

# Dark Matter, Dark Energy, and Our Preposterous Universe

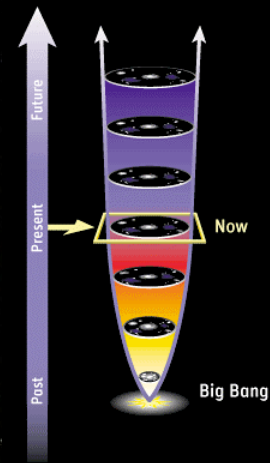
Sean Carroll  
California Institute of Technology  
*cosmicvariance.com*



# The universe is big, and getting bigger.

100  
billion  
galaxies

100  
billion  
stars per  
galaxy

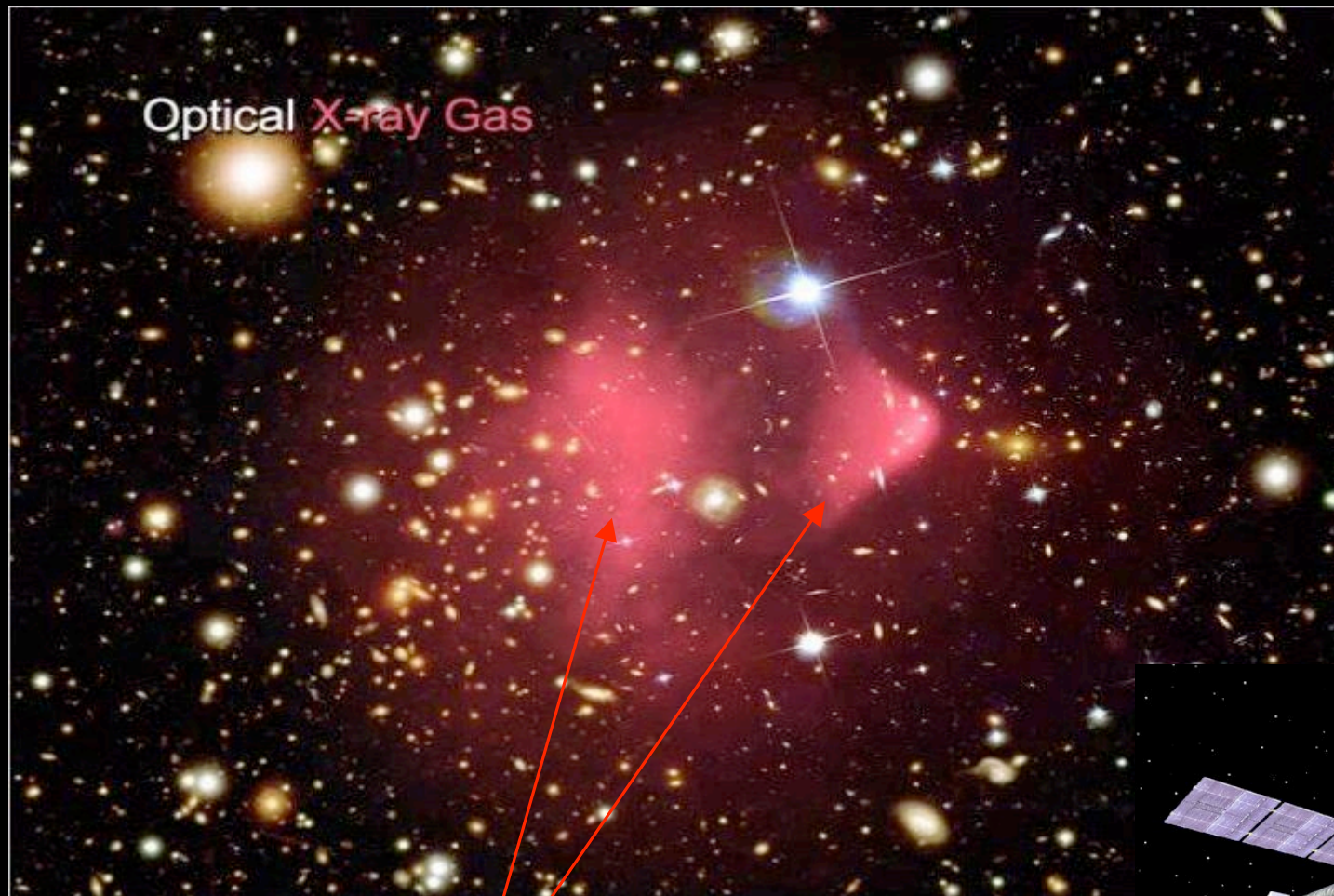


14 billion  
years old



Hubble Space Telescope

# Bullet Cluster

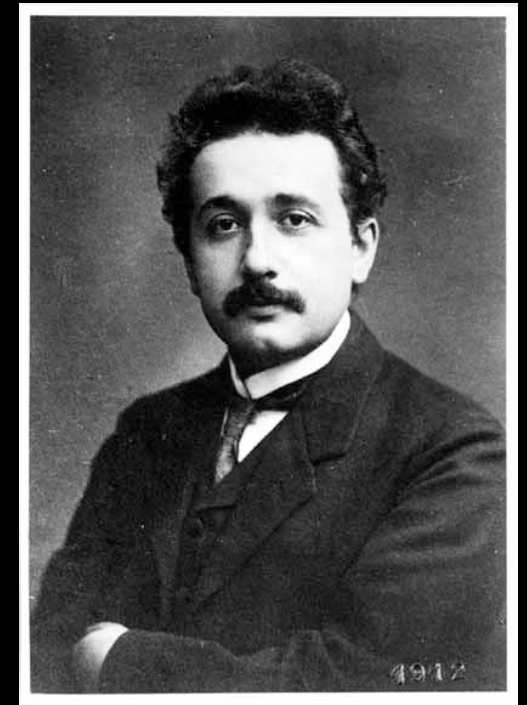
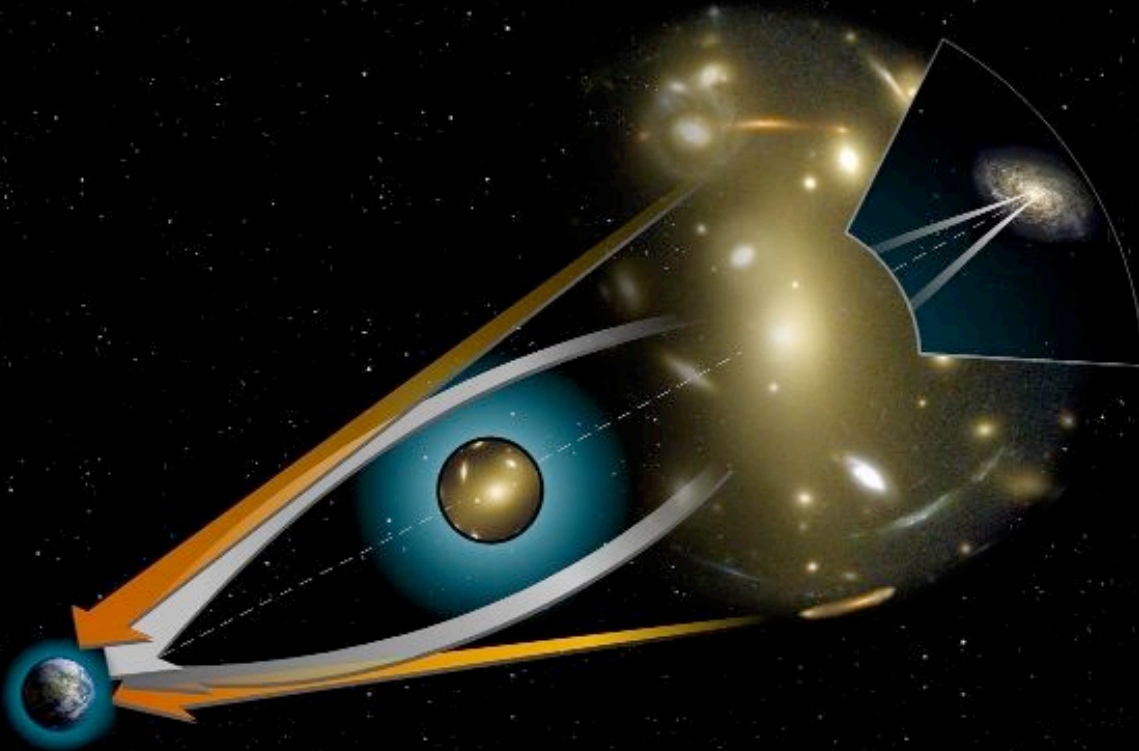


