Modeling mass independent of anisotropy

A tool to test galaxy formation theories

arXiv: 0908.2995

Joe Wolf
(UC Irvine)

September, 2009

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(Please feel free to interrupt)

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Team Irvine:

Greg Martinez

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Greg Martinez *James Bullock* *Manoj Kaplinghat* *Erik Tollerud*



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OCIW: Josh Simon Yale: Marla Geha Ricardo Munoz

Itemized Outline

This list will appear several times. (Good transition point to ask questions.)

- Motivation
- Describe our mass modeling technique
- Derive a new mass estimator that is independent of anisotropy
- Apply the new mass estimator
- New spectroscopic observations of M31 dSphs
- The future: SIM & proper motions

Motivation

- I want to understand how galaxies form.

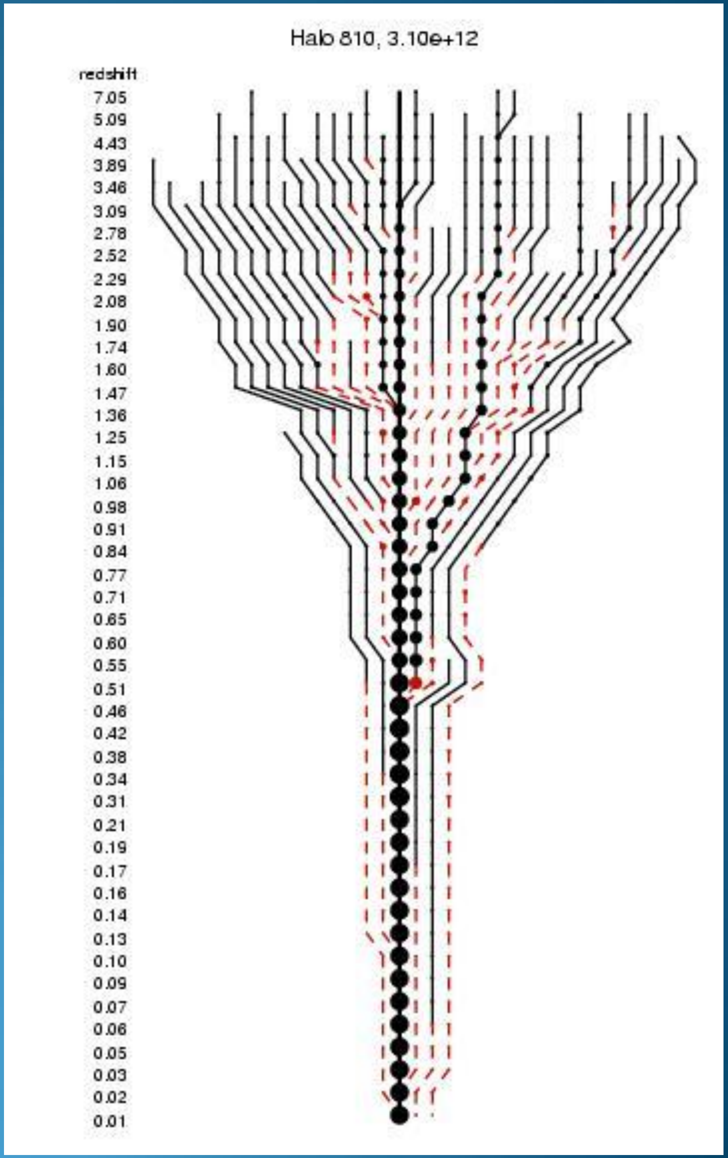
- Need to create a large scale simulation that implements hydrodynamics originating from first principles.

- Really hard to implement. Important feedback operates on many different scales. Galaxy properties sensitive to small changes.
  E.g. AGN: pc scales, Reionization: Mpc scales.

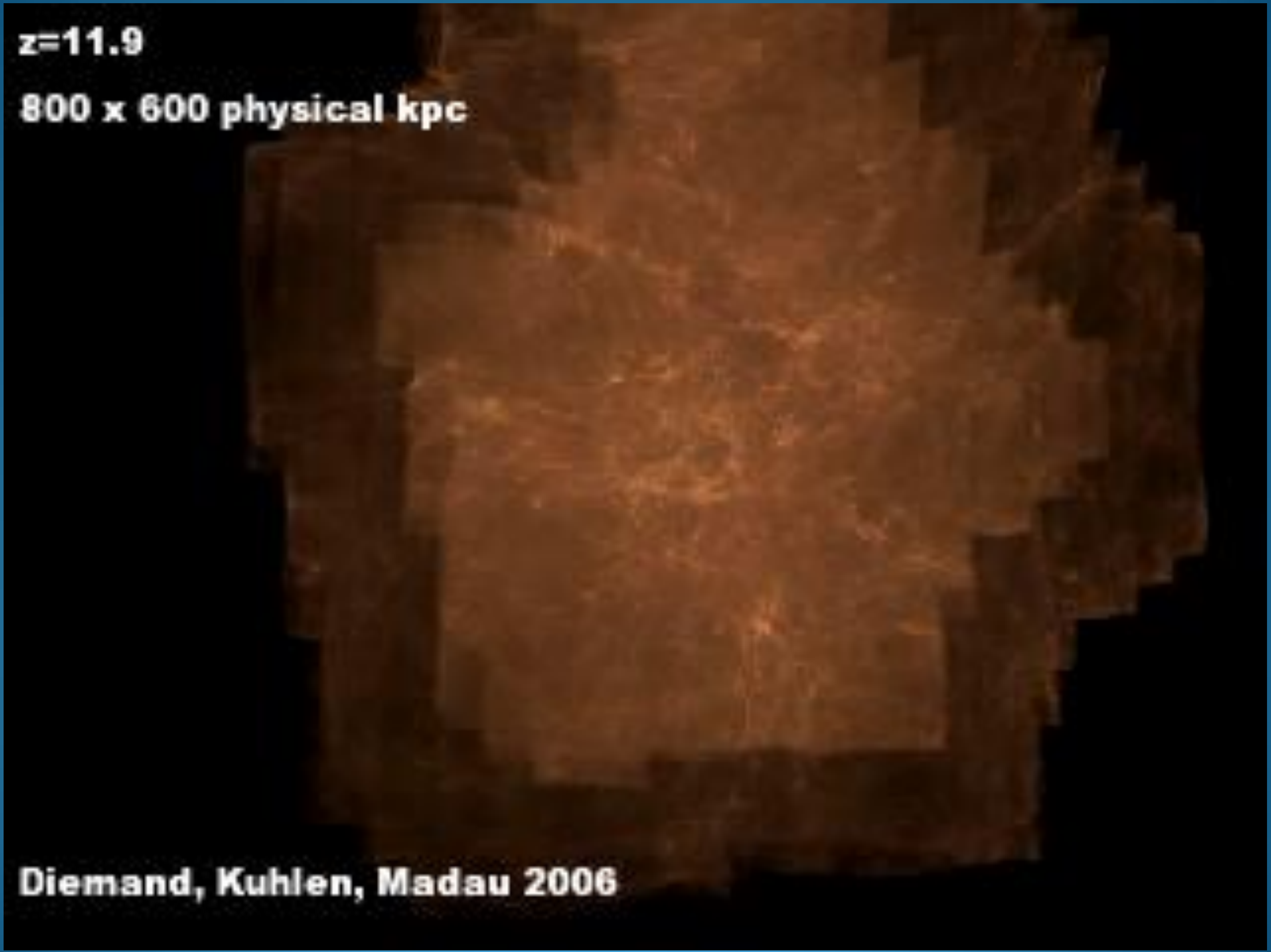
Basic Picture

Galaxies sit deeply embedded inside of DM halos (White & Rees 78), which formed hierarchically: small halos merge to form large halos.

Kyle Stewart et al. 2008



Basic Picture: Via Lactea



Simulation + observation

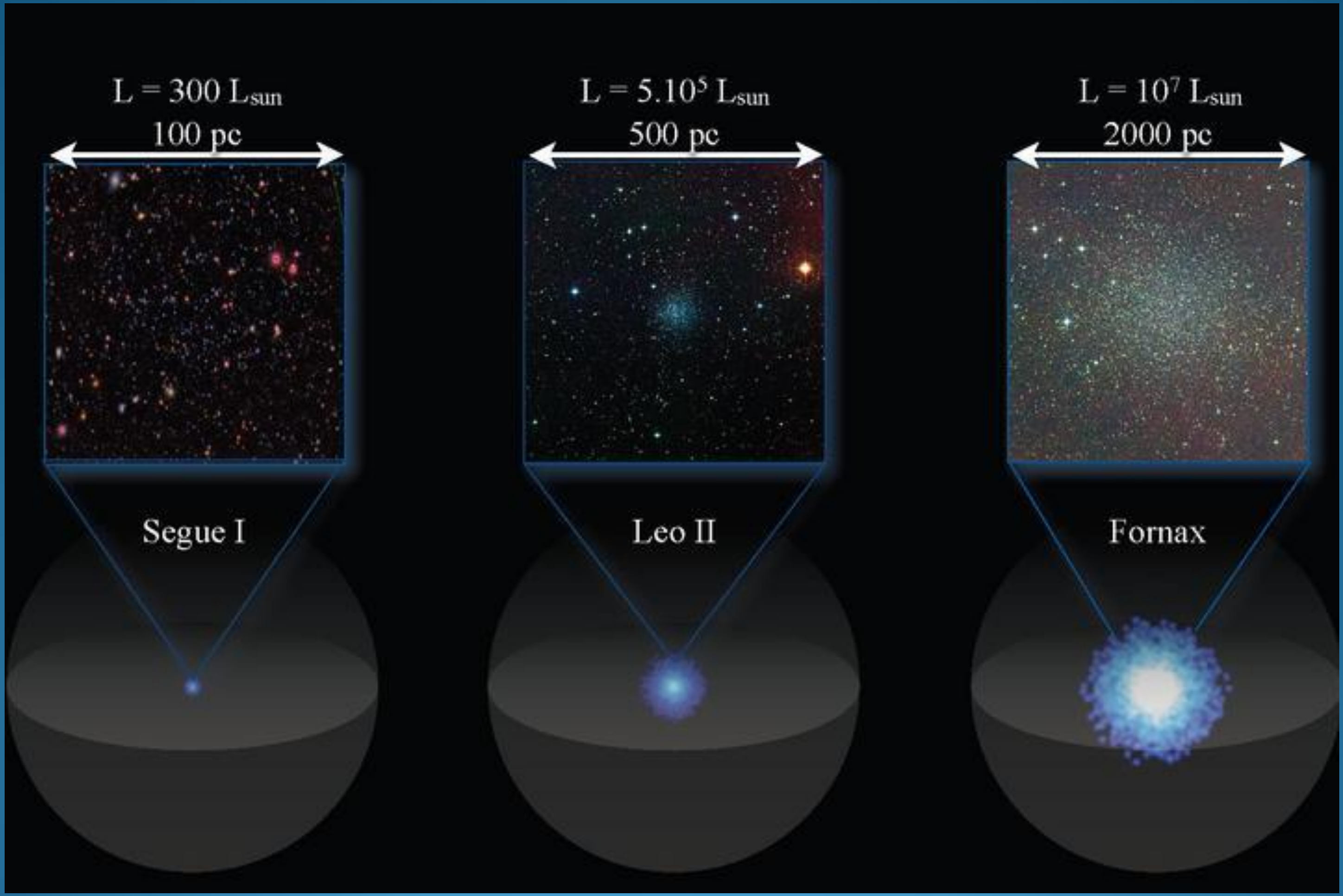


Figure: James Bullock

Basic Picture

- The observed sizes, shapes, dispersions, and metallicities of today’s MW dwarf galaxies are most likely similar to the time of infall (maybe).

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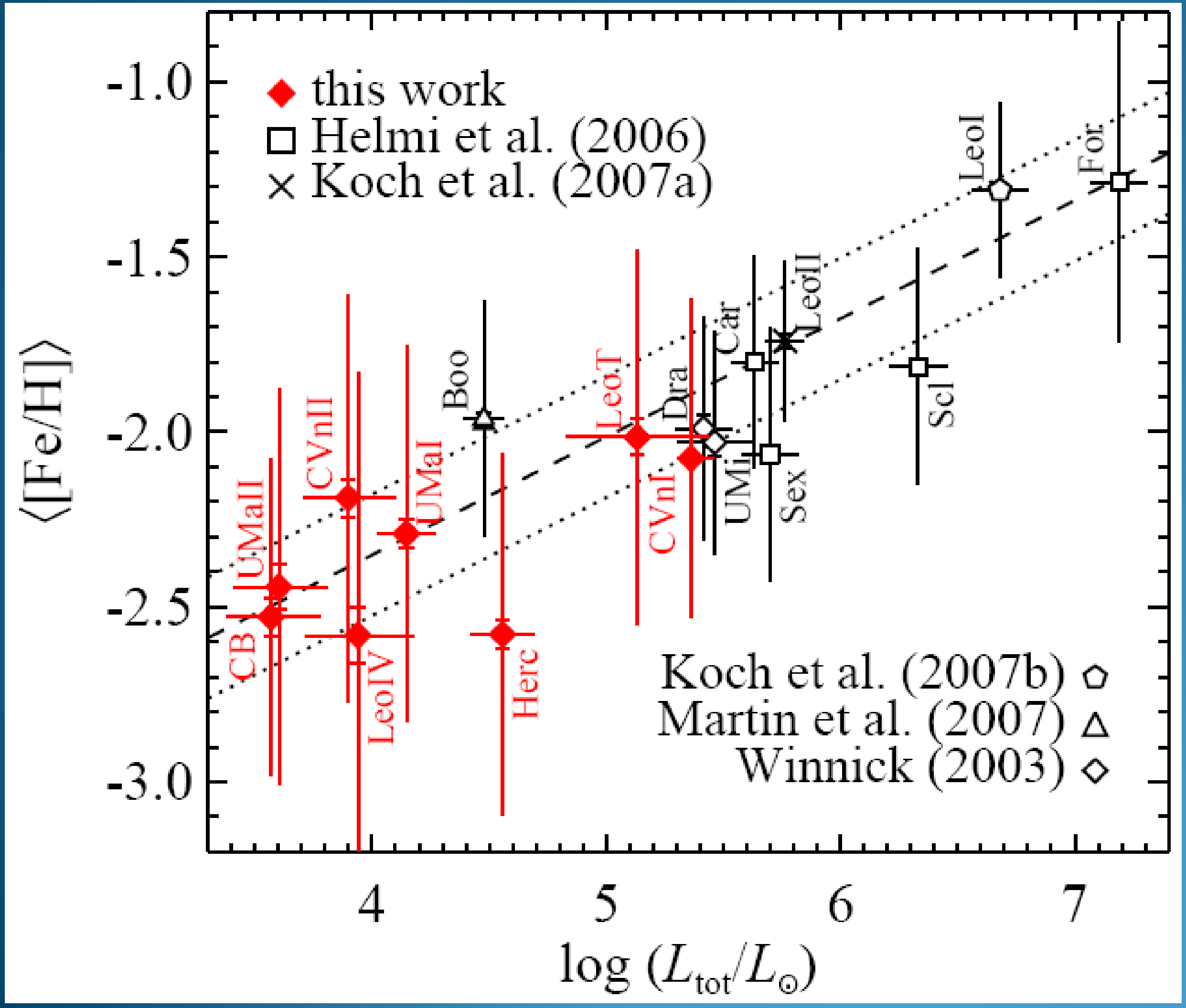
- Some hints of the relationship between today's dwarfs and the buildup of the MW stellar halo

Galactic Archaeology

Today's population: Survivors + first infall



Evan Kirby et al. 2008

Galactic Archaeology

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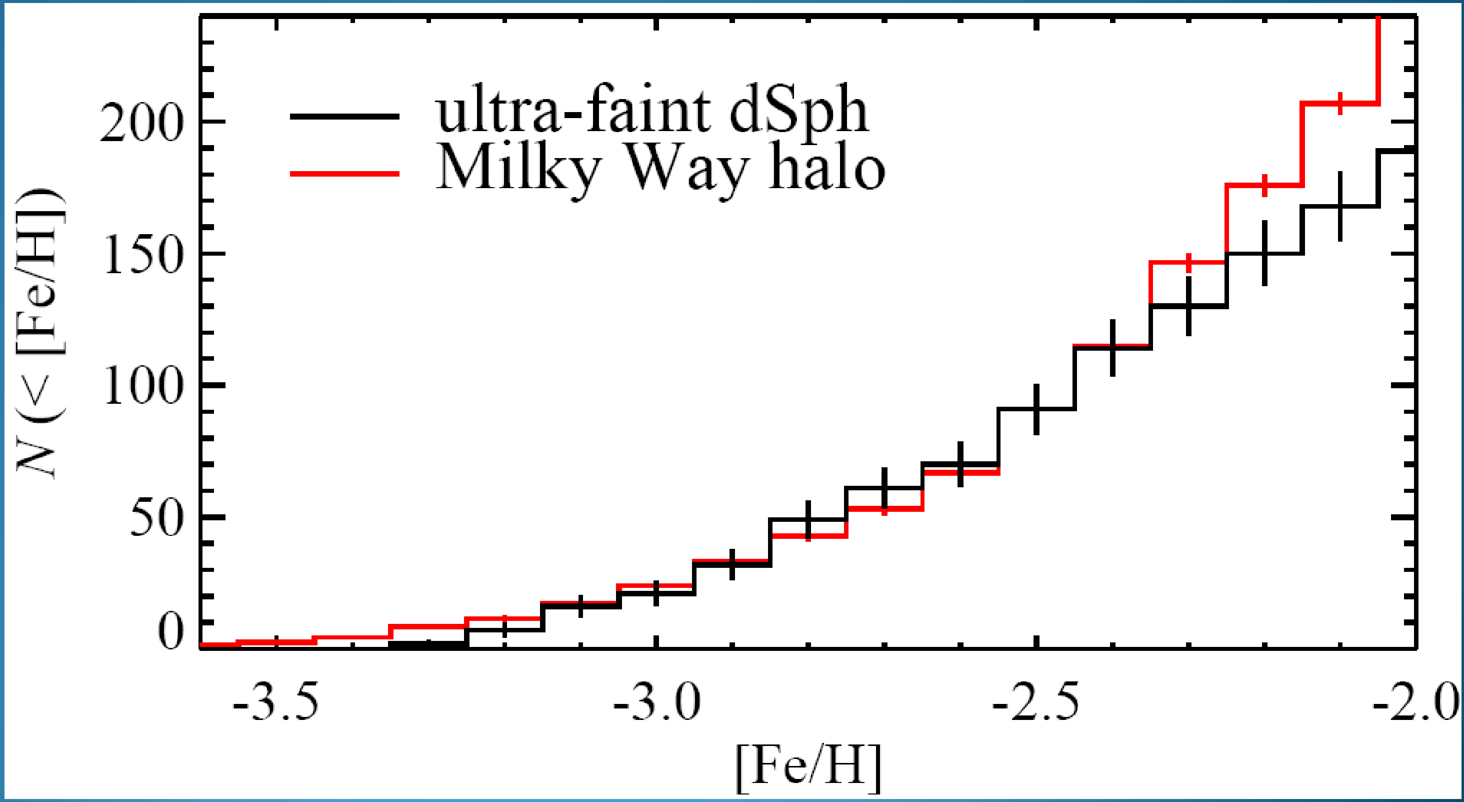
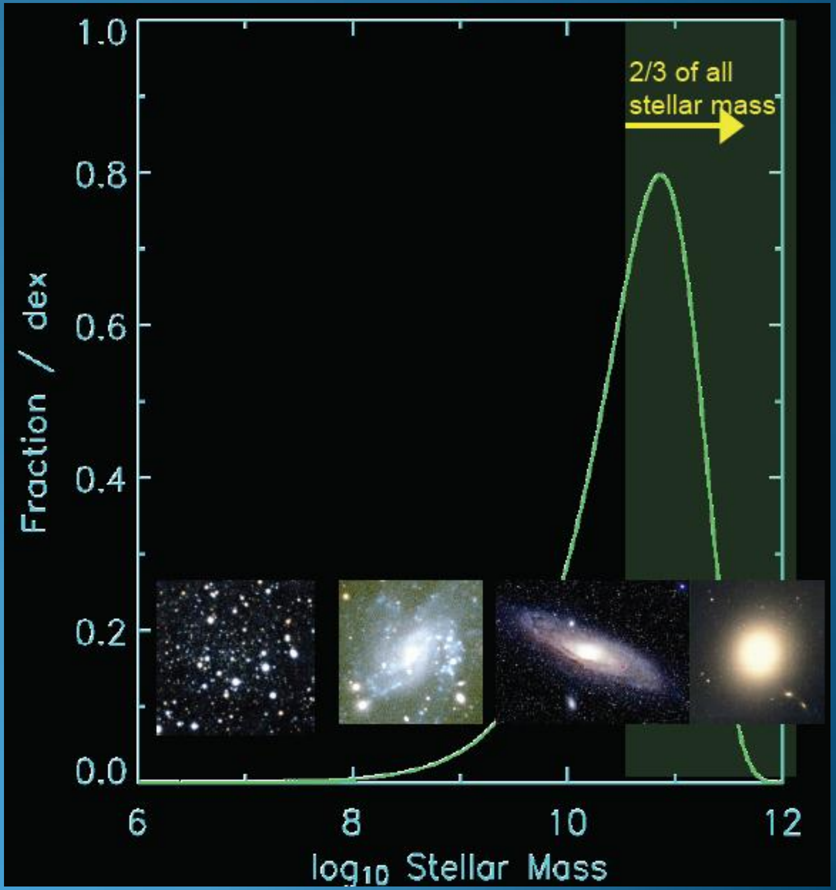


Evan Kirby et al. 2008

Basic Picture

- But I'm not convinced.
- As Hans-Walter likes to point out:



Bell et al. 2003

Interesting conversations

- There conversations are interesting, but I still have looming questions (which I won't discuss here).

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- Lesson: we don't have a consensus on the nature of dwarf galaxies. Not good…these are the simplest objects and we need to understand them first.

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- There conversations are interesting, but I still have looming questions (which I won't discuss here).
- Lesson: we don't have a consensus on the nature of dwarf galaxies. Not good…these are the simplest objects and we need to understand them first.
- Scarier: While LCDM works well at reproducing the large-scale structure of the universe, it doesn't do so well on small scales…or maybe it does? Depends on feedback prescriptions. 😐

More issues

- LCDM simulations generally agree (unlike hydrodynamic simulations).
  Still, two significant problems exist:

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   1. Overabundance of substructure→"Missing Satellites problem" (MSP).

  2. Disagreements between inner density shape:
  LCDM produce cusps.
  LSBG rotation curves prefer cores.

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  2. Disagreements between inner density shape:
  LCDM produce cusps.
  LSBG rotation curves prefer cores.

- WDM a possible solution. *Need accurate mass estimates to attempt to solve both problems.*

Looking at MSP w/o masses

- Foreground junk in SDSS turns out to remind us how little we actually know.
- Many over-densities turn out to be bound, DM-dominated objects.

The Local Group

The dwarf galaxy pond before SDSS:

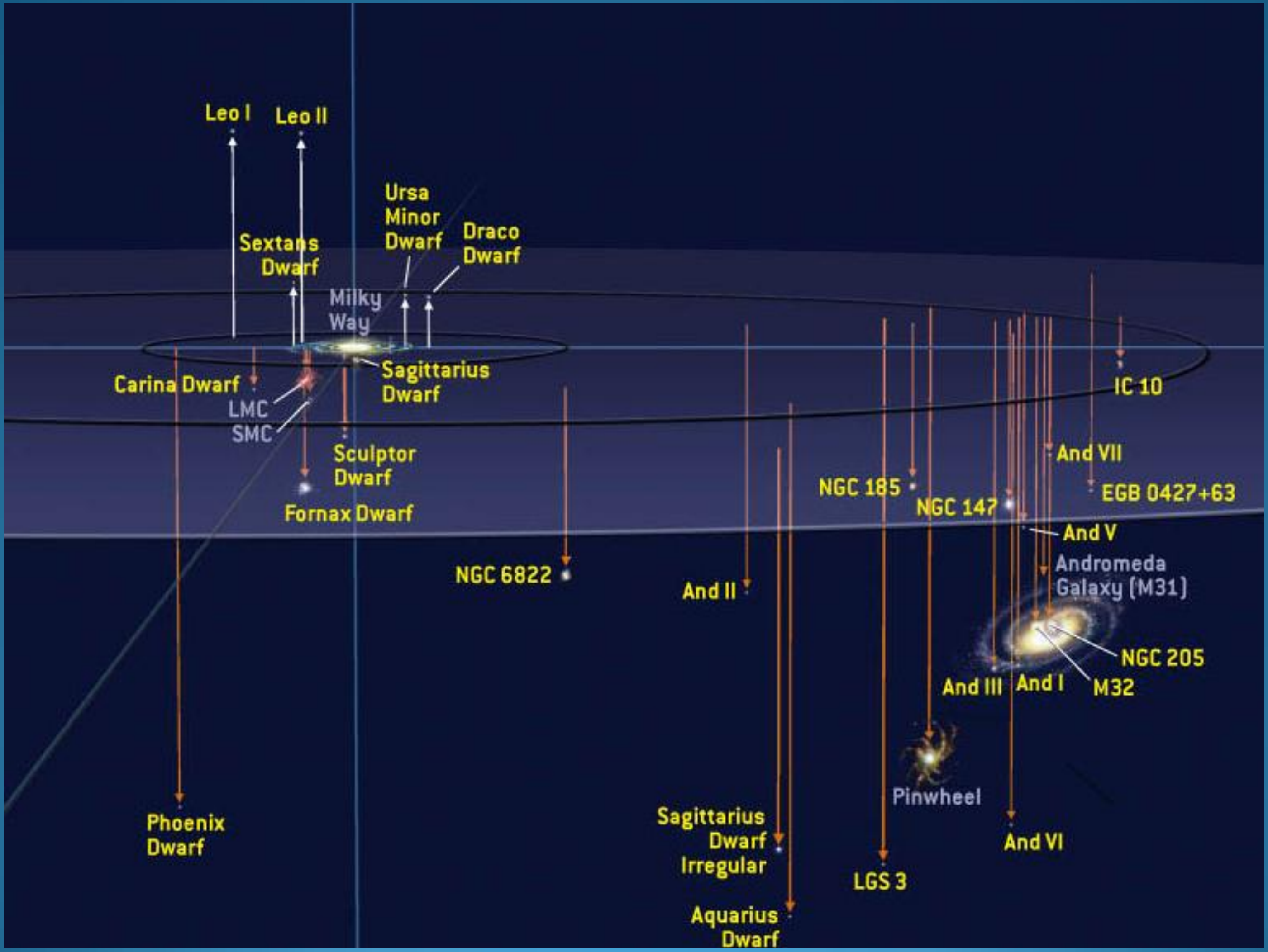


Figure: Roen Kelly / Astronomy

The Local Group

The dwarf galaxy pond after SDSS:

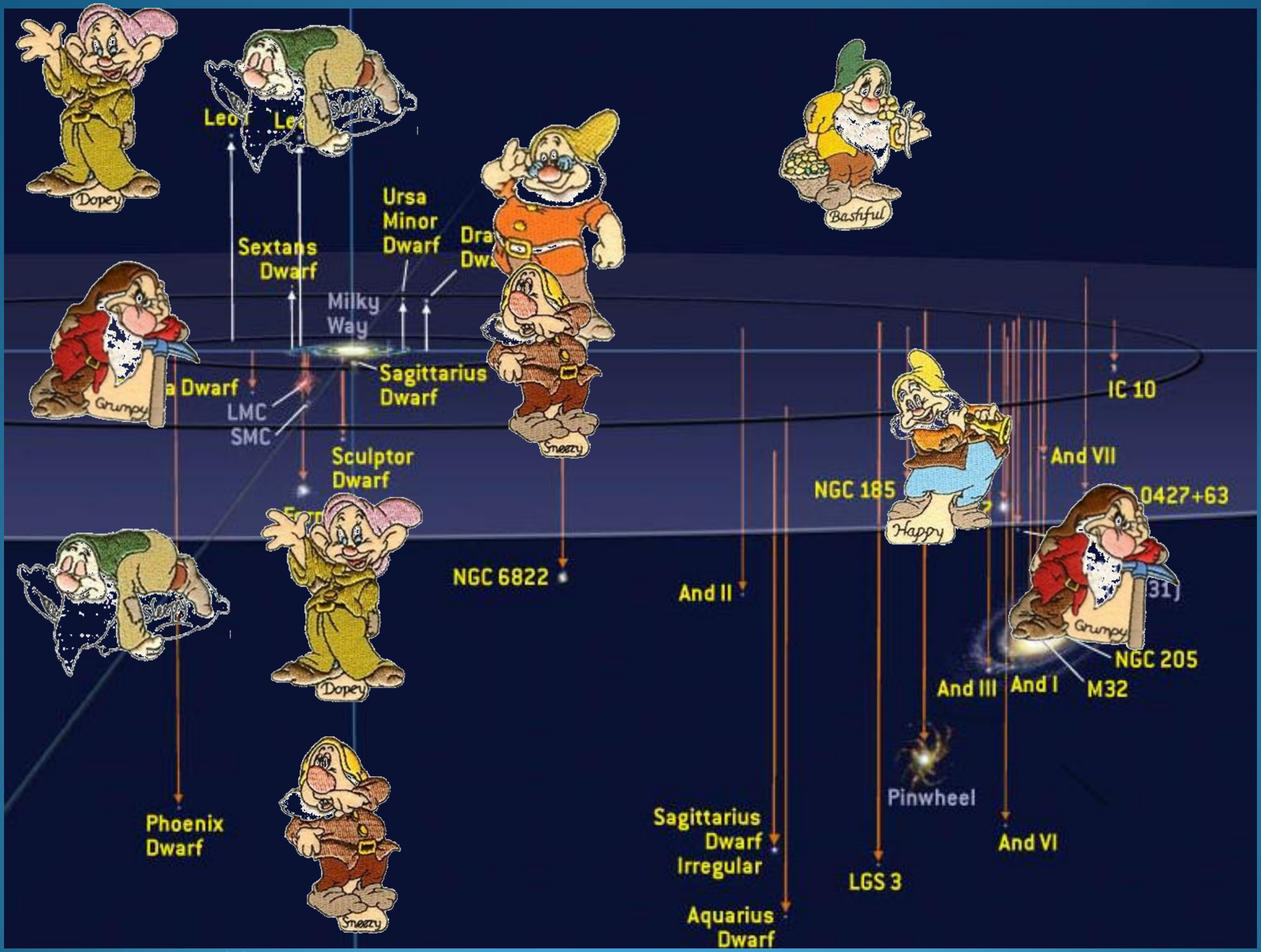


Figure: Roen Kelly / Astronomy

Looking at MSP w/o masses

- Our understanding of the local group has changed radically in the past four years, and current/future surveys (LSST, Pan-STARRS, PAndAS, SEGUE II, SMS, etc) are going to continue to help answer questions (and most likely will pose new problems).

Looking at MSP w/o masses

- SDSS only looked at ~¼ of the sky. ~10 new dwarfs found → ~30 more dwarfs should exist.
- But what if faint objects exist at large radii also? Need to correct for incompleteness.

