Testing the cosmological model using the growth rate of structure in the local universe

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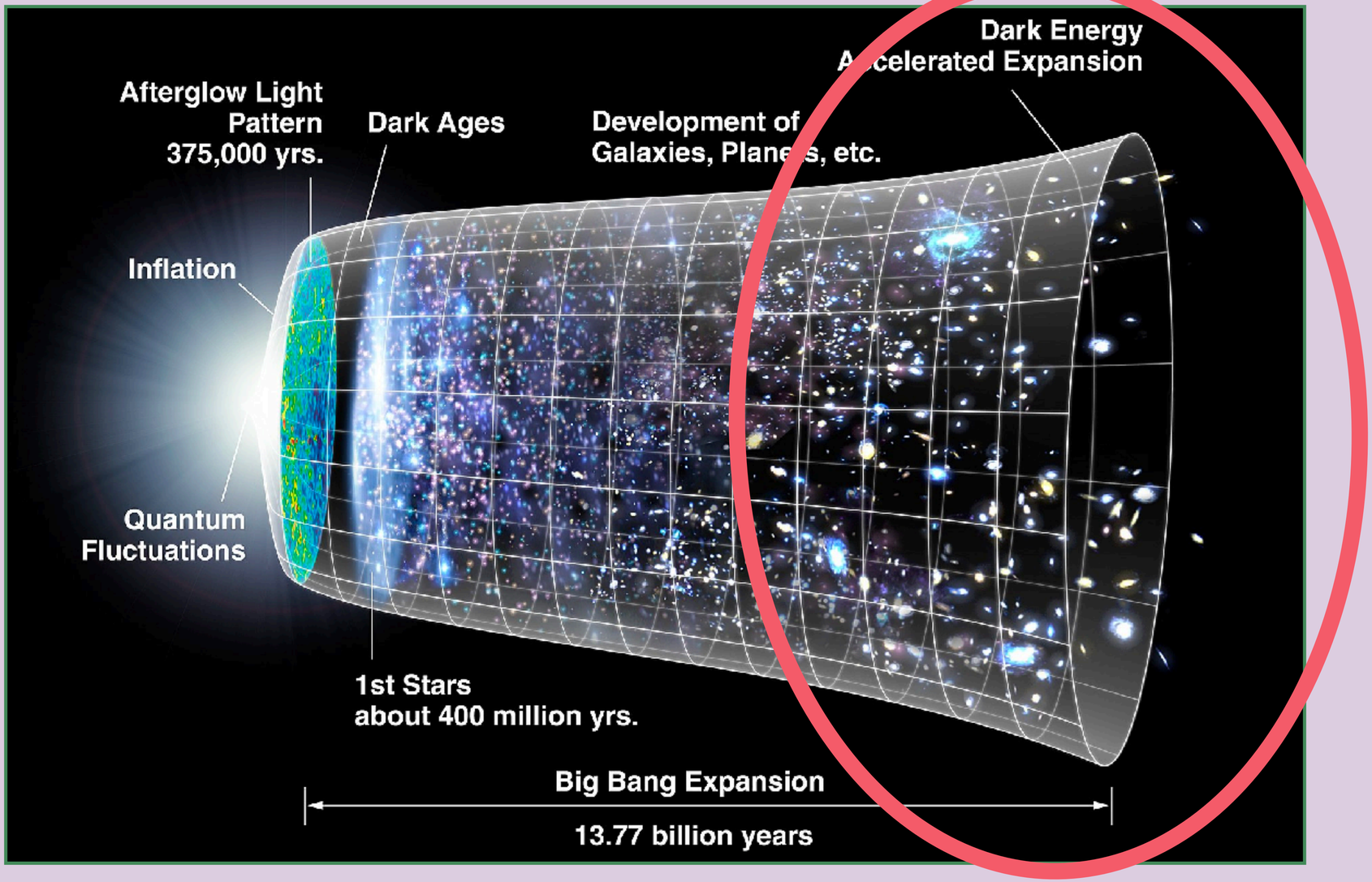
A Brief Introduction



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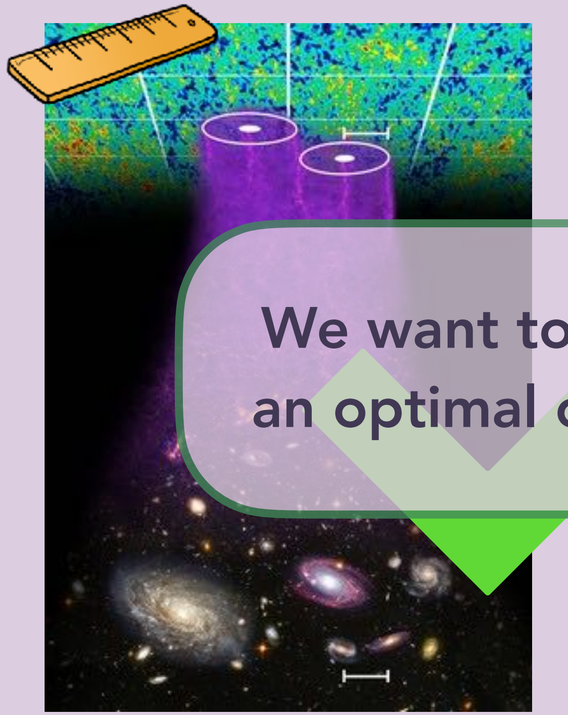
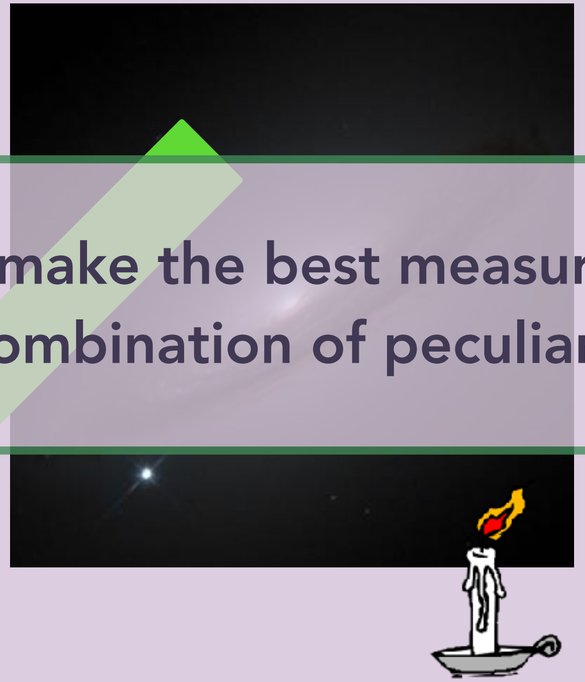
Expansion and growth

The current rate of expansion of the Universe is accelerating and we don’t know why

How can we test the standard model, and look for the effects of (potential) new gravitational physics?

