CENTER FOR COSMOLOGY
UNIVERSITY OF CALIFORNIA, IRVINE

Sweating the small stuff:

simulating dwarf galaxies, ultra-faint dwarf galaxies, and their own tiny satellites

Coral Wheeler
UC Irvine

UC Berkeley TAC Seminar
10-26-2015

James Bullock (UCI)
Andrew Pace (UCI)
Jose Oñorbe (MPIA)
Shea Garrison-Kimmel (Caltech)
Mike Boylan-Kolchin (UT Austin)
Alex Fitts (UT Austin)
Evan Kirby (Caltech)
Oliver Elbert (UCI)
Phil Hopkins (Caltech)
Dusan Keres (UCSD)

Why sweat the small stuff?

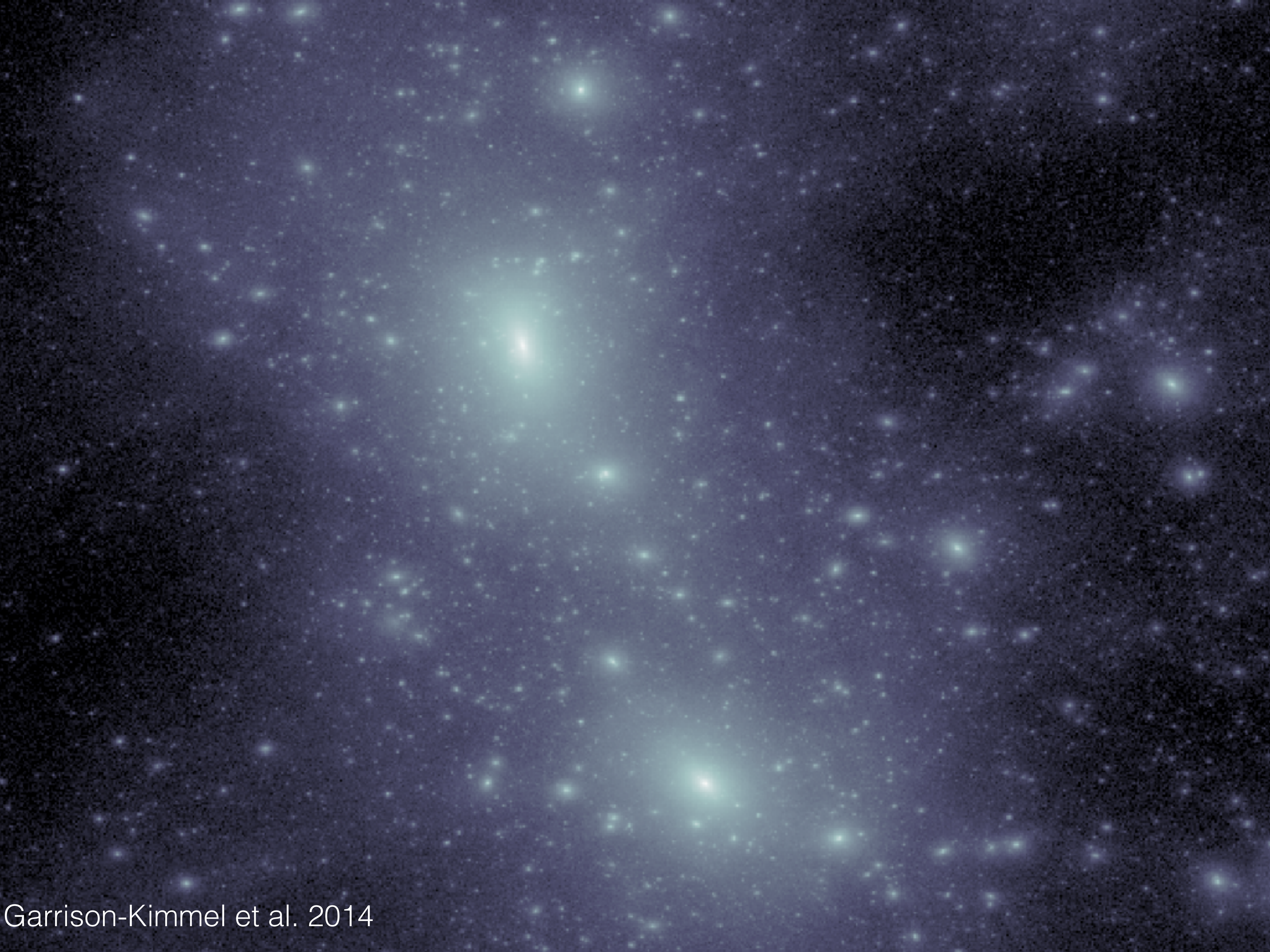
$10^3\ M_\odot \lesssim M^* \lesssim 10^9\ M_\odot$

- Missing satellites problem - why are there so few dwarf satellites?

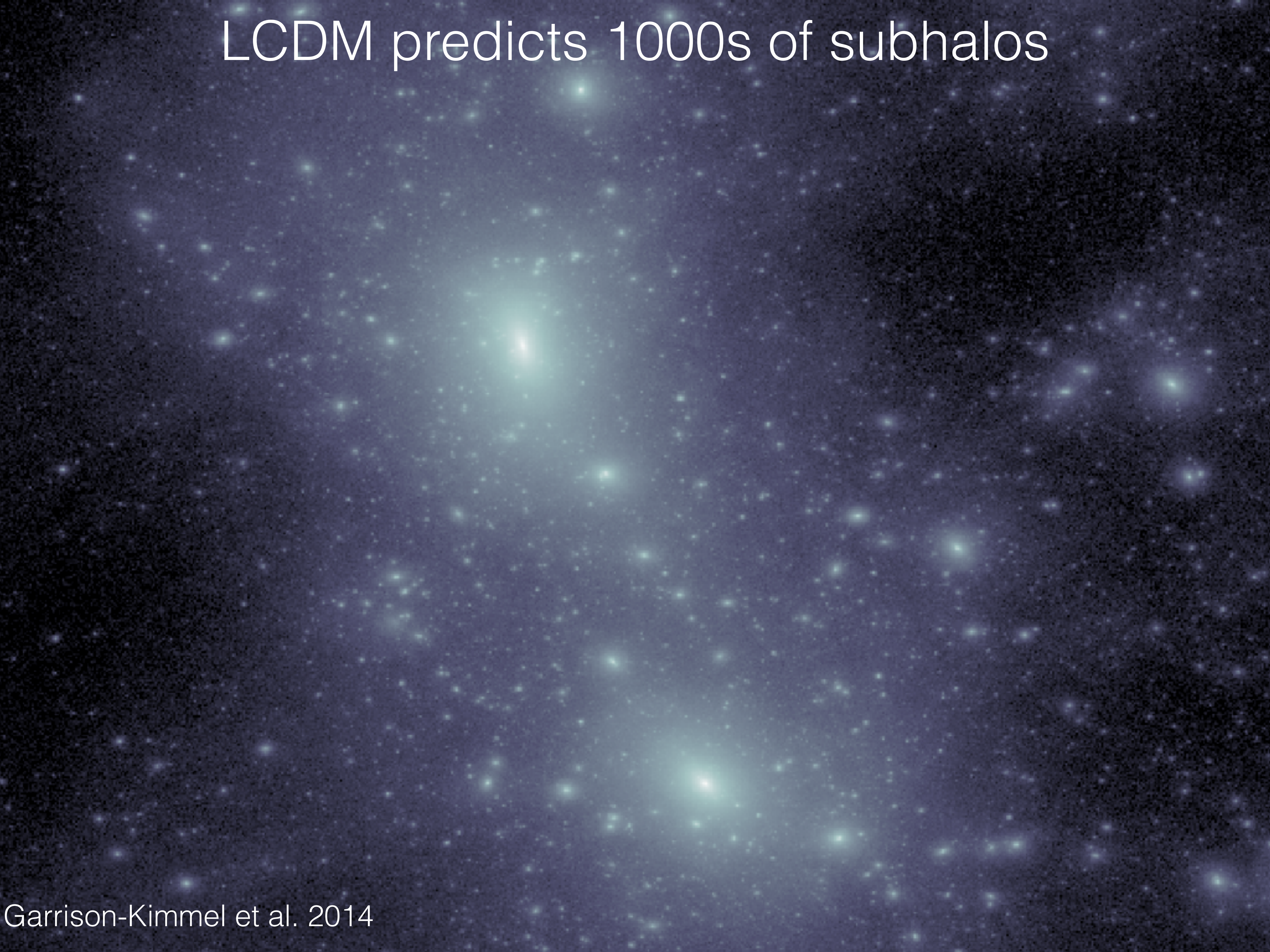
- Ancient populations - what shuts down star formation in ultra-faint dwarfs?

- Age gradients - how do dwarfs obtain inverted age gradients?

- dIrr/dSphs - why are there different dwarf galaxy populations near and far from MW / M31?

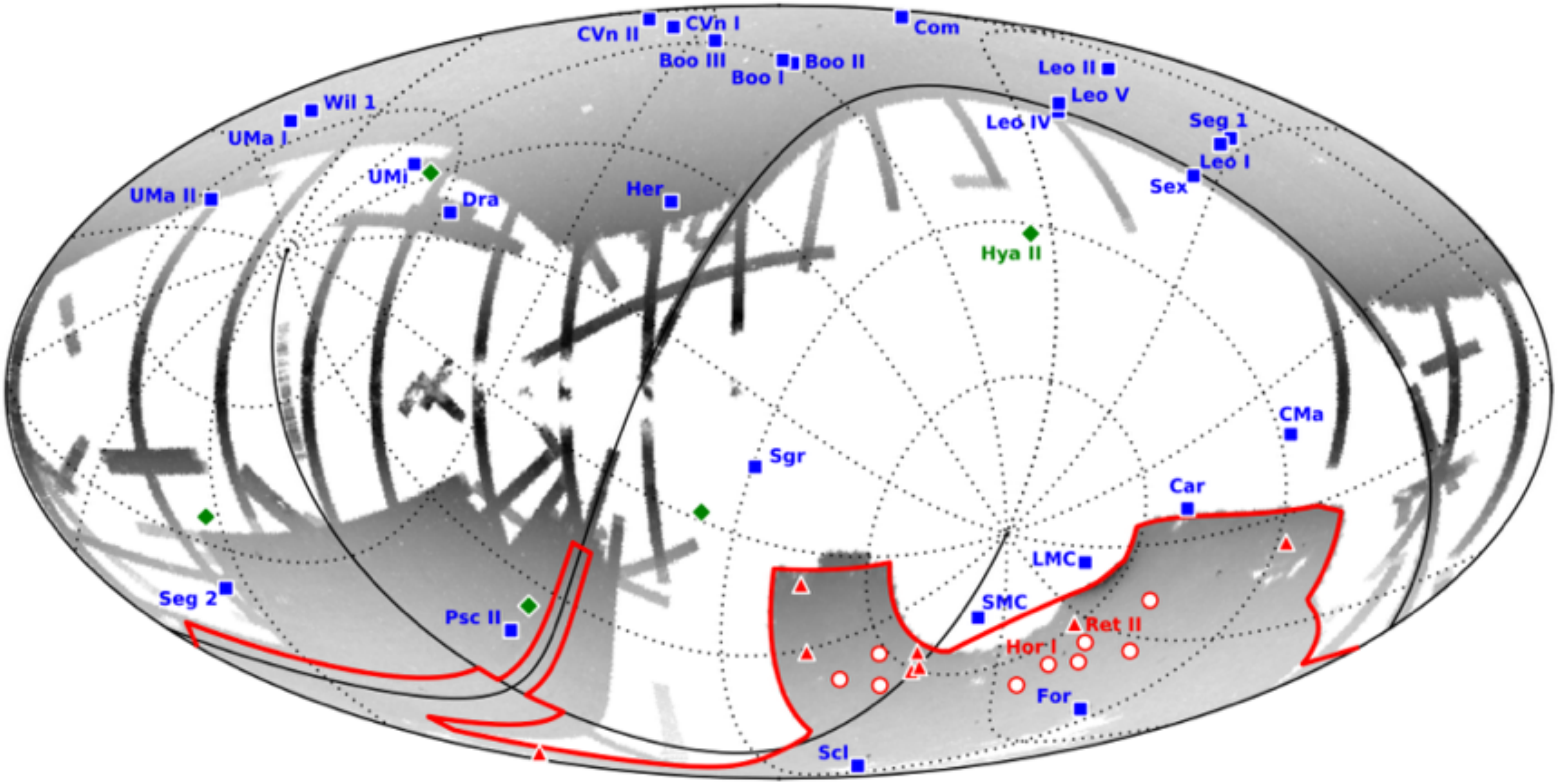

Garrison-Kimmel et al. 2014

LCDM predicts 1000s of subhalos



Garrison-Kimmel et al. 2014

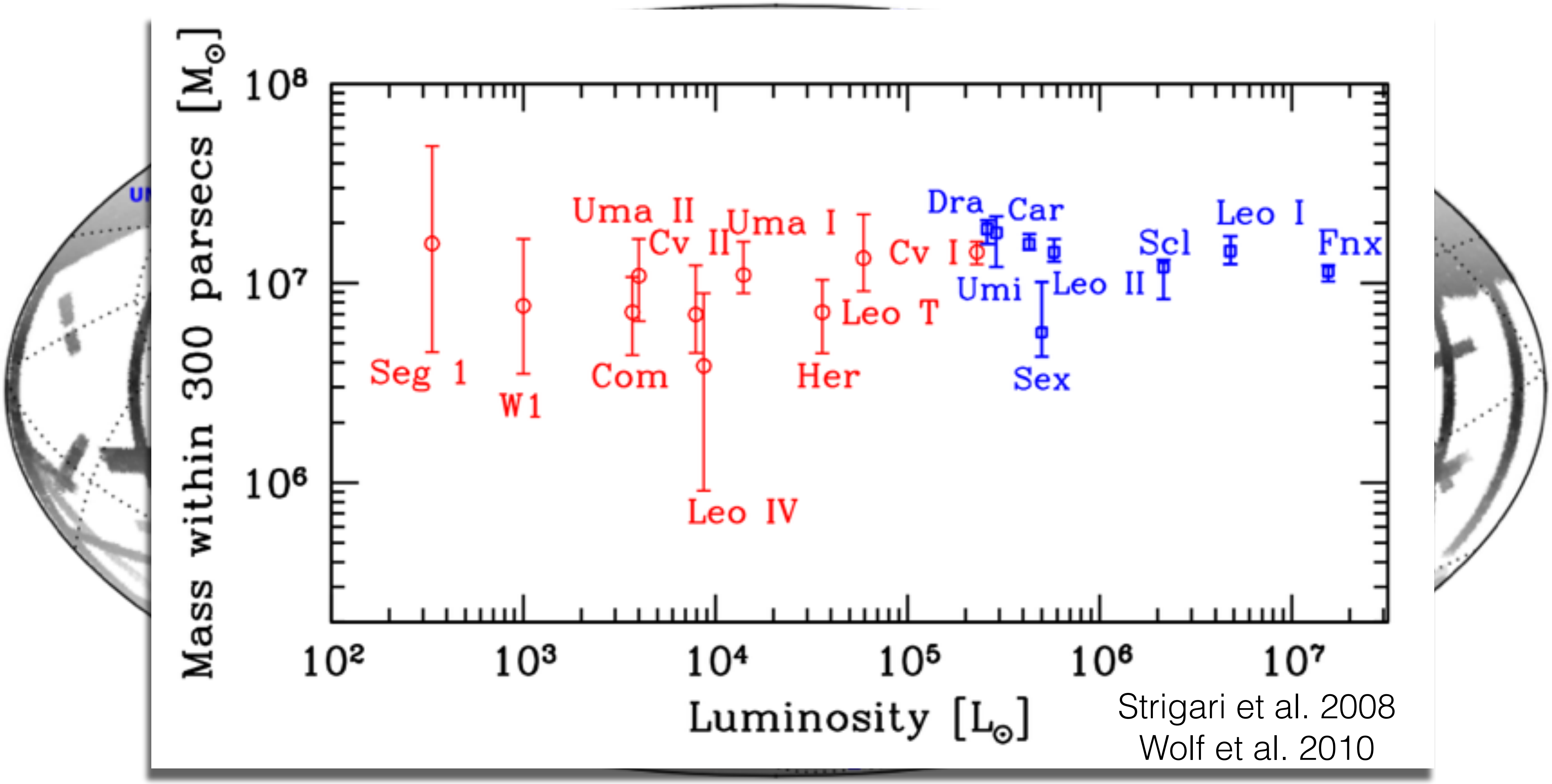
Currently ~30 known MW satellites



Drlica-Wagner et al. 2015

Koposov 2015, Leavens 2015, Martin 2015, Kim 2015, Kim & Jerjen 2015b

Occupy halos of similar mass: ~3 x 10^9 $M_\odot$

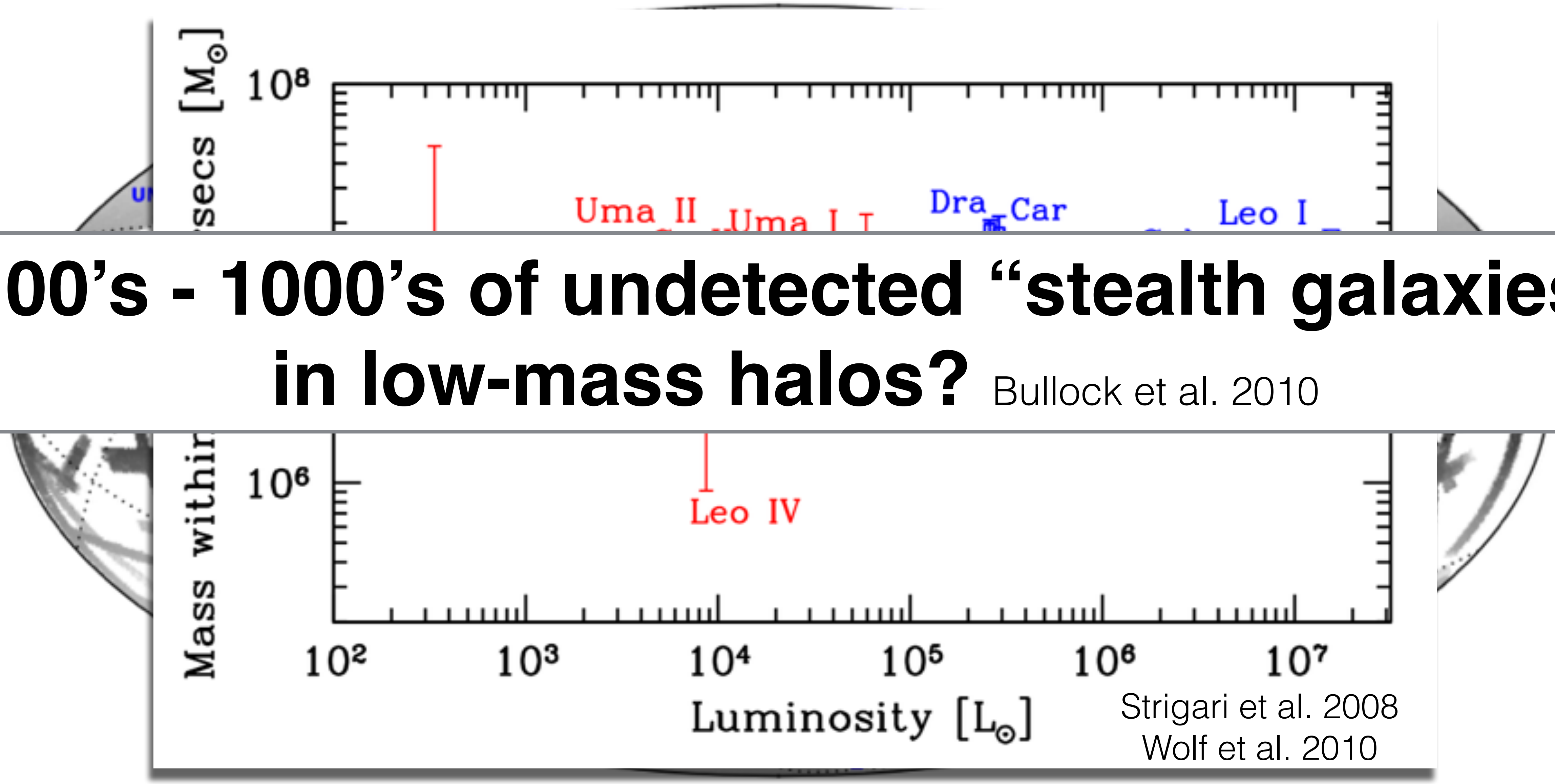


Strigari et al. 2008
Wolf et al. 2010

Drlica-Wagner et al. 2015

Koposov 2015, Leavens 2015, Martin 2015, Kim 2015, Kim & Jerjen 2015b

Selection Effect?

