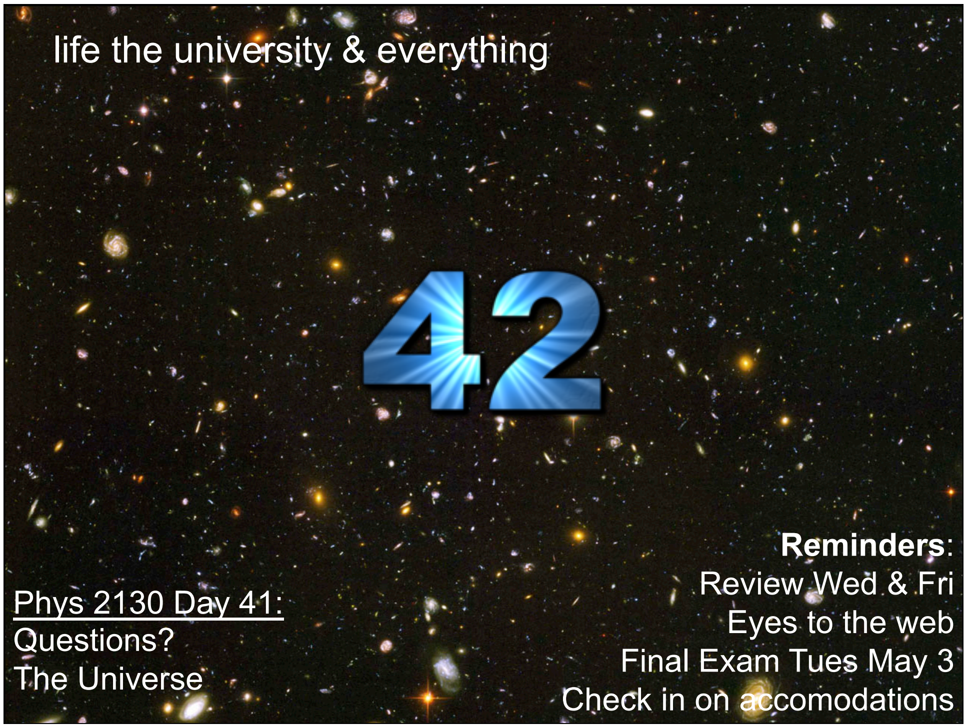


Today

Today:
- how big is the universe?
- how old is the universe?
- what is the past and future of the universe?
- if time, what's it made of… / what we don't know…

Problem with cosmology:

- Only one experiment and it is taking long time.
- Hard to control or wait long enough.

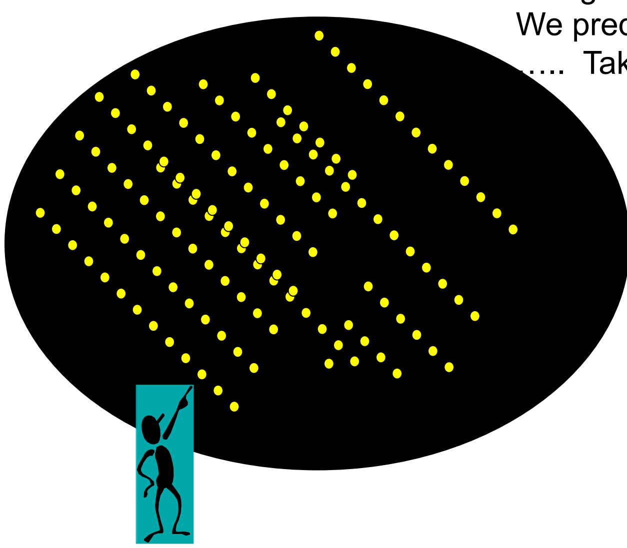
Compromise–

1) make consistent with laws of physics about light, atoms etc.,
2) think hard about all possible options that satisfy 1,
3) try to predict stuff not yet looked for. (use logic and reason!) *Challenge me- other explanations, etc.*
4) test theory with computer simulation, do the results match observations?

In your lifetime, age of universe changed by several billion years, and volume changed by ~ factor of 2…

look up what do we see? bunch of little lights on black background.

Model 1 for universe: **Black ceiling with bunch of little lights stuck on.**

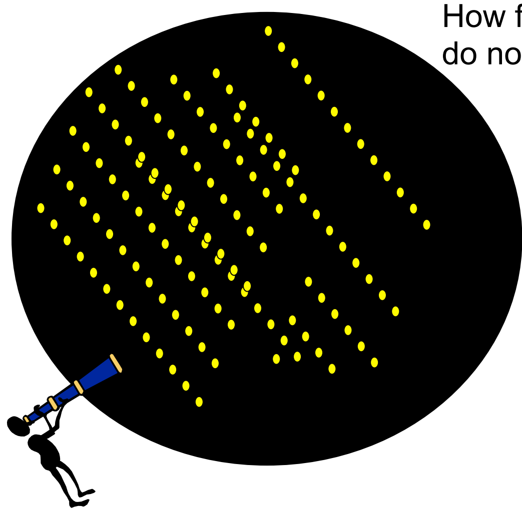


Using this model,
We predict no relative motion.
…. Take more data.
Problem?

a. no
b. some move
c. all move

b. some move.

Look with telescope.
Ones that move also look like round objects with all kinds of stuff on them, moons around them. **<u>Planets.</u>**

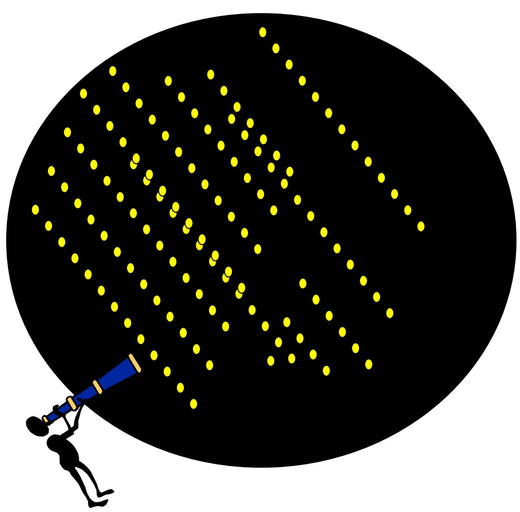


How far away are the ones that do not move? (stars)

a. 10 x distance to moon.
b. 1000 x DtM.
c. x 1 million DtM.
d. x 100 million DtM.
e. x 10 billion DtM.

