Dark Matter Searches with Dwarf Galaxies

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Aspen Winter Conference, January 21st, 2010

based on:

RE, N. Sehgal, L.E. Strigari (arXiv: 0902.4750, PRD)

RE, N. Sehgal, L.E. Strigari, M. Geha, J.D. Simon (to appear)

Outline

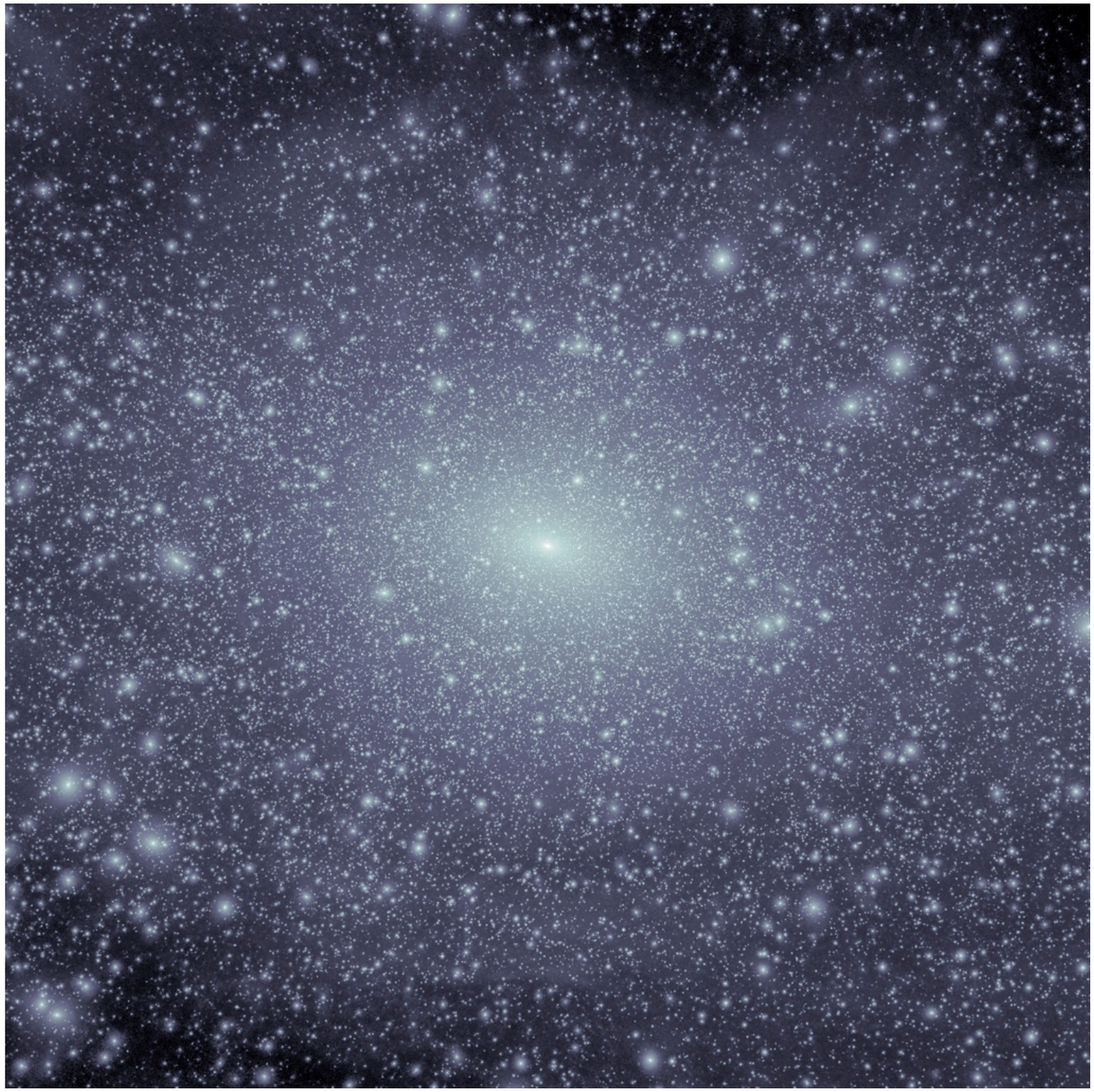
- Dwarf Galaxies probe dark matter properties
- Dwarf Galaxies are great targets for Indirect Detection of Dark Matter
- Constraints and Prospects for Fermi, Atmospheric Cherenkov Telescopes, and IceCube

A Milky-Way DM Halo

[Diemand et.al.]

Via Lactea II
Simulation

(only DM, no baryons)



800 kpc cube

A Milky-Way DM Halo

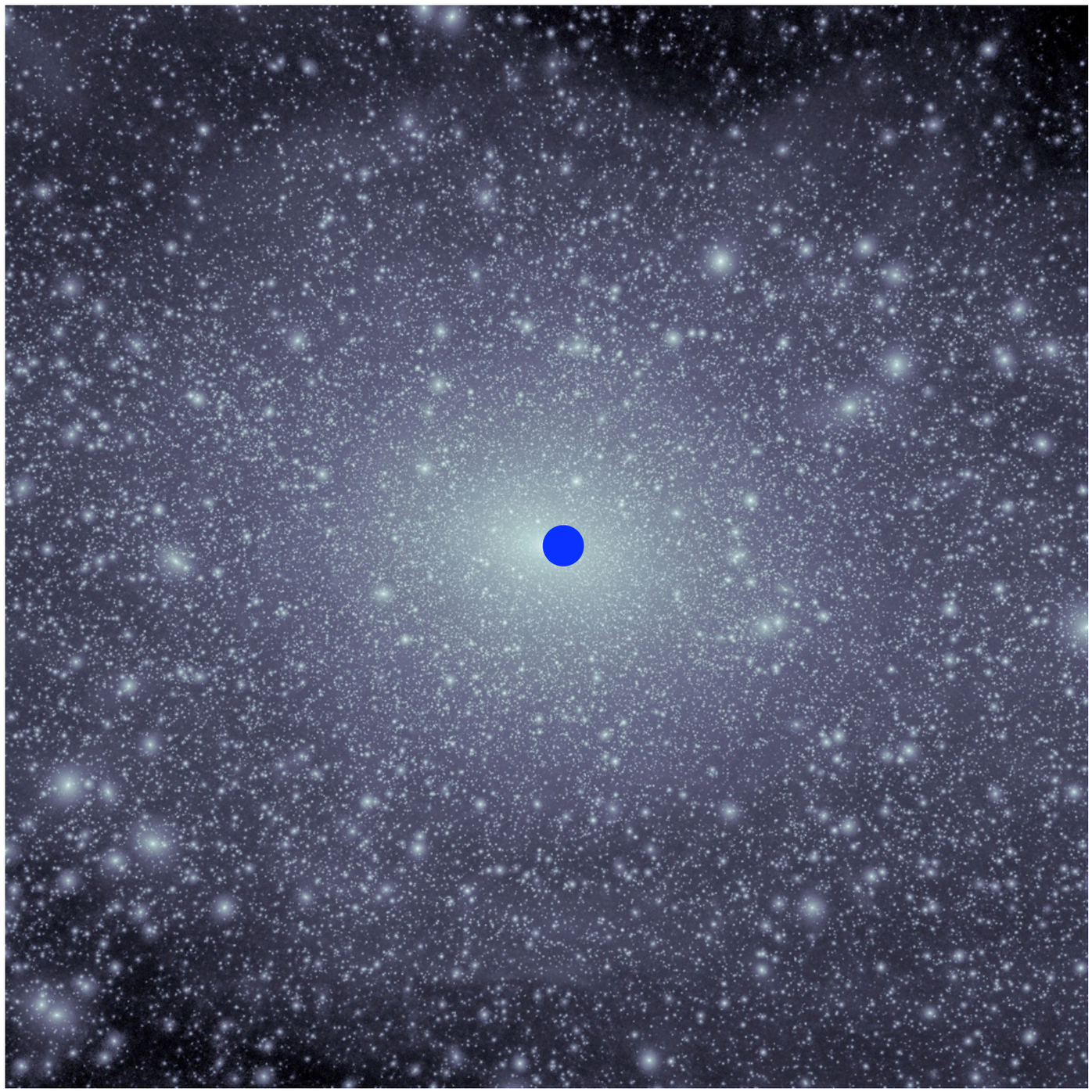
[Diemand et.al.]

Via Lactea II
Simulation

(only DM, no baryons)

