Cosmological parameters from the SFI++ survey

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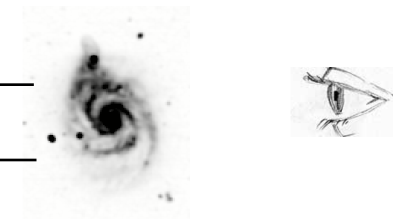
Outline

- Why care about peculiar velocities?
- The SFI++ survey
- Analysis Method
- Results
- Conclusions & Future data sets

Cosmological Velocity Field

- The motion at a point in space due to the gravitational attraction of surrounding masses; distinct from the expansion
- Usually measured using tracers e.g.: galaxies; SN1a; galaxy clusters
- Radial motion of a galaxy (v_p) is therefore:
  - $cz = H_0 d + v_p$
- Better than the galaxy density field because: the velocities are directly related to the underlying gravitational potential field
- Worse that the galaxy density field because: really hard to measure accurately!



$$\boxed{v = -i\, a(t)\dot{a}(t) \frac{\mathbf{k}}{k^2} \delta(k) \frac{dD}{da}}$$

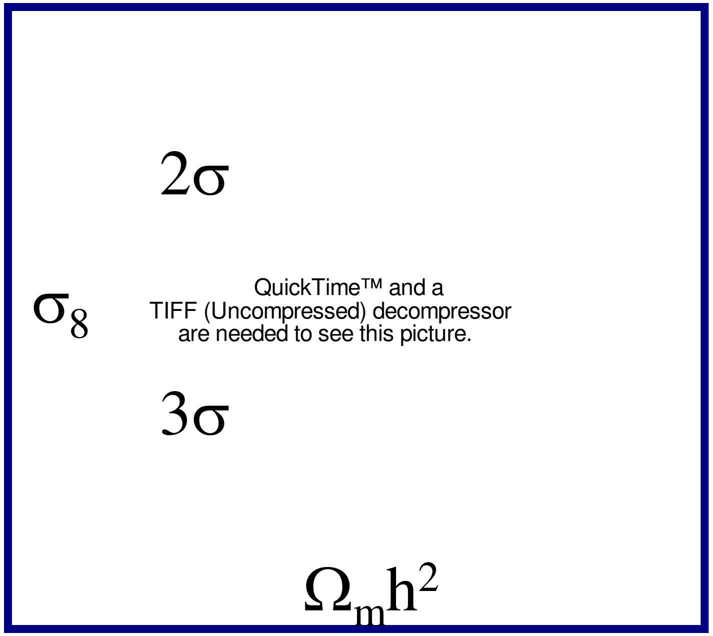
In linear theory the velocity field is directly related to the density field, and the growth of structure: dD/da

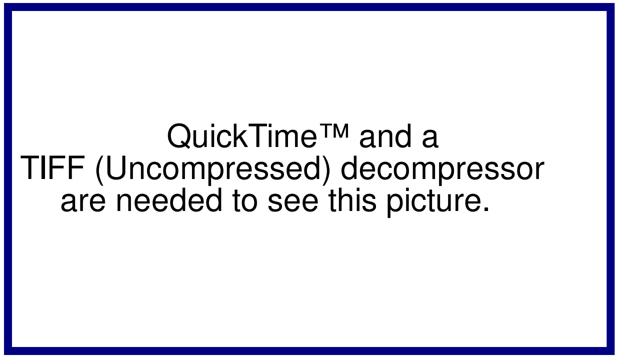
Why is this interesting?

- Don't need to worry (as much) about galaxy biasing
- Only way to measure redshift zero clustering
  - WMAP5 ΛCDM: σ_8=0.80+/-0.03, ΛCDM+ν: σ_8=0.67+/-0.08
- Very sensitive to the derivative of the growth function
  - Use growth of structure to detect departures from ΛCDM
- They are a "useful" systematic of BAO and SN1a measurements
  - You will have to care!
- Recent large-scale bulk flow measurements seem to disagree with ΛCDM ….

