6dFGS: Baryon Acoustic Oscillations and the local Hubble Constant

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Collaborators: Chris Blake + the 6dFGS team

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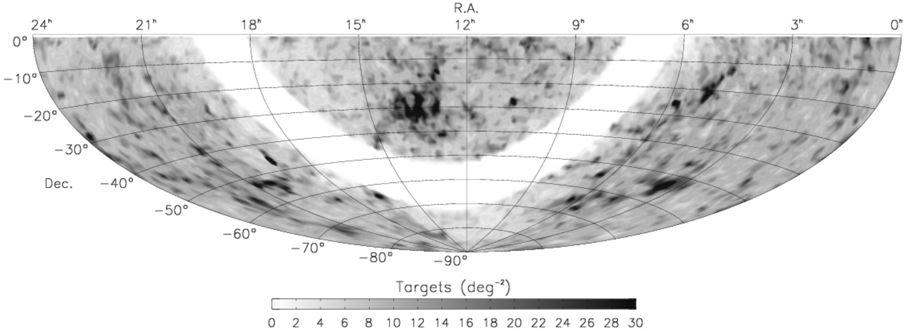
Lawrence Berkeley National Lab

Outline of the talk

1. The 6dF Galaxy Survey
2. What do BAO constrain?
3. 6dFGS results
4. What if $N_{\rm eff} = 4$?
5. How sensitive is the 6dFGS constraint to the calibration by the CMB? PLANCK vs. WMAP

What is 6dFGS?

- Spectroscopic survey of southern sky (17,000 deg^2).
- Primary sample from 2MASS with $K_{tot} < 12.75$; also secondary samples with $H < 13.0$, $J < 13.75$, $r < 15.6$, $b < 16.75$.
- Median redshift $z \approx 0.05$ ($\approx$ 220 Mpc).
- Effective volume $\approx 8x10^7 h^{-3}\,\mathrm{Mpc}^3$ (about as big as 2dFGRS).
- 125.000 redshifts (137.000 spectra).



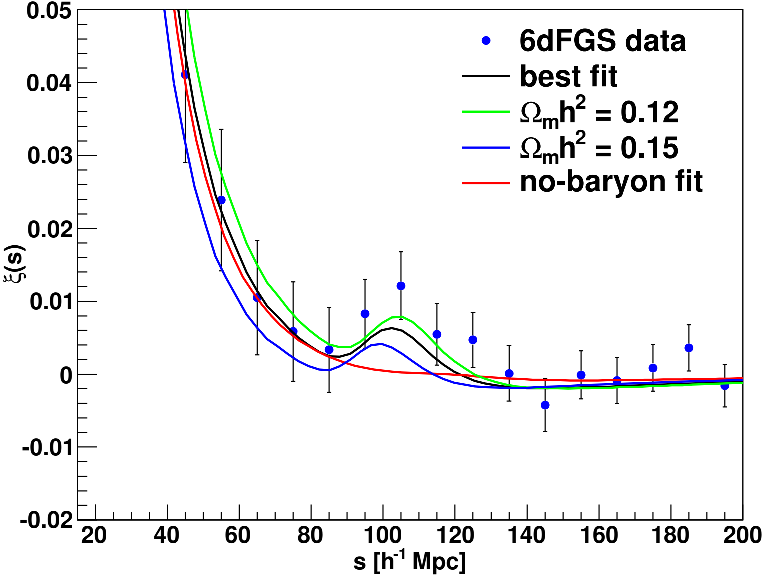
What do BAO constrain?

1. The sound horizon scale is set by the physical matter- and baryon density, $\Omega_m h^2$ and $\Omega_b h^2$.
2. We can get these two values from the CMB $\rightarrow$ the BAO scale in the galaxy survey turns into a standard ruler.
3. A standard ruler enables a distance measurement. The ultimate cosmology tool!
4. This enables us to measure the Friedmann eq., $H(z)$

$$H(z) = H_0 \left[\Omega_m a^{-3} + \Omega_\Lambda a^{-3(1+w)}\right]^{1/2}.$$

5. At low redshift, $a \approx 1$, a distance measurement constrains only H_0 (similar to the distance ladder technique).

