Modeling mass independent of anisotropy

A new advancement in galactic dynamics

Wolf et al. 2010 MNRAS

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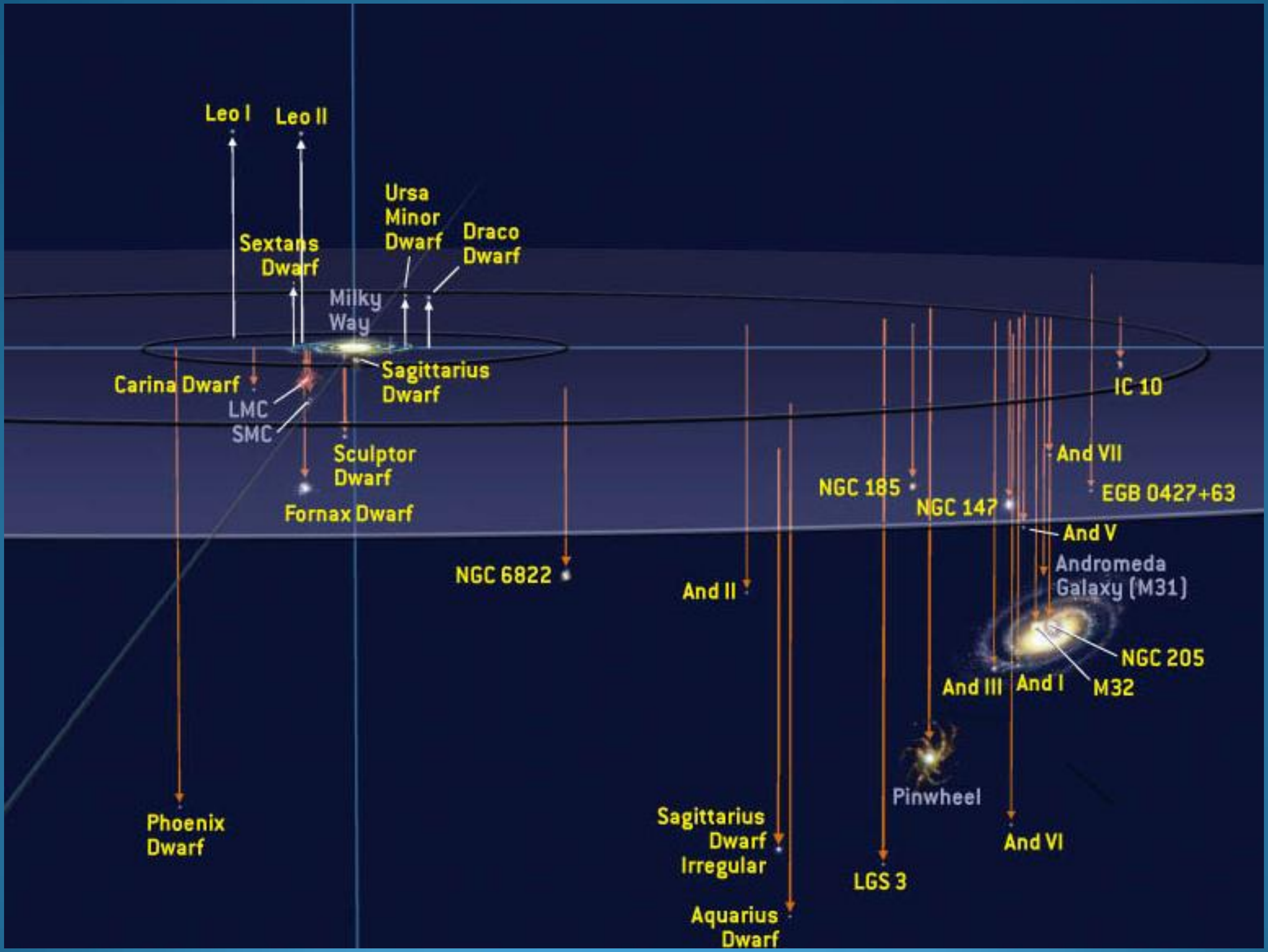
Outline

1. An introduction to the local group

2. A new mass estimator: accurate without knowledge of anisotropy/beta

3. Utilizing new mass estimator to probe galaxy formation scenarios & to connect small and large scales

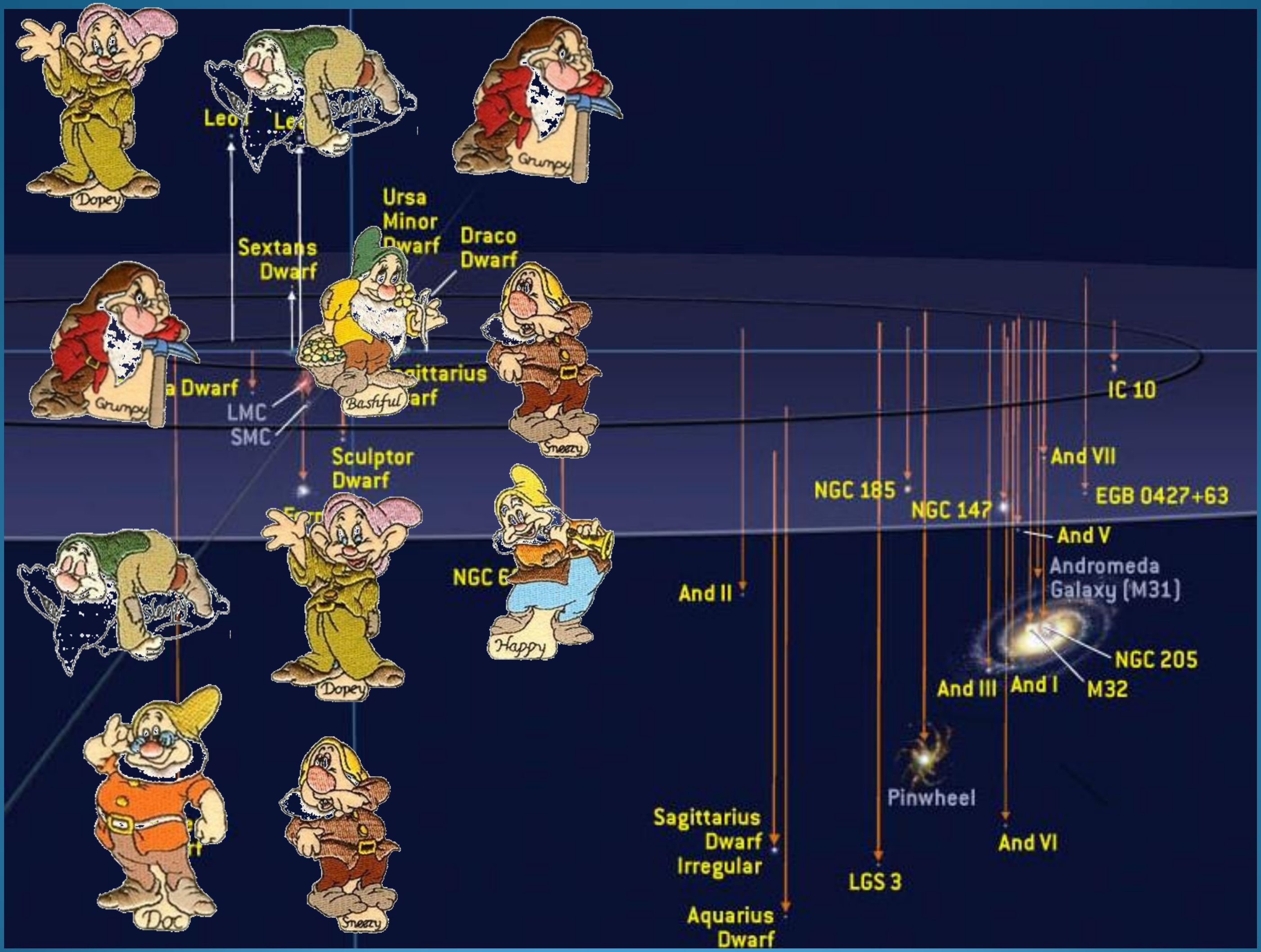
The Local Group



Roen Kelly / Astronomy

The Local Group

The new dwarf galaxy pond after SDSS:



Roen Kelly / Astronomy

Why study dwarfs?

