Cosmology

from ground based surveys

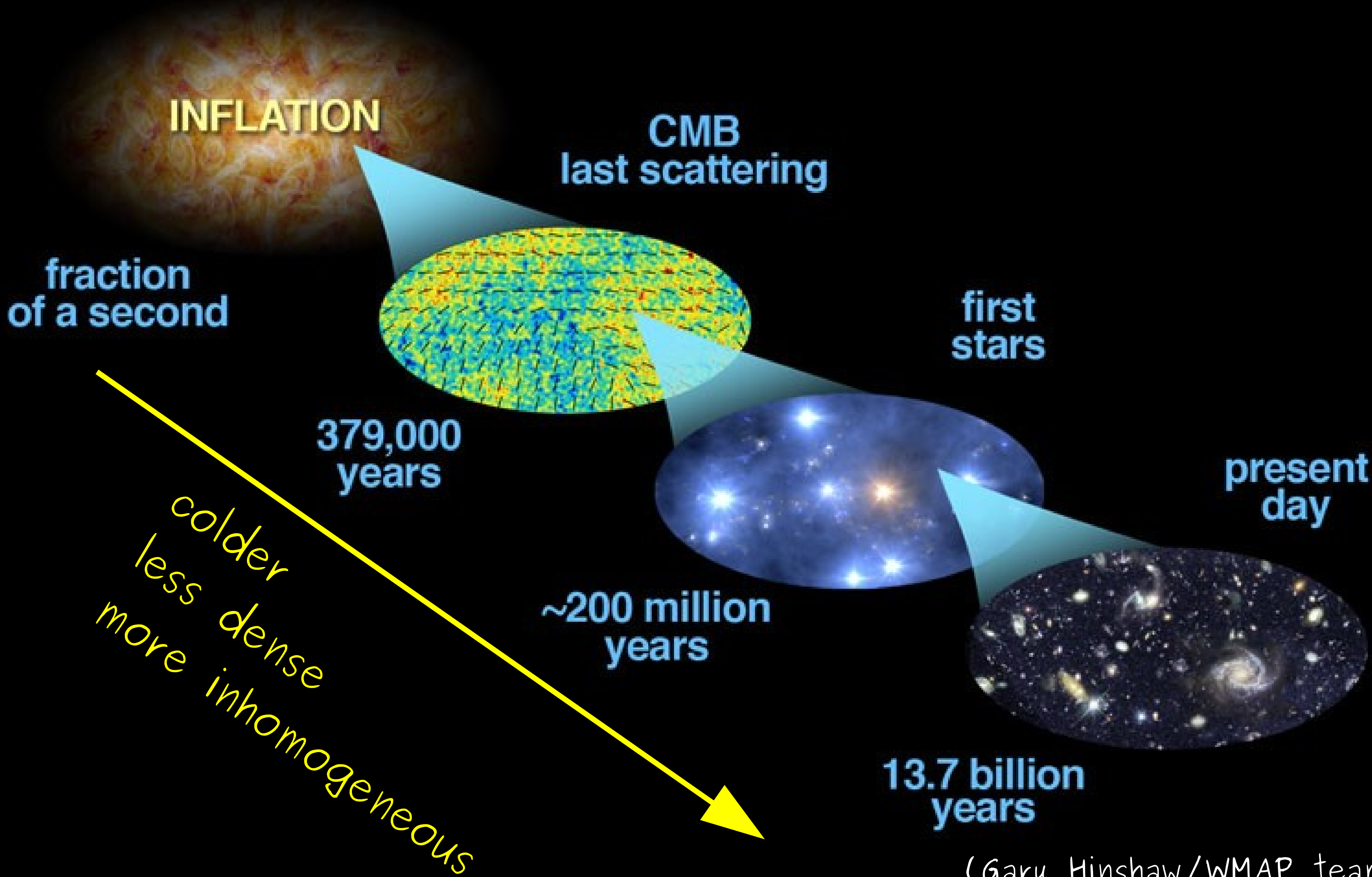
Recontres de Blois 2010

Anže Slosar, BNL

Introduction

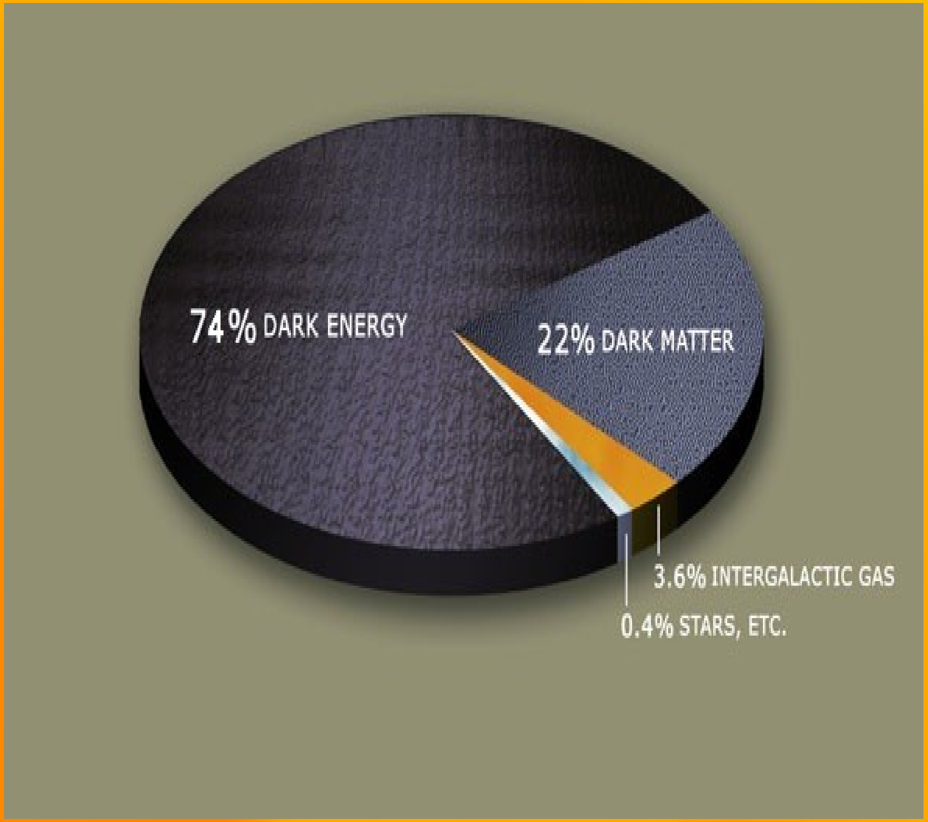
* What can cosmology tell you
* What are the relevant buzzwords
* Cosmological parameters:
  - some we know
  - some we want to know
  - some we don't care

Evolution of the Universe



(Gary Hinshaw/WMAP team)

The Dark Sector



- To make it work, we need dark sector
- Dark matter:
    - Cold, pressureless, non-interacting stuff
    - Collapses under its own gravity
- Dark energy:
    - Drives accelerated expansion of the Universe

