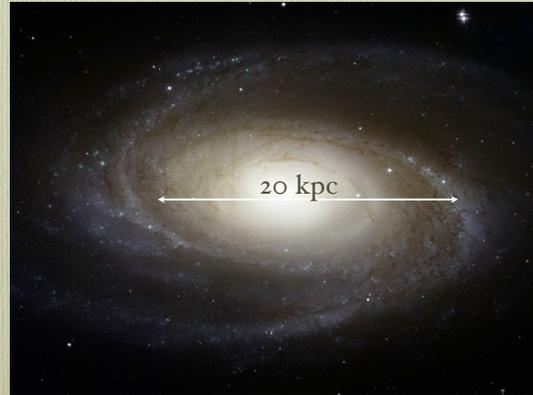


1. Doesn't it make you feel humble!

- Space is big. Really big. You won't believe how vastly, hugely, mind-bogglingly big it is. Hitchhiker's guide to the Galaxy.
- How big is the universe?



- The **smallest** things we will talk about are galaxies: typically 10 billion stars

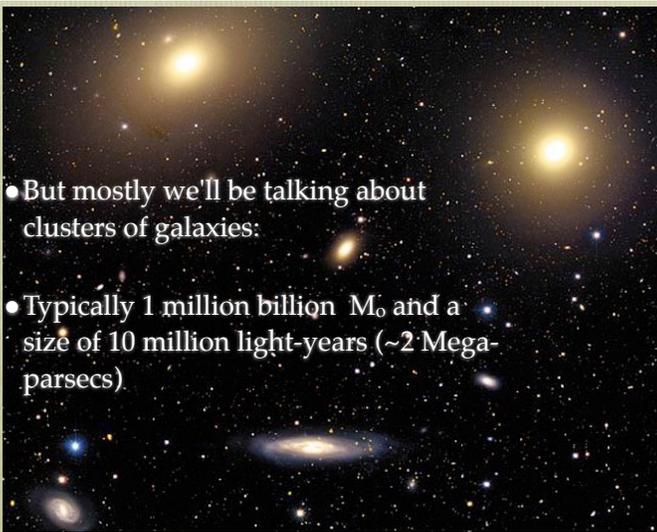


M81 in Ursa Major
HST picture



- 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 Megaparsecs)



- And the further out we go, the more we see



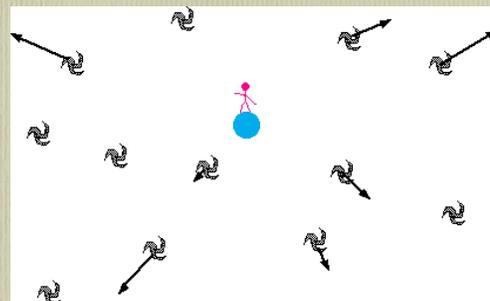
2. So how did it all begin?

At a time when the earth became hot
At a time when the heavens turned about
At a time when the sun was darkened
.....
Darkness of the sun, darkness of the night
Nothing but night

Kumulipo (Hawaiian Creation Chant)



Found by Hubble (1920's) that distant galaxies are receding from us:

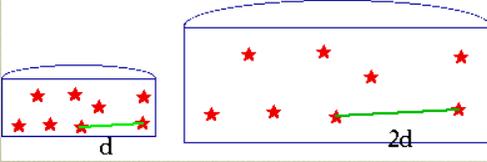


Speed increases with distance: a galaxy at 1 million parsecs is receding from us at 70 km/s



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.



Peter Watson

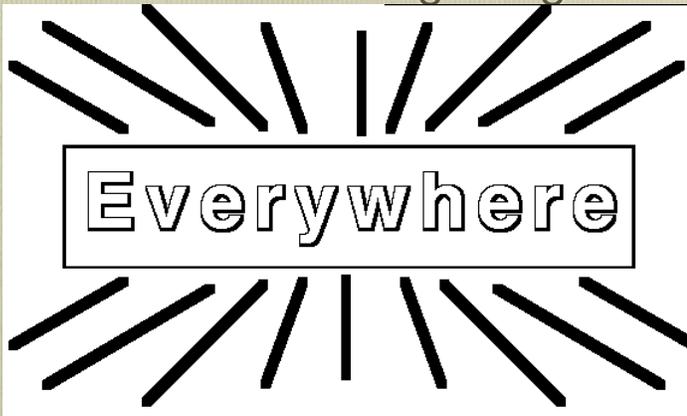
We can run the movie backwards.

- 14 billion years ago, **everything** was in the same place.
- So the universe had a beginning, the big bang.



Peter Watson

Where was the Big Bang?



Peter Watson

- Think of a balloon: our universe is the 2-Dimensional surface
- 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.

