ROAD TO CTA

THE QUEST FOR DARK MATTER WITH CHERENKOV TELESCOPES

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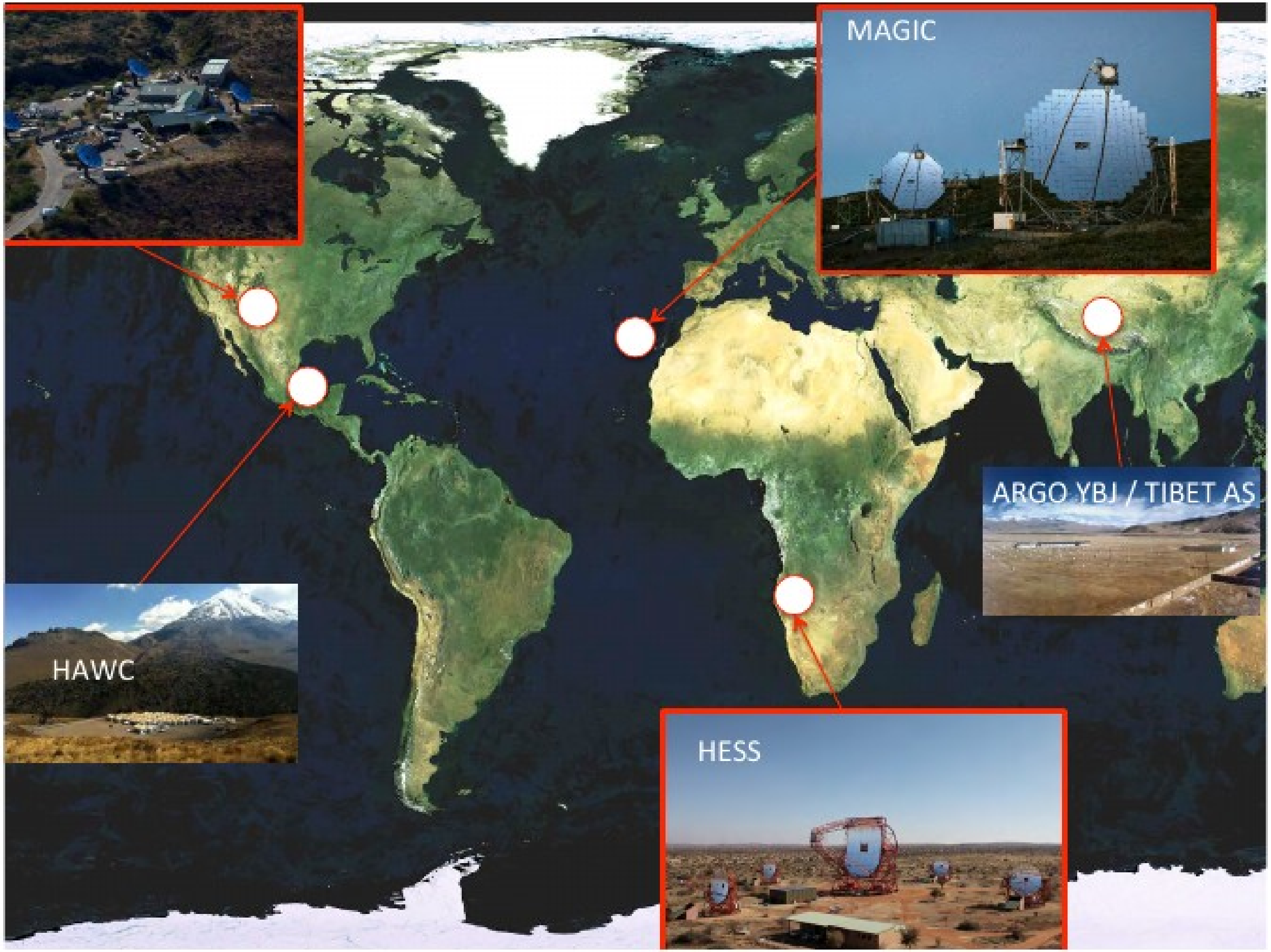
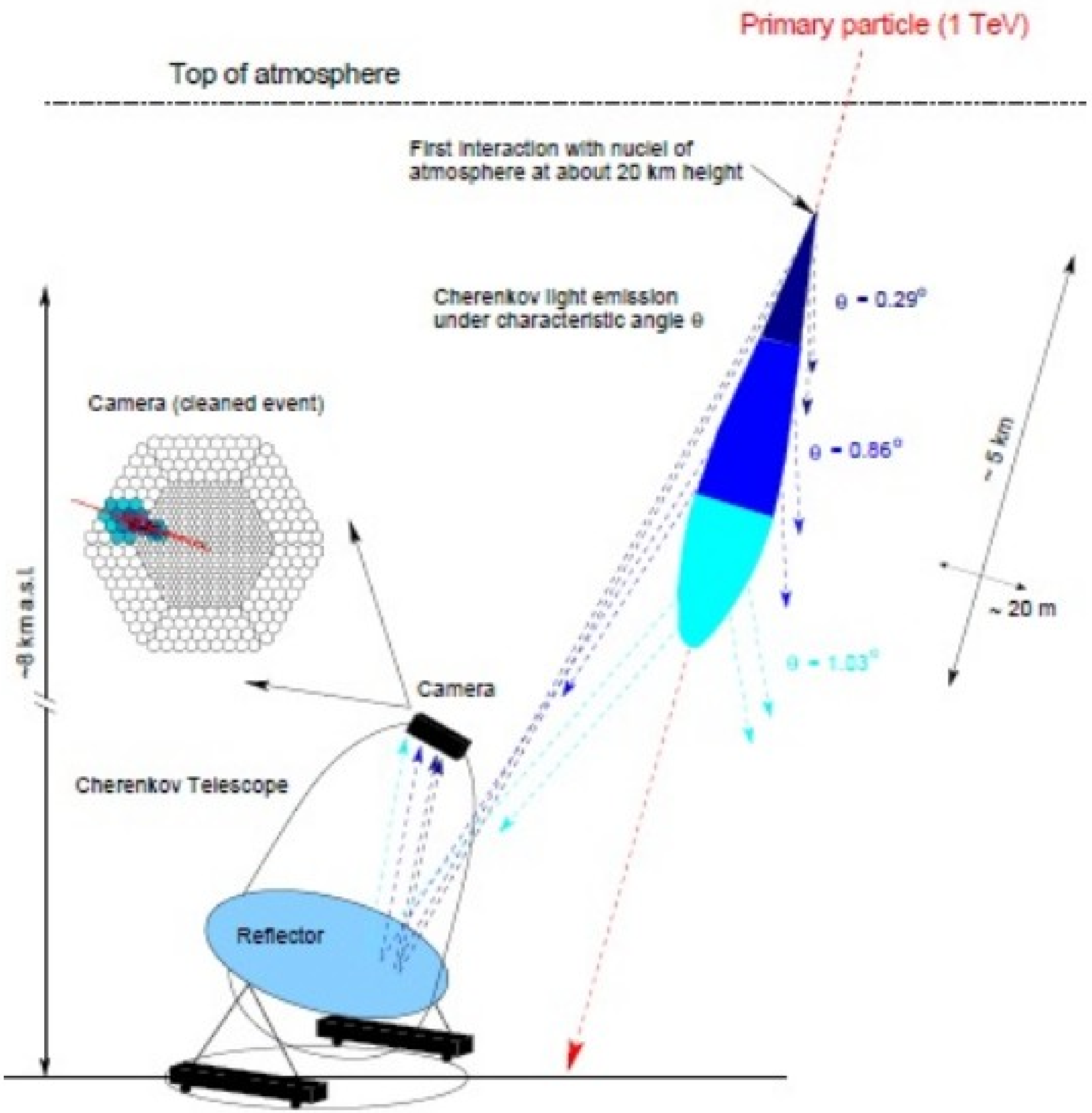
OUTLINE

