Dark Matter, Dark Energy and Einstein

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August 19, 2017

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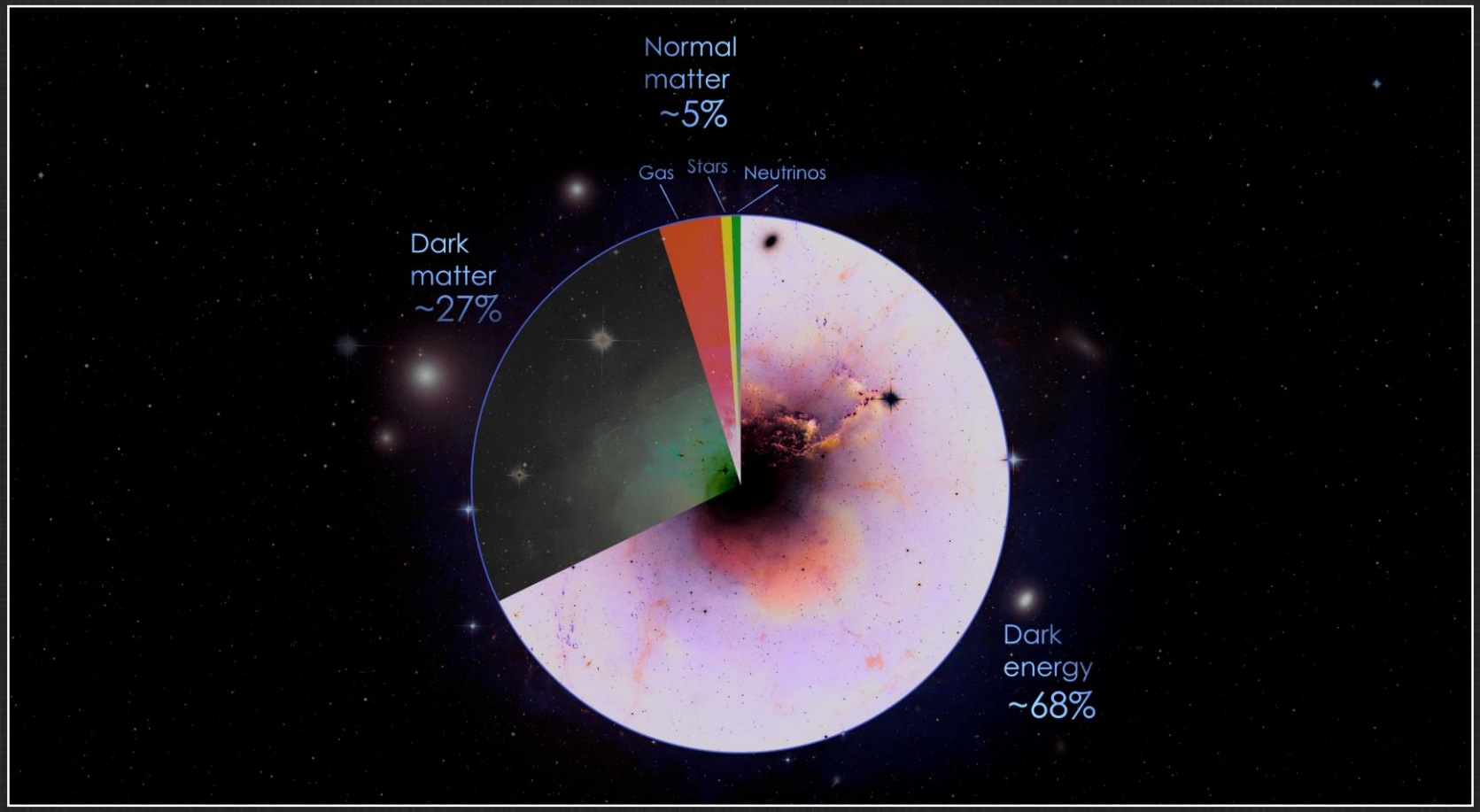
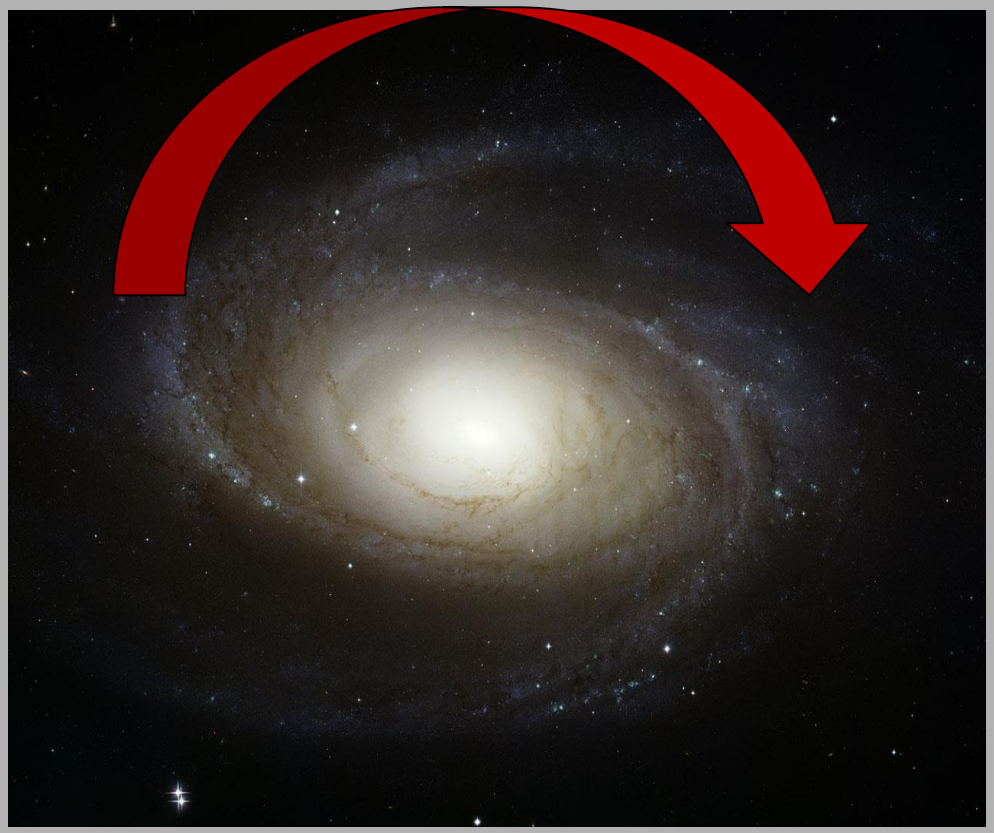
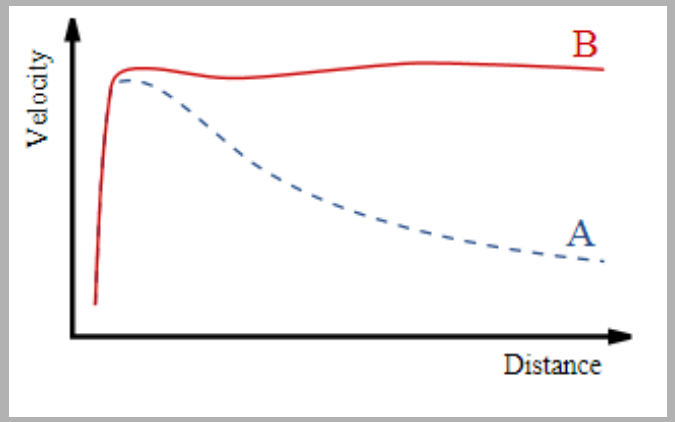
The Universe as a Pie Chart



