DARK MATTER

...and the rather embarrassing state of Modern Cosmology

THE UNIVERSITY OF EDINBURGH

Imperial College London

LIP

SUPA

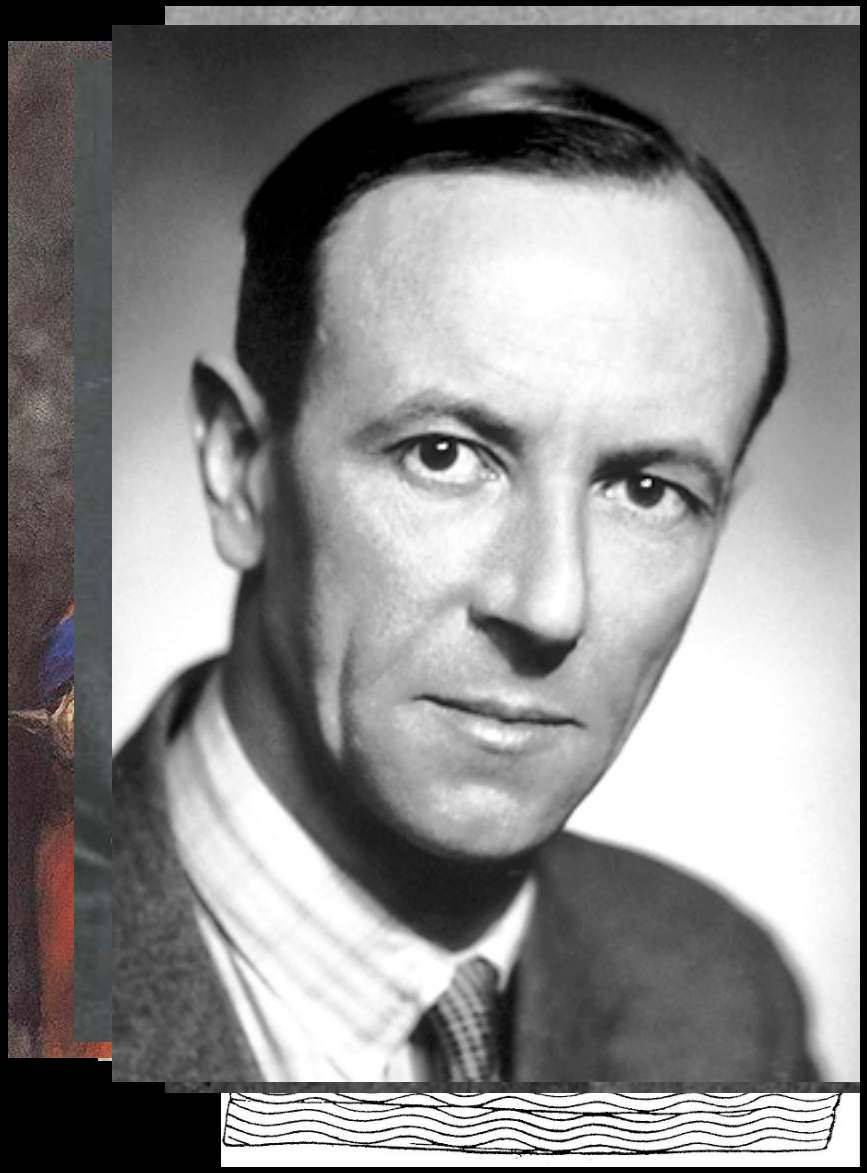
The BIG questions

What is the nature of the Universe?

How has the Universe evolved?

What is the Universe made of?

Ancient history



Modern history

Fritz Zwicky
1933

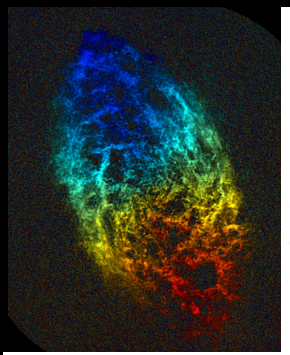
Early evidence for Dark Matter

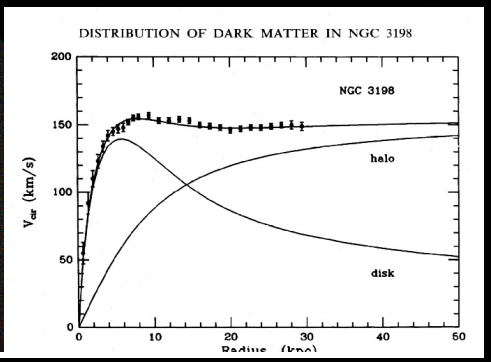
1: Looked at
Galaxy clusters

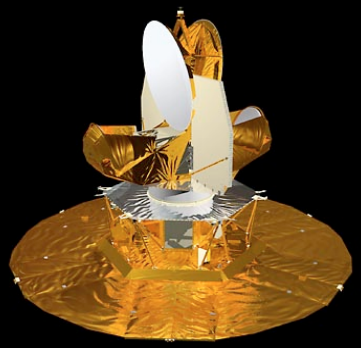
2. Observed their motion

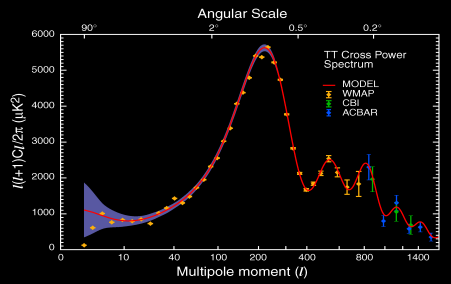
3: Applied the laws of physics that we know

