Decrypting the Universe

Large Surveys for Cosmology

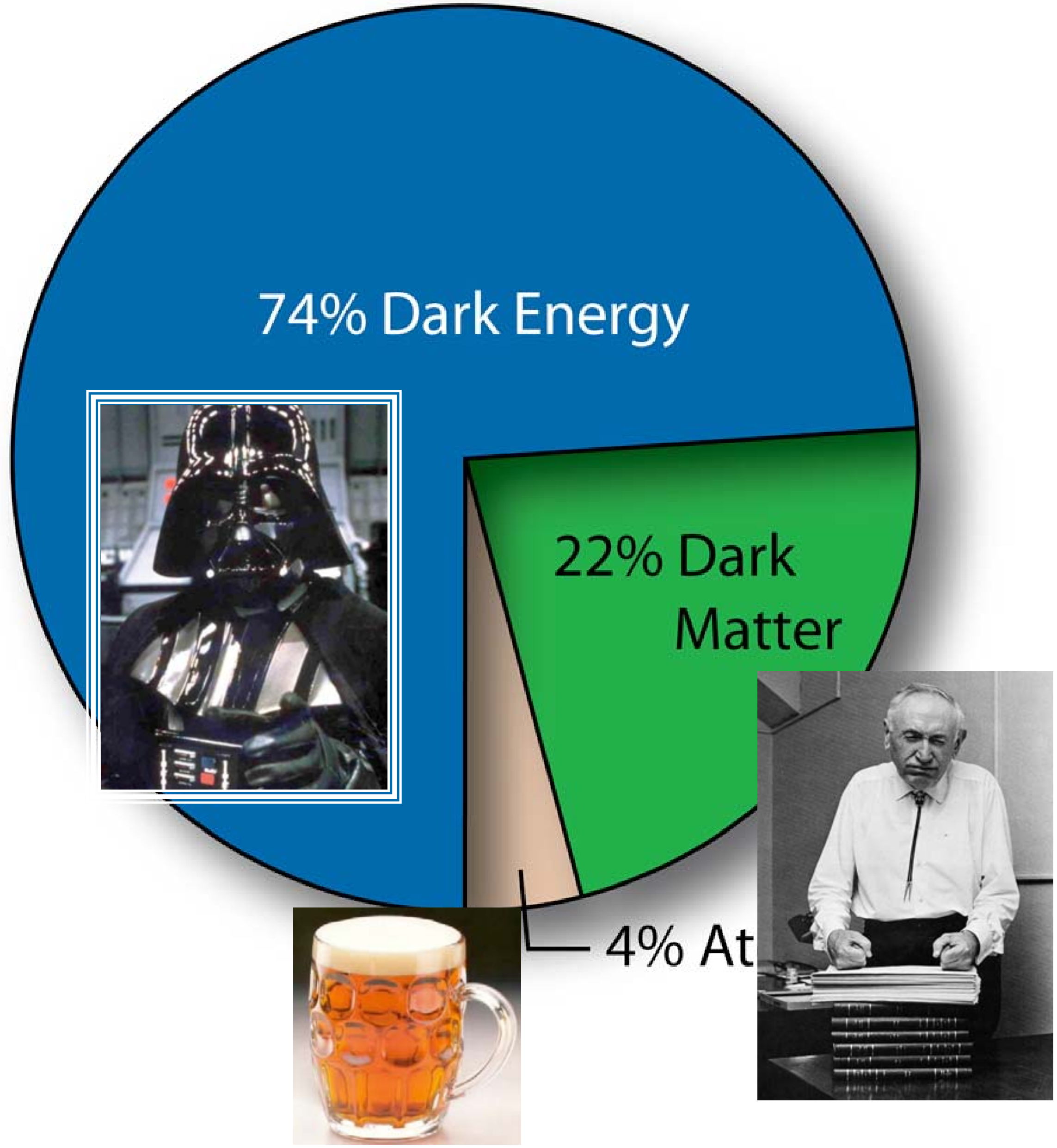
Observational Summary

Richard Ellis (Caltech)

24th-26th October 2007
Edinburgh, Scotland
Joint Royal Observatory Edinburgh / JSPS
Core-to-Core Program Workshop

Reminder: Purpose of Workshop

"The goal is to decrypt the content of the Universe, which also requires a deep understanding of the link between mass and light. Therefore the objective is to cover not only methods to uncover the essence of dark energy, but also relevant dark matter, gravity and galaxy formation theories and observations. The discussion will consider recent survey results, near-term prospects of on-going projects, followed by an examination of how more ambitious and long-term plans may best address these issues".



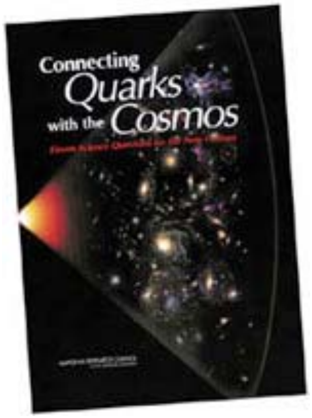
Conference Summary

Richard Ellis, Caltech

RAPID PROGRESS IN ONE YEAR!

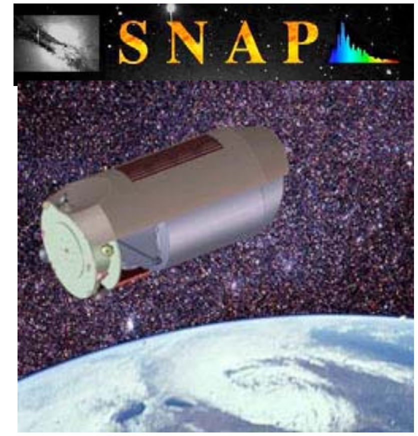
Cosmology with photometric & spectroscopic surveys *Tokyo, Nov 2006*

Proposals for Tracking Dark Energy



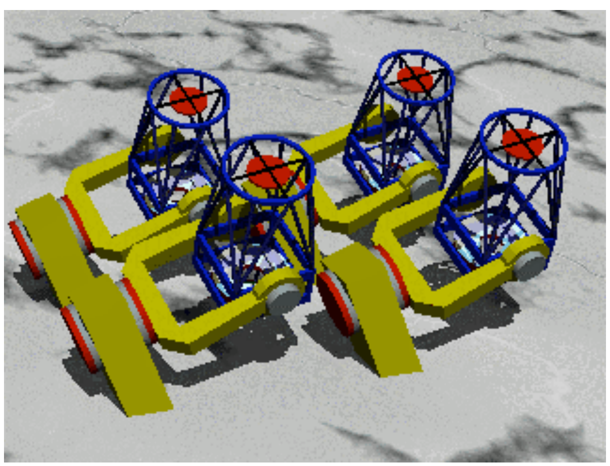
DoE/NASA initiated studies of Joint Dark Energy Mission) following Turner report (also DETF, PPARC, ESA/ESO reports)

