The Dark Matter discovery potential of the Cherenkov Telescope Array

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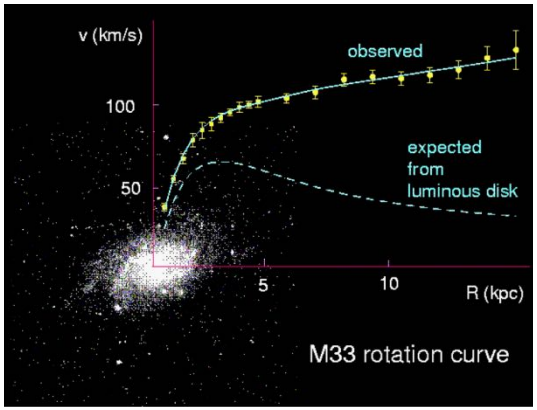
Sexten 2017 Gamma-ray Astrophysics with CTA, Sexten 24-29 July 2017

Dark Matter EVIDENCE

In 1933, the astronomer Zwicky realized that the mass of the luminous matter in the Coma cluster was much smaller than its total mass implied by the motion of cluster member galaxies.

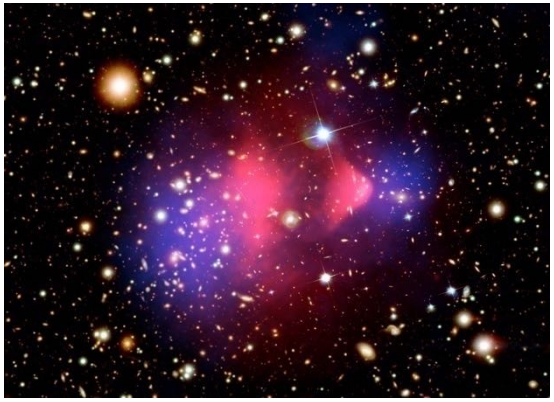
Since then, even more evidence:

Rotation curves of galaxies

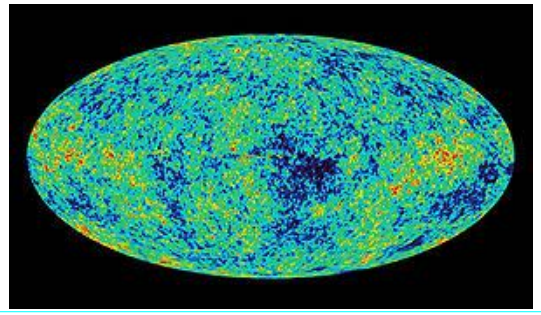


Gravitational lensing

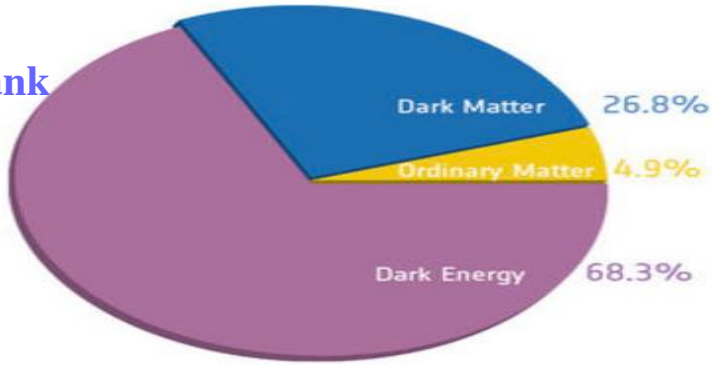
Bullet cluster



Structure formation as deduced from CMB



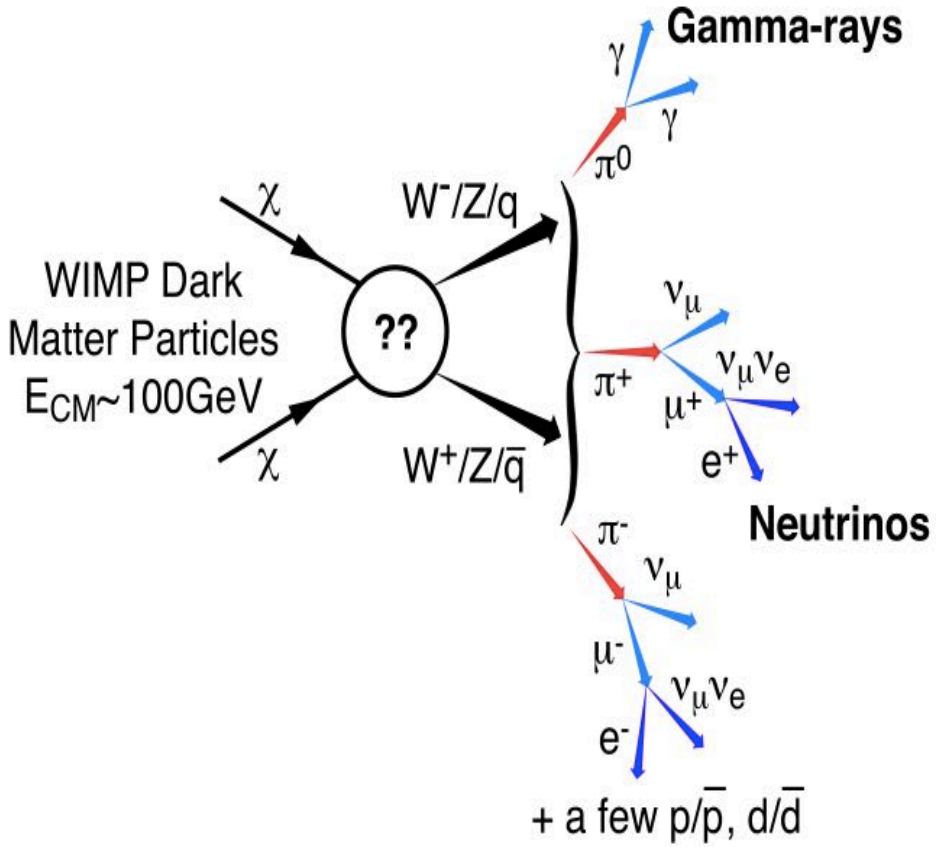
Data by Plank imply:

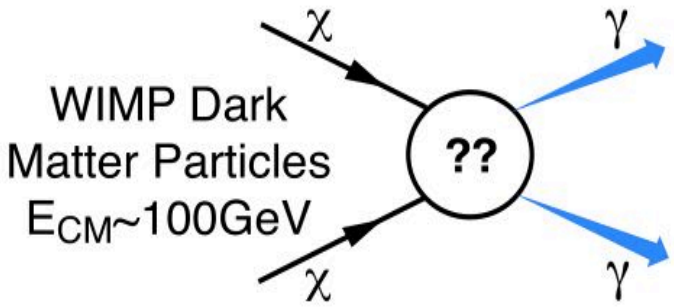


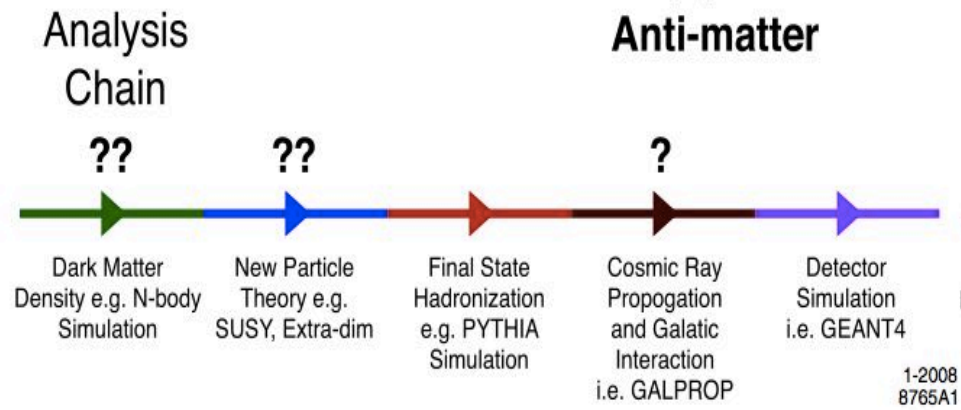
$\Omega_{Dm} \approx 26.8\%$

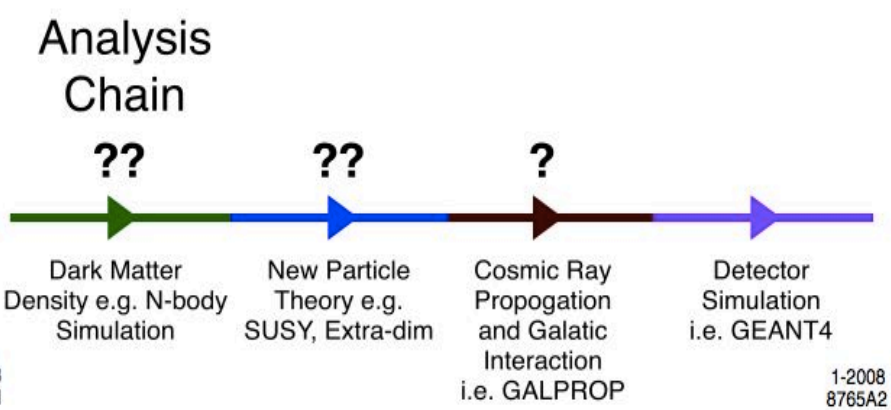
$\Omega_{M} \approx 4.9\%$

Annihilation channels









Dark Matter Search: Targets and Strategies

Satellites

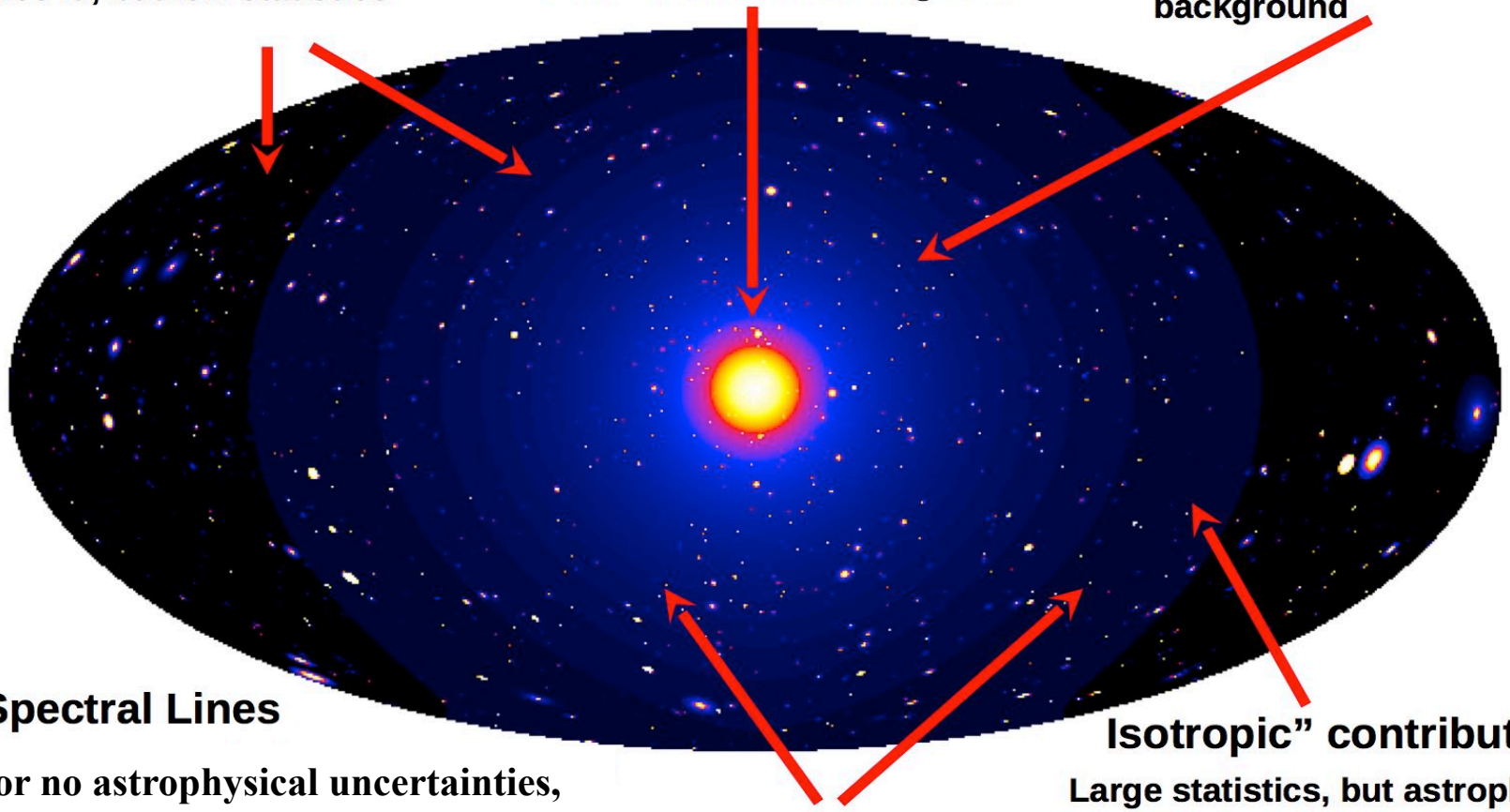
Low background and good source id, but low statistics

Galactic Center

Good Statistics, but source confusion/diffuse background

Milky Way Halo

Large statistics, but diffuse background



Spectral Lines

Little or no astrophysical uncertainties, but low sensitivity because of expected small branching ratio

