THE SEARCH FOR DARK MATTER HALO SUBSTRUCTURE WITH GAMMA RAYS

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'Very High Energy Phenomena in the Universe'

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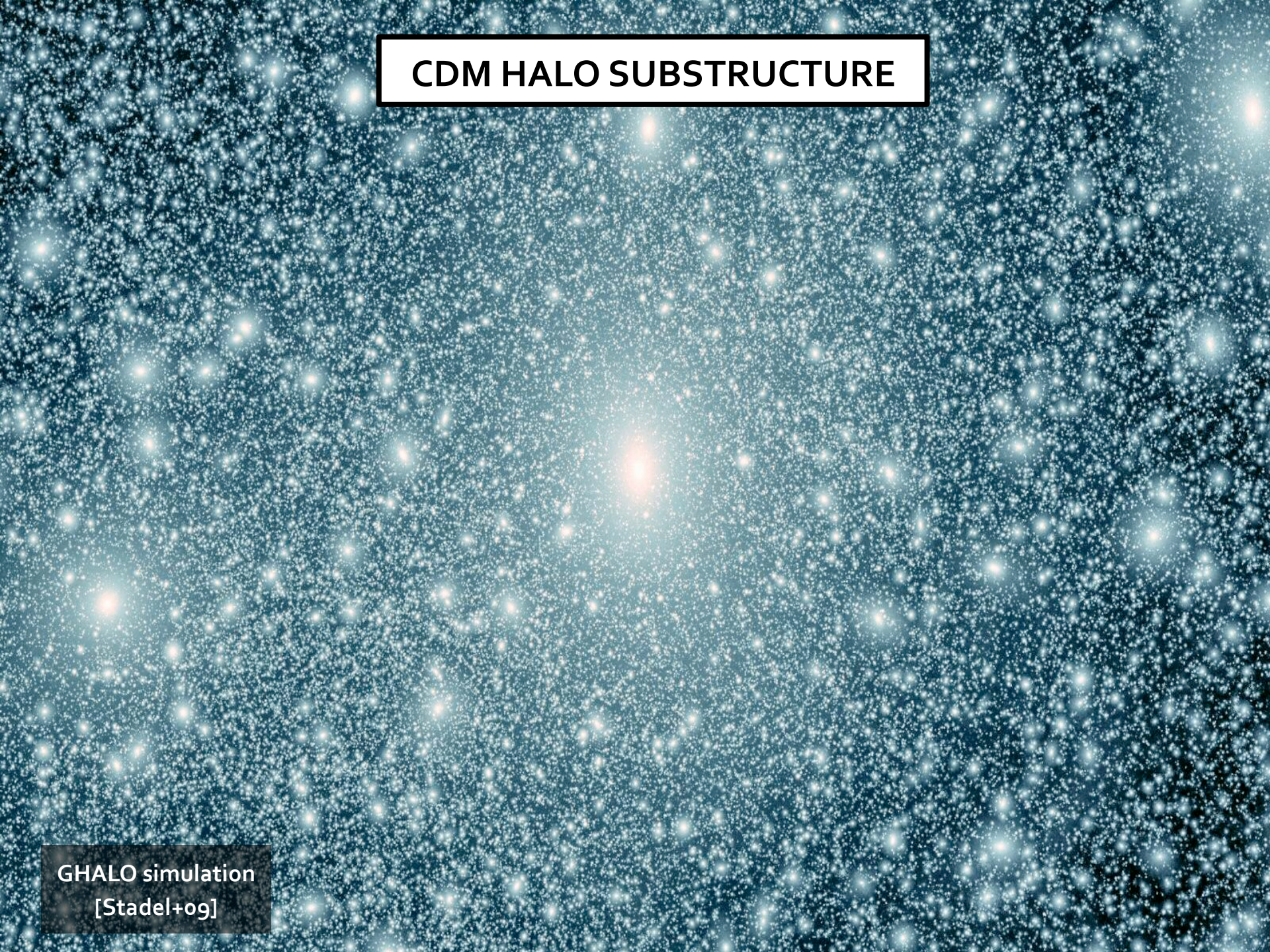
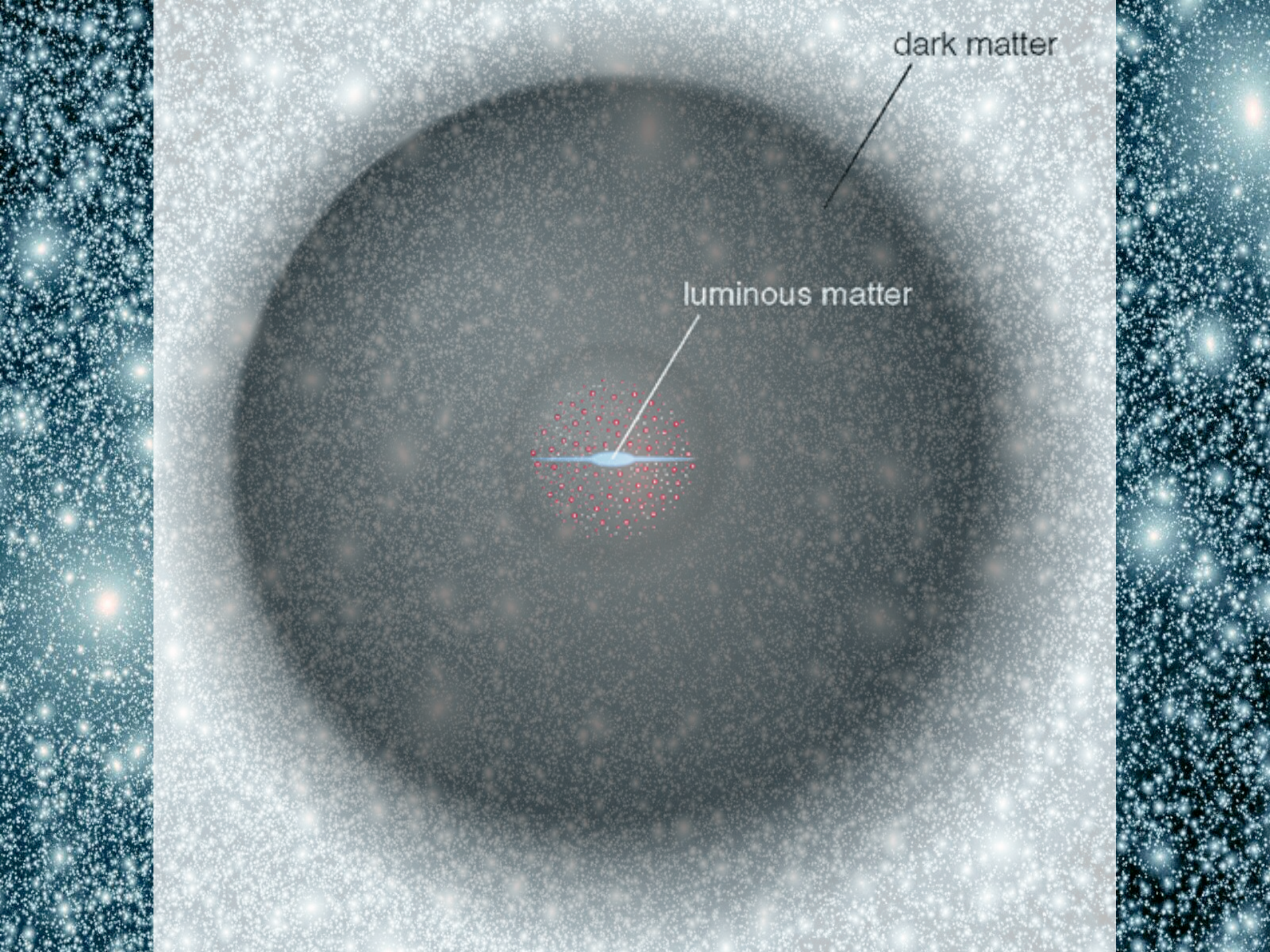
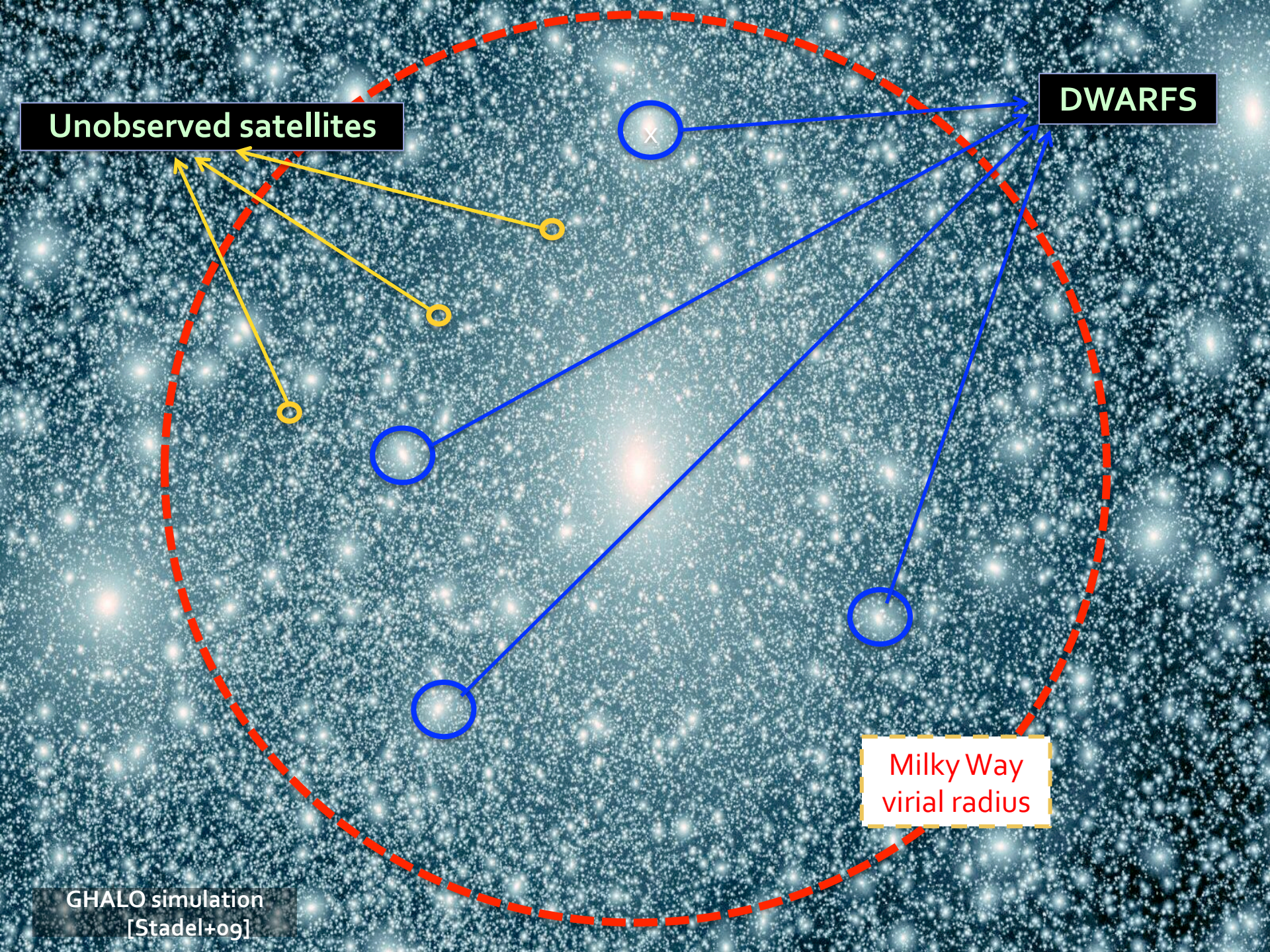
CDM HALO SUBSTRUCTURE



