ASTRI Astrofisica con Specchi a Tecnologia Replicante Italiana

INAF Istituto Nazionale di Astrofisica / National Institute for Astrophysics
Universidade de São Paulo, Instituto de Astronomia, Geofisica e Ciencias Atmosferica
MIUR
North-West University / Yunibesiti ya Bokone-Bophirima / Noordwes-Universiteit

Indirect Dark Matter searches with the ASTRI mini-array in the framework of the Cherenkov Telescope Array

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Outline of the talk

✧ The ASTRI Project in the framework of CTA

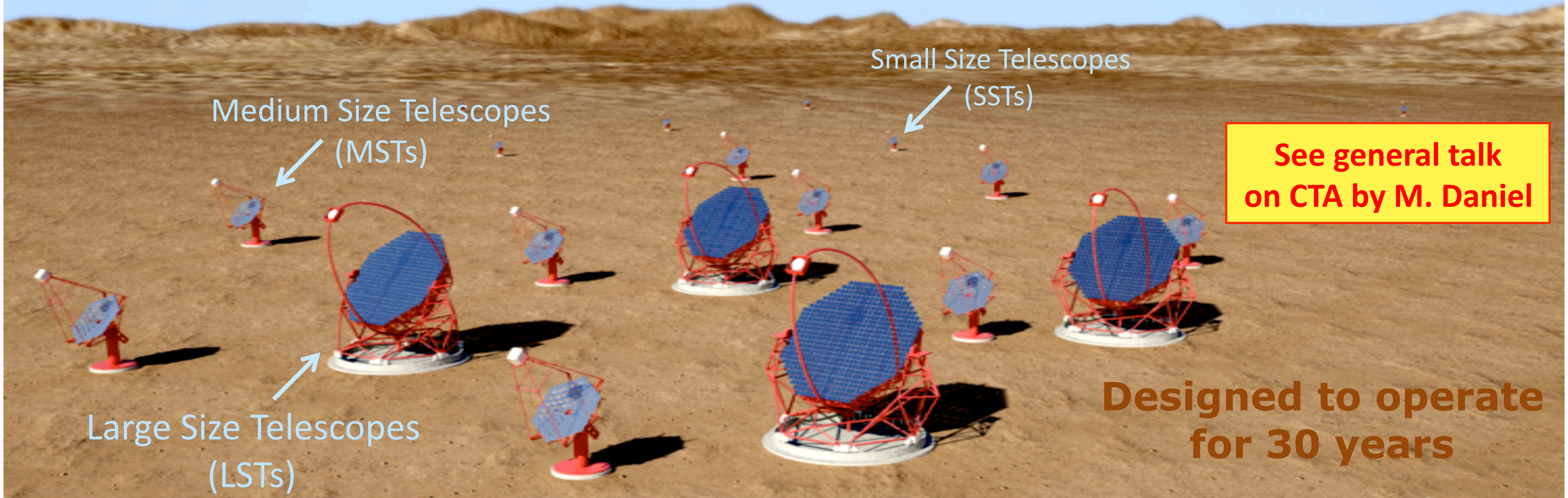
✧ Dark Matter and dSph targets

✧ Dark Matter searches with the ASTRI mini-array

✧ Summary and outlook

The Cherenkov Telescope Array (CTA) Project

- Next generation ground based Gamma-ray Observatory
- Open observatory
- Two sites with total > 100 telescopes (LSTs+MSTs+SSTs)
  - Southern Site: Near Paranal in Chile (selected for negotiations)
  - Northern Site: La Palma, Canary Islands (selected for negotiations)
- 31 nations, ~300M€ project

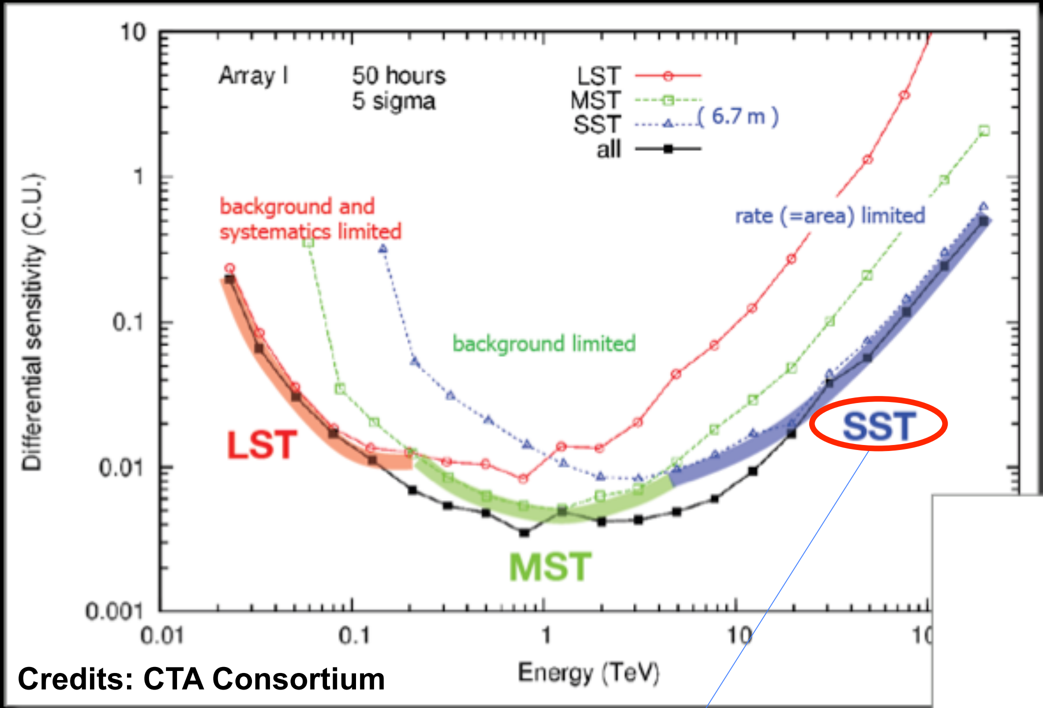


The ASTRI Project

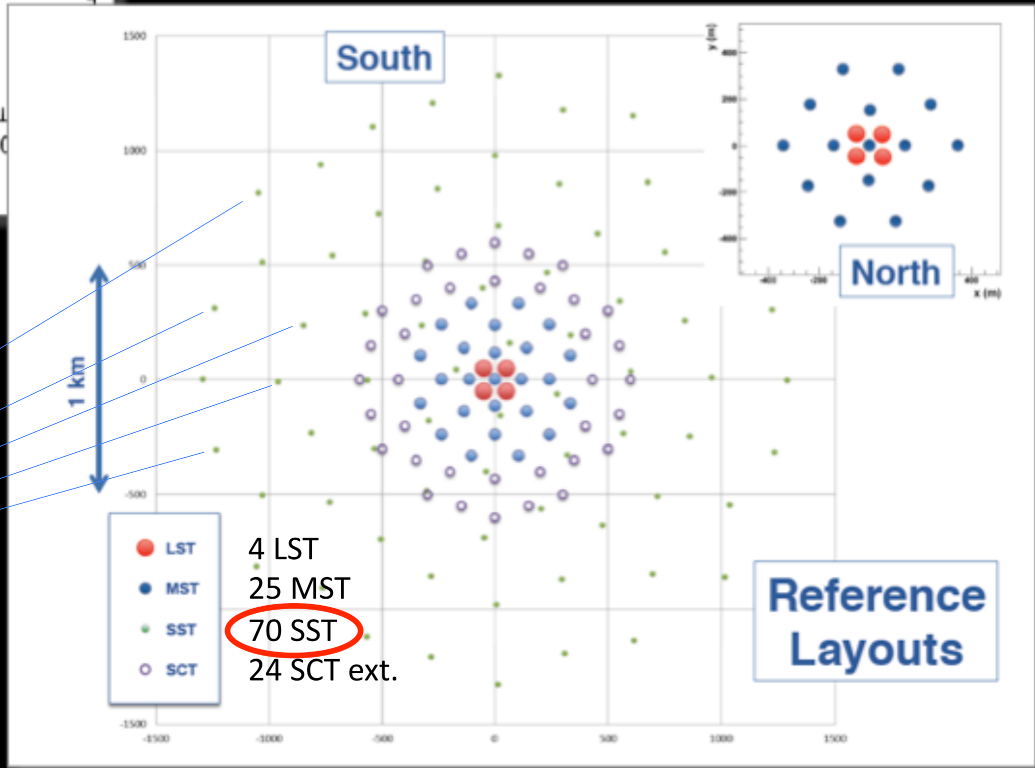
The **ASTRI Project** (led by INAF) has two main goals:

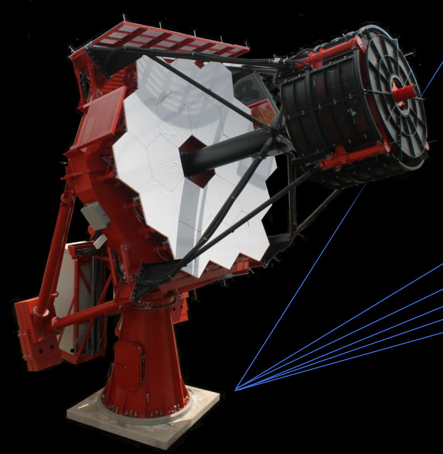
- an **end-to-end prototype** of the CTA small-size telescope in a dual mirror configuration (**ASTRI SST-2M**), inaugurated on 2014 Sept. 24th and currently under testing at the INAF observing station on Mt. Etna (Sicily)
- an **ASTRI mini-array** composed of **9 SST-2M telescopes** proposed to be installed at the chosen CTA Southern site in 2017

ASTRI in the framework of CTA



We aim at the production and deployment of about half (~35) of the CTA SST sub-array to explore the energy range above the TeV threshold





ASTRI SST-2M

The ASTRI SST-2M mini-array

Led by the Italian National Institute for Astrophysics in collaboration with:

Universidade de São Paulo & FAPESP, Brazil

North-West University, South Africa

Proposed to be installed at the final southern CTA site as one of the CTA precursors (implementation in 2017)

ASTRI SST-2M mini-array performance

✧ **Preliminary performance**

based on MC-CTA Prod2
and official CTA-MC pipelines

✧ **Sensitivity**

slightly better than H.E.S.S.
above ~10 TeV for an array
composed of 9 telescopes

✧ **Angular resolution**

a few (4–5) arcmin

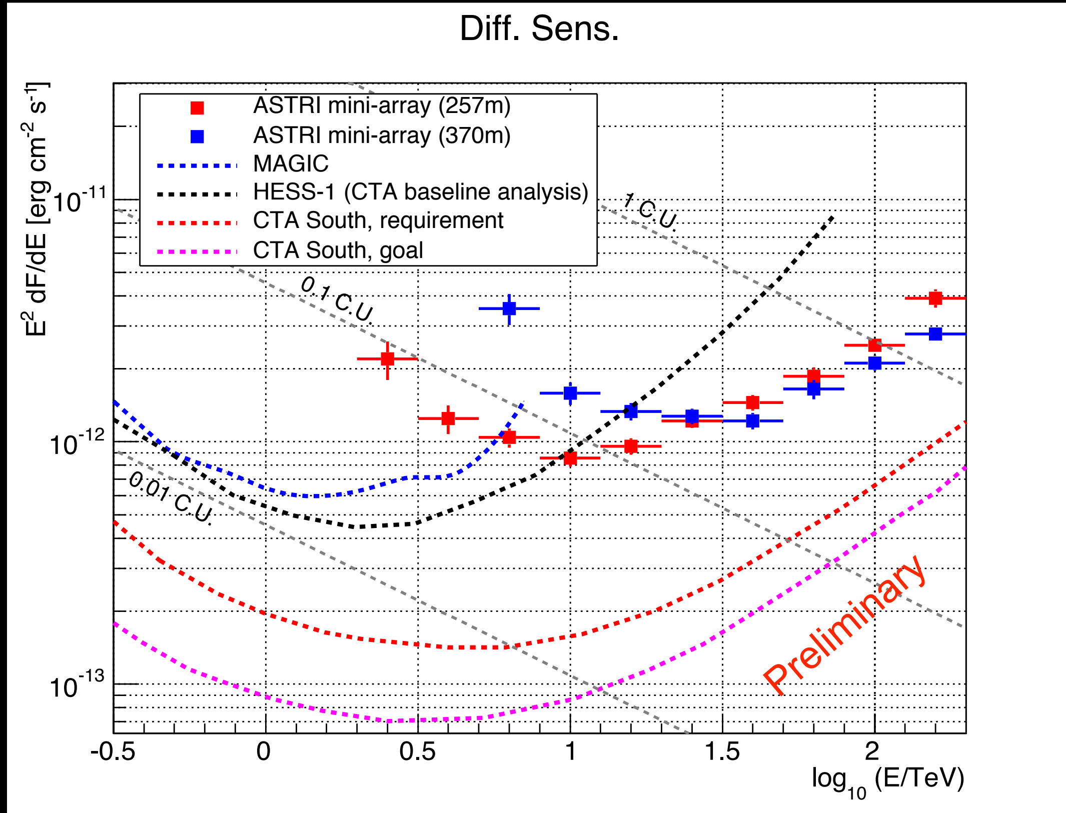
✧ **Energy resolution**

of the order of 10-15%

✧ **Wide field of view**

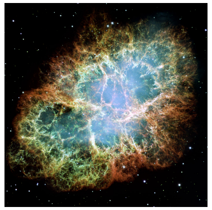
~10°

Di Pierro et al., proc. TAUP 2015, in press



ASTRI SST-2M mini-array targets

Supernova Remnants

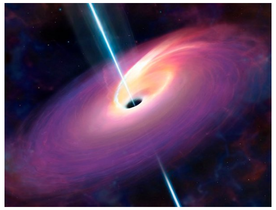


- SNRs
- Pevatrons
- SNRs interacting with molecular clouds

PWNe

Gamma-ray Binaries

Extreme BL Lacs



- Synchrotron peak > 1 keV
- Inverse Compton peak > 1 TeV

Less beamed AGNs

- Radio galaxies

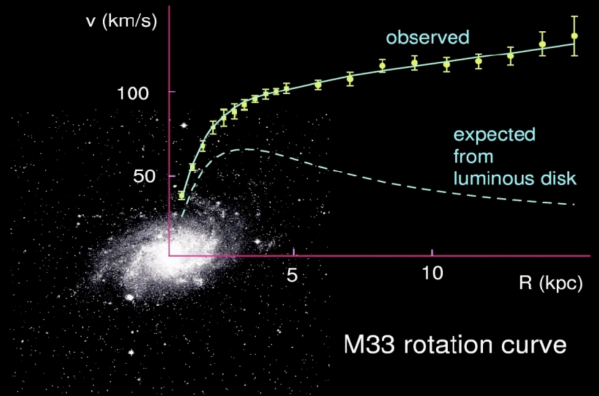
Starburst Galaxies

Dark Matter and exotic physics

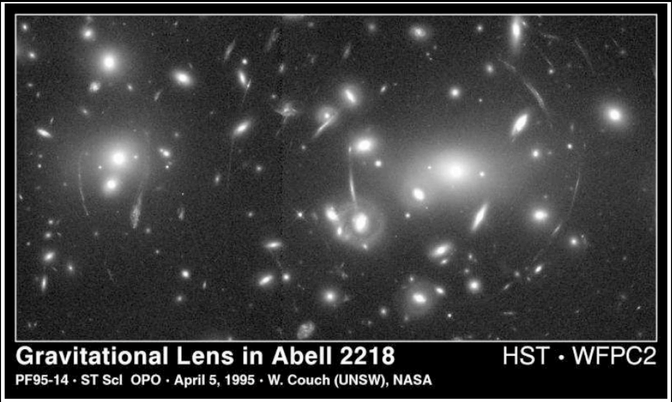
Dark Matter

✧ Compelling evidences from a large (~85%) non-baryonic component of the matter density of the Universe at all astrophysical scales

