Anisotropic Jeans models of 260 galaxies with MCMC

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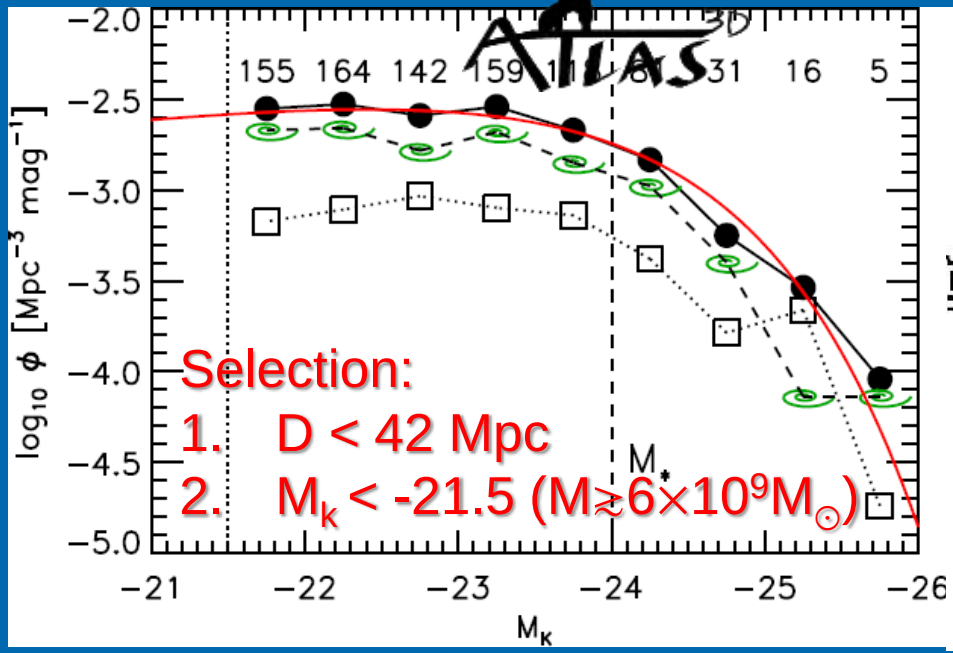
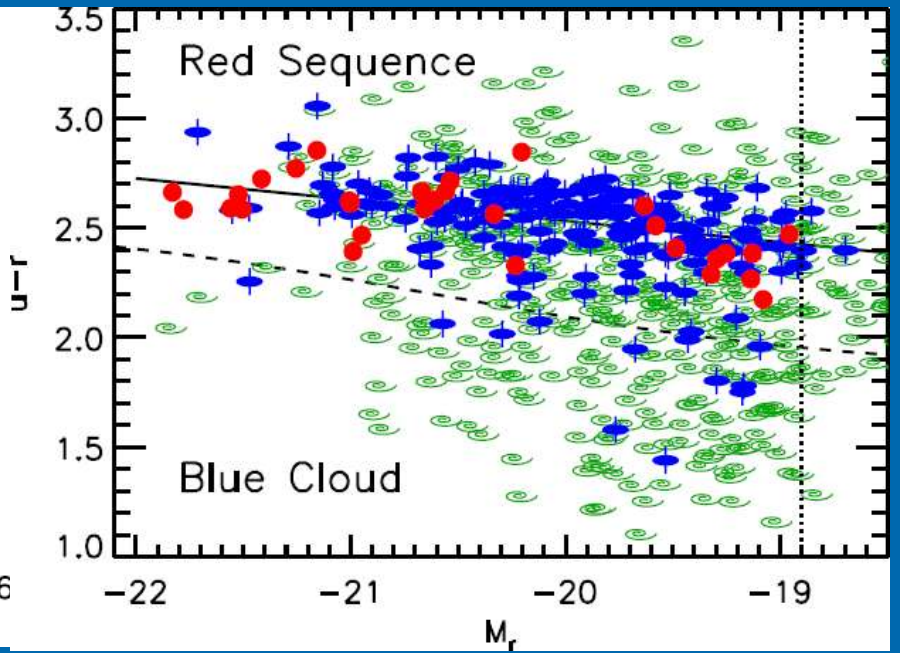
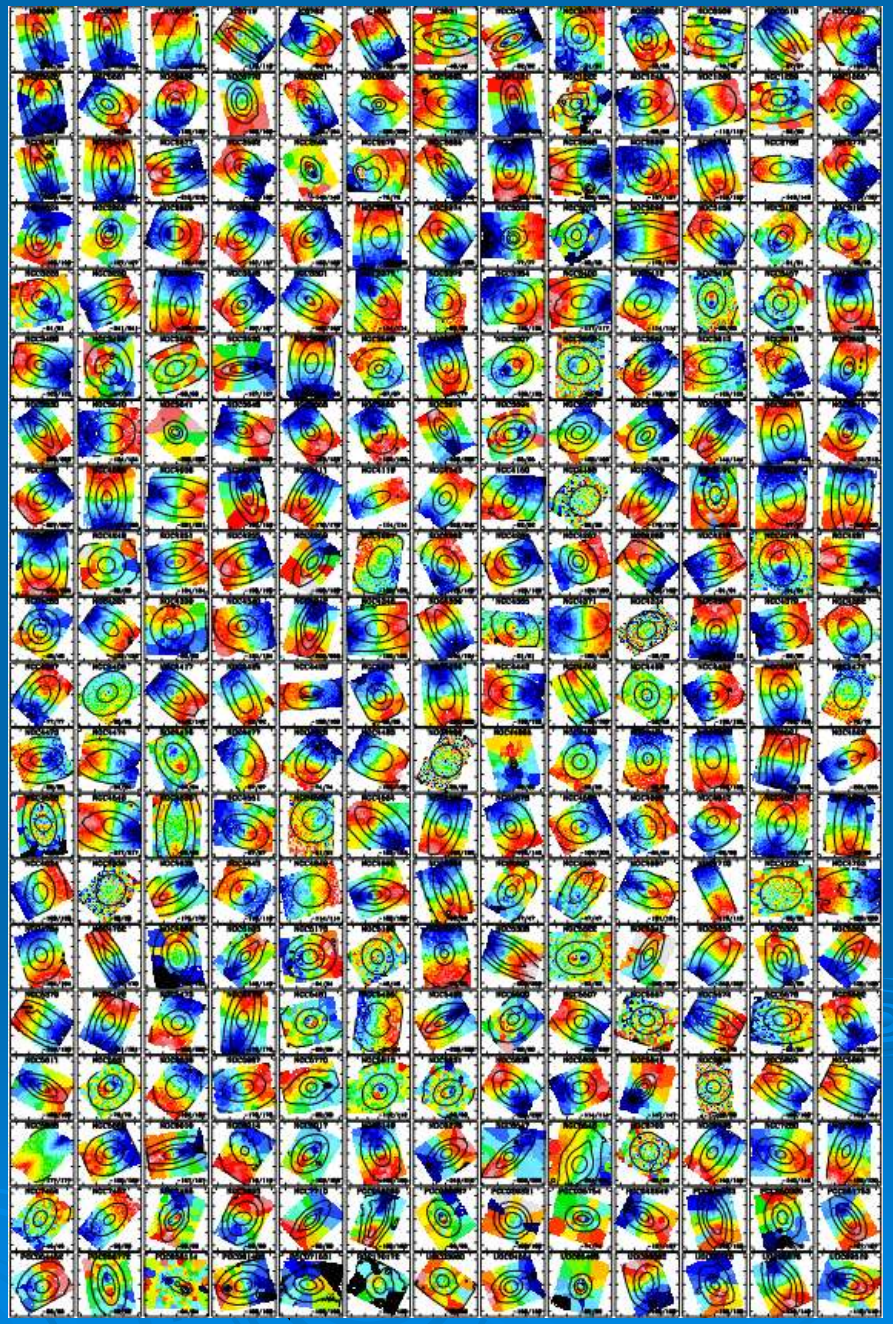
The ATLAS^{3D} sample of ETGs