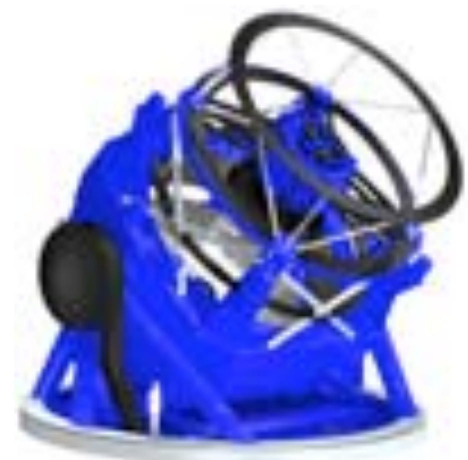
Contenders: SNAP, Destiny, ADEPT
Also ESA considers DUNE/SPACE



Shorter term initiatives on the ground:

Pan-STARRS (2007) Dark Energy Survey (2010), VST (2008), Subaru HSC/WFMOS (2011+), LSST (2014..+)





But Dark Energy is Not Universally Popular..

Positive opinions: ***(e.g Kolb astro-ph/07081199)***

• Dark Energy is the most pressing problem in the physical sciences; whatever the outcome, the impact on our view of the Universe will be profound

• We cannot ignore what we don't understand; this is the ultimate scientific adventure

Negative opinions: ***(e.g White astro-ph/07042291)***

• DE studies, if supported, would dominate our observing facilities for next 20 years & might offer improved precision without any further understanding. If w = -1.0000 in 2020 what will we have learned?

• DE will distract resources & young people from more tractable and fruitful astrophysical questions.

• Becoming particle physicists: `a community chasing one goal'

Reflections on Sociology of Dark Energy

- It’s certainly clear that the `mystery’ of DE is currently attracting resources; it features in many national `roadmaps’

- It’s not obvious for how long this will be the case, especially without progress, and there are risks we won’t deliver

- Best we can offer is that good science is delivered regardless

- There is no such thing as a `pure DE mission’: all the projects we discussed will contribute richly to other science

- So maintaining breadth of purpose in new initiatives is very important

Explosion of Cosmology Projects

- Reaping CFHT LS (Mellier, Sullivan)
- Reaping BAOs with SDSS/2dF (Percival)
- Broader exploitation of SuPrimeCam (Yamada)
- BAO with HETDEX (Hill)
- Planning for HSC (Miyazaki, Ouchi, Doi), FMOS (Totani)
- DES (Lahav), PanSTARRS (Phleps), PAU (Jimenez)
- BAOs with BOSS (Padmanabhan), WFMOS (Parkinson)
- From LOFAR (Best) to SKA (Rawlings)
- ESA Cosmic Visions: DUNE (Refregier)/SPACE
- NASA/DoE BEPAC: JDEM (SNAP, ADEPT, Destiny)

Reflections on Projects

- Surveys can deliver far more than was originally intended (2dF/SDSS); helps to be general purpose
- Homogeneity of data alone can represent a huge step forward even without major improvement in technology (CFHT LS)
- New analysis techniques can sometimes equal the gain of improved facilities
- Combination of wide field + aperture can dominate progress (SuPrimeCam)
- Imaging alone will not maximize progress (PanSTARRS, DES, LSST); limiting factor in many areas is now spectroscopy (lensing, SNe, galaxy formation..)

Nearby Cosmology

Lots of opportunities:

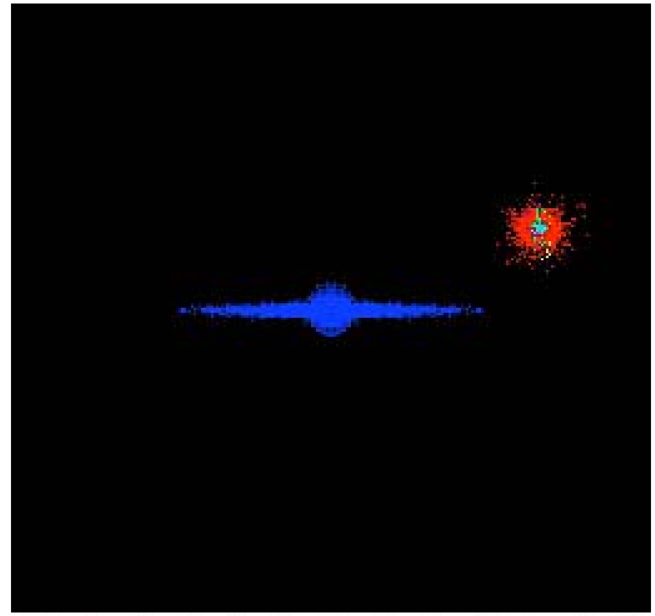
1. Stellar kinematic studies: identifying sub-components in phase space and detailing past merger events (Helmi)

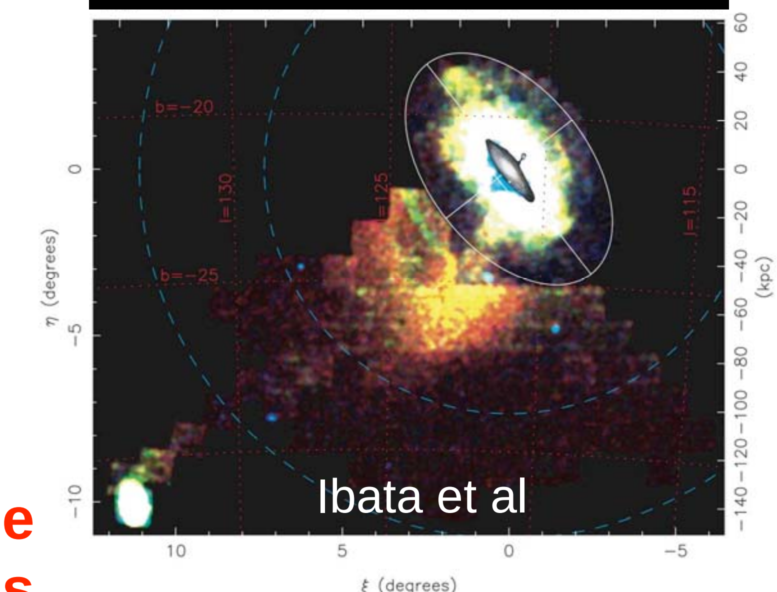
2. Equivalent studies for nearby galaxies (M31, M33…) (Chiba, Font)

