Astronomical Insights into Dark Matter Particle Constraints

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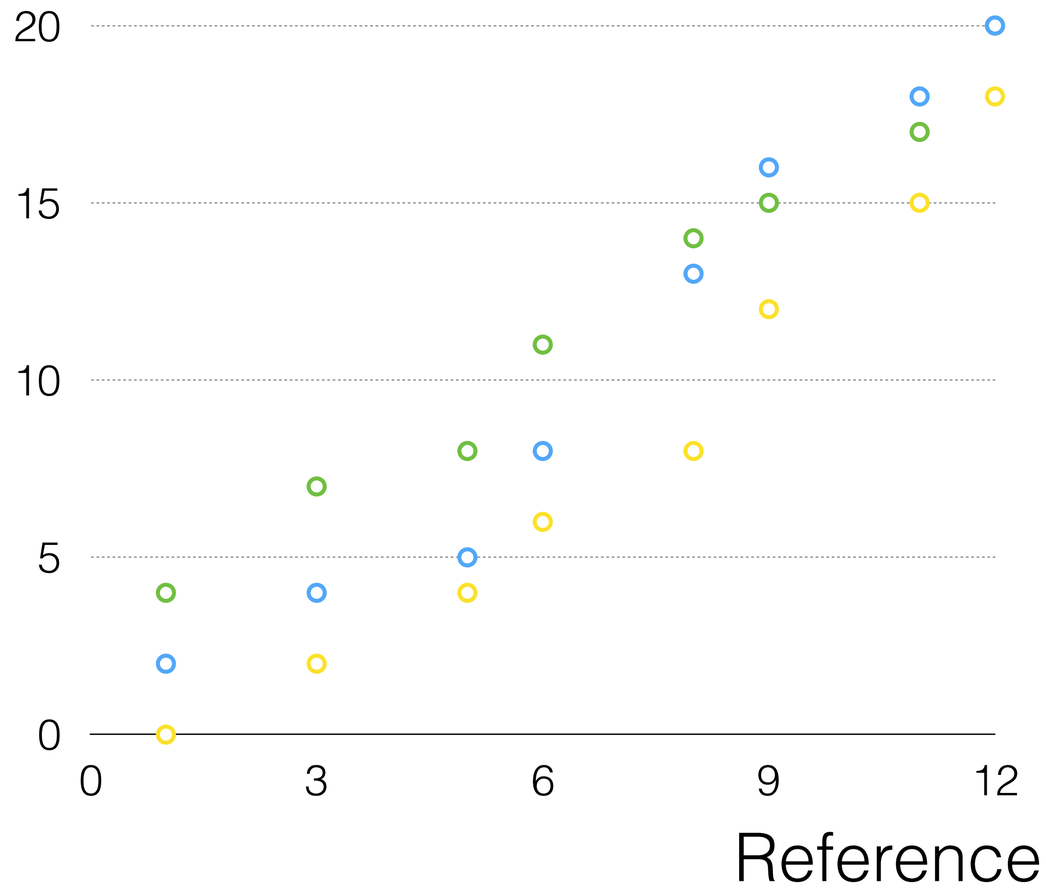
LLNL-PRES-680590
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

The vast majority of our understanding of dark matter has come from astrophysical probes.

We are just hitting our stride!

Astronomical probe

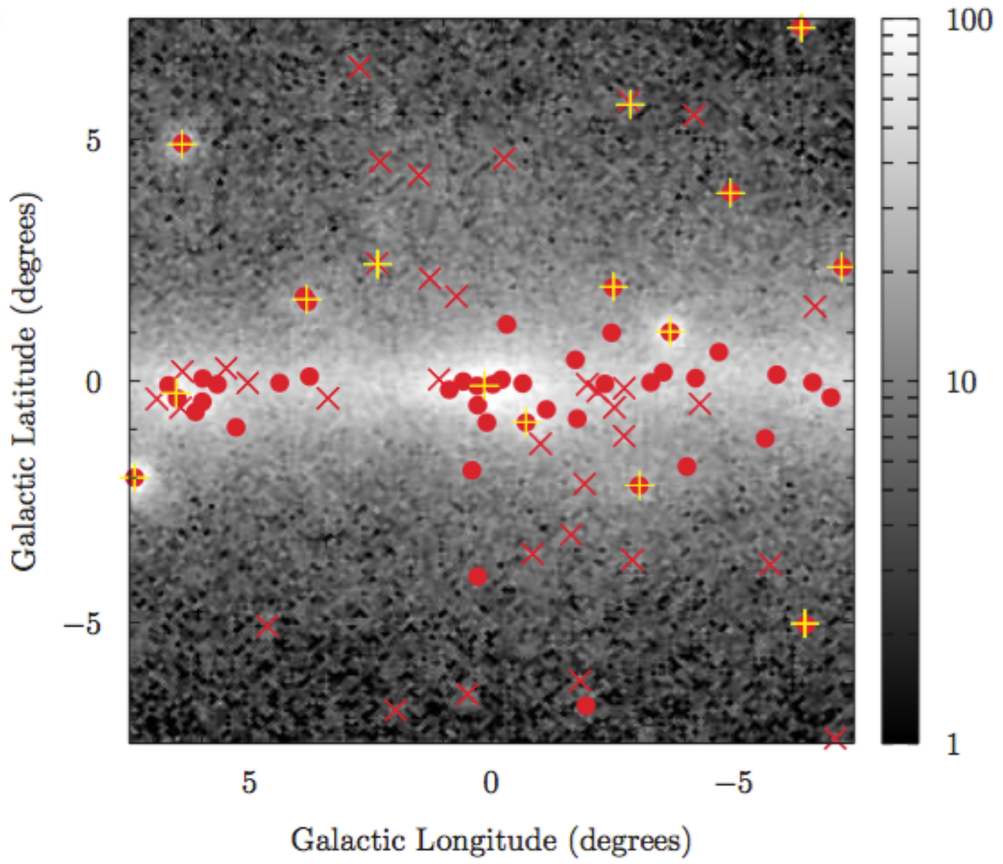
- What about dark matter it constrains
- How it works
- Biggest strengths
- Biggest weaknesses
- Telescope / detector / method