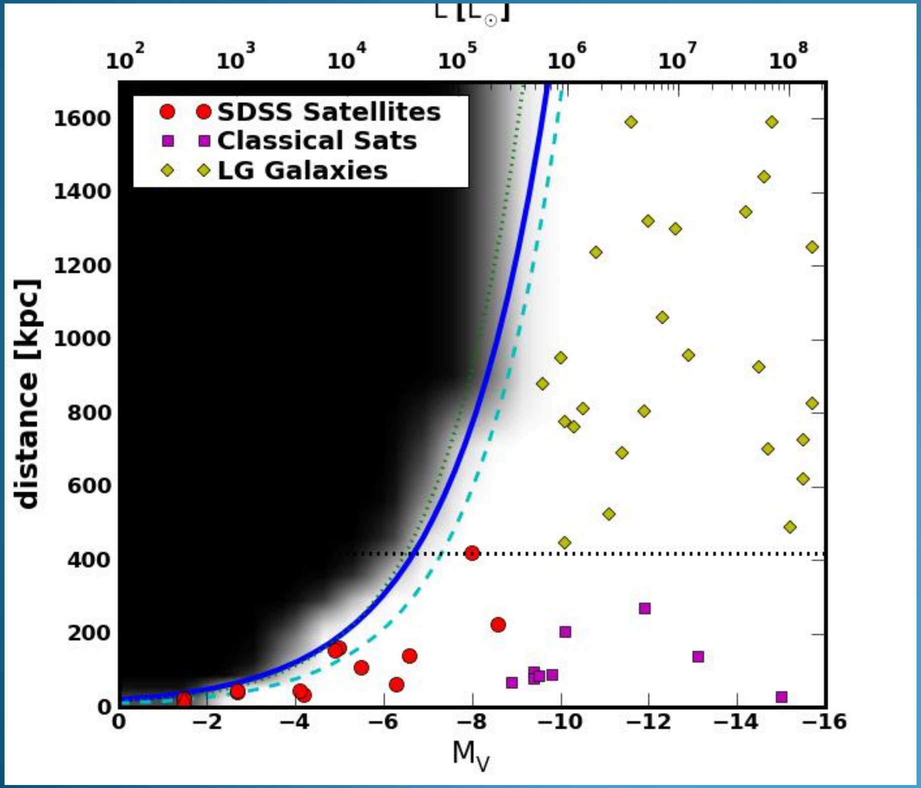


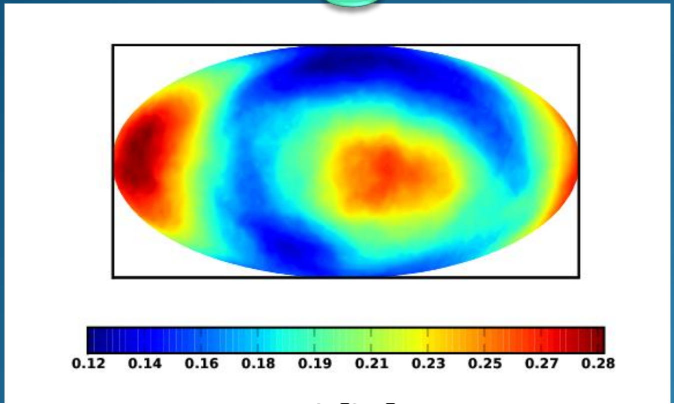
Figure: Tollerud et al. 2008

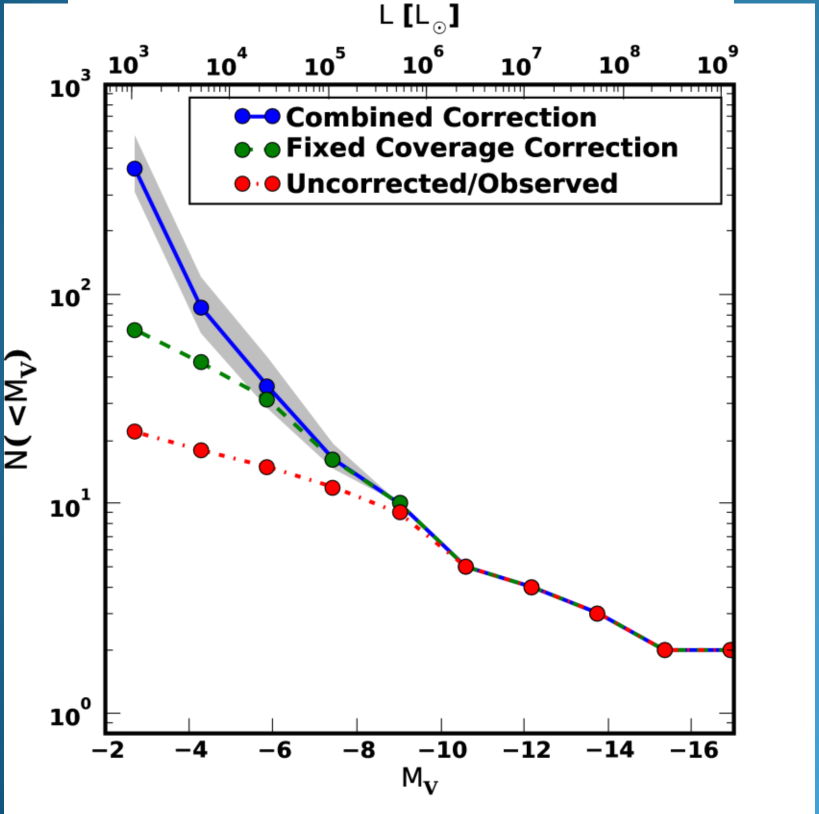
Lines: Koposov et al. 2007

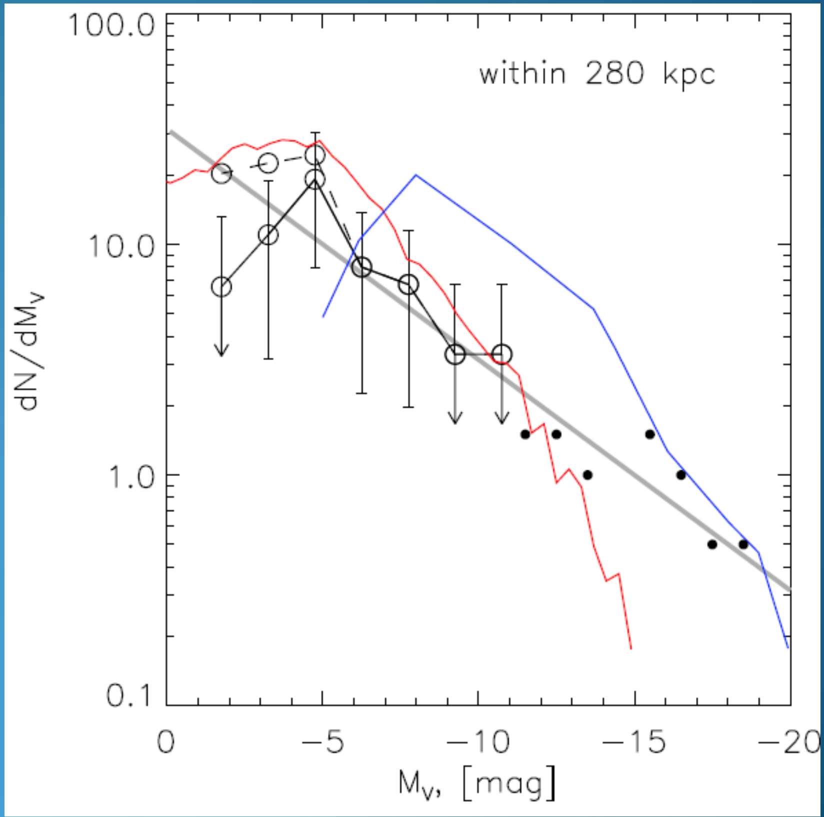
Shaded region:
Walsh, Willman, & Jerjen 2008

Looking at MSP w/o masses

Tollerud et al. 2008







Koposov et al. 2008

Sounds tough…

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Sorry ☹

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Sorry ☹

But maybe there's hope?

Let's see if any improvements can be made with mass determinations?
Very important for comparing observations to simulations.

Itemized Outline

- ~~Motivation~~
- Describe our mass modeling technique
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Different modeling techniques

With stellar kinematics, common techniques are:

1. $V^2 = GM/r$
2. Virial Theorem
3. Orbit modeling
4. Distribution function modeling
5. Jeans Equation

#1 only works for rotational-supported systems.
#3 and #4 need quality data to provide good constraints.
#2 and #5 are simple and can be used with limited data sets.

Consider the simplest assumption: spherical symmetry

The Scalar Virial Theorem

Unfortunately, the spherically symmetric SVT is not very useful given the data most observers obtain.

The SVT only provides large bounds on the mass within an often not well-defined stellar extent (see Merritt 1987):

$$\frac{\langle \sigma_{\mathrm{los}}^2 \rangle}{\langle r_\star^{-1} \rangle} \leq \frac{G\,\mathrm{M}_{\mathrm{lim}}}{3} \leq \frac{r_{\mathrm{lim}}^3 \langle \sigma_{\mathrm{los}}^2 \rangle}{\langle r_\star^2 \rangle}$$

The Scalar Virial Theorem

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$$0.7\langle\sigma^2_{\rm los}\rangle \leq \frac{GM_{\rm lim}}{r_{\rm lim}} \leq 20\langle\sigma^2_{\rm los}\rangle$$

Assuming a King stellar distribution with r_{lim}/r_{core}=5

Spherical Jeans Equation

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

Consider a spherical, dispersion-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

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

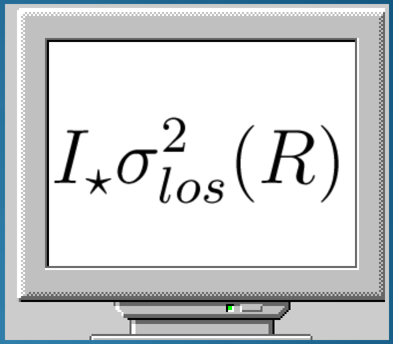
Assume known: 3D deprojected stellar density

Radial dispersion (depends on beta)

Free function

Explanation (with pictures)

Basic idea behind Jeans analysis:



$M(r)$

$\beta(r)$

(Note the one-way arrow)

Mass modeling of hot systems

Jeans Equation

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

Velocity Anisotropy (3 parameters)

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

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$$\rho(r) = \frac{\rho_s e^{-r/r_{cut}}}{(r/r_s)^c[1+(r/r_s)^a]^{(b-c)/a}}$$

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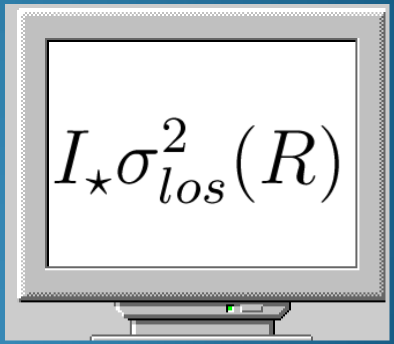
Using a Gaussian PDF for the observed stellar velocity distribution, we marginalize over all free parameters (including photometric uncertainties) using a Markov Chain Monte Carlo (MCMC).

Explination (with pictures)

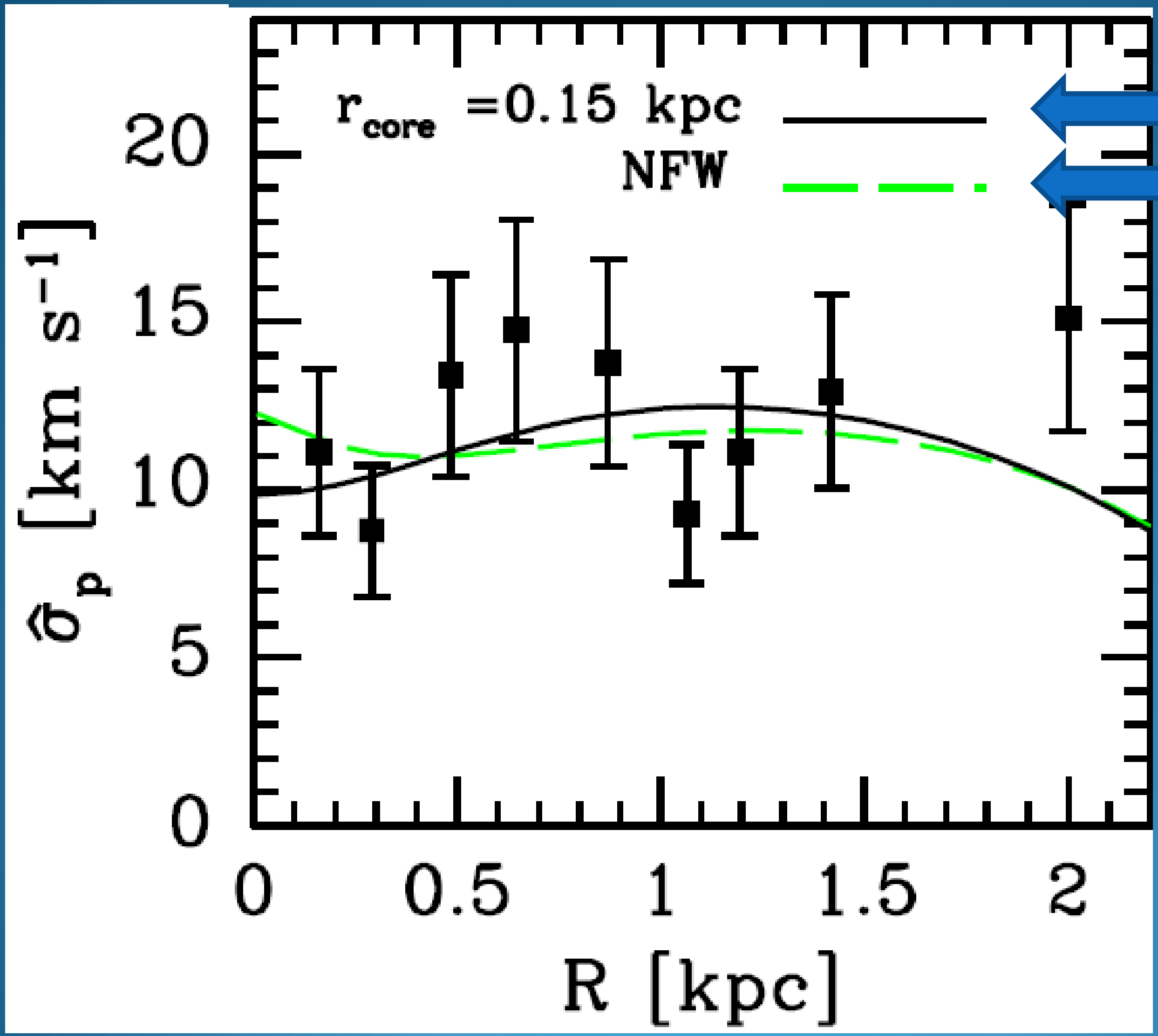
MCMC algorithm picks favorable combinations of M and β that produce dispersions that match the observed velocities. β is not constrained from just LOS data, but M may be constrained...if we are clever.



$M(r)$

$\beta(r)$

Mass-Beta Degeneracy



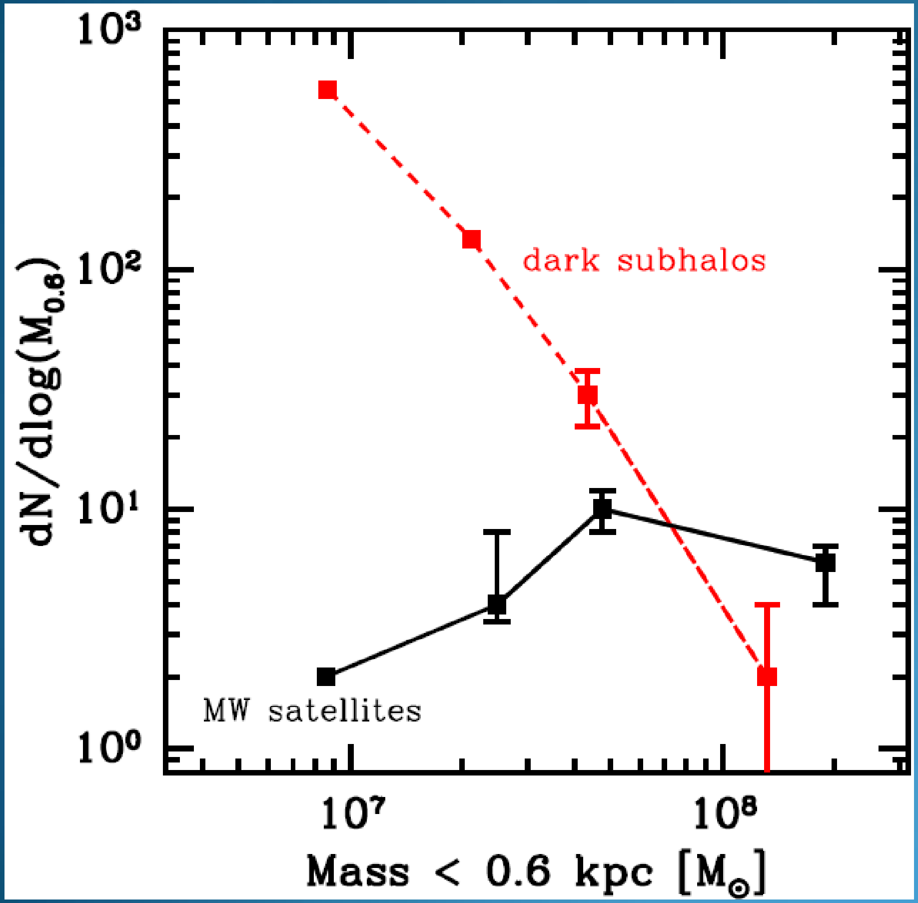
Core

Cusp

Strigari et al. 2006, ApJ

Looking at MSP with masses

- What can we learn by deriving accurate masses?



Strigari et al. 2007

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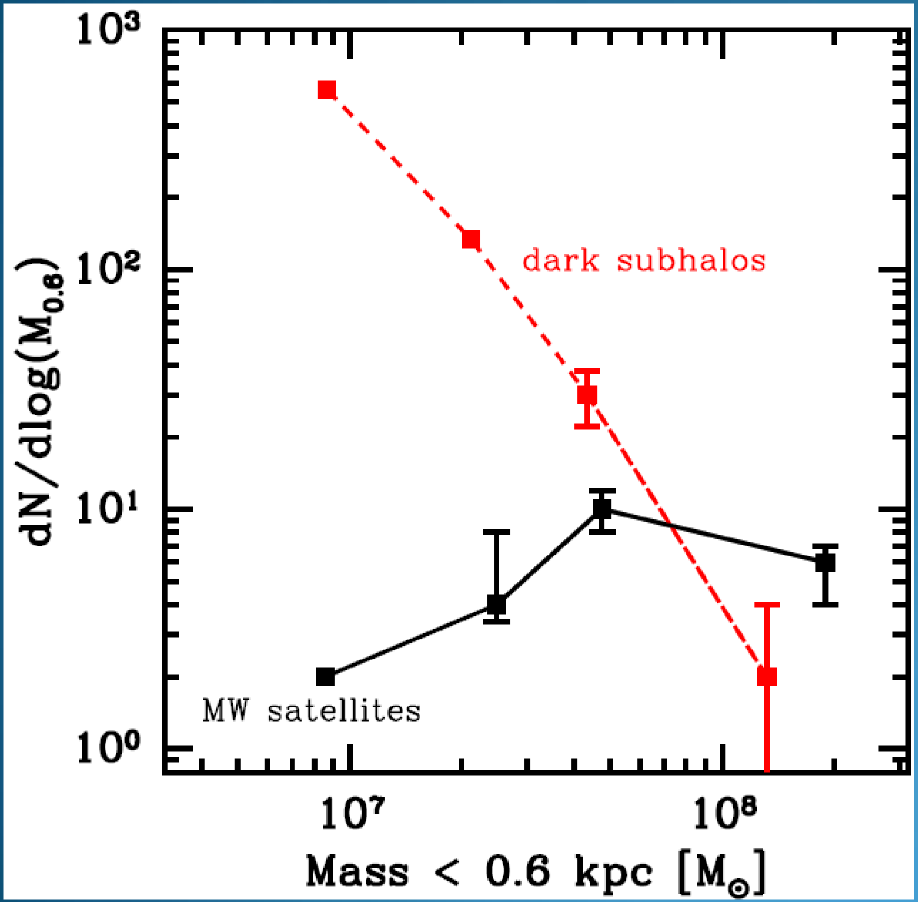
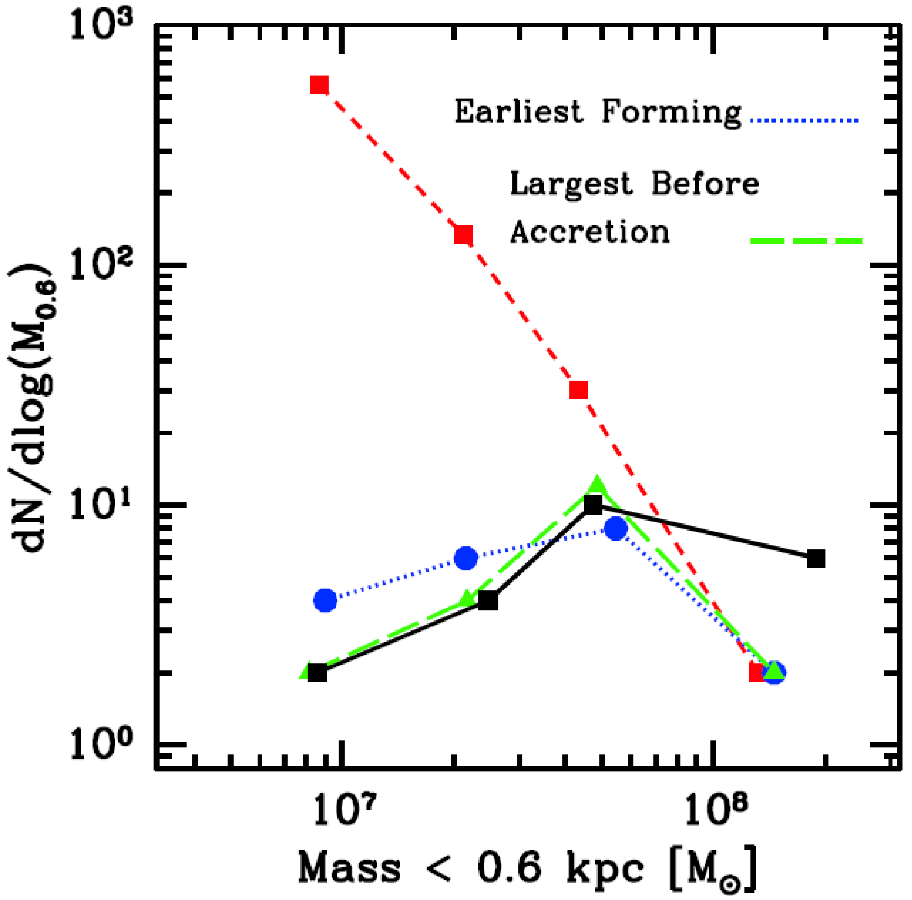
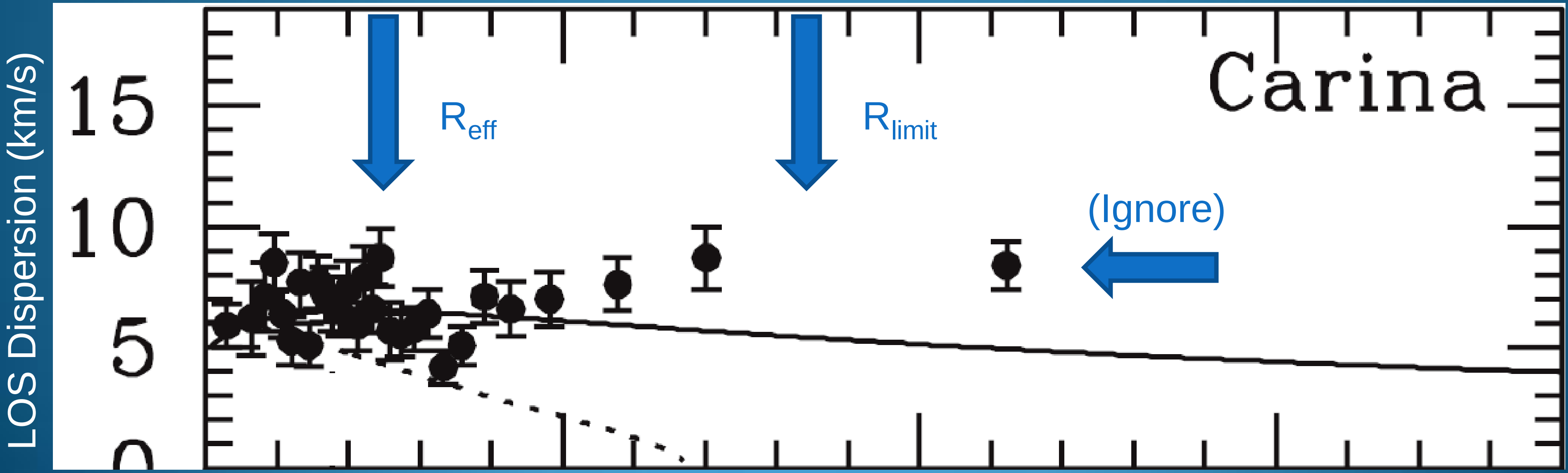




Strigari et al. 2007

Thought Experiment

Given the following kinematics…



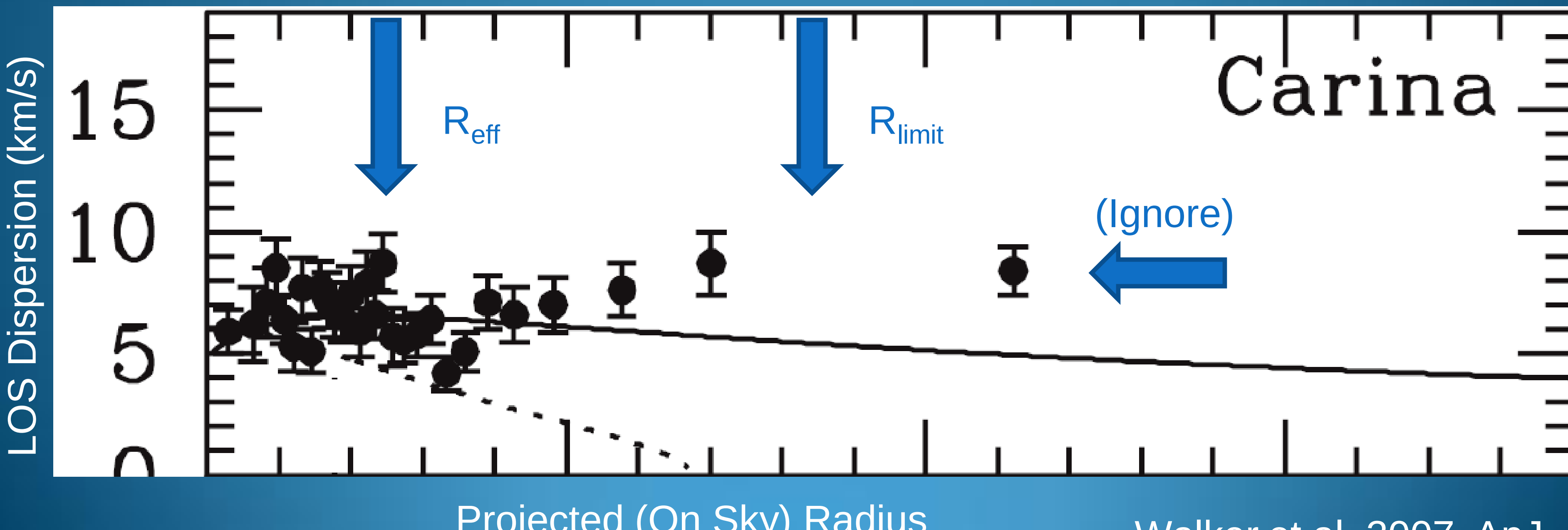
Walker et al. 2007, ApJ

Thought Experiment

Given the following kinematics, will you derive a better constraint on mass enclosed within:

a) $0.5 * r_{1/2}$ b) $1.0 * r_{1/2}$ c) $1.5 * r_{1/2}$

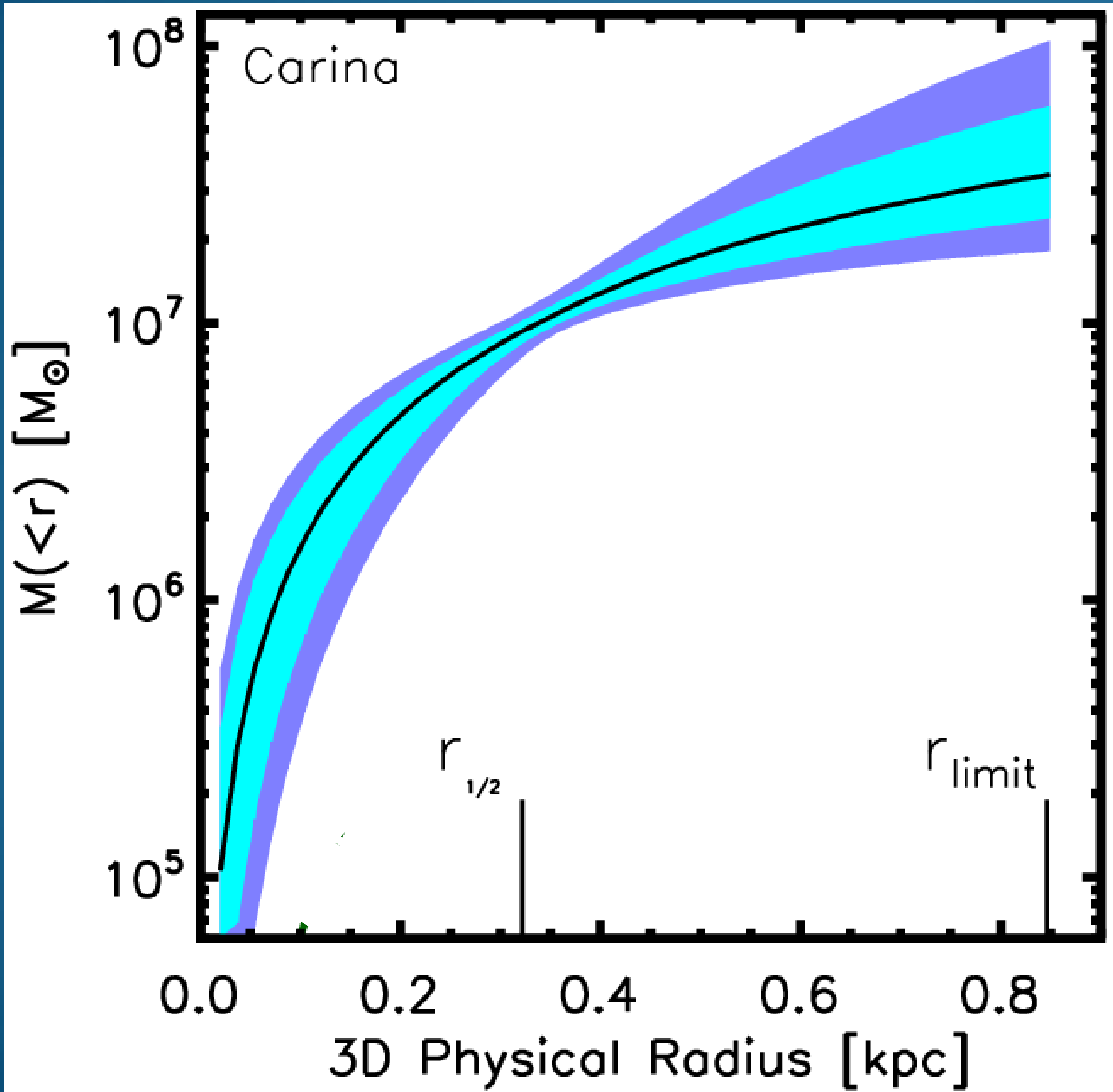
Where $r_{1/2}$ is the derived 3D deprojected half-light radius of the system. (The sphere within the sphere containing half the light).



