Astrophysical Probes of Dark Matter

Alex Drlica-Wagner

Fermilab/UChicago

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Astrophysical Probes of Dark Matter

Probed via Gravity

Minimum Halo Mass:
warm DM; strongly-interacting DM; fuzzy DM; etc.

Halo Shape:
self-interacting DM; fuzzy DM; etc.

Compact Objects:
Primordial black holes; etc.

etc.

Probed via Standard Model Coupling

Indirect Detection:
WIMPs; sterile neutrinos; extra dimensions; etc.

Energy Transport:
Axion-like particles; dark photons; millicharged particles etc.

etc.

Astrophysical Probes of Dark Matter

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etc.

Annika's Talk

Probed via Standard Model Coupling

Kerstin's Talk

Indirect Detection:
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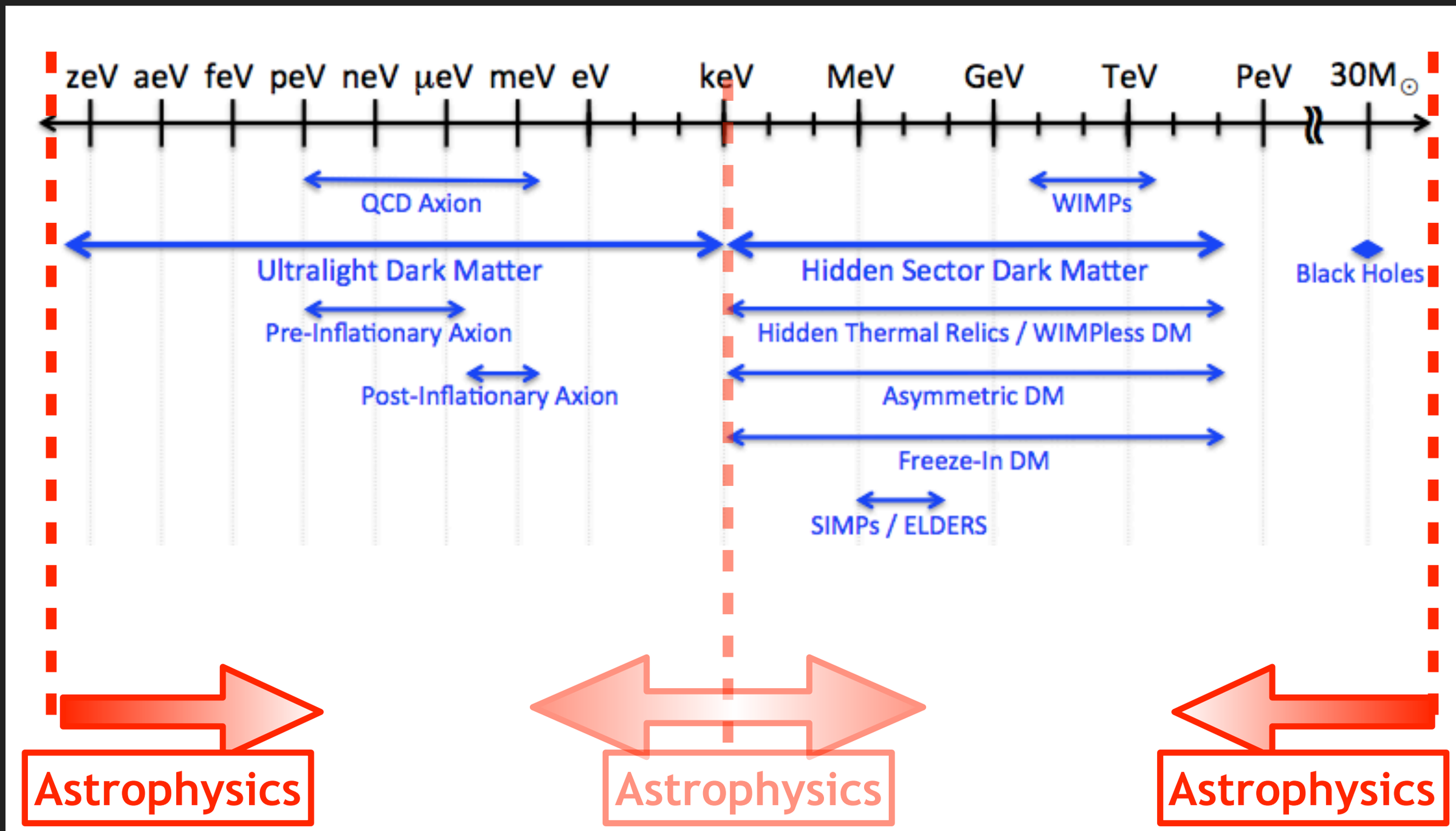
Energy Transport:
Axion-like particles; dark photons; millicharged particles etc.

etc.

Dark Matter Landscape

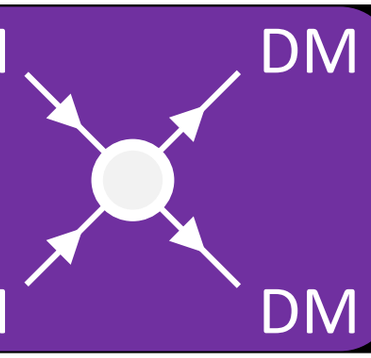
10^{-21} eV

10^{67} eV

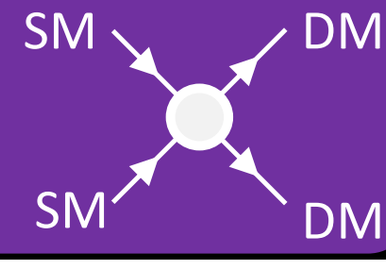


Cosmic Visions: New Ideas in Dark Matter (2017)

Astrophysical Probes



Particle Colliders

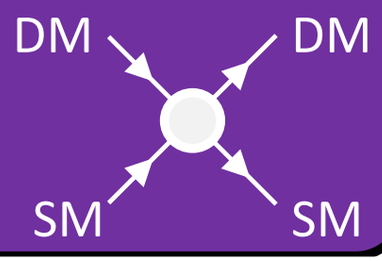


Astrophysics provides the only robust, positive measurement of dark matter.

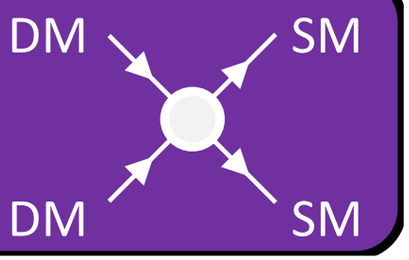
Dark Matter

Require Coupling to Standard Model

Direct Detection



Indirect Detection



Use the

to learn about the

Simulations

Cold Dark Matter

Warm Dark Matter

e.g., Sterile Neutrino

Lovell et al. (2012)

Cold Dark Matter

Self-Interacting Dark Matter

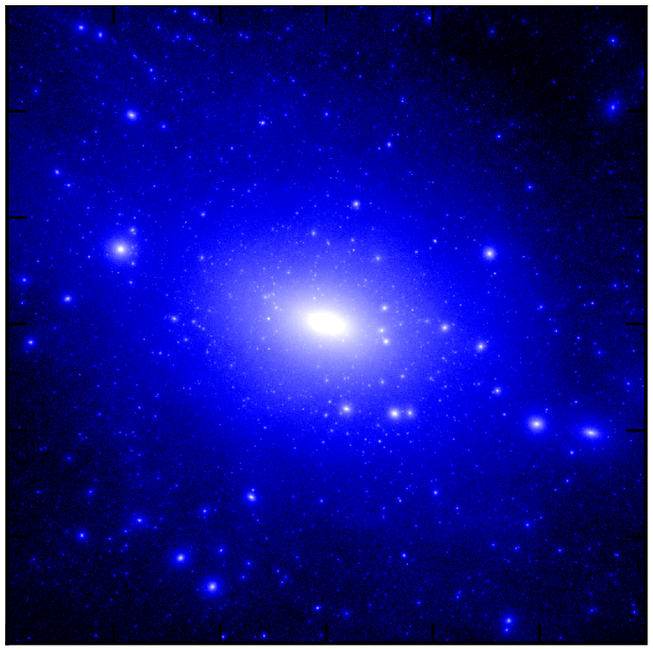
e.g., Dark photon

Vogelsberger et al. (2016)

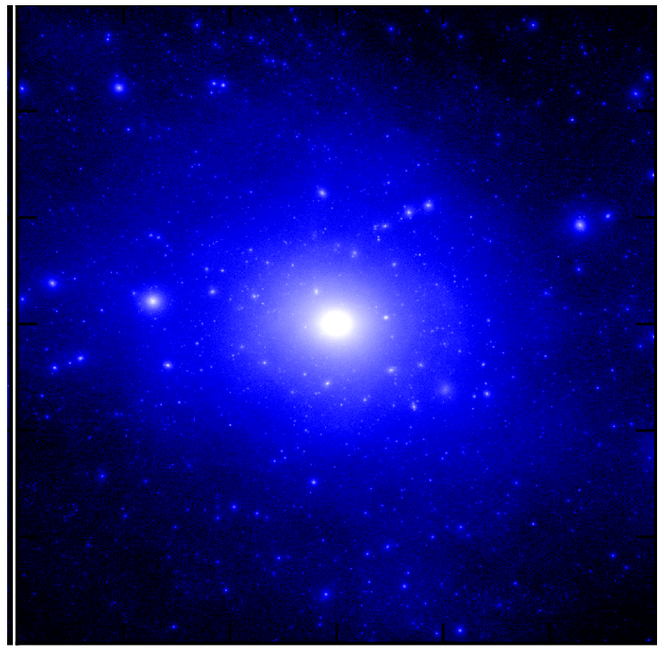
Baryonic* Physics

Astrophysical processes also impact halo structure

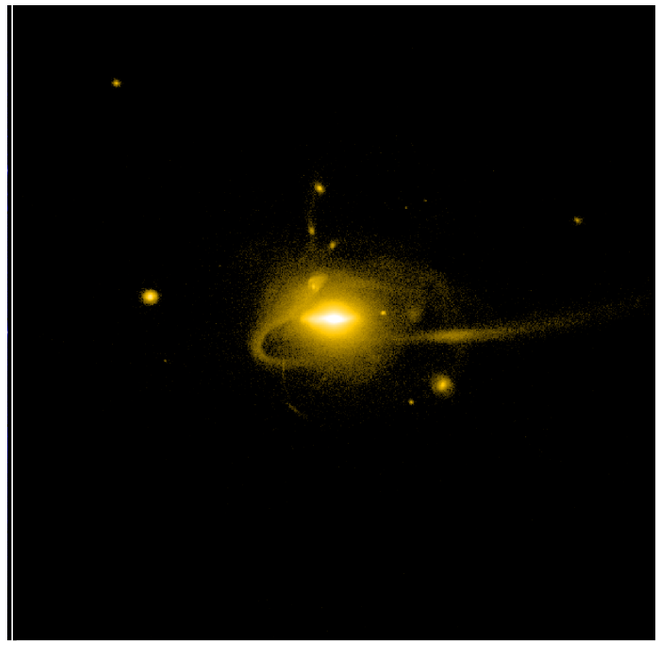
Dark Matter
(Dark Matter Only)



Dark Matter
(Dark Matter + Baryons)



Stars
(Dark Matter + Baryons)



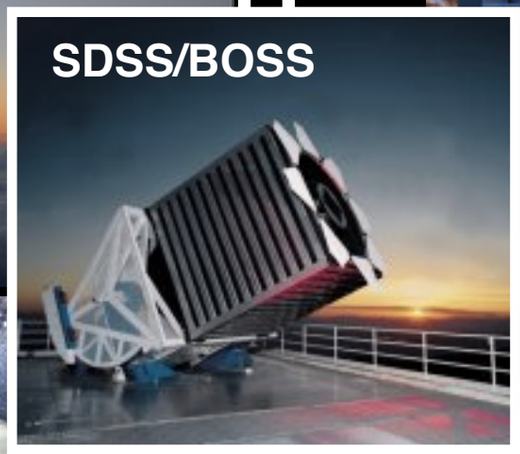
Wetzel et al. (2016)

High-resolution cosmological simulations are now able to robustly include core elements of baryonic physics at Milky Way scales (e.g., FIRE/Latte, EAGLE/APOSTLE, etc.)