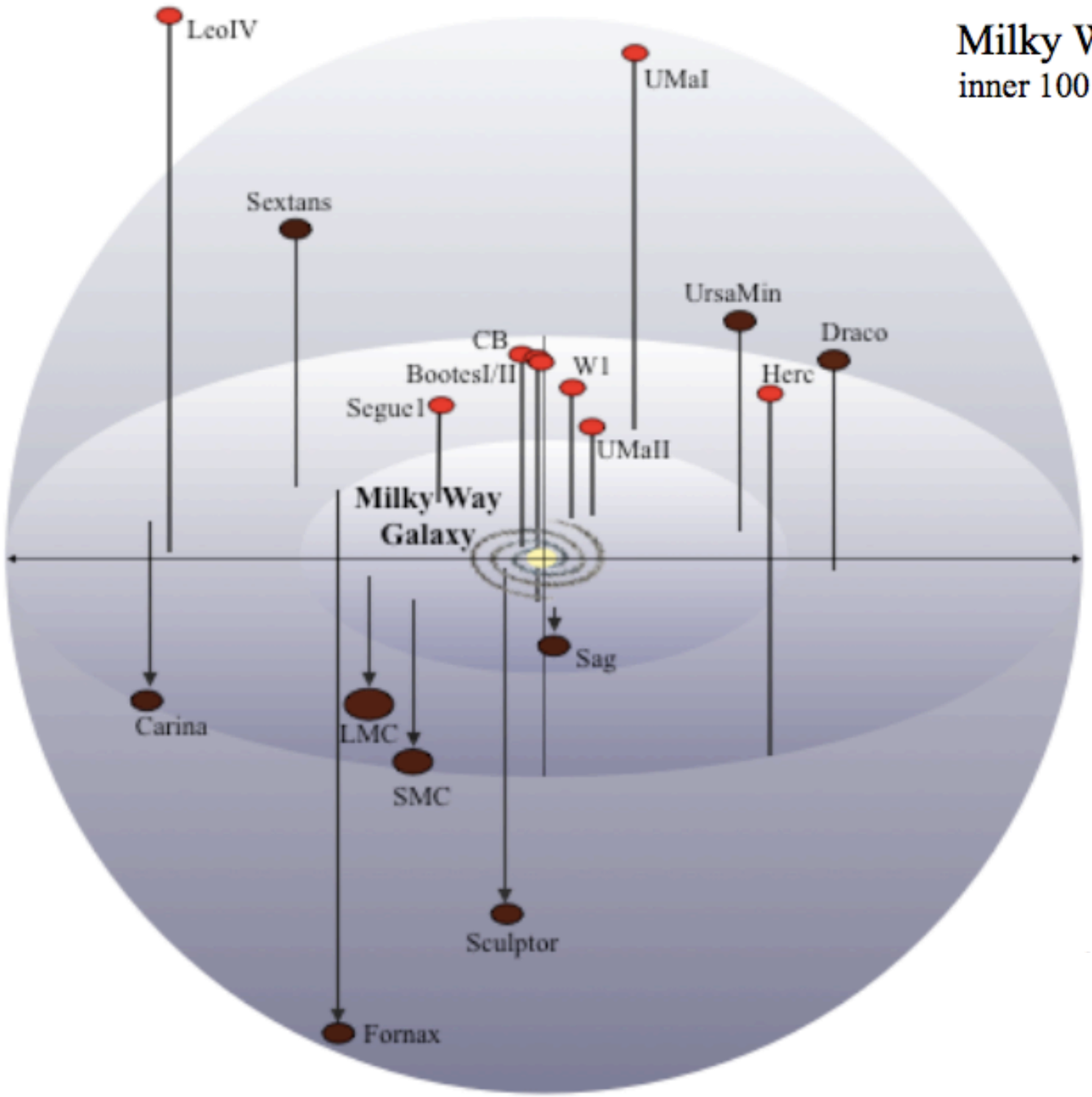
visible Milky Way
galaxy ~30 kpc

some subhalos will
form stars and
become dwarf galaxies



800 kpc cube

Known Nearby Dwarf Galaxies



Milky Way
inner 100 kpc

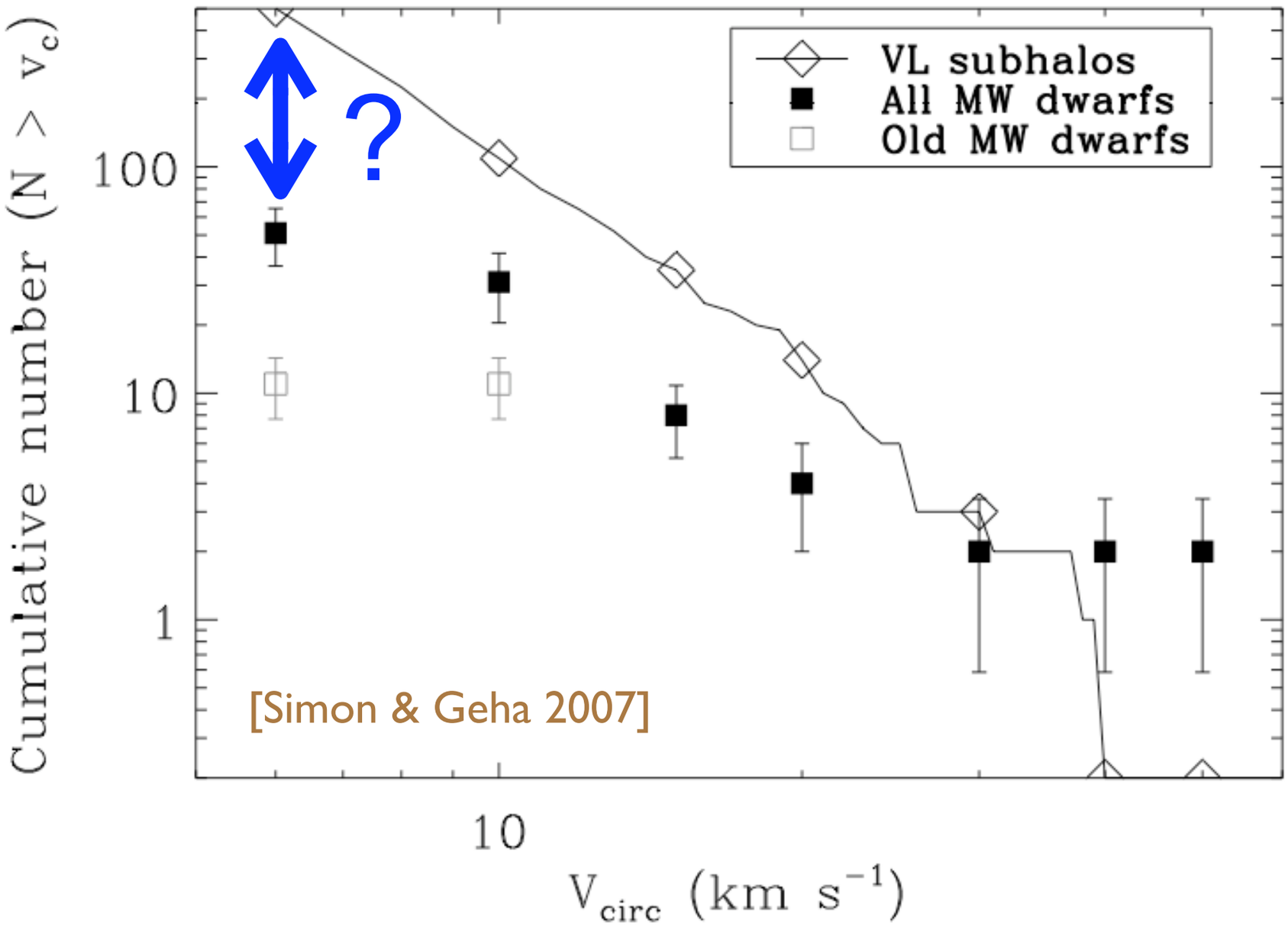
"Classical Dwarfs"
(pre-2005)

"Ultra-faint" Dwarfs
(post-2005, SDSS)

[Geha]

Dwarfs probe Dark Matter Properties

e.g. Missing Satellite Problem in "Cold DM" model



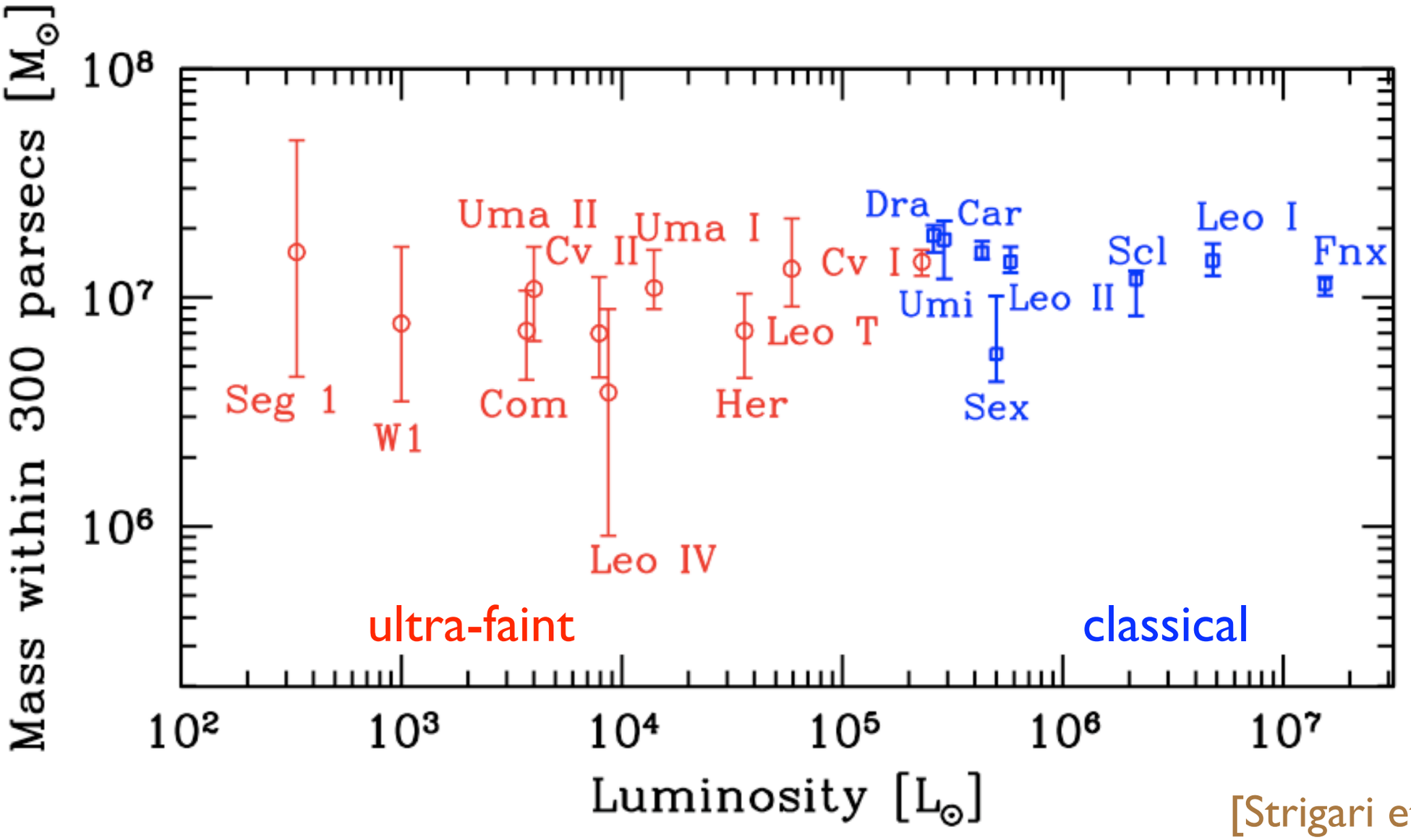
more massive ⟶

warm DM?

self-interacting DM?

suppressed star formation at low-masses?

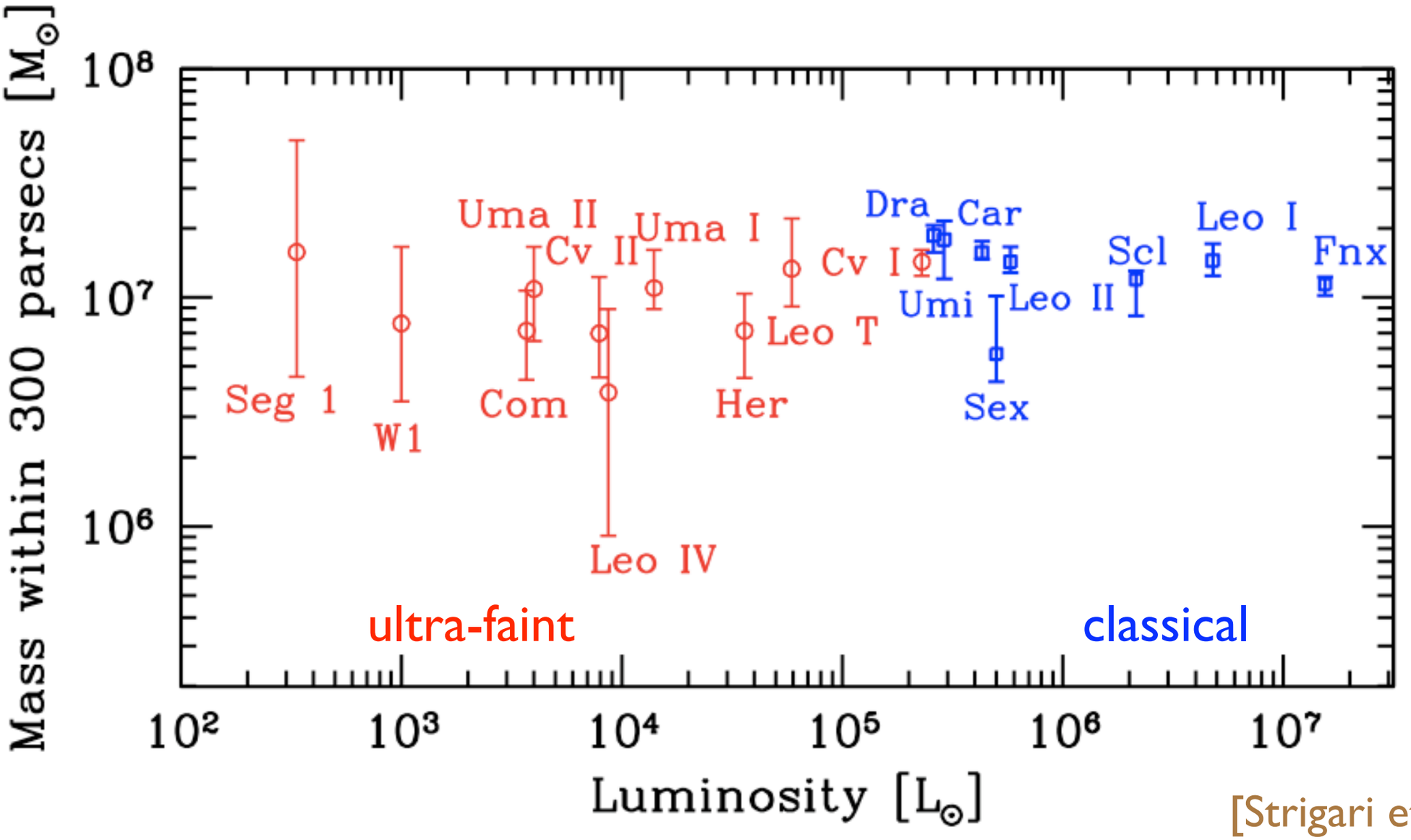
Dwarfs have common mass scale within 300 pc



