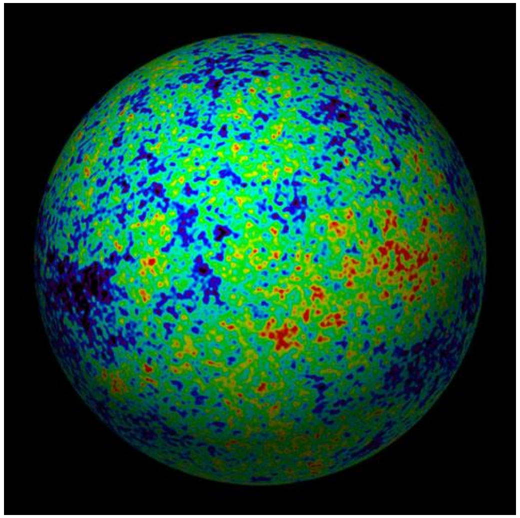
The Future of
Large-Scale Cosmological Surveys

Jordi Miralda Escudé
ICREA Professor
University of Barcelona
ESO, Munich 9-3-2009

Challenges for a new era of observational cosmology

WMAP

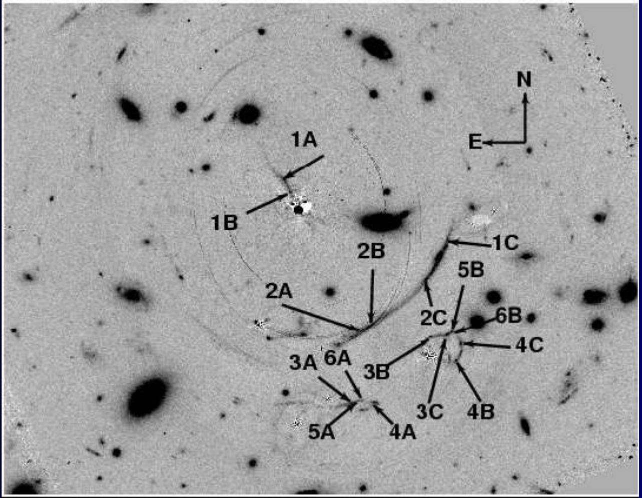


- **We are gradually reaching the physical limit of the horizon for the volume of the universe we have observed: the Universe is very small!**
- **New era of "claustrophobic cosmology" demands increased number of objects, statistical precision, and control of systematic errors.**
- **How can we address the fundamental mysteries on the composition of the universe?**
  - **Nature of dark matter: In the absence of direct detection, study halo profiles, axis ratios and substructure, deviations from CDM power spectrum…**
  - **Acceleration of the expansion, so far consistent with a cosmological constant: precision measurements of expansion rate and growth factor. Are there dark energy fluctuations, distinguishable from dark matter?**
  - **Origin of primordial fluctuations: are the fluctuations perfectly adiabatic and Gaussian?**

Inquiring on dark energy and primordial fluctuations leads to maximize survey volume

- Global dark energy properties:
  - Expansion rate, H(z): Baryon Acoustic Oscillations, standard candles.
  - Growth factor: Weak lensing, peculiar velocities (cluster evolution: limited by baryonic physics complexity).
- Are there dark energy fluctuations?
  - Effects on weak lensing, peculiar velocities, ISW. Very hard to measure for high dark energy sound-speed!

- Broad range of other science to do with smaller area surveys:
  - Massive lensing clusters: dark matter distribution, high-z galaxy population.
  - Absorption systems – galaxy correlations



