Deconstructing BAOs: A Comparison of Methods

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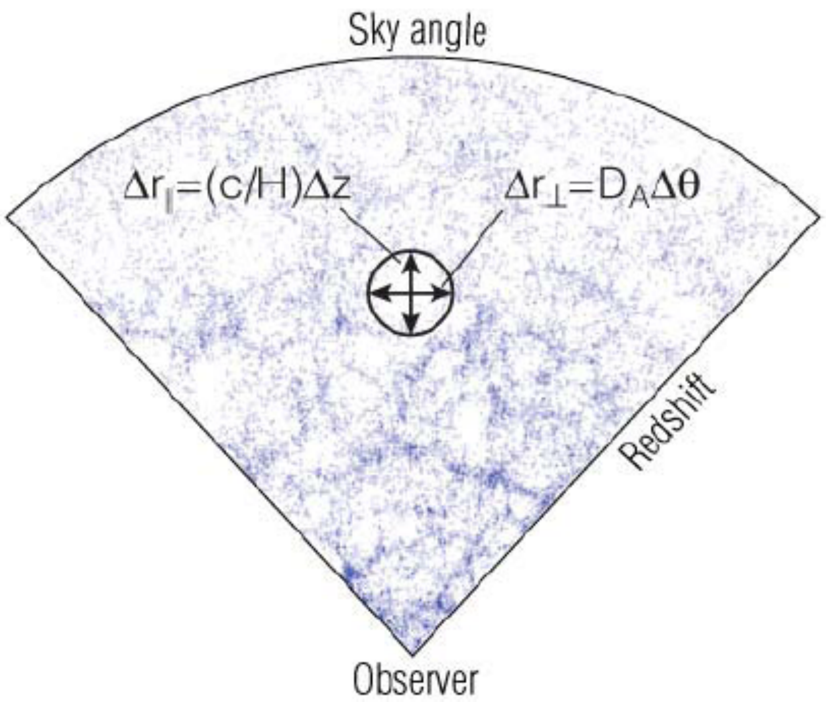

Rassat et al. 2008 (arxiv 0810.0003)

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Luca Amendola (Rome)
Francisco Castander (Barcelona)
Thomas Kitching (Oxford)
Martin Kunz (Sussex/Geneva)
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Irfu cea saclay

Outline

- Concordance cosmology
- Origin of BAOs
- Current detections from BAOs
- What is the BAO method?
  - Building blocks of the power spectrum
  - Description of 3 methods in Rassat et al.
- Comparison of results of 3 methods with and without Planck priors
- Comparison of dependence on non-linear cut-off
- Some systematics: Magnification bias
- Conclusion

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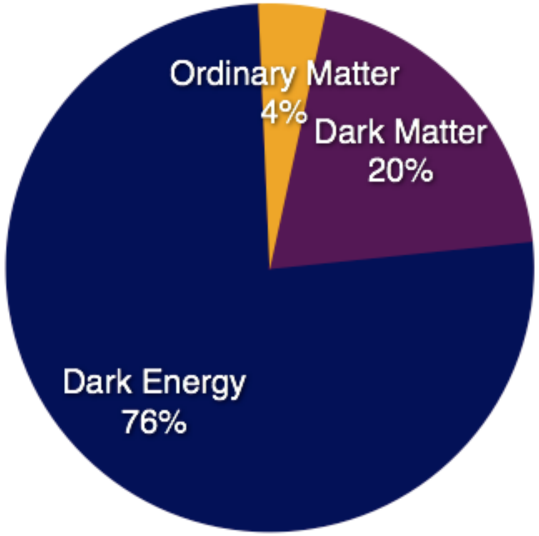
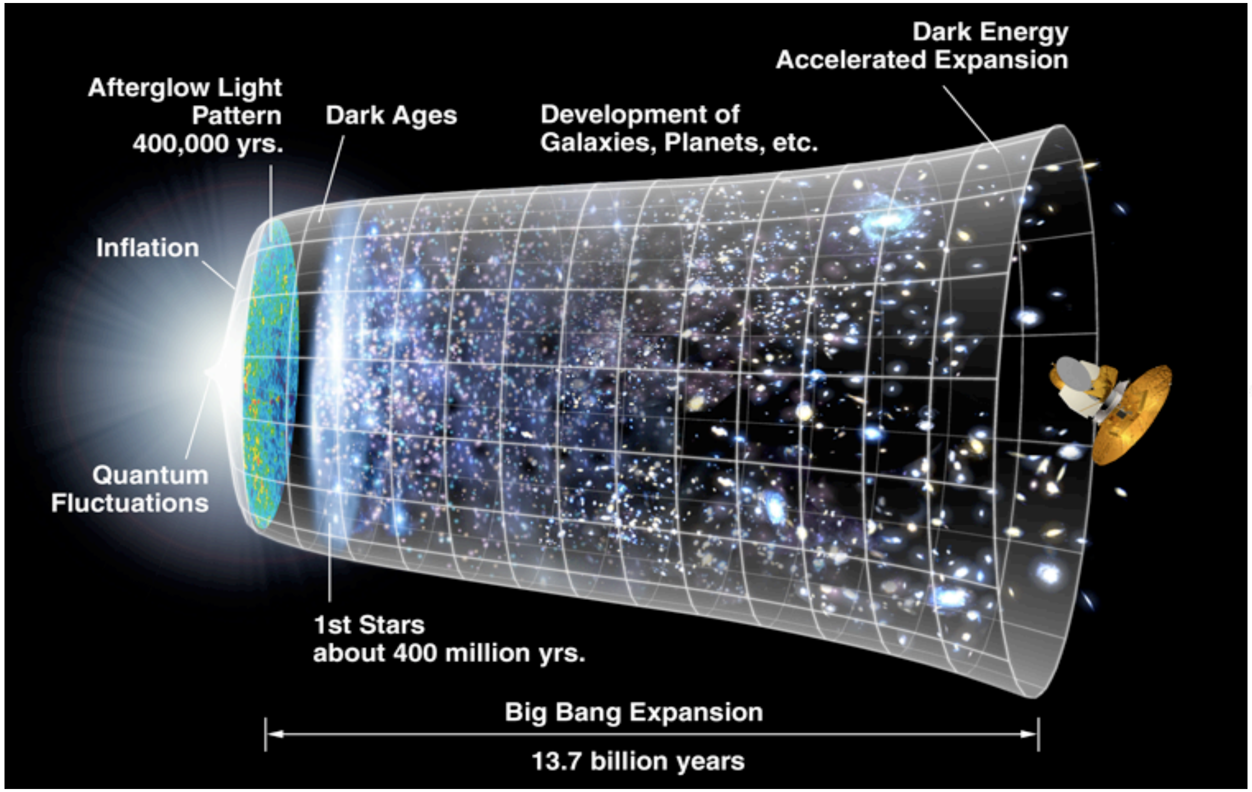
Outstanding Questions in Cosmology

