,  
we just don't live there.



# String Theory

---



(Graviton: particle associated with gravity)

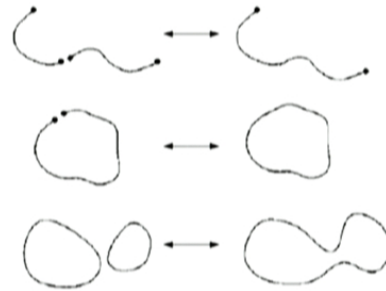


The theory of gravitons does not work!  
(not a good quantum theory of gravity)

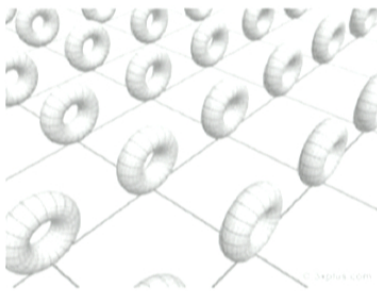


# String Theory

---



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



The solution: make the extra dimensions small!

# String Theory

---

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



$\Lambda$  : energy stored in the extra dimensions.



# String Theory

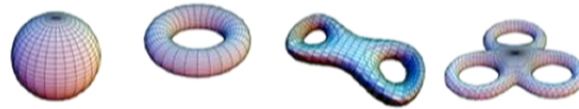
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$\Lambda$  : energy stored in the extra dimensions.

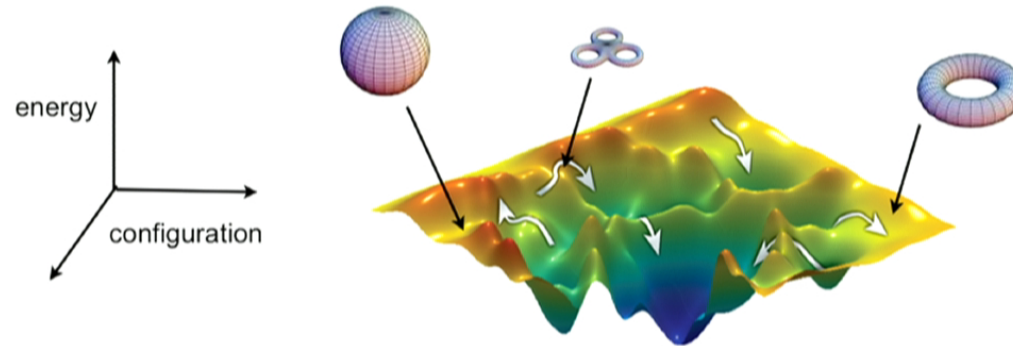
- The extra dimensions can assume many configurations:



$10^{500}$

Many possible values of  $\Lambda$ !

# The String Theory Landscape

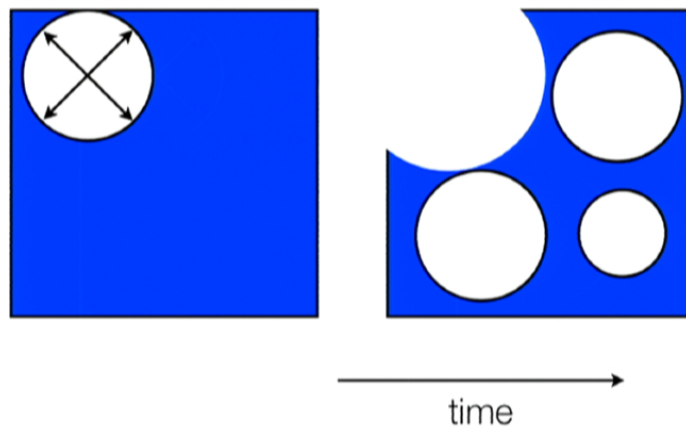


- Configurations can be deformed into one another.
- Can each of these configurations be physically realized?

