The Dark Matter Programme of the Cherenkov Telescope Array

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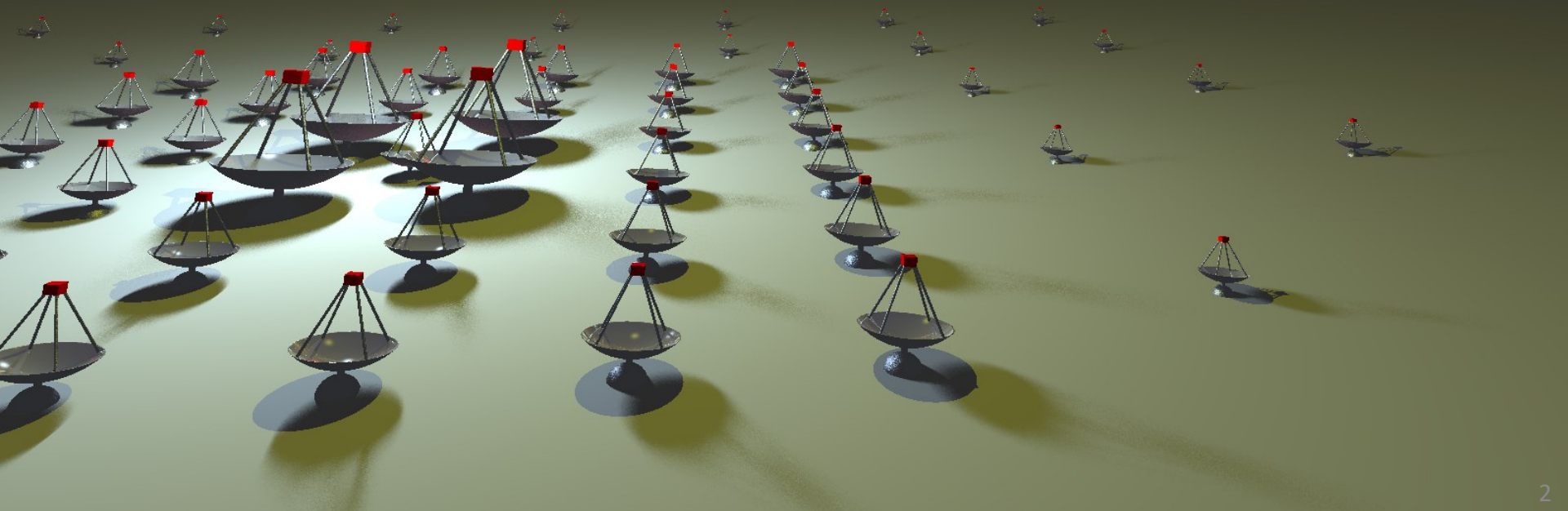
MAGIC Dark Matter Workshop 16-17 January 2019 Barcelona

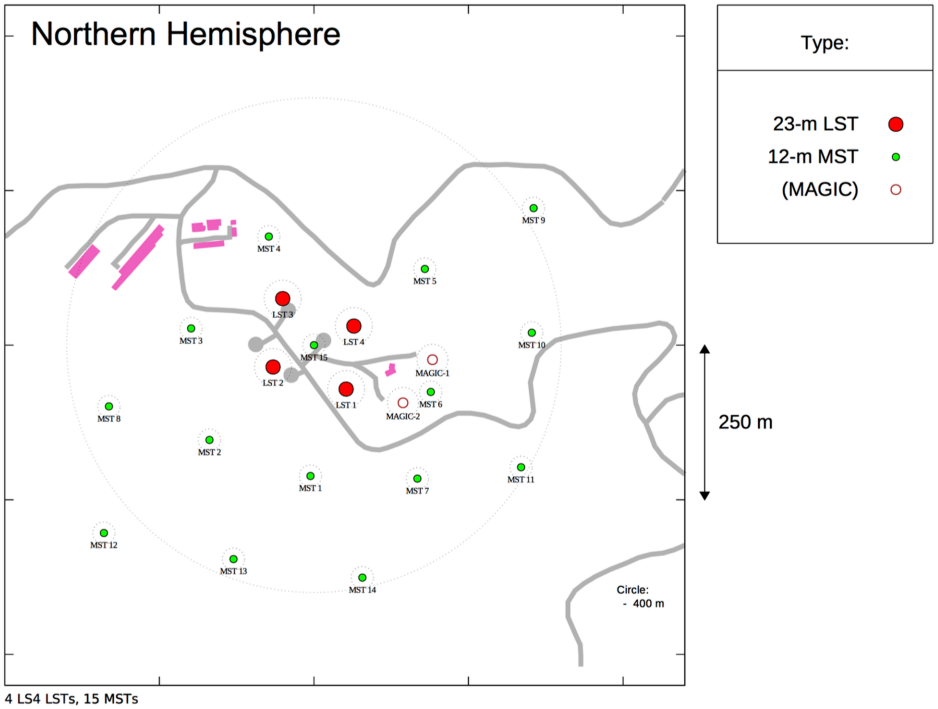
cta
cherenkov telescope array

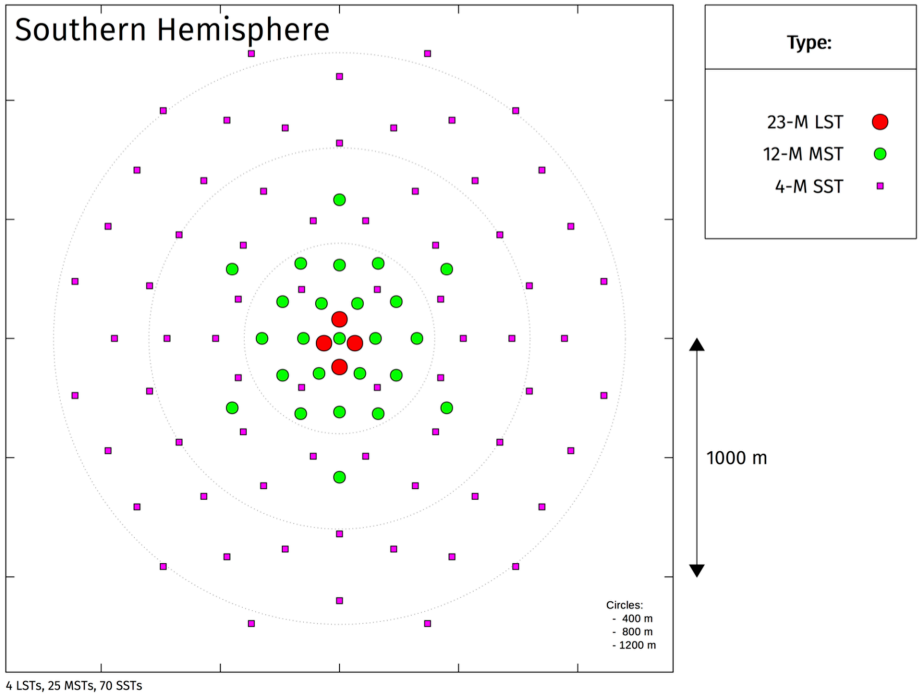
CTA PROJECT

- Next generation ground based Gamma-ray observatory
- Open observatory
- Two sites with more than 100 telescopes
  - Southern Site: Near Paranal, Chile
  - Northern Site: La Palma, Canary Islands, Spain
- 32 nations, ~300M€ project +100M€ manpower



CTA sites and proposed telescope layouts



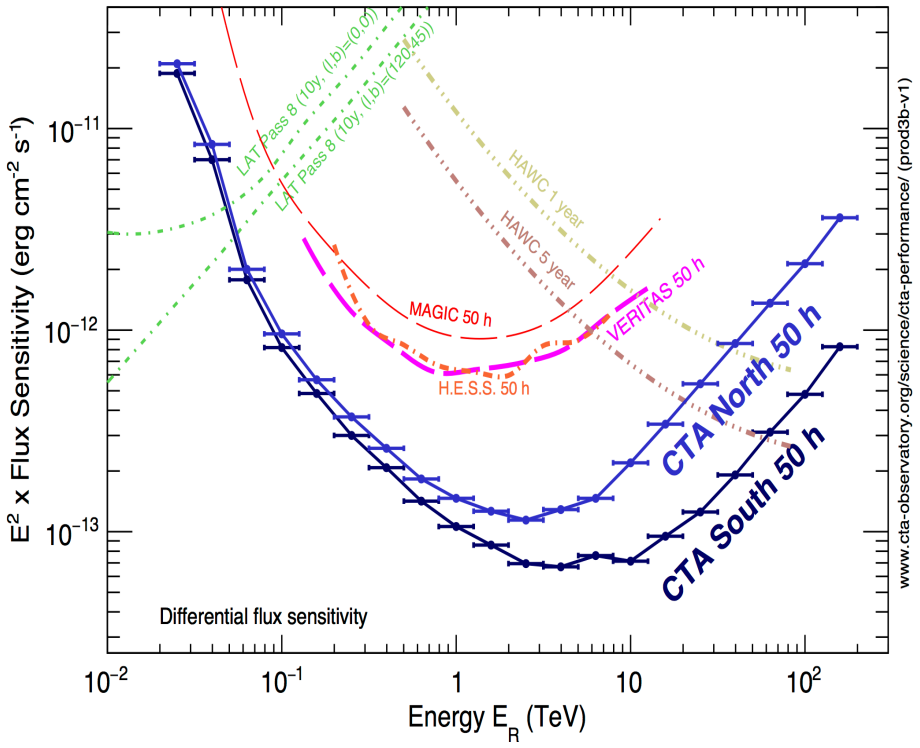


CTA PERFORMANCE

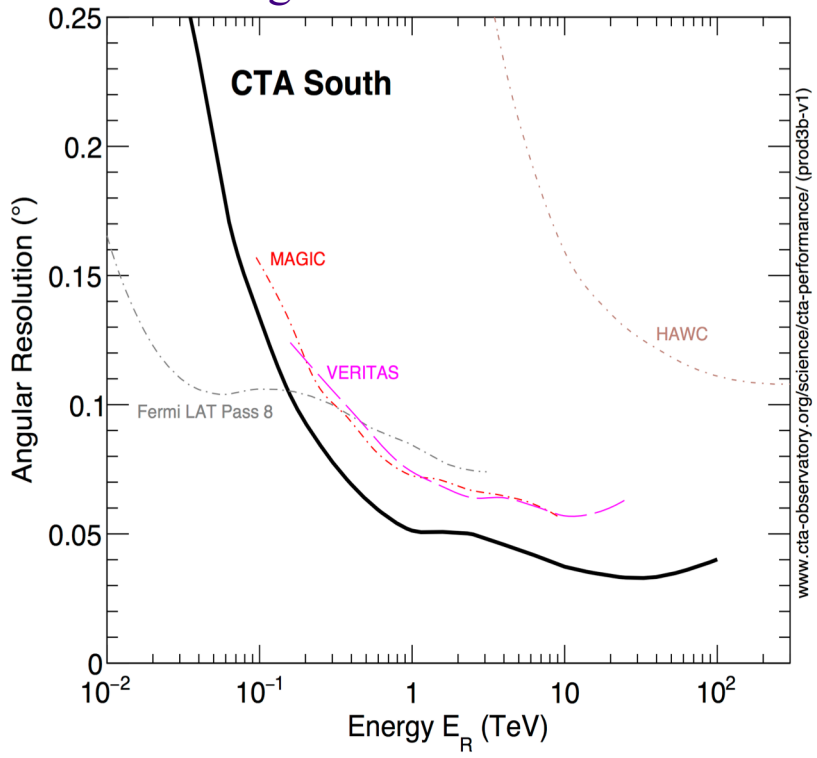
Southern Site:
- 4 Large-size telescopes
- 25 Medium-size telescopes
- 70 Small-size telescopes

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

Differential sensitivity



Angular resolution



CTA PERFORMANCE

Southern Site:

4 Large-size telescopes

25 Medium-size telescopes

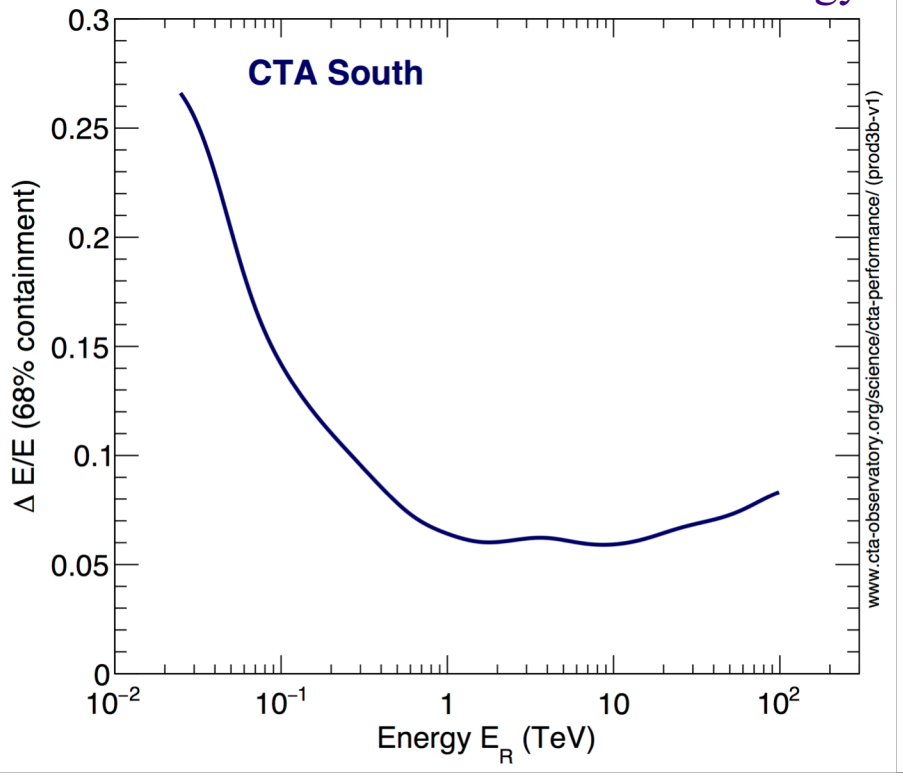
70 Small-size telescopes

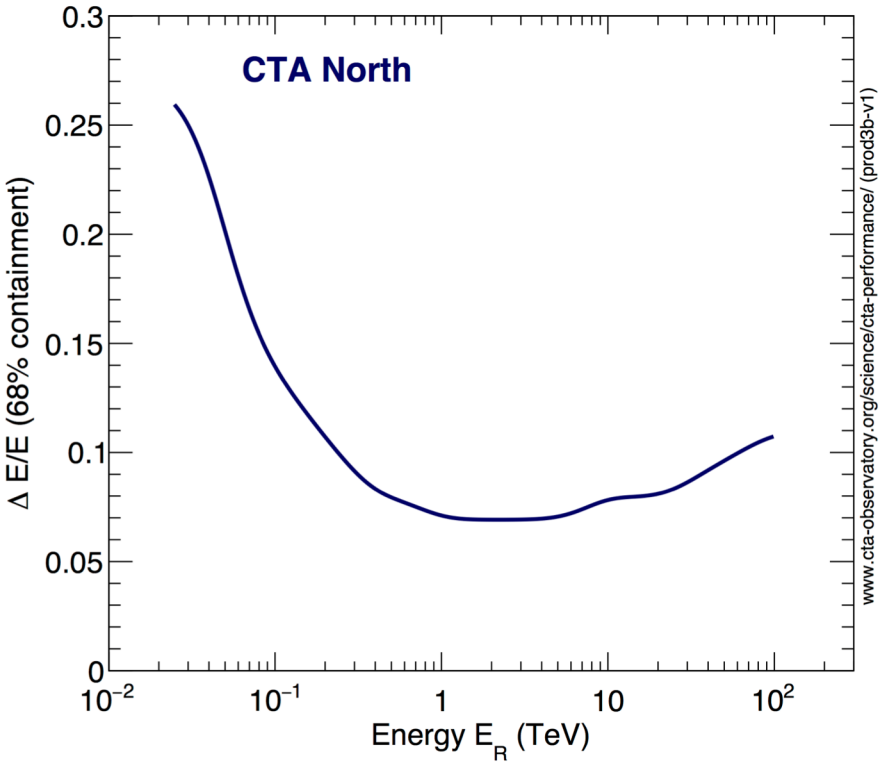
Northern Site:

