Constraining the Halos of Massive Galaxies with Globular Clusters

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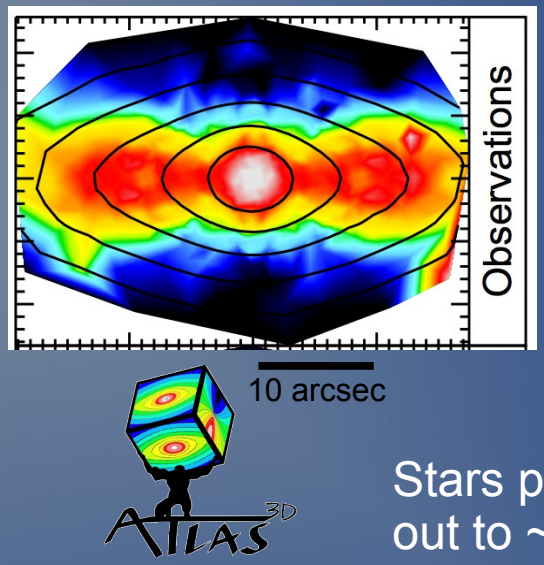
Halos of Early-Type Galaxies

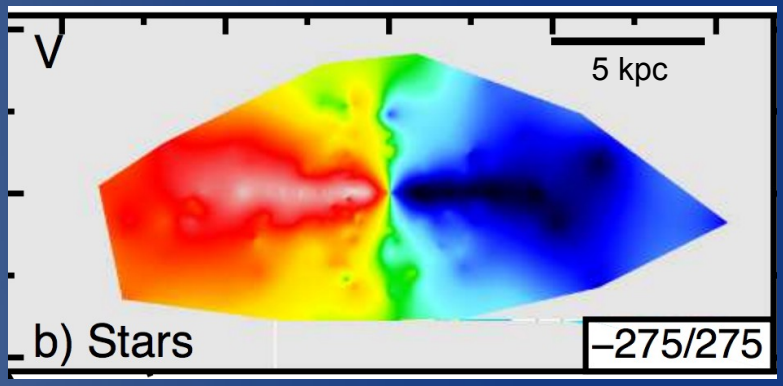
ETG Surveys:

- Stars: ATLAS^{3D} out to 1R_{eff} (Cappellari et al. '11)
- Stars: SMEAGOL out to ~3 R_{eff}
- PNe + GCs: out to > 10 R_{eff} (PN.S and SLUGGS)

What do observations of halos tell us about ETGs?

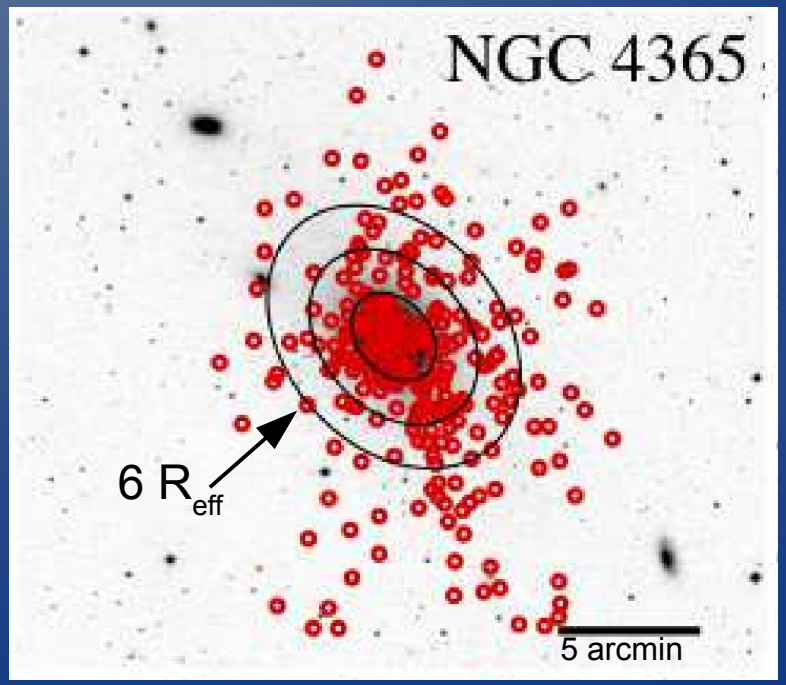
- Large sample of galaxies
- Tracers out to large galactocentric radii
- Include shape and anisotropy





Stars probe out to ~ 3 R_{eff}

Arnold et al. '11



GCs can probe out to > 10 R_{eff}

Pota et al. '13

SAGES Legacy Unifying Globulars and Galaxies Survey (SLUGGS)

See Jean Brodie's talk today!

SLUGGS Survey: (http://sluggs.ucolick.org)