3. Abundance analyses: `chemical tagging' for more accurate identification of sub-components R~20,000

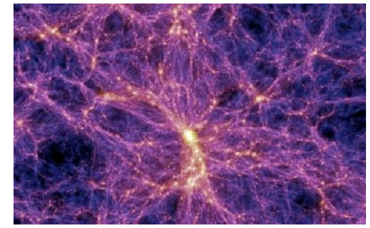
→ Assembly history of local galaxies

2-m/4-m based spectrographs will be insufficient to maintain this progress

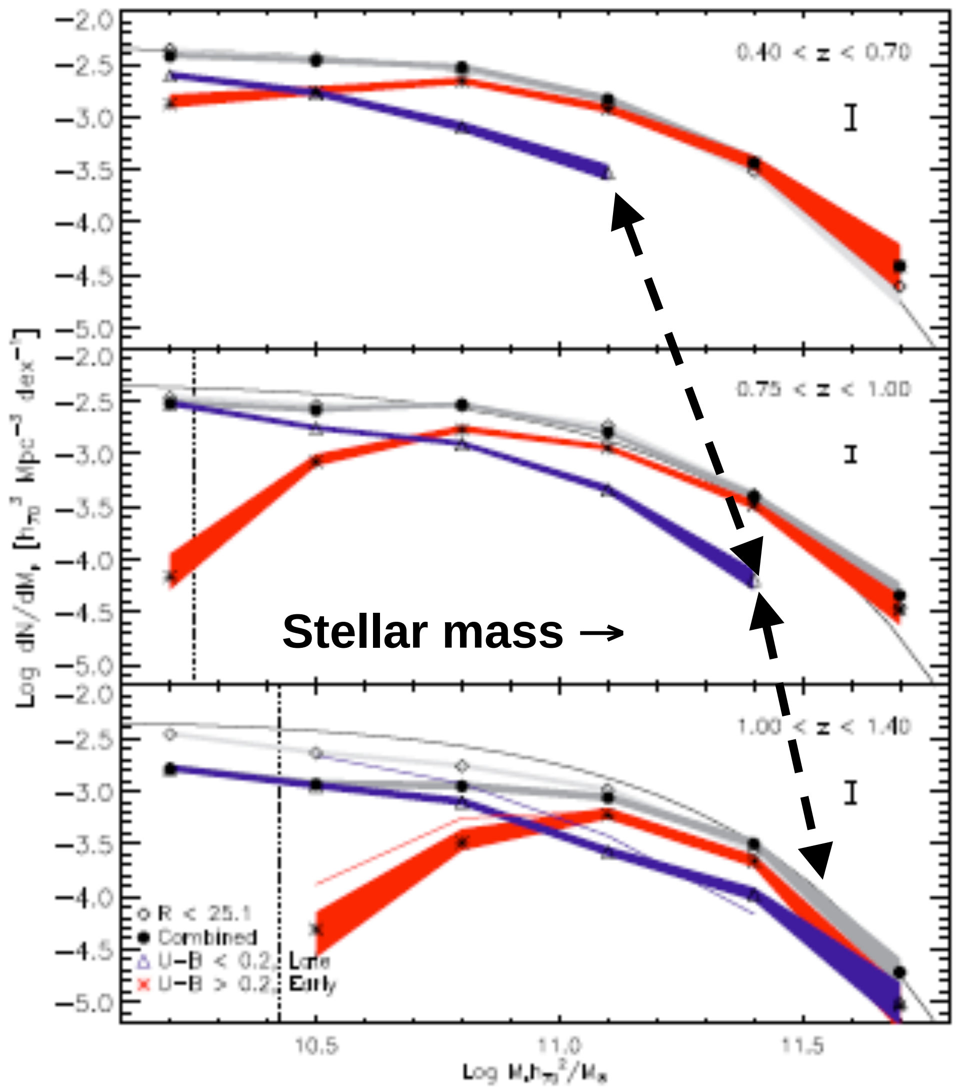




Galaxy Formation z < 3

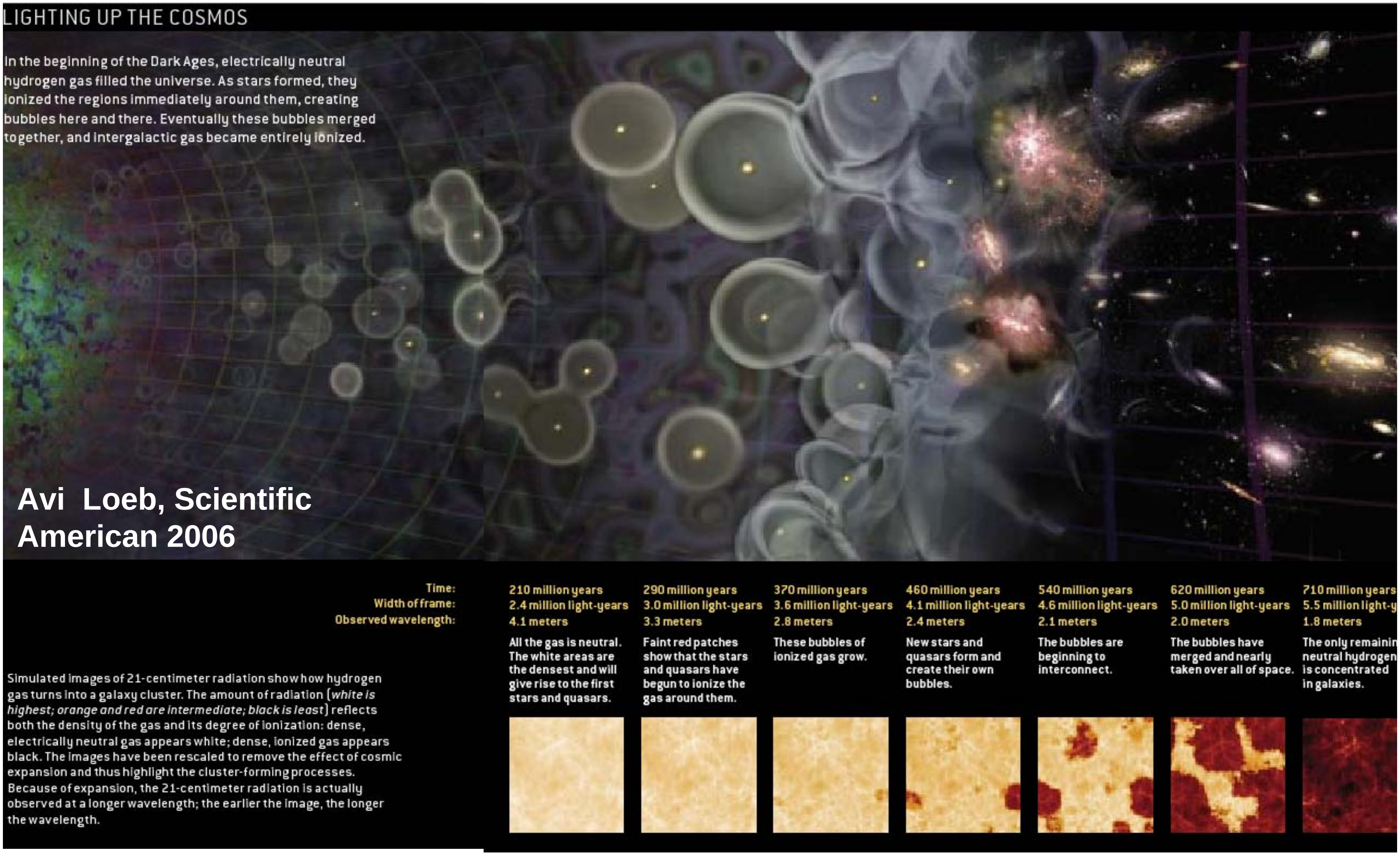


- DM assembly provides the framework for galaxy formation (Cole)
- But many additional features now required to match properties of baryons
  - feedback/BHs
  - environment
  - ….
- Rich datasets coming in (UKIDSS, MUSYC, Spitzer)