4 Large-size telescopes

15 Medium-size telescopes

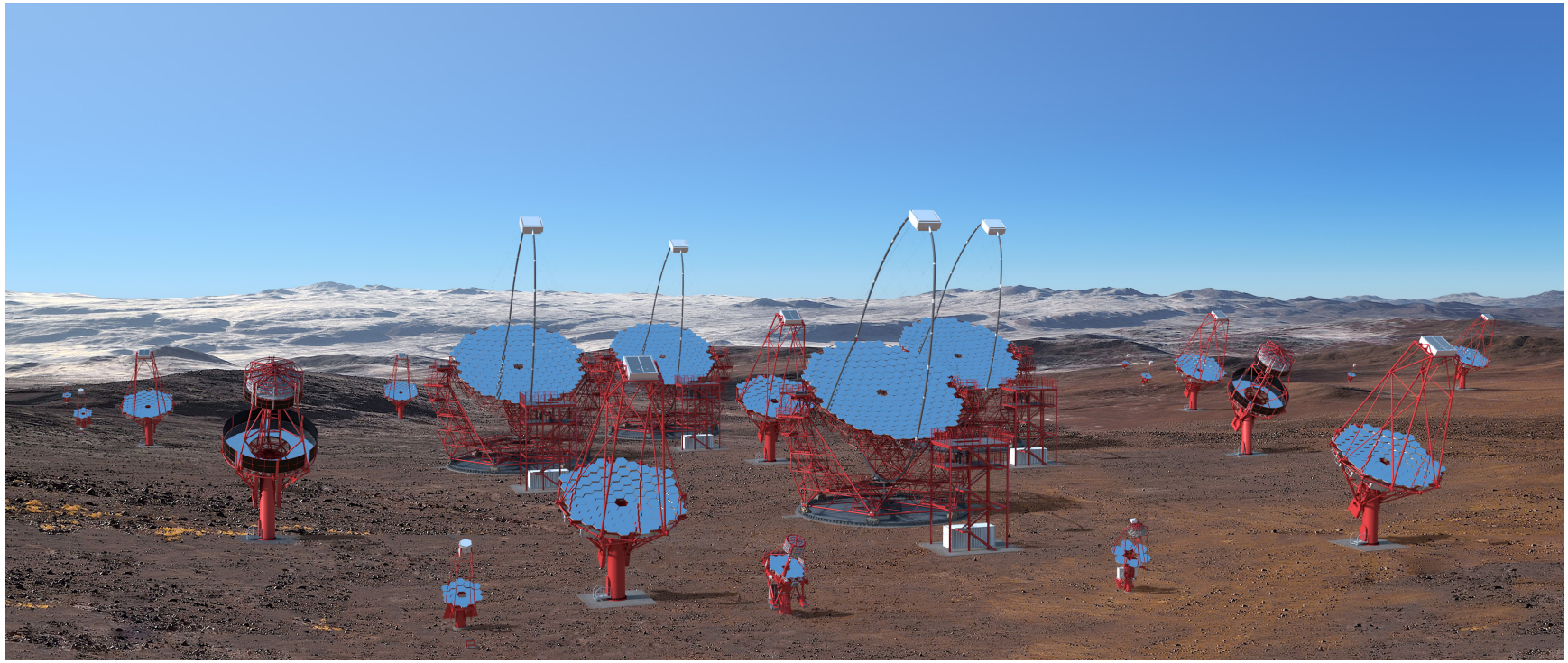
Energy Resolution





Latest News: Final Agreements Signed for CTA's Southern Hemisphere Site in Chile

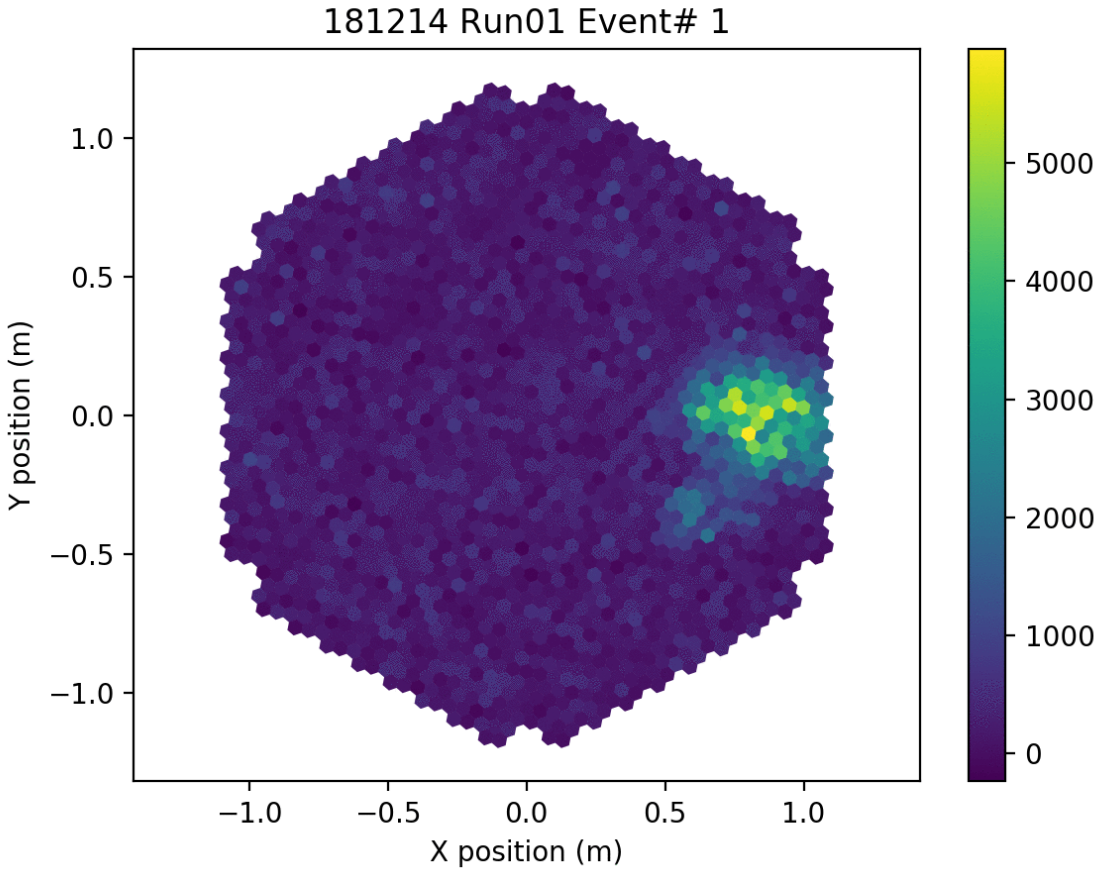
Santiago, Chile – On 19 December 2018, the Cherenkov Telescope Array Observatory (CTAO) and the European Southern Observatory (ESO) signed the final agreements needed for CTA's southern hemisphere array to be hosted near ESO's Paranal Observatory in Chile. Construction on both the northern and southern arrays is expected to begin in 2020.



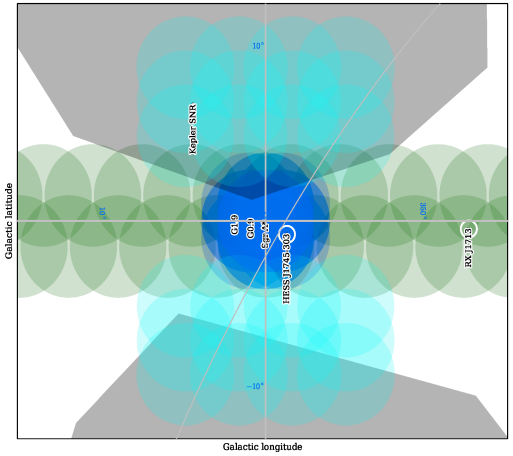
Rendering of the South Site

Latest News: Large-Sized Telescope Prototype Records its First Light

On the night of 14-15 December 2018, the Large-SizedTelescope (LST) prototype recorded its first Cherenkov light on the northern site of the Cherenkov Telescope Array (CTA), located at the Instituto de Astrofísica de Canarias' (IAC's) Observatorio del Roque de los Muchachos (ORM), on the Canary island of La Palma.

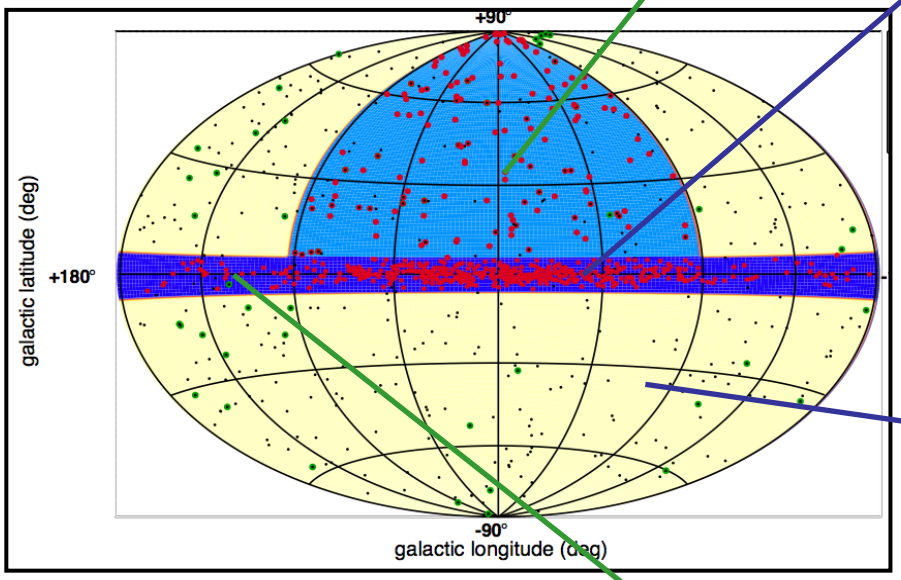


The Survey Key Science Projects



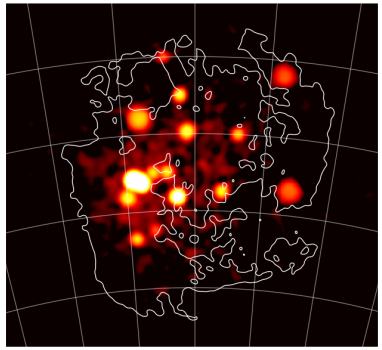
Extragalactic Survey:

Unbiased survey of ¼ sky to ~6 mCrab
VHE population study, duty cycle
New, unknown sources; 1000 h



Galactic Centre Survey:

ID of the central source
Spectrum, morphology of diffuse emission
Deep DM search
Central exposure: 525 h, 10°x10° : 300 h



Science with the Cherenkov Telescope Array
World Scientific
https://doi.org/10.1142/10986
[arXiv:1709.07997] ~364 pp.

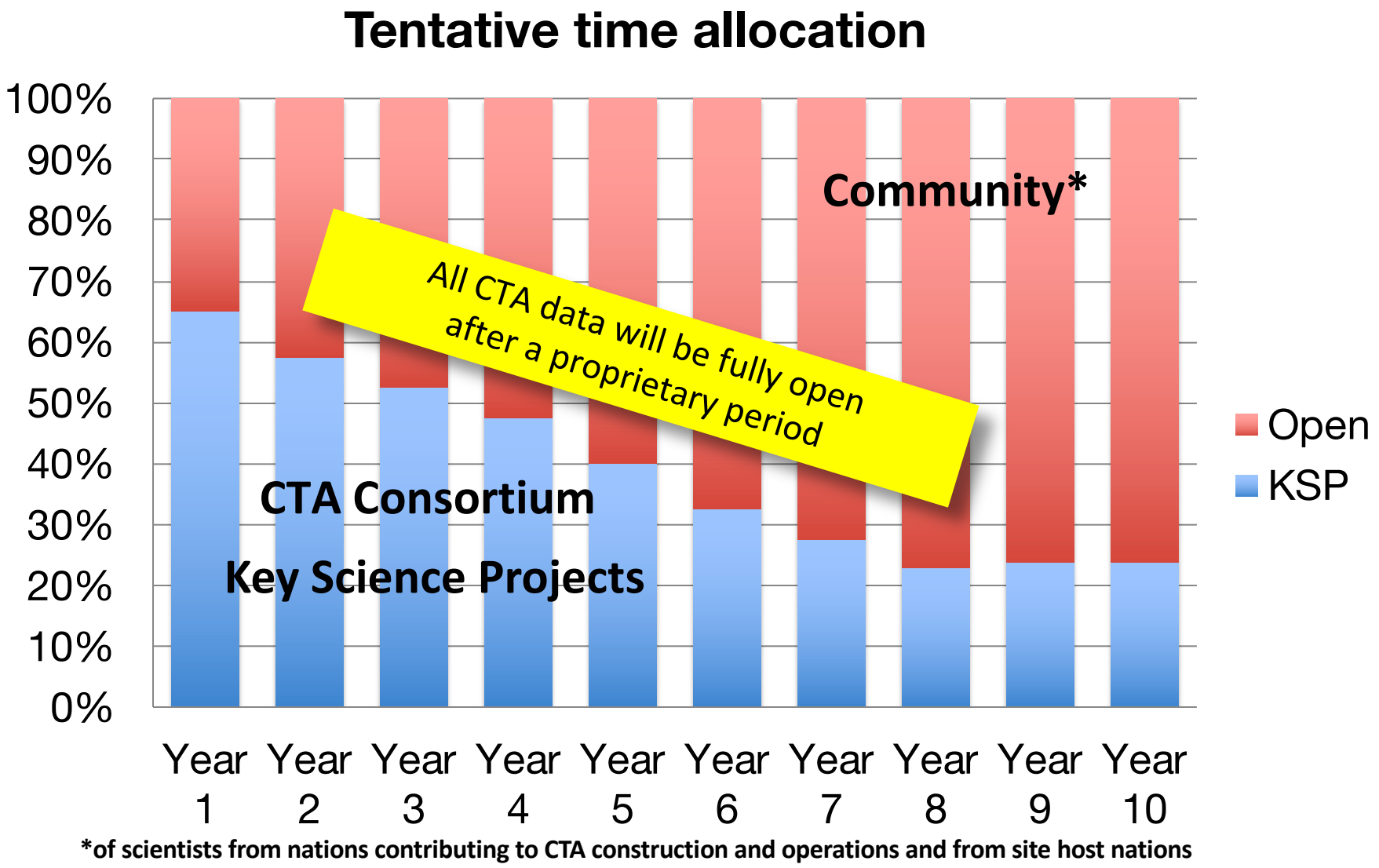
Galactic Plane Survey:

Survey of entire plane to ~2 mCrab
Galactic source population: SNRs, PWNe, etc.
PeVatron candidates, early view of GC, 1620 h

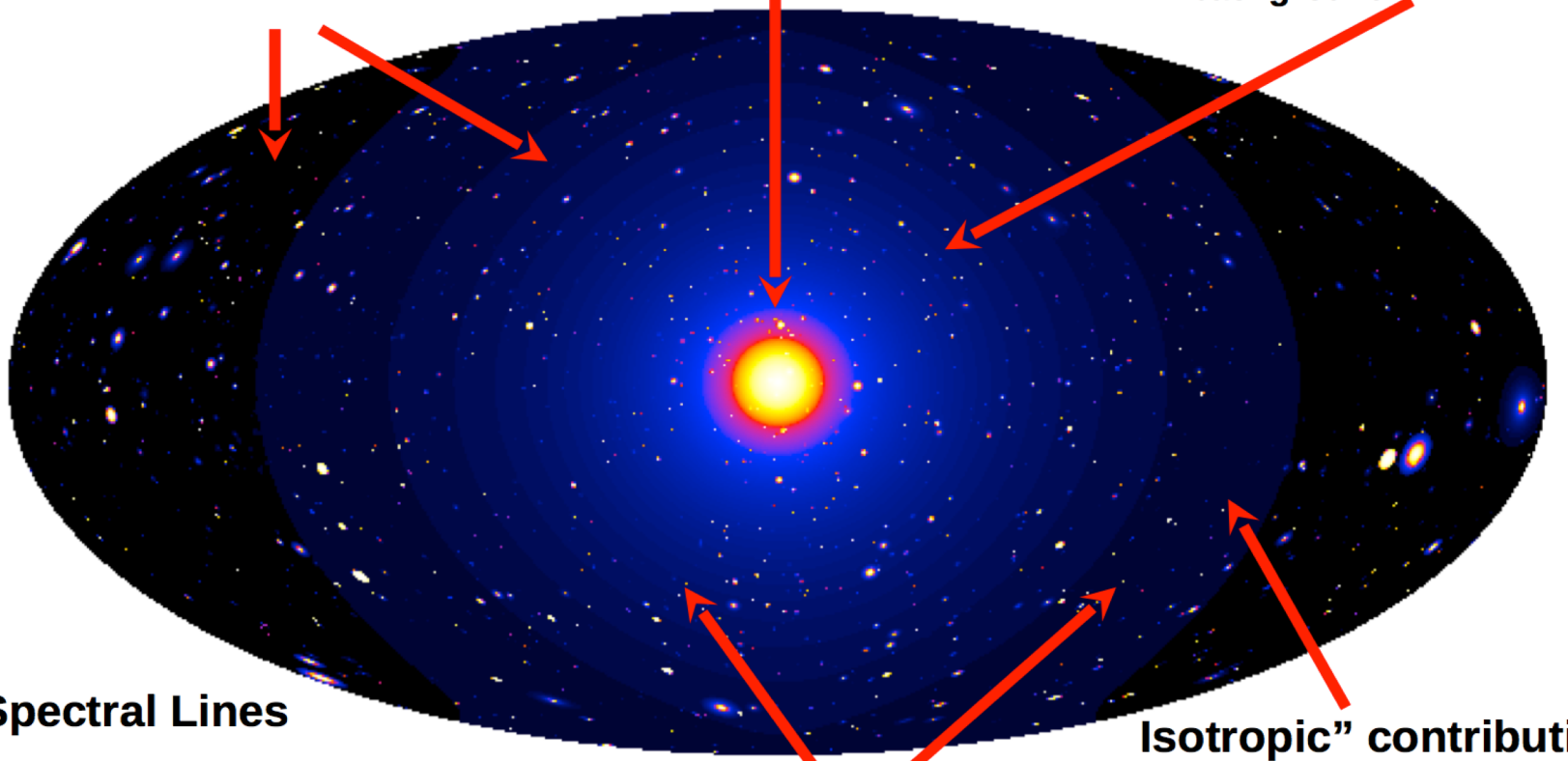
Large Magellanic Cloud Survey:

Face-on satellite galaxy with high SFR
Extreme Gal. sources, diffuse emission (CRs)
DM search; 340 h in six pointings

Time Allocation & Community Access



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

Galaxy Clusters

Low background, but low statistics

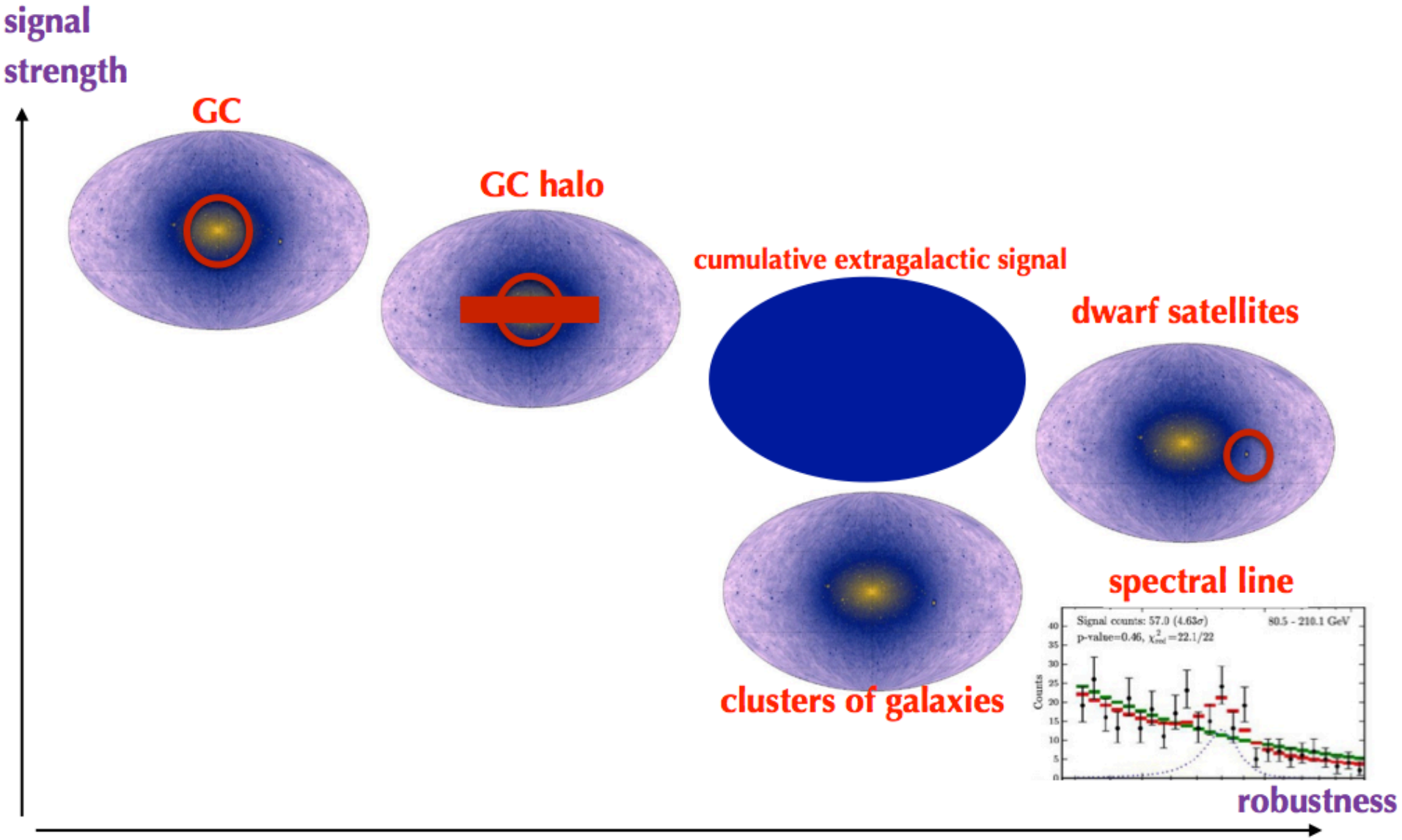
Isotropic" contributions

Large statistics, but astrophysics, galactic diffuse background

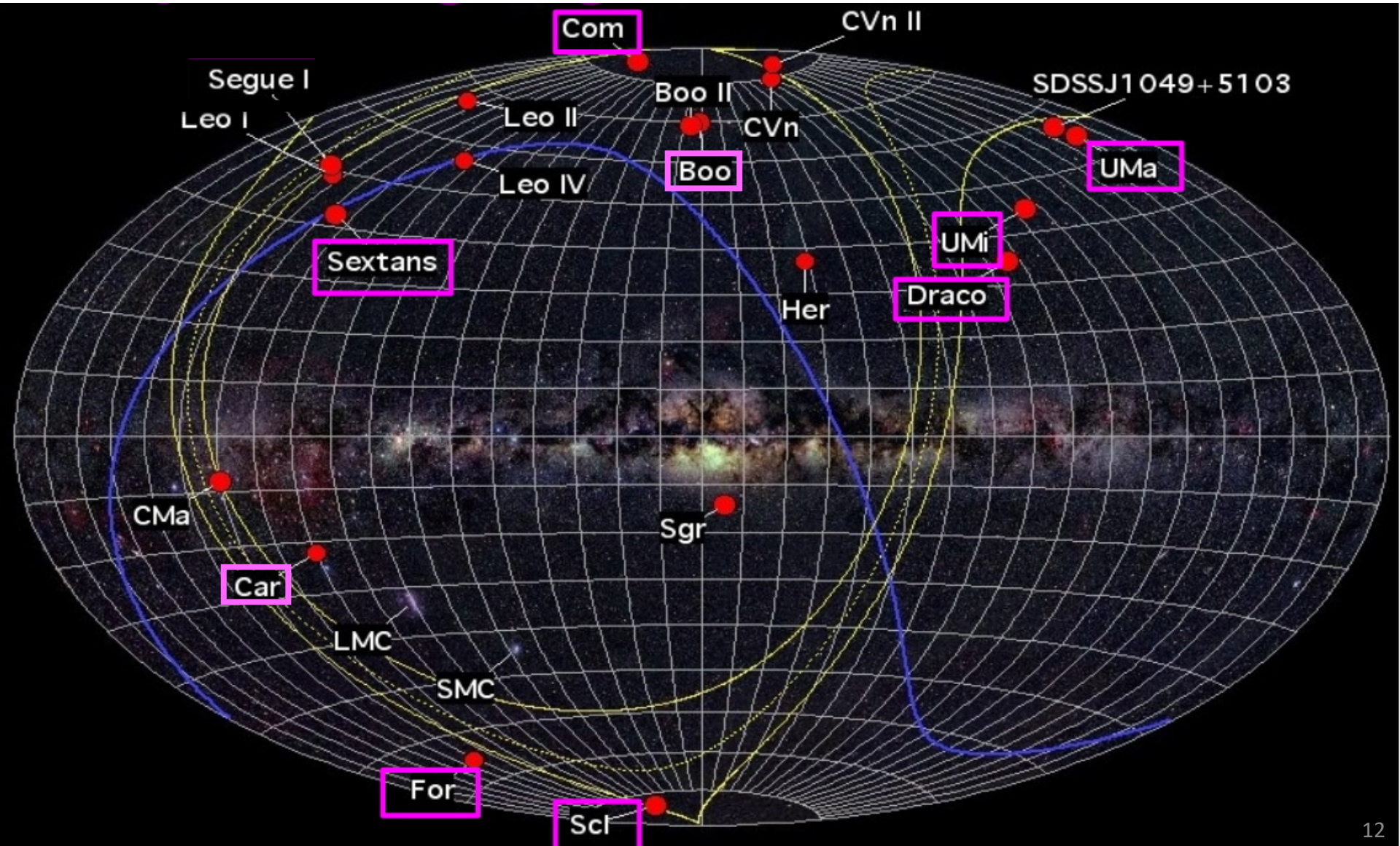
Dark Matter simulation: Pieri+(2009) arXiv:0908.0195

Dark Matter Search: Targets and Strategies

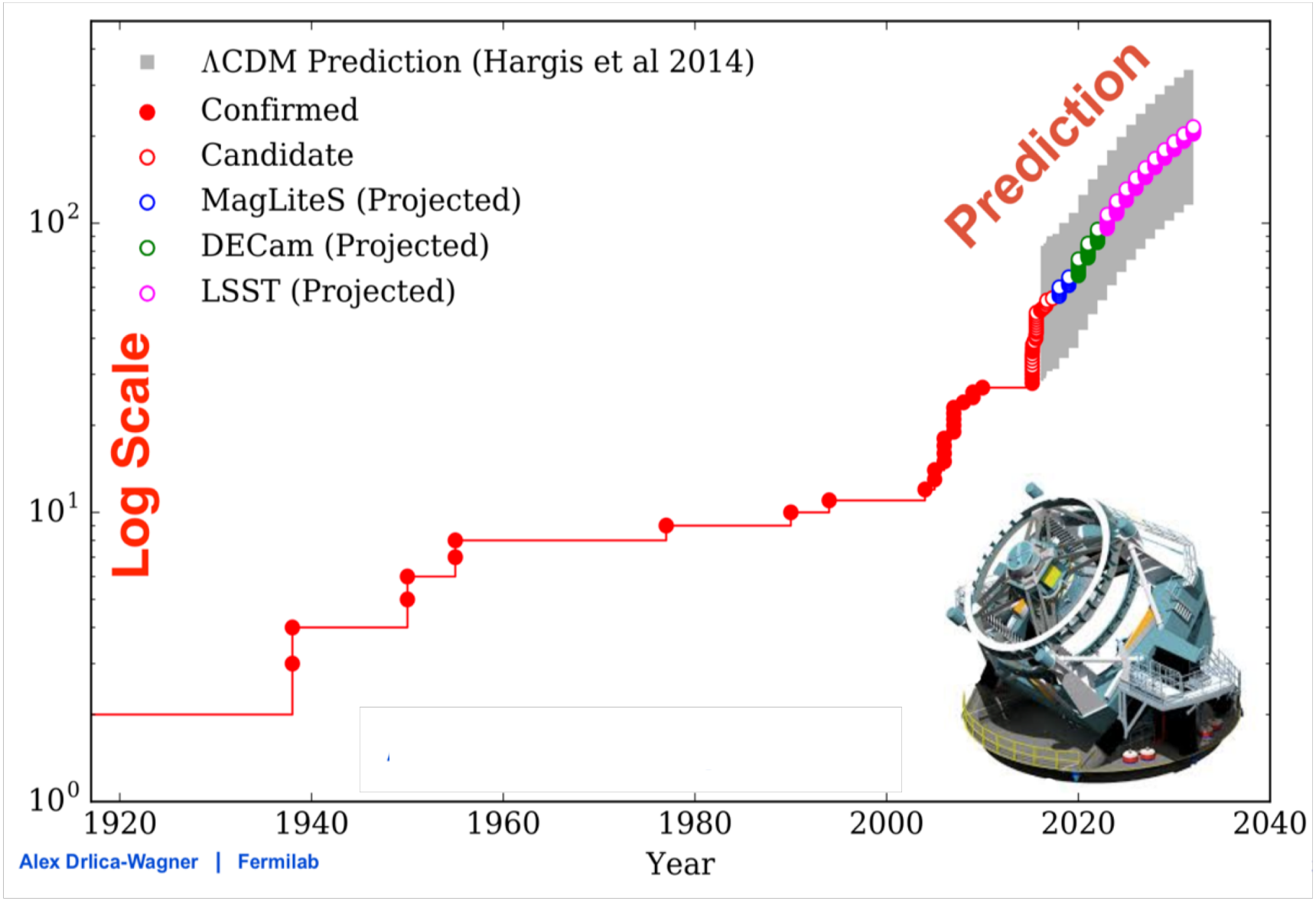
(Another way to see it)