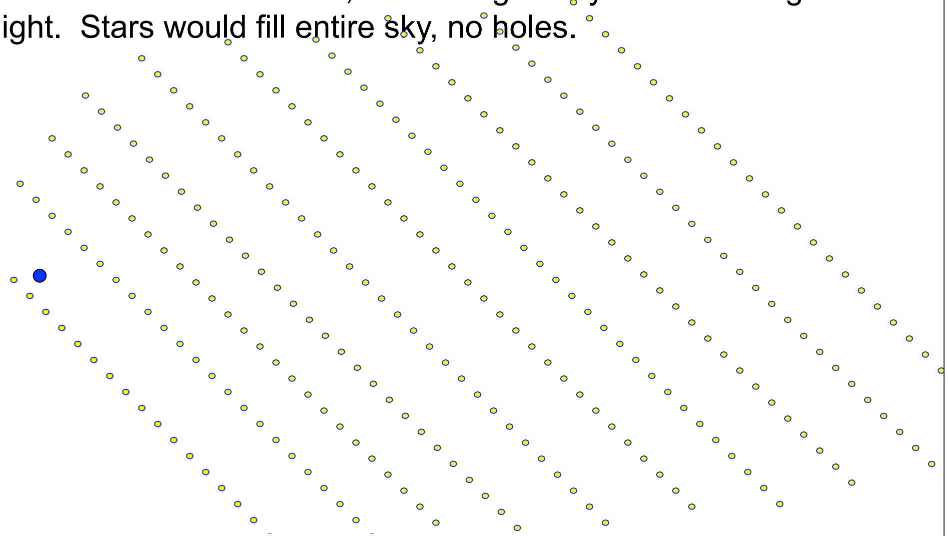
How to find out?
Distance and speed are key to understand the nature of the universe.

Observations show various range of brightness.
Maybe the dim ones are farther away?
<u>Model #2: Planets are close,</u> then infinite space with stars spread out uniformly through it. Always has been like that.



Problem with this model?
Would predict you see stars anywhere you looked so entire sky would be very bright.

Close stars brighter, far ones dimmer but more.
If infinite number of stars, entire "Night" sky would be bright with light. Stars would fill entire sky, no holes.

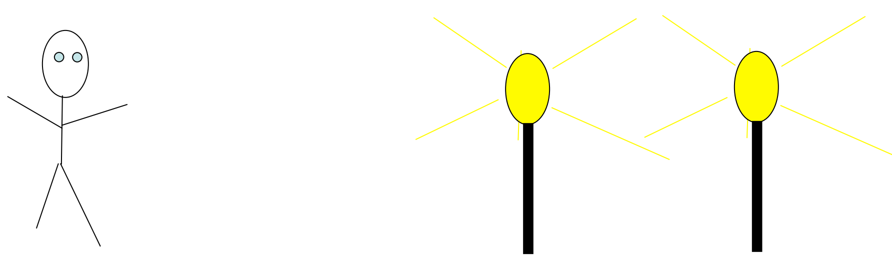


There must be an "edge" beyond which no stars.. or shining too short a time for light to have reach us.

Where is the edge?

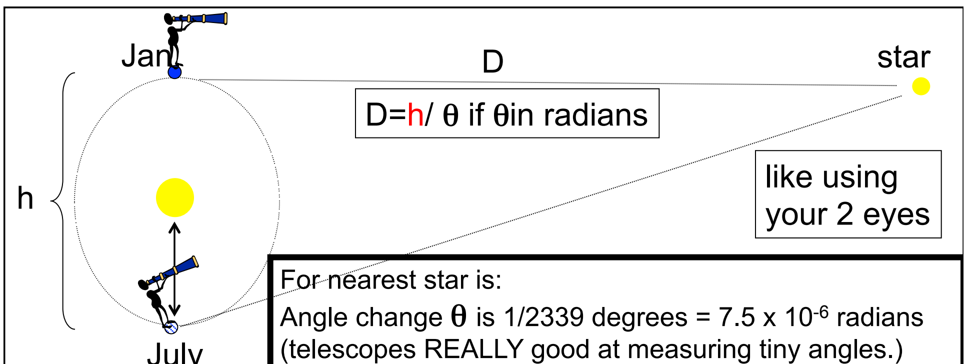
How can we tell how far away stars are?

Two lights in dark. Which is farther away?
How to tell? **Think of group answer.**



a. farther one less bright- Intensity = Power/$4\pi r^2$, smaller r, bigger I
b. parallax, move head, farther away moves less.

Which finger is closer?



Earth-sun dist = 1.5×10^{11} m

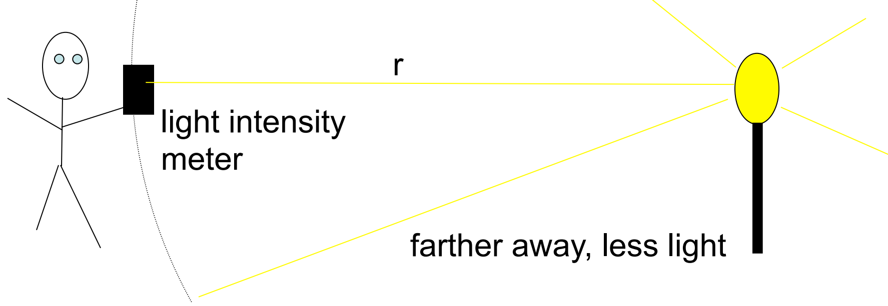
For nearest star is:
Angle change θ is 1/2339 degrees = 7.5×10^{-6} radians
(telescopes REALLY good at measuring tiny angles.)
D = (2 x Earth-sun dist)/ (7.5×10^{-6})
= 4×10^{16} m = 4 light years
= 100 million x dist. to moon

1 light year = distance light travels in a year.
= 3×10^{8} m/s x 3.15×10^{7} s = 9.5×10^{15} m .
Boulder to India 0.1 light seconds; Earth to sun = 8 light min

Stars are long ways away!! Can measure stars out to 3×10^{19} m this way before angles too small = 3000 light years. So can measure distance for ~5 million stars, but only 1/40,000 th of stars in Milky W.

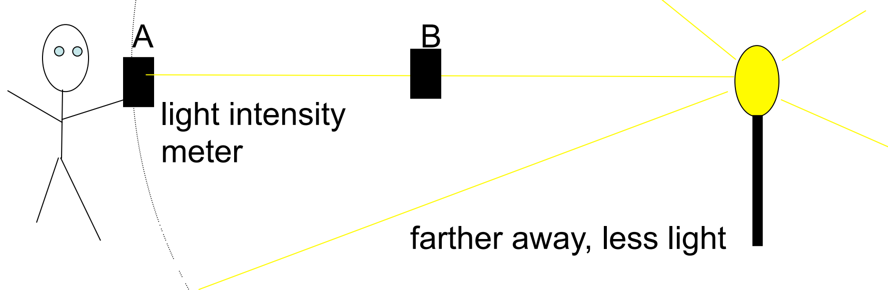
Whole bunch of others stars (200 billion)
But parallax only good to 3,000 lt yr, then angles too small to measure. How to get farther stars?

