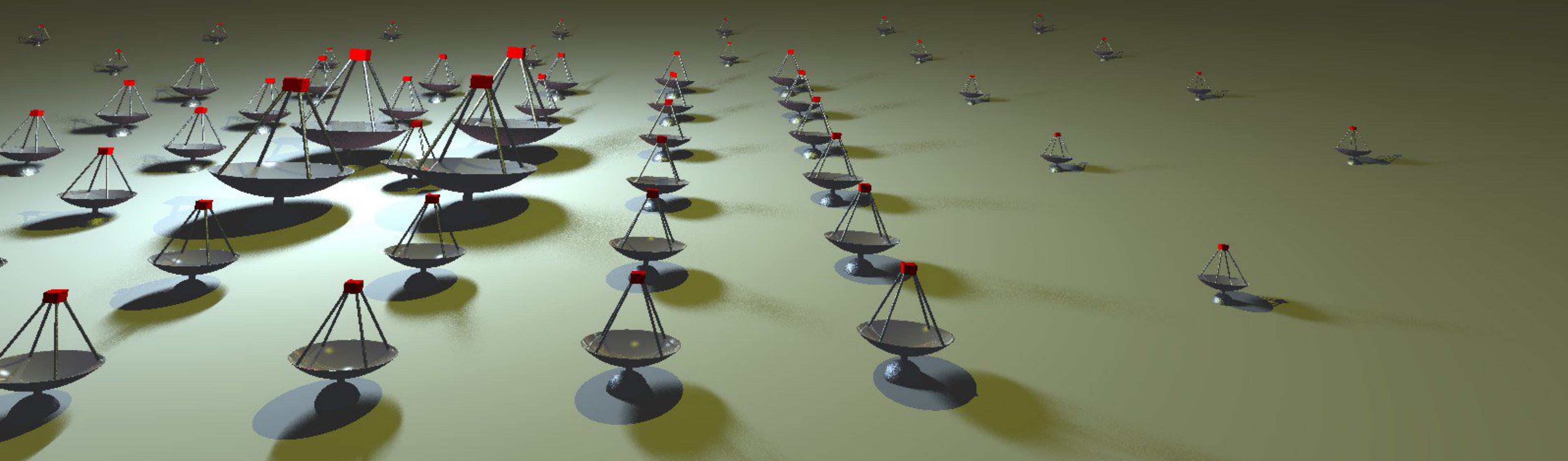
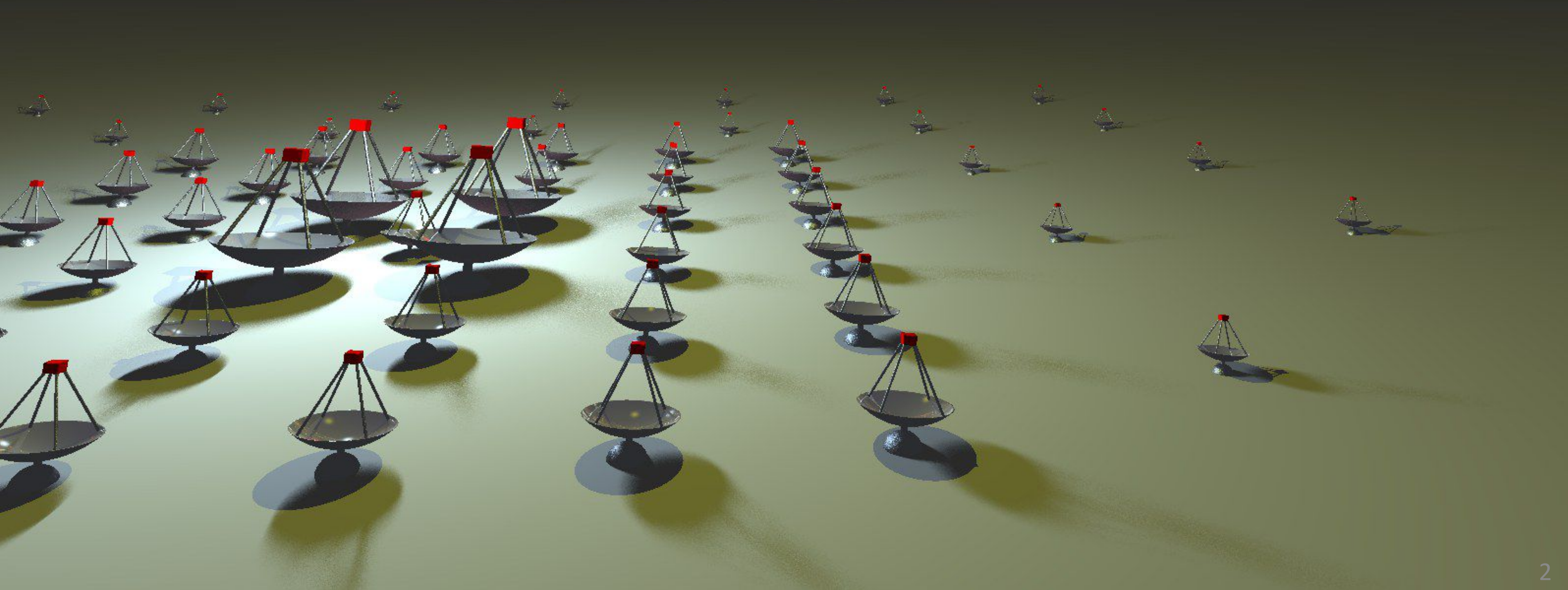
The Dark Matter Programme of the Cherenkov Telescope Array

Aldo Morselli
INFN Roma Tor Vergata

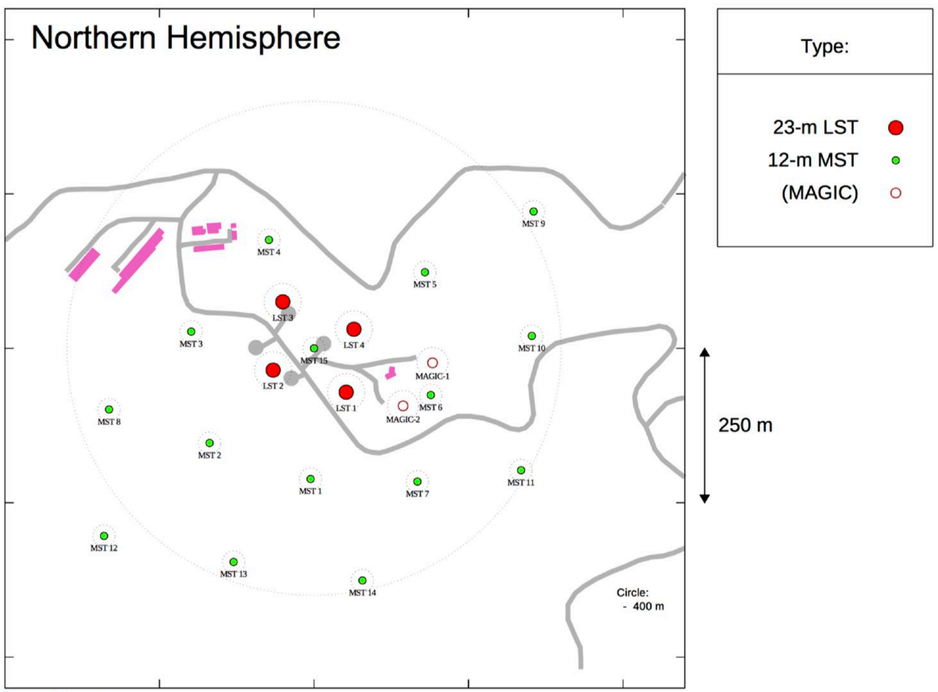


CTA PROJECT

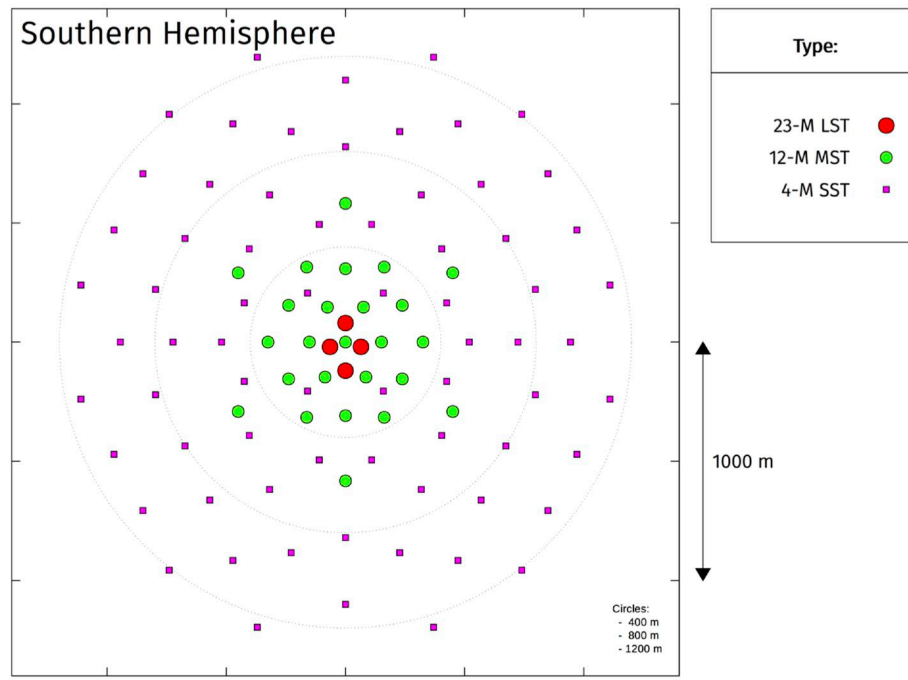
- Next generation ground based Gamma-ray observatory
- Open observatory
- Two sites with more than 100 telescopes
    - Southern Site: Near Paranal, Chile
    - Northern Site: La Palma, Canary Islands, Spain
- 32 nations, ~300M€ project +100M€ manpower



CTA sites and proposed telescope layouts



4 LS4 LSTs, 15 MSTs



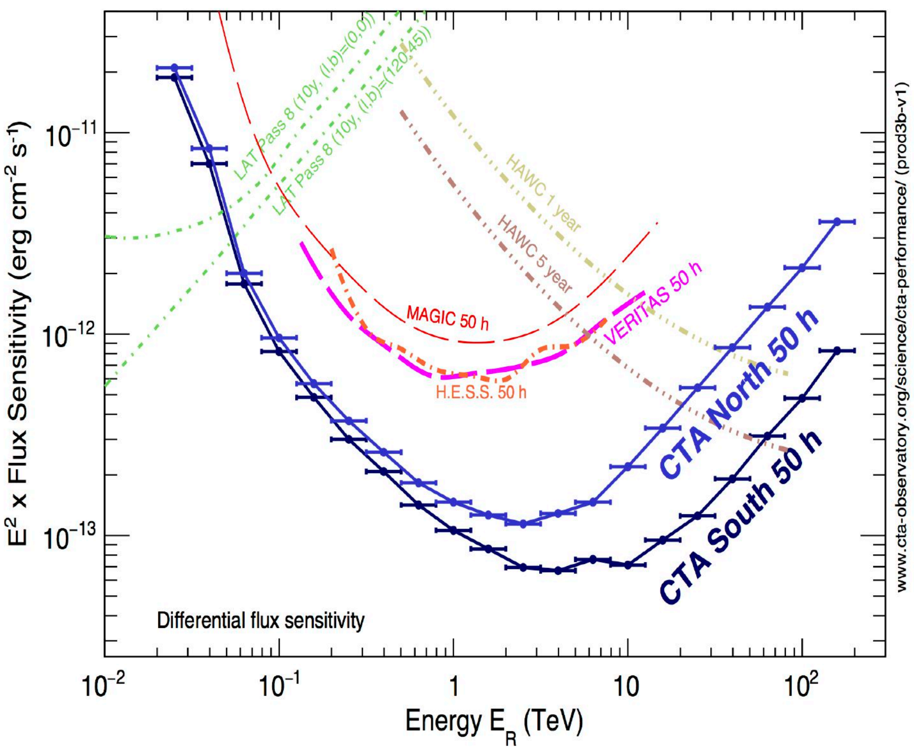
4 LSTs, 25 MSTs, 70 SSTs

CTA PERFORMANCE

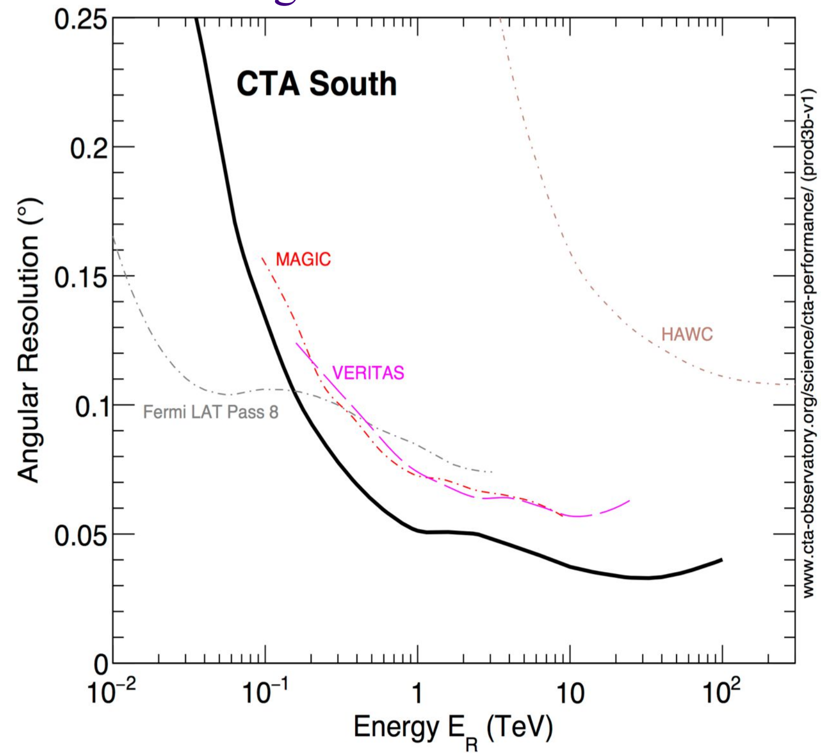
Southern Site:
- 4 Large-size telescopes
- 25 Medium-size telescopes
- 70 Small-size telescopes