Peter Watson



Peter Watson

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



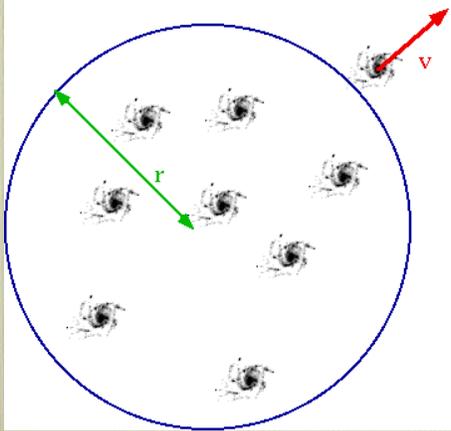
The sky becomes black,
Earth sinks into the sea
From Heaven fall the bright stars
The sea ascends in storm to Heaven
It swallows the Earth
the air becomes sterile.

From the Hyndluljod (Iceland)

Will the universe will expand forever?

Peter Watson

How hard do we need to throw a galaxy on the "outside" so that it never falls back?



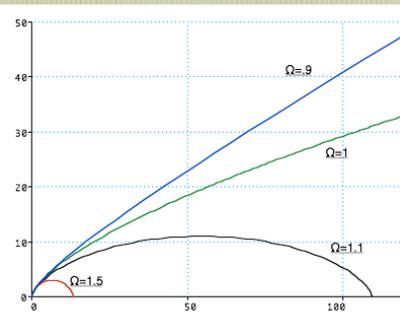
Peter Watson

- If we know how big the universe is, we know its mass
- We also know how fast the galaxies are moving
- 3 lines of Grade-12 maths, and we find the "critical density" of the universe: call it Ω
- $\Omega = 1$ means 6 Hydrogen atoms in a cubic metre on average)
- If the earth was at this density it would weigh **~1 milligram**

Peter Watson

- 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 years
- 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

Peter Watson

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.



Nahuatl Myth

Peter Watson

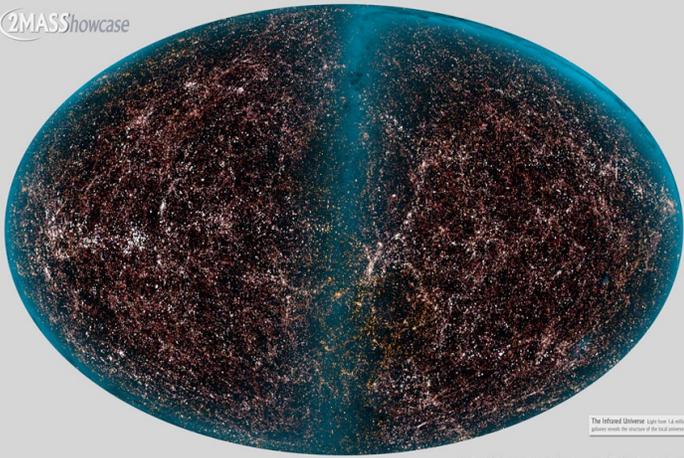
So how do we weigh the universe?

- 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

Peter Watson

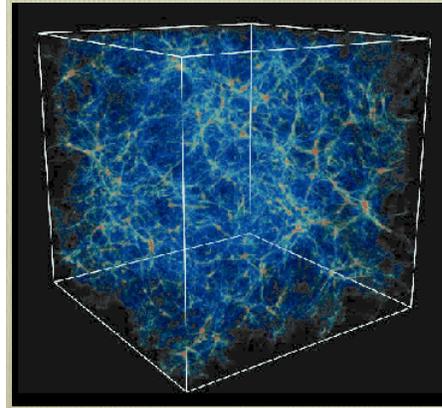
This is one million galaxies

2MASS showcase



The Mass At St. George Image-Mosaic, Infrared Processing and Analysis Center/Caltech & University of Massachusetts

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



Need to average over huge volume

The universe is a very lumpy place on a small scale!

Density: $\Omega \sim .003$

Peter Watson

SO the universe lasts forever!