- How much further with semi-analytic models?



Bundy et al 2006

Theorists' View of Cosmic Reionization

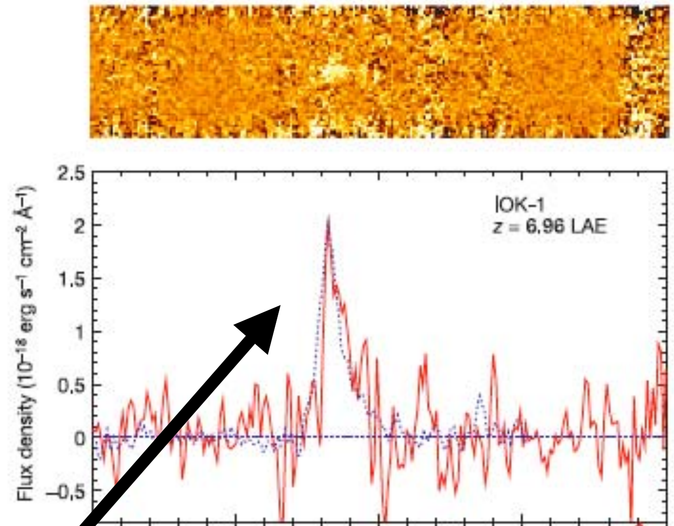


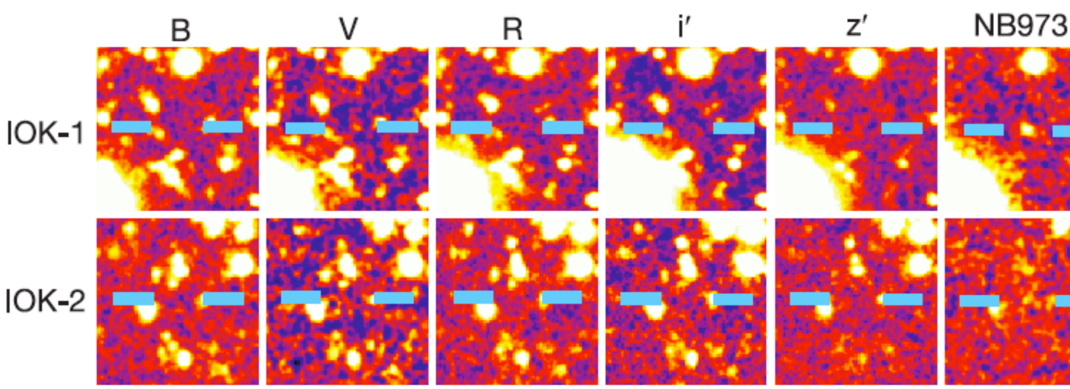
But did it really happen like this..?

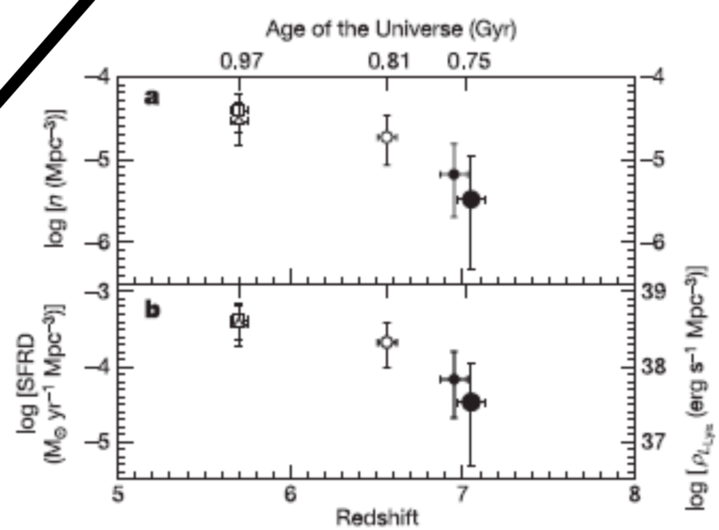
A galaxy at a redshift $z = 6.96$

Nature 443, 186 (2006)

Masanori Iye[1,2,3], Kazuaki Ota[2], Nobunari Kashikawa[1], Hisanori Furusawa[4], Tetsuya Hashimoto[2], Takashi Hattori[4], Yuichi Matsuda[5], Tomoki Morokuma[6], Masami Ouchi[7] & Kazuhiro Shimasaku[2]







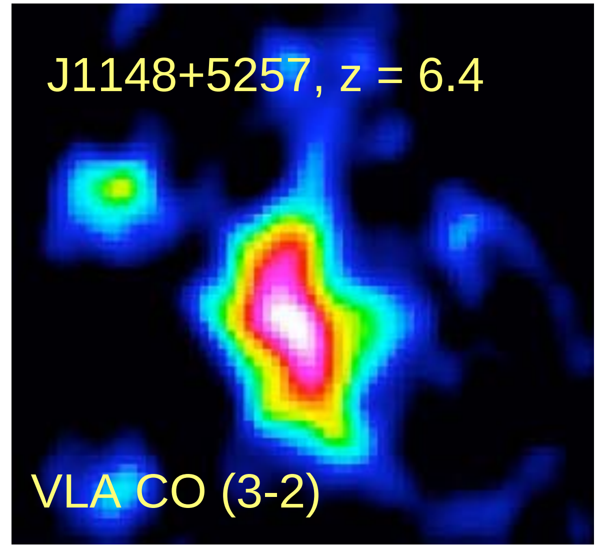
How will the story of reionization unfold?

