

Astronomical Insights into Dark Matter Particle Constraints

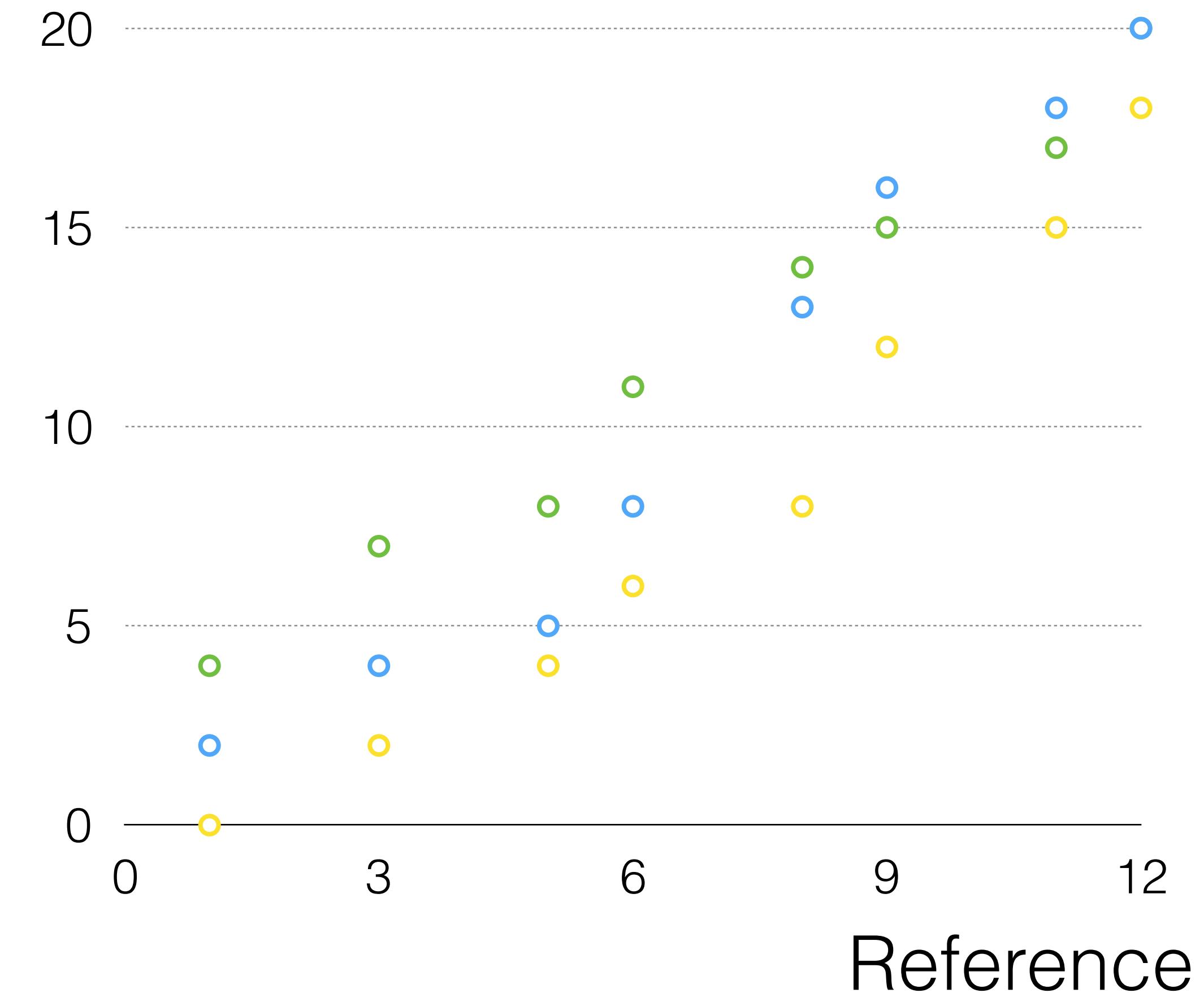
William A Dawson
Lawrence Livermore National Lab

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

We are just hitting our stride!

Astronomical probe

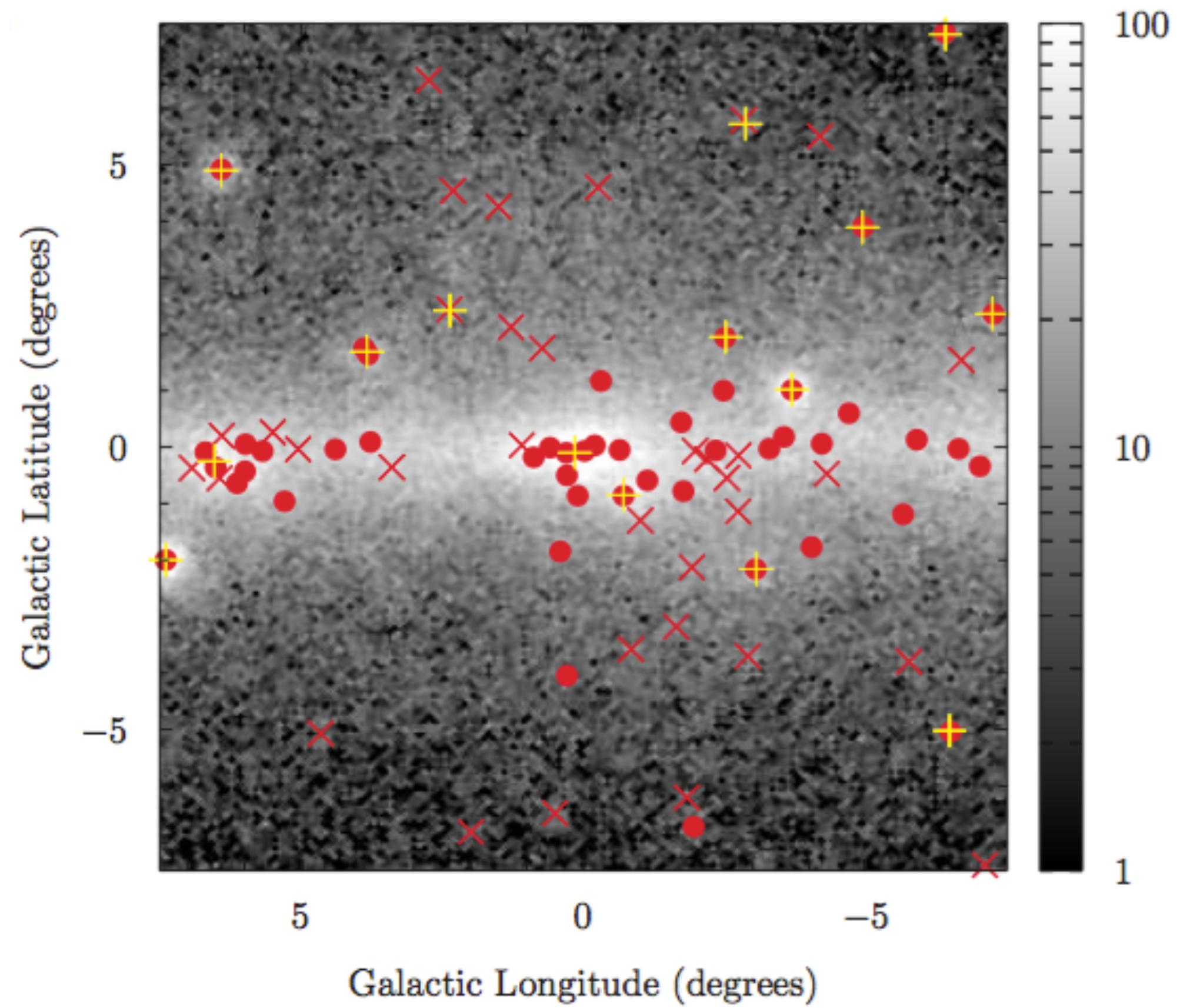
- What about dark matter it constrains
- How it works
- Biggest strengths
- Biggest weaknesses
- Telescope / detector / method