[Strigari et.al. 2008]

A new scale in Galaxy Formation?

Dwarfs have common mass scale within 300 pc



[Strigari et.al. 2008]

A new scale in Galaxy Formation?

Also rules out Thermal Warm DM with mass < 1 keV

Dwarf Galaxies as Targets for Indirect Detection of Dark Matter

Rouven Essig SLAC

Dwarf galaxies: Excellent Targets

Sizeable Signal

- Nearby, DM dominated
- use stellar kinematics to determine expected flux
- low velocity dispersion: $v_{\rm dwarf} \sim v_{\rm halo}/20$

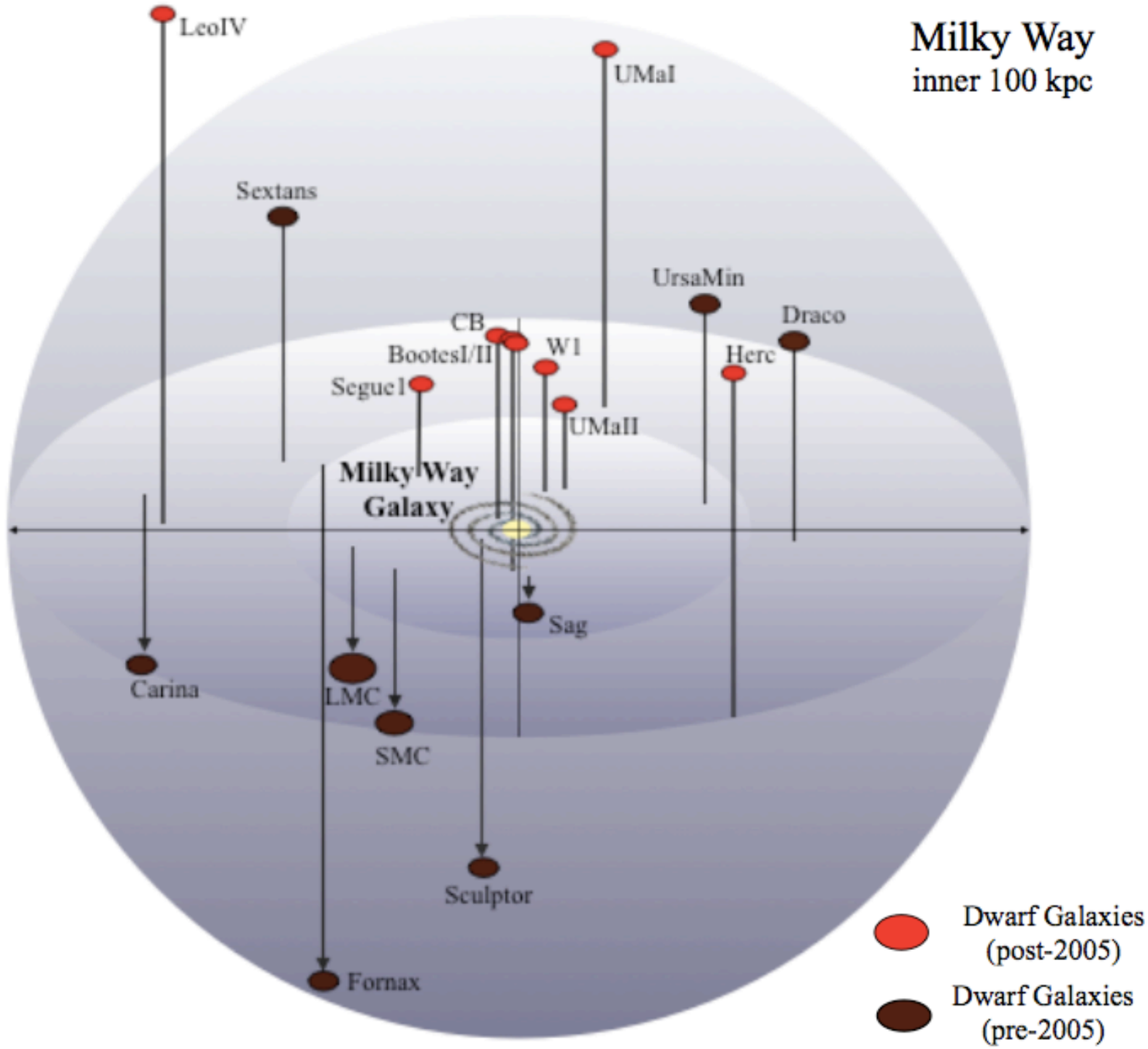
  (Sommerfeld enhanced DM annihilation?)

Low Background

- high galactic latitude
- no intrinsic gamma-ray sources

Any signal would be *very* suggestive of dark matter

Existing Data

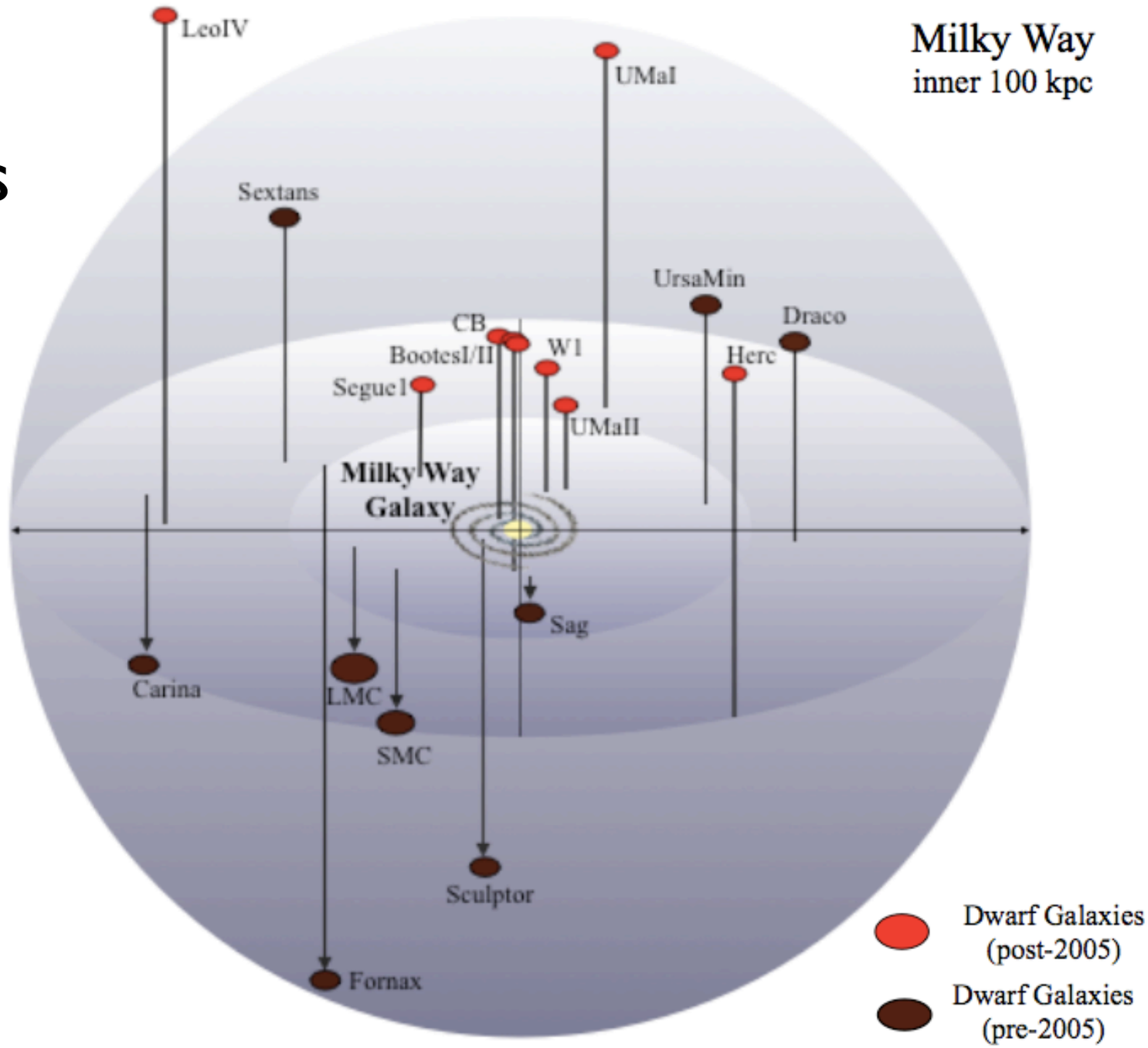


[Geha]

Existing Data

Fermi observes all dwarfs

$\gamma - \text{rays}$



[Geha]

