Parameter estimation with NMAGIC particle models and the dark matter halo of the intermediate luminosity elliptical galaxy NGC 4494

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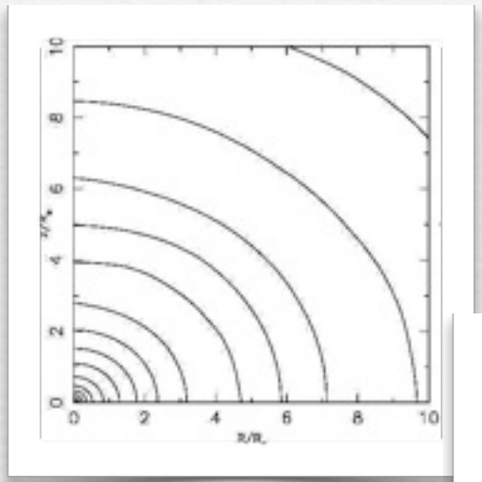
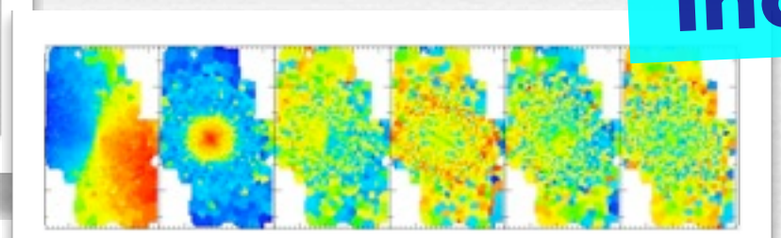
RINGBERG, 12 IV 2012

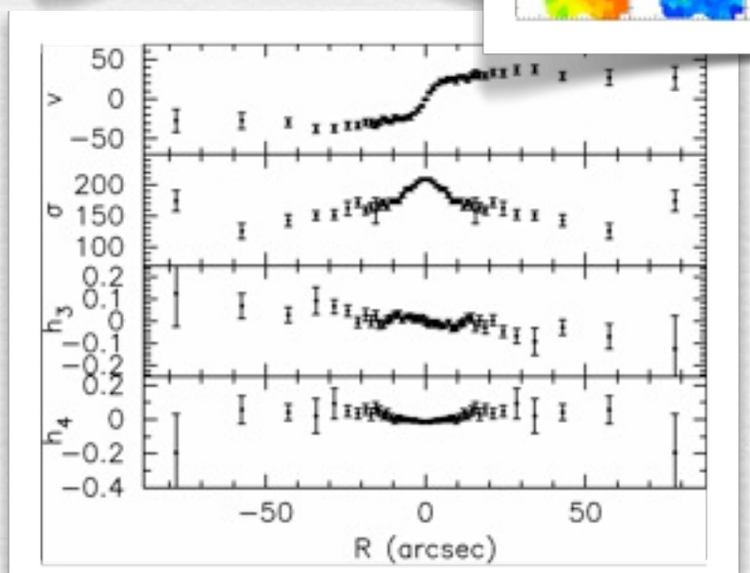
Outline

- Introduction: accuracy of made-to-measure NMAGIC particle models, importance of good observational data
- Intermediate luminosity ellipticals and their dark halos
- NGC 4494: observational data, NMAGIC axisymmetric models
- How well can we recover the dark matter halo parameters with NMAGIC?
- Conclusions

Introduction: NMAGIC M2M particle models

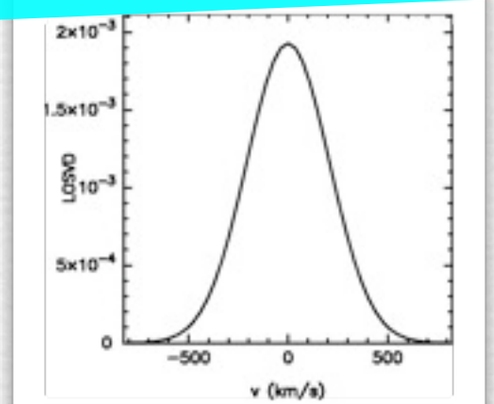






Model a great variety of observational data...

including discrete velocities!



... using particles with adjustable weights

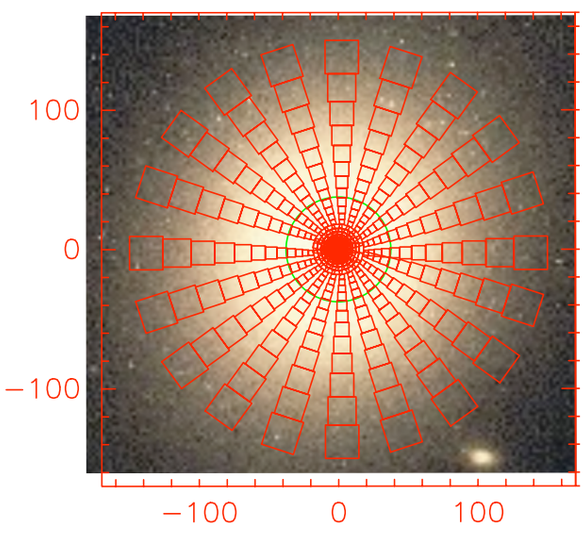
$$\frac{dw_i}{dt} = \varepsilon w_i(t) \left[\mu \frac{\partial S}{\partial w_i} - \sum_j \frac{K_j[\mathbf{z}_i(t)]}{\sigma(Y_j)} \Delta_j(t) + \sum_k \delta_{ki} \left(\frac{1}{\sqrt{2\pi}} \frac{e^{-(v_k - v_{z,i})^2/2\sigma_k^2}}{\hat{\mathcal{L}}_k} - \frac{1}{l_k} \right) \right]$$

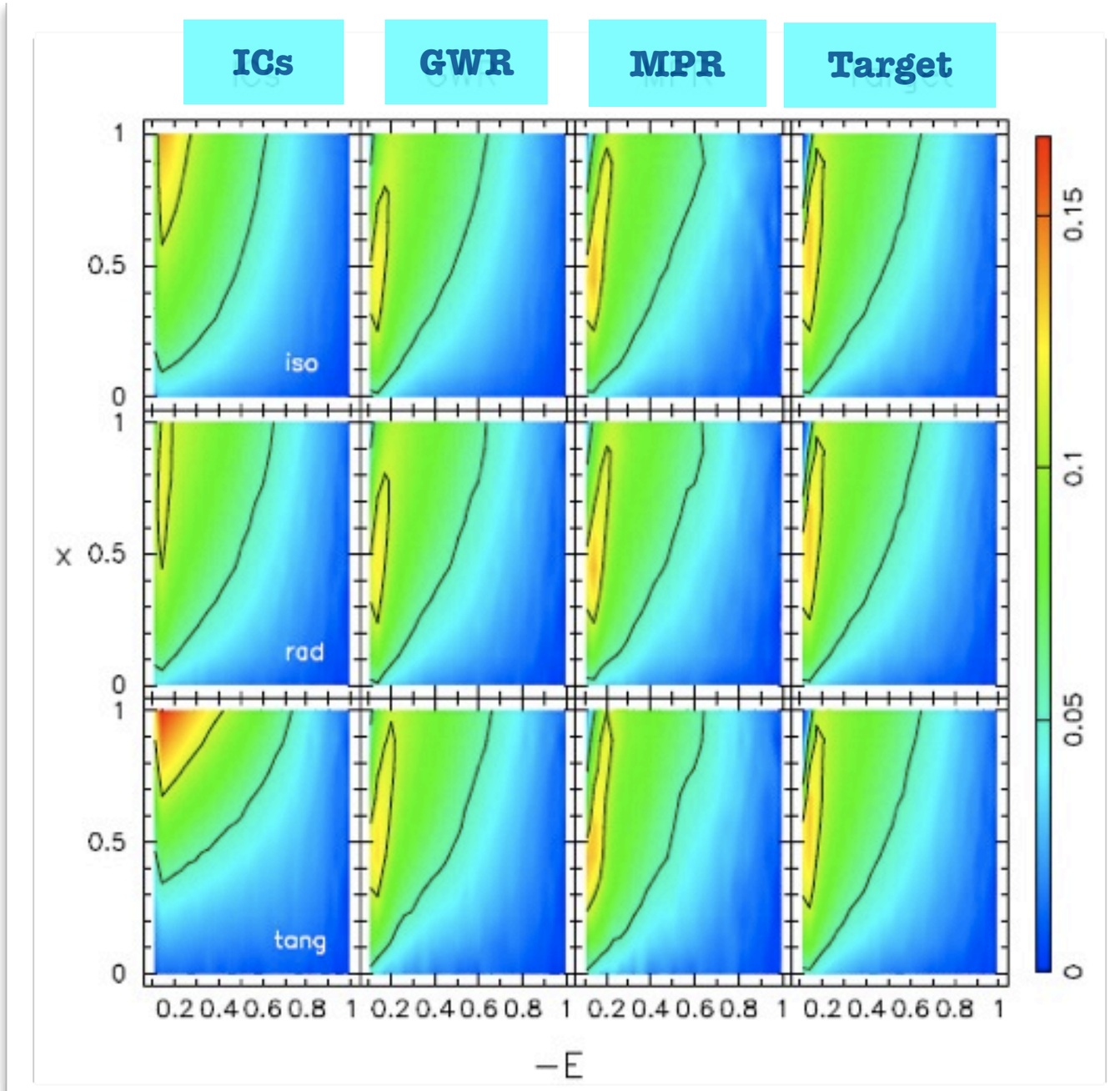
Syer & Tremaine 96, de Lorenzi+07, 08

How accurate NMAGIC is

Morganti & Gerhard 12

* Convergence to a theoretically unique solution: for a truncated spherical target galaxy with idealized data, NMAGIC models show that the target can be recovered accurately and independent of the initial particle model.





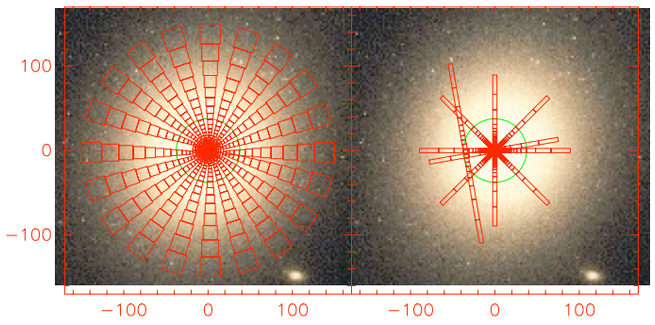
Accuracy of 12% at a resolution of 30x10 linear bins in (E,x)

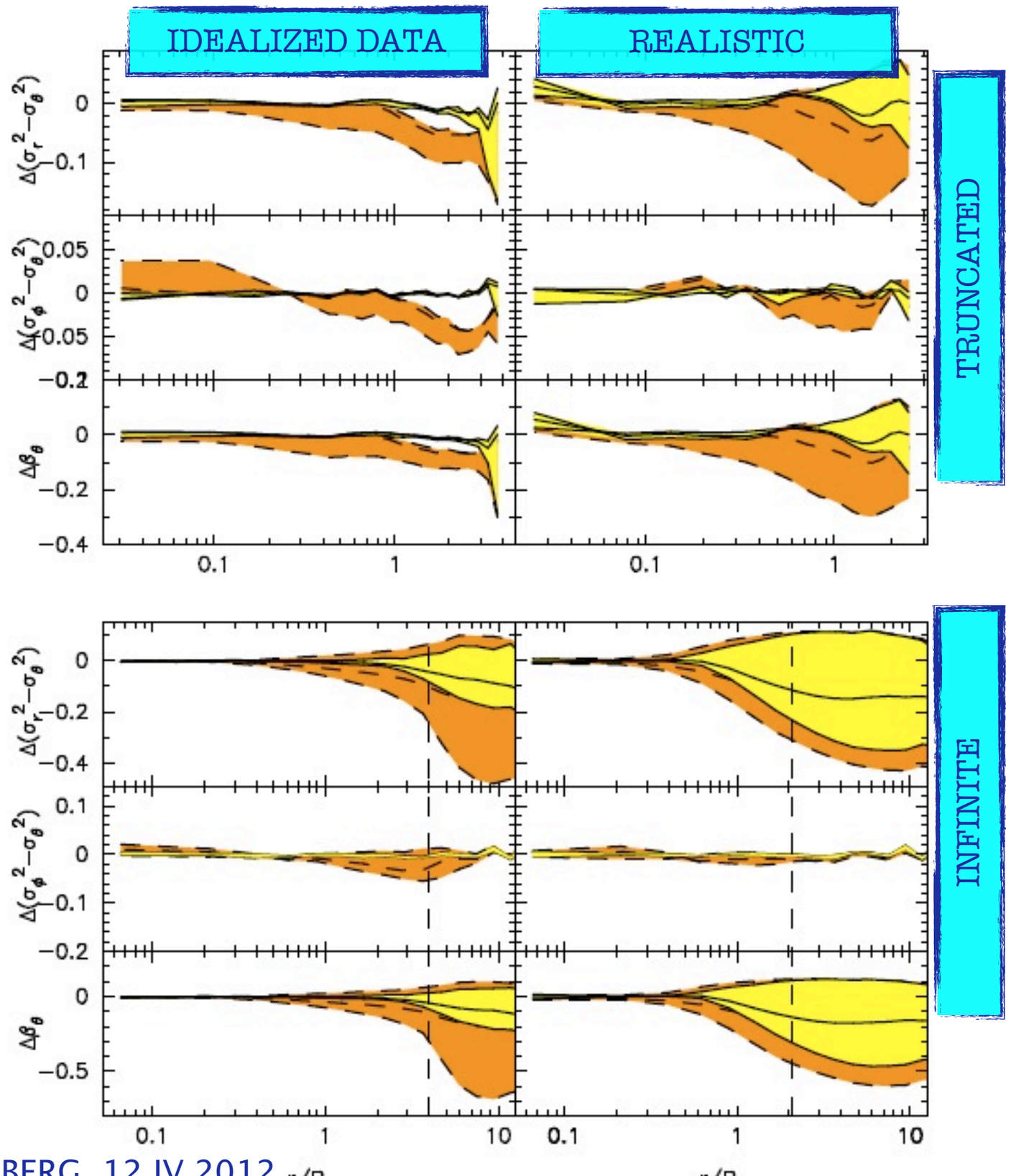
Effect of imperfect data

Morganti & Gerhard 12

* Lack or poor quality of the data introduce degeneracies in the dynamical modelling results, and a dependence on the initial particle model.

