Tracing the peculiar velocity field through the galaxy luminosity function at $z \sim 0.1$

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(with Adi Nusser and Enzo Branchini; arXiv:1405.6710)

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Outline

1. Motivation / Methodology
   - Peculiar velocities from LF variations
   - Estimating power spectra
2. Application to SDSS DR7
3. Conclusions

Peculiar velocities from LF variations

Basic concept

- Peculiar motion introduces systematic variations in the observed luminosity distribution of galaxies (Nusser et al. 2011; Tammann et al. 1979)

$$M = M_{\rm obs} + 5\log_{10}\frac{D_L(z_{\rm obs})}{D_L(z)}$$

- To first order in linear theory ($c = 1$):

$$\frac{z_{\rm obs} - z}{1 + z_{\rm obs}} = V(t,r) - \Phi(t,r) - {\rm ISW} \approx V(t,r)$$

- Maximize probability of observing galaxies given their magnitudes and redshifts:

$$\log P_{\rm tot} = \sum_i \log P_i(M_i|z_i, V_i) = \frac{\phi(M_i)}{\int_{a_i}^{b_i}\phi(M)dM}$$

- Method **independent** of galaxy bias and traditional distance indicators
- However: meaningful results require large number statistics

  → large galaxy (spectroscopic or photometric) redshift surveys

Peculiar velocities from LF variations

Velocity model and large-scale power estimation

- Our approach: sample velocity field in redshift bins: $V(t, \mathbf{r}) \to \tilde{V}(\hat{\mathbf{r}})$
- Expand binned velocity field in SHs:

$$\tilde{V}(\hat{\mathbf{r}}) = \sum_{l,m} a_{lm} Y_{lm}(\hat{\mathbf{r}})$$

- For large galaxy numbers, likelihood function is well approximated by a Gaussian (simplifies computation enormously):

$$\log P_{\mathrm{tot}}(\mathbf{d}|\mathbf{x}) \approx -\frac{1}{2}(\mathbf{x}-\mathbf{x}_0)^T \Sigma^{-1}(\mathbf{x}-\mathbf{x}_0) + \mathrm{const}, \quad \text{where } \mathbf{x}^T = \left(\{q_j\}, \{a_{lm}\}\right)$$

- Marginalize over LF parameters $\{q_j\}$ and construct posterior for $C_l = \left\langle |a_{lm}|^2 \right\rangle$ by applying Bayes' theorem:

$$P\left(\{C_l\}\right) \propto \int P\left(\mathbf{d}|\{a_{lm}\}\right) P\left(\{a_{lm}\}|\{C_l\}\right) da_{lm}$$

- Assume $\{a_{lm}\}$ as normally distributed
- For a ΛCDM model prior, $C_l = C_l\left(\{c_k\}\right)$:

$$C_l = \frac{2}{\pi} \int dk k^2 P_\Phi(k) \left| \int dr W(r) \left(\frac{l j_l}{r} - k j_{l+1} \right) \right|^2$$

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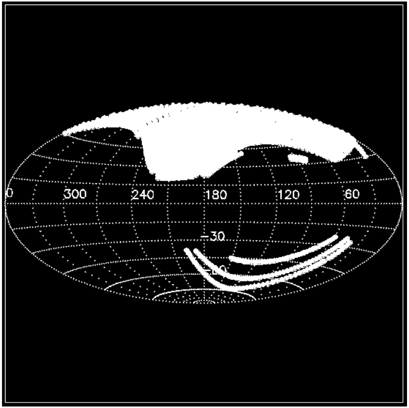
2. Application to SDSS DR7
   - "Bulk flows"
   - Estimating C_l's
   - Cosmological constraints
3. Conclusions

SDSS Data Release 7 Galaxy Catalog

NYU Value-Added Galaxy Catalog (Blanton et al. 2005)