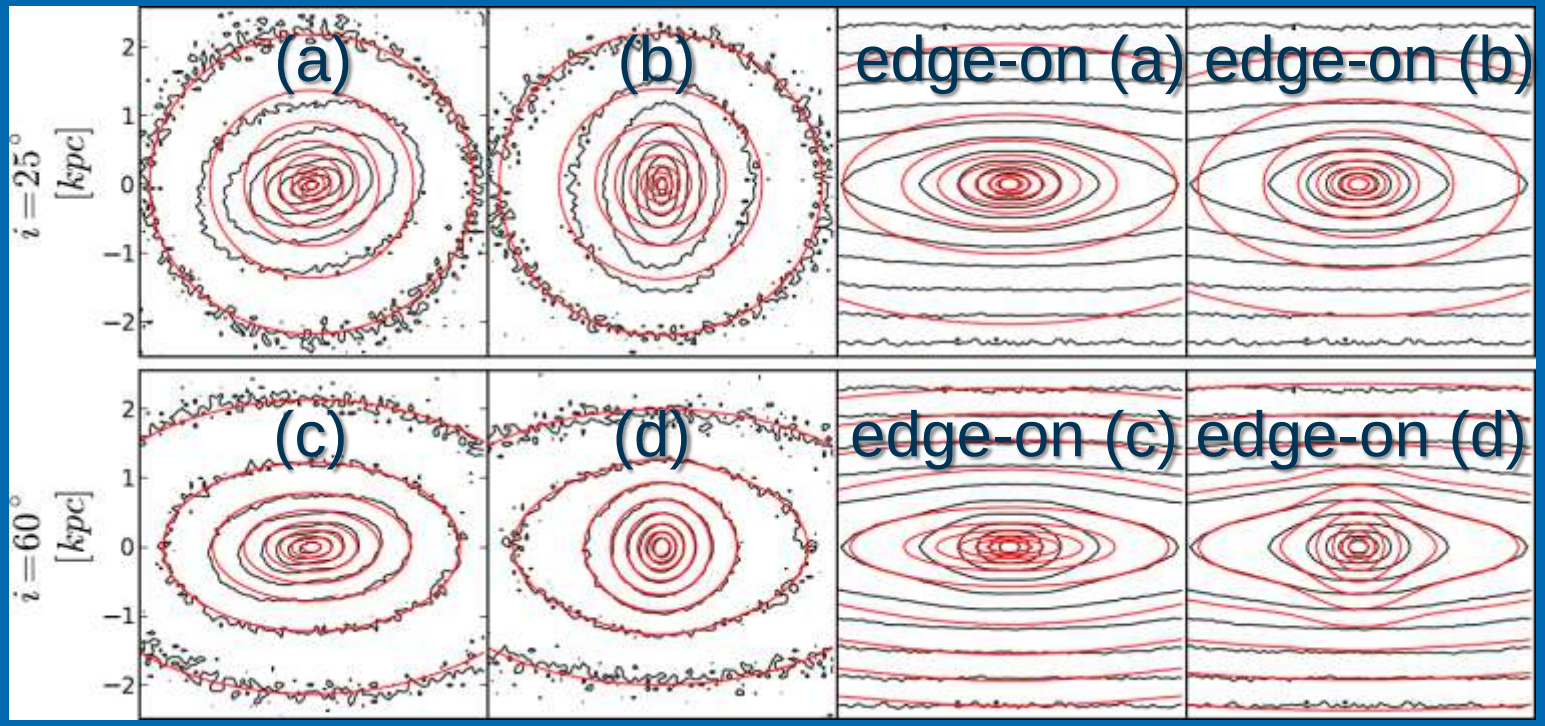
Compare with LF Bell et al. (2003) ; On red sequence of Baldry et al. (2004)

- Clean and simple volume-limited sample selection (Cappellari+11a [P1])
- Luminosity function representative of local Universe
- 260 ATLAS^{3D} ETGs galaxies mostly on red sequence (As in Strateva et al. 2001; Conselice 2006; van den Bergh 2007)



Images (Cappellari+11a [P1]) Stellar velocities (Krajnovic+11 [P2])

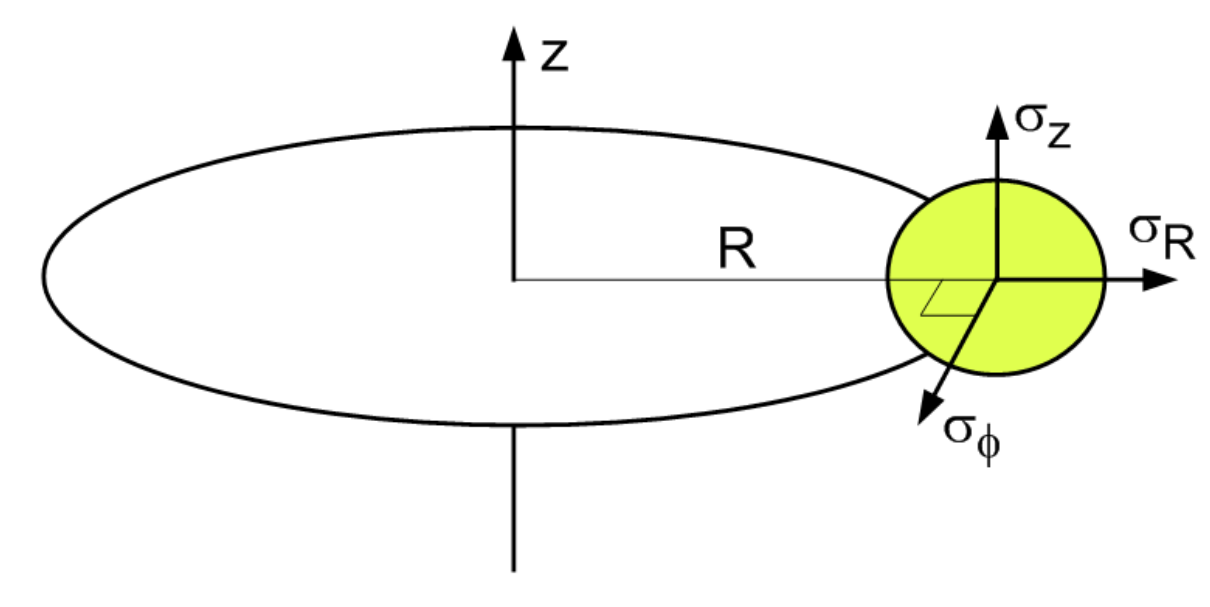
Modelling problems



Simulations of barred galaxies (Lablanche+12 [P12])