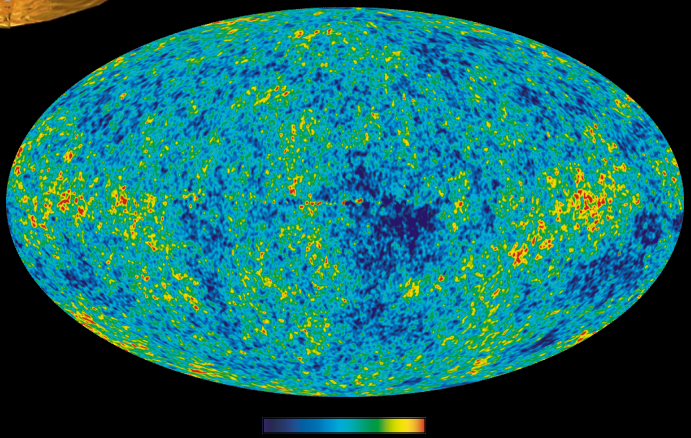
4: Deduced that there must be more mass present than is seen

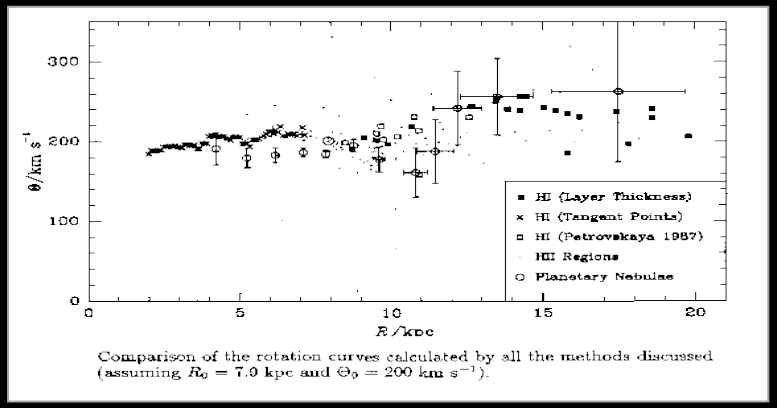




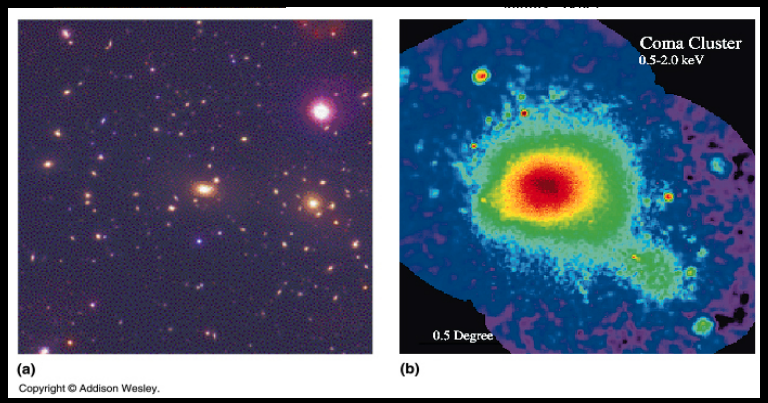


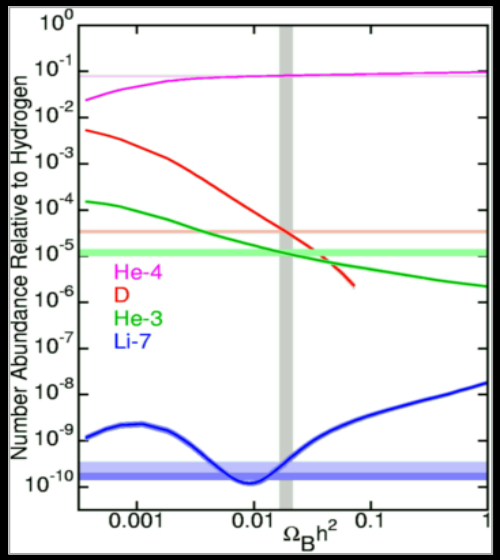


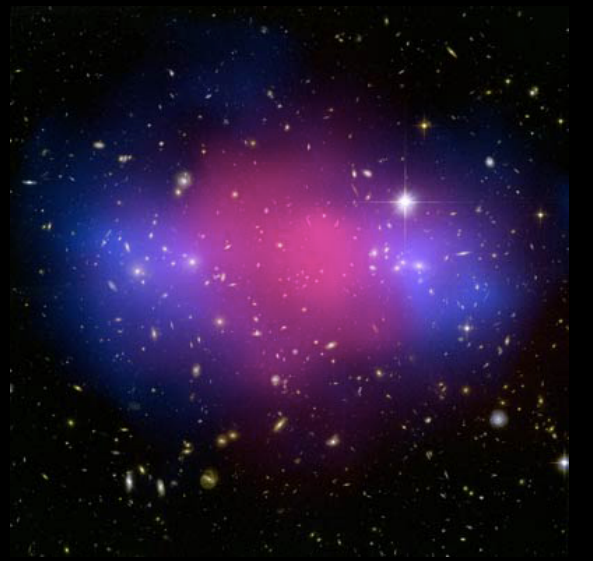


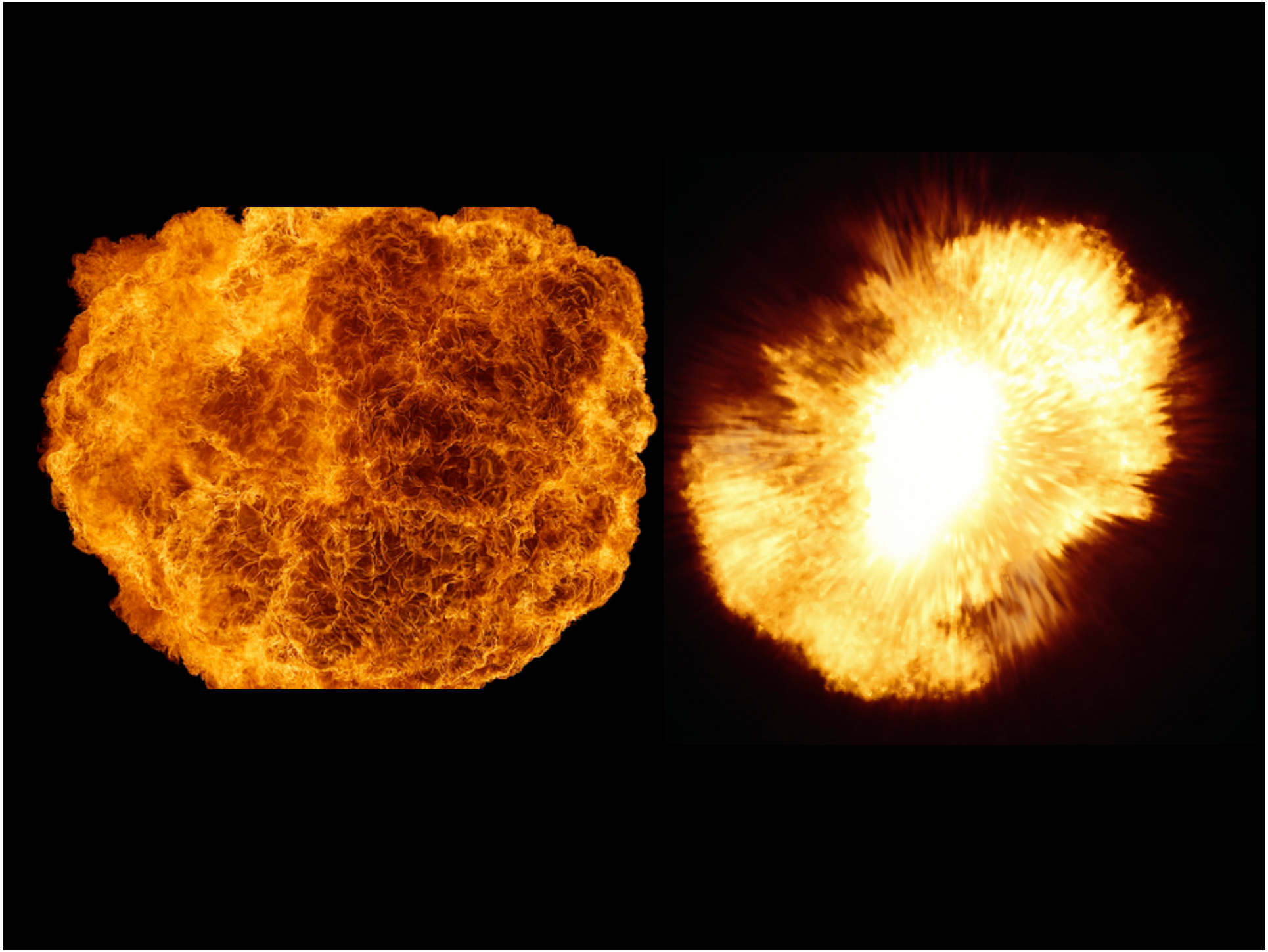


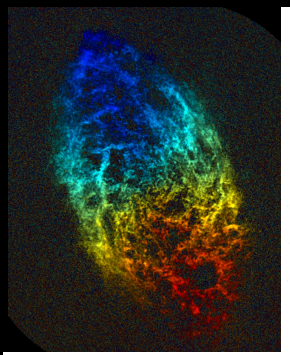
Comparison of the rotation curves calculated by all the methods discussed (assuming $R_0 = 7.9$ kpc and $\Theta_0 = 200$ km s^{-1}).

