The Dark Matter Program and Capabilities Beyond γ-Rays: Status and Perspectives

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OUTLINE

- Overview on CTA fundamental and exotic physics
- Status and perspectives of the CTA dark matter program
- Status and perspectives of the CTA capabilities beyond γ-rays
- Summary

Overview on CTA fundamental and exotic physics

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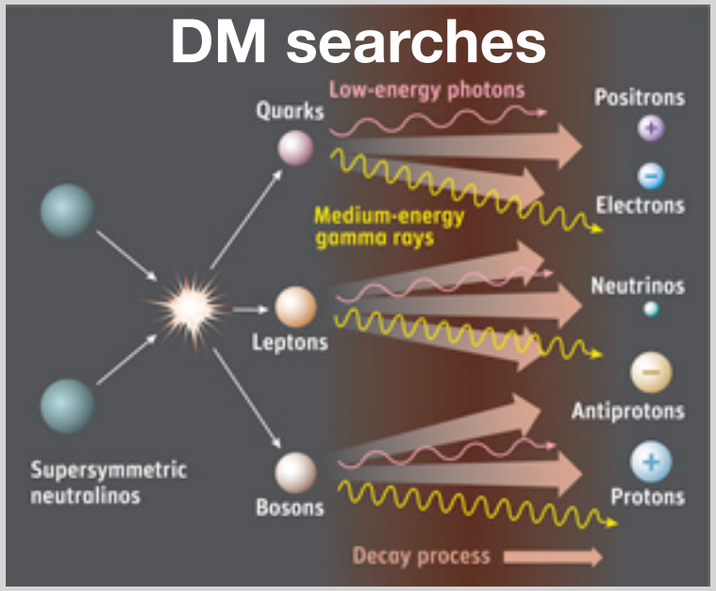
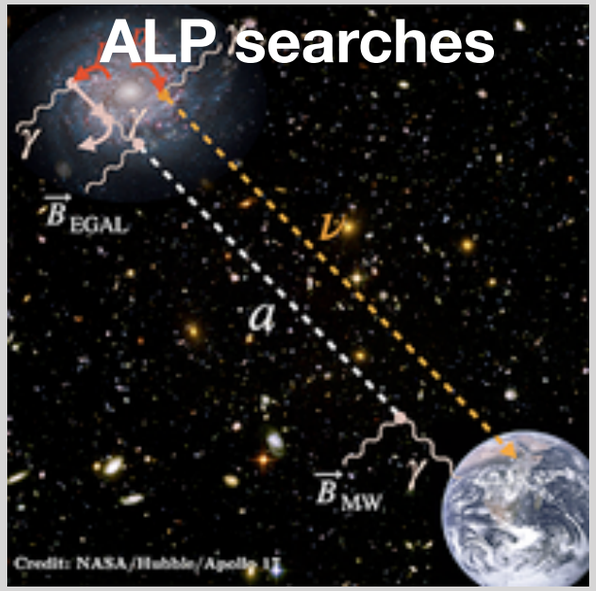
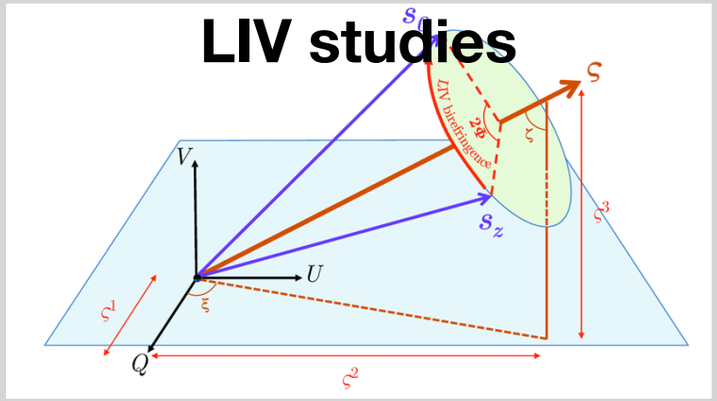
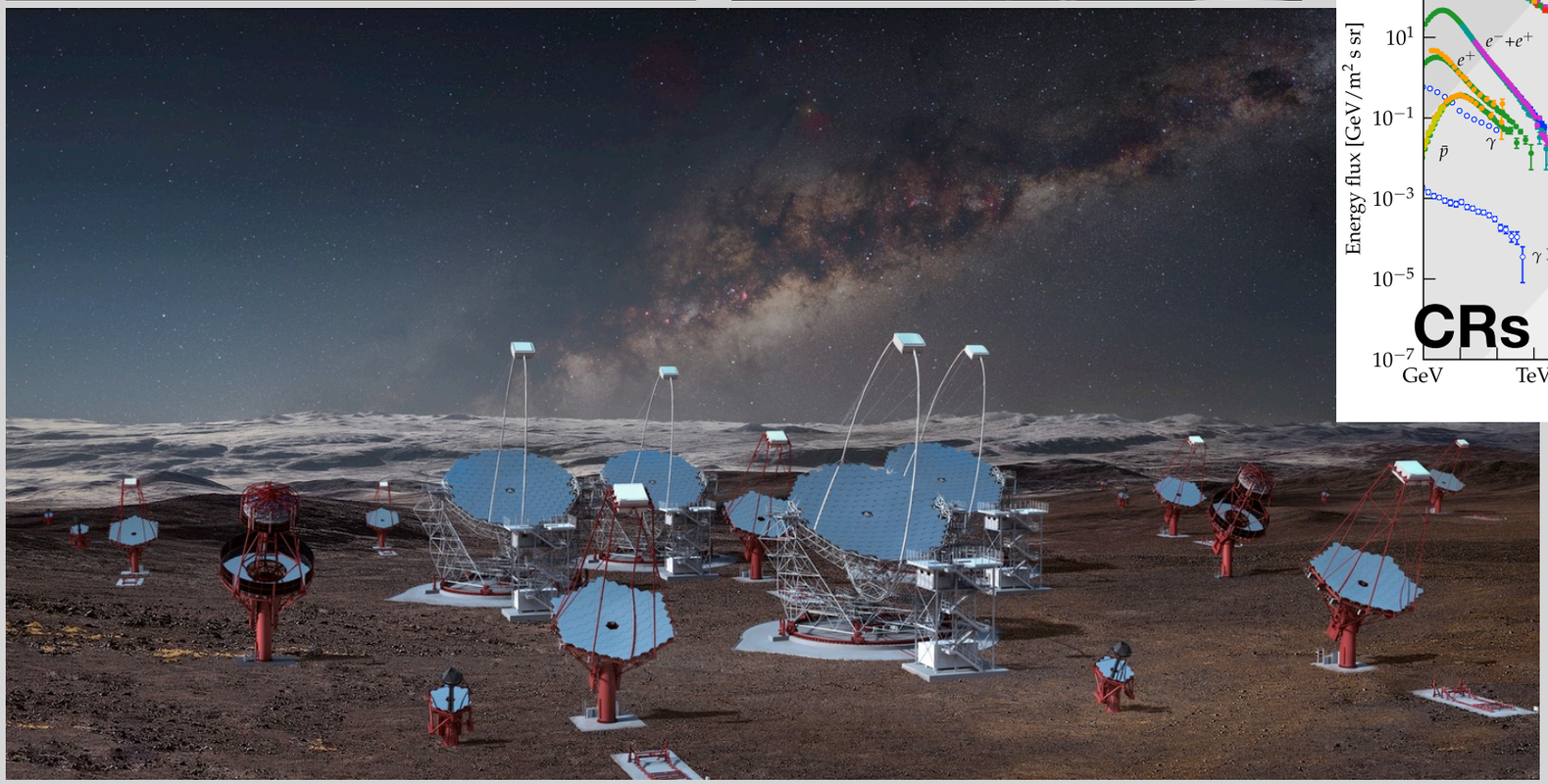
- CTA is a powerful tool for a range of astroparticle, fundamental and exotic physics topics.