* The reliability of the models is limited to those regions in which good observational data exist.
→ Get data as far out as possible!





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Application: modelling the halos of Ellipticals

Outer halos of ellipticals are interesting:
dark matter dominates, formation history
may be preserved longer in the orbits

We construct NMAGIC dynamical models to study the dynamics of stars out into the halo using a variety of observational data

NGC 3379

Normal ellipticals, PNe as discrete tracers of the stellar VD

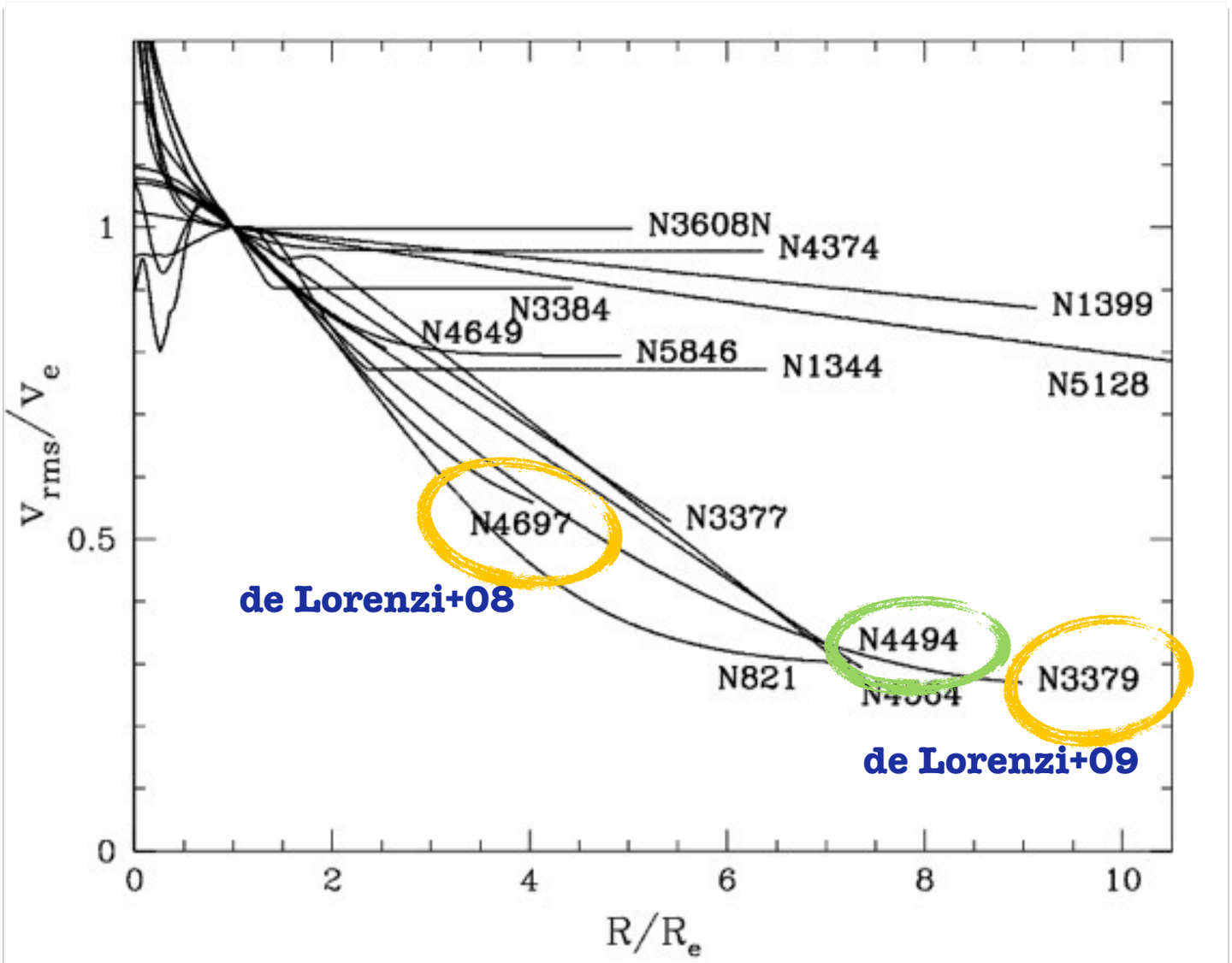
Romanowsky+03, Cappellari+06, Thomas+07, Napolitano+09, de Lorenzi+08, 09, Morganti+12 (in prep)

NGC 4649

Massive ellipticals, potential from X-ray

Humphrey+06, Shen & Gebhardt 10, Das+11

Two flavours of elliptical galaxy halos



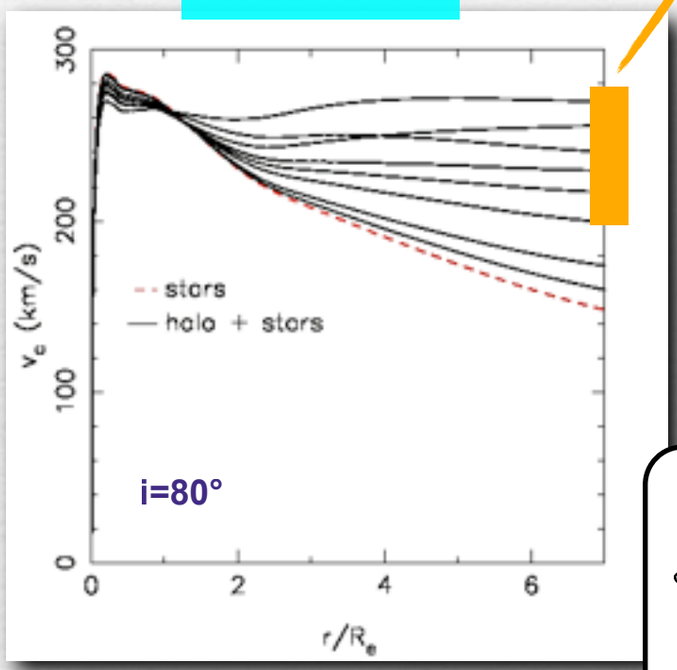
Coccato+09: study kinematics of ellipticals to large radii using PNe. Combined sample of 16 ellipticals (updated).

- Two main groups of galaxies: slightly or strongly declining mean rms velocity profile from the centre outwards.
- Massive and boxy slow rotators have nearly flat mean rms velocity and dispersion profiles.
- Galaxies with steeper rms profiles are fast rotators of intermediate luminosity.

Halos of Intermediate Luminosity Ellipticals

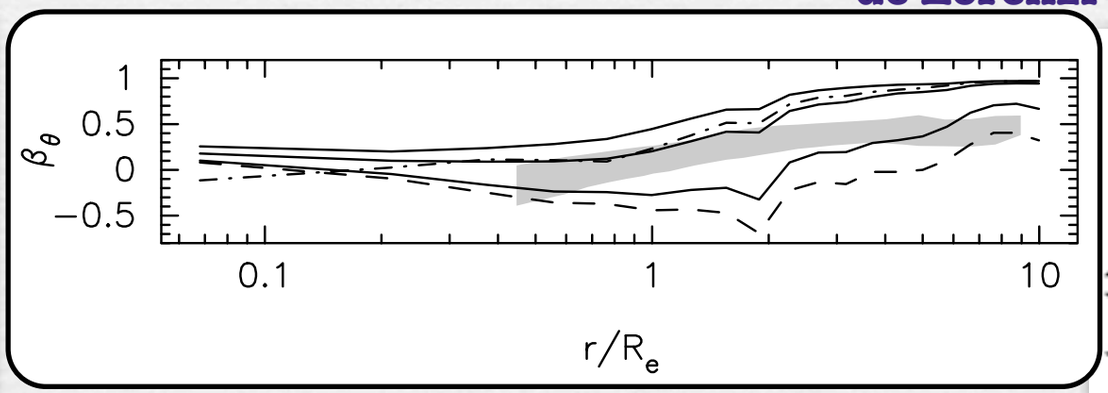
A **range** of potentials and anisotropy profiles are consistent with photometric and kinematic data