Existing Data

Fermi observes all dwarfs

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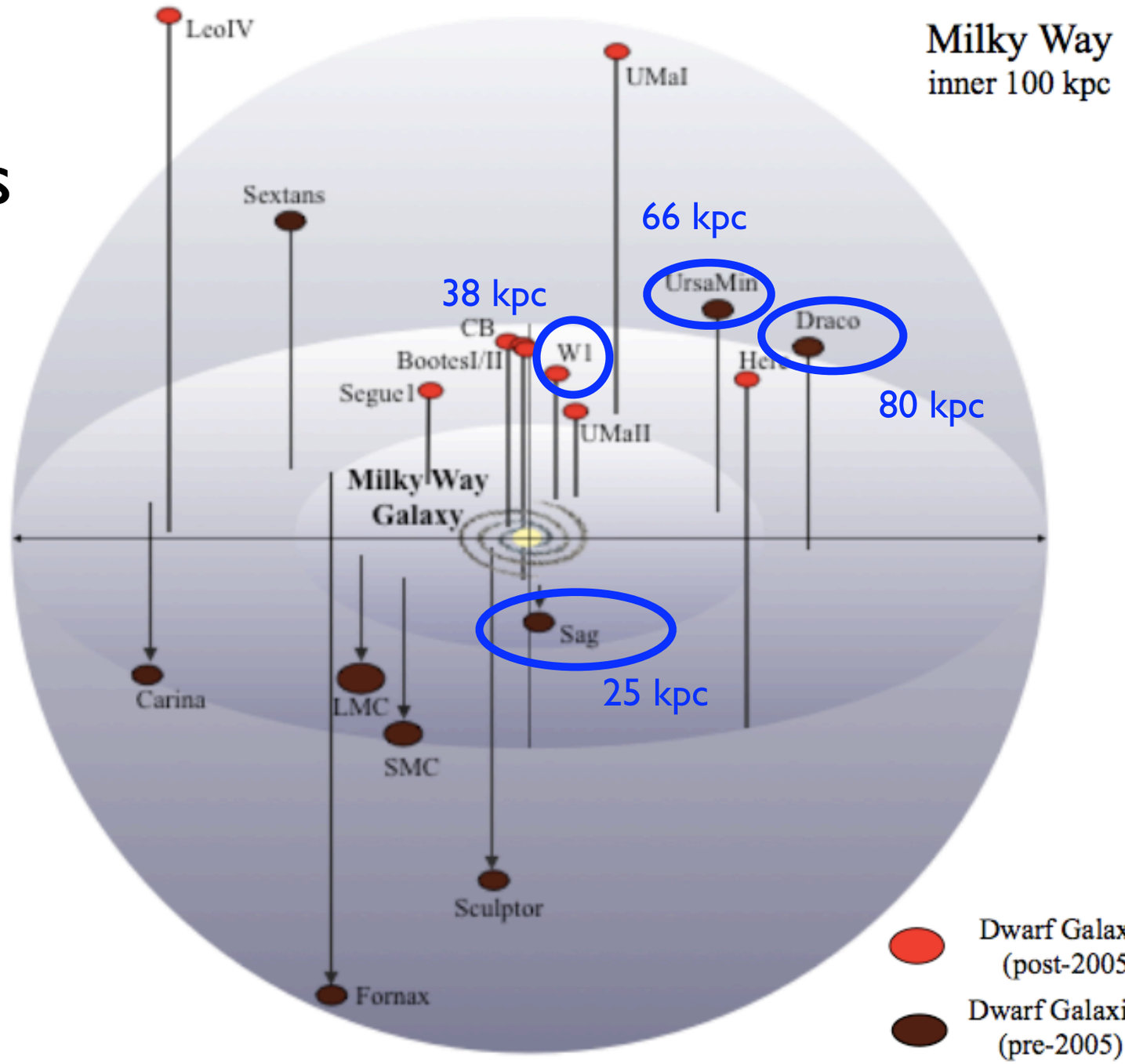
Blue: Observed by ACTs

VERITAS, MAGIC
HESS, CANGAROO

$\gamma - \text{rays}$



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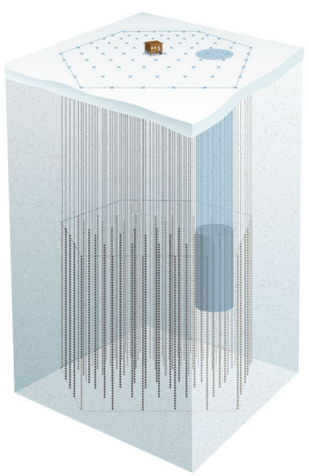
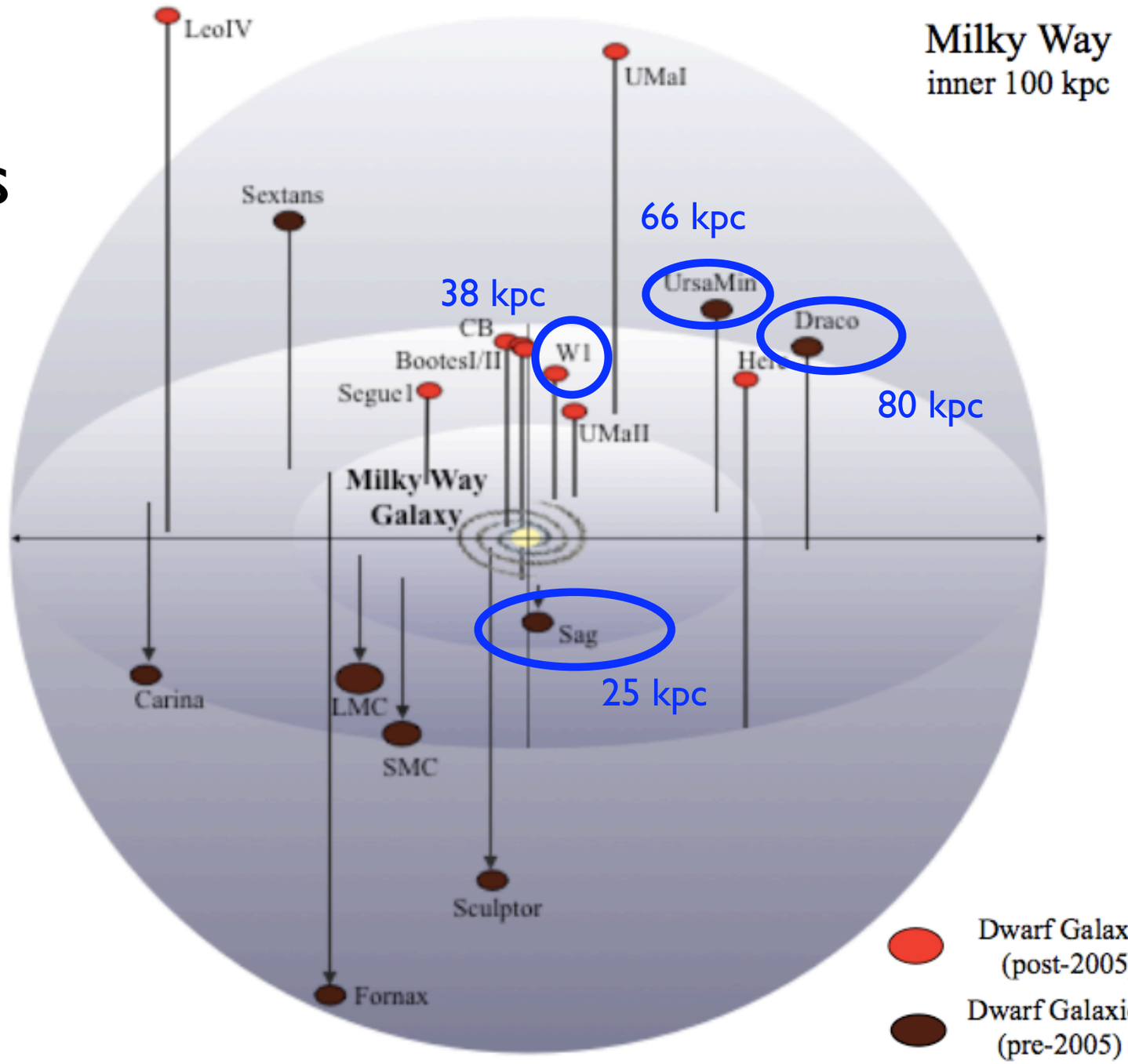


IceCube

data coming

$\nu's$



[Geha]

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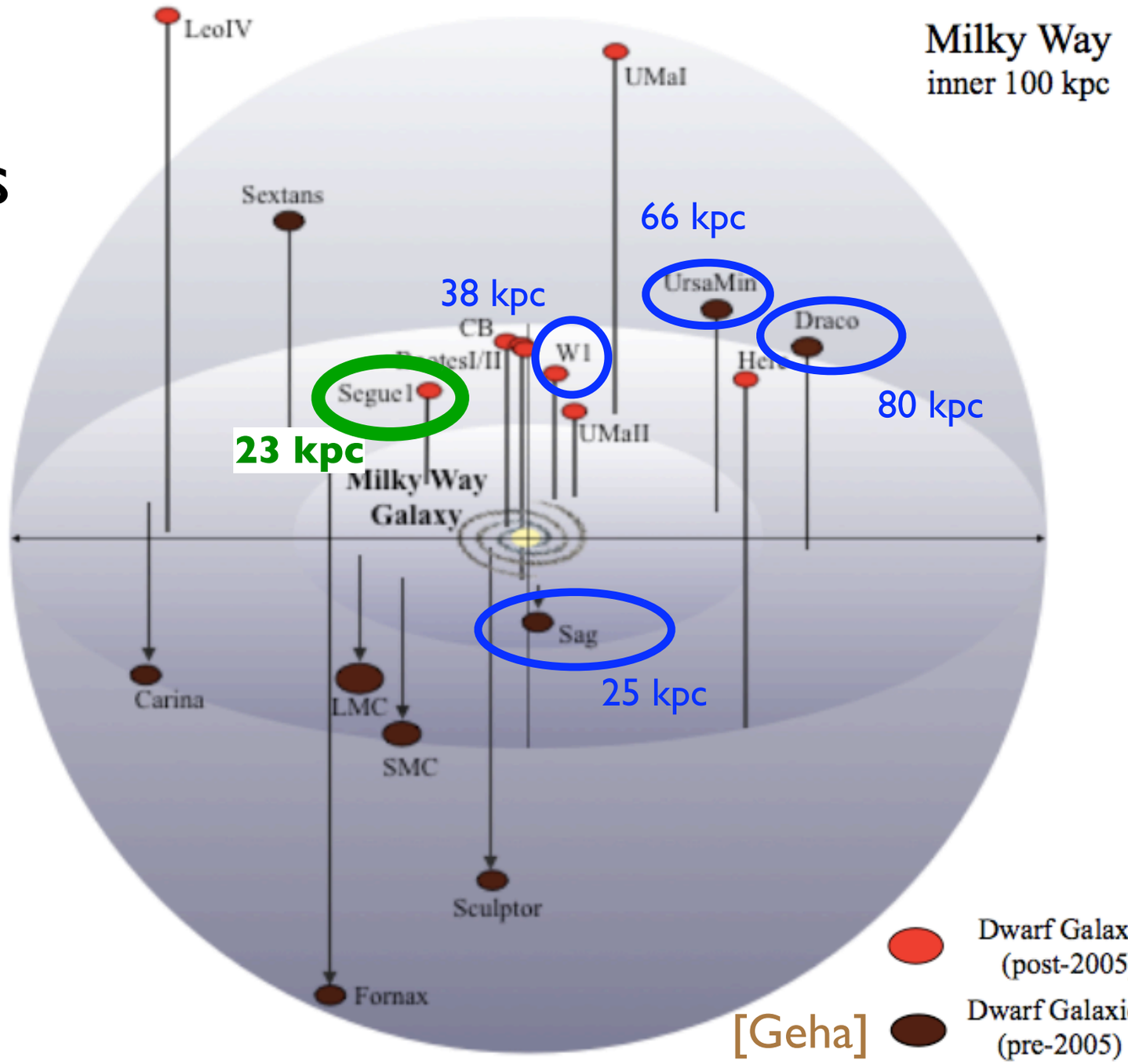
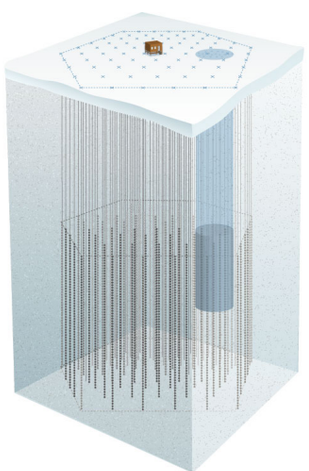




IceCube

data coming

$\nu's$

Segue 1: best target? (MAGIC is analyzing data!)