- Use r-band magnitudes (Petrosian)
- $14.5 < m_r < 17.6$
- $-22.5 < M_{\text{obs}} < -17.0$
- Consider two velocity bins:

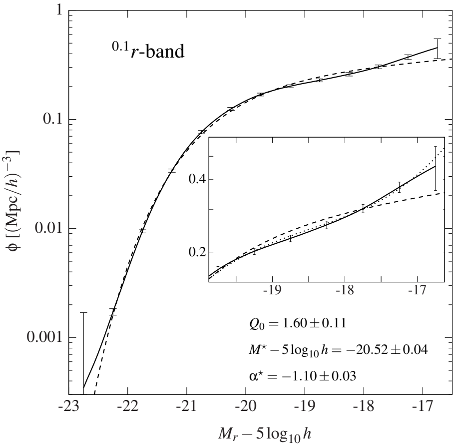
  $0.02 < z_1 < 0.07 < z_2 < 0.22$
- $N_1 \sim 1.5 \times 10^5$, $N_2 \sim 3.5 \times 10^5$
- Adopt pre-Planck cosmological parameters (Calabrese et al. 2013)

- Realistic mocks for testing

  → SDSS footprint
  → photometric offsets between stripes
  → overall tilt over the sky

LF estimators

“Non-parametric” spline-estimator of $\phi(M)$

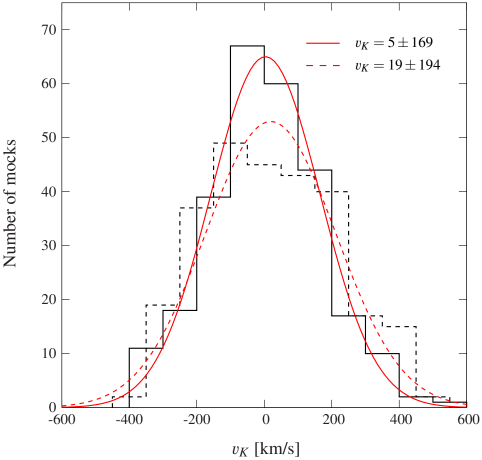


- Normalization unimportant for our analysis
- Two-parameter Schechter function does quite well
- To reduce errors, adopt more flexible form for $\phi(M)$
- Model $\phi(M)$ as a spline with sampling points $\{\phi_j(M)\}$ for $M_j < M < M_{j+1}$
- Advantage: smoothness, nice analytic properties for integrals / derivatives)
- Parameterize luminosity evolution:

$$e(z) = Q_0(z - z_0) + \mathcal{O}\left(z^2\right)$$

"Bulk flow" estimates for SDSS DR7

Mocks versus data



Estimates for the "dipole"

- Mask allows only measurement of combined multipoles
- First z-bin:

$$v_x = -175\ (-227, -151) \pm 126 \text{ km/s}$$
$$v_y = -278\ (-326, -277) \pm 111 \text{ km/s}$$
$$v_z = -147\ (-239, -102) \pm 70 \text{ km/s}$$

- Second z-bin:

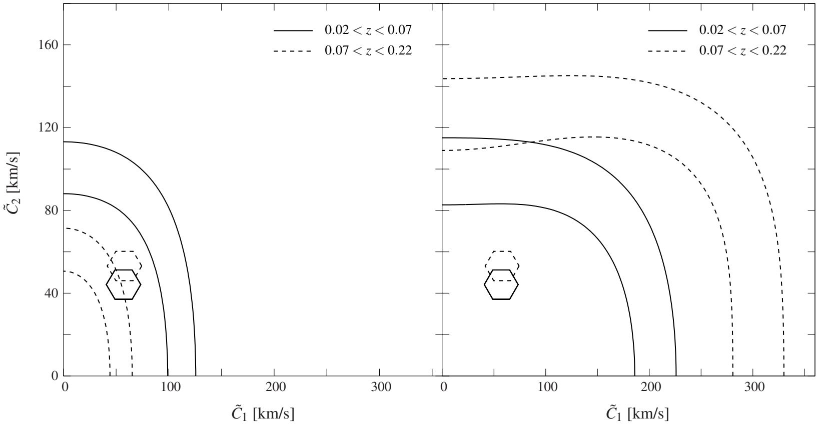
$$v_x = -340\ (-367, -423) \pm 90 \text{ km/s}$$
$$v_y = -409\ (-439, -492) \pm 81 \text{ km/s}$$
$$v_z = -45\ (-25, -150) \pm 69 \text{ km/s}$$