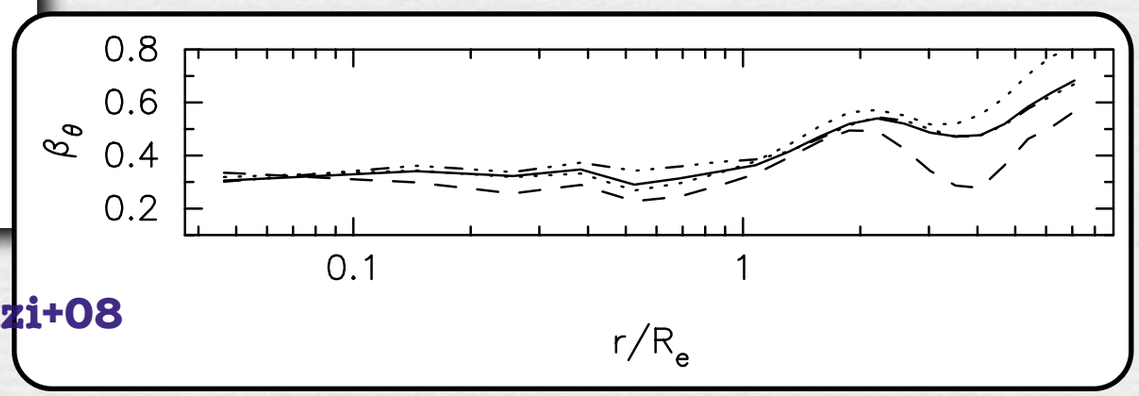
NGC 4697



PNe LH limits at 1σ

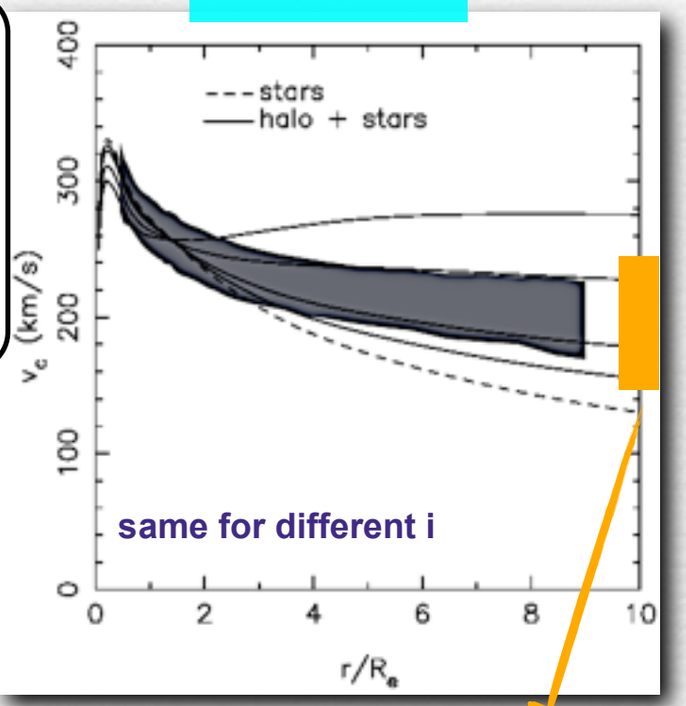
de Lorenzi+09





de Lorenzi+08

NGC 3379



PNe LH limits at 1σ

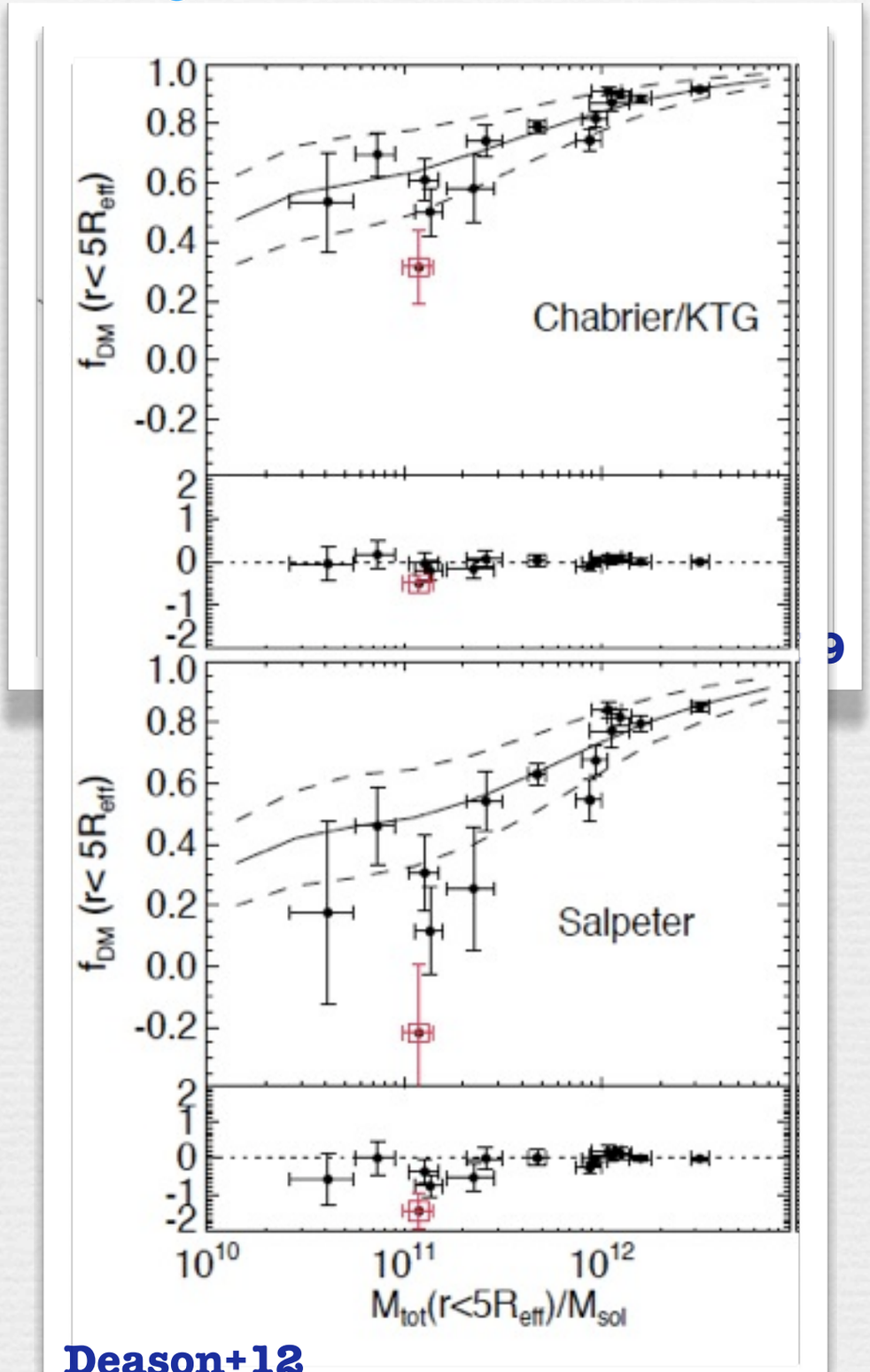
Higher order moments of LOSVD to 2Re, but not for PNe → Mass-anisotropy(-shape) degeneracy

NGC 4494: our new target galaxy

- It belongs to the family of Ellipticals with falling mean rms profile, like NGC 3379 and NGC 4697. Are their halos similar?

- It has a curiously low dark matter fraction within $5R_{eff}$ (Romanowsky+03, Napolitano+09, Deason+12)

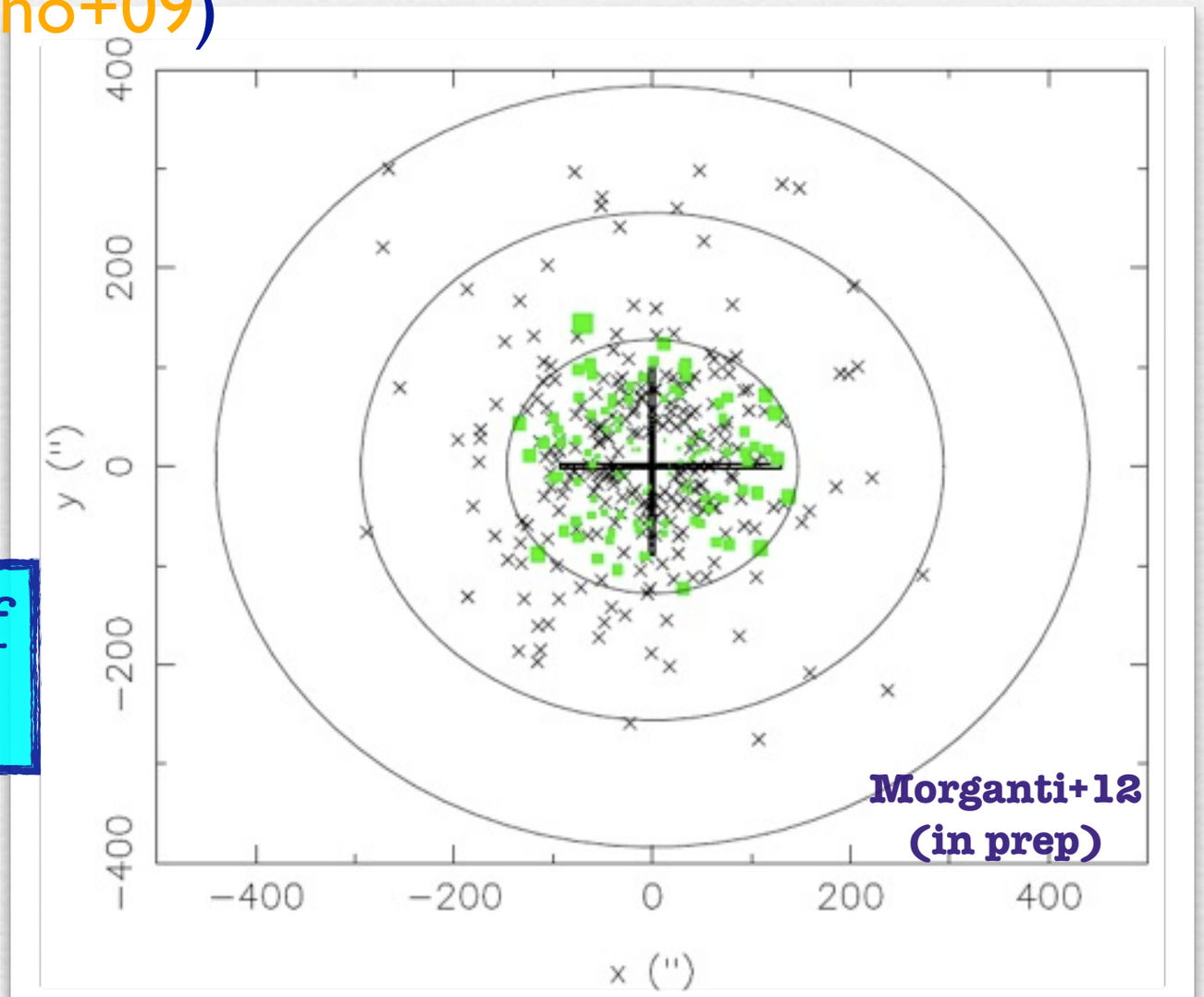
- Kinematic data are available out to $3.5R_{eff}$ (new slitlets data, Foster+11), and 7 R_{eff} (255 PNe velocities, Napolitano+09)



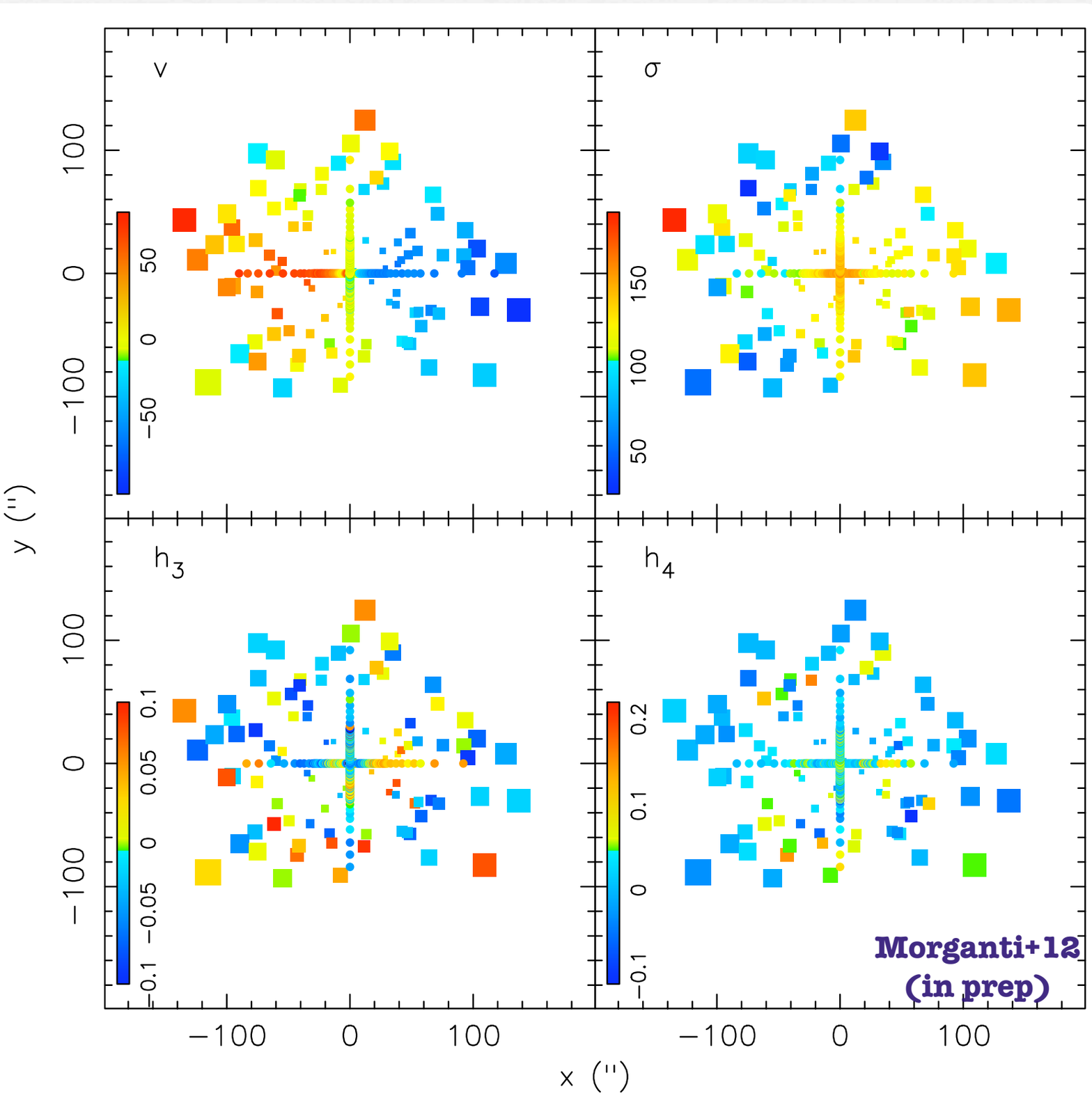
NGC 4494: observational data

- Combined photometric profile: SB, ellipticity, a4 (Napolitano+09)
- Long-slit kinematics along major and minor axis (Coccato+09)
- PNe radial velocities (Napolitano+09)
- Slitlets spectra (Foster+11)