Recent large scale flow results

- Watkins, Feldman & Hudson (2009)
  - Use all galaxy PV catalogues
  - Data suggest the bulk flow within a Gaussian window of 50Mpc/h is 407+/-81km/s (not rms)
  - Probability of this flow in WMAP5 normalised ΛCDM universe is of order 1%
  - Similar result in Lavaux et al. (2008) using 2MASS
- Kashlinsky et al. (2008)
  - Use kSZ effect measured from CMB+X-ray data





Challenges

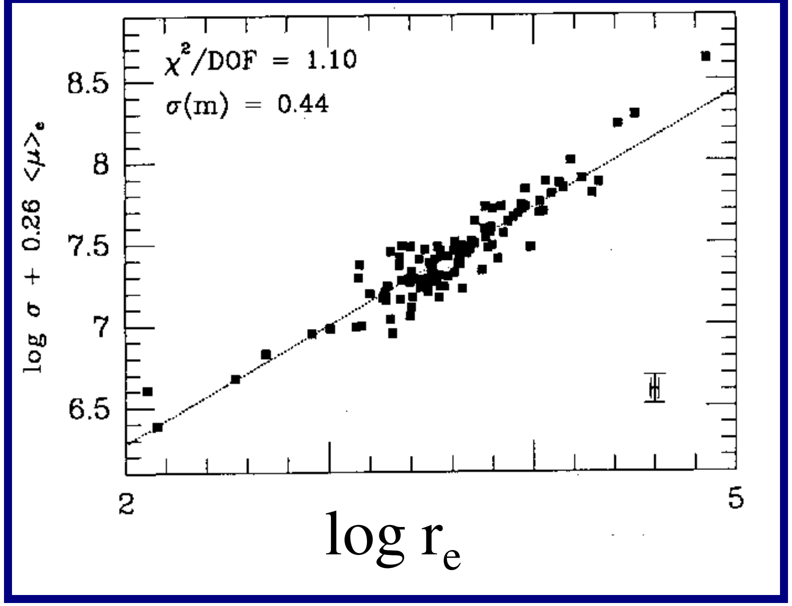
- Large errors
  - Galaxy peculiar velocities use FP or Dn-σ scaling relations: 15-22% distance error
  - SN1a use peak brightness-width relation: 5-10% distance error
  - ~(kSZ may have errors of just 100km/s)
- Malmquist bias
  - If error is >8% distance then non-uniform sampling due to the inhomogeneous density distribution induces spurious flows if not corrected
- Nonlinearities

$cz=H_0d+v_p$

-measure z, d

-get v_p

Fundamental Plane:



Spiral Field I Band: SFI++ Survey

- 5000 spiral galaxies (Masters et al. 2006) with rotation widths measured from:
  - HI line widths (60%)
  - Hα (40%)
- Peculiar velocity sample (Springob et al. 2007, 2009)
  - Corrected for Malmquist bias using 2MASS
  - 4053 galaxies with median z=0.019
  - Distance errors ~22% of the distance
  - Sample covers most of the sky above the Galactic plane

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Blue: cz<1000km/s

Cyan: 1000<cz<3000km/s

Green: 3000<cz<5000km/s

Yellow: 5000<cz<7000km/s

Red: 7000<cz<9000km/s

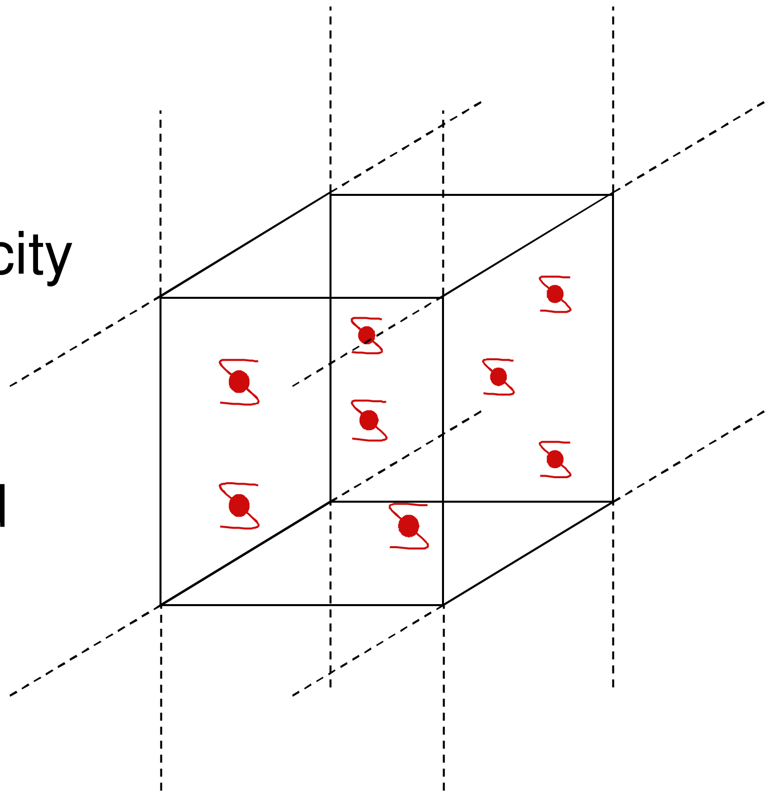
Magenta: cz>9000km/s

Smoothing method

- Need to smooth over radial velocity field:
  - Average out nonlinear scales
  - Apply some data compression
- We choose to smooth with a grid
  - Simple window function