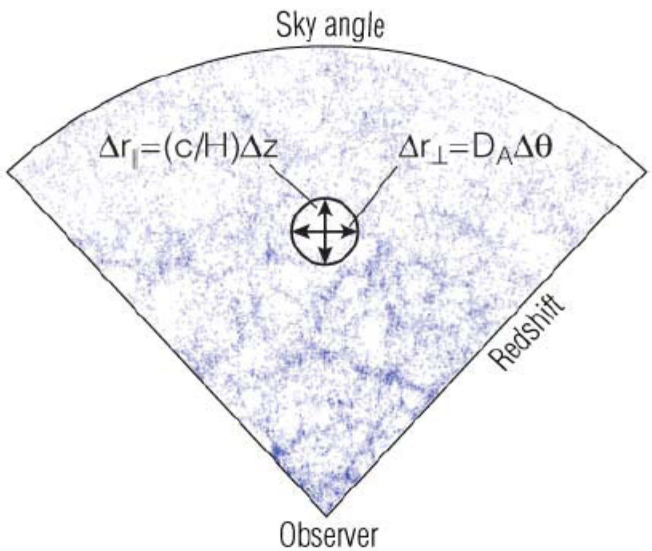
Outstanding questions:

- Nature of the dark energy
- Nature of the dark matter
- Initial conditions (inflation?)

