

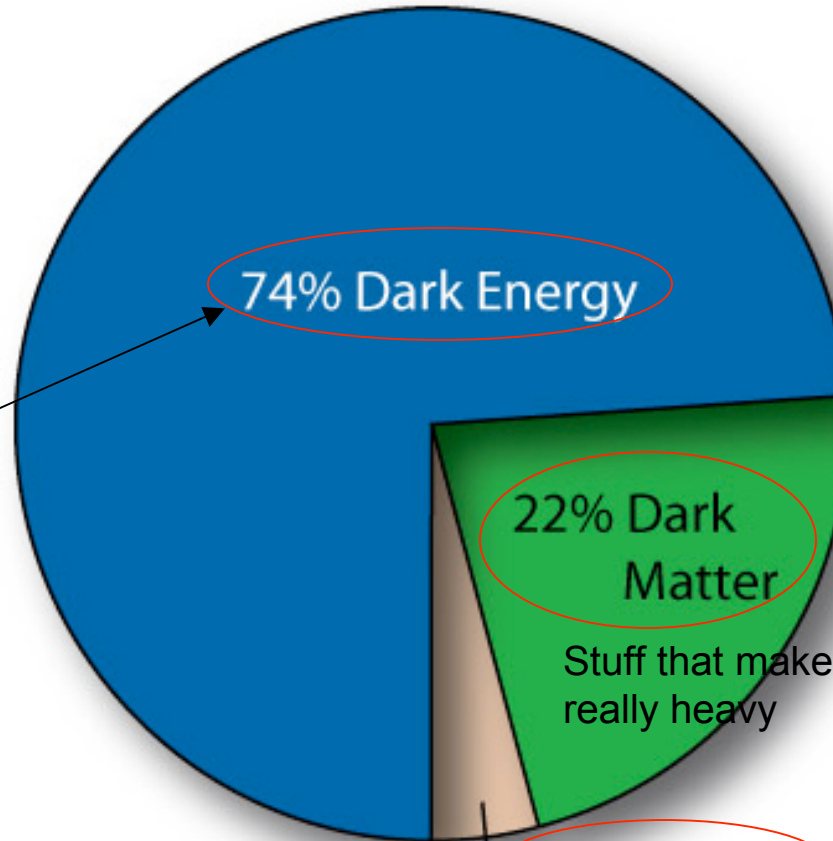
# ***Dark Matter & Dark Energy***



***Gil Holder***

# Current state of our “understanding” of the universe

Stuff that makes the  
universe accelerate



22% Dark  
Matter

Stuff that makes things look  
really heavy

4% Atoms

Stuff that we actually understand and  
interact with (kind of...)



***Facts are meaningless. You can use facts to prove anything that's even  
remotely true. Facts, schmacts.***

# ***Dark Energy: the universe is accelerating***



***Uh, excuse me, Professor Brainiac, but I worked in a nuclear power plant for ten years, and, uh, I think I know how a proton accelerator works.***

# *The expanding universe*

- The universe is getting bigger
- How do we know?
  - Light goes at a known speed
  - Light wavelength (colour) gets stretched by expansion of universe
    - Things that are further away from us are sending signals coming from an earlier time
    - Colour of received light tells us how much the universe has stretched
    - Stuff that is further away from us has been stretched more



*The ugly side of expansion....*



*Sure thing, giant beer.*

The expanding universe thing has some serious upside!