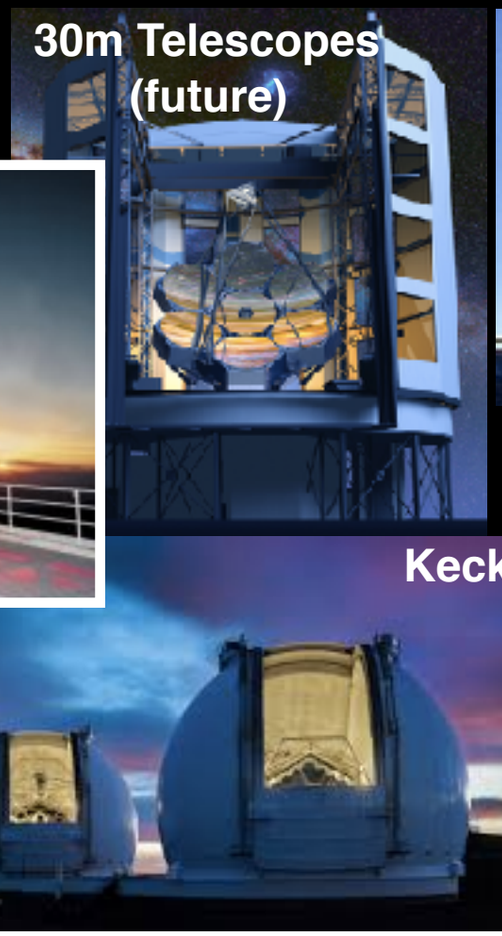
***Jargon**: Astrophysicists use “baryons” to refer to all standard model particles

Current and Near-Future Experiments

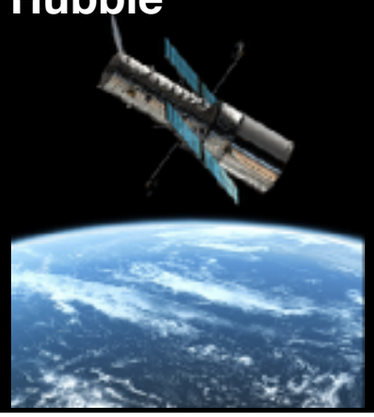
Wide-Area Imaging



Spectroscopic Measurements

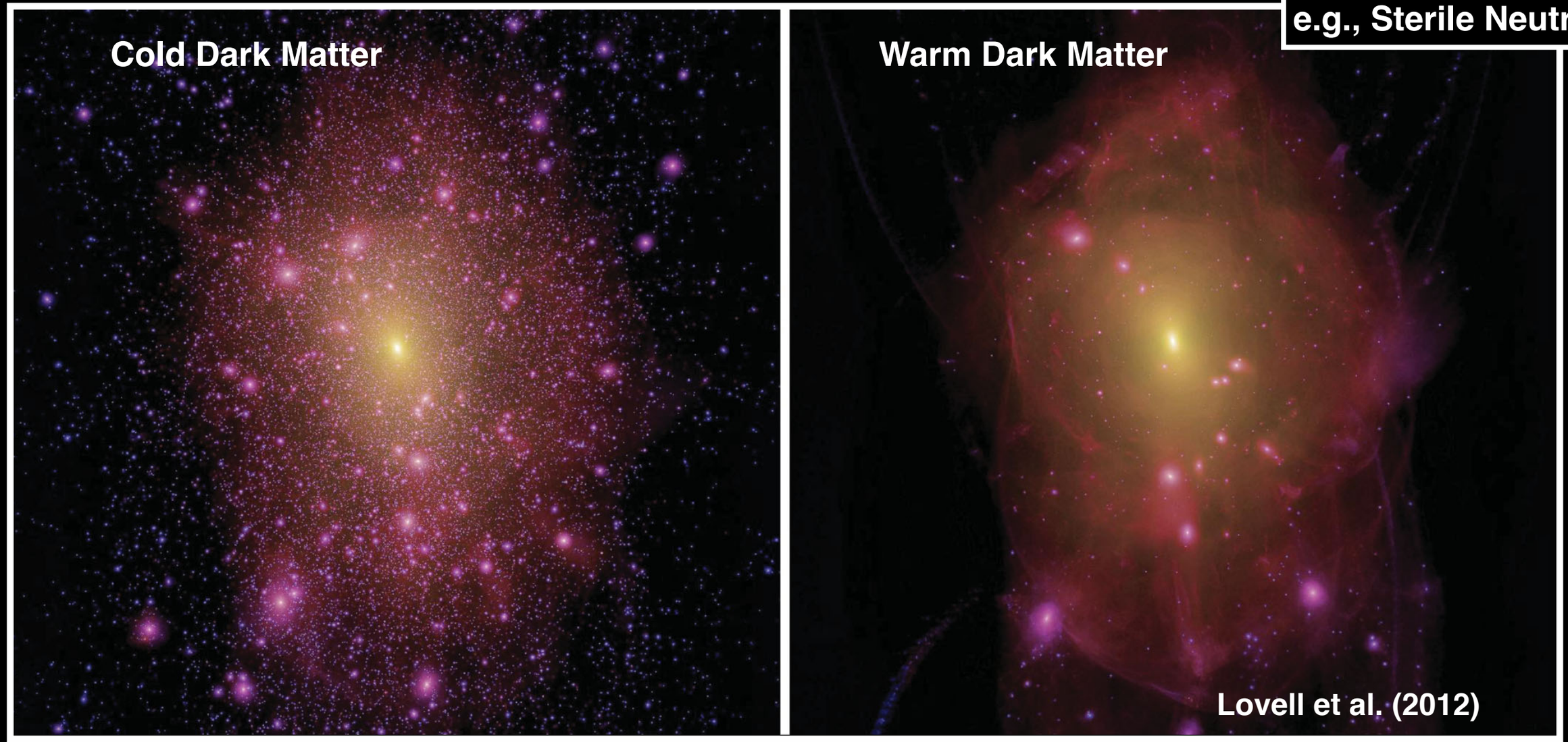


High Resolution Imaging



The Smallest Dark Matter Halos

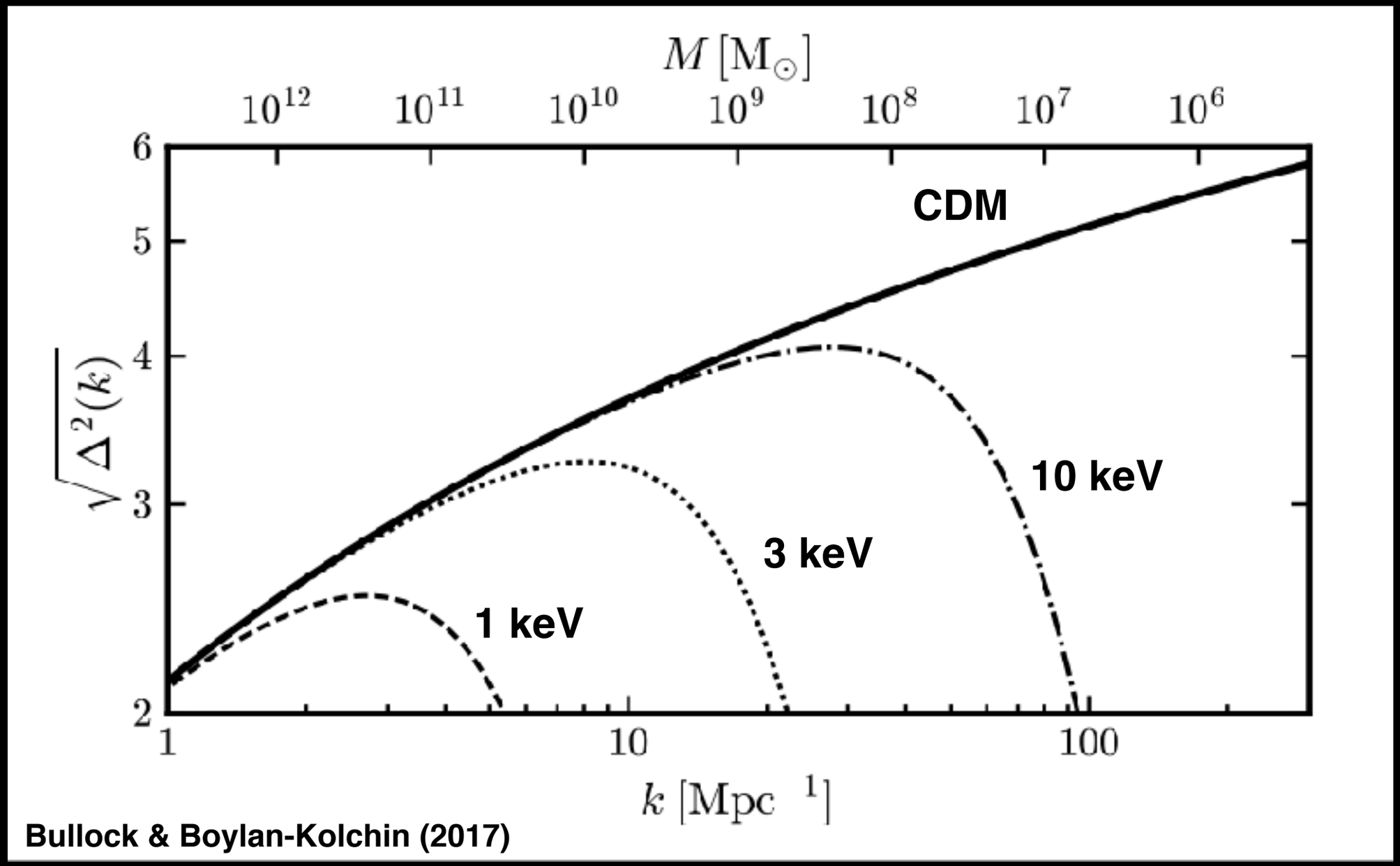
Warm Dark Matter



Warm Dark Matter

Smaller Halos

Halo Mass



Bullock & Boylan-Kolchin (2017)

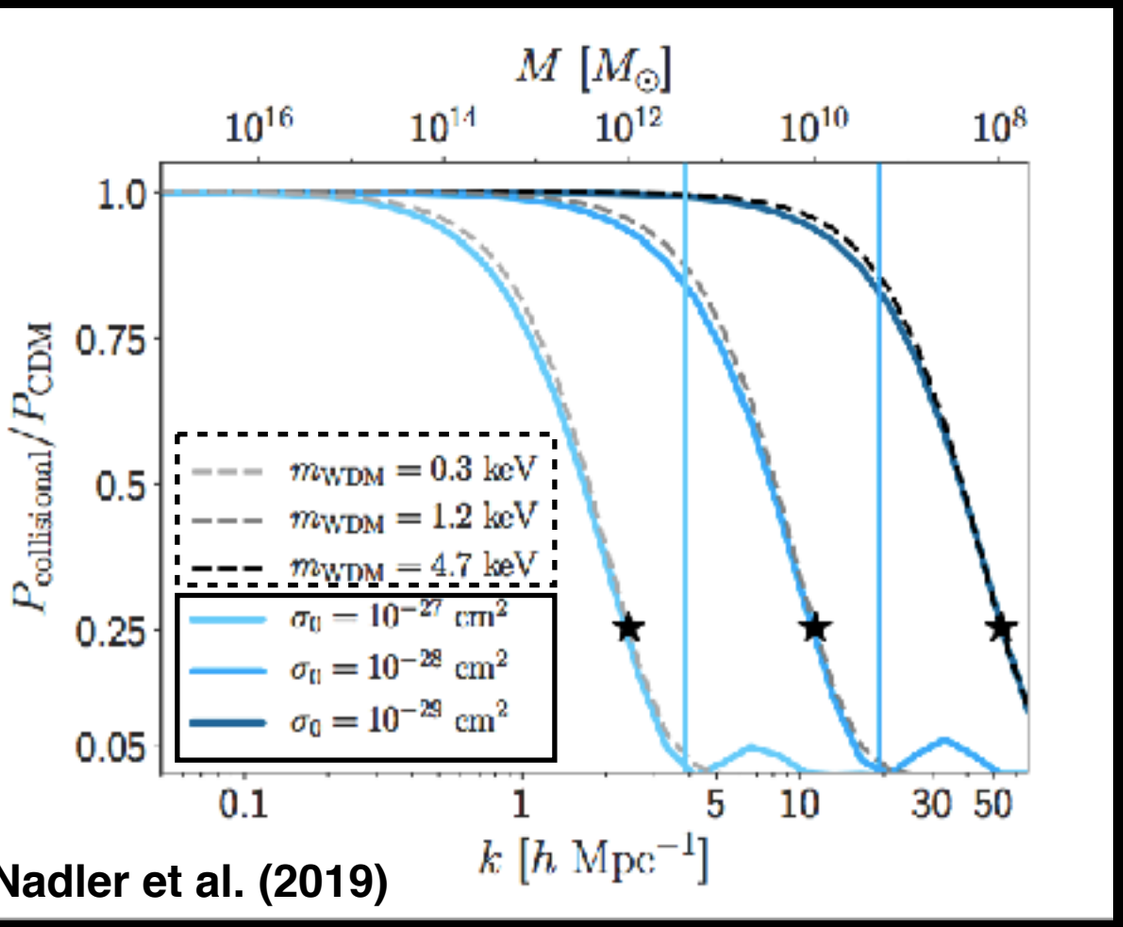
Proxy for the Number of Halos

Fewer Halos

Wavenumber (inverse length scale)

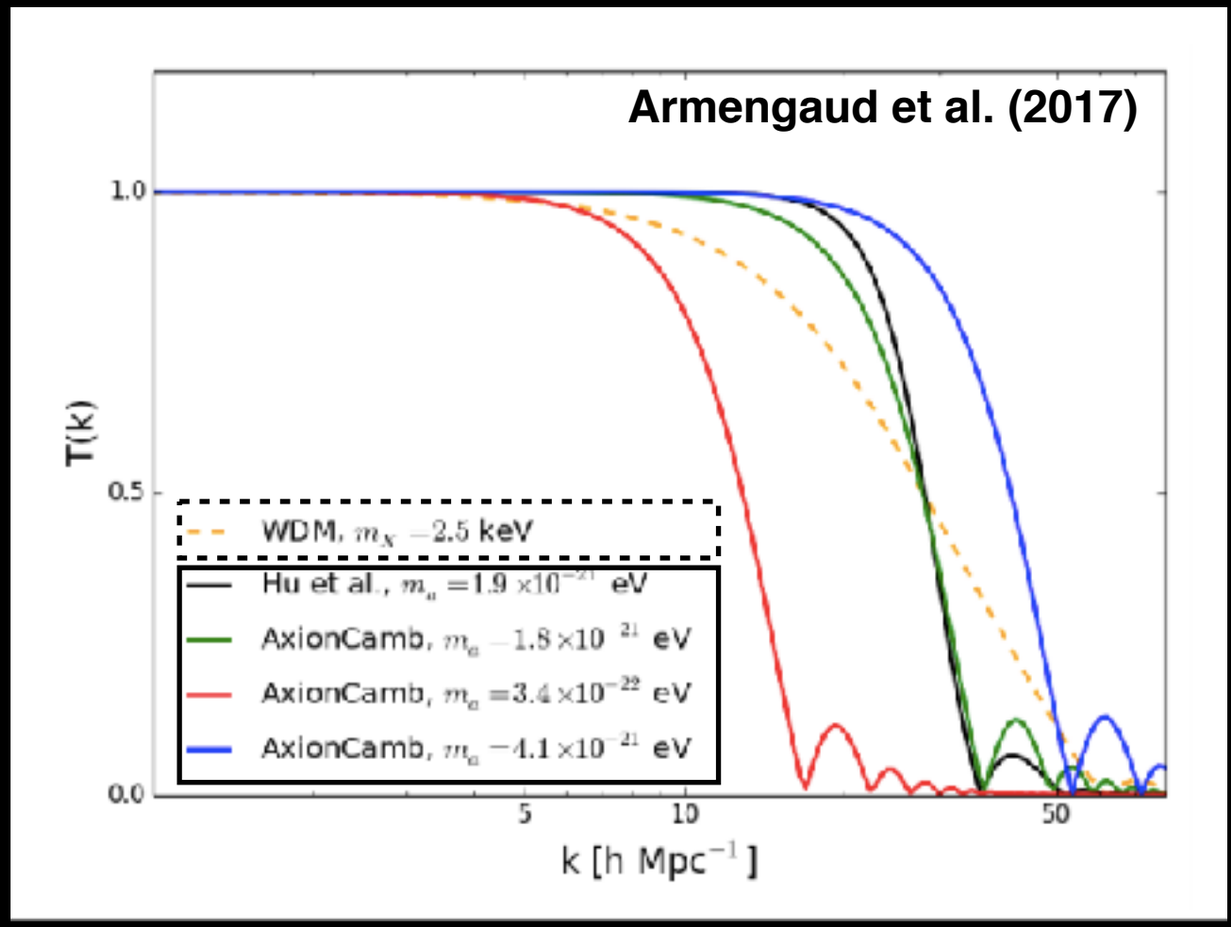
Suppression of Structure

Baryon Scattering



Nadler et al. (2019)

