THE SEARCH OF DARK SATELLITES WITH GAMMA RAYS

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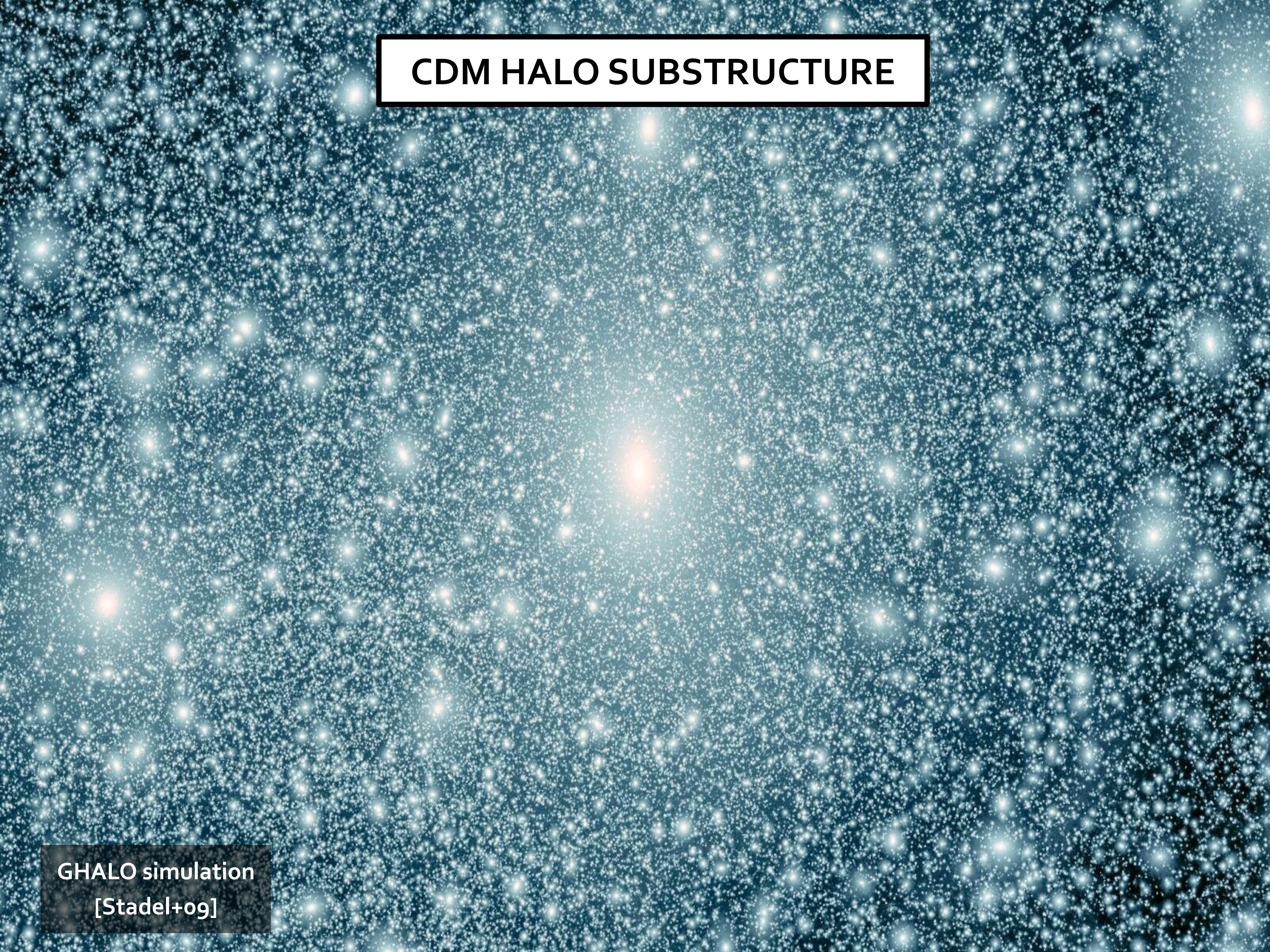
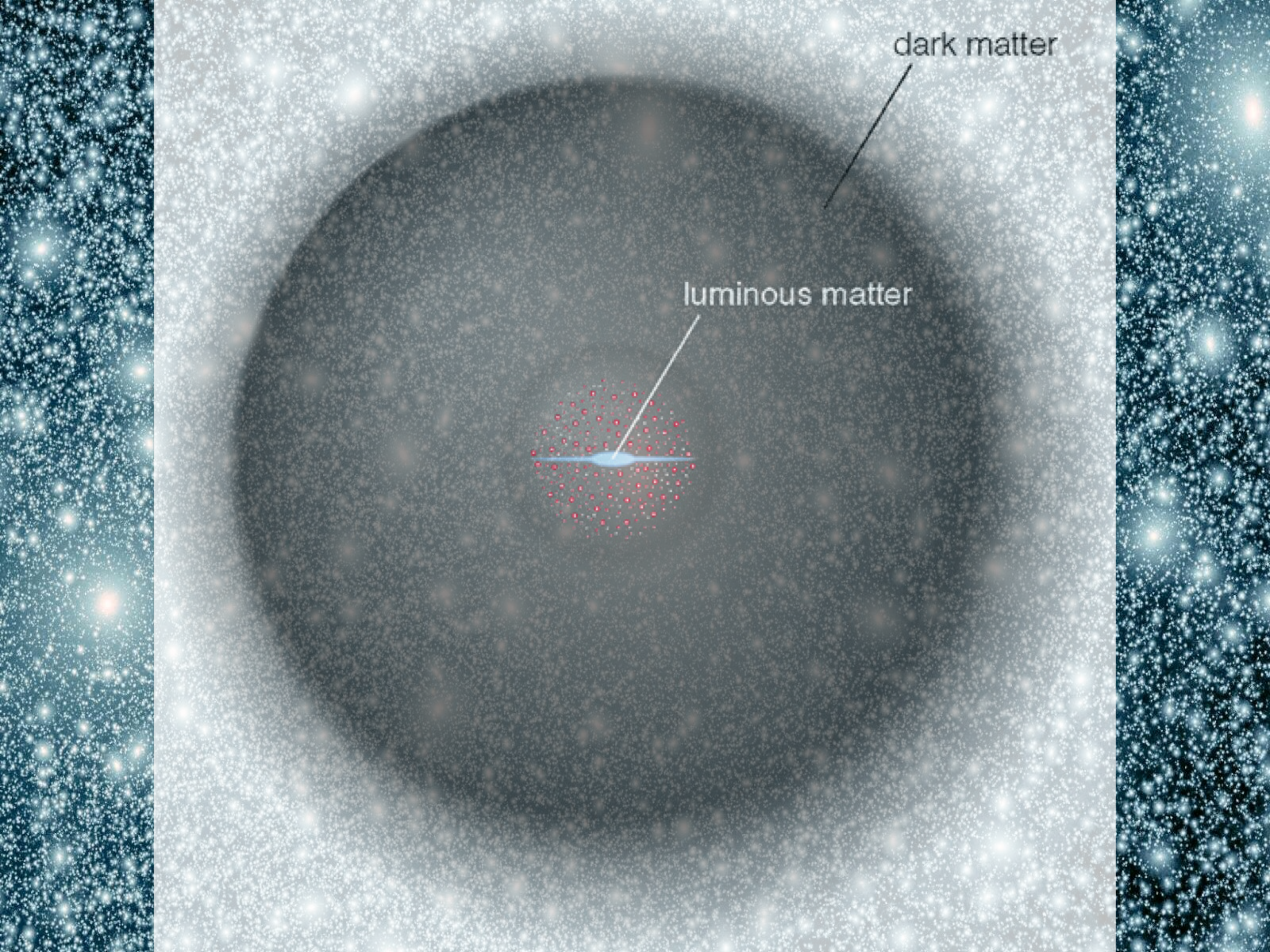
‘A rainbow of dark sectors’ – ACP Winter Workshop