- "Kashlinsky-direction"

$$v_1 \approx 120 \pm 115 \text{ km/s}$$
$$v_2 \approx 355 \pm 80 \text{ km/s}$$

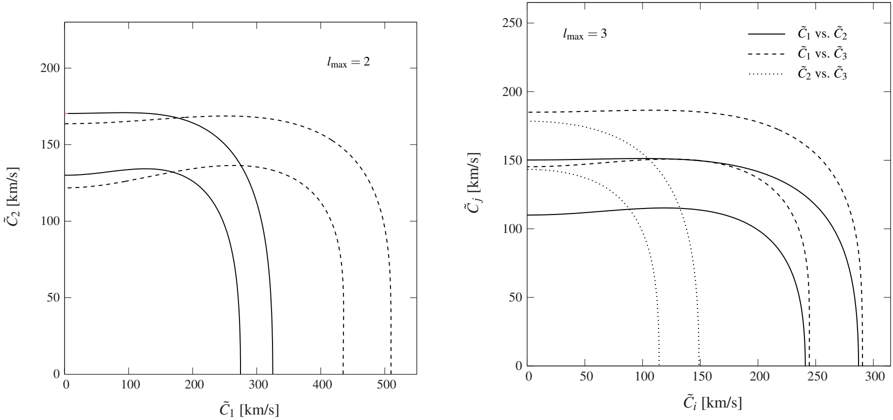
Constraints on the power spectrum

Influence of a photometric tilt (random mock, $l_{\max} = 2$)



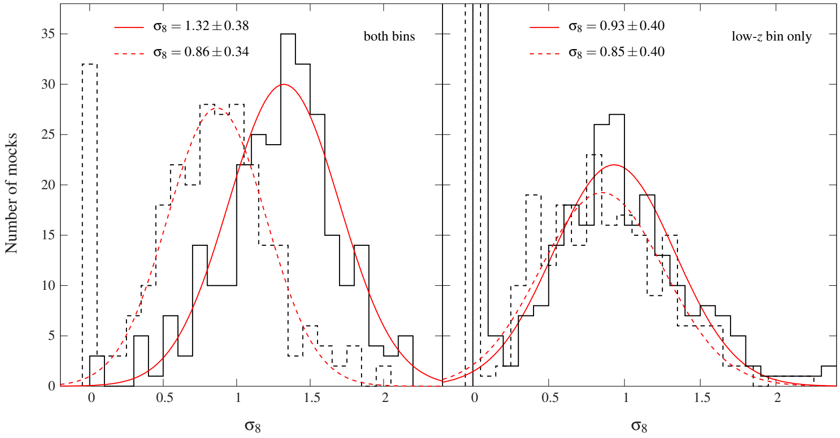
Constraints on the power spectrum

Results for SDSS data ($l_{max} = 2, 3$)



