ASTRONOMICAL INSIGHTS INTO DARK MATTER PARTICLE CONSTRAINTS

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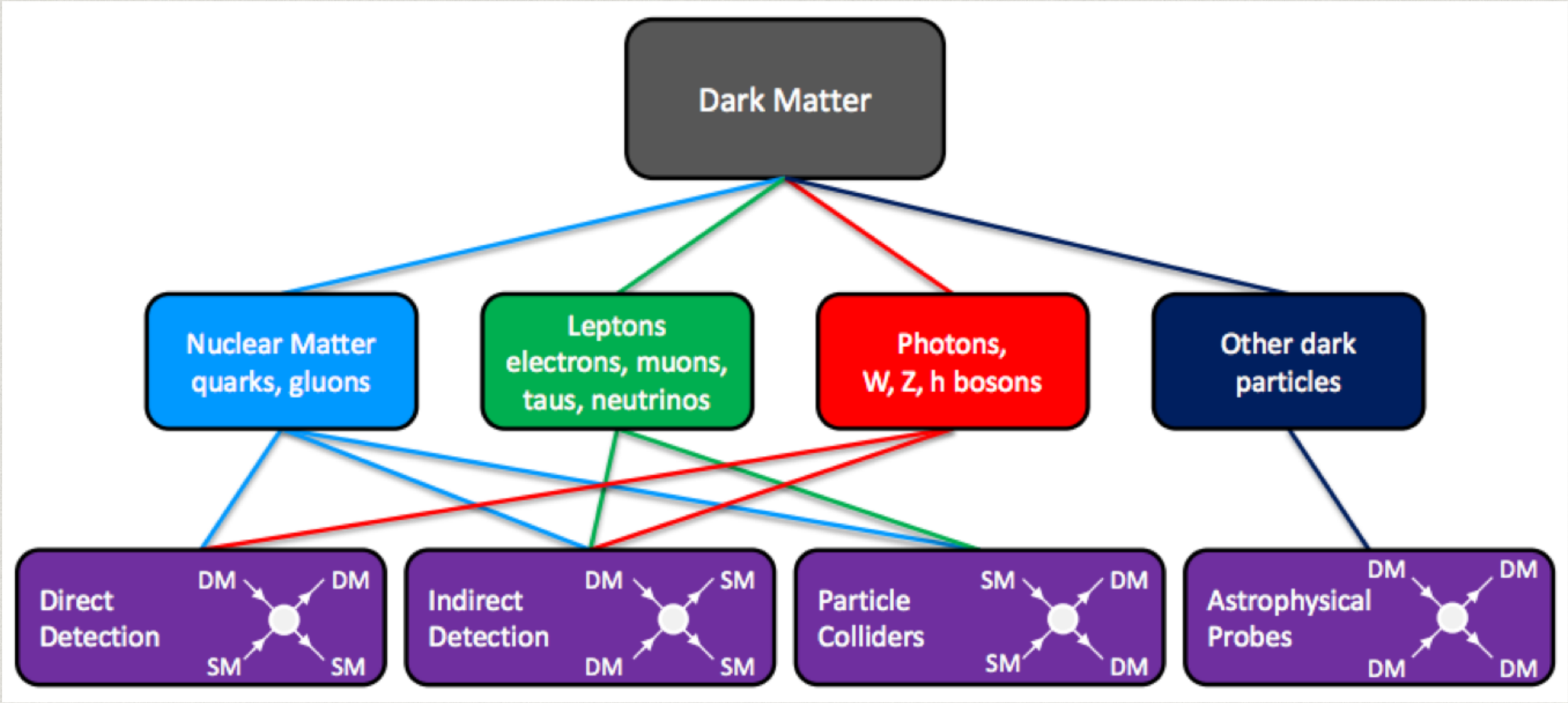
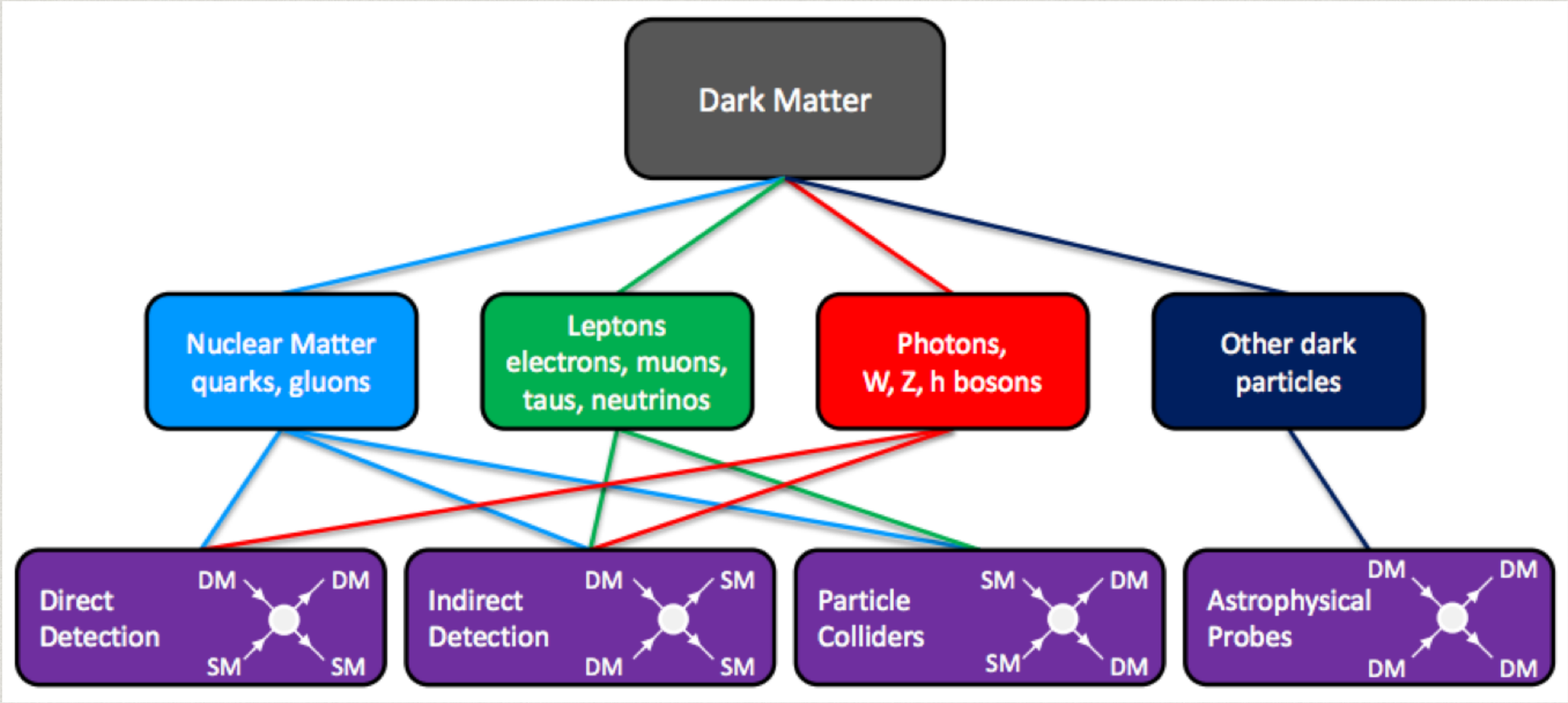
Probes of Dark Matter