Fuzzy Dark Matter



Dark matter models that suppress small-scale structure are probed by the existence of the smallest dark matter halos

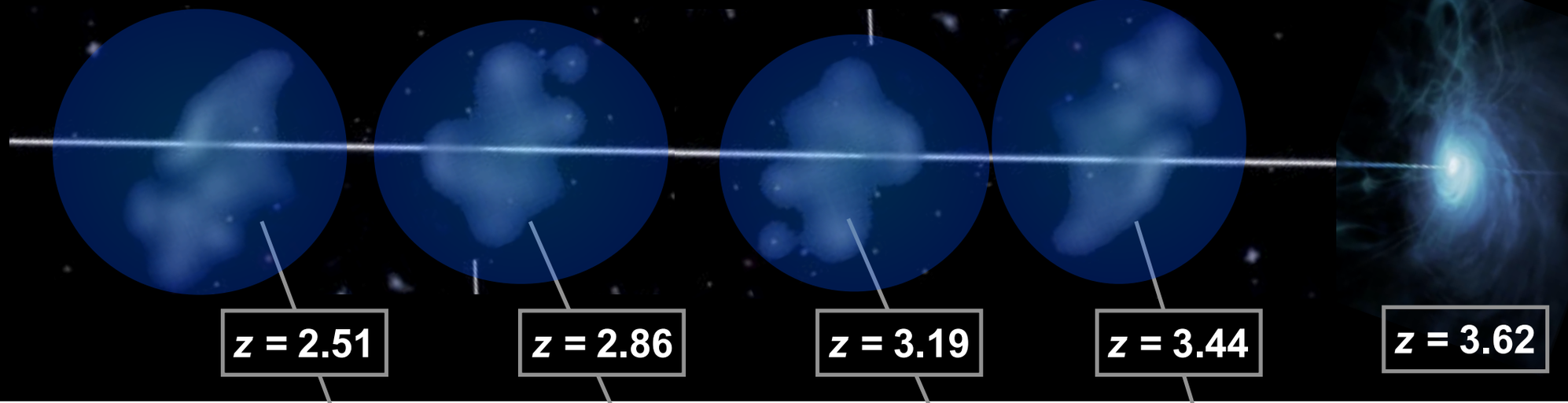
How do we measure small halos?

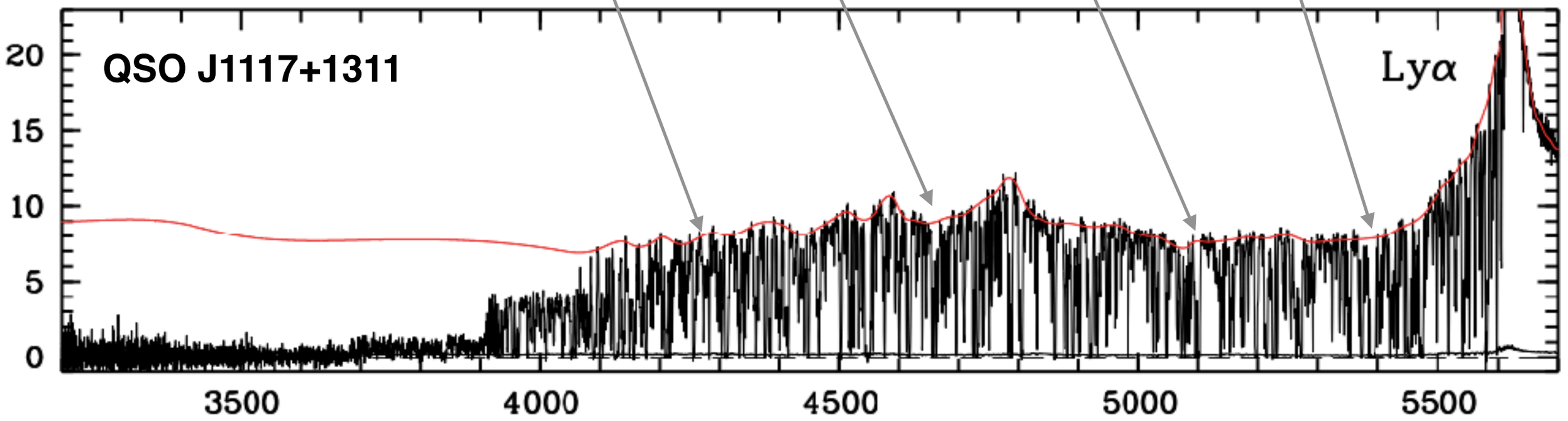
Lyman-α Forest

Hydrogen Absorption in Dark Matter Halos

Spectrograph

Distant Quasar

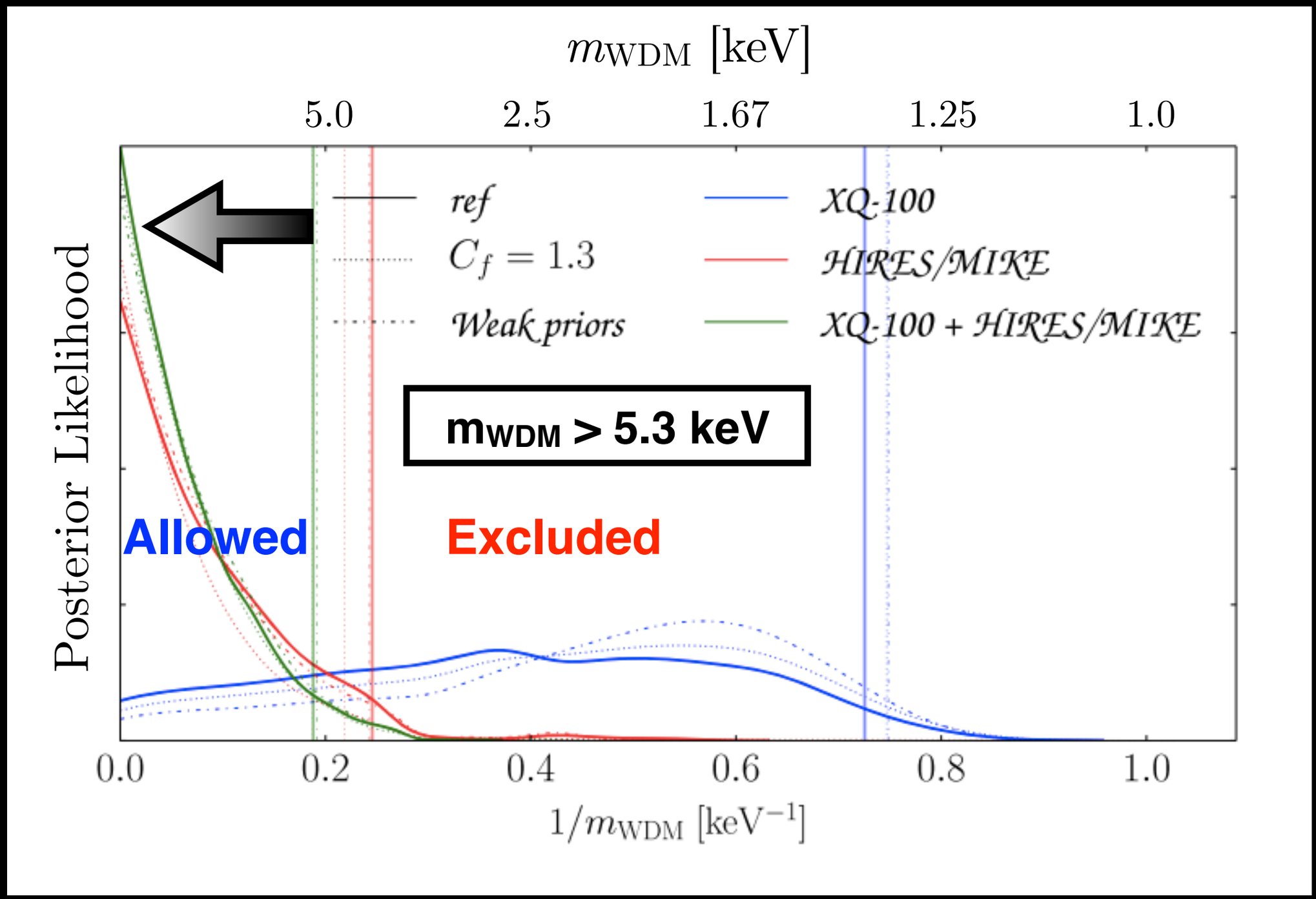




López et al. (2016)

Wavelength (nm)

Lyman-α Forest



Iršič et al. (2017)