today



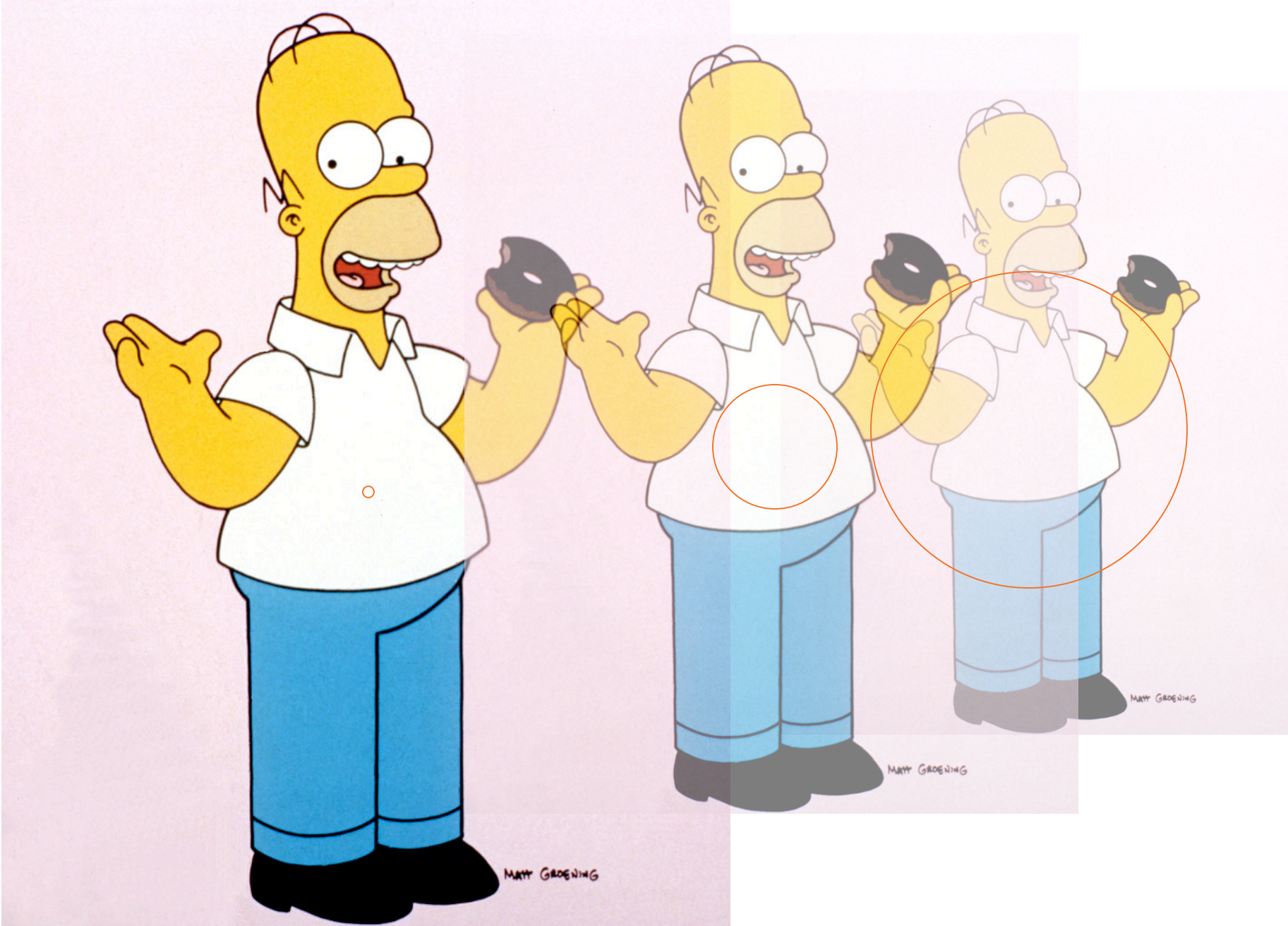
earlier





Remember that light we see today comes from earlier times, and the further away it is the longer it has taken to get to us (and the more the universe has expanded!)



