# Cosmology with TAIPAN : What could we learn?

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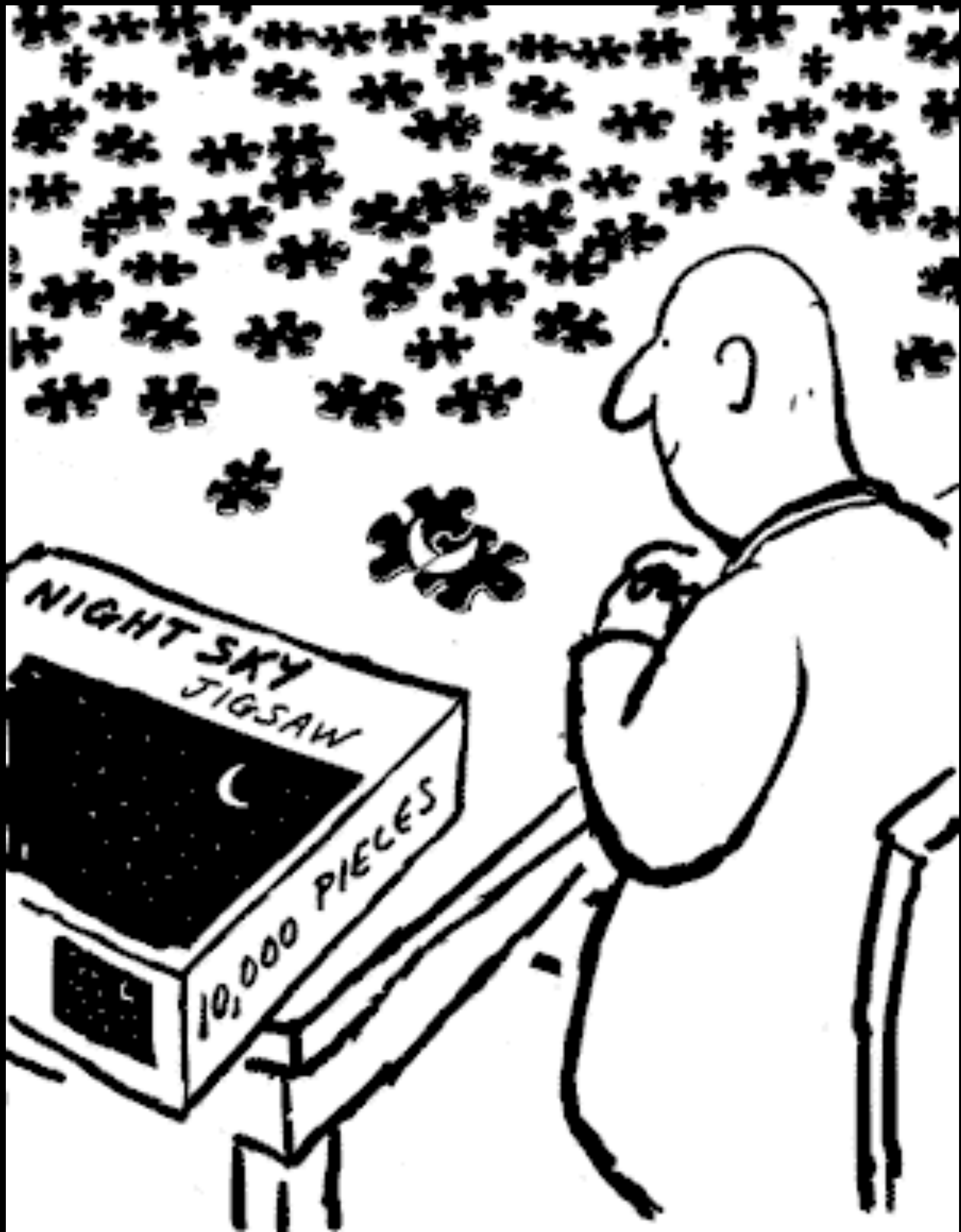
# Cosmological physics




What is "dark energy" ?

1) new, missing matter-energy component

2) failure of the laws of gravity on cosmic scales

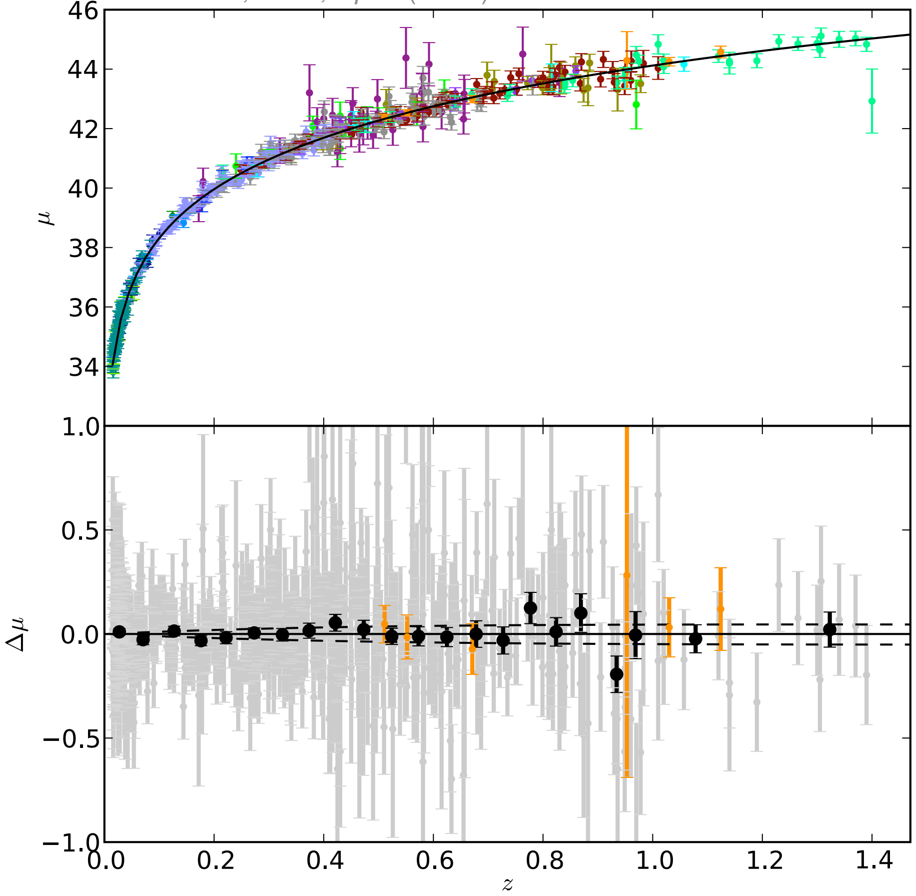
3) failure to correctly model inhomogeneity

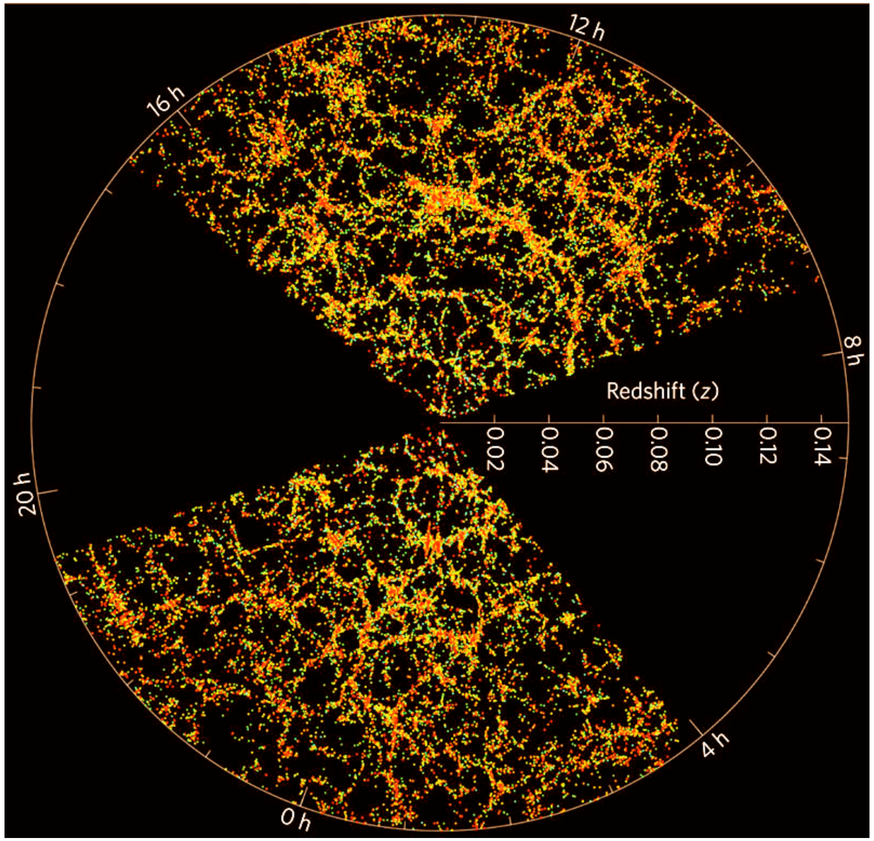
# Probes of the cosmological model

How fast is the Universe expanding with time?