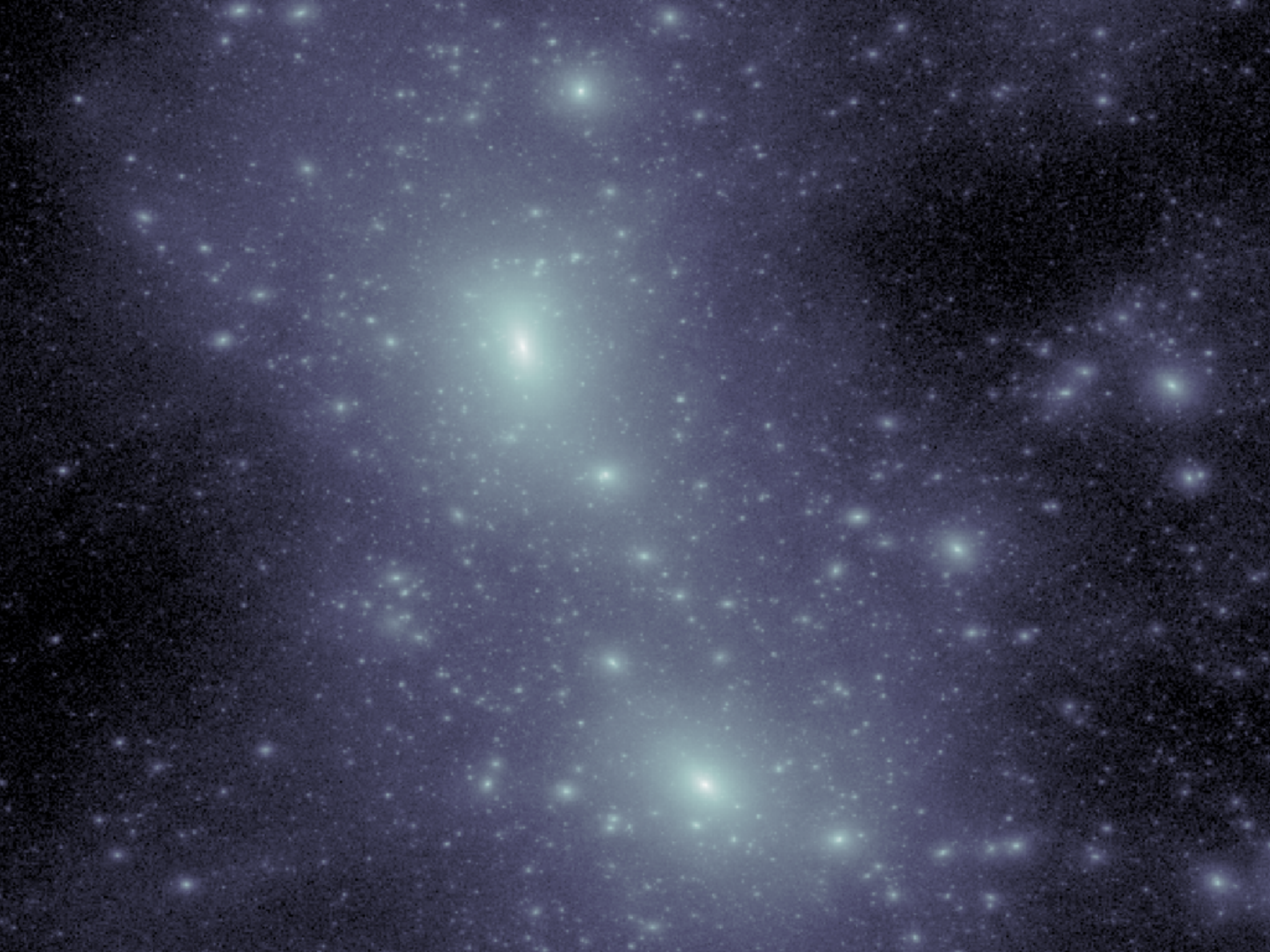


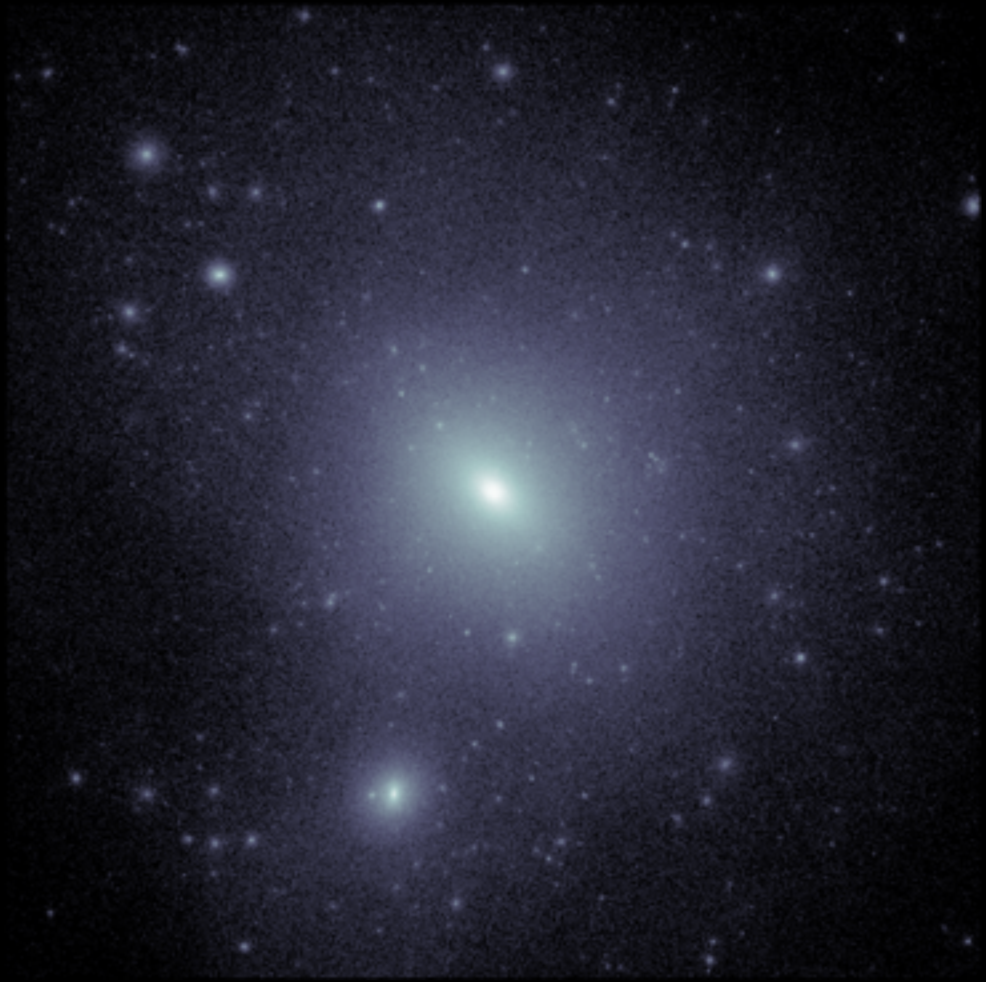
Strigari et al. 2008
Wolf et al. 2010

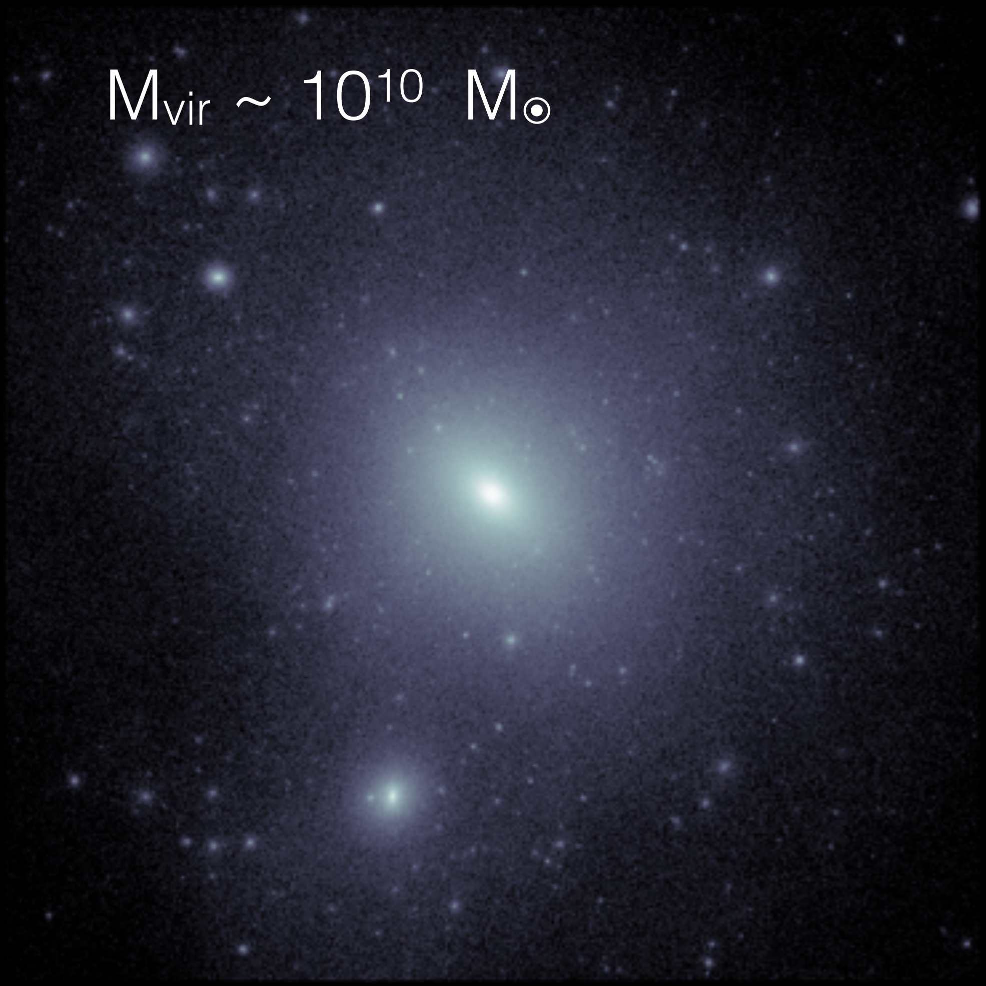
100's - 1000's of undetected "stealth galaxies" in low-mass halos? Bullock et al. 2010

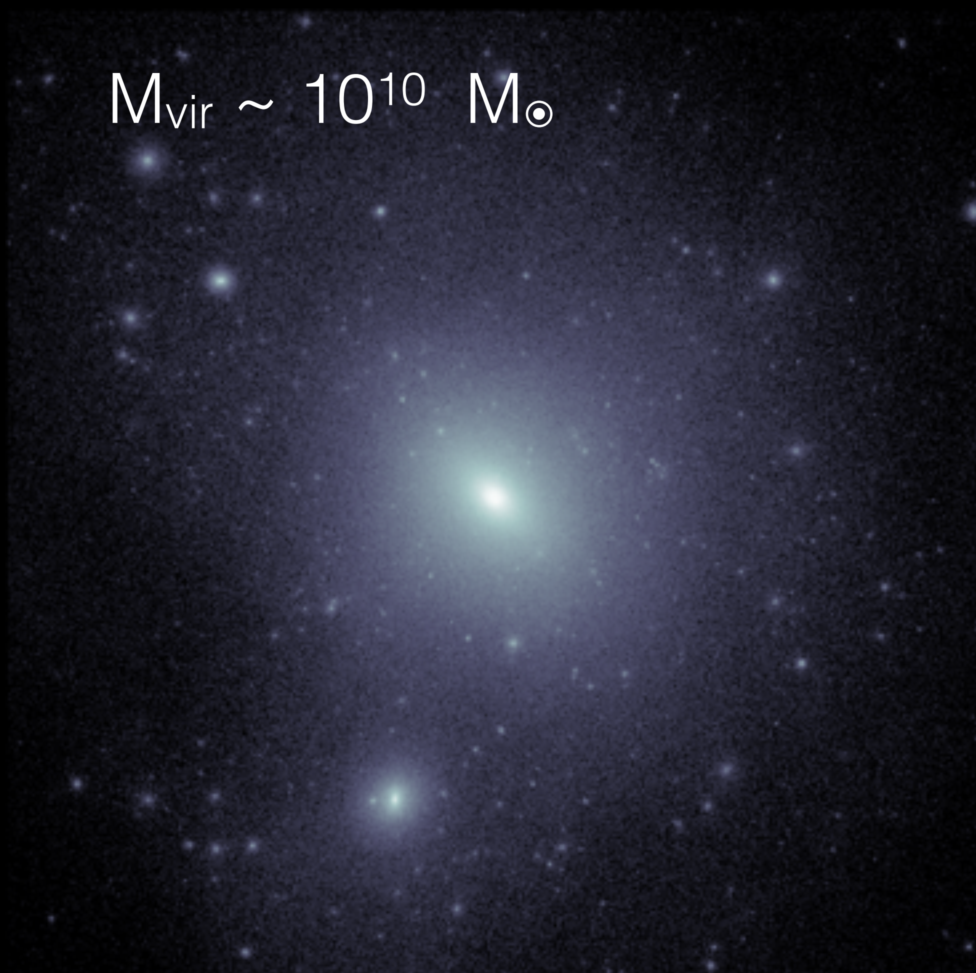
Drlica-Wagner et al. 2015

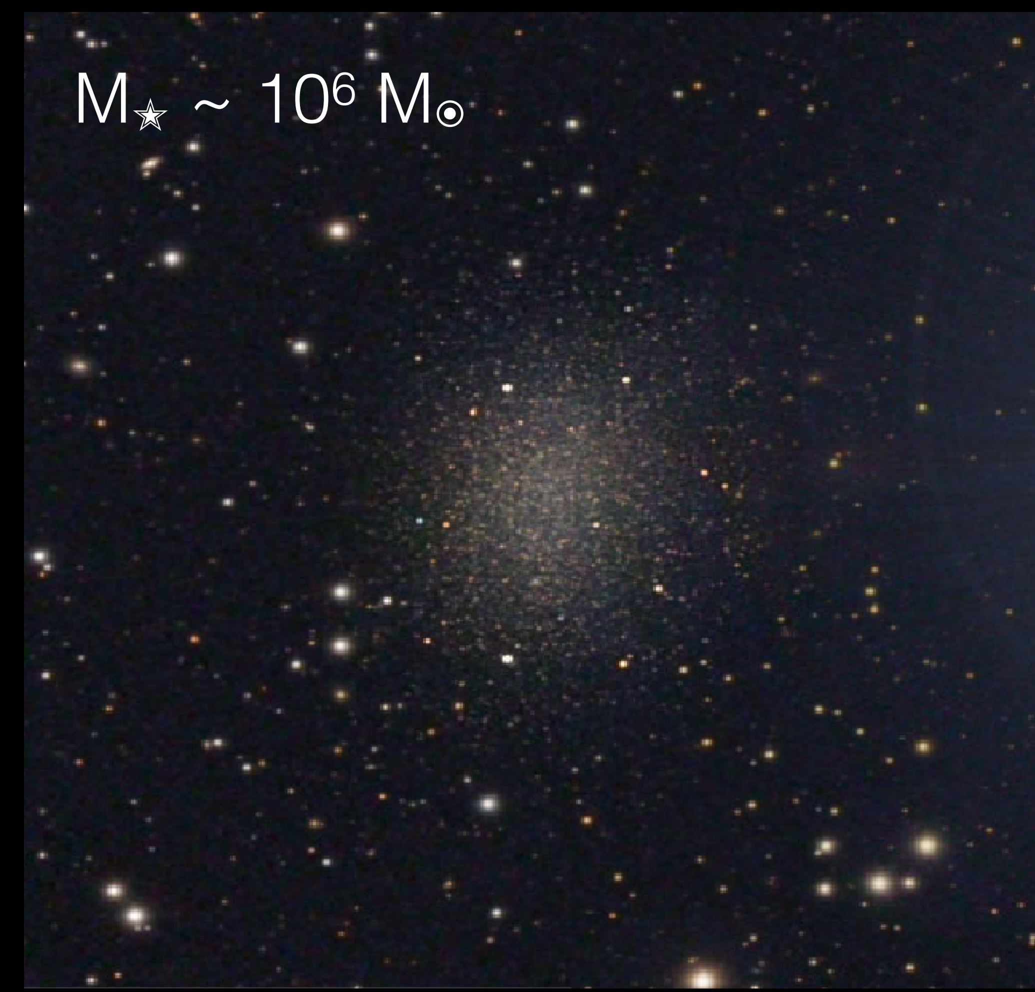
Koposov 2015, Leavens 2015, Martin 2015, Kim 2015, Kim & Jerjen 2015b

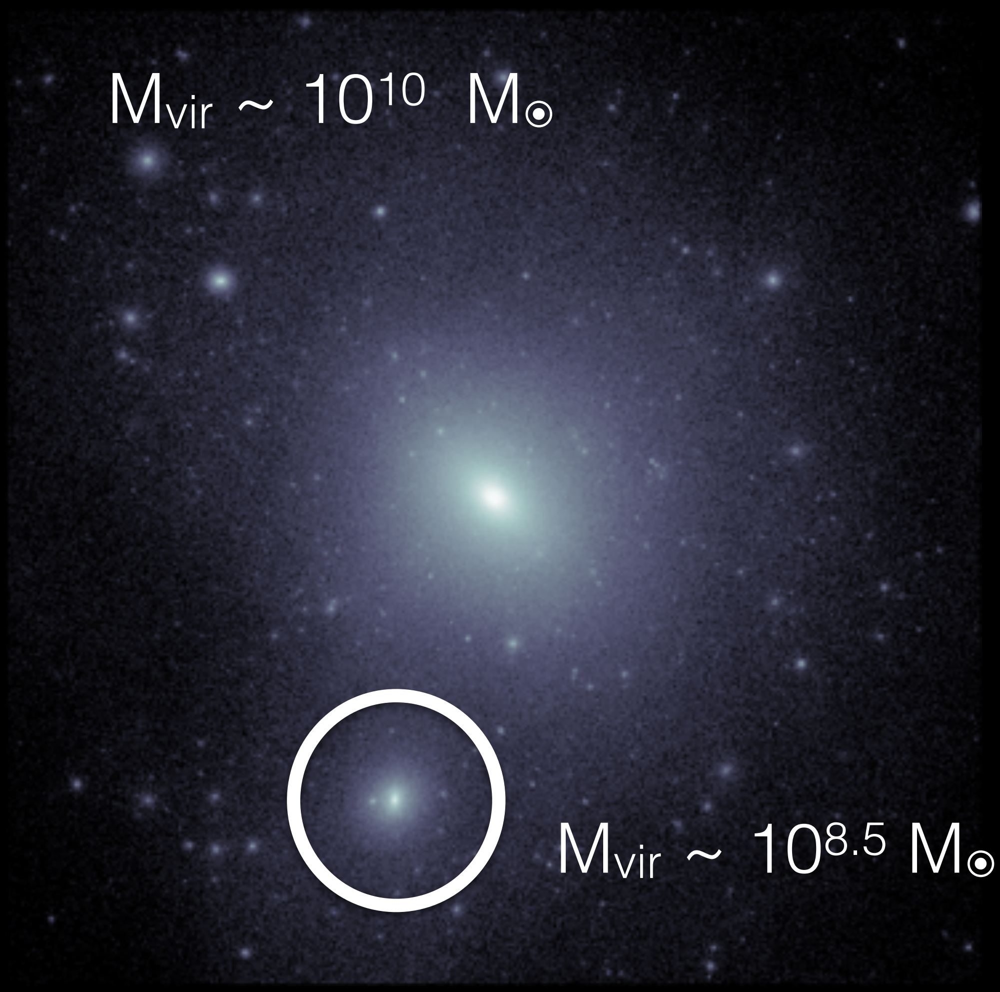




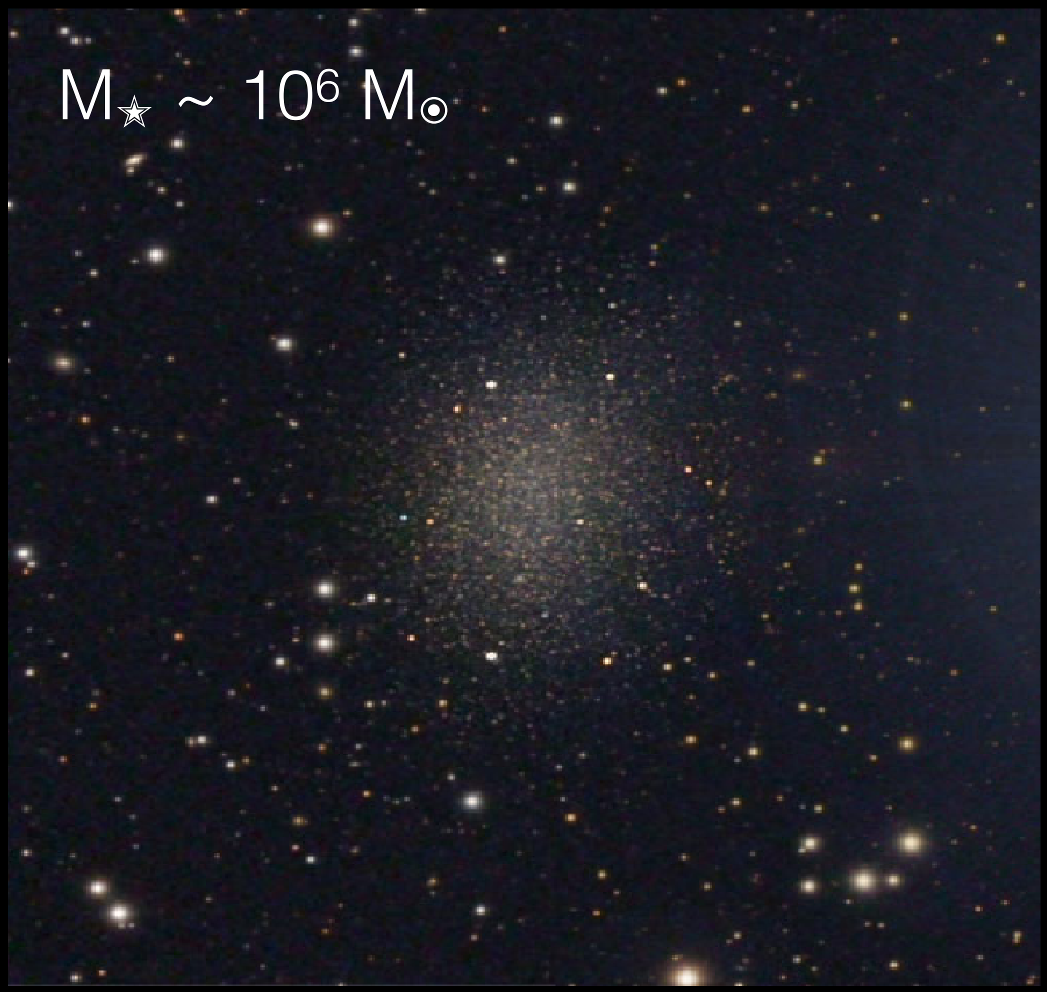

$M_{vir} \sim 10^{10}\ M_{\odot}$


$M_{vir} \sim 10^{10}\ M_\odot$

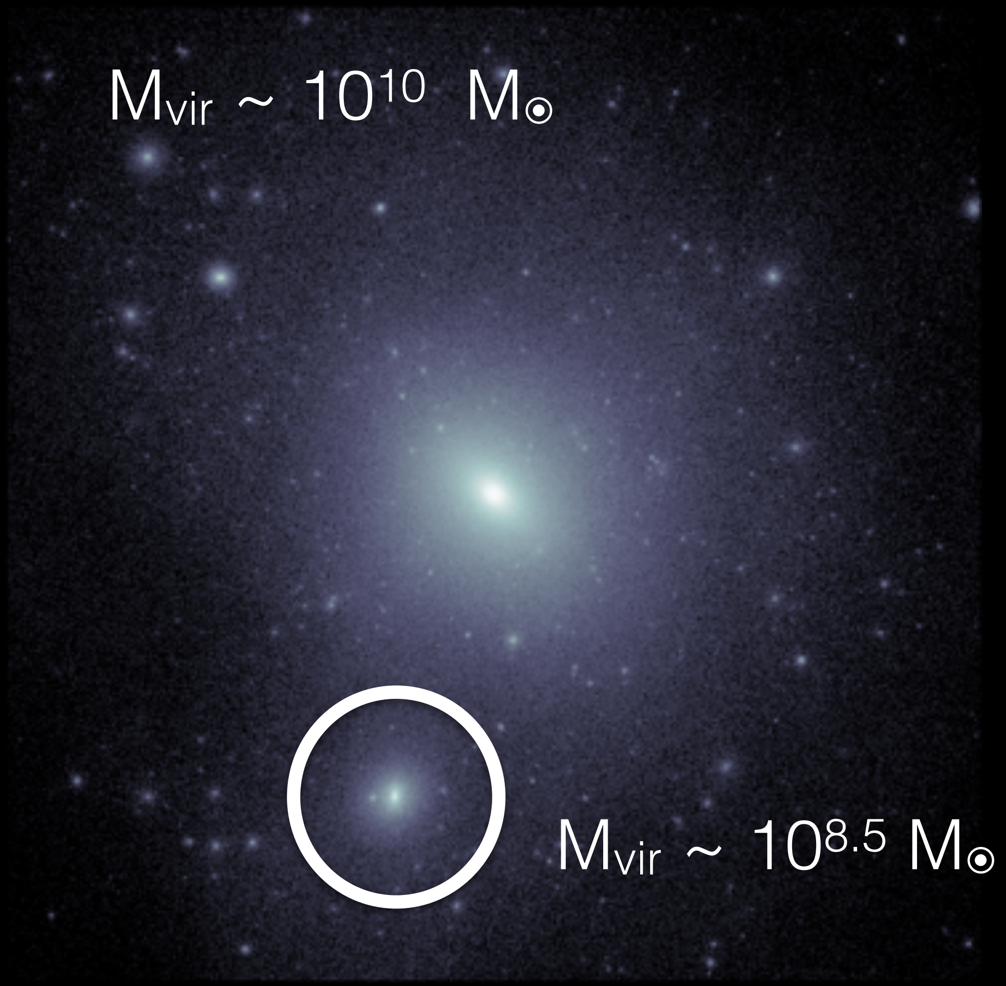

$M_\star \sim 10^{6}\ M_\odot$



$M_{vir} \sim 10^{10}\ M_\odot$
$M_{vir} \sim 10^{8.5}\ M_\odot$



$M_\star \sim 10^6\ M_\odot$


$M_{vir} \sim 10^{10}$ $M_\odot$
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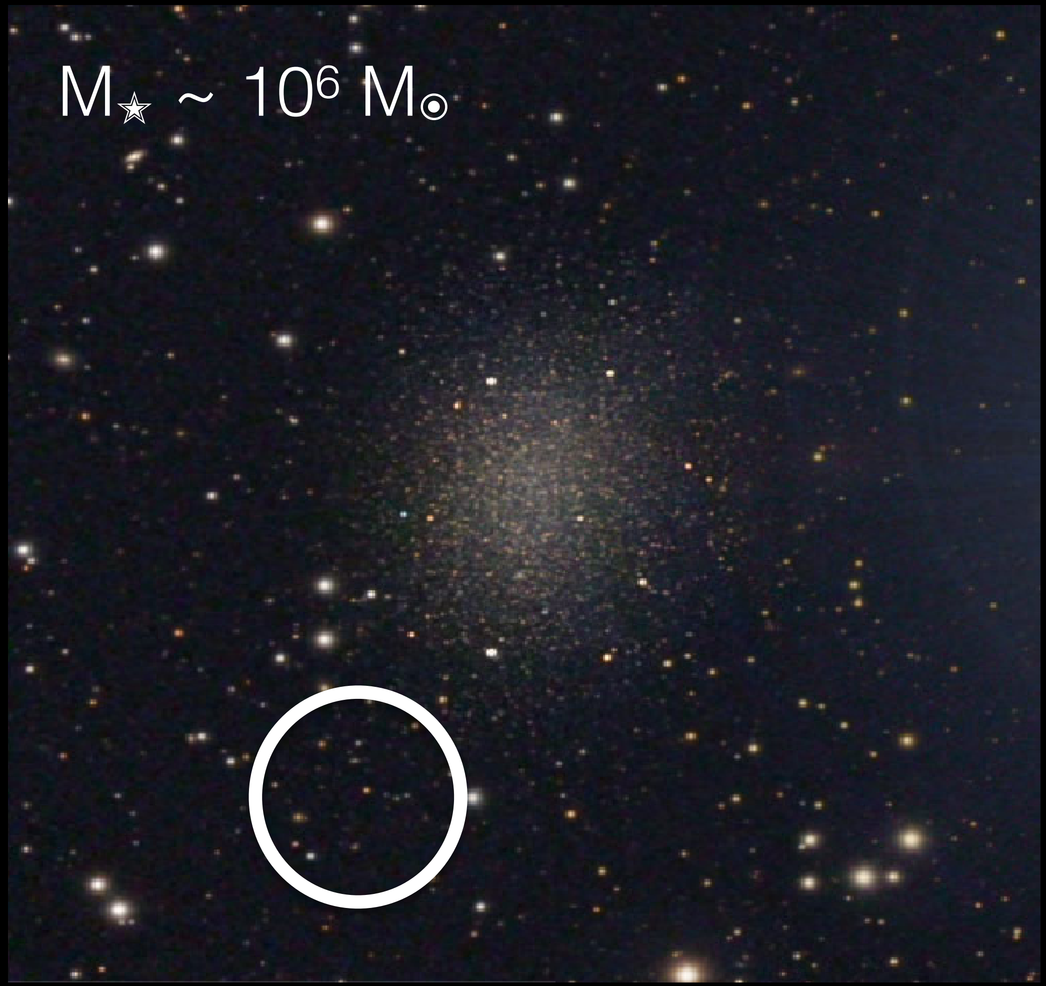
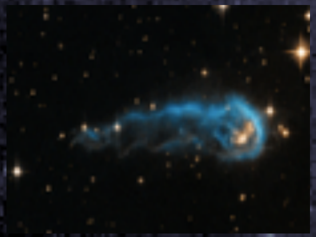