Gravity







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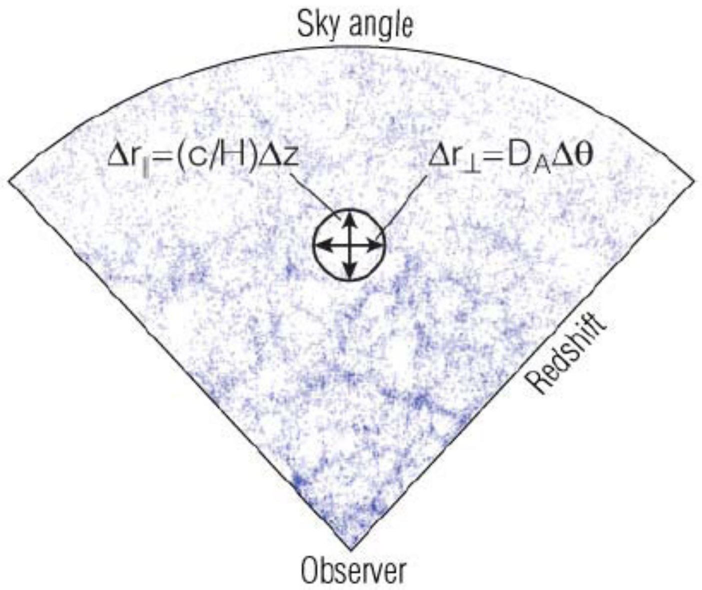
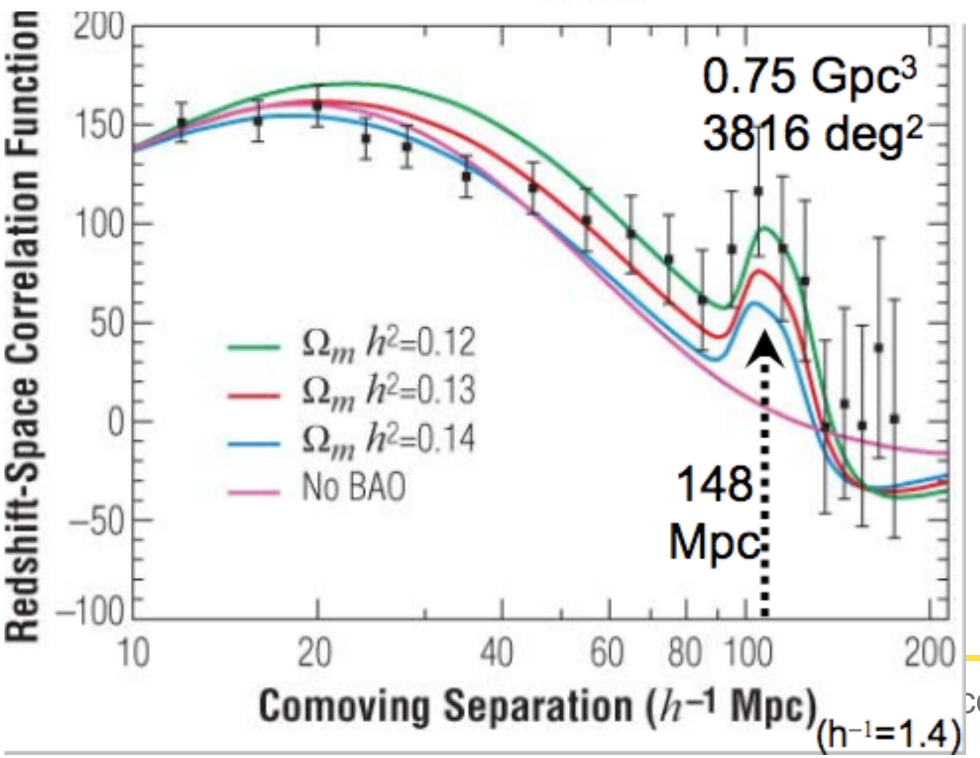
Baryon Acoustic Oscillations





Eisenstein 2005

- Early Universe: before recombination, photons and baryons were coupled through Compton scattering
- In dense regions this fluid underwent gravitational collapse which was stopped by the baryon fluid -> creates a characteristic scale
- Large scale fluctuations in the observed galaxy field are relics of primordial fluctuations
- Characteristic scale is present in CMB and Galaxy Field.
- Both transverse and radial modes will present characteristic scale in Galaxy Field
- In real space this corresponds to a single bump, in Fourier space to a series of acoustic peaks (BAO)

Detection of BAO implies:

- Evidence that large scale fluctuations grow following linear perturbation theory from z_{CMB} to today

- Evidence for presence of Dark Matter (wiggle amplitude would be much larger if baryons only)

- Standard rod: in both radial H(z) and tangential $D_A(z)$ directions → probe of dark energy

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(Some) Current Detections of BAOs

Data	Author	Significance
PSCz, APM, Abell/ ACO Cluster	Miller, Nichol, Batuski 2001	2.2 sigma, i.e. 'possible'
2dF GRS	Percival et al 2001	2 sigma
SDSS LRG	Eisenstein et al. 2005	"First clear detection" 3 – 3.4 sigma
SDSS LRG	Huetsi 2006a	
SDSS LRG + DR5	Percival et al. 2006a	3 sigma
SDSS LRG + DR5 + 2dF	Percival et al. 2007b	$-2\Delta\ln L \approx 6$
MaxBCG (Clusters)	Huetsi et al. 2007	2 sigma

The Future of BAOs

- Current data does not cover enough cosmological volume to be constraining without the help of external data sets

➔ only detections possible at the moment

- Dark Energy Task Force (DETF, Albrecht et al 2006) and ESA-ESO Working Group on Fundamental Cosmology (Peacock et al 2006):

  BAO will be a fundamental tool for precision cosmology and for probing dark energy

- Many papers on future contraints using BAOs. (Seo & Eisenstein 2003, Seo & Eisenstein 2007, Blake et al 2006, Dolney et al. 2006, Amendola et al. 2007+ many others)

- BAO considered a 'robust' probe
- Not a uniquely defined BAO method

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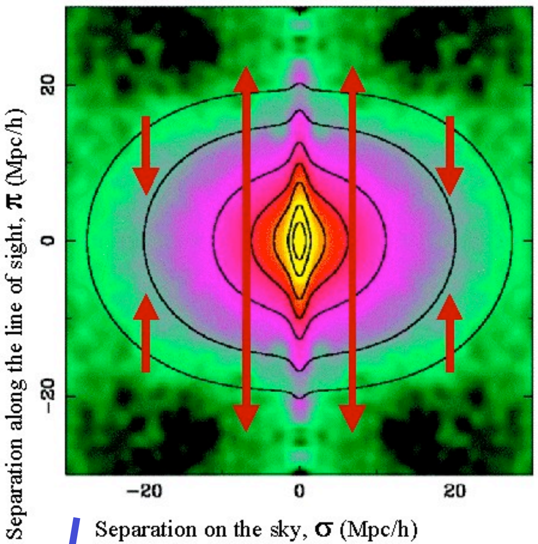
BAOs and Galaxy clustering: Building Blocks of P(k)

