RECENT GAMMA-RAY DARK MATTER SEARCHES WITH THE FERMI LAT

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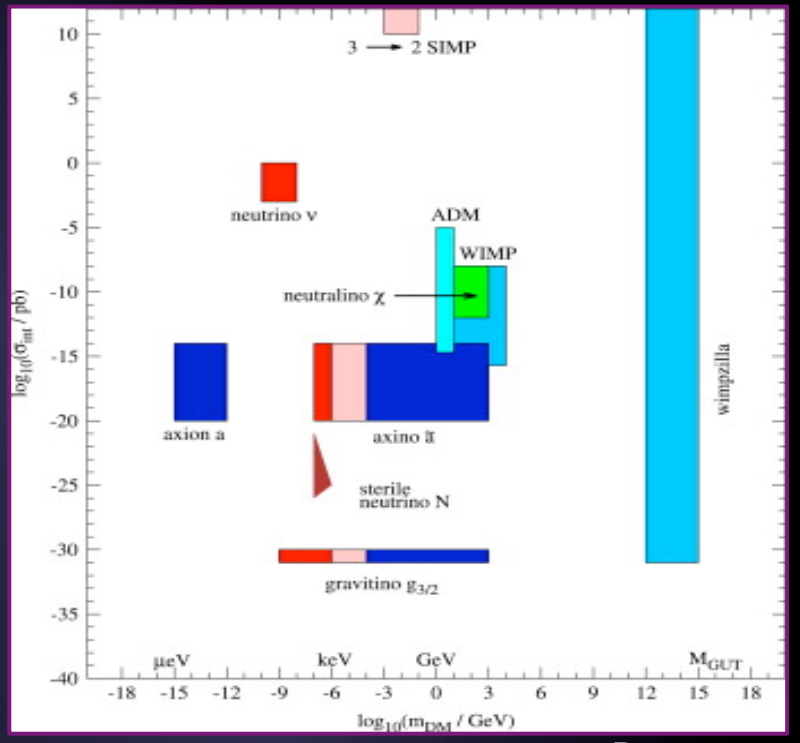
RENATA thematic meeting

Canfranc, 6 February 2018

WIMP dark matter searches

- ✓ Many dark matter (DM) particle candidates beyond the Standard Model.
- ✓ Weakly Interacting Massive Particles among the preferred ones.



Baer+14

Approaches to the WIMP:

A. Direct detection: scattering of DM particles on target nuclei.

B. Direct production of DM particles at the lab.

C. Indirect detection: DM annihilation products (neutrinos, antimatter, gammas)

The DM annihilation γ-ray flux

$$F(E_\gamma > E_{th}, \Psi_0) = J(\Psi_0) \times f_{PP}\left(E_\gamma > E_{th}\right)$$

photons cm^{-2} s^{-1}

Astrophysics | **Particle physics**

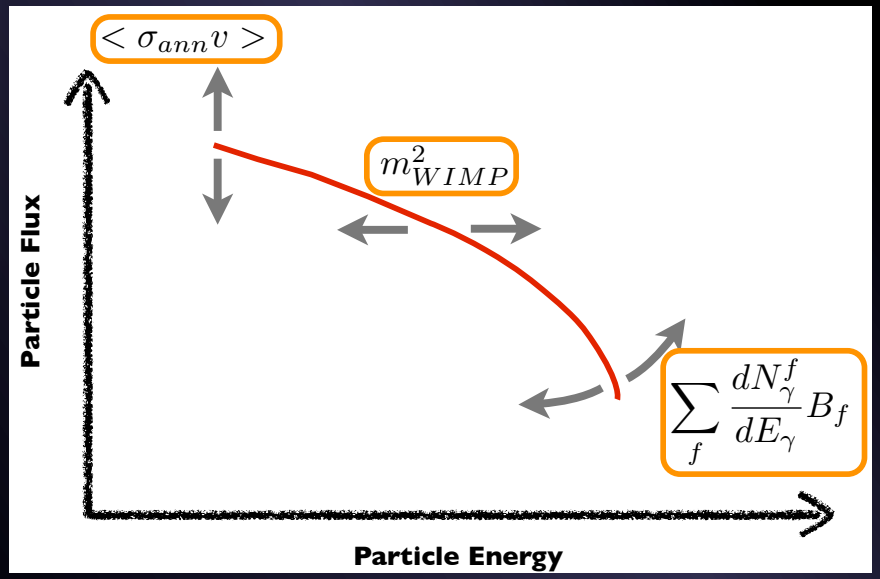
Integration of the squared DM density

J-FACTOR

$$J(\Psi_0) = \frac{1}{4\pi} \int_{\Delta\Omega} d\Omega \int_{l.o.s.} \rho^2_{DM}[r(\lambda)] d\lambda$$

$$f_{PP} \propto \sum_f \frac{dN^f_\gamma}{dE_\gamma} B_f \frac{\langle \sigma \cdot v \rangle}{m_\chi{}^2}$$

- N_g : number of photons per annihilation, $E > E_{th}$
- $\langle \sigma v \rangle$: cross section
- m_χ: neutralino mass



Present gamma-ray observatories

E. range: 20 MeV → 1 TeV
E. resolution: ~10% @ GeV
FoV: ≈ 2.4 sr
Angular res.: ~0.2°@10 GeV
Aeff ~ m^2

Fermi LAT
[>2008]

E. range: 0.1 → 100 TeV
E. resolution: ~20% @ 10 TeV
FoV: ≈ 2 sr
Angular res.: ~0.2°@10 TeV
Aeff ~22,000 m^2

HAWC
[>2015]

MAGIC
[>2003]

HESS
[>2002]

VERITAS
[>2006]

E. range: 50 GeV → 10TeV
E. resolution: ~20%
FoV: ≈ 4 deg.
Angular res.: ≈ 0.1°
Aeff ~ 10^5 m^2

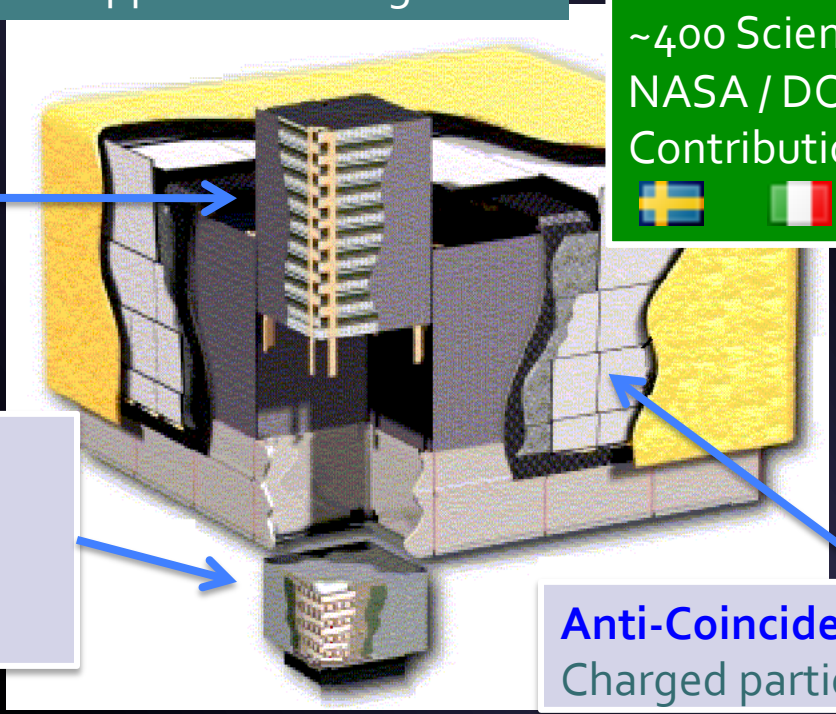
DESY/Milde Science Comm./Exozet

The Fermi Large Area Telescope

LAUNCHED IN JUNE 2008
Mission approved through 2018

Fermi LAT Collaboration:
~400 Scientific Members,
NASA / DOE & International Contributions

Si-Strip Tracker:
convert $\gamma \rightarrow e^+e^-$
reconstruct γ direction
EM v. hadron separation



[1.8 m x 1.8 m x 0.7 m]

Hodoscopic CsI Calorimeter:
measure γ energy
image EM shower
EM v. hadron separation

Anti-Coincidence Detector:
Charged particle separation

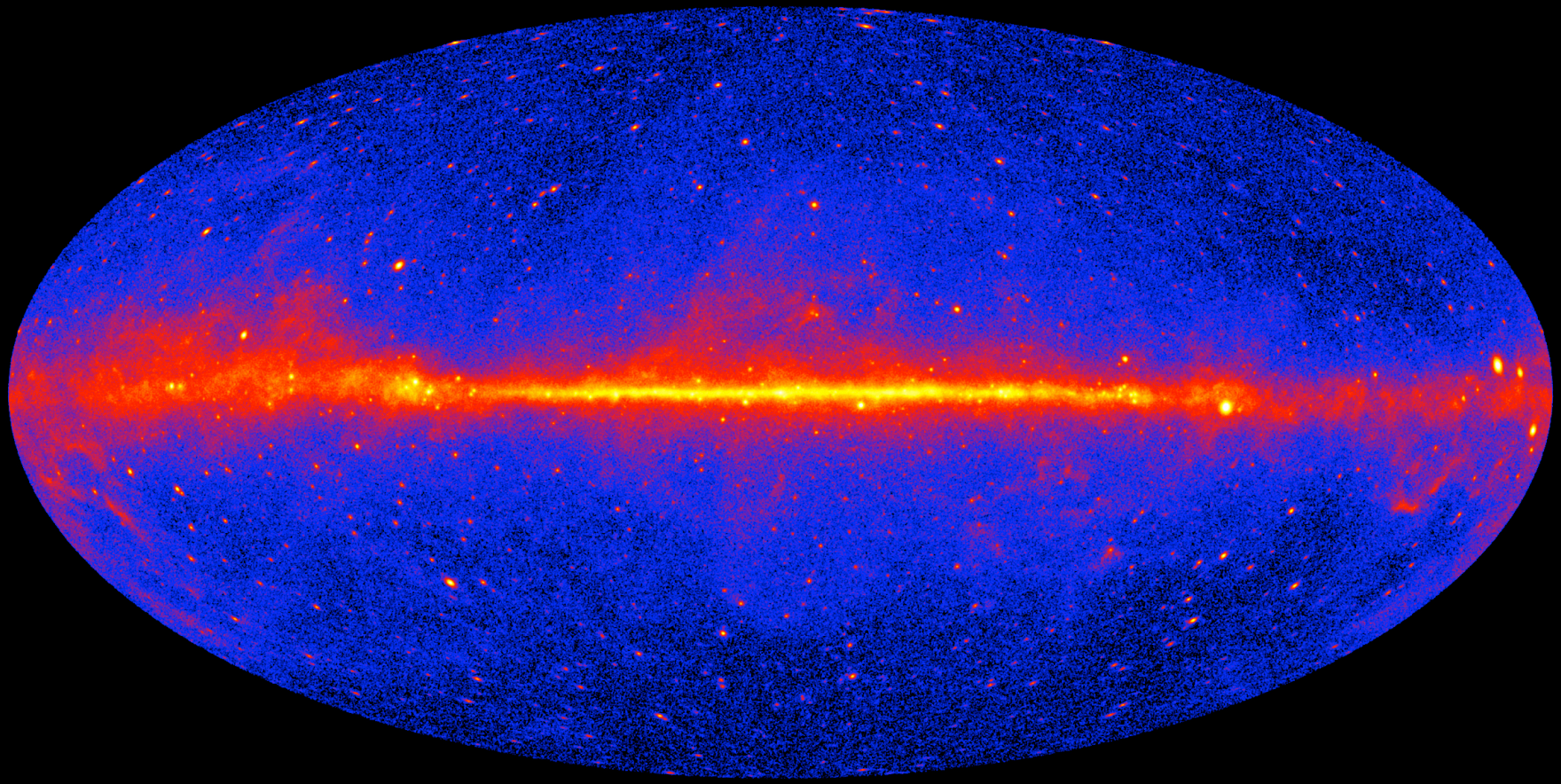
Trigger and Filter:
Reduce data rate from ~10kHz to 300-500 HZ