Sand et al. 2004

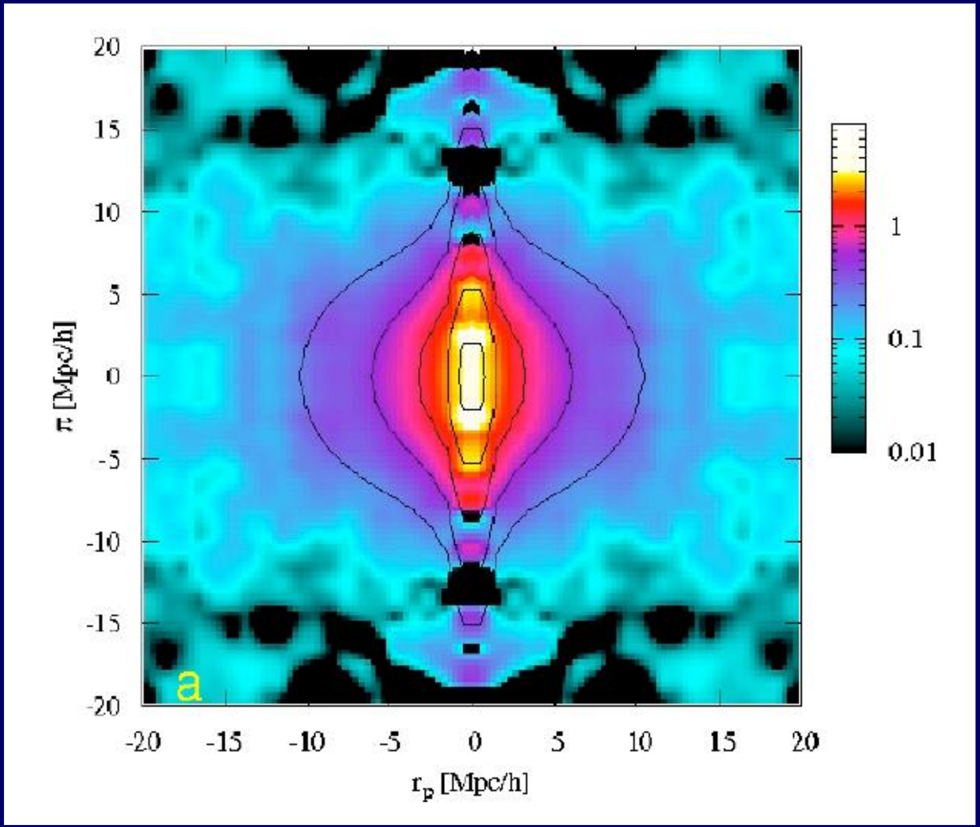
Weak lensing (DES, PANSTARRs, VST…)

Wittman et al. 2006, Deep Lens Survey

- Most important systematic errors:
  - PSF control (especially ground-based!)
  - Photo-z errors calibration

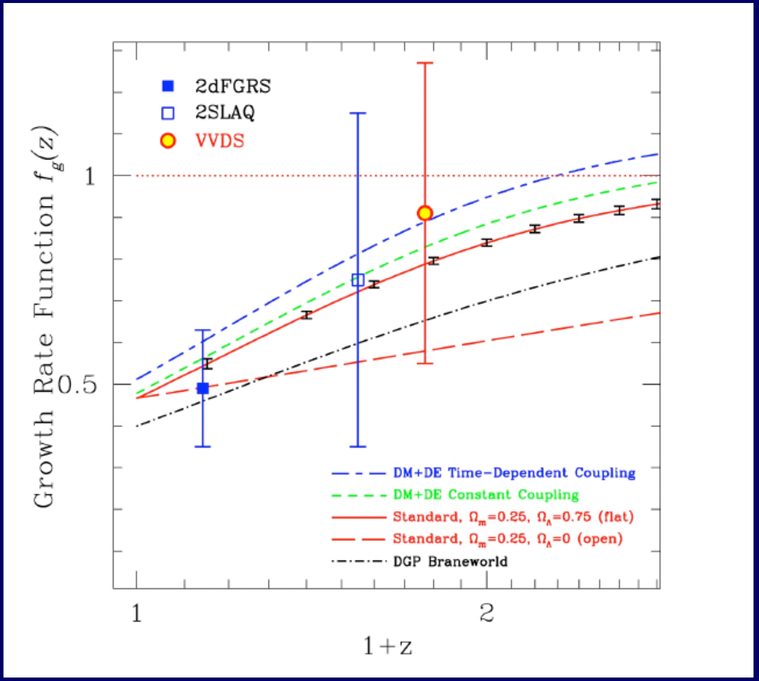
- **Survey needs for dark energy applications:**
  - **Large-area imaging surveys, good PSF control, photo-z**
  - **Spectroscopic surveys for photo-z calibration.**
- **Smaller area surveys in strong-lensing clusters should be very useful for studies of dark matter distribution and high-z galaxies.**

