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Dark Matter Search with Cherenkov Telescope Array

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Introduction

γ -ray search of DM

Varieties of candidates:

DM=non-baryonic matter in the Universe of $\Omega_{\text{DM}}h^2 \sim 0.12$

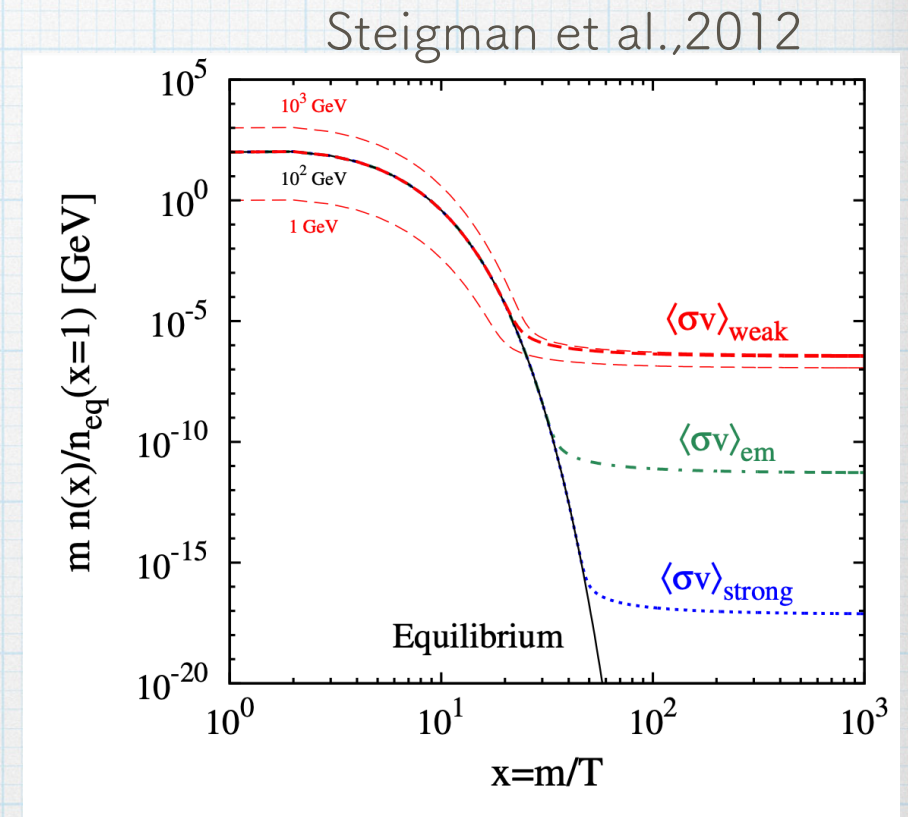
- Weakly Interacting Massive Particle (WIMP)
- Strongly/self- interacting massive particle (SIMP)
- sterile neutrino
- axion and/or axion-like particle (ALP)
- primordial black hole (PBH)...

Common assumption:

DM can interact with the Standard Model sector

WIMP

- the mass $m_{\text{DM}} \sim \mathcal{O}(\text{GeV}) - \mathcal{O}(\text{TeV})$
- freeze-out scenario to achieve the relic abundance $\Omega_{\text{DM}} h^2 \sim 0.12$
- the annihilation cross-section $\langle \sigma v \rangle \sim \mathcal{O}(10^{-26} \text{cm}^3 \text{s}^{-1})$



process: $\text{DM} + \text{DM} \rightarrow \text{SM} + \text{SM}$ exist

CTA for WIMP

WIMP signal in γ -ray

DM+DM \rightarrow

- 2γ
- $q\bar{q} \rightarrow \pi^0 + \dots \rightarrow 2\gamma + \dots$
- $W^+W^- \rightarrow q + \dots \rightarrow \gamma + \dots$
- $l^+l^- \rightarrow \nu(\bar{\nu}), W^\pm + \dots \rightarrow \gamma + \dots$