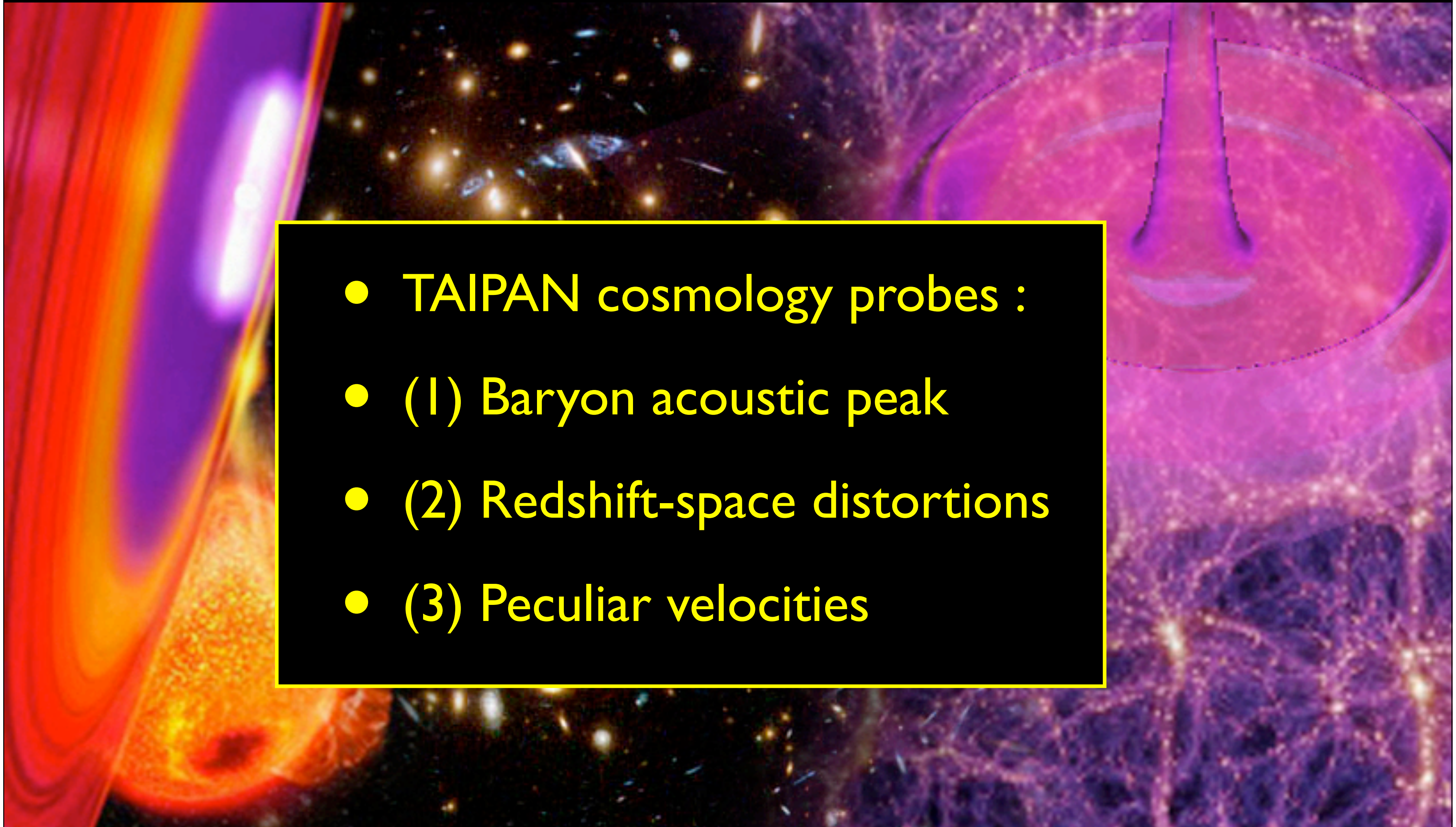
How fast are structures growing within it?

Supernova Cosmology Project
Amanullah, et al., *Ap.J.* (2010)



# Probes of the cosmological model

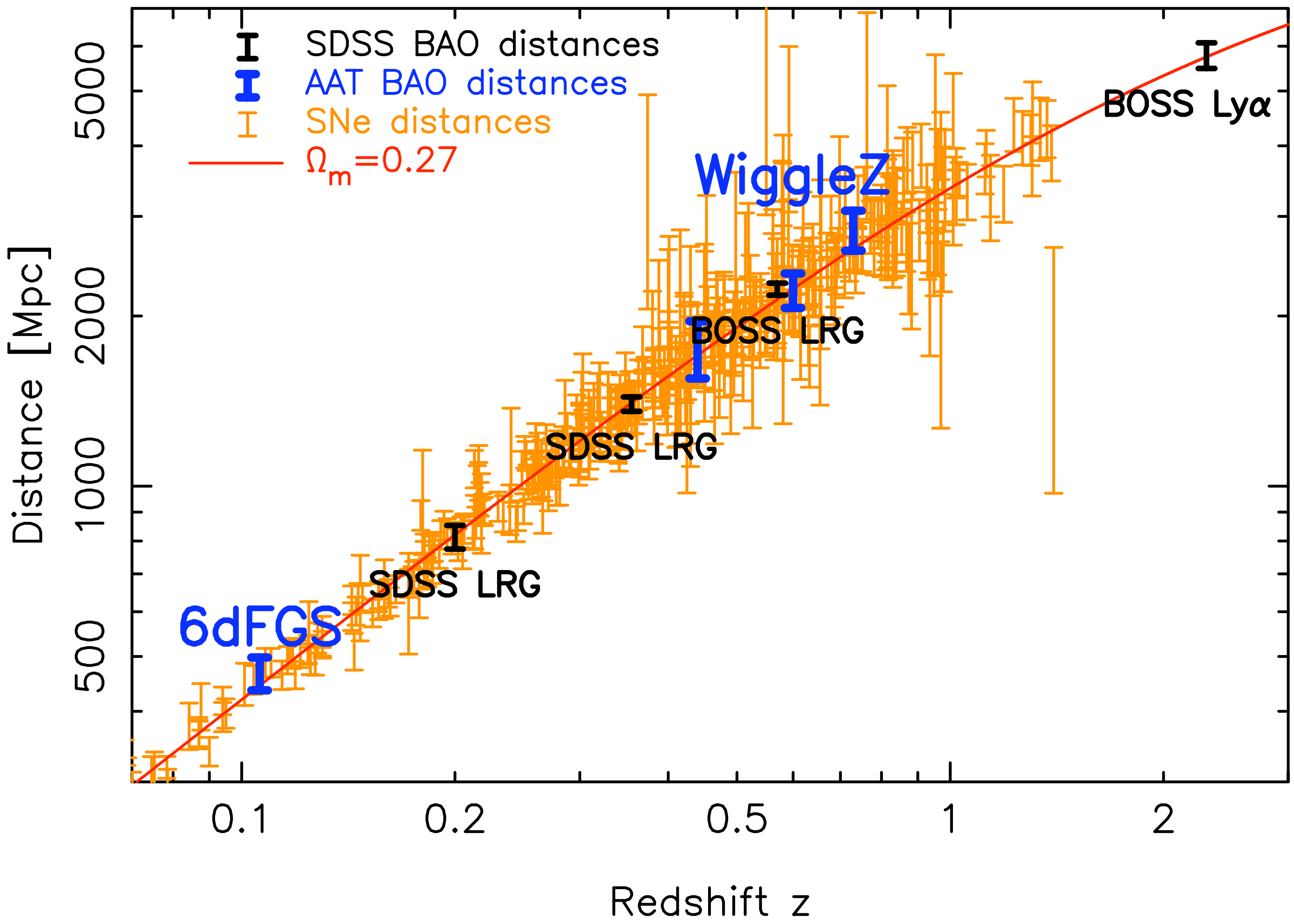


- TAIPAN cosmology probes :
- (1) Baryon acoustic peak
- (2) Redshift-space distortions
- (3) Peculiar velocities

Image credit : Lawrence Berkeley National Laboratory

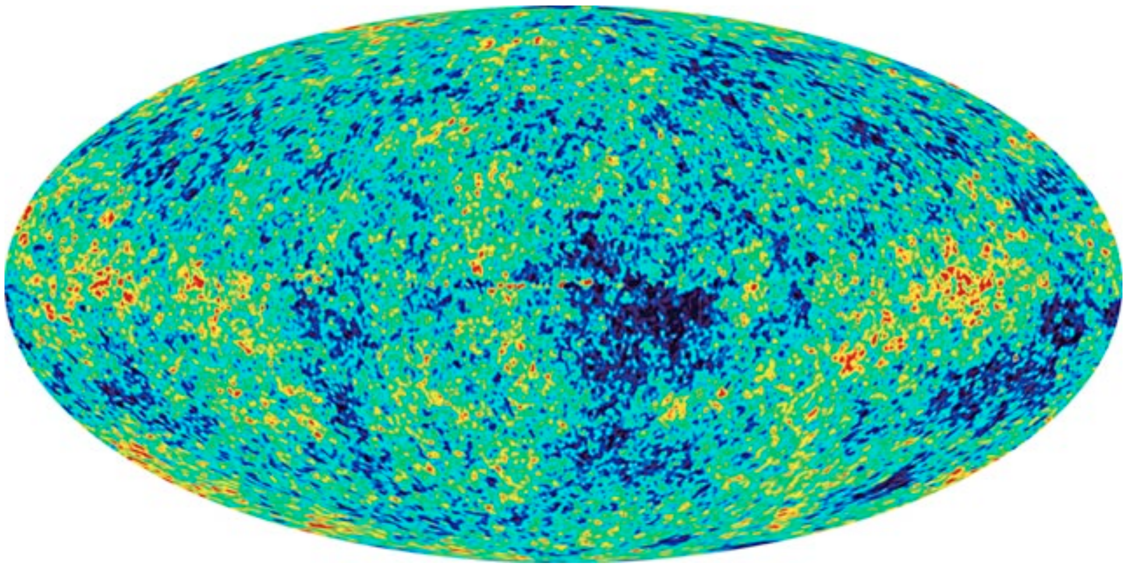
# Probe 1 : baryon acoustic peak

- Standard ruler in galaxy clustering pattern which allows the mapping out of cosmic distances



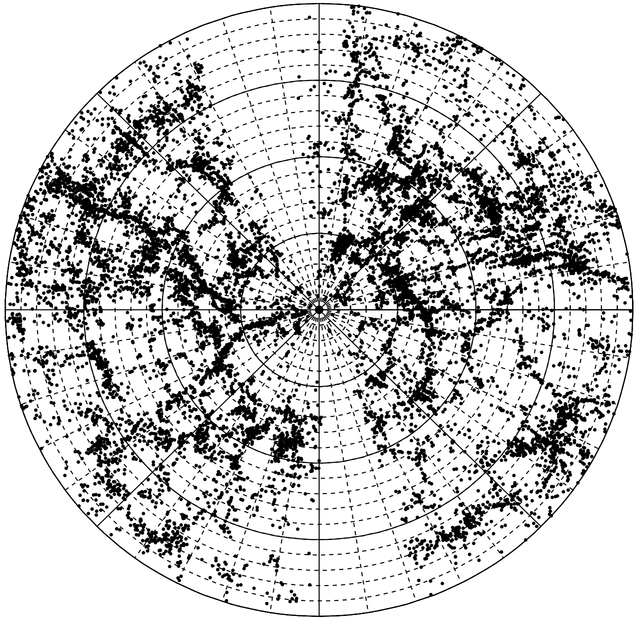
# Probe 1 : baryon acoustic peak

- Standard ruler in galaxy clustering pattern which allows the mapping out of cosmic distances
- Calibrated in units of Mpc using CMB physics with accuracy of 1.1% [WMAP] , 0.25% [Planck]