Standard cosmological model

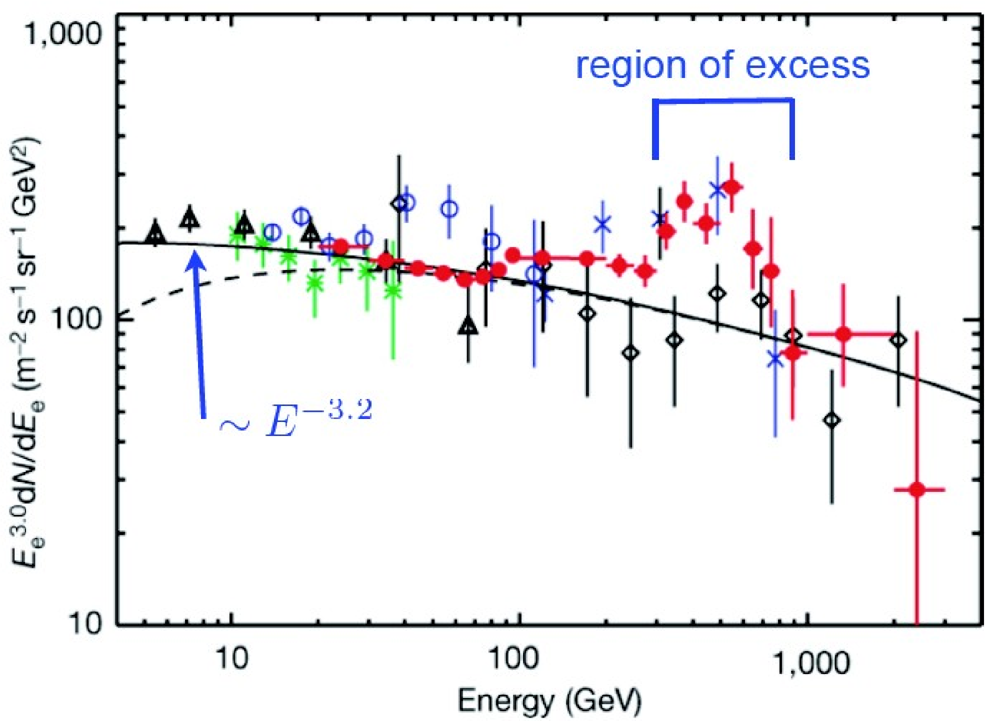
- General macroscopic picture well understood
- The microscopic picture and relation to the fundamental physics remain to be understood:
  - What is the nature of dark matter and dark energy?
  - How the dark sector fits with the standard model of particle physics
  - Does gravity obey general relativity on all scales and at all energies?
  - How did it all begin? Is inflation an accurate description of the early universe?

Measuring the Universe

- Homogeneous expansion:
  - Measures content and geometry of the Universe
  - BBN, CMB peak positions, BAO, supernovae
- Growth of structure:
  - CMB peaks, galaxy power spectra, RS distortions, Lyman-alpha forest
- GR requires consistency between the two

PAMELA, ATIC, etc

- Interesting, but absolutely no control over gastrophysics.
- Stuff in this talk can be made robust.



J. Chang *et al.* Nature **456** 362-365 (2008)

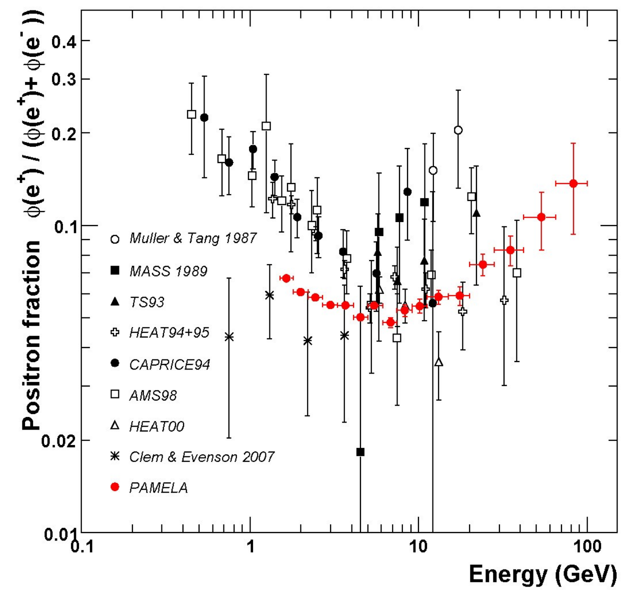
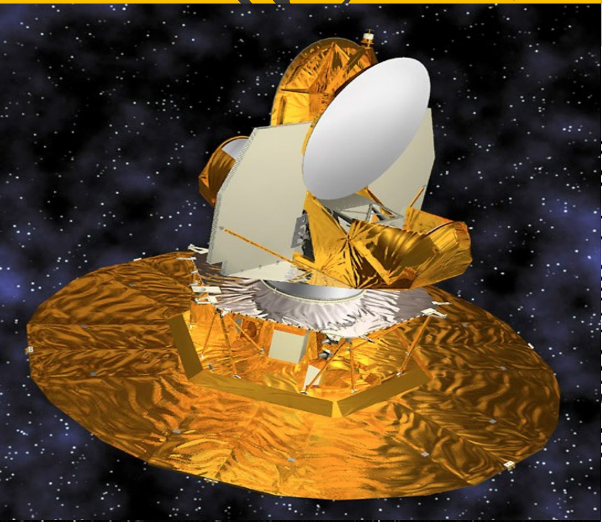
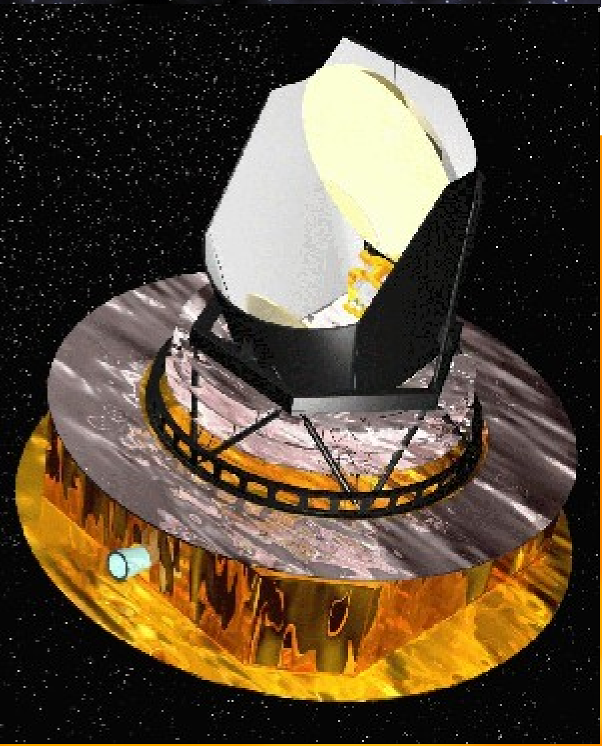
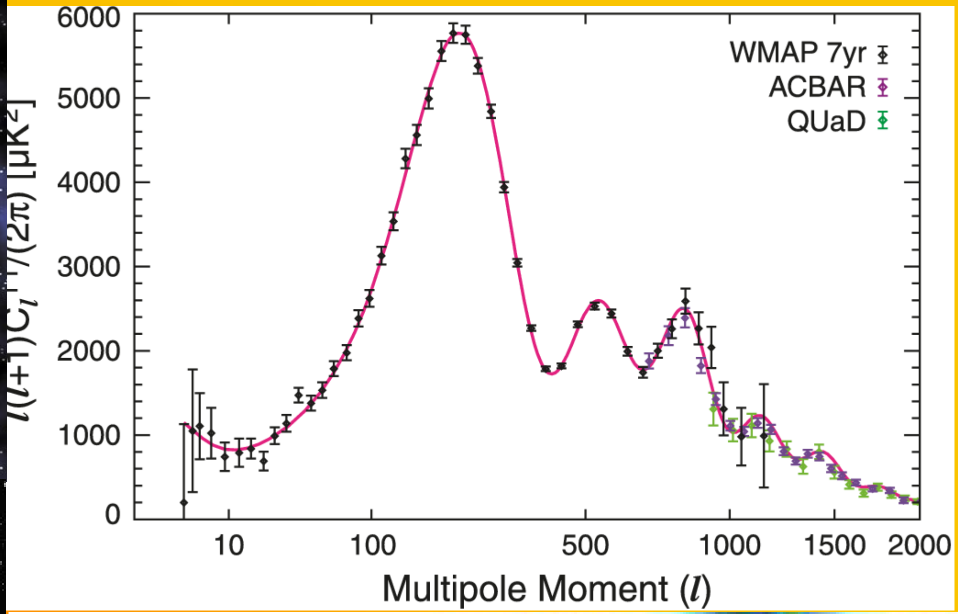