intergalactic gas left behind by the collision of two clusters of galaxies



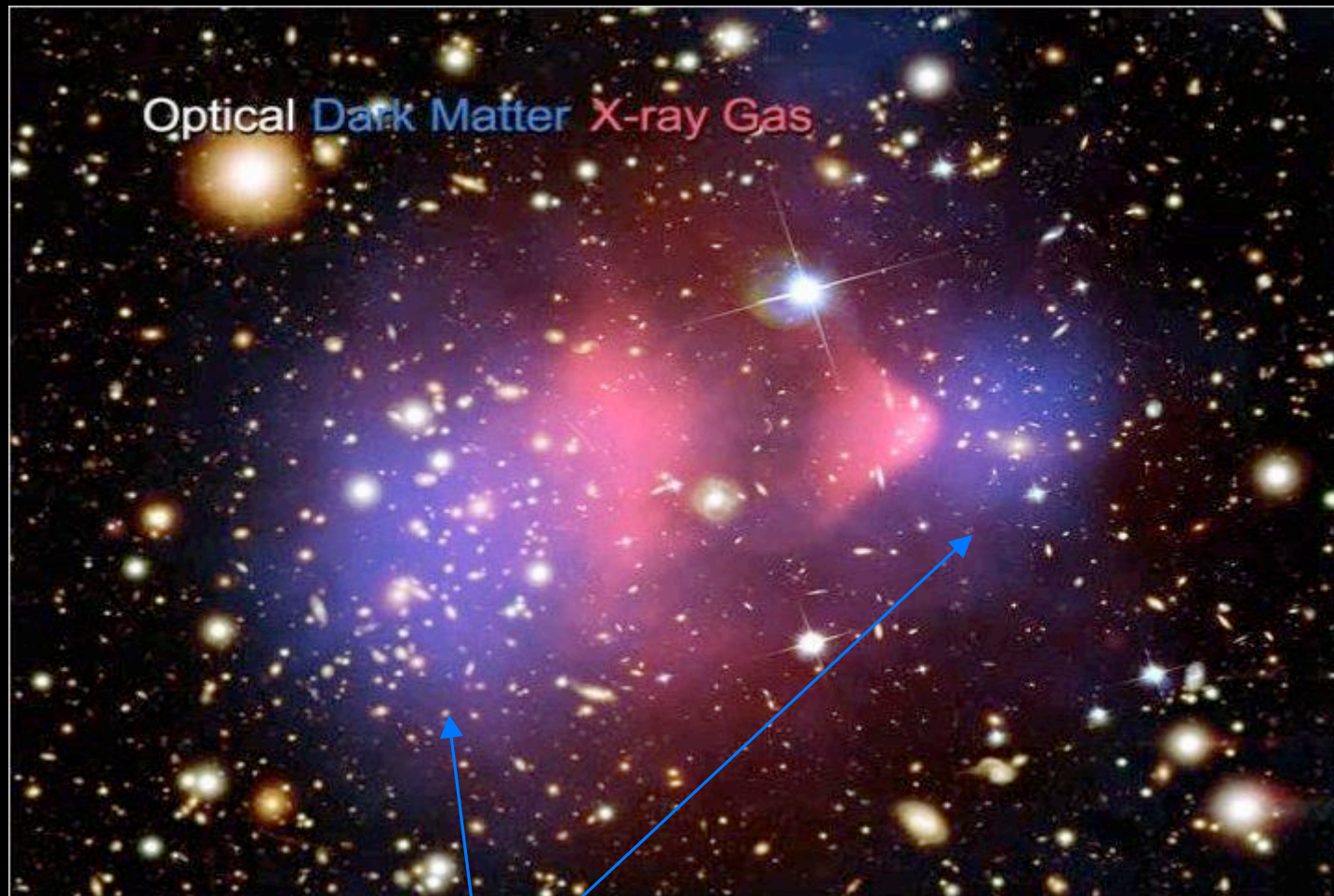
Chandra X-ray Observatory

## Is what we see all there is?

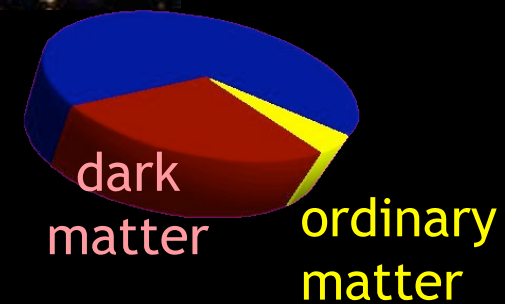


Einstein: all forms of matter and energy cause gravity, and are affected by gravity. By observing how light is deflected (“gravitational lensing”), we can detect gravitational fields, and *weigh the universe*.

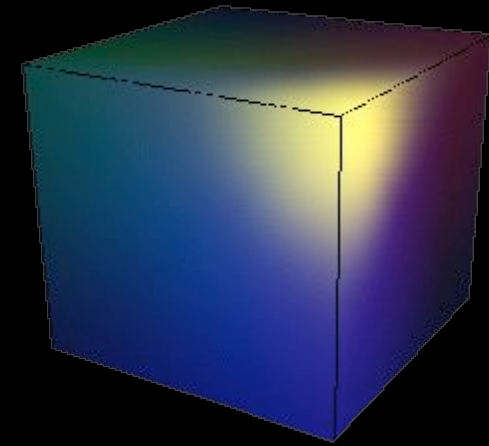
# Bullet Cluster



gravitational field is centered on a different source than the ordinary matter -- dark matter