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

Differential sensitivity



Angular resolution



CTA PERFORMANCE

Southern Site:
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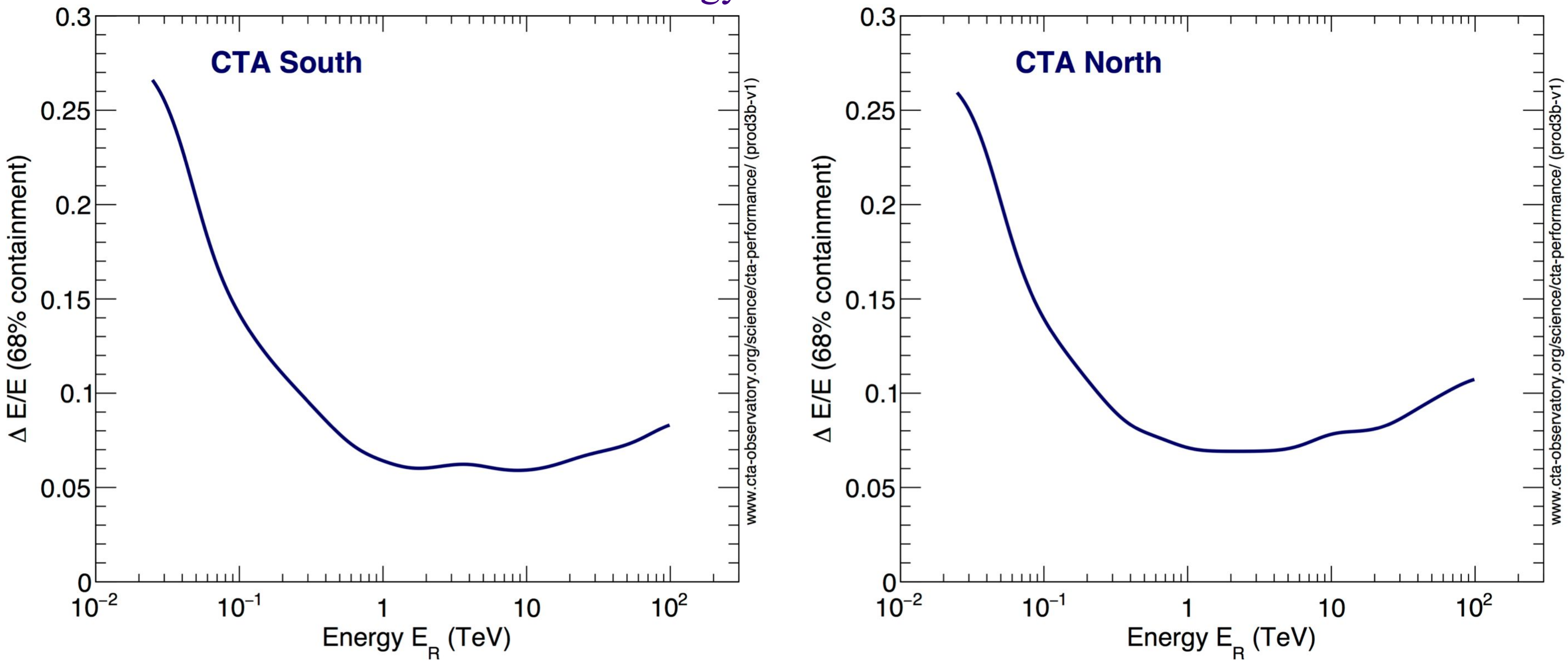
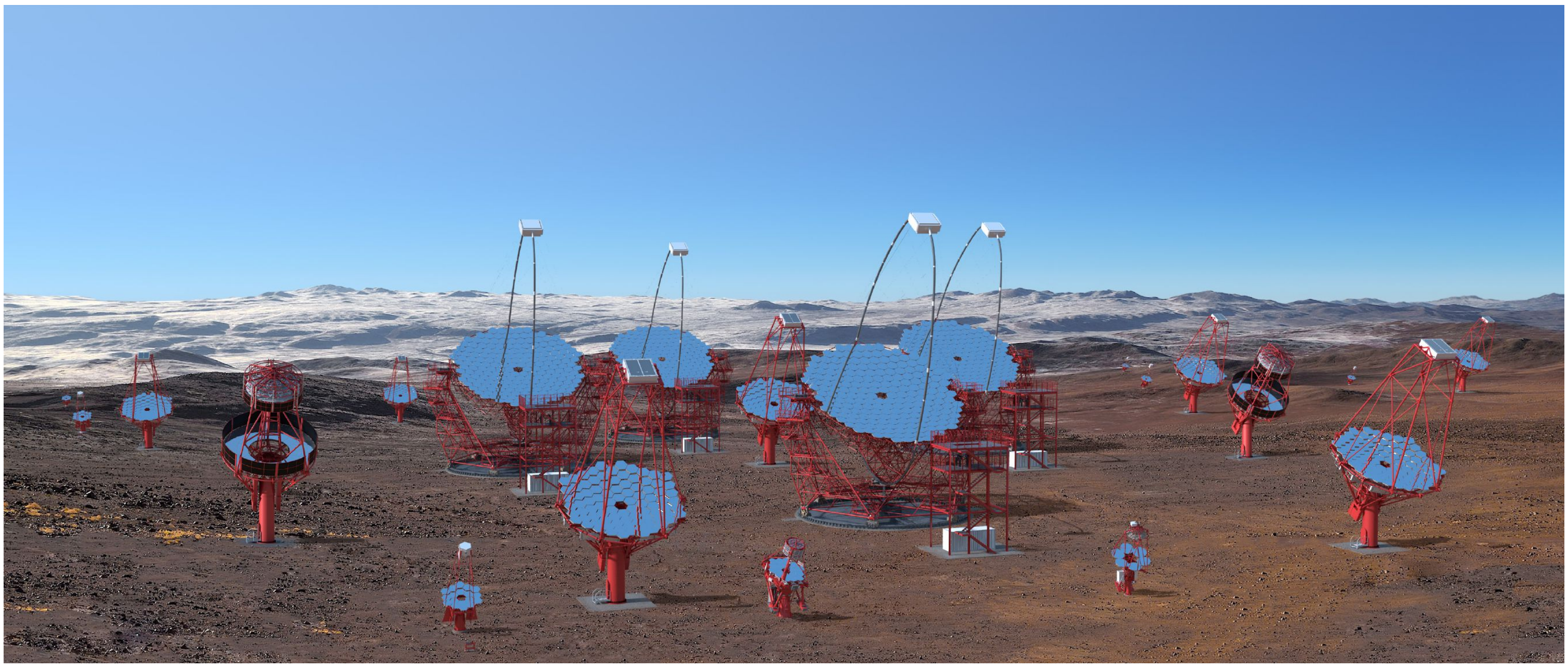
Energy Resolution



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

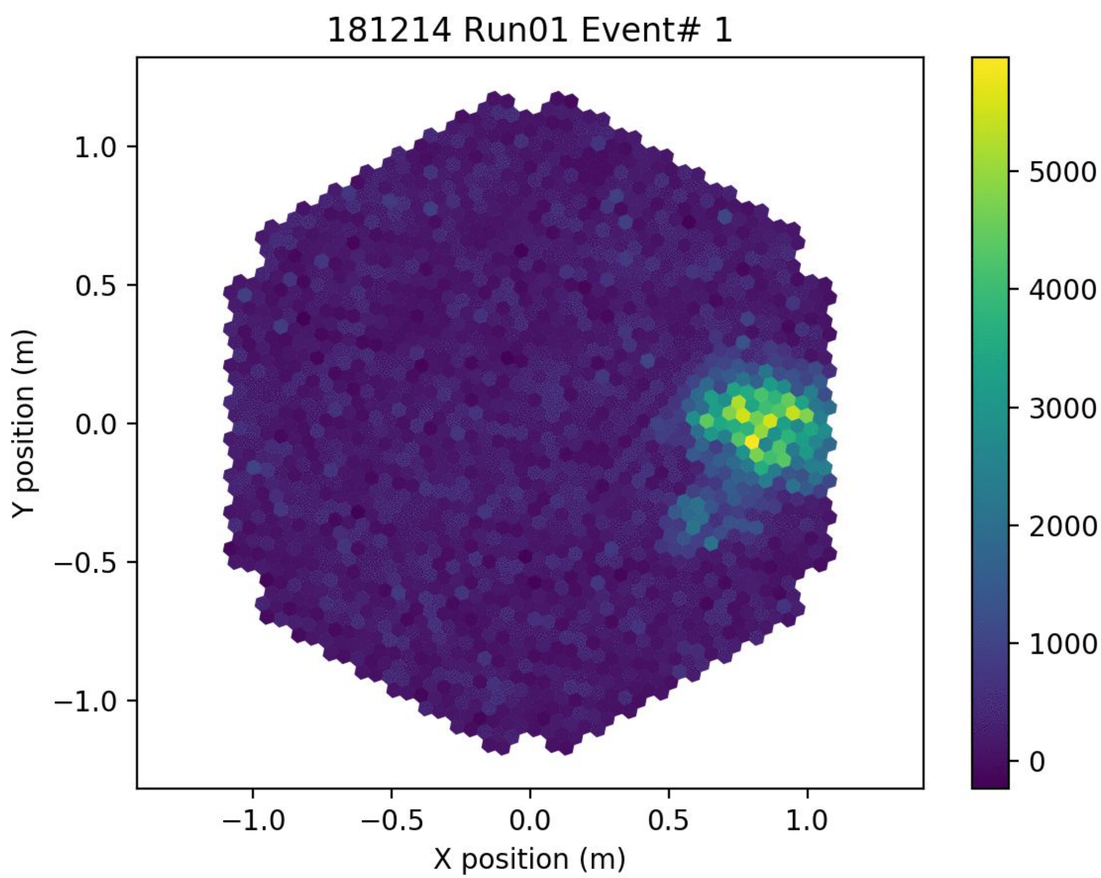
Santiago, Chile – On 19 December 2018, the Cherenkov Telescope Array Observatory (CTAO) and the European Southern Observatory (ESO) signed the final agreements needed for CTA's southern hemisphere array to be hosted near ESO's Paranal Observatory in Chile. Construction on both the northern and southern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



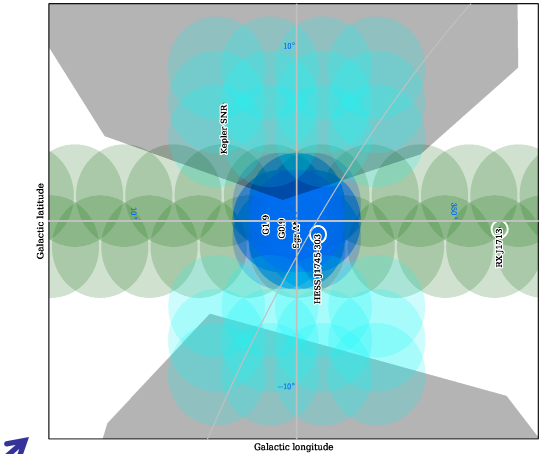
Rendering of the South Site

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.

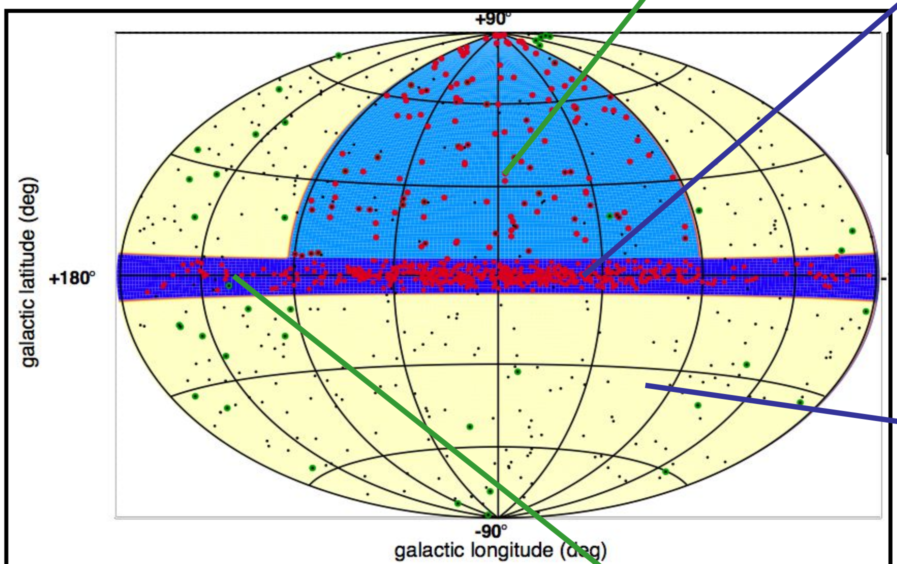


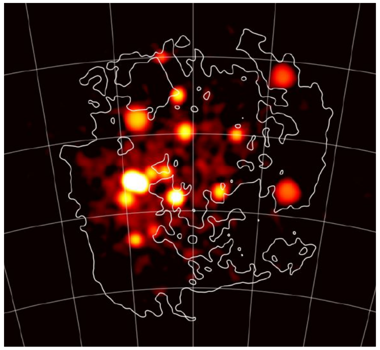
The Survey Key Science Projects



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, 10ºx10º : 300 h



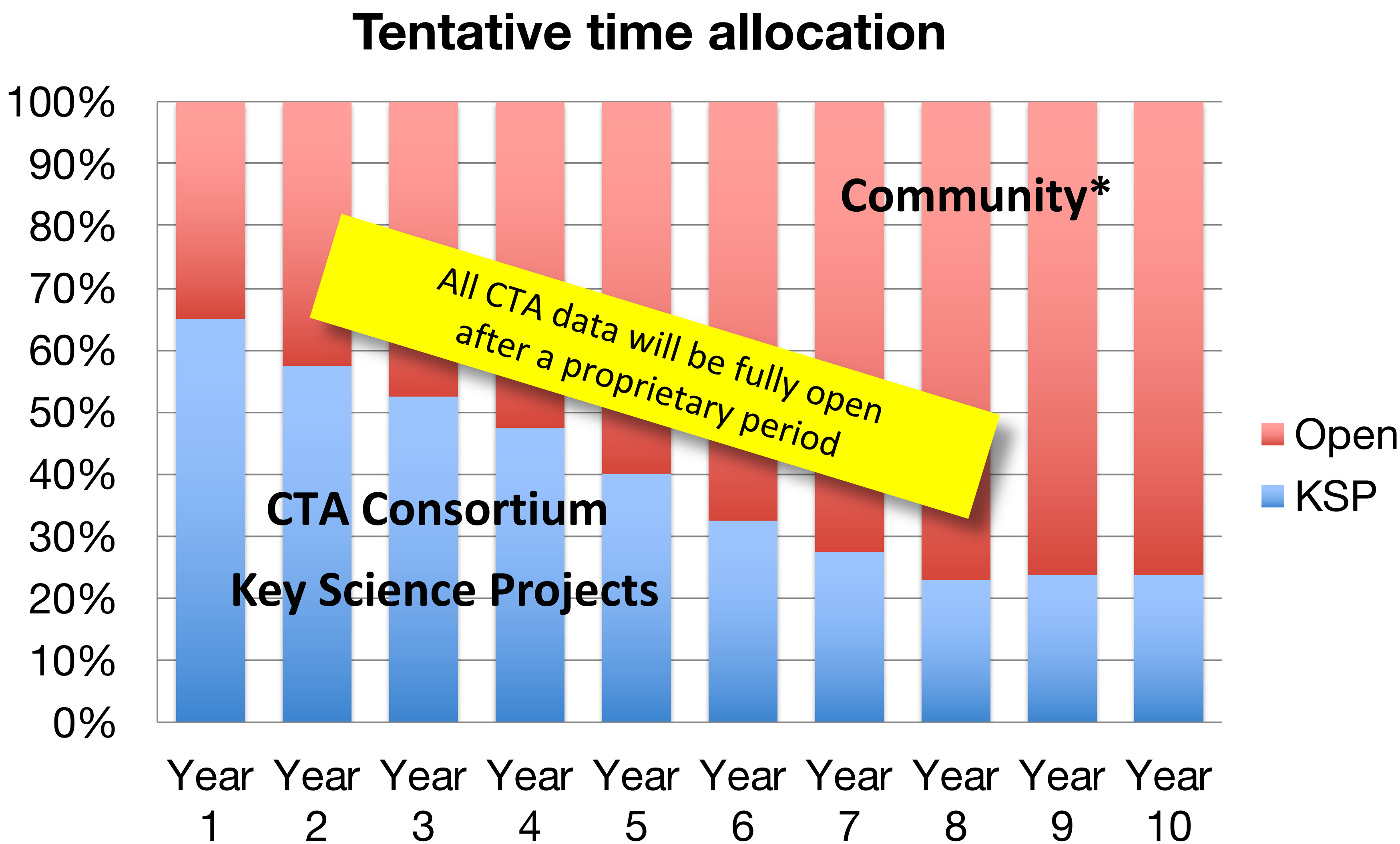


Science with the Cherenkov Telescope Array
World Scientific
https://doi.org/10.1142/10986
[arXiv:1709.07997] ~364 pp.

