Peculiar velocities from the fundamental plane in SDSS

How far can we go?

Matt George
UC Berkeley / LBL

with David Schlegel and Uros Seljak
~80,000 early types at $z < 0.1$
with fundamental plane parameters

7600 deg.$^2$ over northern Galactic cap

Well-calibrated photometry, spectroscopy

Measurement errors:
1% flux
4% size
11% velocity dispersion
How far can we go?

Per object:
- Signal: $v_{\text{pec}} \sim 200 \text{ km/s}$
- Noise: $\sigma_{\text{DI}} \sim 0.2cz \sim 6000 \text{ km/s (}z/0.1\text{)}$

$$N_{\text{obj}} \sim 80,000(z_{\text{max}}/0.1)^3$$
(SDSS Main sample starts to be incomplete at $z\sim0.08$)

$$S/N = v_{\text{pec}}/(\sigma_{\text{DI}}/\sqrt{N_{\text{obj}}})$$
$$\sim 9\sqrt{z_{\text{max}}/0.1}$$

If systematics can be controlled, there is power in large $N$
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<th>Weak Lensing</th>
<th>Peculiar Velocities</th>
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<td>$\gamma$</td>
<td>$v_{\text{los}}$</td>
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<td>galaxy-galaxy lensing $&lt;\gamma \delta_g&gt;$</td>
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<td>cosmic shear $&lt;\gamma \gamma&gt;$</td>
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<td>S/N per object</td>
<td>$\sim 1/30$</td>
<td>$\sim 1/30 \times (0.1/z)$</td>
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<td>dominant stat. uncertainty</td>
<td>shape noise ($\sim 30%$)</td>
<td>scatter in distance indicator ($\sim 20%$ for FP)</td>
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<td>systematics</td>
<td>shear calibration, photo-zs, intrinsic alignments</td>
<td>FP fitting, Malmquist bias, velocity bias?</td>
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Fitting the Fundamental Plane

Must account for selection cuts and heteroskedasticity

Joint-normal distribution describes relationship between \( M, \log(R), \) and \( \log(\sigma_v) \)

10 parameter model: means, covariance matrix, and passive evolution in \( M \)

Maximize likelihood:

\[
P(x_i) = \frac{1}{(2\pi)^{N/2}|V + E_i|^{1/2}f_i} \exp\left[-\frac{1}{2}(\hat{x}_i^T(V + E_i)^{-1}\hat{x}_i)\right]
\]

\[
\mathcal{L} = \prod_i P(x_i)
\]

\( x_i = \{M, \log(R), \) and \( \log(\sigma_v)\}_i \)

\( V = \text{cov}[x] \)

\( E_i = \text{cov}[\sigma_{x_i}] \)

\( f_i = \text{renormalization for cuts} \)

Saglia 2001, Bernardi 2003
Mock Data

3-d Gaussian model is a good description of the data
Estimating Velocities from the Fundamental Plane

2-d example:
Assume shift is along y direction
Maximize $P(y|x)$
Estimating Velocities from the Fundamental Plane

2-d example:

Get covariance matrix
Estimating Velocities from the Fundamental Plane

2-d example:
Assume shift is along y direction
Estimating Velocities from the Fundamental Plane

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Observables and FP covariance matrix
\[ \mu \equiv \langle \{ M_r, \log(R_{deV}/\text{kpc}), \log(\sigma_v) \} \rangle \]
\[ \mathbf{x} \equiv \{ M_r, \log(R_{deV}/\text{kpc}), \log(\sigma_v) \} - \mu \]
\[ C_{FP} \equiv \text{cov}(\mathbf{x}) \]

The effect of velocities on FP observables
\[ \mathbf{x}^s \approx \mathbf{x}^r + \eta \zeta \]
\[ \eta \equiv \Delta \log D \quad \zeta \equiv \frac{d\mathbf{x}}{d \log D} \]

Maximum likelihood estimator for shifts
\[ \frac{d}{d \eta} P(\mathbf{x}|\eta, C_{FP}) = 0 \]
\[ \hat{\eta} = \mathbf{x}^s^T C_{FP}^{-1} \zeta \]
\[ \sigma_{\hat{\eta}} = \zeta^T C_{FP}^{-1} \zeta \]
Status

First run of velocities, measuring velocity correlations

Issues to address:

velocity likelihood is lognormal
check residual FP correlations (z, Z, environment, age, etc.)
add priors to deal with Malmquist bias (P(v) is not flat)
other systematics?

Plans:

Joint measurement of $<\delta_g \delta_g>$, $<v \delta_g>$, $<vv>$
Luminosity bins $\rightarrow$ bias dependence of velocities?
Velocities around interesting structures, e.g. Great Wall
Halo model density reconstruction
Compare local bulk flow with flows in independent volumes
Other prospects

Even larger data sets:
SDSS LRGs: N~110,000, z~0.35
BOSS: N~1.5 million, z~0.5
SDSS photometric FP: N~8.4 million, z~0.45, $\sigma_{\Delta I} \sim 35\%$
   (cf. Huff & Graves 1111.1070 magnification)

But...
   larger errors on observables
   evolution in scaling relations
   sparser sampling
   swamped by systematics?

Key issues:
   Limiting factors at higher z
   How best to complement redshift-space distortions