Modeling mass independent of anisotropy

A comparison between Milky Way and Andromeda satellites

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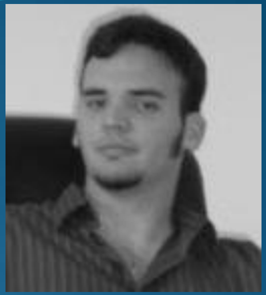
Team Irvine:



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Yale: Marla Geha Ricardo Munoz

Heigh Ho...

Collaborators

Mass modeling of hot systems

Spherical Jeans Equation

$$r\frac{d(\rho_\star \sigma_r^2)}{dr} = \frac{-GM(r)}{r}\rho_\star(r) - 2\beta(r)\rho_\star\sigma_r^2$$

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Velocity Anisotropy (3 parameters)

$$\beta(r) = (\beta_\infty - \beta_0)\frac{r^2}{r_\beta^2 + r^2} + \beta_0$$

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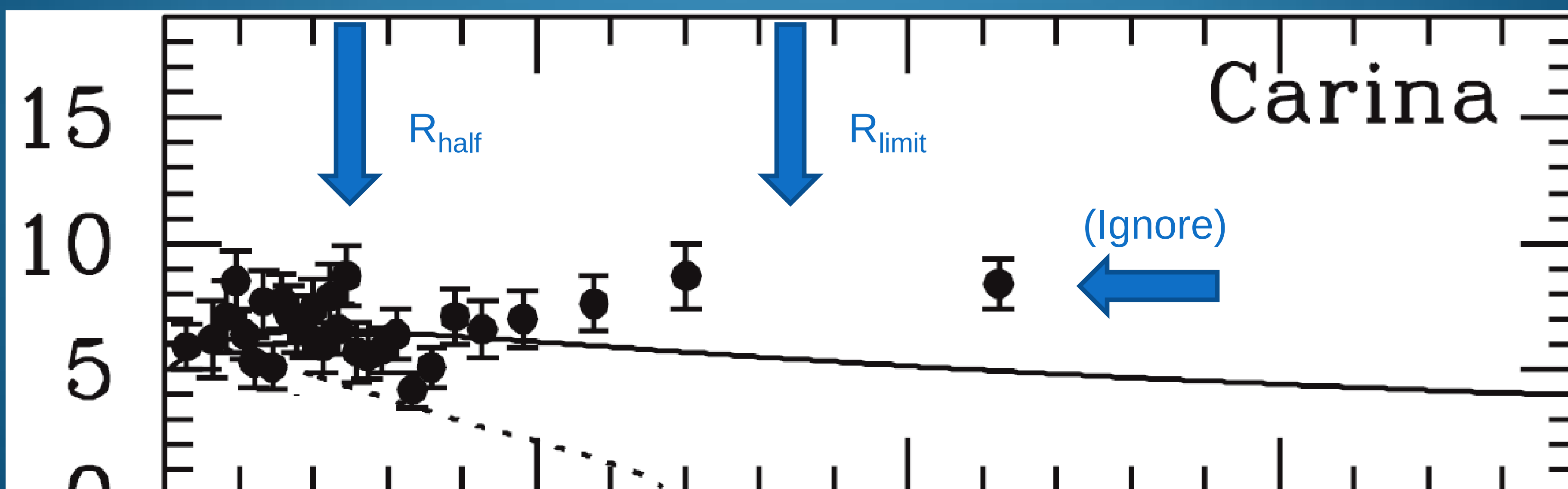
Using a Gaussian PDF for the observed stellar velocities, we marginalize over all free parameters (including photometric uncertainties) using a Markov Chain Monte Carlo (MCMC).

Given this data

Using the individual stars that make up this dispersion profile…

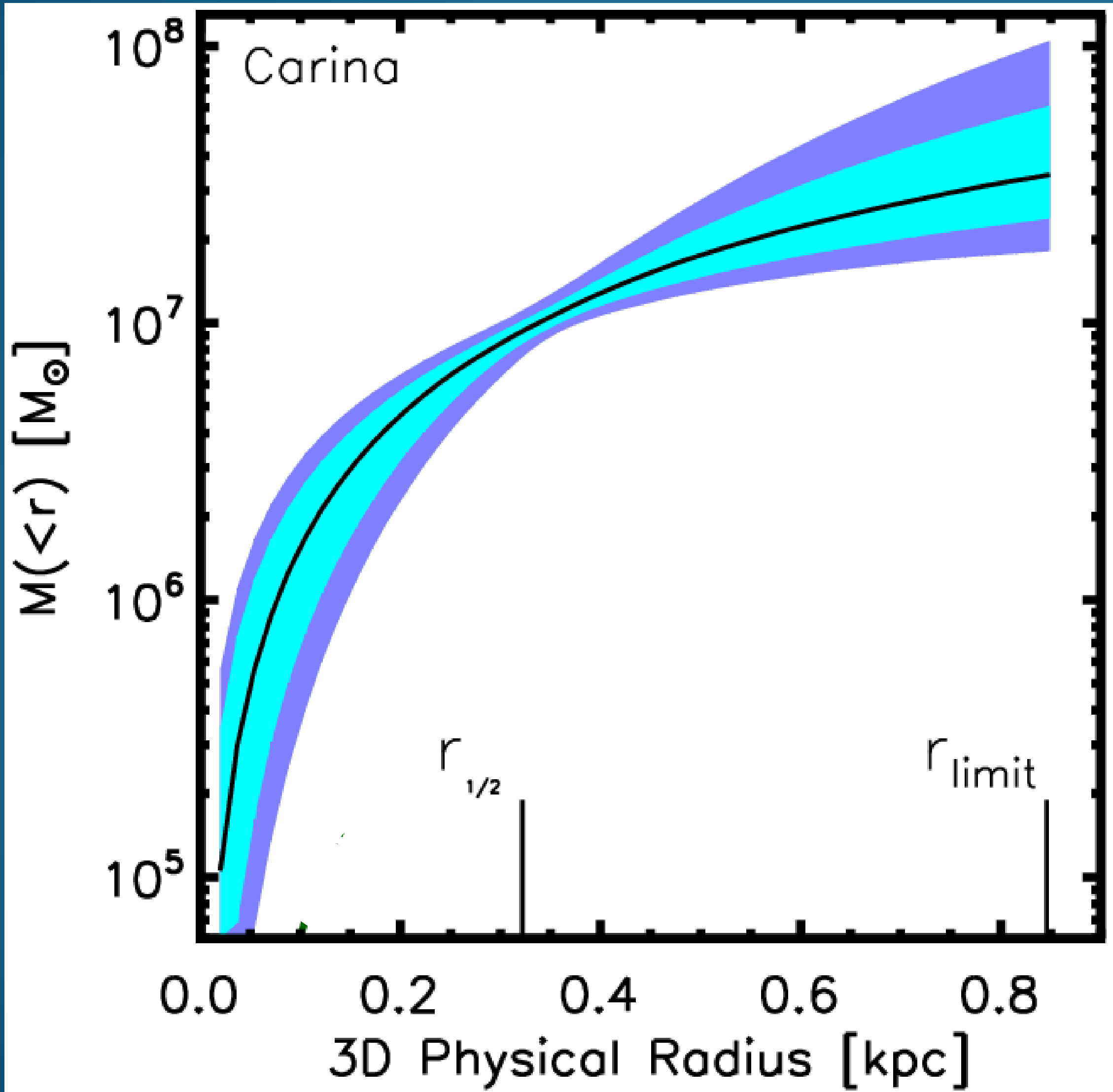


LOS Dispersion (km/s)

Projected (On Sky) Radius

Walker et al. 2007, ApJ

We derive the following

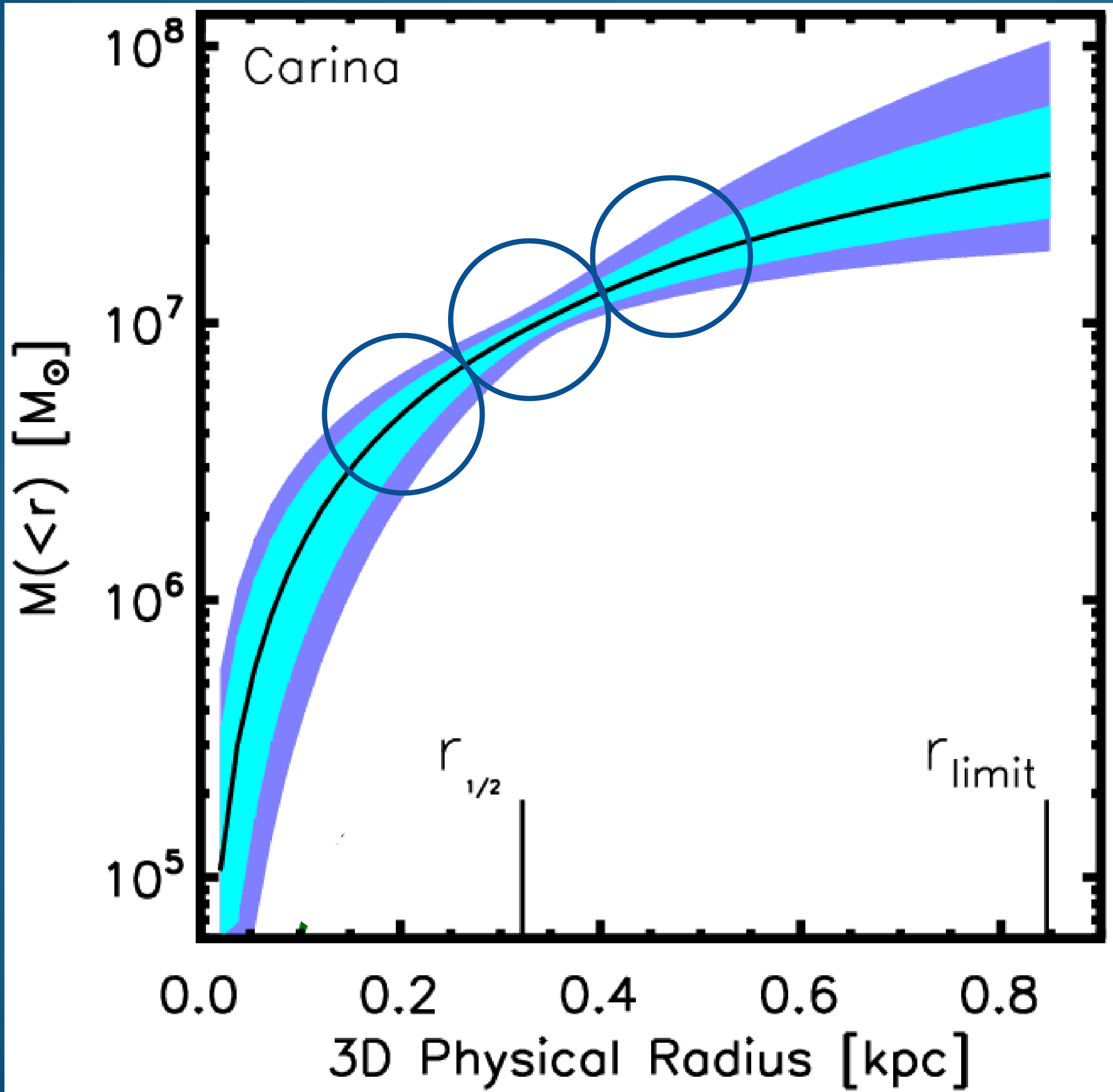


<u>Confidence Intervals:</u>
Cyan: 68%
Purple: 95%

Joe Wolf et al., in prep

Hmm…

It turns out that the mass is best constrained within $r_{1/2}$, and despite the given data, is less constrained for $r < r_{1/2}$ than $r > r_{1/2}$.



