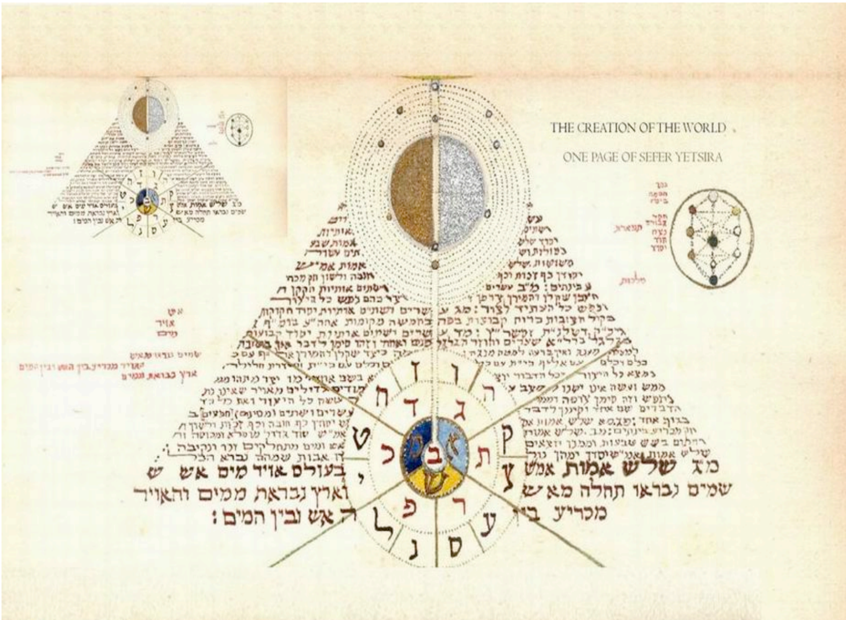
The RAS Gerald Whitrow Lecture 2014

The enigma of Dark Matter & Dark Energy: have we been here before?

Ofer Lahav (UCL)



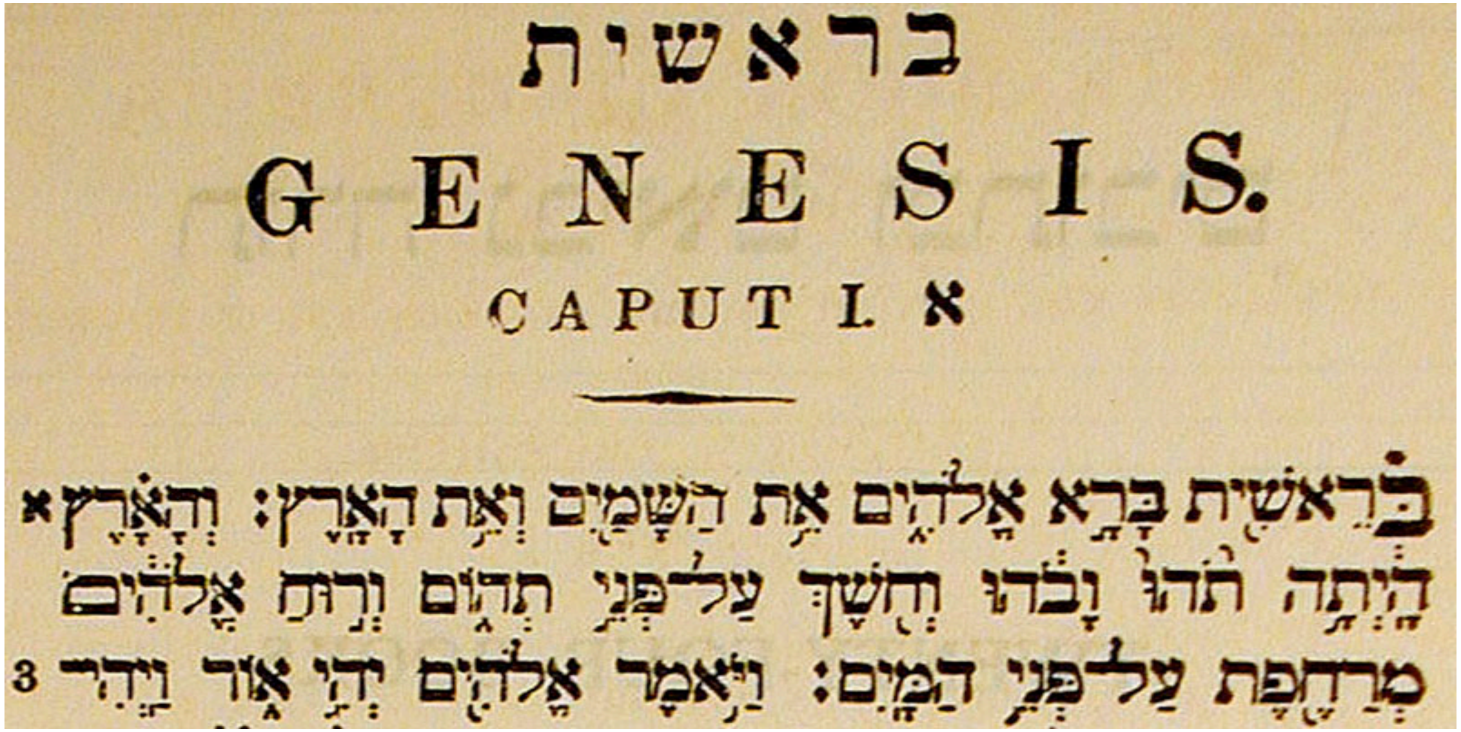
Gerald Whitrow (1912-2000)

- Mathematician, cosmologist and science historian (at Imperial College)
- Published five books, including
  The Natural Philosophy of Time
- Extragalactic Background paper (Whitrow & Yallop 1964)
- Previous GW Lectures(2001-2012):
  J. Barrow, P. Davies, C. Frenk, G. Ellis,
  A. Vilenkin, A. Liddle

Outline

- Dark Matter & Energy as of 2014
- The pre-SN paradigm shift to DE
- Have we been here before?
  - Newton's linear force
  - Neptune and Mercury
- Globalization: do we over-interact?
- The cognitive limit of collaboration size

