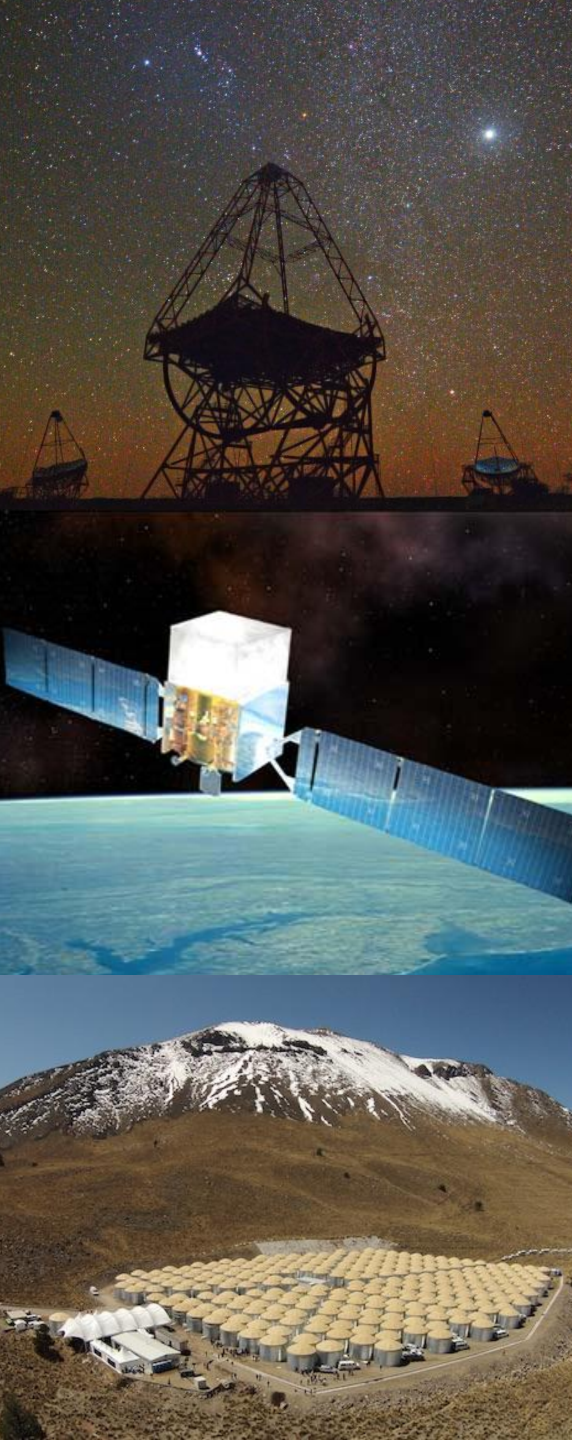


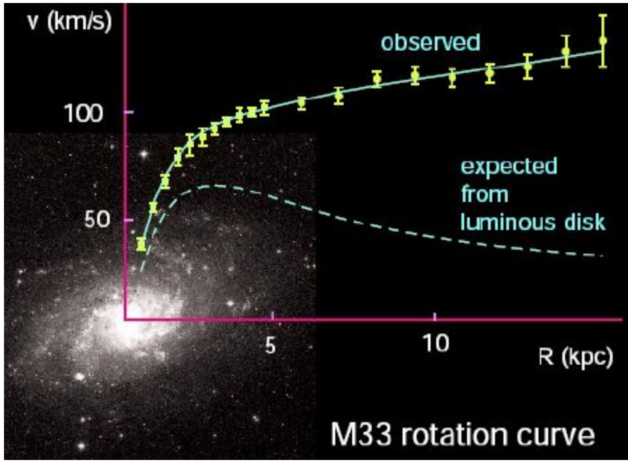
Searching for Dark Matter with Cosmic Gamma rays

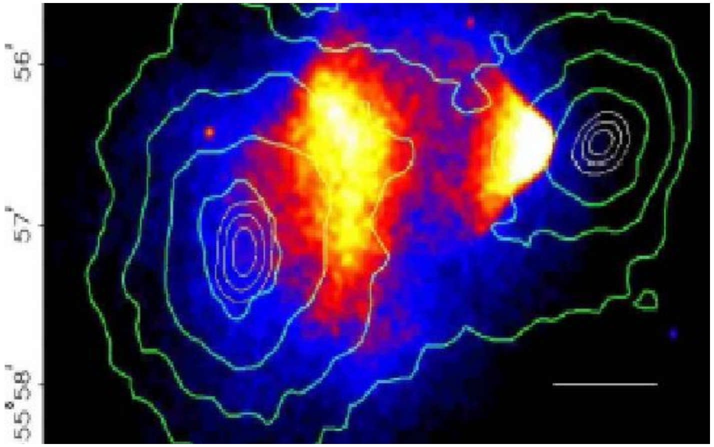
Andrea Albert
Los Alamos National Laboratory

Friday August 14th, 2020
Snowmass CF1 Townhall

Dark Matter Primer

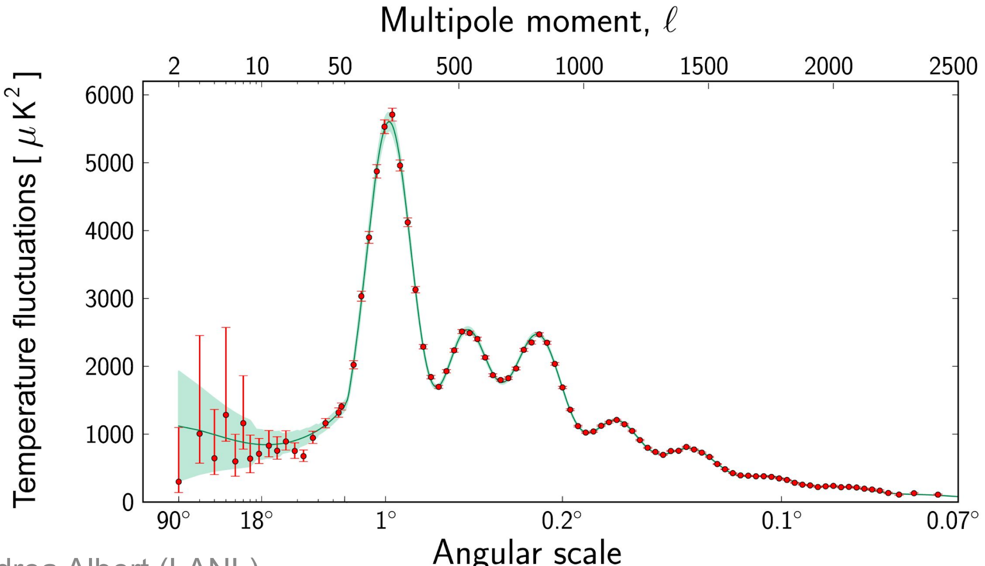
- Galaxies form in Dark Matter *halos* of various sizes, which make up most of their *mass*
  - Coma Cluster + Virial, F. Zwicky (1937)
  - Rotation Curves, V. Rubin et al 1980)