annihilation cross-section / mass

Gamma-ray emission

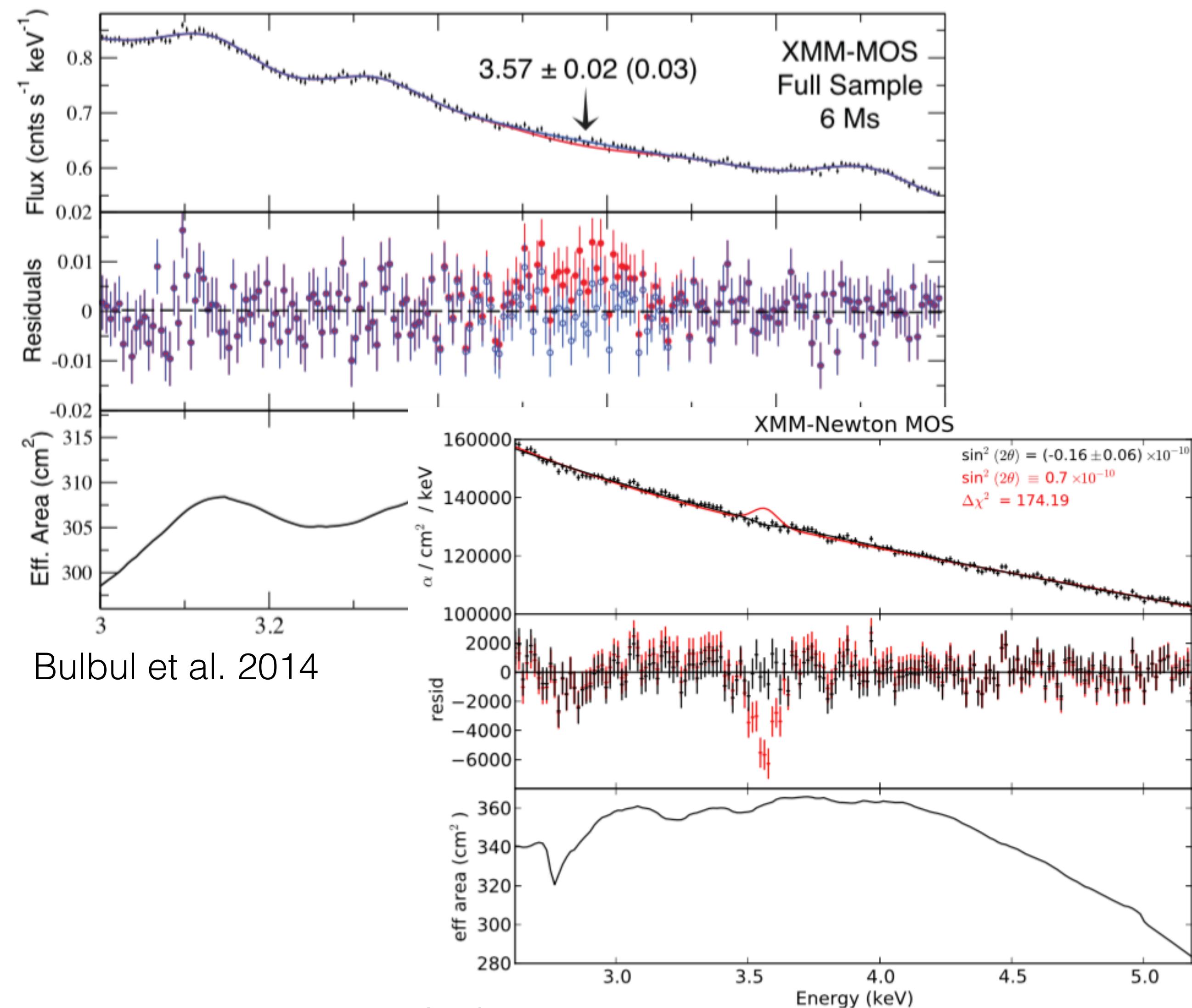
- Look for Gamma-ray decay product in dwarfs, galaxies, and clusters
- Pro: clear signal in center of Milky Way
- Con: could be baryons (e.g. pulsars); not seen in dwarfs or clusters
- Fermi, Cherenkov Telescopes, [CTA], [PANGU]



Fermi Collaboration 2015

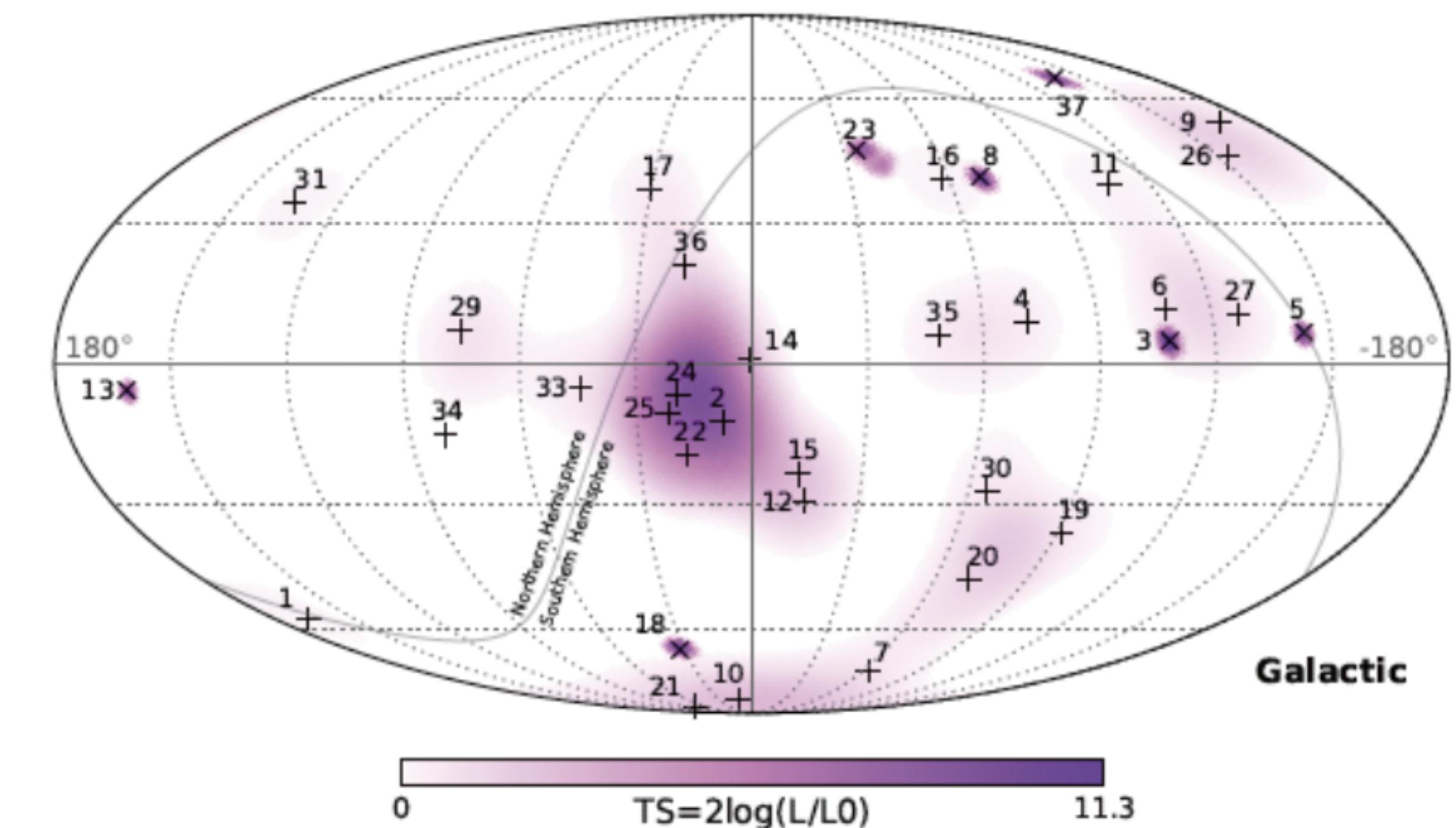
X-ray Emission

- 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]