$M_\star \sim 10^6$ $M_\odot$

DWARF GALAXIES ON FIRE

Hopkins et al. 2014

Oñorbe et al. 2015
Wheeler et al. 2015

Radiation pressure



Stellar winds

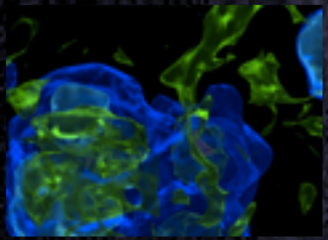
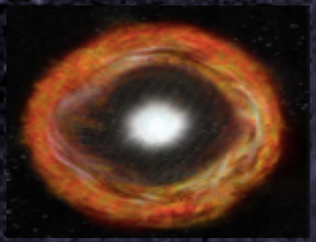
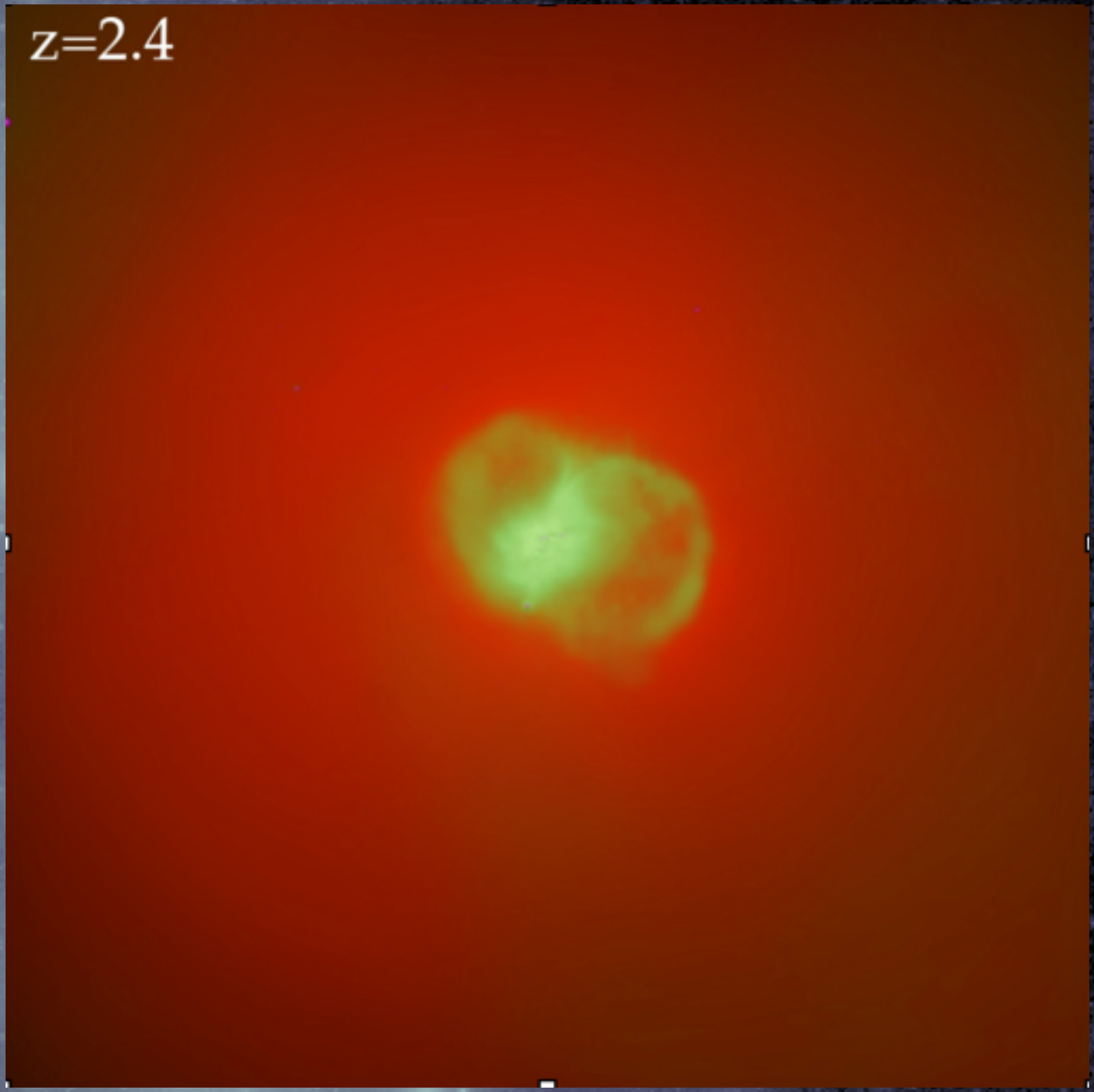


Photo-Ionization



Supernovae Type I and II



DWARF GALAXIES ON FIRE

Hopkins et al. 2014

Oñorbe et al. 2015
Wheeler et al. 2015

High Resolution:

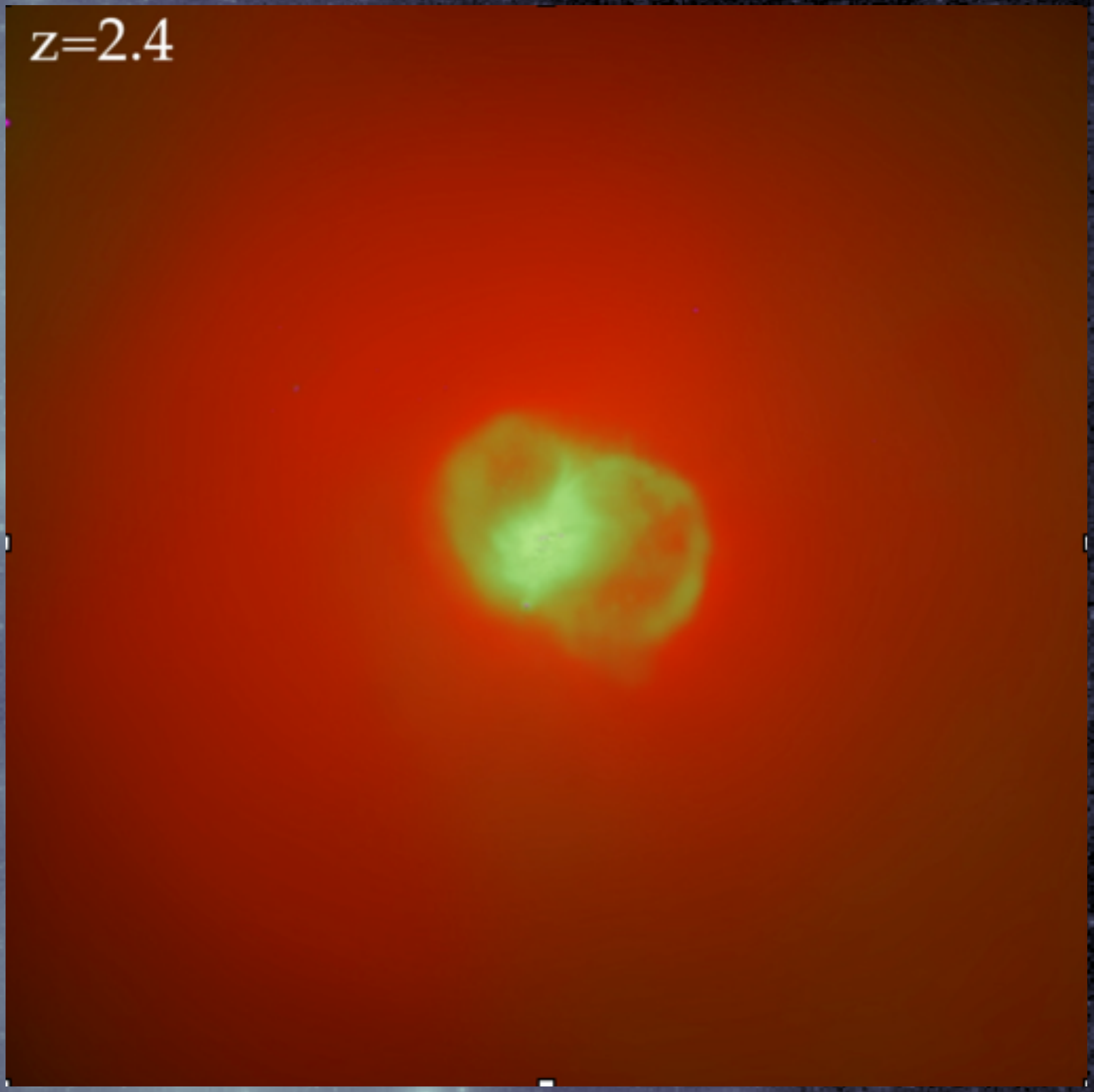
- $m_{dm} \sim 1000\ M_{\odot}$
- $m_{gas} \sim 250\ M_{\odot}$
- DM $f_{res} \sim$ 25pc
- Gas f_{res} = 1-3pc

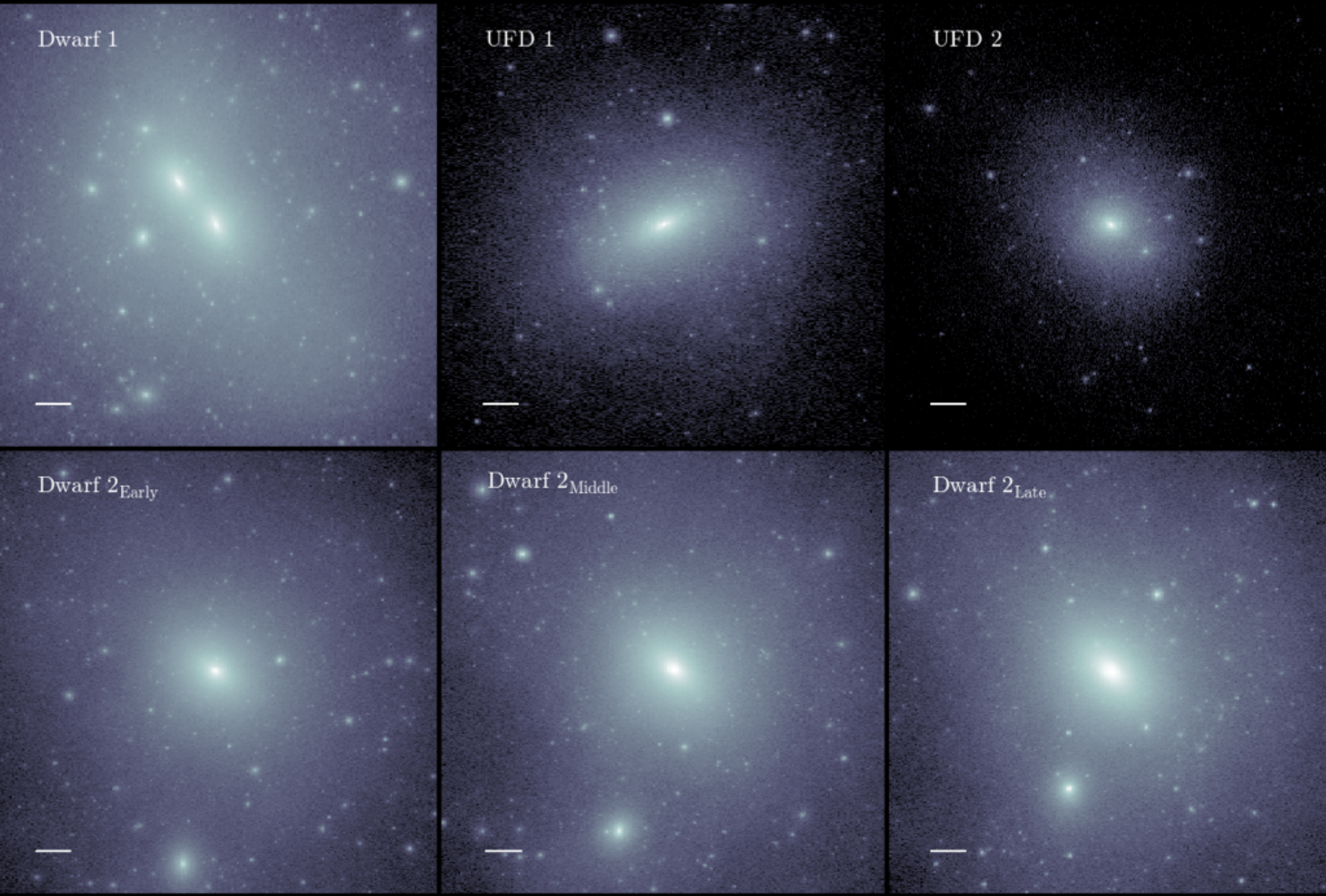
4 Halos:

- 2 'Dwarfs': $M_{HALO} \sim 10^{10}\ M_{\odot}$
- $M_{\star} \sim 10^{6}\ M_{\odot}$
- 2 'UFDs': $M_{HALO} \sim 10^{9}\ M_{\odot}$
- $M_{\star} \sim$?

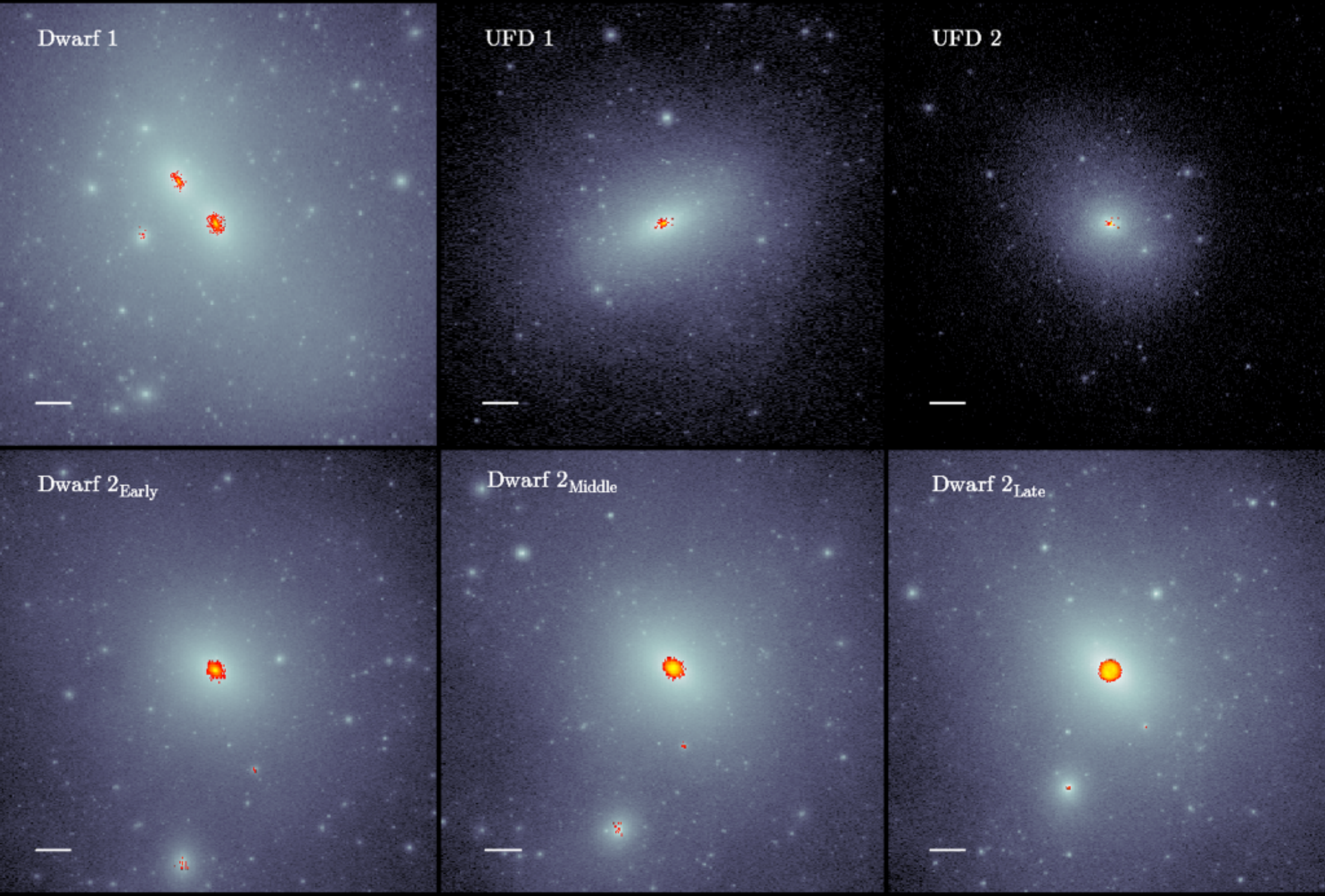
1 Dwarf run 3 times

- Identical ICs
- Small changes to subgrid energy injection method and force softening

