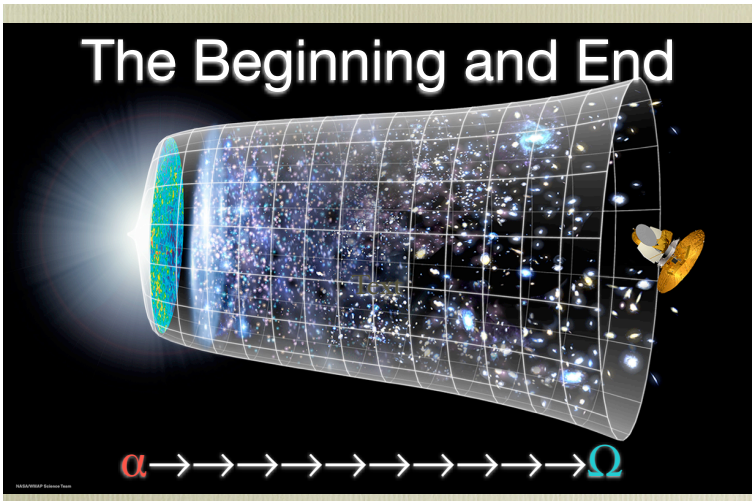
The Beginning and End

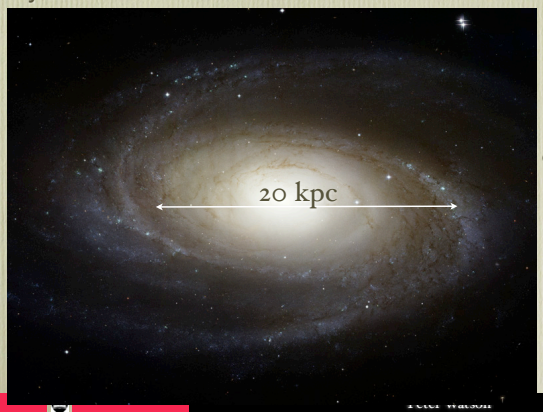


Carleton UNIVERSITY

Statutory Warning

- This lecture is for mature audiences only
- Extreme violence may be caused to your preconceptions
- Allergy alert: This talk may contain peanuts
- Allergy alert: This talk may contain ~~peanuts~~ formulas

- A reminder: the smallest things we will talk about are galaxies:
- typically 10 billion stars and a size of 100000 light years



- M81 in Ursa Major: HST picture

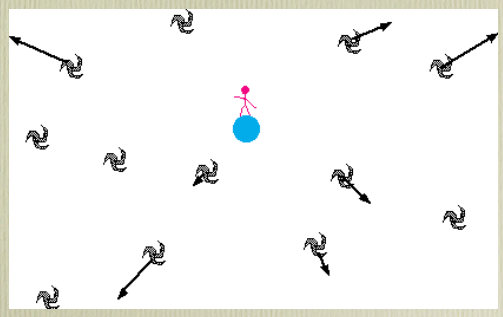
- But mostly we'll be talking about clusters of galaxies:
- Typically 1 million billion $M_\odot$ and a size of 10 million light-years (~2 Mega-parsecs)

2. So how did it all begin?

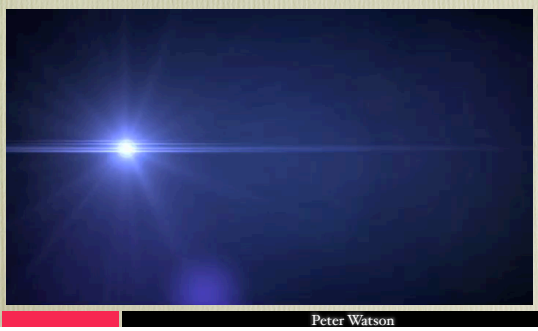
The water beetle was sent on an exploration, and after darting about on the surface and finding no rest, it dived down to the depths, whence it brought up a bit of mud, from which the earth grew by accretion.

Apache Creation Myth

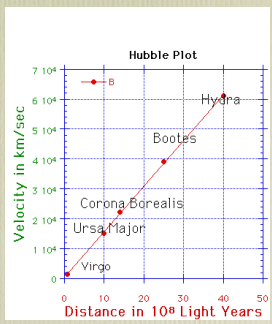
- Found in 1920's (Hubble, Humason, Slipher) that faint galaxies are receding from us:
- fainter the galaxy, faster the recession.