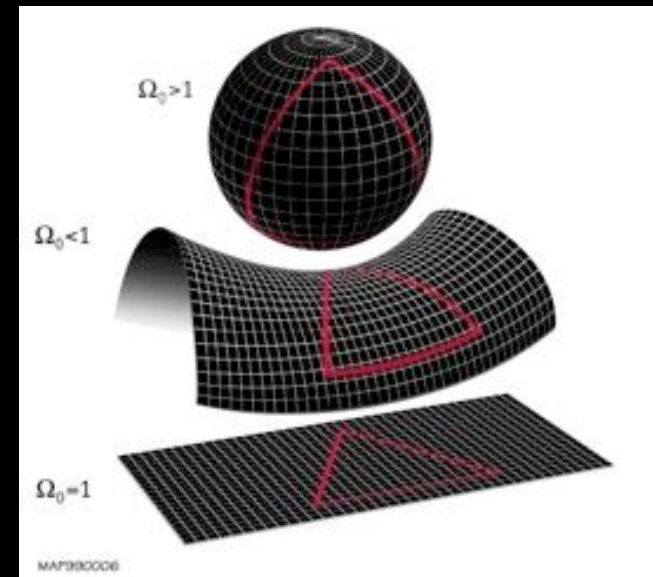
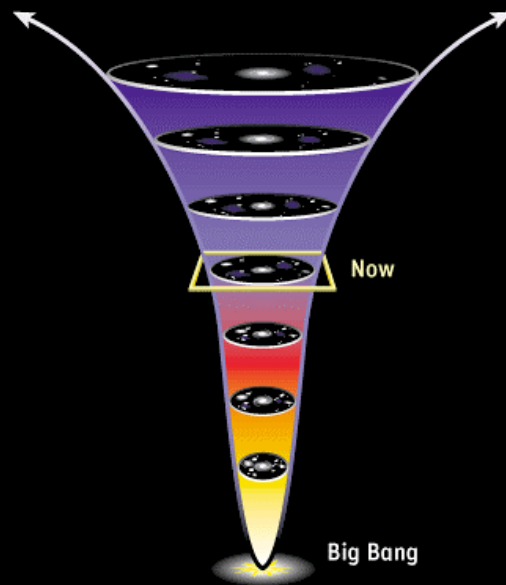


Even more surprising: there is energy in between galaxies, in the fabric of space itself -- Dark Energy, constant through time and space.



false-color image of dark energy

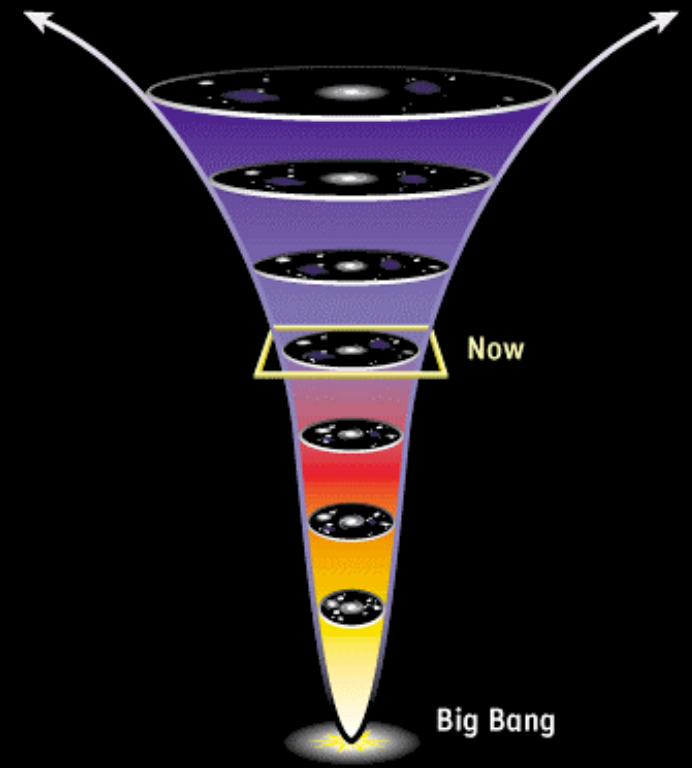
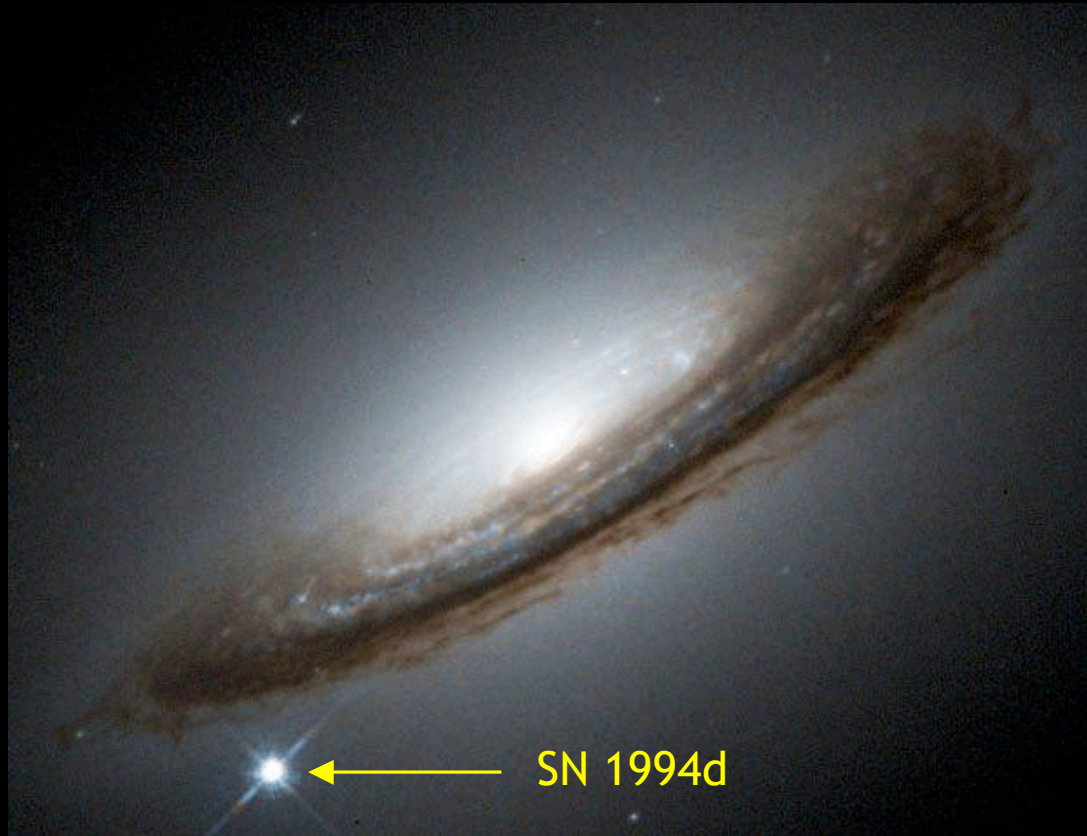
How do we know?