annihilation cross-section / mass

Gamma-ray emission

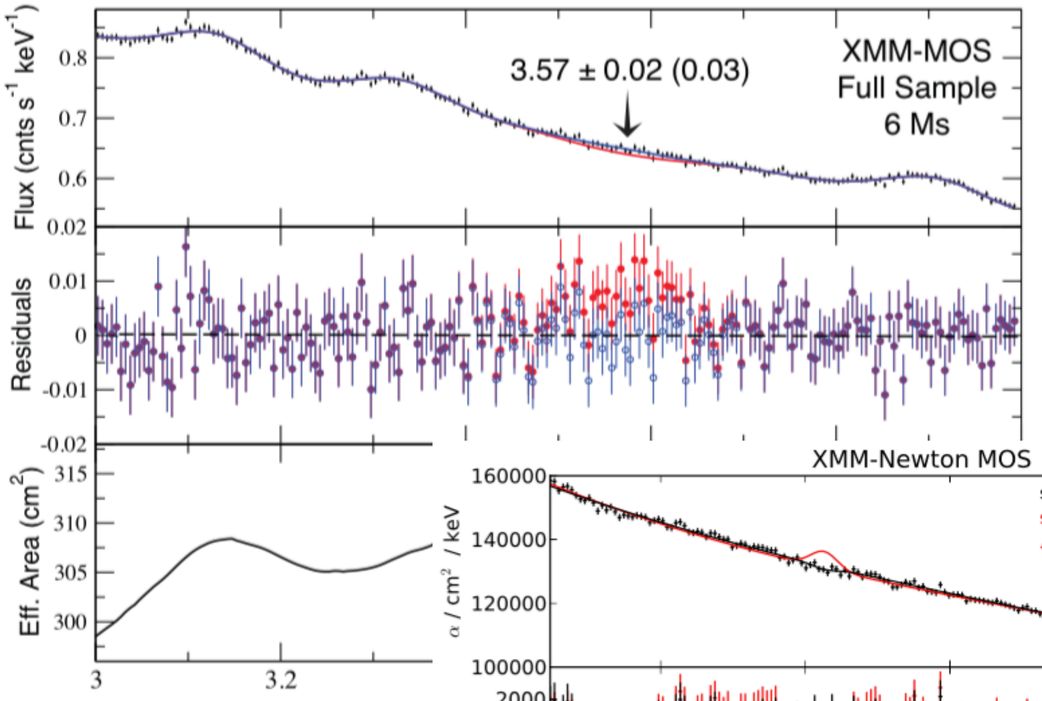
- Look for Gamma-ray decay product in dwarfs, galaxies, and clusters
- Pro: clear signal in center of Milky Way
- Con: could be baryons (e.g. pulsars); not seen in dwarfs or clusters
- Fermi, Cherenkov Telescopes, [CTA], [PANGU]



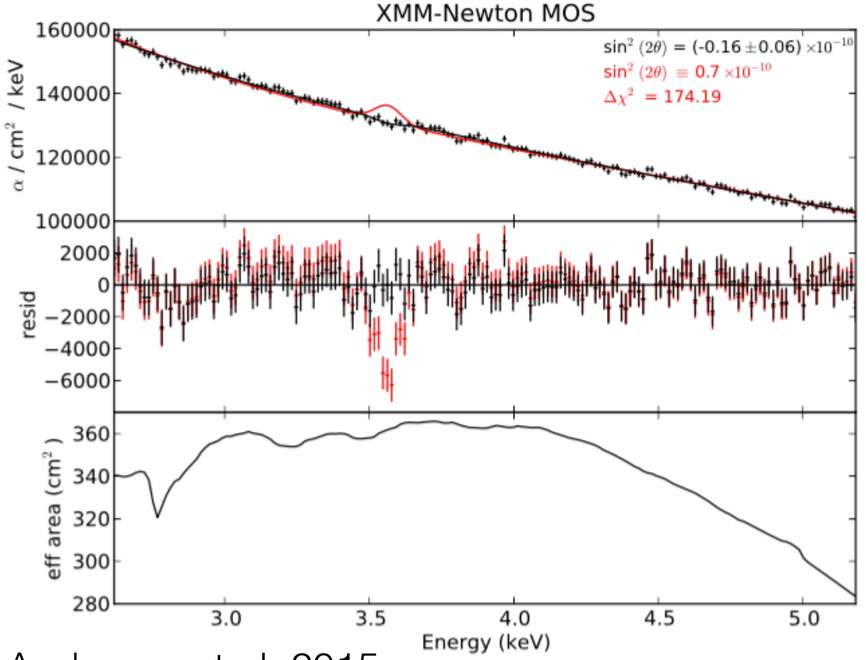
Fermi Collaboration 2015

X-ray Emission

- Look for X-ray decay product in galaxies, and clusters
- Pro: a signal has been seen; could use merging clusters
- Con: could be baryons (e.g. potassium); mixed results, not seen in stacked galaxies
- Chandra, XMM, Suzaku, NuStar, [Astro-H], [Smart-X]