Sky Survey:
2.5 sr field-of-view
whole sky every 3 hours

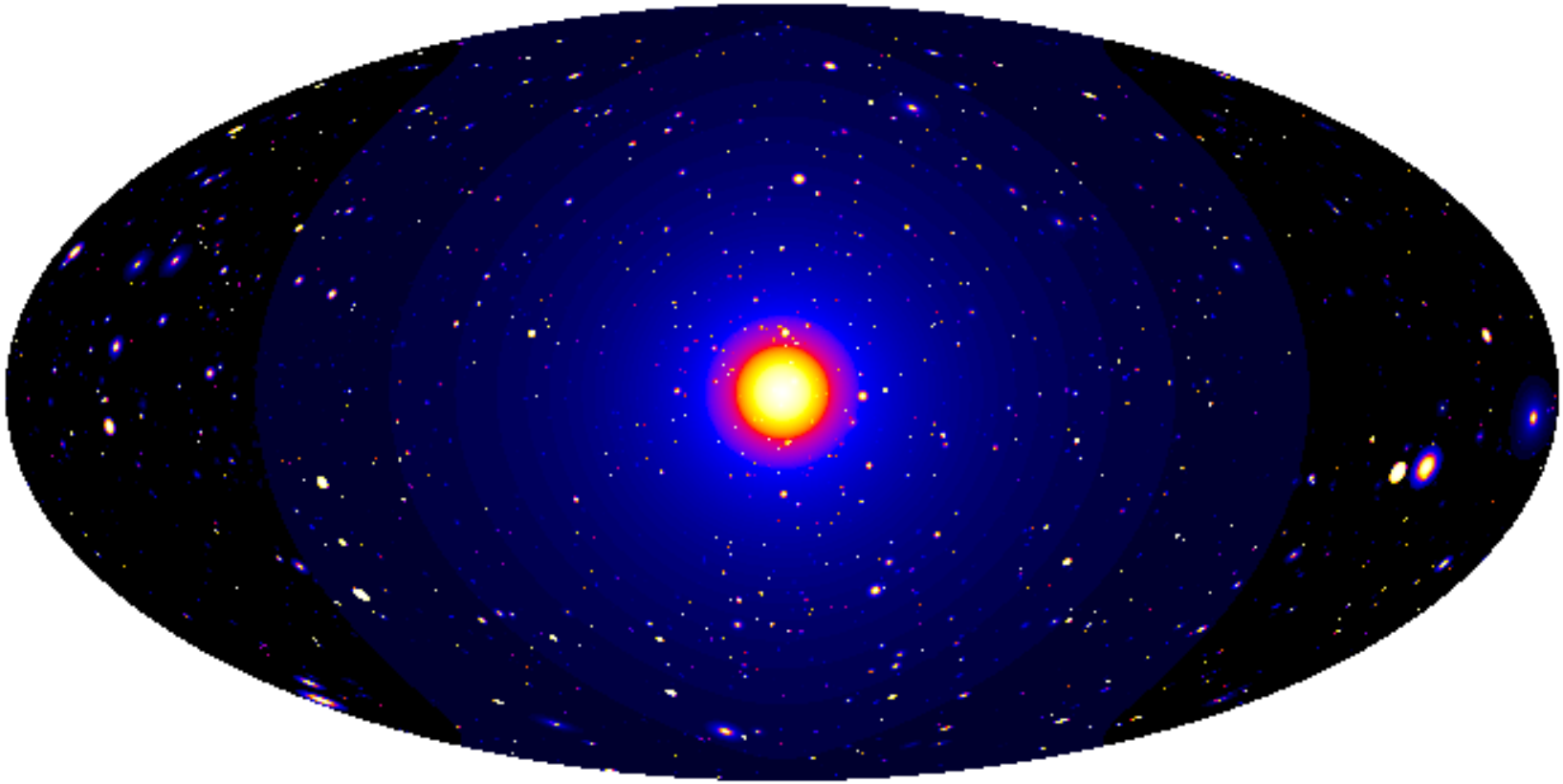
Public Data Release:
All γ-ray data made public within 24 hours (usually less)

THE GAMMA-RAY SKY above 1 GeV

5 years of Fermi LAT data



The dark matter-induced gamma-ray sky

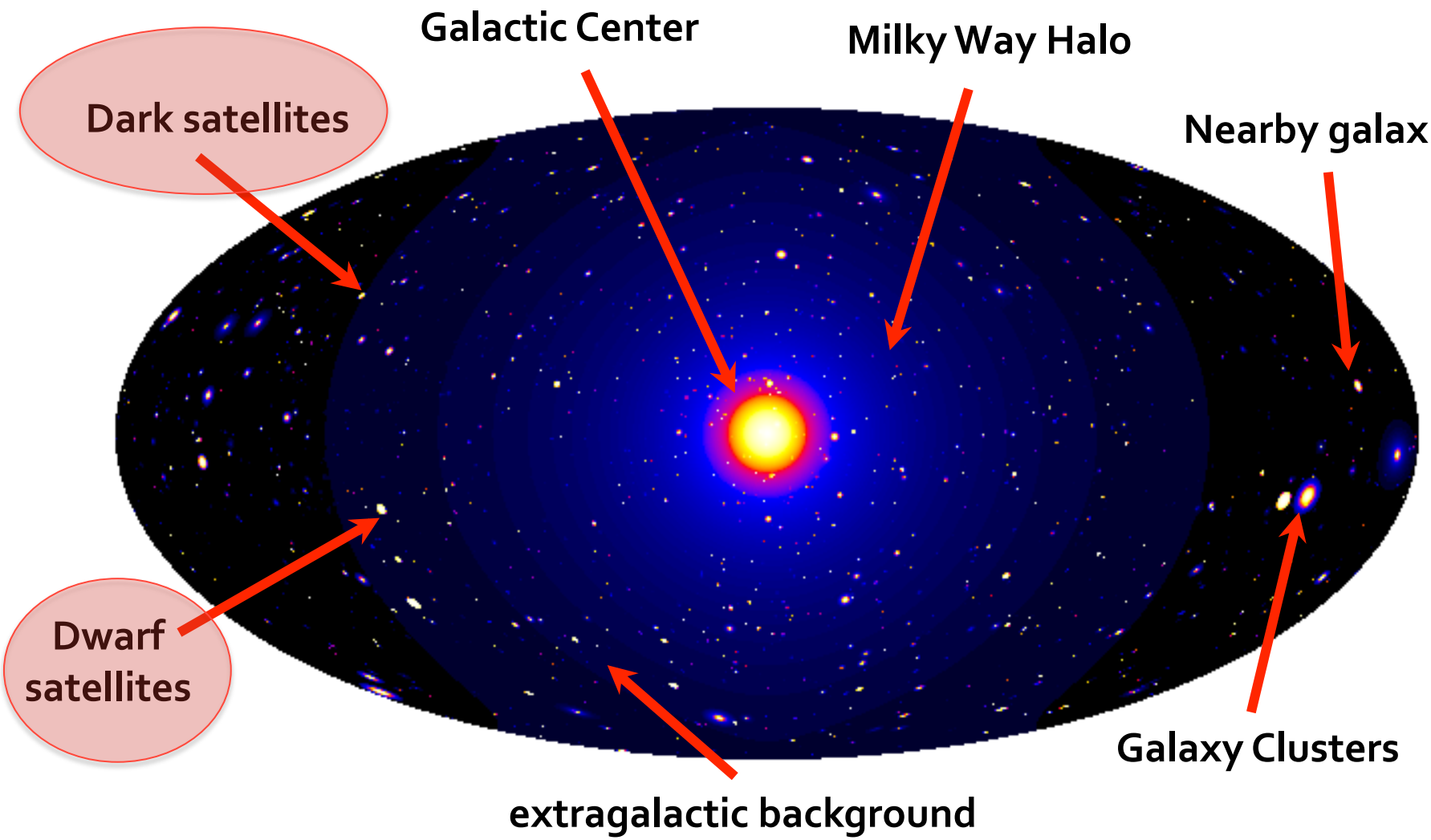


Dark Matter simulation:
Pieri+09, arXiv:0908.0195

Need to disentangle dark matter annihilations from 'conventional' astrophysics.

Crucial to understand the astrophysical processes in great detail.