- The Cherenkov telescopes: overview
- The quest for dark matter in the Universe
- The Cherenkov Telescope Array (CTA)
- Detection feasibility of DM signals with CTA
- Conclusions

1. The Cherenkov telescopes: overview



- Gamma rays **cannot** be directly observed in atmosphere;
- Cherenkov light produced by their interaction with atmospheric nuclei **can** be observed by UV/optical reflection telescopes;
- observed by an instrument at a certain incidence angle, the Cherenkov beam is projected elongated on the camera plane;
- many telescopes into an array => **reconstruction of event direction in the sky**.



Instr.	Tels. #	Tel. A (m^2)	FoV (°)	Tot A (m^2)	Thresh. (TeV)	PSF (°)	Sens. (%Crab)
H.E.S.S.	4	107	5	428	0.1	0.06	0.7
MAGIC	2	236	3.5	472	0.05(0.03)	0.06	0.8
VERITAS	4	106	4	424	0.1	0.07	0.7

- Thanks to Cherenkov telescopes, imaging of VHE (>30 GeV) galactic sources and discovery of new galactic and extragalactic sources (>150);

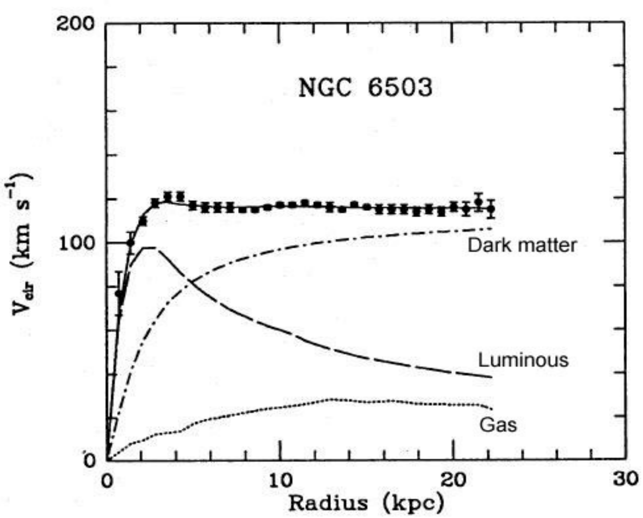
- better knowledge of diffuse gamma rays and electrons;

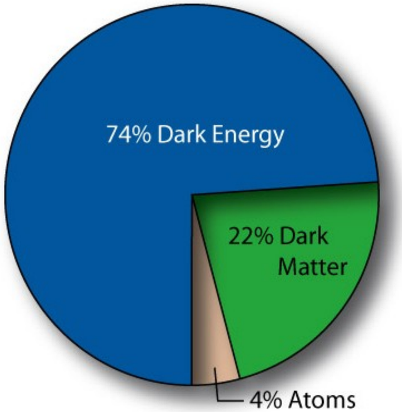
- comparable success in HE domain (the Fermi realm): 10x increases in number of known sources;

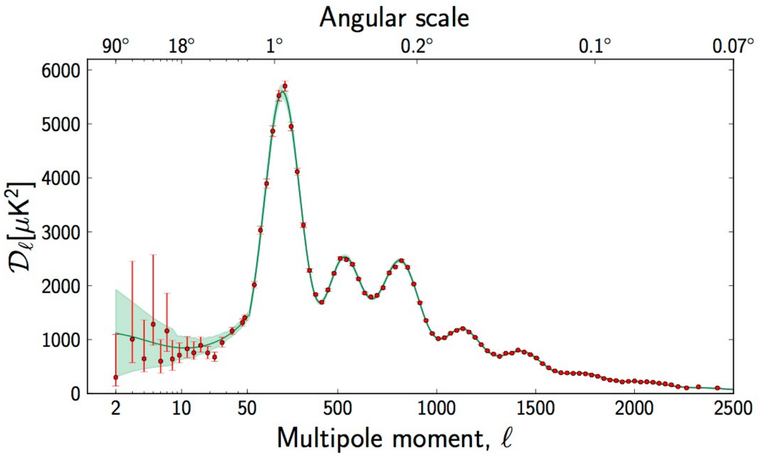
- **new tools to study cosmic rays (=> SNRs), photon propagation (=> Universe transparency, vacuum energy, Lorentz invariance tests, cosmology), dark matter**.

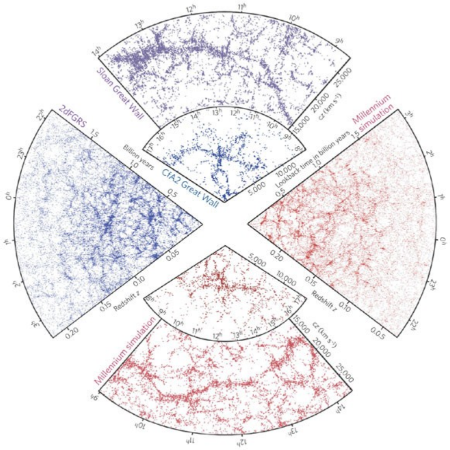
2. The quest for dark matter in the Universe

- Dark matter (DM) is the major component of the Universe matter content;
- its existence inferred from several astrophysical/cosmological observations.









- Current (most plausible) cold DM candidates:

WIMPS

- No charge (electromagnetic & color)
- High particle mass & non-relativistic
- Interaction intensity & cross section similar to weak int.