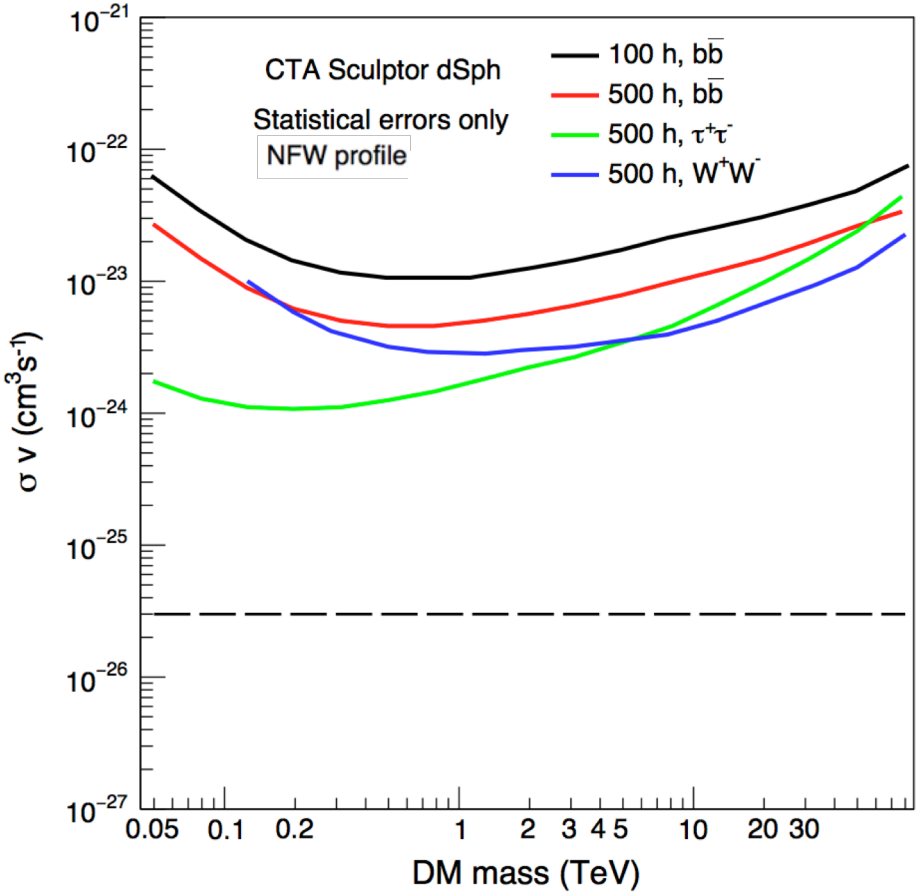
Classical Dwarf spheroidal galaxies: promising targets for DM detection

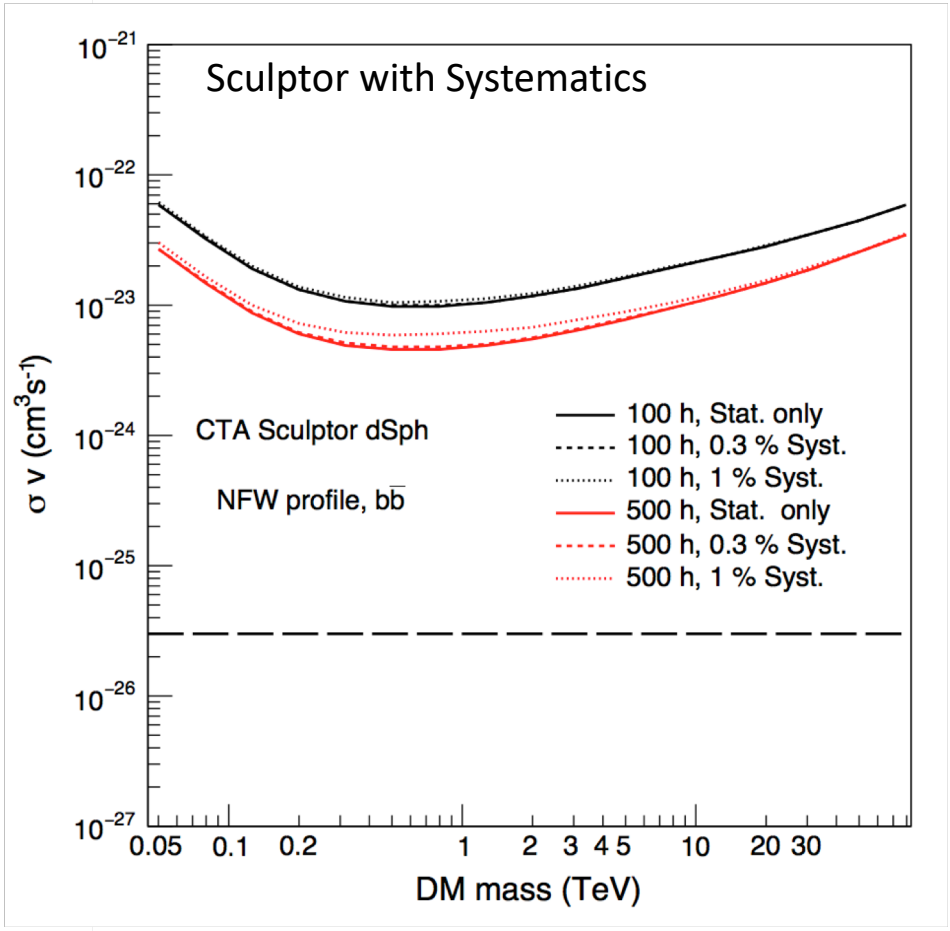


Dwarf Spheroidal Galaxies: Growing number of known targets



Dwarf Spheroidal Galaxies: CTA Sensitivity





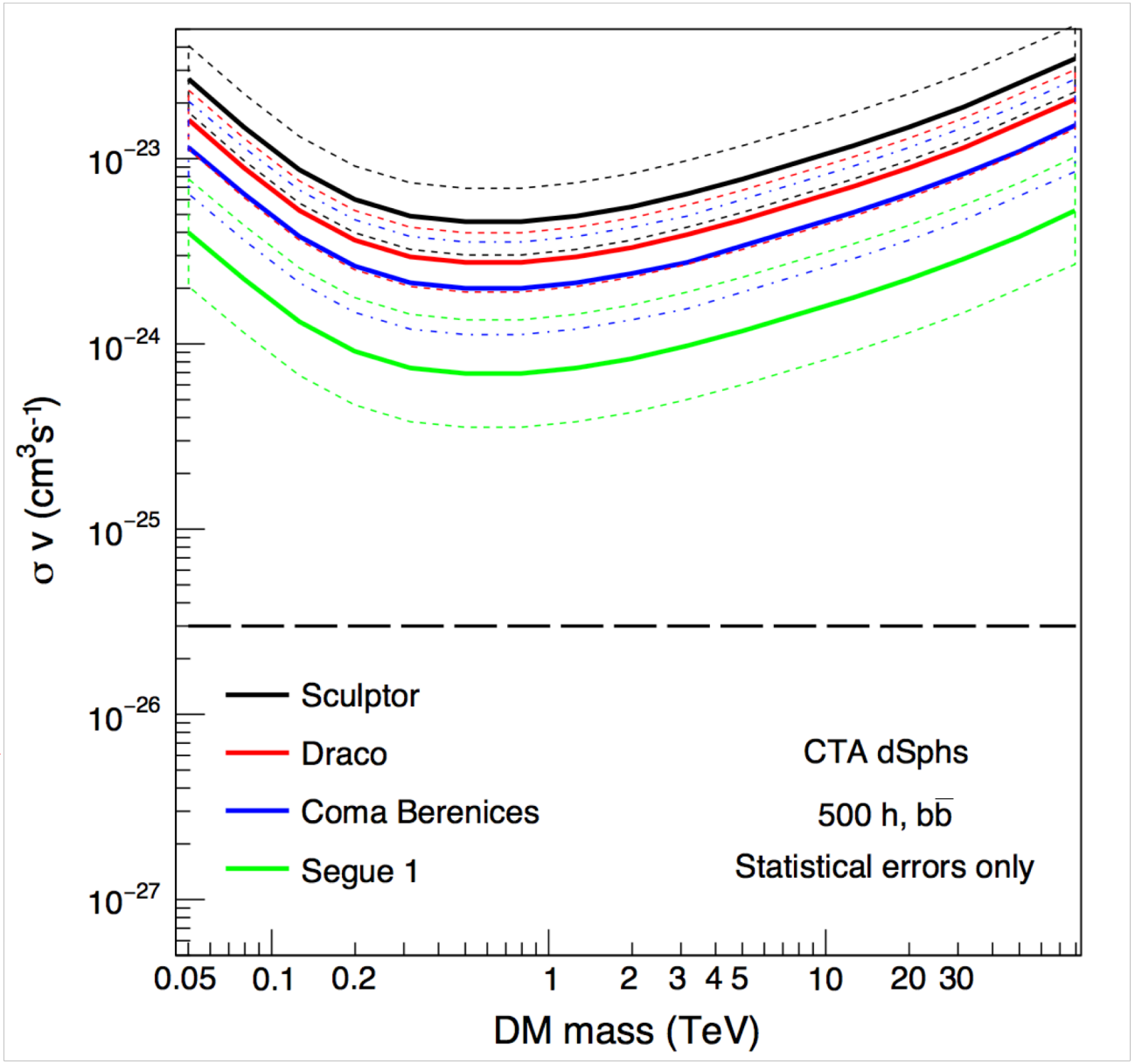
There are several of the newly discovered dSph that have a better case for being a promising target,
Will choose most promising targets before observations with the latest knowledge.

Dwarf Spheroidal Galaxies: CTA Sensitivity

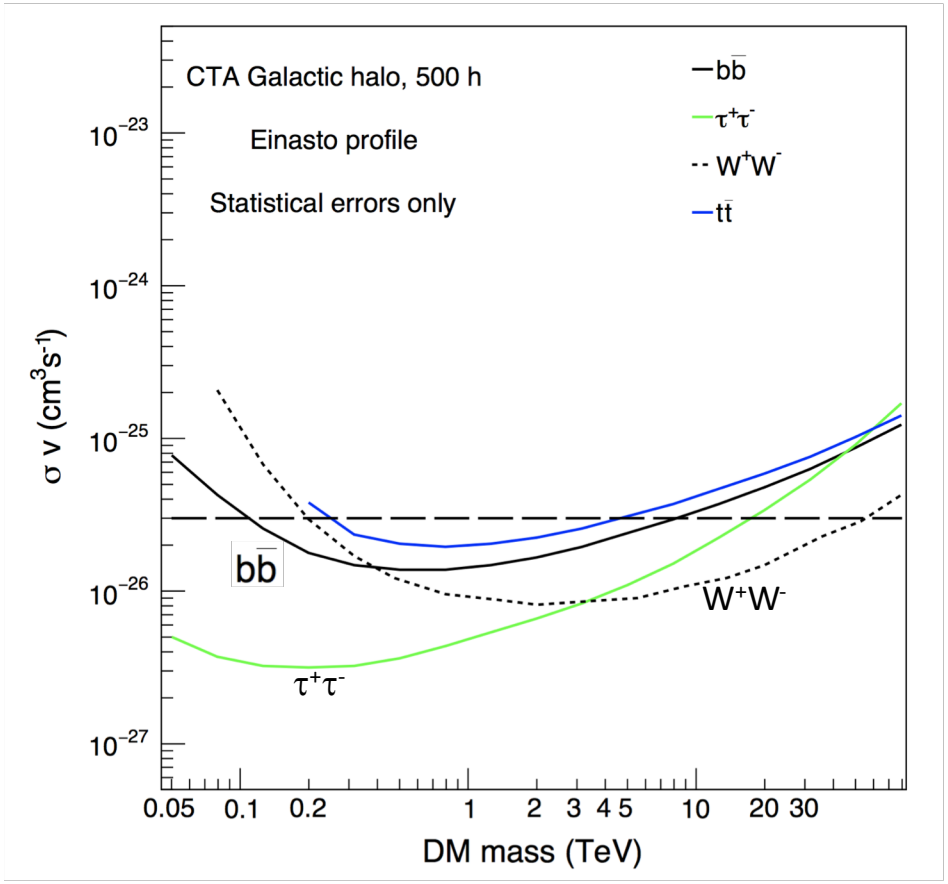
for different Dwarfs.