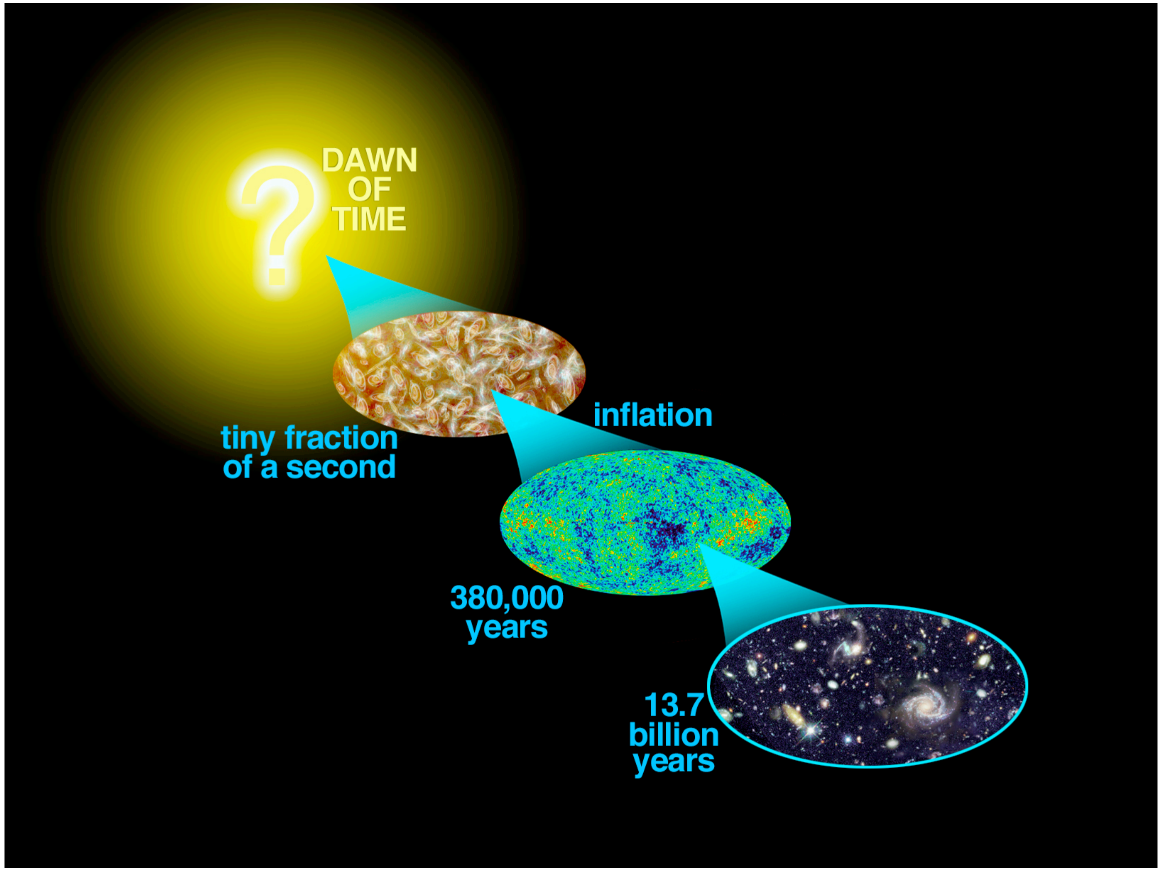
At the beginning …



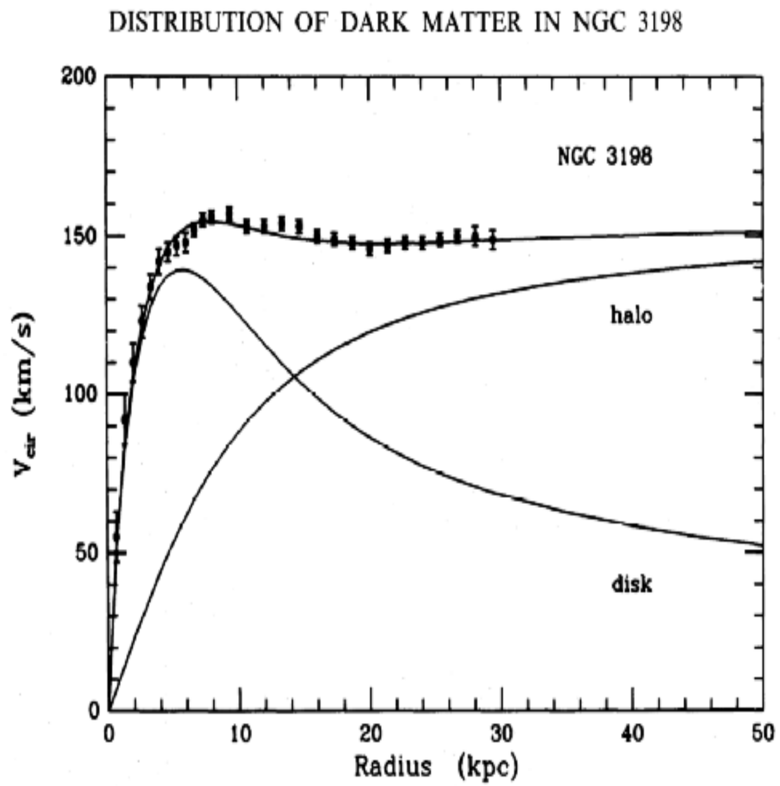
History of Cosmology

Era	Size of Universe	Age of Universe	Speed of light
Ancient	10^8 km	10^4 years	infinite
1900	10^{17} km	infinite	3×10^5 km/sec
Now	$>10^{23}$ km	13.7 Gyr	3×10^5 km/sec

