Peculiar velocities from the fundamental plane in SDSS

How far can we go?

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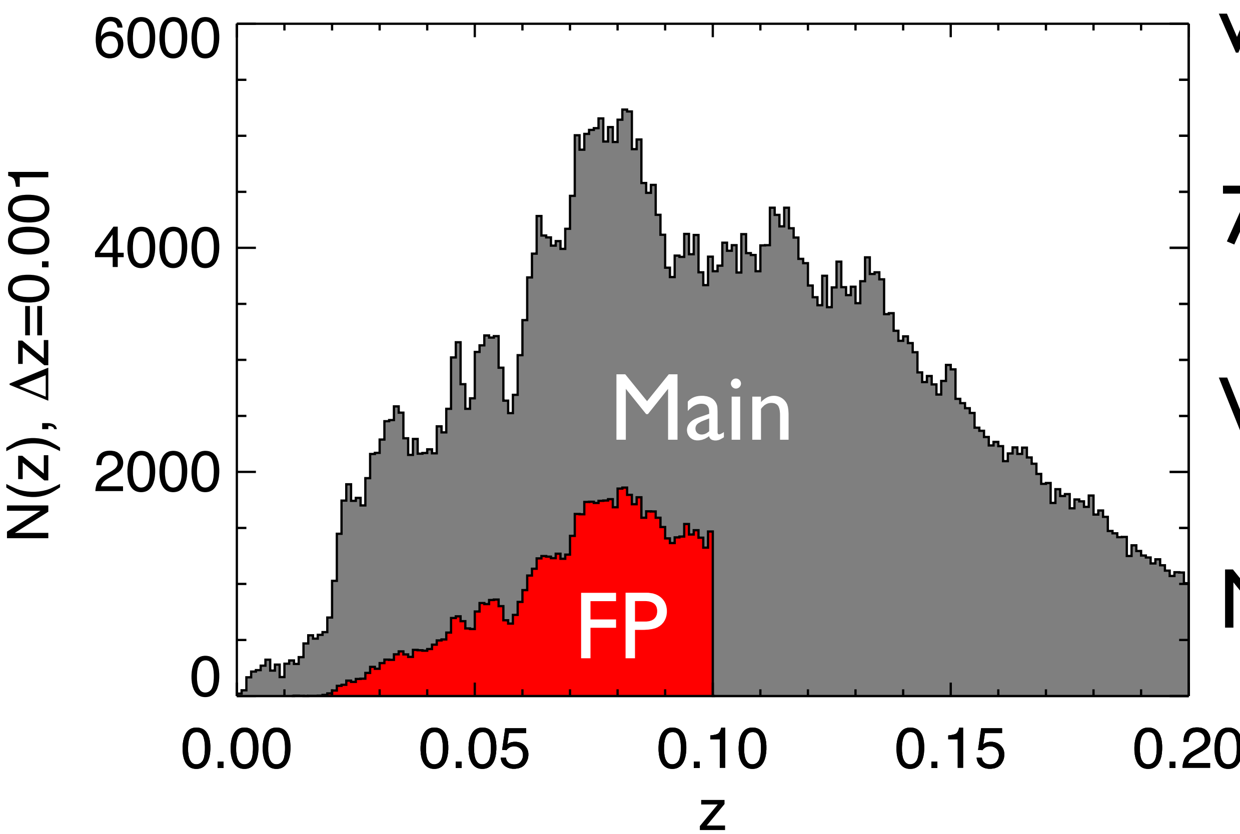
SDSS Sample



~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: $v_{pec} \sim 200$ km/s

Noise: $\sigma_{DI} \sim 0.2cz$

~ 6000 km/s $(z/0.1)$

$N_{obj} \sim 80{,}000(z_{max}/0.1)^3$

(SDSS Main sample starts to be incomplete at z~0.08)

$S/N = v_{pec}/(\sigma_{DI}/\sqrt{N_{obj}})$

$\sim 9\sqrt{z_{max}/0.1}$

If systematics can be controlled, there is power in large N

	Weak Lensing	Peculiar Velocities
"observable"	γ	v_{los}
analyses	galaxy-galaxy lensing $<\gamma\delta_g>$ cosmic shear $<\gamma\gamma>$	cross-correlation $<v\delta_g>$ auto-correlation $<vv>$
S/N per object	~1/30	~1/30 x (0.1/z)
dominant stat. uncertainty	shape noise (~30%)	scatter in distance indicator (~20% for FP)
systematics	shear calibration, photo-zs, intrinsic alignments	FP fitting, Malmquist bias, velocity bias?