z=0.0

Milky Way Satellites

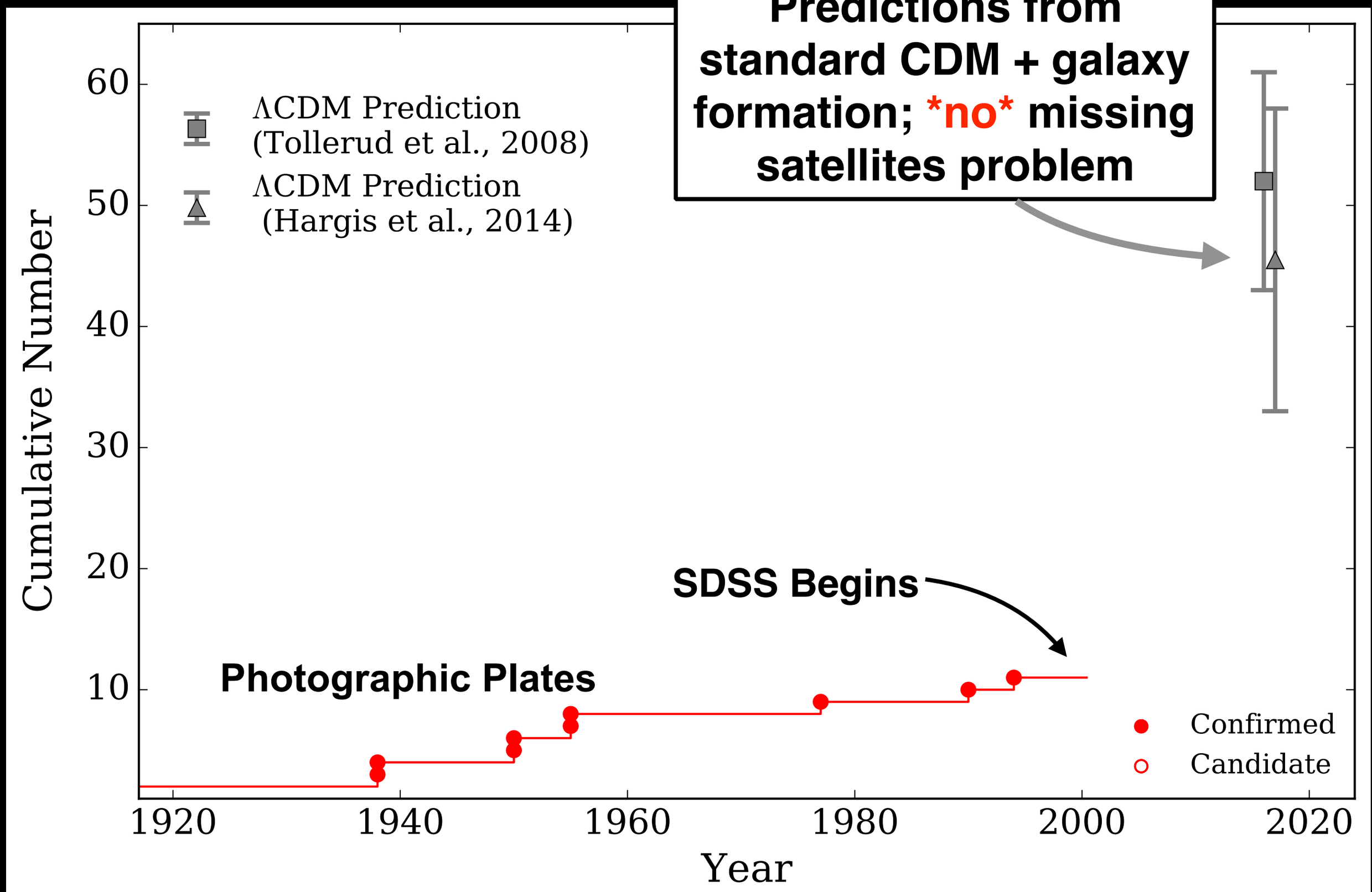
Simulation of Dark Matter

The Milky Way

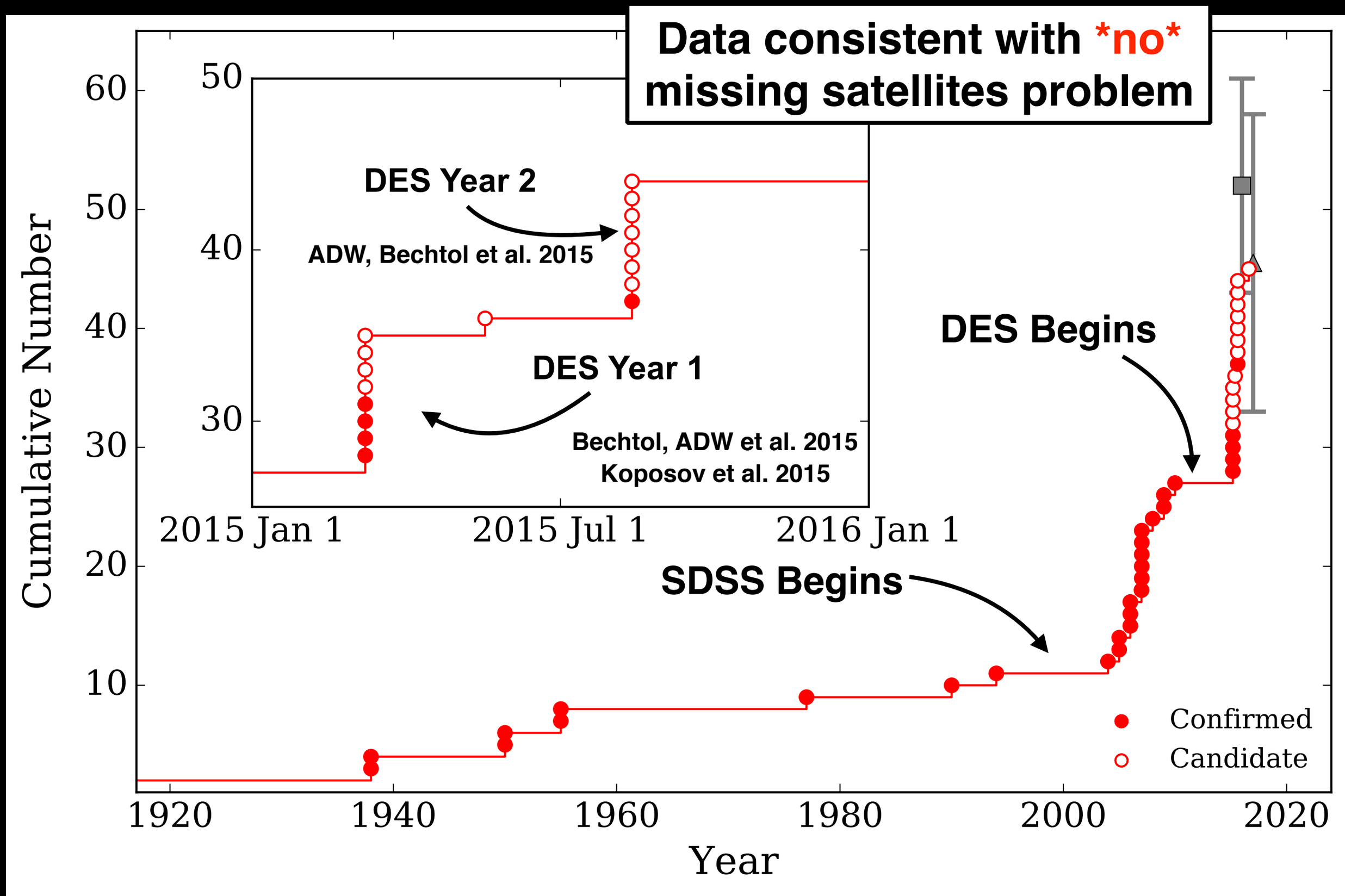
???

80 kpc

Satellite Galaxy Discovery Timeline

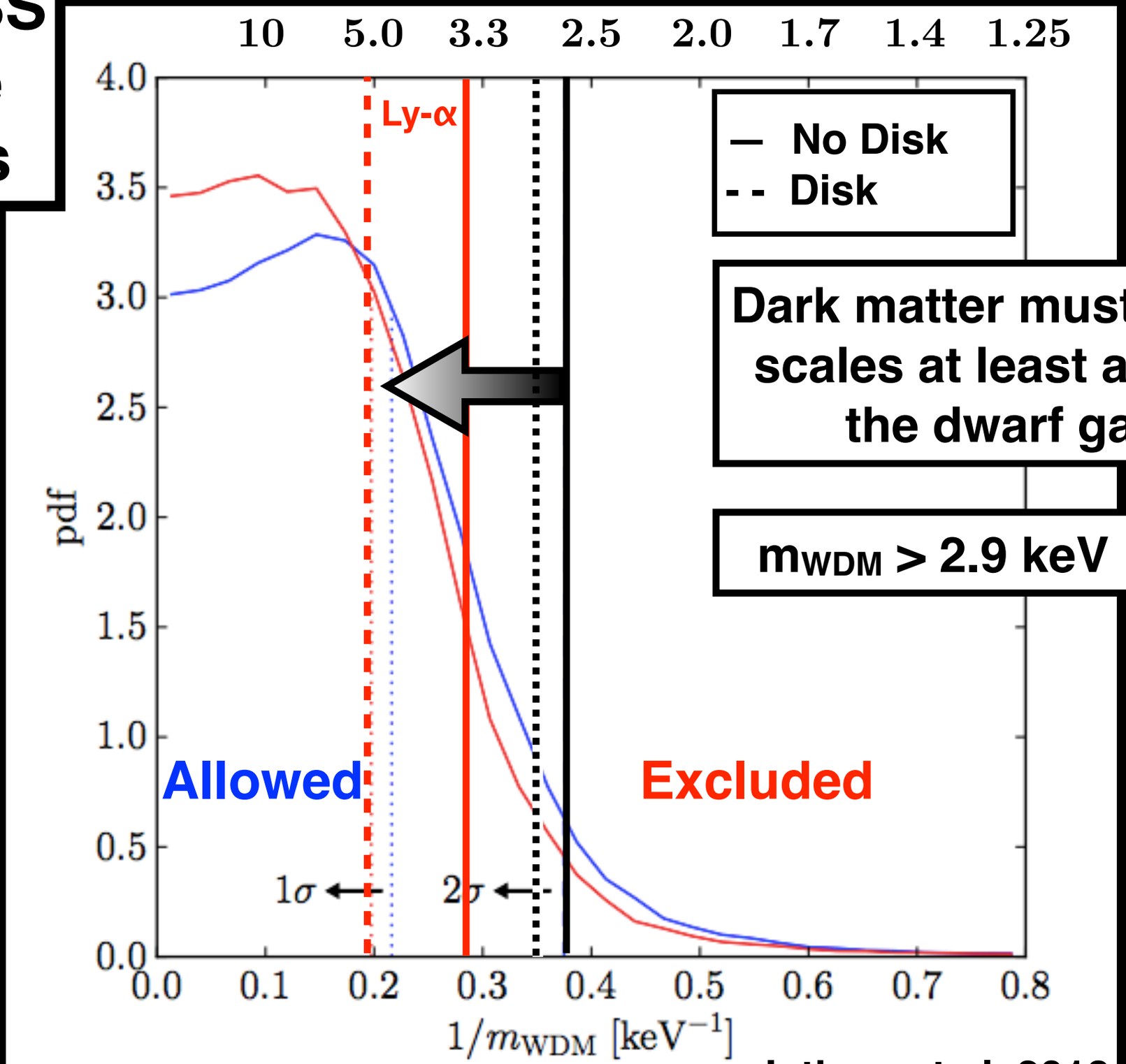


Satellite Galaxy Discovery Timeline



Constraints on Warm Dark Matter

Only SDSS Satellite Galaxies

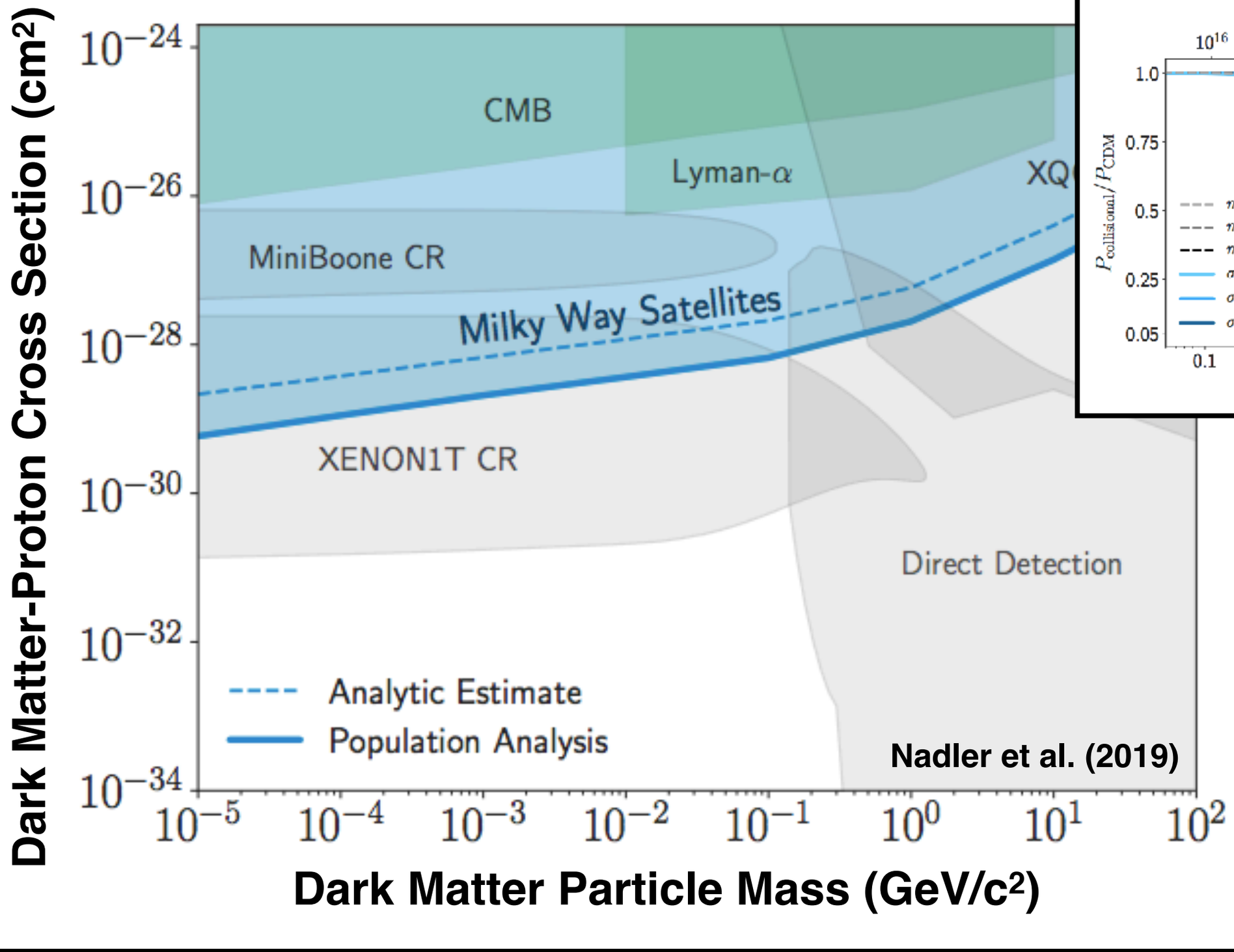


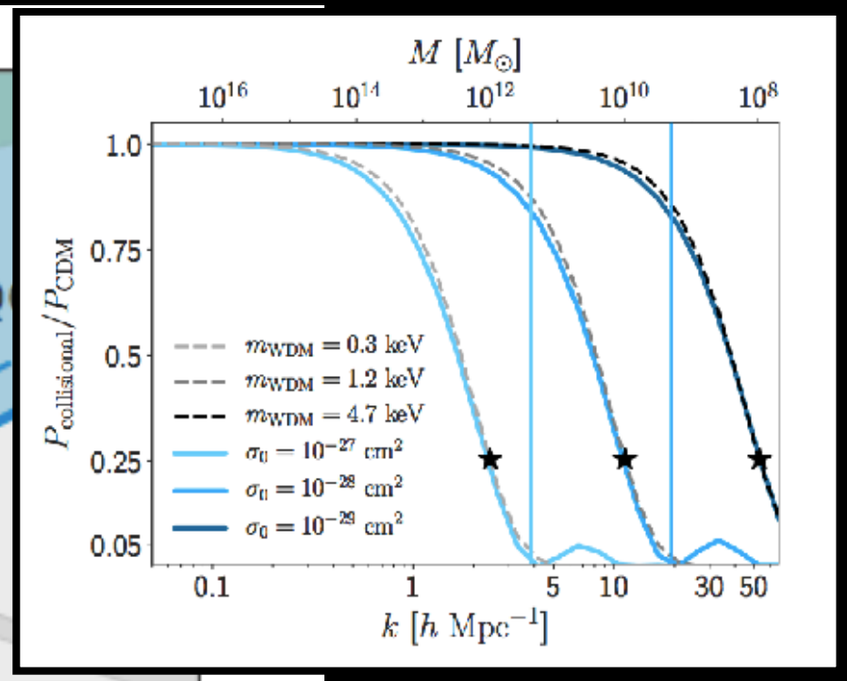
Dark matter must cluster on scales at least as small as the dwarf galaxies