current facilities

- Fermi-LAT

satellite, survey

- MAGIC

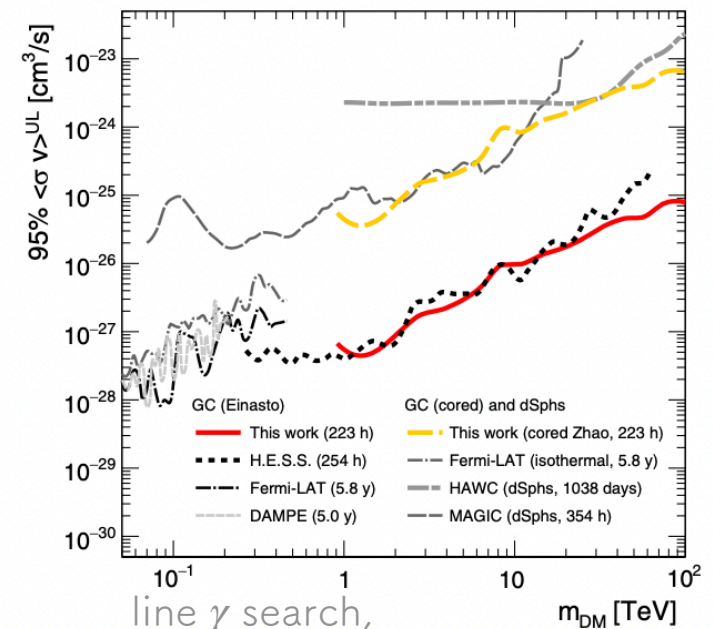
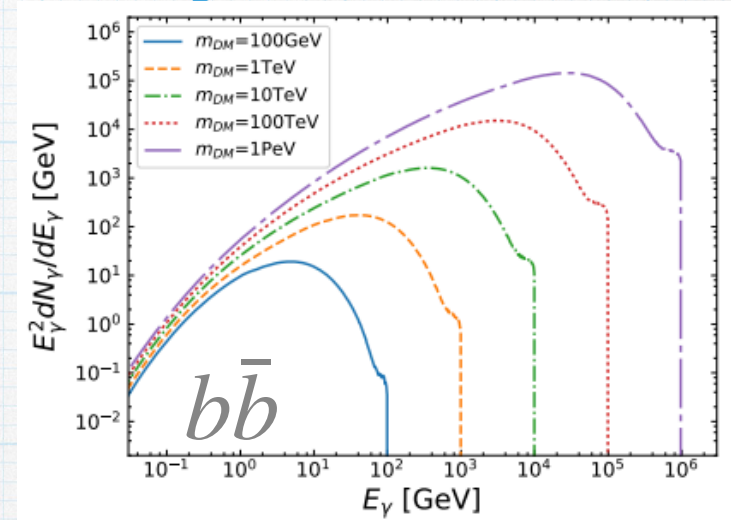
imaging atmospheric Cherenkov telescopes, pointing

- VERITAS

- H.E.S.S.