Fitting the Fundamental Plane

Must account for selection cuts and heteroskedasticity

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

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

Maximize likelihood:

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

$$\mathcal{L} = \prod_i P(\boldsymbol{x}_i)$$

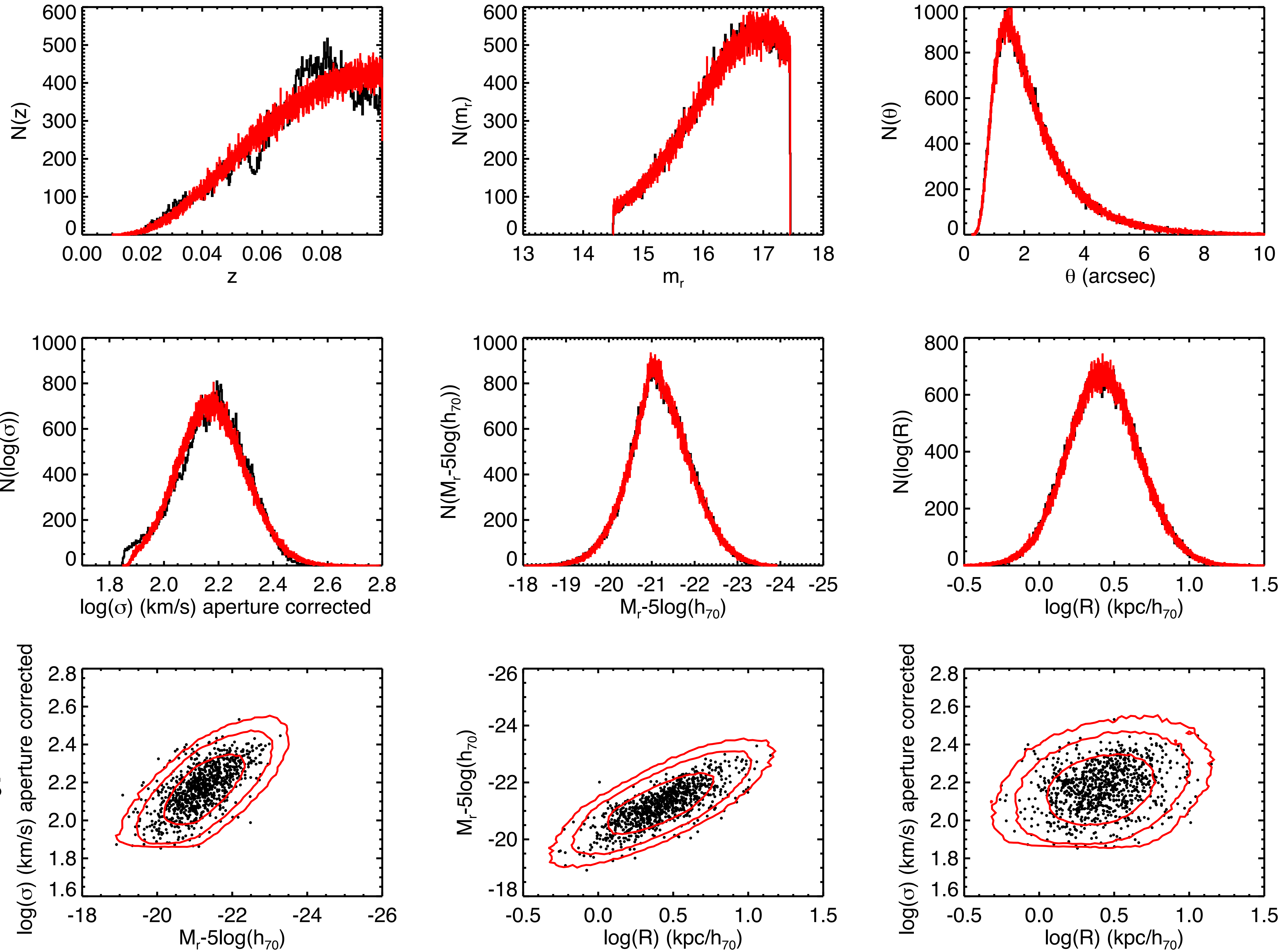
$\mathbf{x}_i$={M, log(R), and log(σ_v)}$_i$
$\mathbf{V}$=cov[$\mathbf{x}$]
$\mathbf{E}_i$=cov[$\sigma_{\mathbf{x}i}$]
f_i=renormalization for cuts

