An ESO Chile Workshop
Satellites and Streams in Santiago

CENTER FOR COSMOLOGY
UNIVERSITY OF CALIFORNIA, IRVINE

Sweating the small stuff:

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

arXiv:1504.02466

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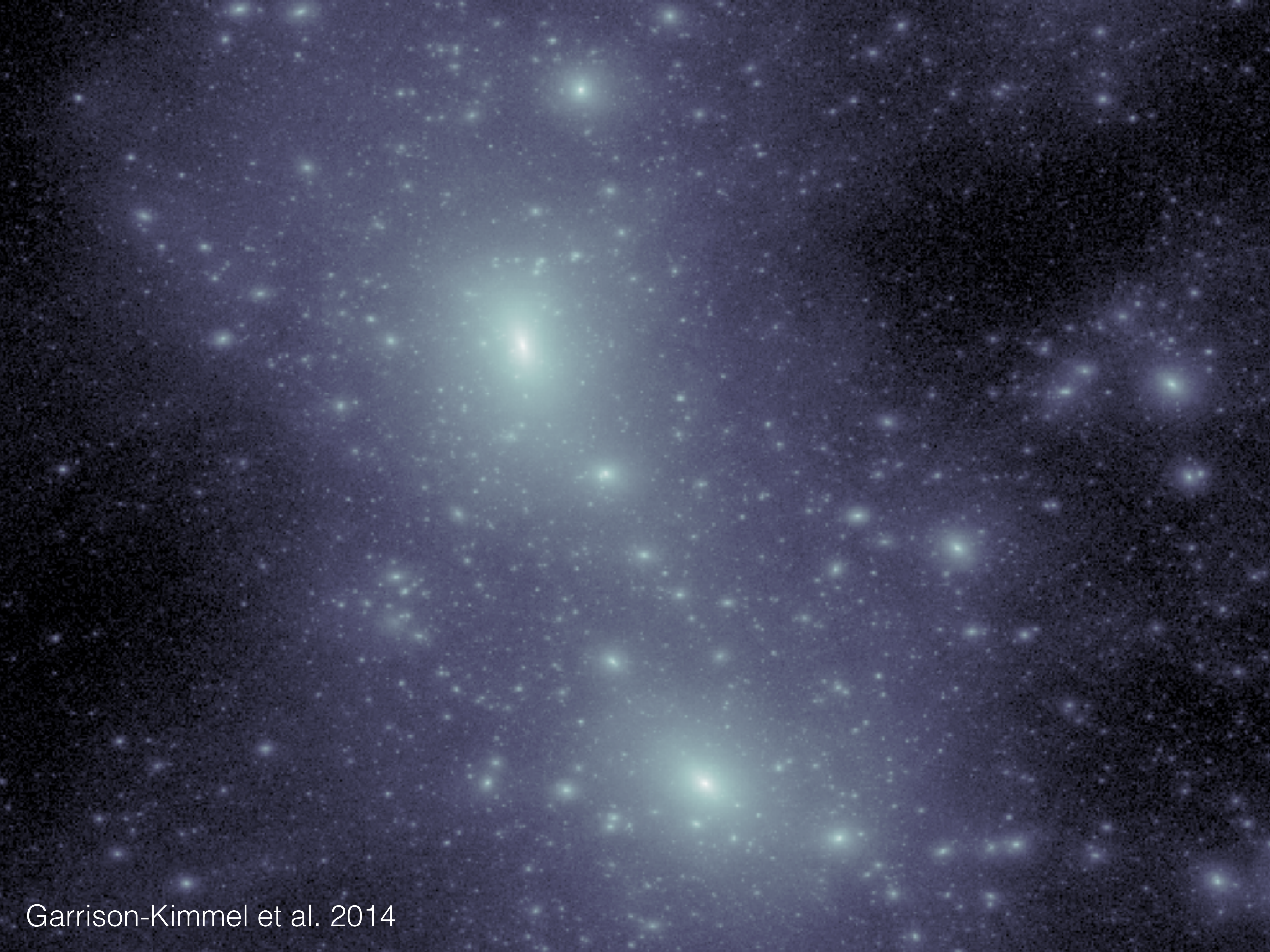
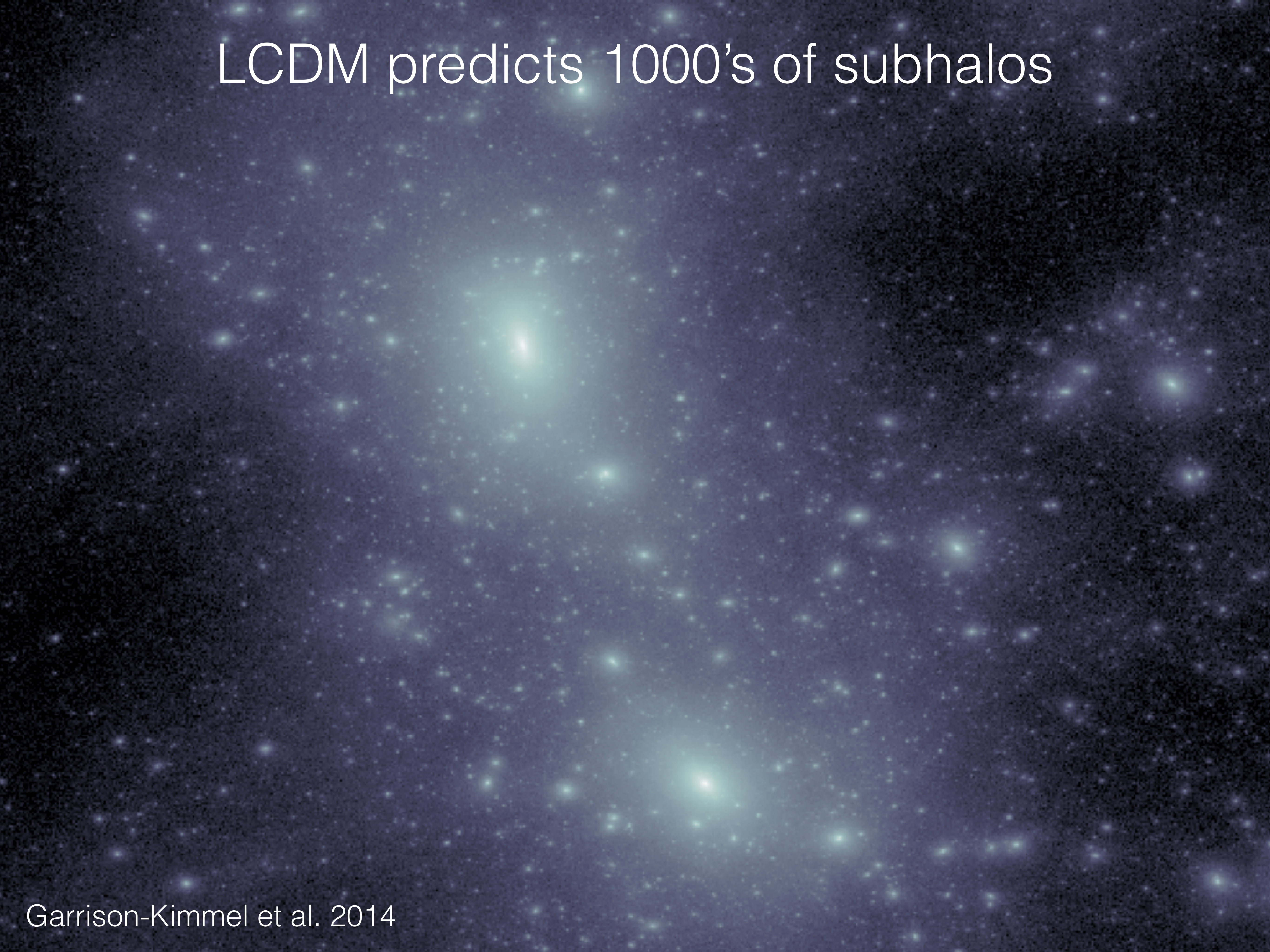
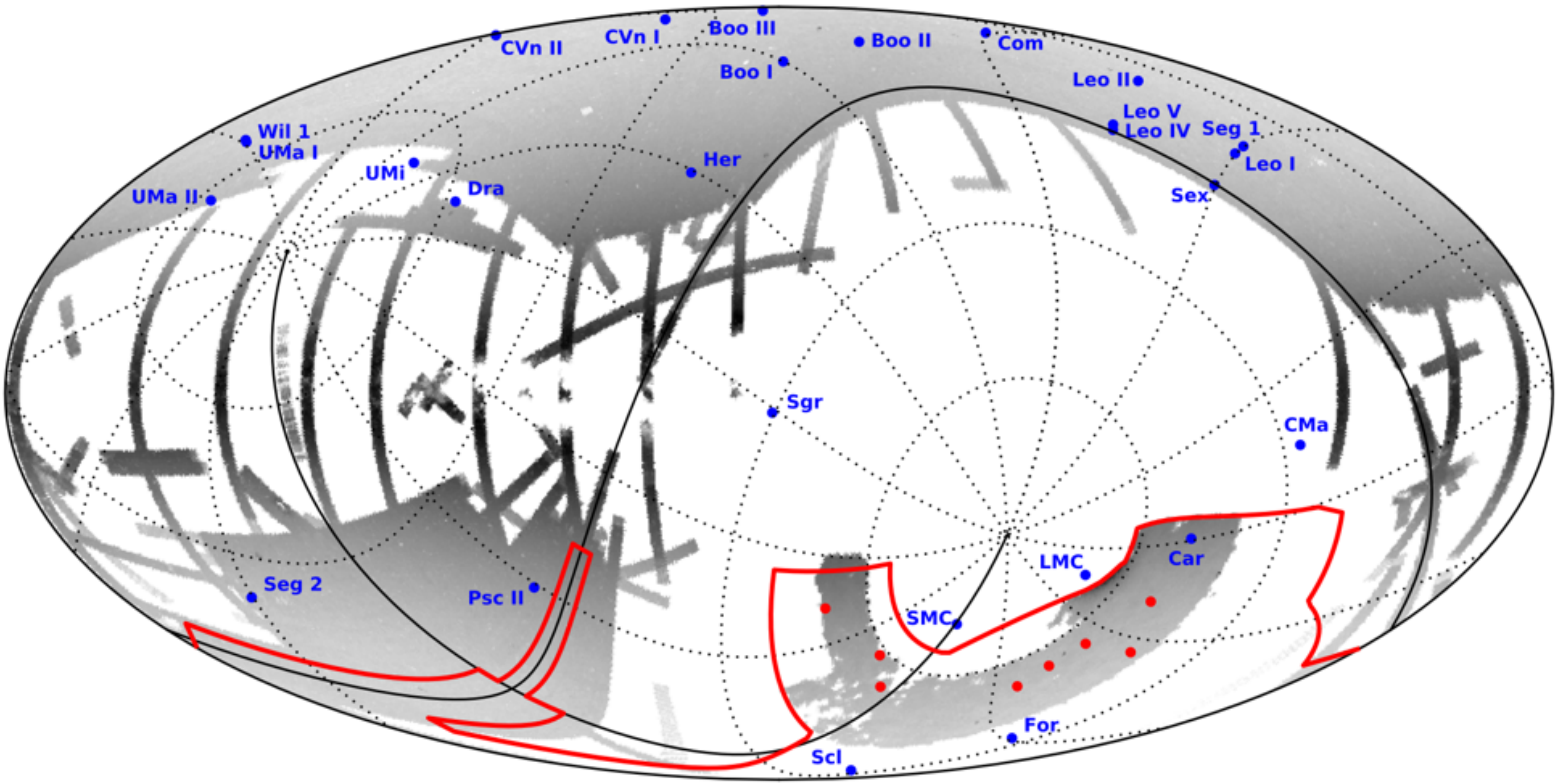