Imaging: Subaru/Suprime-Cam

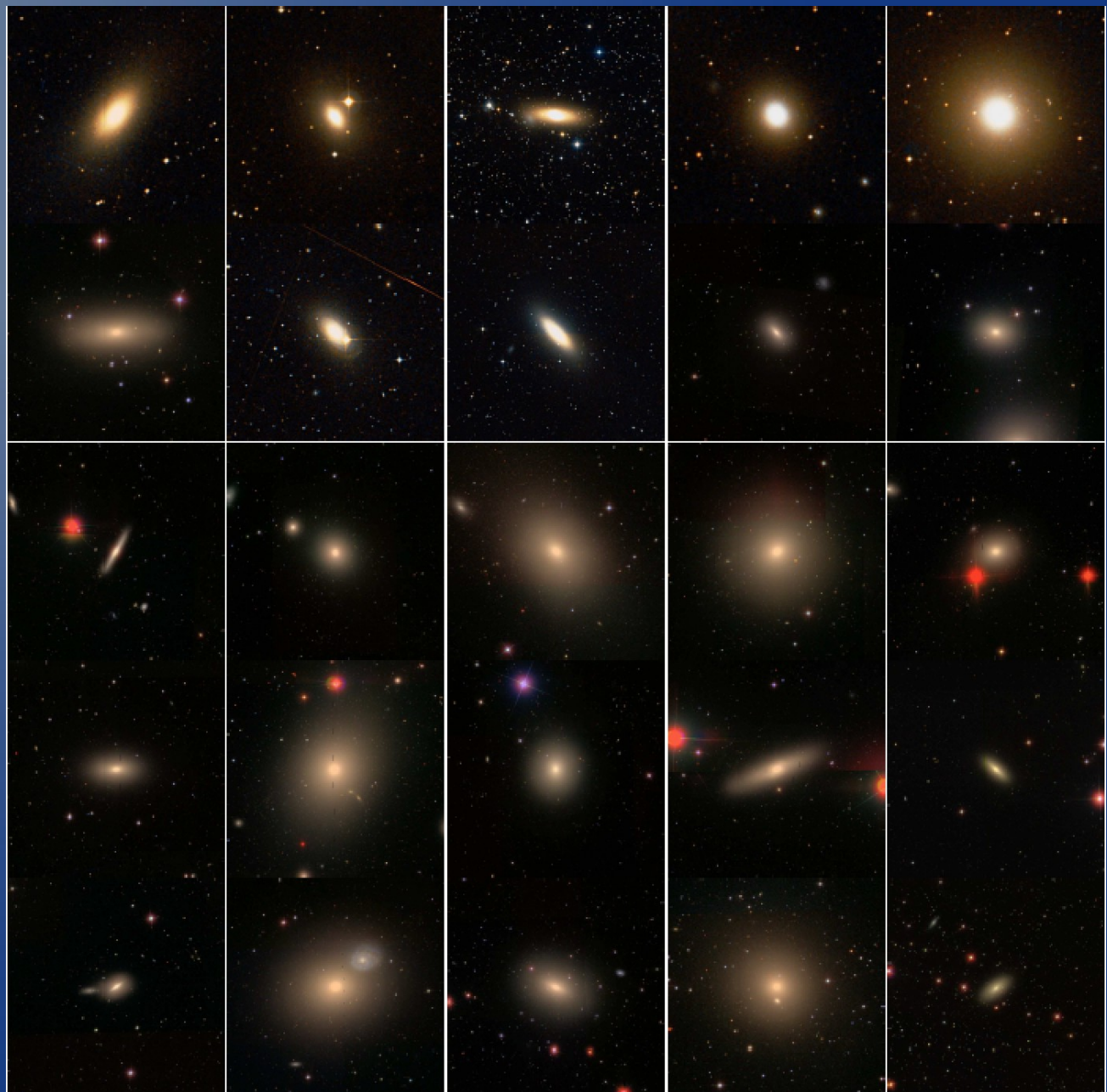
Spectroscopy: Keck/DEIMOS

25 ETGs

- $-22 > M_K > -26$ (~50x in stellar mass)
- Distances < 30 Mpc

Kinematic and metallicity information for

- Stars out to ~ 3 R_{eff}
- Globular cluster (GC) out to >10 R_{eff}



70 x 70 kpc

SDSS & DSS images

Estimating Mass Profiles with Globular Clusters

- Power-law distribution functions (PDLF): phase space probability density function (Evans et al. '97, Deason et al. '11, '12)

Assumptions:

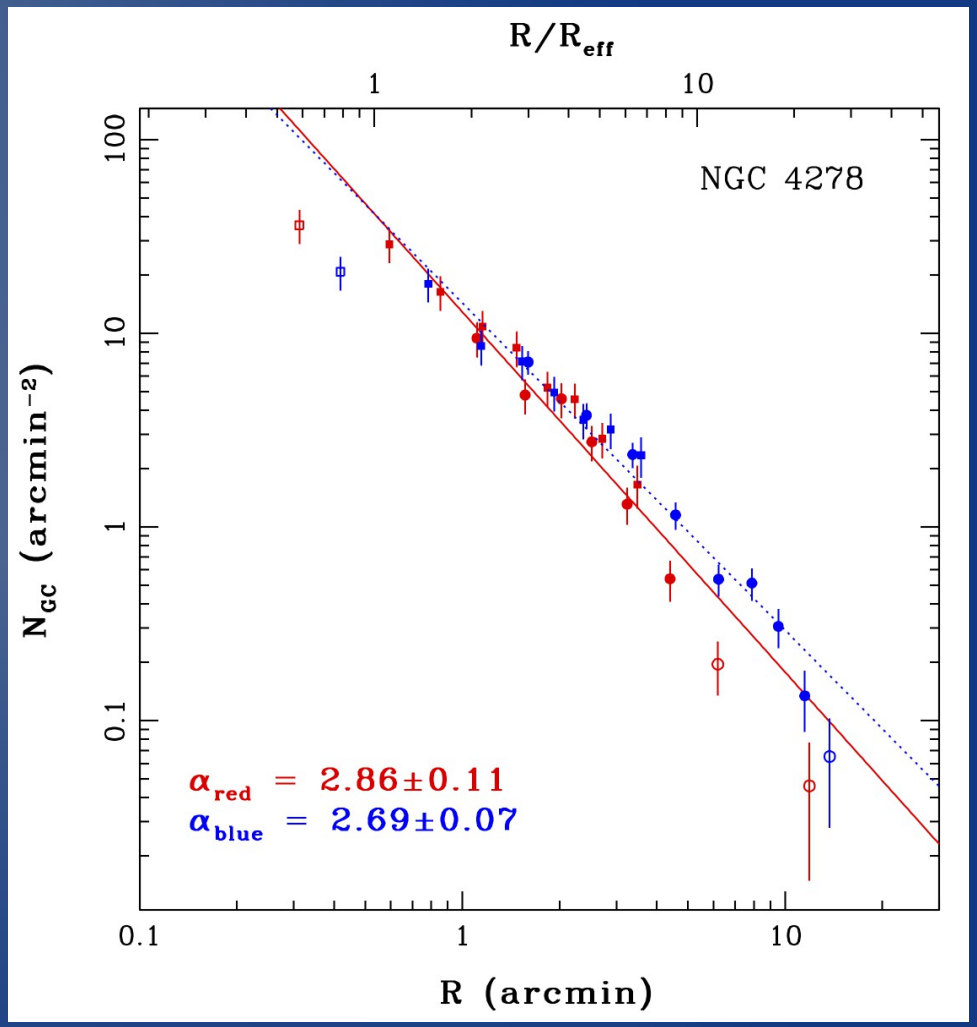
- Potential: $\Phi \alpha r^{-\gamma}$
- Tracer density: $j \alpha r^{-\alpha}$