The pillars of the Big Bang theory: galaxy recession, the CMB, light elements

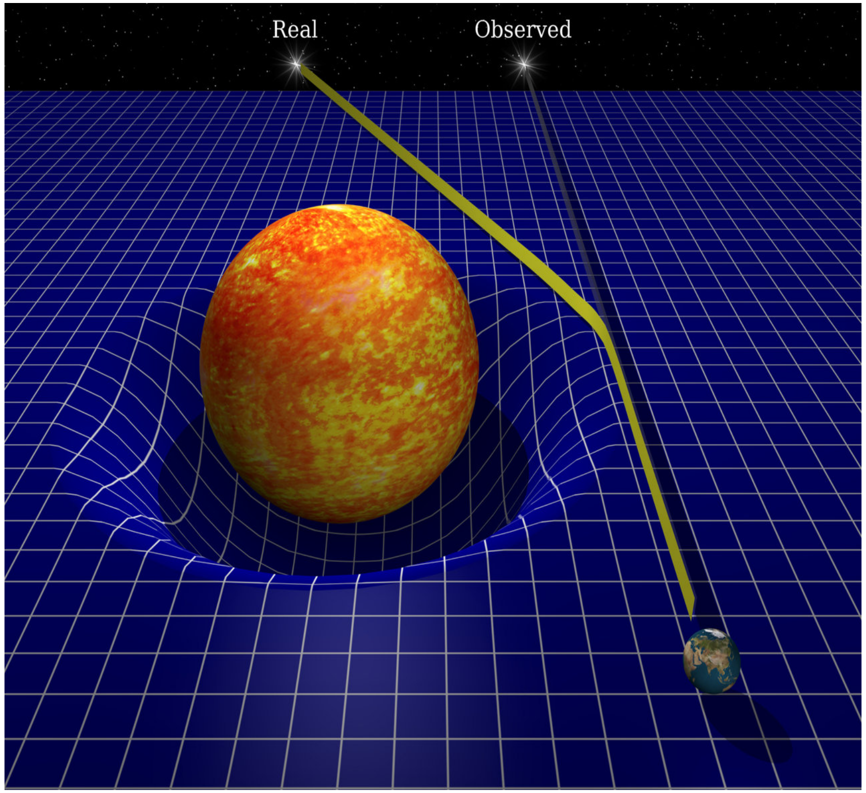


Rotation curves of spirals are flat: dark matter halos or modified gravity?



Vera Rubin et al. (1970s)

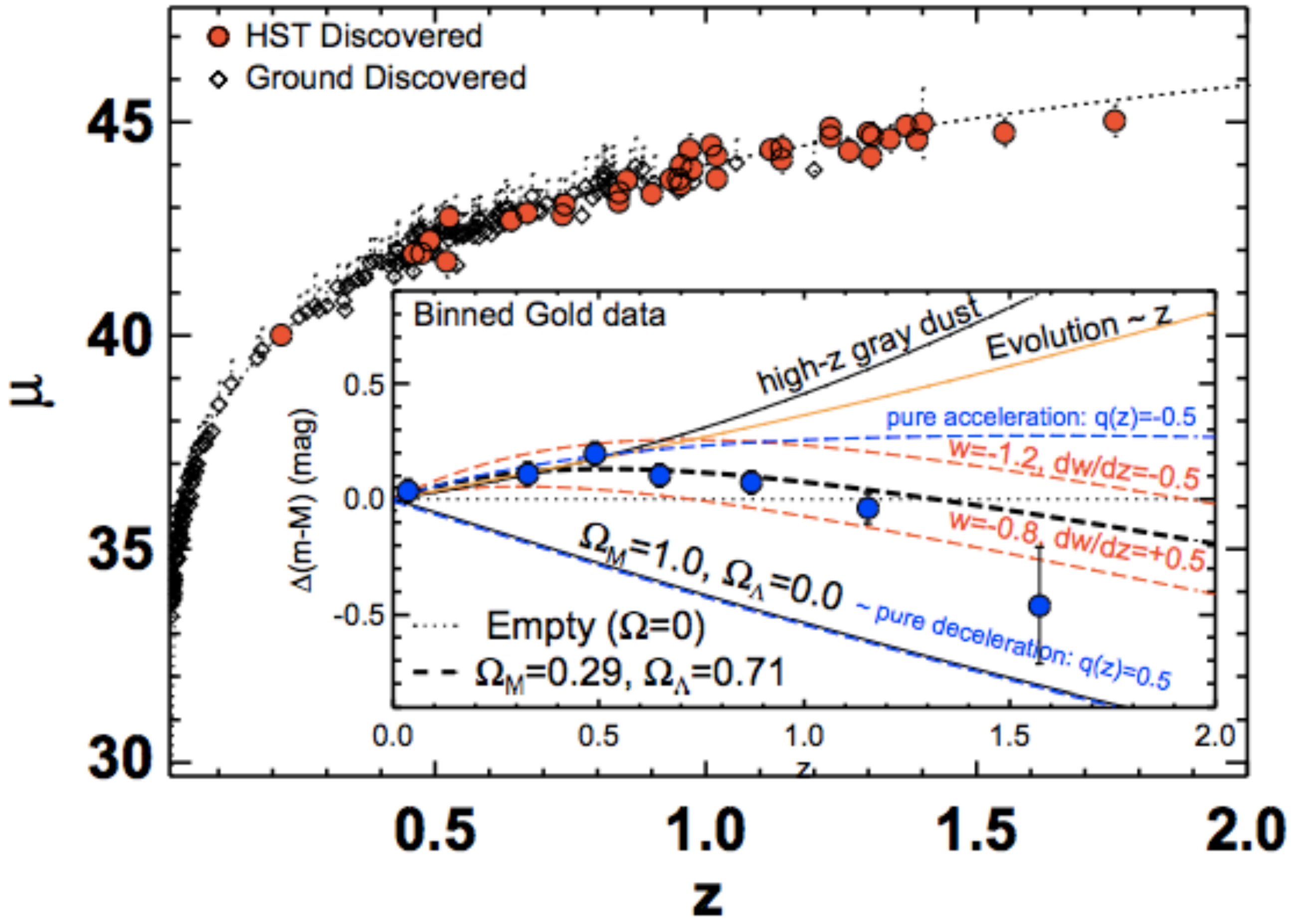
Gravitational Lensing: Confirms the dark matter problem in clusters as noted by Zwicky (1930s)



Cluster of galaxies observed with the Hubble Space Telescope (CLASH)

