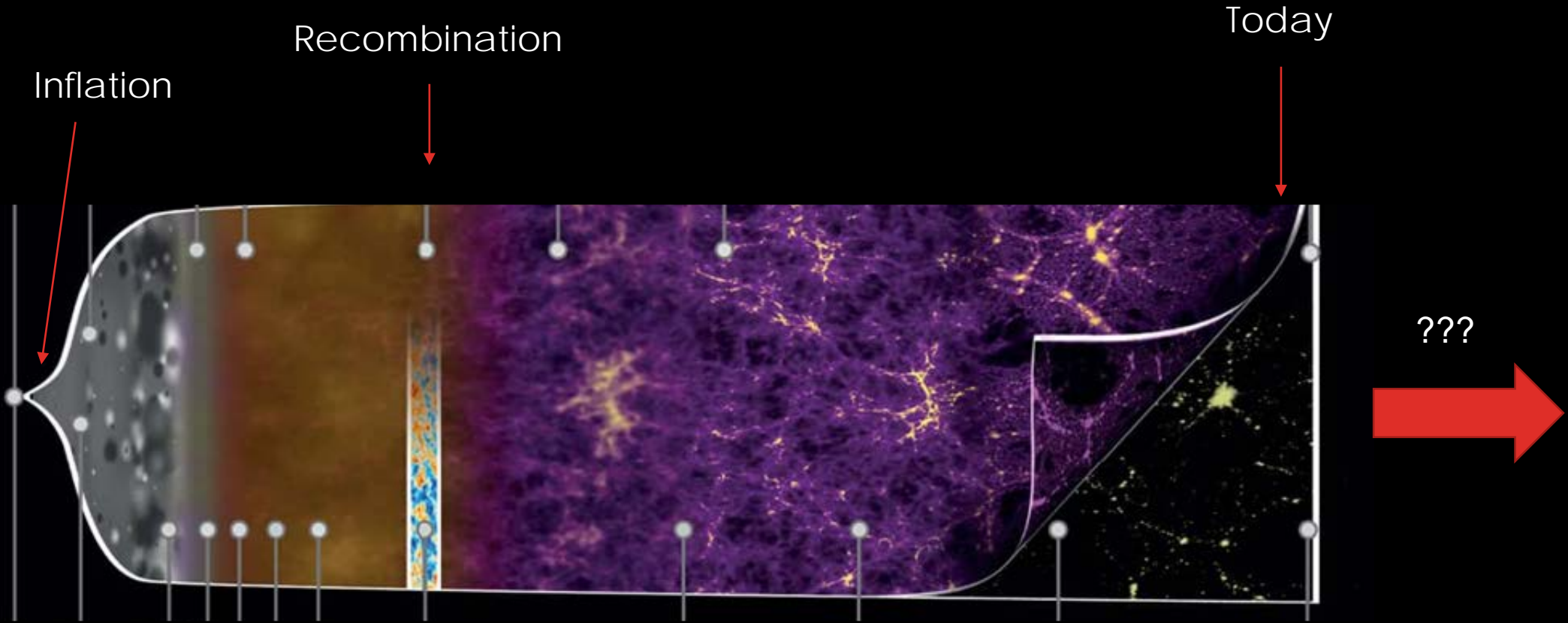


Ways the Universe Could End

Dan Hancock