Isotropic" contributions

Large statistics, but astrophysics, galactic diffuse background

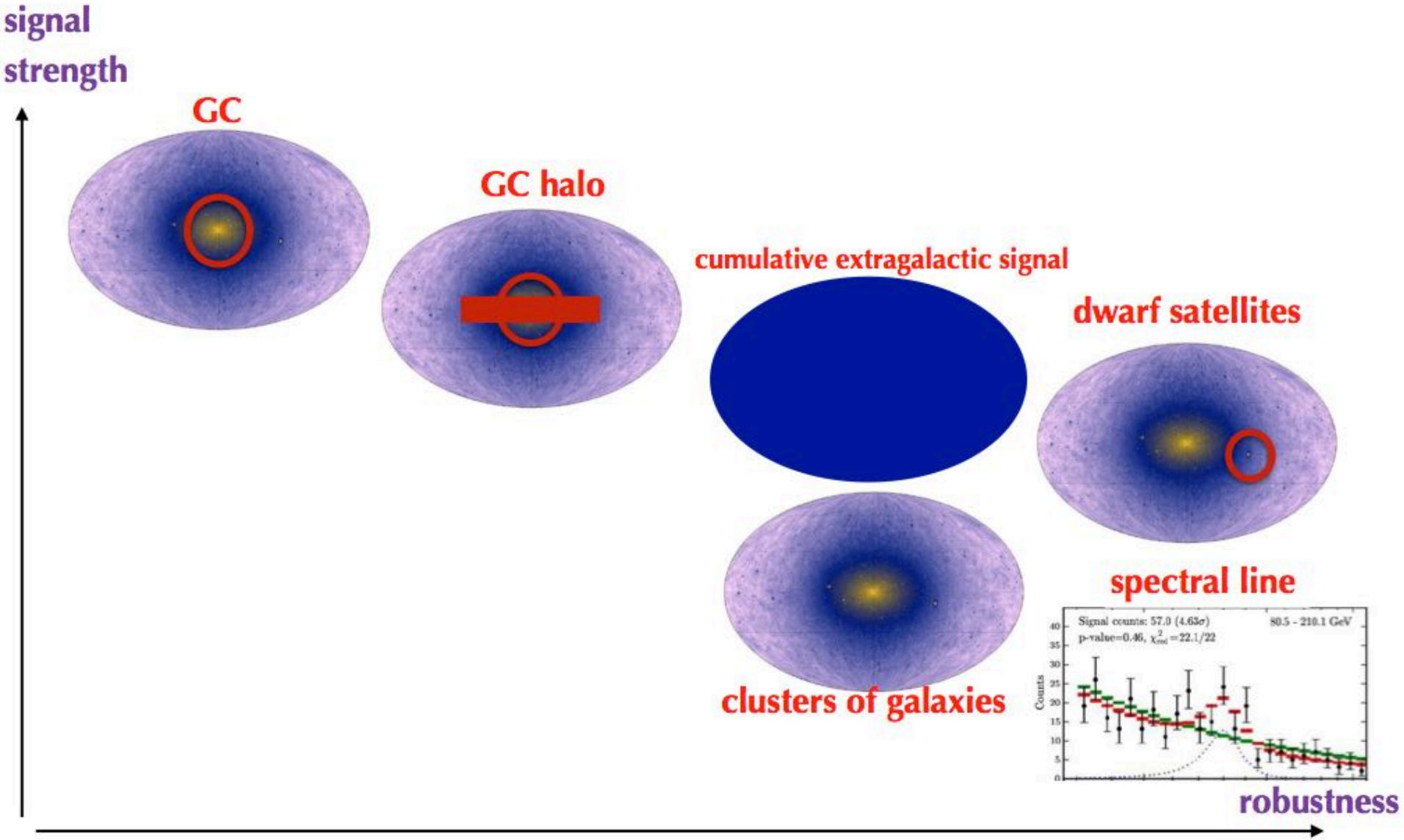
Galaxy Clusters

Low background, but low statistics

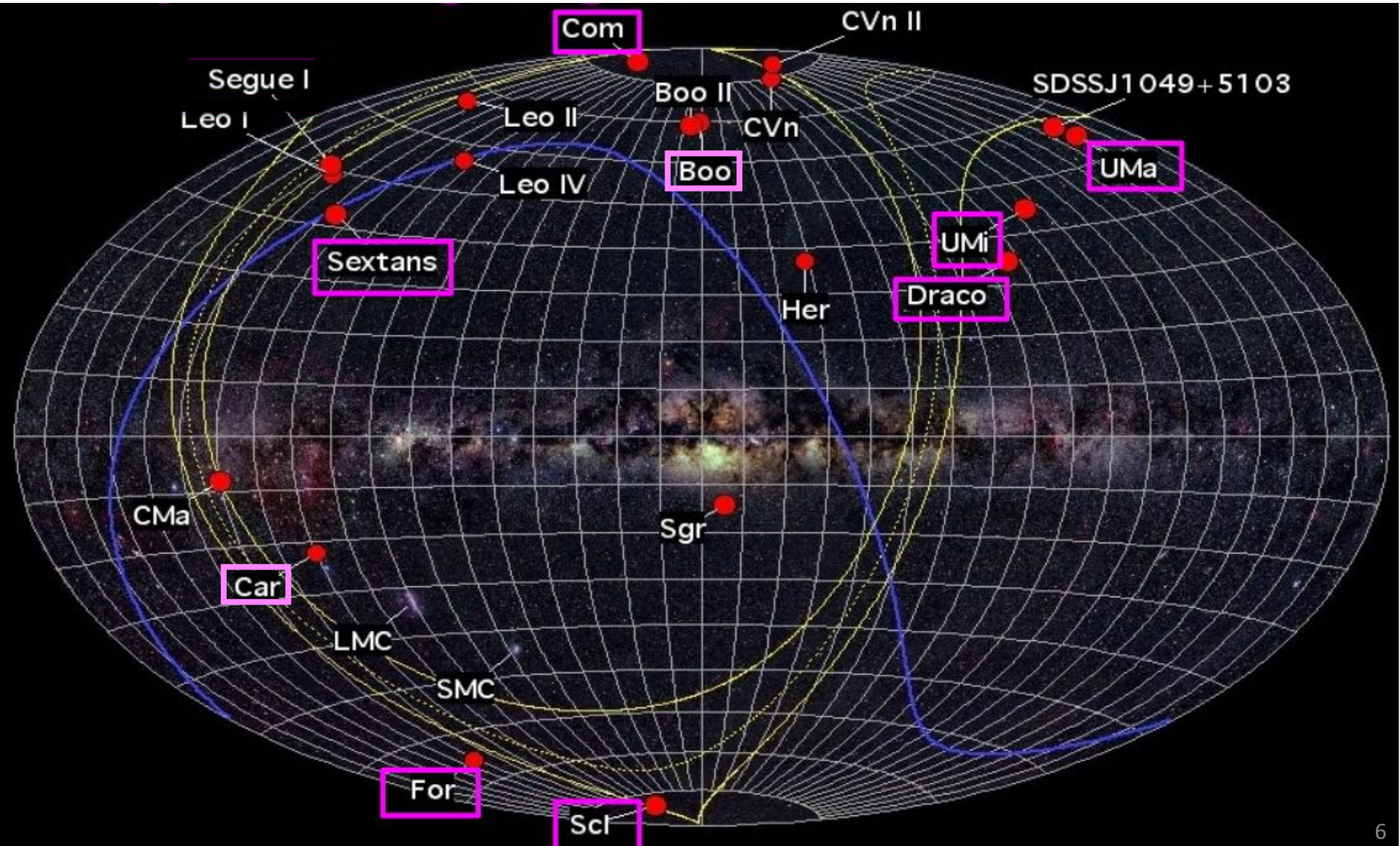
Dark Matter simulation: Pieri+(2009) arXiv:0908.0195

Dark Matter Search: Targets and Strategies

(Another way to see it)



Classical Dwarf spheroidal galaxies: promising targets for DM detection



Dark Matter in the Milky Way (from simulations)

Springel et al. (Nature, 2005)

2015: New DES Dwarf Spheroidal Galaxies Candidates

The Washington Post

Speaking of Science

Nine new dwarf galaxies full of dark matter found just chilling around the Milky Way

By Rachel Feltman March 10

For the first time in a decade, astronomers have found new dwarf galaxies -- ones with just billions of stars or even less compared with the hundreds of billions in our own -- orbiting the Milky Way. And they've found *nine* of them. That's the most that have ever turned up at once. The findings were published Tuesday in the Astrophysical Journal.

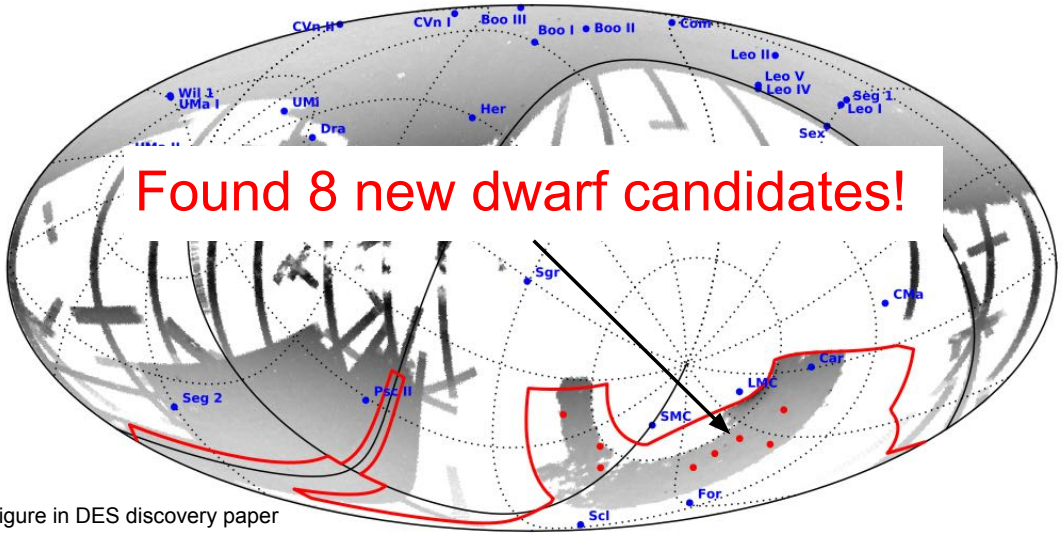


figure in DES discovery paper

LAT Collaboration – DES Collaboration agreement – Feb 2015

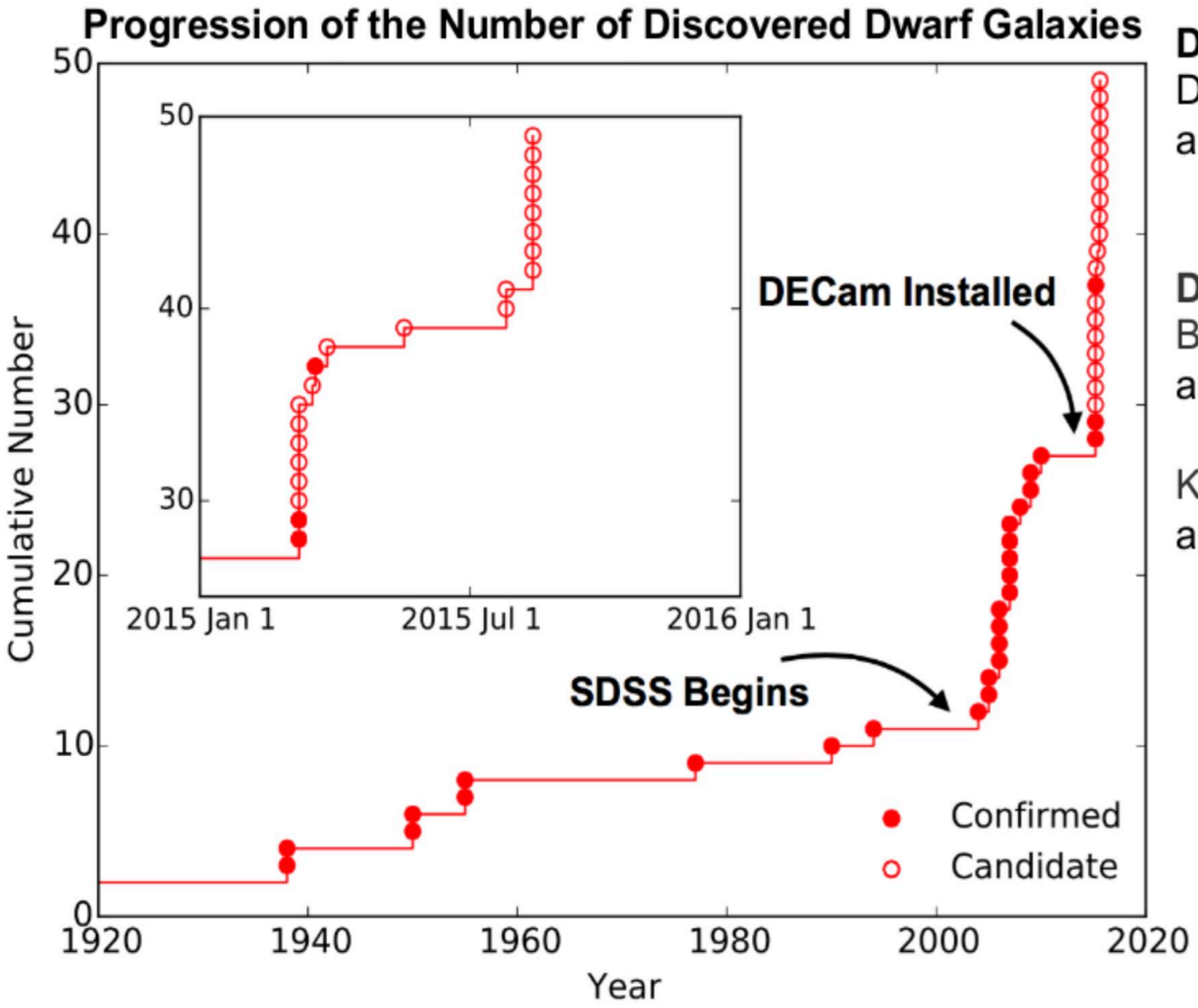
- first joint paper "Search for Gamma-Ray Emission from DES Dwarf Spheroidal Galaxy Candidates with Fermi-LAT Data" ApJL 2015, 809,L4,arXiv:1503.02632