Dark Matter History

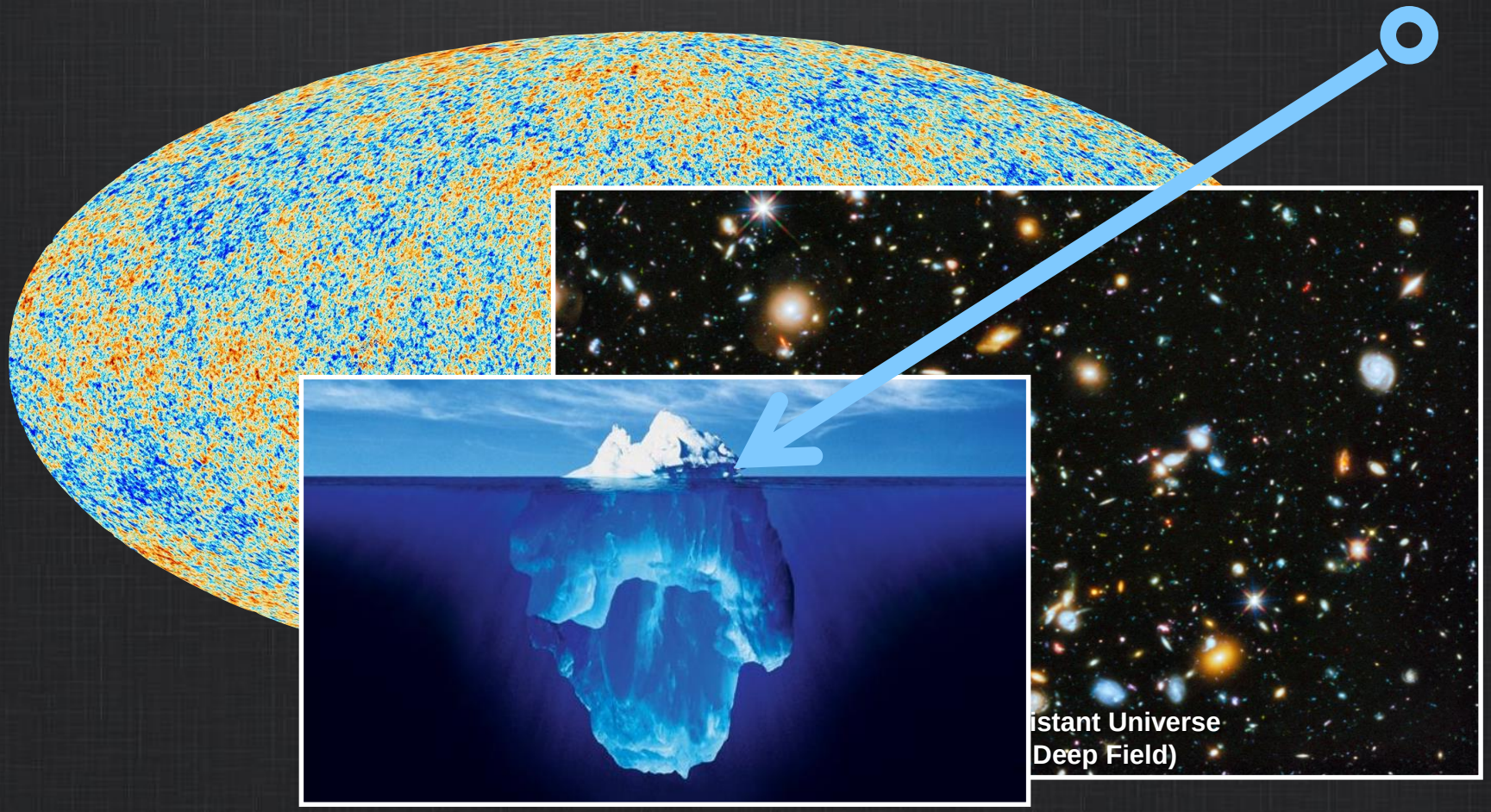
Originally postulated in the 1930s to explain galaxy ‘rotation curves’