Cosmic Frontiers Working Groups 1-4

Astrophysical probes are leading the way on two of the avenues to studying dark matter



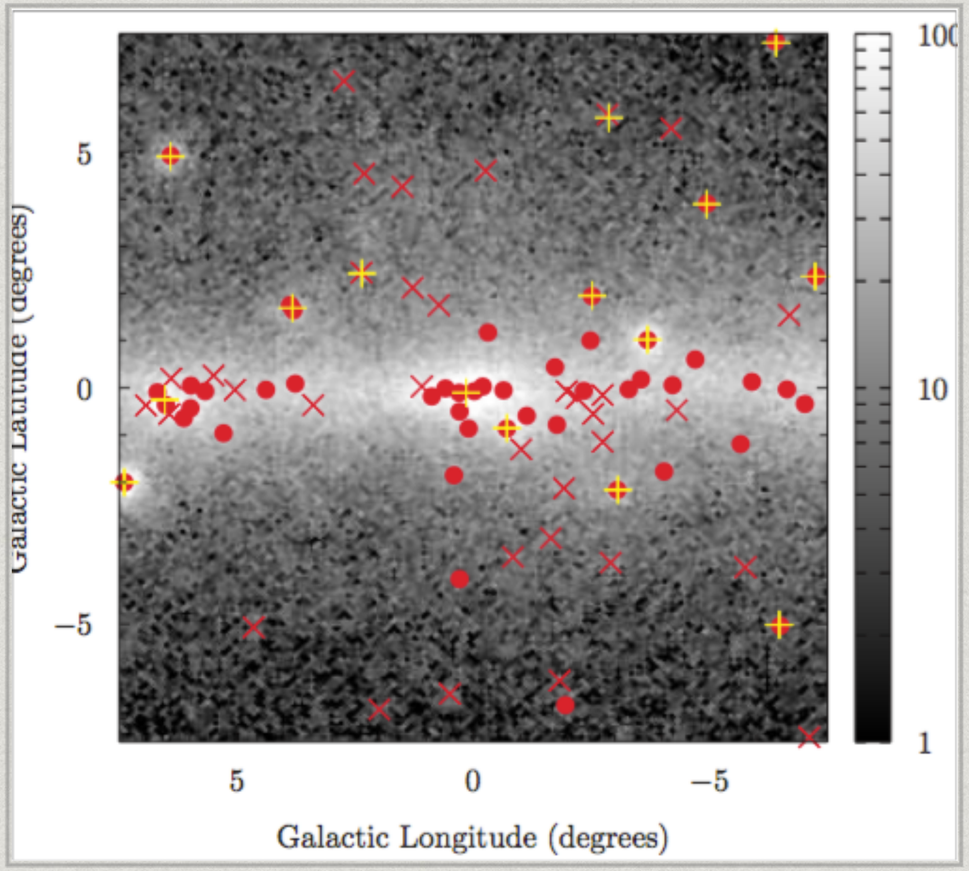
Cosmic Frontiers Working Groups 1-4

Observational Dark Matter Probes

Astrophysical DM Probe	Scattering DM	Annihilating DM	Warm DM	Observatory/Survey/Method
Stellar Streams	x		x	Gaia, DES, HSC, LSST, Euclid, WFIRST
Gamma-ray Emission (MW, dwarf, clusters, merging clusters)		x		Fermi, Cherenkov telescopes
Number of dwarf satellites			x	DES, HSC, LSST, Euclid, WFIRST
Ly-alpha forest			x	Optical spectroscopy, etc.?
CMB	x	x	x	Planck, ACT, SPT, etc.?
Dark matter halo profiles (dwarf to cluster)	x			Optical spectroscopy, strong lensing, weak lensing
Galaxy strong lensing			x	DES, HSC, LSST, Euclid, WFIRST, HST, Ground-based AO
Cluster-cluster mergers	x	x		Strong and weak lensing, optical spectroscopy, X-ray
Galaxy-cluster mergers	x			Strong lensing, optical spectroscopy
Neutrino emission (from sun etc.)	x	x		Icecube, etc.
Velocity distribution of stars in MW	x		x	Gaia, 4MOST, MKSE, WEAVE