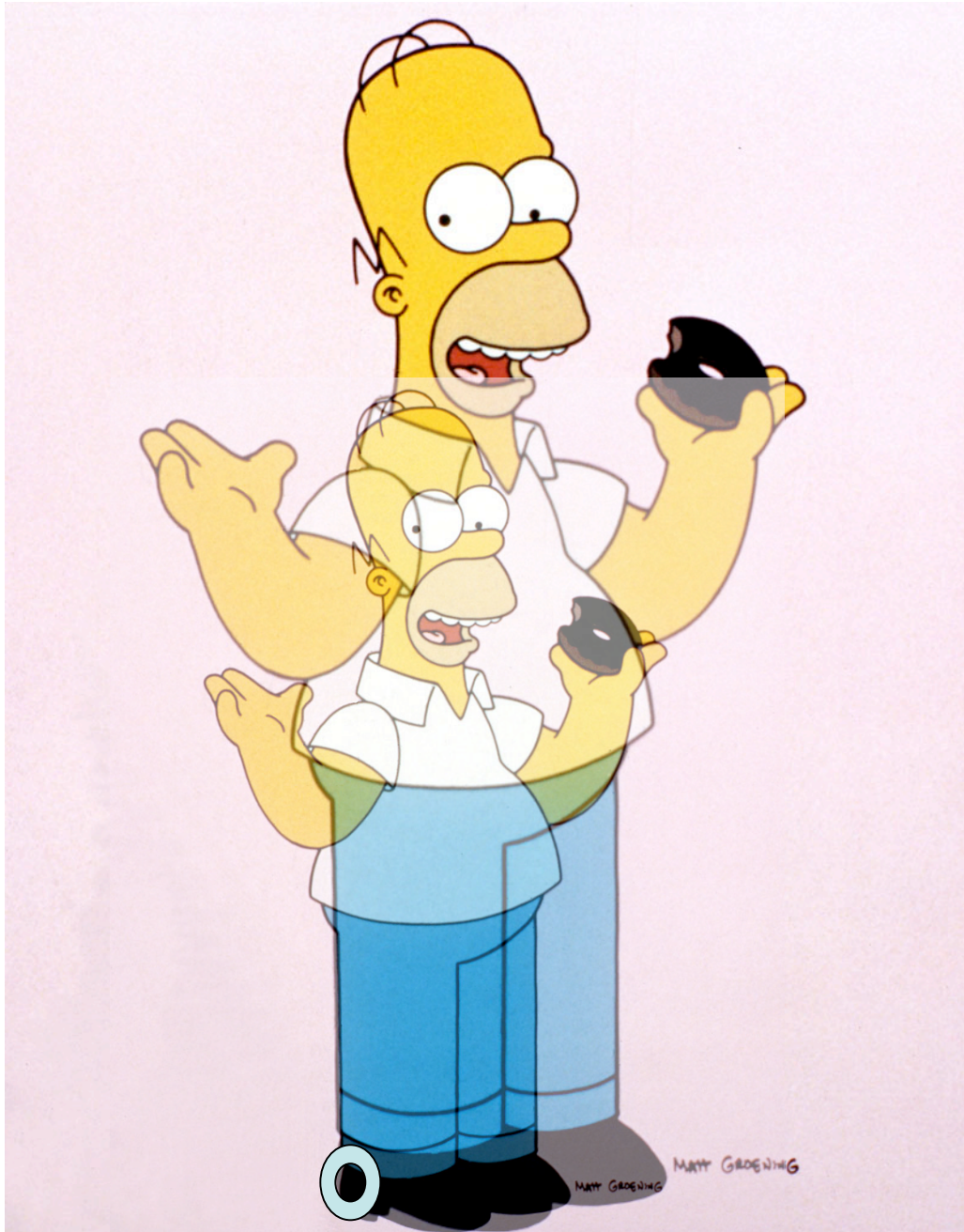


today



earlier

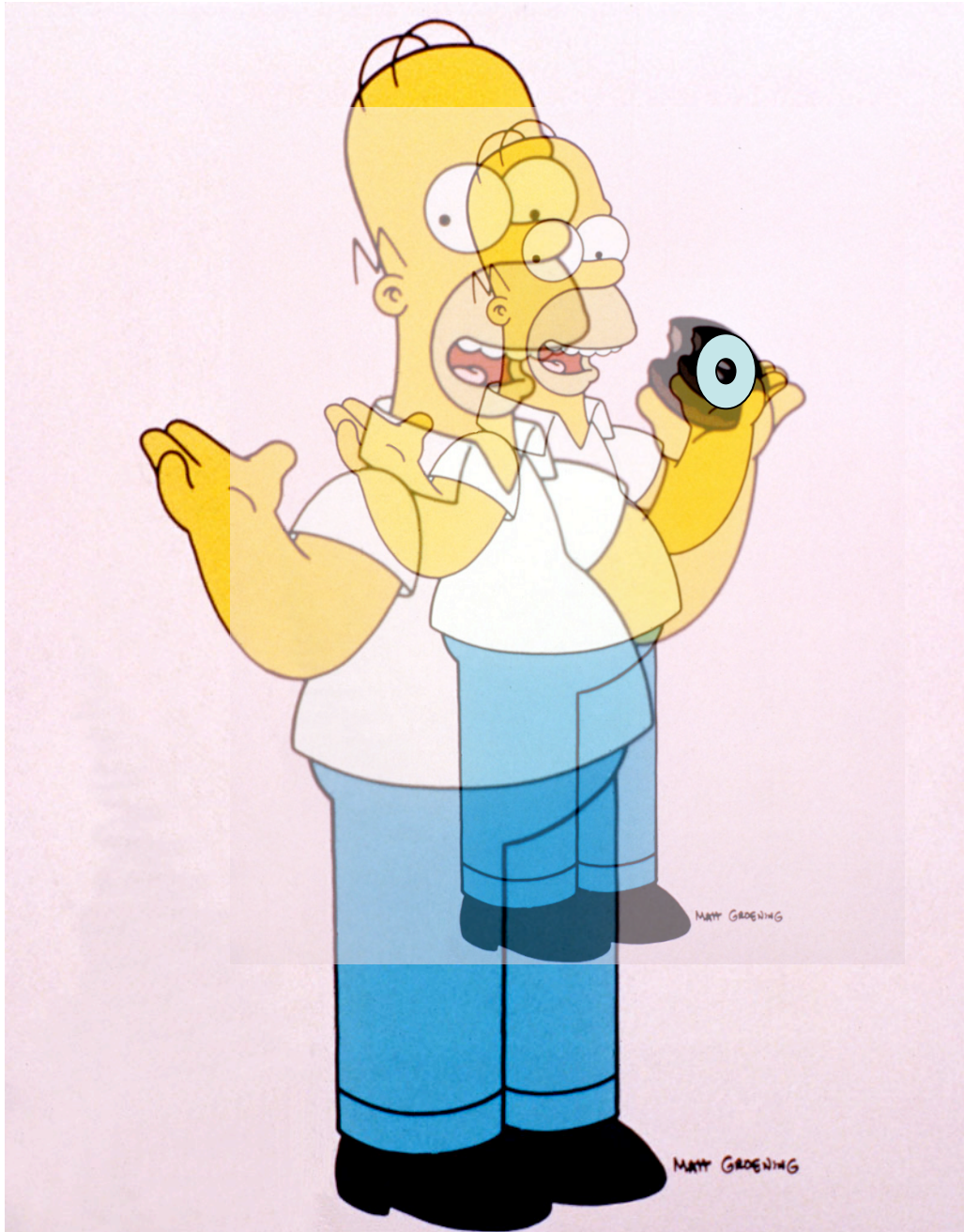




Everyone will think they are at the center of the universe (big surprise)

Expansion is homogeneous (everyone sees it) and isotropic (same expansion in every direction you look)

Things further away have their wavelengths stretched more



Everyone gets to be  
at the center

Expansion is  
homogeneous  
(everyone sees it)  
and isotropic (same  
expansion in every  
direction you look)

Things further away  
have their  
wavelengths  
stretched more



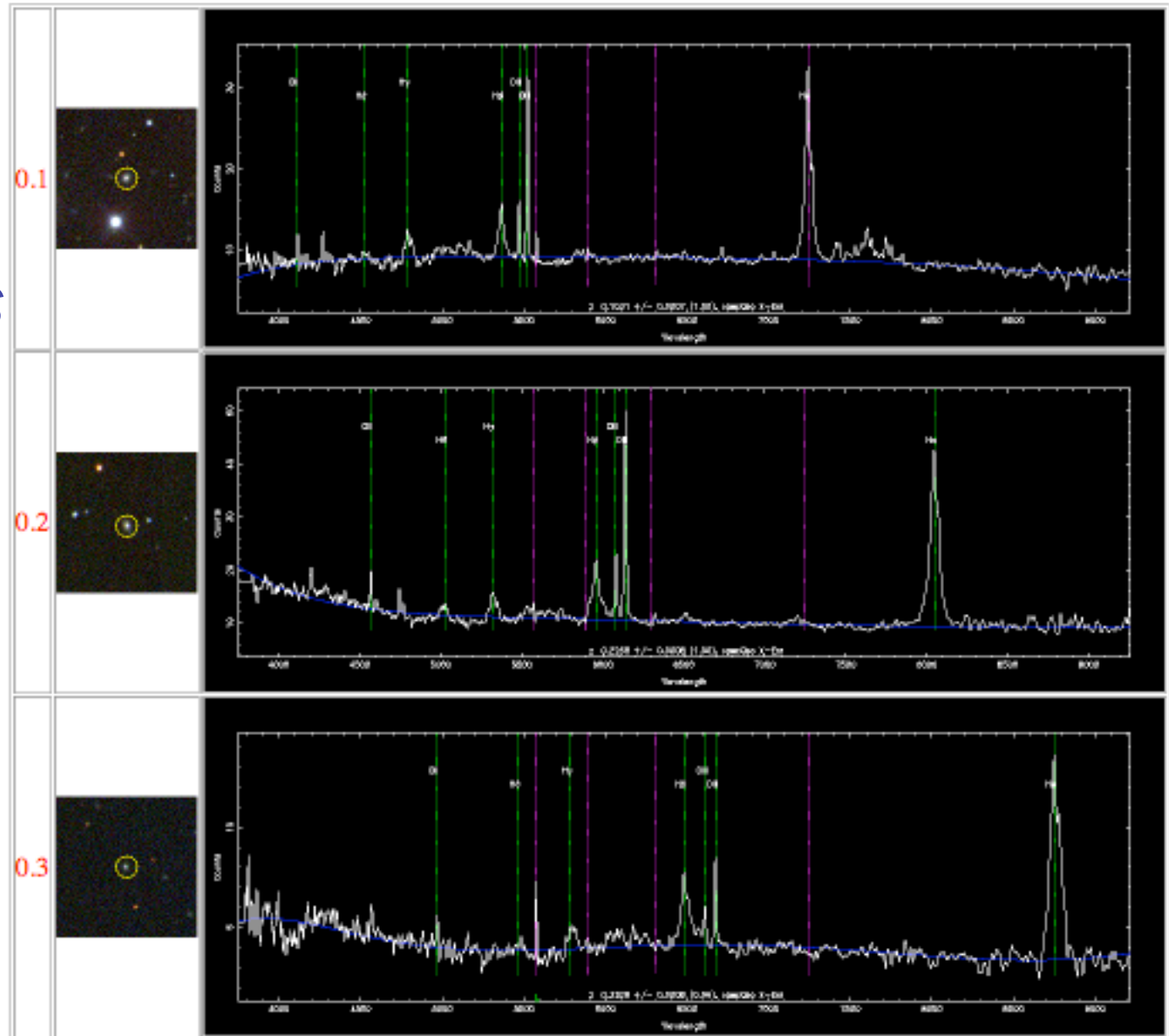
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Things further away  
have their  
wavelengths  
stretched more