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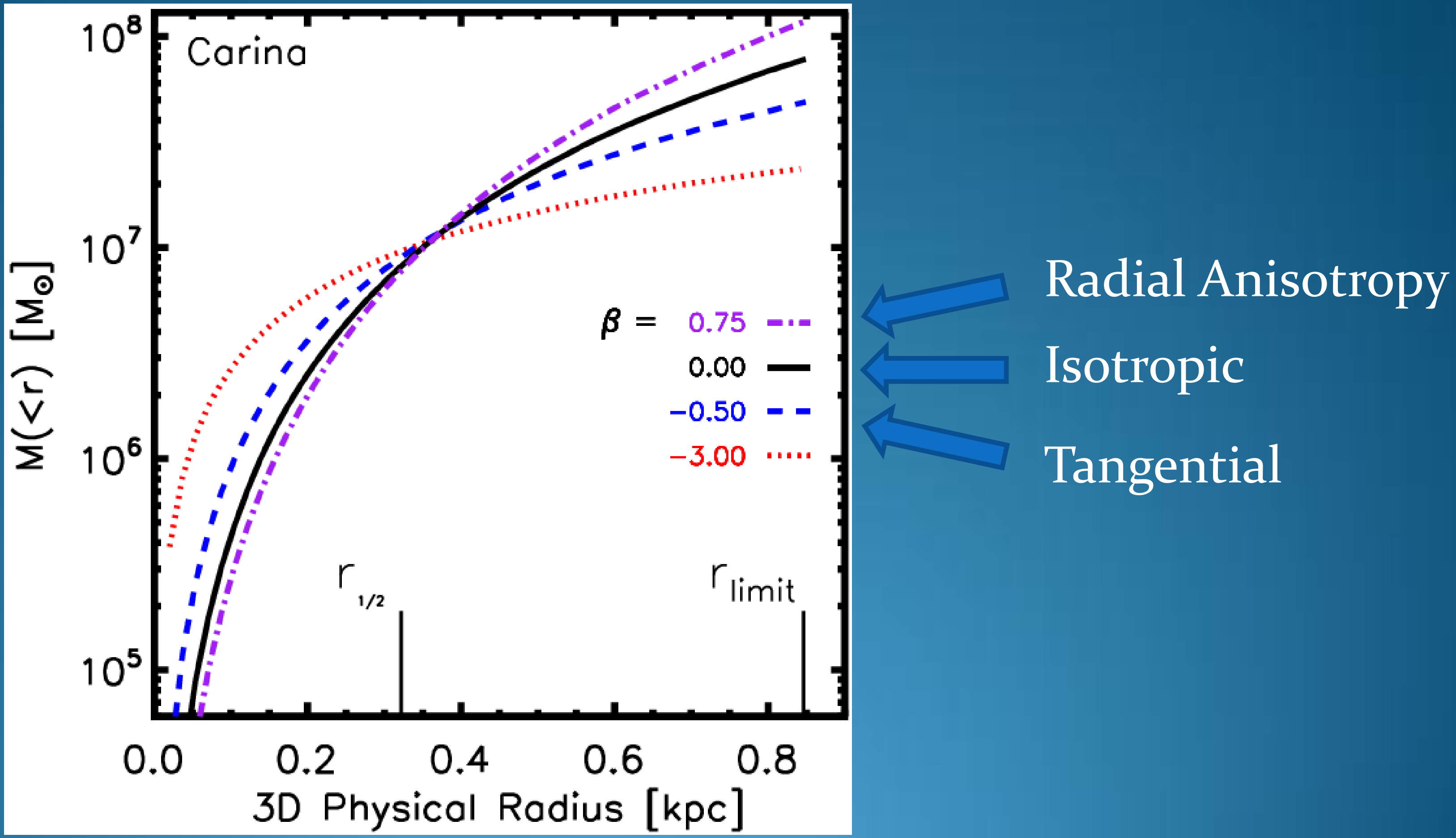
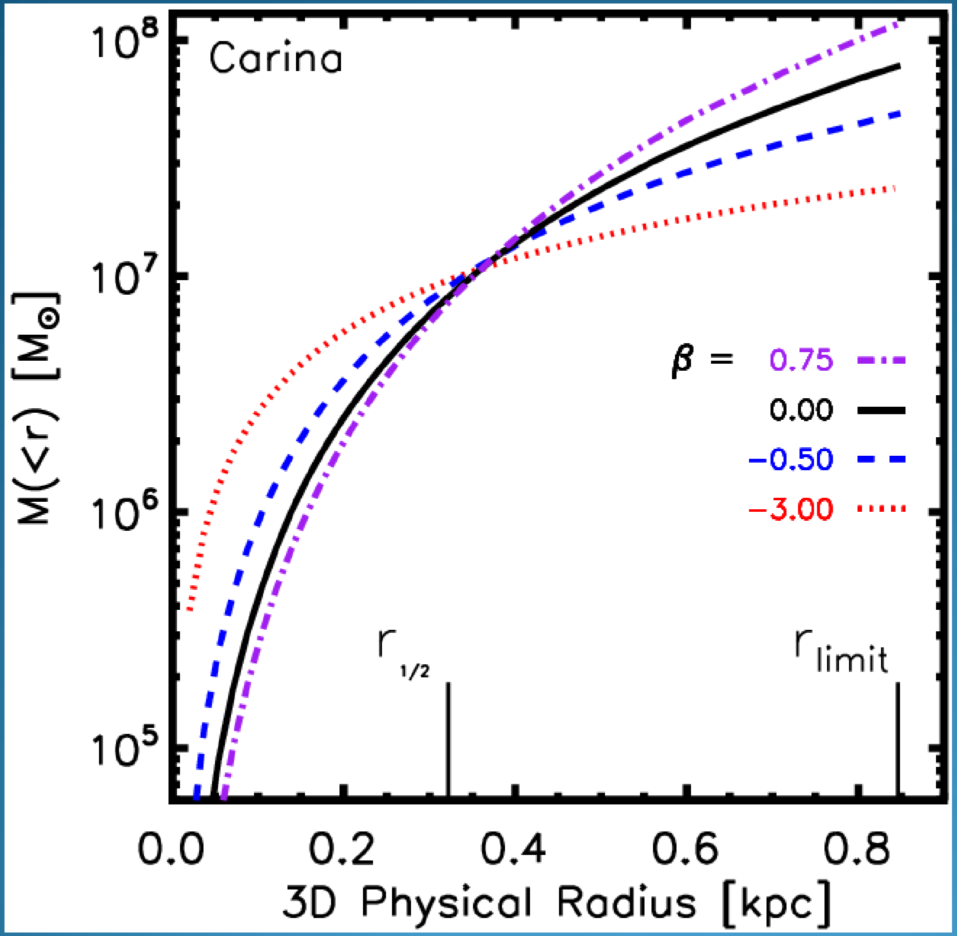
Anisotrwhat?



Joe Wolf et al., in prep

Anisotrwhat?

Center of system:
Observed dispersion is radial



Edge of system: Observed dispersion is tangential

Radial Anisotropy

Isotropic

Tangential

Joe Wolf et al., in prep

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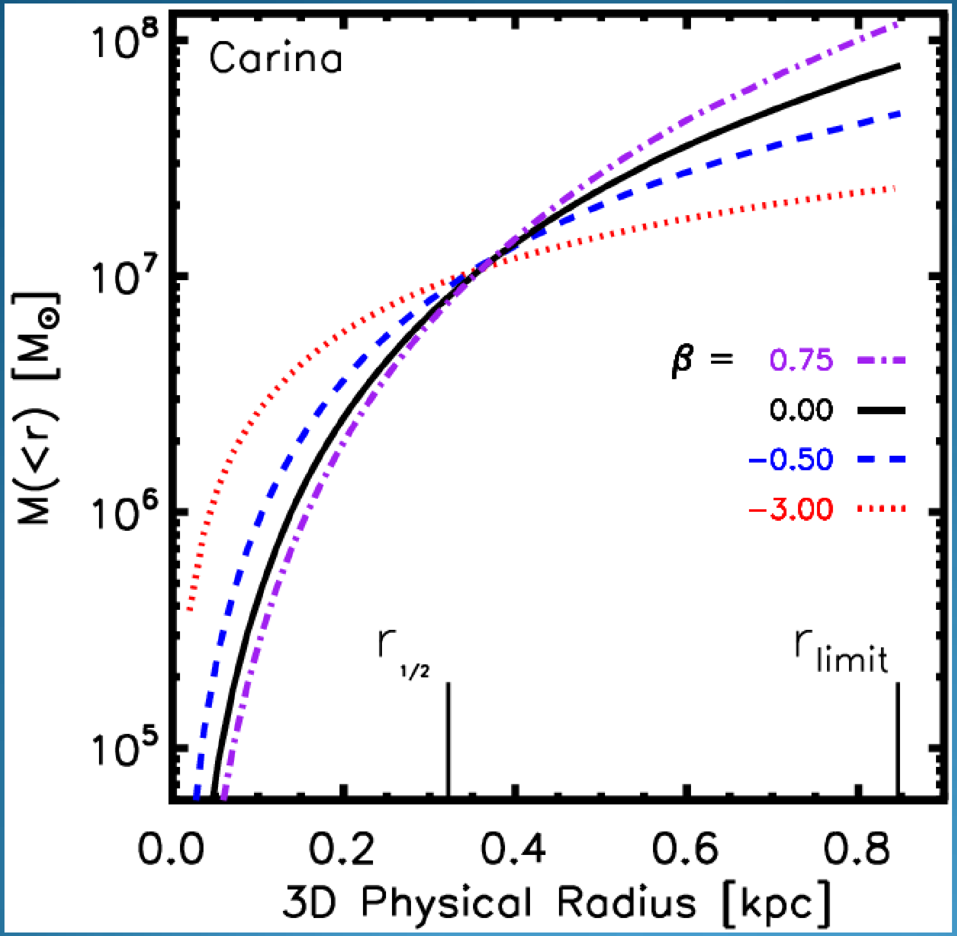