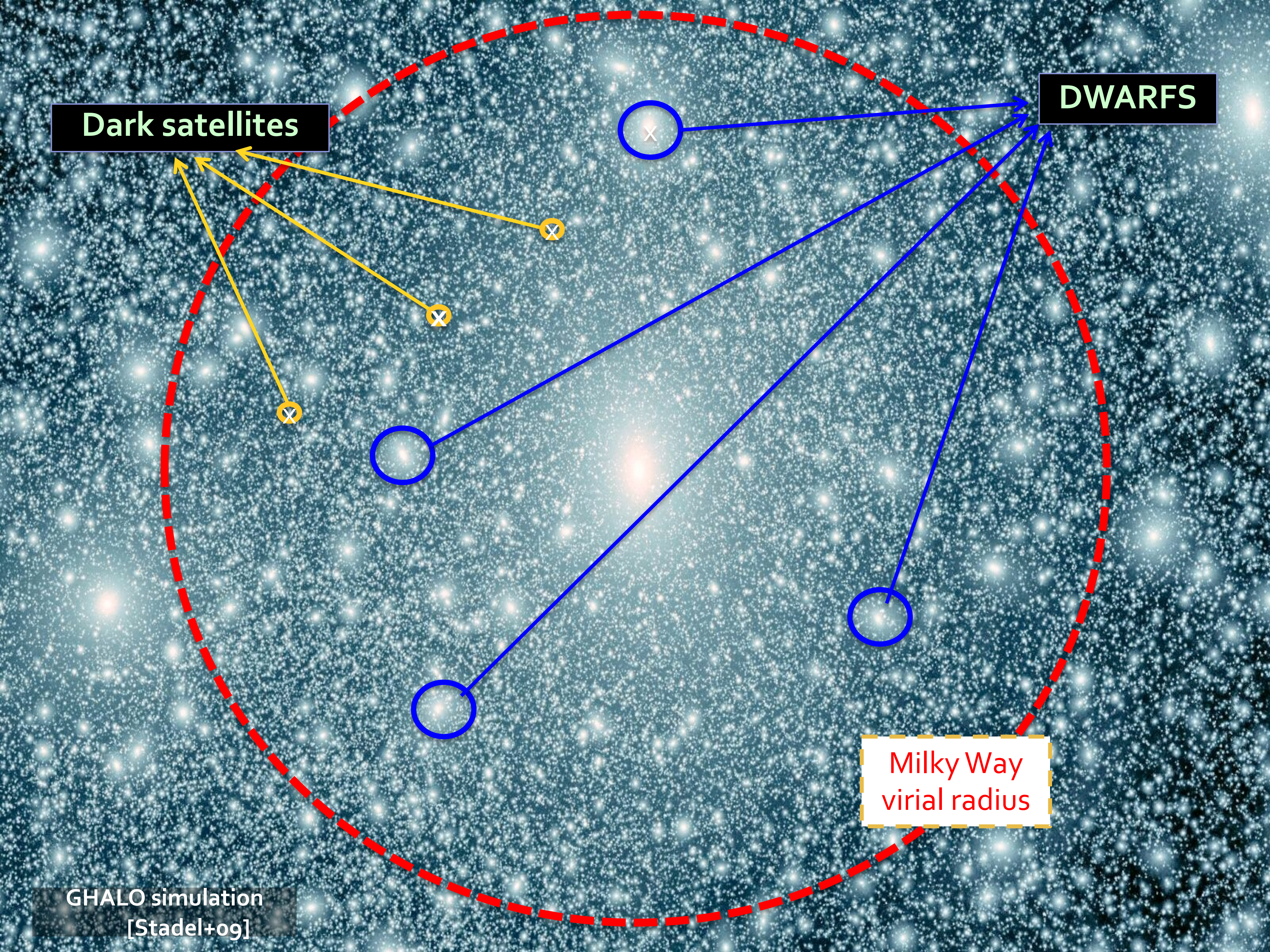
Zoom, March 22 – April 1 2021

CDM HALO SUBSTRUCTURE



GHALO simulation
[Stadel+09]

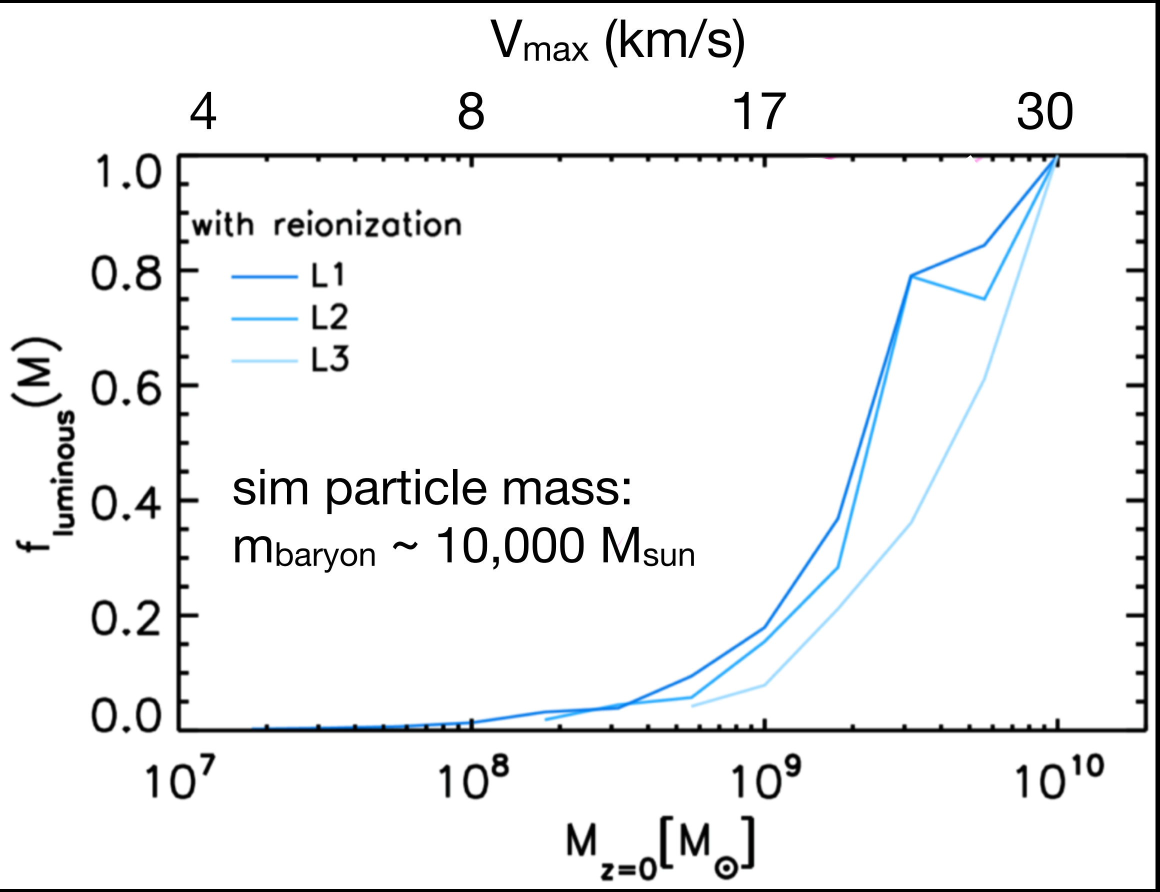

dark matter
luminous matter


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

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

The most massive subhalos will host visible satellite galaxies

Light subhalos expected to remain completely dark.