Garrison-Kimmel et al. 2014

LCDM predicts 1000's of subhalos



Garrison-Kimmel et al. 2014

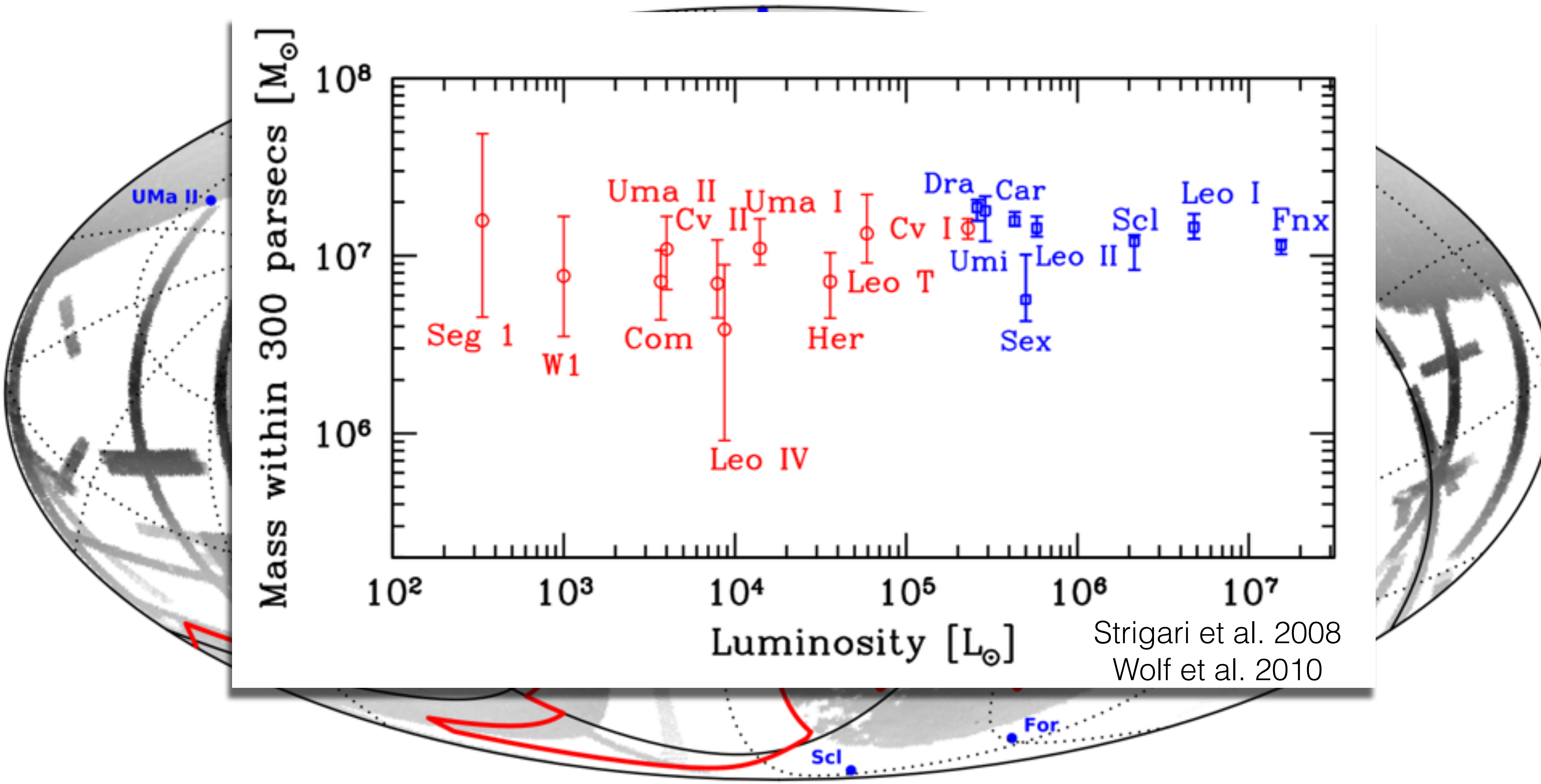
Currently ~30 known MW satellites



DES Collaboration 2015

Koposov 2015, Leavens 2015, Martin 2015, Kim 2015

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



Strigari et al. 2008
Wolf et al. 2010

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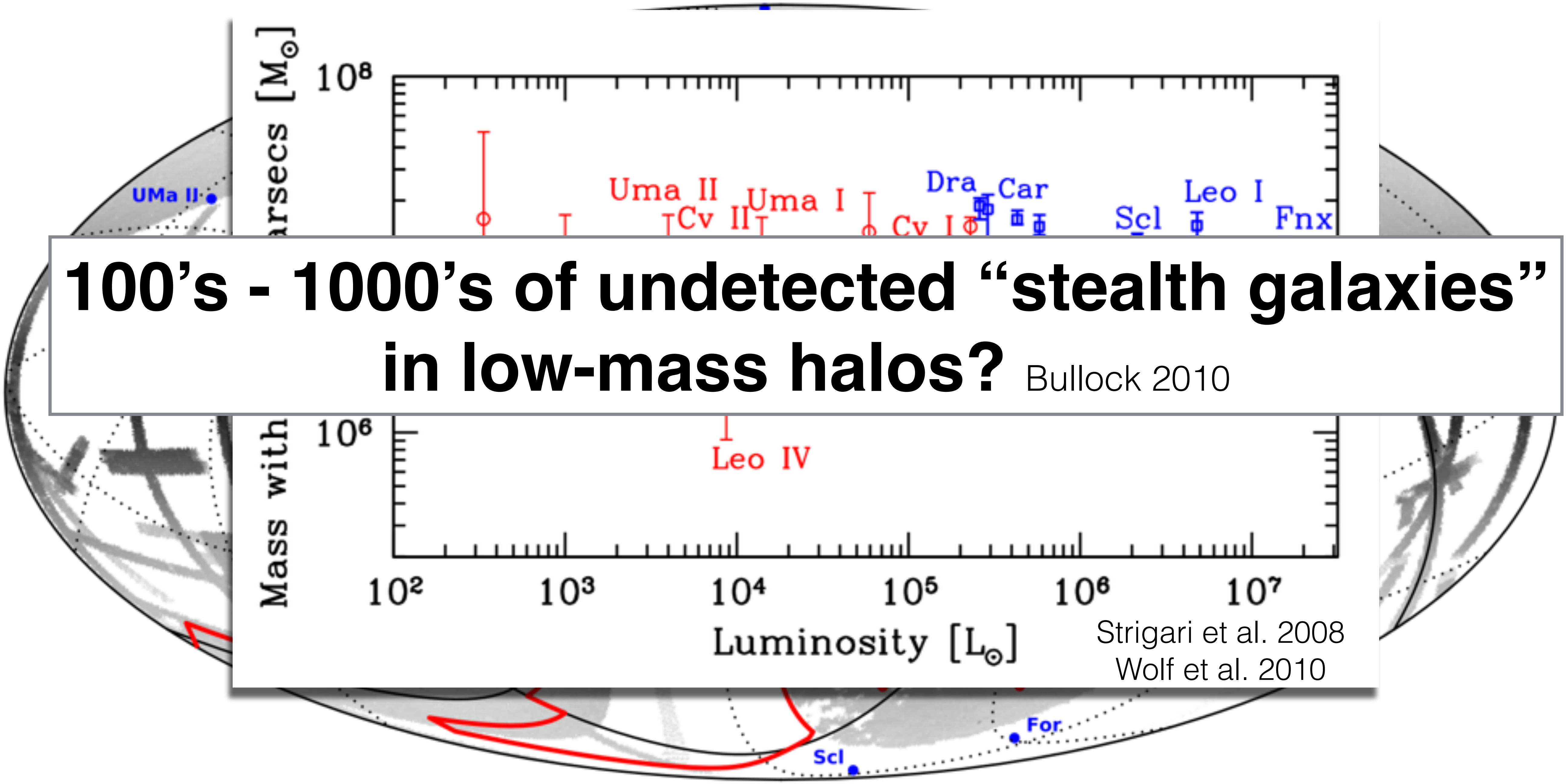
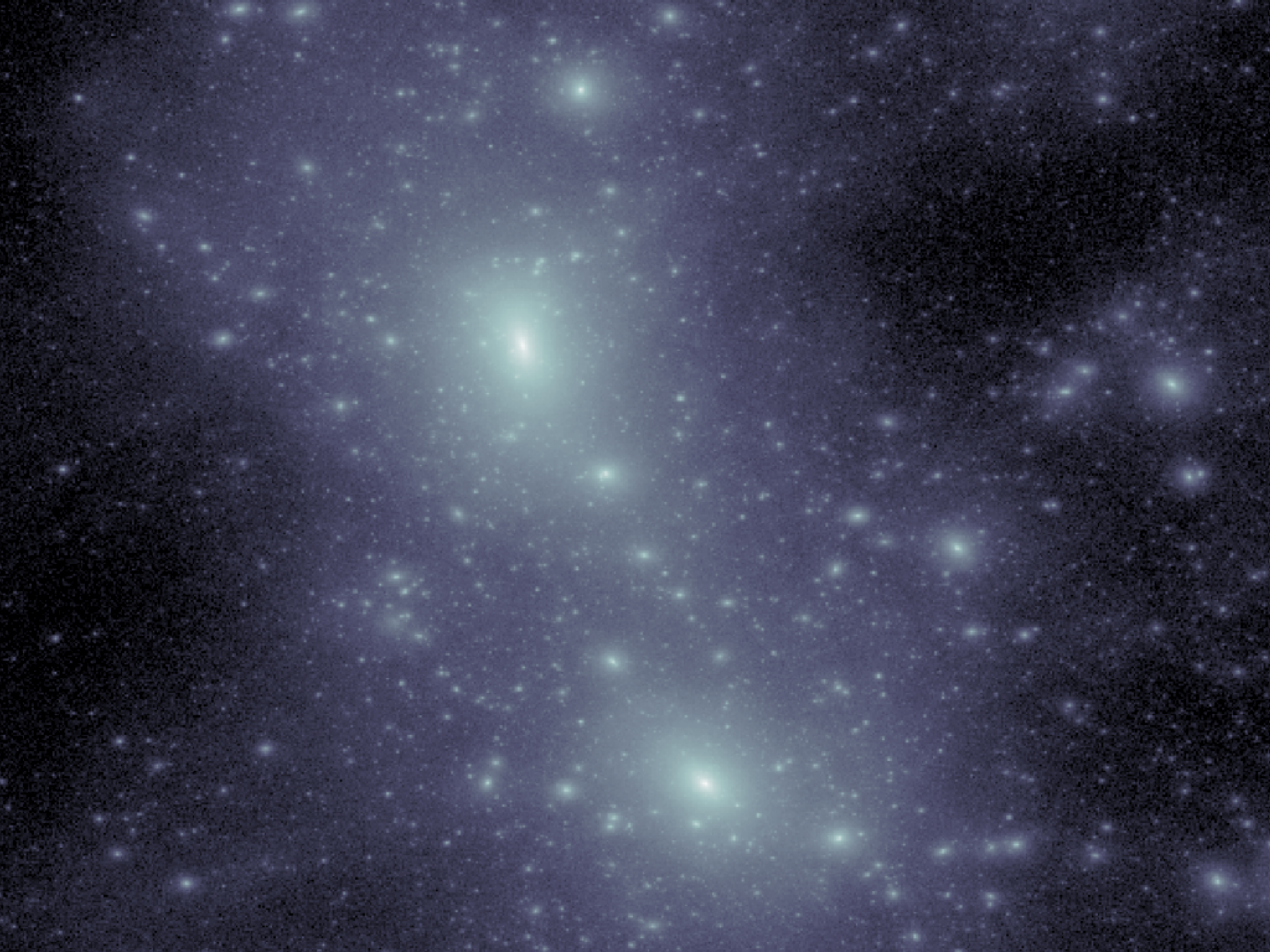


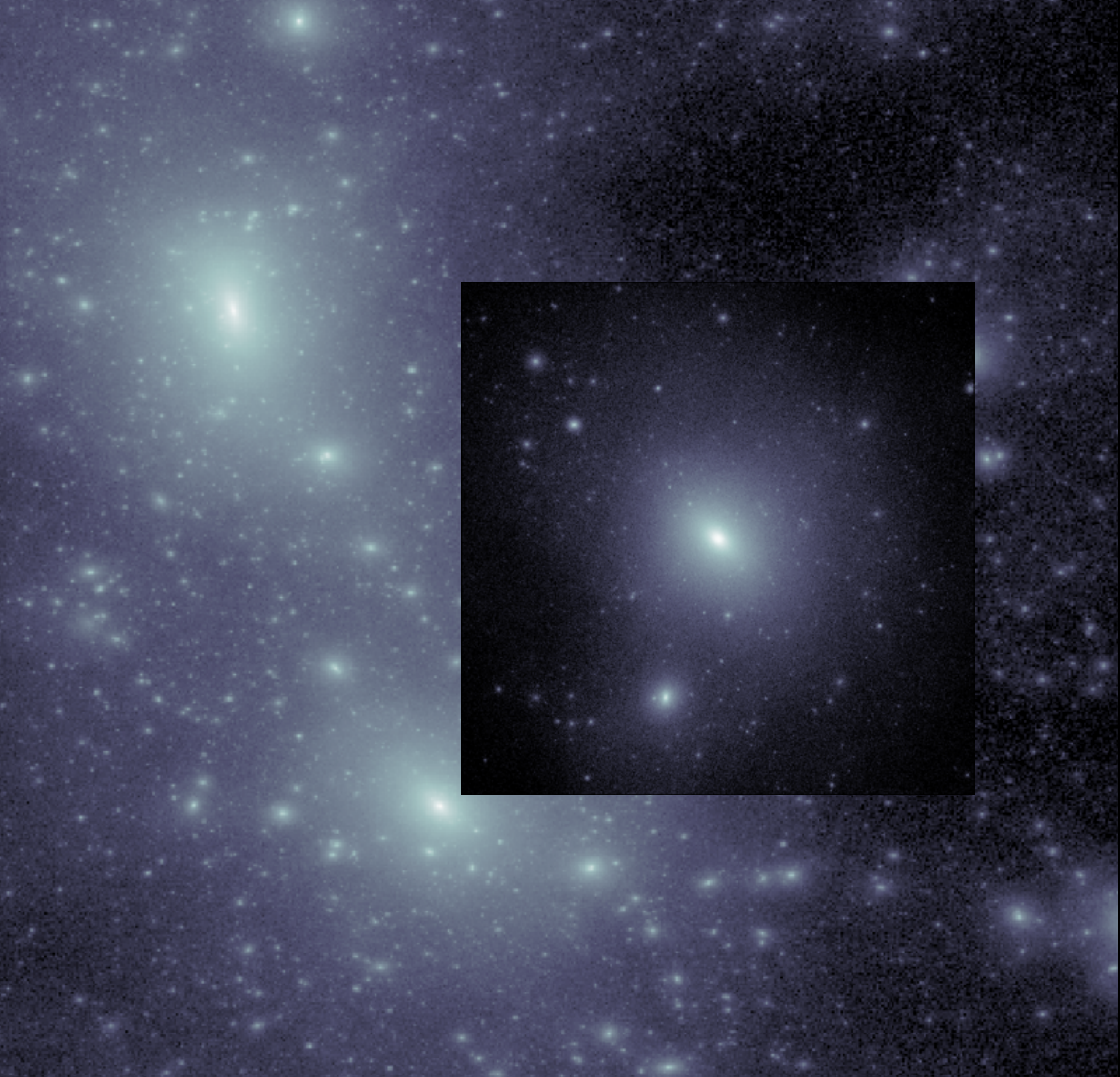
Strigari et al. 2008
Wolf et al. 2010

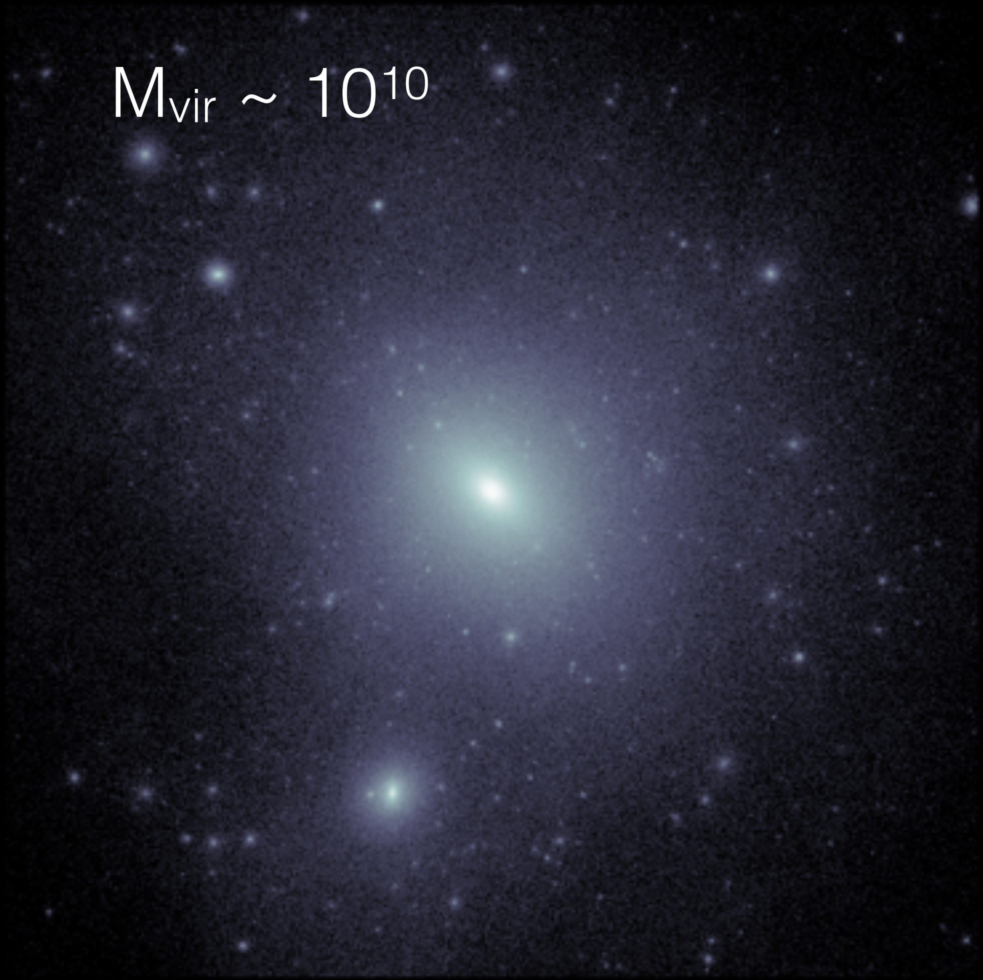
100's - 1000's of undetected "stealth galaxies" in low-mass halos? Bullock 2010