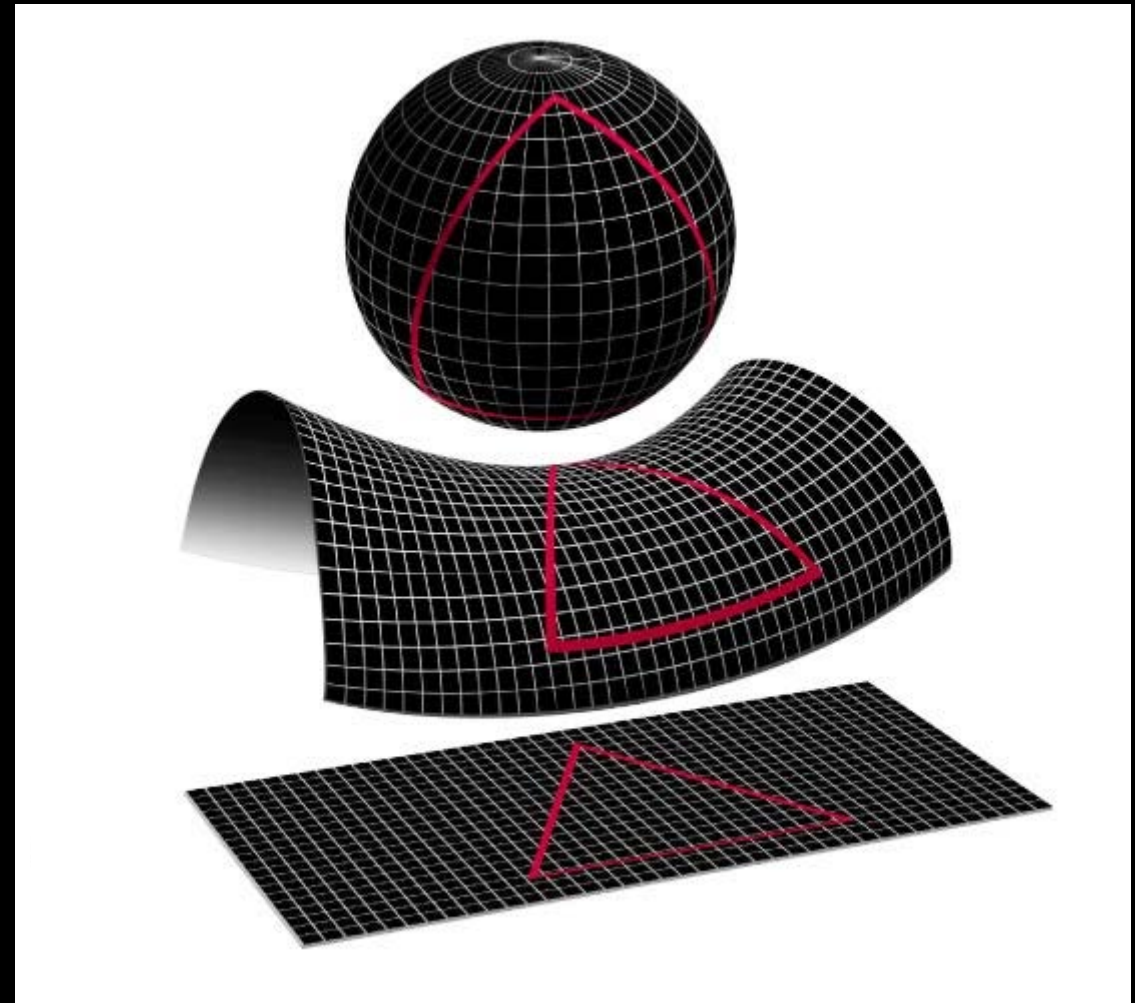
Evolution of the Universe



How Can We Estimate the Future?

