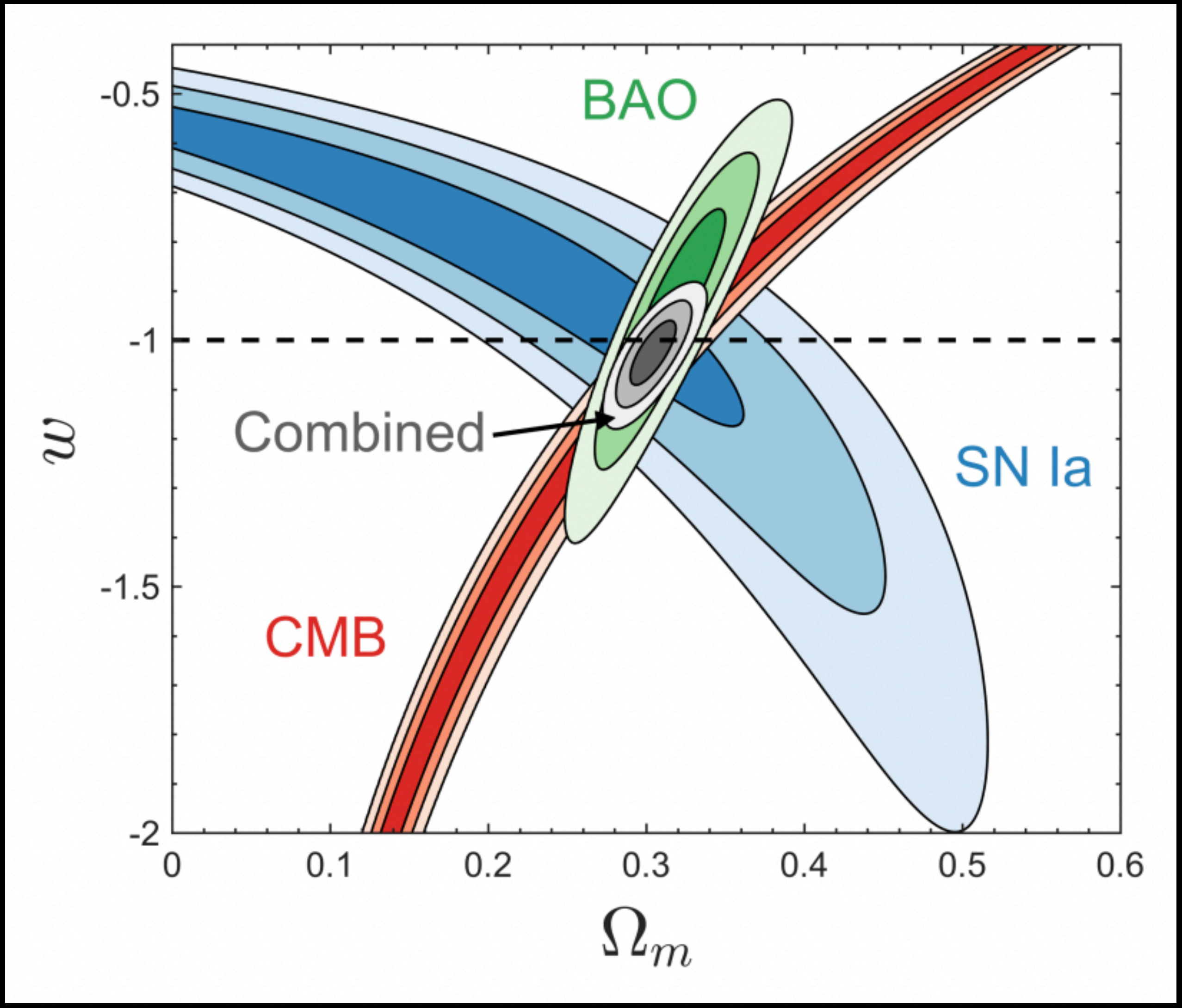
Cosmic surveys as a probe of dark matter

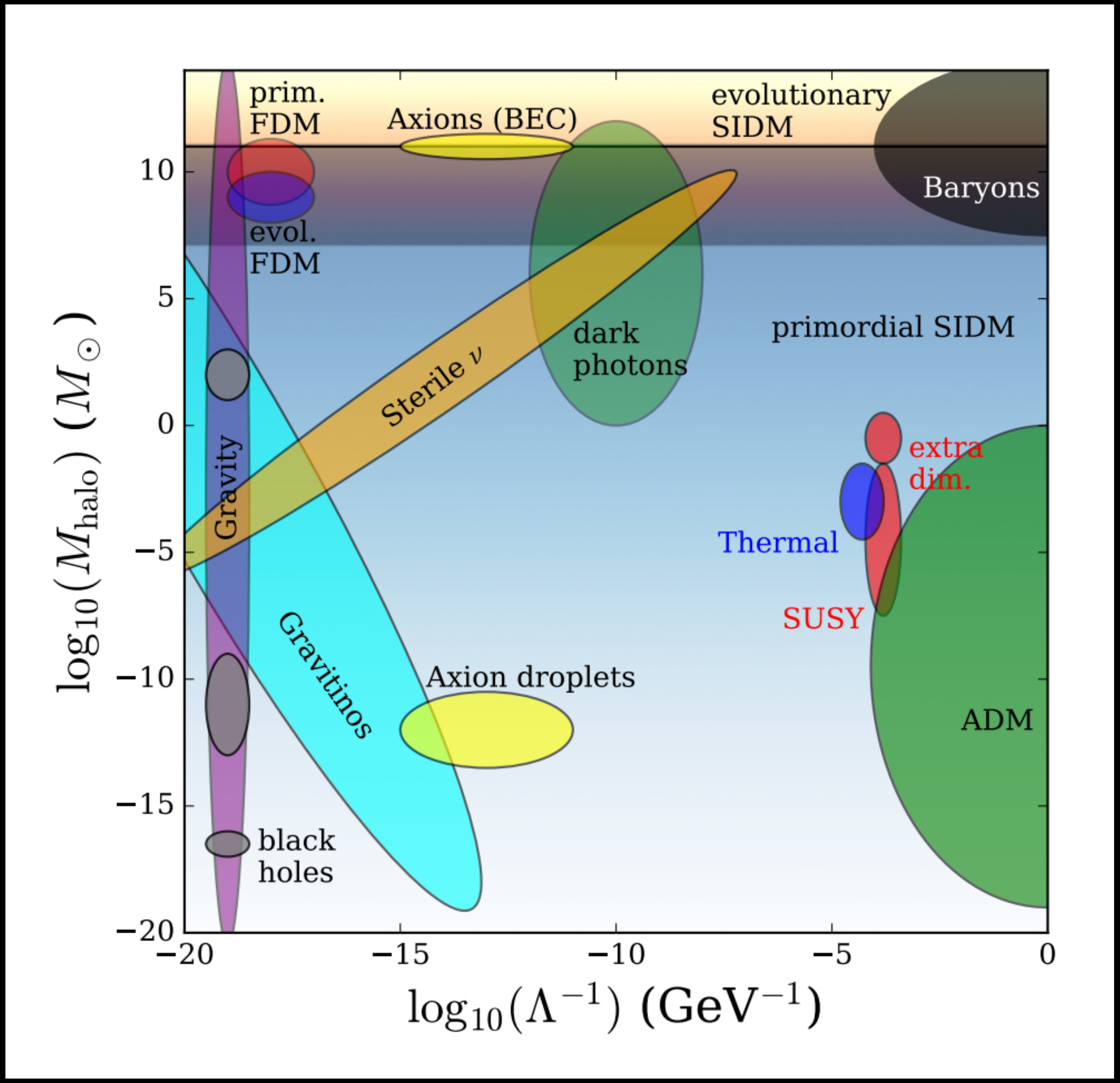
Ting Li (李婷)
University of Toronto
TeVPA 2021, Oct 27 2021
Chengdu, China

Huterer & Shafer 2018



Cosmology/Dark Energy

Buckley & Peter 2017



Dark Matter (DM)

Support for Construction of Direct Detection Dark Matter Experiments in Particle Astrophysics

PROGRAM SOLICITATION
NSF 13-597

National Science Foundation

Directorate for Mathematical & Physical Sciences
Division of Physics

Letter of Intent Due Date(s) ***(required)*** (due by 5 p.m. proposer's local time):

October 16, 2013

Full Proposal Deadline(s) (due by 5 p.m. proposer's local time):

November 26, 2013

II. PROGRAM DESCRIPTION

There are three complementary methods for studying dark matter: (1) accelerator searches for dark matter particle production, (2) indirect detection of dark matter annihilation within the Galaxy, and (3) the direct detection of Galactic dark matter particles that pass through terrestrial detectors. This solicitation invites proposals for the next generation direct detection experiments.

Program Announcement
To DOE National Laboratories

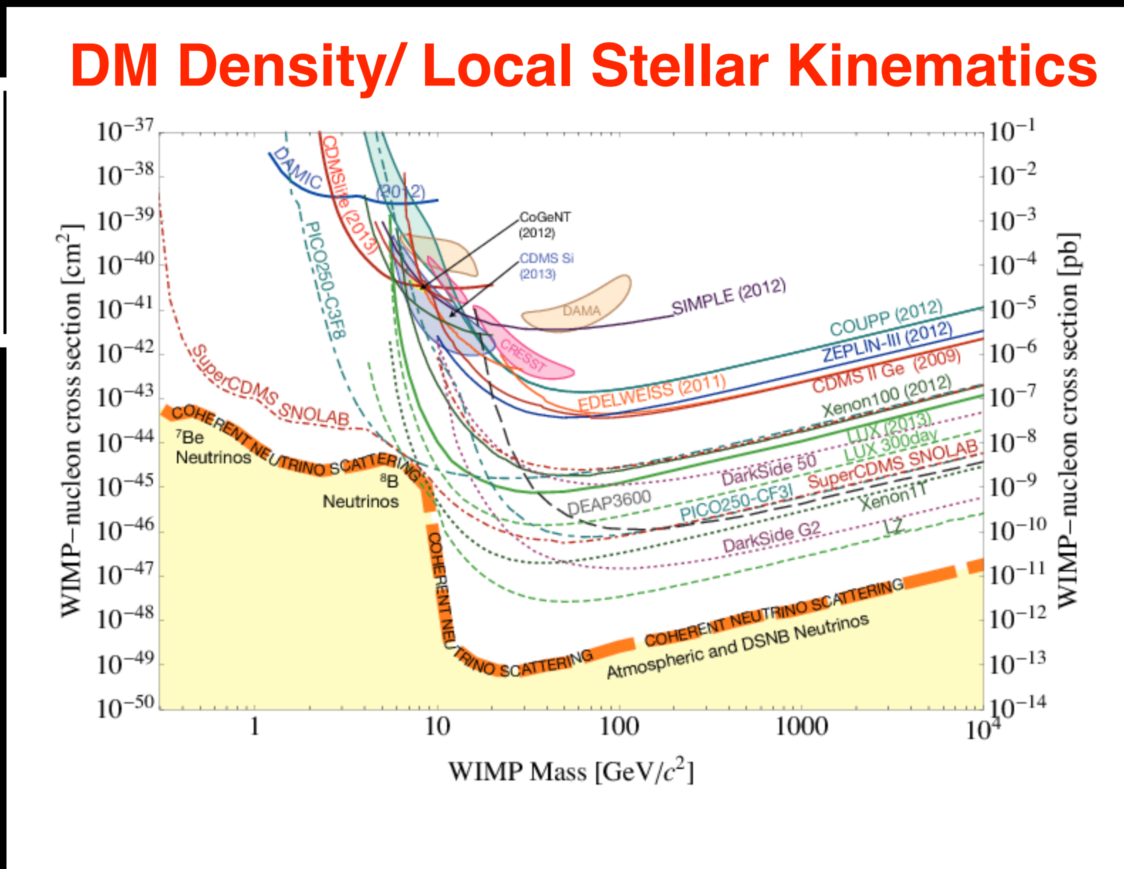
LAB 12-597

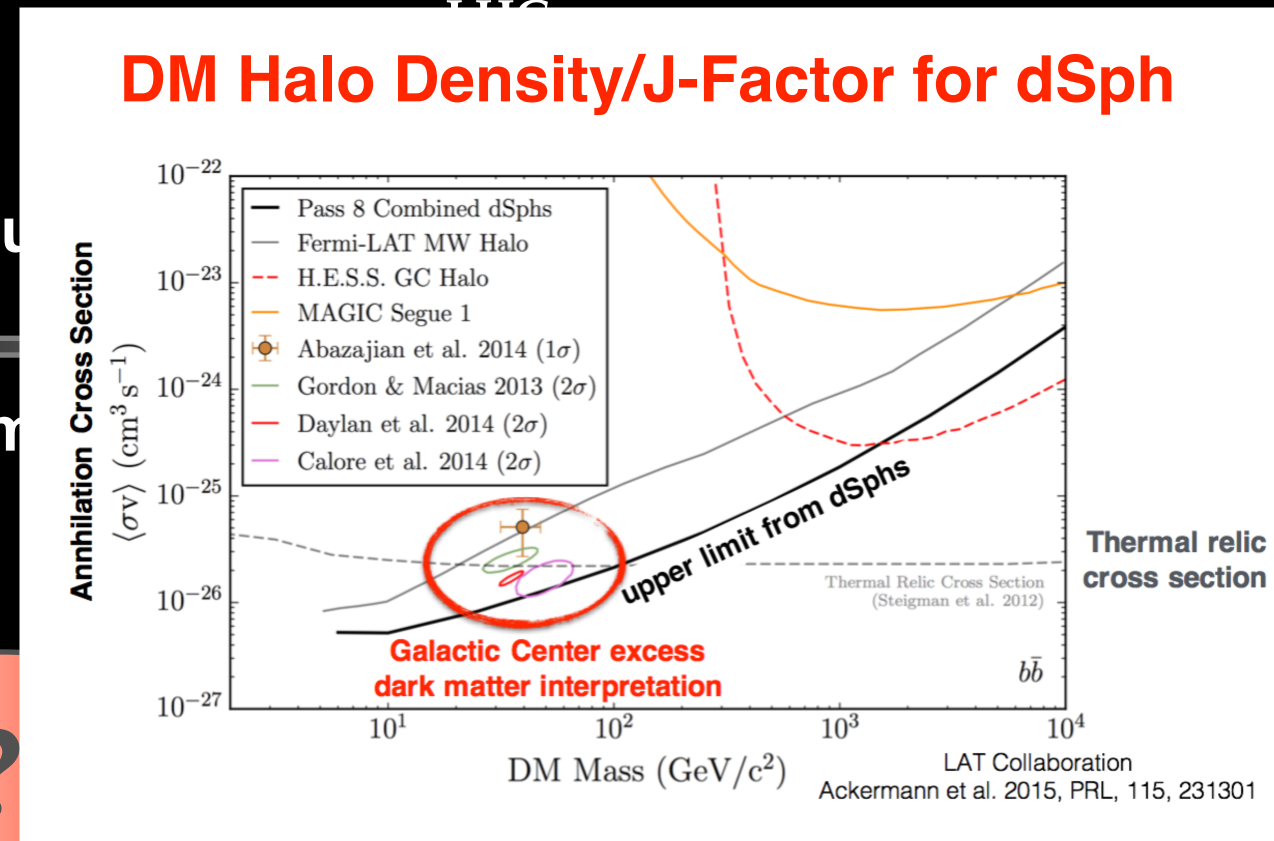
Office of Science
Office of High Energy Physics

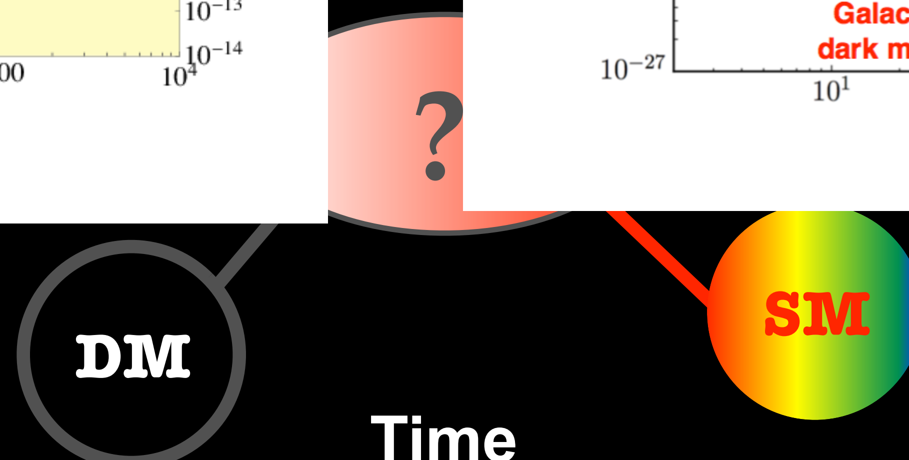
Second Generation Dark Matter Experiments

Investigation Requirements: There are three complementary methods for searching for dark matter: (1) accelerator searches for dark matter particle production, (2) indirect detection of dark matter annihilation within the Galaxy, and (3) the direct detection of Galactic dark matter particles that pass through terrestrial detectors. This Announcement solicits proposals for support of future second-generation experiments of the third type only, those that conduct direct-detection searches for dark matter particles.