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Joe Wolf et al., in prep

Newly derived analytic equations **predict** that the effect of anisotropy is minimal ~$r_{1/2}$. E.g.:

$$M(<r;0) - M(<r;\beta) = \frac{\beta(r)\, r\, \sigma_r^2(r)}{G}\left(\frac{d\ln\rho_\star}{d\ln r} + \frac{d\ln\sigma_r^2}{d\ln r} + \frac{d\ln\beta}{d\ln r} + 3\right)$$

Mass-anisotropy degeneracy has effectively been *terminated* at $r_{1/2}$:

Derived equation under several simplifications:

$$M_{1/2} = 3\, r_{1/2}\, \sigma^2_{LOS}/G$$

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Derived equation under several simplifications:

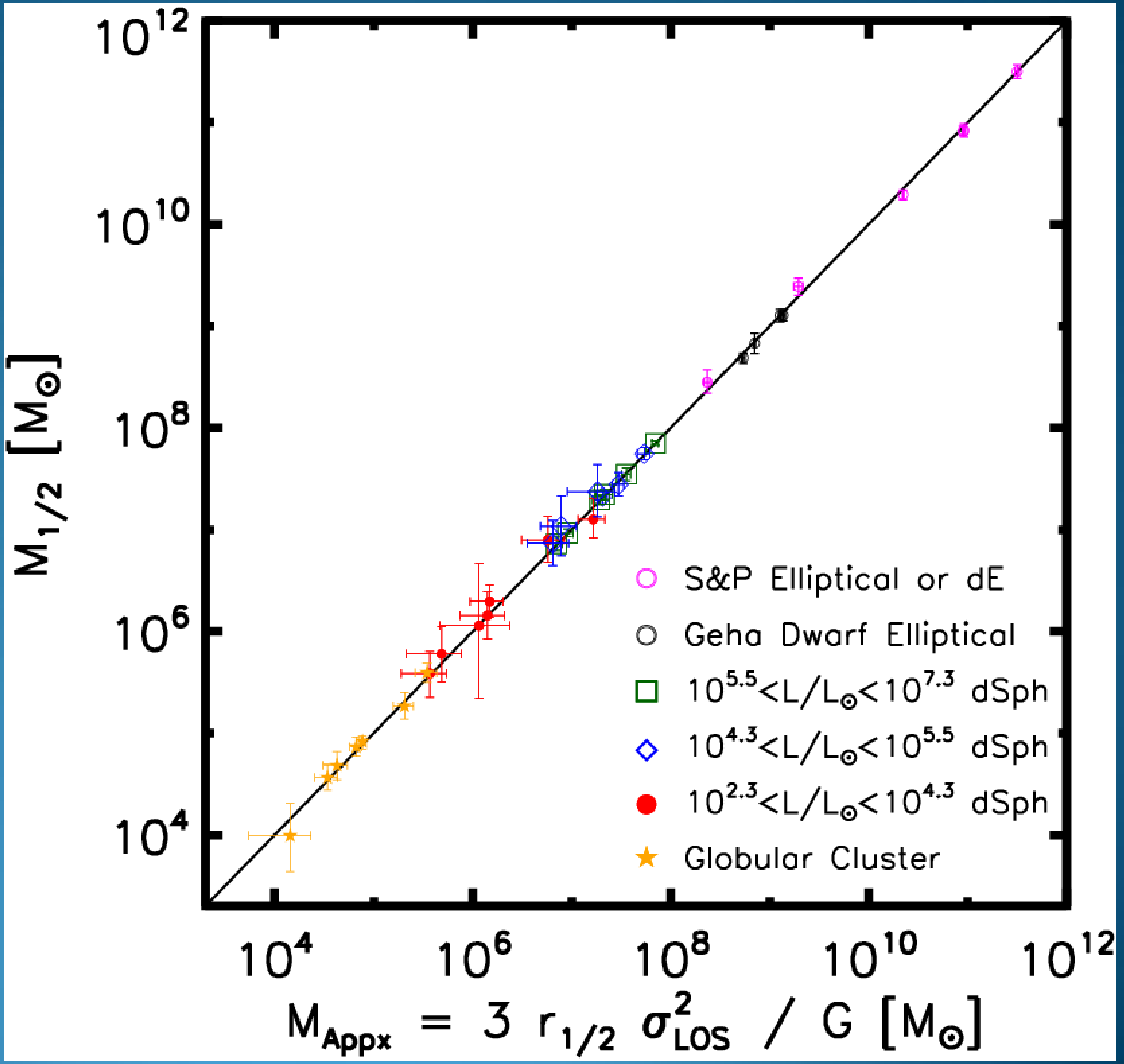
$$M_{1/2} = 3\, r_{1/2}\, \sigma^2_{LOS} / G$$

$$\frac{M_{1/2}}{M_\odot} \simeq 930 \frac{R_{half}}{pc} \left(\frac{\sigma_{LOS}}{km/s} \right)^2$$

$r_{1/2} \approx 4/3 * R_{half}$

Really?

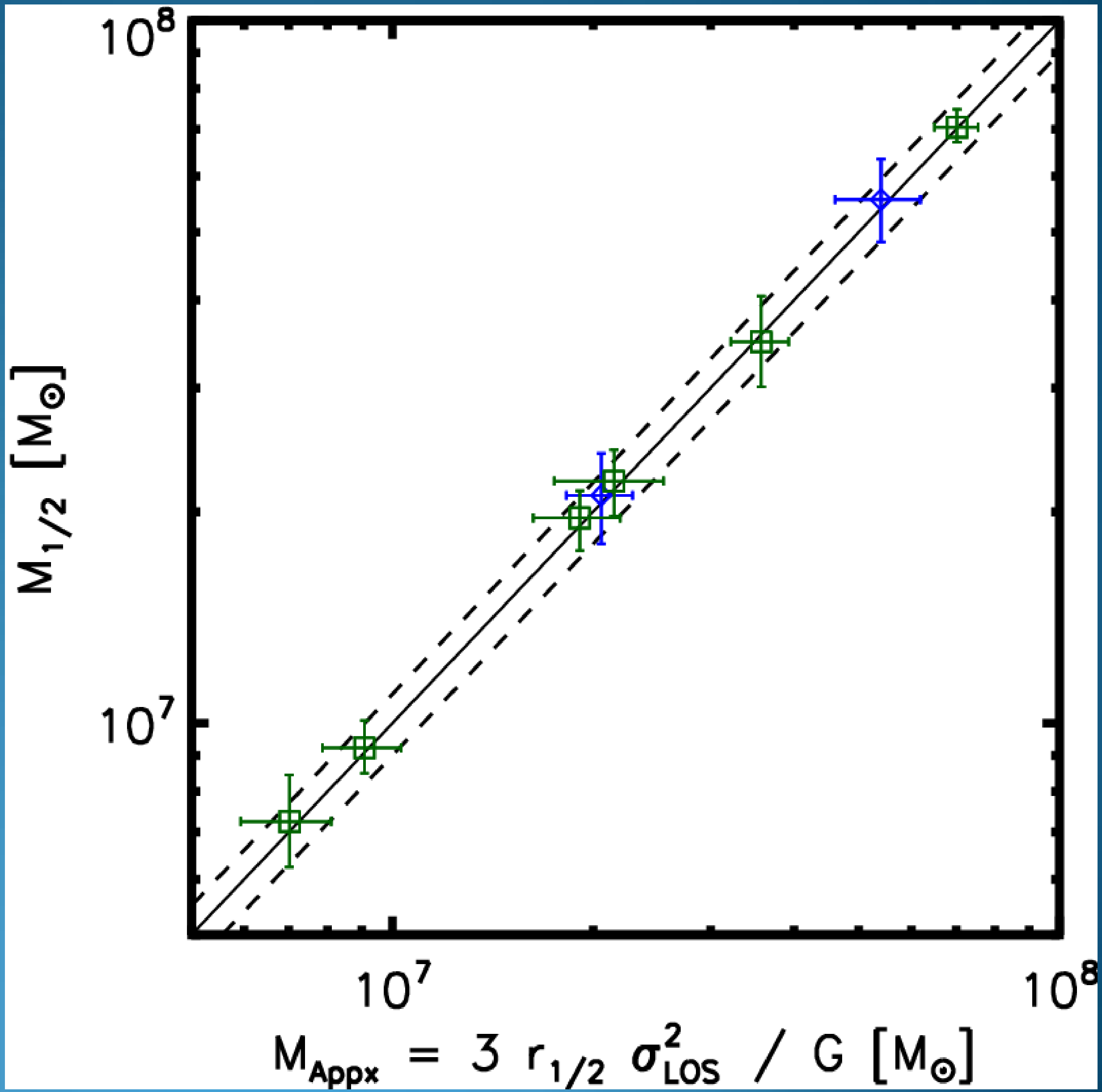
Boom!
Equation tested on systems spanning almost **eight** decades in half-light mass after lifting simplifications.



Joe Wolf et al., in prep

Boom!

