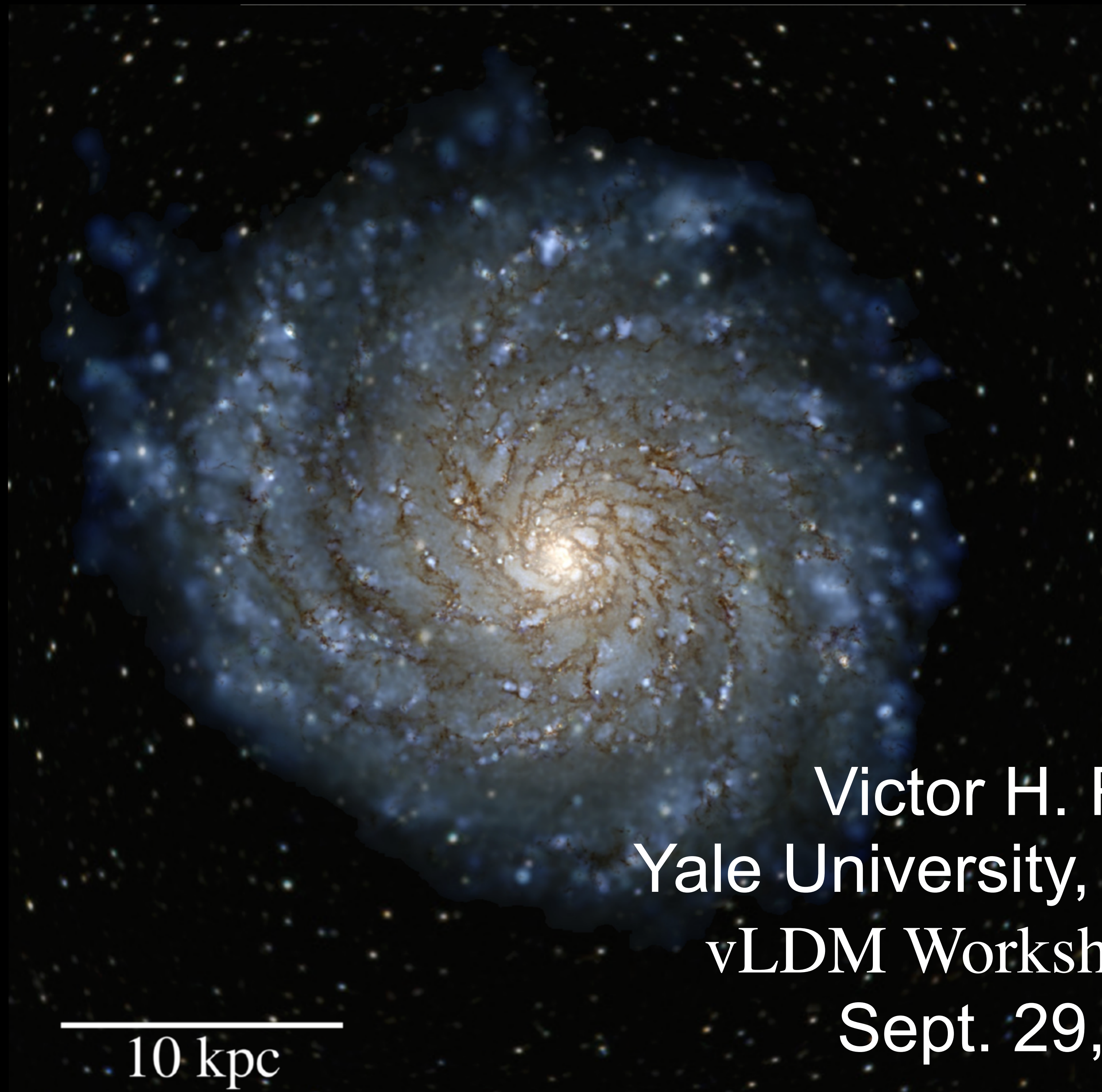
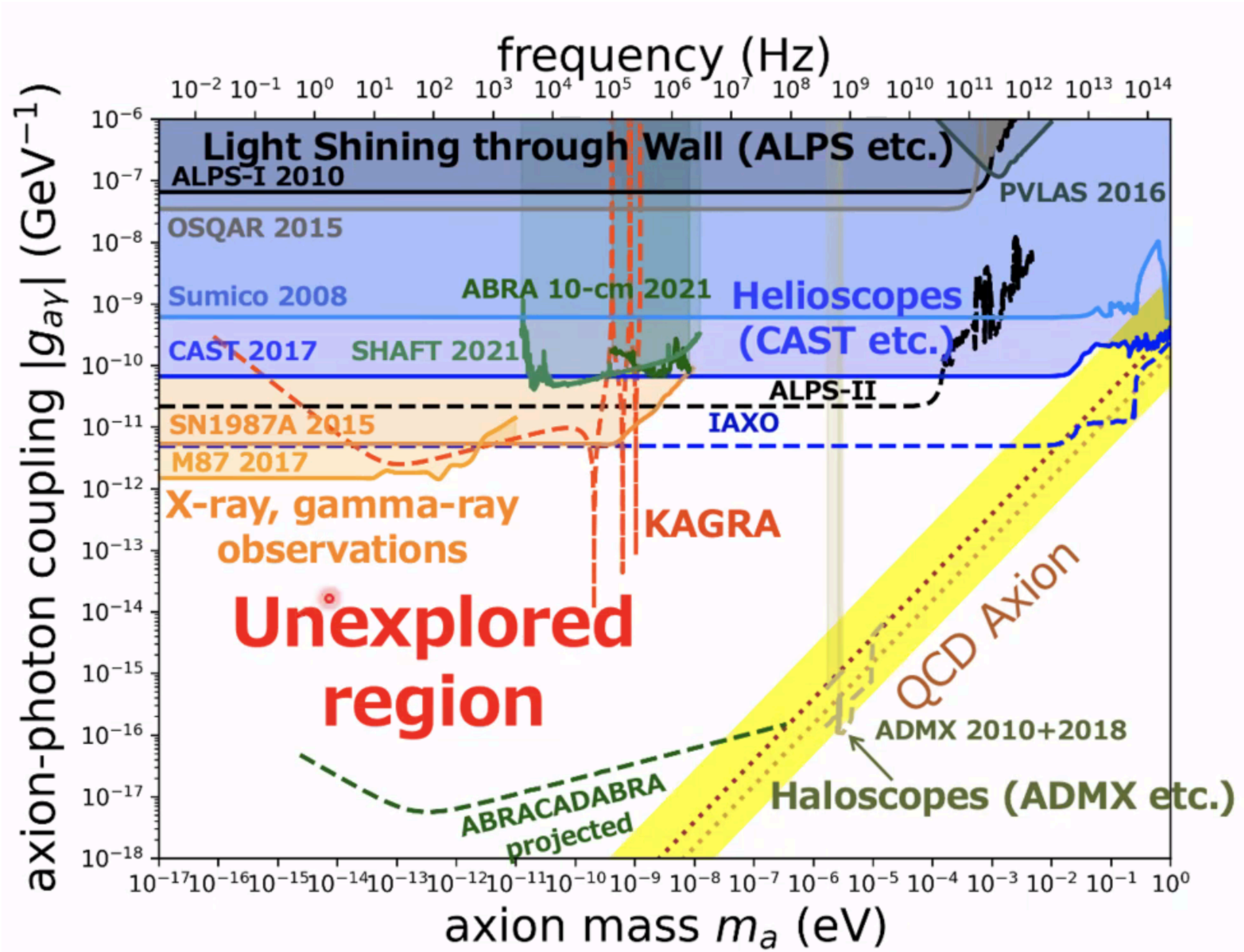
Constraints to SFDM from internal structure and orbital information of Milky Way satellites



