

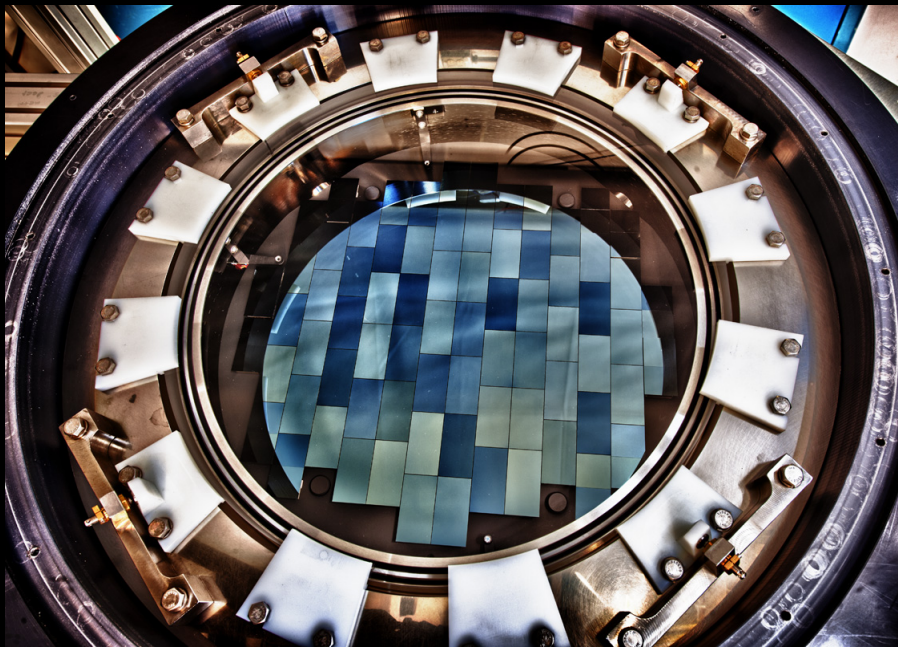
Can the World's Largest Digital Camera Answer Cosmological Questions?

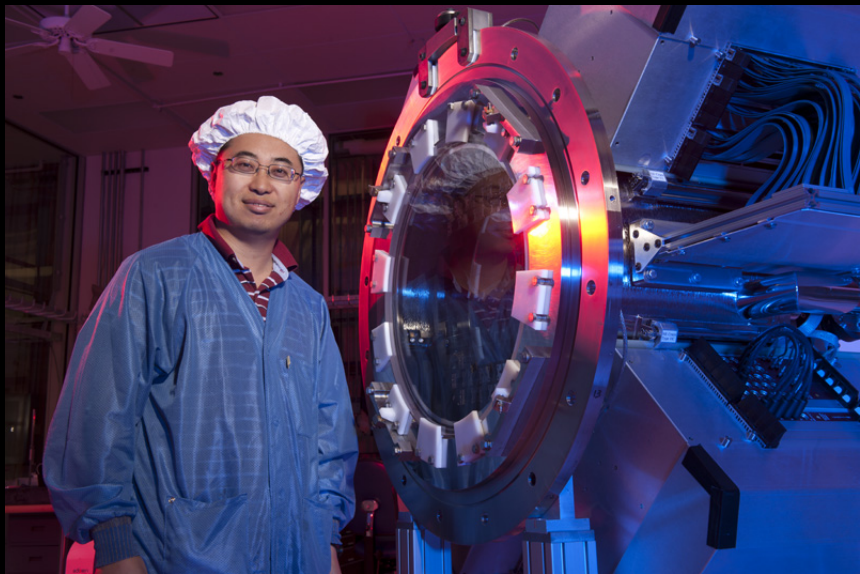
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Presentation to the Orwell Astronomical Society
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Find the presentation at <https://tinyurl.com/y7w542eb>