GHALO simulation
[Stadel+09]


dark matter
luminous matter


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

The role of DM halo substructure in (indirect) DM searches

Both *dwarfs* and *dark satellites* are highly DM-dominated systems

→ **GOOD TARGETS**

The *clumpy distribution* of subhalos inside larger halos may boost the annihilation signal importantly.

→ **"SUBSTRUCTURE BOOSTS"**

The role of DM substructure in (indirect) DM searches

Both *dwarfs* and *dark satellites* are highly DM-dominated systems

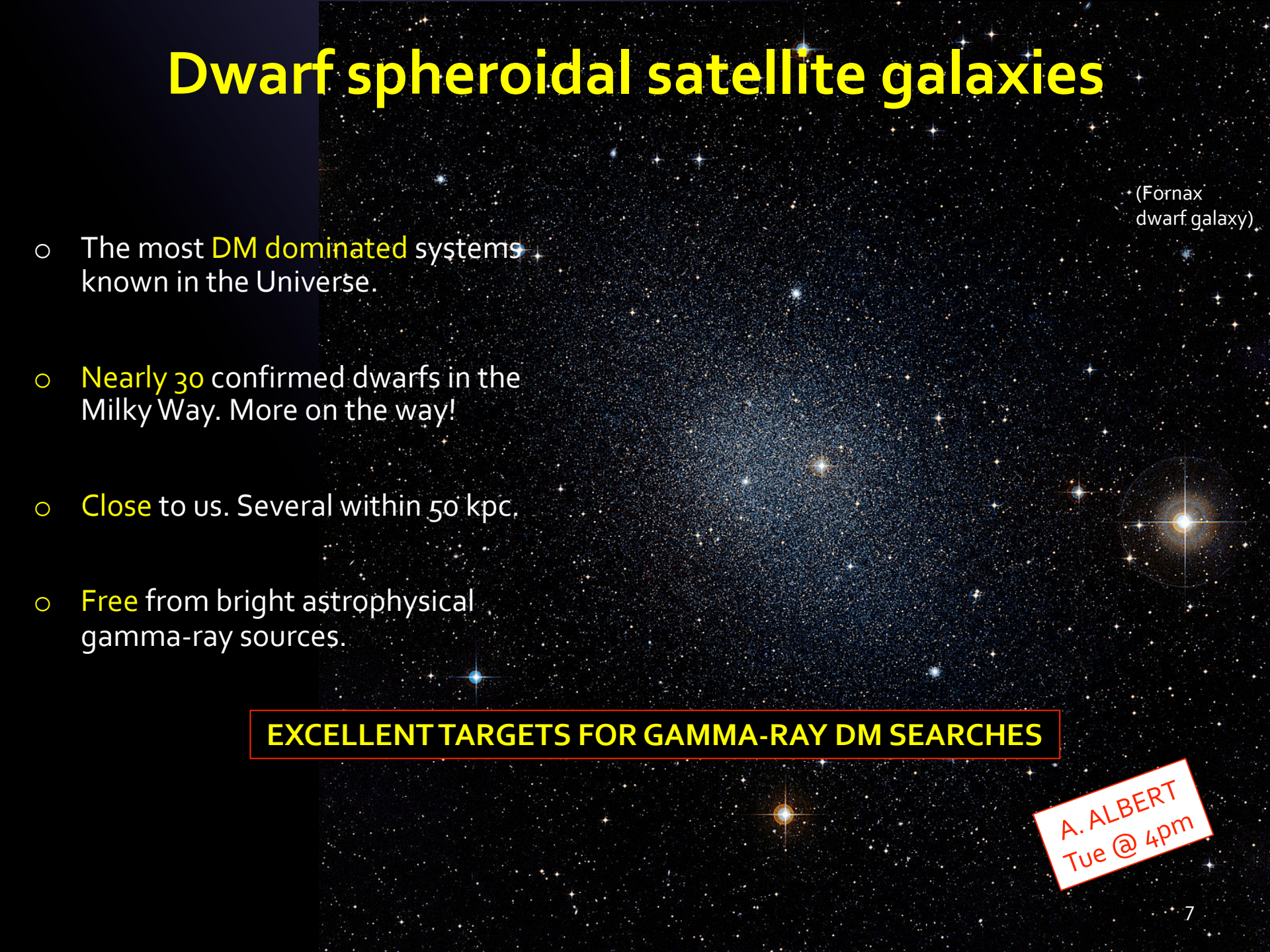
→ GOOD TARGETS

THIS TALK

The *clumpy distribution* of subhalos inside larger halos may boost the annihilation signal importantly.

→ "SUBSTRUCTURE BOOSTS"

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.

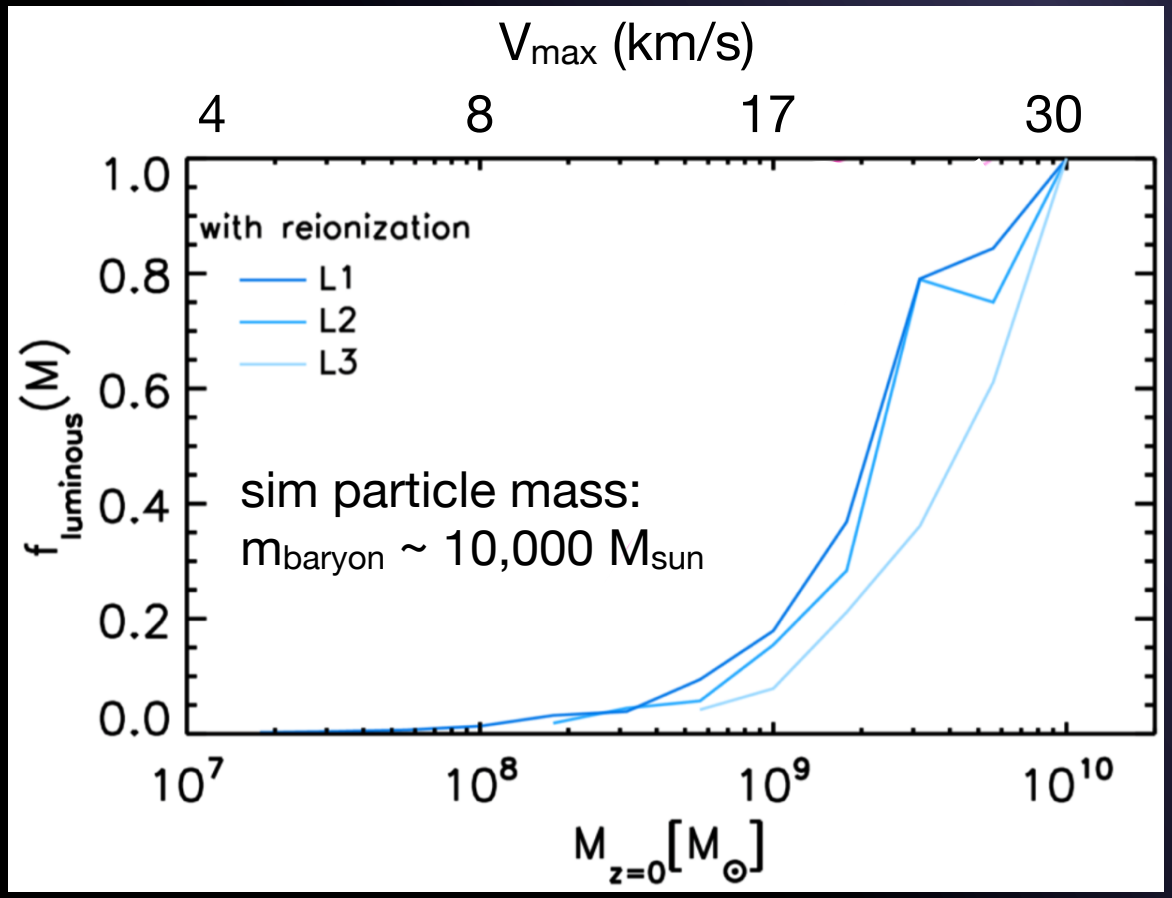
EXCELLENT TARGETS FOR GAMMA-RAY DM SEARCHES

A. ALBERT
Tue @ 4pm

DM subhalos (a.k.a. 'dark satellites')

The most massive subhalos will host visible satellite galaxies

Light subhalos expected to remain completely dark.



[Sawala+15]

Every **halo** is dark below ~8 km/s ~ 10^8 M_{sun}

Subhalos can lose >90% of its mass due to tidal forces

→ dark subhalos < 10^7 M_{sun}

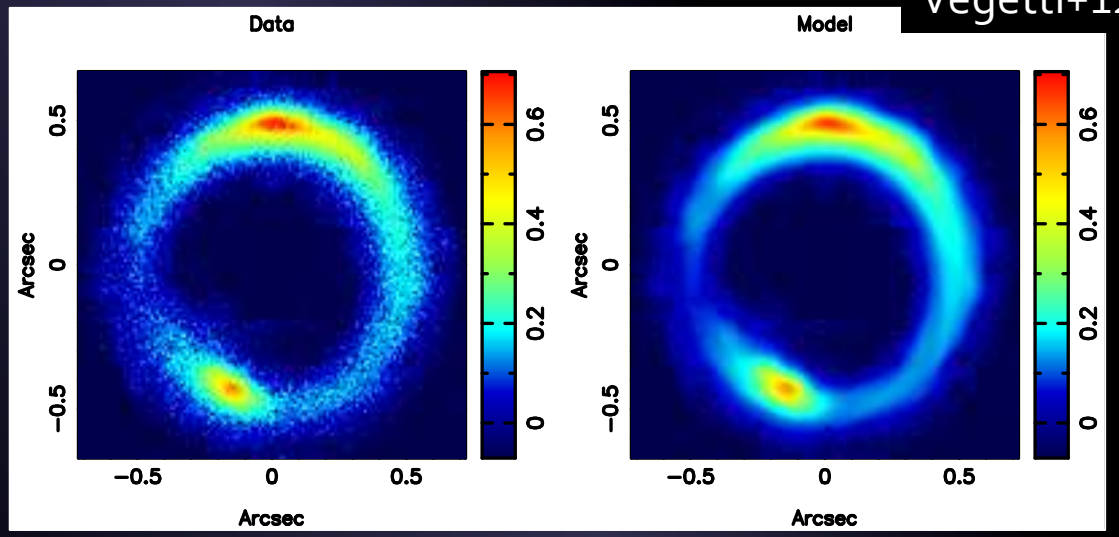
Similar results by Gnedin'00; Hoeft+06; Okamoto+08; Ocvirk+16; Fitts+17; etc