Next 2 years:

- Consolidation of Lyα LF evolution 5<z<7 (Subaru)
- Improved dropout mass density estimates z~5-6 (HST/Spitzer)
- Confirmation of various z > 7 candidates
- Detailed studies of z~5-6 galaxies (AO-fed IFU spectrographs)

- Next 5 years
  - Systematic exploration of 8<z<12 (HST WF3, IR nb)
  - ALMA & 21cm surveys
- 2015+: Era of JWST and 20-40m ELTs

ALMA - tracing early gas and dust



Carilli et al (astro-ph/0703.799)

ALMA enables sub-kpc imaging of gas & dust at z~6 (typically SFRs ~ 10 $M_{\odot}$ yr^{-1})

- Current VLA targets are ULIRGs or QSOs
- Extending this technique to Lyα emitters located by JWST and TMT will become practical

Upcoming Radio Surveys

LOFAR: Low Frequency ARray; Netherlands
www.lofar.org

21cmA/PAST: Primeval Structure Telescope; China
web.phys.cmu.edu/~past

MWA: Mileura Widefield Array; Australia
space.mit.edu/RADIO/research/mwa.html

SKA: Square Kilometre Array
www.skatelescope.org

Major challenge = foregrounds: terrestrial noise, HII regions…

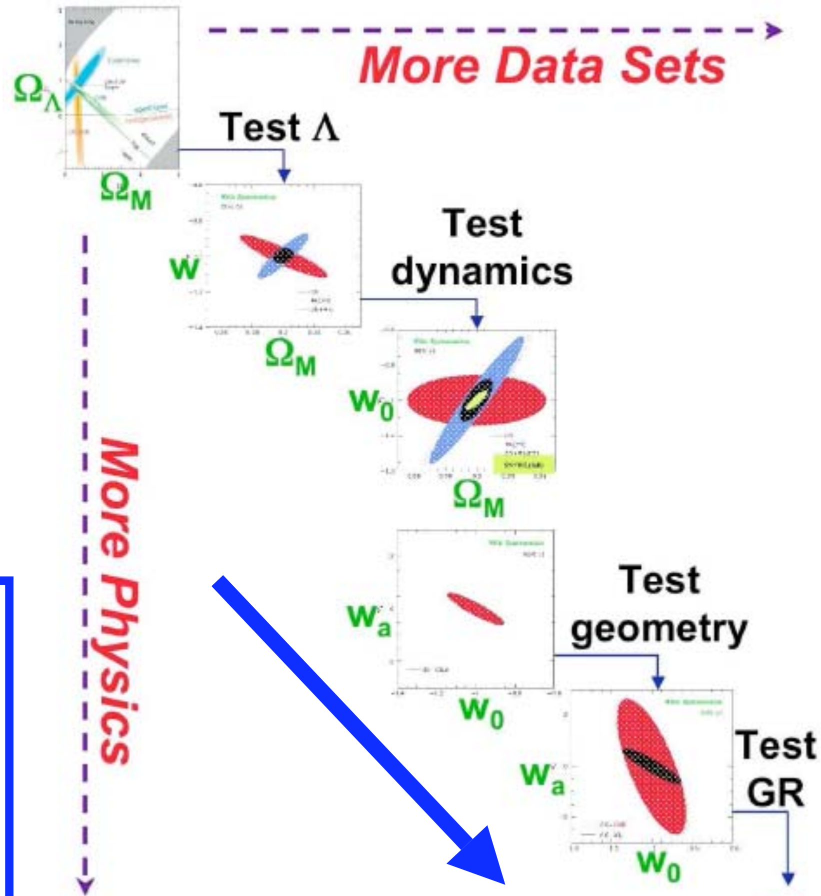
Stepwise Approach to Dark Energy

- Dark energy has no agreed physical basis

  constant $\Lambda \rightarrow$ static $w \rightarrow$ dynamic

  $w = w_0 + w_a (1-a)$

  $w(t)$ has no naturally-predicted form
- Wrong parameterization can lead to incorrect deductions: models are degenerate!
- Incremental approaches:
  - reject null hypothesis of Λ ($w \neq -1$)
  - prove via more than one method $w \neq$ const
  - derive empirical evolution a(t), G(t), $d_A(z)$, so test GR



Linder

Consumer's Guide to Methods for Measuring *w*

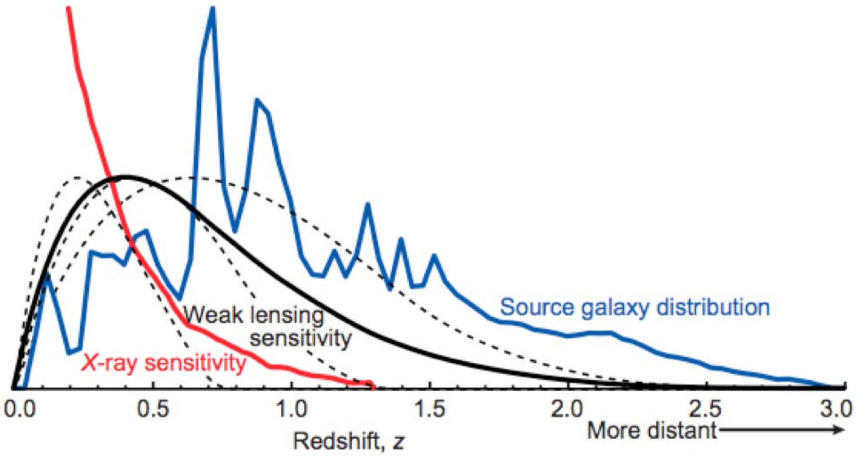
- **Type Ia Supernovae: $d_L(z)$ to z ~ 2**
  - Most well-developed with rich datasets
  - Ongoing with various ground-based/HST surveys
  - Key issue is physics/evol^n: *do we understand SNe Ia?*
- **Weak lensing: G(t) to z ~ 1.5**
  - Less well-developed but promising; requires photo-z's
  - Relative merits of ground and space debated
  - Key issues are *fidelity, calibration*
- **Baryon "wiggles": $d_A(z)$, H(z) to z=3**
  - Late developer: cleanest *requiring huge surveys*
- **Cluster counts, ISW etc..**