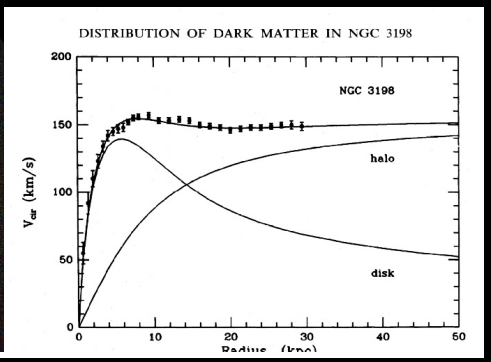


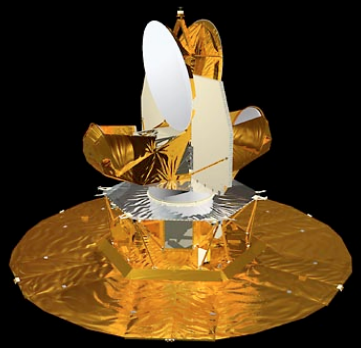


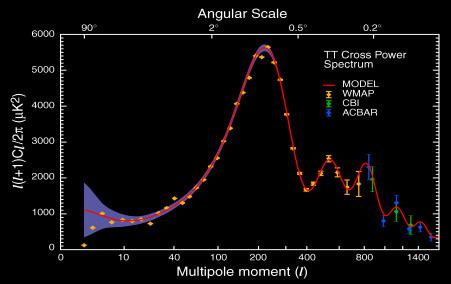


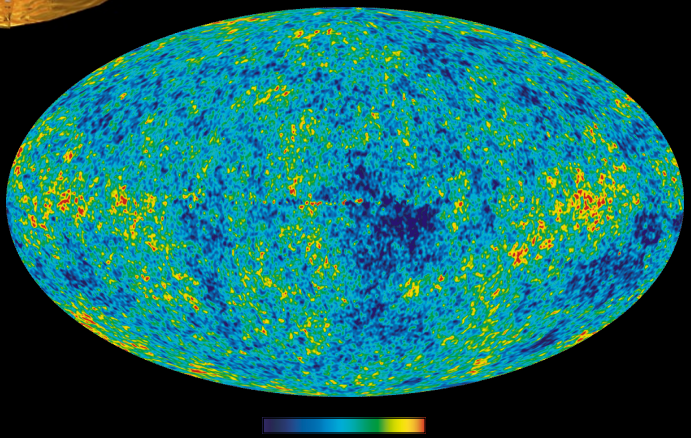


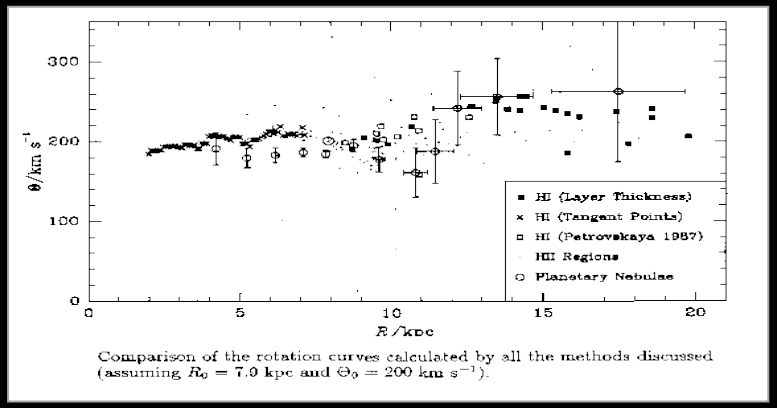