The Hunt for Dark Matter





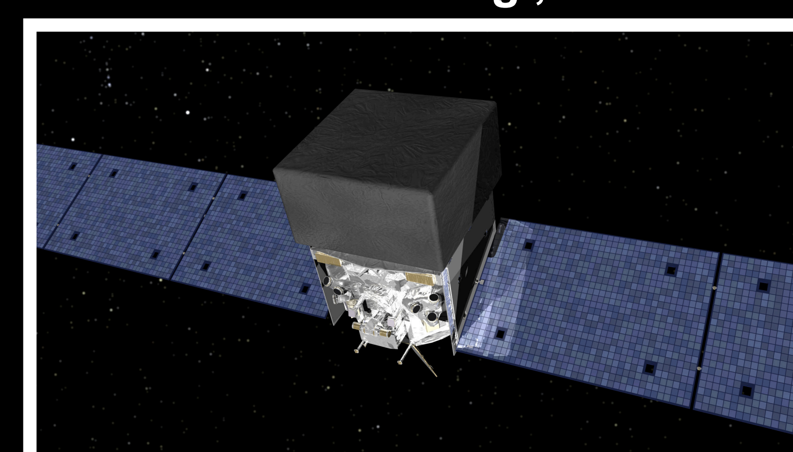


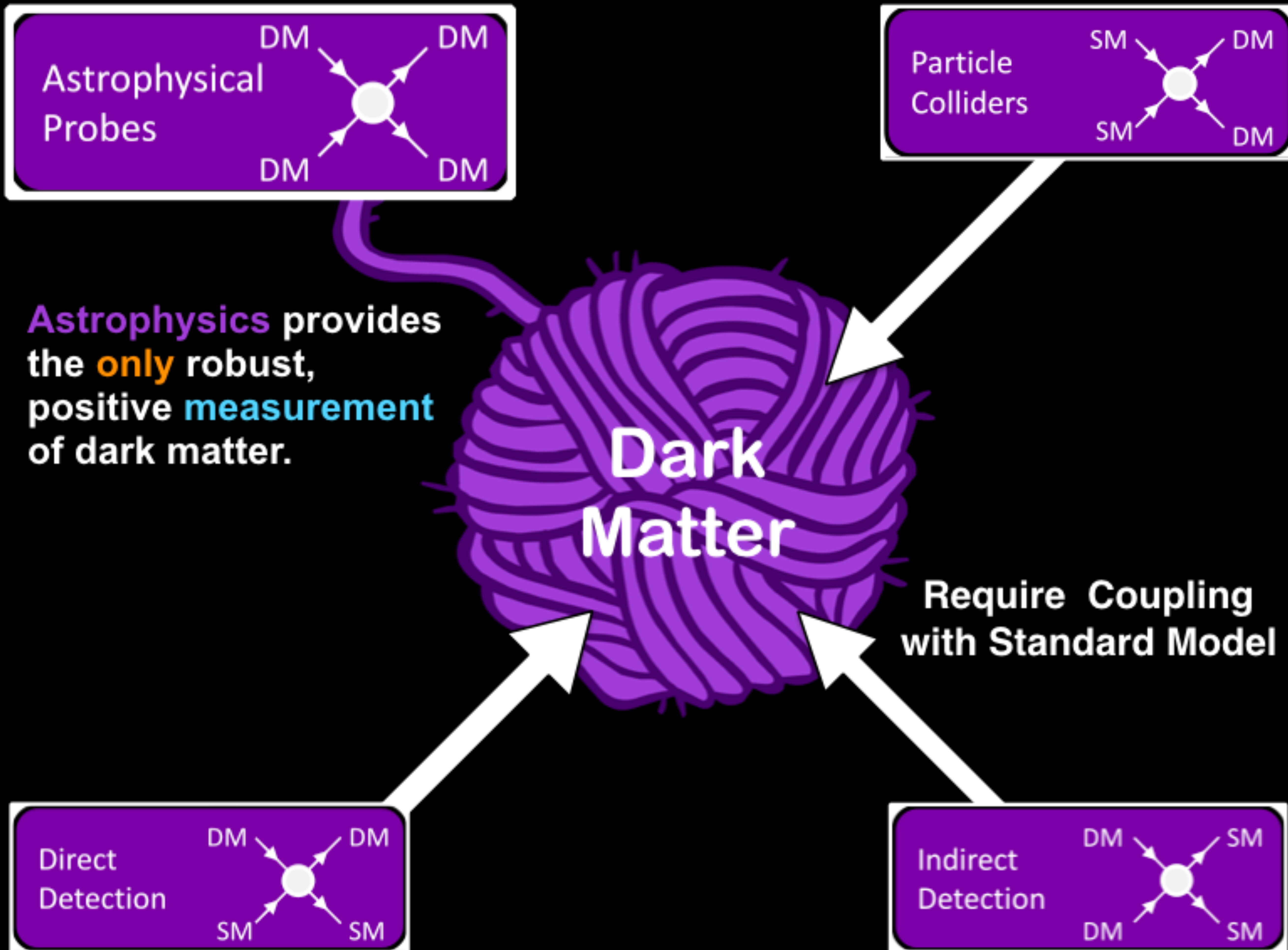
e.g., LUX

Time

Indirect Detection

e.g., Fermi-LAT





Astrophysical Probes
DM DM DM DM
Particle Colliders
SM DM SM DM
Astrophysics provides the only robust, positive measurement of dark matter.
Dark Matter
Require Coupling with Standard Model
Direct Detection
DM DM SM SM
Indirect Detection
DM SM DM SM

LSST Science Collaborations

There are currently eight active LSST Science Collaborations. Additional information about their work and membership can be found at the links below or by contacting the individual chairs, or the LSSTC Science Collaborations Coordinator (LSSTCSCC), Federica Bianco.

Galaxies

Michael Cooper (UC Irvine); Brant Robertson (University of California Santa Cruz);

Stars, Milky Way, and Local Volume

John Bochanski (Rider University); John Gizis (University of Delaware); Nitya Jacob Kallivayalil (University of Virginia);

Solar System

Meg Schwamb (Gemini Observatory Northern Operations Center); David Trilling (Northern Arizona University);

Dark Energy

Eric Gawiser (Rutgers The State University of New Jersey); Phil Marshall (KIPAC);

Active Galactic Nuclei

Niel Brandt (Pennsylvania State University);

Transients/variable stars

Federica Bianco (New York University); Rachel Street (LCO);

Strong Lensing

Charles Keeton (Rutgers-The State University of New Jersey); Aprajita Verma (Oxford University);

Informatics and Statistics

Tom Loredo (Cornell University); Chad Schafer (Carnegie Mellon University);

There is no dark matter science collaboration arXiv.org > astro-ph > arXiv:astro-ph/0005381

Astrophysics

[Submitted on 18 May 2000 (v1), last revised 25 Jul 2000 (this version, v2)]

The Dark Matter Telescope

J. A. Tyson, David Wittman (Bell Labs, Lucent Technologies), J. R. P. Angel (University of Arizona)

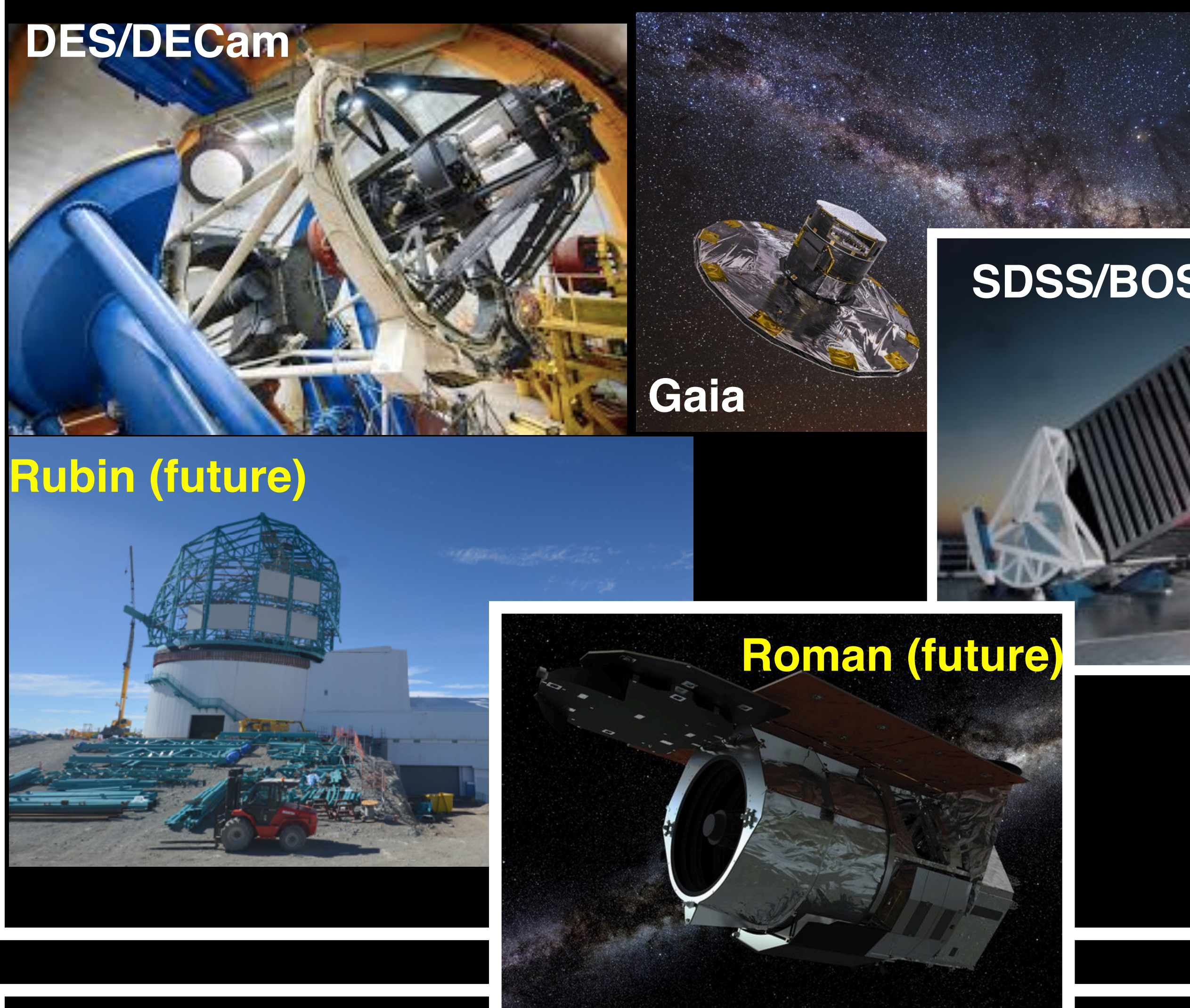
U.S. Particle Physics P5 Report, 2014

Table 1
Summary of Scenarios

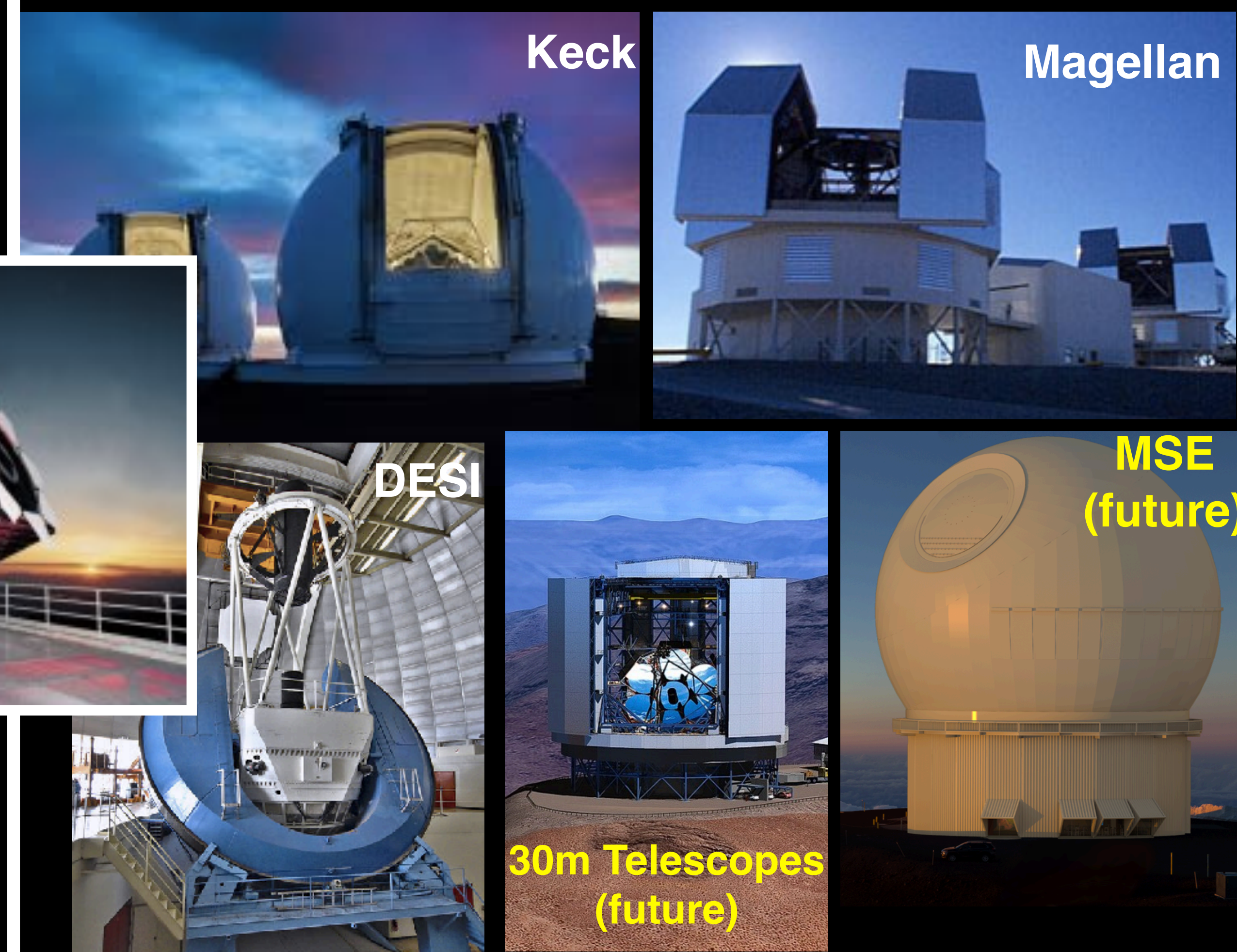
Project/Activity	Scenarios: Scenario A	Scenario B	Scenario C	Science Drivers: Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	Technique (Frontier)
Large Projects									
Muon program: Mu2e, Muon g-2	Y, Mu2e small reprofile needed	Y	Y					✓	I
HL-LHC	Y	Y	Y	✓		✓		✓	E
LBNF + PIP-II	Y, LBNF components delayed relative to Scenario B.	Y	Y, enhanced		✓			✓	I,C
ILC	R&D only	R&D, possibly small hardware contri-butions. See text.	Y	✓		✓		✓	E
NuSTORM	N	N	N		✓				I
RADAR	N	N	N		✓				I
Medium Projects									
LSST	Y	Y	Y		✓		✓		C
DM G2	Y	Y	Y			✓			C

Current and Near-Future Experiments

Wide-Area Imaging

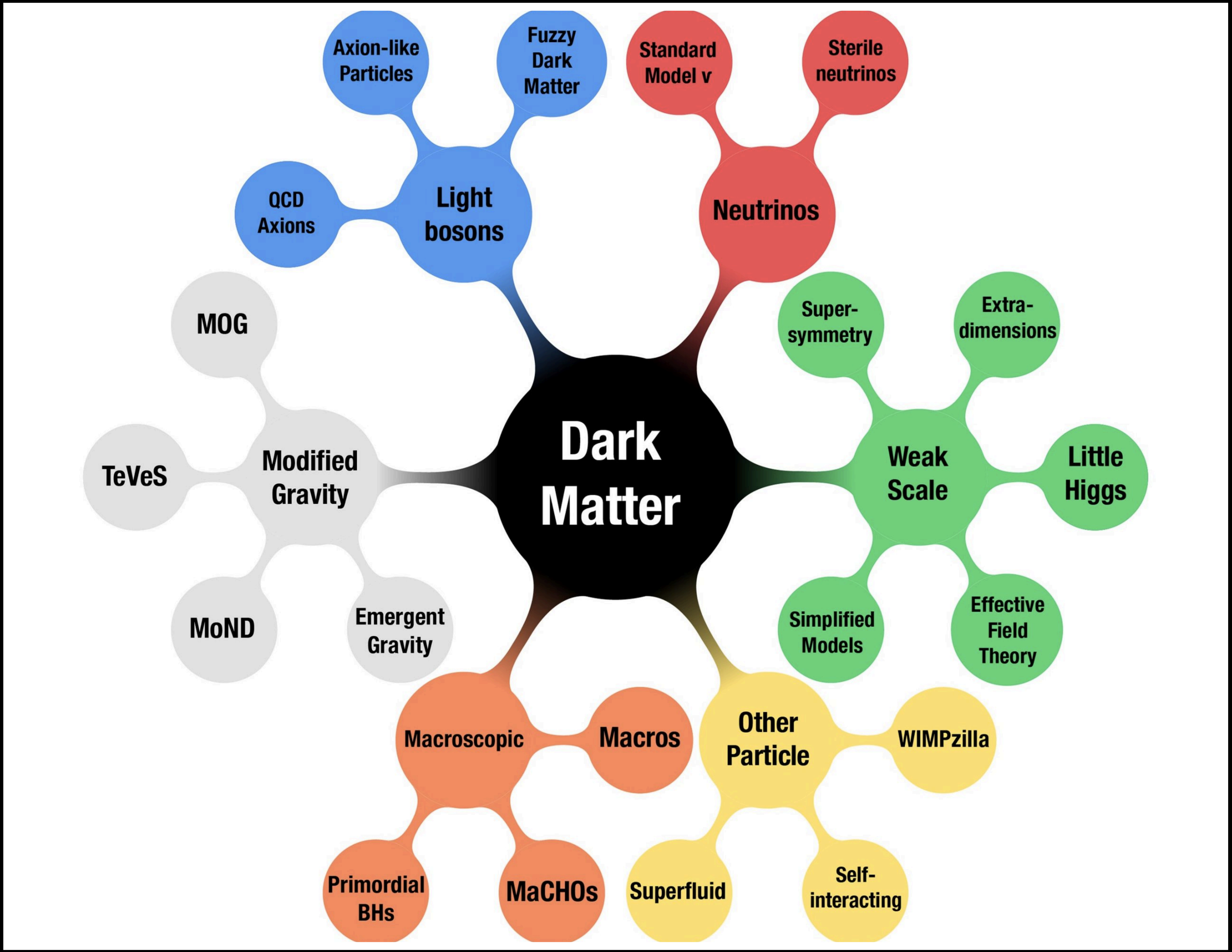


Spectroscopic Measurements



High Resolution Imaging

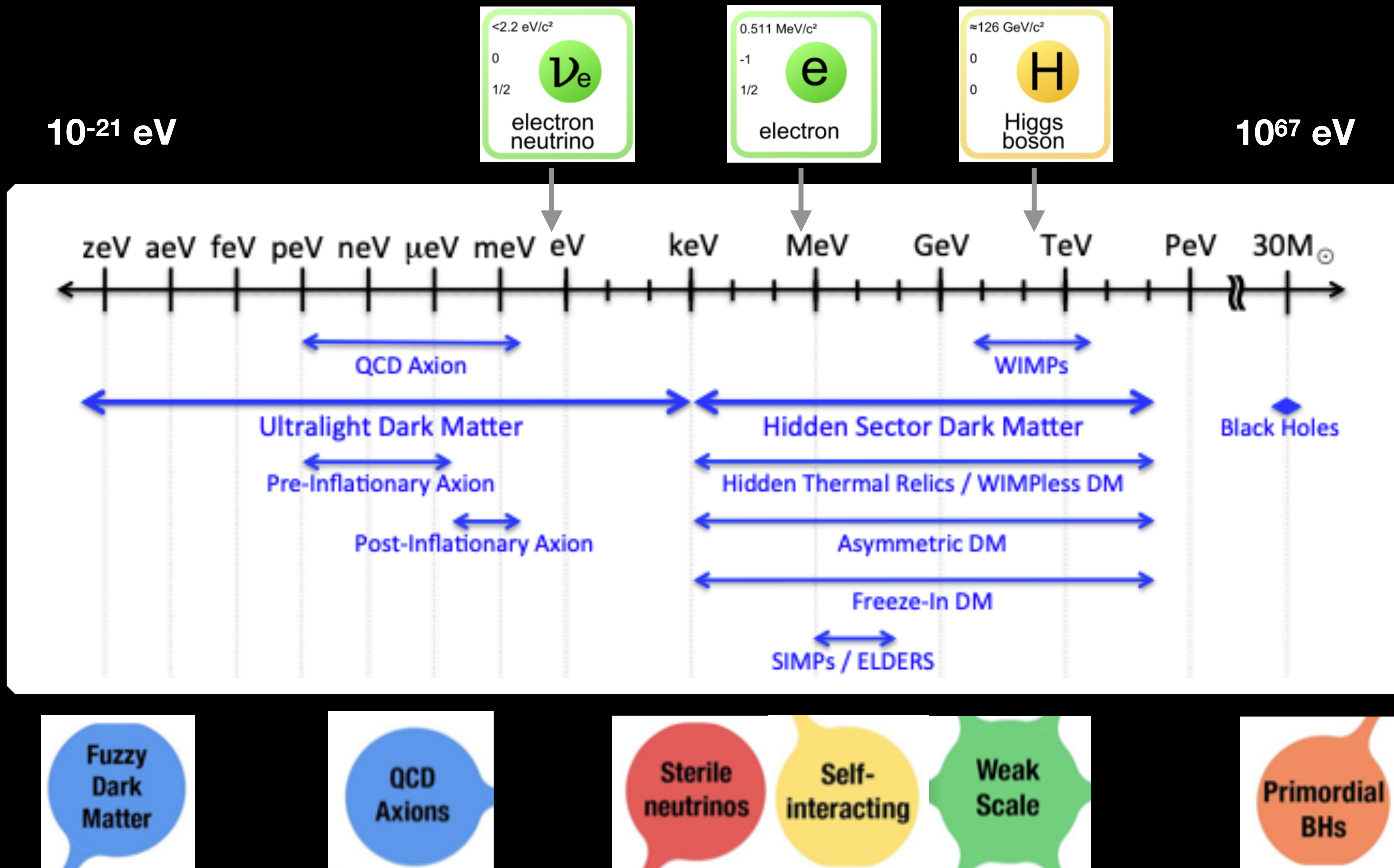
Dark Matter Candidates



Bertone & Tait, Nature 562, 51 (2018)