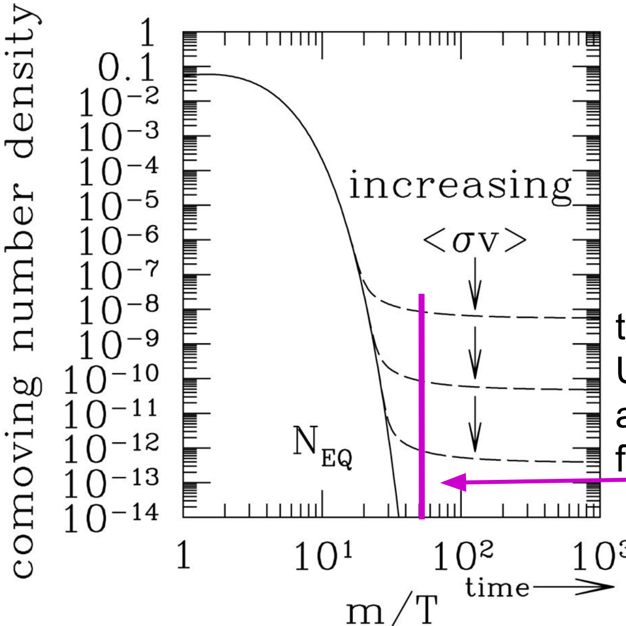
- Dark Matter is virtually *collisionless*
  - The Bullet Cluster, D. Clowe et al (2006)

- Dark Matter is *non-baryonic*
  - CMB acoustic oscillations
  - Big Bang nucleosynthesis



Thermal WIMPs

- **Weakly Interacting Massive Particle (WIMP)**
  - **WIMPs may be thermal relics**
  - **e.g. neutralino (SUSY, electrically neutral, stable)**
- **Assuming a weak scale σ_{ann} at freeze yields observed relic abundance**
  - **$\langle\sigma v\rangle_{ann} \sim 3\times10^{-26}$ cm^3/s**

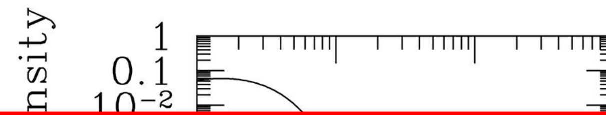


E. Kolb and M. Turner, *The Early Universe*, Westview Press (1994)

- **Thermal WIMPs predicting the correct relic abundance makes them a very promising model to test!**
- **Thermal WIMP mass limit ~100 TeV (unitarity bound)**

Thermal WIMPs

- Weakly Interacting Massive Particle (WIMP)
  - W
  - e.g
    ne
- Assu
  yields
  - <σ



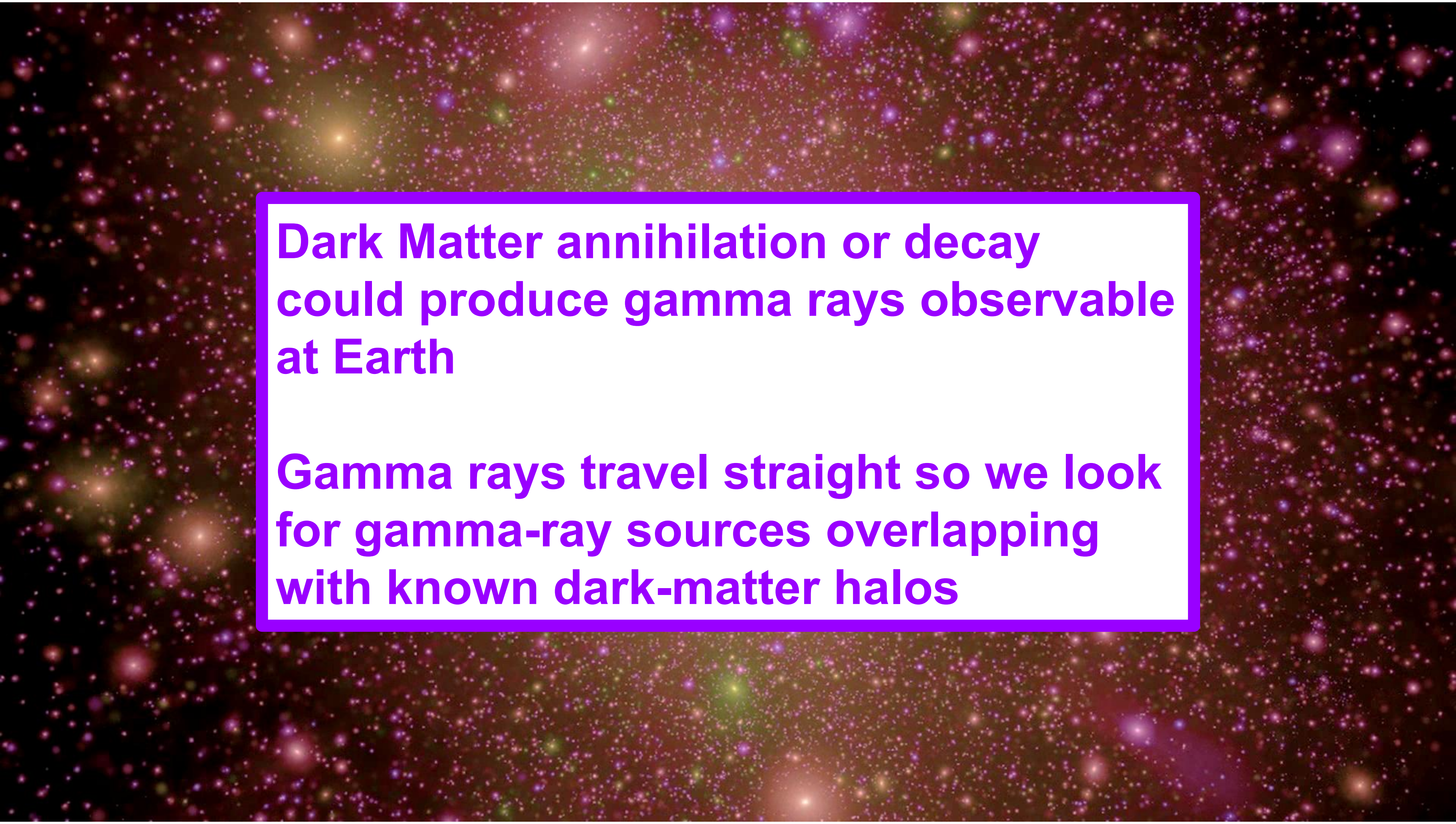
I focus on thermal WIMPs, but there are several other dark matter candidates you can probe with cosmic gamma rays

- Axions and Axion Like Particles
- Sterile Neutrinos
- Primordial black holes
- Gravitinos
- etc

e in early
iverse when
ount of DM
ezes out

rner, *The Early*
w Press (1994)

Gamma rays from DM



Dark Matter annihilation or decay could produce gamma rays observable at Earth

Gamma rays travel straight so we look for gamma-ray sources overlapping with known dark-matter halos

Aquarius Simulation (Springel et al 2008)