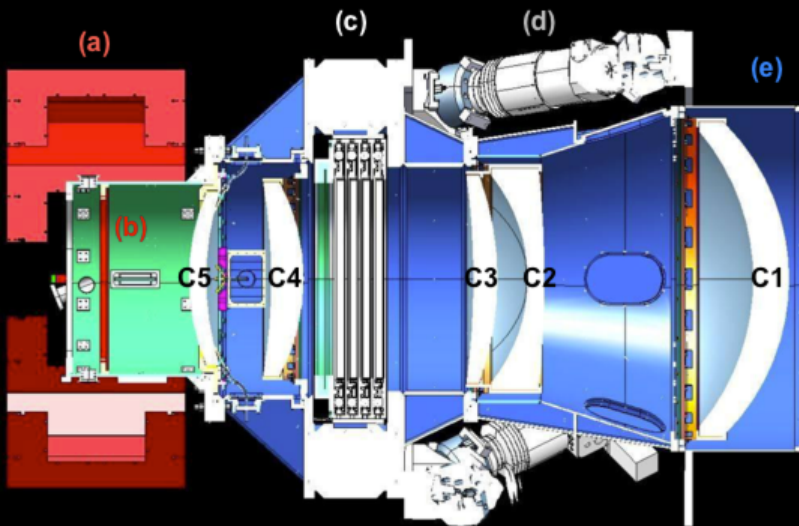




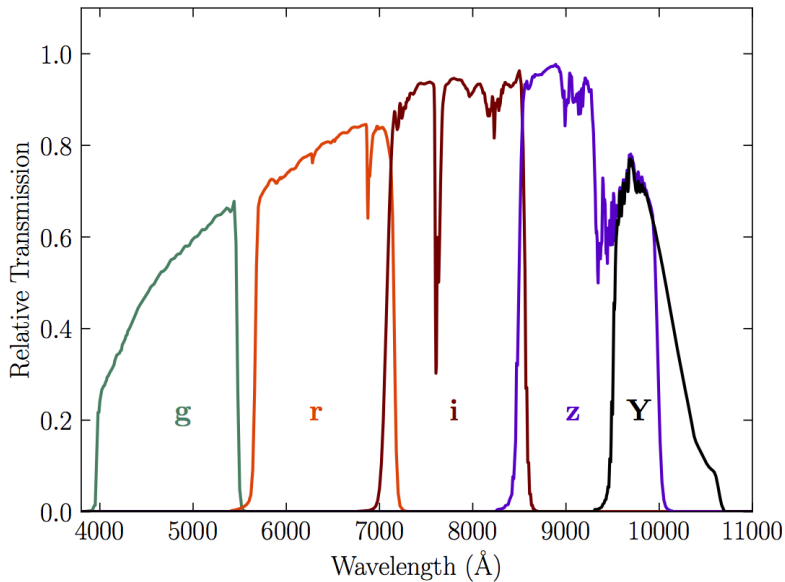
Detector

- ▶ Detector has 62 chips ('CCDs')
- ▶ Each CCD is 3 cm by 6 cm and has $2048 \times 4096 = 8$ megapixels
- ▶ Total of 500 megapixels.
- ▶ Each pixel is 15 microns square.
- ▶ The CCDs are unusually thick \implies more infrared light captured.
- ▶ Why do we want to capture infrared light?





- ▶ Detector is part of a camera called 'DECam'.
- ▶ Built in part at University College London.
- ▶ Five lenses - largest is 1m diameter.
- ▶ Five filters: green, red, and three infrared colours.







The Telescope

- ▶ The DECam camera is attached to the Victor Blanco Telescope at the Cerro-Tololo Inter-American Observatory in Chile
- ▶ 4m main mirror; $10m^2$ collecting area
- ▶ First light 1976; largest Southern Hemisphere telescope until 1998
- ▶ At 2200 m altitude
- ▶ Ritchey-Chrétien design

Optical system: Telescope plus camera

- ▶ The camera is at prime focus.
- ▶ f2.7
- ▶ Field of view: 2 deg diameter; $3deg^2$ area.
- ▶ 0.26 arcsec per pixel ('pixel scale').