Dark Matter Candidates

https://arxiv.org/abs/1707.04591

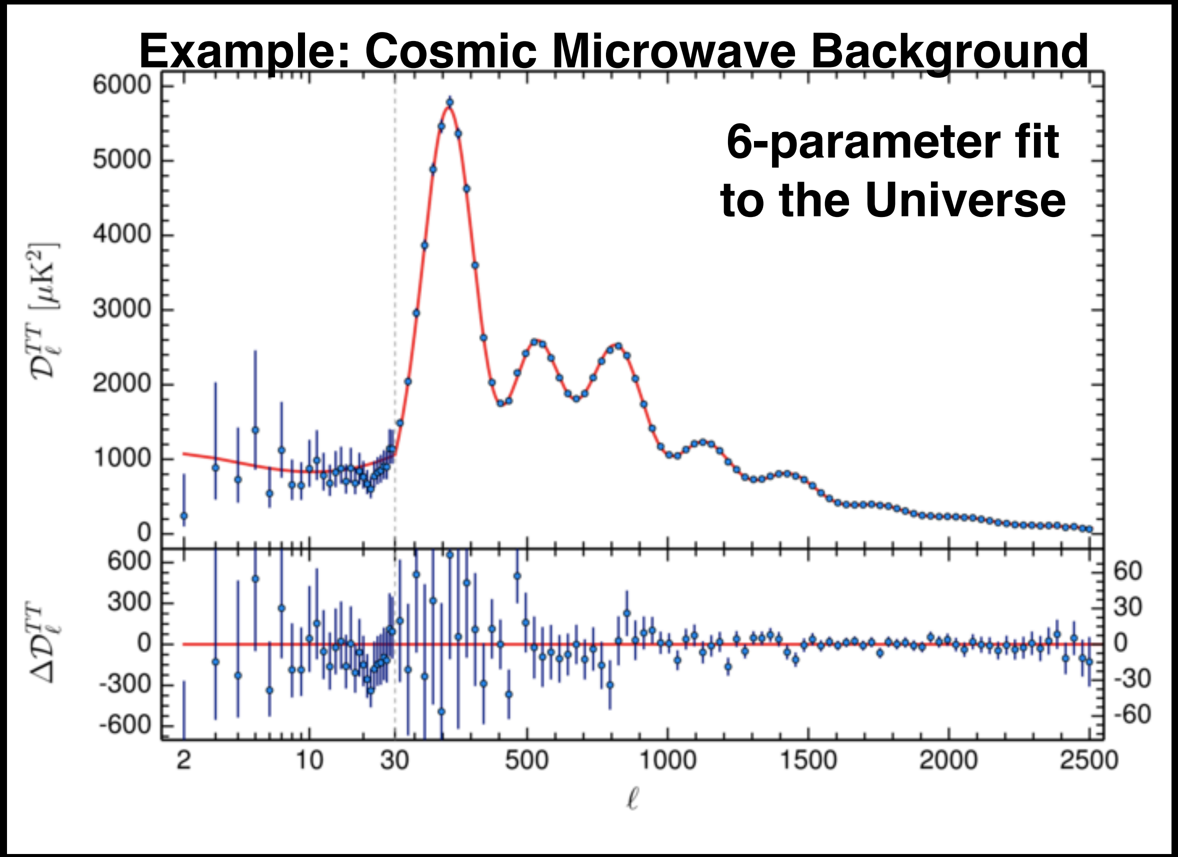


What have we learned about dark matter from astrophysical observations?

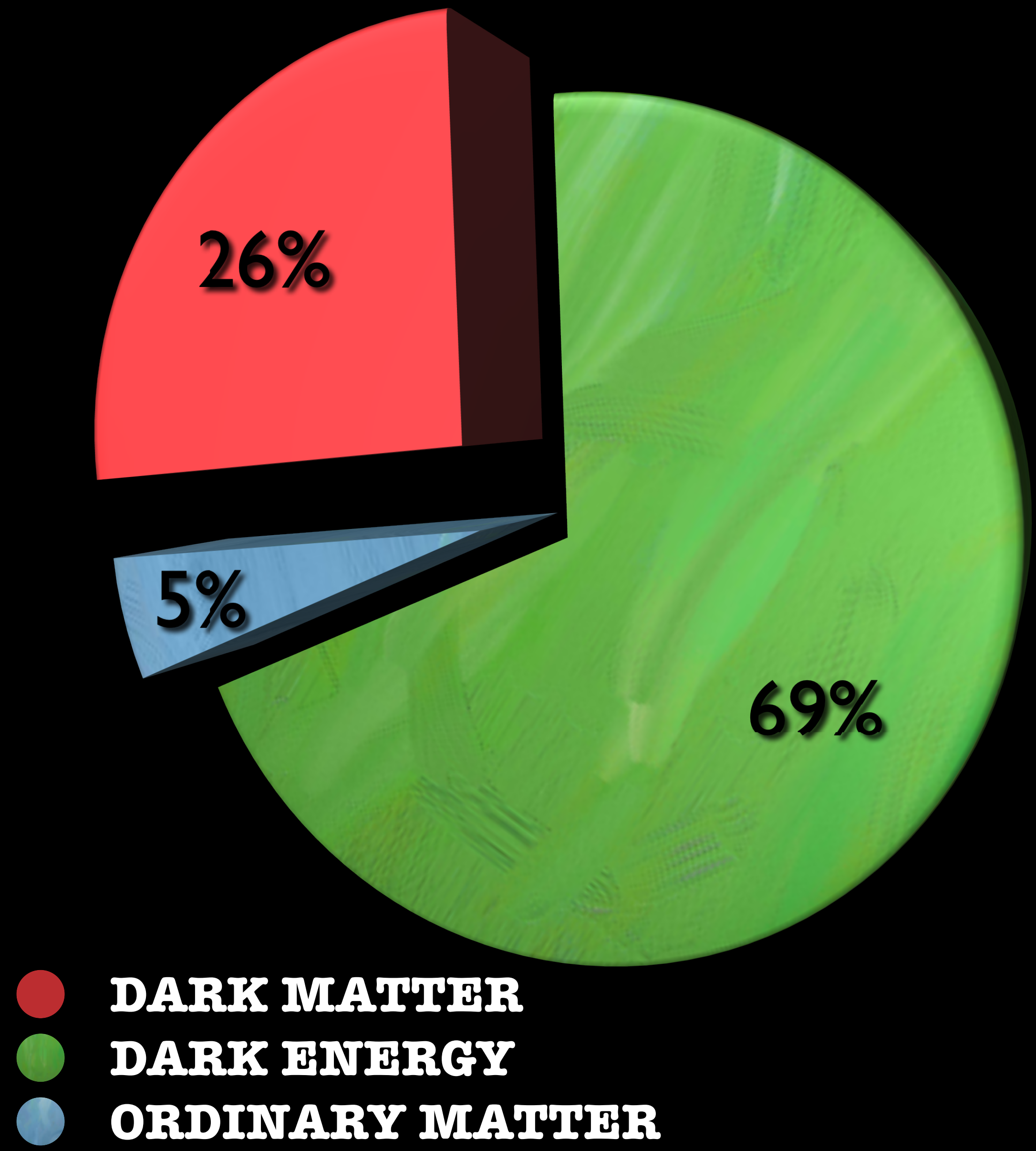
What have we learned about dark matter from astrophysical observations?

- Dark matter is not baryon. Dark matter consist of 25% of the universe — CMB, BBN

ΛCDM Universe



Planck Collaboration (2016)



CDM — Cold, Collisionless Dark Matter

What have we learned about dark matter from astrophysical observations?

- Dark matter is not baryon. Dark matter consist of 25% of the universe — CMB, BBN

- Dark matter cannot be hot (i.e. sub-keV-mass) — Structure Formation

The Large-Scale Structure of the Universe

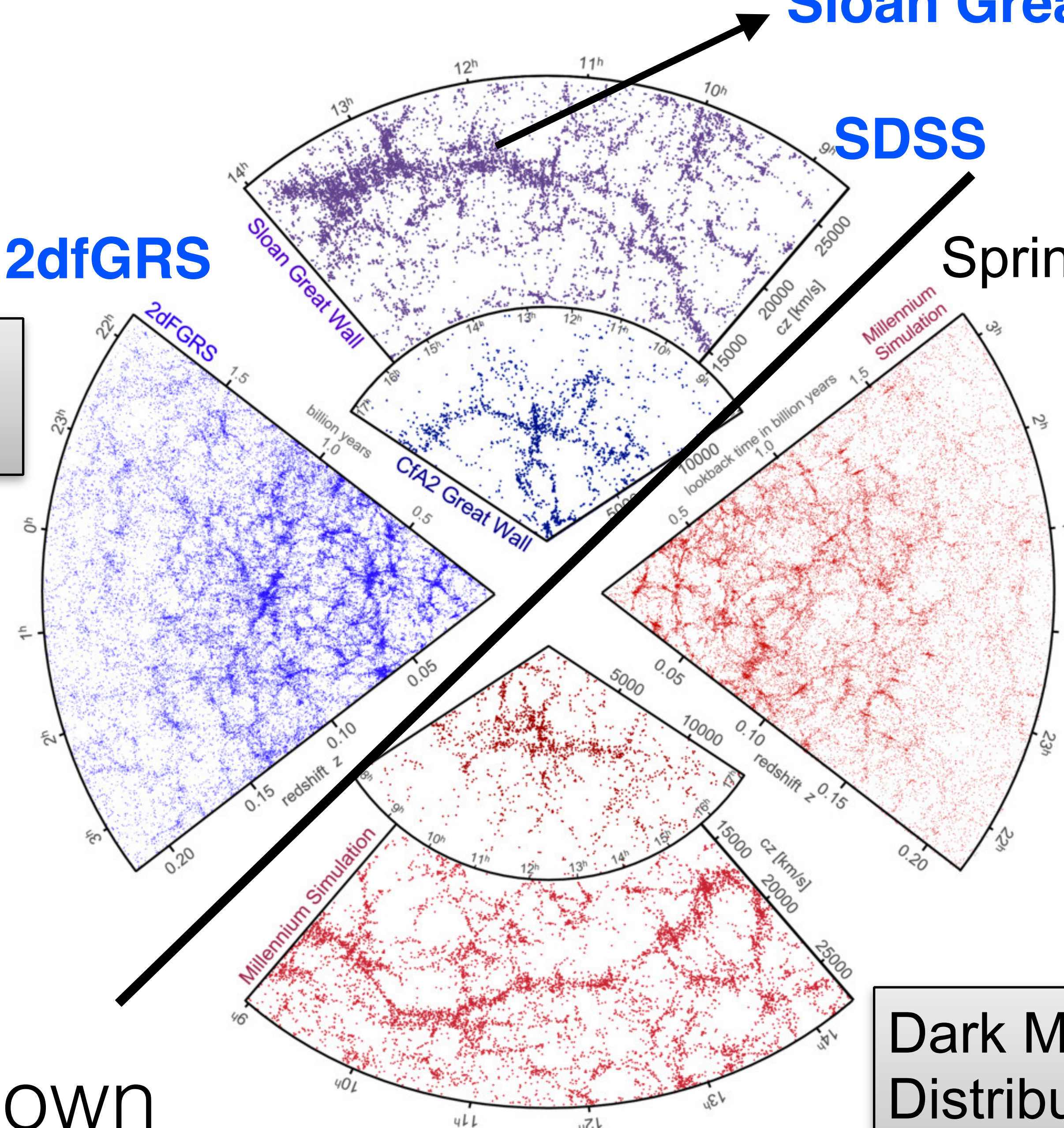
Sloan Great Wall

SDSS

2dfGRS

Springel et al. (2006)

Galaxy Distributions from Observations



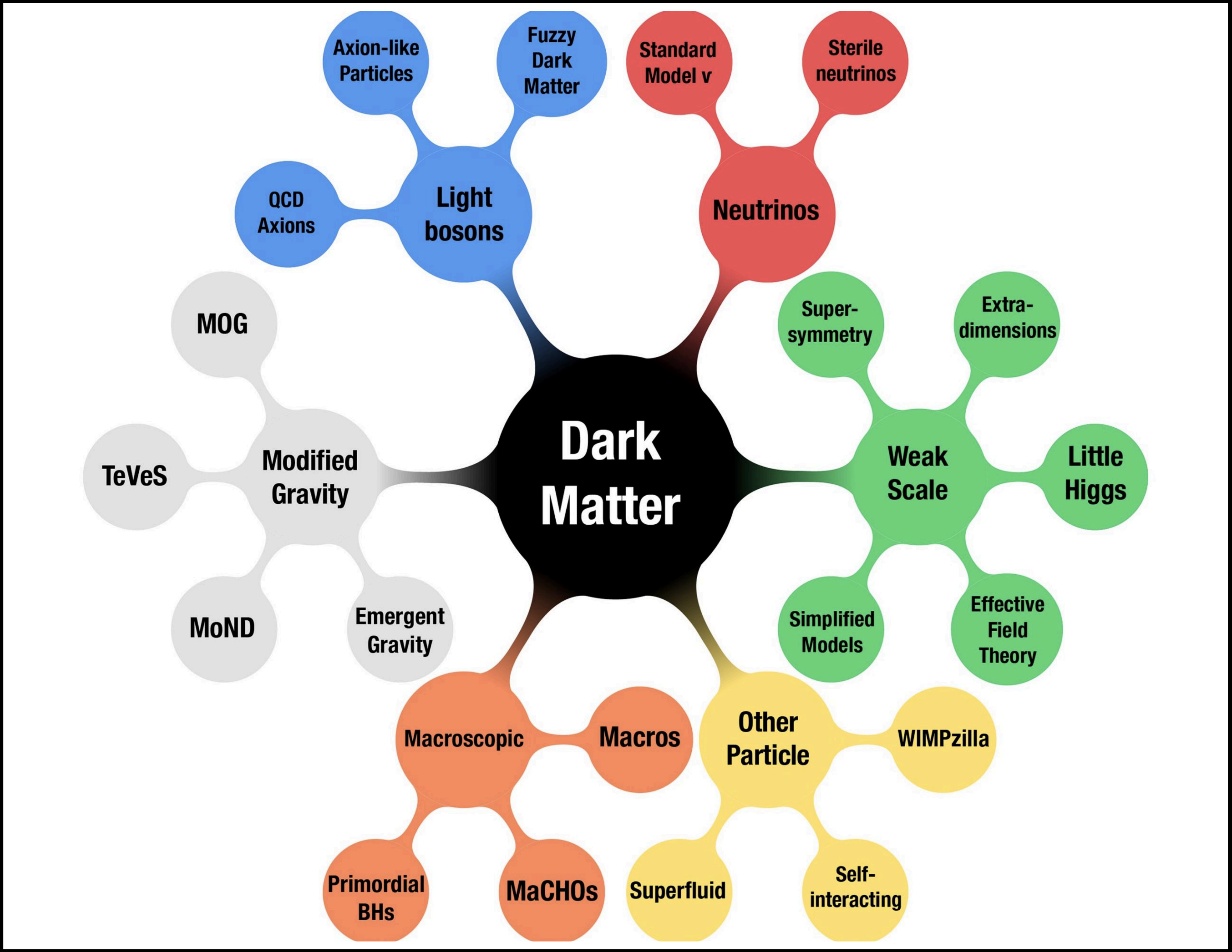
Dark Matter Distribution from Simulations