Expansion of the Universe

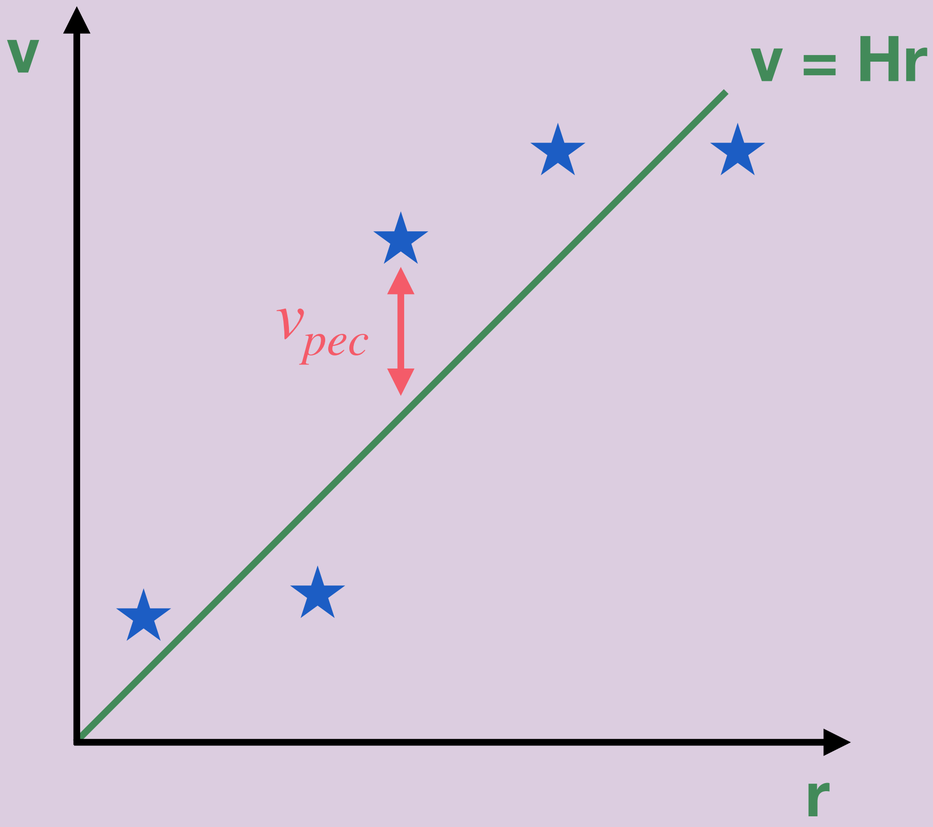




Growth of structure

We want to make the best measurement of the local growth rate through an optimal combination of peculiar velocity and galaxy clustering statistics

Peculiar velocities



$$1 + z_{obs} = (1 + z_{cos}) \cdot (1 + v_{pec}/c)$$

Can be measured directly from standard candle measurements

Probe fluctuations of gravitational physics, linking motion to the underlying matter distribution on the largest scales