Gamma-ray Emission

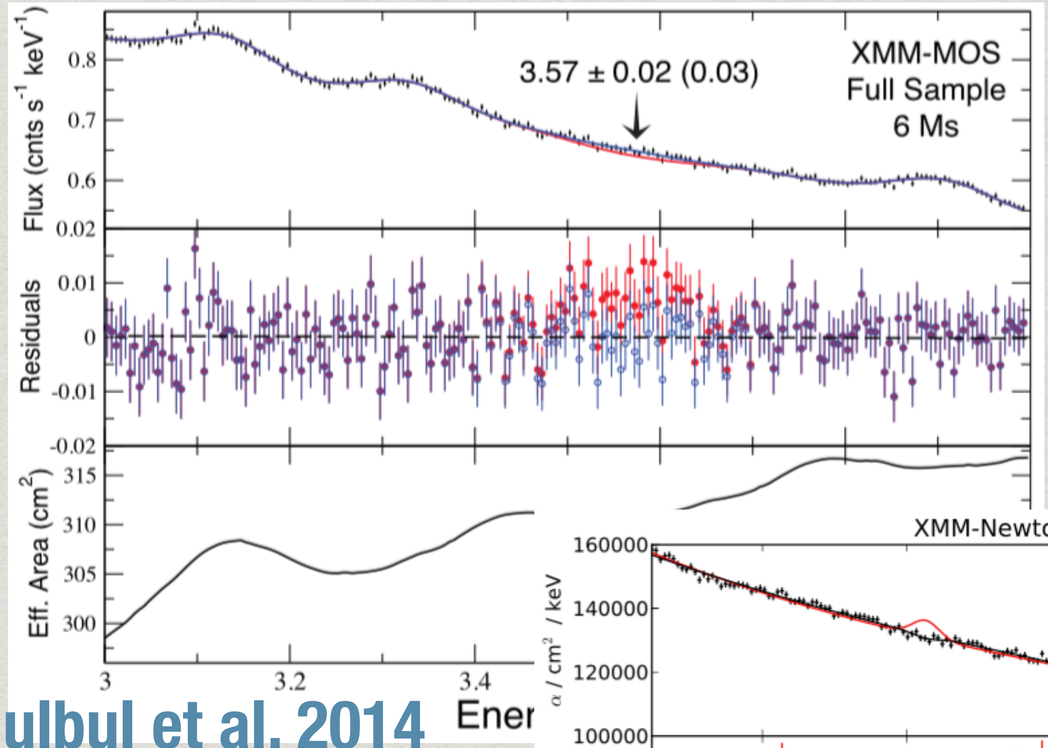
- Milky Way Center
- Stacked Clusters
- Stacked Dwarfs
- (Others?
- Possibly how current studies could be improved?



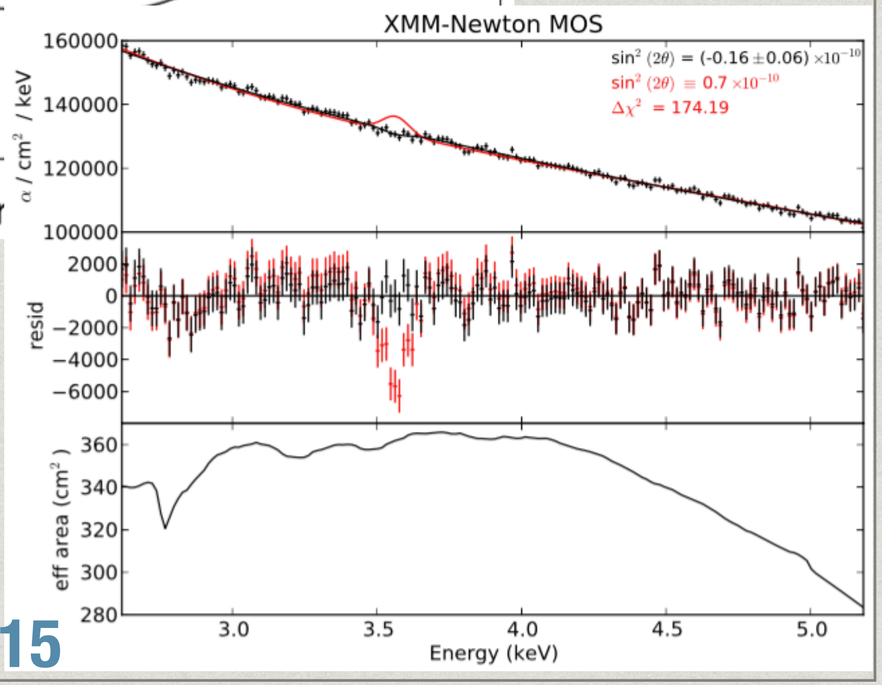
Fermi-LAT Collaboration 2015

X-ray Emission

- Stacked galaxy clusters (merging galaxy clusters)
- Stacked galaxies
- Others?