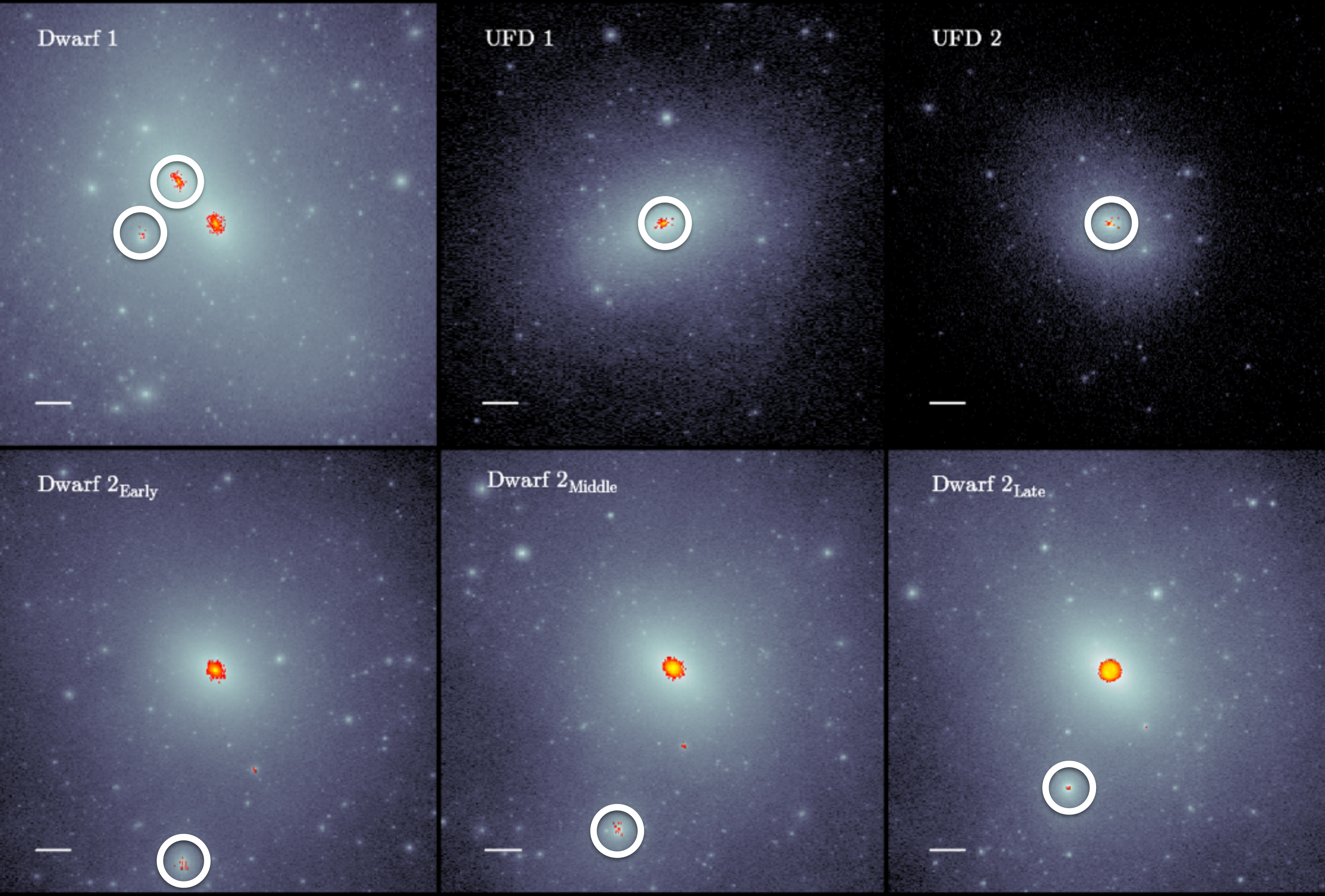




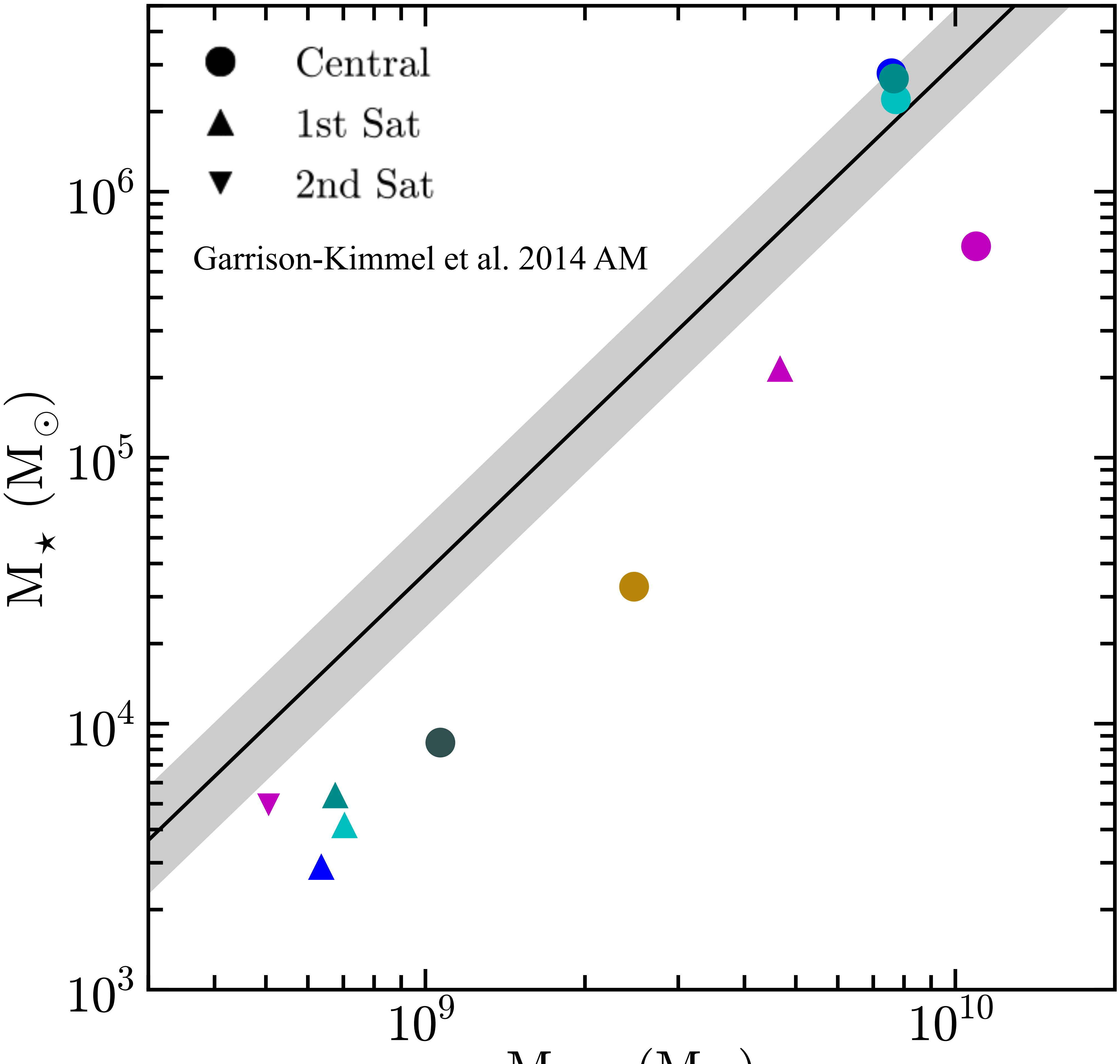
Wheeler et al. 2015



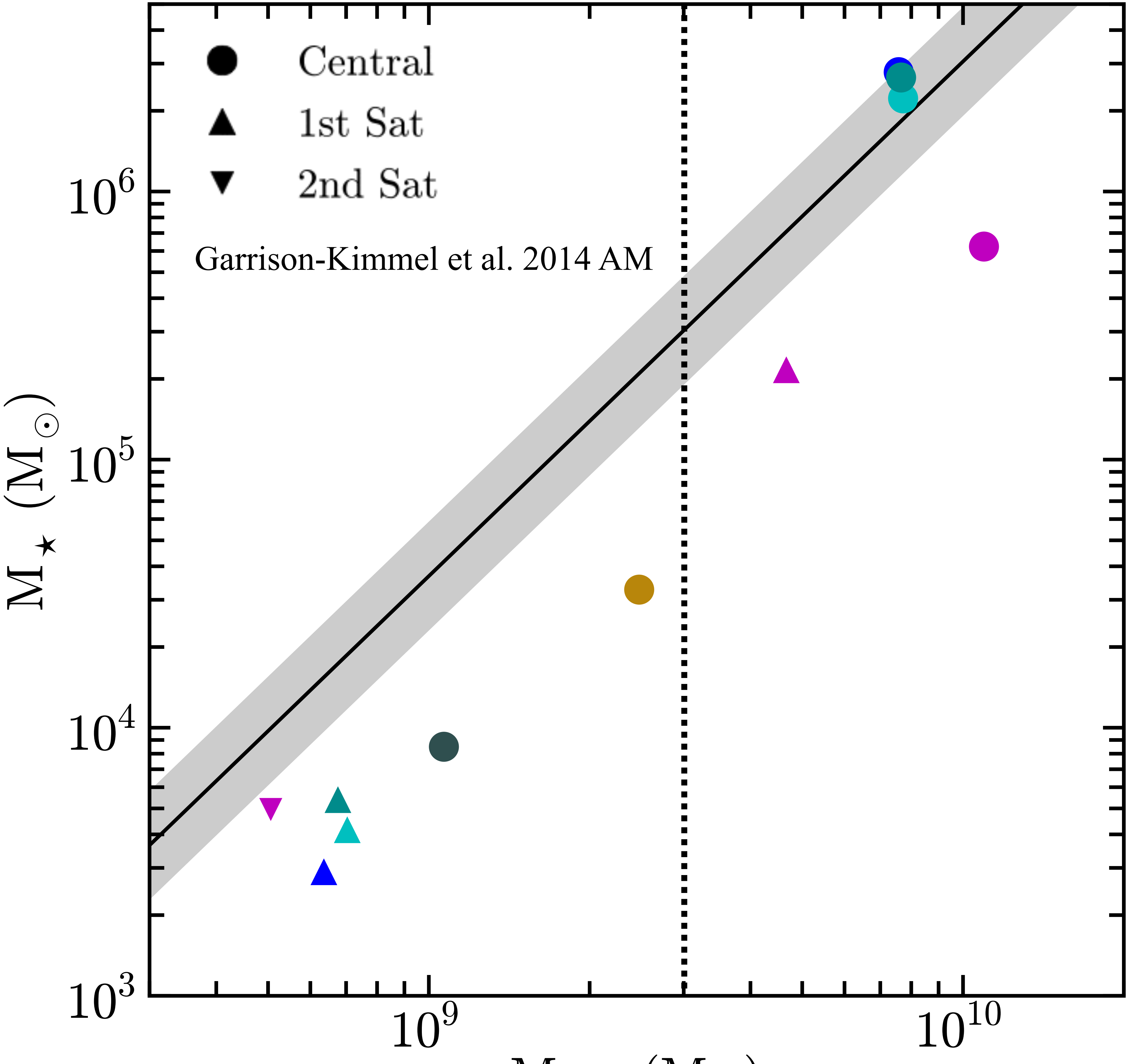
Wheeler et al. 2015



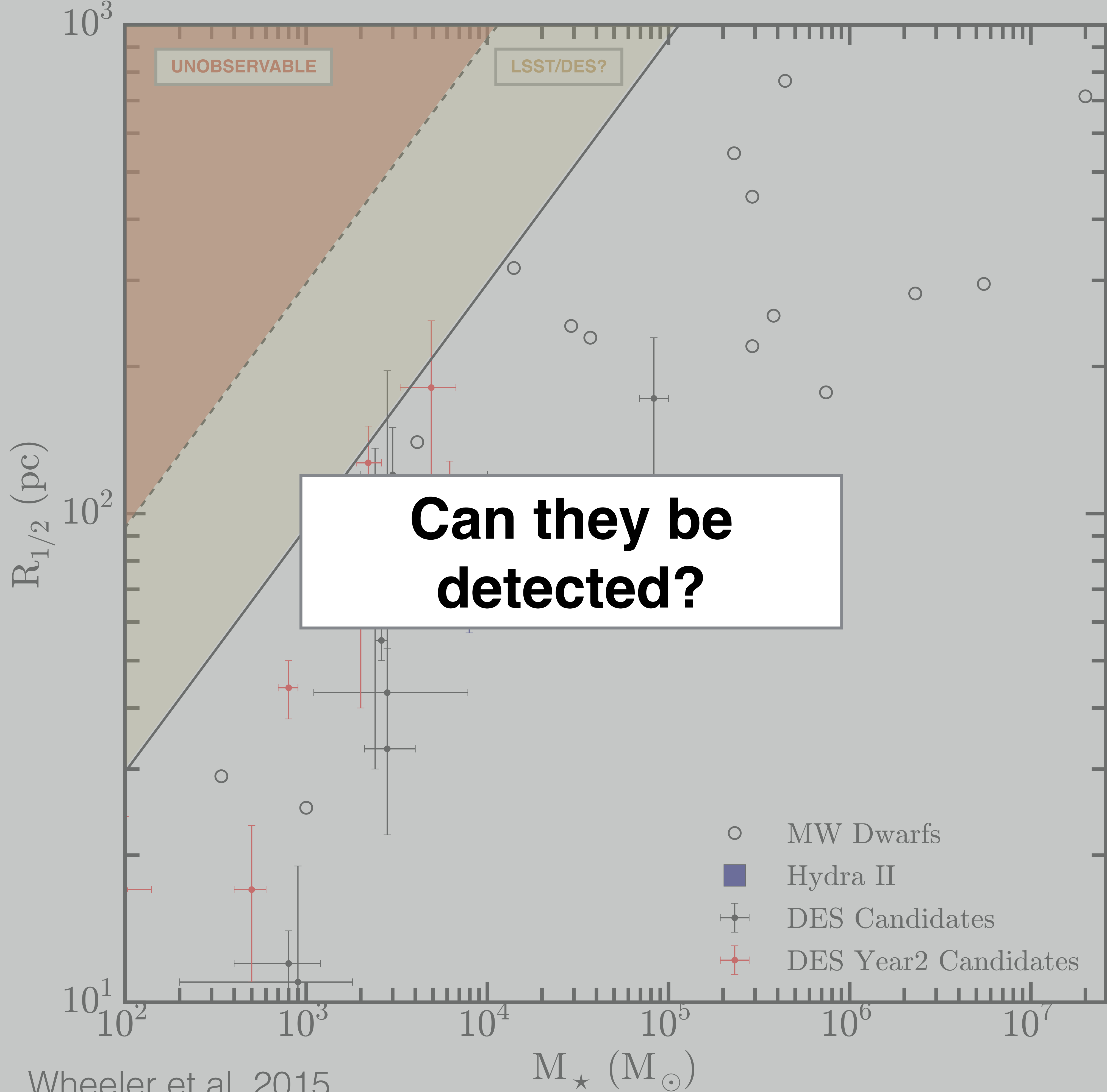
Wheeler et al. 2015



Wheeler et al. 2015

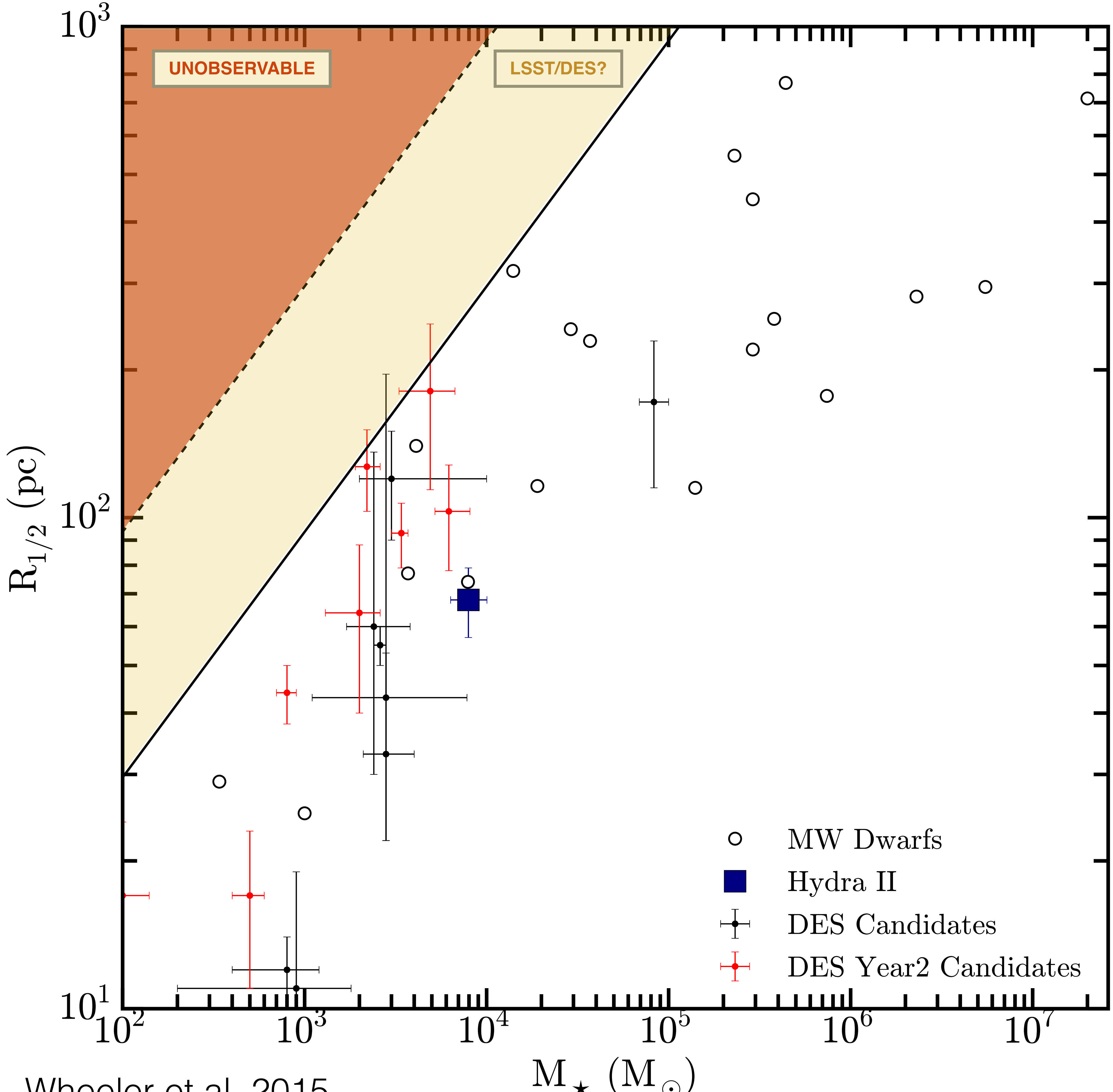


Wheeler et al. 2015

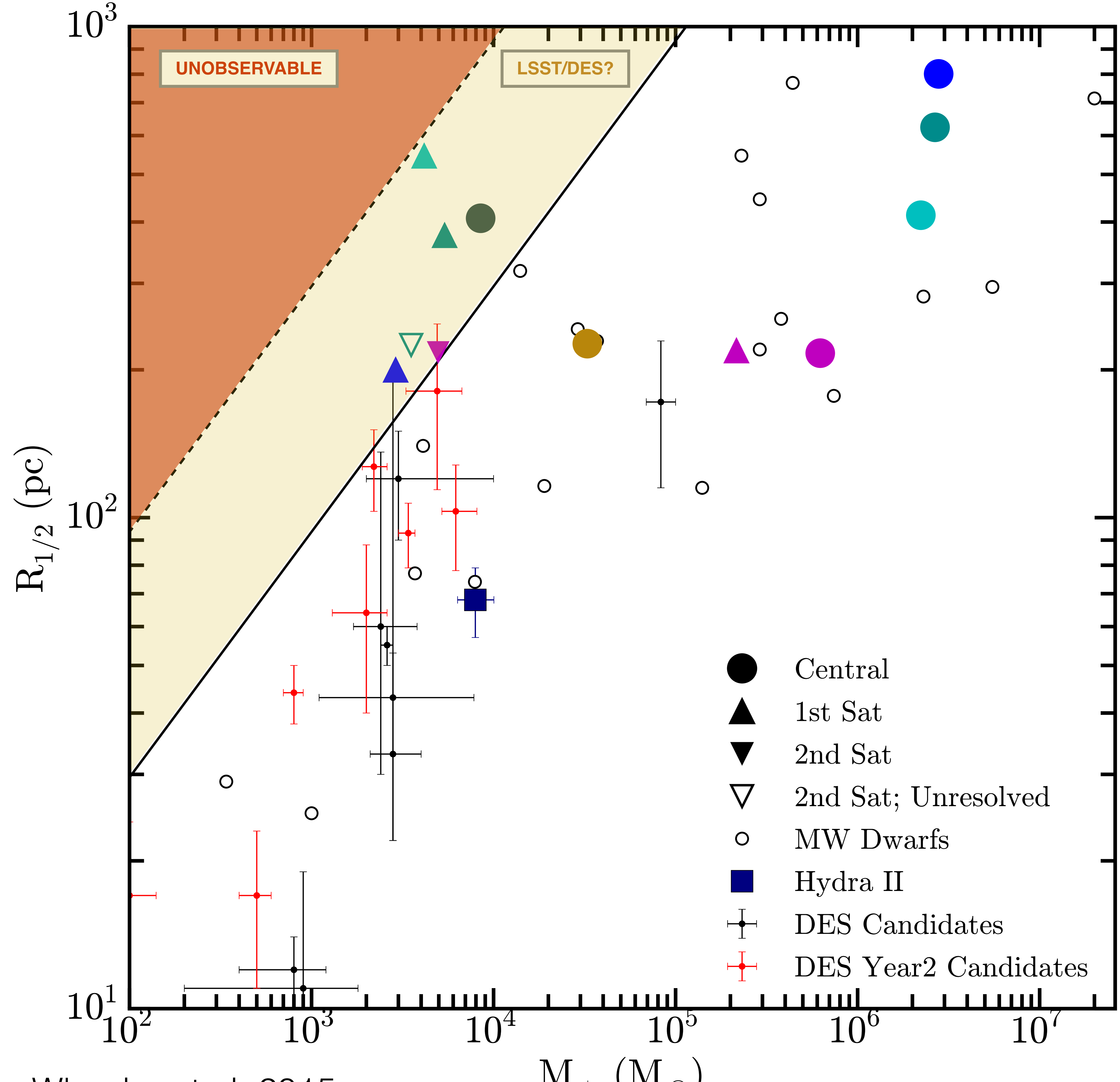


Can they be detected?

Wheeler et al. 2015



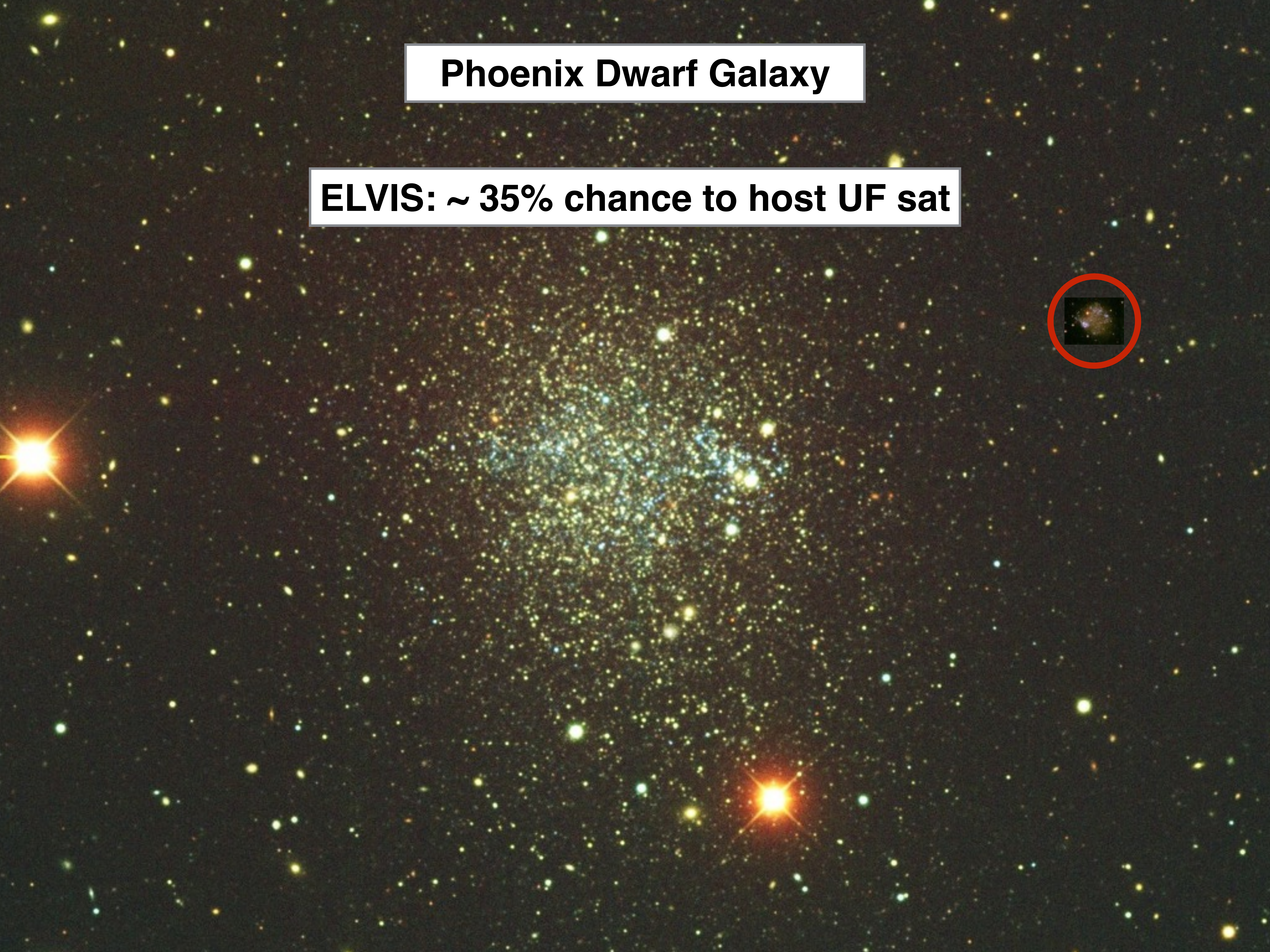
Wheeler et al. 2015

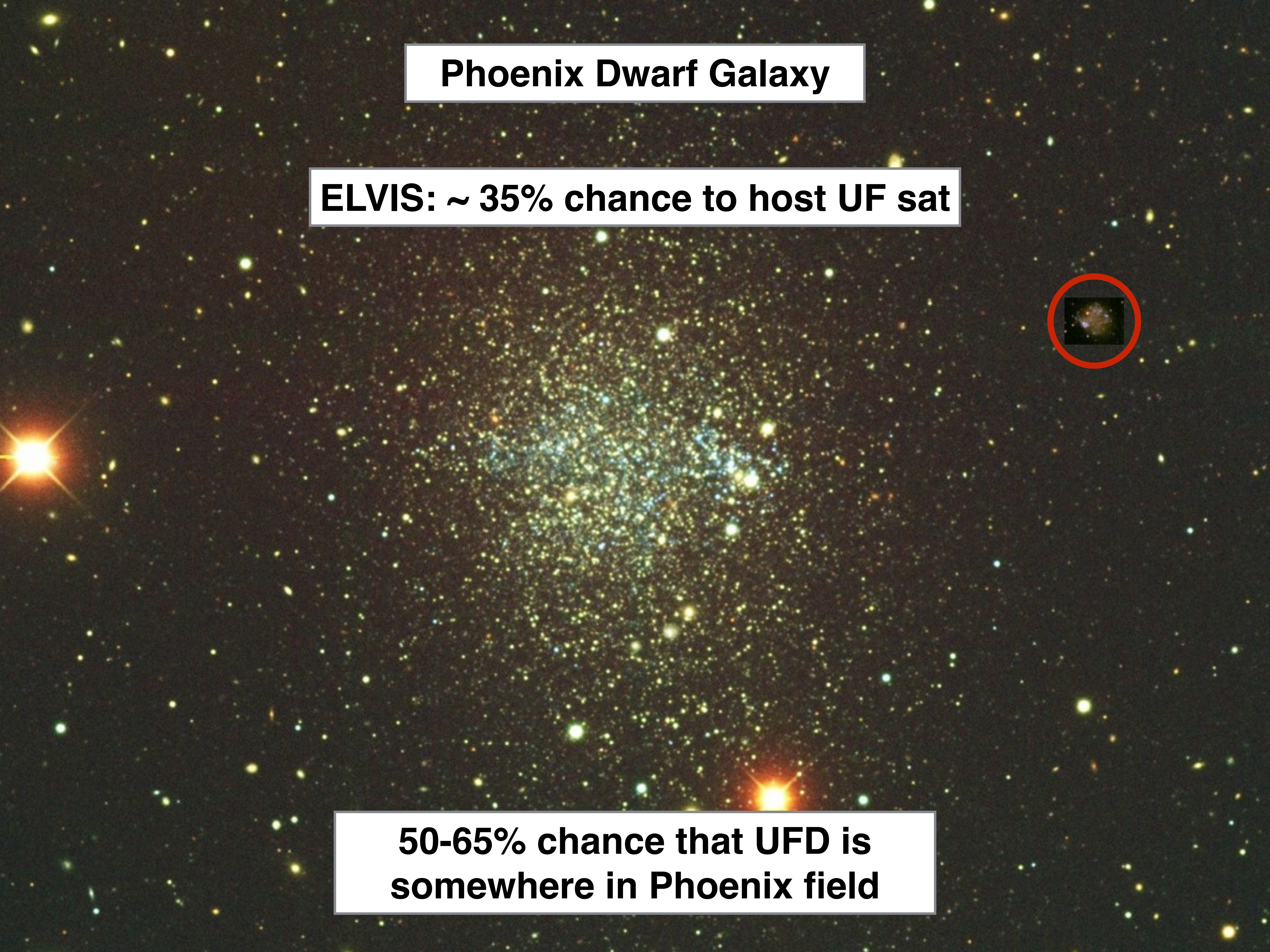


Wheeler et al. 2015

Dark Energy Survey (DES) / DECam


Phoenix Dwarf Galaxy


Phoenix Dwarf Galaxy
ELVIS: ~ 35% chance to host UF sat


Phoenix Dwarf Galaxy
ELVIS: ~ 35% chance to host UF sat
50-65% chance that UFD is somewhere in Phoenix field

Sand et al. 2015: Antlia B Dwarf

arXiv:1508.01800

Antlia B: A faint dwarf galaxy member of the NGC 3109 association

D. J. Sand, K. Spekkens, D. Crnojević, J. R. Hargis, B. Willman, J. Strader, C.J. Grillmair

(Submitted on 7 Aug 2015)

We report the discovery of Antlia B, a faint dwarf galaxy at a projected distance of ~72 kpc from NGC 3109 (M_V ~ −15 mag), the primary galaxy of the NGC 3109 dwarf association at the edge of the Local Group. The tip of the red giant branch distance to Antlia B is D=1.29 ±0.10 Mpc, which is consistent with the distance to NGC 3109. A qualitative analysis indicates the new dwarf's stellar population has both an old, metal poor red giant branch (≳10 Gyr, [Fe/H]~−2), and a younger blue population with an age of ~200-400 Myr, analogous to the original Antlia dwarf, another likely satellite of NGC 3109. Antlia B has \ion{H}{1} gas at a velocity of $v_{helio,HI}$ =376 km s^{-1}, confirming the association with NGC 3109 (v_{helio} =403 km s^{-1}). The HI gas mass (M_{HI} =2.8±0.2×10^5 $M_\odot$), stellar luminosity (M_V =−9.7±0.6 mag) and half light radius (r_h =273±29 pc) are all consistent with the properties of dwarf irregular and dwarf spheroidal galaxies in the Local Volume, and is most similar to the Leo P dwarf galaxy. The discovery of Antlia B is the initial result from a Dark Energy Camera survey for halo substructure and faint dwarf companions to NGC 3109 with the goal of comparing observed substructure with expectations from the Λ+Cold Dark Matter model in the sub-Milky Way regime.

Comments: 7 pages, 3 figures. Submitted to ApJL

Subjects: **Astrophysics of Galaxies (astro-ph.GA)**

Cite as: **arXiv:1508.01800 [astro-ph.GA]**

(or **arXiv:1508.01800v1 [astro-ph.GA]** for this version)

Submission history

From: David J. Sand [view email]

[v1] Fri, 7 Aug 2015 20:03:51 GMT (1465kb)

Which authors of this paper are endorsers? | Disable MathJax (What is MathJax?)

Future work will present a resolved stellar analysis of the halo of NGC 3109, as well as Hubble Space Telescope (HST) imaging of Antlia B and other faint dwarf galaxy candidates

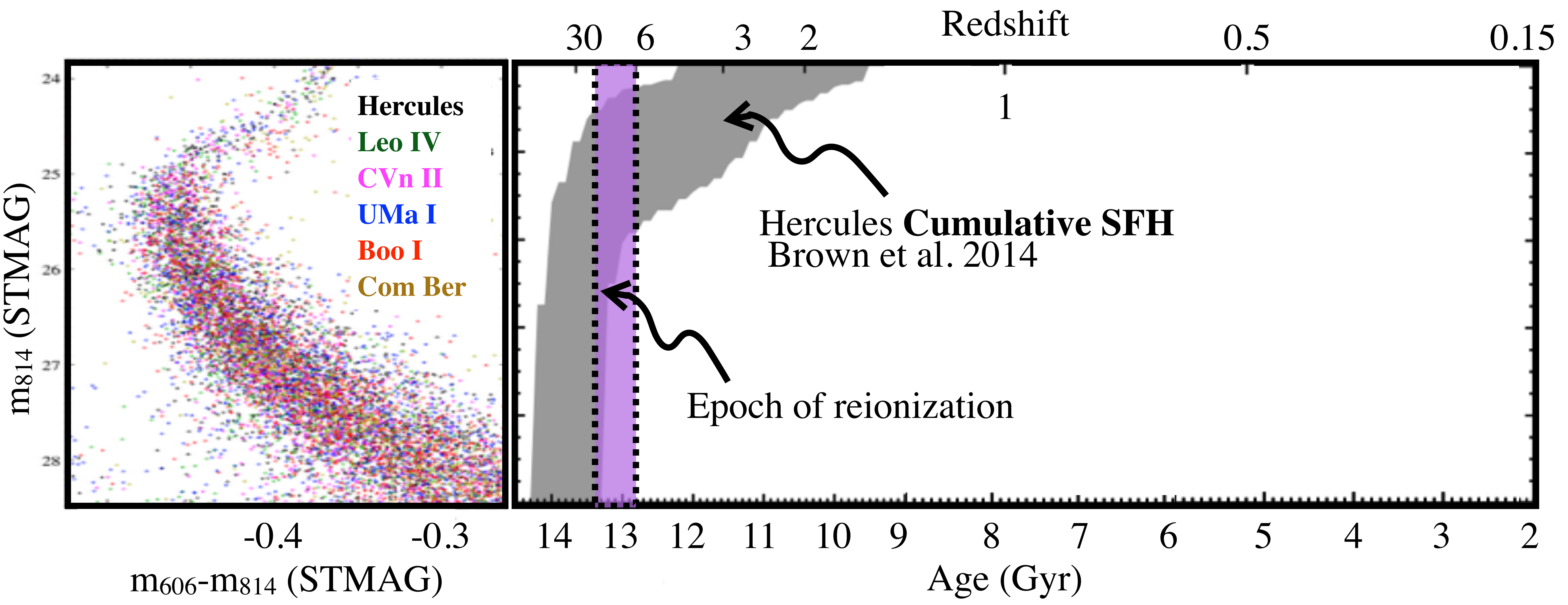
- Missing satellites problem - why are there so few dwarf satellites?

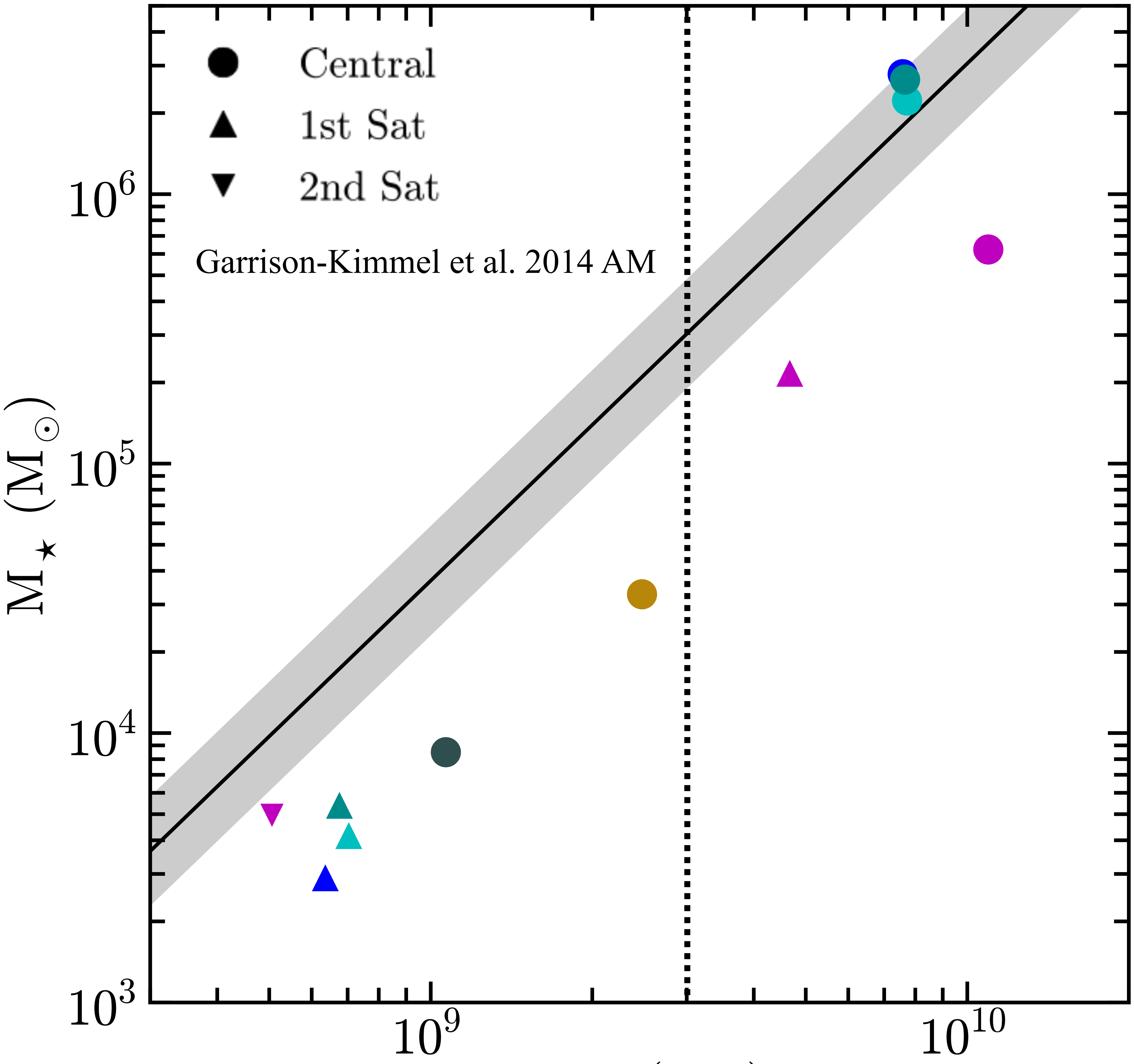
- Ancient populations - what shuts down star formation in ultra-faint dwarfs?