$$\boxed{W^2(\underline{k}) = \left(\frac{8}{L^3} \prod_{i=x,y,z} \frac{\sin(k_i L/2)}{k_i^3} \right)^2}$$

  - Doesn't preferentially pick out high density peaks (c.f. FOF)
  - Fast computation
- For full details see AA et al. (2008) 2008, MNRAS, 389, 1739



$$\boxed{\begin{aligned} v_{sm} &= \langle v_i \rangle \\ \varepsilon_{sm} &= \frac{\langle \varepsilon_i \rangle}{\sqrt{n}} \end{aligned}}$$

Velocity correlation function

- From the linear relation between velocity and density field

$$v(k) = -i\ a(t)\dot{a}(t)\frac{k}{k^2}\partial(k)\frac{dD}{da}$$

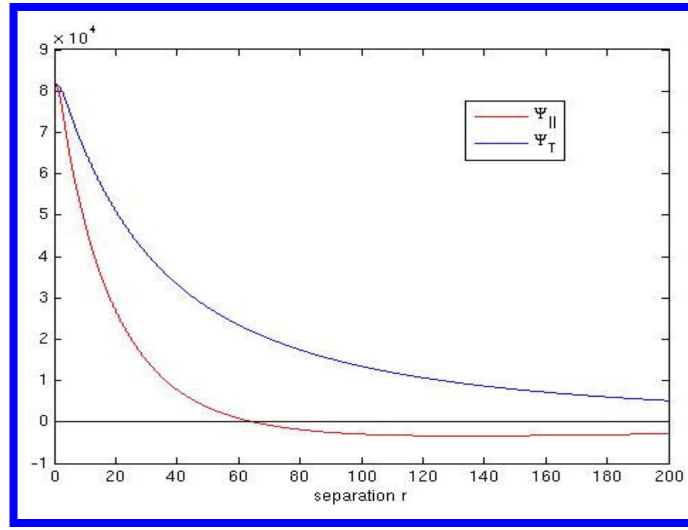
- Can show that:

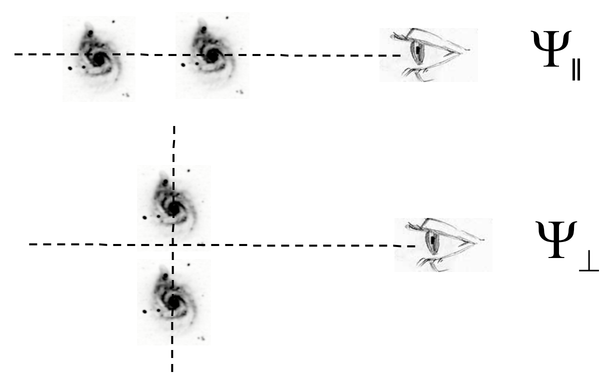
$$\xi_{ij} = \left\langle (v_i \cdot \hat{r}_i)(v_j \cdot \hat{r}_j) \right\rangle = \sin\theta_i \sin\theta_j \Psi_{\parallel} + \cos\theta_i \cos\theta_j \Psi_{\perp}$$

  - where: $\cos\theta_X = \hat{r}_X \cdot \hat{r}$

$$\Psi_{\parallel} = \frac{\left(H_0 \Omega_m^{\gamma}\right)^2}{2\pi^2} \frac{j_0^{'}(kr)}{kr} \int P(k) W^2(k)\ dk$$

$$\Psi_{\perp} = \frac{\left(H_0 \Omega_m^{\gamma}\right)^2}{2\pi^2} j_0^{''}(kr) \int P(k) W^2(k)\ dk$$