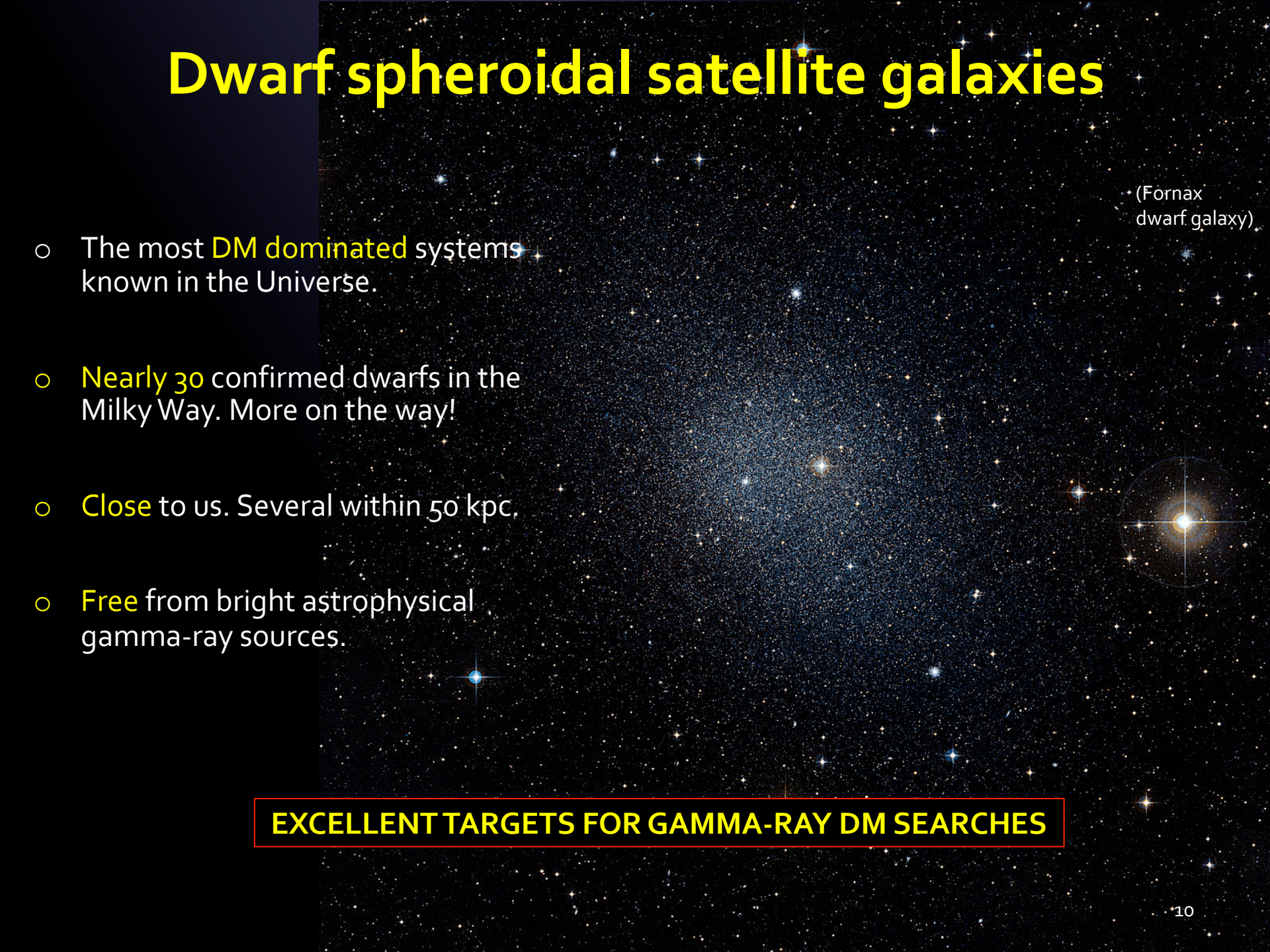
(WIMP) Dark Matter search strategies



+ Spectral Lines

Dark Matter simulation: Pieri+(2009) arXiv:0908.0195

Dwarf spheroidal satellite galaxies

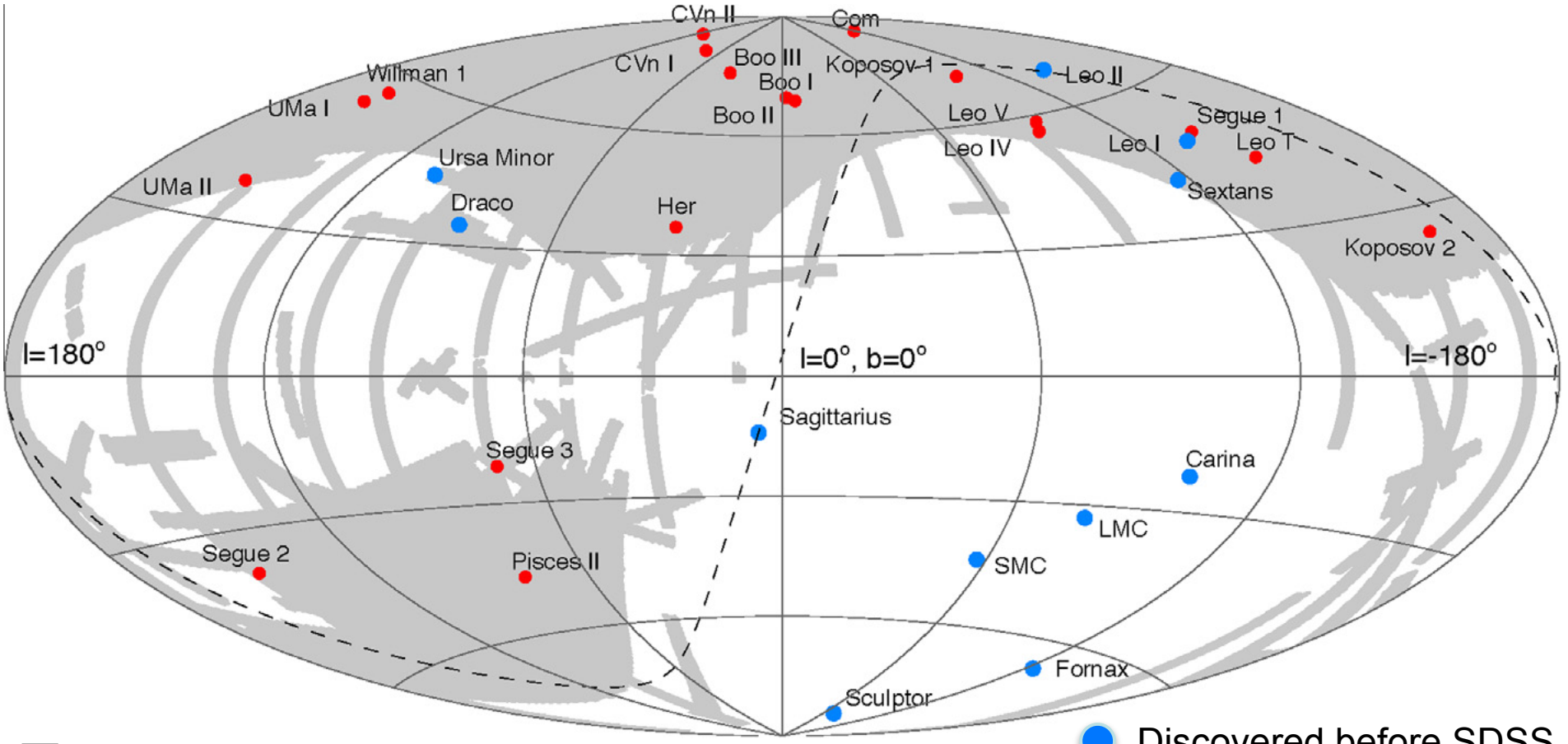


(Fornax dwarf galaxy)

- The most DM dominated systems known in the Universe.
- Nearly 30 confirmed dwarfs in the Milky Way. More on the way!
- Close to us. Several within 50 kpc.
- Free from bright astrophysical gamma-ray sources.

EXCELLENT TARGETS FOR GAMMA-RAY DM SEARCHES

Census of dwarfs (circa 2014)



Sky Covered by SDSS

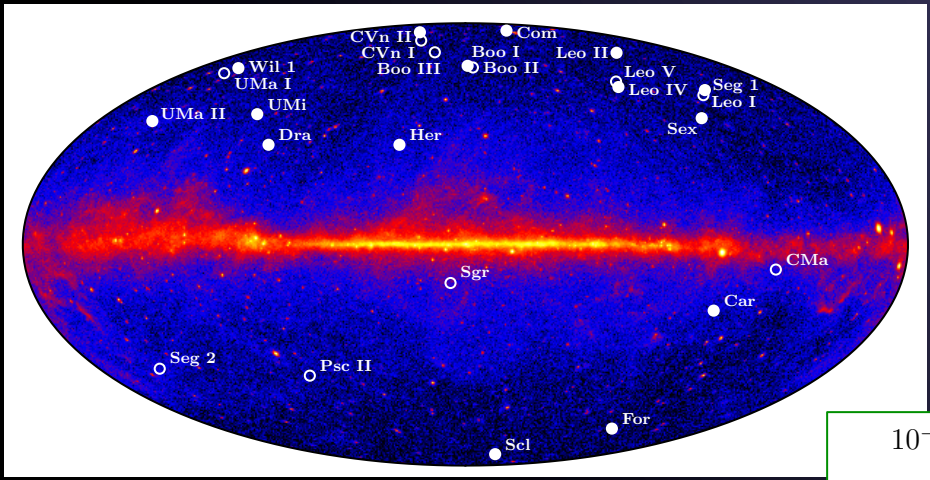
Discovered before SDSS (classical dwarfs)

Discovered with SDSS (ultra-faint dwarfs)

(Belokurov 2013)

[A. Drlica-Wagner, Berolo, Sep 17]

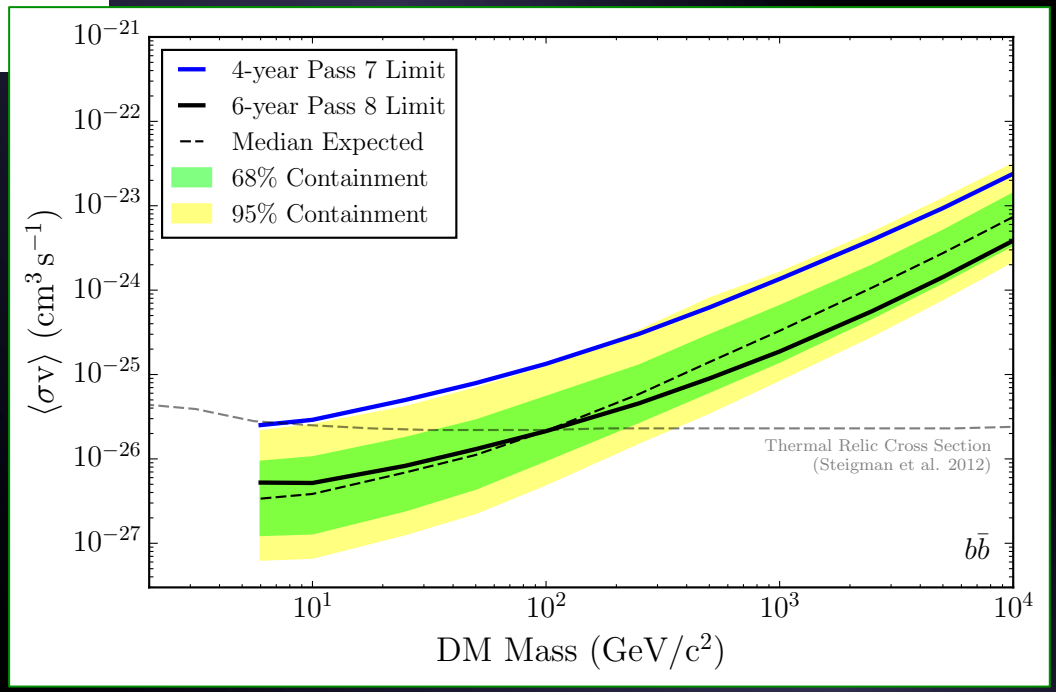
Fermi-LAT DM search in dwarfs



[Ackermann+15, the LAT collab., 1503.02641]

Joint likelihood analysis of **15 dwarfs**

Makes use of Pass 8 data



No gamma signal → DM limits

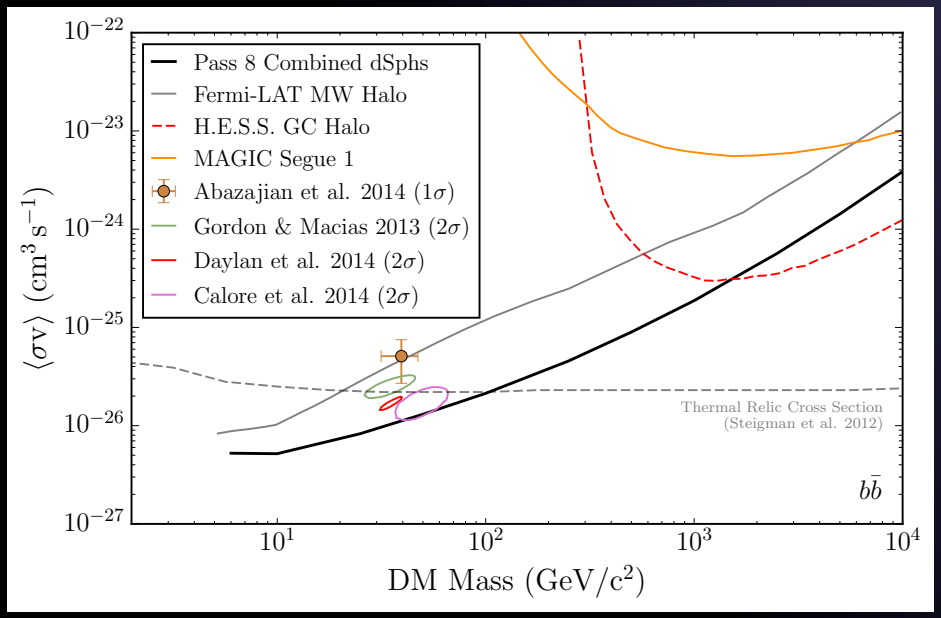
Excludes thermal WIMPs <100 GeV

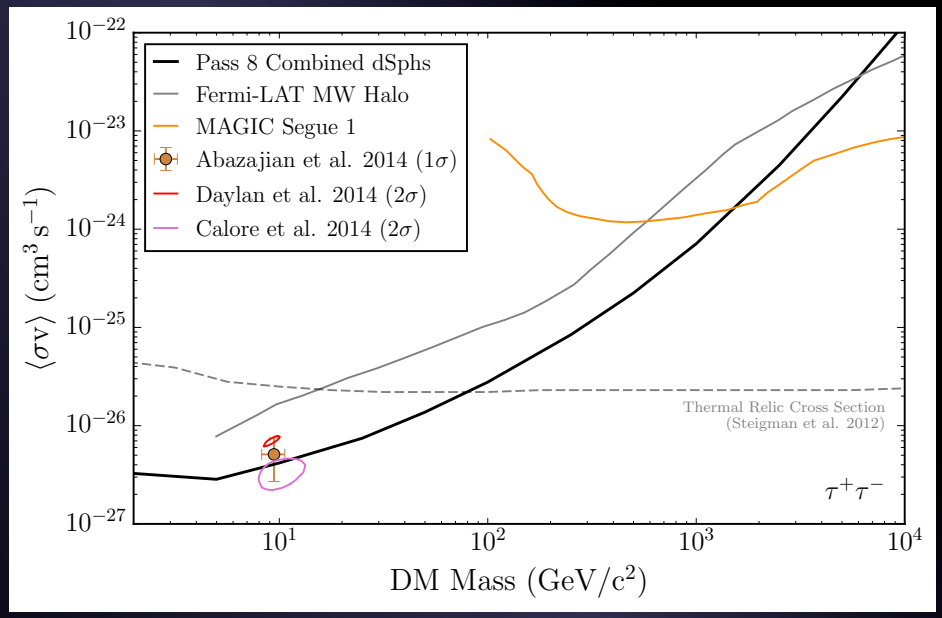
Expectation bands from control regions

Relevance of DM limits from dwarfs

Most robust and competitive limits in the <1 TeV WIMP mass regime so far.

Dwarfs as a test of the GeV GC excess.