- Deprojection non-unique (unless axisymmetric and edge-on)
  (Gerhard+Binney96, Romanowsky+Kochanek97, Magorrian99)
- 50% of our sample likely barred
- Deprojection is major obstacle for accurate models
- Range of data quality: only V and σ for 40% of the sample

Anisotropy and velocity ellipsoid



- $\beta = 1 - \frac{\sigma_z^2}{\sigma_R^2}; \gamma = 1 - \frac{\sigma_\phi^2}{\sigma_R^2}; \delta = 1 - \frac{2\sigma_z^2}{\sigma_R^2+\sigma_\phi^2} = \frac{2\beta-\gamma}{2-\gamma}$
- δ is measured by the (V/σ,ε) diagram (Binney78,05)
- β, γ require dynamical models
- $\sigma_R = \sigma_\phi \rightarrow (\delta = \beta;\ \gamma = 0)$: Oblate velocity ellipsoid

Anisotropy of flattened ETGs

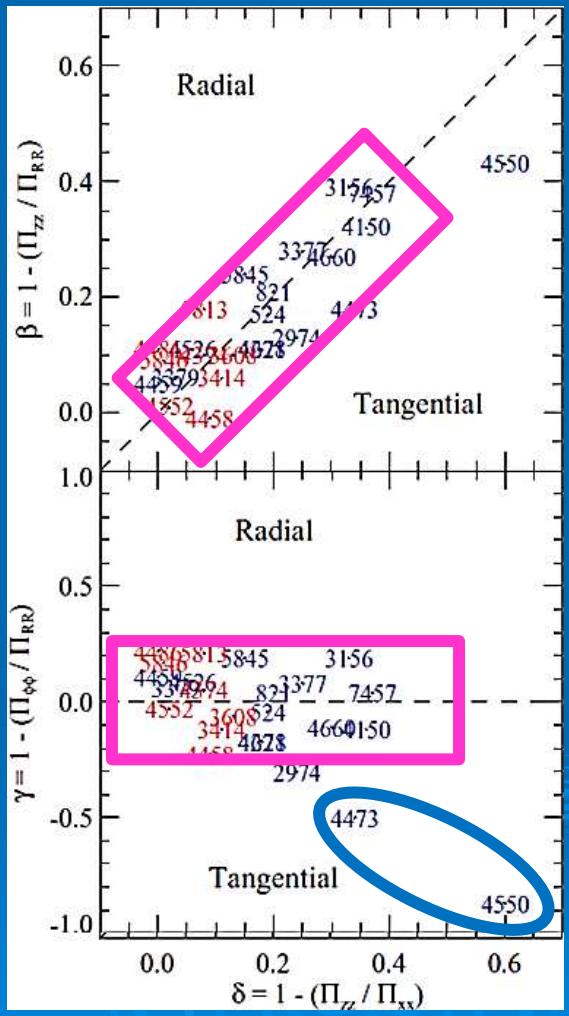
- SAURON integral-field data
- Schwarzschild's axisymmetric models
- 24 galaxies (Cappellari+07)
- Global anisotropy approximation

→ $\delta \approx \beta \; and \; \gamma \approx 0$

(2 important exceptions)

→ Oblate velocity ellipsoid!

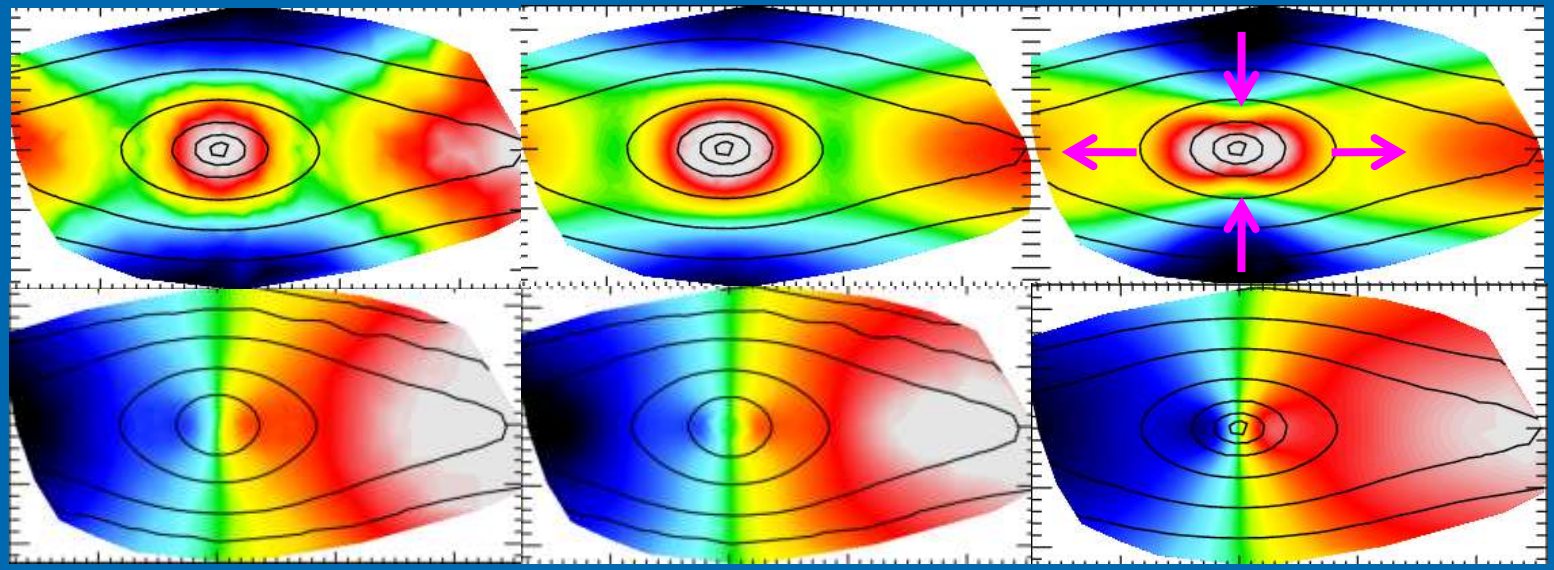
- Independently confirmed in Coma (Thomas+09)