Least luminous galaxy known (M/L~1000)

[Geha et.al.]

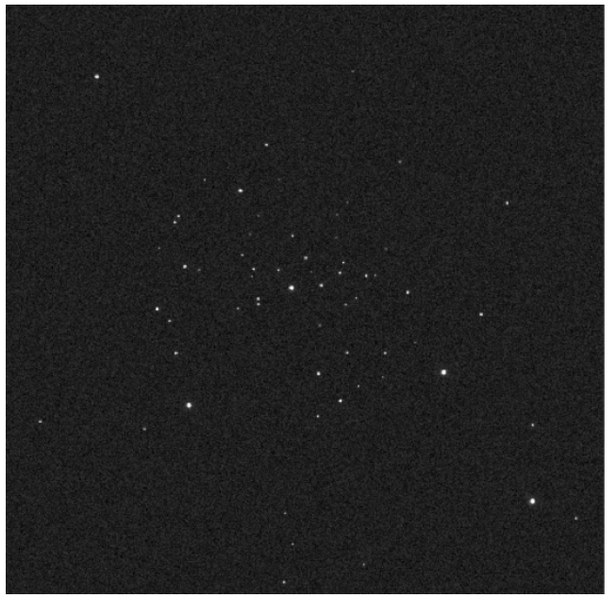
Compare Draco & Segue 1

Draco (discovered 1954)

data on >200 stellar velocities

classical dwarf

Segue 1 (discovered 2006)



New stellar data is being analyzed (~65 stars)

[Simon et. al.]

ultra-faint dwarf

$\gamma,\ \nu$ flux $\propto\ \mathcal{L} \sim \int \rho^2$ determined from stellar velocities

$$\mathcal{L}_{\mathrm{Segue\ 1}} \sim 35\, \mathcal{L}_{\mathrm{Draco}}$$ (preliminary!!)