2dF team

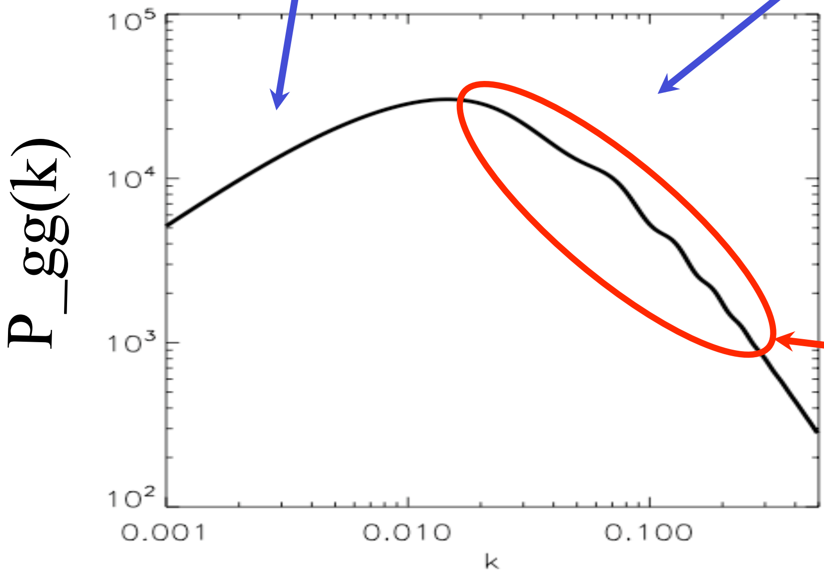


Linear Redshift Distortions

General Shape of smooth P(k)

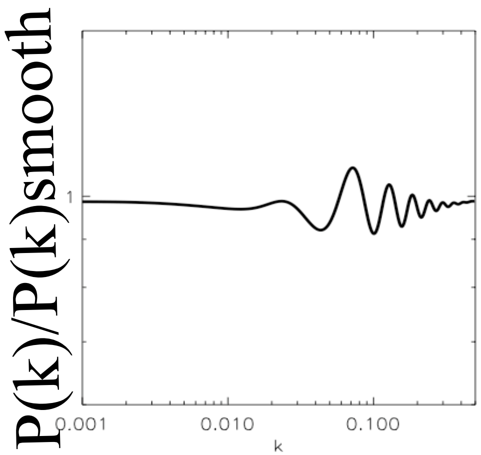
Growth

g(a), $\frac{d \ln g(a)}{d \ln a}$



Detected by Eisenstein et al 2005 (SDSS)

BAO: Baryon Acoustic Oscillations



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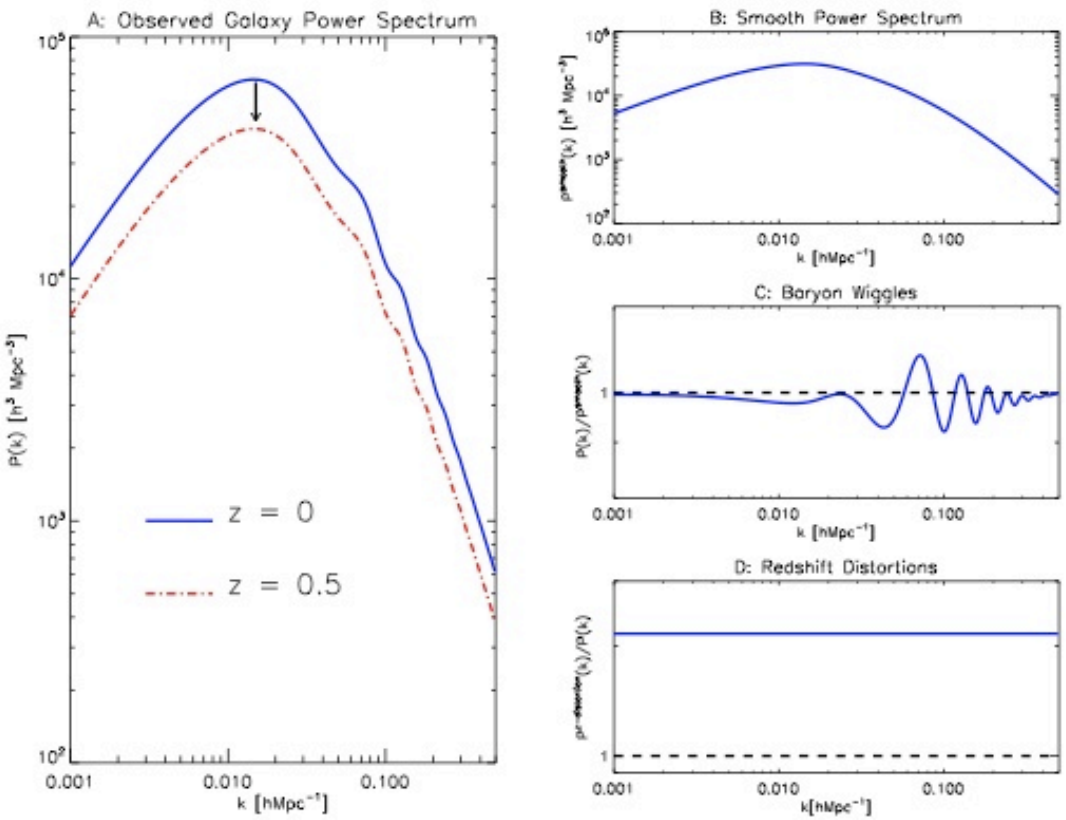
3 methods used in Rassat et al.