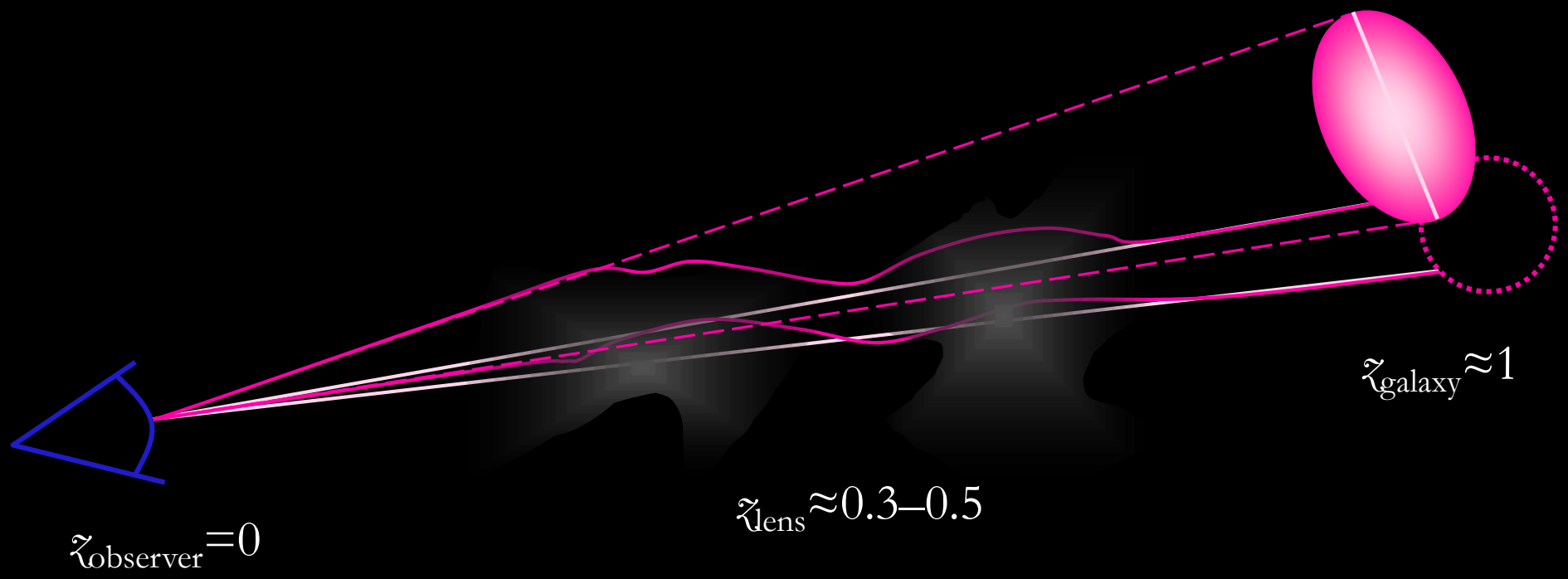


Galaxy M81 as seen from the Hubble Space Telescope

Dark Matter is Driving the Growth of Galaxies



Gravitational Lensing

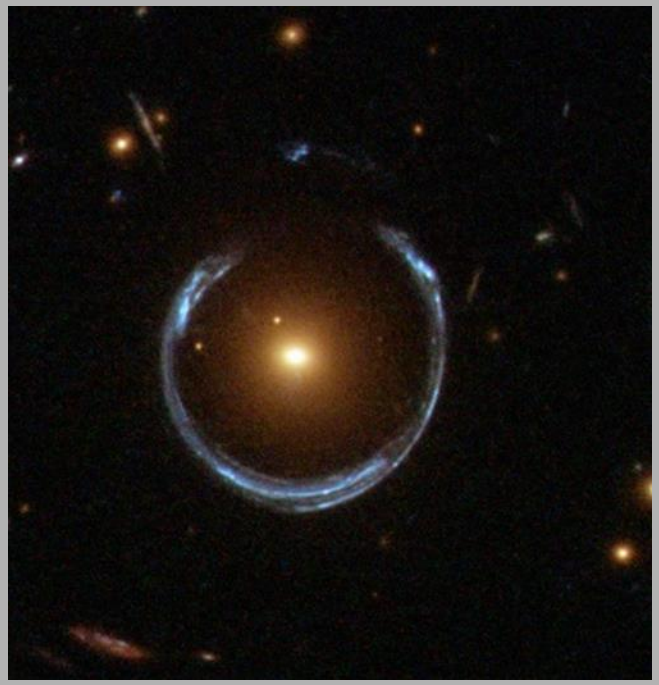


If there is any intervening large-scale structure, light follows the distorted path (exaggerated). Background images are magnified and sheared by ~2%, mapping a circle into an ellipse. Like glass lenses, gravitational lenses are most effective when placed half way between the source and the observer.