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

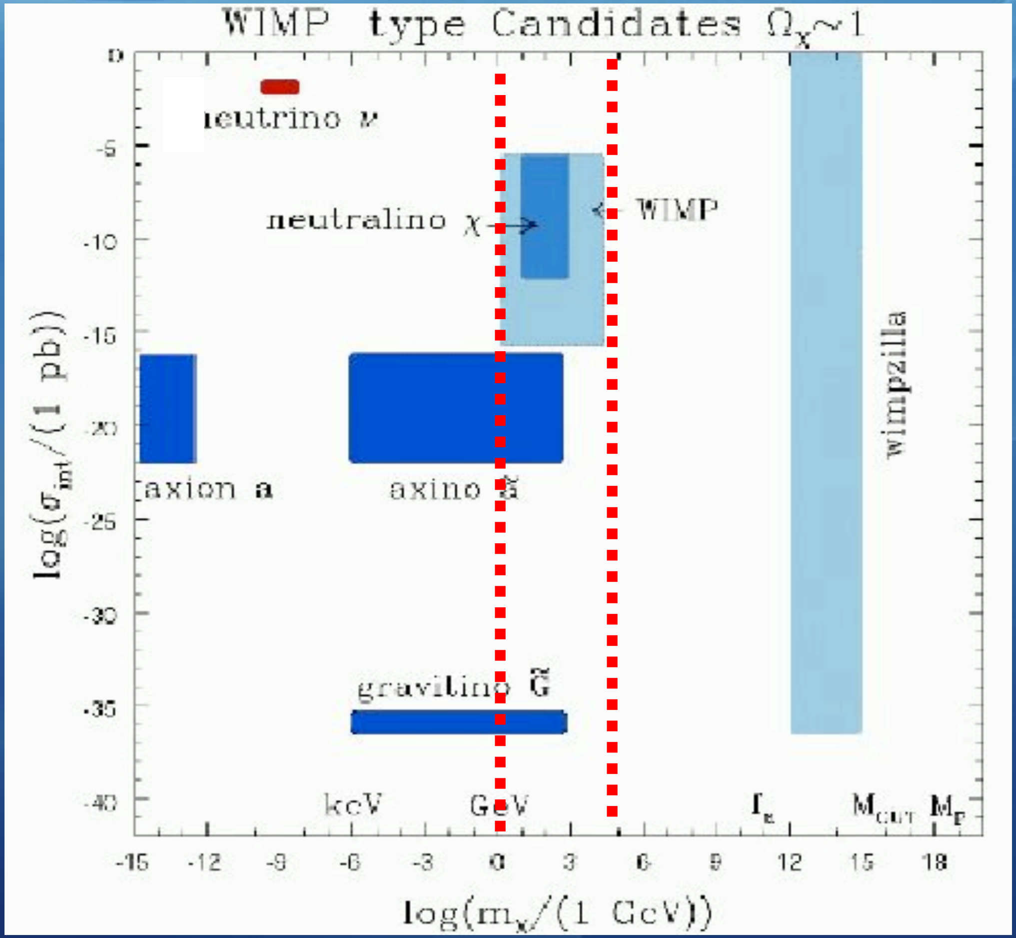


*of scientists from nations contributing to CTA construction and operations and from site host nations

Dark Matter

Dark Matter Candidates

- Kaluza-Klein DM in UED
- Kaluza-Klein DM in RS
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworld DM
- Heavy neutrino
- NEUTRALINO
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes



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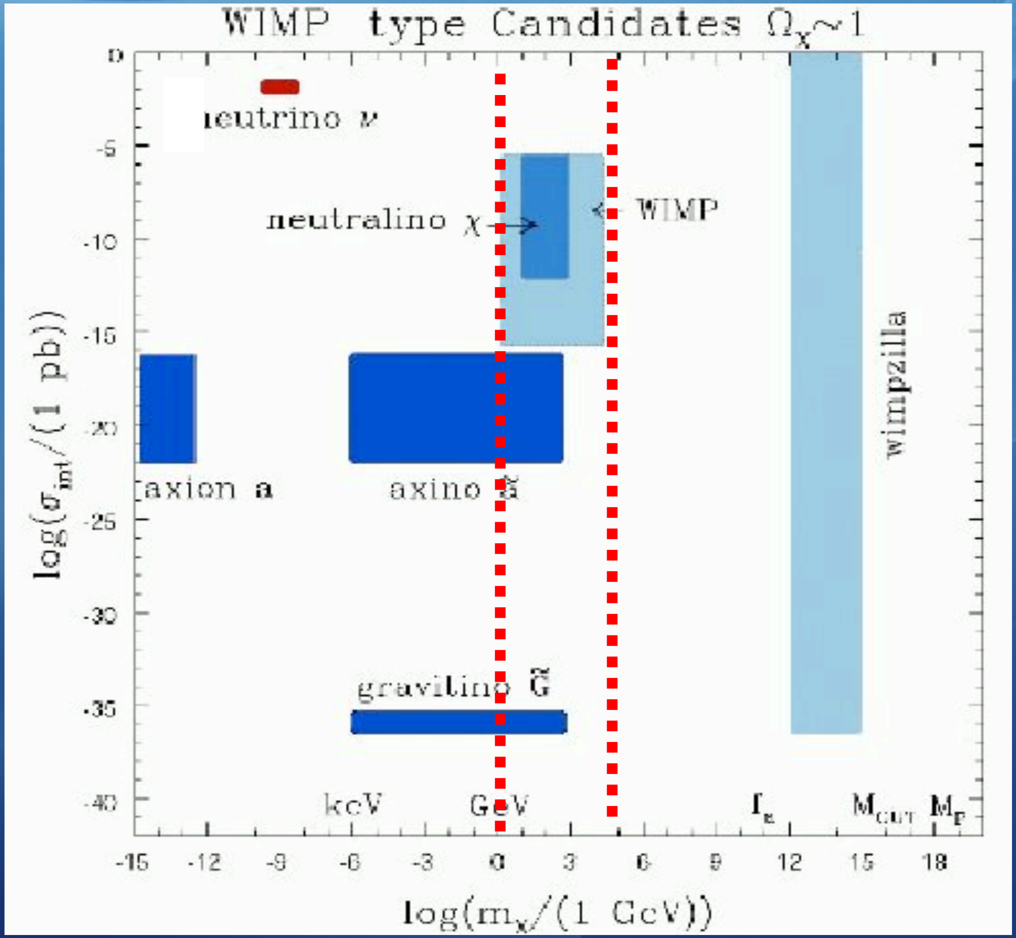
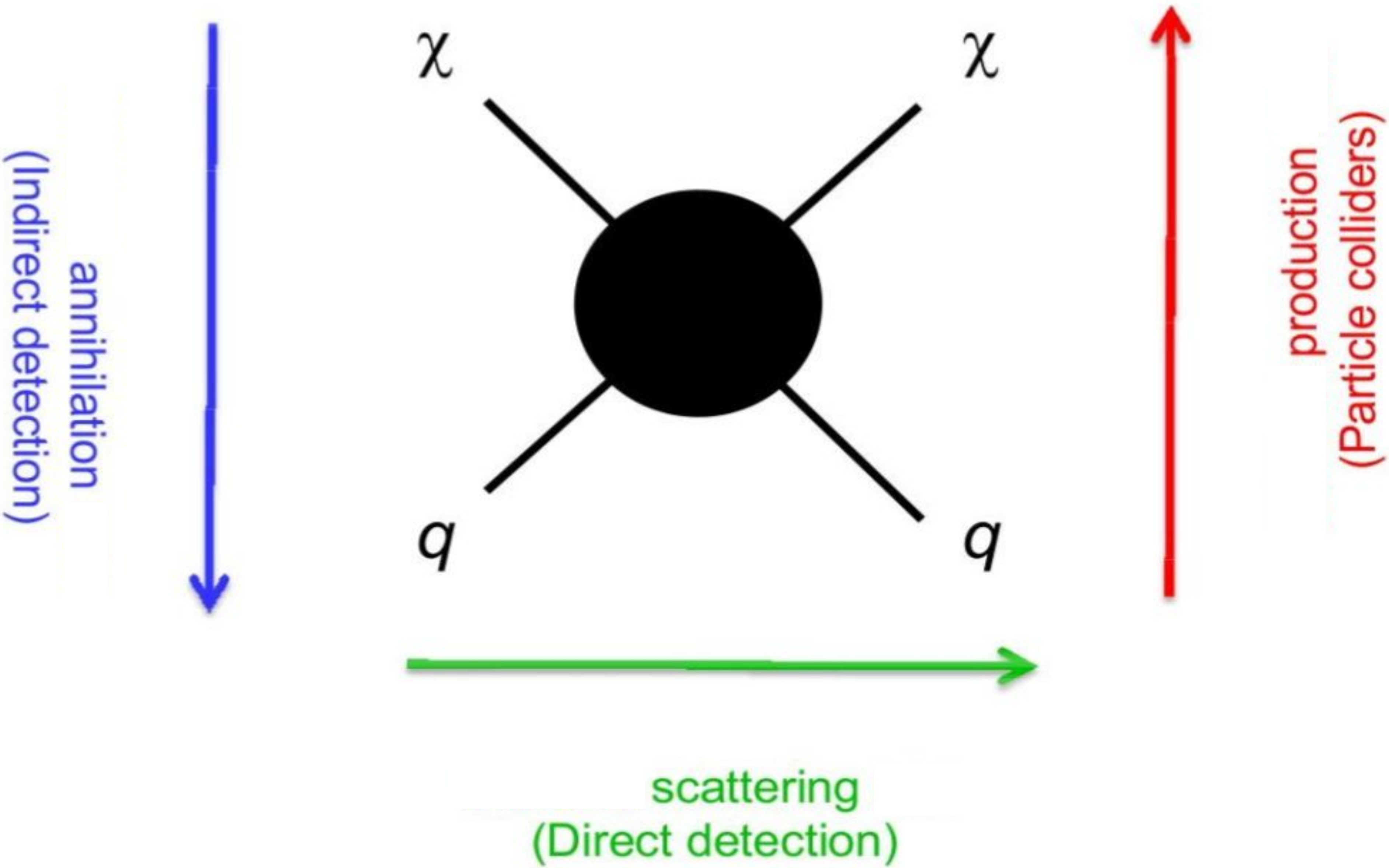
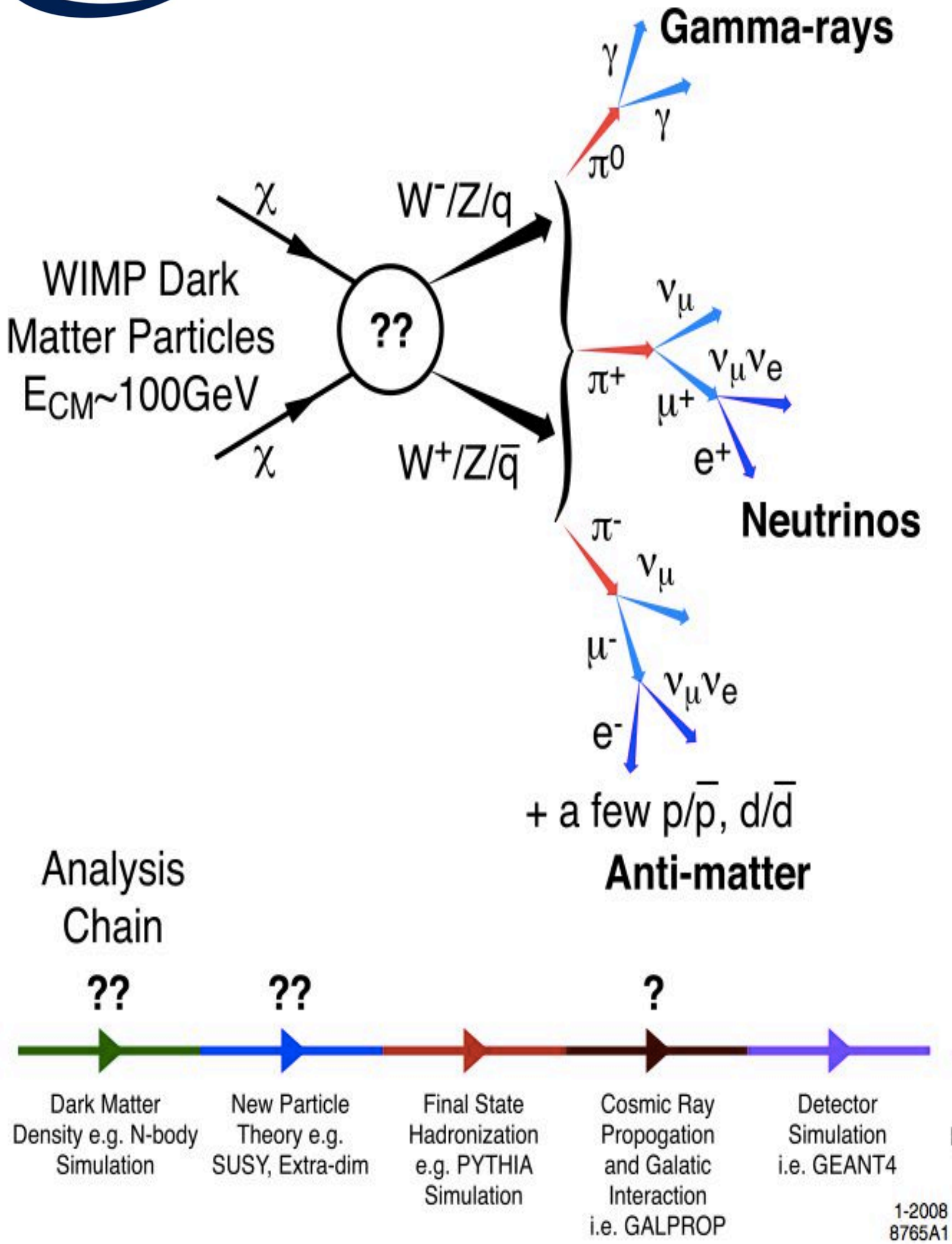
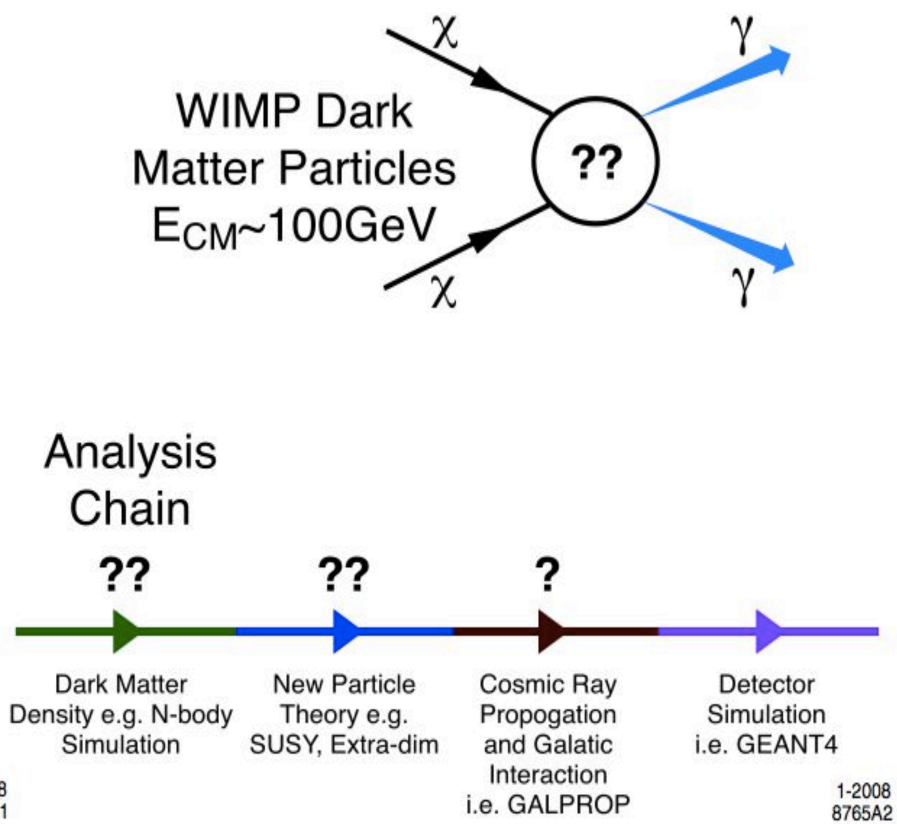