- Application to a low-z survey measures $H_0$

# Existing low redshift measurement!

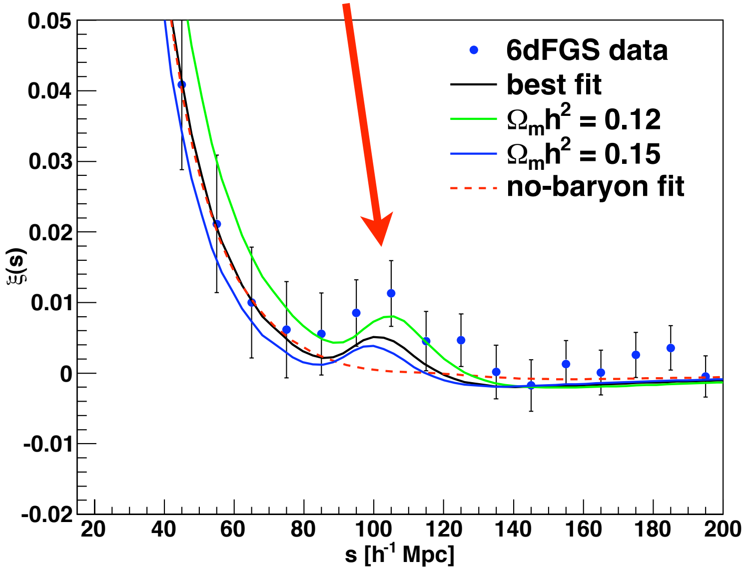


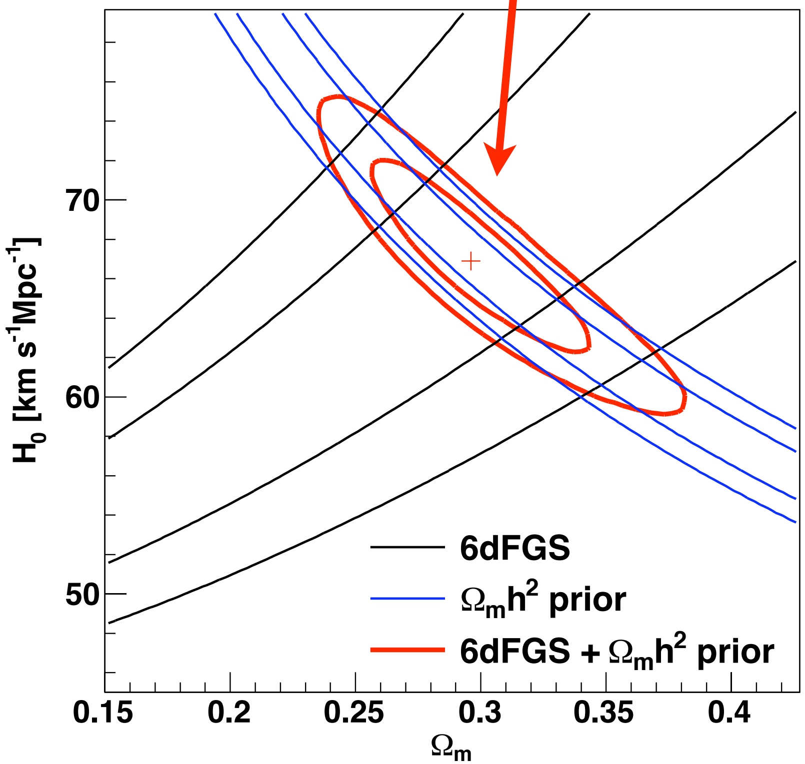
6dF Galaxy Survey

Beutler et al. (2011)

$H_0$ = 67.0 +/- 3.2 km $s^{-1}$ $Mpc^{-1}$

D(z=0.1) = 456 +/- 27 Mpc



# Why measure $H_0$?

- Local expansion rate is a fundamental cosmic parameter (e.g. important for determining the age of the Universe)
- Independent determination of $H_0$ can improve the measurement of other parameters (e.g. dark energy, neutrino numbers/masses)
- Interesting systematic comparison with other local $H_0$ measurements (Cepheids, masers, supernovae)
- Is a TAIPAN baryon acoustic peak measurement of $H_0$ competitive with other techniques and probes?

# Survey simulations

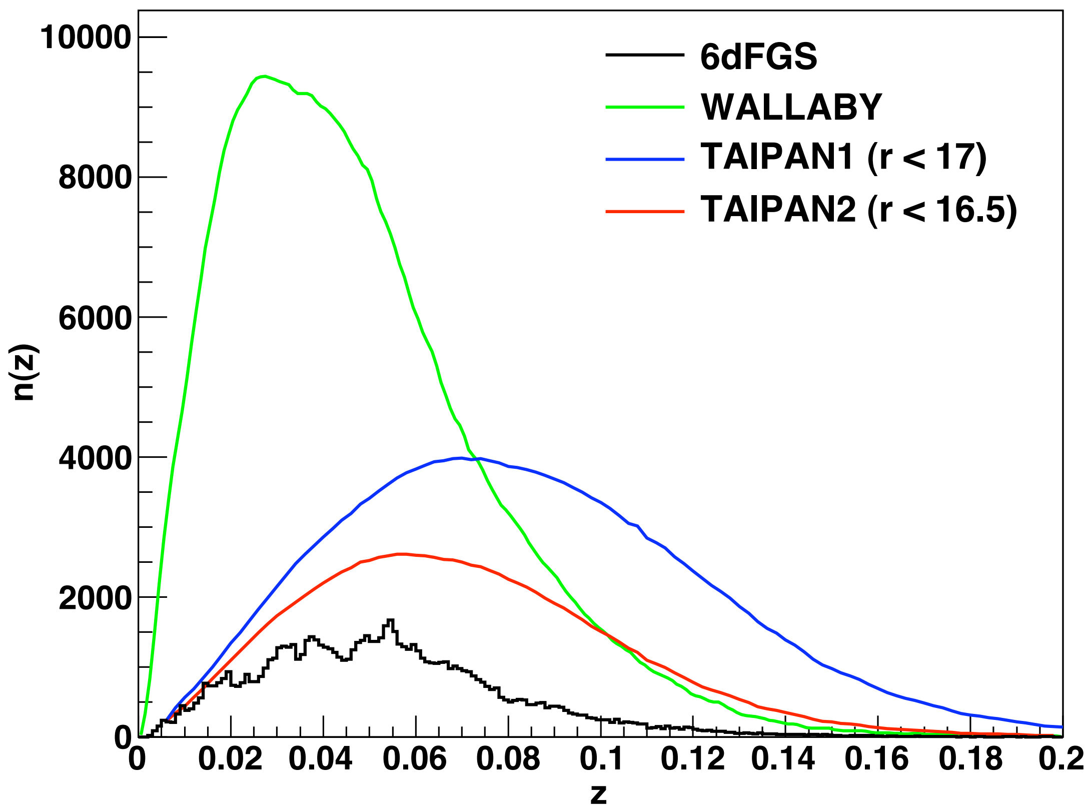
- Simulation from Beutler et al. (2011)

Simulation method :

- Create many clustered "lognormal realizations" to simulate the experiment

- Consider two TAIPAN scenarios (r<16.5, r<17)

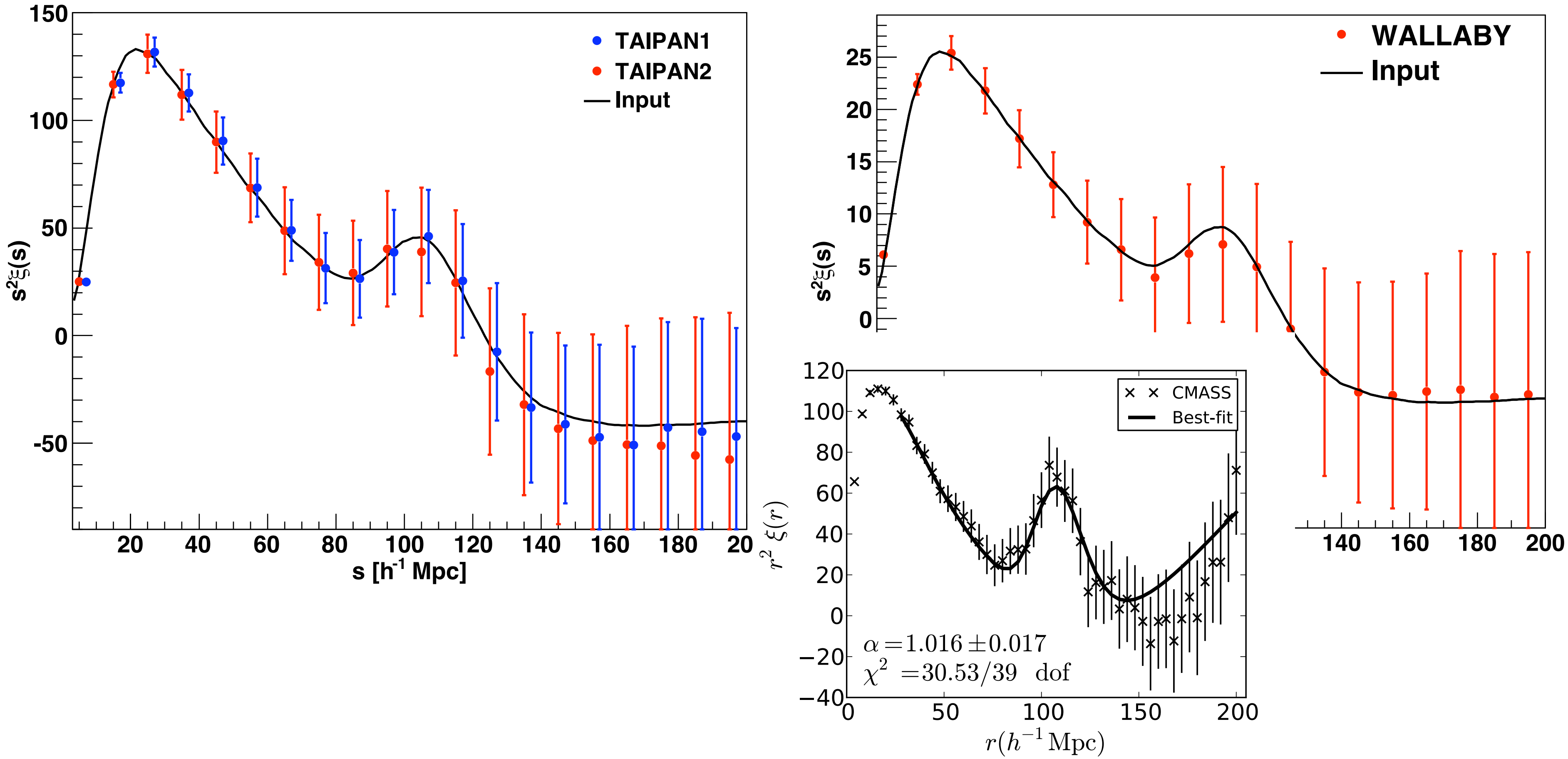
- Use the ensemble of realizations to determine significance and accuracy of acoustic peak measurement