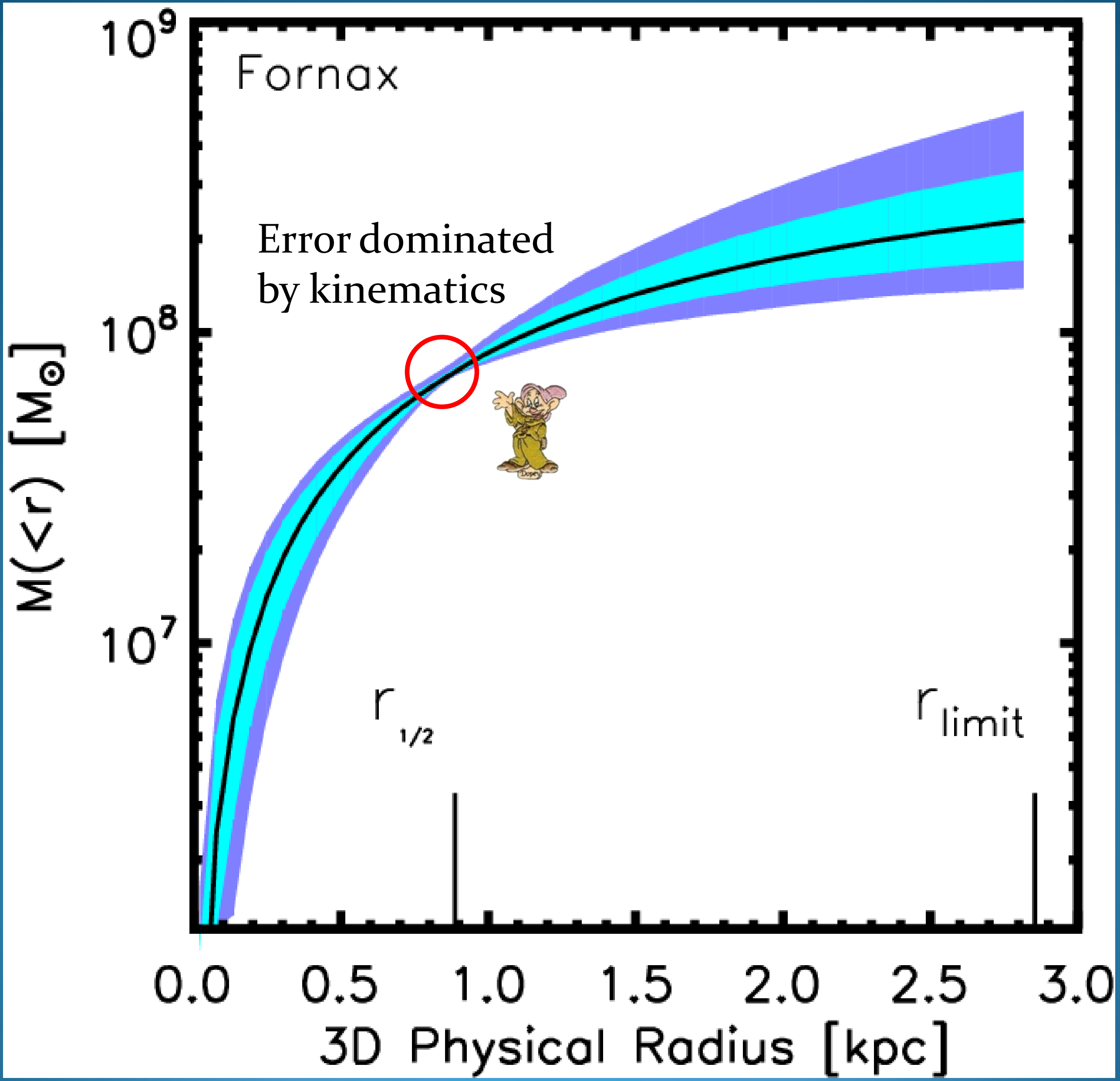
“Classical” MW dwarf spheroidals



Dotted lines:
10% variation in
factor of 3 in M_{Appx}

Joe Wolf et al., in prep

Mass Errors: Origins



Joe Wolf et al., in prep

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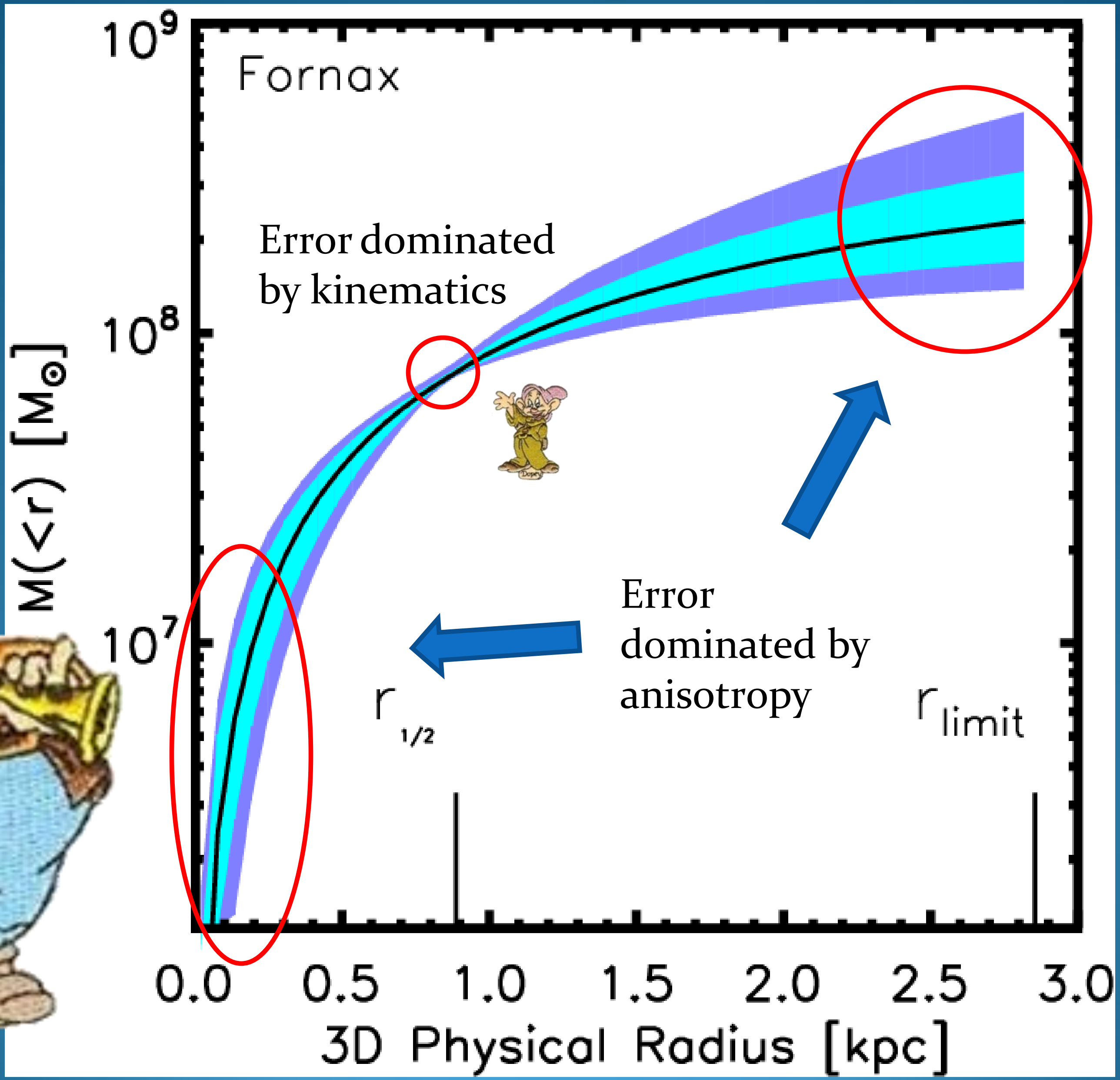
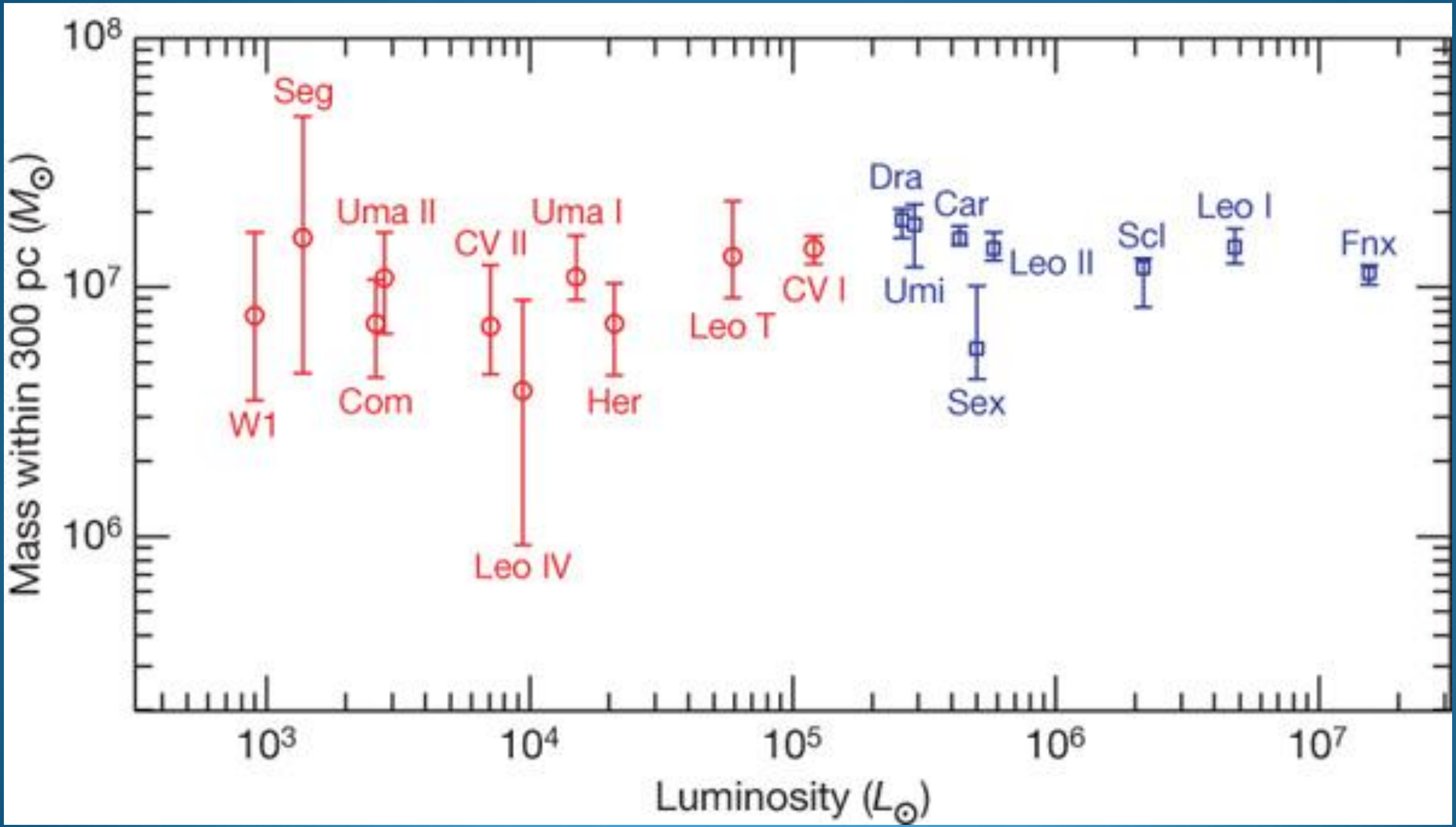


Joe Wolf et al., in prep

Applications: dSphs

A common mass scale? $M(<300) \sim 10^7\ M_{sun} \rightarrow M_{halo} \sim 10^9\ M_{sun}$