A Penny in the Pool

Strong Lenses

ESA/NASA



MACS J0416.1-2403; STScI

Einstein's Equation

$$G_{\mu\nu} = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$$

Gravity, which curves space

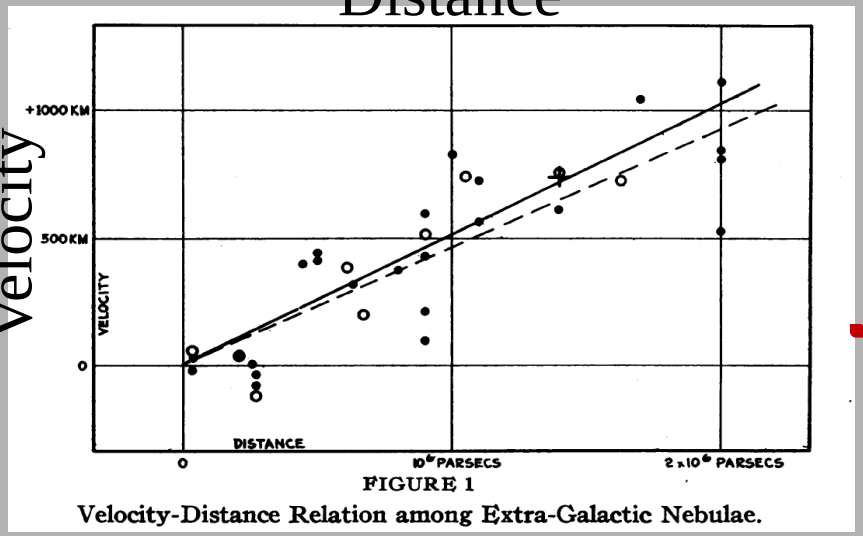
Stuff, matter and energy

Cosmological Constant, supports the universe from collapsing under gravity

Einstein added the cosmological constant Λ so his equations would work for a static universe (which was considered aesthetically pleasing)

An Eternal (?) Expansion

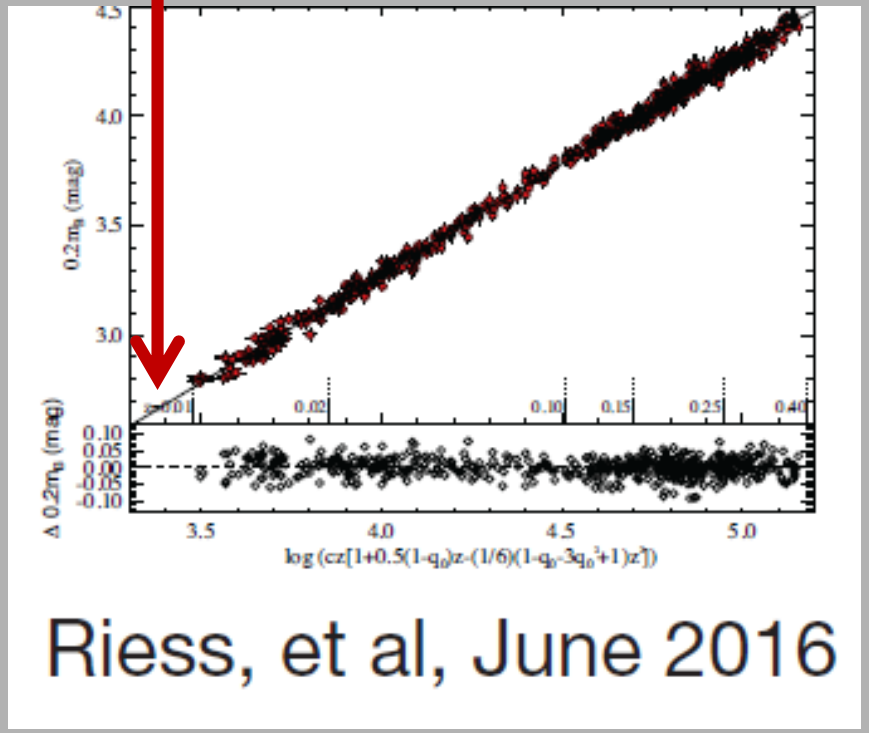
Distance



The farther away something is, the faster it is moving away, *in all directions!*

Hubble, 1929

Hubble Space Telescope



Einstein's Blunder (?)

$$G_{\mu\nu} = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$$

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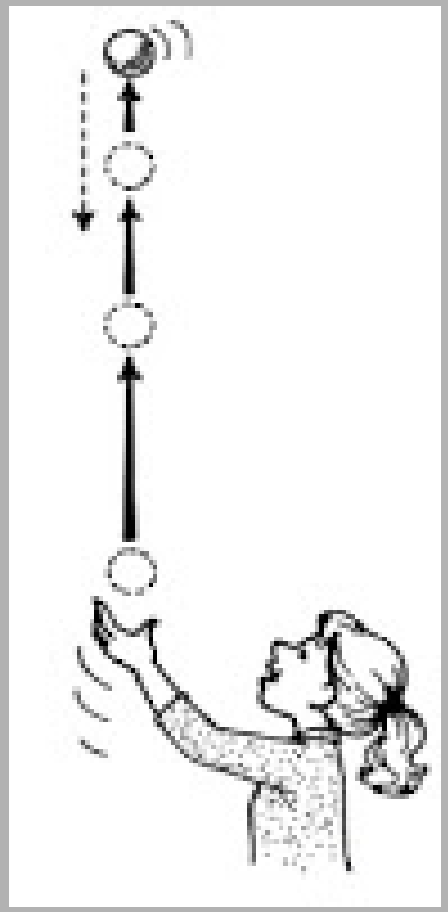
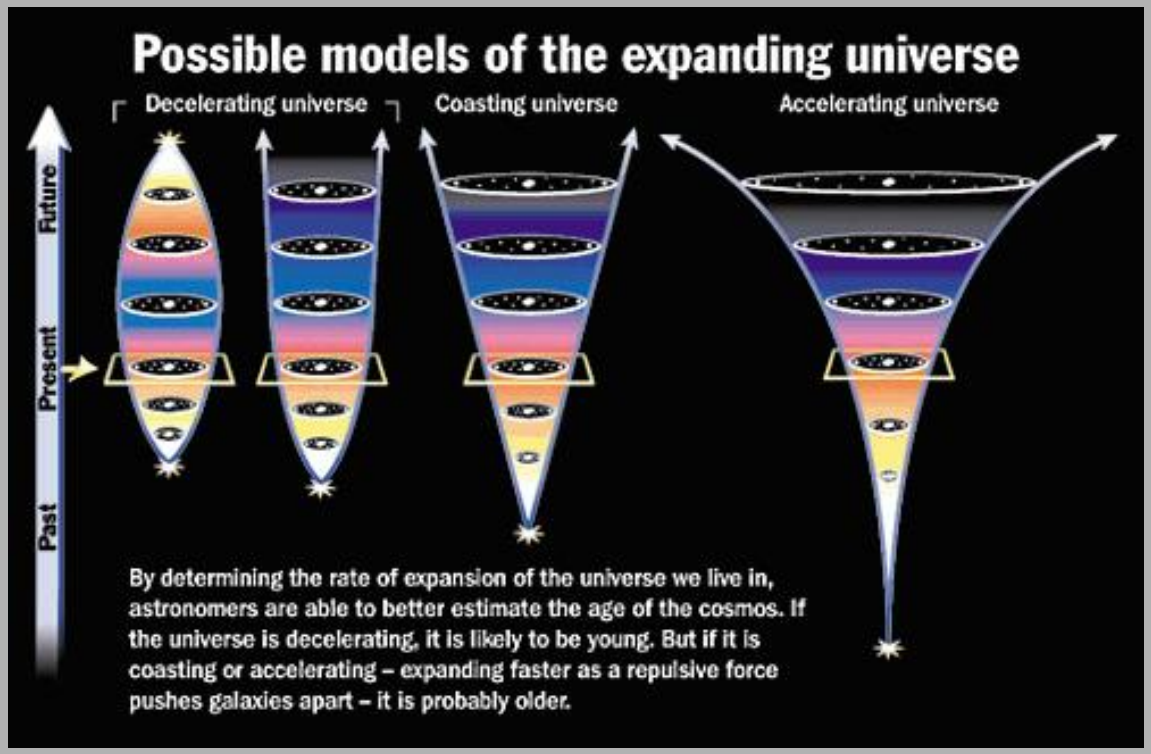
Dark Energy