- Blue shift: something moving towards us (and appears hotter)
- Red shift: something moving away from us (and appears cooler)
- Note no information about transverse motion

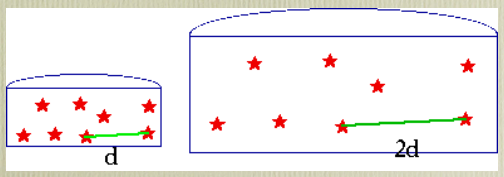


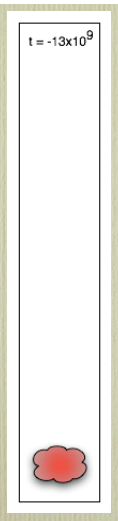
- Hubble was able to measure distances to closer clusters and found that velocity ~ distance
- v=Hd
- H is Hubble constant
- a galaxy at 1 Mpc is receding from us at 70 km/s



Big Bang (once over lightly)

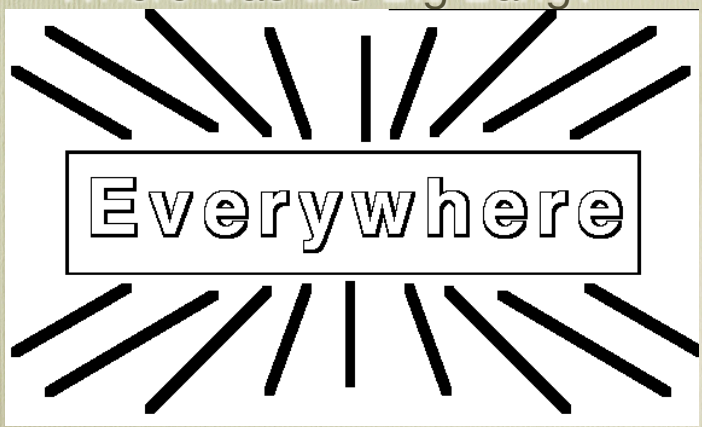
- Note: although all galaxies are receding from us, we are not at the centre
- in a currant cake model, as it cooks, all currants see all the others as receding.





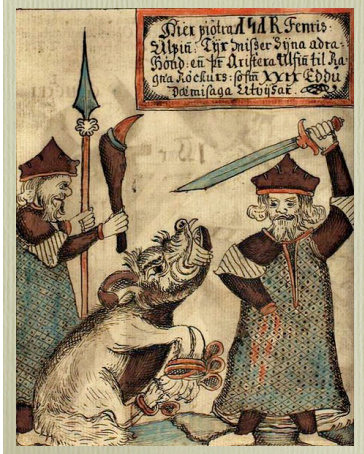
- We can invert H: it gives us a time
- 1/H = 14 billion years
- What does this time represent?
- Must be age of universe i.e. 14 billion years ago, **everything** was in the same place.
- So the universe had a beginning, implied by the big bang.
- We can run this backwards

Where was the Big Bang?



- A 2-Dimensional analog is the surface of a balloon: Note
- It has no centre in 2-D space.
- Deflating it reduces it to zero size: space and time had no meaning before the Big Bang
- The galaxies are not receding from us: space is expanding.
- We require a curved 2-D (really 3-D) surface embedded in a 3-D (really 4-D) volume.

3. What's going to happen in the end?

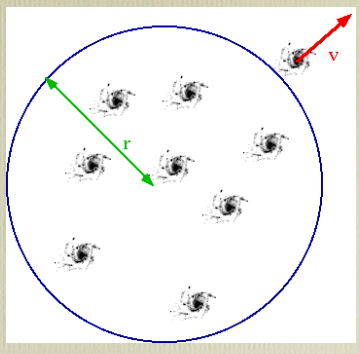


The sky becomes black,
Earth sinks into the sea
From Heaven fall the bright stars
The sea ascends in storm to Heaven
It swallows the Earth
the air becomes sterile.

From the Hyndluljod (Iceland)

- Will the universe will expand forever?

- Let's use this to predict the end!
- How hard do we need to throw a galaxy on the "outside" so that it never falls back?

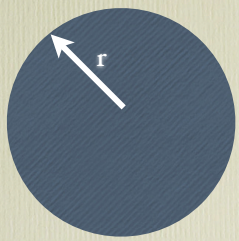


- Energy must be conserved:

$$\frac{1}{2}mv^2 - \frac{GMm}{r} = 0$$

But $v = Hr$ and total mass "inside" depends on the density

$$M = \frac{4\pi}{3}\rho r^3$$

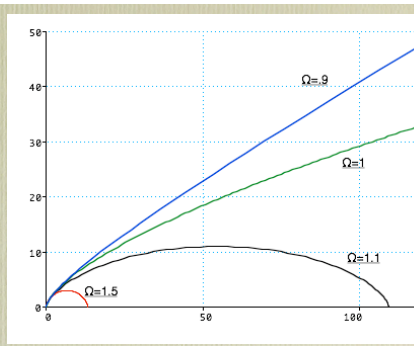


So $$H^2r^2 = 2G\frac{4\pi}{3}\rho r^2$$

- (we got lucky: the r cancels out!).
- We can turn this round and write it as an equation for ρ
- Hence the critical density $$\rho_0 = \frac{3H^2}{8\pi G}$$
  - ρ_0~6 Hydrogen atoms m^{-3} (Number is slightly flaky)
  - Better: if the earth was at this density it would weigh ~1 milligram.

