Dynamical modelling of dwarf spheroidal galaxies

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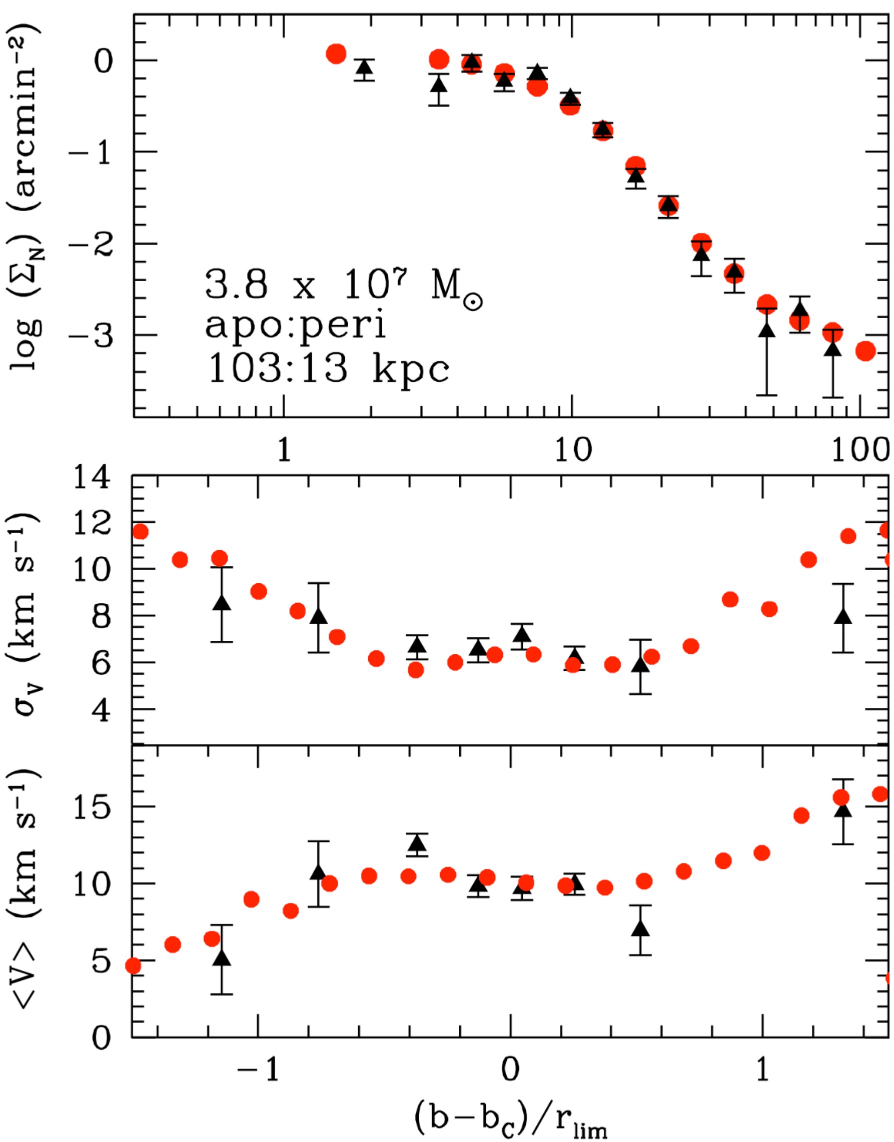
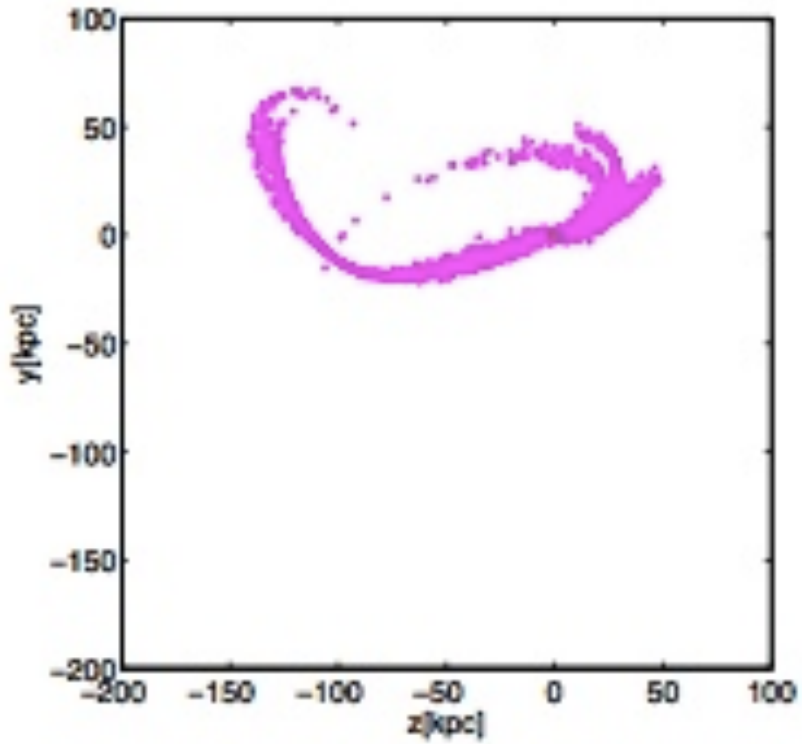
Tides in Milky Way dSphs?

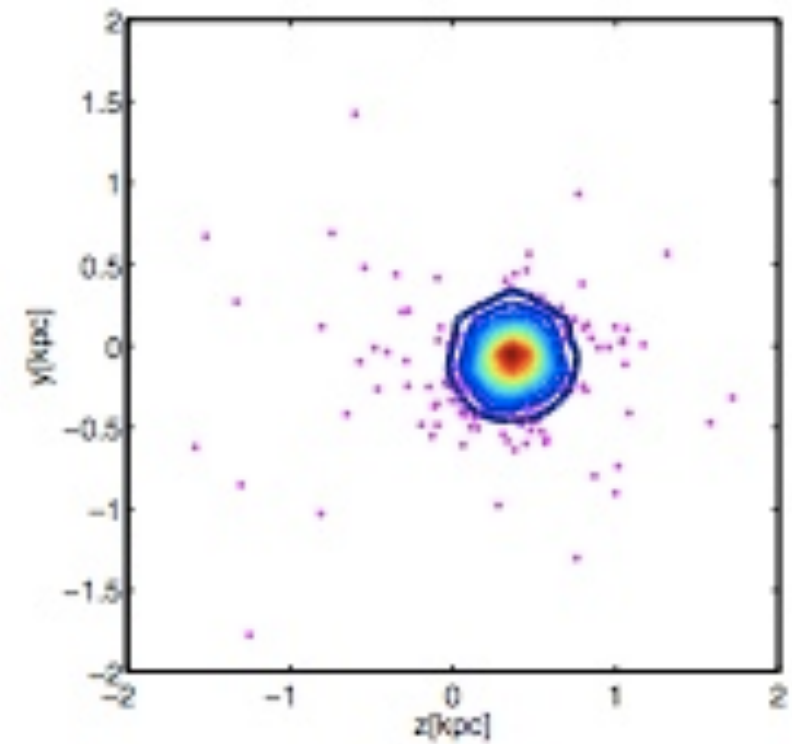


Munoz et al. (2008)

- Tidally perturbed, mass-follows-light models shown to reproduce data for Carina (Munoz et al. 2008)
- Similar claims for LeoI and Fornax (Lokas et al., 2008; Klimentowski et al., 2007)
- All dSphs orbit Milky Way: expect tidal perturbation at some level
- Need systematic study of allowed orbits/mass models and degeneracies

Modelling tidally disturbed dSphs: a new approach





Ural et al., in prep.

- Combine full N-body simulations with Markov Chain Monte Carlo
- Explore degeneracies between orbit and mass estimates

The method

- Generate present-day position and velocity for Carina using observed error bars on proper motion
- Integrate orbit backwards 5 Gyr in Milky Way potential
- Insert N-body realisation of Carina (stars + dark matter)
- Evolve model forward to present day
- Calculate surface brightness profile and line of sight velocity dispersion profile and compare with observations
- Use MCMC to generate sequence of models with varying $\rho_0,\ r_\mathrm{s},\ \rho_{0,*},\ r_{\mathrm{s},*},\ \mu_{\alpha\cos\delta},\ \mu_\delta$

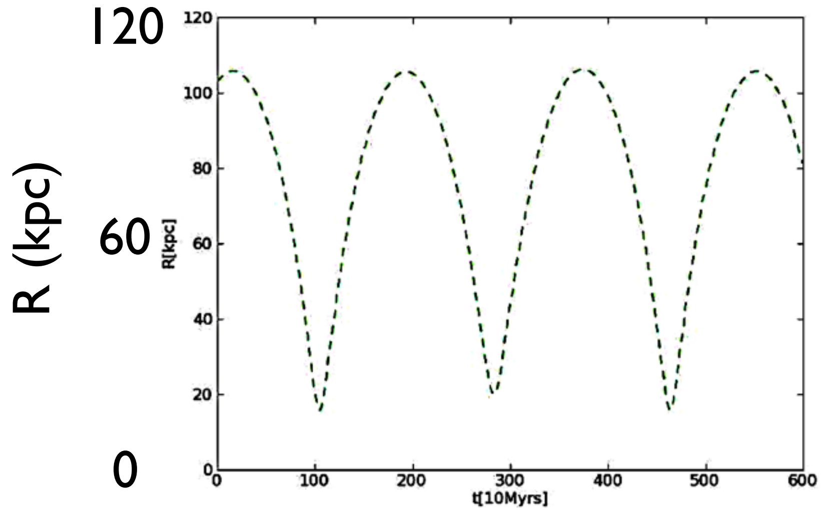
Assumptions

- dSph progenitors were initially spherical
- 2-component models (stars + dark matter)
- No significant evolution of Milky Way potential over past 5 Gyr
- Initial halo profile has form ($\gamma = 0, 0.5, 1$):

$$\rho(r) = \frac{\rho_0}{\left(\frac{r}{r_{\rm s}}\right)^{\gamma}\left(1 + \frac{r}{r_{\rm s}}\right)^{4-\gamma}}$$

