

Black is the Colour And 0 is the Number

Peter Watson

Why Dark Matter and Dark Energy Rule the Universe

Physics as a Creation Myth



Peter Watson

A Creation Myth??????????

In the beginning the Universe was created. This has made a lot of people very angry and has been widely regarded as a bad move. Many people believe that it was created by some sort of God, though the Jatravartid people of Viltvodle Six firmly believe that the entire Universe was in fact sneezed out of the nose of a being they call the Great Green Arkleseizure.

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The Jatravartids, who live in perpetual fear of a time that they call "The Coming of the Great White Handkerchief", are small blue creatures. However, the Great Green Arkleseizure theory was not widely accepted outside Viltvodle Six, and so one day a race of hyper-intelligent beings built themselves a gigantic computer called Deep Thought to calculate once and for all the answer to the Ultimate Question of Life, the Universe and Everything.

which was, of course,

Peter Watson

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From "The Hitchhiker's Guide to the Galaxy", Douglas Adams

- Ingredients for a creation myth:
 1. Doesn't it make you feel humble!
 2. So how did it all begin?
 3. What's going to happen in the end?
 4. There is still a big dark mystery out there.
 5. Things were so much simpler back then
 6. Fortunately, there is a special place for us.
 7. But what happened before?
 8. What a beautiful story!

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Spiral Galaxies

- Some are spread out, like NGC6946
- About 10 billion stars
- About 20,000 parsecs across
- Can't see individual stars: red patches are "star nurseries"



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- Some are tightly wound up, like M31 (the Andromeda galaxy)



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- Some galaxies have grabbed hold of other galaxies
- This is M51



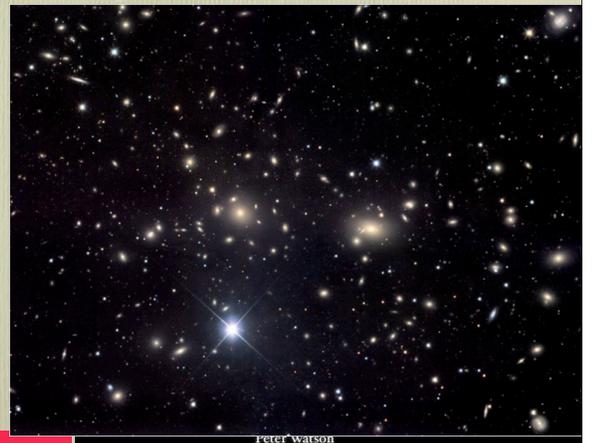
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Galaxies group together
Some are tightly packed
Stefan's quintet



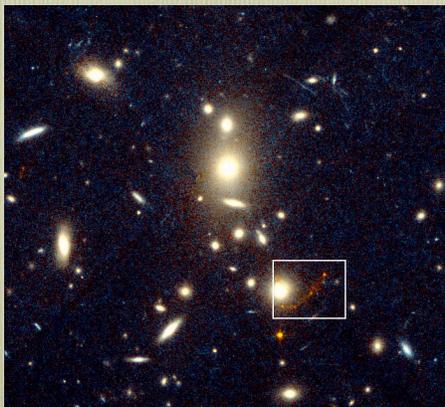
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The Coma cluster is made up of 10000 galaxies
Apart from one bright star, almost all the objects are galaxies



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- But there are more



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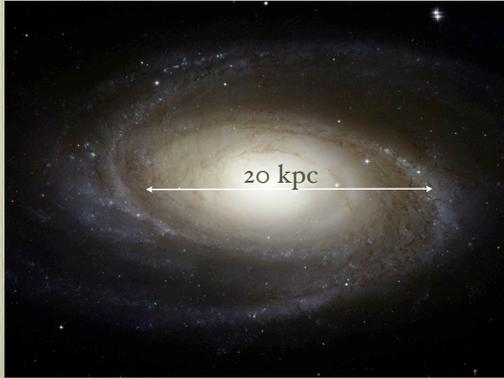
- And the further out we go, the more we see



So how big is the universe?