Method 2 for measuring distance. Brightness.



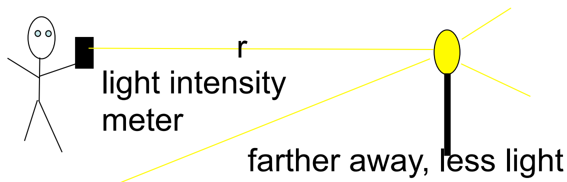
Method 2 for measuring distance. Brightness.

Light bulb, dark room.
Measure intensity at point A and then at point B:
Reading at A will be
a. twice as large as B,
b. same B,
c. 1/2 of B
d. 1/4 of B
e. 1/8 of B



Problem with method- <u>not all stars are same brightness.</u>
but using parallax get to check how well it works with
5 million or so!

Approach:
Identify type and temperature of stars by looking at colors emitted
Connect up exact type and temperature of star with amount of
power produced. (Hotter … more in blue, more power)!
http://phet.colorado.edu/simulations/sims.php?sim=Blackboc
Use brightness to measure distance to rest of stars.



Universe is a very big place!!
Billions of light years (long ways)

Hubble- amazing discovery in 1929. Almost all galaxies moving away from us. Farther are moving faster!

1. How did he come to this amazing conclusion?

2. What does this say about the behavior and age of universe?

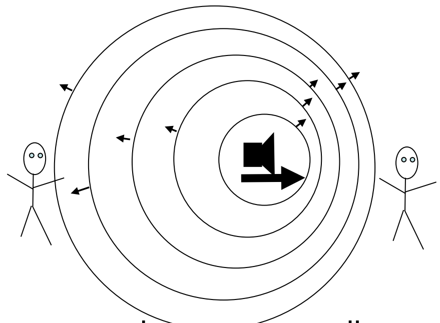
3. Do we have any proof?

Want to compare distance star is away with its velocity. Know how to measure distance, but how to measure velocity of something thousands of light years away?? Can't touch.

Sound of spinning ball. Close eyes. I'll spin the ball around
Can you tell from sound:
1. when going towards you, when away?
2. when spun slowly, vs when spun fast?

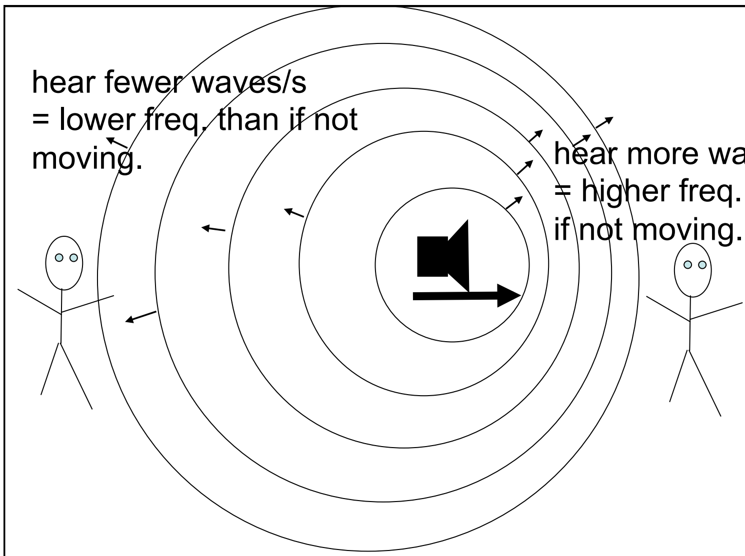
<u>Doppler shift- how frequency changes with relative velocity.</u>

When the ball is moving towards you,
does it sound different than if I hold it still?
a. no, b. higher tone, c. lower tone
b. higher



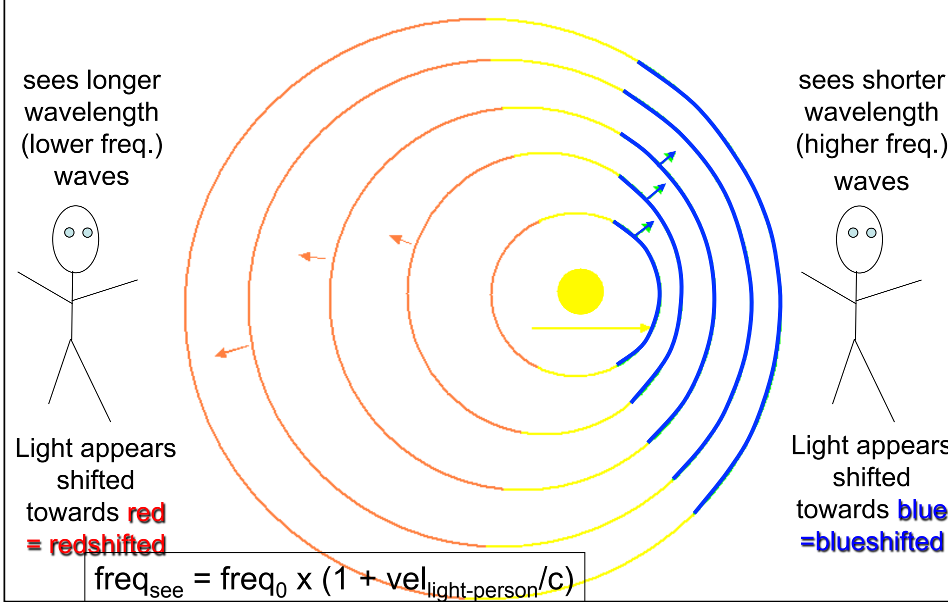
More sound waves get to you in front in a given period of time. So higher frequency.

sound waves spreading out at speed of sound. In front pile up, in back spread out.
What tone when moving away?
demo sound applet



$$f_{hear} = f_0 \times (1 + vel_{speaker\text{-}person}/vel_{sound})$$

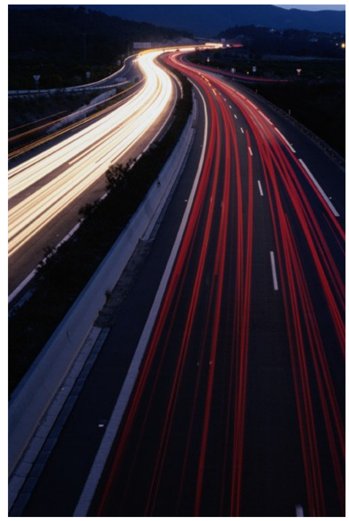
Doppler Shift



$$freq_{see} = freq_0 \times (1 + vel_{light\text{-}person}/c)$$

Think of the freeway at night!