DM subhalo searches

I. (Strong) LENSING

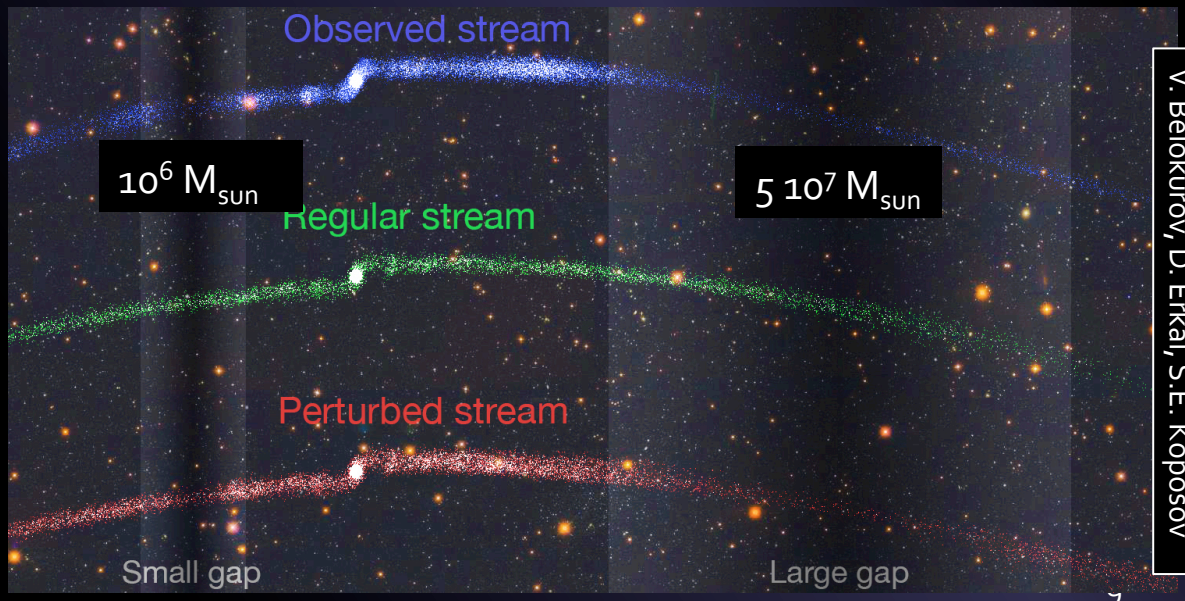
[Vegetti+10,12,18;
Hezaveh+16;
Nierenberg+14,17;
Birrer+17]

Vegetti+12



II. STELLAR GAPS

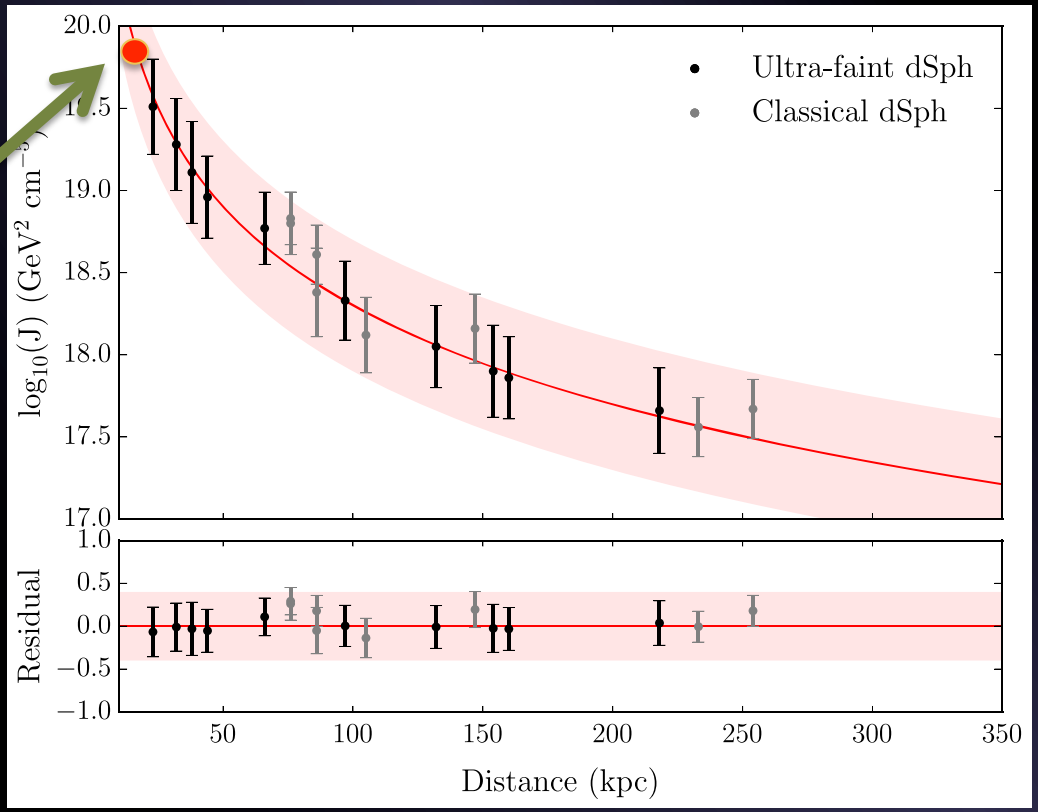
[Carlberg 12,15;
Erkal+15, 16, 17]



DM SUBHALO SEARCHES:
III. GAMMA RAYS

- If DM is made of WIMPs and annihilates → gamma rays
- Maybe the only way to probe subhalo masses below ~10^7 solar masses
- The only subhalo search that provides info on the nature of the DM particle.