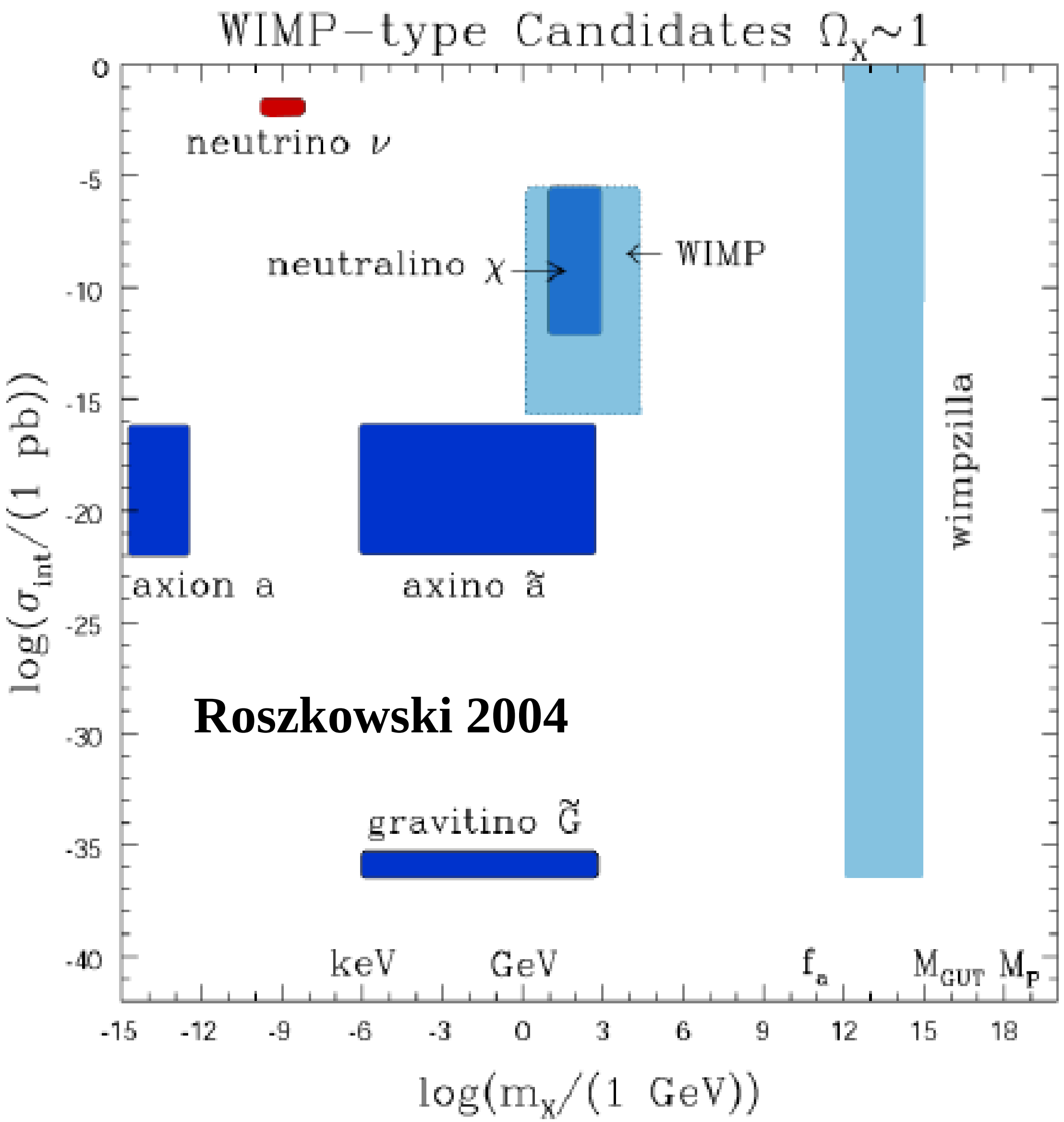
MACHOS

- “Conventional” astronomical objects (asteroids to BHs)
- Very low or null luminosity

AXIONS

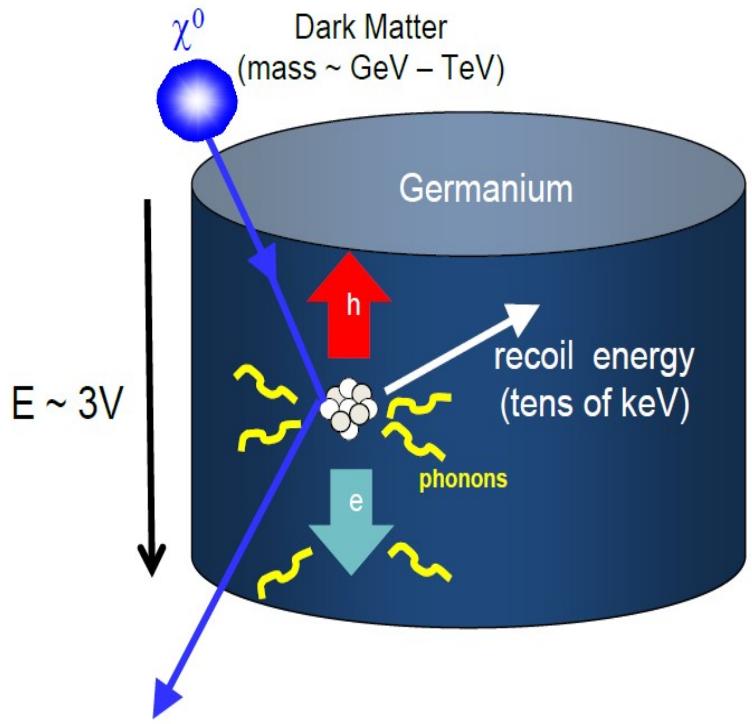
- No electric charge
- Very low mass ($10^{-6} < m < 10^{-2}$ eV/c^{2})
- No spin
- Very weak interaction with ordinary matter

- A review of the DM candidates zoo (particles only)...