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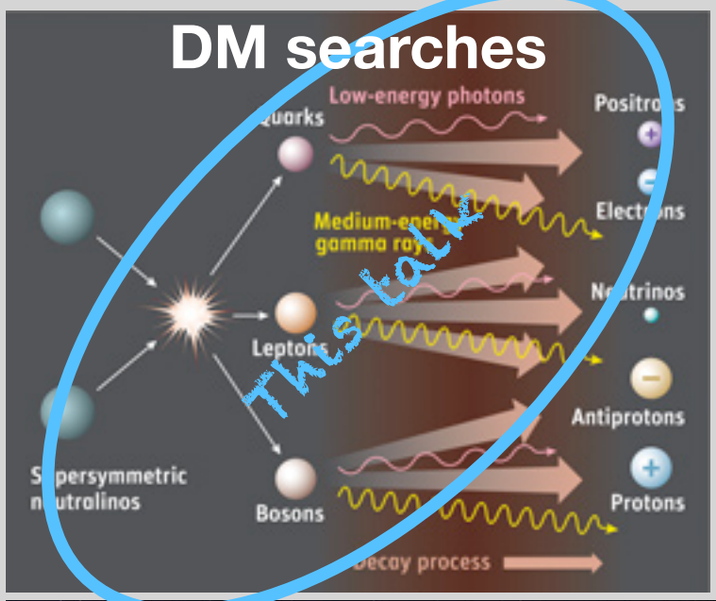
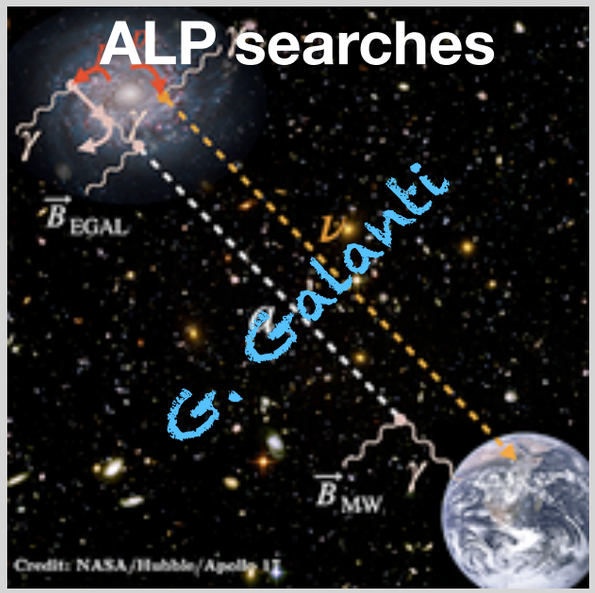
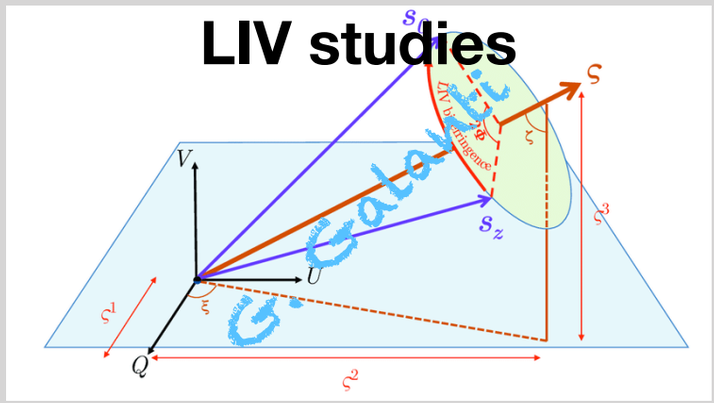
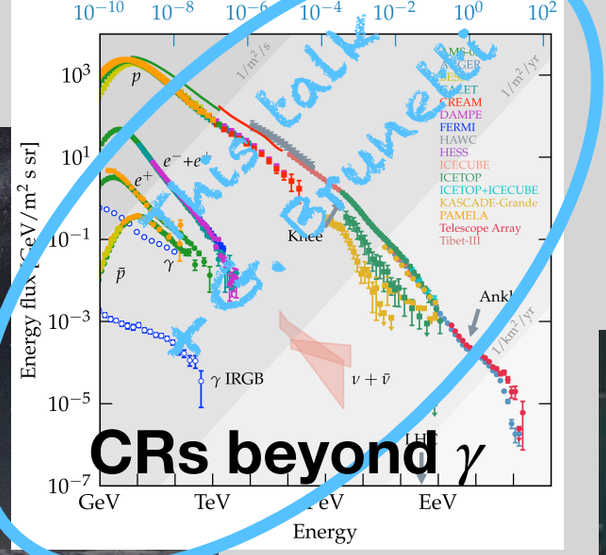
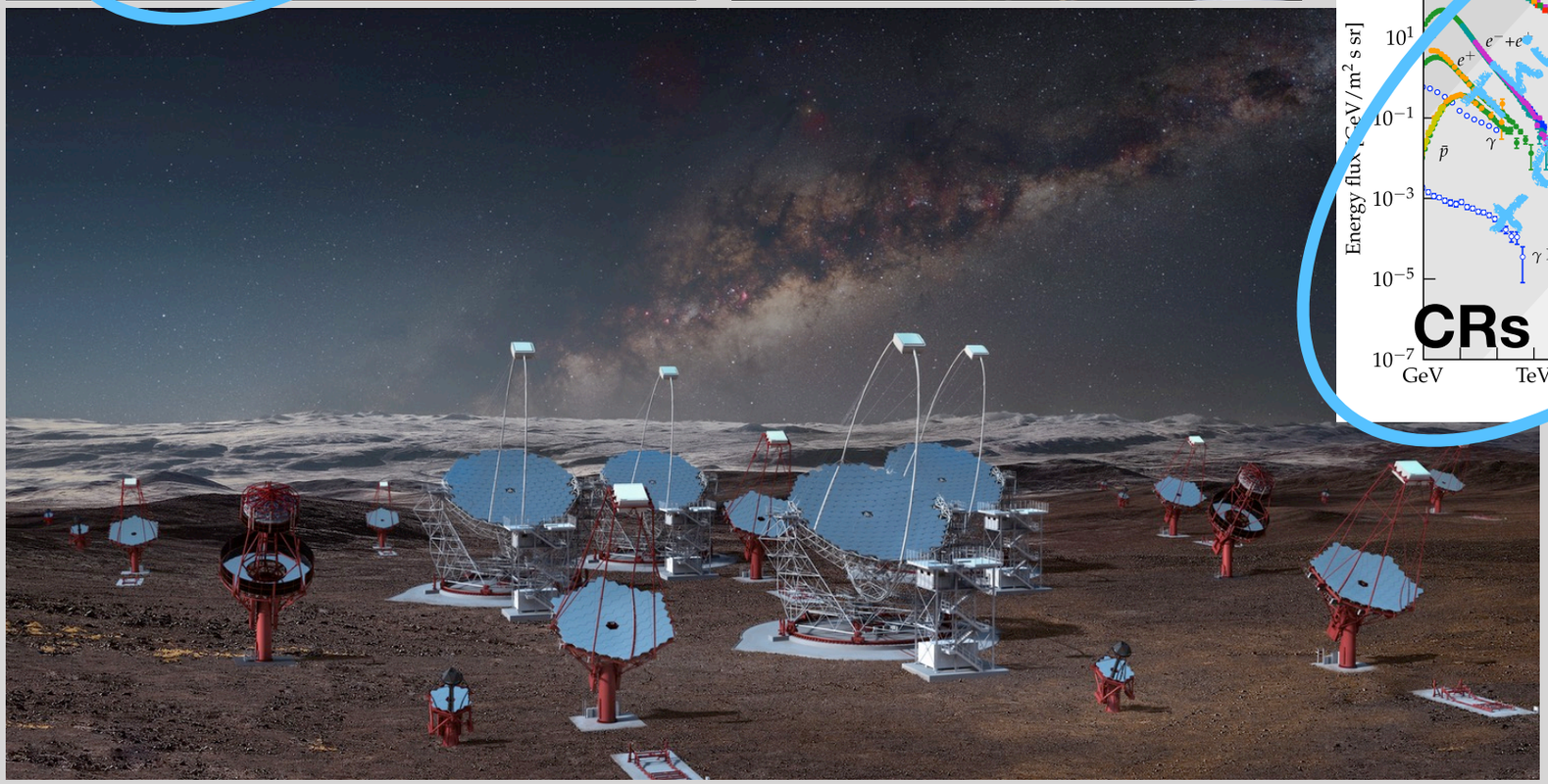
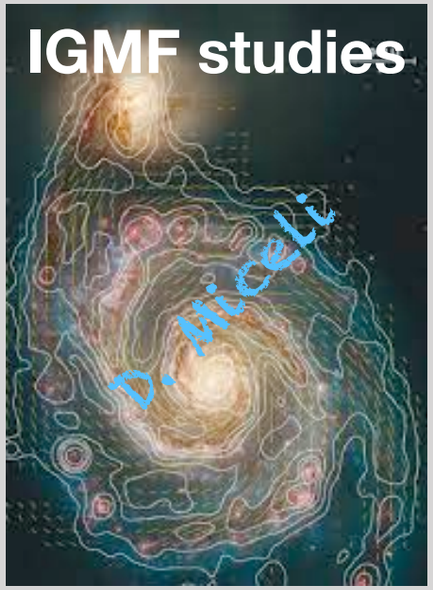












Overview on CTA fundamental and exotic physics

- CTA astroparticle, fundamental and exotic physics organized in 2 main working groups (WGs):

- **Dark Matter and Exotic Physics (DMEP) WG**
  - Searches of signatures from particle dark matter (DM) self-interaction
  - Searches of axion-like particle (ALP) signatures
  - Studies of Lorentz invariance violation (LIV) processes
  - Constraints on the intergalactic magnetic field (IGMF) intensity

- **Cosmic Rays WG**
  - Construction of the charged cosmic ray (CR) spectra (electrons, protons, nuclei)

- Lots of synergies with other WGs (+ MWL/MM)!
  - Particle DM self-interaction: Galactic + Extragalactic
  - ALPs: Extragalactic + Transients
  - LIV: Galactic + Extragalactic + Transients
  - IGMF: Extragalactic + Transients
  - CRs: Galactic + Extragalactic