Galaxy formation

1. Subhalos merge to form larger galaxies

2. Surviving dwarfs may be fossil relics of first galaxies

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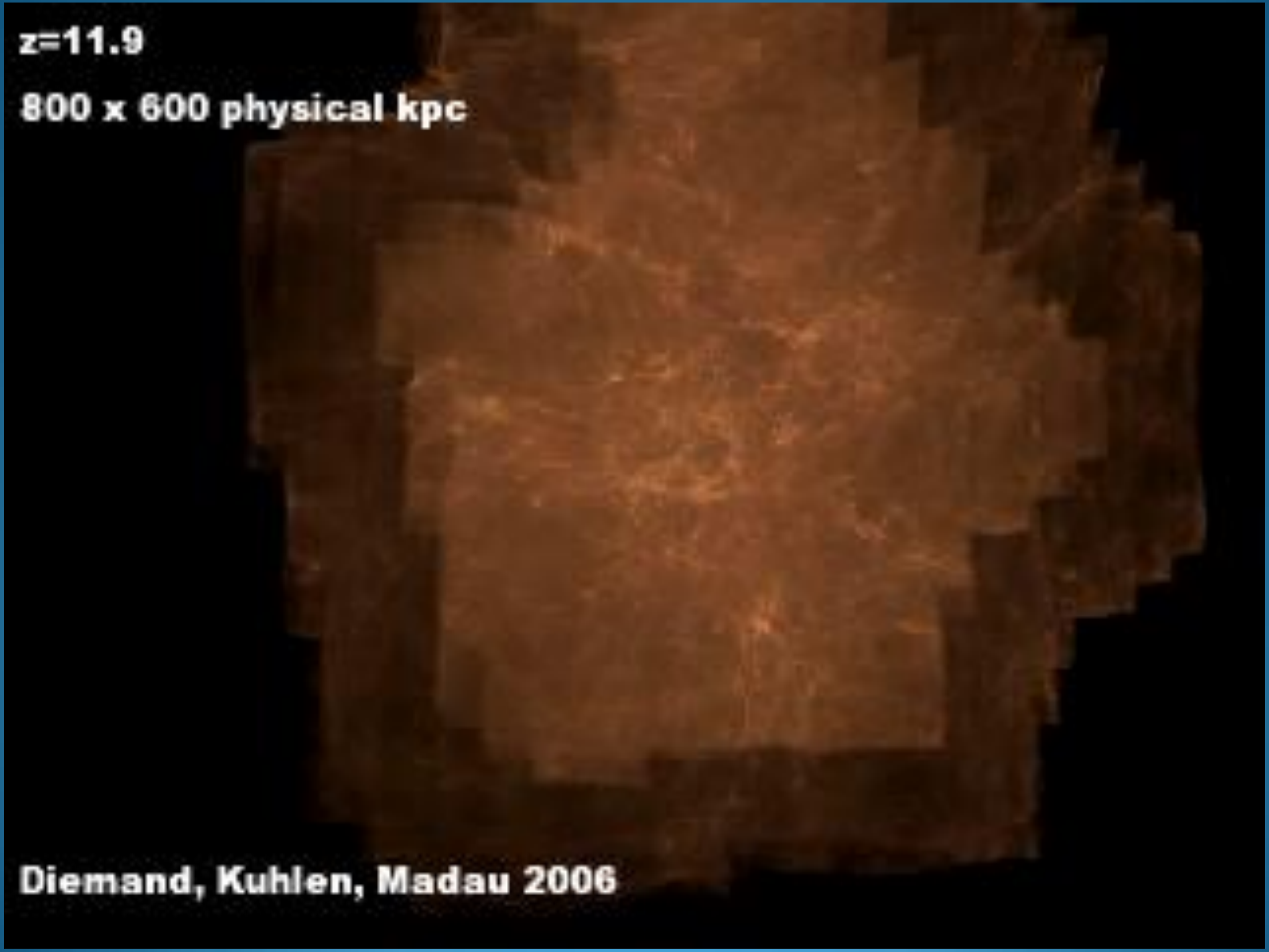
Large scale cosmology

1. Adjusting cosmological parameters affects small scale structure as well. Thus, models **must** be able to reproduce small scale structure.

Hierarchical galaxy formation

Subhalos are the building blocks of all larger galaxies.



Simulation vs observation

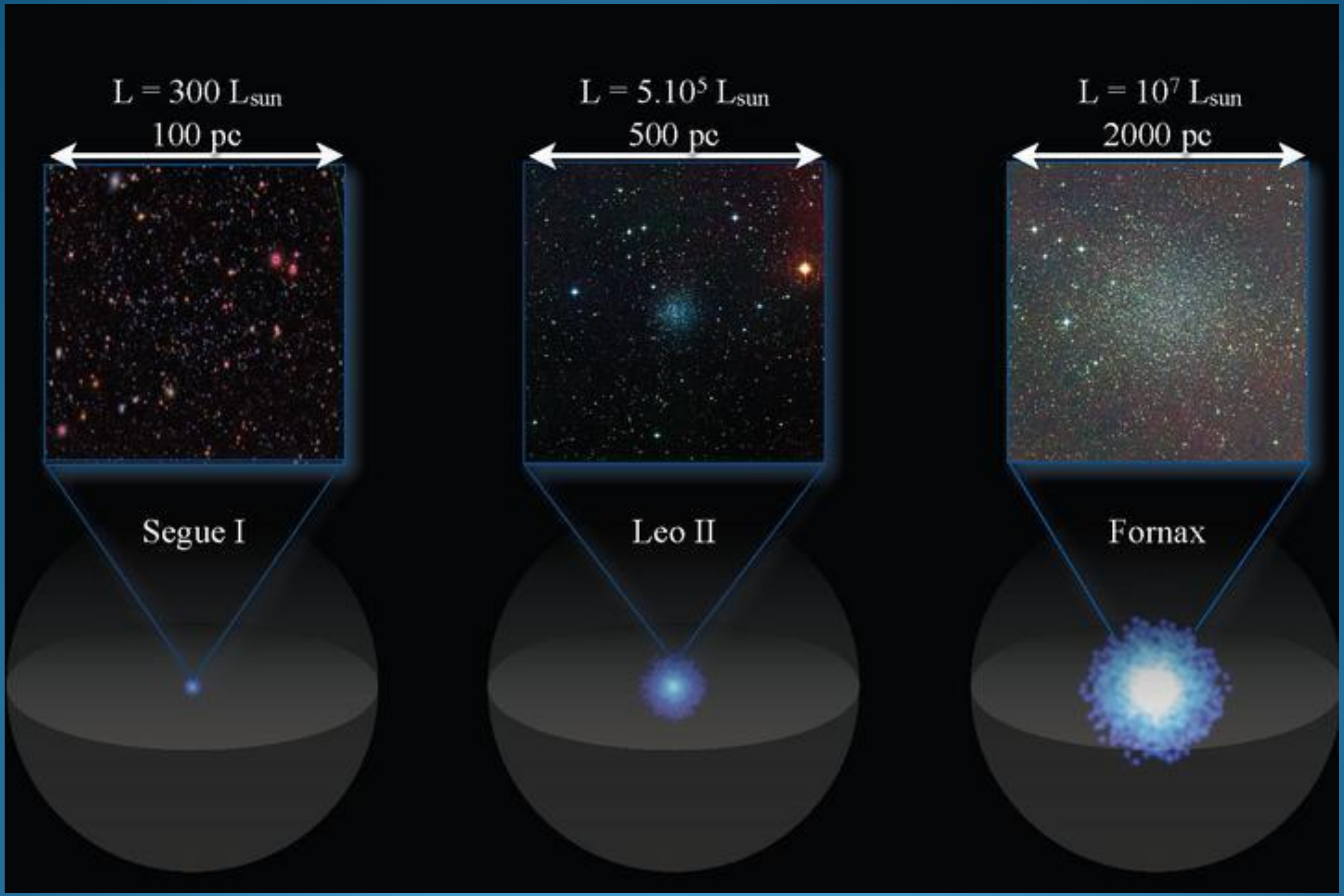
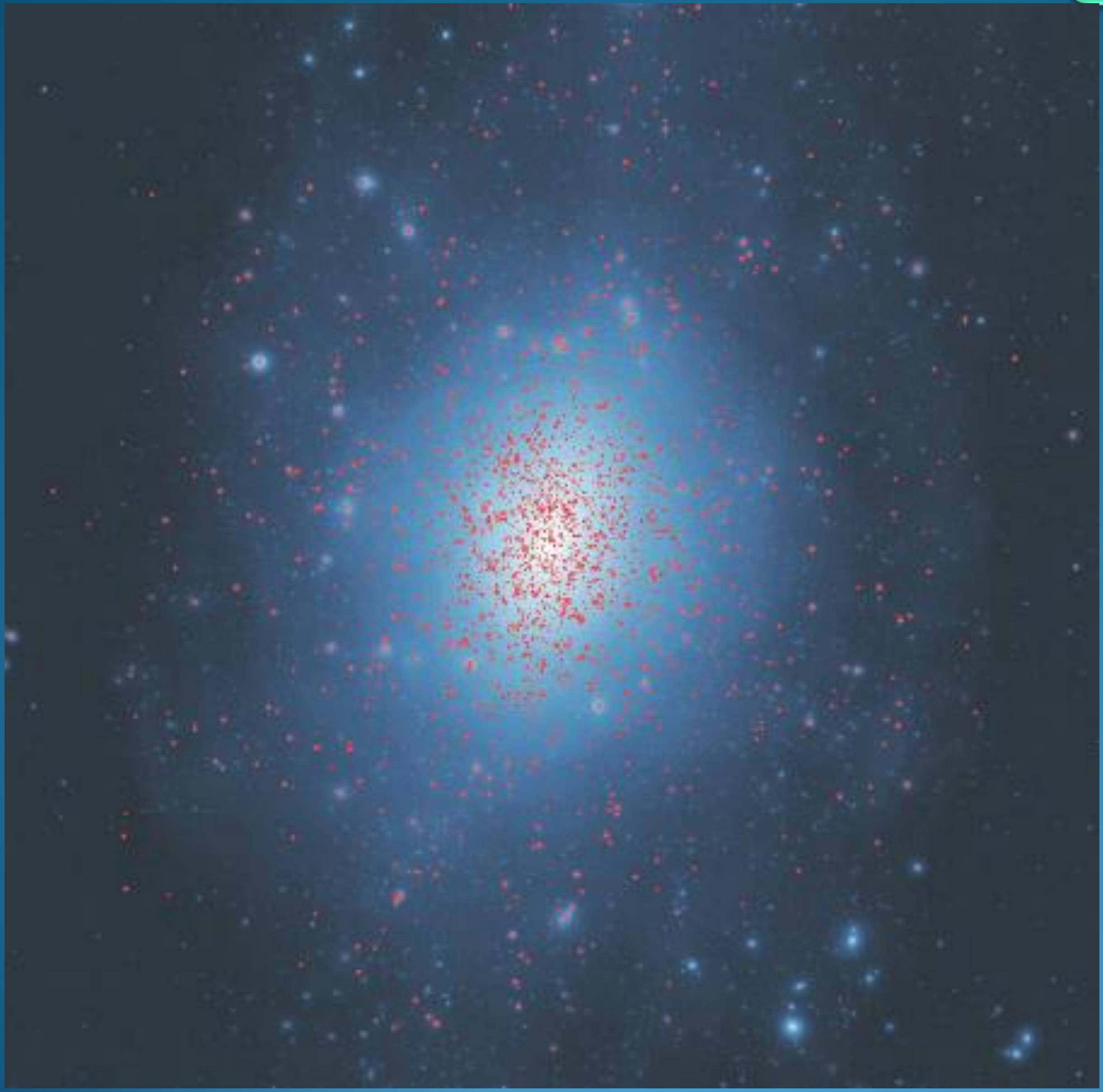