Spatial coverage of kinematic data

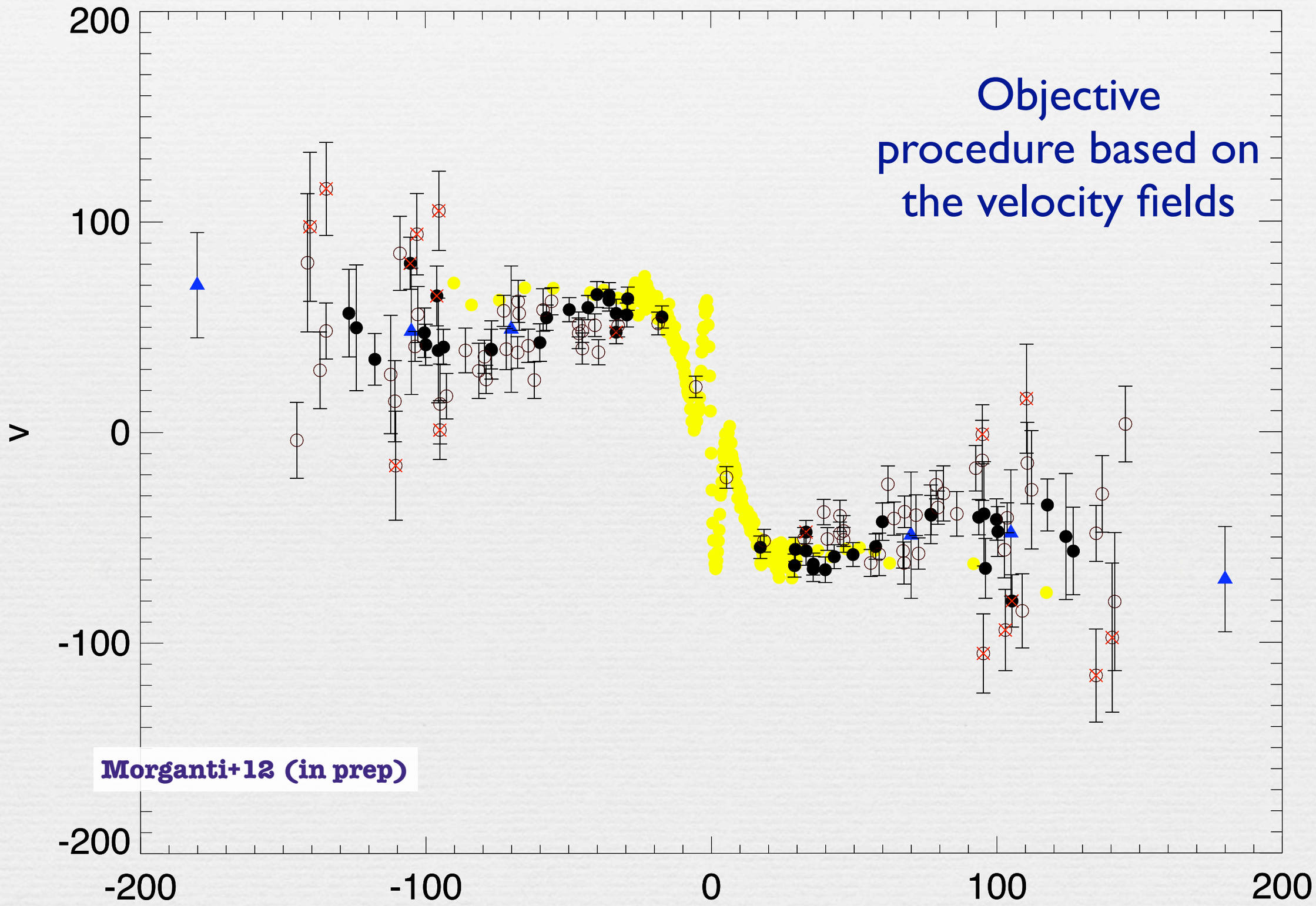


NGC 4494: new slitlets data (Foster+11)



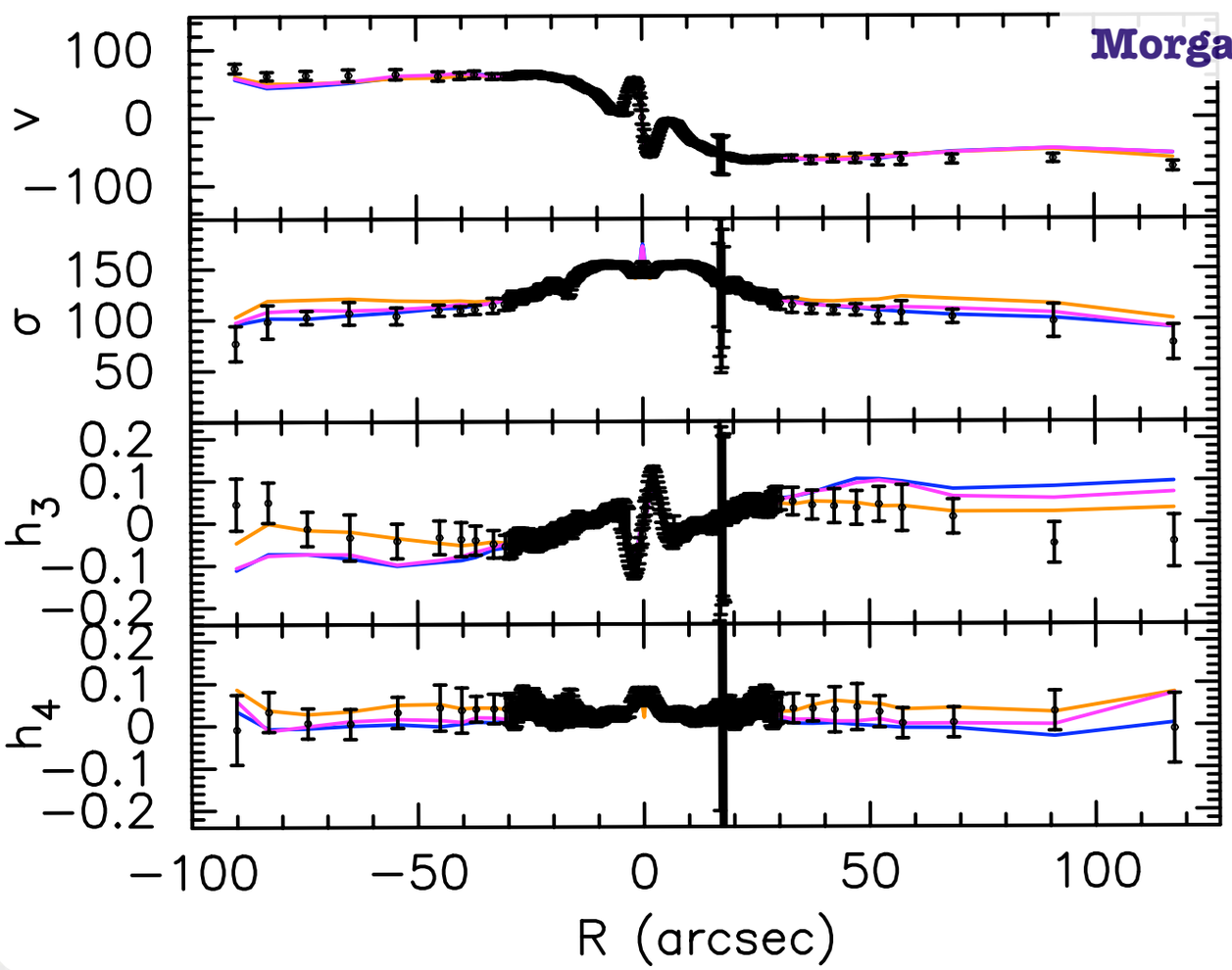
Kinematics in long-slits and slitlets

NGC 4494: removal of outliers

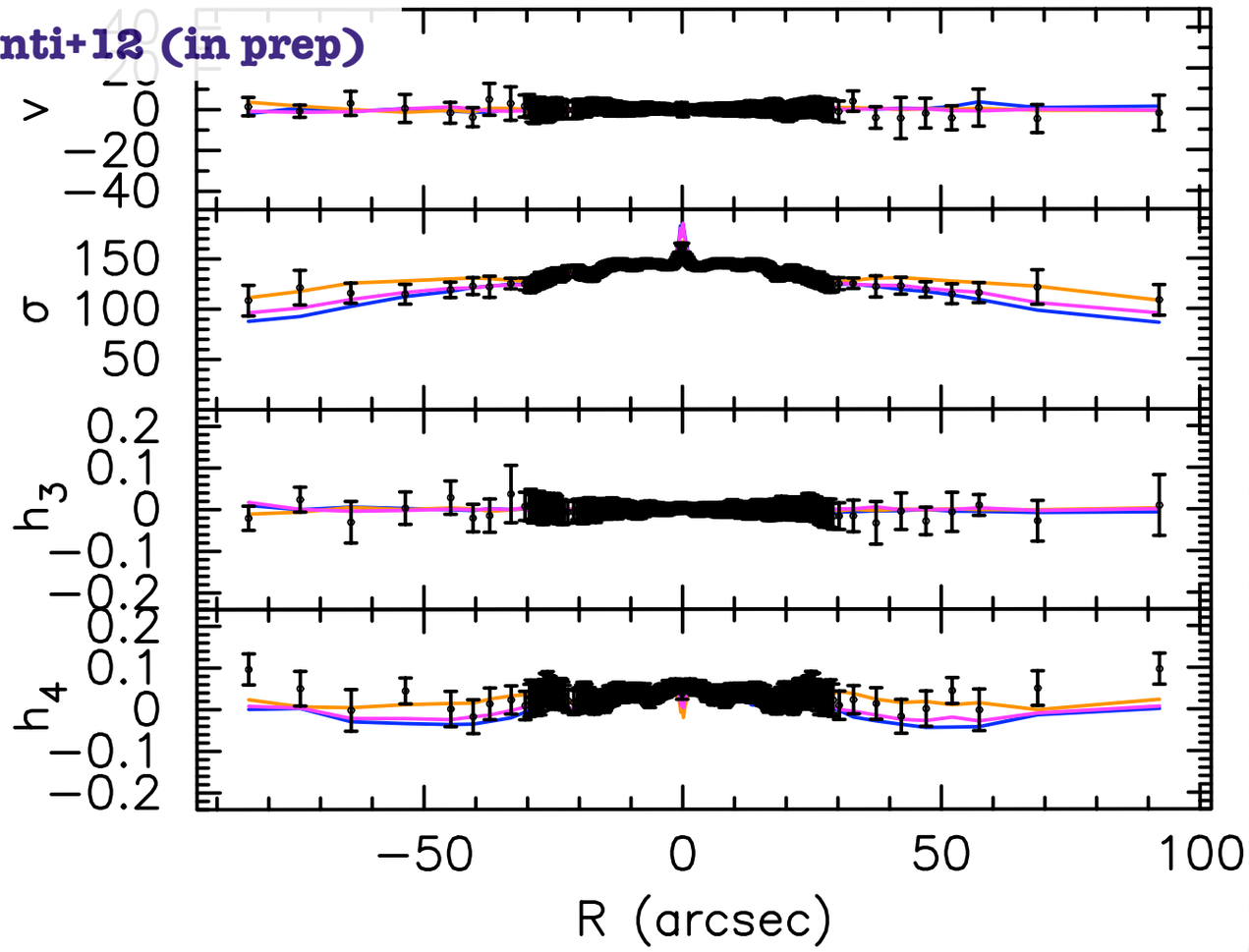


NGC 4494: axisymmetric NMAGIC models in different dark halos

$$\phi = \phi_\star + \frac{v_0^2}{2}\ln(r_0^2 + r^2)$$



Morganti+12 (in prep)



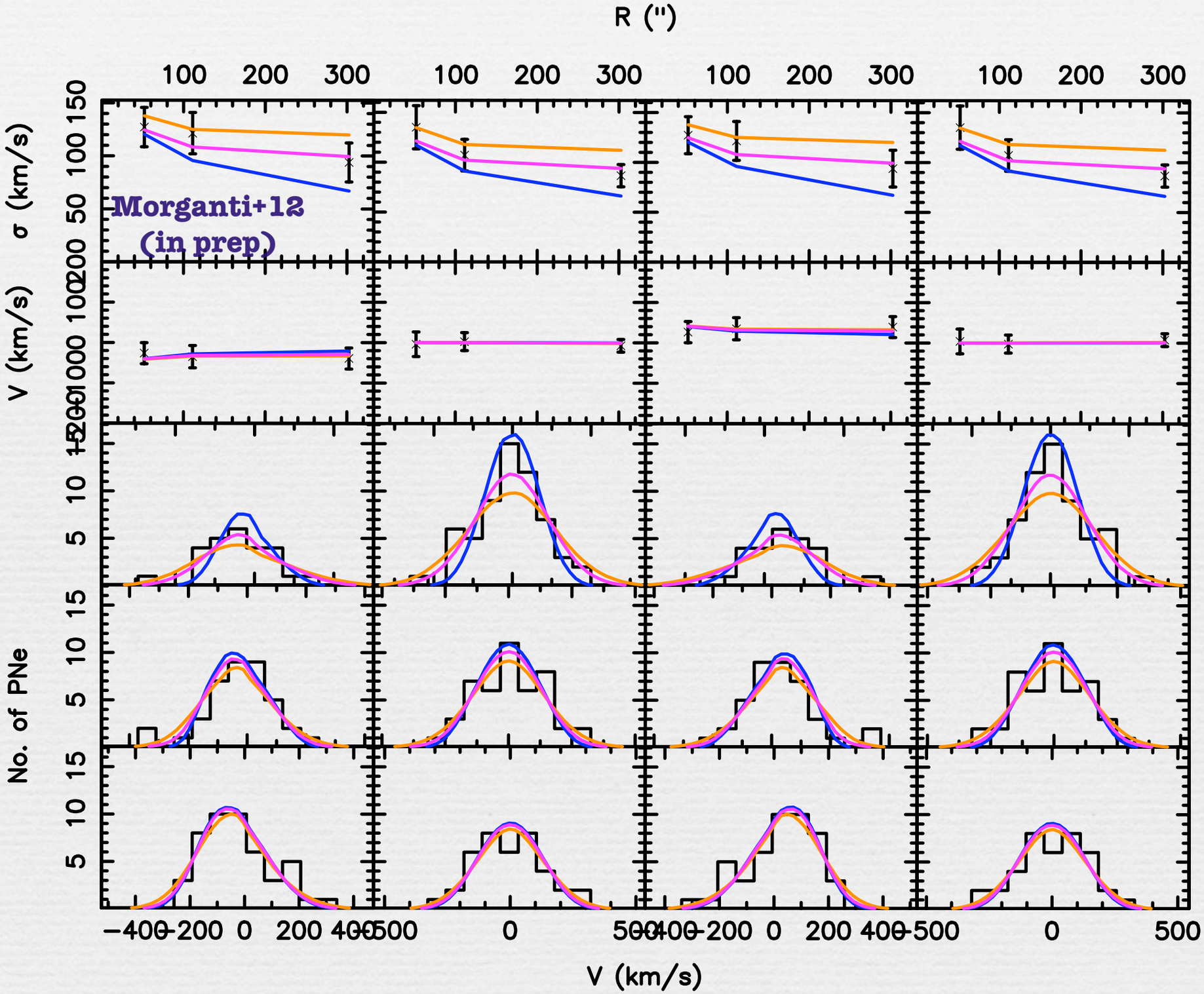
Blue: no DM

Orange: best-fitting absorption line kinematics

Purple: best-fitting PNe

Edge-on models.
Lower inclination to be done!