Likelihood analysis

- Likelihood function

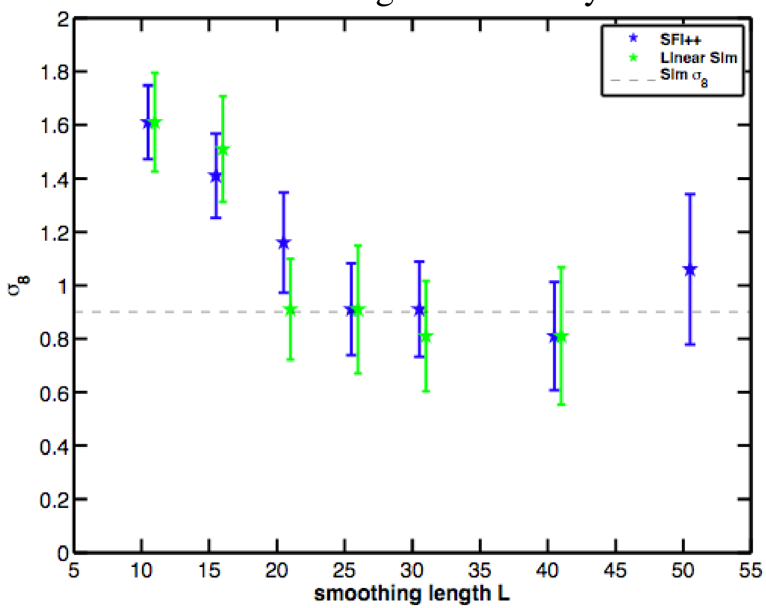
velocity correlation function of grid cells

$$L(\Theta) = \frac{1}{\sqrt{(2\pi)^N \det\left[\xi_{ij}(\Theta)\right]}} \exp\left(-\frac{1}{2}\sum_{i,j}^{N} v_i\, \xi_{ij}^{-1}(\Theta) v_j\right)$$

model parameters

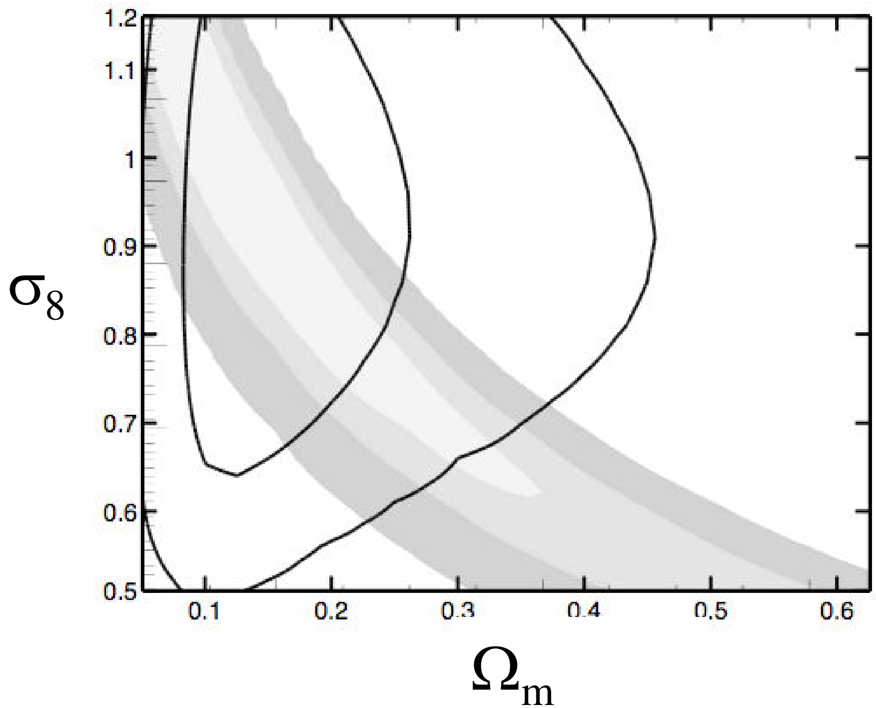
average cell velocity

- Smoothing method was rigorously tested in AA et al. (2008)
- Double check smoothing method for SFI++:
  - Vary σ_8 only
  - Blue points: SFI++ data
  - Green points: simulation of SFI++ data (σ_8=0.9)
- Optimum L=25Mpc/h



Parameter constraints

- Marginalised constraints
  - $\sigma_8 = 0.91^{+0.22}_{-0.18}$
  - $\Omega_m = 0.13^{+0.10}_{-0.04}$
  - Consistent with ΛCDM to 1-σ
- Contours
  - Solid contours: our constraints
  - grey-scale contours: 100 deg^2 weak lensing survey
- Comparison to other PV estimates
  - Gordon, Land & Slosar (2007) using 124 SN1a $\sigma_8 = 0.79 \pm 0.22$
  - Watkins, Feldman & Hudson (2009) 2-σ limit $\sigma_8 \approx 1.7 \pm 0.59$