Saglia 2001, Bernardi 2003

Observed properties

Physical properties

Correlations



Mock
Data

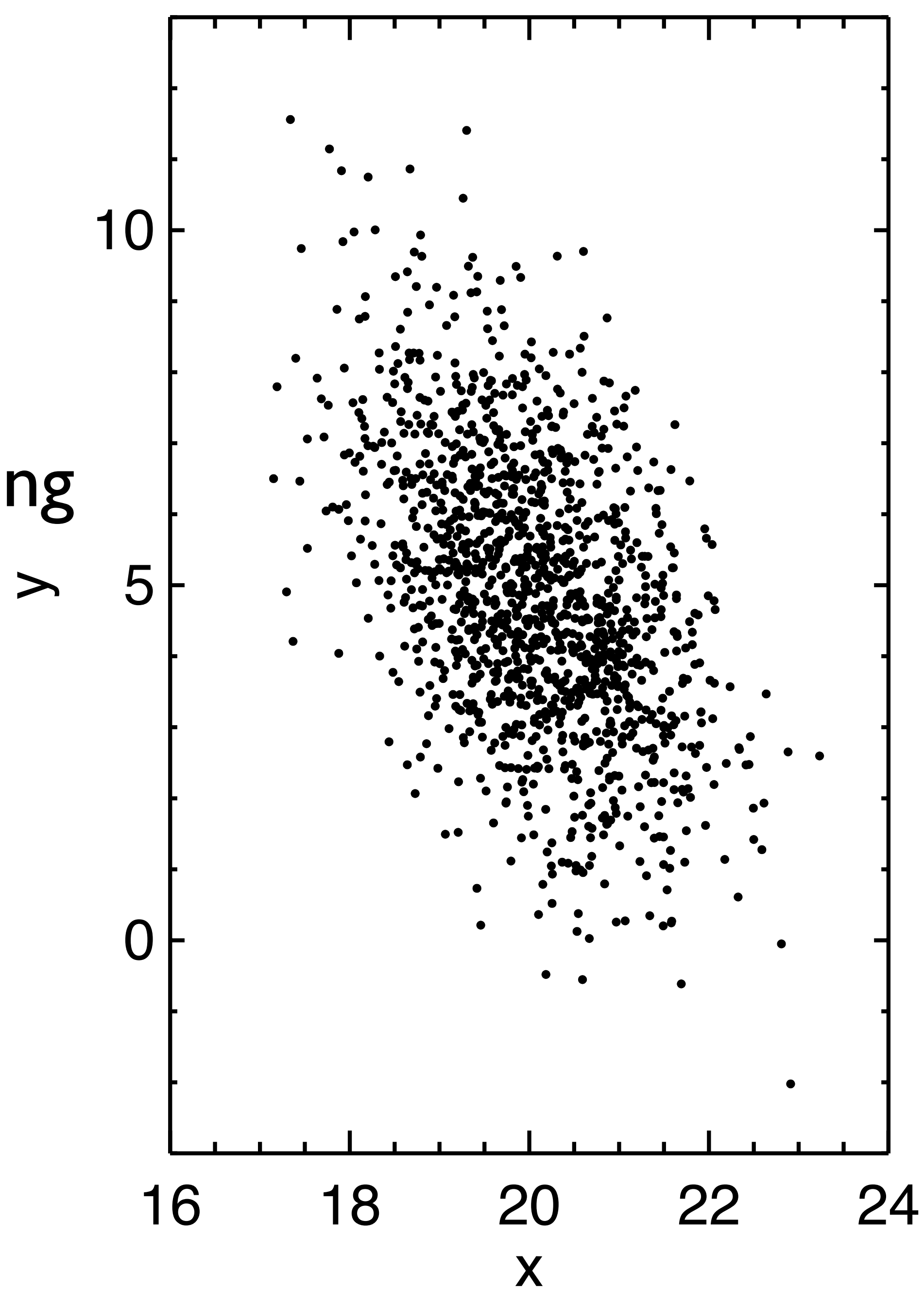
3-d Gaussian model is a good description of the data