# Survey simulations

- Simulation from Beutler et al. (2011)

Average galaxy correlation functions :



# Survey simulations

- Simulation from Beutler et al. (2011)

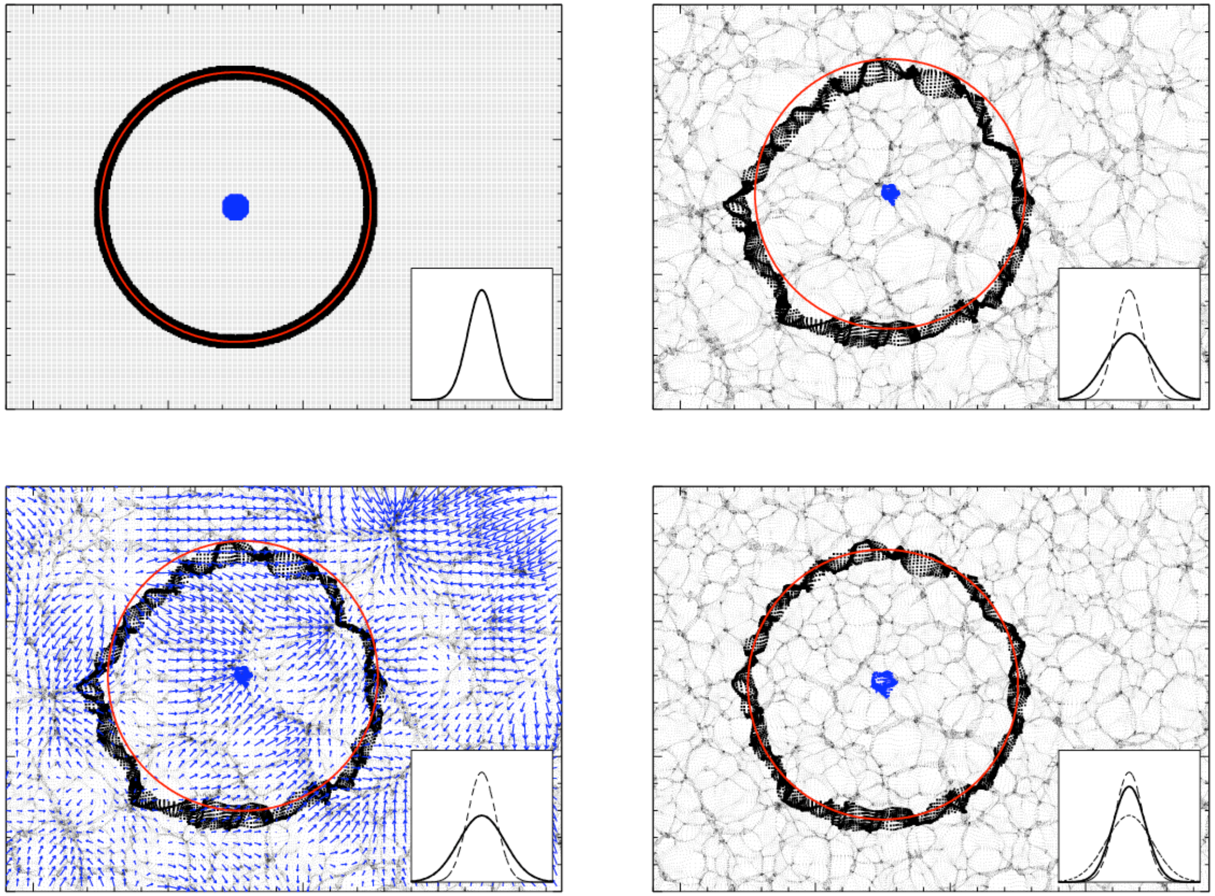
| Survey | $N_{gal}$ | Sky fraction | $V_{eff}$ $(Gpc/h)^3$ | BAO significance | Distance error |
|---|---|---|---|---|---|
| 6dFGS | 80,000 | half | 0.08 | 1.7+/-0.7 [2.4!] | 6% |
| TAIPAN (r<16.5) | 220,000 | half | 0.13 | 2.1+/-0.7 | 6% |
| TAIPAN (r<17) | 410,000 | half | 0.23 | 3.5+/-0.8 | 3% |
| WALLABY | 600,000 | full | 0.12 | 2.1+/-0.7 | 7% |

- TAIPAN r<17 will provide 3% distance measurement

# Survey simulations

- Can we do better? Yes!
  - We can select galaxies to fill space more uniformly [e.g. photo-z]
  - We can use "reconstruction" of the acoustic peak

Padmanabhan et al. (2012)

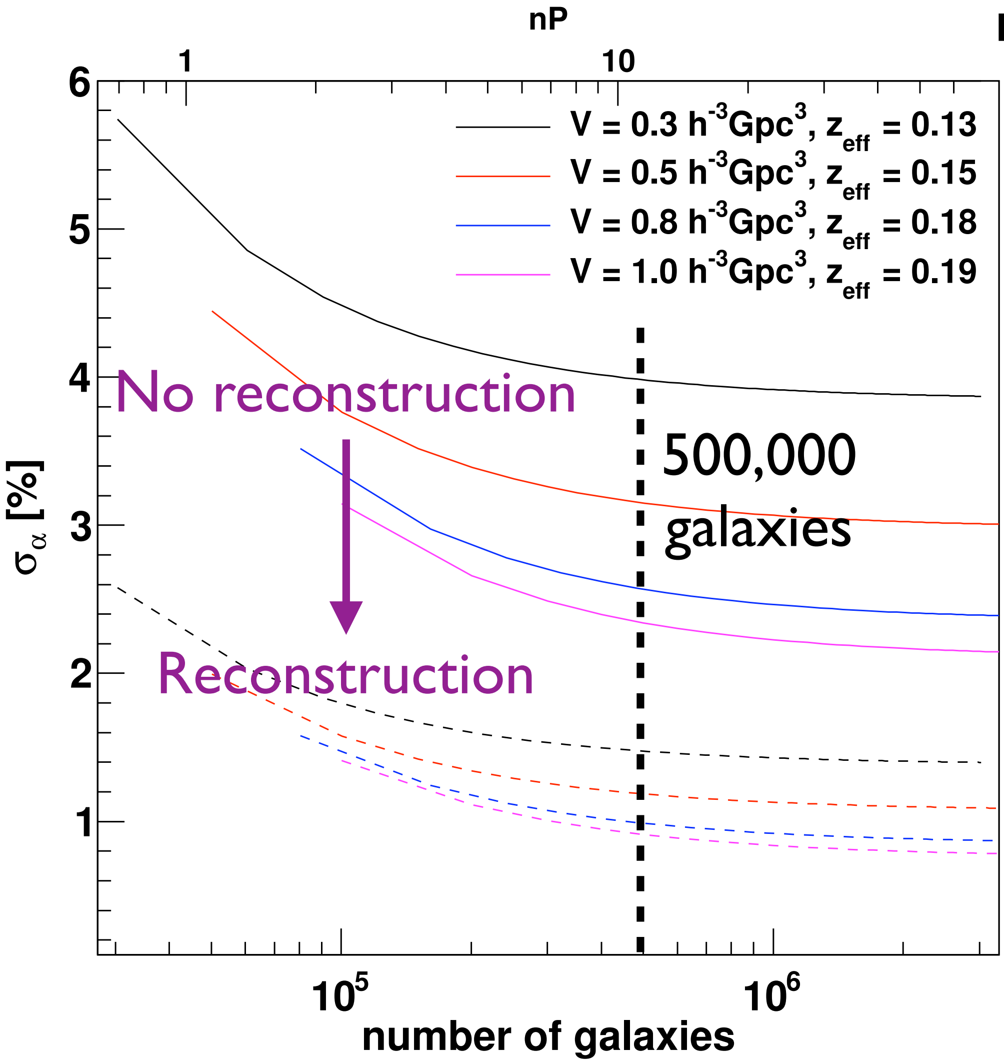


# Survey simulations

- Can we do better? Yes!