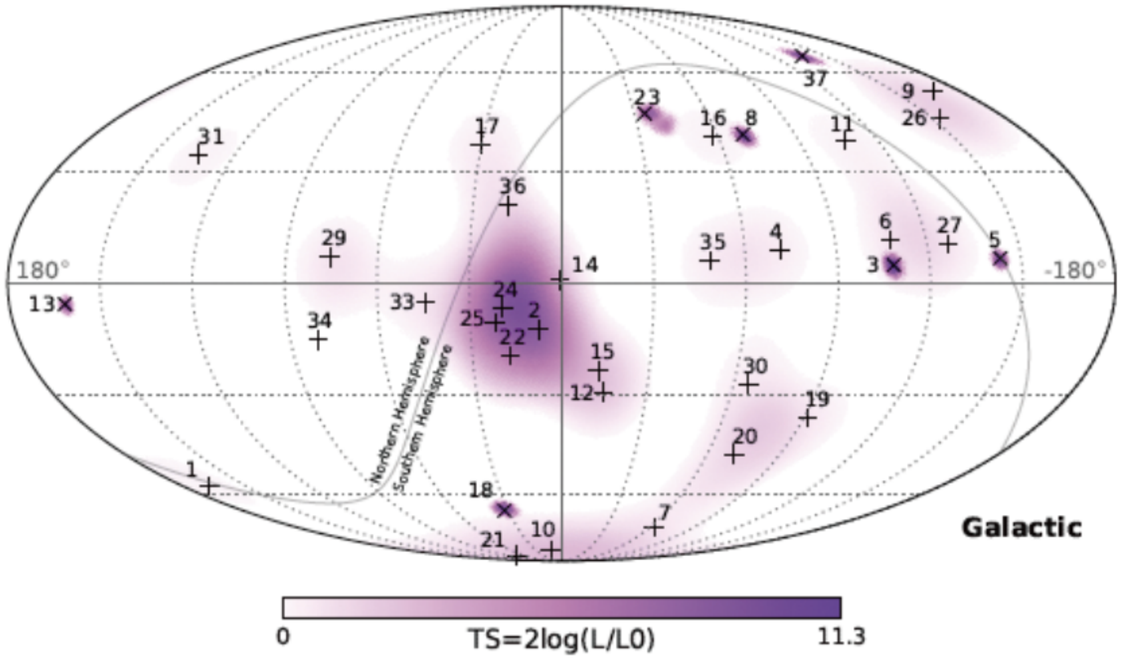
Bulbul et al. 2014



Anderson et al. 2015

Neutrinos

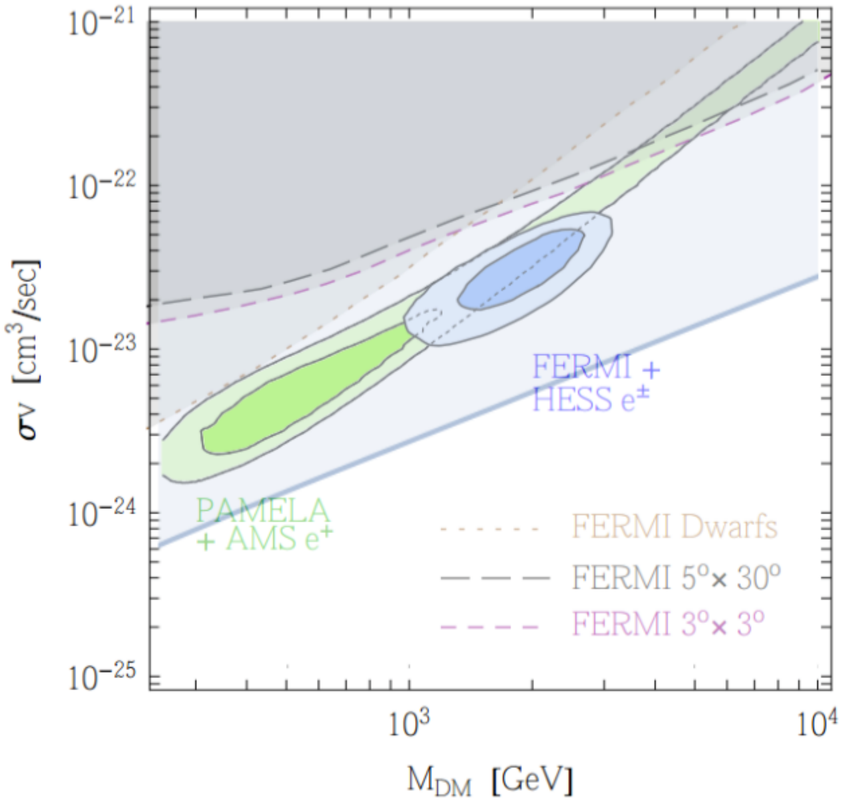
- Look for neutrino annihilation products of DM gravitationally trapped in the sun or earth; anisotropy in the neutrino arrival distribution
- Pro: also constraint of scattering cross-section
- Con: large PSF; lower SNR; lots of modeling uncertainty
- Neutrino detectors (e.g., IceCube)



Rott 2015, AAPPS Bulletin

Positrons

- Detect local fraction of positrons, which could be decay product of DM
- Pro: strong signal
- Con: could be baryons; Neutrinos and CMB are inconsistent with DM source picture
- PAMALA, AMS-02

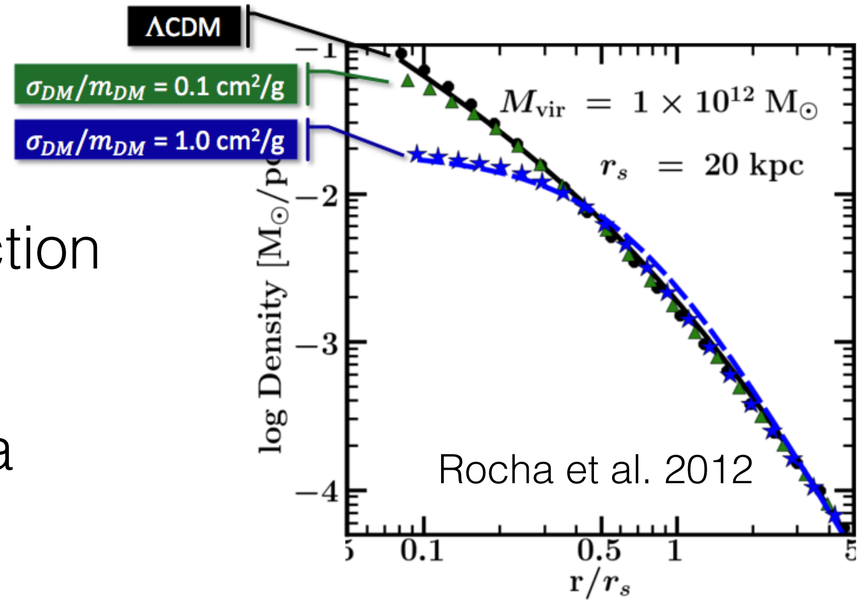


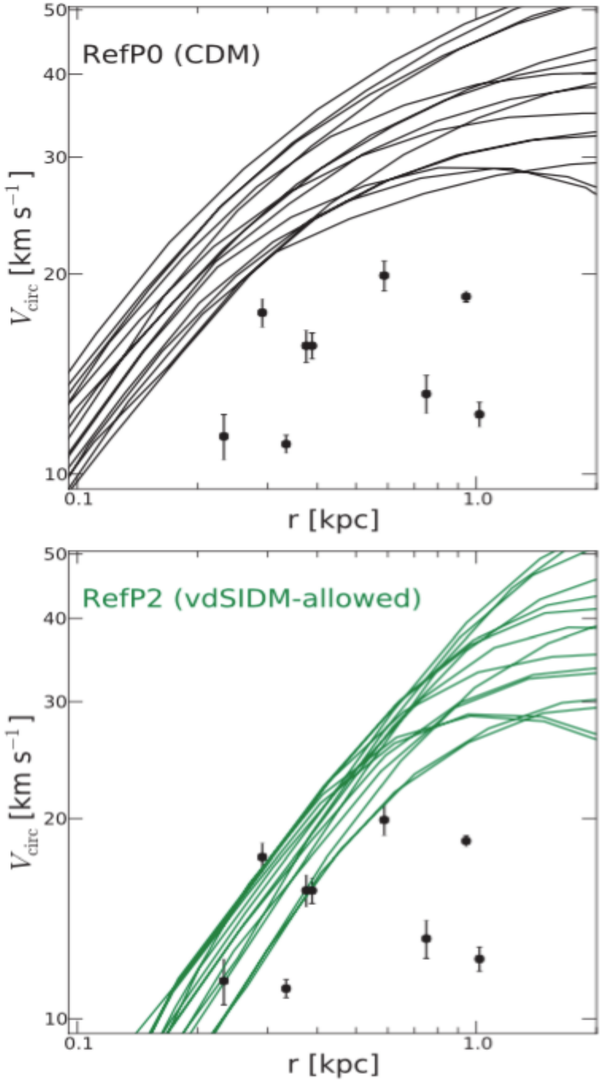
Tracy Slatyer (AMS Days @ CERN 2015)
modified version of figure from Cirelli et al. 2008

scattering cross-section / mass

Dwarf galaxies: mass profile

- AKA: cusp-core problem, Too-Big-To-Fail
- Measure velocity of stars to infer DM density distribution
- DM dominated structures; very sensitive to scattering cross-section
- DM signal is degenerate with baryonic effects (e.g. supernova feedback)
- Optical survey, spectroscopy