# Redshifts

Cosmological redshifts first observed by Slipher (1912)



Sloan Digital Sky Survey quasars

# *Exploding stars: Supernovae*

nearby



It is thought that for at least some supernovae they all have the same intrinsic brightness ( $10^{36}$  W light bulbs)

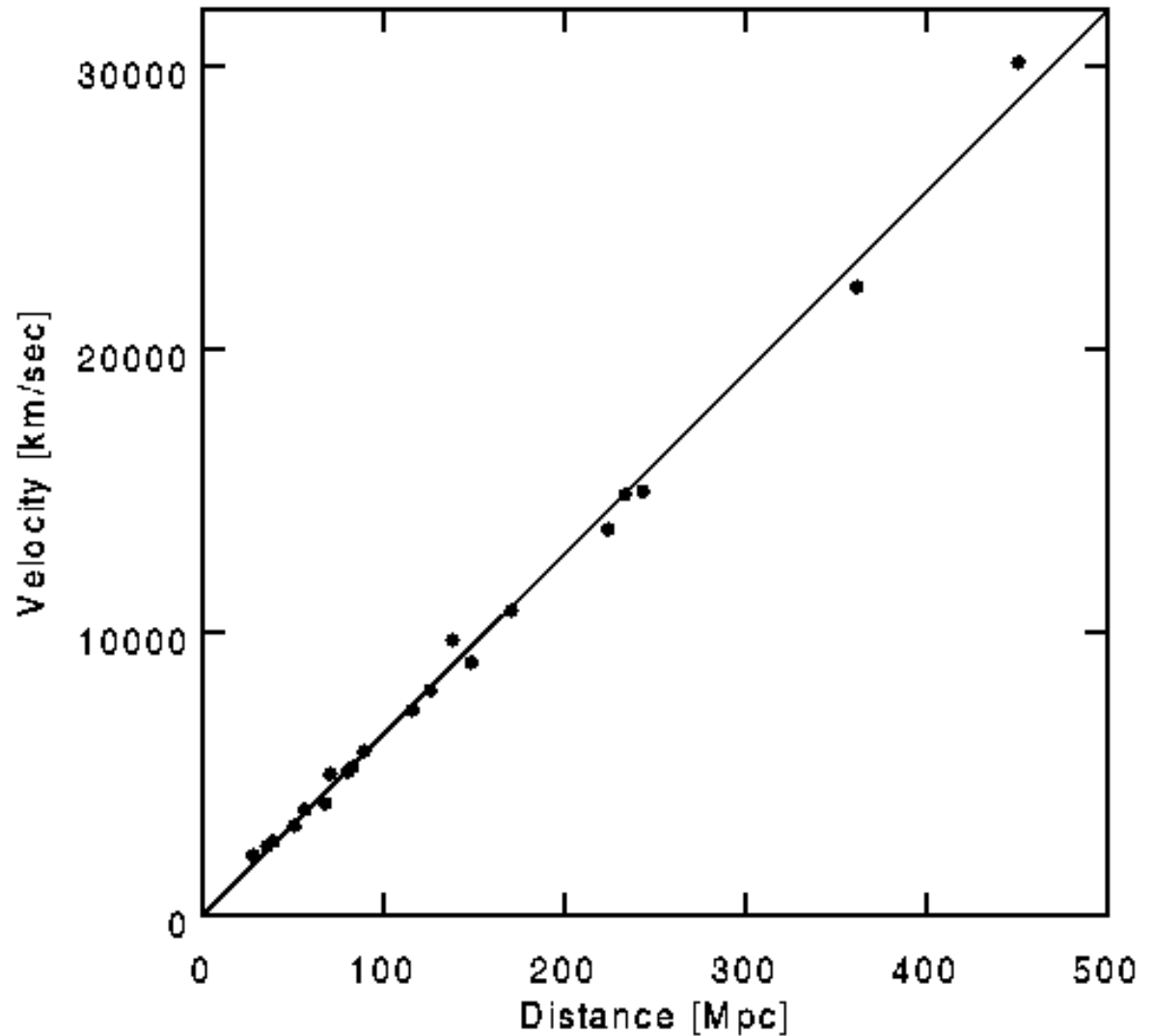
distant



# Hubble's Law

Things that are further away are moving away from us faster !

(if we interpret the wavelength stretch as being due to source actually moving)