Fisher matrix prediction from Florian Beutler for constant number-density surveys with and without reconstruction :

- 1% distance measurement with optimal pre-selection and reconstruction




Rough mag limit

r=17.5

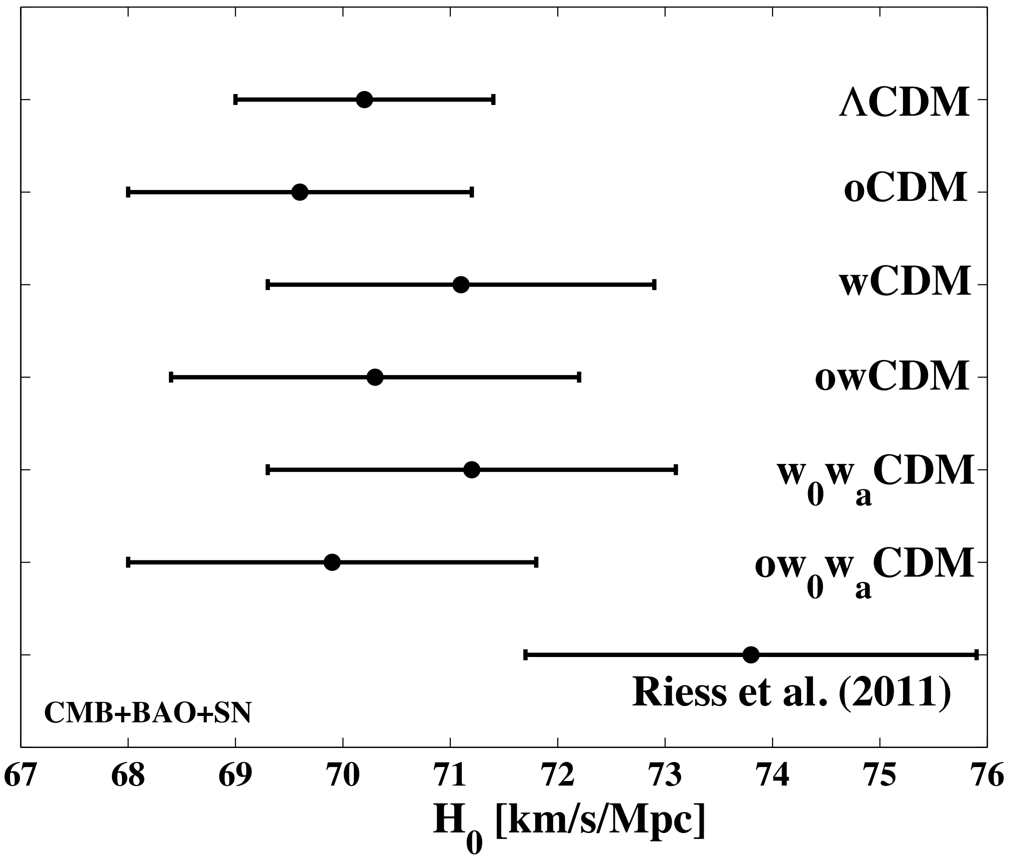
r=18.0

r=18.5

# Is this competitive?

- Does this help current measurements of dark energy?

Mehta et al. (2012)

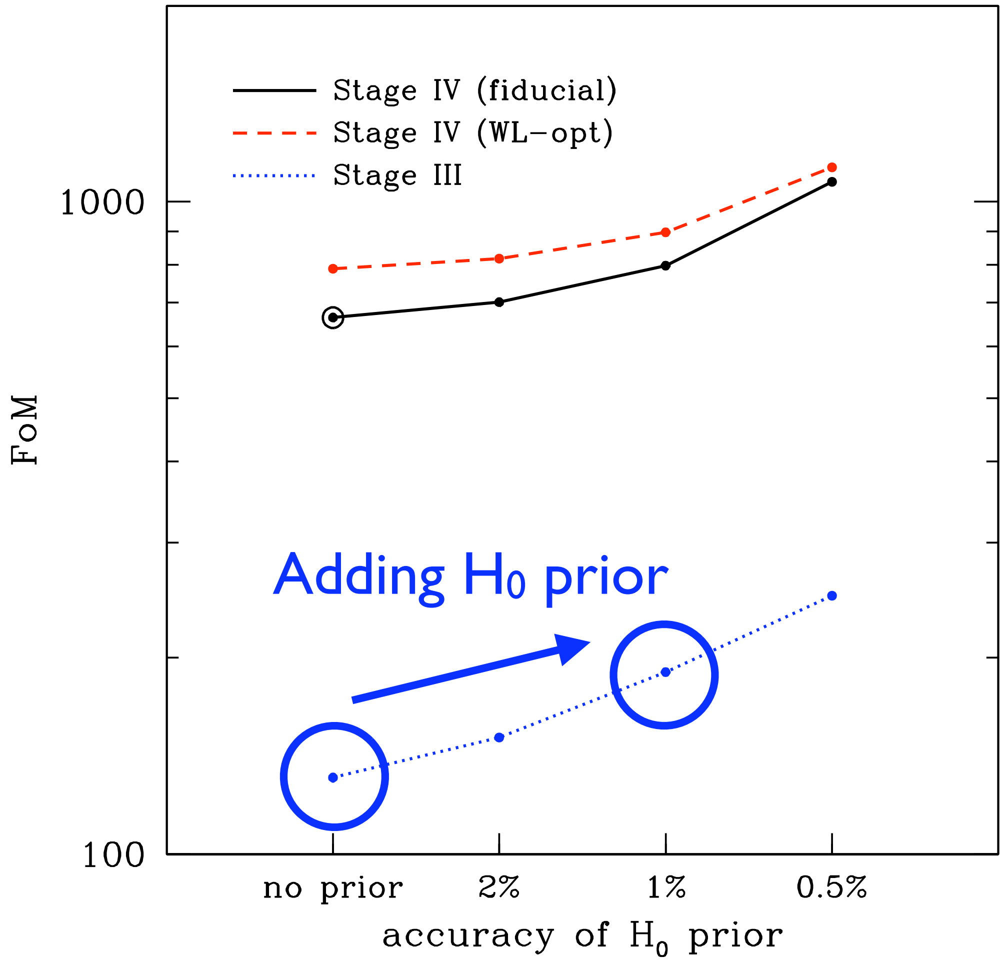



- Other probes already measure $H_0$ to 1-2% [N.B. assuming a cosmological model]
- If w(z) is an unknown function, then a local $H_0$ measurement is the only way to determine the age of the Universe
- An interesting tension exists with local standard candle measurements [Riess et al. 2011, Freedman et al. 2012]

# Is this competitive?

- Does this help future measurements of dark energy?

Weinberg et al. (2012)

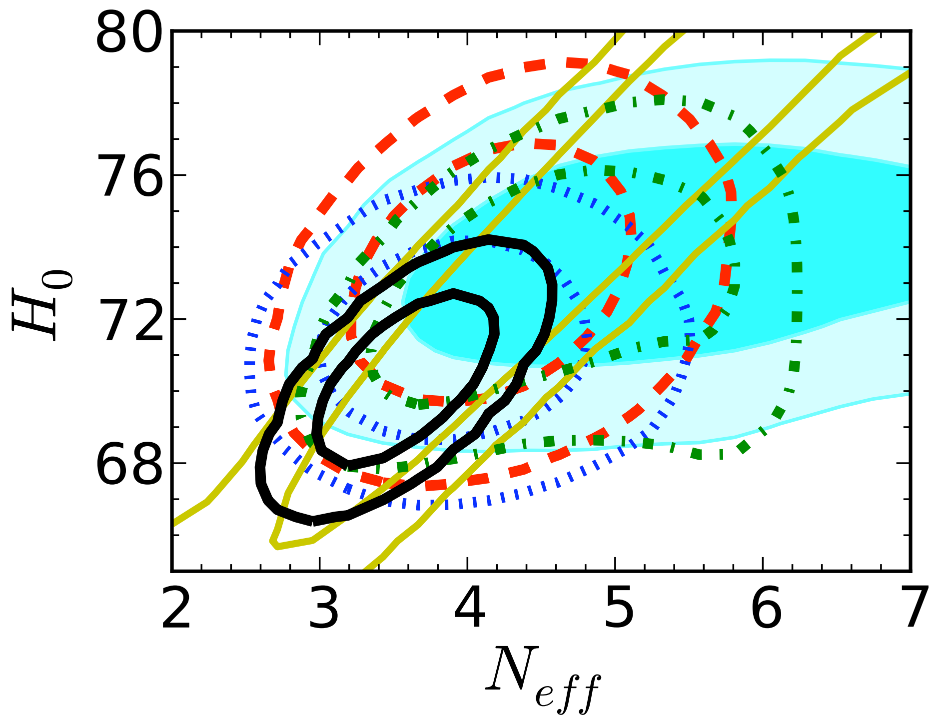


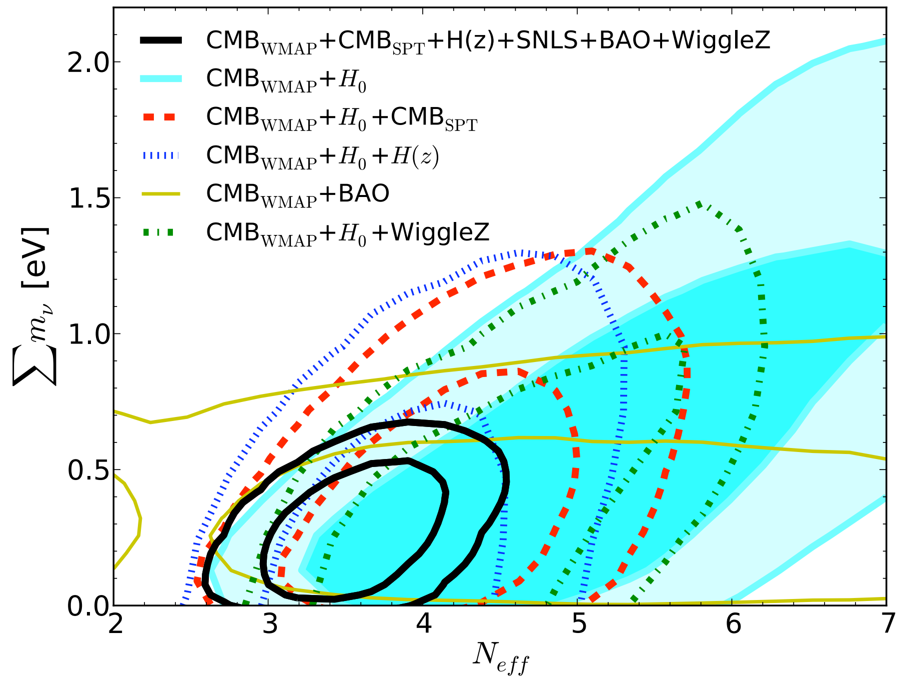

- Assuming ($w_0$, $w_a$) model, 1% $H_0$ measurement adds about 40% to Stage III dark energy experiments [e.g. BOSS, DES, etc.]
- Adds very little to Stage IV experiments [e.g. LSST, SKA, etc.]

# Is this competitive?

- Does this help measure other parameters?

- Number of neutrinos and $H_0$ are currently correlated
- Intriguing hints from cosmological data that $N_{eff} > 3$ [95% confidence]
- Unfortunately other datasets (Planck) are more powerful here ...