(Cappellari+07)

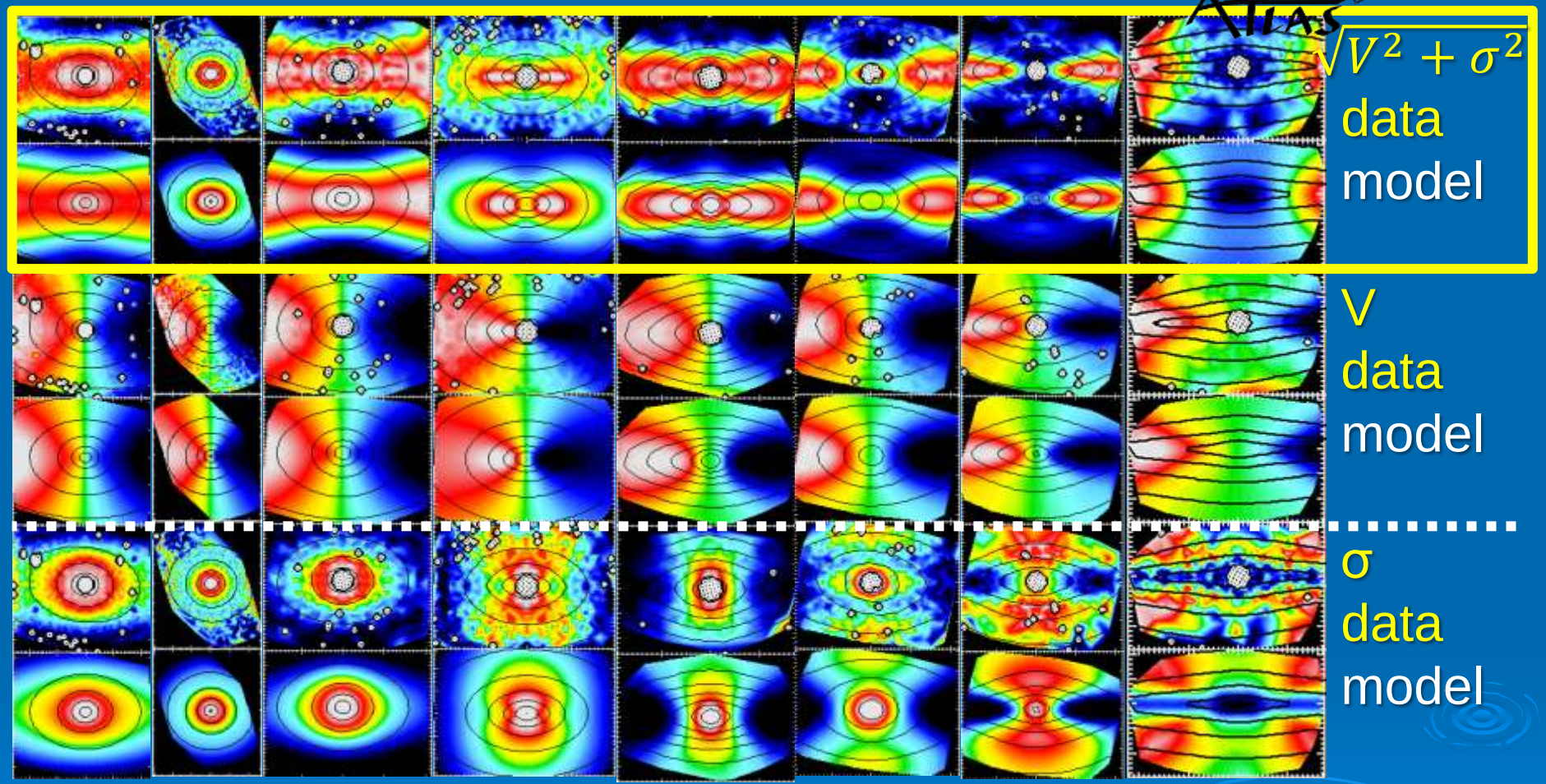
Jeans Anisotropic MGE (JAM)

SAURON stellar kinematics | JAM model $\sigma_z < \sigma_R$ | Isotropic model $\sigma_z = \sigma_R$



- Use Multi-Gaussian Expansion to fit images (Emsellem+94)
- Efficient anisotropic Jeans solution with $\sigma_z < \sigma_R$ (Cappellari 08)
- Just two parameters (i, σ_z/σ_R) fit shape of both V_{rms} and V! (http://purl.org/cappellari/idl)