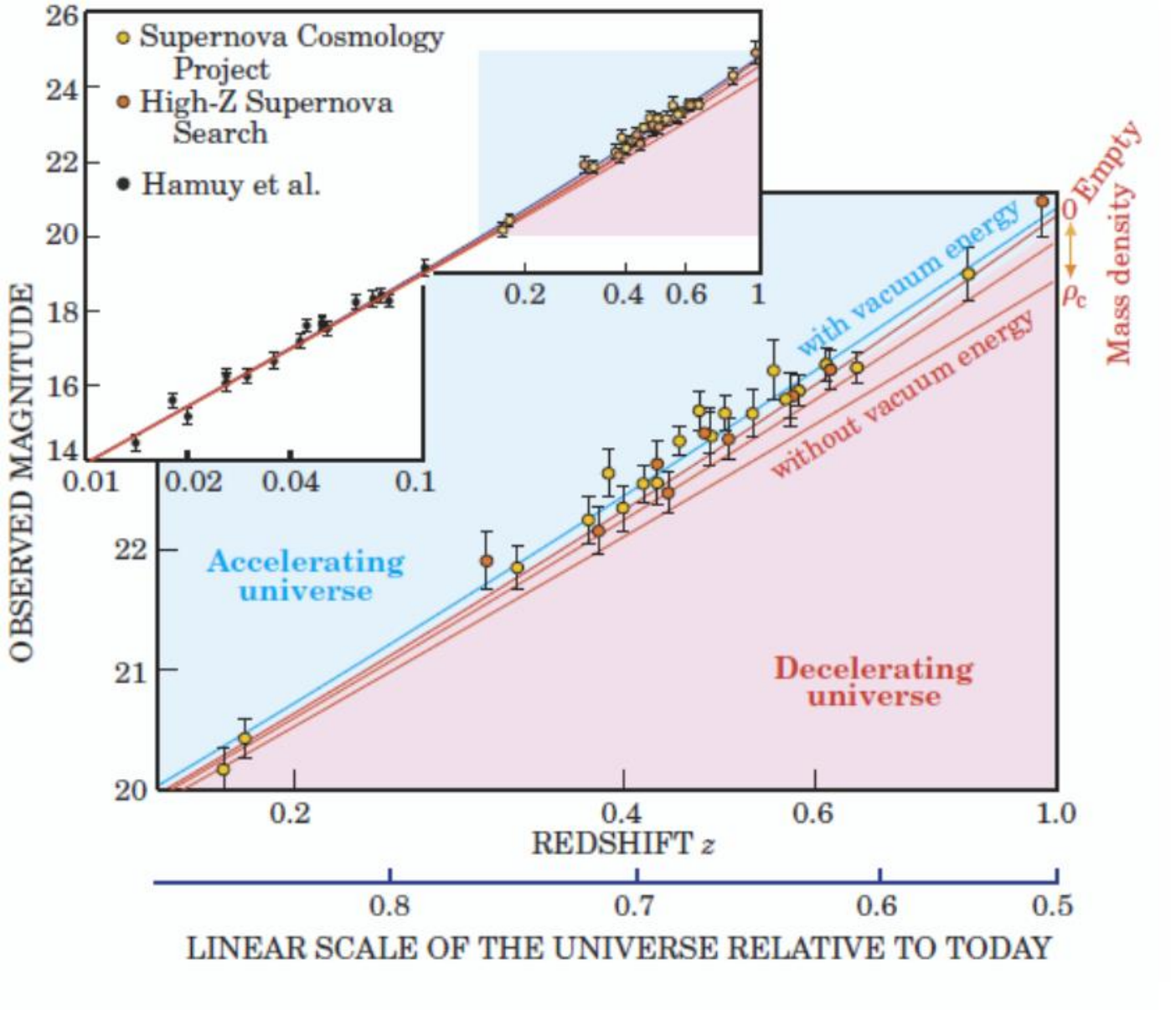




Credit: Adam Reiss, Hubblesite.org

Credit: http://elshareitforfree.blogspot.com/p/forces-and-motion.html

Accelerating Expansion



Einstein's Blunder (?)