CDM vs HDM

bottom-up vs top-down

hierarchical vs fragmentation

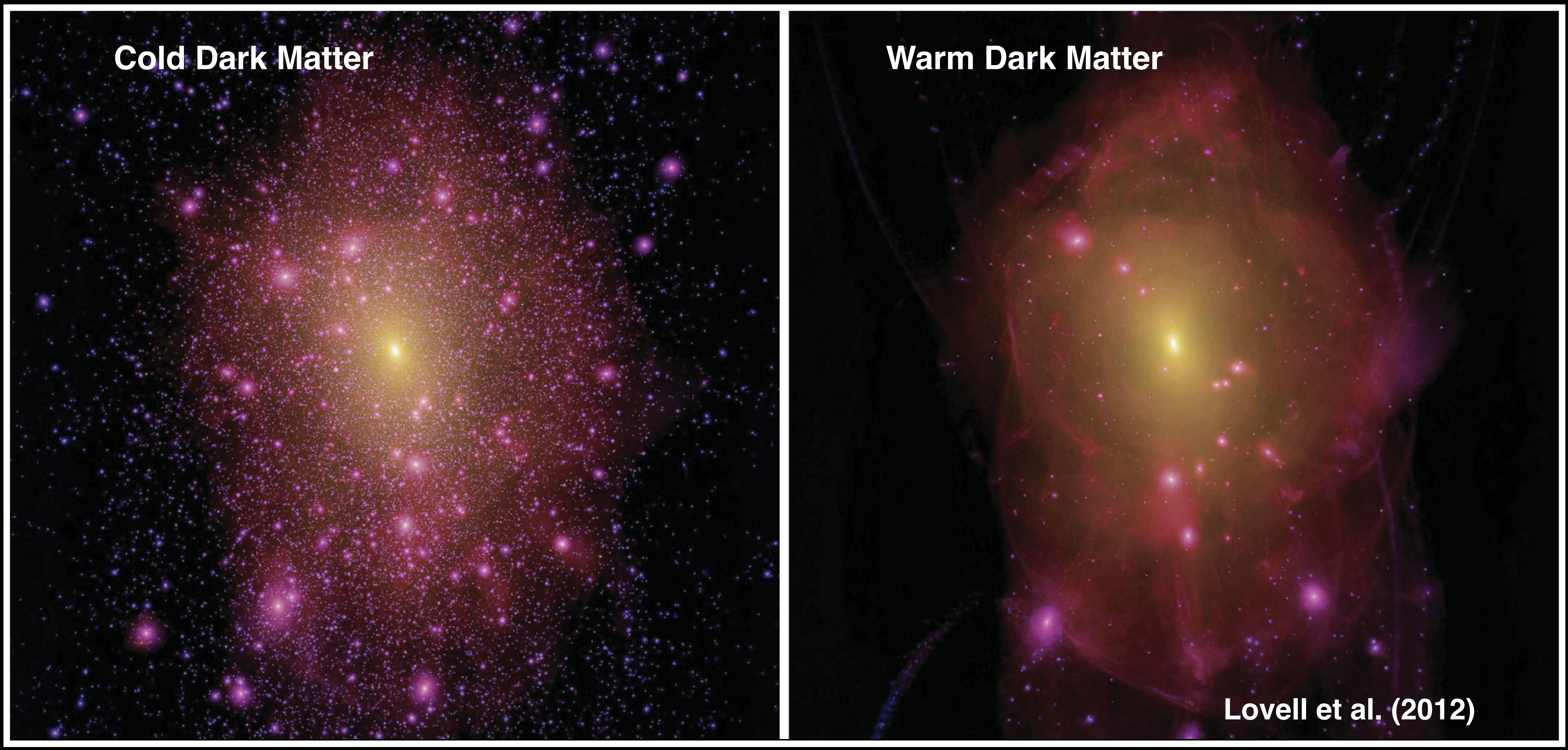
Dark Matter Candidates



Bertone & Tait, Nature 562, 51 (2018)

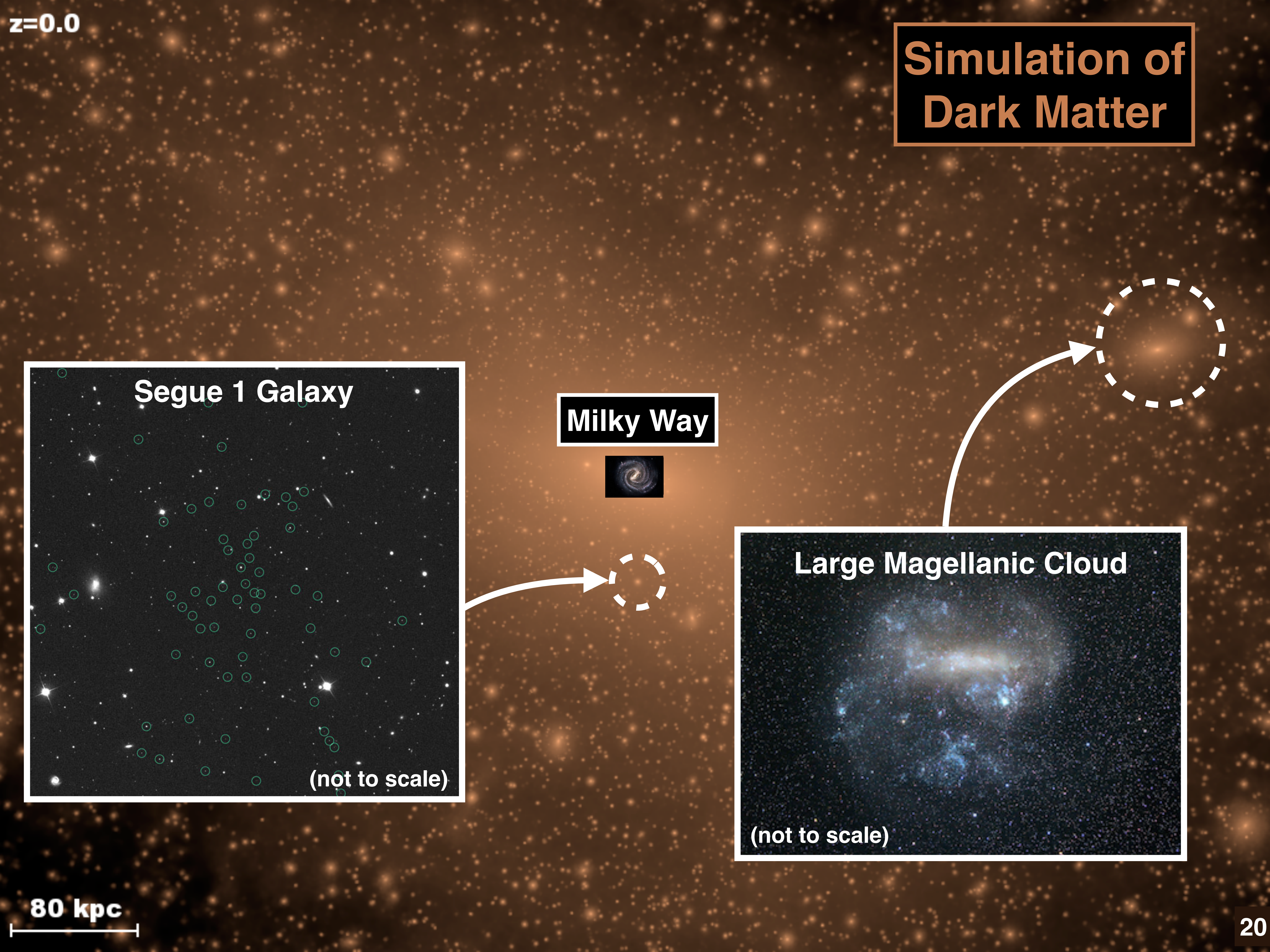
The Small-Scale Structure of Dark Matter

Simulations

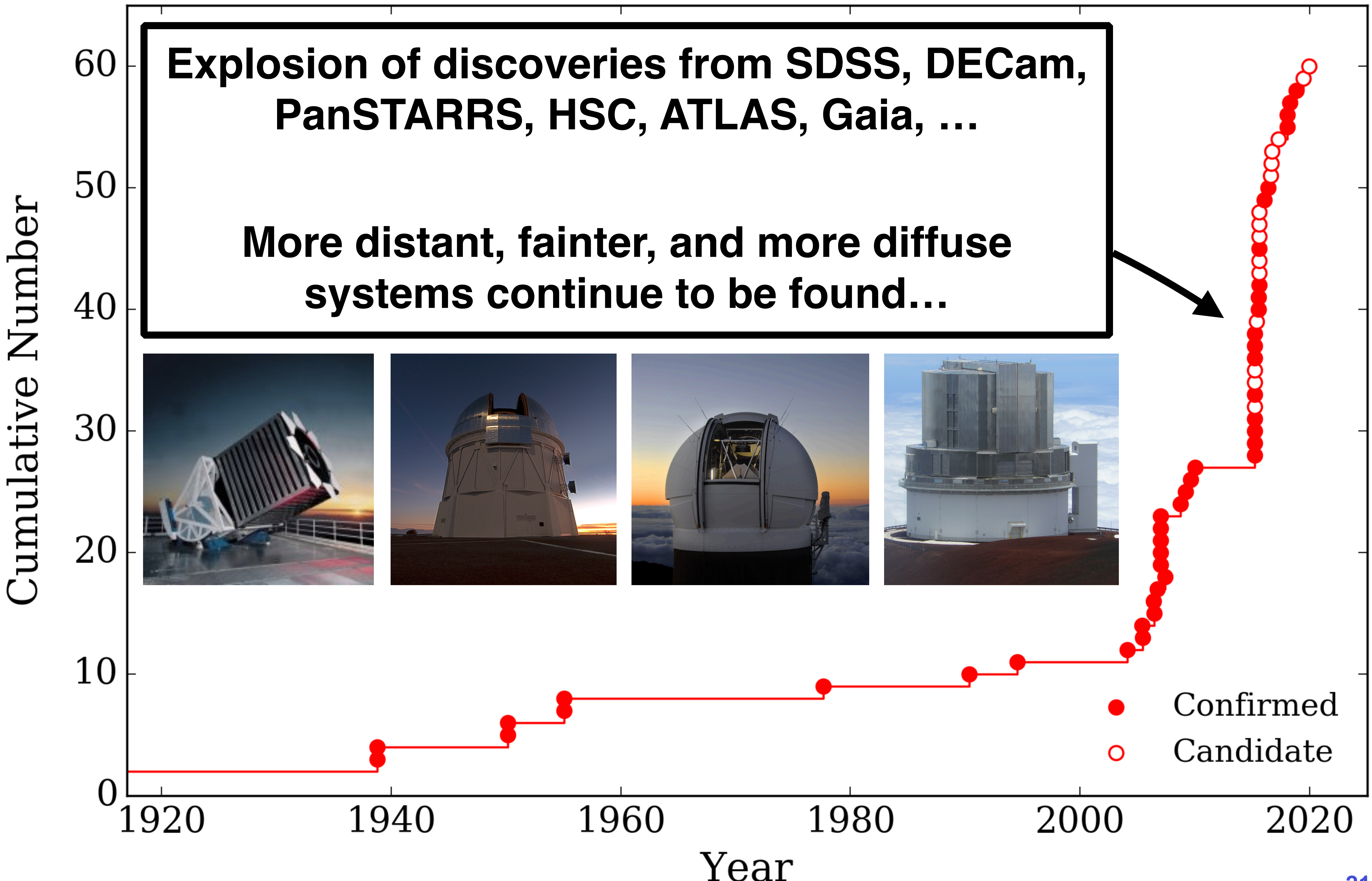


e.g., Sterile Neutrino

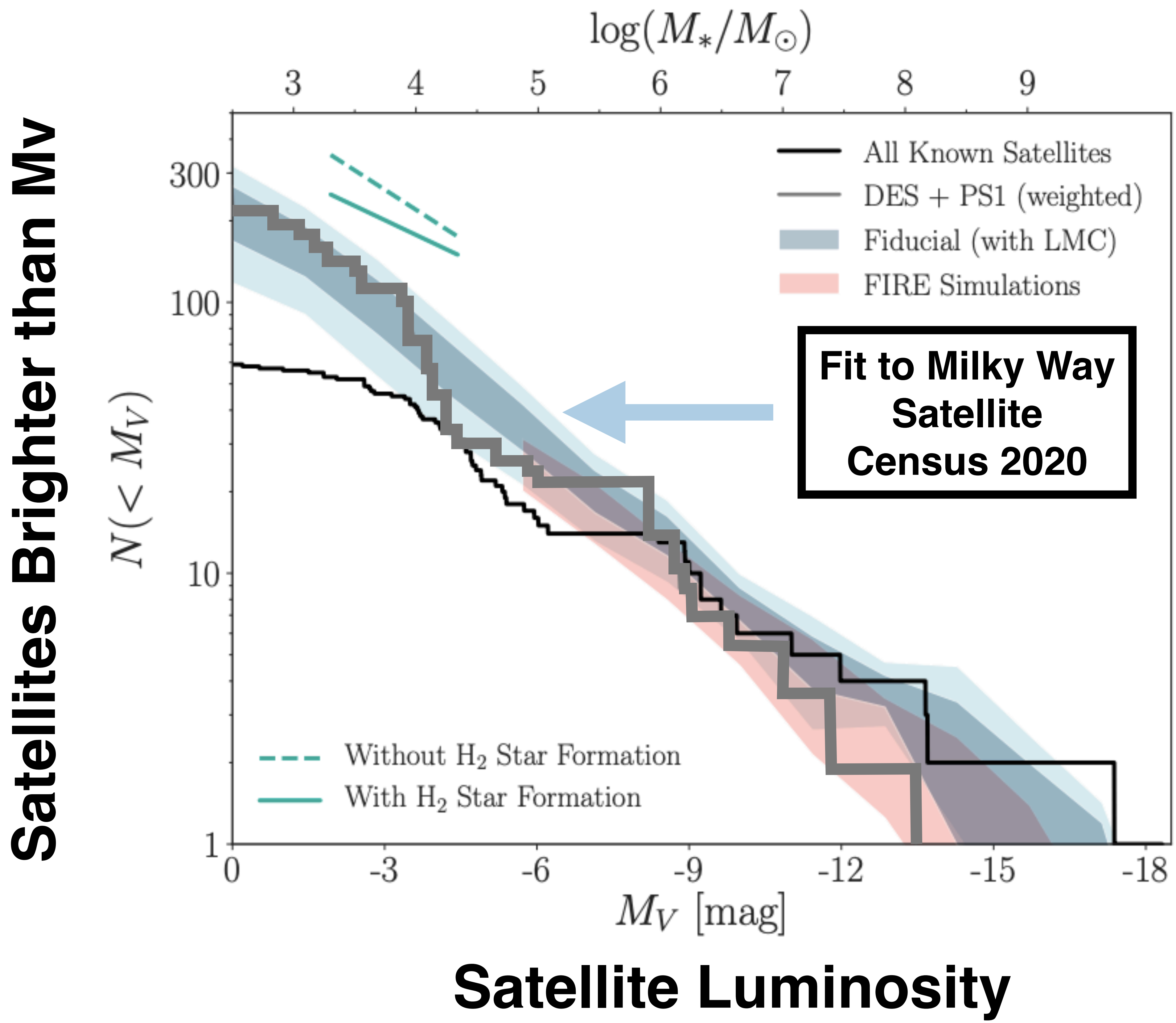
Subhalo mass function


z=0.0
Simulation of Dark Matter
Segue 1 Galaxy
(not to scale)
Milky Way
Large Magellanic Cloud
(not to scale)
80 kpc

Milky Way Satellite Galaxy Discovery Timeline



Milky Way Satellite Luminosity Function



Observed satellites are consistent with CDM + galaxy formation.

There is no missing satellites problem!

See also: Jethwa et al. 2018, Newton et al. 2018, Kim et al. 2018, Applebaum et al. 2020

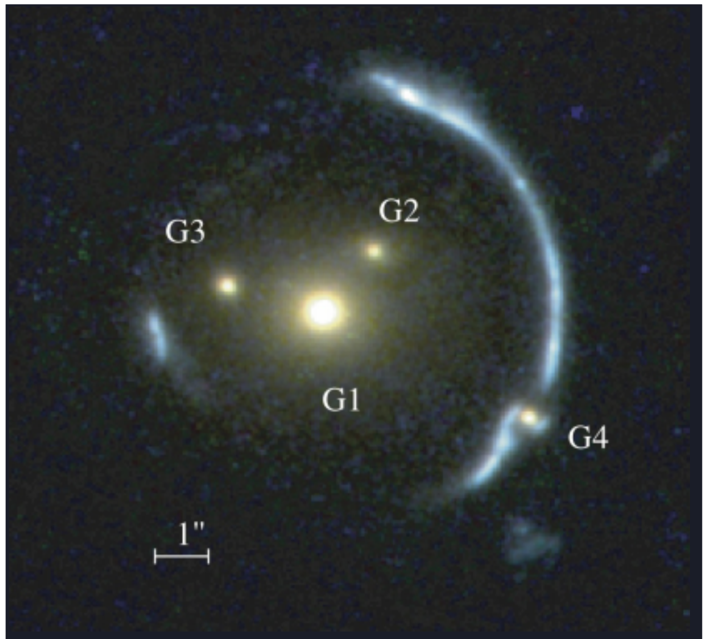
Nadler et al. ApJ 893, 48 (2020)