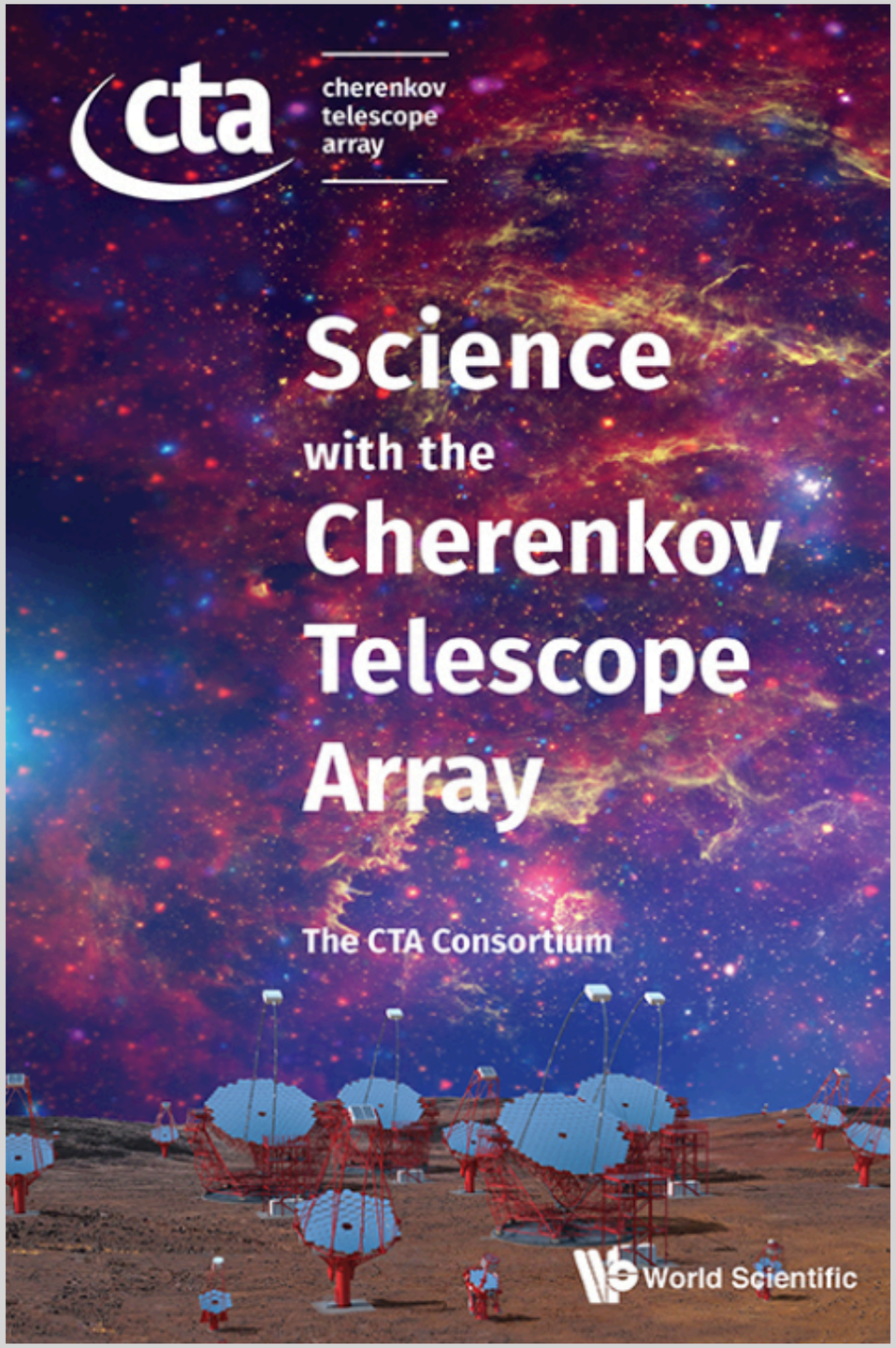
Overview on CTA fundamental and exotic physics

- Every side of the CTA science (including DM program and capabilities beyond γ-rays) described in a dedicated book.

- *Science with the Cherenkov Telescope Array* published in 2019 (World Scientific Pub.).

DM program:
38 pages

Capabilities beyond γ:
8 pages

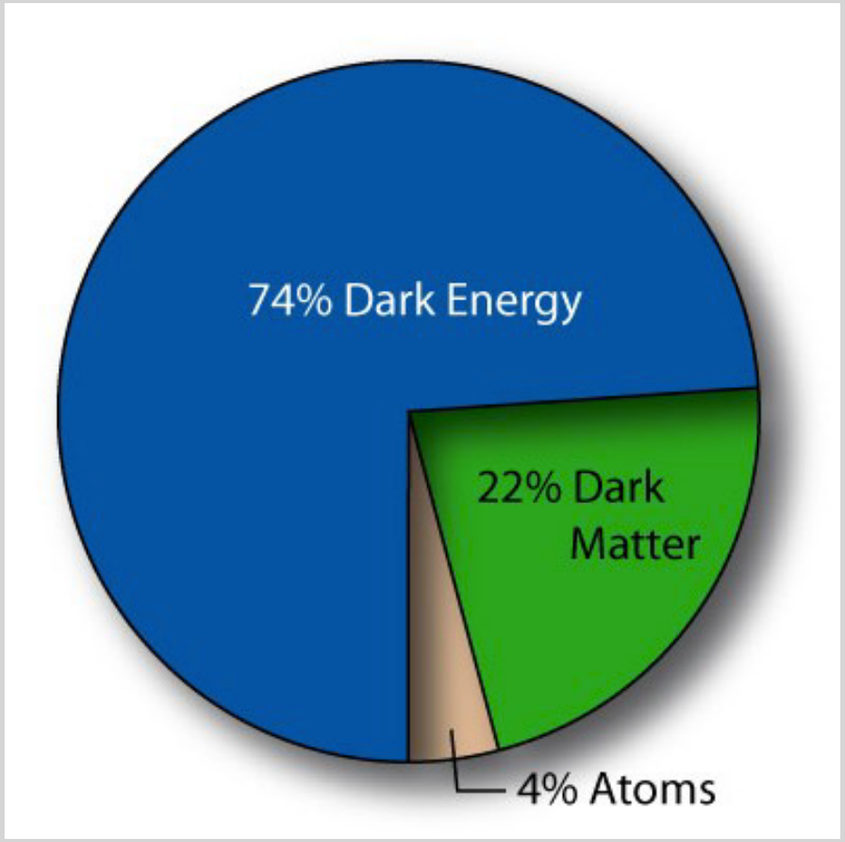


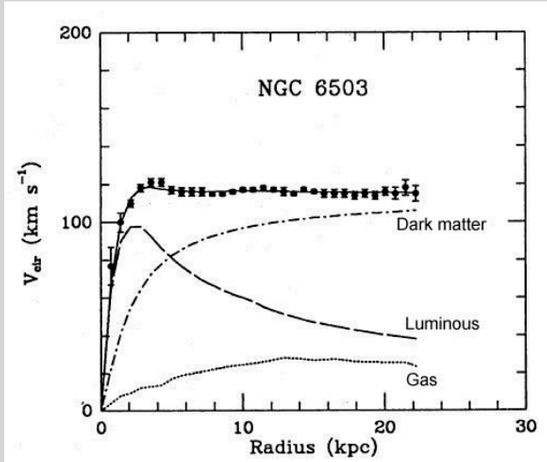
The CTA dark matter program: status and perspectives

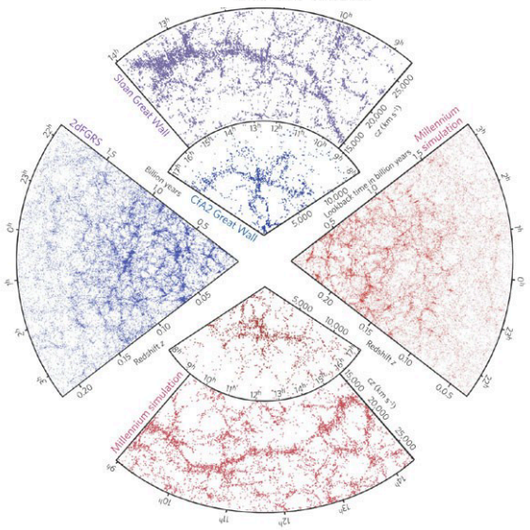
The CTA DM program: status and perspectives

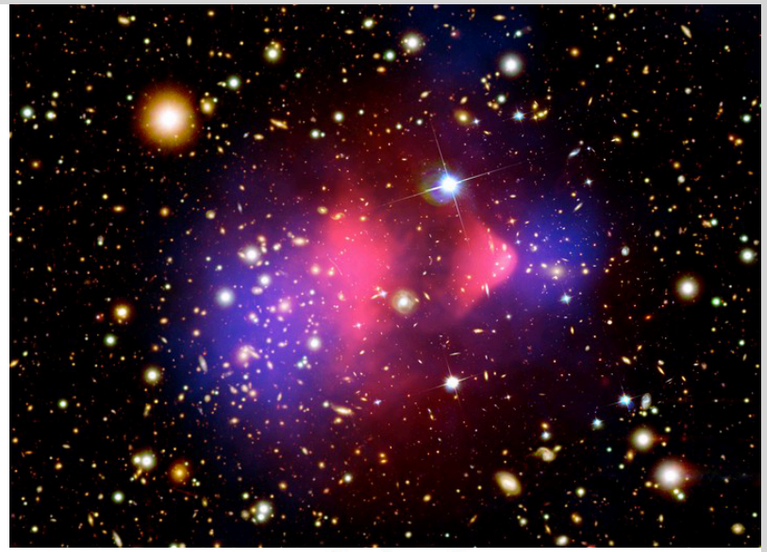
- Dark matter (DM) is the major component of the Universe matter content (~22% of the total energy budget);

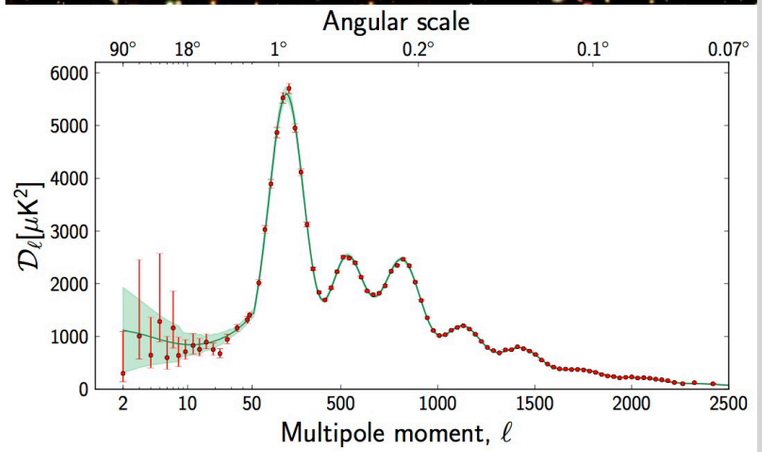
- its existence only indirectly inferred so far from several astrophysical/cosmological observations.