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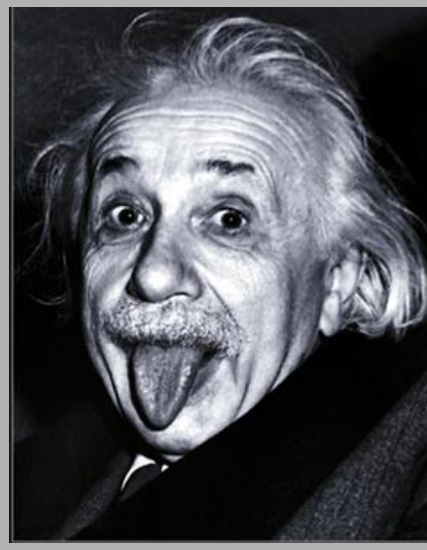

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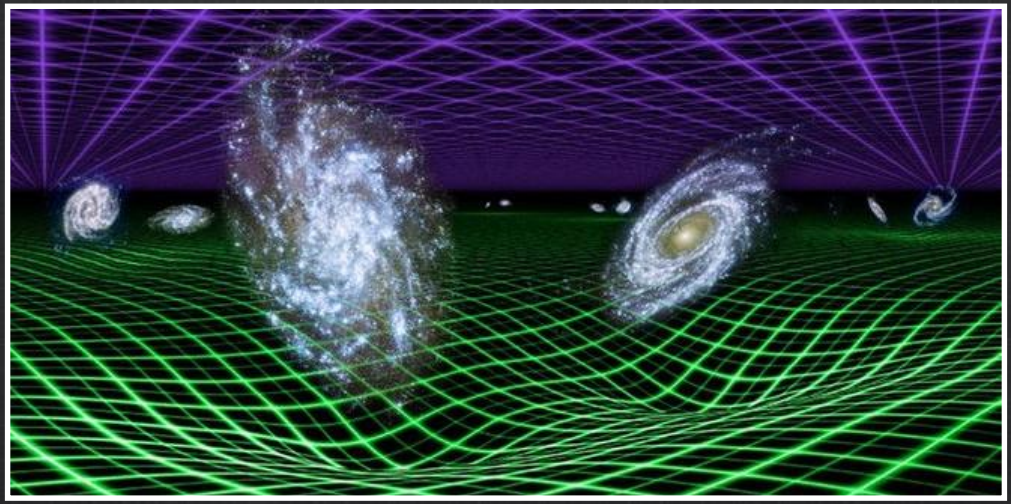
Push-Pull: Dark Energy vs Dark Matter



Dark Energy
Is a repulsive force
Affects the speed at which the Universe expands
Causes everything to move away from everything else

Dark Matter
Affected by the attractive force of gravity
Affects how "clustered" objects are
Causes objects to want to move towards one another

<u>Our Best Guess</u>

Dark Energy may *eventually rip the Universe apart!*

…sorry.

To be sure, lets go and measure both dark matter and dark energy!

#NASAWFIRST

The fate of the Universe -1

Universes with Dark Energy that is not very strong (about what we think it is now)

- eternal expansion
- other galaxies eventually disappear beyond the horizon (no more extragalactic astronomy!)
- The end of cosmology
- gravitationally bound objects stay bound (Earth, the solar system, our galaxy)