	Broad Band Power	Overall Amplitude	Tangential BAO scale	Radial BAO scale	Wiggle Amplitude	Redshift Space Distortions
Full $P(k)$	√	(√)	√	√	√	(√)
'Wiggles only'	–	–	√	√	–	–
$C(\ell)$	√	(√)	√	–	√	√



1) Seo & Eisenstein 2003:
Full P(k)
Marginalise: beta(z), amplitude [sig8, growth, b(z)]

2) Seo & Eisenstein 2007:
"Wiggles only"

3) Dolney et al 2006: C(l)
Marginalise: b(z), sig8

	Advantages	Disadvantages
Full P(k)	•Information from a large range of scales •Probes geometry and growth	•Strong dependence on bias •Non-linearities & non-linear redshift distortions •Redshift distortion far-field approximation •Measurement dependent on cosmology
Wiggles Only	•Weak dependence on bias and non-linearities	•Mesurement dependent on cosmology •Information from limited range of scales
C(l)	•Spherical harmonic measurement not dependent on cosmology •Redshift distortions exact in C(l)	•Strong dependence on bias •2d loses 3d information

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Compare 3 methods for exactly same assumptions

Survey Configuration and non-linear cut-off:

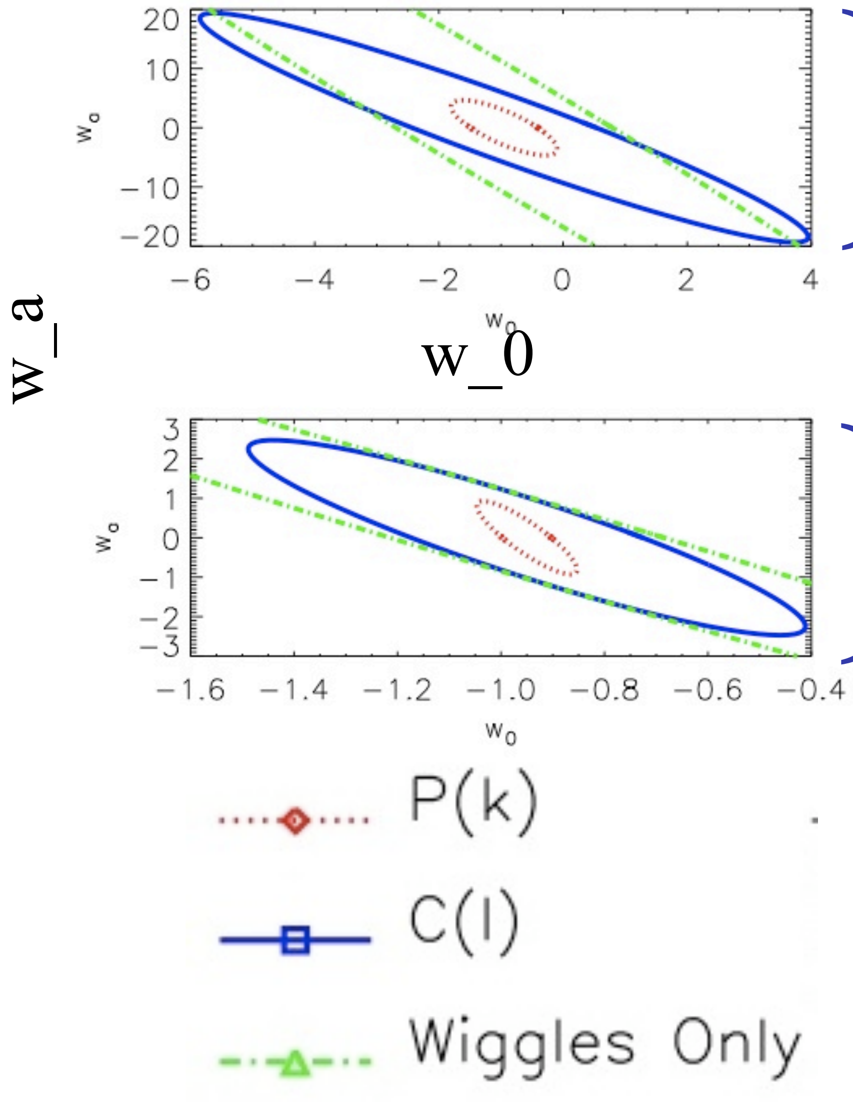
	Ground Based Survey	Space Based Survey
DETF denomination	BAO-IIIS-o (WFMOS-like, "wide" only)	BAO-IVS-o (Optical/NIR JDEM Spatial Mission)
Sky coverage	$2,000\text{deg}^2$ ($f_{\text{sky}} = 0.05$)	$10,000\text{deg}^2$($f_{\text{sky}} = 0.25$)
Redshift range	$0.5 < z < 1.3$ (4 bins)	$0.5 < z < 2$ (8 bins)
Bias prescription	$b_g(z) = \sqrt{1+z}$	
k-range	$k_{\text{min}} = 10^{-3}$, $k_{\text{max}} < 0.25$ or $\sigma(R) < 0.20$	