The CTA DM program: status and perspectives

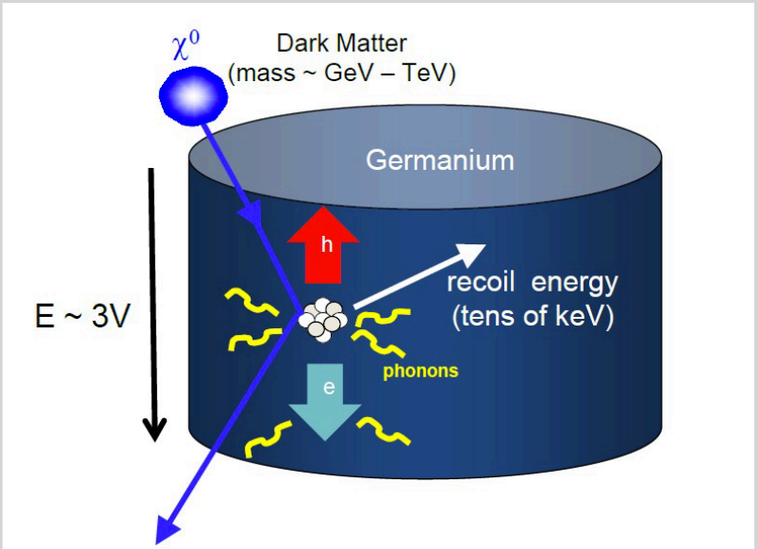
- Particle DM characteristics:
  - large masses (from cosmology)
  - small cross sections with baryonic matter (from direct detection and production experiments)

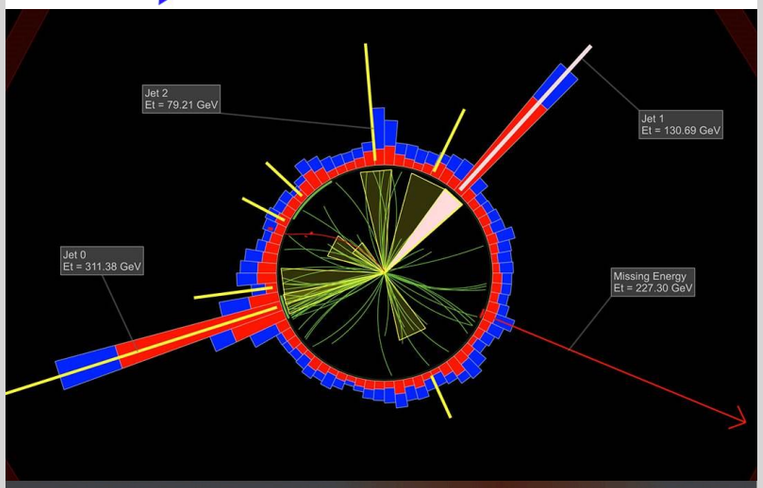
- Cherenkov telescopes look for production of VHE photons from DM self-interaction (annihilation or decay).

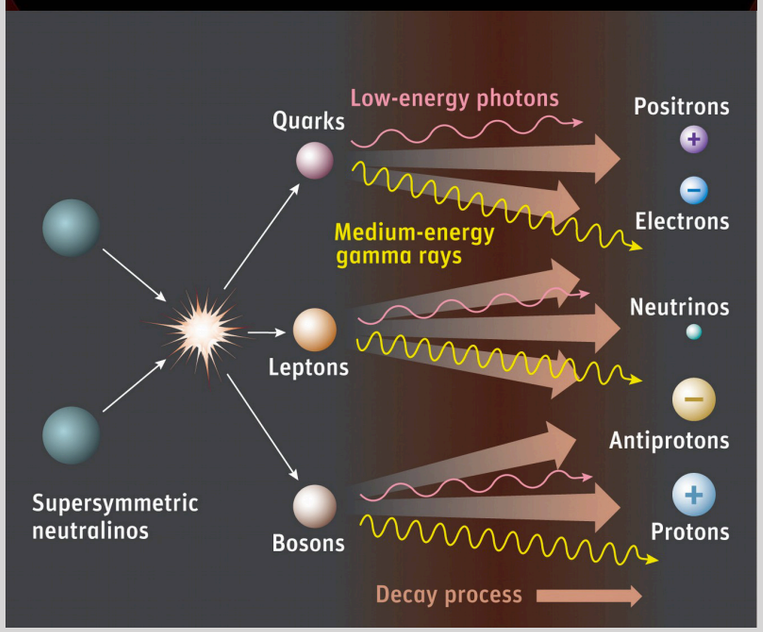
Direct detection

Production

Indirect detection

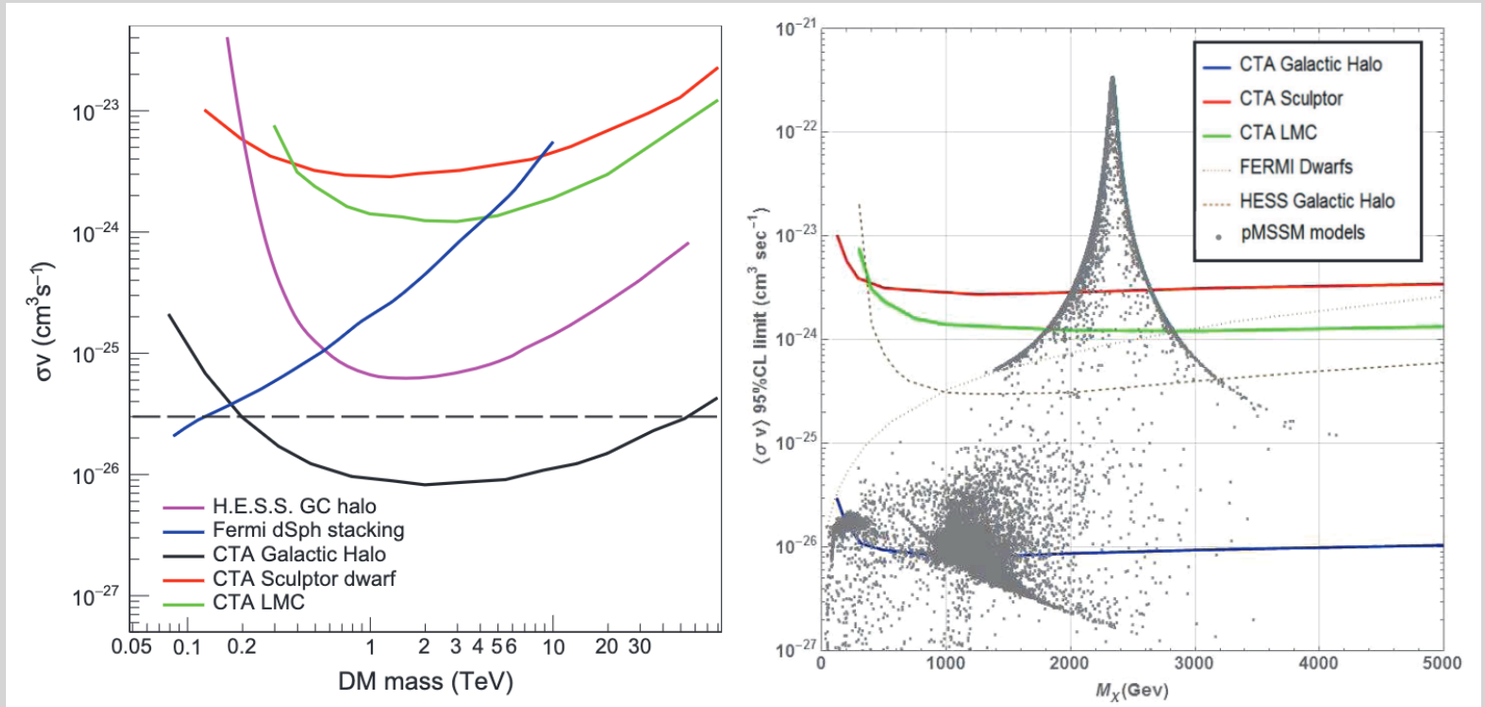






The CTA DM program: status and perspectives

- *Science with CTA*: large focus on DM annihilation;
- best results will be likely achieved by Galactic Centre (GC) observations;
- GC best region for both continuous emission and monochromatic lines **if DM profile is cuspy**.