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



Adapted from Albert+15

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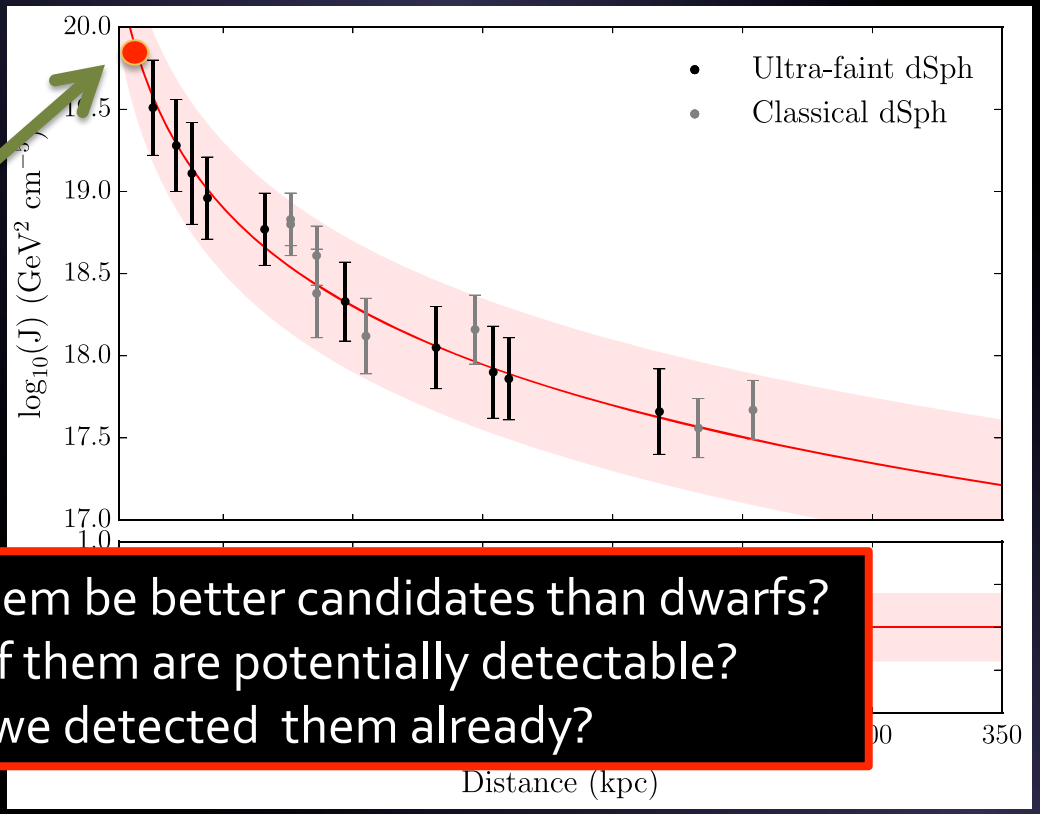

Adapted from Albert+15

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

Dark satellites' search in Fermi-LAT catalogs

Around 1/3 of sources in LAT catalogs are unidentified (~1000 unIDs in the 3FGL)

Exciting possibility: some of them may be subhalos annihilating to gammas!

Objective: to build a list of potential DM subhalo candidates by identifying those unIDs compatible with DM subhalo annihilation.

Method:

Apply a series of '*filters*' based on expected DM signal properties.

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Most common filters used:

1. Associations
2. Variability
3. Latitude
4. Multiwavelength emission
5. Spectrum
6. Extension

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Results:

1. A few VIP candidates → dedicated LAT analyses, IACT follow-ups…
2. A few more subhalo candidates (yet uncertain) → set DM constraints
3. No unIDs compatible with DM? → best achievable constraints

DM constraints from LAT unIDs?

$$F(E > E_{th}) = J_{factor} * f_{pp}(E > E_{th})$$

Astrophysics (Density profile, distance…)

Particle Physics (channel, annihilation spectra…)

$$\langle \sigma v \rangle \propto \frac{m_\chi^2 \cdot F_{min}}{J_{factor} \cdot \int_{E_{th}}^{E} \left(\frac{dN}{dE}\right) dE} = \frac{m_\chi^2 \cdot F_{min}}{J_{factor} \cdot N_\gamma}$$

Instrument

Theory

Simulations

N-body simulations → dark satellites' J-factors and spatial properties.

↓

LAT sensitivity to DM annihilation → number of detectable subhalos.

↓

Number of predicted detectable subhalos VS. number of remaining unIDs in catalogs.

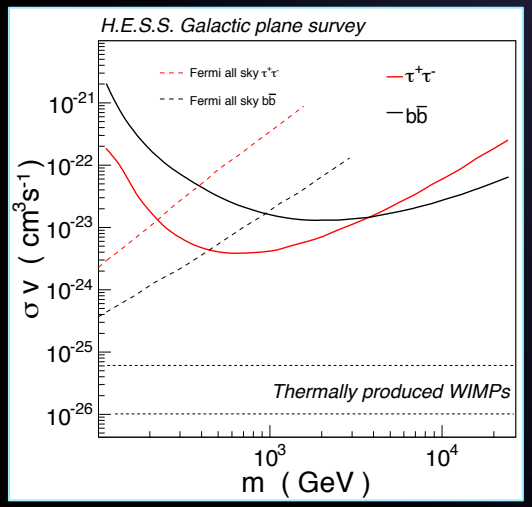
↓

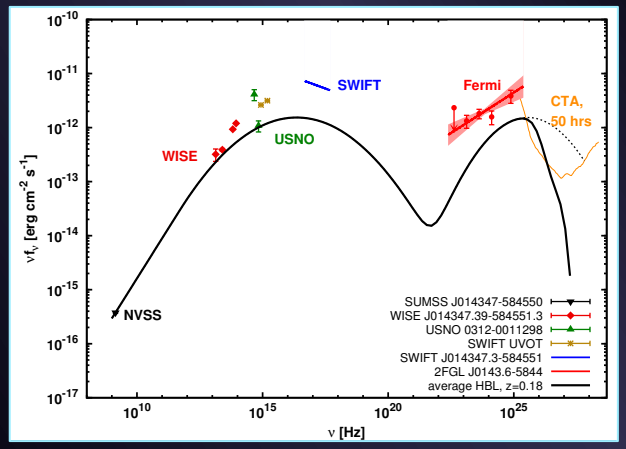
DM CONSTRAINTS

The less DM candidates left in catalogs the better the DM constraints.