Galaxy-Galaxy Strong Lensing

- Flux ratio anomalies of lensed quasar

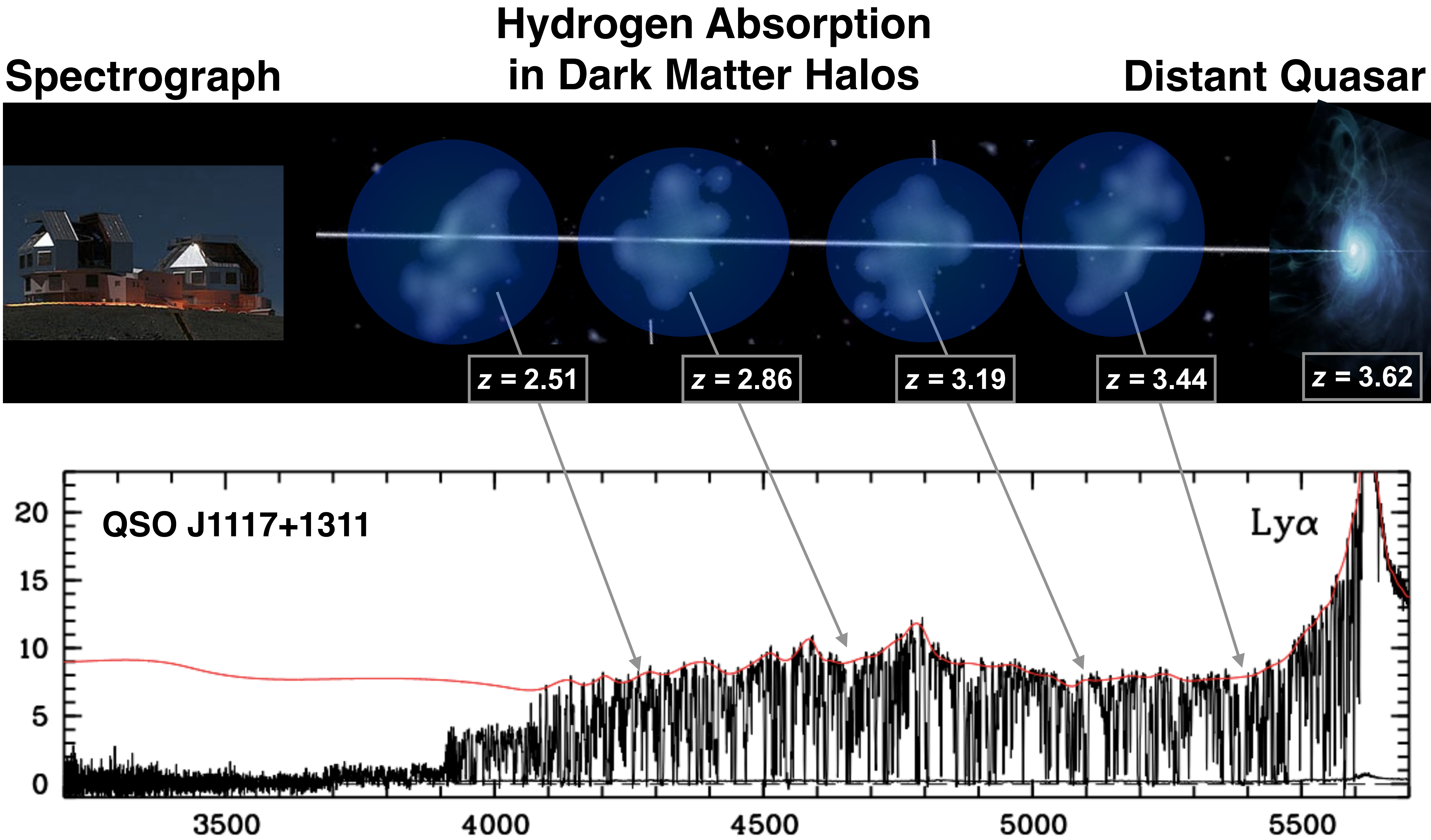
Suyu et al.; HST

- Gravitational Imaging: Substructure perturbations in lens arcs/rings



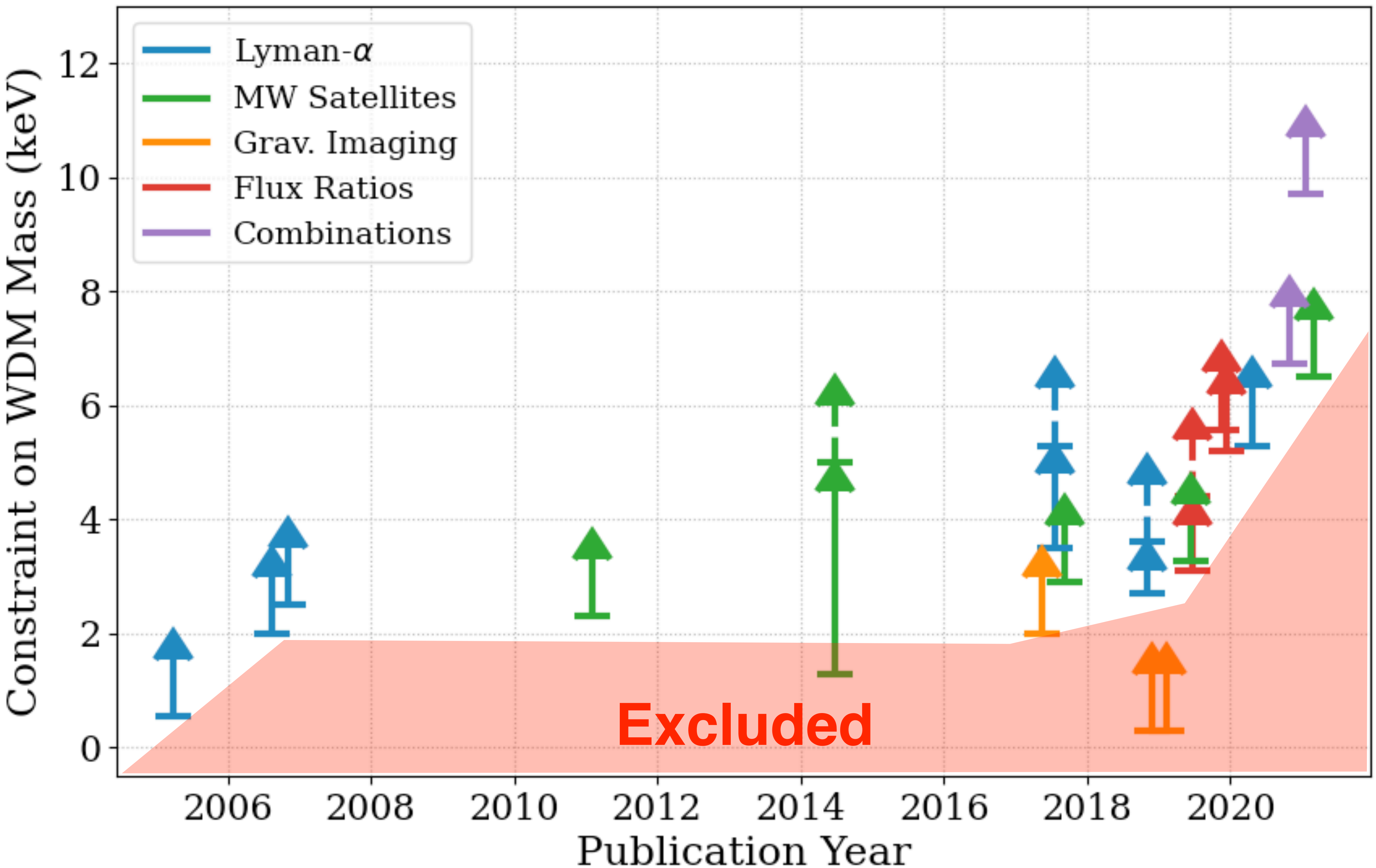
Lin et al. (2009); HST

Lyman-alpha Forest Measurements



López et al. (2016)

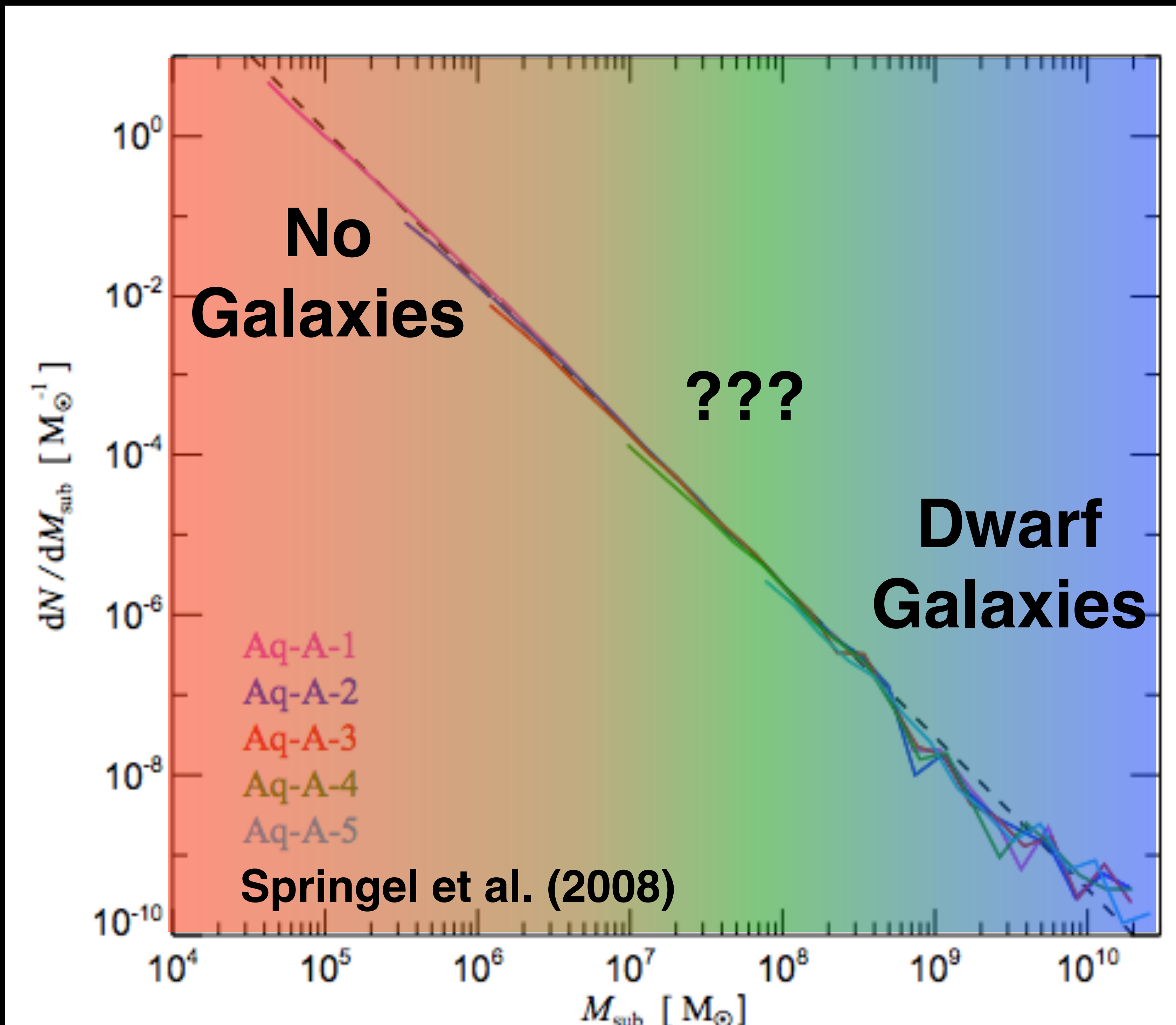
Warm Dark Matter Constraints



Constraints from: Viel et al. 2005, Viel et al. 2006, Seljak et al. 2006, Polisensky et al. 2011, Kennedy et al. 2014, Birrer et al. 2017, Irsic et al. 2017, Jethwa et al. 2017, Murgia et al. 2018, Vegetti et al. 2018, Ritondale et al. 2019, Gilman et al. 2019a,b, Hseuh et al. 2019, Palanque-Delabrouille et al. 2020 Enzi et al. 2020, Nadler et al. 2019,2021a,b

Pushing to Lower Mass

Dark Matter Halo Abundance

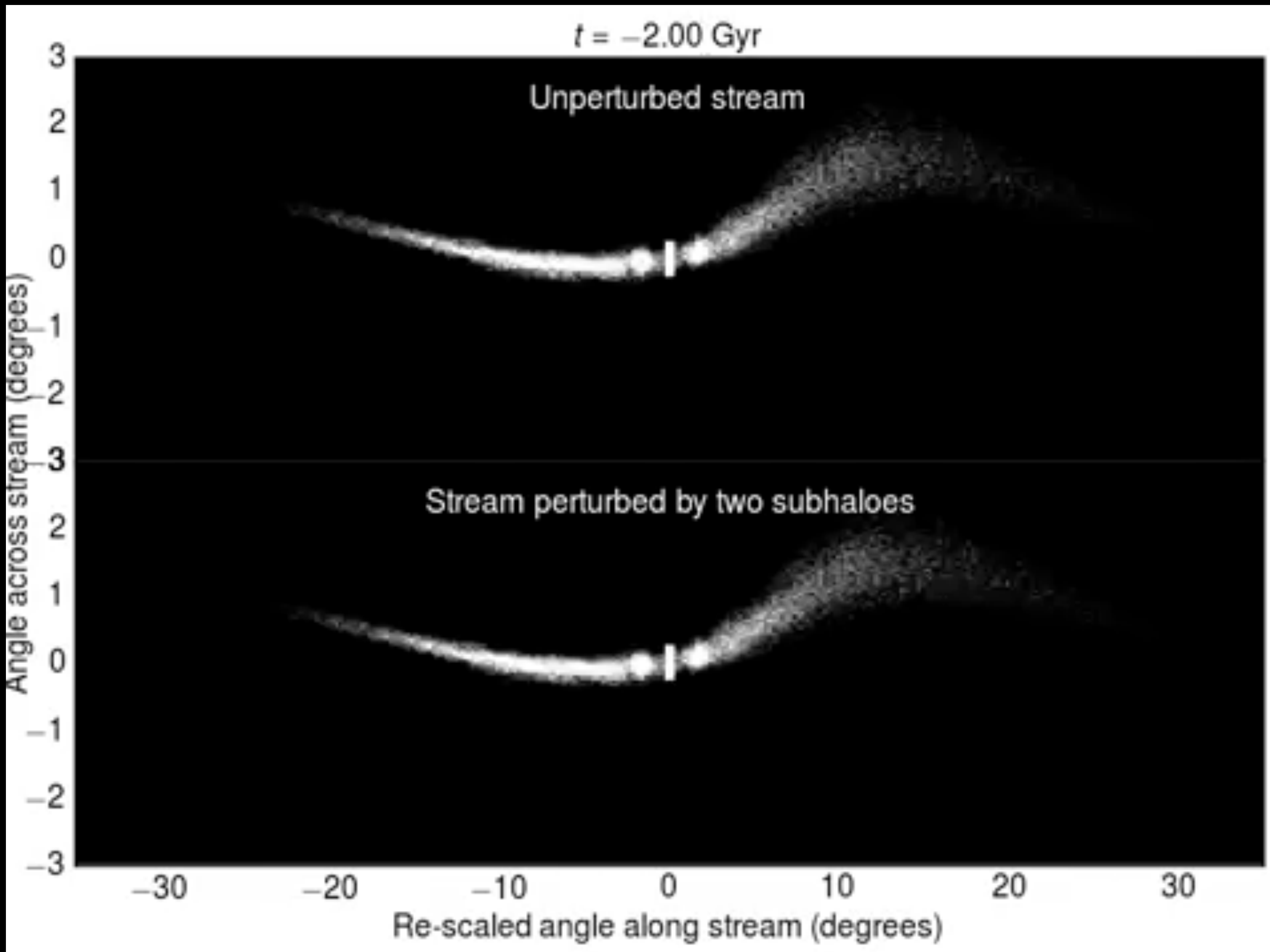


Dark Matter Halo Mass ($M_\odot$)

Standard CDM predicts the existence of **small subhalos**.

How do we detect **completely dark** subhalos?

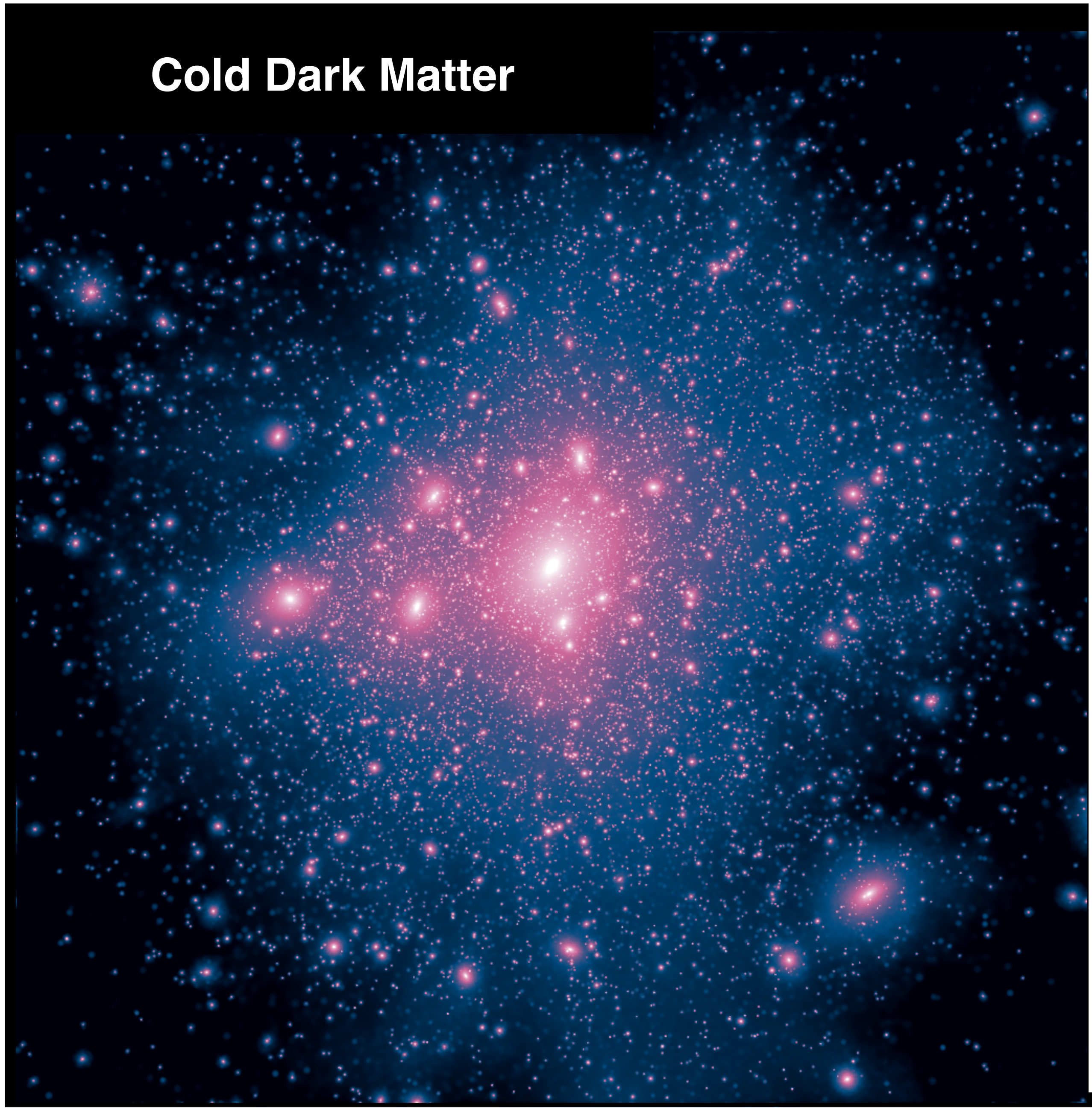
Perturbations to Tidal Streams

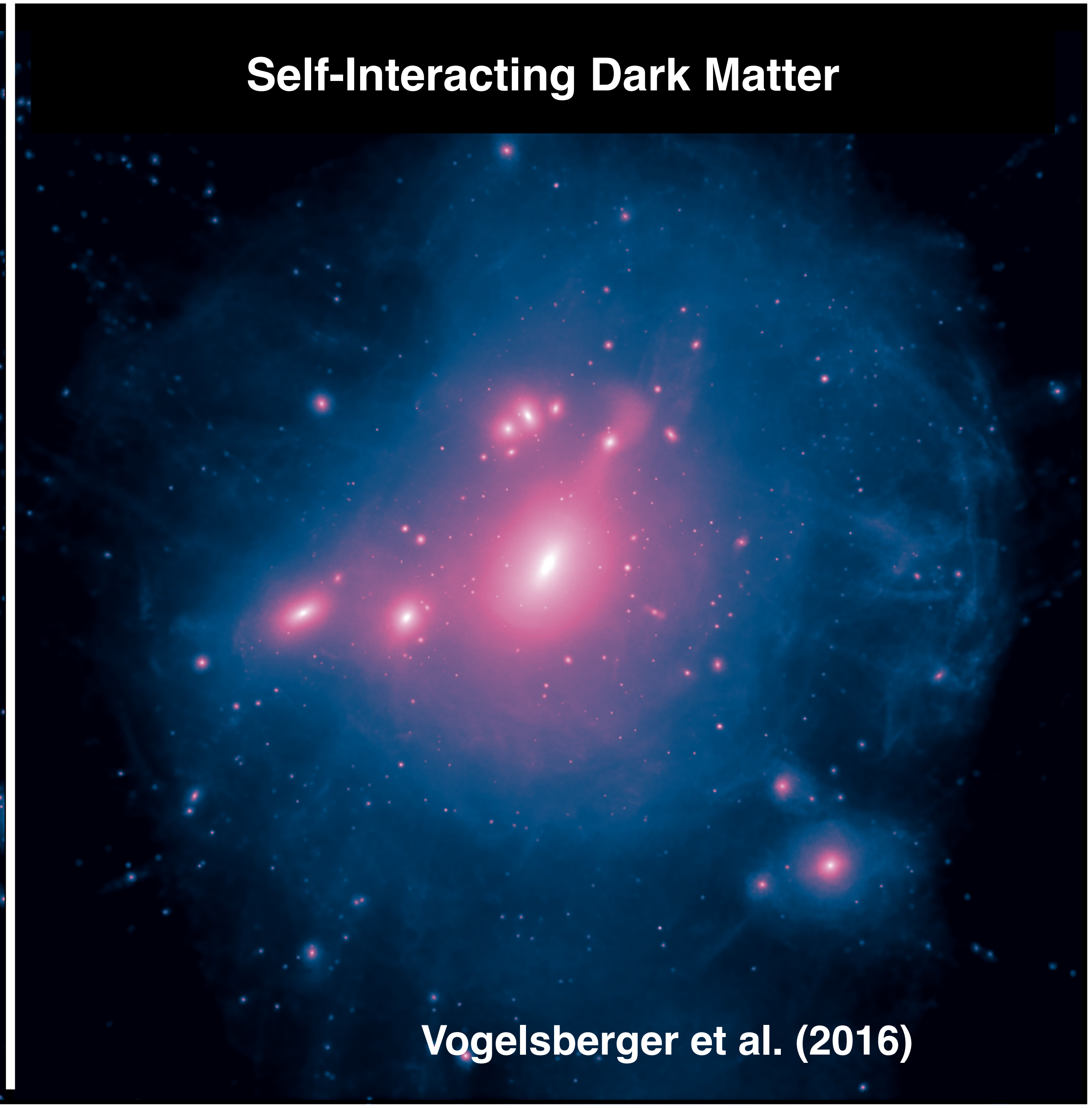


Erkal et al. (2017)