  • analysis of observations of 8 new Dwarf Spheroidal Galaxies found by DES:

  Bechtol, et al. arXiv:1503.02584

  also found by Koposov, et al. arXiv:1503.02079

Dwarf Spheroidal Galaxies: Growing number of known targets



DES Year 2 Data:
Drlica-Wagner+,
arXiv:1508.03622

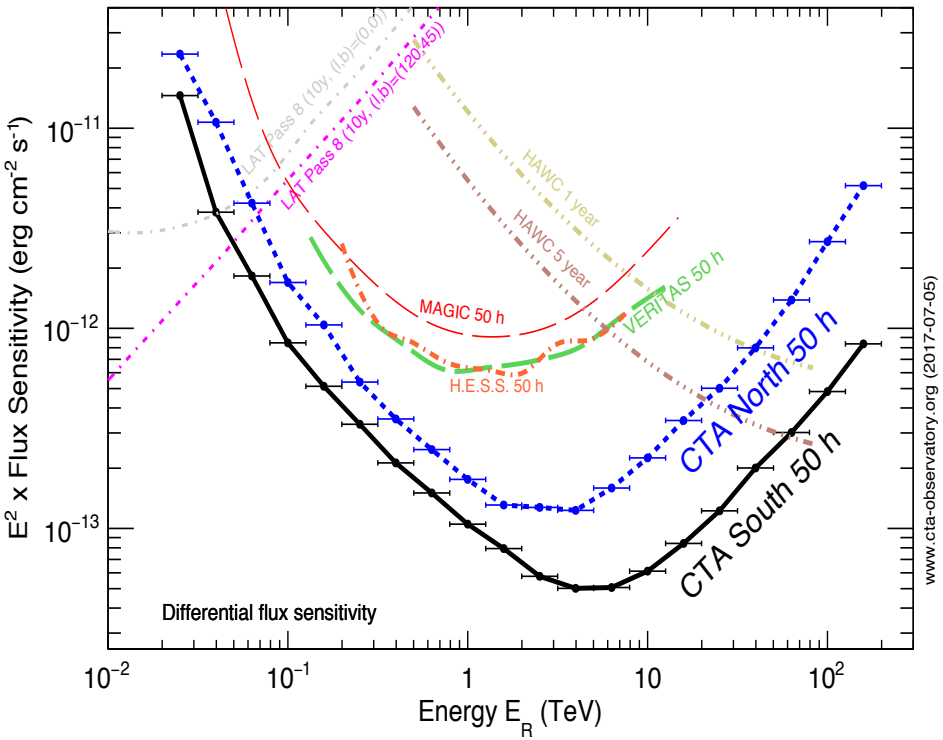
DES Year 1 Data:
Bechtol+:
arXiv:1503.02584

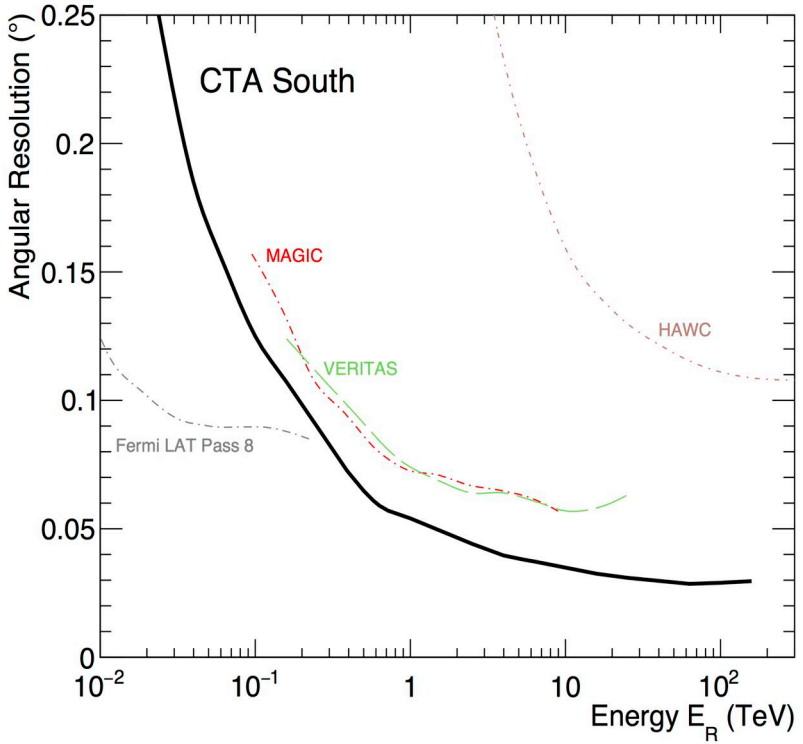
Koposov+:
arXiv:1503.02079

CTA PERFORMANCE

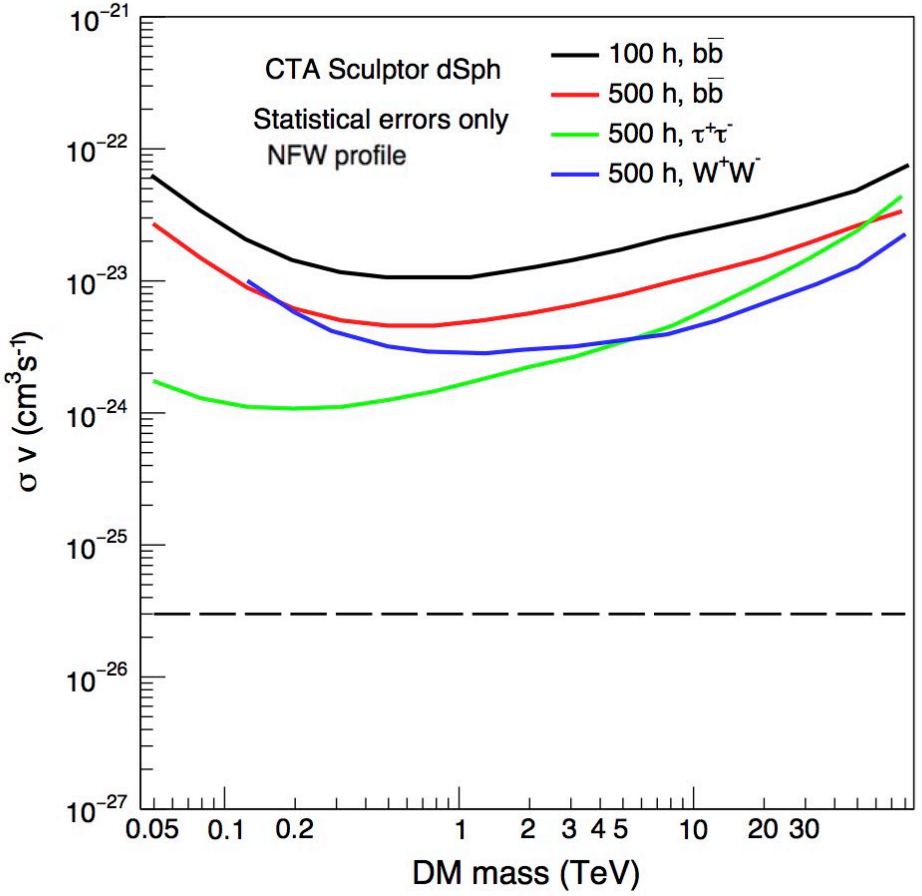
Southern Site:
- 4 Large-size telescopes
- 25 Medium-size telescopes
- 70 Small-size telescopes

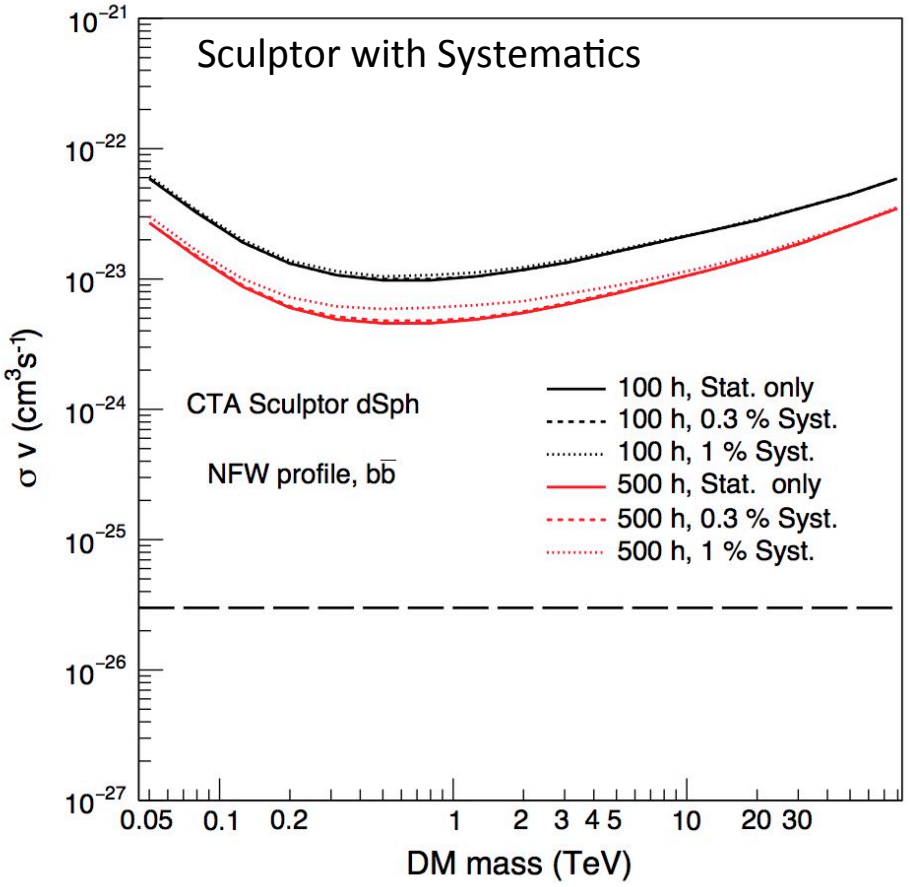
Northern Site:
- 4 Large-size telescopes
- 15 Medium-size telescopes





Dwarf Spheroidal Galaxies: CTA Sensitivity

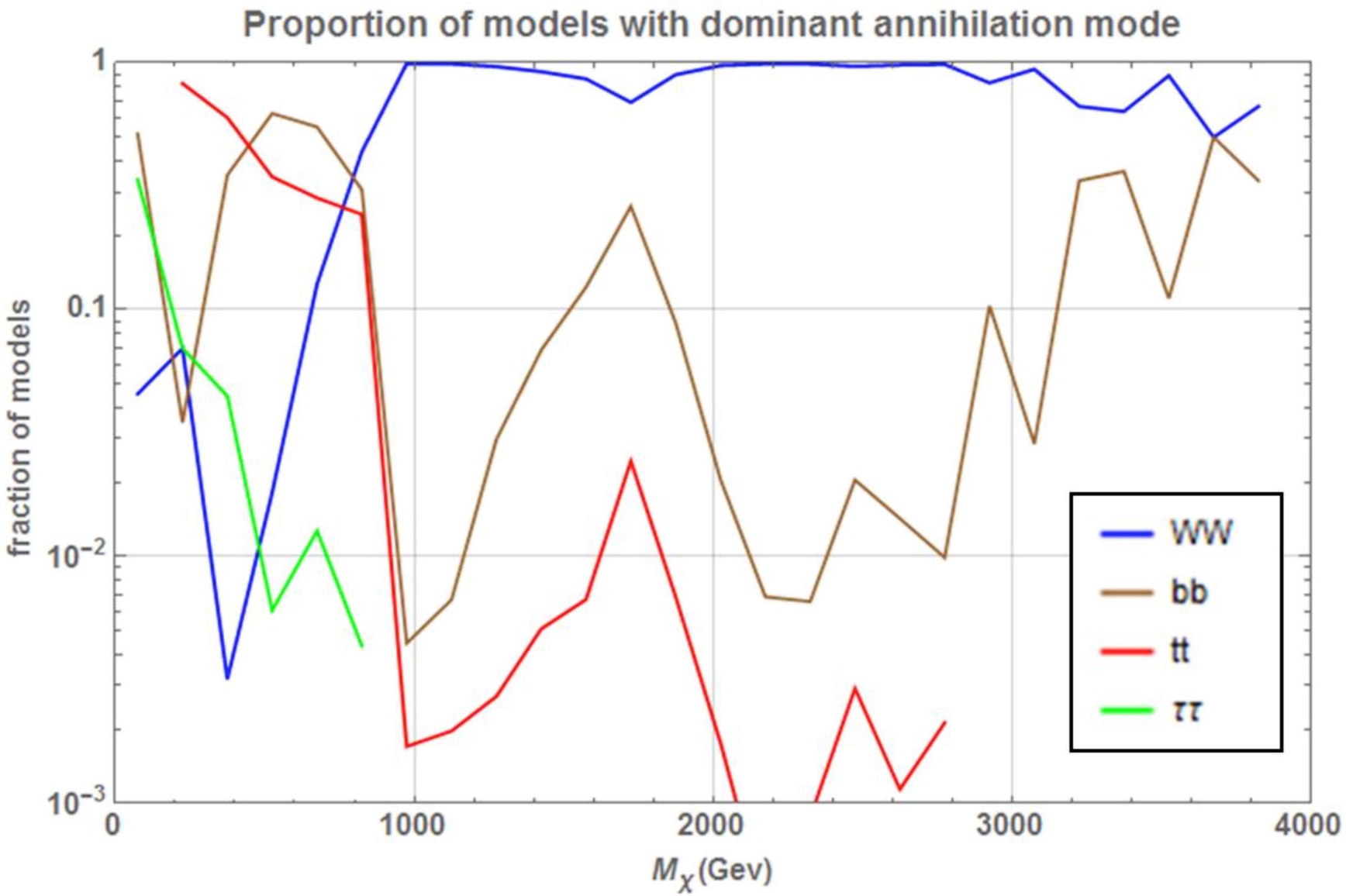




There are several of the newly discovered dSph that have a better case for being a promising target,