Walker et al. 2007, ApJ

Hmm…

A CAT scan of 50 mass likelihoods at different radii:

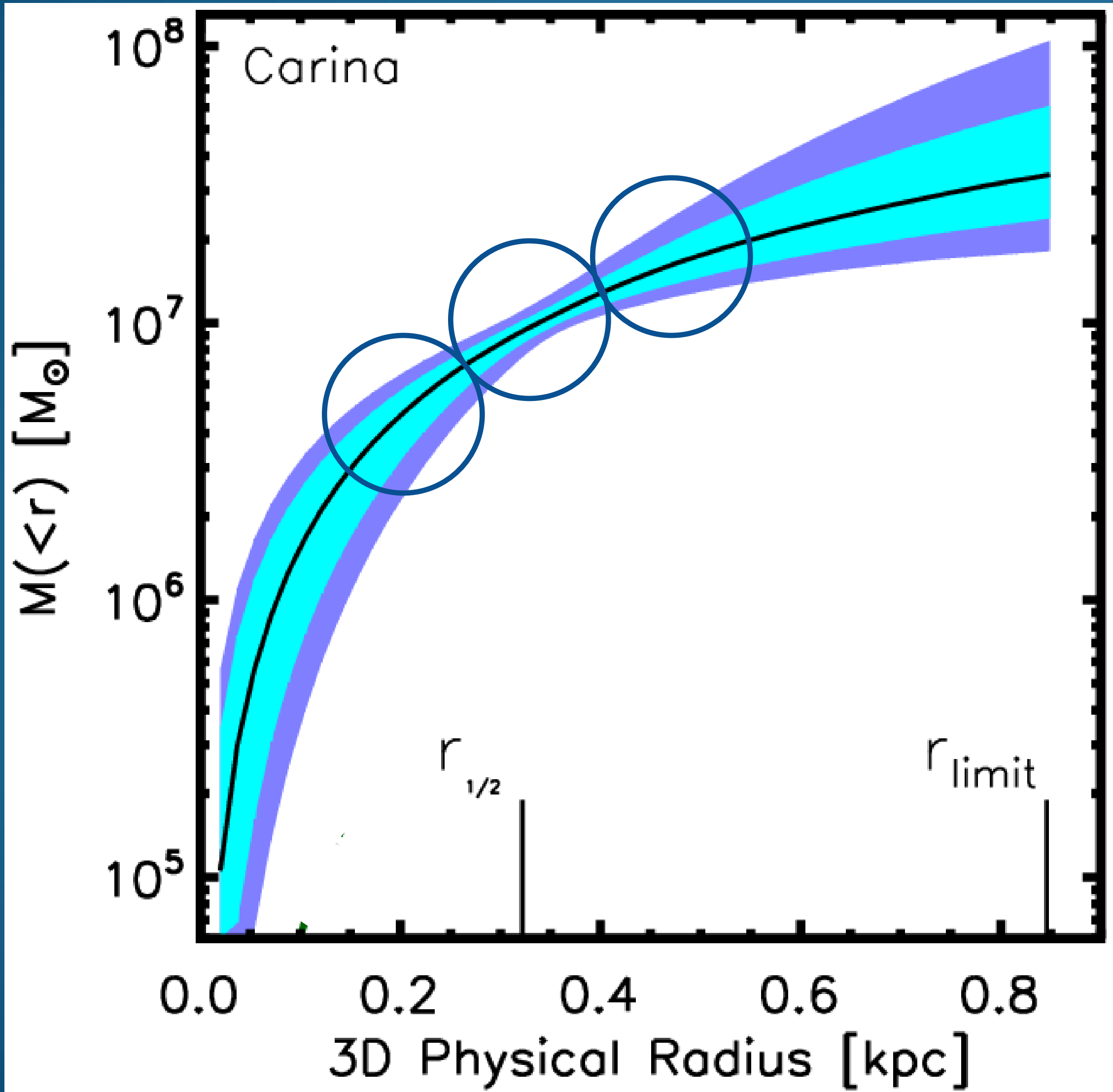


<u>Confidence Intervals:</u>
Cyan: 68%
Purple: 95%

Joe Wolf et al., 0908.2995

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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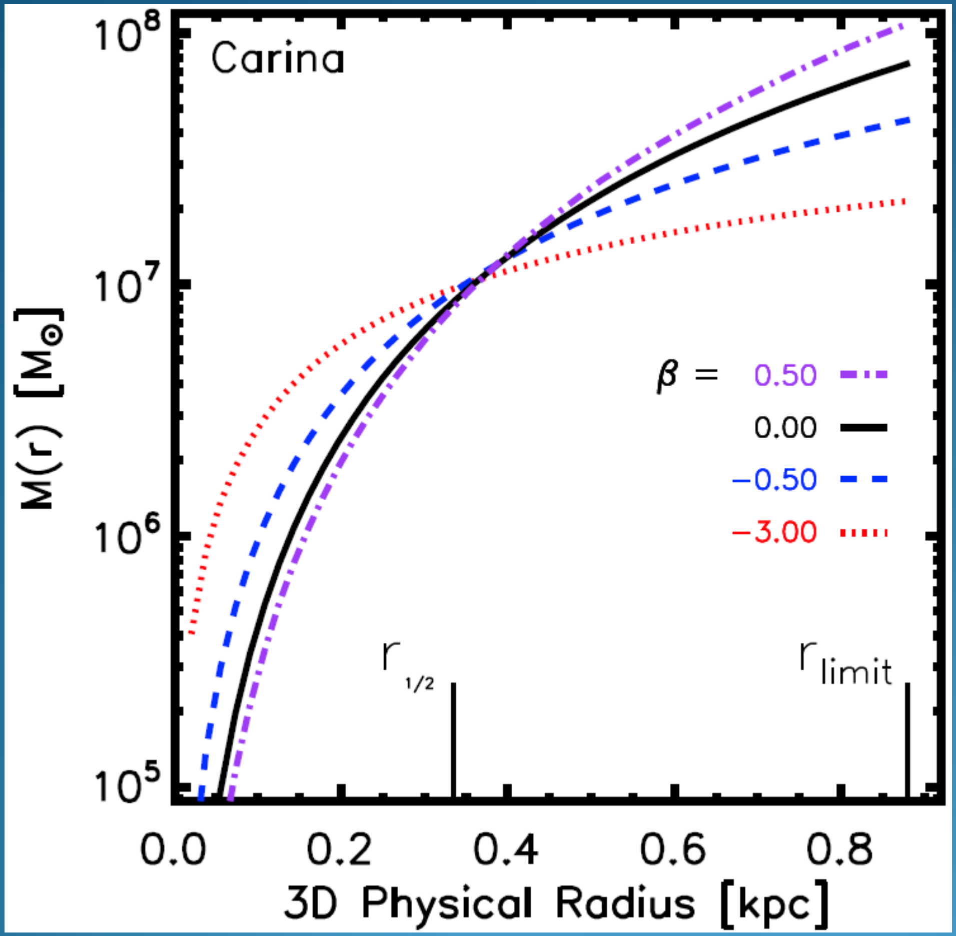
Anisotrwhat?



Radial Anisotropy

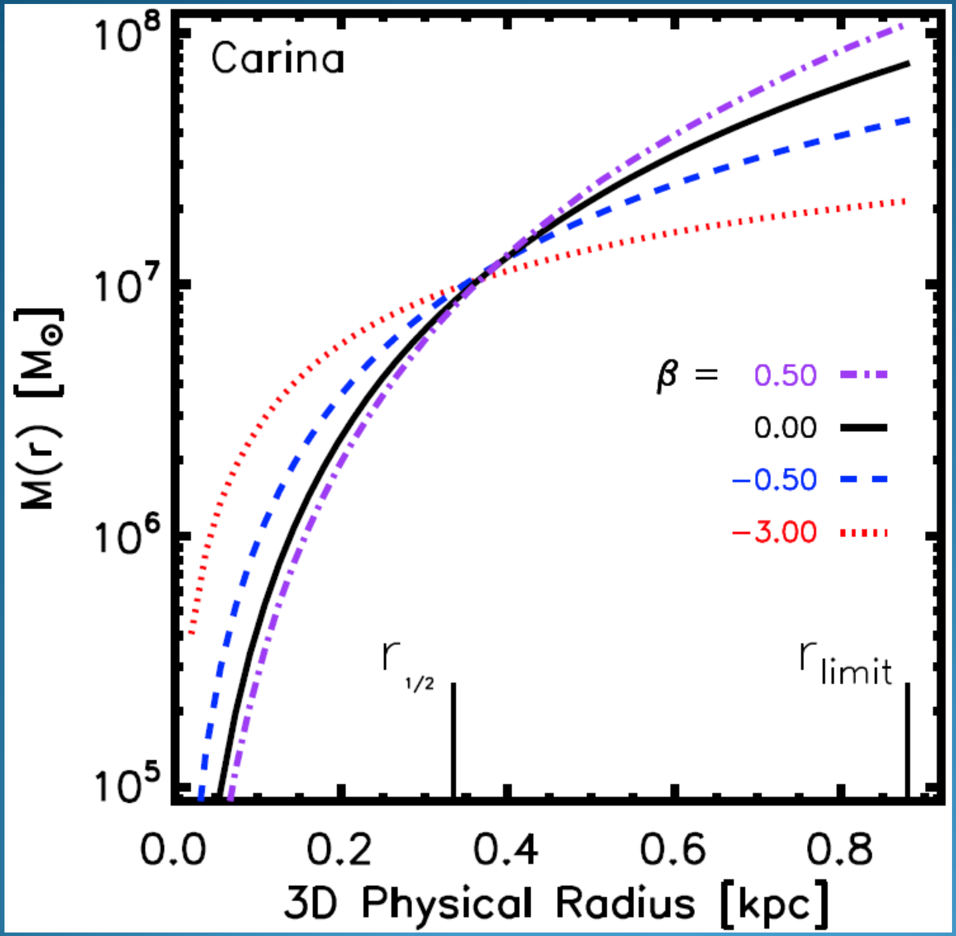
Isotropic

Tangential

Joe Wolf et al., 0908.2995

Center of system:
Observed dispersion is radial

Anisotrwhat?



Edge of system: Observed dispersion is tangential

Radial Anisotropy

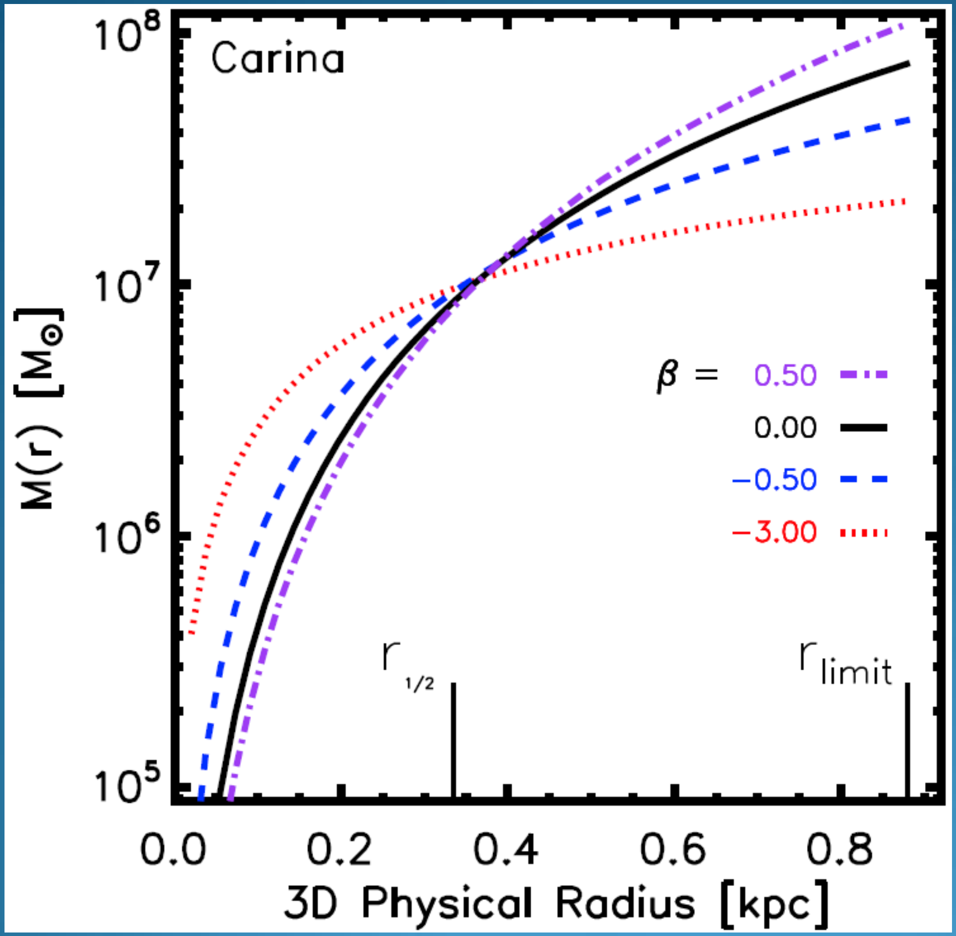
Isotropic

Tangential

Joe Wolf et al., 0908.2995

Center of system:
Observed dispersion is radial

Anisotrwhat?



Edge of system: Observed dispersion is tangential

Radial Anisotropy

Isotropic

Tangential

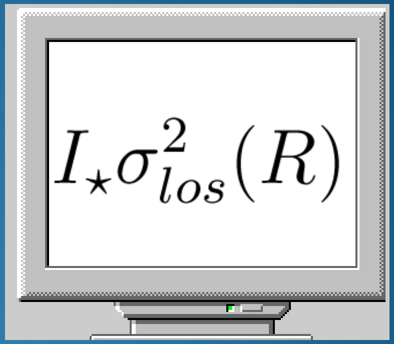
Newly derived analytic equations **predict** that the effect of anisotropy is minimal near $r_{1/2}$ for observed stellar densities:

Joe Wolf et al., 0908.2995

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

Explanation (with pictures)

We have found a way to invert the problem*:



$M(r)$

$\beta(r)$

* Mamon & Boué 0906.4971: Independent derivation.

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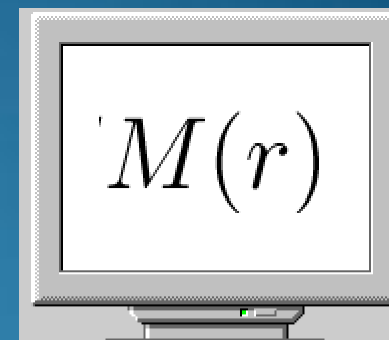

$I_\star \sigma^2_{los}(R)$

$\beta(r)$

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Derivation

$$I_\star \sigma_{los}^2(R) = \int_{R^2}^{\infty} \rho_\star \sigma_r^2(r) \left[1 - \frac{R^2}{r^2}\beta(r)\right] \frac{dr^2}{\sqrt{r^2 - R^2}}$$

R = 2D projected on-sky radius

r = 3D deprojected physical radius

To get this in the form of an Abel inversion, need to get rid of R in the integrand (but needed, as is, inside of the kernel)

Derivation

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Simple, but not obvious

$$\int_{R^2}^{\infty} \frac{\rho_\star \sigma_r^2}{r^2} \frac{(1-\beta)r^2 + \beta(r^2 - R^2)}{\sqrt{r^2 - R^2}} dr^2$$

Invertible

Maybe Invertible?

Derivation

$$I_\star \sigma_{los}^2(R) = \int_{R^2}^{\infty} \rho_\star \sigma_r^2(r) \left[1 - \frac{R^2}{r^2}\beta(r)\right] \frac{dr^2}{\sqrt{r^2 - R^2}}$$

$$\int_{R^2}^{\infty} \frac{\rho_\star \sigma_r^2}{r^2} \frac{(1-\beta)r^2 + \beta(r^2 - R^2)}{\sqrt{r^2 - R^2}} dr^2$$

$$\int_{R^2}^{\infty} \frac{\rho_\star \sigma_r^2 (1-\beta)}{\sqrt{r^2 - R^2}} dr^2 - \left(\sqrt{r^2 - R^2} \int_{r^2}^{\infty} \frac{\beta \rho_\star \sigma_r^2}{\tilde{r}^2} d\tilde{r}^2 \right)\Bigg|_{R^2}^{\infty}$$

$$+ \int_{R^2}^{\infty} \left(\int_{r^2}^{\infty} \frac{\beta \rho_\star \sigma_r^2}{\tilde{r}^2} d\tilde{r}^2 \right) \frac{1}{2} \frac{dr^2}{\sqrt{r^2 - R^2}}$$

Derivation

$$I_\star \sigma_{los}^2(R) = \int_{R^2}^{\infty} \left[\frac{\rho_\star \sigma_r^2}{(1-\beta)^{-1}} + \int_{r^2}^{\infty} \frac{\beta \rho_\star \sigma_r^2}{2\tilde{r}^2} d\tilde{r}^2 \right] \frac{dr^2}{\sqrt{r^2 - R^2}}$$

No more R dependence in the brackets!

We can now use an Abel inversion to write the bracketed term as a function of the left-hand side!

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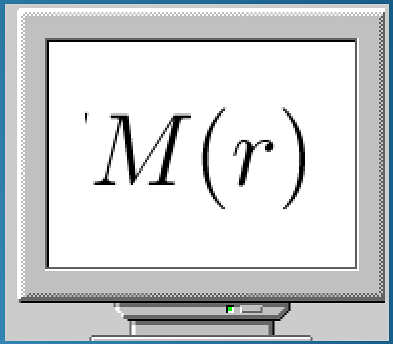
It turns out this isn’t very useful, as you will need to know the second derivative of the left-hand side.
(See Appendix A of Wolf et al. 0908.2995
and Mamon & Boué 0906.4971)

What's next?

Given these tools, let's search for a radius where the mass is independent of the anisotropy.



$I_\star \sigma^2_{los}(R)$

$\beta(r)$

“The happiest thought of my life”

$$I_\star \sigma_{los}^2(R) = \int_{R^2}^{\infty} \left[\frac{\rho_\star \sigma_r^2}{(1-\beta)^{-1}} + \int_{r^2}^{\infty} \frac{\beta \rho_\star \sigma_r^2}{2\tilde{r}^2} d\tilde{r}^2 \right] \frac{dr^2}{\sqrt{r^2 - R^2}}$$

If the LHS is observable, it must be independent of an assumed anisotropy.

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Since this equation is invertible, a unique solution must exist.

Thus, the bracketed terms must be well determined, no matter the assumed anisotropy.

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Therefore, we can equate the isotropic integrand with any arbitrary anisotropic integrand:

$$\rho_\star \sigma_r^2 \Big|_{\beta=0} = \rho_\star \sigma_r^2 [1 - \beta(r)] + \int_r^{\infty} \frac{\beta \rho_\star \sigma_r^2 d\tilde{r}}{\tilde{r}}$$

“The happiest thought of my life”

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Take a derivative with respect to ln(r)
and then subtract the Jeans Equation:

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$$\rho_\star \sigma_r^2 \Big|_{\beta=0} = \rho_\star \sigma_r^2 [1 - \beta(r)] + \int_r^\infty \frac{\beta \rho_\star \sigma_r^2 d\tilde{r}}{\tilde{r}}$$

Take a derivative with respect to ln(r) and then subtract the Jeans Equation:

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

We present in depth arguments as to why the middle two terms should be small, and we also demonstrate that the first term = -3 near $r_{1/2}$ for most observed galaxies and stellar systems which are in equilibrium.

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

Derived equation under several simplifications:

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

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

Derived equation under several simplifications:

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

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

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

Wait a second…

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

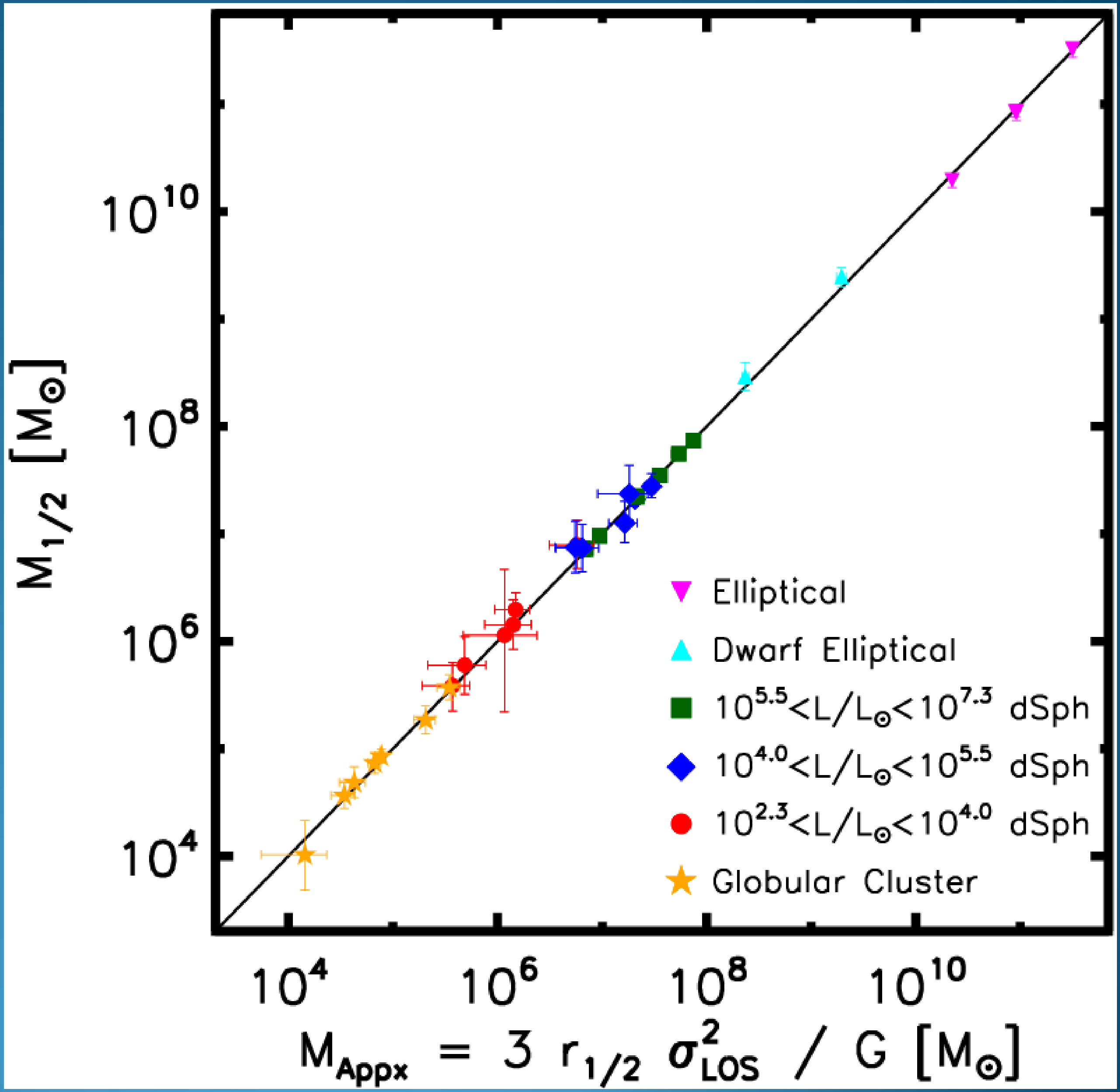
$$M_{1/2} = 3\,G^{-1}\,r_{1/2}\,\langle \sigma_{\mathrm{los}}^{2} \rangle$$

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 anisotropy.

Really?

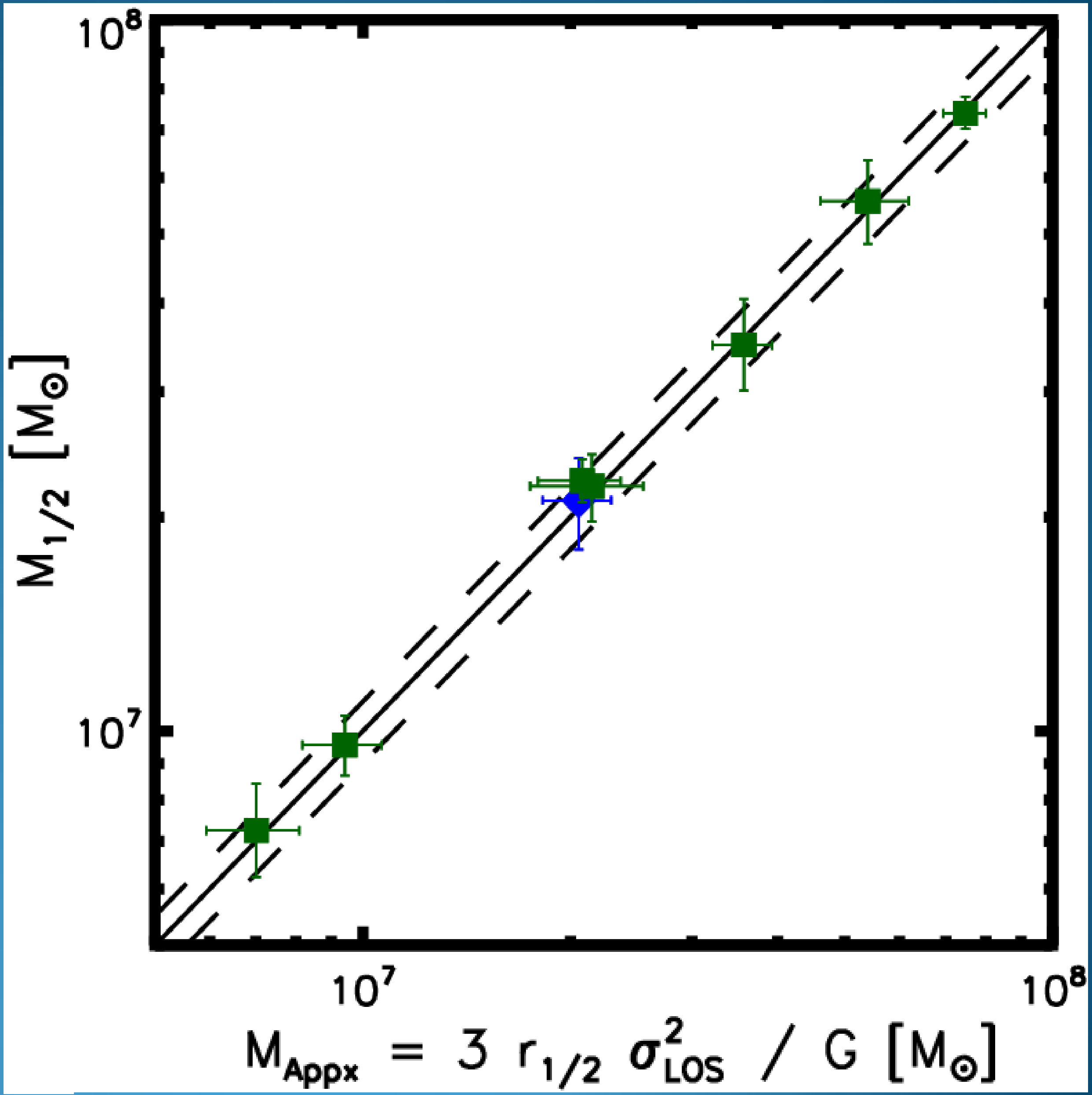
Boom!
Equation tested on systems spanning almost **eight** decades in half-light mass after lifting simplifications.



Joe Wolf et al., 0908.2995

Boom!

