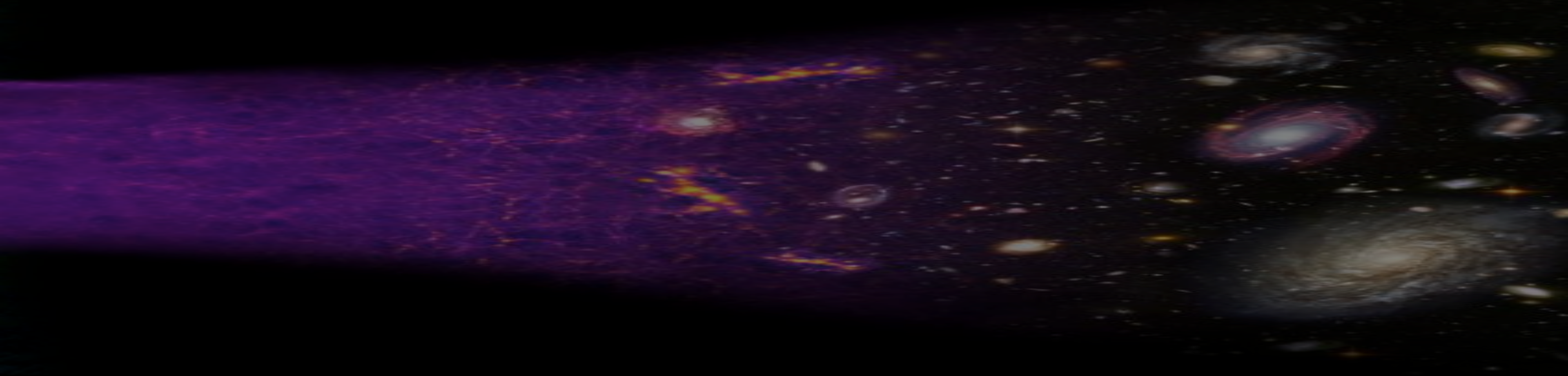


WiggleZ Dark Energy Survey

(almost) Final Results

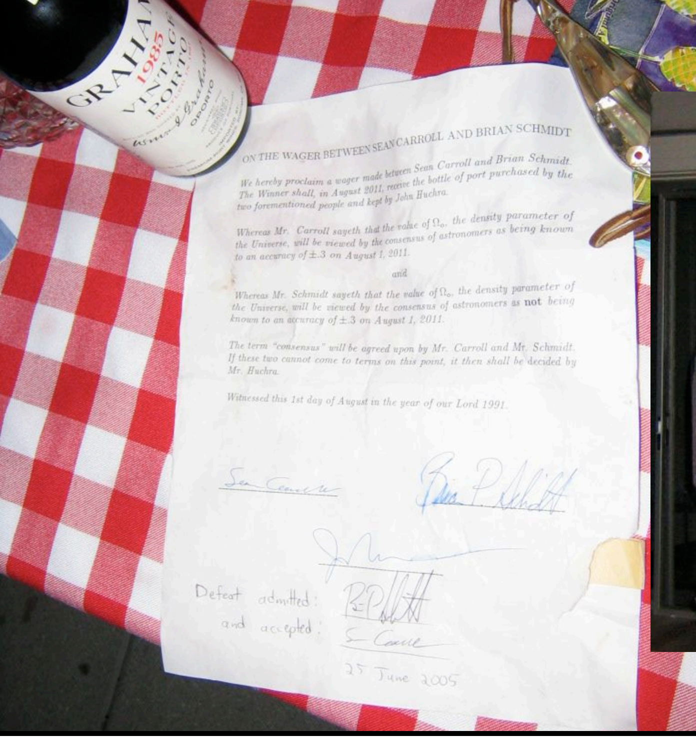
Tamara Davis

University of Queensland

and the whole WiggleZ team:

UQ: Michael Drinkwater, **Tamara Davis**, **David Parkinson**, **Signe Riemer-Sorensen**, Russell Jurek (now at ATNF)
Swinburne: Warrick Couch, **Chris Blake**, Karl Glazebrook, **Greg Poole**, Darren Croton, **Eyal Kazin**, Felipe Marin
AAO: Matthew Colless, Rob Sharp, Sarah Brough; Sydney: Scott Croom, Ben Jellife; ANU: Mike Pracy;
UBC: David Woods; Caltech: Chris Martin, Ted Wyder; Carnegie: Barry Madore
Plus students, associate members, and frequent collaborators, including **Morag Scrimgeour** and **Florian Beutler**


The prize



ON THE WAGER BETWEEN SEAN CARROLL AND BRIAN SCHMIDT

We hereby proclaim a wager made between Sean Carroll and Brian Schmidt. The Winner shall, in August 2011, receive the bottle of port purchased by the two forementioned people and kept by John Huchra.

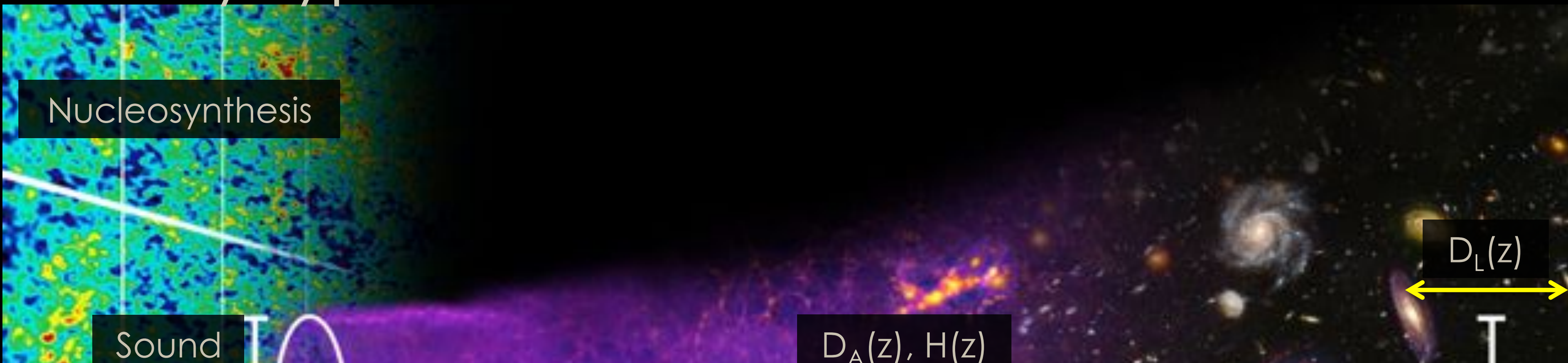
Whereas Mr. Carroll sayeth that the value of Ω_0, the density parameter of the Universe, will be viewed by the consensus of astronomers as being known to an accuracy of ± 0.3 on August 1, 2011.

Whereas Mr. Schmidt sayeth that the value of Ω_0, the density parameter of the Universe, will be viewed by the consensus of astronomers as **not** being known to an accuracy of ± 0.3 on August 1, 2011.

The tern "consensus" will be agreed upon by Mr. Carroll and Mr. Schmidt. If these two cannot come to terms on this point, it then shall be decided by Mr. Huchra

Witnessed this 1st day of August in the year of our Lord 1991.

Many types of observations = concordance



Hinshaw et al. 2013,
Nine-year WMAP

TABLE 4
SIX-PARAMETER ΛCDM FIT; *WMAP* PLUS EXTERNAL DATA[a]

Parameter	*WMAP*	+eCMB	+eCMB+BAO	+eCMB+H_0	+eCMB+BAO+H_0
Fit parameters					1.5%
$\Omega_b h^2$	0.02264 ± 0.00050	0.02229 ± 0.00037	0.02211 ± 0.00034	0.02244 ± 0.00035	0.02223 ± 0.00033
$\Omega_c h^2$	0.1138 ± 0.0045	0.1126 ± 0.0035	0.1162 ± 0.0020	0.1106 ± 0.0030	0.1153 ± 0.0019
Ω_Λ	0.721 ± 0.025	0.728 ± 0.019	0.707 ± 0.010	0.740 ± 0.015	$0.7135^{+0.0095}_{-0.0096}$ 1.6%
$10^9 \Delta^2_{\mathcal{R}}$	2.41 ± 0.10	2.430 ± 0.084	$2.484^{+0.073}_{-0.072}$	$2.396^{+0.079}_{-0.078}$	2.464 ± 0.072
n_s	0.972 ± 0.013	0.9646 ± 0.0098	$0.9579^{+0.0081}_{-0.0082}$	$0.9690^{+0.0091}_{-0.0090}$	0.9608 ± 0.0080
τ	0.089 ± 0.014	0.084 ± 0.013	$0.079^{+0.011}_{-0.012}$	0.087 ± 0.013	0.081 ± 0.012
Derived parameters					
t_0 (Gyr)	13.74 ± 0.11	13.742 ± 0.077	13.800 ± 0.061	13.702 ± 0.069	13.772 ± 0.059
H_0 (km/s/Mpc)	70.0 ± 2.2	70.5 ± 1.6	68.76 ± 0.84	71.6 ± 1.4	69.32 ± 0.80
σ_8	0.821 ± 0.023	0.810 ± 0.017	$0.822^{+0.013}_{-0.014}$	0.803 ± 0.016	$0.820^{+0.013}_{-0.014}$
Ω_b	0.0463 ± 0.0024	0.0449 ± 0.0018	0.04678 ± 0.00098	0.0438 ± 0.0015	0.04628 ± 0.00093
Ω_c	0.233 ± 0.023	0.227 ± 0.017	0.2460 ± 0.0094	0.216 ± 0.014	$0.2402^{+0.0088}_{-0.0087}$
$z_{\rm eq}$	3265^{+106}_{-105}	3230 ± 81	3312 ± 48	3184 ± 70	3293 ± 47 3.7%
$z_{\rm reion}$	10.6 ± 1.1	10.3 ± 1.1	10.0 ± 1.0	10.5 ± 1.1	10.1 ± 1.0

[a] ΛCDM model fit to *WMAP* nine-year data combined with a progression of external data sets.

Overview

What is WiggleZ?

Cosmology Results I'll talk about

Distances using BAO

Paper 1: $z = 0.6$
Paper 2: $z=0.44$, 0.6, 0.73

Homogeneity

Growth at high-z

Neutrinos

Paper 1: mass
Paper 2: N_{eff}

H(z) using Alcock-Paczynski

Paper 1: +SNe
Paper 2: +BAO

Full P(k) analysis
Data Release
CosmoMC

Results I'll skip

- 2D BAO
- Reconstruction
- Non-Gaussianity with Higher-order clustering
- Genus/Topology
- Non-standard cosmologies
- Variations in G

WiggleZ, main cosmology papers:

Paper	Lead authors	Title: "The WiggleZ Dark Energy Survey:"	arXiv
BAO's at z=0.6	Blake, Davis, Poole, Parkinson et al., 2011	testing the cosmological model with baryon acoustic oscillations at z= 0.6	1105.2862
BAO's in 3 redshift bins	Blake, Kazin, Beutler, Davis, Parkinson, et al. 2011	mapping the distance-redshift relation with baryon acoustic oscillations	1108.2635
Growth in 4 redshift bins	Blake, et al. 2011	the growth rate of cosmic structure since redshift z=0.9	1104.2948
Alcock-Paczynscki + SNe	Blake, Glazebrook, Davis, et al. 2011	measuring the cosmic expansion history using the Alcock-Paczynski test & distant Se	1108.2637
Alcock-Paczynscki + BAO	Blake, et al. 2012	joint measurements of the expansion and growth history at z < 1	1204.3674
Homogeneity	Scrimgeour, Davis, Blake, James, Poole, Staveley-Smith et al. 2012	the transition to large-scale cosmic homogeneity	1205.6812
Neutrino mass	Riemer-Sørensen, Blake, Parkinson, Davis, et al. 2012	Cosmological neutrino mass constraint from blue high-redshift galaxies	1112.4940
Data release and full cosmological analysis	Parkinson, Riemer-Sørensen, Blake, Poole, Davis et al. 2012	Final data release and cosmological results	1210.2130
Turnover in power spect.	Poole, Blake, Parkinson, et al. 2012	Probing the epoch of radiation domination using large scale structure	1211.5605
WiggleZ extensions			
Varying constants	Nesseris, Blake, Davis, Parkinson 2011	Constraining the evolution of Newton's constant using the growth rate of structure	1107.3659
Number of neutrinos	Riemer-Sørensen, Parkinson, Davis, Blake 2012	Simultaneous constraints on the number and mass of relativistic species	1210.2131

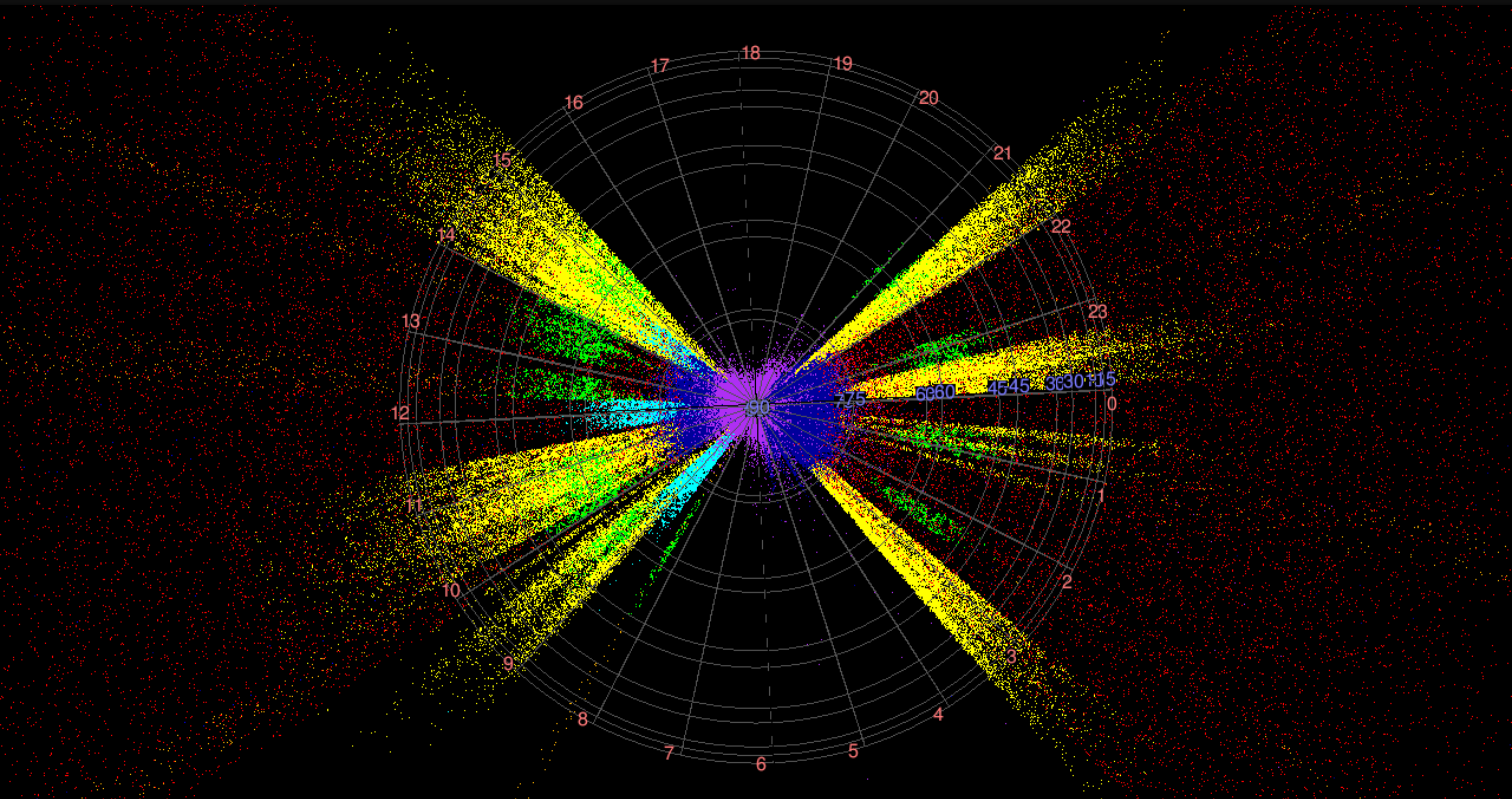


WiggleZ survey fields
(compared to other AAT surveys)

7 equatorial fields, each 100-200 deg^2

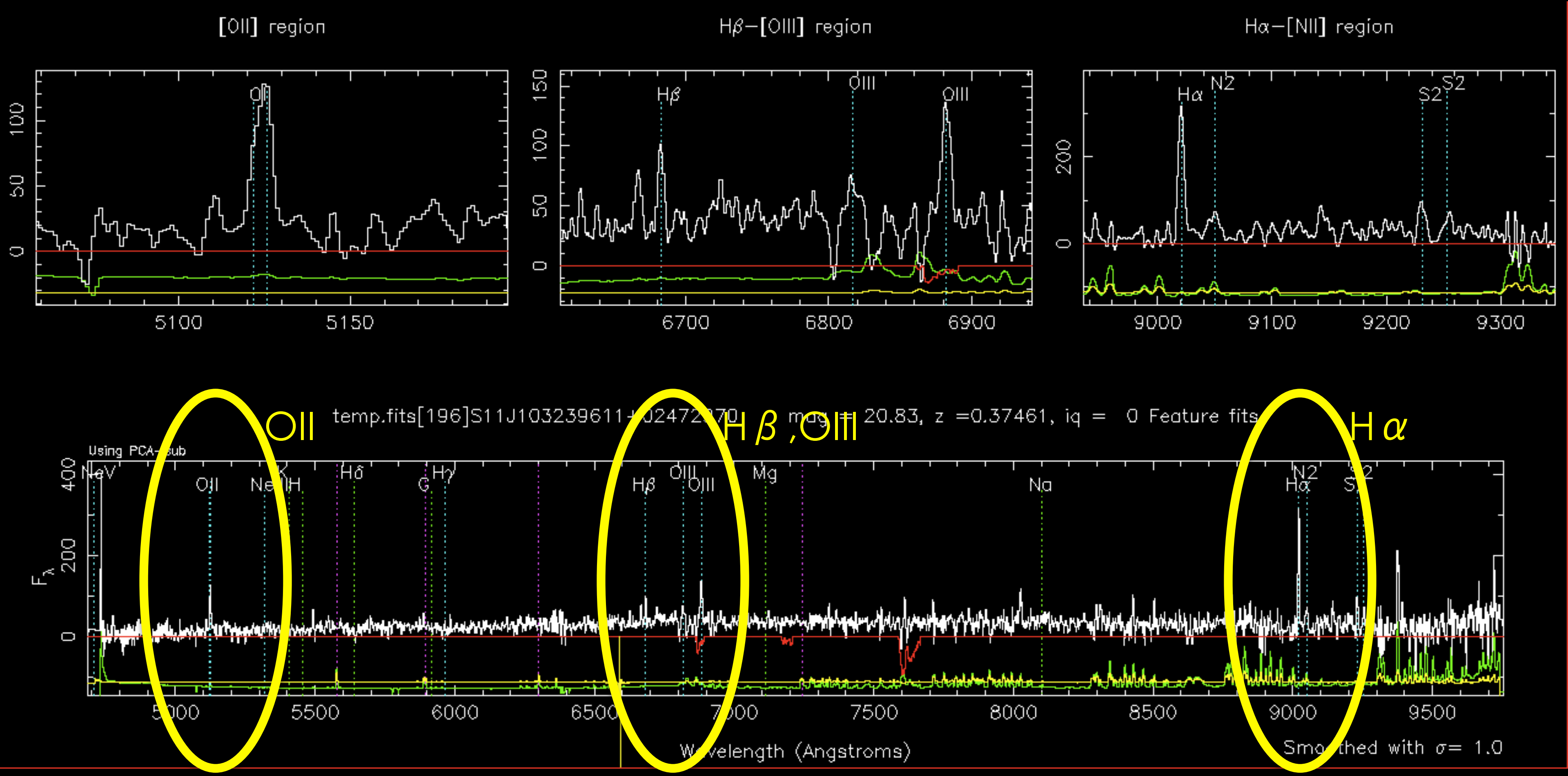
>9° on side, ~3 x BAO scale at z > 0.5

Physical size ~ 1300 x 500 x 500 Mpc/h

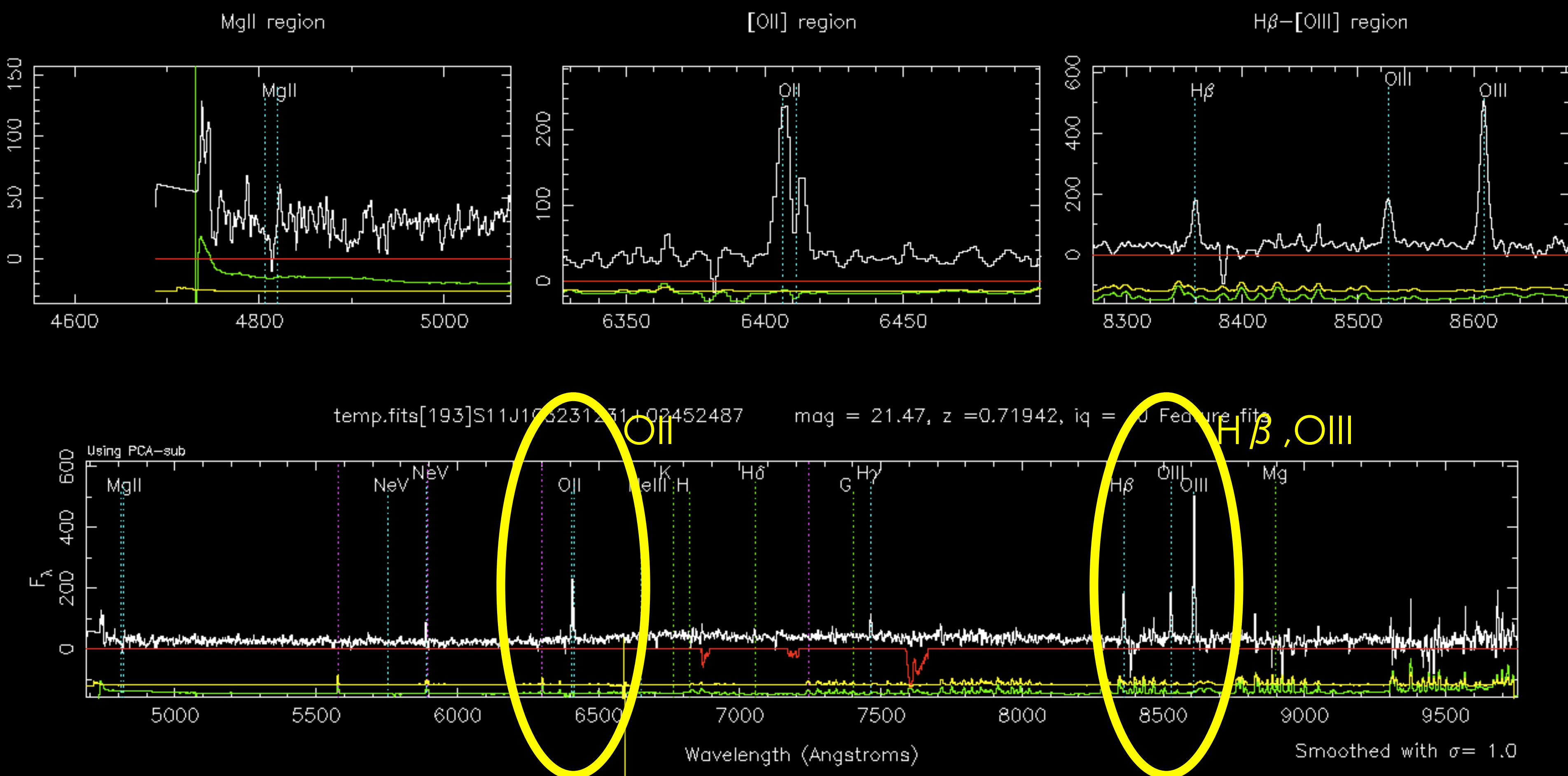


6dFGS (purple), 2dFGRS (blue), MGC (navy), GAMA (cyan), 2SLAQ-LRG (green), WiggleZ (yellow), 2SLAQ-QSO (orange), 2QZ (red); the celestial sphere is at z=1.