Strigari, Bullock, Kaplinghat, Simon, Geha, Willman, Walker 2008, Nature

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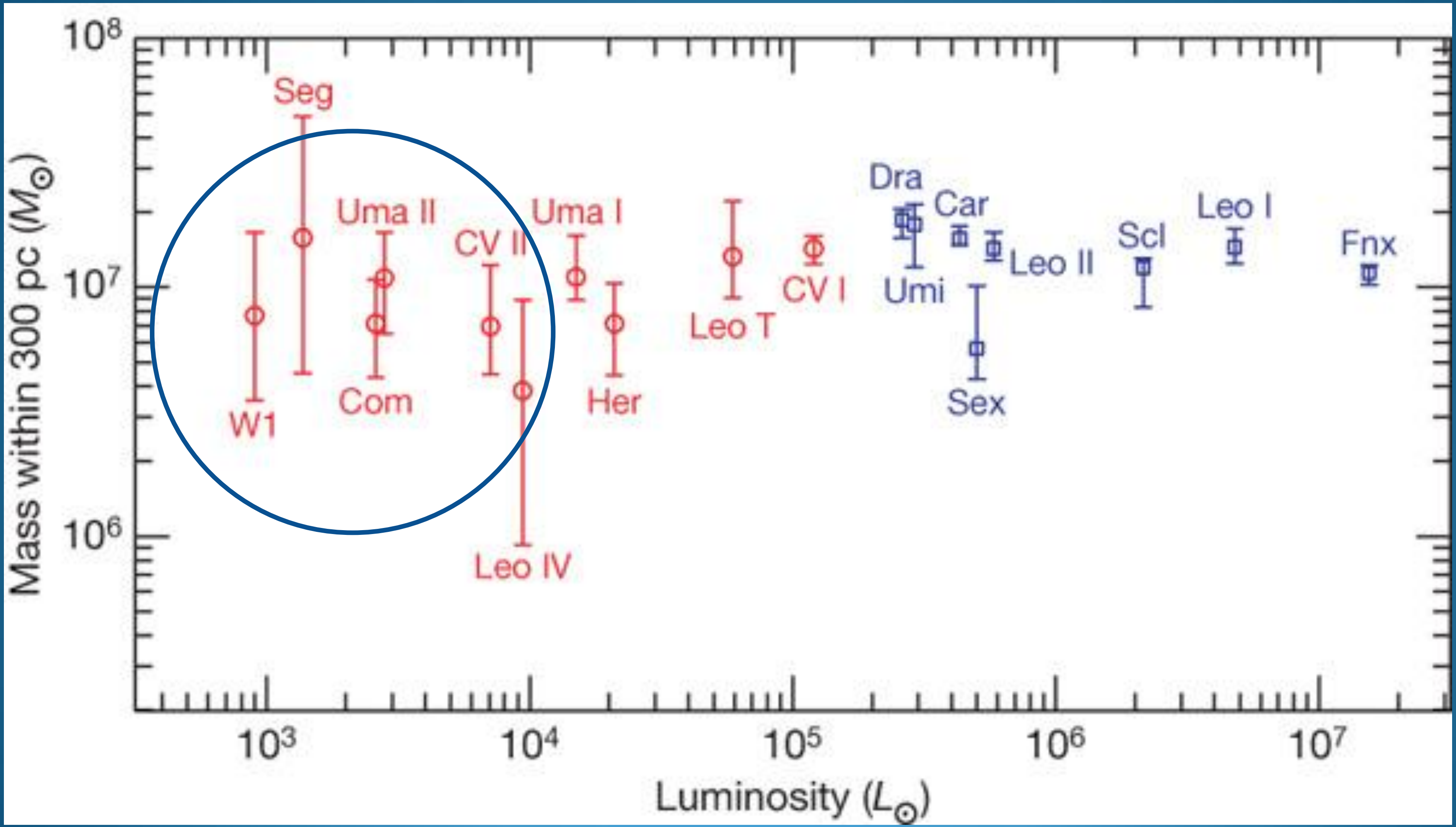

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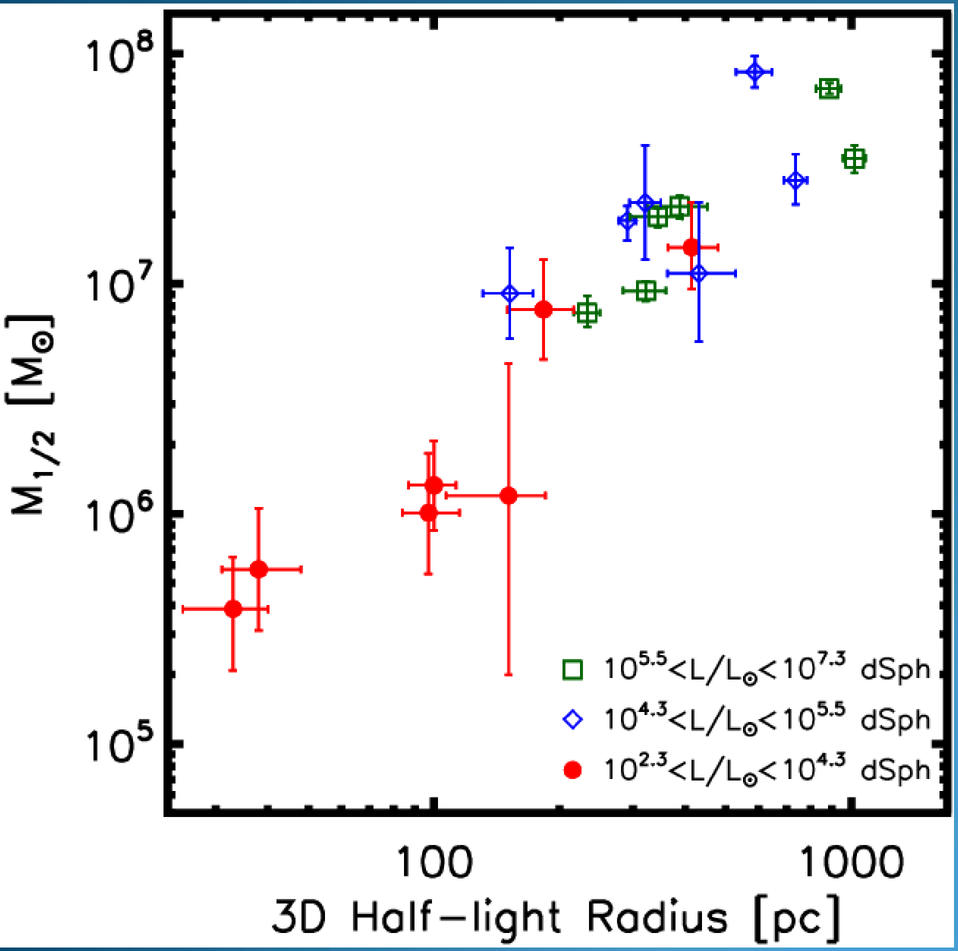
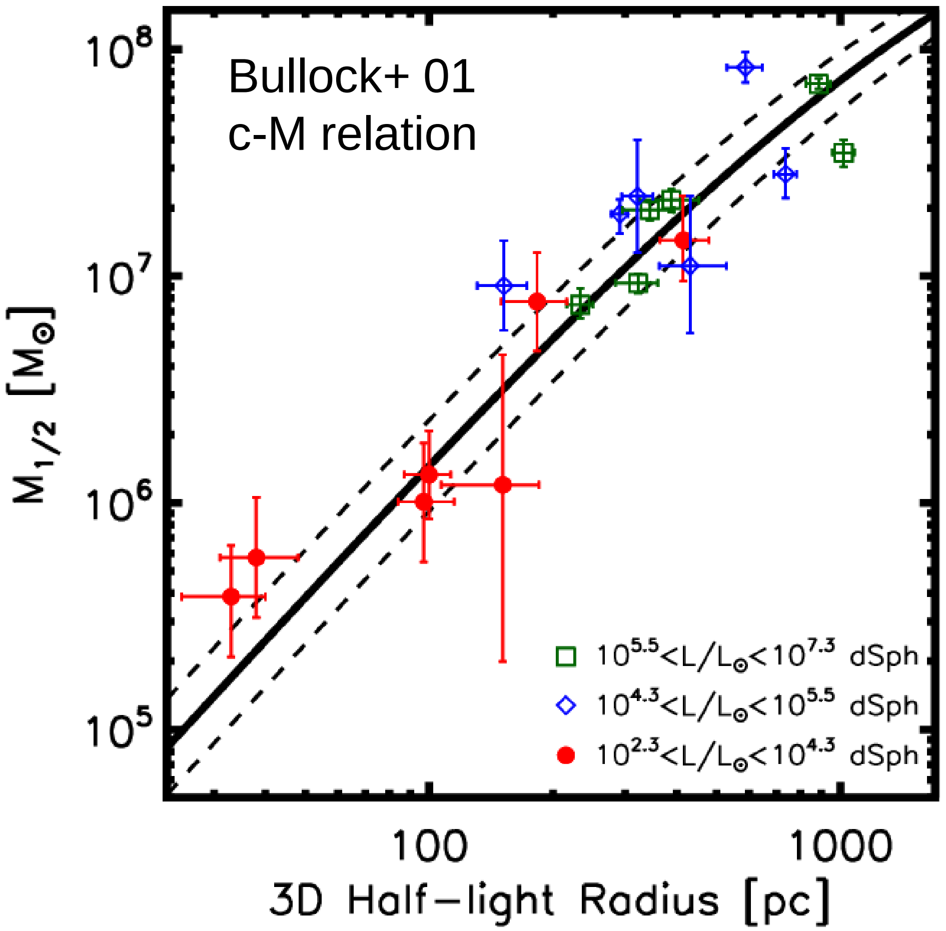