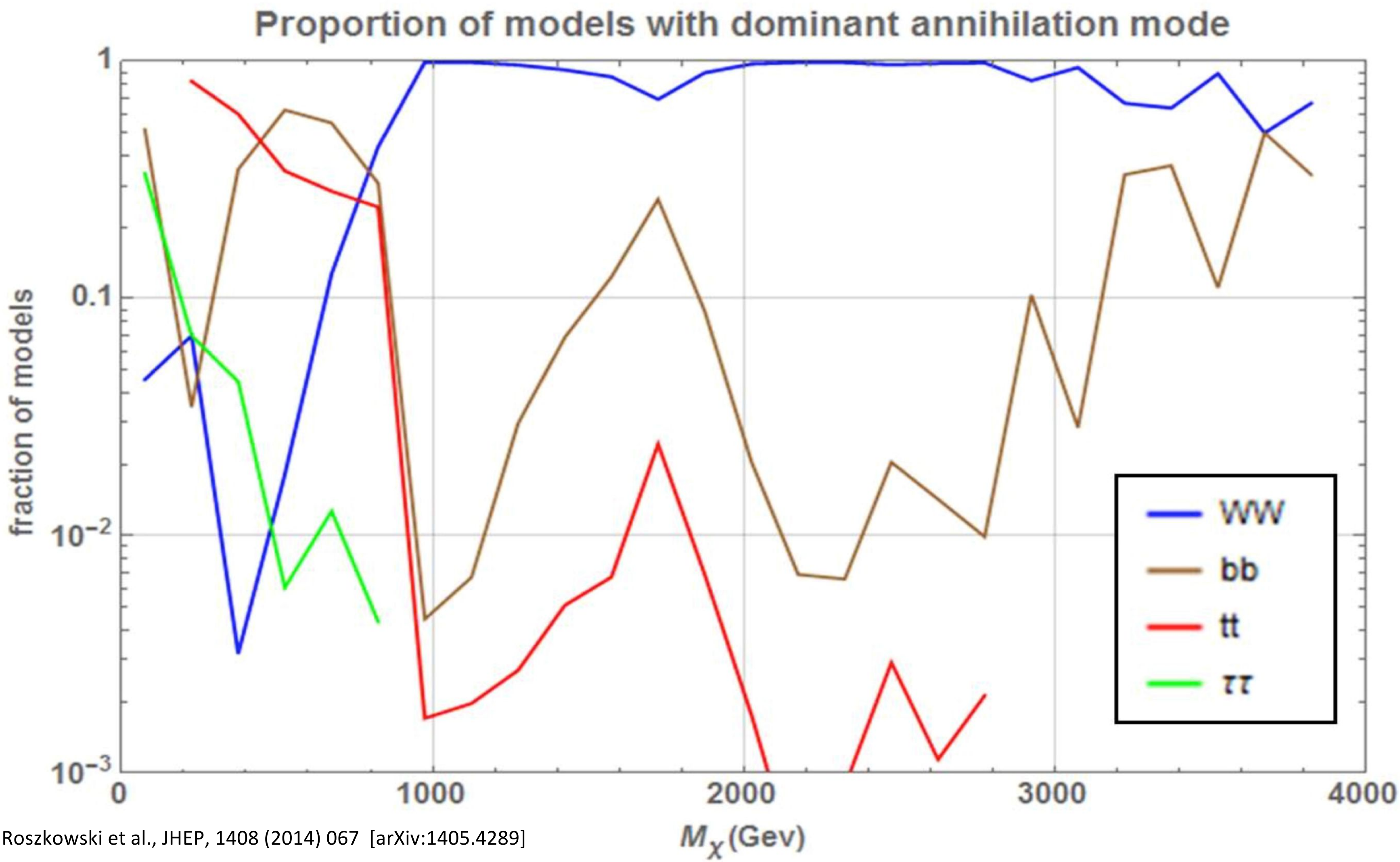

annihilation
(Indirect detection)
χ
χ
q
q
production
(Particle colliders)
scattering
(Direct detection)

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]

Dark Matter Search: Targets and Strategies

Satellites

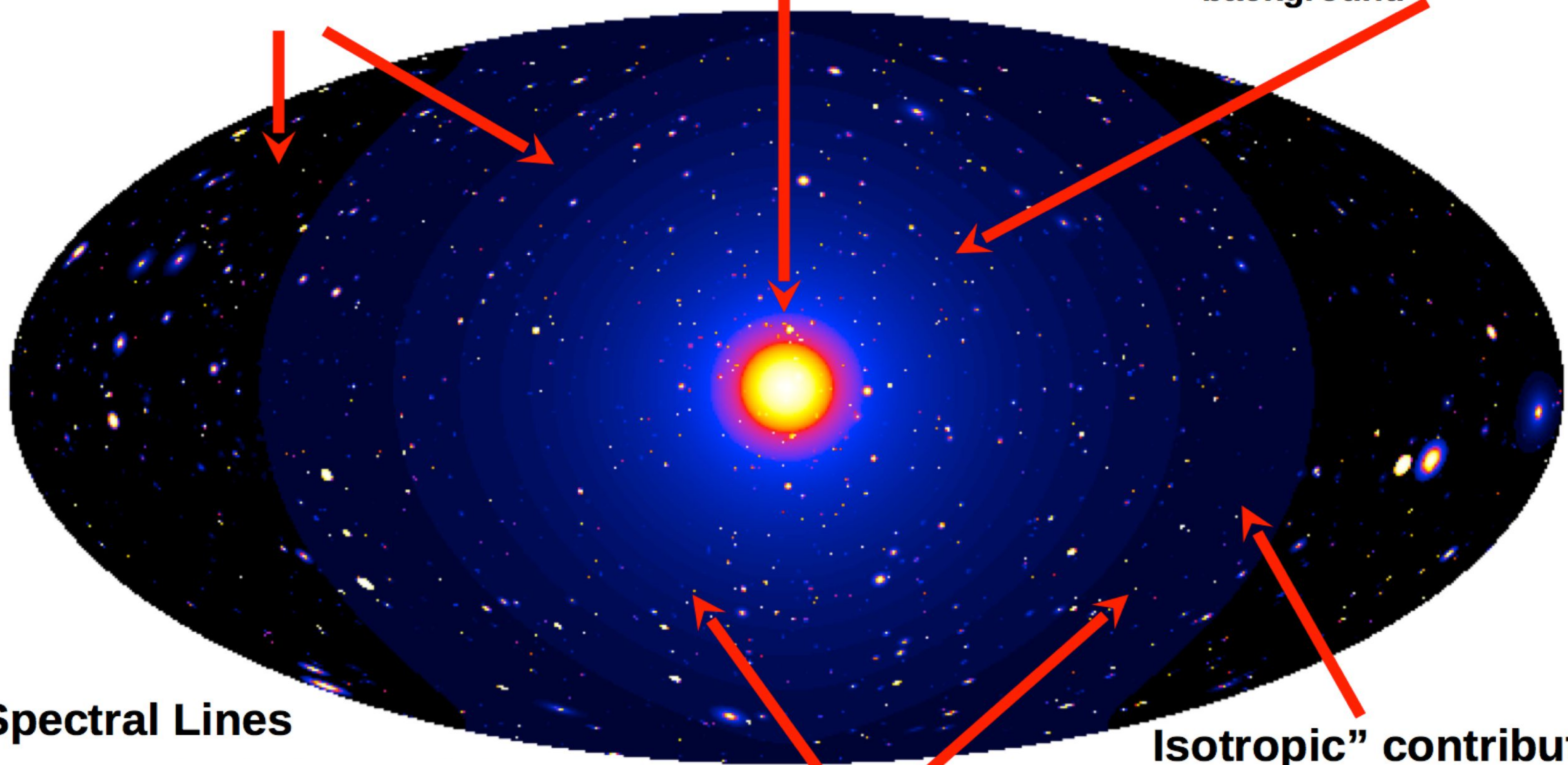
Low background and good source id, but low statistics

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

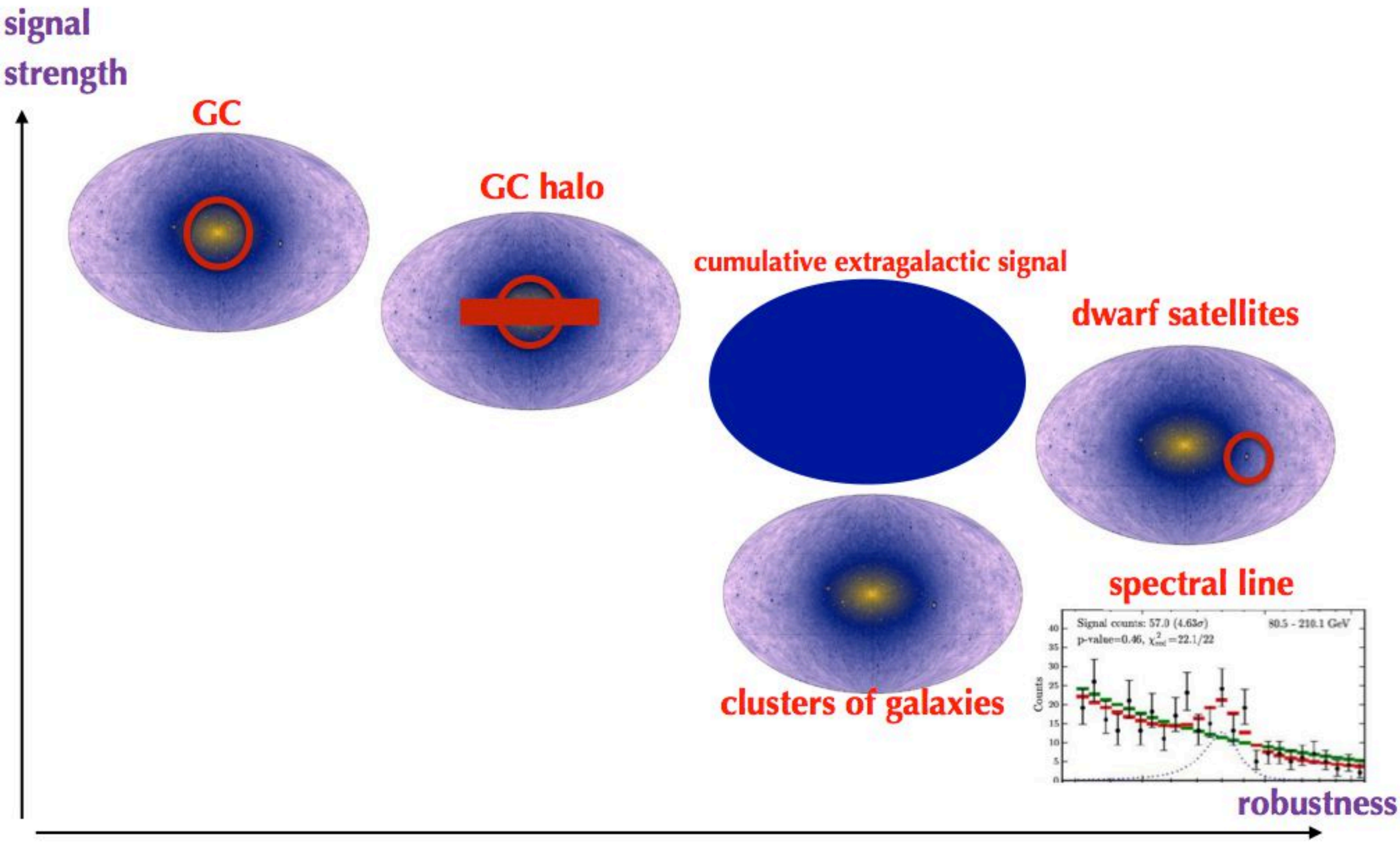
Isotropic" contributions

Large statistics, but astrophysics, galactic diffuse background

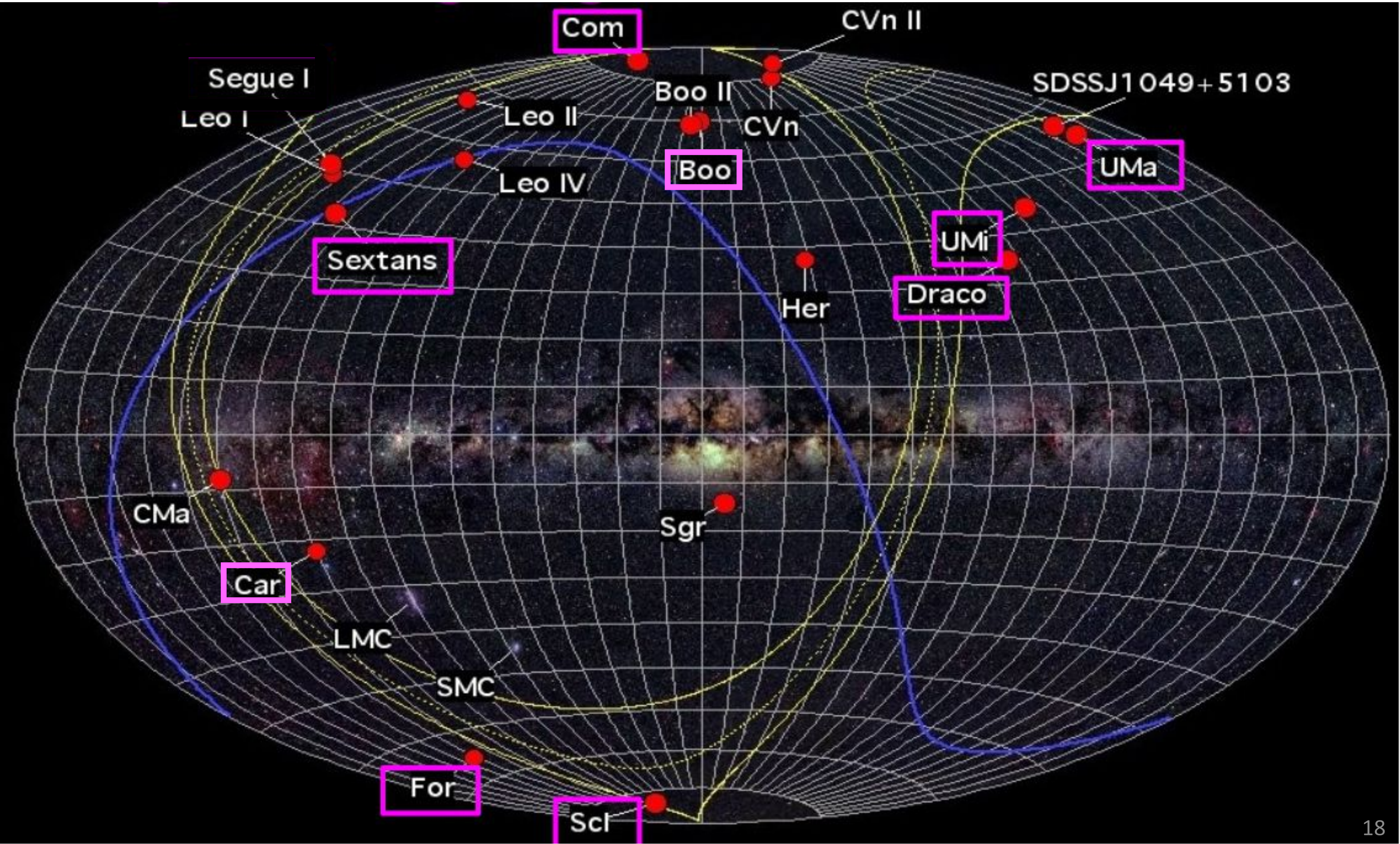
Dark Matter simulation:
Pieri+(2009) arXiv:0908.0195

Dark Matter Search: Targets and Strategies

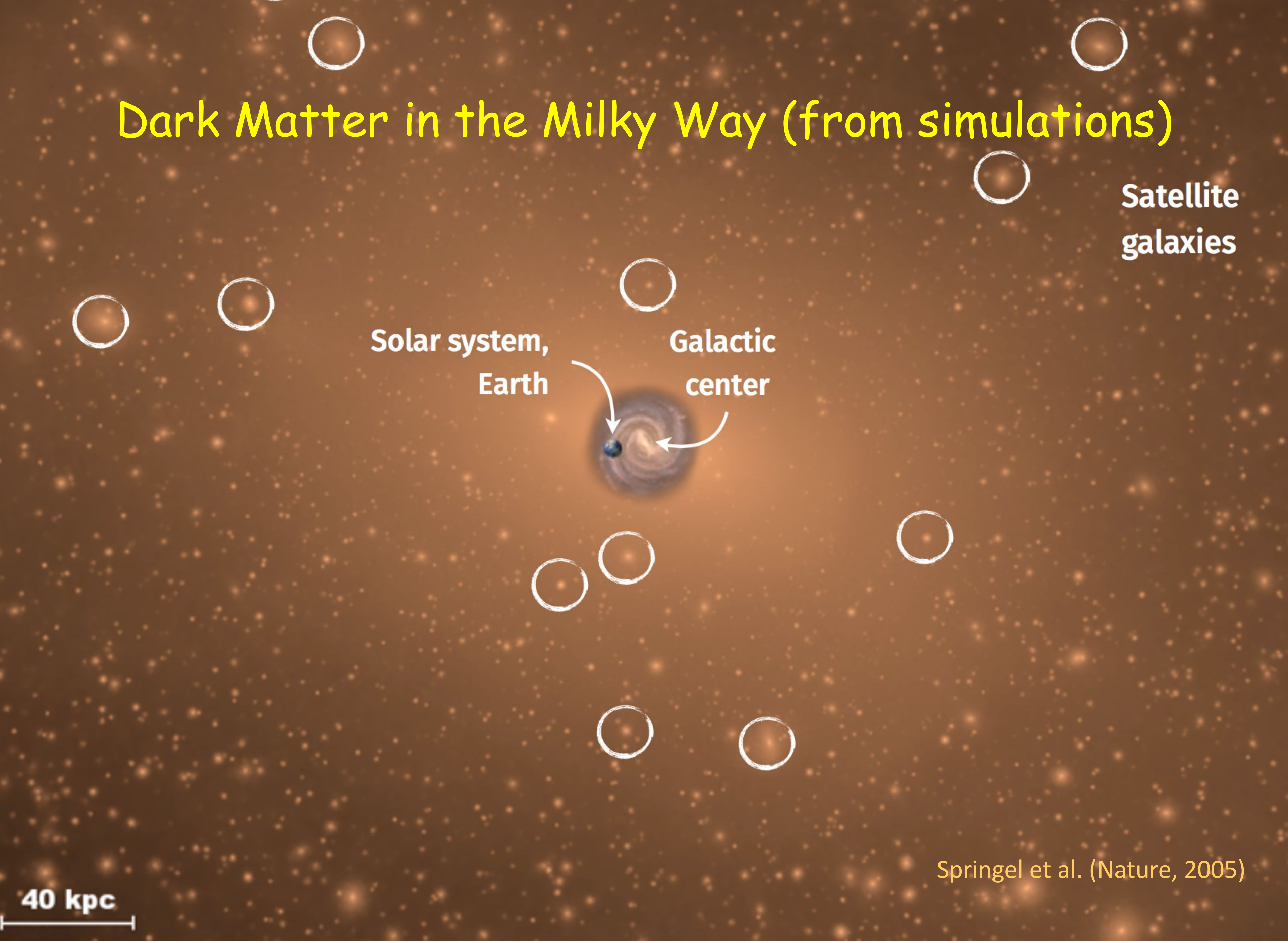
(Another way to see it)