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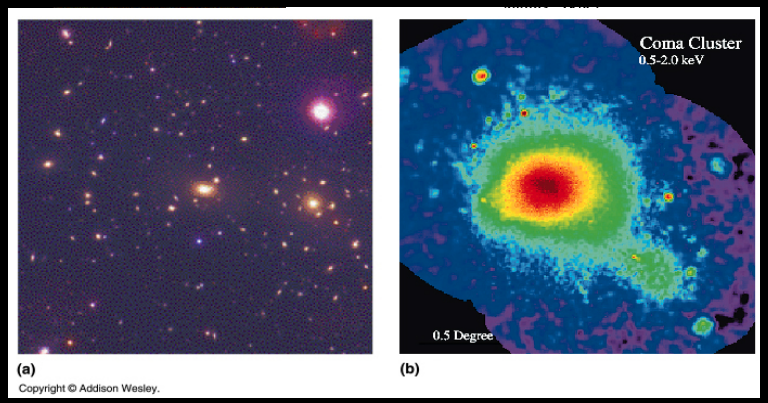
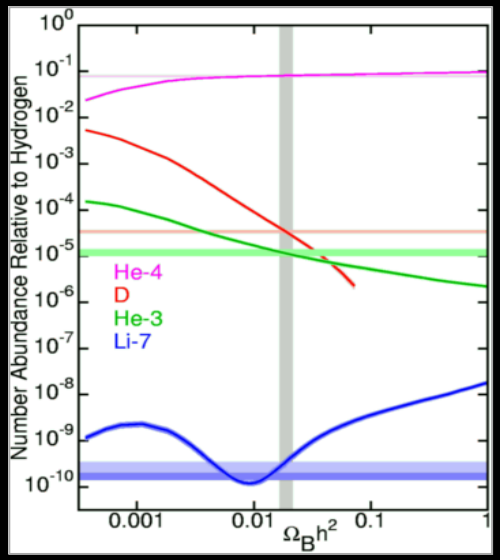
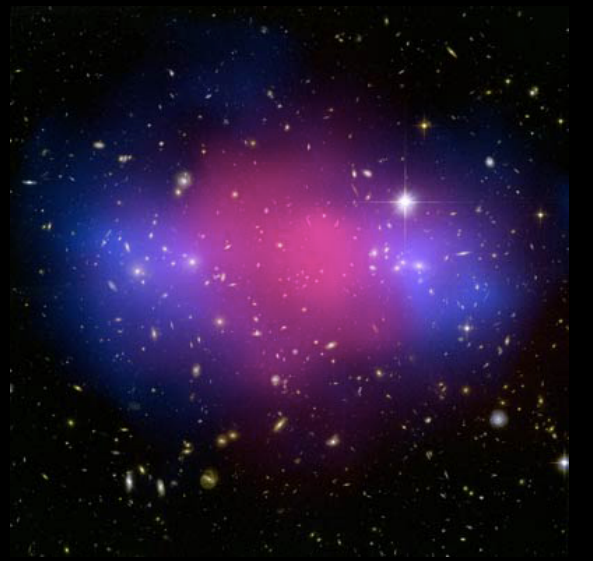
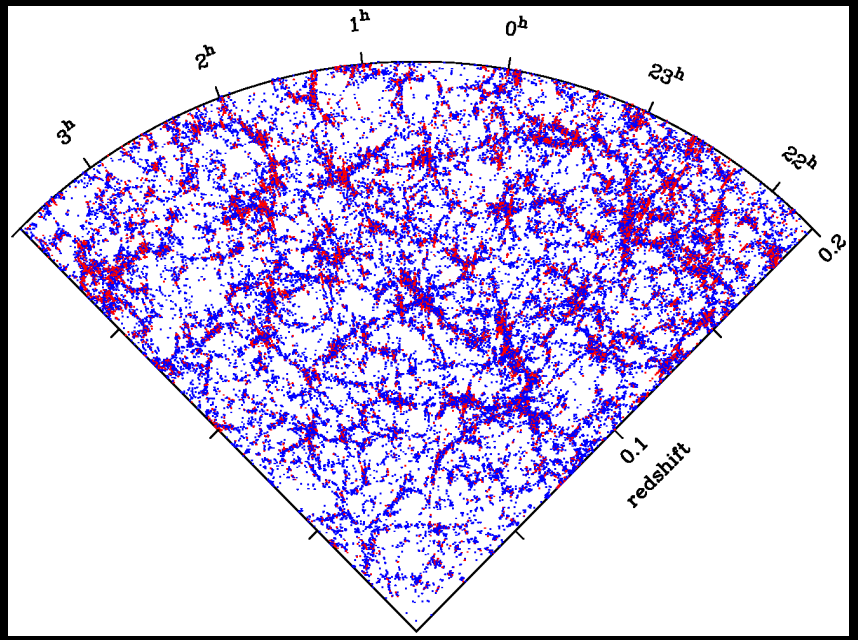
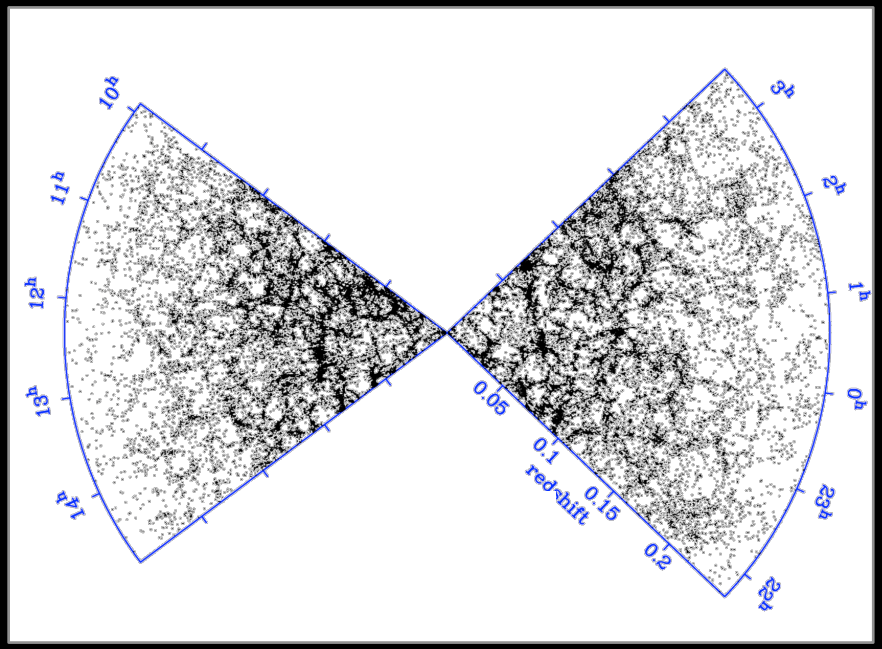