Redshift distortions: measure the Kaiser effect



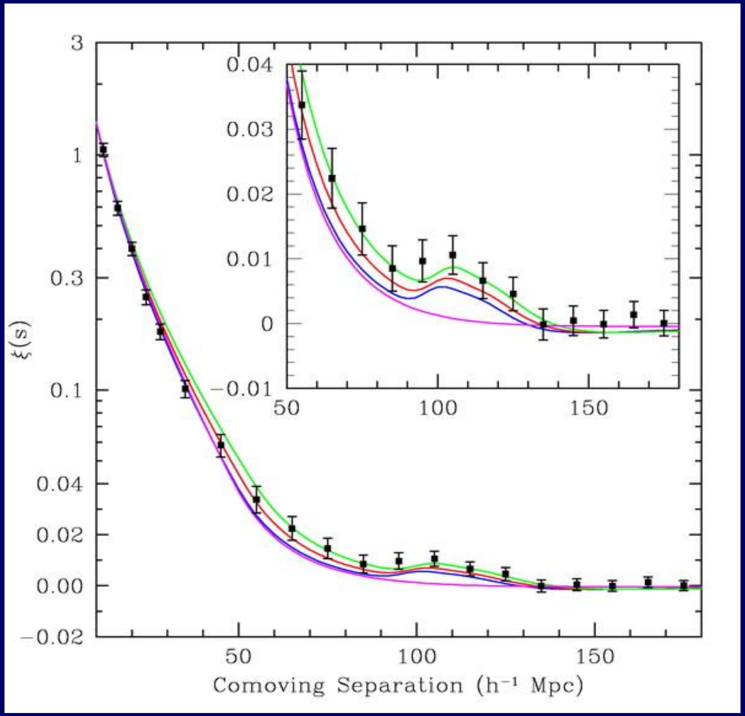
- Need to go to sufficiently large scales, with accurately modelled selection function.
- Use galaxies with different bias.
- Probe possible modified gravity.

Guzzo et al. 2008, VVDS

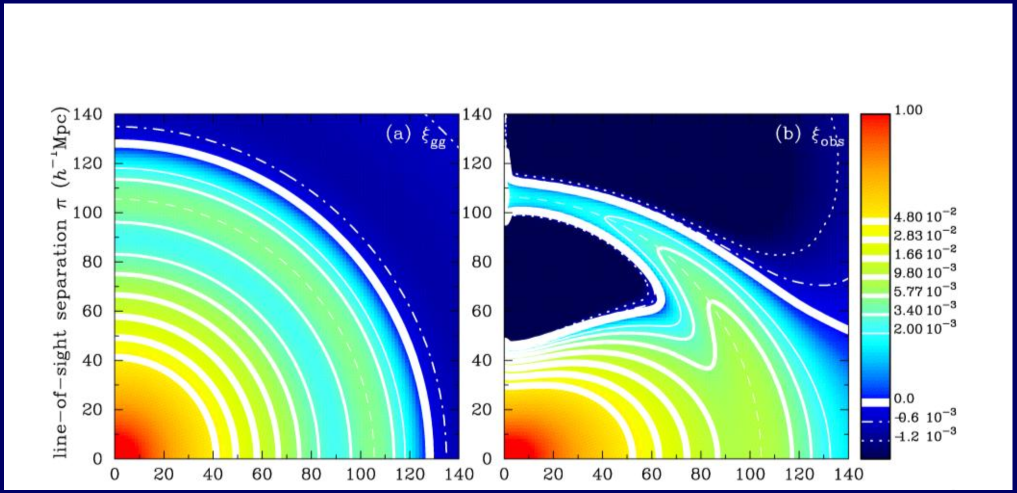


Baryon Acoustic Oscillations: measuring H(z)

- Use the Bao peak as a standard ruler.
- With reduced noise, we can measure the correlation function in redshift-space to obtain both $d_A(z)$ and H(z).
- Systematics: photometric calibration, particularly for photo-z.