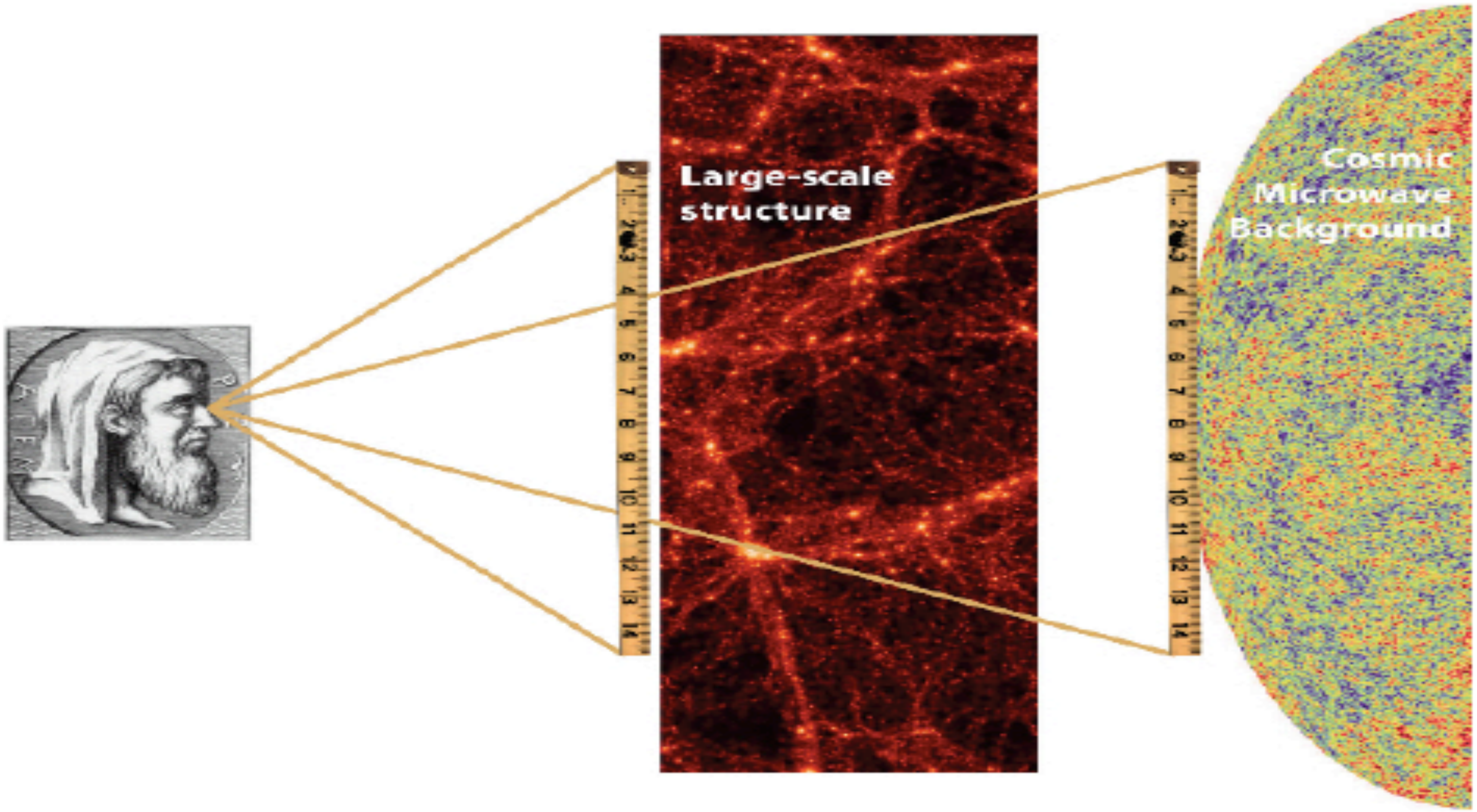
SN2014J
Discovered at UCL's Observatory (ULO) at Mill Hill (Fossey et al.)

Using standard candles to measure dark energy

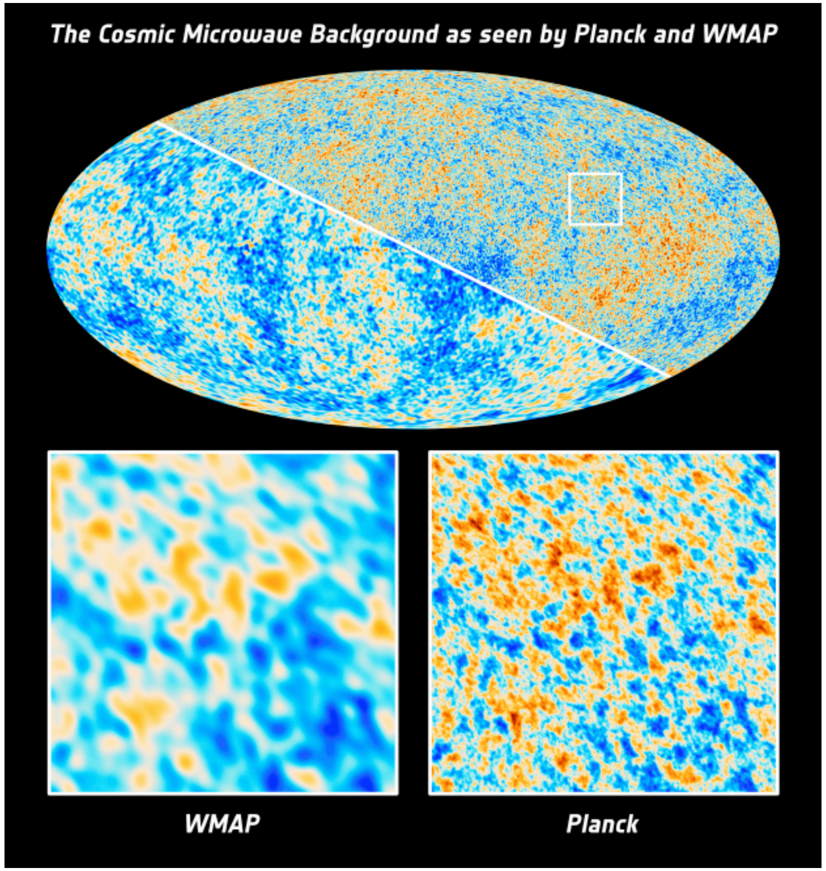


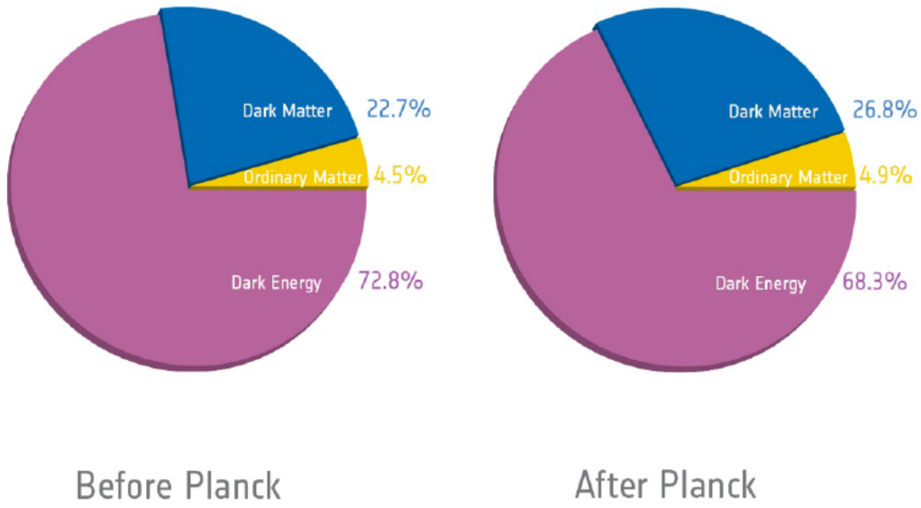
Riess et. al. (2007)