WIMP Dark Matter Targets

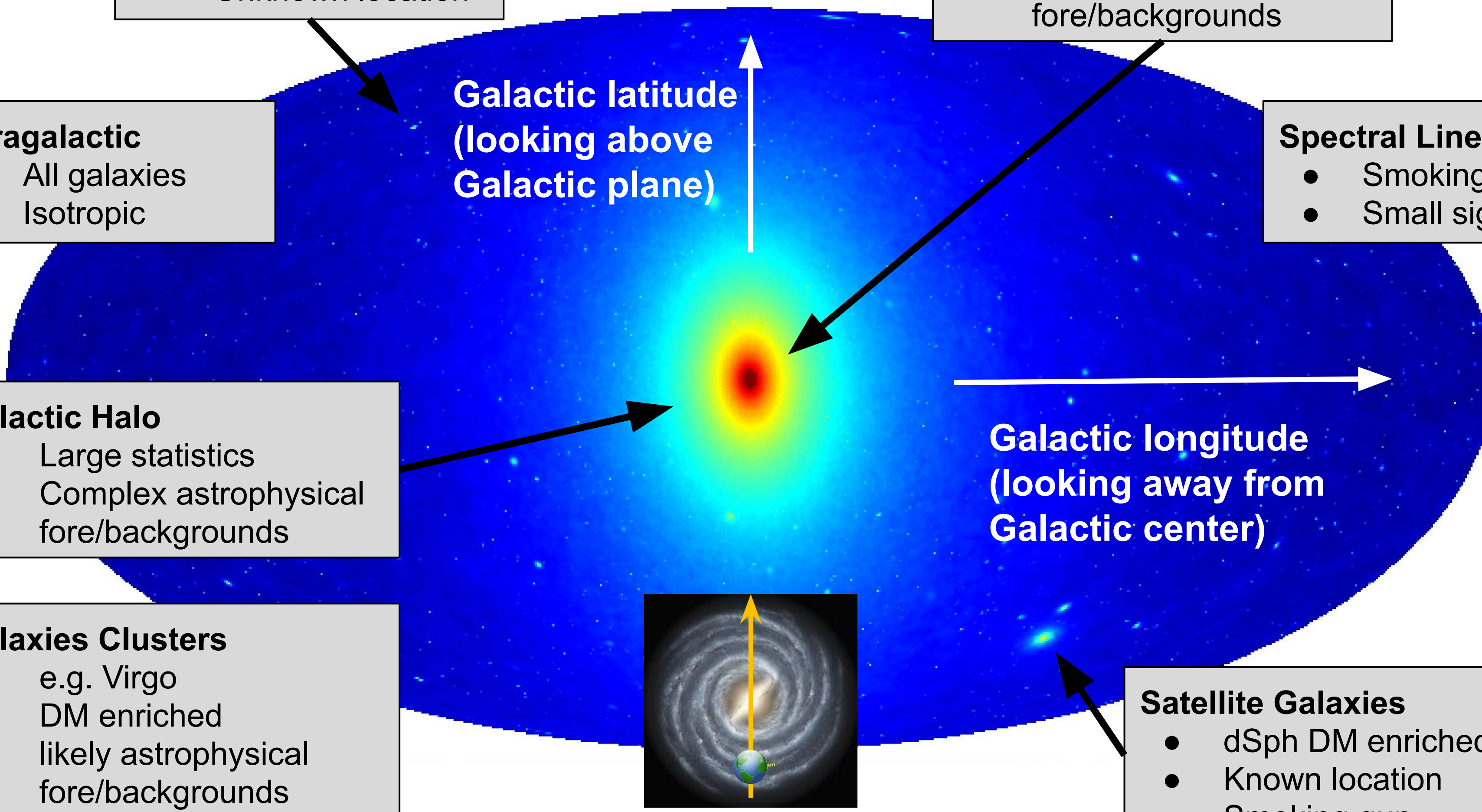
Los Alamos NATIONAL LABORATORY EST. 1943

DM clumps in Halo
- Few backgrounds
- Unknown location

Galactic Center
- Large statistics
- Complex astrophysical fore/backgrounds

Extragalactic
- All galaxies
- Isotropic

Spectral Lines
- Smoking gun
- Small signal



Galactic Halo
- Large statistics
- Complex astrophysical fore/backgrounds

Galaxies Clusters
- e.g. Virgo
- DM enriched
- likely astrophysical fore/backgrounds

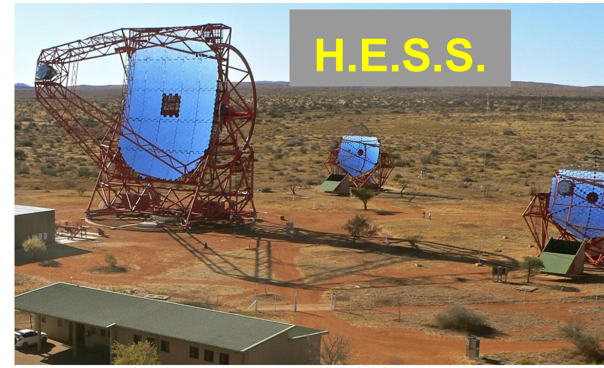
Satellite Galaxies
- dSph DM enriched
- Known location
- Smoking gun

Aquarius (A1) simulation

Current Gamma-ray Observatories

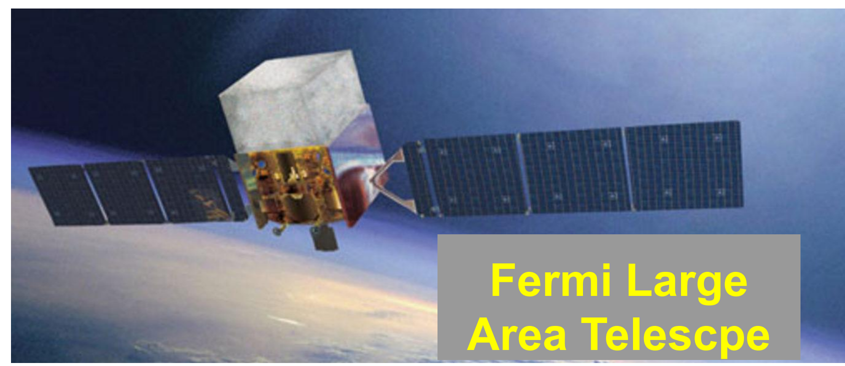
Tucson, Arizona
31° North Latitude, ~5° f.o.v.
~85 GeV -- ~50 TeV

La Palma, Canary Islands
29° North Latitude, ~5° f.o.v.
~30 GeV -- ~30 TeV



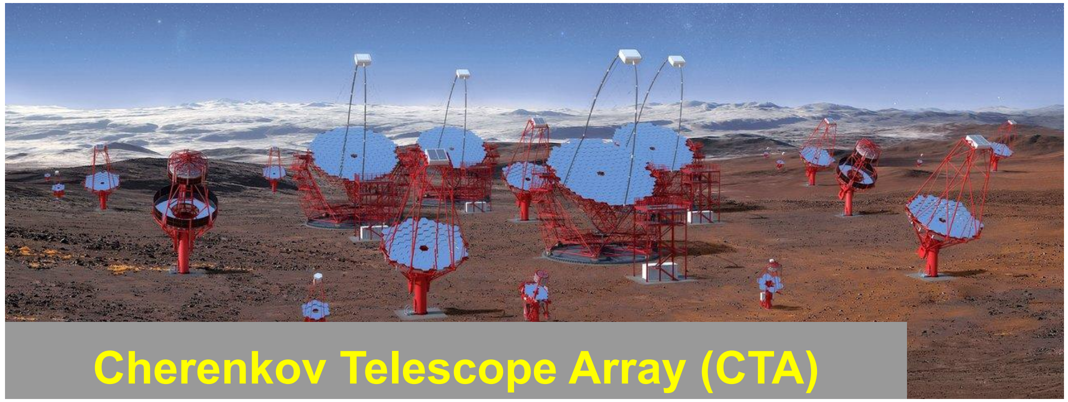
Khomas Highland of Namibia
23° South Latitude, ~5° f.o.v.
~30 GeV -- ~100 TeV

Parque Nacional Pico de Orizaba, México
19° North Latitude, ~2 sr f.o.v.
~50 GeV -- ~100 TeV, 100% Duty Cycle