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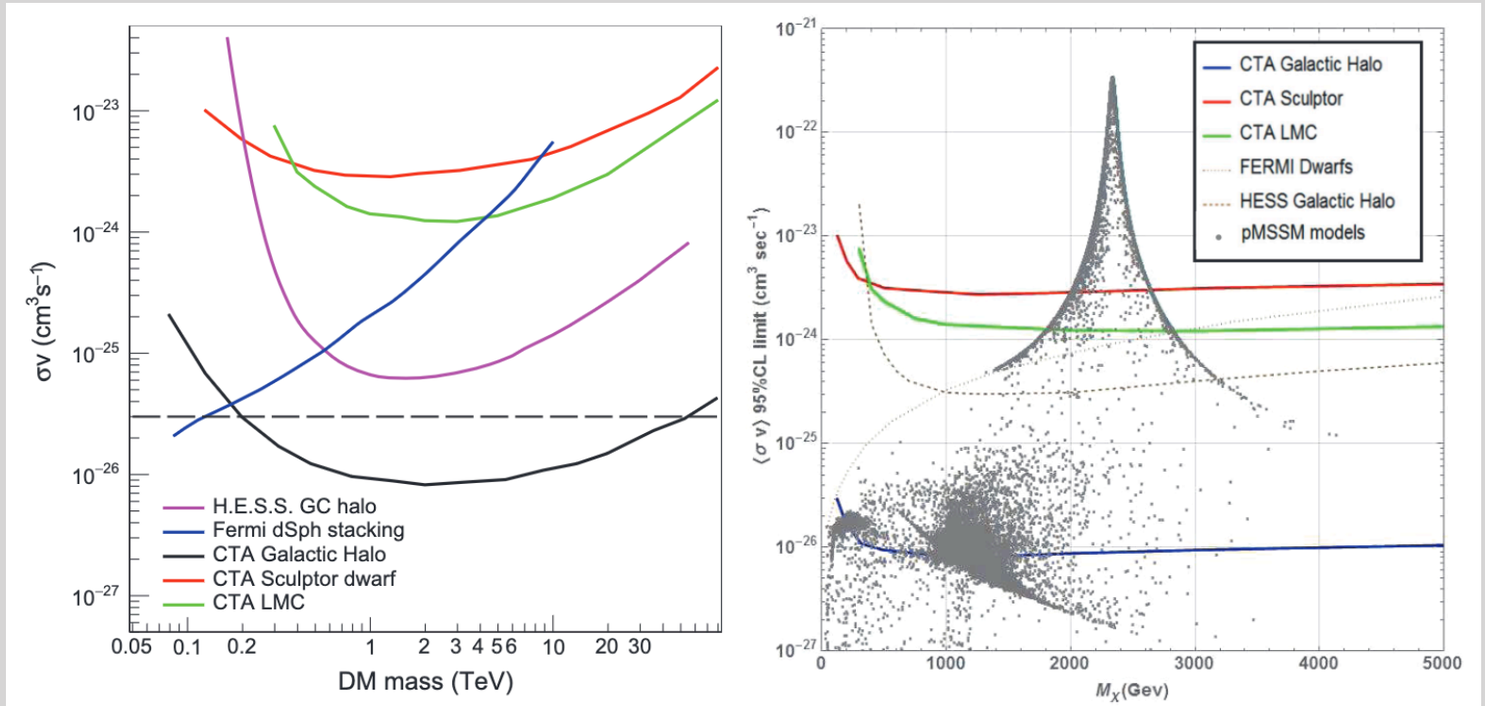


>2 o.o.m. less sensitivity in case of cored DM profile!

The CTA DM program: status and perspectives

- Open issues:
  1. the **exact shape** of the Milky Way's **DM density profile** is still **unknown** (cored or cuspy?) => **bias in the expected signal intensity**;
  2. the amount of emission from **potential contaminants** in the GC region is **high** (diffuse bkg, unresolved pt-like sources, Fermi bubbles) => **difficult data analysis**.

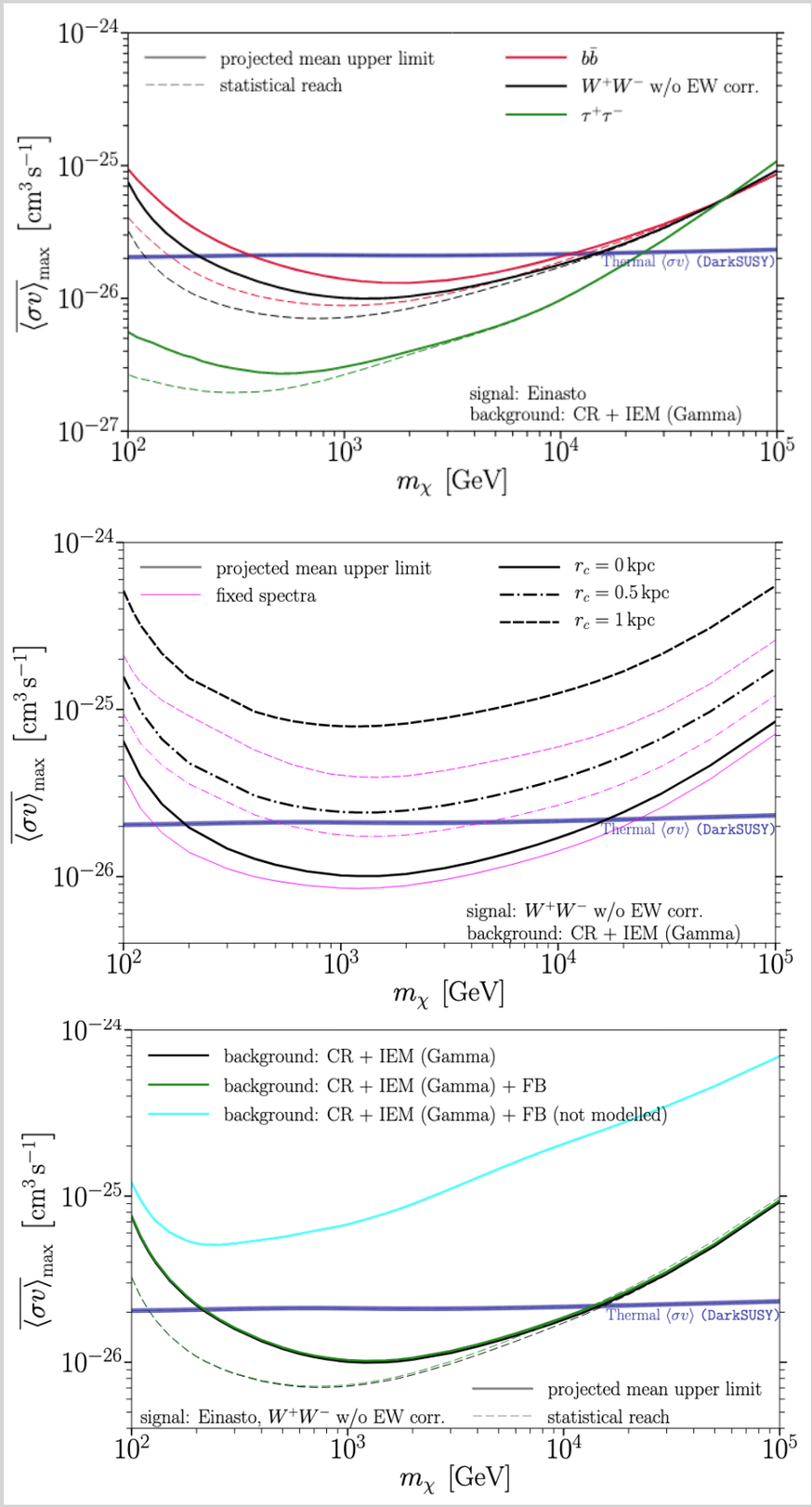
- Where to intervene:
  — improve the modeling of the DM density profile in the GC region (simulations/MWL data);
  — improve the modeling of the bkg emission to ease its subtraction (deeper/more resolved MWL data).

The CTA DM program: status and perspectives

- Paper dedicated to the GC observing simulations published in 2021 (JCAP 01, 057);

- CTA performances substantially confirmed (possibility to explore DM x-sections below thermal relic limit);

- **different choices of DM density profile** and/or **presence of contaminations** (e.g., emission from Fermi bubbles emission) can greatly affect the results.