Constraints and Prospects for

Fermi

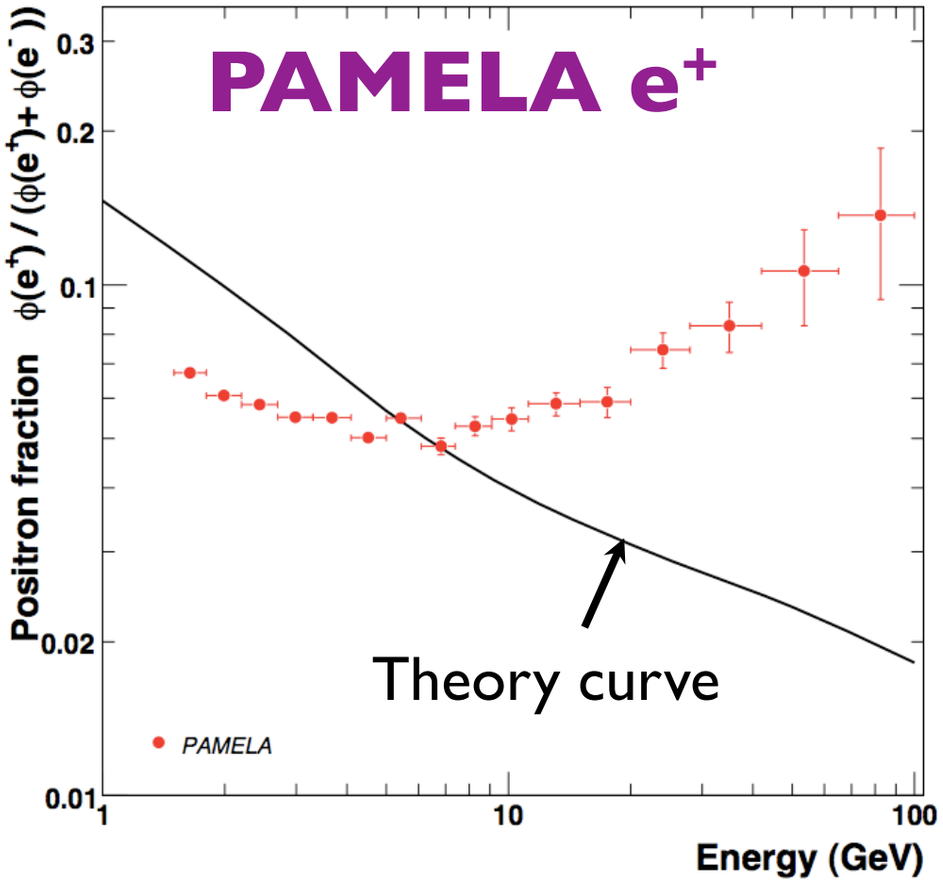
Atmospheric Cherenkov Telescopes

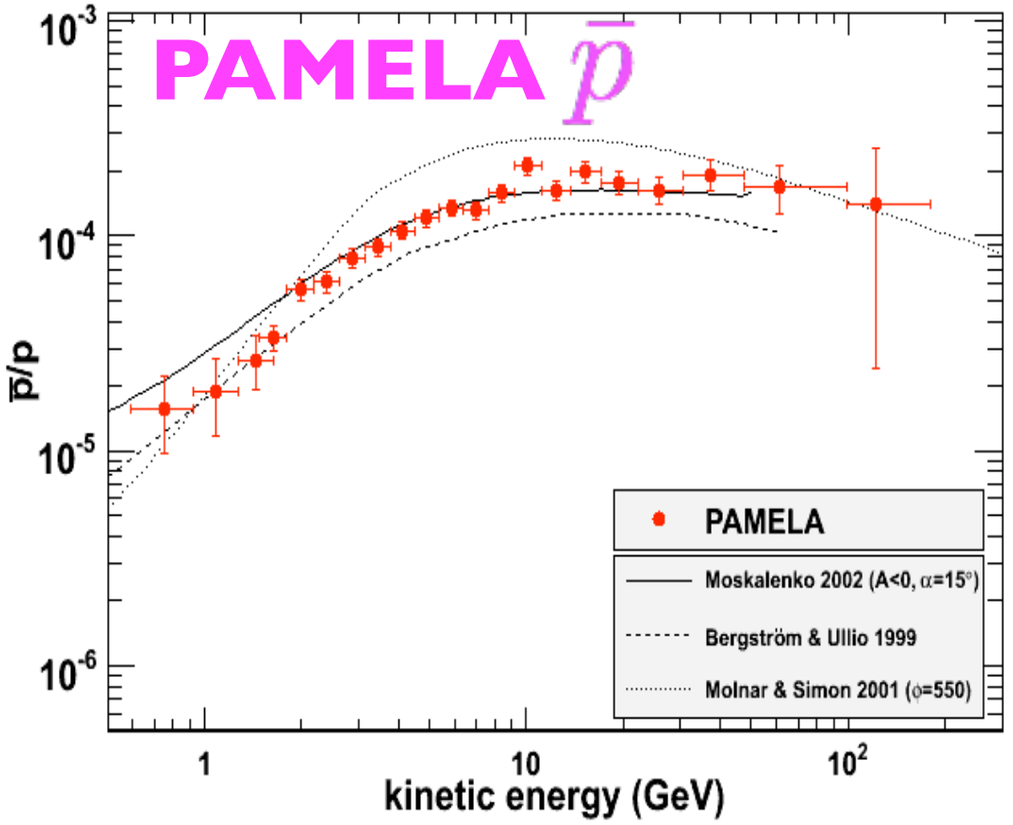
IceCube

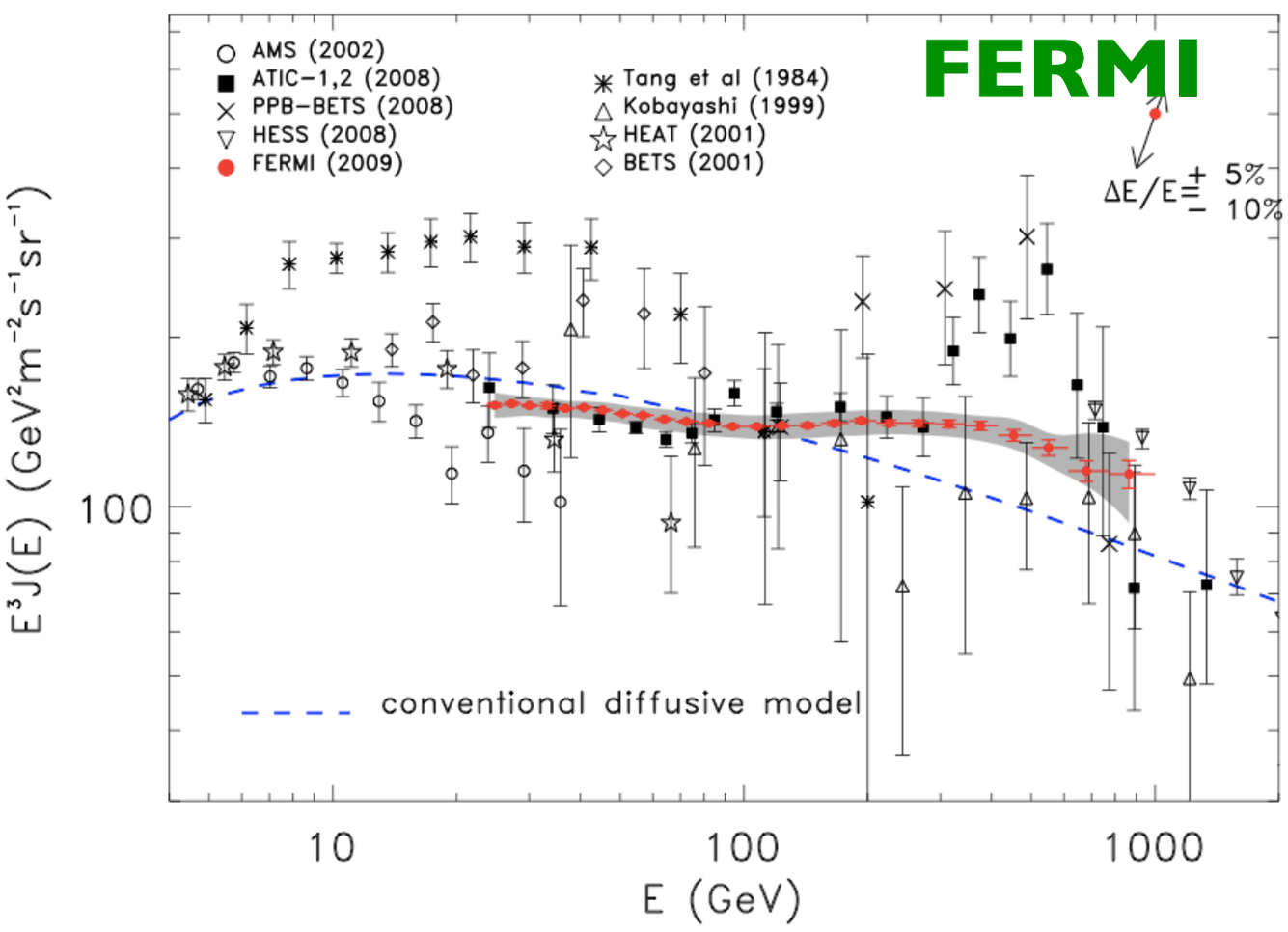
Rouven Essig SLAC

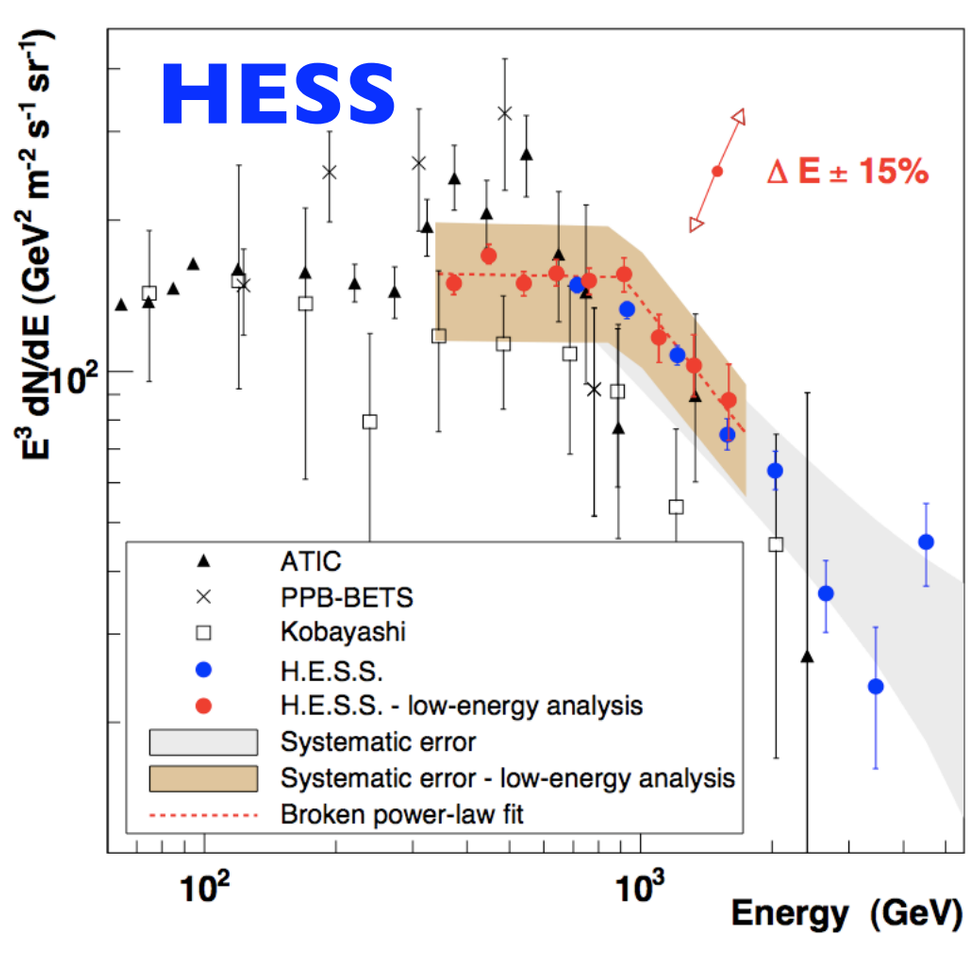
This Talk:

Focus on models explaining this data

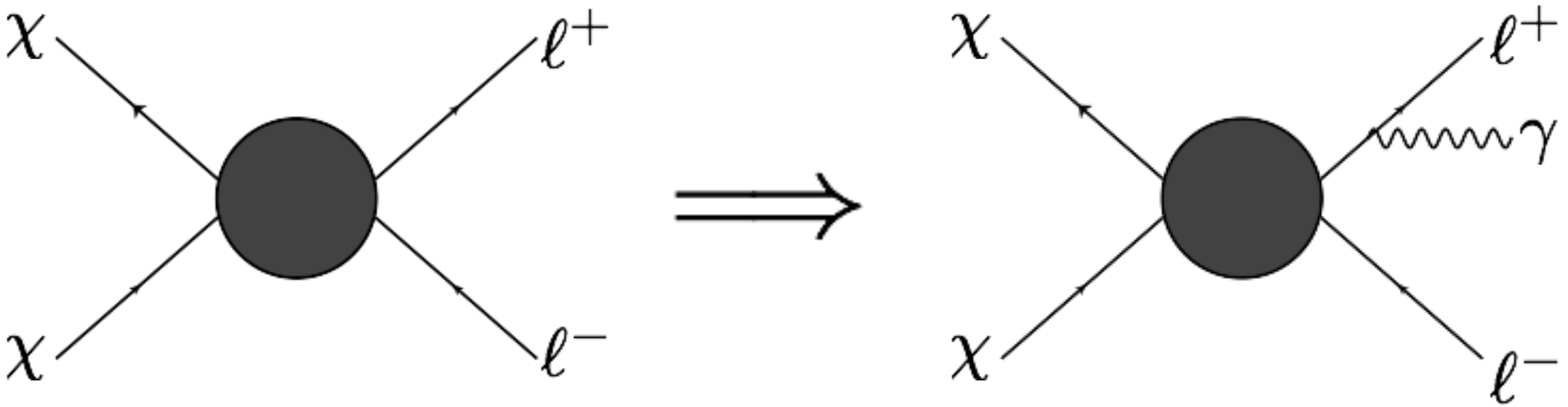






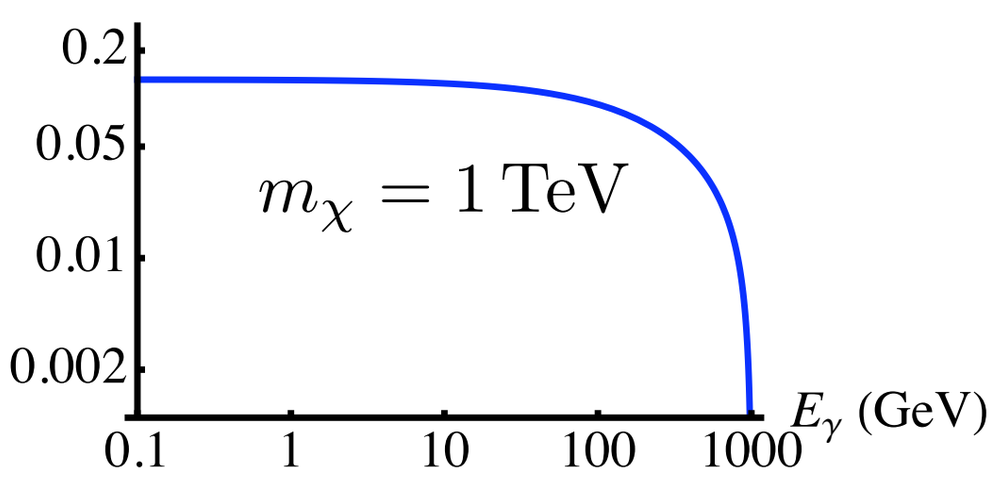


- Gamma Rays guaranteed from "Final State Radiation"



$E_\gamma \frac{dN_\gamma}{dE_\gamma}$ Distinctive spectrum

[Beacom et.al. (2004)]
[Birkedal et.al. (2005)]

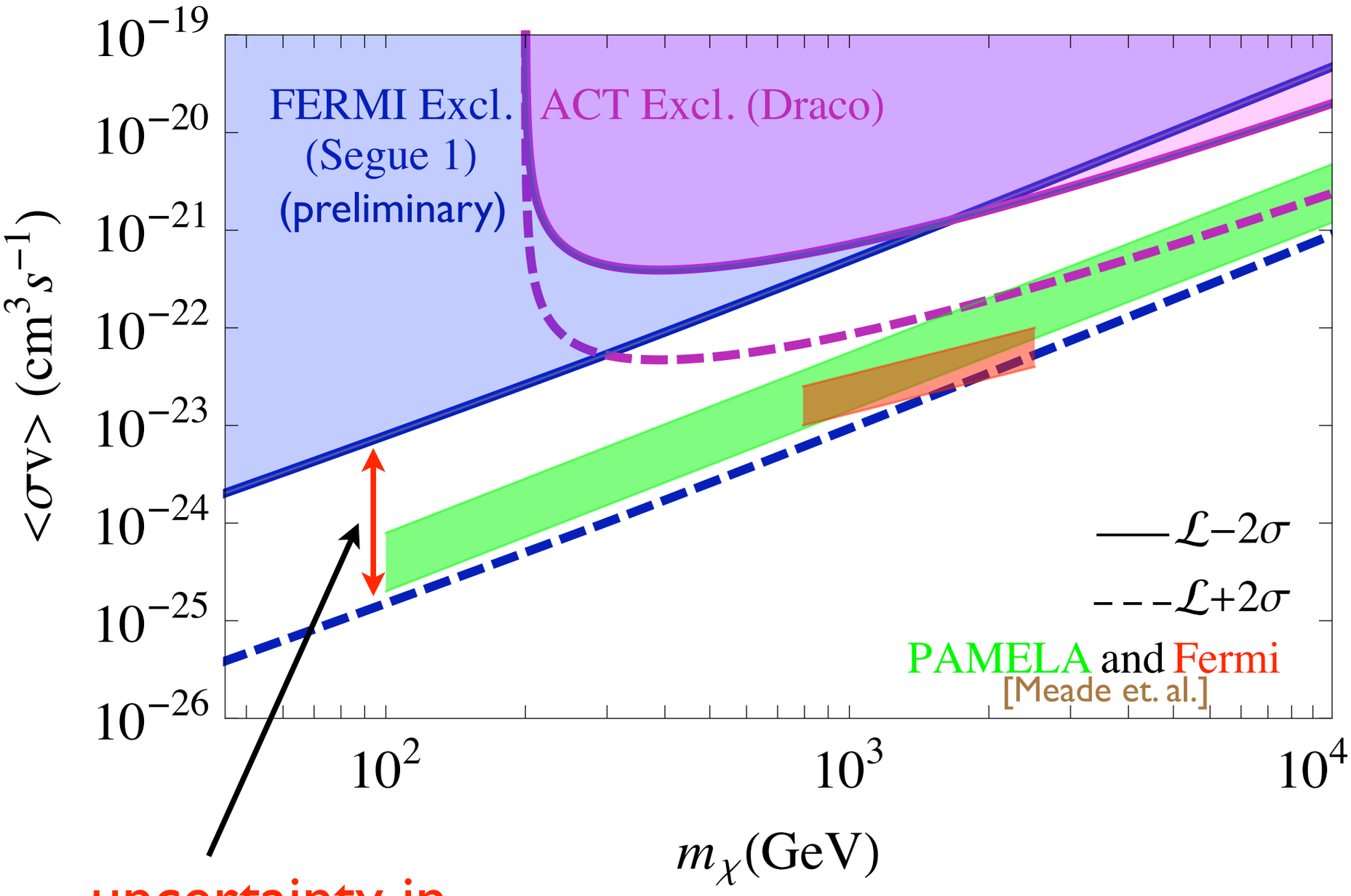


- Neutrinos guaranteed if $\ell = \mu, \tau$

$$\tau \longrightarrow \mu \nu_\mu \nu_\tau \ , \ \mu \longrightarrow e \nu_e \nu_\mu$$

