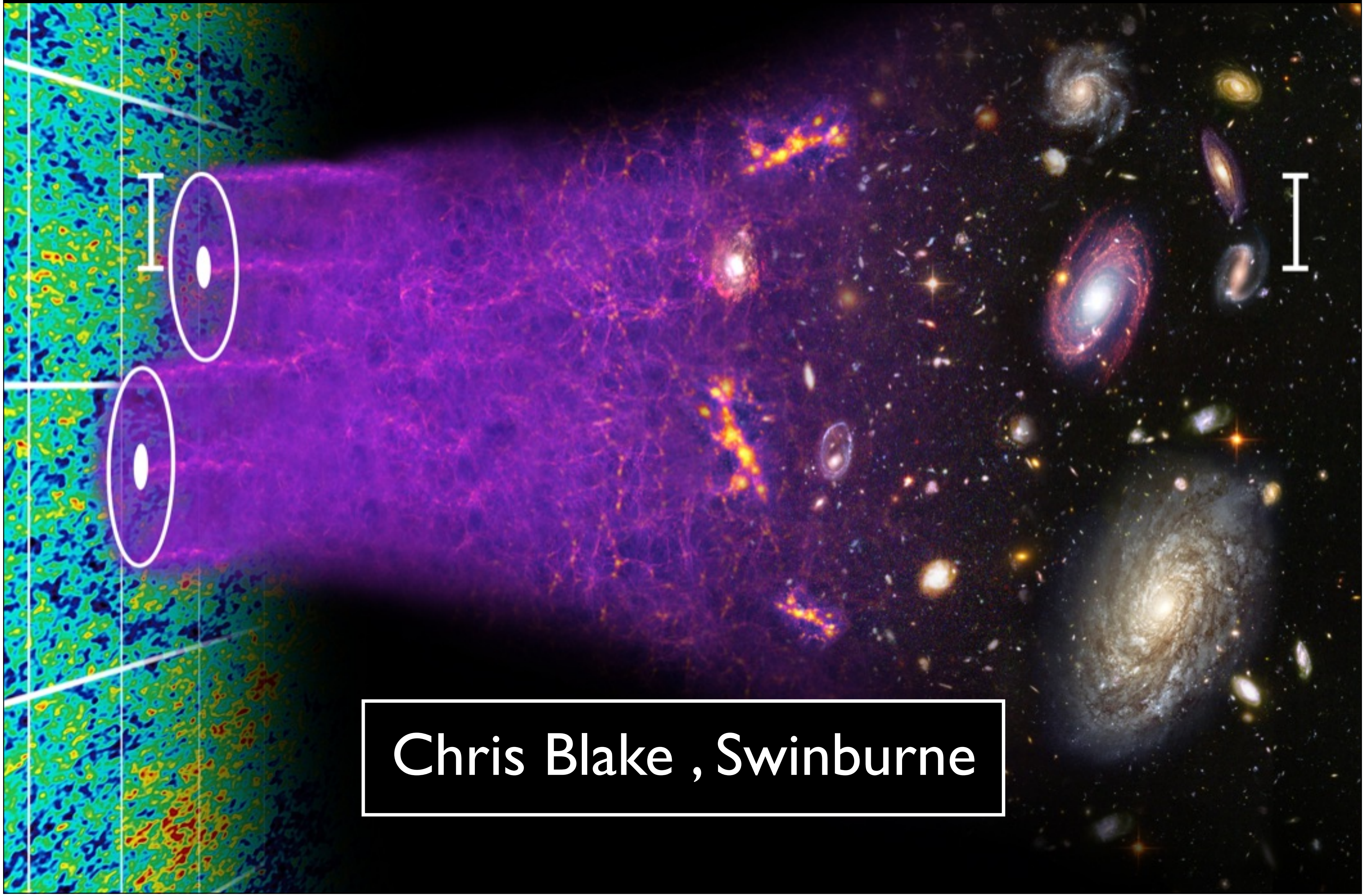
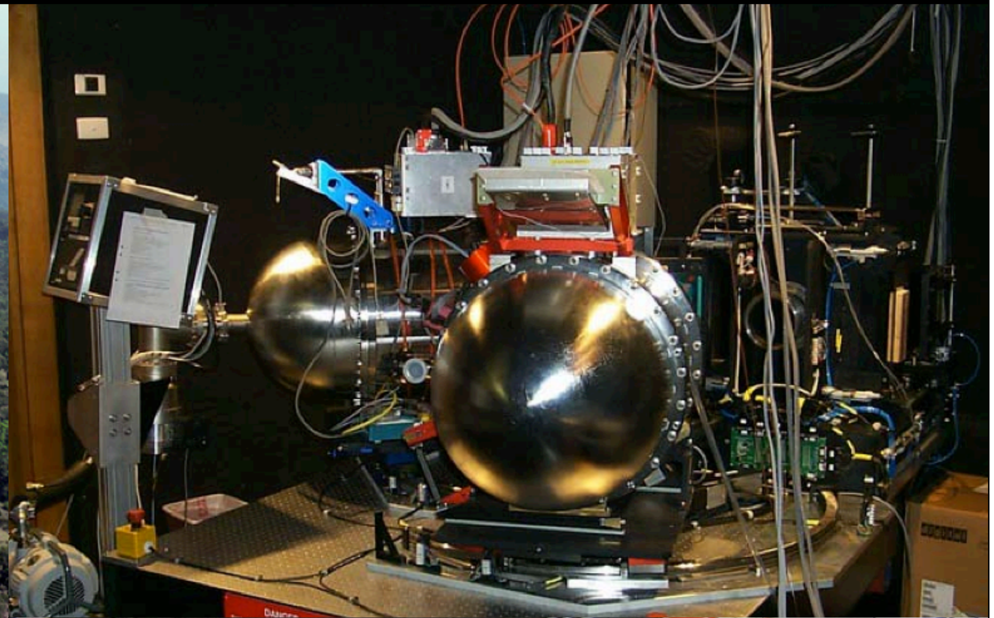
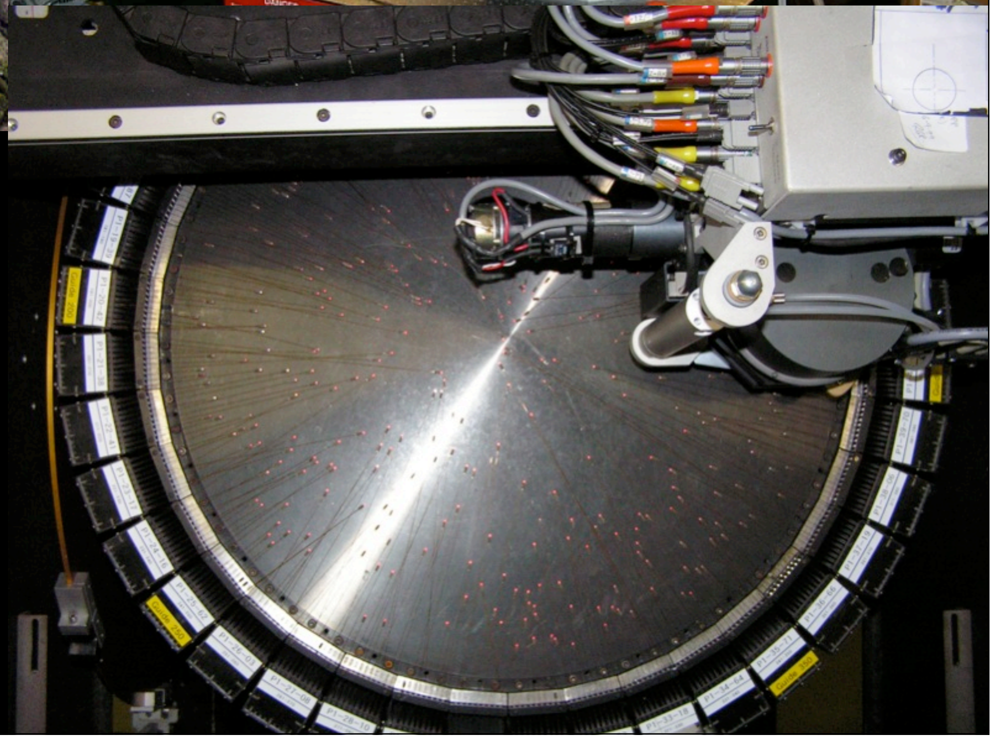
Three ways to measure cosmic distances