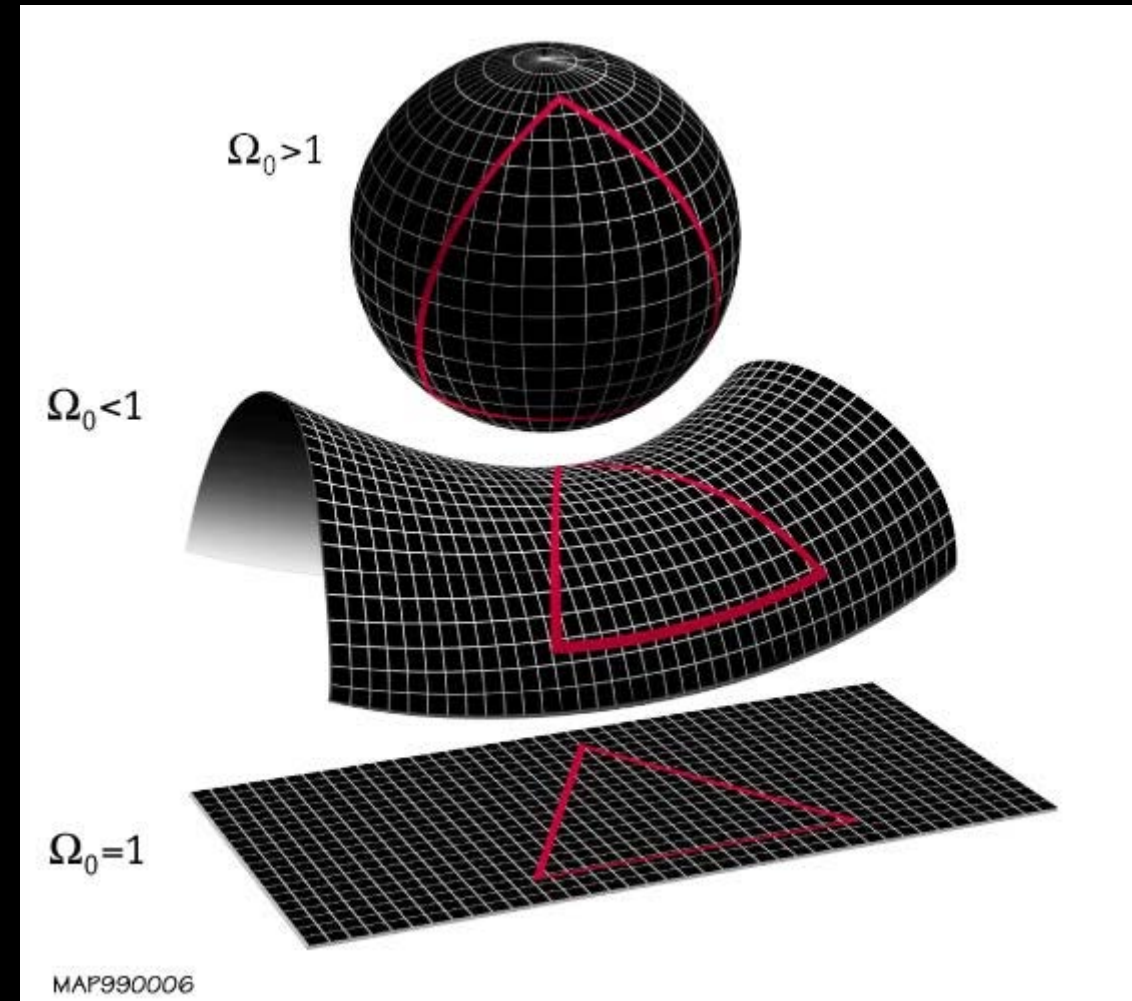
<https://wikimedia.commons>

- The Universe is One Big Complex System
- Inherent Properties of Spacetime
- Influence Due to other Universes
- Geometry
- Interactions Between Forces



Best Guesses

- Inherent Properties of Spacetime
 - Repulsive Energy?
- Influence Due to other Universes
 - None?
- Geometry
 - Flat?
- Interactions Between Forces
 - Standard Model?



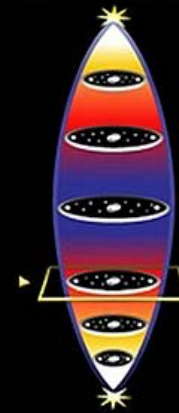
Make Assumptions

- Inherent Properties of Spacetime
 - Repulsive Energy?
- Influence Due to other Universes
 - None.
- Geometry
 - Flat.
- Interactions Between Forces
 - Standard Model?

Main Possibilities

- The Universe Accelerates Quickly
 - Big Rip
- The Universe Begins Accelerating in a Negative Direction
 - Big Crunch
- The Universe Accelerates, but not as Quickly
- The Universe is Expanding Continuously
 - Big Freeze