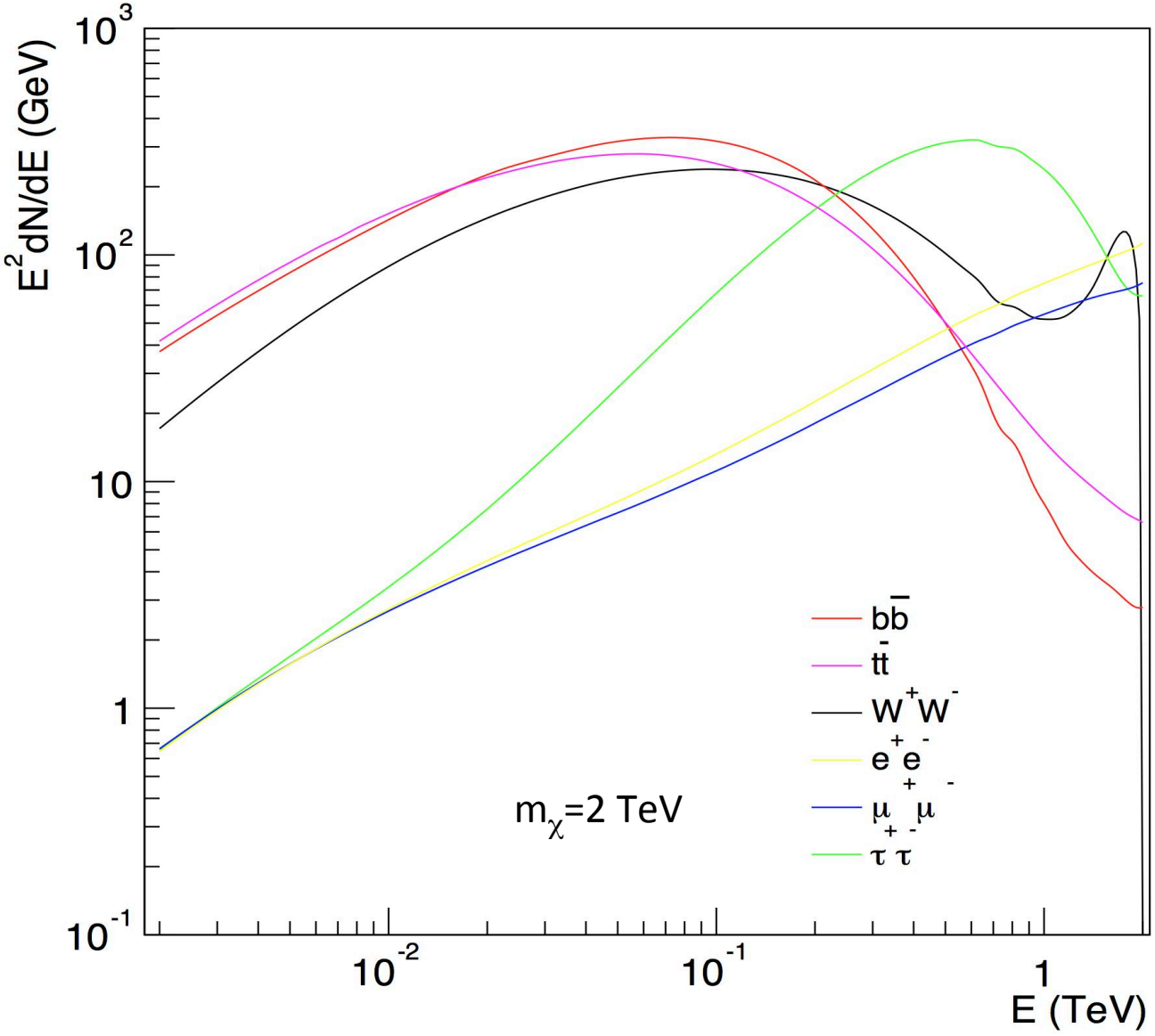
Will choose most promising targets before observations with the latest knowledge.

Which channel to choose?
Example: The dominant annihilation modes in the pMSSM scan

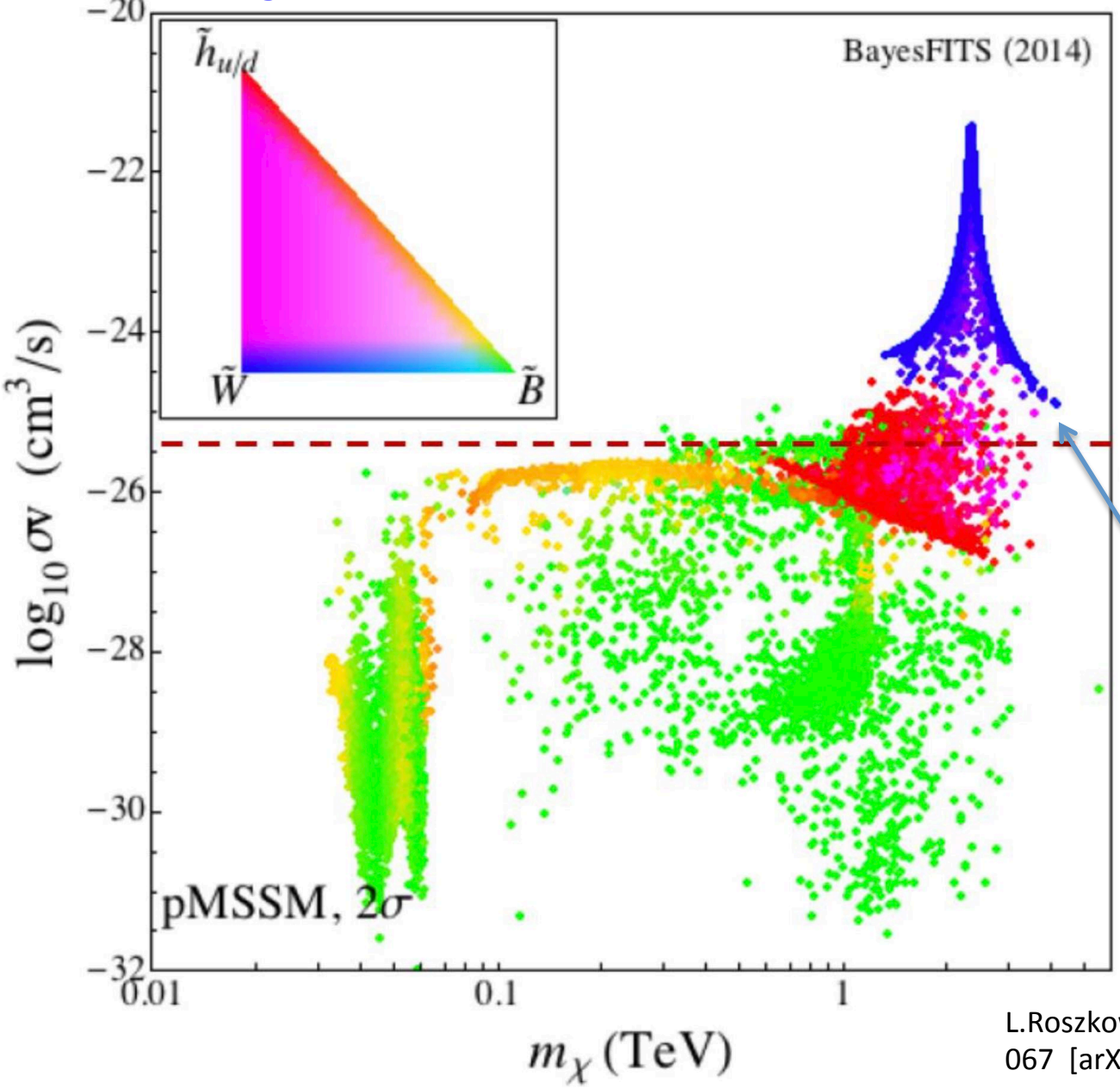


Annihilation spectra for the continuum signals from the quark, lepton and gauge boson primary channels

The line-like feature expected from the virtual internal Bremsstrahlung process contribution is particularly prominent for the W^+W^- channel



Remember: the "thermal" cross section is only a reference value. The real cross section can be higher or lower



Example: Annihilation cross-section points from a 19 dimensional pMSSM fit

"thermal" cross-section
3×10^{-26} cm^3 s^{-1}

Note that a strong enhancement of the annihilation cross section occurs for winos around 2-3 TeV due to Sommerfeld enhancement.

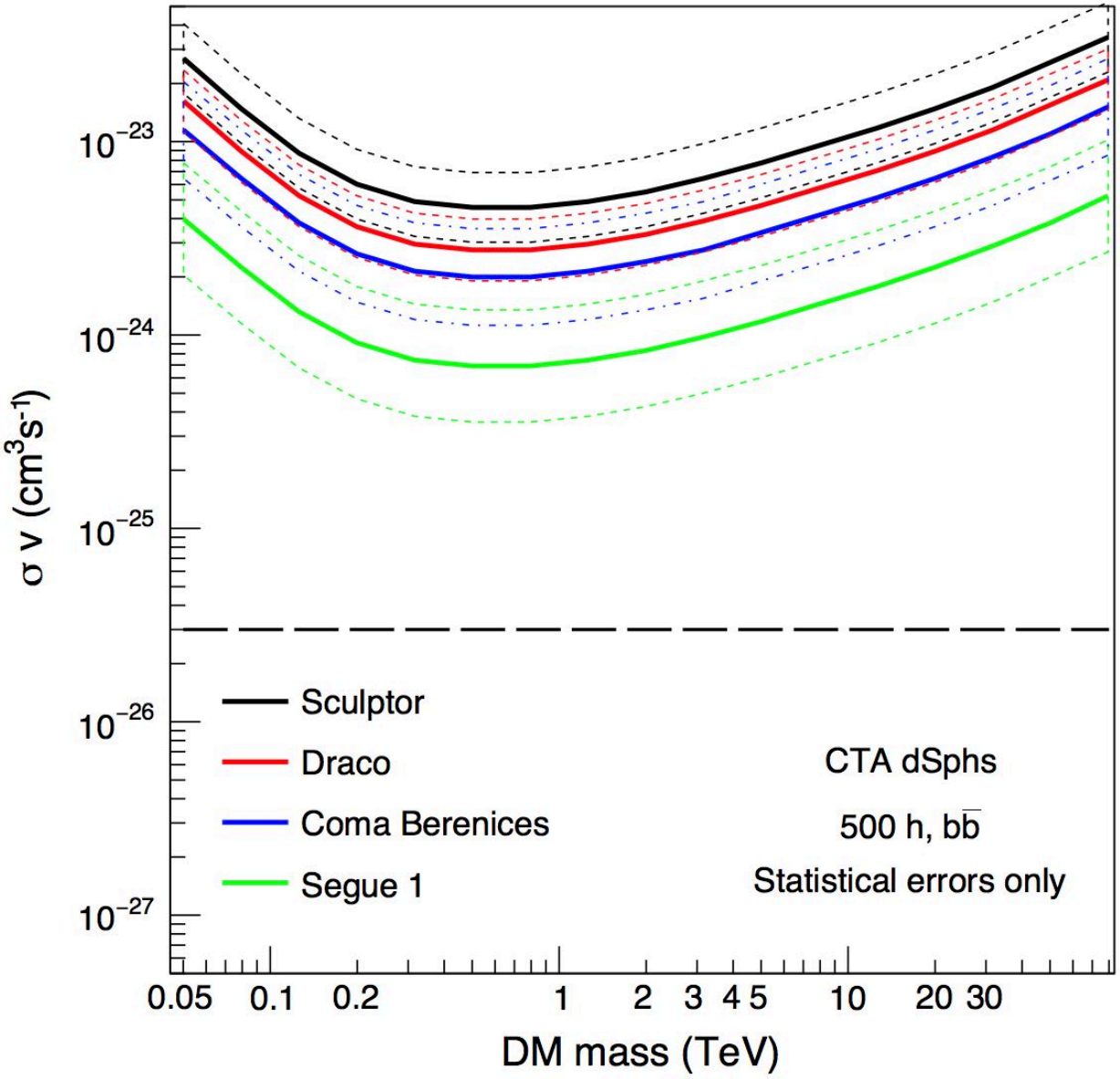
L.Roszkowski et al., JHEP, 1408 (2014) 067 [arXiv:1405.4289]