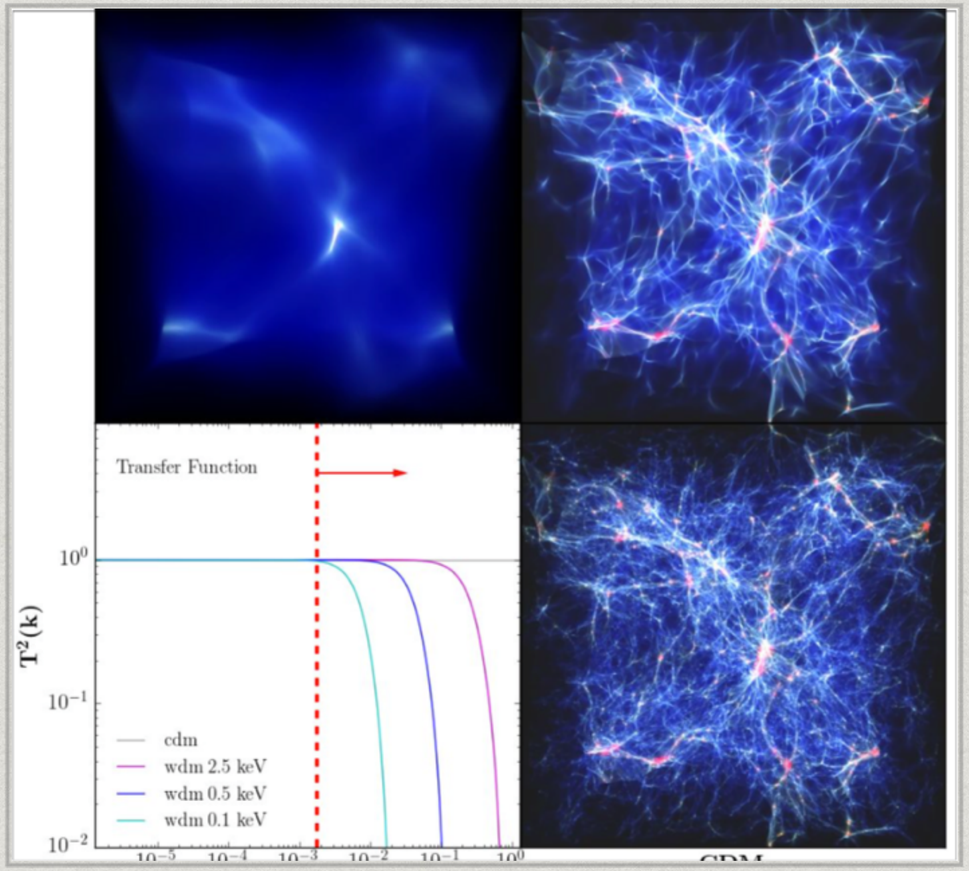
Bulbul et al. 2014



Anderson et al. 2015

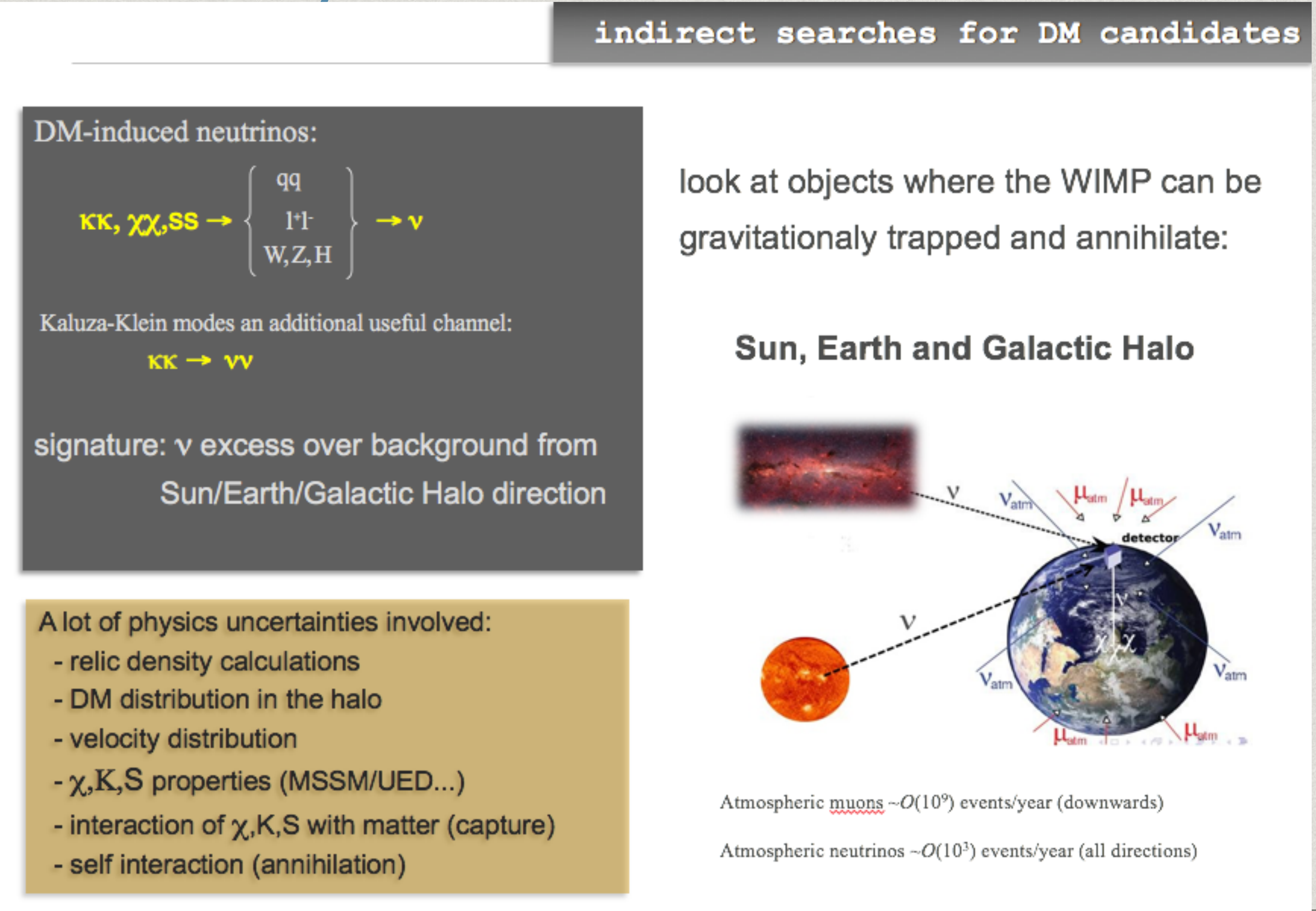
Lyman-alpha forest

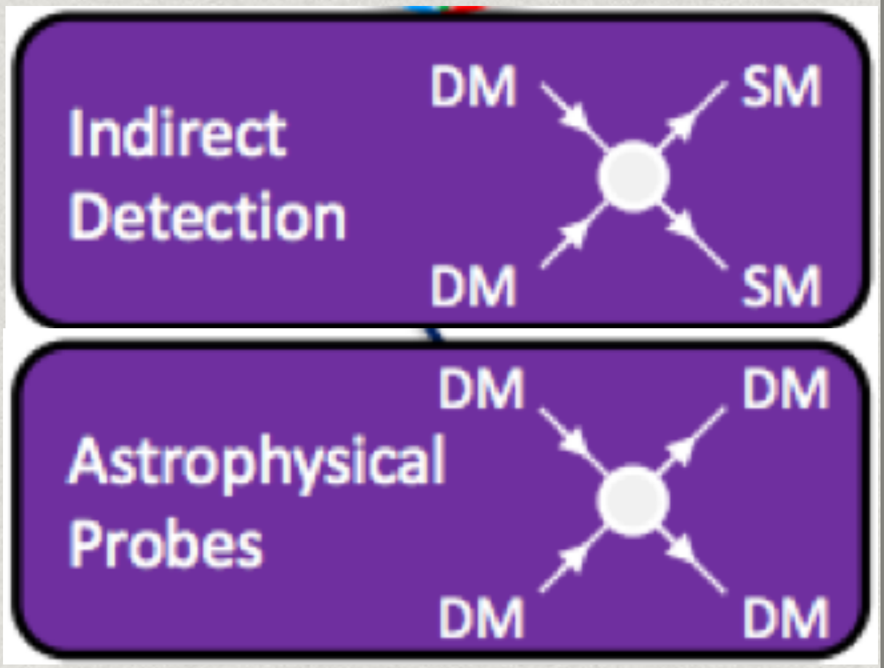
- constraint on dark matter temperature (there-by mass)
- Tightest constraint on warm dark matter