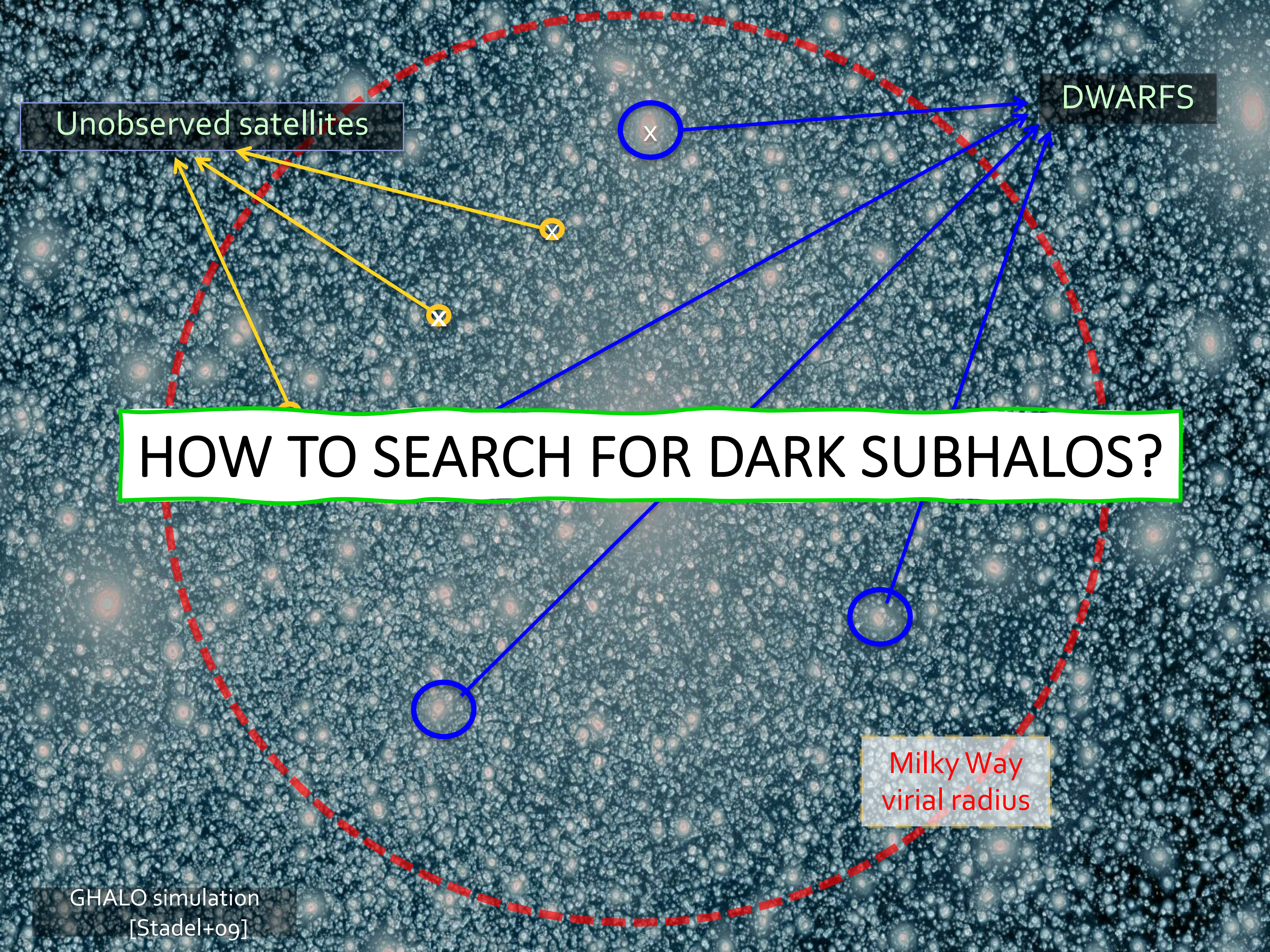
Every **halo** is dark below ~8 km/s ~ 10^8 M_{sun}

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

→ dark subhalos < 10^7 M_{sun}

[Sawala+15]

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



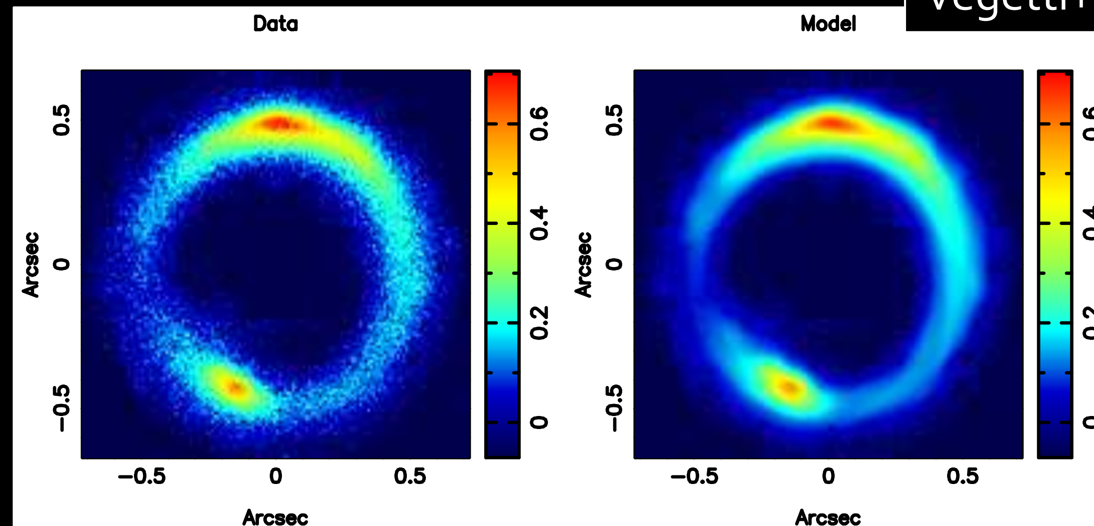
Unobserved satellites
DWARFS
HOW TO SEARCH FOR DARK SUBHALOS?
Milky Way
virial radius
GHALO simulation
[Stadel+09]