Results


6dFGS data
best fit
$\Omega_m h^2 = 0.12$
$\Omega_m h^2 = 0.15$
no-baryon fit
$\xi(s)$
$s\ [h^{-1}\ \mathrm{Mpc}]$
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
20
40
60
80
100
120
140
160
180
200

Results

$$\xi_{\rm model}(s) = B(s)b^2\left[\xi(s) * G(r) + \xi_1^1(r)\frac{\partial\xi(s)}{\partial s}\right]$$

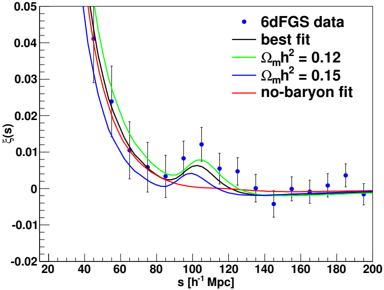
Crocce & Scoccimarro (2008), Sanchez et al. (2008),

$$\xi_1^1(r) = \frac{1}{2\pi^2}\int_0^\infty dk\; kP_{\rm lin}(k)j_1(rk)$$

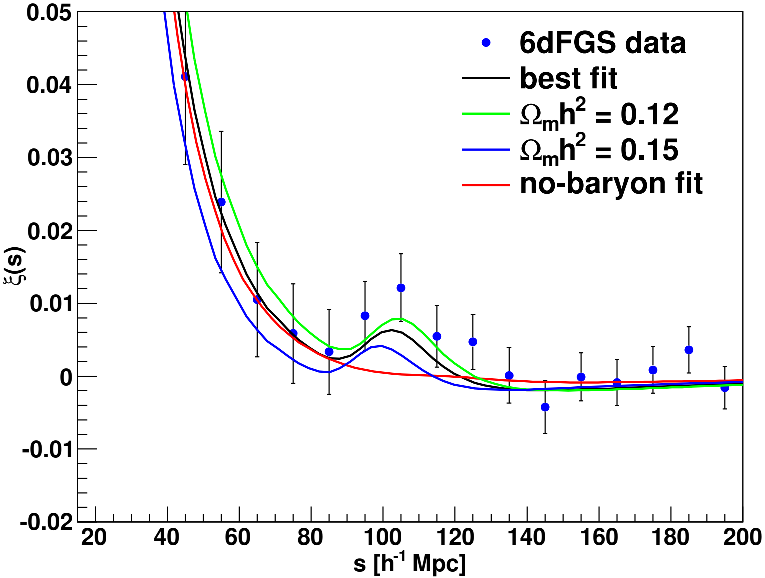
$$\xi(r) = \frac{1}{2\pi^2}\int_0^\infty dk\; k^2P_{\rm lin}(k)j_0(rk)$$

$$\tilde{G}(k) = \exp\left[-(k/k_*)^2\right]$$

Eisenstein et al. (2007), Eisenstein, Seo & White (2007)



Results



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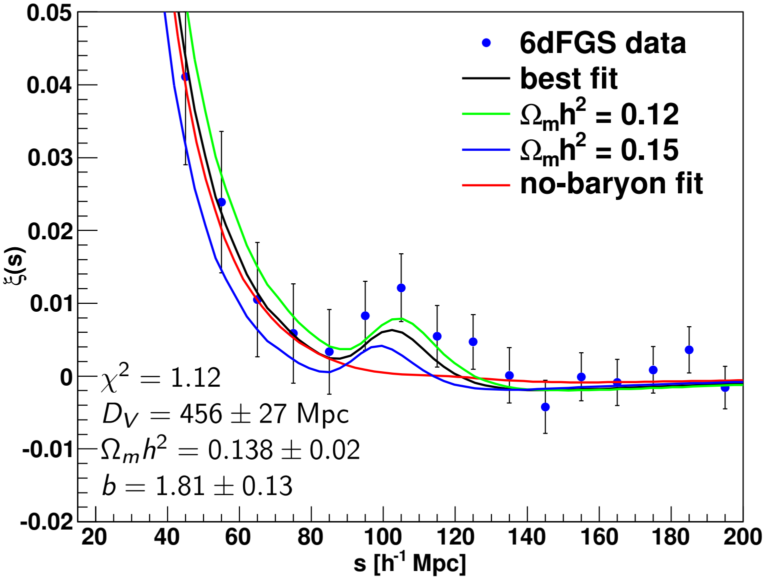