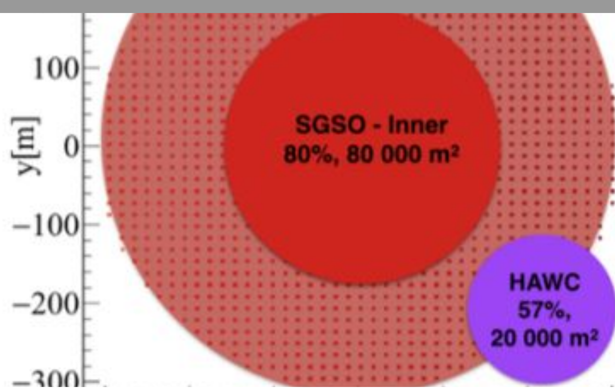
Low earth orbit (565 km)
28.5° orbital inclination, ~2 sr f.o.v.
20 MeV -- > 300 GeV, 100% Duty Cycle
(AGILE has similar technology, but has limited energy resolution)

Partially Built and Future Gamma-ray Observatories



Northern Array: La Palma 29° N Latitude | Southern Array: Paranal Chili 24.6° South Latitude
~10° f.o.v. | ~50 GeV -- ~200 TeV

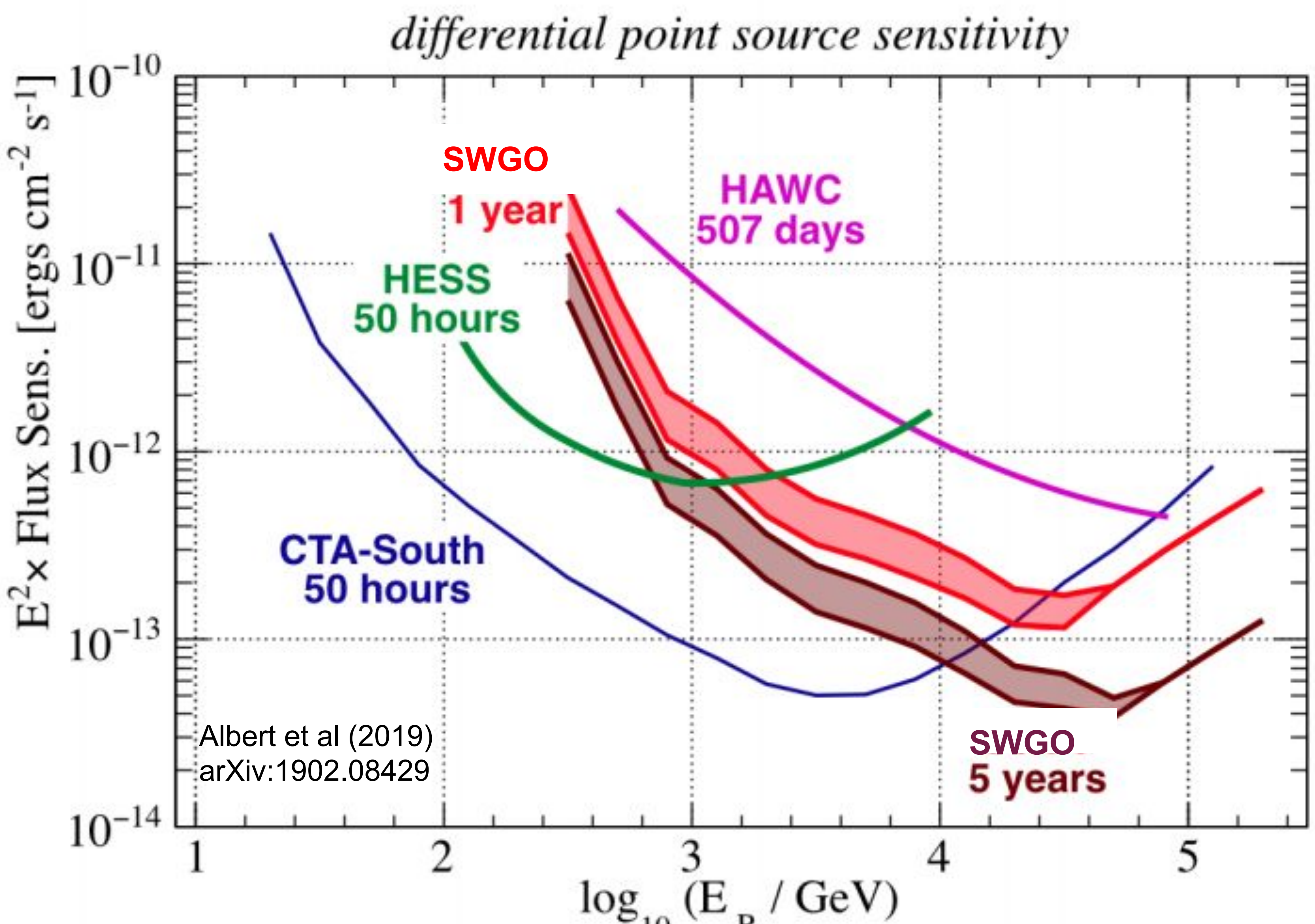
Southern Wide Field of View Gamma Ray Observatory (SWGO)



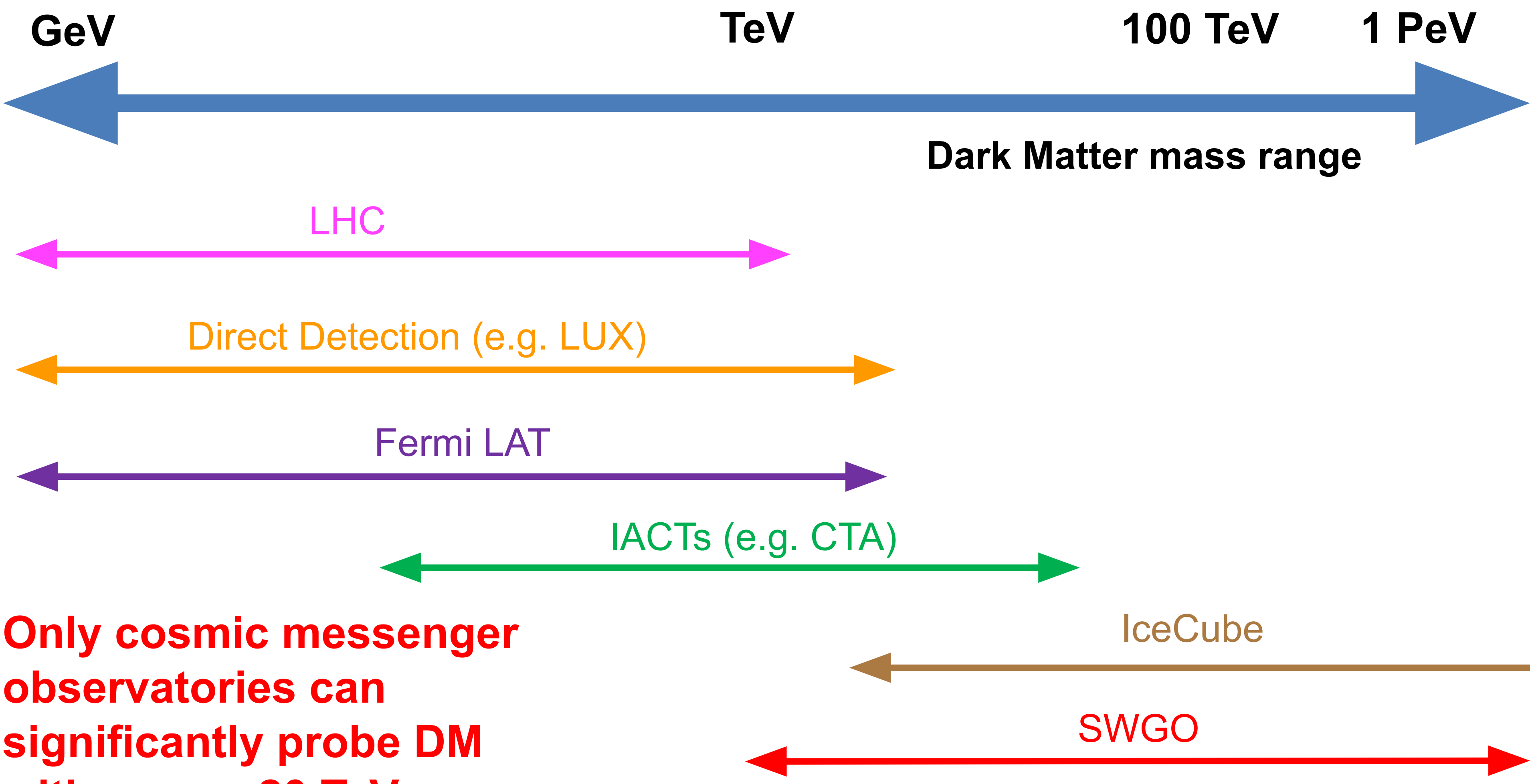
Location TBD (Southern Hemisphere)
~20° South Latitude, ~2 sr f.o.v.
~500 GeV -- ~500 TeV, 100% Duty Cycle