Example spectrum: z=0.37



Example spectrum: z=0.72

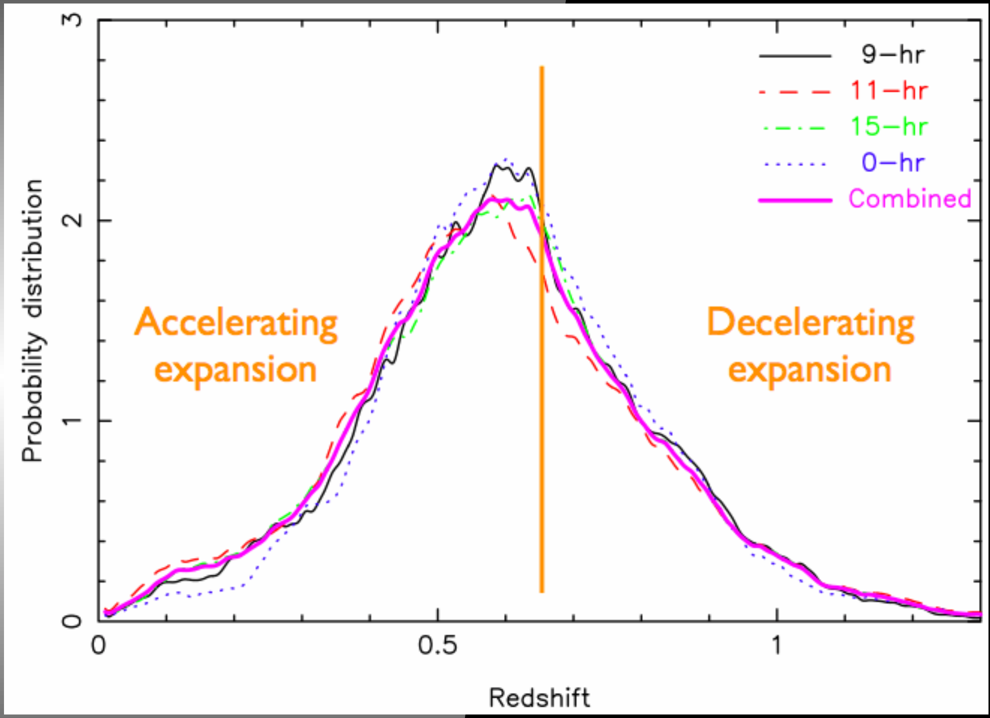


Redshifts become less certain above $z \sim 1$ because we lose $H\beta$

Understanding our survey

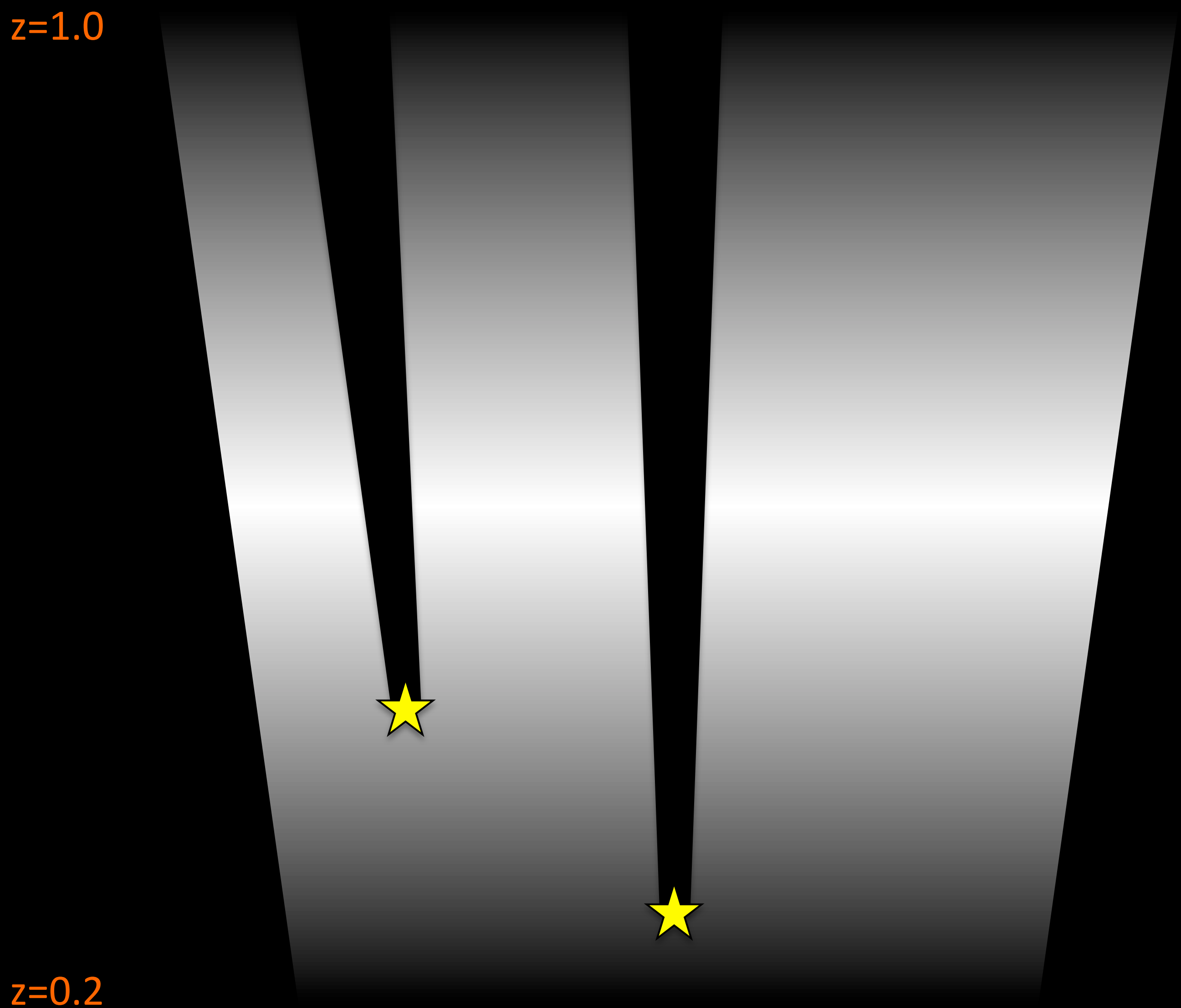
z=1.0

Redshift distribution

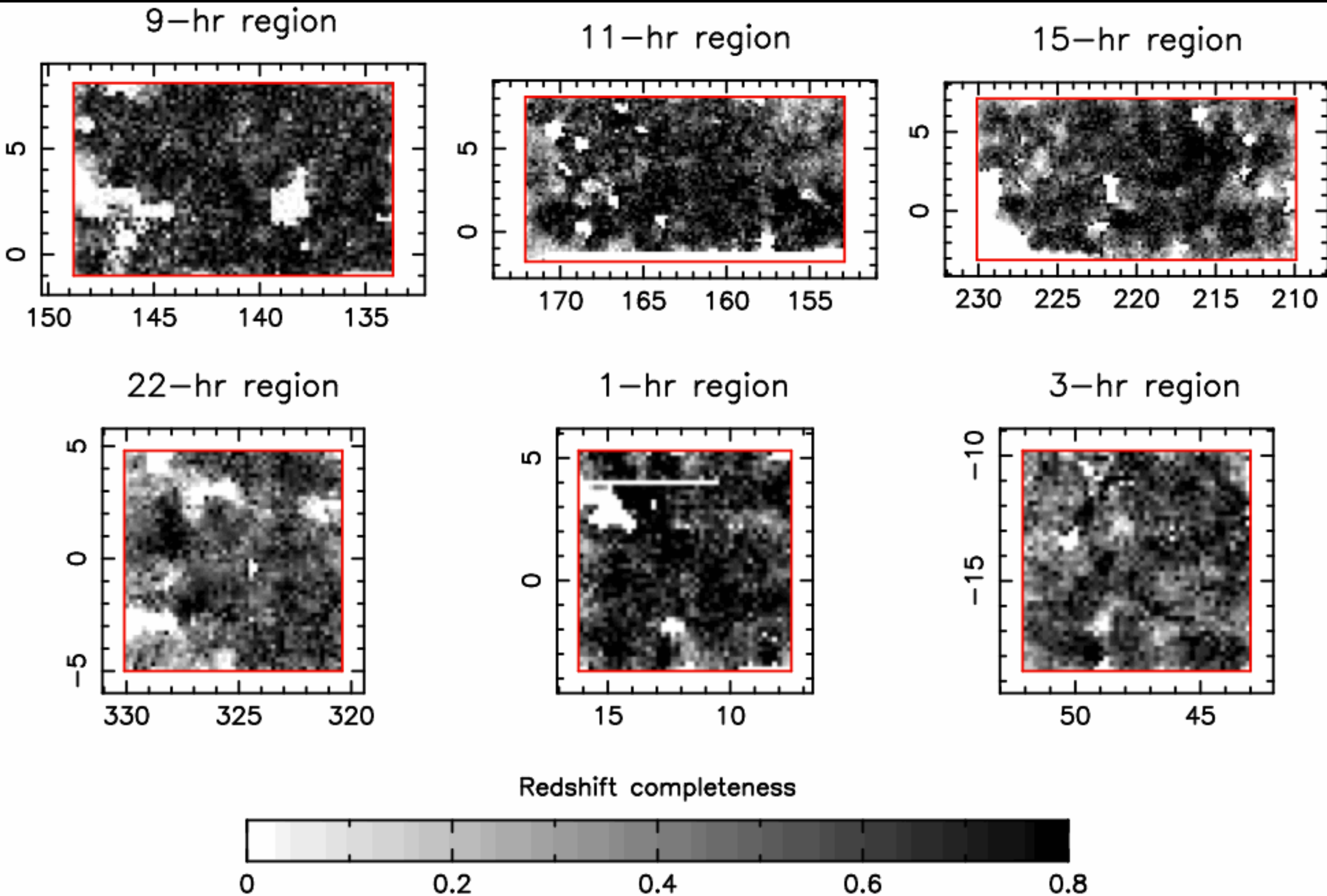


z=0.2

Understanding our survey

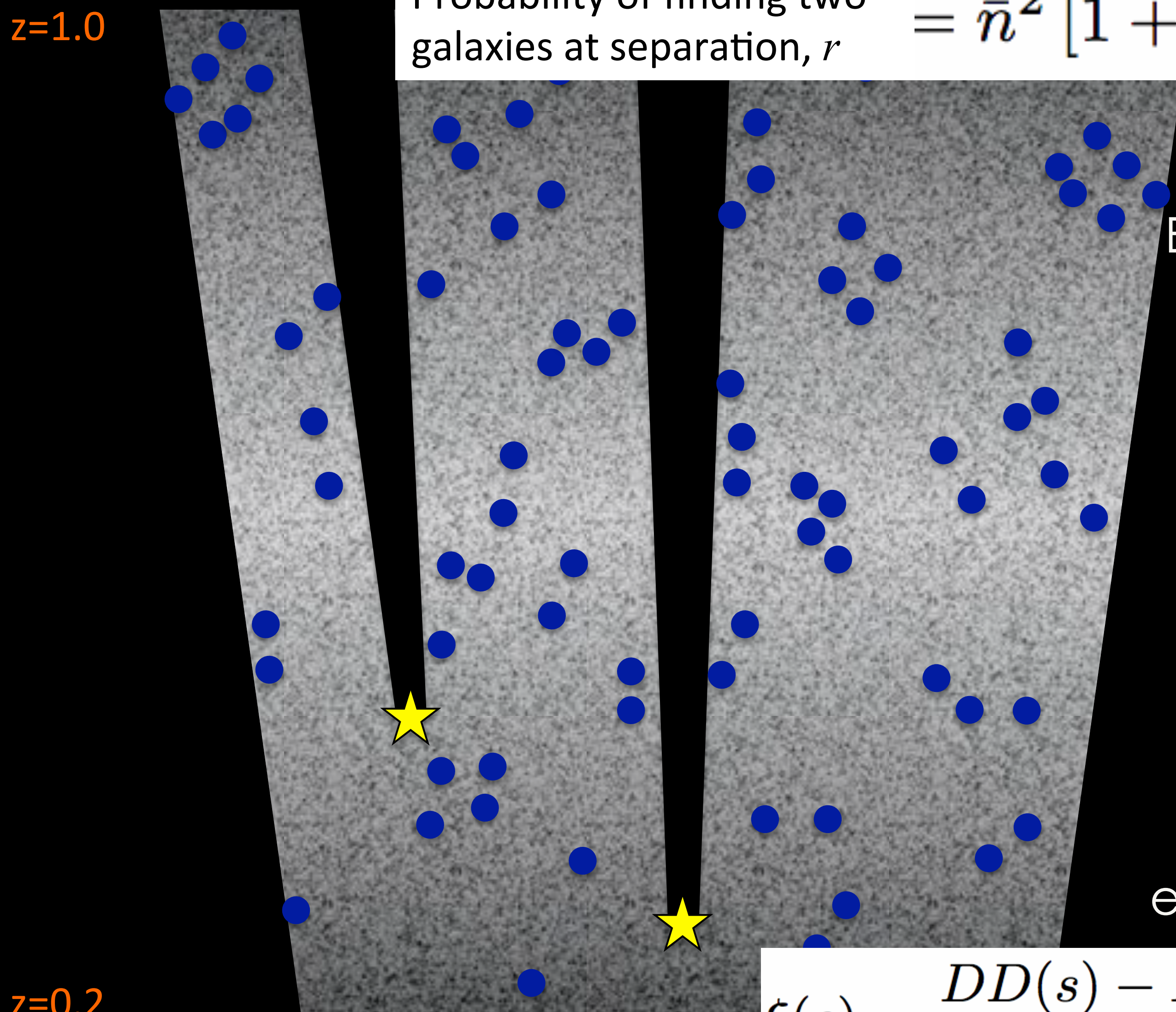


WiggleZ regions



Understanding our survey

Probability of finding two galaxies at separation, r $= \bar{n}^2 \left[1 + \xi(r)\right] \delta V_1 \delta V_2$



Excess likelihood of finding two galaxies at separation r

Landy-Szalay estimator (1993)

$$\xi(s) = \frac{DD(s) - DR(s) + RR(s)}{RR(s)}$$

Gregory Poole
The GiggleZ
Simulation Suite

SWINBURNE

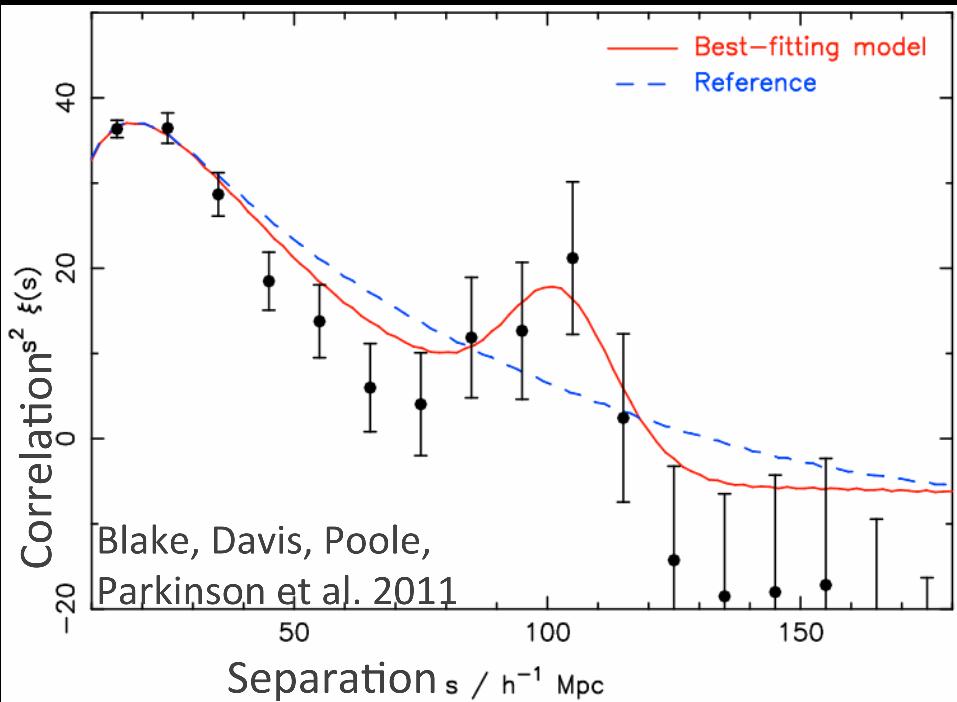
CENTRE FOR ASTROPHYSICS AND SUPERCOMPUTING

Blake, Davis, Poole, Parkinson et al. 2011
Blake, Kazin, Beutler, Davis, Parkinson et al. 2011

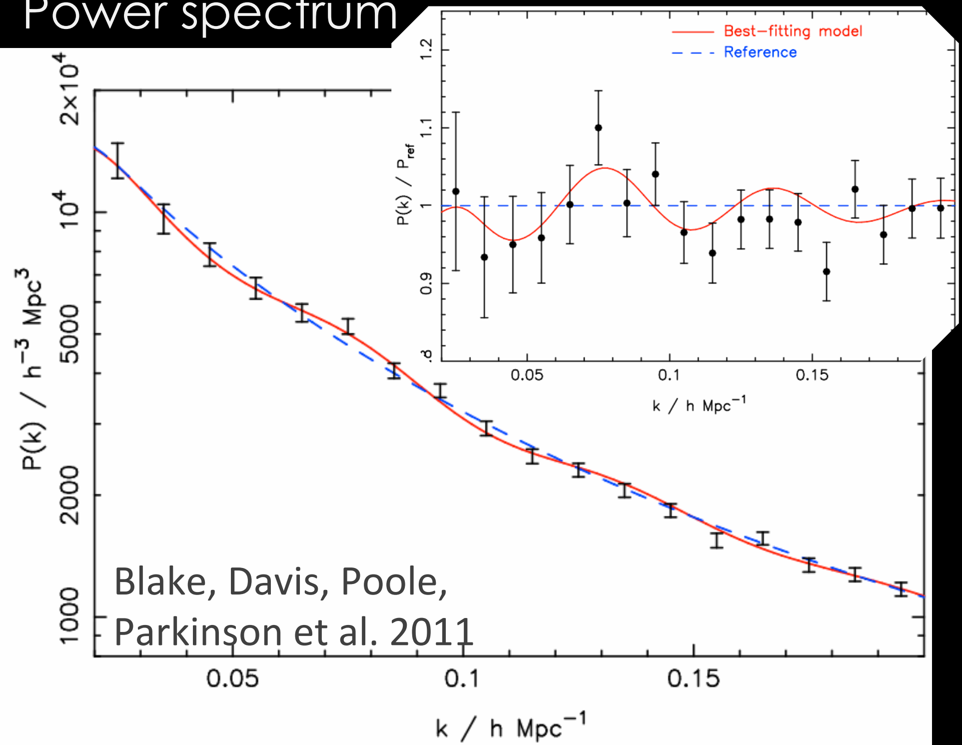
1. BARYON ACOUSTIC OSCILLATIONS

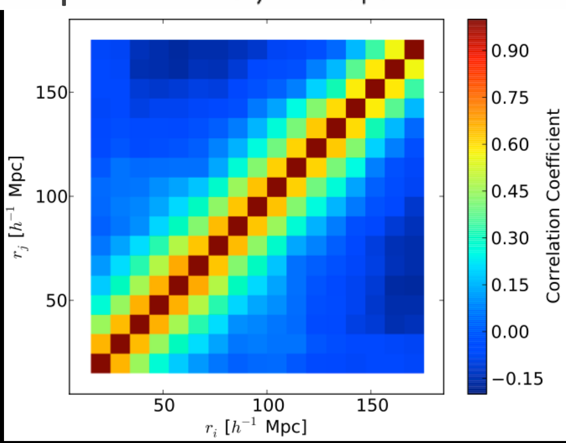
BAO-1: Single redshift bin

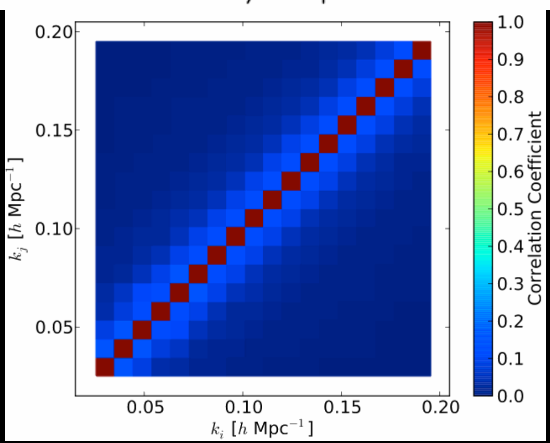
Correlation Function



Power spectrum







Measuring the distance scale

$$d_z \equiv \frac{r_s(z_\mathrm{d})}{D_V(z)}$$

BAO

$$A(z) = \frac{\sqrt{\Omega_\mathrm{m} H_0^2}}{cz} D_V(z)$$

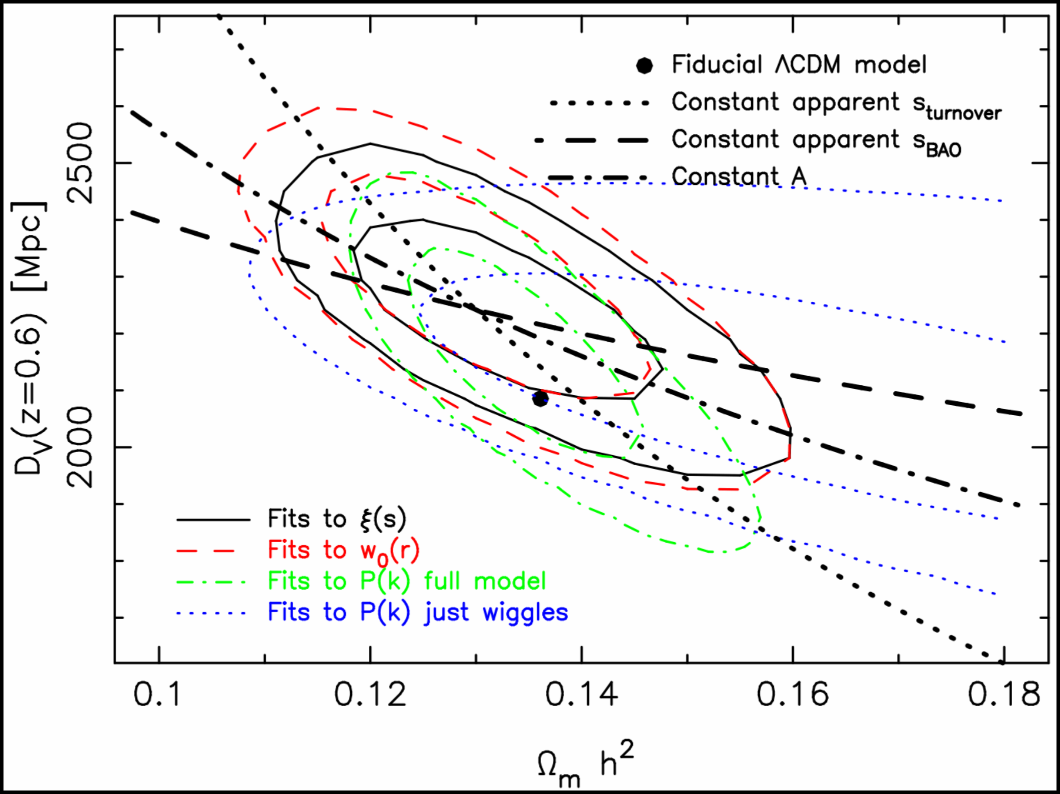
$$\theta_A \equiv \frac{r_s(z_*)}{d_A(z_*)}$$

CMB

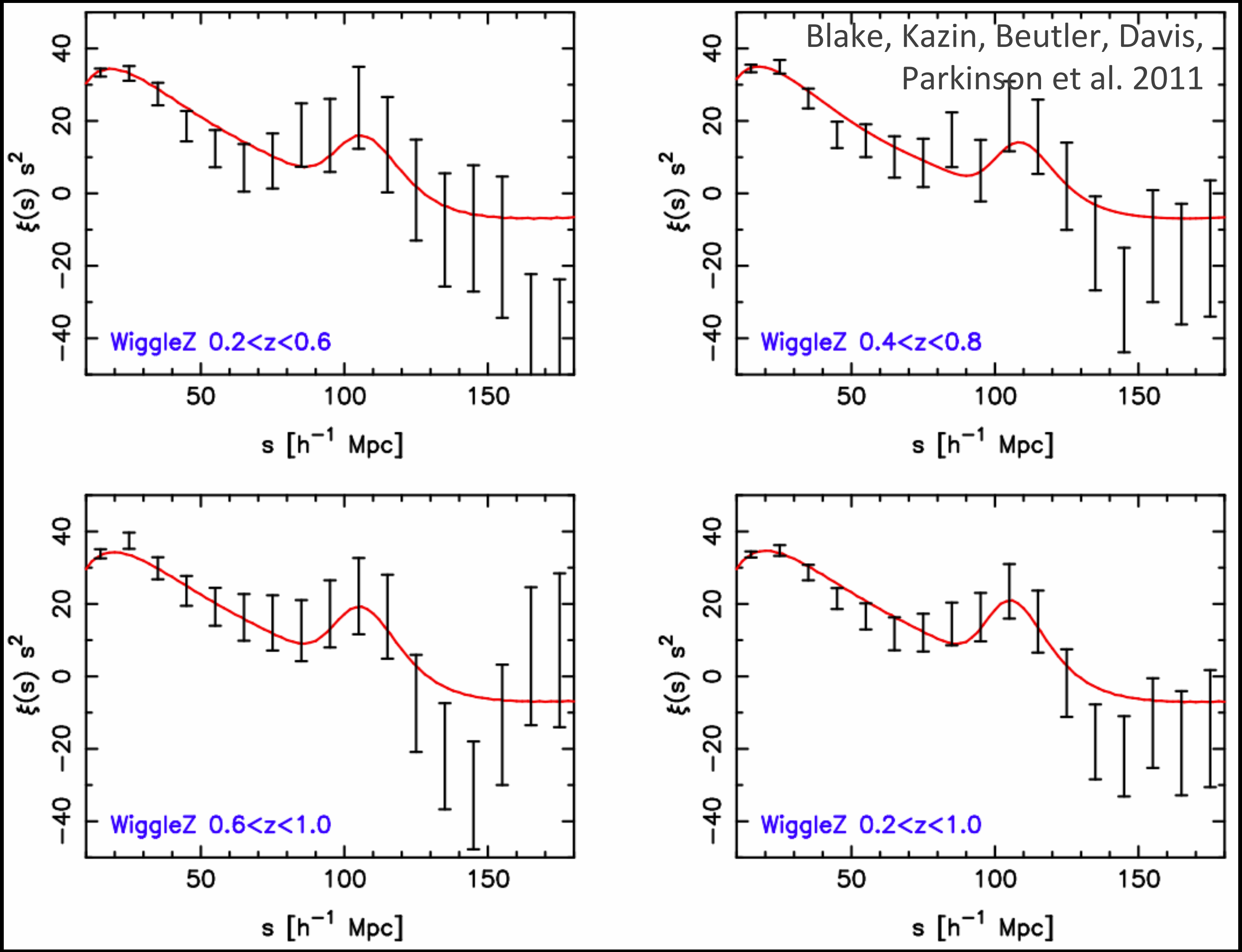
$$\mathcal{R}(z_*) = \sqrt{\Omega_\mathrm{m} h^2}\, d_A(z_*)$$

Two Tangential One Radial

$$D_V(z) = \left[\underbrace{(1+z)^2 D_A(z)^2}_{\text{Two Tangential}} \underbrace{\frac{cz}{H(z)}}_{\text{One Radial}}\right]^{1/3}$$

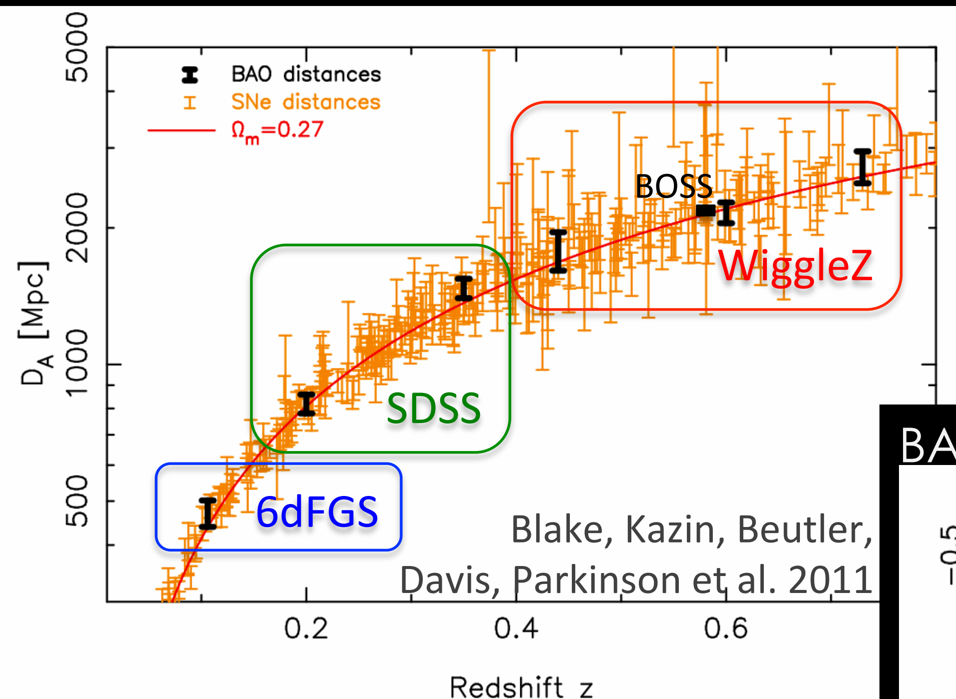


BAO-2: Three redshift bins



WiggleZ – Baryon Acoustic Oscillations

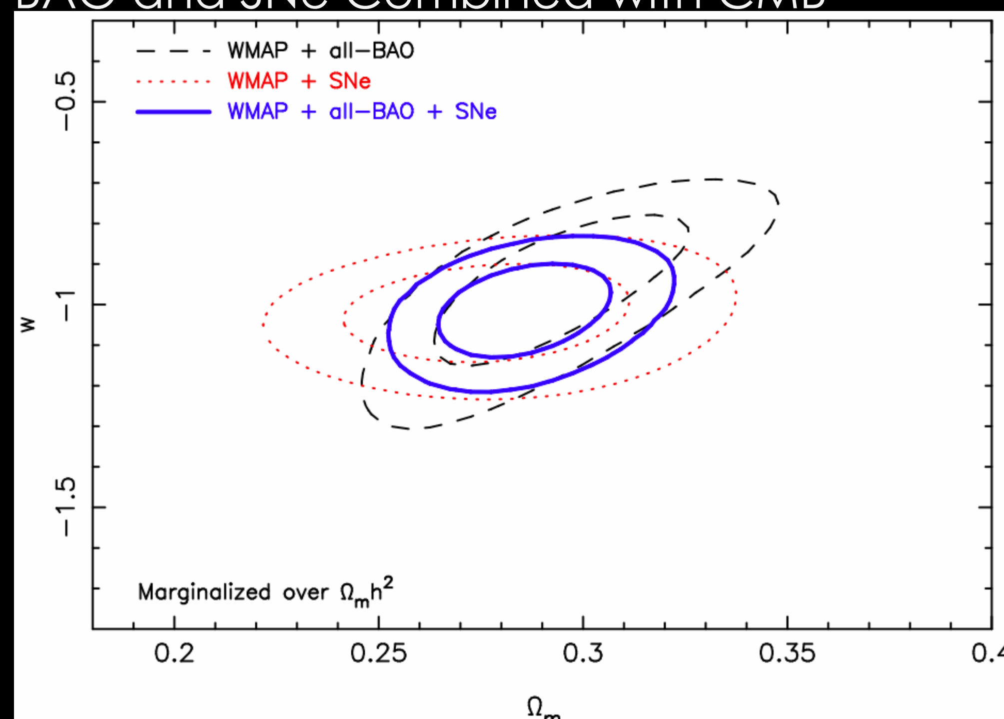
Compared to supernovae



No longer need SNe!