Estimating Velocities from the Fundamental Plane

2-d example:

Assume shift is along y direction

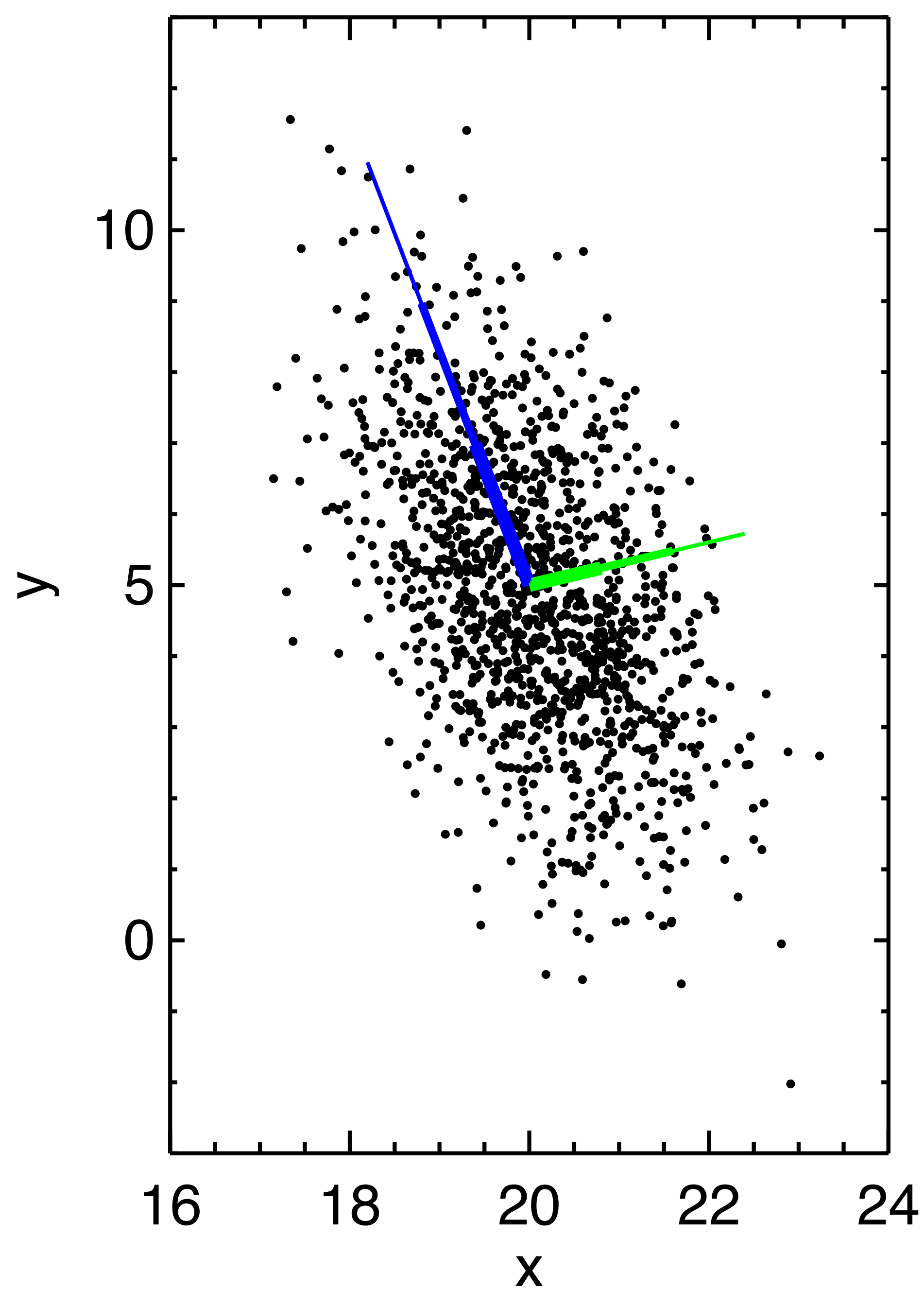
Maximize P(y|x)



Estimating Velocities from the Fundamental Plane

2-d example:

Get covariance matrix



Estimating Velocities from the Fundamental Plane

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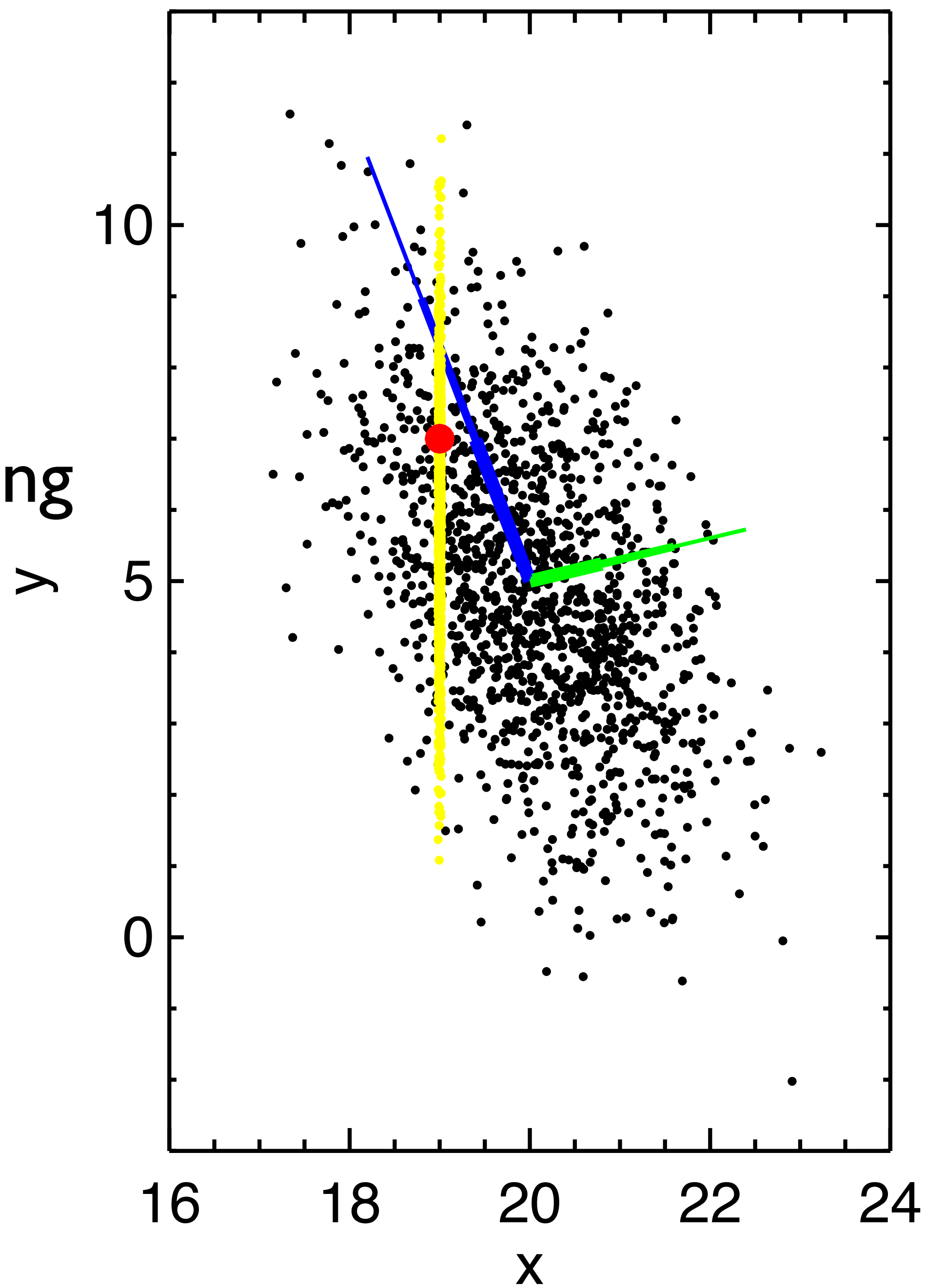