Chris Blake , Swinburne

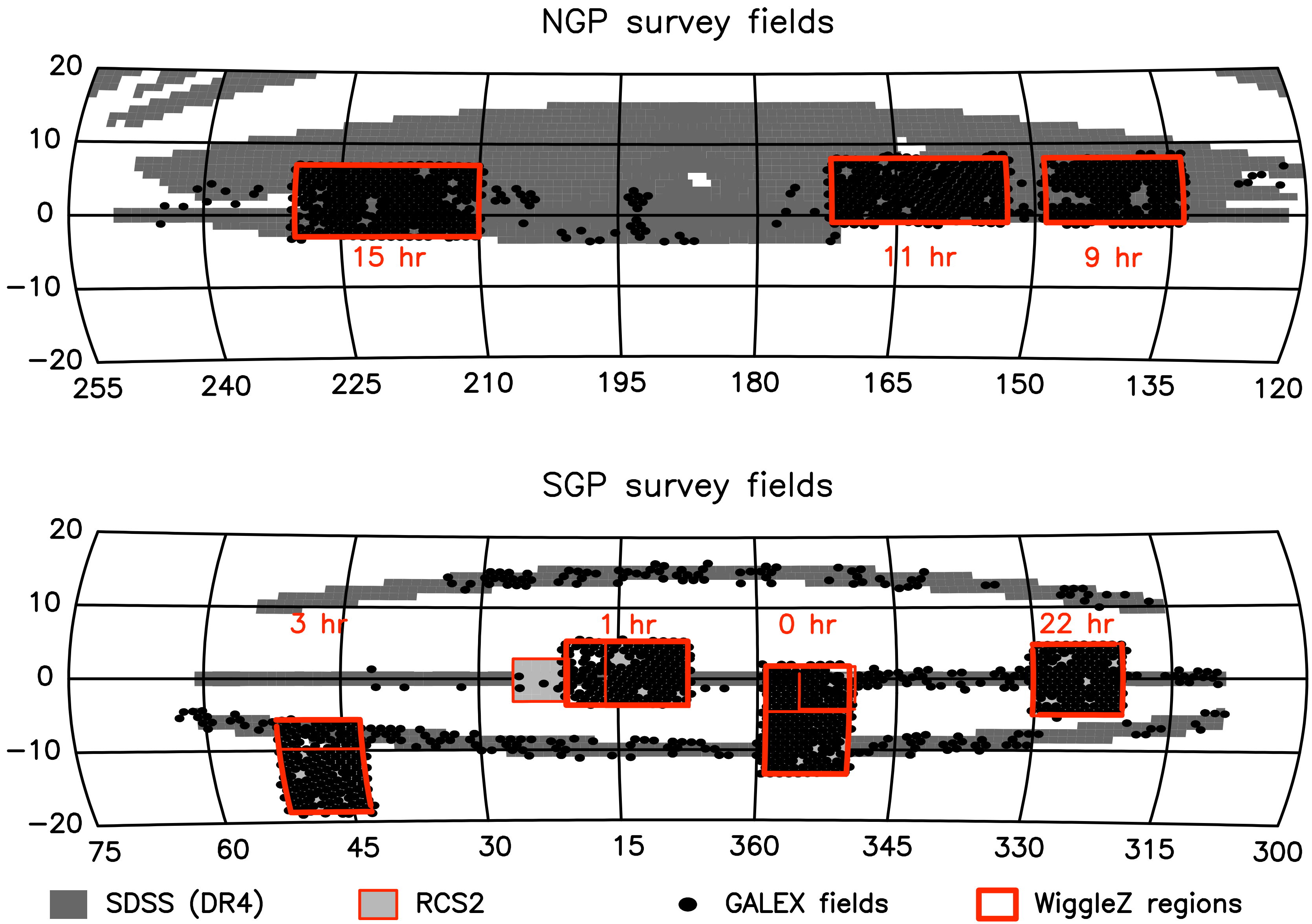
The WiggleZ Dark Energy Survey



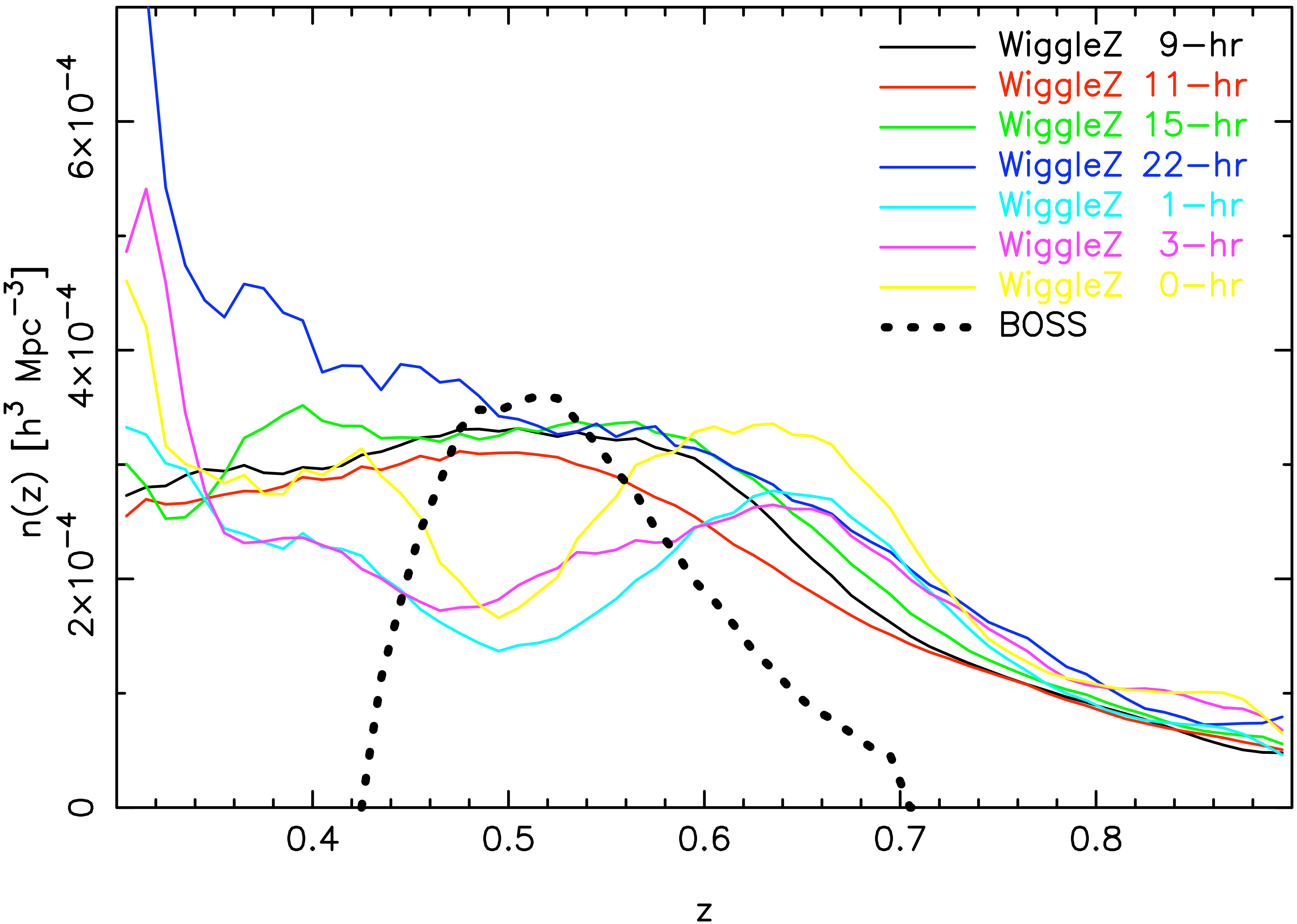


- 1000 sq deg , 0.2 < z < 1.0
- 200,000 redshifts
- blue star-forming galaxies
- Aug 2006 - Jan 2011