Classical Dwarf spheroidal galaxies: promising targets for DM detection

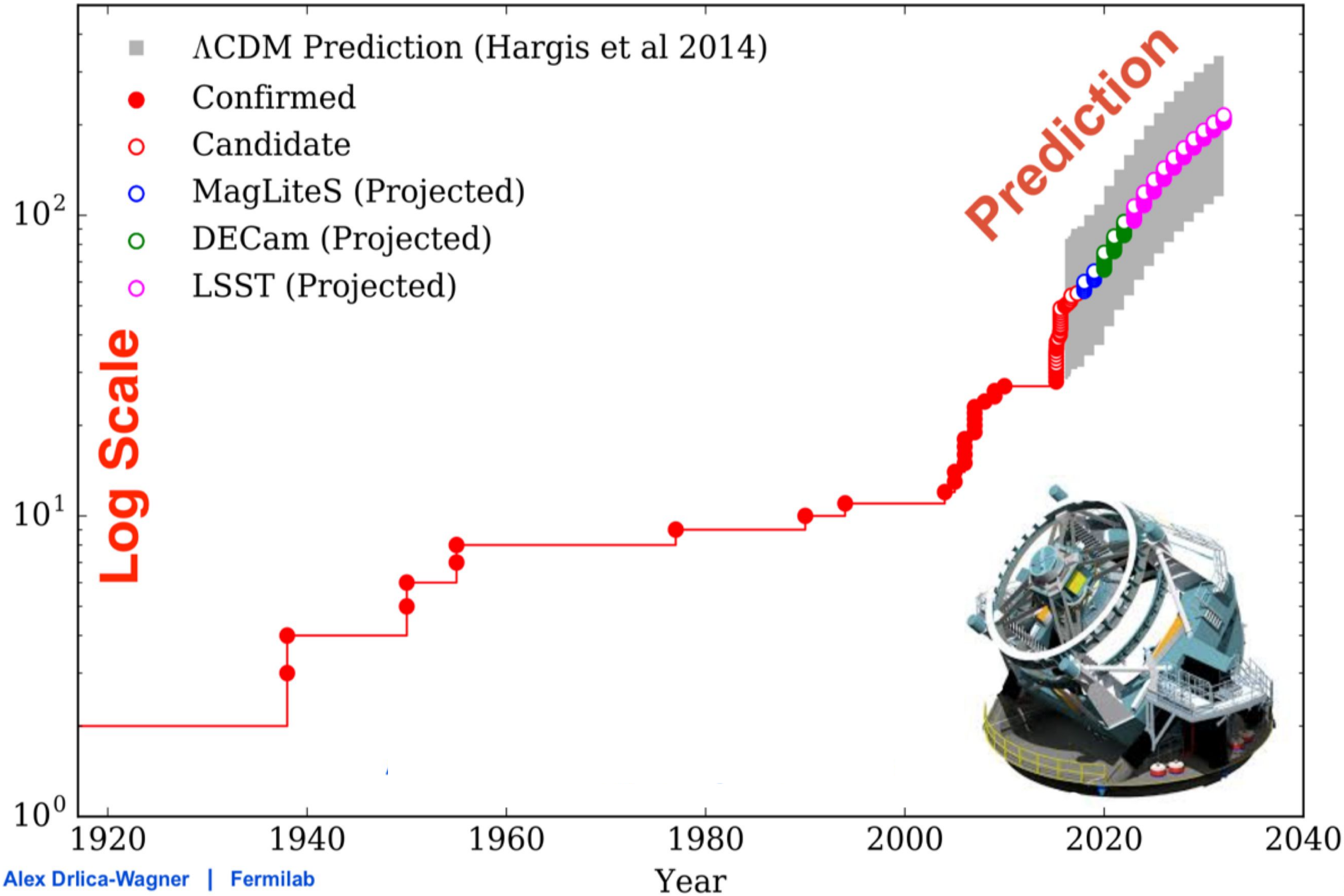


Dark Matter in the Milky Way (from simulations)



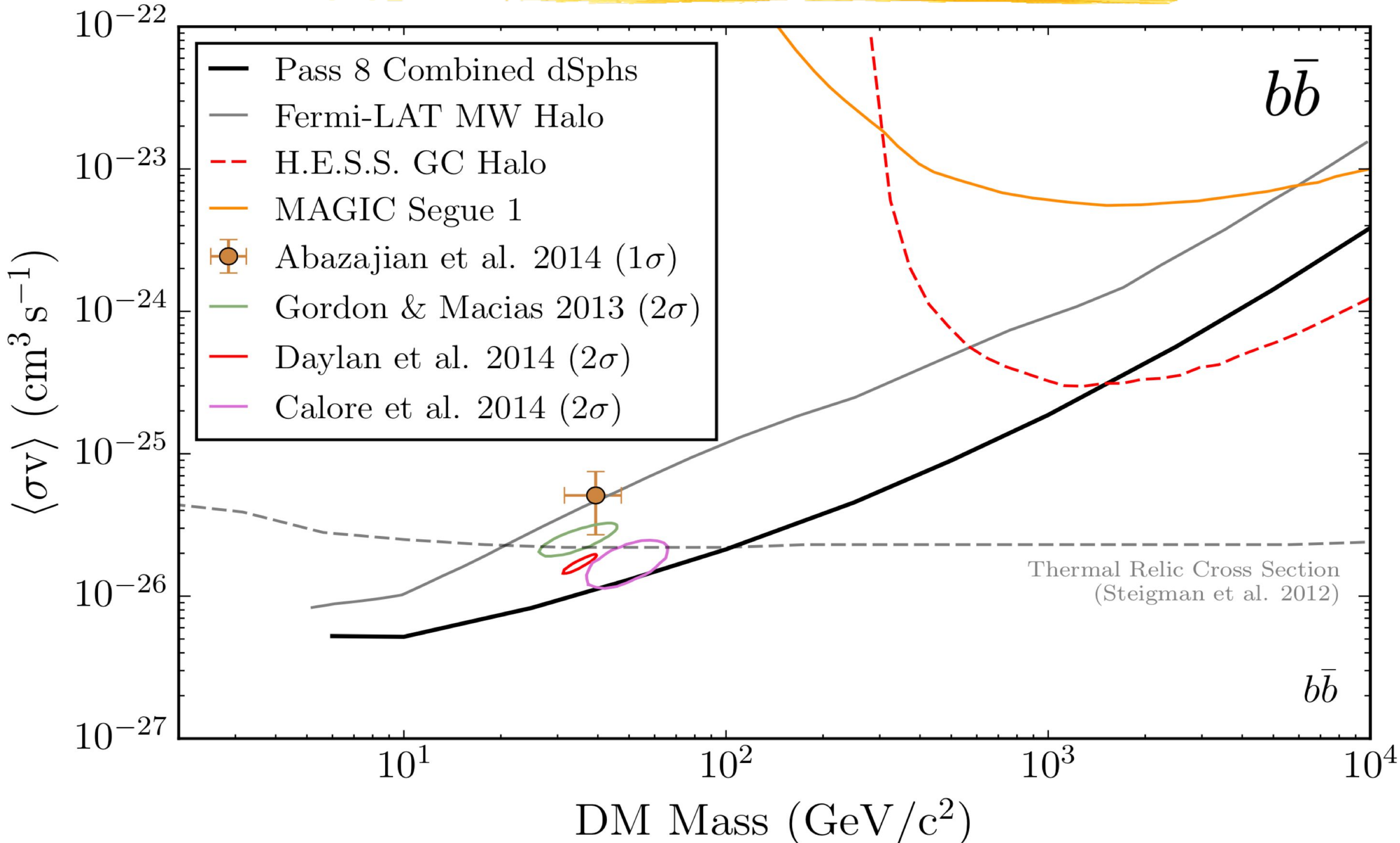
Springel et al. (Nature, 2005)

Dwarf Spheroidal Galaxies: Growing number of known targets



Alex Drlica-Wagner | Fermilab

Dwarf Spheroidal Galaxies upper-limits (6 years)



M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

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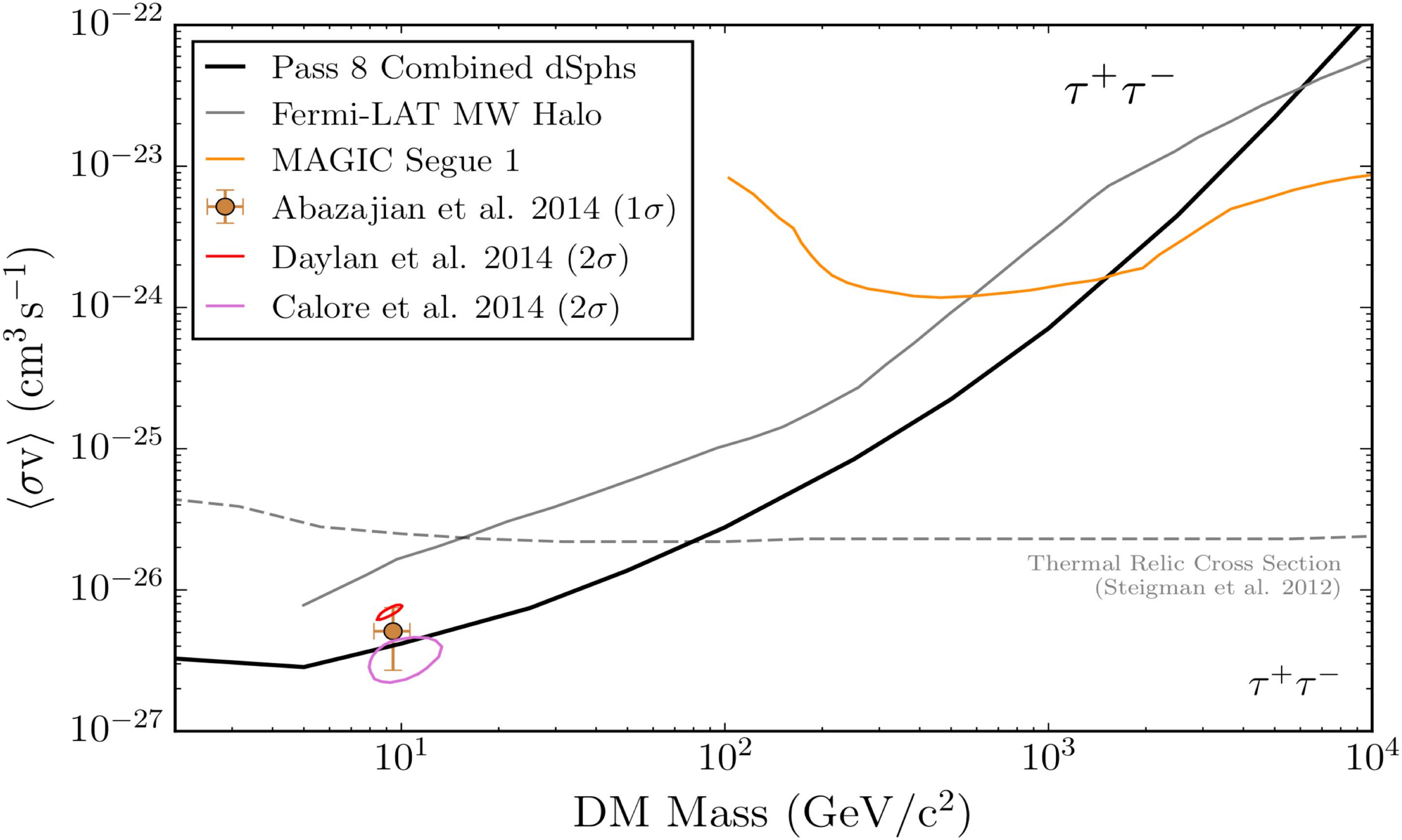