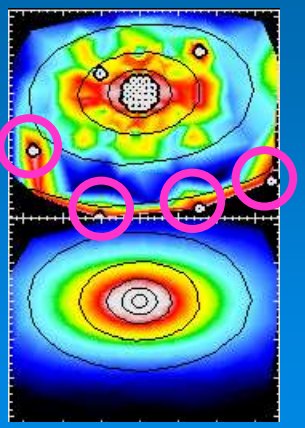
Sample JAM models for

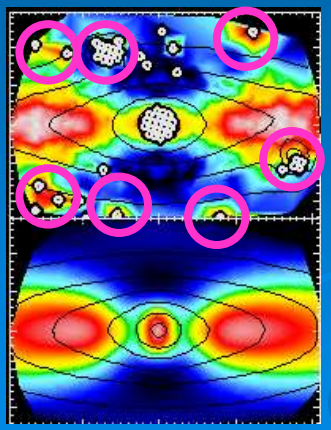


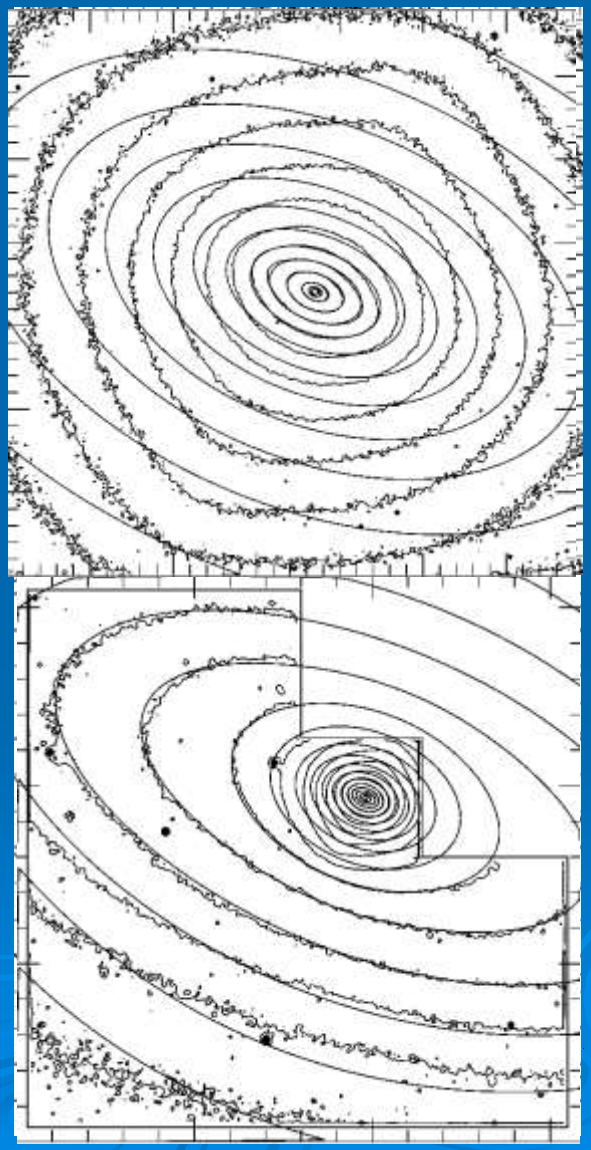
- Large variations in observed kinematics
- Kinematics shape well 'predicted' by JAM (i, σ_z/σ_R)
- Caveat: JAM not accurate for slow rotators (10% sample)

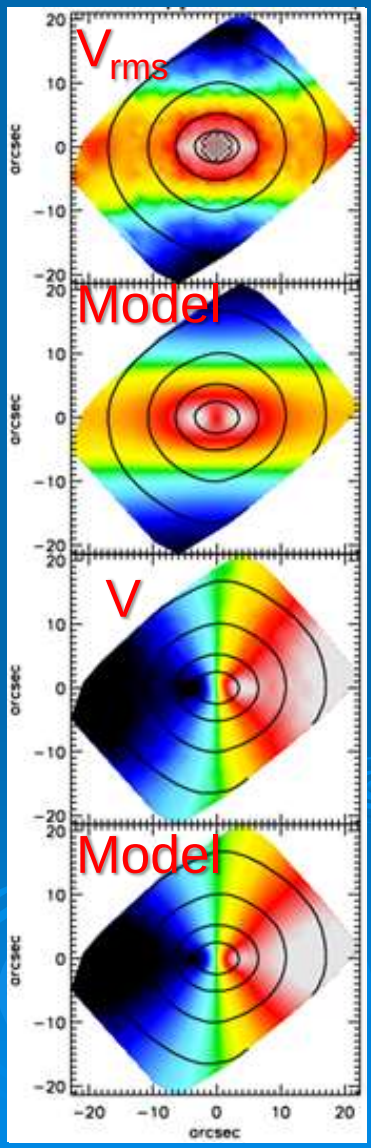
Uncovering modelling problems

- JAM approximates inner dynamics of disk galaxies
- Useful reference to uncover exceptions
- Most JAM fits problems
  - hidden bars
  - low inclination
  - interactions
- JAM can flag bad kinematics bins