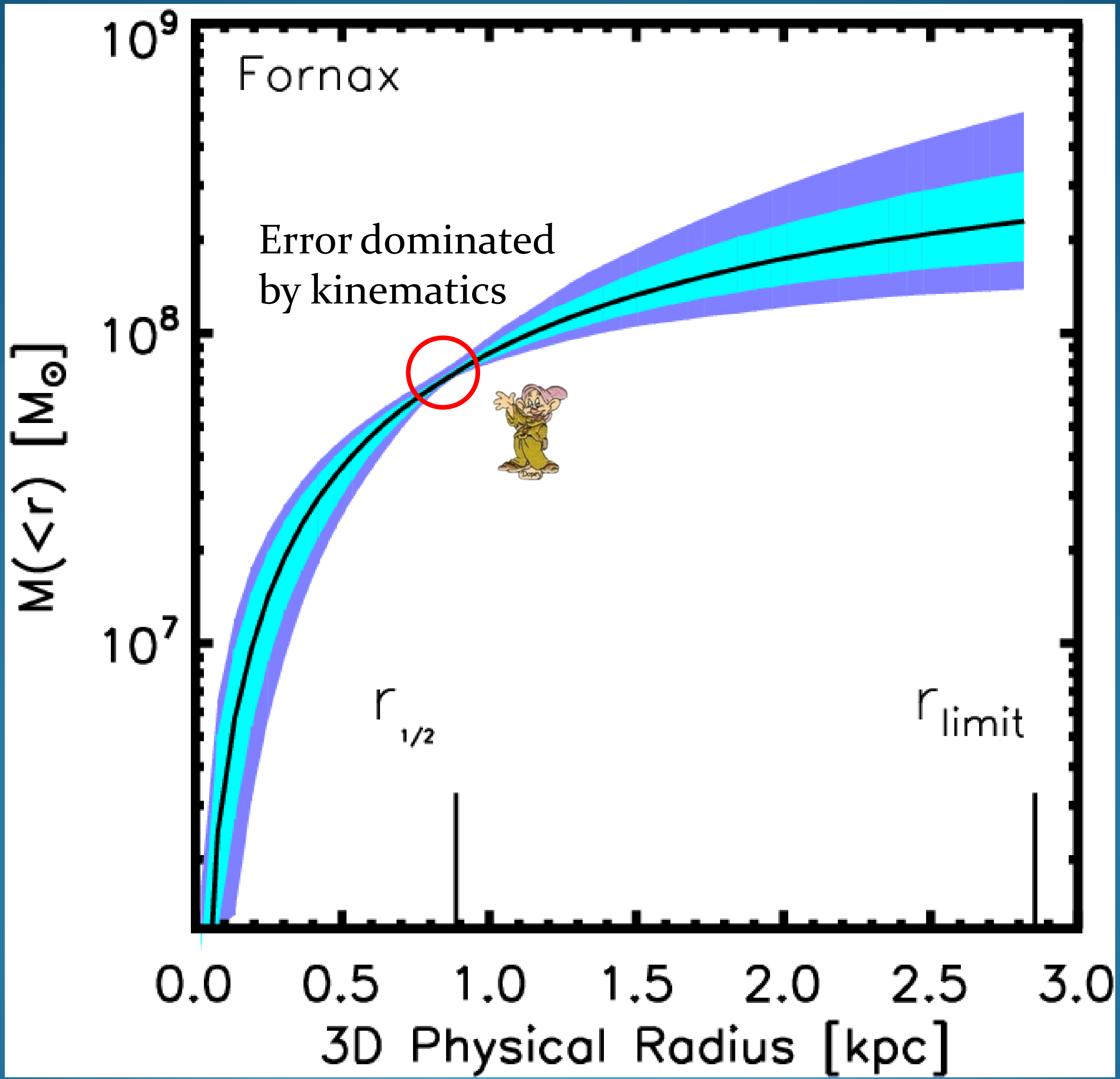
"Classical" MW dwarf spheroidals



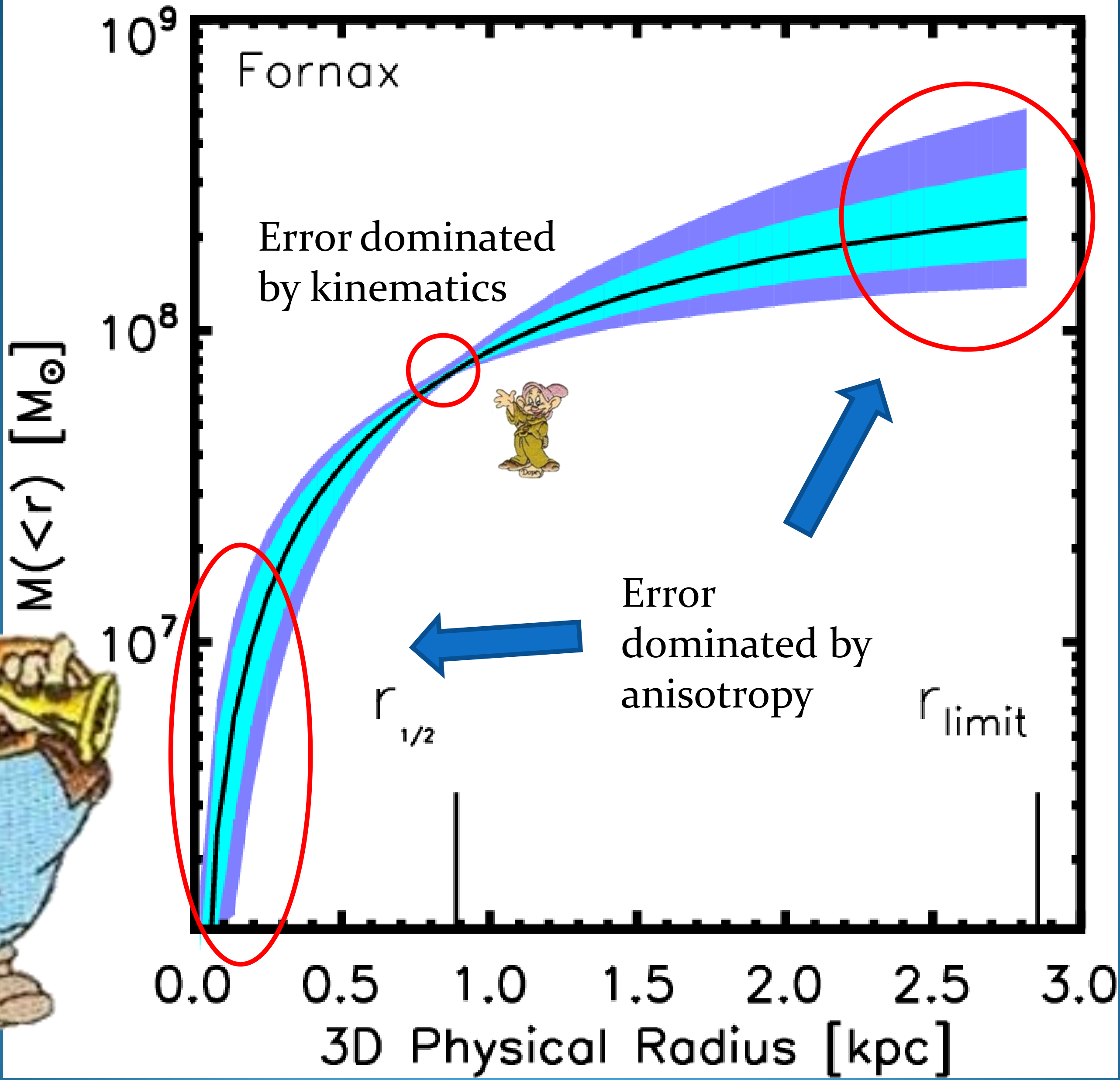
Dotted lines:
10% variation in
factor of 3 in M_{Appx}

Joe Wolf et al., 0908.2995

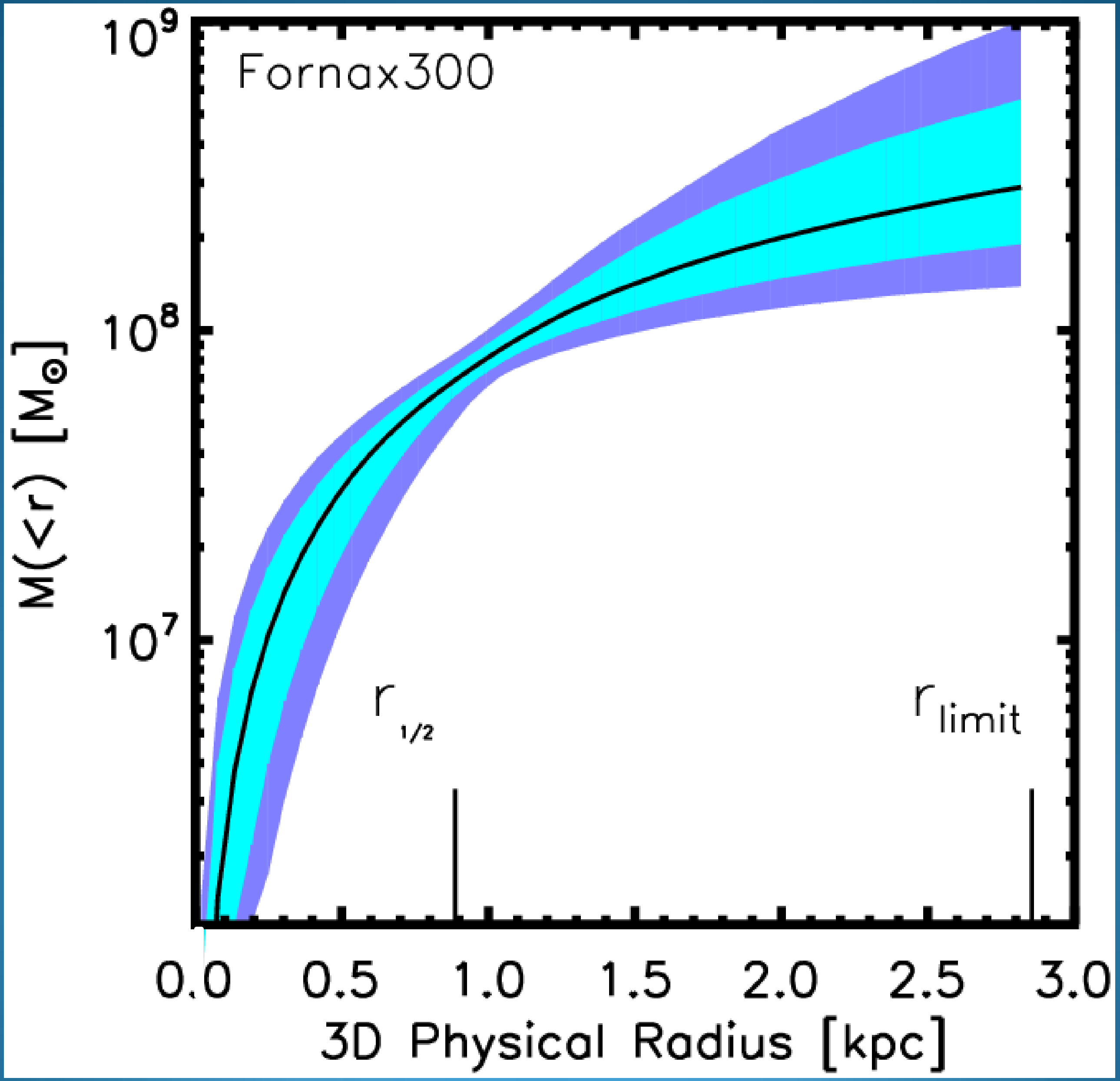
Mass Errors: Origins



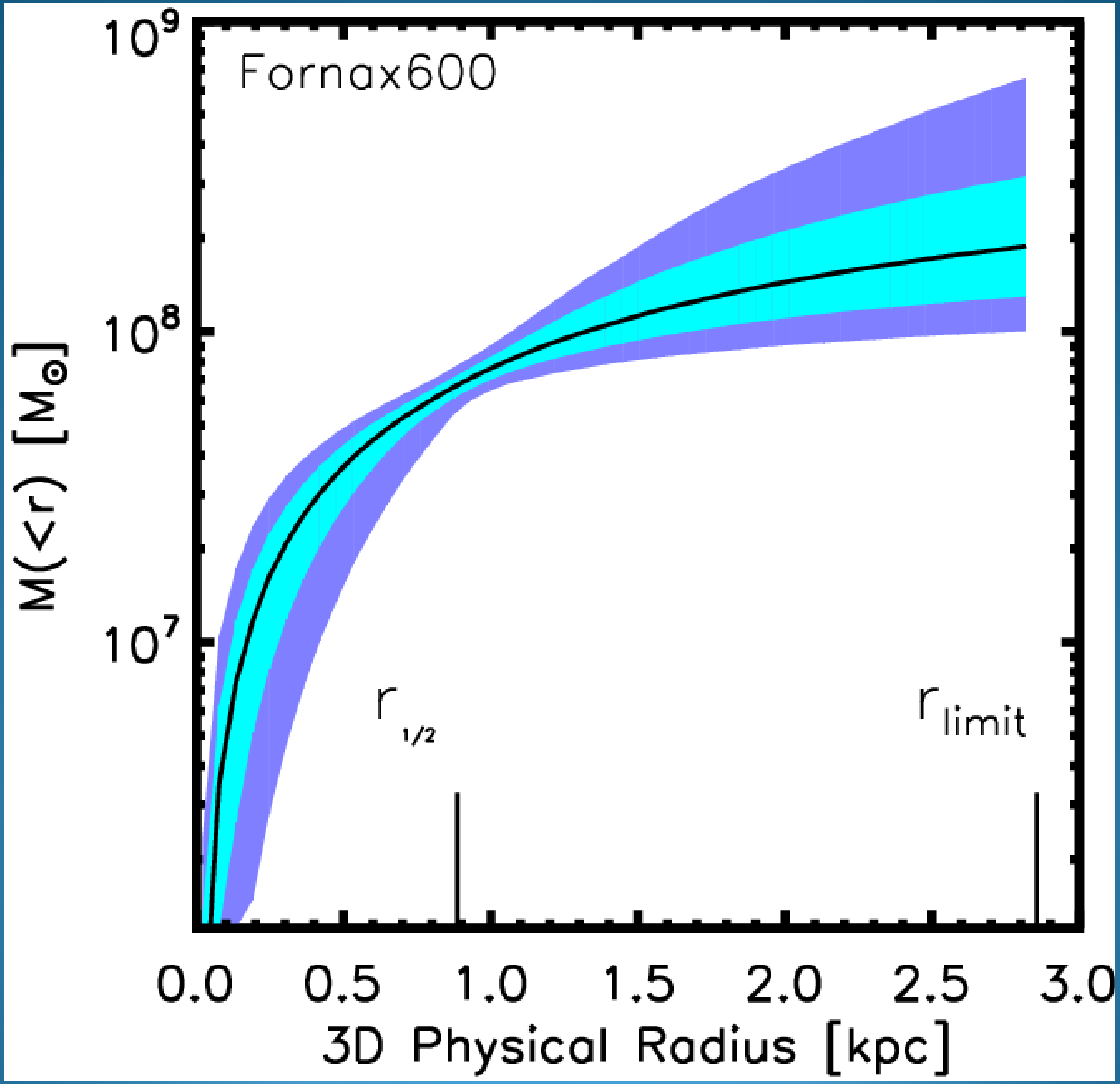
Mass Errors: Origins



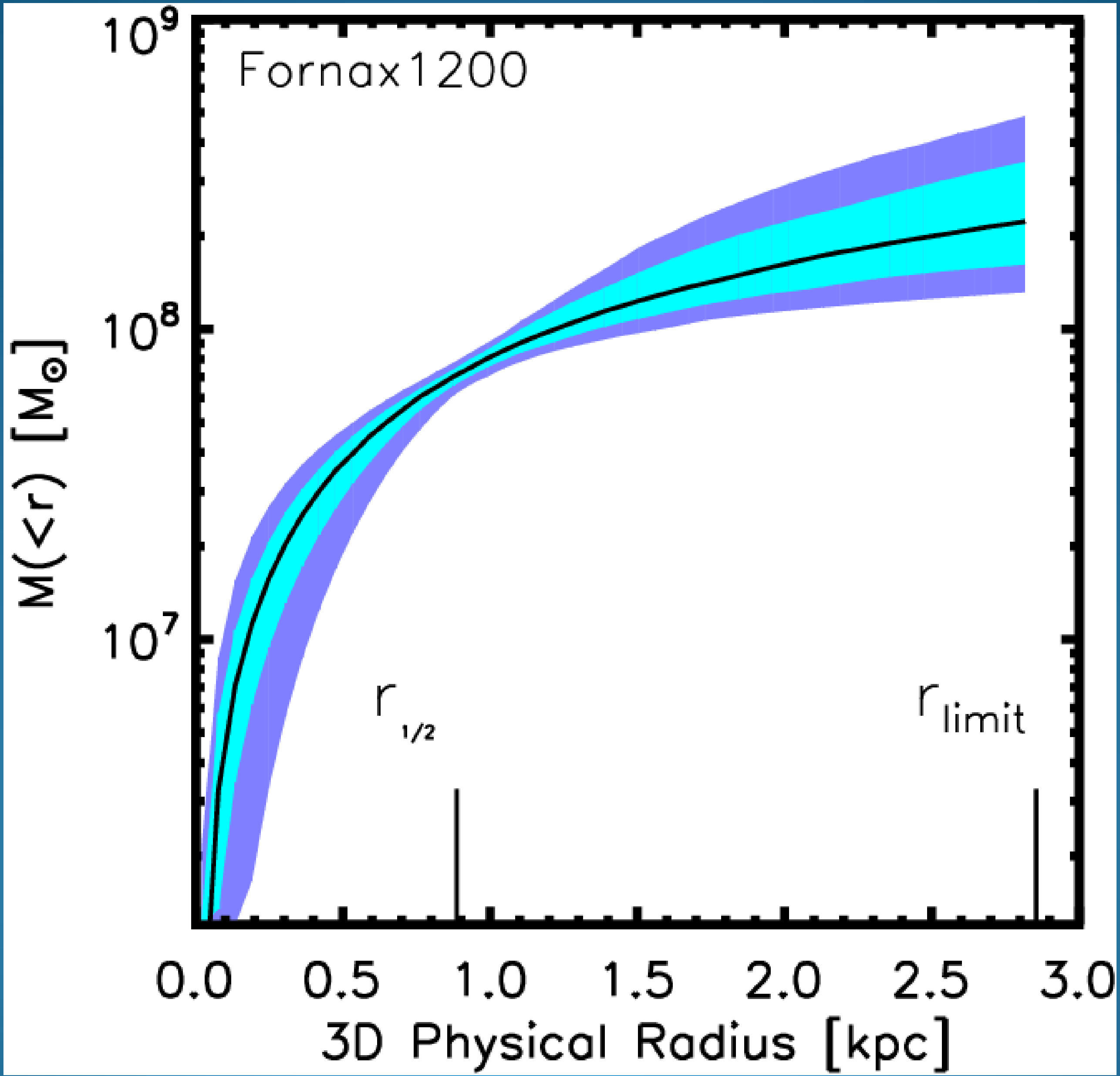
Mass Errors: 300 stars



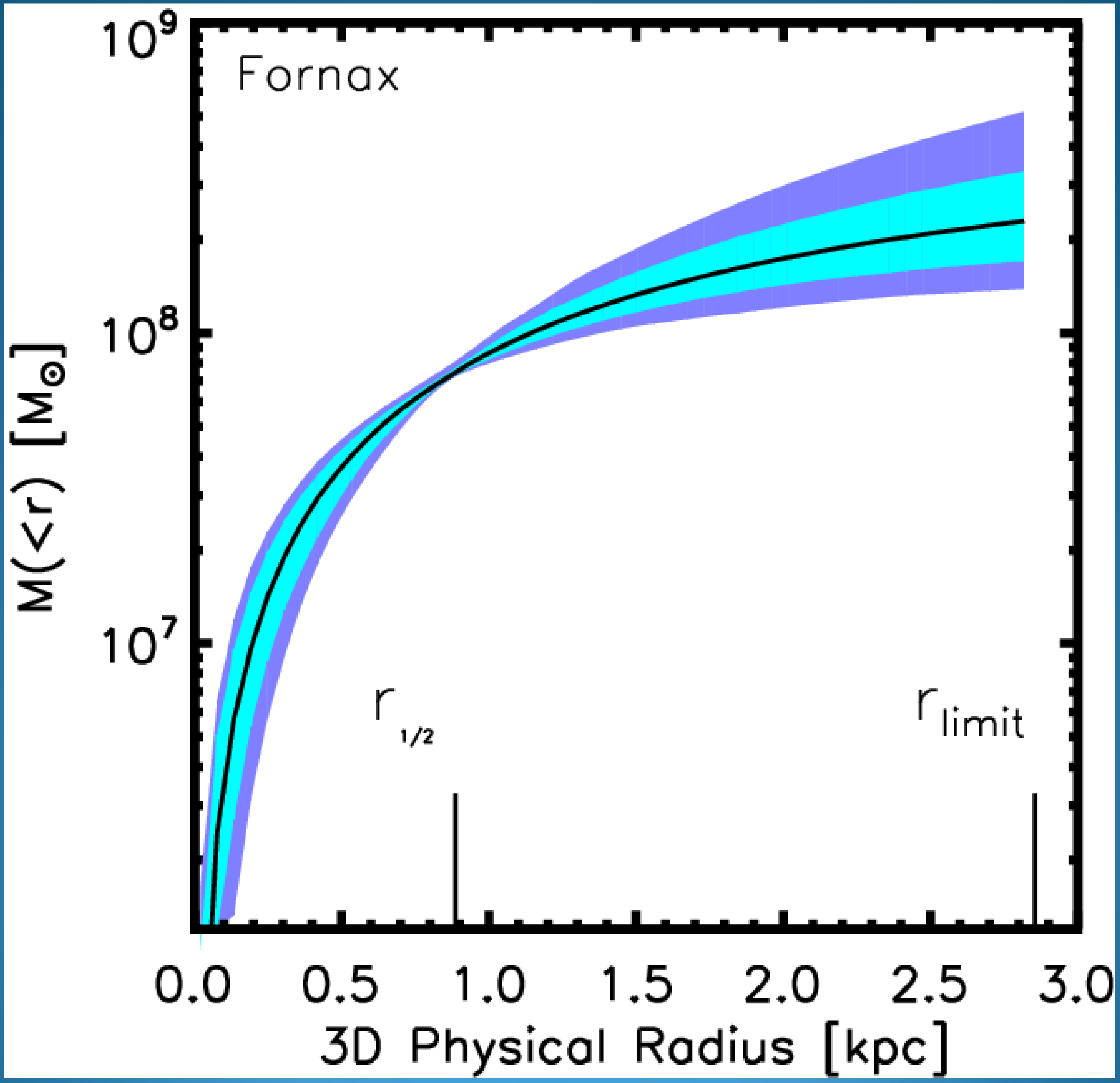
Mass Errors: 600 stars



Mass Errors: 1200 stars



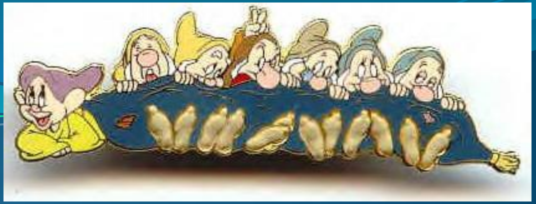
Mass Errors: 2400 stars



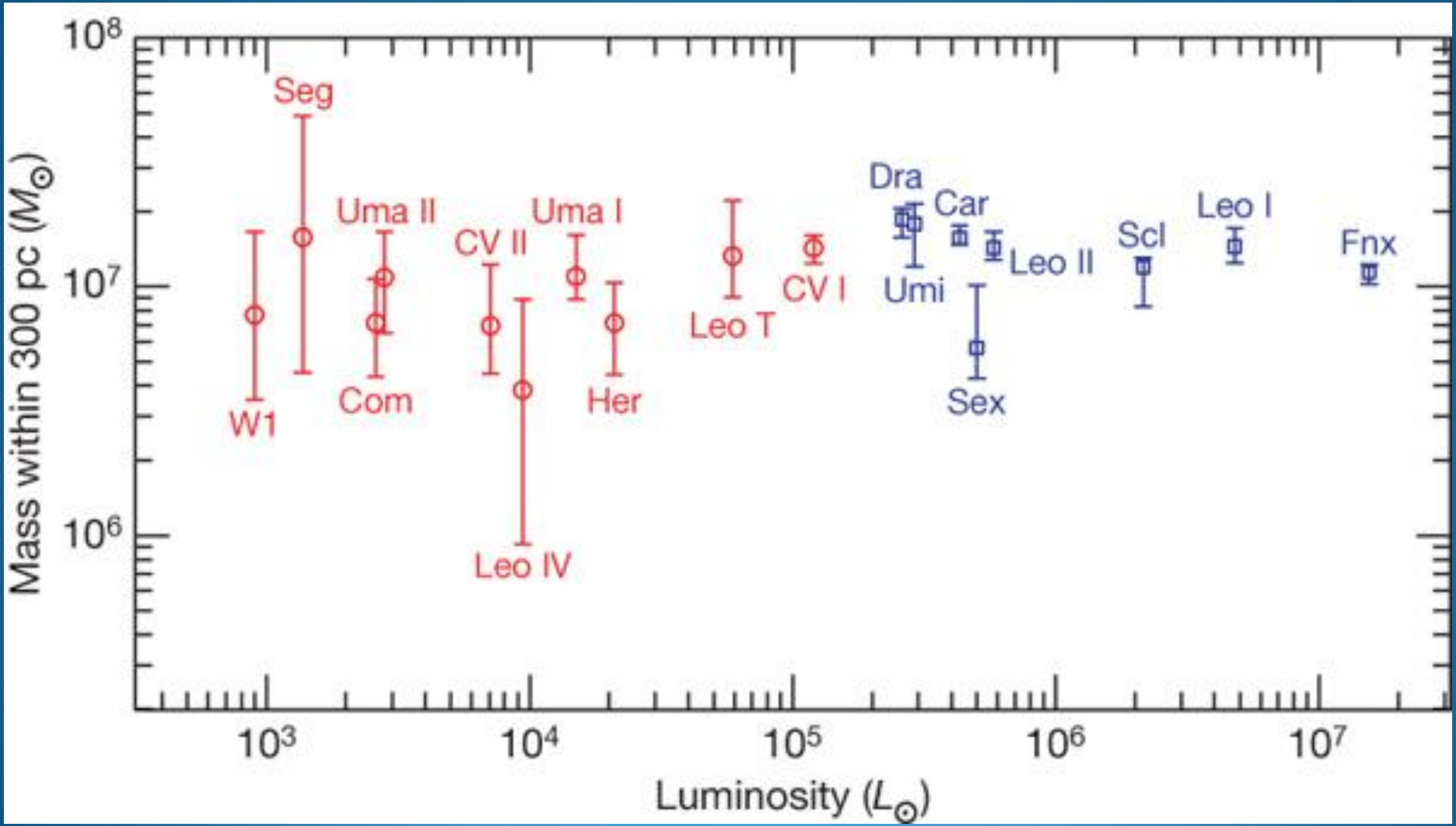
Itemized Outline

- ~~Motivation~~
- ~~Describe our mass modeling technique~~
- ~~Derive a new mass estimator that is independent of anisotropy~~
- Apply the new mass estimator
- A word on the effect of binary star systems
- New spectroscopic observations of M31 dSphs
- Effects of priors → cusp or core?
- The future: SIM & proper motions

Applications: dSphs



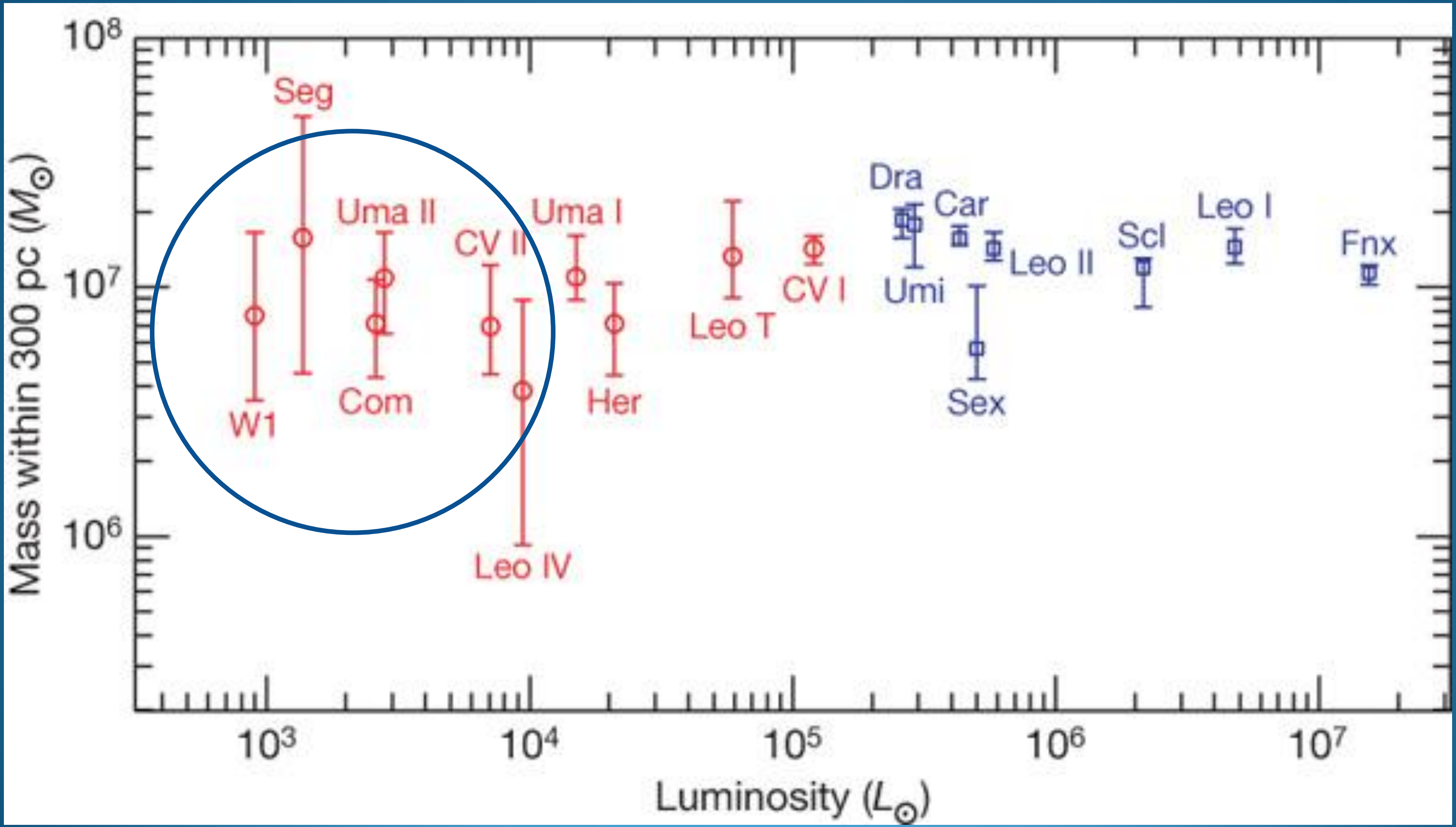
A common mass scale? M(<300)~10^7 M_{sun} → M_{halo}~10^9 M_{sun}



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

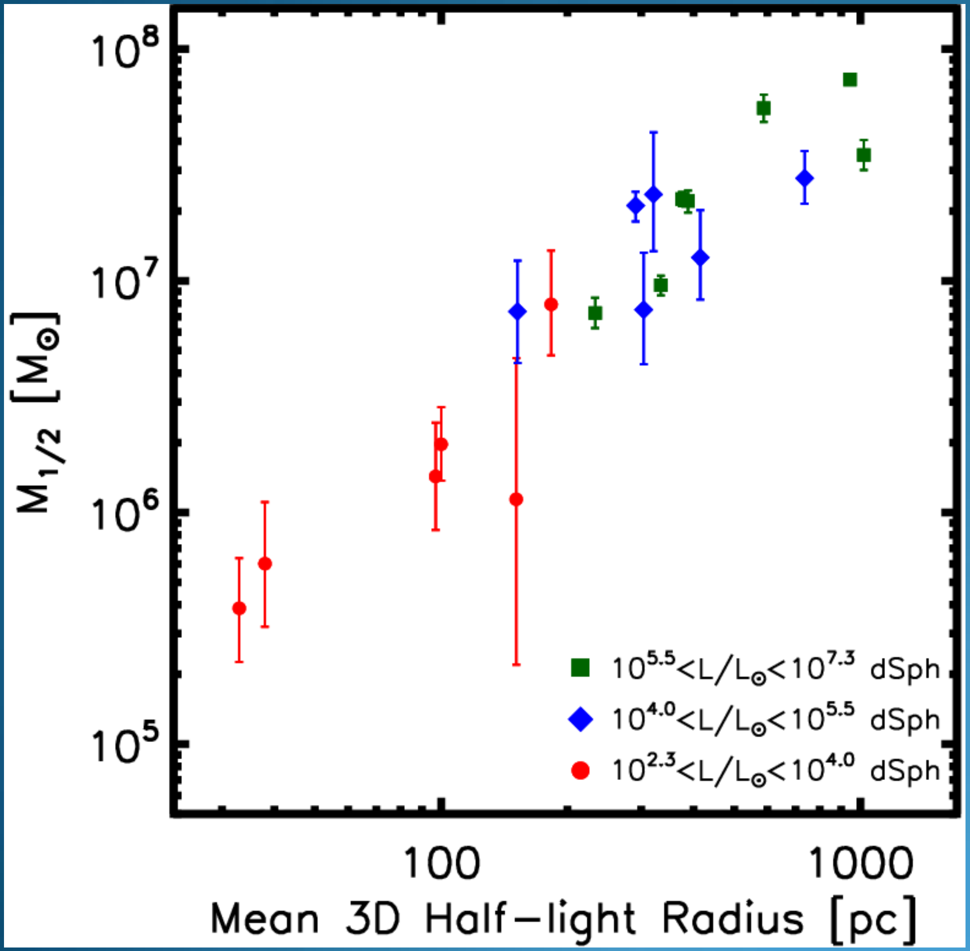
Applications: dSphs

A common mass scale? M(<300)~10^7 M_{sun} → M_{halo}~10^9 M_{sun}



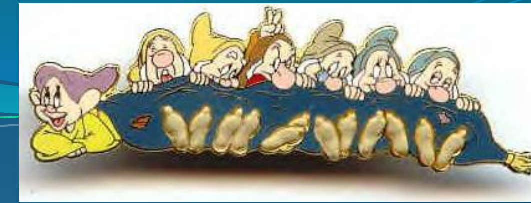
Strigari, Bullock, Kaplinghat, Simon, Geha, Willman, Walker 2008, Nature