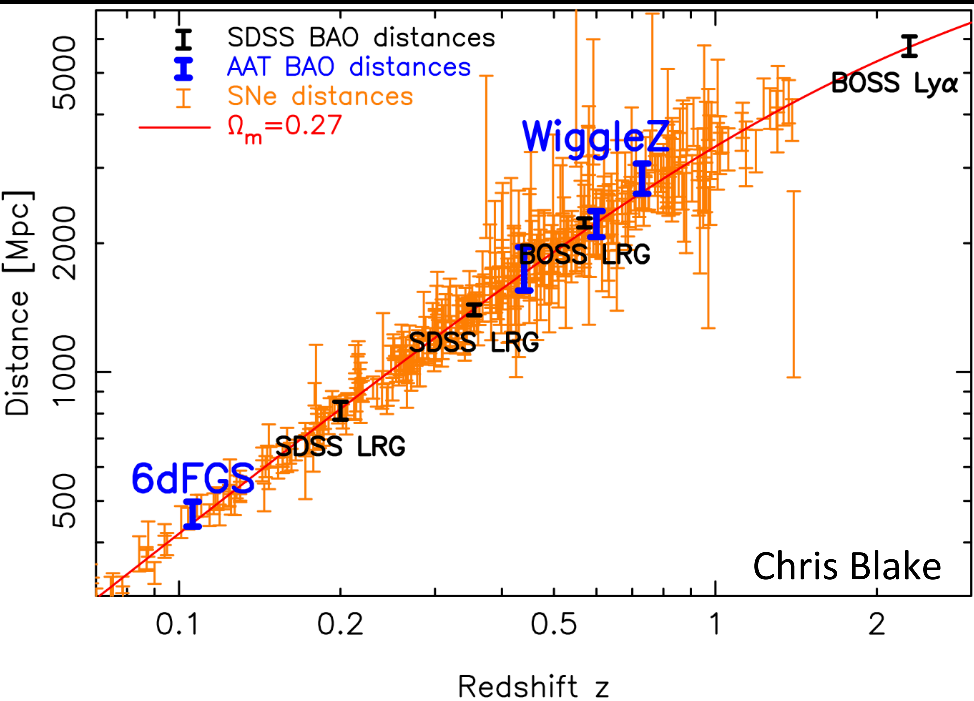
BAO distances alone now require acceleration!

BAO and SNe Combined with CMB



WiggleZ – Baryon Acoustic Oscillations

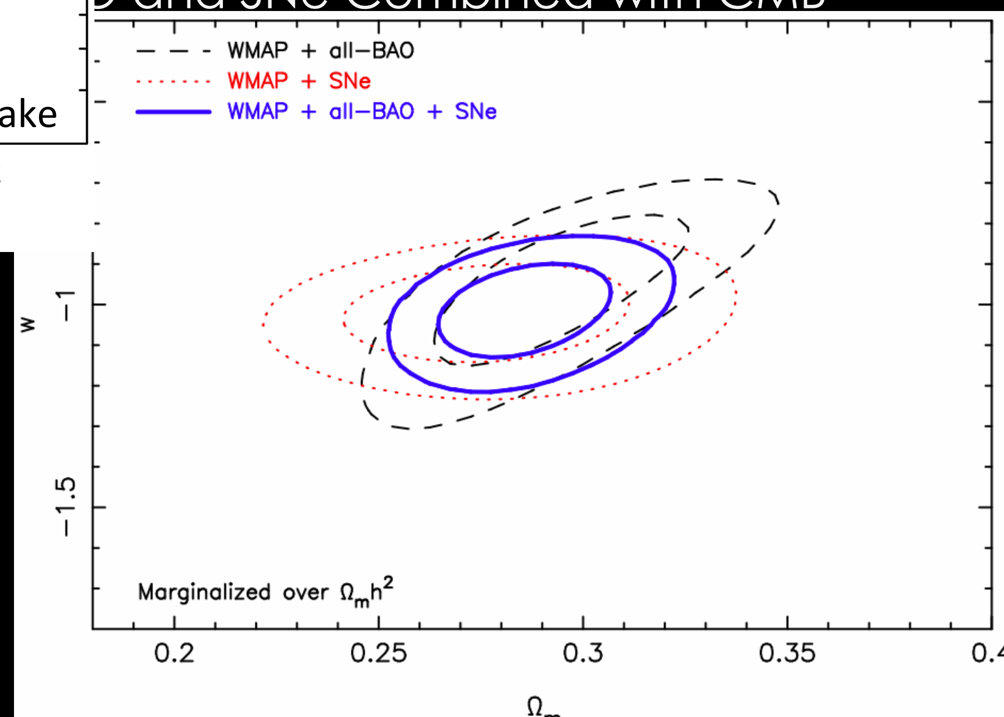
Compared to supernovae



No longer need SNe!

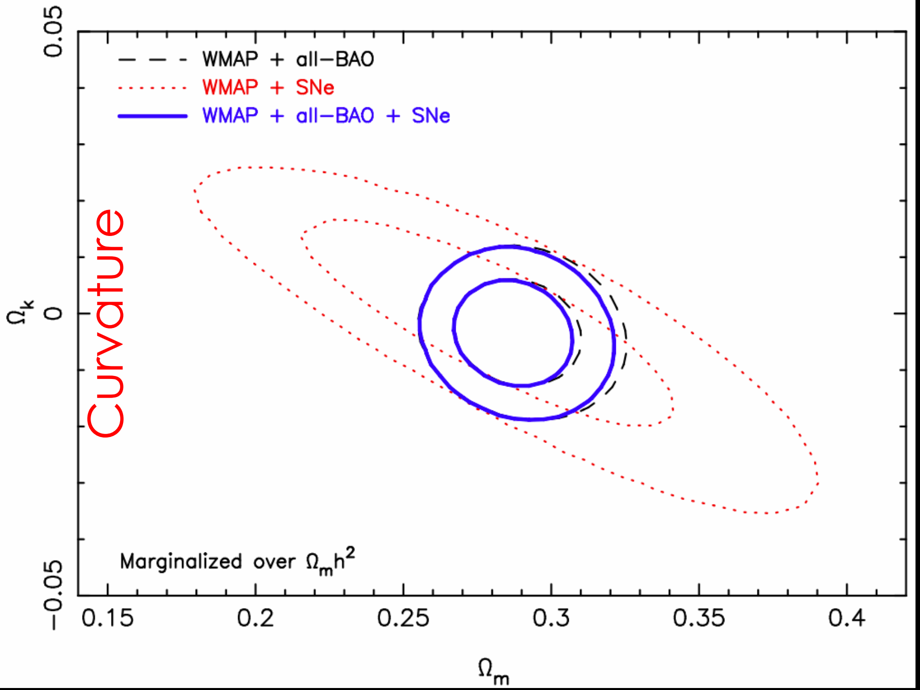
BAO distances alone now require acceleration!

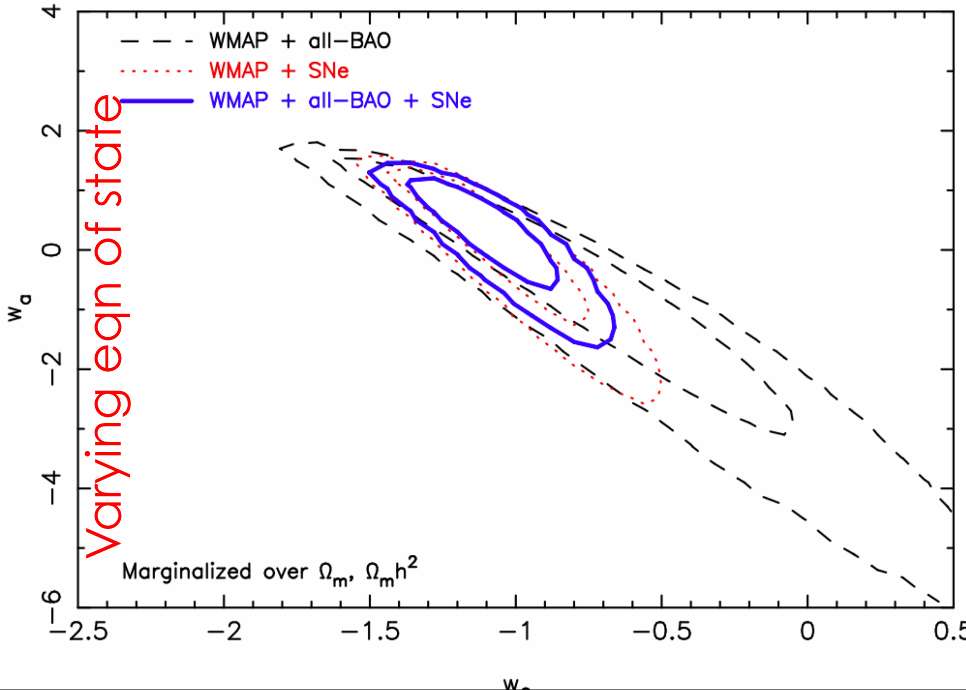
D and SNe Combined with CMB



We don't know what is causing the acceleration

(And the leading candidate, vacuum energy, is 10^{120} too large)

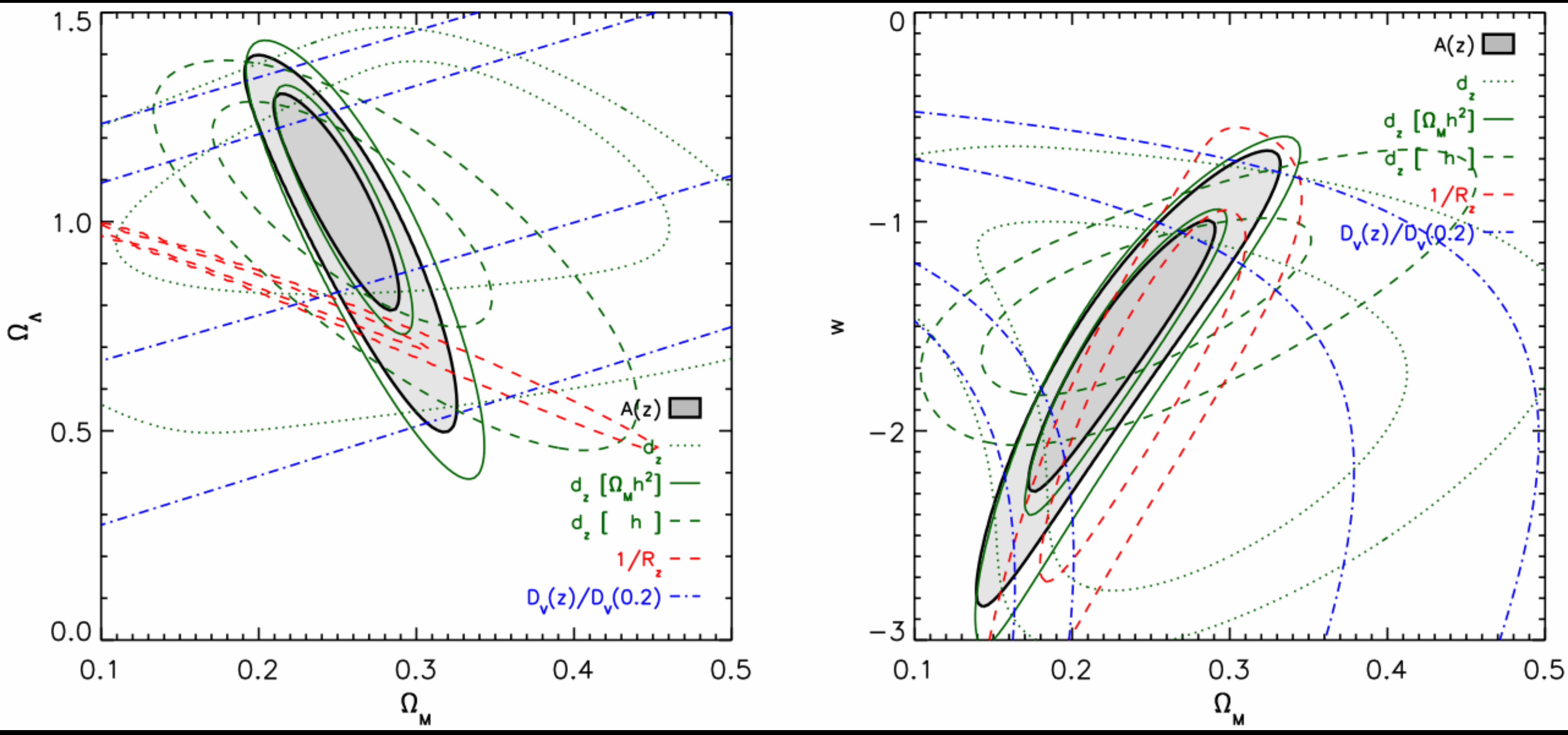




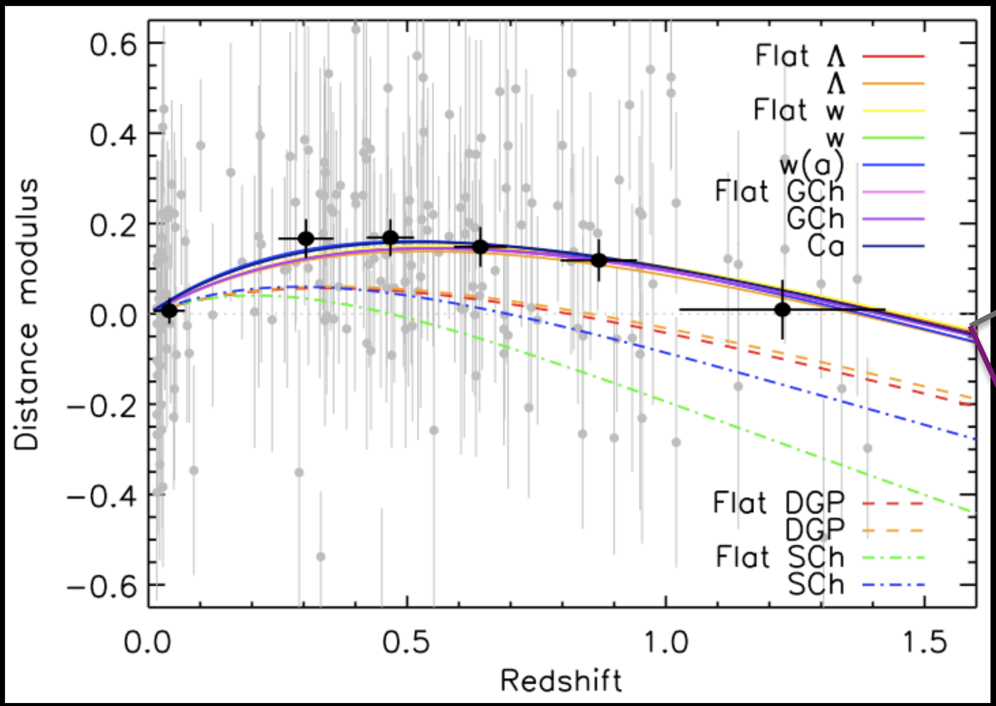
Final combined results

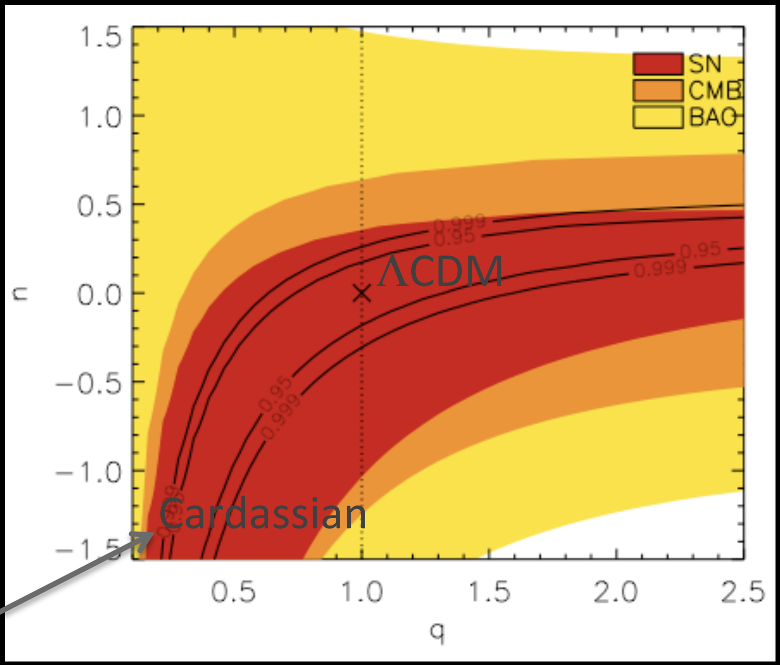
Model	χ^2	d.o.f.	Ω_m	$\Omega_m h^2$	h	Ω_k	w_0	w_a
Flat ΛCDM	533.1	564	0.290 ± 0.014	0.1382 ± 0.0029	0.690 ± 0.009	–	–	–
Flat wCDM	532.9	563	0.289 ± 0.015	0.1395 ± 0.0043	0.696 ± 0.017	–	-1.034 ± 0.080	–
Curved ΛCDM	532.7	563	0.292 ± 0.014	0.1354 ± 0.0054	0.681 ± 0.017	-0.0040 ± 0.0062	–	–
Curved wCDM	531.9	562	0.289 ± 0.015	0.1361 ± 0.0055	0.687 ± 0.019	-0.0061 ± 0.0070	-1.063 ± 0.094	–
Flat $w(a)$CDM	531.9	562	0.288 ± 0.016	0.1386 ± 0.0053	0.695 ± 0.017	–	-1.094 ± 0.171	0.194 ± 0.687

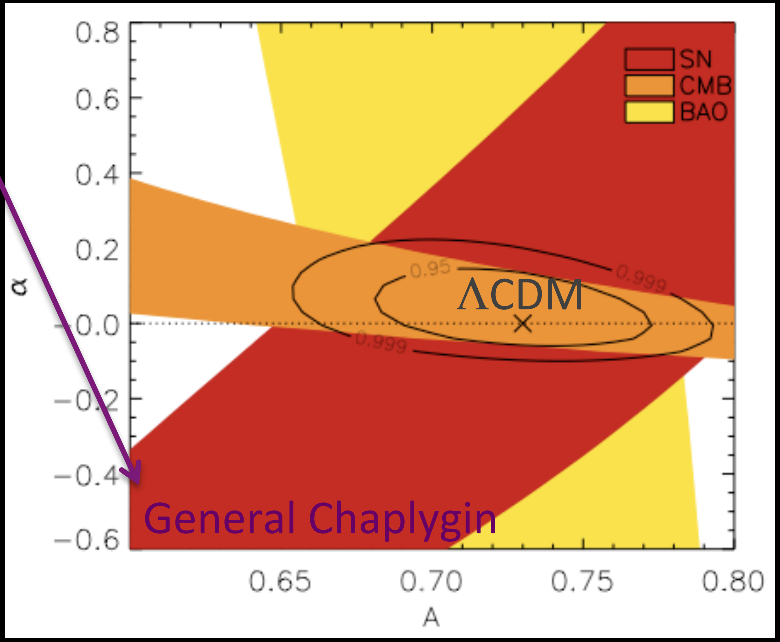
Many ways to use BAO



Some models can't be distinguished using only distance data







Davis et al. 2007

Other types of measurements needed

- Growth

overdensity

$$f = \boxed{\frac{d(\ln \delta)}{d(\ln a)}} \sim \Omega_M(z)^{\gamma}$$

γ = 6/11 in ΛCDM
γ = 6/10 in CDM
γ = 11/16 in DGP

γ is different in different models

- Amplitude of density fluctuations at present day

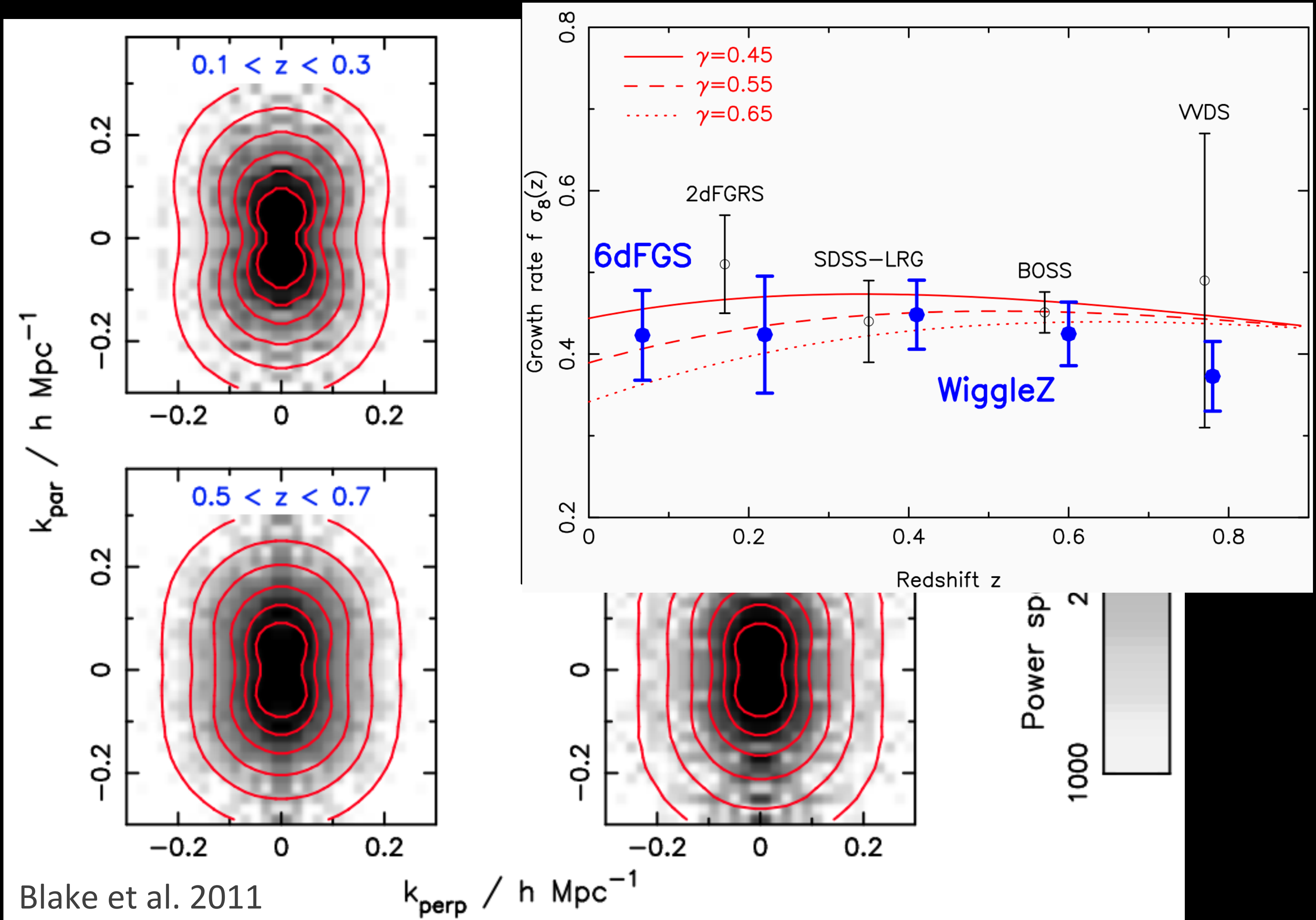
$$\sigma_8$$

1. measure density in spheres 8 Mpc in radius
2. calculate the dispersion

Blake et al. 2011

2. GROWTH OF STRUCTURE

WiggleZ – Growth of Structure

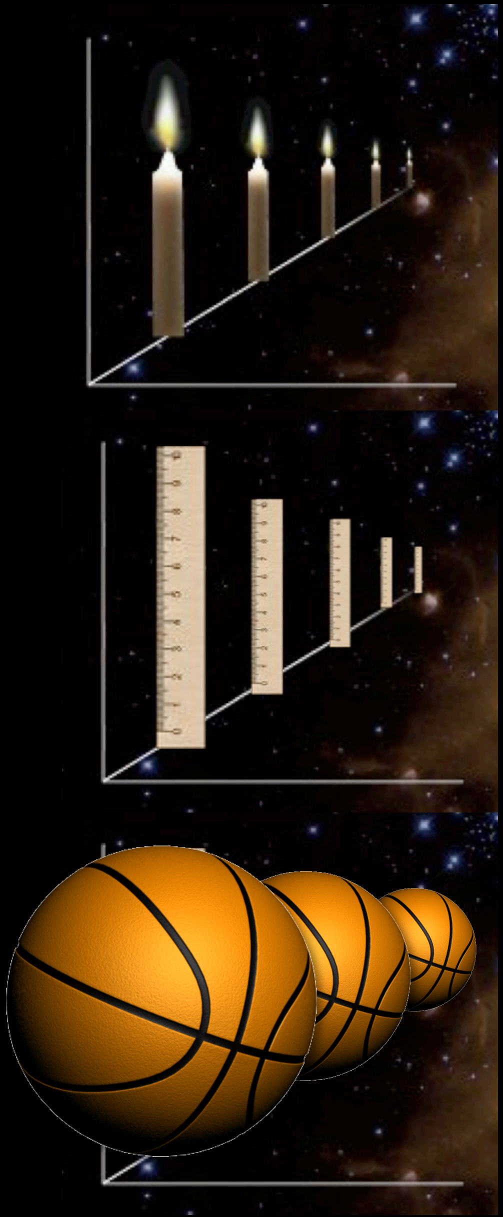


Blake et al. 2011

Blake, Glazebrook, Davis et al. 2011

3A. H(Z) ALCOCK-PACZYNSKI + SN

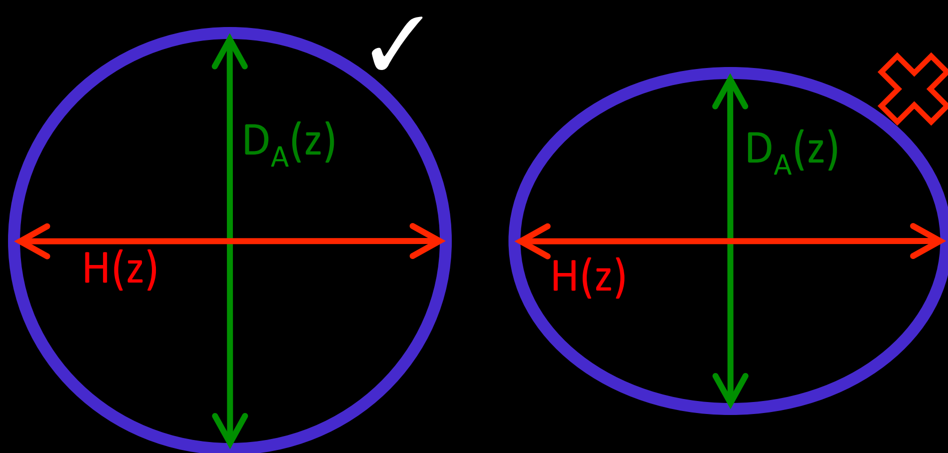
BAO – a standard sphere



- SNe = radial info (line of sight)
- CMB = tangential info (surface of sphere)

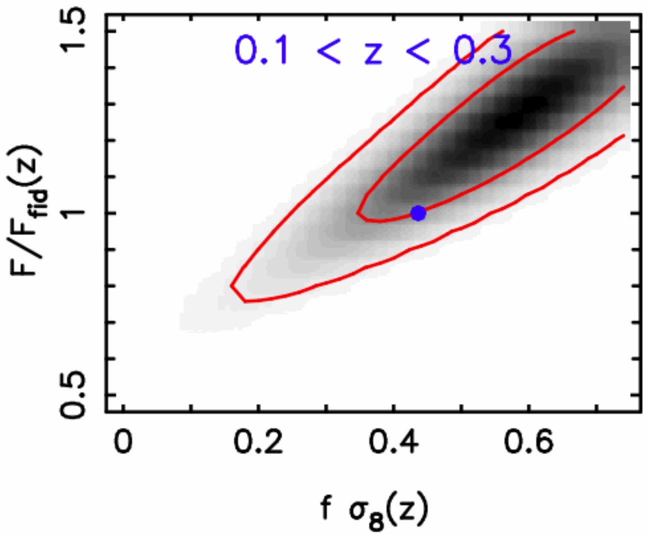
- BAO can be applied radially to give H(z) <u>AND</u> tangentially to give $D_A(z)$

Alcock-Paczynski test:



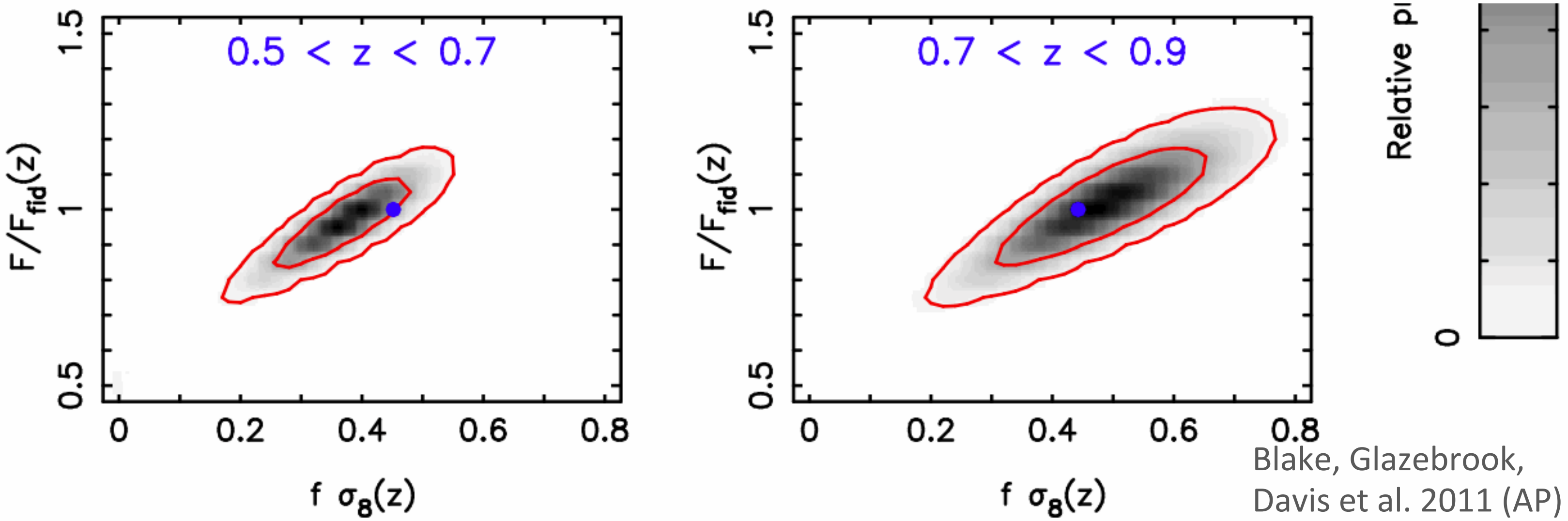
Alcock-Paczynski / z-space distortions

H_{fid}/H $D_A/D_{A,fid}$



$$
\begin{aligned}
P'_{\rm gal}(k') &= \frac{1}{f_\perp^2 f_\parallel} b^2 P_m \left(\frac{k'}{f_\perp} \sqrt{1+\mu'^2 \left(\frac{1}{(f_\parallel/f_\perp)^2} - 1 \right)} \right) \\
&\times \left[1+\mu'^2 \left(\frac{1}{(f_\parallel/f_\perp)^2} - 1 \right) \right]^{-2} \\
&\times \left[1+\mu'^2 \left(\frac{\beta+1}{(f_\parallel/f_\perp)^2} - 1 \right) \right]^{2} \\
&\times D\left(\frac{k'_\parallel \sigma_v}{f_\parallel} \right)
\end{aligned}
$$

Ballinger et al. 1996



Blake, Glazebrook, Davis et al. 2011 (AP)

WiggleZ – Measurement of H(z)

WiggleZ measures

$$(1+z)D_A(z)H(z)/c$$

Supernovae measure

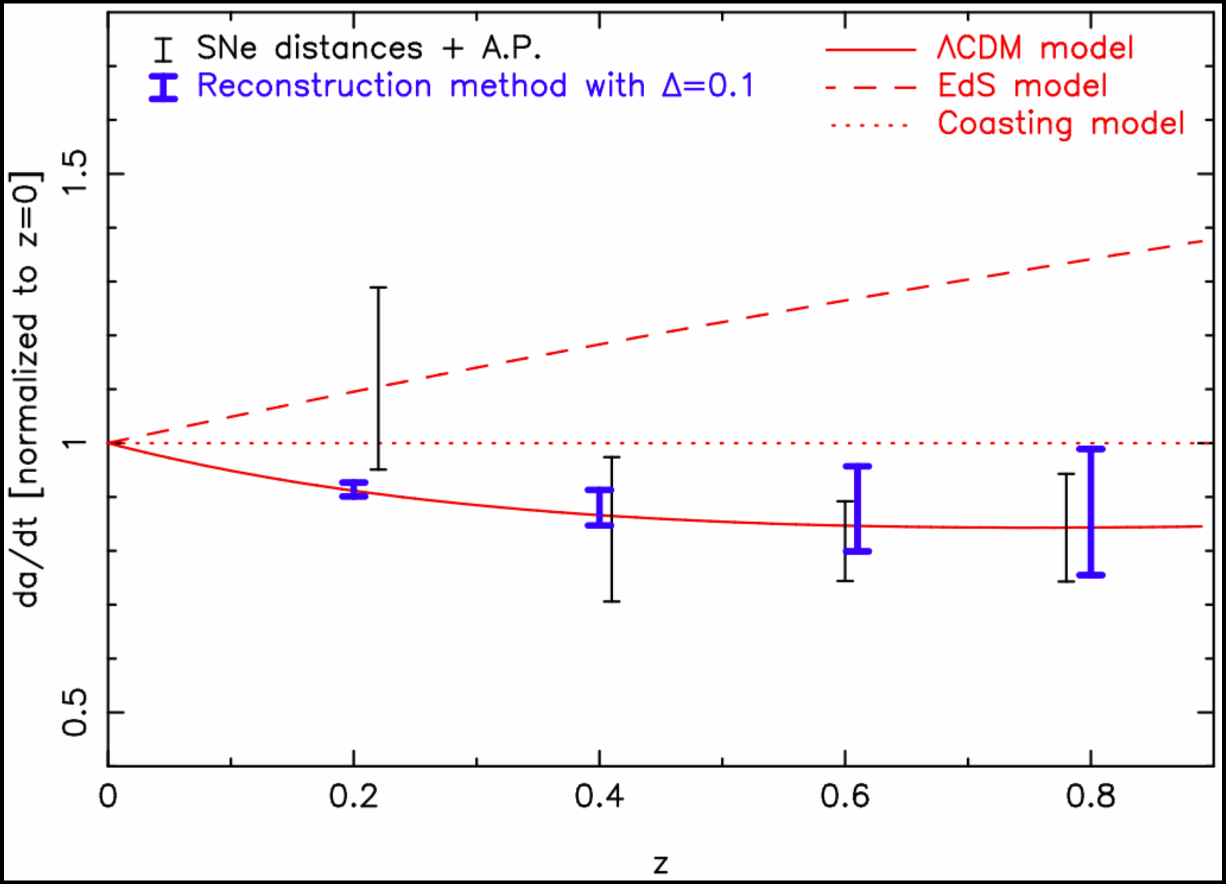
$$D_L(z)\,H_0/c$$

Distances are related by

$$D_L(z) = D_A(z)\,(1+z)^2$$

So the ratio gives

$$H(z)/H_0$$



Blake et al. 2012

3B. H(Z) ALCOCK-PACZYNSKI + BAO

WiggleZ growth + AP + BAO

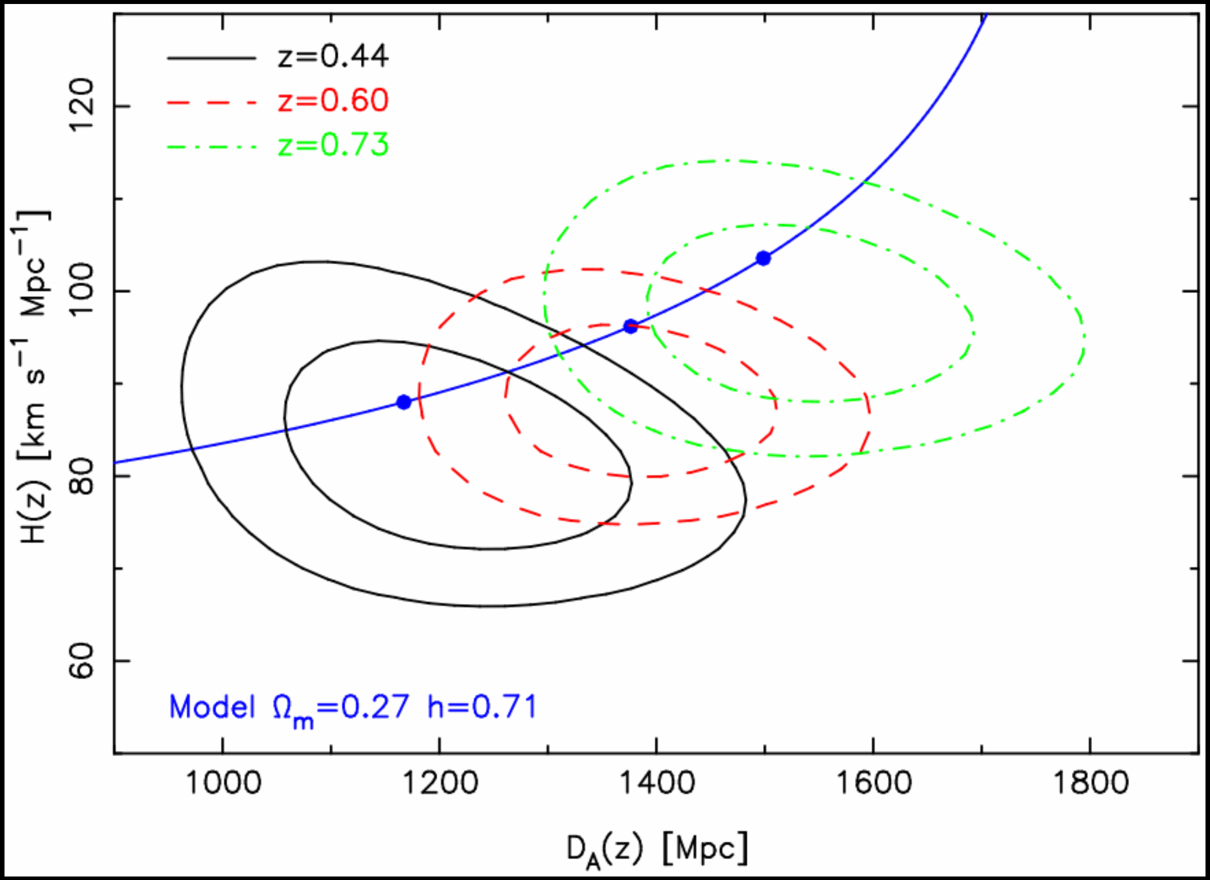
WiggleZ AP measures

$$F \propto D_A H$$

WiggleZ BAO measures

$$A \propto (D_A^2/H)^{1/3}$$

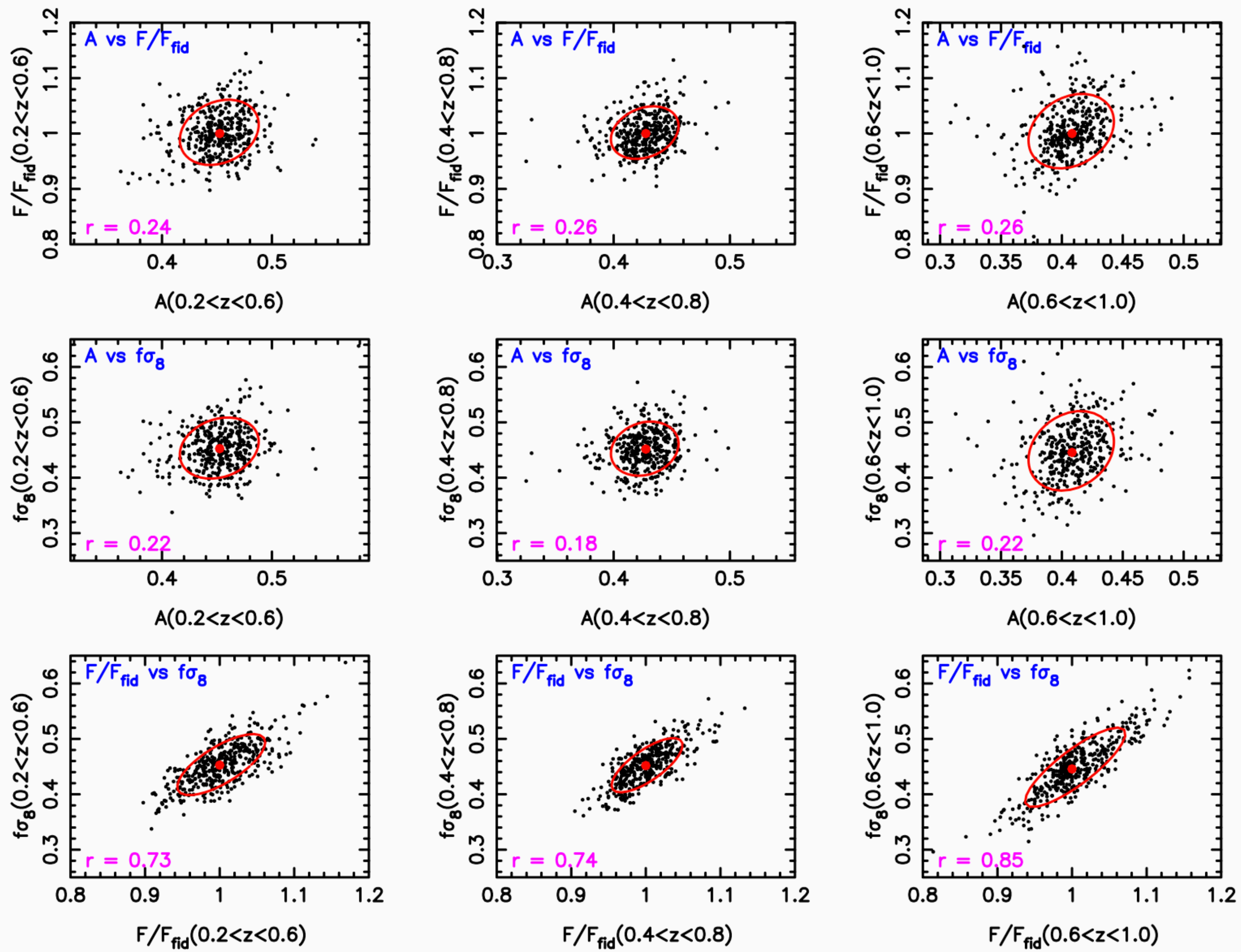
So the combination allows us to measure distance and expansion rate separately



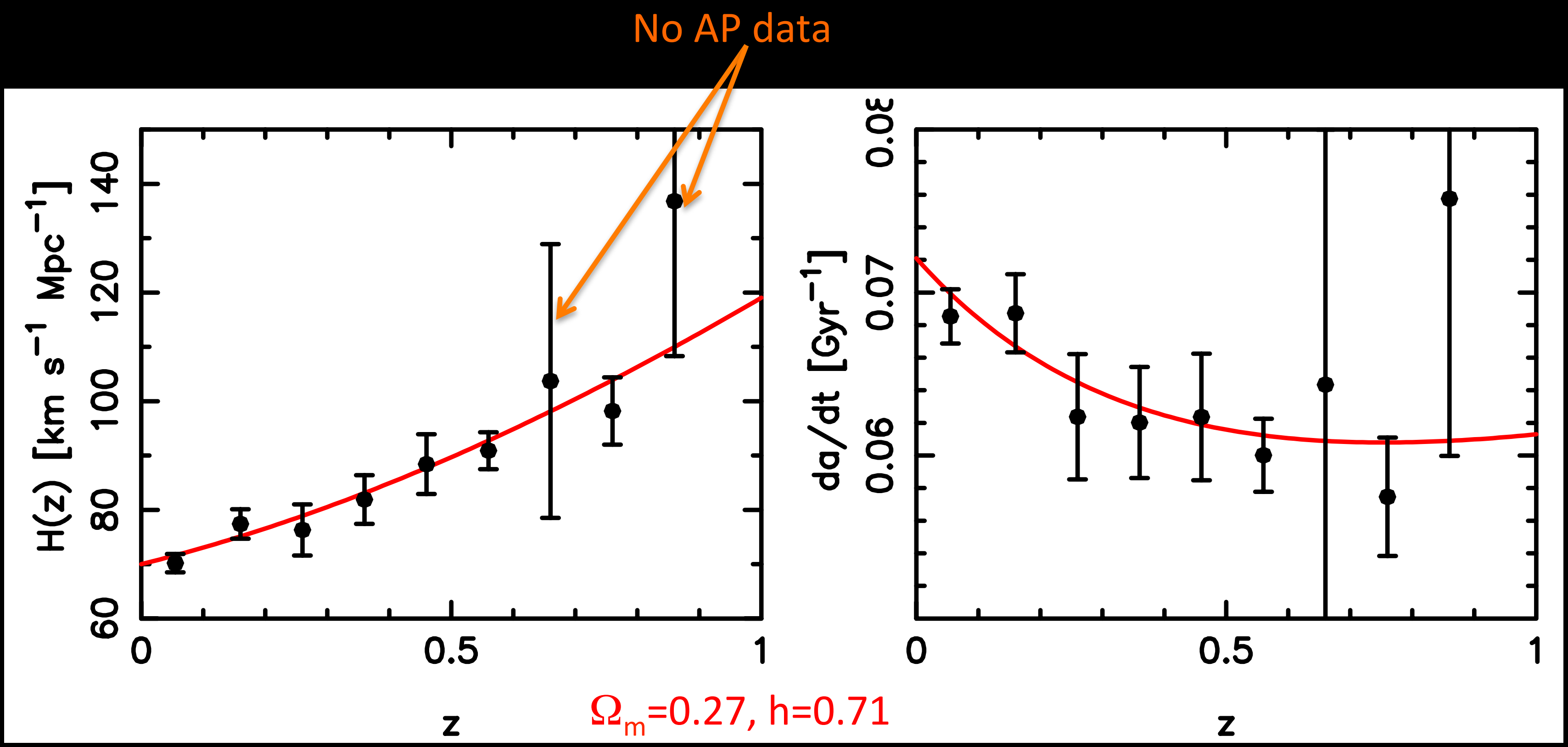
Marginalized over $\Omega_m h^2$, with CMB prior (Komatsu et al. 2009) of 0.1345±0.0055

Covariances

400 lognormal realizations per WiggleZ field and per z-slice (7200 total)



Combined with other BAO, SNe, and $\Omega_m h^2$



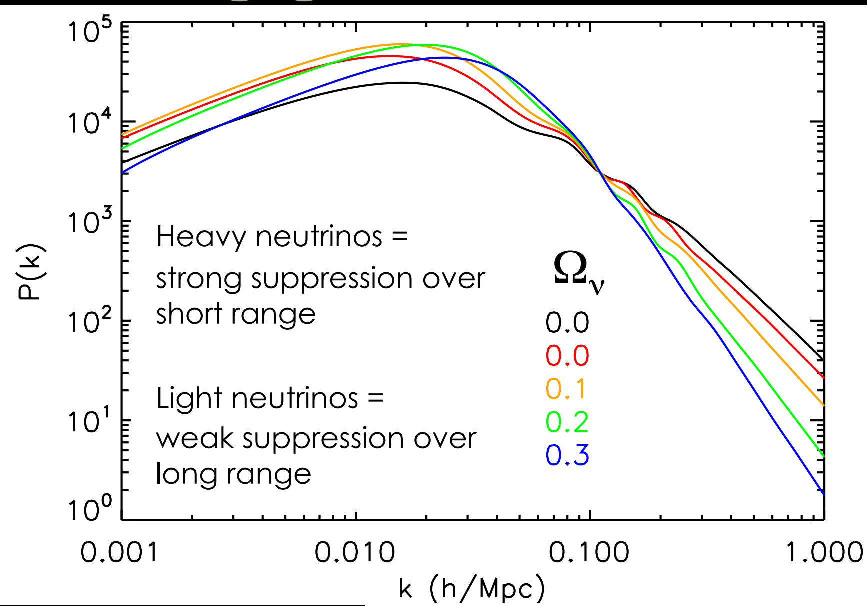
WiggleZ and BOSS (AP+BAO)
6dFGS and SDSS BAO
SNe (Union)
WMAP $\Omega_m h^2$ (not distances)

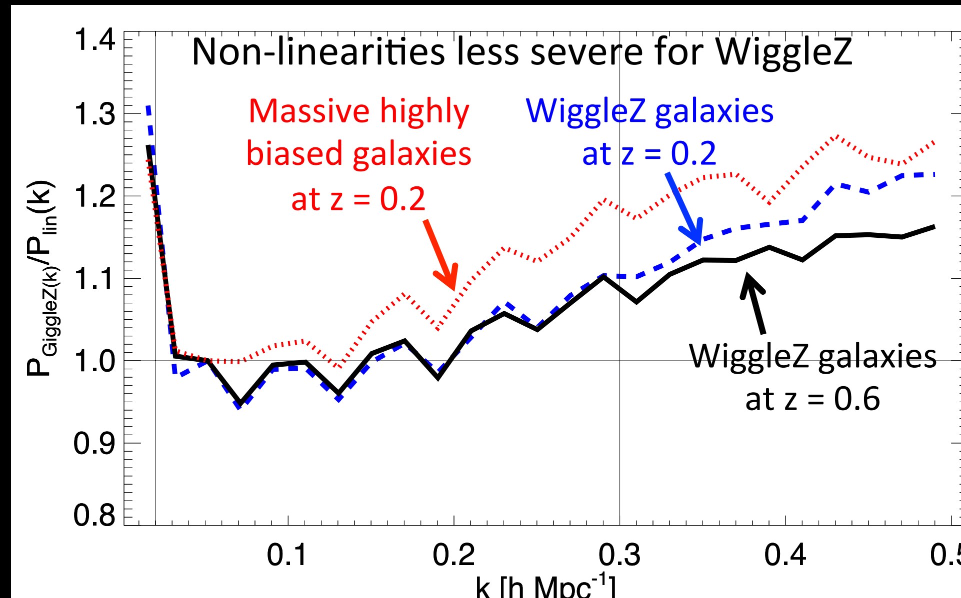
Riemer-Sørensen, Blake, Parkinson, Davis, et al. 2012
Riemer-Sørensen, Parkinson, Davis, Blake, et al. 2013
Riemer-Sørensen, Parkinson, Davis 2013

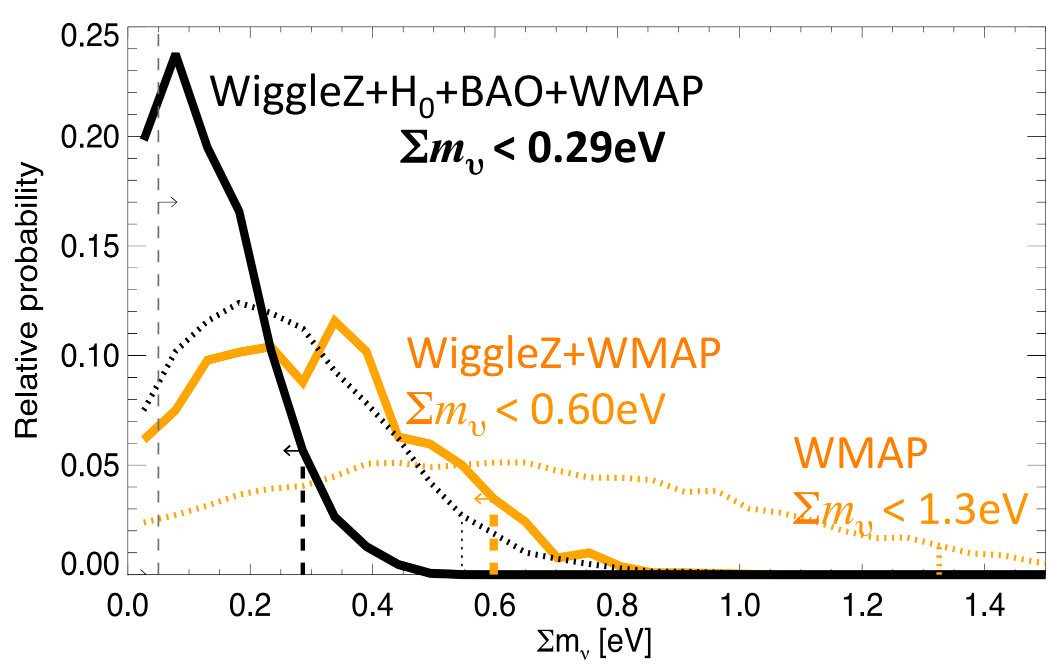
4. NEUTRINO MASS AND N_{EFF}

WiggleZ: Neutrino mass

Riemer-Sørensen et al. 2012





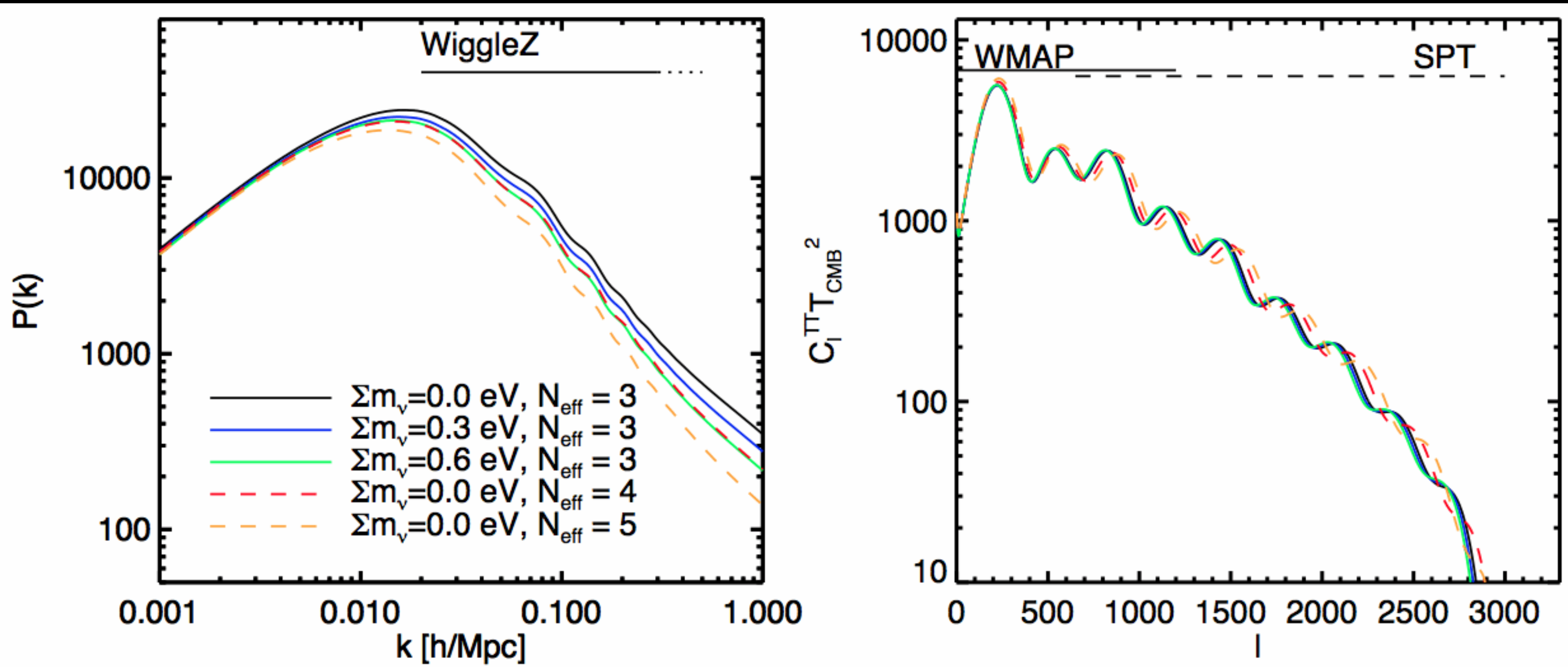


SDSS (Reid et al. 10)
$\Sigma m_\upsilon < 0.62$eV
Photo (dePutter 12)
$\Sigma m_\upsilon < 0.28$eV
Ly-α (Seljak et al. 06)
$\Sigma m_\upsilon < 0.17$eV