- We'll talk about $\Omega=\rho/\rho_0$: indirect measure of the density
- $\Omega=1$ means the universe is exactly critical density
- The entire future of the universe is given by this one number!!!!!!!!!
- I am the Alpha and Omega, the Beginning and the End, saith the Lord. Revelations I v7.

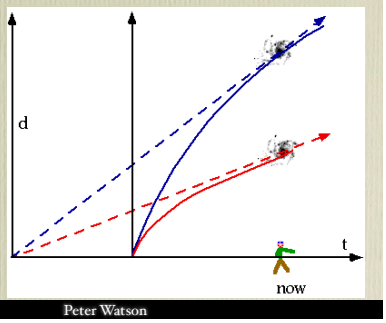
- if $\Omega > 1$ Universe comes to nasty end in ~ 50 billion yr.
- if $\Omega = 1$ Universe expansion slows down but never stops: "critical universe"
- if $\Omega < 1$ continues to expand forever



So we need to weigh the universe

- Note that this implies that the rate of expansion must change.
- Gravity will slow down expansion in the early stages, so Hubble's constant isn't a constant...
- when the universe was smaller, v was larger so H must have been bigger.

- Better "the Hubble parameter".



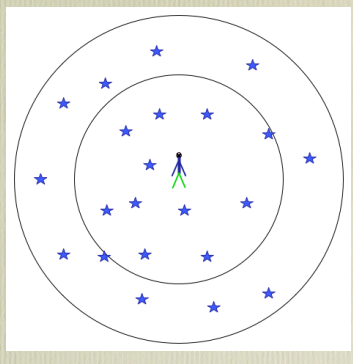
Let's pretend:

- We live in an open universe.
- Time began 14 billion years a… has no end.
- Laws of physics don't c…
- We know (or sus… the ones that matter.

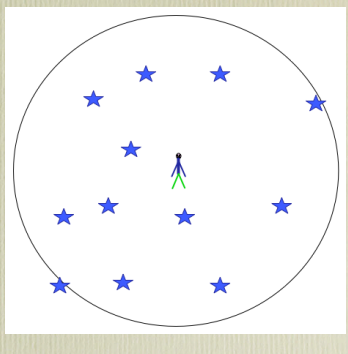
What happens in the end?

"Open" implies

- expanding (into what? Remember the balloon analogy)
- Possibly infinite, but finite in what we can see.
- Note that we would expect to see more as the universe expands



- Not necessarily: can be that the galaxies recede so fast we see the same number



What happens in the end?

i.e how does the universe evolve, assuming that it is expands for ever?

When temperature of everything is the same, then can do no work, hence .....nothing!

Heat Death of the Universe

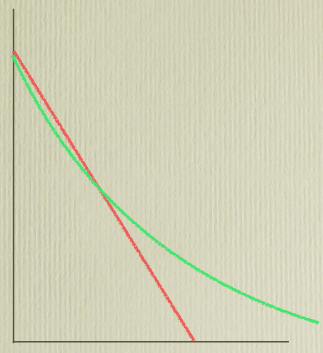
"This is the way World ends,

not with a Bang, but a Whimper"

T.S. Eliot

Except that....

- Does the universe end up at the same temp quickly
- or slowly!



Dyson's three questions

- Does the universe totally freeze?
- Is it possible for life and intelligence to survive?
- Is it possible to communicate across the expanding universe?

- No
- Yes
- Maybe

Time Scales

- Life cycle of large stars (formation to supernova)
- 10 million years = 10^7 yr.
- Current age of sun
- 4.5 billion years ~ 10^9 yr
- Time since Big Bang
- 14 billion years ~ 10^{10} yr
- Statutory warning: none of the numbers from now on are going to be very accurate

- Life cycle of small stars (formation to white dwarf)
- 10 trillion years = 10^{13} yr
- Hydrogen runs out (so no new stars)
- 100 trillion years = 10^{14} yr
- Detachment of planets by near collision
- 1000 trillion years = 10^{15} yr.
- Destruction of galaxies (black holes form at centre, stars drift off)
- 1 million-trillion years = 10^{18} yr.

- Decay of orbits by gravitational radiation
- 1 trillion-trillion years = 10^{24} yr
- Lifetime of proton (possibly)
- 1 trillion-trillion-trillion years = 10^{36} yr.
- Decay of black holes (Hawking radiation)
- 1 trillion-trillion-trillion-trillion-trillion years = 10^{60} yr.
- Note that on these time scales, solid matter is liquid (!)