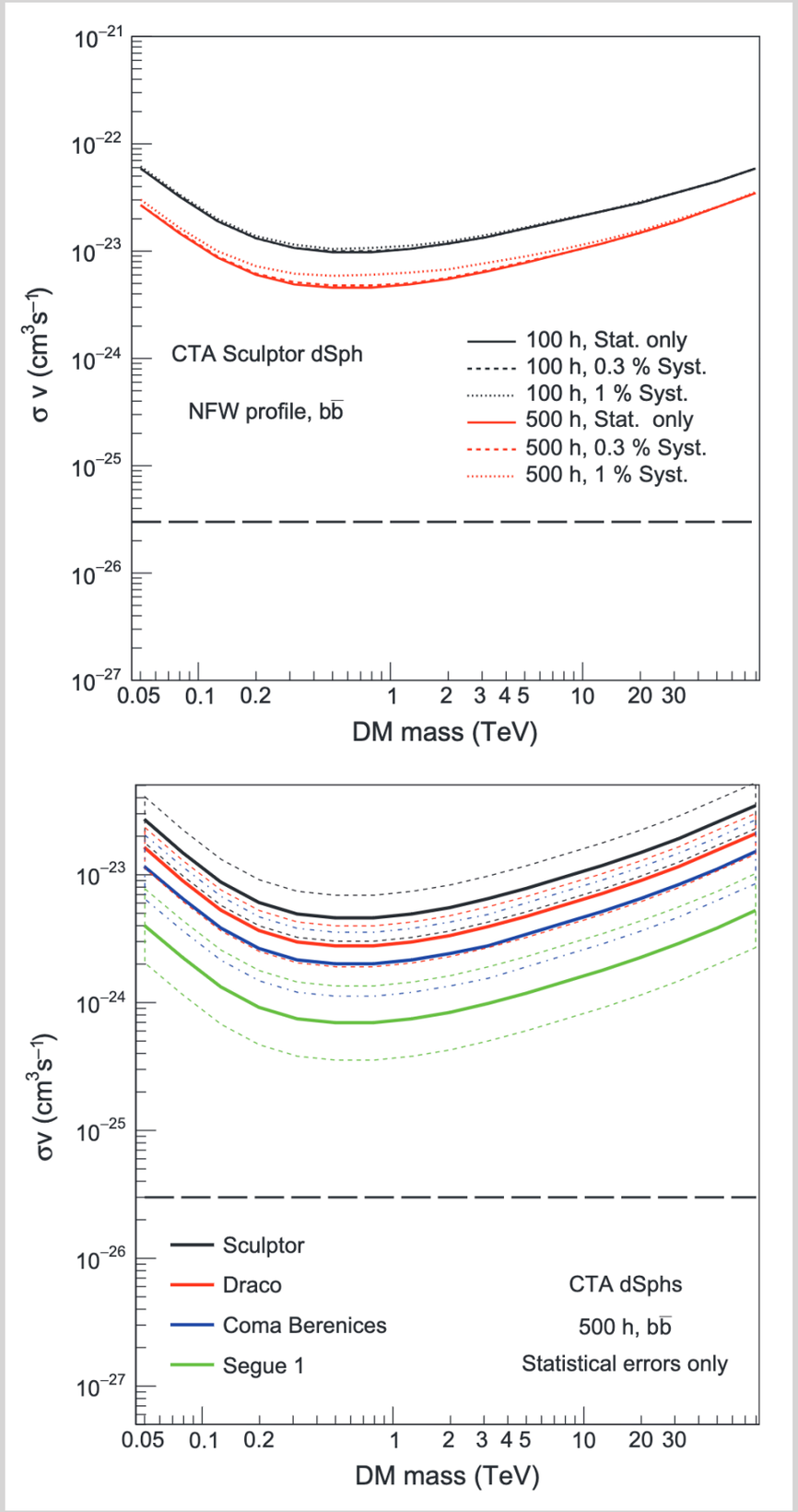


The CTA DM program: status and perspectives

- Dwarf spheroidal galaxies (dSphs): optimal targets for an unambiguous DM detection;

- **less uncertainties** in the DM profile shape (cuspy), but also **less DM amount** w.r.t. GC;

- largest drivers of the signal biases:
  — **uncertainty on the total DM amount** (= astrophysical factor)
  — **ongoing tidal disruption in some targets**

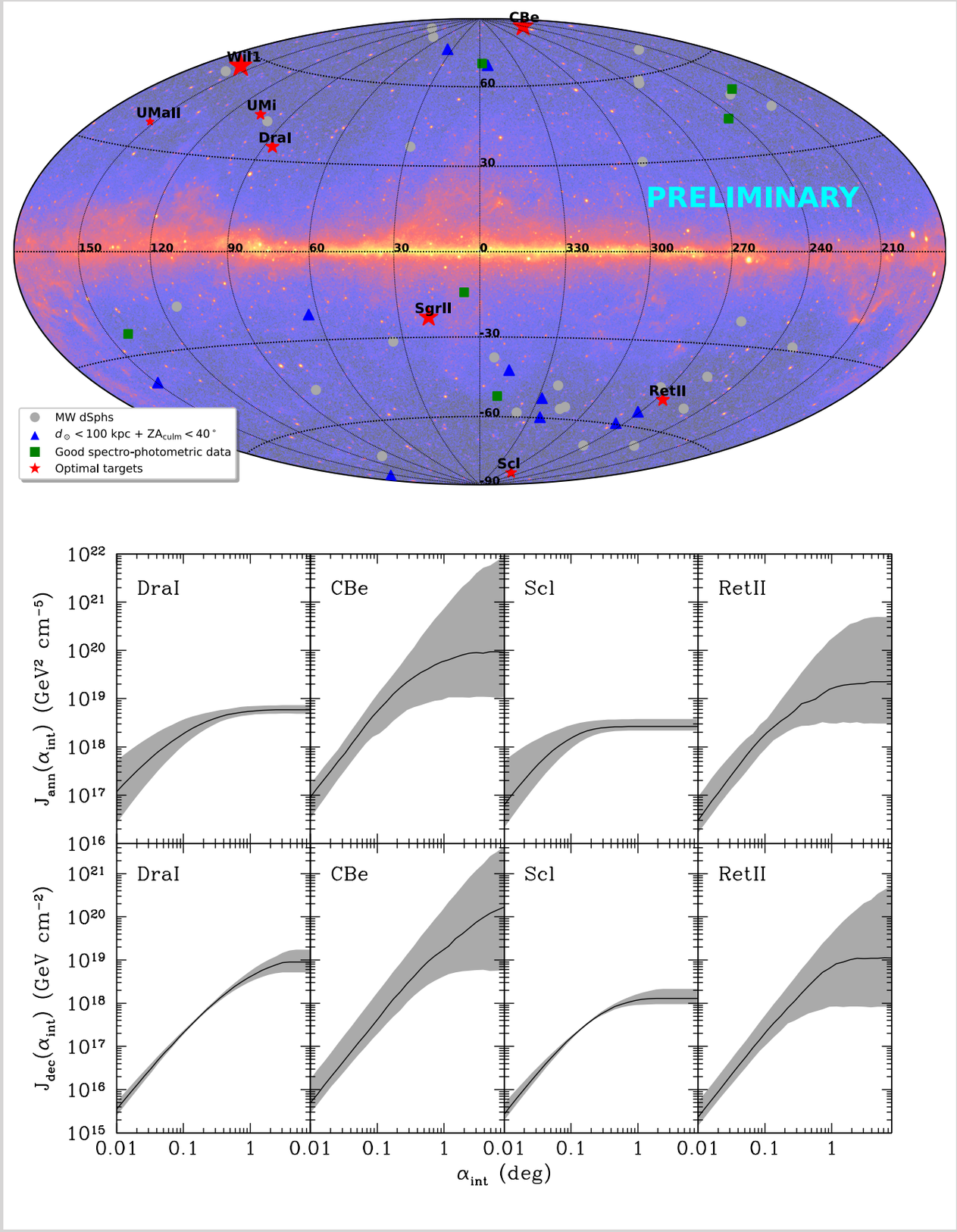


The CTA DM program: status and perspectives

- Paper dedicated to dSph observing simulations close to completion (within 2023);

- **thorough reanalysis** of dSph astrophysical factors performed;

- final production of CTA sensitivity curves underway, with **several biases taken into account**.



The CTA DM program: status and perspectives

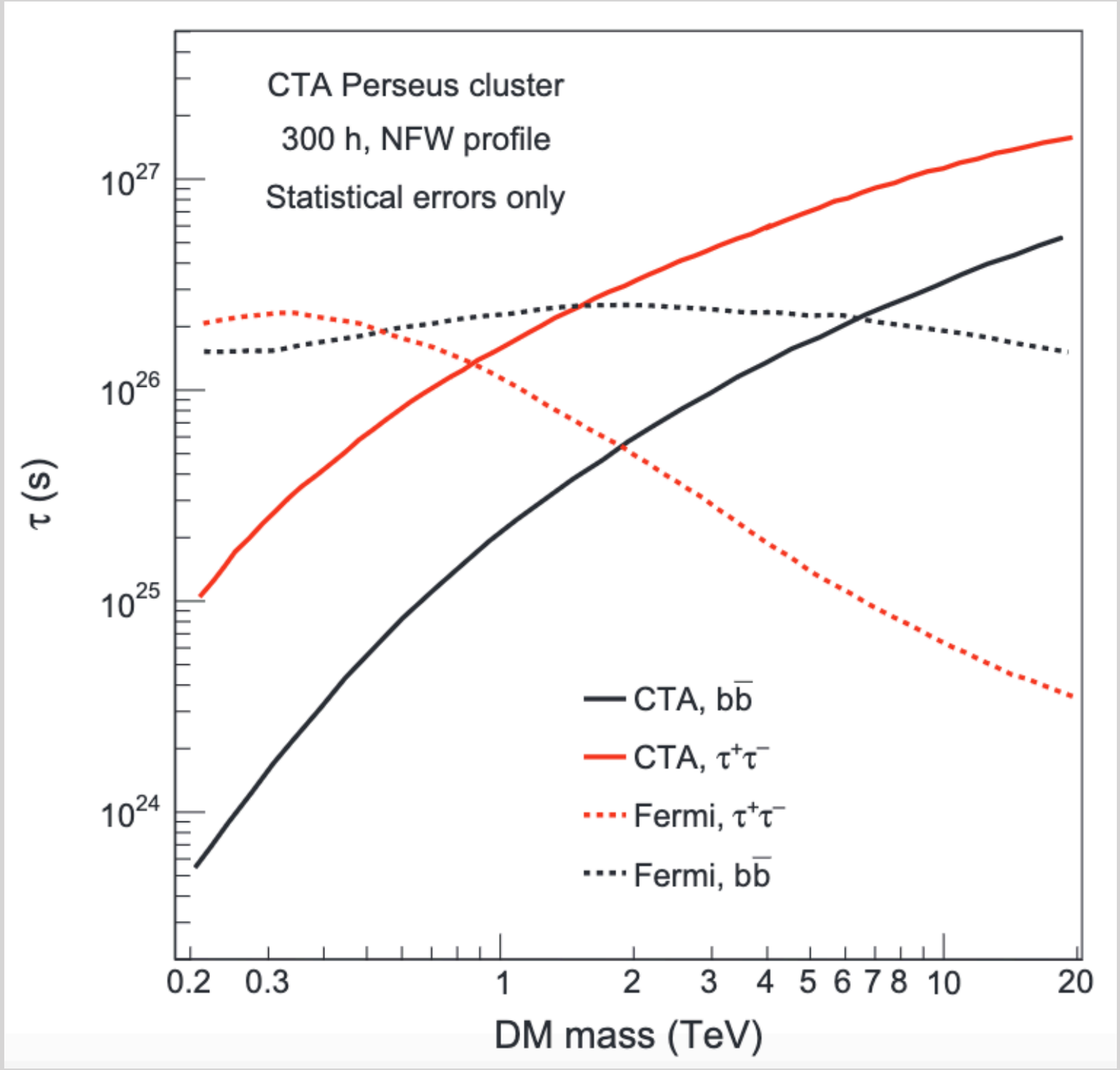
- Open issues:
  1. the **determination** of dSph **astrophysical factors** can be **challenging** (especially for faint targets) => **biases in the expected signal intensity**;
  2. an appropriate **general treatment** of **measurement biases** (triaxiality, tidal disruption degree) is still **missing** => **biases in the expected signal intensity**.