h=0.742±0.036
Reiss et al. 09

To k=0.3;
To k=0.1 we get
$\Sigma m_\upsilon < 0.39$eV

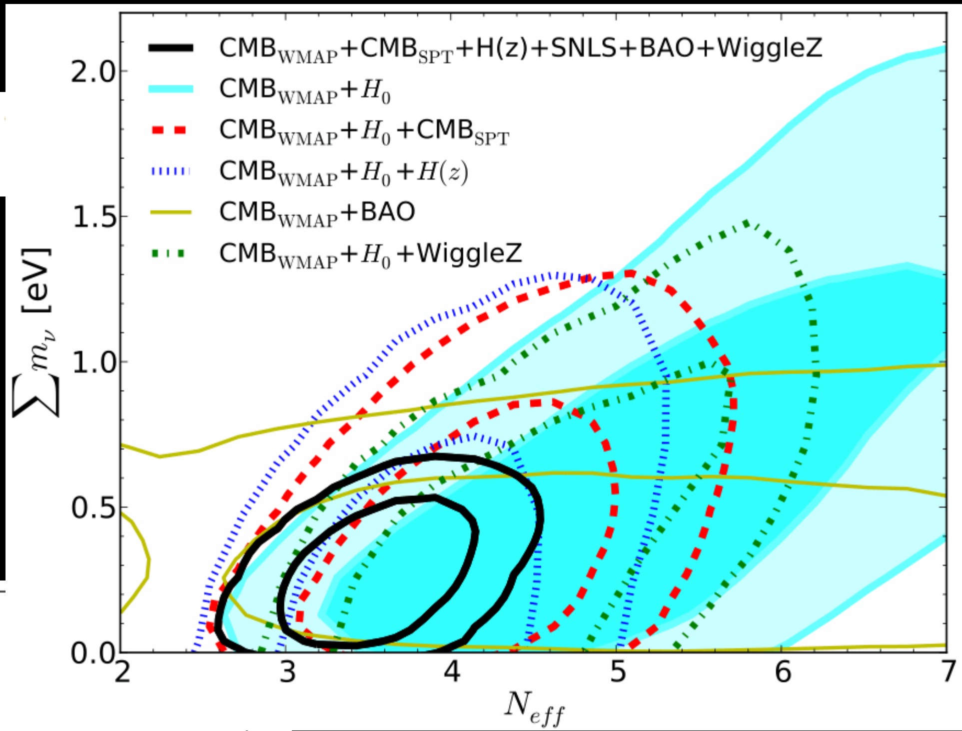
Paper 2: Neutrino mass + number

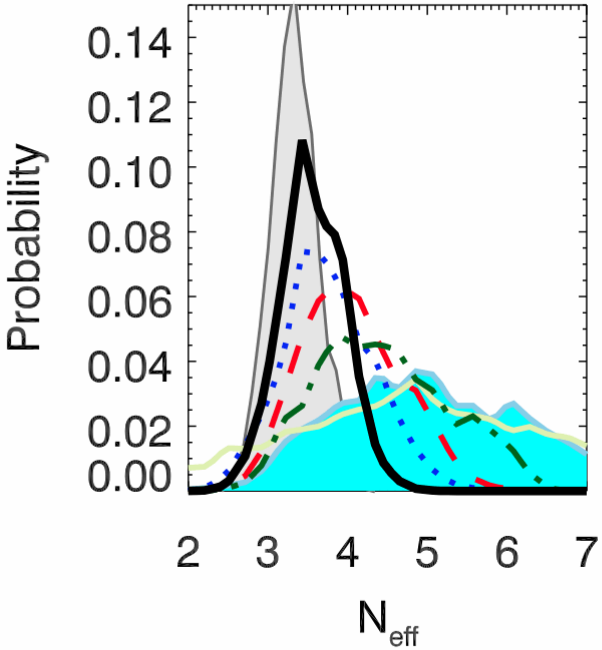


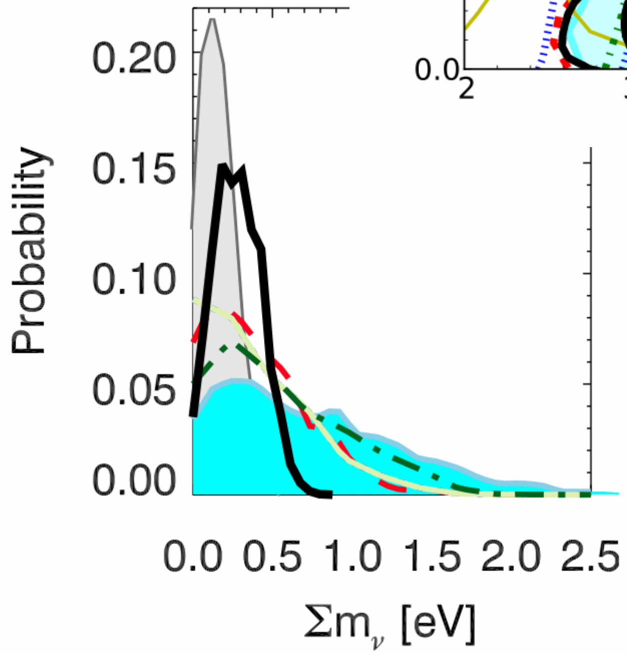
Simultaneous constraints on N_{eff} & m_ν

$$N_{\rm eff} = 3.58^{+0.15}_{-0.16}(68\%\,{\rm CL})$$
$$^{+0.55}_{-0.53}(95\%\,{\rm CL})$$

$$\sum m_\nu < 0.60\,{\rm eV}(95\%\,{\rm CL})$$





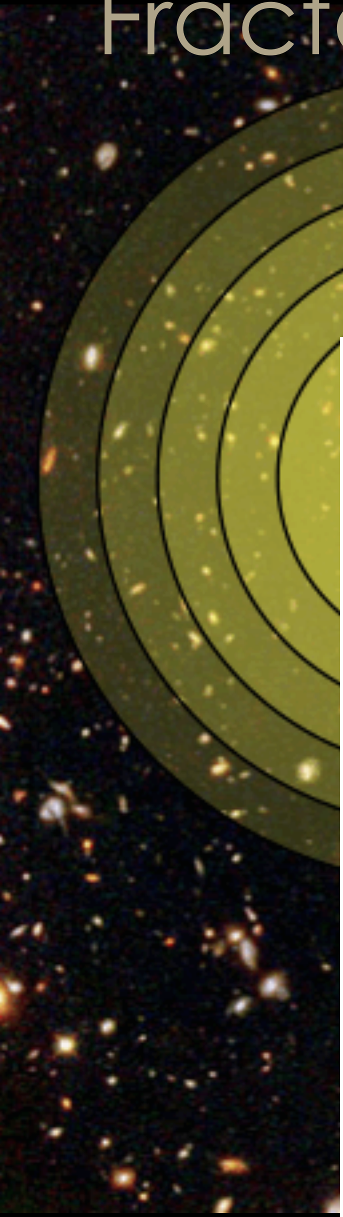


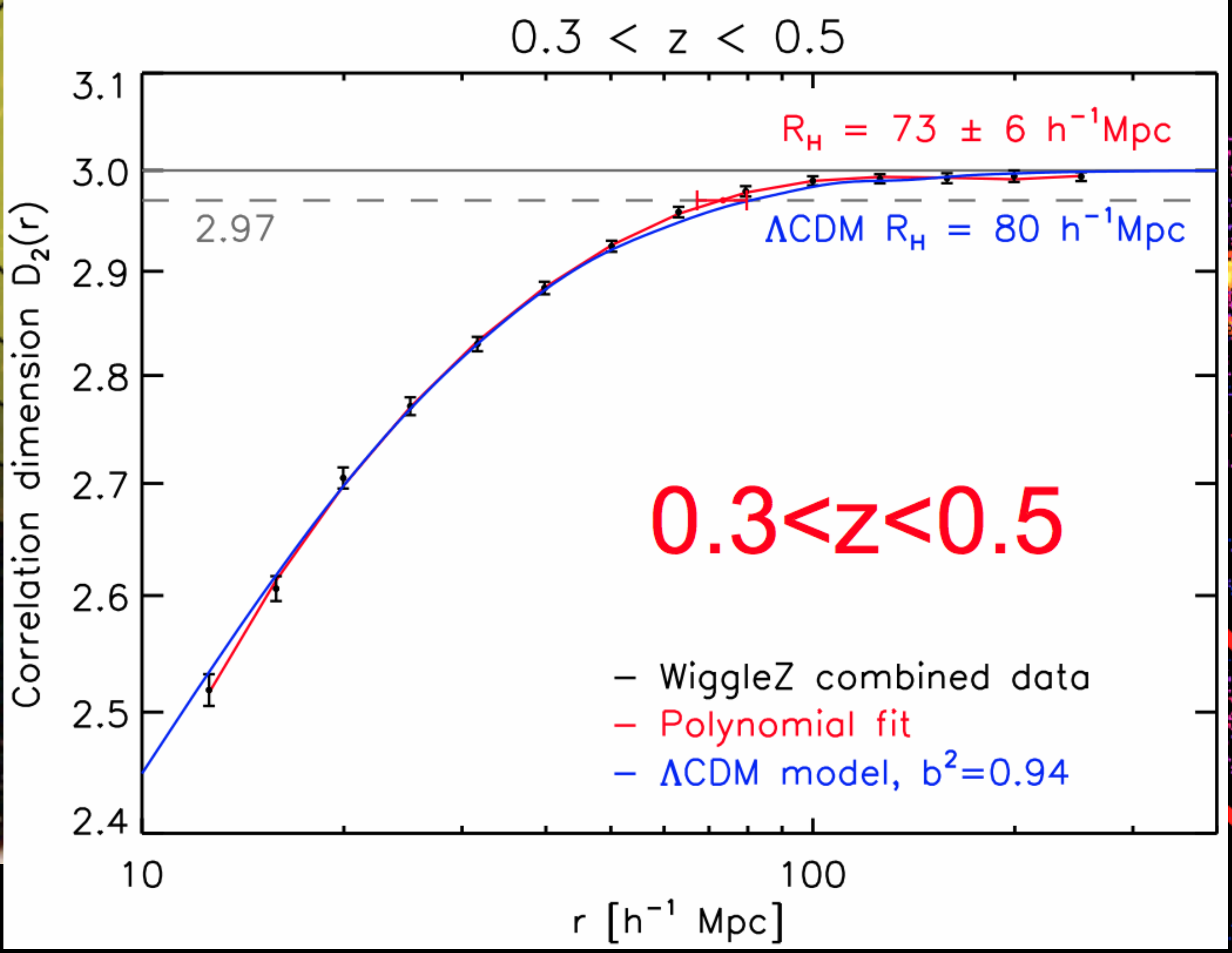
Scrimgeour, Davis, Blake et al. 2012

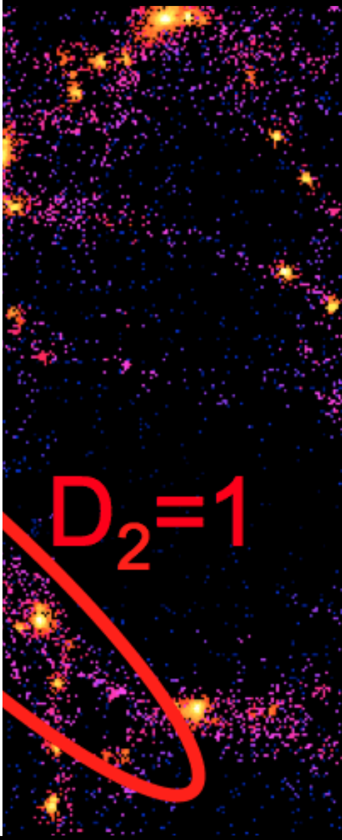
5. HOMOGENEITY

Fractal dimension (Morag Scrimgeour, ICRAR)

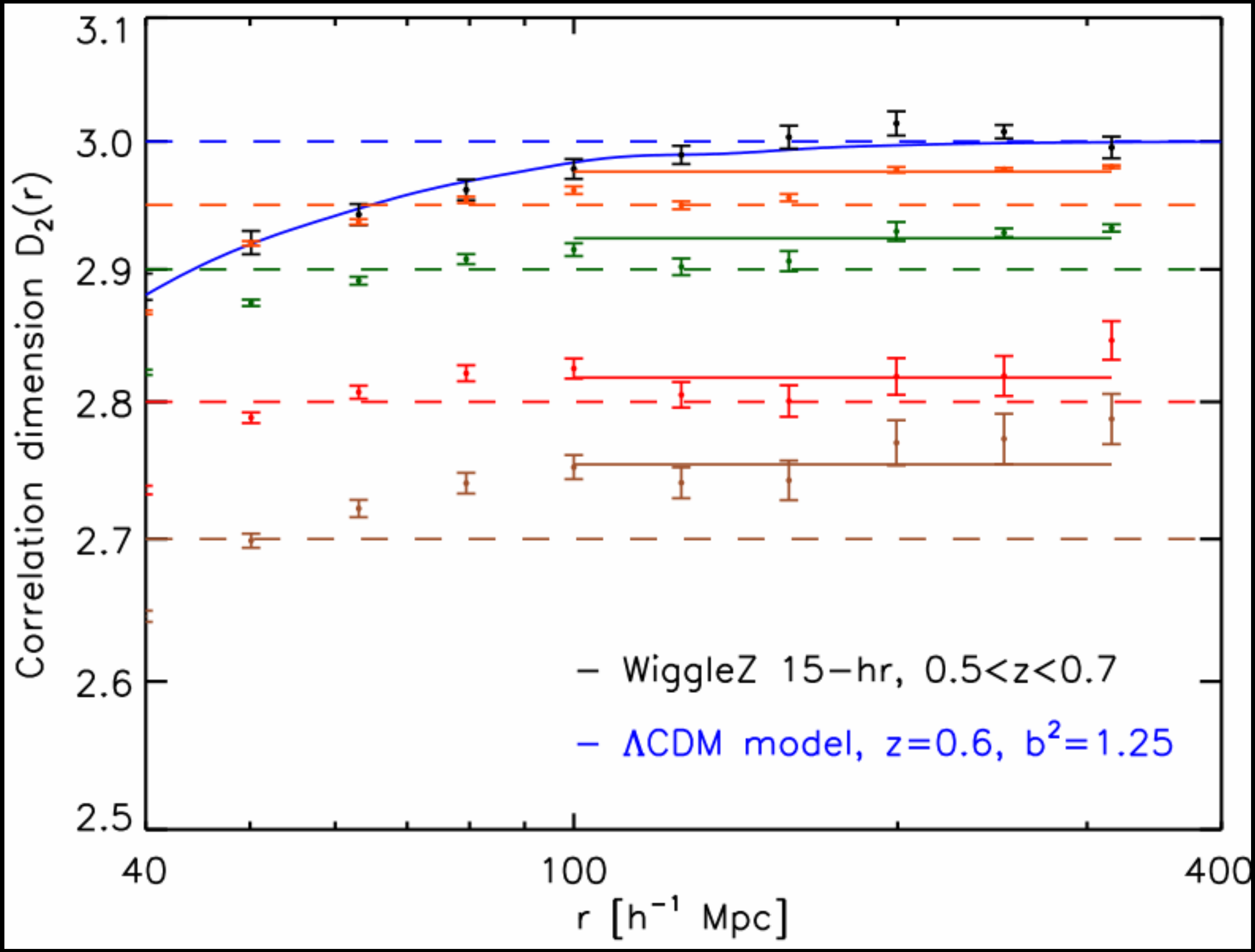
$$N(<r) \propto r^{D_2}$$







Fractal models



Parkinson, Riemer-Sørensen, Blake, Poole, Davis, et al. 2012

6. FULL POWER SPECTRUM DATA RELEASE + COSMOMC

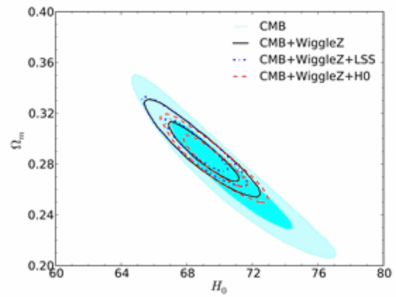
Full analysis, Data, and CosmoMC

WiggleZ data

http://www.smp.uq.edu.au/wigglez-data

This page provides data products associated with the WiggleZ Dark Energy survey measurement of the galaxy power spectrum, described in axiv:1003.5721, Blake et al 2010, and arxiv:1210.2130, Parkinson et al 2012. We also make available a module for the Cosmological analysis code CosmoMC. We also make available the random catalogues used for the WiggleZ BAO measurement, as described in arxiv:1108.2635, Blake et al 2011.

If you have any questions regarding this data set, or associated module, please contact David Parkinson, d.parkinson [at] uq.edu.au.

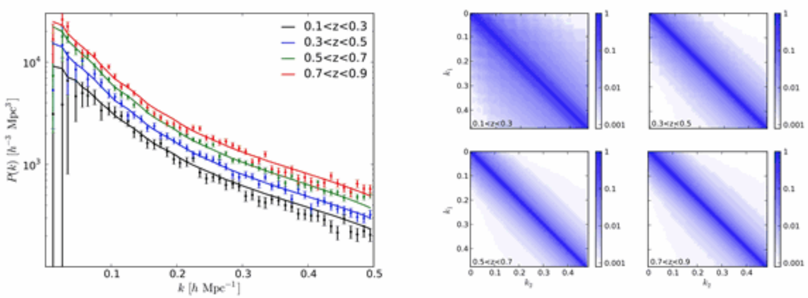


Parameter constraints for WiggleZ combined with other data sets

Module

The CosmoMC module can be downloaded from here. The module provides a slightly updated version of some of the source files for CosmoMC, and includes the details of the non-linear *P(k)* modelling needed to analyse the data up to to maximum wavenumber of k=0.3 h/Mpc.

Data



Power spectra (*left*) and covariance matrices (*right*) for the four redshift bins, averaged over the seven regions.

Final results

Model	Parameter	CMB + WiggleZ	+ H_0	+ SN-Ia	+ BAO	+ H_0 + BAO
Flat ΛCDM	$100\Omega_b h^2$	2.238 ± 0.052	2.255 ± 0.050	2.240 ± 0.053	2.239 ± 0.050	2.253 ± 0.050
	$\Omega_{\rm CDM} h^2$	0.1153 ± 0.0027	0.1145 ± 0.0026	0.1150 ± 0.0028	0.1152 ± 0.0024	0.1146 ± 0.0024
	100θ	1.039 ± 0.002	1.040 ± 0.002	1.039 ± 0.003	1.039 ± 0.002	1.039 ± 0.002
	τ	0.083 ± 0.014	0.084 ± 0.014	0.083 ± 0.014	0.083 ± 0.014	0.084 ± 0.014
	n_s	0.964 ± 0.012	0.968 ± 0.012	0.965 ± 0.013	0.964 ± 0.012	0.968 ± 0.011
	$\log(10^{10} A_s)$	3.084 ± 0.029	3.086 ± 0.029	3.085 ± 0.030	3.083 ± 0.029	3.086 ± 0.029
	Ω_m	0.290 ± 0.016	0.283 ± 0.014	0.288 ± 0.017	0.289 ± 0.013	0.284 ± 0.012
	$H_0 [\mathrm{km\,s^{-1}\,Mpc^{-1}}]$	68.9 ± 1.4	69.6 ± 1.3	69.1 ± 1.6	69.0 ± 1.2	69.5 ± 1.2
	σ_8	0.825 ± 0.017	0.825 ± 0.017	0.825 ± 0.017	0.825 ± 0.017	0.825 ± 0.017
Flat wCDM	$100\Omega_b h^2$	2.265 ± 0.062	2.253 ± 0.057	2.228 ± 0.055	2.247 ± 0.056	2.253 ± 0.056
	$\Omega_{DM} h^2$	0.1164 ± 0.0036	0.1146 ± 0.0030	0.1157 ± 0.0030	0.1147 ± 0.0029	0.1148 ± 0.0030
	100θ	1.039 ± 0.003	1.039 ± 0.003	1.038 ± 0.003	1.039 ± 0.003	1.039 ± 0.003
	τ	0.084 ± 0.015	0.084 ± 0.014	0.082 ± 0.014	0.084 ± 0.014	0.084 ± 0.014
	n_s	0.975 ± 0.019	0.968 ± 0.014	0.962 ± 0.014	0.967 ± 0.014	0.968 ± 0.014
	$log[10^{10}$	3.096 ± 0.031	3.086 ± 0.030	3.082 ± 0.029	3.085 ± 0.030	3.086 ± 0.030
	w	-0.525 ± 0.293	-1.007 ± 0.084	-1.062 ± 0.072	-0.973 ± 0.086	-1.008 ± 0.085
	Ω_m	0.487 ± 0.132	0.283 ± 0.018	0.844 ± 0.028	0.294 ± 0.018	0.284 ± 0.018
	H_0	55.2 ± 8.4	69.7 ± 2.1	70.5 ± 2.3	68.4 ± 2.0	69.7 ± 2.1
	σ_8	0.664 ± 0.110	0.826 ± 0.032	0.844 ± 0.028	0.815 ± 0.033	0.827 ± 0.032
ΛCDM	$100\Omega_b h^2$	2.215 ± 0.055	2.263 ± 0.054	2.256 ± 0.054	2.252 ± 0.054	2.262 ± 0.052
	$\Omega_{\rm CDM} h^2$	0.1118 ± 0.0039	0.1162 ± 0.0039	0.114 ± 0.0042	0.1150 ± 0.0038	0.1161 ± 0.0038
	100θ	1.038 ± 0.003	1.040 ± 0.003	1.040 ± 0.003	1.040 ± 0.003	1.040 ± 0.003
	τ	0.086 ± 0.014	0.088 ± 0.015	0.089 ± 0.014	0.088 ± 0.015	0.088 ± 0.014
	n_s	0.958 ± 0.013	0.970 ± 0.013	0.969 ± 0.013	0.968 ± 0.013	0.969 ± 0.013
	$\log(10^{10} A_s)$	3.072 ± 0.031	3.101 ± 0.031	3.096 ± 0.031	3.096 ± 0.031	3.101 ± 0.030
	Ω_m	0.454 ± 0.058	0.287 ± 0.029	0.303 ± 0.038	0.302 ± 0.020	0.288 ± 0.016
	Ω_k	-0.046 ± 0.017	0.001 ± 0.008	-0.005 ± 0.012	-0.004 ± 0.006	0.000 ± 0.005
	H_0 $[\mathrm{km\,s^{-1}\,Mpc^{-1}}]$	54.65 ± 3.8	69.86 ± 3.6	67.7 ± 4.7	67.6 ± 2.3	69.9 ± 3.6
	σ_8	0.782 ± 0.024	0.838 ± 0.023	0.825 ± 0.026	0.829 ± 0.022	0.838 ± 0.023

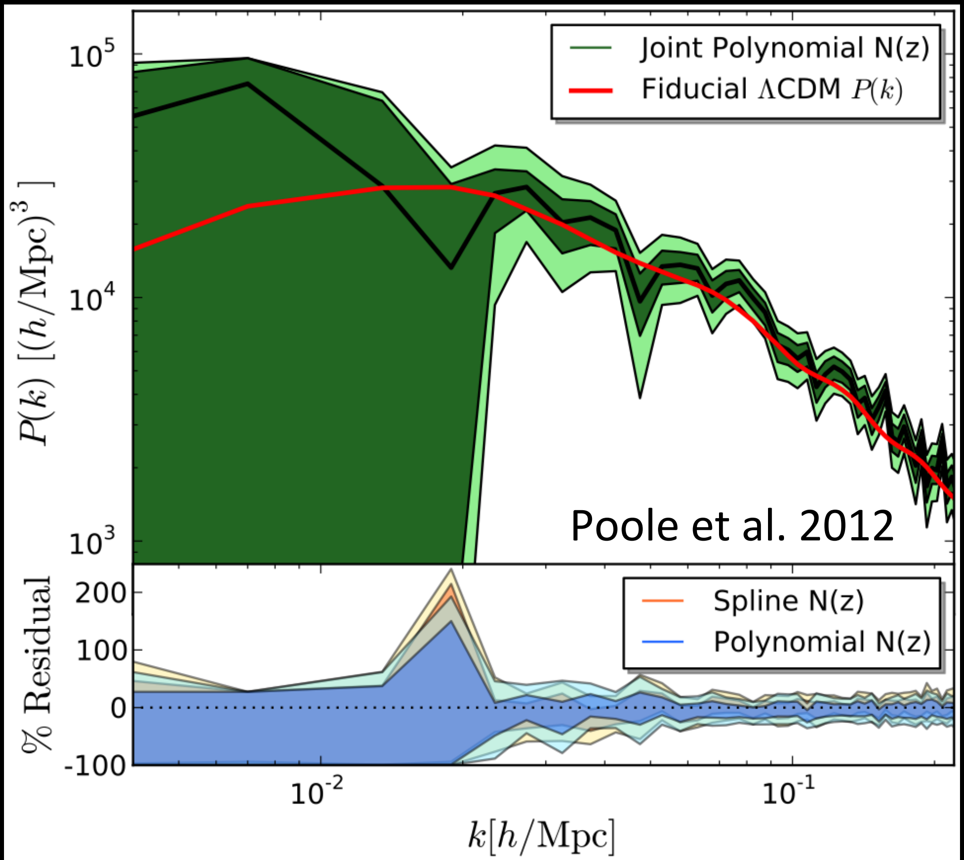
Final results

(ΛCDM wins)

Poole, Blake, Parkinson, et al. 2013

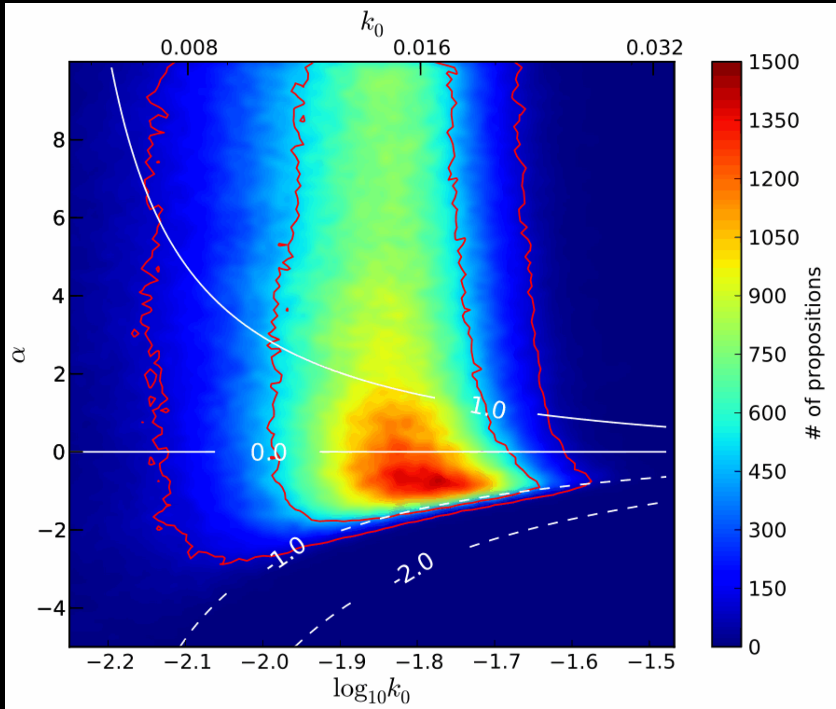
7. TURNOVER

Turnover in the Power Spectrum



$z_{\mathrm{eff}} = 0.62$

$$k_0 = 0.0160^{+0.0041}_{-0.0035}$$



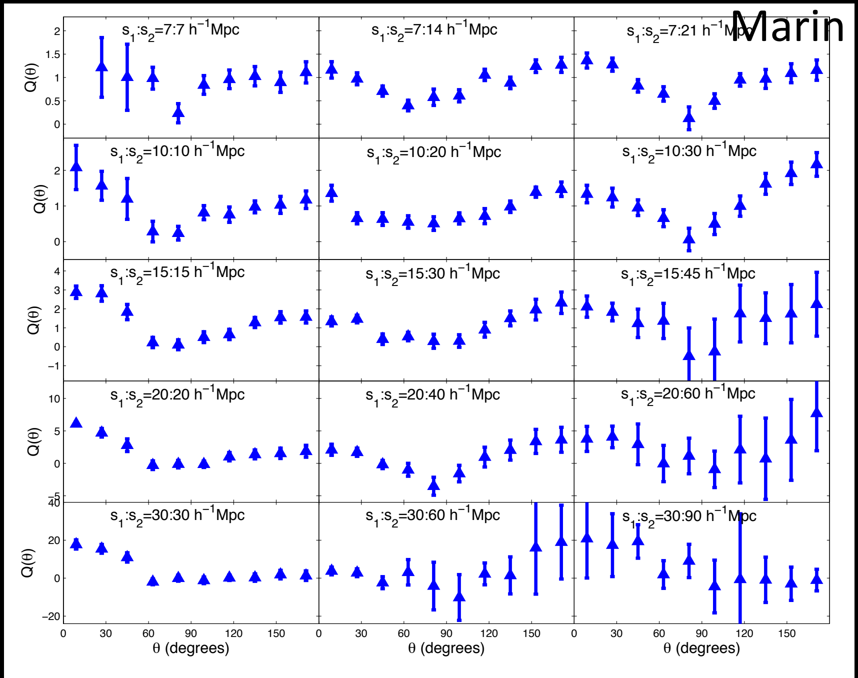
WiggleZ and Friends….