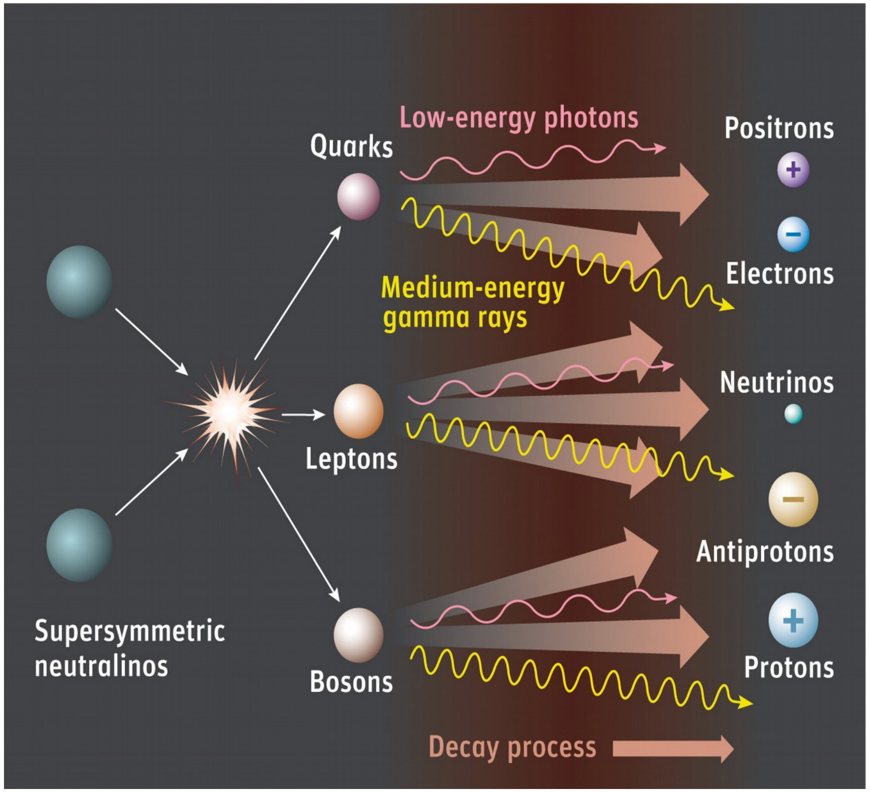


- Since DM cross section for interaction with baryonic matter is extremely small, events of dark-baryonic matter interaction (*direct detection*) are very rare;
- *indirect detection* looks instead for production of gamma-rays from DM self-interaction (annihilation or decay), so it can be attempted with gamma detectors.

DIRECT DET.



INDIRECT DET.



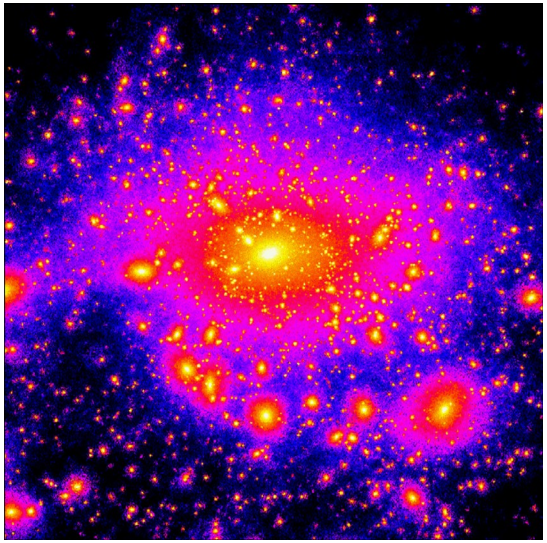
3. Main targets of observation

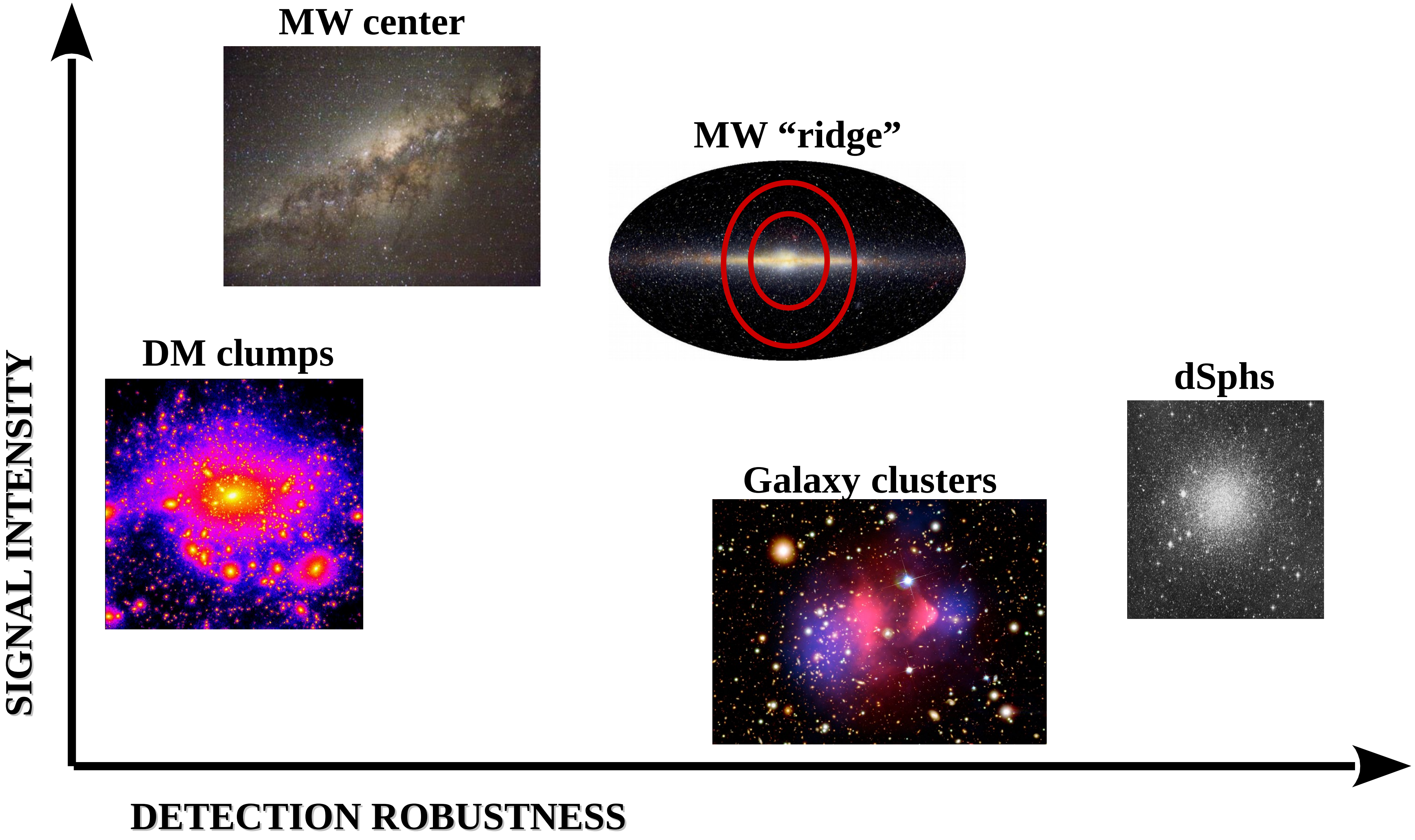
Milky Way center & MW "ridge" (very close, but risk of high bkg due to Galactic sources & central BH)