- Age gradients - how do dwarfs obtain inverted age gradients?

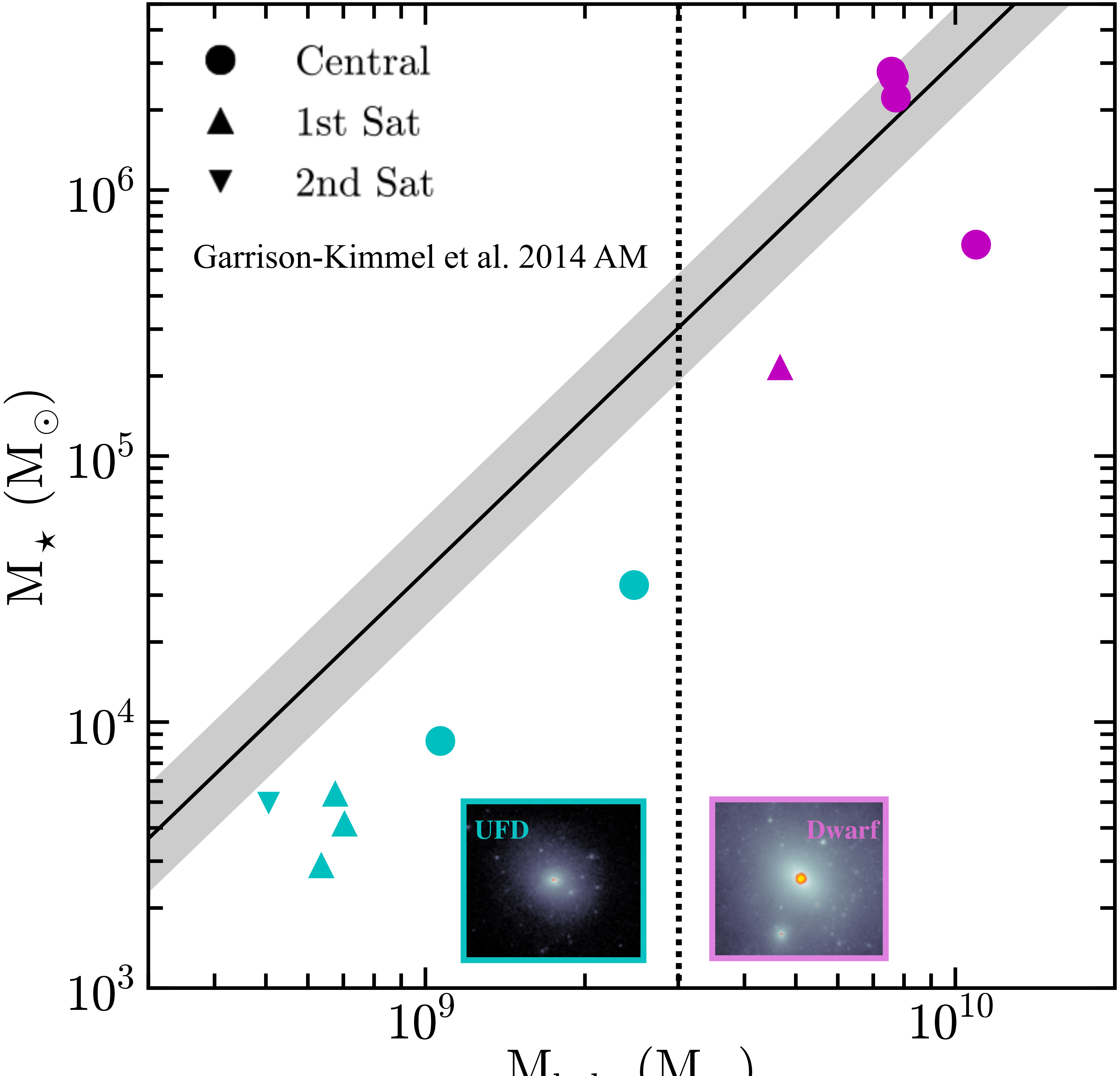
- Dwarf morphology - why are dSphs thicker and non-rotating?

Ultra-faint MW sats have ancient stellar populations



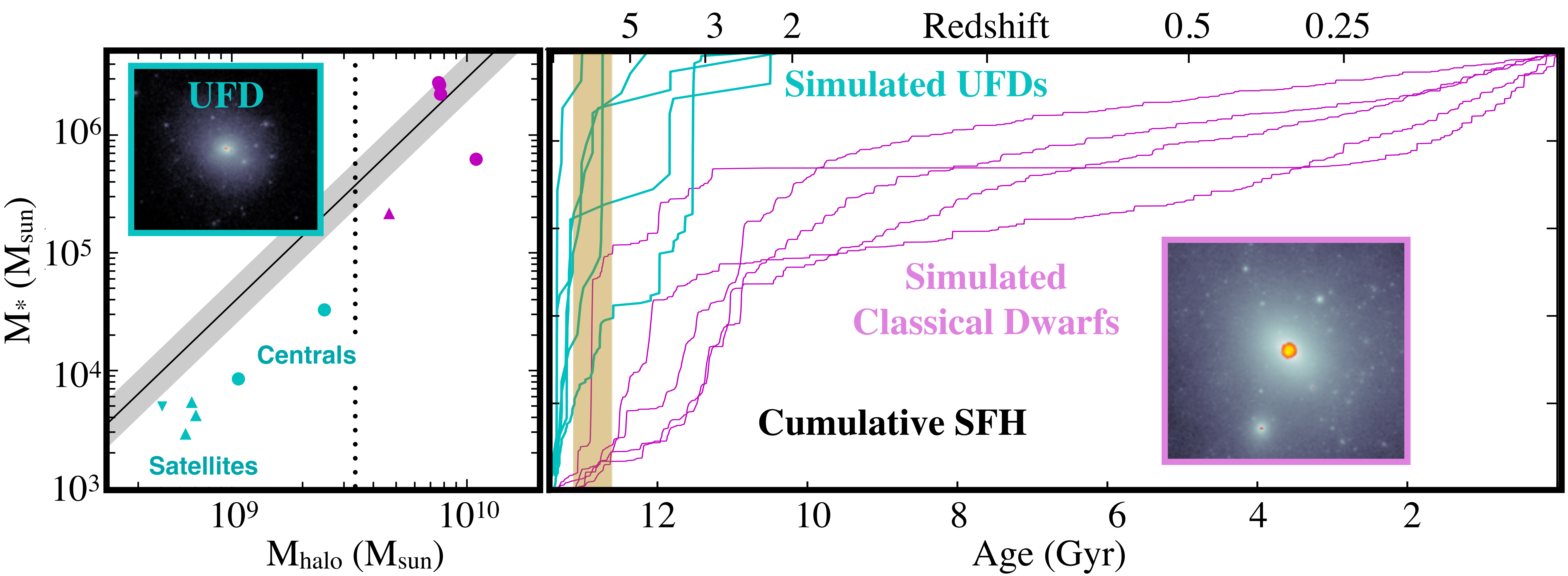


Wheeler et al. 2015



Wheeler et al. 2015

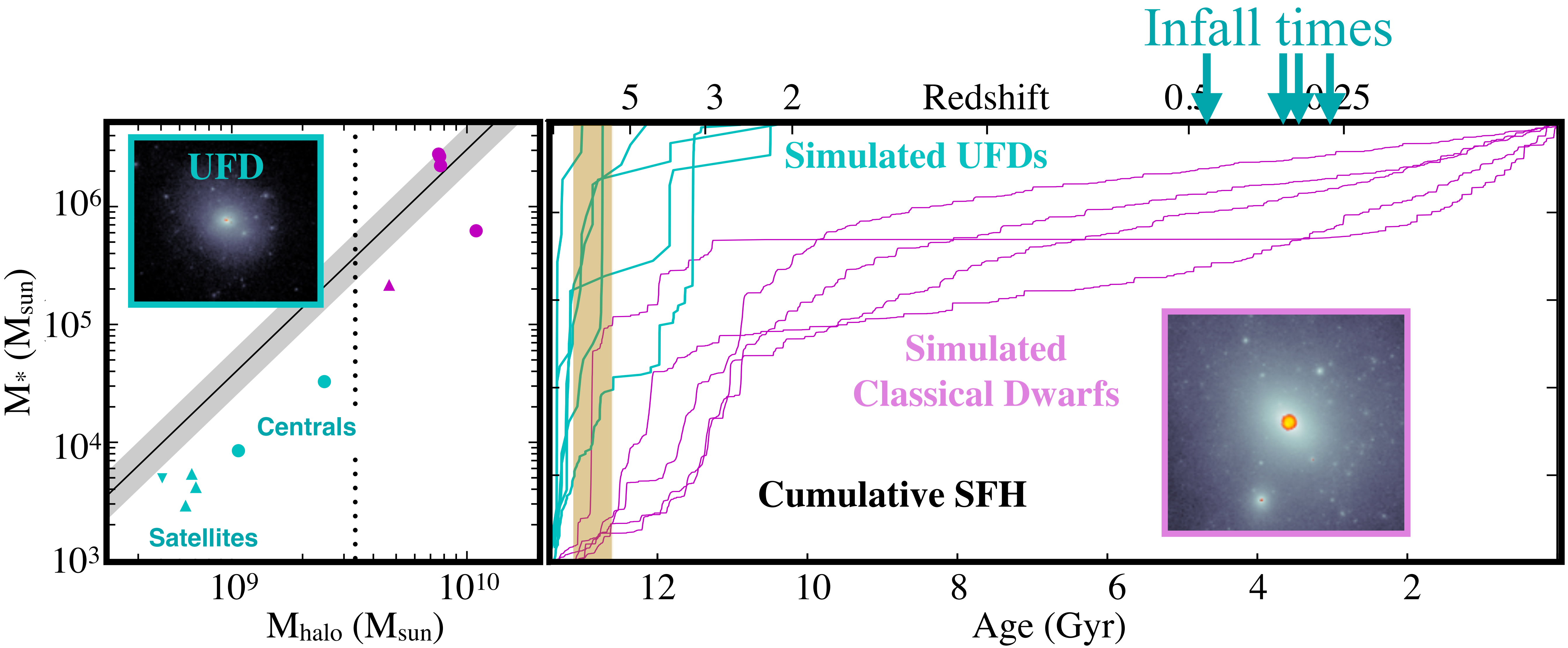
Simulated UFDs have ancient stellar pops



Wheeler et al. 2015

Both satellites & centrals

Simulated UFDs have ancient stellar pops



Wheeler et al. 2015

Quenching unrelated to infall, likely reionization

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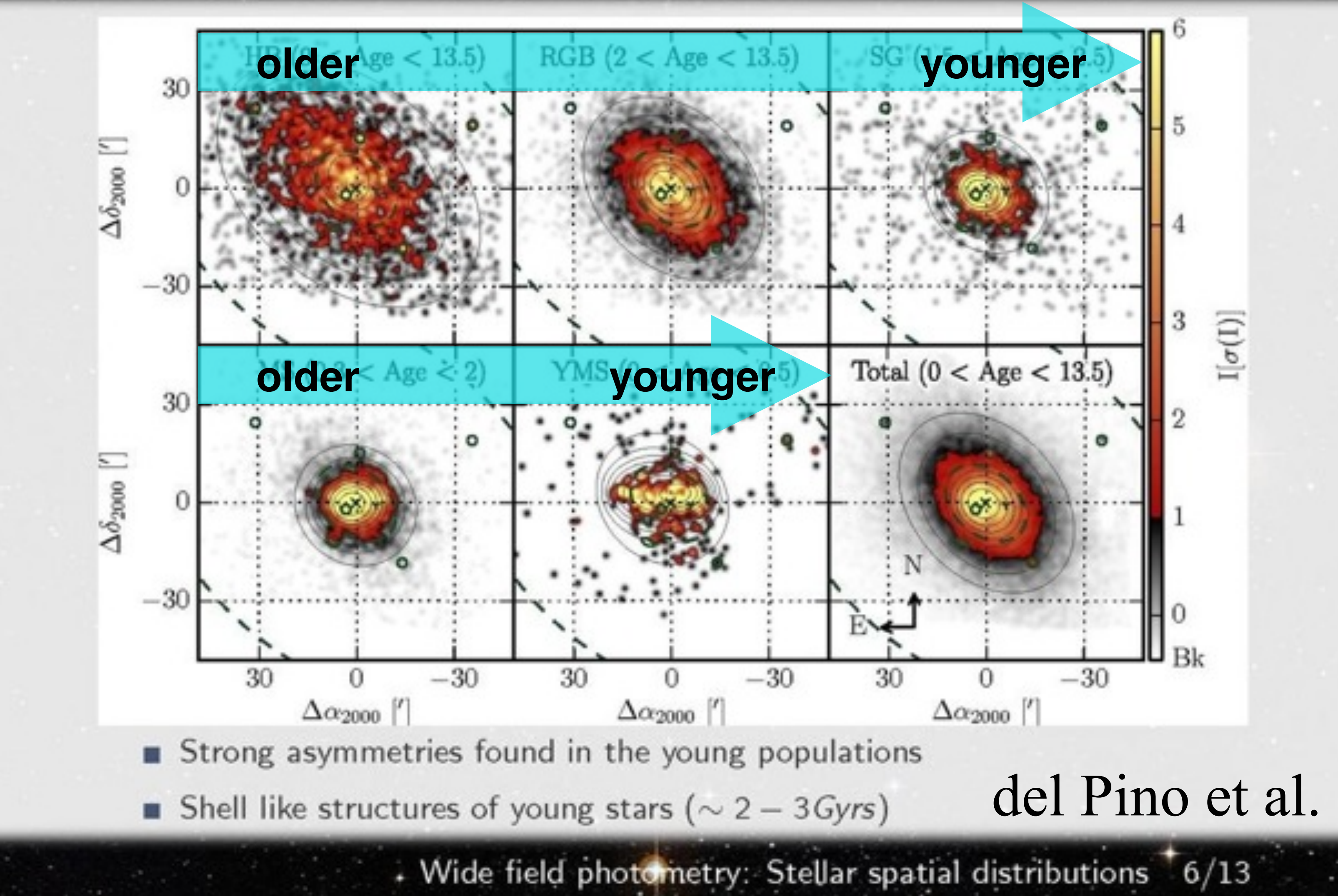
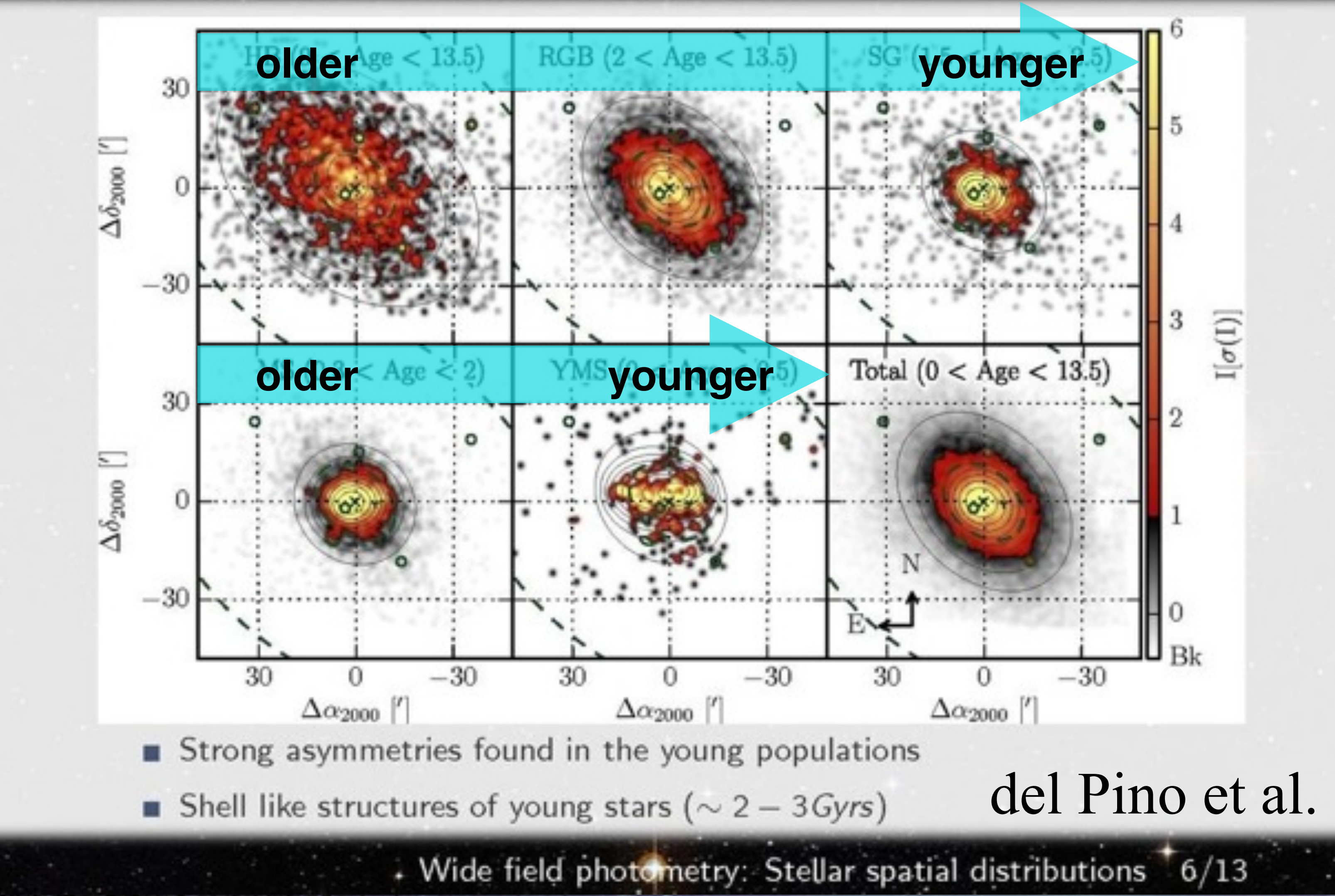


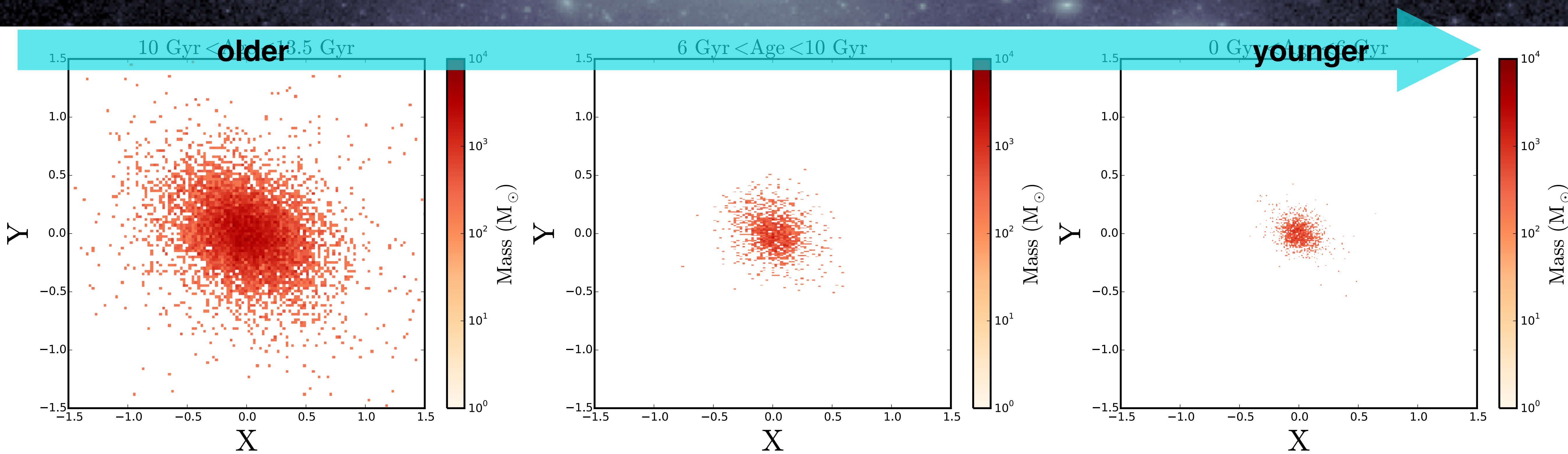
In dwarfs, older stellar pops are more extended than younger ones



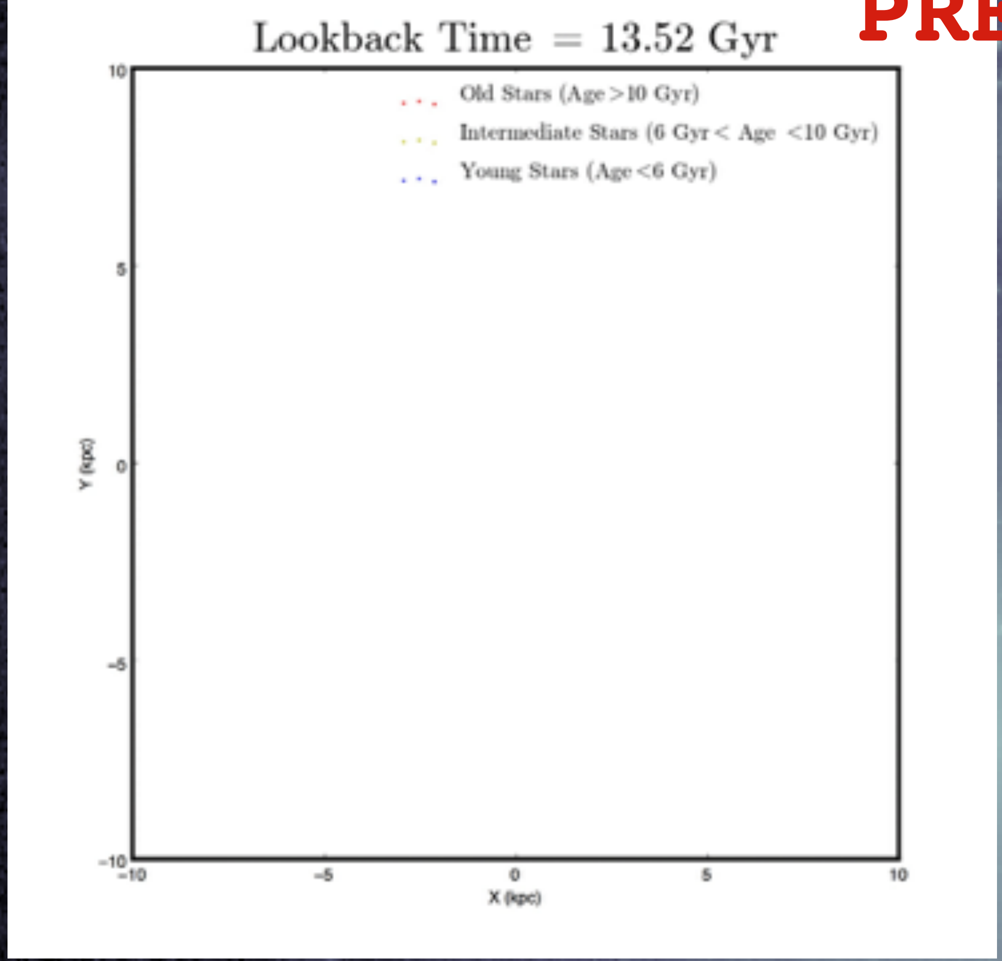
del Pino et al.