Take a slice and compare with observation....





It all works, beautifully!

So what is this *Dark Matter*

Where did it come from?

Particle Physics to the Rescue

The 'Standard Model'

Fundamental particles: Electrons, quarks, gluons...

Fundamental forces: Electromagnetic, weak, strong

Works very very well at saying 'HOW'

But it doesn't really answer 'WHY?'

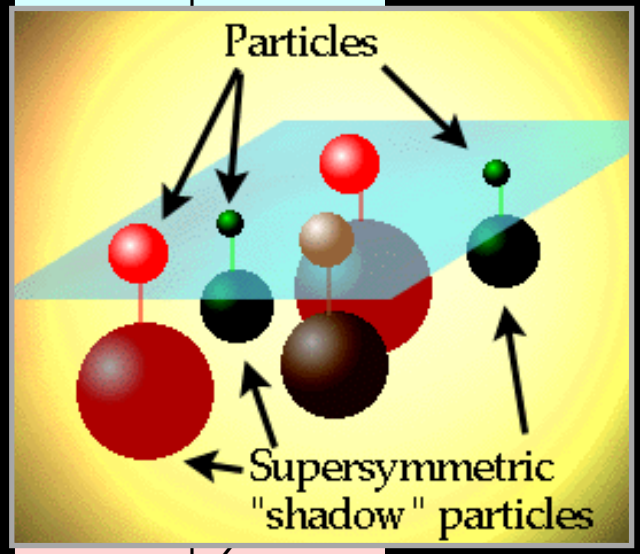
But there is a theory that does!

SUPERSYMMETRY

SUPERSYMMETRY

- Explains why we see the range of particles and forces that we do
- Predicts more particles we have yet to see
- The lightest of these, the WIMP, has just the right properties to be dark matter
- Would have been made in the Big Bang; stable; big influence on cosmology
- It's an *independent* prediction!

Particle type	Particle
	Z
	Photon
	Gluon
	Higgs



Conclusion: There is more matter out there than what we can see in stars, planets etc.