The Universe becomes a lonely place

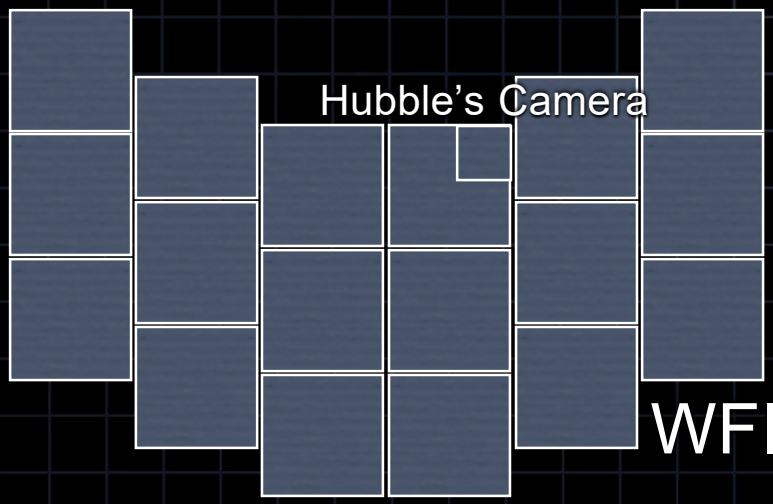
The fate of the Universe -2

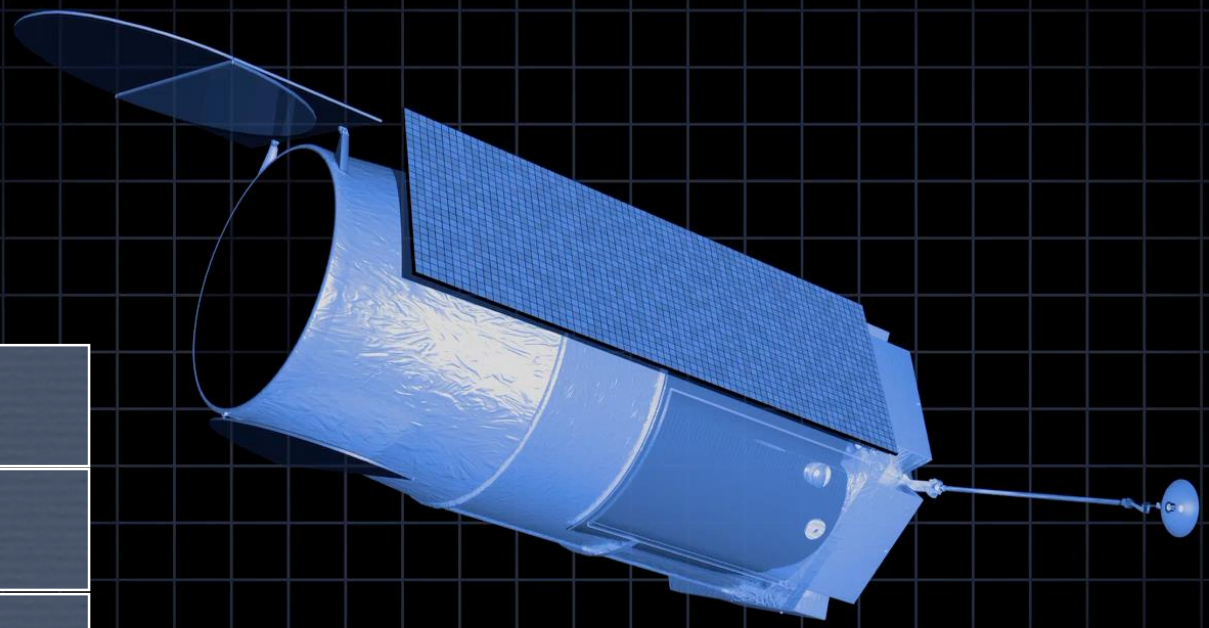
Universes with Dark Energy and ***w*** < -1 :

- Universe will be increasingly dark energy dominated in the future
- dark energy density becomes infinite
- gravitationally bound objects torn apart
- Even solar system exploration becomes impossible!
- Eventually, even atoms break apart!
- **the "Big Rip" – spacetime itself rips apart**
- **if *w*** = -1.5, Big Rip happens in **22 billion years** (current age… 13.7 Billion years)
  - At T-60 Million years, galaxies would rip apart
  - At T- 3 months solar systems would rip apart
  - At T- a few minutes, stars and planets would rip apart
  - At the end, even atoms would rip apart

Caldwell et al (2003), "Phantom Energy and Cosmic Doomsday"