Joe Wolf et al., in prep

Applications: dSphs

A common mass scale? Plotted: $M_{halo} = 10^9\, M_{sun}$

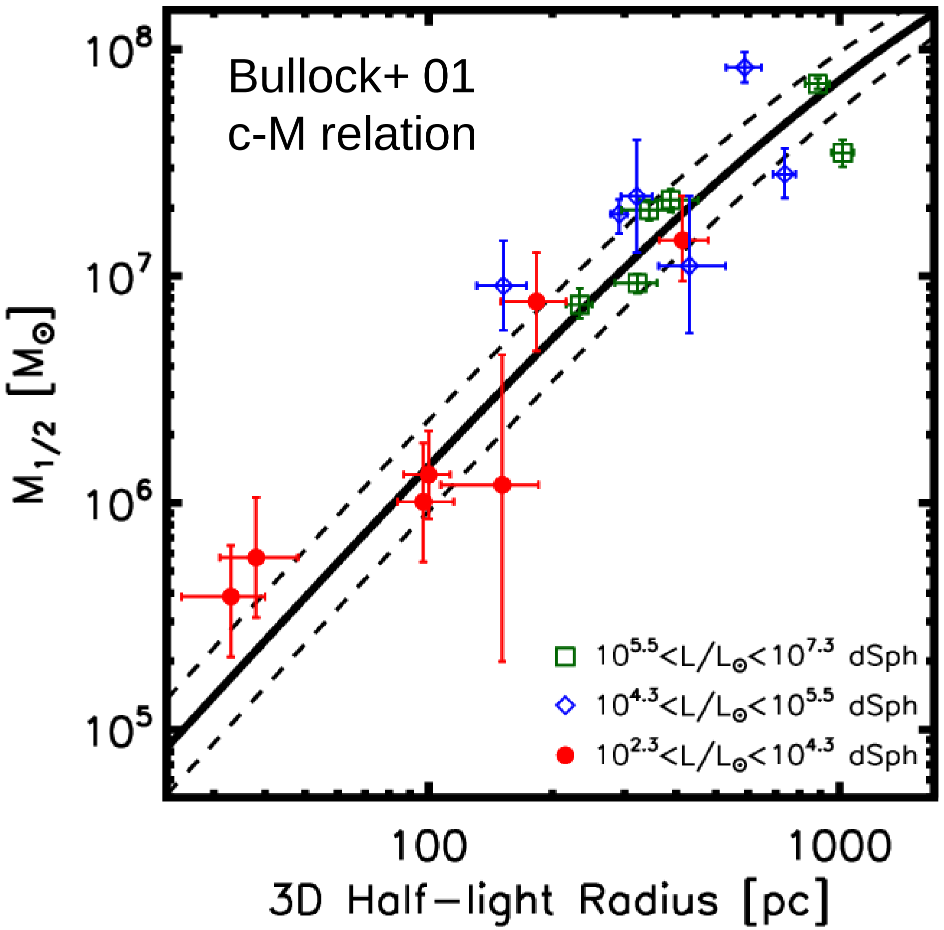


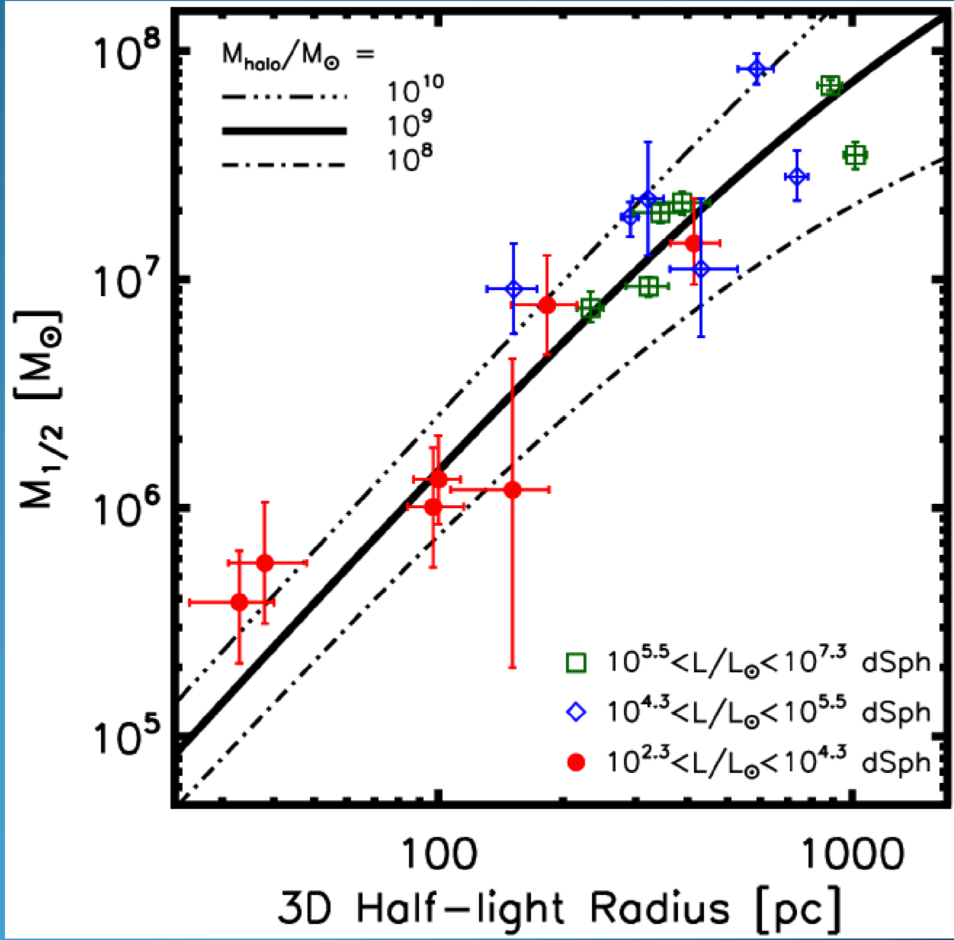
Notice: No trend with luminosity, as might be expected!

Joe Wolf et al., in prep

Applications: dSphs

A common mass scale? Plotted: $M_{halo} = 10^9\ M_{sun}$
Minimum mass threshold for galaxy formation?





Notice: No trend with luminosity, as might be expected! Joe Wolf et al., in prep

Another dataset: M31

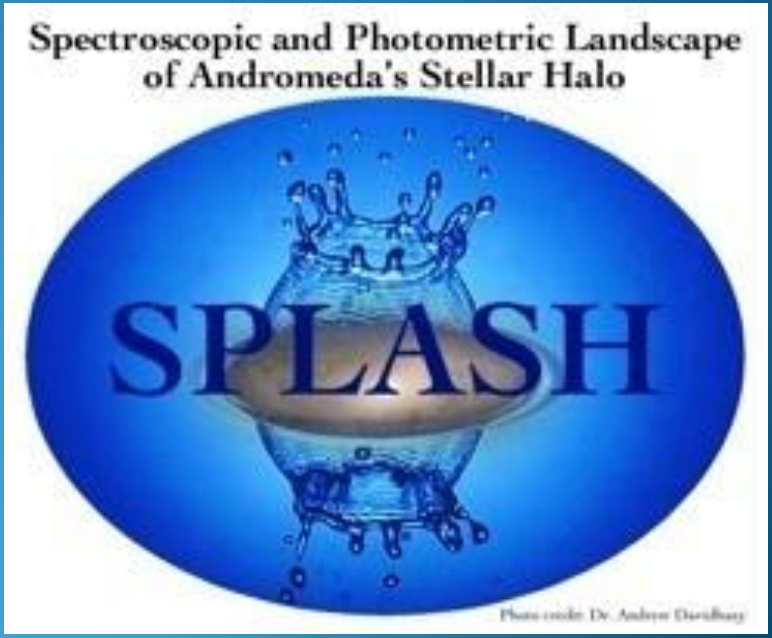
UC Irvine: James Bullock, Manoj Kaplinghat, Erik Tollerud, Joe Wolf, Basilio Yniguez

UC Santa Cruz: Raja Guhathakurta (SPLASH PI), Karrie Gilbert, Evan Kirby

STScI: Jason Kalirai

Yale: Marla Geha

And others involved in SPLASH →

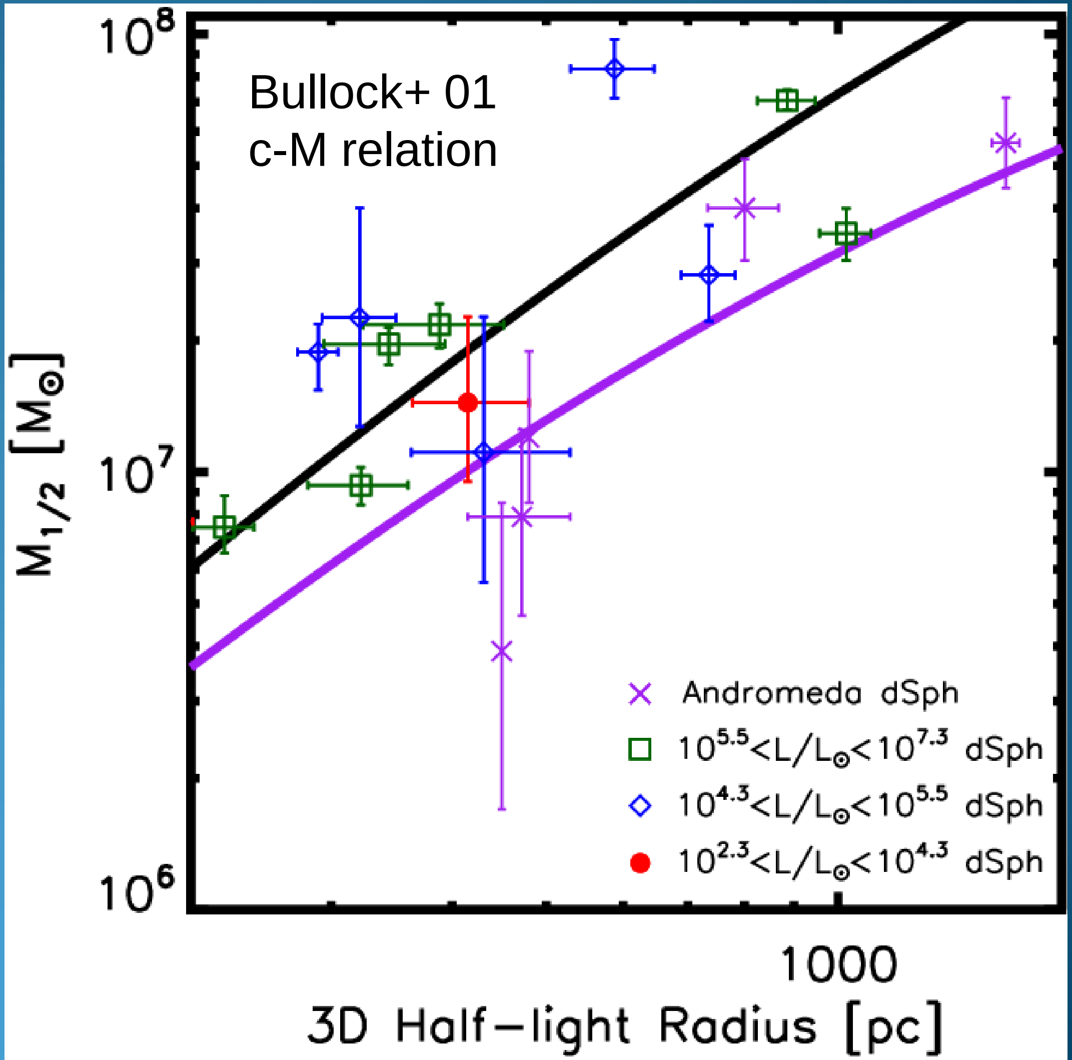


M31 dSphs: Bigger but less massive!

Spectroscopic data from Keck/DEIMOS.

DM halo mass offset by ~10.
M(<300 pc) offset by ~2.