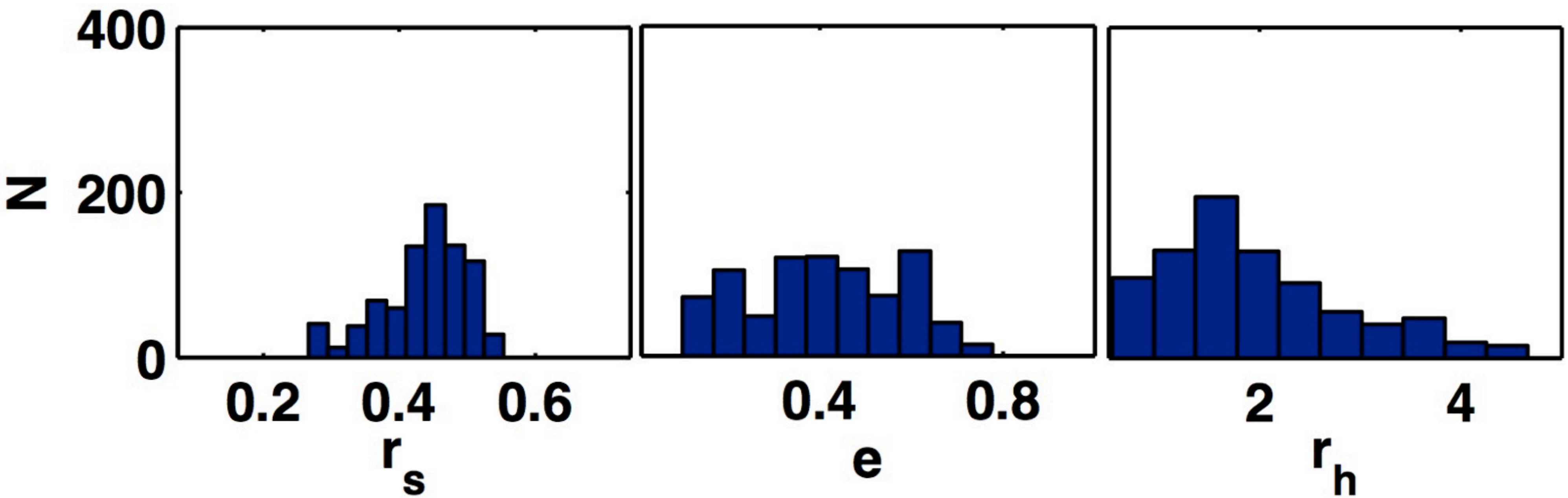
- Stellar profile based on fit to current distribution

Tests with artificial data

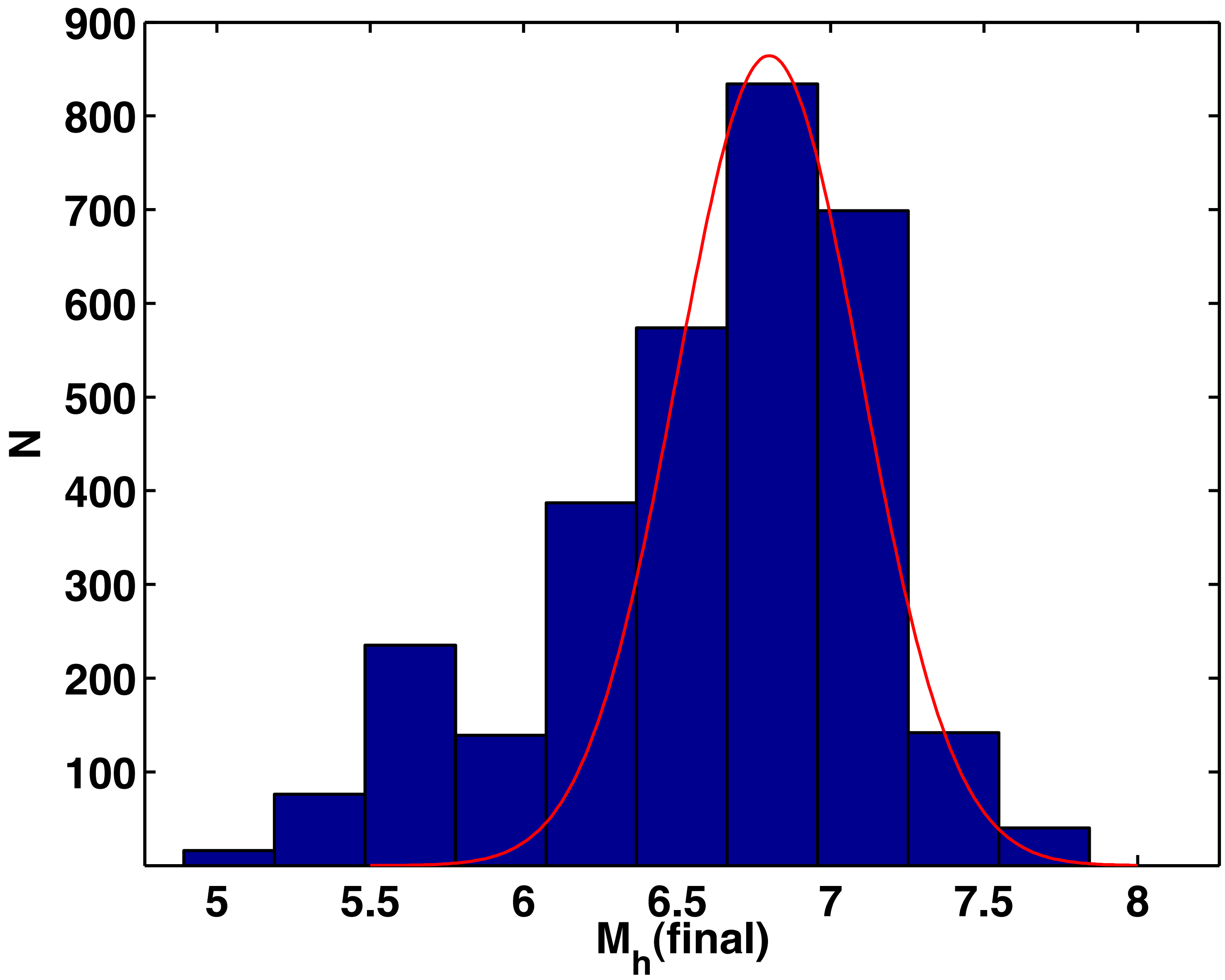


- Progenitor placed on eccentric orbit

- Approx. 3000 models in MCMC analysis

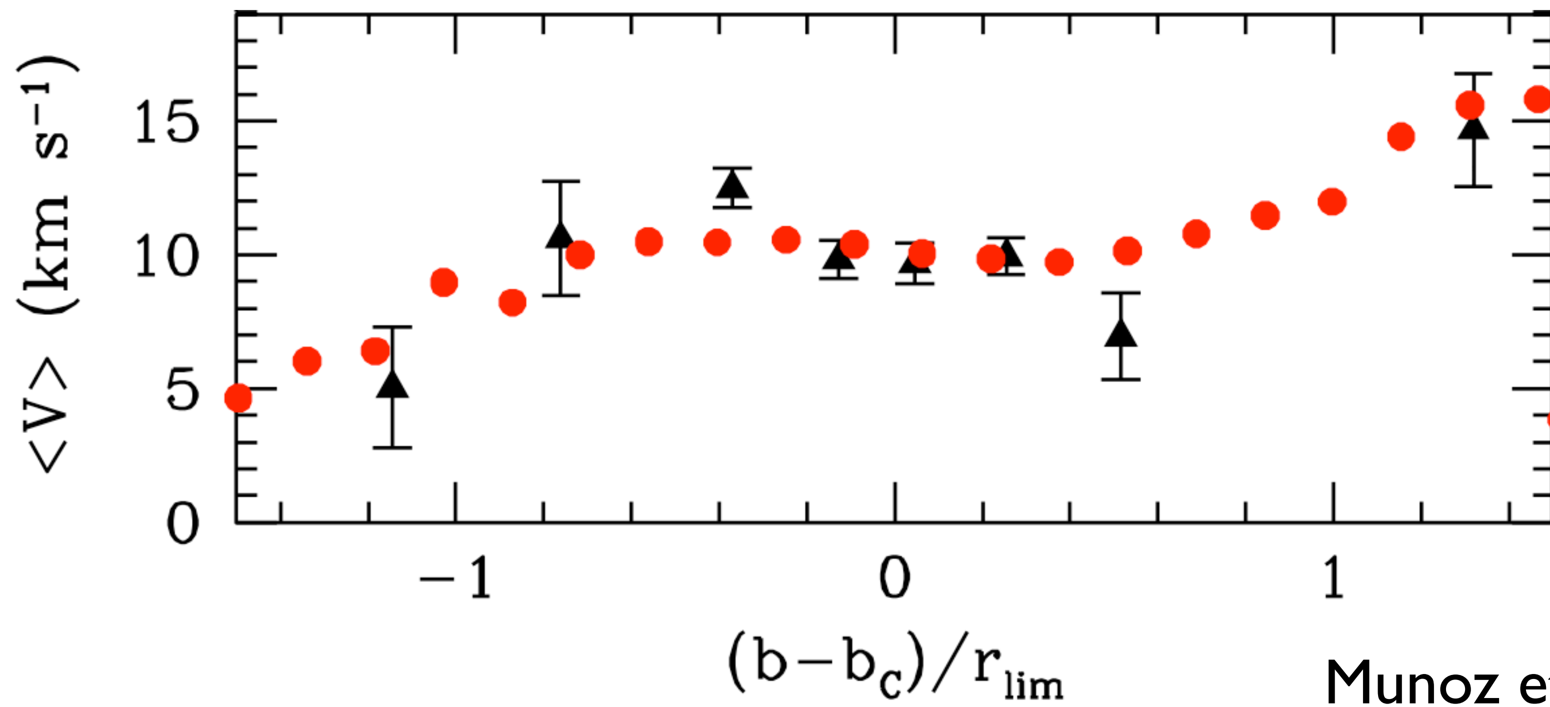


Tests with artificial data



Chains recover correct mass of dSph at end of simulation

Velocity gradient in Carina?