Galaxy rotational curves

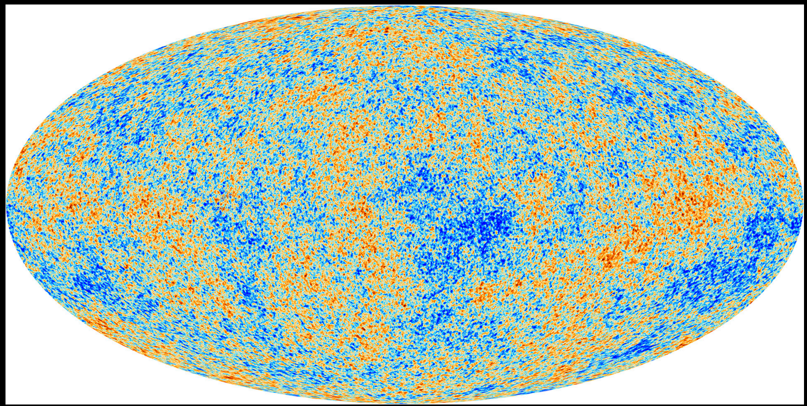


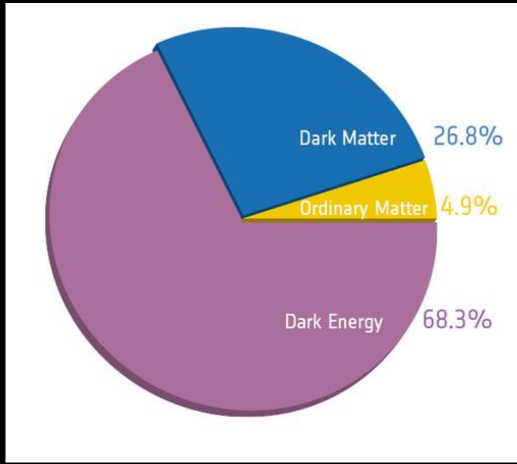
Gravitational lensing



Colliding clusters

CMB anisotropies





ΛCDM model seems to fit all current cosmological data

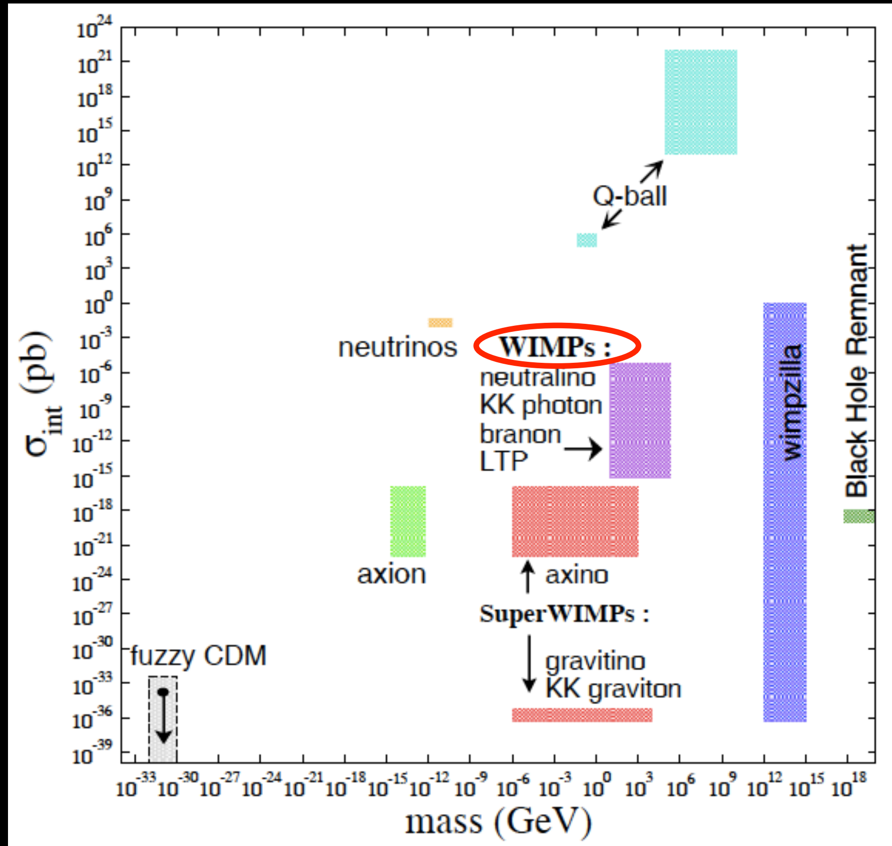
Planck Coll. 2015, *arXiv:1502.01589* (submitted to A&A)

WIMPs

✧ Standard Cosmological scenario:
Λ-Cold-Dark-Matter (ΛCDM), Ω_{DM}~0.27

✧ WIMPs are a class of particularly interesting CDM candidates:
- Neutral electric and color charges
- Interaction at weak scale
- Stable on cosmological scales
- Correct relic density
- Massive
- NON-BARYONIC origin
- May produce signals detectable by current or next-generation experiments

✧ Several SM extensions contain WIMP candidates: Supersymmetry (SUSY), minimal SM extensions, extra dimensions models, and others



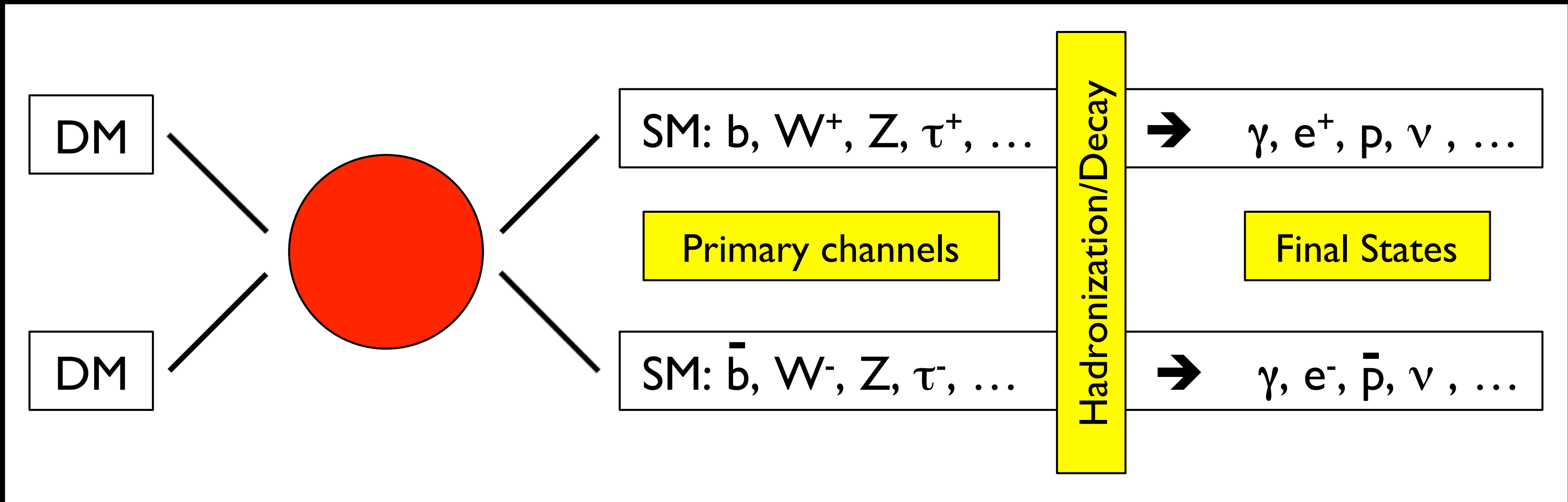
Present WIMPs mass range:
$m_{DM} \gtrsim$ 10 GeV up to tens of TeV

$\langle\sigma v_{DMDM}\rangle \sim 3 \times 10^{-26}$ cm$^3 \cdot$ s^{-1}

Indirect Dark Matter searches

✧ DM searches: **Direct / Indirect / Direct Production / Astrophysical Probes**

✧ Indirect searches for detection of SM products (**including gamma-rays**) from annihilation or decay of Dark Matter particles:



✧ Gamma-rays as final states are of major interest because:

- do not suffer from propagation effects
- trace back to abundance / distribution of DM
- show peculiar spectral features (*smocking guns*)

➔ Identification of DM mass and reaction process

➔ Disentangle from astrophys. bkg

Indirect Dark Matter searches

✧ Expected **differential gamma-ray fluxes:**

$$\frac{d\Phi(\Delta\Omega)}{dE'} = \frac{d\Phi^{PP}}{dE'} \times J(\Delta\Omega)$$

	Particle Physics factor:	Astrophysical factor:
Annihilation:	$\frac{d\Phi^{PP}}{dE'} = \frac{1}{4\pi}\frac{\langle\sigma_{ann}v\rangle}{2m_\chi^2}\frac{dN}{dE'}$	$J_{ann}(\Delta\Omega) = \int_{\Delta\Omega}\int_{los}\rho^2(l,\Omega)dl\,d\Omega.$
Decay:	$\frac{d\Phi^{PP}}{dE'} = \frac{1}{4\pi\,\tau_\chi m_\chi}\frac{dN}{dE'}$	$J_{dec}(\Delta\Omega) = \int_{\Delta\Omega}\int_{los}\rho(l,\Omega)dl\,d\Omega.$
	Large uncertainties from Fund. Phys. No target dependences (straightforward stacking analysis)	Large uncertainties from DM profiles (robust limits from less uncertain targets)

Possible targets

✧ *Galactic center?*

+ Highest *J-factor*
− Very high astroph. bkg
− Uncertainties on inner DM distribution
− Southern Hemisphere

✧ *Galactic halo?*

+ High *J-factor*
− Not fully-free from astroph. bkg
− Extended
− Southern Hemisphere

✧ *Galaxy Clusters?*

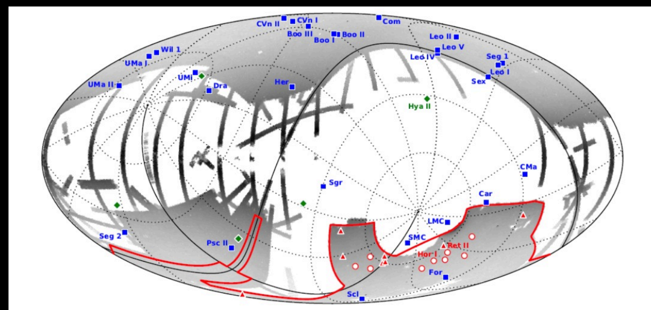
+ Huge amount of DM
− High astroph. bkg
− Extended
− High uncertainties on *J-factors*

✧ *DM Clumps?*

+ Free from astroph. bkg
+ Nearby and numerous
− To be found!
− Bright enough?