m_{WDM} > 2.9 keV

Jethwa et al. 2018

Constraints on Baryon-Scattering

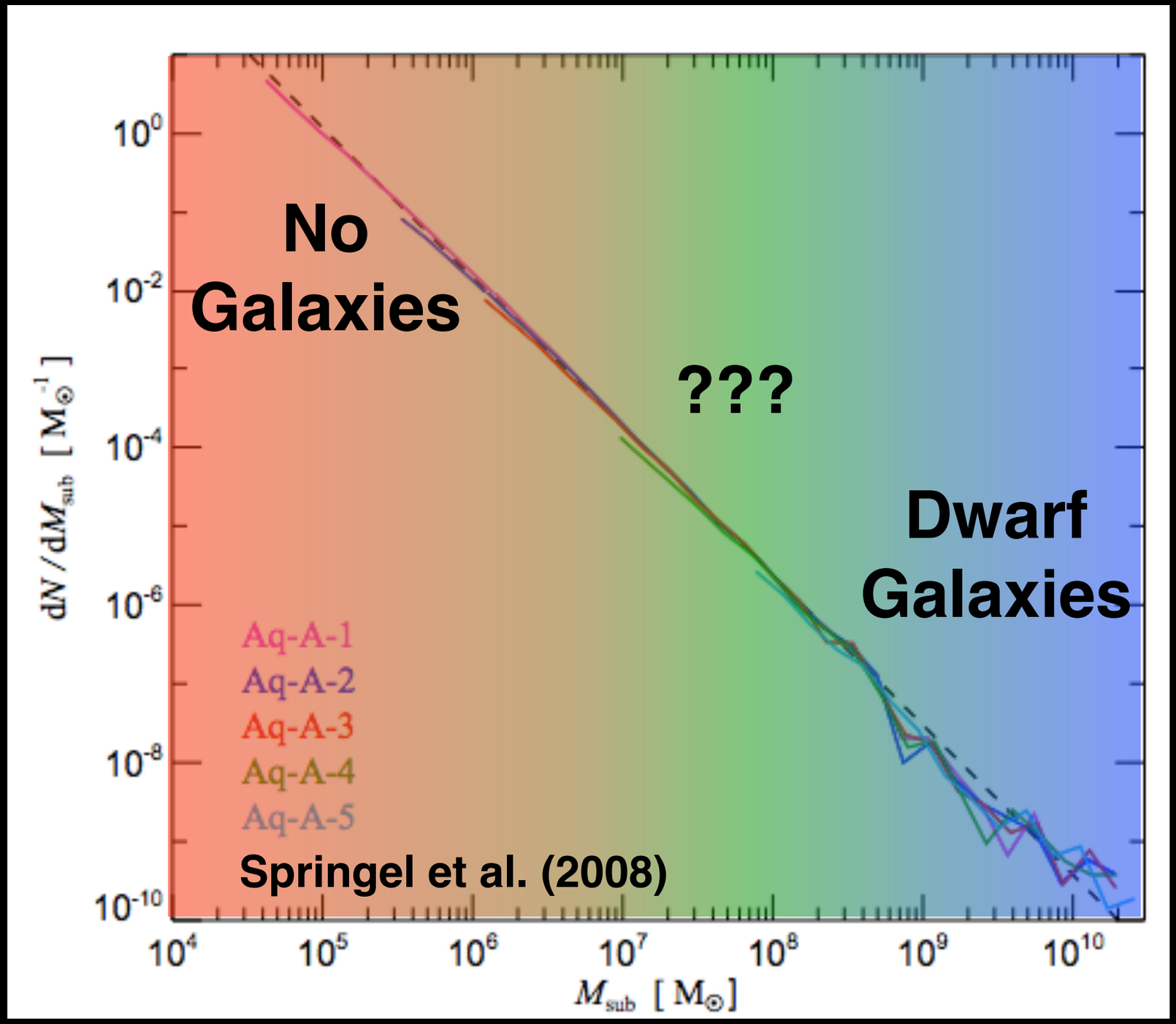




Nadler et al. (2019)

Only using SDSS Satellites

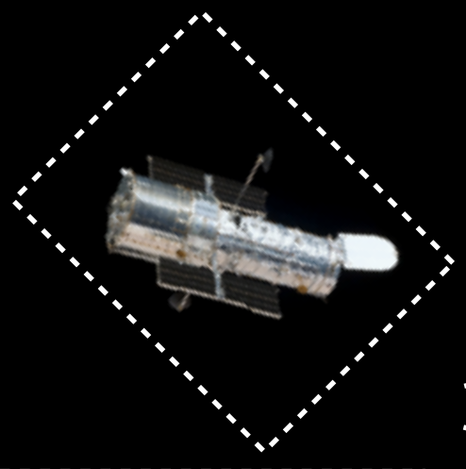
Pushing to Lower Mass

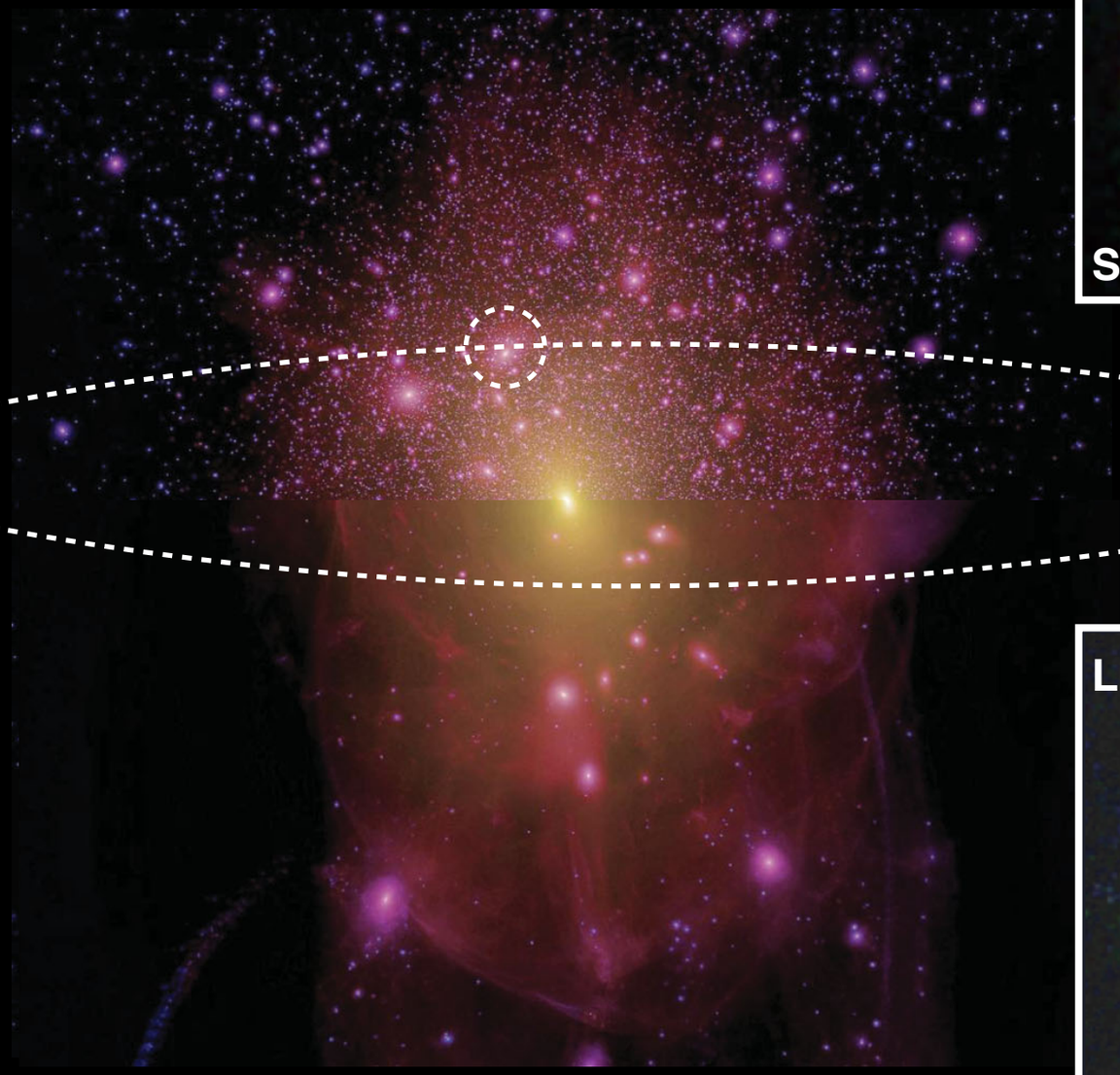


Standard CDM predicts the existence of small subhalos.

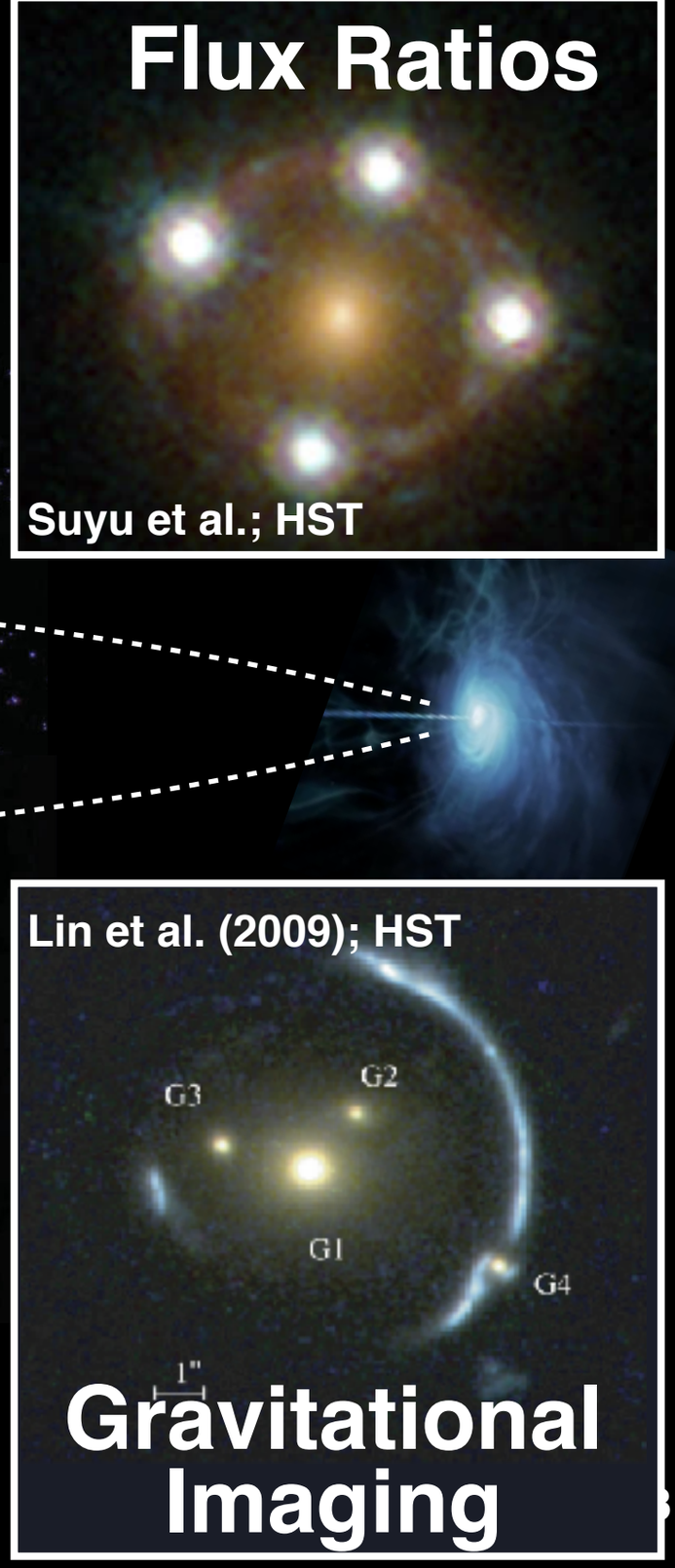
How do we detect completely dark subhalos?

Strong Gravitational Lensing



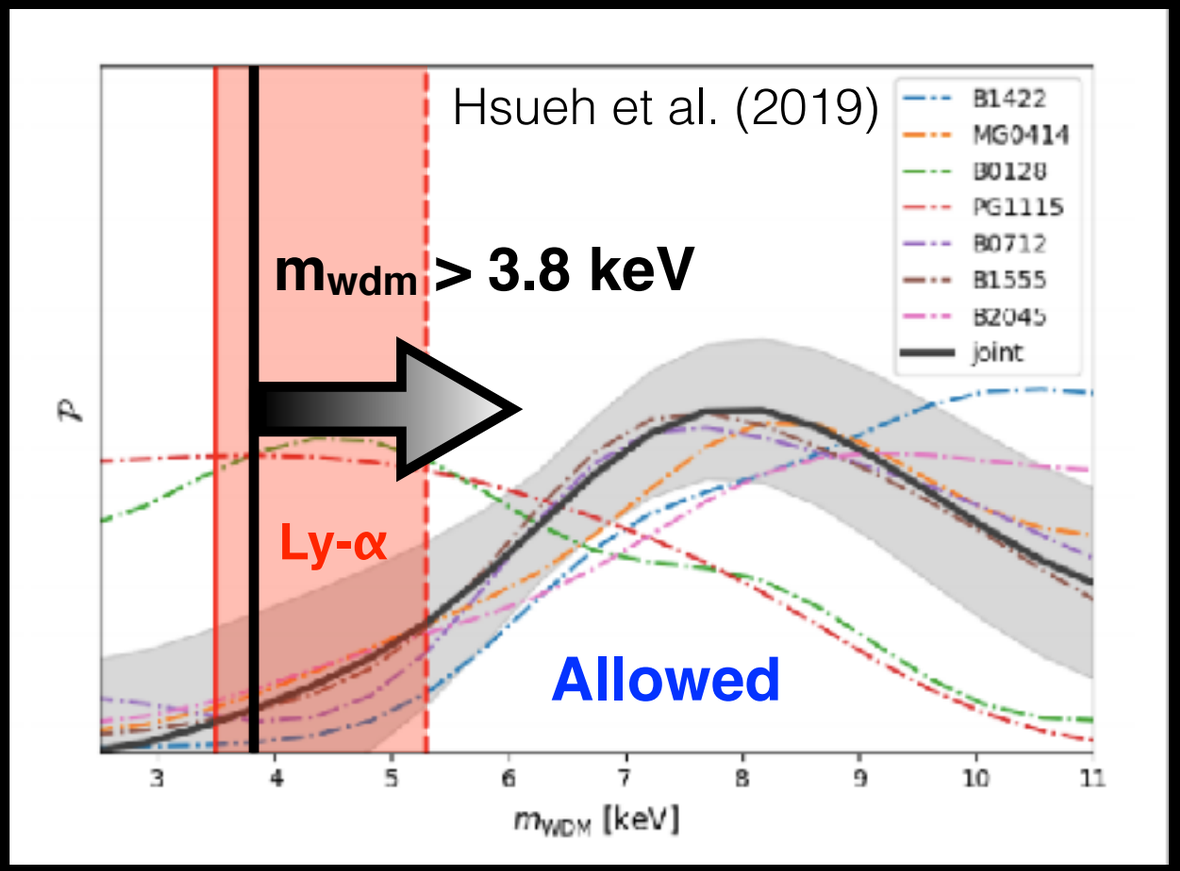


Lovell et al. (2012)