- The red lights are going away from you
- The blue/white lights are coming towards you



Δfreq = freq$_0$ x (vel$_{object}$/c)

c = wavelength x freq.
= λf

So if knew freq$_0$ which is frequency of light emitted by star, and then measured how much freq shifted, can figure out velocity.

But how can we know freq$_0$???

a. all stars same colors as sun, just compare with it
b. each type of star gives off all its light at one particular wavelength. Just need table for different types of stars.
c. the particular colors of hydrogen atoms in the stars
d. the particular colors of neon atoms stars

ans. c. d. would work also except very little neon in stars

So look at color of star, see how it is shifted, can tell how fast it is moving toward or away from us.
Have certain VERY precise known light frequencies coming from stars.

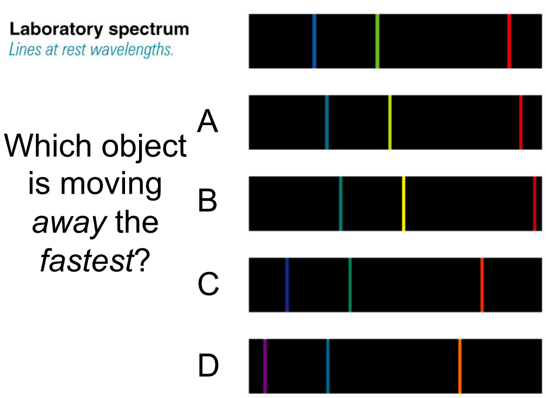
Atomic hydrogen spectral lines (certain colors you looked at)!
The pattern of different colors tells us it is hydrogen
Can see **tiny** shifts in these colors.
Size of the shift allows precise measurement of star velocity relative to us. Can see even if star is in another galaxy!

Lines caused by Hydrogen

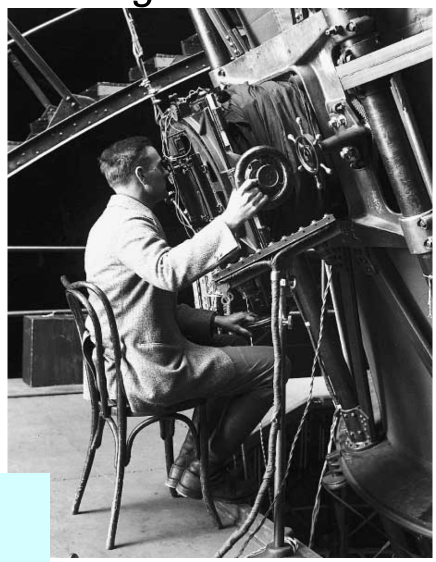
To use Doppler shift, you must know the rest-velocity wavelengths

- Usually involves measuring the gas in a lab (on Earth)
- Then, measure redshift or blueshift of the astronomical object to get the velocity towards or away you.

Which object is moving *away* the *fastest*?



Edwin Hubble measured distances and velocities for a handful of galaxies



- *He noticed that:*
  1) *Nearly all galaxies were moving away from us*
  2) *the further away a galaxy was, the faster it was moving*

Hubble using 100" Hooker telescope at Mt. Wilson (above LA)

Edwin Hubble measured distances and velocities for a handful of galaxies

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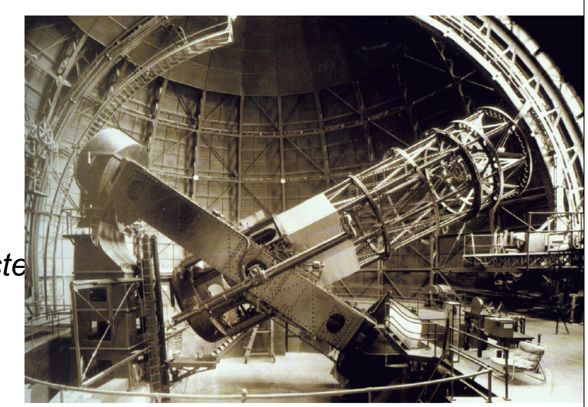
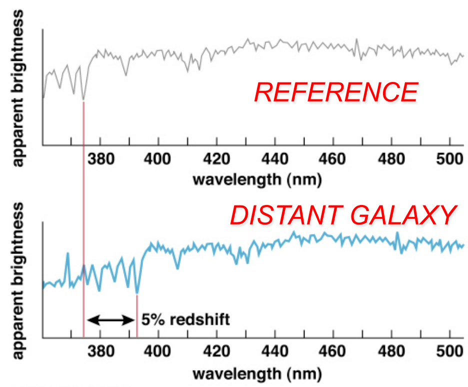


Hubble using 100" Hooker telescope at Mt. Wilson (above LA)

How did Edwin Hubble get distances and velocities?

- *Distance: He made a slightly incorrect, but pretty close assumption*
  - *He assumed the brightest object in all galaxies was always the same luminosity*
- *Velocity: Looked at the spectra from these galaxies and match with expected spectra*