# Cosmic Phase Transitions

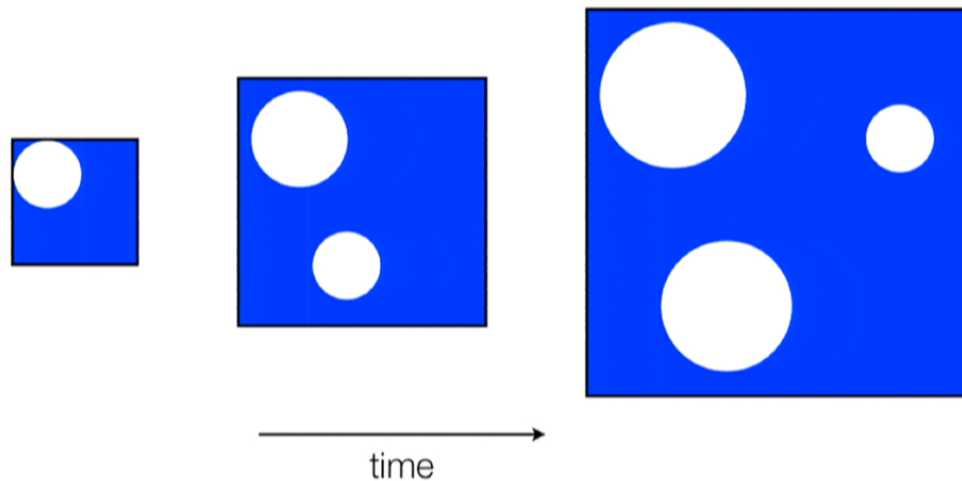
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- In a static or decelerating universe:



# Cosmic Phase Transitions

- In an accelerating universe:



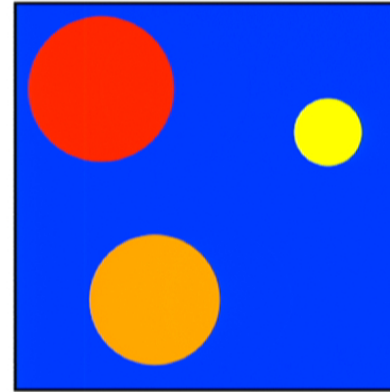
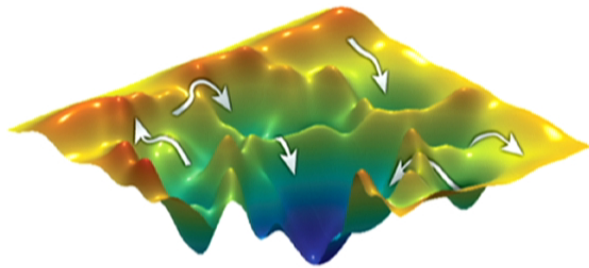
## Eternal Inflation

When the rate of bubble formation is lower than the rate of expansion, accelerated expansion doesn't end everywhere!