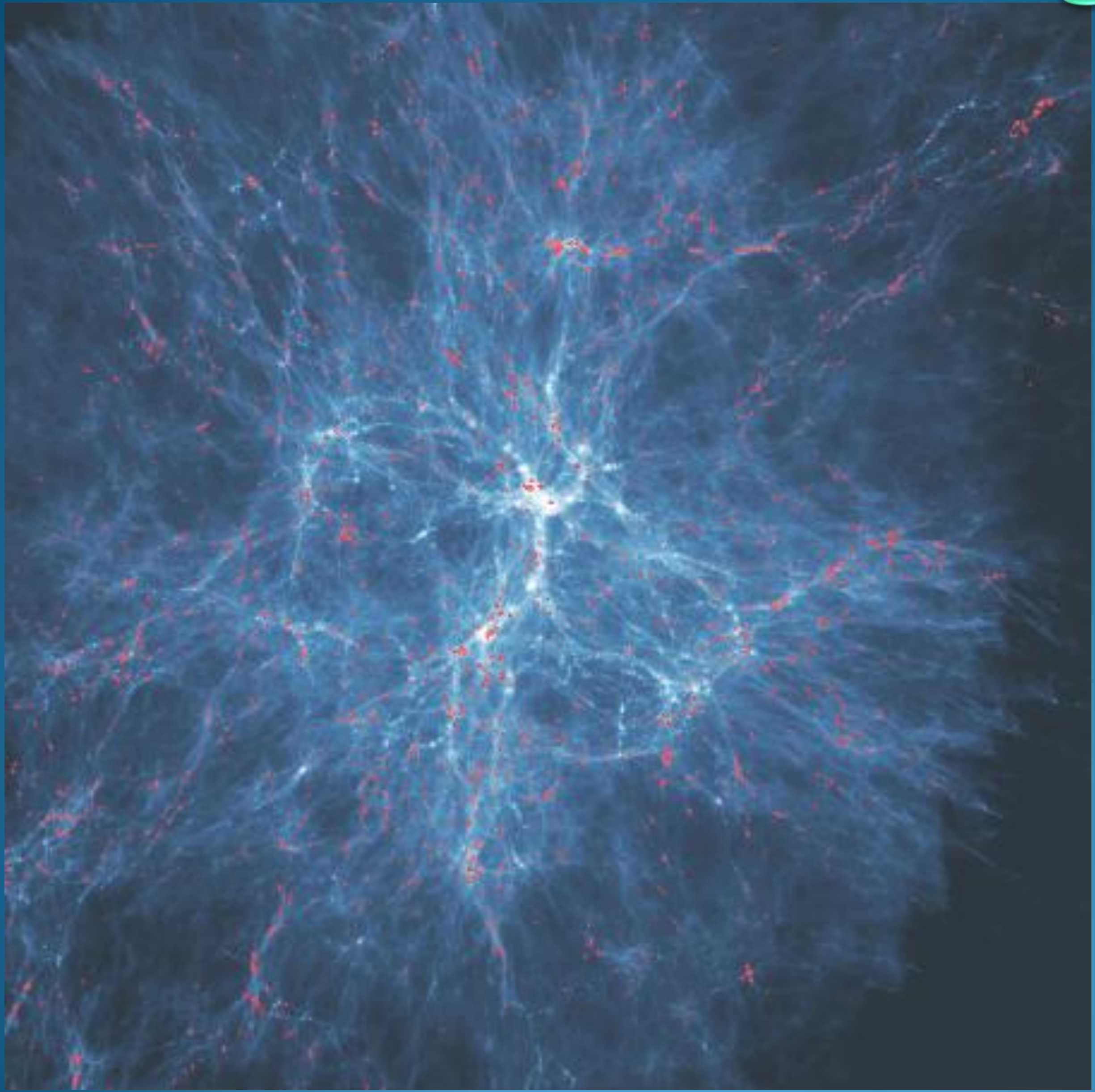
Figure: James Bullock

Galactic Archaeology: VL2



Madau et al. 2008

Galactic Archaeology: VL2

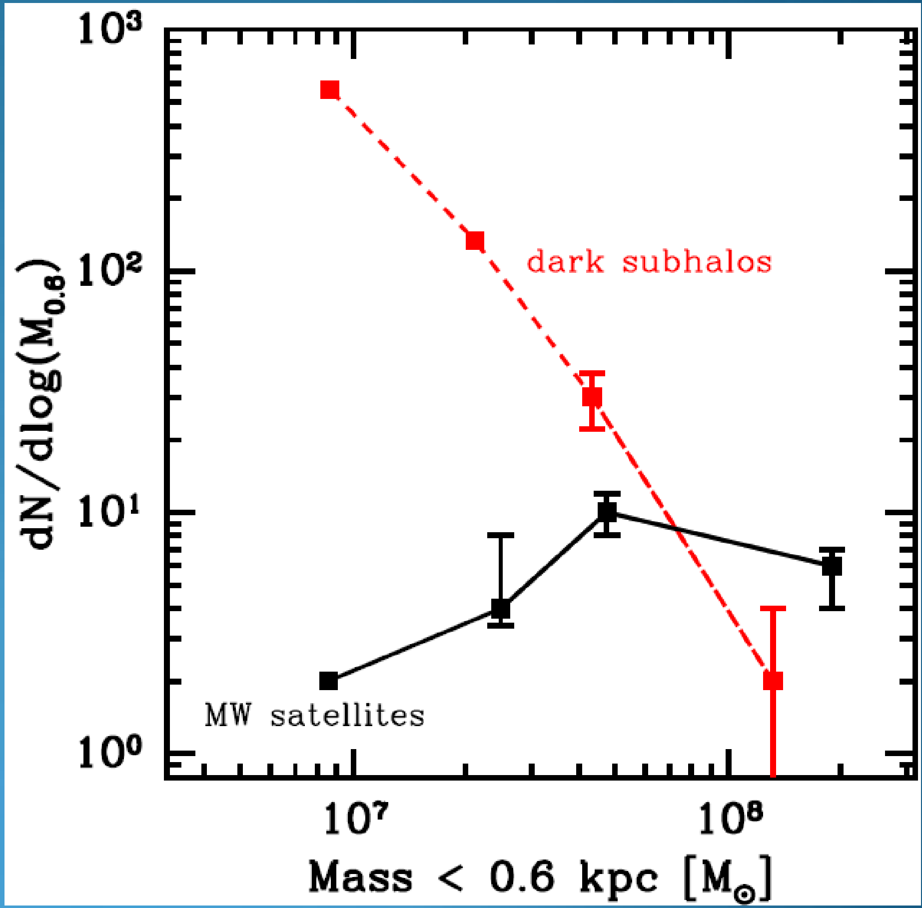


Madau et al. 2008

Why study dwarfs?