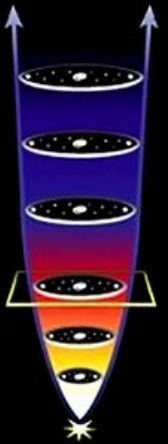
Big Crunch



Big Rip



Big Freeze

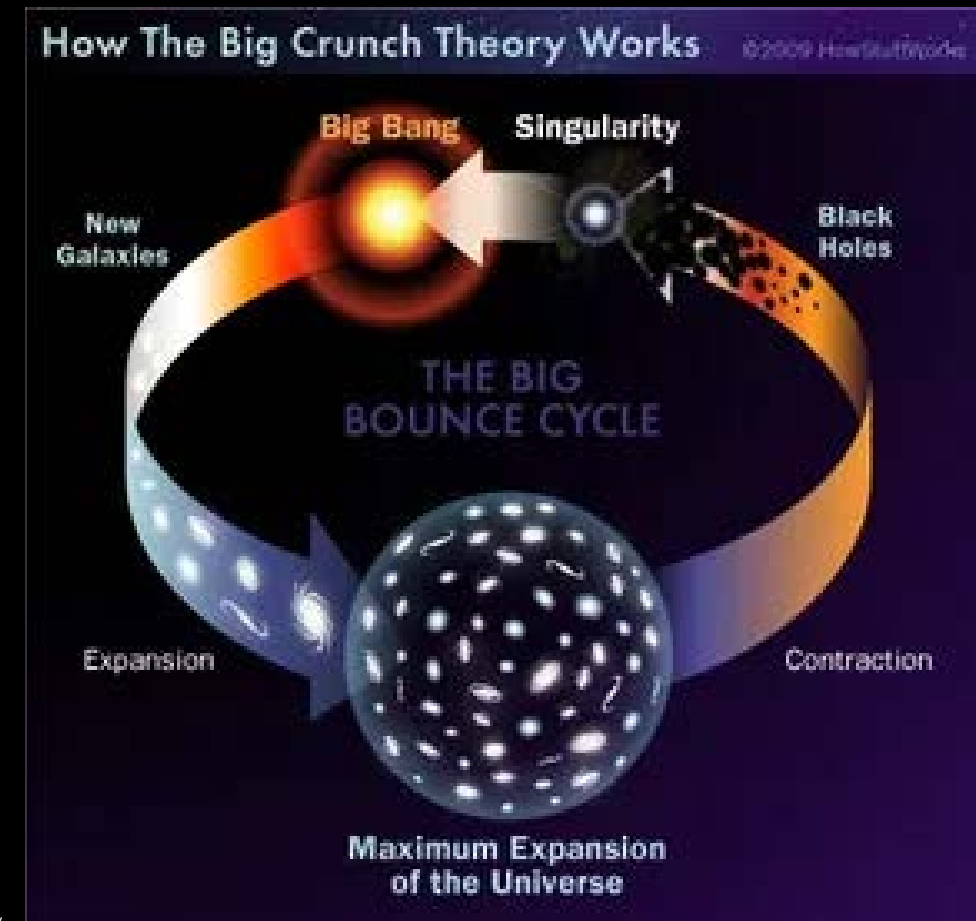


The Big Crunch

- Gravity is Dominant
- The Universe Becomes a Singularity
 - Just like Big Bang Proposes

The Big Crunch

- From this Singularity, a New Big Bang Happens
 - Cyclic process
 - Big Bounce



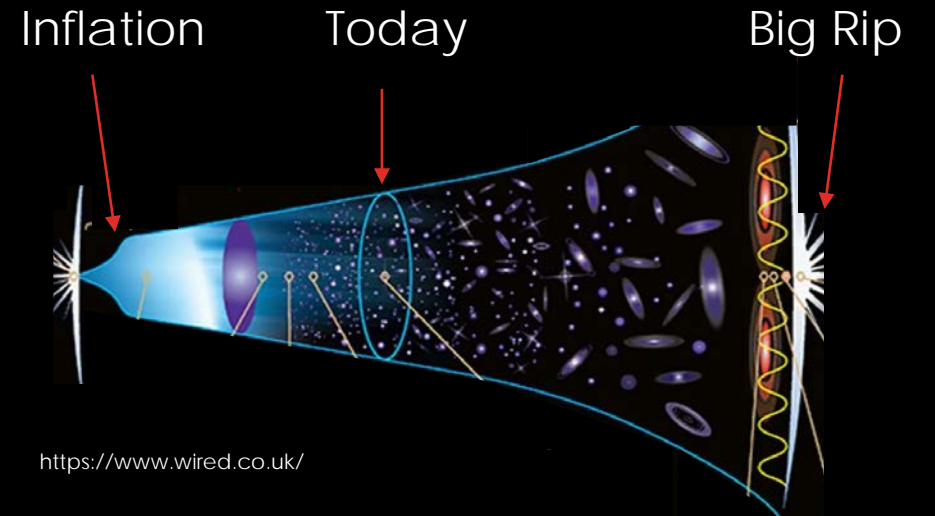
The Big Rip

- Dark Energy Becomes Dominant
 - Overcomes forces

- Expansion Accelerates Quickly

The Big Rip

- Time Approaches a Finite Value
 - Dark energy's effect becomes more dominant
 - Hubble constant approaches infinity
 - Everything gets torn apart