Victor H. Robles
Yale University, YCAA fellow

vLDM Workshop, Tokyo,
Sept. 29, 2021

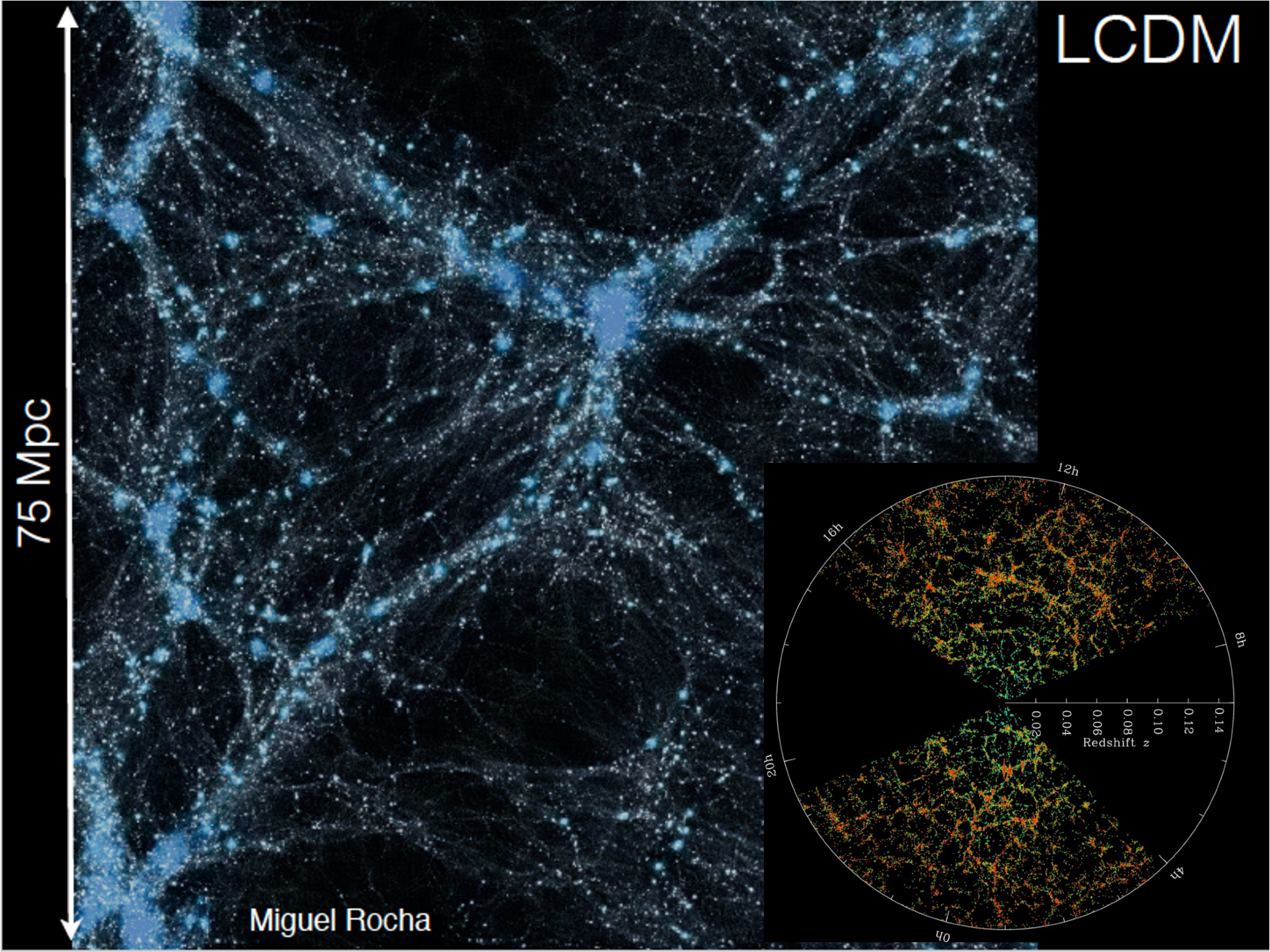
Dark Matter searches: Axion-photon coupling



Our goal is to detect ultra light DM.

We can narrow down the mass parameter space using alternative methods beyond the axion-photon coupling

Look at astrophysics (useful if DM has gravitational coupling only)



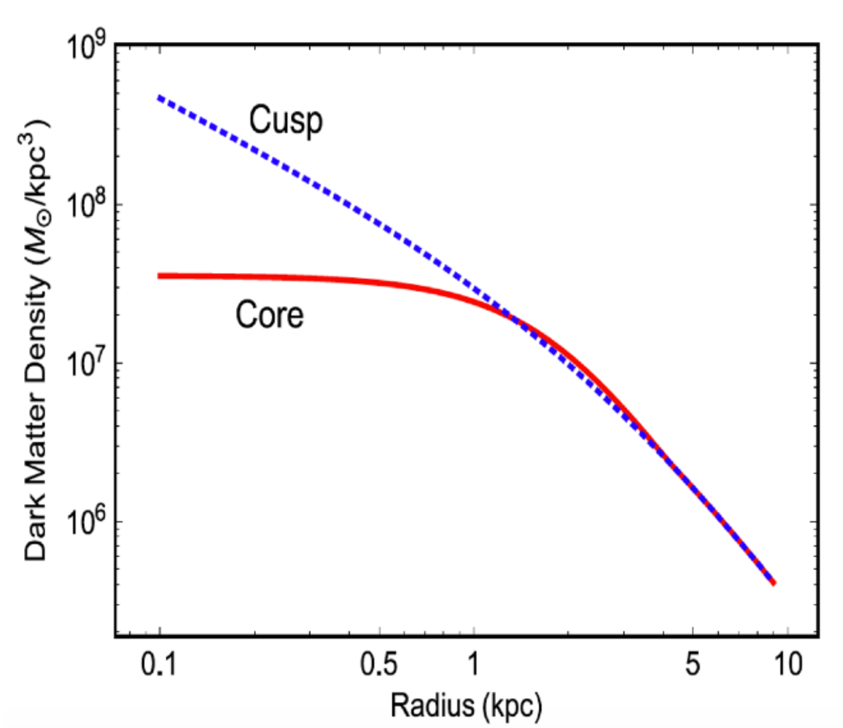
LCDM
75 Mpc
Miguel Rocha
12h
16h
8h
20h
4h
0h
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Redshift z

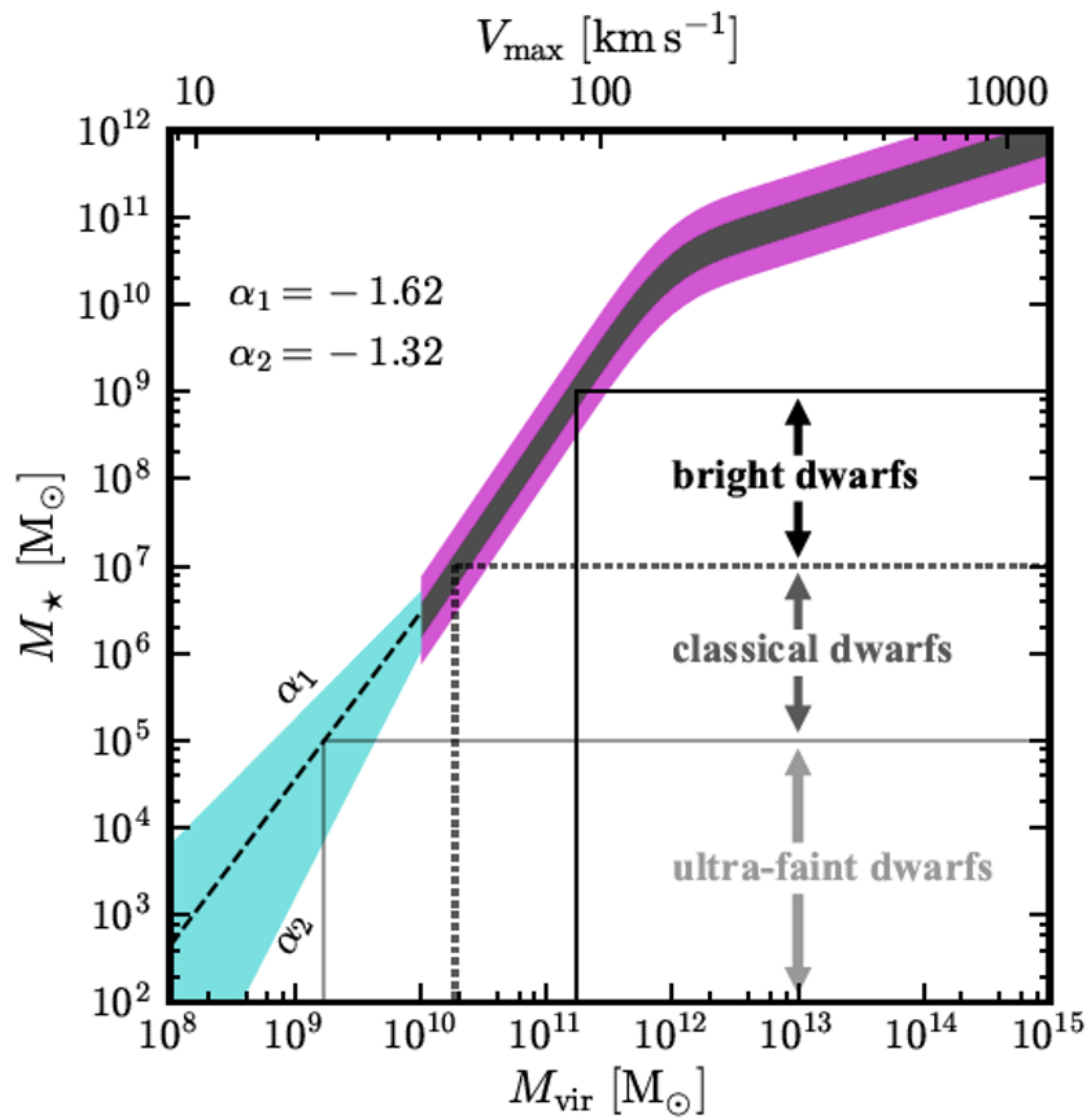
Stellar-halo mass relation for isolated galaxies