Two significant problems with ΛCDM on small scales:

1. Cusp vs core
2. Missing satellite problem



Strigari et al 2007

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Will not discuss these in detail now (feel free to ask me afterward). Just wanted to remind you all that ΛCDM may still need modification on the small scale!

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Knowing accurate masses useful for testing galaxy formation theories, which includes demonstrating the connectedness of all galactic scales!

Mass modeling of hot systems

Many gas-poor dwarf galaxies, ellipticals, and clusters have a significant, usually dominant hot component. They are pressure-supported, not rotation supported.

Consider a spherical, pressure-supported system whose stars are collisionless and are in equilibrium. Let us consider the Jeans Equation:

Unknown: Anisotropy

$$\beta \equiv 1 - \frac{\sigma_t^2}{\sigma_r^2}$$

We want mass

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

Free function

Assume known: 3D deprojected stellar density

Radial dispersion (depends on beta)

In the interest of time

I will skip the details of the dynamical analysis in this talk (feel free to ask afterward).

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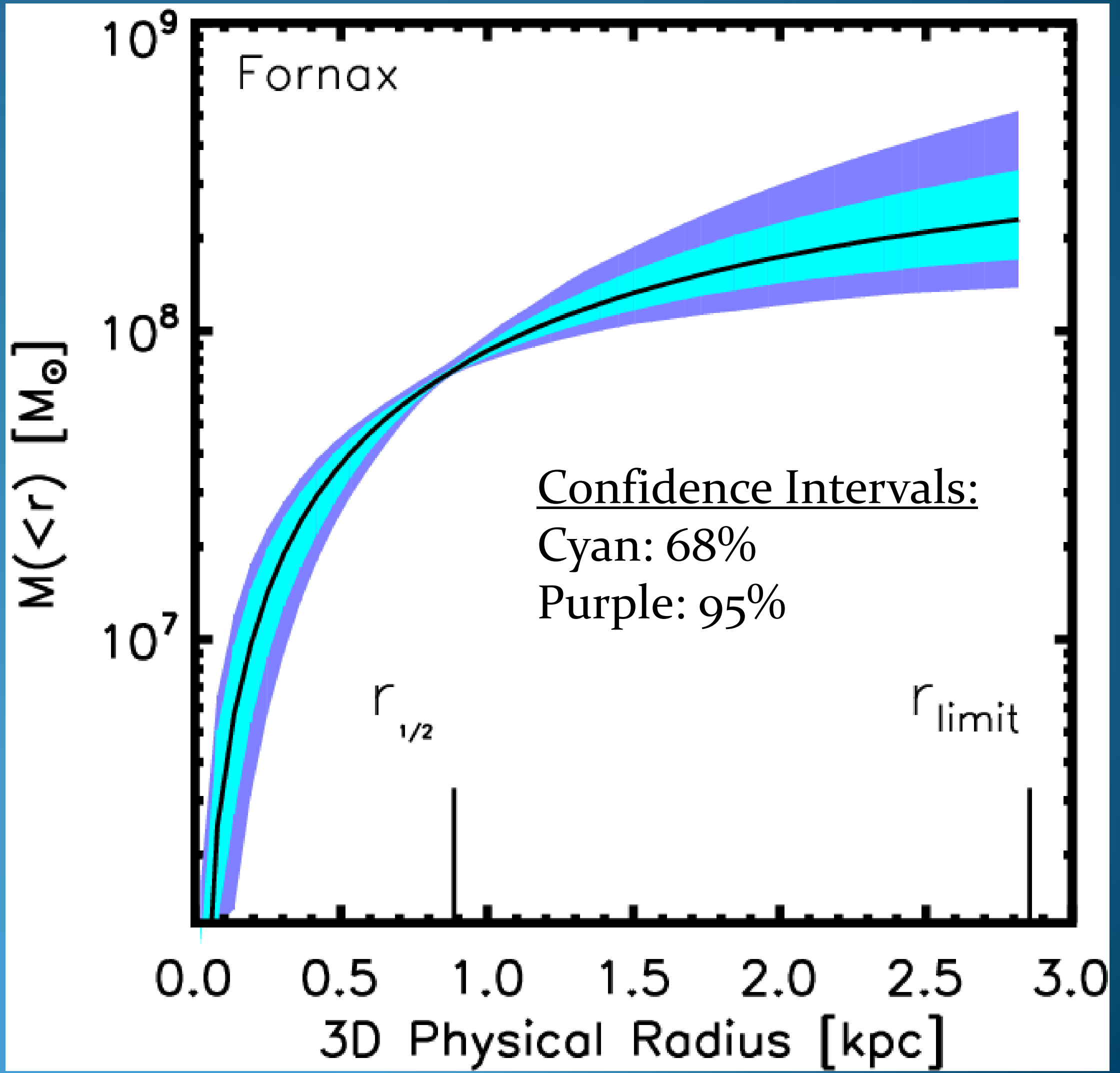
<u>Summary:</u>
MCMC algorithm is able to produce mass likelihoods from line-of-sight kinematics and photometry.



Joe Wolf et al.
arXiv: 0908.2995

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

Derived equation under several simplifications:

$$M_{1/2} = 3\,G^{-1}\,r_{1/2}\,\langle\sigma^2_{\rm los}\rangle$$

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$$M_{1/2} = 3\,G^{-1}\,r_{1/2}\,\langle\sigma_{los}^2\rangle$$

$$\frac{M_{1/2}}{M_\odot} \simeq 930\,\frac{R_{eff}}{pc}\,\frac{\langle\sigma_{los}^2\rangle}{km^2\,s^{-2}}$$

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

Wait a second…

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

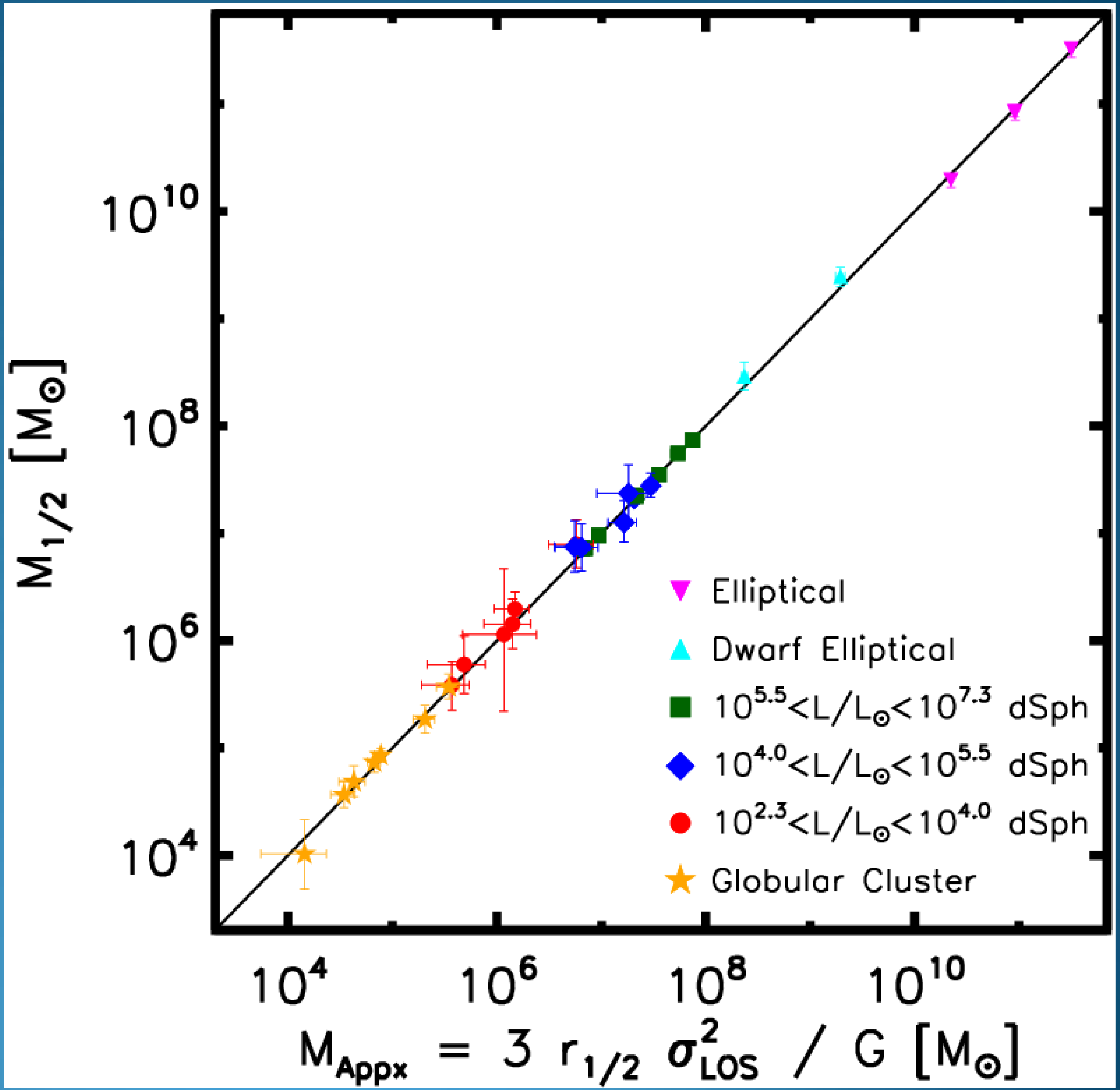
$$M_{1/2} = 3\,G^{-1}\,r_{1/2}\,\langle\sigma_{\mathrm{los}}^2\rangle$$

Nope! The SVT only gives you limits on the total mass of a system.