Dark Energy Survey

- ▶ The camera is being used as part of a survey to collect information about the locations of many distant galaxies.
- ▶ We only care about distant galaxies. Milky Way stars, comets, nearby galaxies and so on are actually bad for us (as they block our view of distant objects).
- ▶ We only do statistical analysis on the data - we don't actually care about the details of any one particular object.
- ▶ Survey lasts six years - year six is just starting.
- ▶ Survey covers one-fifth of the entire celestial sphere.
- ▶ Each patch imaged ten times with each of the five filters.
- ▶ Each exposure is 90 seconds.
- ▶ TODO: What magnitude?

Dark Energy Survey

- ▶ The project involves over 400 scientists at 25 institutions in 7 countries.
- ▶ Funding is primarily from the U.S. Department of Energy.
- ▶ U.K. institutions are UCL and the Universities of Cambridge, Edinburgh, Portsmouth, Sussex and Nottingham.

Cosmological redshift

- ▶ It's easy to measure the sky coordinates RA and DEC of each object.
- ▶ But we also want to know how far away the object is, to place it properly in three-dimensional space.
- ▶ The expansion of the Universe 'stretches' lightwaves, making the wavelength longer (redder). This is 'cosmological redshift'.
- ▶ From the redshift we can infer the distance (more redshift \implies more distant).

Photometric redshifts

- ▶ If we could point a spectrograph at each object, then we could precisely measure the redshift noting how much the spectral lines have shifted.
- ▶ This would take too long!
- ▶ But we get some (very coarse) spectral information by measuring the brightness through each of the five filters.
- ▶ From this we can get a 'good enough' estimate of the redshift.
- ▶ What can go wrong: small old nearby red galaxy and large old distant blue galaxy are indistinguishable.

Why a survey?

- ▶ So what do we do with all these galaxy positions?

- ▶ Cosmology is the study of the Universe on its largest scales.

Cosmological questions

- ▶ Did the Universe have a beginning and if so old is it now?
- ▶ Is the Universe expanding and if so how fast?
- ▶ What types of matter and energy predominate in the Universe and what are their densities?
- ▶ What is the mass of the neutrino?

Cosmological questions that we don't work on

- ▶ How big is the Universe?
- ▶ What caused the Big Bang?
- ▶ Are there other Universes?

We (currently) have no tools to use to answer these questions.

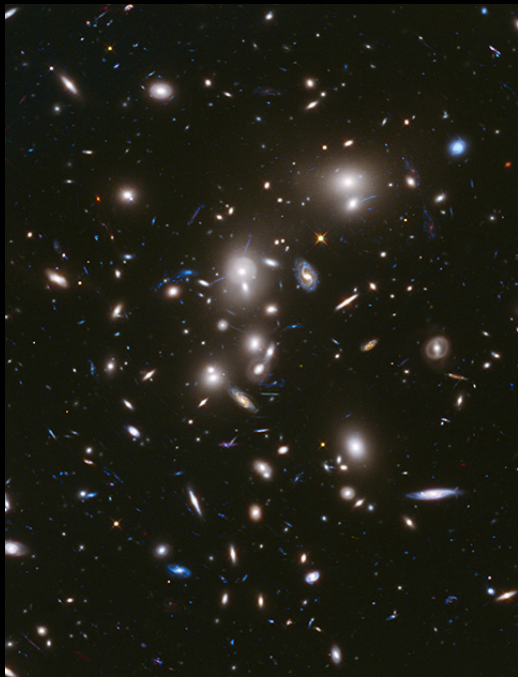
First principles

There is strong evidence that:

- ▶ There was a Big Bang - an initial hot and dense state - and the Universe has been expanding ever since.
- ▶ The Universe is more-or-less the same everywhere and we are not in a 'special' location.
- ▶ Einstein's theory ('General Relativity') correctly describes how gravity works.

So how can we answer these comological questions?

- ▶ One main method is to look at how 'clustered' galaxies are.
- ▶ Galaxies aren't randomly distributed through space - instead, they cluster together under the influence of gravity.



Clustering

- ▶ The older the Universe, the longer time gravity has had to operate, so the more clustering.
- ▶ The more stuff in the Universe, the more gravity, so the more clustering.
- ▶ The two effects are similar but distinguishable.