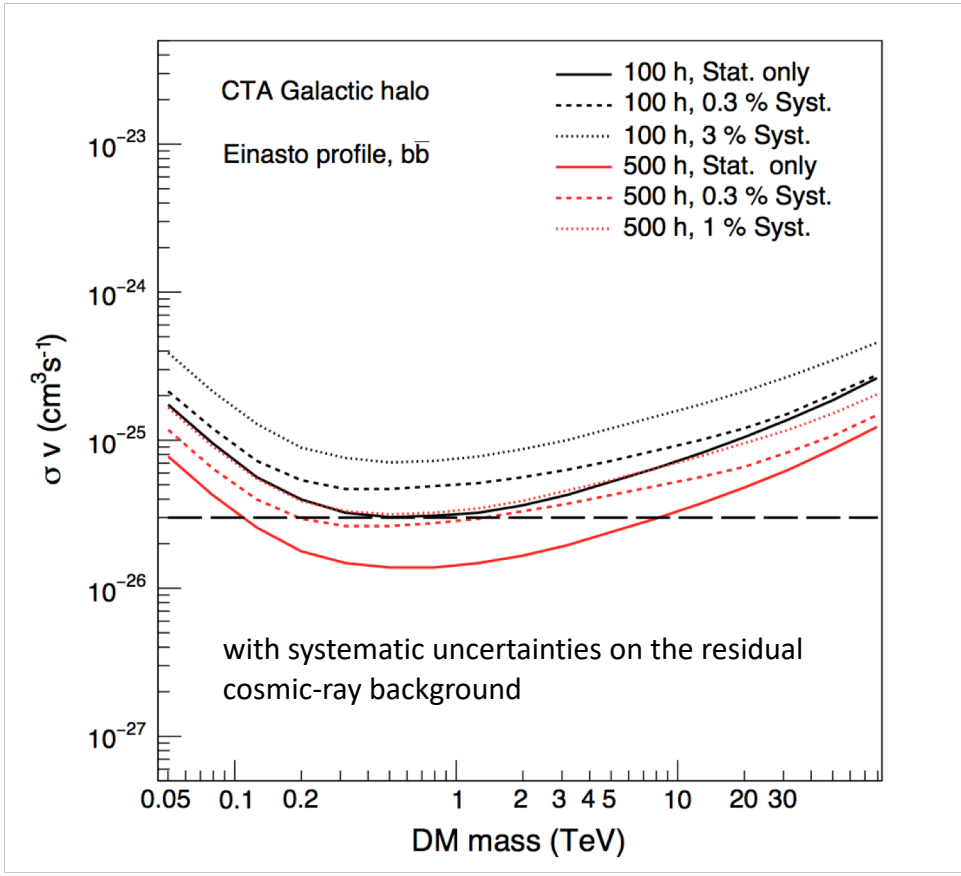
Dashed lines correspond to ±1σ on the J-factors

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

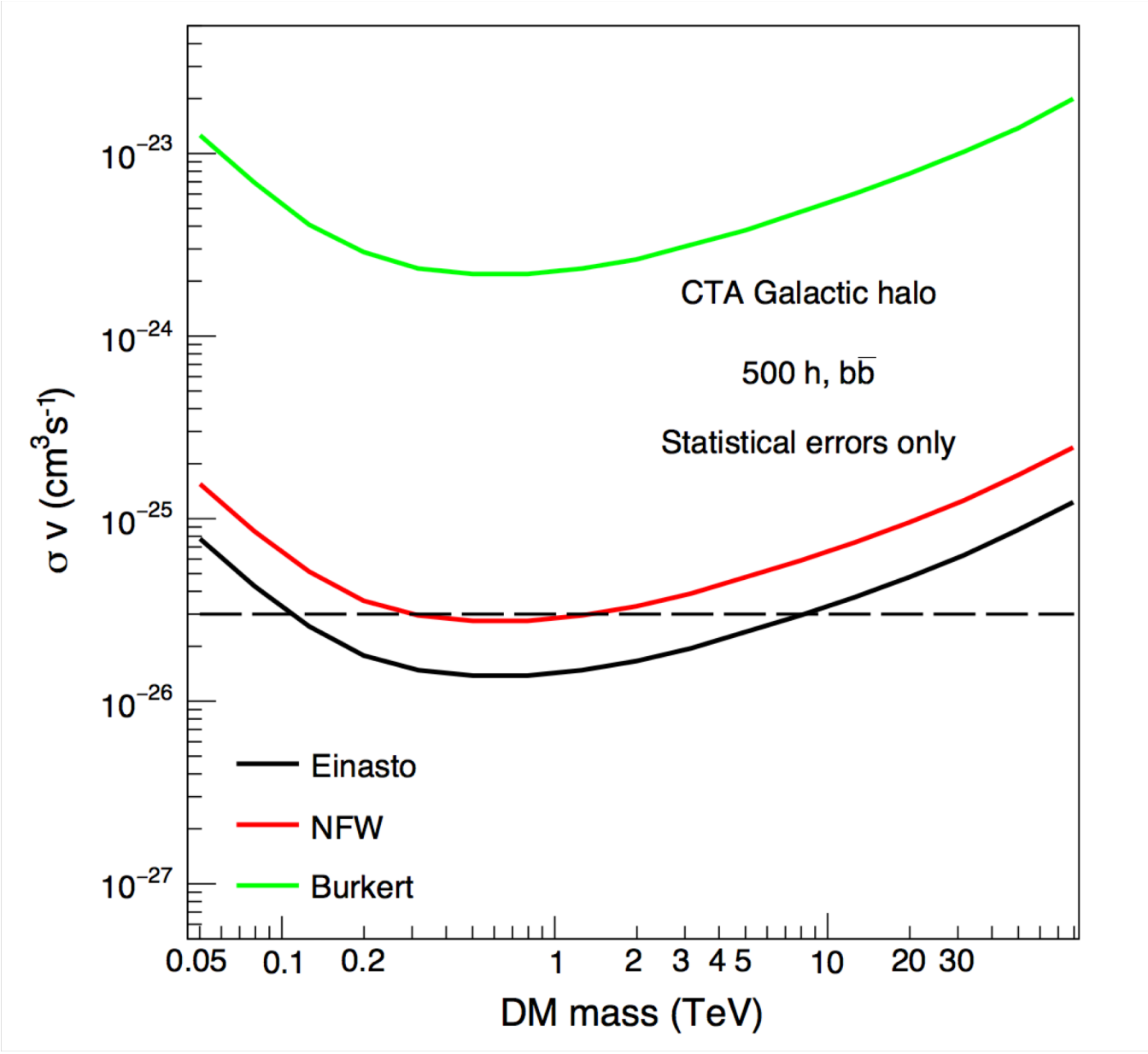




The predictions shown here can be considered optimistic, even when systematics errors are included, as we do not consider the effect of the Galactic diffuse emission as background for DM searches that can affect the results by ~ 50%
This will be investigated in detail in a forthcoming publication by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

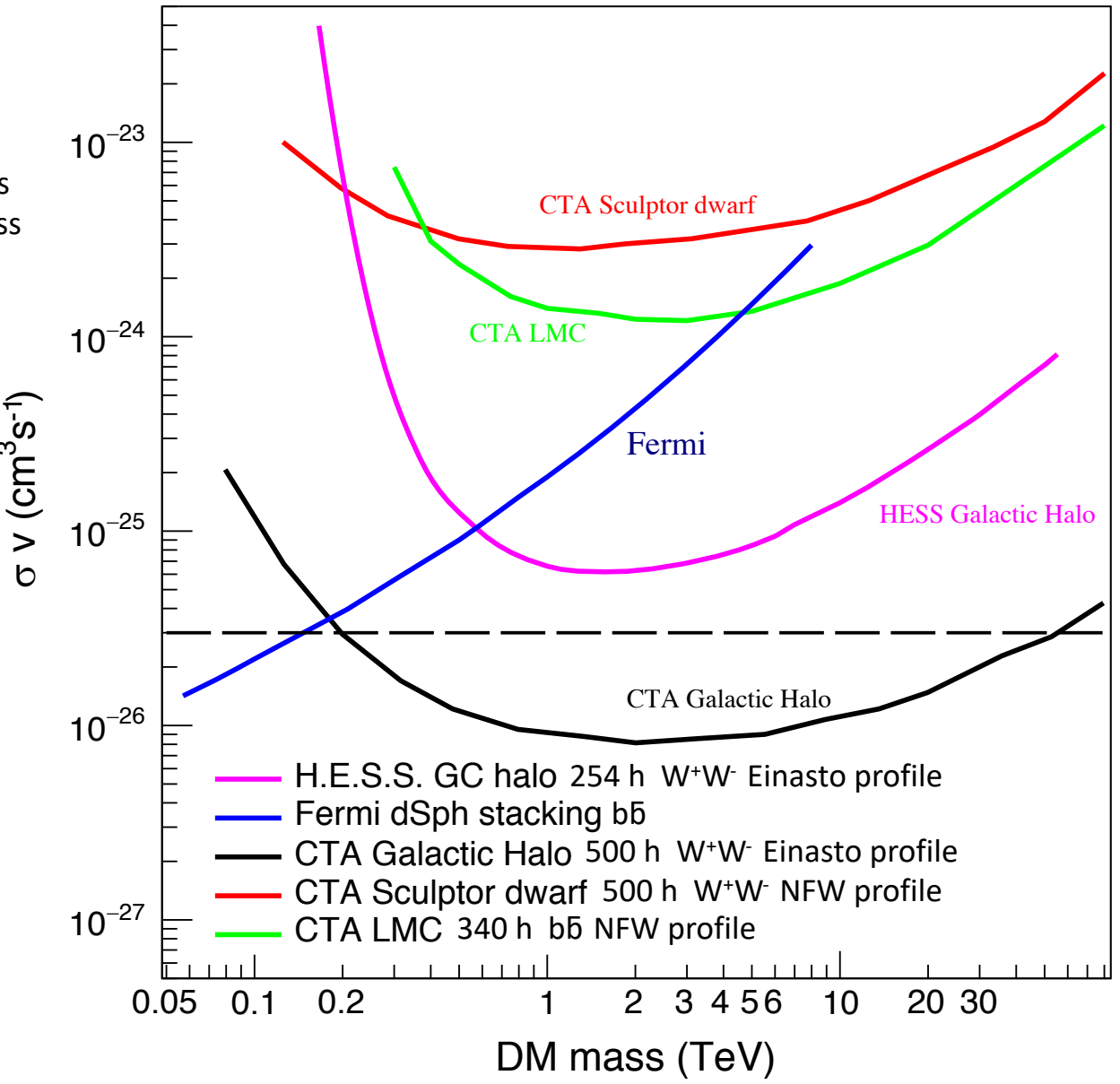
CTA Galactic Halo DM upper-limits

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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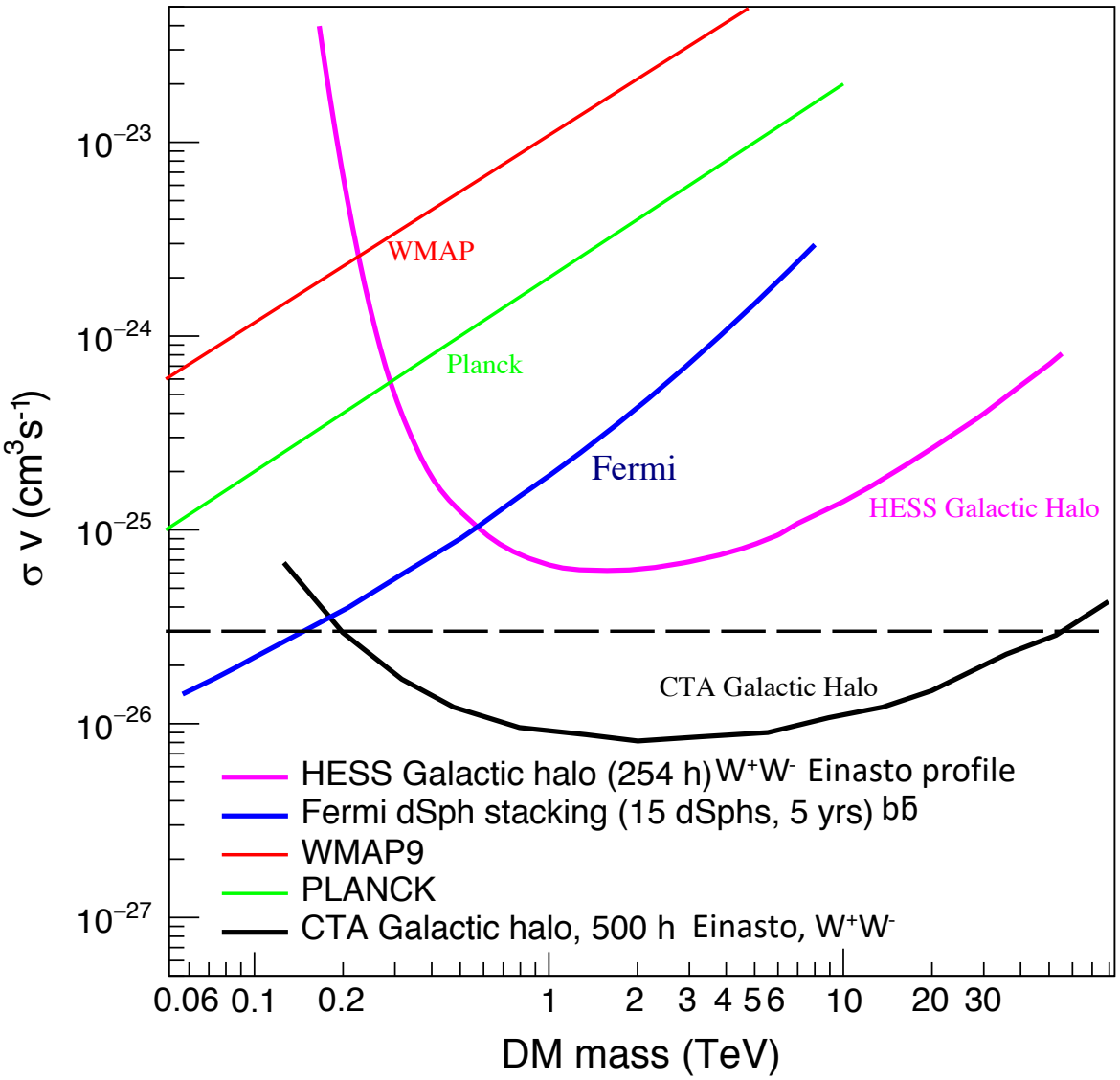
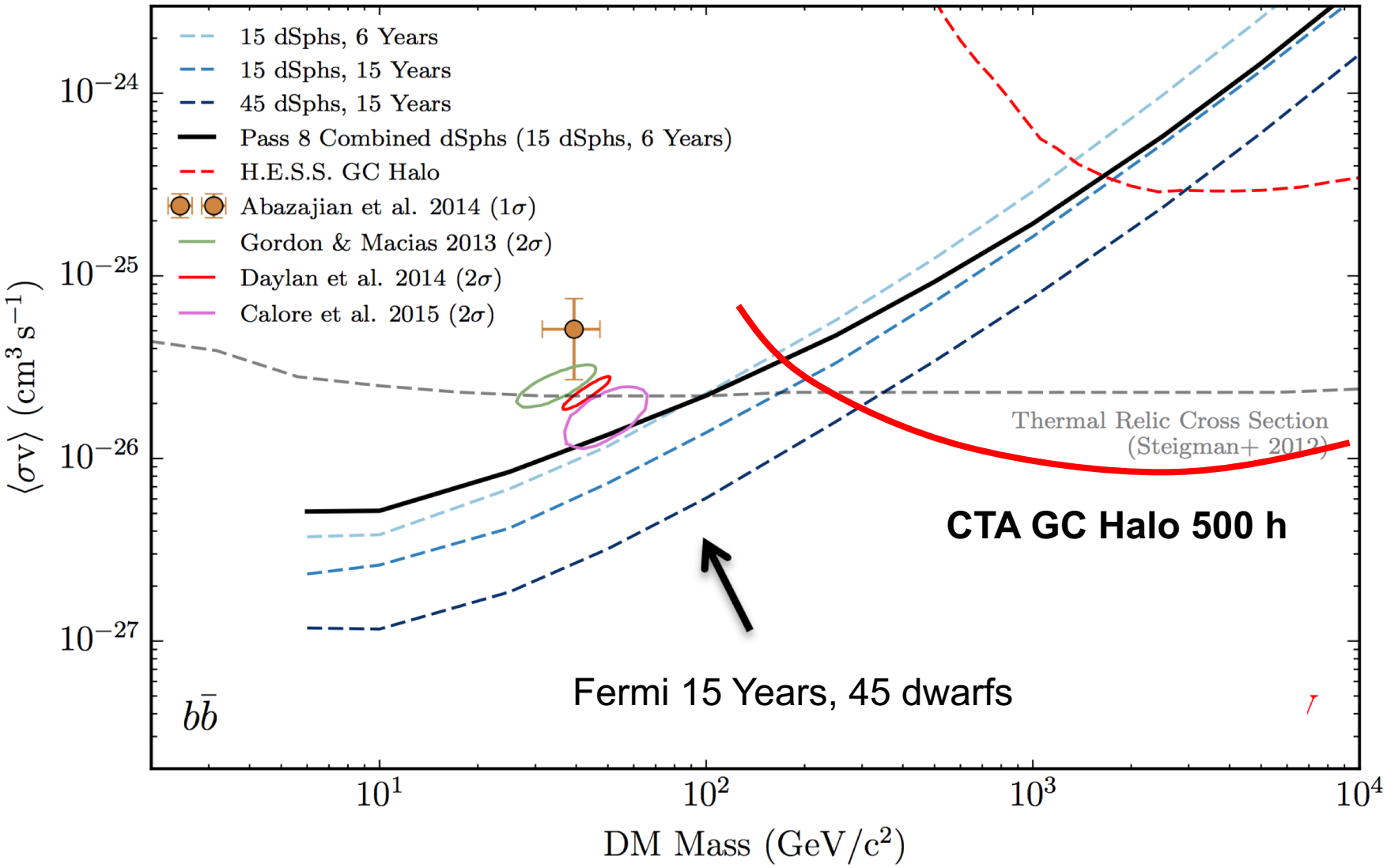