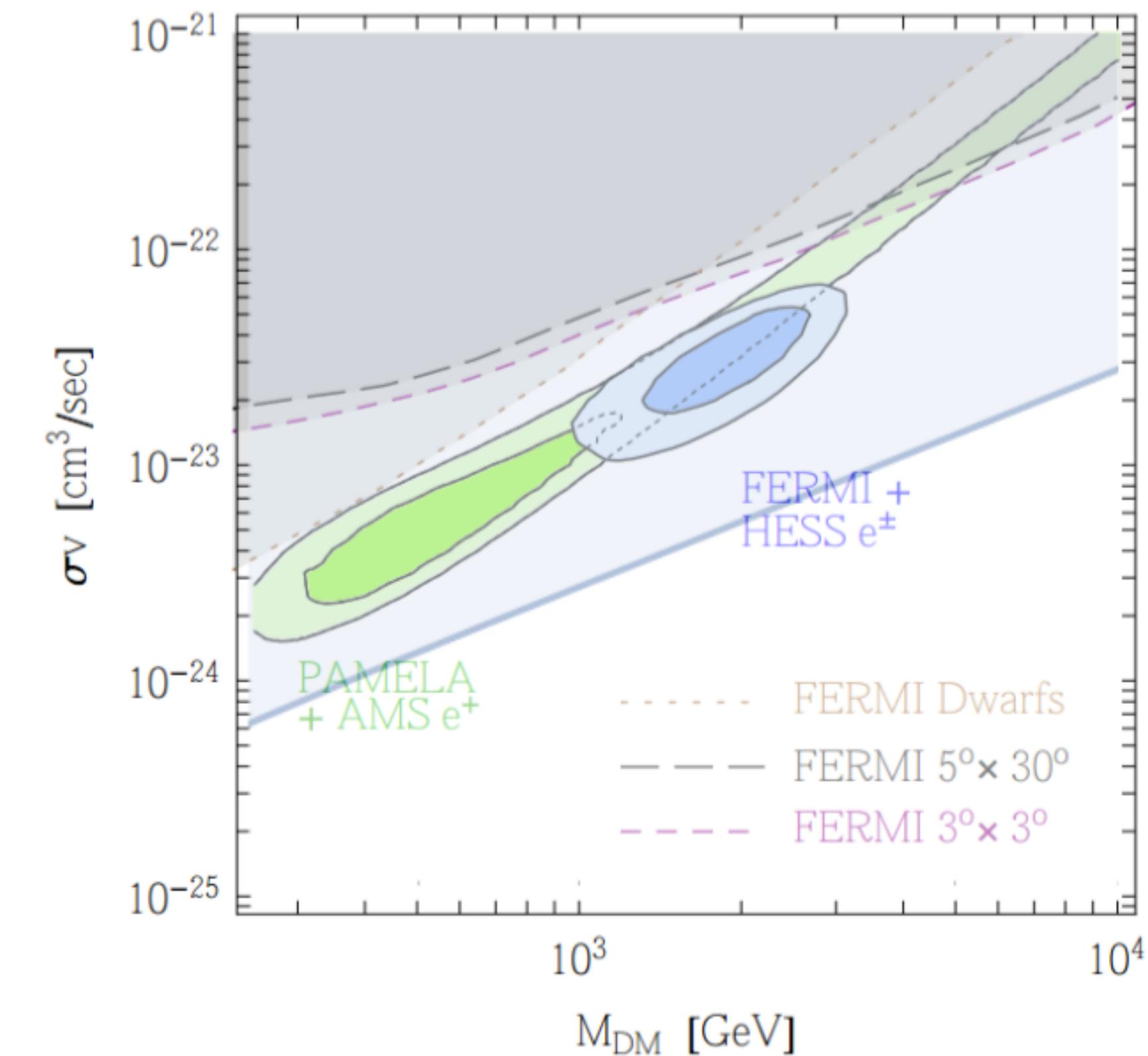
Neutrinos

- 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)



Positrons

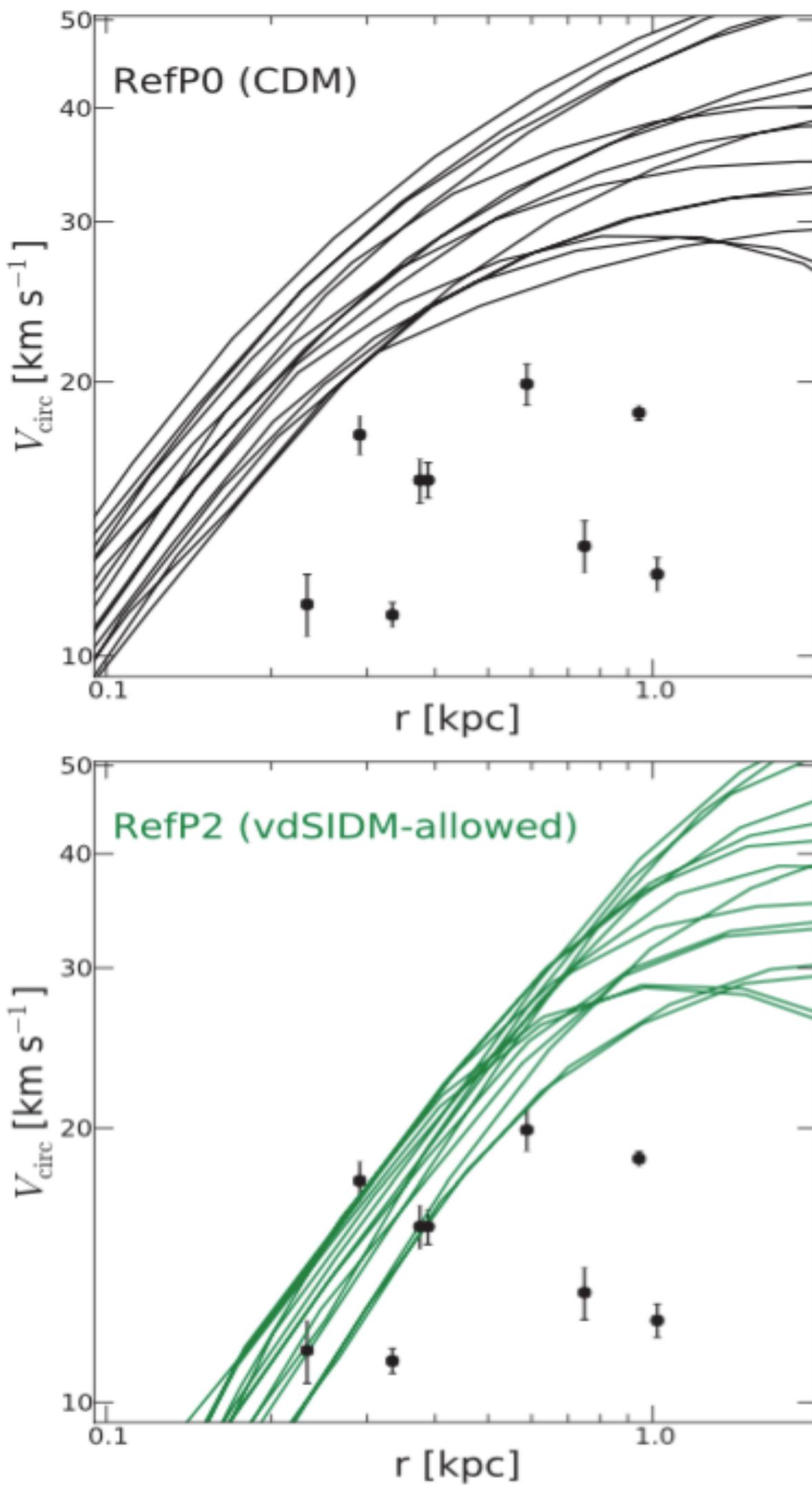
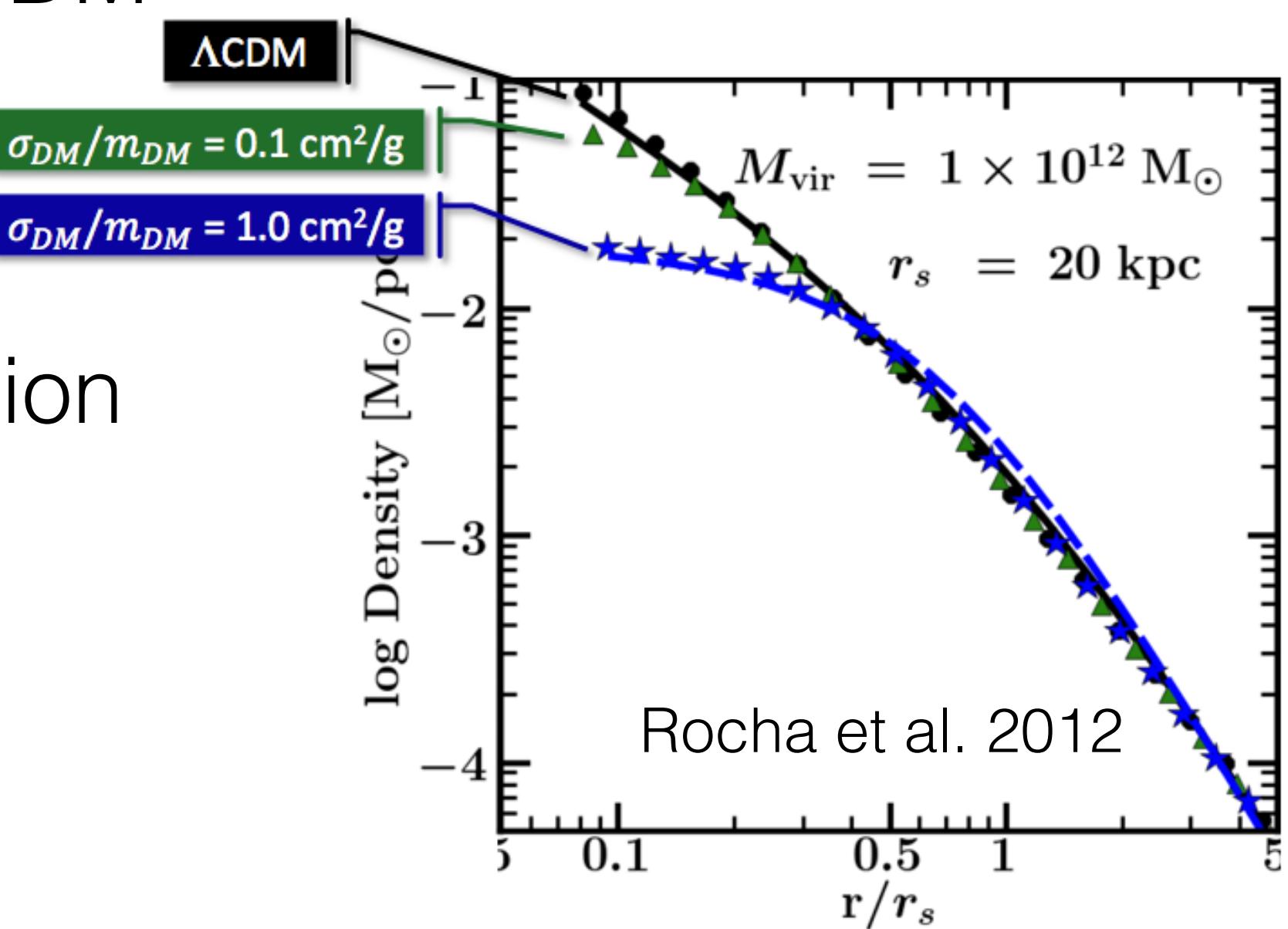
- Detect local fraction of positrons, which could be decay product of DM
- Pro: strong signal
- Con: could be baryons; Neutrinos and CMB are inconsistent with DM source picture
- PAMELA, AMS-02