Applications: dSphs

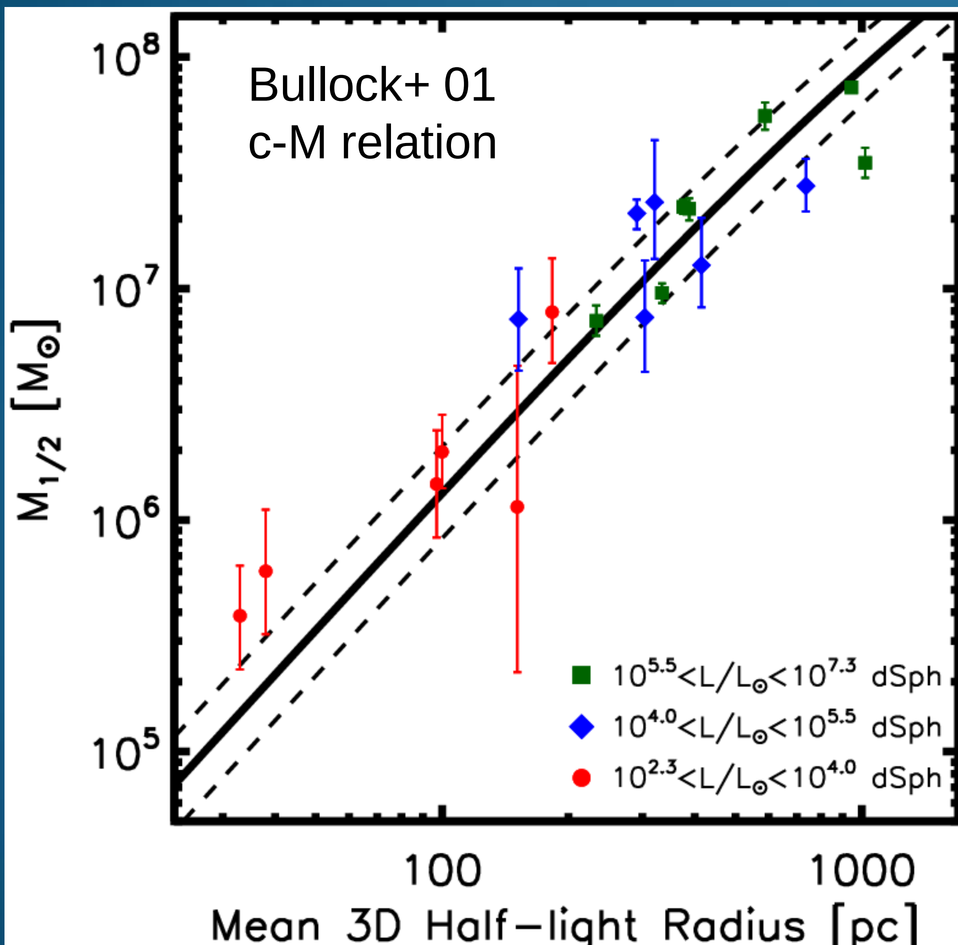


Joe Wolf et al. 0908.2995

Applications: dSphs



A common mass scale? Plotted: $M_{halo} = 3 \times 10^9 \, M_{sun}$

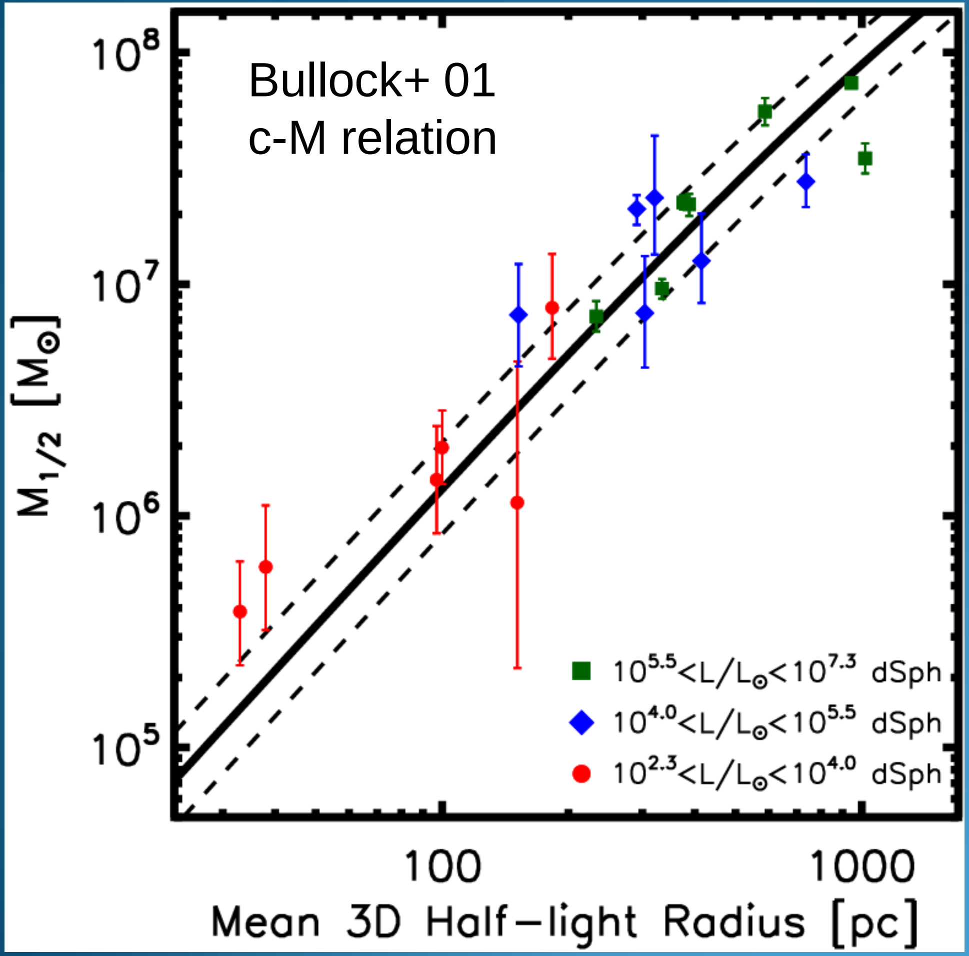


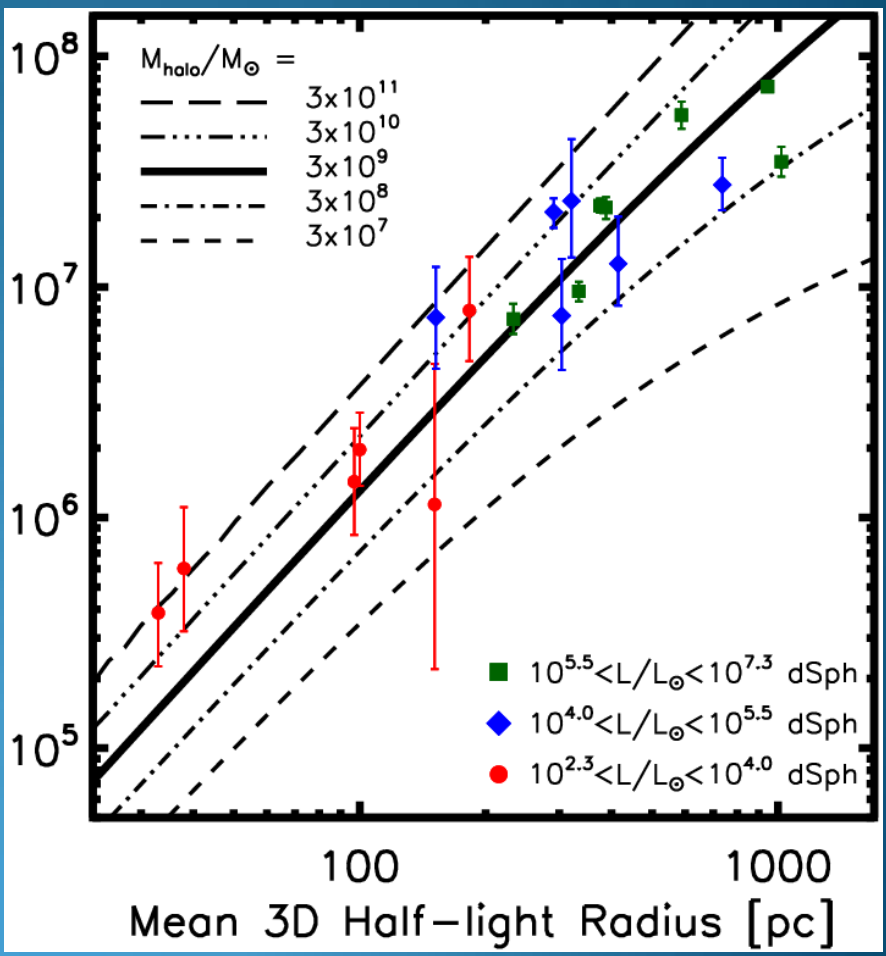
Joe Wolf et al. 0908.2995

Applications: dSphs

A common mass scale? Plotted: $M_{halo} = 3 \times 10^9 M_{sun}$

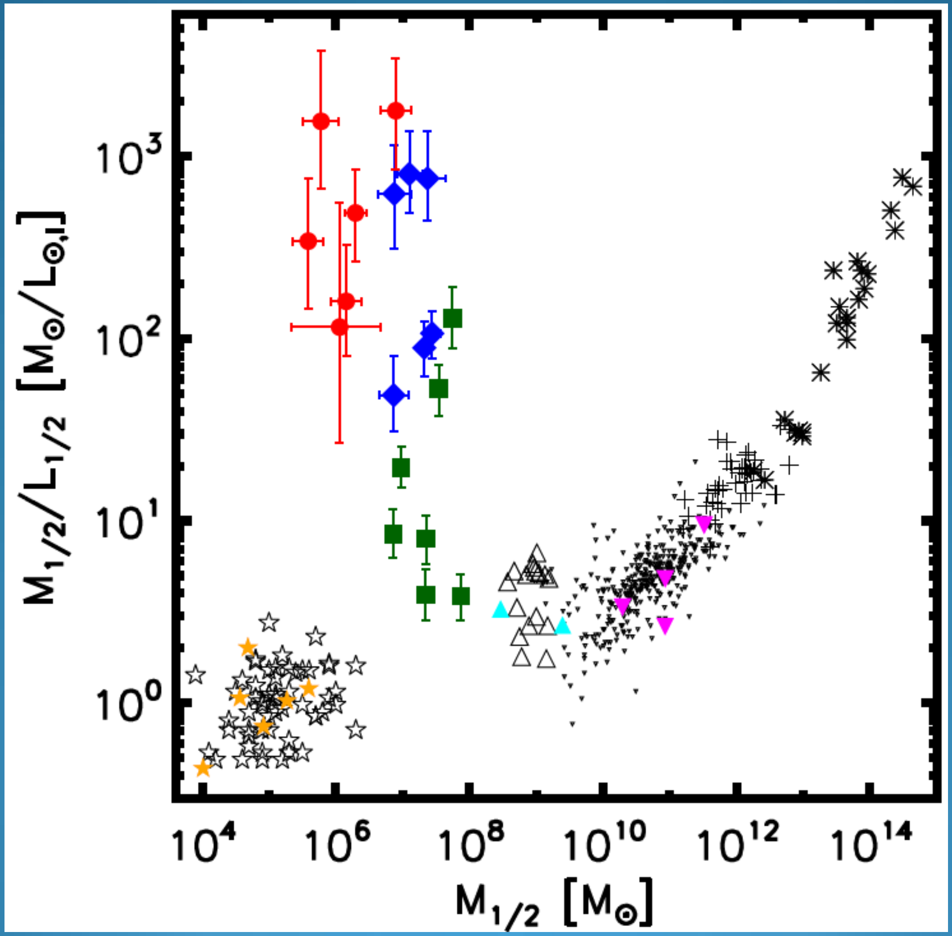
Minimum mass threshold for galaxy formation?





Notice: No trend with luminosity, as might be expected! Joe Wolf et al. 0908.2995

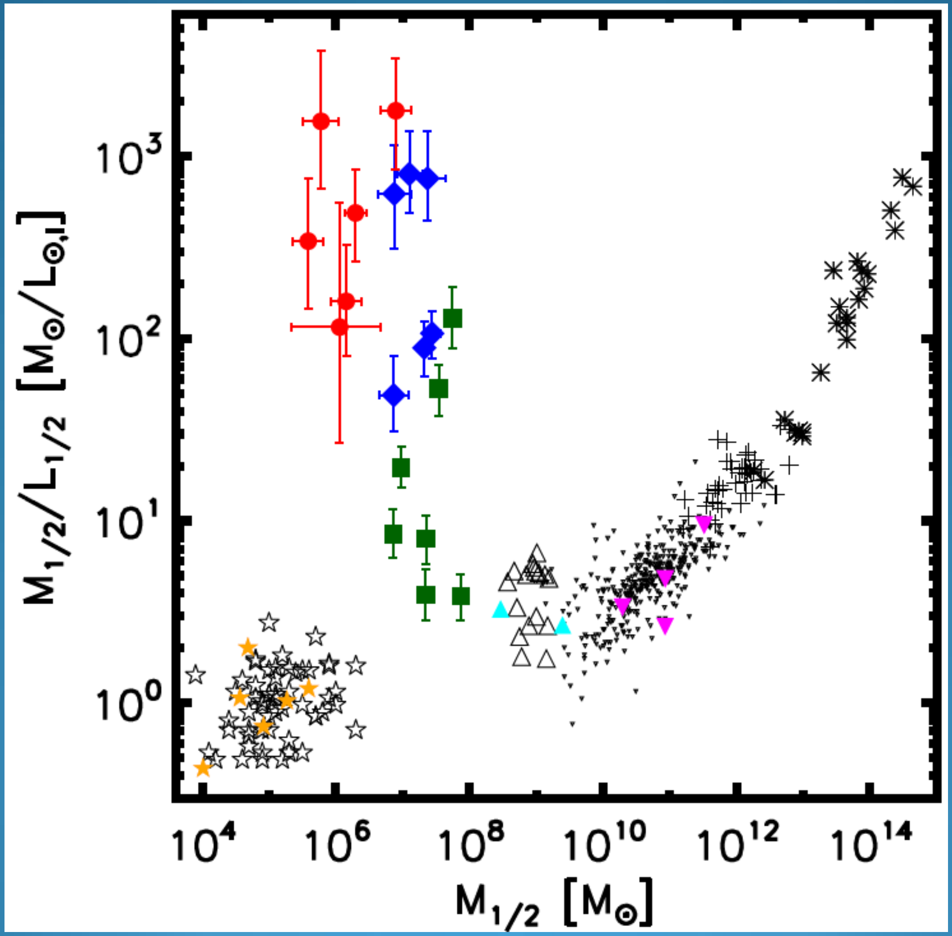
Applications: Global



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.



Joe Wolf et al., 0908.2995

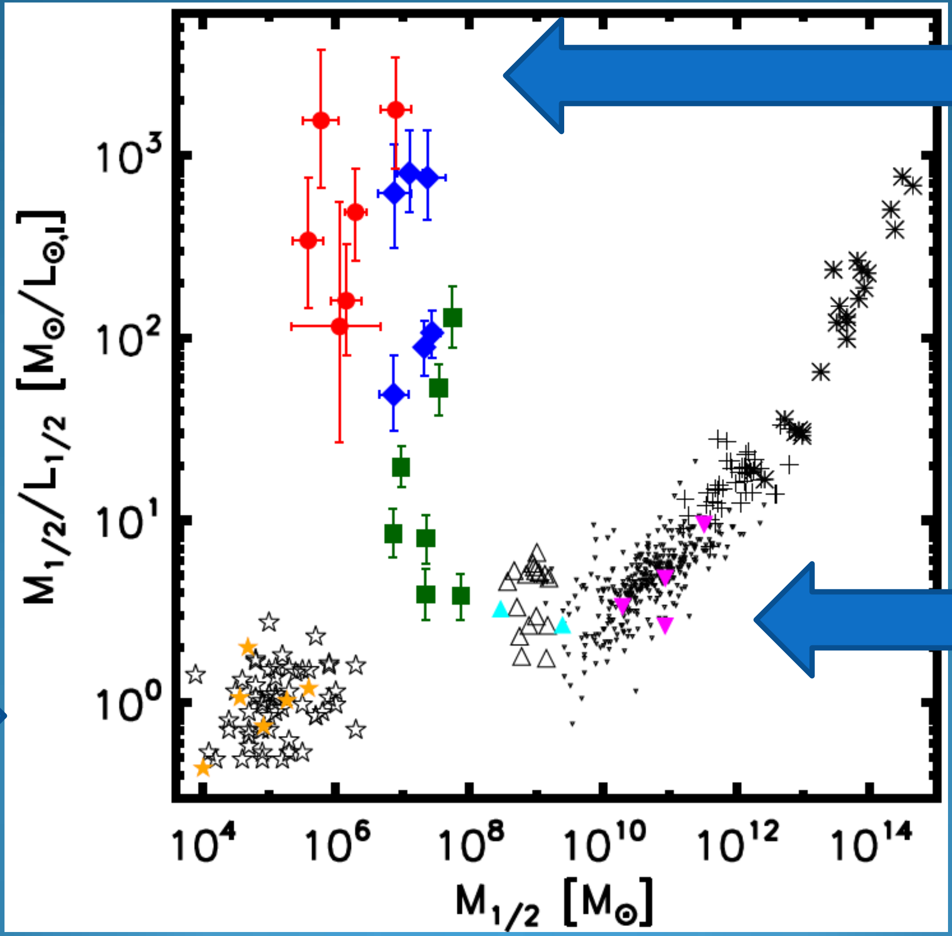
Applications: Global

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

Ultrafaint dSphs: most DM dominated systems known!

Globulars: Offset from L* by factor of three

(Hmm…)

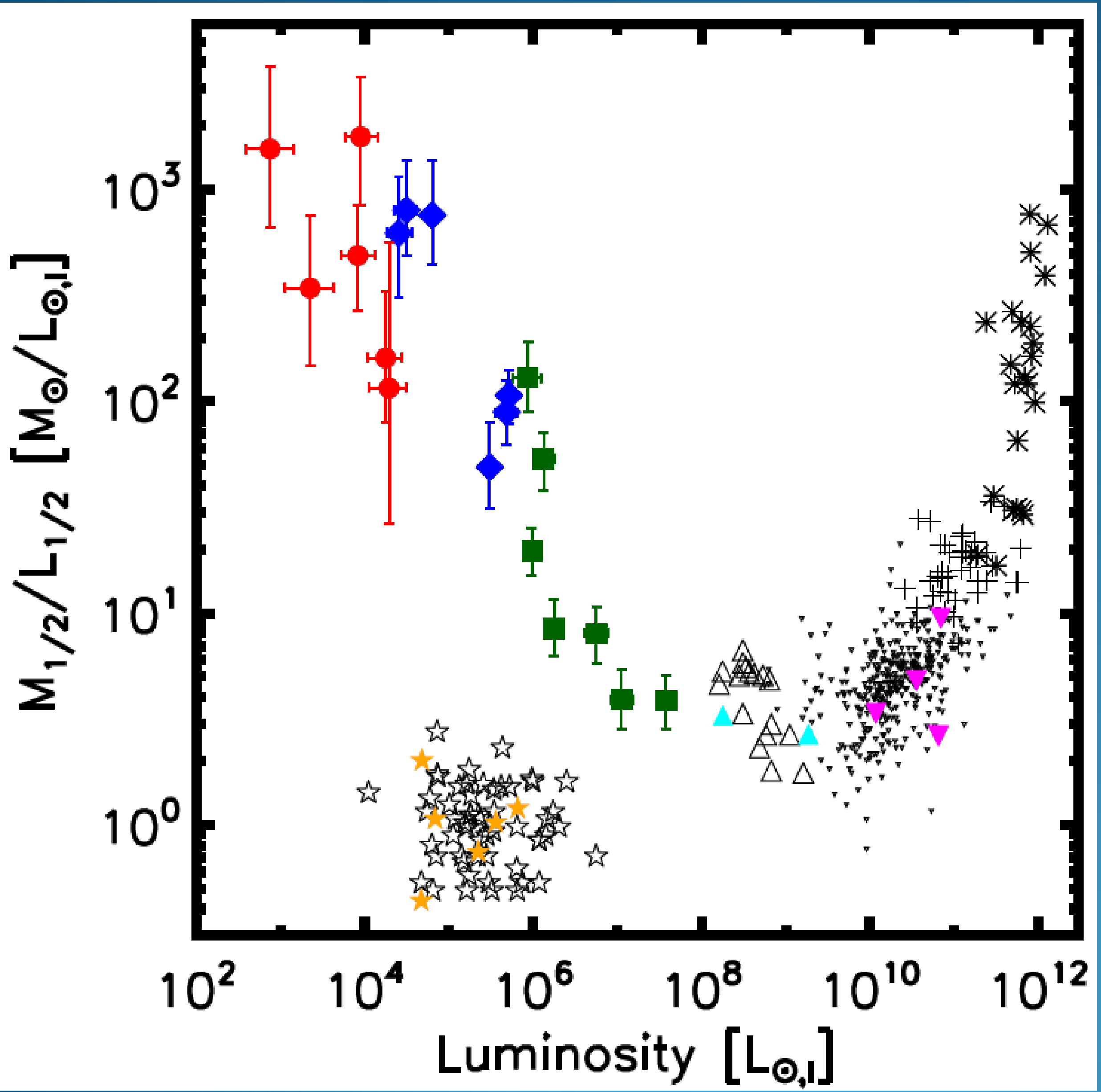


Inefficient at galaxy formation

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

Looking at the FP in a new way

Fundamental Plane:
Independent Observables

MLR:
Intrinsic Properties

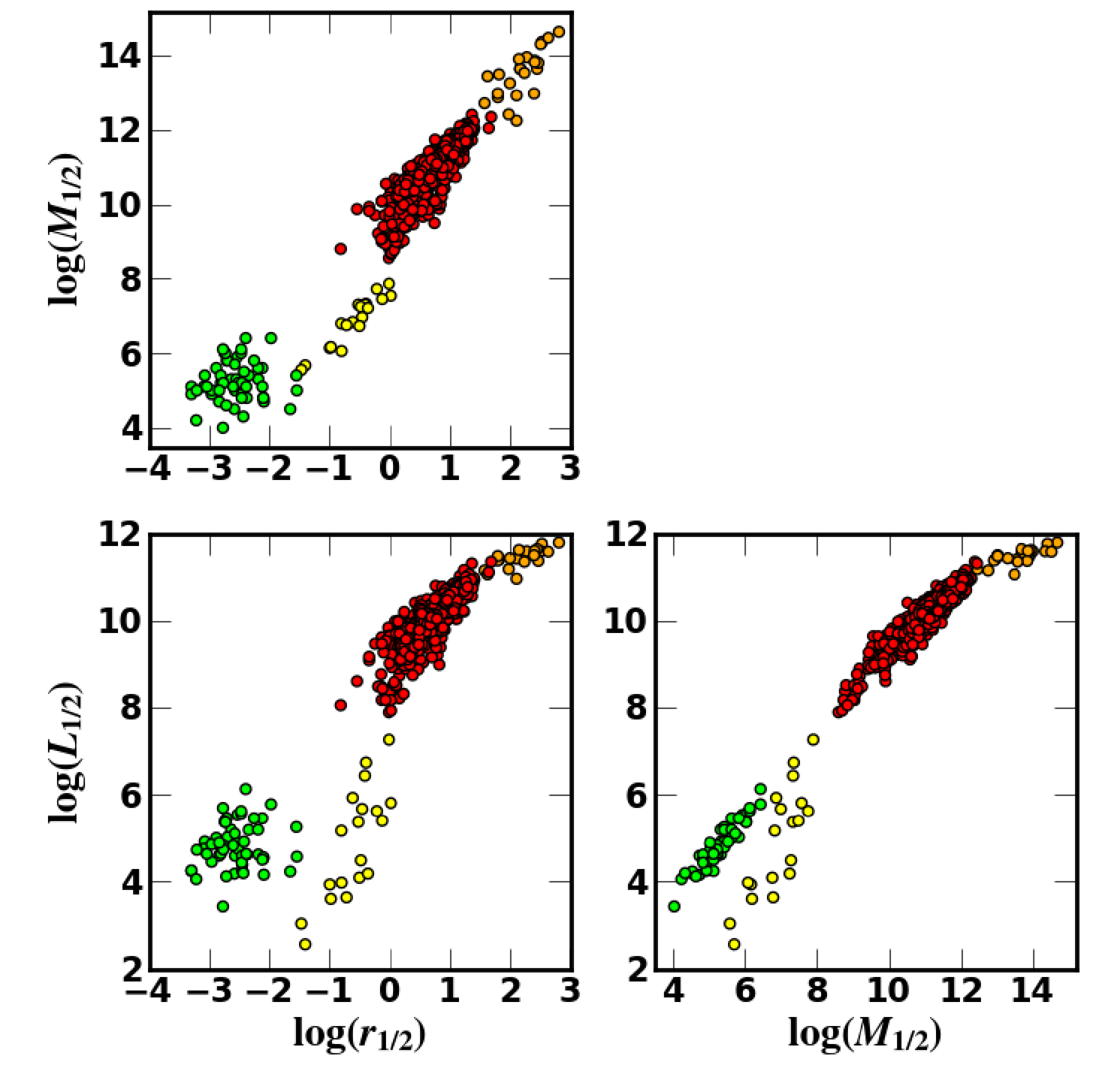
σ → $M_{1/2} = 3\,G^{-1}\,r_{1/2}\,\langle\sigma_{\rm los}^2\rangle$ → $M_{1/2}$

$R_{\rm eff}$ → $r_{1/2} \simeq 4/3\,R_{\rm eff}$ → $r_{1/2}$

$I_{\rm eff}$ → $L_{1/2} = \frac{1}{2}\,I_{\rm eff}\,\pi\,R_{\rm eff}^2$ → $L_{1/2}$

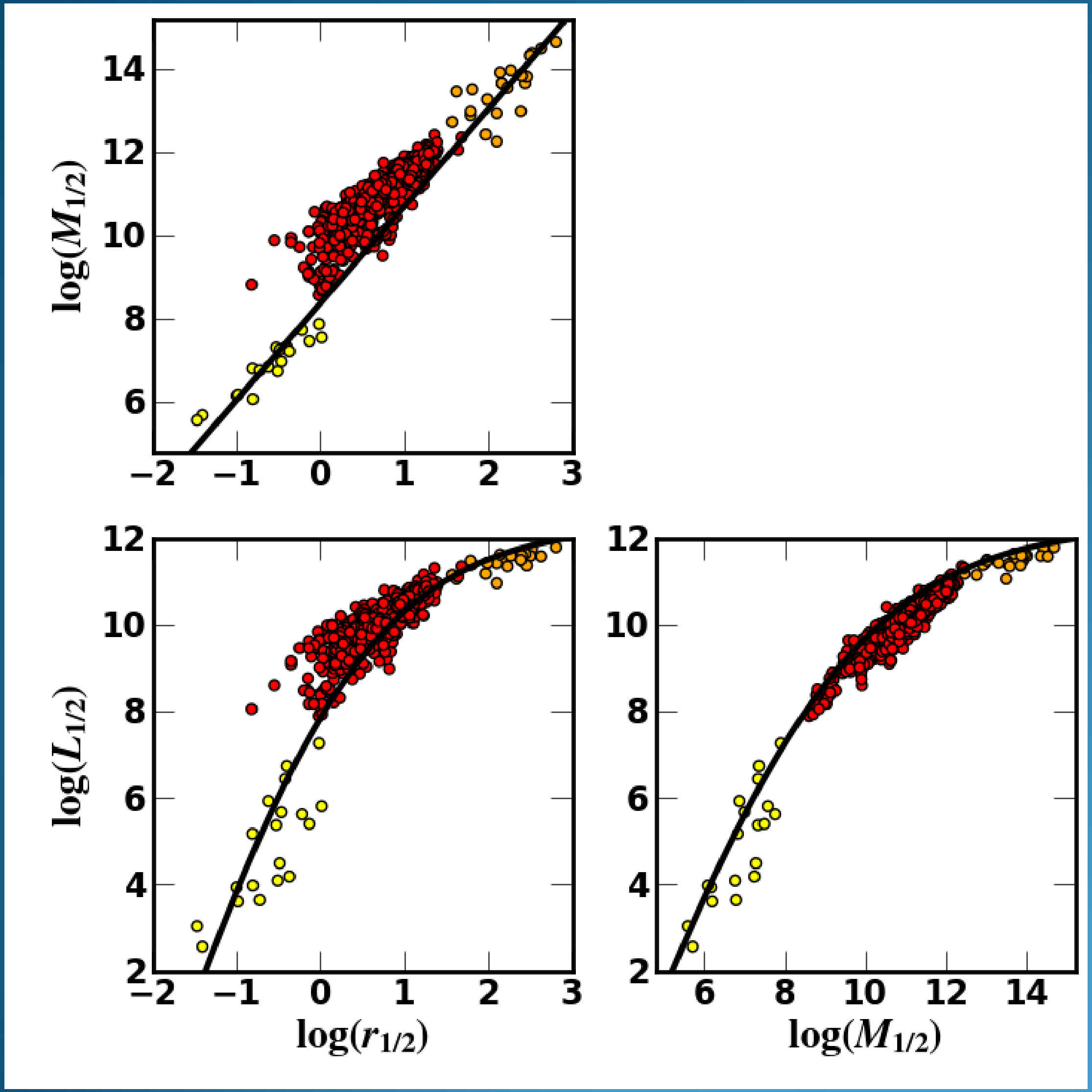
Erik Tollerud, JW, et al. in prep.

MLR Space

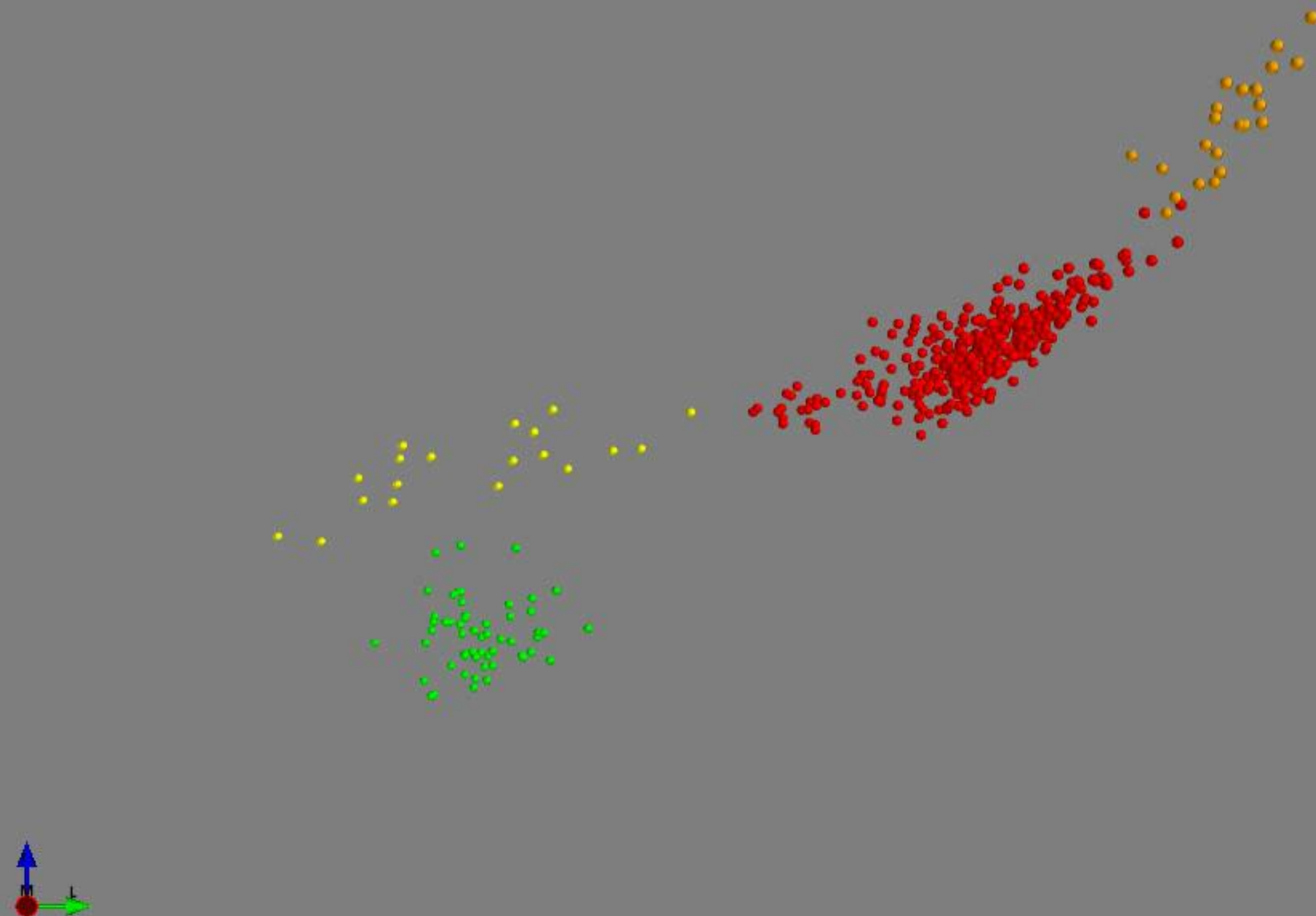


Erik Tollerud, JW, et al. in prep.