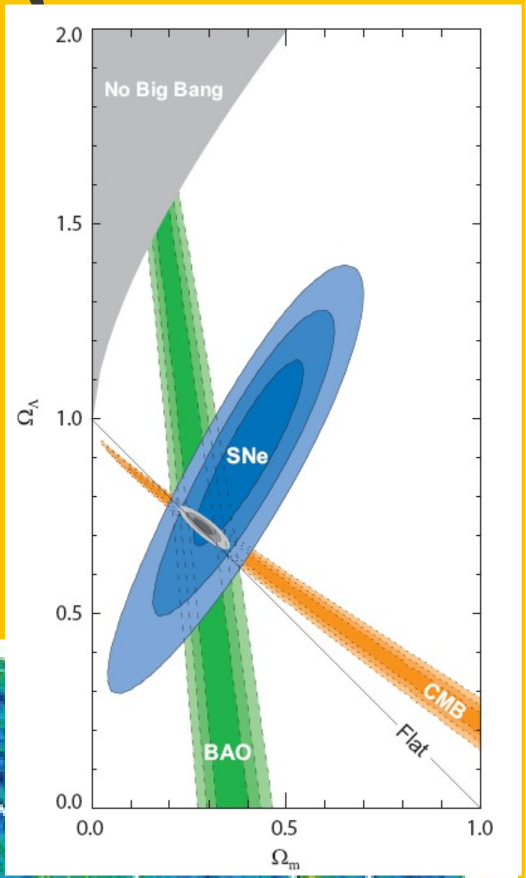
FIG. 3: **PAMELA positron fraction with other experimental data.** The positron fraction measured by the PAMELA experiment compared with other recent experimental data[24, 29, 30, 31, 32, 33, 34, 35]. One standard deviation error bars are shown. If not visible, they lie inside the data points.

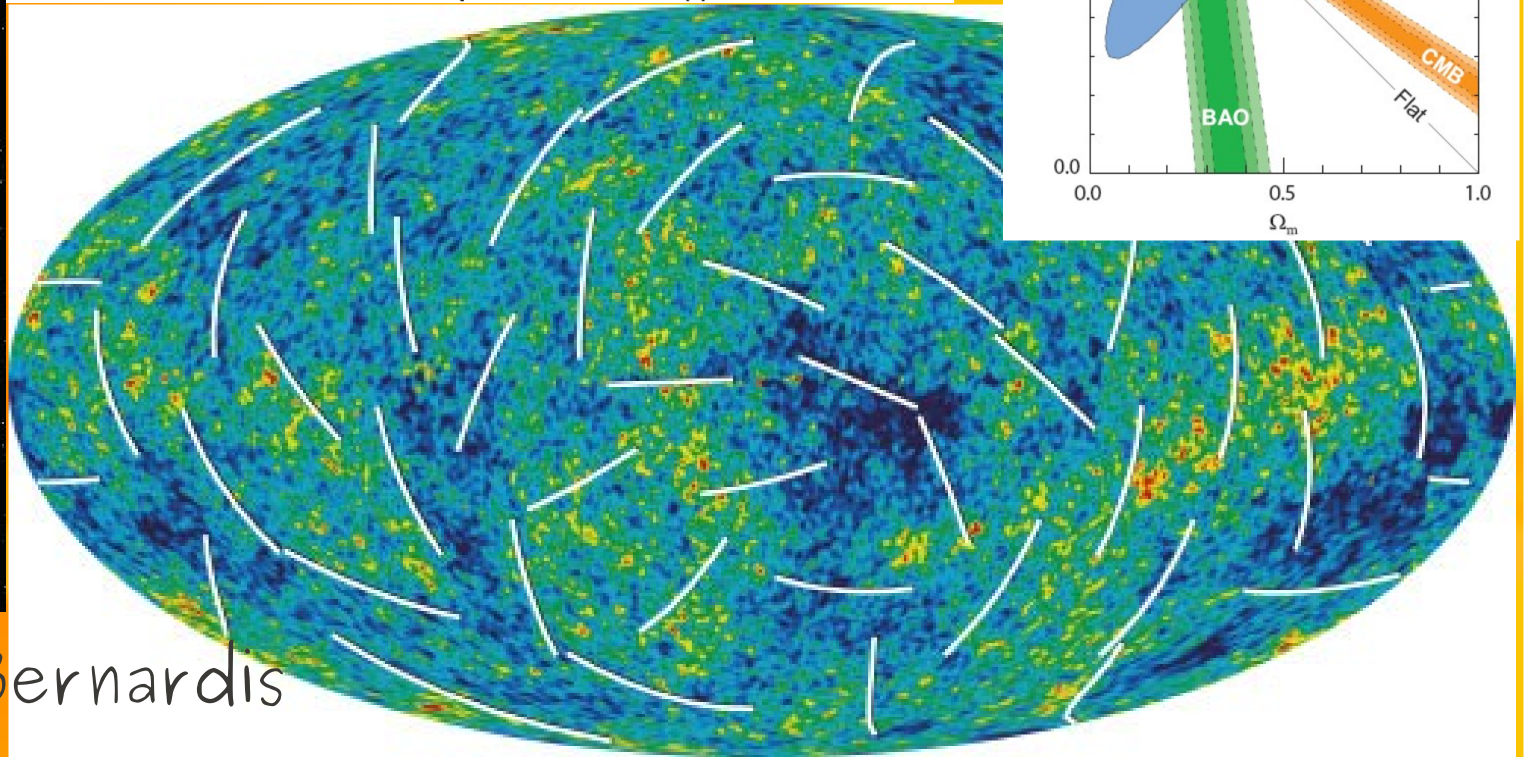
CMB: WMAP, Planck + g.b. polari











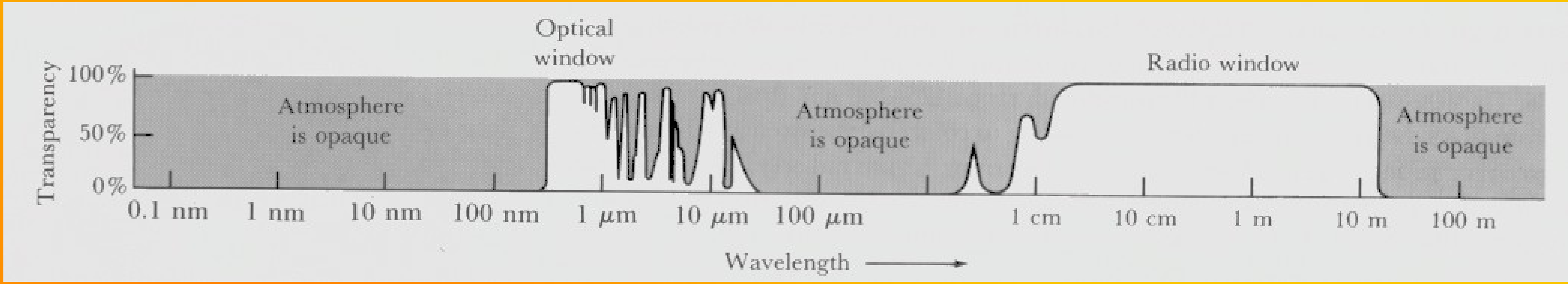
See talk by de Bernardis

Doing stuff from the ground

- Advanges:
  - Very cheap
  - Fast development compared to space
  - Can poke/upgrade your instrument
  - No weight/size constraints
  - No bandwidth constraints