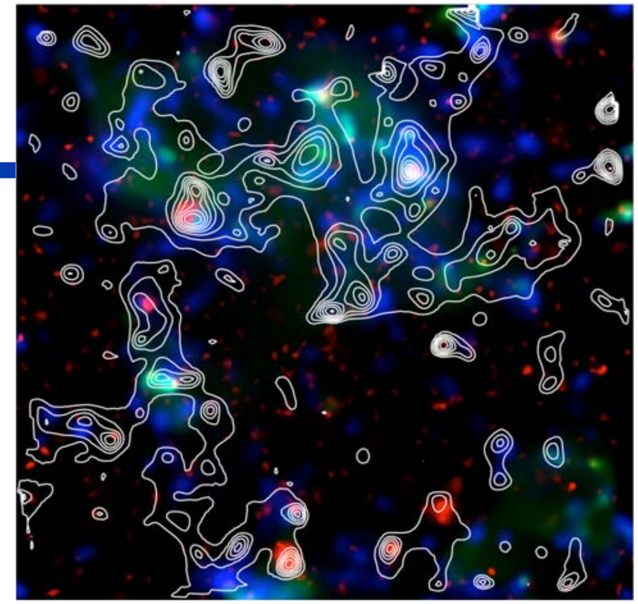
Potential SN Systematics in measuring w(a)

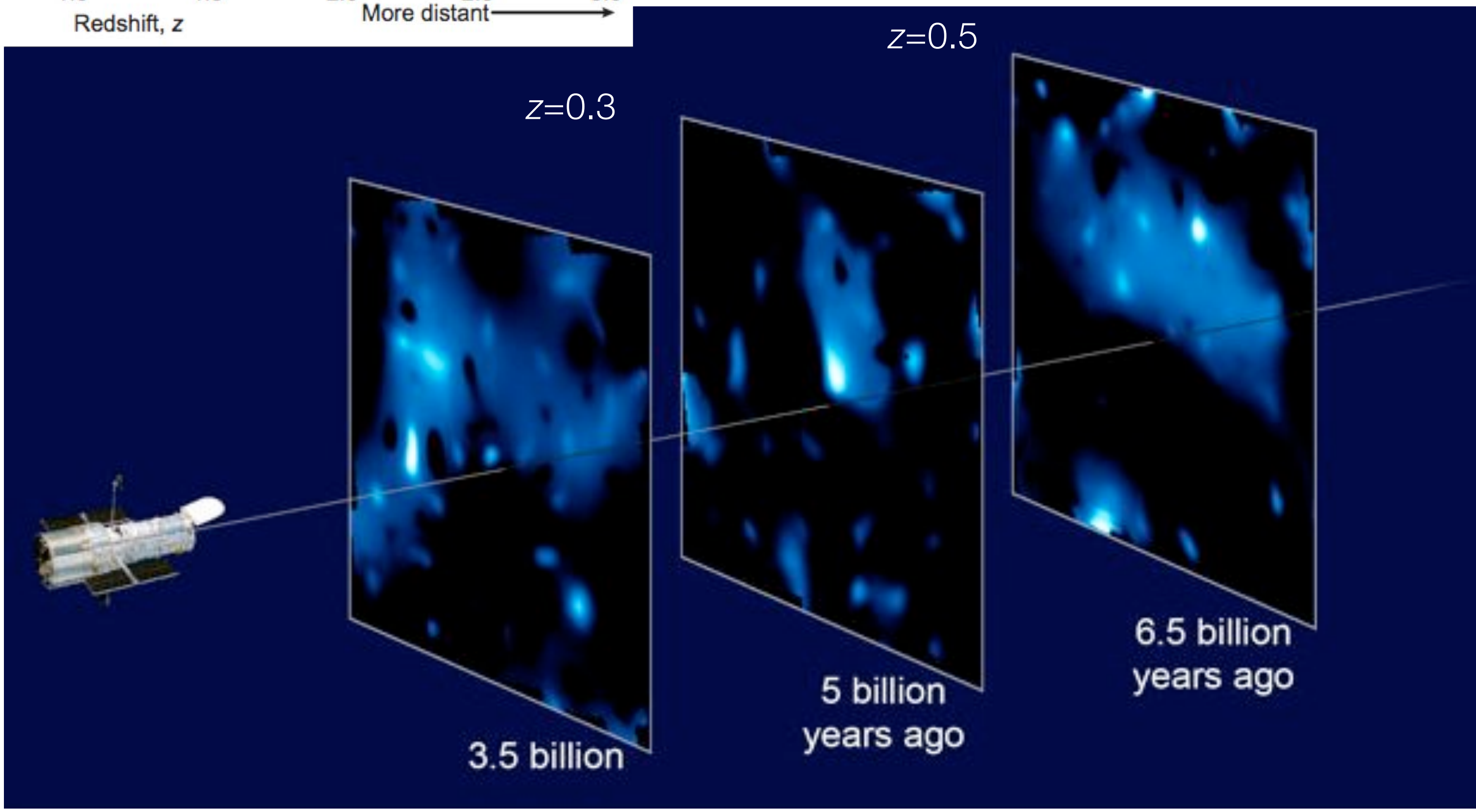
- "Experimental Systematics"
  - *Calibration, photometry, Malmquist-type effects*
- Contamination by other SNe or peculiar SNe Ia
  - *Minimized by spectroscopic confirmation*
- Non-SNe systematics
  - *Peculiar velocities; Hubble Bubble; Weak lensing*
- K-corrections and SN spectra
  - *UV uncertain; "golden" redshifts; spectral evolution?*
- Extinction/Colour
  - *Effective R_V; Intrinsic colour versus dust*
- Redshift evolution in the mix of SNe
  - *"Population drift" – environment?*
- Evolution in SN properties
  - *Light-curves/Colors/Luminosities*

Increasing knowledge of SN physics

Weak Lensing Tomography



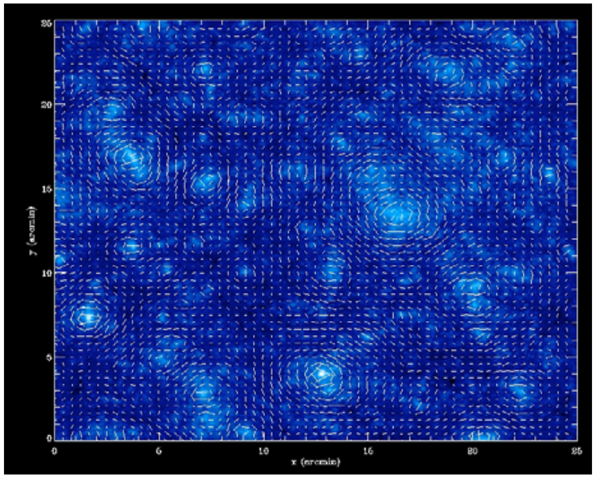




Massey
et al
(2007)