DM limit improvement estimate in 15 years (2008- 2023)



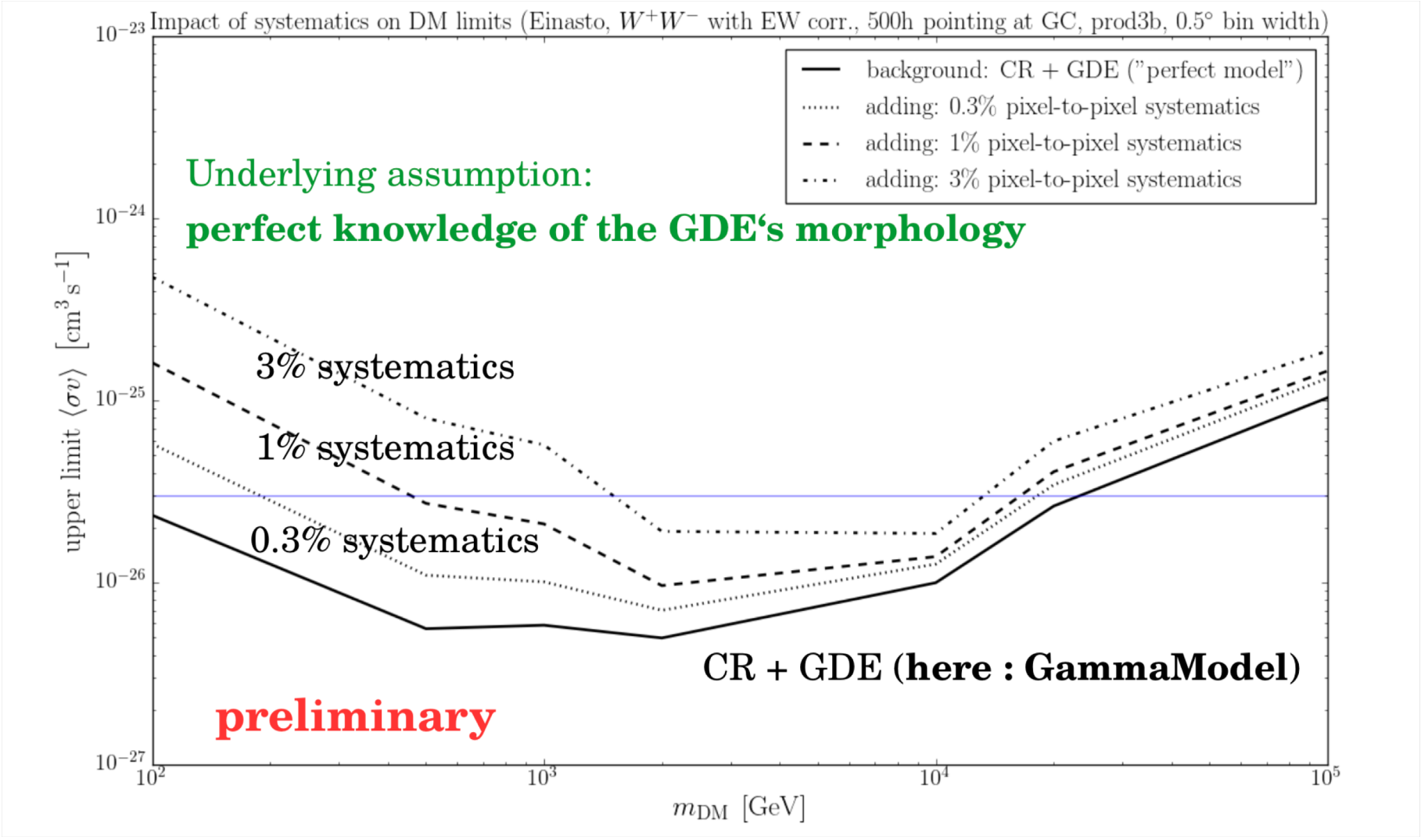
Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

An example of the work in the GC Dm Task Force

Consider the WW – channel with simplified EW corrections ...

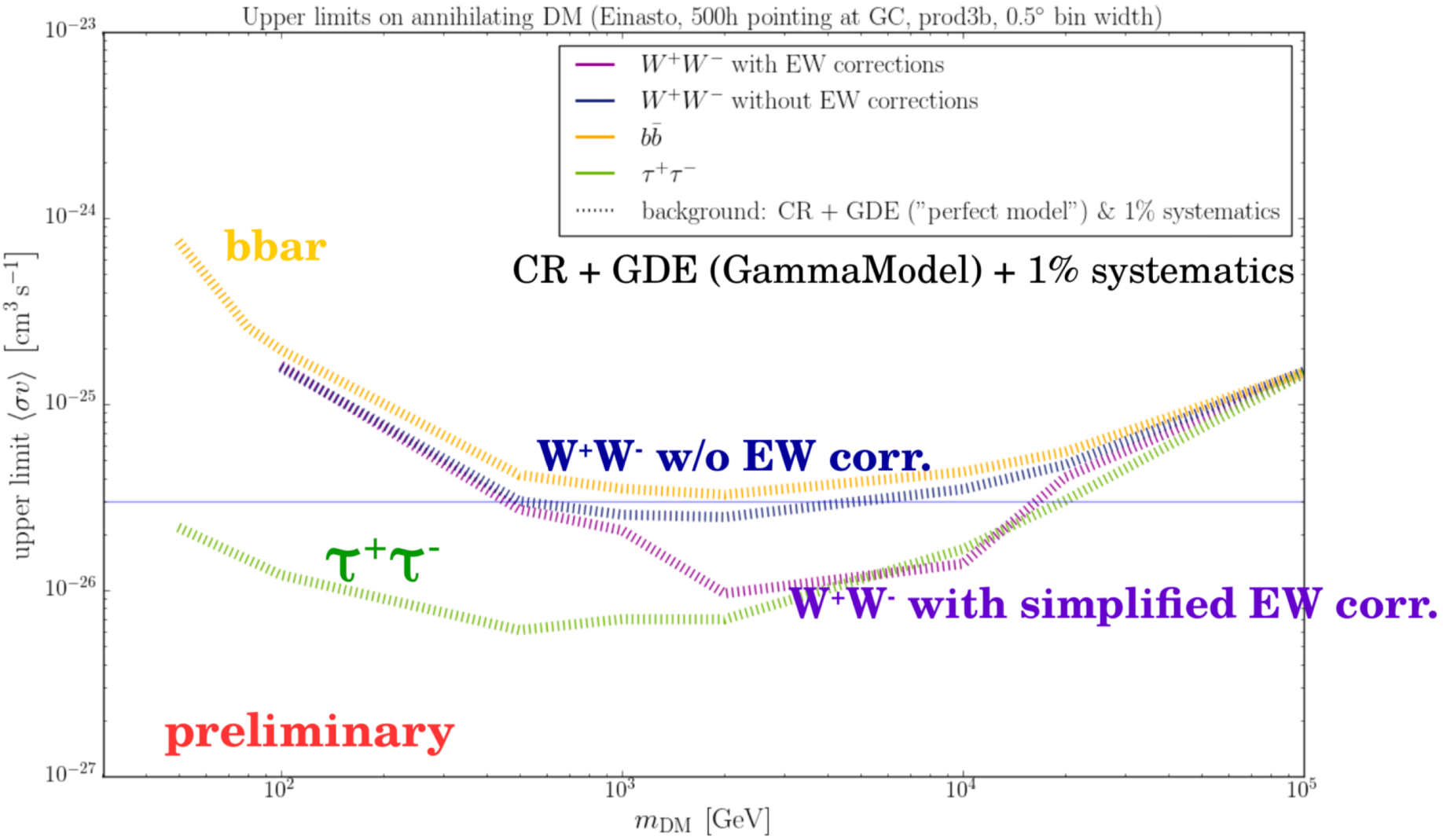
→ Assume "perfect" modelling of the Galactic Diffuse Emission (GDE) with the GammaModel template.

→ What is the effect of varying the level of pixel-to-pixel systematics?



An example of the work in the GC Dm Task Force (2)

Pixel-to-pixel systematics have the largest impact on the DM limits within our approach.
→ How do different annihilation channels compare?



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.

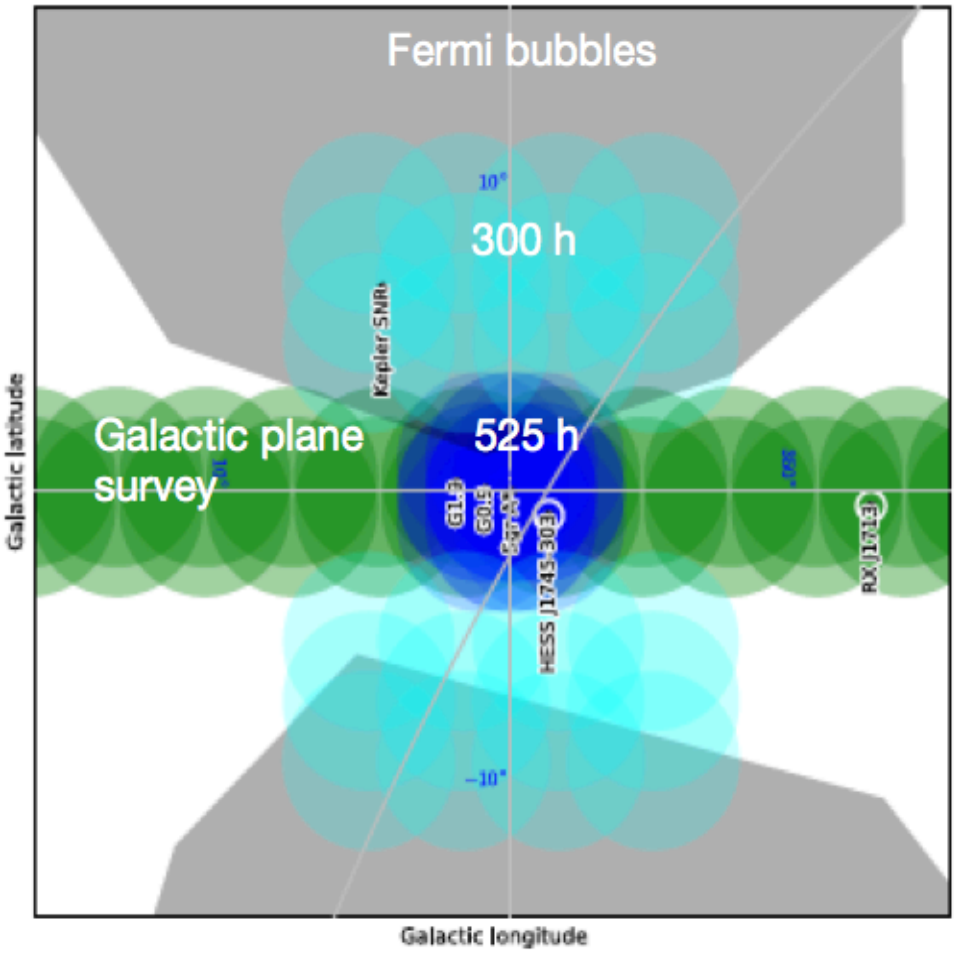
DEEP OBSERVATIONS OF GC REGION

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

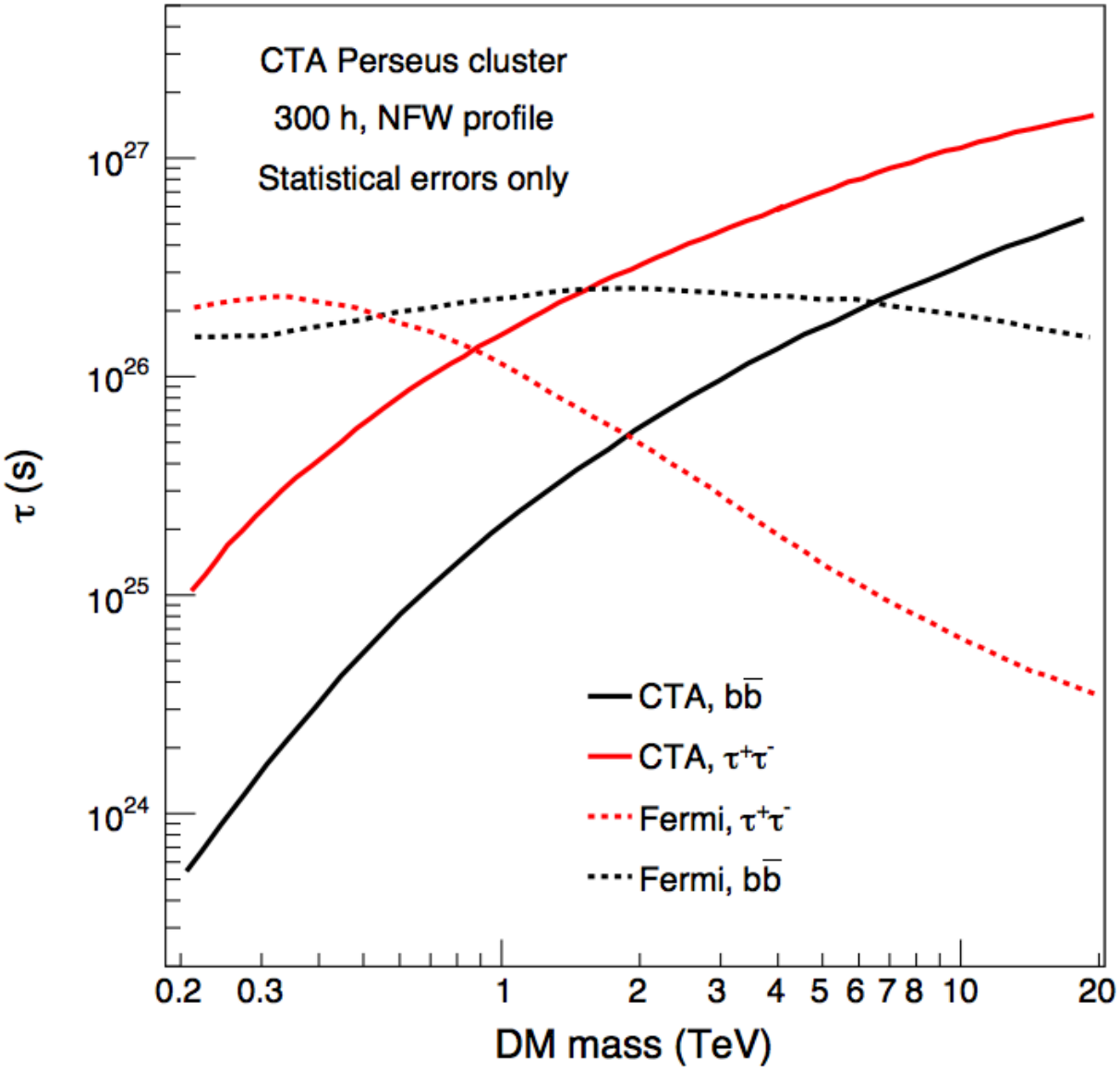
- GC and GC DM halo
- Understand "backgrounds" pin down VHE sources and map diffuse emission
- Astrophysics of SNRs (multiple sources, e.g. G1.9, …)
- Astrophysics of PWNe and Pulsars
- Extended objects such as Central Radio lobes (central ±1°) and arc features.