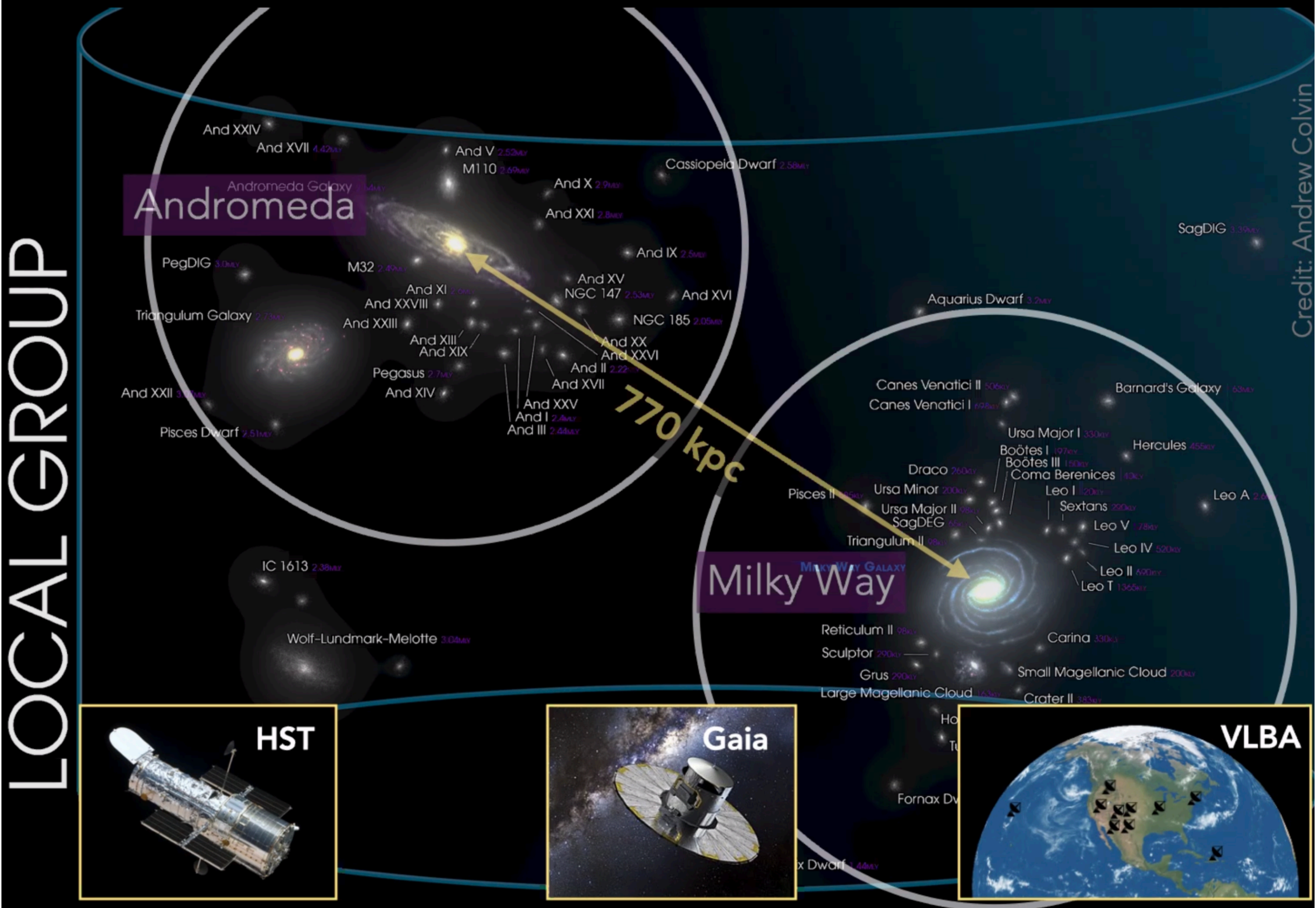
Low mass galaxies have
$M_\star/M_{vir} \leq 10^{-3}$
Great candidates to test DM predictions
(DM dominated systems)

Notably:
CDM issues appear at such scales:
LSB galaxies, dwarfs
Cusp-core, Too-big-to-Fail, etc.

Bullock&Boylan-Kolchin17 (review)







Full 6D phase space information is available for > 50 MW satellites and M31 + 4 satellites!

Satellite discoveries in our own Milky Way

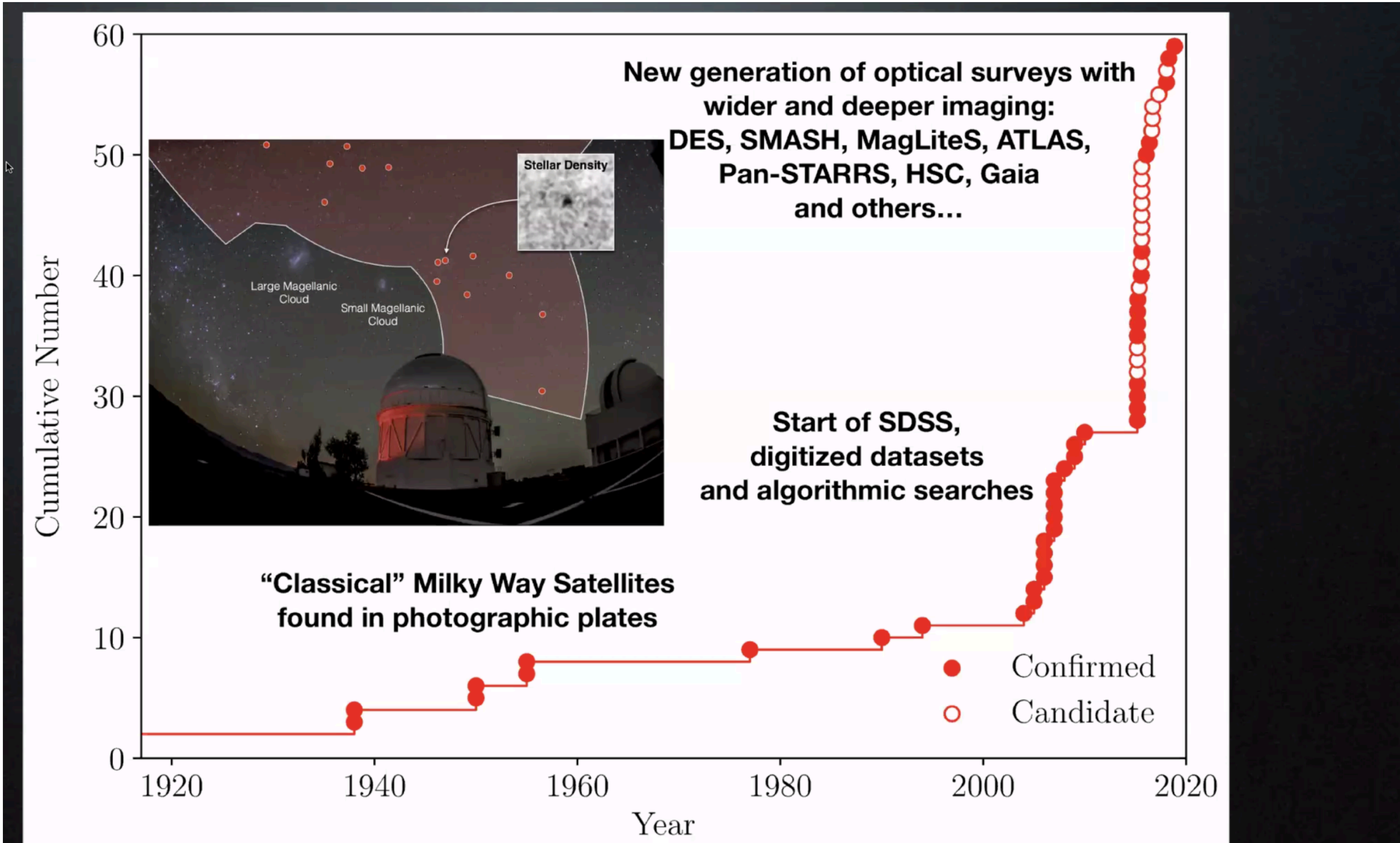
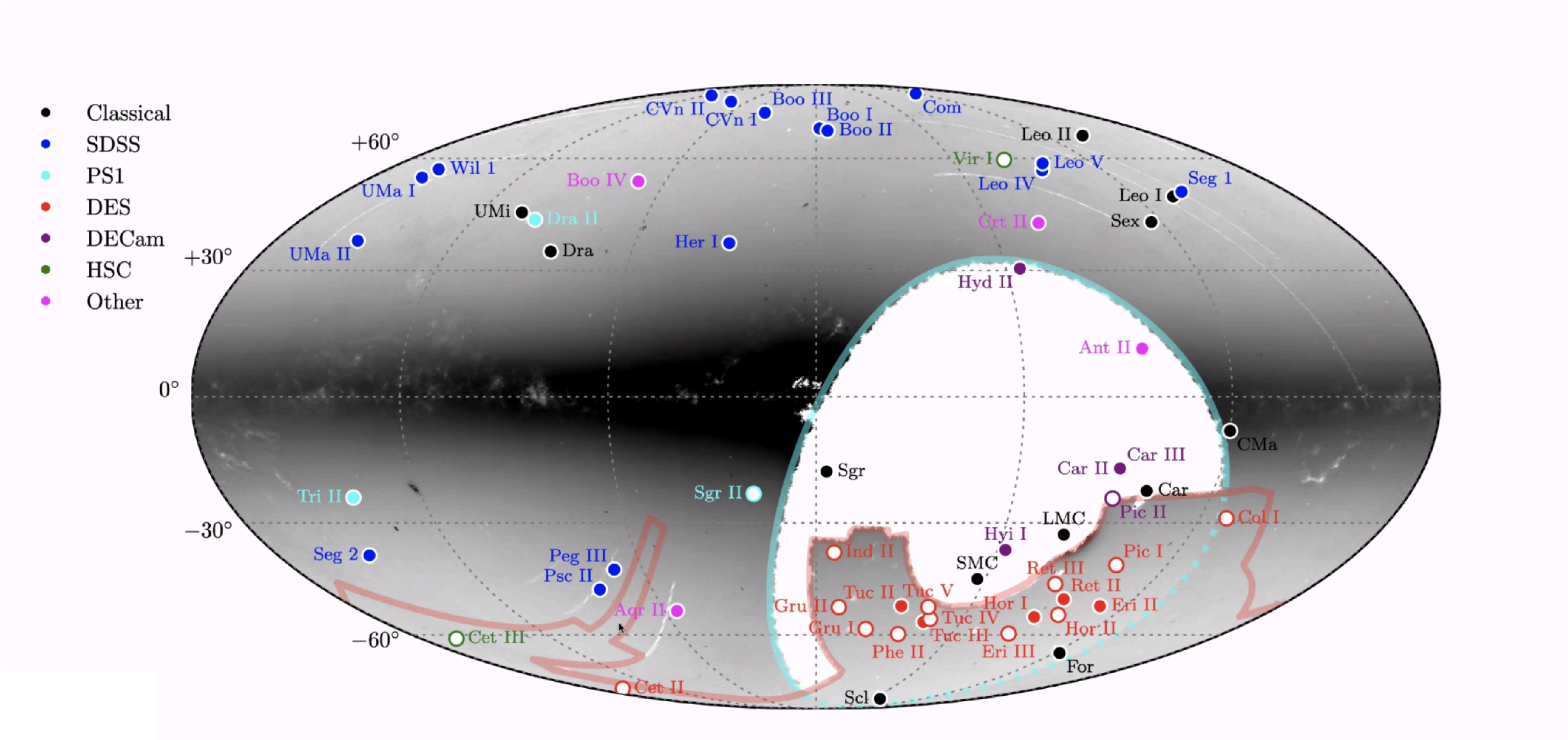