Dwarf Spheroidal Galaxies: CTA Sensitivity

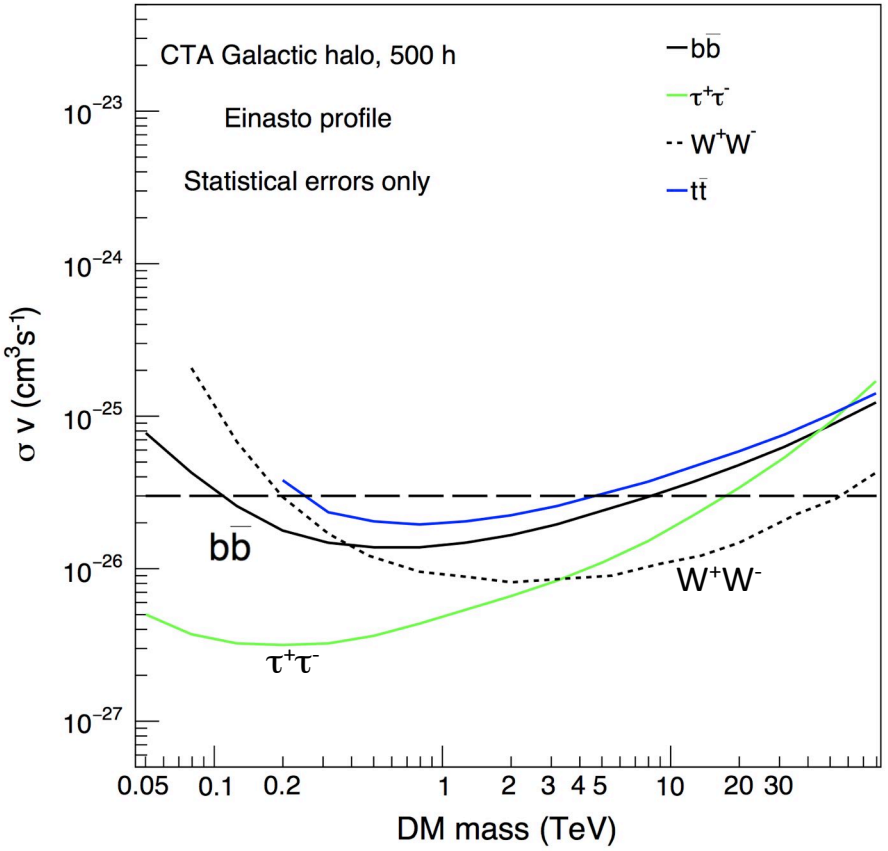
for different Dwarfs.

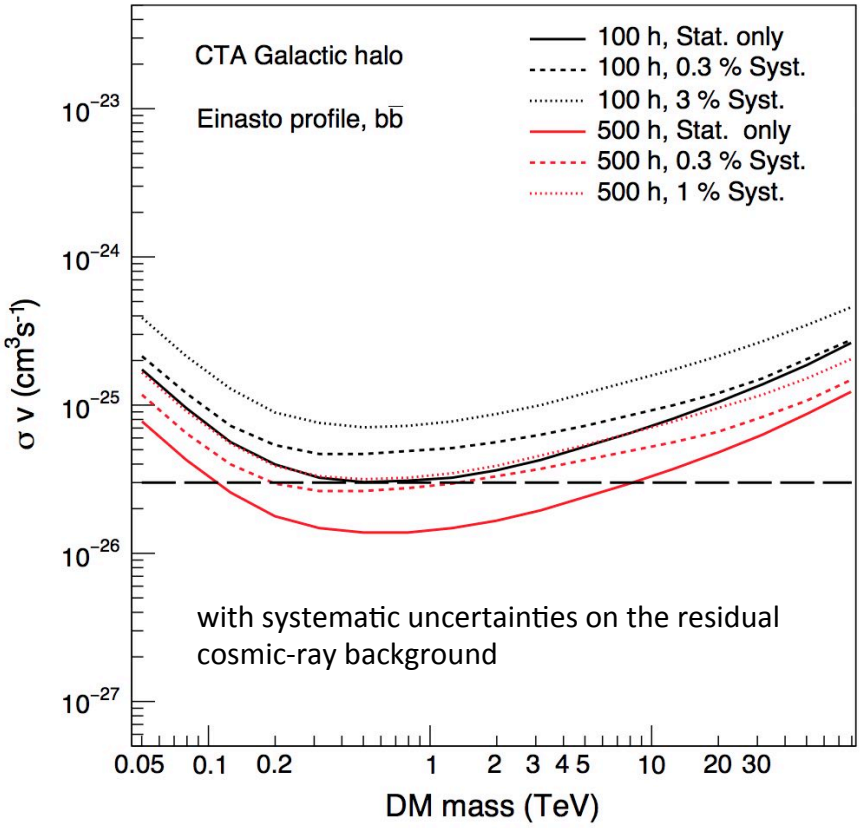
Dashed lines correspond to ±1σ on the J-factors

N.B. recent doubts on Segue 1 J-factor due to interlopers in stellar-kinematic samples.
V. Bonnivard et al., arXiv: 1506.08209



CTA Galactic Halo DM upper-limits

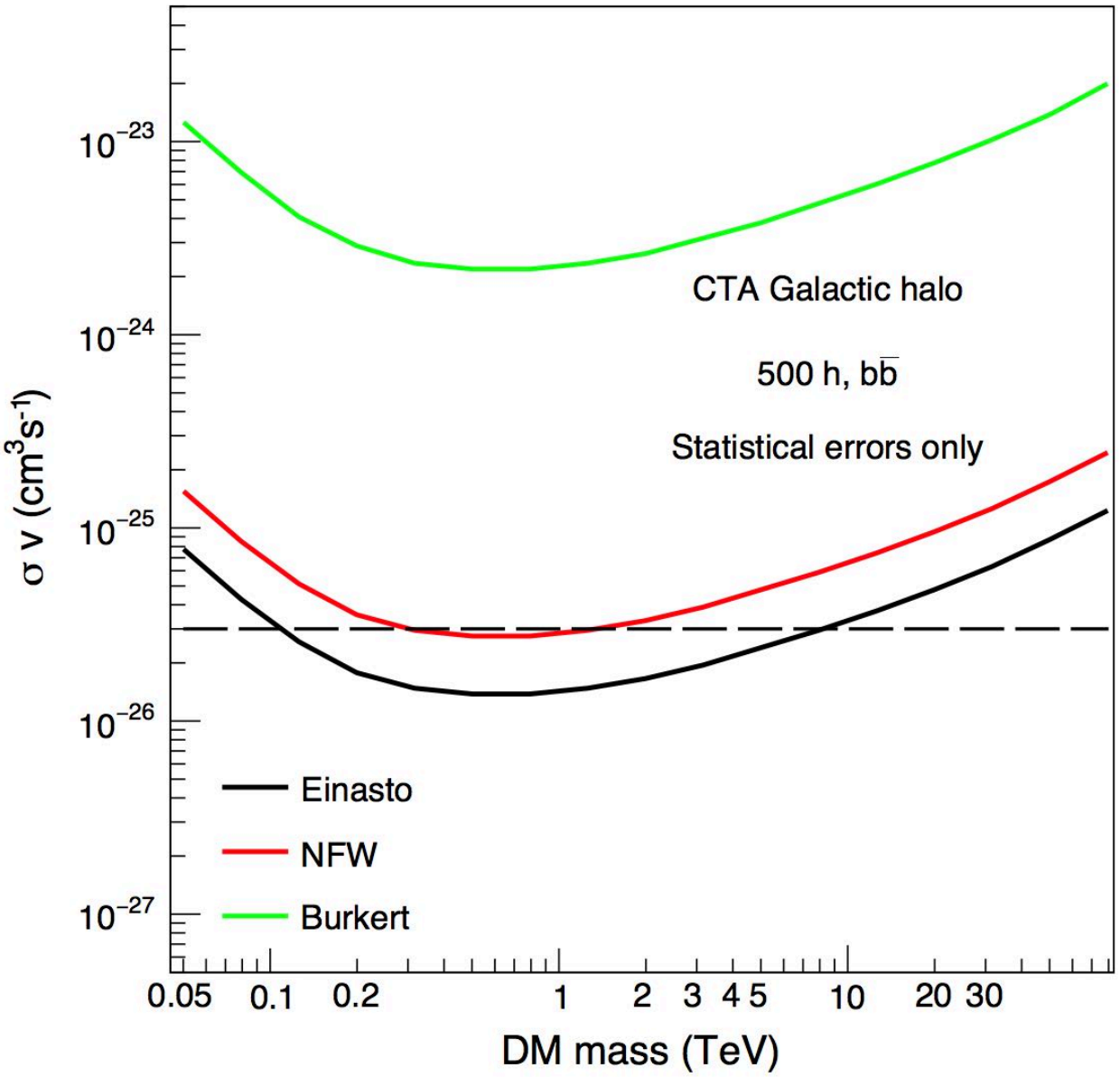




The predictions shown here can be considered optimistic, even when systematics errors are included, as we do not consider the effect of the Galactic diffuse emission as background for DM searches that can affect the results by ~ 50%
This will be investigated in detail in a forthcoming publication by the CTA Consortium.

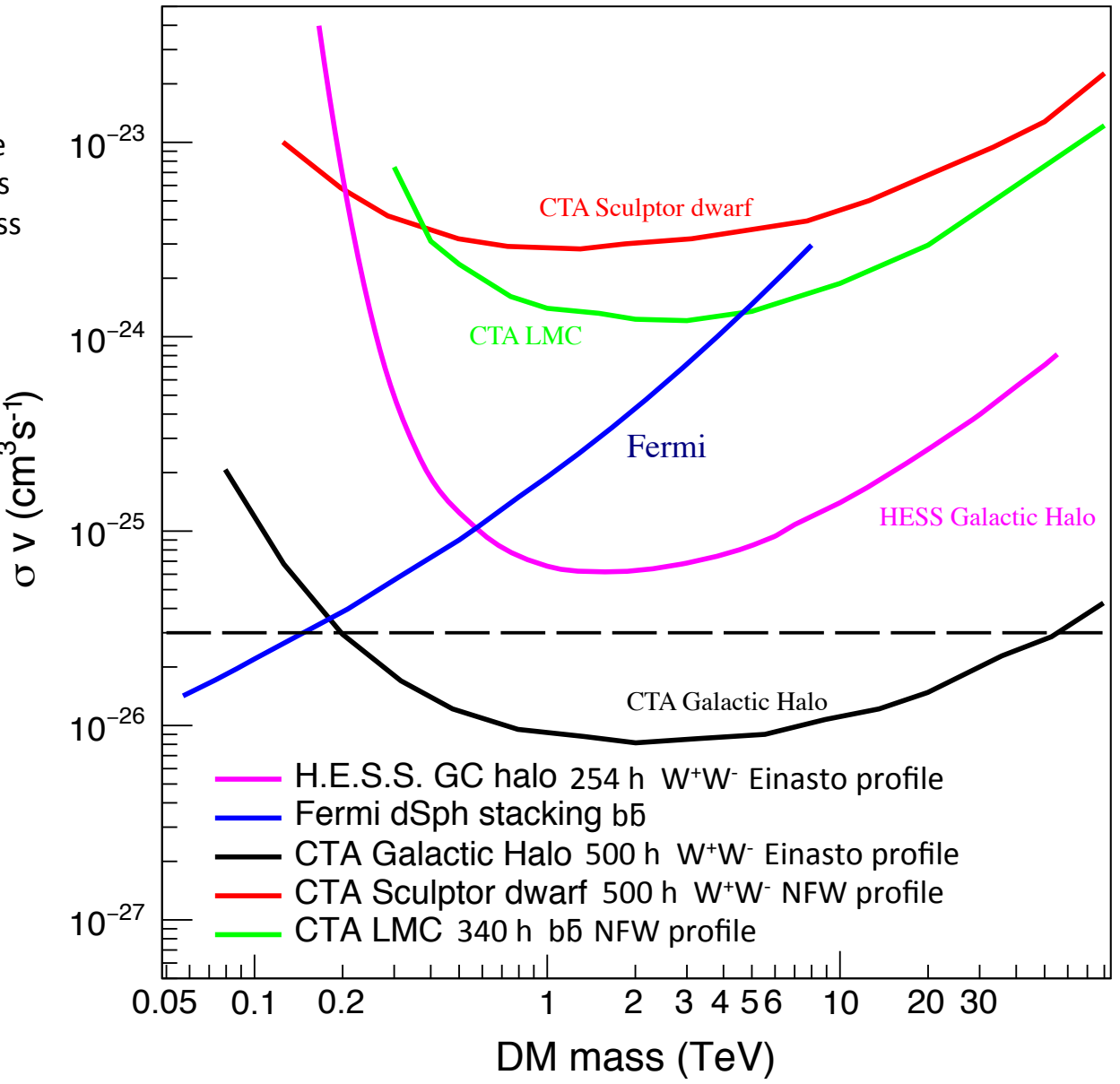
CTA Galactic Halo DM upper-limits

Effect of the different Halo profiles



CTA, Fermi,HESS DM upper-limits

Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section
The expectation for CTA for the Galactic Halo
is for the Einasto profile and is optimistic as includes
only statistical errors.
The effect of the Galactic diffuse emission can affect
the results by ~ 50%
As we saw in the previous slides the limits from dwarfs are much less dependent from the systematic uncertanties