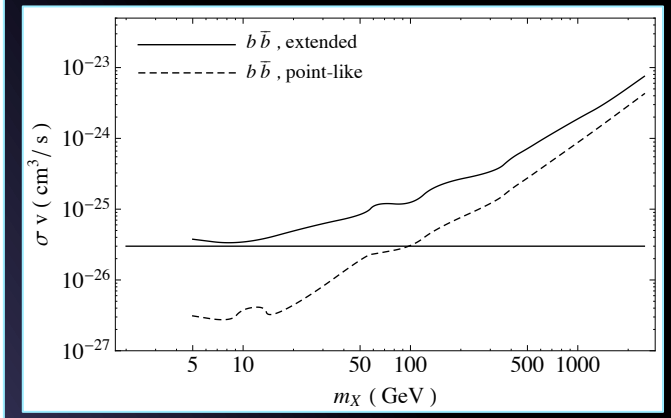
(Some) past work

Brun+11

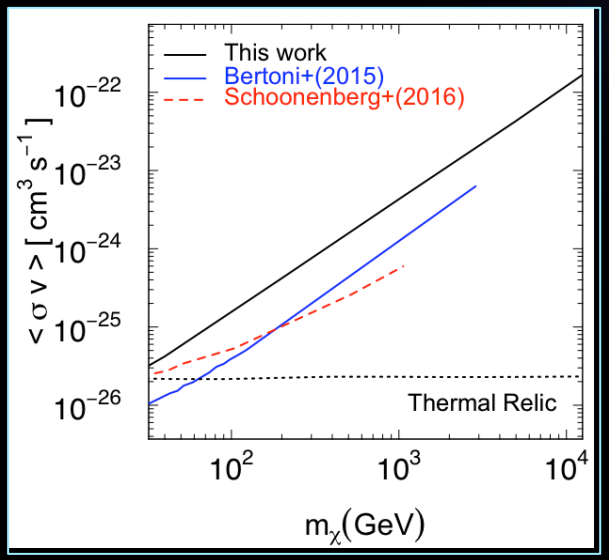




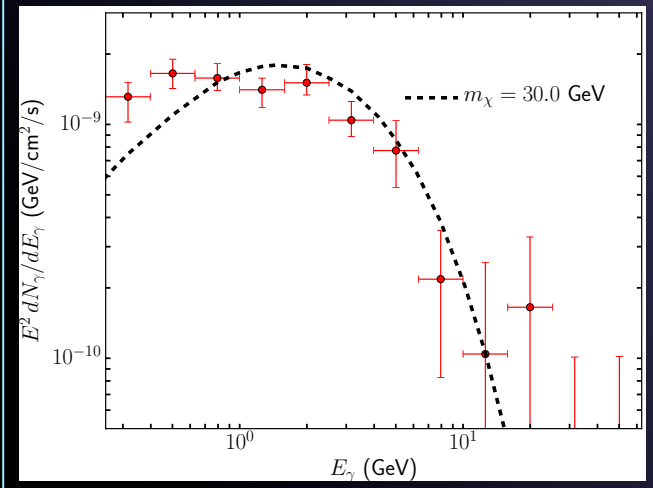
Zechlin+12;+13



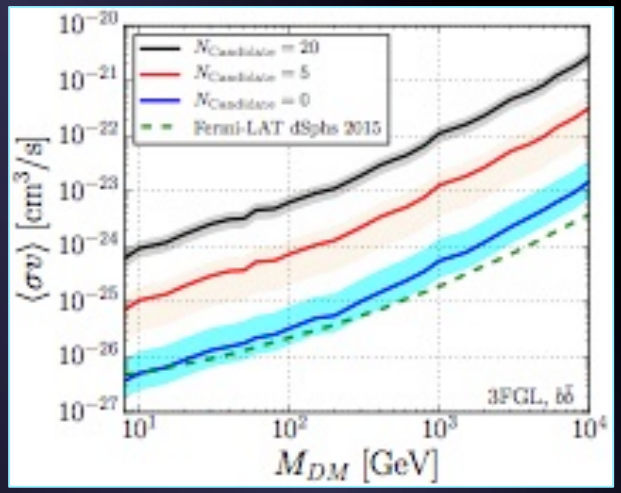
Berlin&Hooper 13



Mirabal+16



Bertoni+16



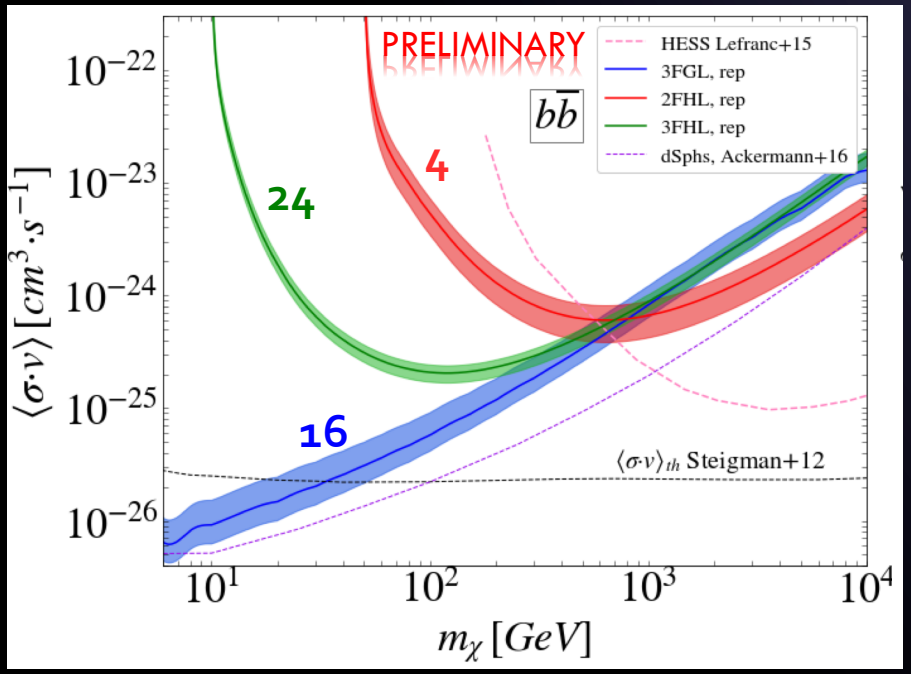
Calore+17

Also: Tasitsiomi&Olinto 02; Pieri+05; Kuhlen+07; Springel+08; Anderson+10; Belikov+12; Ackermann+12; Berlin&Hooper+13; Hooper+16; Schoonenberg+16

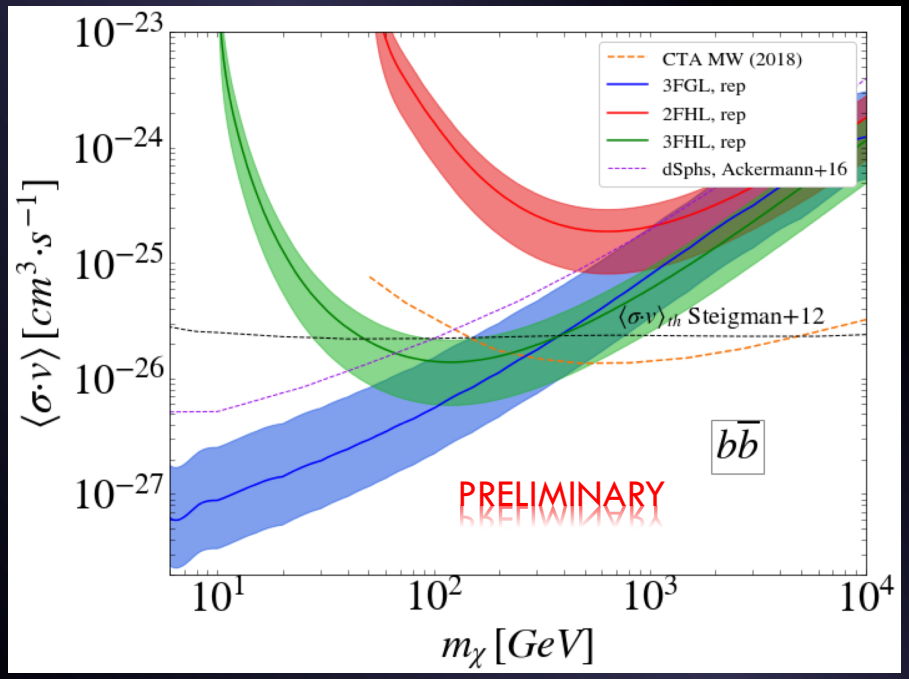
New LAT work ongoing

[J. Coronado-Blázquez, MASC et al., in prep.]