Baur et al. 2015

Neutrinos from possible dark matter decay in center of sun

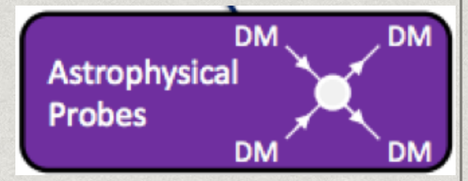




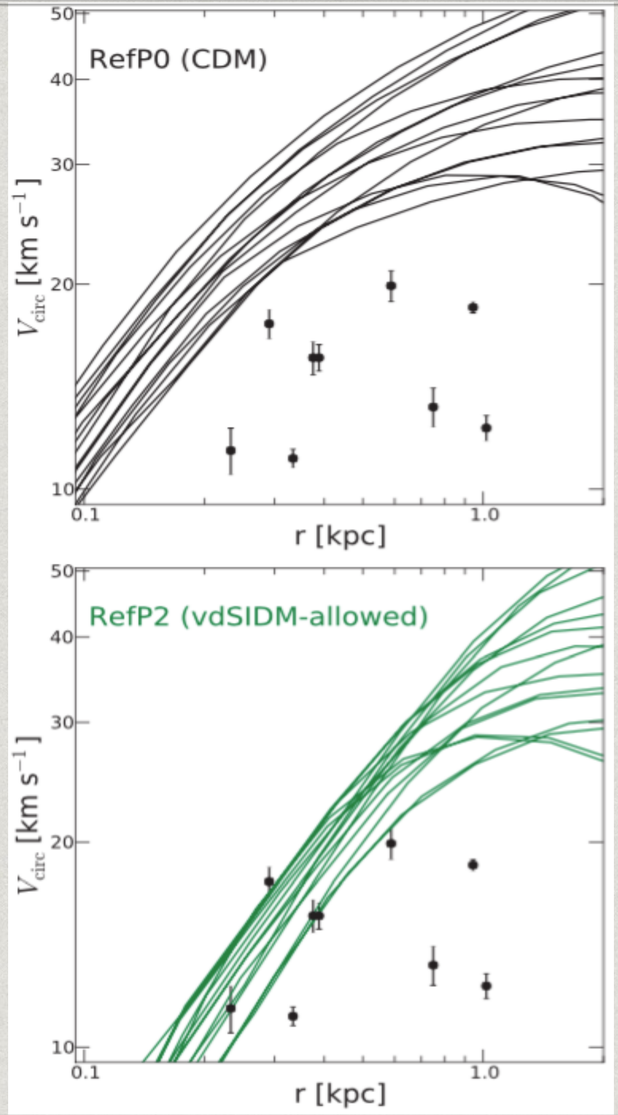
- using flux limits for annihilation products of DM that are at the center of the sun due to DM-DM interactions

Slide from Carlos de los Heros

Dwarf galaxies: mass profile

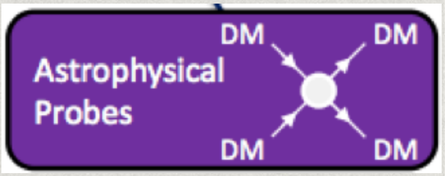


- cusp-core problem
- too big to fail
  - how they could be explained by standard model effects