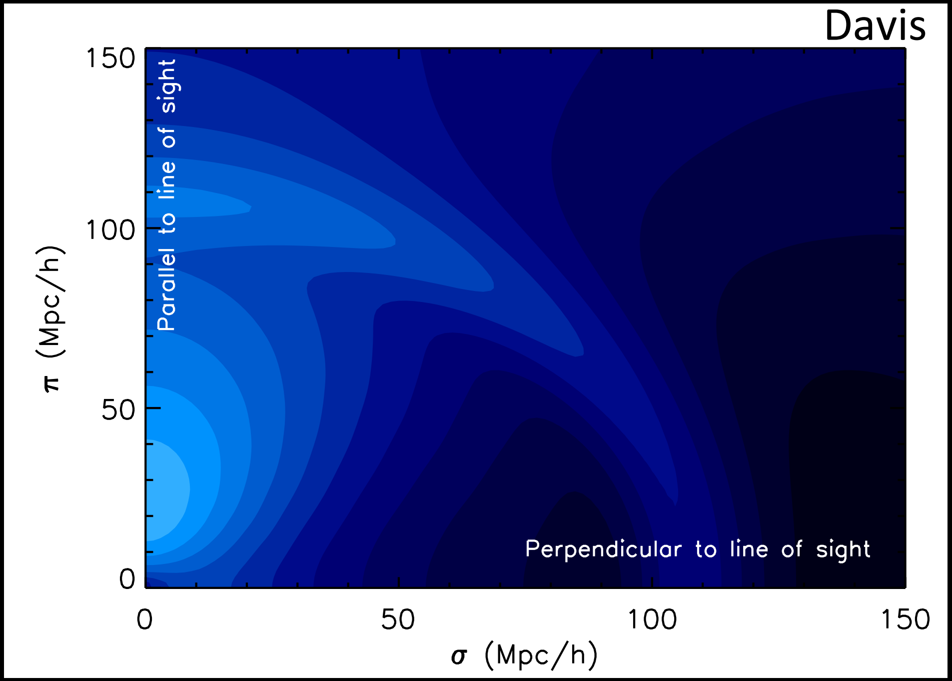
8. FUTURE

Other Upcoming Results (with WigglerZ at this conference)

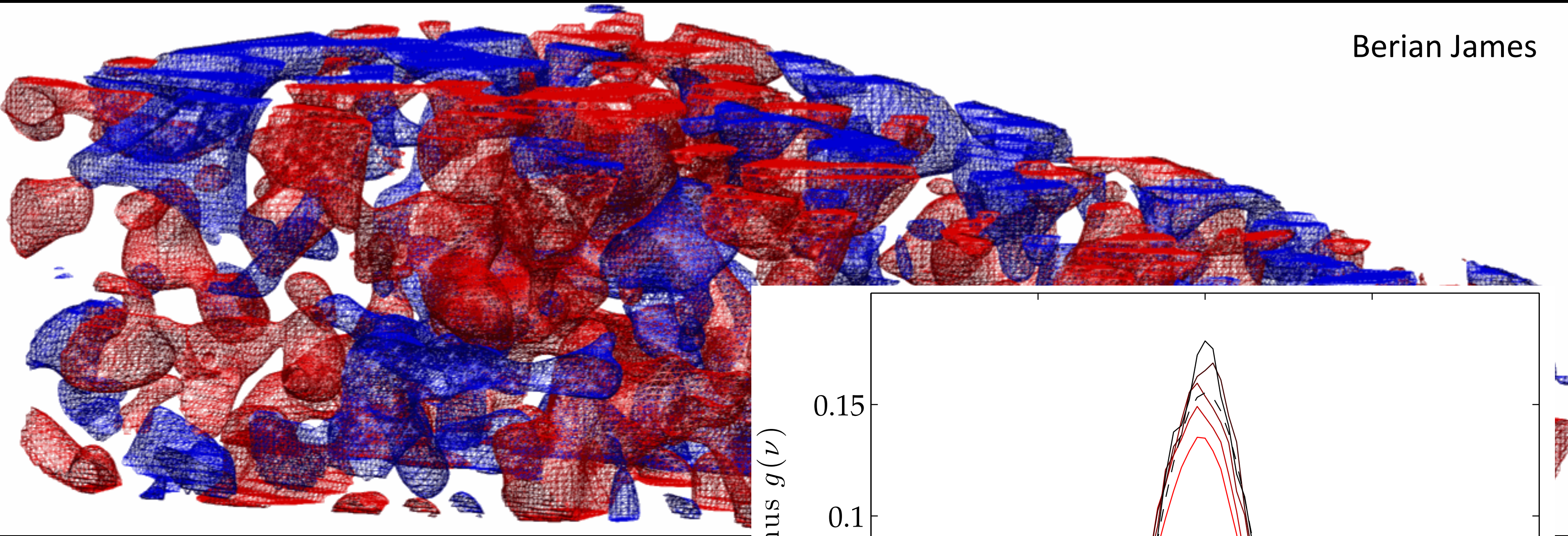
Higher-order statistics
(see Felipe Marin)

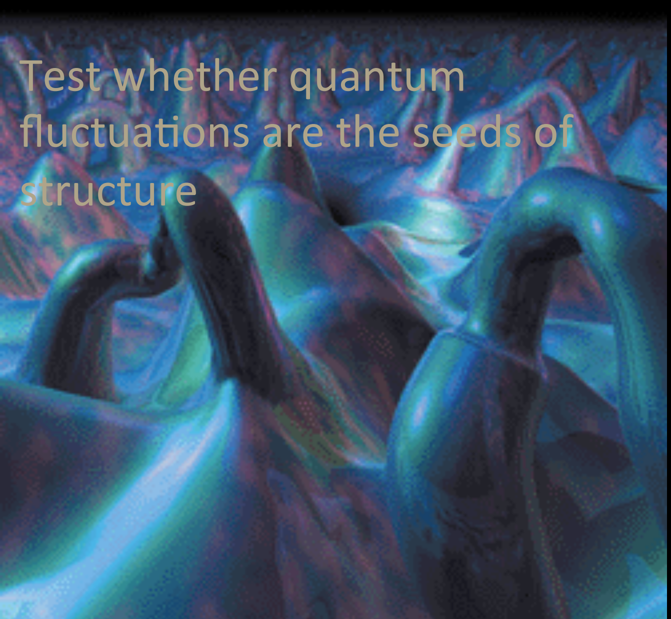
2D BAO and reconstruction
(see Eyal Kazin)

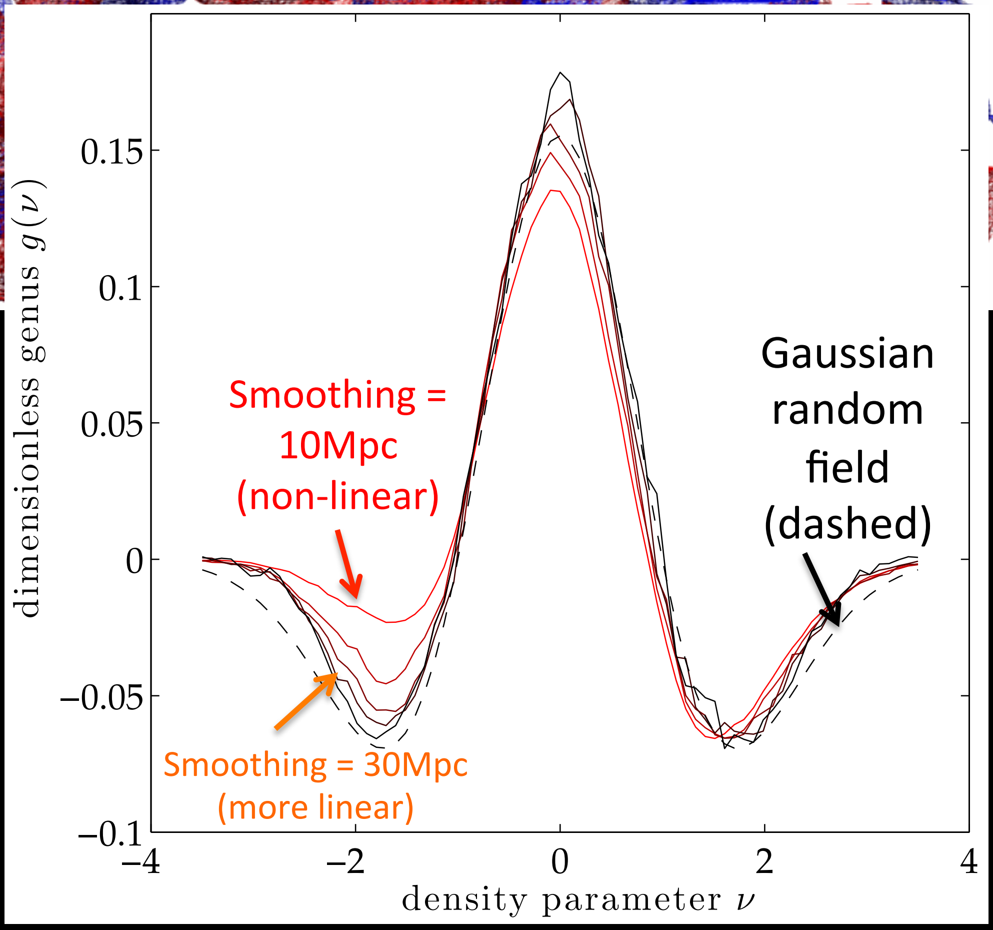




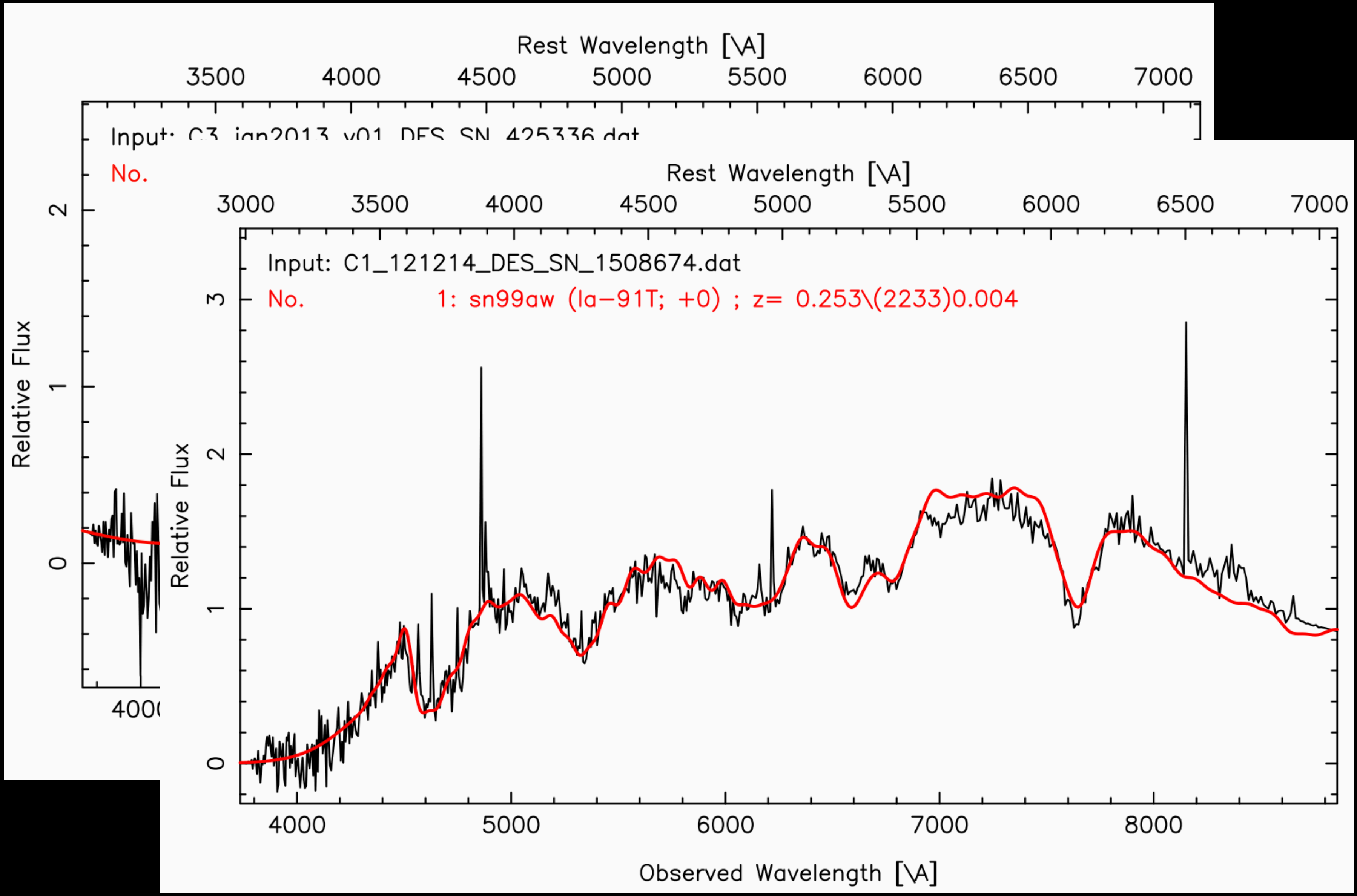
Topology: Genus curve





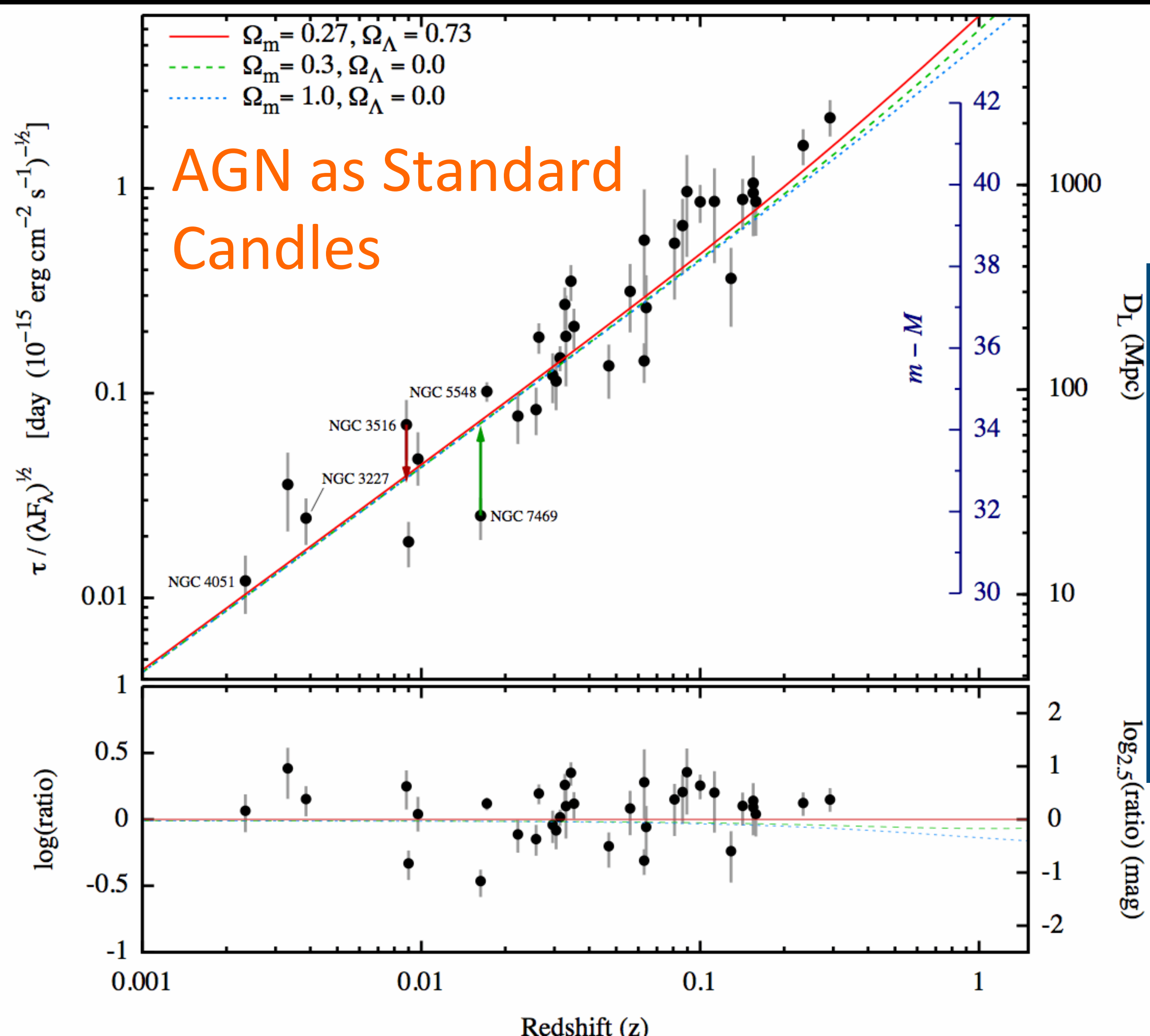


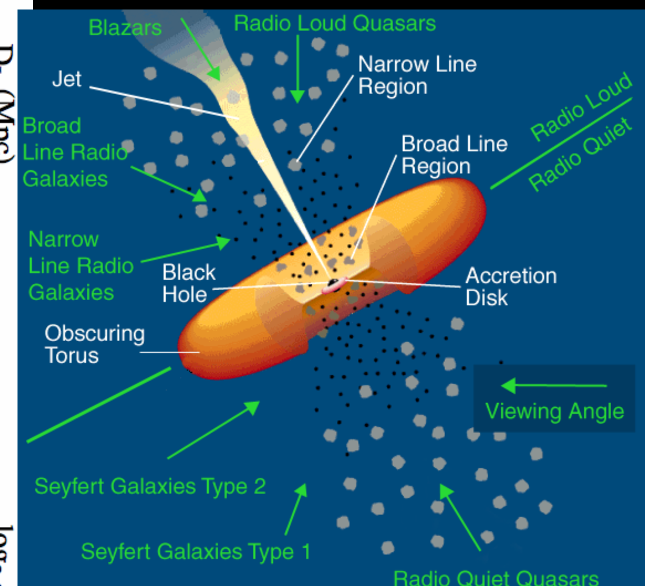
Future – OzDES?



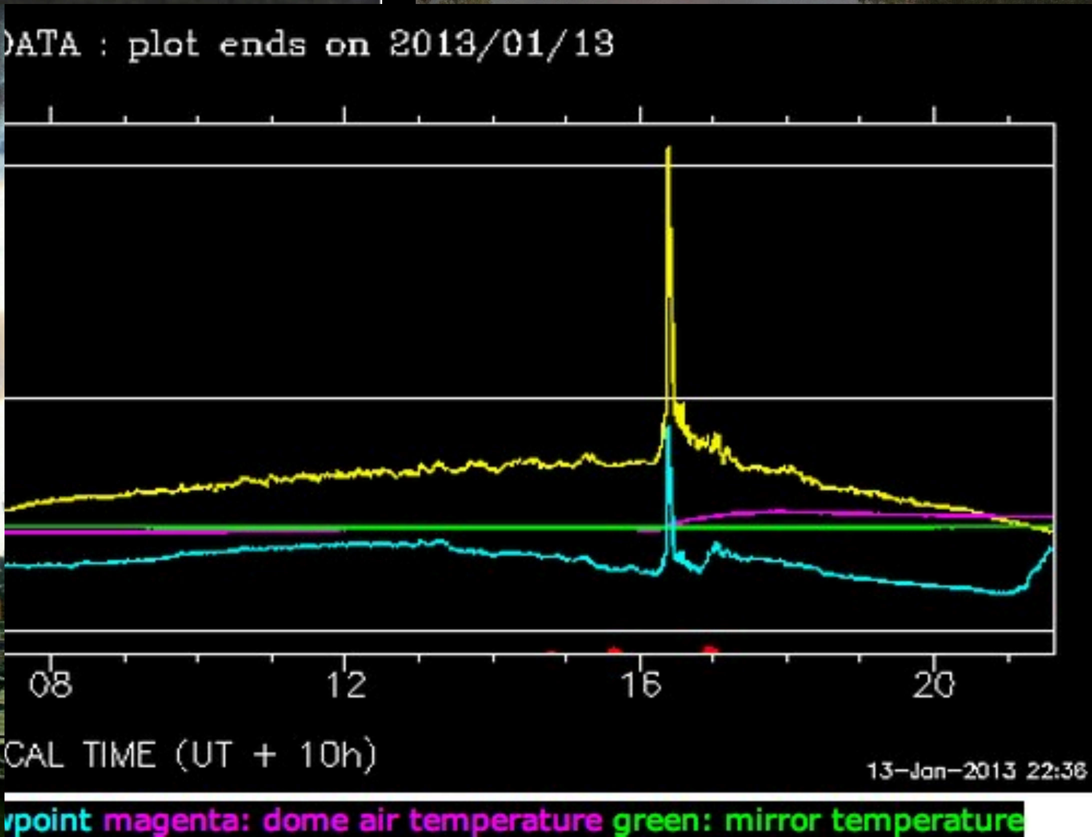
Future – Quasars give distances??

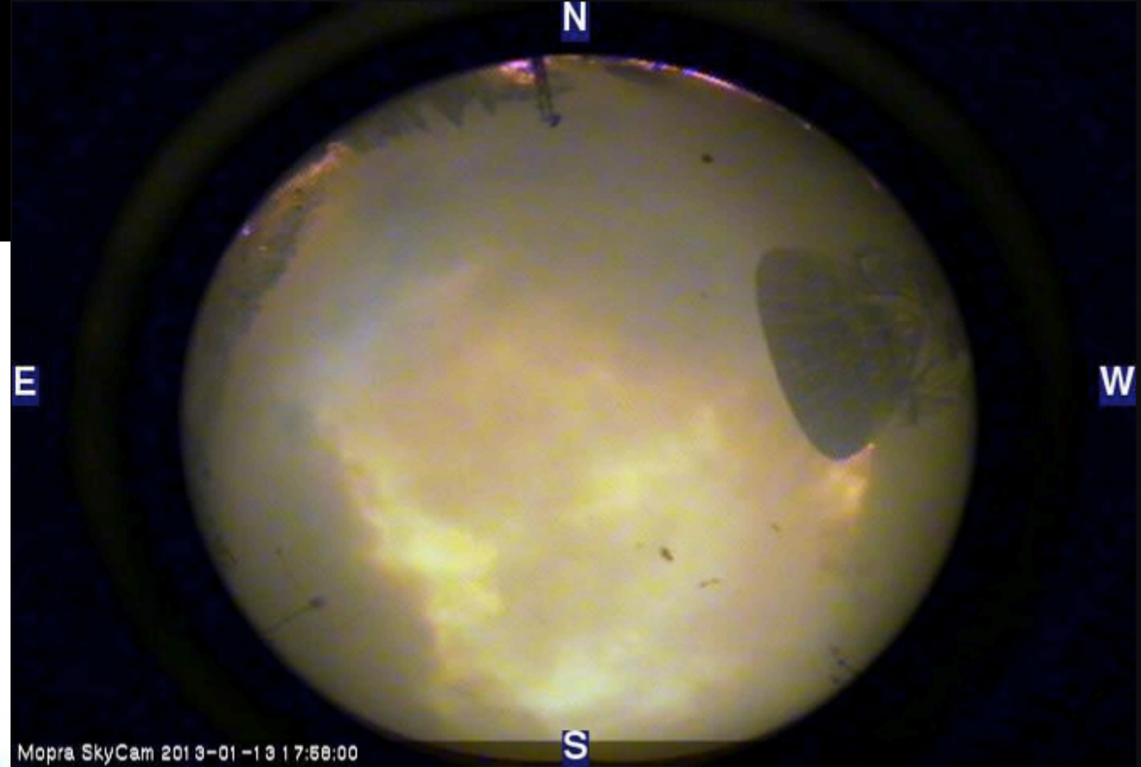
(Watson, Denney, Vestergaard & Davis 2011)





Fire…


plot ends on 2013/01/13
08
12
16
20
TIME (UT + 10h)
13-Jan-2013 22:36
magenta: dome air temperature green: mirror temperature



N
E
W
S
Mopra SkyCam 2013-01-13 17:58:00


FTS site webcam 2013-01-13 10

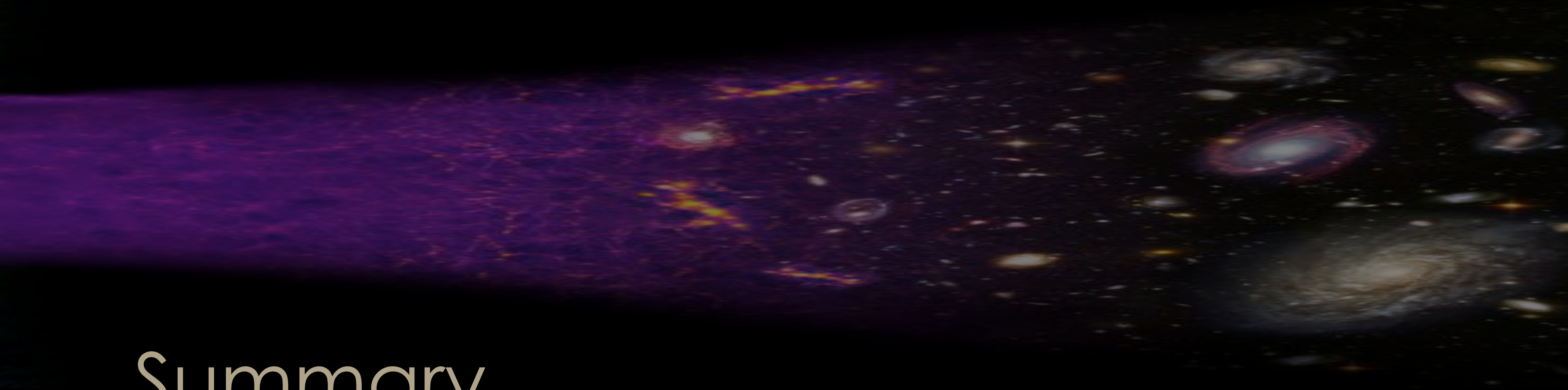

FTS site webcam 2013-01-13 10:51:19


FTS site webcam 2013-01-13 10:06:05
2013-01
10:06:35


HATSouth @ SSO 2013-01-13 22:15:30

But all is well.