CTA, HESS, FERMI, PLANK DM upper-limits

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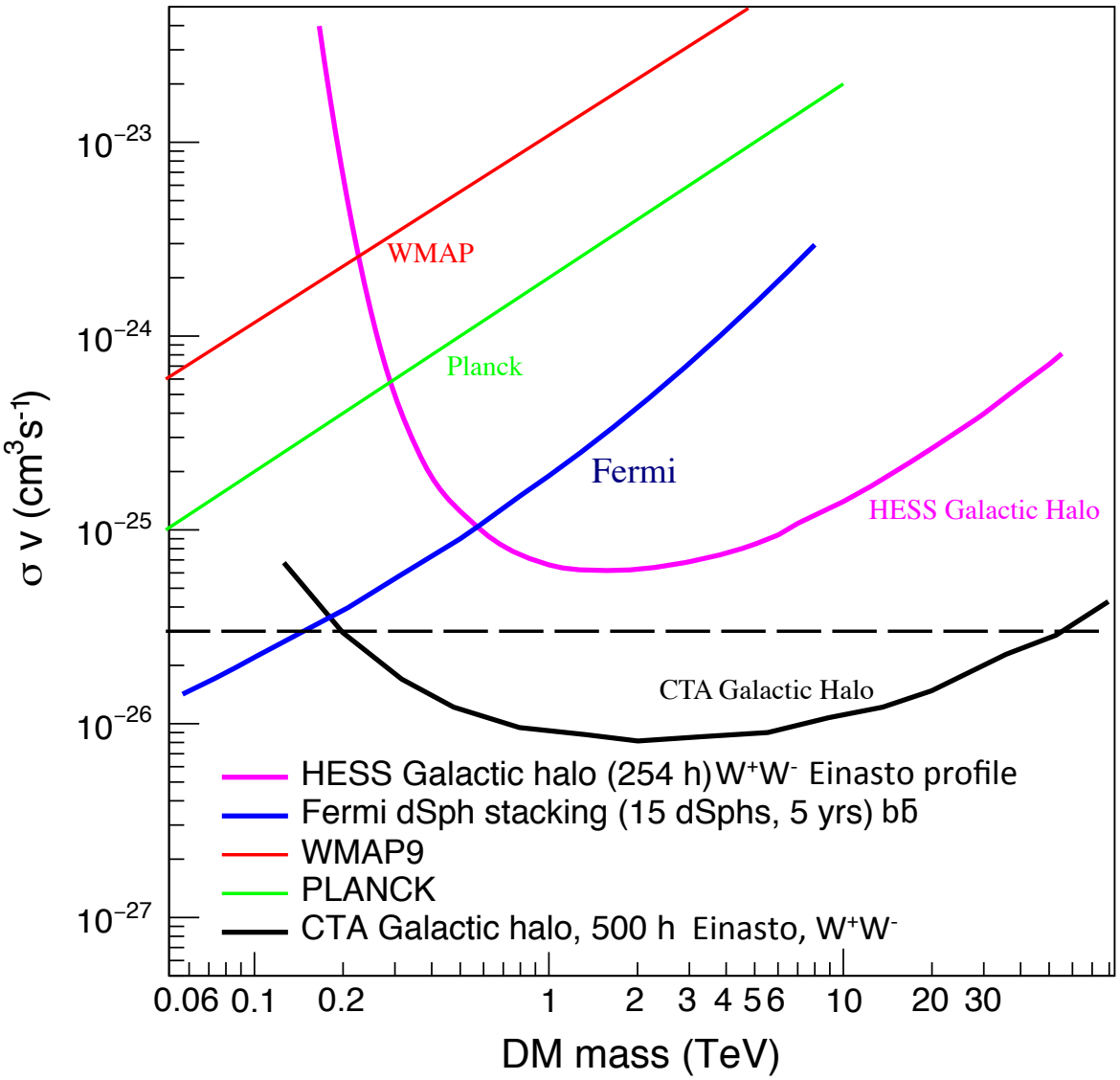
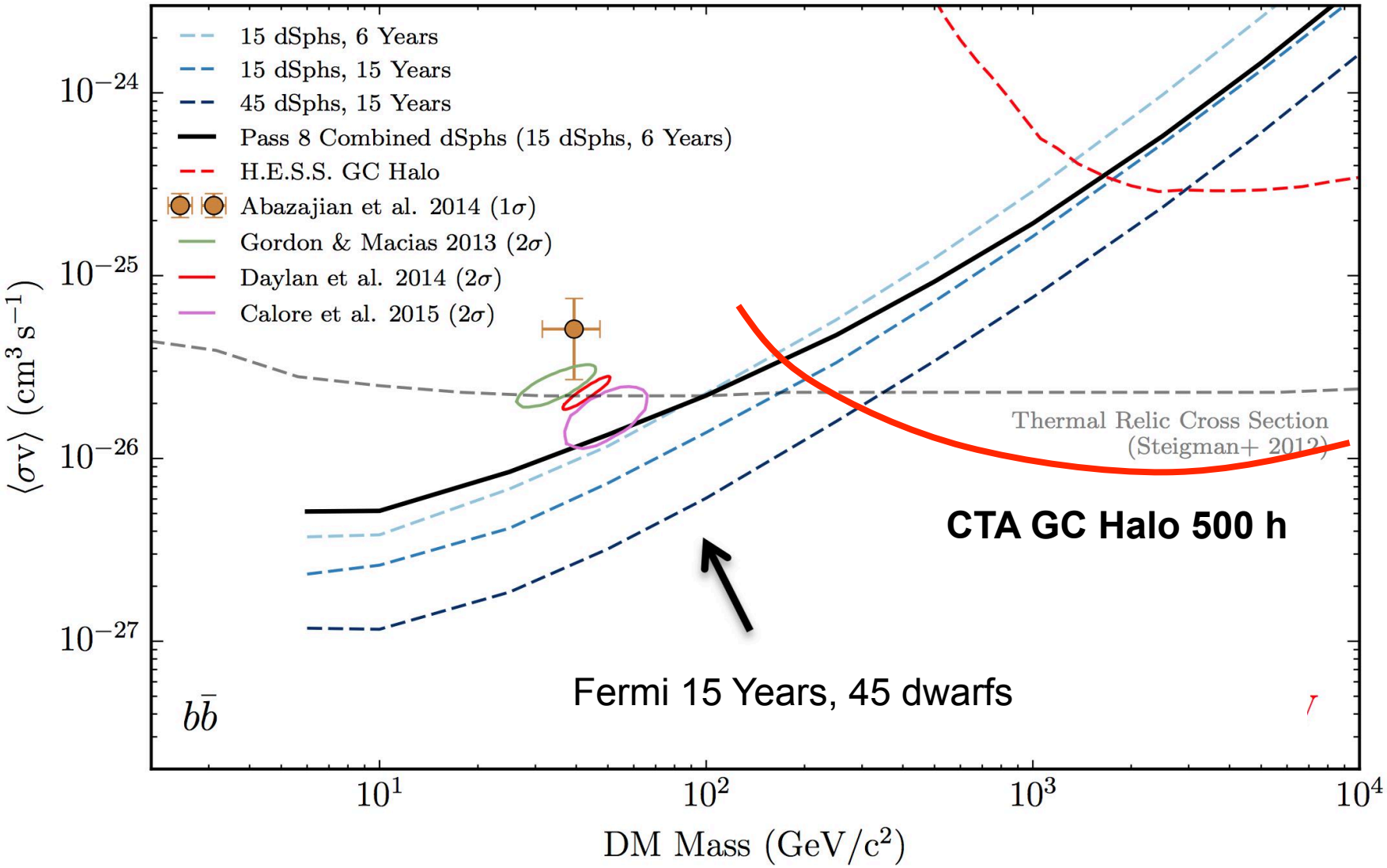
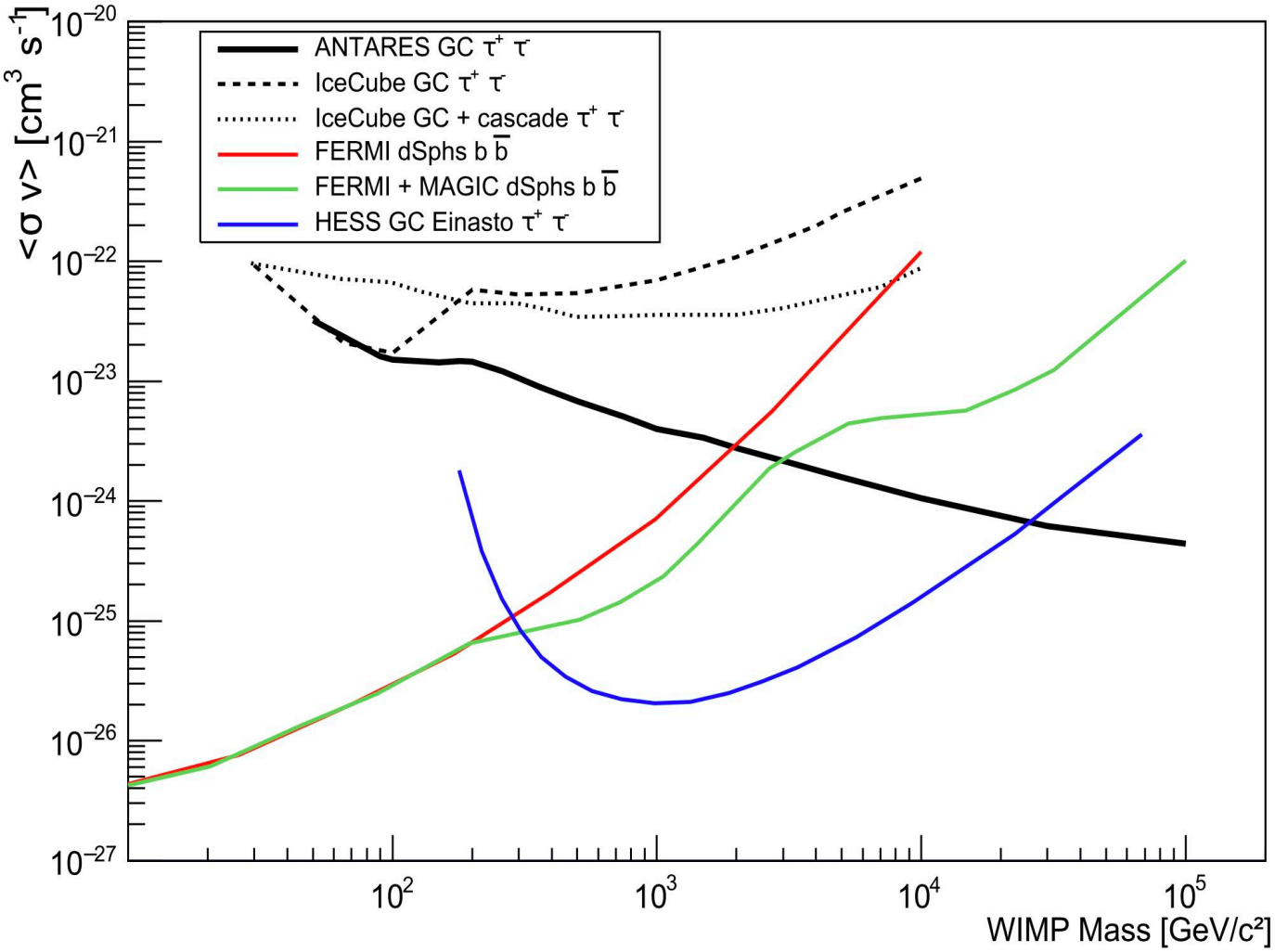


DM limit improvement estimate in 15 years (2008- 2023)



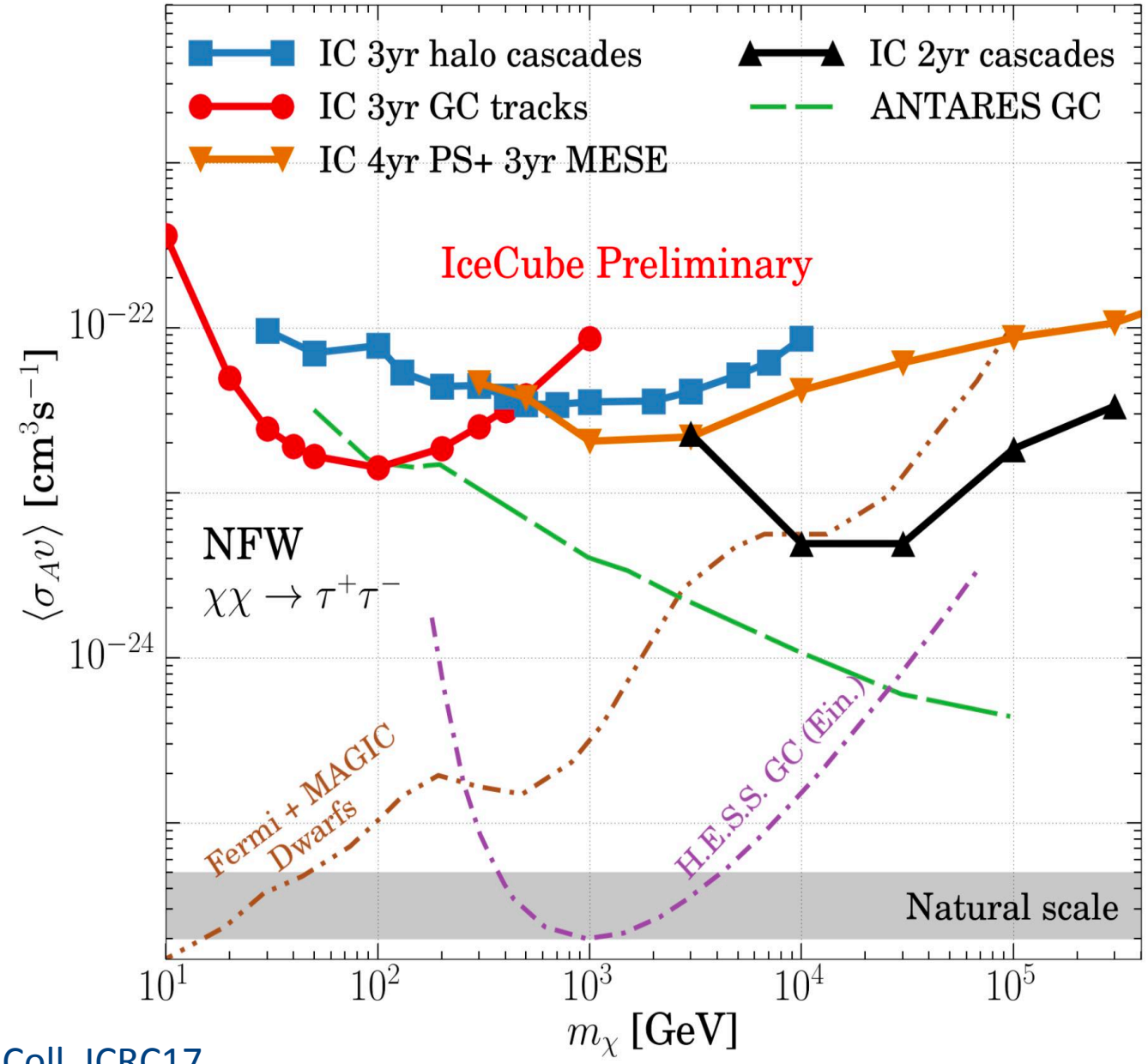
Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