Tracer population can be spherically symmetric or flattened

Inputs:

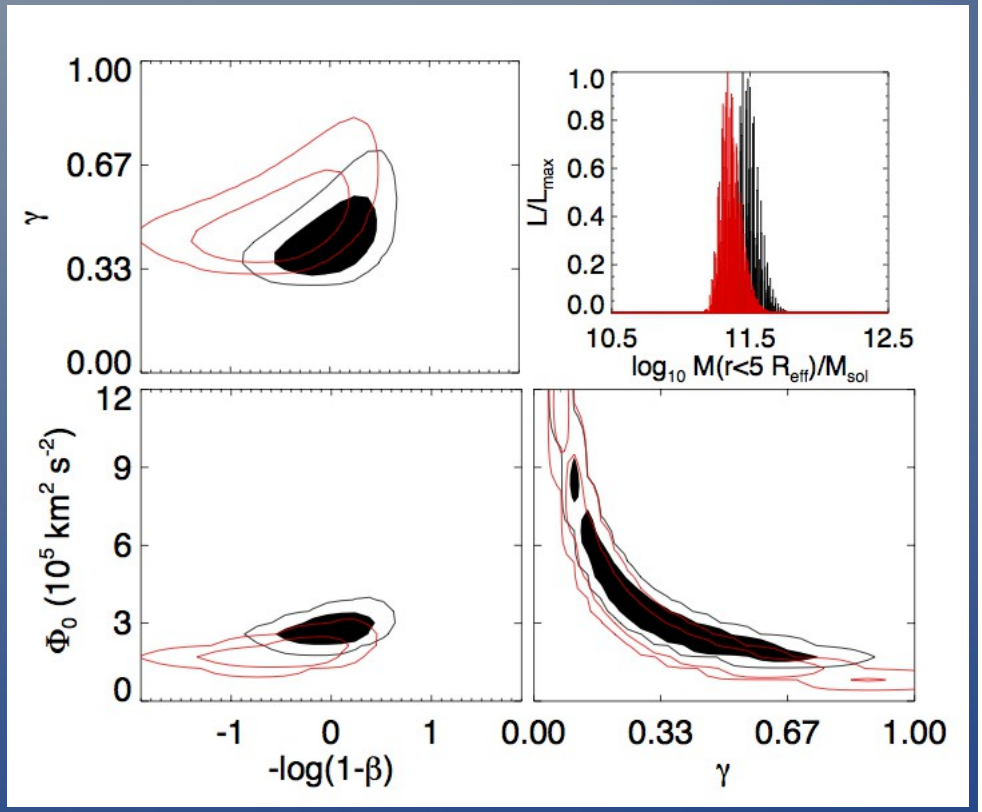
- Positions, radial velocities, surface density slope

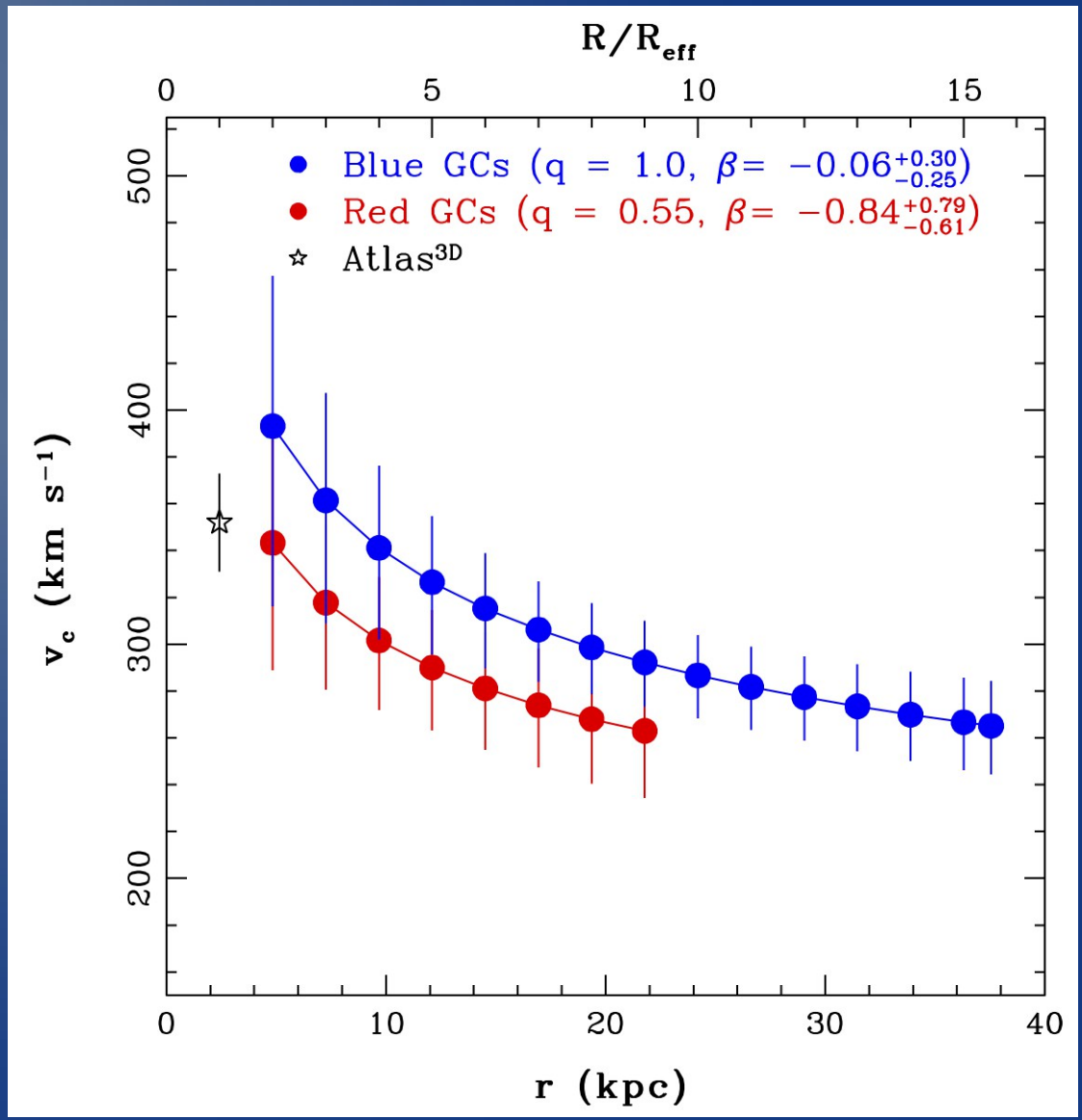
Maximum likelihood analysis constructed from l.o.s. velocity distribution:



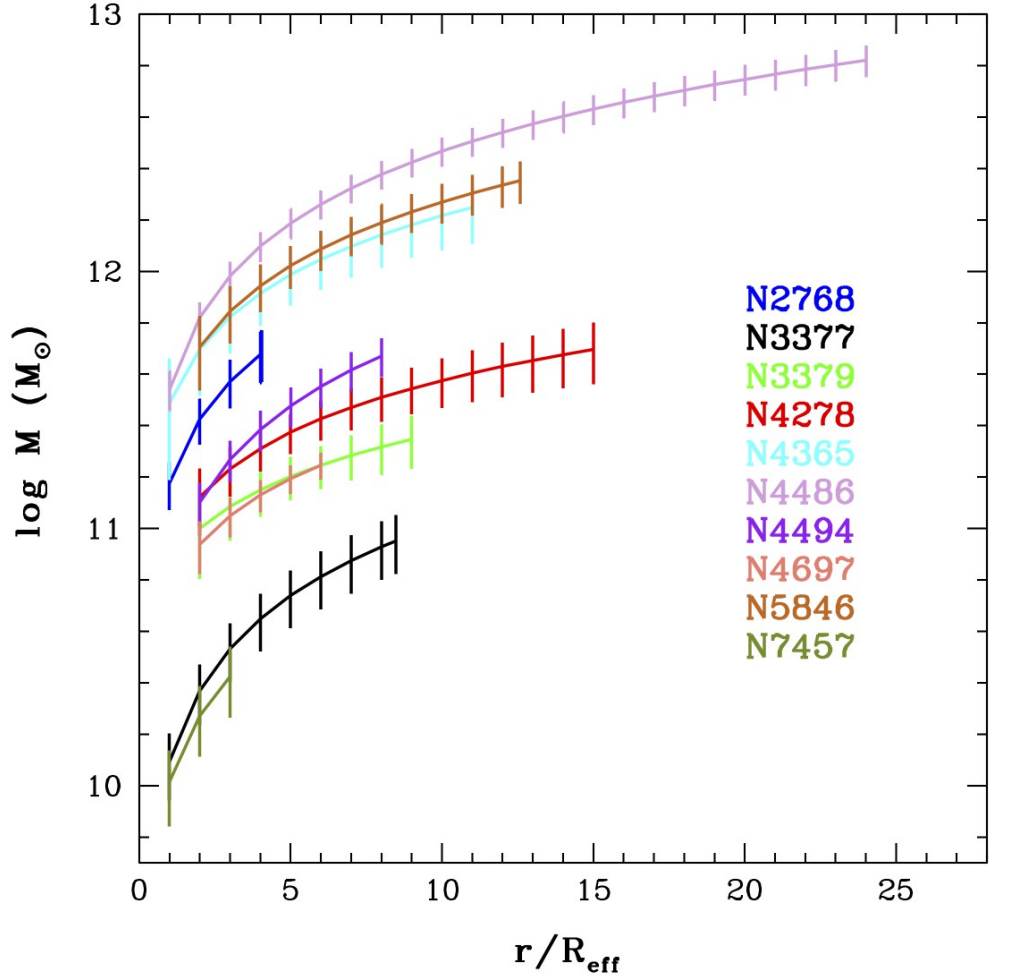
- Potential and slope: Φ and γ ⟶ total mass of the galaxy
- Anisotropy: β ⟶ orbital motion of tracers