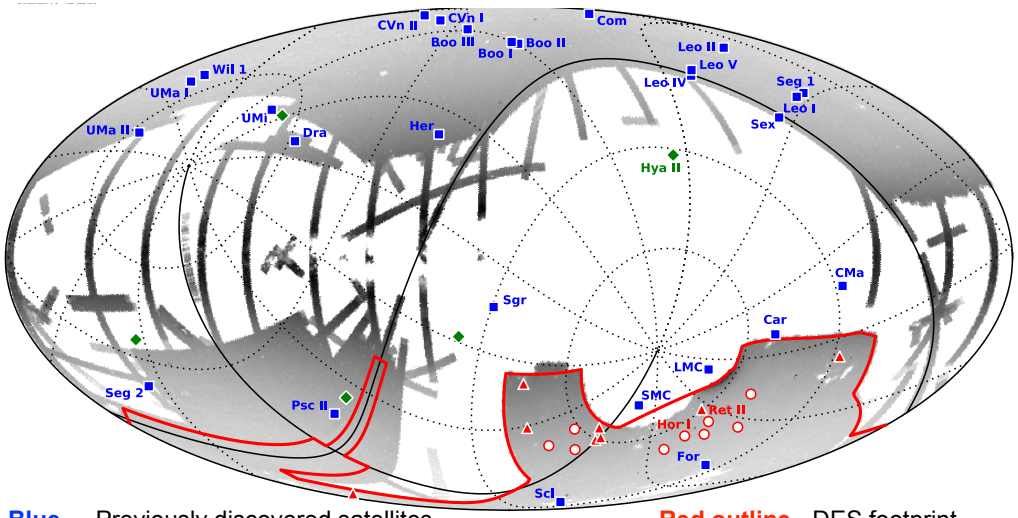




[Ackermann+15, the Fermi-LAT collab., 1503.02641]

→ Will we be able to refute the GC excess in the future??

DES: Recent discovery of new satellites



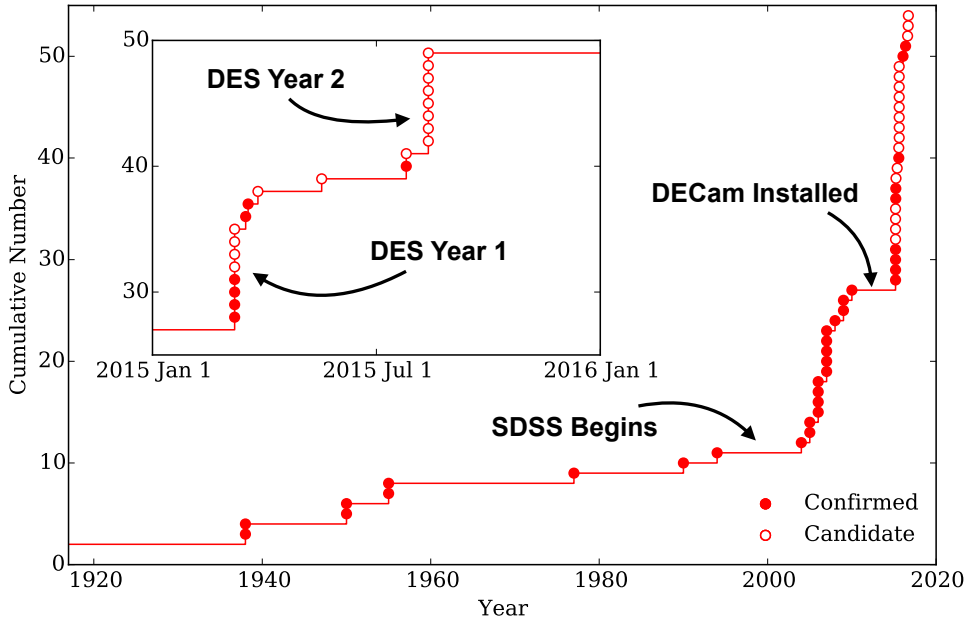
Blue - Previously discovered satellites
Green - Discovered in 2015 with PanSTARRS/SDSS

Red outline - DES footprint
Red circles - DES Y1 satellites
Red triangles - DES Y2 satellites

>20 NEW DWARF CANDIDATES in 2015 alone!

[these dwarfs will help to improve the DM limits]

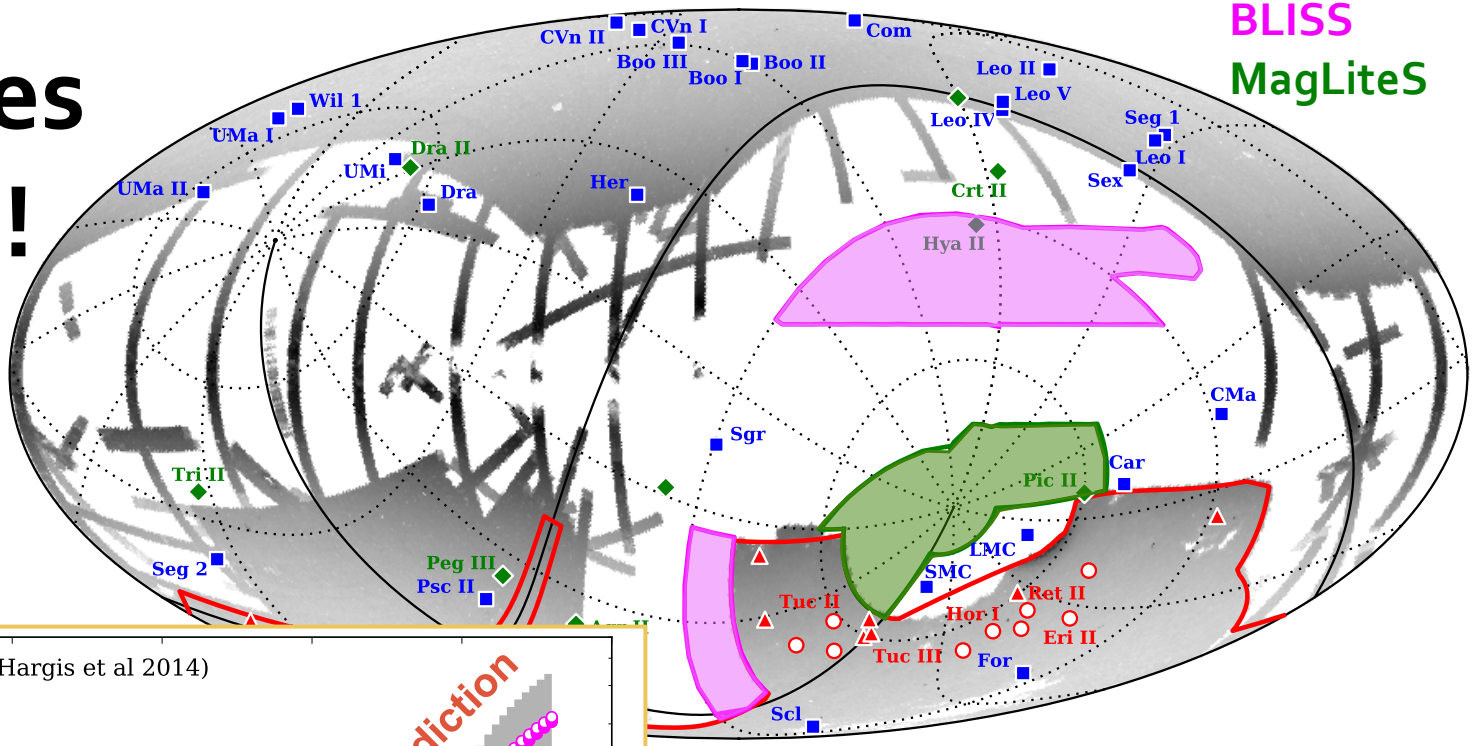
Bechtol+15
Drlica-Wagner+15
Leavens+15
Koposov+15
Kim&Jerjen15
Kim+15
Martin+15

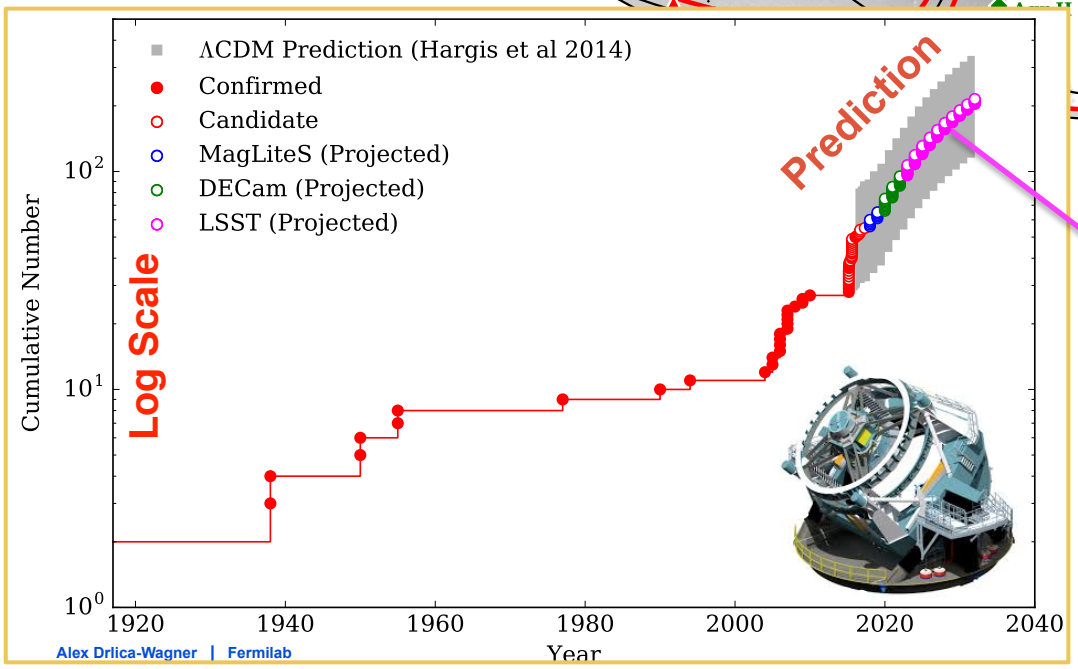


A. Drlica-Wagne
[*Barolo, Sep 2017*]

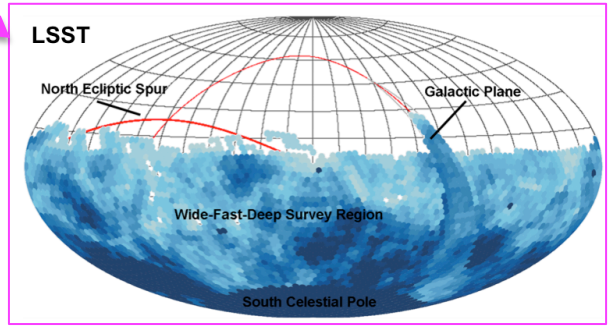
More discoveries to come!