f = Growth rate of structure

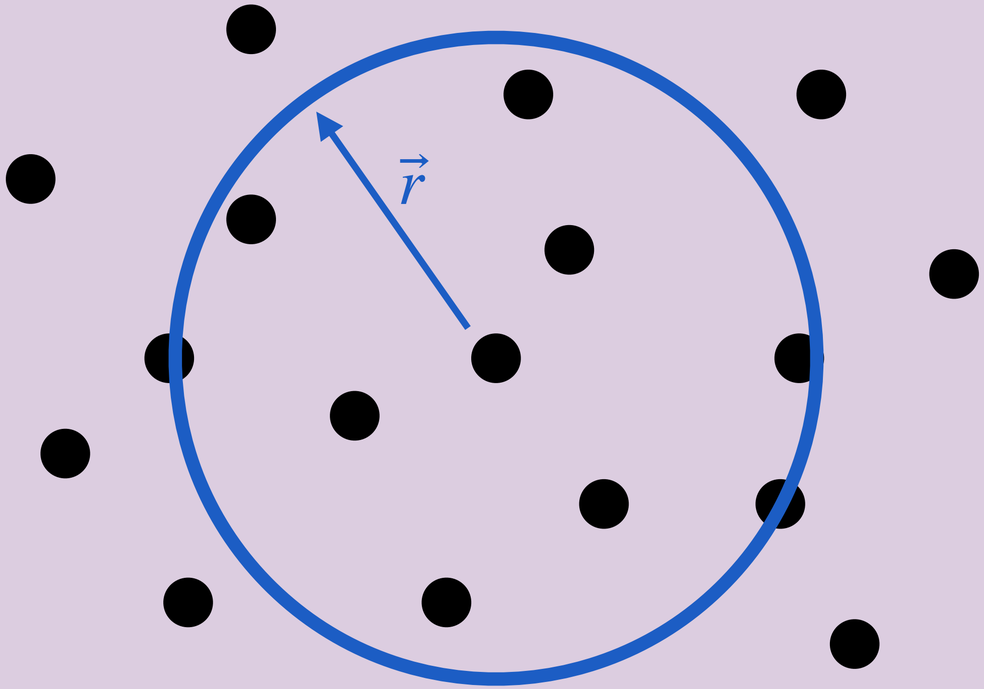
σ_8 = Amplitude of fluctuations

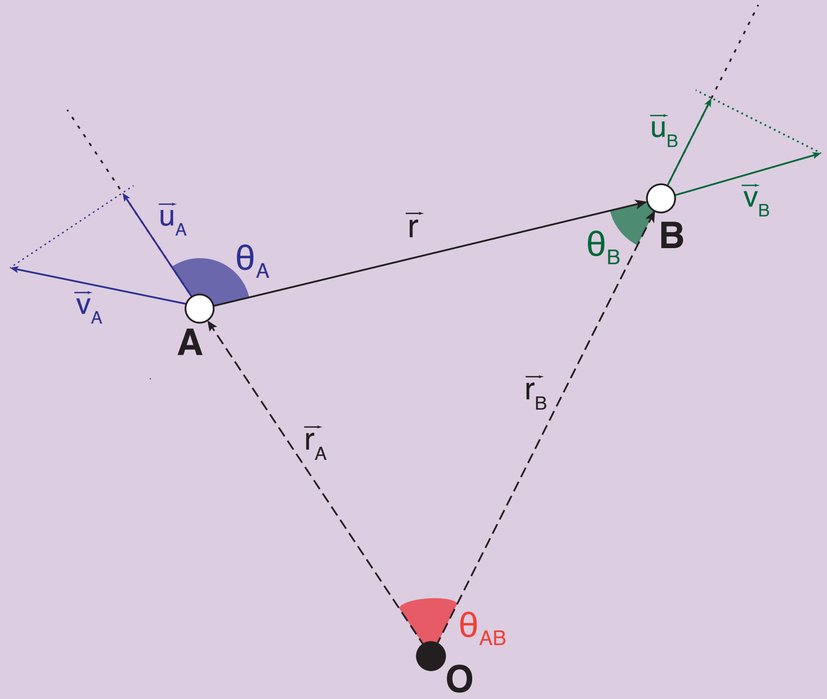
Different theories of gravity predict different behaviours

Correlation functions

Galaxy-galaxy correlation function

Tendency for galaxies at a given separation to cluster under the influence of gravity





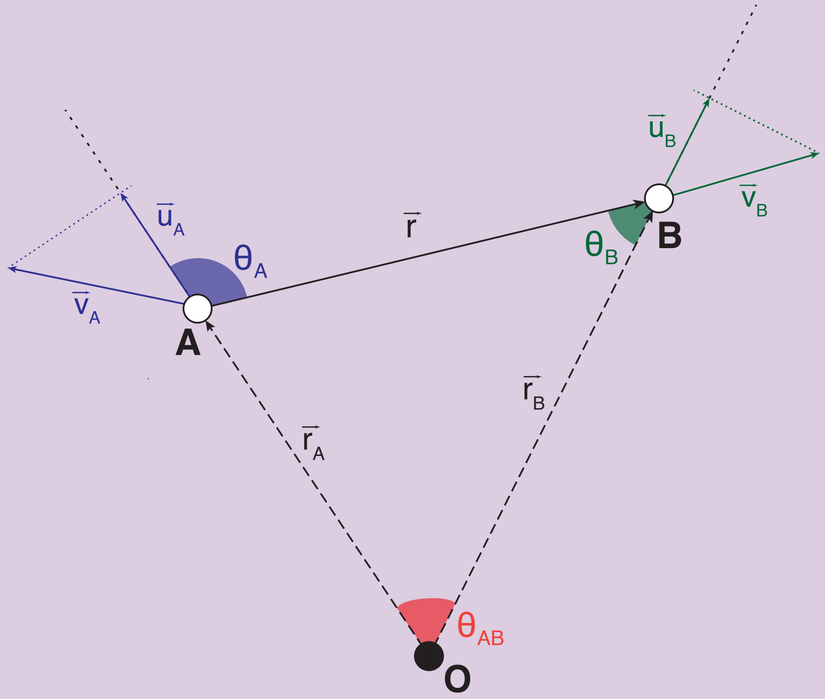
Galaxy-galaxy correlation function is the average measure of these correlations: $\langle \delta_A \delta_B \rangle$

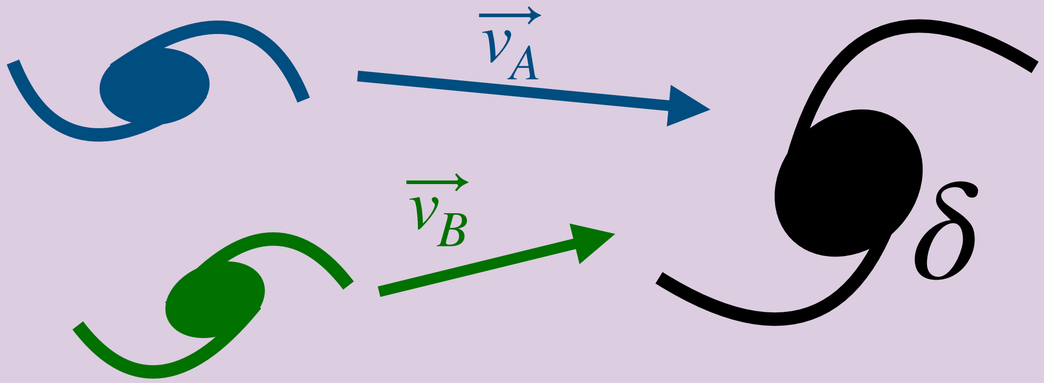
Correlation functions

Velocity-velocity correlation function

Velocities of galaxies are correlated due to the force of gravity acting on them

Velocity correlation function is the average measure of these correlations: $\langle v_A v_B \rangle$