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

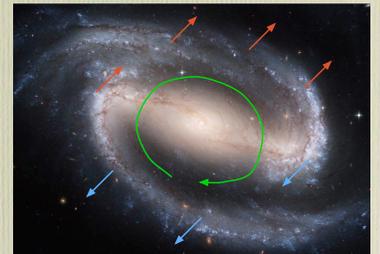


Density: $\Omega \sim .01$

Peter Watson

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

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



Peter Watson

- Stars are moving **much** too fast.
- We can estimate the galaxy must be surrounded by an invisible halo with **40** times the mass of the visible galaxy....!
- i.e. the stars represent a tiny amount of the mass in a galaxy.
- **What is the rest?**

Peter Watson

Large clusters of galaxies

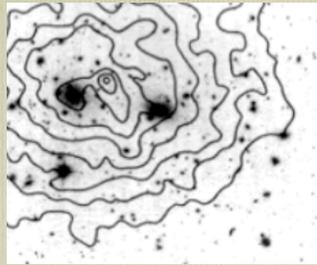
- Galaxies in a cluster move around
- Faster moving galaxies imply more mass in cluster, so measure speed
- **300** times more invisible matter than visible



Peter Watson

A check: The Coma cluster

- Clusters contains a lot of hot gas, which produces X-rays.
- Picture shows contours of X-rays.

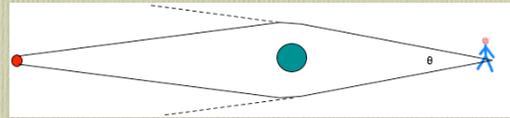


but the X-rays don't come from where the matter is



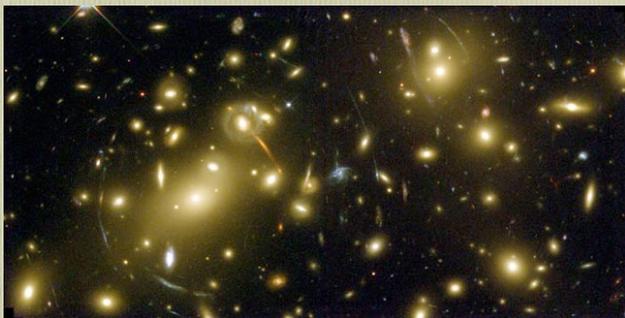
Peter Watson

Also large masses bend light



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

Peter Watson



- 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 $\Omega=1$



Peter Watson

Two Questions

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

Peter Watson

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



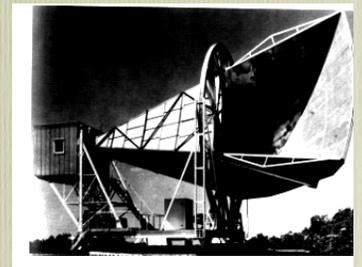
Peter Watson

Cosmic Microwave Background Radiation

Early universe was very simple: no stars or galaxies.

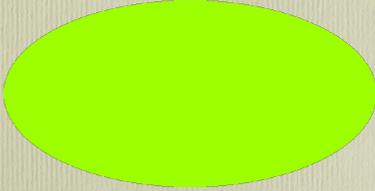
However, it was very hot: hot things radiate....

Universe is "full" of light: fossil light from Big Bang, discovered accidentally by Penzias and Wilson (1964)



Peter Watson

- COBE launched 1990.
- Means we can take a snapshot of the universe just after the Big Bang, but it's cooled down!
- The temperature of the sky: blue is 0° K (absolute zero!), red is 4 °K.



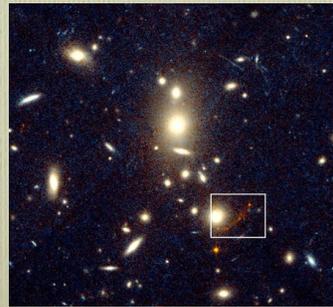
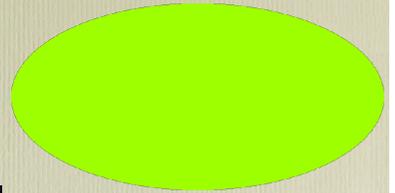
Almost completely uniform:

- In fact a sort of



Peter watson

How did this

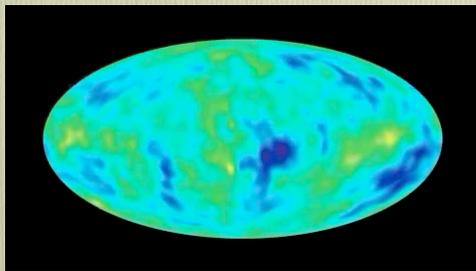


Become this?



Peter Watson

- Structure is there at 1 millionth of a degree!
- COBE gives us very crude picture
- WMAP is much finer



Peter Watson

Can't do it this way

- But WMAP can tell us it's flat



Peter Watson

- Why the hell do we need it?

First matter and dark matter are just mixed

Then the DM gets cold and makes lumps

So now the matter gets cold and clumps onto the DM



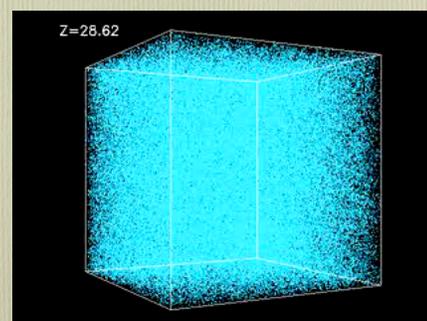
But you only see the matter !