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



M81 in Ursa Major
HST picture

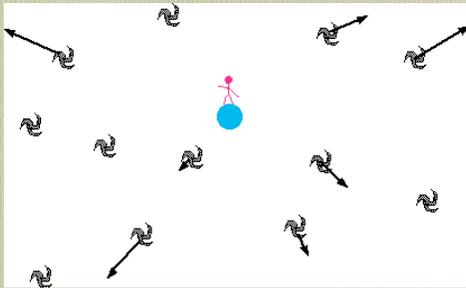


- But mostly we'll be talking about clusters of galaxies:

- Typically 1 million billion M_{\odot} and a size of 10 million light-years (~2 Mega-parsecs)



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

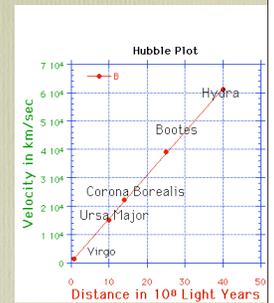


- velocity increases with distance

- $v = Hd$

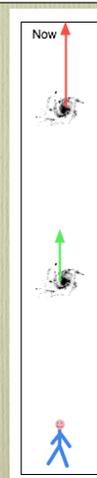
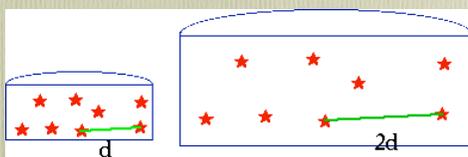
- H is Hubble constant

- a galaxy at 1 million parsecs is receding from us at 70 km/s



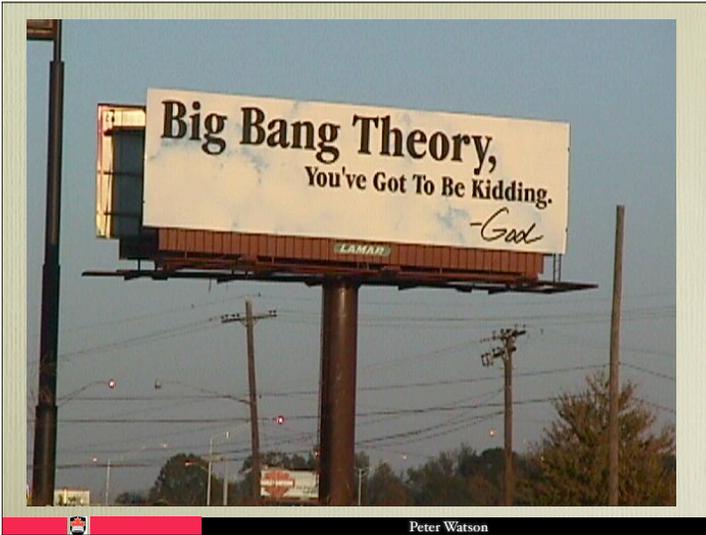
Big Bang (once over lightly)

- 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.



- 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.





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?

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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:
 - 6 Hydrogen atoms in a cubic metre
 - Better: if the earth was at this density it would weigh **~1 milligram**
- Peter Watson

- We'll use Ω : $\Omega=1$ 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 1 v7.
- Peter Watson

- 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

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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

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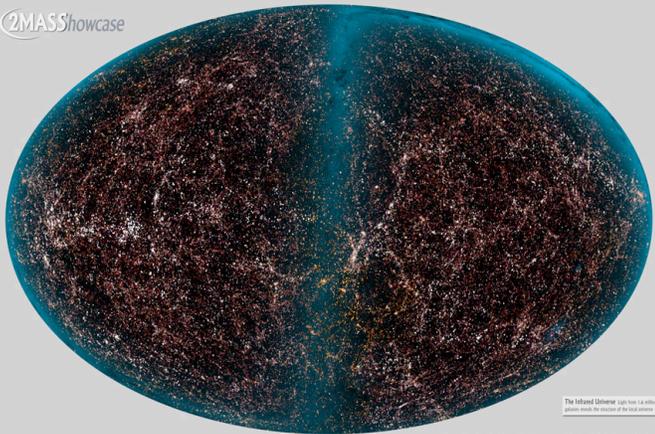
So how do we weigh the universe?