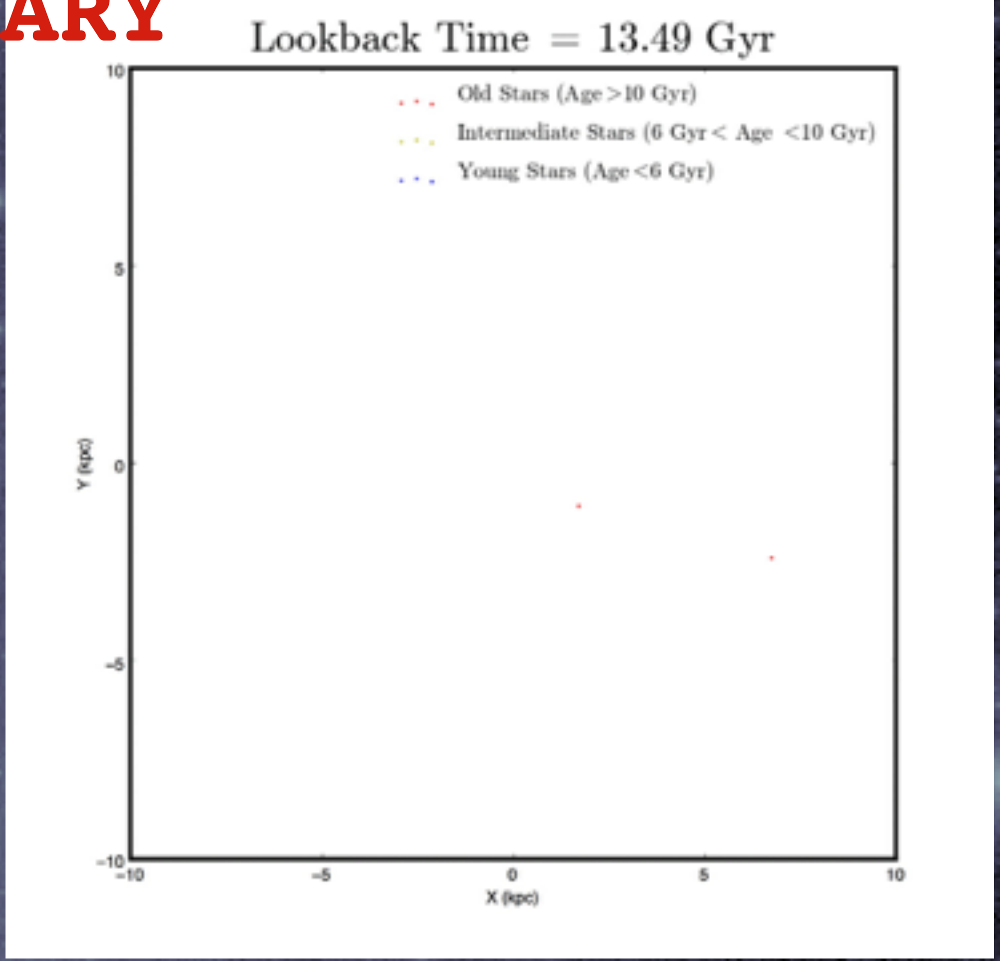
In dwarfs, older stellar pops are more extended than younger ones

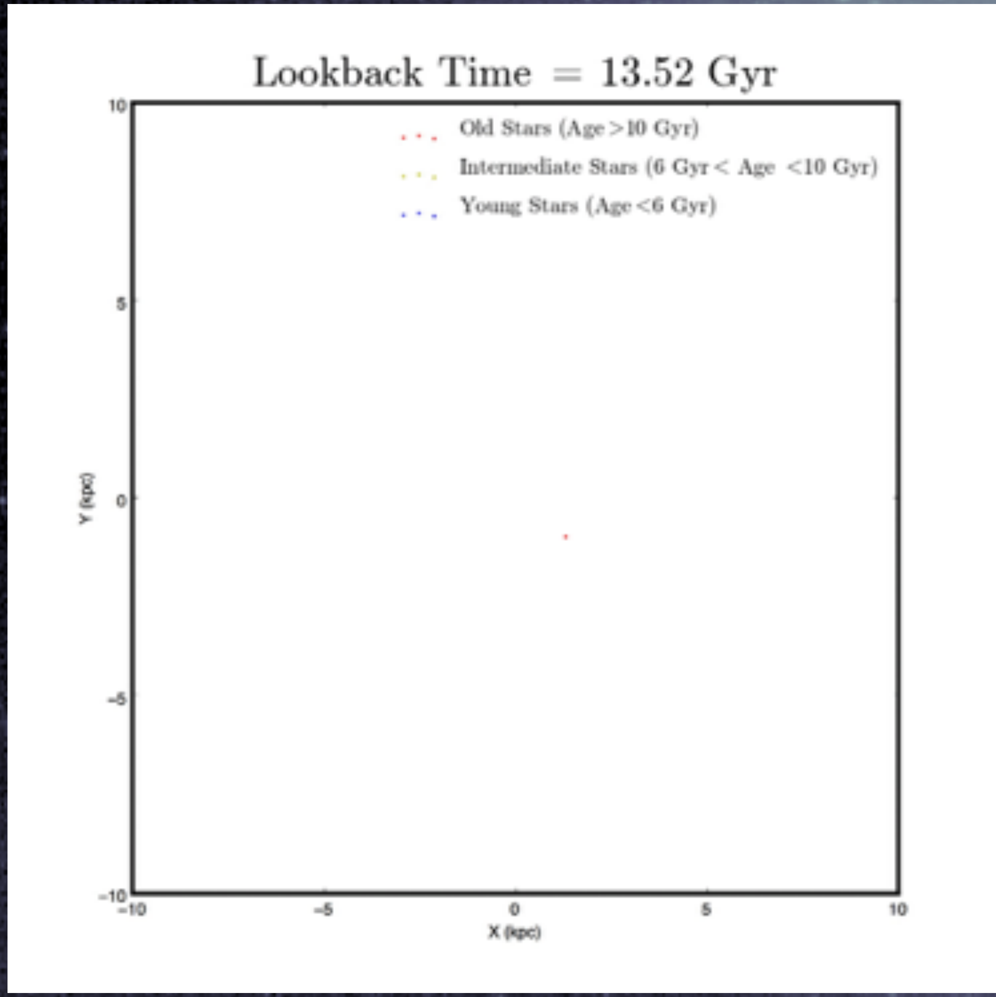
PRELIMINARY

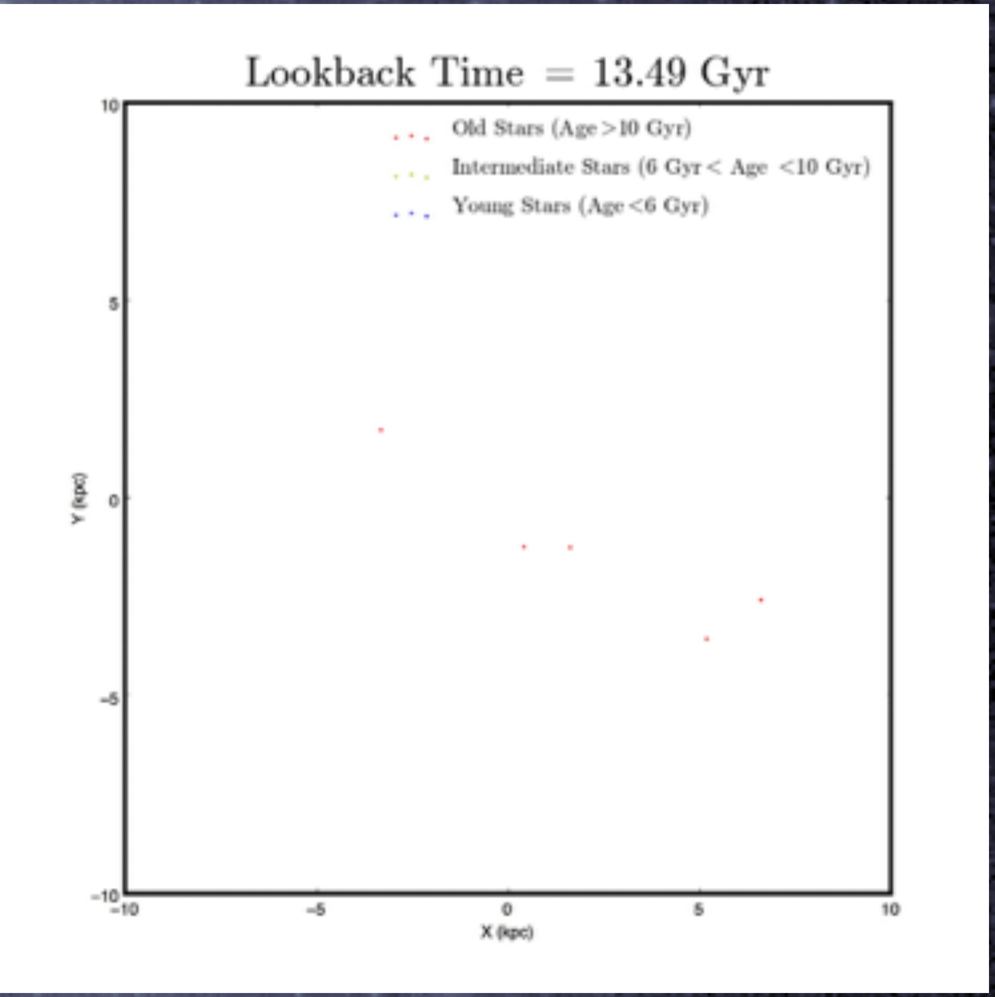


PRELIMINARY









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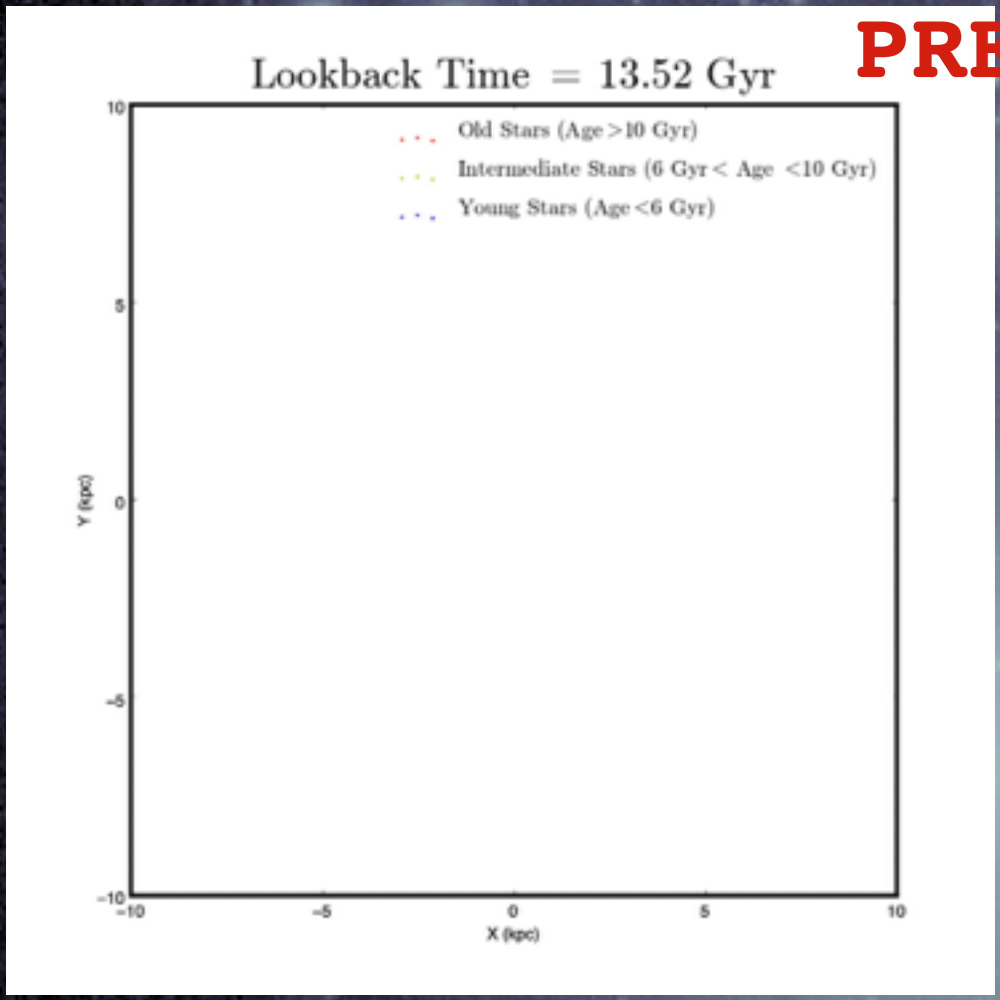