CTA legacy data set

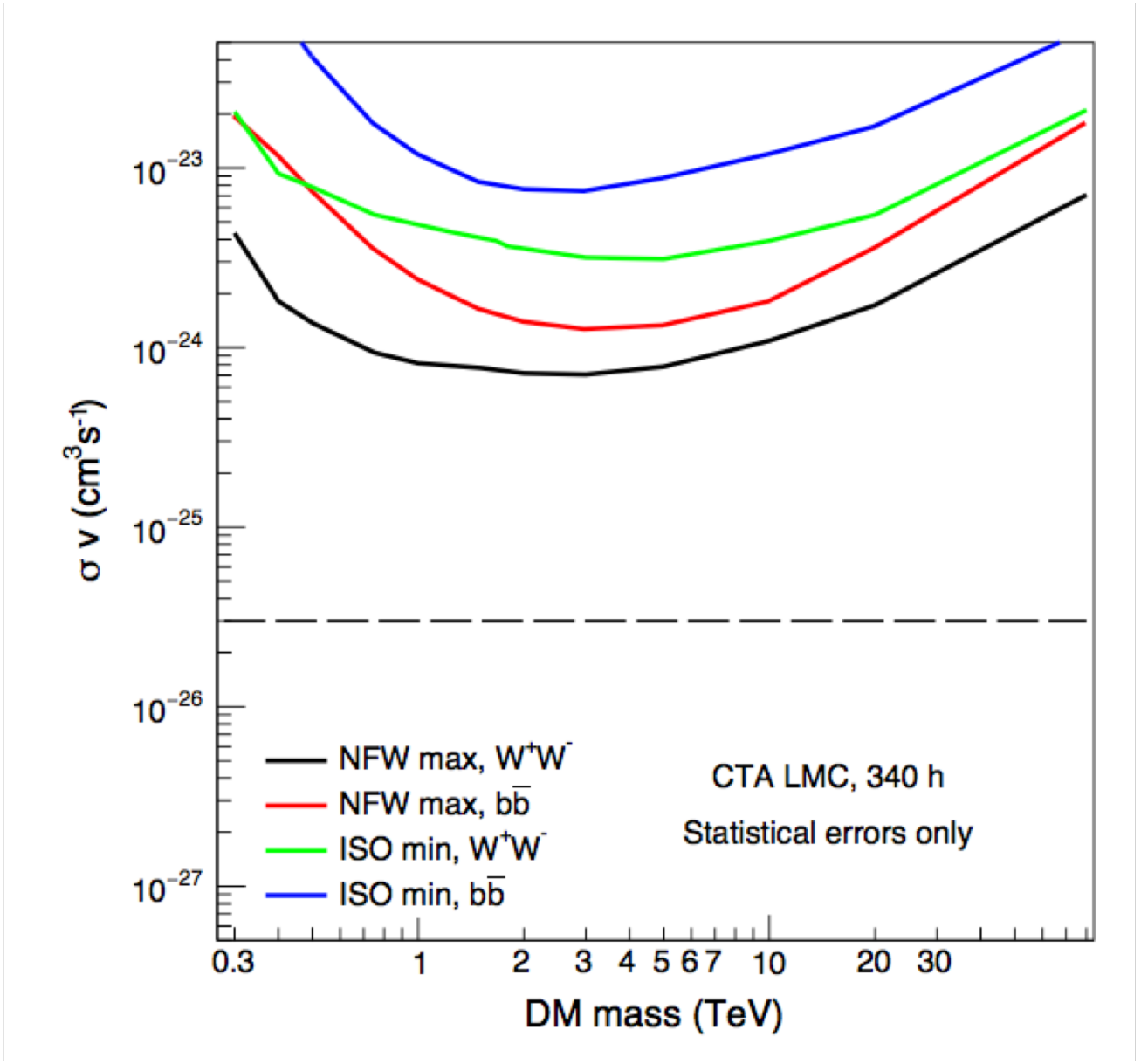
Perseus cluster

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



DM Consortium Publications

- Dark Matter in the Galactic Centre (KSP)
- Dark Matter in Dwarf Spheroidal Galaxies (KSP)
- Dark Matter in the Large Magellanic Cloud
- Dark Matter in Clusters of Galaxies
- Dark Matter lines

In Coordination with other groups

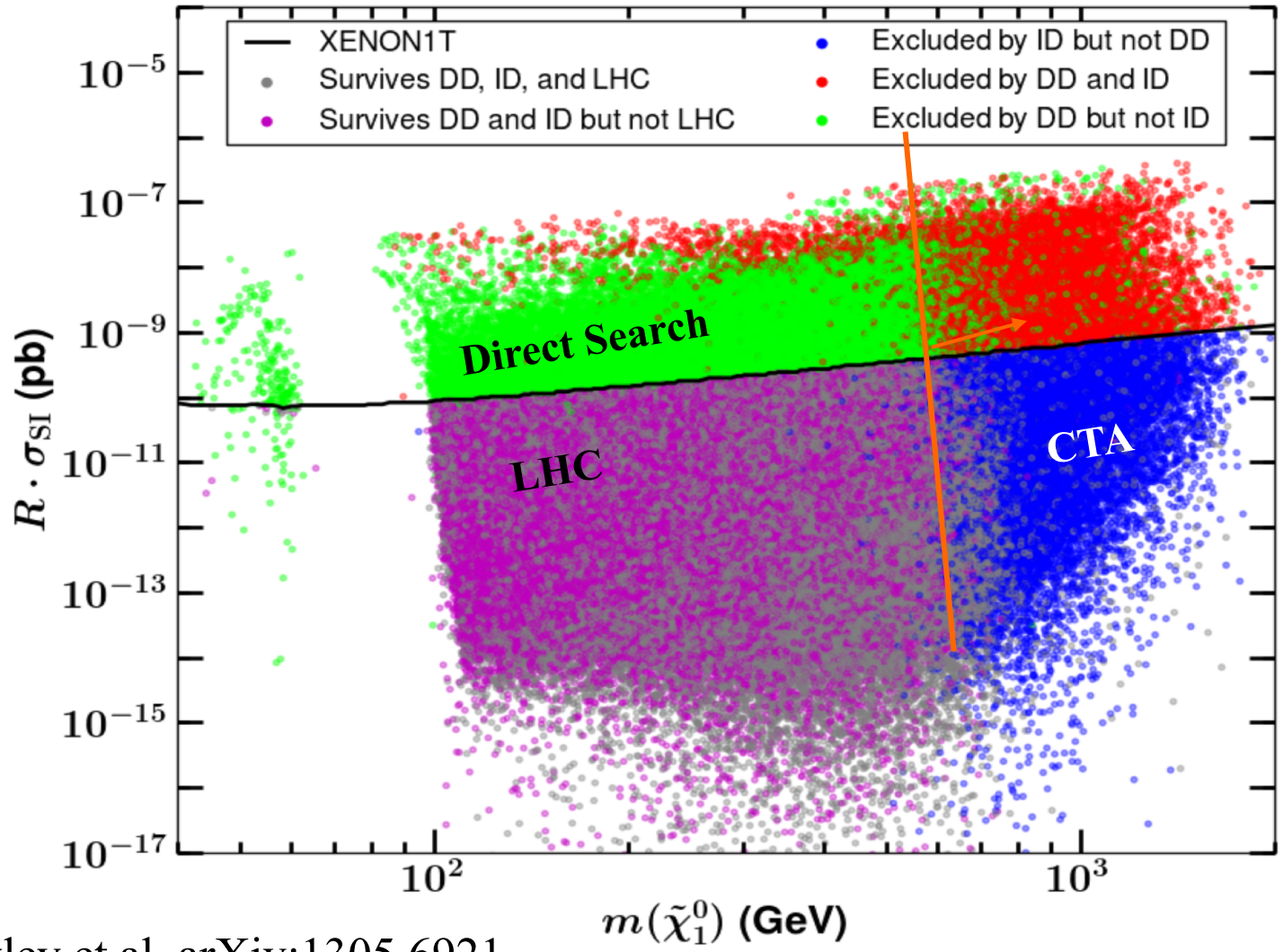
- Dark Matter in the Large Magellanic Cloud

in coordination with CR SWG

- Dark Matter in the Galactic Centre paper

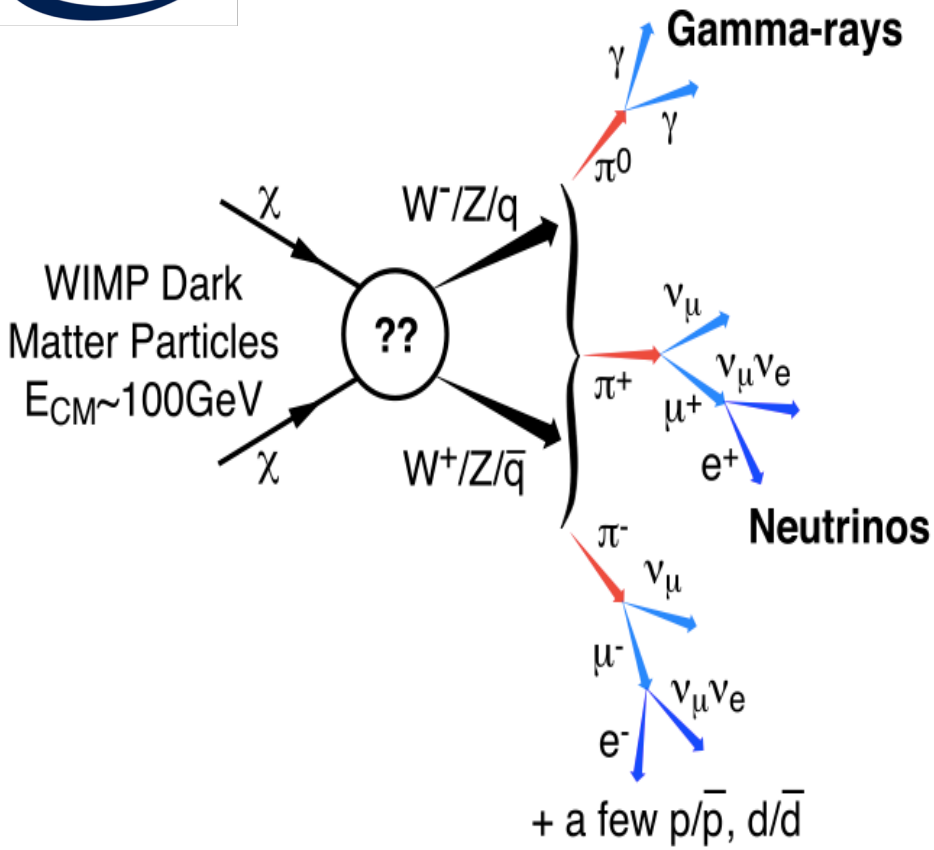
in coordination with the Galactic Centre survey team

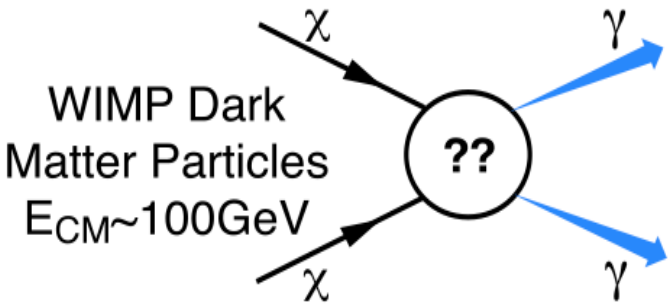
Complementarity and Searches for Dark Matter in the pMSSM