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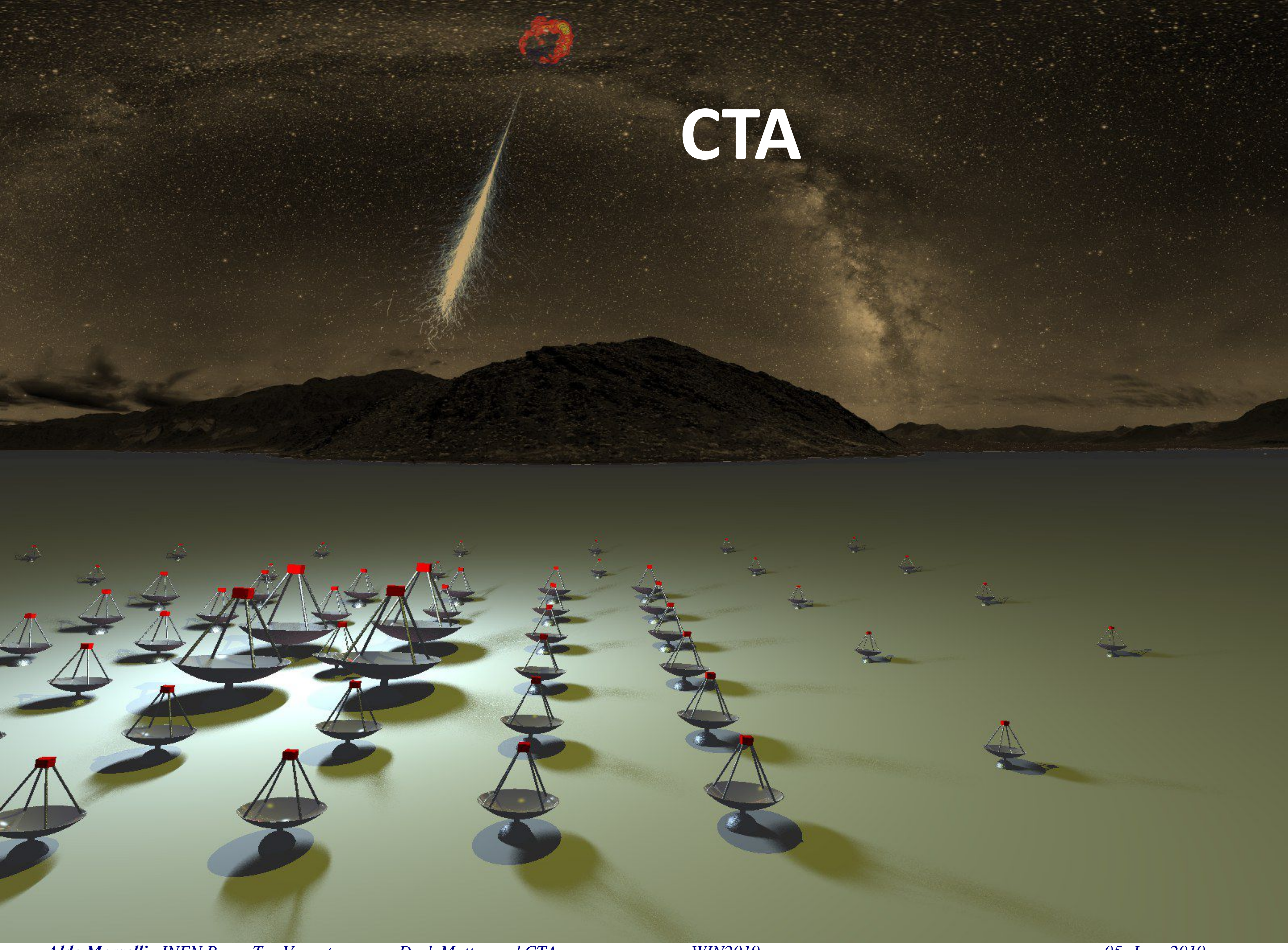
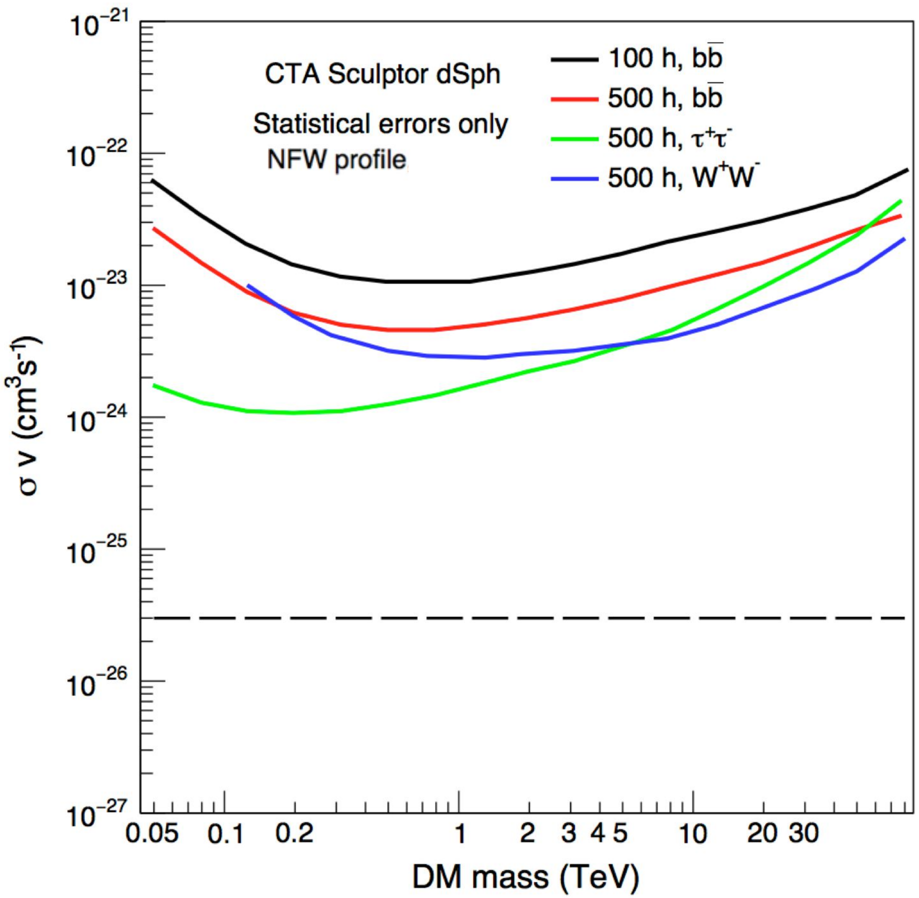
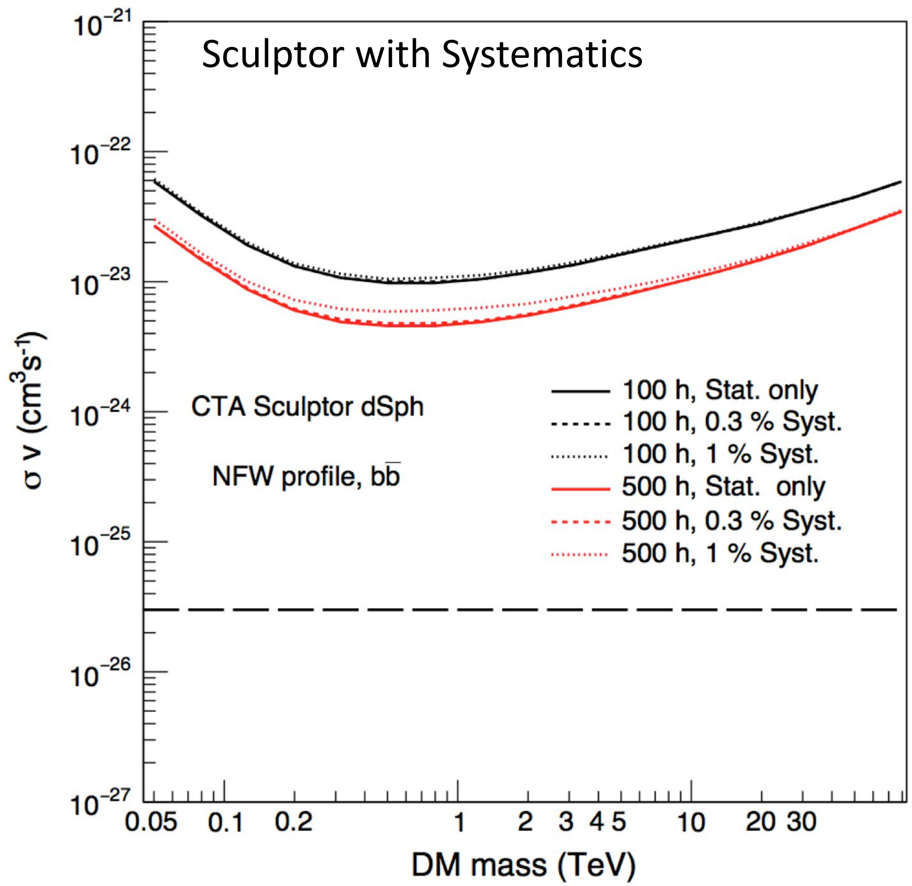

CTA

Dwarf Spheroidal Galaxies: CTA Sensitivity

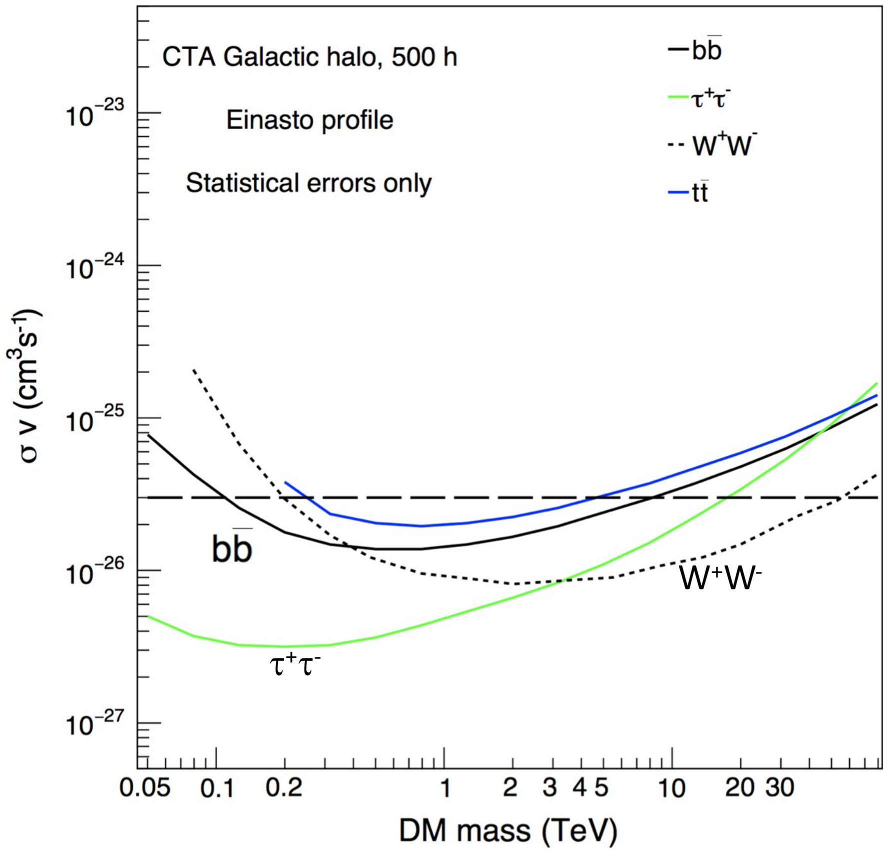


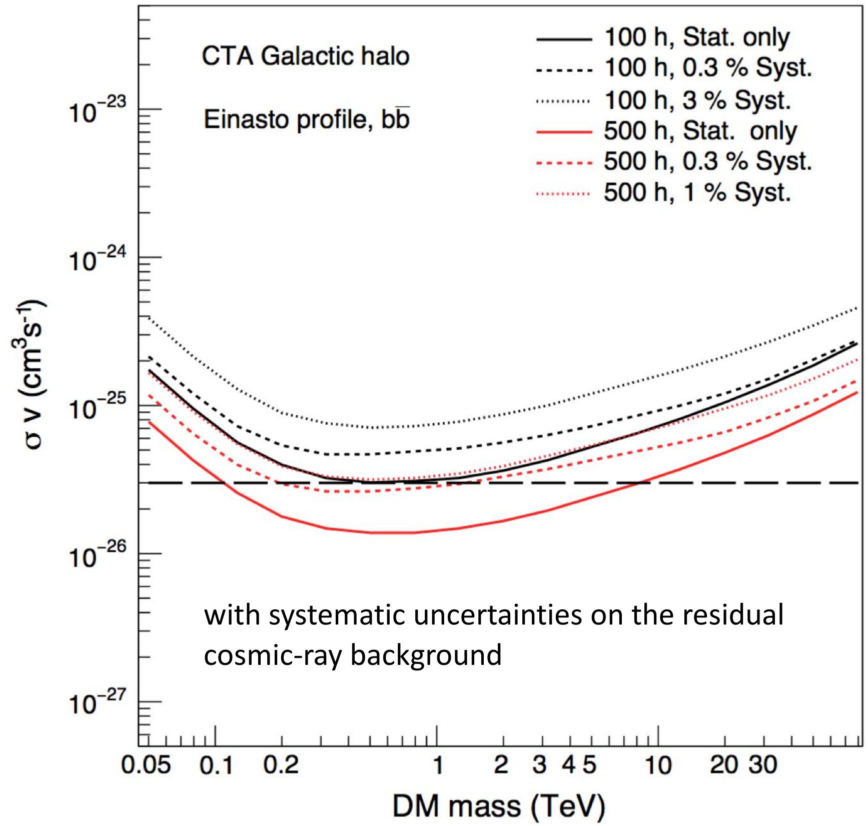


There are several of the newly discovered dSph that have a better case for being a promising target,

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

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.