scattering cross-section / mass

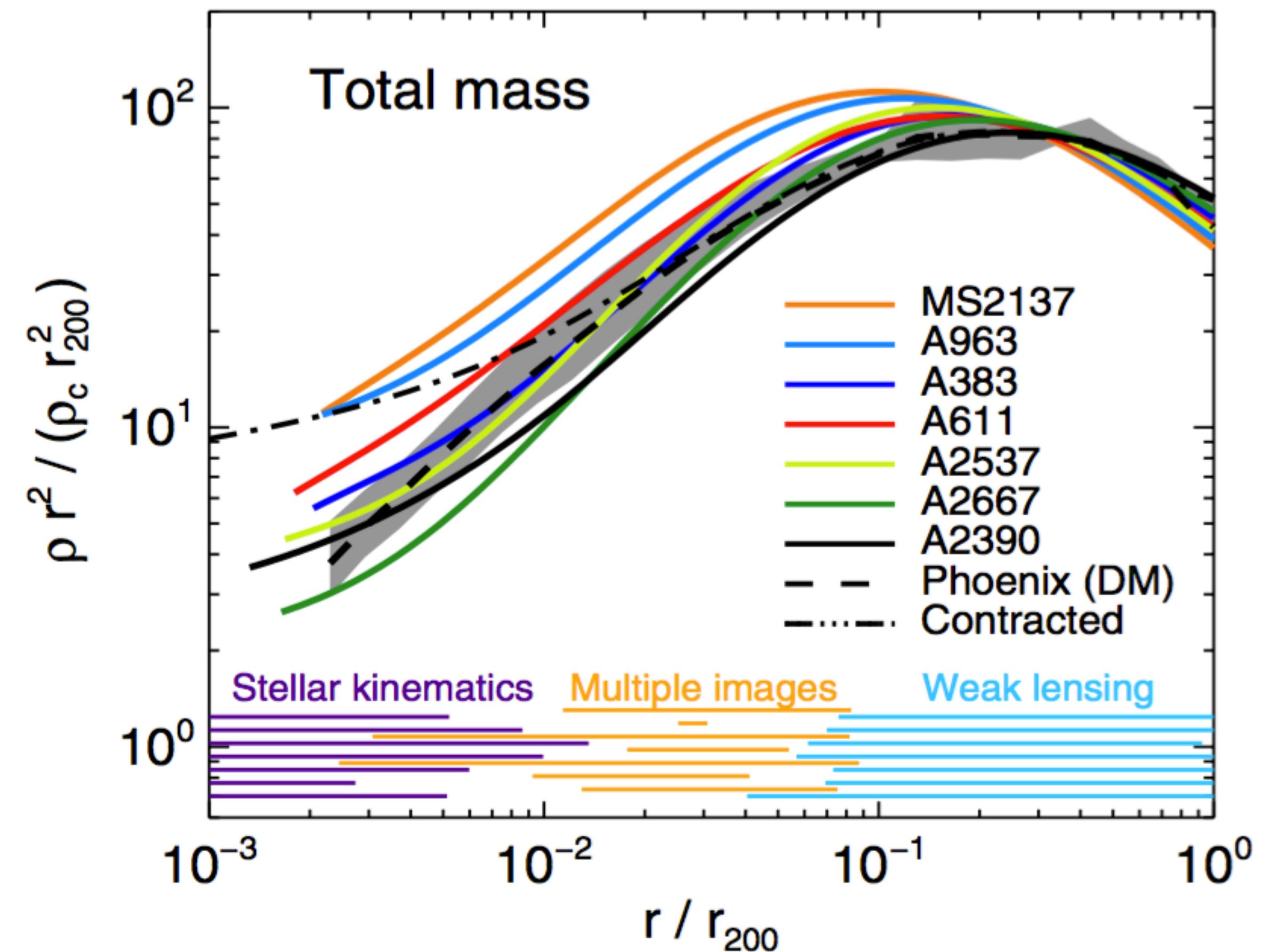
Dwarf galaxies: mass profile

- 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



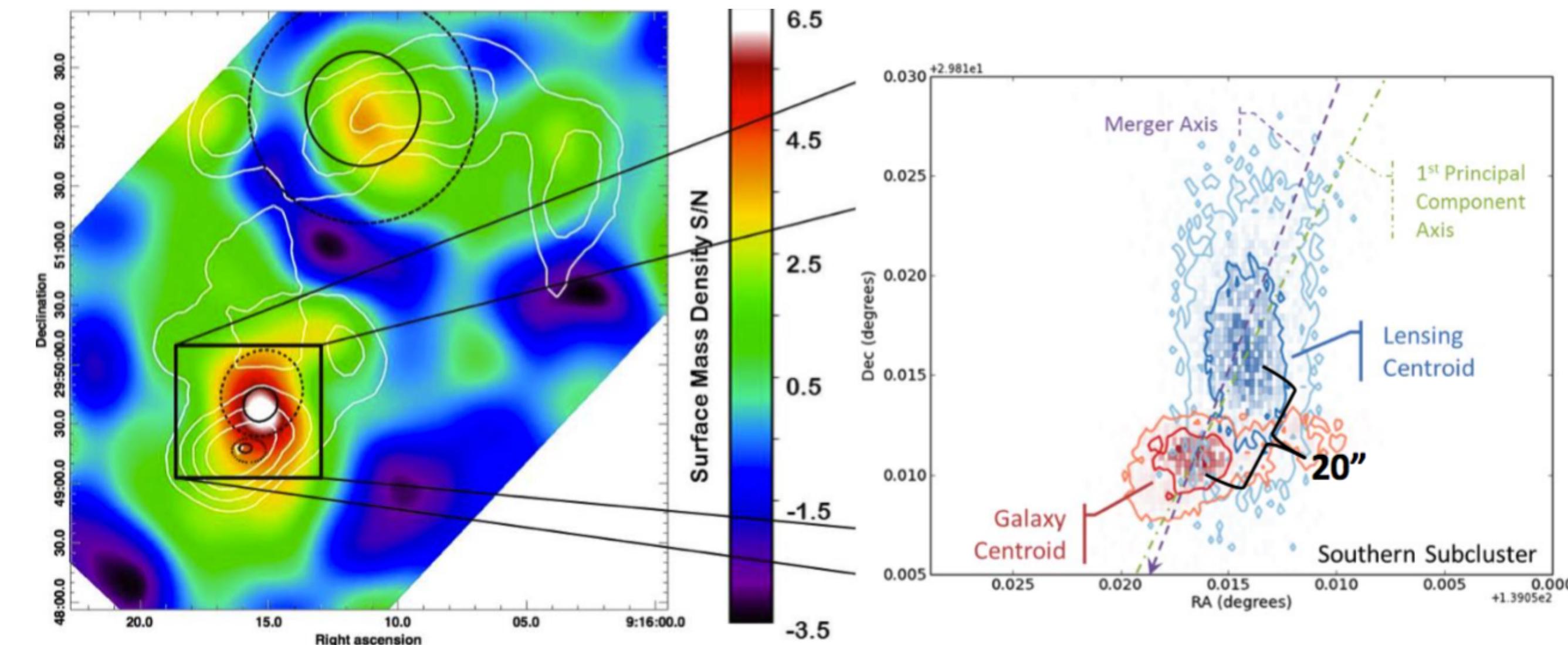
Galaxy clusters: mass profile

- 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