✧ *Dwarf Galaxies?*

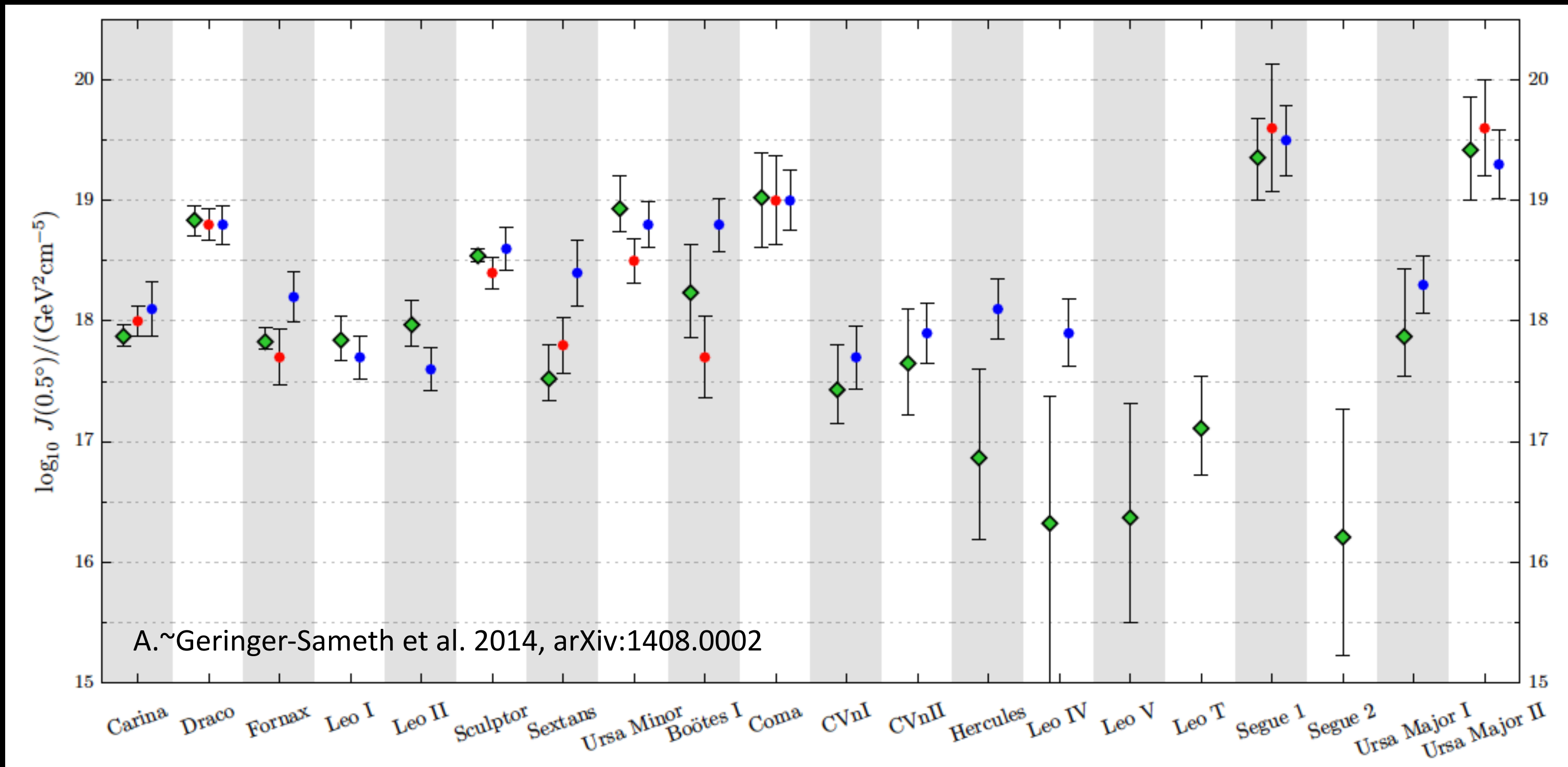
+ DM dominated (high M/L ratios)
+ Free from astroph. bkg
+ Close (<~100 kpc)
+ Slightly extended at most
+ Less uncertainties on *J-factors*
− *J-factors* ~100 lower than for GC



dSPhs

In the late past years **SDSS** discoveries extended the dwarf galaxy regime to extremely low luminosities and size (adding new faint objects, the UFD, to the classical dwarf satellite as MW companions).

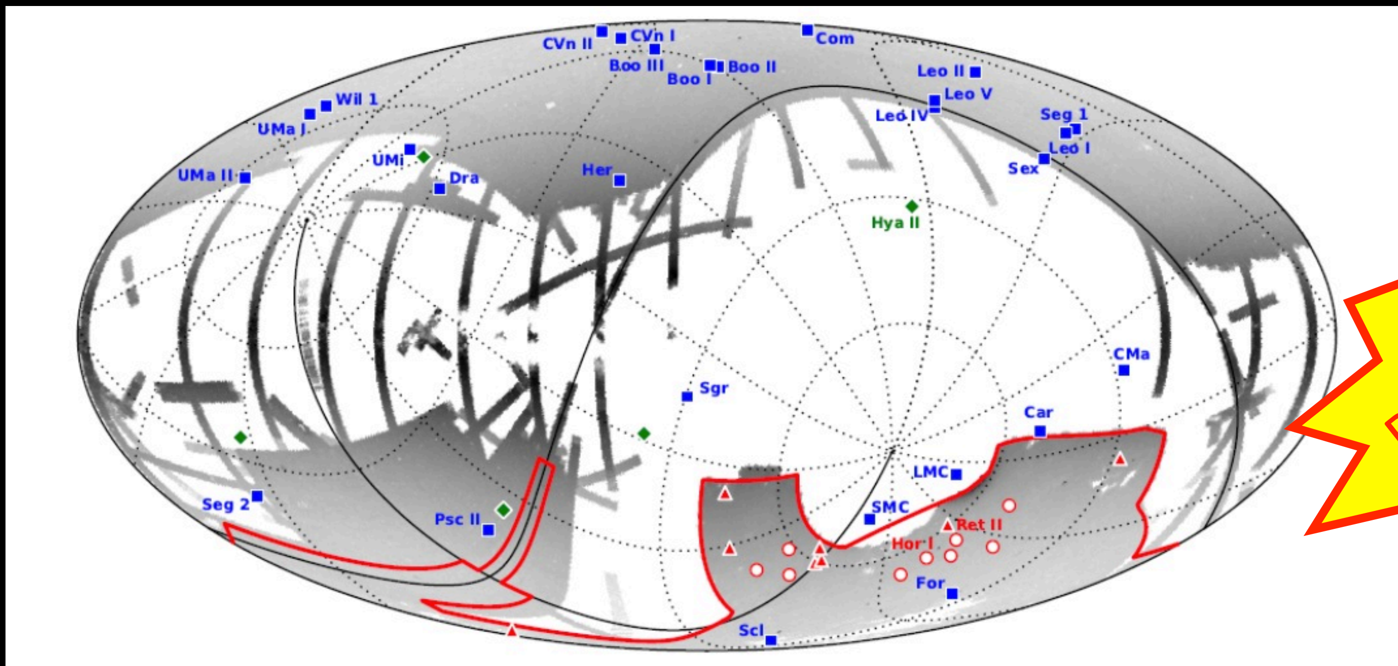
✧ ~25 (classical and ultra-faint) dwarf Spheroidal galaxies (dSphs) known up to 2014



dSPhs

New surveys ongoing devoted to a deep scan of the sky: **DES, PanSTARRS, VST, ATLAS, etc**, expanded the surveyed region significantly. To date despite only a third of the sky has been inspected, new dwarf satellite of MW have already been identified. **GAIA** is also foreseen to contribute.