Figure from Keith Bechtol

Search of nearly full Sky using DES Y3 + PanSTARRS

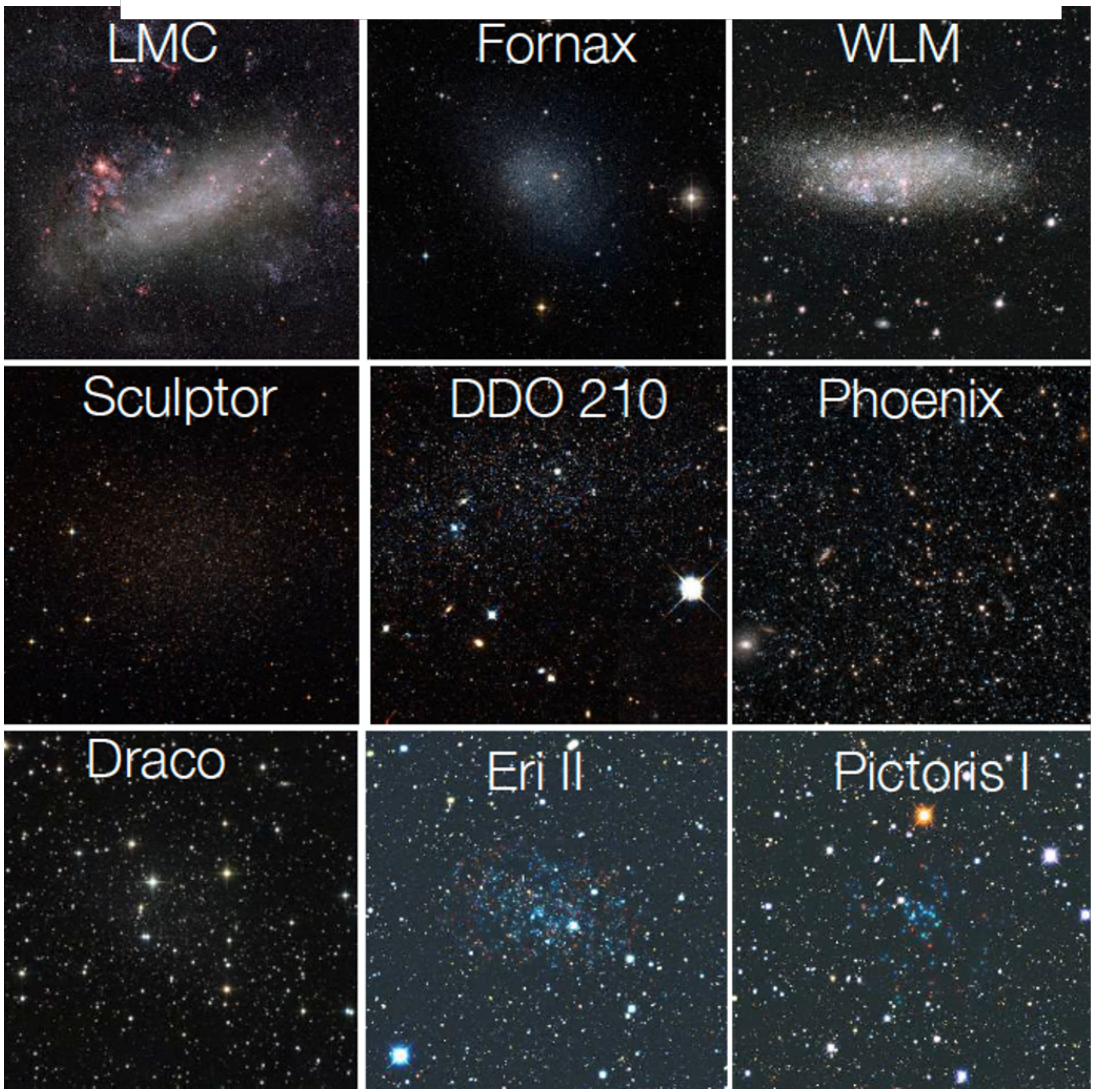


Drlica-Wagner, Bechtol, and the DES Milky Way Working Group, 2020

Cosmological de Broglie wavelength(~kpc):

$$\frac{\lambda}{2\pi} = \frac{\hbar}{mv} = 1.92\,\mathrm{kpc}\left(\frac{10^{-22}\,\mathrm{eV}}{m}\right)\left(\frac{10\,\mathrm{km\,s^{-1}}}{v}\right)$$

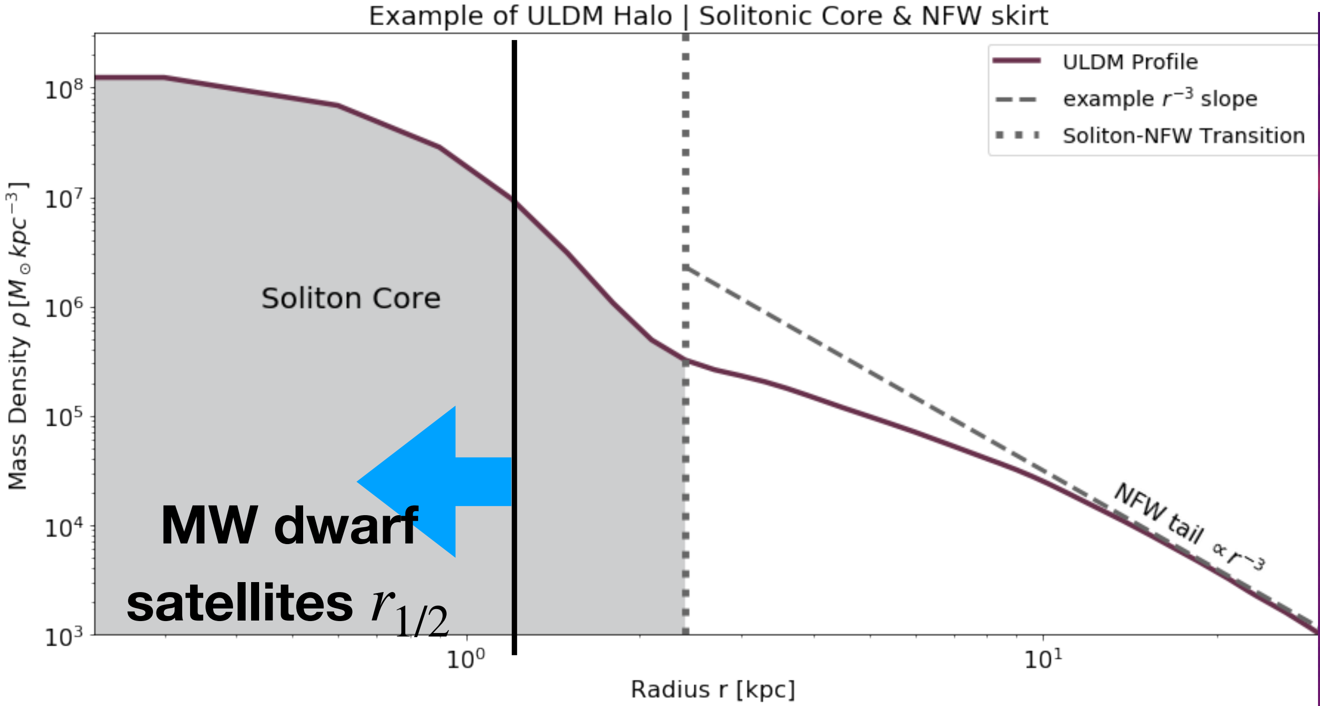
~Dwarf galaxy half-light radii!