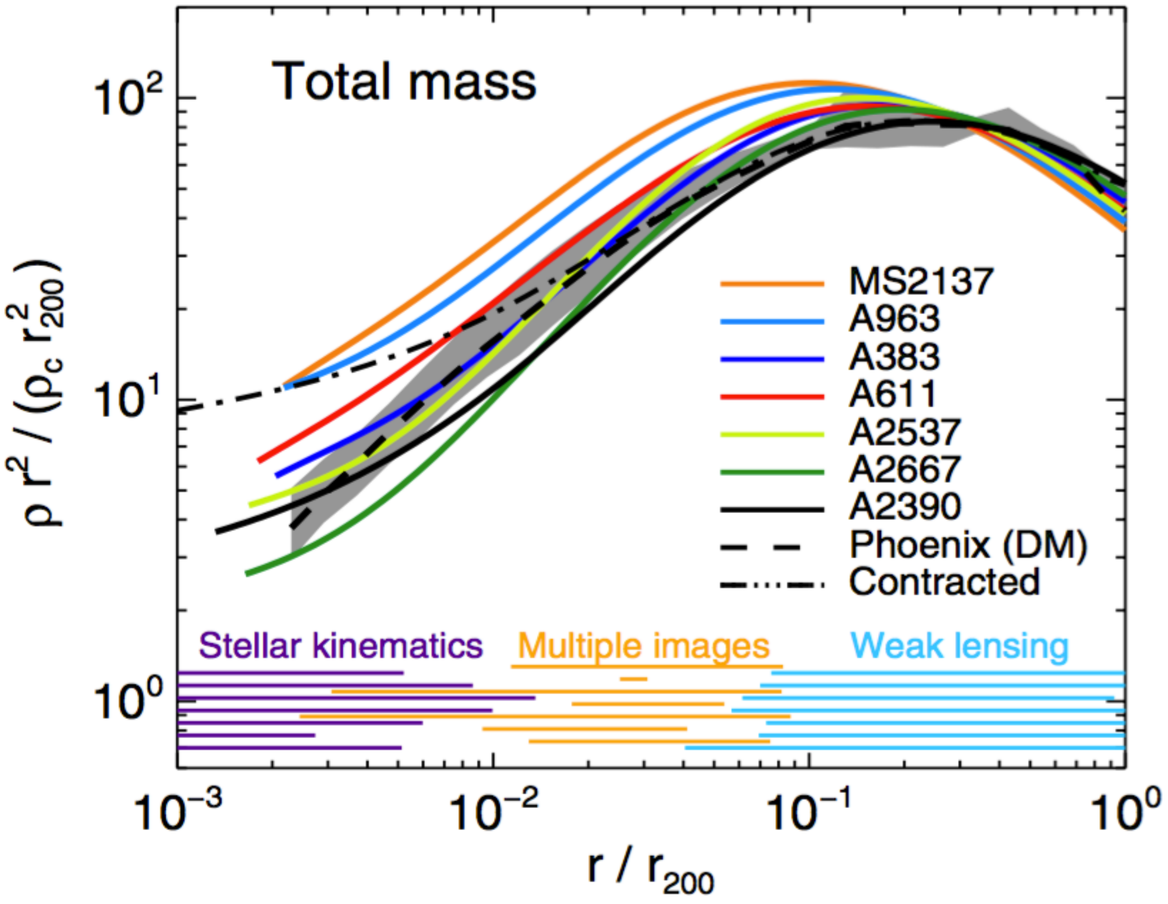




Vogelsberger et al. 2012

Galaxy clusters: mass profile

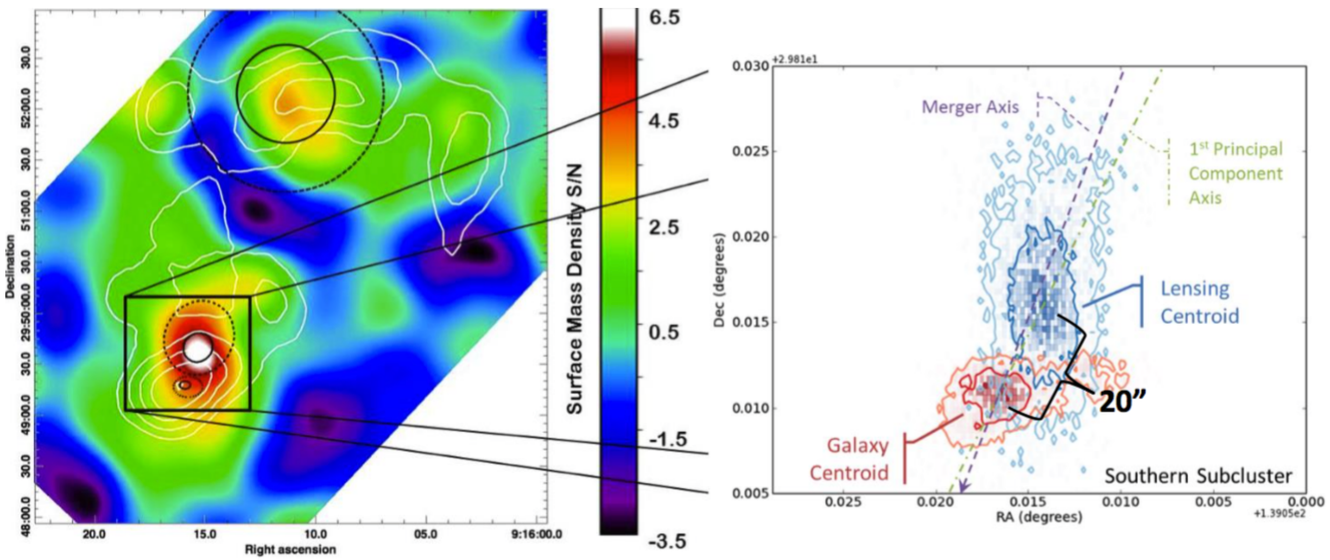
- SIDM will cause cored density profile; measure with BCG velocity dispersion, strong & weak lensing
- Pro: different physics and velocities compared to dwarfs
- Con: many degenerate baryonic effects (e.g. AGN feedback); scale of order BCG
- Optical (space) photometry and spectroscopy