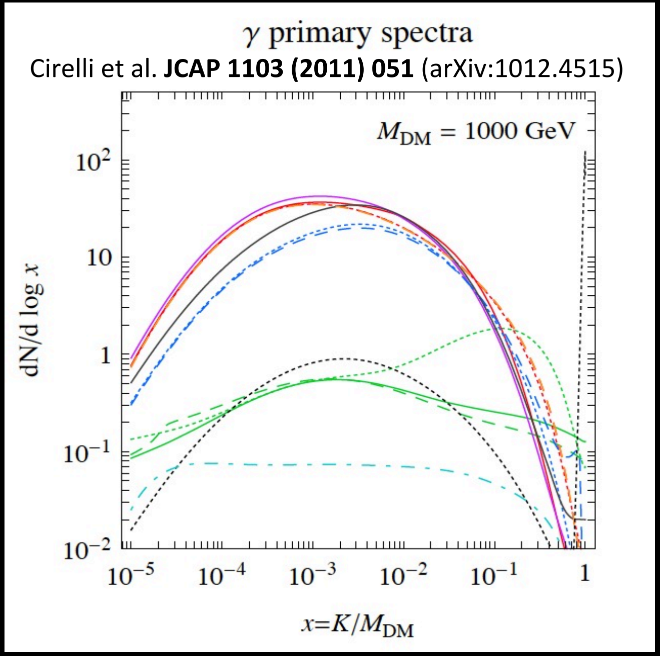
- ✧ 17 new faint MW satellites (around LMC and SMC, Southern Hemisphere) from 2-years **DES** data in 2015 (*arXiv:1503.02079, arXiv:1503.02584, arXiv:1505.04948, arXiv:1508.03622*). Spectroscopy studies foreseen.
- ✧ 5 new faint MW satellites discovered in **PanSTARRS1 3p survey** (*arXiv:1503.05554, arXiv:1503.08268, arXiv:1507.07564*)

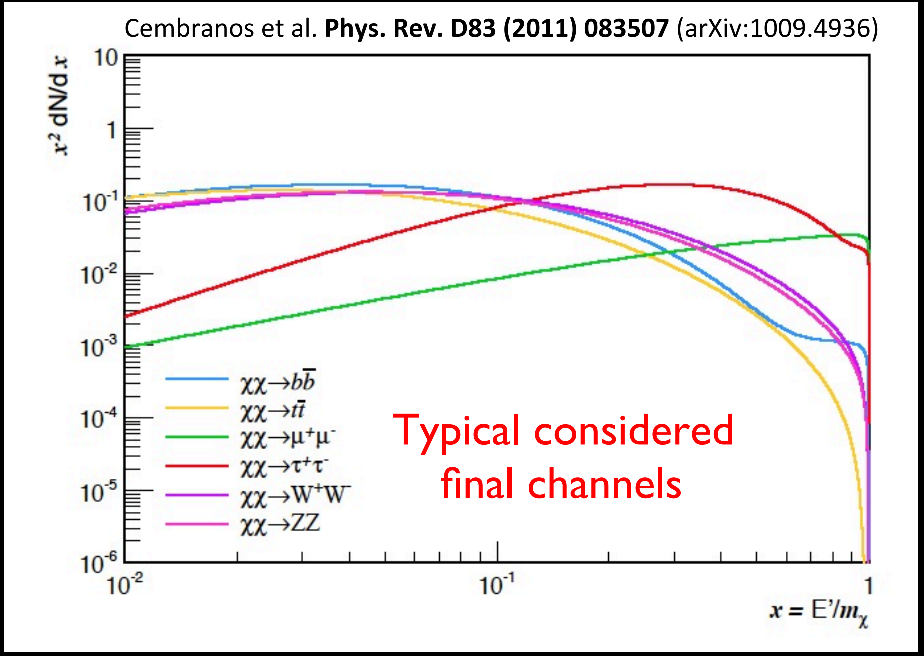


Rapidly growing population!

✧ All computations are based on ***Full Likelihood*** analysis by *J. Aleksić, J. Rico, M. Martinez* ***JCAP 10 (2012) 032*** *(arXiv:1209.5589)*. The method has been recently implemented by the authors in a *C++* based code available for MAGIC and CTA publications

✧ The expected spectra from DM particle annihilation/decay have been produced with PYTHIA v8.2 and/or taken from *Cirelli et al.* ***JCAP 1103 (2011) 051*** *(arXiv:1012.4515)*. These spectra extend up to 100 TeV

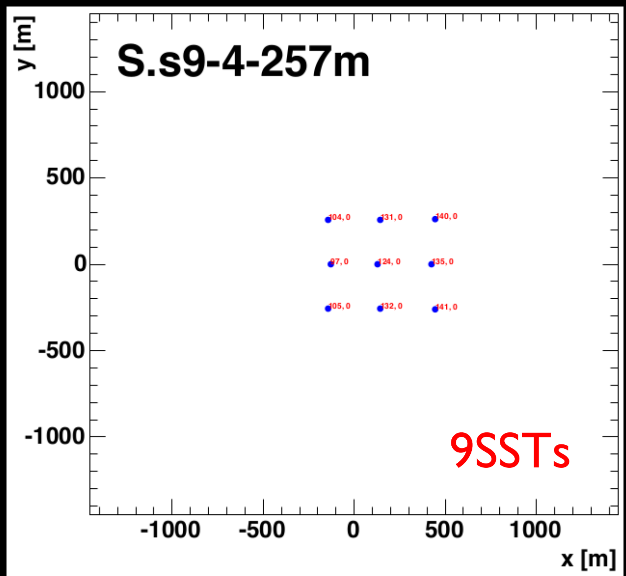


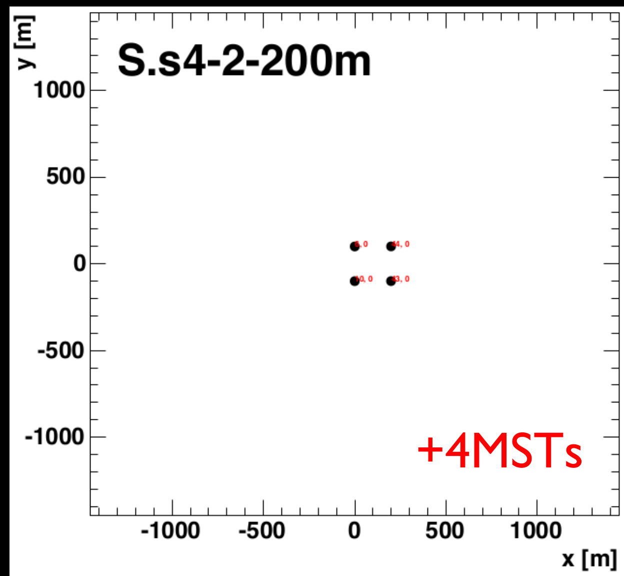


Dark Matter searches with the ASTRI mini-array

✧ 2 sets of Instrument Response Functions (IRFs) have been taken into account for providing **Mini-Array** (MA) preliminary prospects for DM searches:

- **MA(9SSTs[257m]) IRFs** (from CTA-MC Prod2*, official CTA-MC-PIPE*)
  - **Eth ~1.5 TeV**
- **MA(9SSTs[257]+4MSTs[200m])** IRFs (from CTA-MC Prod2*, official CTA-MC-PIPE*)
  - **Eth ~80 GeV**





**Hassan et al. (2015), proc. 34th ICRC, arXiv:1508.06075*
**Bernlöhr et al., Astropart. Phys. (2013), 43, p171–188 (arXiv:1210.3503)*

Dark Matter searches with the ASTRI mini-array

✧ Sensitivity prospects computed for

- ASTRI mini-array (9 SSTs) ➔ IRF from CTA-MC Prod2* + official CTA-MC-PIPE*
- ASTRI mini-array + 4MSTs ➔ IRF from CTA-MC Prod2* + official CTA-MC-PIPE*
- MAGIC ➔ IRF from MAGIC Collaboration
- CTA-N ➔ IRF from CTA Consortium

✧ *In all cases:* **160h of observations of a Segue1-like dSph**

(as in *J. Aleksić et al.* ***JCAP 02 (2014) 008*** *(arXiv:1312.1535)*)

D ≈ 23 kpc
M/L ≈ 3400 $M_\odot/L_\odot$
M ≈ 6×10^5 $M_\odot$
J ≈ 1.1×10^{19} GeV^2 cm^{-5}

✧ Considered annihilation channels:

$b\bar{b}$, W^+W^-, $\tau^+\tau^-$, $\mu^+\mu^-$ ($t\bar{t}$, e^+e^-, ZZ also computed)

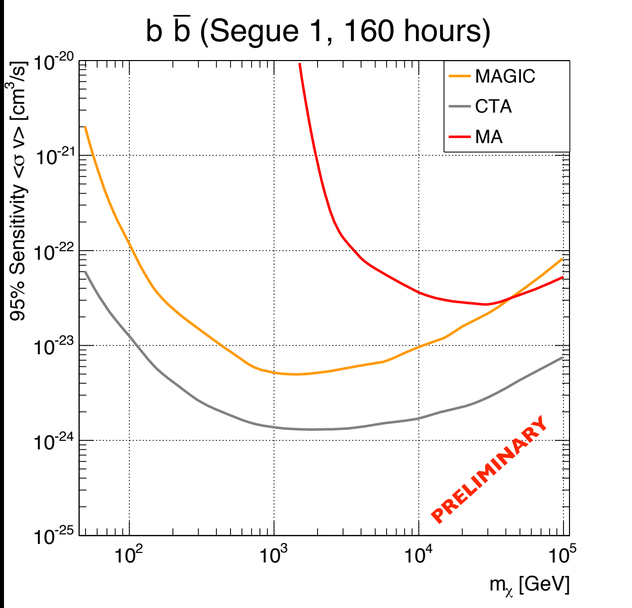
✧ Sensitivity prospects for MAGIC and CTA in agreement with the published results (and results from other groups) ➔ important consistency cross-check