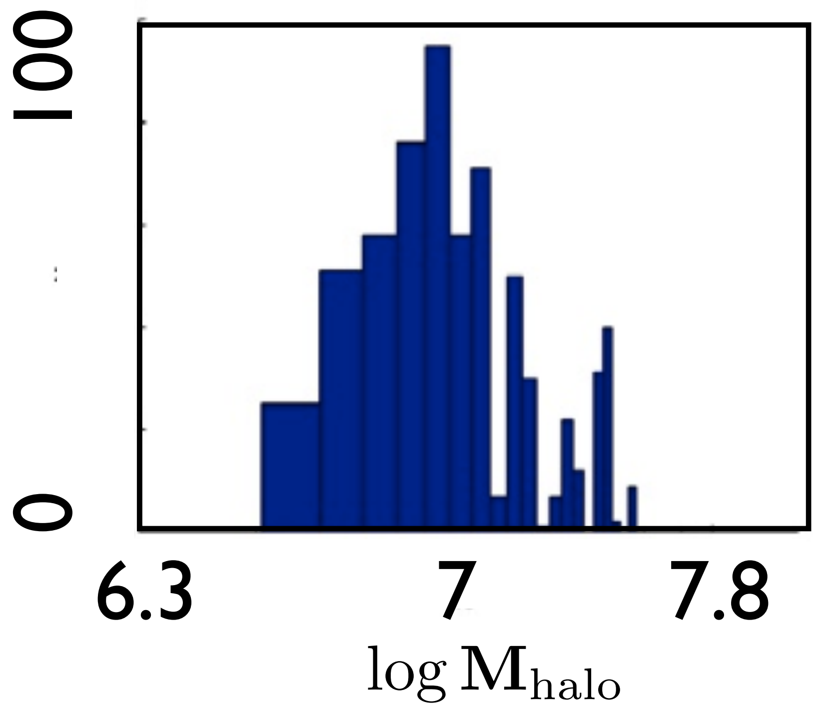


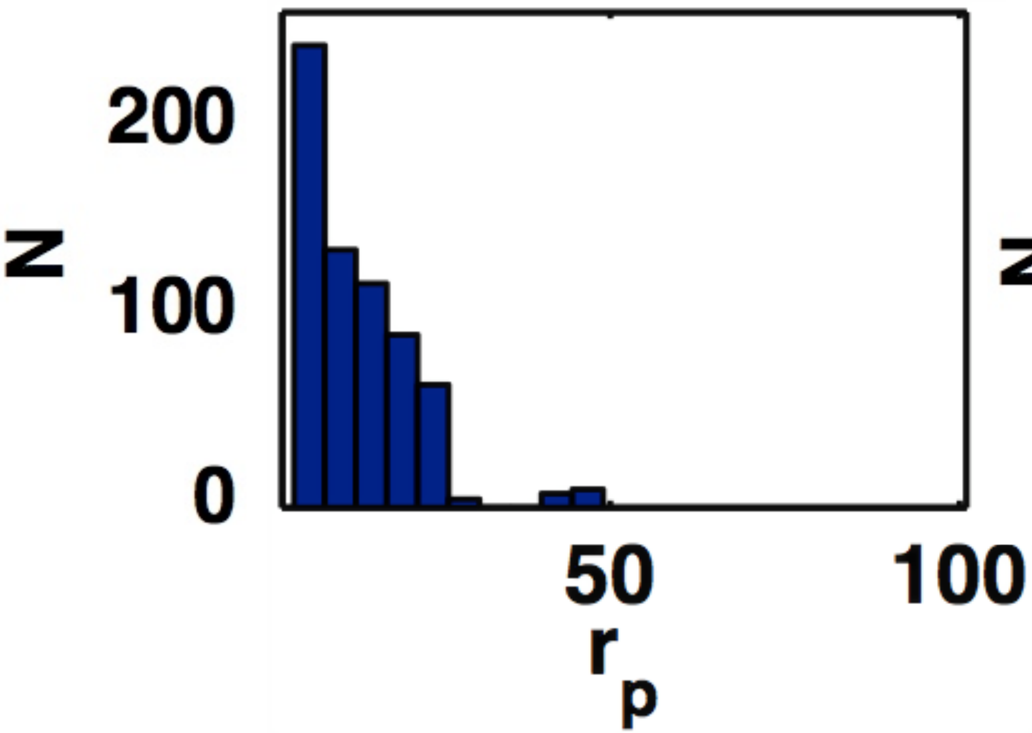
Munoz et al. 2008

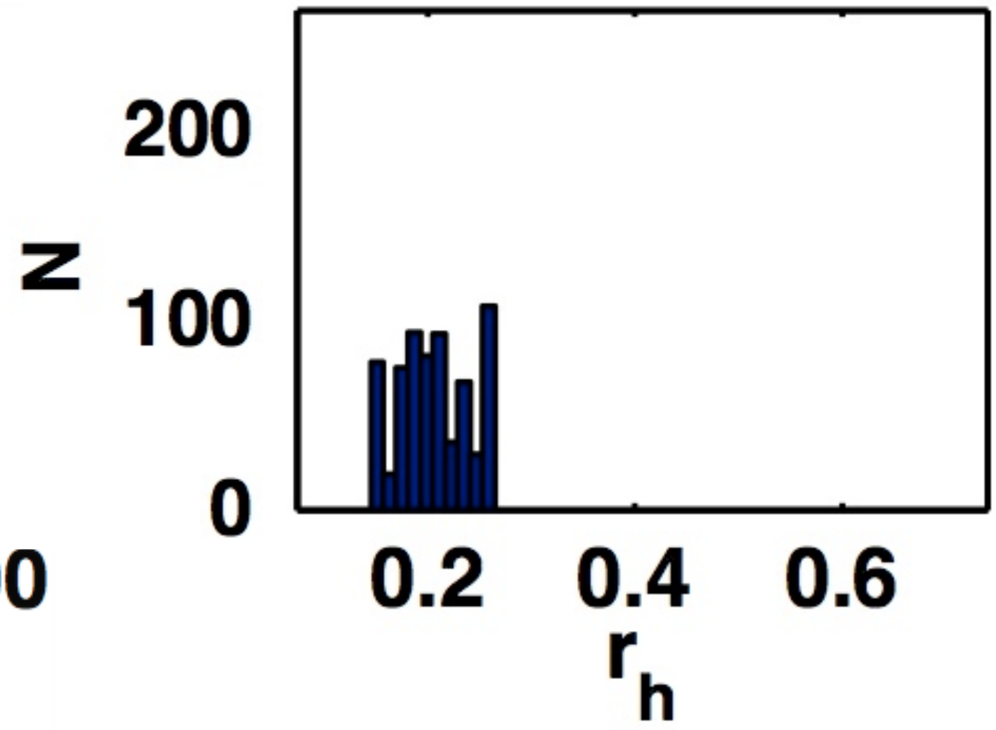
- Relies on data on outer bins, i.e. small numbers of stars