Dwarf spher. galaxies (high *M/L* and almost no bkg, but small haloes under current angular resolution)

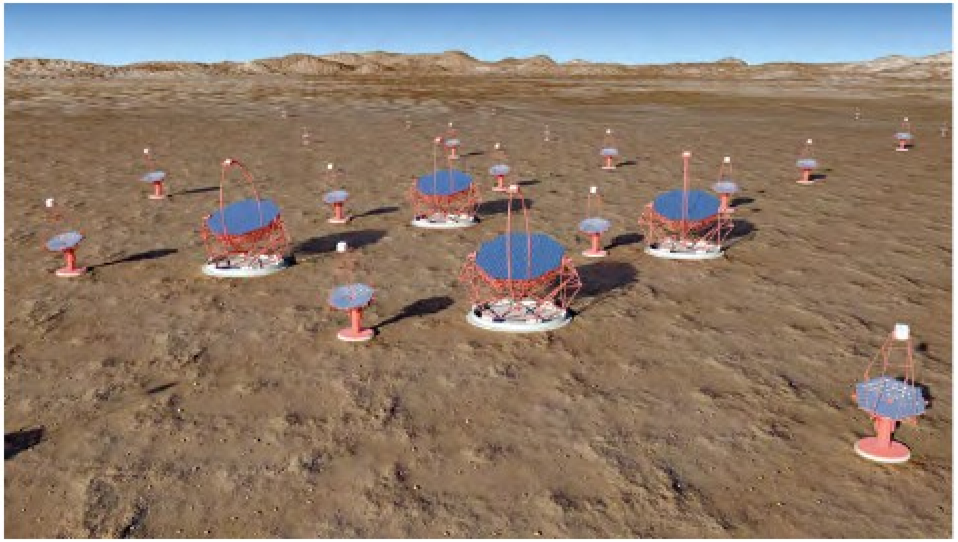
Galaxy clusters (high DM content, but far and maybe contaminated by bkg due to hot ICM & AGN activity)

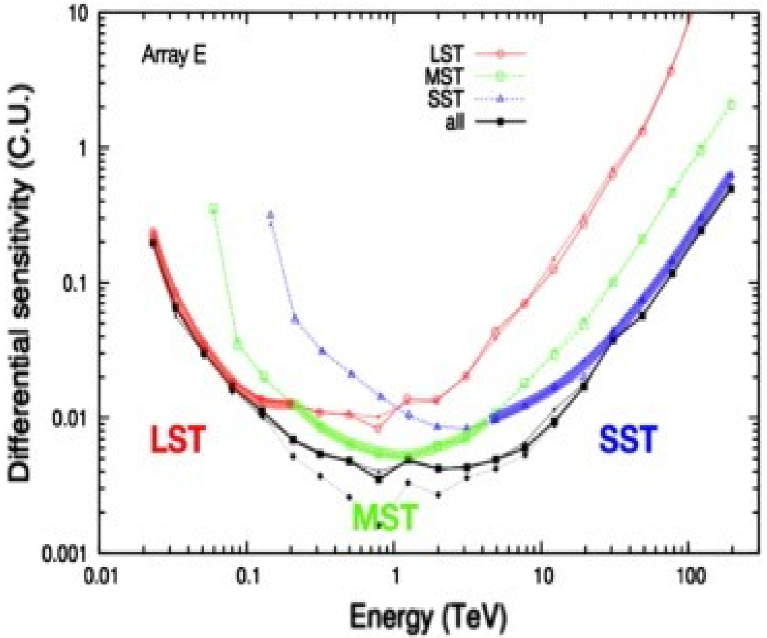
Dark clumps (conceptually dSphs without stars, but same issues + their existence only theoretical so far)




MW center
MW “ridge”
DM clumps
dSphs
Galaxy clusters
SIGNAL INTENSITY
DETECTION ROBUSTNESS

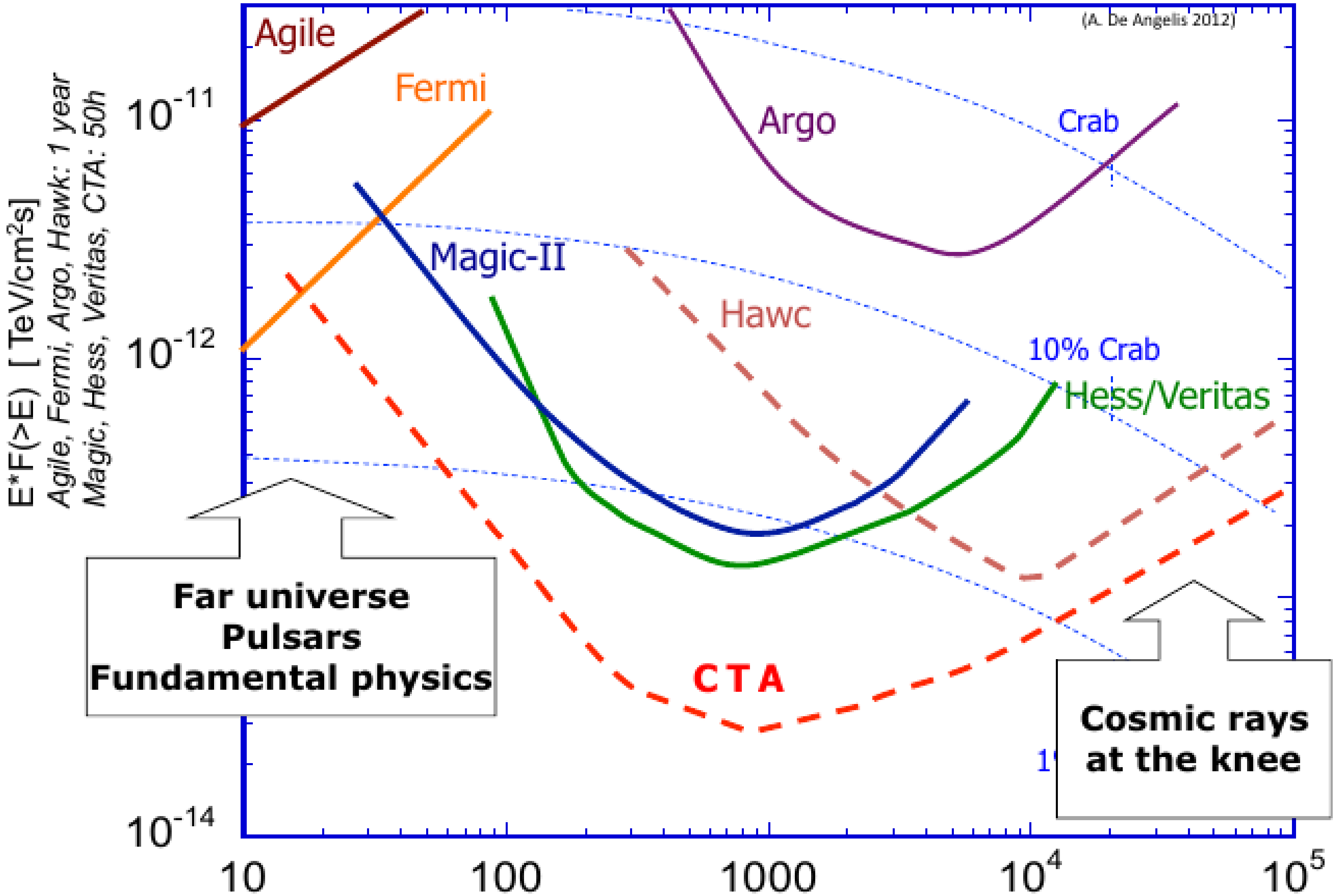
4. The Cherenkov Telescope Array (CTA)