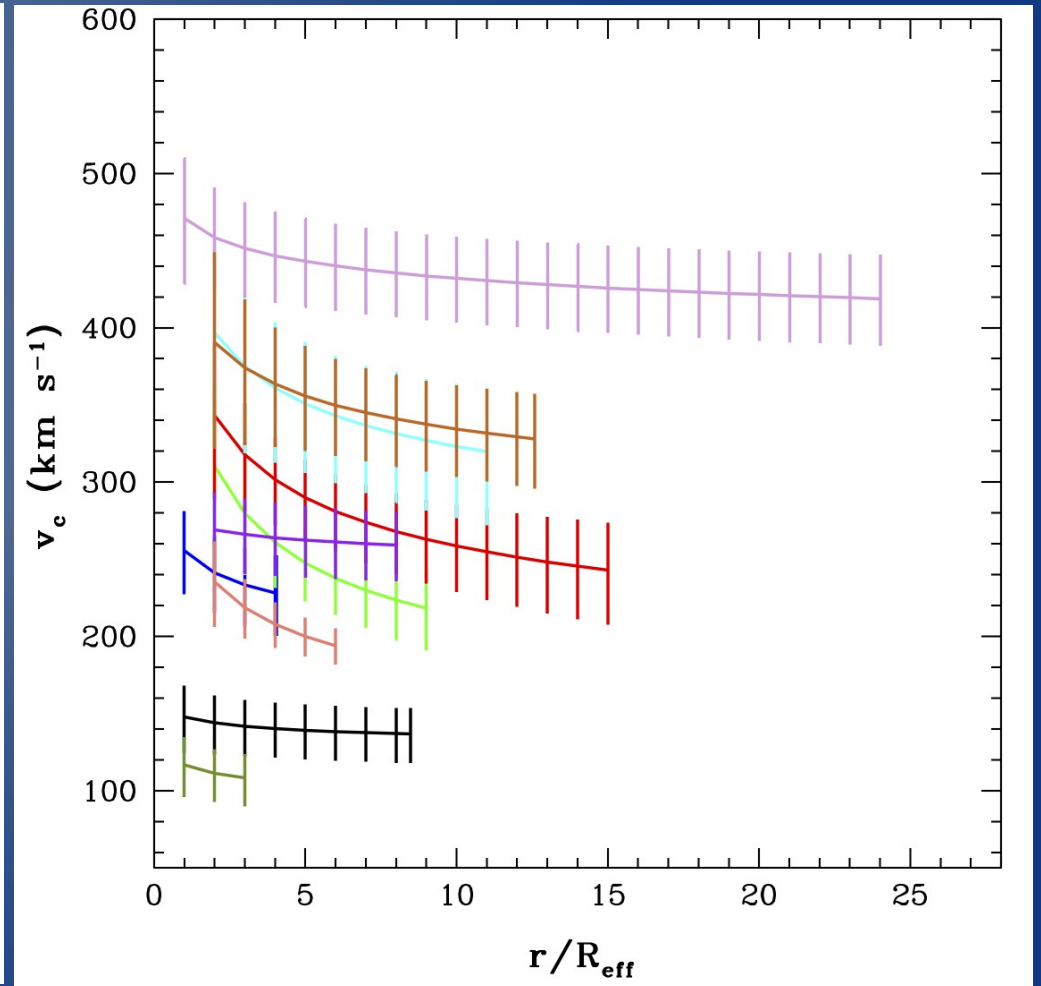
Estimating Mass Profiles with Globular Clusters