- 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

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This is one million galaxies

2MASS Showcase

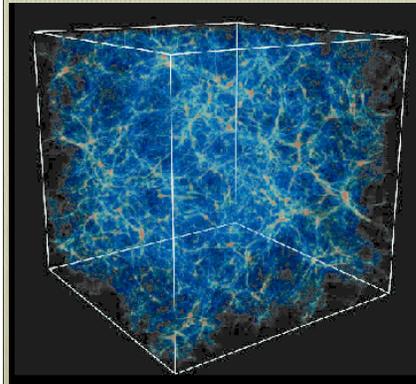


The Infrared Universe: Light from 1.4 million galaxies inside the radius of the full moon.

The Mission of the Large Space Telescope Infrared Processing and Analysis Center (IPAC) at the University of California, Berkeley.

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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: $\Omega \sim .003$

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SO the universe lasts forever!

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

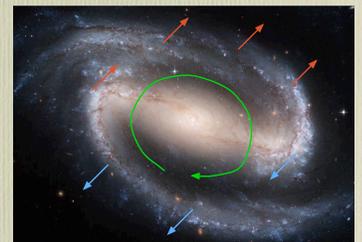


Density: $\Omega \sim .01$

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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



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- Stars are moving **much** too fast.
- 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?**



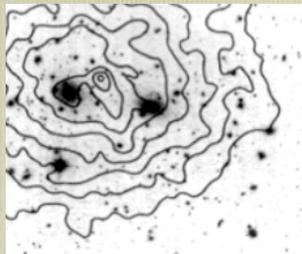
Large clusters of galaxies

- 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

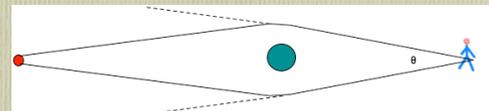
- Clusters contains a lot of hot gas, which is strong X-ray source.
- Picture is negative optical + contours of X-rays.



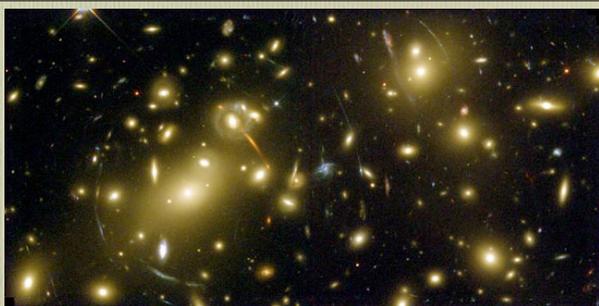
but the X-rays don't come from where the matter is



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 $\Omega=1$



Two Questions

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

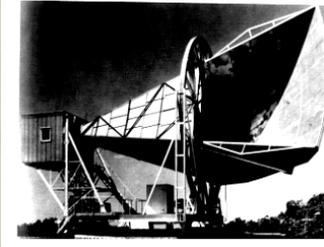


Cosmic Microwave Background Radiation

Early universe was very simple: no stars or galaxies.

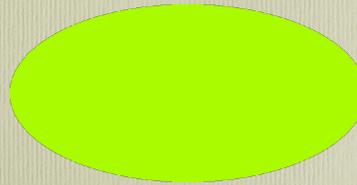
However, it was very hot: hot things radiate....

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



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- 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 .



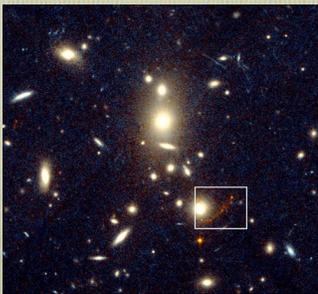
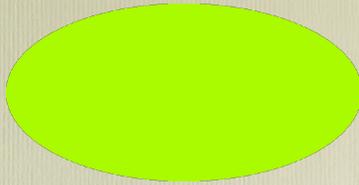
Almost completely uniform: actual temperature is 2.73°K .