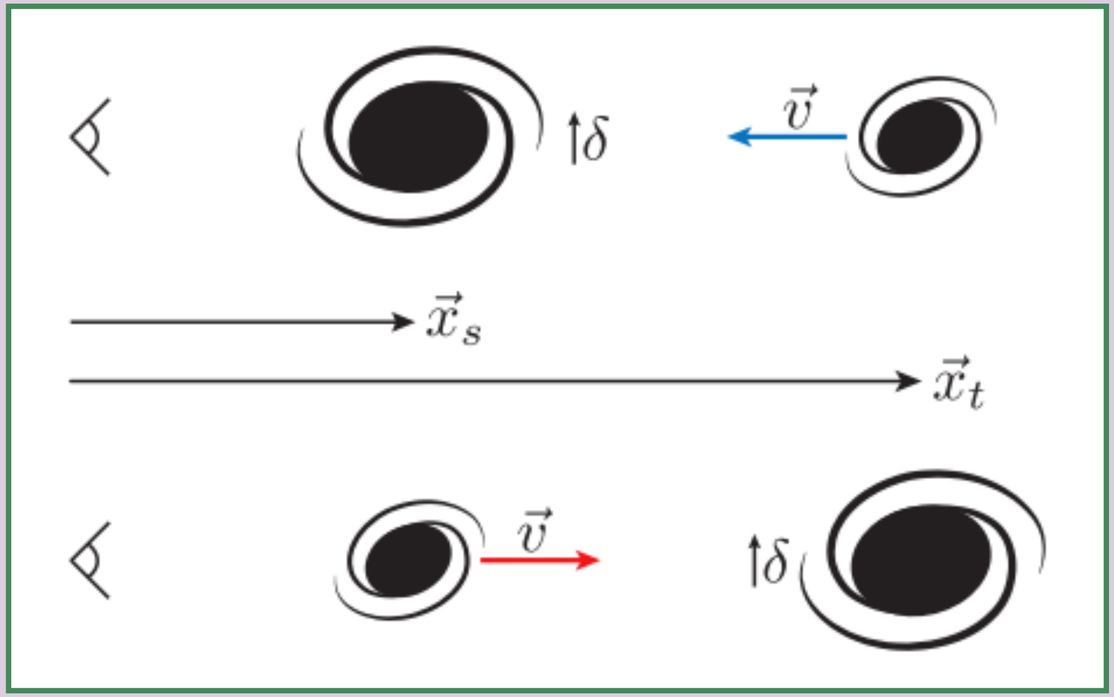


We measure ψ_1 and ψ_2 , characterising correlations between radial velocities both perpendicular and parallel to the line of sight

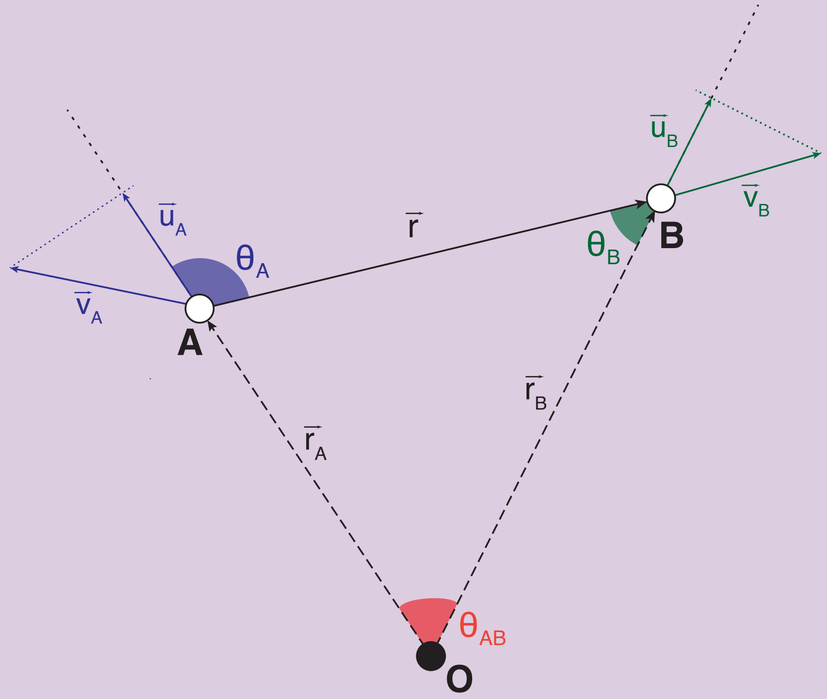
Correlation functions

Galaxy-velocity correlation function

Increasing the matter overdensity at a point will pull galaxies towards it through gravity



Adams & Blake (2017)



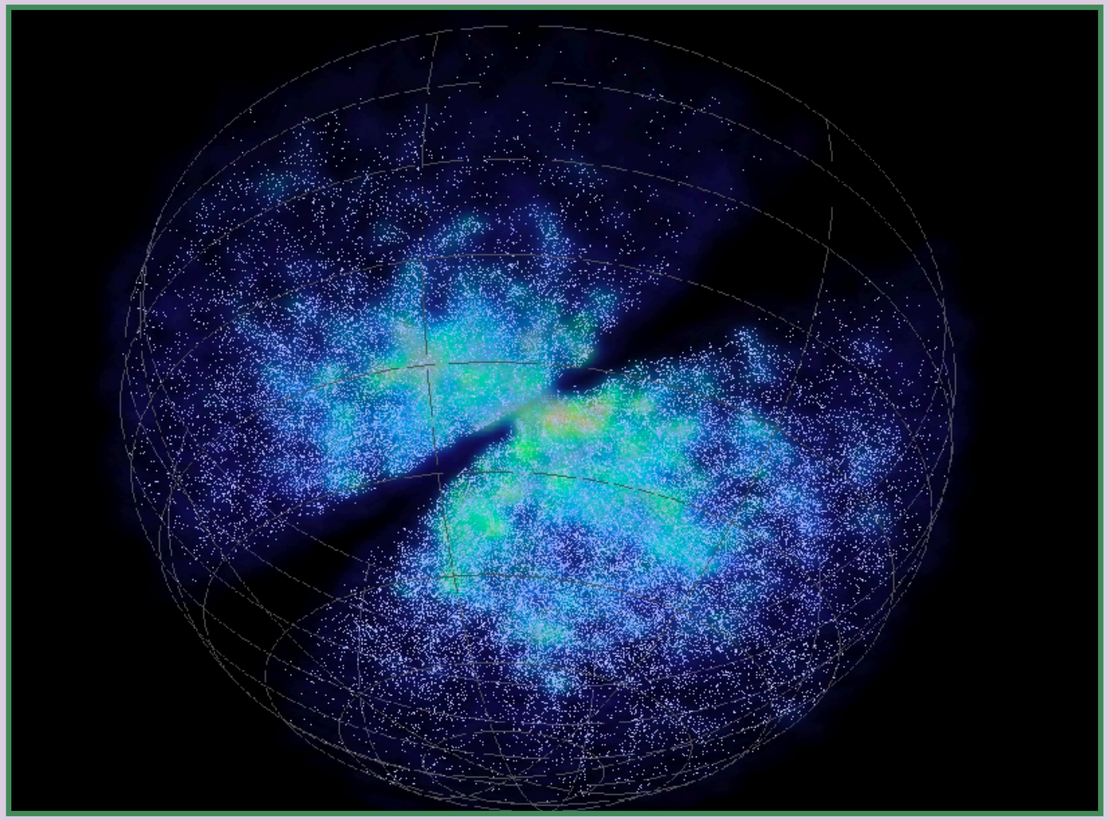
Galaxy-velocity correlation function is the measure of this average infall: $\langle v_r \rangle$