Central fiducial cosmology:

Parameter	Central fiducial value
Ω_m	0.25
Ω_b	0.0445
Ω_{DE}	0.75
w_0	-0.95
w_a	0
h	0.70
n_s	1

Forecasts using
Fisher matrix calculations

Comparison of Dark Energy Constraints



Ground Based Survey
Wide Stage III DETF

Space Based Survey
Stage IV DETF

FoM can change by up to a factor of 35 between Wiggles only and full P(k) method

Comparison of cosmological constraints

	Fourier space BAO 'wiggles only'		Spherical Harmonic Space $C(\ell)$		Fourier space Full $P(k)$	
Ground Based Survey (with Planck priors)						
Ω_m	2.04	(0.170)	0.303	(0.162)	0.137	(0.01)
Ω_b	> 10	(0.0303)	0.122	(0.0290)	0.0310	(0.002)
$\Omega_{\rm DE}$	1.99	(0.156)	1.25	(0.163)	0.215	(0.016)
w_0	6.28	(2.42)	3.23	(1.69)	0.56	(0.25)
w_p	1.15	(0.184)	0.979	(0.650)	0.358	(0.07)
w_a	> 10	(5.41)	> 10	(4.45)	3.07	(0.65)
h	> 10	(0.238)	2.38	(0.227)	0.13	(0.016)
n_s	-	(0.00465)	1.54	(0.00465)	0.165	(0.0045)
Dark energy FoM	< 0.090	(1.2)	< 0.10	(0.35)	0.91	(21)
Space Based Survey (with Planck priors)						
Ω_m	0.181	(0.0385)	0.0367	(0.0254)	0.00985	(0.003)
Ω_b	> 10	(0.00687)	0.0193	(0.00463)	0.00221	(0.0006)
$\Omega_{\rm DE}$	0.178	(0.0375)	0.113	(0.0251)	0.0692	(0.005)
w_0	0.990	(0.377)	0.355	(0.331)	0.0638	(0.049)
w_p	0.197	(0.0410)	0.147	(0.0955)	0.0313	(0.02)
w_a	3.94	(0.878)	1.63	(0.610)	0.612	(0.10)
h	> 10	(0.0539)	0.244	(0.0360)	0.0118	(0.004)
n_s	-	(0.00463)	0.182	(0.00450)	0.0106	(0.0034)
Dark energy FoM	1.5	(28)	4.2	(17)	52	(502)

Wiggles > C(l) > P(k)