Current Fermi & ACT limits

[RE, Sehgal, Strigari, Geha, Simon]



Fermi data:
9 months of data

[Farnier, RICAP'09]
[Wang, CINC'09]

ACT data:
VERITAS obs. of Draco [0810.1913]

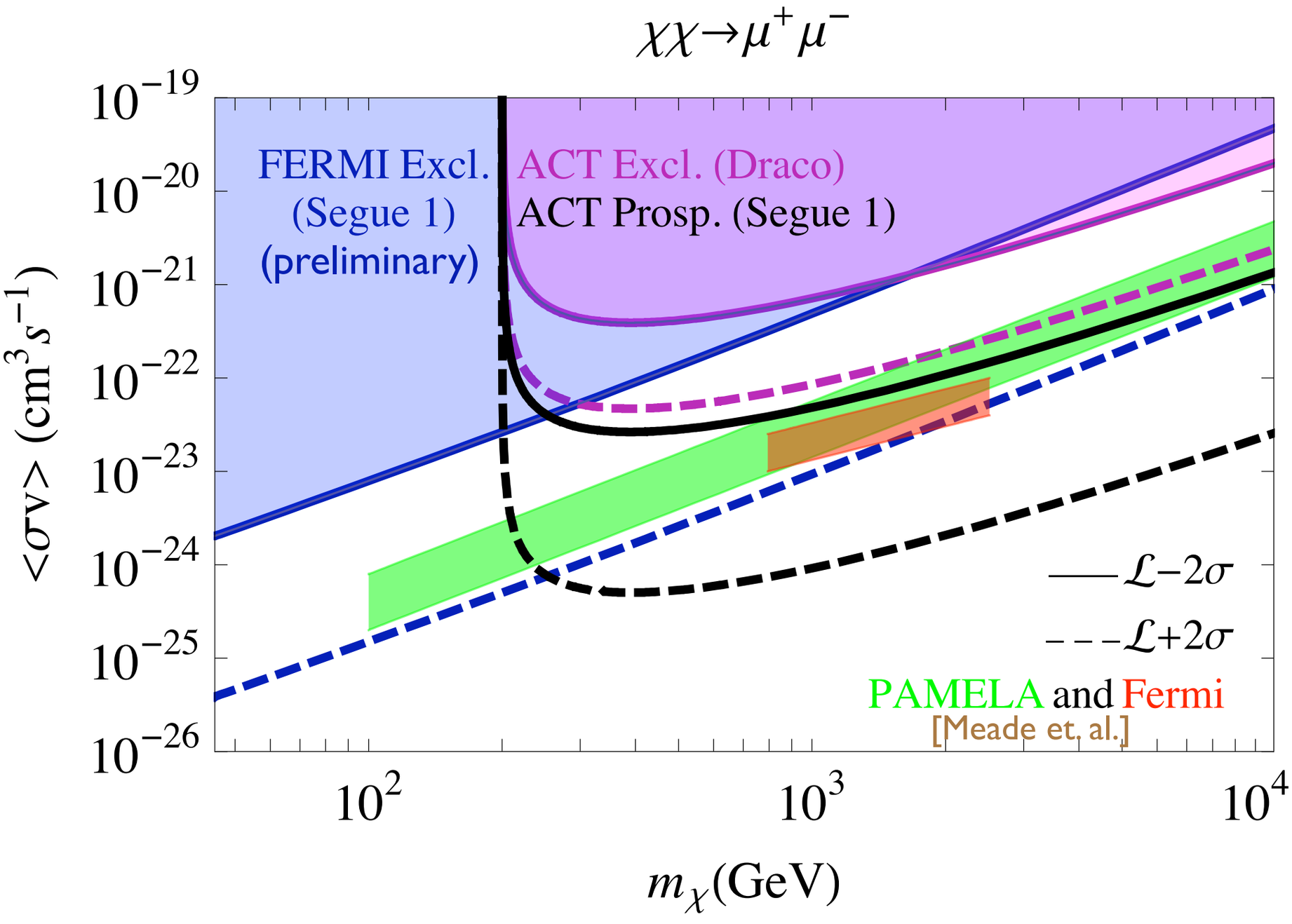
uncertainty in

$$\mathcal{L} \propto \int \rho^2$$

Fermi better at lower masses,
ACTs at higher masses

Prospects for MAGIC & VERITAS from Segue 1

[RE, Sehgal, Strigari, Geha, Simon]



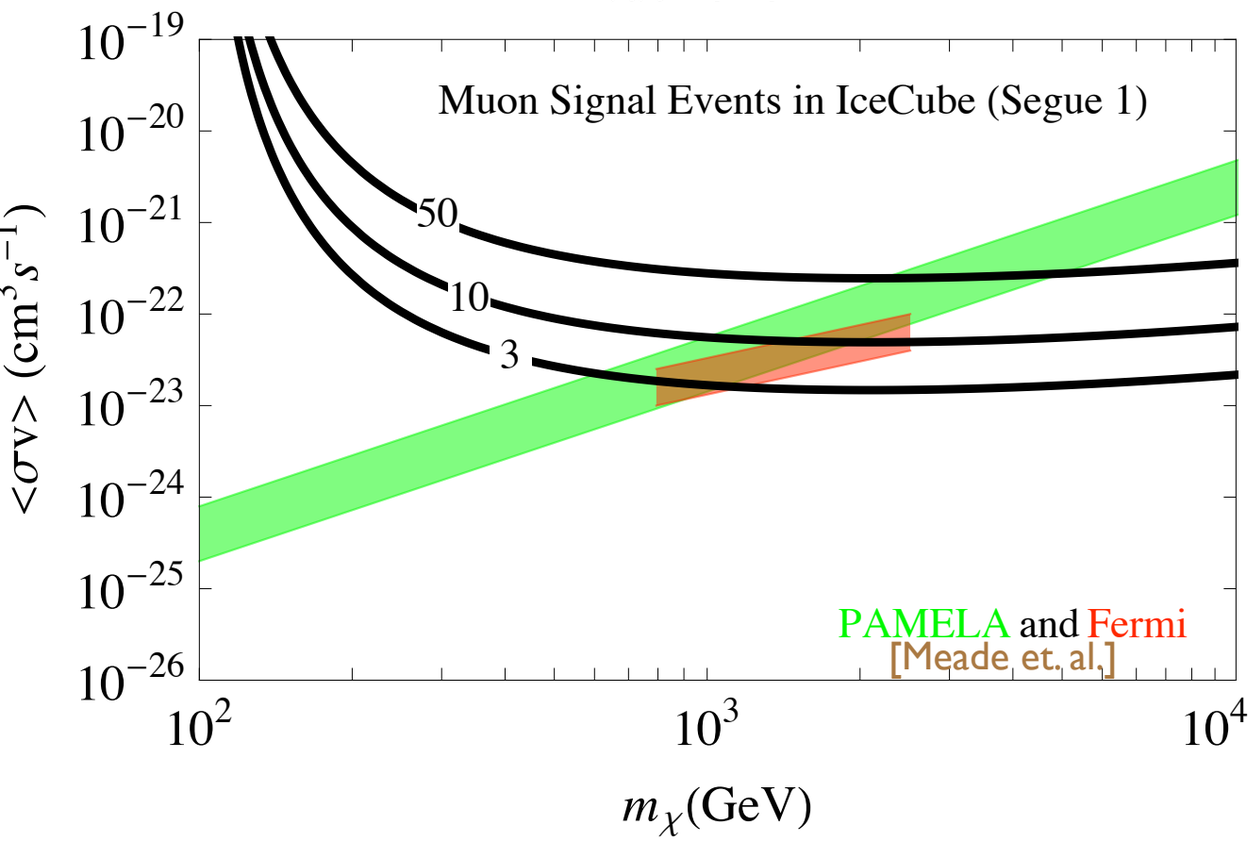
(preliminary)

IceCube Prospects for $\chi\chi \to \mu^+\mu^-$

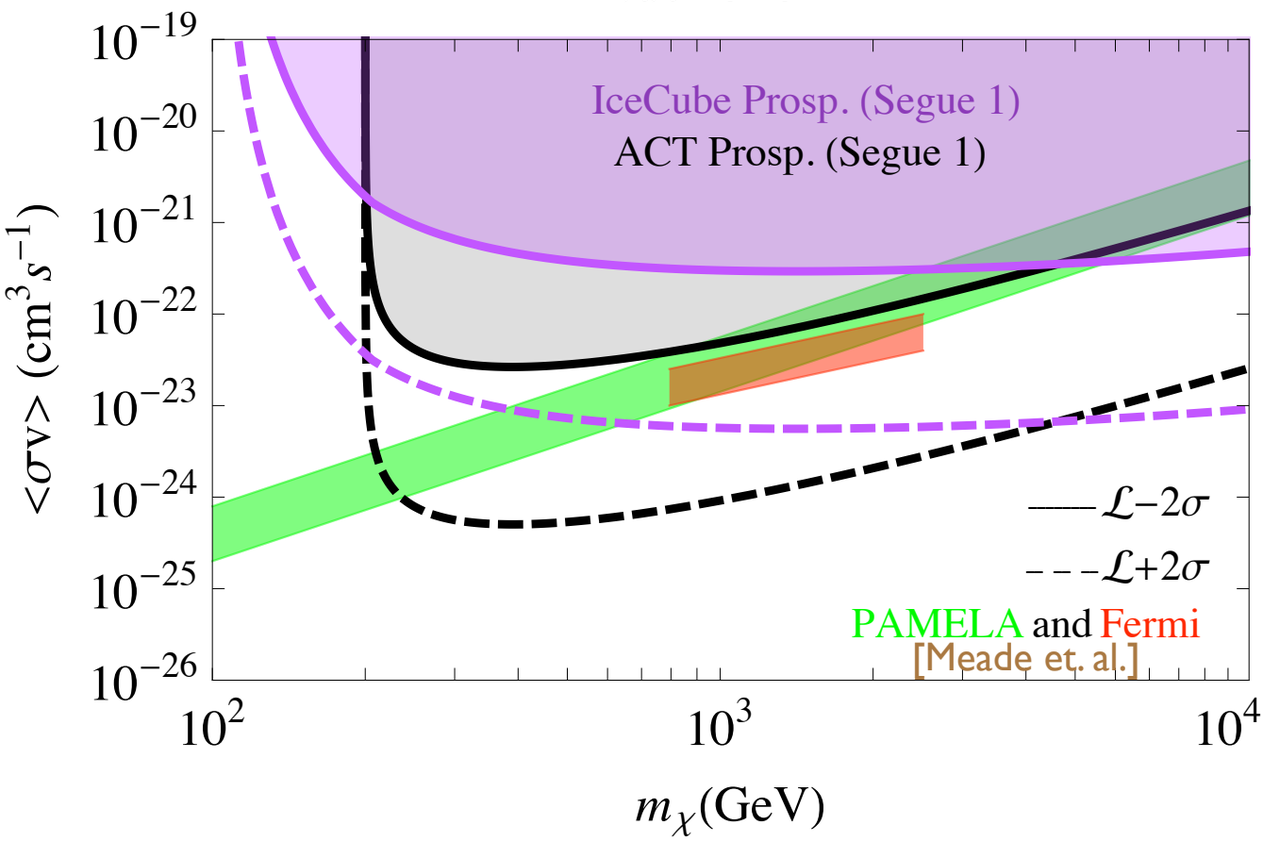
[RE, Sehgal, Strigari, Geha, Simon]