6dFGS

6-degree Field Galaxy Survey - consists of a redshift survey (6dFGSz) containing 125 071 galaxies and a velocity survey (6dFGSv) containing 8885 galaxies

Covers southern sky (|b| > 10°), 41% of total sky

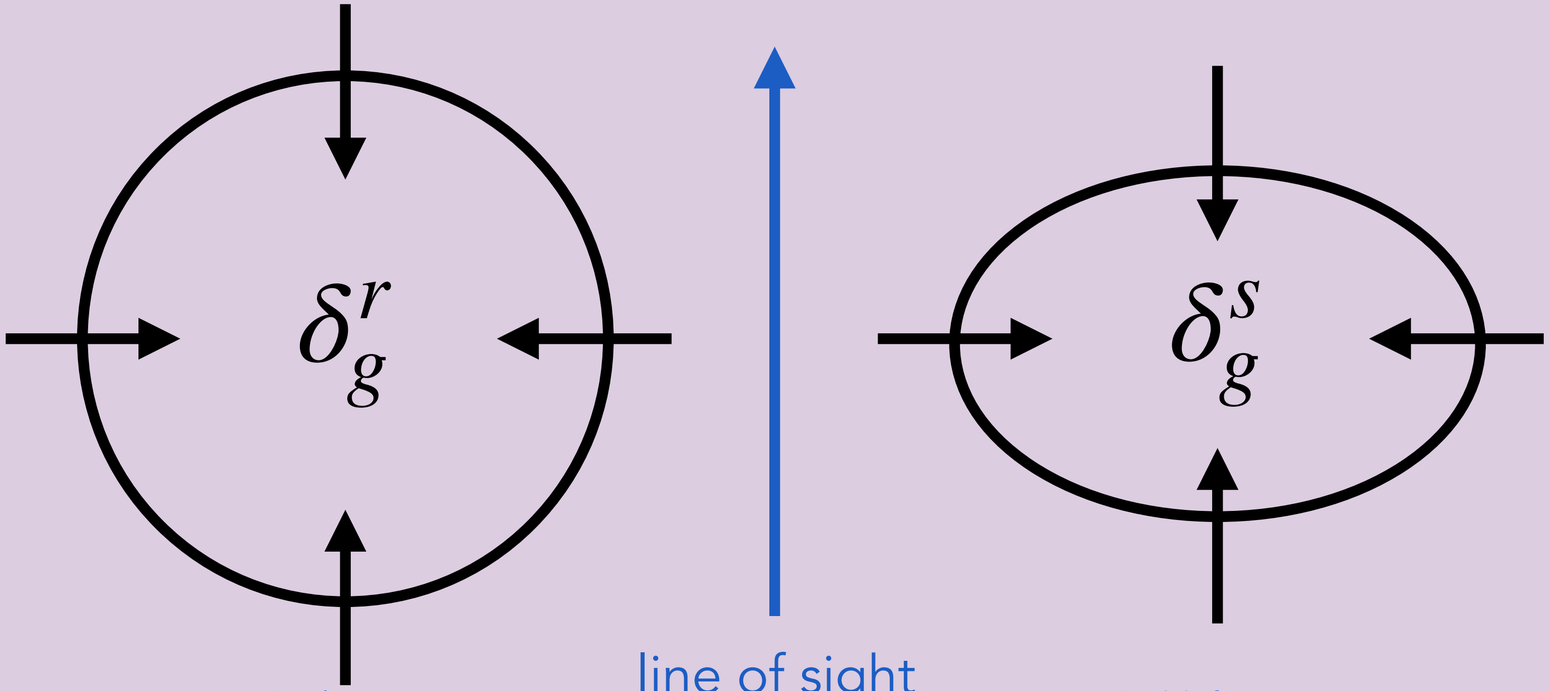
Median redshift of z = 0.053

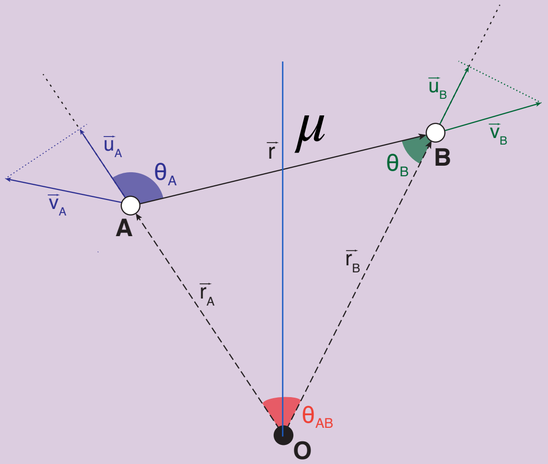


Redshift Space Distortions
RSD

Another source of growth information is to measure the redshift-space distortions (RSD) in the clustering distribution of galaxies in redshift space

$$1 + z_{obs} = (1 + z_{cos}) \cdot (1 + v_{pec}/c)$$





Amplify galaxy overdensities, imprinting dependence on the angle to the line of sight, μ

$$\delta_g^s(k) = [1 + f\mu_k^2]\, \delta_g^r(k)$$

Linear RSD theory is able to measure $f\sigma_8$ and $b\sigma_8$

$$\delta_g^s(k) = [1 + f\mu_k^2]\delta_g^r(k) \qquad (P_{mm}(k) \propto \sigma_8^2)$$