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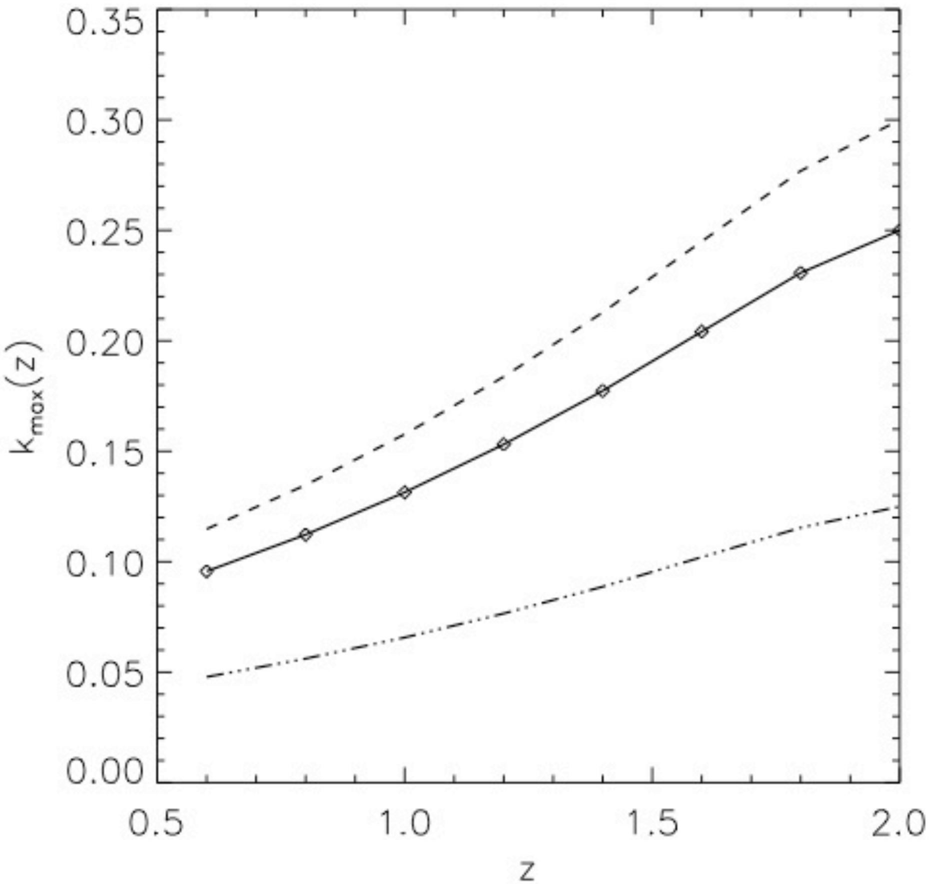
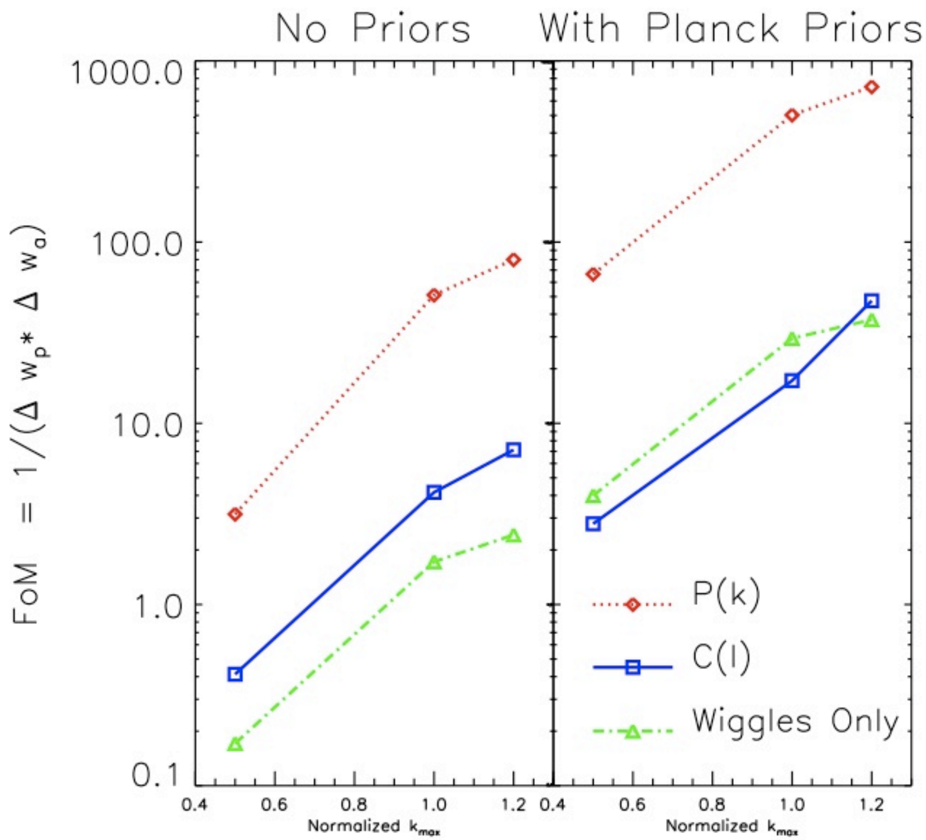
Dependence of FoM on non-linear cut-off