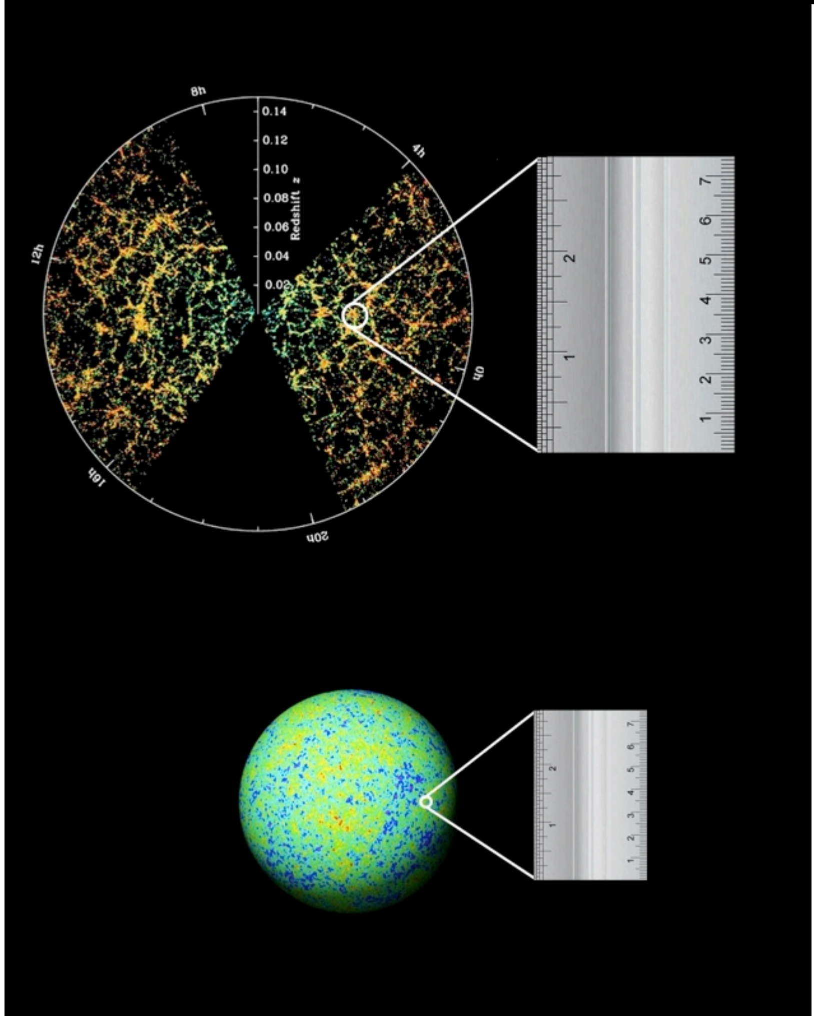
Sky coverage



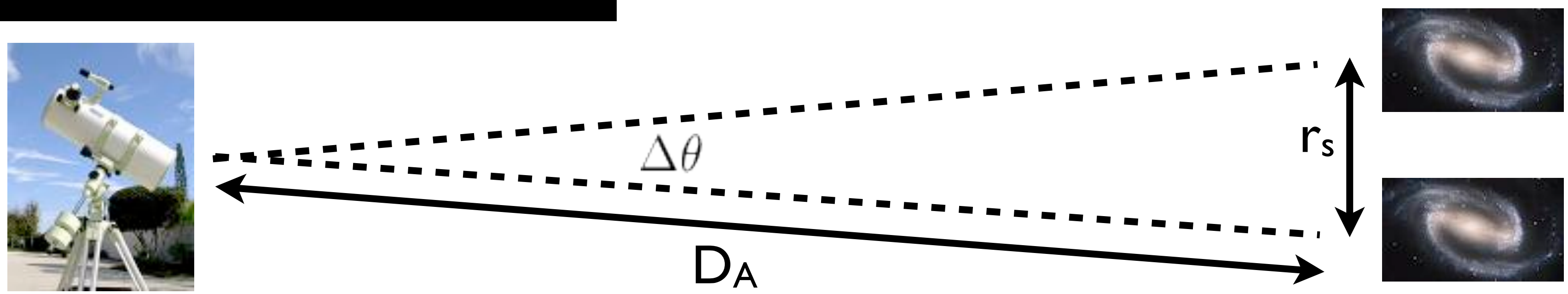
Redshift distribution



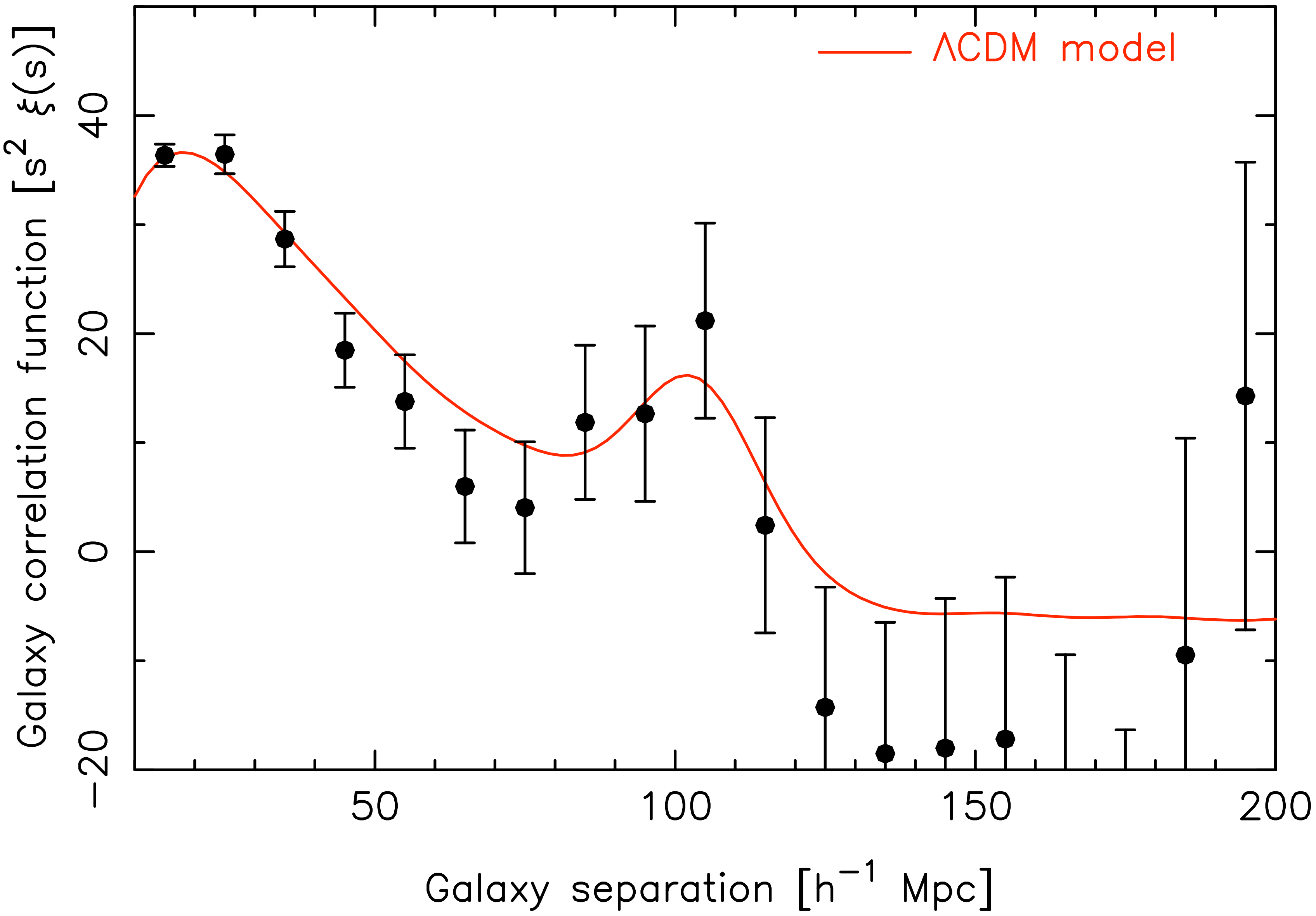
Method 1 : baryon acoustic peak



- Preferred co-moving separation of 105 h^{-1} Mpc between clumps imprinted at recombination
- We observe a preferred angular separation between galaxies at some redshift
- Allows distance determination by simple geometry