Standard rulers – Baryonic Acoustic Oscillations (detected by 2dF and SDSS in 2005)

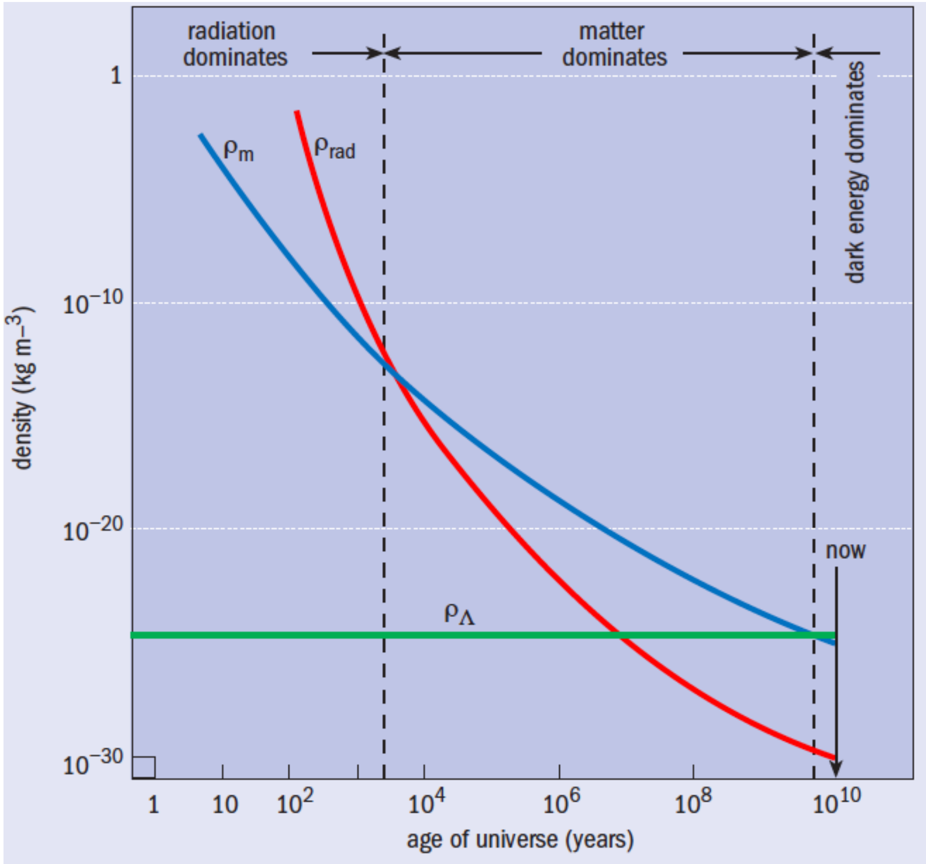


Planck CMB 2013





The Evolution of Matter, Radiation and Lambda

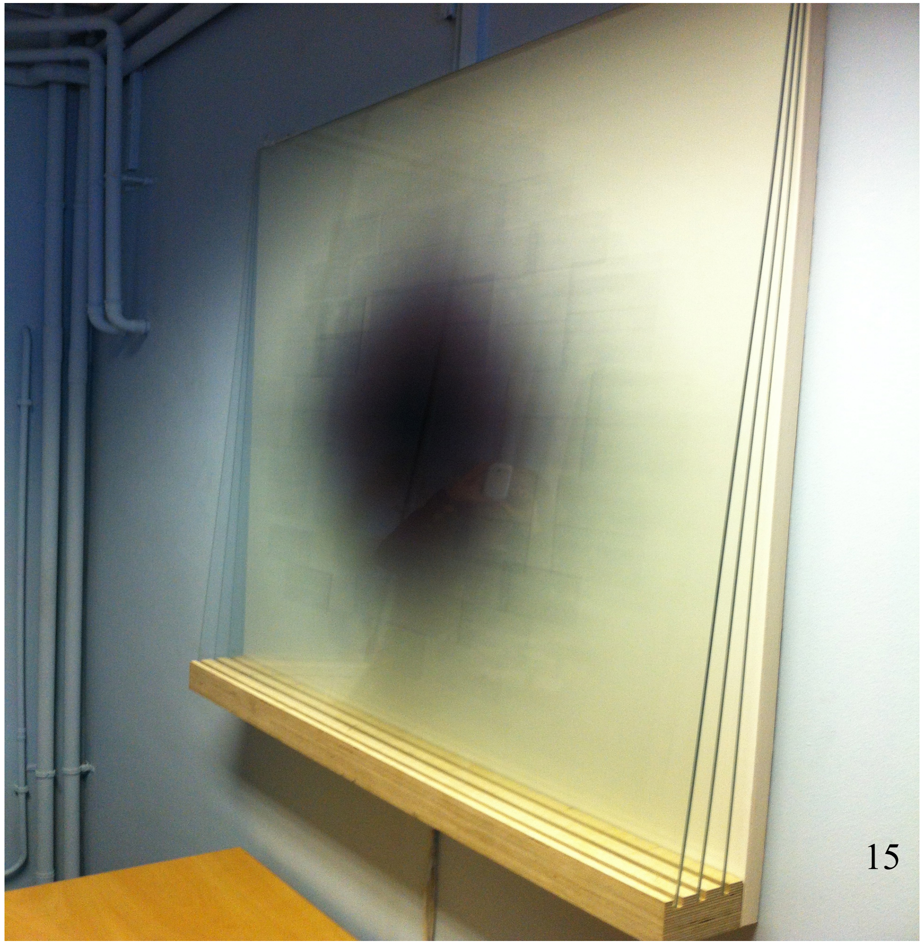


So what is Dark Energy?