Non-linear cut-off

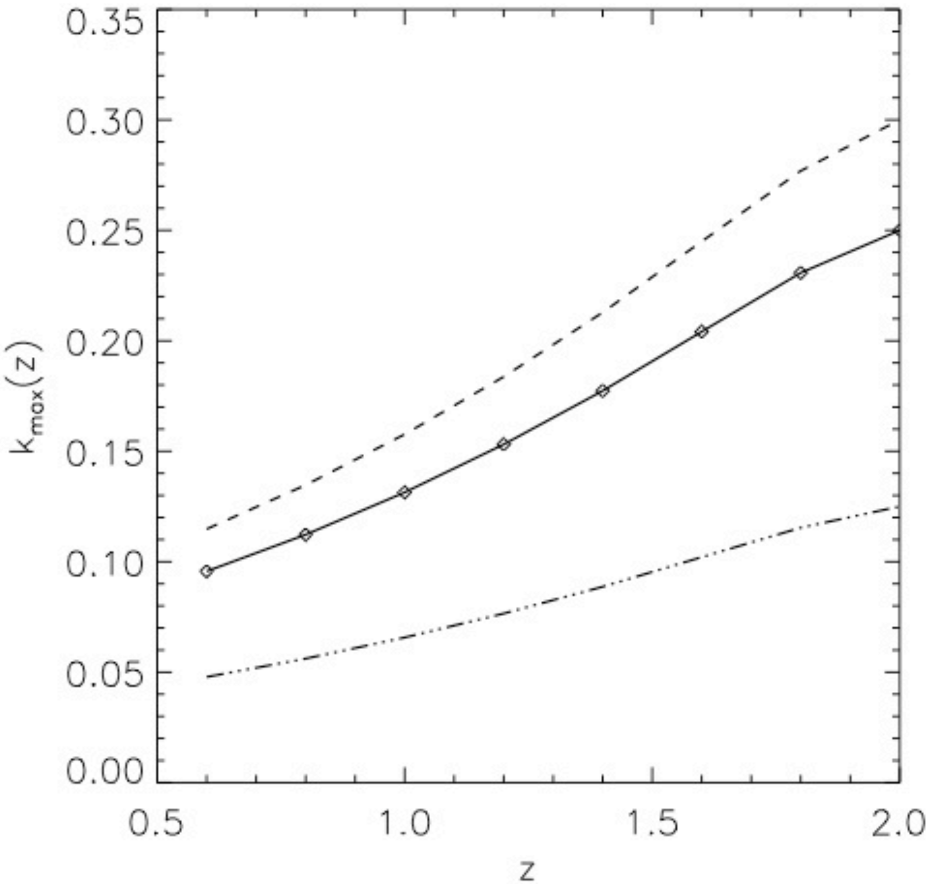


Dependence of FoM

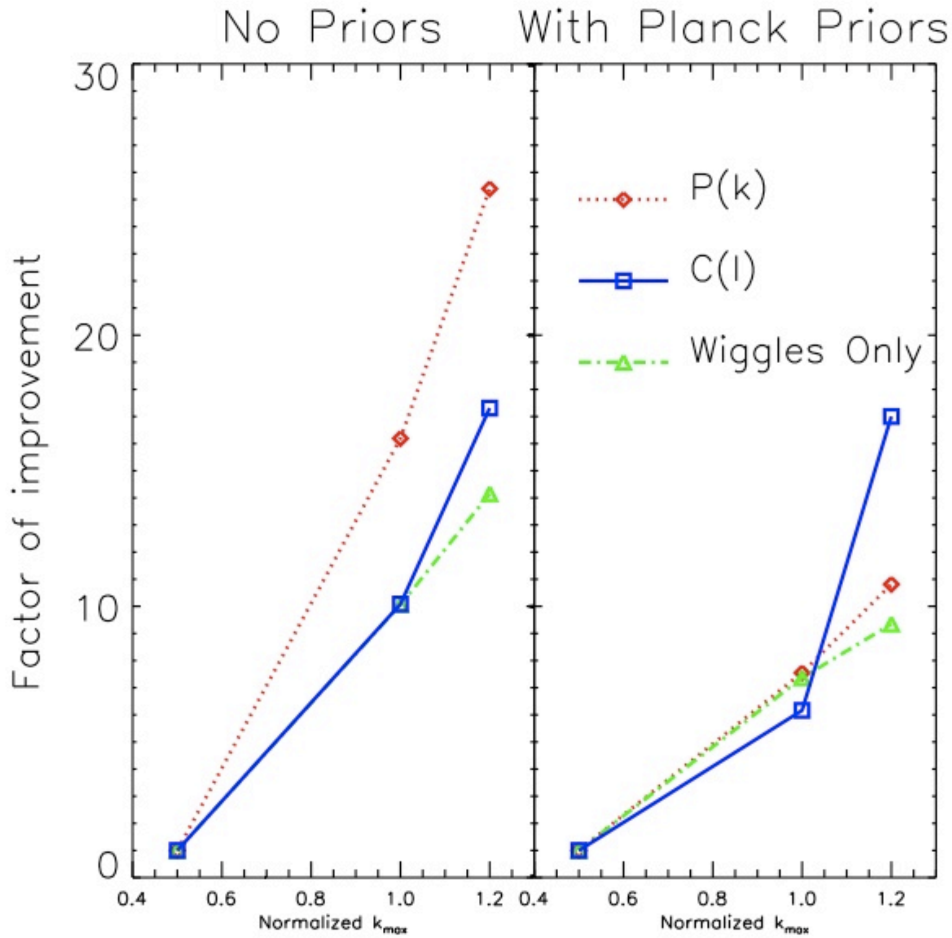


Factor of improvement and non-linear cut-off

Non-linear cut-off



Dependence on Factor of improvement



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Systematics: Lensing

- Hui, Gaztanaga, Loverde (arxiv:0710.4191)

Weak limit: lensing = shear + magnification

- Magnification bias will affect galaxy correlations:
  - Effect large for correlation function xsi(r) , up to 15% on position of peak
  - Effect less important in Fourier space P(k)
  - Currently haven't quantified effect of FoM for wiggles only and P(k) method
  - Affect transverse BAO scale in Fourier space analysis
  - *Solution?* Treat P(k) and Magnification simultaneously as both contain information

Conclusions

- BAO features recently observed in galaxy field
- Fundamental tool for precision cosmology
- Not a uniquely defined BAO method

- Compare three methods full P(k), wiggles only, C(l) for future ground and space based surveys

- Constraints from wiggles only > those from C(l) > those from P(k)
- FoM can be 35 times larger for P(k) than wiggles only method
- When adding Planck priors, wiggles only and C(l) constraints are similar, constraints from P(k) method are always tighter.
- Hierarchy in dependence on non-linear cut-off

- BAO: powerful probe, necessary to quote method used

- Magnification bias: affects transverse BAO – treat P(k) and mag. bias simultaneously

The end