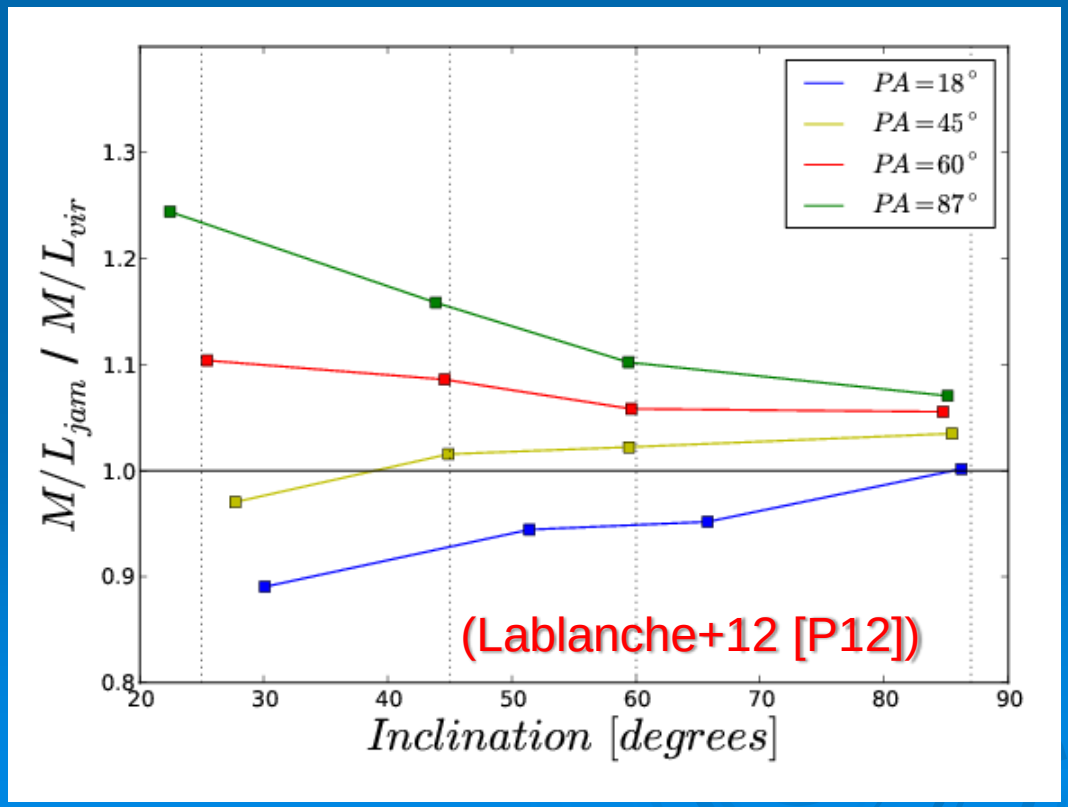


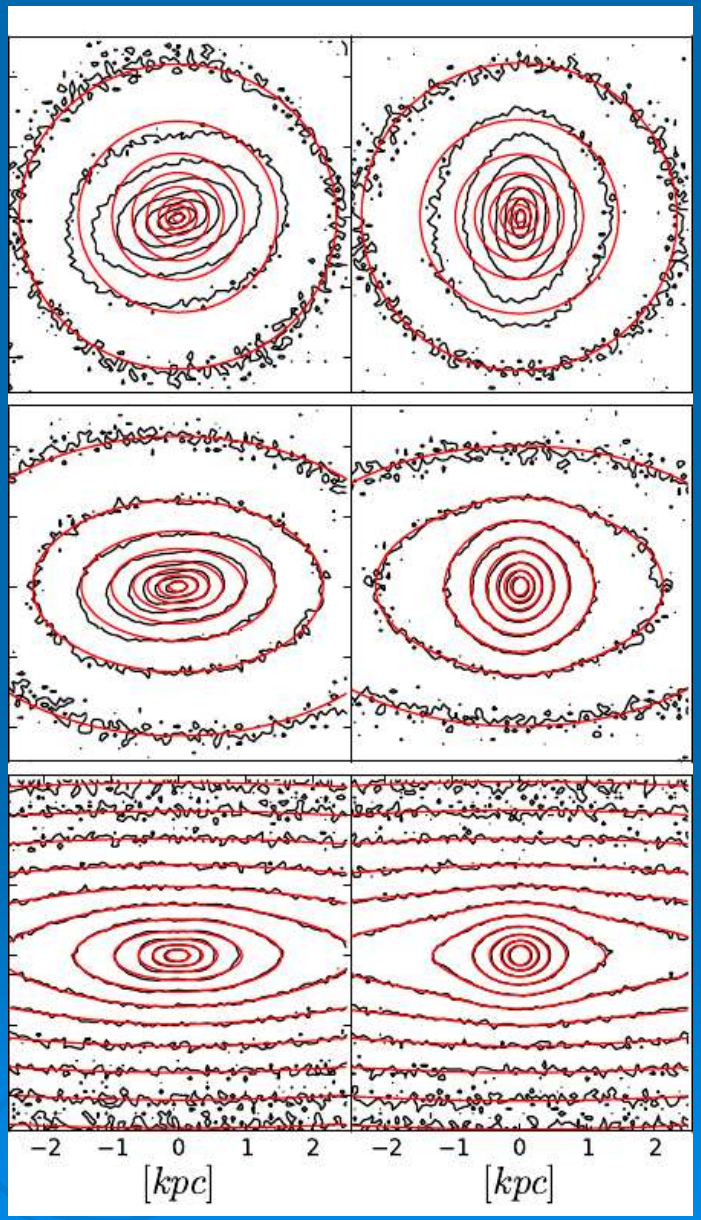


(Scott, MC, et al. 2009)

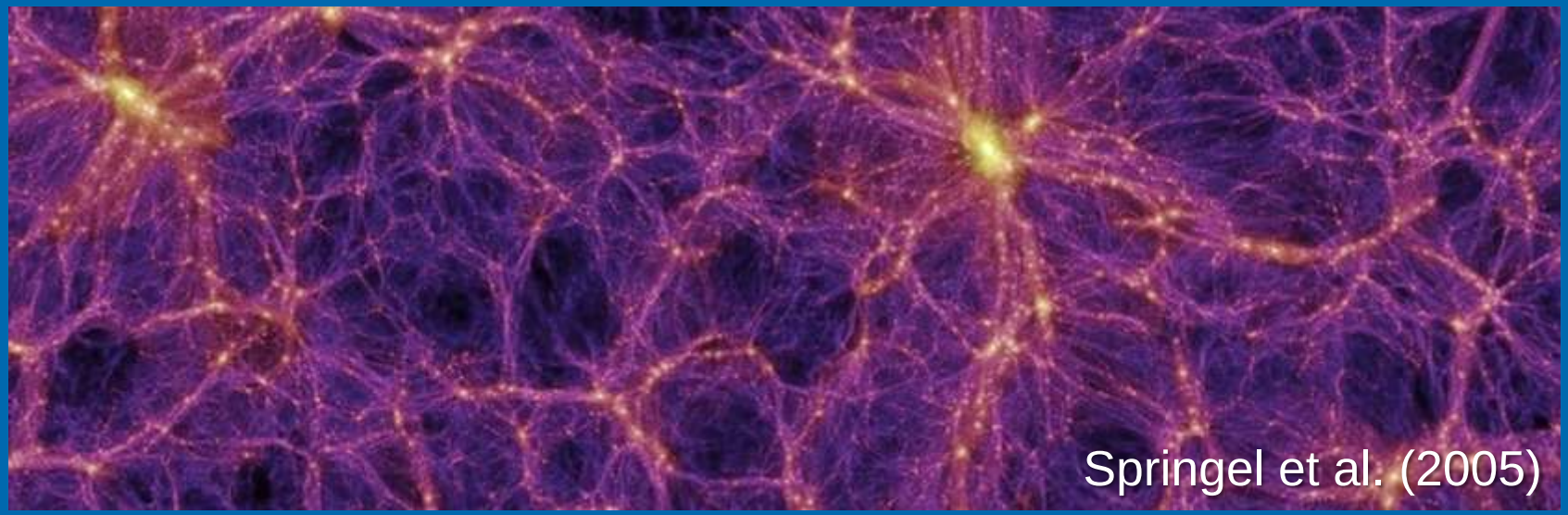
Impact of bars on M/L

- MGE models of barred fast rotators
  - Trying to recover M/L
  - For various inclinations and bar PAs
  - M/L error < 15% for i > 40





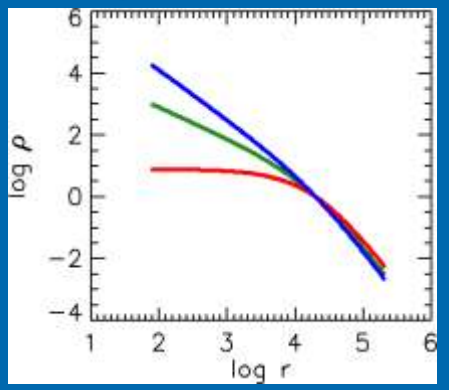
But where is dark matter?



- JAM 'predicts' kinematics from galaxy images
  - Accurate photometric model essential
  - Global anisotropy remarkably homogeneous
  - Total density closely follow stellar one (within $1R_e$)