Riemer-Sorensen et al. (2012)

# Is this competitive?

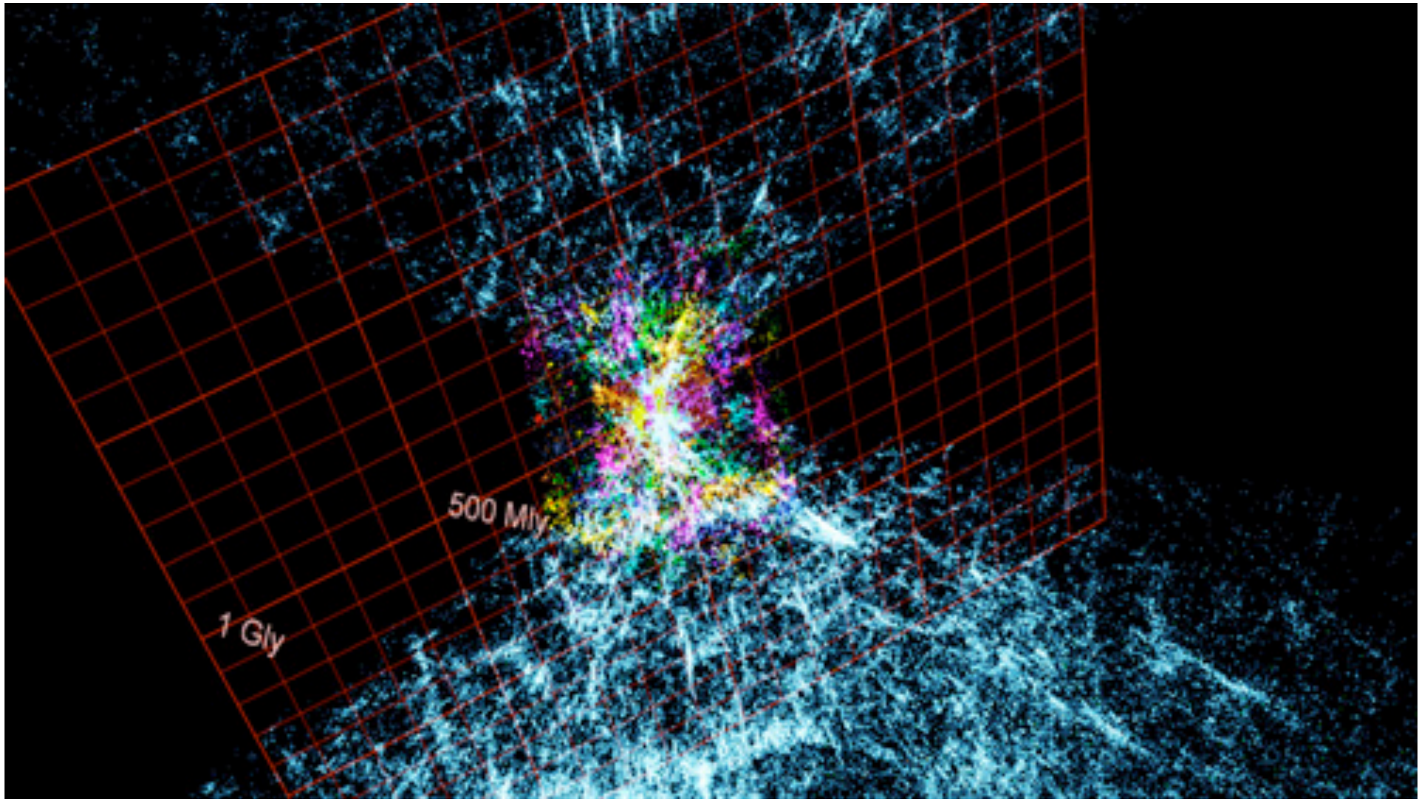
- Interesting discrepancies between $H_0$ measurements?

| Method | $H_0$ [km/s/Mpc] | Reference |
|---|---|---|
| Cepheids / masers / SNe | 73.8 +/- 2.4 | Riess et al. (2011) |
| Cepheids | 74.3 +/- 2.1 | Freedman et al. (2012) |
| Baryon acoustic peak | 67.0 +/- 3.2 | Beutler et al. (2011) |
| All cosmology | 68.9 +/- 1.1 | Samushia et al. (2012) |

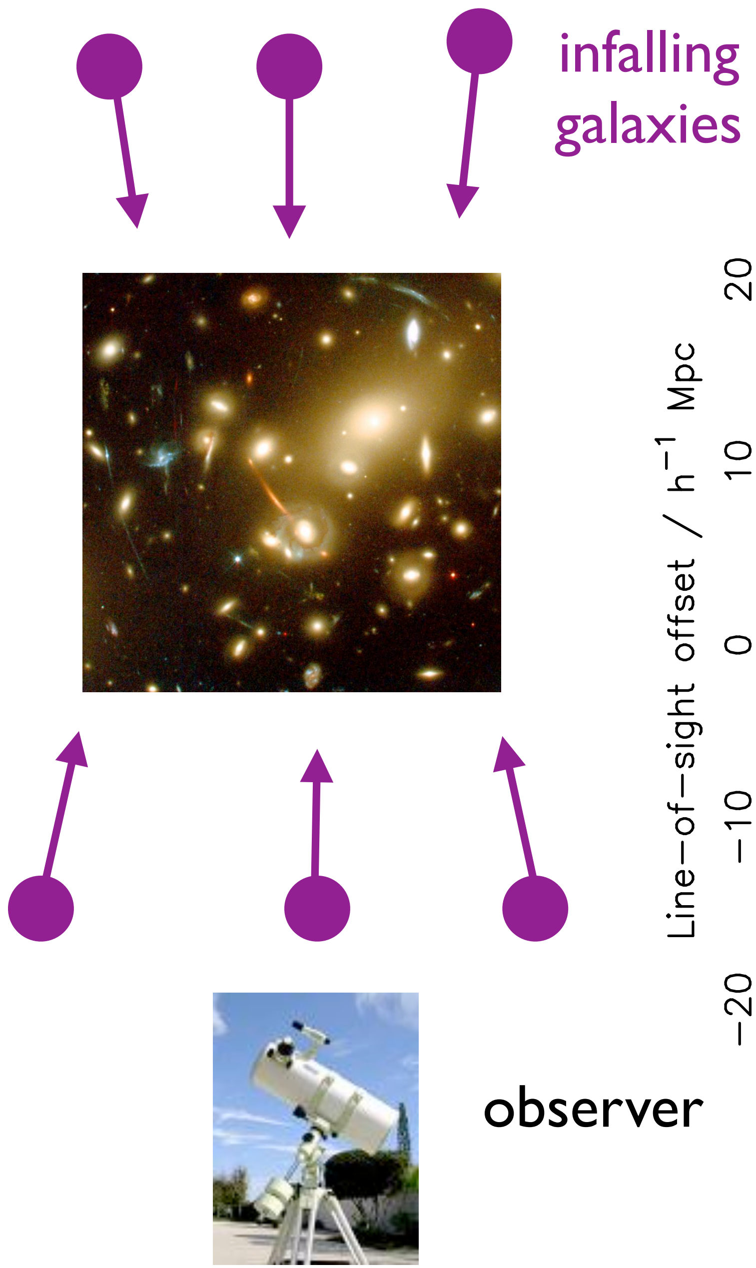
# Is this competitive?

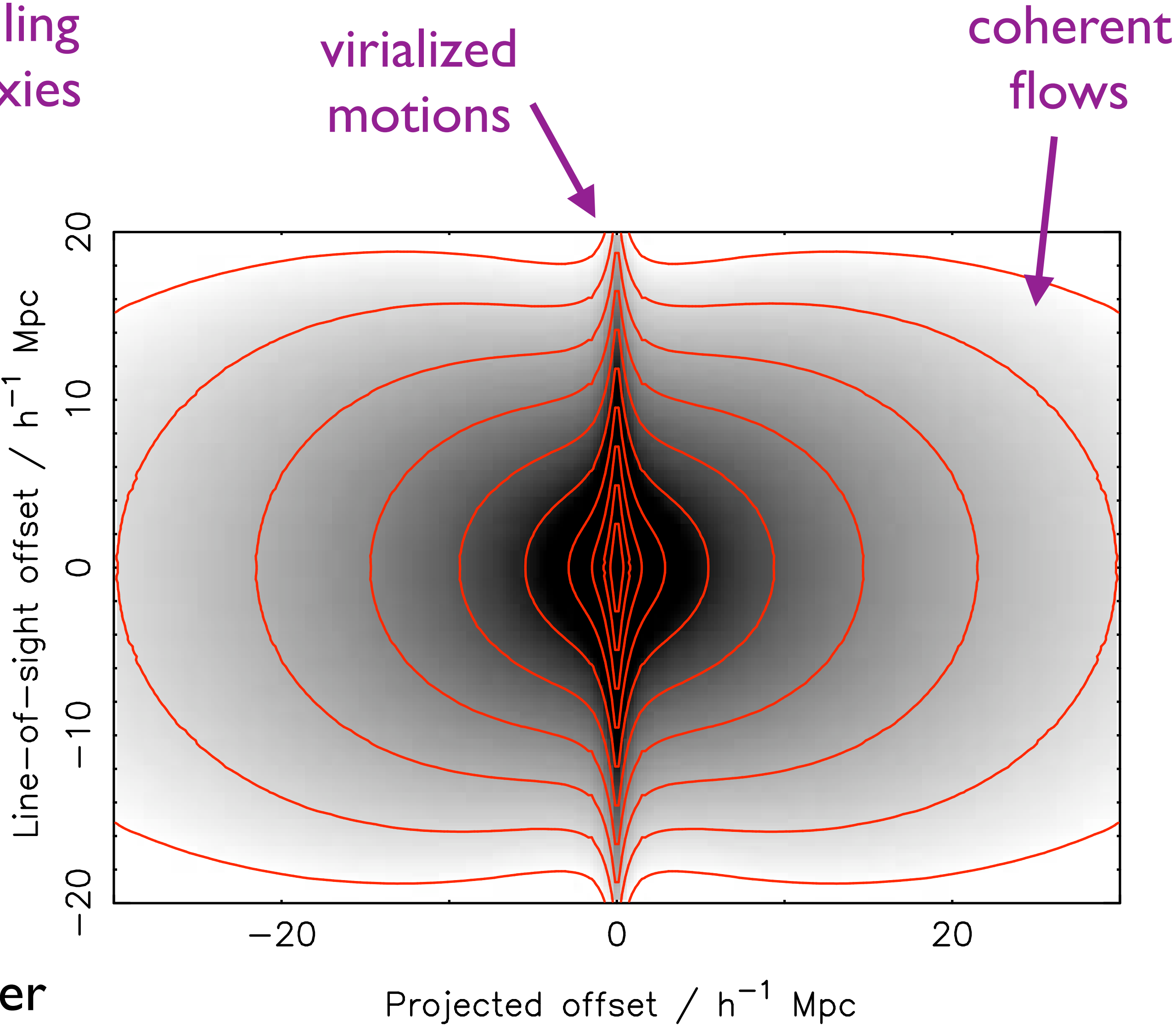
- Interesting discrepancies between $H_0$ measurements?