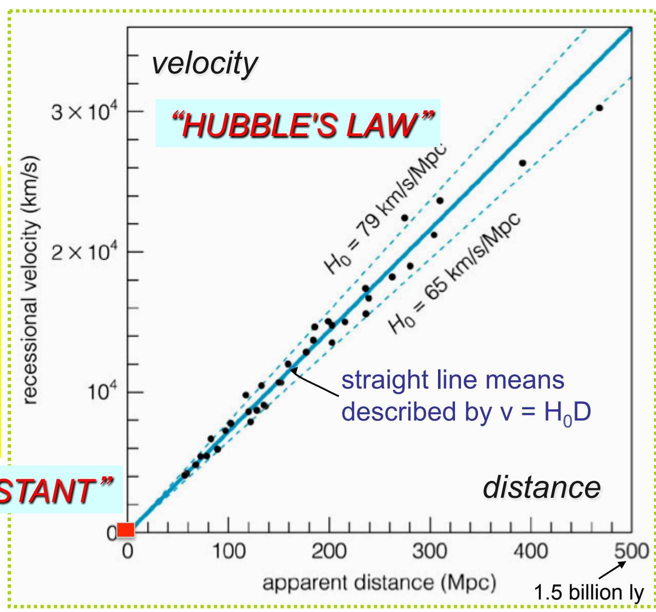


1 pc ≈ 3.3 ly

Best current values for expansion

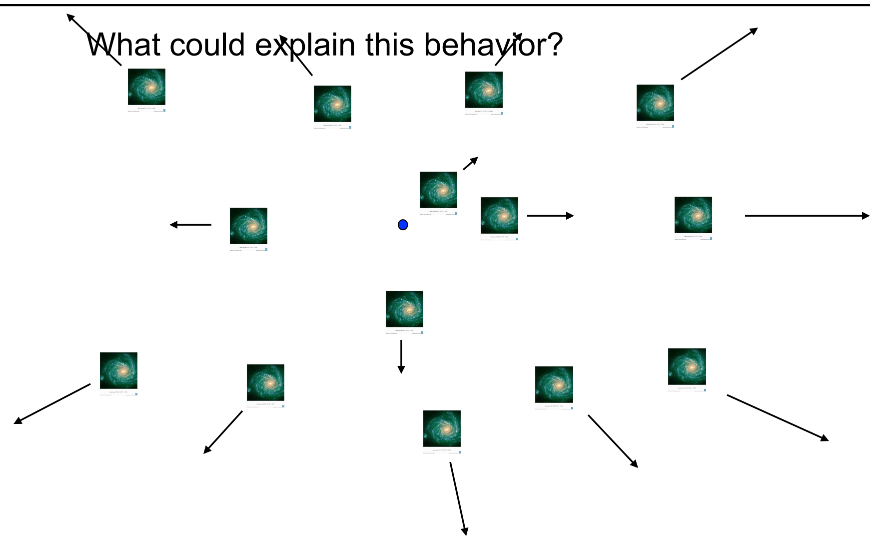
H_o = 71 +/- 4 km/s/Mpc

"HUBBLE'S CONSTANT"

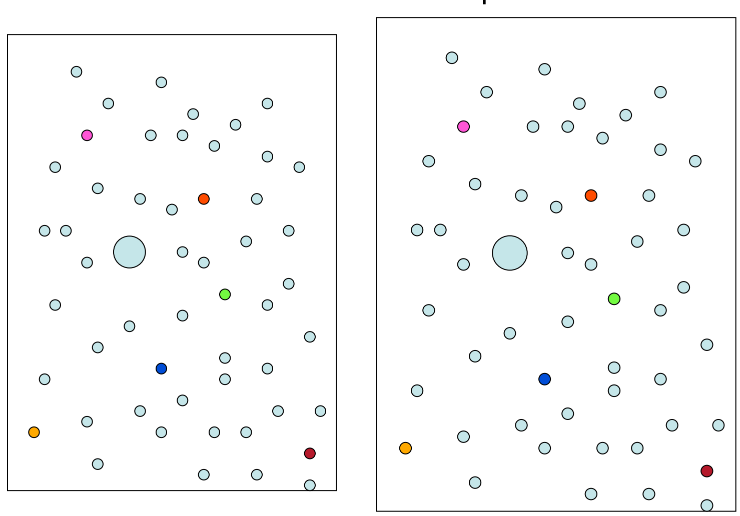


Hubble's 1929 plot extended only to 2 Mpc, H_o was ~500!

What could explain this behavior?

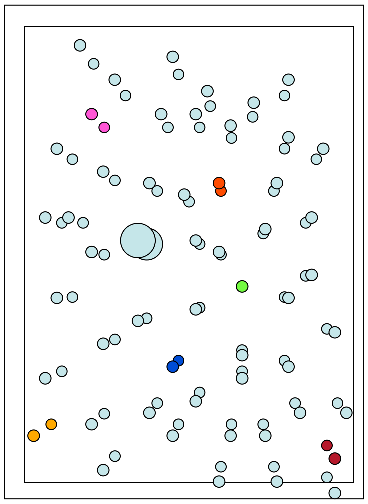


expanded universe



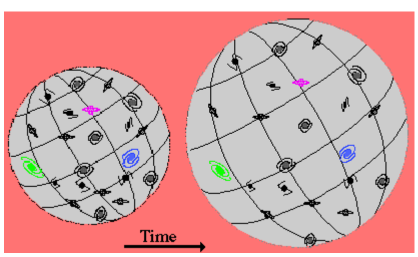
1. green to green, 2. blue to blue, 3. pink to pink

expanded universe

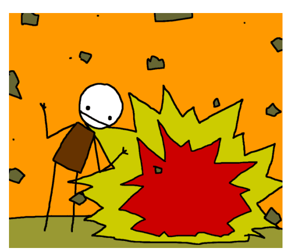


1. green to green, 2. blue to blue, 3. pink to pink

a little complicated… Like expanding out on surface of expanding balloon. All parts appear to spread out from each other.
Where center was, not so obvious.



vs.



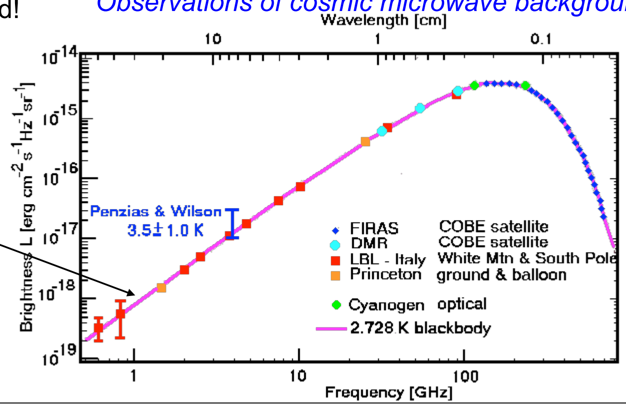
Thought experiment: If all expanding now…run the clock backwards.
There must have been a time when everything was in one place.

What would happen if all matter in universe start expanding out of big bang?
(George Gamow, CU) Predicted in 1948.
Start out as EM energy, expands and cools. After ~100,000 years. cold enough (3000 K) to turn into atoms. But universe has continued to expand by a factor of 1000 since then. Should look like light (far IR) emitted from an object of about 3 K above absolute zero. ("Cosmic Microwave Background")

In 1964 Penzias and Wilson (working for a telephone company) accidentally discovered!