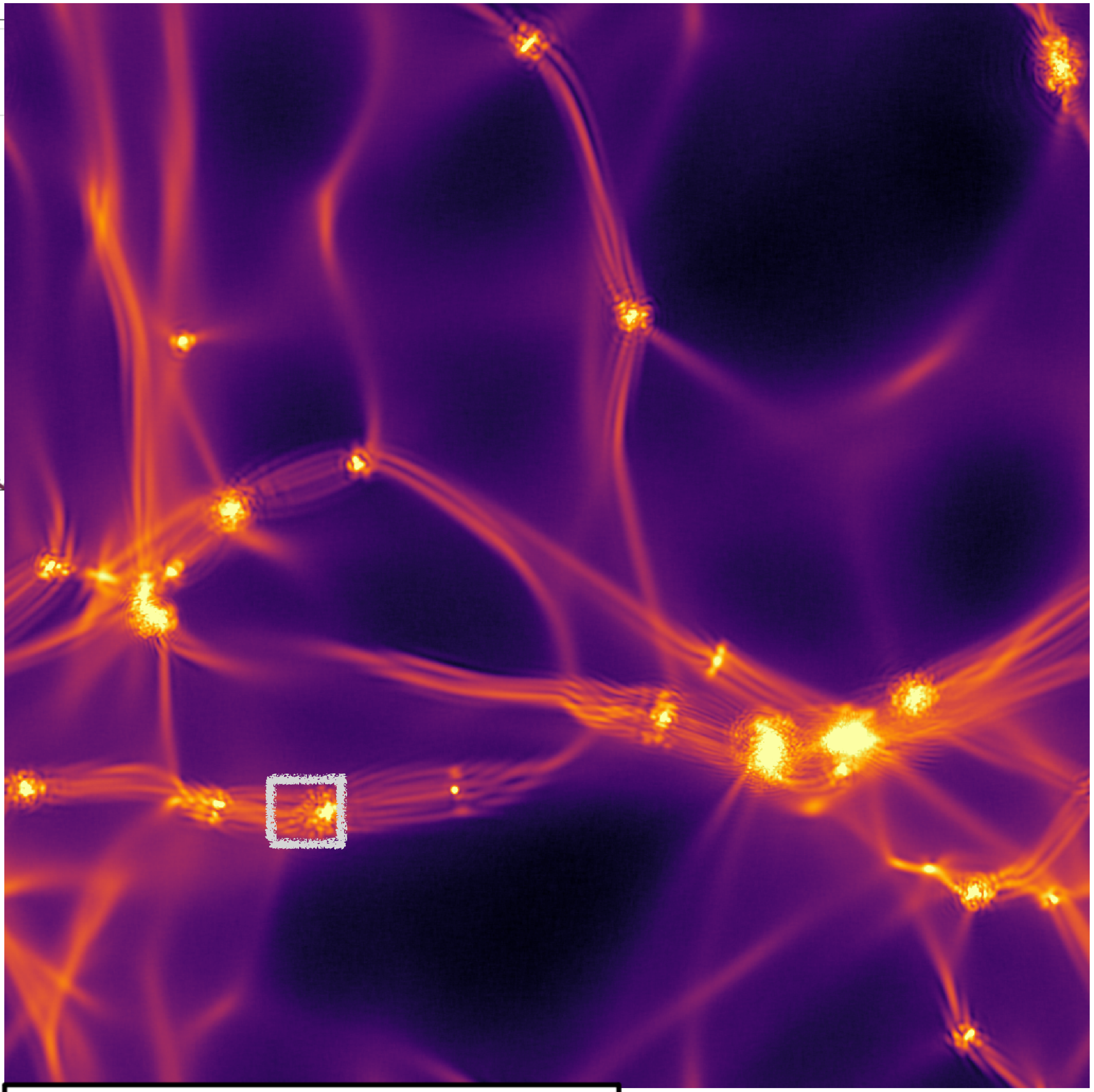
McConnachie 2015,Simon+19

Are SFDM halos consistent with dwarf galaxies?

SFDM Halo Structure



Cosmological Simulation Mocz+19



Soliton Profile

$$\rho_c(r) \simeq \rho_0[1 + 0.091 \cdot (r/r_c)^2]^{-8}$$

$$\rho_0 \simeq 3.1 \times 10^{15} \left(\frac{2.5 \times 10^{-22}\ \mathrm{eV}}{m}\right)^2 \left(\frac{\mathrm{kpc}}{r_c}\right)^4 \frac{M_\odot}{\mathrm{Mpc}^3}.$$

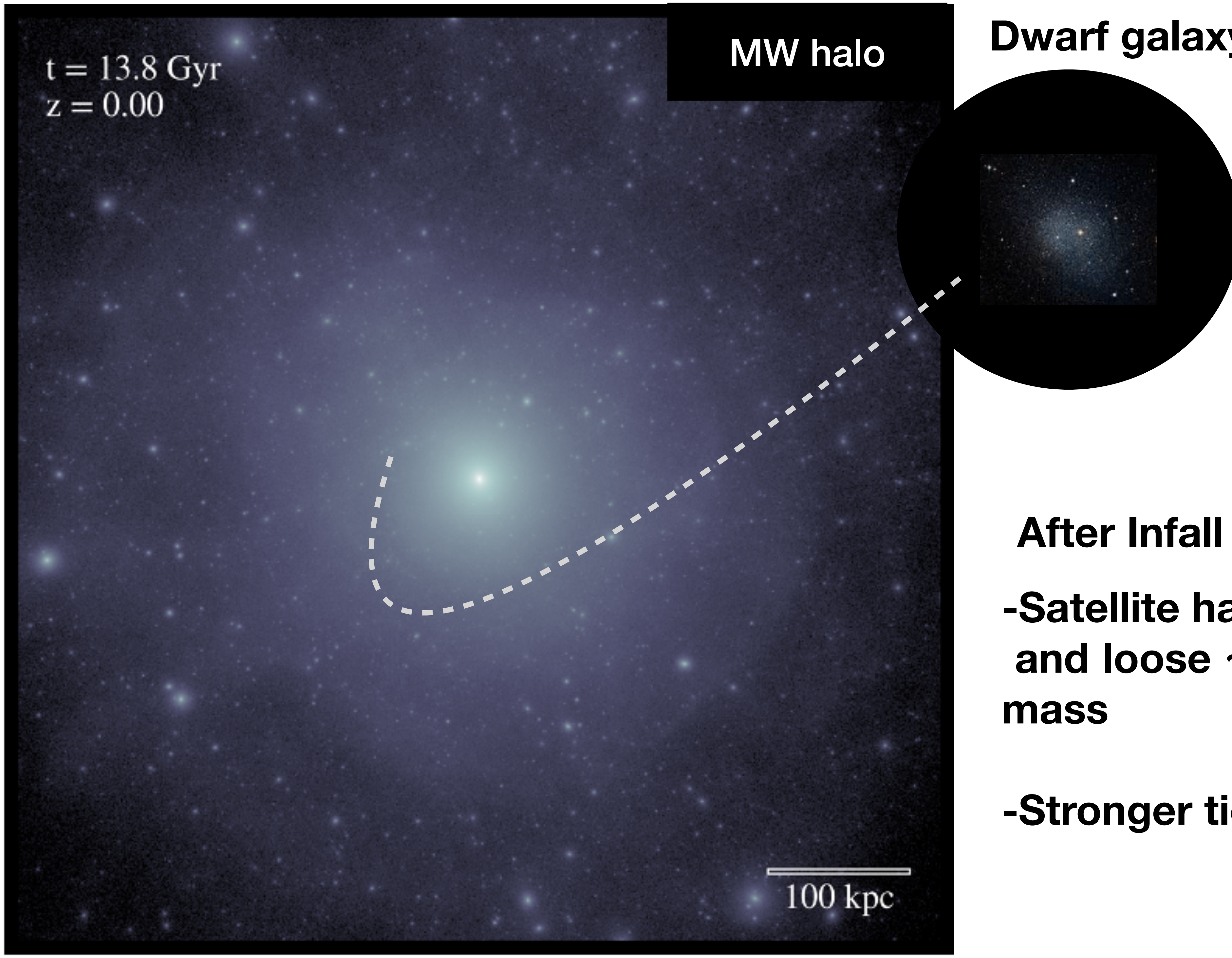
Sin94,Matos+01;Guzman+00;
Schive+14;Mocz+17,19;Robles+19

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi + mV\psi$$

$$\nabla^2 V = 4\pi G(\rho - \overline{\rho})$$

Equations of Motion Non-relativistic regime

What Solitons are DYNAMICALLY consistent to host MW Satellite galaxies?