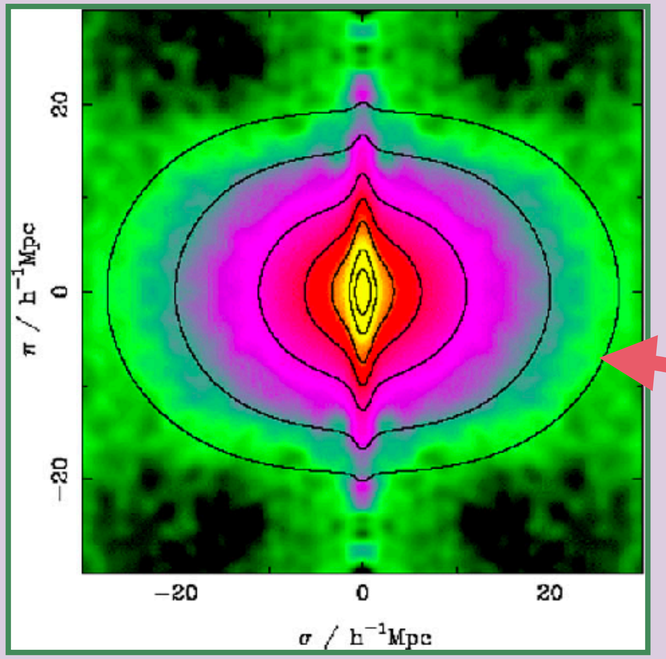
$$P_{gg}(k,\mu) = (b + f\mu^2)^2 P_{mm}(k)$$

$$P_{g\theta}(k,\mu) = (b + f\mu^2) f P_{mm}(k)$$

$$P_{\theta\theta}(k) = f^2 P_{mm}(k)$$

b = Linear galaxy bias

Virialised motion



Coherent flows

Peacock et al. (2001)

We can capture the cosmological information contained in RSD via the multipole moments of the galaxy-galaxy auto-correlation and galaxy-velocity cross correlation

$$\xi_{gg}^{\ell}(r) = \frac{i^{\ell}}{2\pi^2}\int dk\, k^2 j_{\ell}(kr) P_{gg}^{\ell}(k)$$

$$\ell = 0, 2$$

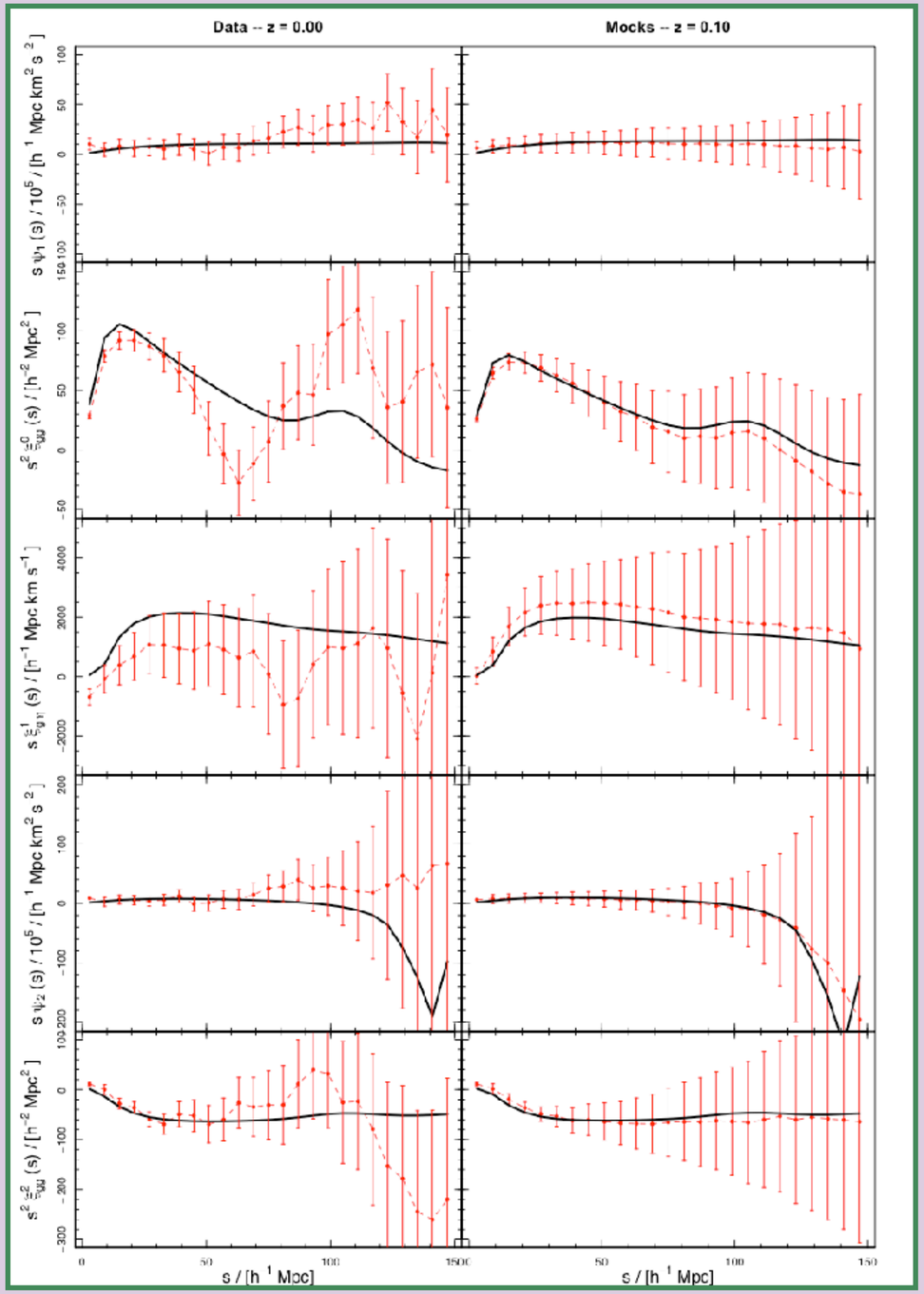
$$\xi_{gu}^{1}(r) = -\frac{aH}{2\pi^2}\int dk\, k j_1(kr)\left(P_{g\theta}^{0}(k) + \frac{2}{5}P_{g\theta}^{2}(k)\right)$$

$$\xi_{gu}^{3}(r) = \frac{aH}{2\pi^2}\int dk\, k j_3(kr)\left(\frac{3}{5}P_{g\theta}^{2}(k) + \frac{4}{9}P_{g\theta}^{4}(k)\right)$$

$$\psi_{\parallel}(r) = \frac{H^2a^2f^2}{2\pi^2}\int dk\, P_{\theta\theta}(k)\frac{j_1(kr)}{kr}$$