Ángel R. López-Sánchez



Summary

WiggleZ is a great data set, with many interesting cosmology results

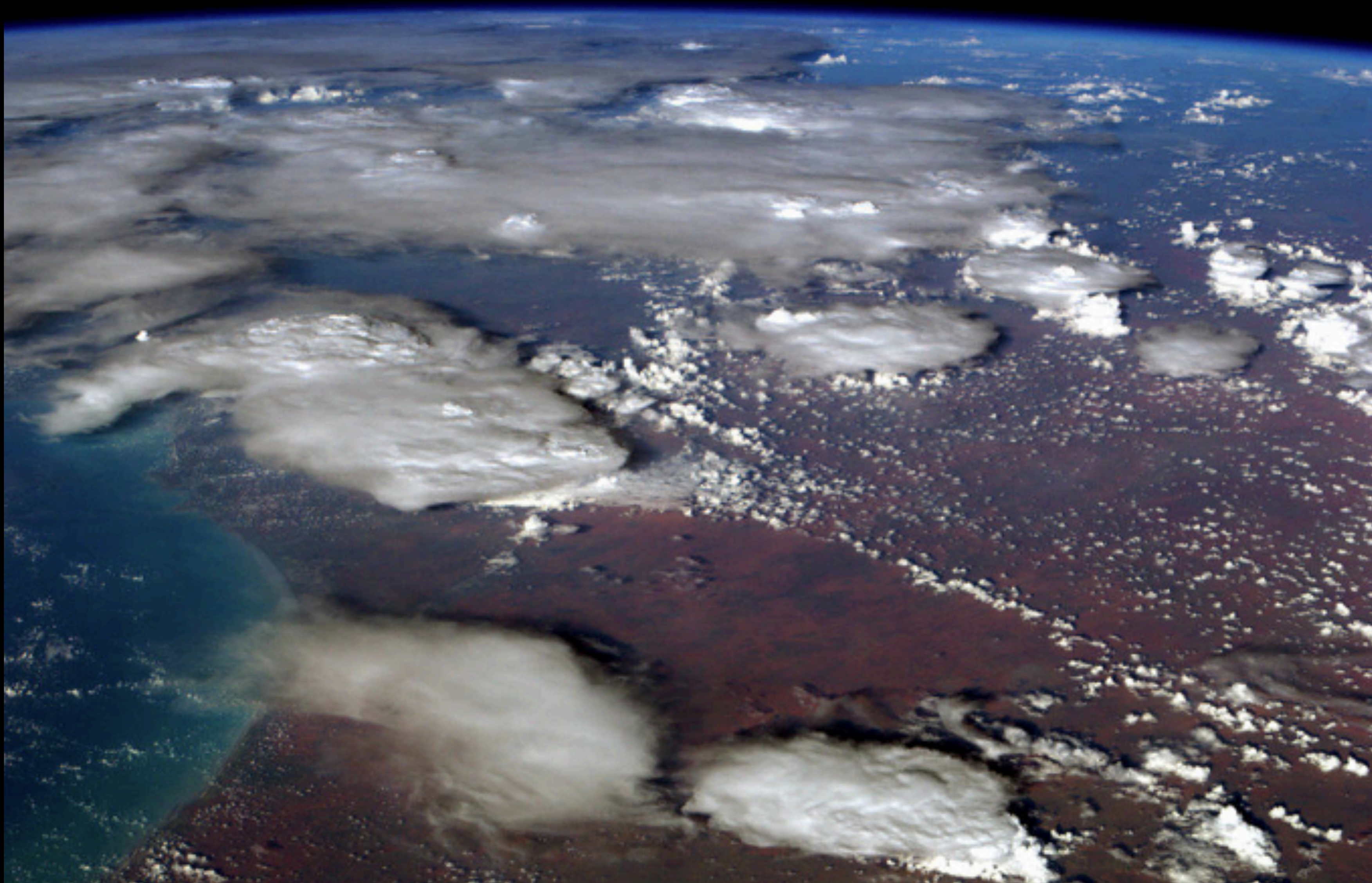
We've released our data and CosmoMC module

We hope you would like to use it and are happy to work with you to help

WiggleZ, main cosmology papers:

Paper	Lead authors	Title: "The WiggleZ Dark Energy Survey:"	arXiv
BAO's at z=0.6	Blake, Davis, Poole, Parkinson et al., 2011	testing the cosmological model with baryon acoustic oscillations at z= 0.6	1105.2862
BAO's in 3 redshift bins	Blake, Kazin, Beutler, Davis, Parkinson, et al. 2011	mapping the distance-redshift relation with baryon acoustic oscillations	1108.2635
Growth in 4 redshift bins	Blake, et al. 2011	the growth rate of cosmic structure since redshift z=0.9	1104.2948
Alcock-Paczynscki + SNe	Blake, Glazebrook, Davis, et al. 2011	measuring the cosmic expansion history using the Alcock-Paczynski test & distant Se	1108.2637
Alcock-Paczynscki + BAO	Blake, et al. 2012	joint measurements of the expansion and growth history at z < 1	1204.3674
Homogeneity	Scrimgeour, Davis, Blake, James, Poole, Staveley-Smith et al. 2012	the transition to large-scale cosmic homogeneity	1205.6812
Neutrino mass	Riemer-Sørensen, Blake, Parkinson, Davis, et al. 2012	Cosmological neutrino mass constraint from blue high-redshift galaxies	1112.4940
Data release and full cosmological analysis	Parkinson, Riemer-Sørensen, Blake, Poole, Davis et al. 2012	Final data release and cosmological results	1210.2130
Turnover in power spect.	Poole, Blake, Parkinson, et al. 2012	Probing the epoch of radiation domination using large scale structure	1211.5605
WiggleZ extensions			
Varying constants	Nesseris, Blake, Davis, Parkinson 2011	Constraining the evolution of Newton's constant using the growth rate of structure	1107.3659
Number of neutrinos	Riemer-Sørensen, Parkinson, Davis, Blake 2012	Simultaneous constraints on the number and mass of relativistic species	1210.2131

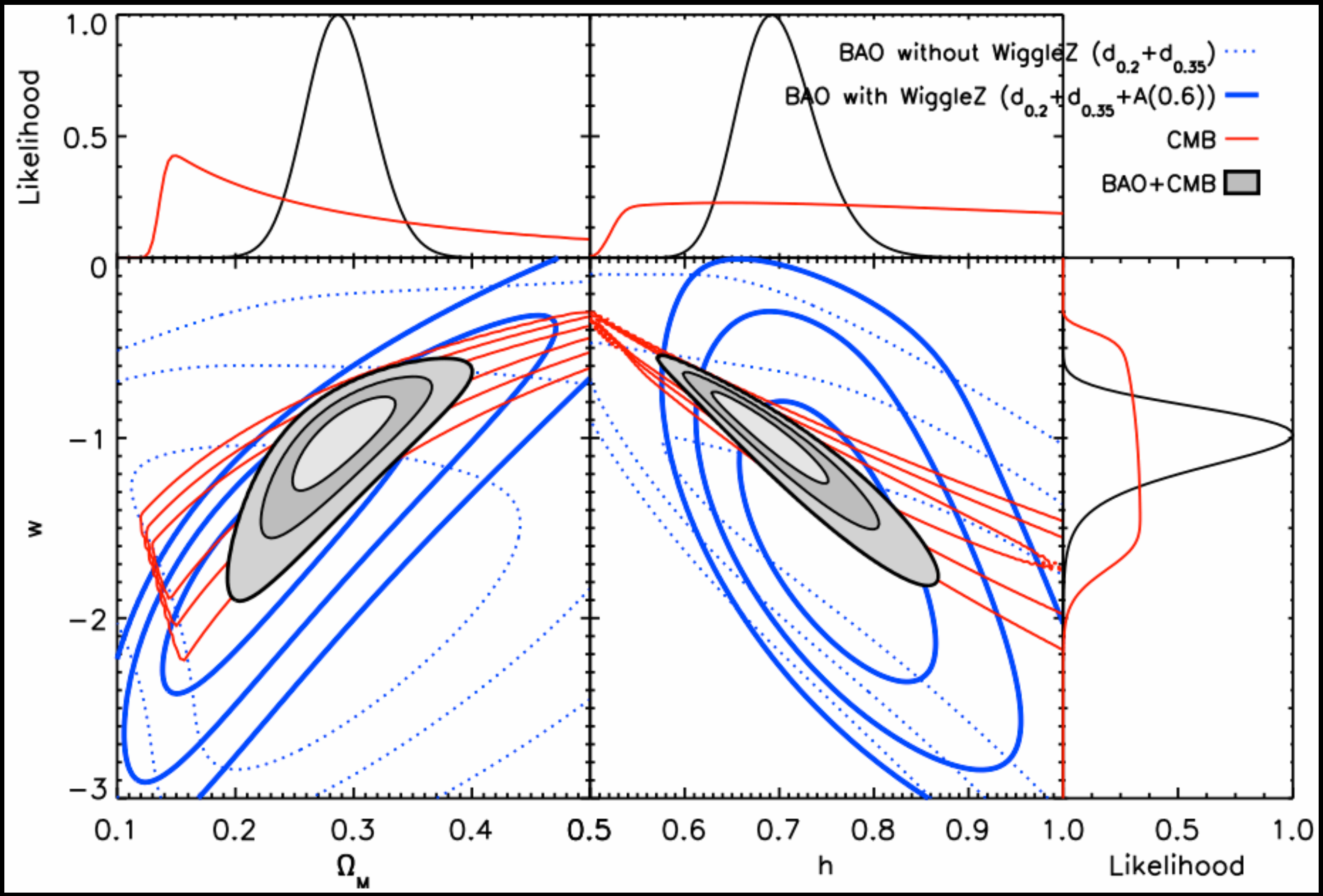
Australian fires from space



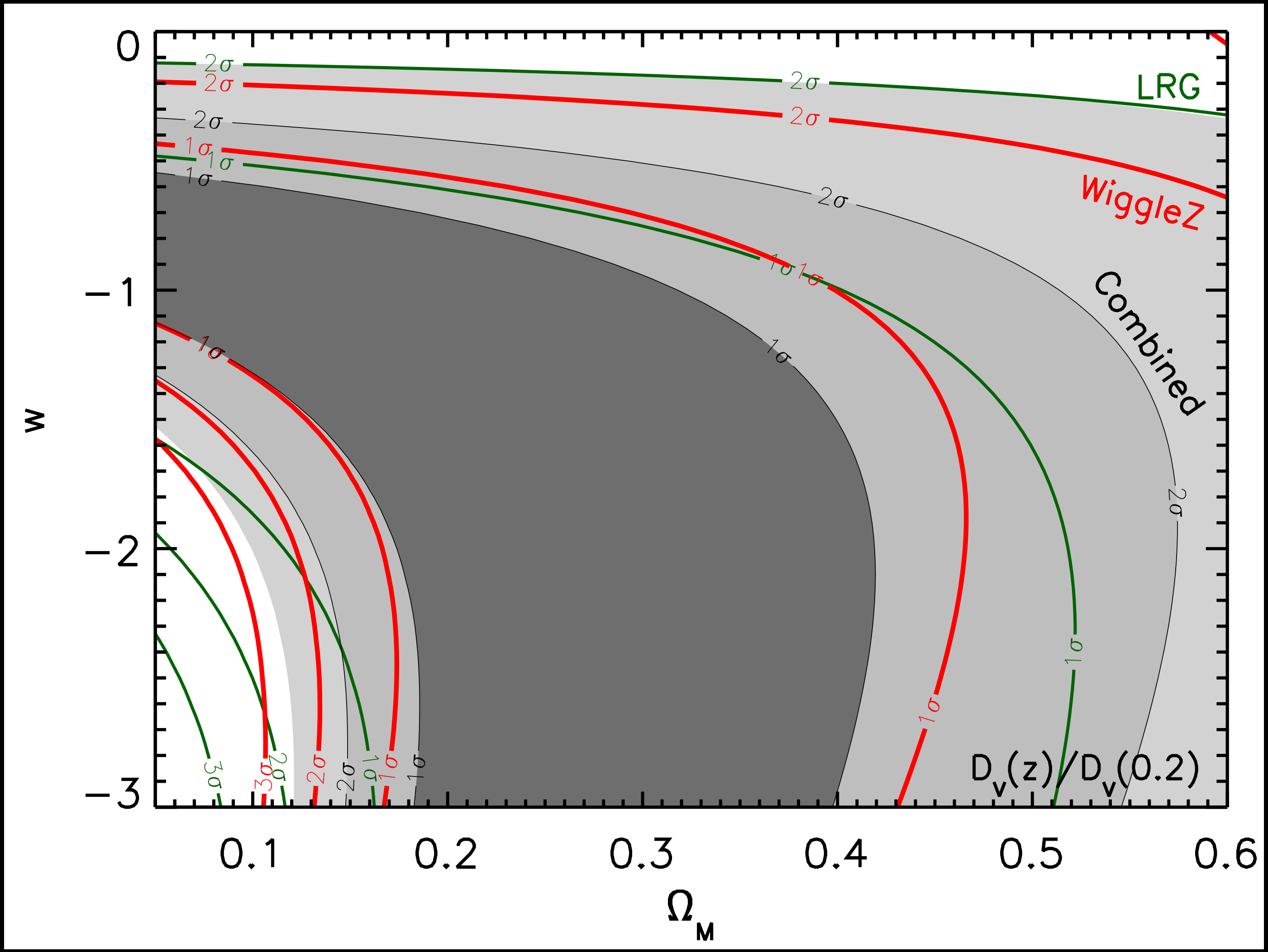
Chris Hadfield (ISS)

A. EXTRA SLIDES

WiggleZ cosmology fits – paper 1

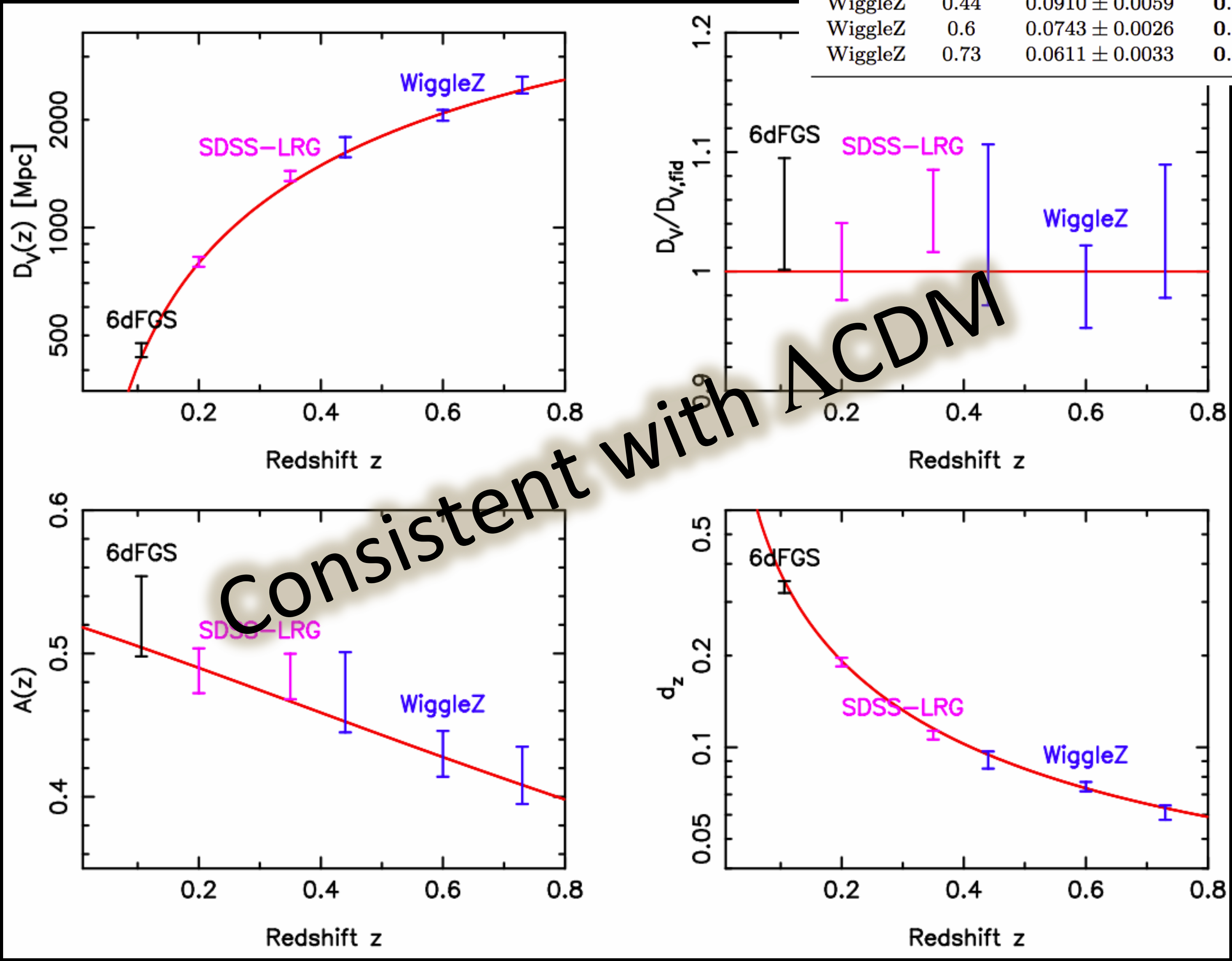


BAO distance ratio only – paper 1



Final WiggleZ BAO results

Sample	z	d_z	$A(z)$
6dFGS	0.106	$\mathbf{0.336 \pm 0.015}$	0.526 ± 0.028
SDSS	0.2	$\mathbf{0.1905 \pm 0.0061}$	0.488 ± 0.016
SDSS	0.35	$\mathbf{0.1097 \pm 0.0036}$	0.484 ± 0.016
WiggleZ	0.44	0.0910 ± 0.0059	$\mathbf{0.473 \pm 0.028}$
WiggleZ	0.6	0.0743 ± 0.0026	$\mathbf{0.430 \pm 0.016}$
WiggleZ	0.73	0.0611 ± 0.0033	$\mathbf{0.415 \pm 0.020}$



Consistent with ΛCDM

Growth of Structure

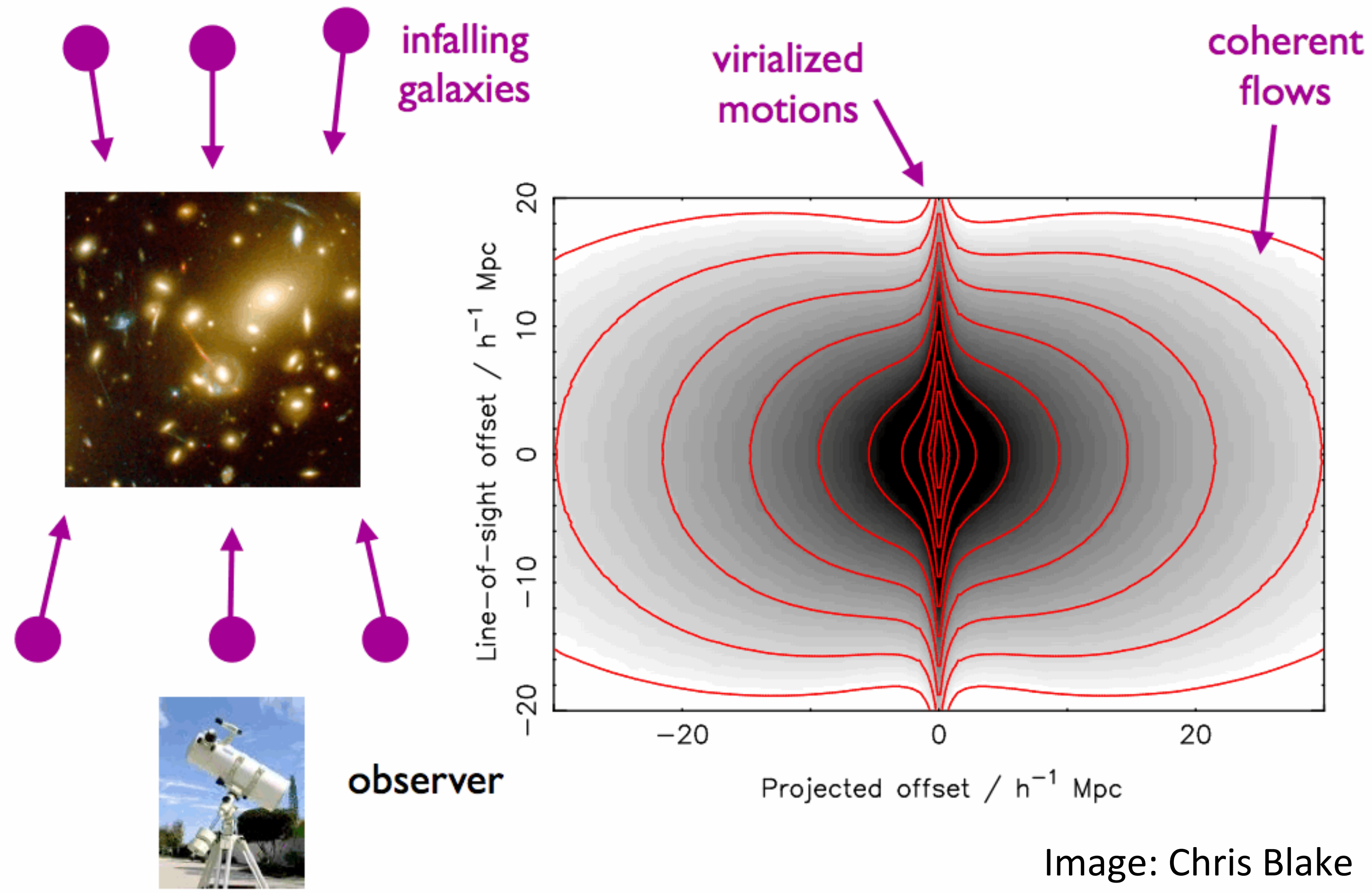
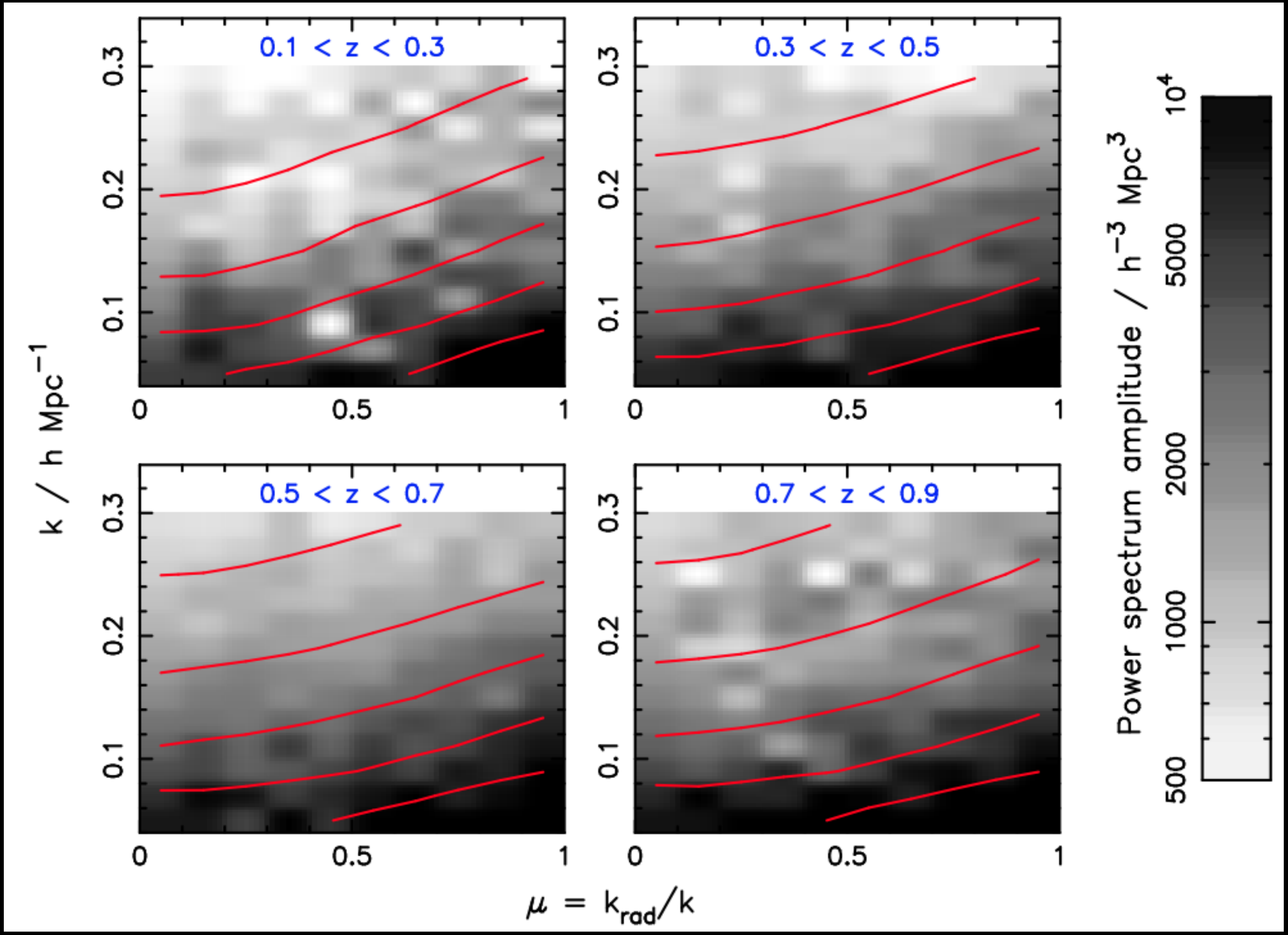
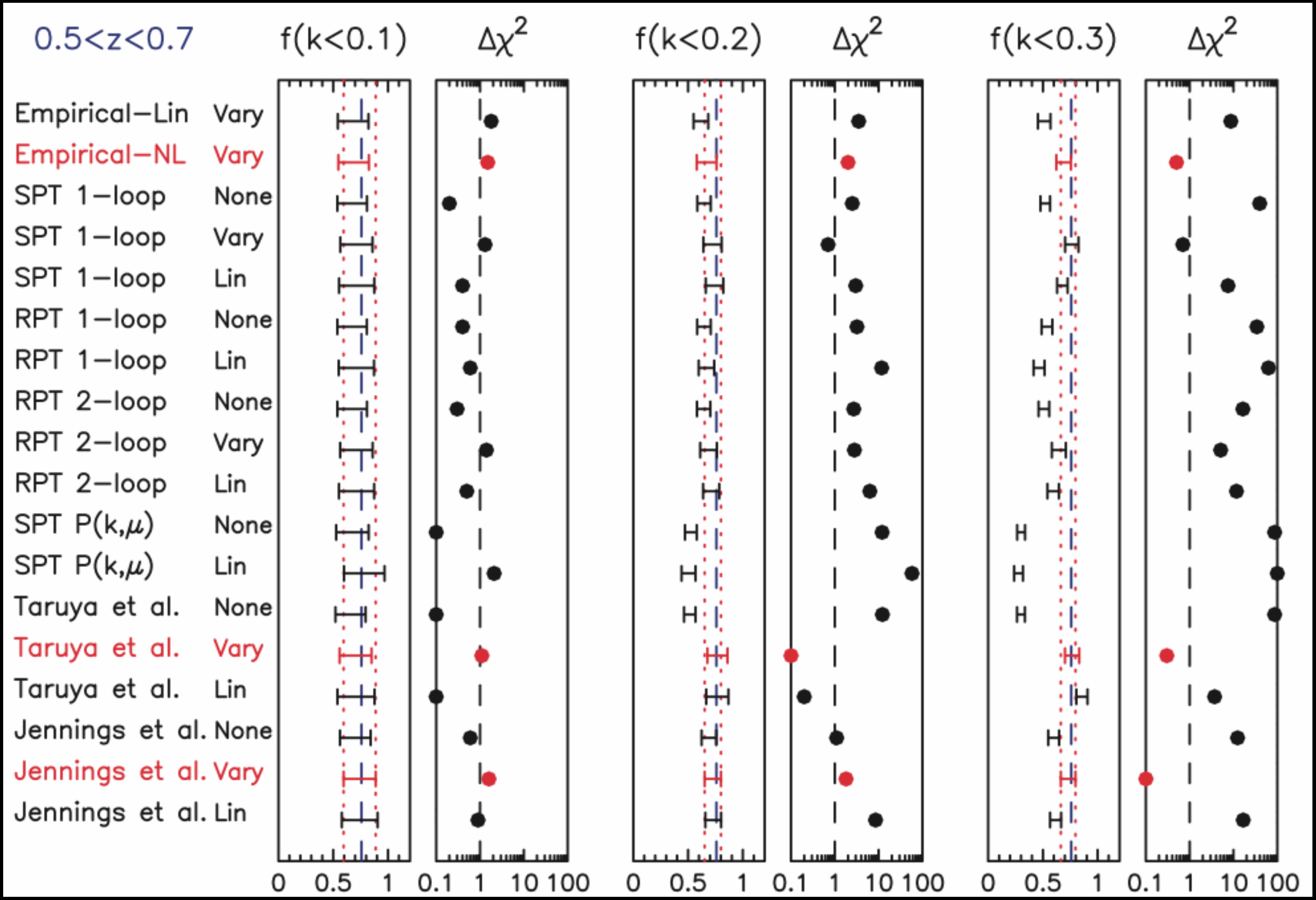