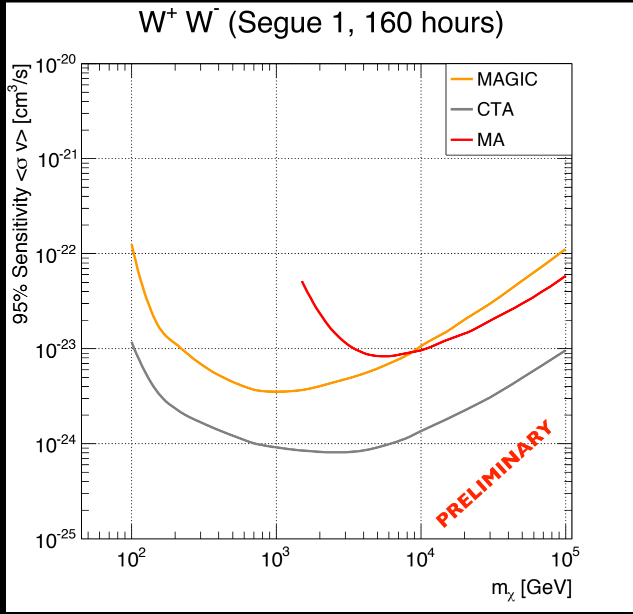
Hassan et al. (2015), proc. 34th ICRC, arXiv:1508.06075

Bernlöhr et al., Astropart. Phys. (2013), 43, p171–188 (arXiv:1210.3503)

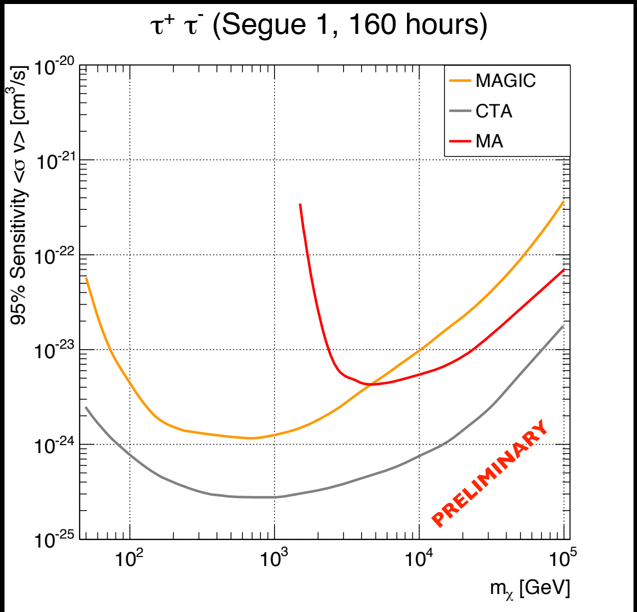
Preliminary prospects

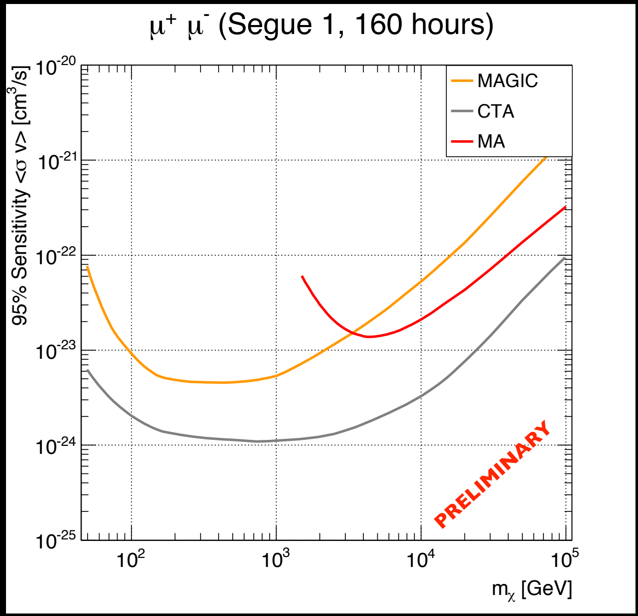
MA = 9SSTs (Eth~1.5TeV)





Giammaria, Lombardi et al., in prep.



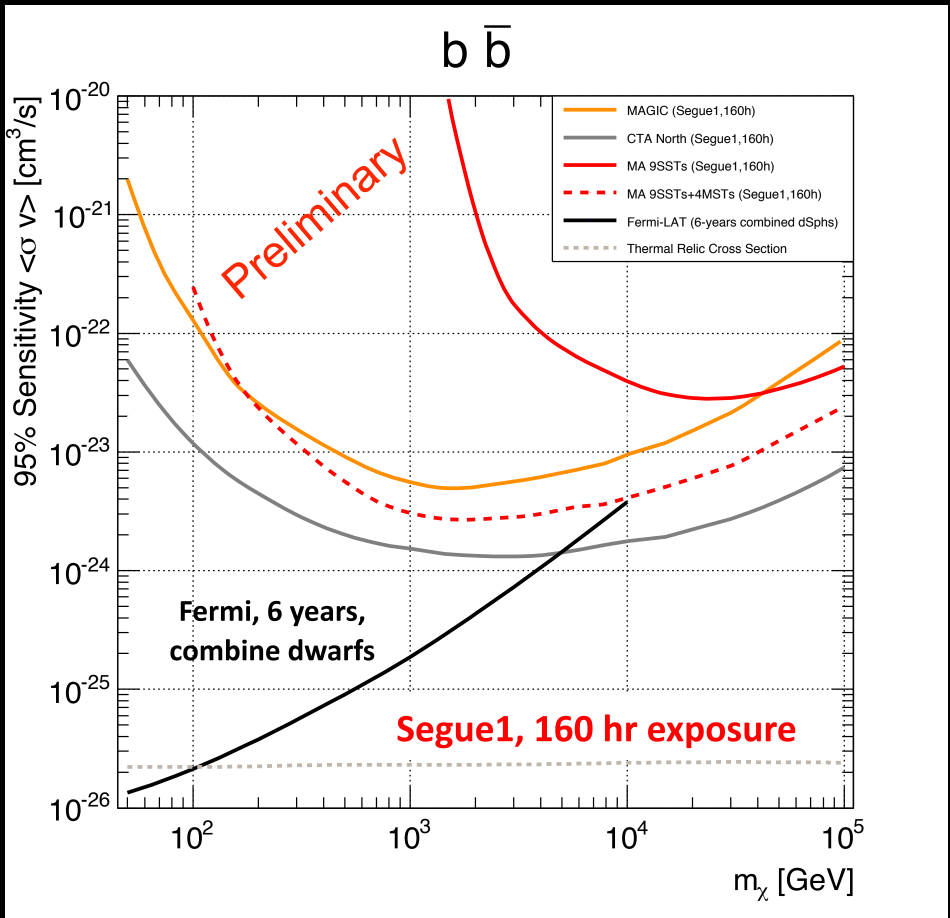


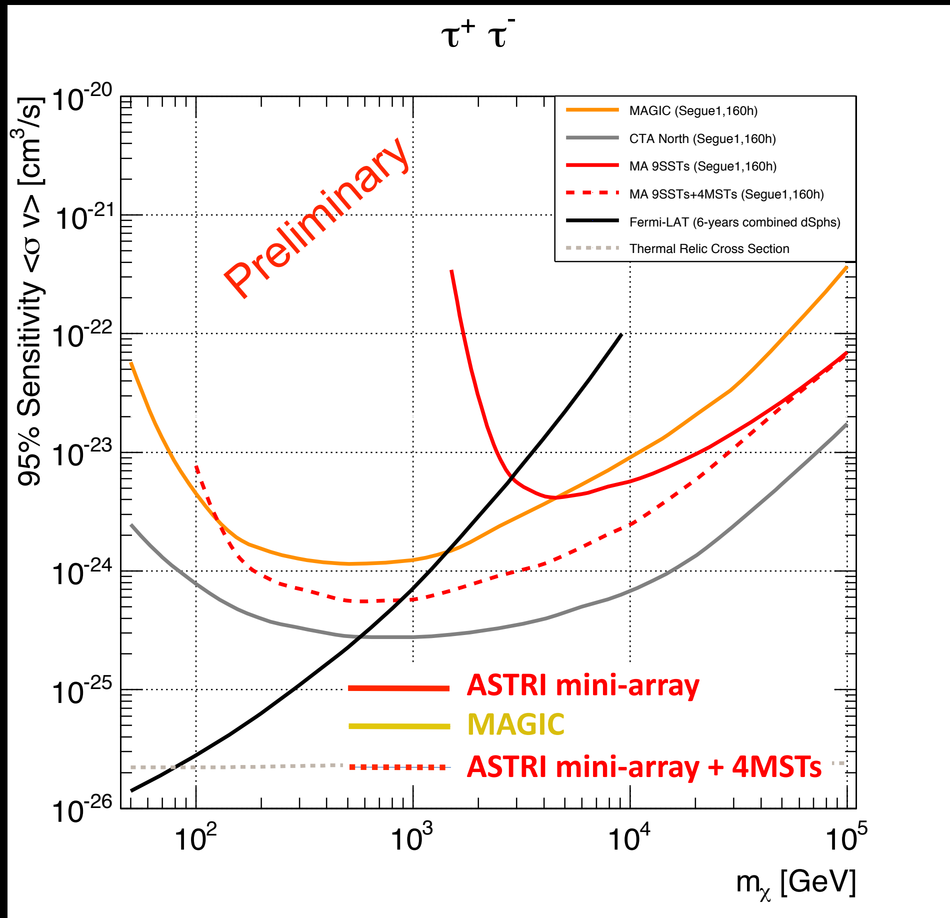
MA(9SSTs): Limited prospects for m_χ> tens of TeV

MA(9SSTs): Interesting prospects for m_χ> few TeVs

Preliminary prospects

Giammaria, Lombardi et al., in prep.





