

Tracing the cosmic velocity field at $z \sim 0.1$ from galaxy luminosities in the SDSS DR7

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

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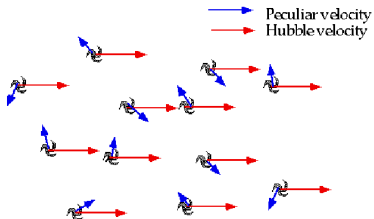


Outline

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

The large-scale peculiar velocity field

A cosmological probe



- No bias issues:
 - Galaxies are honest tracers
- Common approaches:
 - Velocity catalogs
 - SNe, kSZ effect
 - Systematics?
- Need for novel approaches
- Go beyond current limitations and simple BF estimation

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)

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

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

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

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

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

- 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: $V(t, \mathbf{r}) \rightarrow \tilde{V}(\hat{\mathbf{r}})$
- 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):

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

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

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

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

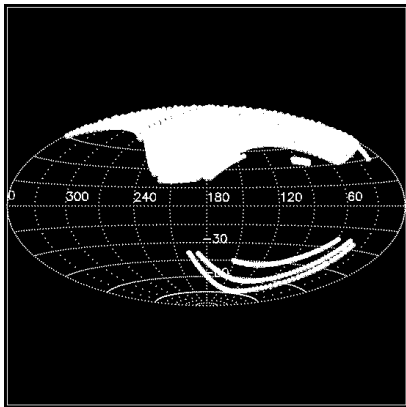
$$C_l = \frac{2}{\pi} \int dk k^2 P_{\Phi}(k) \left| \int dr W(r) \left(\frac{l_{jl}}{r} - k_{jl+1} \right) \right|^2$$

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 - “Bulk flows”
 - Estimating C_l 's
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SDSS Data Release 7 Galaxy Catalog

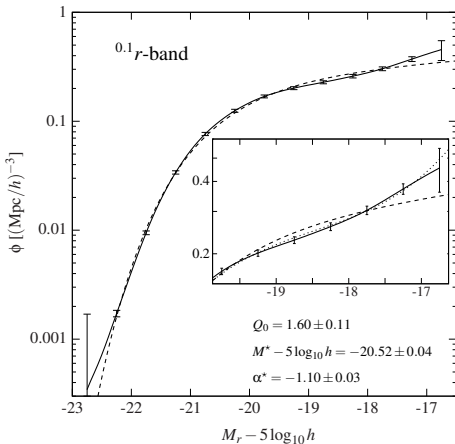
NYU Value-Added Galaxy Catalog (Blanton et al. 2005)



- 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 $\phi(M)$



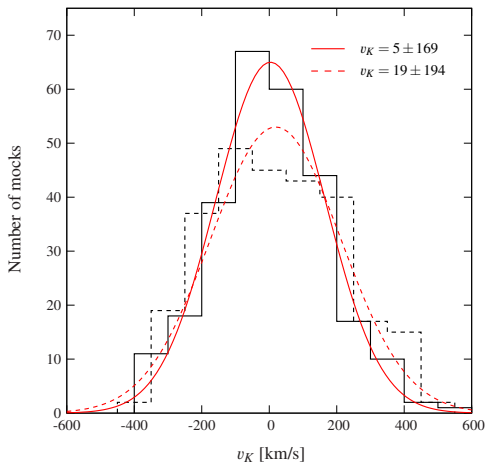
- Normalization unimportant for our analysis
- Two-parameter Schechter function does quite well
- To reduce errors, adopt more flexible form for $\phi(M)$
- Model $\phi(M)$ as a spline with sampling points $\{\phi_j(M)\}$ for $M_j < M < M_{j+1}$
- Advantage: smoothness, nice analytic properties for integrals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

$$e(z) = Q_0(z - z_0) + O(z^2)$$

“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:

$$v_x = -340 (-367, -423) \pm 90 \text{ km/s}$$

$$v_y = -409 (-439, -492) \pm 81 \text{ km/s}$$

$$v_z = -45 (-25, -150) \pm 69 \text{ km/s}$$

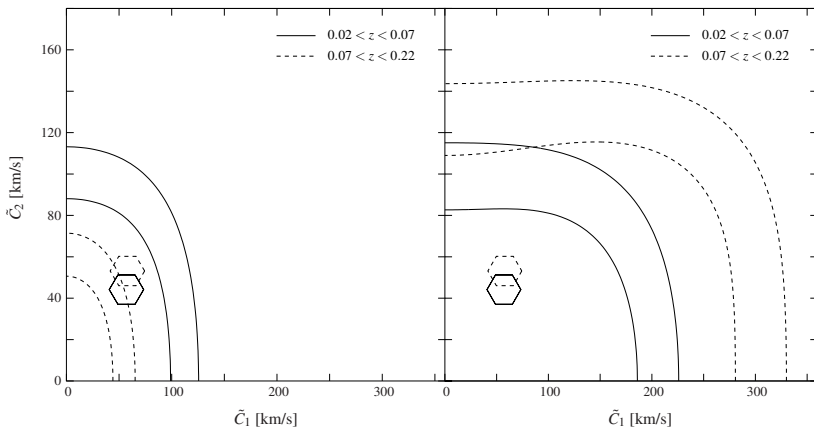
- “Kashlinsky-direction”