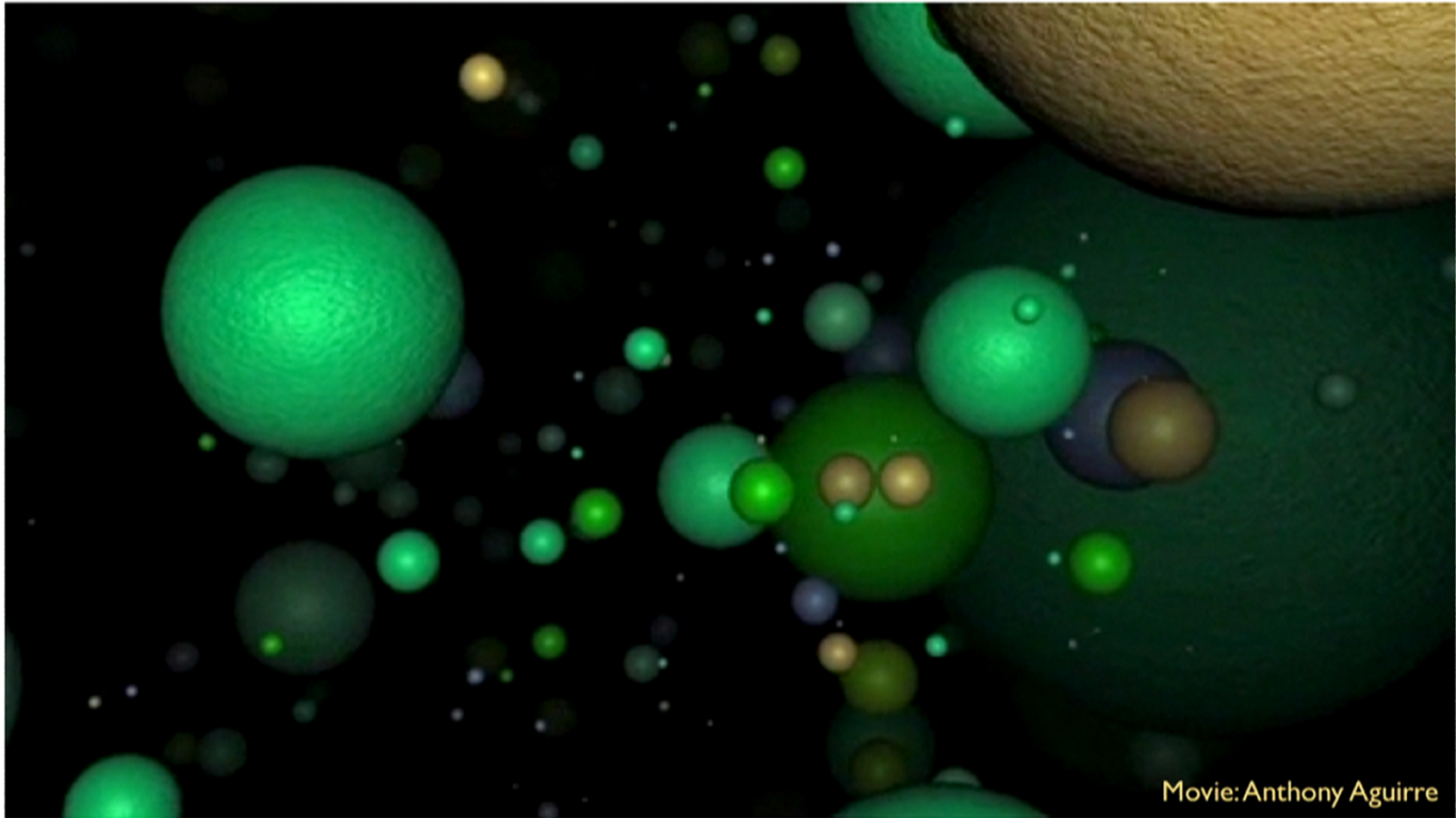


# Eternal Inflation

---



Many values of  $\Lambda$  are realized!

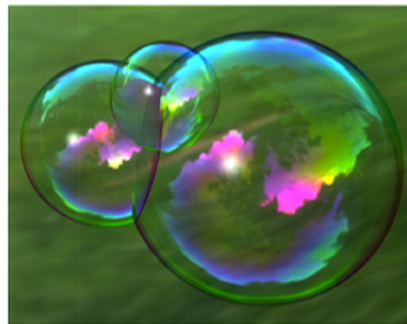


# Observational Tests of Eternal Inflation

---

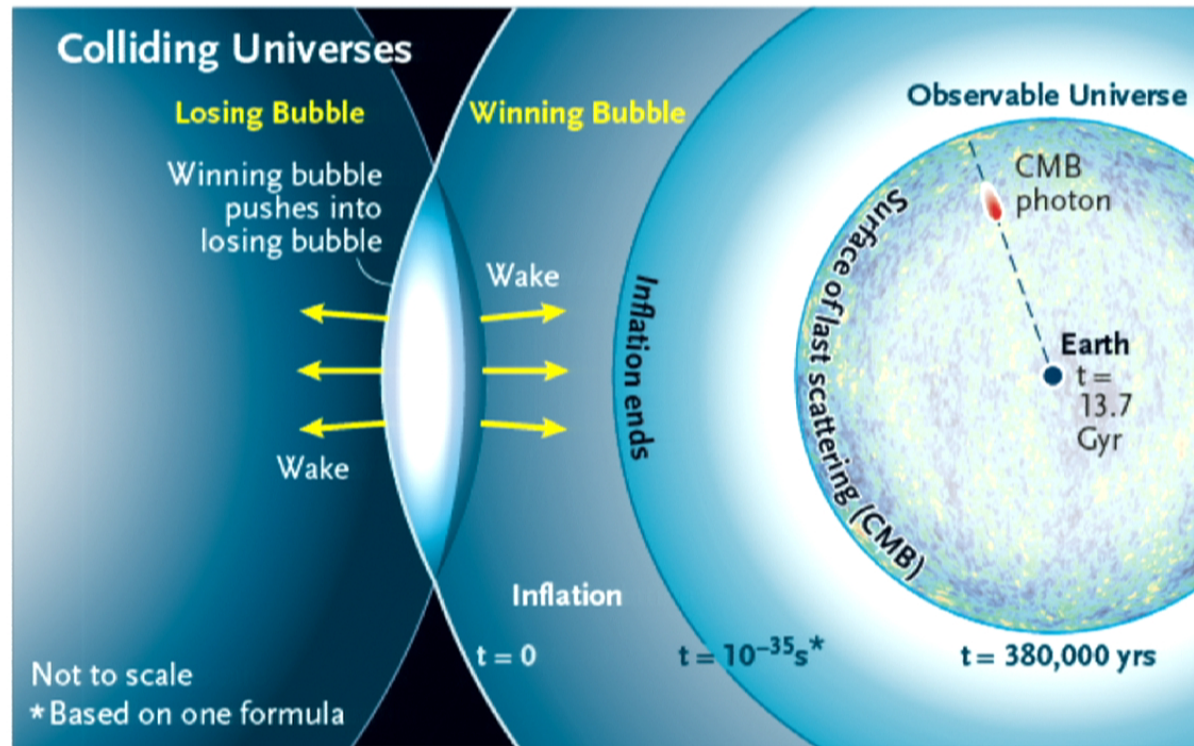
- But is eternal inflation experimentally verifiable?