Biological Time Scales

- Based on the earth
- Time to evolve species (e.g.humanity)
- 1 million years = 10^6 yr.
- Time to evolve class (e.g. Mammals)
- 100 million years = 10^8 yr.
- Time to get from nothing to humans
- 4 billion years = $4x10^9$ yr.
- So we have plenty of time to react

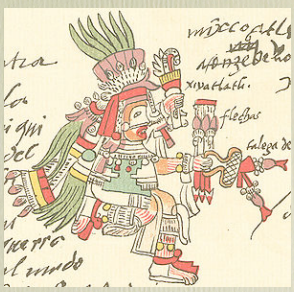
What is basis of consciousness?

- Organic molecules
- Then we are dead when the stars die!
- Matter in general (e.g. Silicon chips, black clouds)
- Then we last much longer.

4. There is still a big dark mystery out there

There is only a single God, Mixcoatl, whose image they possess, but they believe in another, invisible, god, not represented by any image, called Yoalli Ehecatl, That is to say, God Invisible, Impalpable, Beneficent, Protector, Omnipotent by whose strength alone ... rules all things.

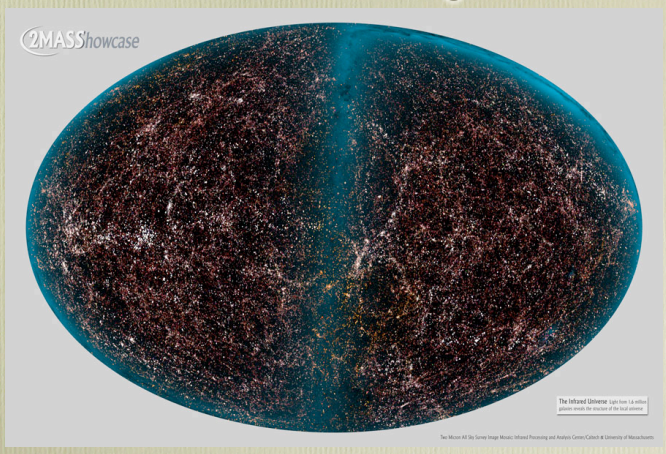
Nahuatlan Myth



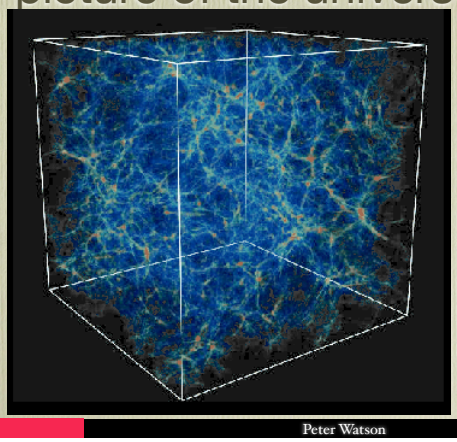
So how do we weigh the universe?

- First Guess: What you see is what you get!
- Can only see luminous matter
- Count number of galaxies in a region of space, assume they consist of stars much like the sun

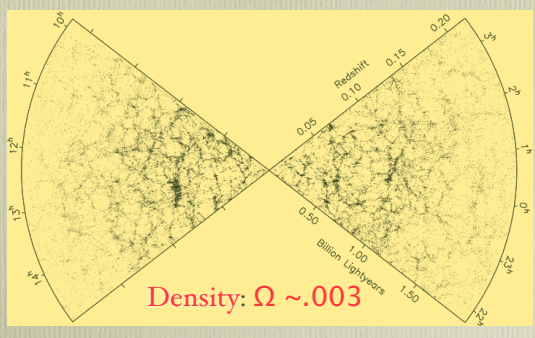
This is one million galaxies



But we need to have a 3-D picture of the universe



- Obviously must average over large enough volume such that universe is smooth
- The universe is a very lumpy place on a small scale!



Each dot is a galaxy!

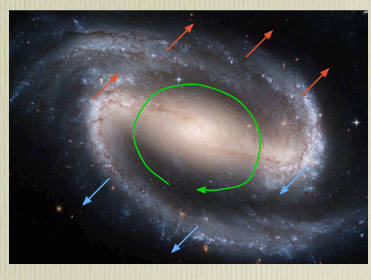
SO the universe lasts forever!

- But wait a moment .....
- We should add in something for non-luminous matter

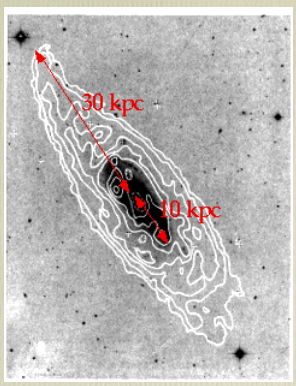
Density: Ω ~.01

But maybe there is some dark matter we can't see....