- Initially, use only surface brightness and velocity dispersion as constraints

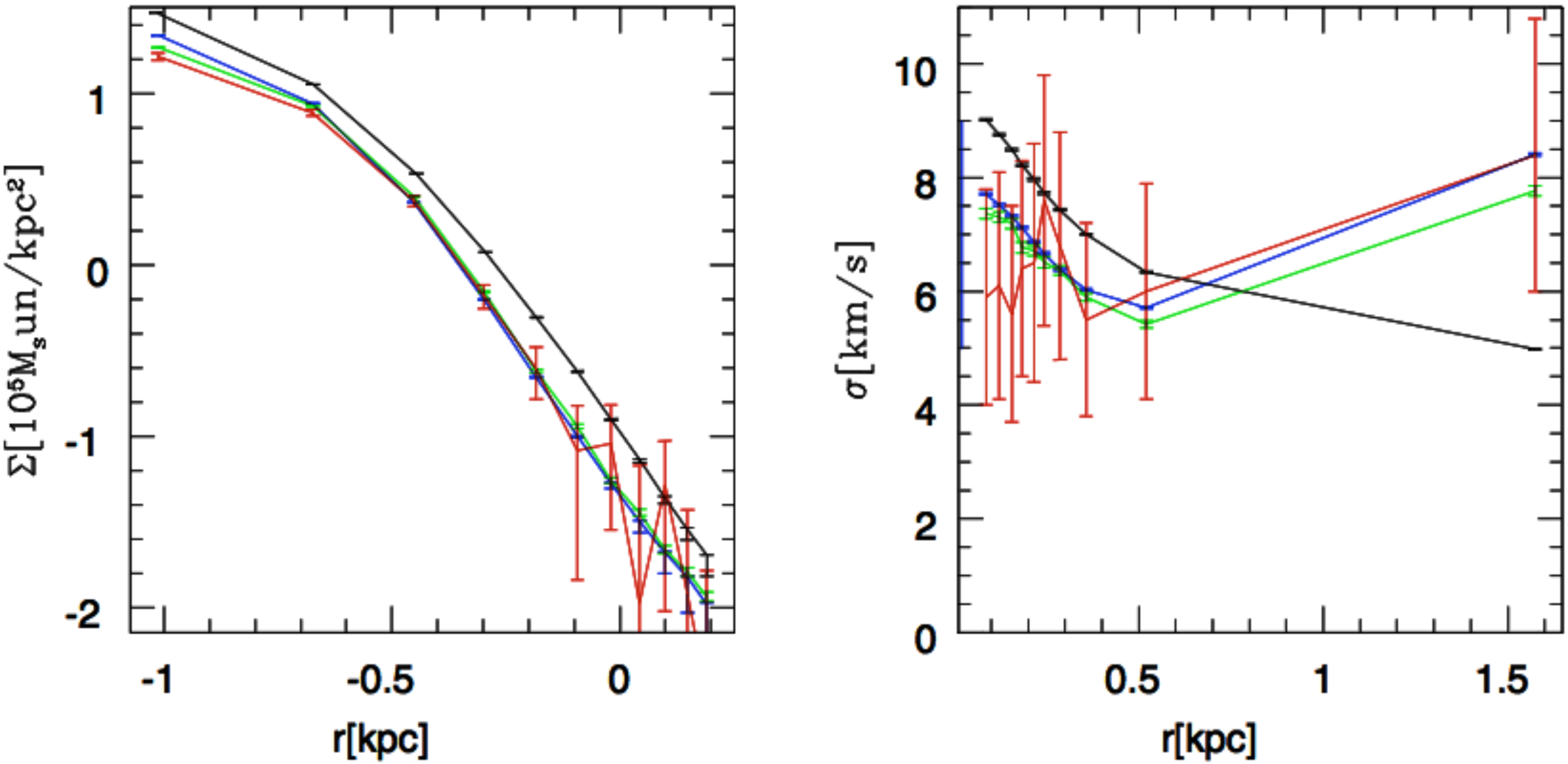
Carina: Mass follows light models





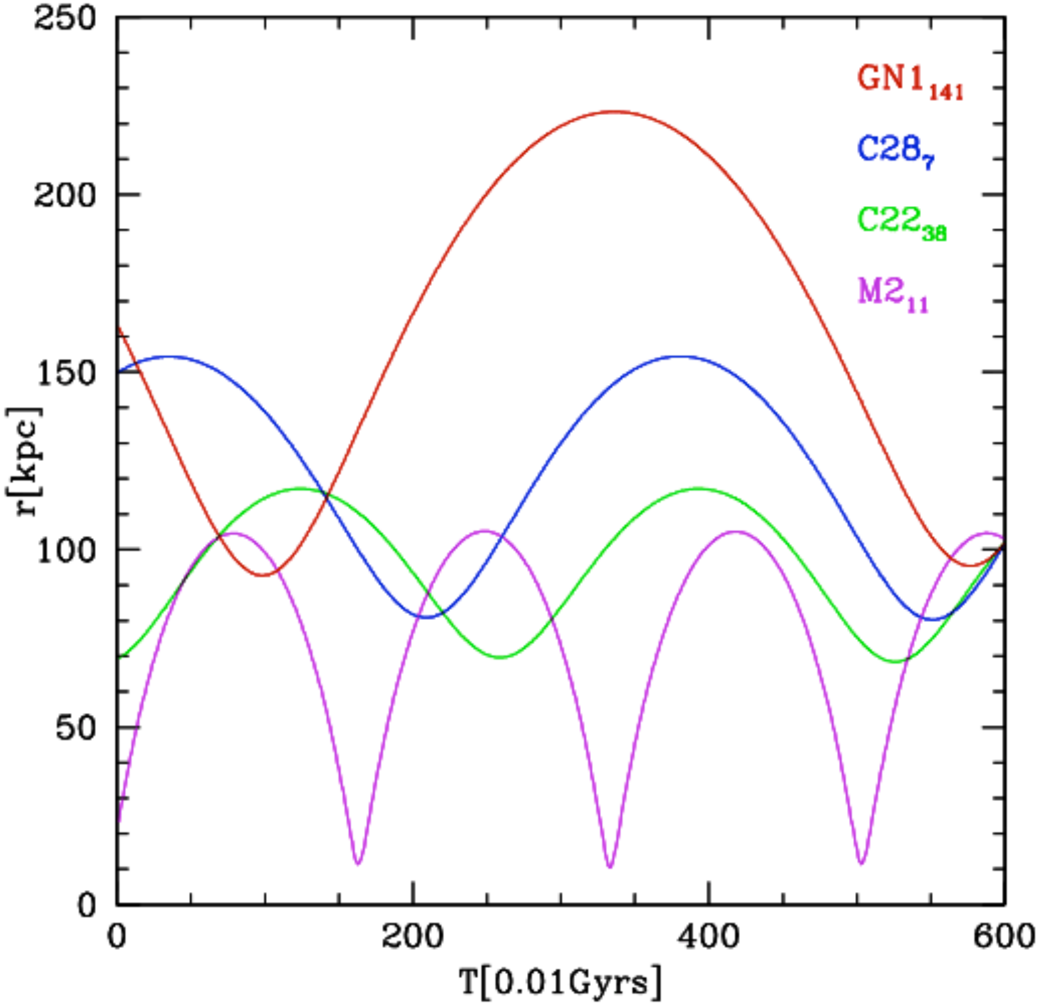


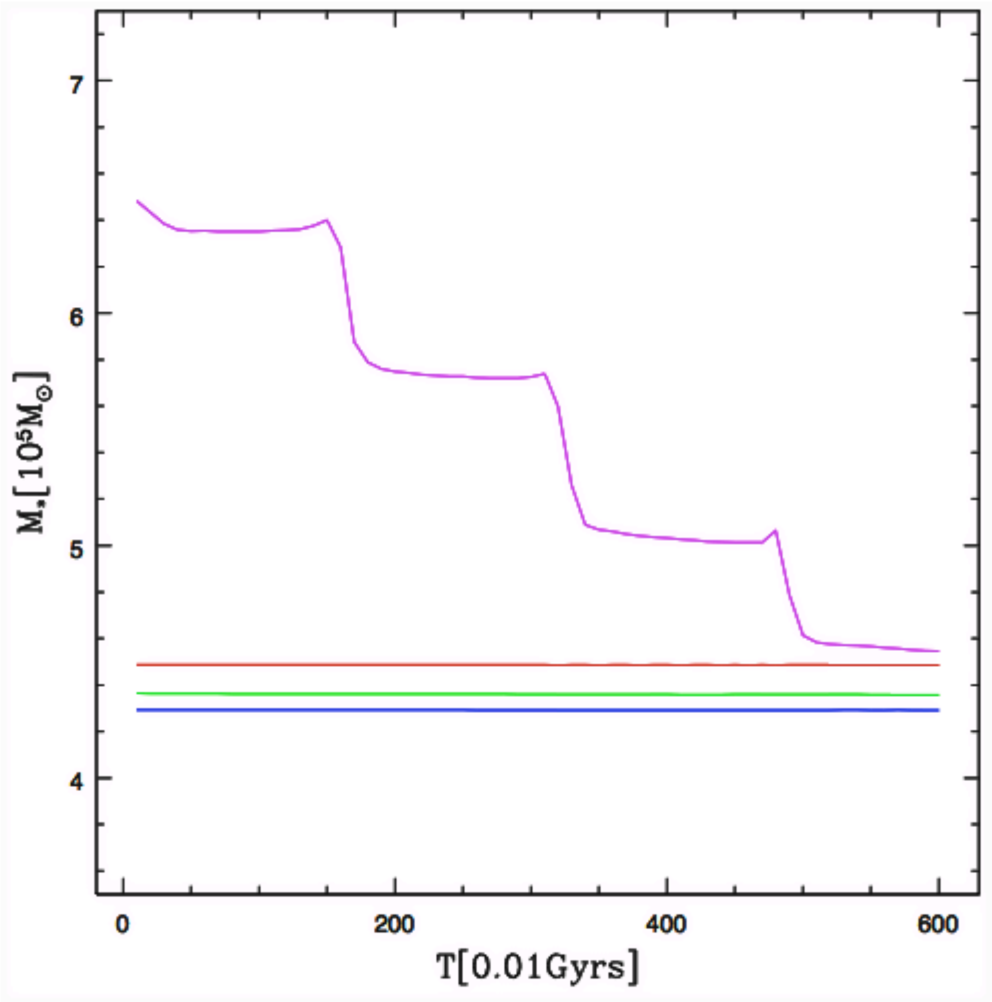
Carina: mass follows light models



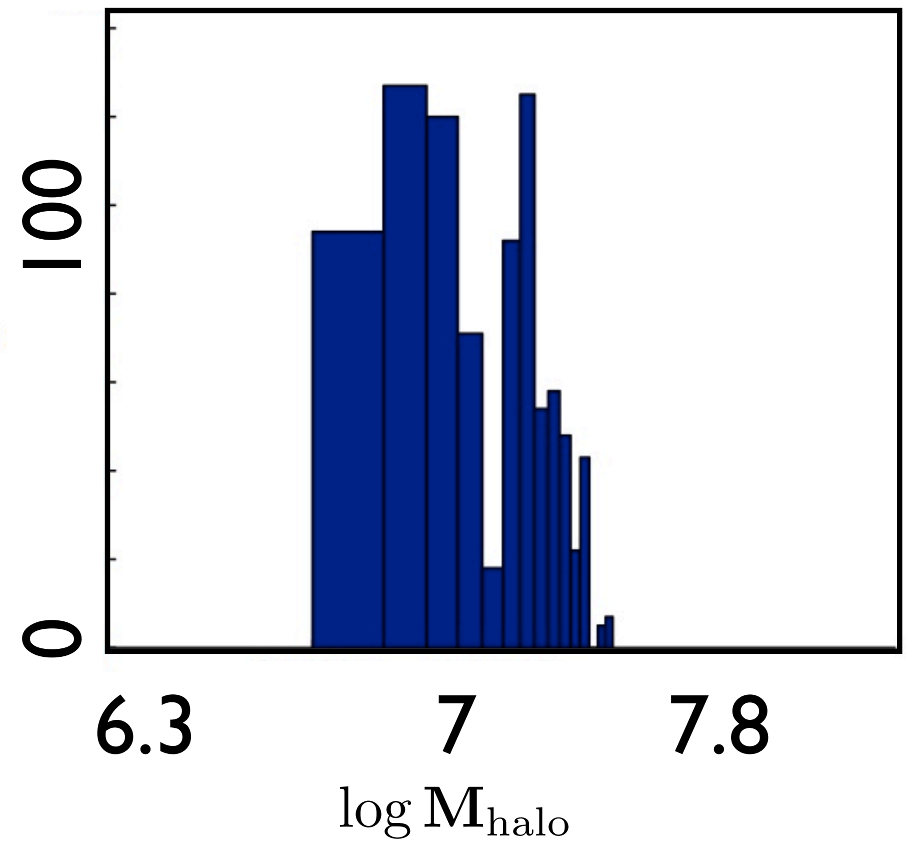
Good match to surface density and velocity dispersion profiles