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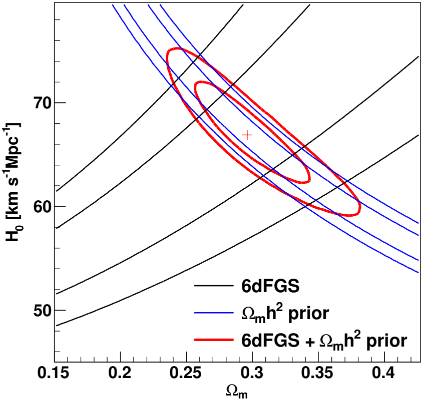
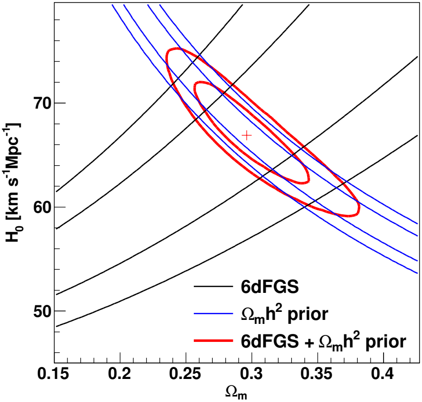
$\Omega_m h^2 = 0.15$
no-baryon fit
$\chi^2 = 1.12$
$D_V = 456 \pm 27$ Mpc
$\Omega_m h^2 = 0.138 \pm 0.02$
$b = 1.81 \pm 0.13$

Cosmological implications





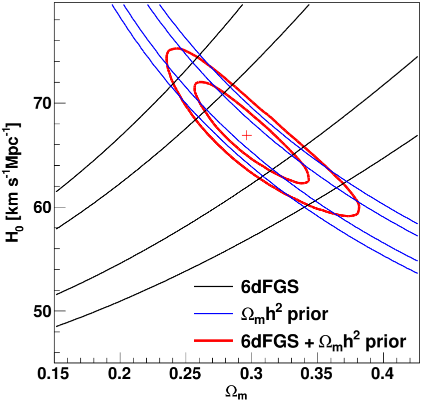
6dFGS: $H_0 = 67.0 \pm 3.2\,\mathrm{km/s/Mpc}$

SH0ES project: $H_0 = 73.8 \pm 2.4\,\mathrm{km/s/Mpc}$ (Riess et al. 2011)

CH Program: $H_0 = 74.3 \pm 2.1\,\mathrm{km/s/Mpc}$ (Freedman et al. 2012)

WMAP9: $H_0 = 70.0 \pm 2.2\,\mathrm{km/s/Mpc}$ (Hinshaw et al. 2012)

Cosmological implications



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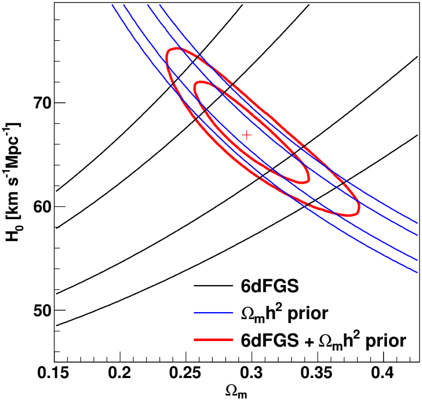
PLANCK: $H_0 = 67.3 \pm 1.2\,\mathrm{km/s/Mpc}$ (Ade et al. 2013)