- Future instrument to observe gamma rays from Earth through Cherenkov emission;
- covered energy range **from ~20 Gev up to ~100 Tev**;
- **large field of view of ~10°**;
- **high angular resolution of ~0°.1** @ 1 TeV (80% PSF);
- **high sensitivity of ~1e-3 Crab** @ 1 TeV;
- more than **70 telescopes**: 4 large-size (LST) + 20 medium (MST) + 50 small (SST);
- 2 arrays, one in Northern and one in Southern emisphere;
- **~200 M€ budget from 27 nations**.

- A factor ~10 of improvement in sensitivity with respect to current arrays!



De Angelis+ 2012

5. Detection feasibility of DM signals with CTA

- Gamma-ray source spectrum *dN/dE* computed assuming that DM particles annihilate (decay) via Standard Model pair production: **quarks**, **leptons**, **vector bosons** (e.g., Cembranos+ 2011);

- in cold-DM scenarios, such pairs are slow => they immediately annihilate into final-state photons;

$$\frac{d\Phi}{dE} = B_F \frac{\langle \sigma v \rangle}{8\pi m_\chi^2} \left(\frac{dN}{dE} \right) J(\Delta\Omega)$$

DM gamma-ray flux

$$J(\Delta\Omega) = \int_{\Delta\Omega} d\Omega \int_{los} \rho_{DM}^2 (l;\Omega)\, dl$$

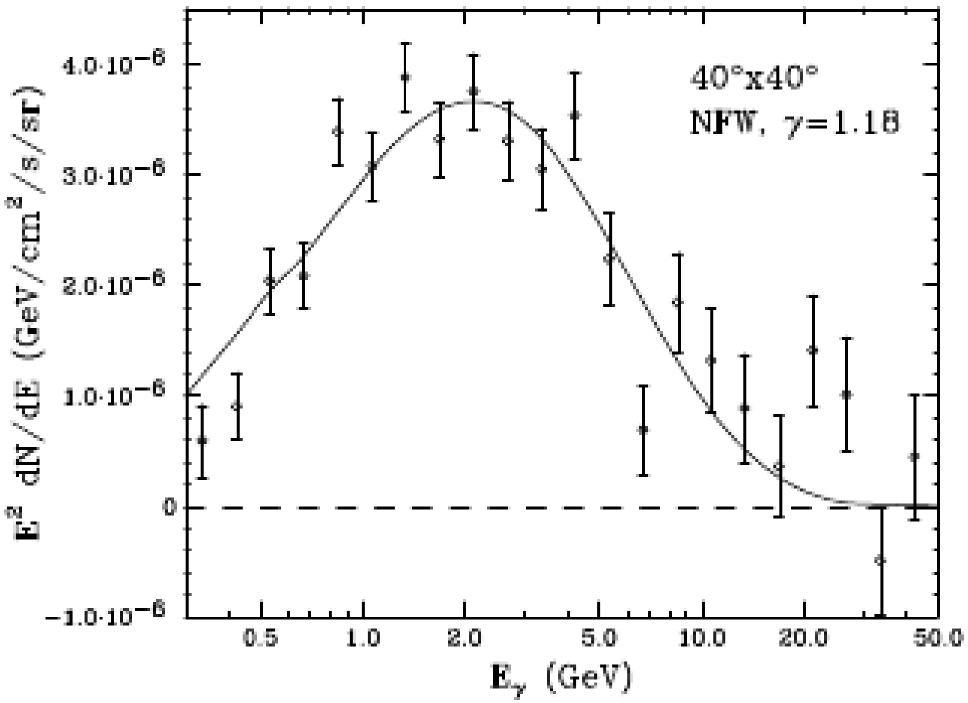
Astrophysical factor for annihilation

- gamma-ray flux: **particle physics** (cross section, DM mass, final-state spectrum + **astrophysics** (*J*-factor);

- but still many uncertainties... (e.g., Doro+ 2013)

- Some recent clues from *Fermi* data (still controversial)...

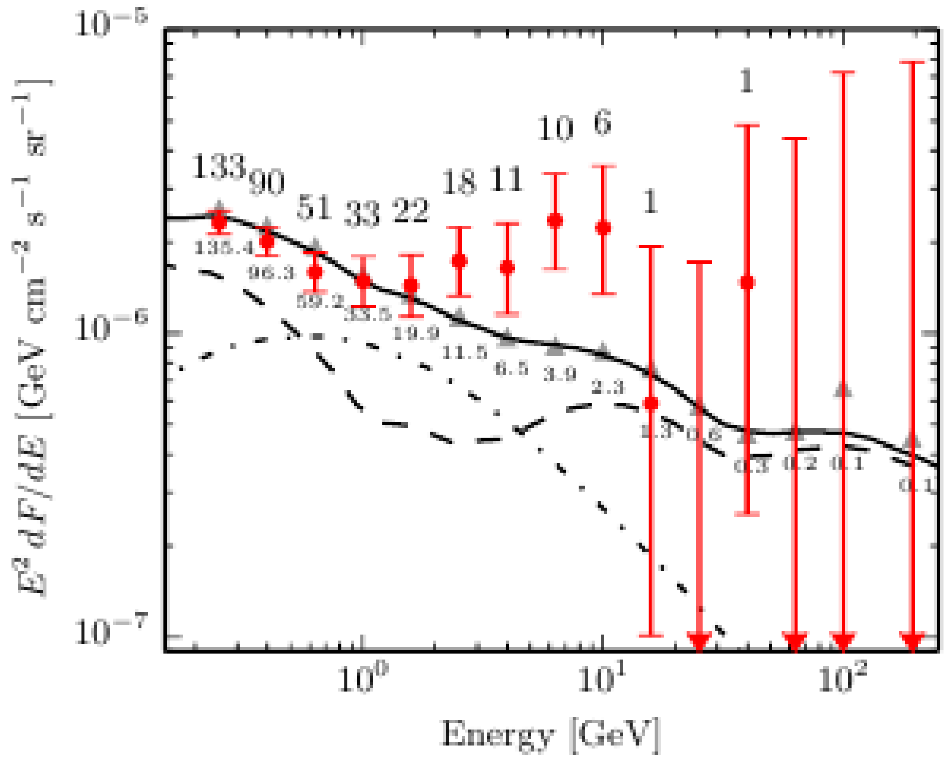
MILKY WAY CENTER (Daylan+ 2014)