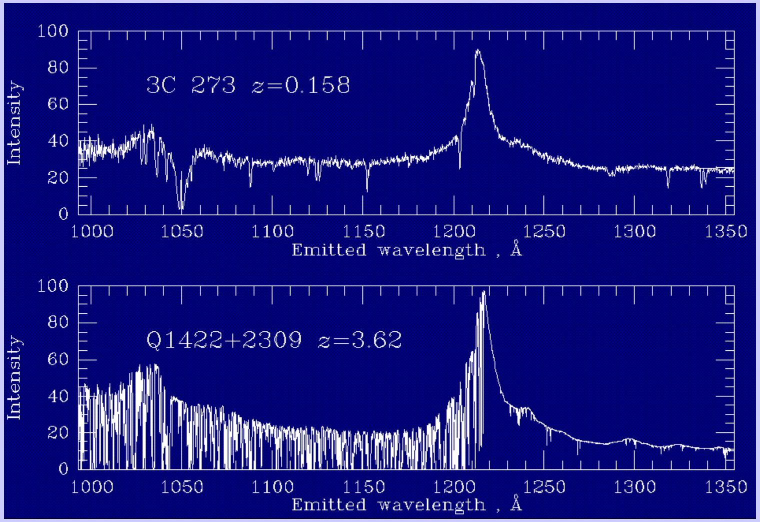
Eisenstein et al. 2005, SDSS

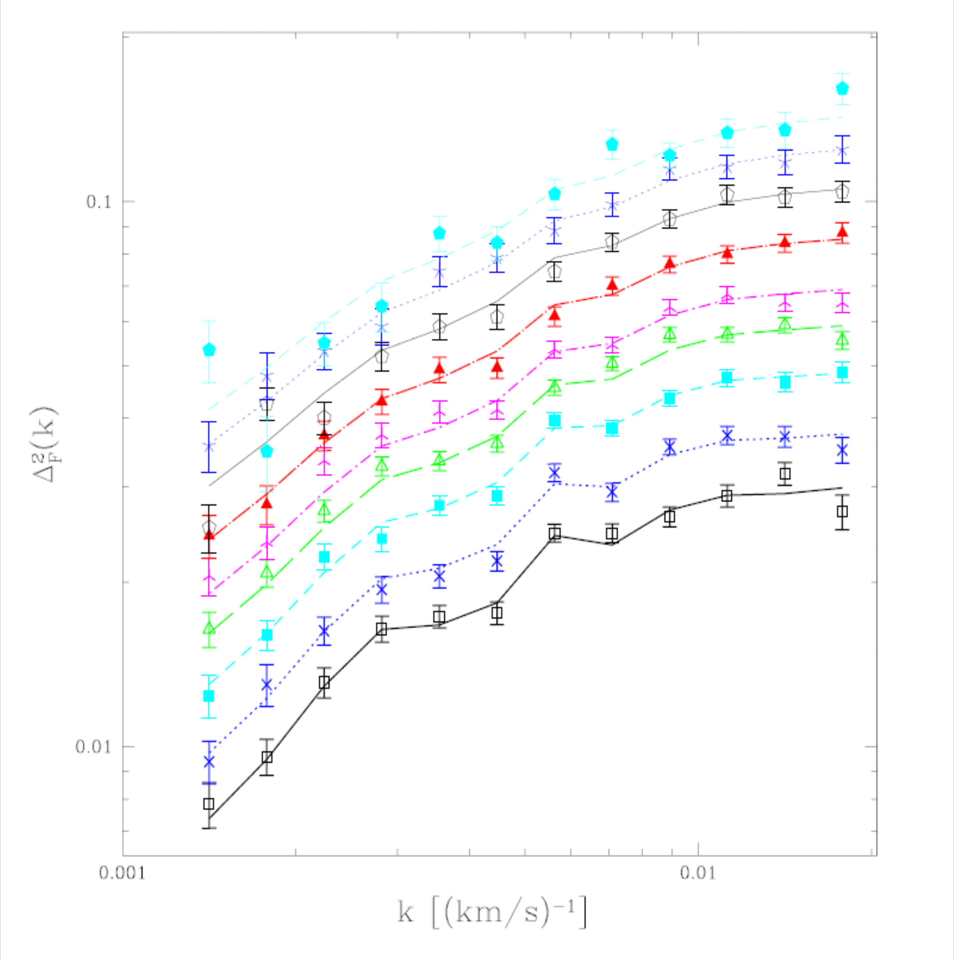


- Tangential BAO: broad-band photometry works.
- Radial BAO: spectroscopic surveys (BOSS, WFMOS).