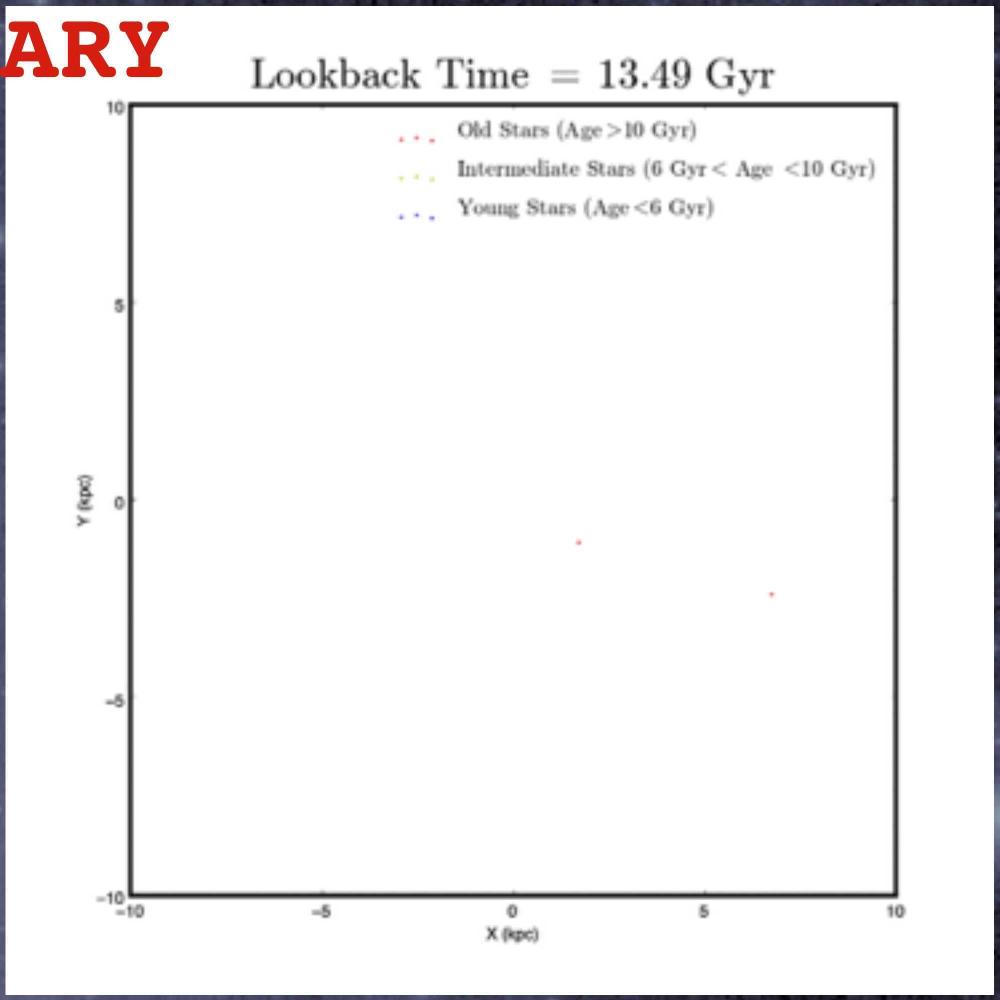

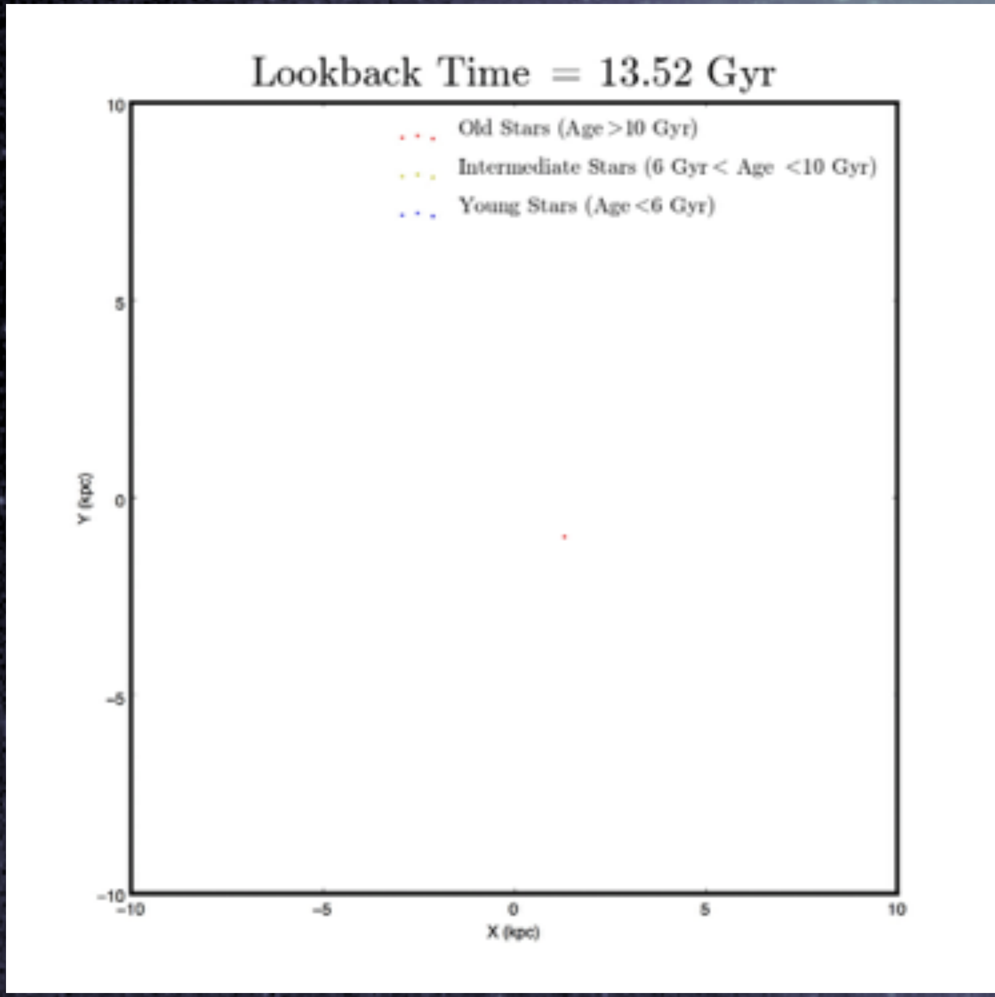

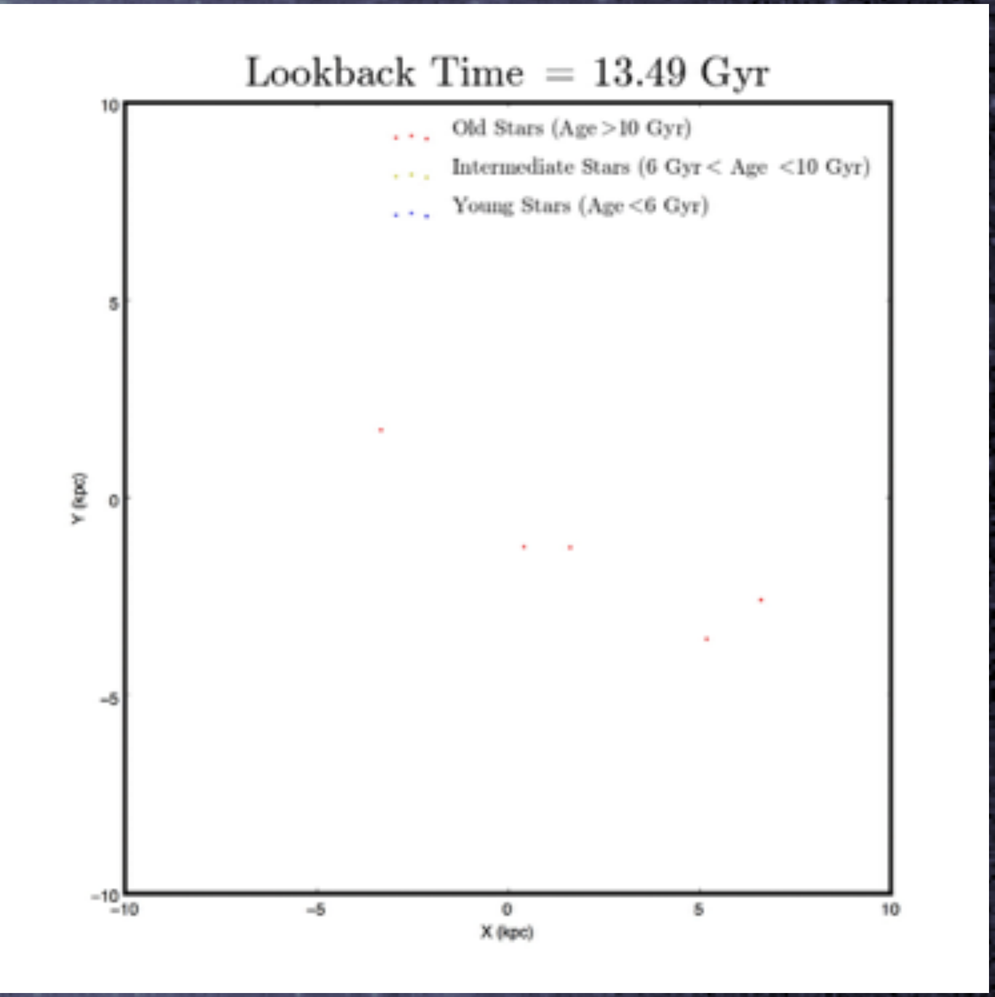

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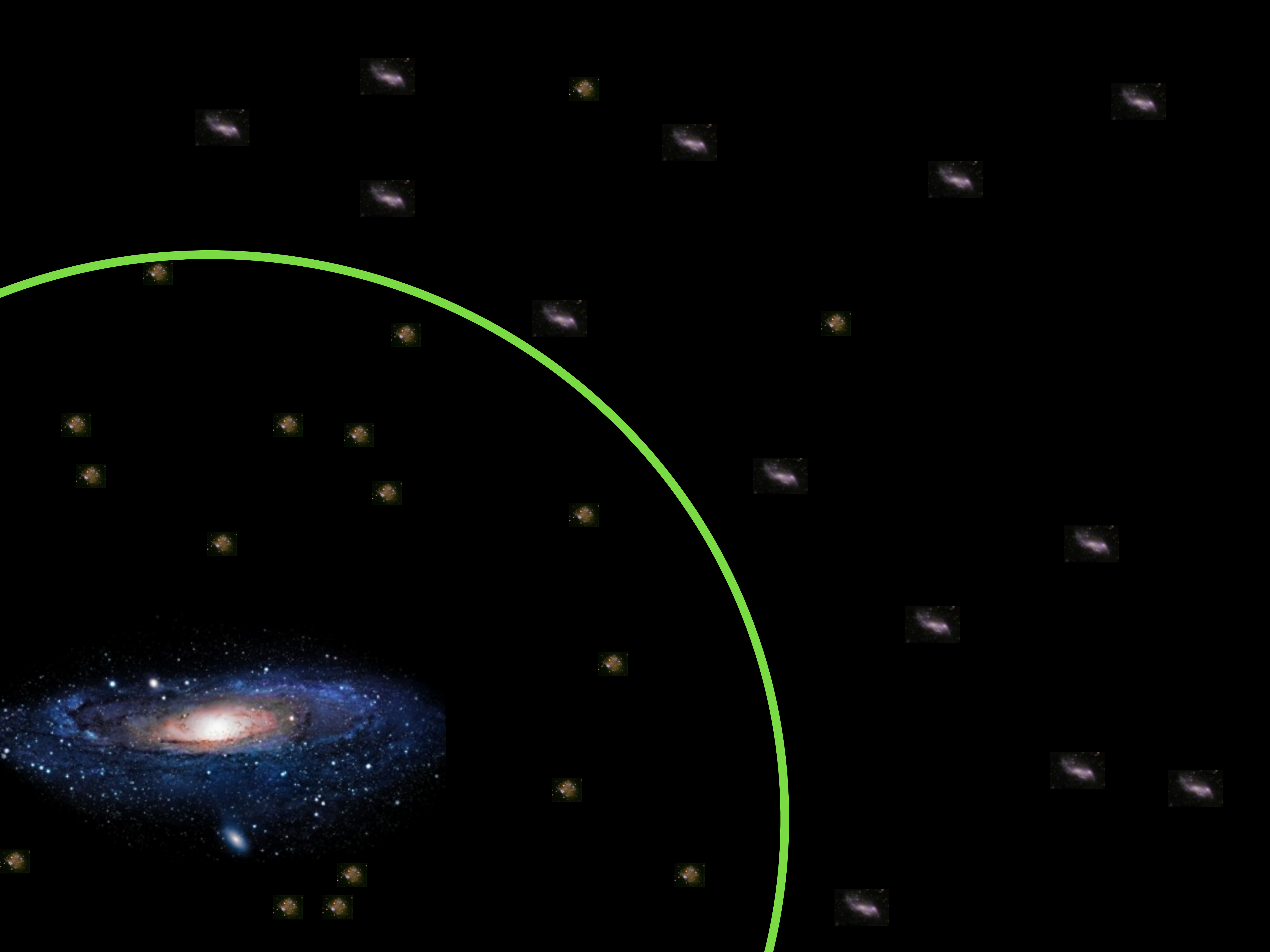
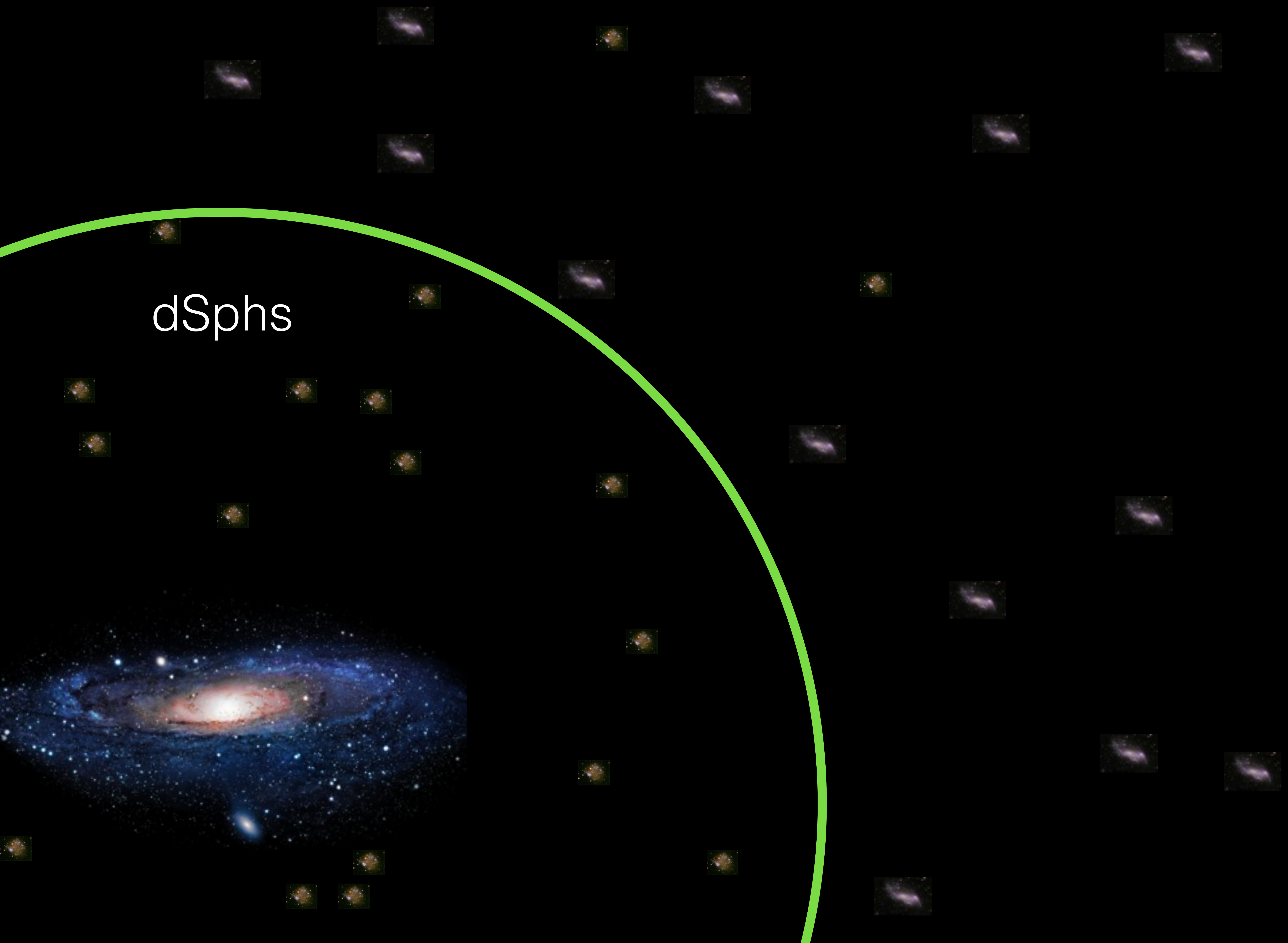
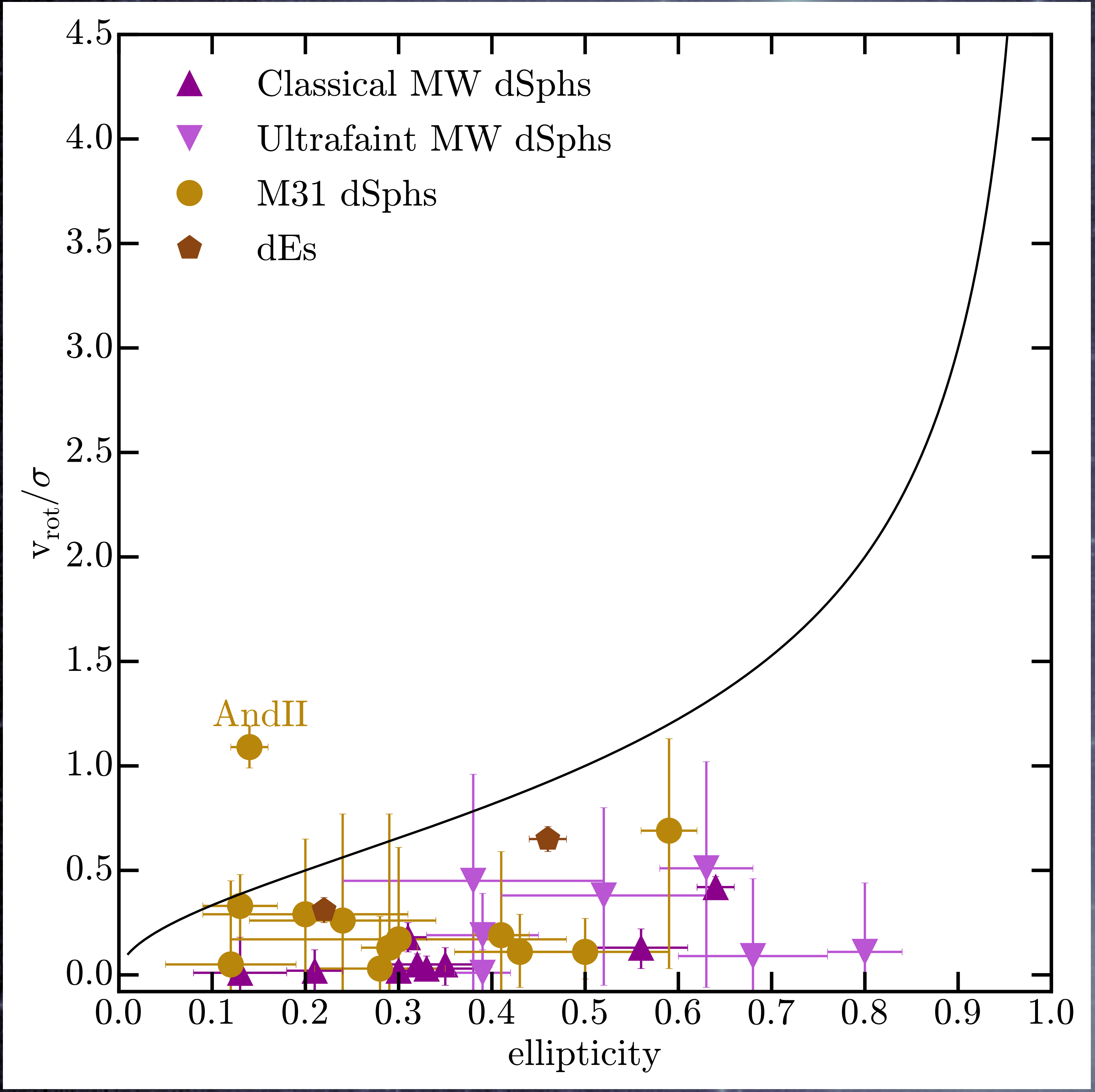



dSphs

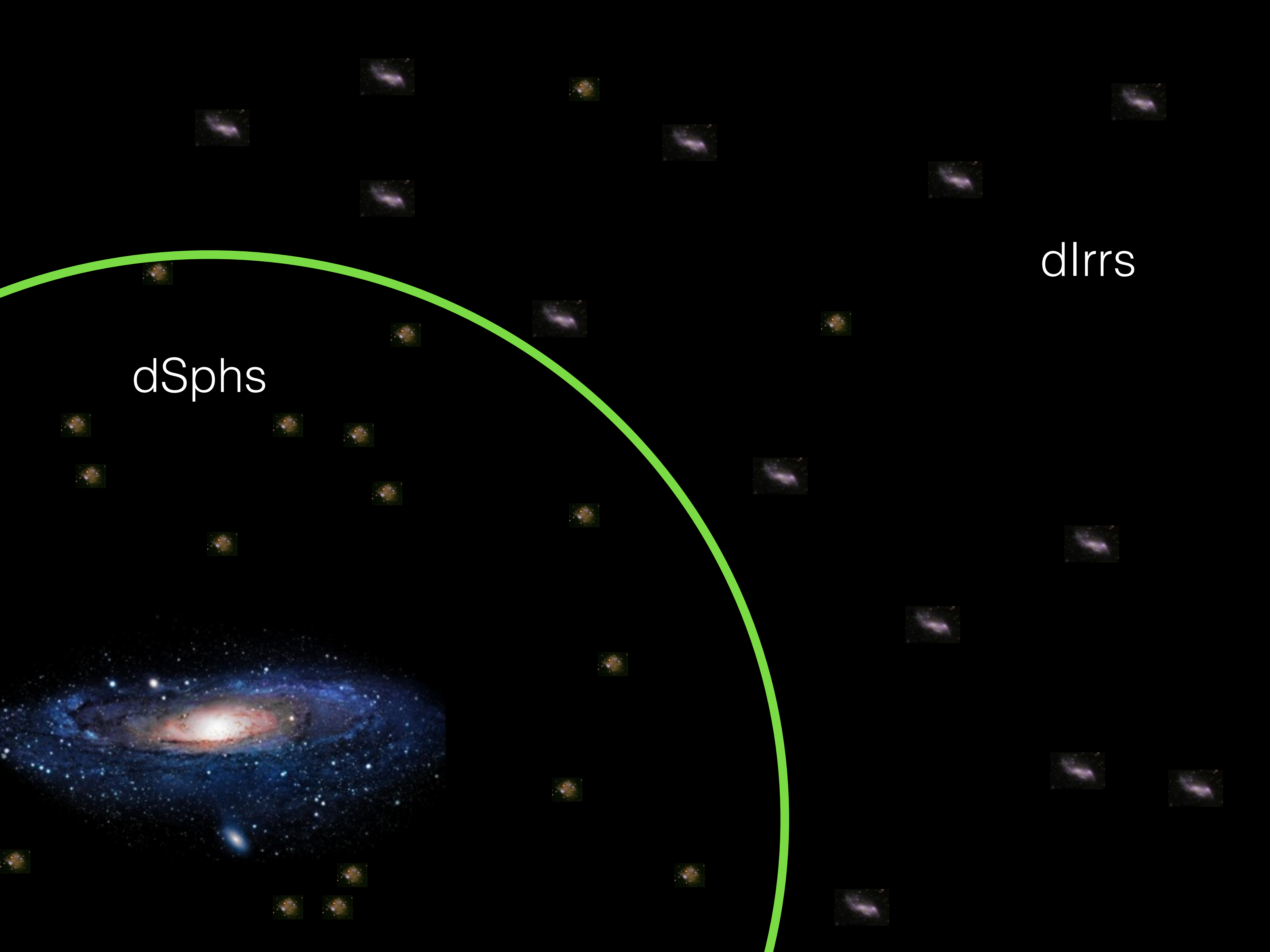
Wheeler et al. *in prep*

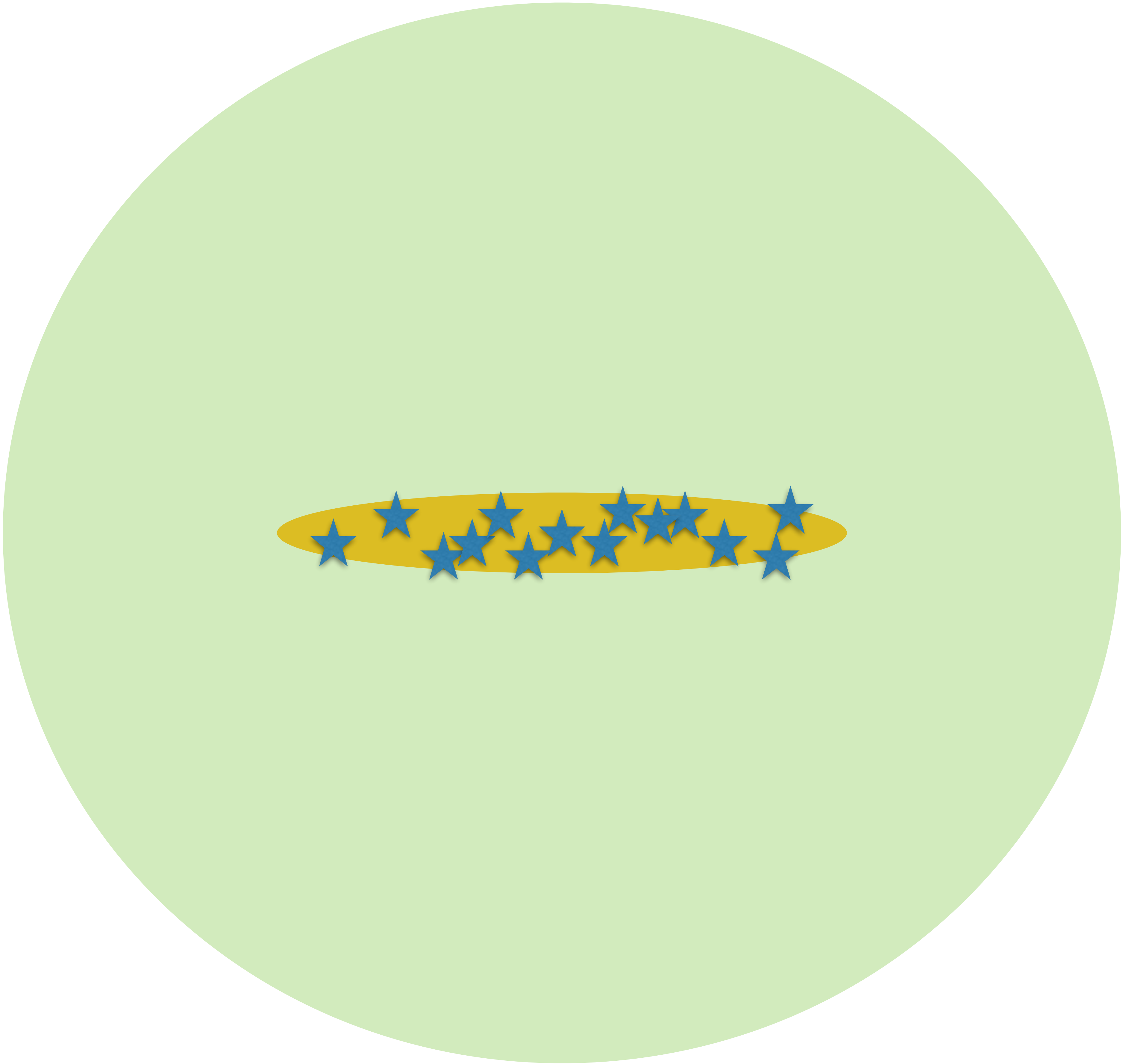
Kazantzidis 2011a

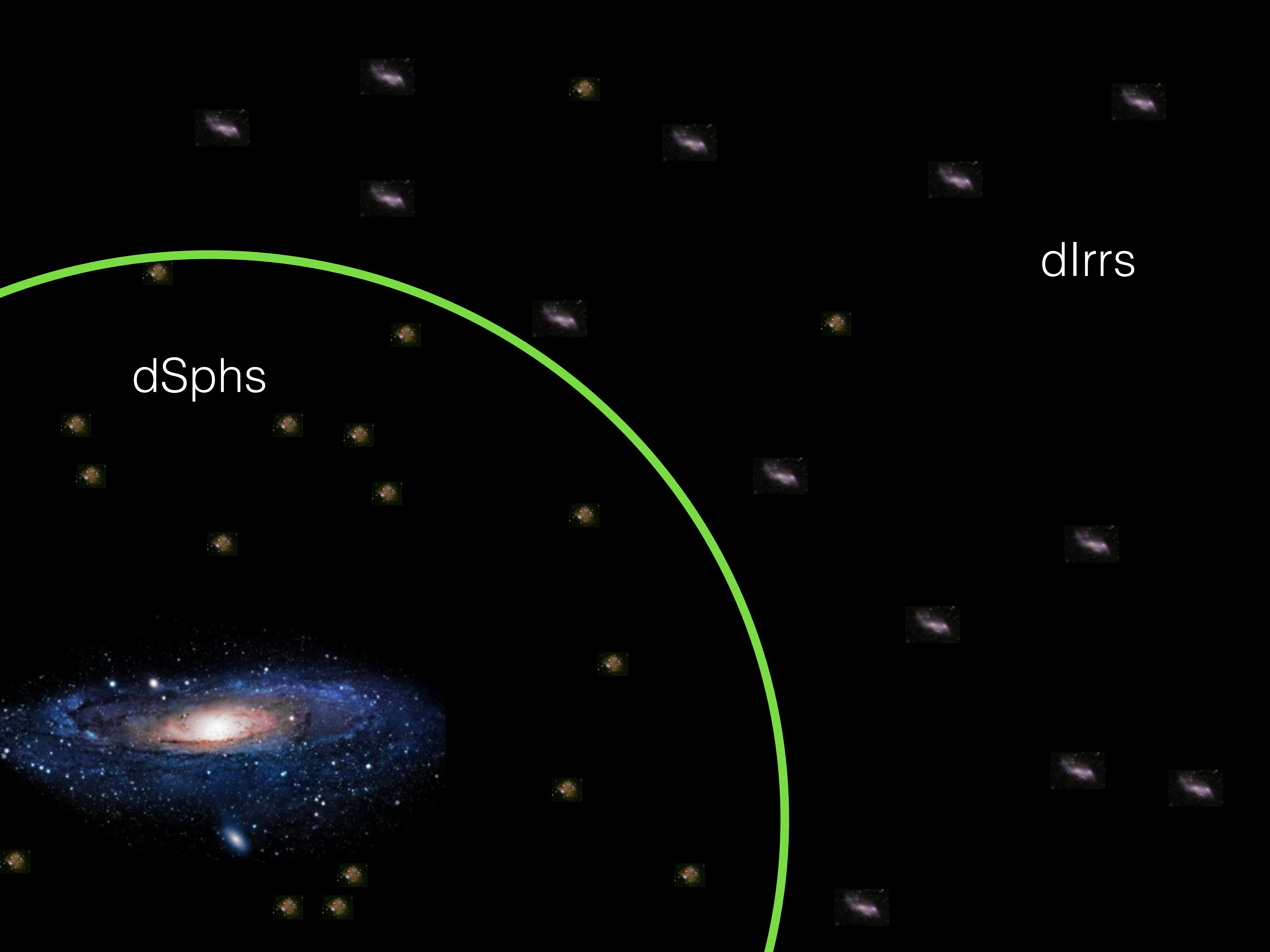


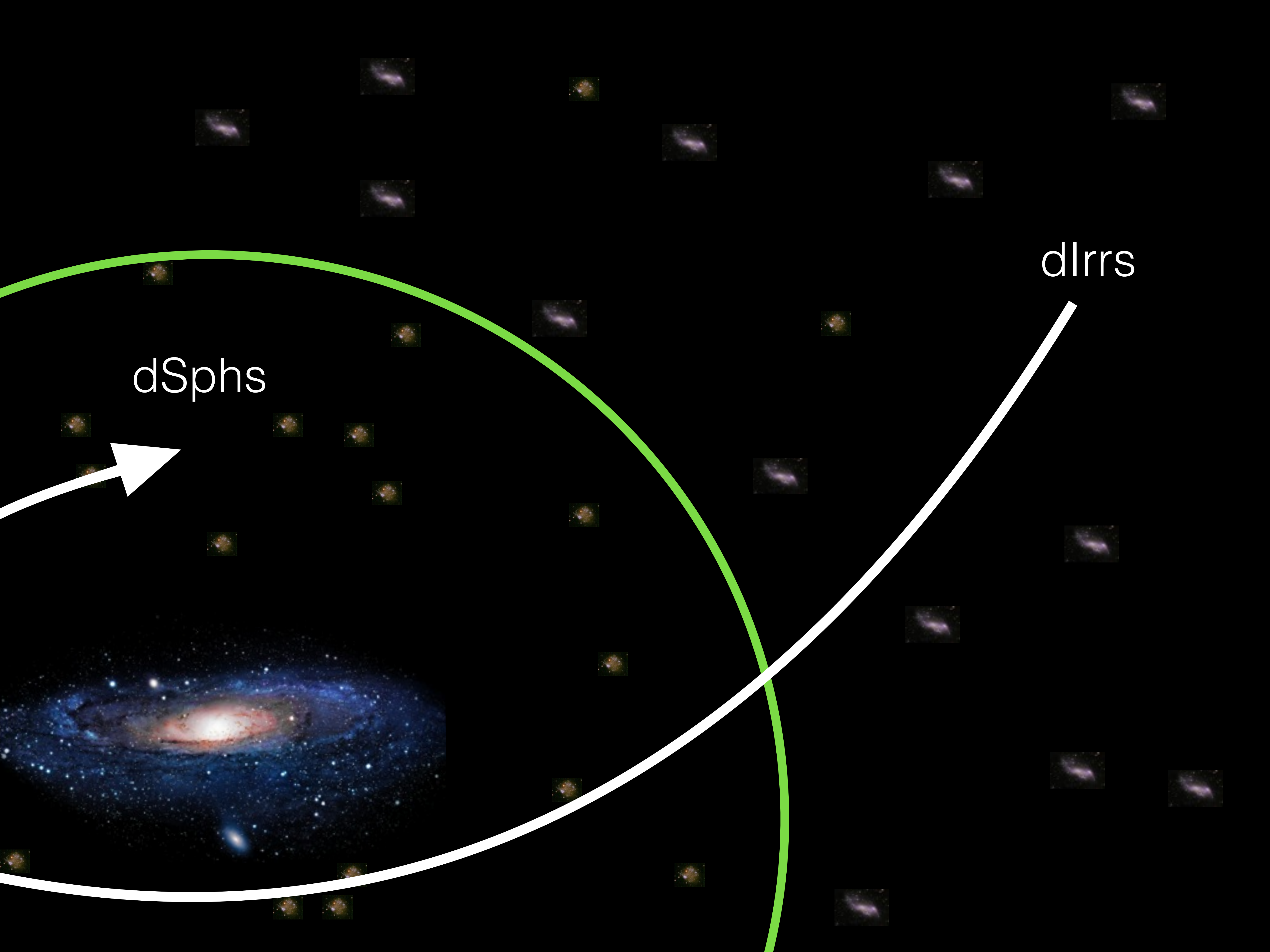
Local Group dwarf spheroidals tend to be dispersion supported

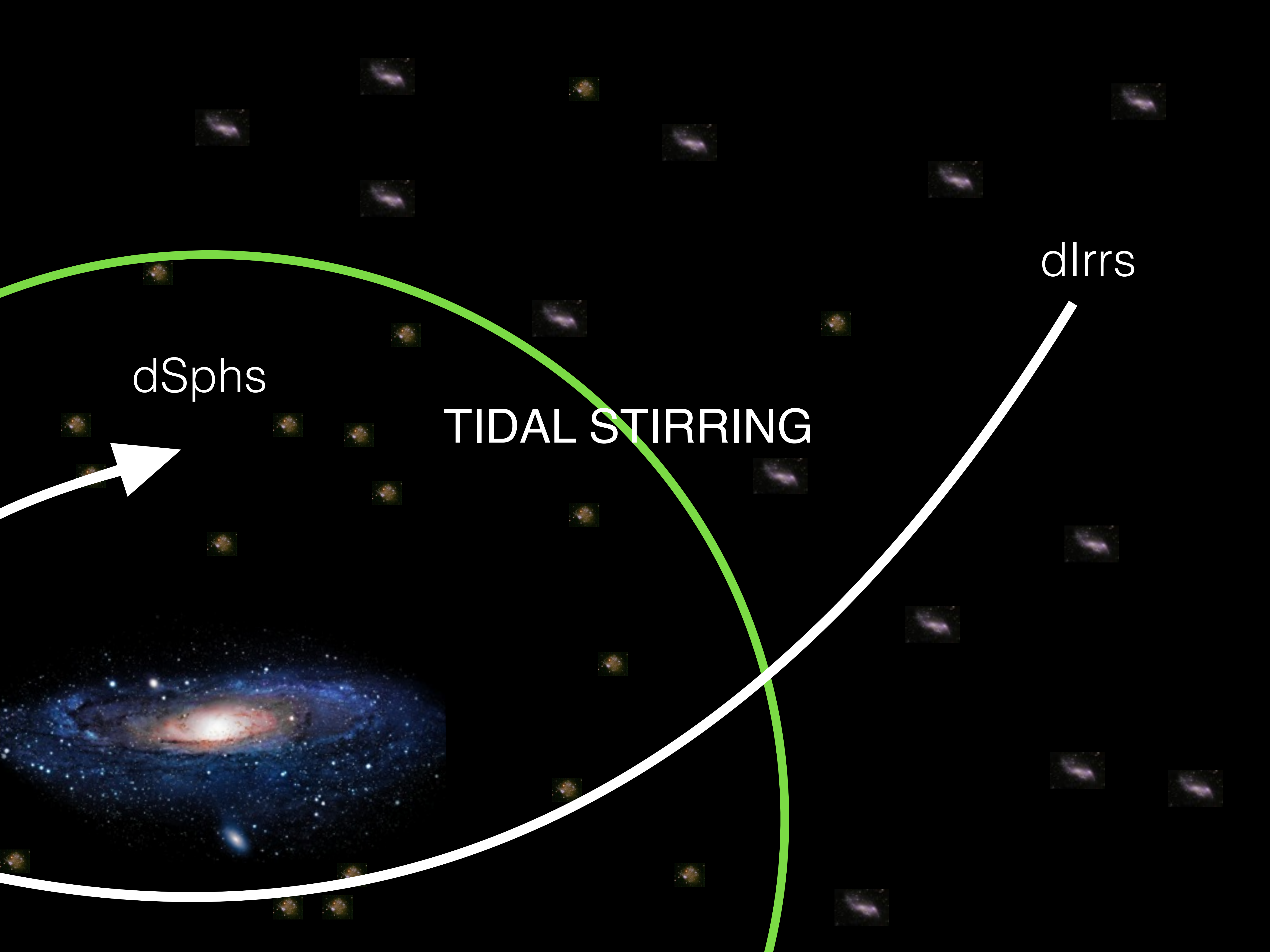
Koch 2007b, Mateo 2008, Walker 2009, Frinchaboy 2012,Walker 2015, Pace 2015, Simon 2007, Koposov 2011, Ho 2012, Tollerud 2012, Collins 2013, Martin 2014, Geha 2010