Dark subhalo searches

I. (Strong) LENSING

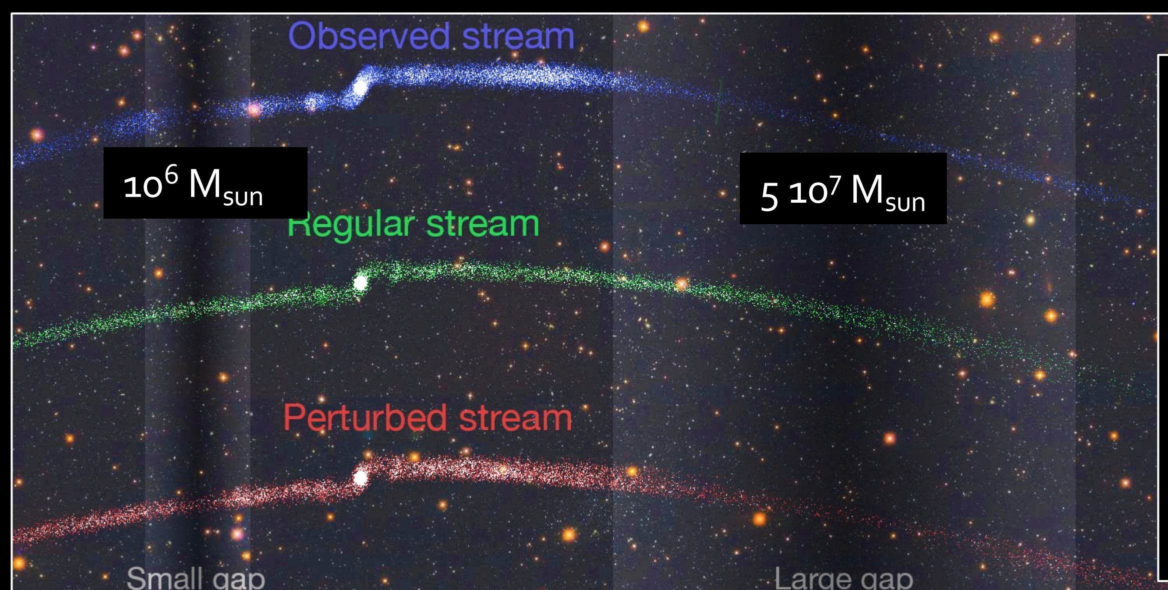
[Vegetti+10,12,18;
Hezaveh+16;
Nierenberg+14,17;
Birrer+17;
Alexander+19; Varma+20;
Meneghetti+20]

Vegetti+12



II. STELLAR GAPS

[Carlberg 12,15;
Erkal+15, 16, 17;
Price-Whelan+18
Boer+18; Banik+19;
Bonaca+19; Malhan+19]



V. Belokurov, D. Erkal, S.E. Koposov

DARK SUBHALO SEARCHES:
III. GAMMA RAYS

- If dark matter (DM) is made of WIMPs → subhalo annihilates → gamma rays
- Maybe the only way to probe subhalo masses below ~10^7 solar masses
  → critical to differentiate LCDM from e.g. WDM cosmology.
- The only subhalo search that provides info on the nature of the DM particle.

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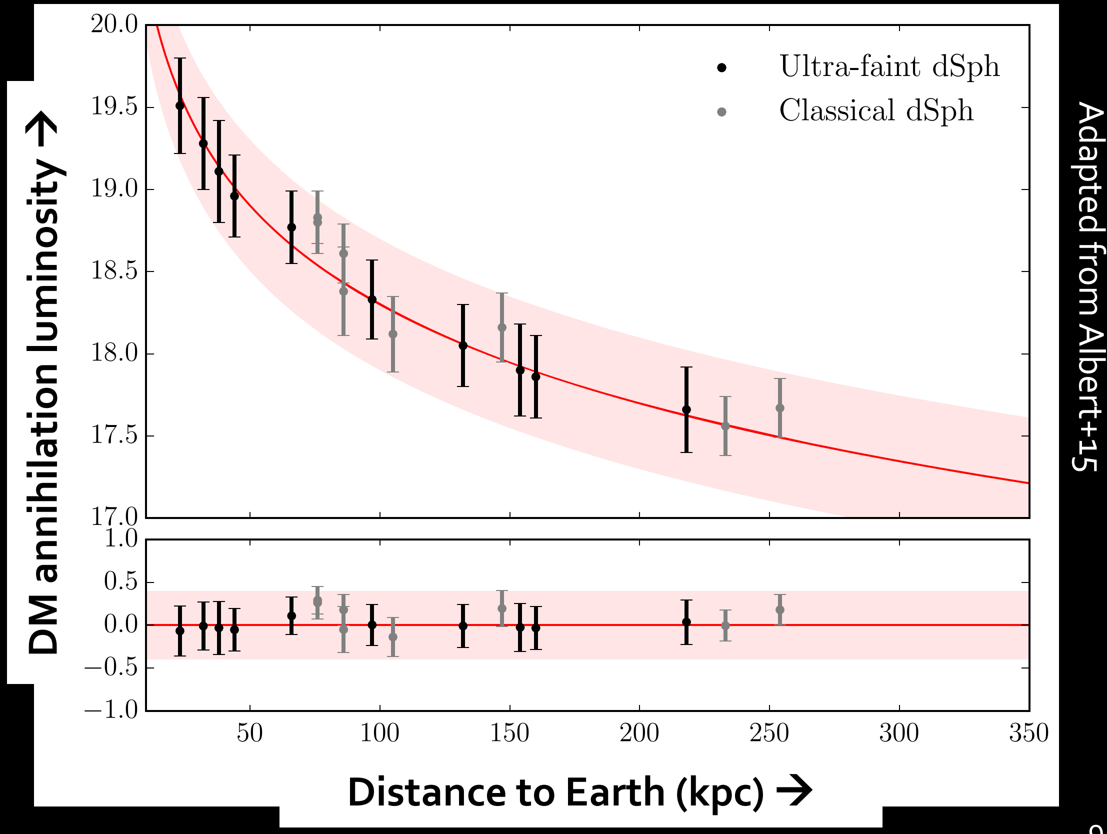

DARK SUBHALO SEARCHES:

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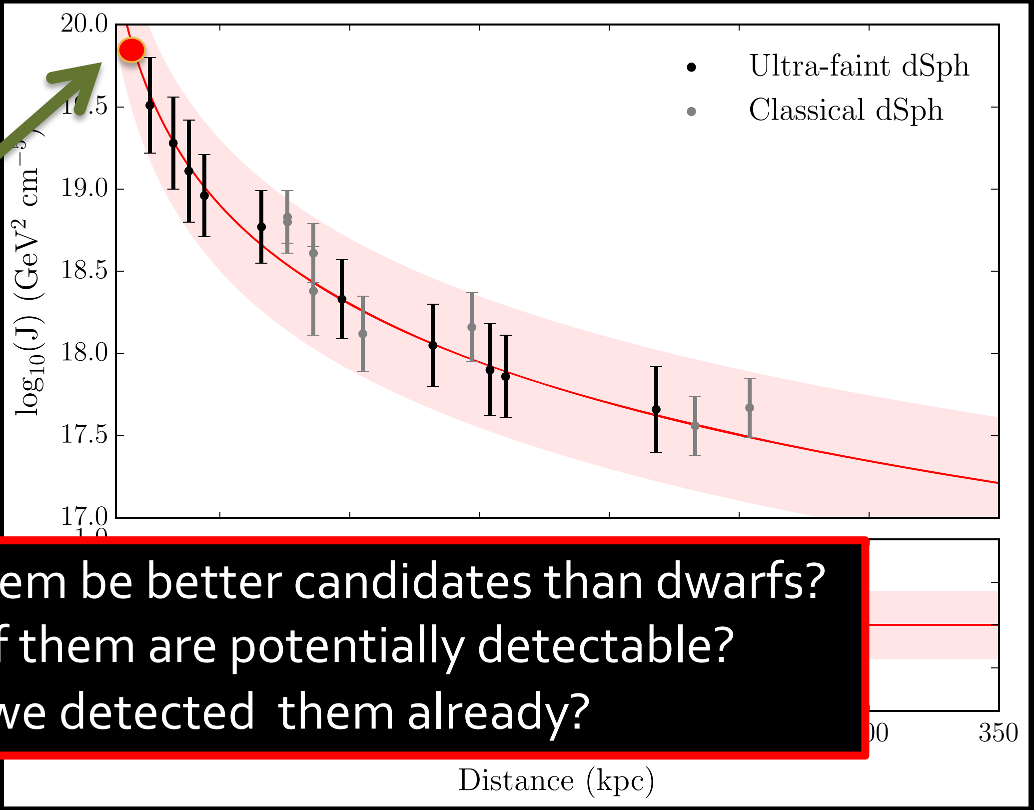
Should we expect any dark subhalo e.g. here?