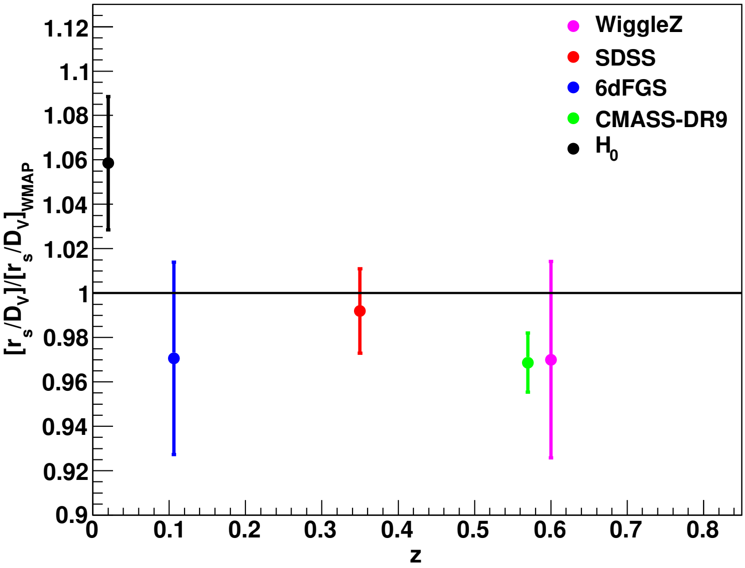
6dFGS: $H_0 = 67.0 \pm 3.2\,\mathrm{km/s/Mpc}$

(SH0ES project): $H_0 = 72.0 \pm 3.0\,\mathrm{km/s/Mpc}$ (Humphreys et al. 2013)

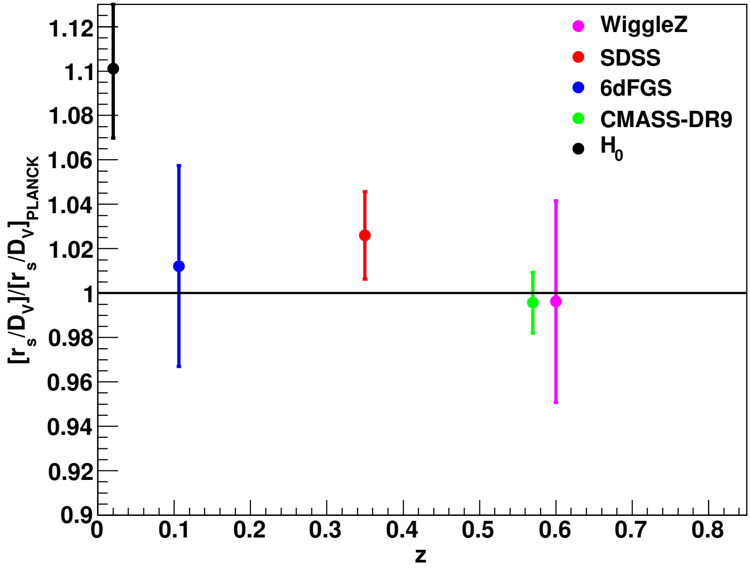
CH Program: $H_0 = 74.3 \pm 2.1\,\mathrm{km/s/Mpc}$ (Freedman et al. 2012)

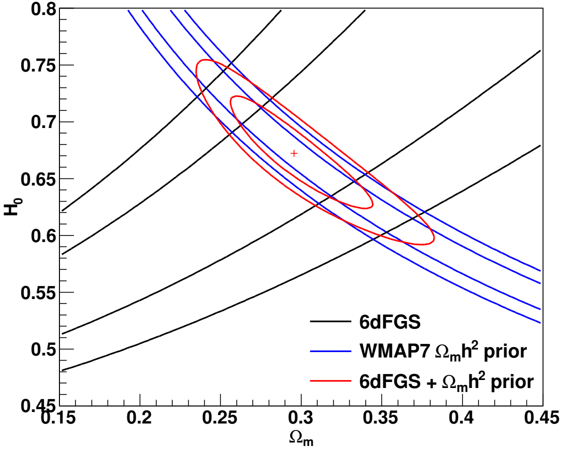
PLANCK: $H_0 = 67.3 \pm 1.2\,\mathrm{km/s/Mpc}$ (Ade et al. 2013)