Newman et al. 2012

Merging Galaxy Clusters

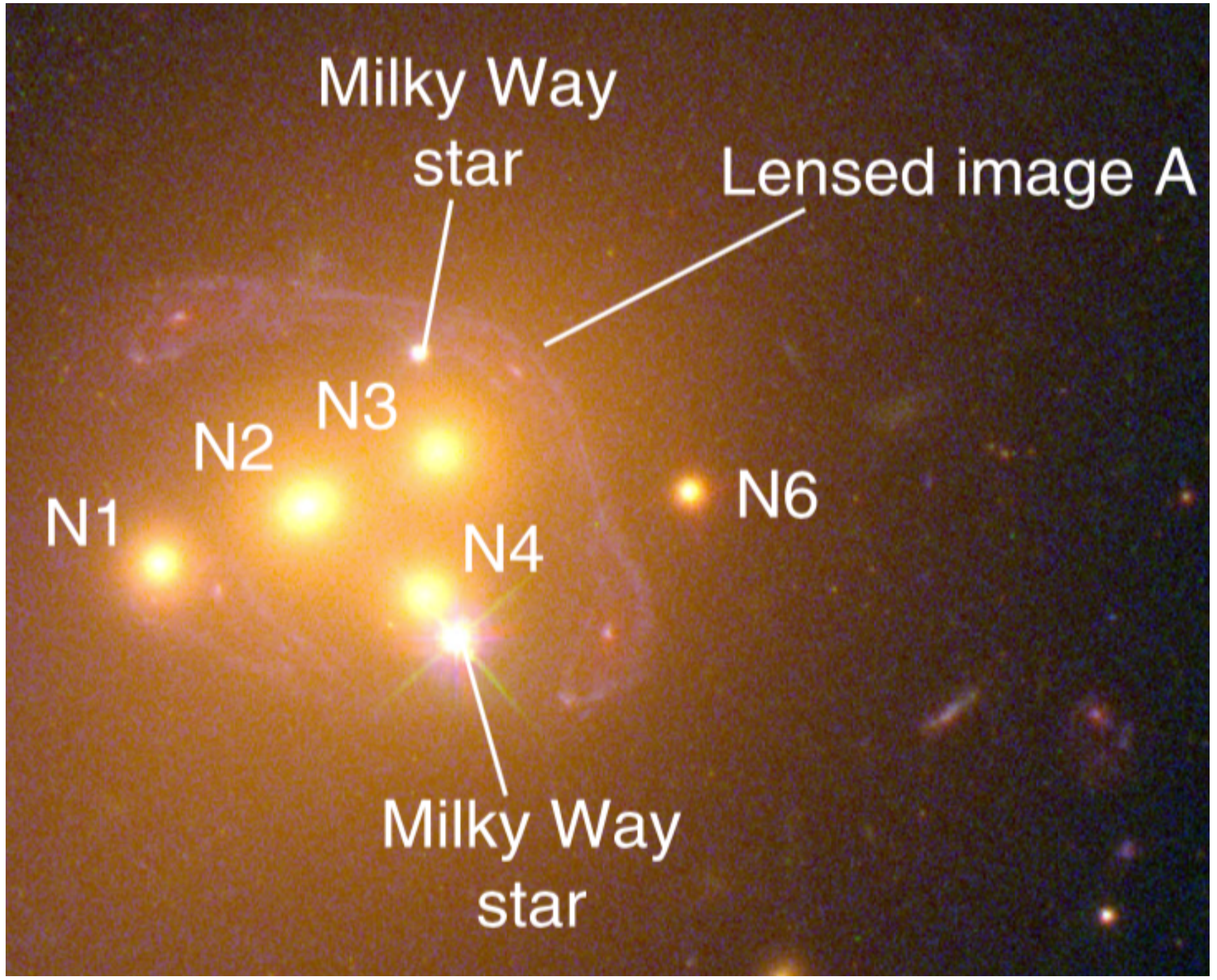
- Look for offsets between distribution of effectively collisionless galaxies and potentially self-interacting DM
- Pro: weakly sensitive to baryonic systematics; directional signal
- Con: complex; requires simulations to translate offset to DM constraint
- Optical photometry & spectroscopy; radio and X-ray help



Dawson 2013

Galaxies falling into clusters

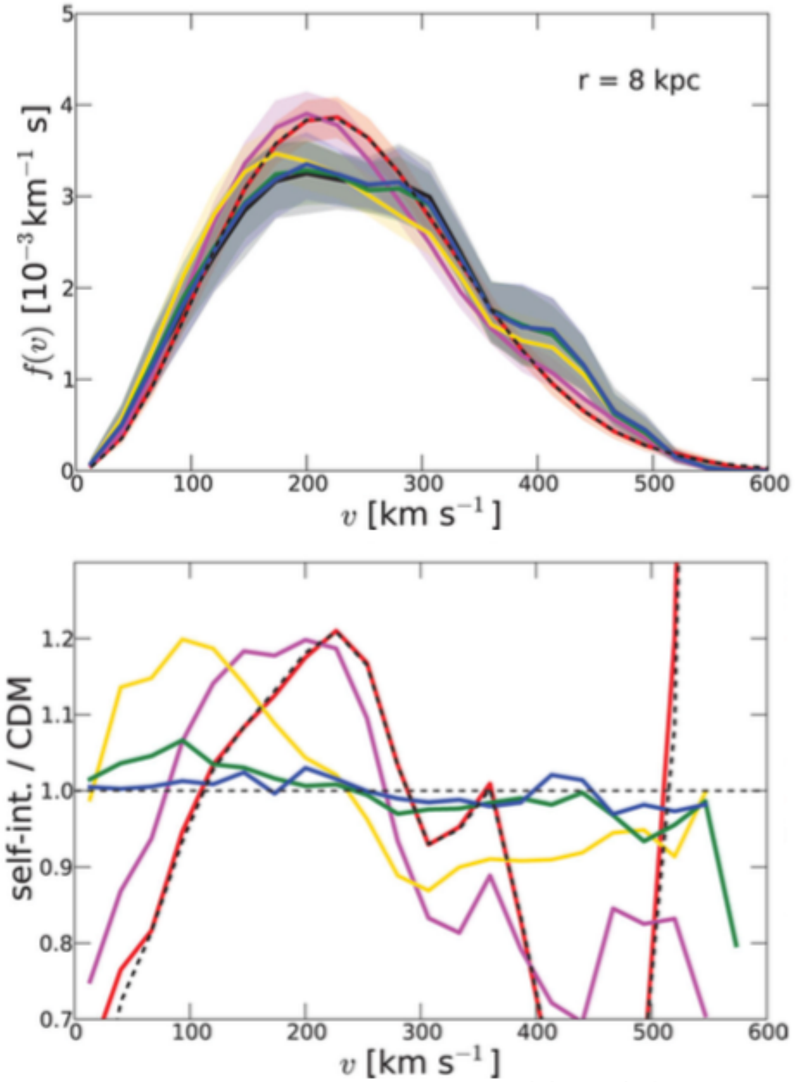
- Use strong lensing to look for DM subhalo trailing galaxy
- Pro: weakly sensitive to baryonic systematics; directional signal
- Con: sensitive to lensing reconstruction; rare
- Space photometry: HST, [WFIRST]



Massey et al. 2015

Milky Way stellar streams

- DM is stripped from in-falling satellites, changes velocity distribution as a function of radius
- Pro: velocity dependence
- Con: currently not clear how affected stars are which lie mostly in center of DM halo
- Gaia