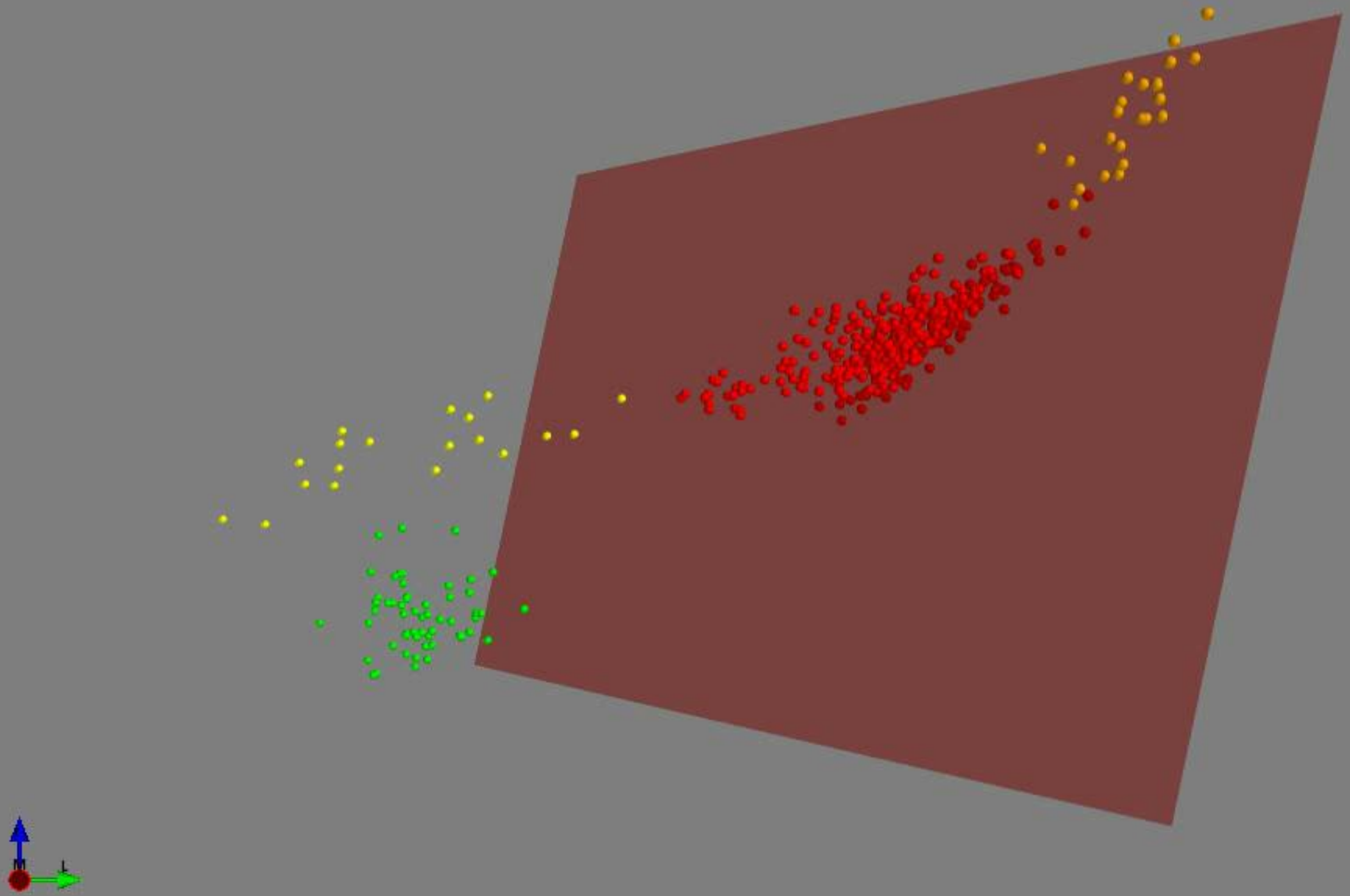
Fundamental Tube



Erik Tollerud, JW, et al. in prep.



Erik Tollerud
UC Irvine


M
L

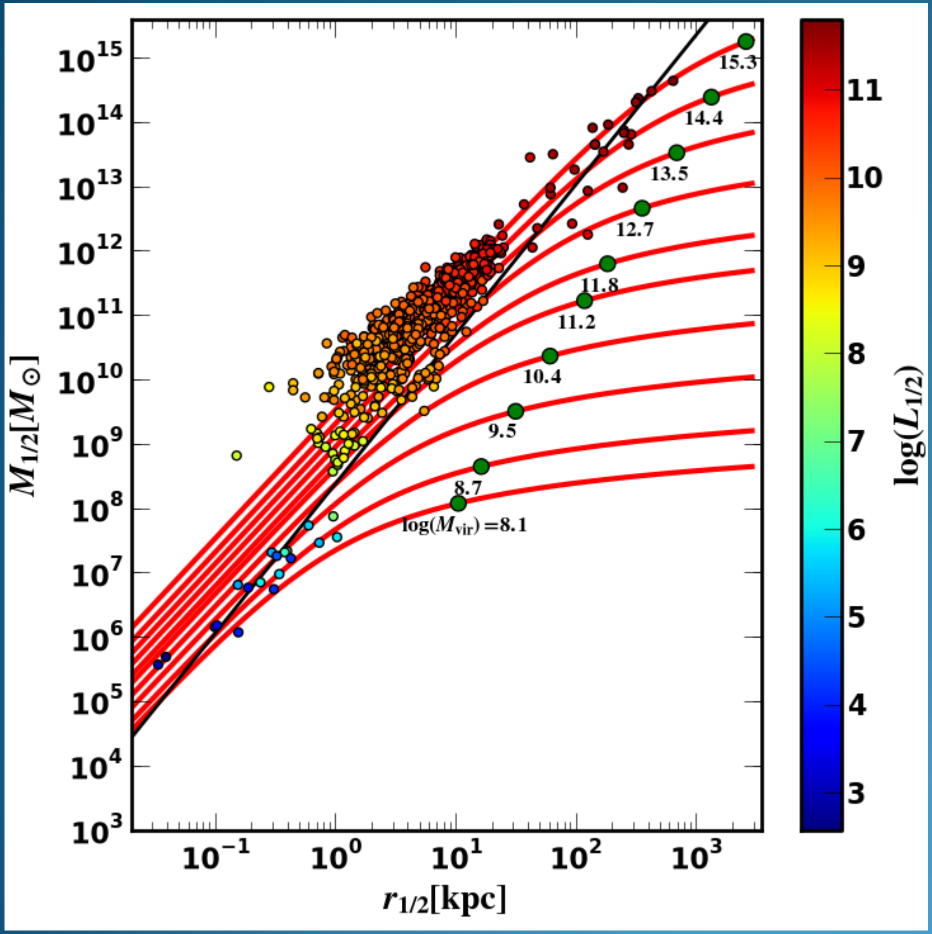
Fundamental Tube

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.

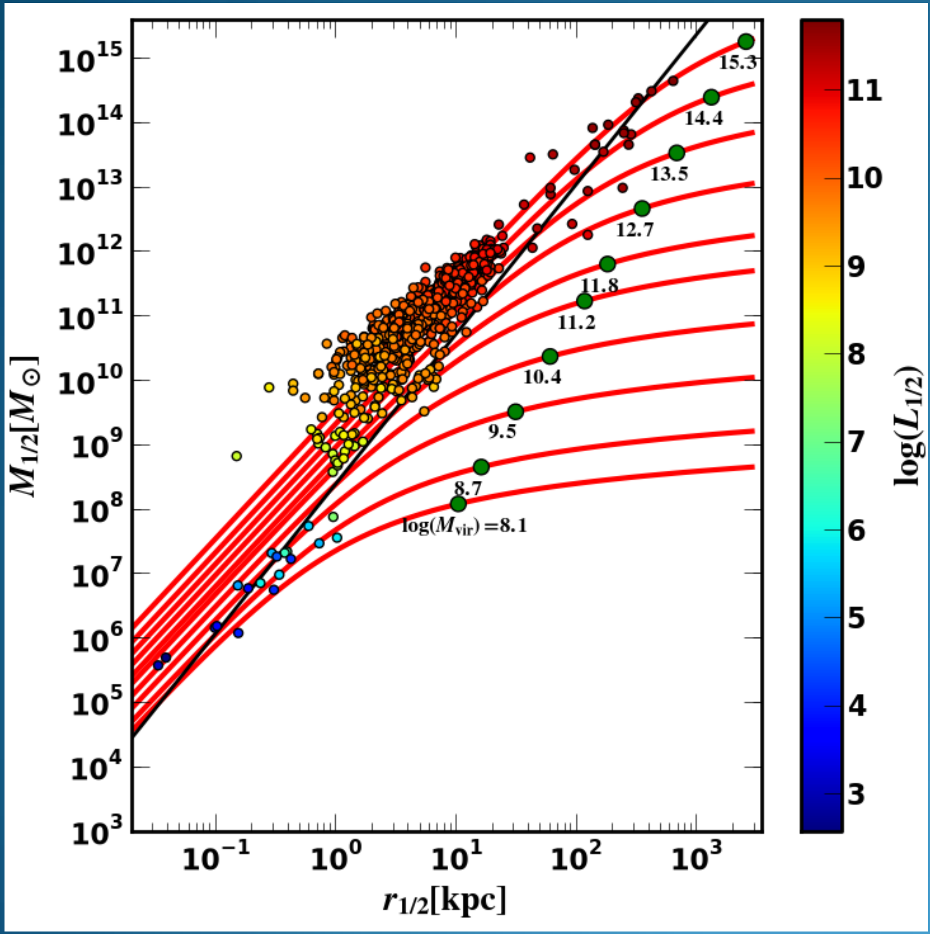
Erik Tollerud, JW, et al. in prep.

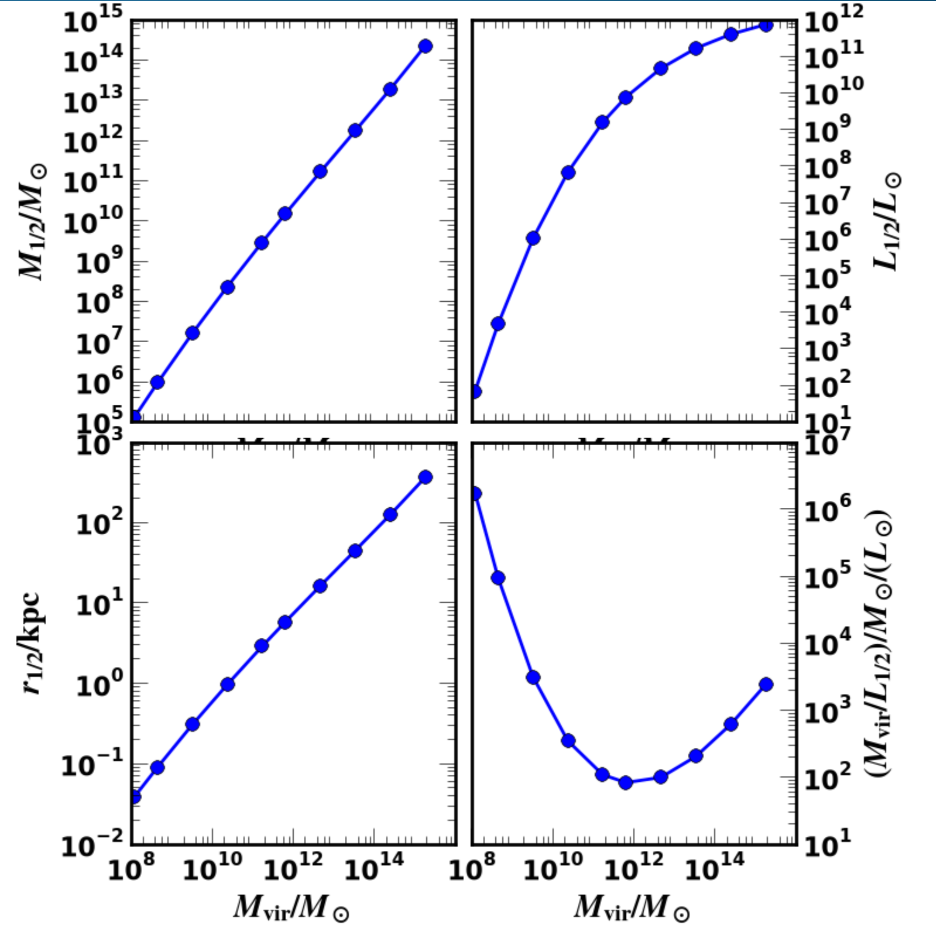
Profile Matching



Erik Tollerud, JW, et al. in prep.

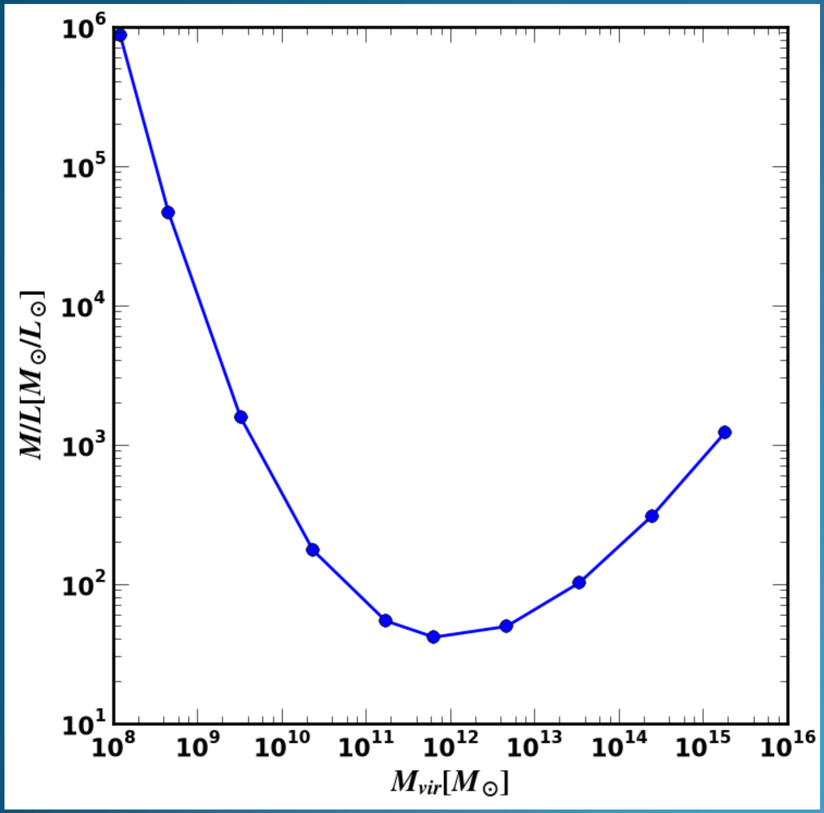
Profile Matching

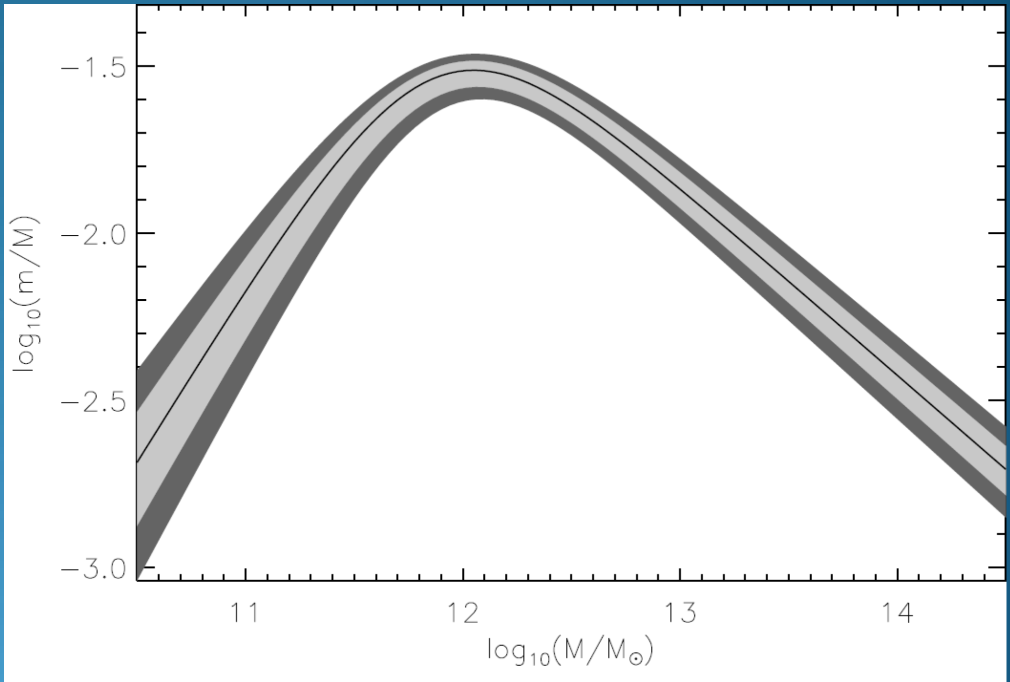




Erik Tollerud, JW, et al. in prep.

Profile Matching

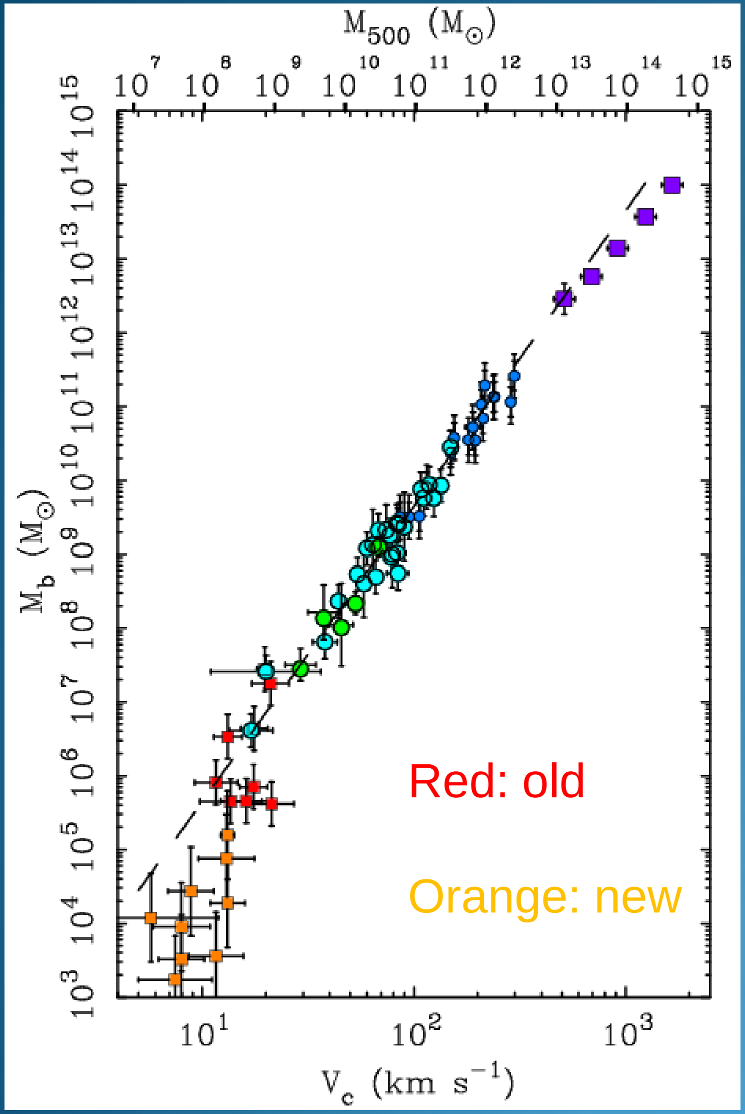




Moster et al. 0903.4682

Erik Tollerud, JW, et al. in prep.

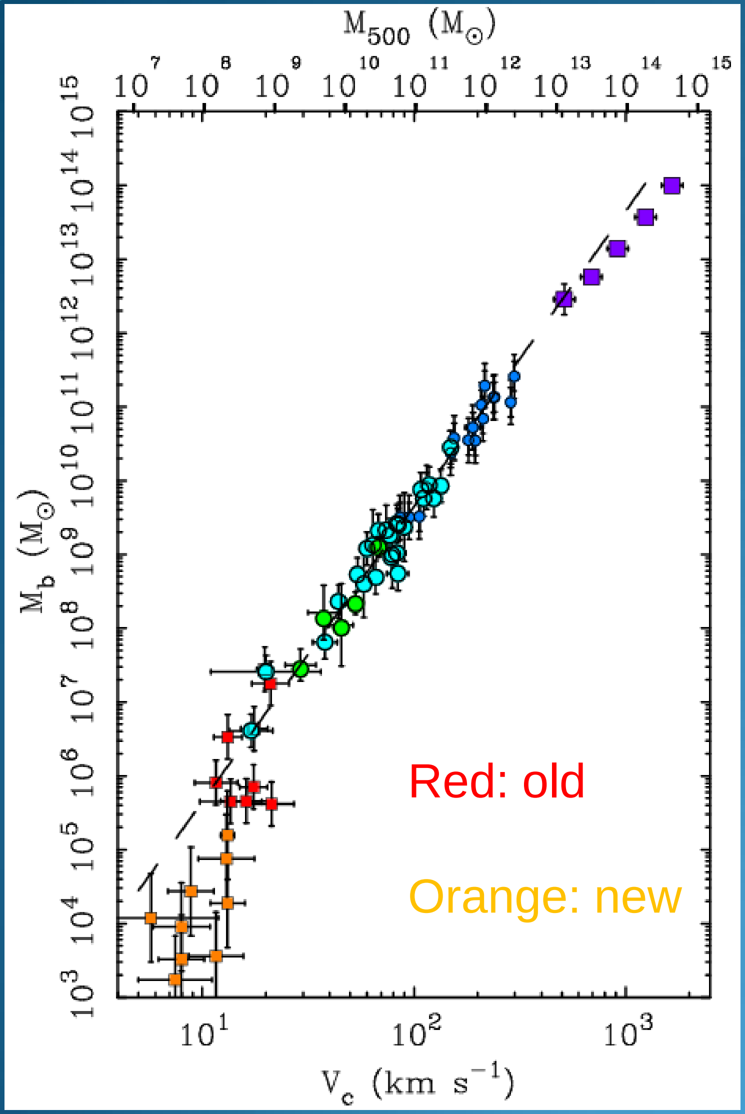
Baryonic Tully-Fisher Relation

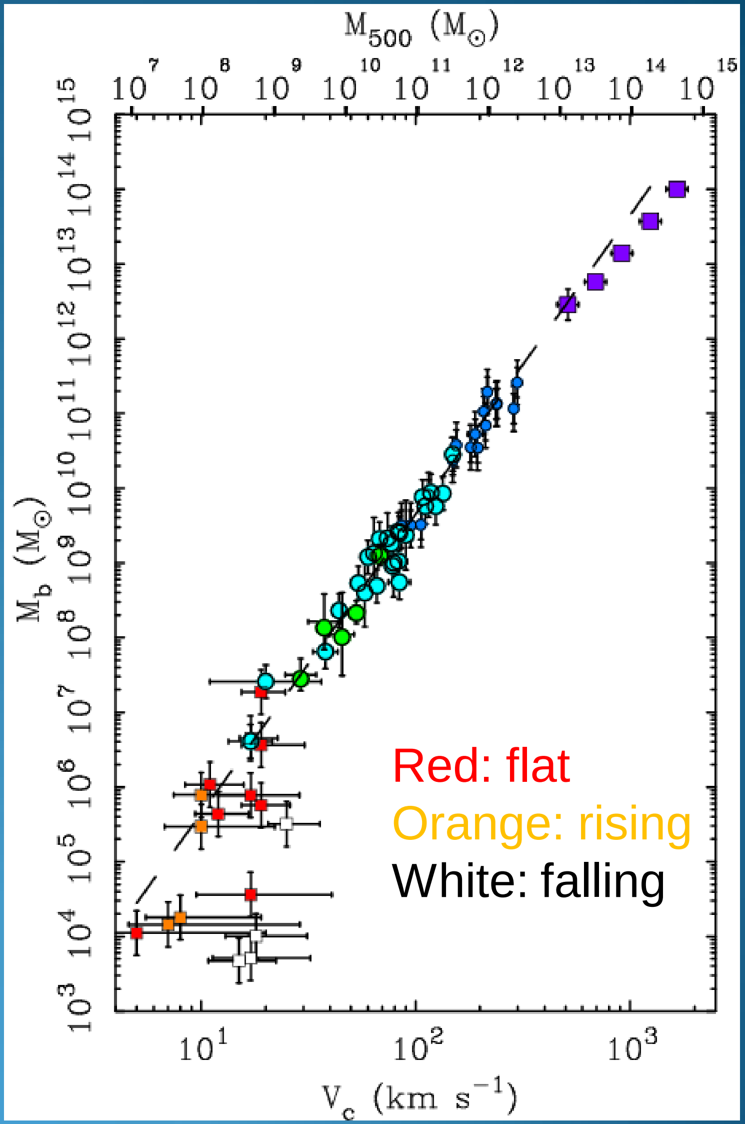


$$V_{circ} \geq \sqrt{3}\,\sigma$$

Stacy McGaugh
& JW in prep.

Baryonic Tully-Fisher Relation





$$V_{\mathrm{circ}} \geq \sqrt{3}\,\sigma$$

Stacy McGaugh
& JW in prep.

$$V_{\mathrm{circ}}(r = r_{\mathrm{last}})$$

Itemized Outline

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- New spectroscopic observations of M31 dSphs
- The future: SIM & proper motions

Another dataset: M31

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

UC Santa Cruz: Raja Guhathakurta (SPLASH PI)