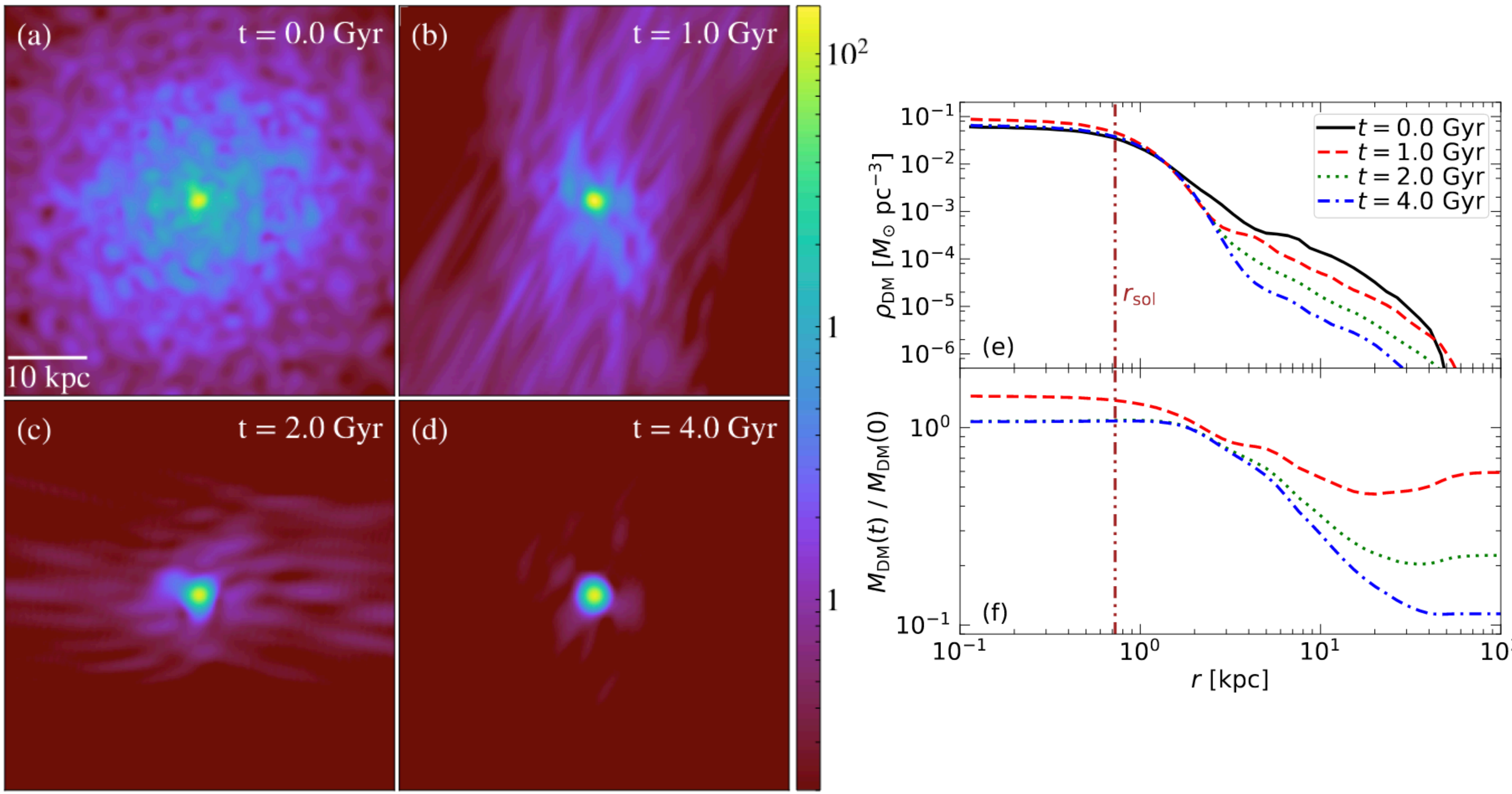
After Infall

-Satellite halos are tidally stripped and loose ~90% of their outer halo mass

-Stronger tidal effects at pericenter

Solitons get their outer envelopes stripped but remain robust to the tidal field of the Milky Way

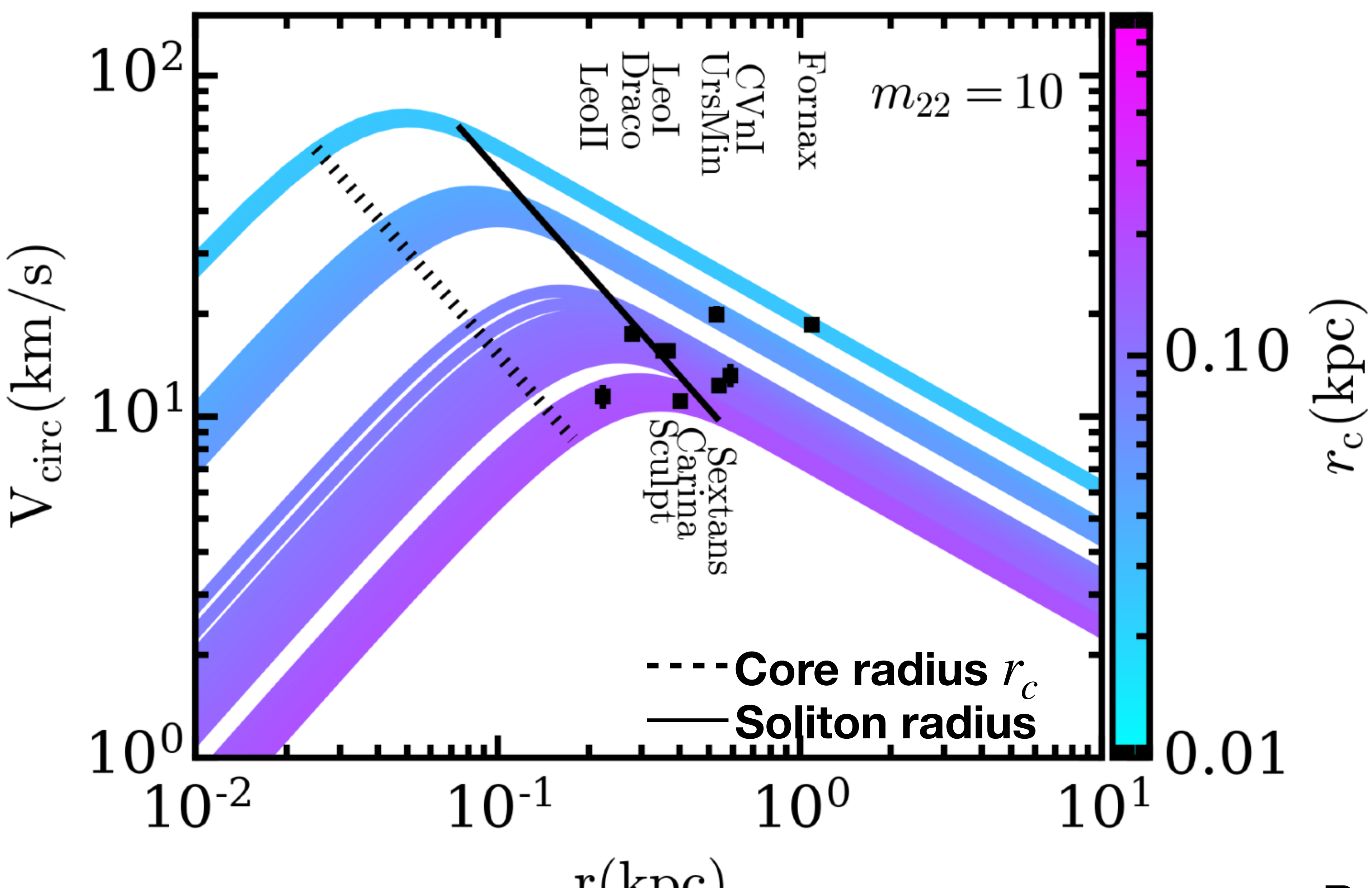
Schive,Chiueh,Broadhurs PRL 124, 201301 (2020)



Assume (naked) Solitons host the brightest dwarf spheroidal MW Satellites

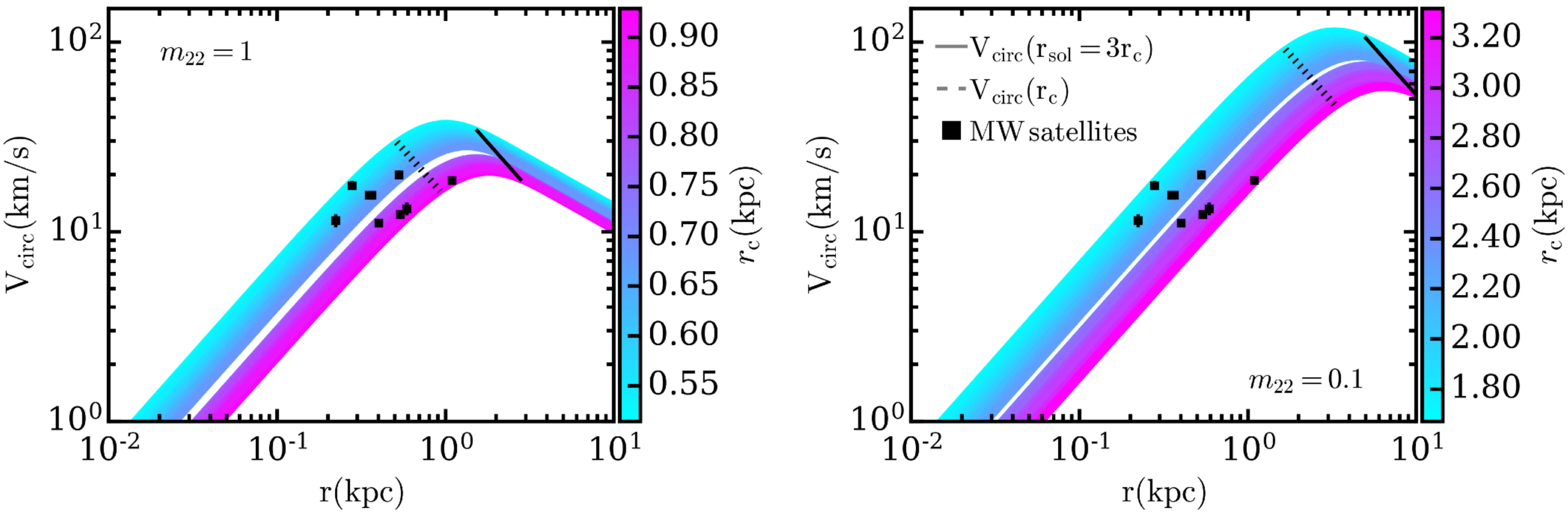
Using the spherical Jeans equation Wolf+10 found that the mass profiles of dispersion-supported galaxies can be constrain. This provides a mass estimate at the deprojected 3D half-light radius!