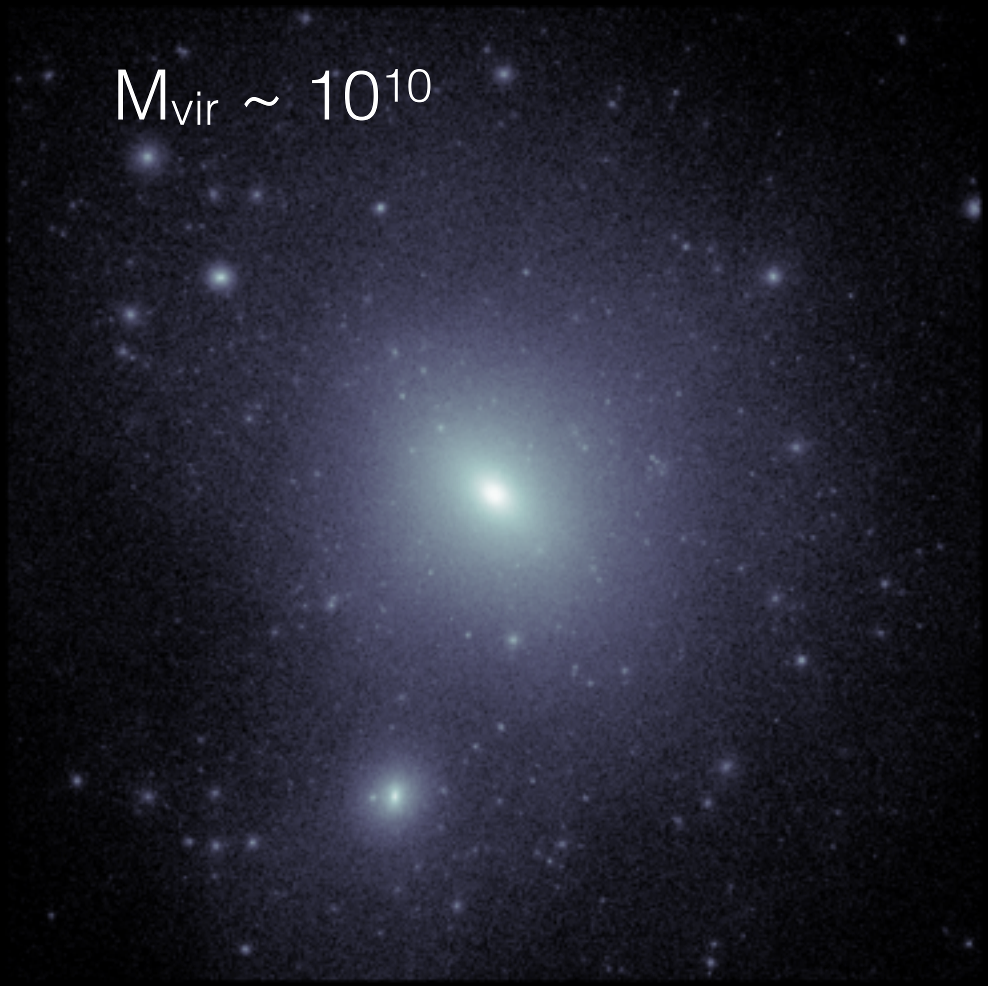
DES Collaboration 2015

Koposov 2015, Leavens 2015, Martin 2015, Kim 2015






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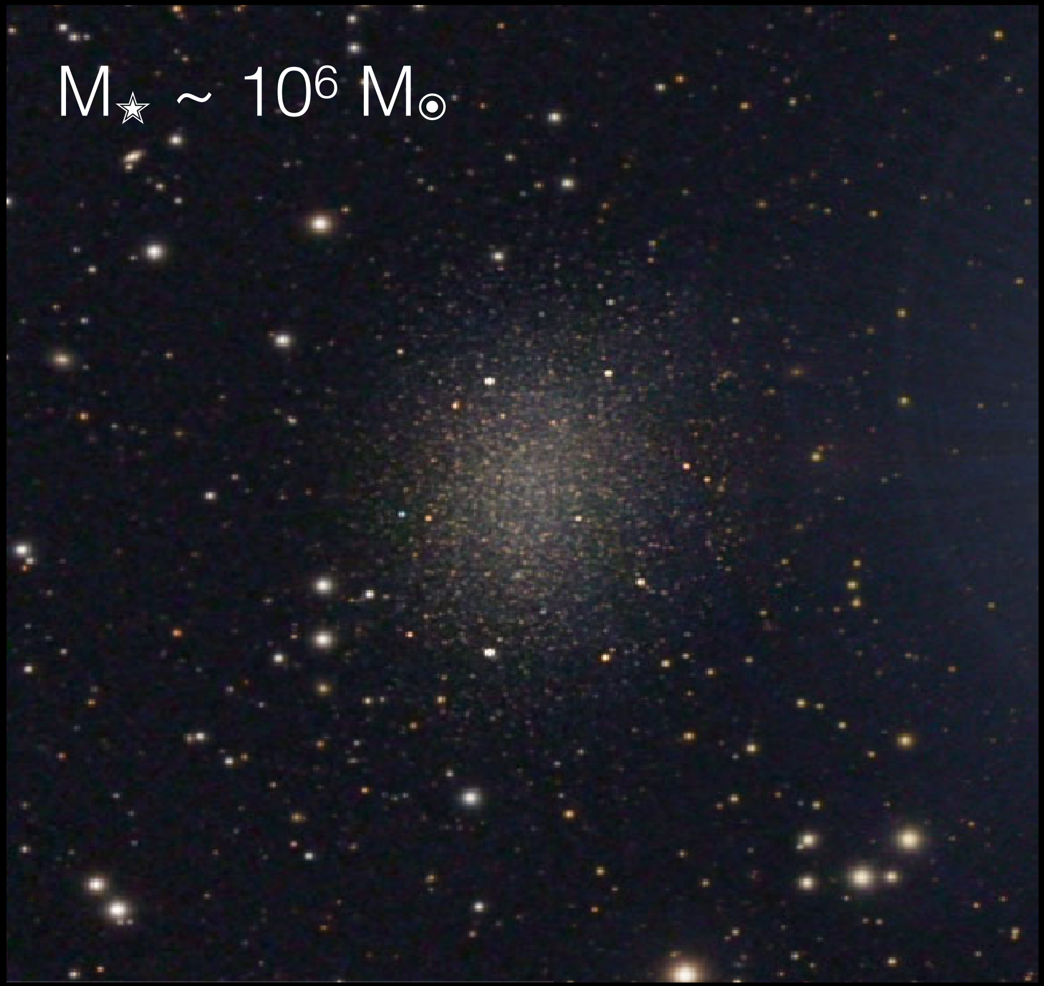
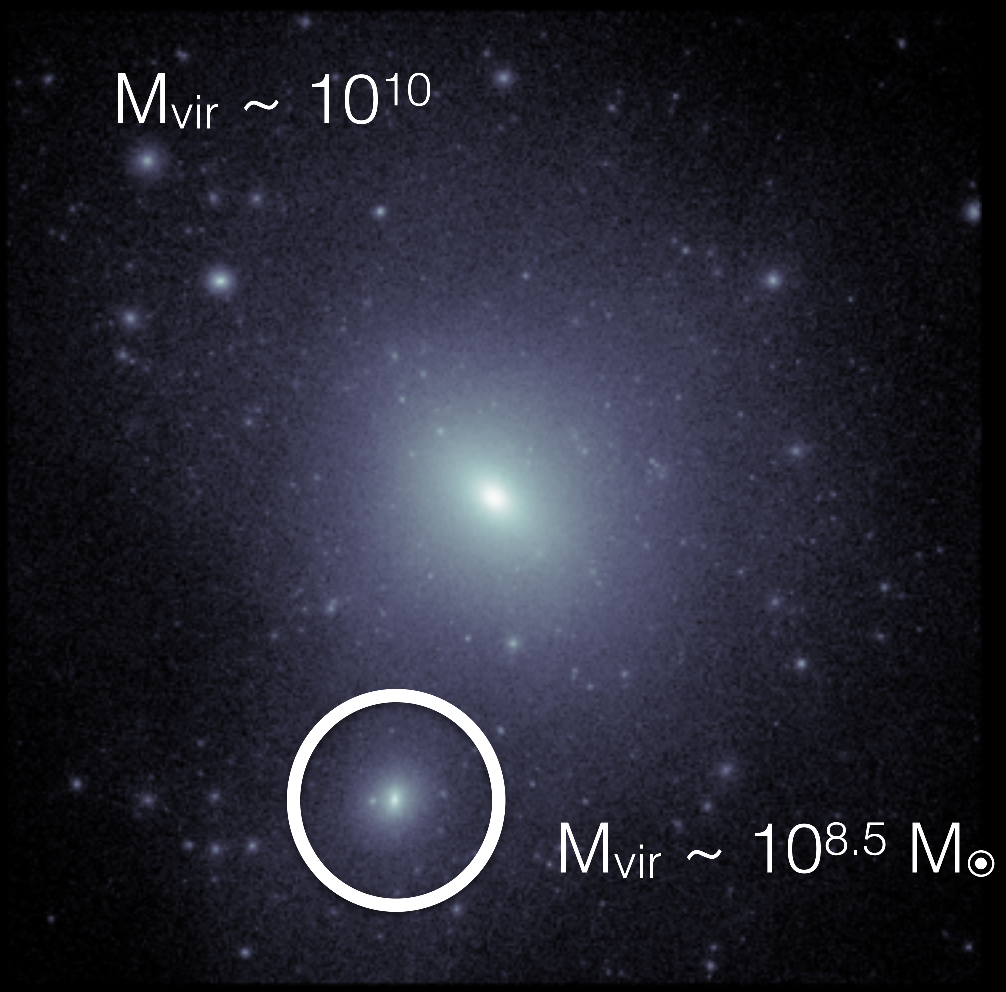
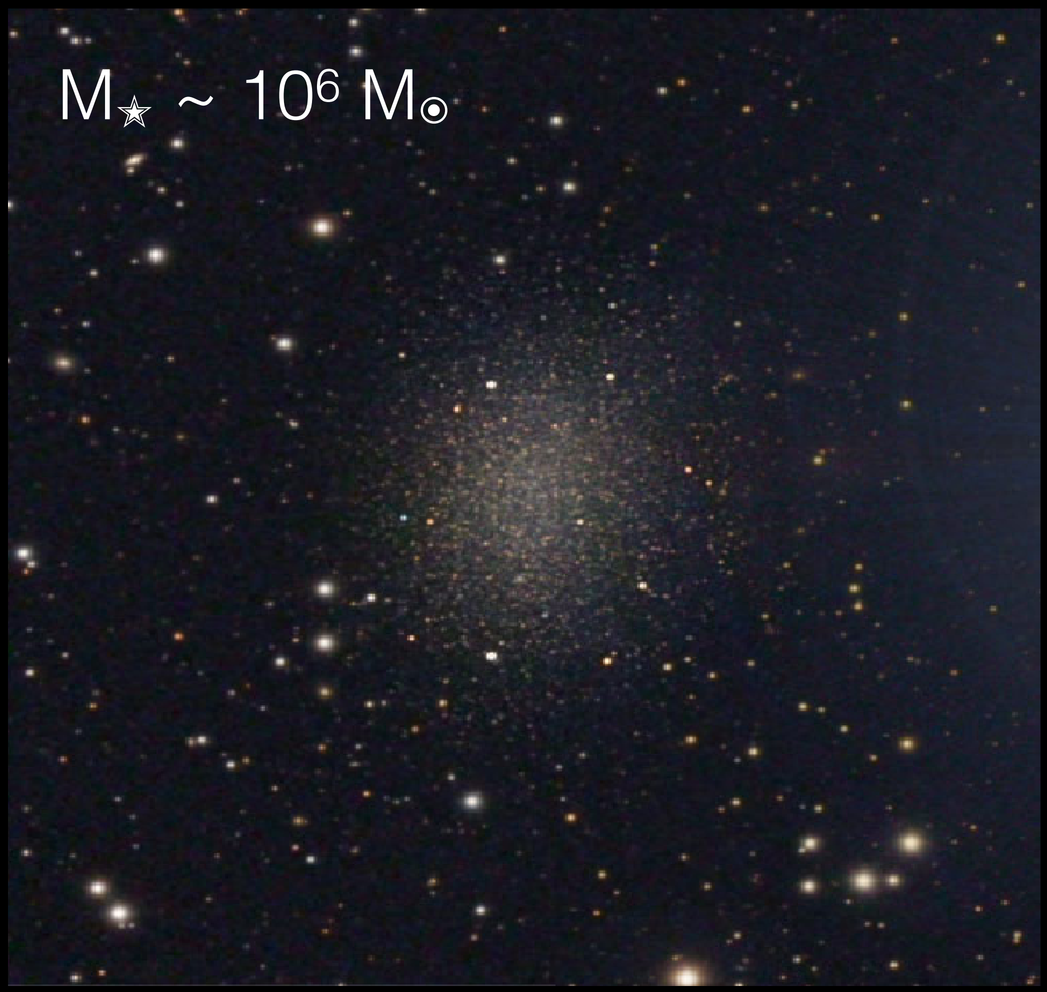