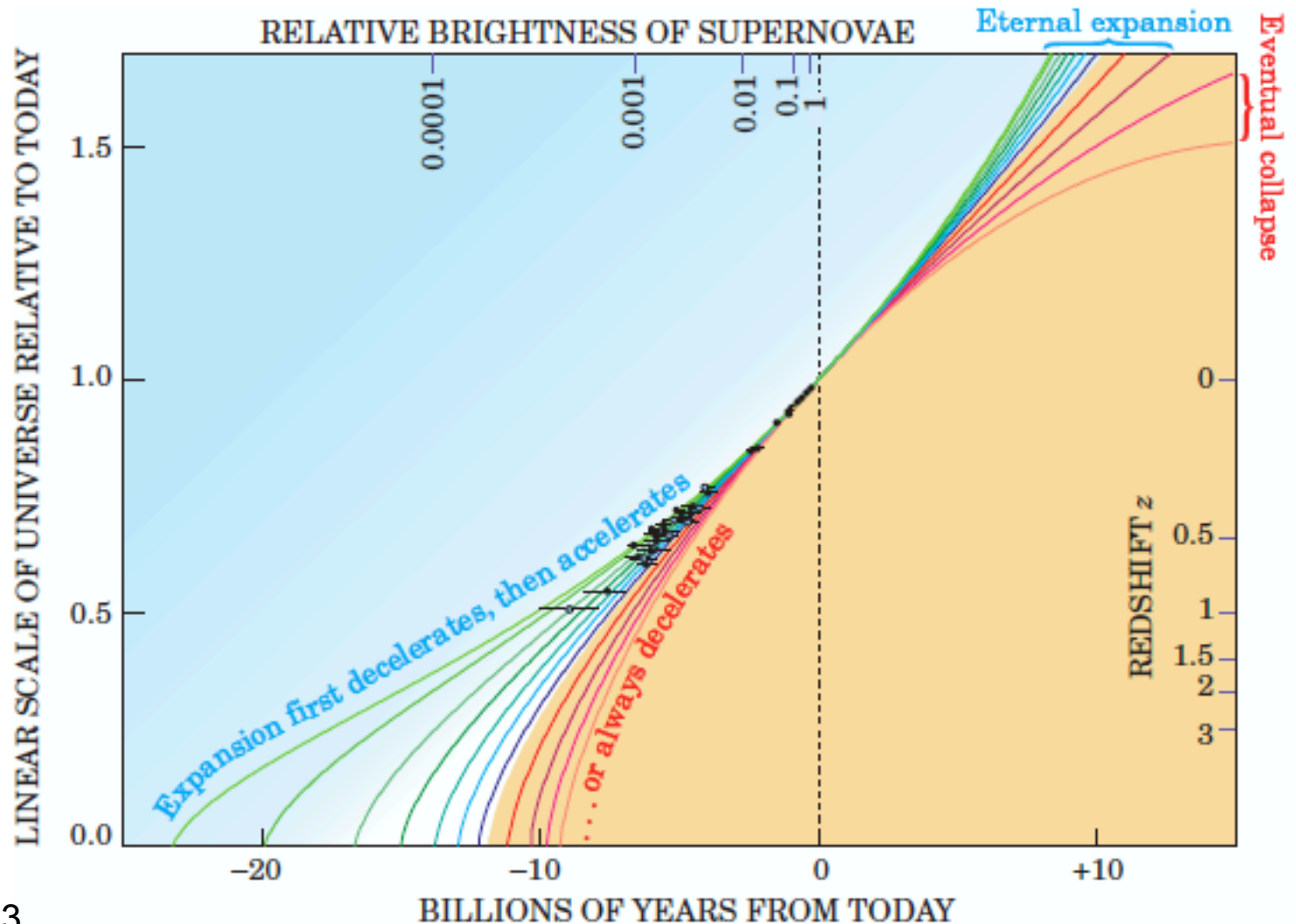
dated Riess et al (1996) via

[http://www.astro.ucla.edu/~wright/cosmo\\_01.htm](http://www.astro.ucla.edu/~wright/cosmo_01.htm)



# Evidence for Dark Energy from Supernovae

The expansion of the universe is accelerating!



Perlmutter 2003

# Why is this weird?

- Einstein was a smart guy:
  - “special” relativity:  $E=mc^2$  (1905)
  - “general” relativity:  $m=E/c^2$  (1915)

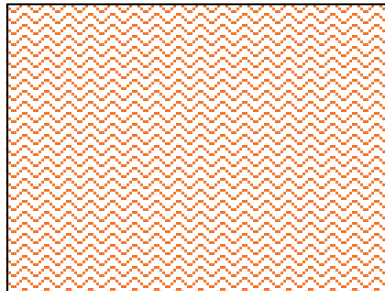
[actually more like Energy+pressure and not just E, but never mind...]

- Gravity cares about energy, not mass



Rocks: (“pressureless”)

squeeze the box, mass stays the same



Gas: (“positive pressure”)

squeeze the box, gas gets hotter, total energy goes up => more gravity



Dark energy: (“negative pressure”)

squeeze the box, total energy goes down => less gravity

# *What is this stuff?*

- All we know: it seems to have the property that if you had a box full of it, if you stretch the box then you end up with more of it in the box such that the amount per teaspoon is about the same

My plans for finding out more:



South pole  
telescope  
(now on!)



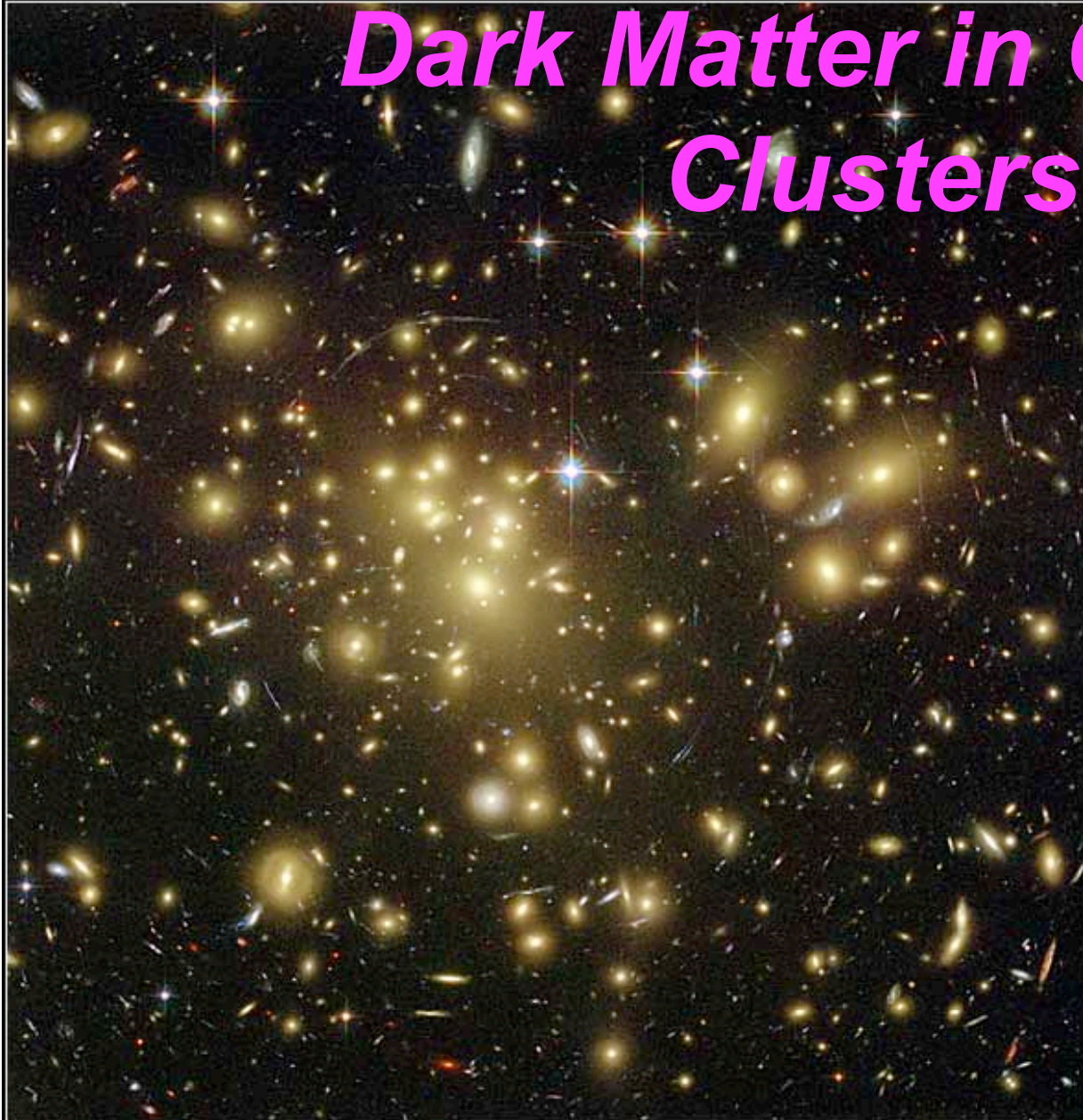
Square kilometre array (10 years from now)