The Shapes of Dark Matter Halos

Simulations



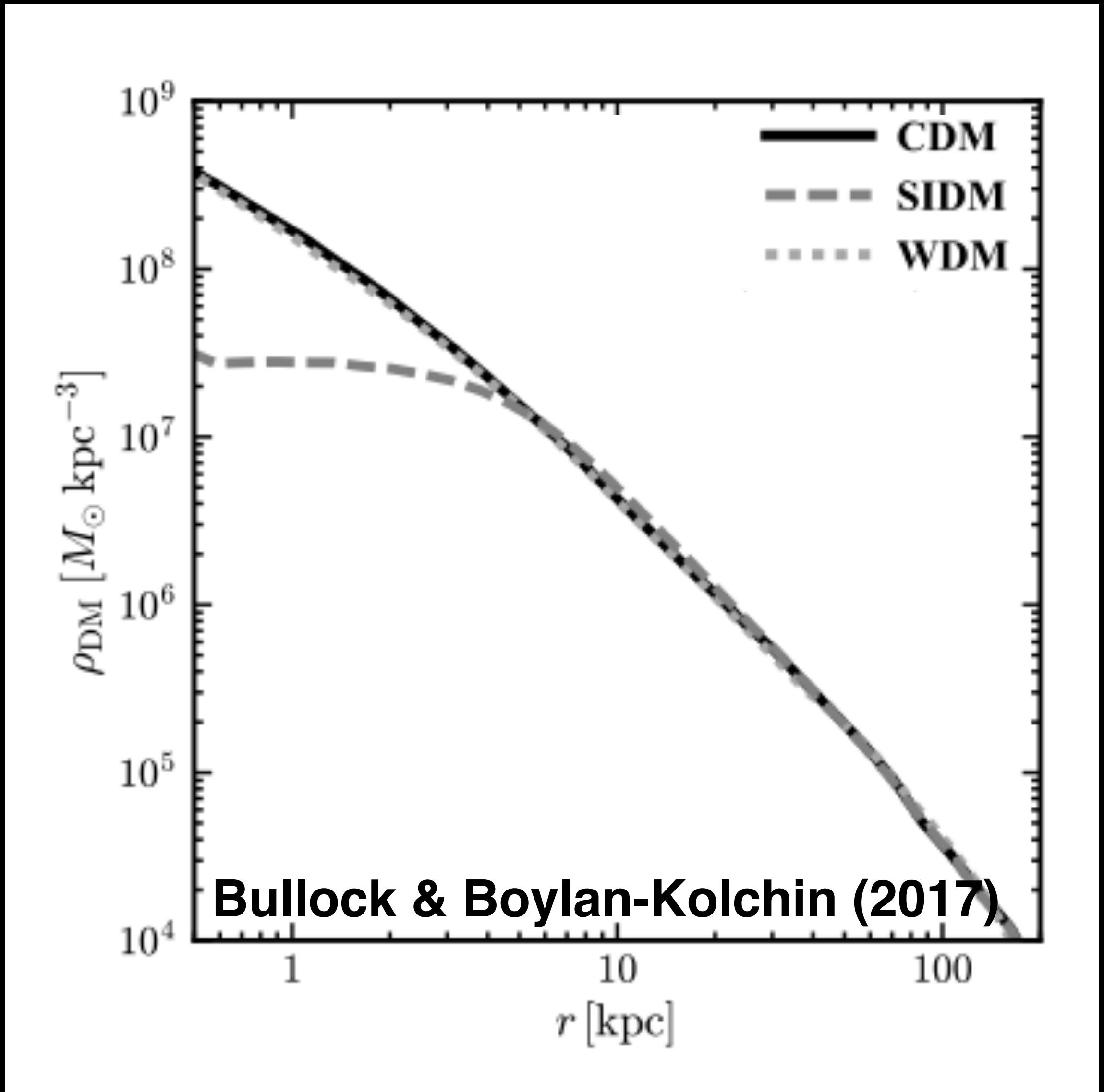


e.g., Dark photon

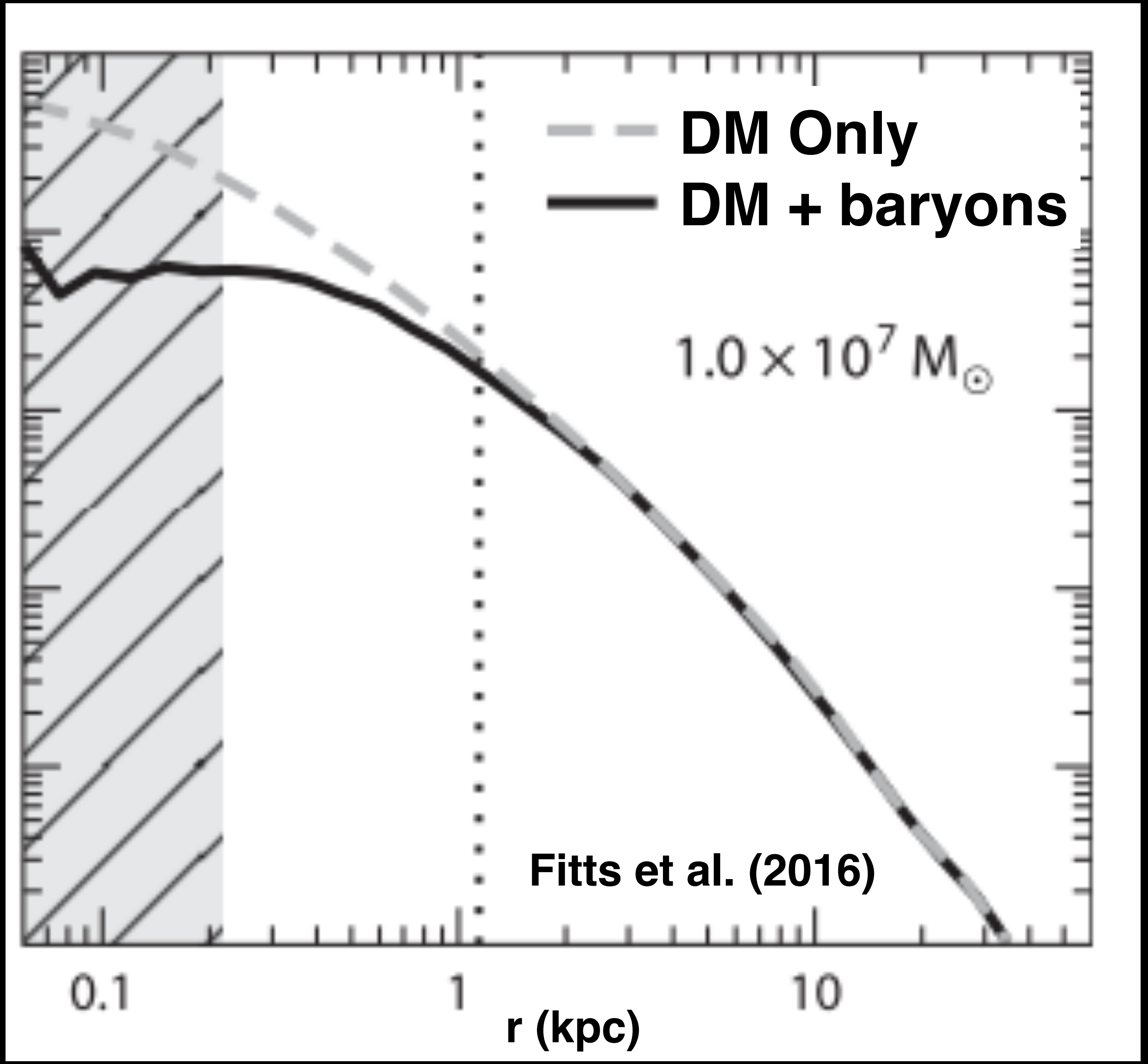
Halo Density Profiles

SIDM reduces central density… but so do baryons

Dark Matter Density

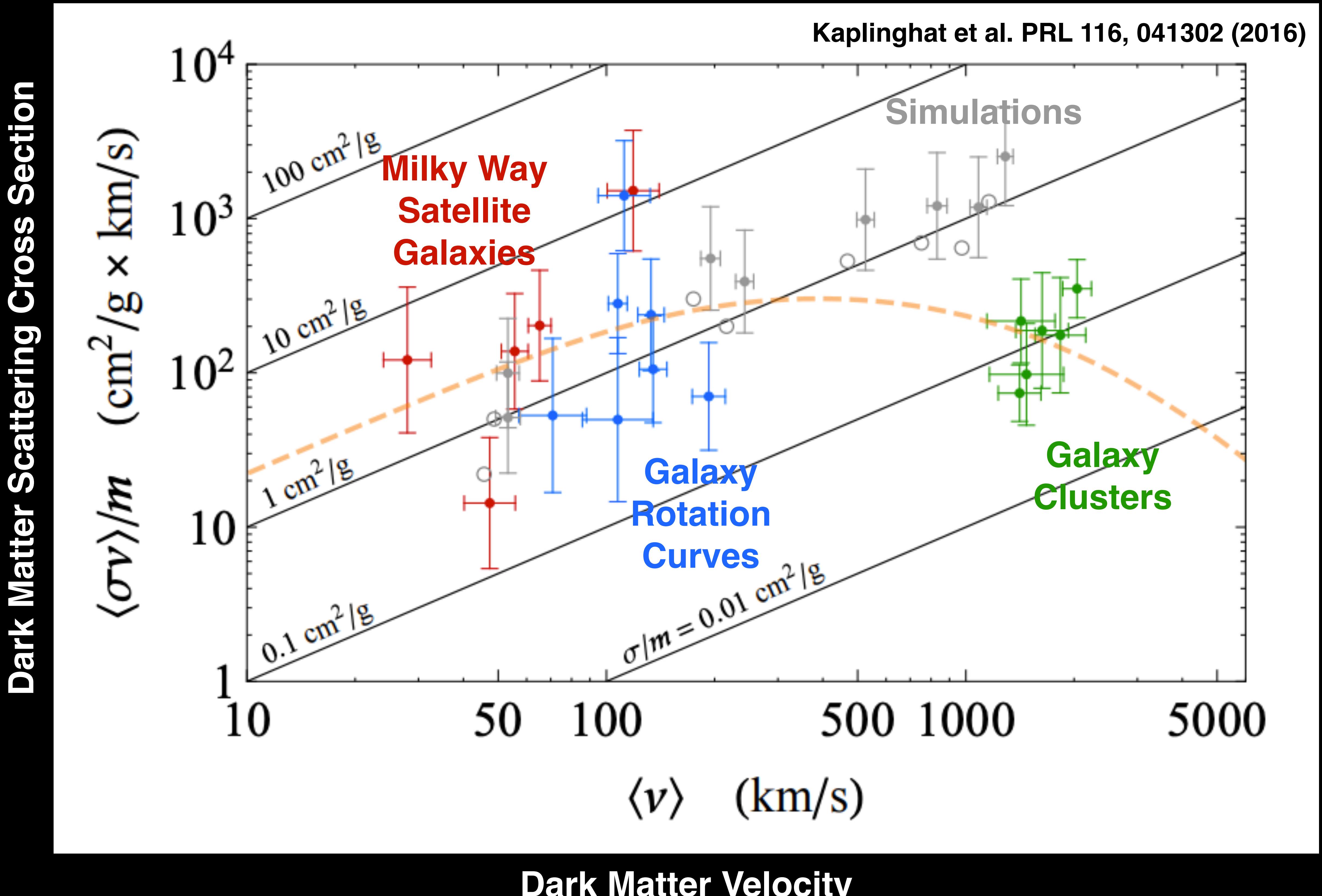


Radius from Galactic Center

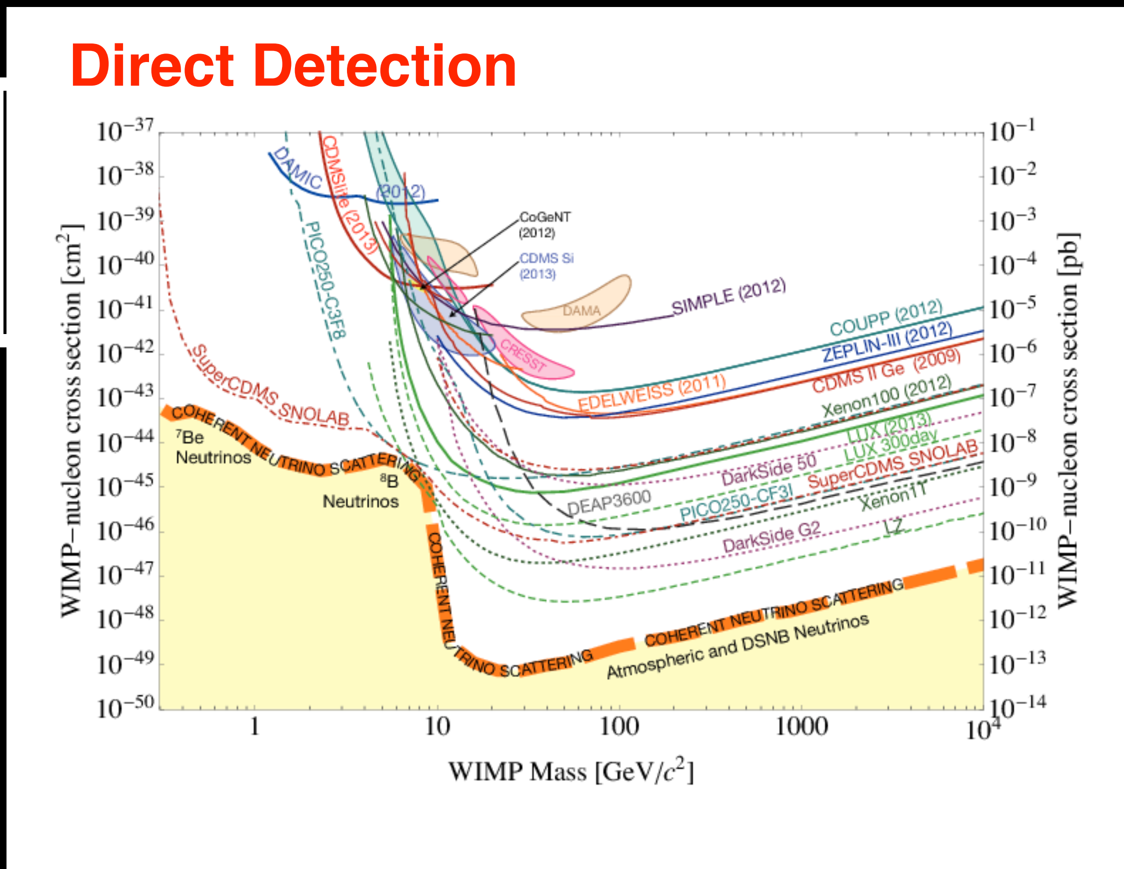


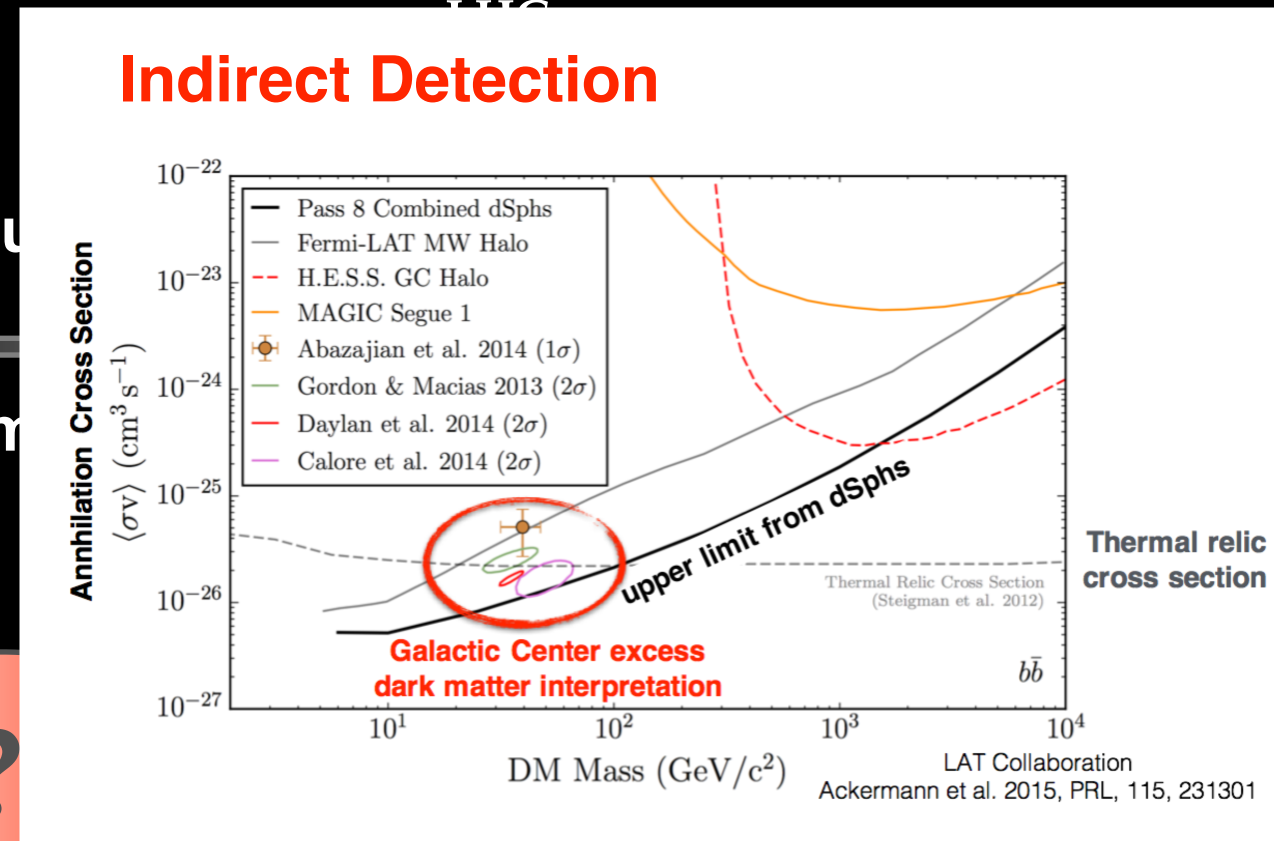
Radius from Galactic Center

Cross Section Constraints

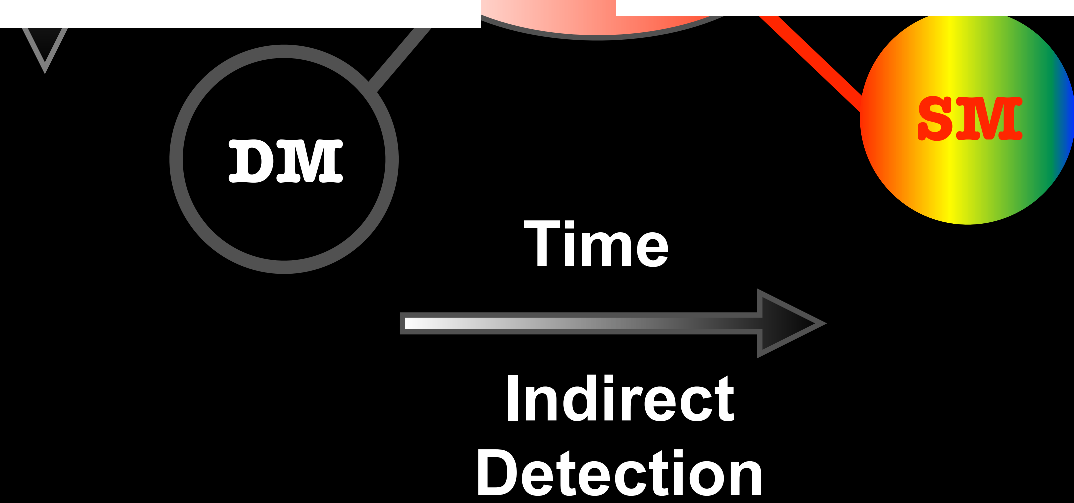