- Search in the most recent LAT catalogs (3FGL, 2FHL, 3FHL)
- Careful unIDs 'filtering' work.
- Precise characterization of LAT sensitivity to DM annihilation.
- Best knowledge of subhalos' structural properties (MASC&Prada14, Moliné+17)
- Repopulation of VL-II N-body simulation below its resolution limit.



Most realistic constraints



Maximum potential (1 subhalo)

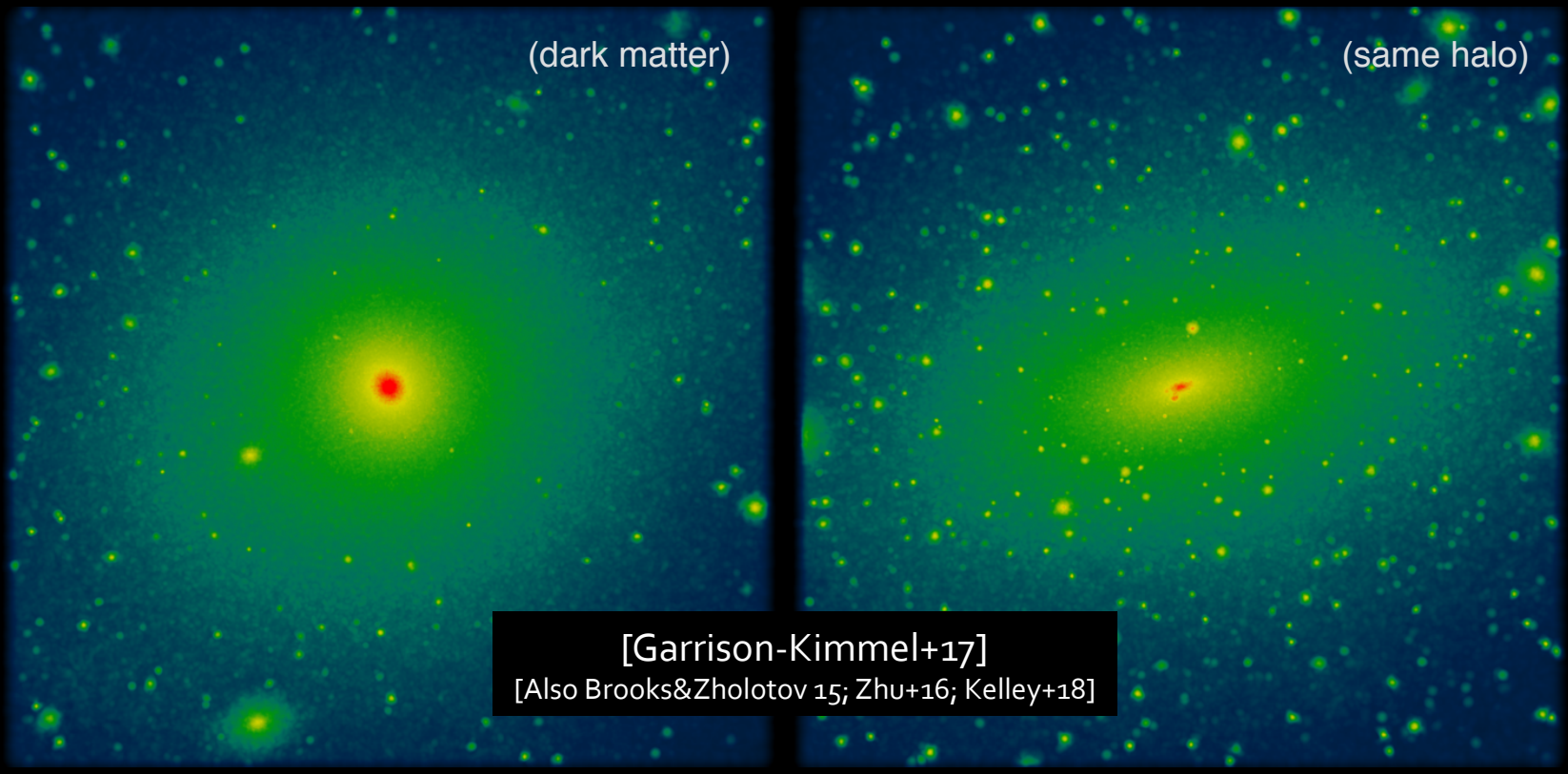
Some OPEN ISSUES

- Subhalo mass function.
- Subhalo structural properties.
- Subhalo survival (to tidal stripping; baryons; dynamical friction).
- Role of baryons on:
  - Subhalo abundance.
  - Subhalo structure.
- Dependence of all the above on distance to host halo center and mass.

OPEN ISSUES (I): Role of baryons

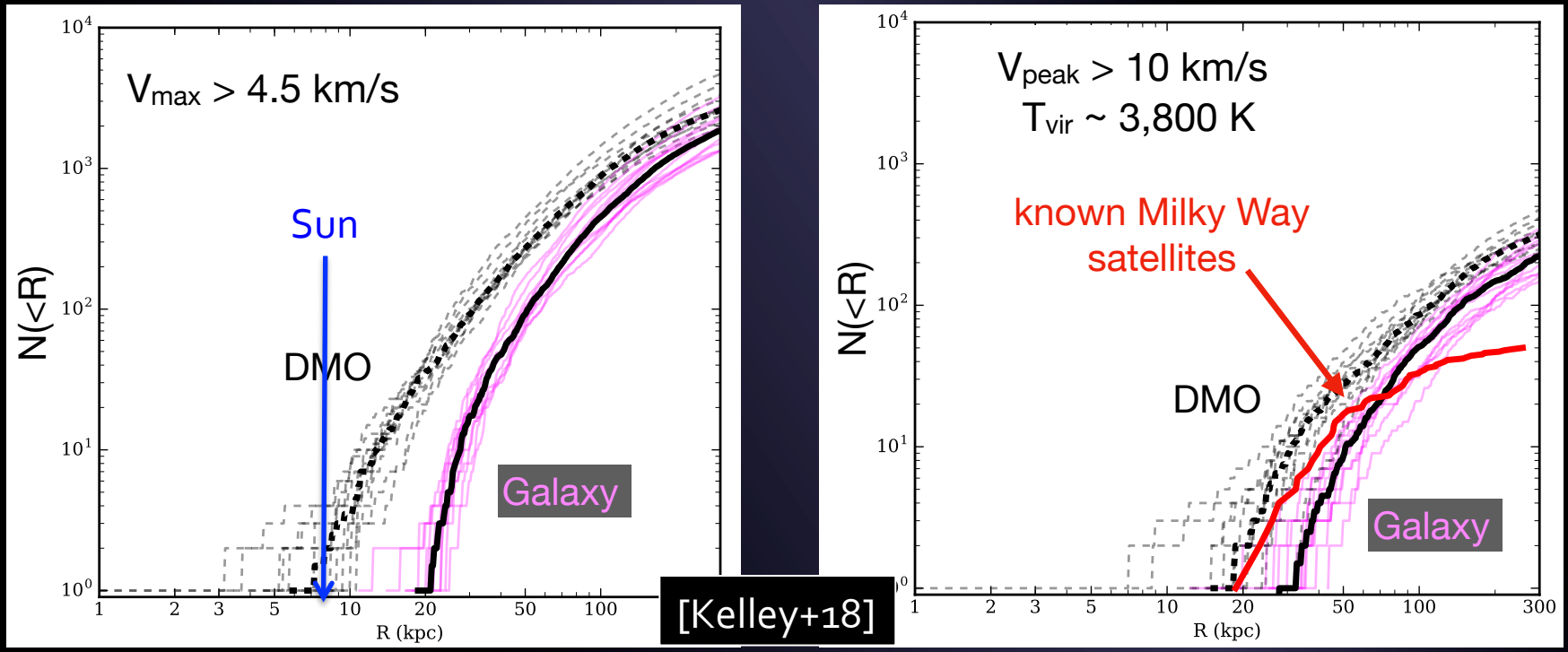
FIRE Hydrodynamics

Pure N-Body



Up to factor ~10 reduction in substructure within ~25 kpc
No substructure within ~20 kpc with V_{max} > 5 km/s

OPEN ISSUES (II): Subhalo survival



[Kelley+18]

Credit: J. Bullock

Radial distribution of massive subhalos in hydro simulations do not match observations!