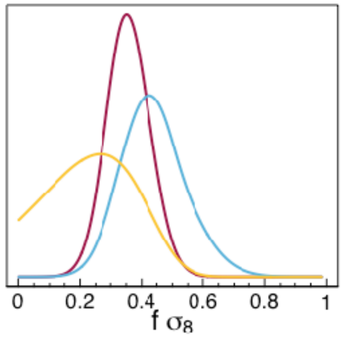
$$\psi_{\perp}(r) = \frac{H^2a^2f^2}{2\pi^2}\int dk\, P_{\theta\theta}(k)\left(j_0(kr) - 2\frac{j_1(kr)}{kr}\right)$$

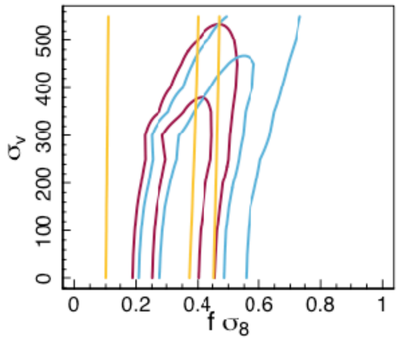
Turner et al. submitted

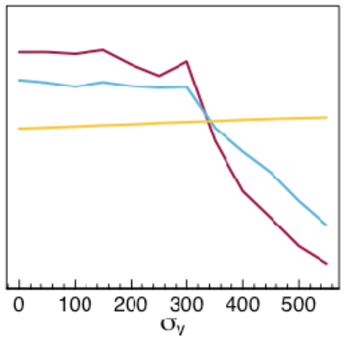


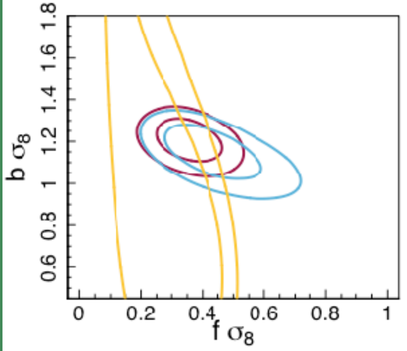
Results

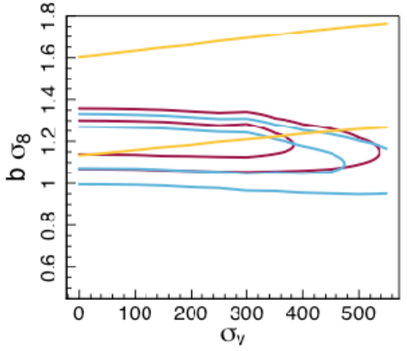
Turner et al. submitted

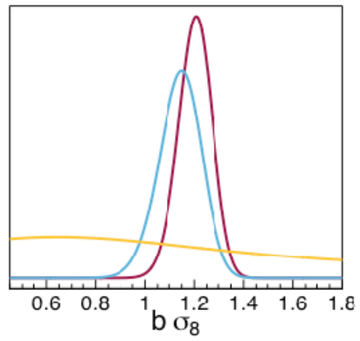












Fitting range:

27 < s < 123 Mpc/h

$\xi^0_{gg} + \xi^2_{gg}$

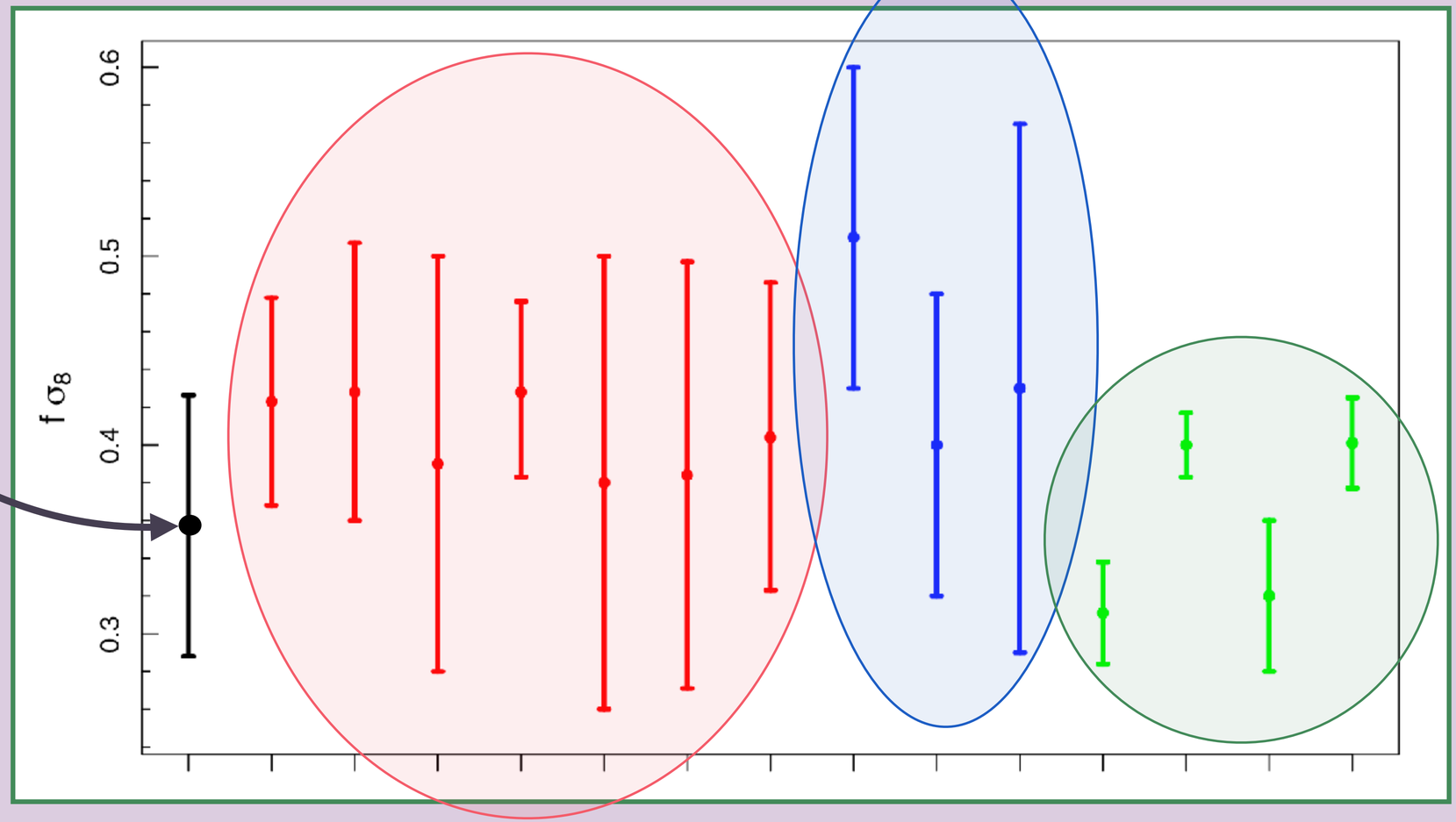
$\psi_1 + \psi_2 + \xi^1_{gu}$

Full five-model fit

Comparisons with recent work

non-6dFGS results

Turner et al.
(submitted)



Velocity-density
reconstructions

Turner et al. submitted

6dFGS results

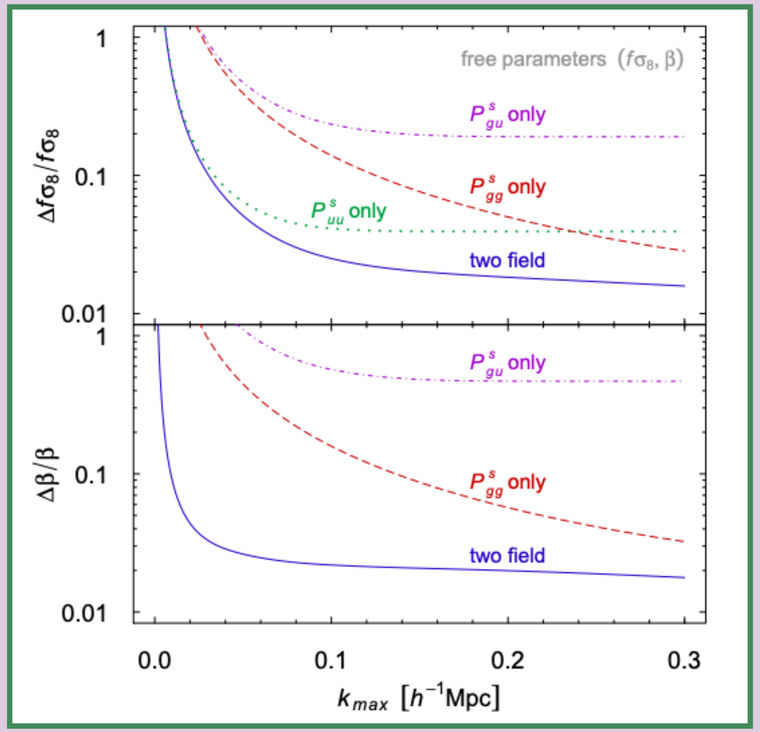
Constraints from future surveys

Cosmic expansion has been measured with **~1% accuracy**, but what about the growth of structure?

Turner, Blake & Ruggeri (2021) predict measurements of $f\sigma_8$ with **~15% measurement error** using a joint analysis of galaxy and velocity cross-correlation and auto-correlation functions

Koda et al. (2013) and **Howlett, Staveley-Smith & Blake (2017)** both forecast that the combination of future redshift and peculiar velocity surveys (two-field) could reach **<3% measurement error**

Koda et al. (2013)



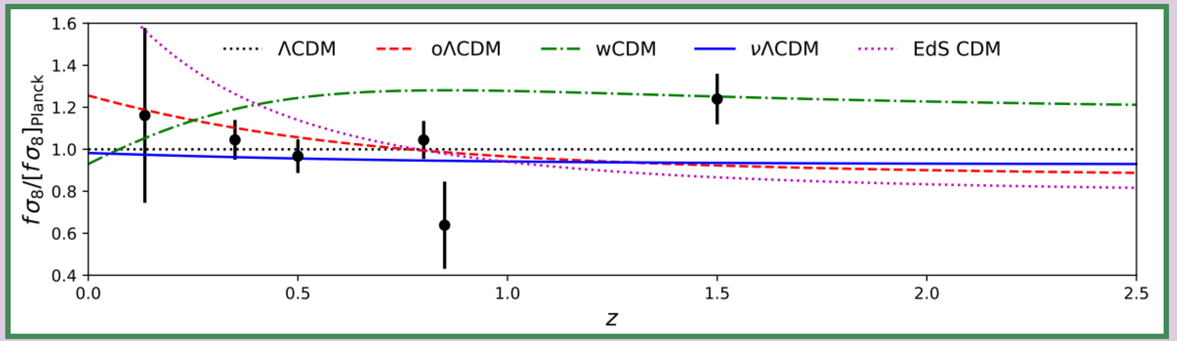
Future surveys will map (nearly) all PVs

Combining DESI and 4MOST Hemisphere survey:

- ~34 000 sq deg covered out to limit of FP
- ~650 000 measured velocities

Feasible that we will be able to measure the growth rate with 2% error in the next decade

eBOSS Collaboration (2020)



Summary

We can combine the effects of RSD with the galaxy-velocity cross-correlation function in order to constrain the growth rate of structure

We can capture this information in multipole moments of the correlation functions

By combining velocity information with RSD information we can produce tighter constraints than if we only considered RSD

Our fits to all five models produced smaller contours than the fit to $\xi^0_{gg} + \xi^2_{gg}$

Our method produces results in agreement with those from recent literature

Other results obtain $f\sigma_8$ from various datasets and methodologies

The method can also be easily scaled up to much larger, future surveys (DESI, 4HS) and can potentially produce measurements of the growth rate with ~2% uncertainty

In the next decade or so we will have ~650 000 velocities with which to make measurements of $f\sigma_8$