Doing stuff from the ground

- Disadvantages:
  - Atmosphere mostly opaque:

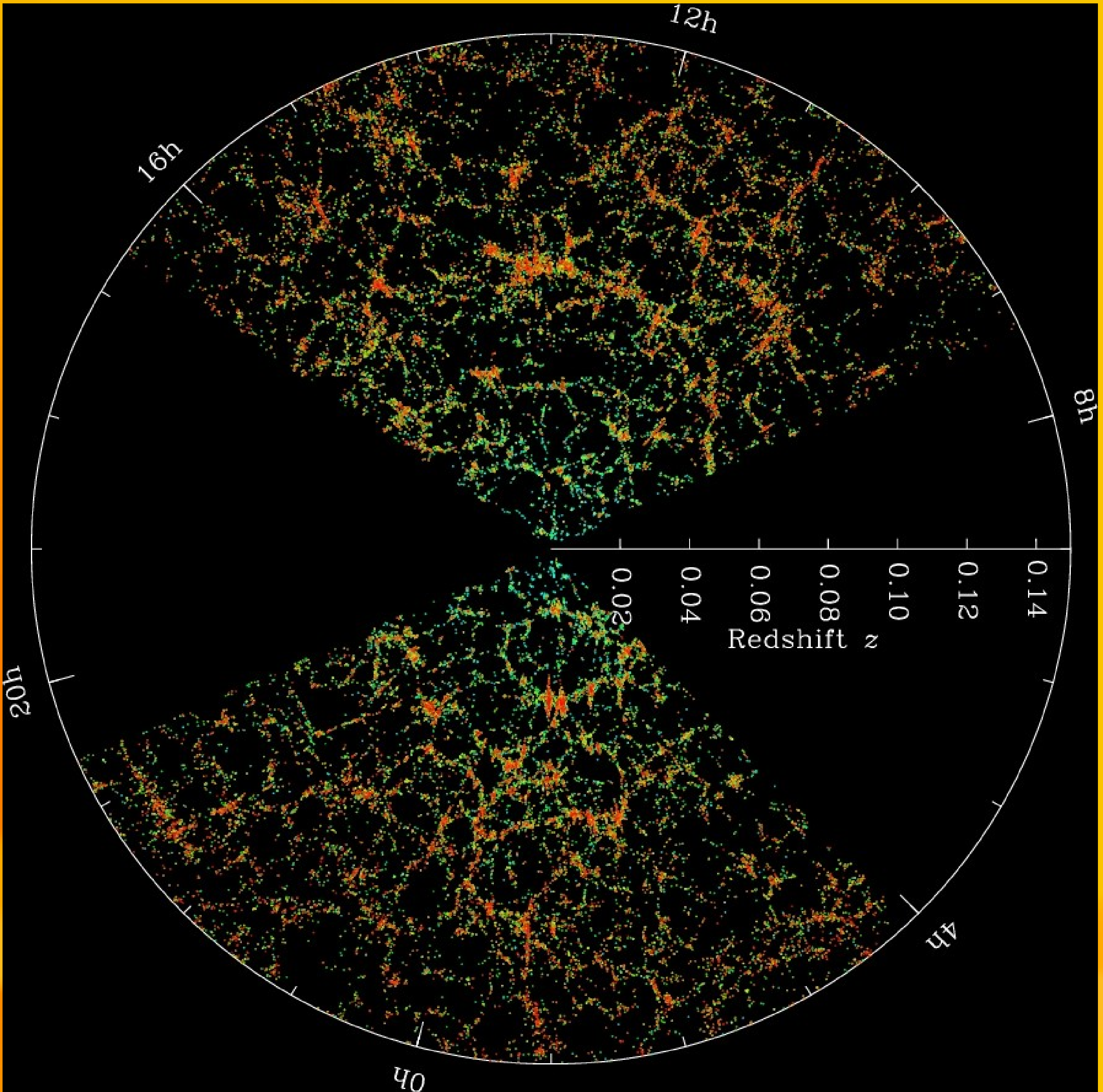


  - Atmospheric seeing impacts SNR, adds systematics
  - Lack of stability
  - Can't see full sky

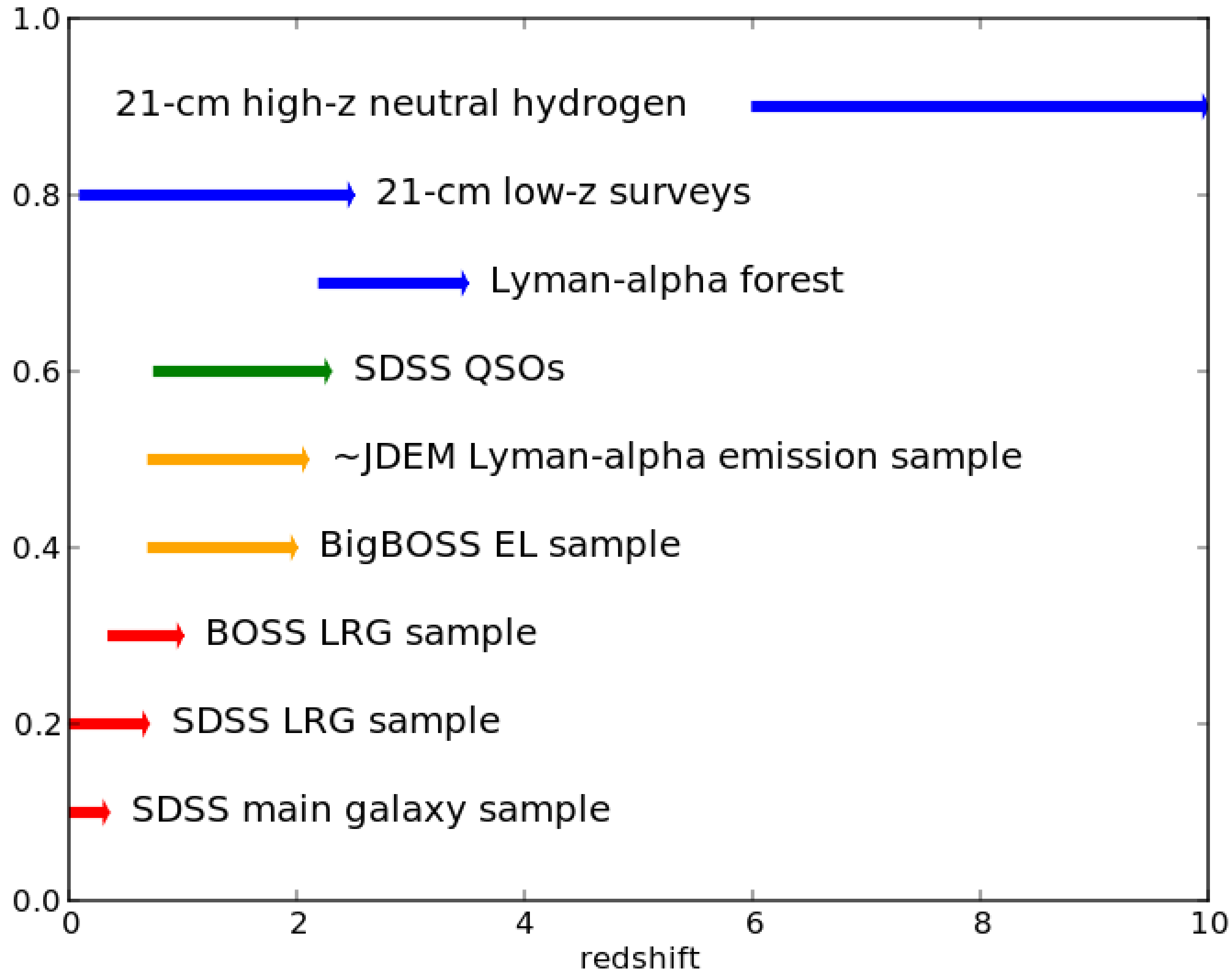
SDSS

- The most influential survey experiment
- Data Release 7:
  - Imaging of 11k sq degrees over 5 bands, 357 mil uniq objects
  - Spectra for 930k galaxies, 120k QSOs, 460k stars, 28k unknown