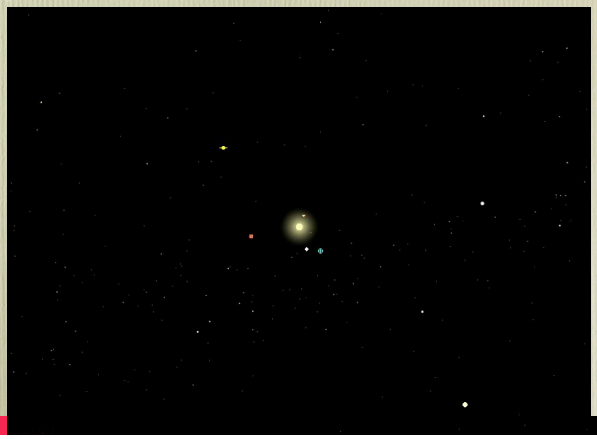
- Spiral galaxies are rotating
- Not fast enough to see, but
- We can measure speed of stars moving towards or away from us



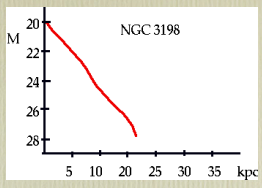
- Typical Spiral (NGC3198) R~ 20 kph
- outer parts are just seen as Hydrogen gas

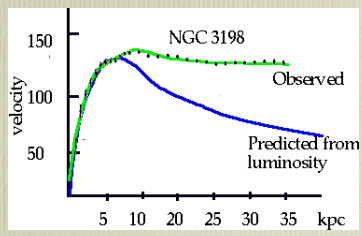


Like the solar system: outer parts should orbit more slowly

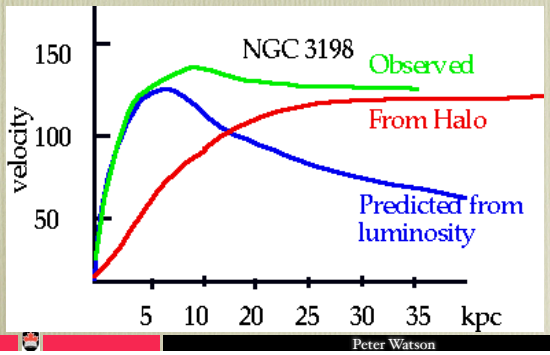


- Lets us measure mass of galaxy, in same way that Newton could use moon to measure mass of earth
- Luminosity of galaxy should reflect mass:
- brightest at centre, so most of mass should be there.





- Can fix this by saying that galaxy has halo of dark matter around it.
- Halo + core add together to give correct curve



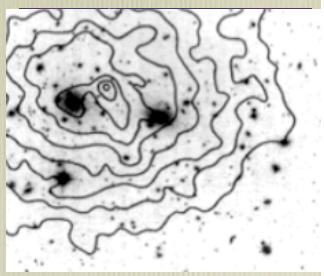
- From this we can estimate the mass of the galaxy
- It must be surrounded by an invisible halo with **40** times the mass of the visible galaxy....!
- i.e. the stars represent a tiny fraction of the mass in a galaxy.
- What is the rest?

Large clusters of galaxies

- Galaxies in a cluster move around
- Faster moving galaxies imply more mass in cluster, so measure speed
- 300 times more invisible matter than visible .....!

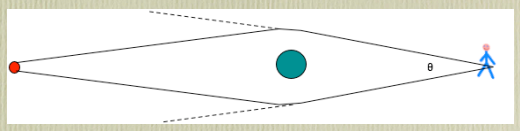
A check: The Coma cluster

- Clusters contains a lot of hot gas, which is strong X-ray source.
- Picture is negative optical + contours of X-rays.



but the X-rays don't come from where the matter is .....

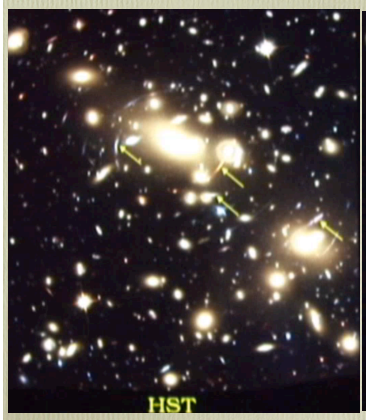
Also large masses bend light



- so we can get multiple images of a distant object
- large clusters show "gravitational lensing"

- Allows us to estimate the mass.
- For Abell 2218 we seem to have at least 300 times as much dark matter as luminous matter
- And it seems that Ω=1