DES
BLISS
MagLiteS



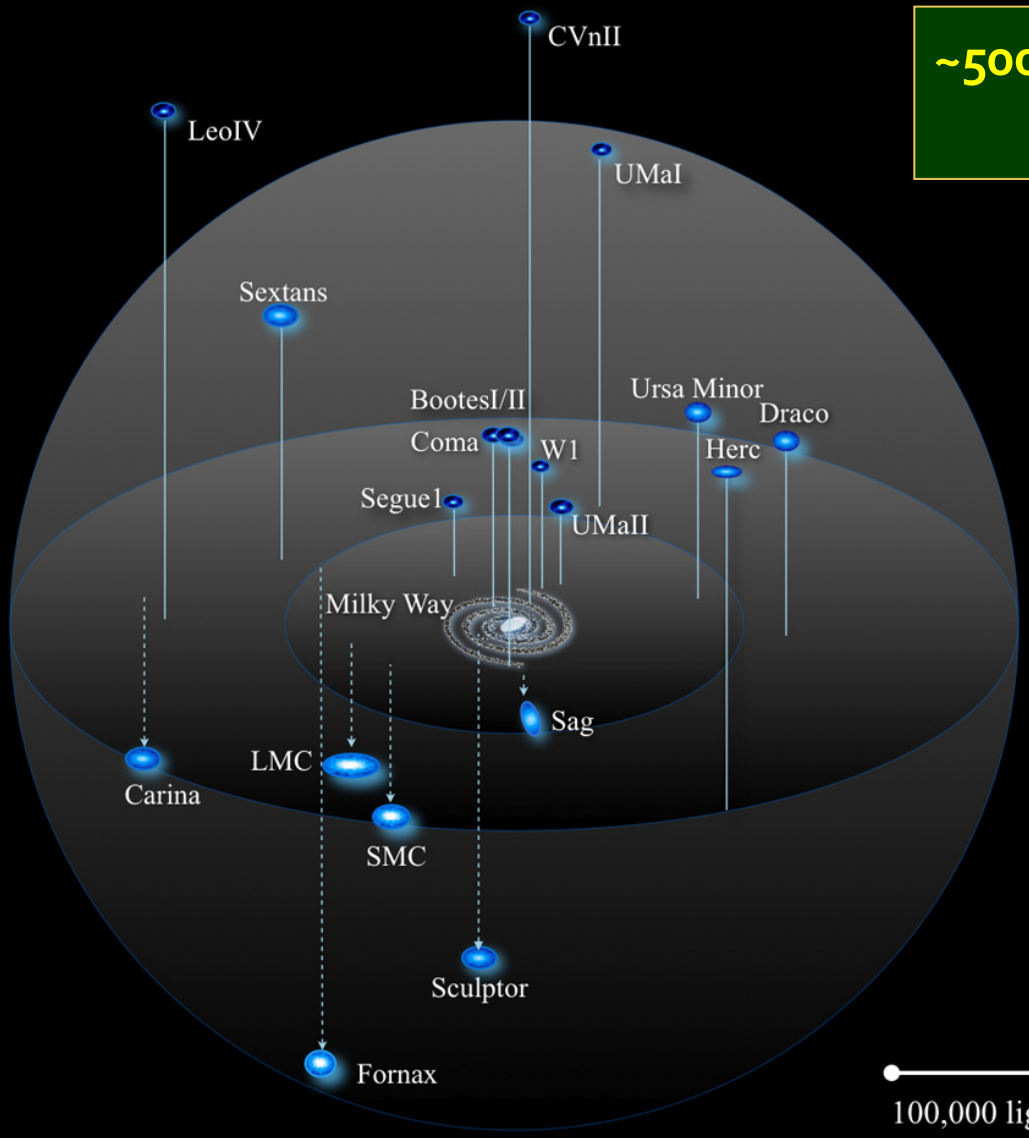


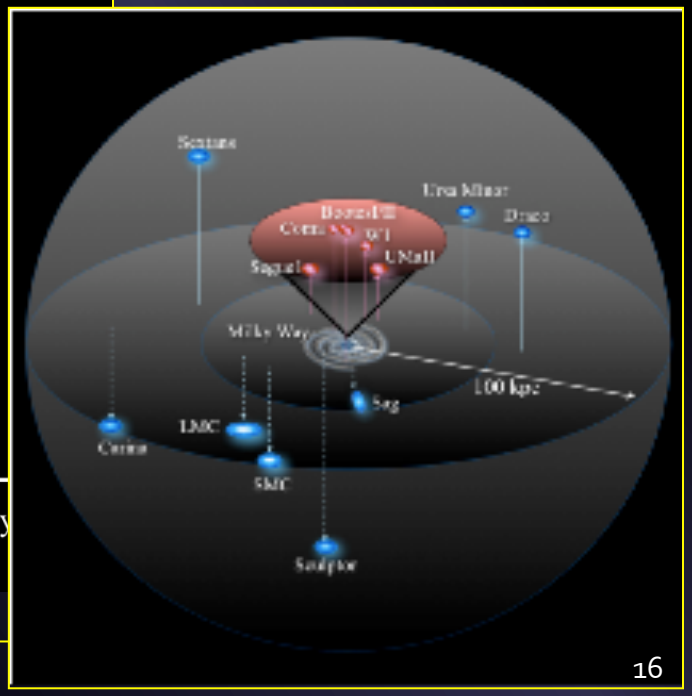
+ LSST coming!



~500 dwarfs inside the virial radius?

(Tollerud+08; Walsh+09; Hargis+14)

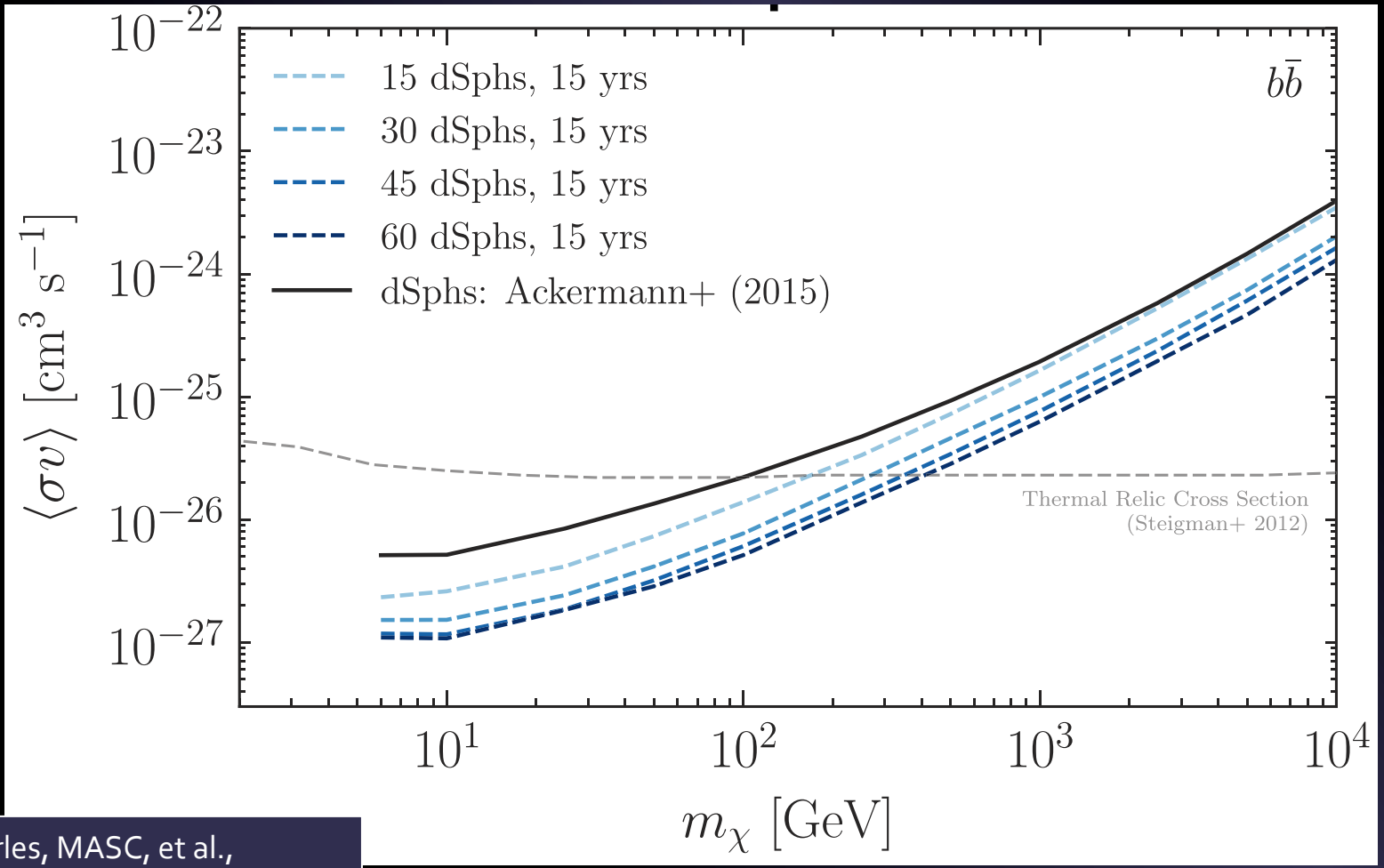




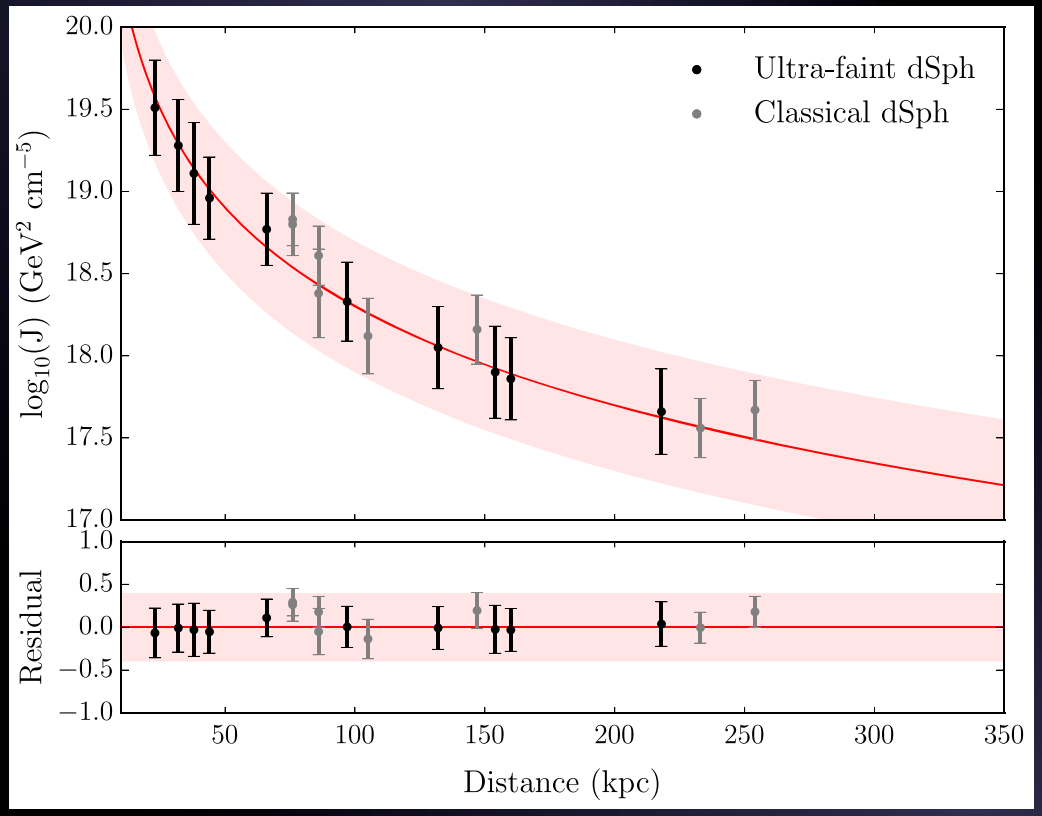
(Bullock et al. 2009)

Expected sensitivity with more dwarfs

(Dwarfs rock!)

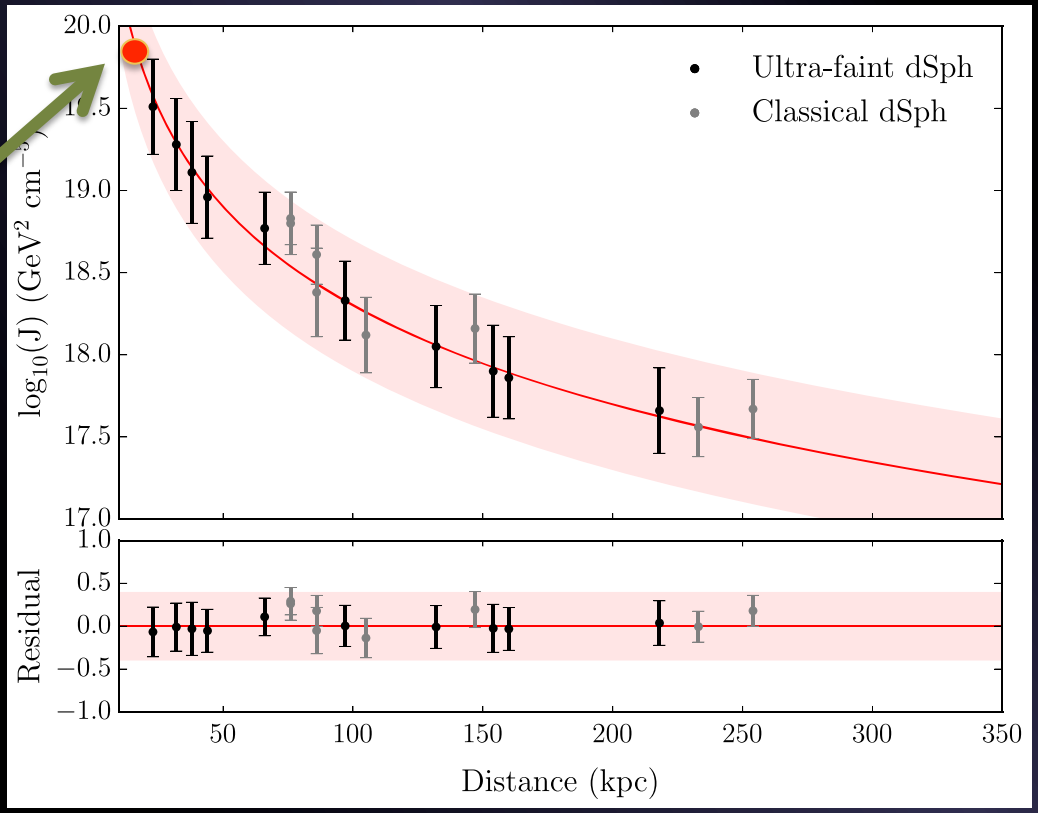


Charles, MASC, et al.,
Physics Reports [1605.02016]



Adapted from Albert+15

Should we expect any satellite e.g. here?