HESS, FERMI, Ice Cube, ANTARES Dark Matter upper-limits



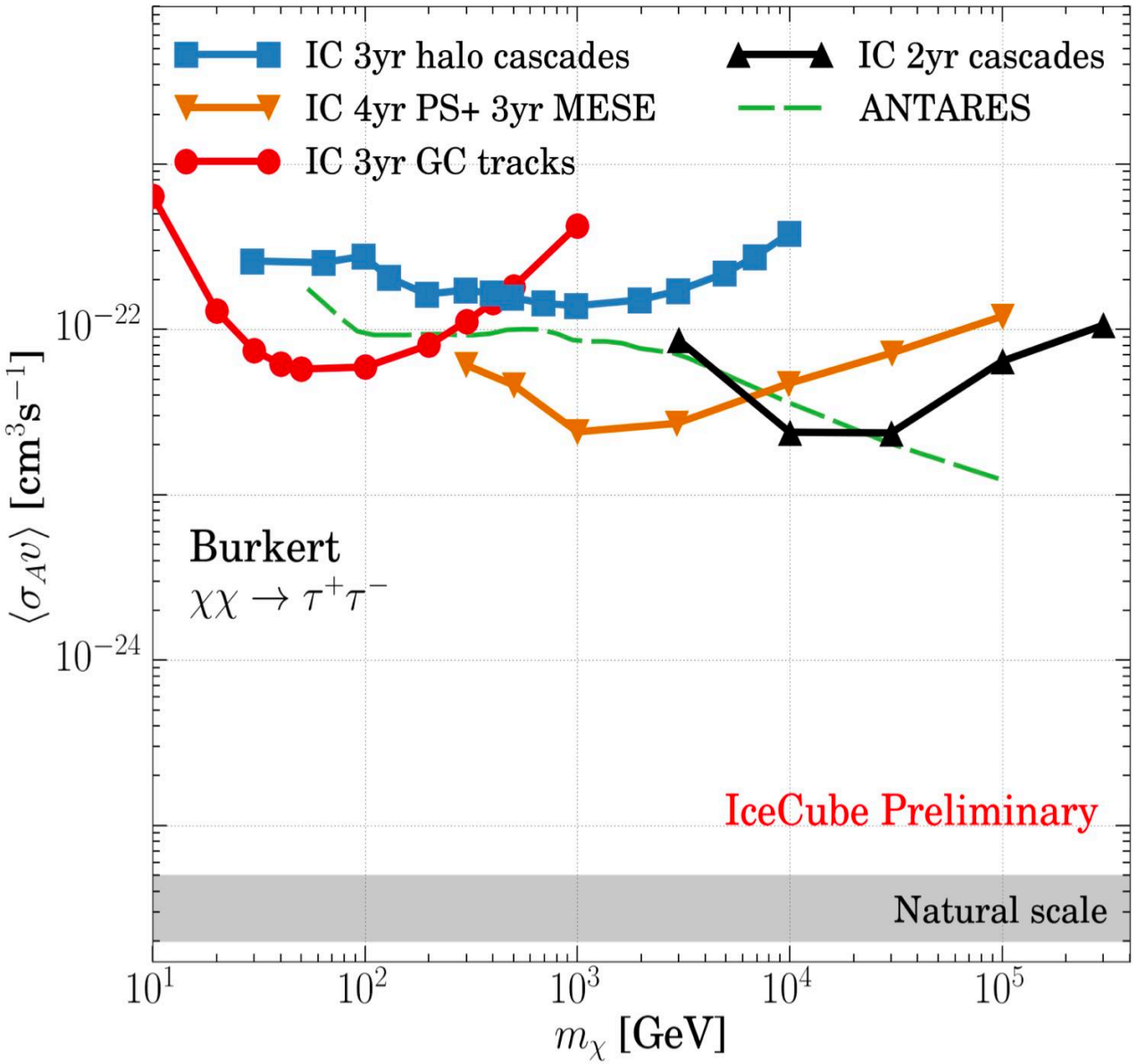
A. Albert, et al. ANTARES Coll. Physics Letters B 769 (2017) 249–254

HESS, FERMI, Ice Cube, ANTARES Dark Matter upper-limits update



S.Flis for the Ice Cube Coll. ICRC17

HESS, FERMI, Ice Cube, ANTARES Dark Matter upper-limits update



S.Flis for the Ice Cube Coll. ICRC17

CTA DM Detection Strategy

Year	1	2	3	4	5	6	7	8	9	10
Galactic halo	175 h	175 h	175 h							
Best dSph	100 h	100 h	100 h							
				in case of detection at GC, large σv						
Best dSph				150 h	150 h	150 h	150 h	150 h	150 h	150 h
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of detection at GC, small σv						
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of no detection at GC						
Best Target				100 h	100 h	100 h	100 h	100 h	100 h	100 h

First 3 years

- The principal target is the Galactic Center Halo (most intense diffuse emission regions removed)
- Best dSph as "cleaner" environment for cross-checks and verification (if hint of strong signal)

Next 7 years

- If there is detection in GC halo data set (525h)
  - Strong signal: continue with GC halo in parallel with best dSph to provide robust detection
  - Weak signal: focus on GC focus to increase data set until systematic errors can be kept under control
- If no detection in GC halo data set
  - Focus observation on the best target at that time to produce legacy limits.

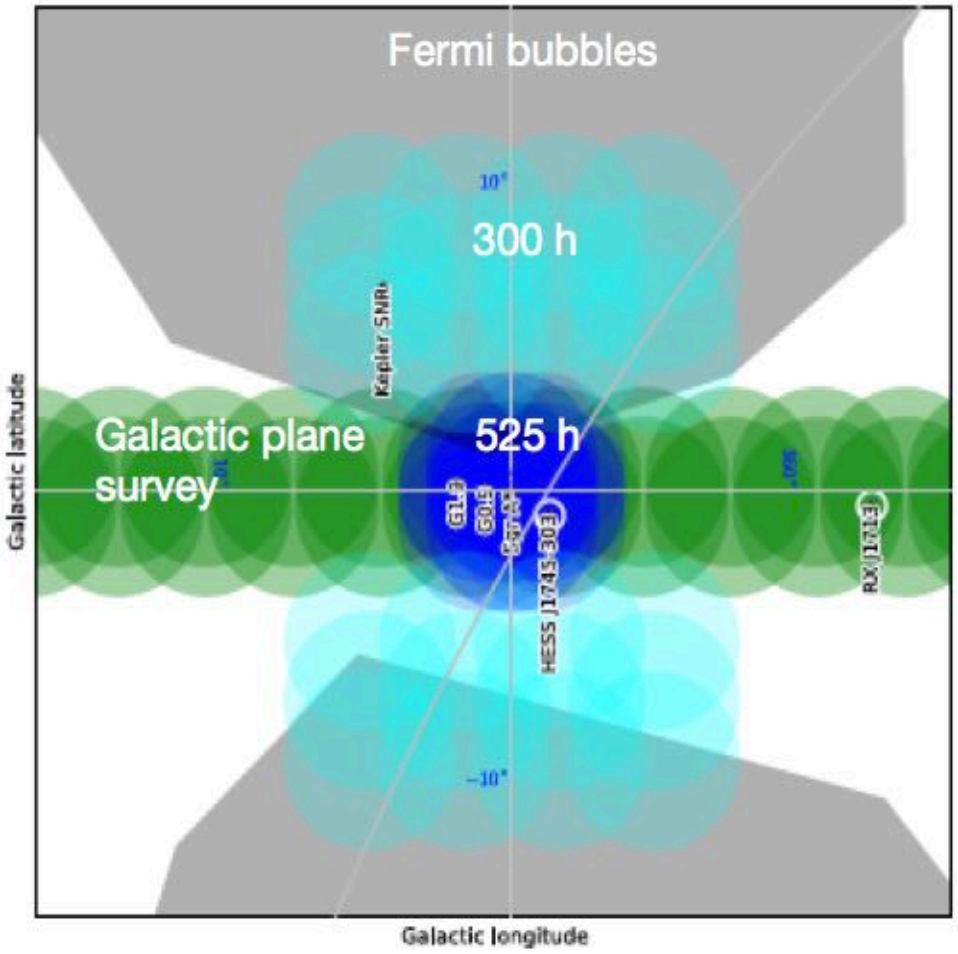
DEEP OBSERVATIONS OF GC REGION

Deep 525 h exposure in the inner 5° around Sgr A*;

Extended 300 h survey of 10°x10° region;

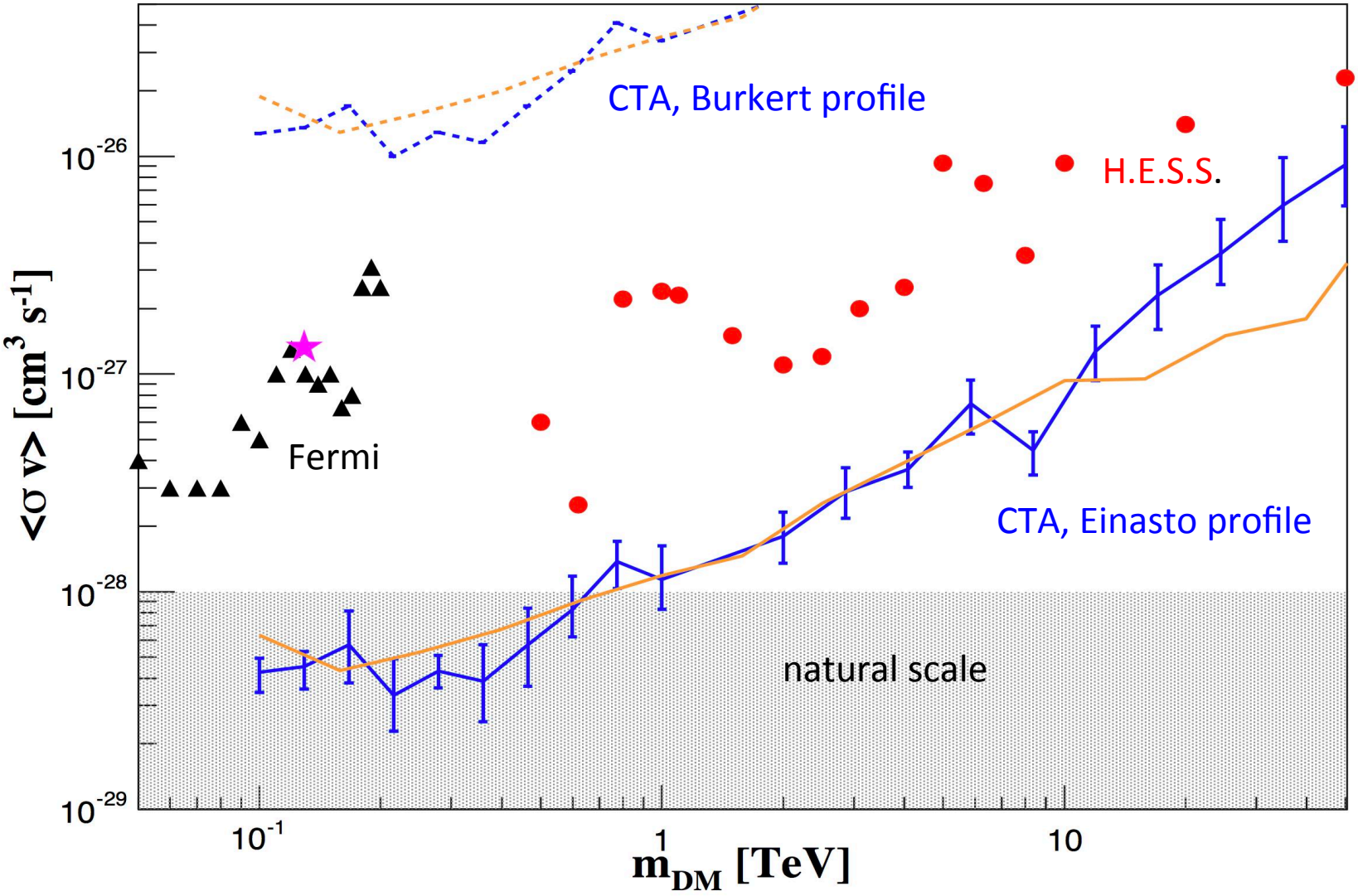
Produce CTA legacy data set for large range of scientific topics, which include

- GC and GC DM halo
- Understand "backgrounds" pin down VHE sources and map diffuse emission
- Astrophysics of SNRs (multiple sources, e.g. G1.9, …)
- Astrophysics of PWNe and Pulsars
- Extended objects such as Central Radio lobes (central ±1°) and arc features.