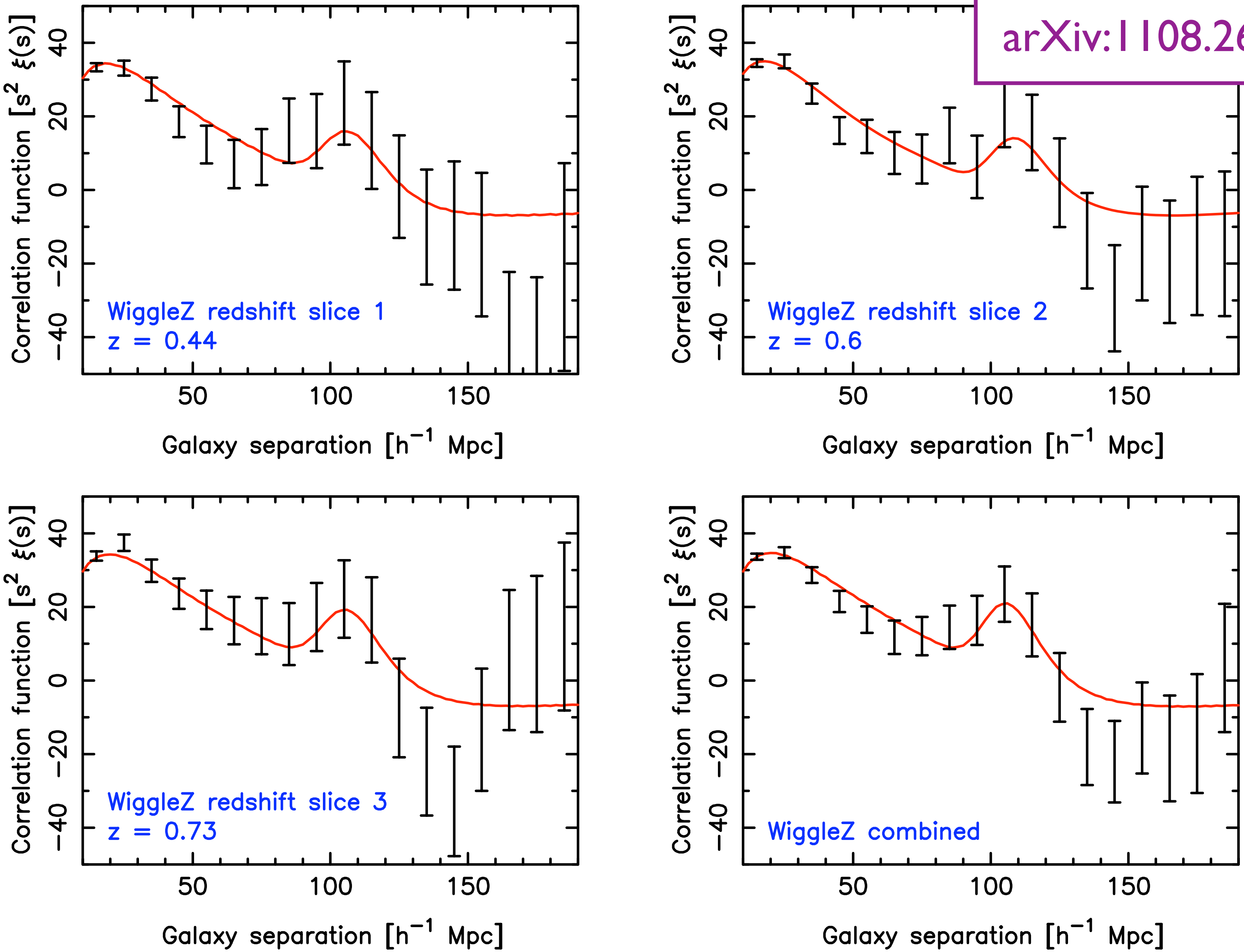


The baryon acoustic peak in WiggleZ

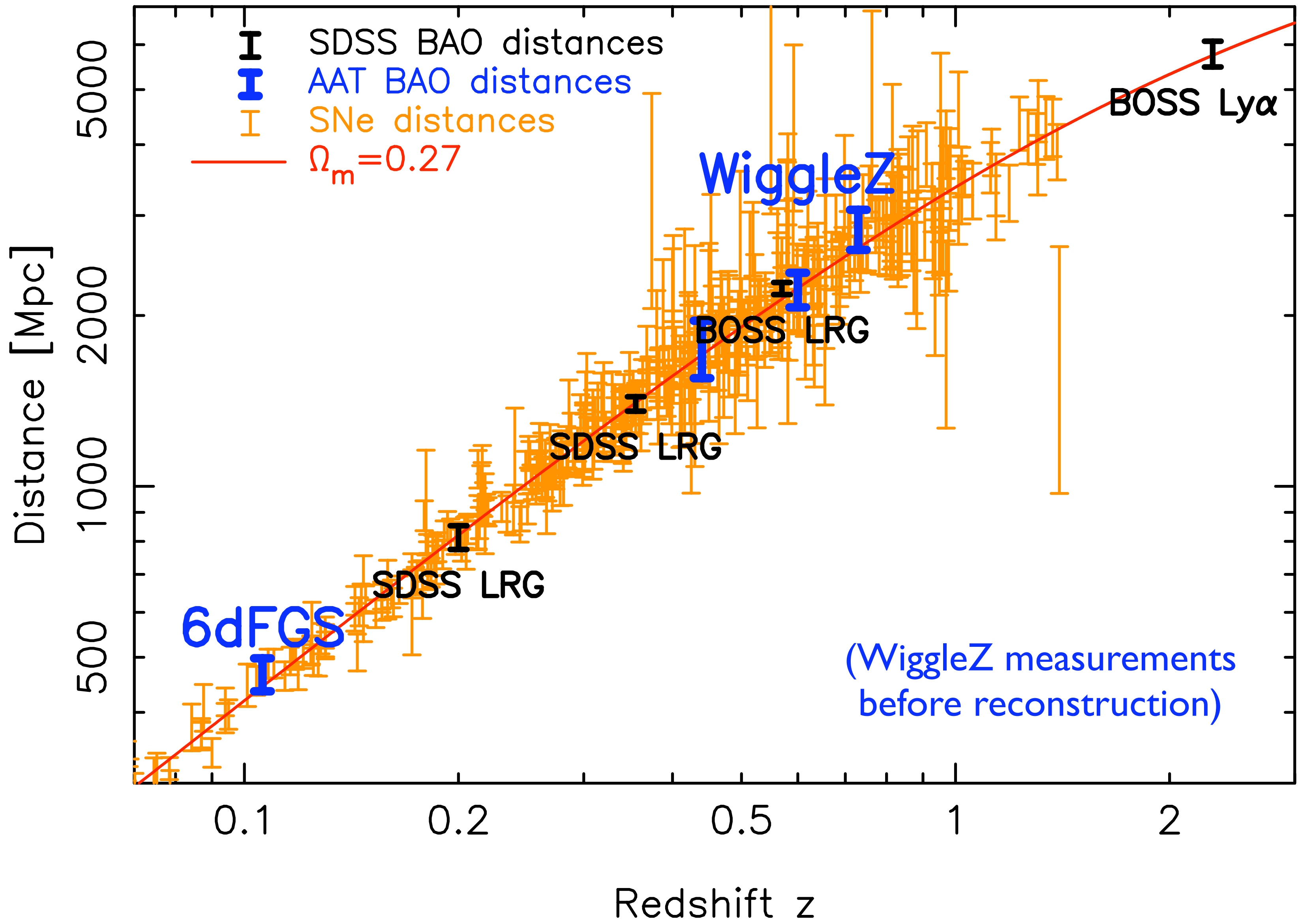


The baryon acoustic peak in WiggleZ

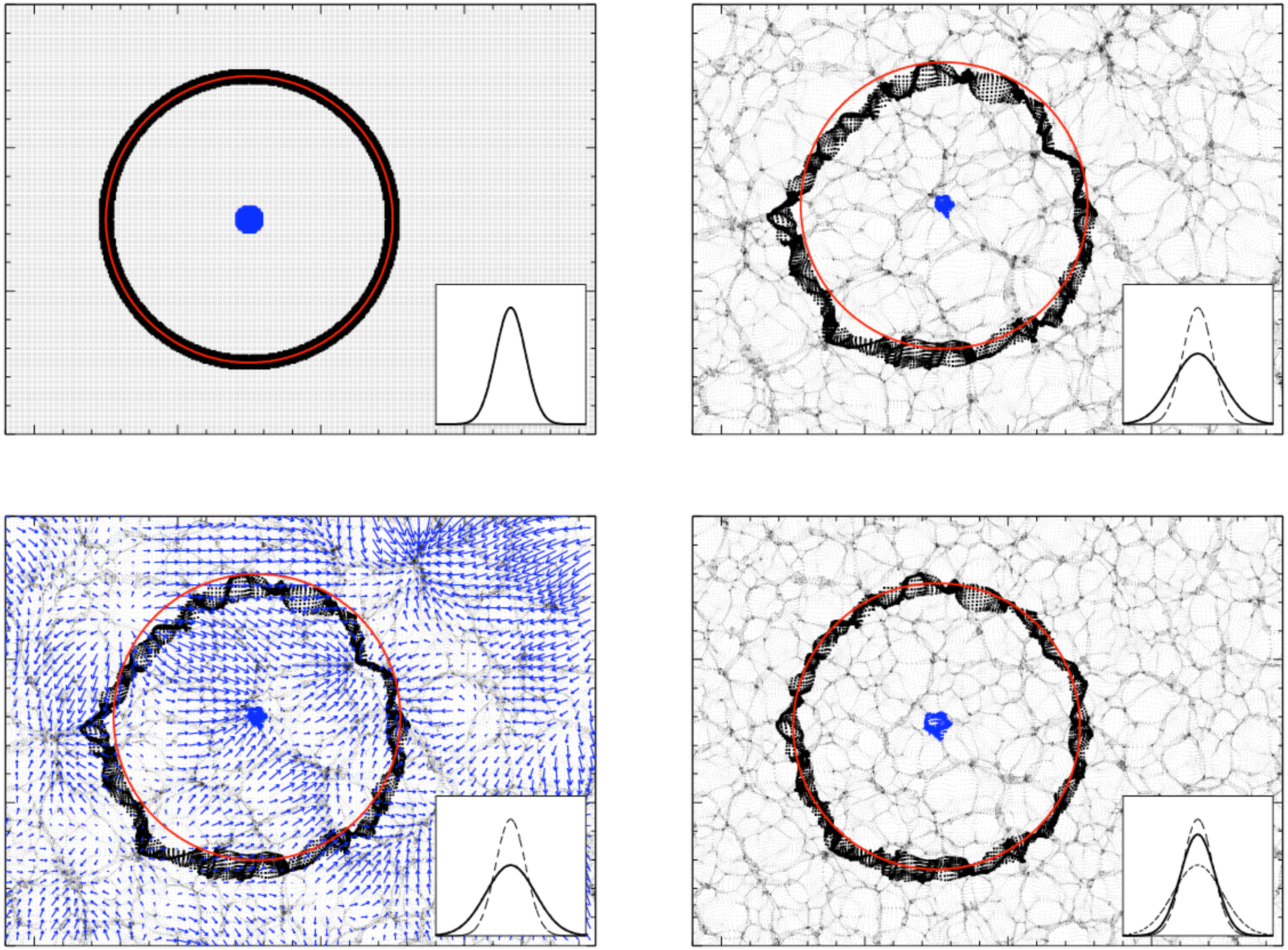
arXiv:1108.2635



BAO Hubble diagram

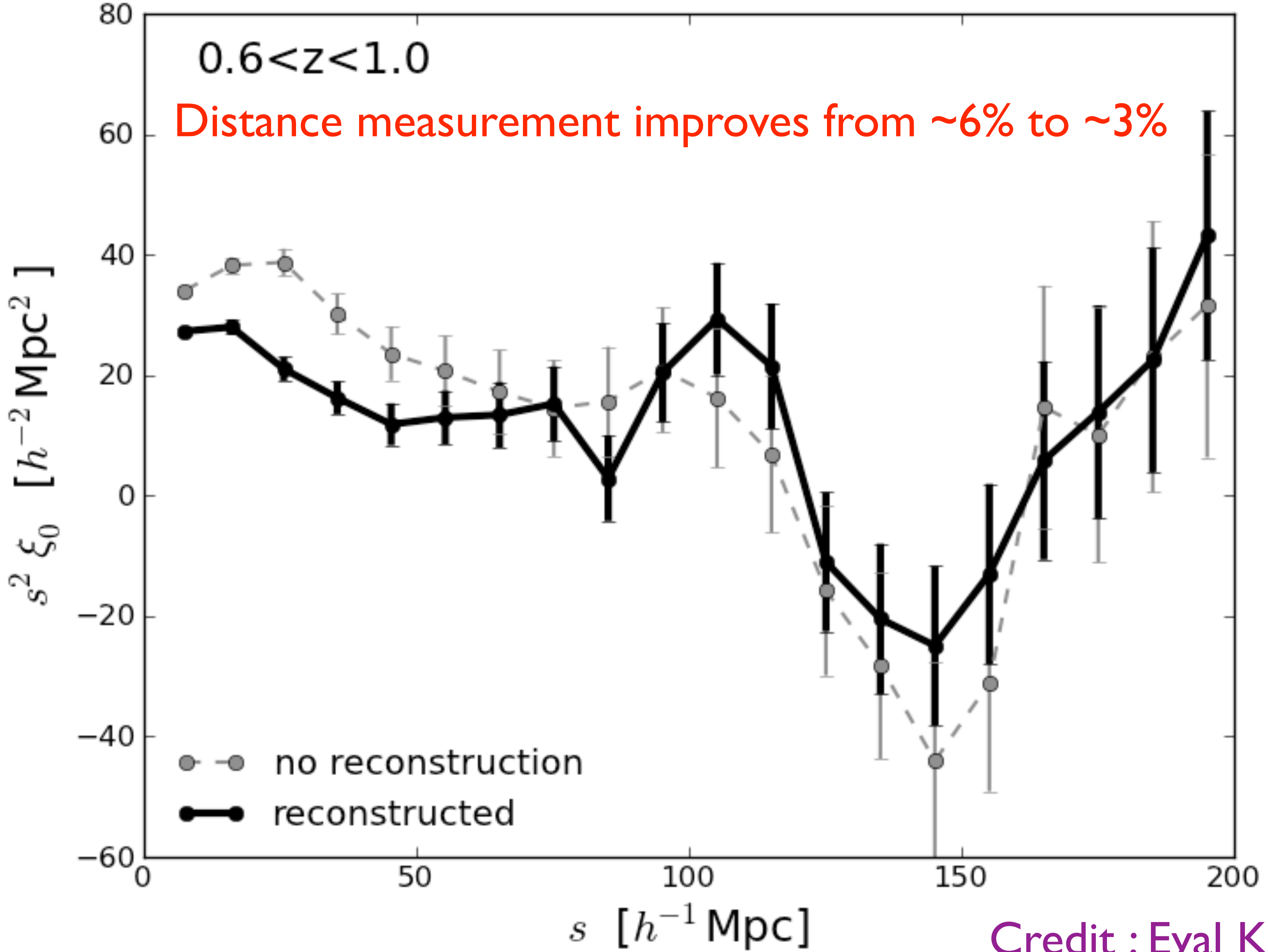