m_χ = 43.0 GeV

$\langle\sigma v\rangle$ = 2.25e-26 cm^3/s

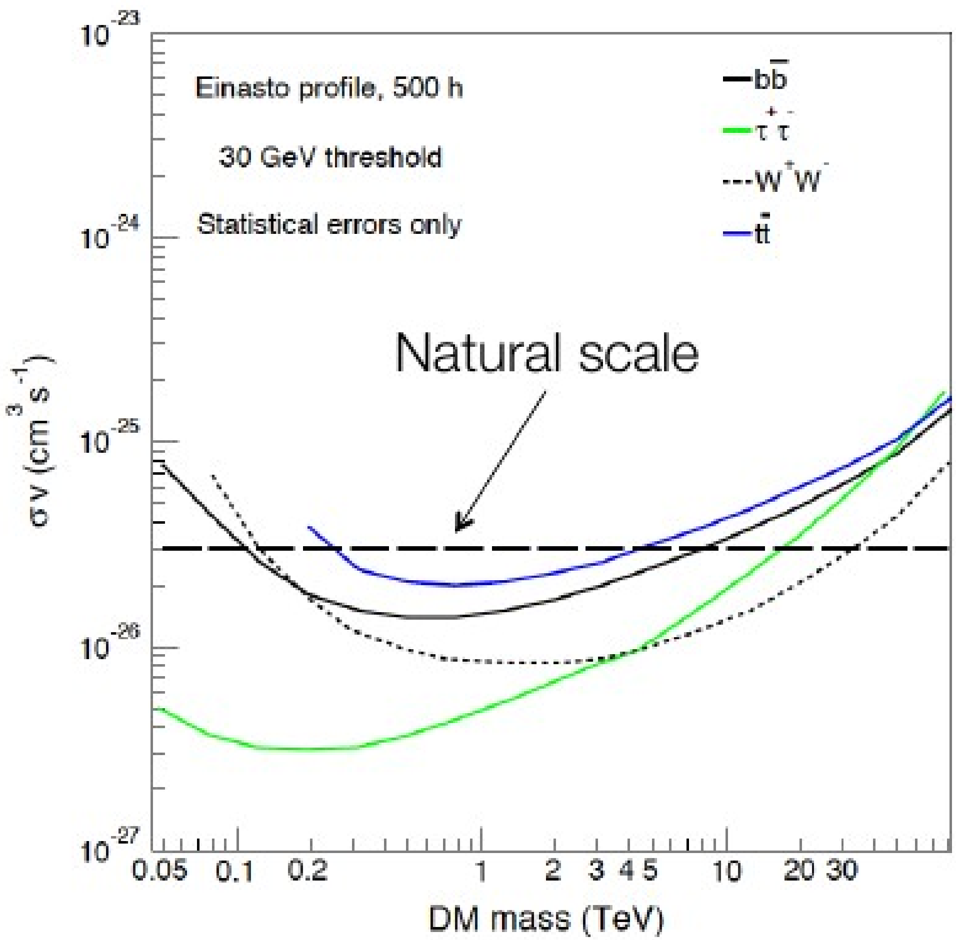
dSph RetII (Geringer-Sameth+ 2015)