Observations of cosmic microwave background

theoretical calc. of what should look like. Thermal radiation from 2.7 K source.
(really cold light bulb)

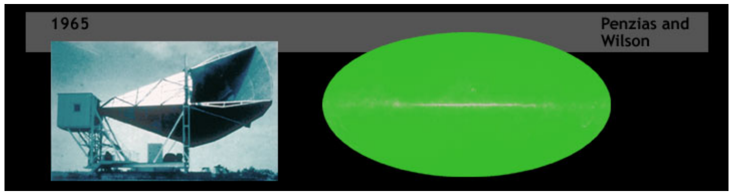


Model of how big bang energy converted into matter also predict ratio of amount of hydrogen/amount of helium in universe. Matches exactly with measurements.

Puzzle- CMB looks very uniform. Big bang started with giant expansion from tiny volume, how did matter end up clumping up to form galaxies, clusters of galaxies, stars, etc. Why not just stay uniform cloud of H and He?

Theory said could be fluctuations in original cosmic fireball. Make little patches of more energy that leads to more mass, then gravity makes clump up. But if was true, remnants of these tiny cosmic fluctuations should have been left on cosmic background radiation.

Satellites to check the CMB out:

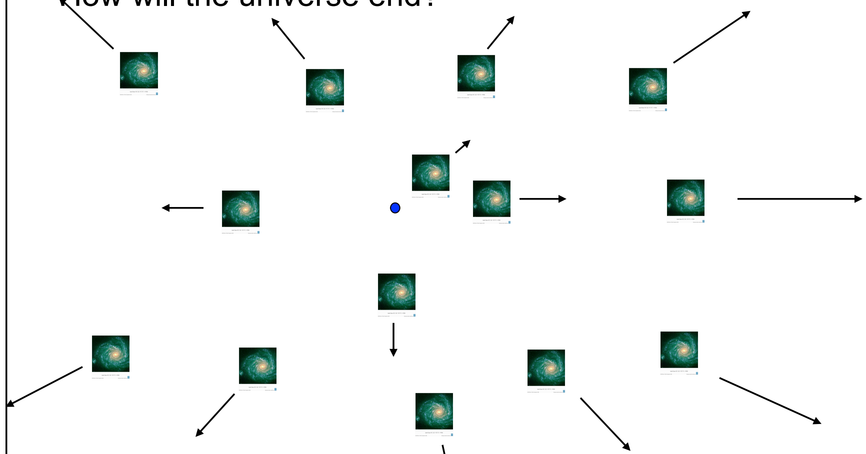


See small amounts (1 in 100,000) changes in size and shape just as theory predicted!

Big Bang origin of universe arguments-- review-

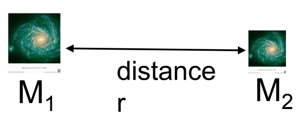
1) Sky not all bright, implies must be edge (in space or time).
2) Hubble expansion, see galaxies moving away. Speed proportional to distance. Implies started *at one place ~15 billion years ago*.
3) That implies universe started super hot and so hot radiation would be left over, but cooling off as univ. expands.
4) This radiation observed. (cosmic background radiation) Looks like thermal radiation from object 2.7 degrees above absolute zero. Just as predicted by big bang theory.
5) Detailed theory said CMB should have tiny wrinkles in intensity corresponding to clumping of matter to get galaxies. Also is observed.

How will the universe end?



Do experiment- start bunch of masses out together
and let fly apart, what will motion be as function of time?
What's your prediction ?
(remember all attracted by gravity of the others)

Gravitational attraction: $F = GM_1 M_2/r^2$ (attractive)



So gravitational attraction must be trying to pull
them all back together. Slowing down expansion.

Shoot off rocket straight up from earth
What different things can happen to it and why?

What basic features determine which it will be?

Gravitational attraction: $F = GM_1 M_2/r^2$ (attractive)

So gravitational attraction must be trying to pull them all back together. Slowing down expansion.

Shoot off rocket straight up-
what different things can happen to it and why?

1) Too much <u>velocity</u> for gravity to stop (escape velocity).
flies off forever .

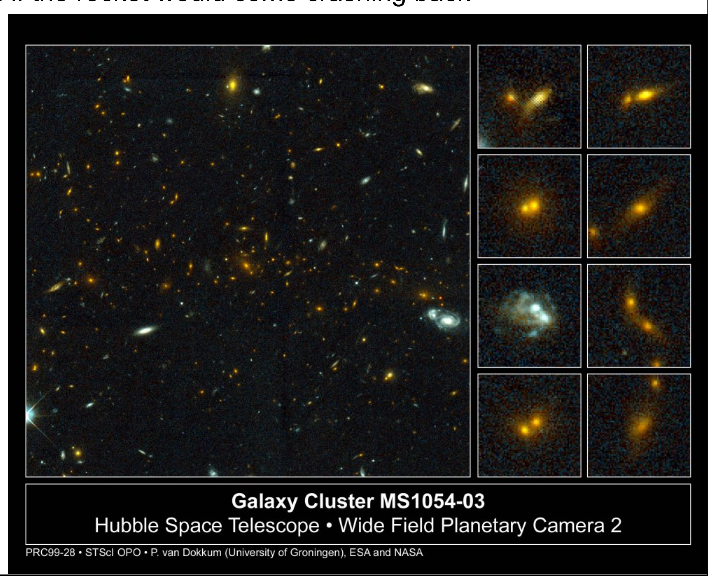
2) Gravity strong enough (too much <u>mass</u>), <u>velocity</u> low enough, stops and ***turns around and crashes back.***

Same goes for the universe. Keeps expanding forever or stops and crashes back in.

Same goes for the universe. Keeps expanding forever or stops and crashes back in.

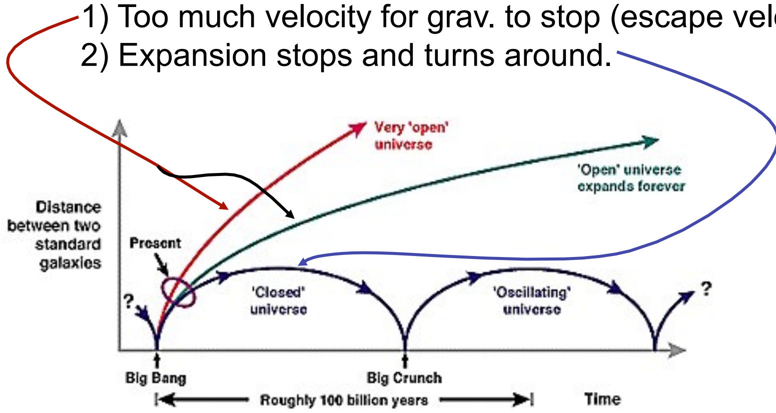
How do we figure out which one will happen? What determined if the rocket would come crashing back down?