$M_{\star} \sim 10^{6}\ M_{\odot}$



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



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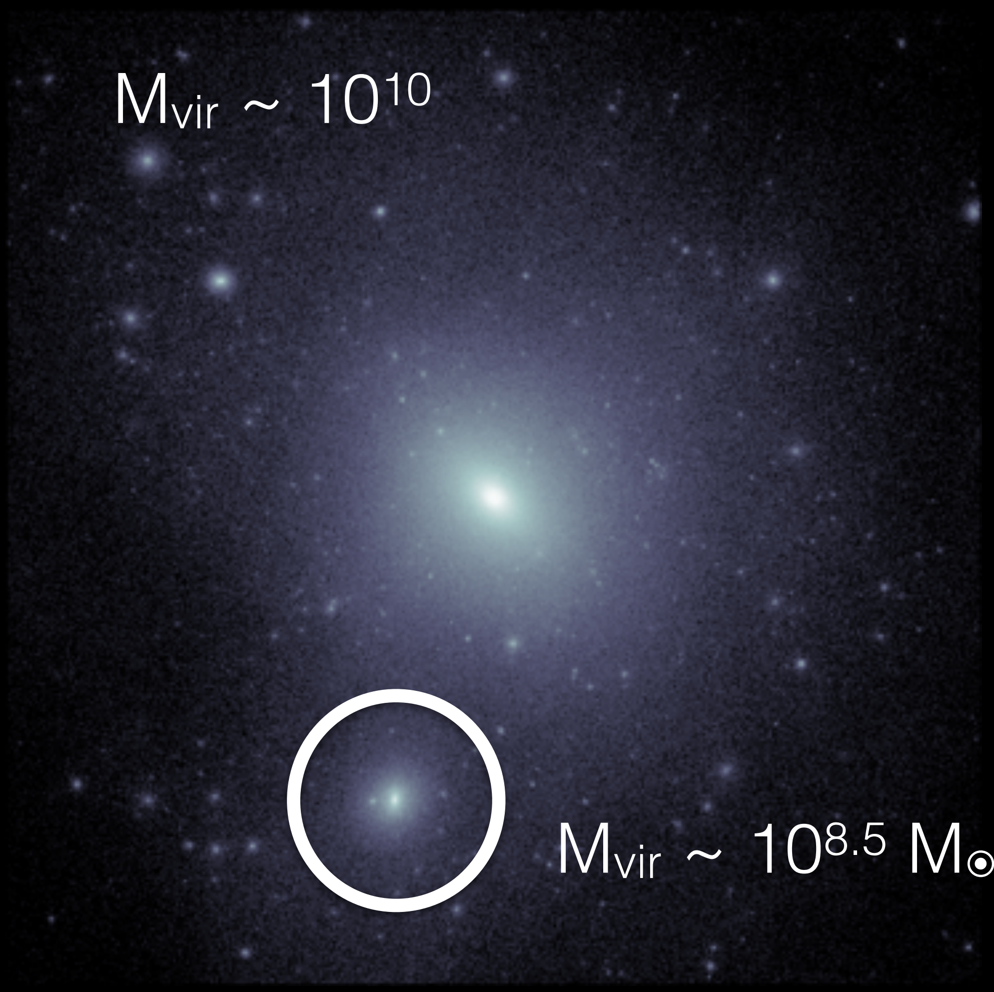
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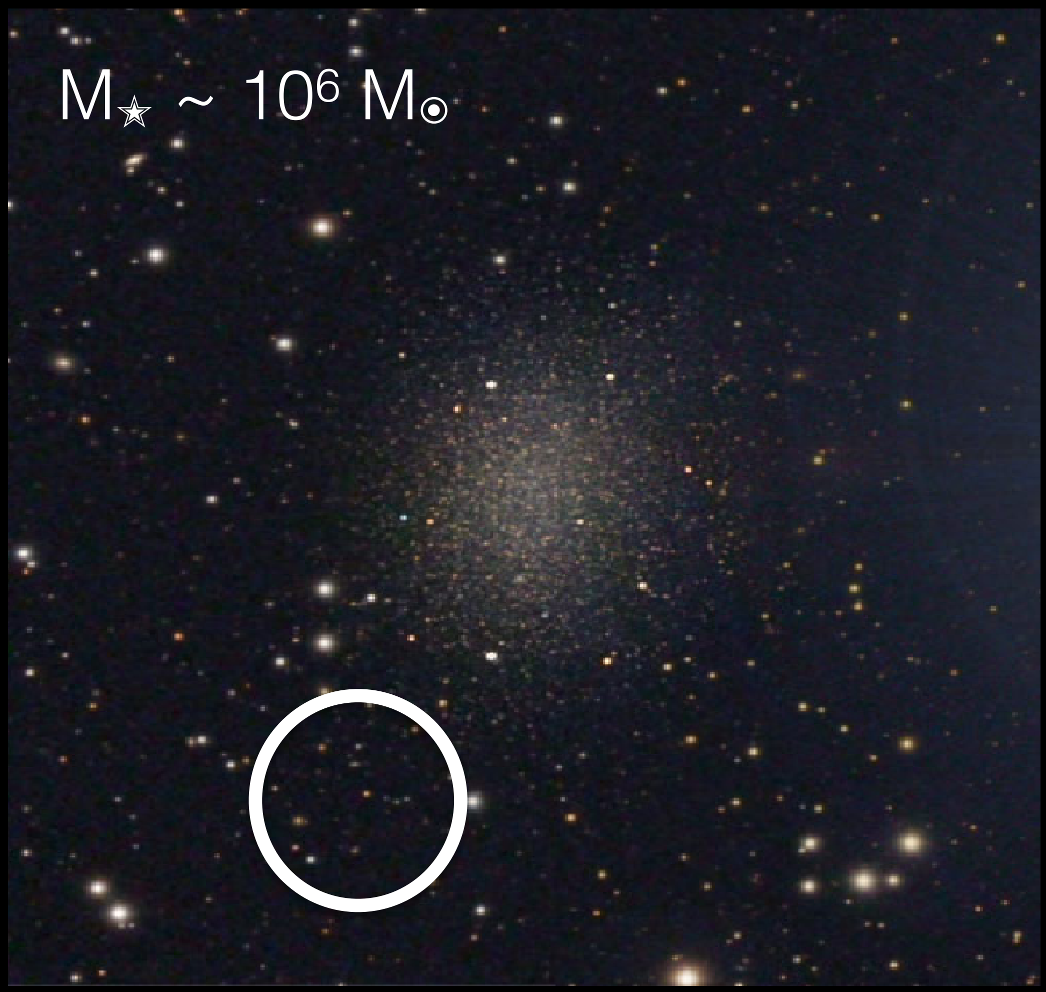
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DWARF GALAXIES ON FIRE

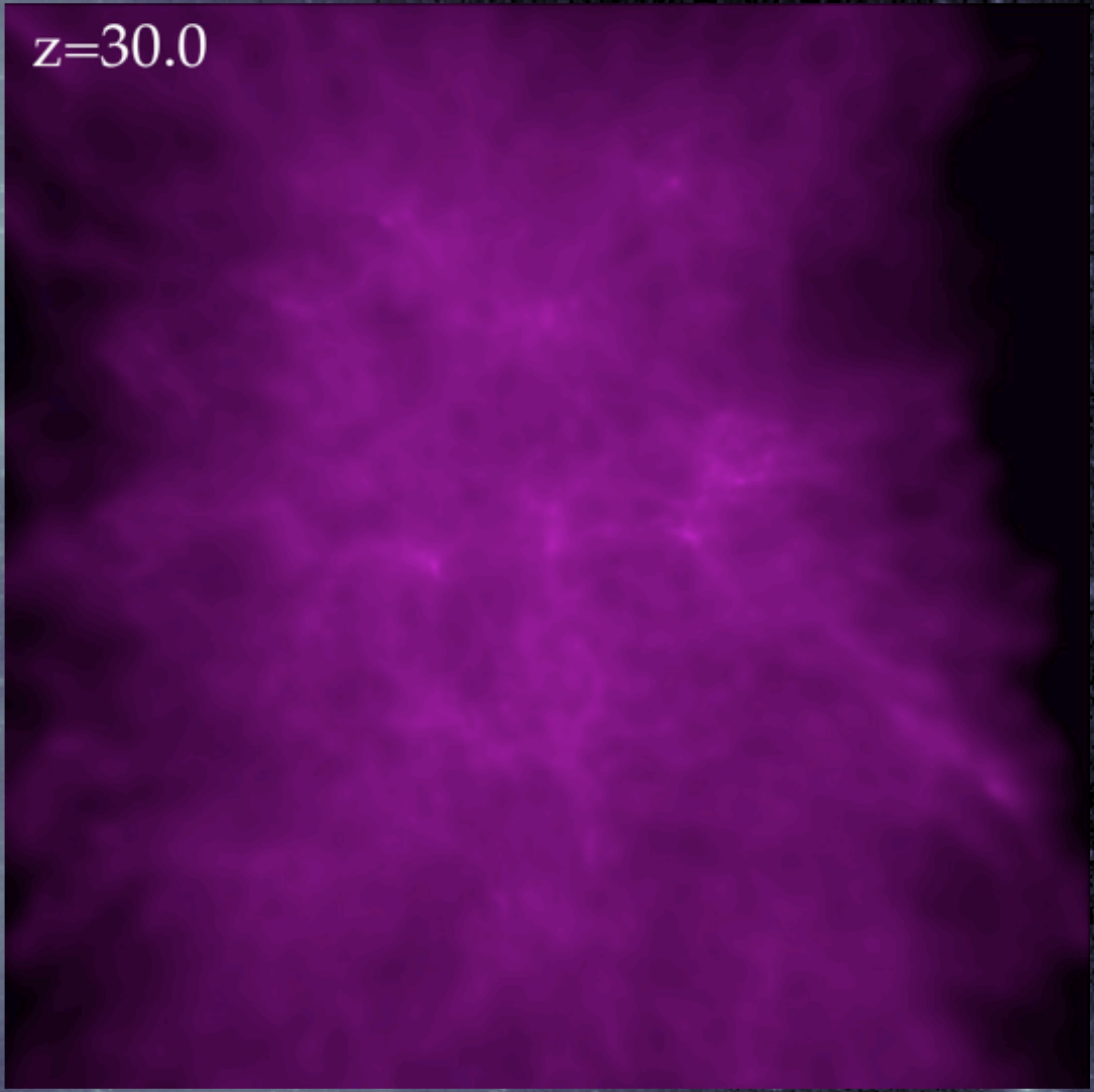
Hopkins et al. 2014 Oñorbe et al. 2015

$m_{dm} \sim 1000\ M_\odot$

$m_{gas} \sim 250\ M_\odot$

DM $f_{res} \sim 25$pc

Gas $f_{res} = 1\text{-}3$pc



<u>4 Halos</u>:

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

<u>1 Dwarf run 3 times</u>

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

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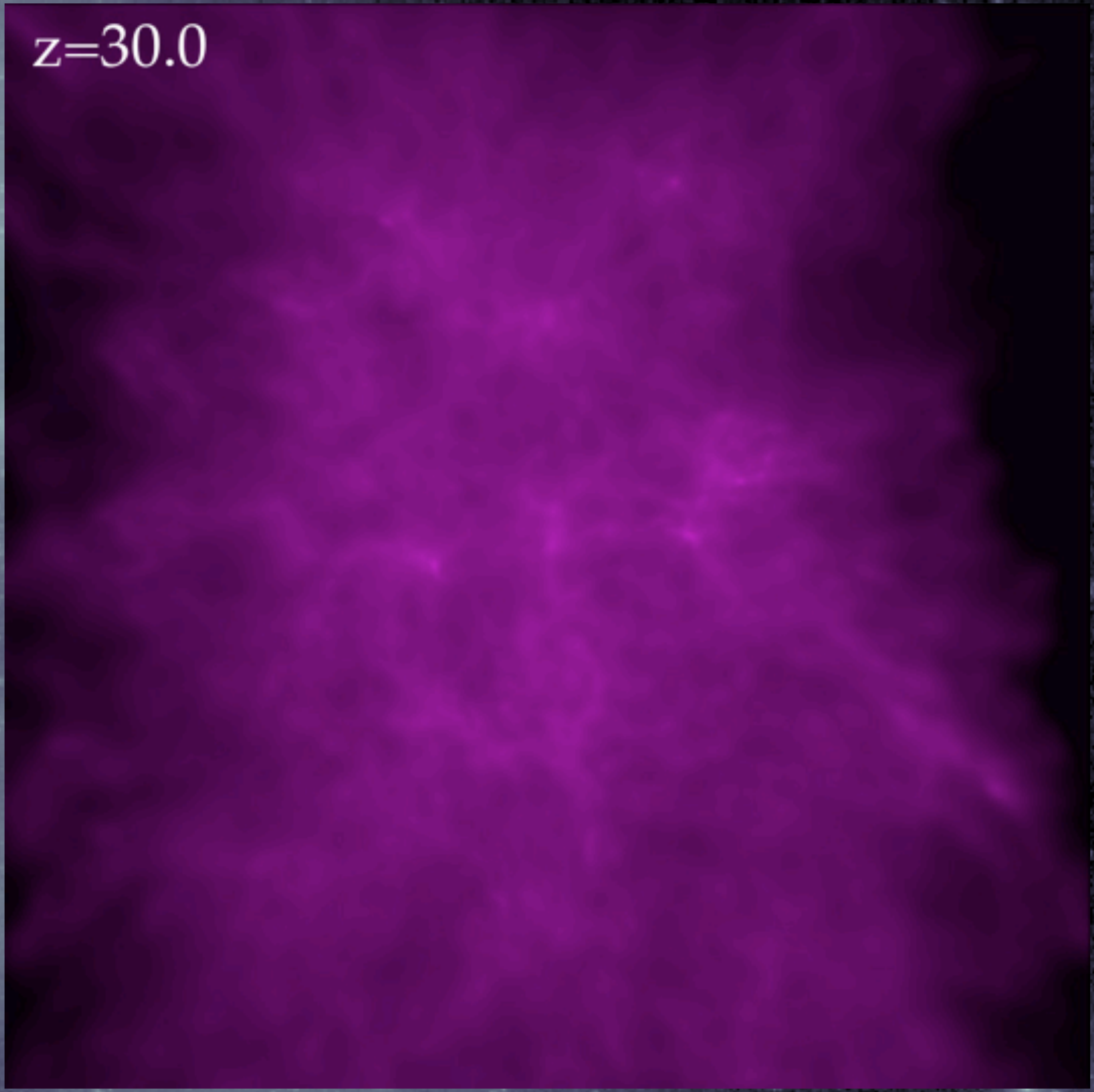
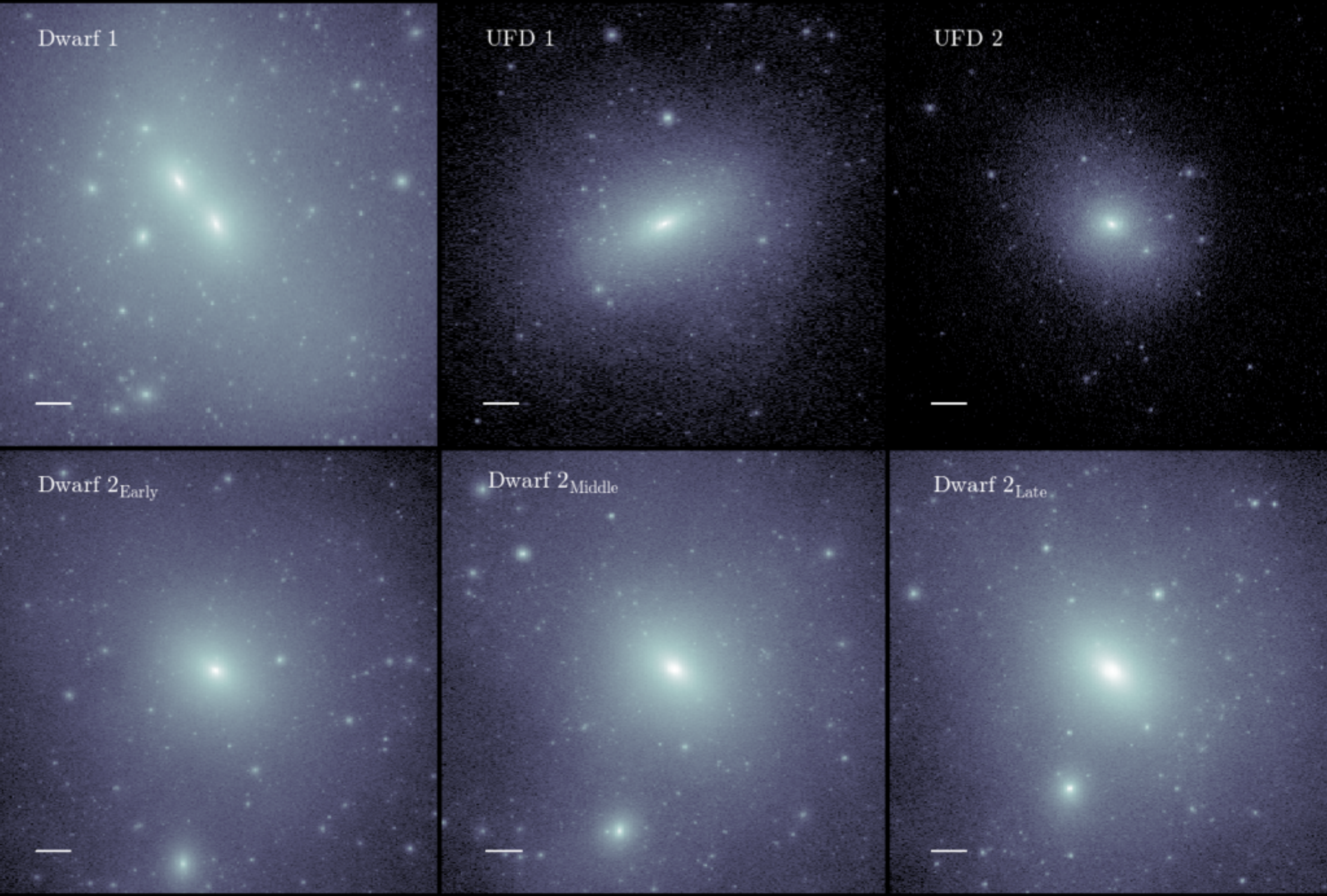
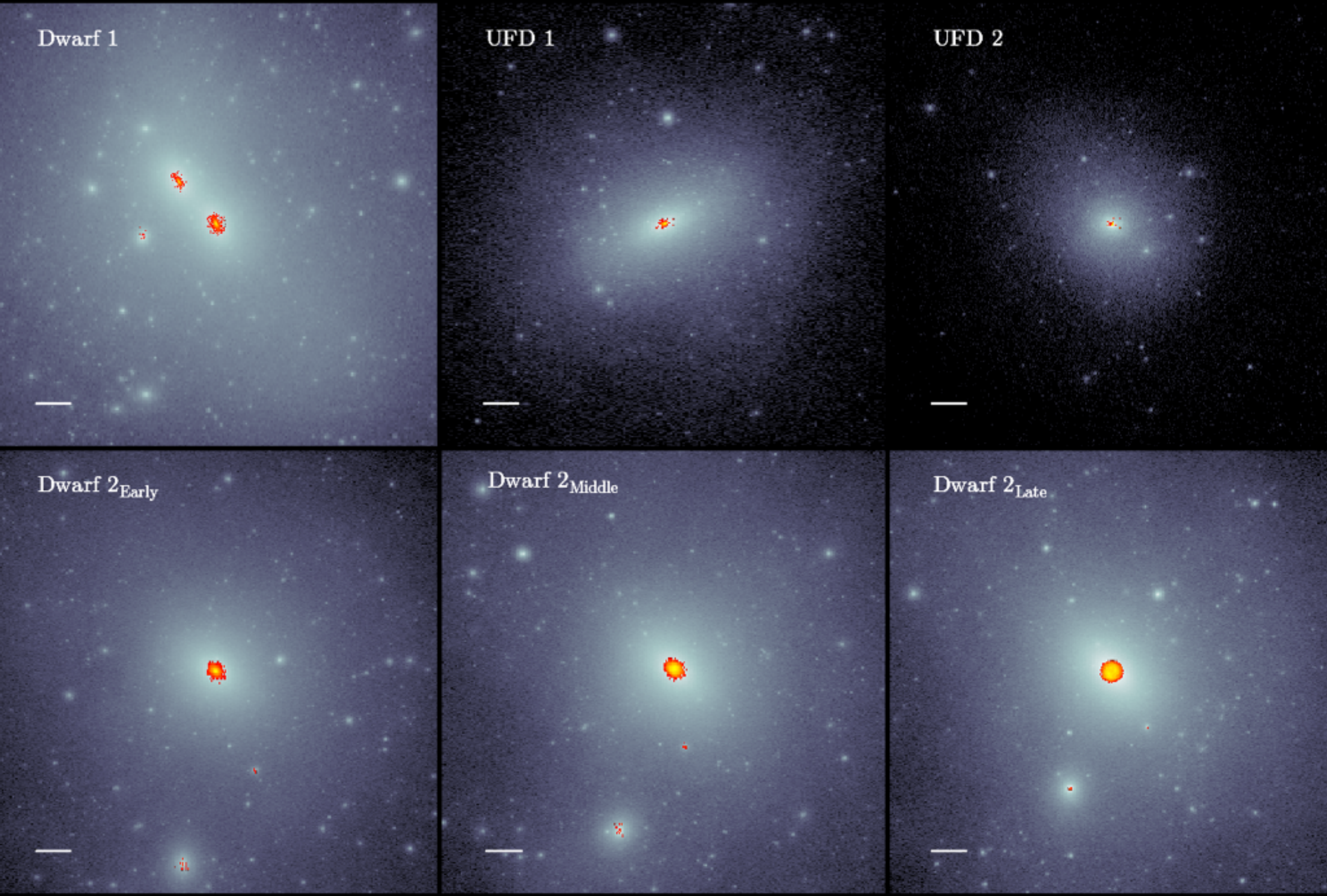
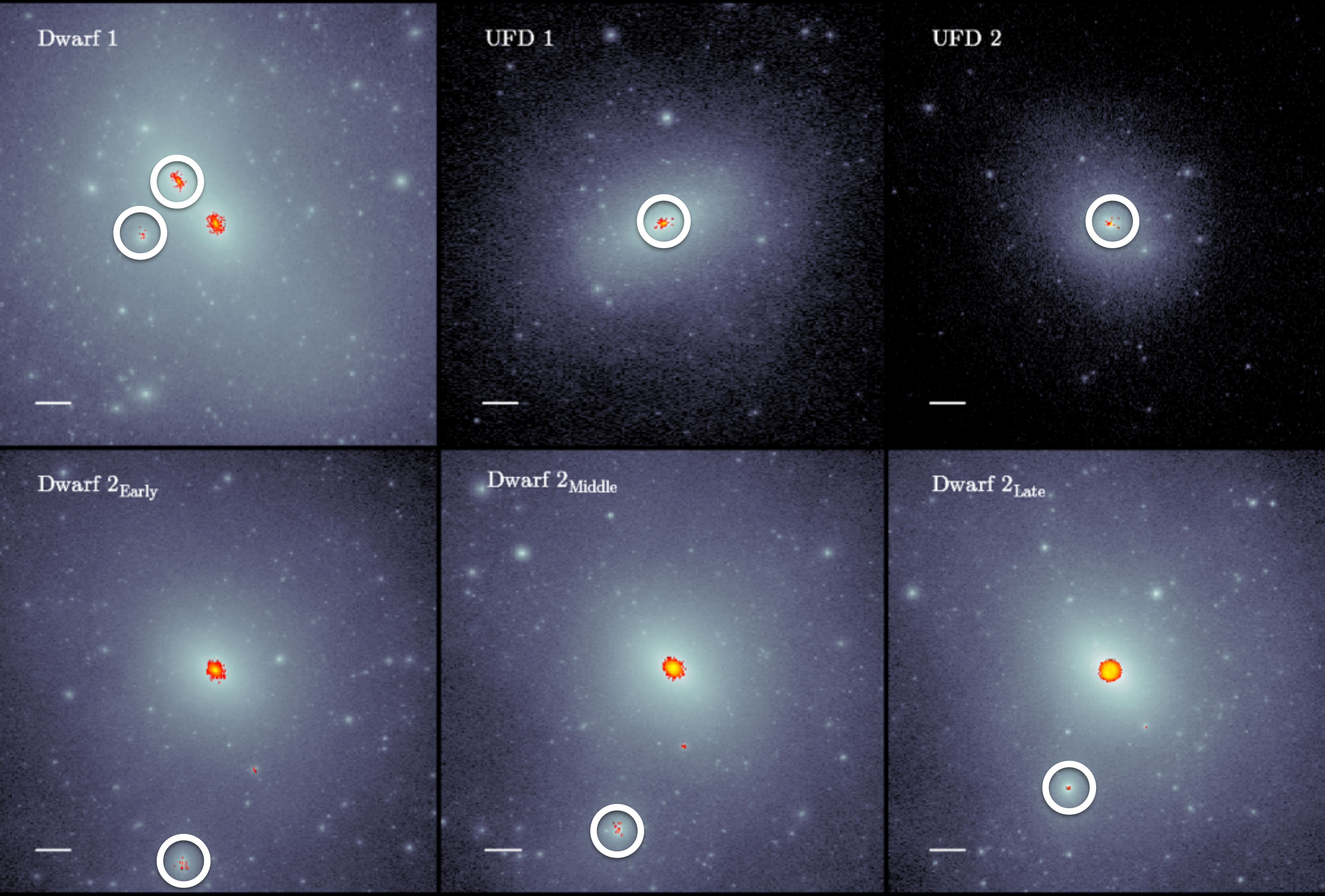




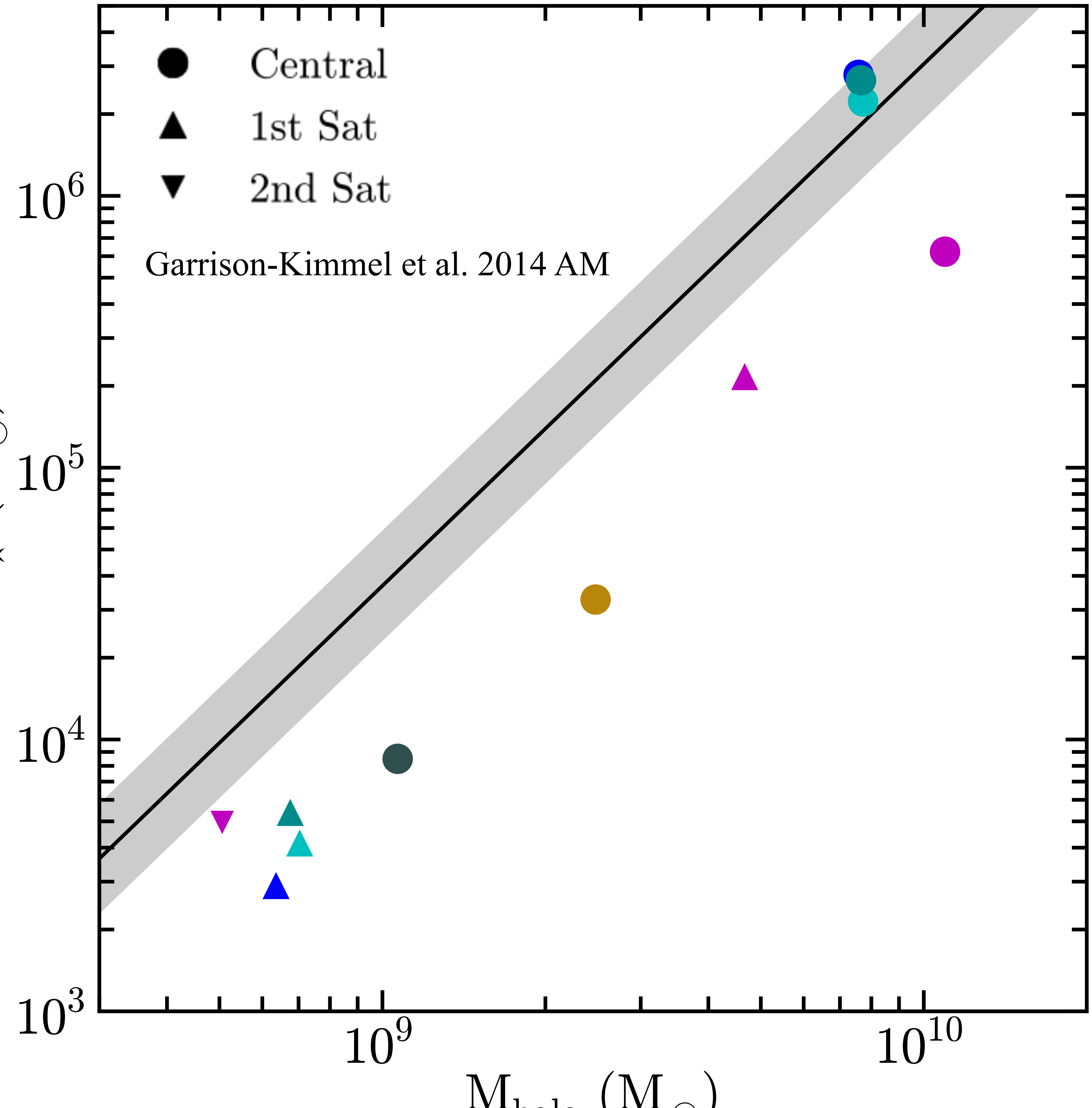
Dwarf 1
UFD 1
UFD 2
Dwarf 2Early
Dwarf 2Middle
Dwarf 2Late