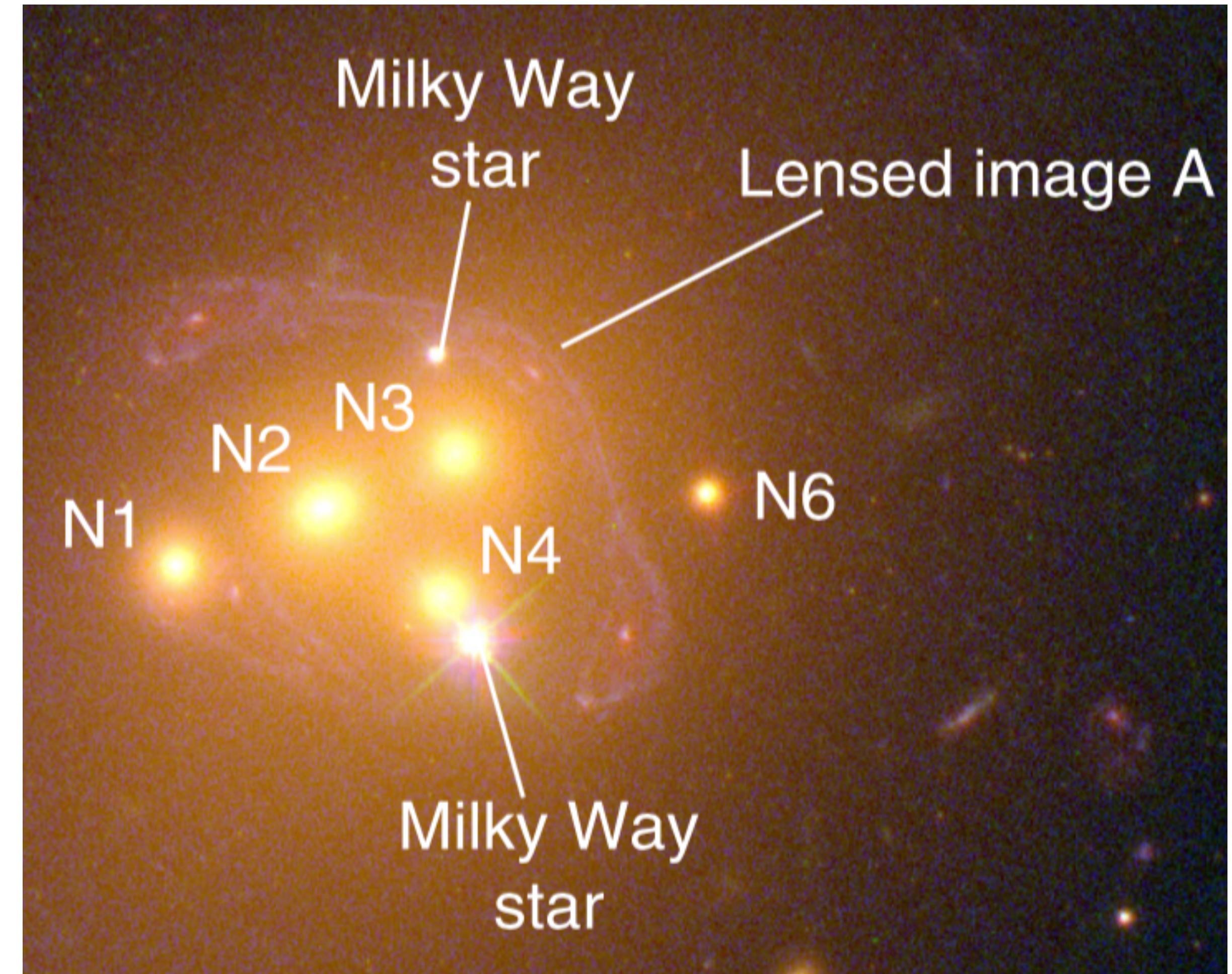
Merging Galaxy Clusters

- 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



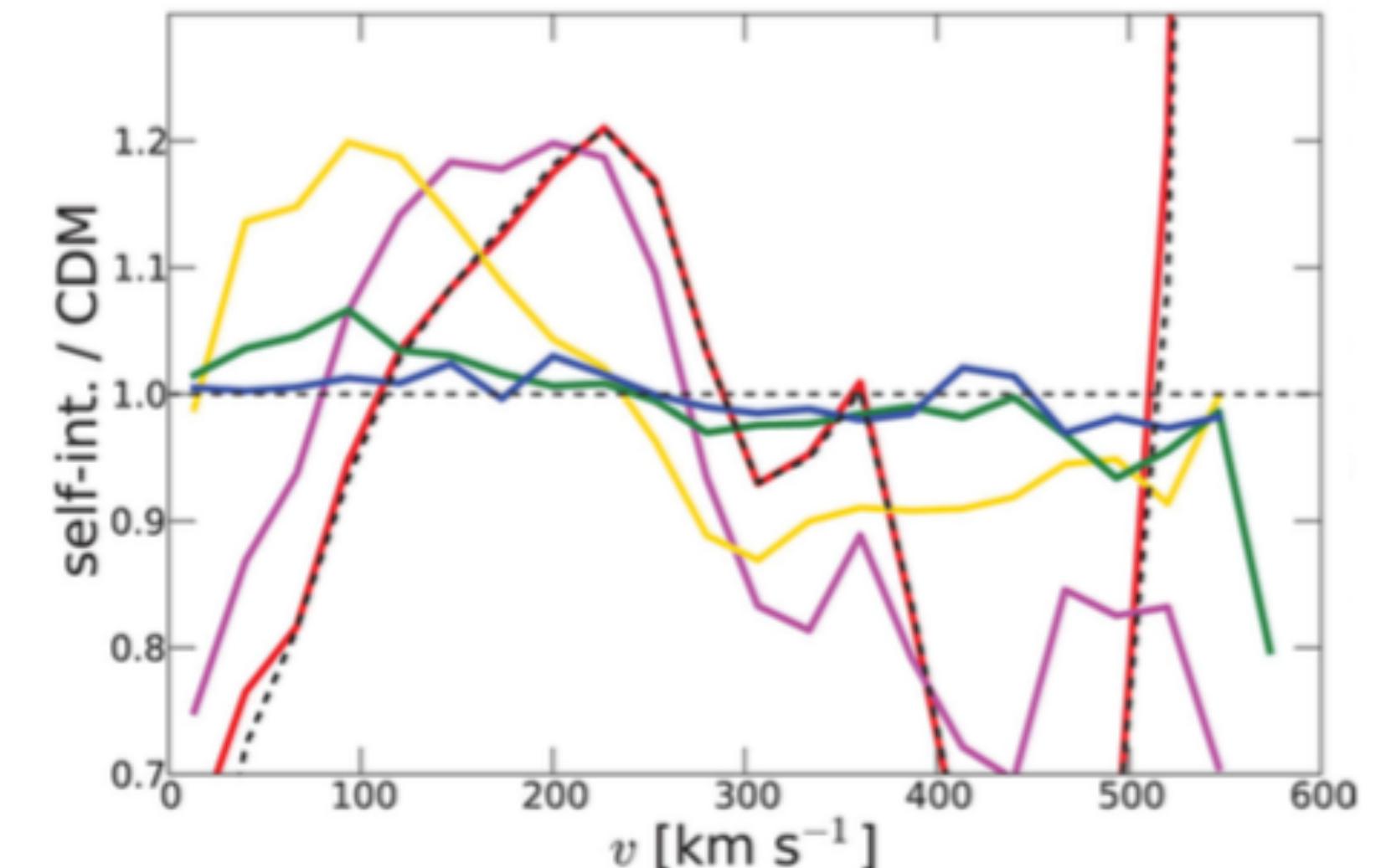
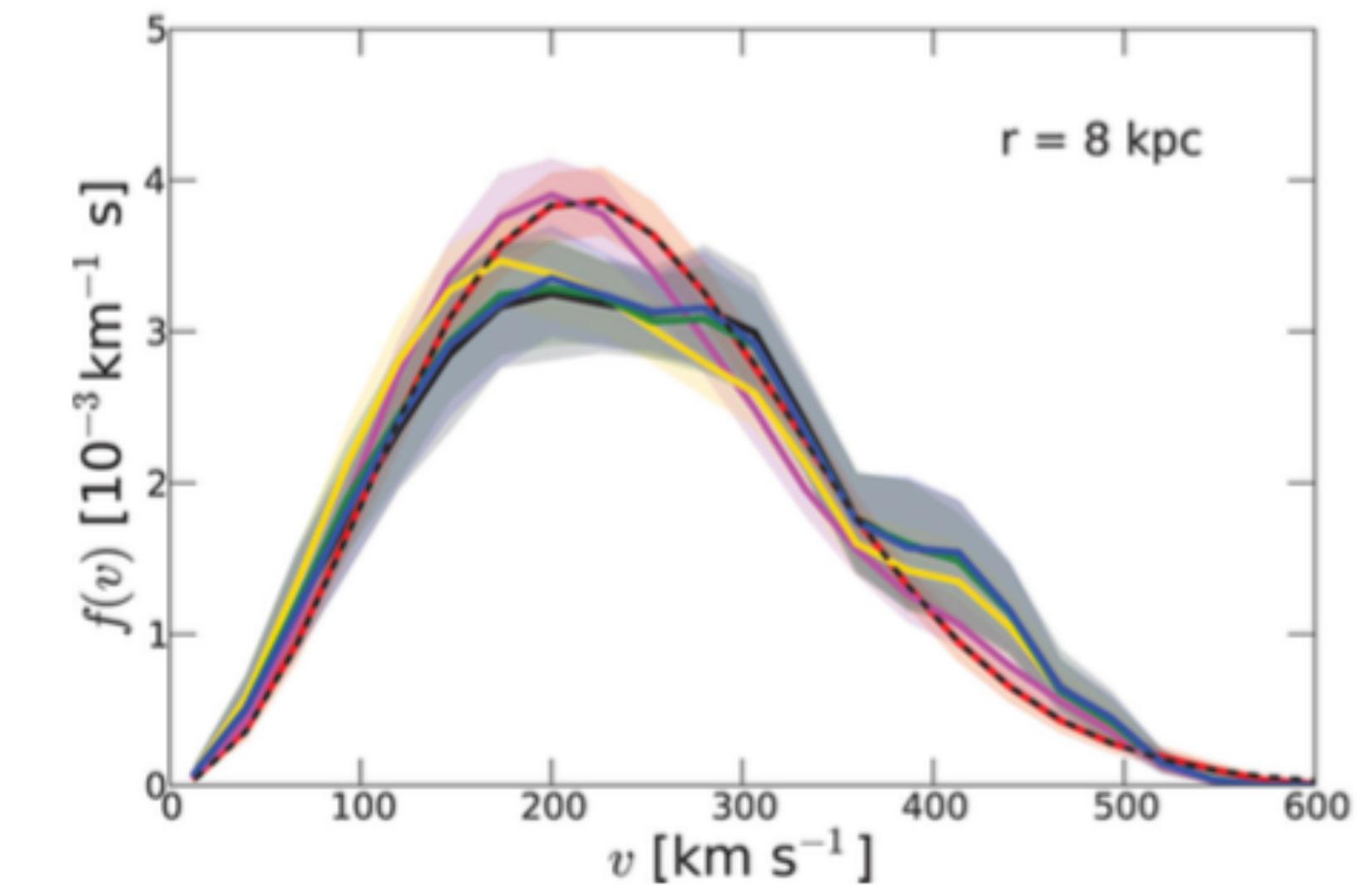
Galaxies falling into clusters

- 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]



Milky Way stellar streams