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

Really?

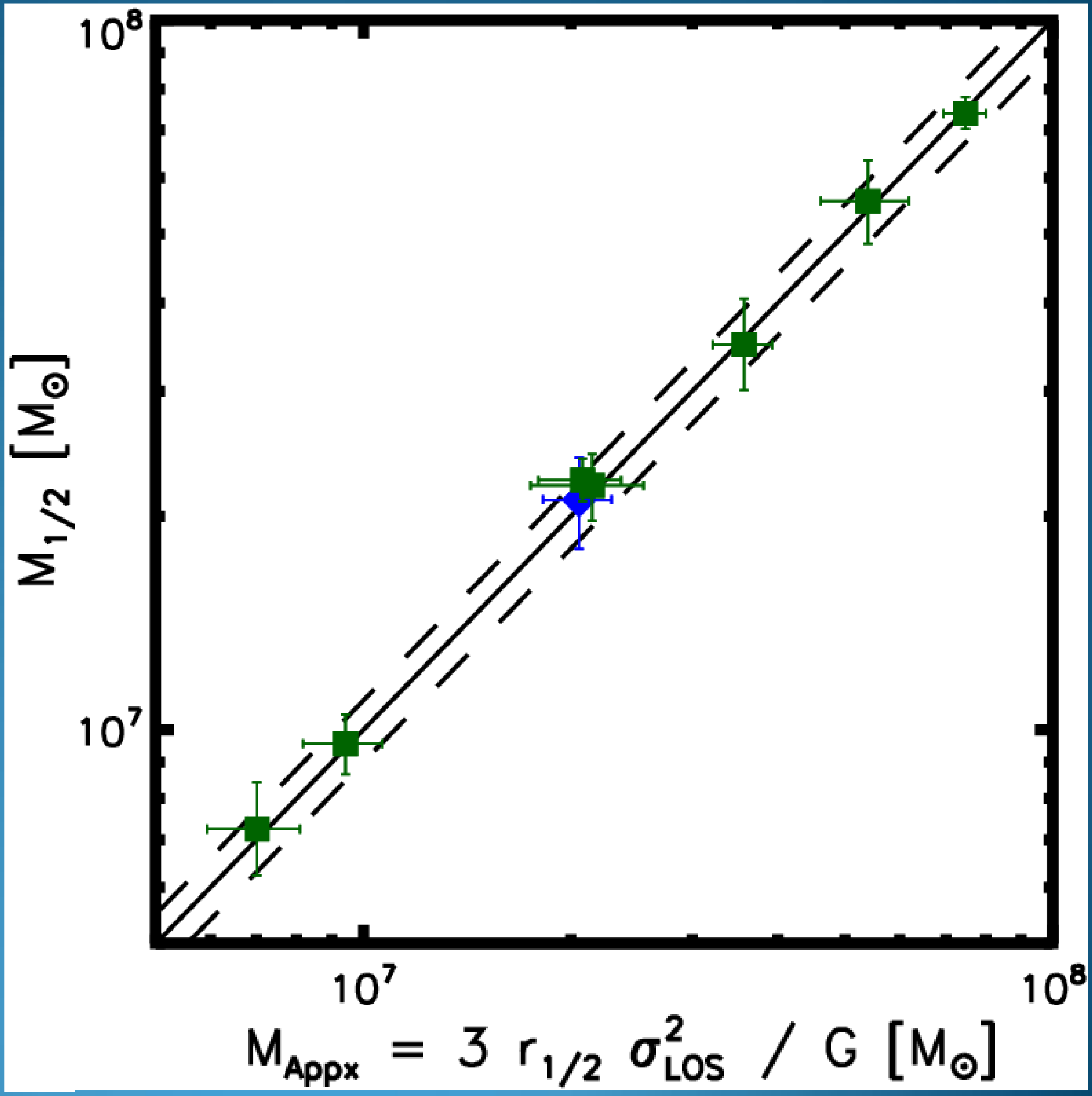
Boom!
Equation tested on systems spanning almost **eight** decades in luminosity after lifting simplifications.



Joe Wolf et al., 0908.2995

Boom!