- Where to intervene:
  — increase the amount of good available dSph data (spectrophotometric observations);
  — include the proper treatment of bias sources in codes for astrophysical factor calculations (simulations-driven coding).

The CTA DM program: status and perspectives

- DM decay explored with galaxy clusters only;

- clusters not used for annihilation due to:
  - — distance
  - — density profile uncertainties
  - — substructure contributions



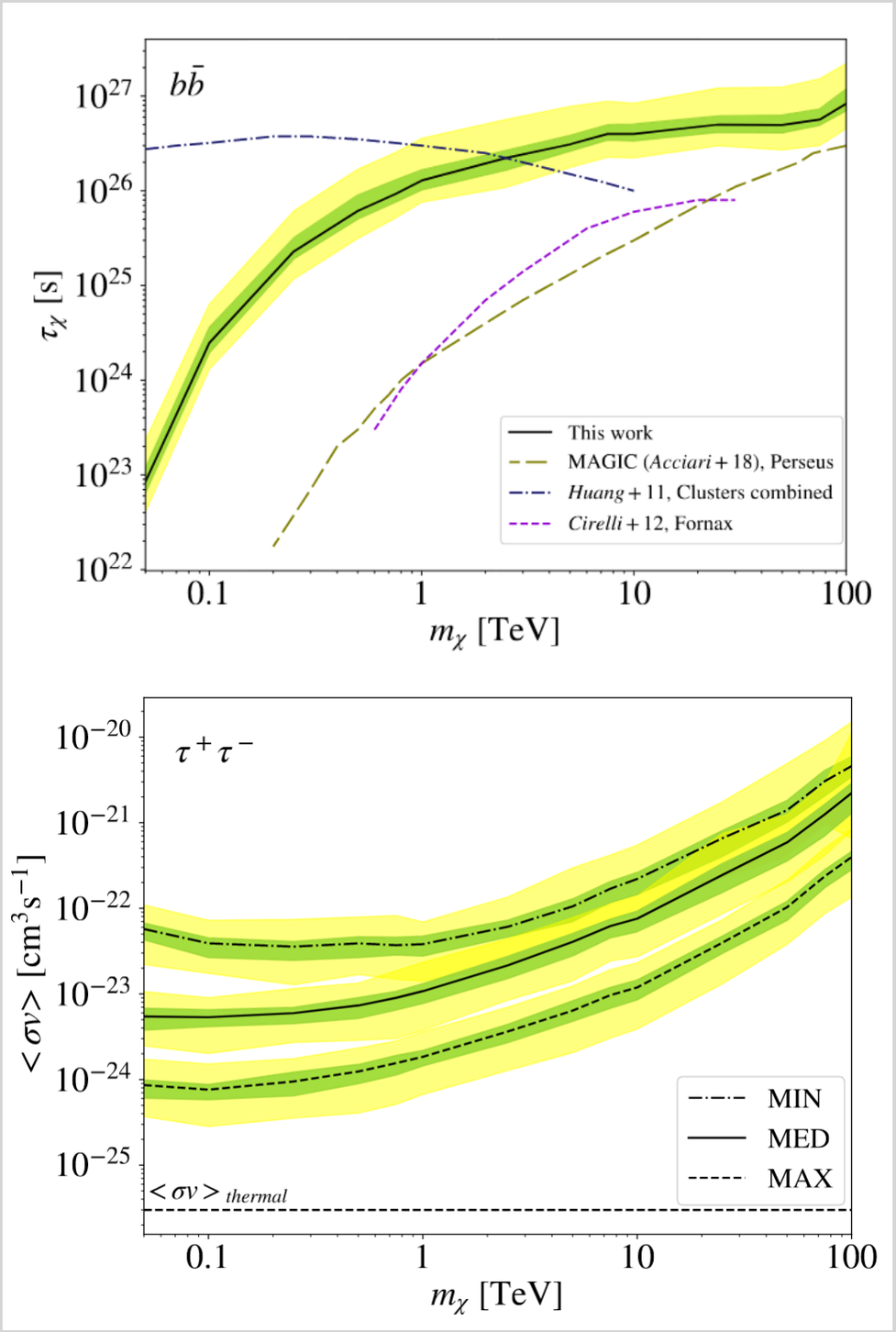
- Lifetimes >10^{27} s probed for multi-TeV DM masses.

The CTA DM program: status and perspectives

- Paper dedicated to the observing simulations of the Perseus cluster open for comments in CTA (until June 13th);

- prospects for both DM annihilation and decay presented;

- results in line with expectations in the case of DM decay, but **strongly dependent on the subhalo population** for DM annihilation.



The CTA DM program: status and perspectives

- Open issues:
  1. the **estimate** of **subhalo contribution** to the DM amount of galaxy clusters is still **uncertain** => **biases in the expected signal intensity** (DM annihilation only).

- Where to intervene:
  — improve the knowledge on DM distribution in galaxy clusters (simulations/MWL data).

See also G. Brunetti's talk!

The CTA capabilities beyond γ-rays: status and perspectives

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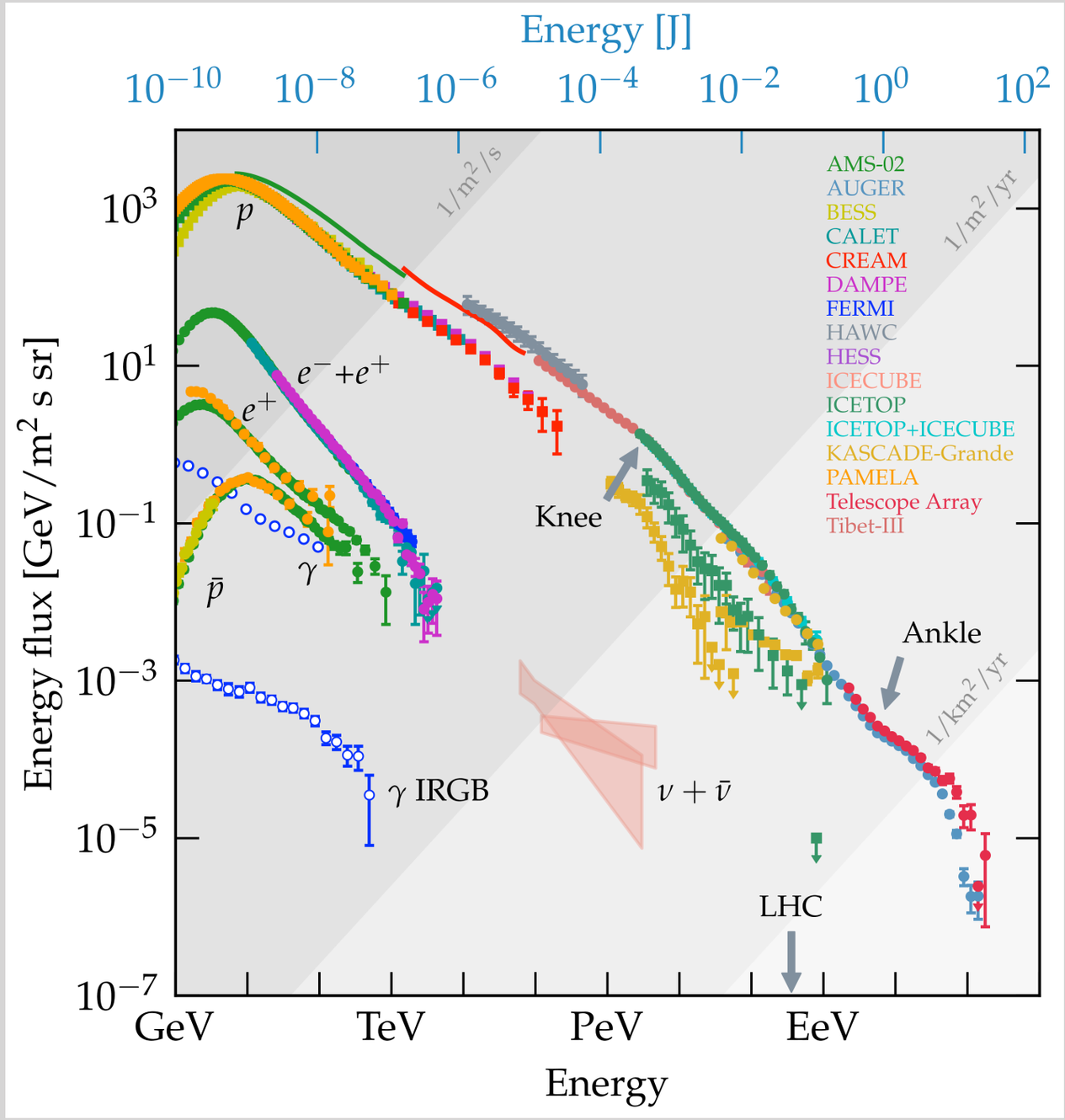
- The origin of cosmic rays (CRs) is still one of the most important open questions in astrophysics;
- Supernova remnants (SNRs) can account for CRs up to ~3 PeV; for higher energies, AGN mechanisms are required.