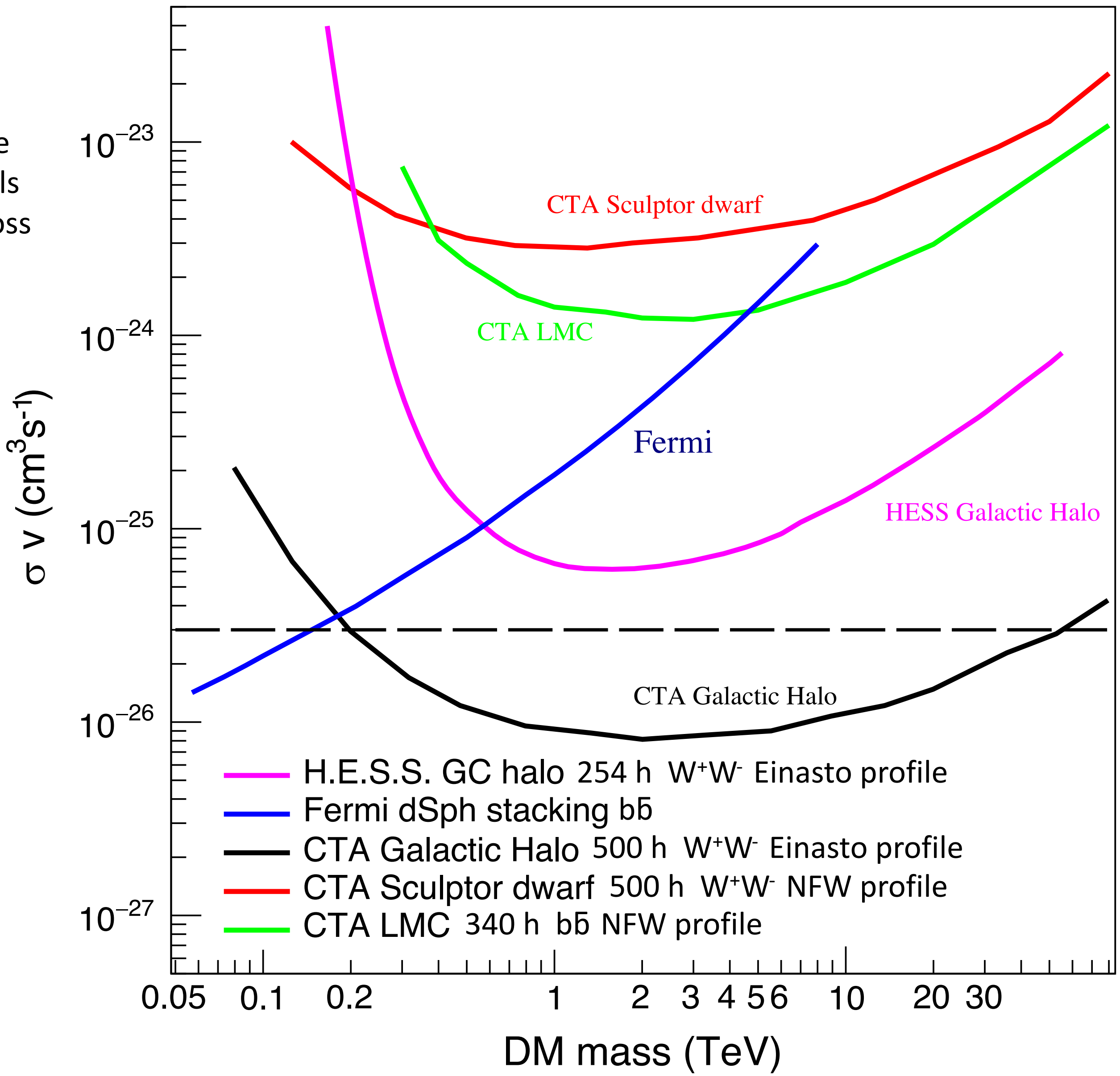
CTA, Fermi,HESS DM upper-limits

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

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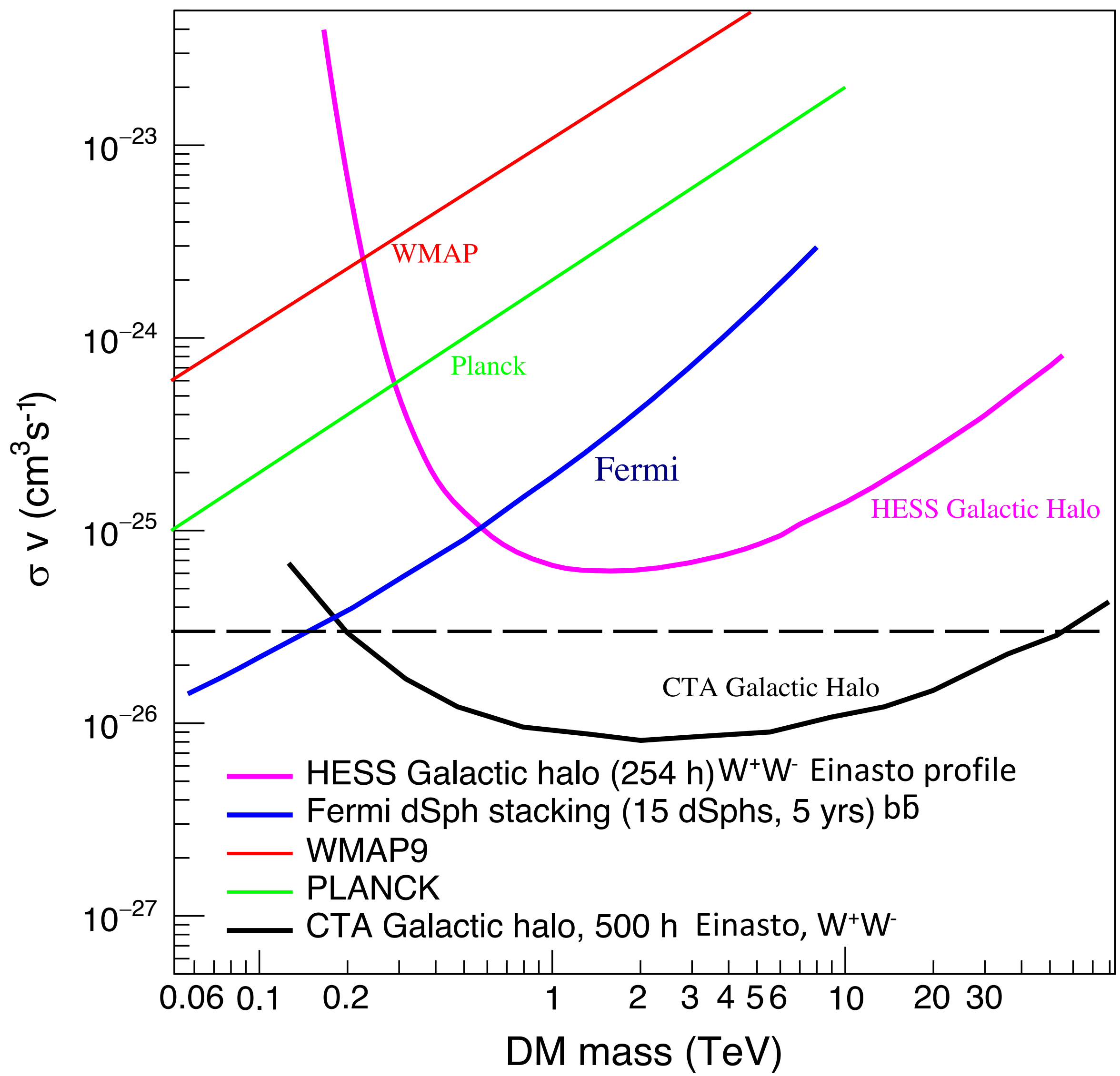
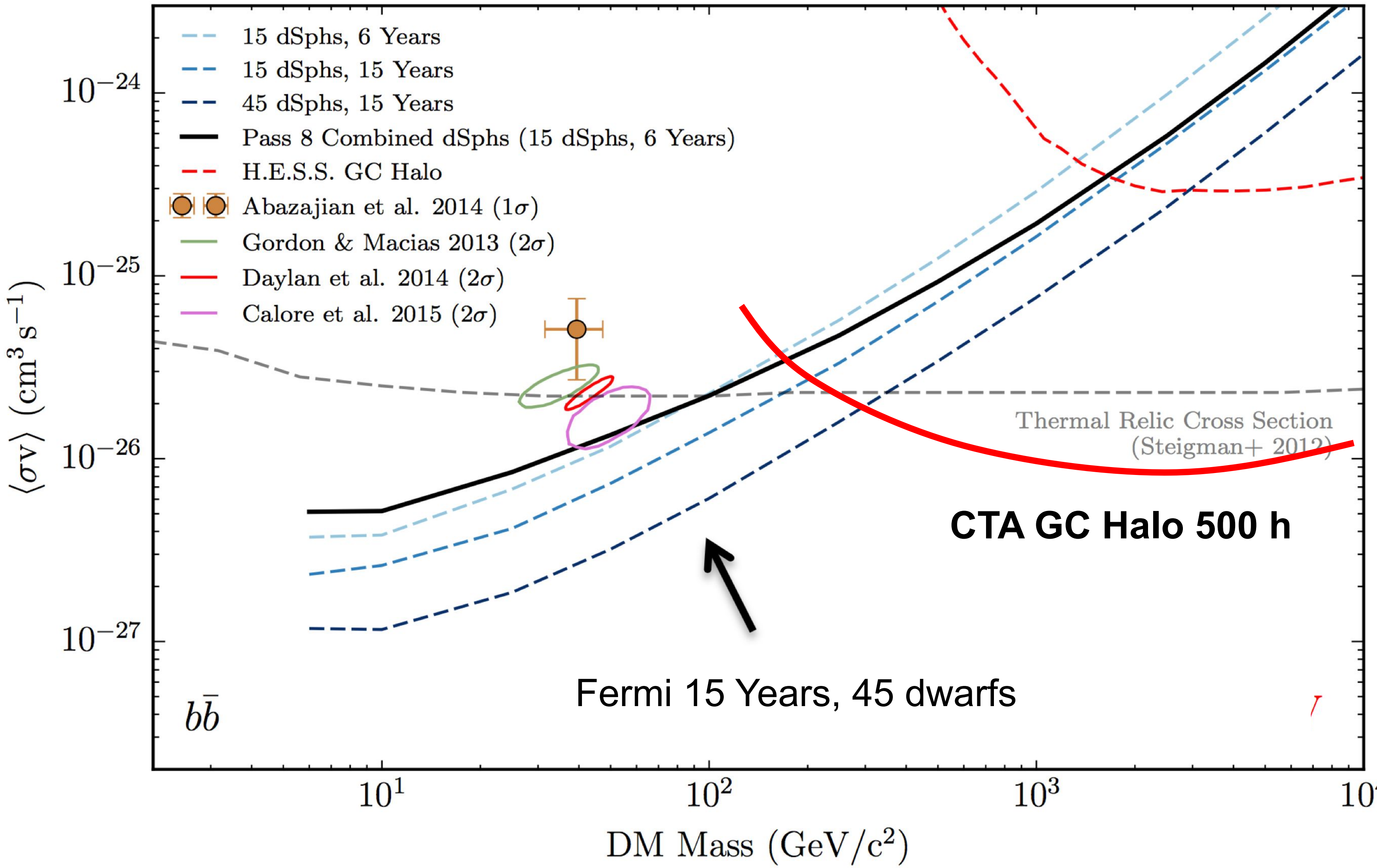


DM limit improvement estimate in 15 years (2008- 2023)



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

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.

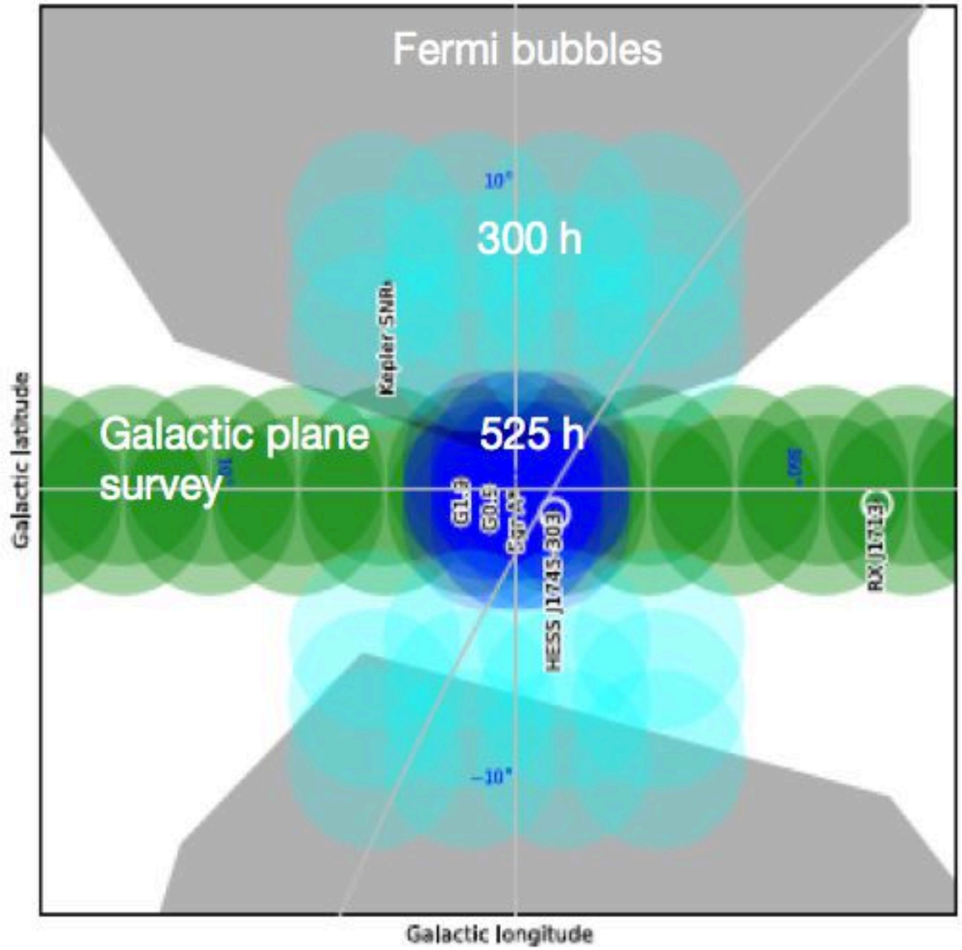
DEEP OBSERVATIONS OF GC REGION

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

Extended 300 h survey of 10°x10° region;

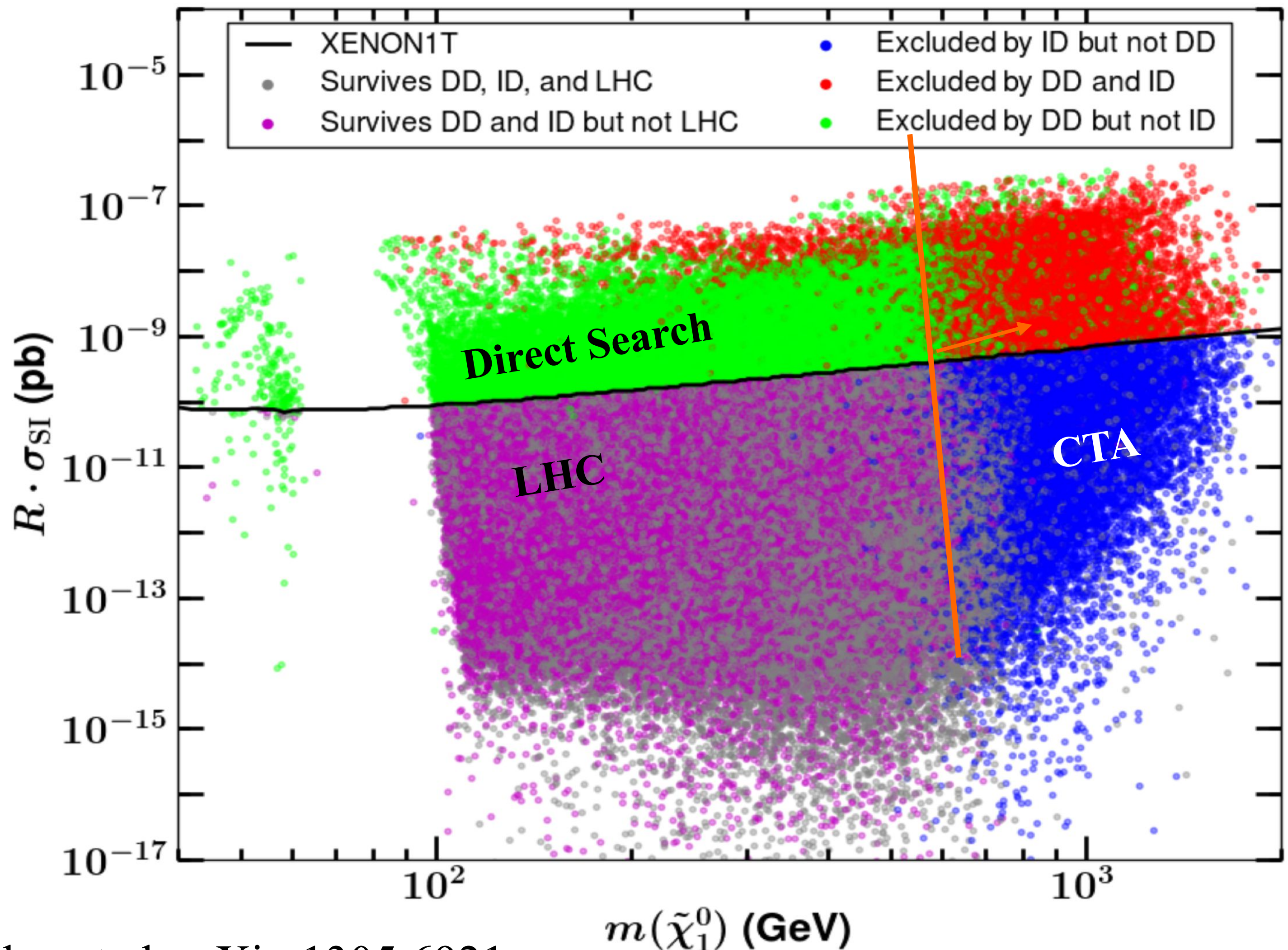
Produce CTA legacy data set for large range of scientific topics, which include

- 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

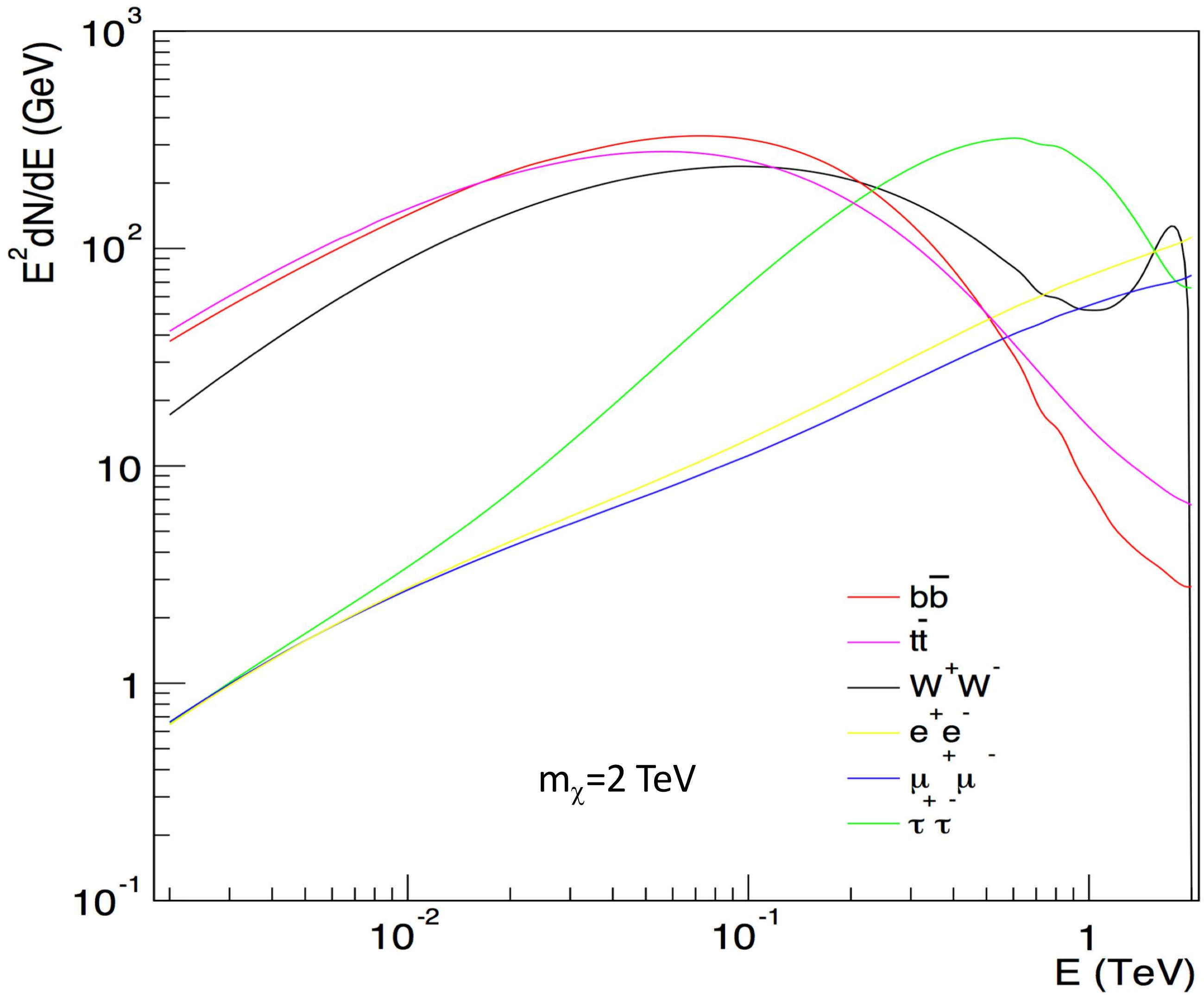
Complementarity and Searches for Dark Matter in the pMSSM