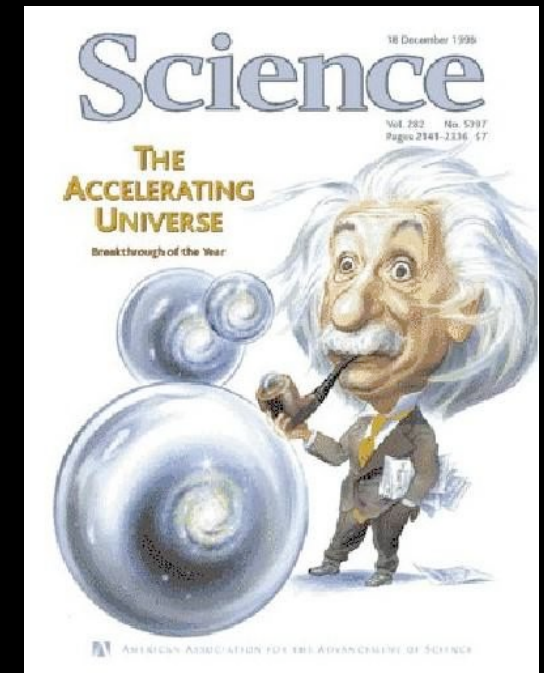
1. Makes the expansion of the universe accelerate.

2. Contributes to the curvature of space.

Supernovae in other galaxies reveal the expansion history of the universe.

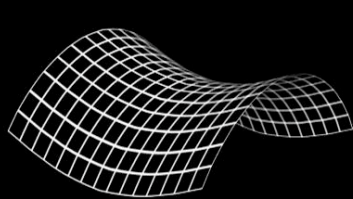
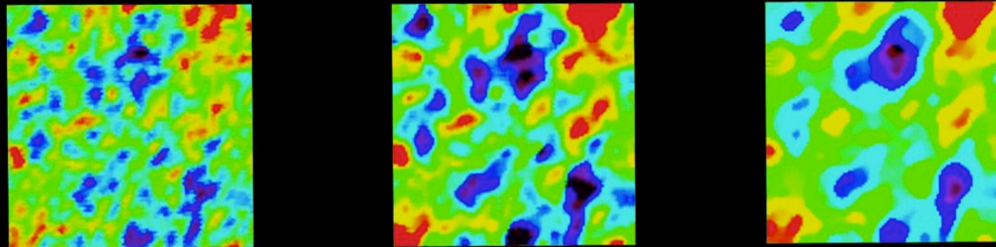


Result (1998): the expansion is speeding up, just as dark energy predicts!

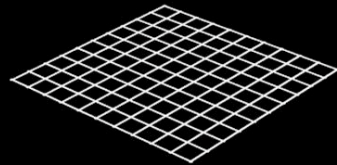


Check: curvature of space measures the total energy of the universe (ordinary + DM + DE).

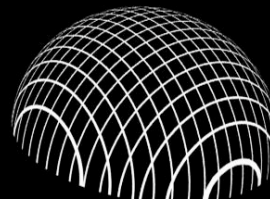
## GEOMETRY OF THE UNIVERSE



**OPEN**



**FLAT**



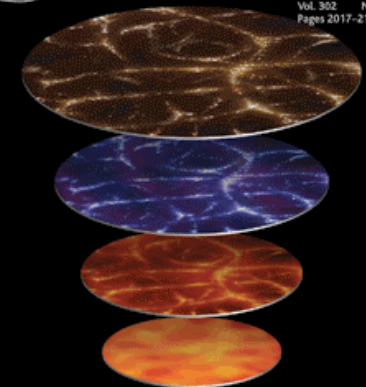
**CLOSED**

Result (2003): Need for dark energy confirmed!