Image: Chris Blake

Growth of Structure – WiggleZ final result

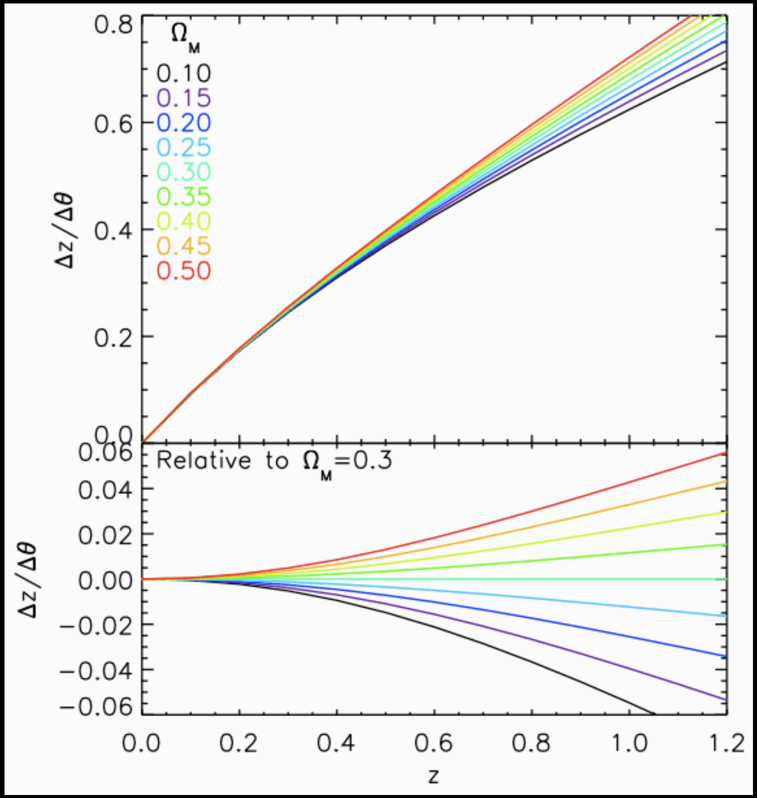


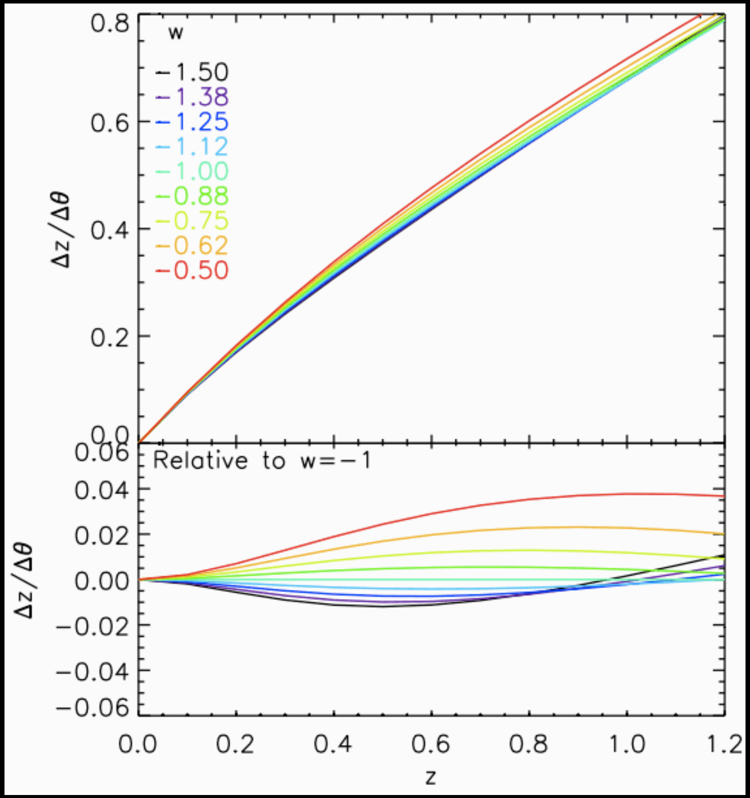
Growth vs model



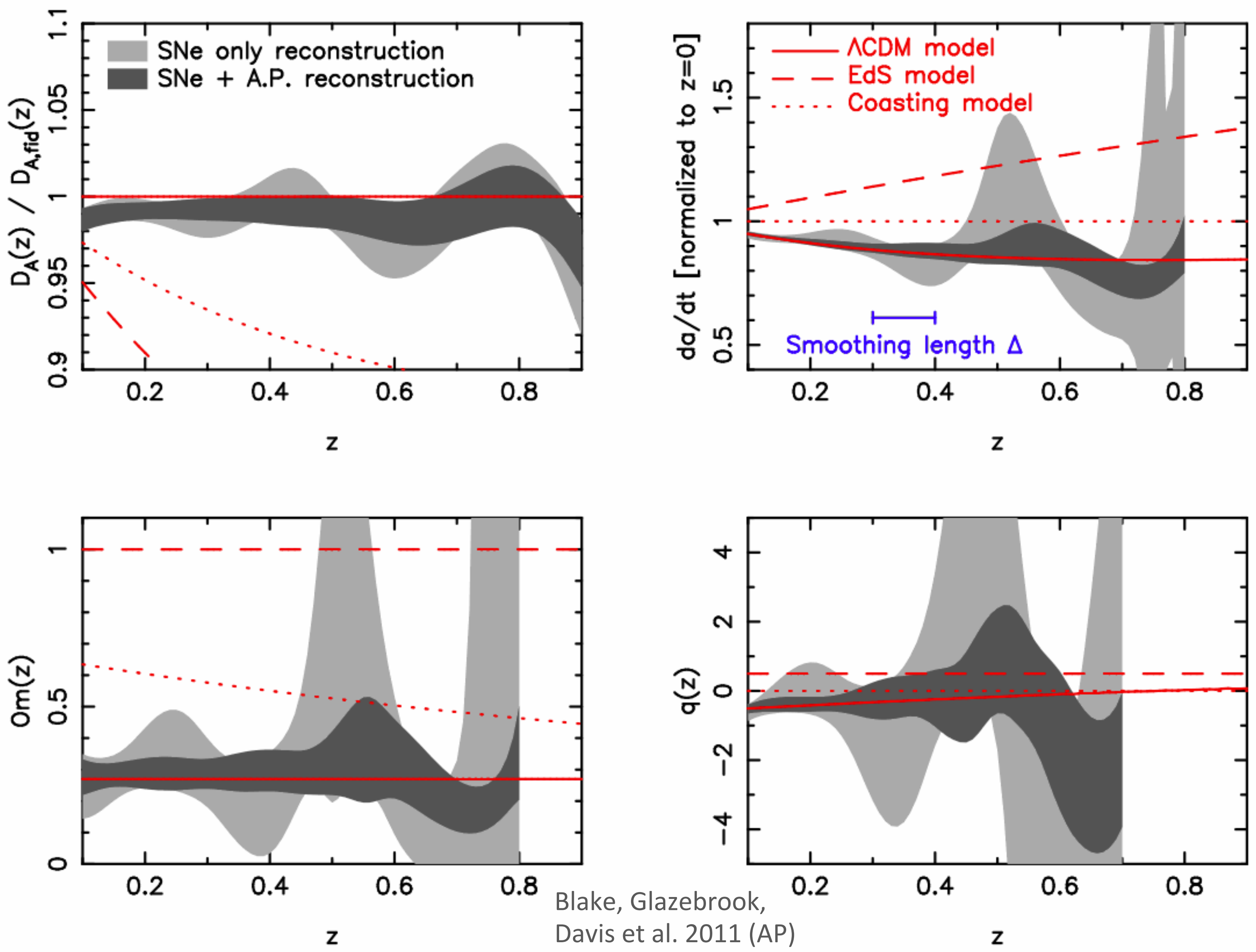
Blake et al. 2011 (Growth)

AP effect


Ω_M
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Δz/Δθ
Relative to Ω_M=0.3
z


w
−1.50
−1.38
−1.25
−1.12
−1.00
−0.88
−0.75
−0.62
−0.50
Δz/Δθ
Relative to w=−1
z

Reconstructions



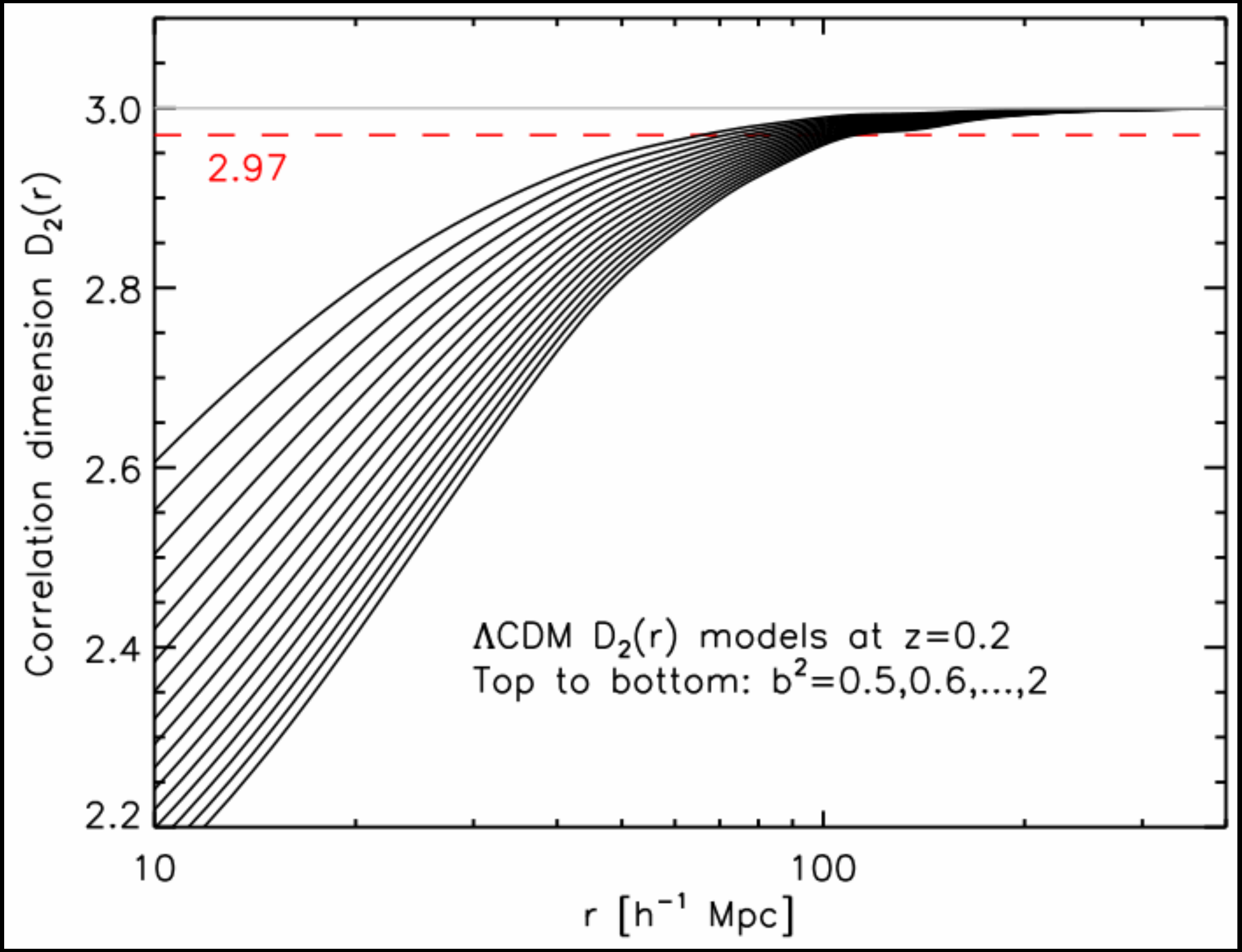
Blake, Glazebrook,
Davis et al. 2011 (AP)

Covariance matrix – (2nd AP paper)

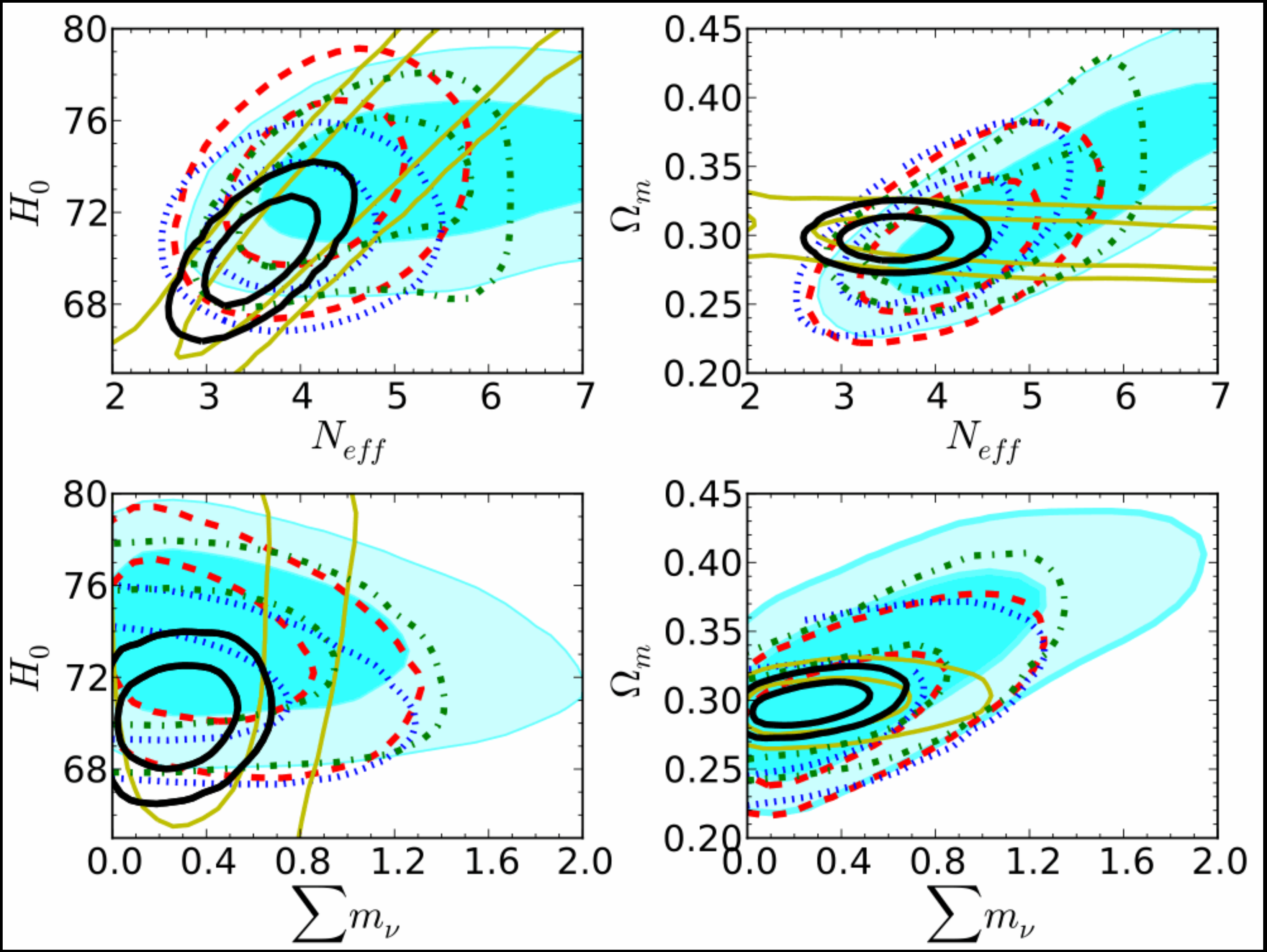
Table 2. This Table lists the values of $10^3\underline{\underline{C}}$, where $\underline{\underline{C}}$ is the covariance matrix of measurements from the WiggleZ Survey data of the acoustic parameter $A(z)$, the Alcock-Paczynski distortion parameter $F(z)$ and normalized growth rate $f\sigma_8(z)$, where each parameter is measured in three overlapping redshift slices (z_1, z_2, z_3) with effective redshifts $z_{\rm eff} = 0.44$, 0.6 and 0.73, respectively, where $z_1 = [0.2, 0.6]$, $z_2 = [0.4, 0.8]$ and $z_3 = [0.6, 1.0]$. The data vector is ordered such that $\underline{Y}_{\rm obs} = (A_1, A_2, A_3, F_1, F_2, F_3, f\sigma_{8,1}, f\sigma_{8,2}, f\sigma_{8,3}) = (0.474, 0.442, 0.424, 0.482, 0.650, 0.865, 0.413, 0.390, 0.437)$. The chi-squared statistic for any cosmological model vector $\underline{Y}_{\rm mod}$ can be obtained via the matrix multiplication $\chi^2 = (\underline{Y}_{\rm obs} - \underline{Y}_{\rm mod})^T \underline{\underline{C}}^{-1} (\underline{Y}_{\rm obs} - \underline{Y}_{\rm mod})$. The matrix is symmetric; we just quote the upper diagonal.

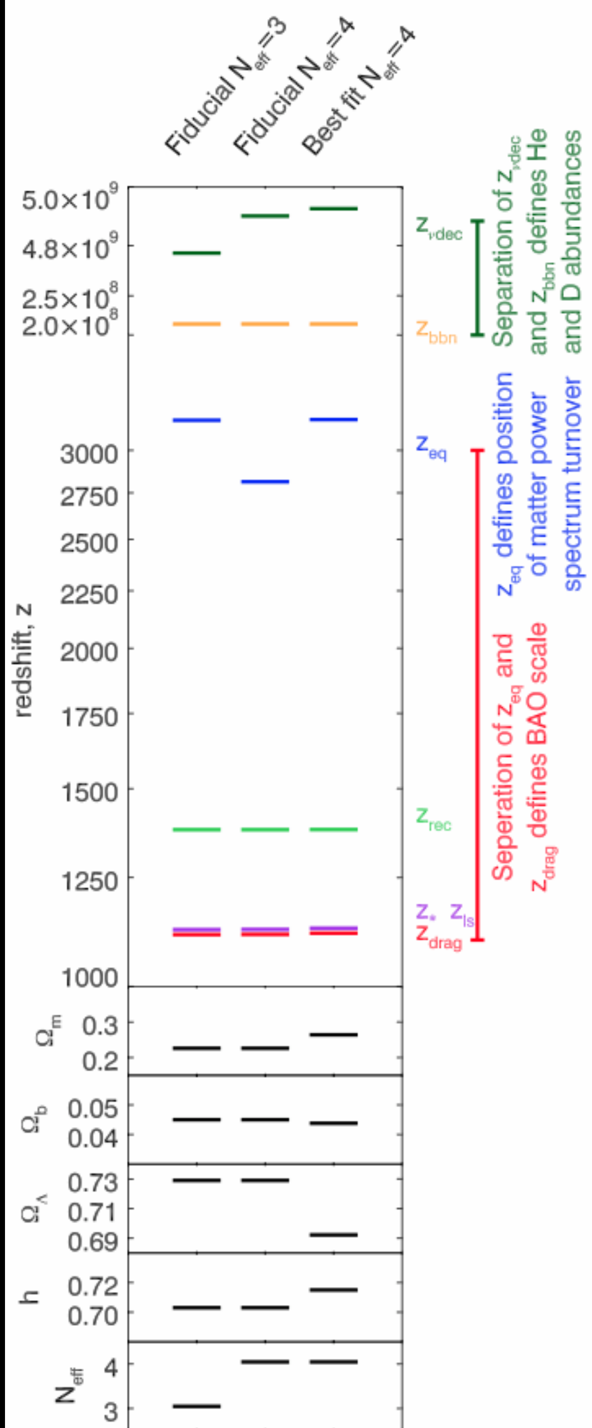
Parameter	$A(z_1)$	$A(z_2)$	$A(z_3)$	$F(z_1)$	$F(z_2)$	$F(z_3)$	$f\sigma_8(z_1)$	$f\sigma_8(z_2)$	$f\sigma_8(z_3)$
$A(z_1)$	1.156	0.211	0.000	0.400	0.234	0.000	0.598	0.129	0.000
$A(z_2)$	-	0.400	0.189	0.118	0.276	0.336	0.080	0.227	0.230
$A(z_3)$	-	-	0.441	0.000	0.167	0.399	0.000	0.146	0.333
$F(z_1)$	-	-	-	2.401	1.350	0.000	2.862	1.080	0.000
$F(z_2)$	-	-	-	-	2.809	1.934	1.611	2.471	1.641
$F(z_3)$	-	-	-	-	-	5.329	0.000	1.978	4.468
$f\sigma_8(z_1)$	-	-	-	-	-	-	6.400	2.570	0.000
$f\sigma_8(z_2)$	-	-	-	-	-	-	-	3.969	2.540
$f\sigma_8(z_3)$	-	-	-	-	-	-	-	-	5.184

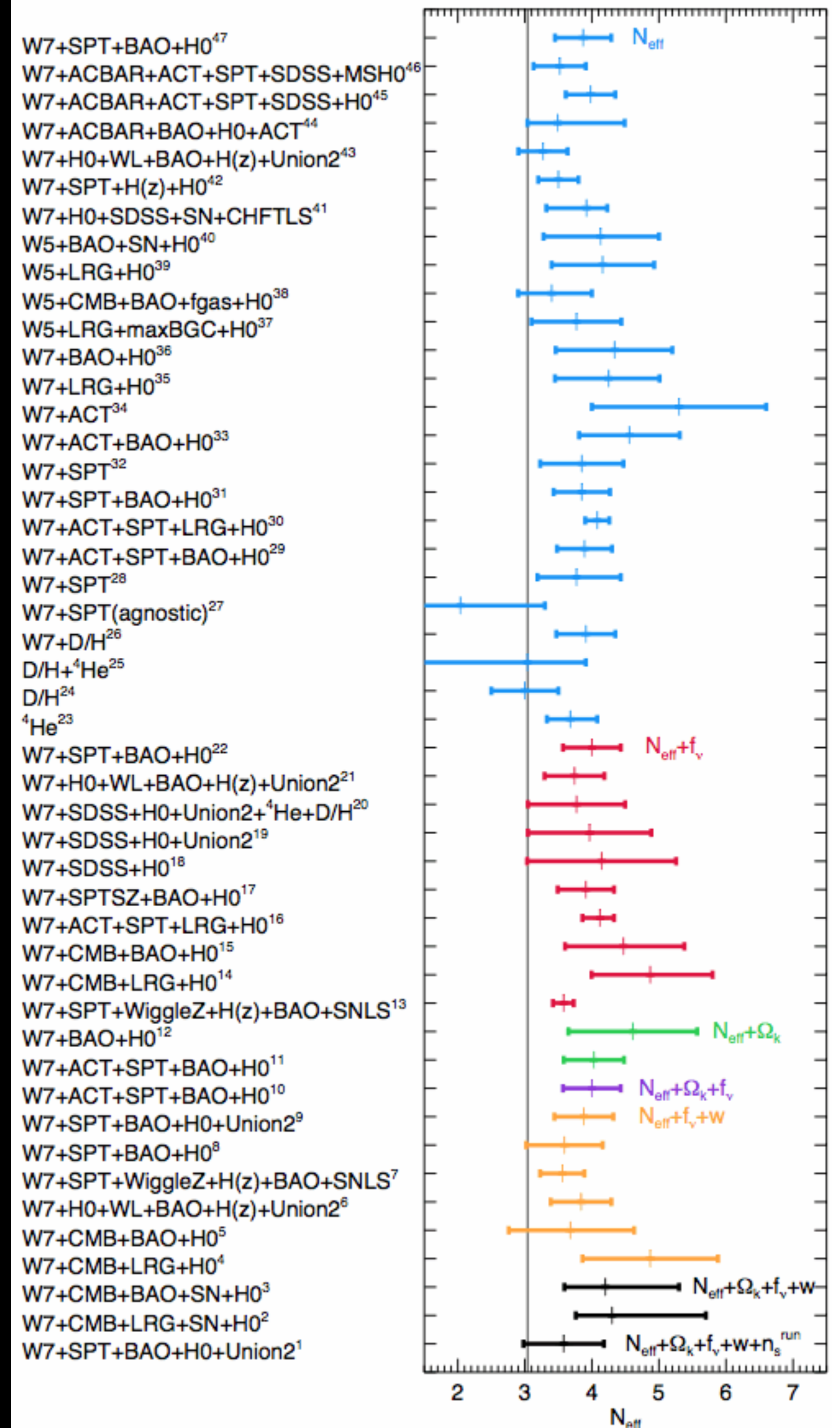
Homogeneity - Dependence on bias



Neutrinos - Degeneracies




Fiducial N_eff=3
Fiducial N_eff=4
Best fit N_eff=4
redshift, z
z_νdec
z_bbn
z_eq
z_rec
z_*
z_ls
z_drag
Separation of z_νdec and z_bbn defines He and D abundances
z_eq defines position of matter power spectrum turnover
Seperation of z_eq and z_drag defines BAO scale
Ω_m
Ω_b
Ω_Λ
h
N_eff


W7+SPT+BAO+H0[47]
W7+ACBAR+ACT+SPT+SDSS+MSH0[46]
W7+ACBAR+ACT+SPT+SDSS+H0[45]
W7+ACBAR+BAO+H0+ACT[44]
W7+H0+WL+BAO+H(z)+Union2[43]
W7+SPT+H(z)+H0[42]
W7+H0+SDSS+SN+CHFTLS[41]
W5+BAO+SN+H0[40]
W5+LRG+H0[39]
W5+CMB+BAO+fgas+H0[38]
W5+LRG+maxBGC+H0[37]
W7+BAO+H0[36]
W7+LRG+H0[35]
W7+ACT[34]
W7+ACT+BAO+H0[33]
W7+SPT[32]
W7+SPT+BAO+H0[31]
W7+ACT+SPT+LRG+H0[30]
W7+ACT+SPT+BAO+H0[29]
W7+SPT[28]
W7+SPT(agnostic)[27]
W7+D/H[26]
D/H+4He[25]
D/H[24]
4He[23]
W7+SPT+BAO+H0[22]
W7+H0+WL+BAO+H(z)+Union2[21]
W7+SDSS+H0+Union2+4He+D/H[20]
W7+SDSS+H0+Union2[19]
W7+SDSS+H0[18]
W7+SPTSZ+BAO+H0[17]
W7+ACT+SPT+LRG+H0[16]
W7+CMB+BAO+H0[15]
W7+CMB+LRG+H0[14]
W7+SPT+WiggleZ+H(z)+BAO+SNLS[13]
W7+BAO+H0[12]
W7+ACT+SPT+BAO+H0[11]
W7+ACT+SPT+BAO+H0[10]
W7+SPT+BAO+H0+Union2[9]
W7+SPT+BAO+H0[8]
W7+SPT+WiggleZ+H(z)+BAO+SNLS[7]
W7+H0+WL+BAO+H(z)+Union2[6]
W7+CMB+BAO+H0[5]
W7+CMB+LRG+H0[4]
W7+CMB+BAO+SN+H0[3]
W7+CMB+LRG+SN+H0[2]
W7+SPT+BAO+H0+Union2[1]
N_eff
N_eff+f_ν
N_eff+Ω_k
N_eff+Ω_k+f_ν
N_eff+f_ν+w
N_eff+Ω_k+f_ν+w
N_eff+Ω_k+f_ν+w+n_s^run

WiggleZ, other papers

Paper	Lead authors	Title: "The WiggleZ Dark Energy Survey:"	arXiv
Small-scale clustering	Blake, Jurek, et al. 2009	small-scale clustering of Lyman-break galaxies at $z < 1$	0901.2587
WiggleZ overview	Drinkwater, ++ et al. 2010	survey design and first data release	0911.4246
Blue galaxy intrinsic alignments	Mandelbum et al. 2011	direct constraints on blue galaxy intrinsic alignments at intermediate redshifts	0911.5347
Selection function	Blake et al. 2011	the selection function and $z = 0.6$ galaxy power spectrum	1003.5721
Kinematics of luminous star-forming galaxies	Wisnioski, Glazebrook, Blake, Wyder, Martin, Poole, Sharp, Couch, Kacprzak, et al.	high-resolution kinematics of luminous star-forming galaxies	1107.3338
Galaxy evolution	Li, Yee, et al. 2012	Galaxy Evolution at $0.25 < z < 0.75$ Using the Second Red-Sequence Cluster Survey	1201.1013

In preparation	Nominal lead authors
BAO theory	Davis, Beutler, Blake, Parkinson, Scrimgeour et al.
2D BAO's	Davis, Kazin, Blake, et al.
Higher-order correlations	Marin et al.
Growth – beyond standard cosmologies	Parkinson et al.
Distances – beyond standard cosmologies	Peet, Davis, et al.
Reconstruction	Kazin et al.