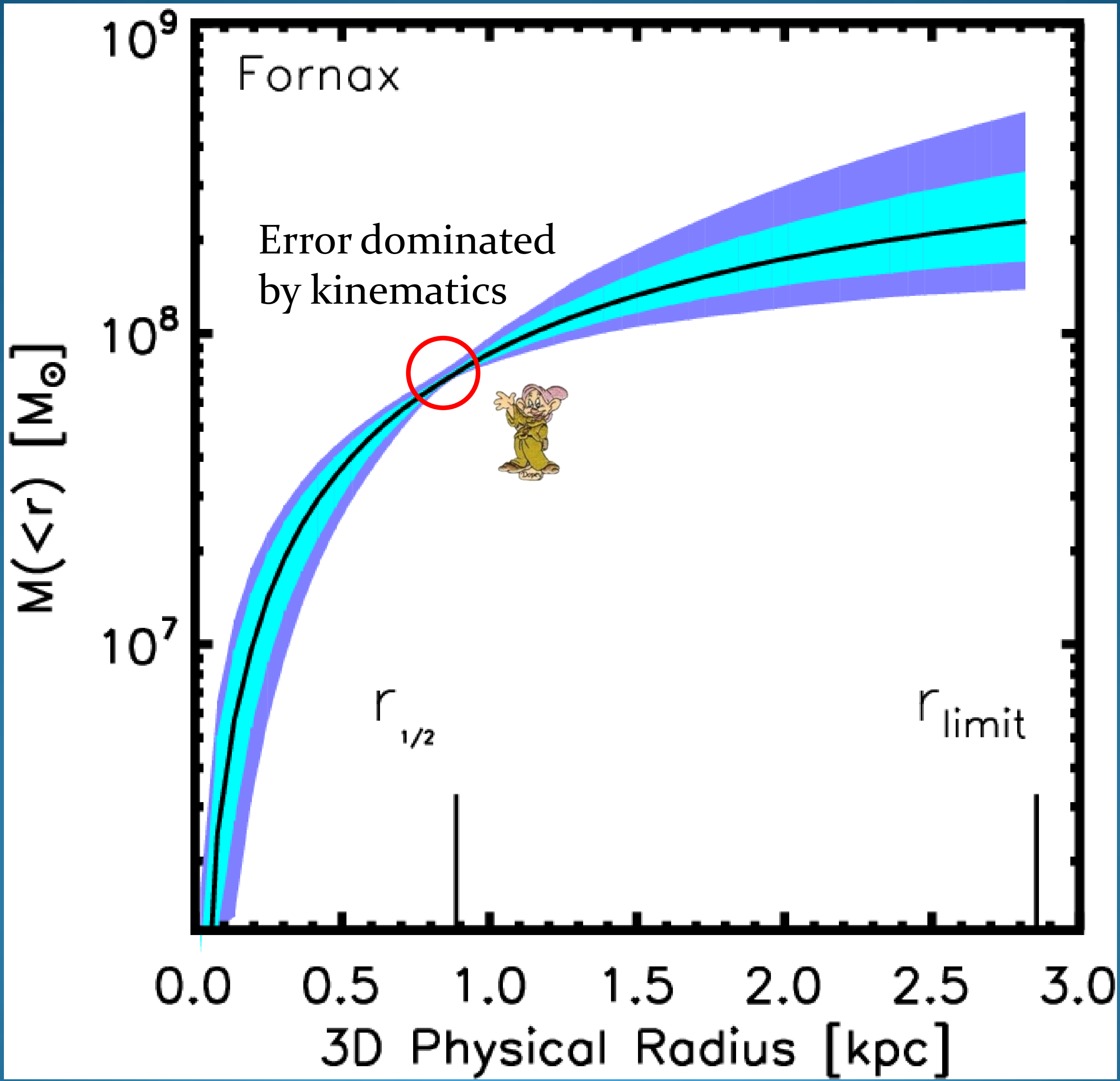
"Classical" MW dwarf spheroidals



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

Joe Wolf et al., 0908.2995

Mass Errors: Origins



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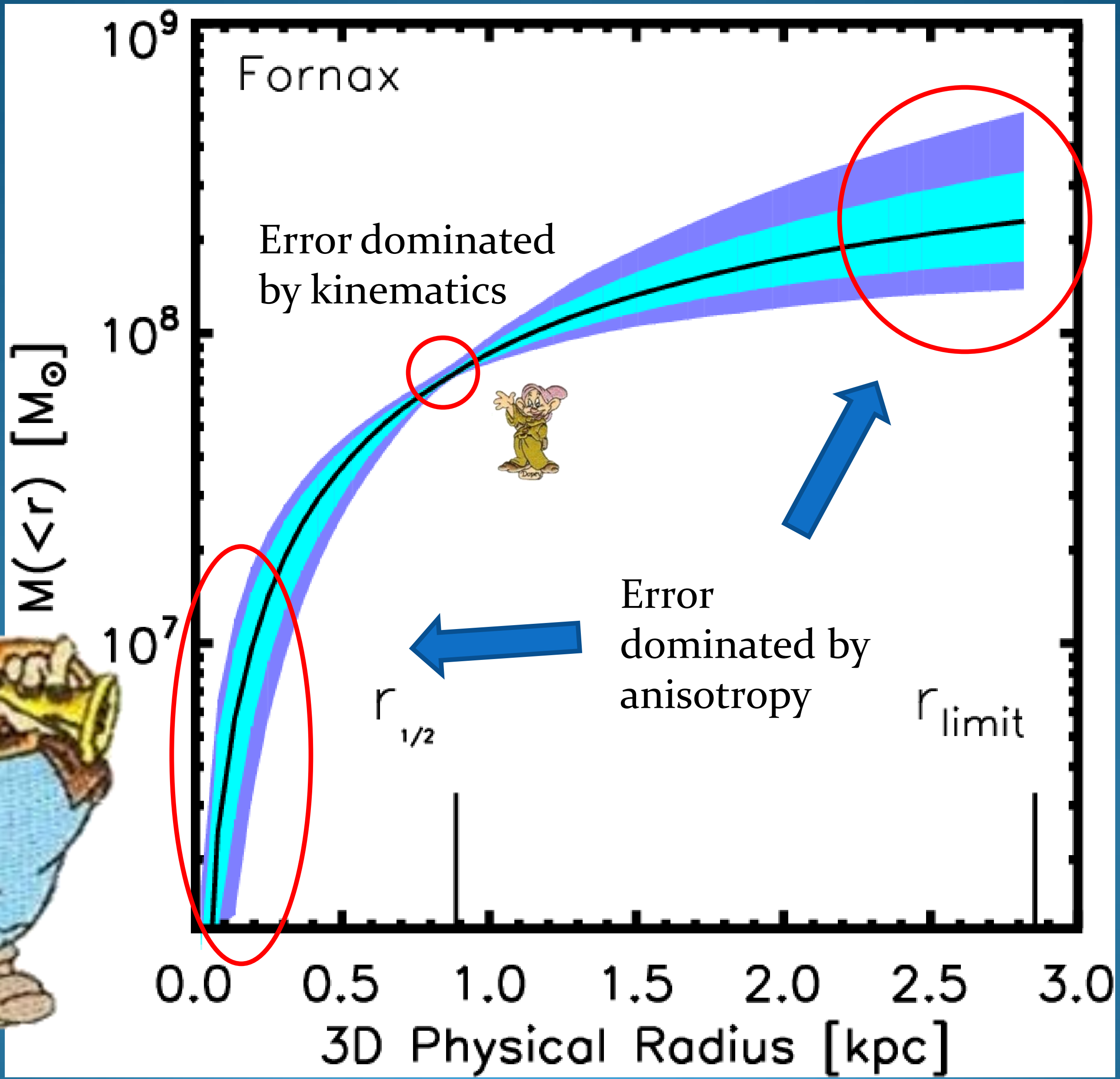
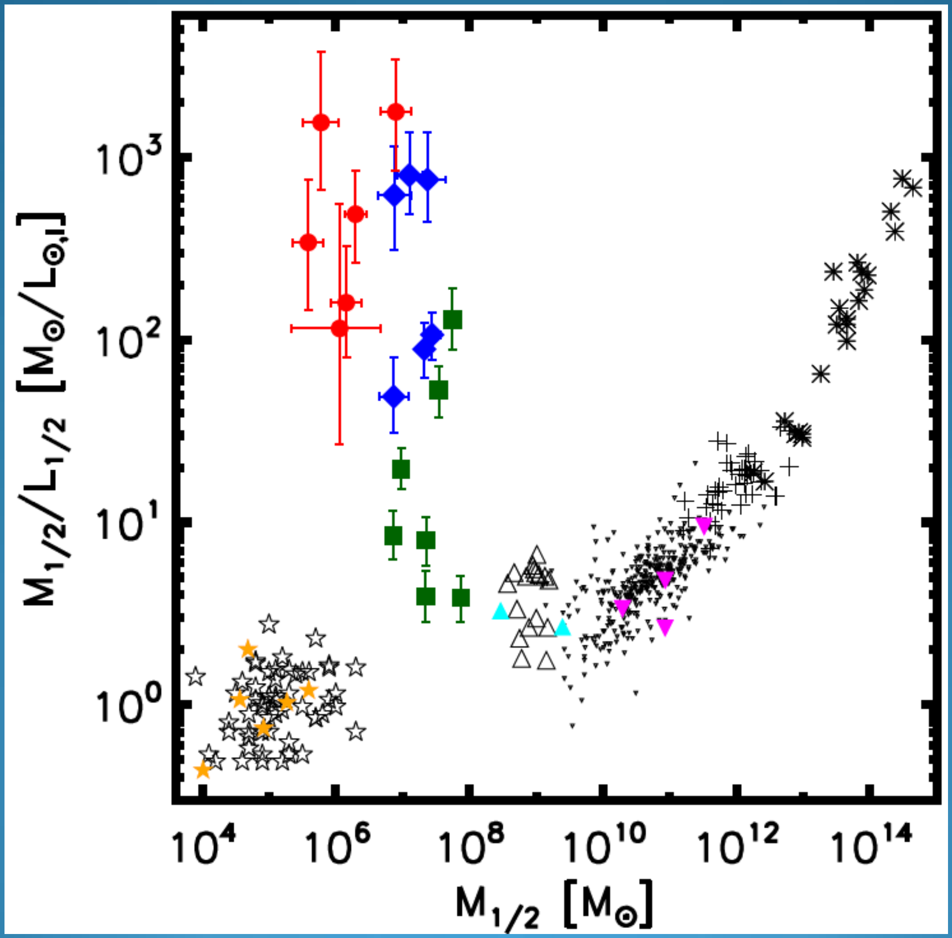