Reconstruction of the acoustic peak



Padmanabhan et al. (2012)

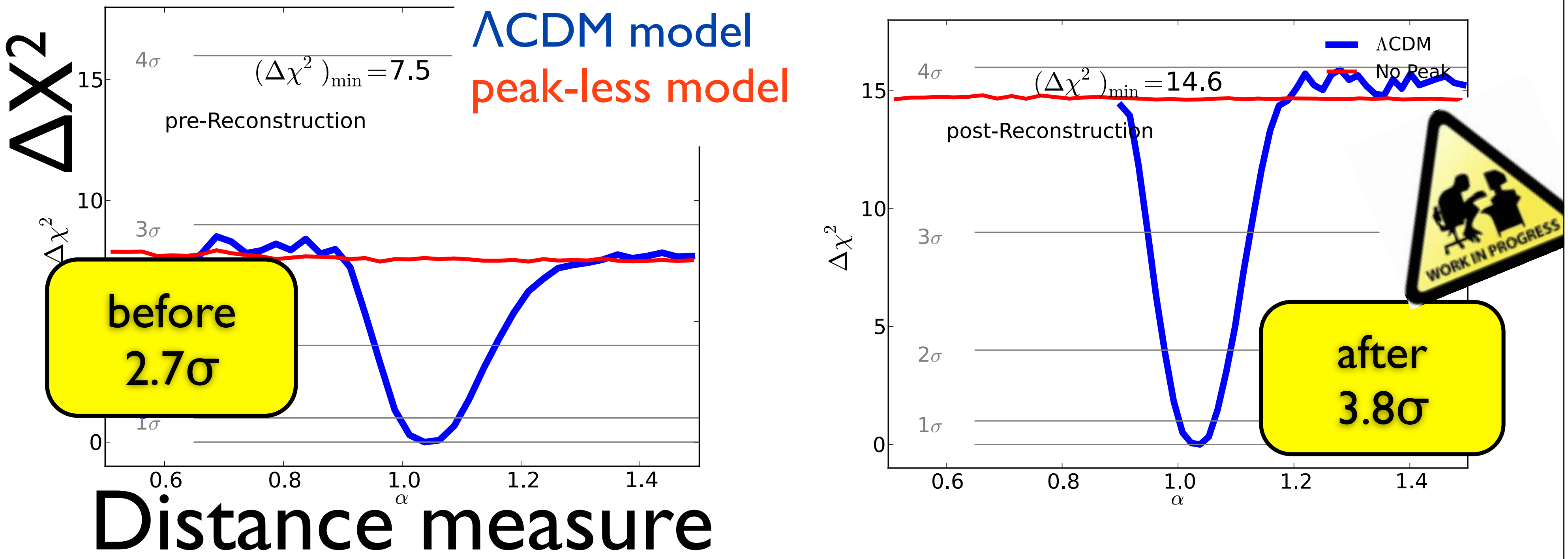
Reconstruction of the acoustic peak



Credit : Eyal Kazin

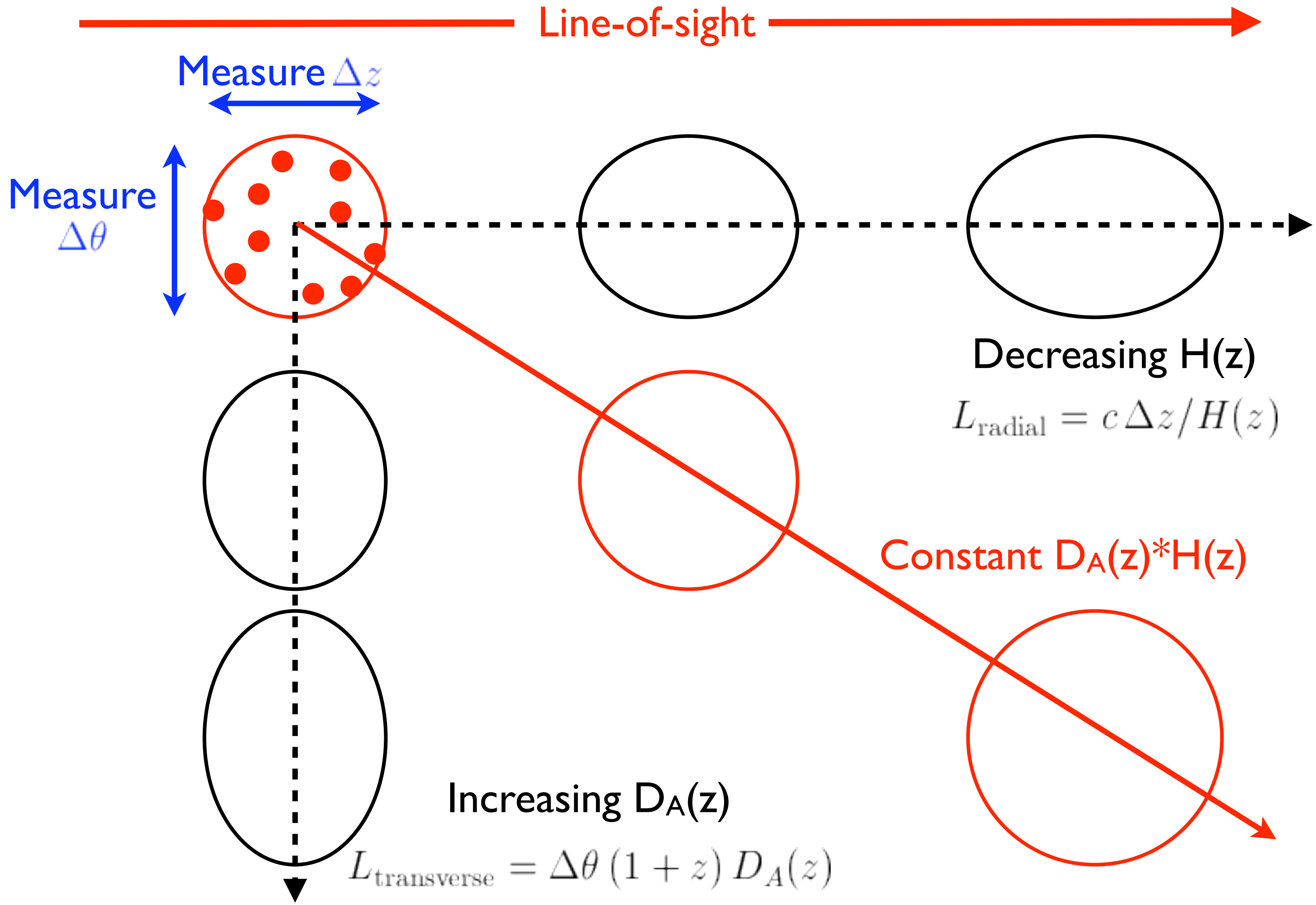
Reconstruction of the acoustic peak

- Reconstruction improves significance of detection:

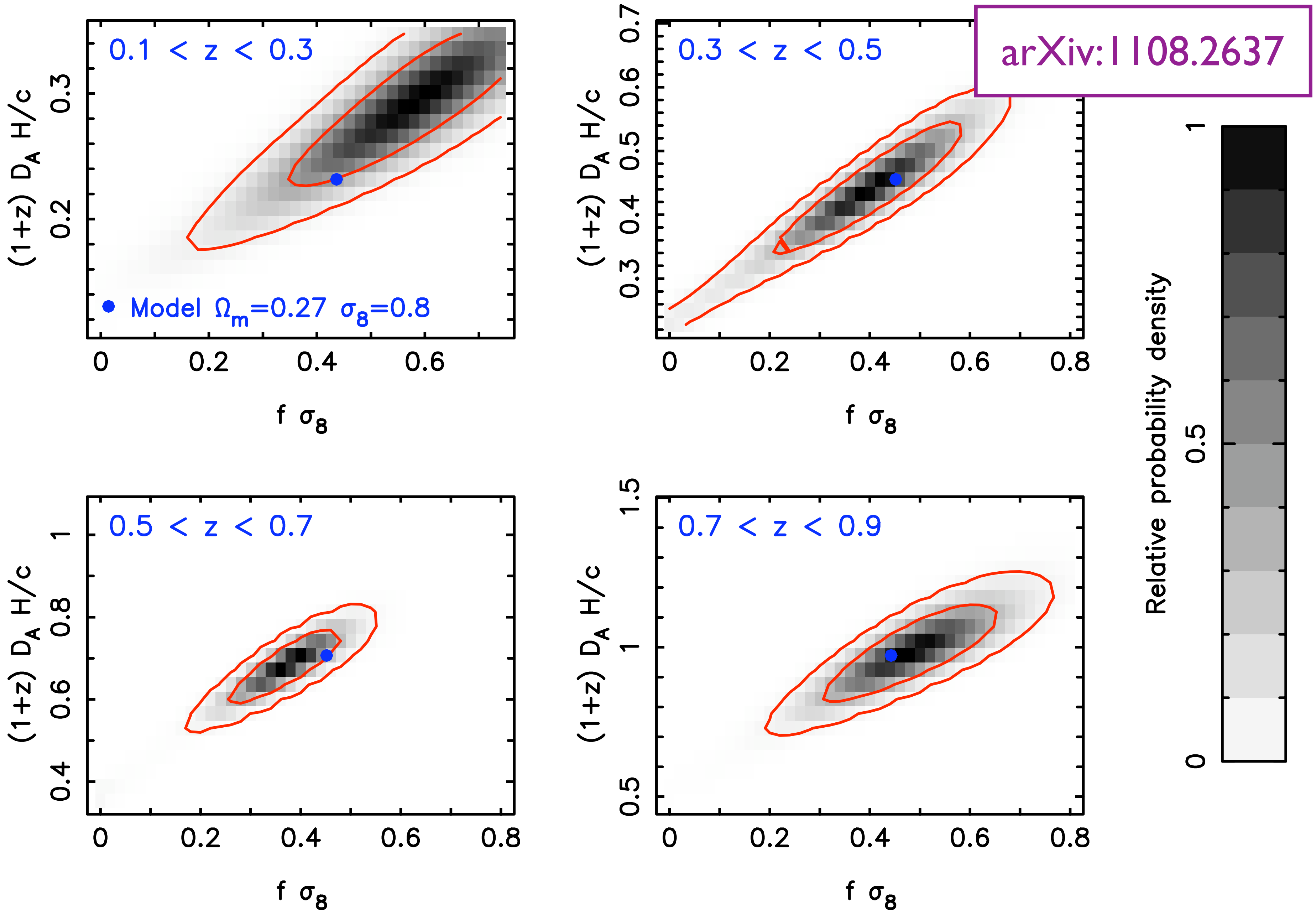


Credit : Eyal Kazin

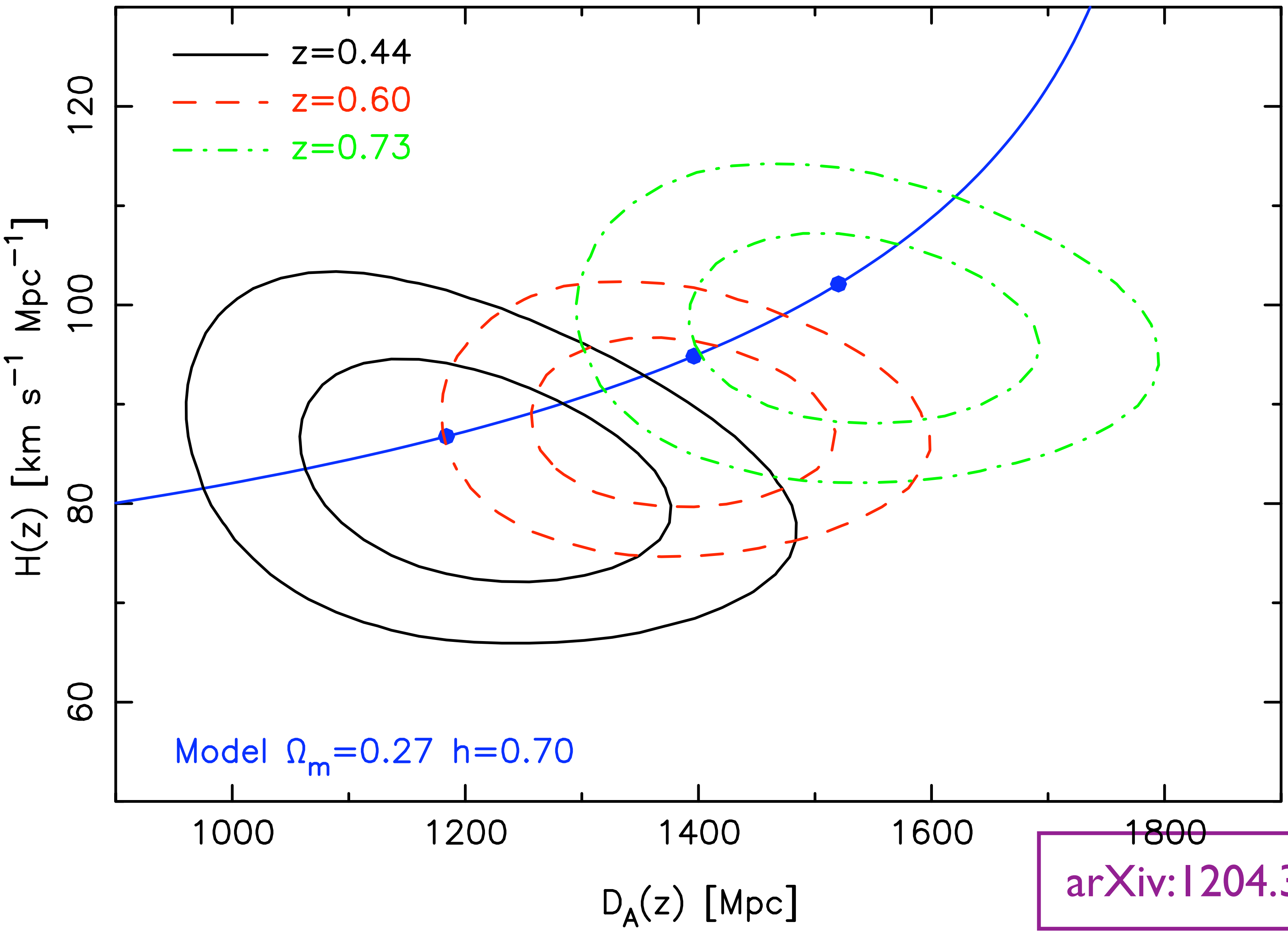
Method 2 : Alcock-Paczynski measurement



Alcock-Paczynski measurement

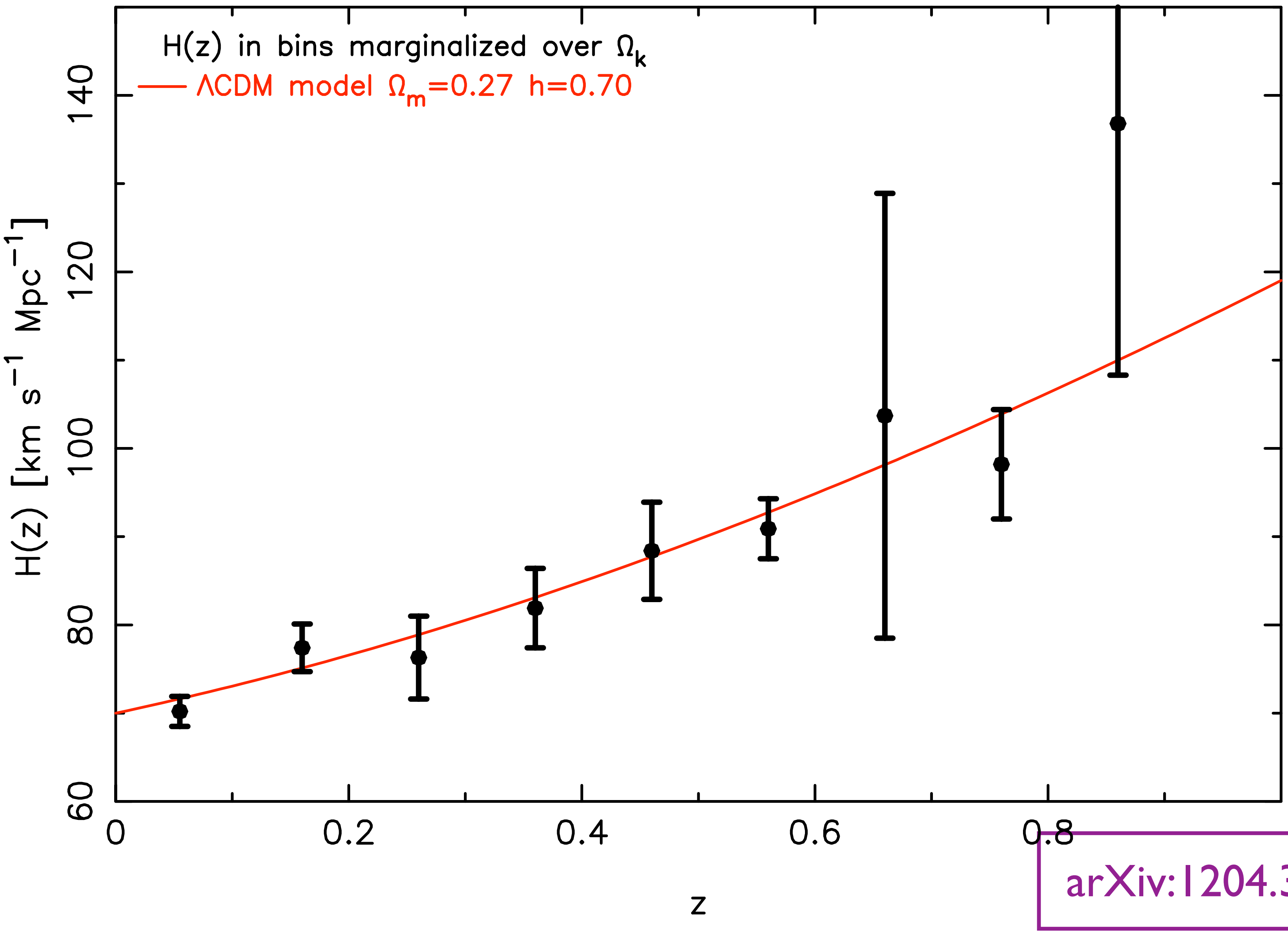


WiggleZ measurements of $D_A(z)$ and $H(z)$



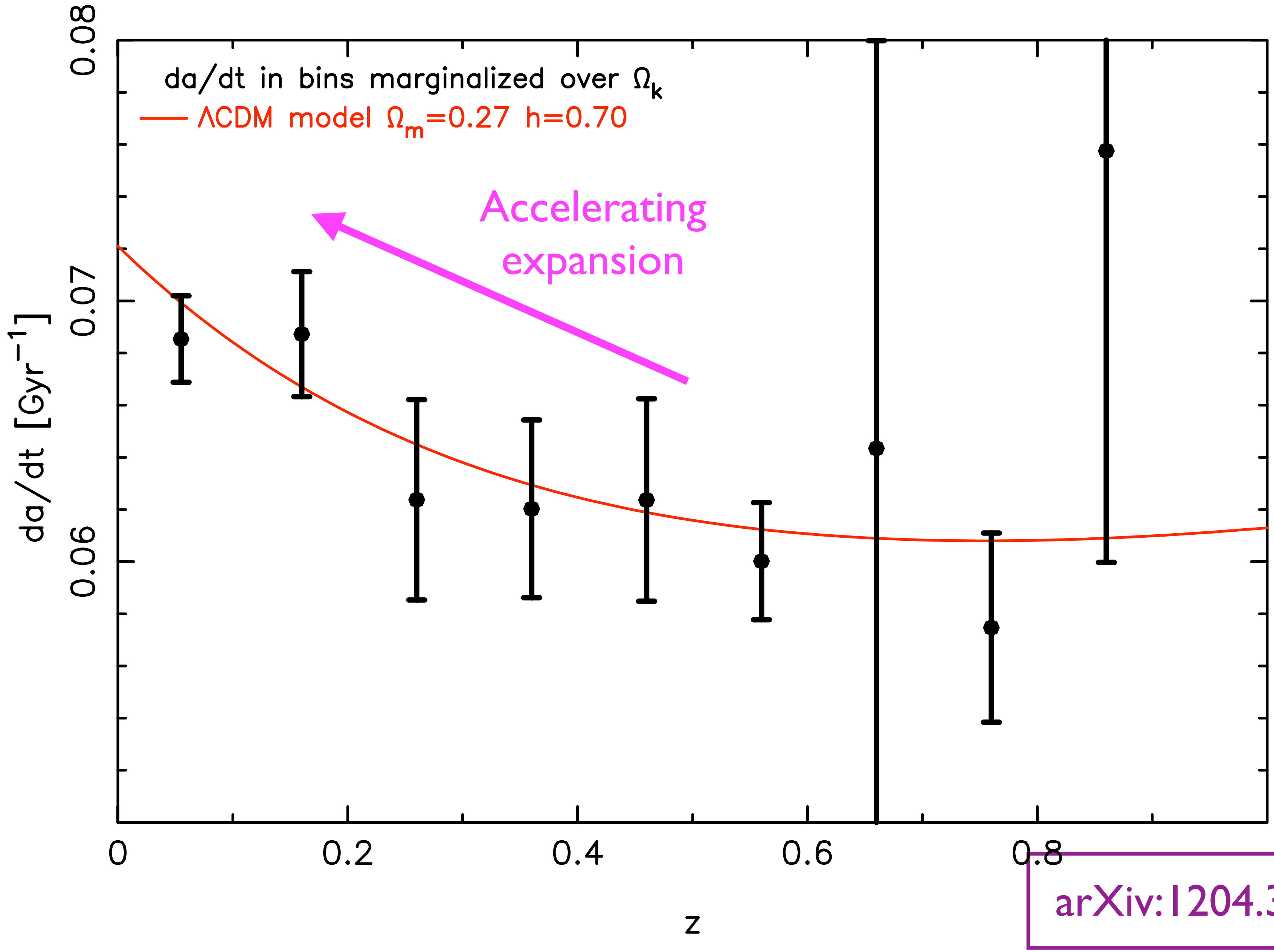
arXiv:1204.3674

Cosmic expansion history



arXiv:1204.3674

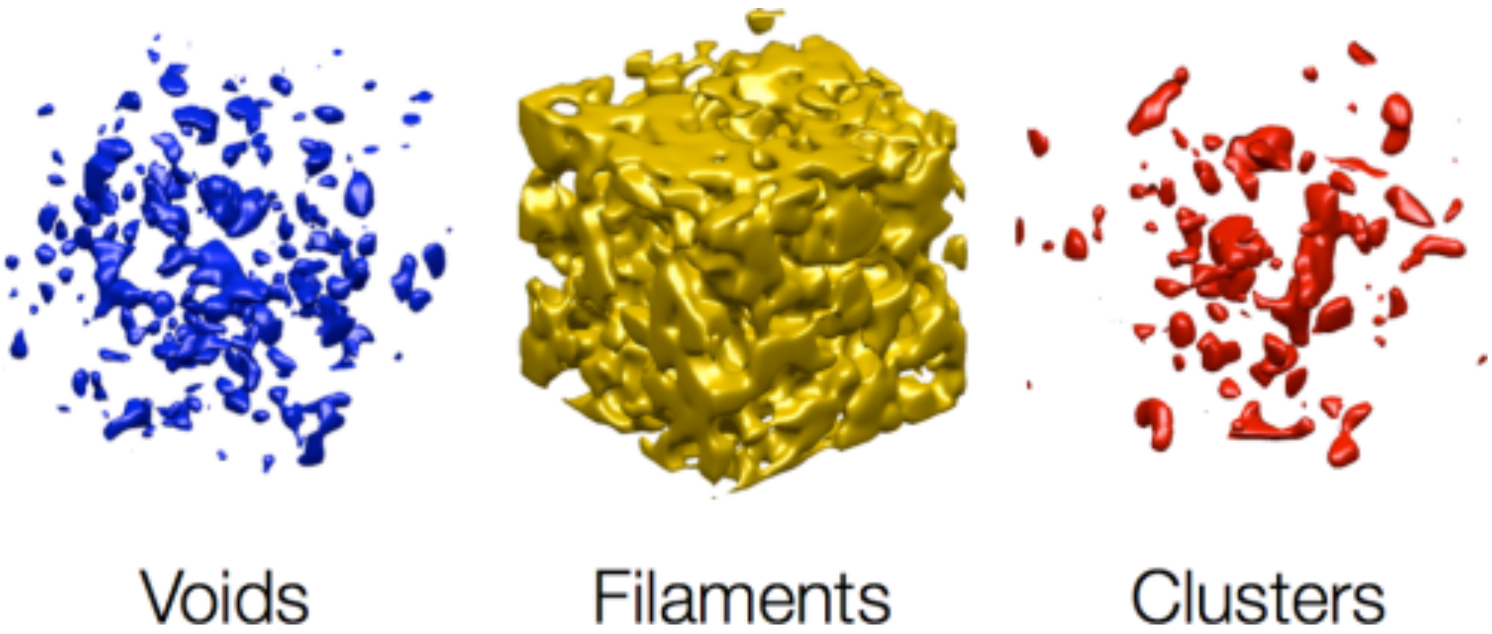
Cosmic expansion history

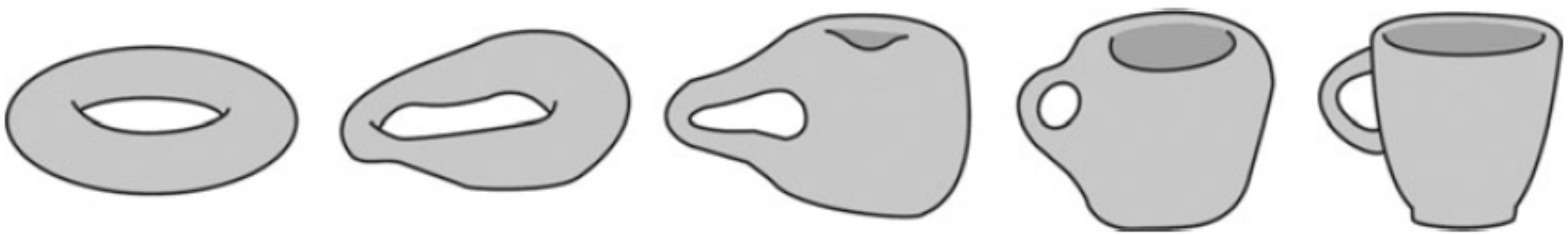


arXiv:1204.3674

Method 3 : topological statistics

- Morphology of the density field (isodensity contours):