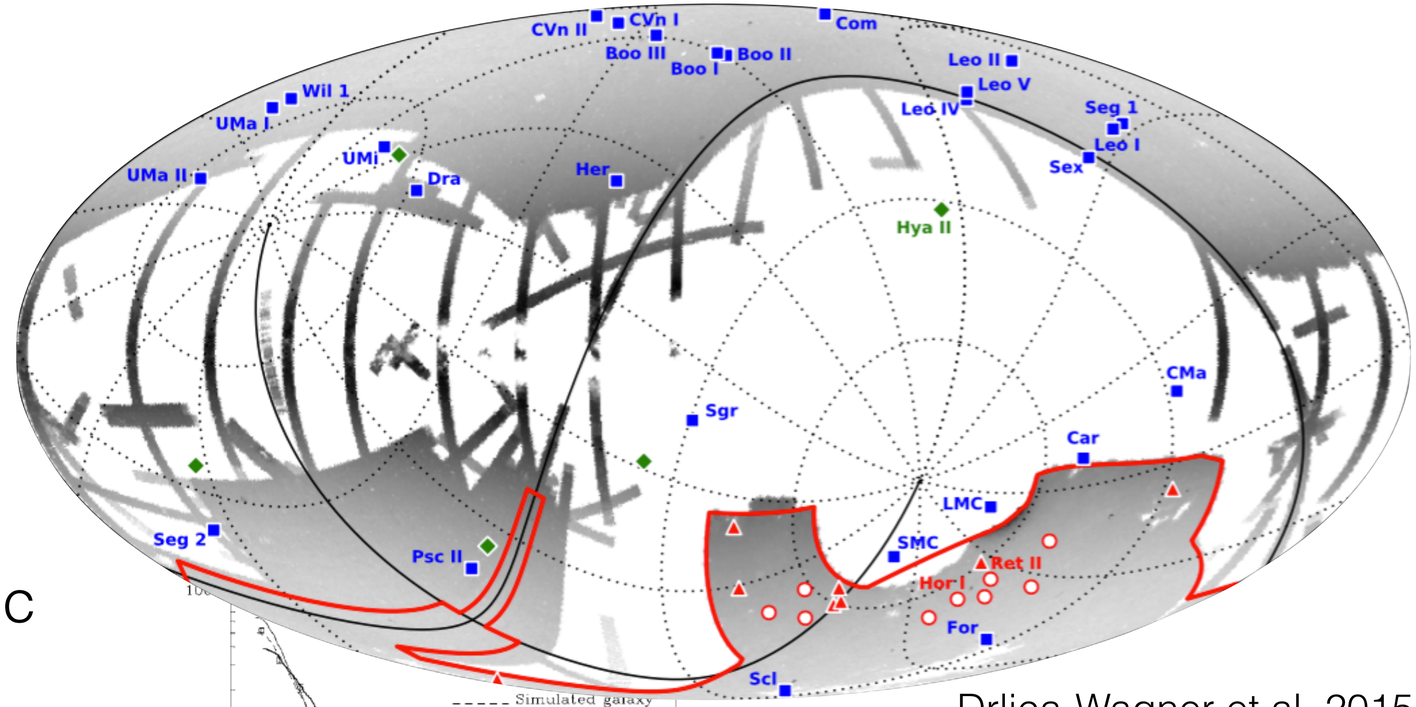


Vogelsberger et al. 2013

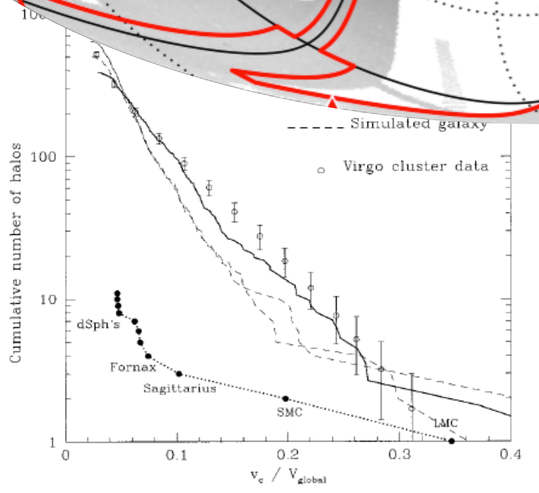
abundance of substructure (warm dark matter constraints)

Census of local substructure

- Survey the number of dwarf galaxies and measure their mass
- Pro: smallest galaxies most sensitive effects of WDM
- Con: strong survey selection effects; could be baryons; mass can be difficult to measure; cosmic variance
- SDSS, DES, etc., [LSST], [Euclid], [WFIRST], spectroscopic followup