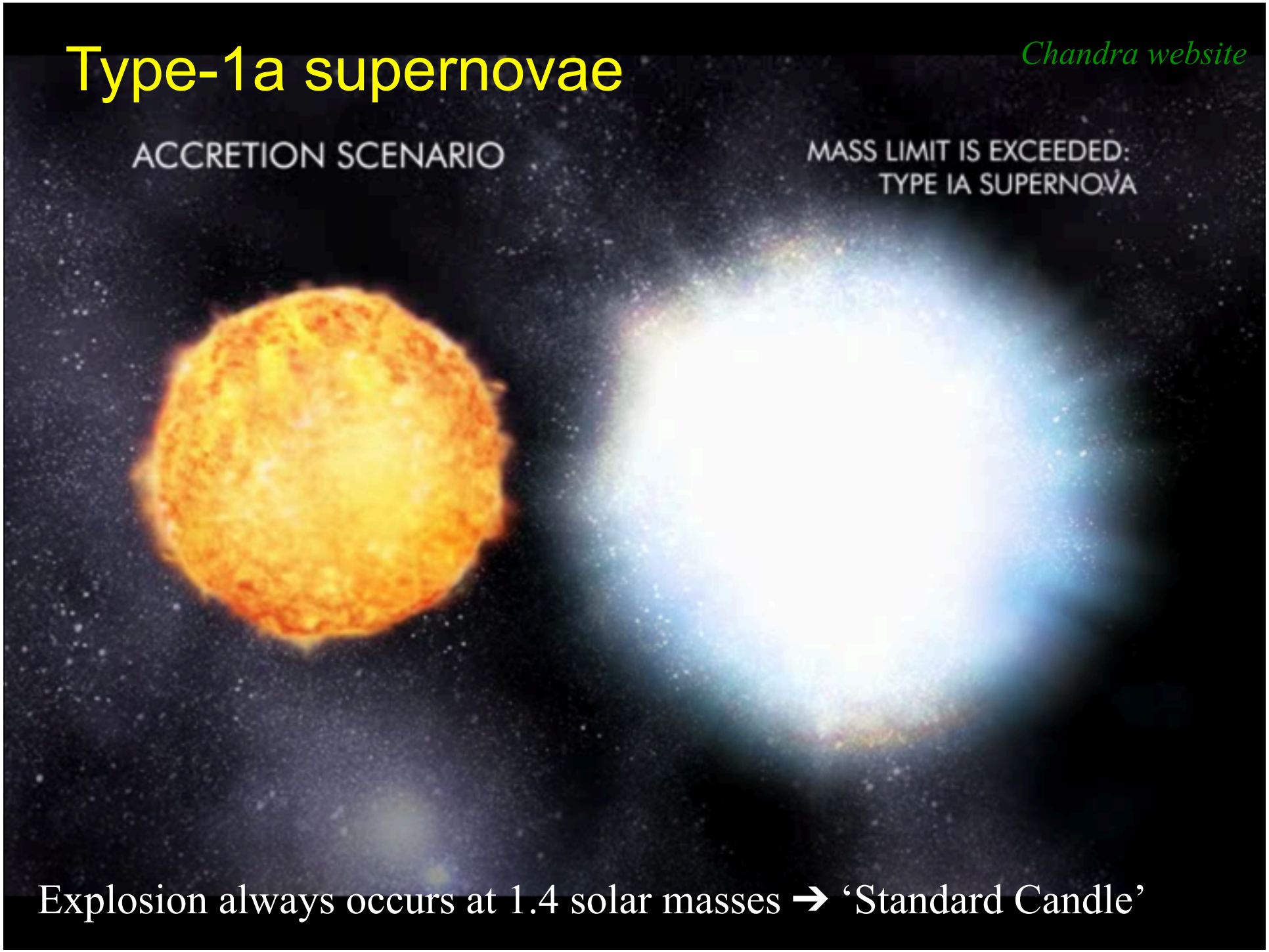
This ‘dark matter’ is fundamentally different to normal matter

We have theories of what this stuff might be, but its never been seen

Then came 1998...

Type-1a supernovae

Chandra website



Explosion always occurs at 1.4 solar masses ➔ ‘Standard Candle’

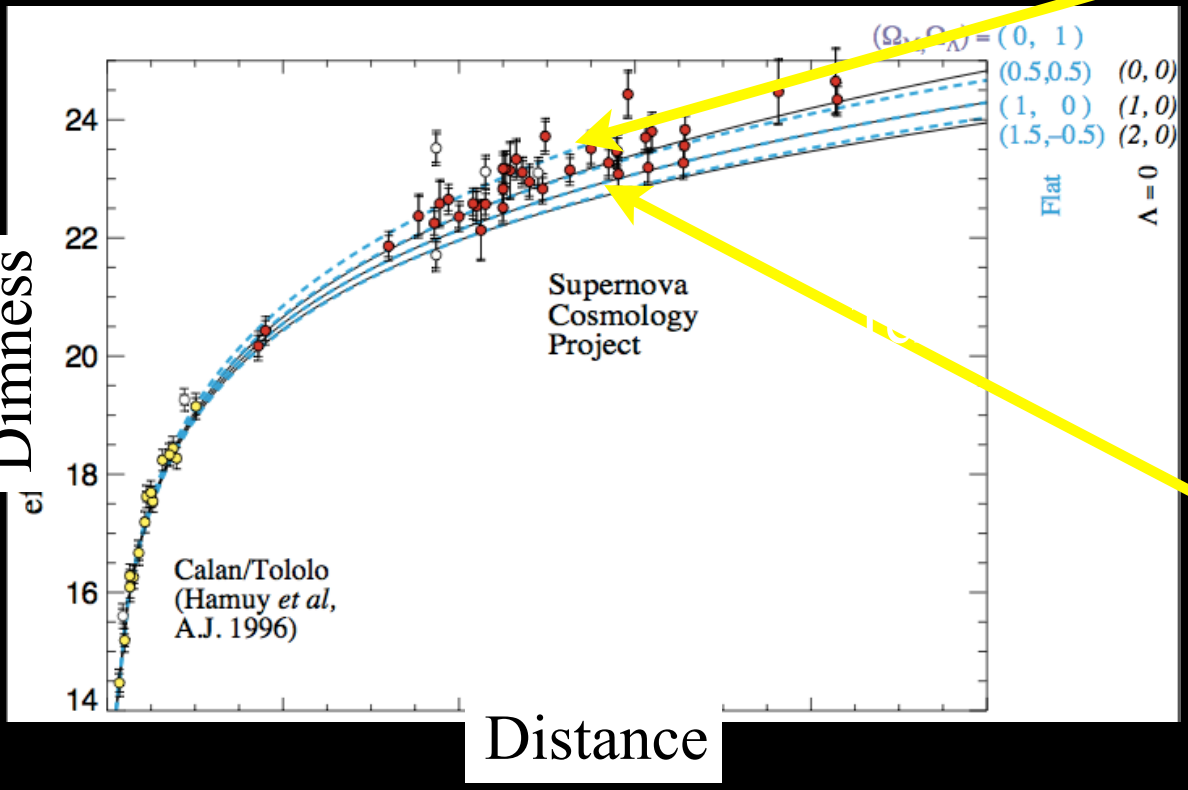
Standard Candles

...If all the candles are ‘standard’, their brightness tells us how far away they are...


Hubble Deep Field image
...The Universe is expanding
...Distant objects move away faster
...Doppler shift tells us how far away they are...