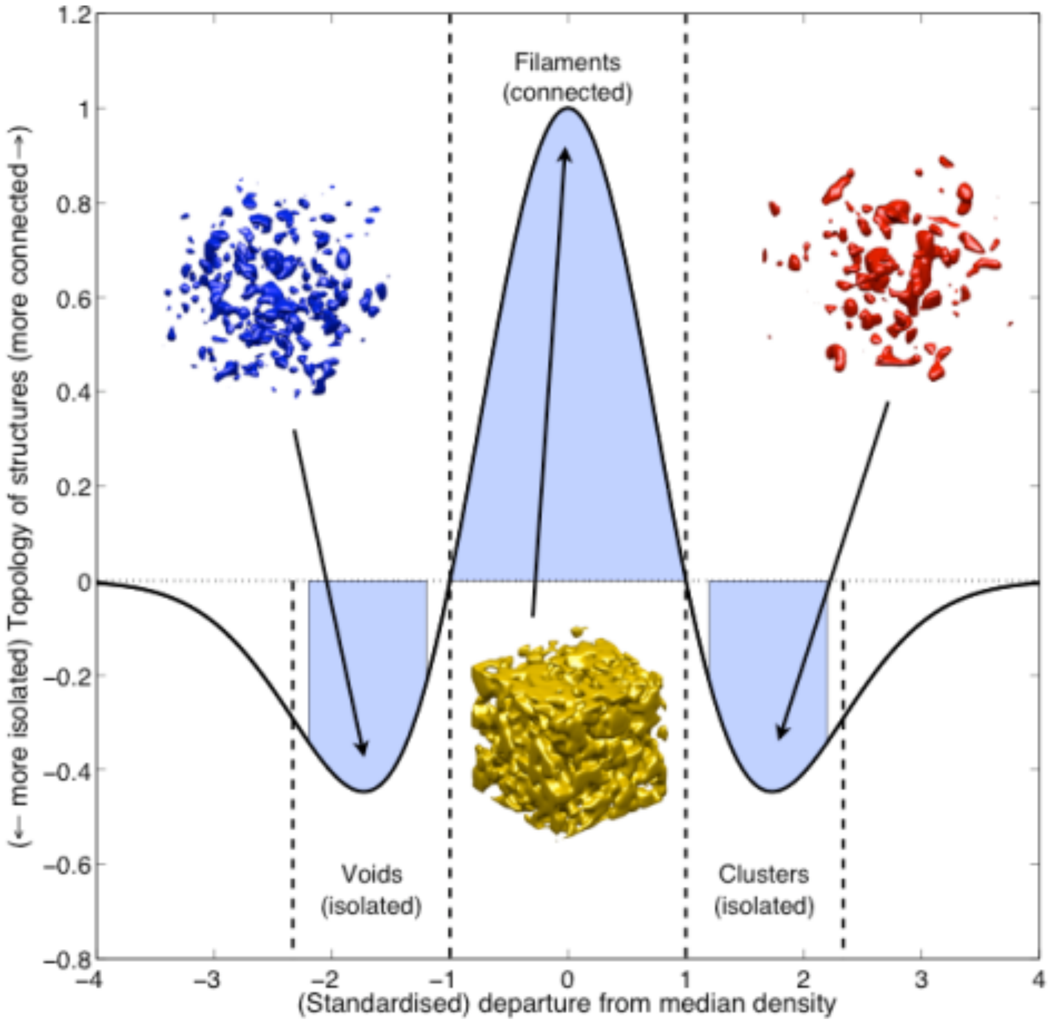




"A topologist cannot distinguish their doughnut from their coffee cup"

Topological statistics

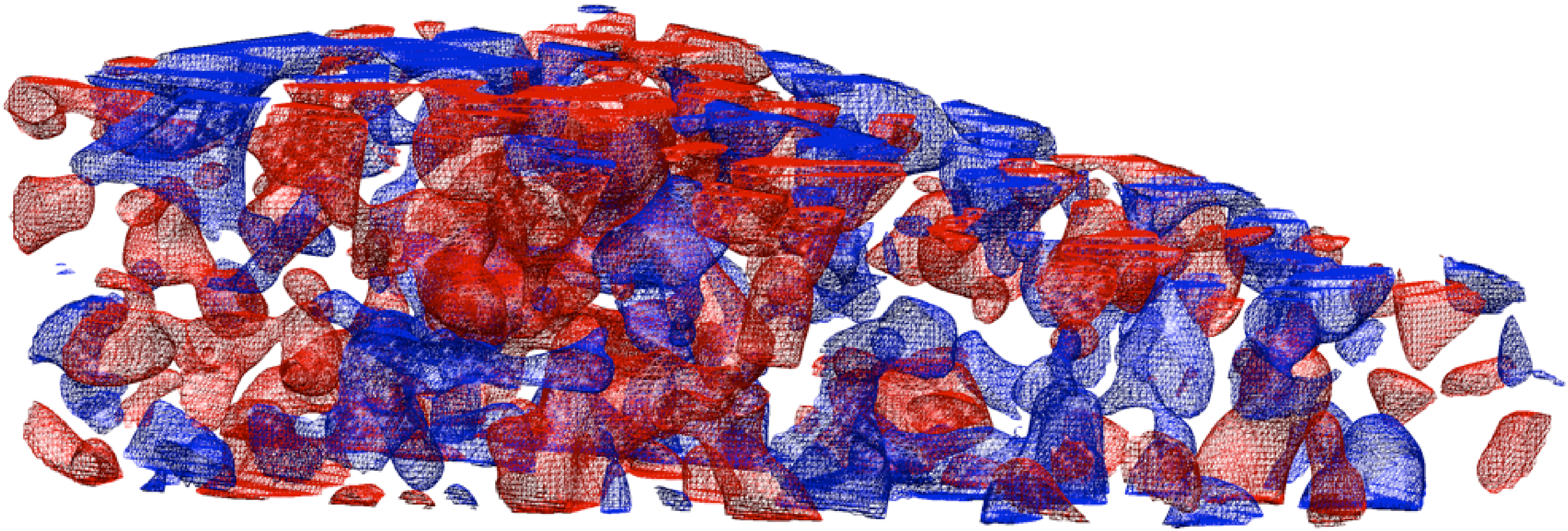
- Genus statistic (a.k.a. Euler characteristic):



Credit : Berian James

Topological statistics

- WiggleZ density field for 15-hr region:



[Visualization of isodensity contours that contain the 20% highest and lowest density regions]

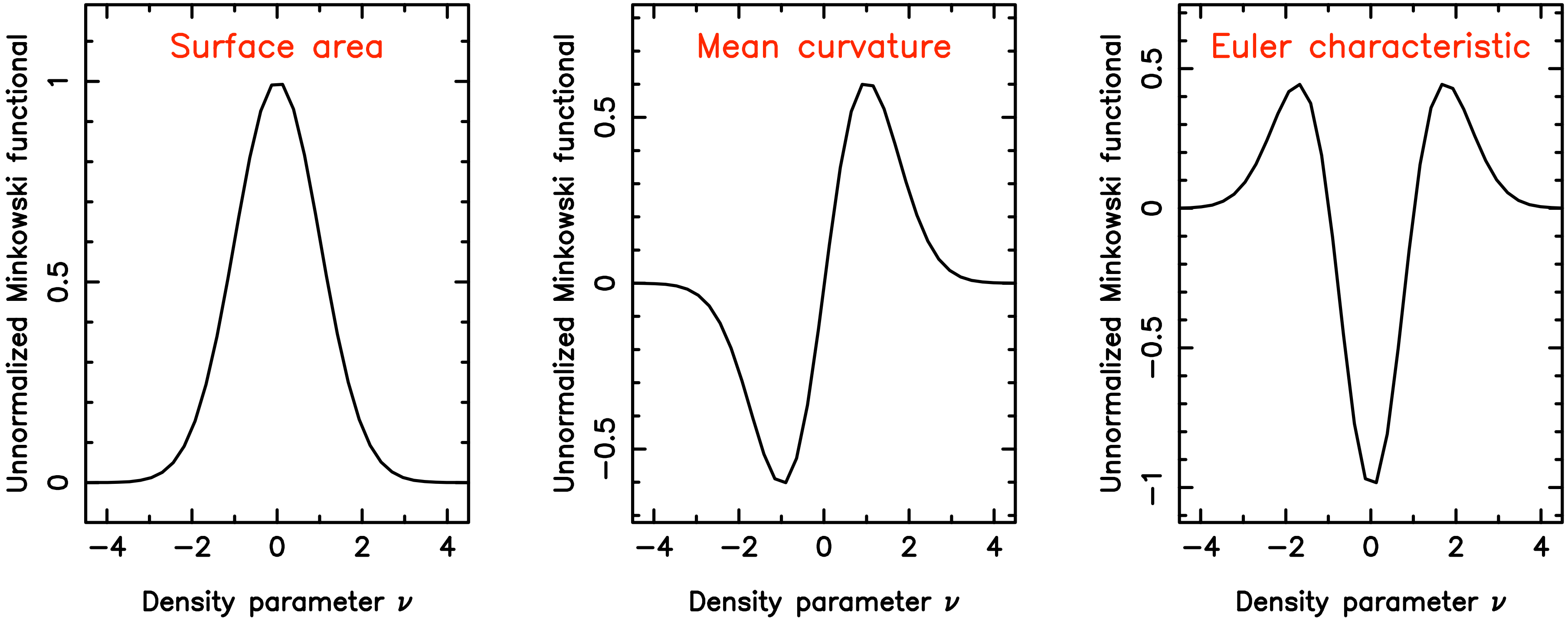
Credit : Berian James

Topological statistics

- Minkowski functionals give complete description

Re-define density: $$V_{\mathrm{frac}}(\nu) = \frac{1}{\sqrt{2\pi}} \int_{\nu}^{\infty} e^{-\nu'^2/2}\, d\nu' = \frac{1}{2}\,\mathrm{erfc}\left(\frac{\nu}{\sqrt{2}}\right)$$

For Gaussian random field :



Topological statistics

- Analogy with number counts method

	Galaxy number counts	Topological statistics
Theory predicts ...	Luminosity function (number of galaxies per unit volume)	Minkowski functionals of Gaussian random field (topology per unit volume)
We measure ...	Galaxy count	Amount of topology
We determine ...	Volume element	Volume element
Evolution ?	Yes	No

Topological statistics

arXiv:0905.2268

LARGE-SCALE STRUCTURE OF THE UNIVERSE AS A COSMIC STANDARD RULER

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School of Physics, Korea Institute for Advanced Study, Seoul 130-722, Korea

Draft version May 14, 2009

ABSTRACT

We propose to use the large-scale structure of the universe as a cosmic standard ruler, based on the fact that the pattern of galaxy distribution should be maintained in the course of time on large scales. By examining the scale-dependence of the pattern in different redshift intervals it is possible to reconstruct the expansion history of the universe, and thus to measure the cosmological parameters governing the expansion of the universe. The features in the galaxy distribution that can be used as standard rulers include the topology of large-scale structure and the overall shapes of galaxy power

arXiv:1005.3631

Using the Topology of Large Scale Structure to constrain Dark Energy

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[3] *Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge MA 02138, USA*