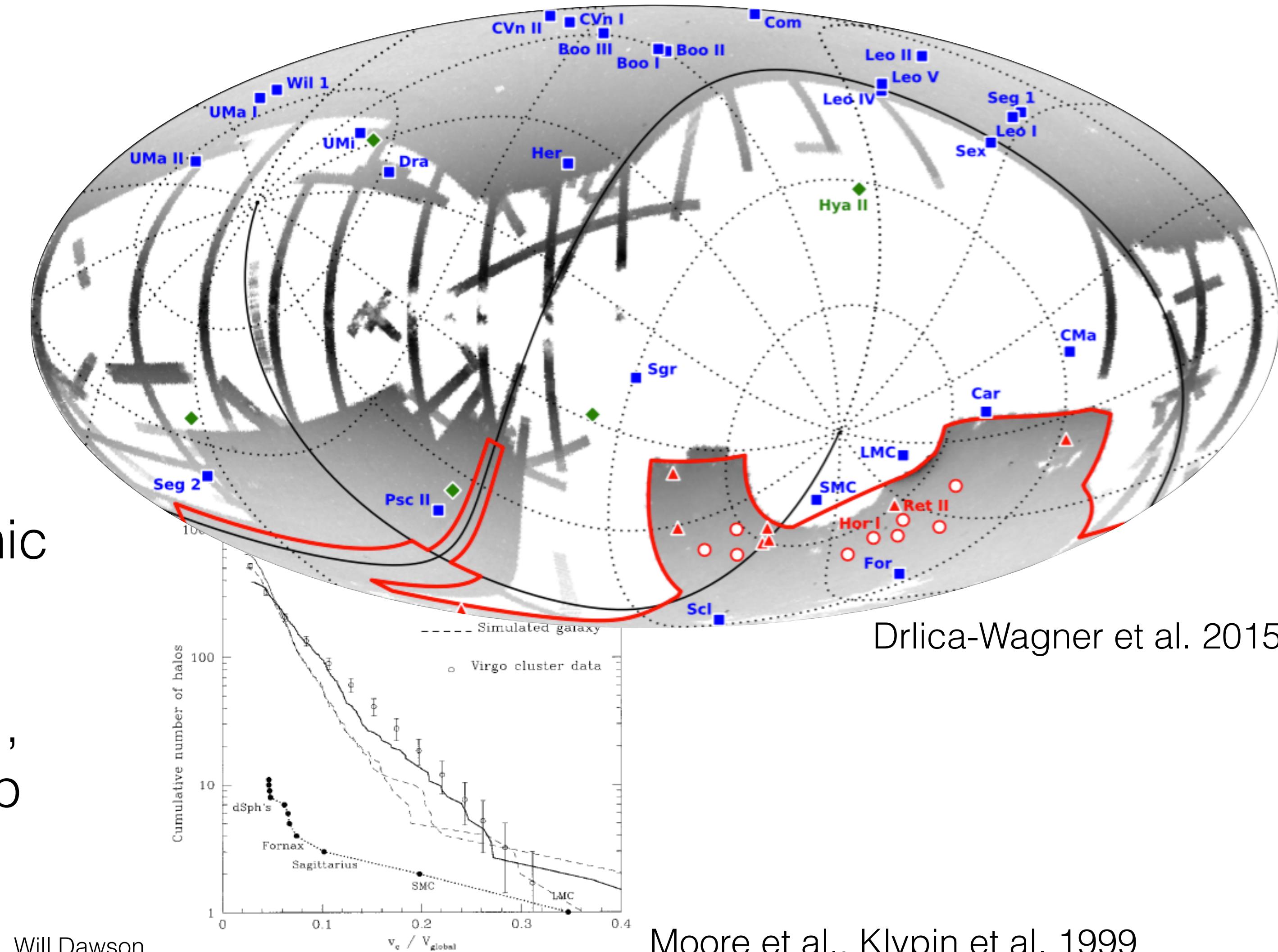
- DM is stripped from in-falling satellites, changes velocity distribution as a function of radius
- Pro: velocity dependence
- Con: currently not clear how affected stars are which lie mostly in center of DM halo
- Gaia



abundance of substructure
(warm dark matter constraints)