Mass Profiles

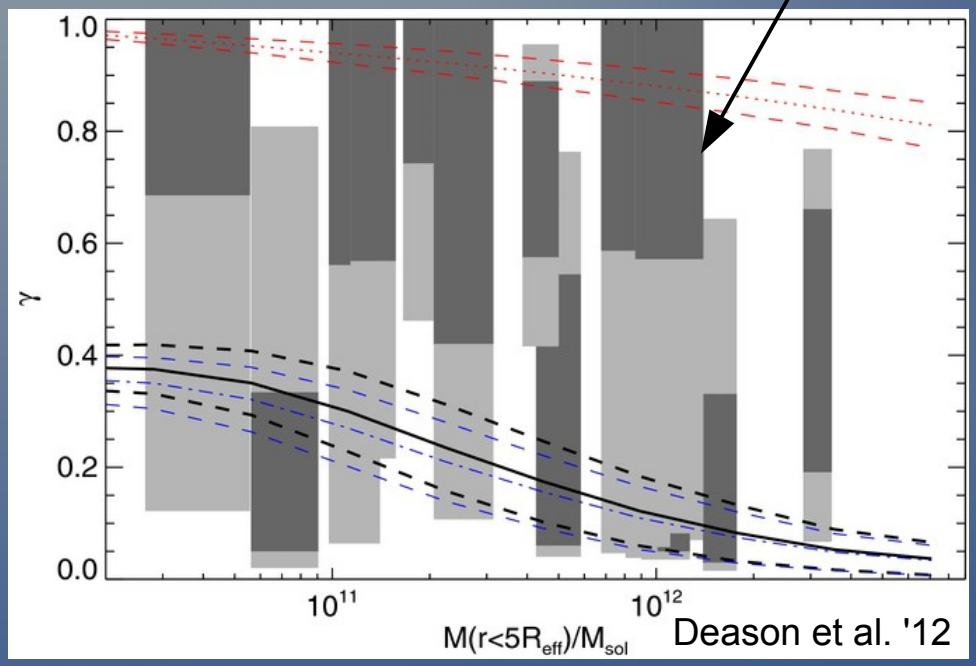




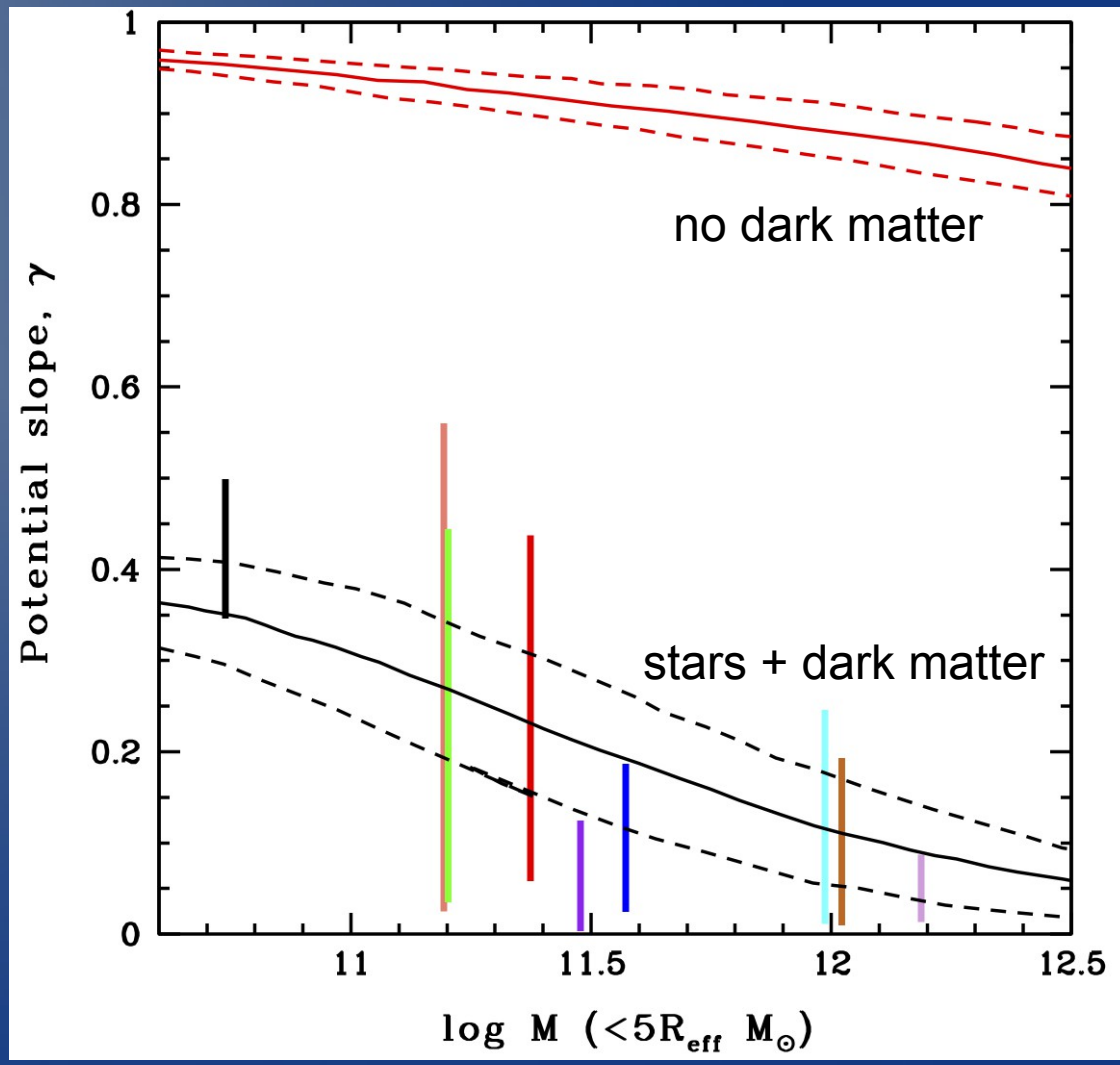
Do our profiles agree with λCDM halos?

Galaxy Potential

68 % confidence range (dark grey)

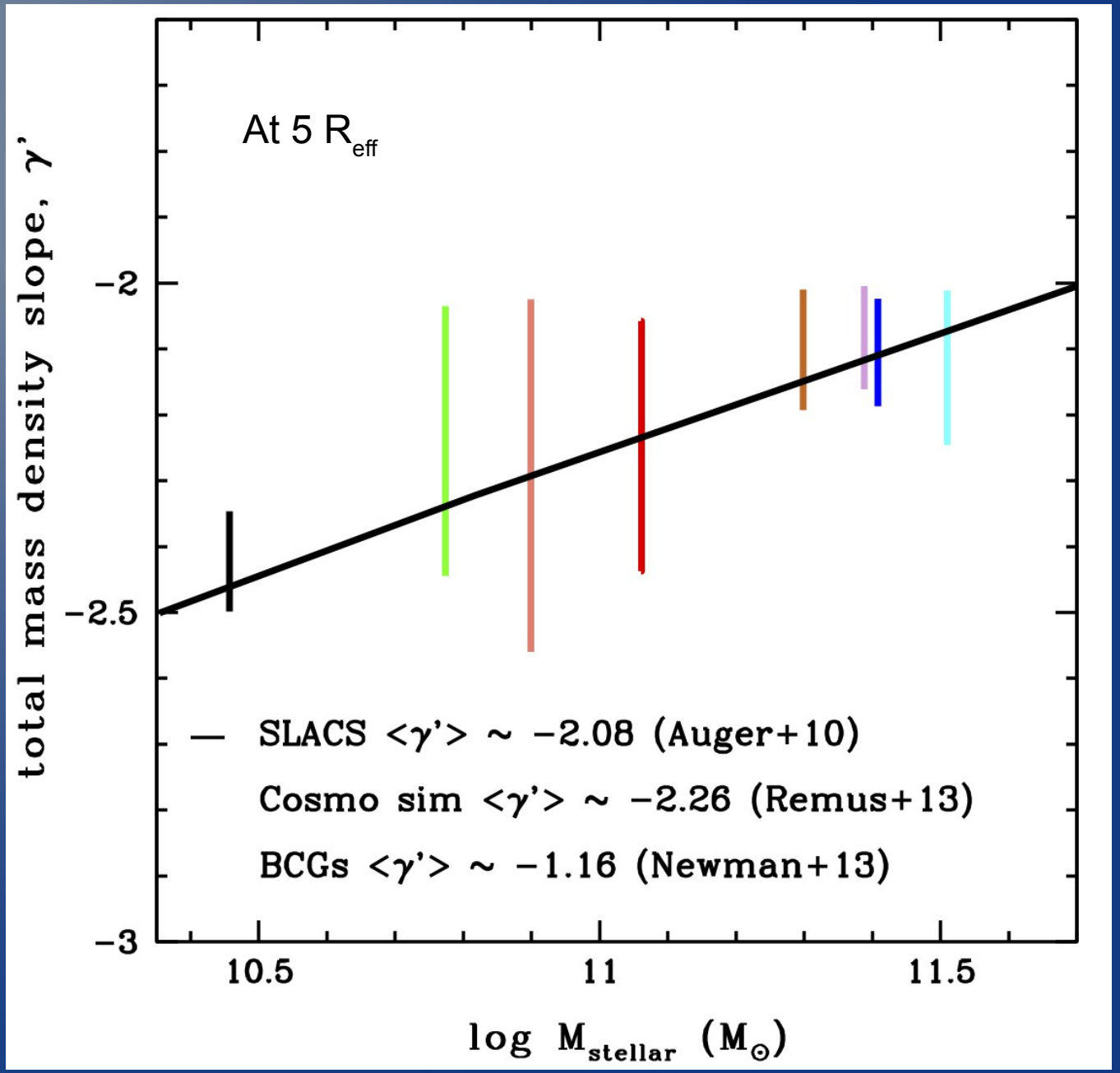


- Potential slope of galaxies follow a dark matter plus stellar bulge model
- Less massive galaxies have steeper potential profiles