SDSS



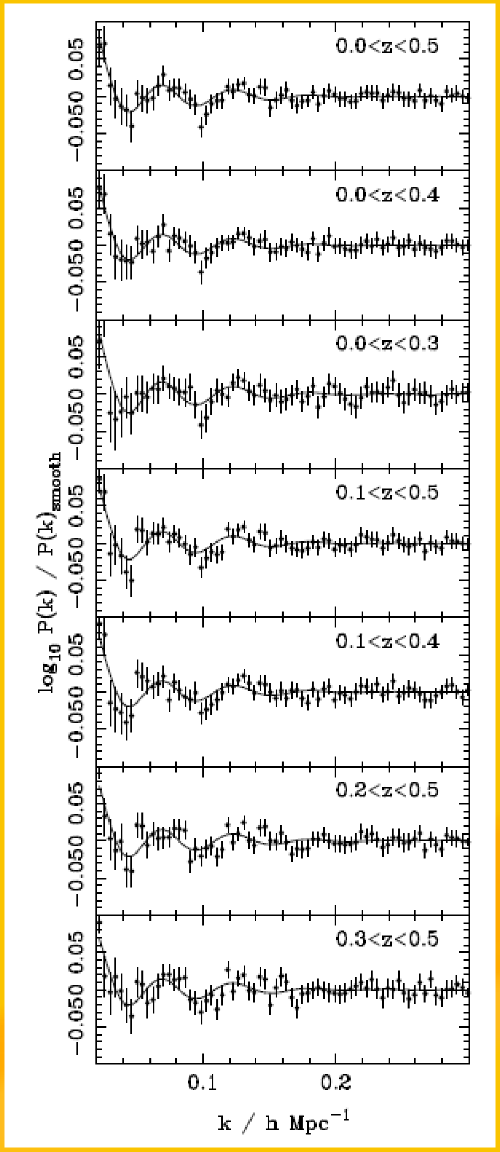
Measuring density fields



Galaxies are few and faint at high-redshift

Low-redshift probes

- Supernovae type Ia: original discovery of DE
- BAO: clean, geometrical probe
- Weak lensing:
  - Sees dark matter rather than galaxies
  - Probes growth of structure
- Other probes:
  - Lyman-alpha forest
  - Clusters & groups



Percival et al, 2009

Where do we stand with DE?

- Dark Energy:
  - Seen in many very different, very independent probes
  - Most promising future probes are BAO, weak lensing
  - Cosmological constant the best candidate: no convincing theoretical alternative
  - Phenomenologically described by parameter

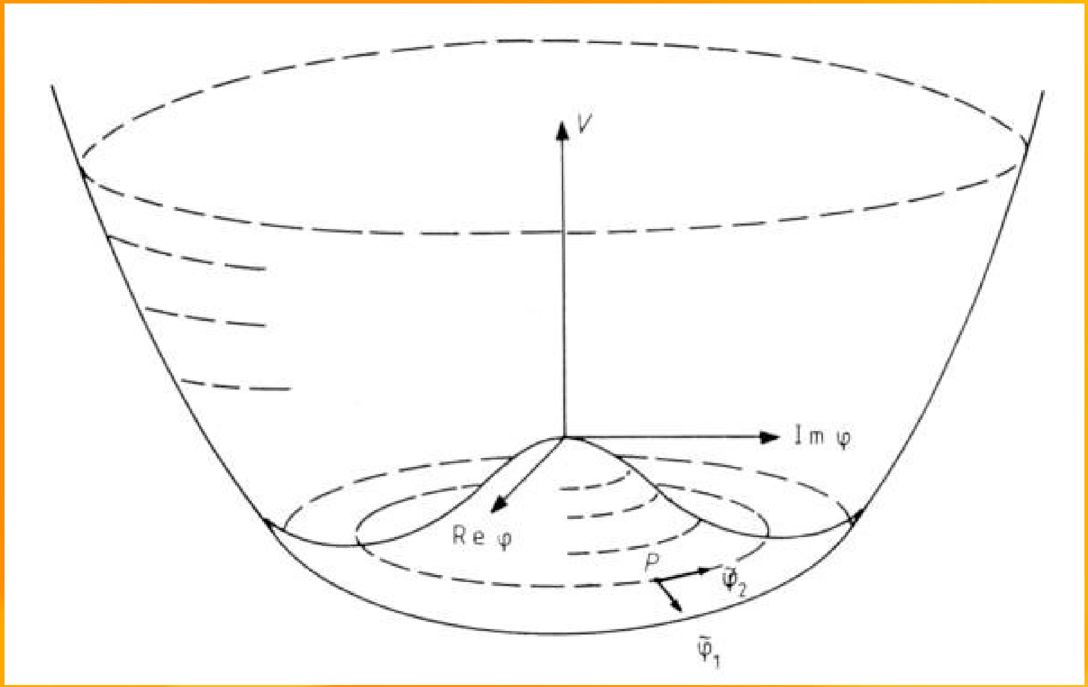
$$w = \frac{p}{\rho}$$

$$\Omega_\Lambda = 0.73 \pm 0.017$$

$$w = -0.92 \pm 0.17$$

Why bother?

Universe without cosmological constant but with a scalar field instead is really quite contrived.



- There is no symmetry protecting vacuum energy
- Even if it is, it would apply to more symmetric state
- If it looks like a duck, swims like and quacks like a duck, it is a duck (Raphael Bousso)

Modified gravity

- Dark energy could be described by modified gravity, after all.
- Easiest to see through consistency relations between 0th and 1st order perturbation theory: background vs growth
- e.g. f(R) gravity: $B_0 < 1.1 \times 10^{-3}$
- No existing models that would not have LCDM as a limit (self accelerated branch of DGP dead)