***Dark Matter: the universe is full of invisible matter that doesn't interact with us***



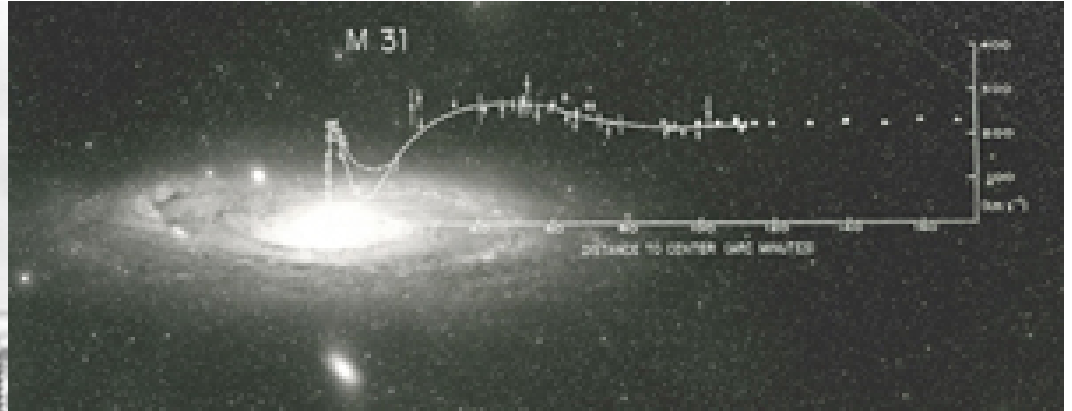
***But my mom says I'm cool***

# Dark Matter in Galaxy Clusters



Measured velocities way too high to be gravitationally bound by observed mass (Zwicky 1933)

# *Dark Matter in Galaxies*



Vera Rubin (1970)

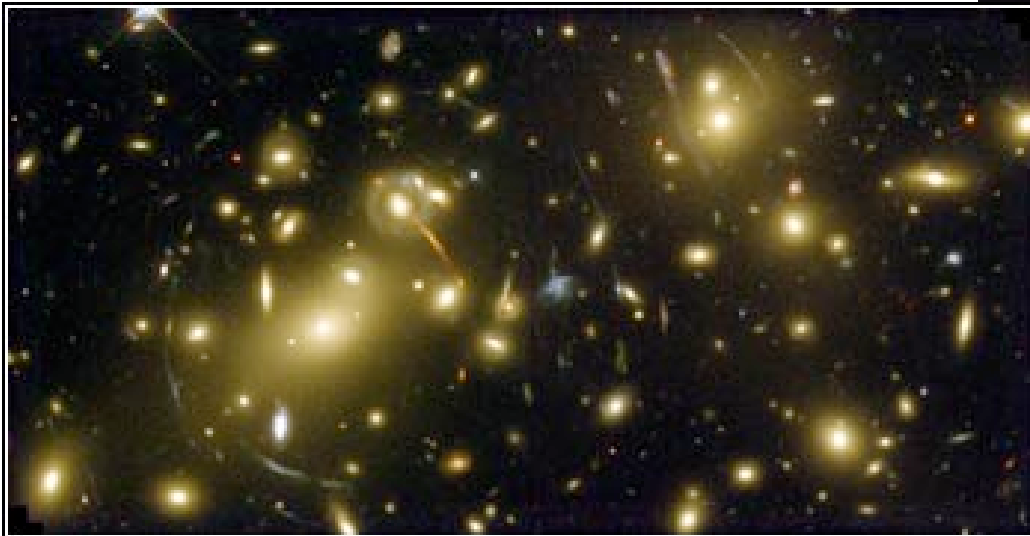
- Rotation velocities way too high at large radii to be bound by observed mass
- Newton says that  $v^2 = GM/R$