- Can now be imaged by talented amateurs
- Thank you Brian Carroll, Barb Popel



Two Questions

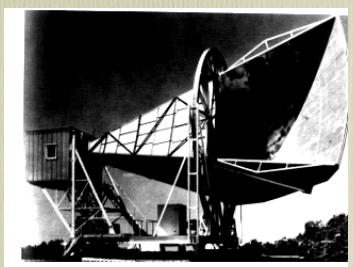
- What the hell?
- i.e. what is the dark matter?
- Why the hell?
- i.e. why is Ω~1: after all it could be anything?
- Actually, there is a limit Ω<3, otherwise universe would be younger than the earth (wouldn't that make the creationists happy!!)

6) Things were so much simpler back then

- It is believed that the first nine inhabitants who had descended from the skies were sexless and sinless and lived on a kind of flavoured earth. Their appetites grew and when they took to eating a sort of huskless rice which cooked itself they became gross and heavy, developed sex and after it crime because they had to work for a living
- Kachin Myth

Cosmic Microwave Background Radiation

- Early universe must have been very simple: no stars or galaxies.
- However, it was very hot: hot things radiate....
- Universe is "full" of light: fossil light from Big Bang, discovered accidentally by Penzias and Wilson (1964)

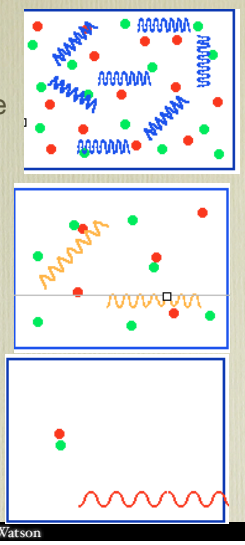


Where does it come from?

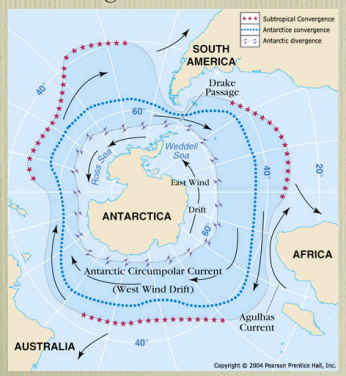
- Gamow (1948) discussed Hot Big Bang for first time, suggested that radiation might be observable.
- Peebles (1964) found T ~ 10°K (and everyone had general feeling that it would be unobservable).
- Note we are measuring temperature on the absolute scale or Kelvin scale
- T (°K) = T (°C) + 273
- 0 °K is lowest possible temp. ~ -273 °C

- This is often the way it is in physics: our mistake is not that we take our theories to seriously, but that we do not take them seriously enough. It is hard to believe that the numbers that we play with at our desks have something to do with the real world.
- Steven Weinberg The First Three Minutes

- This "light" is now at 2.736°, almost uniform in every direction
- Universe was originally a hot-dense fog so the light went nowhere
  - Cools, expands, starts making atoms
- 400000 years after the Big Bang, universe became transparent and radiation has travelling round the universe ever since.



- Have to get above atmosphere and point away from Milky Way
- Subsequent measurements came from balloon flights: BOOMERANG

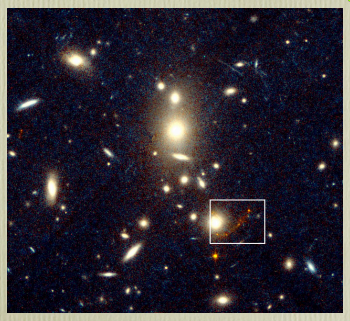


- Finally COBE (Cosmic Background Explorer: 2006 Nobel Prize for Mather and Smoot) launched 1990.
- Means we can take a snapshot of the universe 400,000 years after the Big Bang
- The temperature of the sky: blue is 0° K (absolute zero!), red is 4 °K.

Almost completely uniform: actual temperature is 2.73 °K.

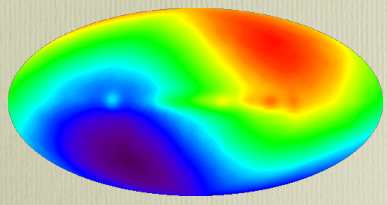
- In fact a sort of .....

How did this

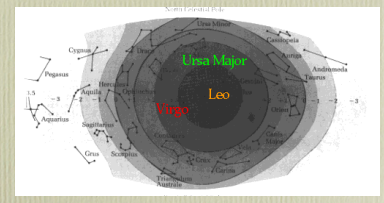


- Become this?