MA(9SSTs): Limited prospects for m_χ > tens of TeV

MA(9SSTs+4MSTs): Promising prospects for m_χ > ~0.1TeV

MA(9SSTs): Interesting prospects for m_χ > few TeVs

MA(9SSTs+4MSTs): Promising prospects for m_χ > ~0.1TeV

Summary and Outlook

✧ Preliminary "comparative" prospects for indirect DM searches with the ASTRI Mini-Array plus a "mixed" configuration with additional 4MSTs:

- The MA(9SSTs) expected performance provides interesting scenario for leptonic annihilation channels above few TeV mass region
- The inclusion of few MSTs in the mini-array is crucial for DM searches and provide promising pre-CTA scenarios for mass range 0.1 – 100 TeV

✧ On-going efforts for more realistic prospects:

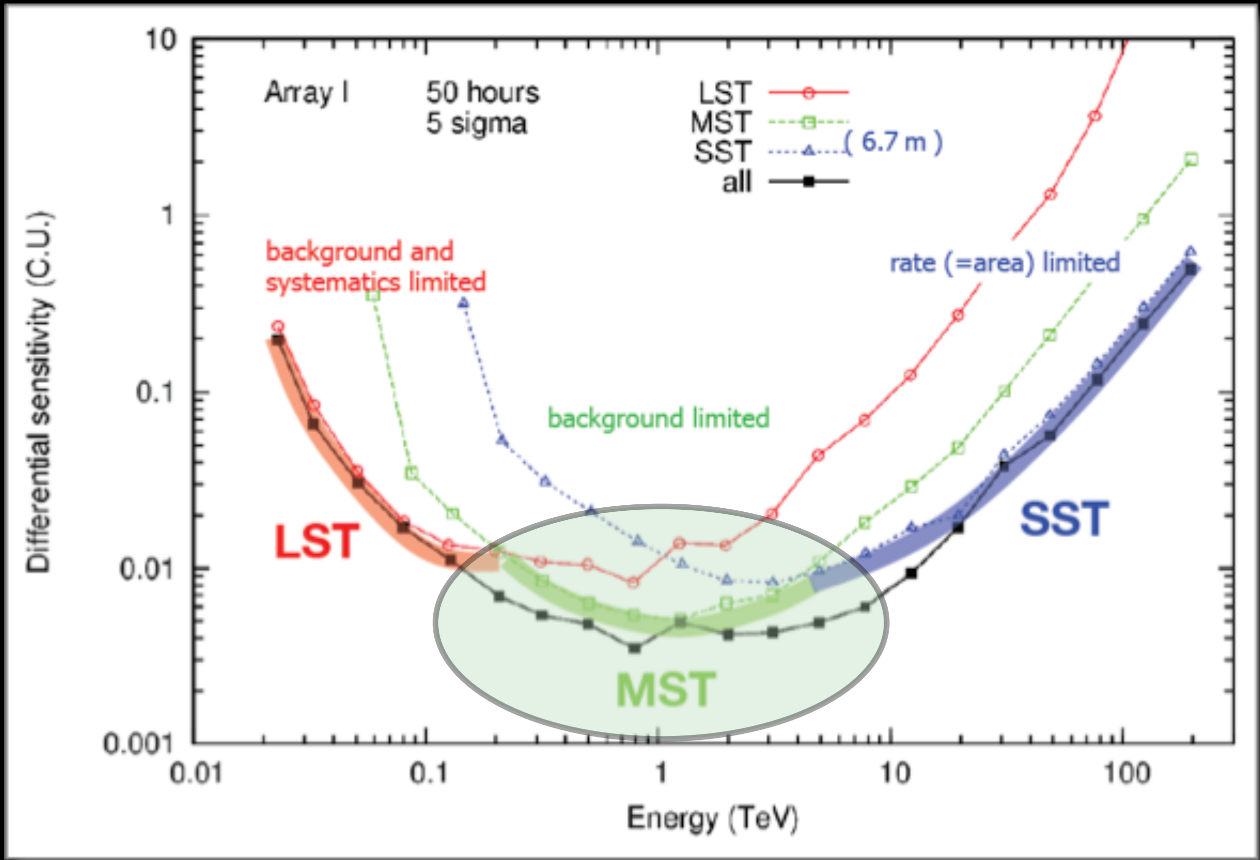
- MC simulations from CTA-MC Prod3 + analysis optimized for DM searches
- Optimization of mini-array and "mixed" array configurations
- DM annihilation/decay spectra with new features: VIB, γ-ray boxes, …
- Selection of new Southern-Hemisphere optimal dSphs targets (from DES)
- Galactic Center/Halo as primary target

✧ Foreseen synergy with CTA Dark Matter group for a feasible Dark Matter search program with proposed CTA-S precursors http://www.brera.inaf.it/astri/

Credit: R. Canestrari

Backup

Synergy with MSTs



Courtesy of the CTA Consortium

Adding a few of MST telescopes to the ASTRI mini-array could be useful in order to:

- ✧ **test trigger performance among different kinds of telescopes**
- ✧ decrease the energy threshold (crucial for e.g. Dark Matter searches)
- ✧ obtain a better energy coverage below 1 TeV

PROPOSED SCHEDULING

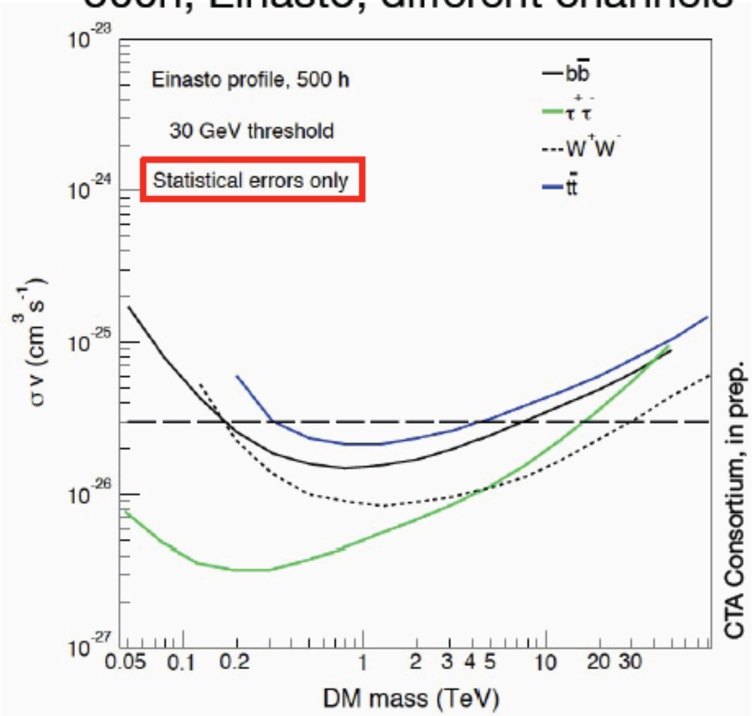
Table 4.1 – Strategy for dark matter observations over ten years with CTA. The first three years are devoted to the deep observation of the Galactic Centre (GC) together with the observation of the best ultra-faint dwarf galaxy. In case of non-detection of the GC, observations starting in the fourth year focus on the most promising target at that time to provide legacy constraints.