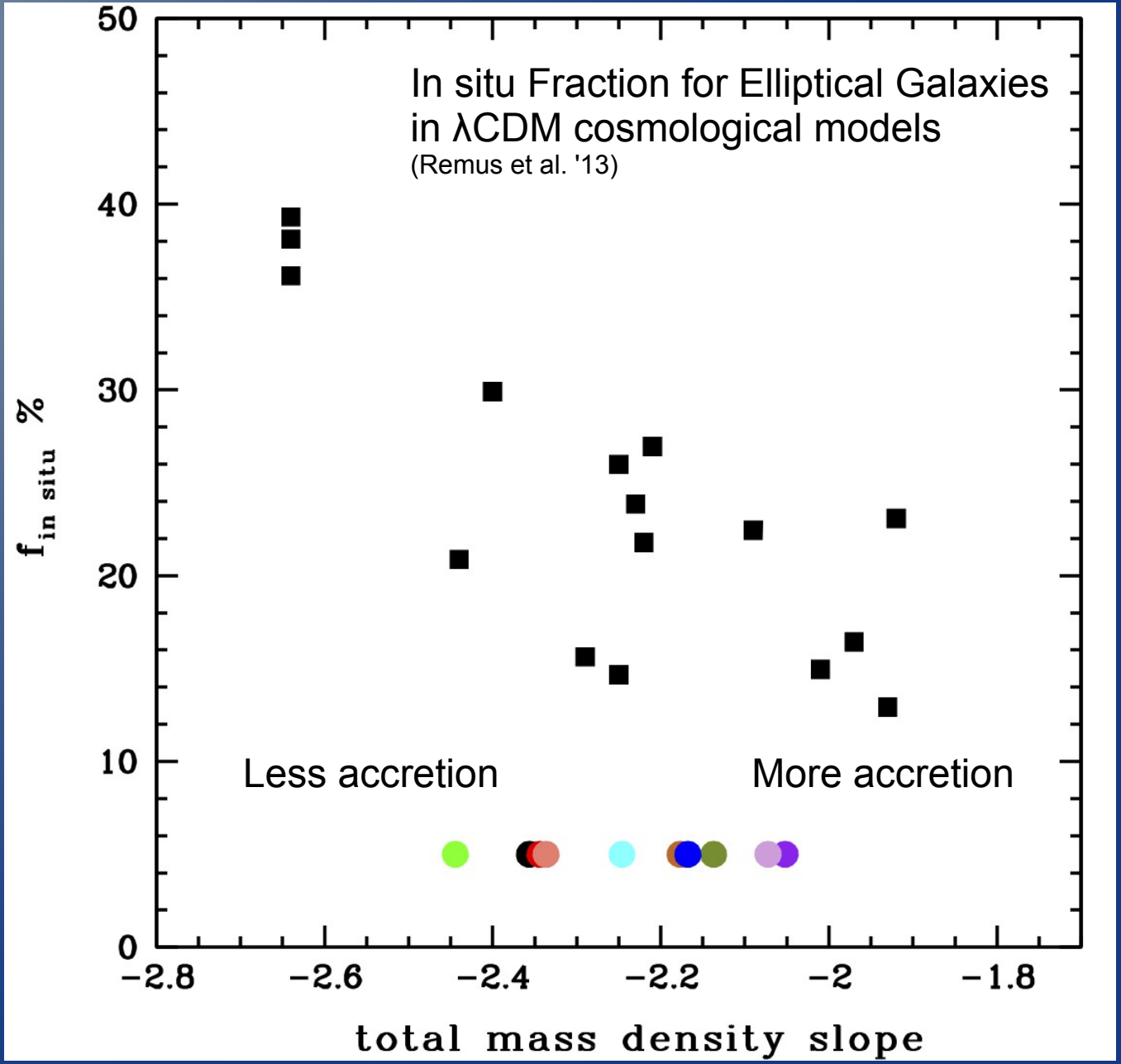
Total Mass Density Slope

- Stellar profiles generated (Scott et al. '13) with M/L (Conroy & van Dokkum '12)
- Total mass density slope 5 R_{eff} ~ nearly isothermal ($\rho \propto r^{-2}$)
- Total mass density is shallower for more massive and bigger galaxies