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 subhalo search with gammas: general methodology

Around 1/3 of sources in gamma-ray catalogs are unidentified (unIDs)
(e.g., ~1700 unIDs in the latest '4FGL-DR2' Fermi-LAT catalog)

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

Search for potential DM subhalo candidates by identifying those unIDs compatible with DM subhalo annihilation.

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

Possible results:

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

DM constraints from gamma-ray unID sources?

VS

dark subhalo J-factors, number density, spatial extension…

instrument sensitivity to DM annihilation, pool of unID sources

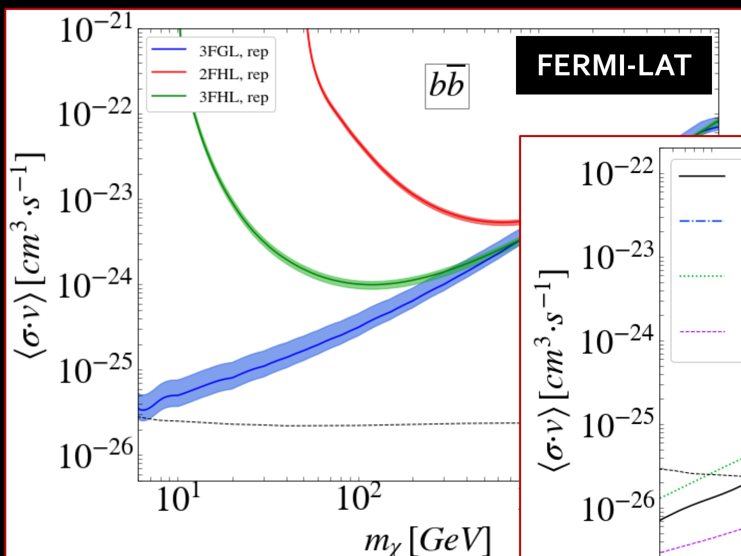
Number of predicted detectable subhalos VS. number of unIDs compatible with DM

DM CONSTRAINTS

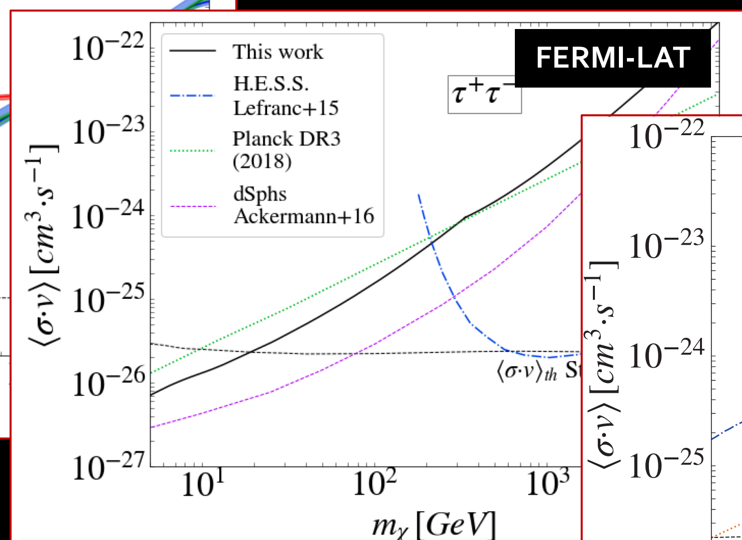
[The less DM candidates among unIDs the better the constraints]

Latest search in gamma-ray catalogs

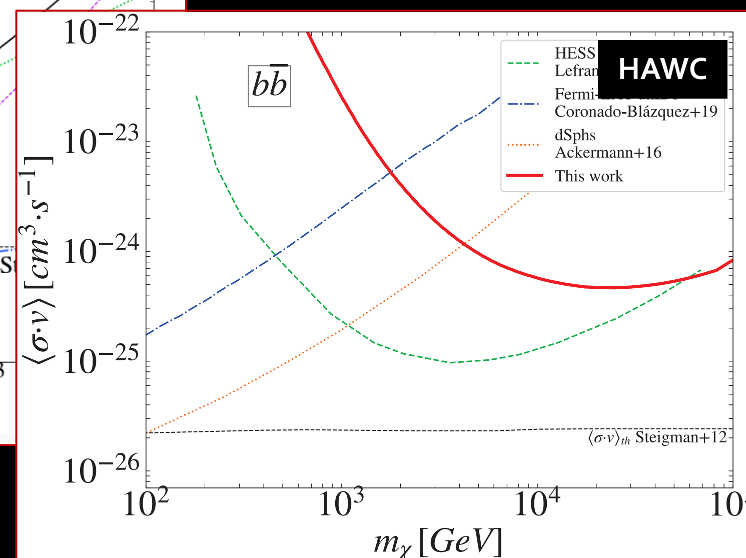
- Previous methodology already proposed and used in several of our papers.
- List of O(1) VIP candidates in the 2FGL+2FHL+ 3FGL Fermi LAT catalogs.
- DM limits competitive with other targets, reach thermal cross section.
- 4FGL search ongoing (Coronado-Blazquez, MASC+, in prep.)



[Coronado-Blázquez, MASC+19]



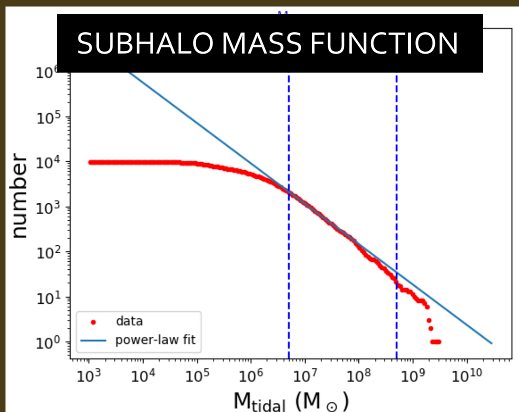
[Coronado-Blázquez, MASC+19b]

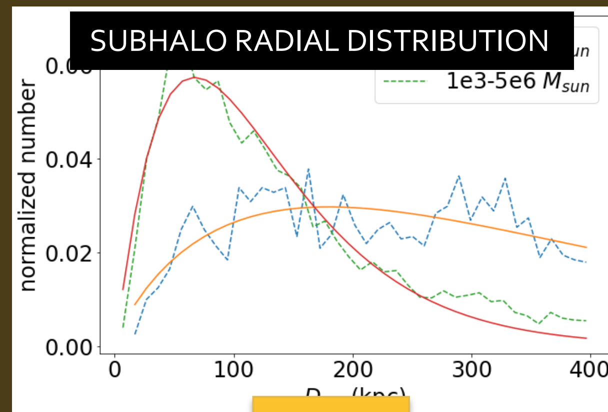


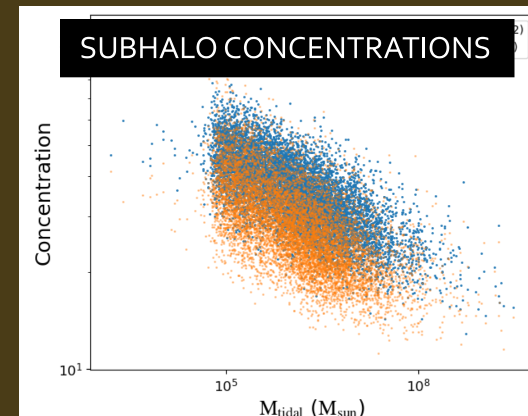
[Coronado-Blázquez, MASC+20]