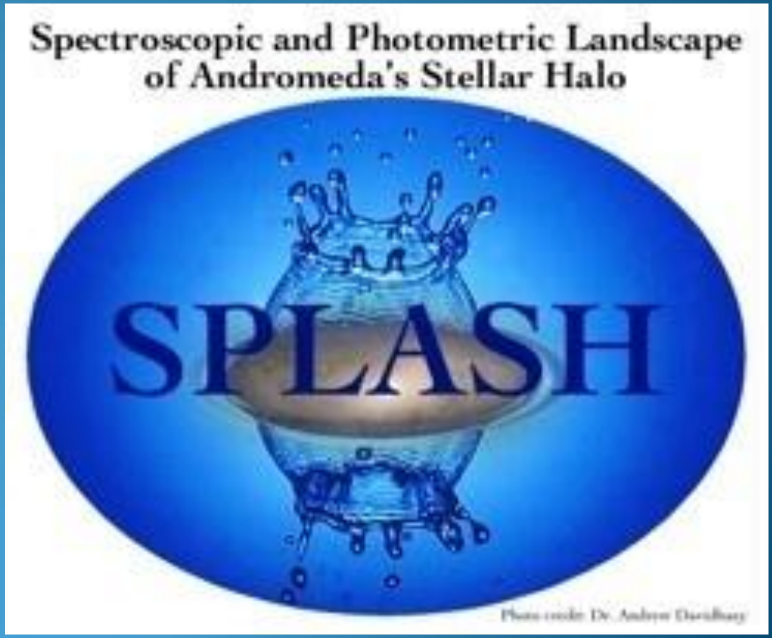
STScI: Jason Kalirai

Yale: Marla Geha

U. Washington: Karrie Gilbert

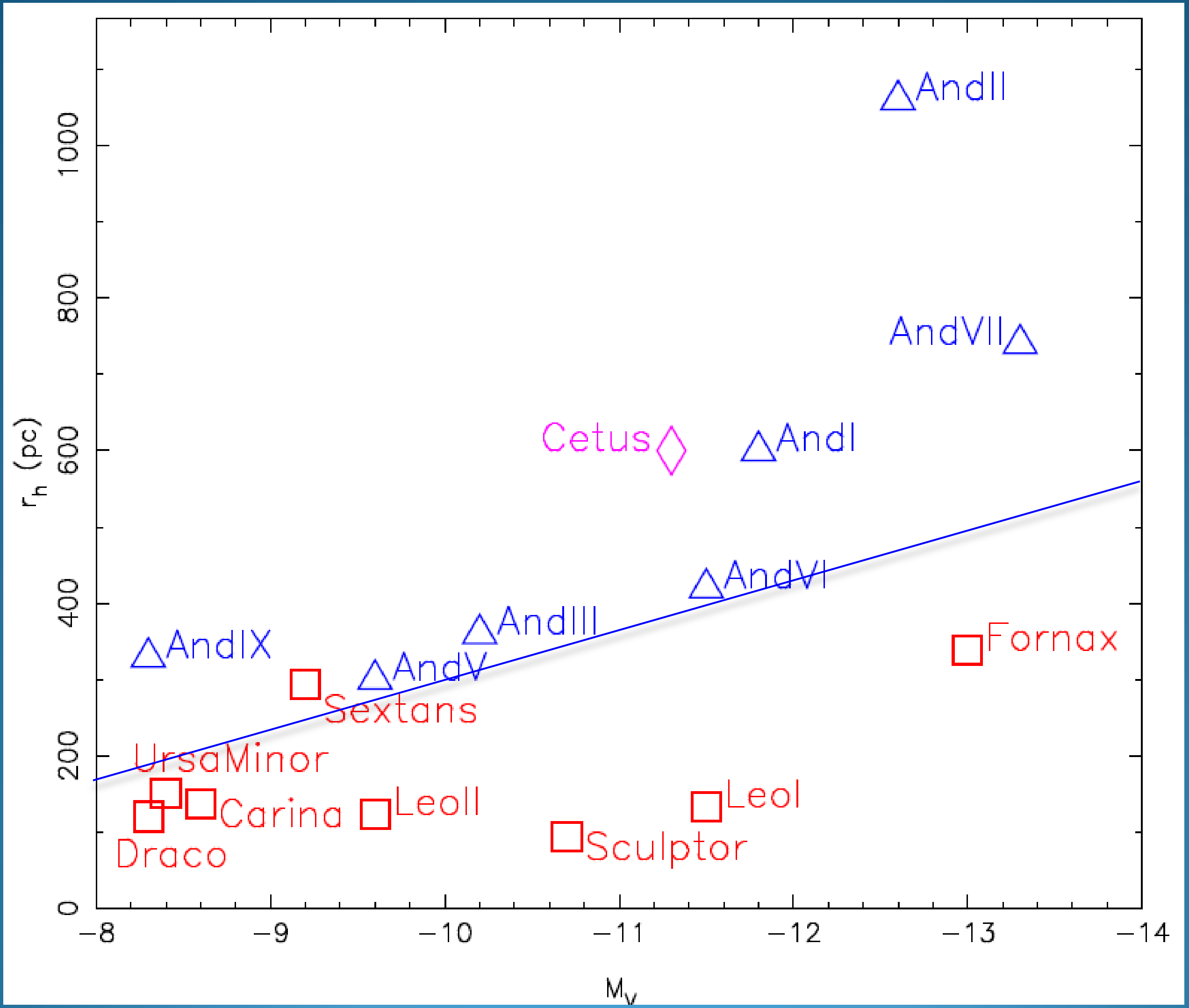
Caltech: Evan Kirby

And others involved in SPLASH →



M31 dSphs: Larger than MW dSphs

Observed half-light radius



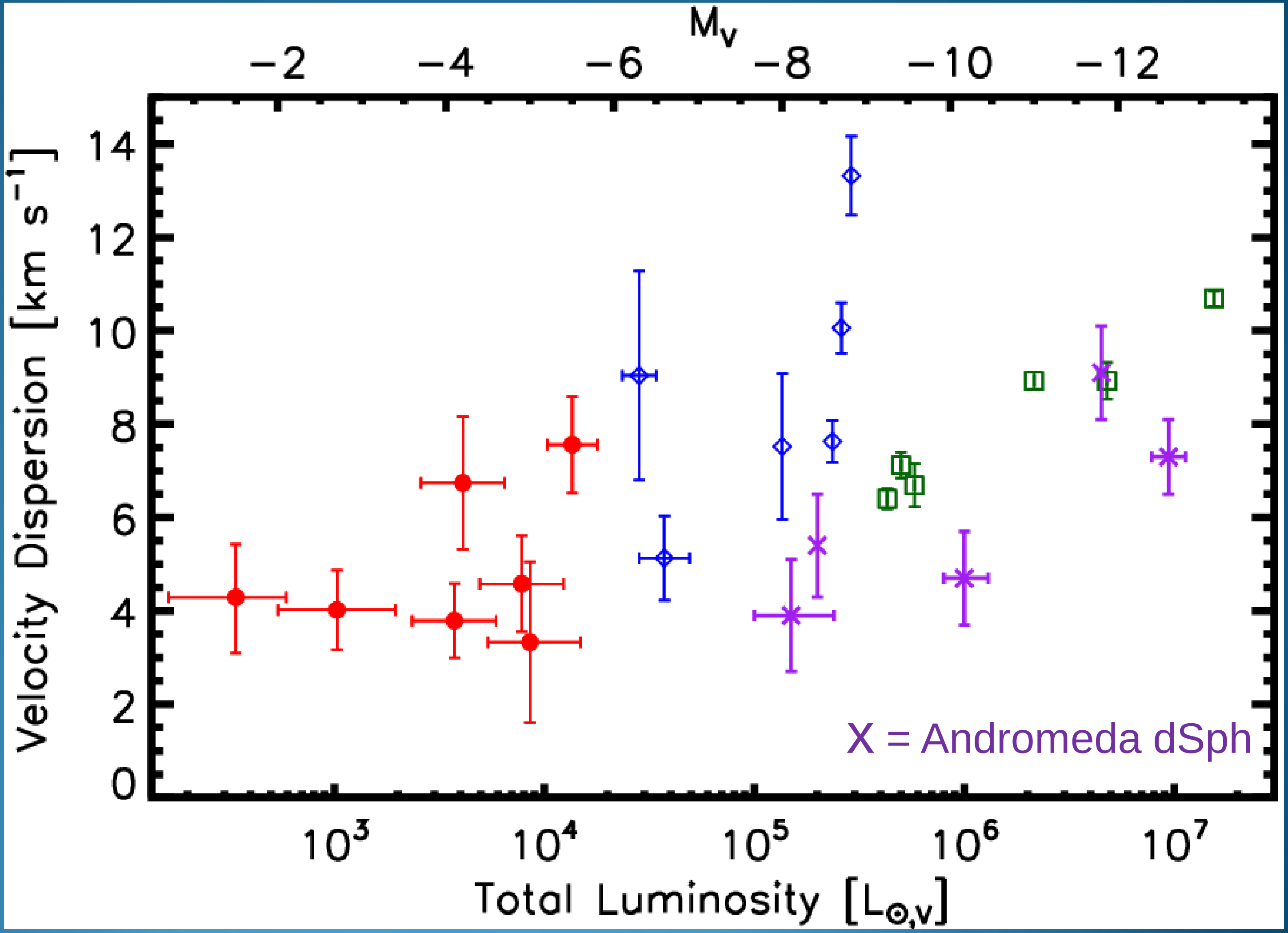
Dim Luminosity Bright

McConnachie & Irwin 2006, MNRAS

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



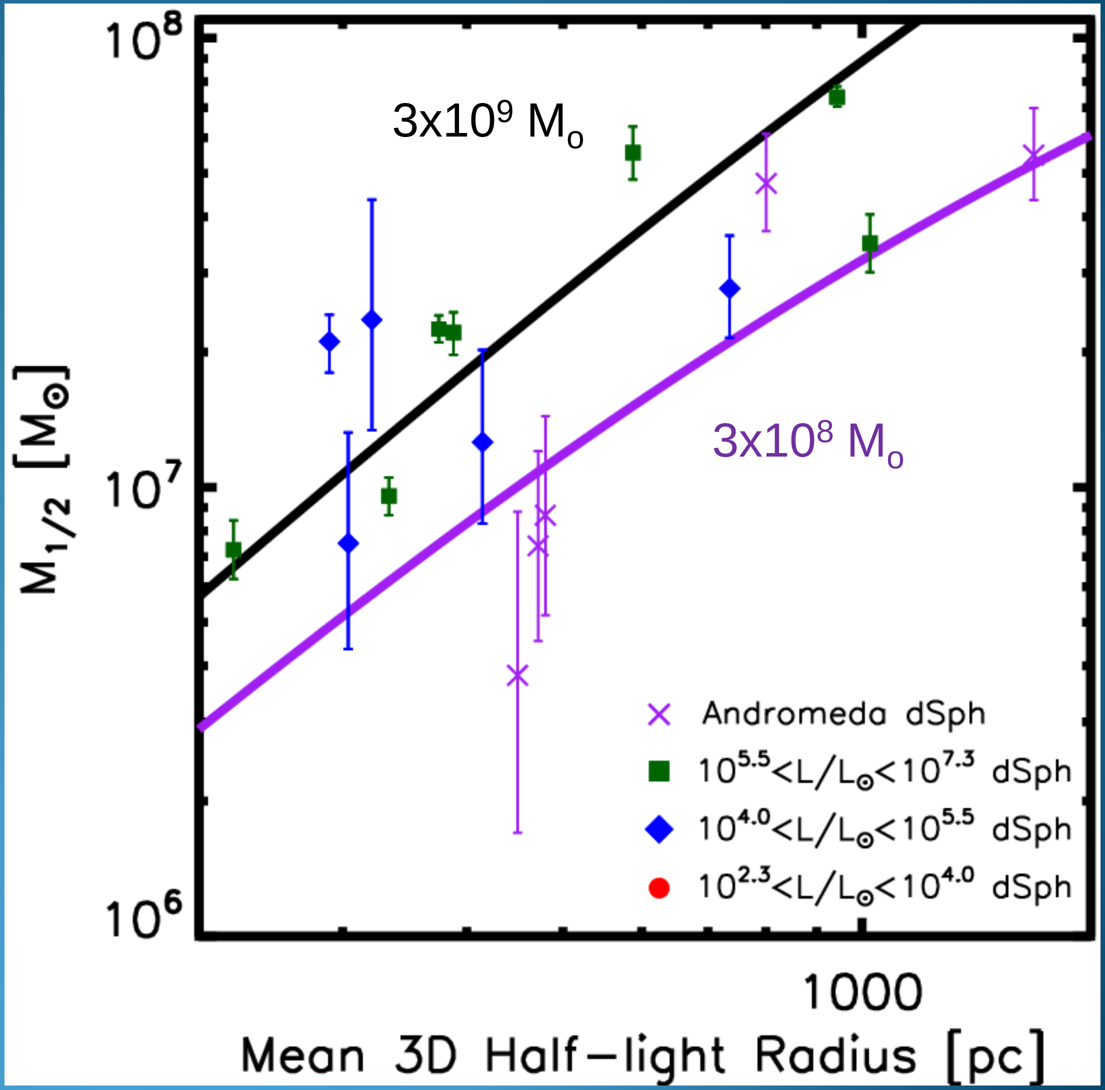
Dispersion data from Kalirai et al 2009, in prep

M31 dSphs: Bigger but less massive!

Spectroscopic data from Keck/DEIMOS: 10 times more than existed before!

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

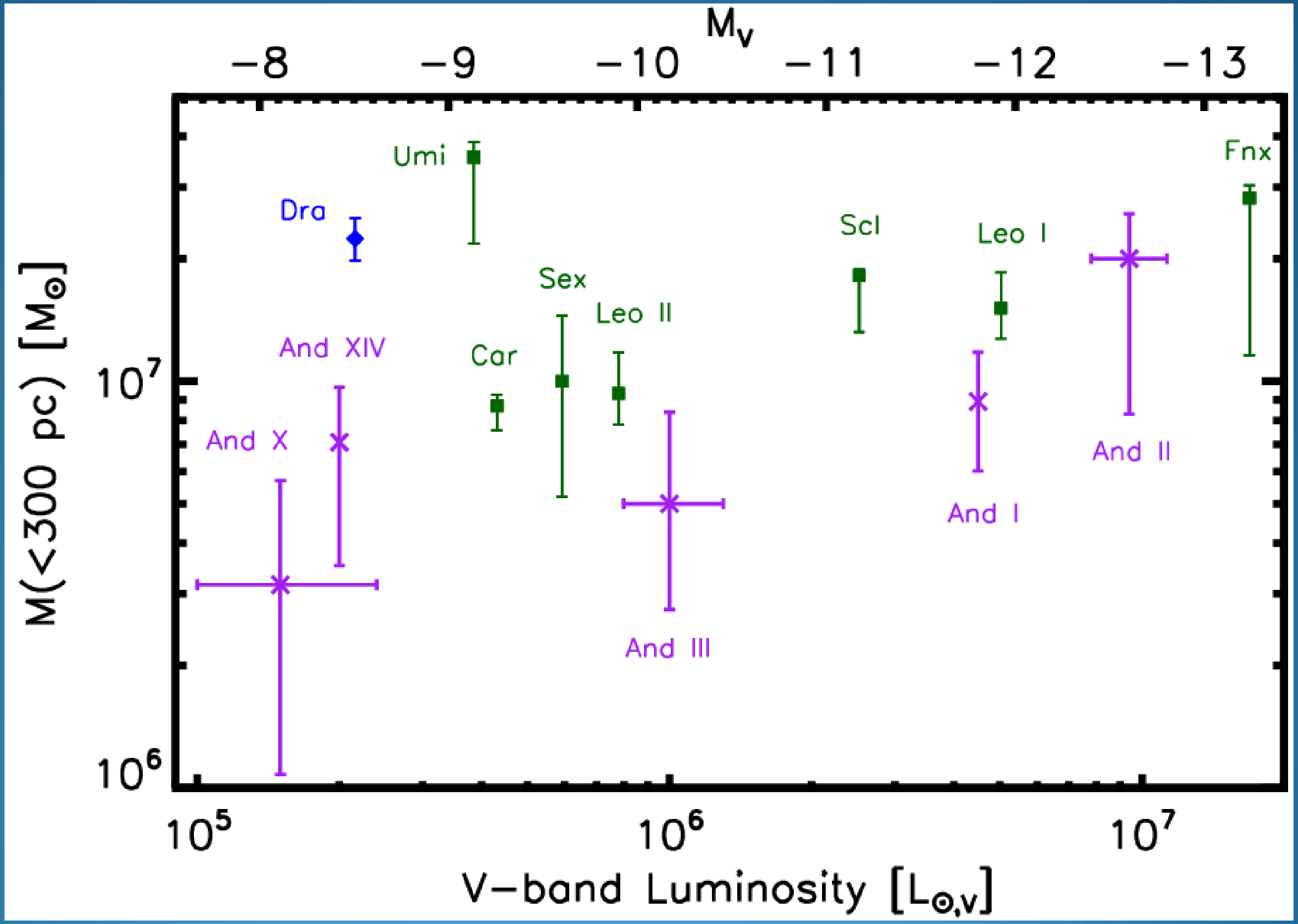
Joe Wolf et al., in prep



M31 dSphs: Bigger but less massive!

CDM Prior on masses

(preliminary)

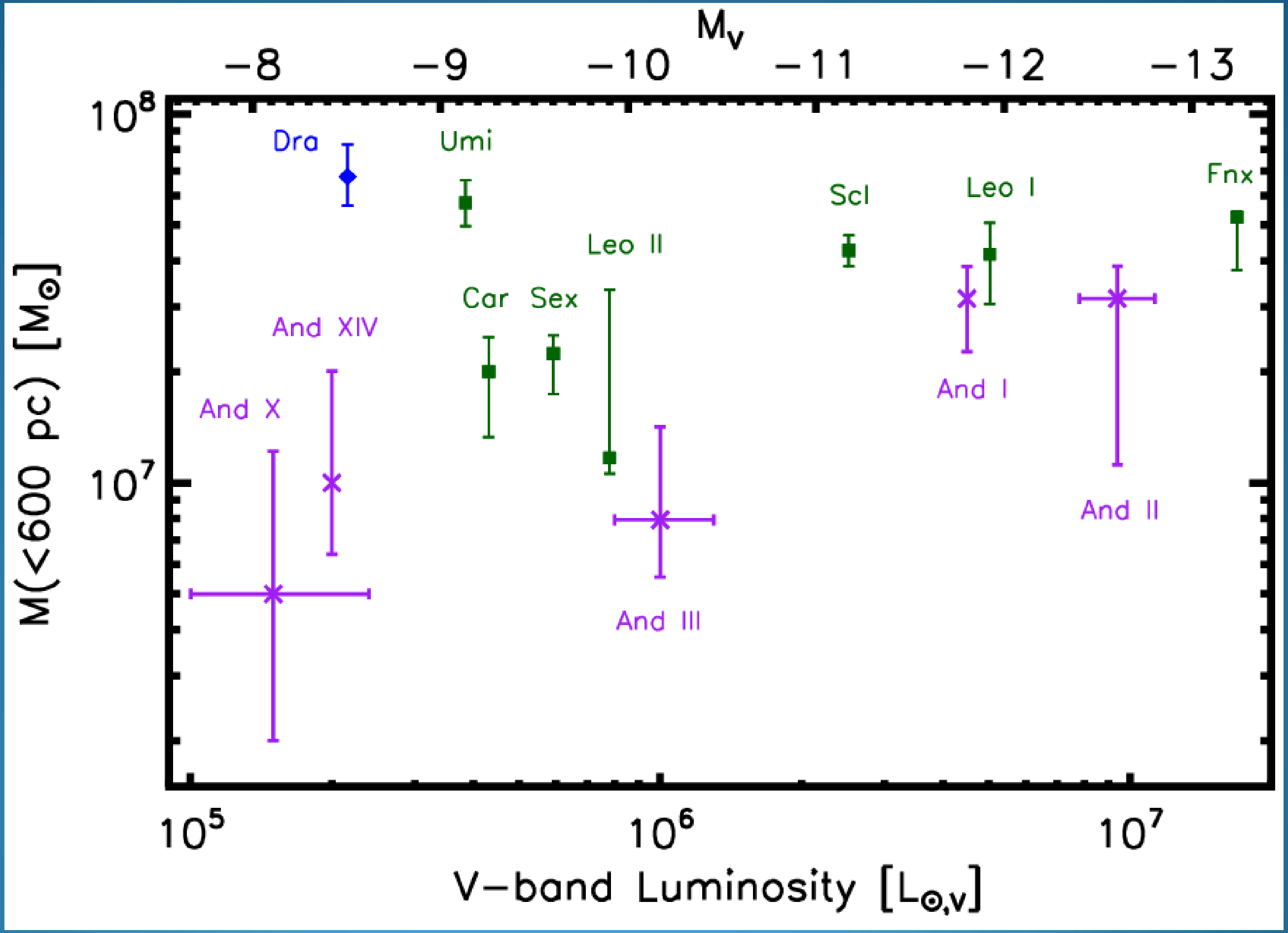


Joe Wolf et al., in prep

M31 dSphs: Bigger but less massive!

CDM Prior
on masses

(preliminary)



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.

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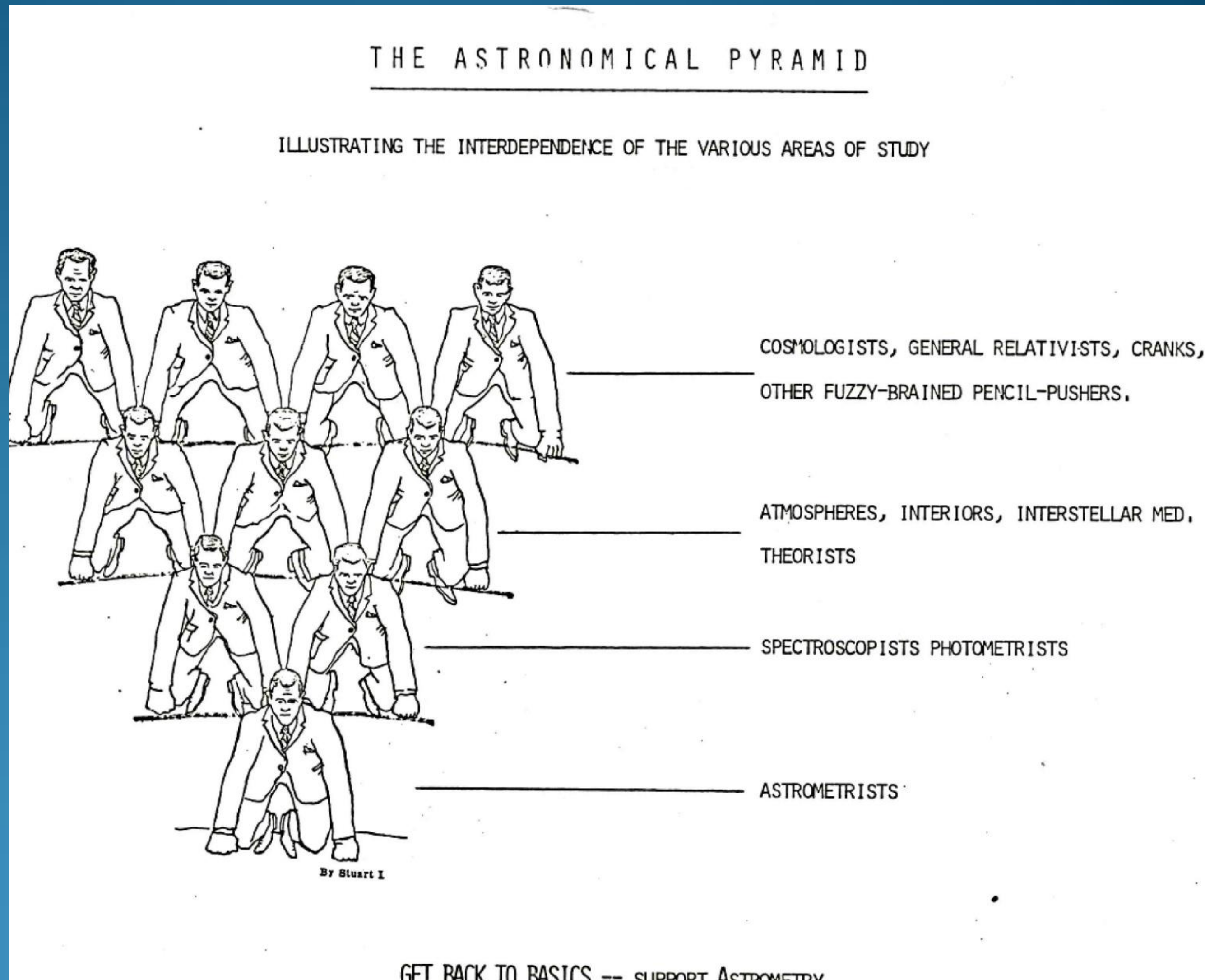
From Earth-Like Planets to Dark Matter…

SIM Lite
Astrometric Observatory:
Late 2015

SIM Lite



by Ron Probst, ~1978
While a grad student at UVa

SIM Lite

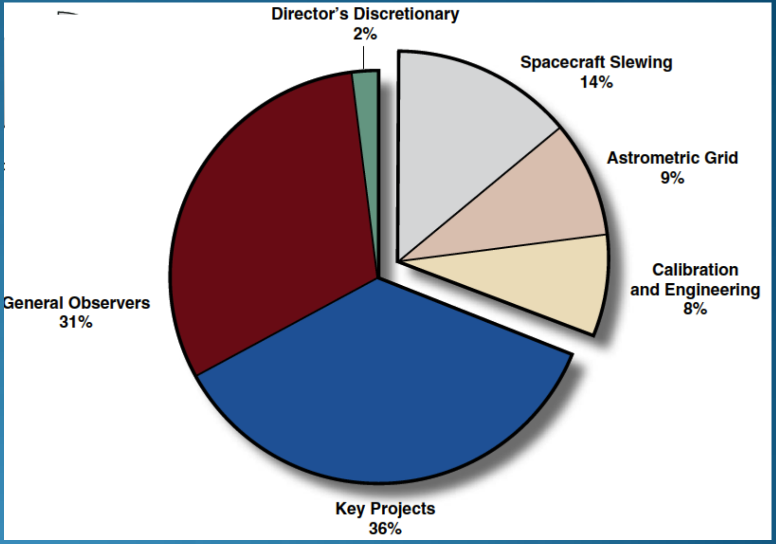
Future Opportunities: General Observer Program

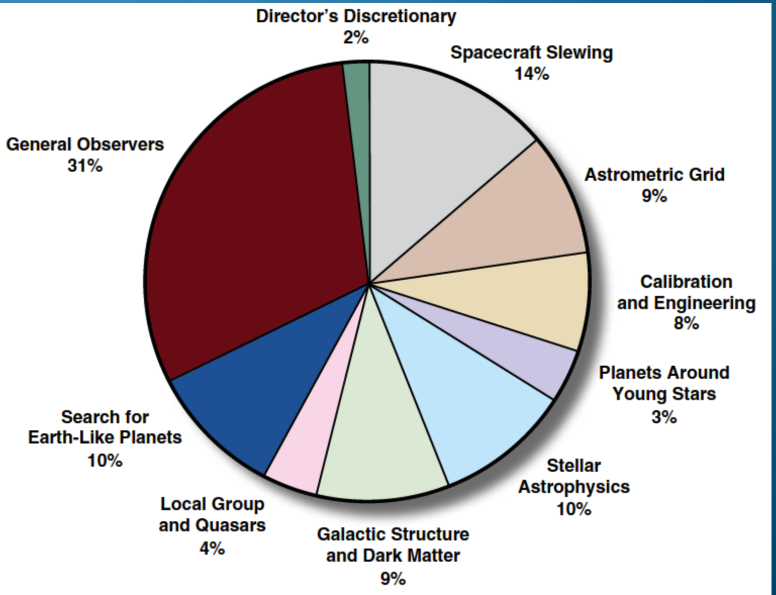
Unofficial plan (may change)

All remaining observing time on SIM Lite will be competed through a General Observer (GO) Call
About 31% of 5 years
This is about half of the total science time

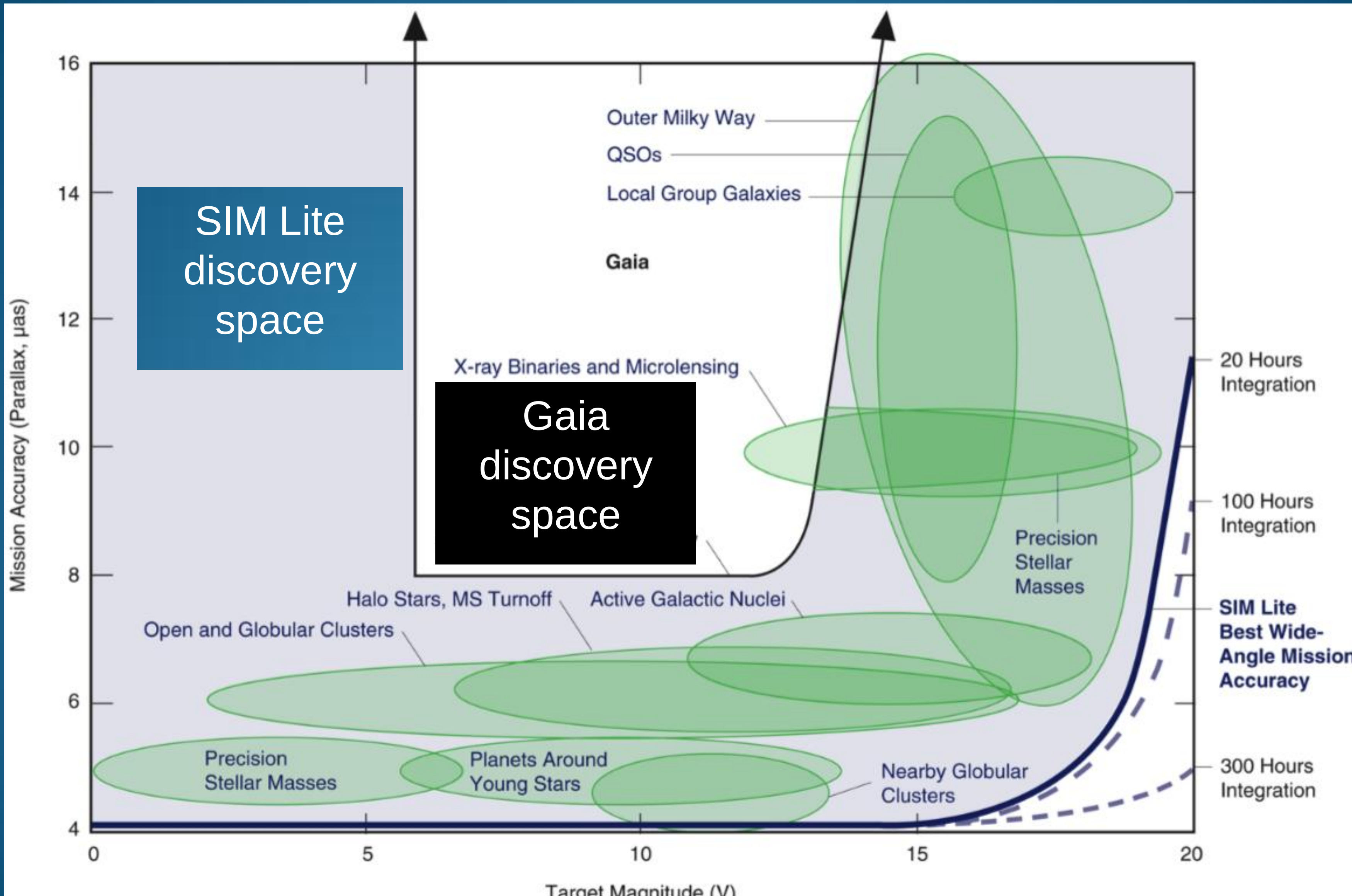
GO Program call will be issued 2-3 years before launch

GO call will be completely open with respect to science topics
Peer review will determine the most promising science

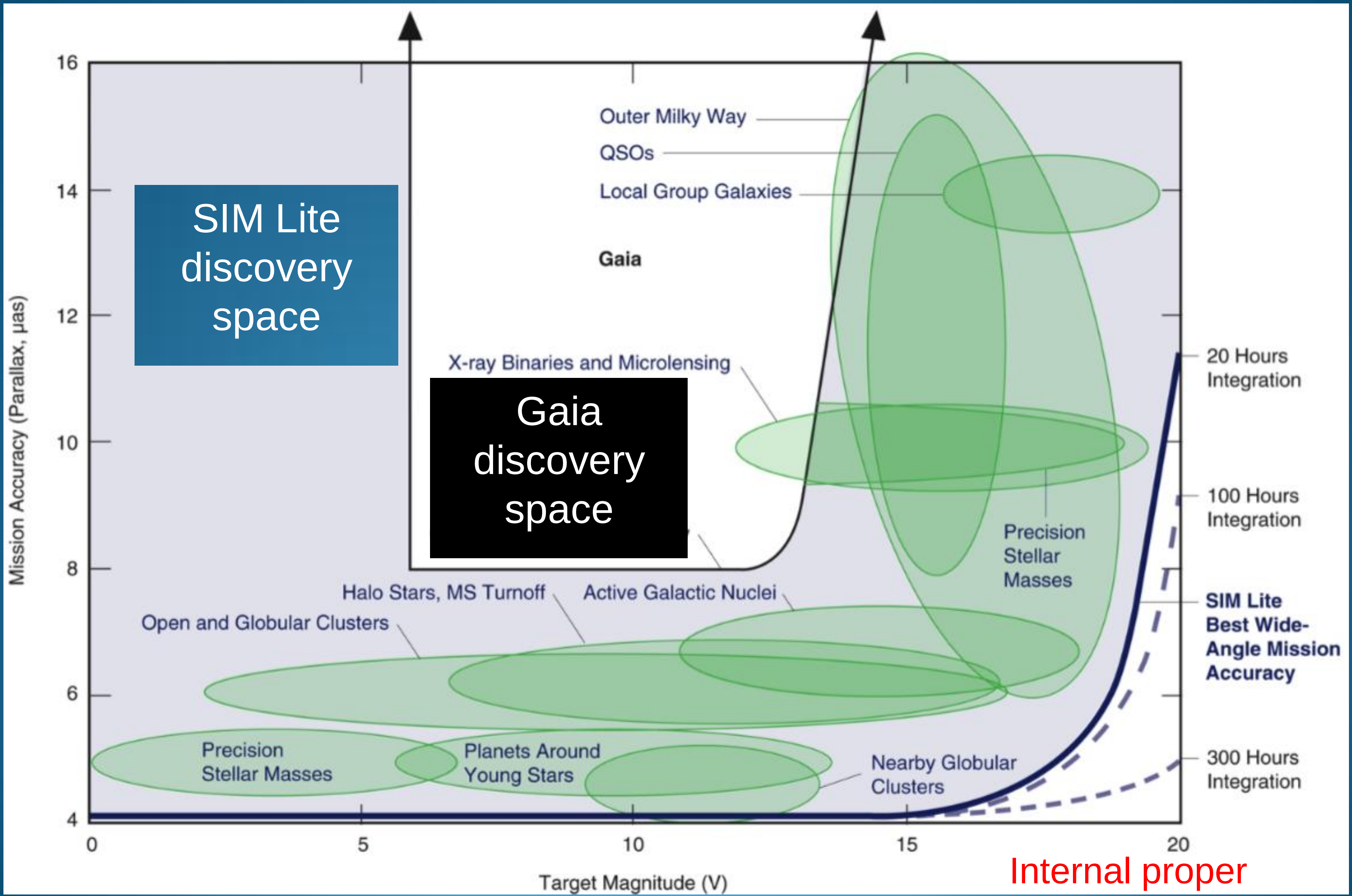




SIM Lite

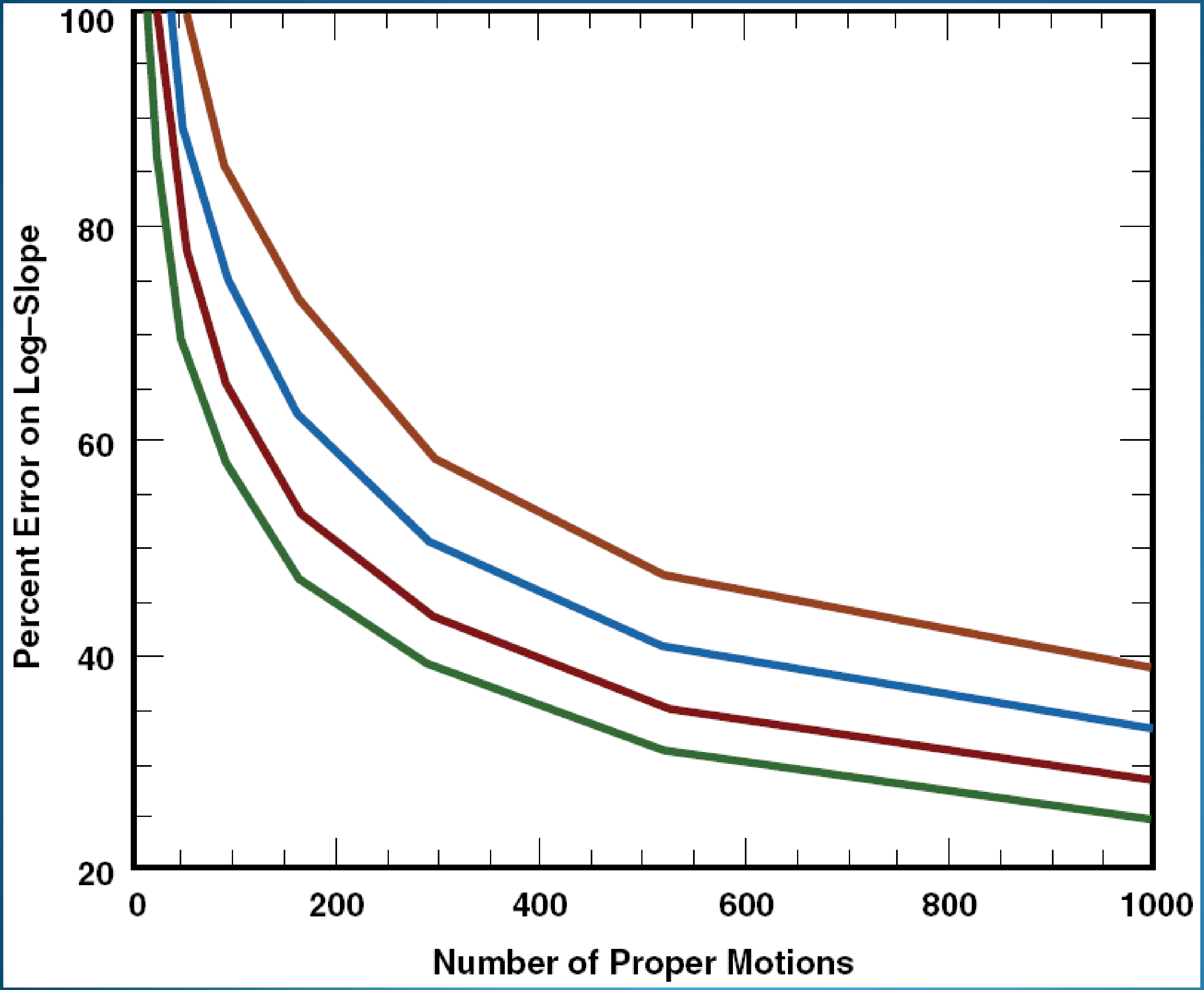

SIM Lite discovery space
Gaia discovery space
Outer Milky Way
QSOs
Local Group Galaxies
Gaia
X-ray Binaries and Microlensing
Precision Stellar Masses
Halo Stars, MS Turnoff
Active Galactic Nuclei
Open and Globular Clusters
Precision Stellar Masses
Planets Around Young Stars
Nearby Globular Clusters
20 Hours Integration
100 Hours Integration
SIM Lite Best Wide-Angle Mission Accuracy
300 Hours Integration
Mission Accuracy (Parallax, µas)
16
14
12
10
8
6
4
0
5
10
15
20
Target Magnitude (V)