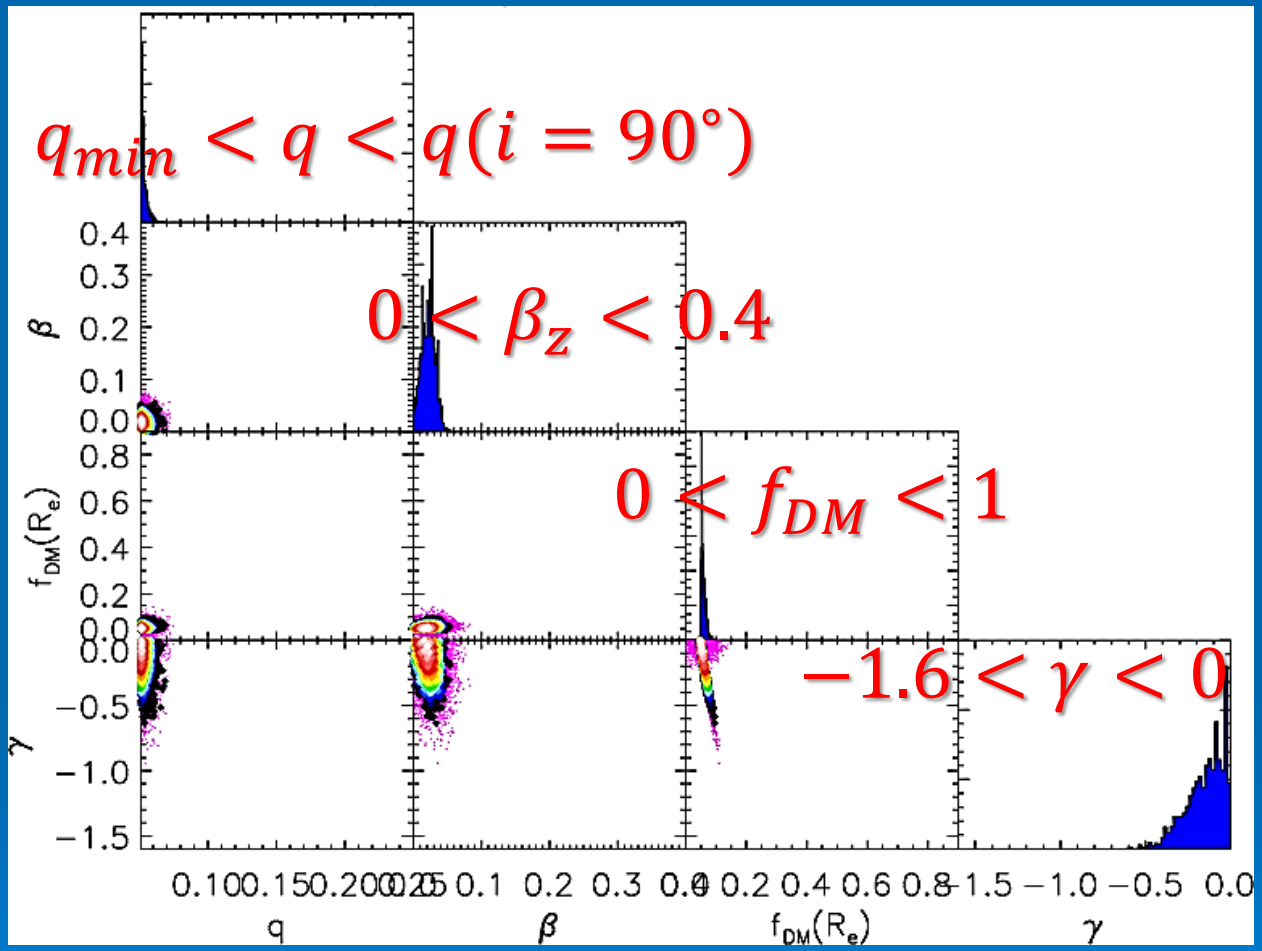
→ little DM (within a sphere of radius $\approx R_e$)

Measuring Stellar M/L



- Generalized NFW halo profile
  - $\rho_{DM}(r) = \rho_s \left(\frac{r}{r_s}\right)^{\gamma} \left(\frac{1}{2} + \frac{1}{2}\frac{r}{r_s}\right)^{-\gamma-3}$
- Sample $(i, \beta_z, \frac{M}{L}, f_{DM}, \gamma)$ via Markov chain Monte Carlo
  - Outer halo profile nearly irrelevant (use fixed break radius r_s)
- $P(\text{model} \mid \text{data}) \propto P(\text{data} \mid \text{model})\, P(\text{model})$
- $P(\text{data} \mid \text{model}) \propto \exp(-\frac{1}{2}\chi^2)$ (→ Gaussian errors)
- *noninformative* (constant) priors (but $-1.6 < \gamma < 0$)
- 10,000 sampled points (=model run) per galaxy
- Adaptive Metropolis method (Haario+01)

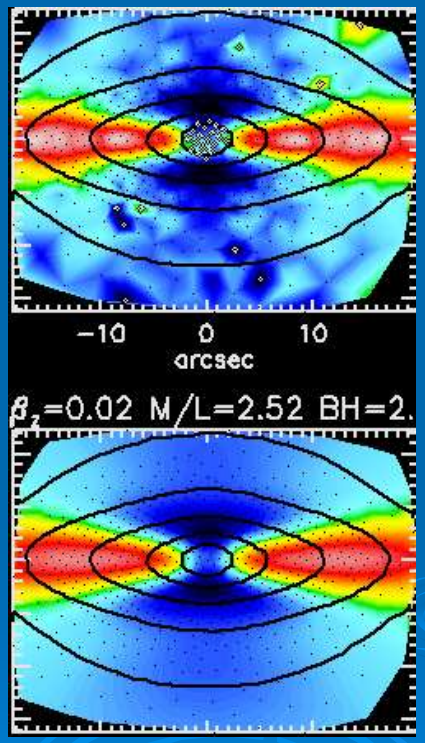
Posterior distribution



Posterior distribution of model parameters: Marginalized 2-dim and 1-dim histograms (see also Barnabé+12)