Also: Tasitsiomi&Olinto 02; Pieri+05; Kuhlen+07; Springel+08; Anderson+10; Brun+11; Belikov+12; Ackermann+12; Zechlin+12;+13; Berlin&Hooper 13; Mirabal+16; Hooper+16; Bertoni+16; Schoonenberg+16; Calore+17; Abeysekara+19

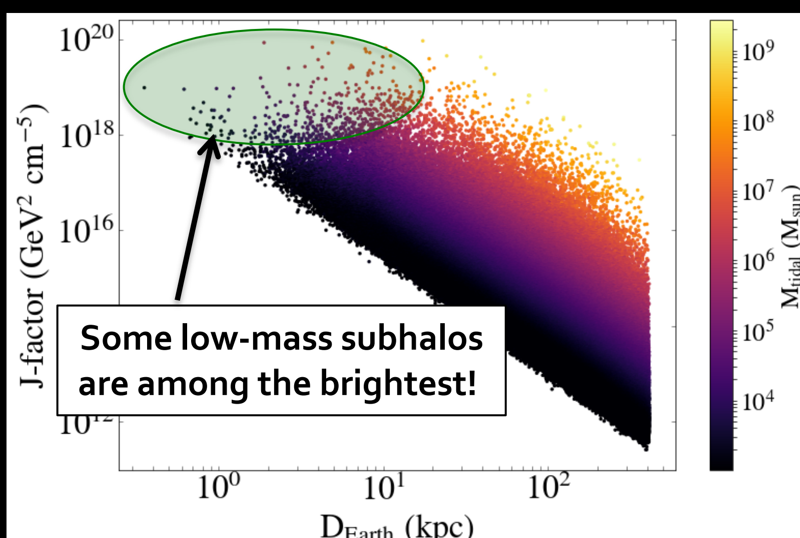
N-body simulation work is critical

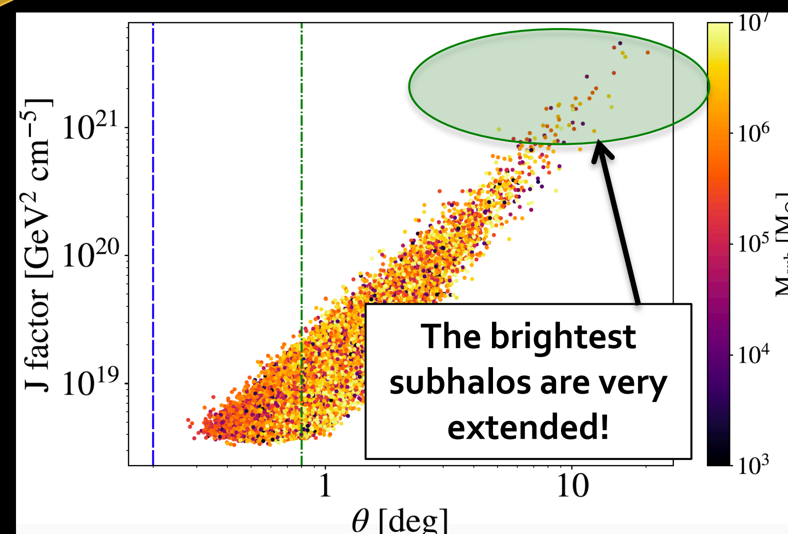






[A. Aguirre-Santaella, MASC, et al., in prep.]





[Coronado-Blázquez, MASC+19] – [Aguirre-Santaella, MASC+, in prep.]

Some OPEN ISSUES on subhalo population

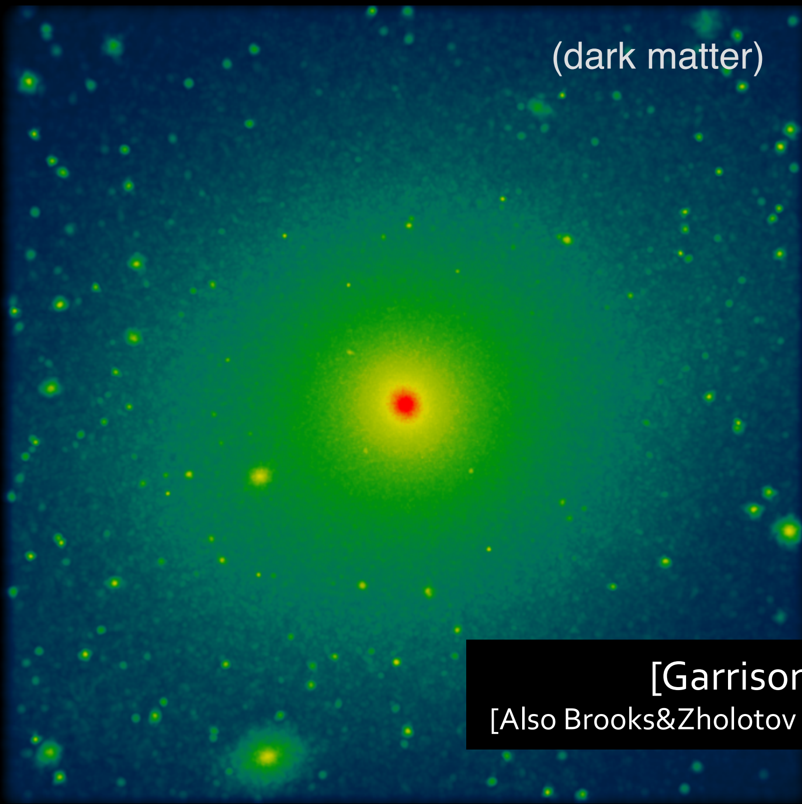
(most relevant for gamma-ray searches)

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

[In particular at Solar Galactocentric radius and for < 10 million solar masses]