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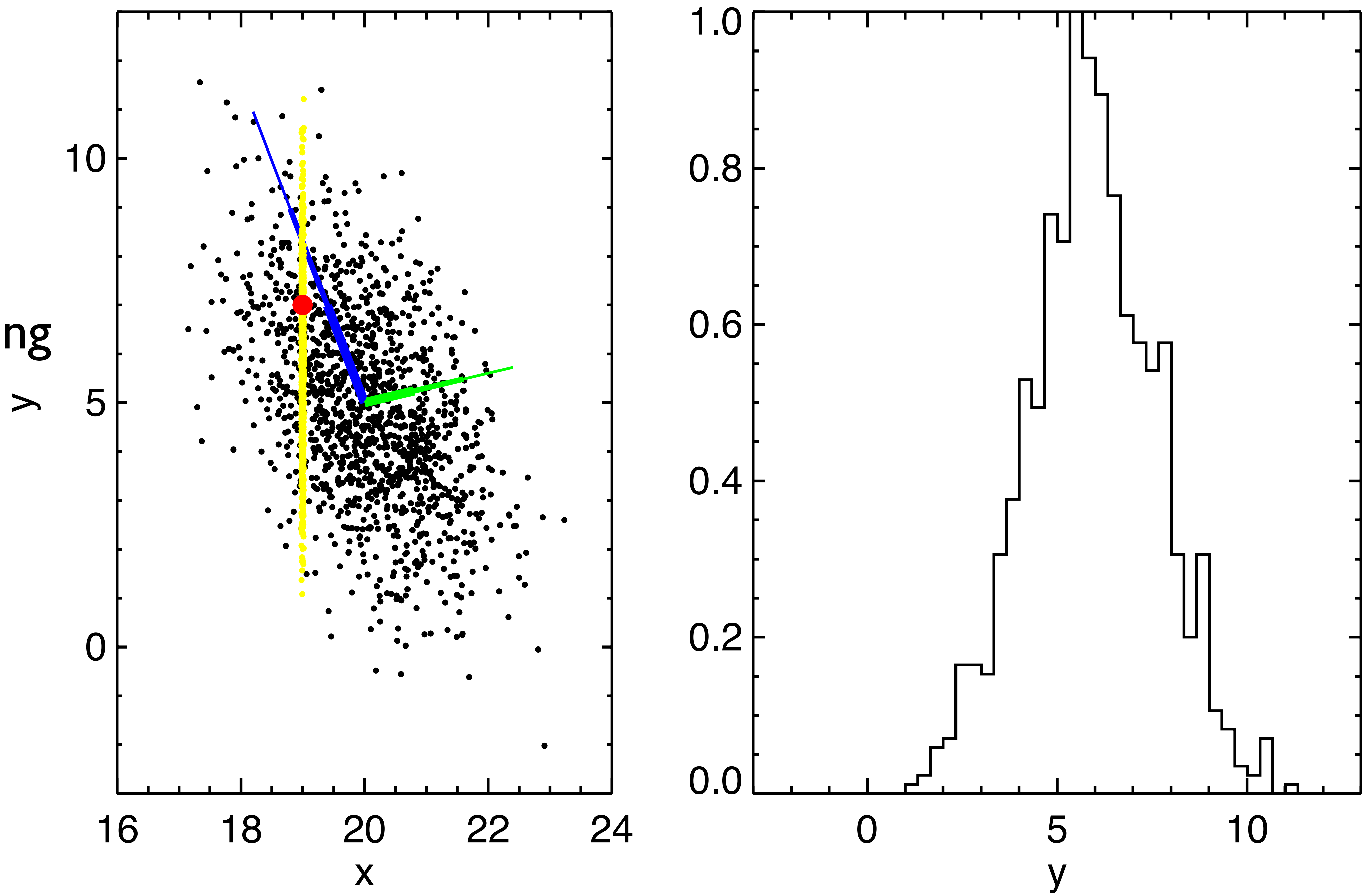