Rotation speed

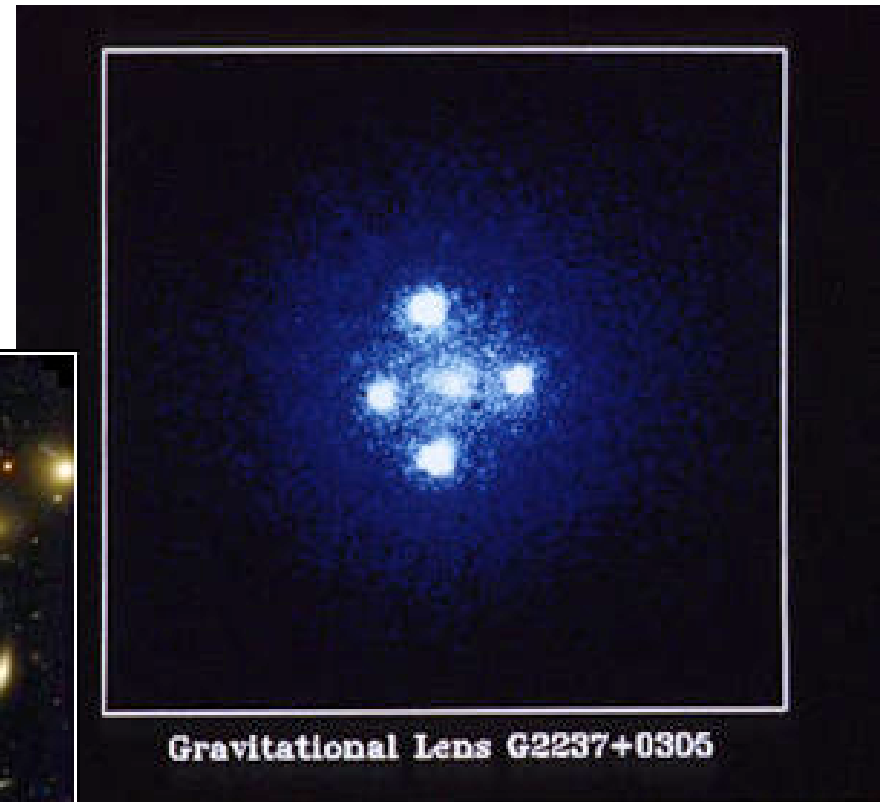
Mass enclosed/Distance from centre

# *Gravitational Lensing*

- Distortion, multiple imaging of distant sources



[www.hubblesite.org](http://www.hubblesite.org)



[http://imagine.gsfc.nasa.gov/docs/features/news/grav\\_lens.html](http://imagine.gsfc.nasa.gov/docs/features/news/grav_lens.html)

# *What is dark matter?*

- All we know: it isn't anything that we have managed to make in the lab
- It doesn't interact with anything as far as we can tell; if it never interacts with something we can see we may never know what this stuff is (but hope springs eternal...)
- Could be black holes, weird new type of particle
- Can't be normal stuff that happens to be hard to see, because you can't be dark at all wavelengths if you are regular stuff (e.g., you can't hide in the infrared very easily)