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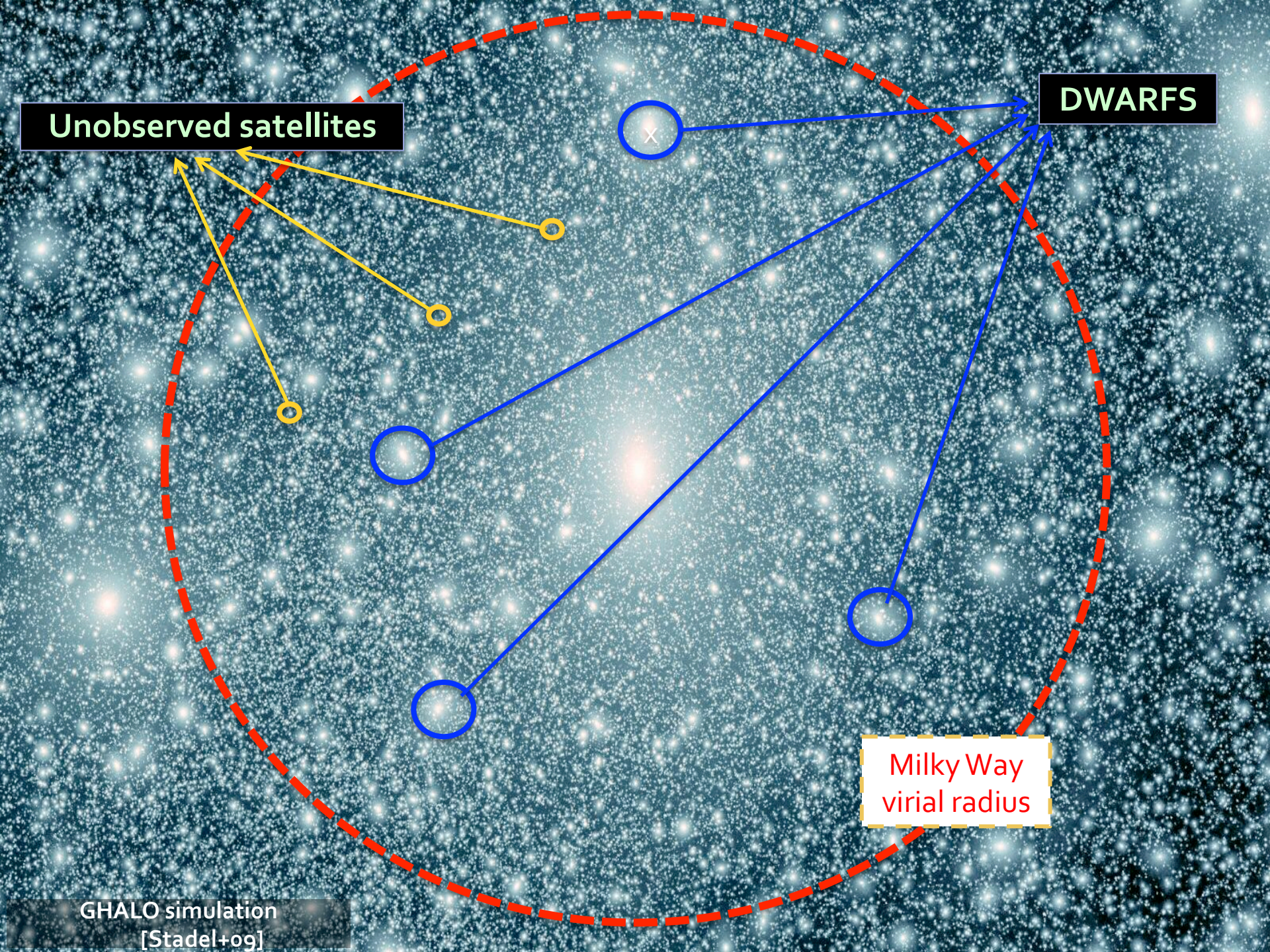
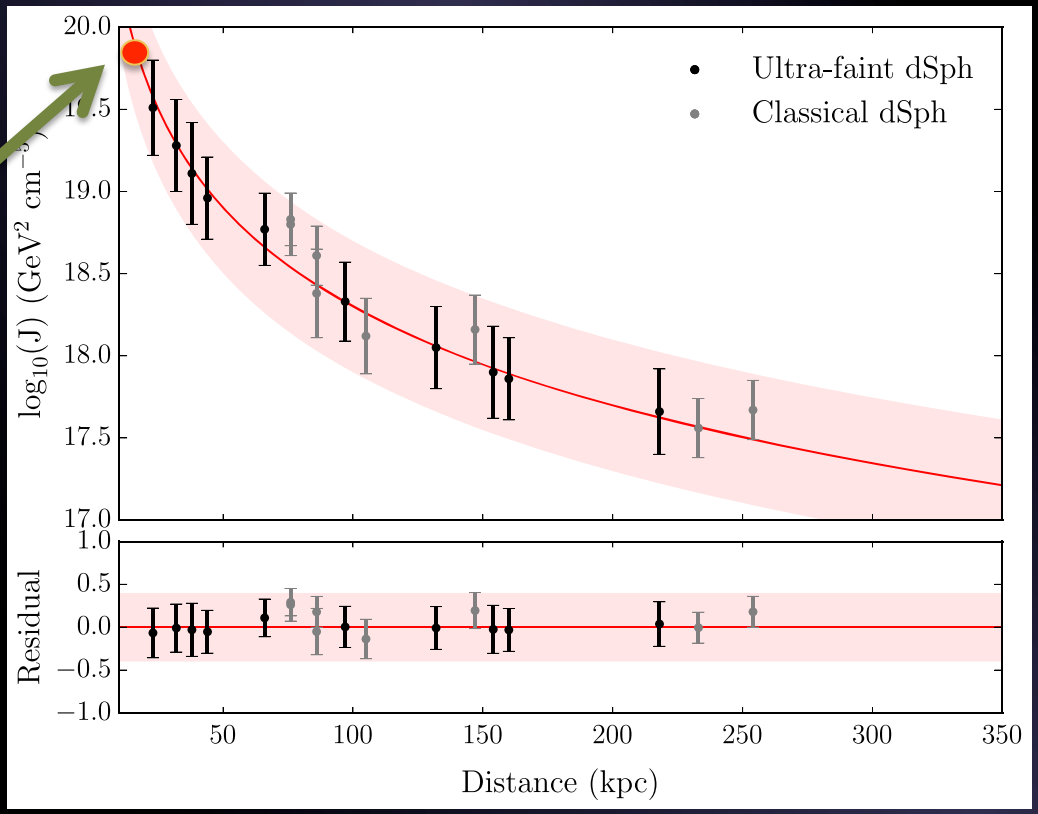

Unobserved satellites
DWARFS
Milky Way
virial radius
GHALO simulation
[Stadel+09]

Low-mass subhalos might host few or no stars → no optical counterpart.
Gamma-rays from DM annihilations may be the only way to find them.

Could some of them be better candidates than dwarfs?
How many of them are potentially detectable?
Have we detected them already?

Should we expect any dark satellite e.g. here?



Adapted from Albert+15

Dark satellites: new work ongoing
(J. Coronado, MASC et al., in prep.)

- Best knowledge of subhalos' structural properties (MASC&Prada14, Moline,MASC+17)
- Repopulation of current N-body simulations to reach lower subhalo masses.
- Search in the most recent LAT catalogs (3FGL, 2FHL, 3FHL)
- Careful characterization of LAT sensitivity to DM annihilation.

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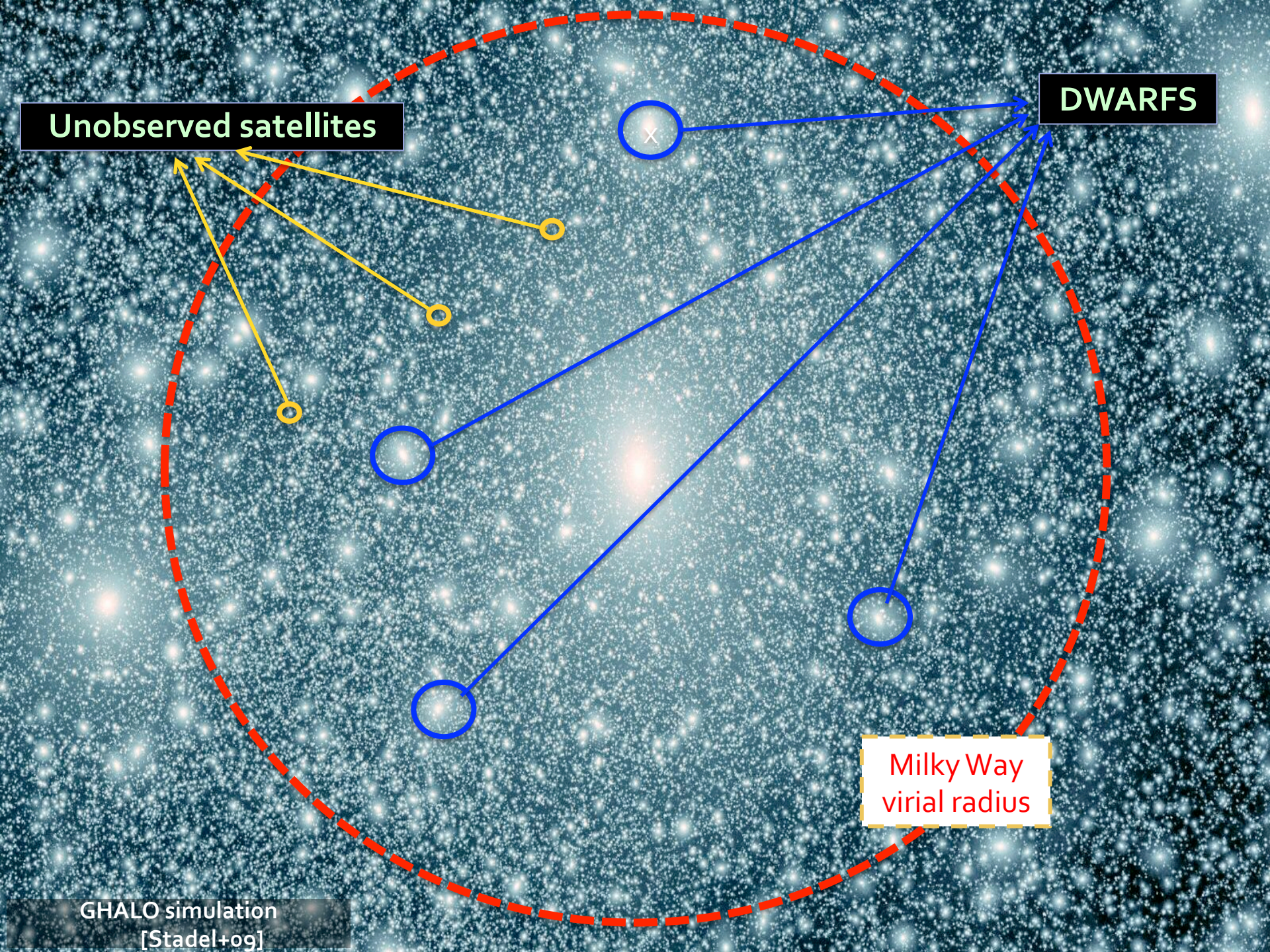
Further details in Javier Coronado's talk!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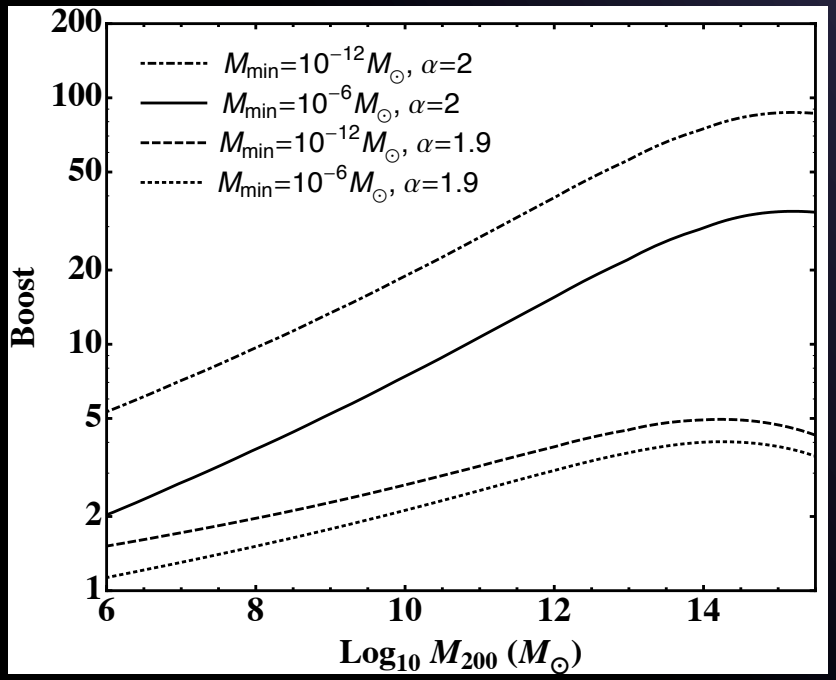
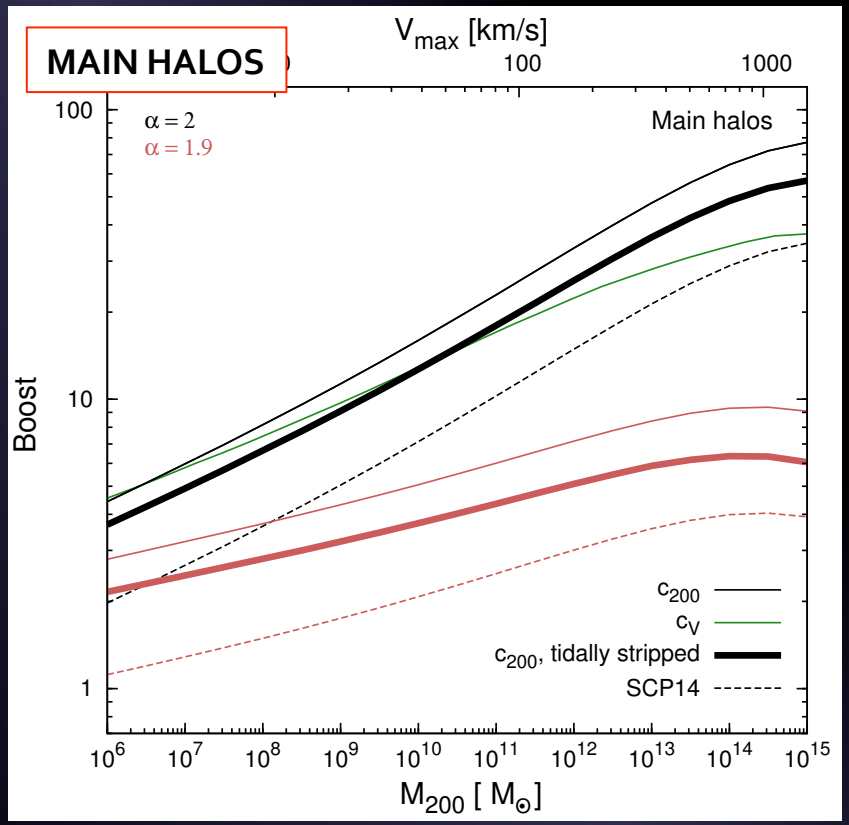
Subhalo boost model(s)