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

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

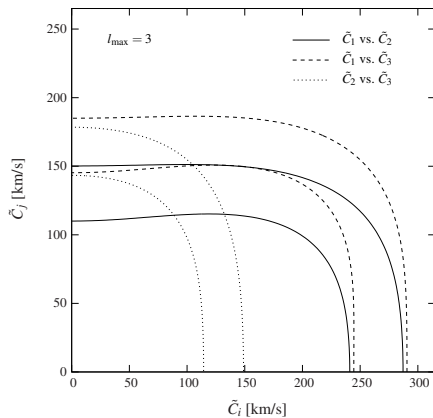
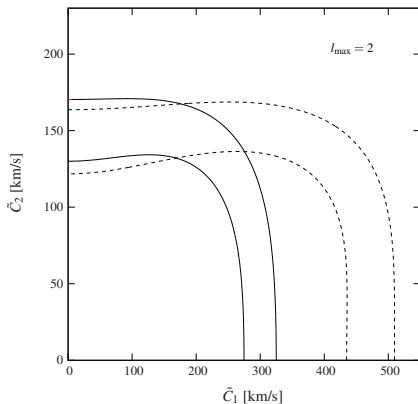
Constraints on the power spectrum

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



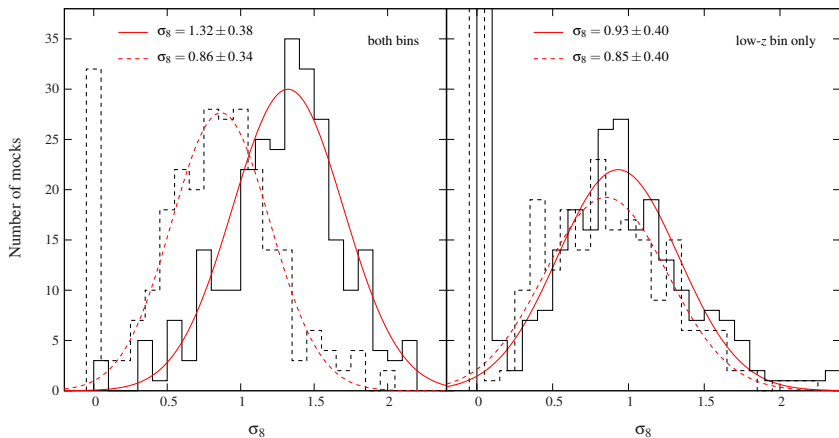
Constraints on the power spectrum

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



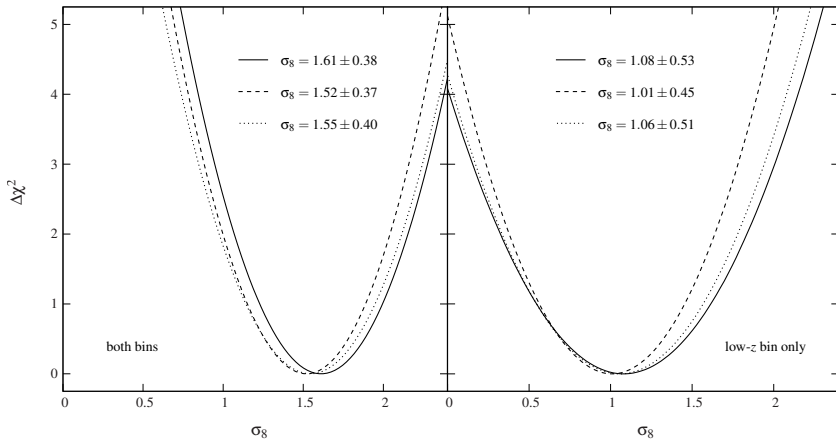
Constraints on σ_8

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



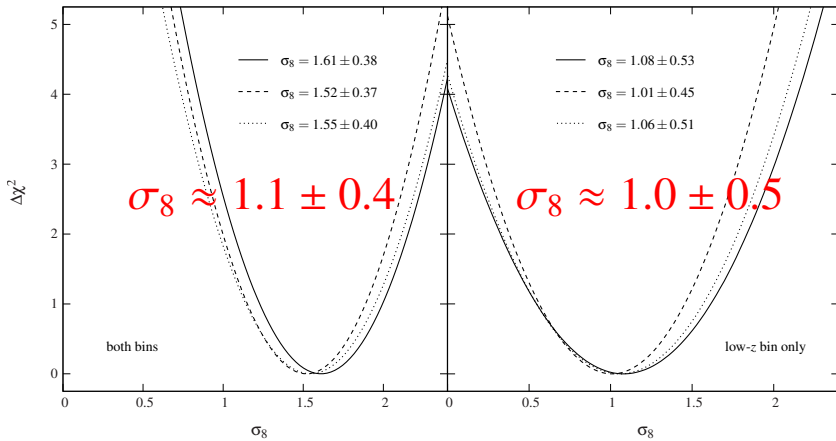
Constraints on σ_8

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



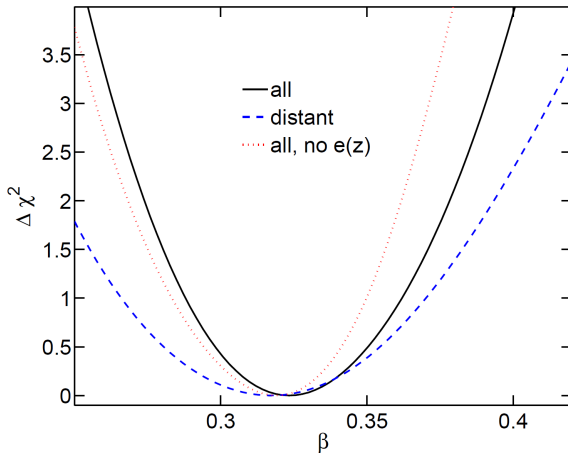
Constraints on σ_8

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 Λ CDM 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
- Currently tackled: environmental dependence of the LF, estimation of β through modeling of density field, new datasets