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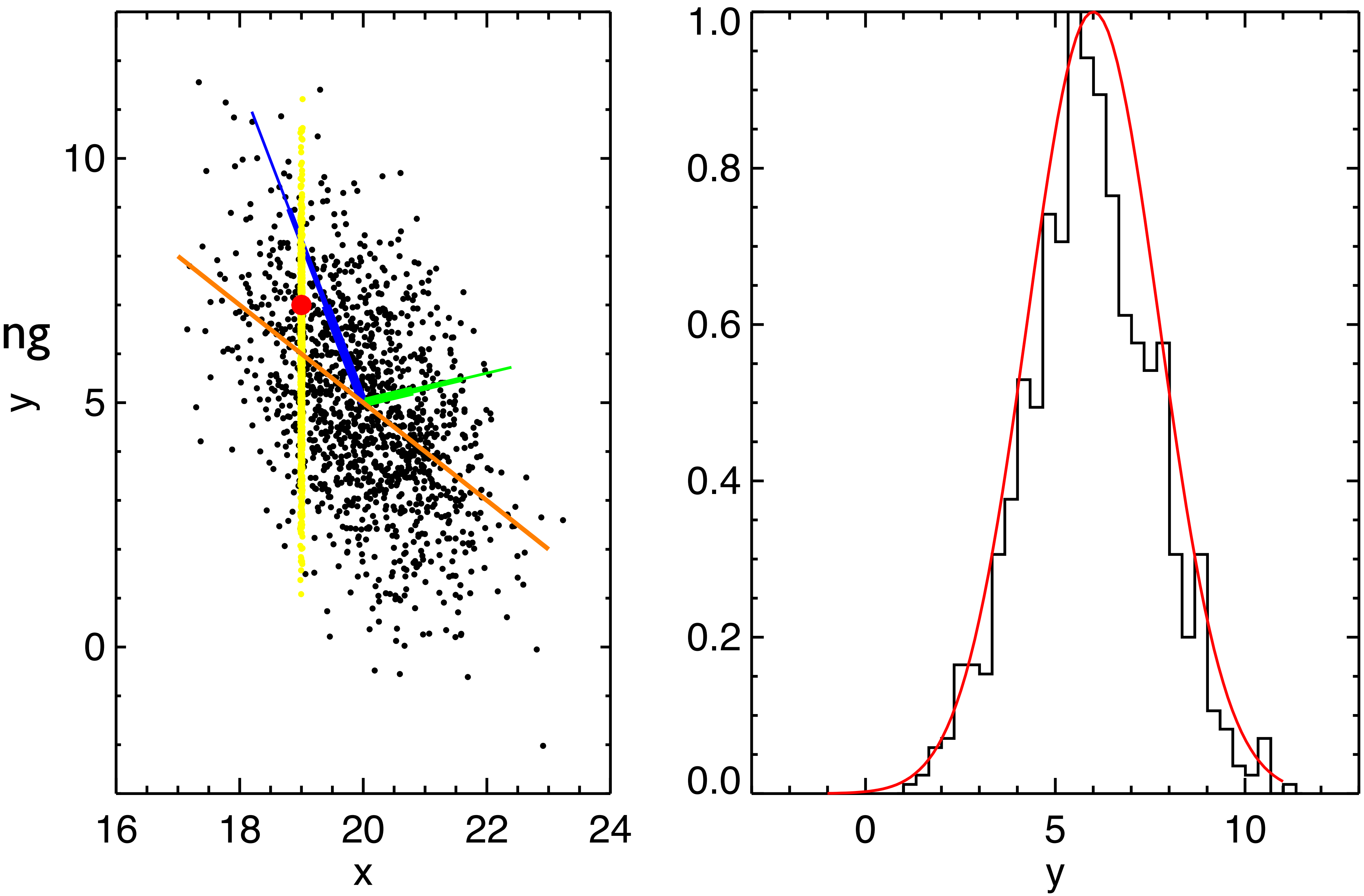

Estimating Velocities from the Fundamental Plane

Observables and FP covariance matrix

$$\mu \equiv \langle \{M_r, \log(R_{\text{deV}}/\text{kpc}), \log(\sigma_v)\} \rangle$$
$$\mathbf{x} \equiv \{M_r, \log(R_{\text{deV}}/\text{kpc}), \log(\sigma_v)\} - \mu$$
$$C_{\text{FP}} \equiv \text{cov}(\mathbf{x})$$

The effect of velocities on FP observables

$$\mathbf{x}^{\mathbf{s}} \approx \mathbf{x}^{\mathbf{r}} + \eta\zeta$$
$$\eta \equiv \Delta \log D \qquad \zeta \equiv \frac{d\mathbf{x}}{d \log D}$$

Maximum likelihood estimator for shifts

$$\frac{d}{d\eta} P(\mathbf{x}|\eta, C_{\text{FP}}) = 0$$
$$\widehat{\eta} = \frac{\mathbf{x}^{\mathbf{s}\,T} C_{\text{FP}}^{-1} \zeta}{\zeta^T C_{\text{FP}}^{-1} \zeta} \qquad \sigma_{\widehat{\eta}} = \zeta^T C_{\text{FP}}^{-1} \zeta$$

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 $\langle\delta_g\delta_g\rangle$, $\langle v\delta_g\rangle$, $\langle vv\rangle$
- Luminosity bins → 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, σ_{DI}~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