- In fact a sort of



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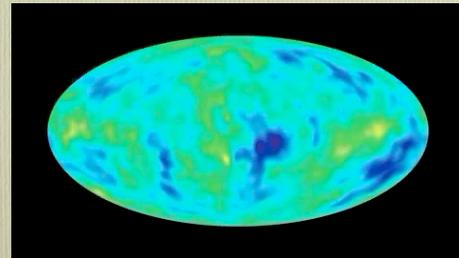
How did this



Become this?

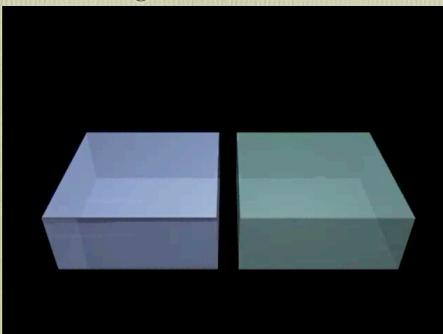
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- Structure is there at 1 millionth of a degree!
- COBE gives us very crude picture
- WMAP is much finer (and Planck is better still)



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



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Two questions

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

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• 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
- E₈ shadow matter
- Cosmic Strings

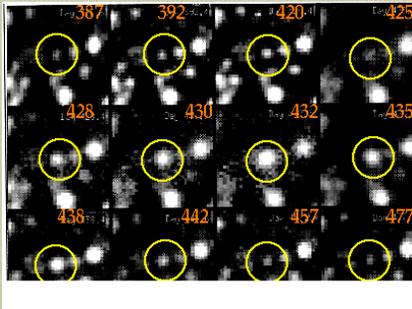


Need to rule out most of these

- e.g. Jupiters/brown dwarfs/black holes
- Massive Compact Halo Objects
- figure out the acronym for yourself!
- If an object passes in front of a star, we can see a brightening of the star's image.



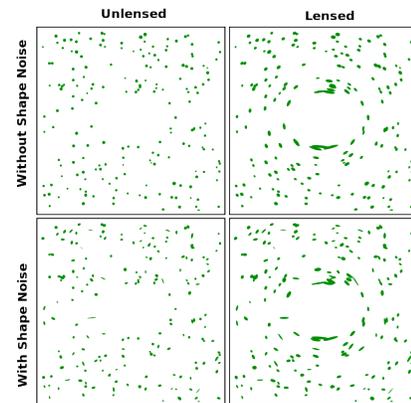
- Need to look a million of stars / night
- Macho 1 "Gold-plated" event



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

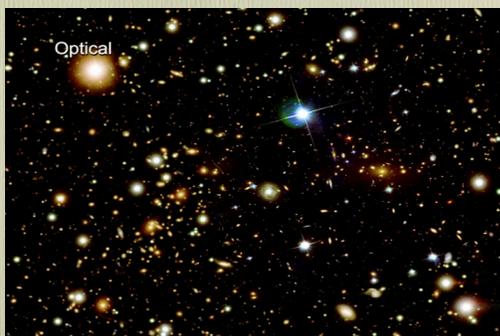


- If you have a lot of galaxies, they are systematically distorted



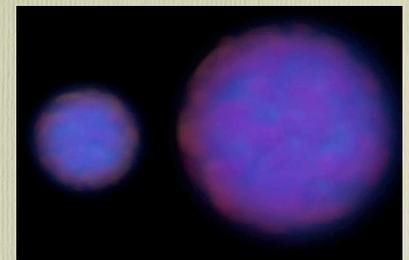
TallJimbo

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

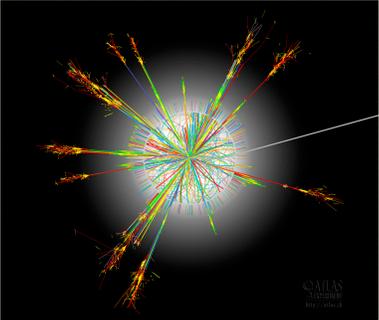


- Brown dwarfs
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- Magnetic Monopoles
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- Eg shadow matter
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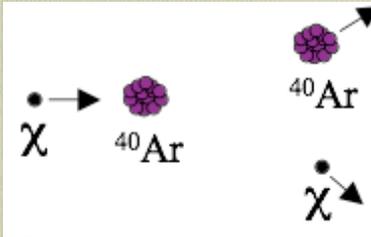
WIMPs ≠ MACHOs