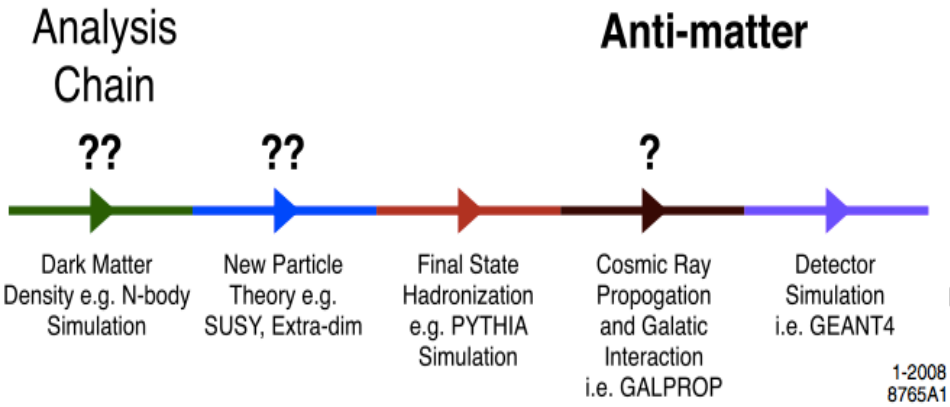


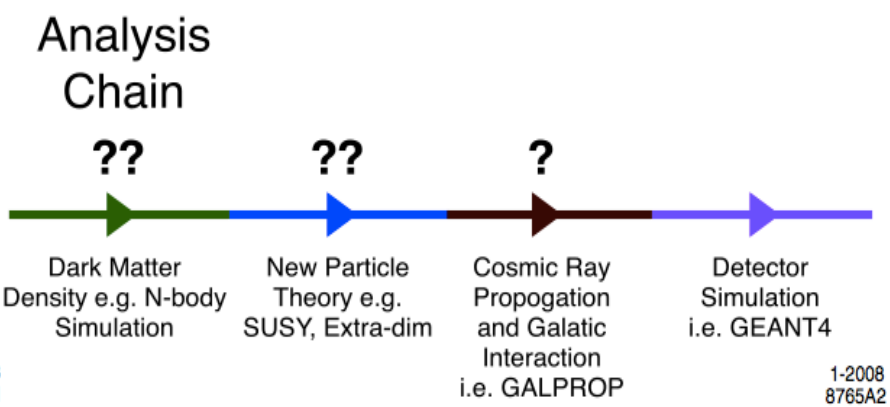
Cahill-Rowley et al. arXiv:1305.6921

Annihilation channels

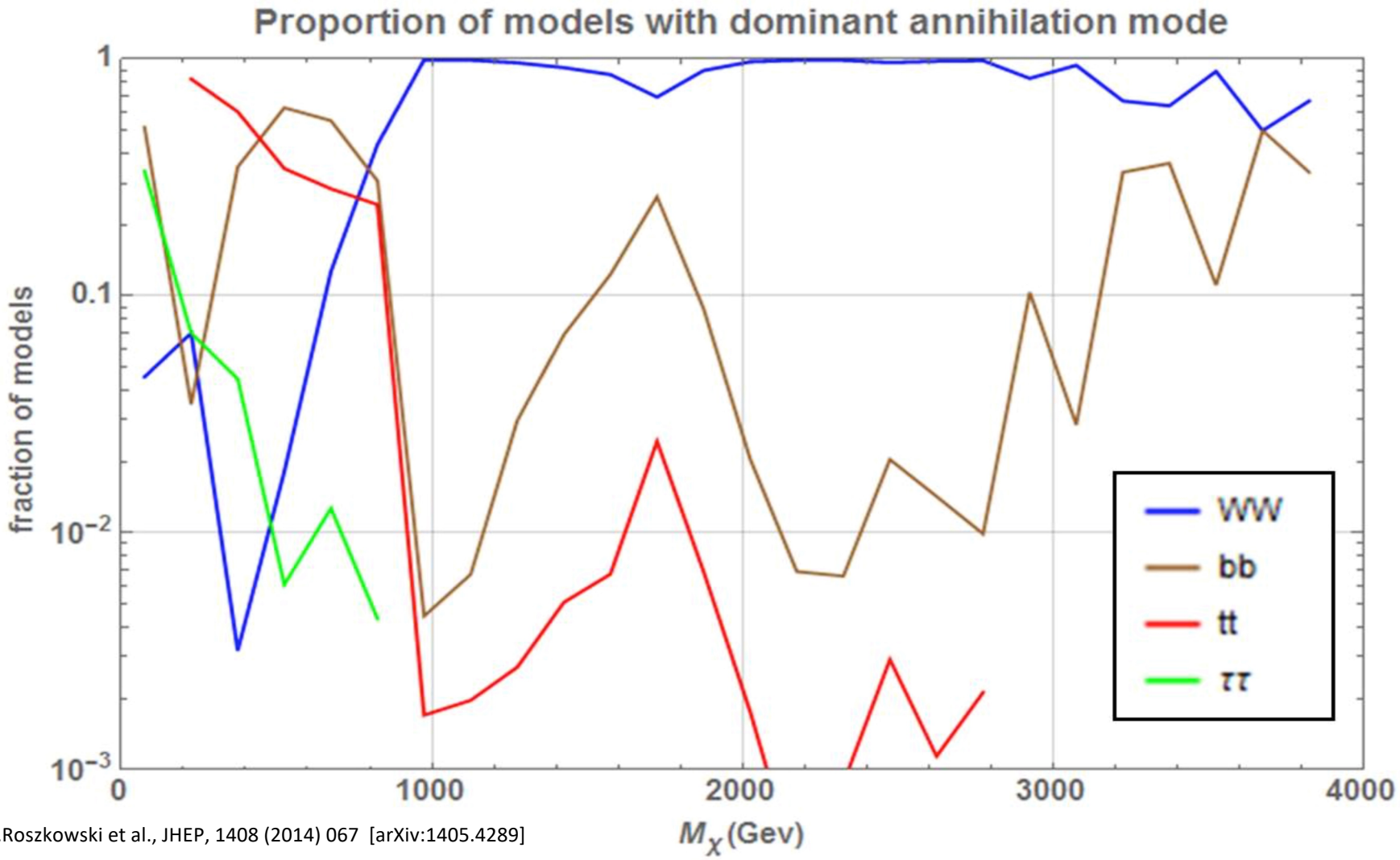








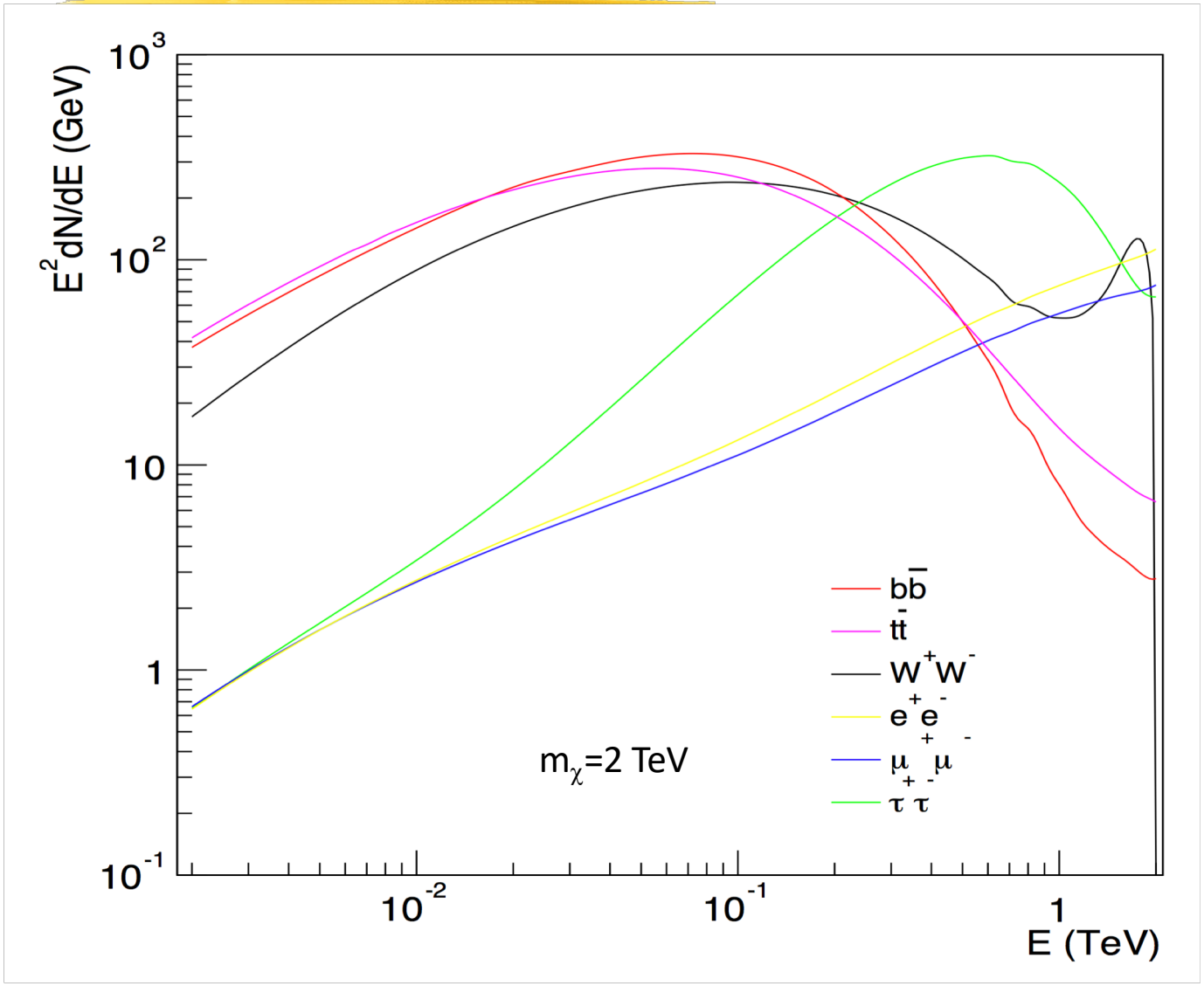
Which channel to choose?
Example: The dominant annihilation modes in the pMSSM scan



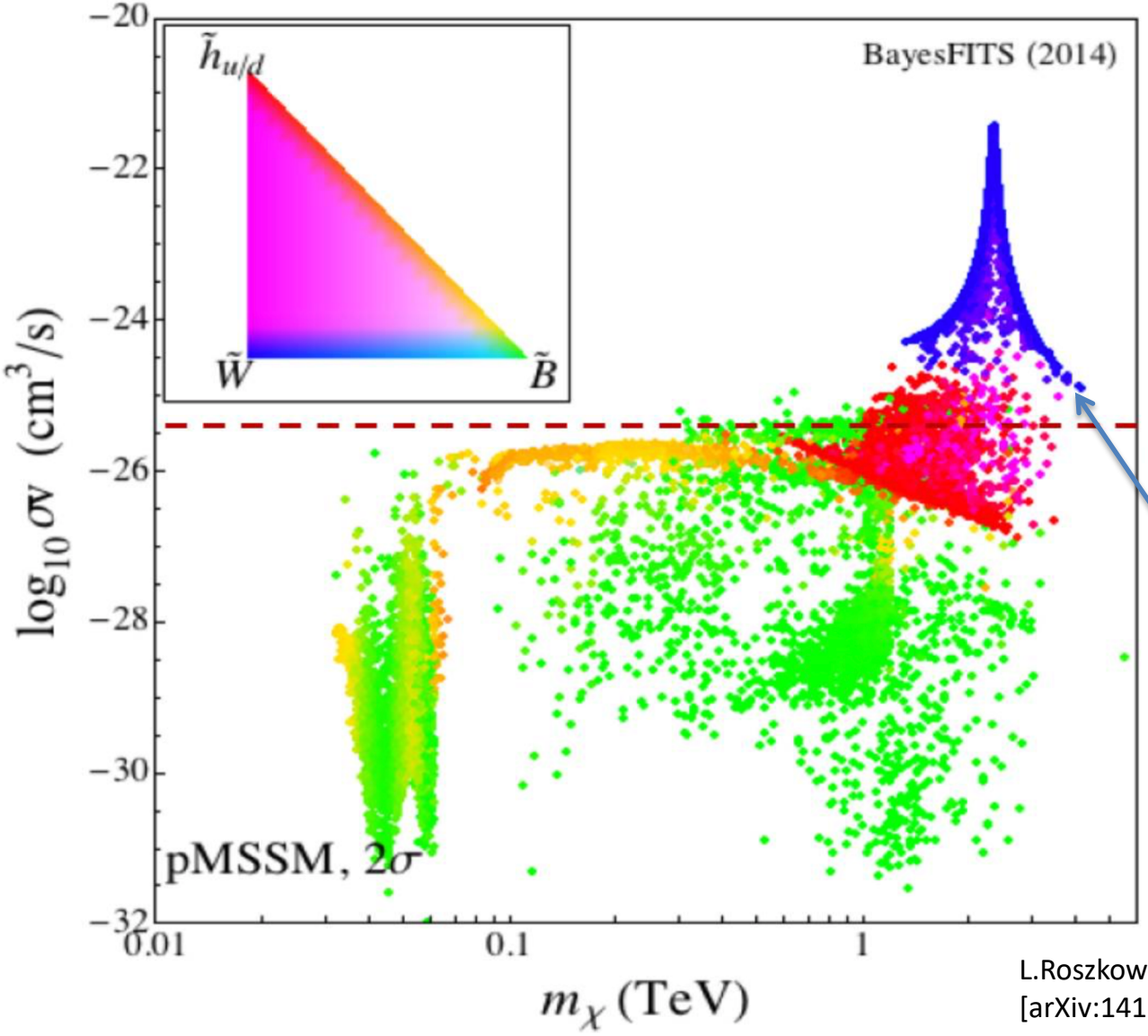
L.Roszkowski et al., JHEP, 1408 (2014) 067 [arXiv:1405.4289]

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



note: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 1502 (2015) 014 [arXiv:1411.5214]

CTA: Analysis Software

A high-level data analysis package for gamma-ray astronomy

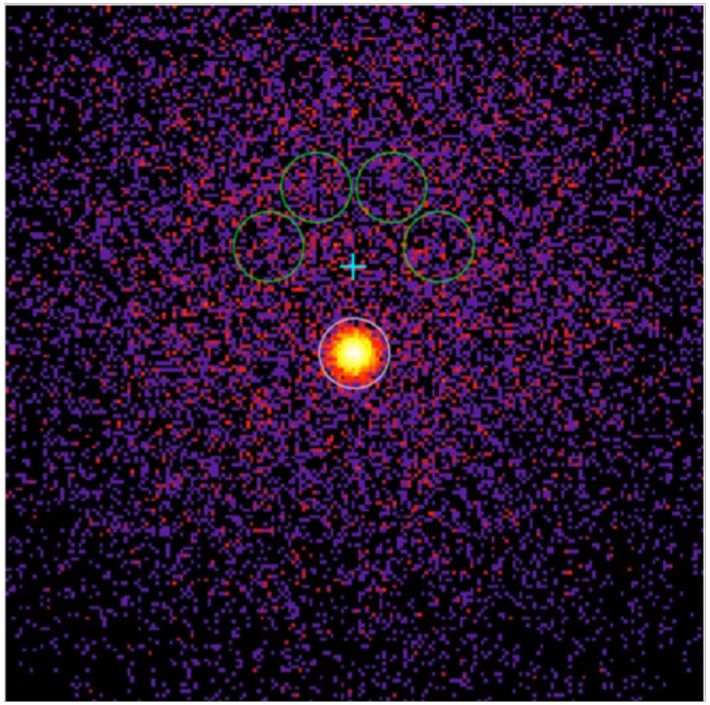
- **GammaLib-CTOOLS:**
  - COMPTEL
  - Fermi/LAT
  - Cherenkov telescopes (CTA, H.E.S.S., MAGIC, VERITAS)
- **Gammapy:**
  - Fermi/LAT
  - Cherenkov telescopes (CTA, H.E.S.S., MAGIC, VERITAS)

CTA: Analysis Software

- All tools needed to generate images, spectra, light and phase curves from CTA DL3 data

– Support for unbinned, binned and stacked 3D/4D maximum likelihood analysis

– Support for classical On/Off IACT analysis (ring background sky maps, reflected region spectra)



Download & Documentation

GammaLib-CTOOLS:
http://gammalib.sourceforge.net/
http://cta.irap.omp.eu/ctools/index.html

Gammapy:
http://gammapy.org/
Both have also regular coding sprints for user and developers

GammaLib+CTOOLS and Gammapy are a high-level data analysis package for gamma-ray astronomy

Both are work in progress

They are very well documented

Gammapy is a python library

CTOOLS is a set of user-friendly command-lines tools that also support python

They are being used in the first Data Challenge

This first Data Challenge is used to comparer both frameworks

And also to improve their analysis algorithms, debugging, ecc.

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.

Thank you !!