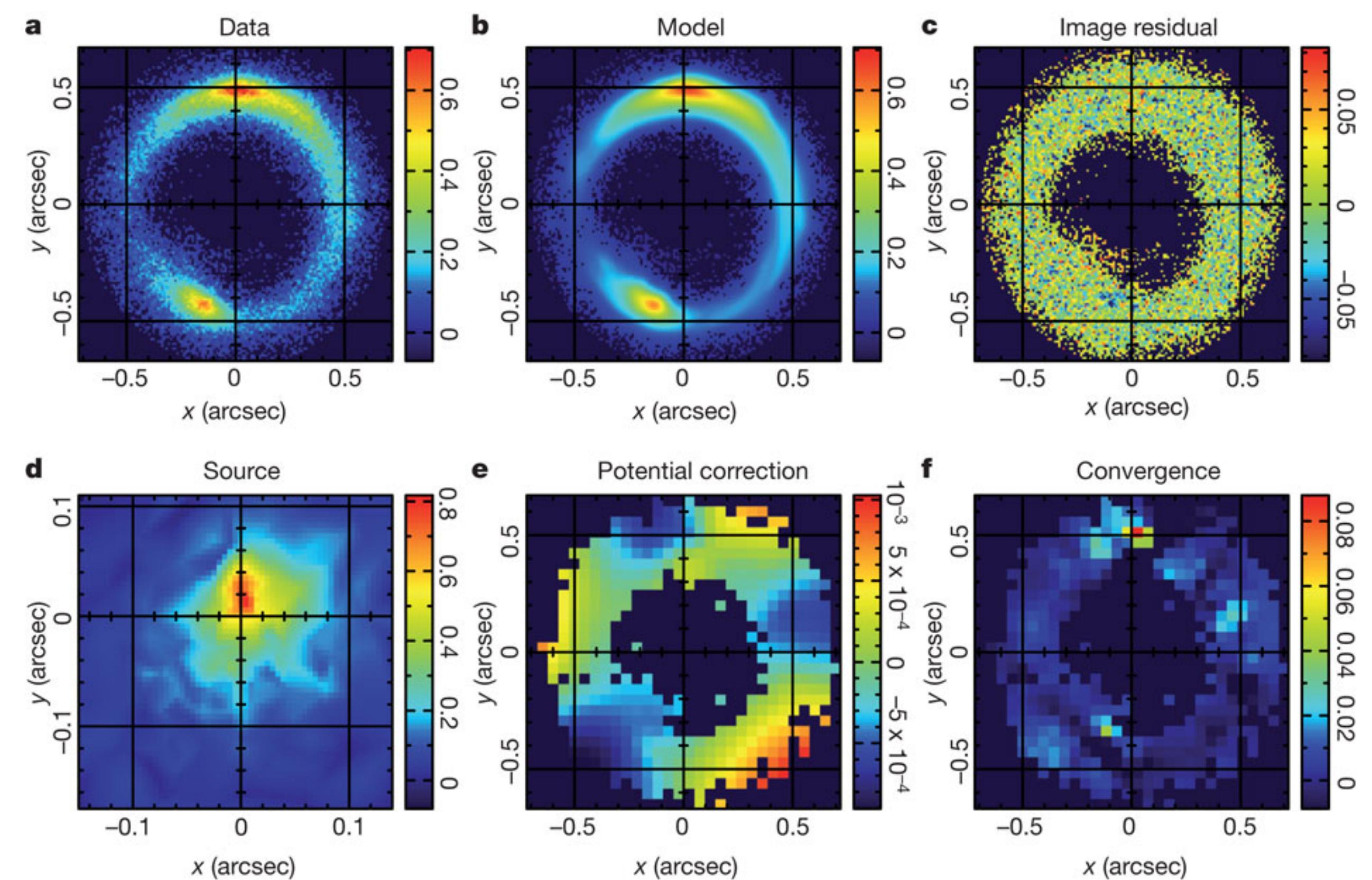
Census of local substructure

- 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



Galaxy-galaxy strong lensing

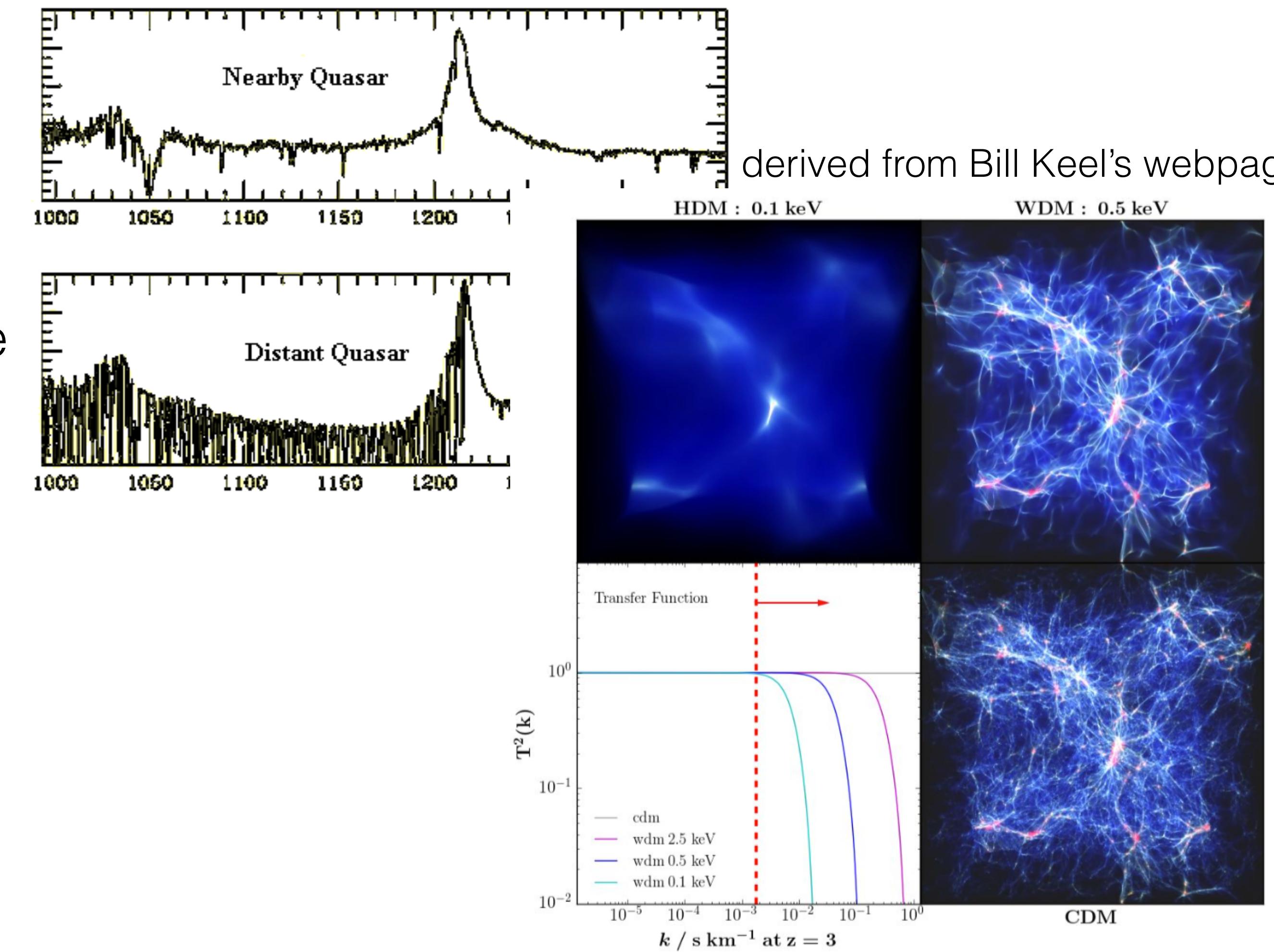
- Substructure will cause flux anomalies in multiply imaged galaxies
- Pro: enables the measurement of substructure in many galaxies as a function of redshift
- Con: uncorrelated line of sight structure systematic
- Ground based AO (e.g. on Keck), HST, [ELT's], [JWST], [WFIRST]