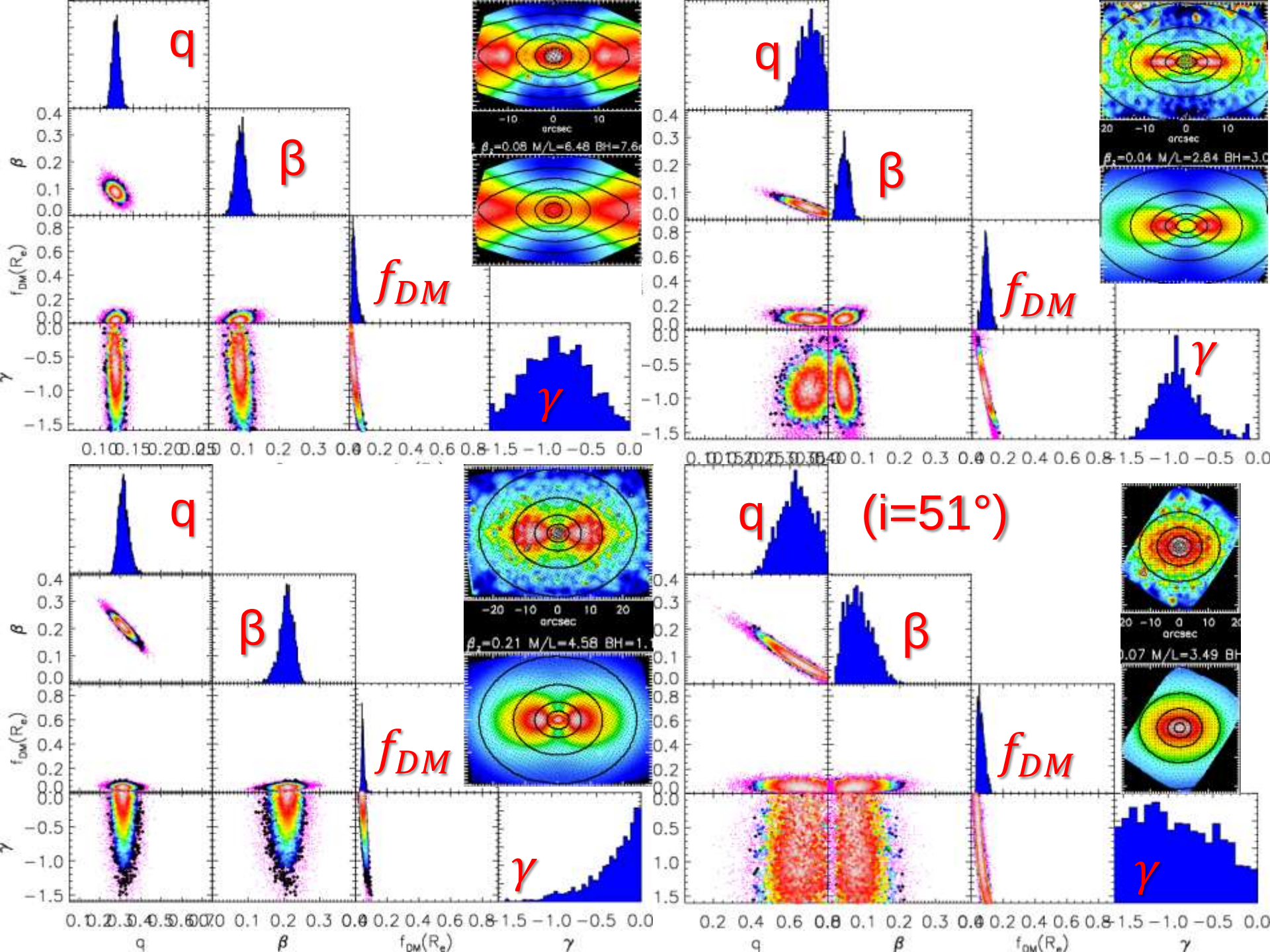
SAURON data

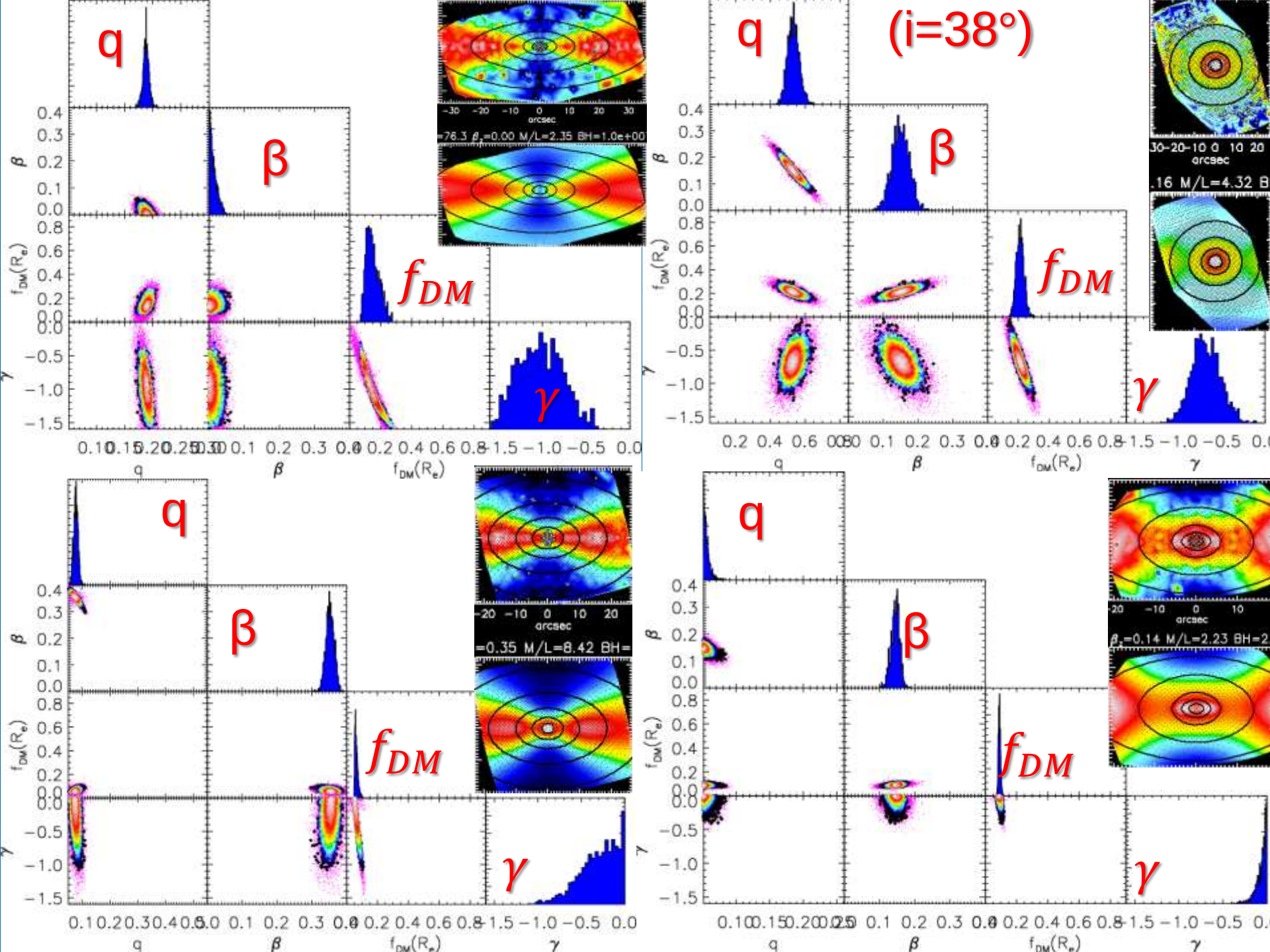
$V_{rms} = \sqrt{V^2 + \sigma^2}$



JAM best fit

$f_{DM}(R_e) = 5\%$


q
β
f_{DM}
γ
(i=51°)
arcsec
$f_{DM}(R_e)$


q
β
f_{DM}
γ
(i=38°)
arcsec
M/L=2.35 BH=1.0e+00
M/L=4.32 B
M/L=8.42 BH=
M/L=2.23 BH=2
$f_{DM}(R_e)$

Conclusions

- Modelling large galaxy samples
- Deprojection is major uncertainty in models
- Most early-type galaxies have simple dynamics
- Kinematics ‘predicted’ by detailed photometry
- Useful reference to flag exceptions / problems
- Accurate constraints on M/L_{stars} and $f_{DM}(R_e)$
- Useful for galaxy surveys (e.g. MaNGA)
- See tomorrow slides for IMF results