So we exist because the DM has made the galaxies!



Peter Watson

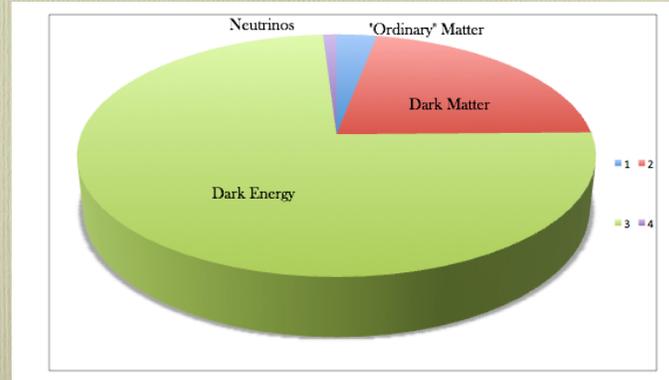
- Need to add dark matter to our soup
- Galaxies will grow out of an almost uniform universe



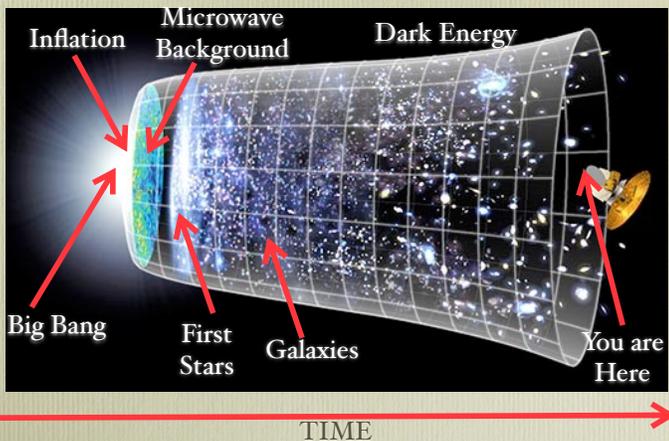
Peter Watson

“I can't believe THAT!” said Alice.
 “Can't you?” the Queen said in a pitying tone. “Try again: draw a long breath, and shut your eyes.”
 Alice laughed. “There's not use trying,” she said: “one CAN'T believe impossible things.”
 “I daresay you haven't had much practice,” said the Queen. “When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast.”

- What can dark energy be?
- List of all well-motivated models for dark energy:



- Our “concordance model” agrees with everything we know!



7. So what happened before?

Then was not non-existent nor existent
 There was no realm of air, no sky beyond,
 What covered in and where? and what gave shelter?
 Who verily knows and who can here declare it
 Whence it was born and whence came this creation
 He, the first origin of creation, whether he formed it all
 or did not form it.
 He verily knows it, or perhaps he knows not.

The Rig Veda X.129 (Hindu)

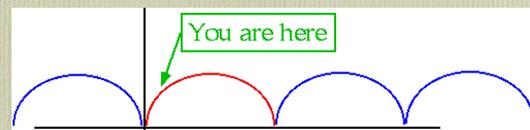
What happened before the Big Bang?

Don't Ask

There is a special hell reserved for people who ask that question.

George Gamow

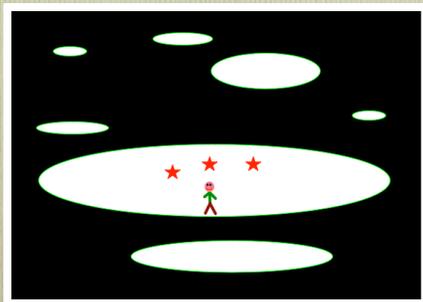
Maybe the Universe Bounces



- We can create models in which the universe bounces
- But they don't work very well

But much more fun:
The universe is a quantum fluctuation

- Implies we can get daughter universes, each with their own big bang



Peter Watson

9. Why does the Universe Exist?

- You're not going to like the answer (Marvin, in the Hitchhiker's Guide to the Galaxy)
- Universes tend to happen from time to time!
- But are they always the same?

Peter Watson

Acknowledgments: most pics from
APOD (Astronomy Picture of the Day), NASA, WMAP
European Space Observatory

Slides will be posted www.physics.carleton.ca/~watson/

Many Thanks to Taylor (Event Manager),
Rick (Cruise Director), Raphael, (light)
Marvin (Sound), Arjay 1 & 2, Jomes, Denis,
Marvin (stage).

Enjoy the rest of your trip
(and look up at the skies!)



Peter Watson