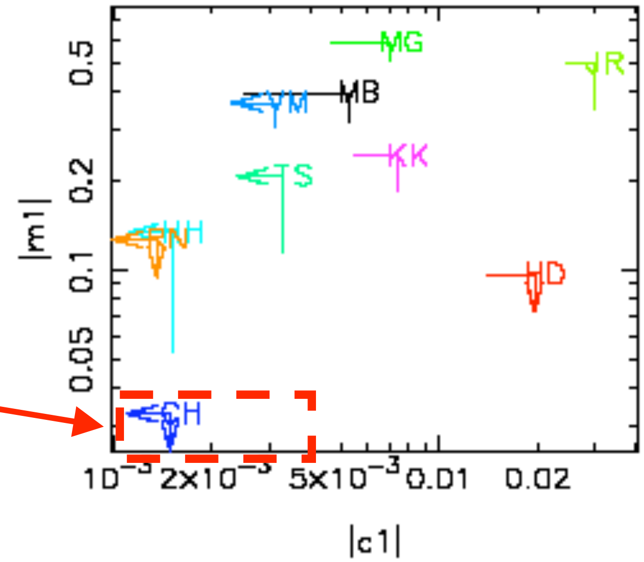
Will Weak Lensing Cut It?

$\Delta\gamma = m_1\gamma + c_1$



STEP project

required precision



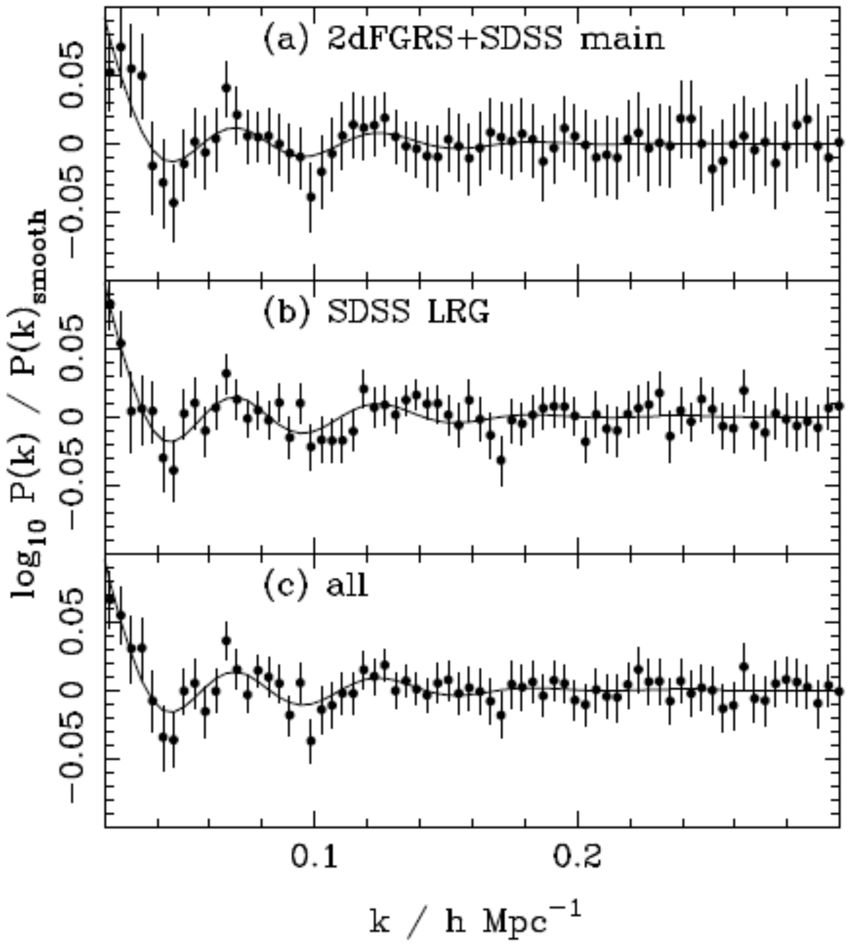
- **Calibration**: Need to measure shear to 10^{-3} & control systematics to $10^{-3.5}$; current best methods 10 x worse. OK if we understand limitations - not clear we do, much work needed (STEP project: Heymans & Rhodes)
- **PSF correction:** Ground versus space: is space required?
- **Redshift distributions**: accurate N(z) for background populations
- **Intrinsic Alignments:** e.g. due to tidal torques; ~few % effect mitigated by down-weighting very close pairs or using photo-z information
- **Shear-Galaxy Correlations:** Subtle bias due to possible correlation of foreground galaxy with density enhancement which could contaminate cosmic shear at 10% level for typical surveys

Future BAO surveys

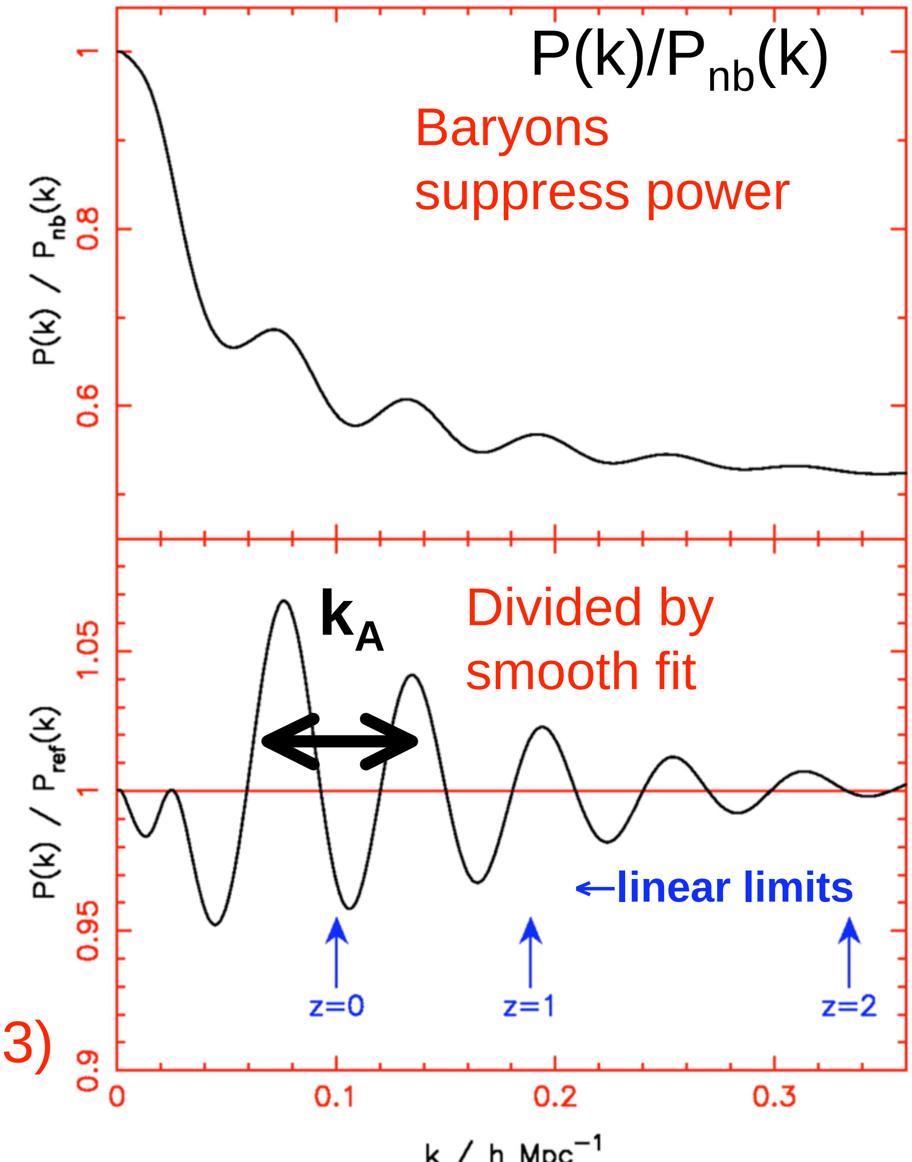
Instrument	Telescope	Redshift range	Area (deg^2)	Survey start	Cost
AAOmega	AAT	0.5–1.0	1000	2006	Already exists
FMOS	Subaru	1.0–1.5	300	2007?	Already exists
HETDEX	HET	1.8–3.8	200	2009	$20M?
SDSS-III	2.5m SDSS	0.3–0.6	8000	2008	$20M?
WFMOS	Subaru	0.5–1.5 2.5–3.5	2000 300	2012?	$40M?
ADEPT	1.3m space NIR slitless spectroscopy	1.3–2	30,000	2012?	$600M