Dwarf 1
UFD 1
UFD 2
Dwarf 2$_{\rm Early}$
Dwarf 2$_{\rm Middle}$
Dwarf 2$_{\rm Late}$



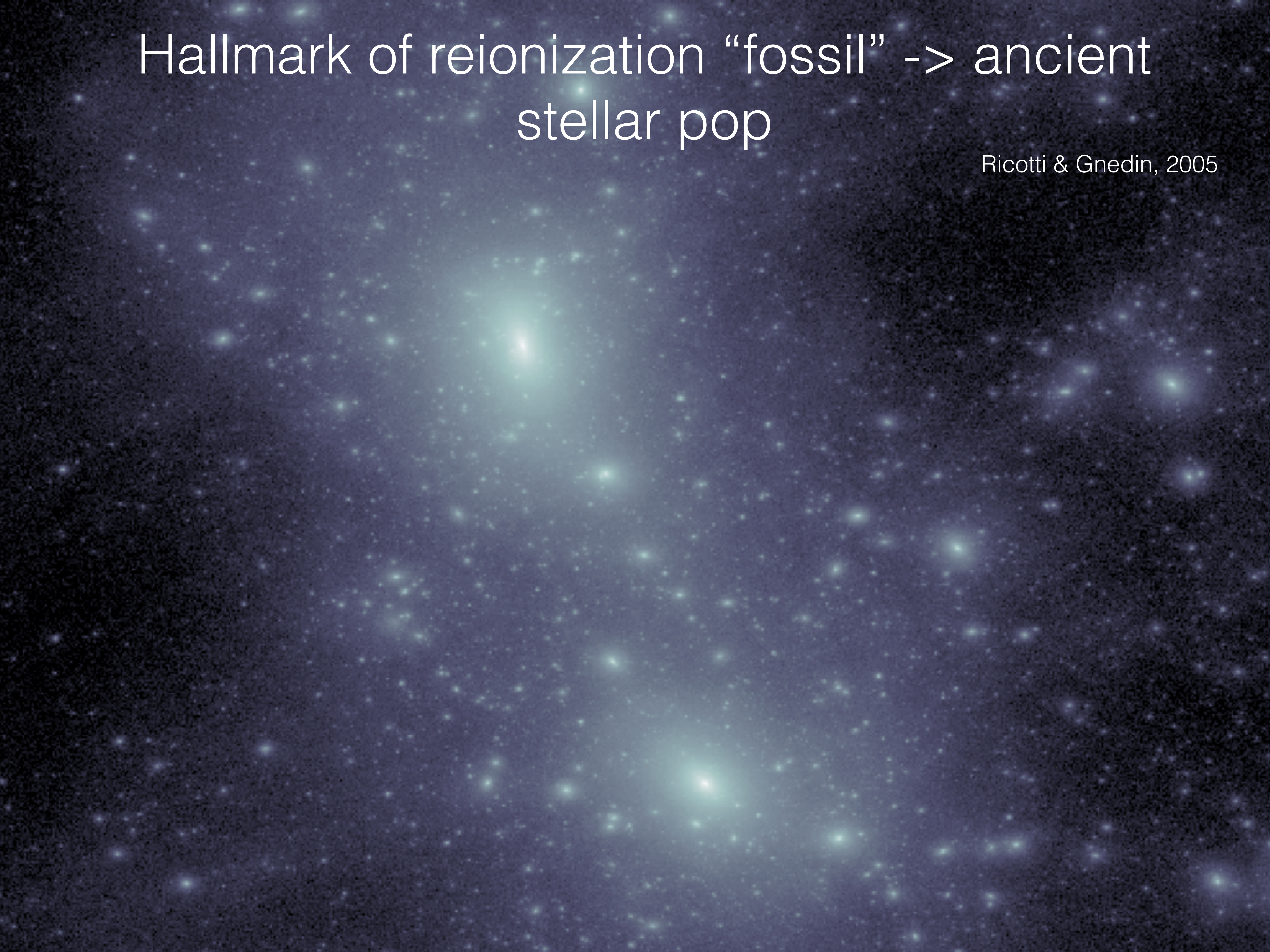
Dwarf 1
UFD 1
UFD 2
Dwarf 2Early
Dwarf 2Middle
Dwarf 2Late



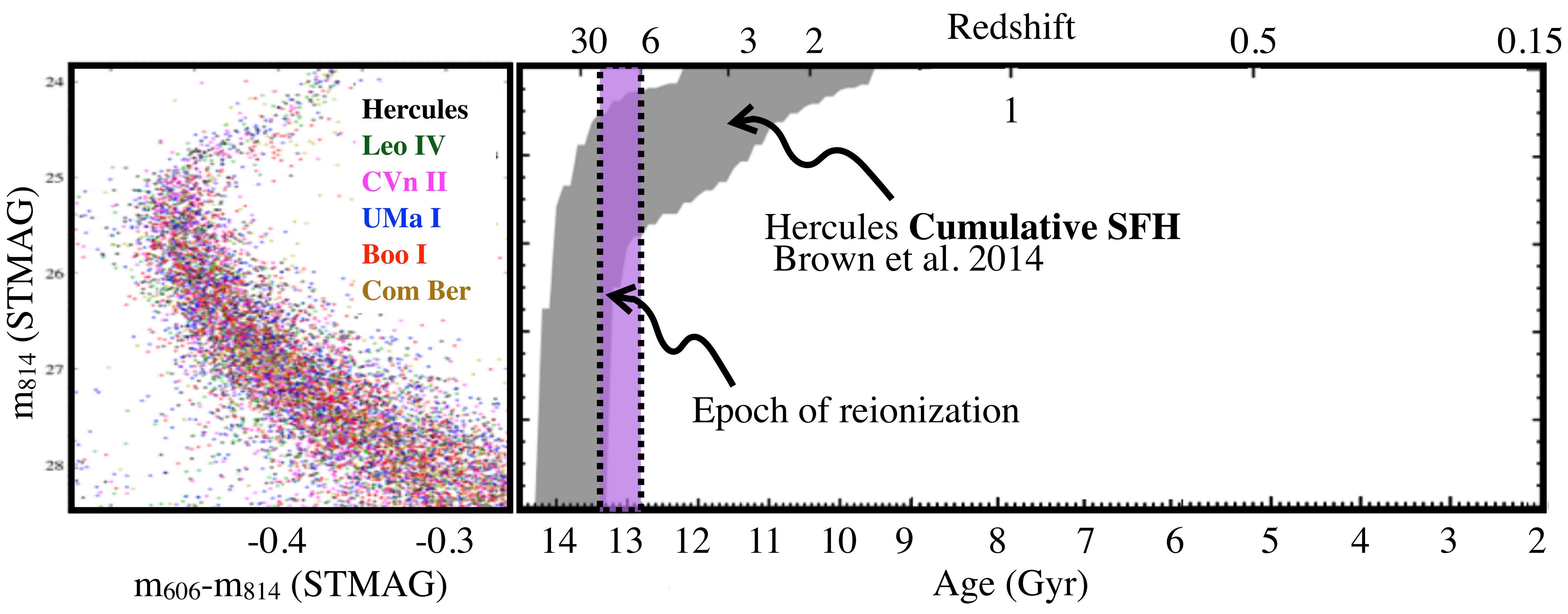
Central
1st Sat
2nd Sat
Garrison-Kimmel et al. 2014 AM
10^3
10^4
10^5
10^6
$M_\star$ ($M_\odot$)
10^9
10^{10}
M_{halo} ($M_\odot$)

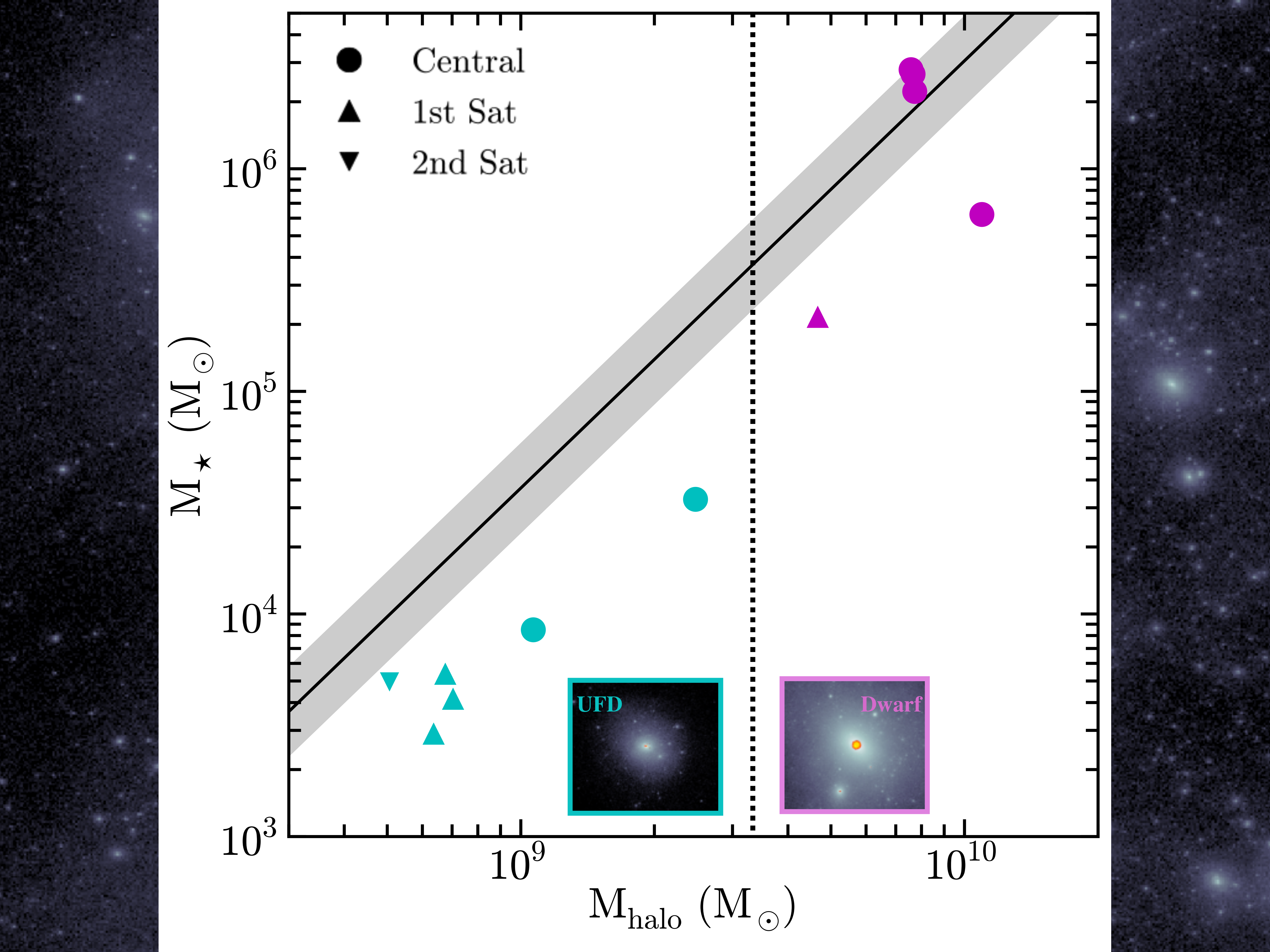
Hallmark of reionization “fossil” -> ancient stellar pop

Ricotti & Gnedin, 2005



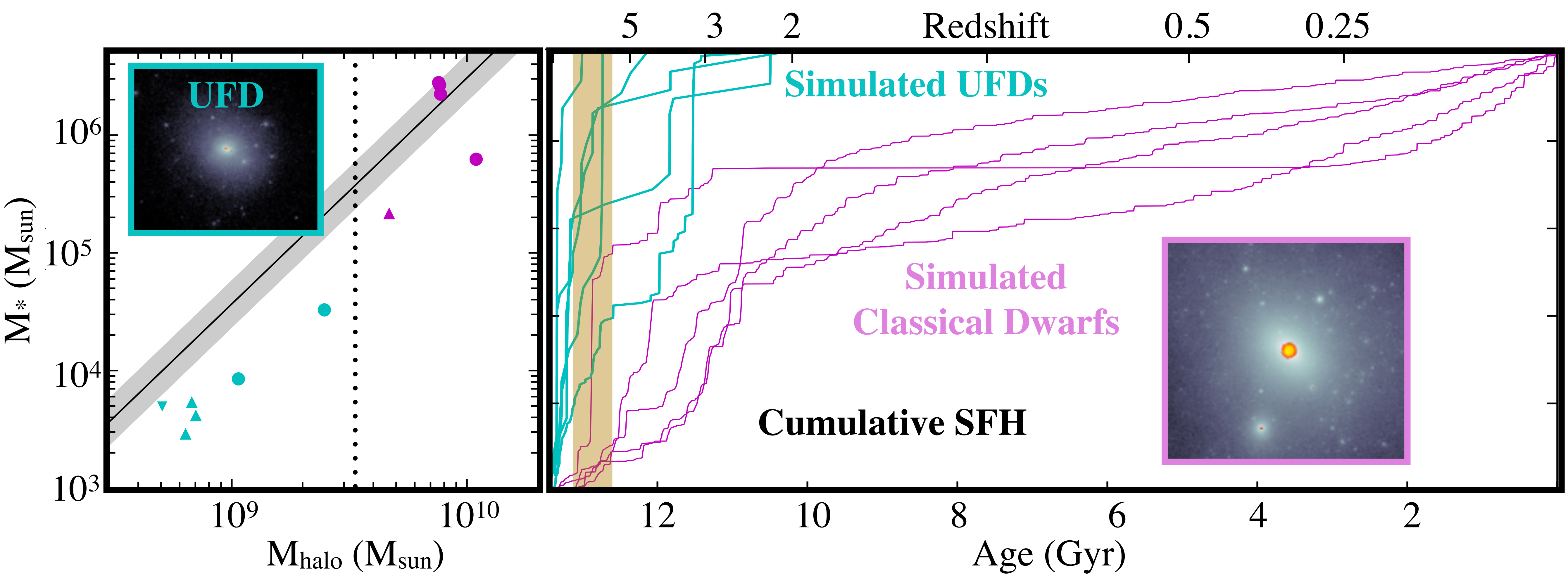
Known UFDs have ancient stellar pops





Central
1st Sat
2nd Sat
UFD
Dwarf
10^3
10^4
10^5
10^6
10^9
10^{10}
$M_\star$ ($M_\odot$)
M_{halo} ($M_\odot$)