Low earth orbit (565 km)
28.5° orbital inclination, ~2 sr f.o.v.
Daocheng, China
~28° Northern Latitude, ~2 sr f.o.v.
30 GeV -- 1 PeV, 100% Duty Cycle

Gamma-ray Observatory Sensitivities

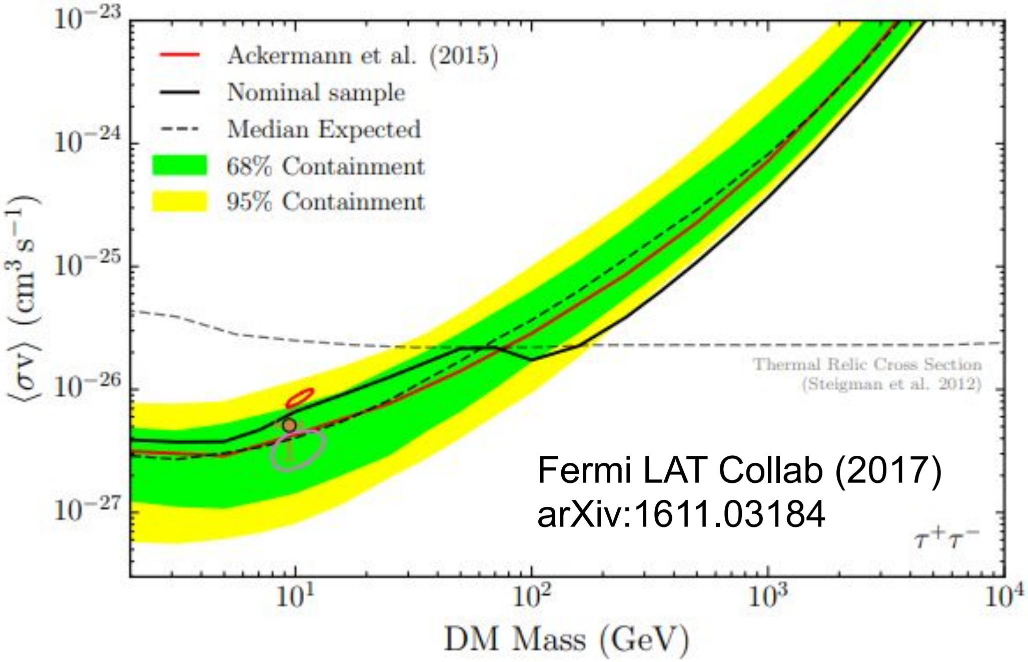


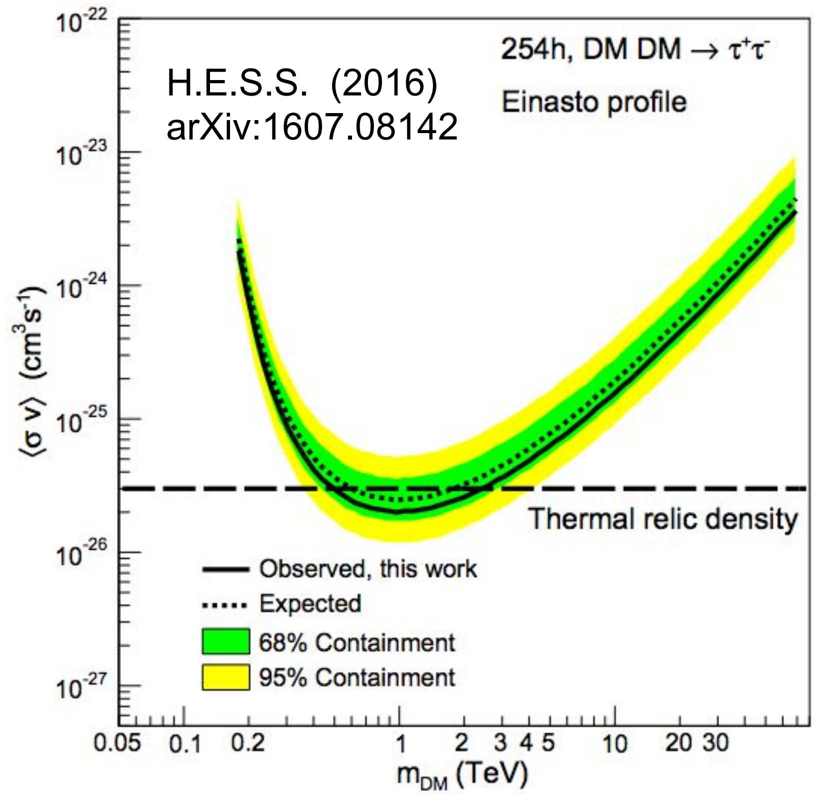
Complementarity of Dark Matter Masses



Only cosmic messenger observatories can significantly probe DM with mass >20 TeV

Current WIMP Limits

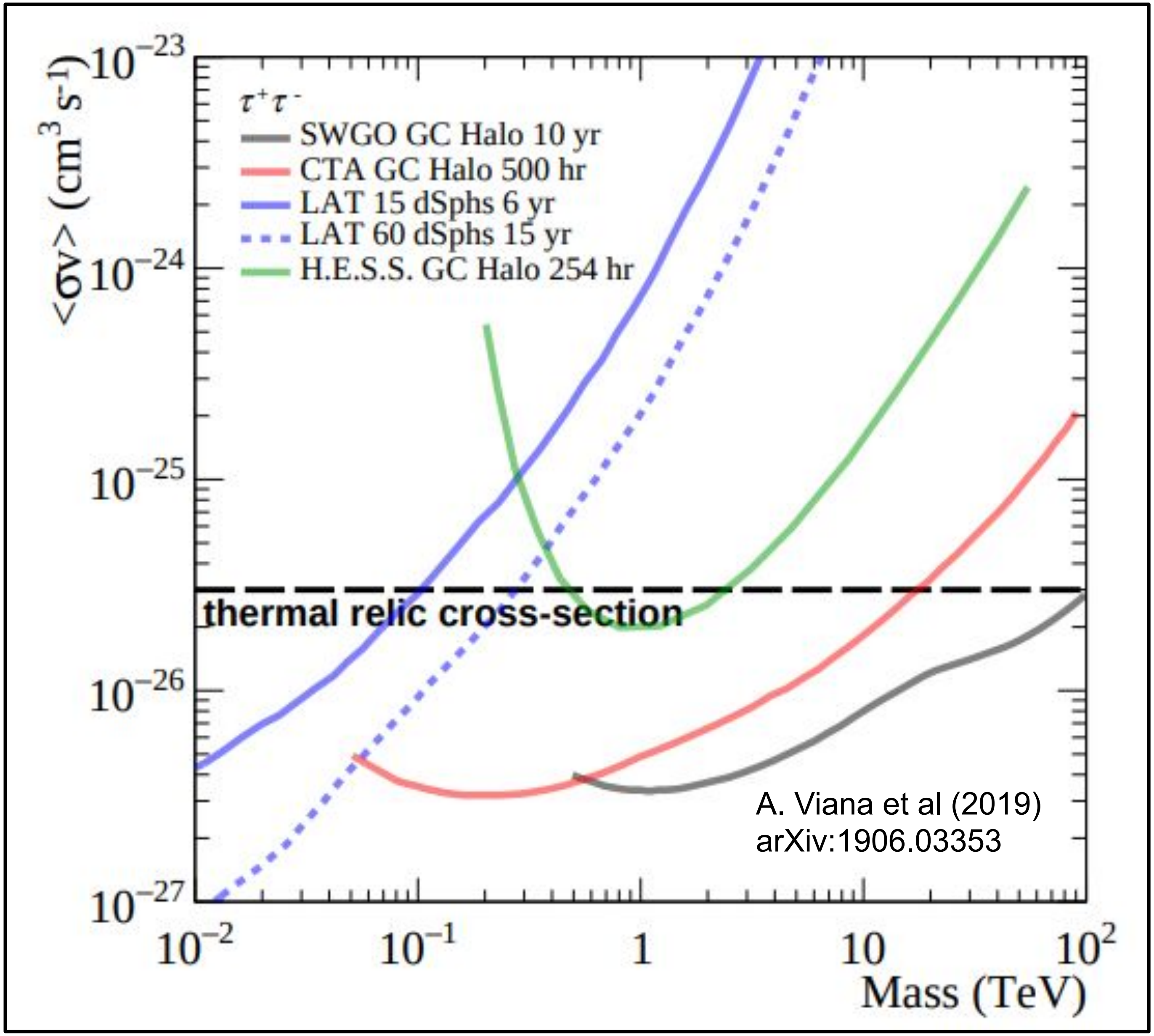