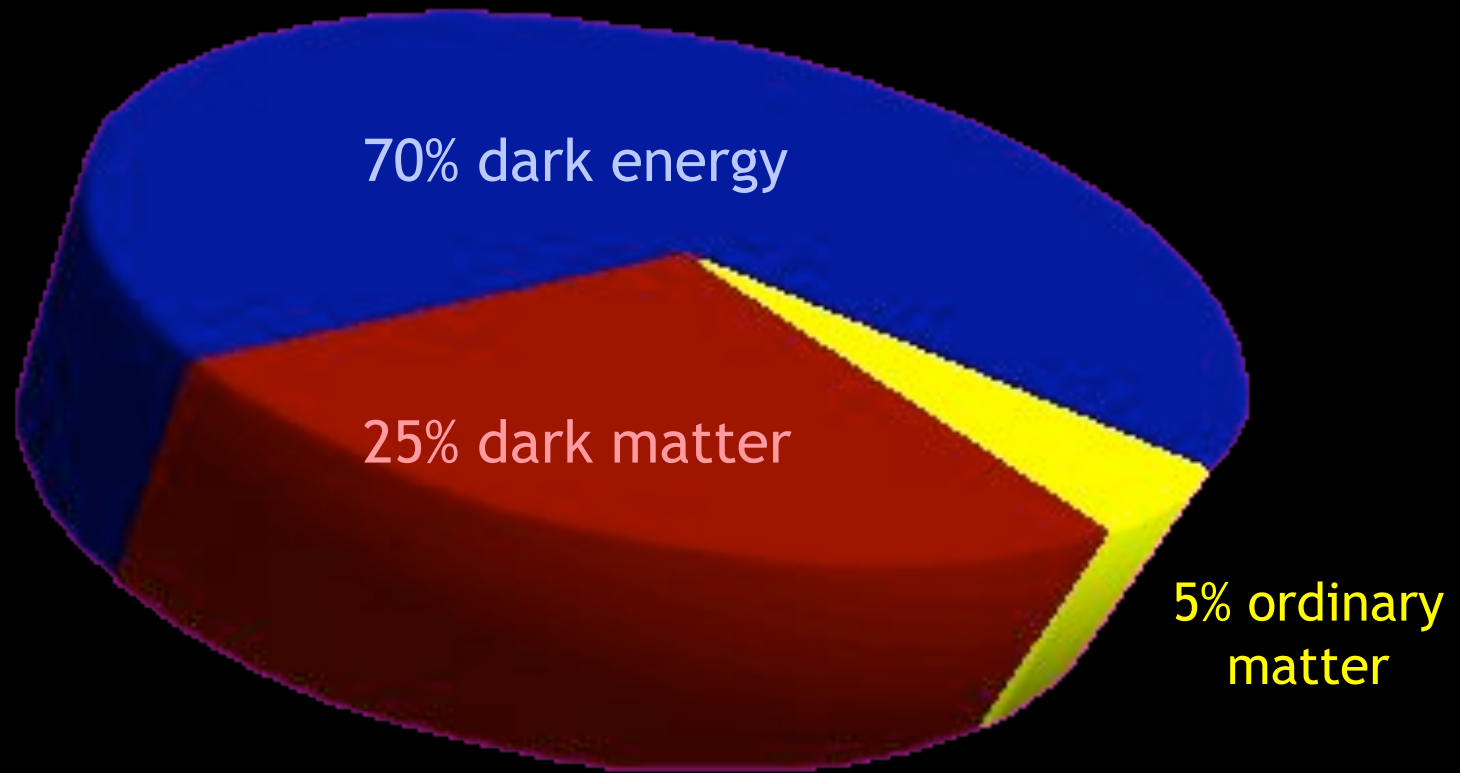
Wilkinson Microwave Anisotropy Probe (WMAP)