The Hunt for Dark Matter

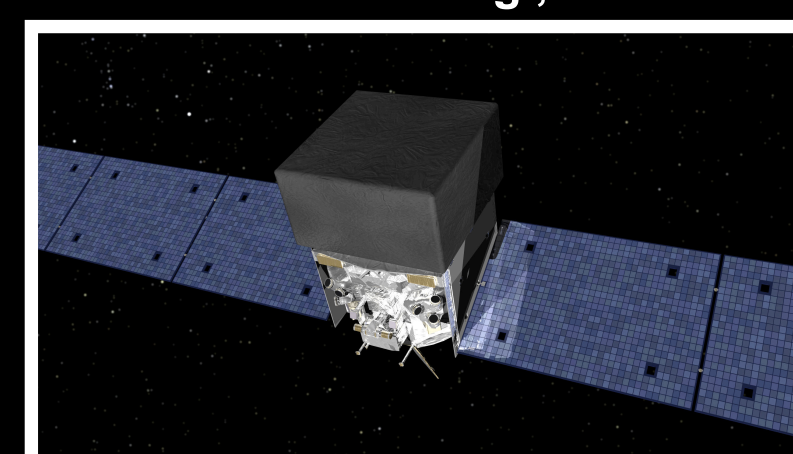


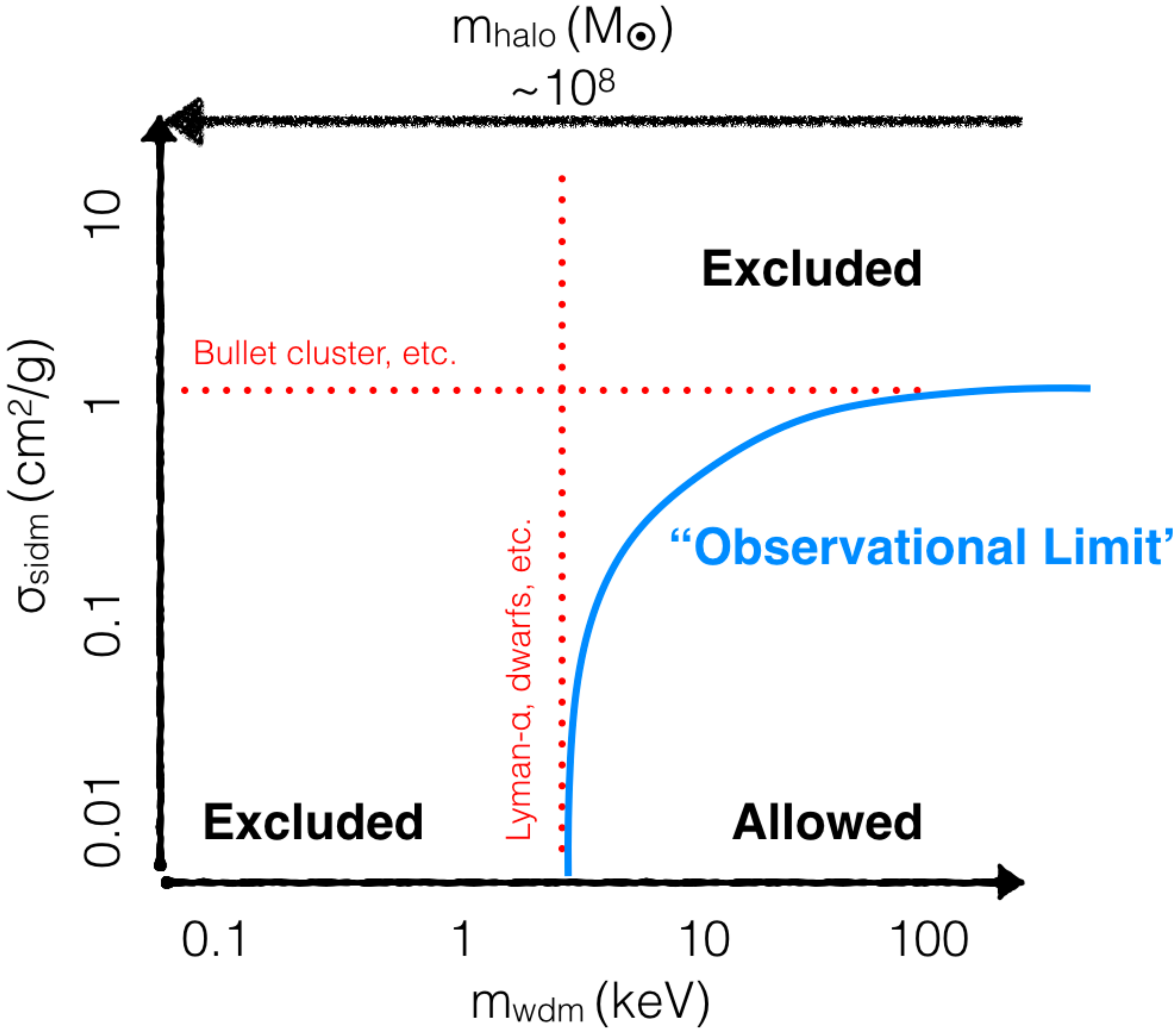


e.g., LUX



e.g., Fermi-LAT



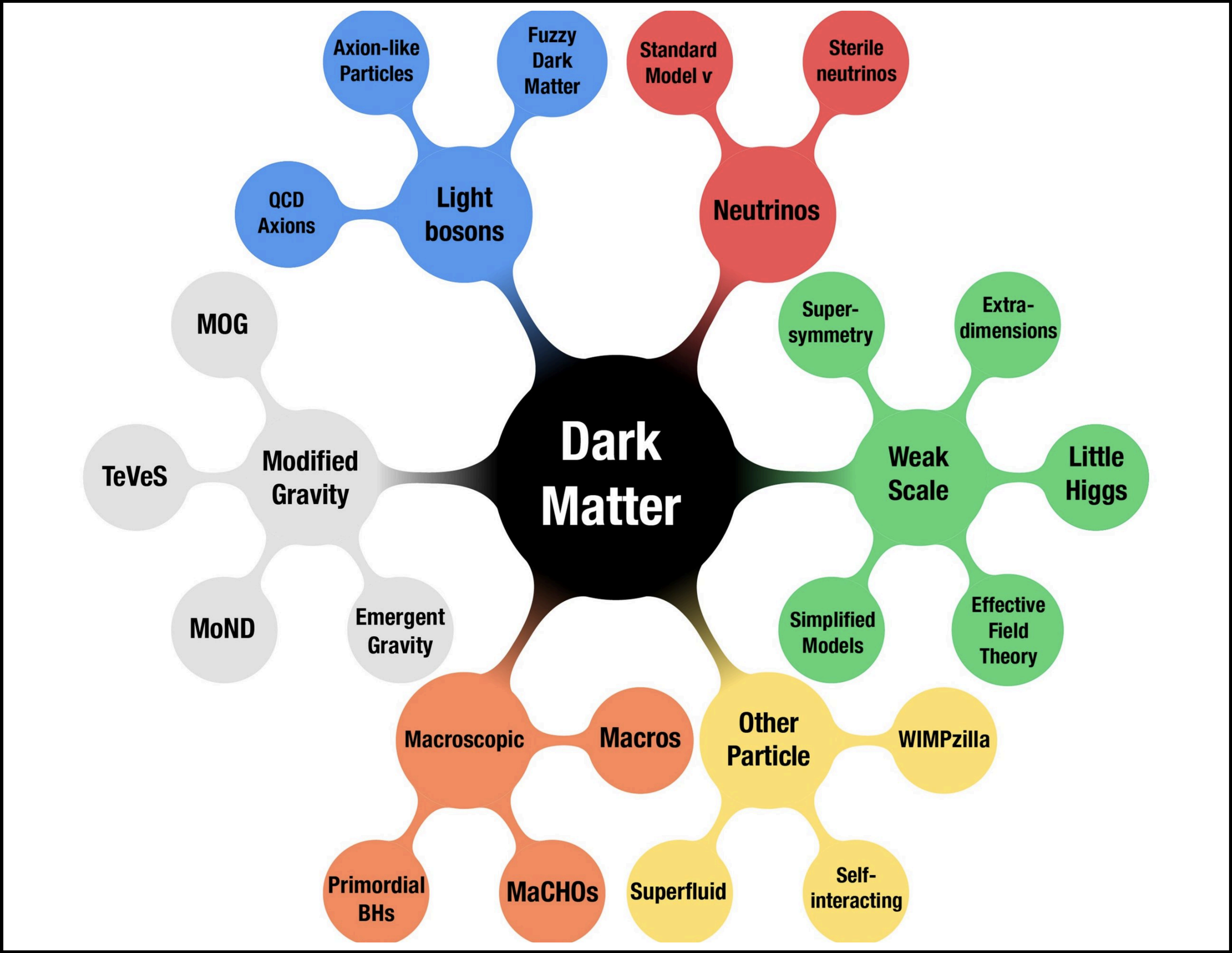


https://github.com/lsstdarkmatter/dark-matter-paper/issues/14

Use the

to learn about the

Dark Matter Candidates



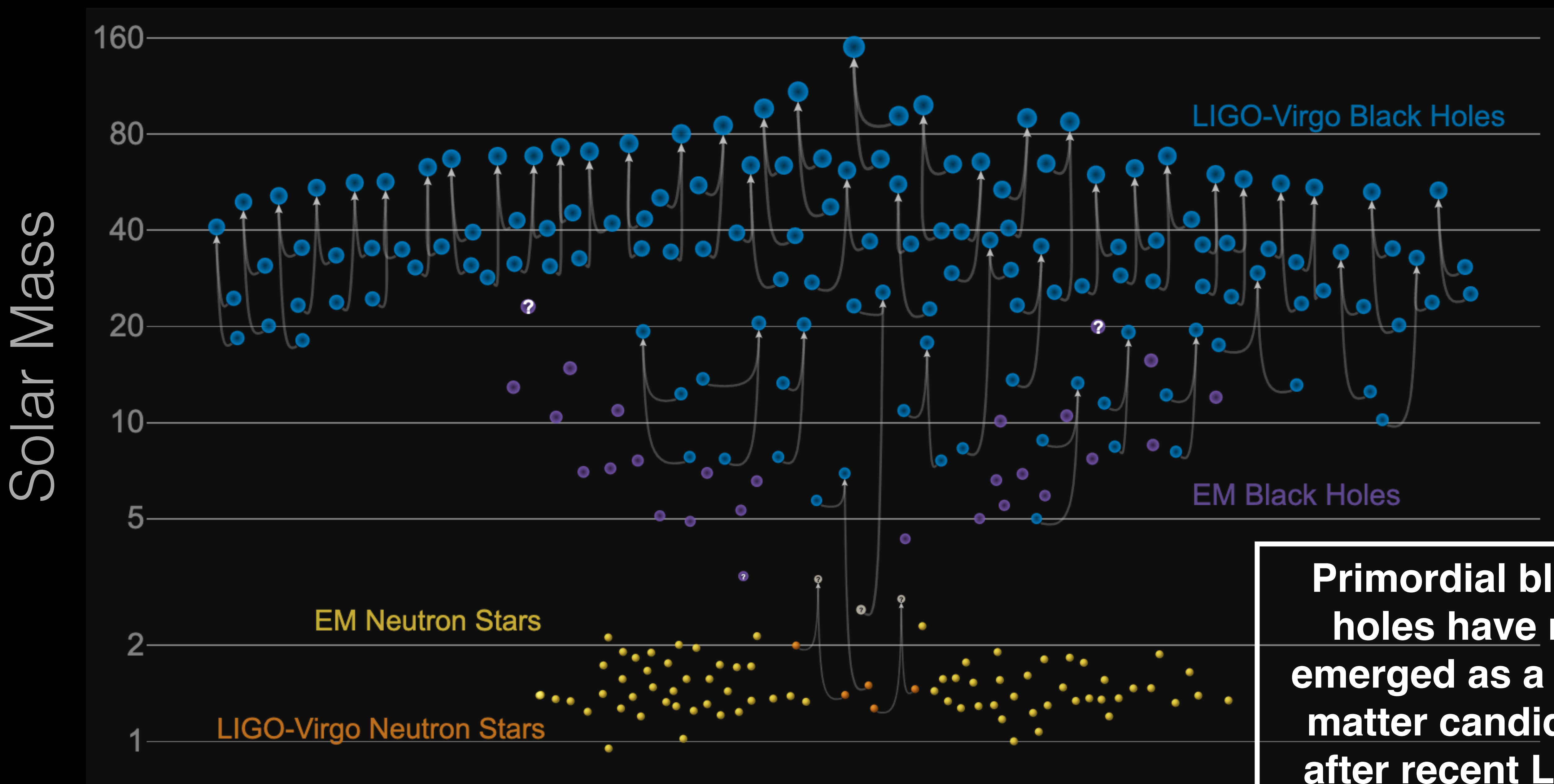
Bertone & Tait, Nature 562, 51 (2018)

Primordial Black Holes

PRL 116, 201301 (2016) PHYSICAL REVIEW LETTERS week ending 20 MAY 2016

Did LIGO Detect Dark Matter?