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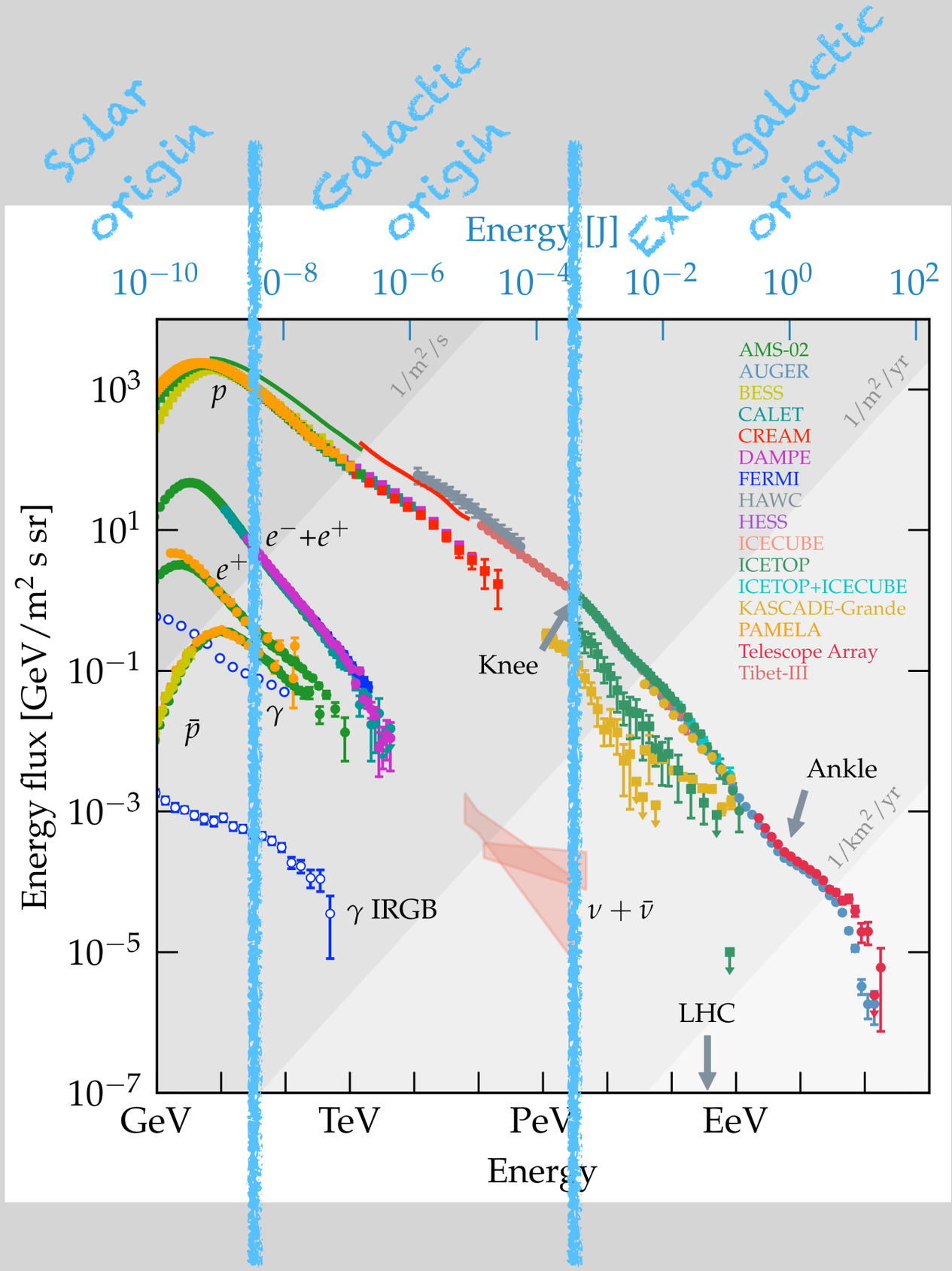
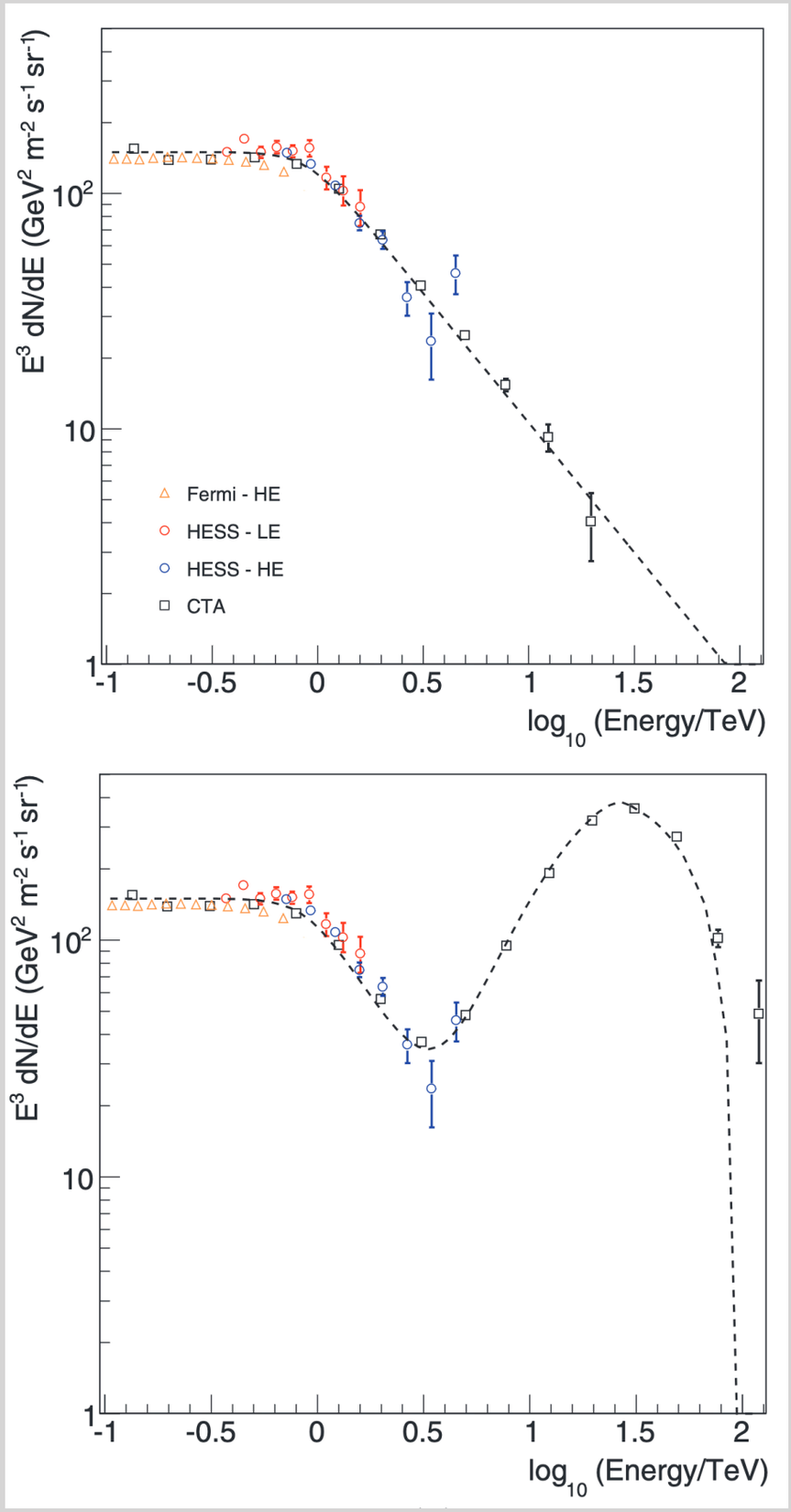


The CTA capabilities beyond γ-rays: status and perspectives

- *Science with CTA*:
  - — focus on CR composition measurements above 100 TeV up to the PeV domain
  - — characterization of the electron spectrum at multi-TeV energies

- Best results will be achieved for **heavy nuclei** (iron spectrum beyond 1 PeV) and for **sky directions containing leptonic sources**.



The CTA capabilities beyond γ-rays: status and perspectives

- CTA main focus on **CR-induced γ-ray signatures** (Astropart. Phys. 150, 102850; LMC draft; Perseus draft; SFR project; GC project);

- electron paper in preparation (see PHYS report @ last CTAO/CTAC Meeting in Granada);

- further advances on the **direct CR measurements** with CTA ***to be proposed*** as topic.

Potential big field still to be opened in CTA!

Summary

Summary

- Many topics of astroparticle/fundamental/exotic physics to be explored in detail with CTA observations;

- several open aspects to be investigated for improvement in the framework of the CTA DM program:
  - better modeling of the DM distribution in astrophysical sources
  - increment of the number of potential targets
  - inclusion of a proper treatment for bias sources in indirect DM searches

- Detailed investigation of the CR spectra still a big open science field in the CTA framework.