$$\mathrm{M}_{1/2} = 3\,G^{-1}\,\langle \sigma^2_{\mathrm{los}} \rangle\,\mathrm{r}_{1/2} \implies V_{\mathrm{circ}}(r_{1/2}) = \sqrt{GM_{1/2}/r_{1/2}}$$



Robles+21

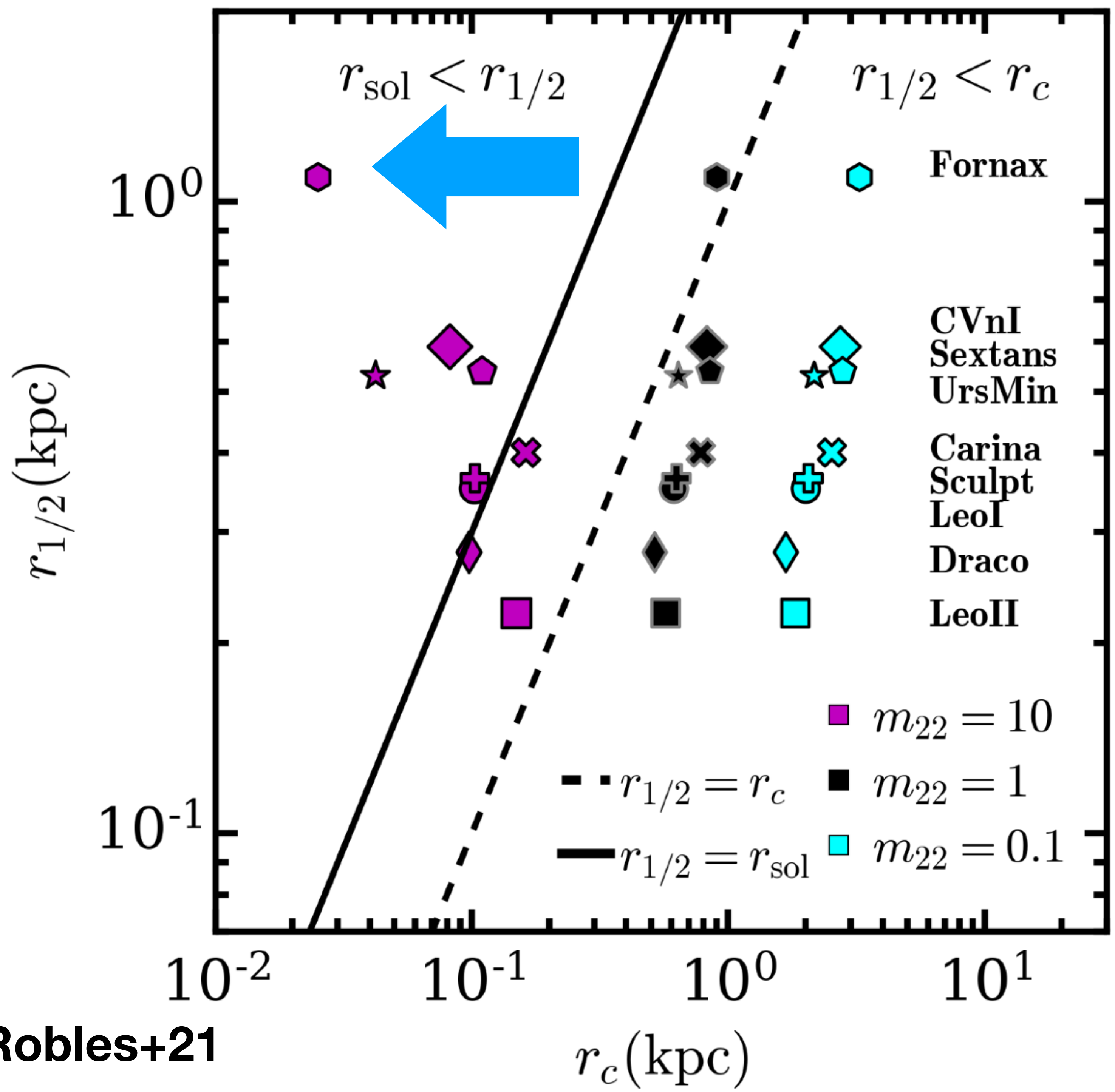
Observed dSph galaxy sizes are well within the core
Solitons are also more massive for smaller m_{22}



Galaxy size vs Soliton core radius

More massive DM bosons imply more compact solitons

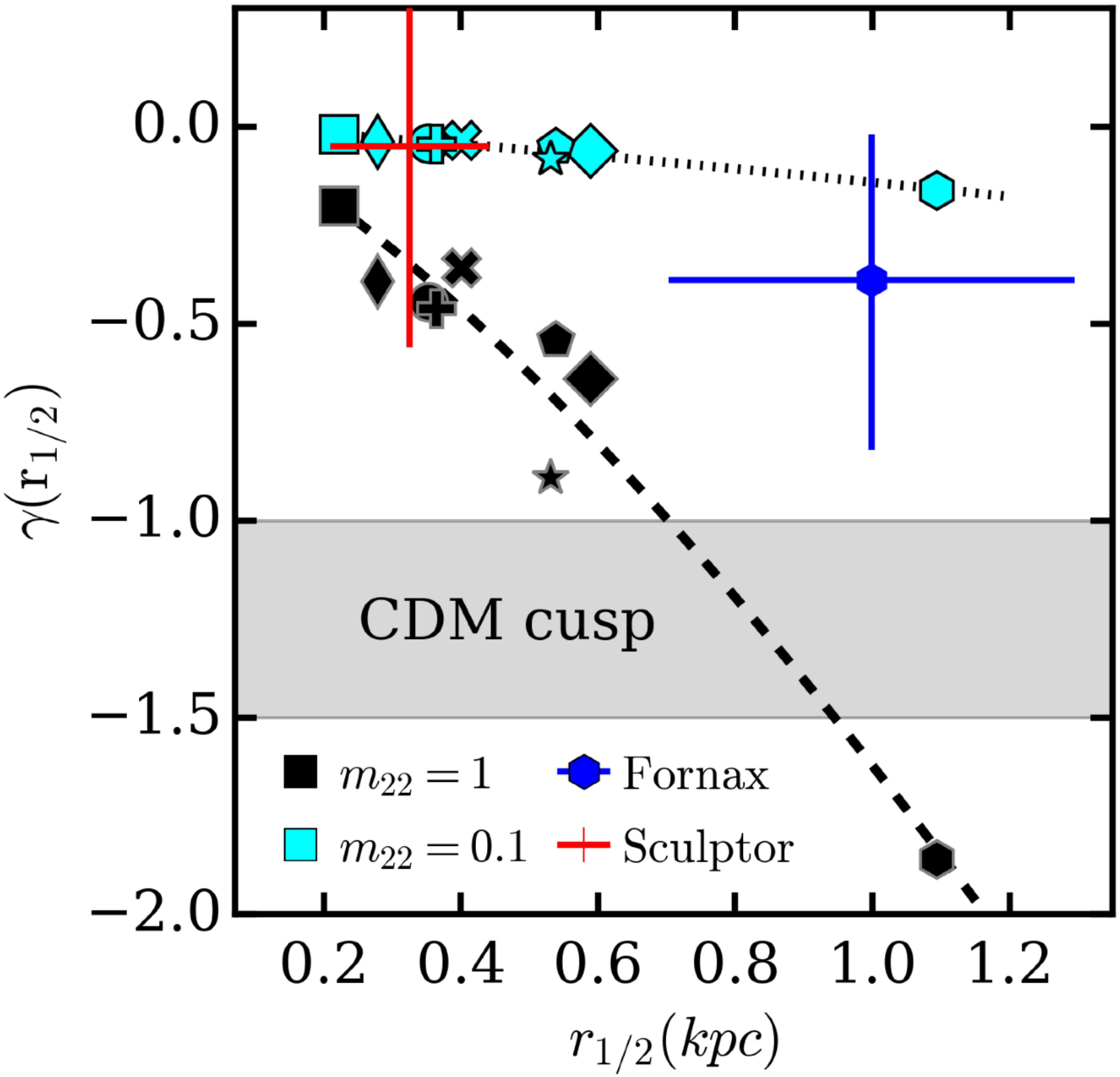
SF fluctuations may trigger instabilities in the stars beyond r_{sol}



Robles+21

We need $m_{22} < 3$ to host all dSphs within solitons subhalos

Central logarithmic density slopes



Large uncertainties!