Courtesy: Karl Glazebrook

Baryon Wiggles: early stages



Percival et al (astro-ph/0705.3323)



Beyond SDSS/2dF: must measure wiggle wavelength as f(z)

BAOs Issues

Evolution of acoustic peak at k_{max}~0.065 Mpc^{-1} (150 Mpc)

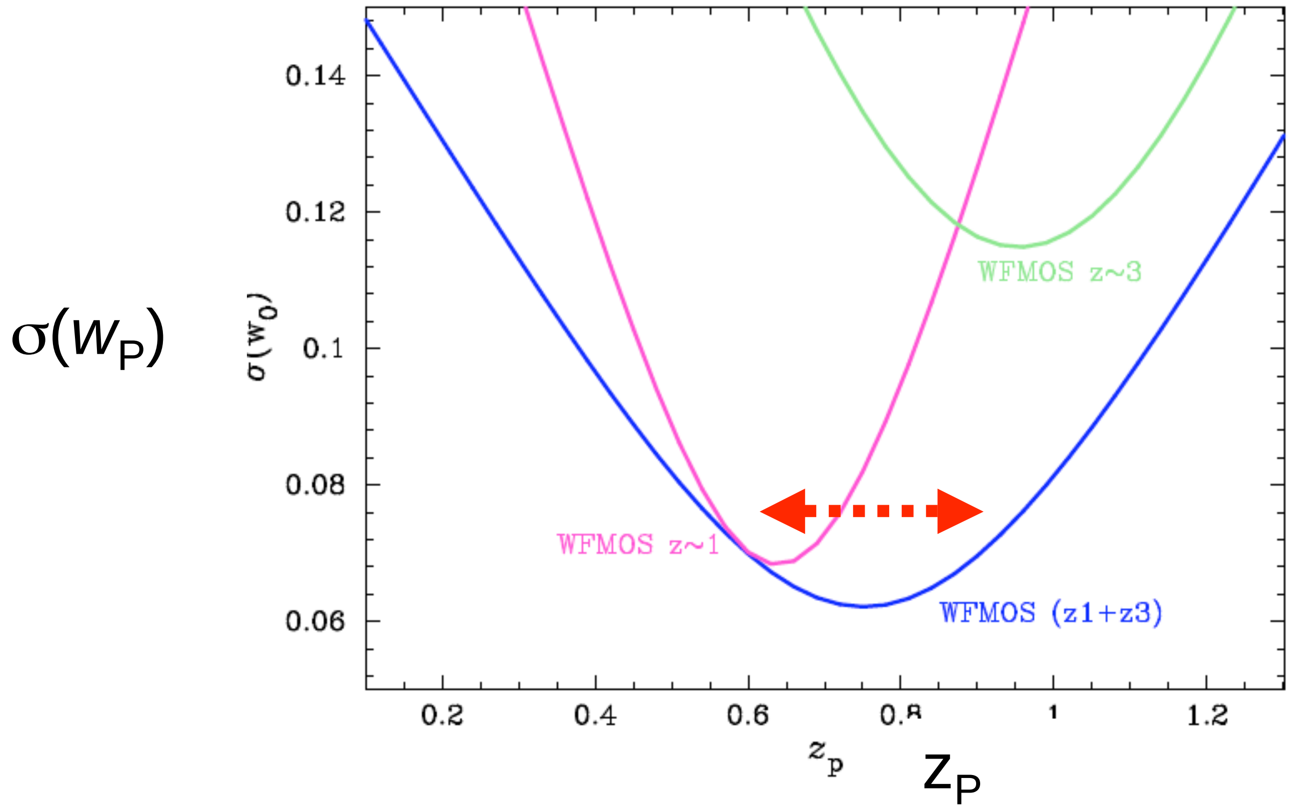
Statistical limitation - fractional error in power spectrum. n (~10^{-4}) density in Mpc^{-3}

$$\sigma_{\ln P} = \frac{2\pi}{(Vk^2\Delta k)^{1/2}} \left(\frac{1+nP}{nP}\right)$$

- Scale-dependent non-linearity biases & reliance on numerical simulations (Angulo)
- Worry many mid-term projects will still have marginal significance, especially if there are surprises
- Substantial ground-based program with different tracers (LRGs, ELGs..) should precede any space-based program
- High z programs (LBGs, LAEs) offer independent probes but not much extra leverage unless *w* strongly evolving.
- Evolving SKA offers exciting and very efficient method

WFMOS Surveys at z~1 and z~3

$$w(z) = w_{\rm pivot} + w_1(z - z_{\rm pivot}).$$



$$z = 1: \quad z_{\rm pivot} = 0.64,$$
$$z = 3: \quad z_{\rm pivot} = 0.98,$$
$$z = 1 + z = 3: \quad z_{\rm pivot} = 0.76,$$

Adding high z survey improves w_p and extends z range only slightly (20% in expansion); do we realistically expect DE to change in such a short time?

Thank you Peder!