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



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

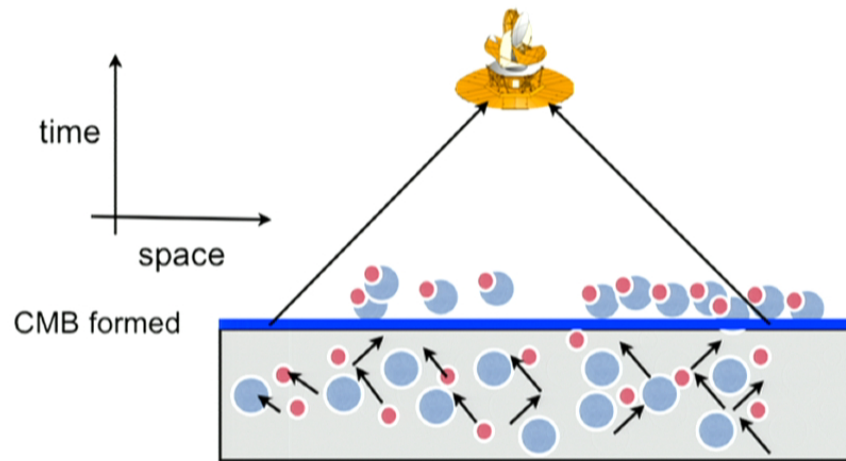
# Observational Tests of Eternal Inflation





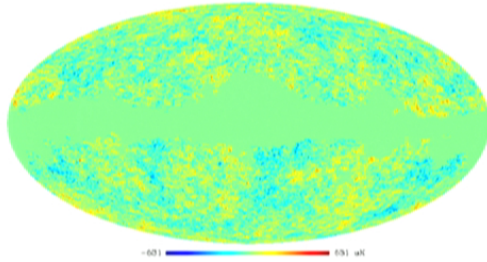
# Cosmic Microwave Background (CMB) radiation

- Temperature anisotropies encode density perturbations.