$\mu \longrightarrow e\nu_e\nu_\mu$ in ice: $\nu_\mu N \longrightarrow \mu N$ (N=Nucleus)

of Signal Events



$S/\sqrt{B} \geq 2$



[see also Sandick, Spolyar, Buckley et.al.] (preliminary)

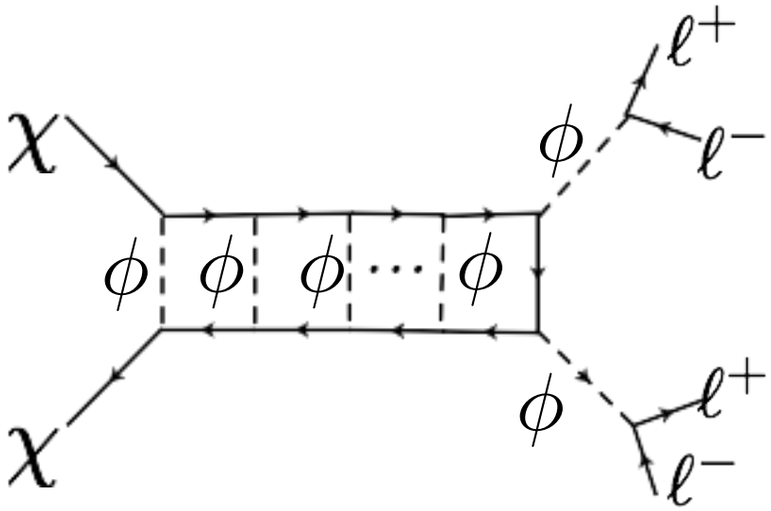
How obtain large DM annihilation cross-section?

many ways... (e.g. Kane et.al., Ibe et.al.)

Sommerfeld enhancement

[e.g. Arkani-Hamed et.al; Pospelov, Ritz; Hisano et.al; March-Russell et.al; Cirelli et.al]

new particle ϕ with $m_\phi \sim 0.1\text{-}1$ GeV



Produces a long-range force

$$\sigma v \propto \frac{1}{v} \Longrightarrow$$

large today
small at freeze-out

$$\frac{v_{\rm dwarf}}{v_{\rm halo}} \sim \frac{1}{20}$$

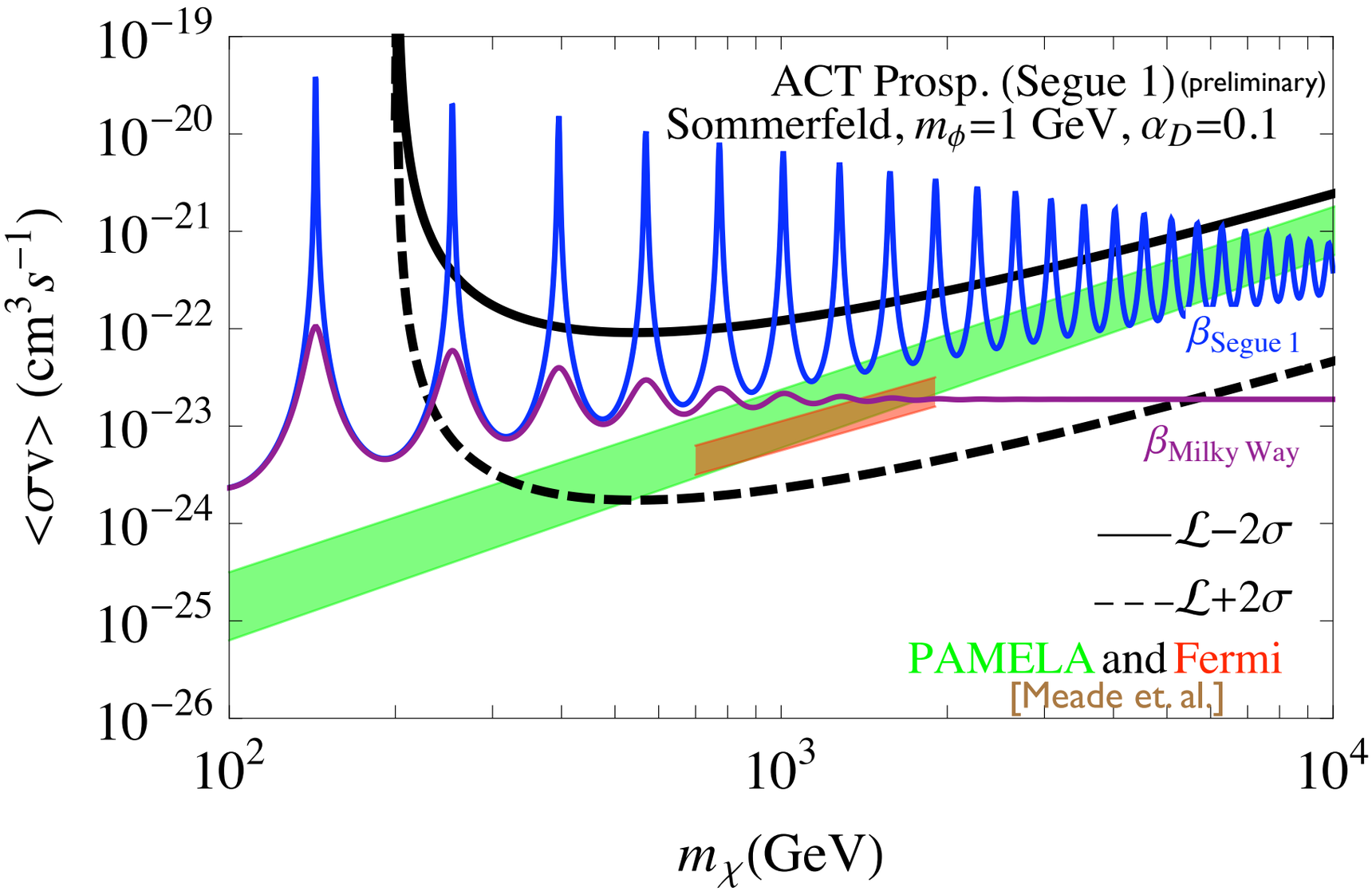
signal potentially enhanced at dwarf !

($\langle \sigma v \rangle$ saturates when $v_\chi \lesssim m_\phi / m_\chi$)

Segue 1 can constrain Sommerfeld enhancement

[RE, Sehgal, Strigari, Geha, Simon]

$$m_\phi = 1\,\mathrm{GeV}$$

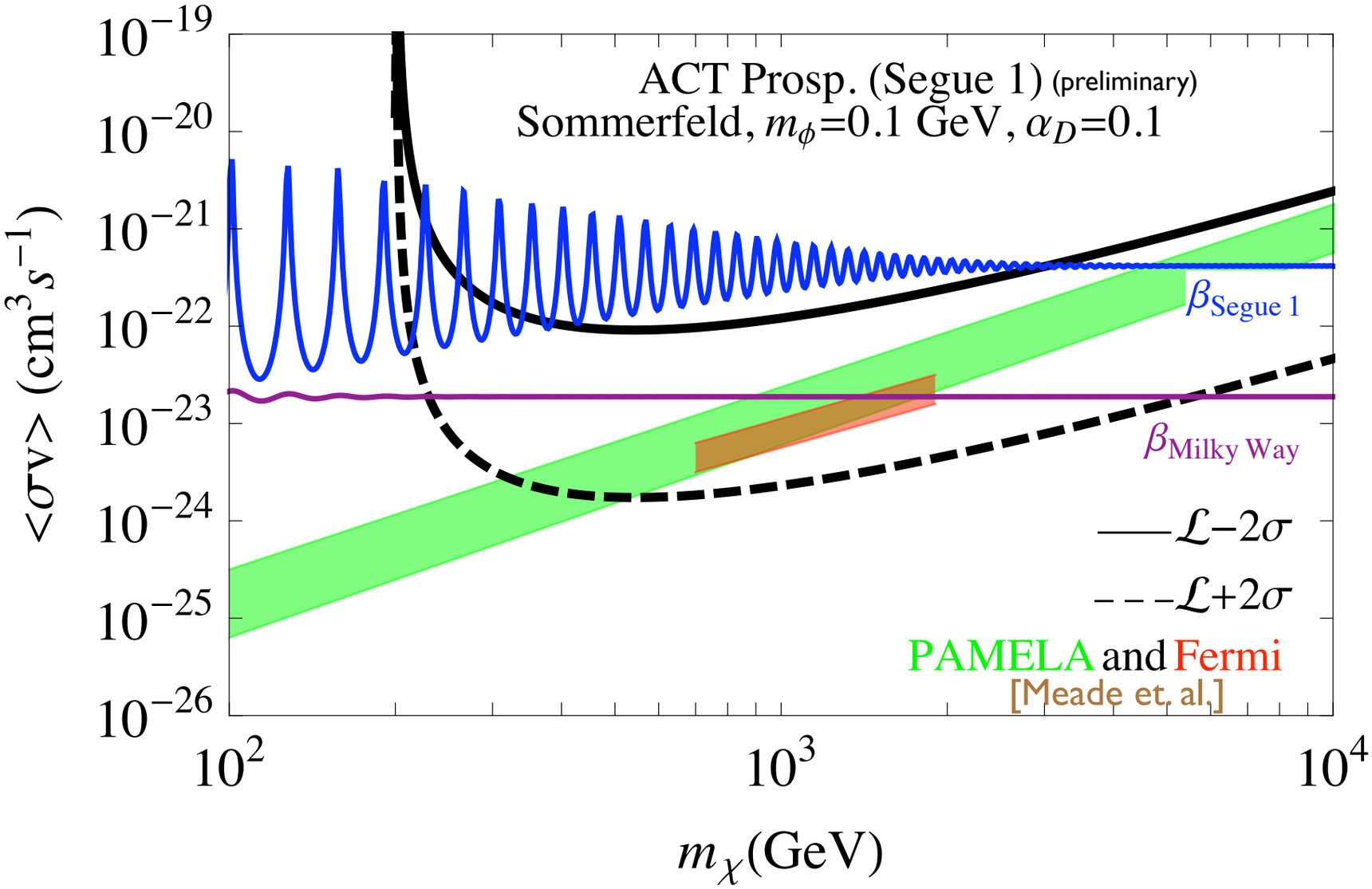


Will probe resonances

Segue 1 can constrain Sommerfeld enhancement

[RE, Sehgal, Strigari, Geha, Simon]

$$m_\phi = 0.1\,\mathrm{GeV}$$



Intriguing prospects!

Summary

- Dwarf Galaxies probe DM properties

  (structure formation, DM self-interactions, ...)

- Great targets for indirect DM detection

  (any signal very suggestive)

- New (preliminary) stellar data for Segue 1: possibly best dwarf target for Fermi, ACTs & IceCube

- Constrain Sommerfeld enhanced models due to low velocity dispersion in dwarfs