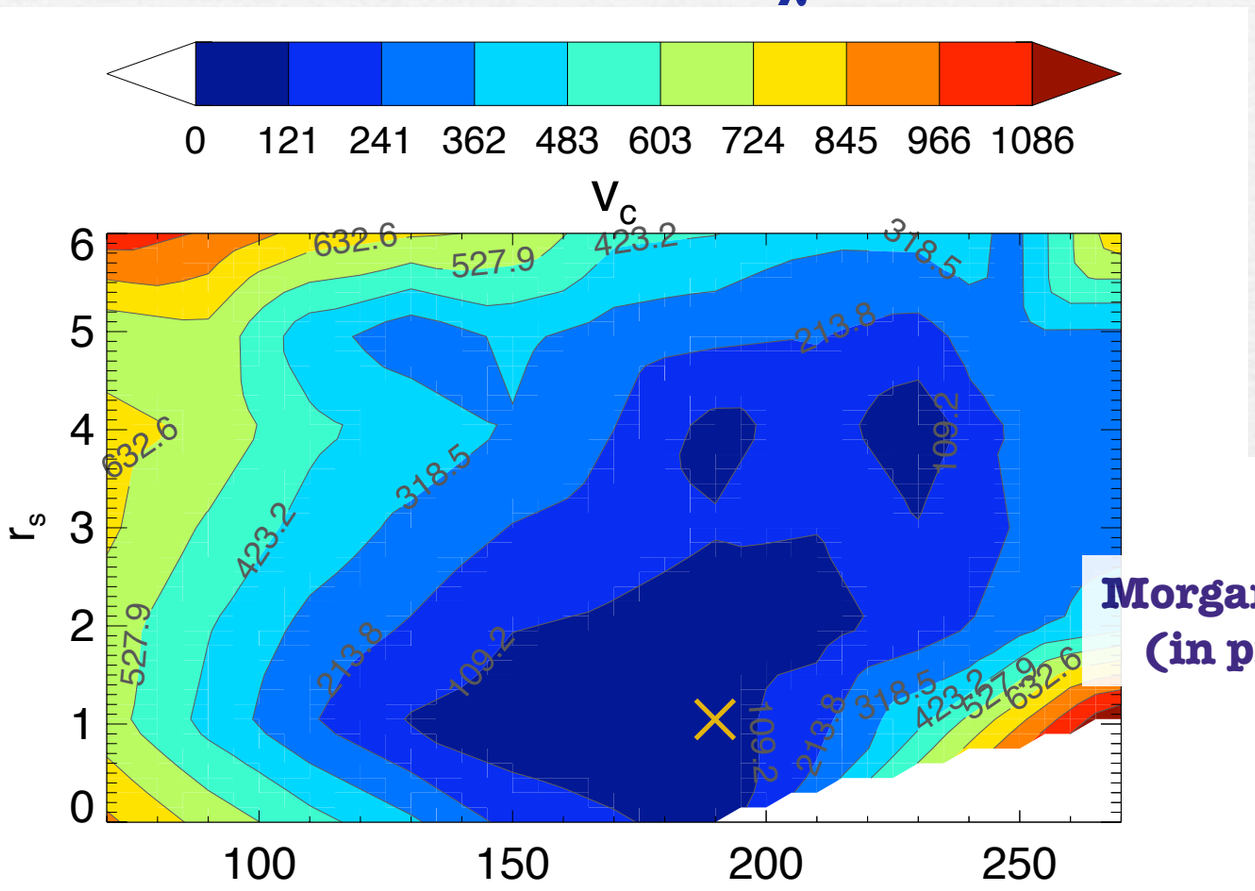
NGC 4494: axisymmetric NMAGIC models



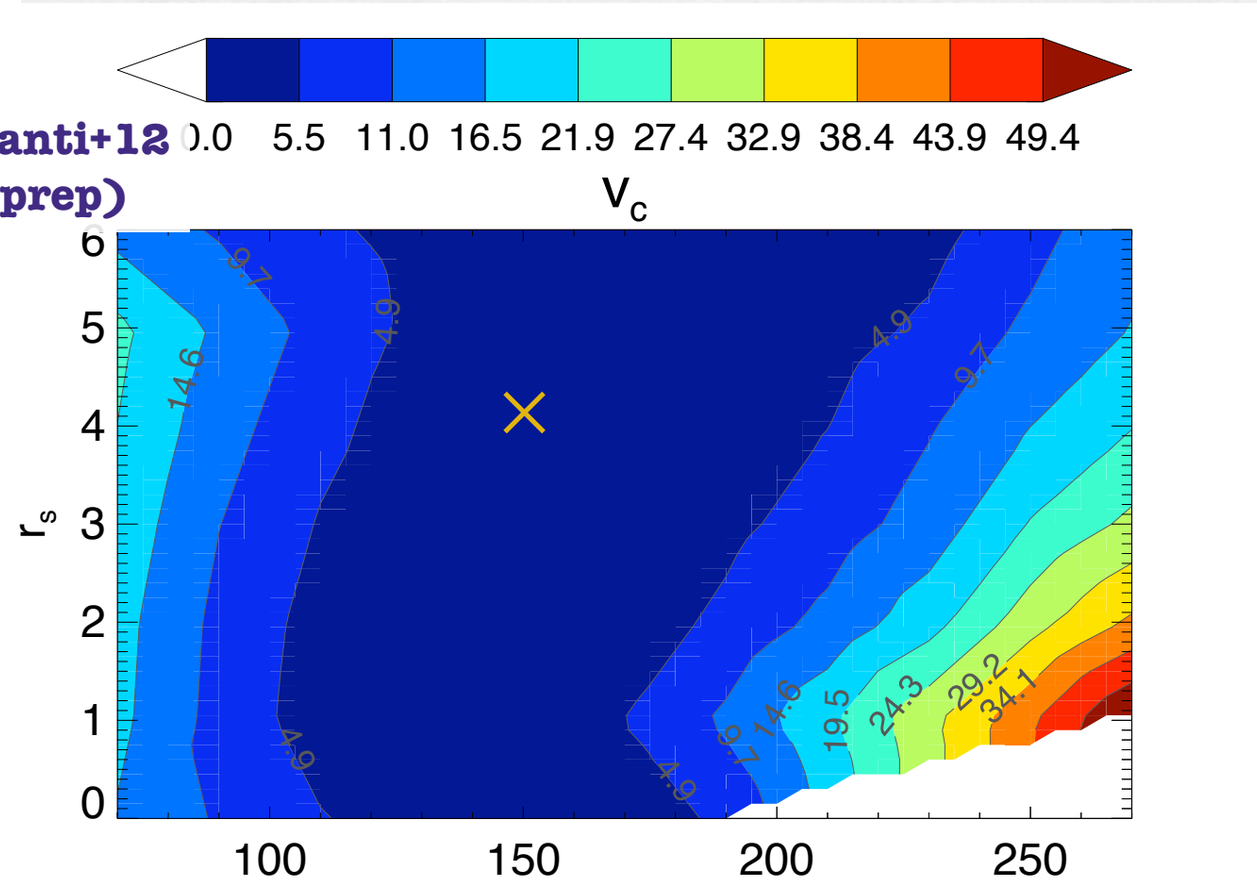
Blue: no DM
Orange: best-fitting absorption line kinematics
Purple: best-fitting PNe

Models for NGC 4494: edge-on results

Contours of $\Delta\chi^2$



Contours of Δlikelihood of PNe



Morganti+12 (in prep)

$$\phi = \phi_\star + \frac{v_0^2}{2}\ln(r_0^2 + r^2)$$

How well can we estimate the dark halo parameters with NMAGIC?

- Construct a target galaxy which is very similar to NGC 4494

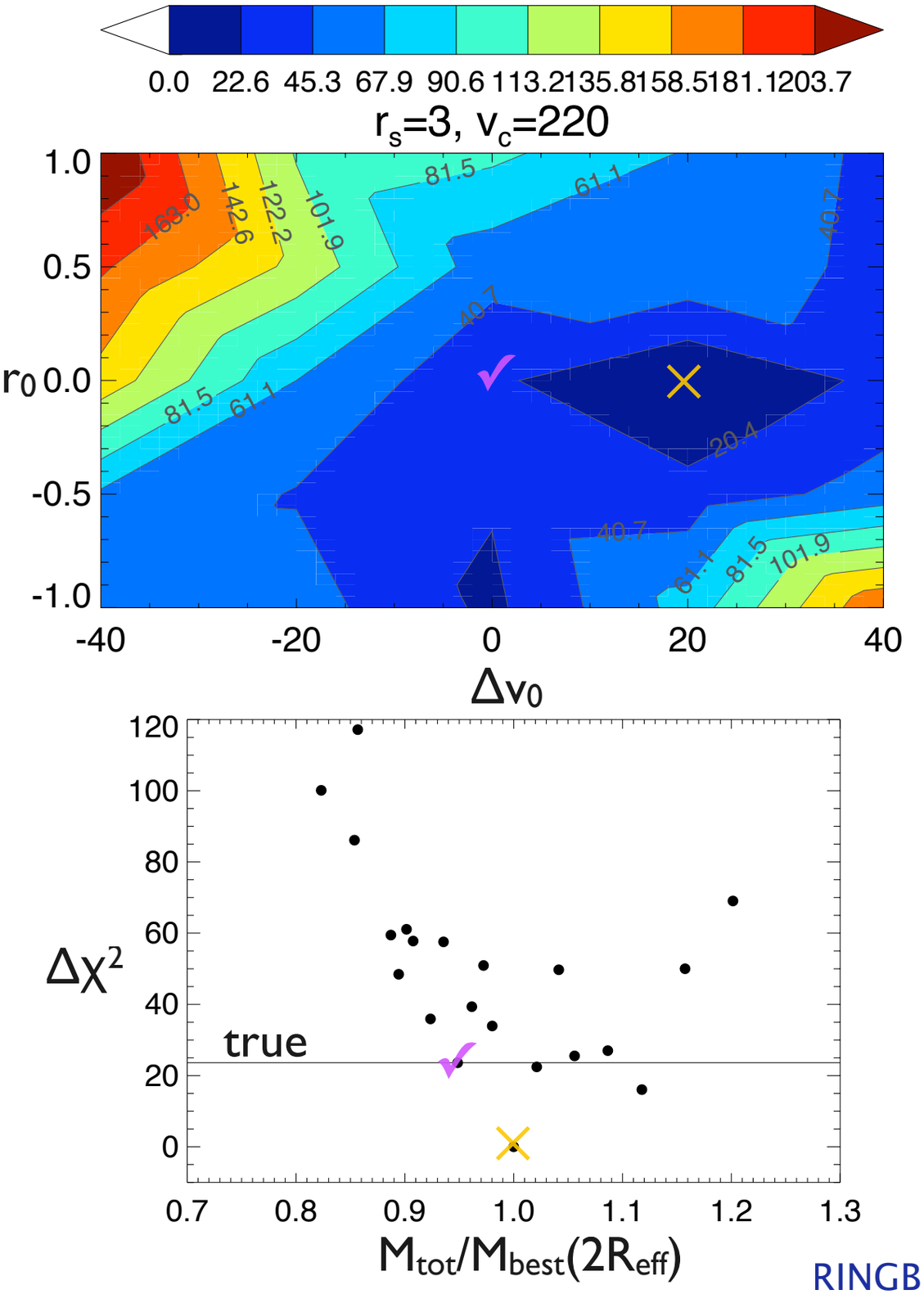
- The NGC 4494-like galaxy is embedded in a known dark matter halo