Veggetti et al. 2012

Lyman-alpha forest

- Use Lyman-alpha absorption 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

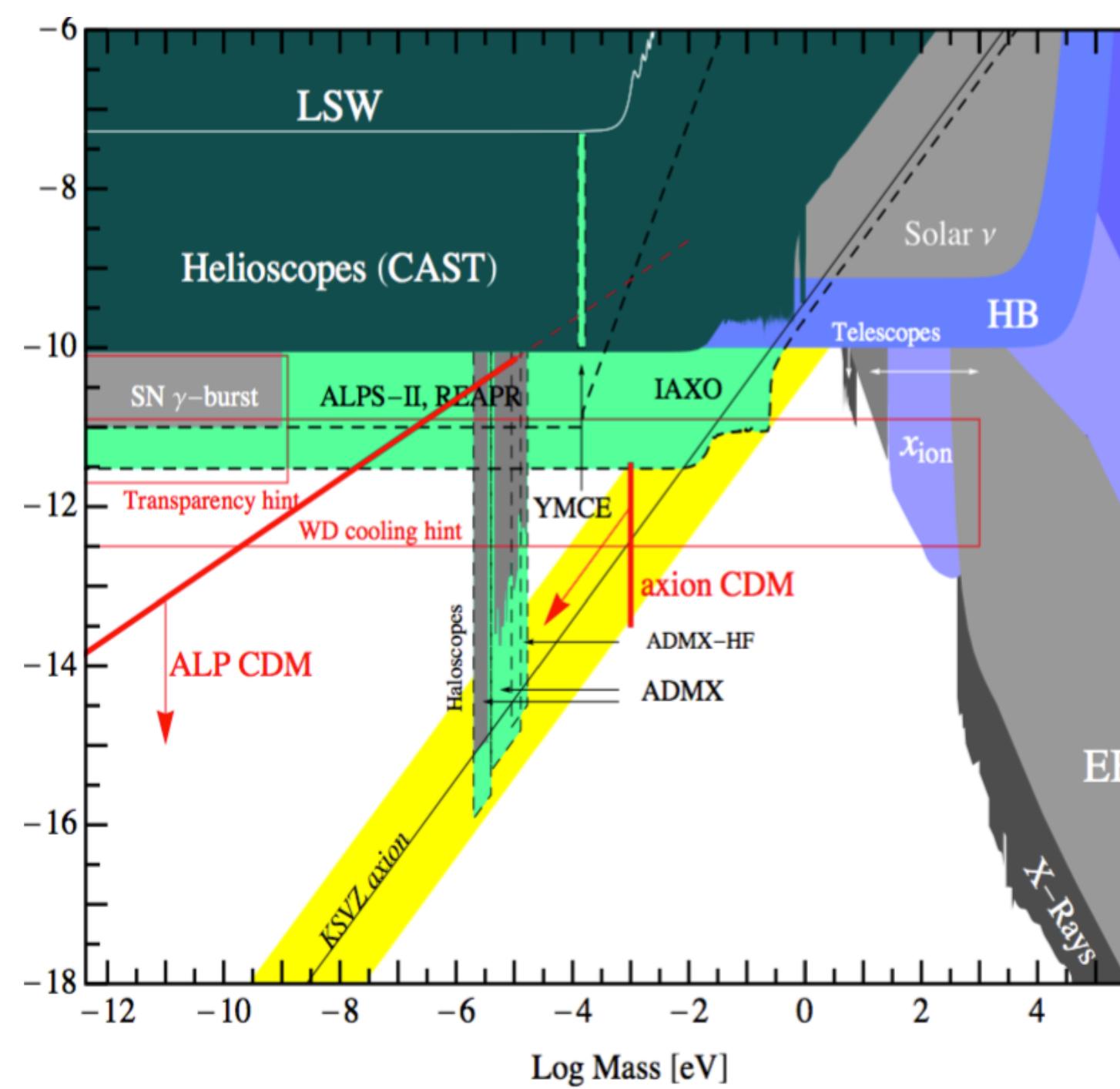


Baur et al. 2015

much more!

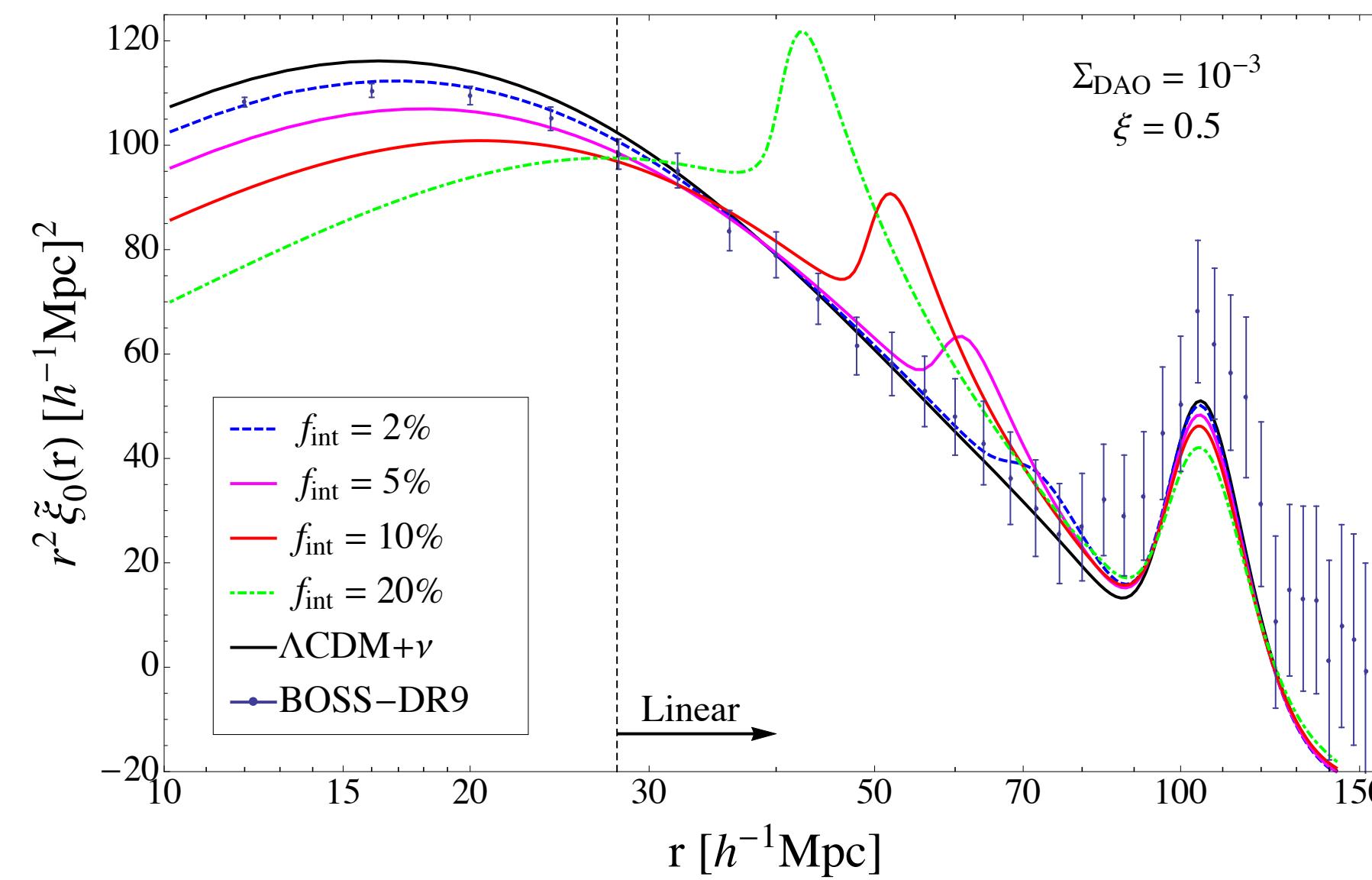
For example:

Axions



Roswald 2012

CMB, e.g. DAO



Cyr-Racine et al. 2013

Pop III Dark Stars

Contribute

Object class	Focus features	Scale	Observations			Dark Matter Derived Properties						Project or Mission	Presently productive	Future potential				
			Photometry	Spectroscopy	UV/OIR Astrometry	Radio/submm	X/g-ray	Phase space density	Amount of mass in substructure $P(\Phi_{\text{K}})$	Power in potential	Turnover scale (in power spectrum or mass scale)	1E2 km/s	Scattering	1E3 km/s	1E4 km/s	local	low z	mod z
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>