- Systematics mimic DE?
- Lambda-CDM, EoS w = -1.00?
- Dynamical scalar field w(z)?
- Signatures of modified gravity?
- Inhomogeneous Universe?
- Multi-verse?
- Something else unpredictable??

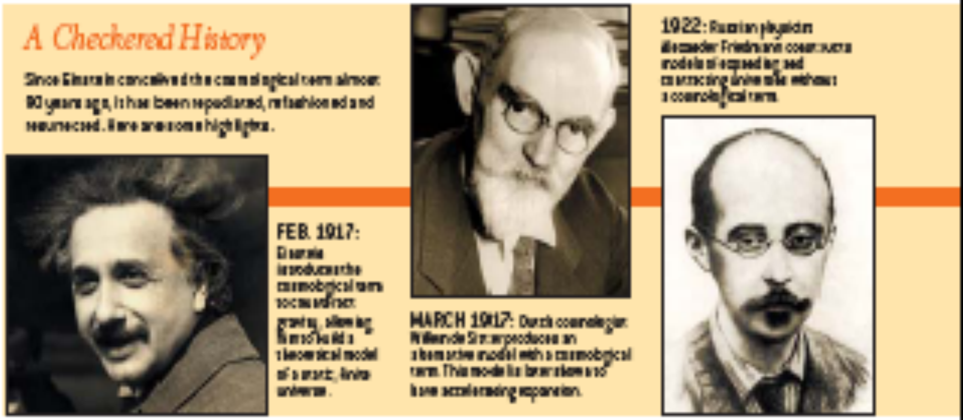
Planck CMB results support LCDM:
“an almost perfect universe”
or “a simple but strange universe”?

DES-inspired artwork by Marie Kaus, on display at UCL's Mill Hill Observatory



Dark Energy found

The Chequered History of the Cosmological Constant Λ



The old problem:
Theory exceeds observational limits on Λ by 10^{120} !

New problems:
- Is Λ on the LHS or RHS?

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- Why are the amounts of Dark Matter and Λ so similar?

Pre-Supernovae paradigm shift to LCDM

- Peebles (1984) advocated Lambda
- APM result for low matter density (Efstathiou et al. 1990)
- Dynamics with Lambda (OL et al. 1991)
- Baryonic fraction in clusters (White et al. 1993)
- The case for adding Lambda (Ostriker & Steinhardt 1995)

Lucy Calder & OL (A&G 2008, Physics World 2010)

Pre-SN papers on Lambda

TESTS OF COSMOLOGICAL MODELS CONSTRAINED BY INFLATION

P. J. E. PEEBLES
Joseph Henry Laboratories, Princeton University
Received 1984 February 6; accepted 1984 March 23

ABSTRACT

The inflationary scenario requires that the universe have negligible curvature along constant-density surfaces. In the Friedmann-Lemaître cosmology that leaves us with two free parameters, Hubble's constant H_0 and the density parameter Ω_0 (or, equivalently, the cosmological constant Λ). I discuss here tests of this set of models from local and high-redshift observations. The data agree reasonably well with $\Omega_0 \sim 0.2$.

Subject heading: cosmology

letters to nature
Nature **348**, 705 - 707 (27 December 1990); doi:10.1038/348705a0

The cosmological constant and cold dark matter

G. EFSTATHIOU, W. J. SUTHERLAND & S. J. MADDOX
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THE cold dark matter (CDM) model[1–4] for the formation and distribution of galaxies in a universe with exactly the critical density is theoretically appealing and has proved to be durable, but recent work[5–8] suggests that there is more cosmological structure on very large scales ($l > 10\ h^{-1}$ Mpc, where h is the Hubble constant H_0 in units of 100 km s^{-1} Mpc^{-1}) than simple versions of the CDM theory predict. We argue here that the successes of the CDM theory can be retained and the new observations accommodated in a spatially flat cosmology in which as much as 80% of the critical density is provided by a positive cosmological constant, which is dynamically equivalent to endowing the vacuum with a non-zero energy density. In such a universe, expansion was dominated by CDM until a recent epoch, but is now governed by the cosmological constant. As well as explaining large-scale structure, a cosmological constant can account for the lack of fluctuations in the microwave background and the large number of certain kinds of object found at high redshift.

Scientific Paradigm

Thomas Kuhn

The Structure of Scientific Revolutions

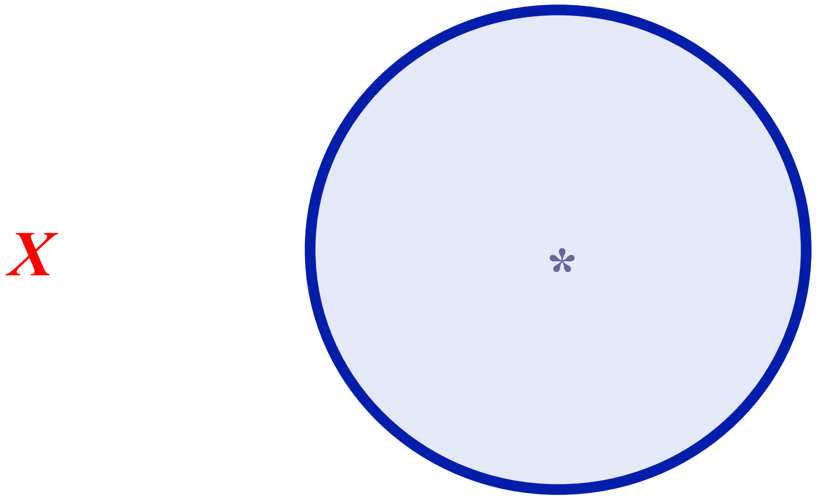
- Science undergoes periodic "paradigm shifts”, instead of progressing in a linear and continuous way.