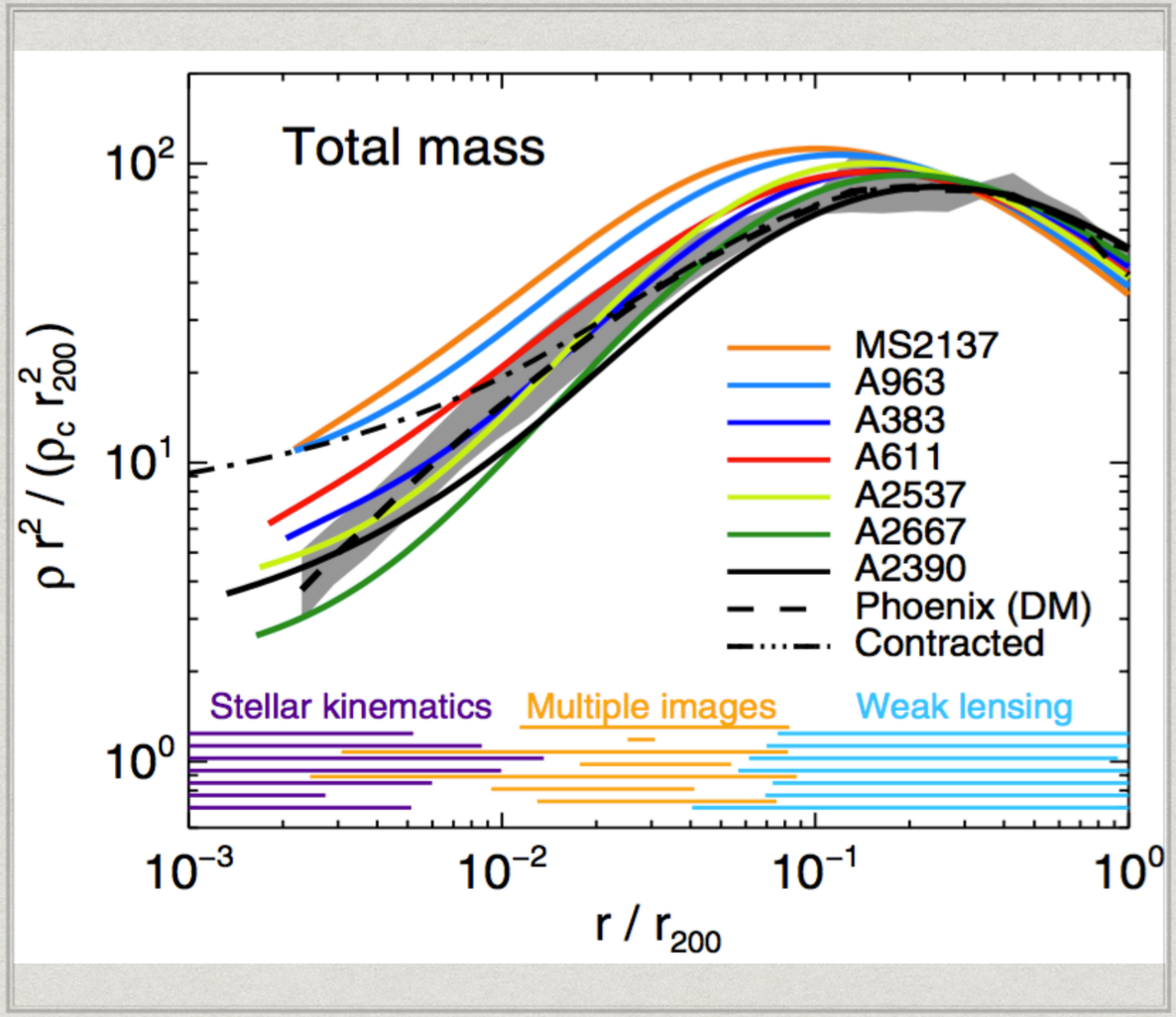


Vogelsberger et al. 2012

Galaxy clusters: mass profile



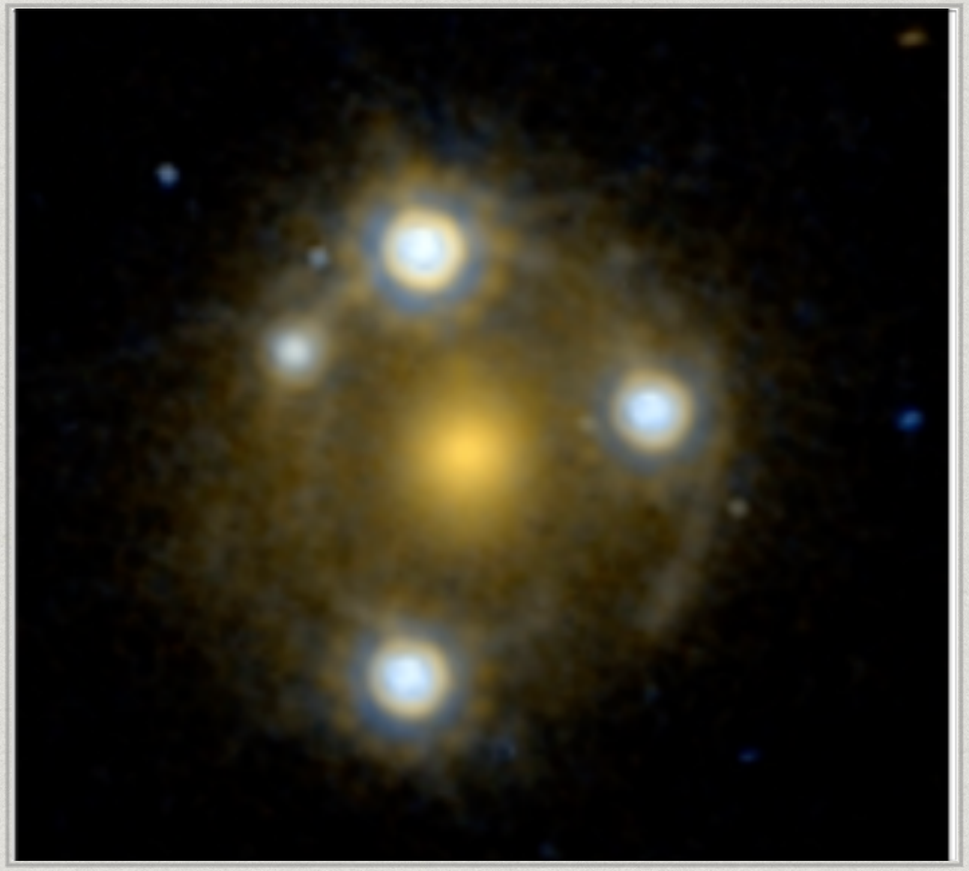
- Inner density profile
- degeneracy with baryonic effects