Sources to use for BAO

- **Luminous Red Galaxies.**
- **Other luminous galaxies: Emission-line galaxies (OII).**
- **Lyα forest (z>2): one quasar spectrum yields many objects, reducing the shot noise (McDonald & Eisenstein 2007).**
- **Survey requirements: spectroscopy of very large number of sources, wide field.**





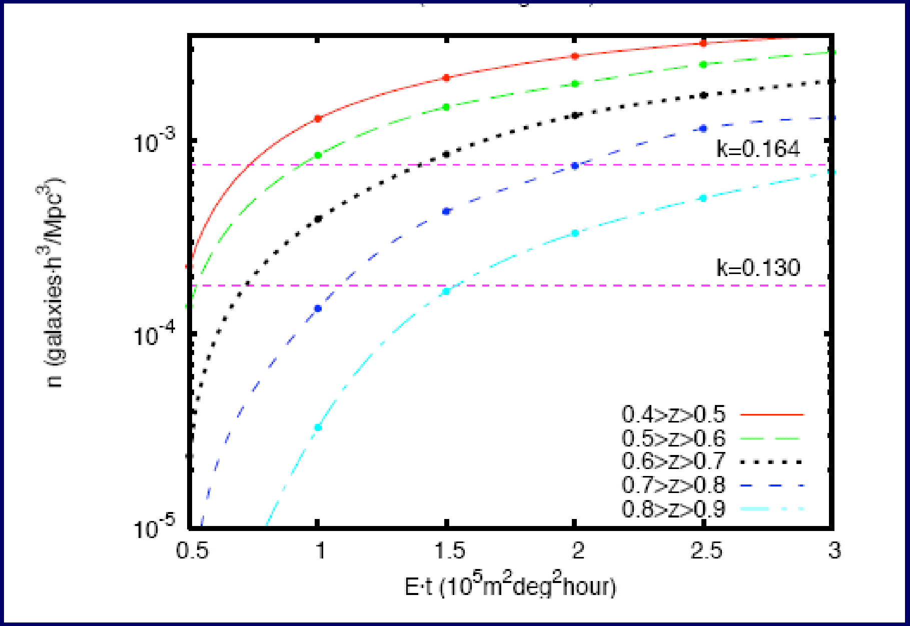
McDonald et al. 2006

Photometric surveys with narrower bands (COMBO-17, Alhambra)

- Photons are collected over a narrower wavelength range only.
- But the number of detected sources is very large, with increased resolution compared to broad bands.
- Efficient use of CCDs implies going deep, and using the majority of the sources for the survey science goals.

Photometric redshifts are not good enough for radial BAO with LRG.

- Collecting only a small fraction of the photons in narrow bands reduces the S/N.
- Variability of observed LRG spectra worsens the achievable photo-z accuracy.
- The proposed PAU Survey (Benítez et al. 2009) would actually measure only 6 million galaxies with redshift errors < 0.3%.
- In comparison, a spectroscopic survey with 1000 fibers (like BOSS) using the same telescope resources would measure the same number of galaxies with spectroscopic redshifts.



Roig et al. 2009

The greater challenge: detecting dark energy fluctuations

- Sound speed of dark energy fluctuations: could it be low?
  - Need better theoretical development: if the sound speed is low, would dark energy behave today like dark matter with increasing mass density? What are the observational constraints?

- If the sound speed is high: fluctuations are detectable only on scales close to the horizon.
  - Requires extremely accurate, all-sky weak lensing from space, cross-correlated with other tracers of mass fluctuations (galaxies, clusters, ISW…).
  - Photometric redshifts for tomography with spectroscopic calibration will continue to be important.

- Thinking big for the future: cosmic astrometry.
  - Proper motions of quasars (100 nas accuracy required)
  - Kinetic SZ effect on large numbers of clusters. Other distance measurements?
  - Obtain 3D peculiar velocities on the largest scales to probe matter and dark energy fluctuations.

Instrumentation challenges

- We will continue to need large numbers of objects:
  - How far can we go with number of fibers, number of slits, increased fields of view?
  - Etendue is more important than aperture.

Summary

- The new era of cosmology needs surveys with maximized volume coverage and number of sources:
  - Baryon Acoustic Oscillations, redshift distortions: galaxies and Lyα forest.
  - All-sky weak lensing.
- Deep, smaller area surveys are more useful for dark matter, galaxy population studies.
  - Strong lensing clusters
  - Cross-correlate galaxies and absorption-line systems.
- Detection of dark energy fluctuations is a future challenge for cosmology
  - Development of advanced space missions for large-scale surveys necessary.
  - Continuous need for ground-based support for photo-z and spectroscopic calibration.