SIM Lite



Internal proper motions of dSphs

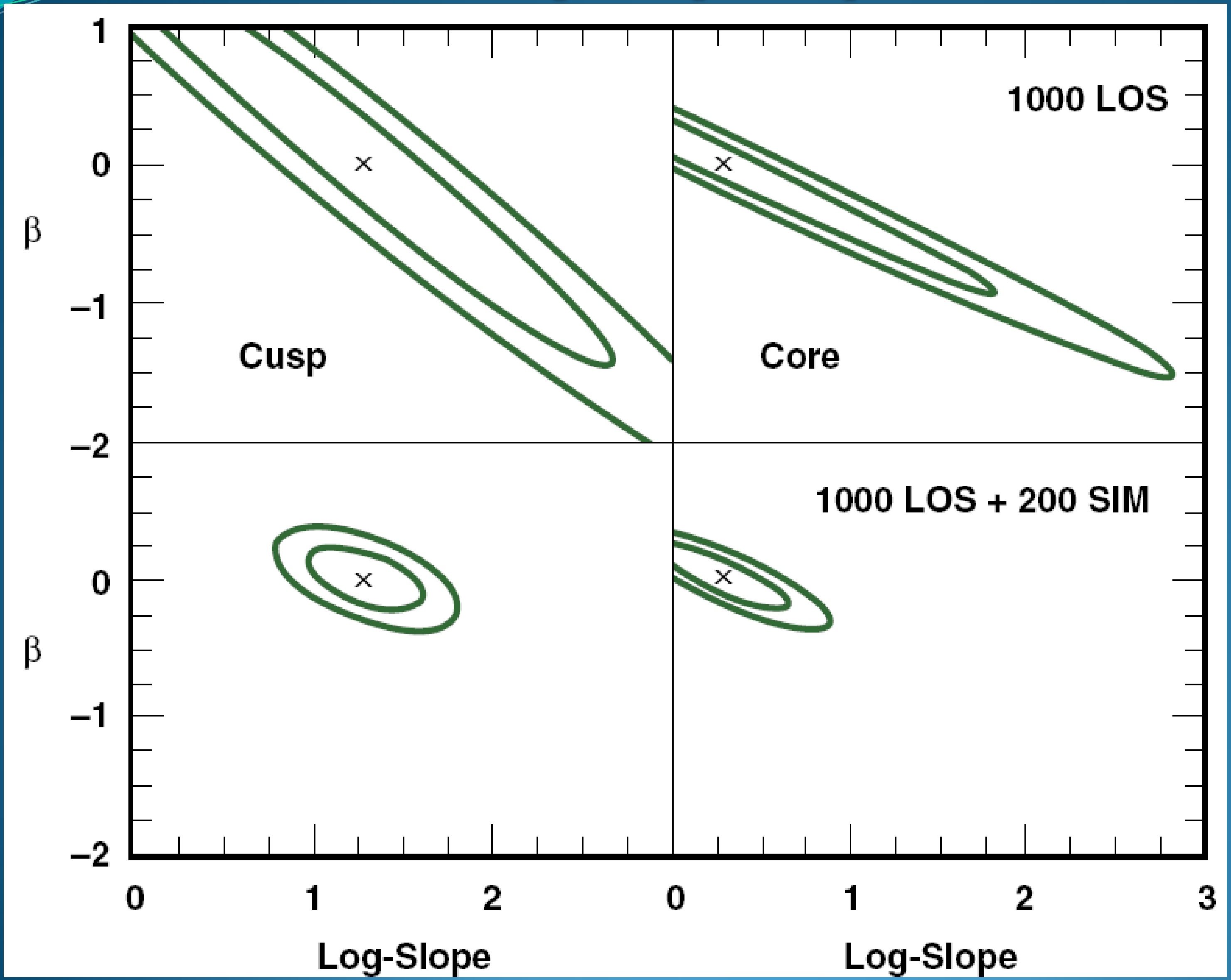
Internal dSph proper motions



Mean PM error
O: 10 km/s
B: 7 km/s
R: 5 km/s
G: 3 km/s

0902.2759

Internal dSph proper motions



Need 1,500 hours of SIM integration time to retrieve 200 PMs of Draco RGBs with a mean uncertainty of 5 km/s

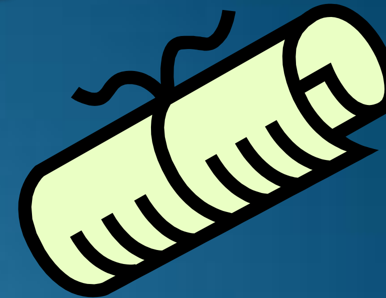
← Log slope near $r_{1/2}$

0902.2759

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 these results.

- Something weird is going on with the M31 dSphs.

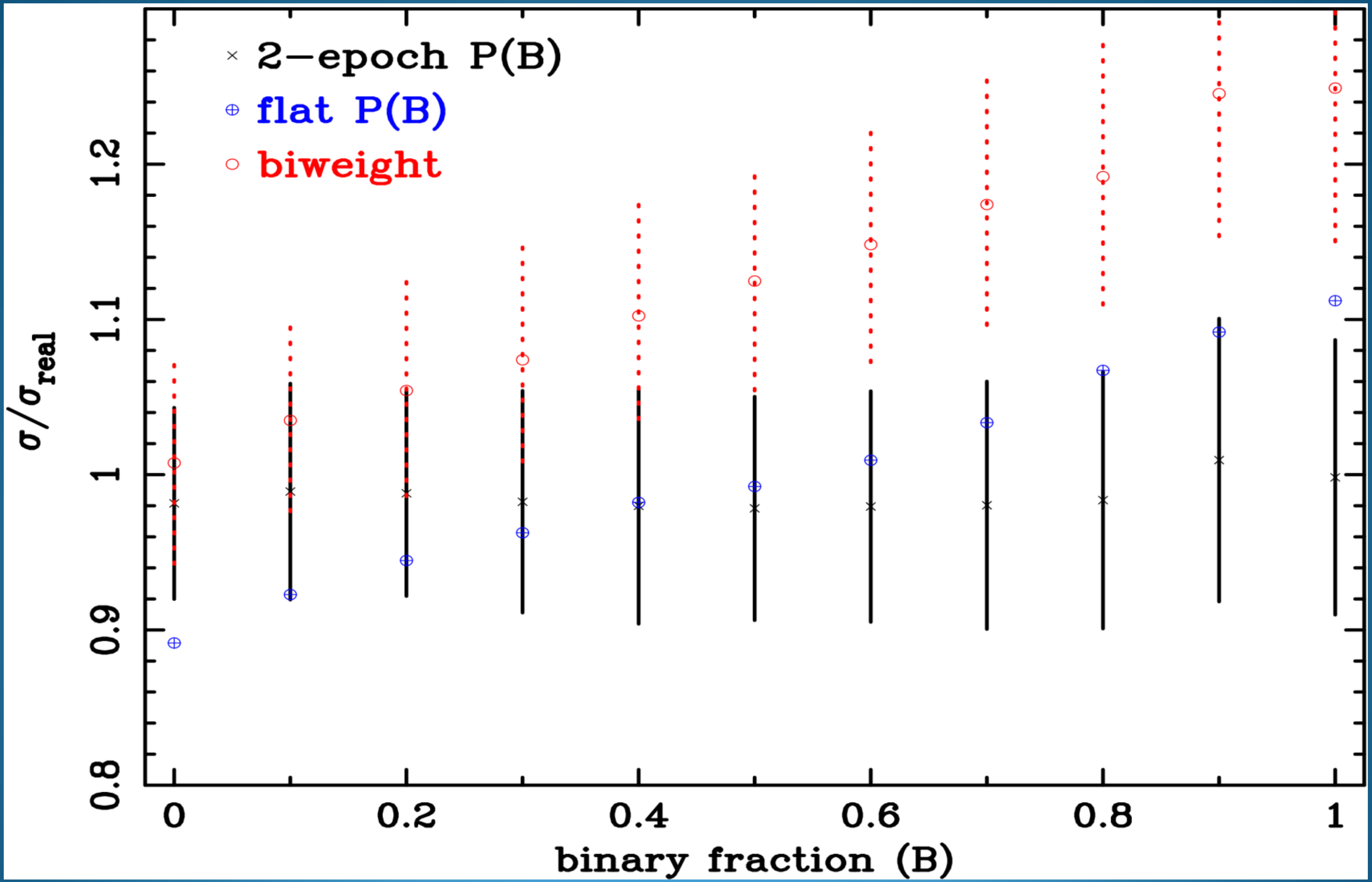
- Inner slopes of dSphs **cannot** be determined with only LOS kinematics. Need internal proper motions to solve cusp-core issue.

- Real conclusion: Job security for astronomers. ☺

Bonus slides

A word on binaries

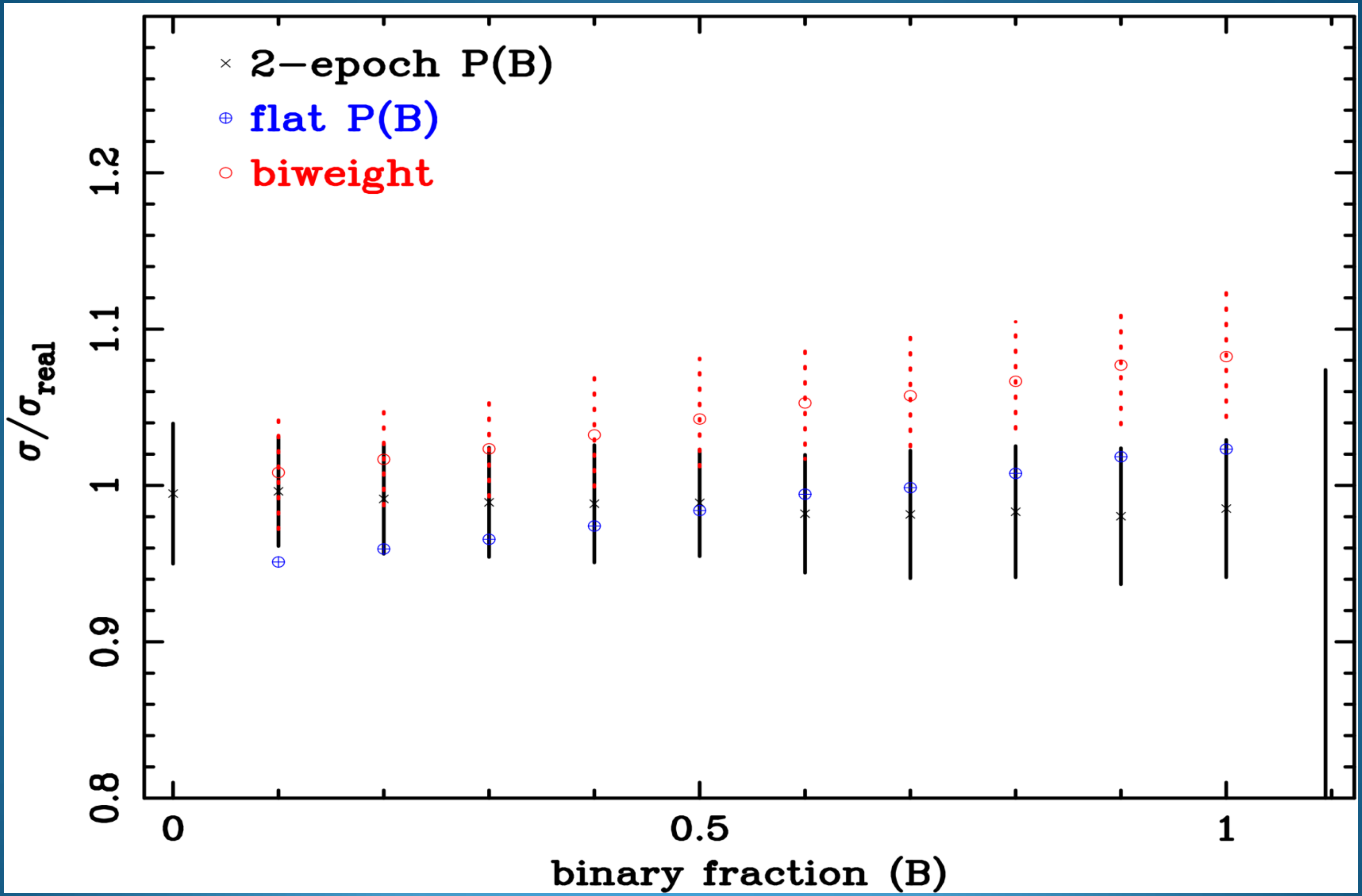
Best fit dispersion (4 km/s) with 200 stars



Quinn Minor, Greg Martinez, et al. in prep

A word on binaries

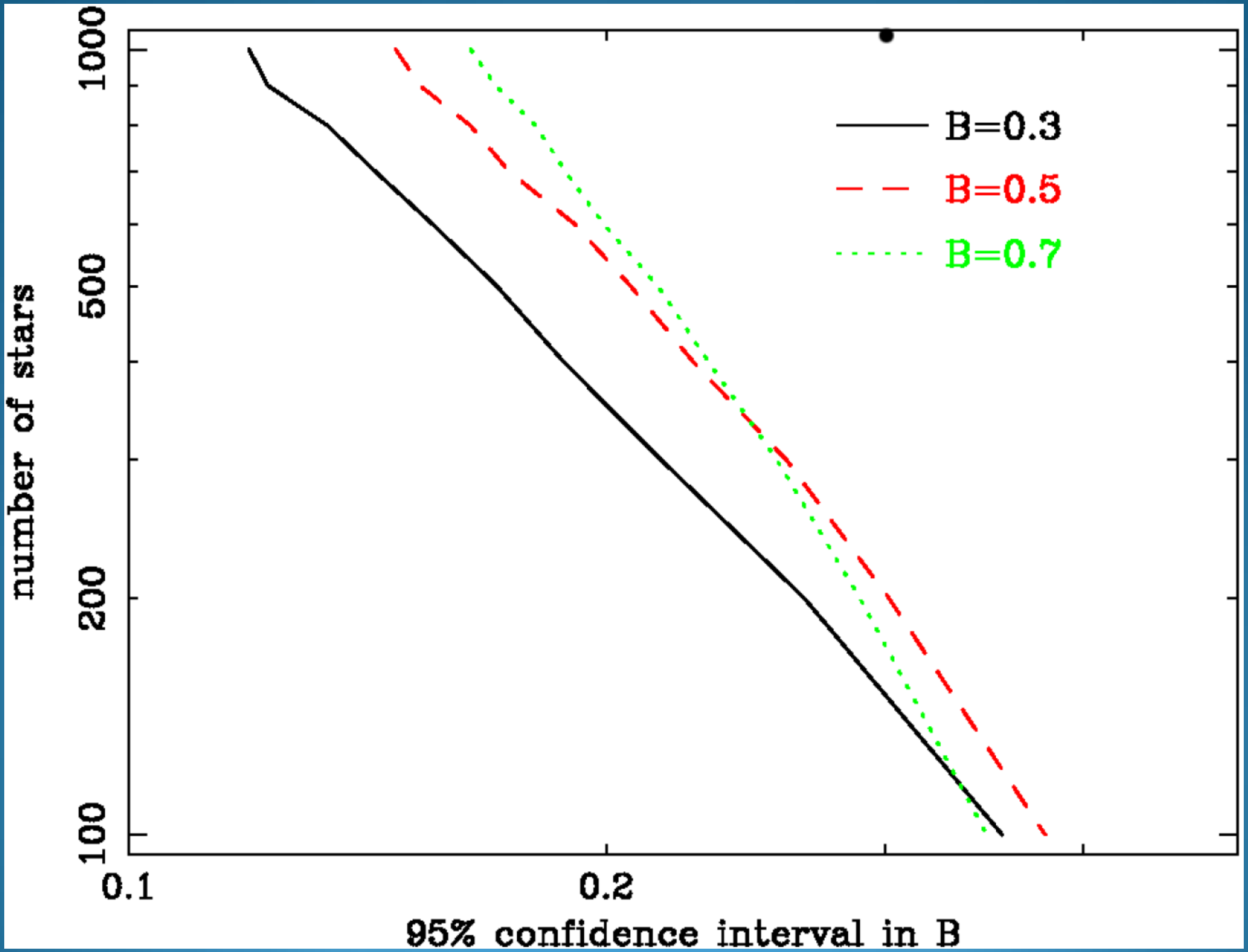
Best fit dispersion (10 km/s) with 500 stars



Quinn Minor, Greg Martinez, et al. in prep

A word on binaries

How many multi-epoch stellar velocities needed to constrain binary fraction (which will provide an additional constraint for detailed galaxy formation theories)?



Quinn Minor, Greg Martinez, et al. in prep

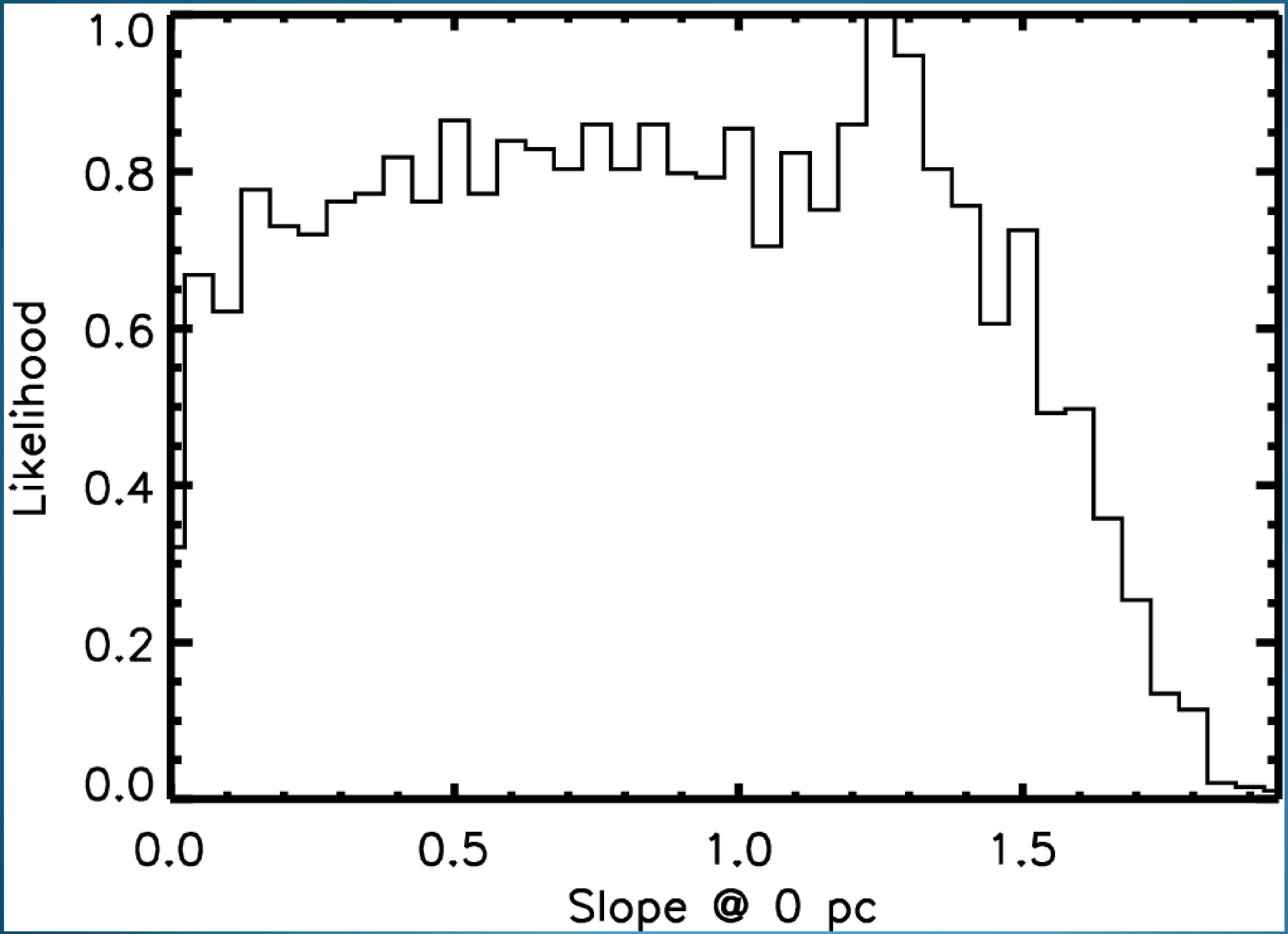
Slopes & Priors – Oh my!

"Can the observed or potentially measurable velocity dispersions tell apart a cusp vs. a core in their centers?" – Extreme Star Formation in Dwarf Galaxies Conference Website, Ann Arbor, Michigan, July 2009

No.
(At least not with LOS kinematics alone.)

Slopes & Priors – Oh my!

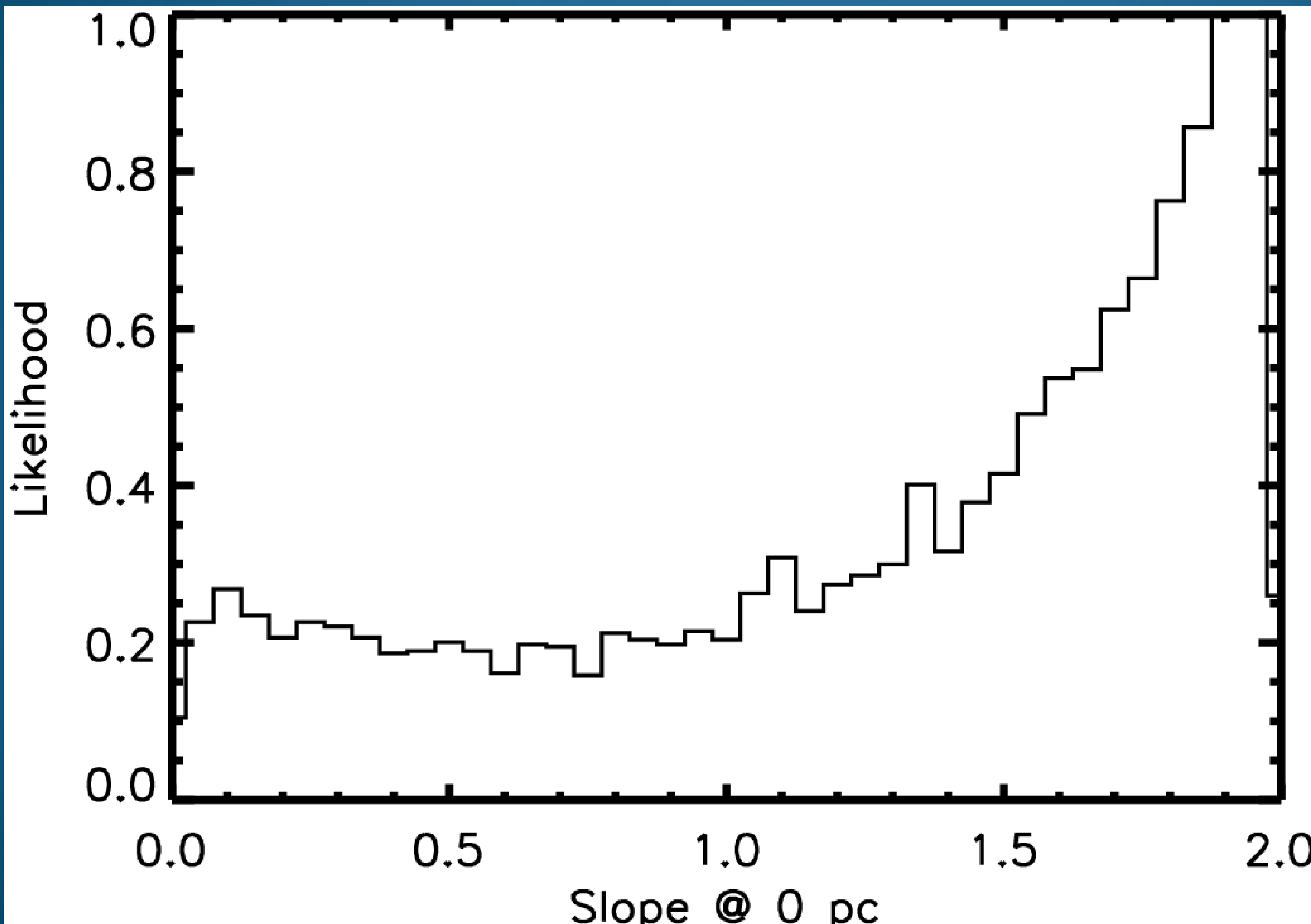
Beta prior #1: Constant beta that is flat from -10 to 0.91.
Gamma = Log slope of Carina at 0 pc



Joe Wolf et al., in prep

Slopes & Priors – Oh my!

Beta prior #2: Constant beta that is as likely to be negative as positive (ranging from -10 to 0.91).



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Slopes & Priors – Oh my!

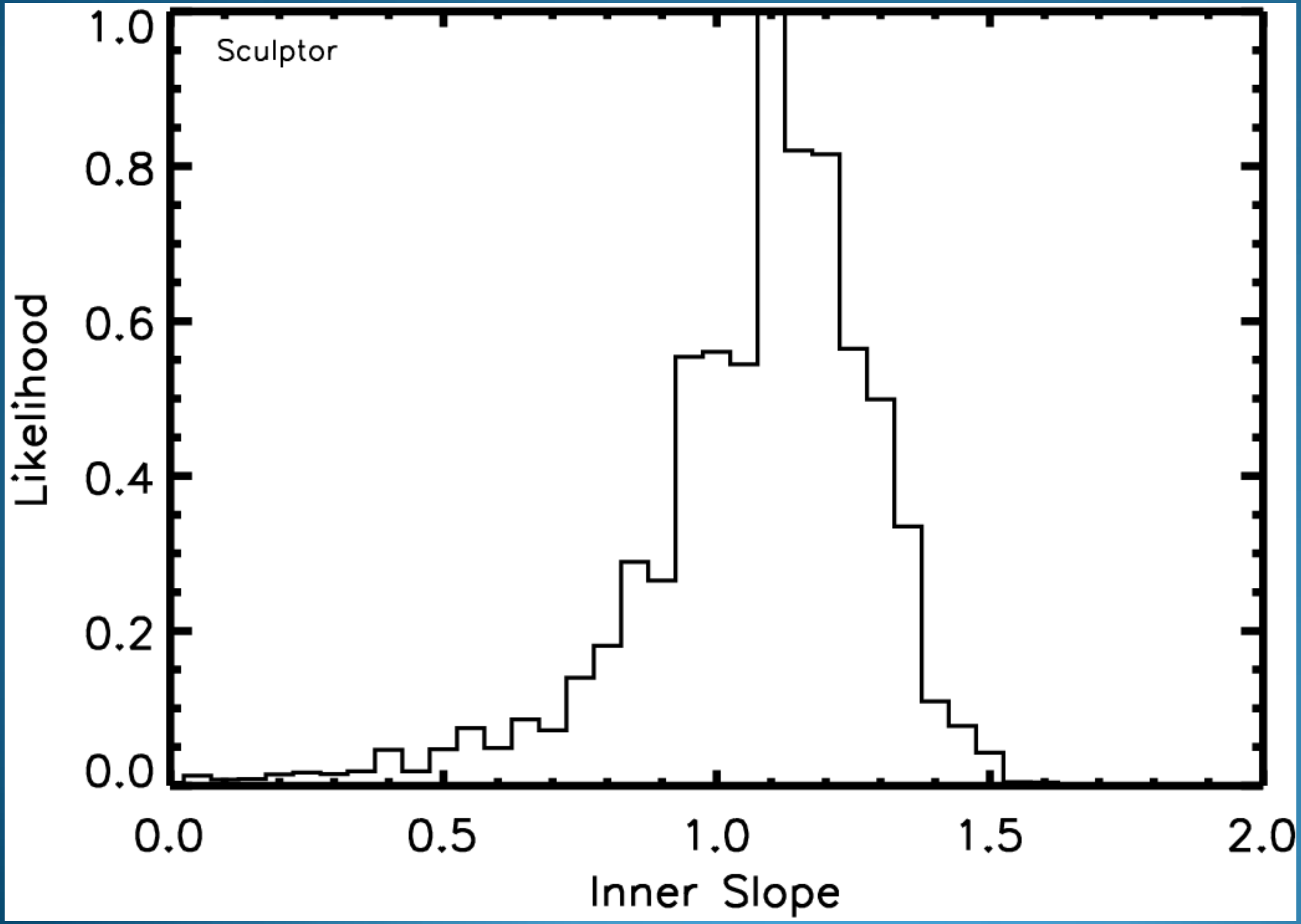
In Bayesian analysis, a prior is always present.

If changing your prior affects your posterior, then you are getting out what you put in.

That is, your data is not constraining your posterior.

Slopes & Priors – Oh my!

G. Gilmore 2007: "Cores always preferred"
Forcing isotropy: 4 of the 8 classical dSphs show no preference for either cores or cusps, and Sculptor strongly prefers a cusp



Joe Wolf et al., in prep