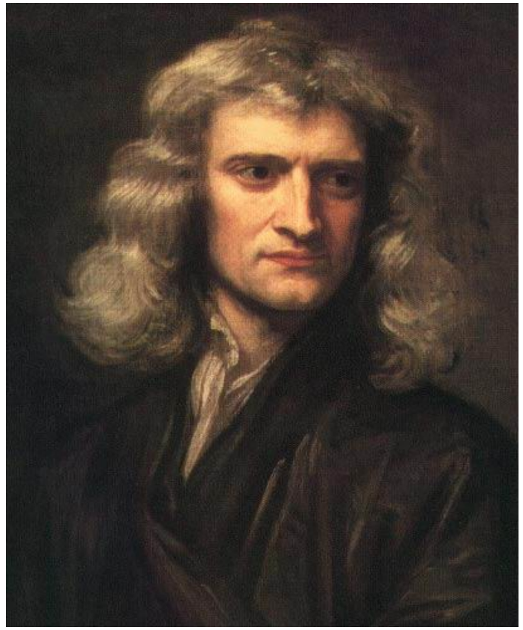
- Scientists can never divorce their subjective perspective from their work; thus, our comprehension of science can never rely on full "objectivity" - we must account for subjective perspectives as well.

The Dark Energy problem: 15, 100 or 330 years old?

The weak field limit of GR:

$$F = -GM/r^2 + \Lambda/3\ r$$





"I have now explained the TWO principle cases of attraction… which is very remarkable"
Isaac Newton, *Principia (1687)*

Lucy Calder & OL
A&G Feb 08 issue
http://www.star.ucl.ac.uk/~lahav/CLrev.pdf (revised)

Weighing the Local Group in the presence of Dark Energy

Partridge, OL & Hoffman

(MNRAS Letters, arXiv:1308.0970)

- At present the Milky Way and Andromeda are:
  - * separated by $r = 770 \pm 40$ kpc
  - * infall at $v = -109 \pm 4$ km/sec

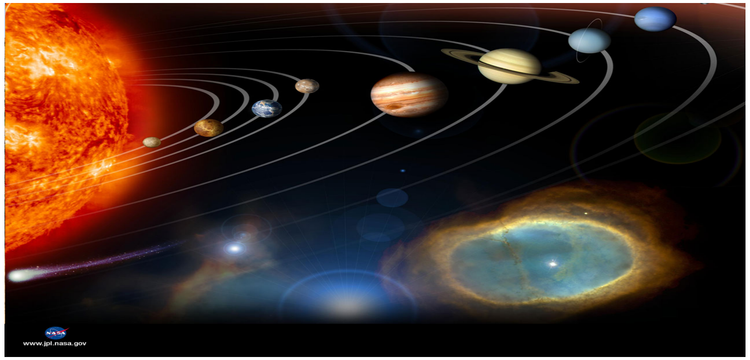
  (Van der Marel 2012)
- Given the age of the universe $t = 13.81 \pm 0.06$ Gyr and Dark Energy fraction of 69% (Planck 2013) we find that the mass is $(4.73 \pm 1.03) \times 10^{12}\ M_{sun}$
- Mass 13% higher than in the absence of Lambda

  cf. Kahn & Woltjer 1959; Lynden-Bell 1981

  Chernin et al. 2009, Binney & Tremaine 2008

Dark Matter or Modified Gravity?

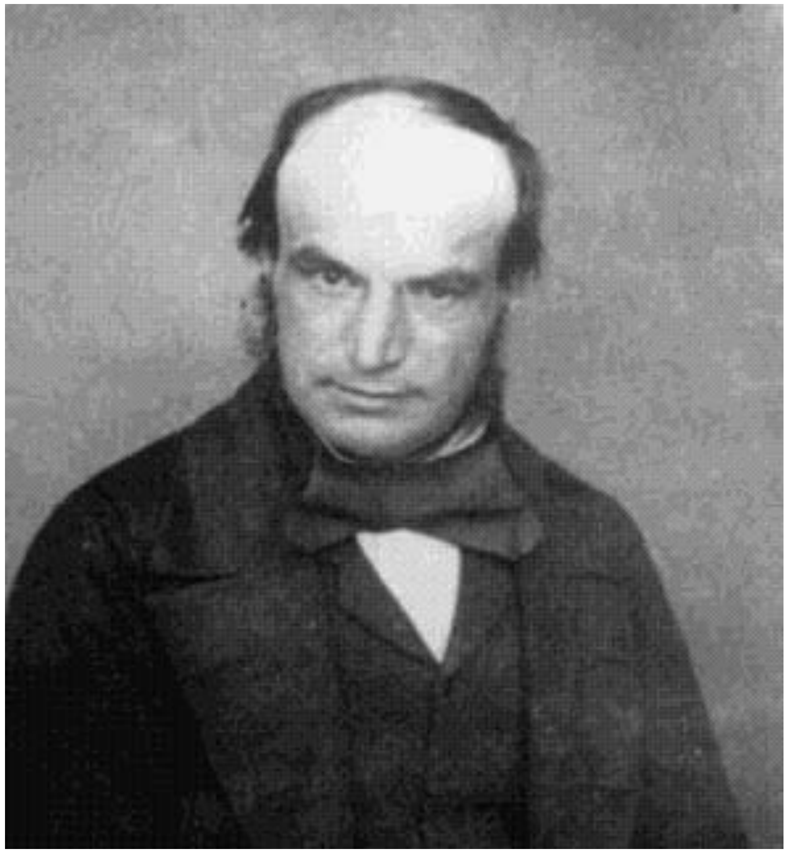
- "Dark Matter": Neptune (discovered 1846)- predicted to be there based on unexplained motion of Uranus.
- "Modified Gravity": Mercury's precession- a new theory (Einstein's General Relativity, 1917) required to explain it.



Predicting Neptune (discovered 1846)

Urban Le Verrier
(1811-1877)

John Couch Adams
(1819-1892)



New Entity or New Theory?

Phenomenon	New Entity	New theory
Uranus' orbit	Neptune	(Bessel's specific gravity ruled out)
Mercury's orbit	(Hypothetical planet Vulcan ruled out)	General Relativity
Beta decay	Neutrino	(violation of angular momentum ruled out)
Galaxy flat rotation curves	Dark Matter?	Modified Newtonian Dynamics?
Accelerating universe (SN Ia and other data)	Dark Energy?	Modified General Relativity?