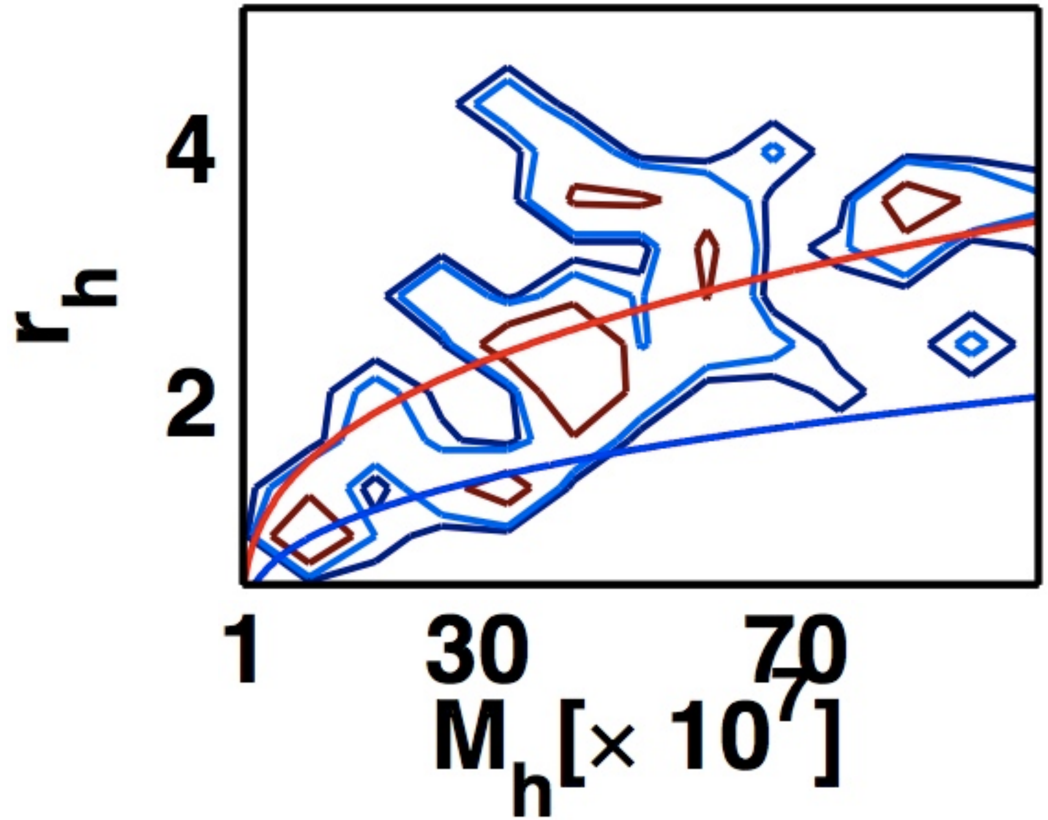
Carina: alternative scenarios





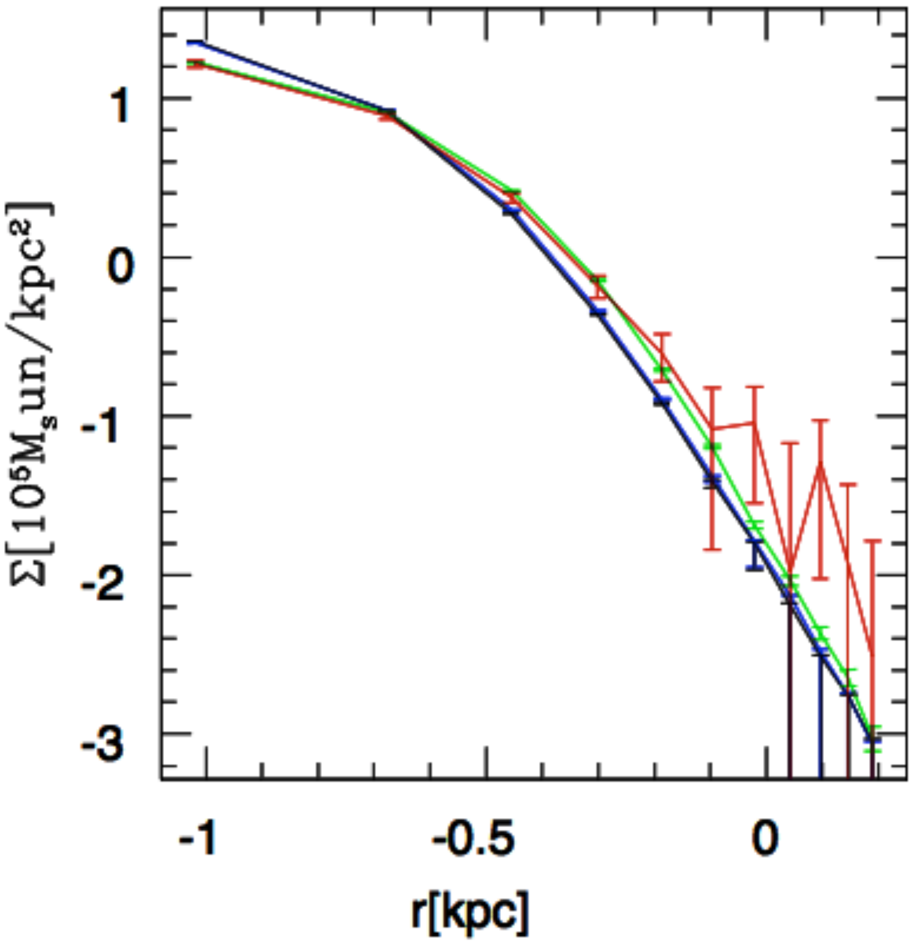
Carina: cusped halo models

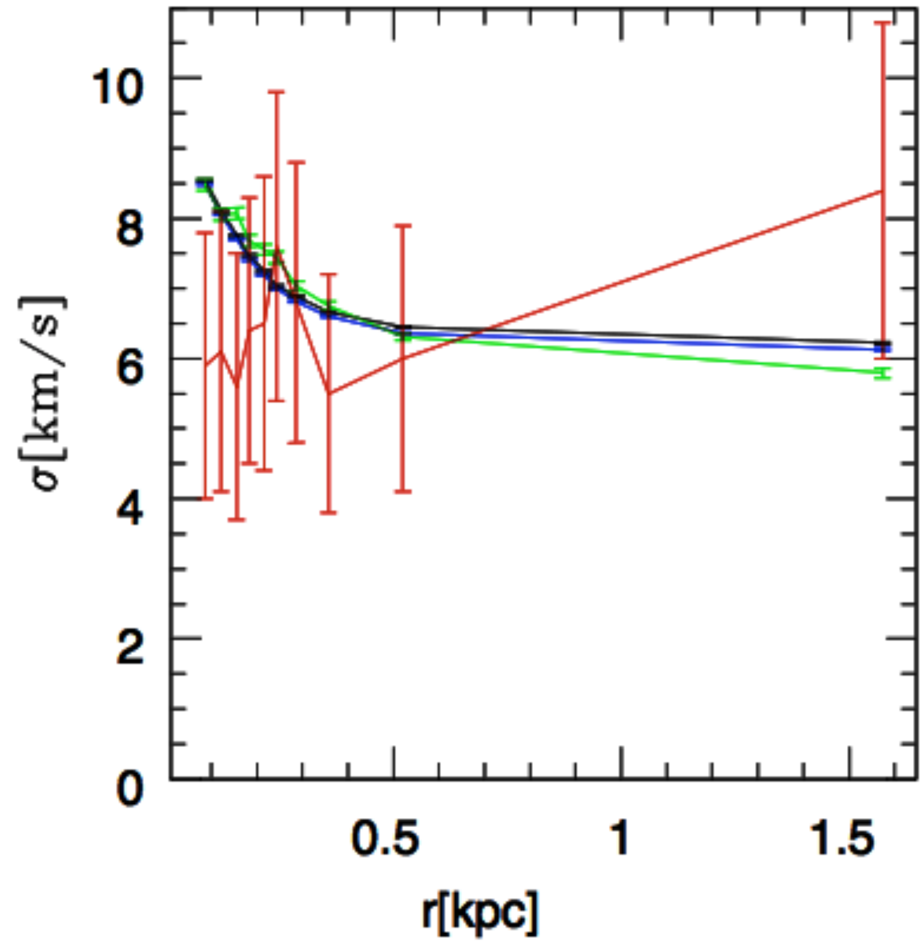




- Enclosed mass is similar to estimate from mass-follows-light models
- Results follow locus of constant halo density