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



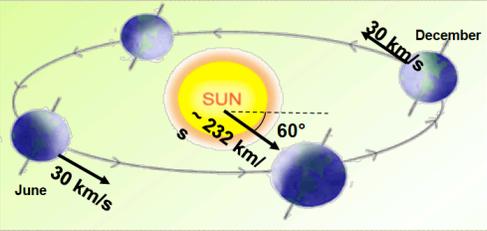
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- But really want to capture one in the wild "in vivo"
- Several use recoil e.g. DEAP



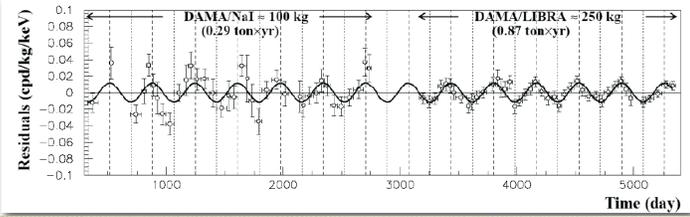
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- The one that "works": DAMA
- based on the idea that your windscreen gets wetter driving into the rain!

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- Which is exactly what they see!



Except that no one knows what they are seeing and it's inconsistent with all other experiments!

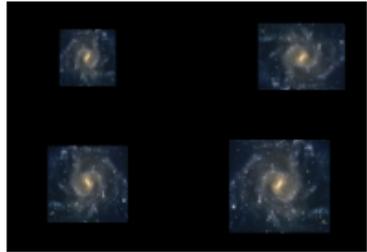
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- Why the hell do we need it?

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

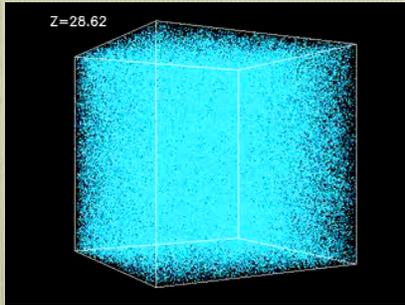


But you only see the matter!

So we exist because the DM has made the galaxies!

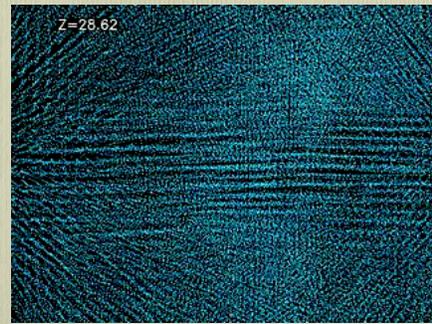
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- Need to add dark matter to our soup
- Galaxies will grow out of an almost uniform universe



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- even on a smaller scale



Peter Watson

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 **W**eakly **I**nteracting **M**assive **P**article

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!

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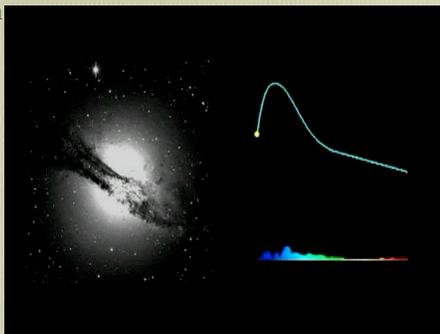
And just when you thought it was safe to go out at night....



- Dark Matter is bad enough, but now dark energy ...

Peter Watson

- Type 1a Supernova
- Very rare (1/ galaxy/century)
- Very bright
- And they are all the same
- This is one in Centaurus A



Peter Watson

- Need to look a long way out with supernovae
- Now use Canada-France Hawaii Telescope



Peter Watson