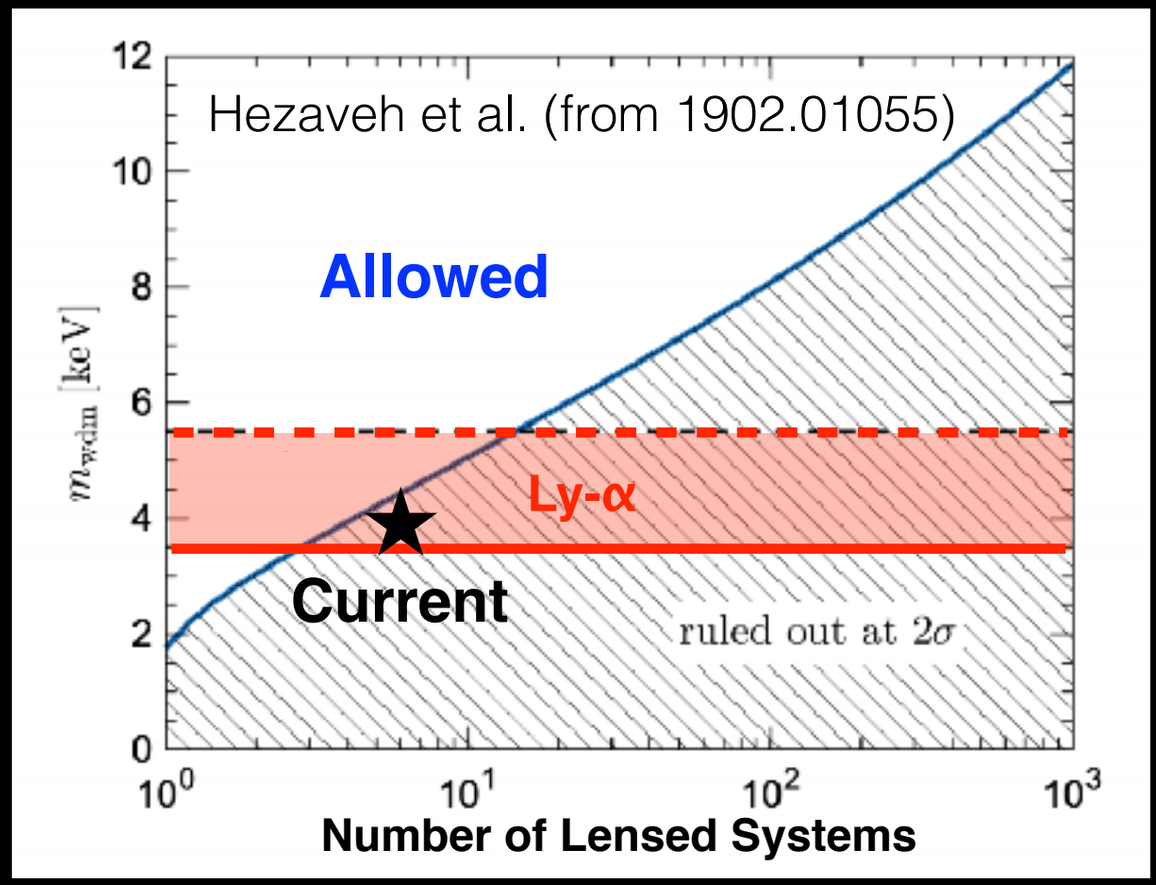
Strong Gravitational Lensing

Current Constraints



7 lensed quasars

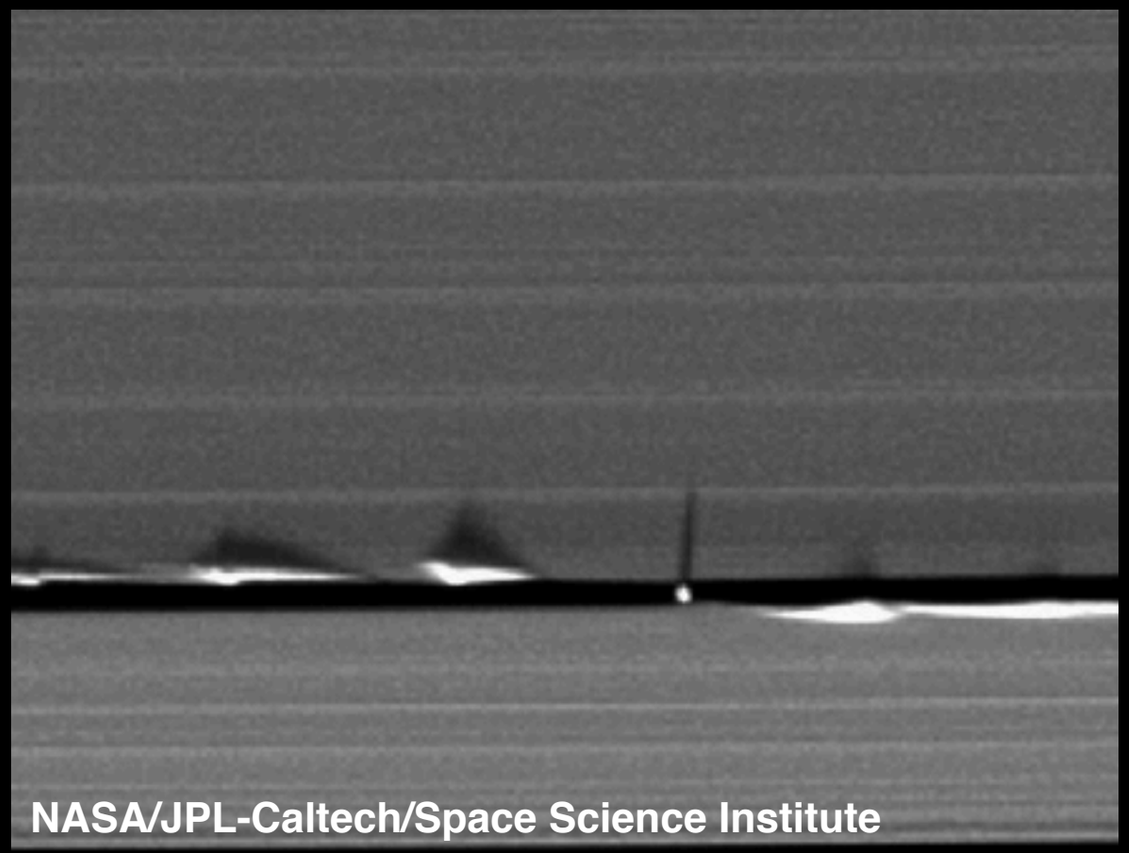
Projections for LSST



Hundreds of systems

Gravitational Perturbations

Rings of Saturn



NASA/JPL-Caltech/Space Science Institute

Sagittarius Stream

Artists Rendition

Amanda Smith, IoA, Cambridge

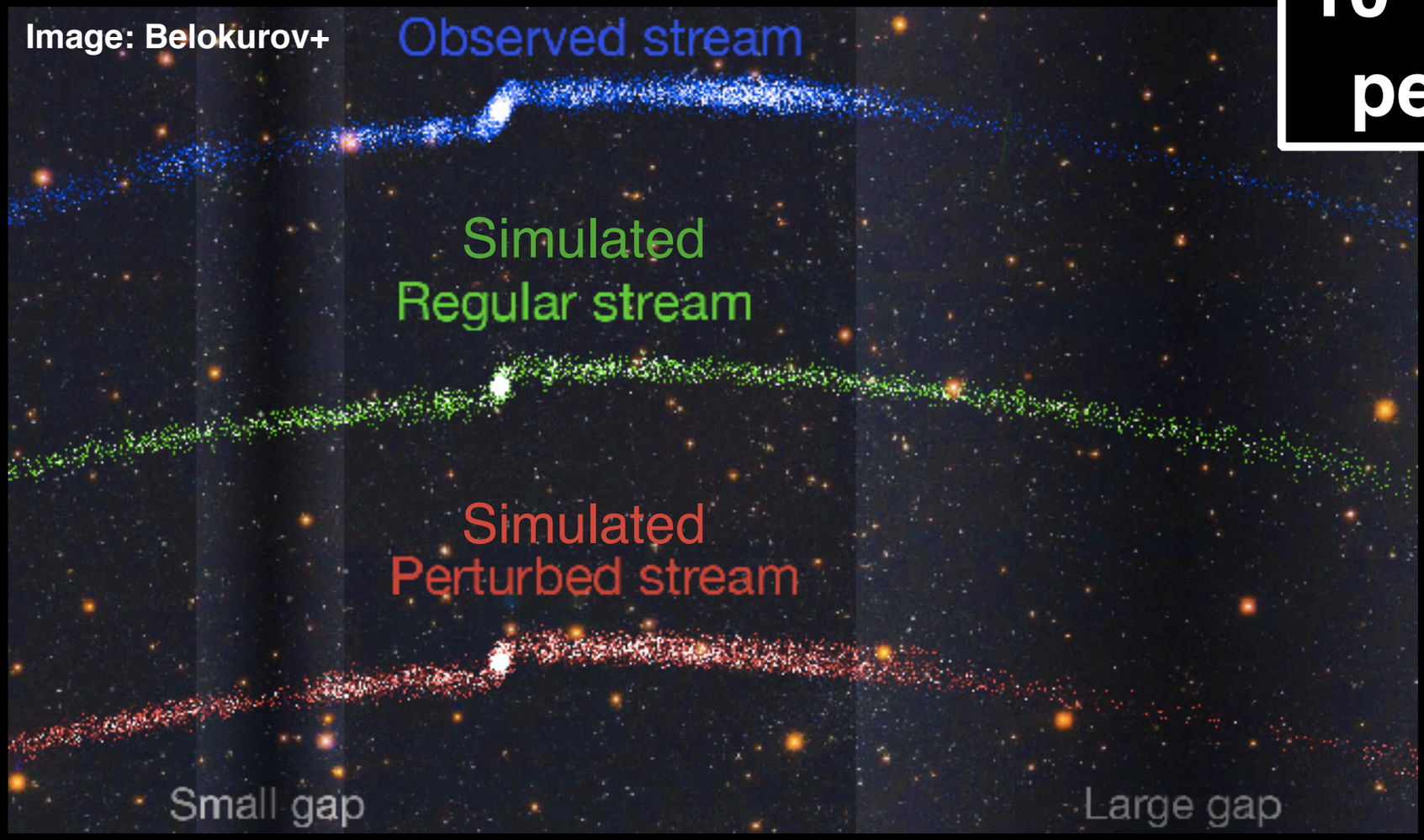
Shepard moons can be detected by their gravitational wake on Saturn's rings

Dark matter substructure can be detected by gravitational disruption of stellar streams

Gaps in Stellar Streams

Possible gaps in Palomar 5

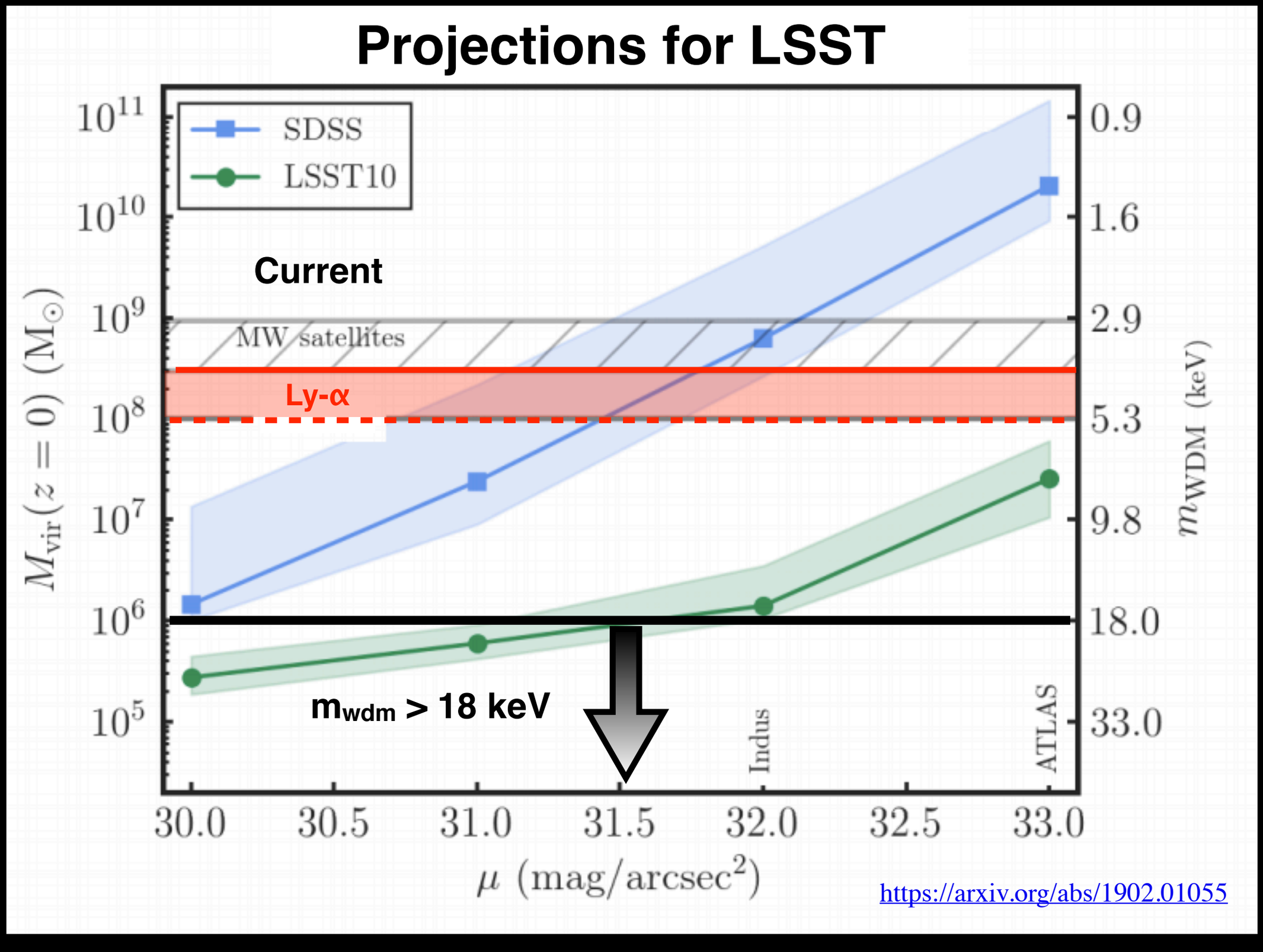
10^6 - 10^8 $M_\odot$ perturber



Erkal et al. (2017); Carlberg et al. (2012)