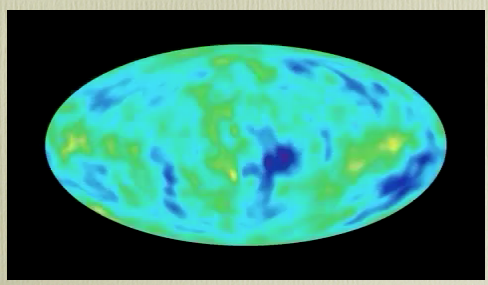
- Need to look on a finer scale
- At .0001 °, we can see something
- Red is "hot", blue is "cold"



- This is just because we are moving through the universe
- Towards Leo at 600 km/s!)



- Structure is there at .000001°K (1 millionth of a degree!)
- COBE gives us very crude picture
- WMAP is much finer



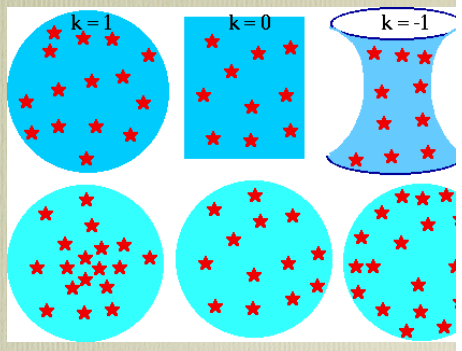
What shape is our universe?

1.Is it like a balloon

2.or a saddle

3.or flat

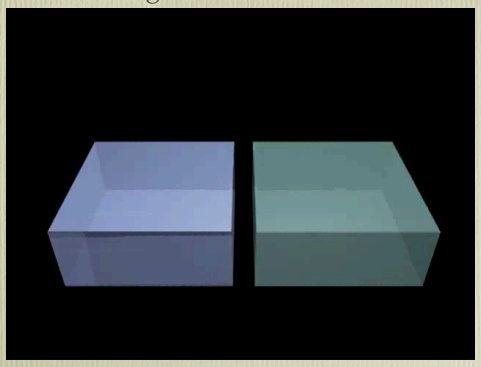
- Count the stars
- (well galaxies)
- if it's 1., more galaxies close to us
- if it's 2., more at large distances



Can't do it this way

- But WMAP can tell us it's flat

- So how did our lumpy universe come out of something so smooth?



Two questions

- What the hell is the dark matter?
- Why the hell do we need it?

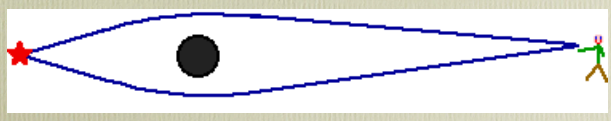
- What the hell is the dark matter?

Answers from 1985!

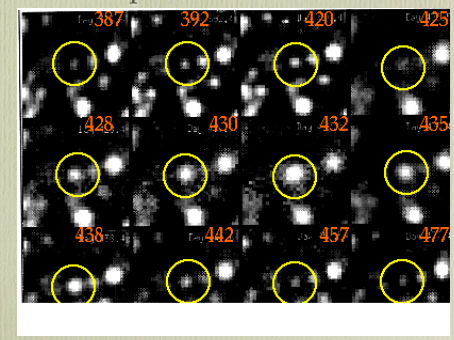
- Brown dwarfs
- Hydrogen gas
- Jupiters
- Hydrogen rain
- Low surface brightness galaxies
- Maxi Black holes
- Mini Black holes
- Neutrinos
- He H^+
- Modified gravity
- Axions
- Weakly Interacting Massive Particles (WIMPS)
- Magnetic Monopoles
- Majorons
- Photinos
- E_8 shadow matter
- Cosmic Strings

Need to rule out most of these

- e.g. Jupiters/brown dwarfs/black holes
- MAssive Compact Halo Objects
- figure out the acronym for yourself!
- If one star passes in front of another, we don't see a double image (as with quasars), but <u>can</u> see brightening as the object passes across a star's image.



- Need to look a million of stars/night
- Macho 1 "Gold-plated" event

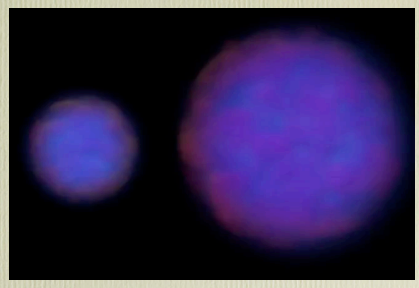


Yes this happens, but not nearly enough to explain dark mater

The Bullet cluster

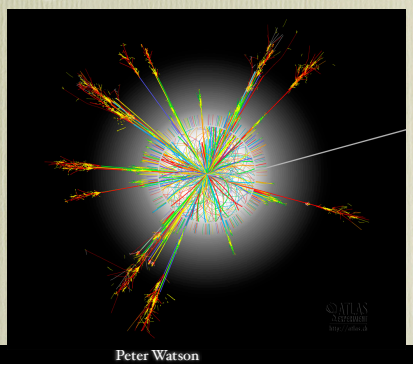
Note that

- We have 2 clusters of galaxies
- the hot gas is not where the clusters are
- the dark matter is!
- So the dark matter is not like a gas
- in fact hardly interacts at all