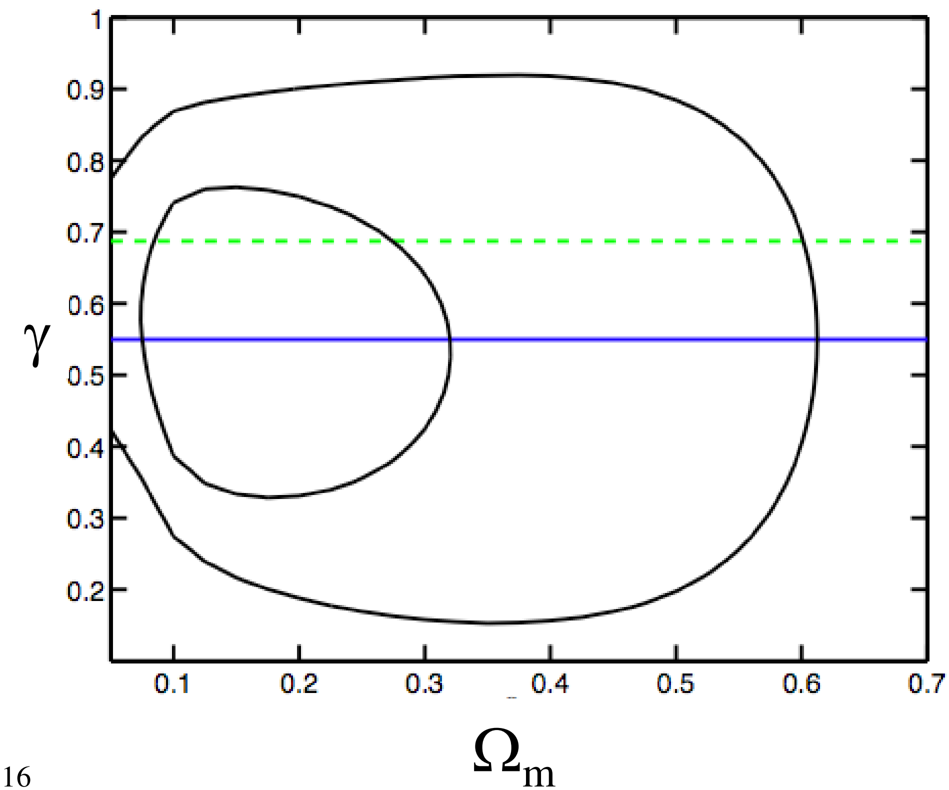


Growth Index γ

- In linear theory, the velocity field is directly related to the growth of structure
- At low redshift

$$\xi_{ij} \propto f^2(\Omega_m) \approx \Omega_m^{2\gamma}$$

- LCDM γ=0.55; DGP γ =0.69
- Marginalised constraint
  - γ=0.55±0.14
- Consistent with other constraints
  - Rapetti et al. (2008) $\gamma = 0.51^{+0.16}_{-0.15}$
  - Nesseris & Perivolaropoulos (2008) $\gamma = 0.67^{+0.20}_{-0.17}$



Conclusions

- Galaxy and SN1a peculiar velocities can provide a low redshift anchor for measuring the evolution of the growth of structure.
- Their sensitivity to the derivative of the growth function mean they are a useful tool for detecting departures from LCDM.
- Our constraints are consistent with many other constraints found in the literature, and with LCDM. However the constraints come from a mix of scales, and are dominated by the smaller scales. Any departure from LCDM on larger scales (> 100Mpc/h) will not be well tested by this data set.
- Because peculiar velocities will be subject to different systematic effects to other probes such as cluster-counts, weak lensing or redshift distortions, they are an important complementary probe of cosmology.

Future velocity field studies

- 6dFGS galaxy velocity data release
  - Expect around 10,000 velocities out to z~0.055
  - Soon!
- SN1a
  - Larger future data sets from SNFactory, SkyMapper, GAIA
- Kinematic Sunyaev-Zeldovich effect
  - Compton scattering of CMB photons by hot electrons in galaxy cluster gas
  - Can measure temperature shift of CMB photons -> line of sight momentum of the cluster
- Redshift distortions
  - Flattening of large scale structures in redshift space is caused by peculiar velocities
  - A systematic error when measuring BAO (with spec-z)
  - BUT can be modelled and contains cosmological information!