WFIRST

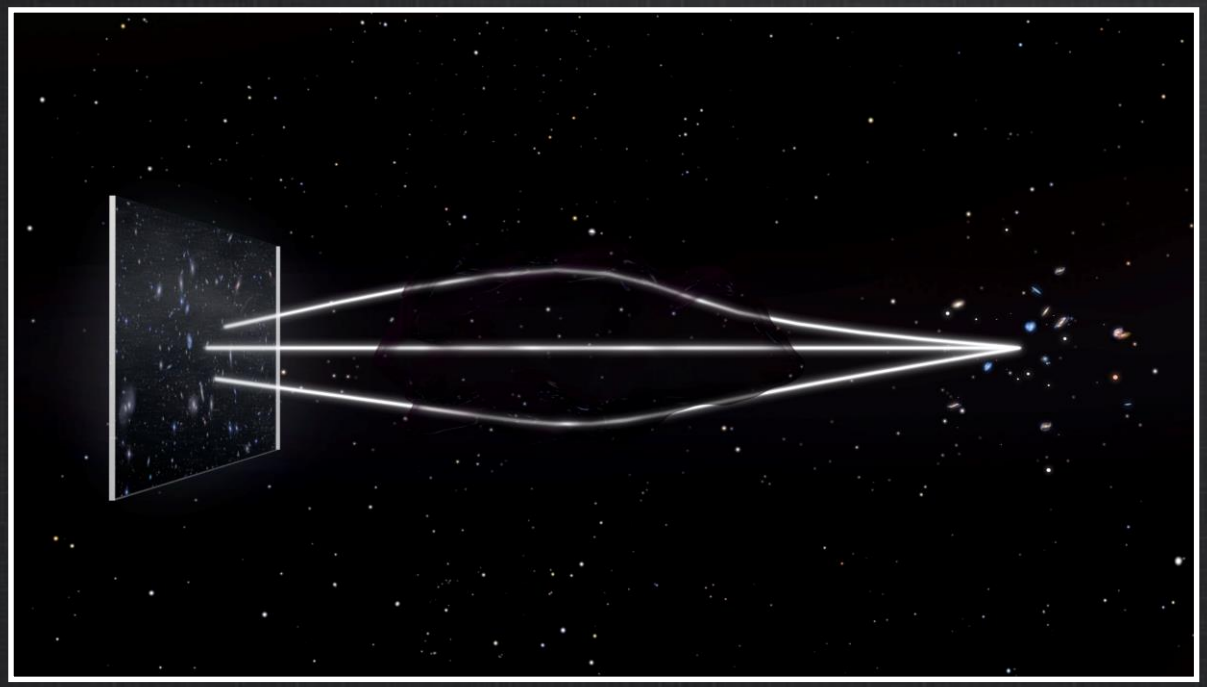


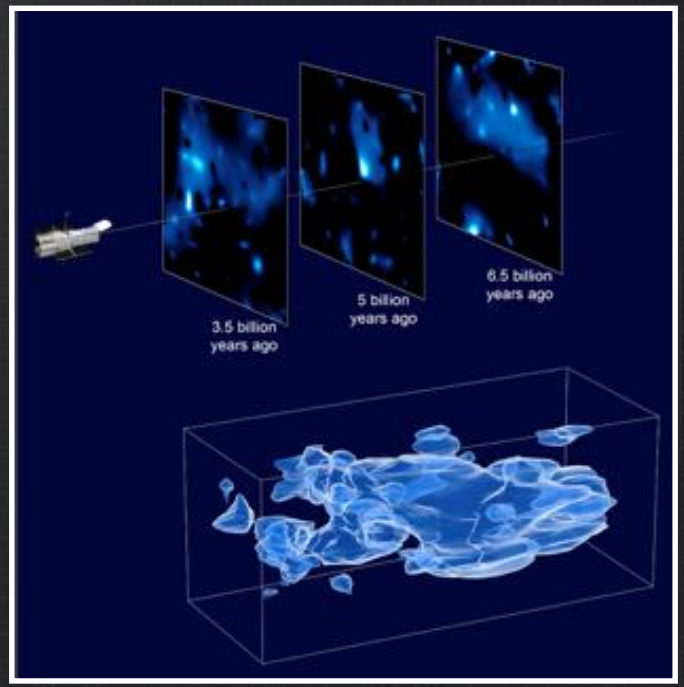


WFIRST's Camera

WFIRST will

measure galaxy shapes to map dark matter and measure the growth of galaxies over the Universe's life

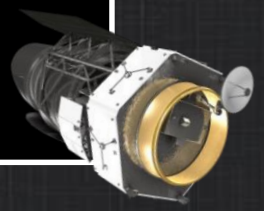




#NSAWFIRST

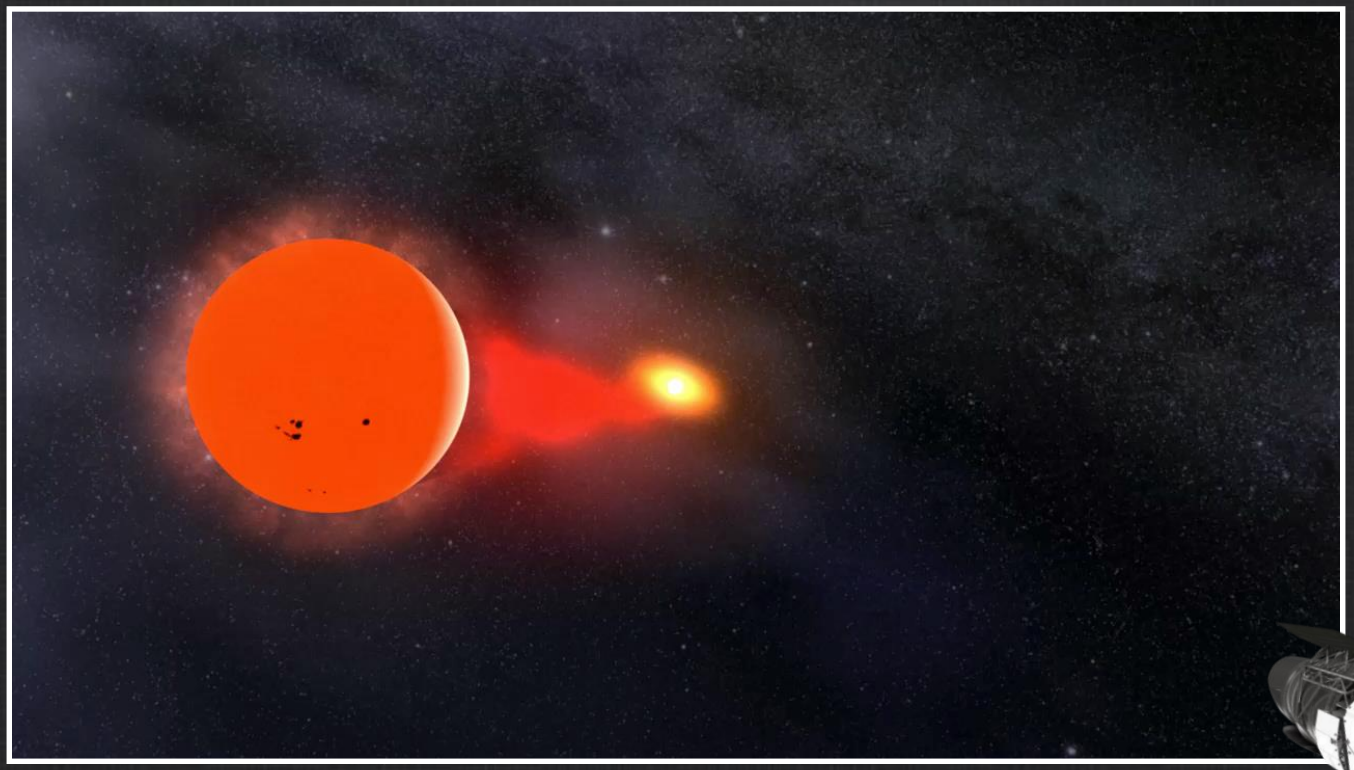
WFIRST will

map the positions of galaxies to establish a cosmic standard ruler to measure the Universe's expansion history

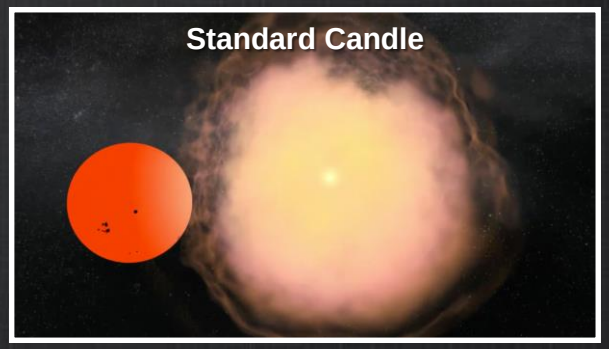


WFIRST will

discover exploding stars (supernovae) across cosmic time to establish precise distances to galaxies



WFIRST's Dark Universe Roadmap



Growth of Structure
(also Expansion History)

Expansion History
(also Growth of Structure)

Expansion History

Determine the Universe's End Fate!