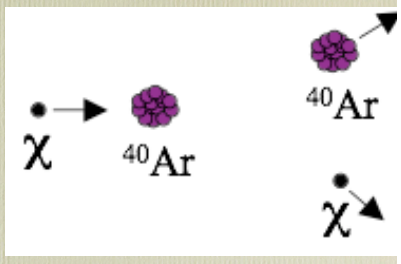


WIMPs≠MACHOs

- Behave like neutrinos but as heavy as atom of lead
- In vitro experiments: might be able to create them (say) at CERN



- But really want to capture one in the wild "in vivo"
- e.g. DEAP
- maybe know by2015!



- ~~Brown dwarfs~~
- ~~Hydrogen gas~~
- ~~Jupiters~~
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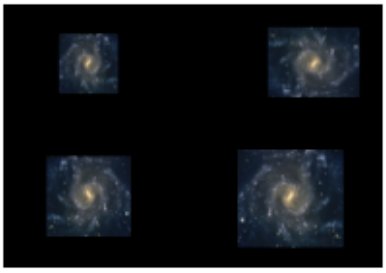
- ~~Magnetic Monopoles~~
- ~~Majorons~~
- ~~Photinos~~
- ~~E_8 shadow matter~~
- ~~Cosmic Strings~~

- Why the hell do we need it?

First matter and dark matter are just mixed

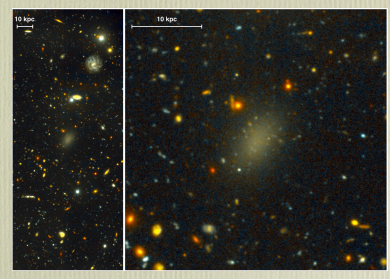
Then the DM gets cold and clumps
So now the matter gets cold and clumps onto the DM



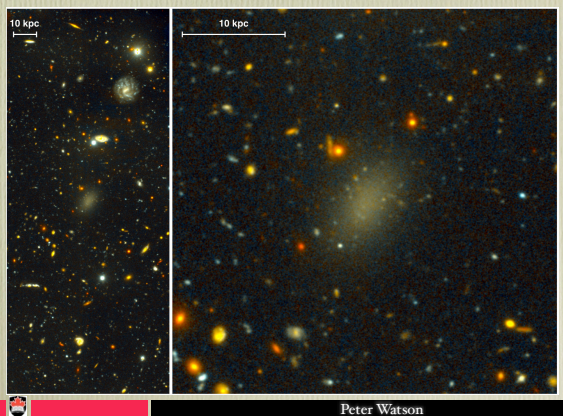
But you only see the matter !
So we exist because the DM has made the galaxies!

IF this story is true we should have "dark galaxies"

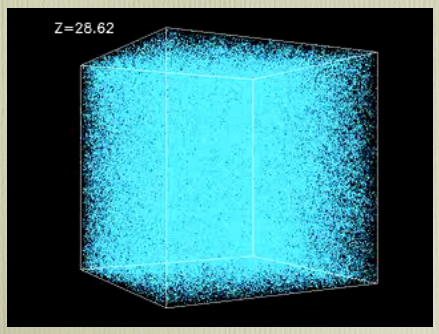
- Galaxies that contain very few stars



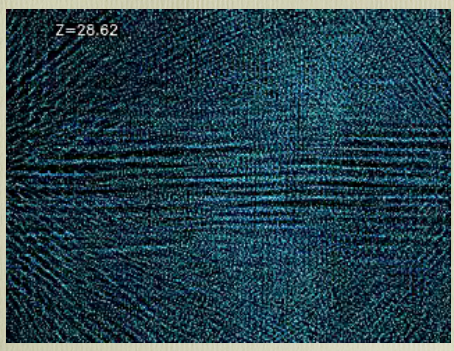
Dragonfly 44 is massive galaxy (stars are moving very fast) Very few stars, so 99.9% DM



- Need to add dark matter to our soup
- Galaxies will grow out of an almost uniform universe



- even on a smaller scale



Two questions and not very good answers!

- What the hell is the dark matter?
- We know what it isn't (gas, planets, rocks, baseballs ...)!
- Most likely a Weakly Interacting Massive Particle: will find out exactly what over the next 10 years
- Why the hell do we need it?
- Because if we don't have any dark matter, the universe blows itself apart before it can form anything!