This measurement needs to be made statistically on the population of streams

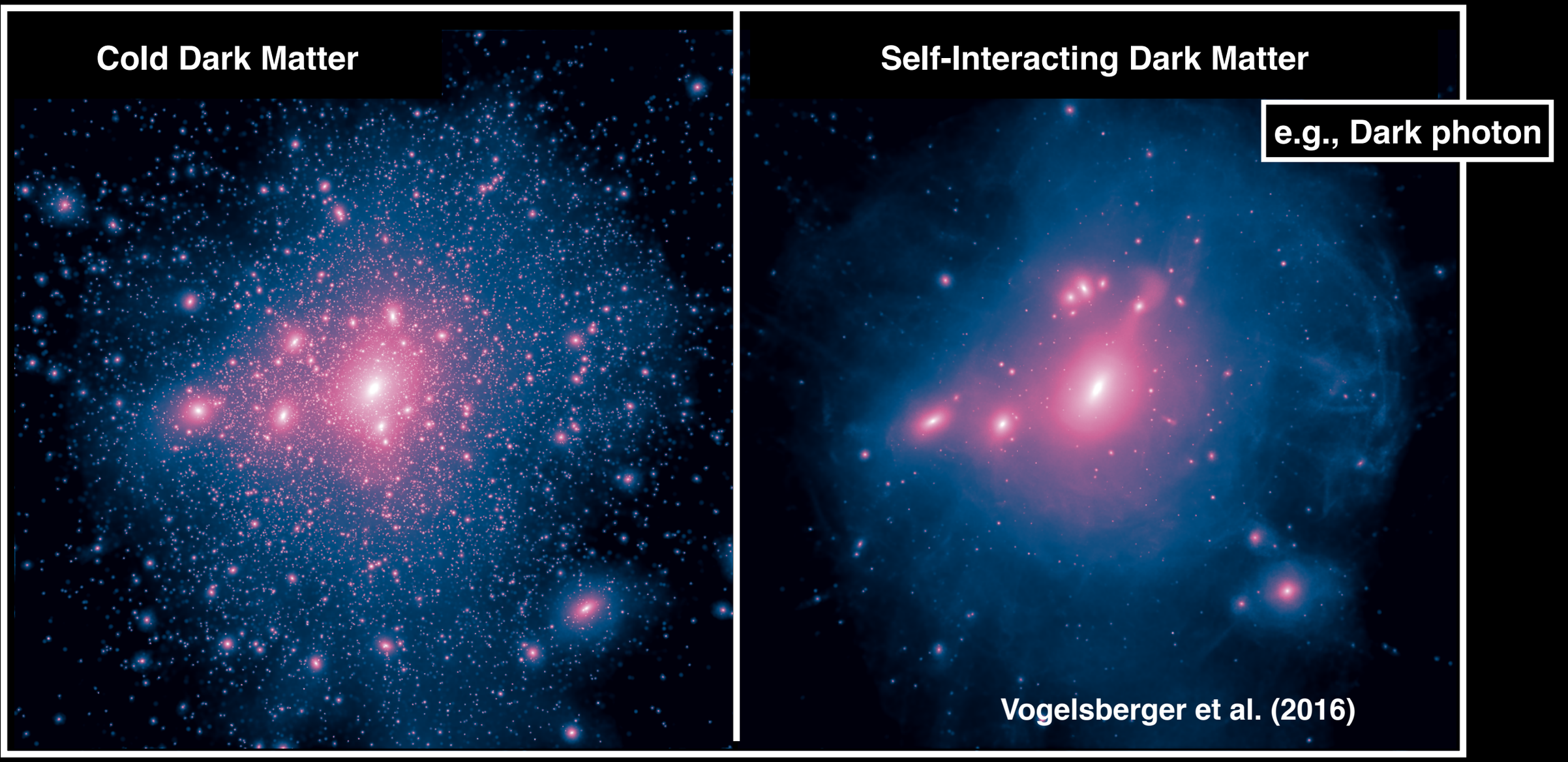
Gaps in Stellar Streams



https://arxiv.org/abs/1902.01055

The Shapes of Dark Matter Halos

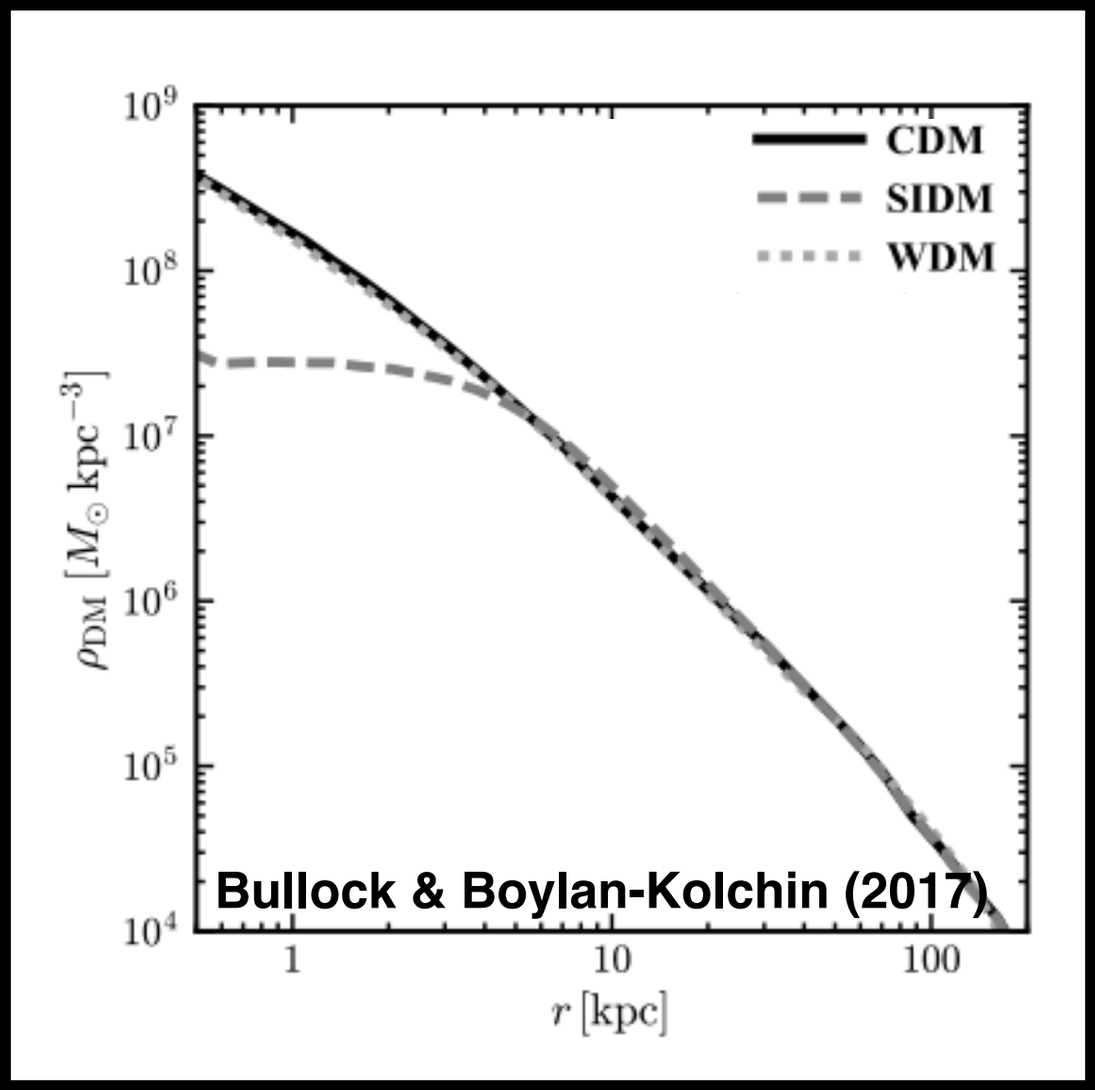
Self-Interacting Dark Matter



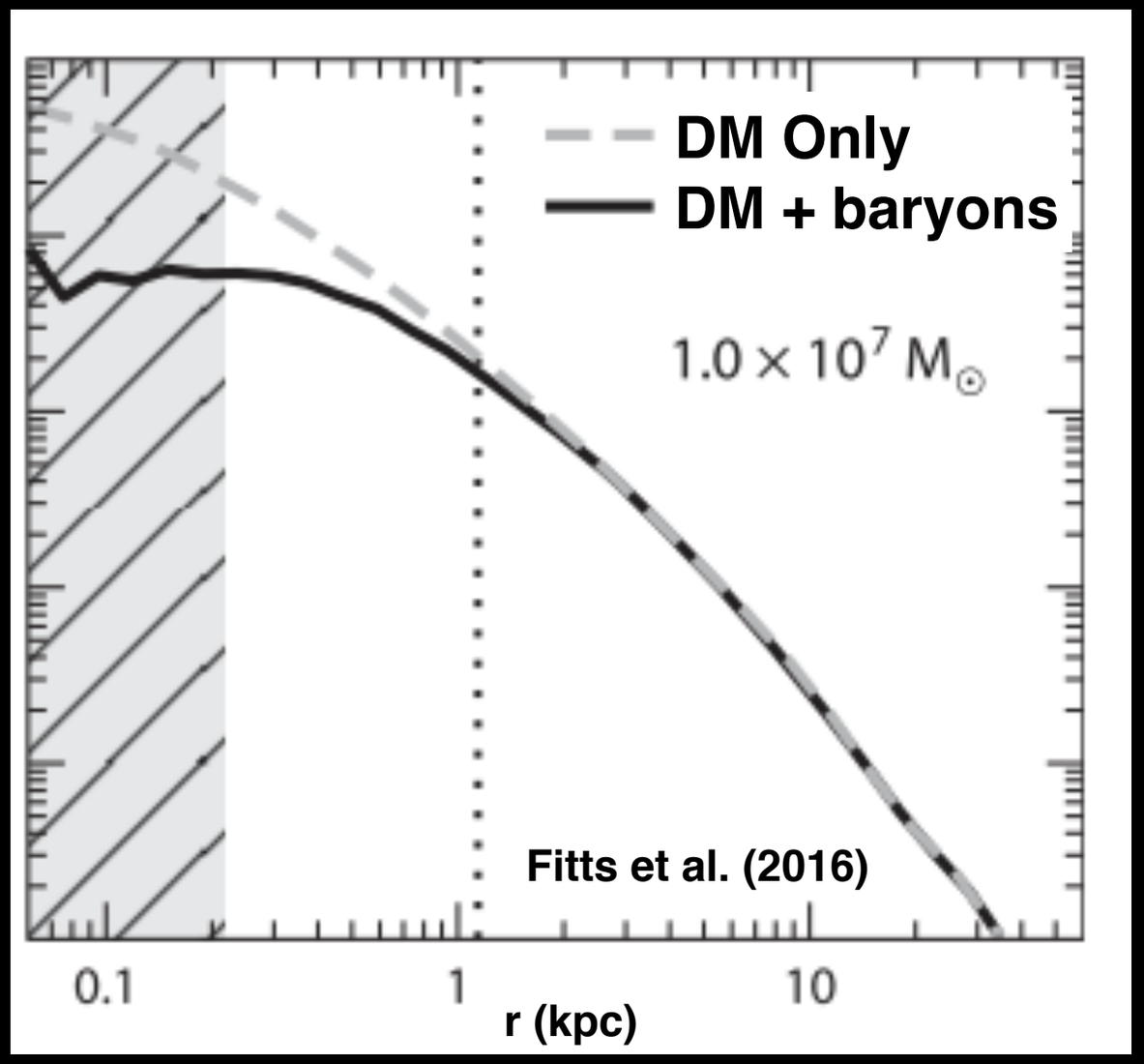
Halo Density Profiles

SIDM surpasses central density… but so do baryons

Dark Matter Density



Radius from Galactic Center



Radius from Galactic Center

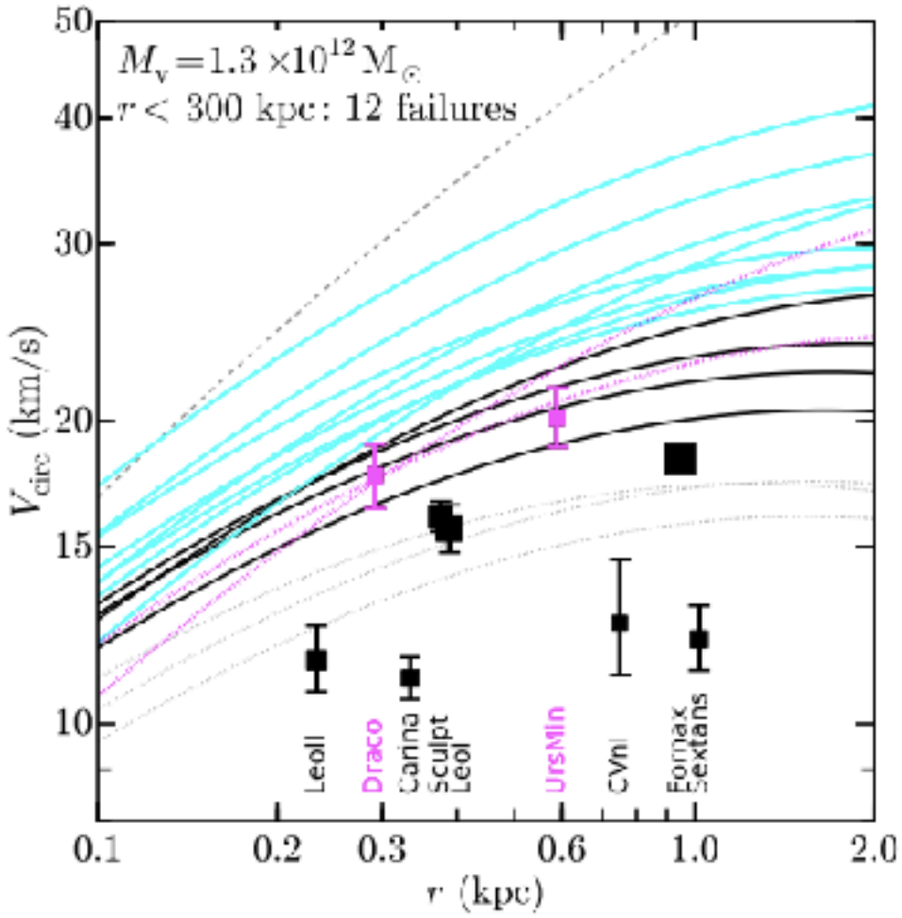
Too Big To Fail

The central regions of dwarf galaxies are less dense than CDM-only simulations

Proxy for Central Density

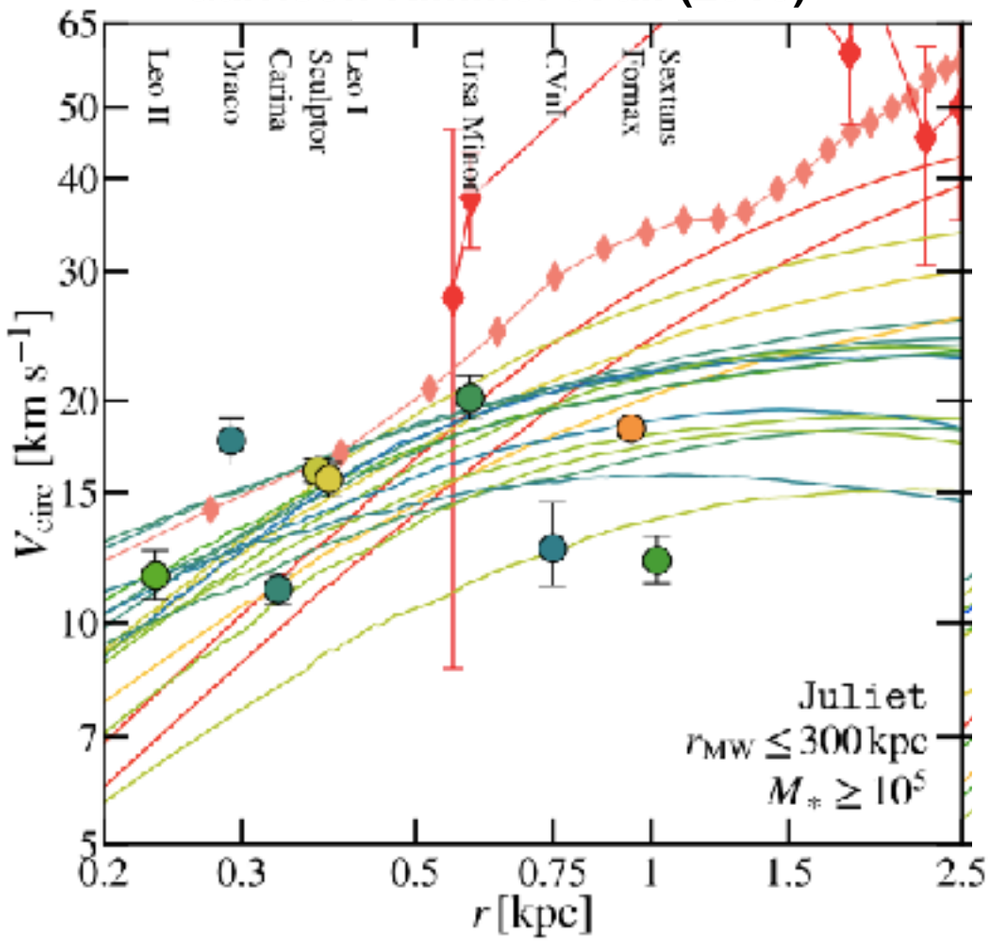
Dark Matter Only

Garrison-Kimmel et al. (2014)



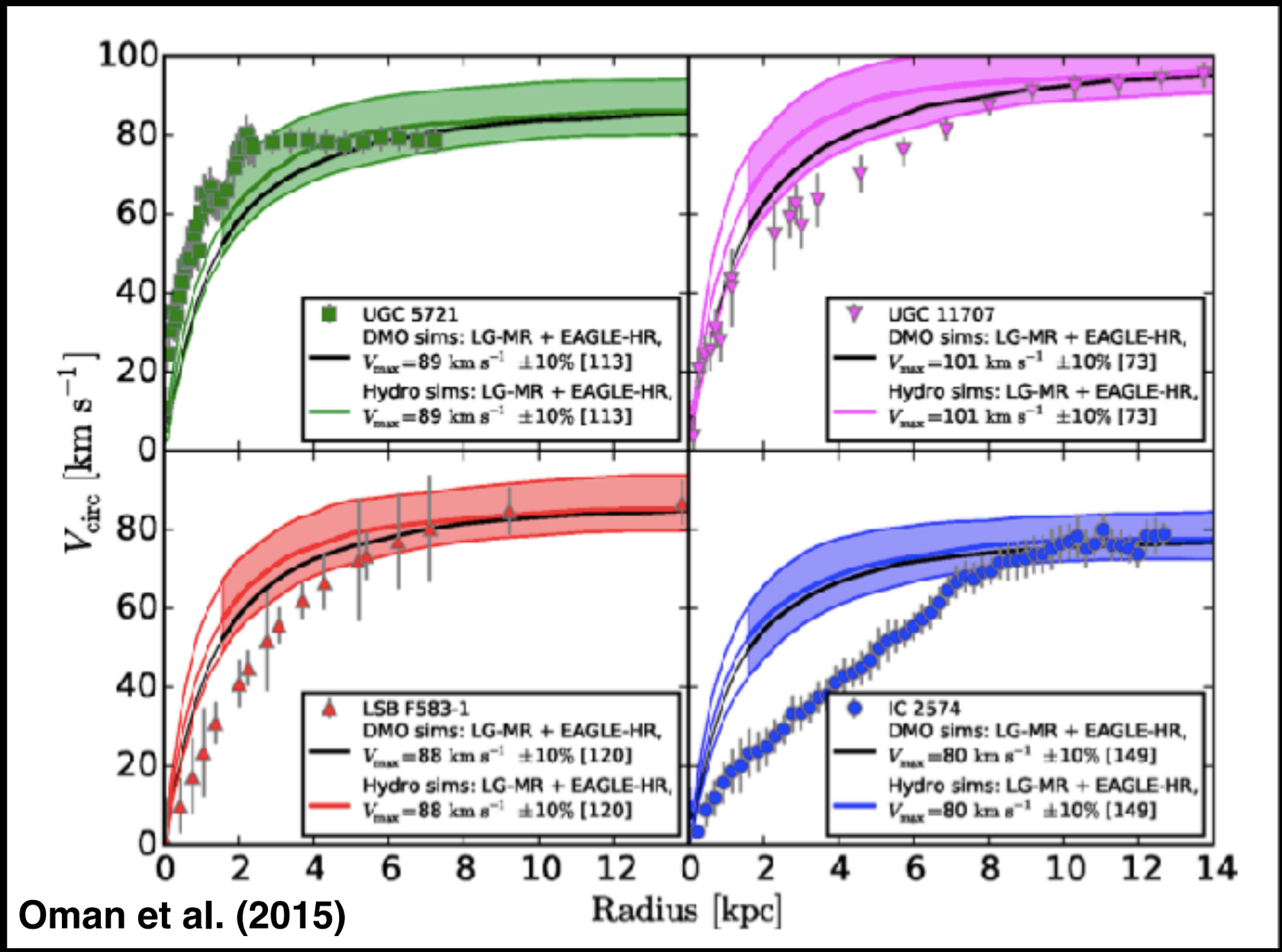
Dark Matter + Baryons

Garrison-Kimmel et al. (2019)