- Use NMAGIC to produce the very same observational data (spatial coverage, error bars) that have been used for the modelling of the real NGC 4494

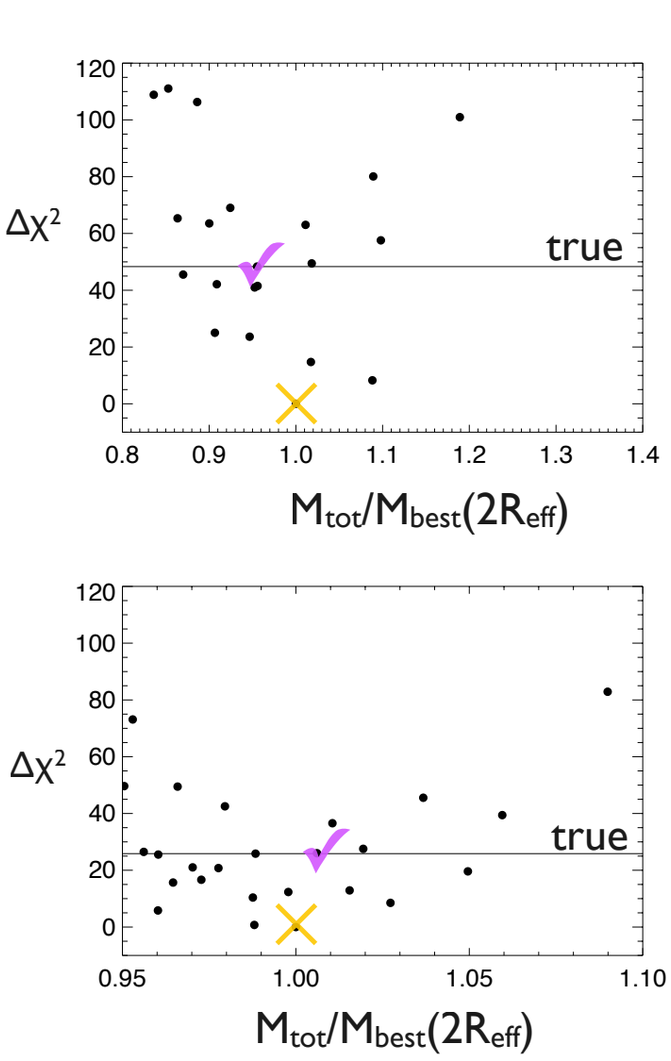
- Use NMAGIC to model the photometric and kinematic data for this NGC 4494-like galaxy with different dark matter halos: see how well we can recover the true parameters

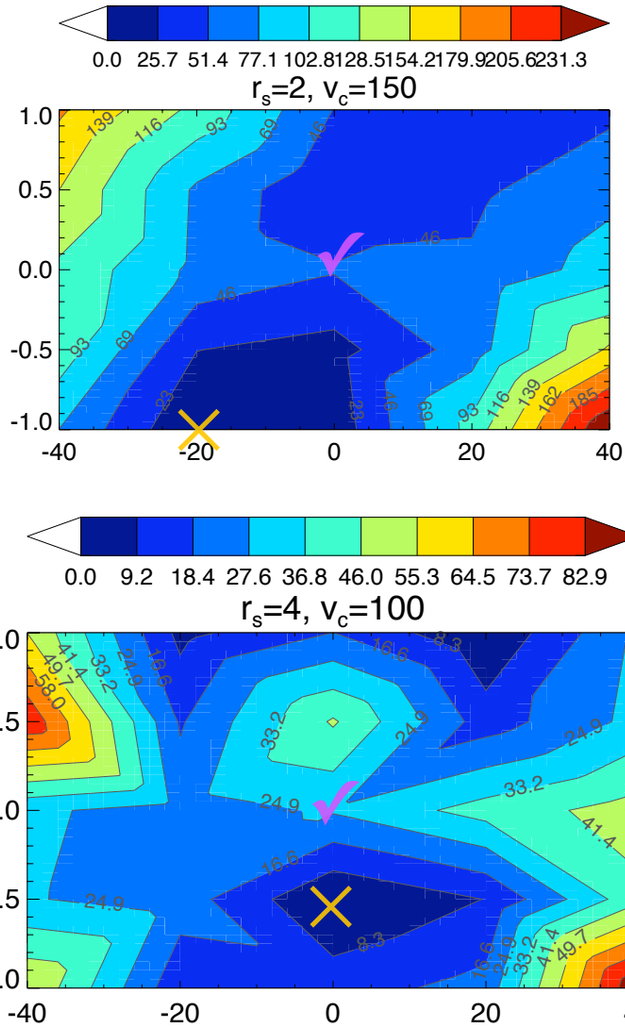
- Repeat the experiment for 10 different NGC 4494-like galaxies embedded in 10 different halos: infer confidence levels

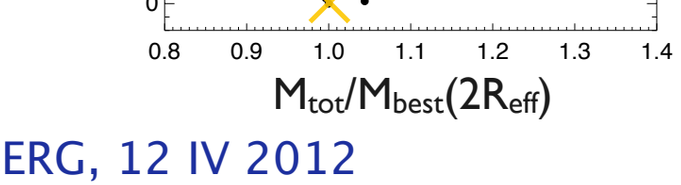
Model the mock NGC 4494-target

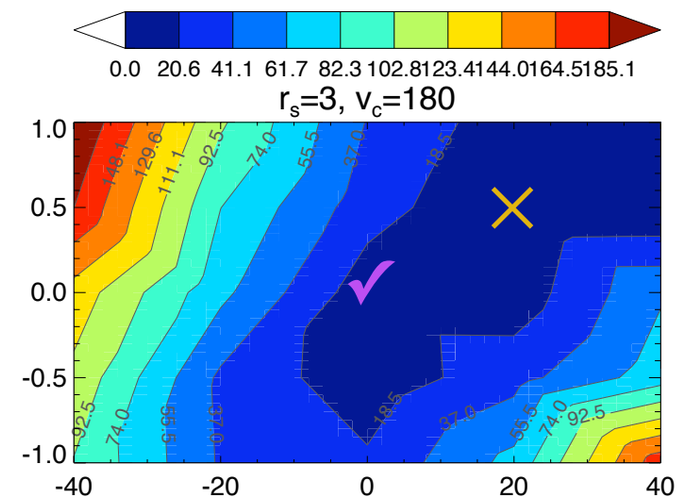


Repeat the experiment for 10 halos



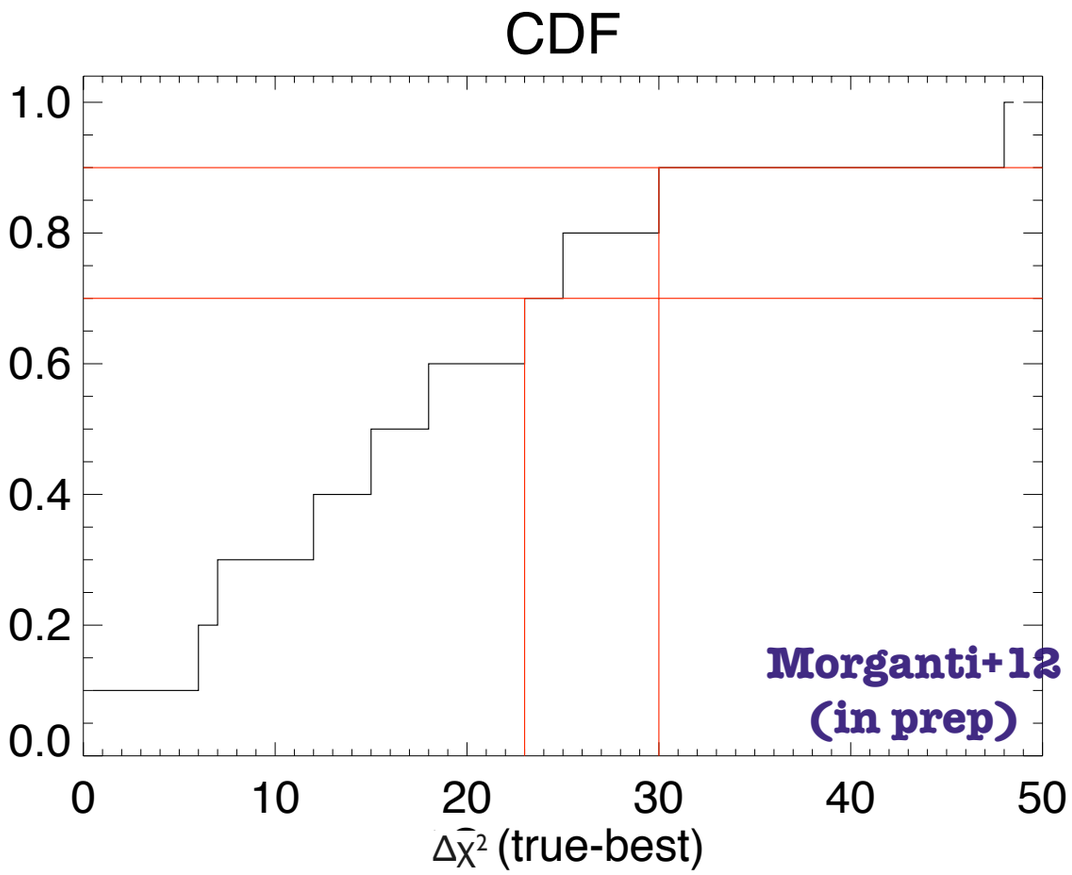






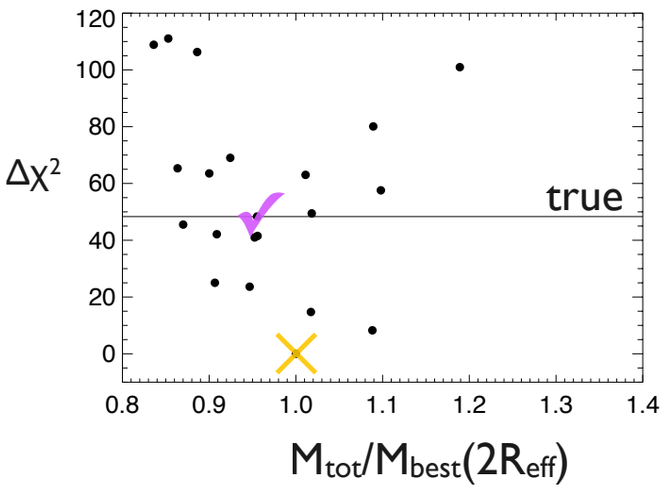
Repeat the experiment for 10 halos

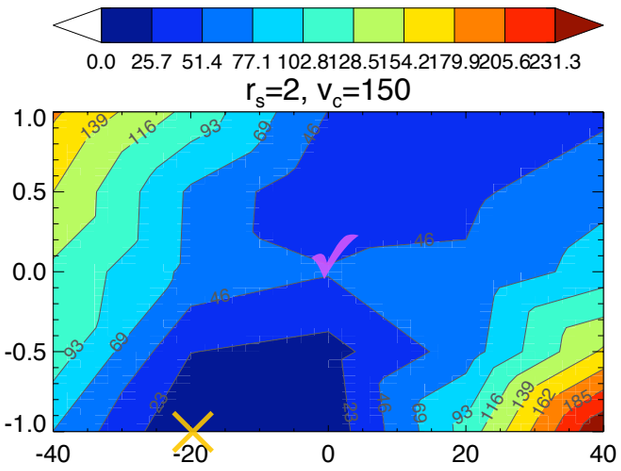
NMAGIC models for these data: $\Delta\chi^2 \neq 1$