The steep slope gradients can be used to distinguish DM masses (Mass estimators at different radii using tangential velocities from Gaia, Lazar+21)

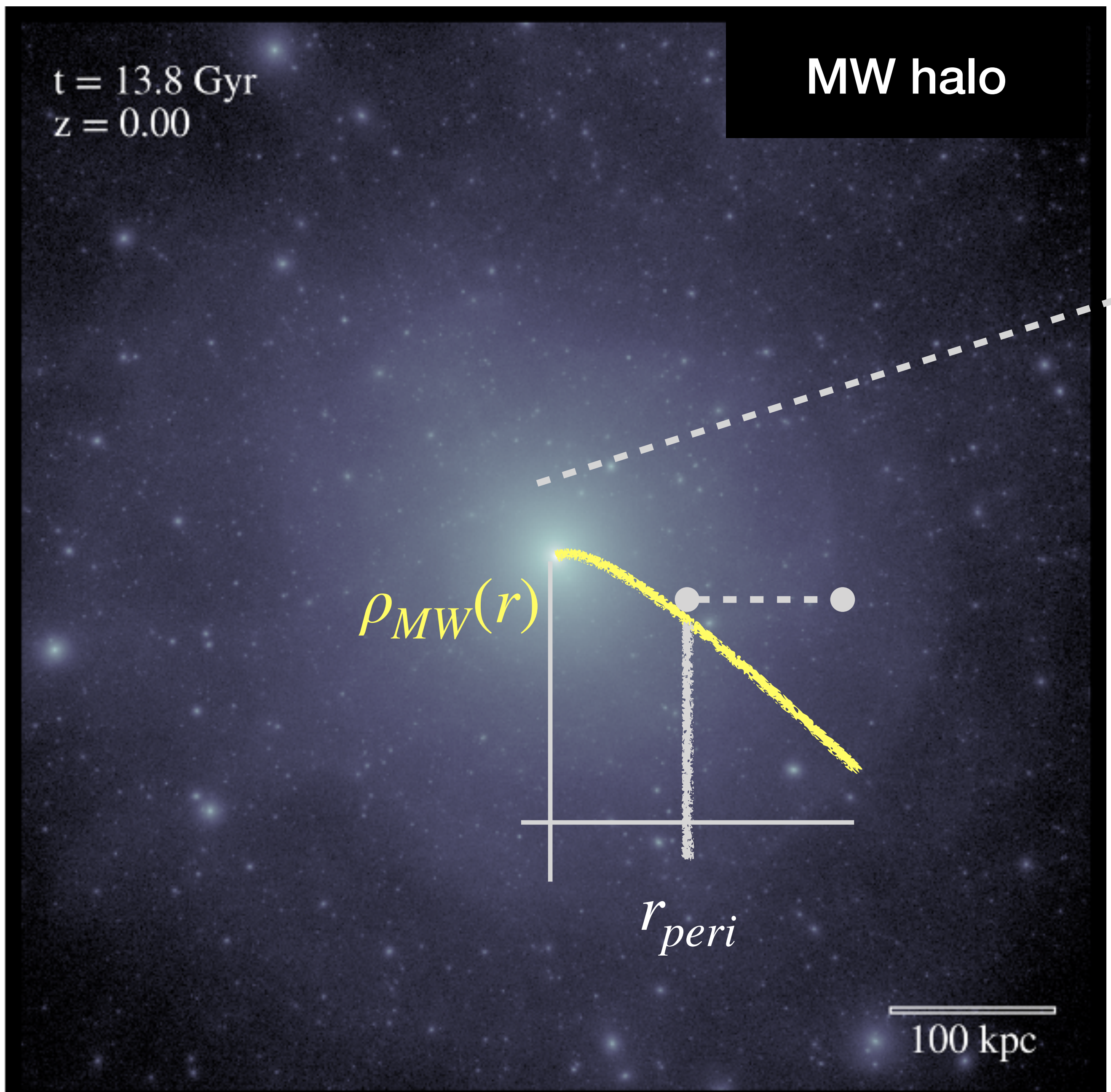
Fornax seems to be in tension with $m_{22} = 1$ (?!)

Robles+21

Kinematic constraints from Gaia pericenters for MW satellites (Fritz+18)

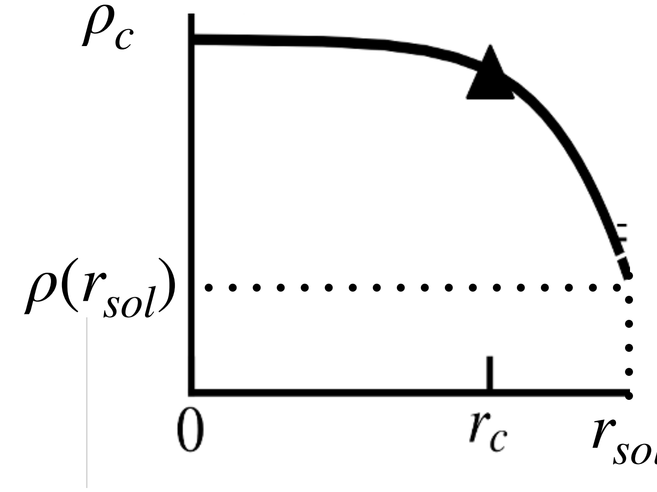
For Solitons to retain their profile within *r*<$r_{\rm sol} = 3r_c$ **we need** $\rho(r_{sol}) \geq \bar{\rho}_{MW}(r_{\rm pericenter})$

Host densities increase towards to center, implying a minimum approach at which Solitons can retain their profiles

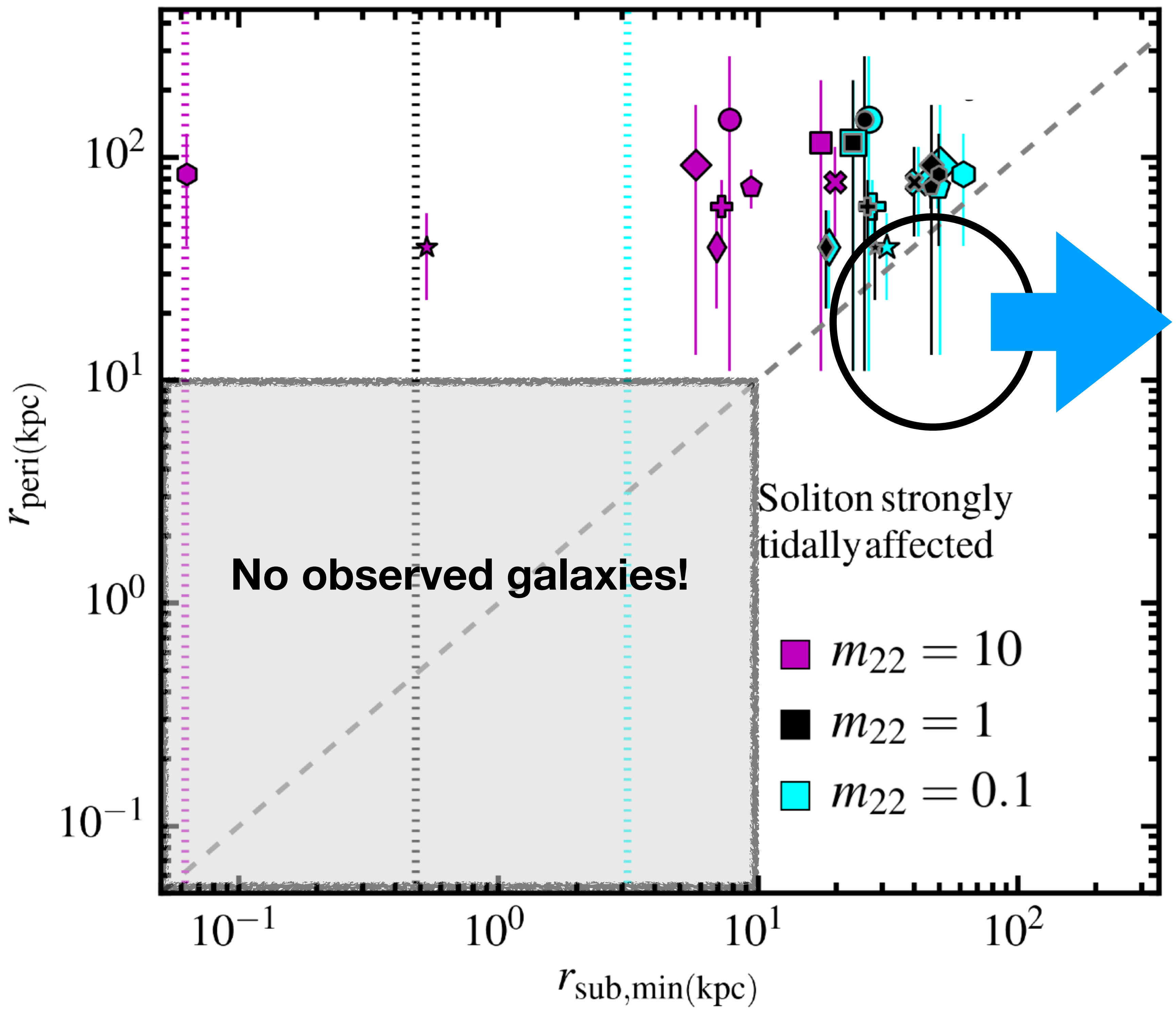


Dwarf galaxy

Soliton



Given Current Gaia uncertainties larger m_{22} are preferred for dSph Soliton subhalos to remain robust at r_{sol}



Orbital motion suggests $m_{22} > 0.1$

Improving Gaia uncertainties for pericenters will provide stronger constraints for the DM mass from kinematical data

Robles+21

Conclusions

Dwarf galaxies in the Milky Way can provide astrophysical constraints to narrow the SFDM mass (guide Earth-based experiments)

Gaia proper motions allow us to combine kinematic + dynamical information to derive new constraints for the boson mass

We find that solitons can host all dSphs AND survive as satellites in the MW for $0.1 < m_{22} < 3$.

$m_{22} > 10$ are possible but imply outer stars may experience gravitational instabilities. SFDM simulations will be insightful to confirm our results.

Central density slopes are a promising new way to disentangle the preferred boson mass!

Mass constraints in LSB galaxies at different radii could rule-out the ultra-light dark matter at the scales $m \sim 10^{-22}$eV (e.g. Gaia proper motions, Ultra Diffuse Galaxies, Ultra-faint dwarfs, next generation of telescopes will aid in this quest)