- Could be a signature of gravitational physics driven by inhomogeneity / backreaction ?  [speculation]



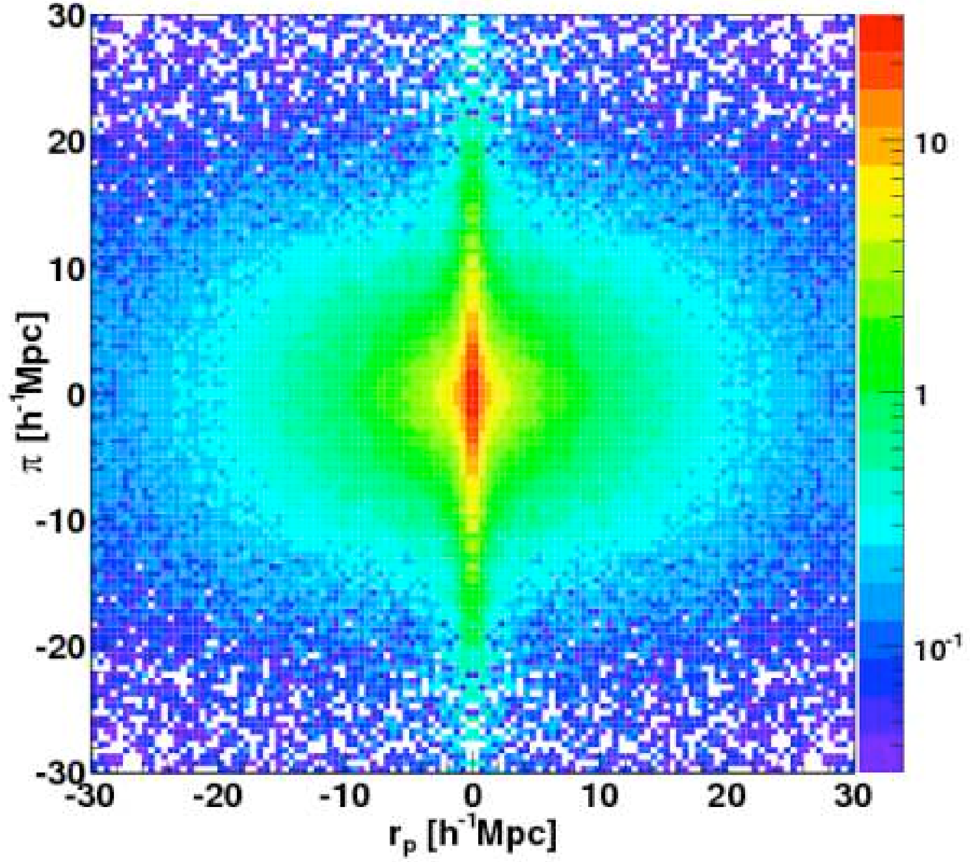
# Probe 2 : redshift-space distortions

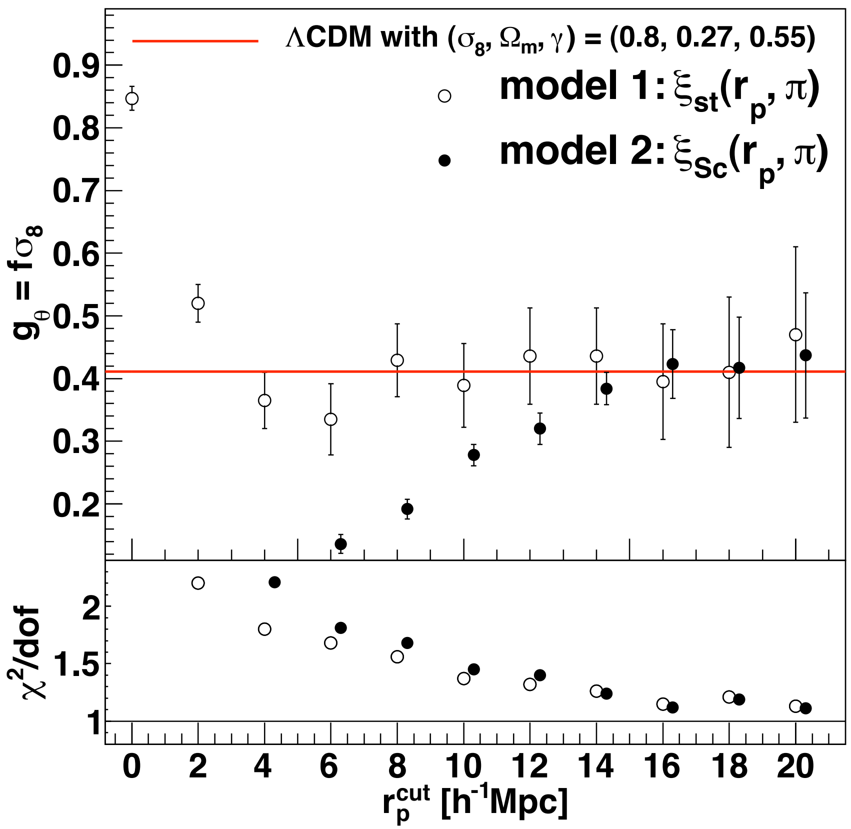


# Probe 2 : redshift-space distortions

- 6dFGS measurement from Beutler et al. (2012)



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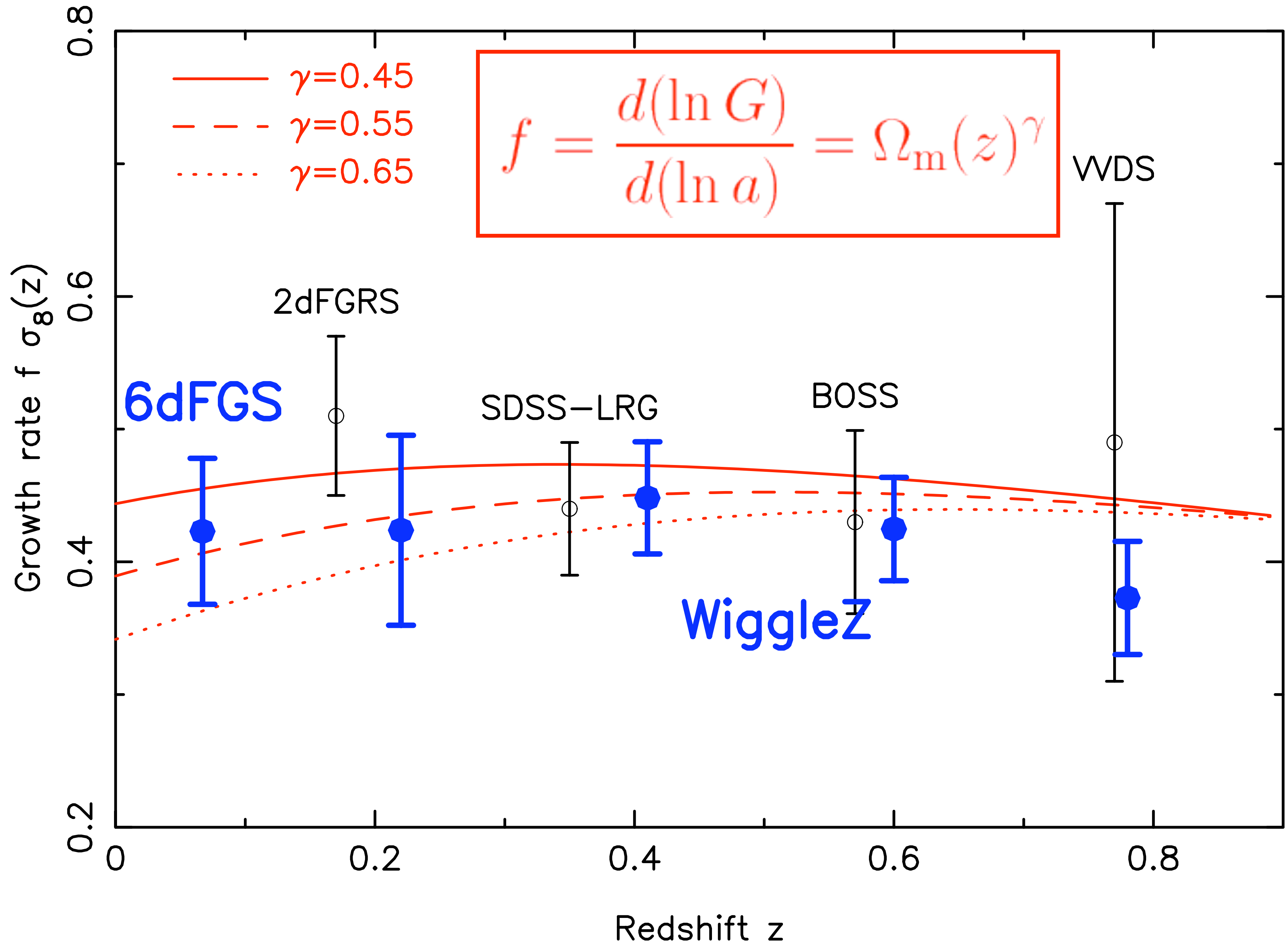


# Why measure RSD at low redshift?

- Advantage : local growth rate is very sensitive to dark energy or modified gravity model
- Advantage : high number density of galaxies may be observed, allowing multiple-tracer techniques
- Disadvantage : structure becomes "non-linear" at low redshift and difficult to model
- Disadvantage : is difficult to cover a sizable volume
- Is a TAIPAN RSD survey competitive?