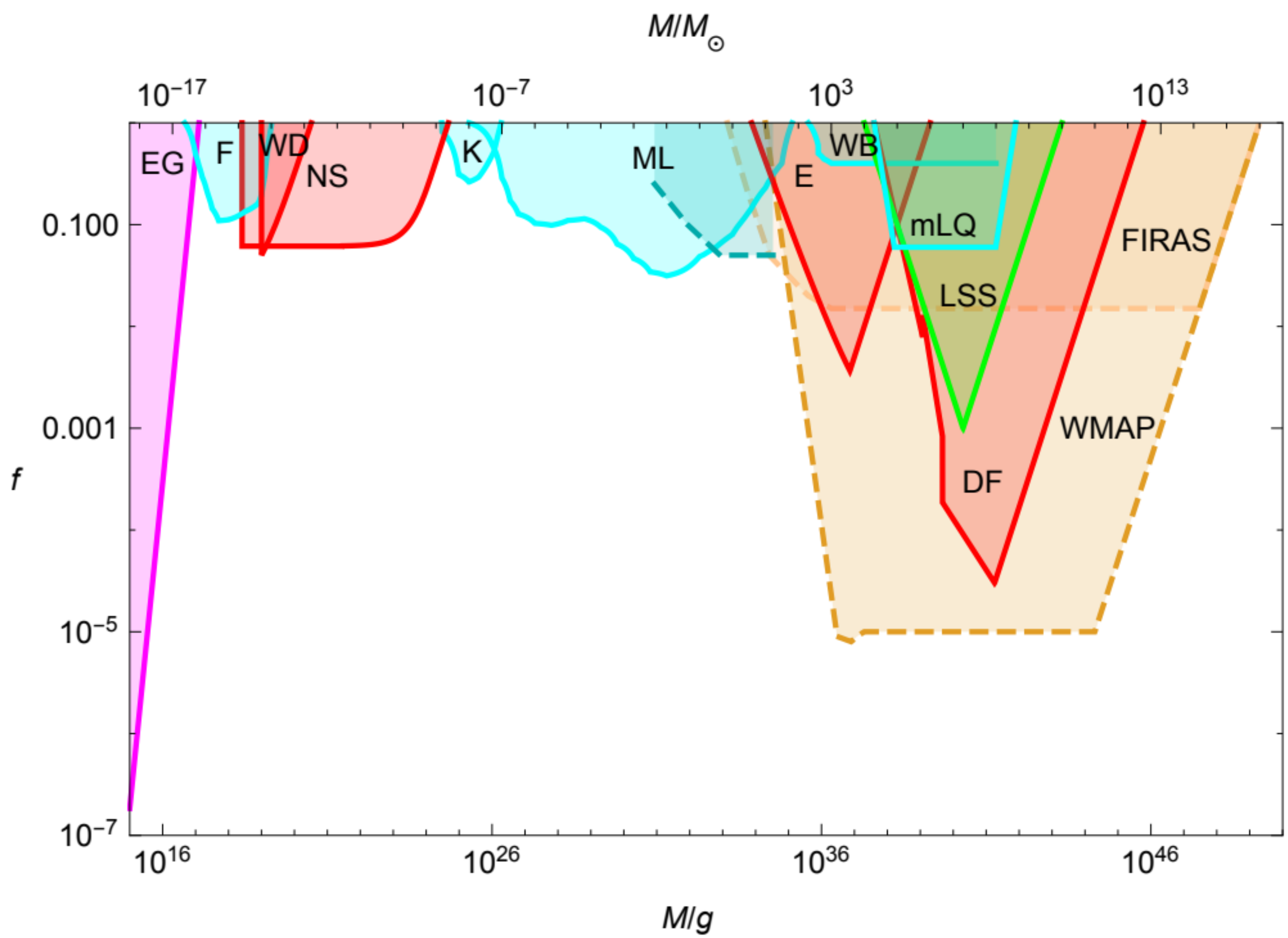
Simeon Bird,* Ilias Cholis, Julian B. Muñoz, Yacine Ali-Haïmoud, Marc Kamionkowski,
Ely D. Kovetz, Alvise Raccanelli, and Adam G. Riess



GWTC-2 plot v1.0
LIGO-Virgo | Frank Elavsky, Aaron Geller | Northwestern

Primordial black holes have re-emerged as a dark matter candidate after recent LIGO discoveries

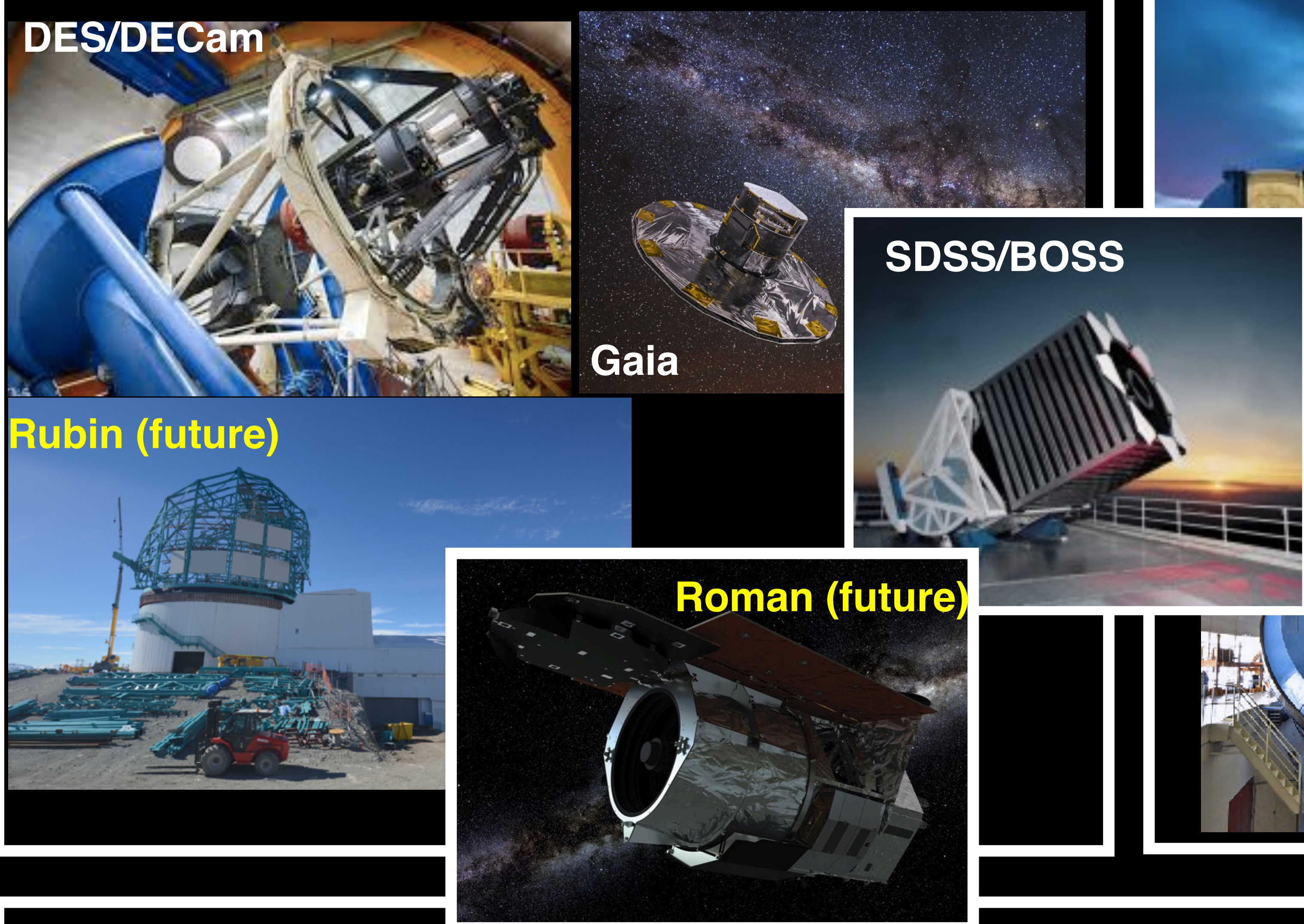
MACHO / Primordial Black Holes



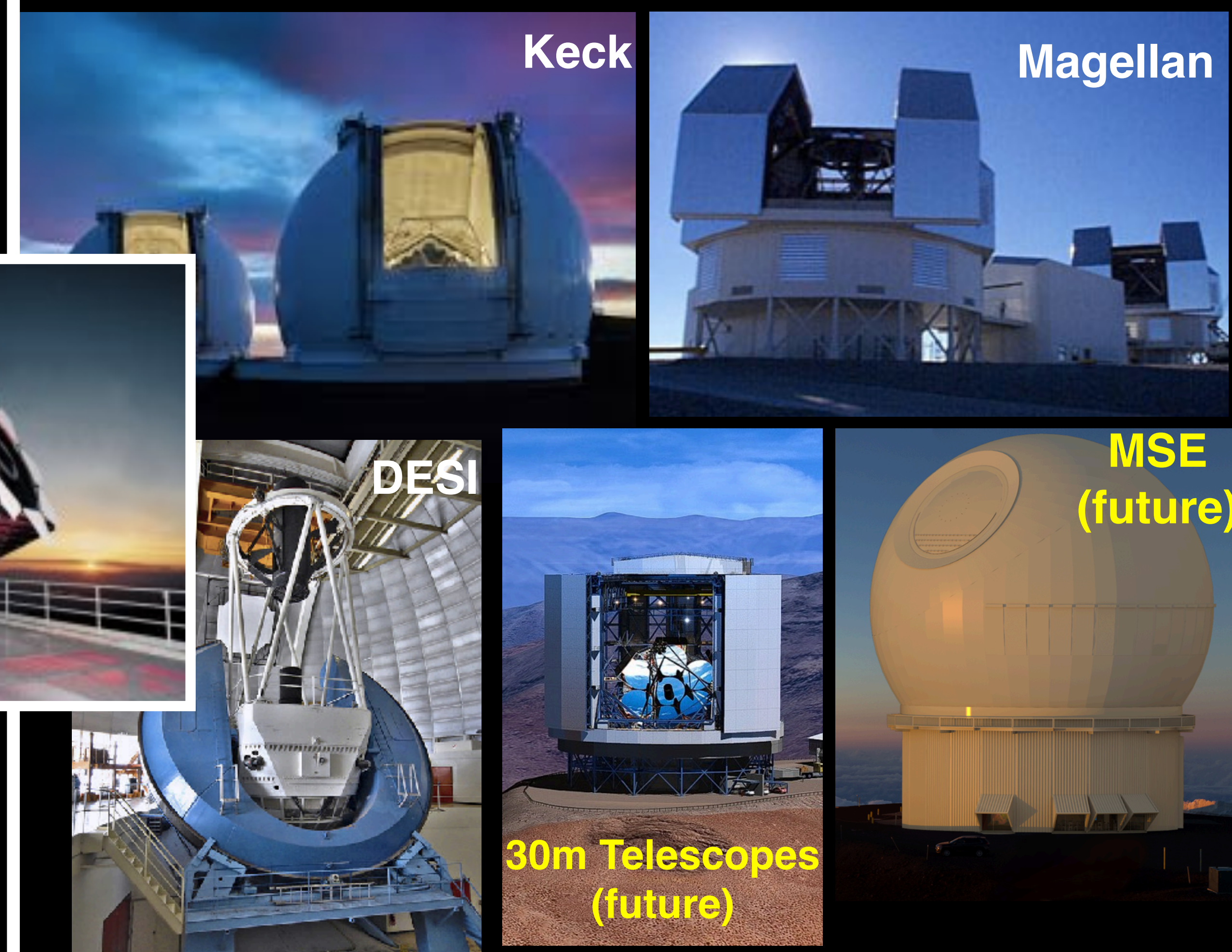
Carr et al. 2017

Current and Near-Future Experiments

Wide-Area Imaging



Spectroscopic Measurements



High Resolution Imaging

Examples of Astrophysical Probes of Dark Matter

- Dwarf Galaxy Luminosity Function
- Density Perturbation in Stellar Streams
- Galaxy-Galaxy Strong Lensing
- Galaxy Clusters for SIDM
- Microlensing for PBH

Bias: Optical Observational Stellar Spectroscopist

Probing the Fundamental Nature of Dark Matter with the Large Synoptic Survey Telescope

LSST Dark Matter Group

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Drlica-Wagner et al, 2019 arXiv:1902.01055

Astrophysical Tests of Dark Matter with Maunakea Spectroscopic Explorer

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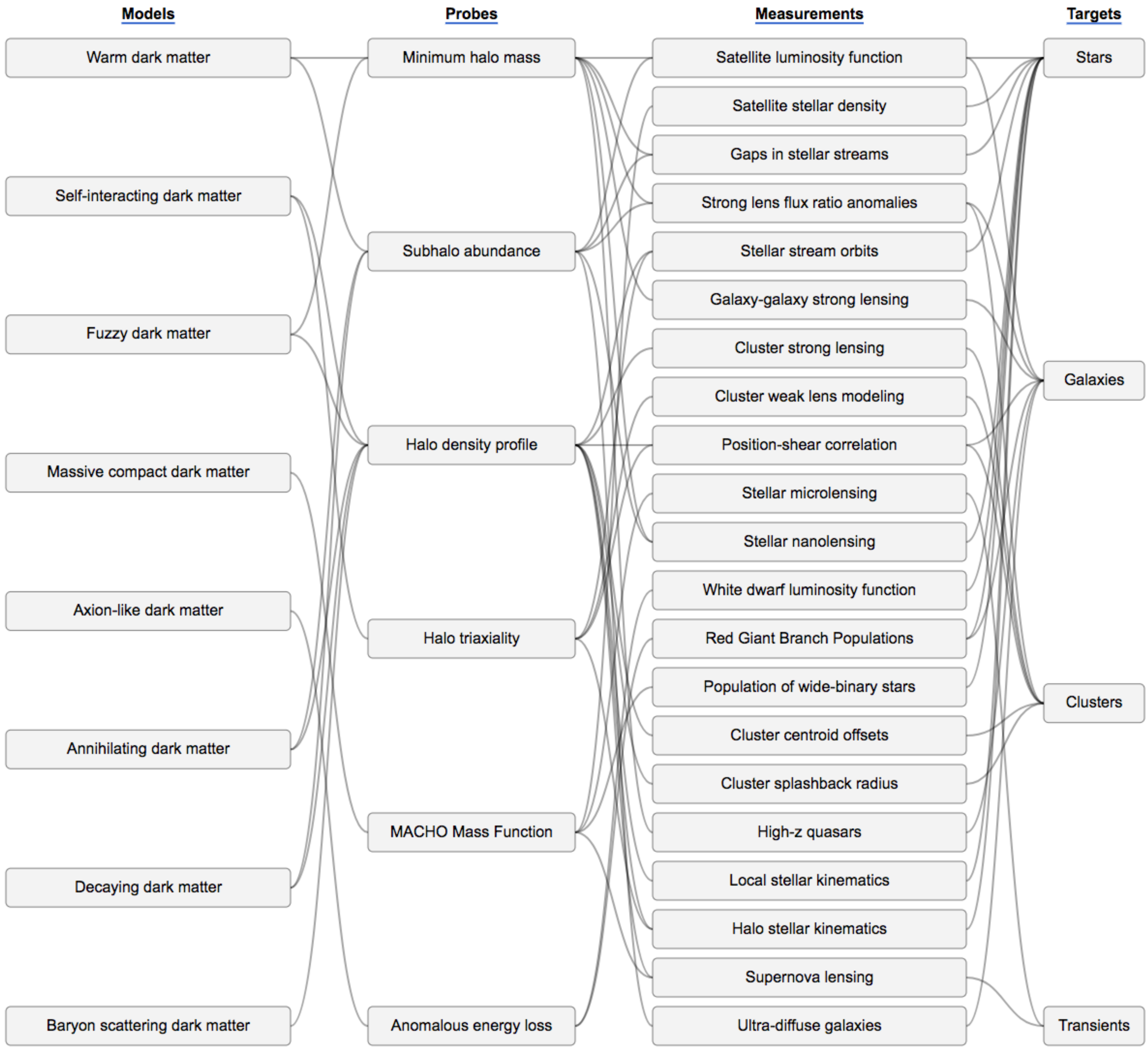
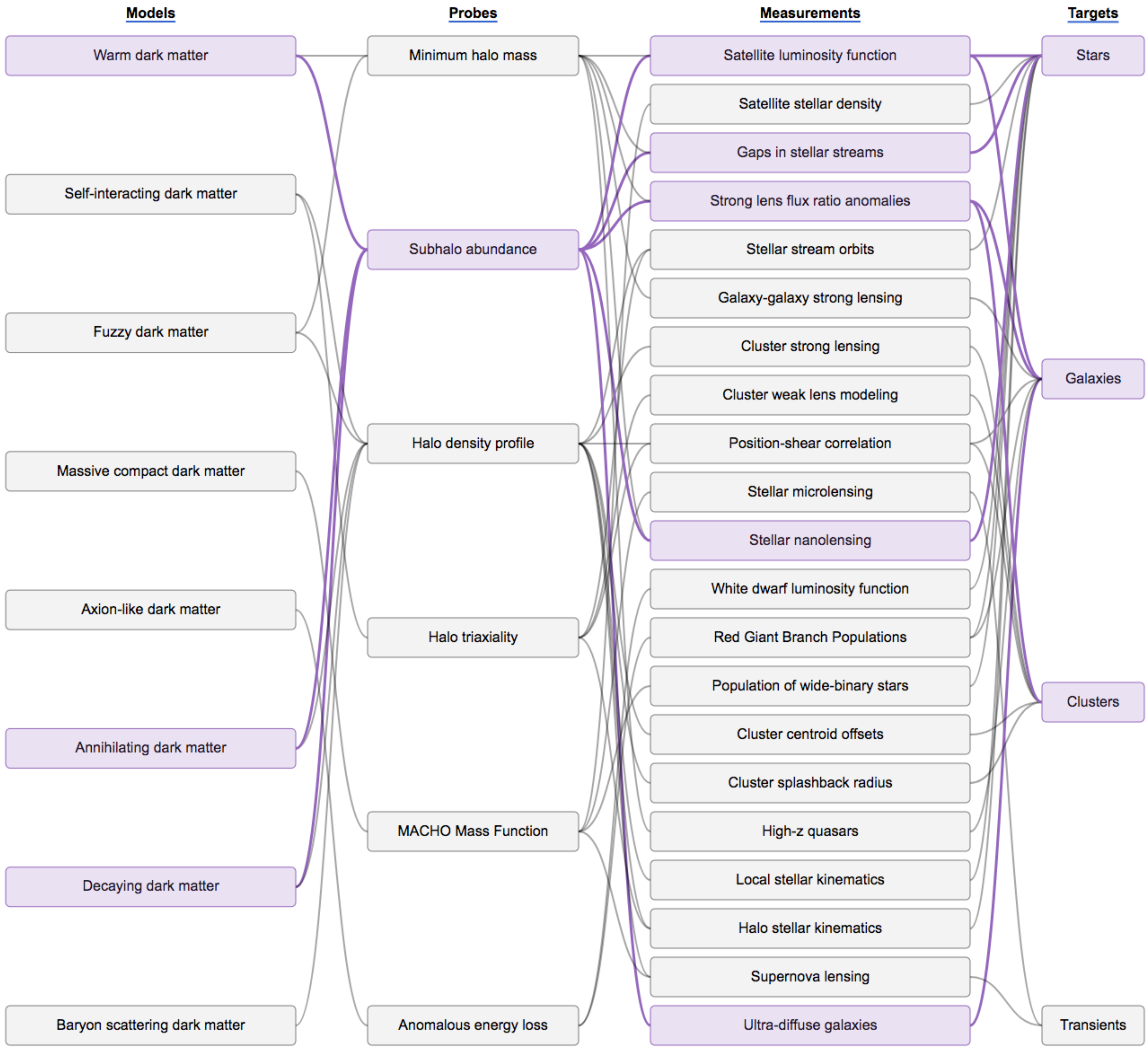
Li et al, 2019

arXiv:1903.03155



https://lsstdarkmatter.github.io/dark-matter-graph/network.html



https://lsstdarkmatter.github.io/dark-matter-graph/network.html

Summary

- Cosmic surveys probe fundamental particle physics of dark matter via gravity.
- Observations and simulations continue to improve the constraints on the dark matter model.
- Exciting new experiments are under construction!
- Next Snowmass is coming in U.S. and we should make sure Astrophysical Probes of Dark Matter will be in the next P5