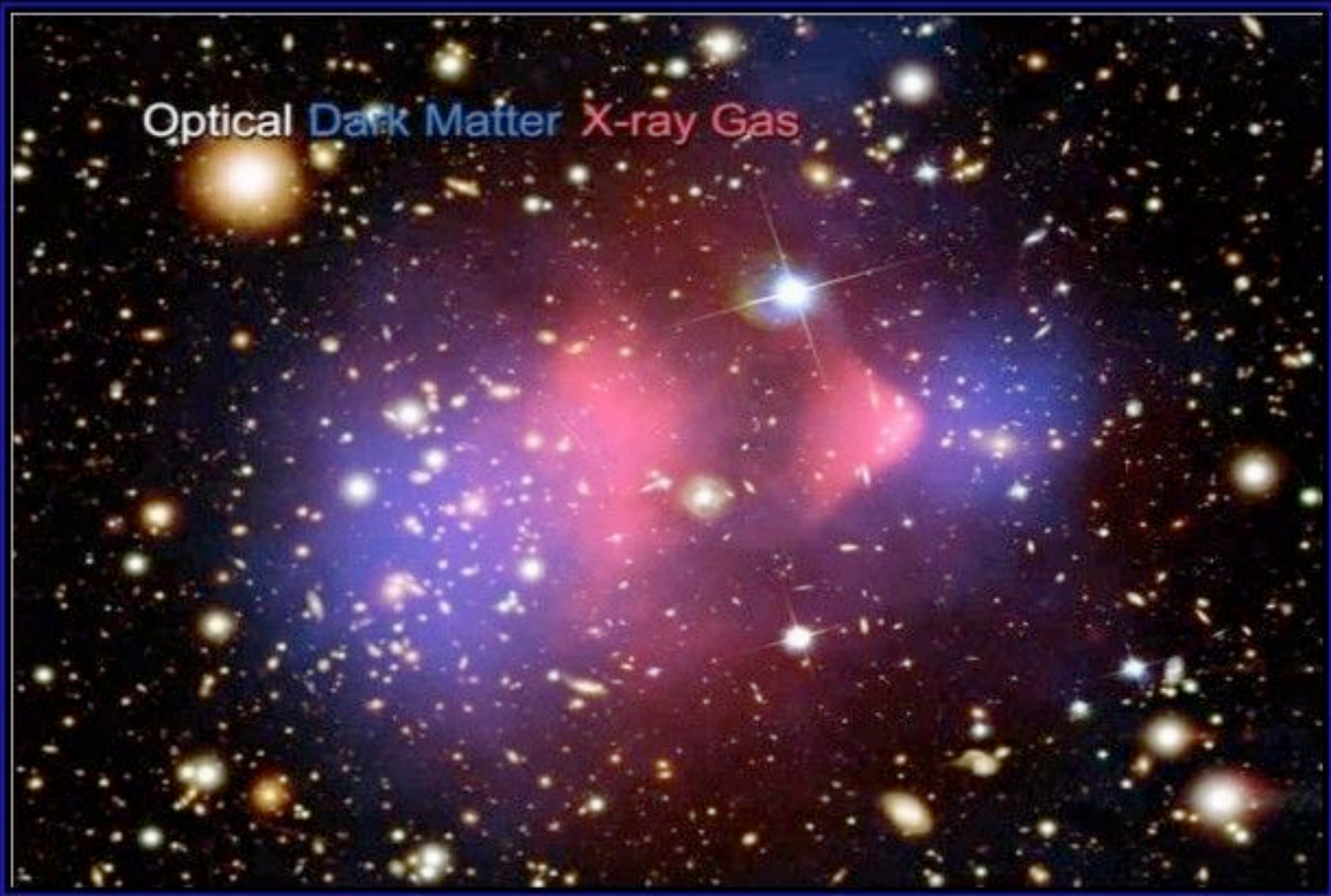
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Pages 2017-2172 \$10



Breakthrough of the Year  
**Cosmic  
Convergence**

We have a complete inventory of the universe.