Newman et al. 2012

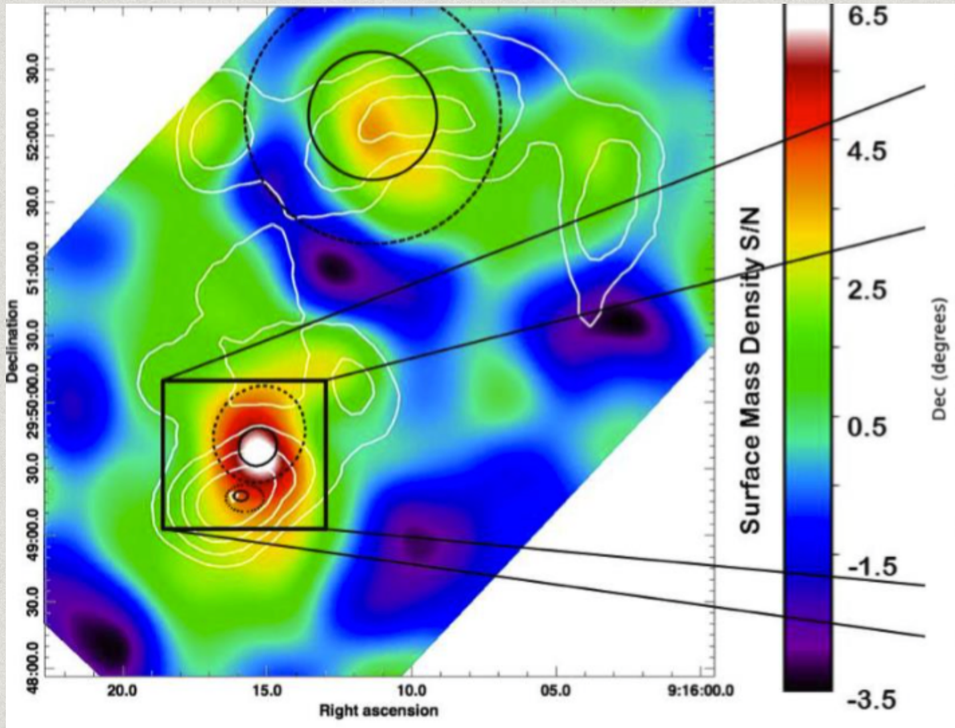
Galaxy-galaxy strong lensing

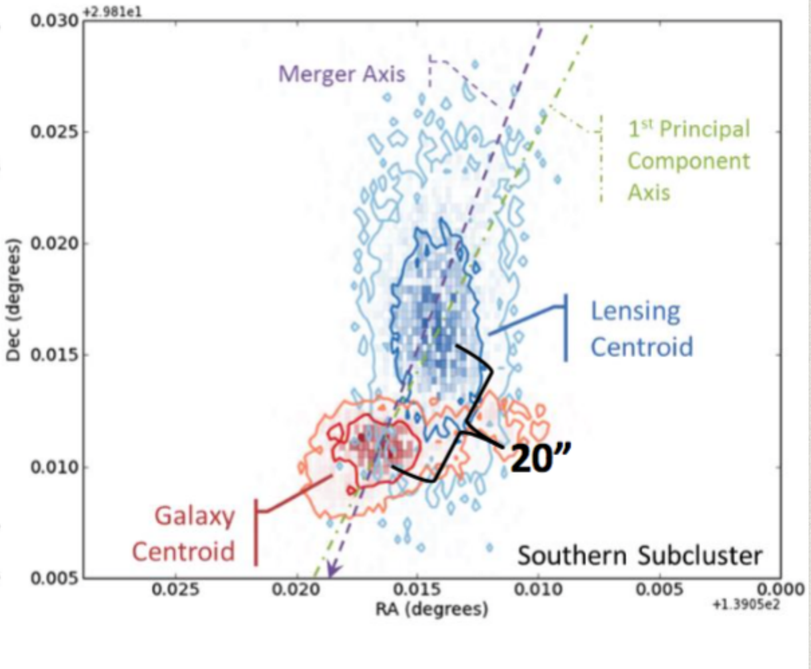
- Probe of amount of substructure



Merging Galaxy Clusters

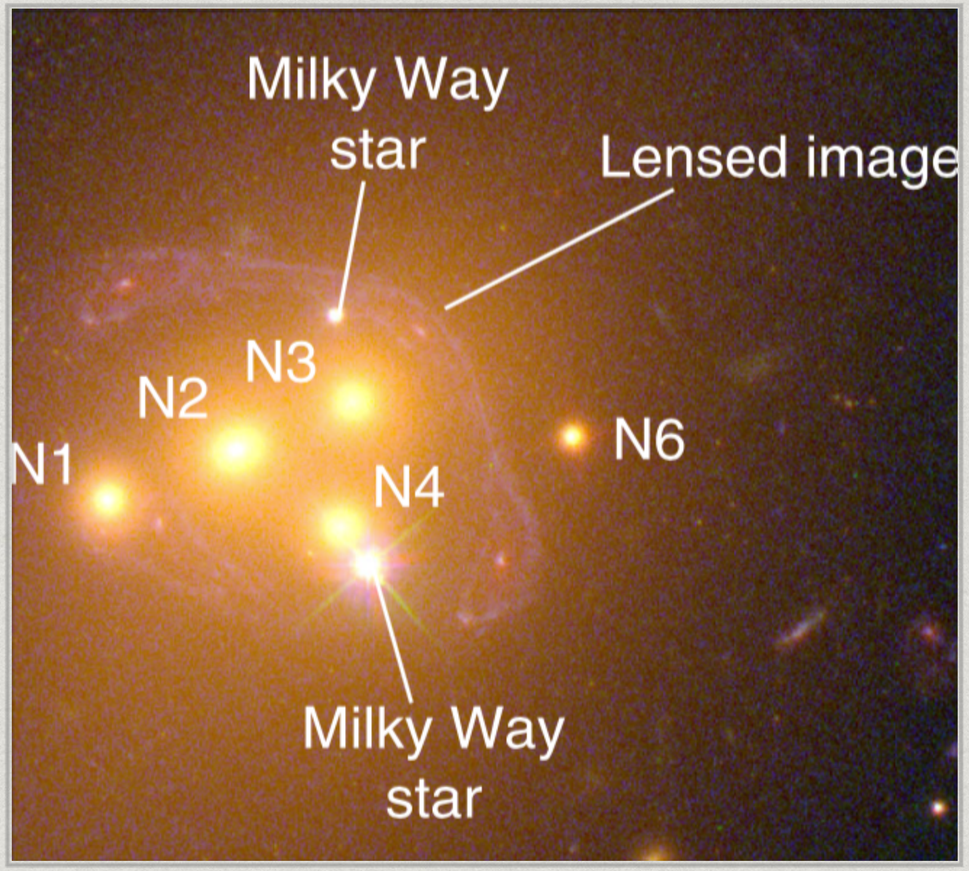
- Offset between galaxies and dark matter
  - either offset of peak
  - or rain drop distribution





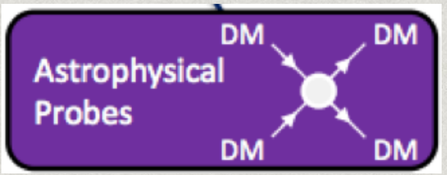
In-falling galaxies

- Galaxy offset from its dark matter sub-halo
- requires fortuitous strong lensing