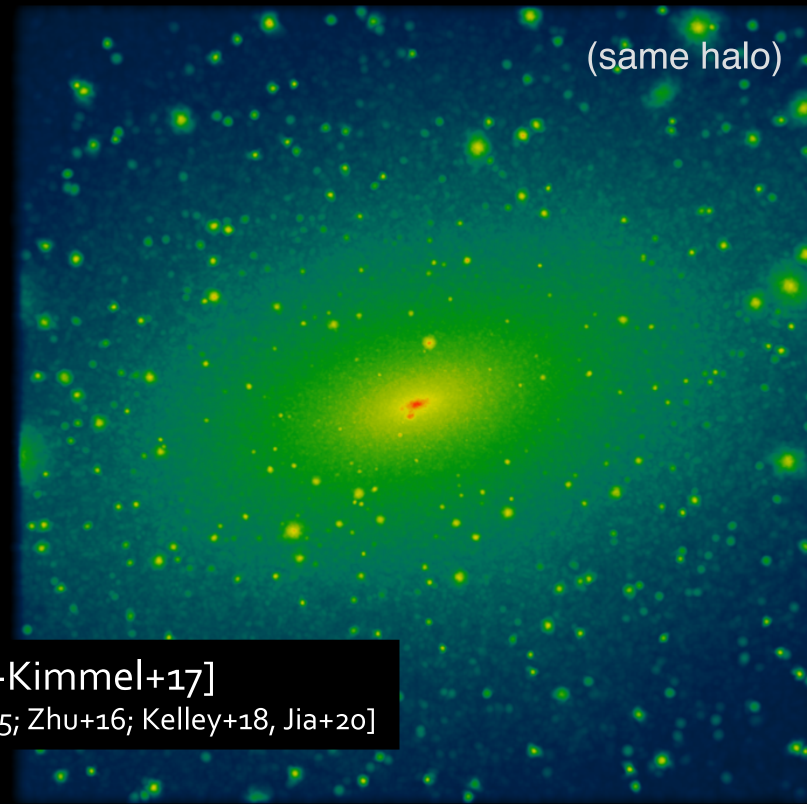
OPEN ISSUES (I): Role of baryons

FIRE Hydrodynamics



100 kpc

Pure N-Body

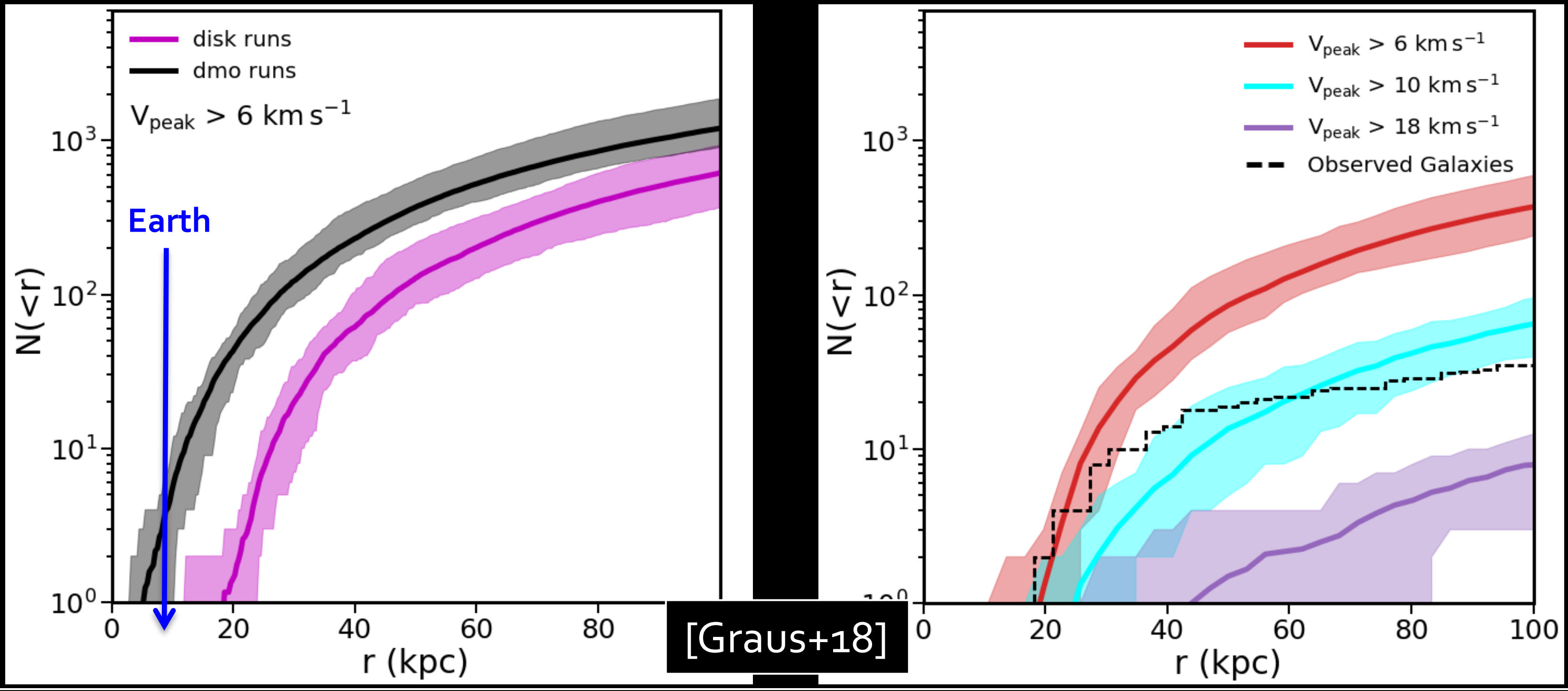


100 kpc

[Garrison-Kimmel+17]
[Also Brooks&Zholotov 15; Zhu+16; Kelley+18, Jia+20]

Up to a factor ~2 reduction in substructure within ~100 kpc
A factor ~10 within ~25 kpc.

OPEN ISSUES (II): Subhalo survival



No substructure within ~20 kpc with V_{max} > 5 km/s.
Yet, radial distribution in hydro simulations do not match observations.

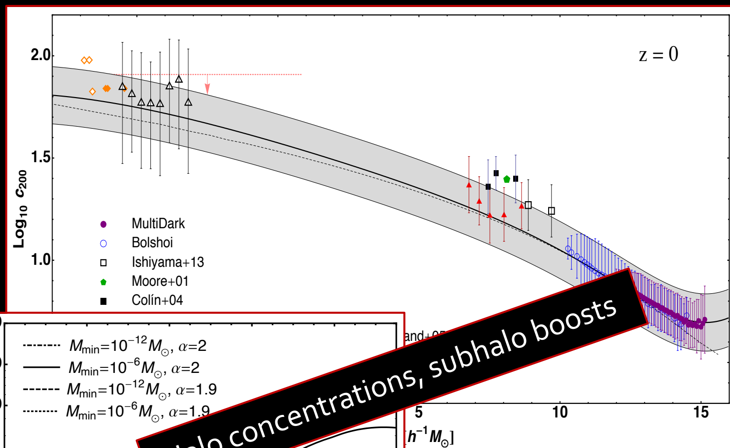
Van den Bosch+18; van den Bosch&Ogiya 18:

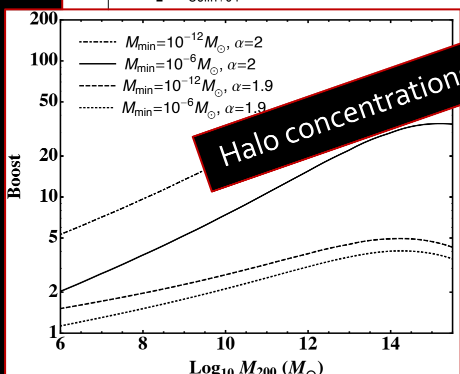
- Subhalo disruption is numerical in origin
- Bound remnant survives provided it is well resolved in the simulation

→ What is the actual subhalo radial distribution?