Same physics apply to the universe, so we survey the universe to see how much matter (mass) is out there…



Galaxy Cluster MS1054-03
Hubble Space Telescope • Wide Field Planetary Camera 2

End of universe?:
1) Too much velocity for grav. to stop (escape velocity).
2) Expansion stops and turns around.



What basic properties determine which it will be?

What is the fate of the Universe?

- *Recollapse to gnaB giB:*
  - *Crushing heat*
  - *Destruction of all matter*
  - *Rebirth?*

Death by Fire

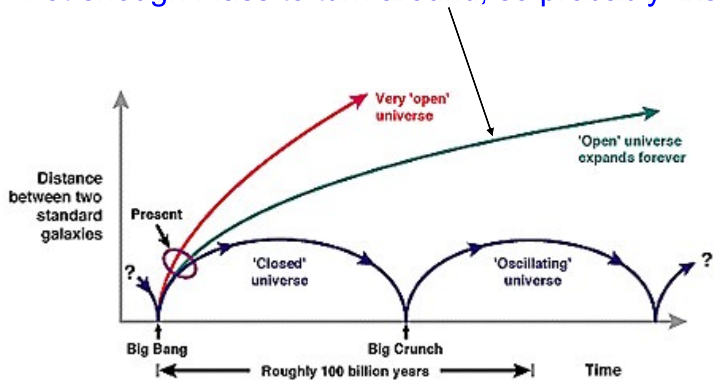
- *Eternal expansion:*
  - *Cold, galaxies dimming*
  - *Star formation slowing*
  - *Everything winds up as a brown dwarf, black dwarf, neutron star or black hole*

Death by Ice

What basic features determine which it will be?

How big the velocity is and how strong the pull to slow it down. Pull only depends on how much mass.

Up until a few years ago best determination was that not enough mass to turn around, so probably like

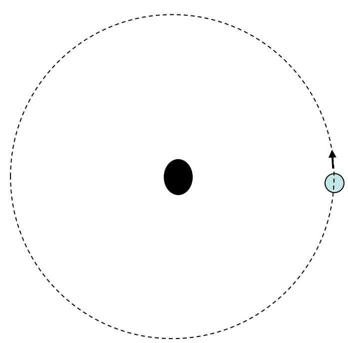


Dark Matter- stuff we can't see. Interacts only by gravity.

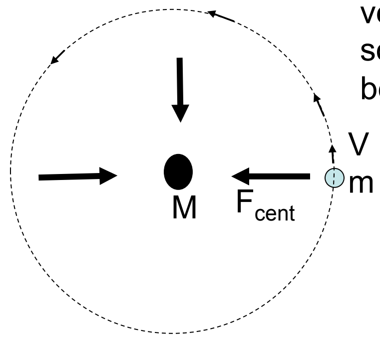
Why do we think it exists and 8 times more of it than normal matter?

Can measure mass in other galaxies!!

Just uses Newton's laws and law of gravity.



circular orbit
what is v doing?

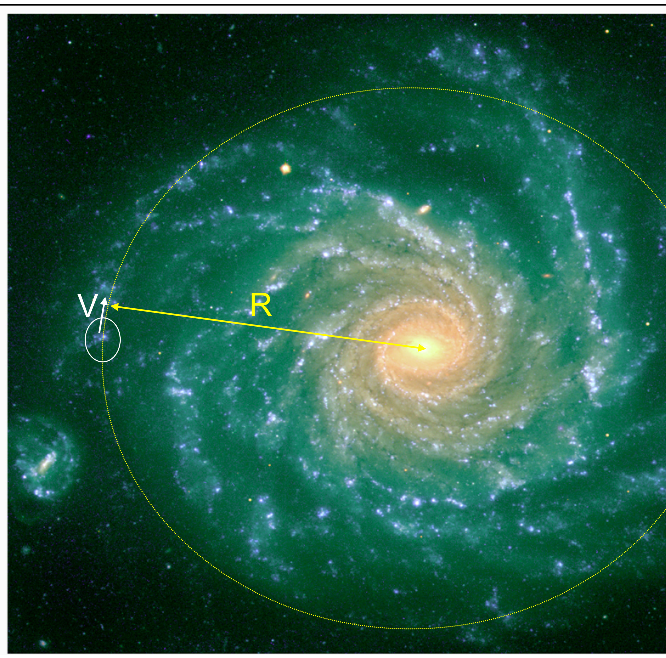


vel. always changing, so must be accel., so must be force F = ma.

to stay in circ. orbit at speed V, works out to need a force towards the center $F_{Cent} = mv^2/R$.

This force provided by gravitational attraction between, M, and m, $F_{Grav} = GMm/R^2 = mv^2/R$.
A little arithmetic gives
Mass at center =M =v^2R/G .

Know G, so measure V and R, to get mass.



M =v^2R/G

Measure R, measure V by Doppler shift. Plug in to get M of all the stuff inside orbit. *1000s of lt years away!*

Physics rules!!

Effect of Black Hole

What if we replaced our own sun with a black hole of the same mass?

a) We would spiral in (to our death!)

b) We would shoot straight in

c) Nothing would change

d) We would spiral out (because it was too weak to hold our orbit)

e) Something else

c) Gravity depends upon mass not size -- same pull inward

What is all this extra mass?

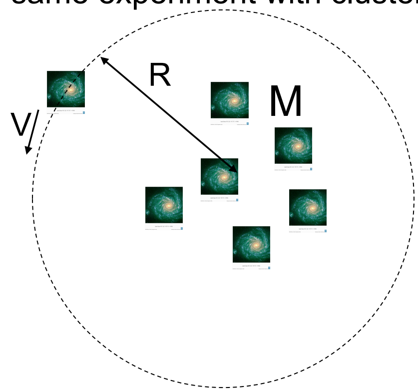
Black holes?

See big ones at middle of galaxies by grav. attraction. (Dopp. Shifts)

Not enough.

So most of the stuff in the universe we have never seen, have no idea what it is like! ← a little disturbing for astronomers!

2. Do same experiment with clusters of galaxies.



Get same result.
M is about 8 times bigger than the mass of the stars in the galaxies.

Data Set #2: Gravitational Lenses

- *Dark (& luminous) matter warps space*
  - *acts like a lens and distorts and magnifies the view of more distant galaxies*
- *We can use the images to reveal how much mass is in the cluster*
  - *Estimated mass of visible galaxies is too small*

Still new work!