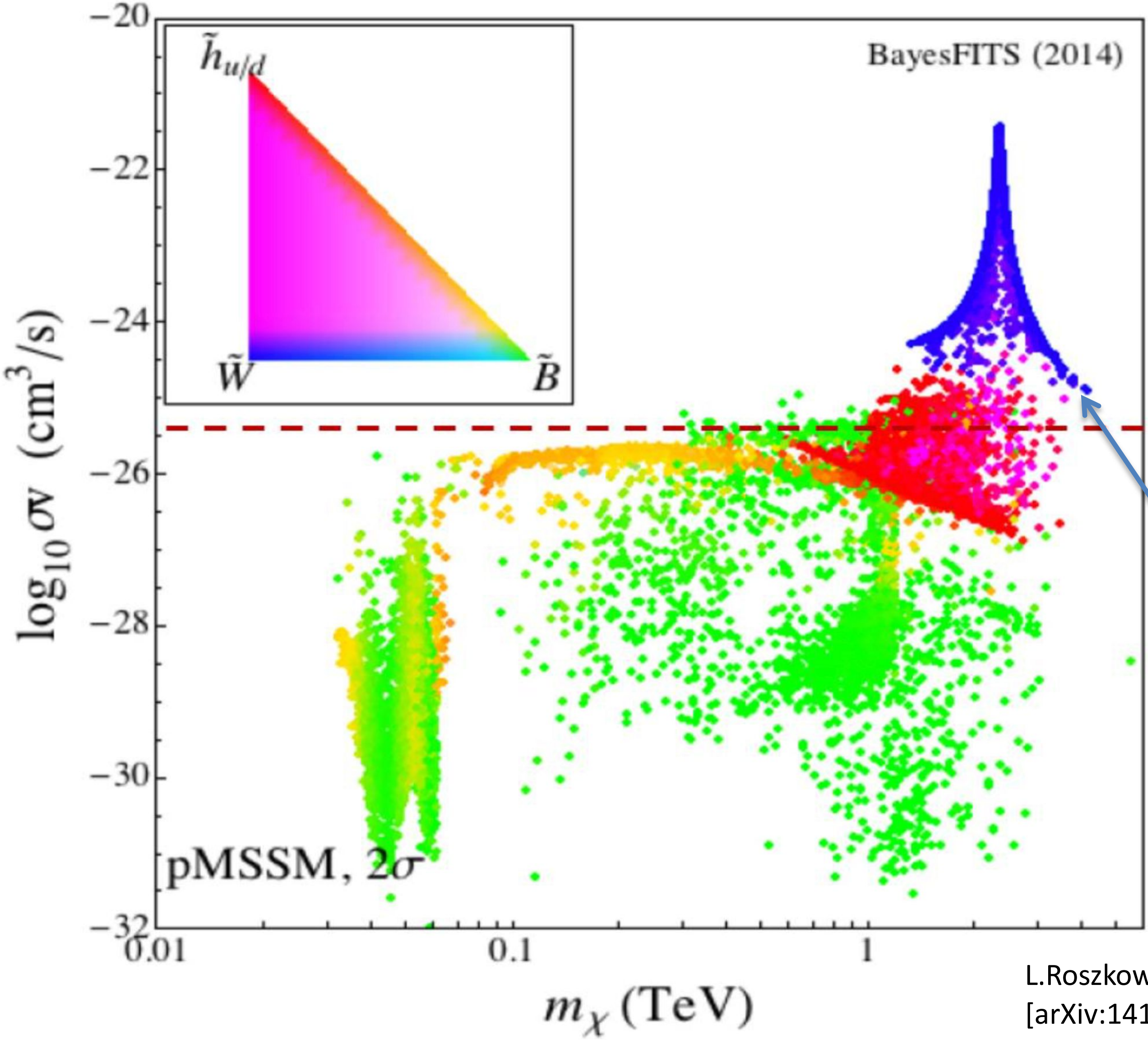
Cahill-Rowley et al. arXiv:1305.6921

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}

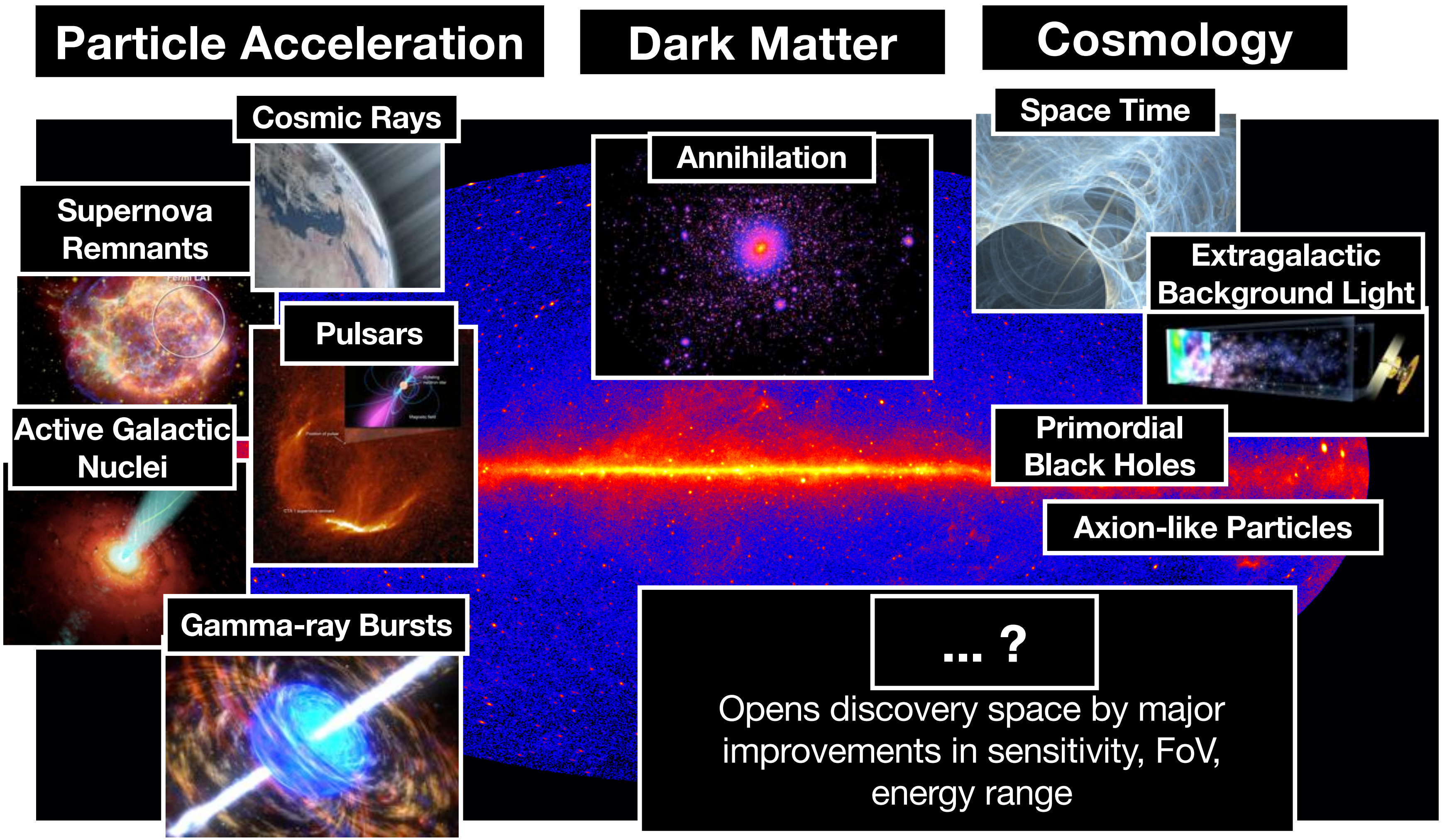
Note that a strong enhancement of the annihilation cross section occurs for winos around 2-3 TeV due to Sommerfeld enhancement.

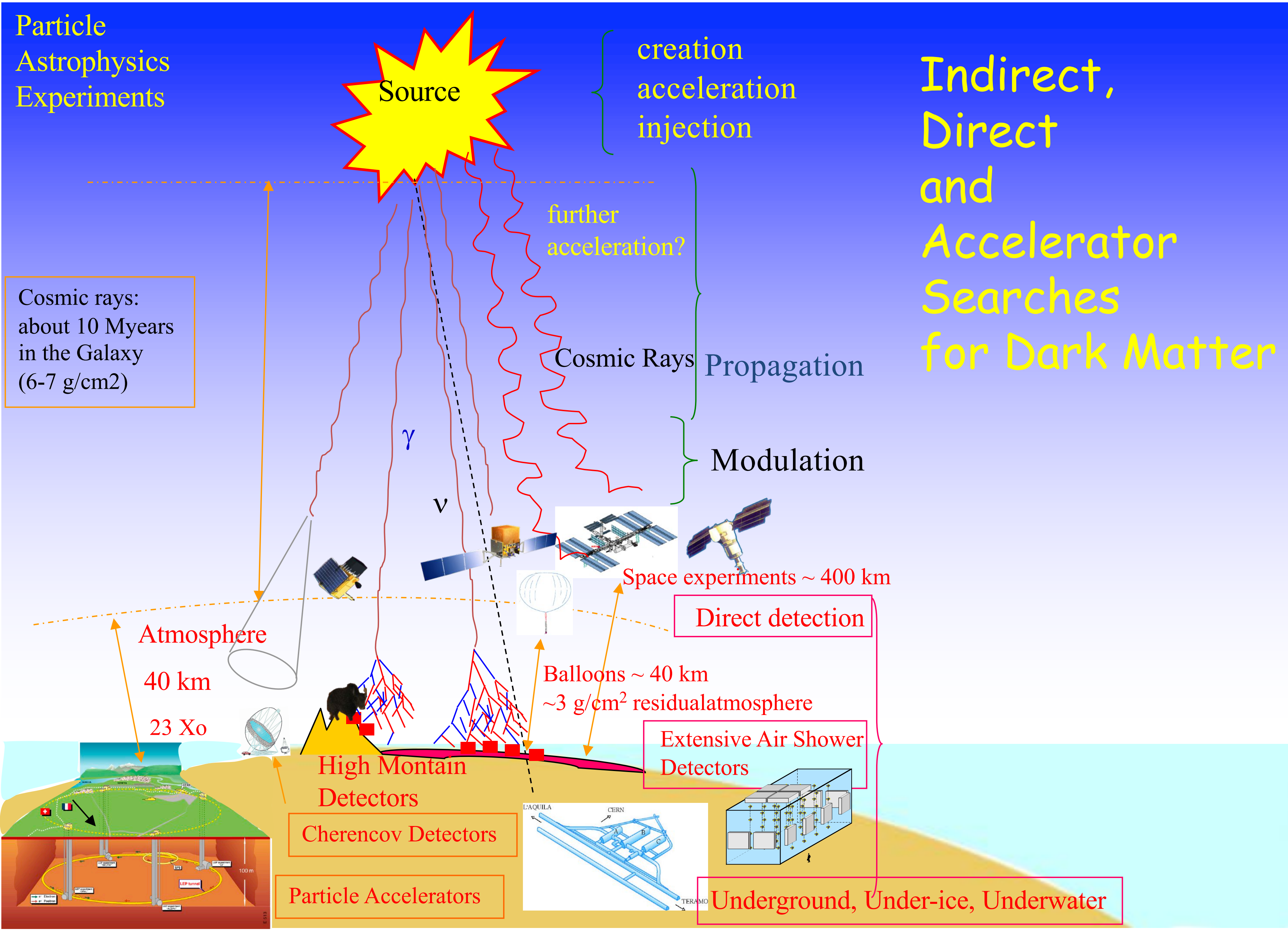
L.Roszkowski et al., JHEP 1502 (2015) 014 [arXiv:1411.5214]

CTA CONTRIBUTION TO DM RESEARCH (SUMMARY)

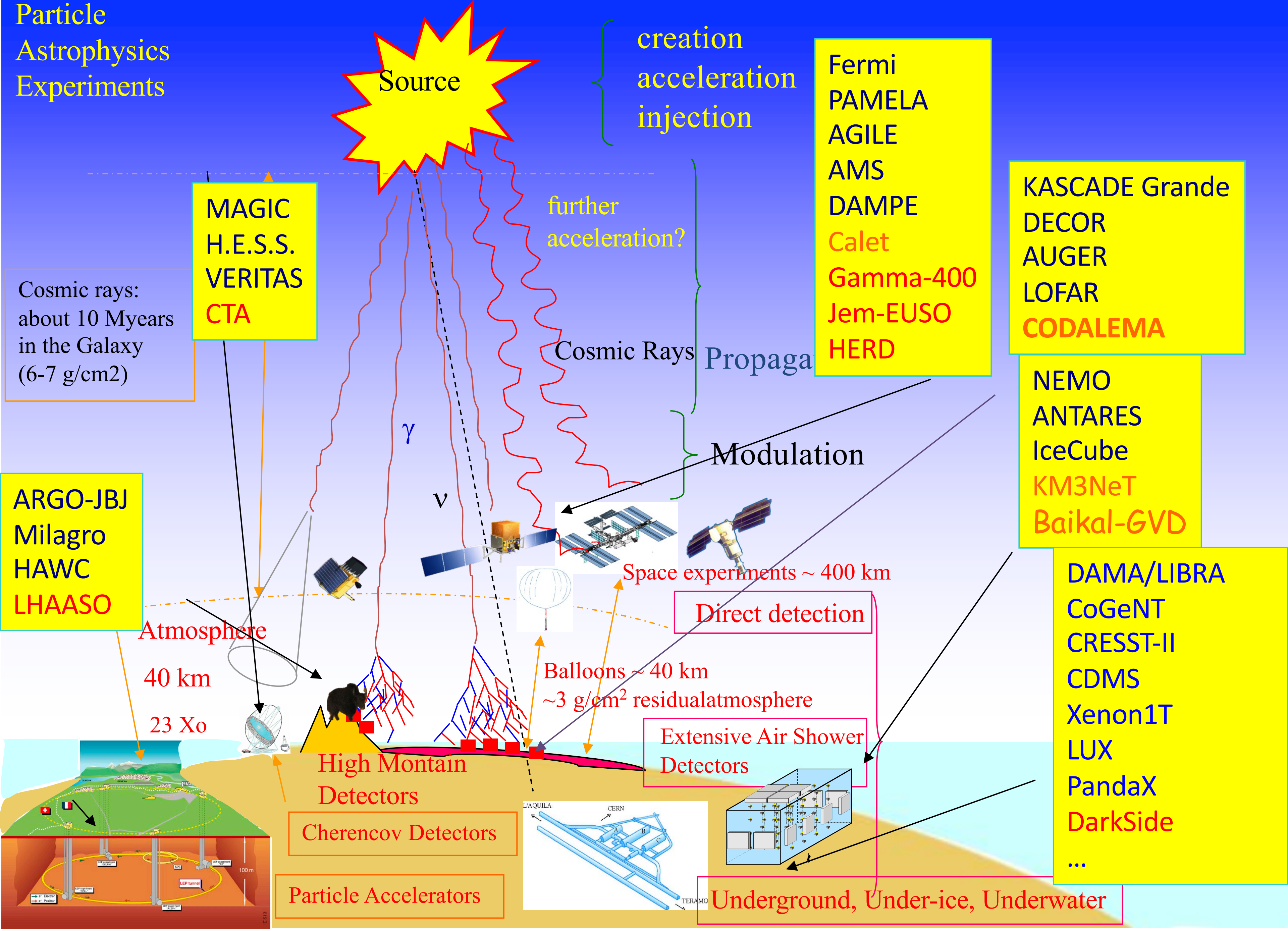
- CTA has good prospects to probe for the first time WIMP models with thermal relic cross-section and masses above 200 GeV;
- Together with Fermi CTA will be able to exclude thermal WIMPs within the mass range from a few GeV up to a few tens of TeV.
- For heavy WIMPs (>TeV) CTA will provide unique observational 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.

Broad Spectrum of Science





Particle Astrophysics Experiments
Source
creation
acceleration
injection
Indirect, Direct and Accelerator Searches for Dark Matter
further acceleration?
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
Cosmic Rays
Propagation
Modulation
γ
ν
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residualatmosphere
Extensive Air Shower Detectors
High Montain Detectors
Cherencov Detectors
Particle Accelerators
L'AQUILA
CERN
TERAMO
Underground, Under-ice, Underwater


Particle
Astrophysics
Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Gamma-400
Jem-EUSO
HERD
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
MAGIC
H.E.S.S.
VERITAS
CTA
further
acceleration?
Cosmic rays:
about 10 Myears
in the Galaxy
(6-7 g/cm2)
Cosmic Rays
Propaga
γ
Modulation
NEMO
ANTARES
IceCube
KM3NeT
Baikal-GVD
ARGO-JBJ
Milagro
HAWC
LHAASO
ν
Space experiments ~ 400 km
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
Xenon1T
LUX
PandaX
DarkSide
…
Direct detection
Atmosphere
40 km
23 Xo
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Thank you !!

CTA Galactic Halo DM upper-limits

Effect of the different Halo profiles