28 May 2010

ABSTRACT

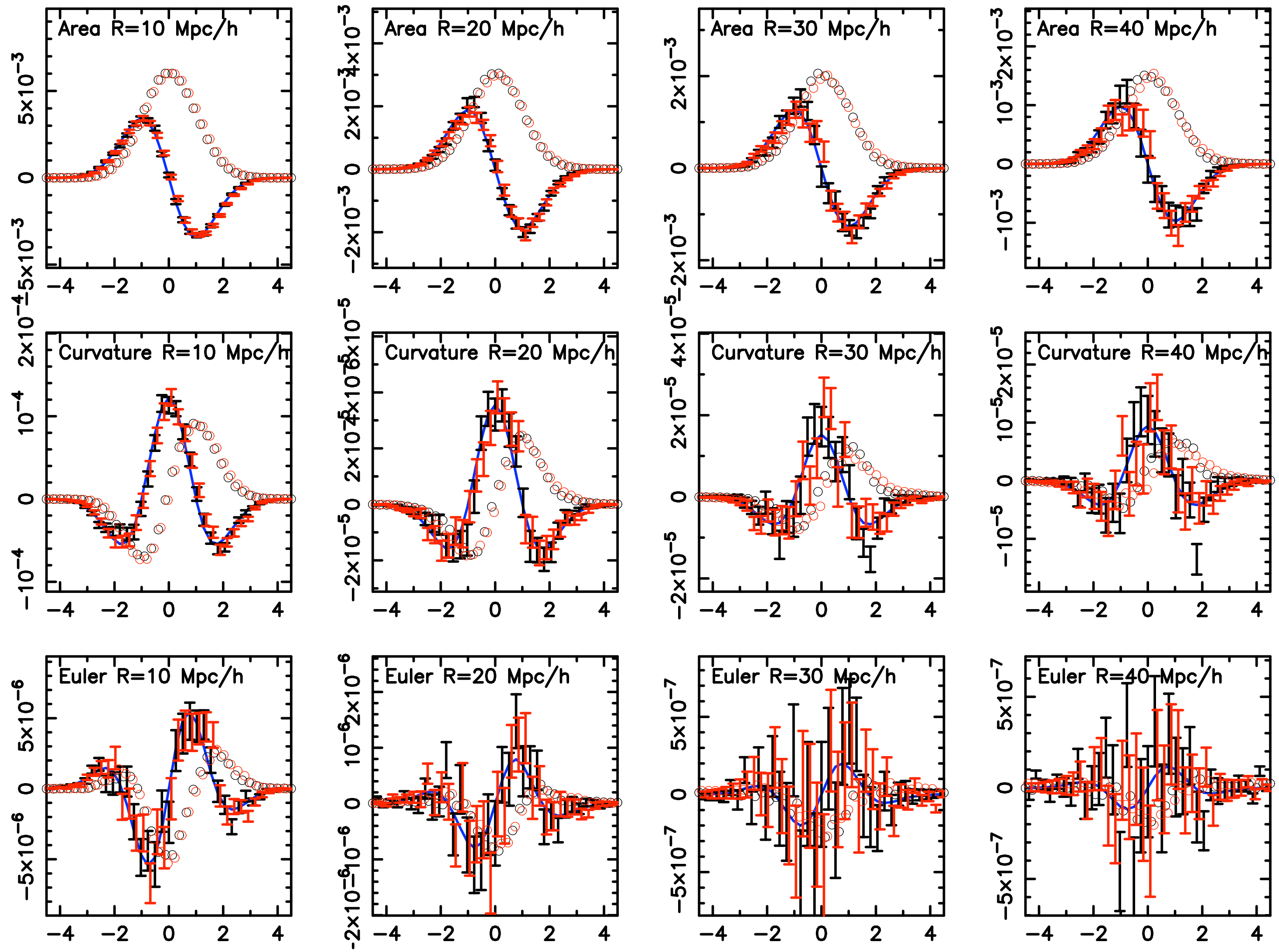
The use of standard rulers, such as the scale of the Baryonic Acoustic oscillations (BAO),

Topological statistics

- Minkowski functionals are an independent method to 2-pt statistics for quantifying large-scale structure
- They are a topological measure unchanged by any density field transformation that preserves rank-ordering (so are conserved over time in linear theory)
- We model them as a Gaussian random field (plus corrections), then the amplitudes of functionals per unit volume are predicted by power spectrum shape
- Observed amplitudes then determine volume element hence $D_V(z)$ [same quantity as measured by BAOs]

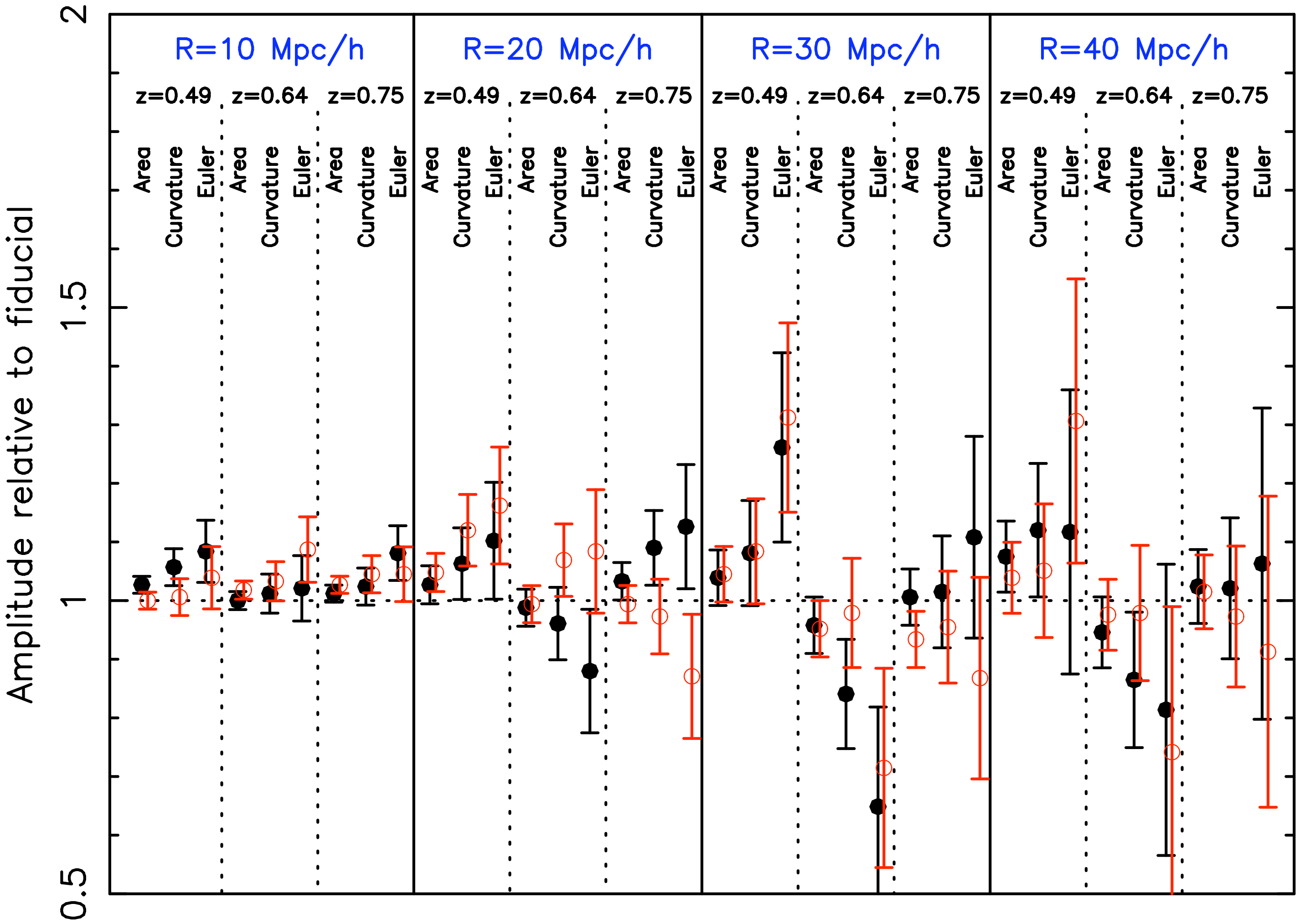
Topological statistics

- WiggleZ Minkowski functional measurements ...



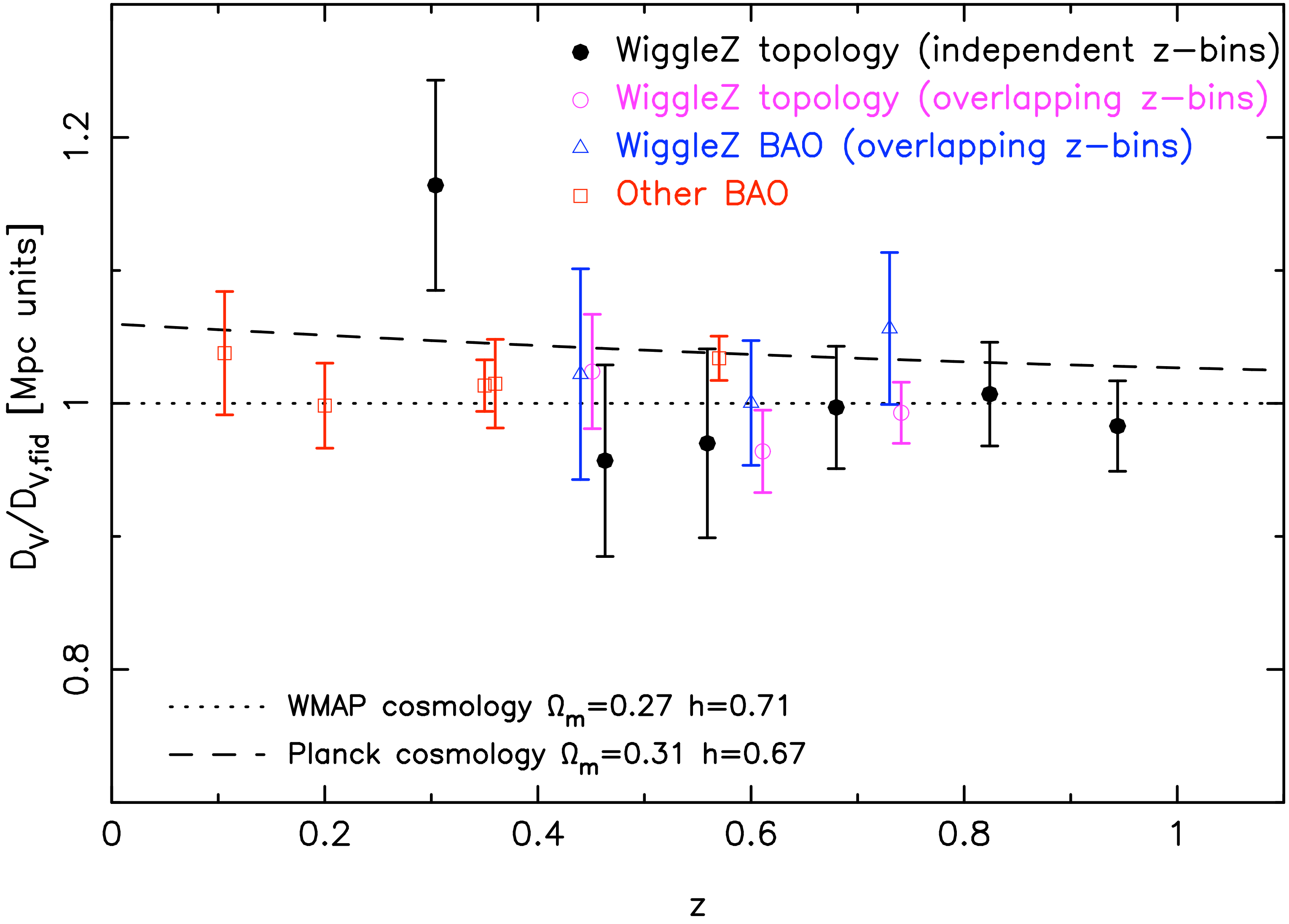
Topological statistics

- Fit amplitudes to these measurements ...



Topological statistics

- Fit distances to these amplitudes ...



Topological statistics

- Fits to WiggleZ Minkowski functionals produce distance determinations which are consistent with, and twice as precise as, fits to WiggleZ BAOs
- We obtain distance errors in the range 3-7% in 6 independent redshift slices across $0.2 < z < 1.0$
- A model power spectrum shape (although not normalization) must be assumed
- Non-linear corrections (RSD, shot noise) need more development ...

Summary of results from WiggleZ

- Baryon acoustic oscillations measure cosmic distances to z=0.8 and provide cross-check with supernovae
- Alcock-Paczynski effect allows direct measurement of the cosmic expansion [H(z)] at high redshift
- Topological measurements produce consistent results with improved errors, but assume more information
- General Relativity + cosmological constant models have been tested in a new way and remain a good fit
- If dark energy behaves as Lambda, what is its physics?