Joe Wolf et al., in prep



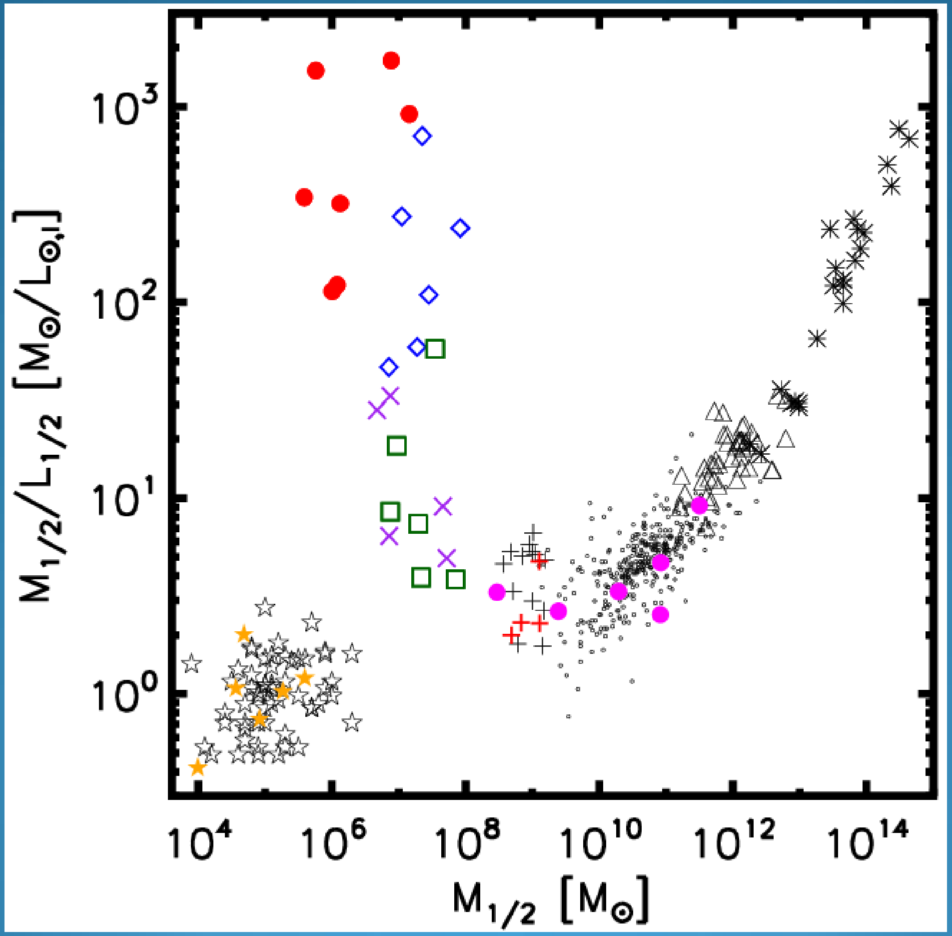
M31: Different Environment?

If M31's DM halo collapsed later → Less dense substructure & later forming star formation.

Interesting:

Brown et al. 2008 find that portion of investigated M31 stellar halo is younger (on average) than MW's.

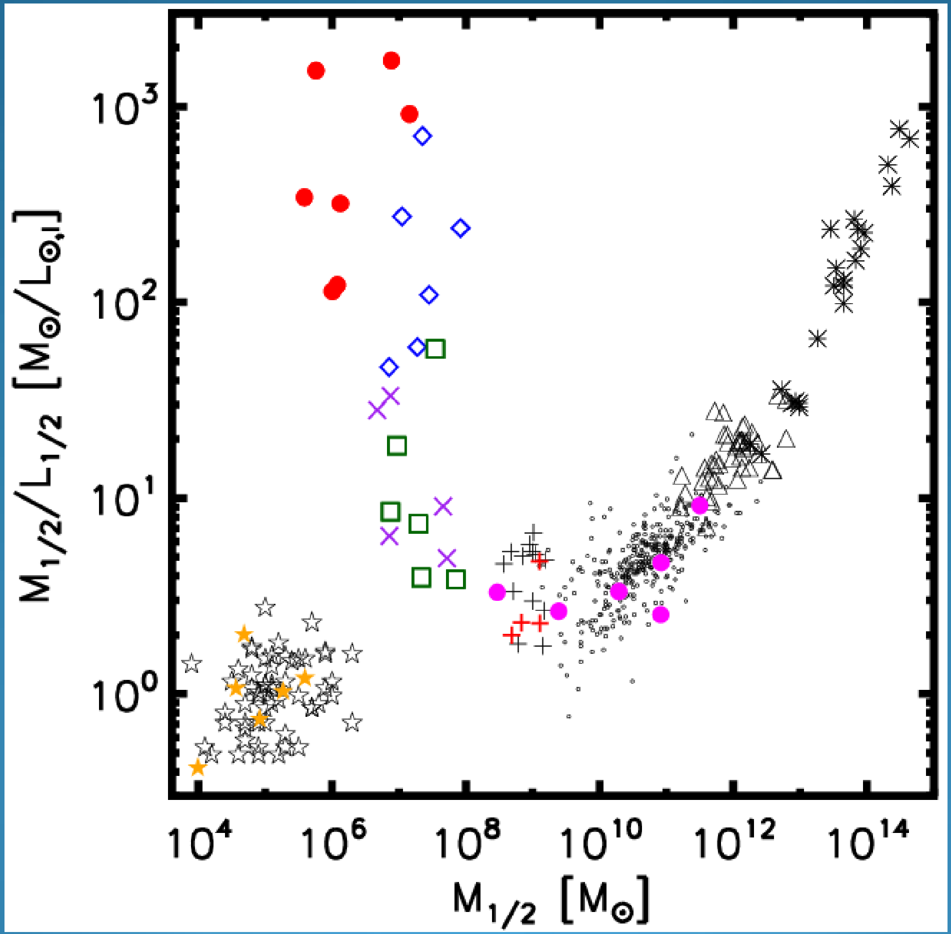
Applications: Global



Joe Wolf et al., in prep

Applications: Global

Much information about feedback & galaxy formation can be summarized with this plot. Also note similar trend to number abundance matching.



Joe Wolf et al., in prep

Applications: Global

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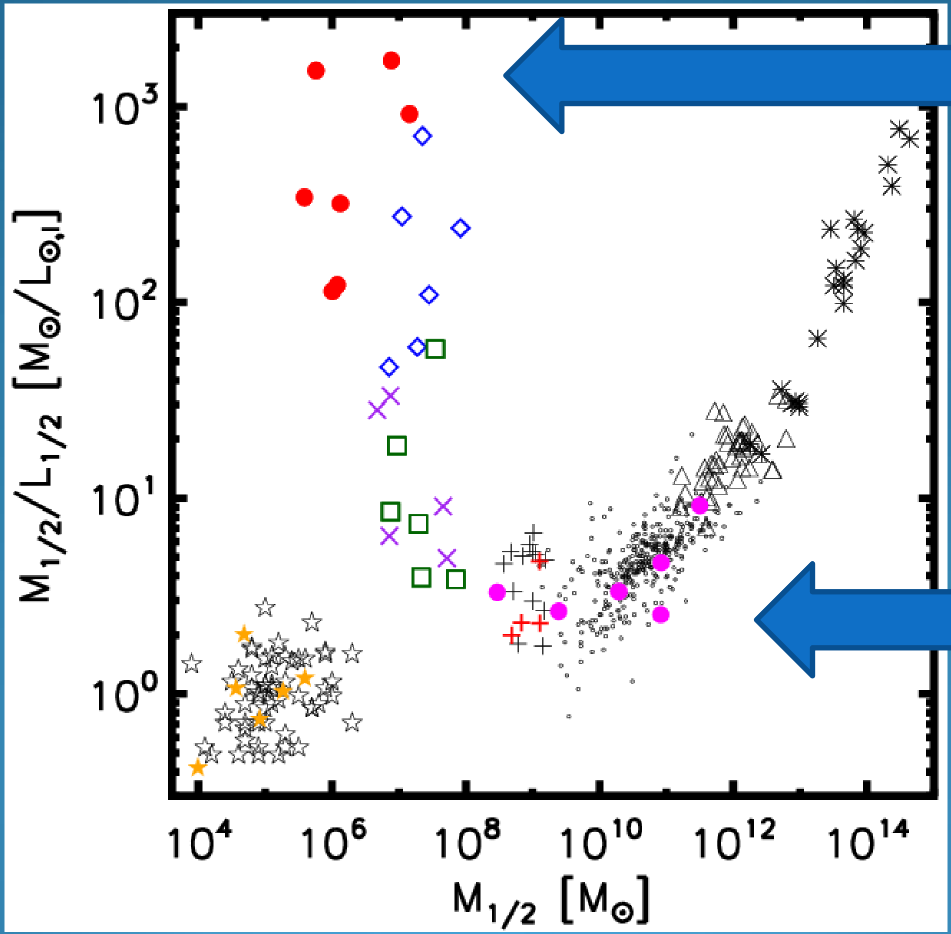
Ultrafaint dSphs: most DM dominated systems known!

Globulars: Little to no dark matter



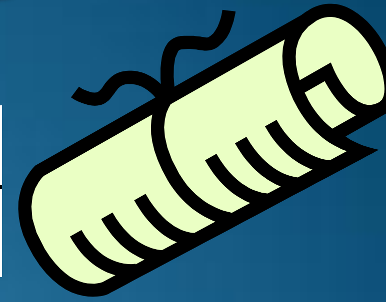
Inefficient at galaxy formation

L_*: Efficient at galaxy formation

Joe Wolf et al., in prep

Take-Home Messages

$$M_{1/2} = 3\, r_{1/2}\, \sigma^2_{LOS} / G$$



$$\frac{M_{1/2}}{M_\odot} \simeq 930\, \frac{R_{half}}{pc} \left(\frac{\sigma_{LOS}}{km/s} \right)^2$$

Lastly, M31 dSphs are less massive at a given radius than the MW population. Environment must be taken into account when considering galaxy formation scenarios.

Extra Slides

Wait a second…

Isn't this just the scalar virial theorem (SVT)?