The Big Freeze

- The Universe is Either Accelerating Slowly or Expanding Constantly
 - Either way, the outcome is similar
- The Universe Progresses as Normal
 - Entropy wins

The Big Freeze

- Galaxies Become Further and Further Apart
 - No visible galaxies outside of our own
- Star Formation Ceases
 - Not enough gas to create new stars
- Black Holes Become Dominant
 - Eventually Hawking radiation disperses all material

Which is Likely?

- Little evidence for Big Crunch
- Evidence of Dark Energy
 - Type 1a supernovae
 - Considers both the Big Freeze and Big Rip

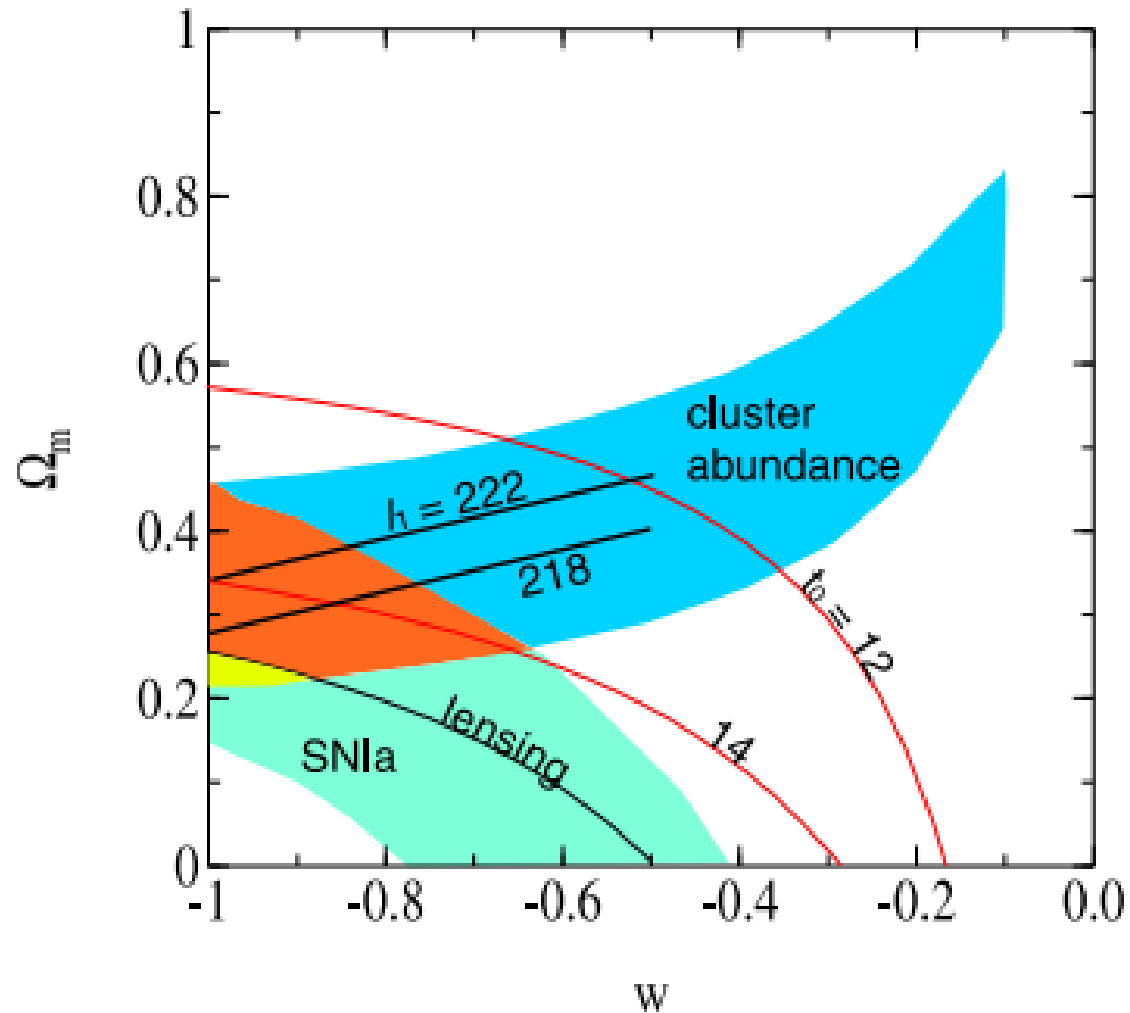
Dark Energy

- Seen as a Reverse-Gravitational Effect
- Pushes Apart Matter
- Constitutes 71% of Matter and Energy Distribution
- Equation of State Parameter, w
 - Pressure divided by energy density

$$H^2 = H_0^2 \left[\Omega_m (1+z)^3 + \Omega_{DE} \exp \left\{ 3 \int_0^z \frac{dz}{1+z} [1 + w(z)] \right\} \right]$$

Dark Energy Parameter w

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Why is $w = -1$ Important?

- If $w > -1$
 - Universe expands
 - Dark energy does not overcome fundamental forces

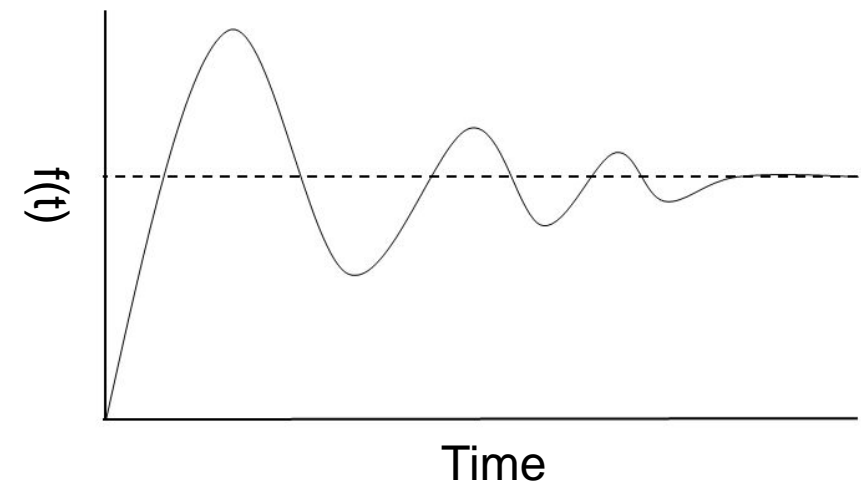
- If $w < -1$
 - Dark energy density increases