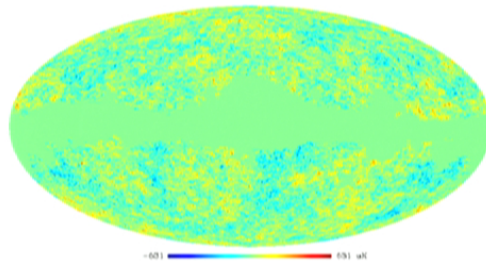


## Searching for collisions

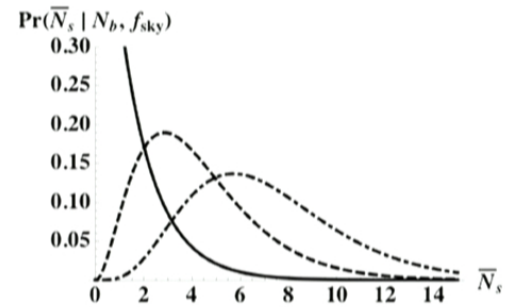
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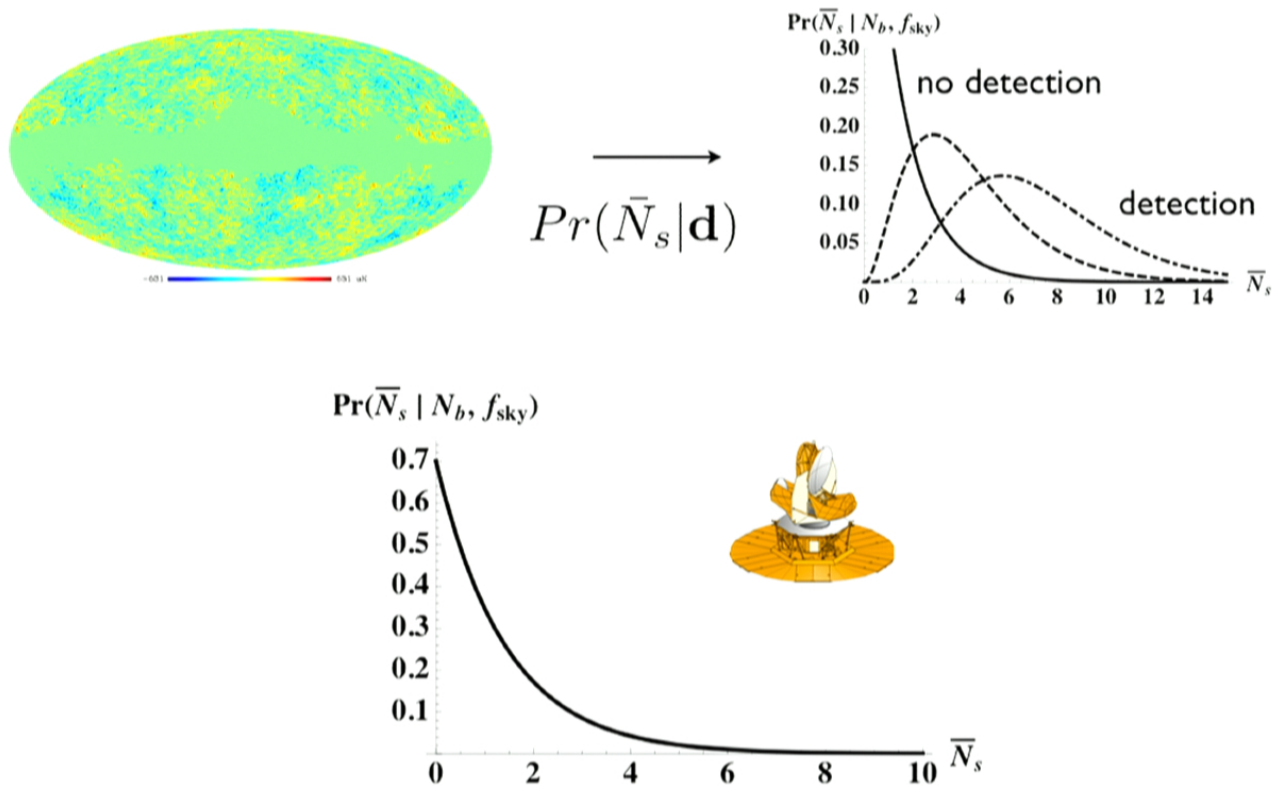
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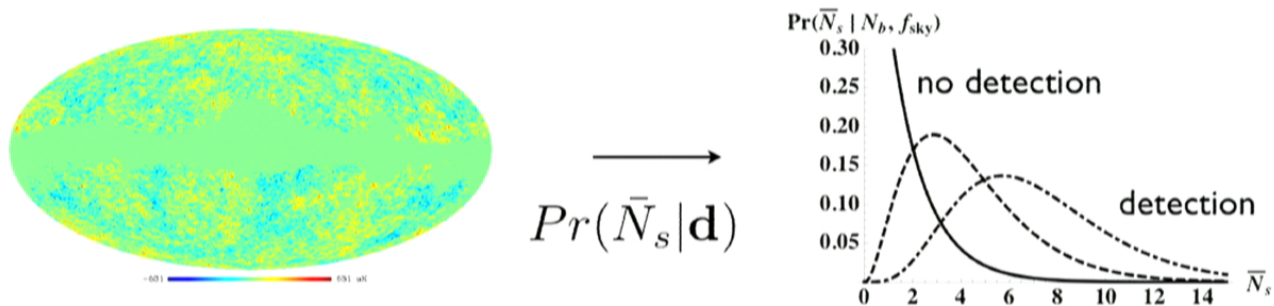
$$\longrightarrow$$
$$Pr(\bar{N}_s | \mathbf{d})$$



# Searching for collisions



# Searching for collisions



$$\Pr(\bar{N}_s | N_b, f_{\text{sky}})$$

0.7  
0.6



First observational test!

0.1

0 2 4 6 8 10  $\bar{N}_s$