Press Release

15-05

April 13, 2015

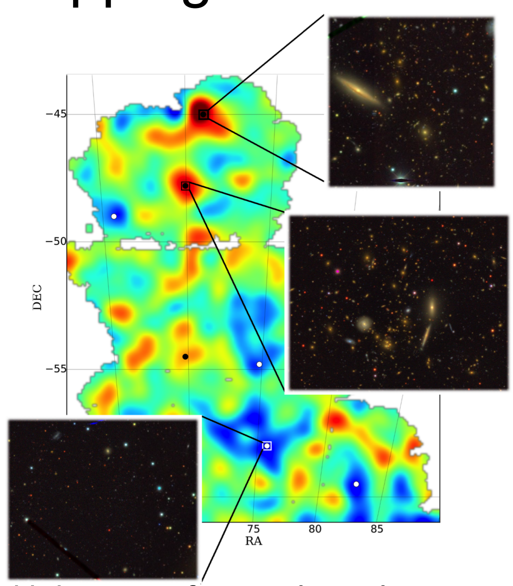
FOR IMMEDIATE RELEASE

Mapping the cosmos: Dark Energy Survey creates detailed guide to spotting dark matter

Analysis will help scientists understand the role that dark matter plays in galaxy formation

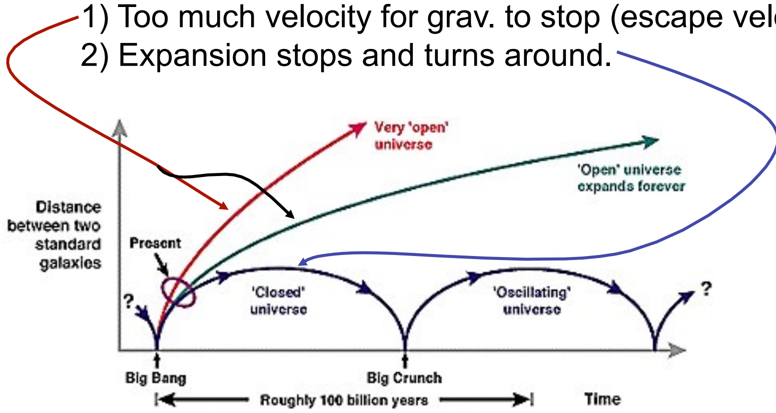
https://www.fnal.gov/pub/presspass/press_releases/2015/Mapping-The-Cosmos-20150413.html

Mapping Dark Matter!



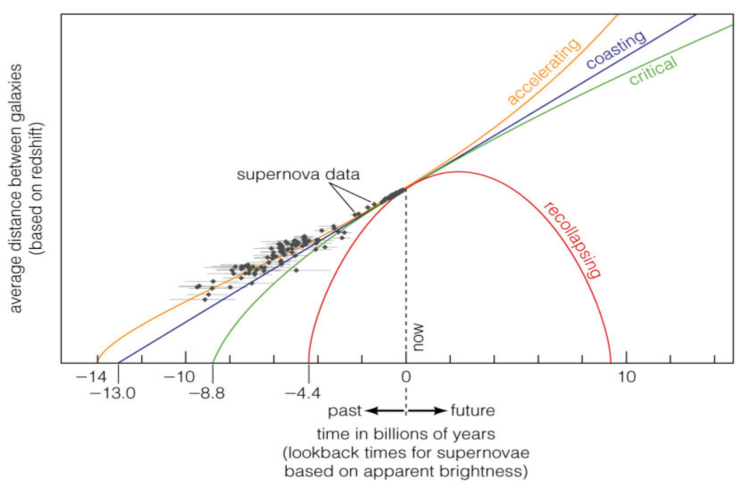
Mass map with images of two galaxy clusters and a cosmic void.
Dark Energy Survey

End of universe?:
1) Too much velocity for grav. to stop (escape velocity).
2) Expansion stops and turns around.



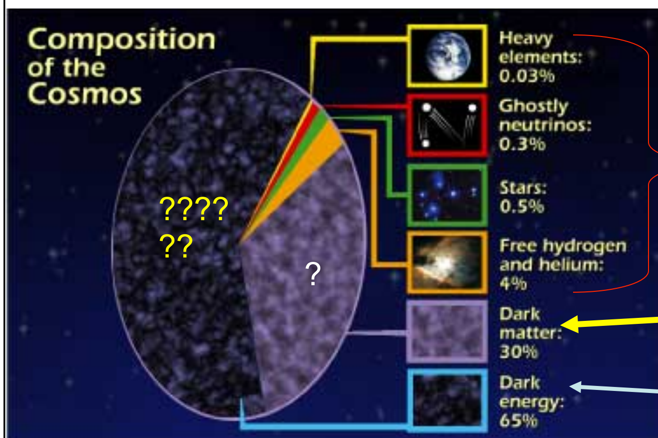
What basic properties determine which it will be?

Supernovae experiments show something entirely different!!



Universe is accelerating?!?! What the …?

Funny thing happened when looking for the mass. Found what we see (stars, dust, planets, comets,…) only small fraction of what is out there!

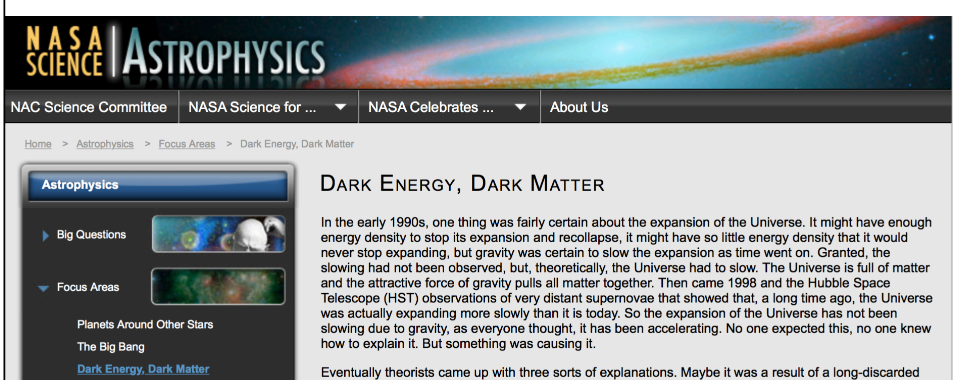


data “pretty good”as to amounts.

mass we don't see, pretty sure it's there

really weird stuff (sort of anti-mass) suggested by newest new data.

Want More?



http://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy/

Summary:
Universe looks like it started with big explosion 14 billion years ago.
Expanding out and cooling off ever since. Formed galaxies, stars, planets, people.
Will likely continue to expand.
(not enough mass/gravitational attraction to stop it.)

We look back in time,
t= d/c. Bigger d, earlier time!