 - Overcoming fundamental forces
 - Hubble constant approaches infinity

Current Parameterization

- $w = -0.991 \pm 0.045 \text{ (stat)} \pm 0.040 \text{ (sys)}$
- Either Situation is Entirely Possible.... HOWEVER

Hypothesis Assumptions

- Assume w to be Constant
- Assume Flat Universal Geometry
- Assume no Effects from Other Universes
- Assume Standard Model



Conclusions

- There are Several Ways the Universe Could End
 - Big Crunch
 - Big Rip
 - Big Freeze
- Further Parameterizing Dark Energy is the Key
- Currently it Seems that the Big Freeze is the Forefront Hypothesis

Sources

- <https://arxiv.org/pdf/1611.01899.pdf#:~:text=The%20condition%20for%20late%20time,be%20a%20function%20of%20time>.
- <https://web.archive.org/web/20141028023702/https://www.preposterousuniverse.com/blog/2004/09/13/phantom-energy/>
- <https://arxiv.org/pdf/astro-ph/9908168.pdf>
- <https://arxiv.org/pdf/astro-ph/0302506.pdf>
- <https://arxiv.org/pdf/0812.2720.pdf>
- <https://web.archive.org/web/20210517014117/https://cds.cern.ch/record/318436/files/9701131.pdf>
- <https://arxiv.org/pdf/astro-ph/0409264.pdf>
- <https://wmap.gsfc.nasa.gov/news/>
- https://www.physicsoftheuniverse.com/topics_bigbang_bigcrunch.html