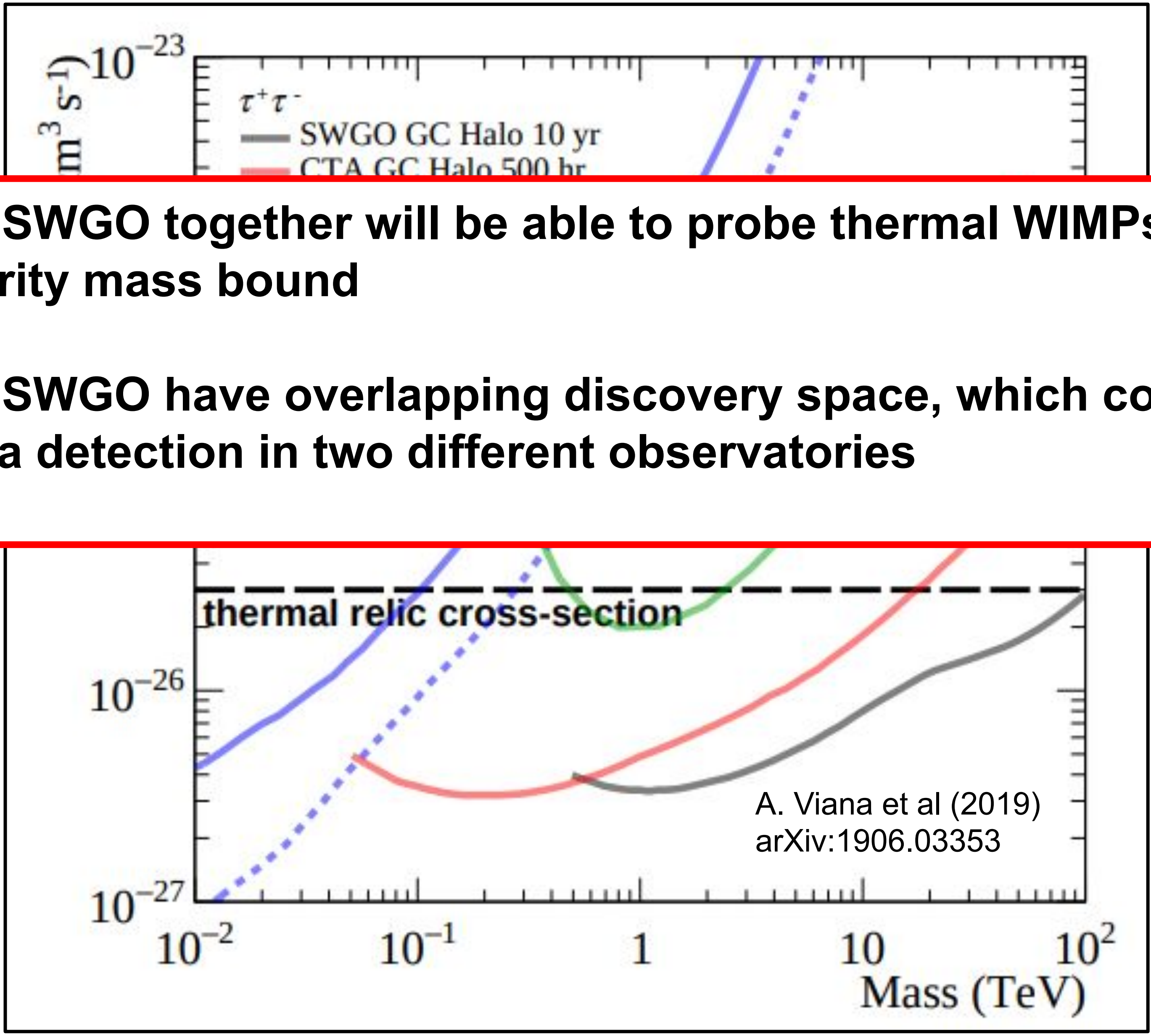
Fermi LAT limits exclude thermal WIMPs for m < 100 GeV
H.E.S.S. Galactic Center limits exclude thermal WIMPs ~few TeV

WIMPs are not dead!

Future DM Sensitivity



Future DM Sensitivity



CTA and SWGO together will be able to probe thermal WIMPs up to the unitarity mass bound

CTA and SWGO have overlapping discovery space, which could result in a detection in two different observatories