Michela Massimi & OL (A&G, June 2014)

Philosophical views on Neptune's case

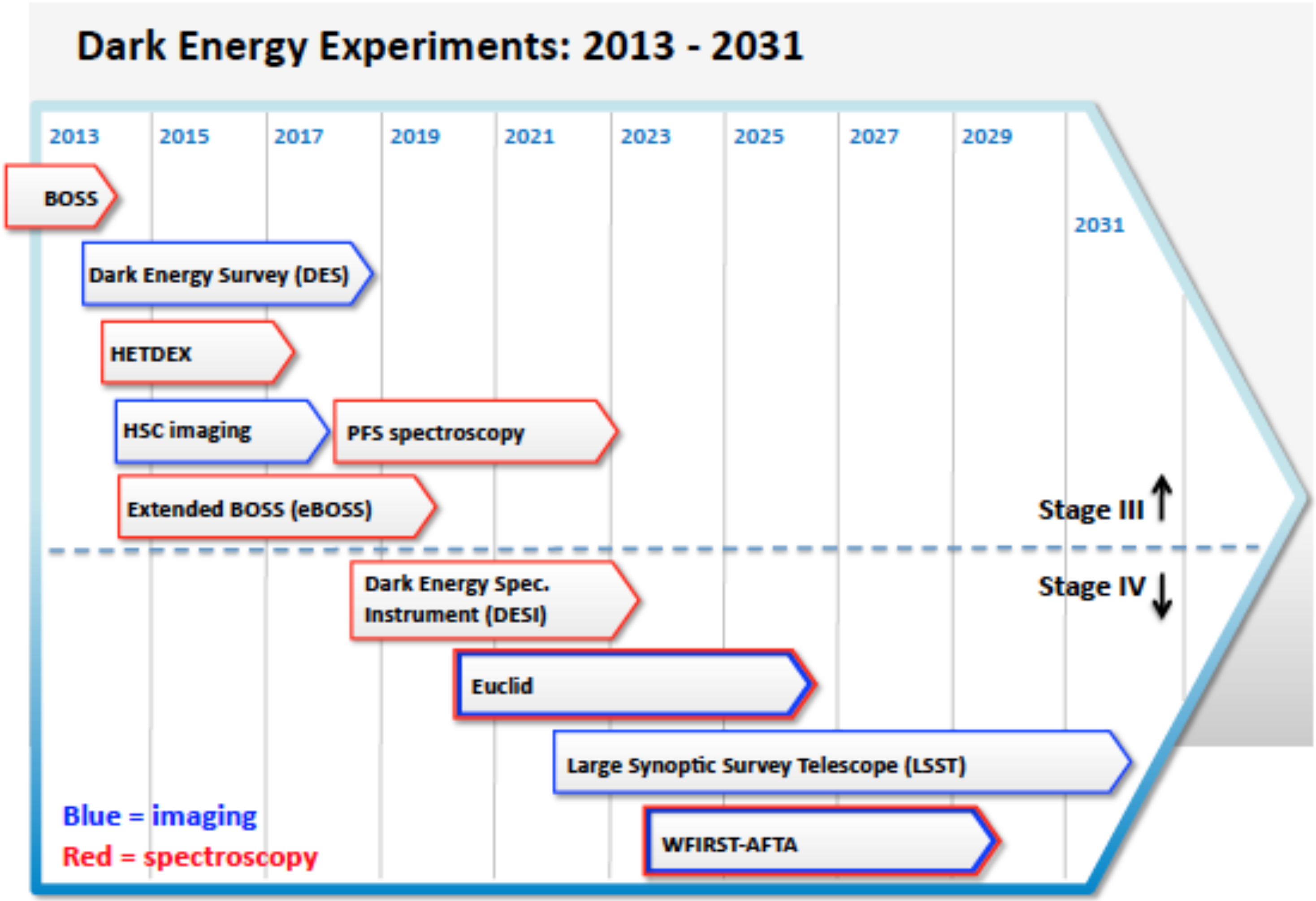
- Karl Popper (1974): Adams and Le Verrier attempted to shelter Newton's theory from falsification.
- Imre Lakatos (1970): 'research programm' includes 'hard core' and 'protective belts'.
- Piere Duhem (1906): Scientists follow their 'good sense' when facing such dilemmas.

Hot Dark Matter vs. Cold Dark Matter

During the Cold War era
in the 1970s and early 1980s:
Hot Dark Matter/top-down (Zeldovich et al) vs.
Cold Dark Matter/bottom-up (Peebles et al.)
Note HDM exists (massive neutrinos), CDM probably exists…

Is the agreement on the LCDM `concordance model' a product of Globalisation?
Do we over-interact at present?

OL, astro-ph/0610713



About $1 per galaxy!

The Dark Energy Survey

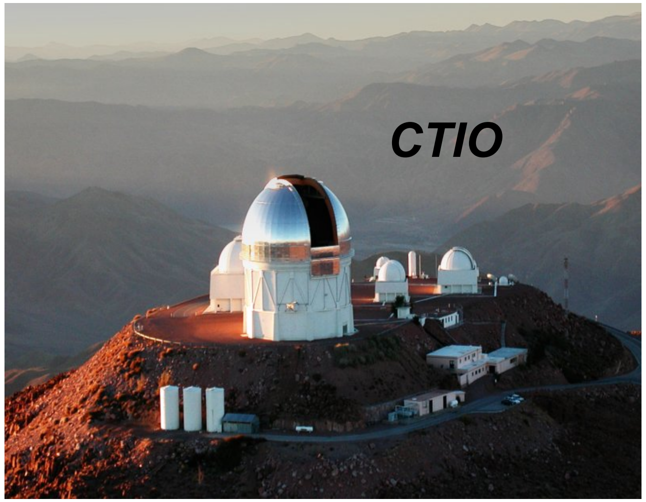
First Light in 9/12, First season 9/13 – 2/14

- Multi-probe approach

  Cluster Counts
  Weak Lensing
  Large Scale Structure
  Supernovae Ia

- Survey strategy

  200 million photometric redshifts (grizY) over 5000 deg^2
  + 4000 SN Ia (30 deg^2 fields)
  + *JHK* from VHS
  +SPT SZ clusters + OzDES spectra + …



How many collaborators can one have?

2dF: 30
DES: 300
Planck:400
Euclid: 1000
LHC: 4000

NAM: 600

Within the primates there is a general relationship between the size of the brain and the size of the social group. Scaling it to humans gives 150 people. This is the cognitive limit to the number of people with whom one can have stable interaction (Dunbar 1992).

Thanks to UCL's cosmologists for many discussions

Discussion

- Exciting times in Dark M & E research: are new entities or new theories needed?
- Historical case studies give insight into present research.
- Cosmology is undergoing an ‘industrial revolution’ – with pros and cons.
- Funding should allow more diversity for thinking ‘outside the box’.