Make use of our better knowledge on subhalo structural properties.

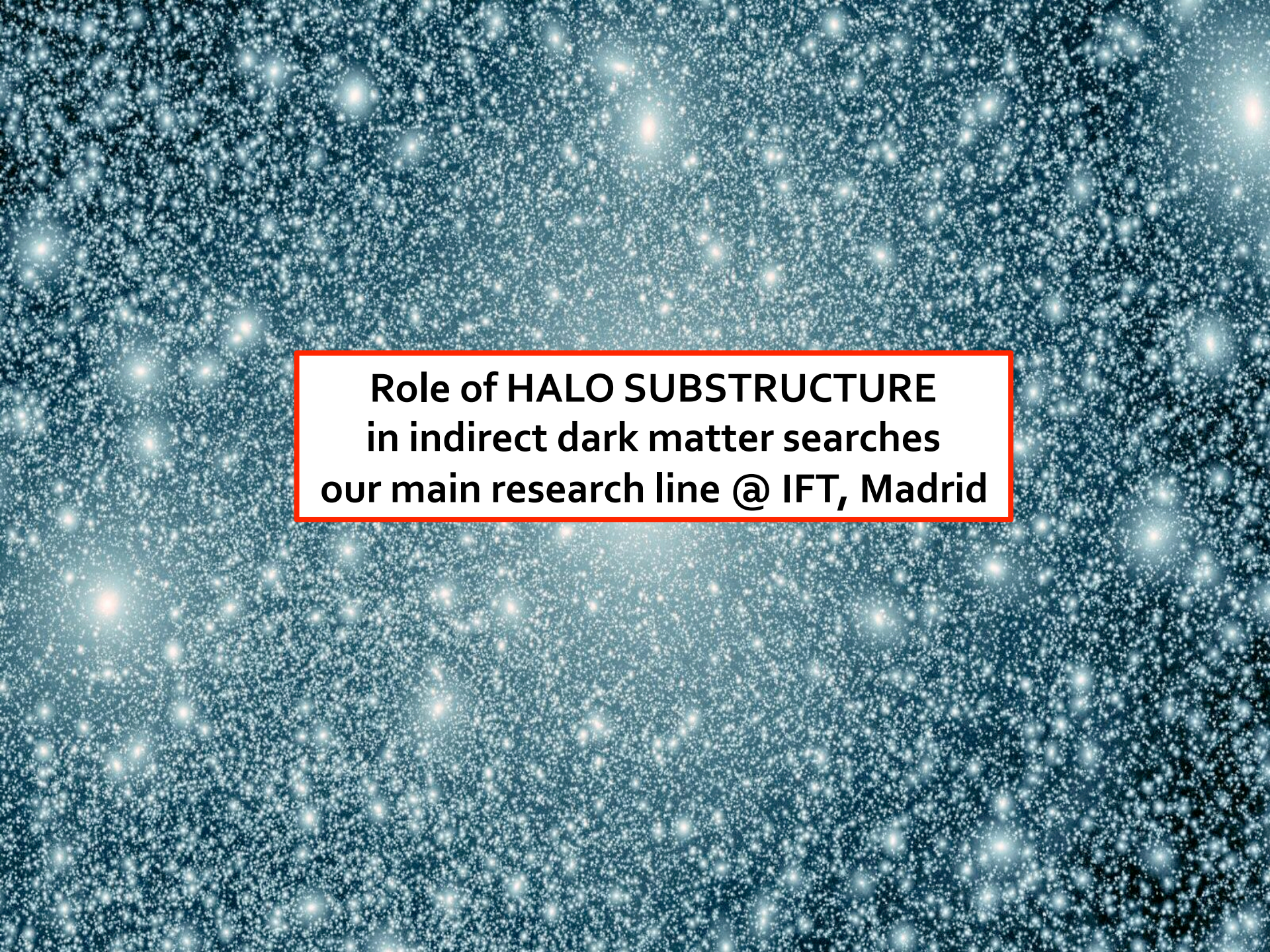


[MASC & Prada 2014]



[Moliné, MASC, Palomares and Prada (2017) MNRAS, 466, 4974]

[Agrees also with Bartels & Ando (2015) and Zavala & Afshordi (2015)]


Role of HALO SUBSTRUCTURE
in indirect dark matter searches
our main research line @ IFT, Madrid

But axions with gammas, too!

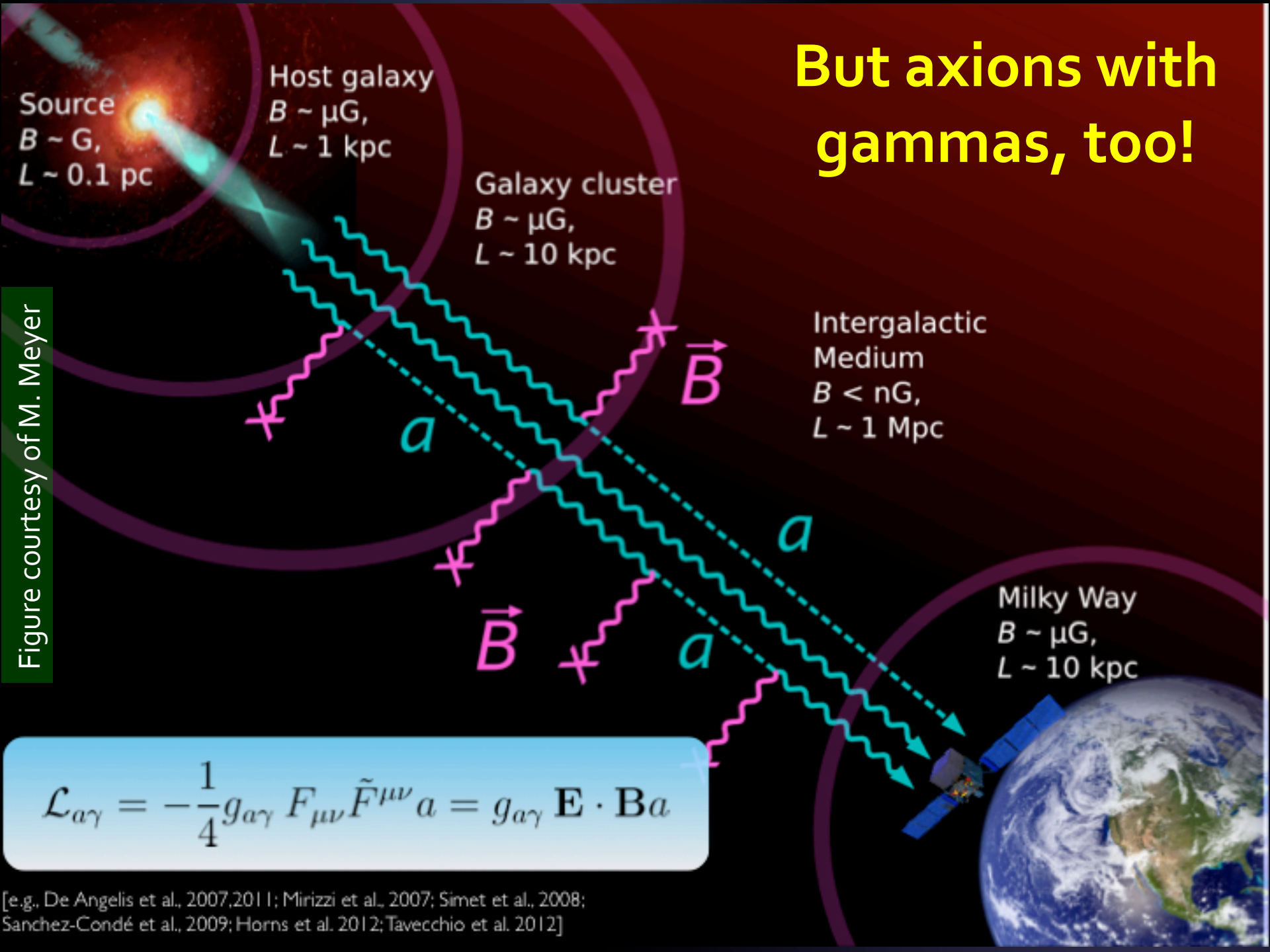
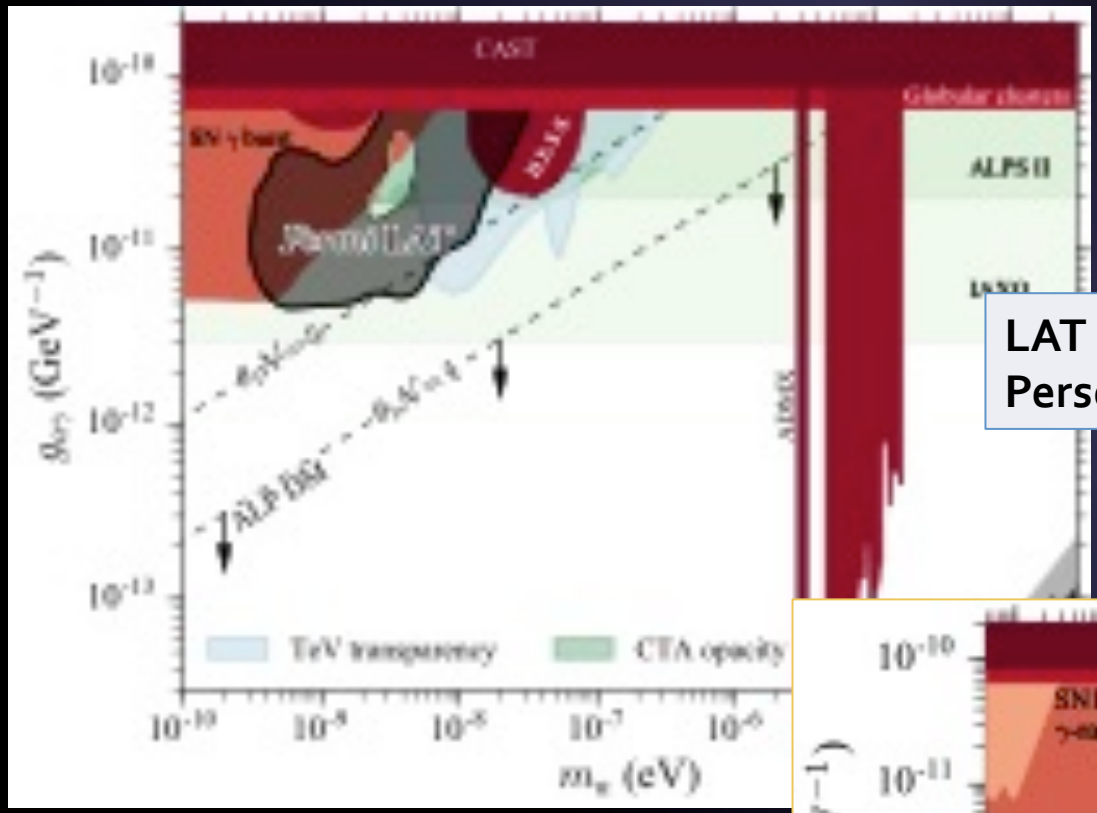