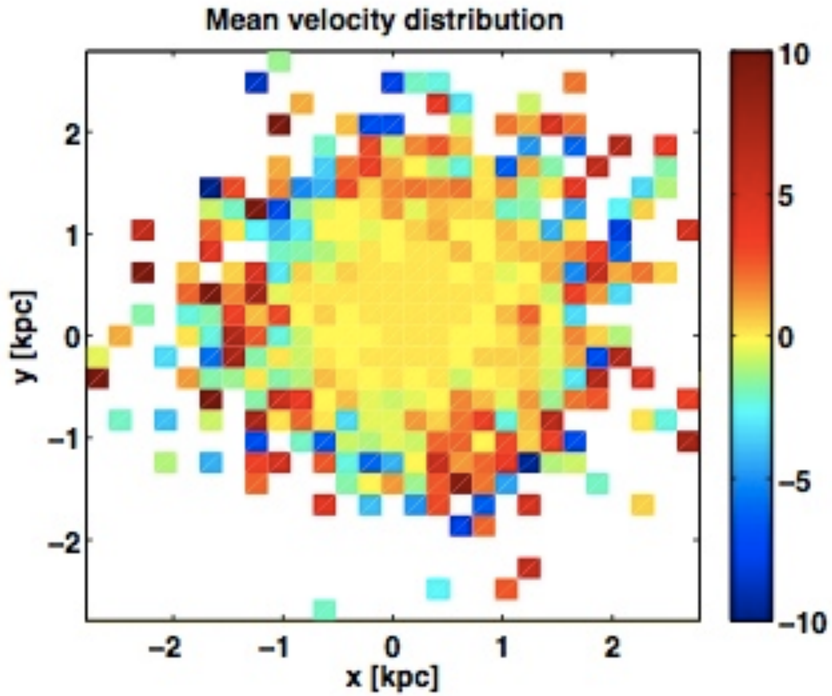
Carina: cusped halo model

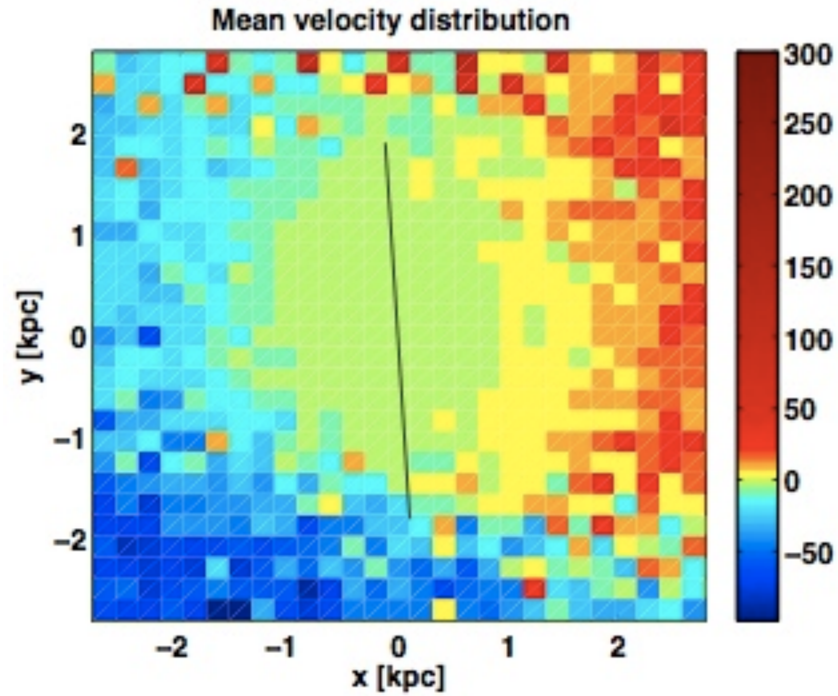


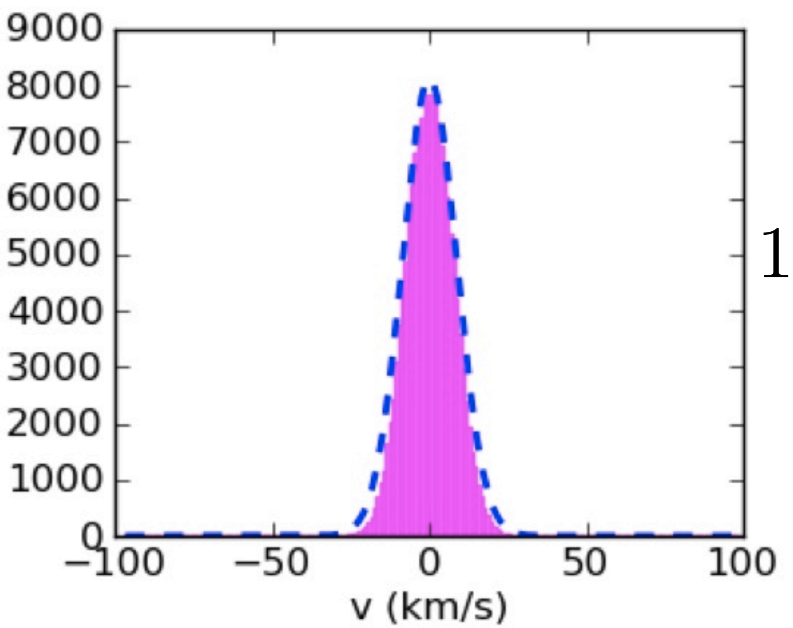


- No tidal perturbation in this model - doesn't match outer stellar distribution
- Removing $r_{\rm h} > 0.5 {\rm kpc}$ restriction may allow perturbed, extended halo models as well

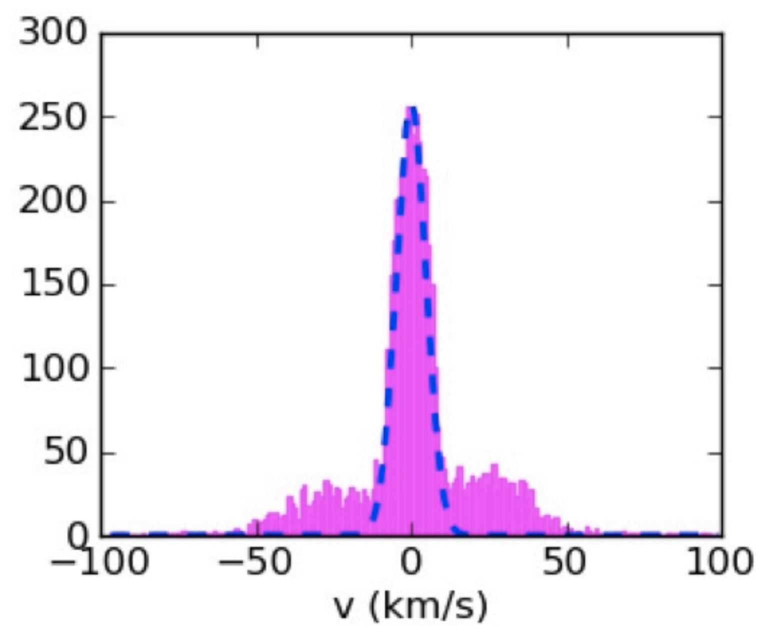
The future: breaking the tidal degeneracy



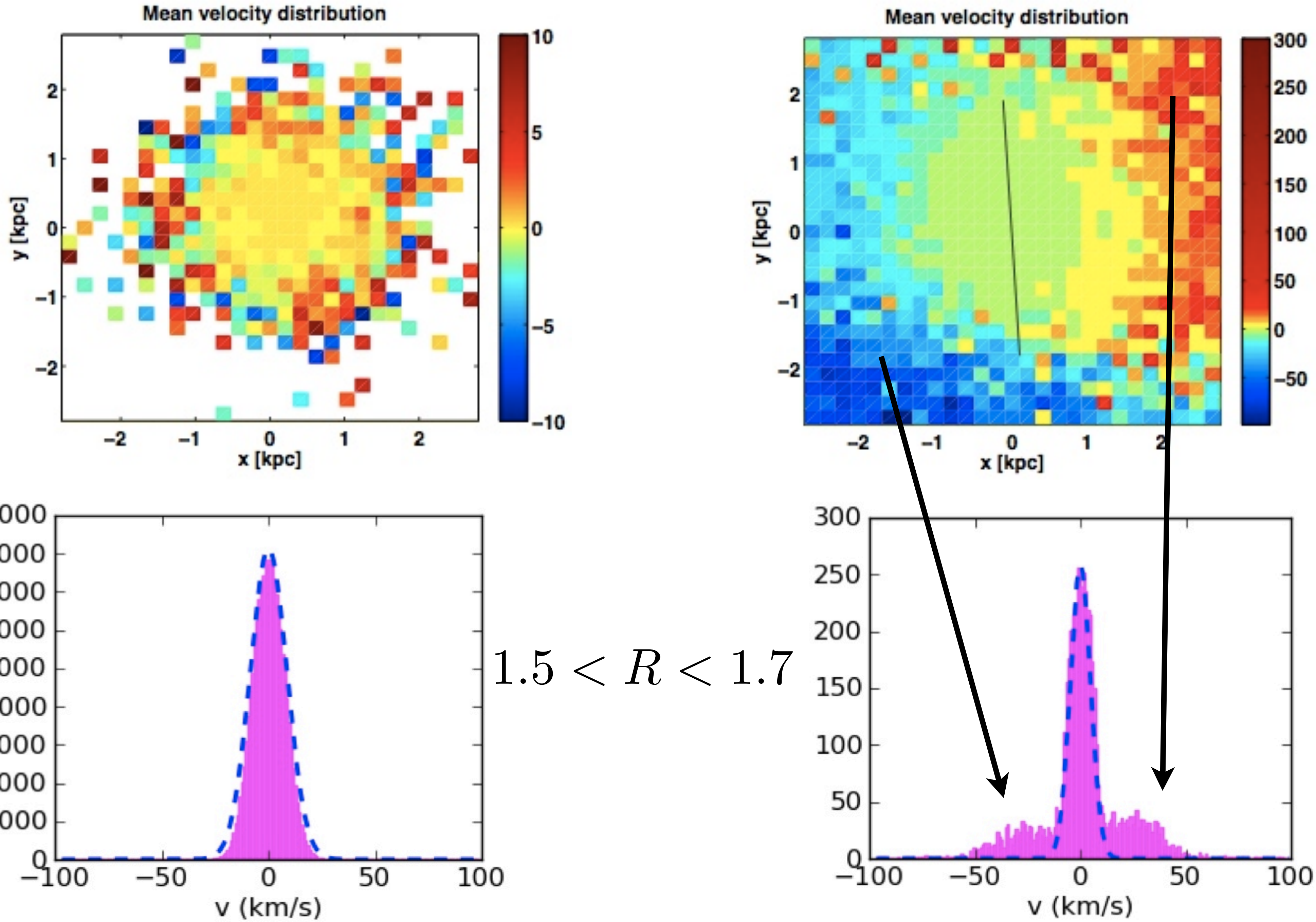




$$1.5 < R < 1.7$$



The future: breaking the tidal degeneracy



Time independent modelling

- General halo profile (spherical):

$$\rho_{\mathrm{halo}}(r) = \frac{\rho_0}{\left(\frac{r}{r_{\mathrm{s}}}\right)^{\gamma}\left(1+\left(\frac{r}{r_{\mathrm{s}}}\right)^{1/\alpha}\right)^{\alpha(\beta-\gamma)}}$$