# Survey simulations

- Simulation from Beutler et al. (2012)

| Survey | Galaxy bias | Growth error (k < 0.1 h/Mpc) | Growth error (k < 0.2 h/Mpc) |
|---|---|---|---|
| 6dFGS | 1.4 | 23% | 8% |
| TAIPAN (r<17) | 1.4 | 11% | 4% |
| WALLABY | 0.7 | 13% | 5% |
| overlap | 1.4 & 0.7 | 10% | 5% |

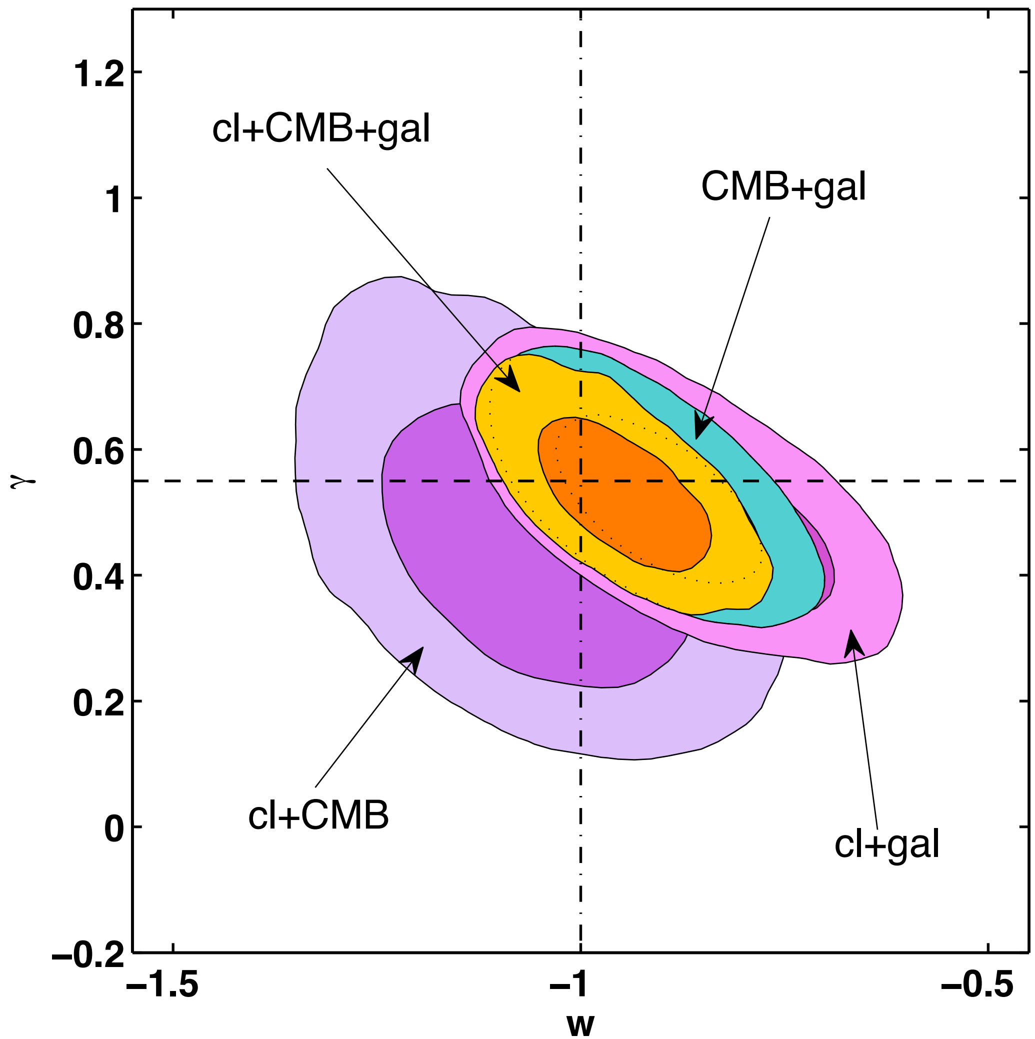
- TAIPAN / WALLABY should increase the accuracy in the z=0 growth rate by a factor of 2

# Is this competitive?

$$f = \frac{d(\ln G)}{d(\ln a)} = \Omega_m(z)^\gamma$$

- Galaxy surveys / CMB / clusters together demonstrate consistency with gamma=0.55 (G.R.), w=-1 (Lambda)
- 6dFGS measurement significant help here, so improved precision would have benefit ...

Rapetti et al. (2012)



# Probe 3 : peculiar velocities

- Direct measurement of galaxy velocities using "standard candle" techniques such as fundamental plane
- The amplitude of the local bulk flow has been claimed as inconsistent with the standard cosmological model
- Velocity and density measurements can be powerfully combined to test models

$$\vec{v}(\vec{r}) = \frac{\Omega_{\rm m}^{0.55}}{4\pi} \int d^3\vec{r'}\, \delta_{\rm m}(\vec{r'})\, \frac{(\vec{r'} - \vec{r})}{|\vec{r'} - \vec{r}|^3}$$

# Why are peculiar velocity surveys useful?

- Advantage : improved measurements of the growth rate from the information added by velocities
- Advantage : greatly improved measurements of (f/b) from cancelling cosmic variance between density and velocity
- Advantage : information contained on large scales
- Disadvantage : large velocity errors, limited maximum redshift, systematics?
- Are peculiar velocities competitive with redshift-space distortions?

# Survey simulations

- Fisher matrix forecasts for density+velocity field:

Koda et al.
(in prep)

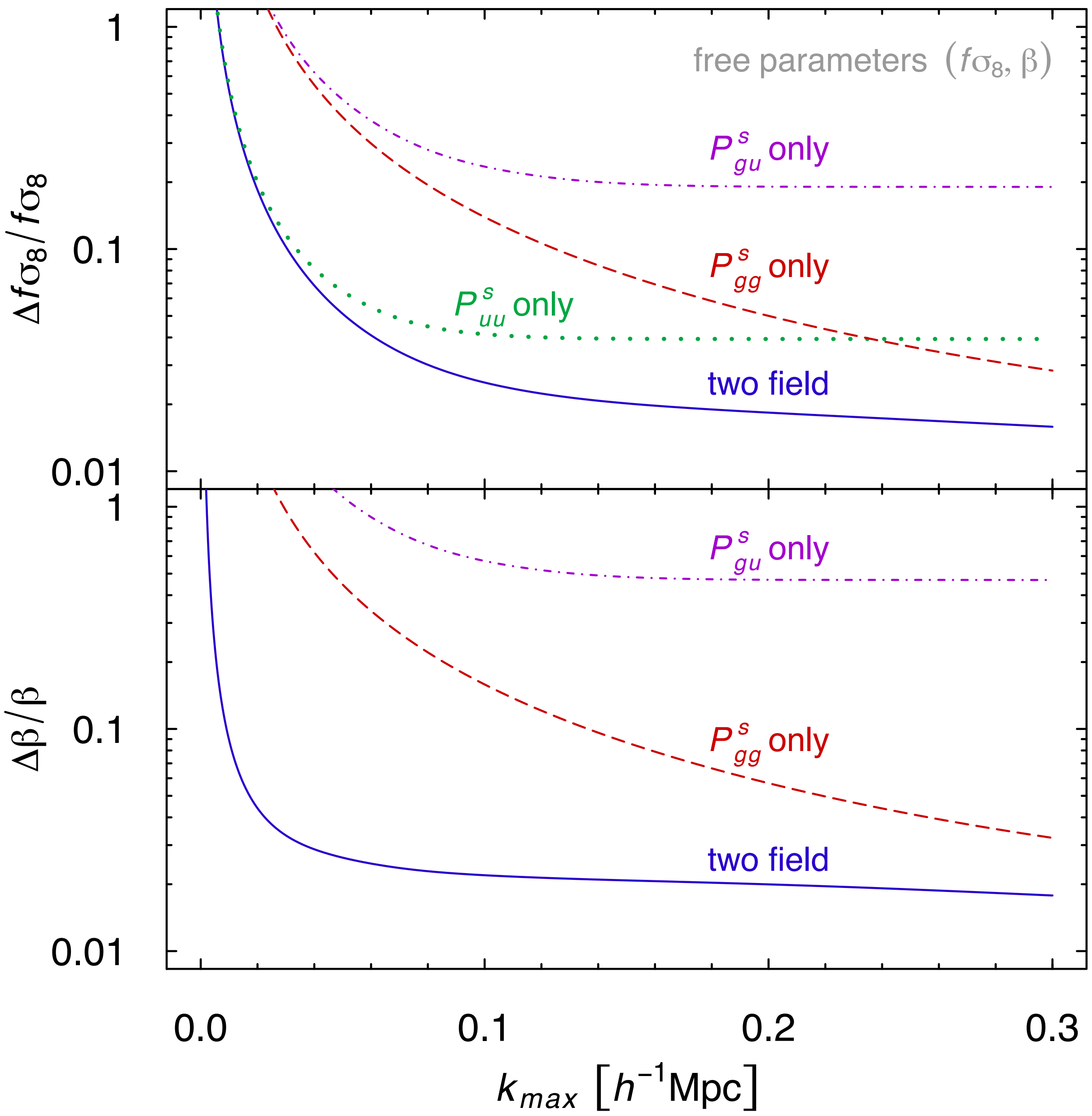
| Survey | Growth error (k < 0.1 h/Mpc) | Growth error (k < 0.2 h/Mpc) |
|---|---|---|
| 6dFGS | 13% | 10% |
| TAIPAN (r<16.5) | 8% | 6% |
| TAIPAN (r<17) | 7% | 5% |
| WALLABY | 4% | 3% |

- 20% distance accuracy assumed and realistic N(z) for each survey
- Few per cent error in growth is achievable (competitive with RSD!)
- Information is concentrated at low k !

# Survey simulations

Koda et al. (in prep)

$$P_v(k) = \frac{H^2 f^2 a^2}{k^2} P_m(k)$$



# Conclusions

- TAIPAN can provide 3% measurement of $H_0$ (1% with optimal selection) but this may not be competitive with other cosmological data by 2020?
- Local $H_0$ measurements could trace gravitation and curvature in a clumpy Universe?
- TAIPAN redshift survey can improve the z=0 growth rate by a factor of 2, resulting in stronger tests of GR
- TAIPAN peculiar velocity survey can produce similar gains using larger-scale modes