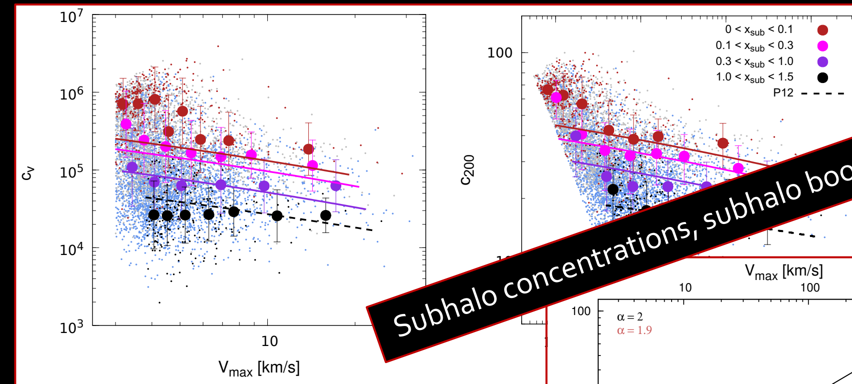
[Also Diemand+07; Peñarrubia+10; Errani&Navarro 20, Webb & Bovy 20]

Already on it…

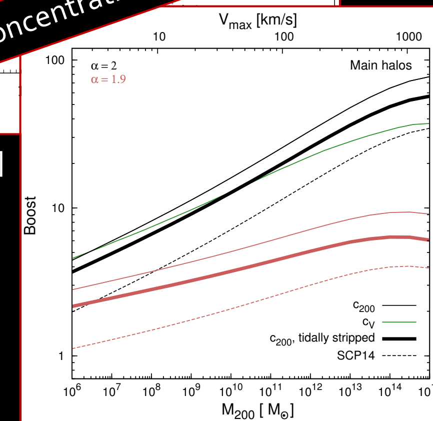




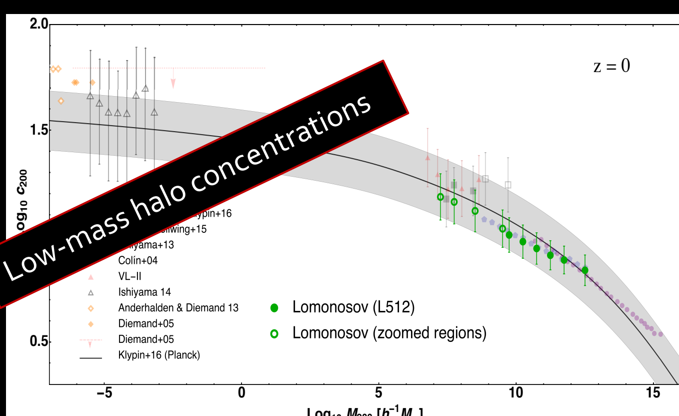
[MASC & Prada 2014]



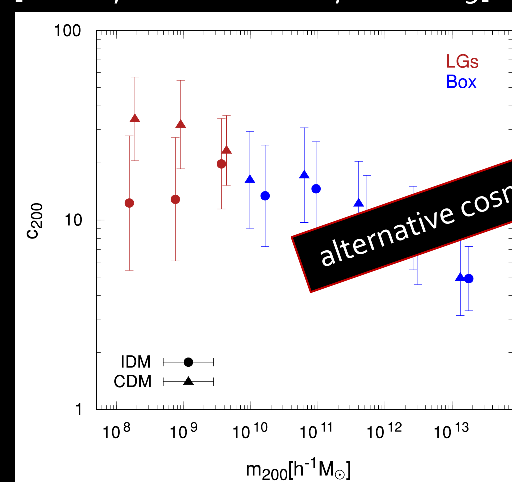
[Moliné, MASC+17]



[Moliné, Schetwschenko, MASC+19]



[Pilipenko, MASC+17]

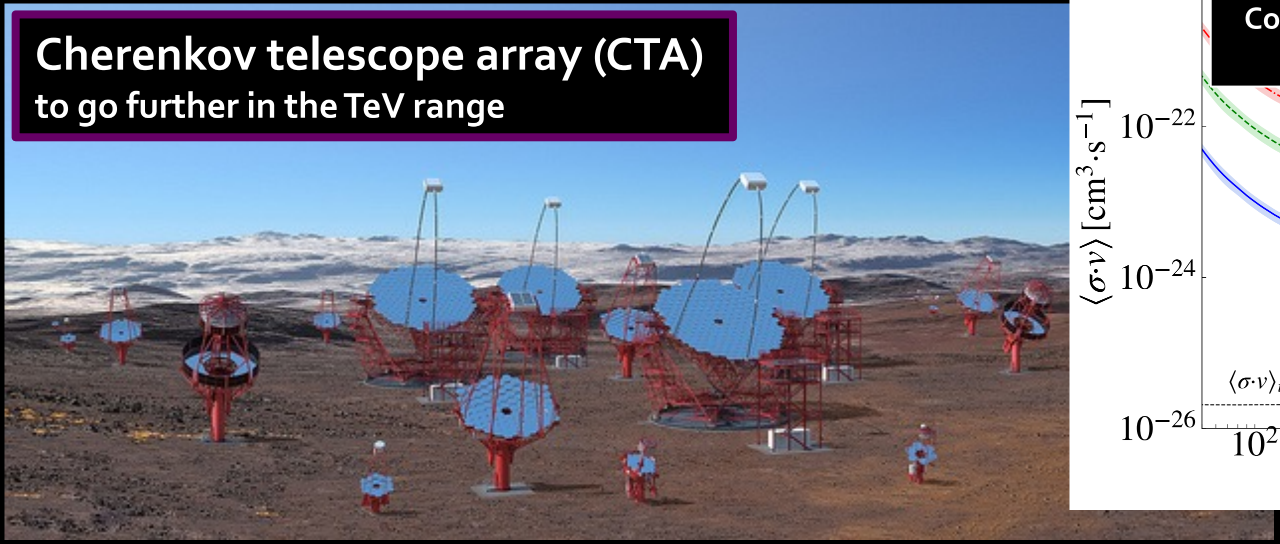


… but further work needed and ongoing

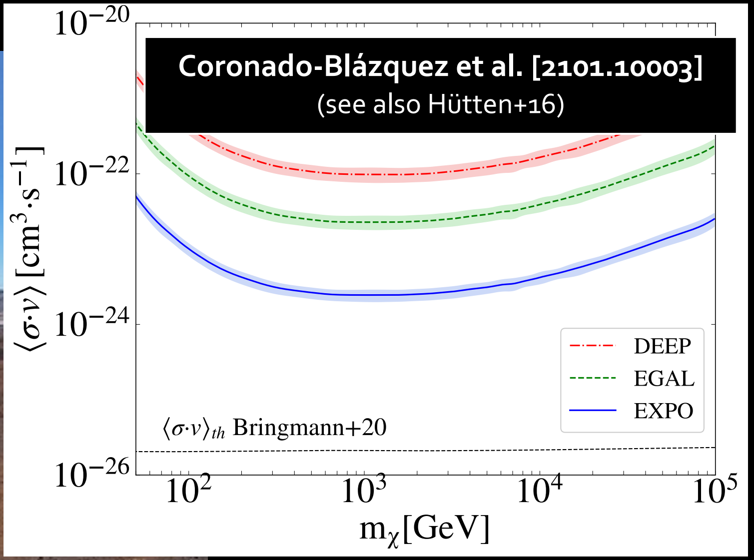
Future

- Dedicated observing proposals at other wavelengths for VIP candidates.
- More refined spectral/spatial unID 'filters' and analyses.
- Search in upcoming gamma-ray catalogs.
- Further numerical work to refine predictions and constraints.
- Use of future gamma-ray facilities (CTA, AMEGO, e-ASTROGRAM…)
- Use of new techniques (e.g., Machine Learning) to disentangle true source type.

Cherenkov telescope array (CTA)
to go further in the TeV range



Coronado-Blázquez et al. [2101.10003]
(see also Hütten+16)



Thanks!

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