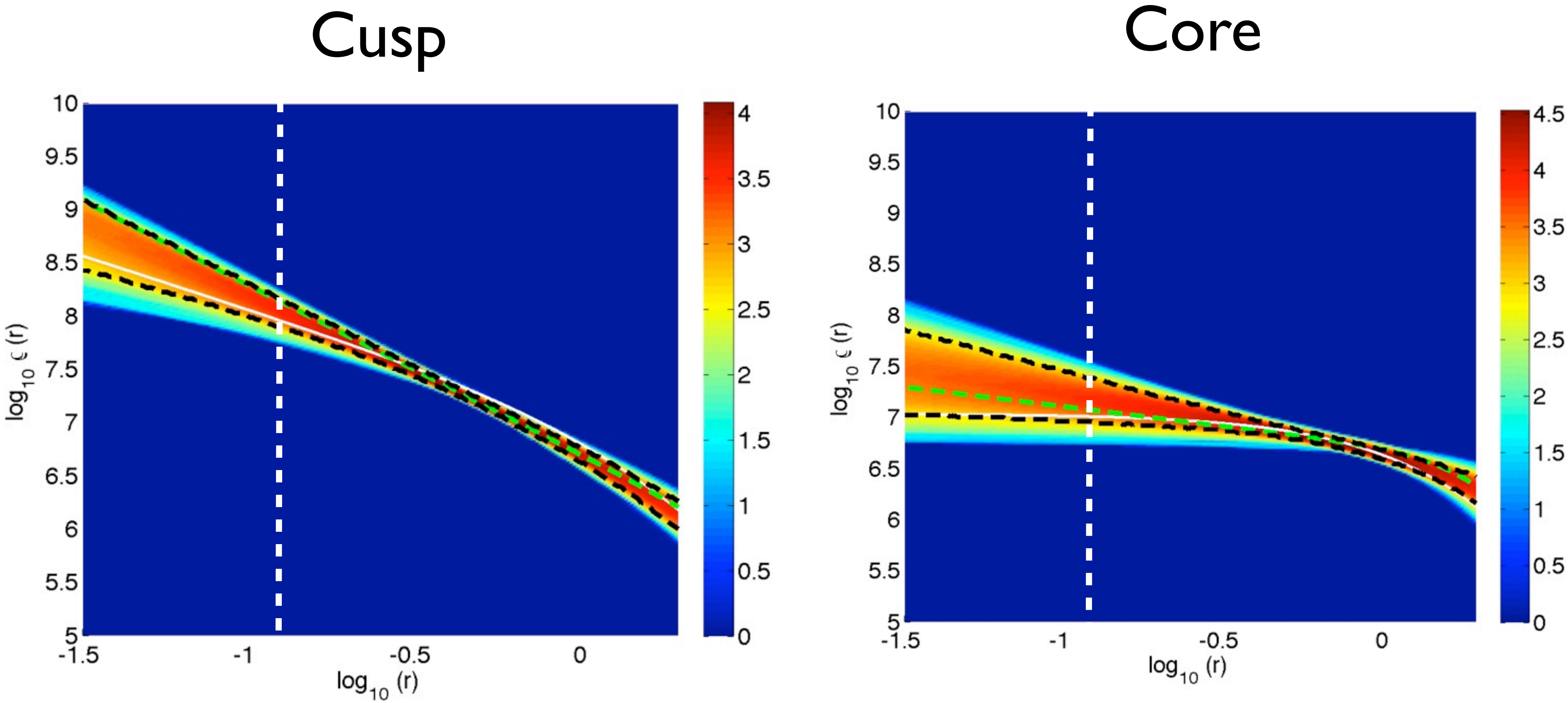
- 2-integral distribution functions F(E,L) constructed using scheme of Gerhard; Saha

- Data analysed star-by-star: no binning

- No assumptions of Gaussianity

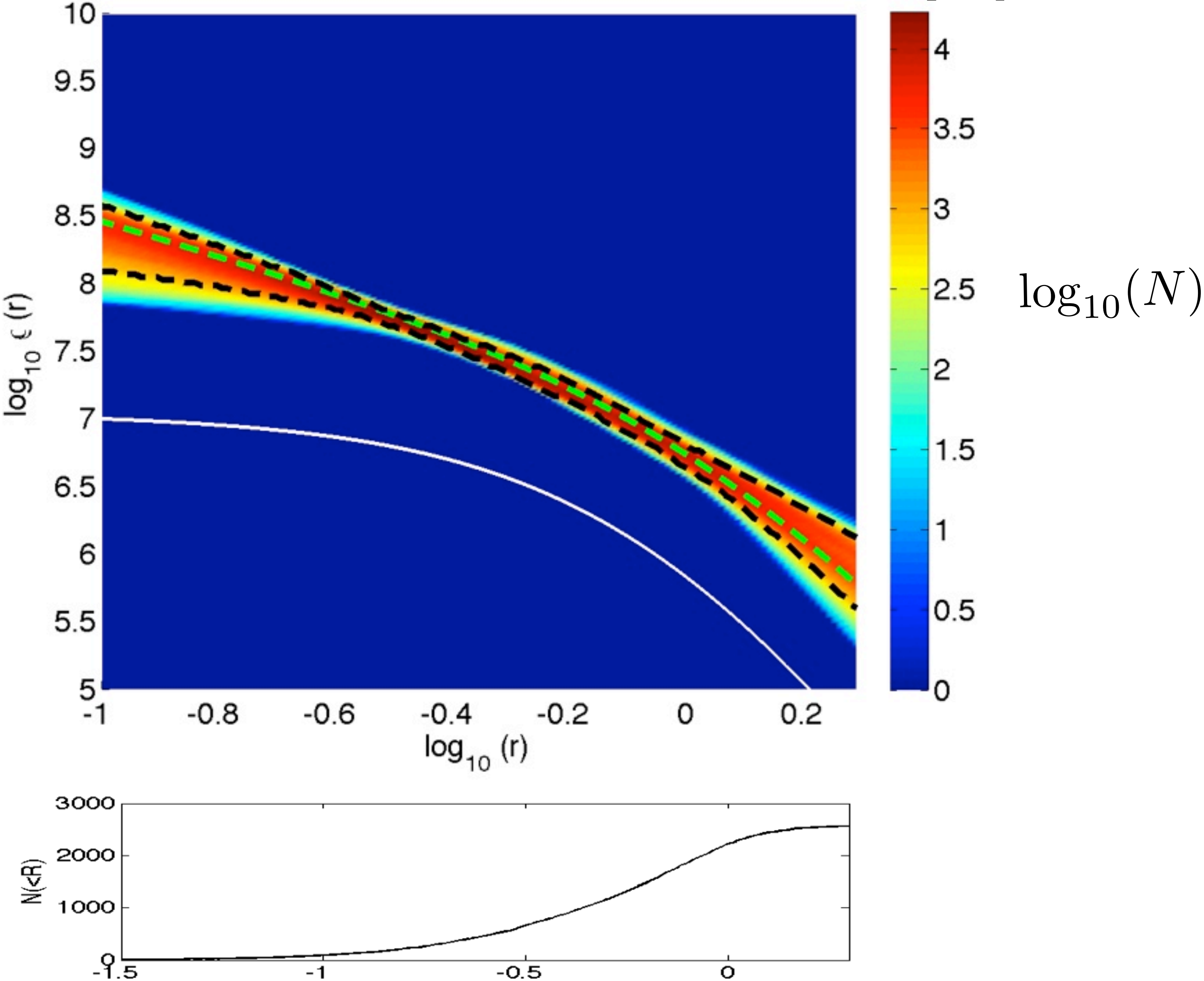
- Markov-Chain-Monte-Carlo used to scan 13 dimensional parameter space

Tests with isotropic models

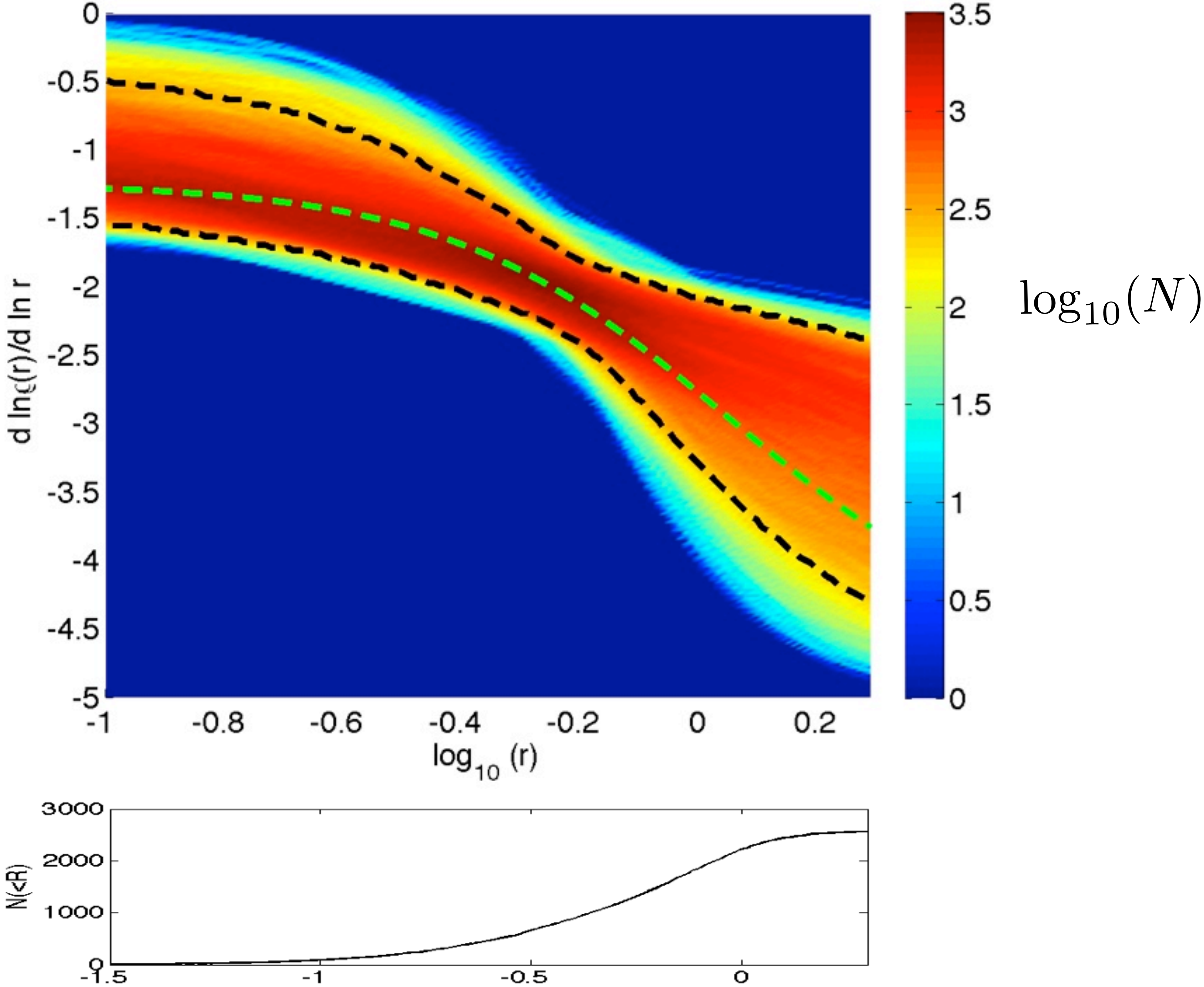


- Artificial data sets of similar size, radial coverage and velocity errors to observed data set in Fornax