Distant Supernovae

SNe are dimmer than that ‘should’ be



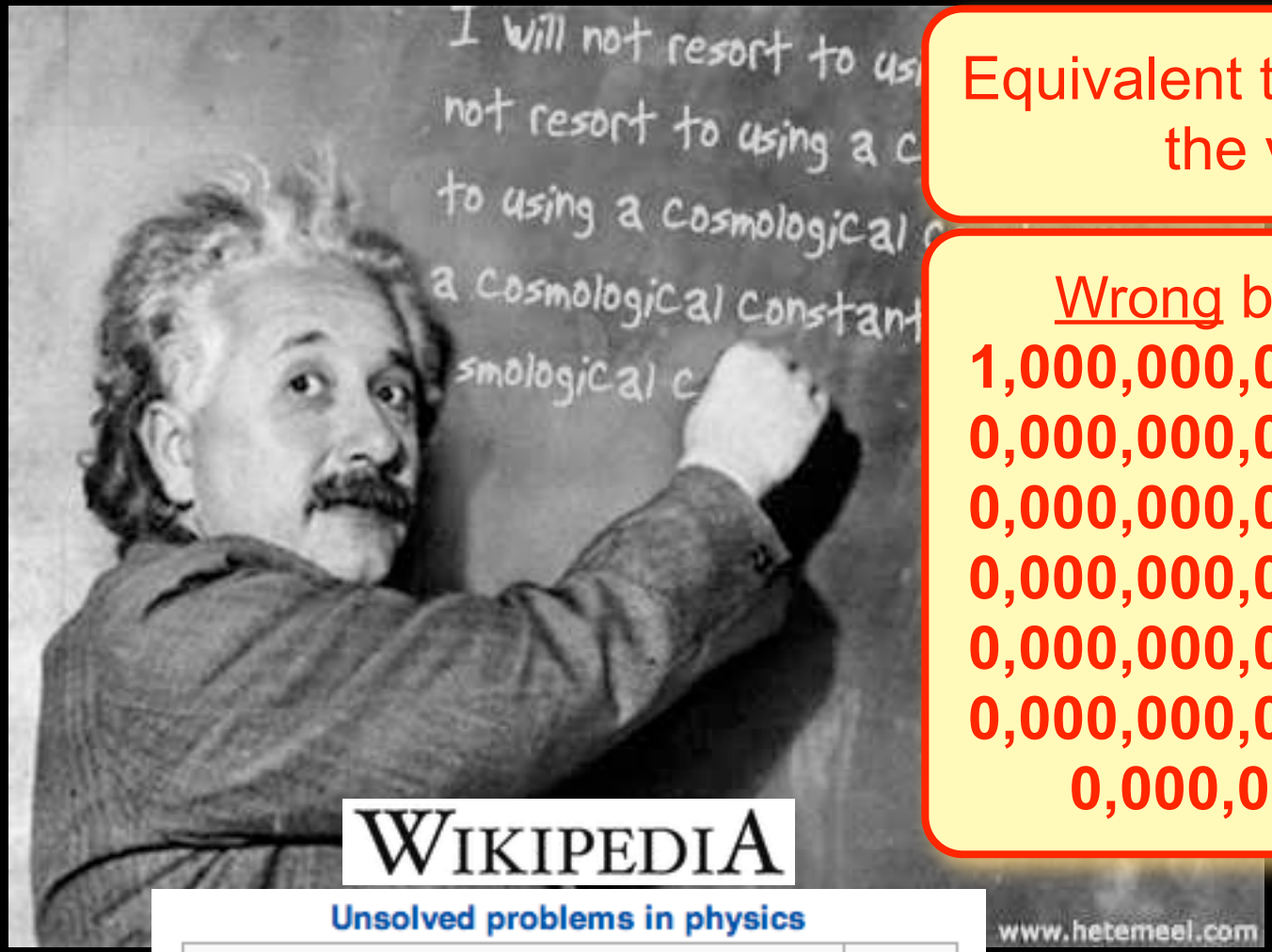
Where SNe would be if Universe is just ‘coasting’ after Big bang

Conclusion: There is ‘something’ pushing distant SNe away faster than expected

That ‘something’ is called *Dark Energy*

We have inklings of what this stuff might be...

A Cosmological Constant?



Equivalent to the energy of the vacuum

Wrong by a factor of
**1,000,000,000,000,000,00
0,000,000,000,000,000,00
0,000,000,000,000,000,00
0,000,000,000,000,000,00
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0,000,000,000,000,000,00
0,000,000,000,000**

WIKIPEDIA

Unsolved problems in physics

Why doesn't the zero-point energy of vacuum cause a large cosmological constant? What cancels it out?

‘Quintessence’