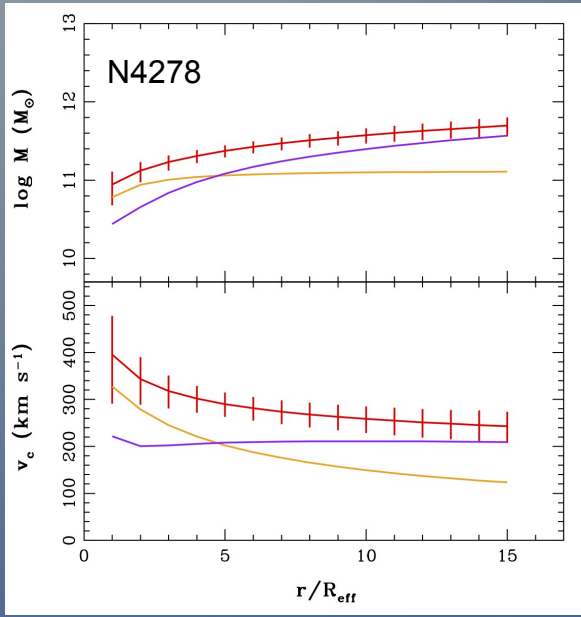


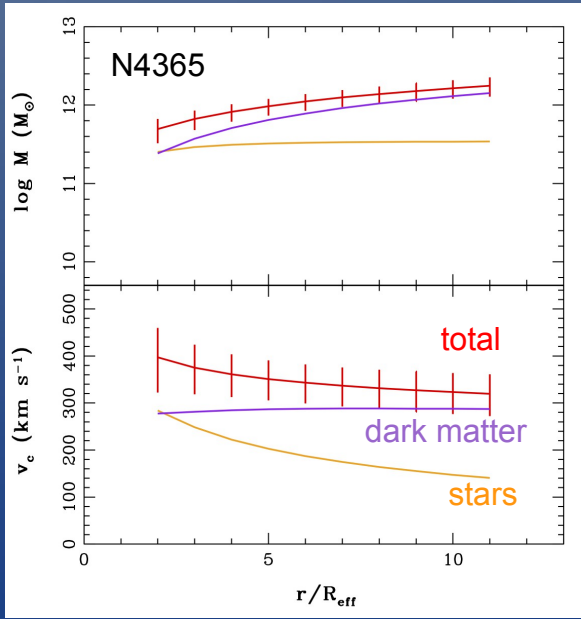
Total Mass Density Slope

- Total mass density slope is shallower for more massive and bigger containing larger dark matter fractions, and for galaxies which have undergone more accretion events.

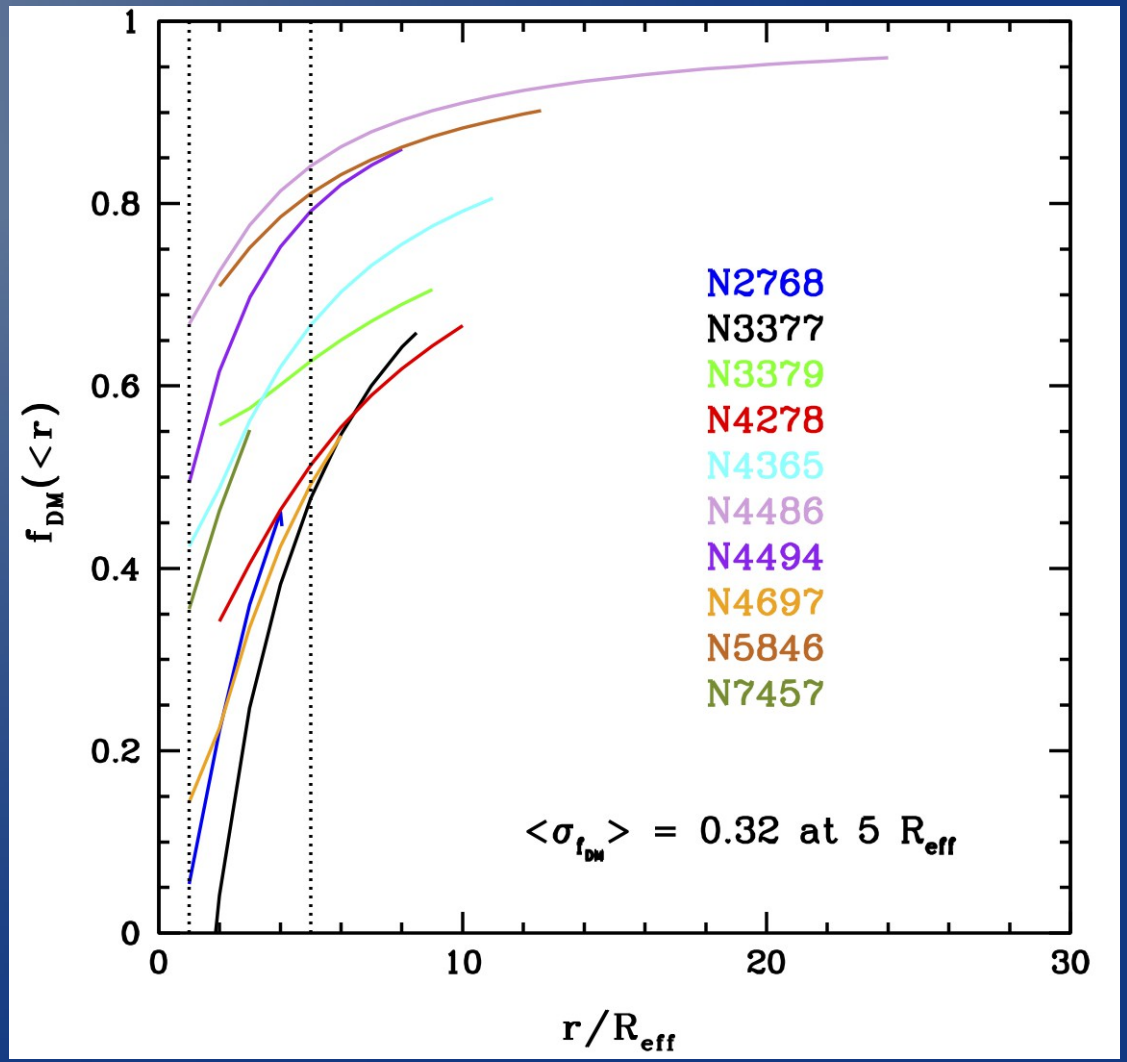


Dark Matter Fractions





- Consistent with simulations for $f_{DM} \sim 0.4 < 5\ R_{eff}$ (Naab et al. '07, Oñorbe et al. 2007) and observations for ellipticals, $f_{DM} \sim 0.4$-0.8 (Napolitano et al. '11, Das et al. '10)



Summary

- SLUGGS survey: targets 25 ETGs obtaining kinematic and metallicity information for GCs out to ~10 R_{eff}
- We obtained potential and anisotropy information for 10 ETG using a PLDF maximum likelihood analysis which now allows for flattening of the tracer population

Preliminary results:

- ETGs have nearly isothermal potentials out to 5 R_{eff}
- Less massive galaxies show evidence for having steeper potentials, steeper total mass densities, lower dark matter fractions, and less accretion ($z \leq 2$) than more massive galaxies

Extend this study to the remaining galaxies in the survey – increase the range of properties and environments of the elliptical galaxies studied.