So here's the plan

- ▶ We agree on a definition of clustering.
- ▶ Theoretical astrophysicists calculate how much clustering they would expect for a range of ages and densities.
- ▶ Astronomers measure how much clustering there actually is.
- ▶ We match the results to see which age/density combination makes theory equal observation.

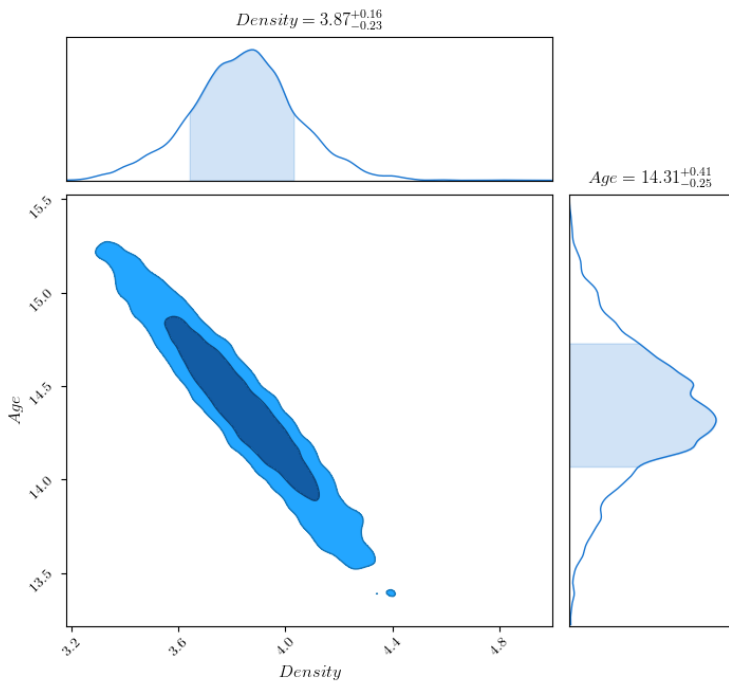


Clustering

- ▶ Measure the distance between each pair of objects. Expect to see lots of pairs with small separation.
- ▶ Draw a histogram of the results.
- ▶ Repeat using randomly positioned objects.
- ▶ Look at the percentage difference between the two histograms.

Conclusions of our exercise

- ▶ Universe is about 14 billion years old.
- ▶ Density of matter is about 4 g per Jupiter volume.



What types of stuff?

- ▶ Our actual analysis is more complicated.
- ▶ The theoreticians actually create clustering graphs for a huge range of densities for different possible types of 'stuff'.

Dark matter

- ▶ They include the possibility that some of the matter doesn't interact with light.
- ▶ Such 'dark matter' doesn't cluster as easily as ordinary matter. [Why not?](#)
- ▶ This gives a recognisable signature in the clustering graph.

Dark energy

- ▶ They also include the possibility that empty space itself has some mass.
- ▶ This mass is called 'dark energy'.
- ▶ This mass is everywhere, and can't cause clustering.

Conclusions

- ▶ If we throw all these stange things into the range of possibilities, then we find that the best match to the observed clustering is:
- ▶ Age of Universe = 14 billion years (as before).
- ▶ Of the 4.3 g per Jupiter volume of matter, only 0.7 g is normal matter (basically hydrogen and helium) and 3.6 g is dark.
- ▶ As well, empty space has a mass of 9 g per Jupiter volume.

Dark Energy

- ▶ Dark energy is not well understood.
- ▶ Normally you must expend energy to increase a volume (think of the piston on a steam locomotive).
- ▶ But dark energy *increases* as space expands. Thus we say that dark energy has a *negative* pressure.

Cosmic acceleration

- ▶ Analysis of the Dark Energy Survey results shows that this pressure is exactly the negative of the energy density (the two quantities have the same units).
- ▶ This negative pressure causes an *acceleration* in the expansion of space.
- ▶ This acceleration was first observed in the 1990s.
- ▶ The acceleration has been slowly building for the last five billion years.
- ▶ This will dominate the future Universe - in the distant future our galaxy will have no near neighbours.

Further reading

DES book

DES public data

Systematic errors?