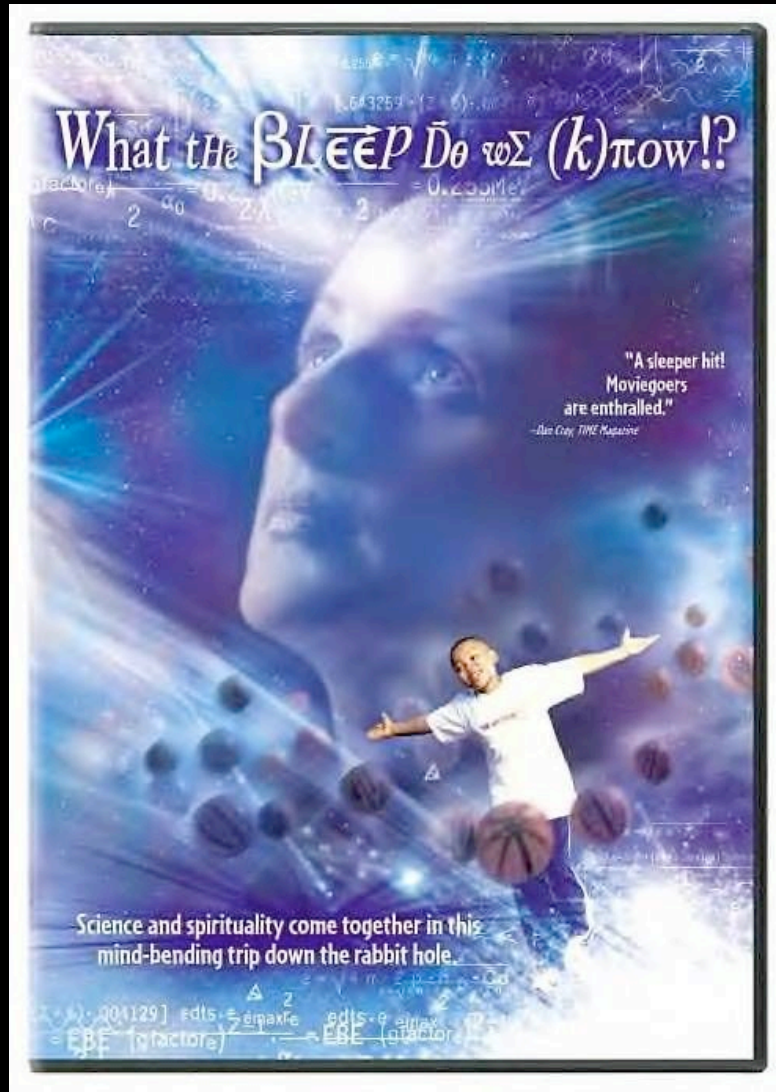


Optical Dark Matter X-ray Gas

# DARK MATTER

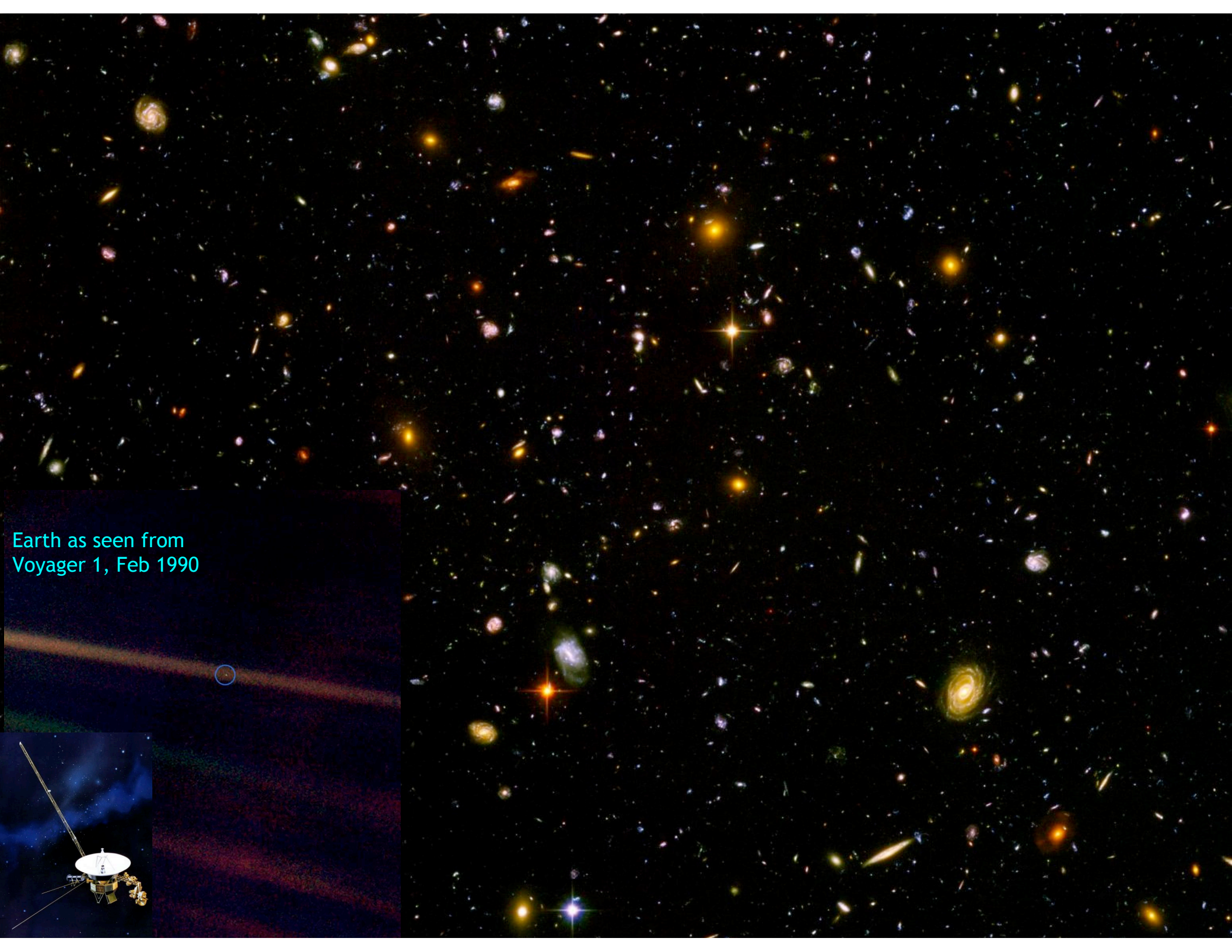
Most of the universe can't even be bothered to interact with you.

# Making demands of the universe



“It is precisely the business of approaching the world with open and authentic wonder, and with a sharp, cold eye, and singularly intent upon the truth, that’s called science.”

-- David Albert, Columbia University



Earth as seen from  
Voyager 1, Feb 1990