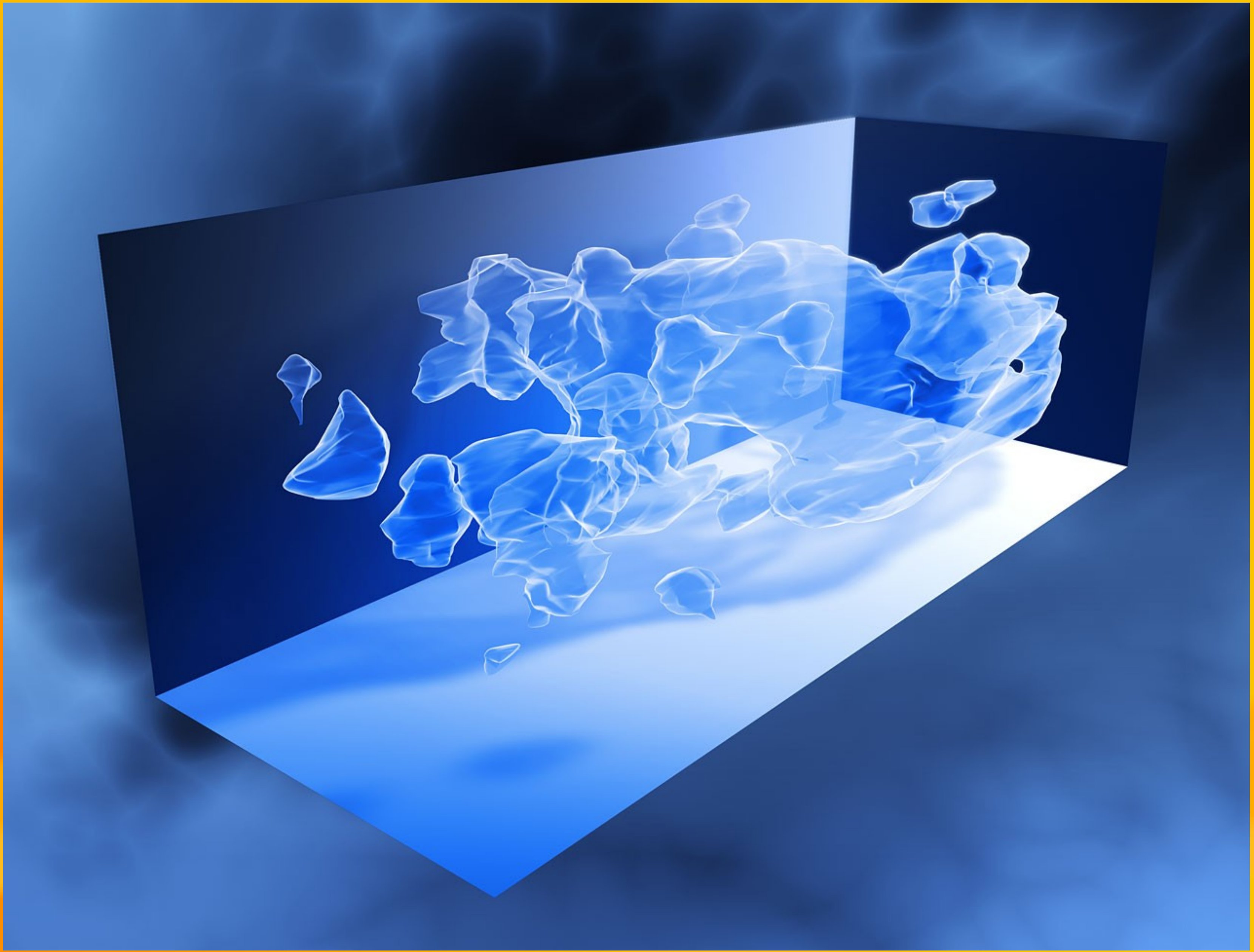
Where do we stand with DM?

- Dark Matter:
  - A cold, non-interacting stuff
  - Limits on its mass quite weak from cosmology: for WDM, m>2.5 keV (Seljak et al)
  - Really unlikely to be explained away on modified gravity
  - More likely to learn about DM from non-cosmological probes: direct detection, LHC signatures, etc.

A note on DM coincidences:

- Coincidence 1:
  - WIMP miracle: WIMPS are naturally produced as thermal relics of the Big Bang with the required density
- Coincidence 2:
  - Baryon and dark matter densities are of the same order of magnitude
- Naively, one of the two must be just a coincidence! (see ADM by Sarkar et al)

Where do we stand with DM?

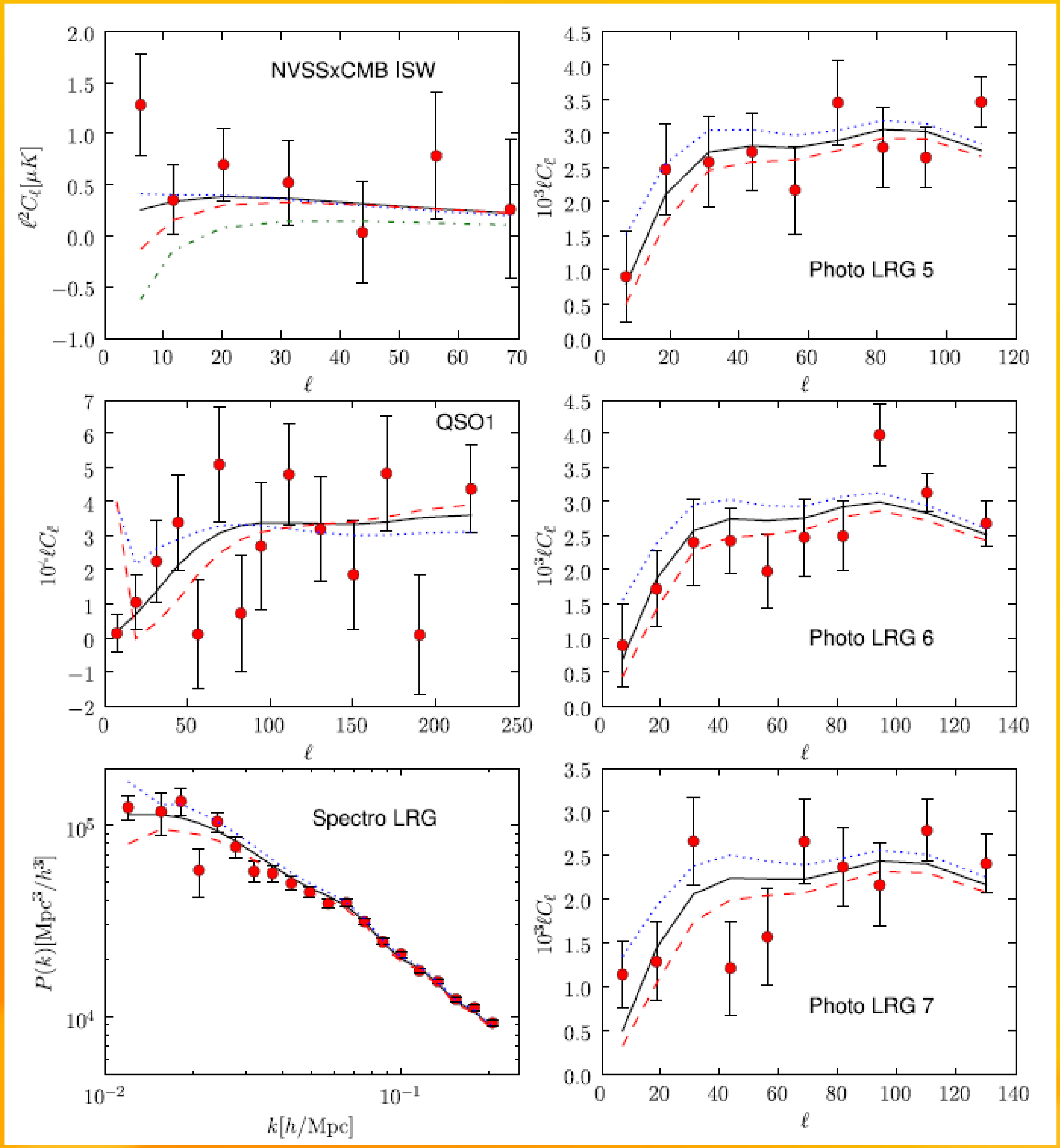


DM scaffolding from COSMOS survey

Where do we stand with inflation?

- Inflation:
  - Very exciting period: $n_s = 0.959 \pm 0.0127$ (but see Pandolfi et al, 2010,)
  - Slow roll inflation predicts n_s less than one by a small parameter!
  - Running of spectral index $O(10^{-3})$ - a clear prediction achievable in the next decade.
  - B-mode polarization, iso-curvature modes: good tests, but no clear goals
  - Primordial non-Gaussianity - very promising.

Primordial NG



- Parametrised in terms of parameter f_NL
- Current limits:

$$-1 < f_{NL}^{\mathrm{local}} < 63$$

- Expected magnitude $-10 < f_{NL} < 10$
- Constrained from CMB and galaxy distribution
- Distinct signature of inflation

Where do we stand with νs?