Year	1	2	3	4	5	6	7	8	9	10
Galactic halo	175 h	175 h	175 h							
Segue 1 (or best) dSph	100 h	100 h	100 h							
				in case of detection at GC, large σv						
Segue 1 (or 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

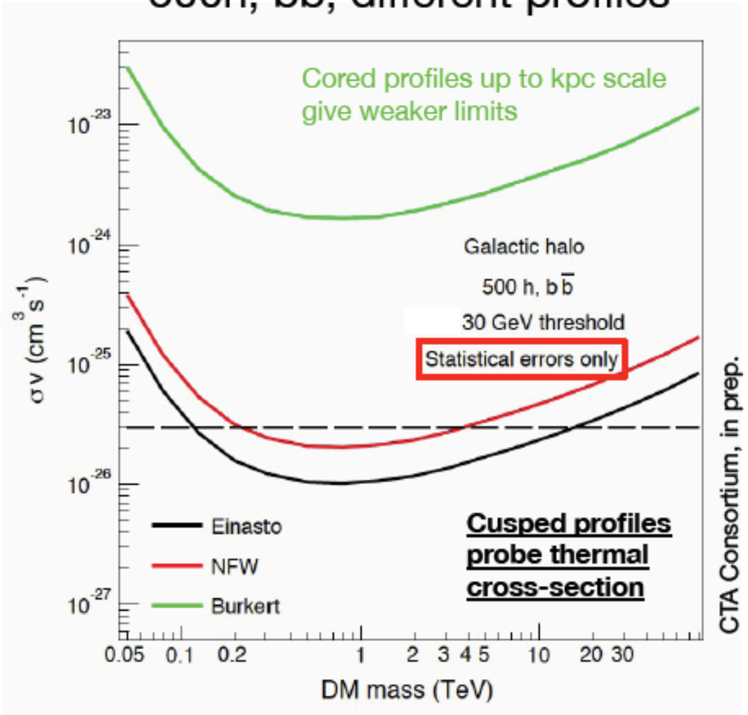
CTA Consortium, in prep.

GALACTIC HALO SENSITIVITY

500h, Einasto, different channels



500h, bb̄, different profiles



- **natural cross-section will be within the sensitivity reach of CTA!**
- very complex environment, extended emission, astrophysical background
- **careful treatment and control of systematics mandatory; work in progress**

Silverwood, H. et al., JCAP 03, 055 (2015)

Lefranc, V., et al., PRD 91, 12 (2015)

DWARF GALAXIES

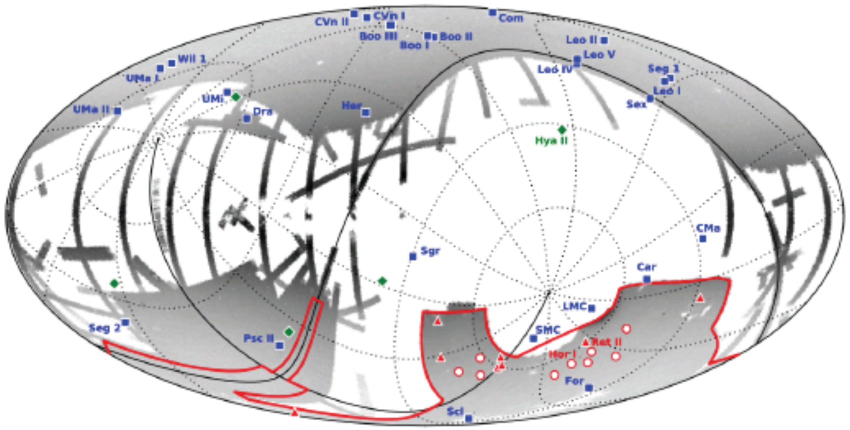
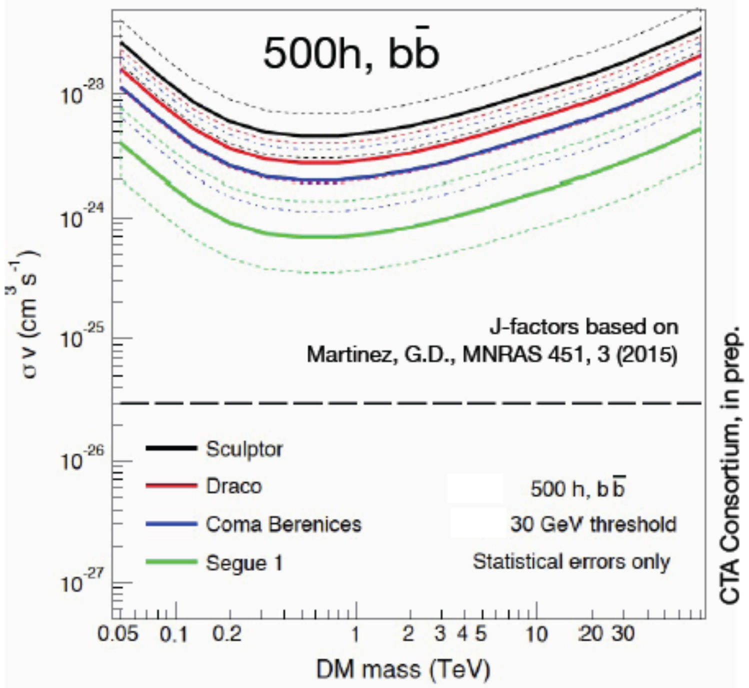


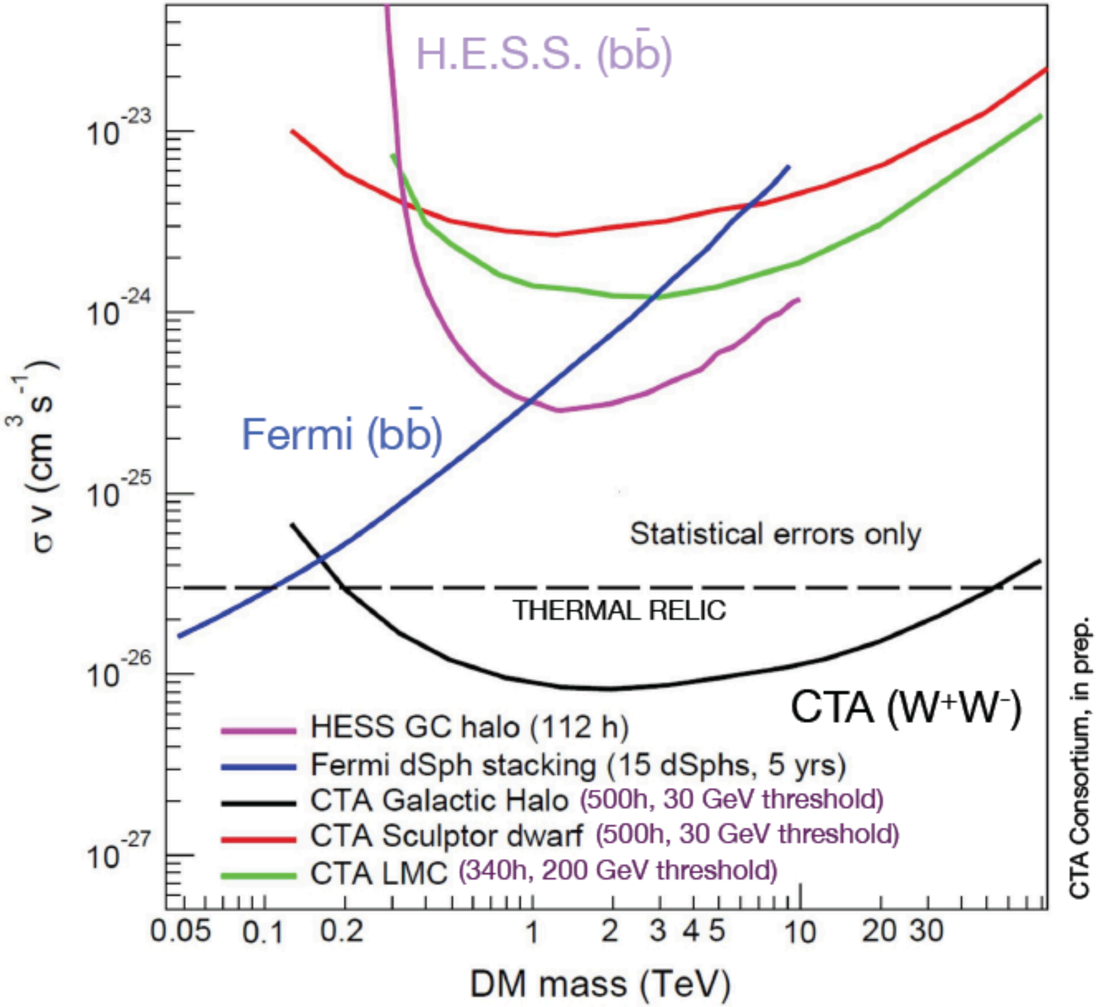
Image credit: A. Drlica-Wagner et al. (DES Coll.), arXiv:1508.03622

- MW satellite galaxies, D= 15 — 250 kpc
- luminosities ≳ 1000 $L_\odot$
- large M/L up to 1000 $M_\odot/L_\odot$
- no astrophysical background
  (no gas content, no gamma-ray emitters)
- new ultra-faint dSphs to be discovered with next-generation sky surveys *(DES, LSST, SkyMapper, Pan-STARRS)*
- ~20 new dSph candidates *already discovered* (of which several with spectroscopic confirmation)



- the best constrained/most promising dSphs known at the time of observation will be chosen
- robust constraints, but a factor of ~30 away from DM expectation

SENSITIVITY OF MAIN TARGETS



- **For Galactic Halo with *cuspy* profile CTA can probe below thermal cross-section**
- Dwarfs observations for crosschecks in cleaner environments and robust long-term legacy limits
- Systematics must be controlled extremely well to achieve statistically-possible sensitivity