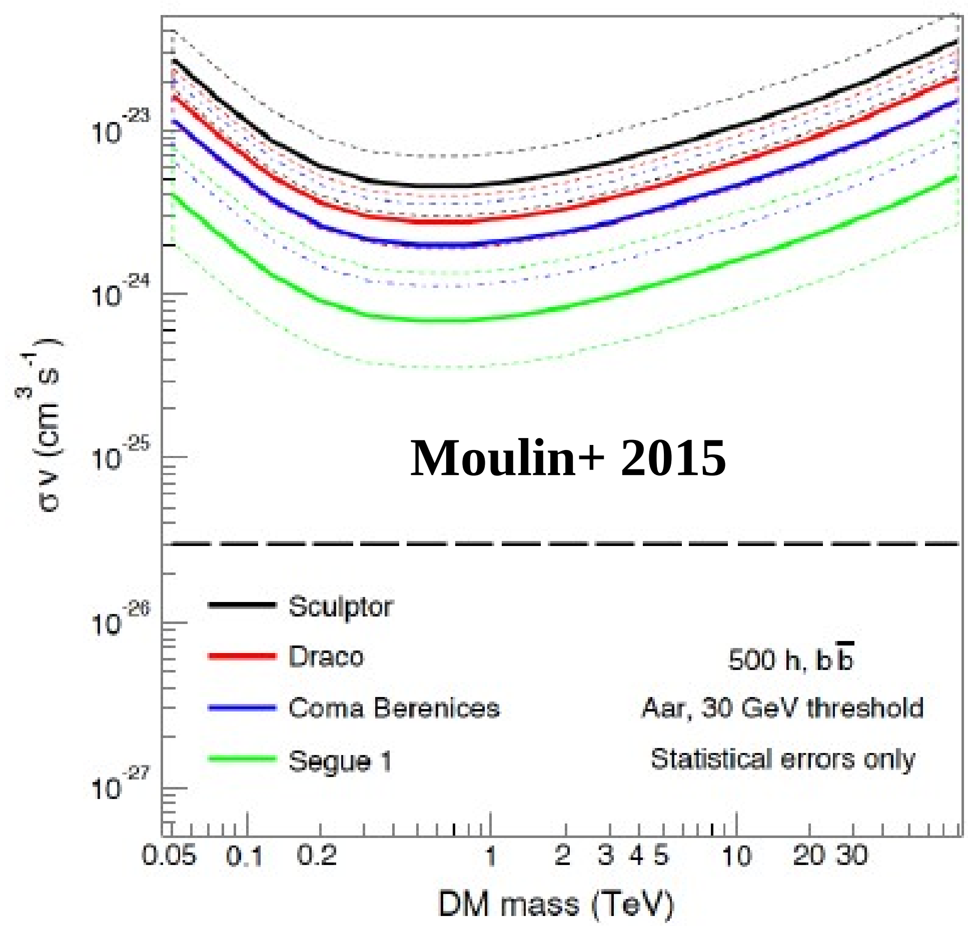


m_χ ~ 100 GeV

$J\langle\sigma v\rangle$ ~ 1e-6 $GeV^2/cm^2/s$

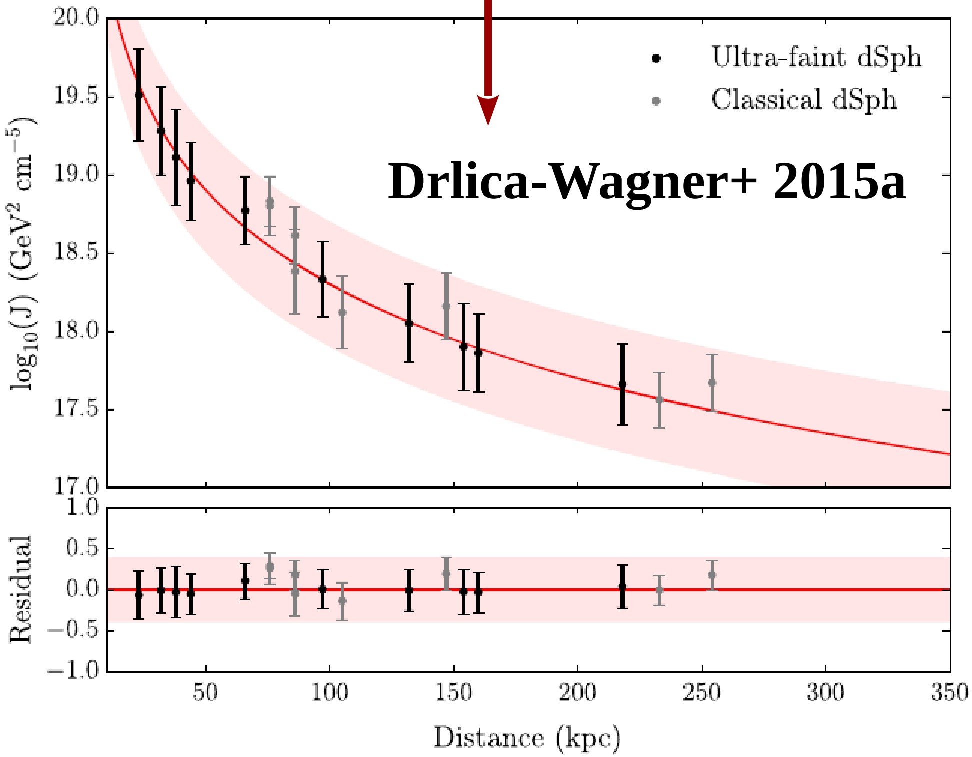
- CTA differential sensitivity allows to detect DM gamma-ray emission depending on **DM particle physics** (cross section, particle mass) & target's **DM content** (i.e., *J*/*D*-factor);

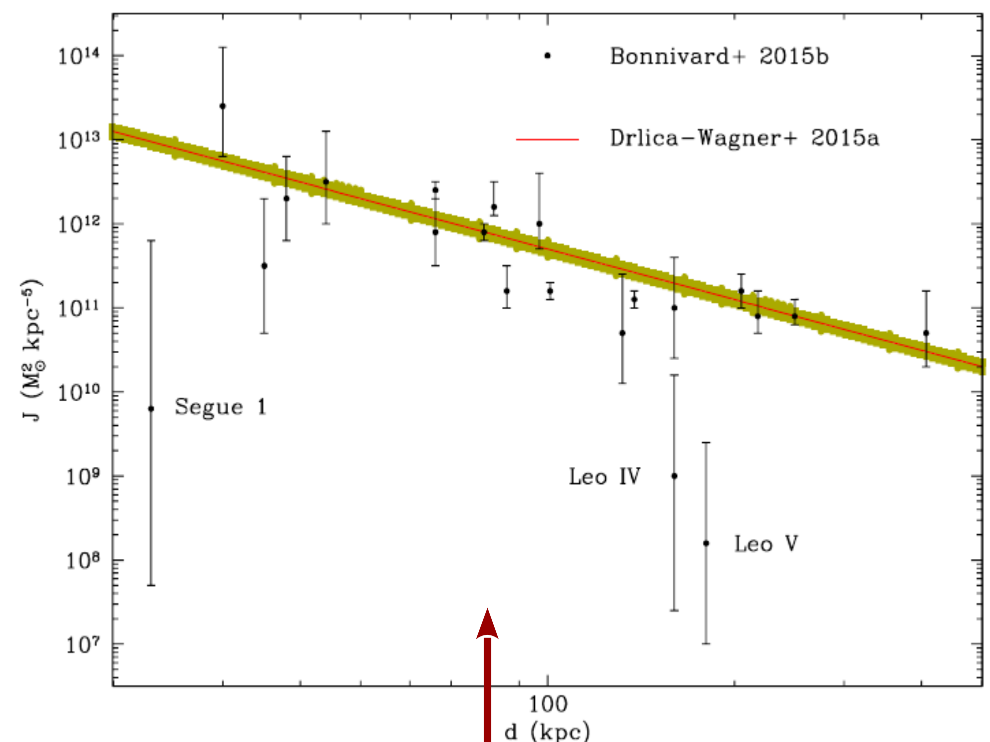




- **determining reliable astrophysical factors** is of paramount importance in order to rank good candidates for observation.

- A “cheap” way to estimate astrophysical factors for DM candidates: **scaling relations**!
- For dSphs with photometric and kinematic measurements: $\boldsymbol{J \propto d^{-2}}$!





- But see revised estimates of *J* using homogeneous samples of member stars for each individual dSph with careful removal of contaminants (Bonnivard+ 2015b)...

5. Conclusions

- With very improved performances with respect to current Cherenkov telescopes, CTA represent the future of ground-based gamma-ray astronomy.

- Indirect detection of DM through gamma rays from DM self-interaction is one of the main scientific targets of this project, and several types of candidates are being studied.

- Milky Way center (very nearby) and dwarf spheroidal galaxies (low bkg) are currently the best potential targets for observation in search of DM signals.

- **Accurate simulations of observation of astrophysical targets** and **careful revision of astrophysical factors to rank candidates** are needed!

THANK YOU!