Figure courtesy of M. Meyer

$$\mathcal{L}_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a = g_{a\gamma} \mathbf{E} \cdot \mathbf{B} a$$

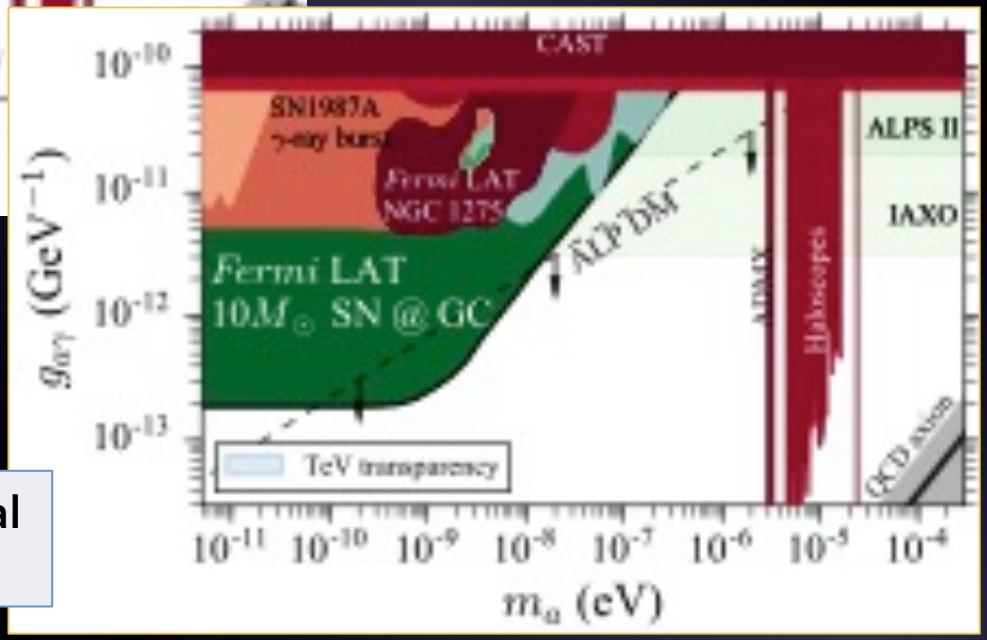
[e.g., De Angelis et al., 2007,2011; Mirizzi et al., 2007; Simet et al., 2008; Sanchez-Condé et al., 2009; Horns et al. 2012; Tavecchio et al. 2012]

Axion constraints with Fermi LAT



[Ajello+16]

LAT data from the Perseus galaxy cluster

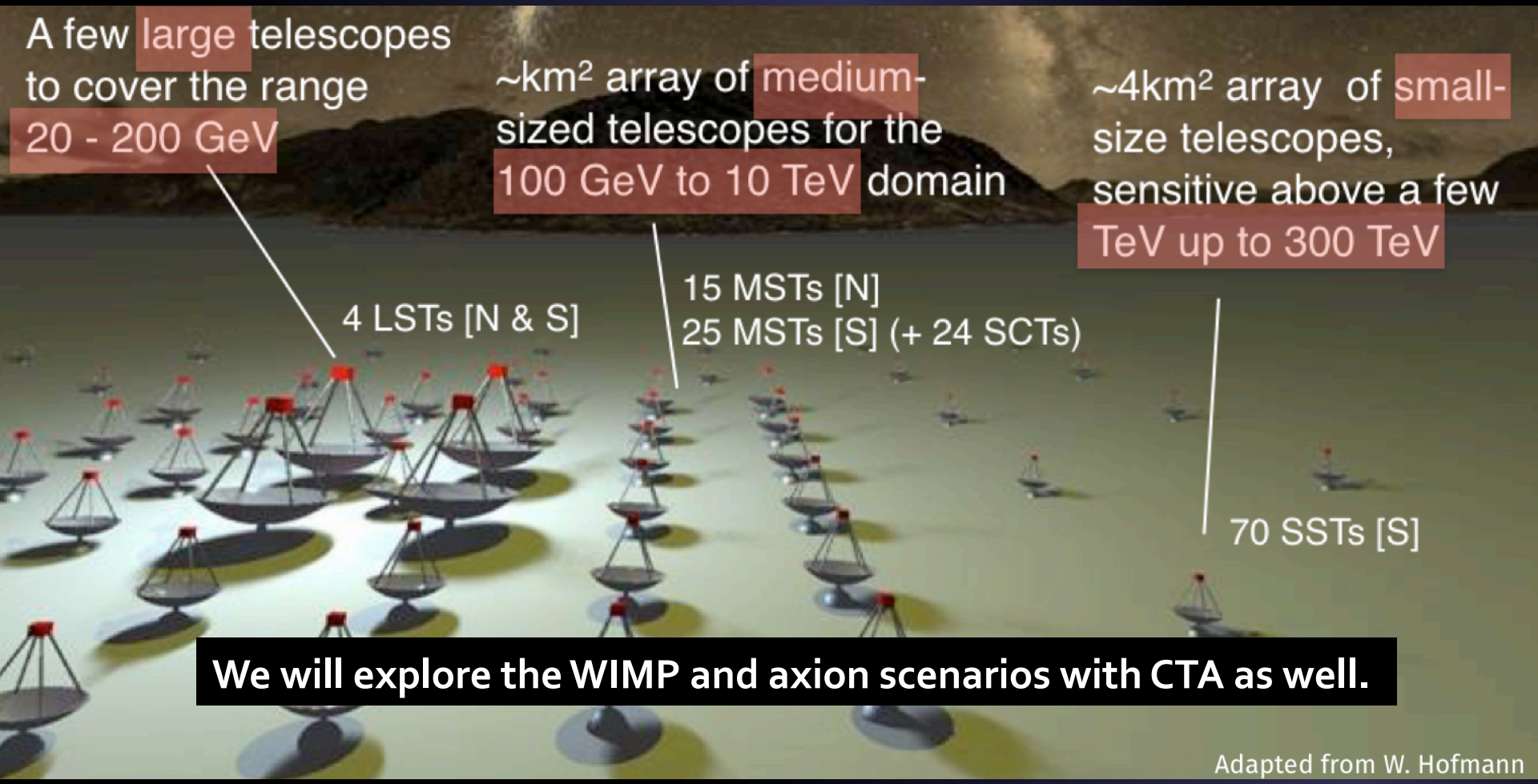


LAT prospects for an hypothetical Galactic supernova

[Meyer+17]

Future: Cherenkov Telescope Array (CTA)

More than 30 countries and 200 institutions.
Northern and Southern arrays.



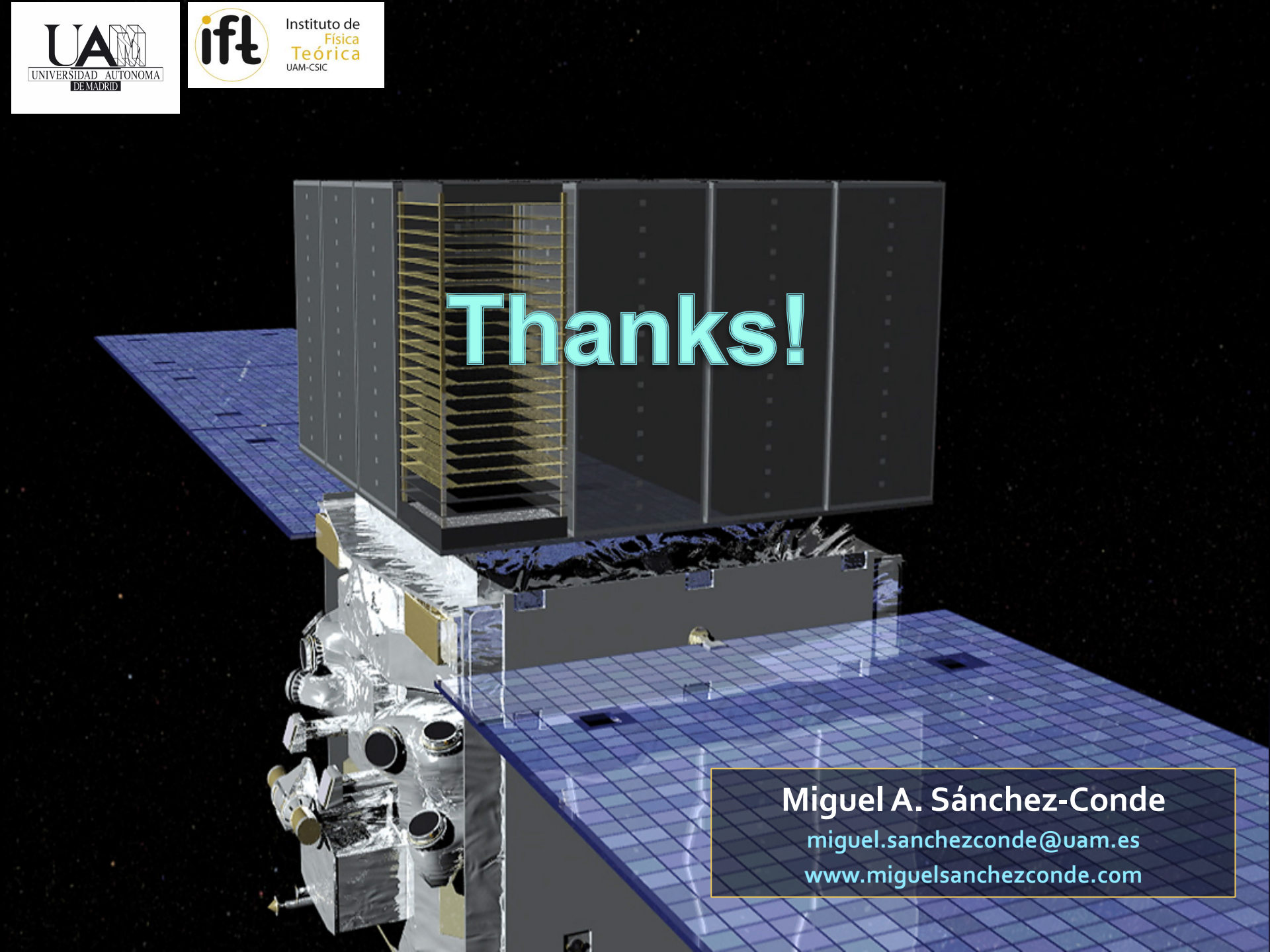
We will explore the WIMP and axion scenarios with CTA as well.

Adapted from W. Hofmann

Main ongoing projects @ IFT
(gamma-ray related)

General: WIMP and axion (gamma-ray) dark matter searches.
Tools: Fermi-LAT, CTA, N-body cosmological simulations.

- **Fermi LAT:**
  - Subhalo searches in LAT catalogs: Coronado's current work.
  - Follow-up of new DES dwarfs.
- **CTA:**
  - Annihilation in dwarf galaxies
  - Annihilation/decay in galaxy clusters
  - Axions in Perseus galaxy cluster.
- **N-body cosmological simulations**
  - Repopulation of current simulations below their resolution limit.
  - New Milky Way size simulations.
  - Refinement of the subhalo boost to annihilation signal.


Thanks!
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