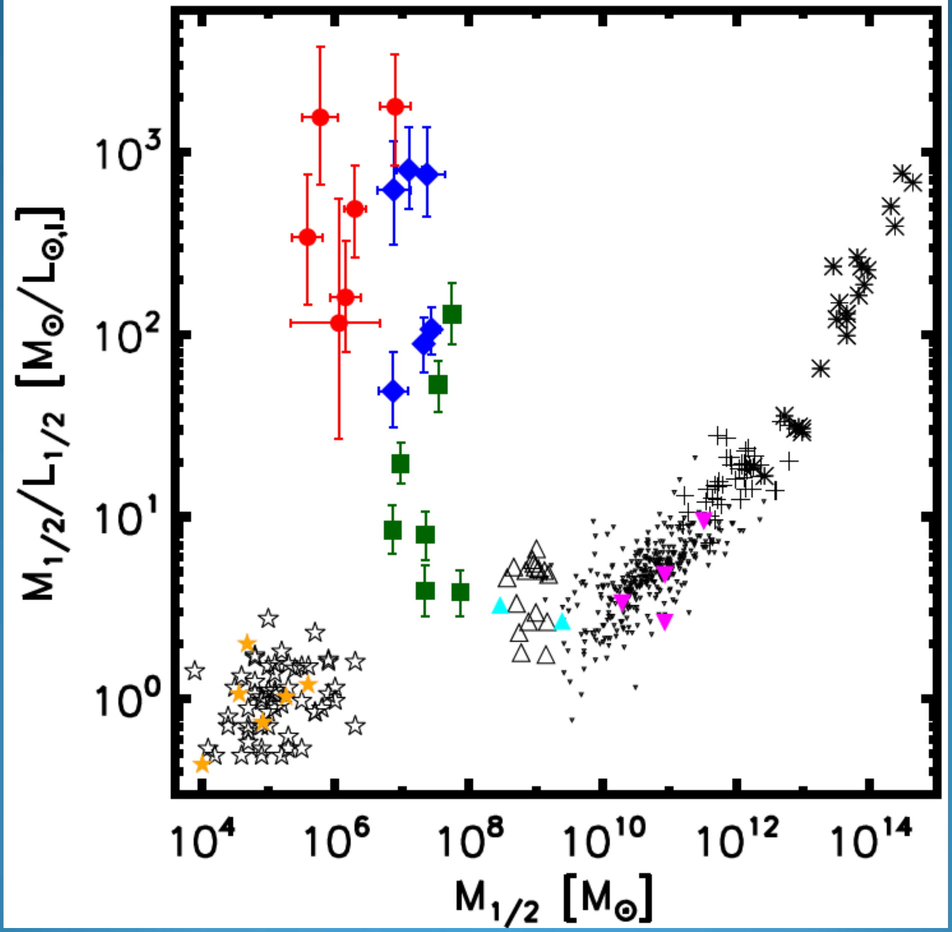
Applications: Global



Joe Wolf et al., 0908.2995

Applications: Global

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



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Applications: Global

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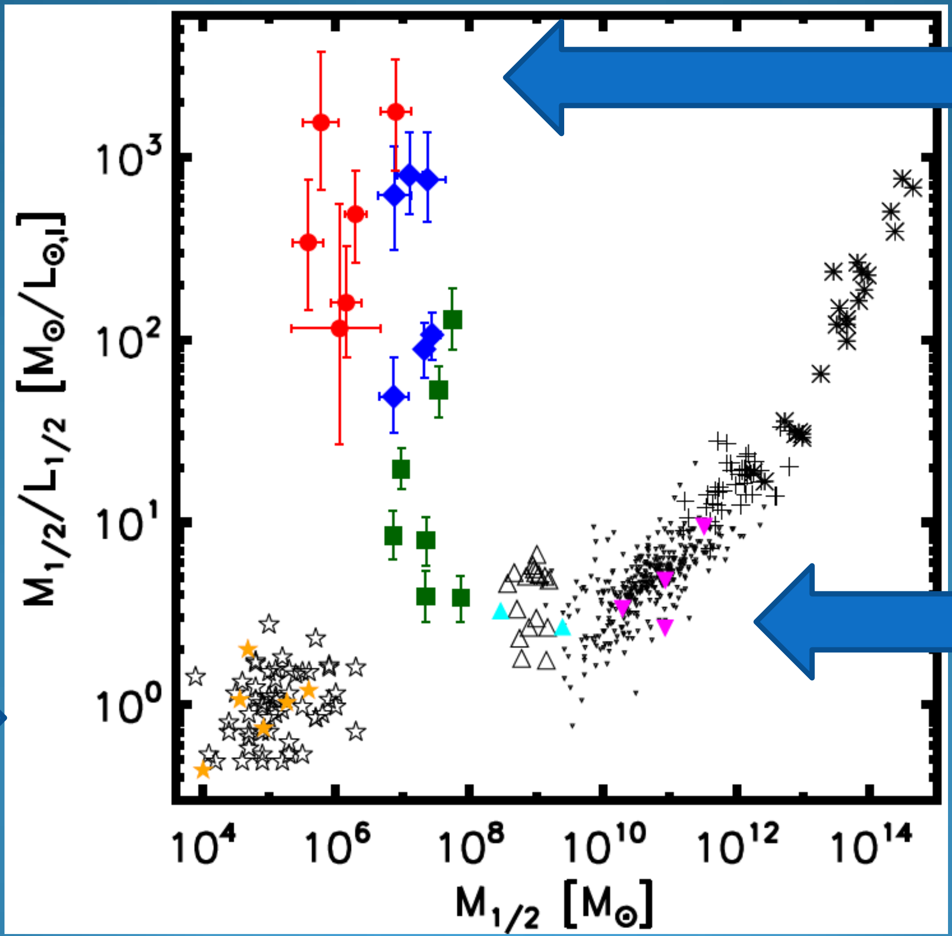
Ultrafaint dSphs: most DM dominated systems known!

Globulars: Offset from L* by factor of three

(Hmm…)

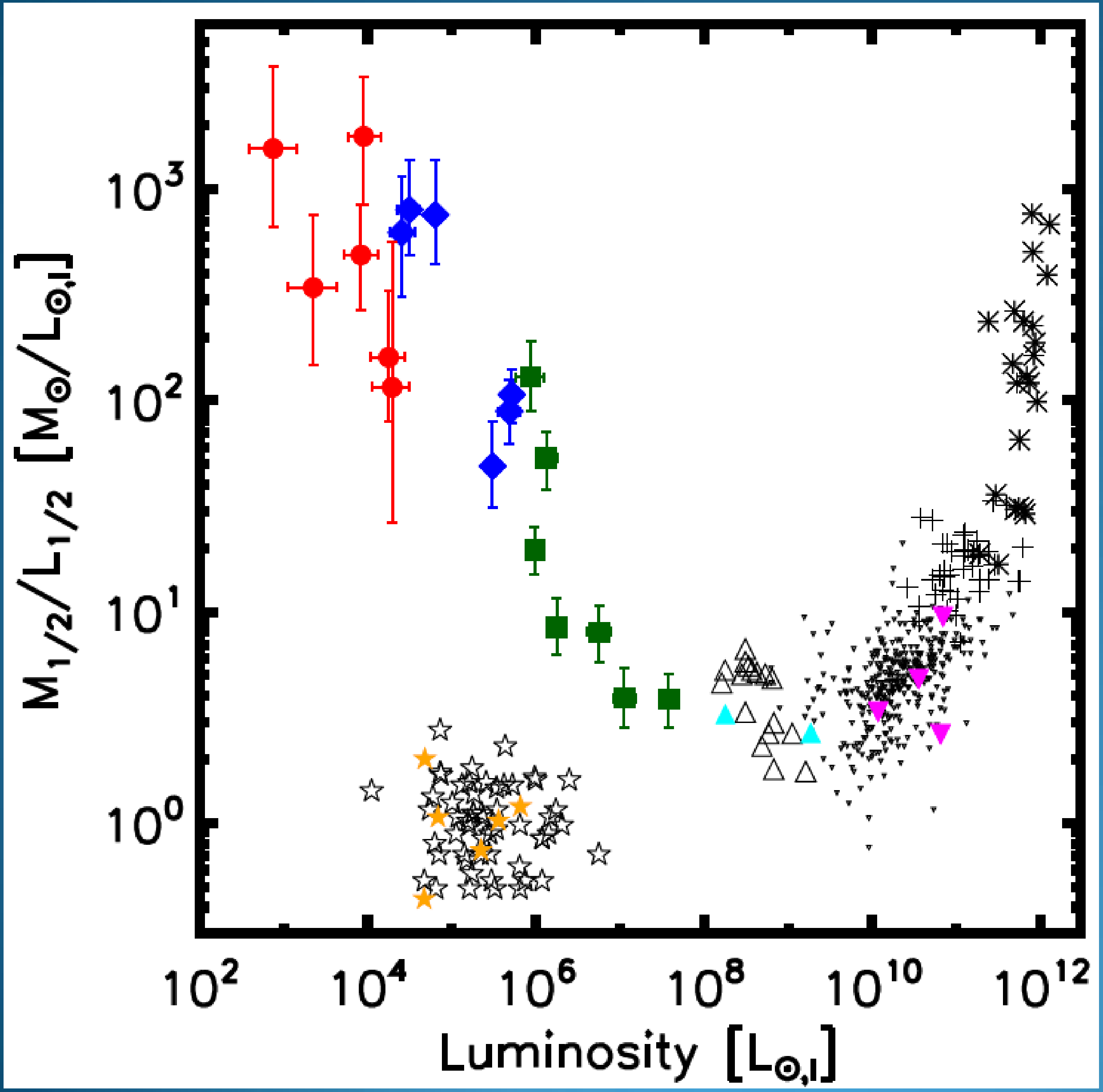


Inefficient at galaxy formation

L_*: Efficient at galaxy formation

Joe Wolf et al., 0908.2995

Applications: Global



Last plot:
Mass floor

This plot:
Luminosity ceiling

Joe Wolf et al., 0908.2995

Connectedfulivenessly

The small and large are more connected that one may previously have thought.