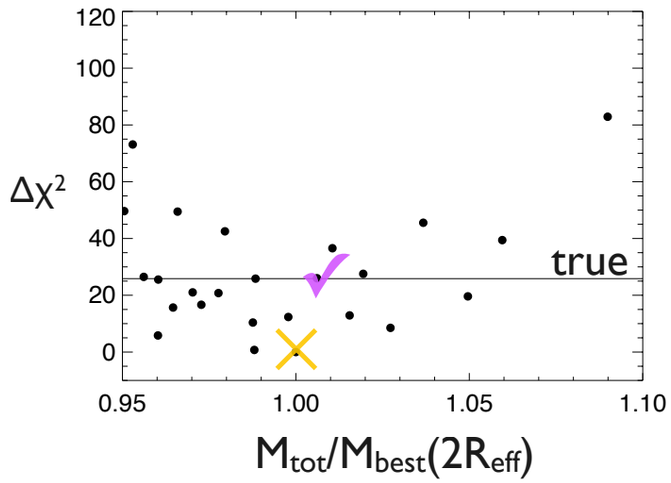


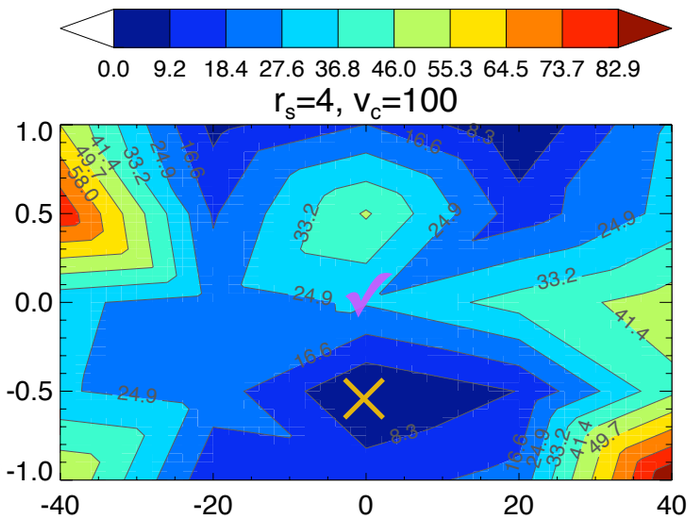
consistent with our modelling accuracy / noise

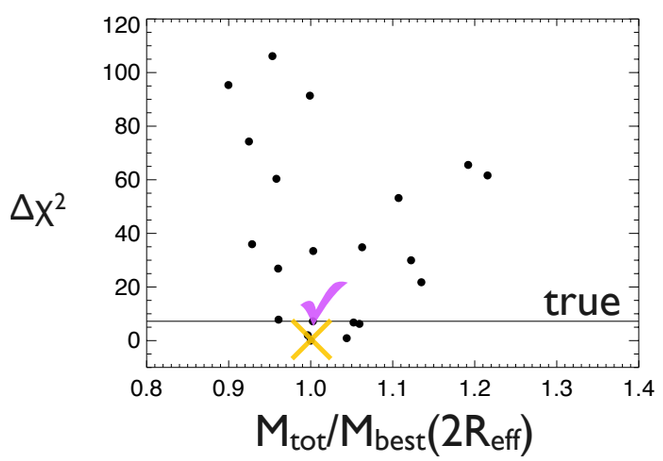
→ Worth testing with the Schwarzschild modelling

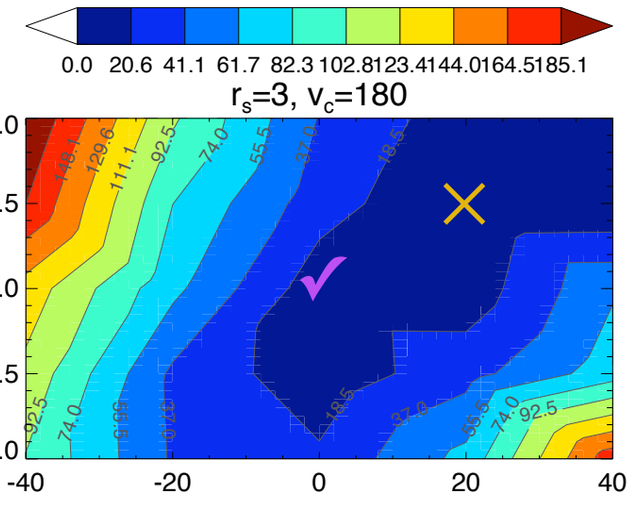




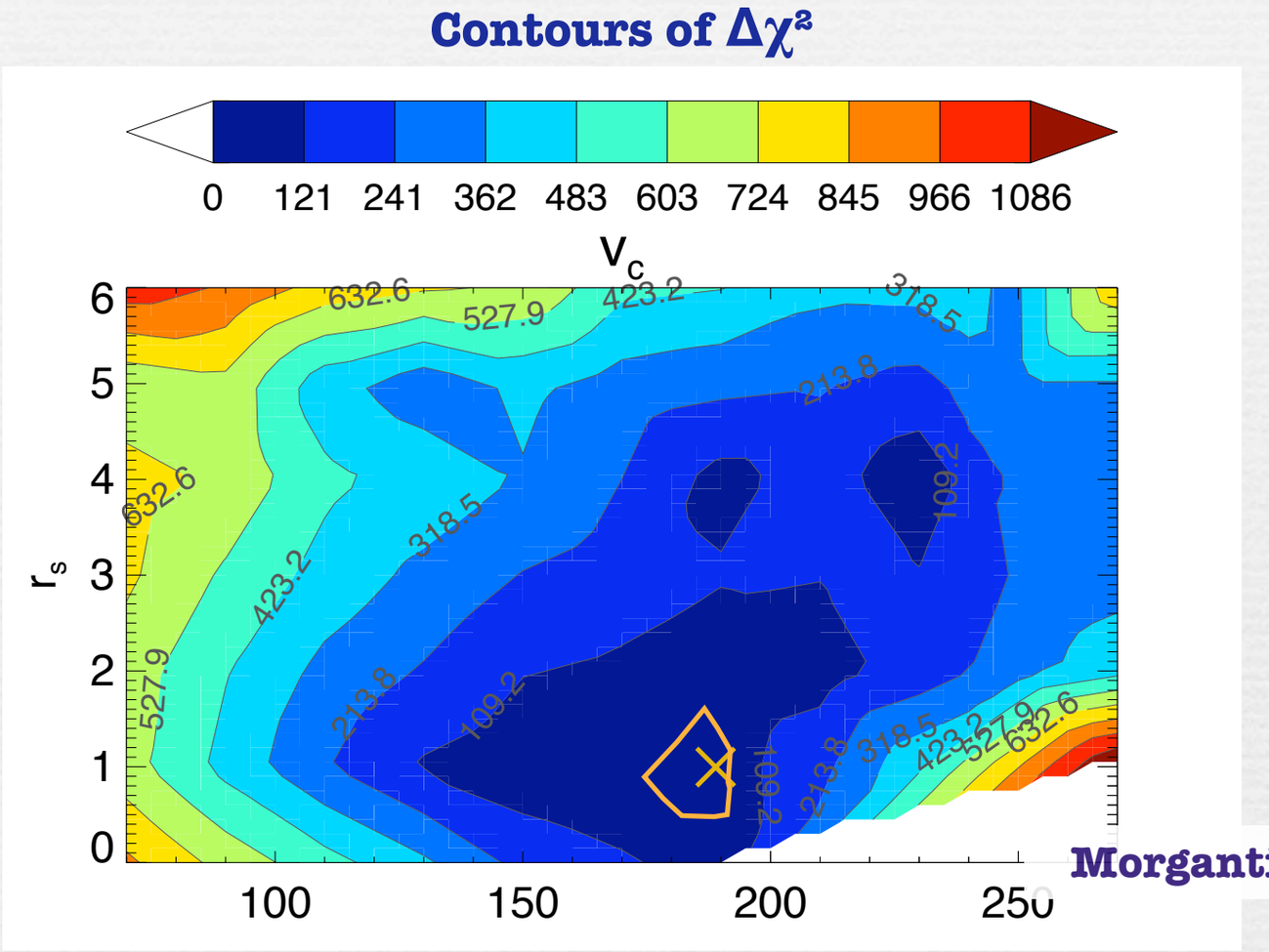


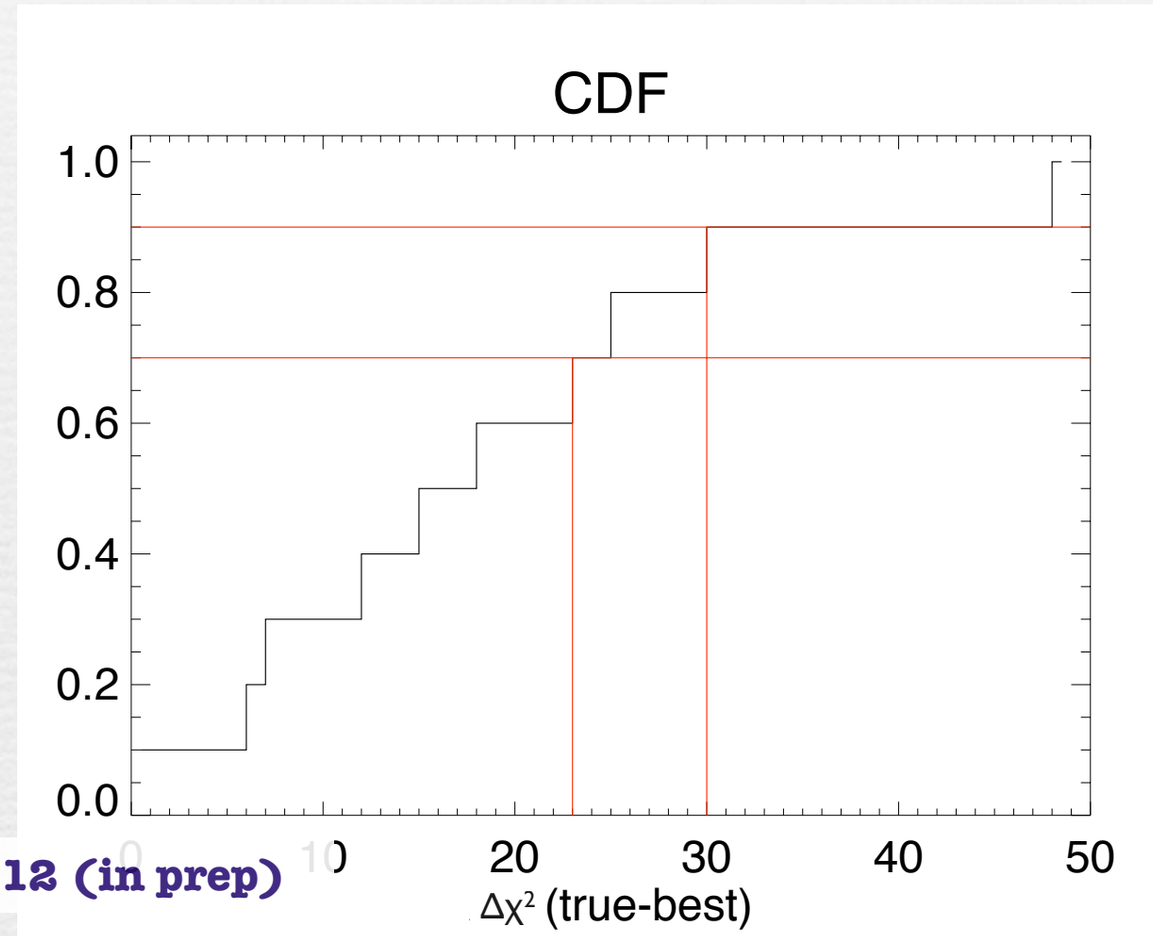






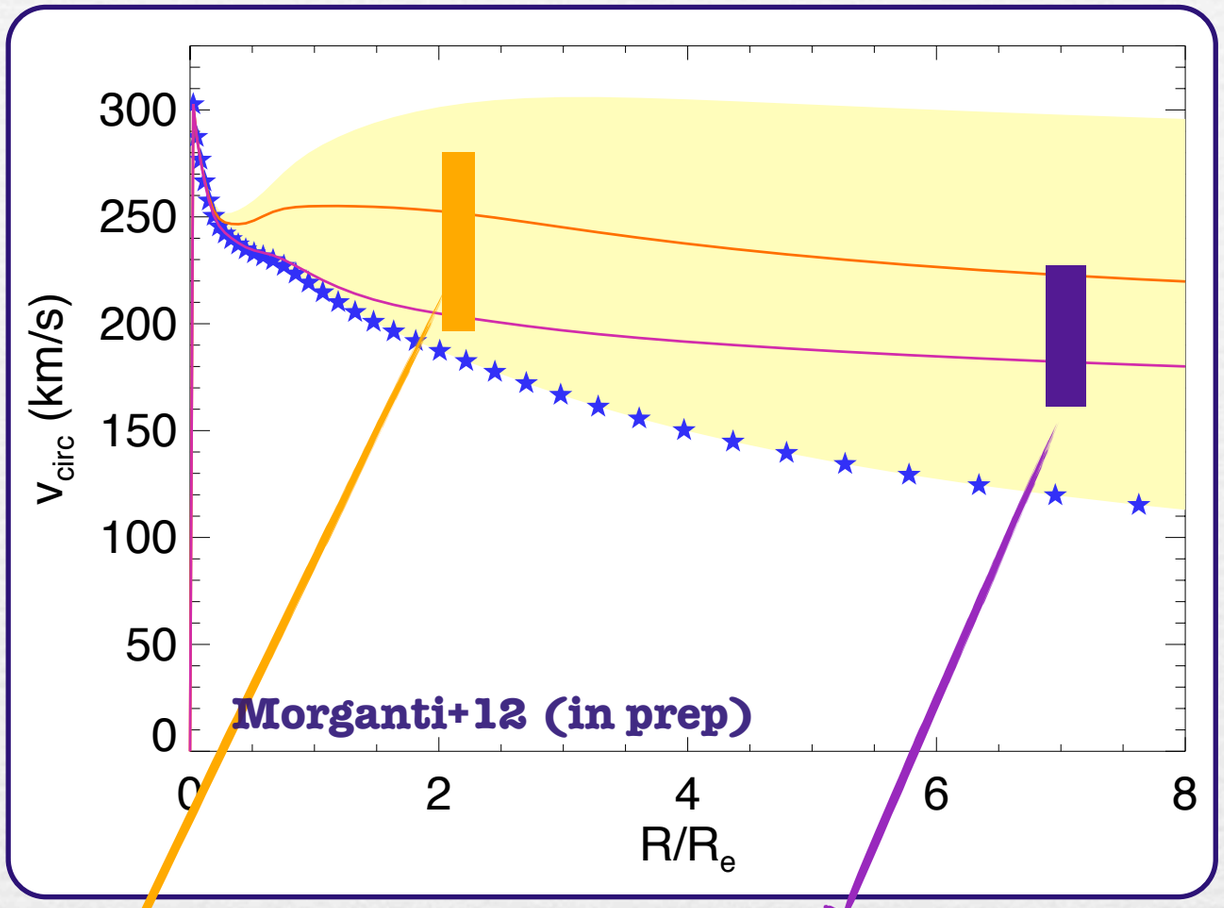
NGC 4494: interpretation of the results





Morganti+12 (in prep)