Cosmological implications



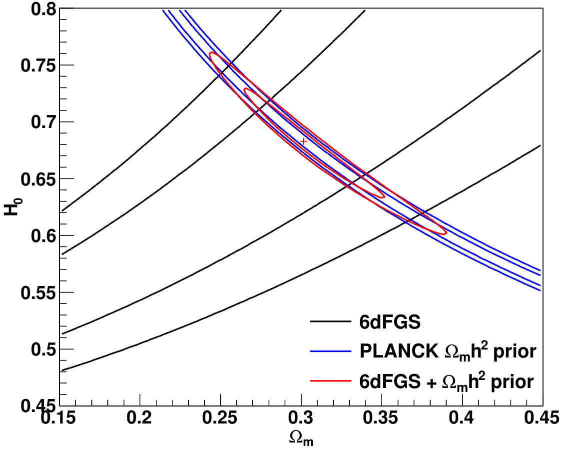
Cosmological implications





best fit for 6dFGS + $\Omega_m h^2$ prior from WMAP7: $67.0 \pm 3.2\,$km/s/Mpc

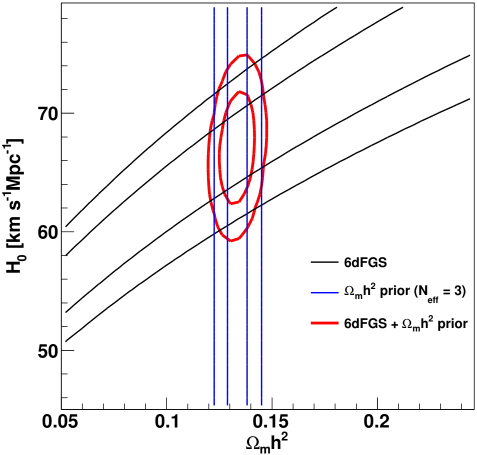
CMB calibration: PLANCK vs. WMAP



best fit for 6dFGS + $\Omega_m h^2$ prior from WMAP7: $67.0 \pm 3.2\,$km/s/Mpc
best fit for 6dFGS + $\Omega_m h^2$ prior from PLANCK: $67.8 \pm 3.2\,$km/s/Mpc

What if $N_{\mathrm{eff}} = 4$?

What BAO surveys measure is r_s / D_V

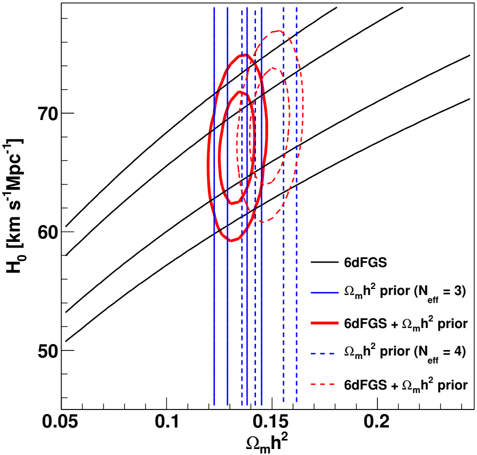


$$N_{\mathrm{eff}} = 3.04 + 7.44 \left(\frac{\Omega_m h^2}{0.1308} \frac{3139}{1 + z_{\mathrm{eq}}} - 1 \right)$$

What if $N_{\rm eff} = 4$?