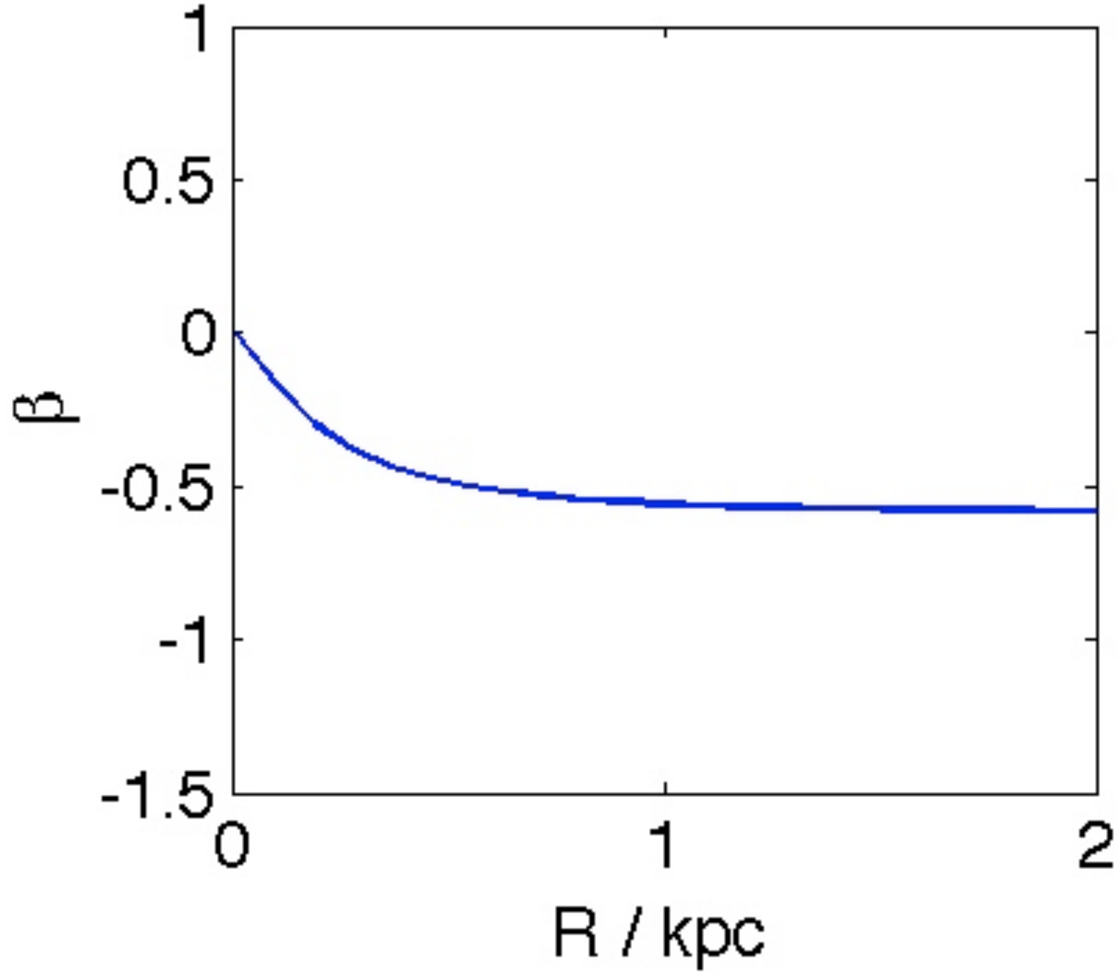
Fornax - PRELIMINARY density profile



Log-slope of mass profile



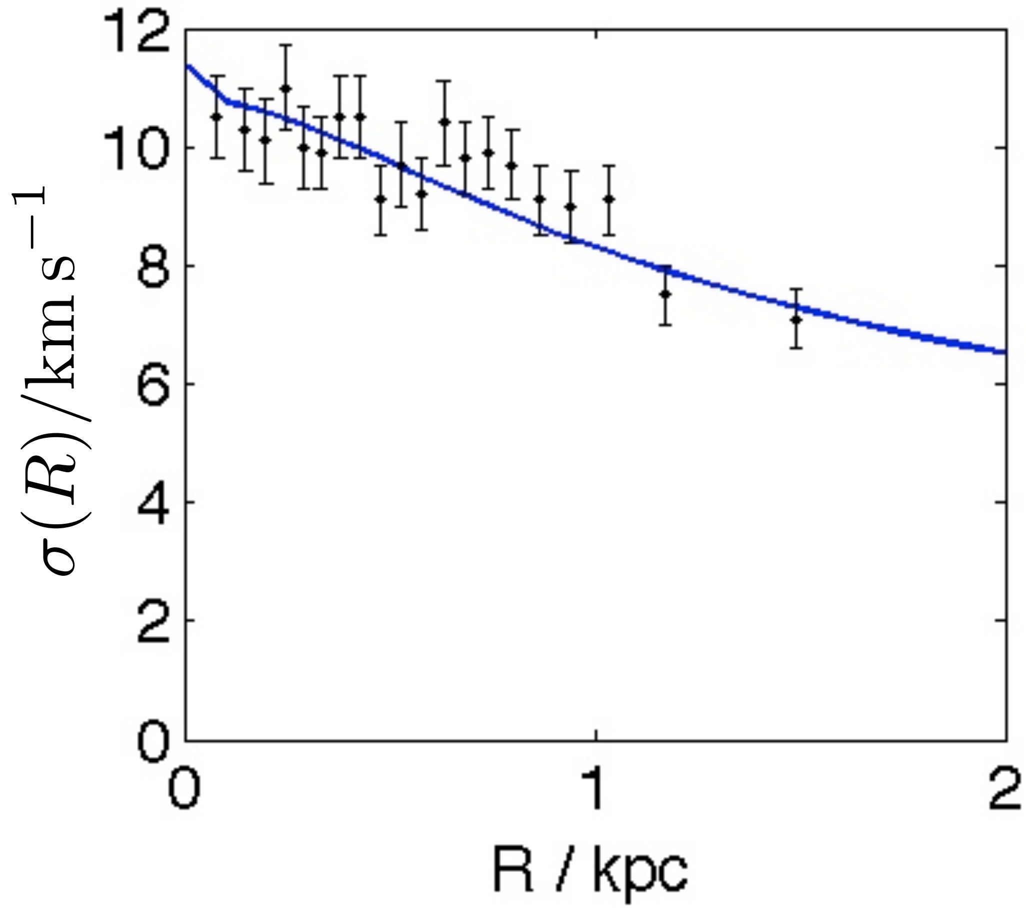
Fornax - anisotropy profile



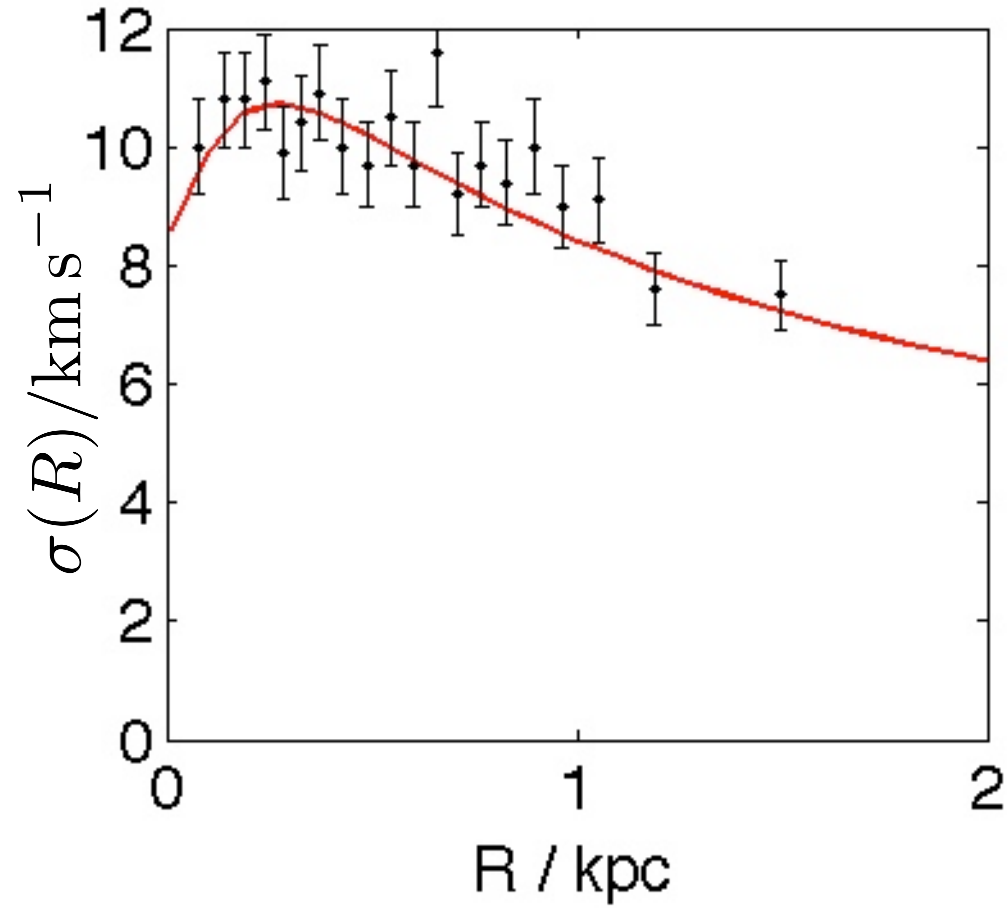
$$\beta(r) = 1 - \frac{v_t^2(r)}{2v_r^2(r)}$$

Fornax - dispersion profile

All data



$\Delta V < 2\mathrm{km\,s^{-1}}$



NB: Dispersion data not used to constrain models

Conclusions

• Combination of MCMC with N-body simulations yields reliable modelling of tidally *perturbed* dSphs (Ural et al. in prep.)

• Carina can be modelled by both tidally perturbed and pristine halo models

• Future surveys of outer reaches of dSphs have potential to break tidal-mass degeneracy fully (Ural et al. in prep.)

• Un-binned radial velocity data **can** be used to measure *density profiles* of dSph dark matter haloes

• Modelling of Fornax dSph suggests halo is cusped on scales $\gtrsim$ 100pc - additional work underway to confirm robustness of models.