Simulated UFDs have ancient stellar pops



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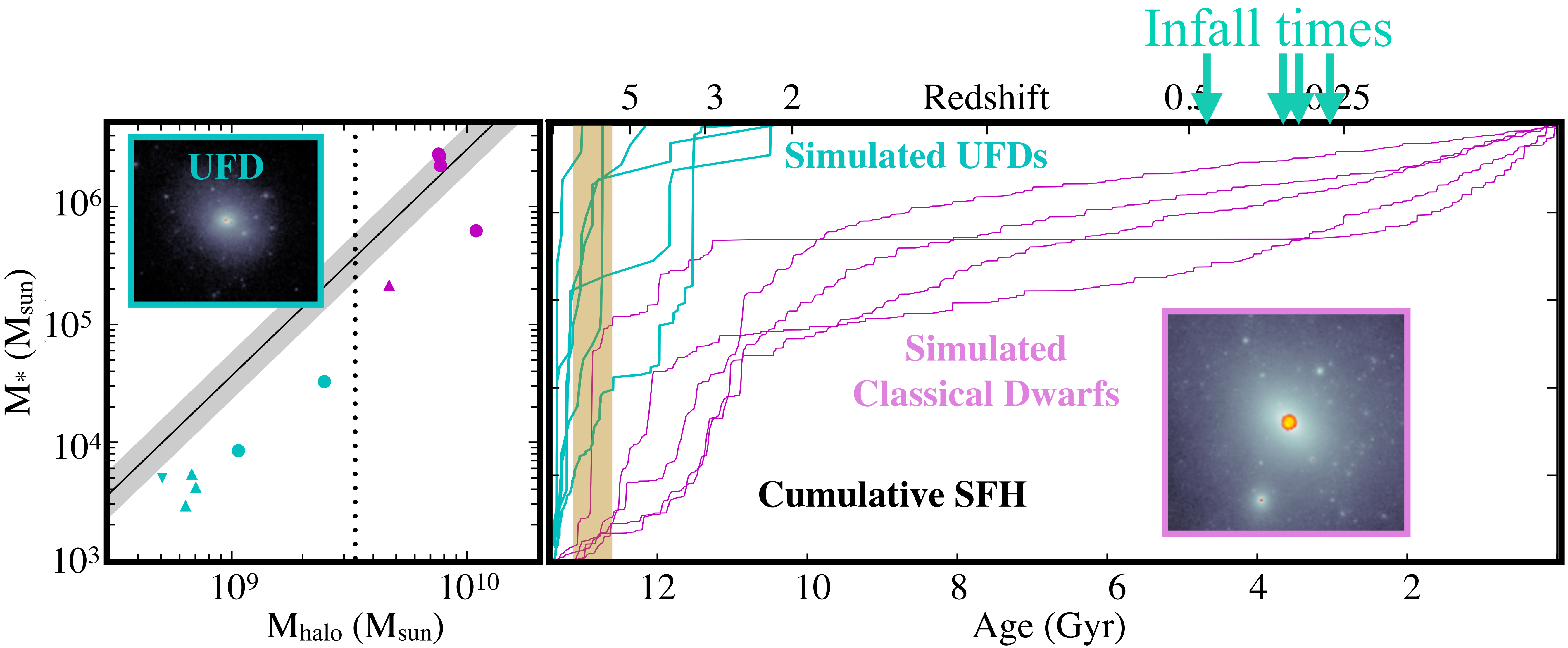

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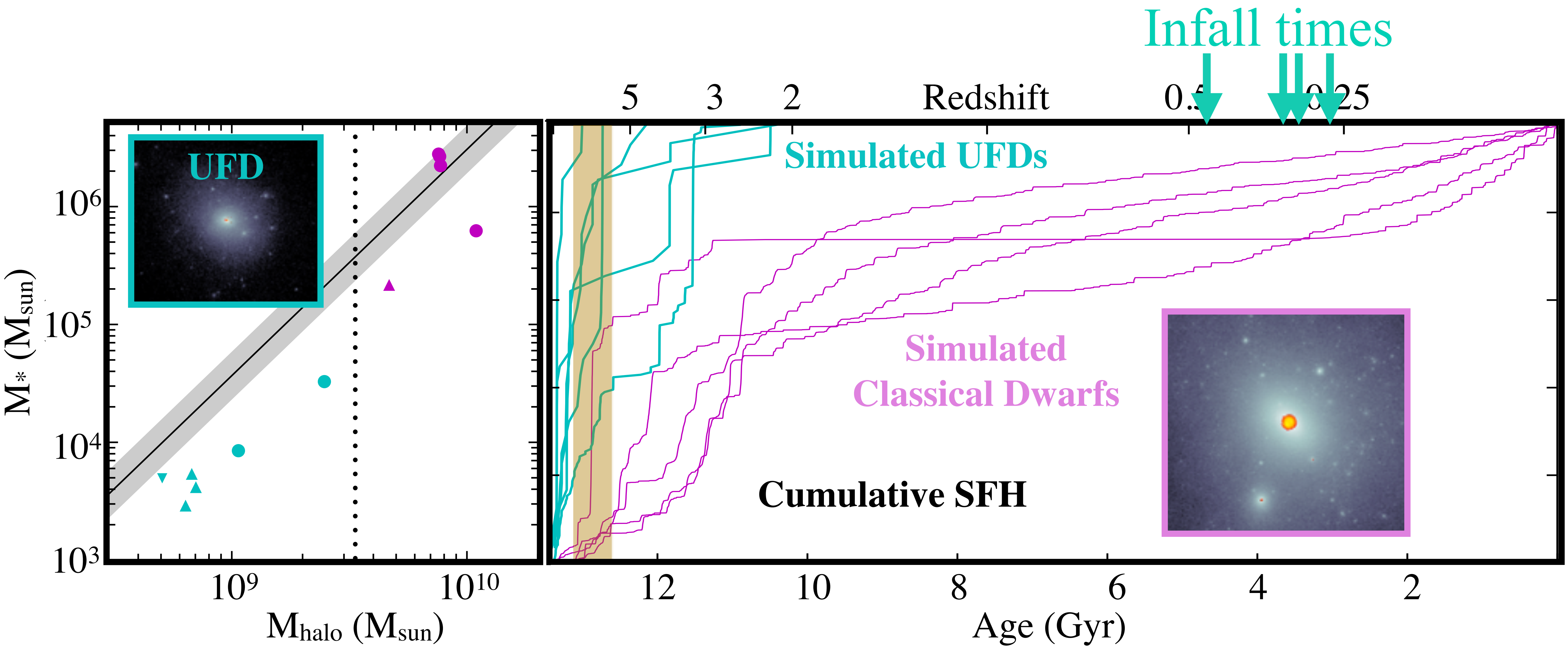
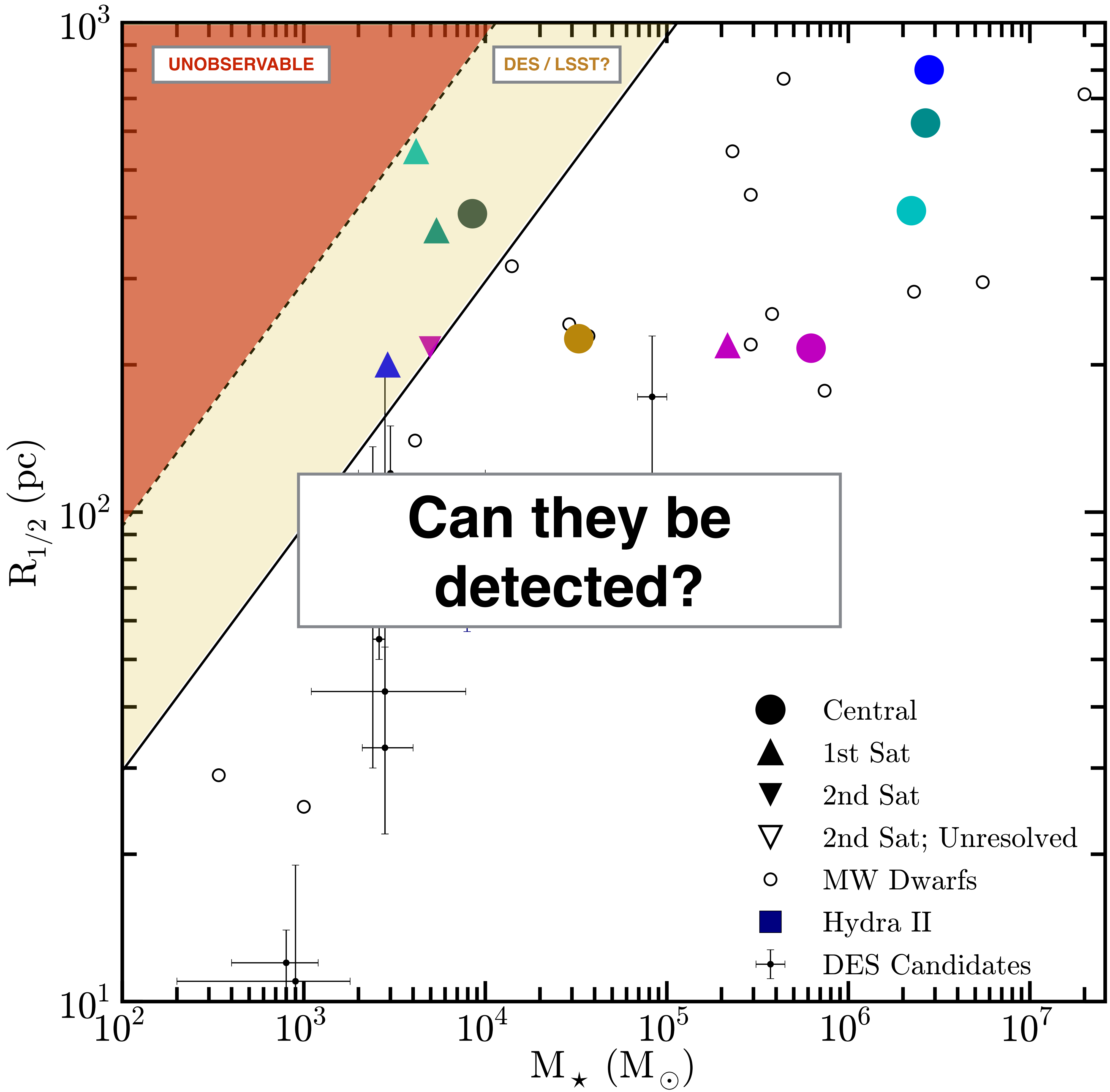
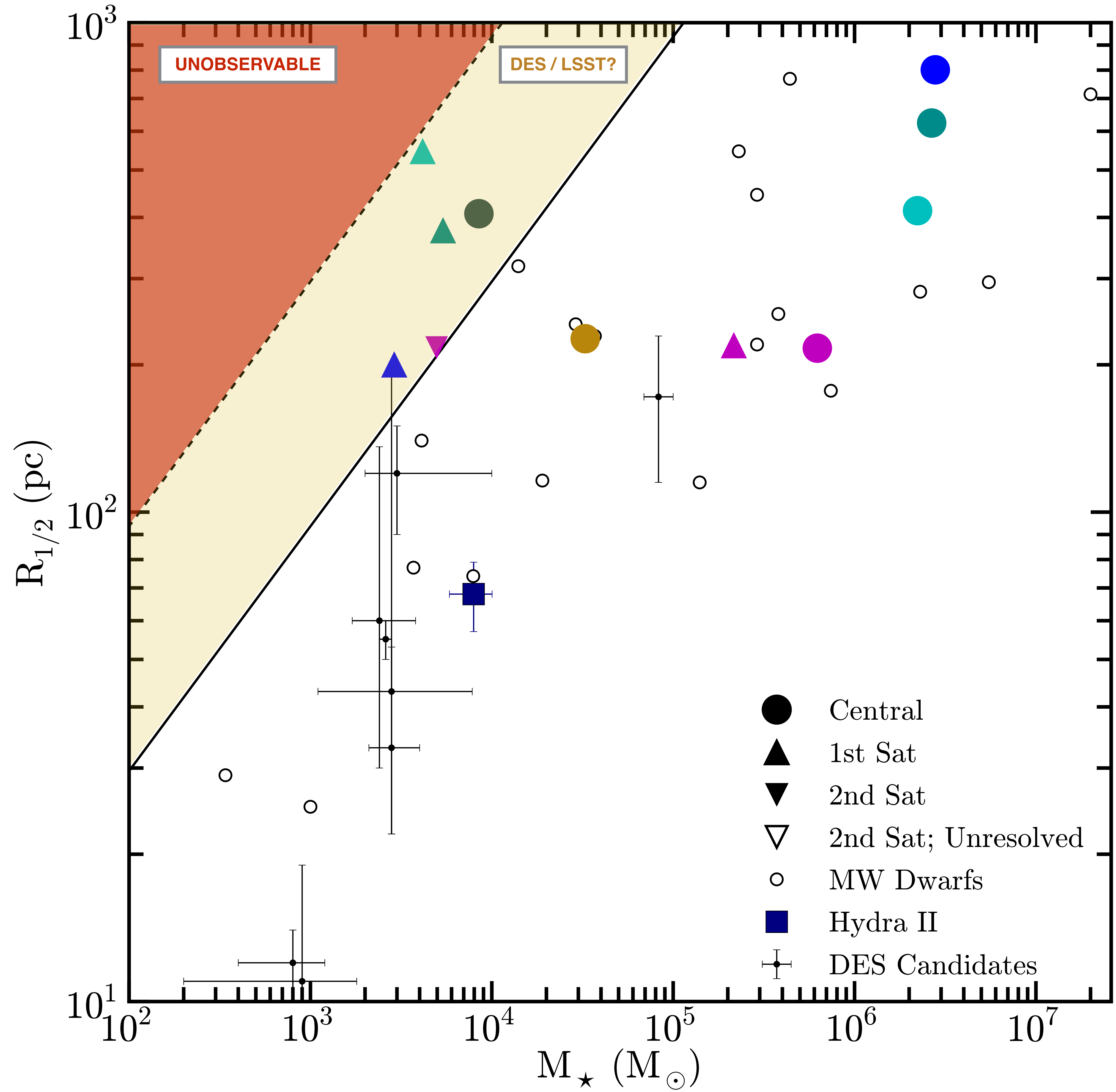


Eri II - likely on first infall with ancient stellar pop



UNOBSERVABLE
DES / LSST?
Can they be detected?
Central
1st Sat
2nd Sat
2nd Sat; Unresolved
MW Dwarfs
Hydra II
DES Candidates
$R_{1/2}$ (pc)
$M_\star$ ($M_\odot$)
10^1
10^2
10^3
10^4
10^5
10^6
10^7