NGC 4494: edge-on models

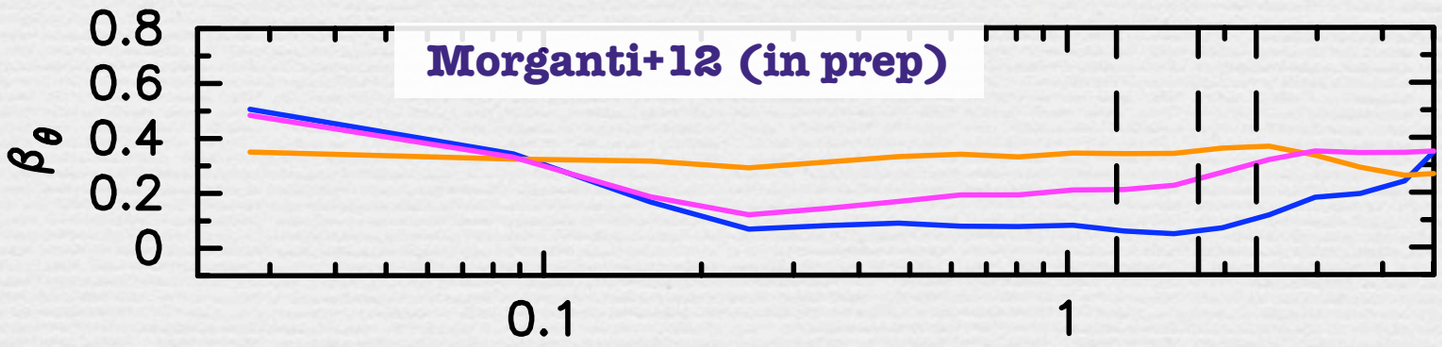


Absorption line data prefer halo v_c=190 km/s, r_s=1R_{eff}. PNe prefer halo v_c=150 km/s, r_s=3R_{eff}.

f_{DM} (5R_{eff}) is about 0.5-0.7; larger than in previous models.

PNe LH limits at 1σ

Preliminary confidence range from $\Delta\chi^2$

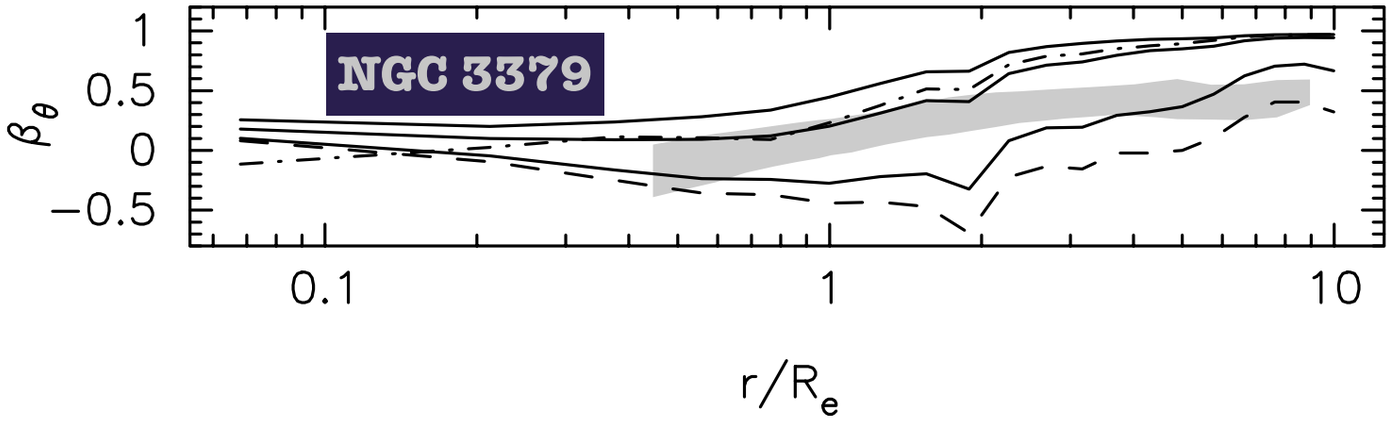


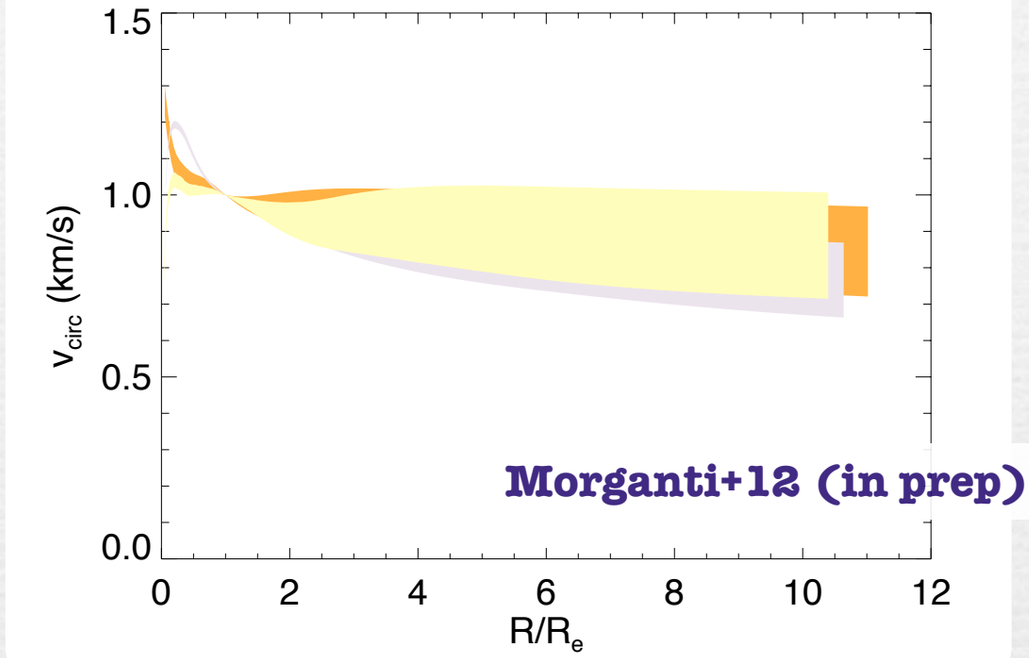
Blue: no DM

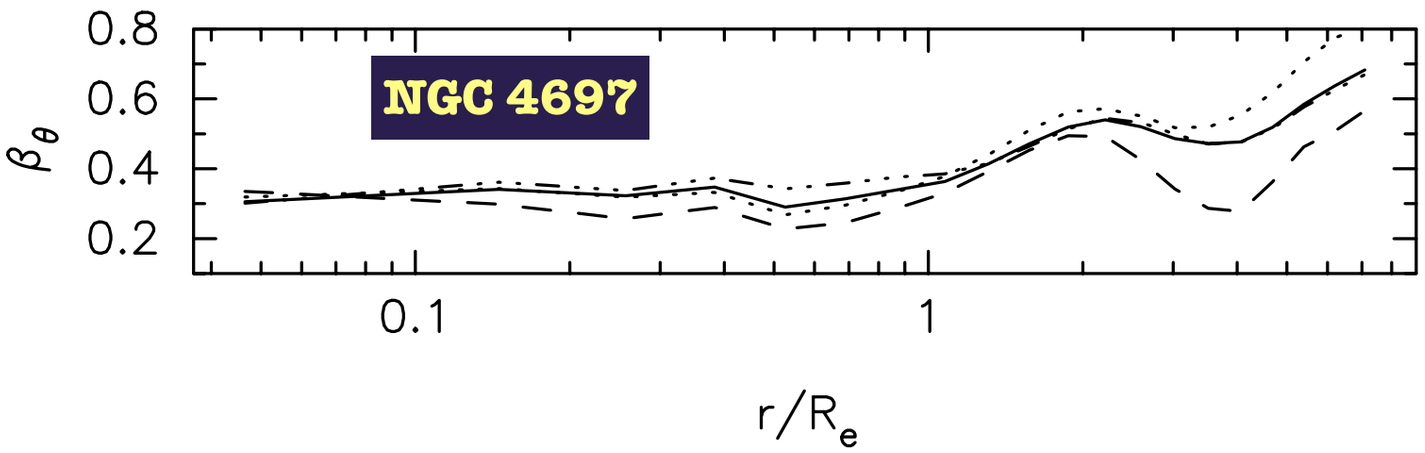
Orange: best-fitting absorption line kinematics

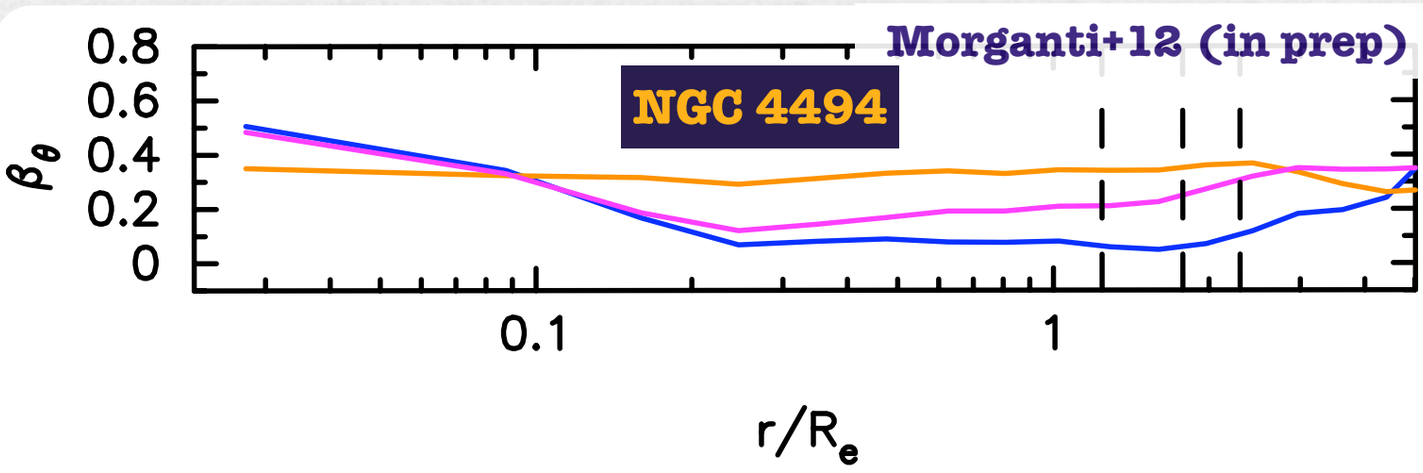
Purple: best-fitting PNe

Results: intermediate luminosity ellipticals









The halos are similar. NGC 4494 is the most extreme case: strong central concentration of baryons

Conclusions

* NMAGIC is a powerful tool to probe the dynamics of galaxies. It is important to get good data as far out as possible.
* We are modelling the intermediate luminosity elliptical NGC 4494 to learn about its halo. Spatial coverage of our kinematic constraints: slitlets to $3R_{eff}$ and PNe radial velocities to $7R_{eff}$.
* We determined the $\Delta\chi^2$ to be used for estimating confidence levels for the halo parameters from simulations. $\Delta\chi^2 \neq 1$.
* In edge-on models, the halo of NGC 4494 has a circular velocity around 150 km/s (PNe)-190 km/s (absorption line kinematics); the dark matter fraction is about 0.5-0.6 at $5R_{eff}$. The best-fitting models are slightly radially anisotropic.
* The halos of the intermediate luminosity ellipticals modelled so far (NGC 3379, NGC 4697 and NGC 4494) are similar. NGC 4494 has a particularly strong central concentration of baryons.