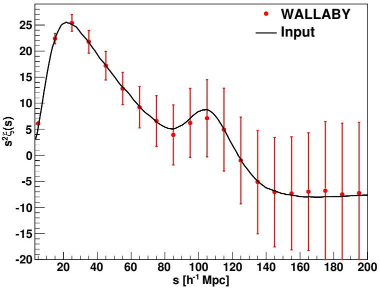
What BAO surveys measure is r_s/D_V

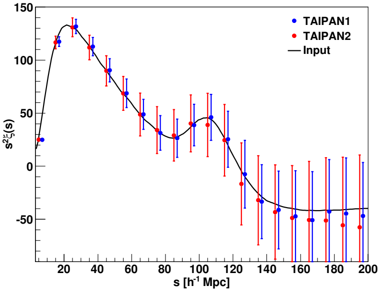
Eisenstein & White (2004)



$$N_{\rm eff} = 3.04 + 7.44\left(\frac{\Omega_m h^2}{0.1308}\frac{3139}{1+z_{\rm eq}} - 1\right)$$

Future outlook





- Riess et al. (2011) claim that they will be able to reduce their error using the distance ladder technique to 1%. see also arXiv:1202.4459
- The 6dFGS BAO measurement might improve (to $\approx 3\%$) using BAO reconstruction.
- Increasing the survey volume at low redshift (WALLABY and TAIPAN, see Beutler et al. 2011), will allow to get better H_0 constraints using BAO (at slightly higher redshift).

Summary

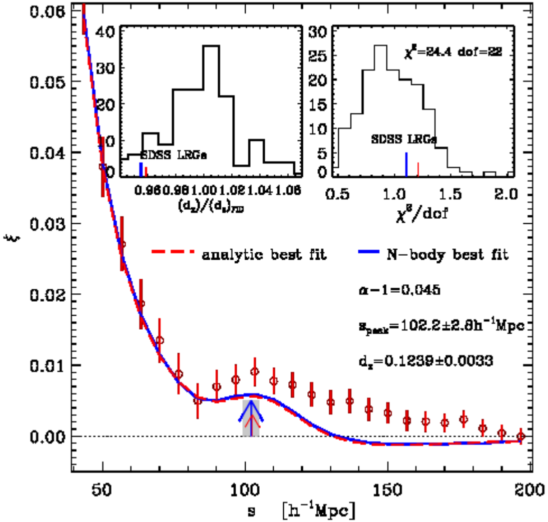
- We used the low redshift BAO detection in 6dFGS to derive the Hubble constant. We found

$$H_0 = 67.0 \pm 3.2 \text{ km/s/Mpc},$$

with WMAP7 and $H_0 = 67.8 \pm 3.2$ km/s/Mpc with PLANCK.
- Our constraint depends on high redshift data, mainly through the calibration of the standard ruler, but this dependency seems fairly robust.
- The 6dFGS measurement of the Hubble constant depends on very basic early universe physics and avoids possible systematic errors coming from the build up of a distance ladder.
- Our result is in mild tension with the result by Riess et al. (2011) and Freedman et al. (2012) using the distance ladder technique, but consistent with other BAO constraints and PLANCK.
- Additional contributions to the expansion history of the Universe (like extra relativistic species), do bias our H_0 constraint, but within PLANCK errors, these uncertainties are small.

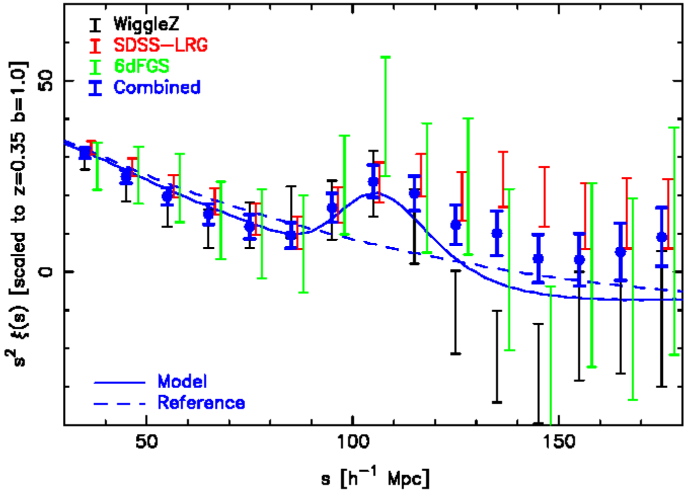
Thank you very much

Cosmological implications



Blake et al. (2011)

Cosmological implications



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