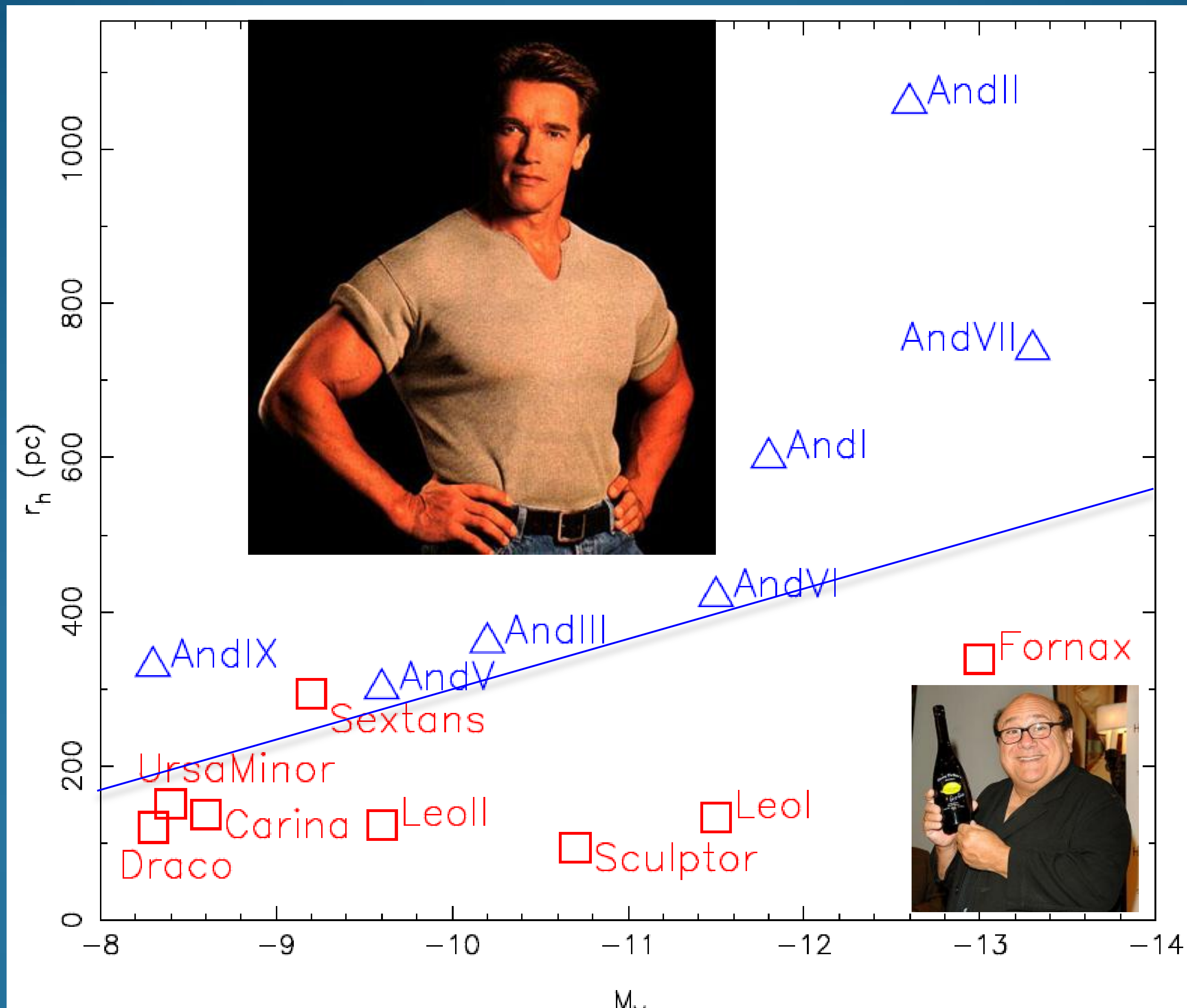
$$M_{1/2} = 3\, r_{1/2}\, \sigma^2_{LOS} / G$$

Nope! The SVT only gives you limits on the total mass of a system. Not knowing the anisotropy will also affect your estimate.

This formula yields the mass within $r_{1/2}$, the 3D deprojected half-light radius, and is accurate independent of our ignorance of anisotropy.

M31 dSphs: Larger than MW dSphs

Observed half-light radius



McConnachie & Irwin 2006, MNRAS

Dim

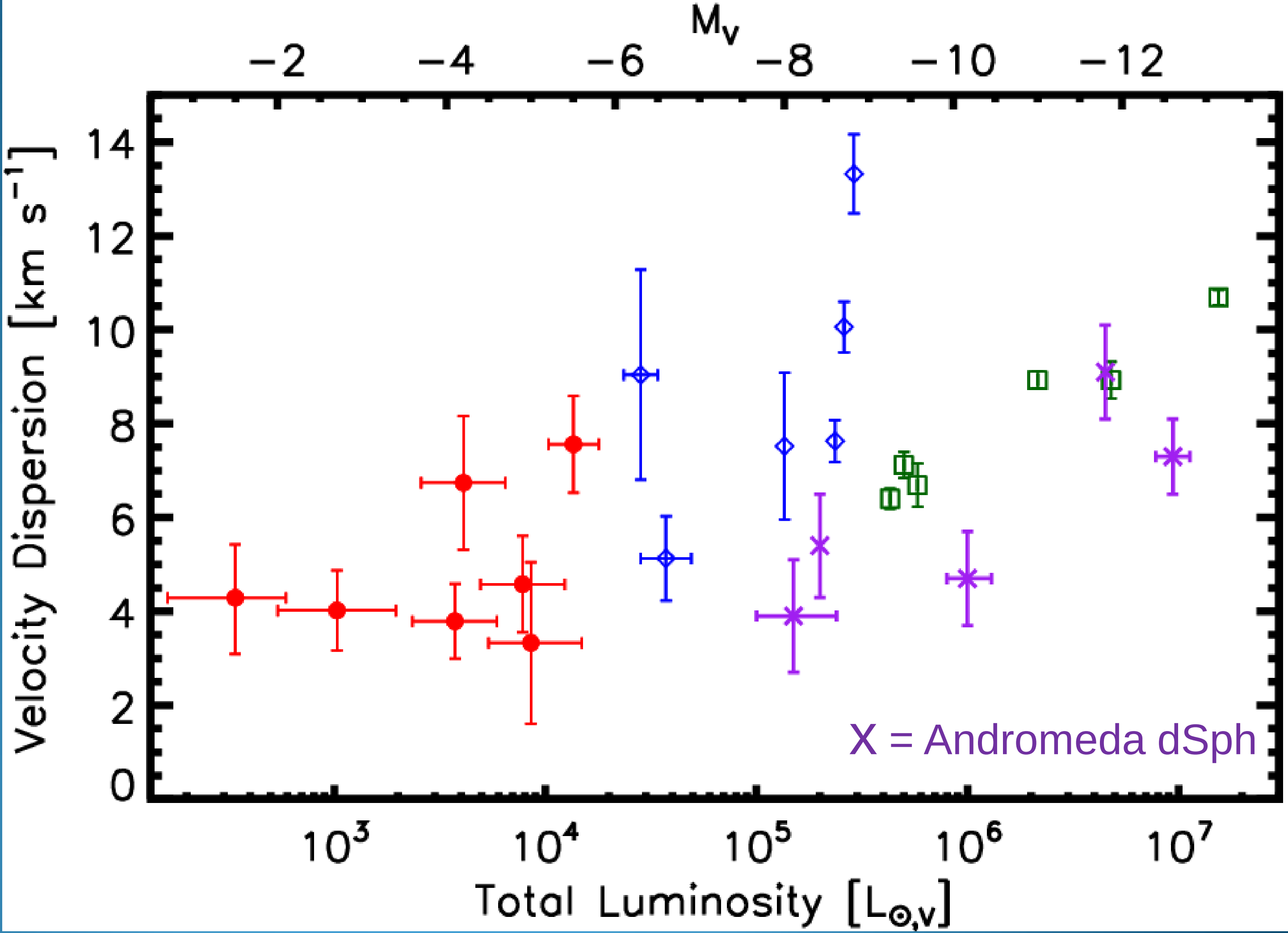
Luminosity

Bright

Dispersion vs Luminosity

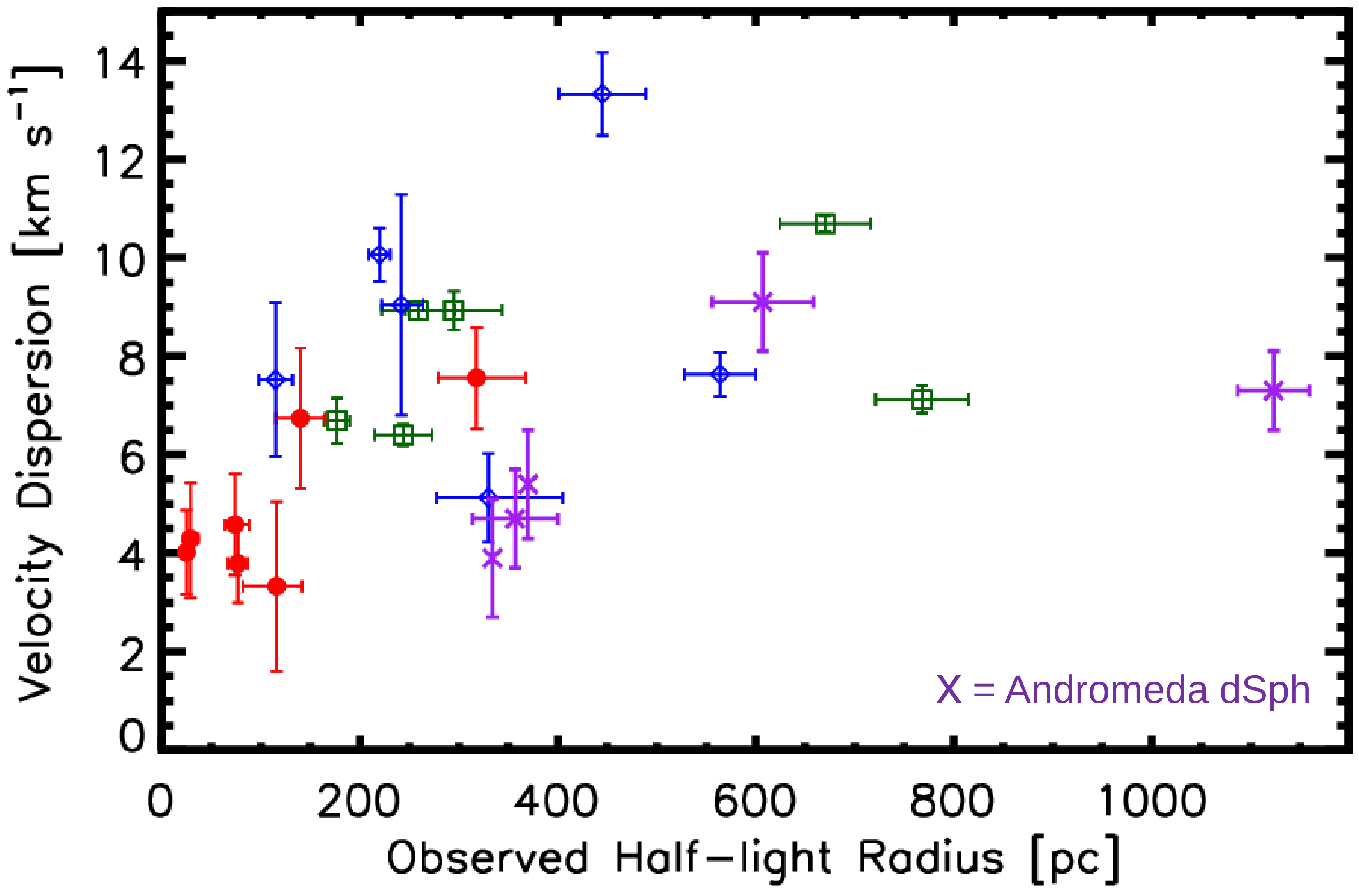
Keck/DEIMOS

And	#	σ km/s
I	76	9.1 ± 1.0
II	95	7.3 ± 0.8
III	43	4.7 ± 1.0
X	22	3.9 ± 1.2
XIV	38	5.4 ± 1.1



Dispersion data from Kalirai et al 2009, in prep

Dispersion vs R_{half}



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