* Neutrinos & relativistic species:
  - Number of rel. species: $N_\nu = 3.75 \pm 0.65$
  - Neutrino mass:
    * Cluster abundance, MegaZ DR7 (95% cl)

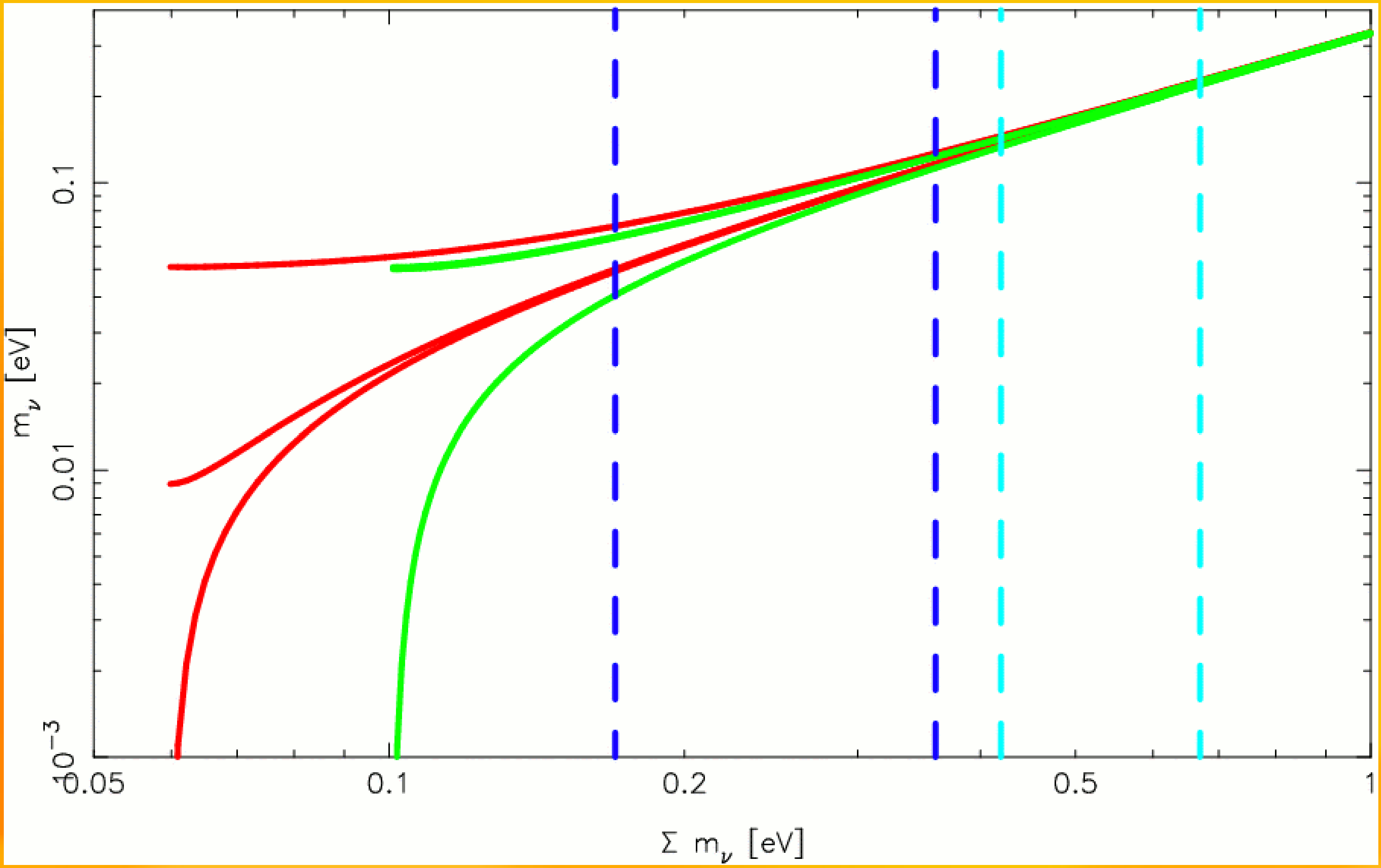
      $$\sum m_\nu < 0.3\mathrm{eV}$$

    * Ly-alpha forest (95% cl):

      $$\sum m_\nu < 0.19\mathrm{eV}$$

    * If you believe us KATRIN will not see anything!

Mass hierarchies



Future:

"California no longer has low-hanging fruits – we don't have any medium-hanging fruits, and we also don't have any high-hanging fruits. We have to take the ladder from the tree and shake the whole tree."
[A Schwarzenegger]

Cosmology is at medium-high hanging fruit stage.

Future:

- Expect progress in:
  - inflationary physics
  - Neutrinos
- Hope for progress in:
  - Dark energy
  - Dark matter
- We do this through new experiments:
  - More wavelengths
  - More sky coverage
  - Deeper
  - Higher fidelity

Currently with galaxies: BOSS

BOSS @ SDSS3:

- 10,000 sq degrees
- Mid res spectrograph
- 2.5 meter telescope
- Millon LRGs to z=0.7
- 160,000 QSO sightlines
- Distance to z=0.3,0.6 and 2.5 with % precision using BAO
- Auxiliary science: neutrinos, non-Gaussianity can be quite exciting

DES

- 5,000 sq degrees imaging
- 5 bands
- 4m Blanco telescope
- 570 Mpix camera, 2.2 deg FoV
- Weak lensing instrument

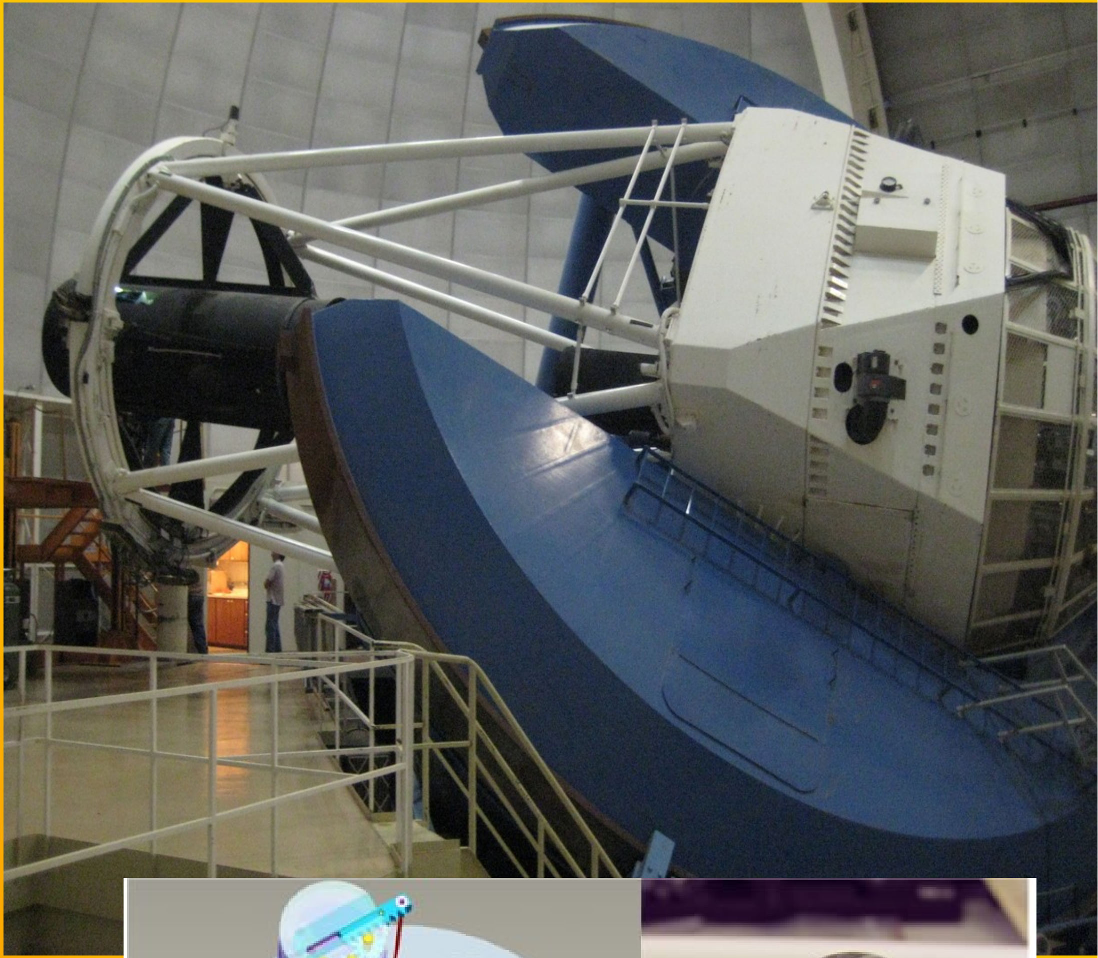
JDEM and Euclid:

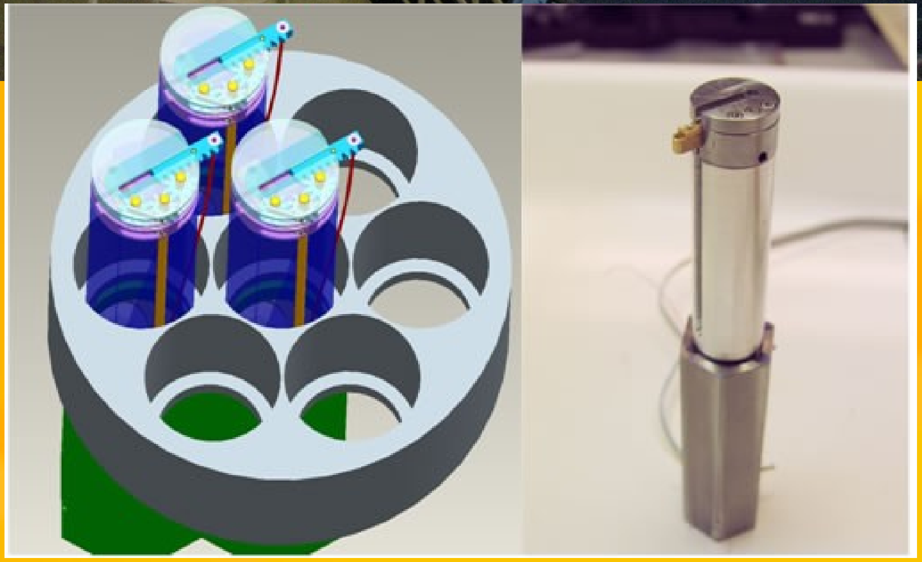
- Measuring dark energy in space through:
    1) BAO
    2) Weak lensing
    3) Supernova Ia (JDEM only)

- Galaxies over 20,000 sq deg up to z=2.0
- None funded
- BOTH to fly is unlikely
- JDEM oscillates in and out of mess
- Launch no early than 2017

BigBOSS

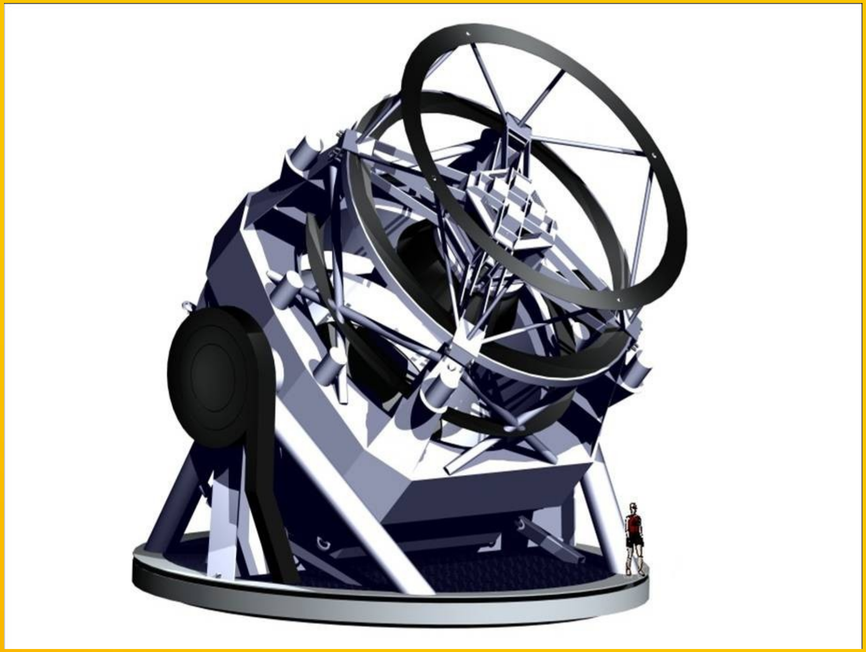
- Idea is to compete with JDEM from ground
- 4000 fibre spectrograph doing BAO on a 4m telescope
- Order of magnitude cheaper than JDEM
- Same people who made SDSS[1,2,3] happen
- First light 2015
- An old 4m has a lot of old 4m users





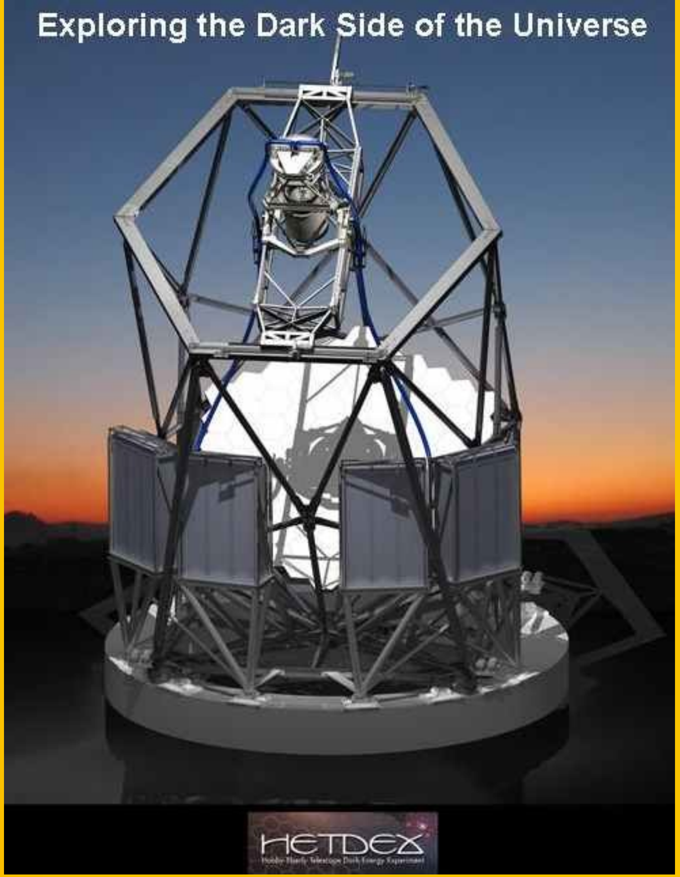
LSST

- Deep, wide, fast
- 6m class telescope with 3deg FoV; imaging in 5 bands; 3.2 Gpix
- Amazing cadence: 15s shots: entire sky in 3 days
- First light 2017
- Requires DOE/NSF cooperation
- Amazing science, but cadence not really required for cosmology



Other disruptors:

- HETDEX:
  - Integral field spectrographs, 34k fibers
  - Million LAE at z=2-4
  - 9m Hobby-Eberly telescope



- **Hyper Supreme Cam** survey:
  - 8m Subaru telescope, 1.5 deg FoV, 5 band imaging
  - Competitive with LSST for weak lensing
  - Replaces WFMOS