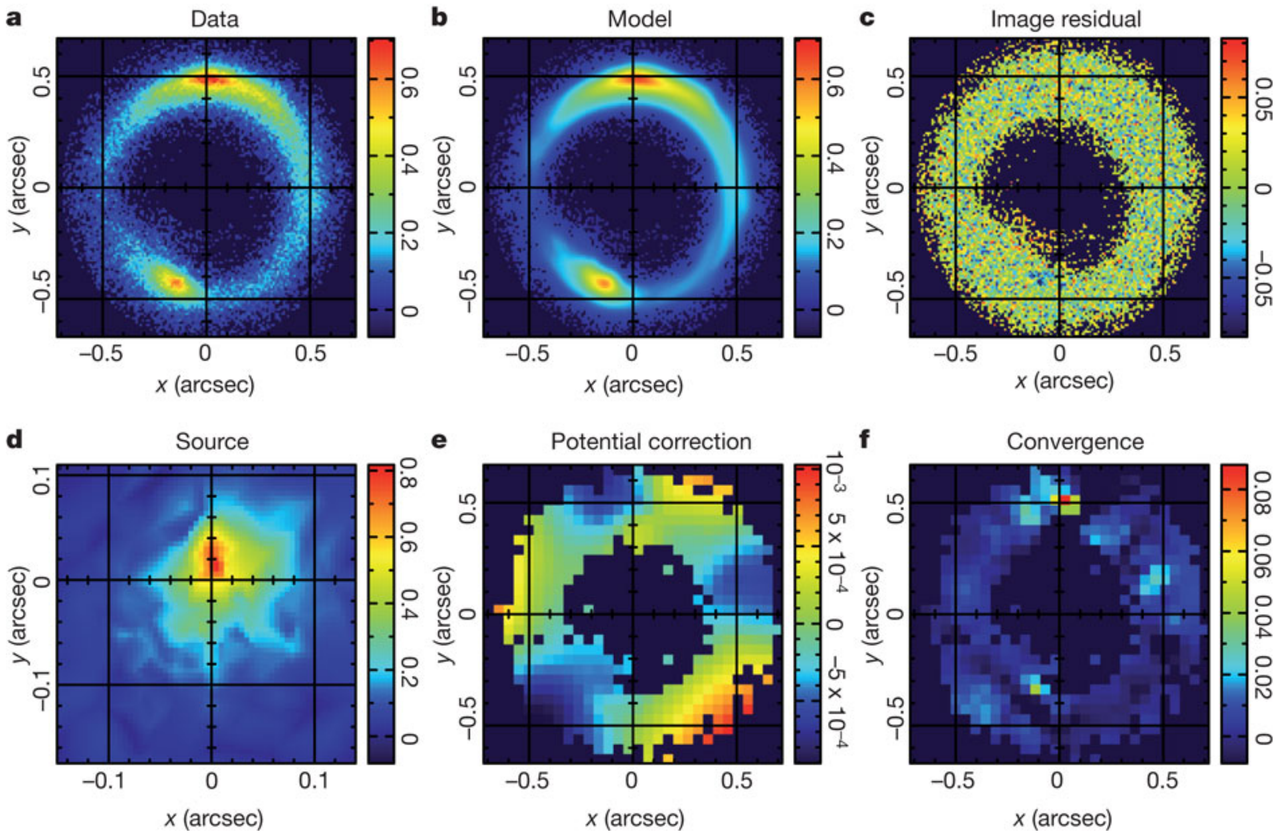
Drlica-Wagner et al. 2015



Moore et al., Klypin et al. 1999

Galaxy-galaxy strong lensing

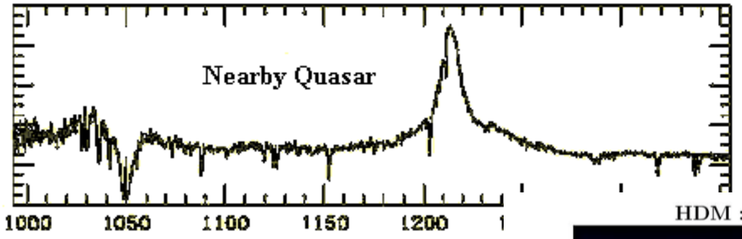
- Substructure will cause flux anomalies in multiply imaged galaxies
- Pro: enables the measurement of substructure in many galaxies as a function of redshift
- Con: uncorrelated line of sight structure systematic
- Ground based AO (e.g. on Keck), HST, [ELT's], [JWST], [WFIRST]



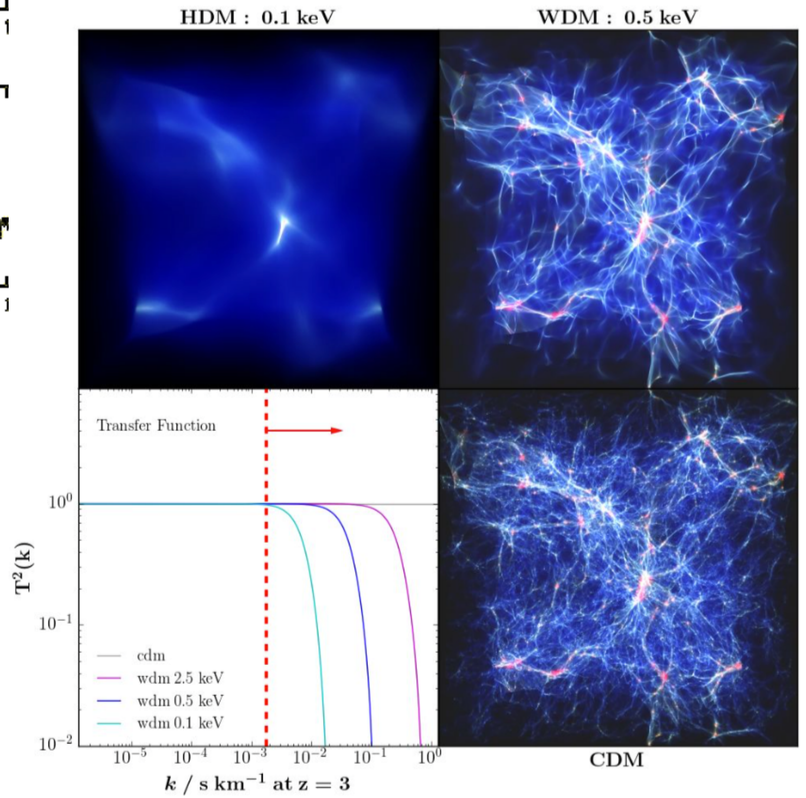
Vegetti et al. 2012

Lyman-alpha forest

- Use Lyman-alpha absorption as as function of redshift to measure substructure as a function of redshift
- Pro: high resolution spectra provide precise consensus as a function of wide range of redshift
- Con: pencil probe; assumption about hydrogen tracing substructure
- Optical survey, high resolution spectrograph



derived from Bill Keel's webpage

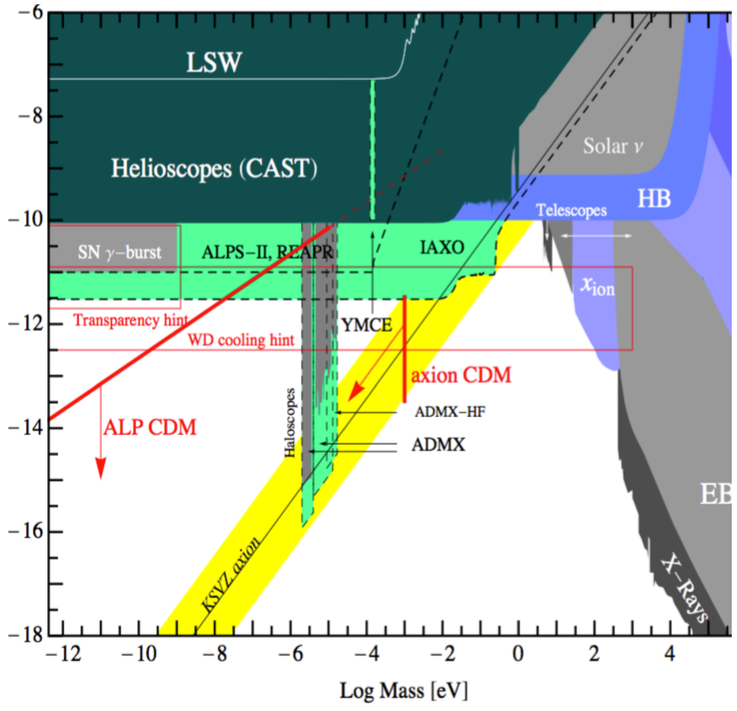


Baur et al. 2015

much more!