Adding baryons largely resolve this discrepancy

Diversity of Rotation Curves



Oman et al. (2015)

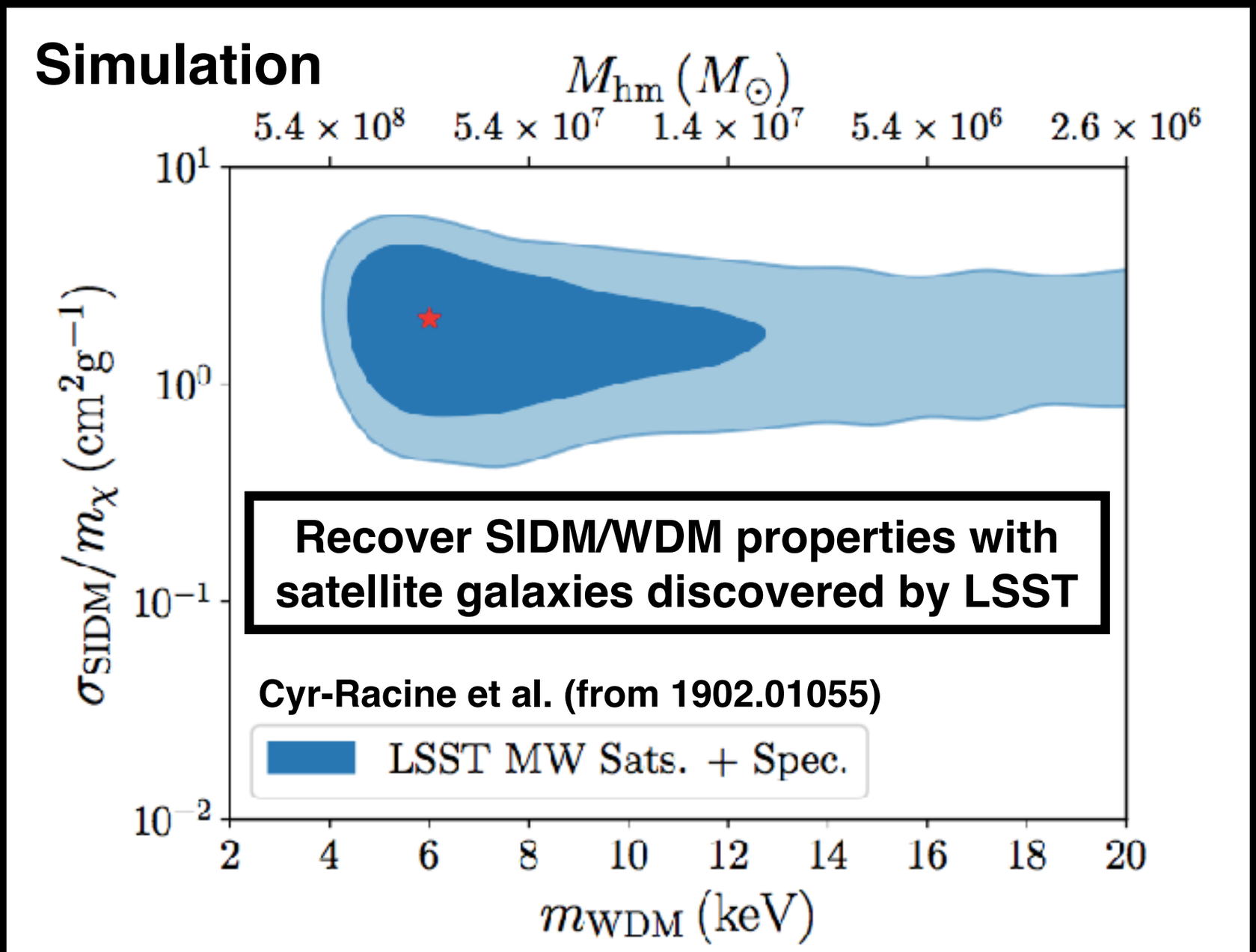
Rotation curves of dwarf spiral galaxies show more diversity than expected from CDM

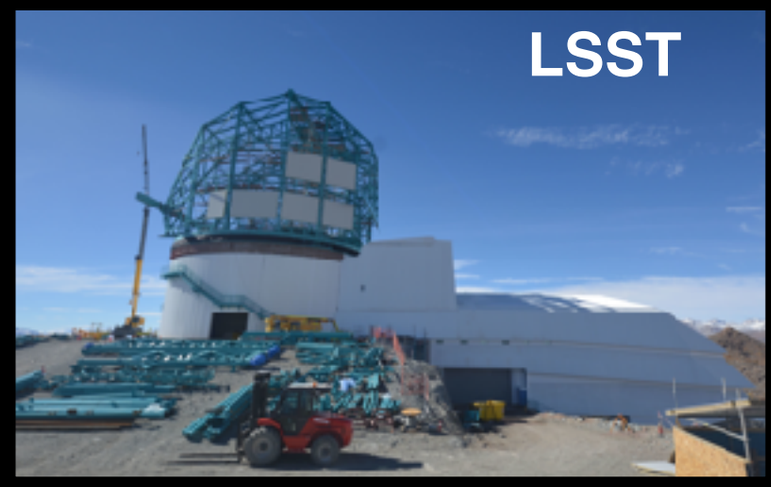
SIDM thermalizes inner regions of halos, tying the baryonic and dark matter distributions

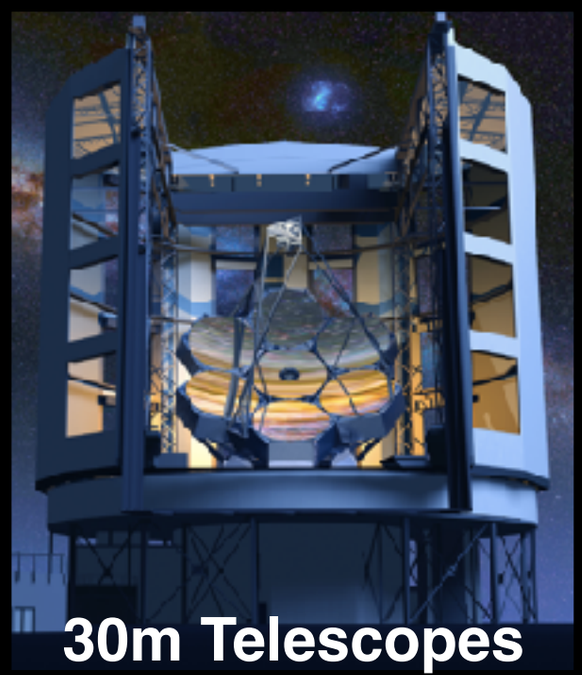
Joint Sensitivity Projections for LSST

Next-generation experiments will be sensitive to WDM and SIDM properties simultaneously

Simulation







Summary

- Astrophysics and cosmology probe **fundamental particle physics of dark matter** via **gravity**.
- Observations and simulations continue to improve our ability to disentangle **dark matter physics** from **baryonic effects**.
- Exciting new experiments are **under construction!**