dIrrs
dSphs



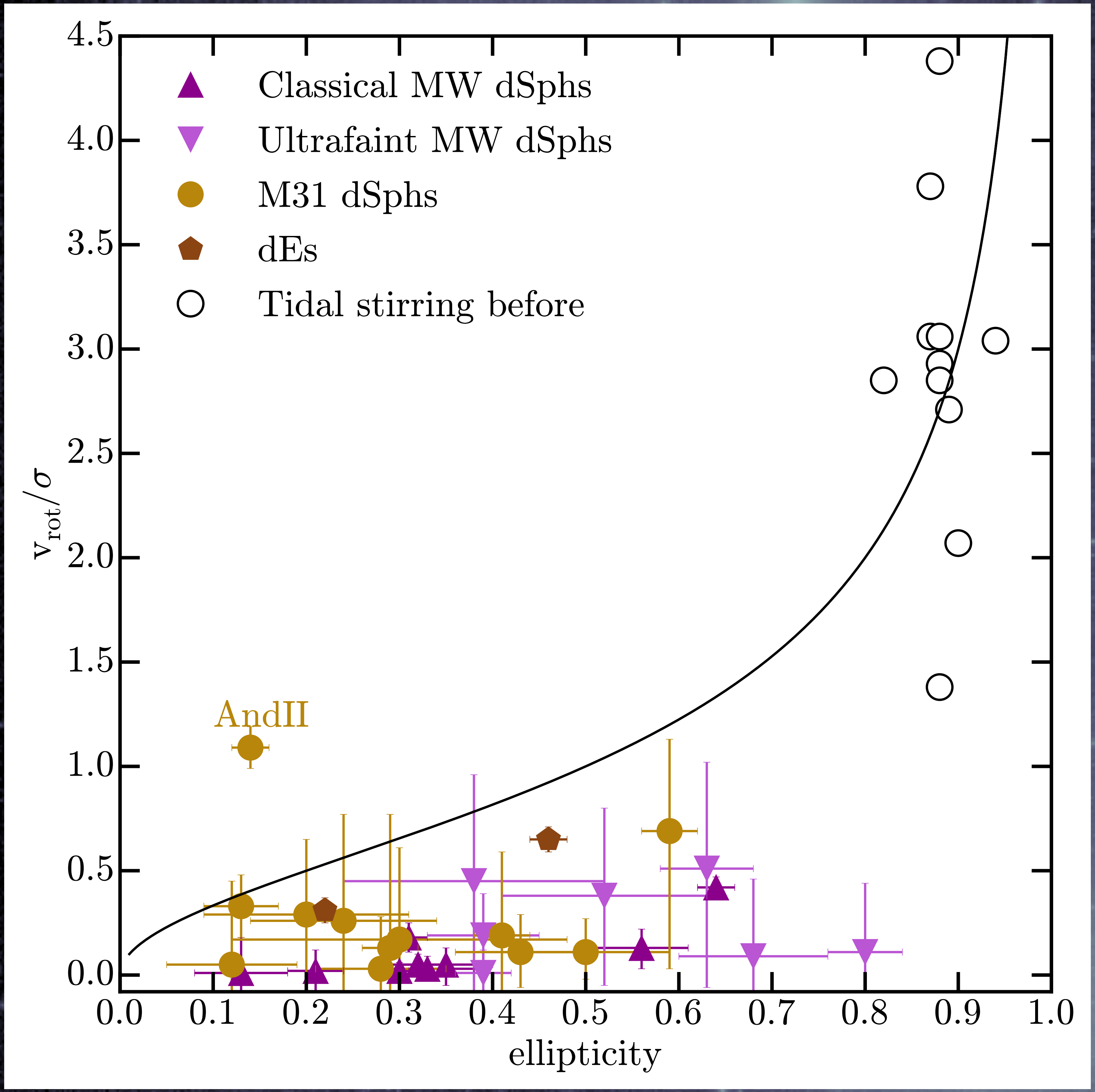

dIrrs
dSphs


dIrrs
dSphs


dIrrs
dSphs
TIDAL STIRRING

Wheeler et al. *in prep*

Kazantzidis 2011a

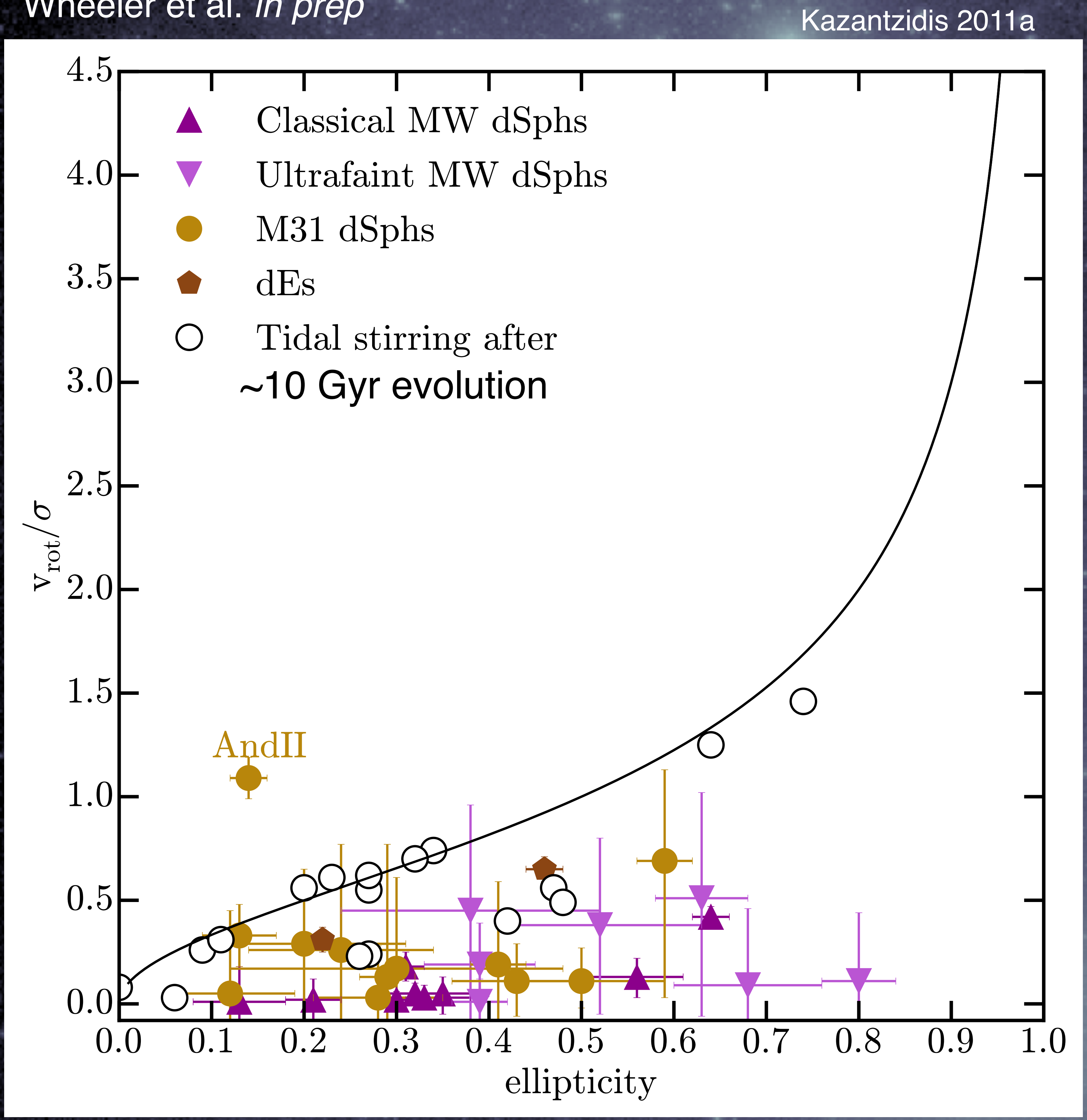


Local Group dwarf spheroidals tend to be dispersion supported

“Tidal stirring” simulations

Koch 2007b, Mateo 2008, Walker 2009, Frinchaboy 2012,Walker 2015, Pace 2015, Simon 2007, Koposov 2011, Ho 2012, Tollerud 2012, Collins 2013, Martin 2014, Geha 2010

Wheeler et al. *in prep*



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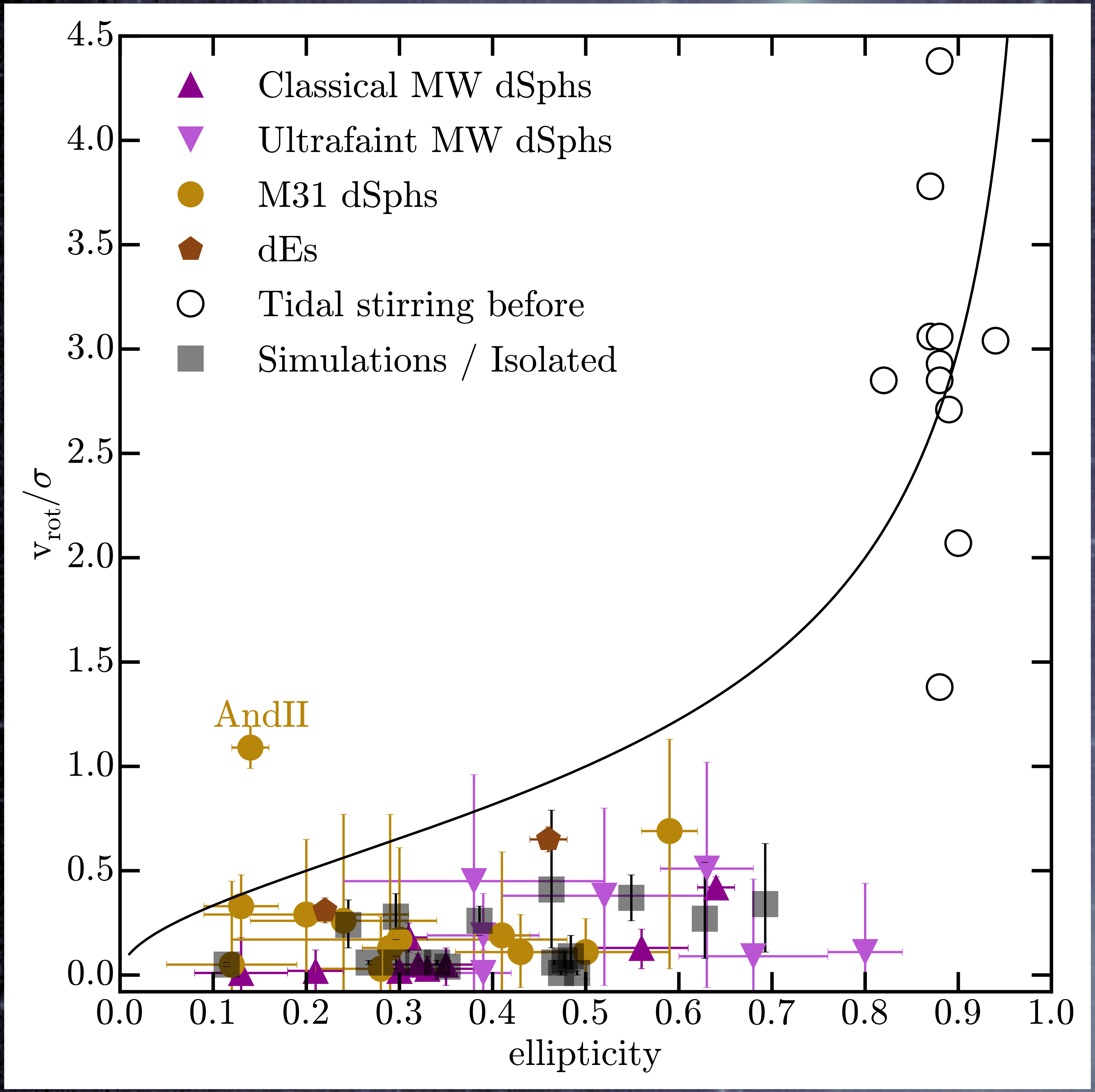
Wheeler et al. *in prep*

Kazantzidis 2011a



Koch 2007b, Mateo 2008, Walker 2009, Frinchaboy 2012,Walker 2015, Pace 2015, Simon 2007, Koposov 2011, Ho 2012, Tollerud 2012, Collins 2013, Martin 2014, Geha 2010

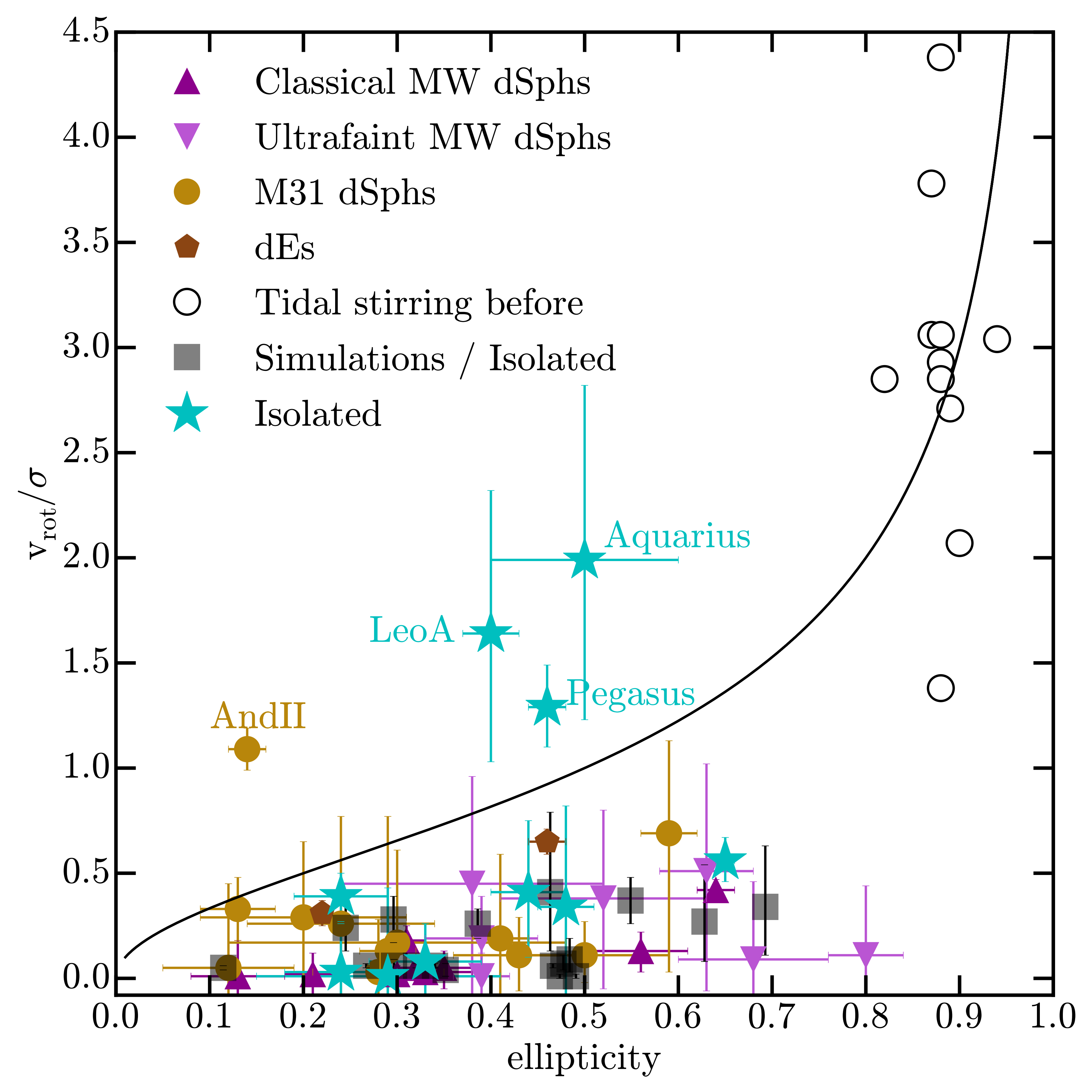
Local Group dwarf spheroidals tend to be dispersion supported

"Tidal stirring" simulations

Isolated FIRE dwarfs already dispersion supported

Wheeler et al. *in prep*

Kazantzidis 2011a



Fraternali 2009, Simon 2007, Kirby 2014, Leaman 2009, Leaman 2012

Local Group dwarf spheroidals tend to be dispersion supported

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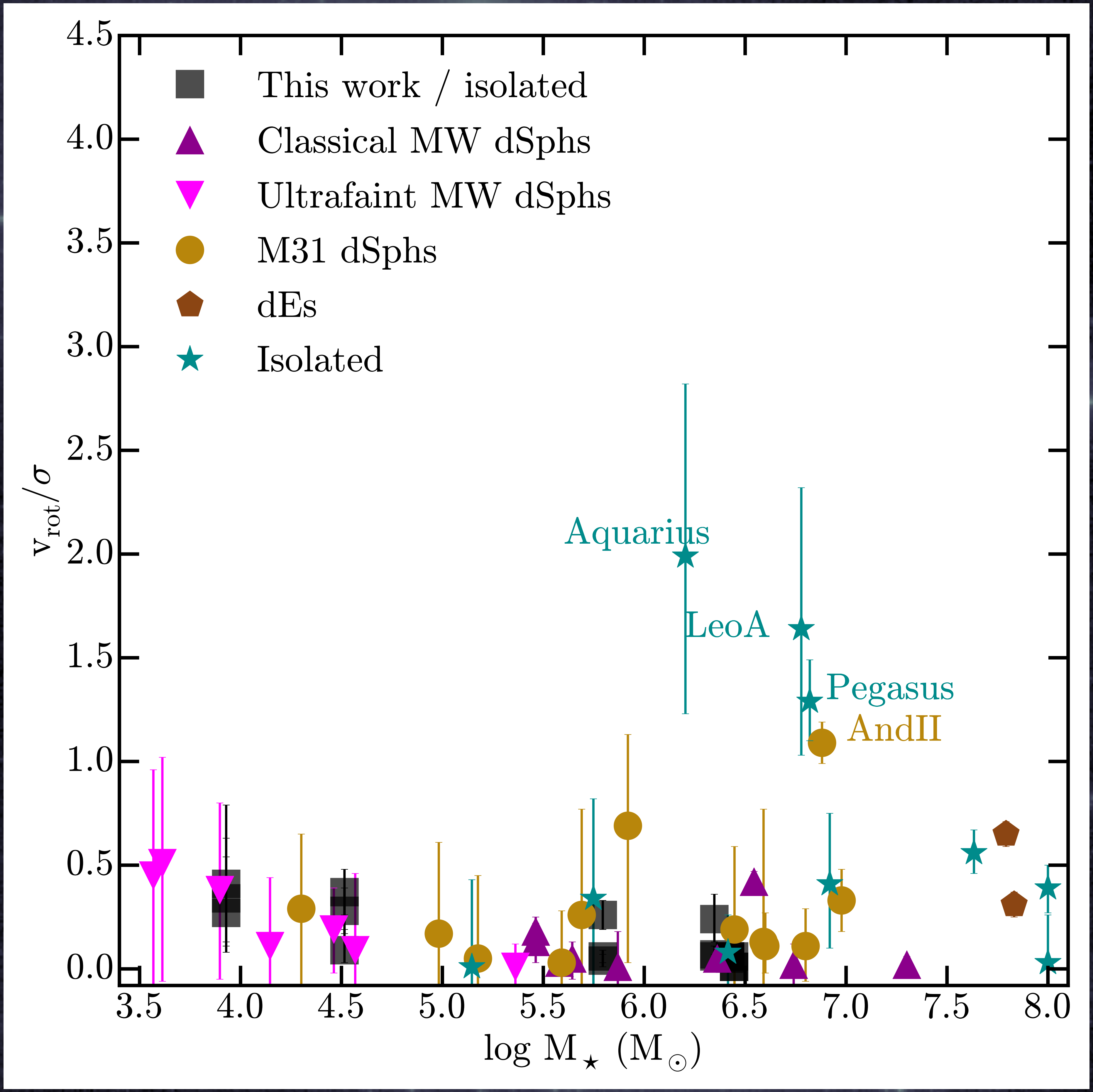
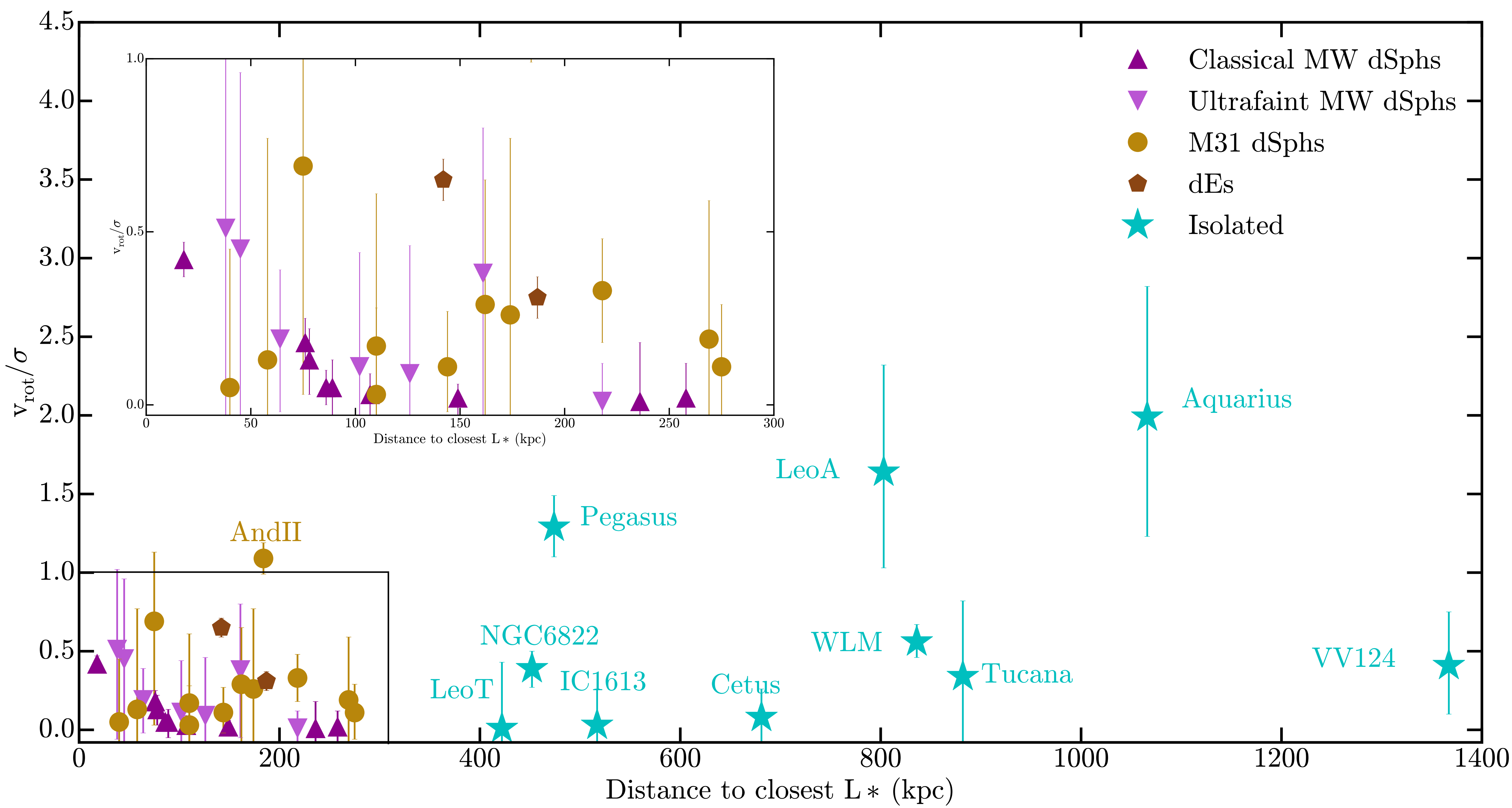
Most isolated dIrr stellar pops dispersion supported!

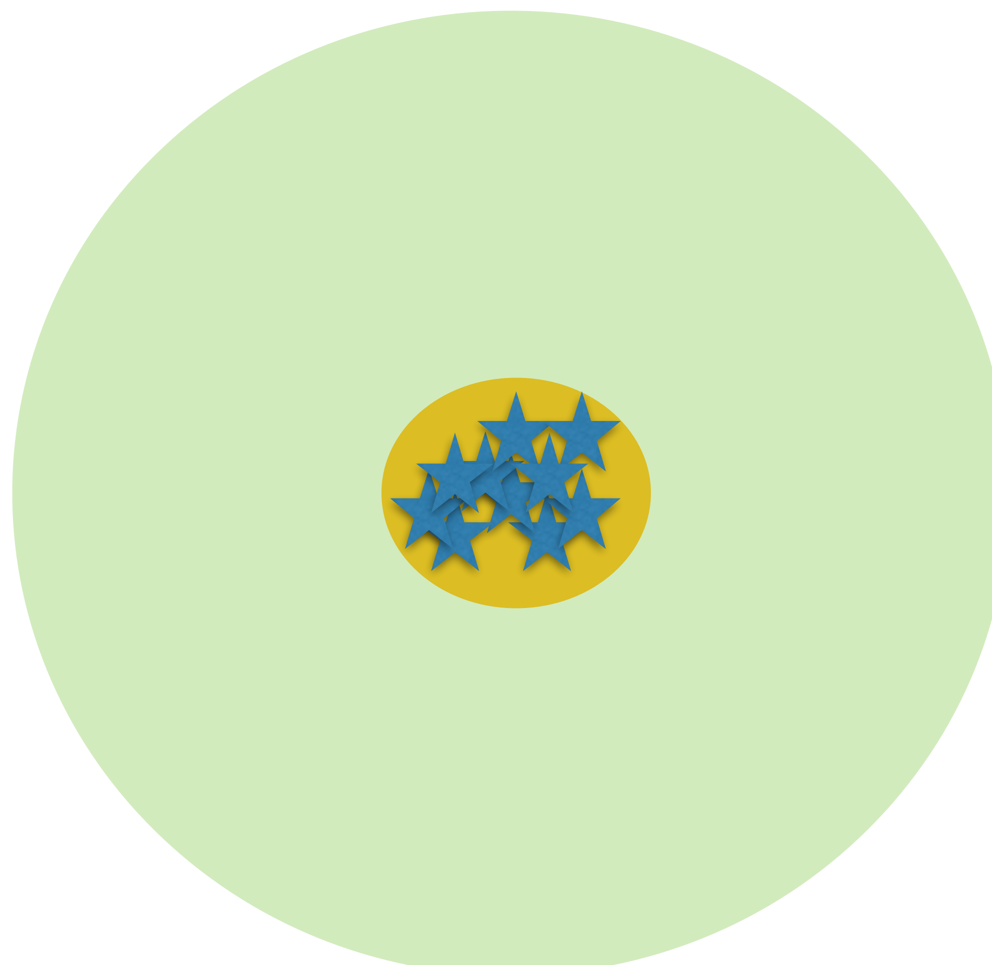
No trend between v/sig and M*



No trend between v/sig and distance to host



Wheeler et al. *in prep*



CONCLUSIONS

- Isolated dwarf galaxies ($M^*\sim10^6\ M_\odot$) in the Local Group should host ultra-faint galaxies ($M^* \sim 3000\ M_\odot$) as satellites.

- "Ultrafaint" galaxies ($M^* < 3\times10^4\ M_\odot$) form most of their stars in the first billion years after the Big Bang -> halos below $M_{halo}\sim3\times10^9\ M_\odot$ at $z = 0$ will have uniformly ancient stellar populations.

- Inverted age gradients in dwarfs can arise out of strong feedback and early mergers.

- Dwarf galaxies initially form thicker than more massive galaxies, and are naturally dispersion-supported

Thank you!


EXTRA SLIDES