Summary

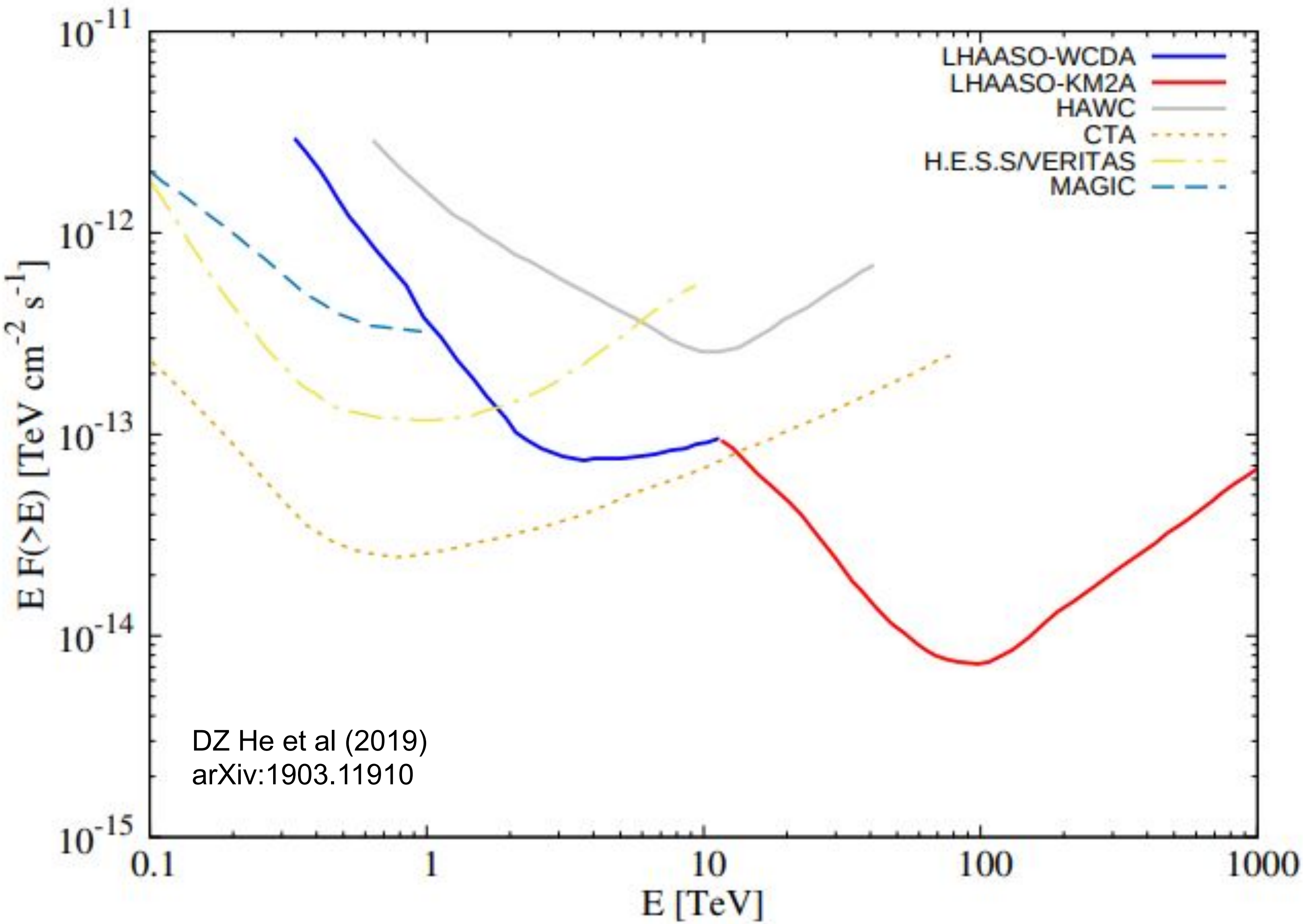
- **Gamma rays are a unique and important probe for particle DM**
  - **Direct pointing allows us to focus on many dark matter rich targets**

- **Current and future gamma-ray observatories give a network on complementary instruments that can perform focused/deep observations as well as all sky surveys**

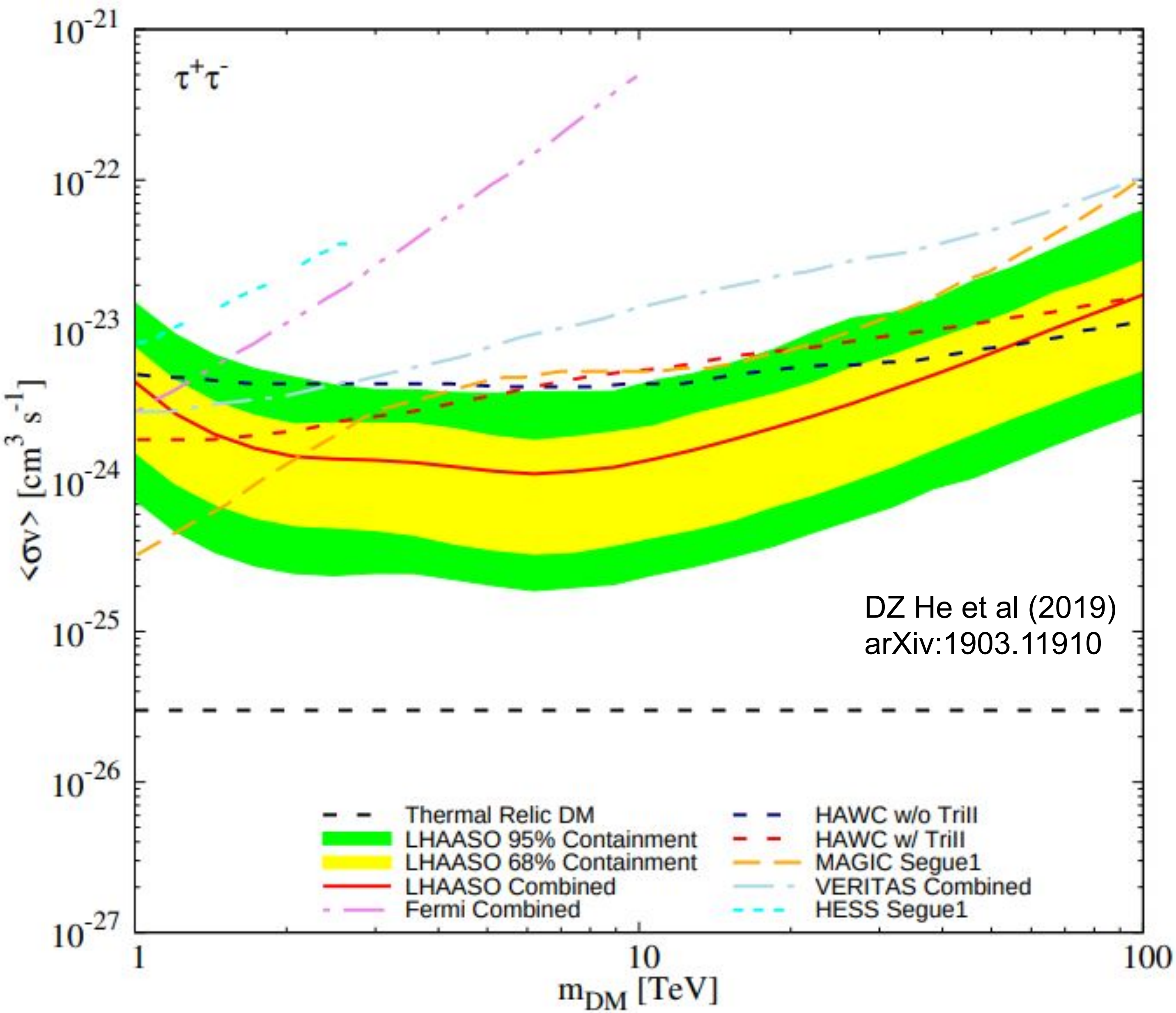
- **WIMPs are not dead!**
  - **Current limits exclude thermal WIMPs only for <100 GeV and ~1 TeV**
  - **Only astrophysical observatories can significantly probe WIMP dark matter above ~20 TeV in mass**

- **Future observatories have the opportunity to search for thermal WIMPs up to ~100 TeV in mass**