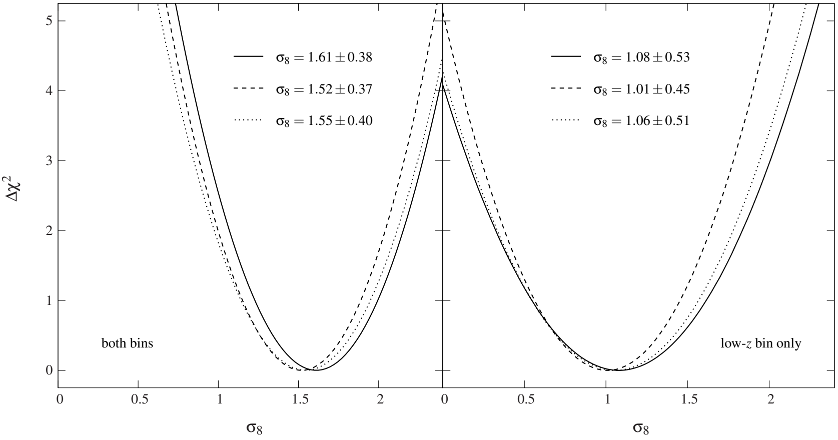
Constraints on σ_8

Results from mock analysis ($l_{\max} = 5$)



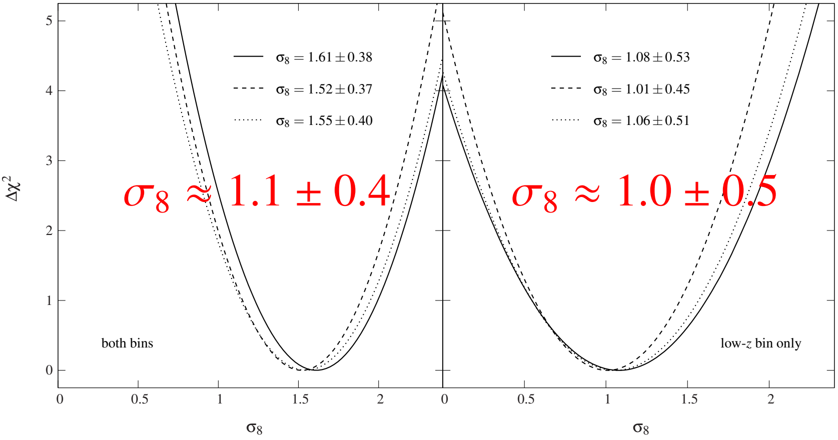
Constraints on σ_8

Results from SDSS data analysis ($l_{max} = 5$)



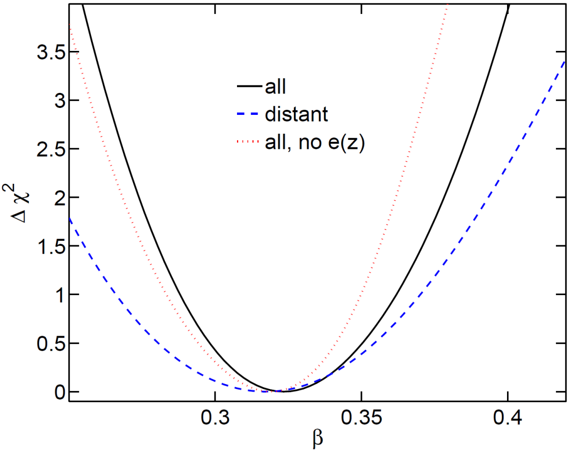
Constraints on σ_8

Results from SDSS data analysis ($l_{max} = 5$)



Alternative way to estimate the growth rate

Constraints on β in the local Universe from 2MRS (Branchini et al. 2012)



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Conclusions

- ML estimators extracting the large-scale velocity field through variations in the observed LF of galaxies offer a powerful and complementary alternative to currently used methods
- Especially at high redshifts, such approaches (appropriately modified) may provide the only way of collecting any meaningful information
- SDSS data are fully consistent with the standard ΛCDM cosmology
- Low-z results robust, high-z results in agreement with known 1% photometric tilt
- Findings are compatible with results from the Planck collaboration (upper BF limit ≈ 250 km/s at a 95% confidence limit)
- Method may be useful for checking / detecting systematics in photometric calibration
- To be tackled: environmental dependence of the LF, estimation of β through modeling of density field, new datasets