UNOBSERVABLE
DES / LSST?
Central
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2nd Sat
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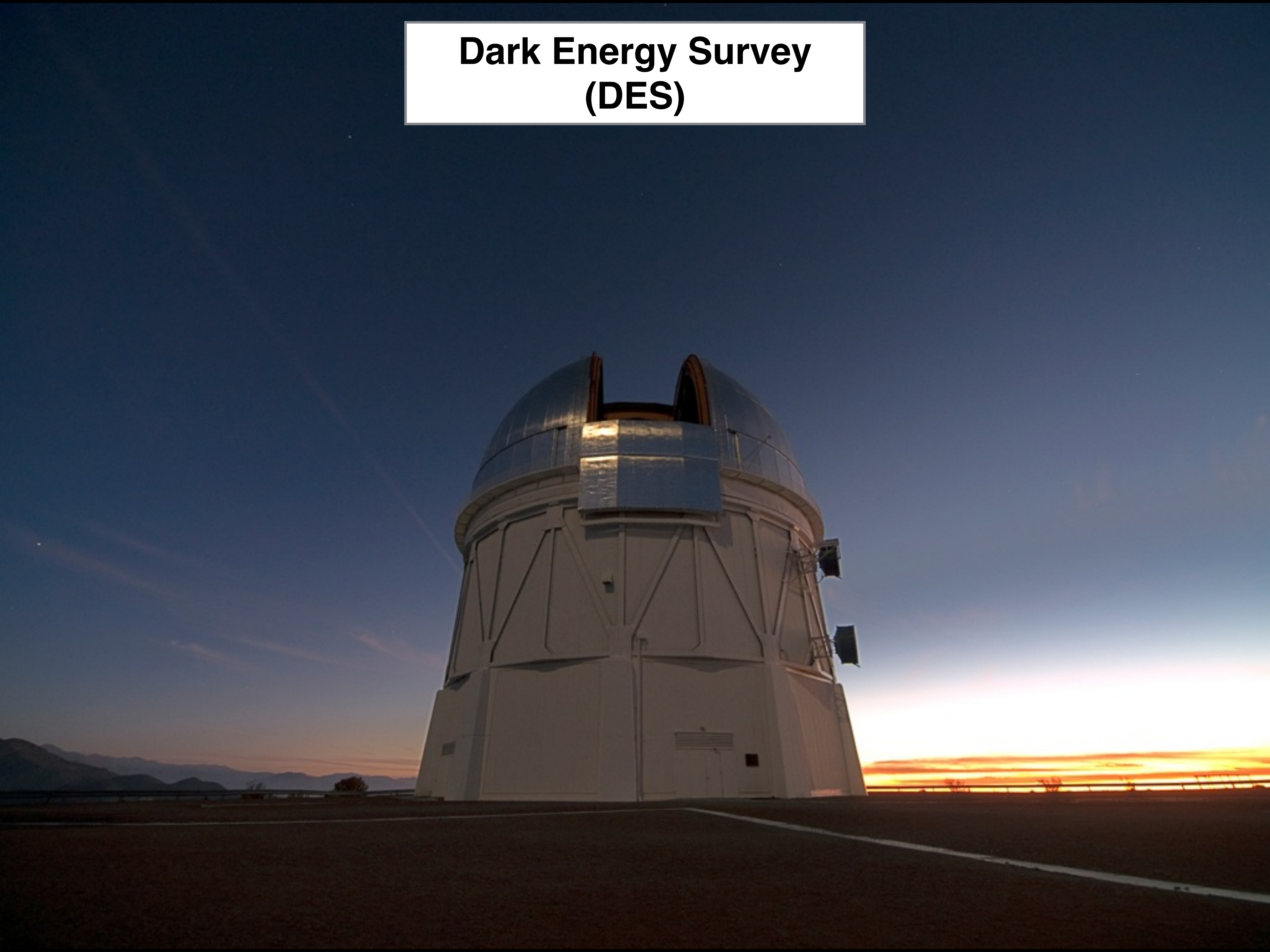
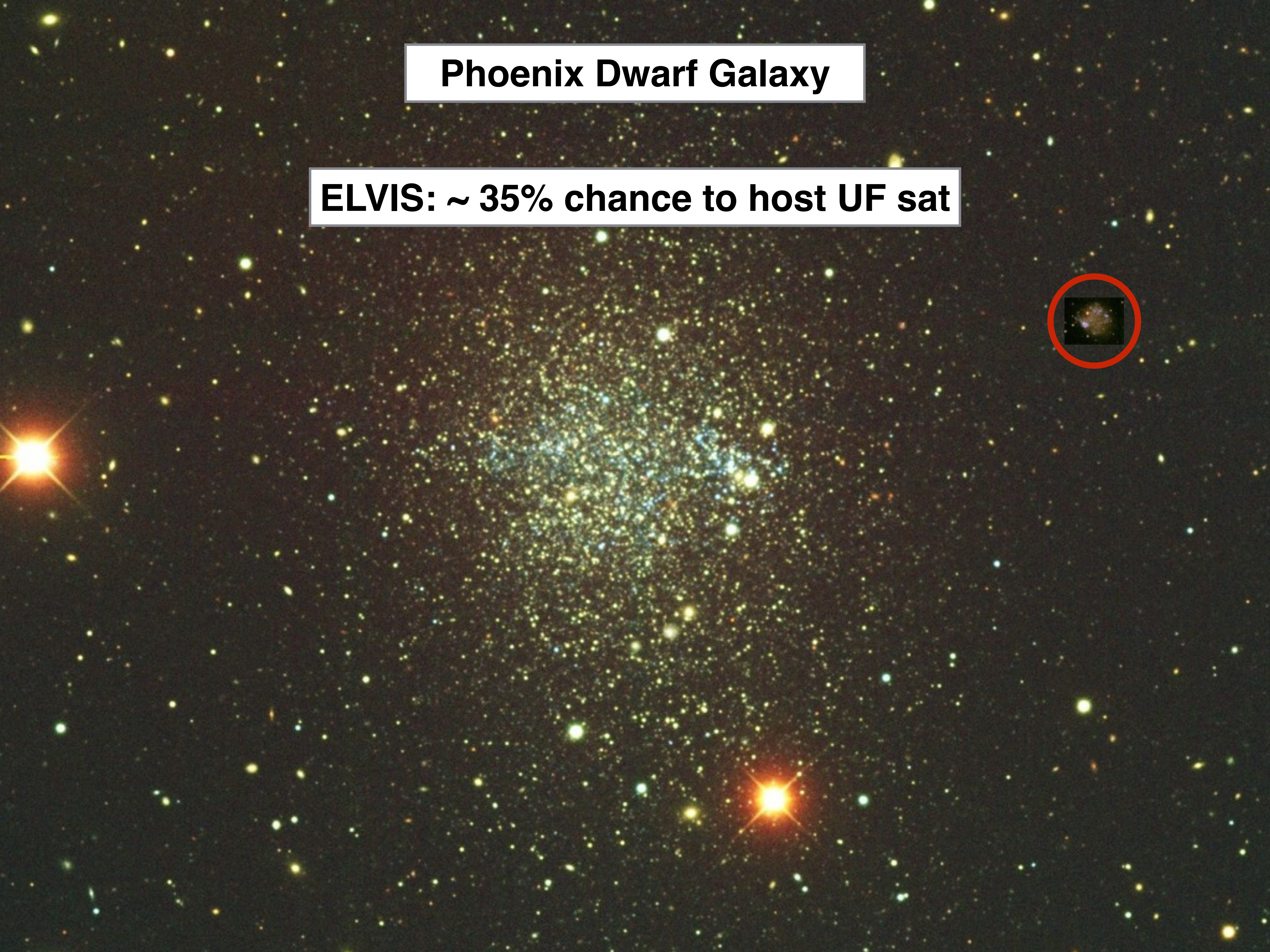
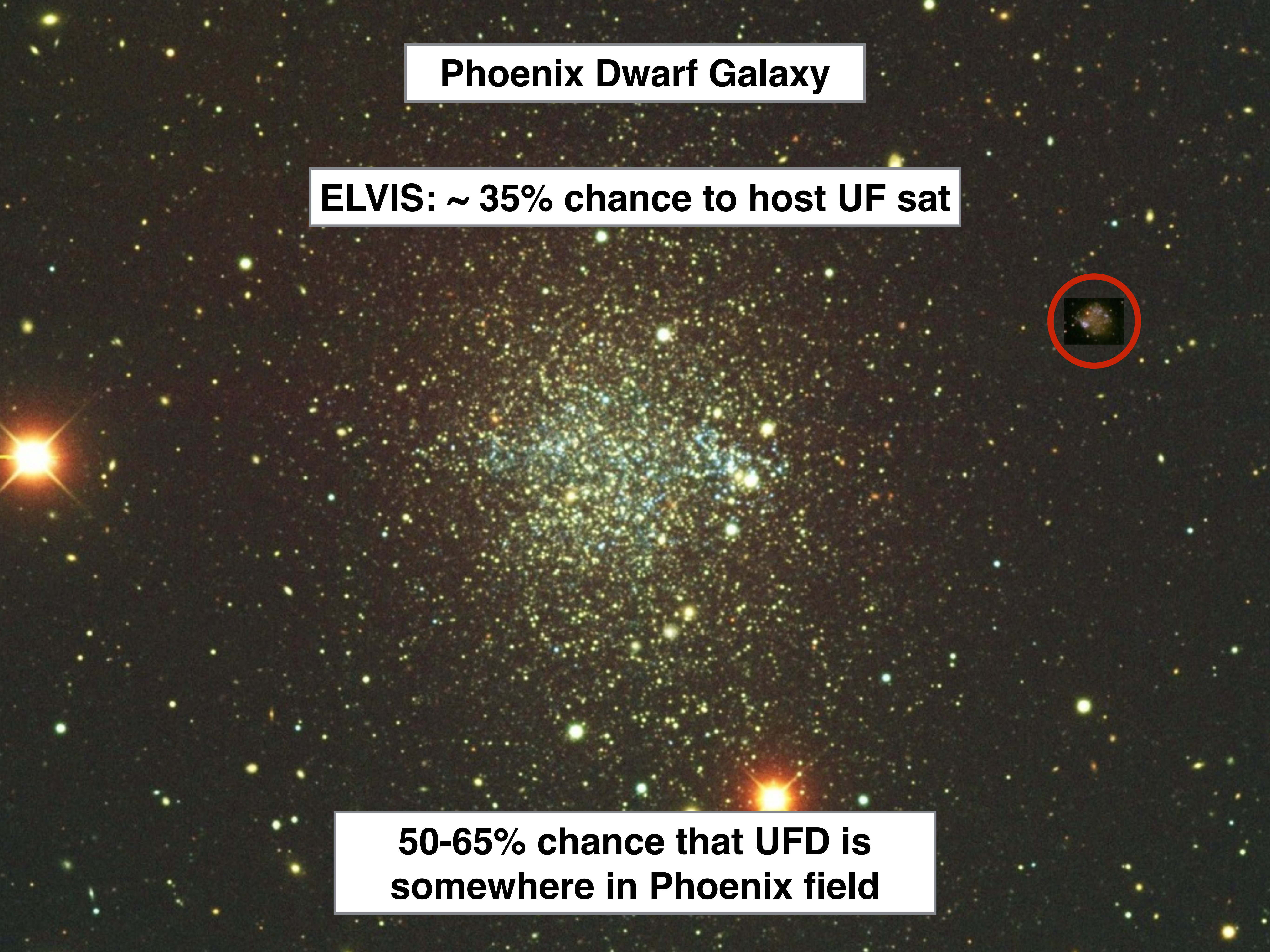
$R_{1/2}$ (pc)
$M_\star$ ($M_\odot$)
10^1
10^2
10^3
10^2
10^3
10^4
10^5
10^6
10^7

Dark Energy Survey (DES)




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

CONCLUSIONS

arXiv:1504.02466

Cornell University Library

arXiv.org > astro-ph > arXiv:1504.02466v1

Astrophysics > Astrophysics of Galaxies

Sweating the small stuff: simulating dwarf galaxies, ultra-faint dwarf galaxies, and their own tiny satellites

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(Submitted on 9 Apr 2015)

We present FIRE/Gizmo hydrodynamic zoom-in simulations of isolated dark matter halos, two each at the mass of classical dwarf galaxies ($M_{vir} \simeq 10^{10} M_\odot$) and ultra-faint galaxies ($M_{vir} \simeq 10^9 M_\odot$), and with two feedback implementations. The resultant central galaxies lie on an extrapolated abundance matching relation from $M_\star \simeq 10^6$ to $10^4 M_\odot$ without a break. Every host is filled with subhalos, many of which form stars. Our dwarfs with $M_\star \simeq 10^6 M_\odot$ each have 1-2 well-resolved satellites with $M_\star = 3 - 200 \times 10^3 M_\odot$. Even our isolated ultra-faint galaxies have star-forming subhalos. If this is representative, dwarf galaxies throughout the universe should commonly host tiny satellite galaxies of their own. We combine our results with the ELVIS simulations to show that targeting ~ 50 kpc regions around nearby isolated dwarfs could increase the chances of discovering ultra-faint galaxies by $\sim 35\%$ compared to random halo pointings, and specifically identify the region around the Phoenix dwarf galaxy as a good potential target.
The well-resolved ultra-faint galaxies in our simulations ($M_\star \simeq 3 - 30 \times 10^3 M_\odot$) form within $M_{peak} \simeq 0.5 - 3 \times 10^9 M_\odot$ halos. Each has a uniformly ancient stellar population (> 10 Gyr) owing to reionization-related quenching. More massive systems, in contrast, all have late-time star formation. Our results suggest that $M_{halo} \simeq 5 \times 10^9 M_\odot$ is a probable dividing line between halos hosting reionization "fossils" and those hosting dwarfs that can continue to form stars in isolation after reionization.

Comments: 12 pages, 6 figures
Subjects: Astrophysics of Galaxies (astro-ph.GA)
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(or arXiv:1504.02466v1 [astro-ph.GA] for this version)

- In the ΛCDM paradigm, dark matter halos of Local Group field dwarfs should be filled with subhalos. Some of them should form stars.

- Isolated dwarf galaxies ($M^* \sim 10^6$ $M_\odot$) in the Local Group should host ultra-faint galaxies ($M^* \sim 3000$ $M_\odot$) as satellites.

- These galaxies form most of their stars in the first billion years after the Big Bang, suggesting a dividing line in halo mass ($M_{halo} \sim 10^{9.5}$ $M_\odot$) below which galaxies at z = 0 will have entirely ancient stellar populations.

- The extended ~50 kpc regions around Local Group "field" dwarfs may provide efficient search locations for discovering new ultra-faint dwarf galaxies. Phoenix is a good target.