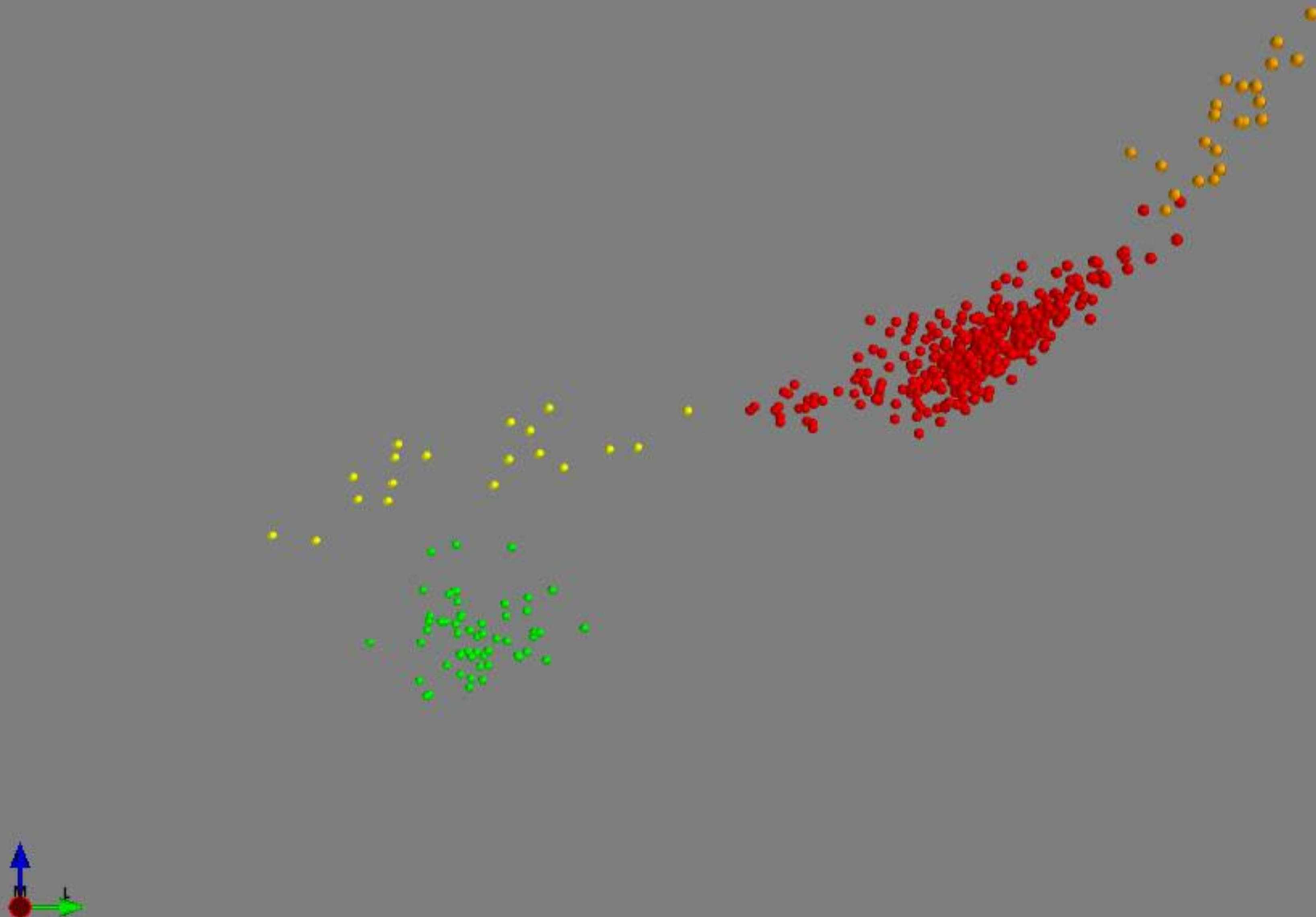
Looking at the FP in a new way

Fundamental Plane: Independent Observables

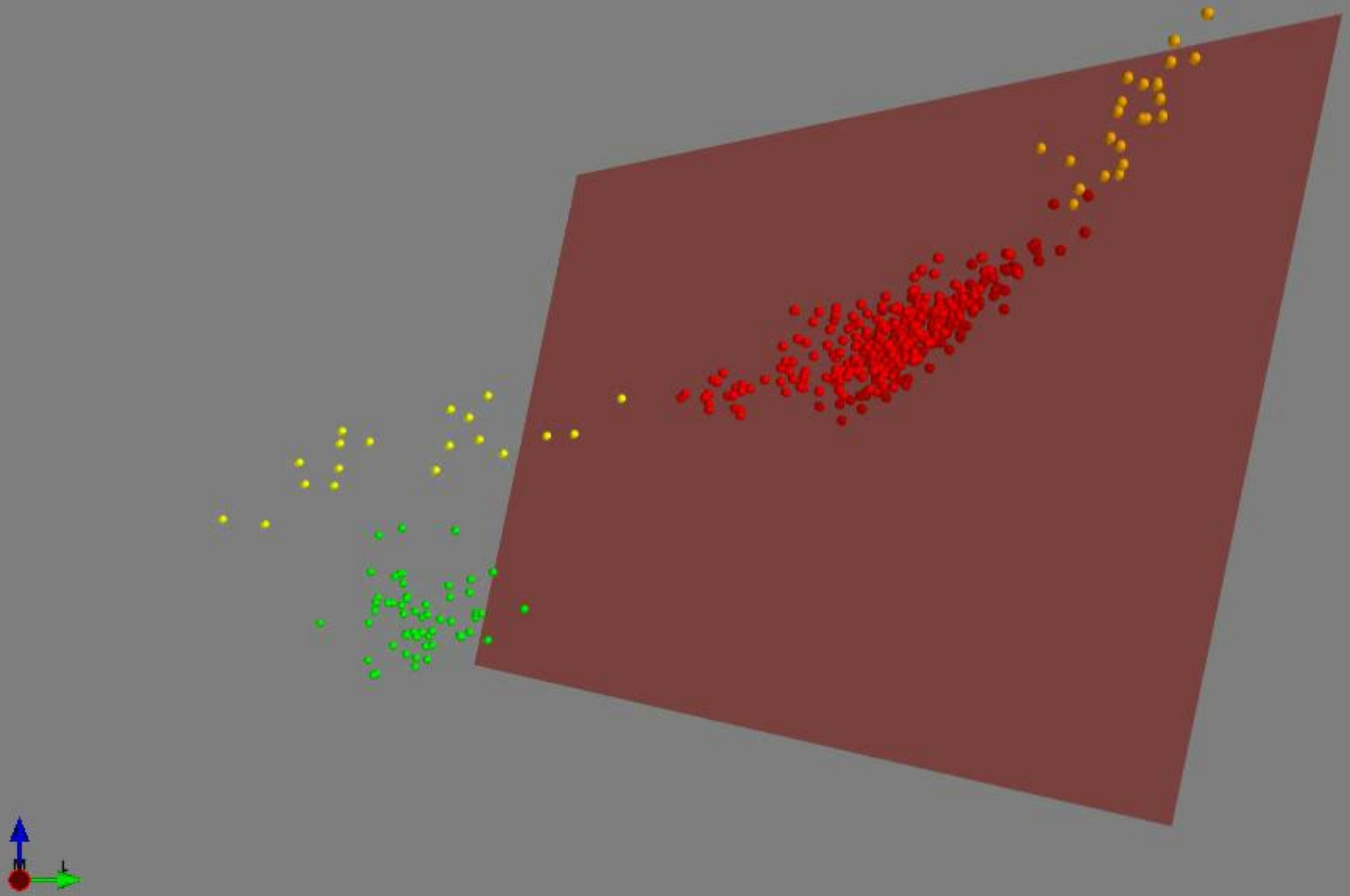
MLR: Intrinsic Properties

Fundamental Plane: Independent Observables		MLR: Intrinsic Properties
σ	$M_{1/2} = 3\,G^{-1}\,r_{1/2}\,\langle\sigma_{los}^2\rangle$	$M_{1/2}$
R_{eff}	$r_{1/2} \simeq 4/3\,R_{eff}$	$r_{1/2}$
I_{eff}	$L_{1/2} = \frac{1}{2}\,I_{eff}\,\pi\,R_{eff}^2$	$L_{1/2}$

Erik Tollerud, JW, et al. in prep.



Erik Tollerud
UC Irvine


M
L

Fundamental Curve

Despite different feedback mechanisms, all systems sitting deeply embedded in DM halos lie on this one tube, which spans 10 orders of magnitude in luminosity!

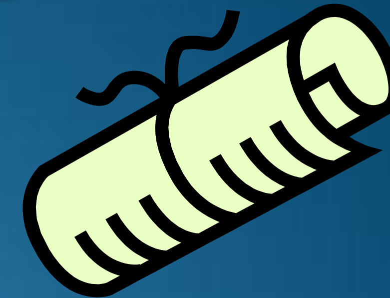
Globular clusters, which do not sit within DM halos, are offset from this tube.

Erik Tollerud, JW, et al. in prep.

Take-Home Messages

$$M_{1/2} = 3\,G^{-1}\,r_{1/2}\,\langle\sigma^2_{\rm los}\rangle$$

$$\frac{M_{1/2}}{M_\odot} \simeq 930\,\frac{R_{\rm eff}}{\rm pc}\,\frac{\langle\sigma^2_{\rm los}\rangle}{\rm km^2\,s^{-2}}$$



- Knowing $M_{1/2}$ accurately without knowledge of anisotropy gives new constraints for galaxy formation theories to match.

- Future simulations must be able to reproduce the observed trends between $M_{1/2}$ and L for all pressure-supported systems, from dwarf spheroidals ($L\sim10^2$) to galaxy clusters ($L\sim10^{12}$).

- Understanding the small scale is important for understanding the large scale…and vice versa! *Joe Wolf et al. 2010, MNRAS*