CTA legacy data set

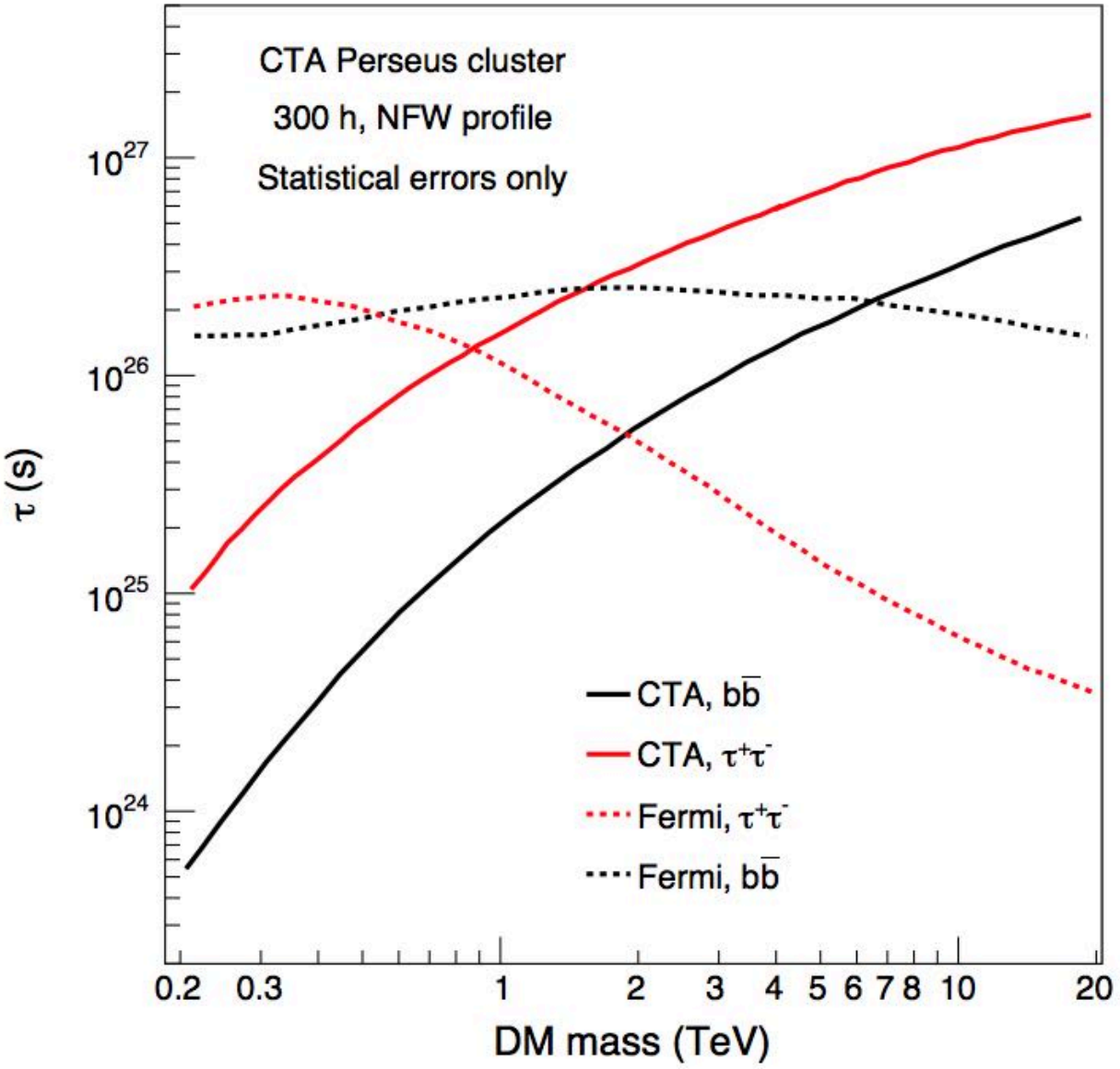
Line search with CTA



500 h of observation of a region with 1^O radius around the Galactic Centre using an unbinned likelihood analysis (blue line) and a differential sensitivity analysis (orange curve) assuming an Einasto profile (dashed for Burkert profile)

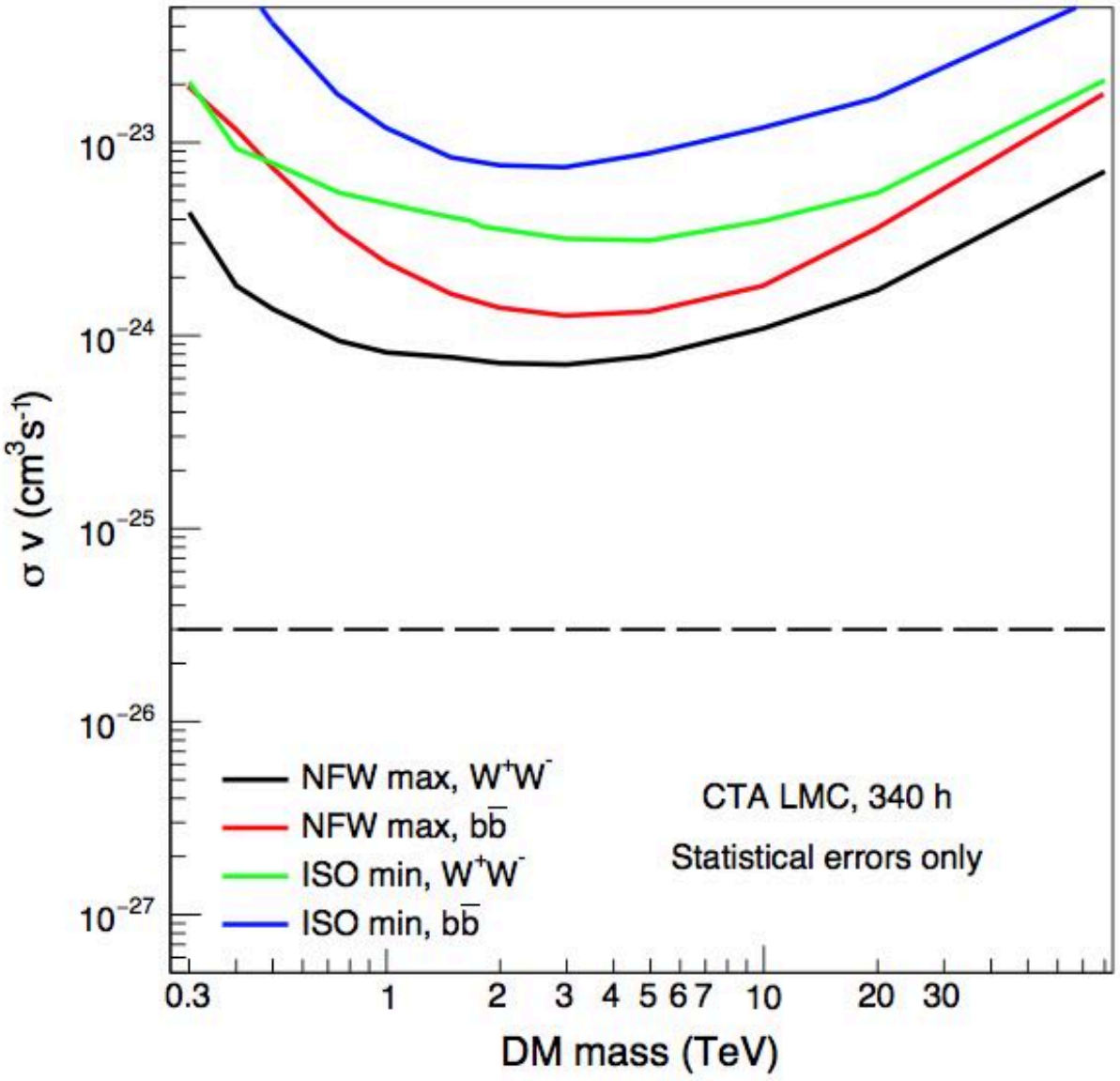
Perseus cluster

Expected CTA sensitivity to the dark matter decay lifetime for 300 h of observation of the Perseus cluster compared with the results from the Galactic Halo by Fermi

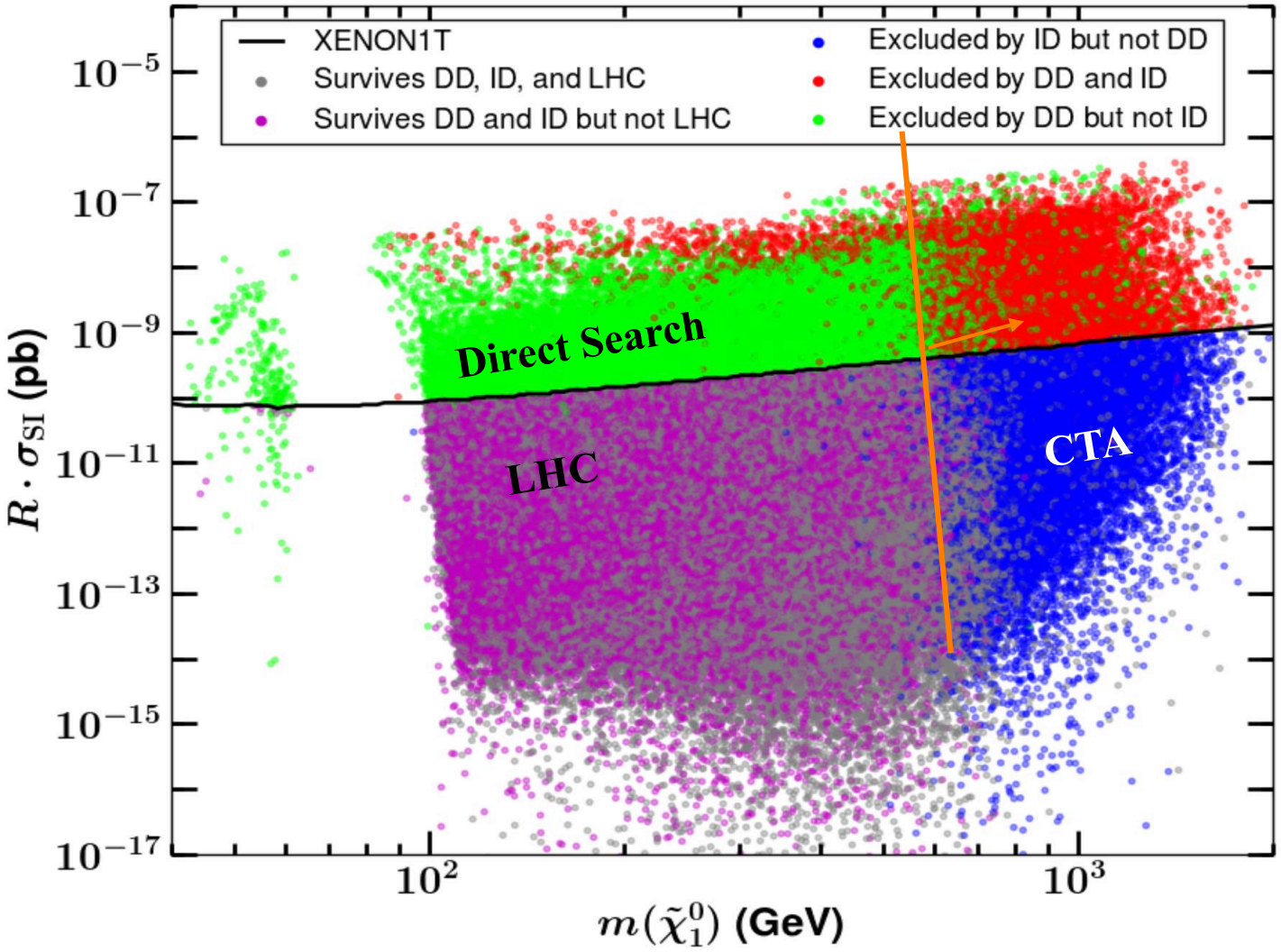


LMC 340 h of observation

CTA sensitivity on from observation of the LMC for 340 hours of observation in the bbar and W^+W^- annihilation channels for both NFW and isothermal (ISO) dark matter profiles. The sensitivities are computed with a 200 GeV energy threshold assuming statistical errors only



Complementarity and Searches for Dark Matter in the pMSSM



Cahill-Rowley et al. arXiv:1305.6921

DMEP Consortium Publications in preparation (updates)

- Dark Matter in the Galactic Halo
- Dark Matter in Dwarf Spheroidal Galaxies
- Dark Matter in the Large Magellanic Cloud
- Dark Matter (and Cosmic Rays) in Clusters of Galaxies
- EBL / ALP / LIV publication
- Lines searches

CTA CONTRIBUTION TO DM RESEARCH (SUMMARY)

- CTA has good prospects to probe for the first time WIMP models with thermal relic cross-section and masses above 200 GeV;
- Together with Fermi CTA will be able to exclude thermal WIMPs within the mass range from a few GeV up to a few tens of TeV.
- For heavy WIMPs (>TeV) CTA will provide unique observational data to probe parameter space not reachable by the other experiments.
- CTA is complementary instrument to LHC and direct DM searches probing some non-overlapping regions of DM particle parameter space.
- If DM is detected by CTA, it will also be possible to explore some properties of DM particle through the study of annihilation channels, etc.
- Control of systematics in deep observations of GC halo and dSph(s) is critical for the success of these studies and will require full knowledge of the instrumentation (hence CTA KSP)
- Better understanding of J factors is essential for interpretation of observational data and derivation of limits.