Beer! Now there's a temporary solution ✘

To alcohol! The cause of, and solution to, all of life's problems. ✘



Doughnuts... is there anything they can't do? ✘



***Is this for real?***

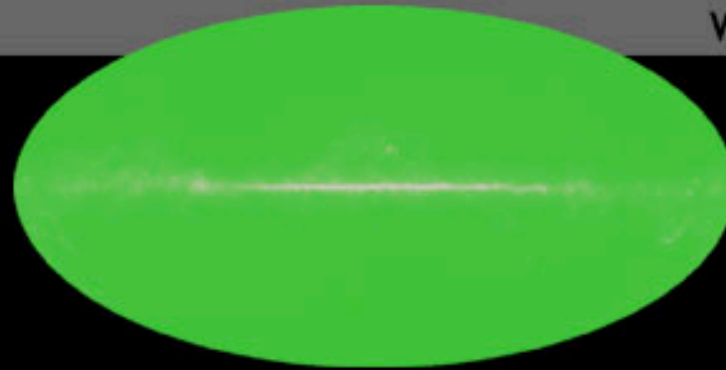


***Me fail English? That's impossible***

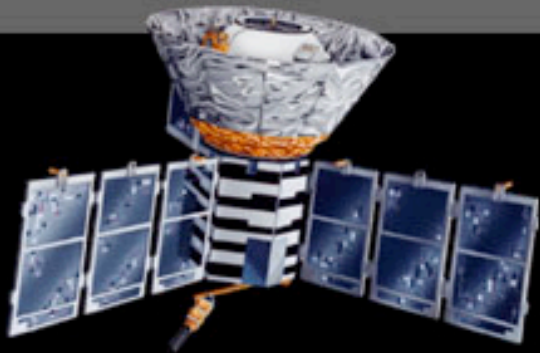
1965



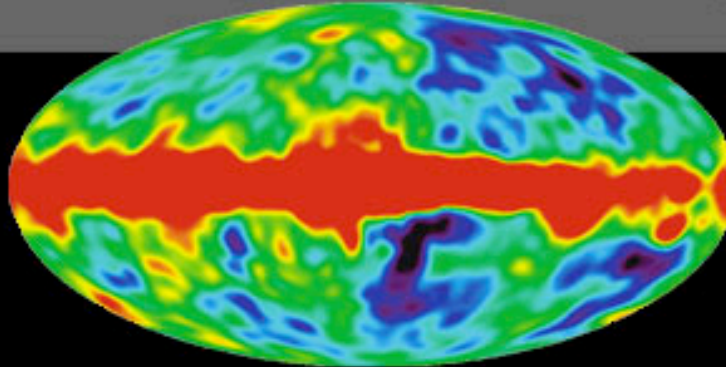
Penzias and  
Wilson



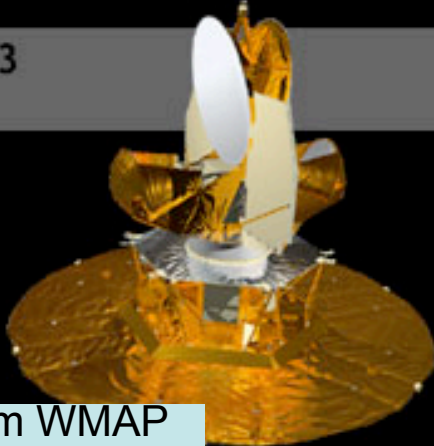
1992



COBE



2003



WMAP

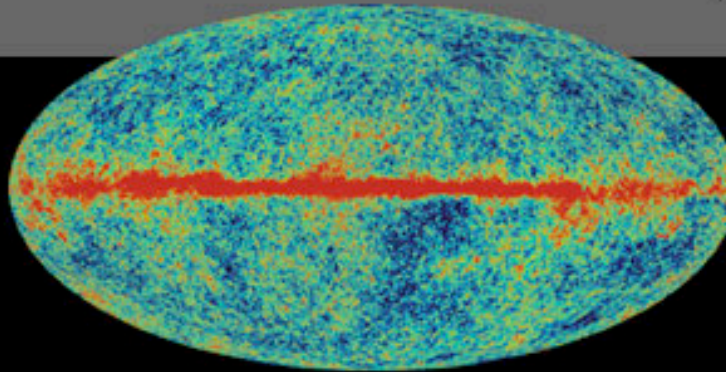
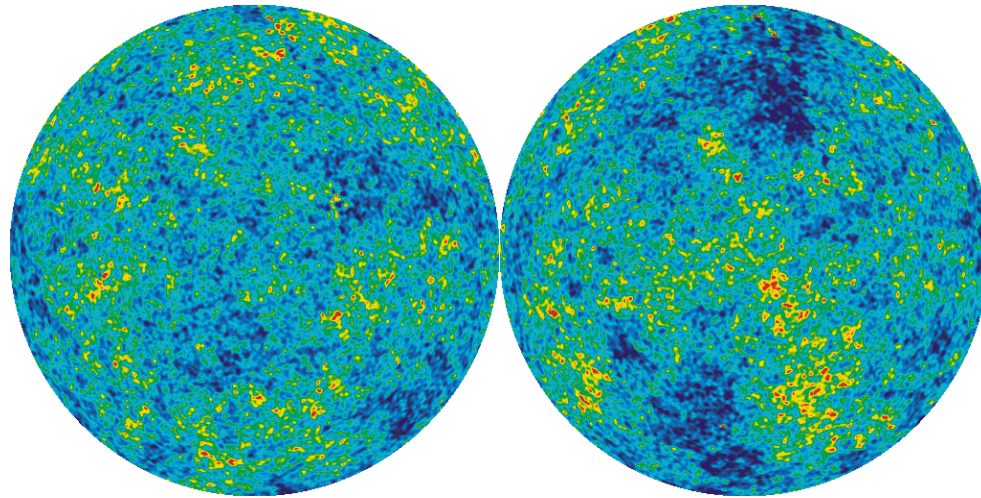


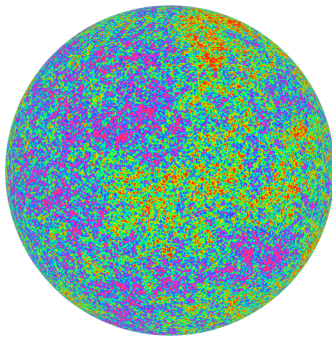
Image from WMAP

# *Cosmic Microwave Background*

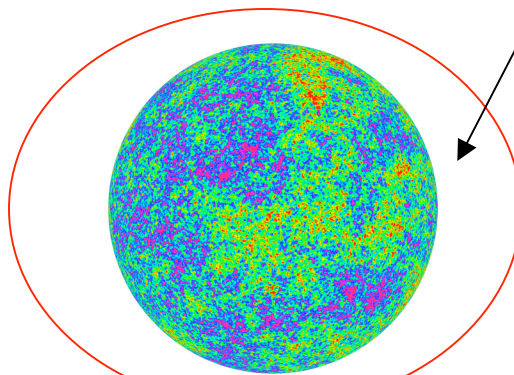


Observed

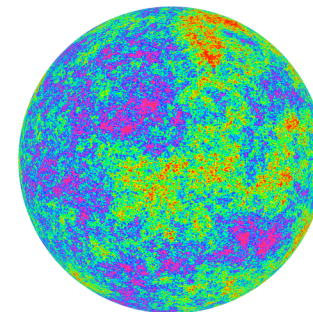
Turns out this one looks best (trust me...)



Simulated, no dark matter

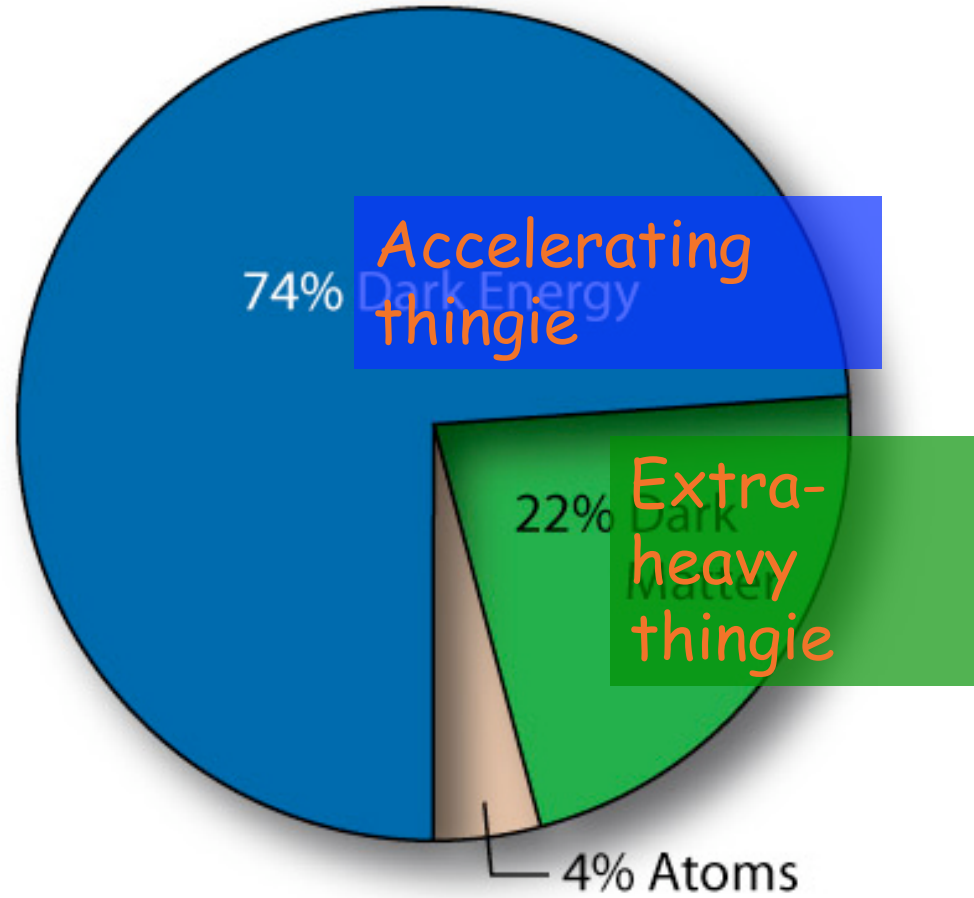


Simulated, with dark matter and dark energy



Simulated, no dark energy

*Current state of  
our  
“understanding”  
of the universe*



***May all your disgraces be private!***