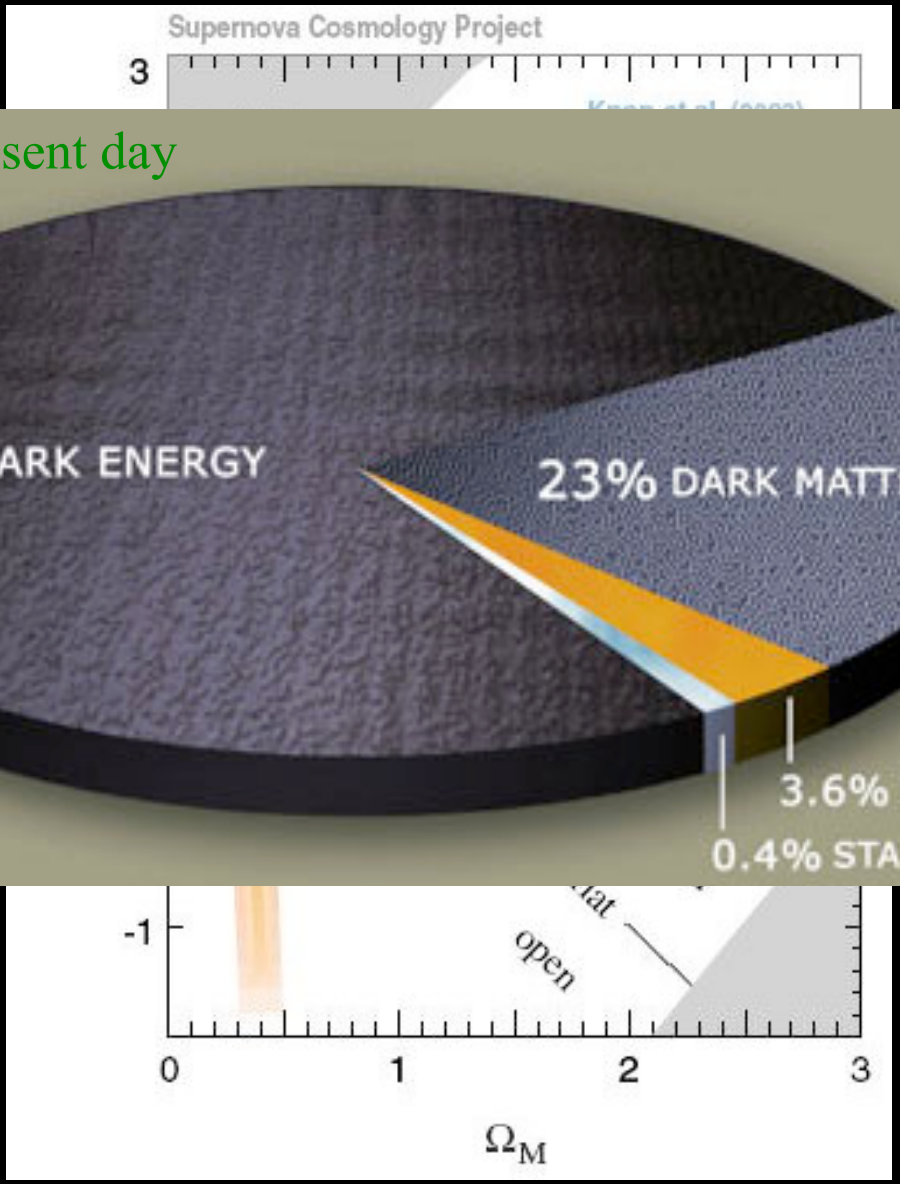
An extra ‘force’ in the Universe

A kind of ‘time-varying’ cosmological constant

Sort of, possibly, justified by supersymmetry

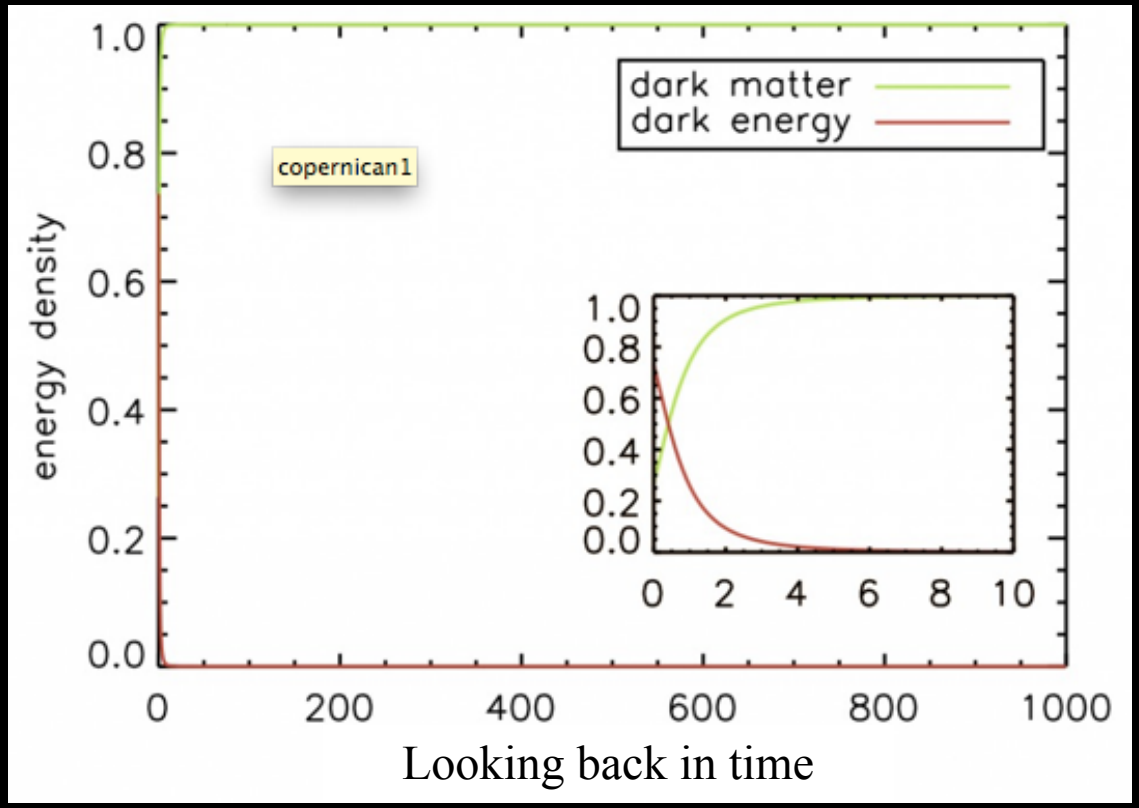
Observational data favour a Cosmological Constant ($w \approx -1$)

Summing it all up



Our Universe, present day

The ‘Why Now?’ Problem



‘Now’ appears to be a *very* special place in time

At any other time, either DM or DE dominates

Summary

We only know what ~4% of the Universe is.

We know next to nothing about ~73%

Our best theories suggest what we are seeing is incredibly unlikely

We have a good idea what another ~23% is

We predict (quite firmly) something completely at odds with observation

And this is called the era of ‘precision cosmology!’

This is an incredibly exciting time to be a scientist!