Van den Bosch+18; van den Bosch&Ogiya 18 [Also: Kazantzidis+04; Diemand+07; Peñarrubia+10]:

- Subhalo disruption is numerical in origin
- Bound remnant survives provided it is well resolved in the simulation.

→ What is the actual subhalo radial distribution?

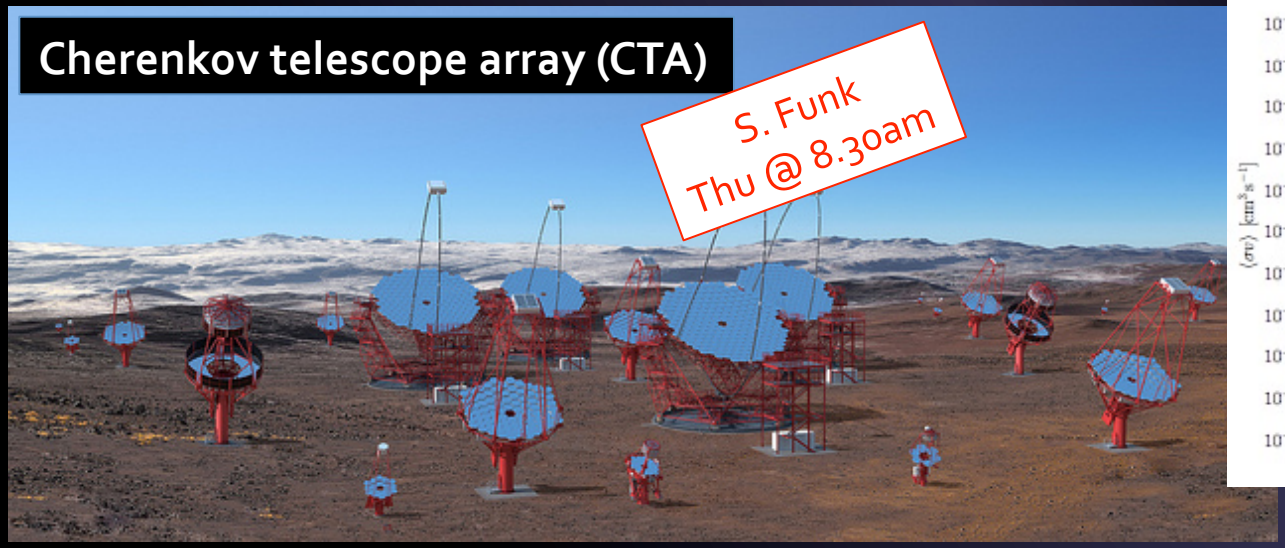
Remarks

- Halo substructure is an unavoidable prediction of ΛCDM.
  - Most massive subhalos (dwarf galaxies) the best targets for indirect DM detection.
  - Less massive subhalos, with no optical counterparts, can be used to set very competitive constraints.
  - Subhalos can significantly *boost* the annihilation signal from halos and alter the signal spatial properties.

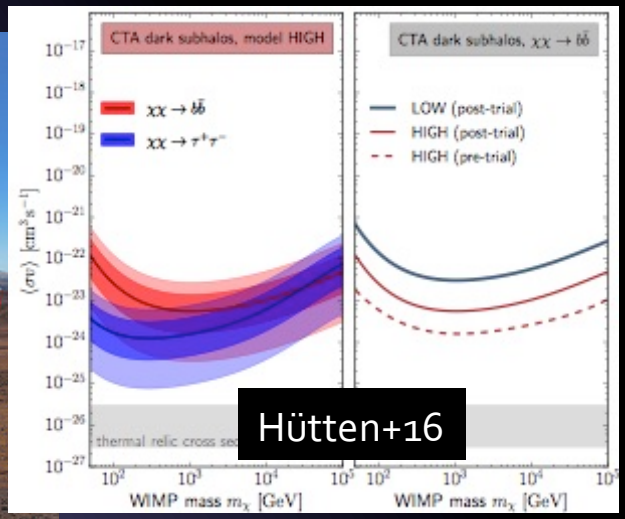
- 'Dark satellites' searches:
  - Current constraints close to the ones from dwarfs.
  - Sensitivity reach can rule out thermal cross section up to few hundred GeV WIMP masses.
  - Up to O(10) intrinsic (ΛCDM) uncertainty difficult to mitigate.

Future of dark satellites' searches with gamma rays

Cherenkov telescope array (CTA)



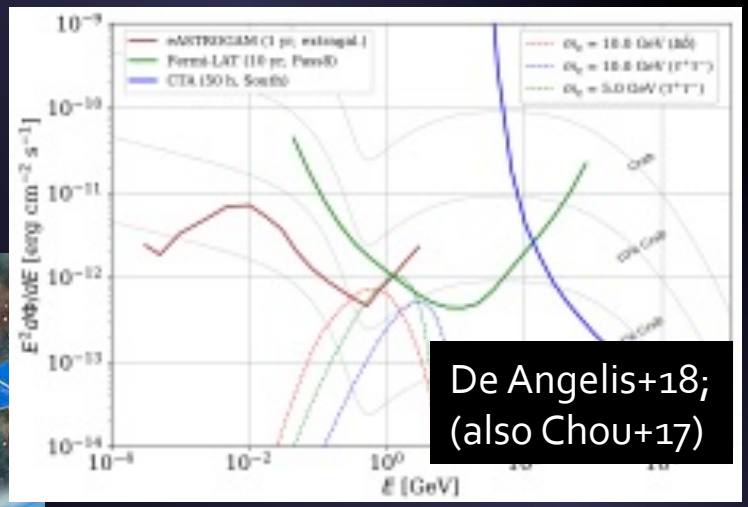
S. Funk
Thu @ 8.30am



Hütten+16

Future MeV/sub-GeV missions

J. McEnery
Thu @ 9am



De Angelis+18;
(also Chou+17)

Future of dark satellites' searches with gamma rays

- Higher resolution DM-only and hydro simulations to shed light on subhalo survival, structural properties, etc.
- New gamma-ray catalogs (e.g., upcoming 4FGL)
- More refined spectral and spatial unID 'filters'
- Possible follow up of VIP candidates with IACTs

DM halo substructure CRITICAL
for current and future gamma-ray DM search strategies.

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