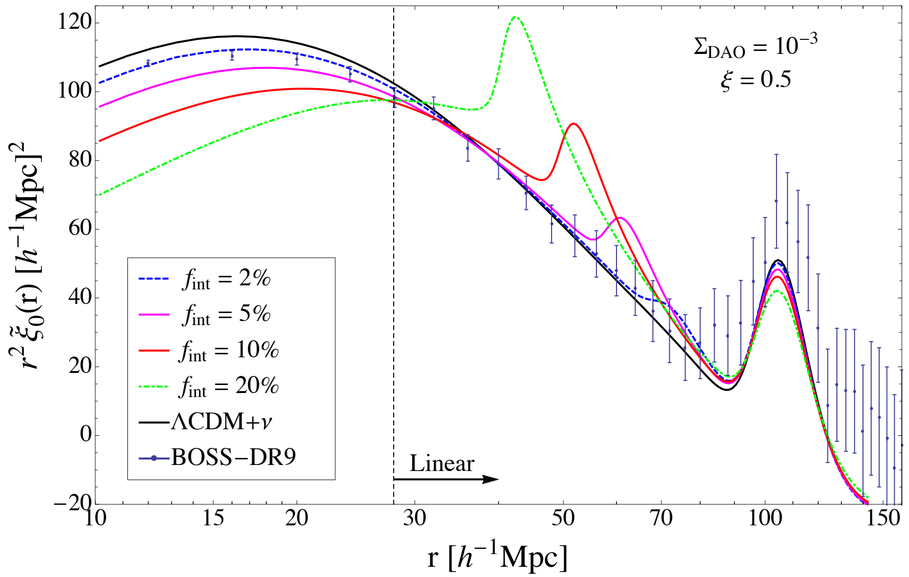
For example:

Axions



Roswald 2012

CMB, e.g. DAO



Cyr-Racine et al. 2013

Pop III Dark Stars

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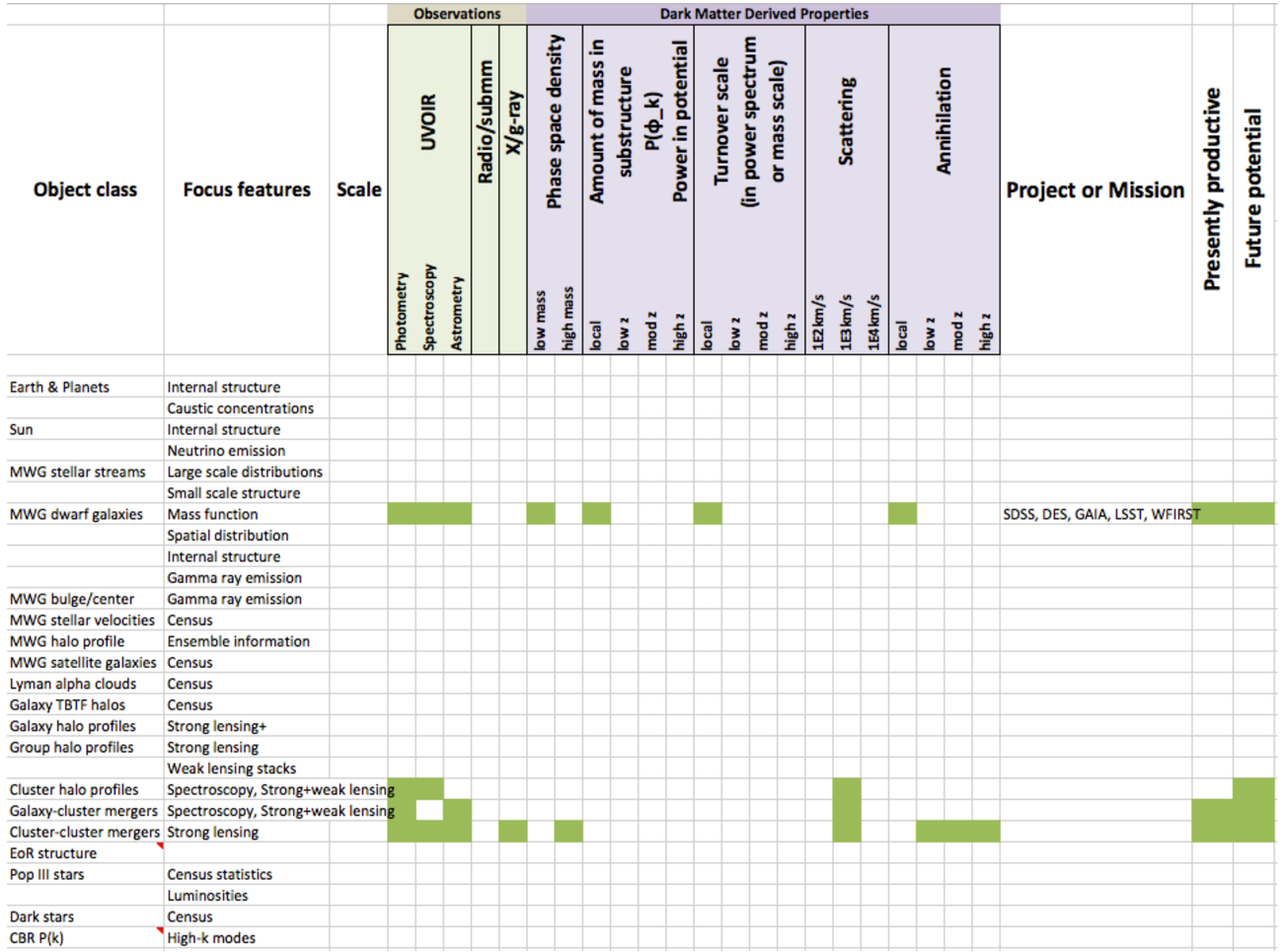
Contribute



Object class	Focus features	Scale	Observations: UVOIR: Photometry	Observations: UVOIR: Spectroscopy	Observations: UVOIR: Astrometry	Observations: Radio/submm	Observations: X/g-ray	Dark Matter Derived Properties: Phase space density: low mass	Phase space density: high mass	Amount of mass in substructure P(ϕ_k) Power in potential: local	Amount of mass in substructure P(ϕ_k) Power in potential: low z	Amount of mass in substructure P(ϕ_k) Power in potential: mod z	Amount of mass in substructure P(ϕ_k) Power in potential: high z	Turnover scale (in power spectrum or mass scale): local	Turnover scale (in power spectrum or mass scale): low z	Turnover scale (in power spectrum or mass scale): mod z	Turnover scale (in power spectrum or mass scale): high z	Scattering: 1E2km/s	Scattering: 1E3km/s	Scattering: 1E4km/s	Annihilation: local	Annihilation: low z	Annihilation: mod z	Annihilation: high z	Project or Mission	Presently productive	Future potential
Earth & Planets	Internal structure																										
	Caustic concentrations																										
Sun	Internal structure																										
	Neutrino emission																										
MWG stellar streams	Large scale distributions																										
	Small scale structure																										
MWG dwarf galaxies	Mass function																								SDSS, DES, GAIA, LSST, WFIRST		
	Spatial distribution																										
	Internal structure																										
	Gamma ray emission																										
MWG bulge/center	Gamma ray emission																										
MWG stellar velocities	Census																										
MWG halo profile	Ensemble information																										
MWG satellite galaxies	Census																										
Lyman alpha clouds	Census																										
Galaxy TBTF halos	Census																										
Galaxy halo profiles	Strong lensing+																										
Group halo profiles	Strong lensing																										
	Weak lensing stacks																										
Cluster halo profiles	Spectroscopy, Strong+weak lensing																										
Galaxy-cluster mergers	Spectroscopy, Strong+weak lensing																										
Cluster-cluster mergers	Strong lensing																										
EoR structure																											
Pop III stars	Census statistics																										
	Luminosities																										
Dark stars	Census																										
CBR P(k)	High-k modes																										

https://github.com/lmoustakas/specialdark