LHAASO Sensitivity



LHAASO Expected Dwarf Limits



CTA Galactic Halo Expected Limits

CTA Consort. (2020)
arXiv:2007.16129

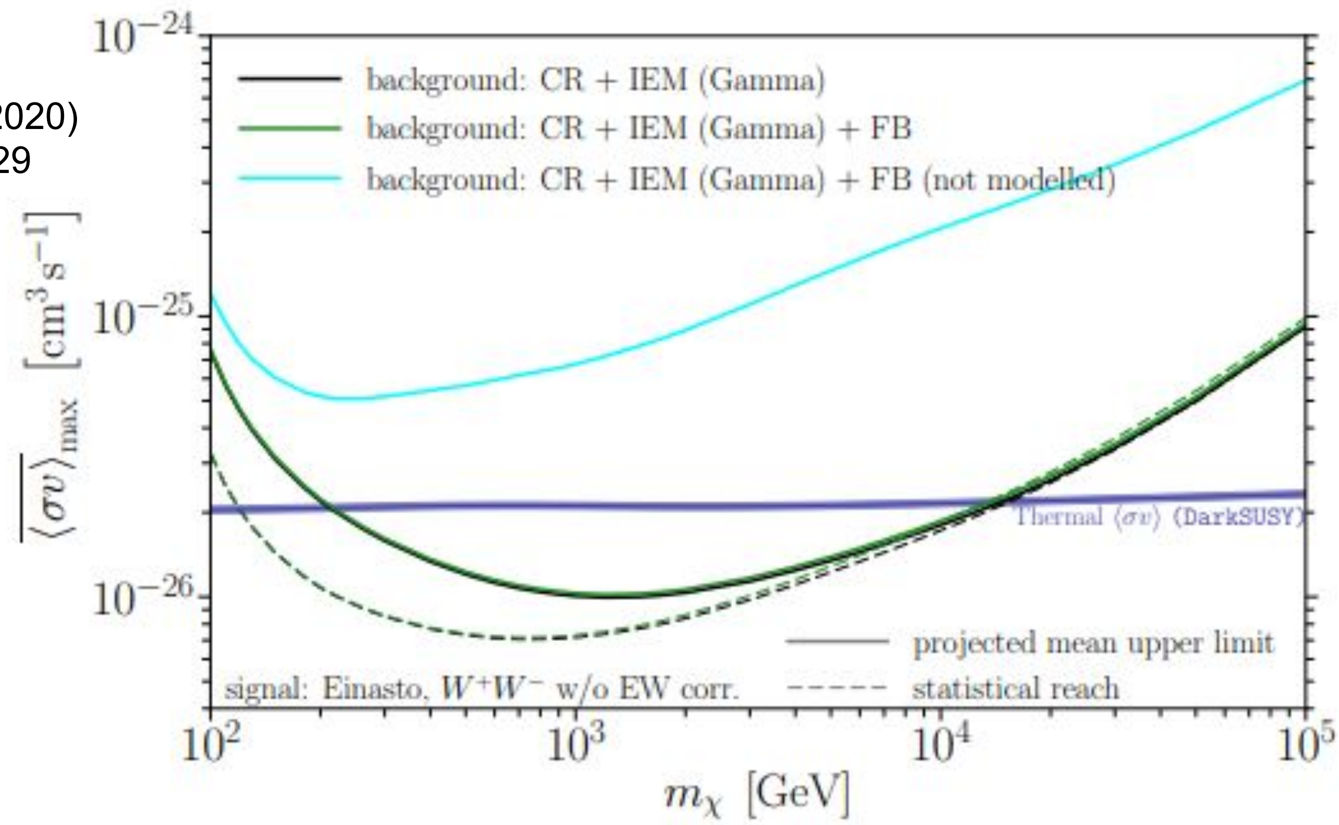
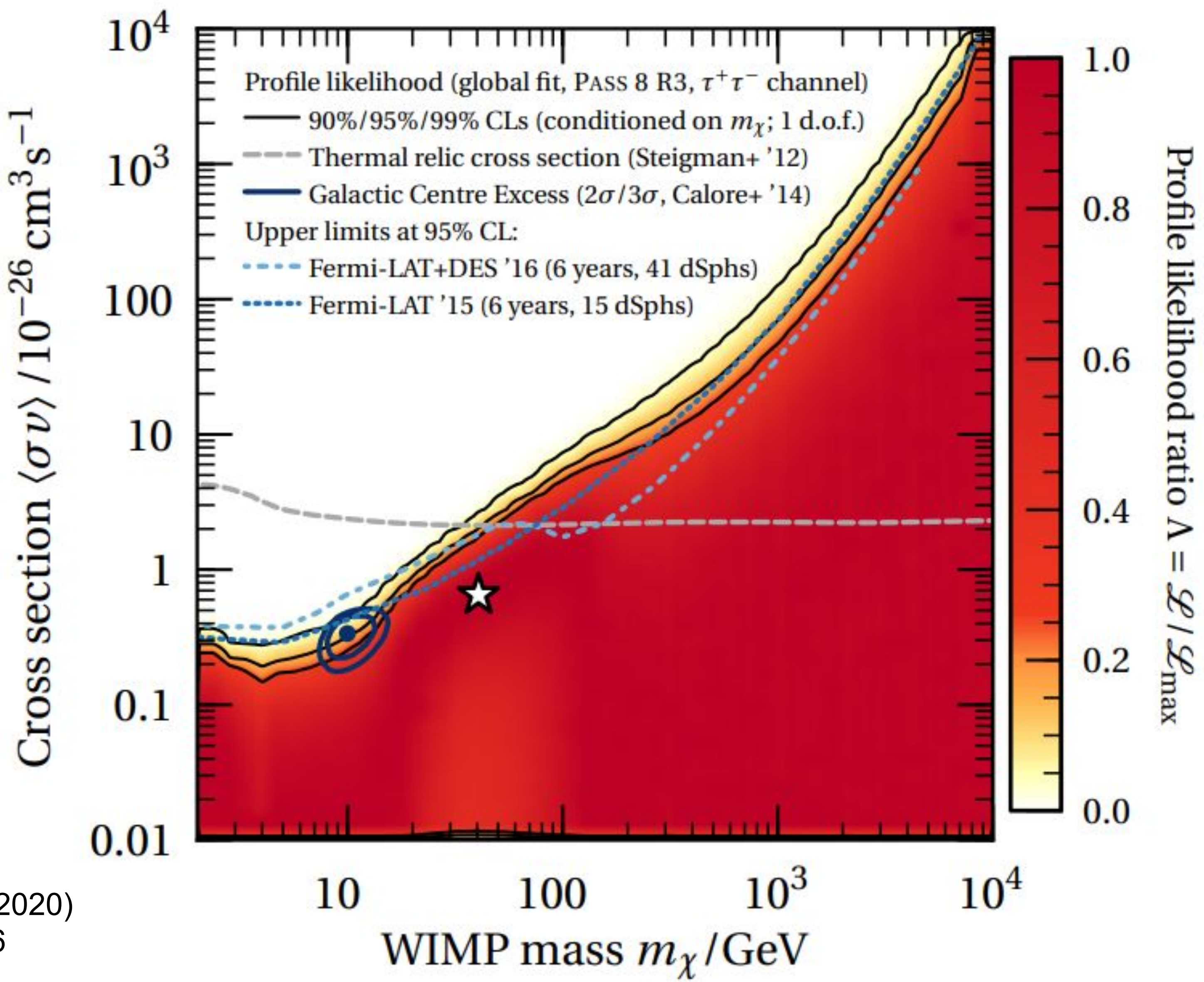


Figure 13: CTA sensitivity to a DM signal for our standard analysis settings (black solid line, as in Fig. 5), after adding an FB template (green solid line, largely overlapping with the black solid line) and the result of an analysis where the FB emission is present in the mock data, but not accounted for in the fitting procedure (cyan solid line). Dashed lines show the 'statistical' reach (neglecting systematic uncertainties in the spatial templates) for the former two cases.

Fermi LAT Limits with 11 yrs and 27 dSphs



Hoof et al (2020)
1812.06986