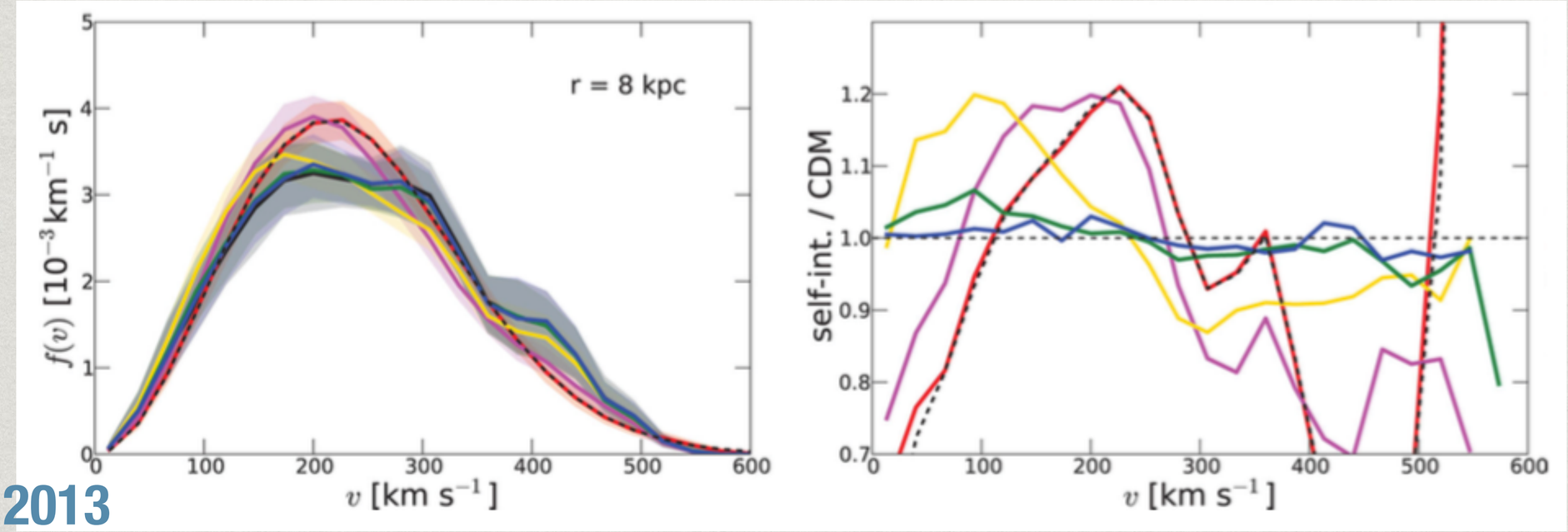


Massey et al. 2015

Stellar streams & velocity distribution in MW



- Velocity distribution varies as a function of cross-section
- Gaia

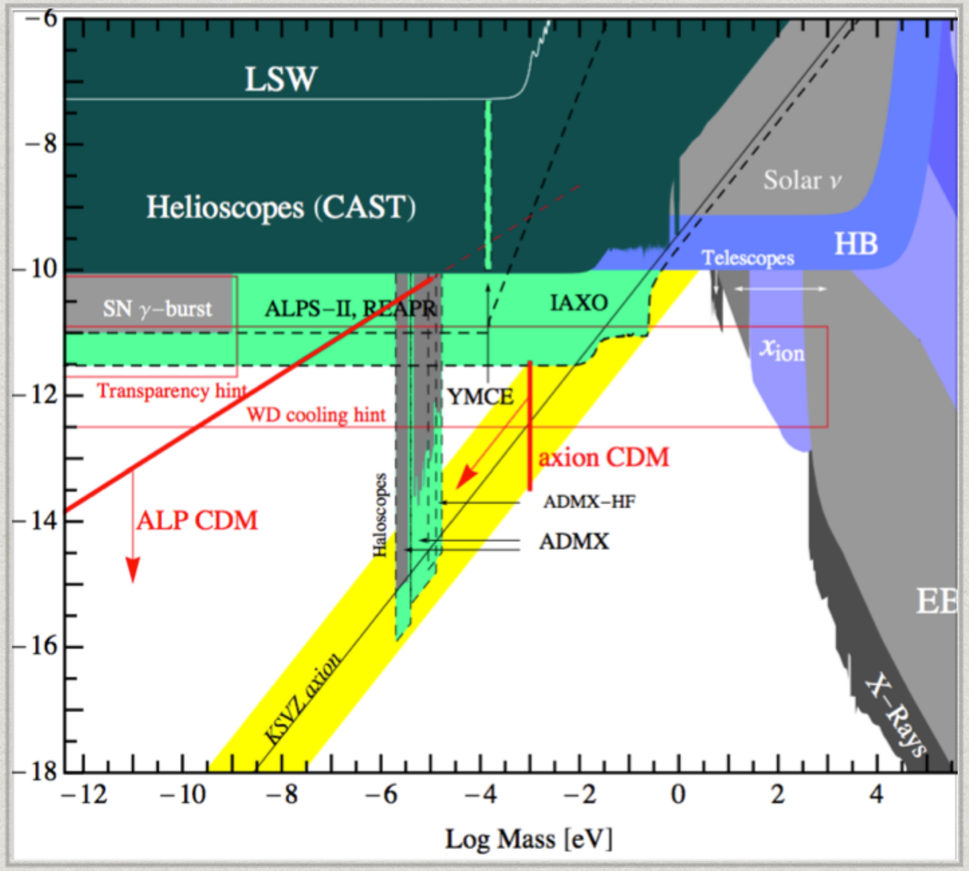


Vogelsberger et al. 2013

CMB BAO

Astrophysical constraints on axions

- Need something about the astrophysical constraints of axion dark matter.
  - perhaps mention Bose-Einstein condensate constraints
- See e.g. Roswald 2012 (blue and gray regions in figure to right) http://adsabs.harvard.edu/abs/2012PDU.....1..116R



Challenge to combine all of these constraints