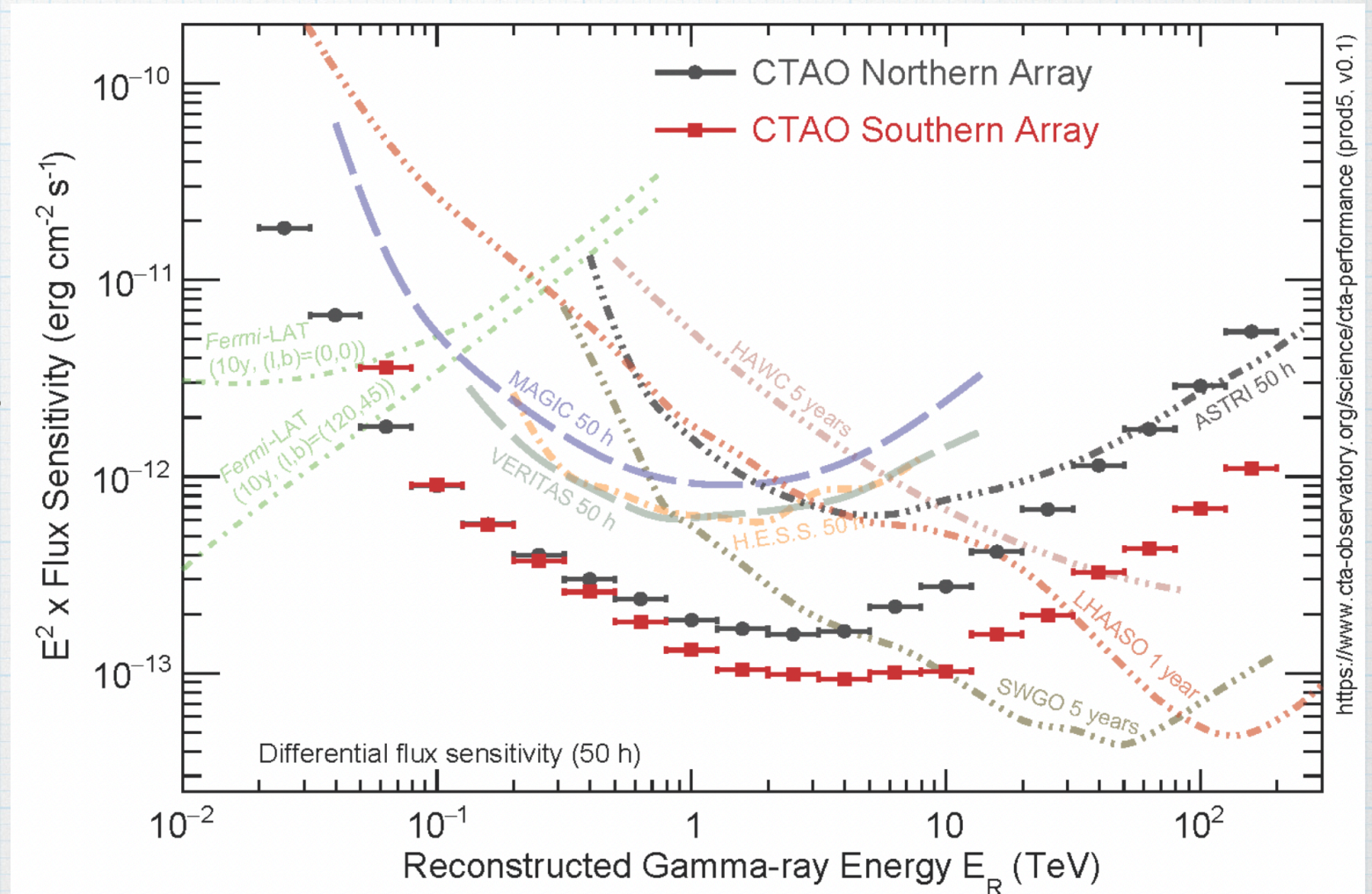
- HAWC

water Cherenkov, survey



CTA

- full-sky coverage
- $\Delta E \sim 10\%$
- $\Delta\theta \sim 0.03^\circ - 0.2^\circ$



Where to look for?

$$\phi_{\text{ann}} = \frac{1}{2} \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{m_{\text{DM}}^2} \int_{E_{\text{th}}}^{m_{\text{DM}}} dE \frac{dN}{dE} \cdot \int_{\Delta\Omega} d\Omega \int_{los} ds \rho_{\text{DM}}^2$$

astrophysical J-factor

high $J \leftrightarrow$ significant signal

- isotropic emissions
- Galactic Center ($J \sim \mathcal{O}(10^{22}) \text{GeV}^2/\text{cm}^5$)
- dwarf spheroidal galaxies ($J \lesssim \mathcal{O}(10^{19}) \text{GeV}^2/\text{cm}^5$)
- nearby galaxies (M31, M33, LMC)
- galaxy clusters

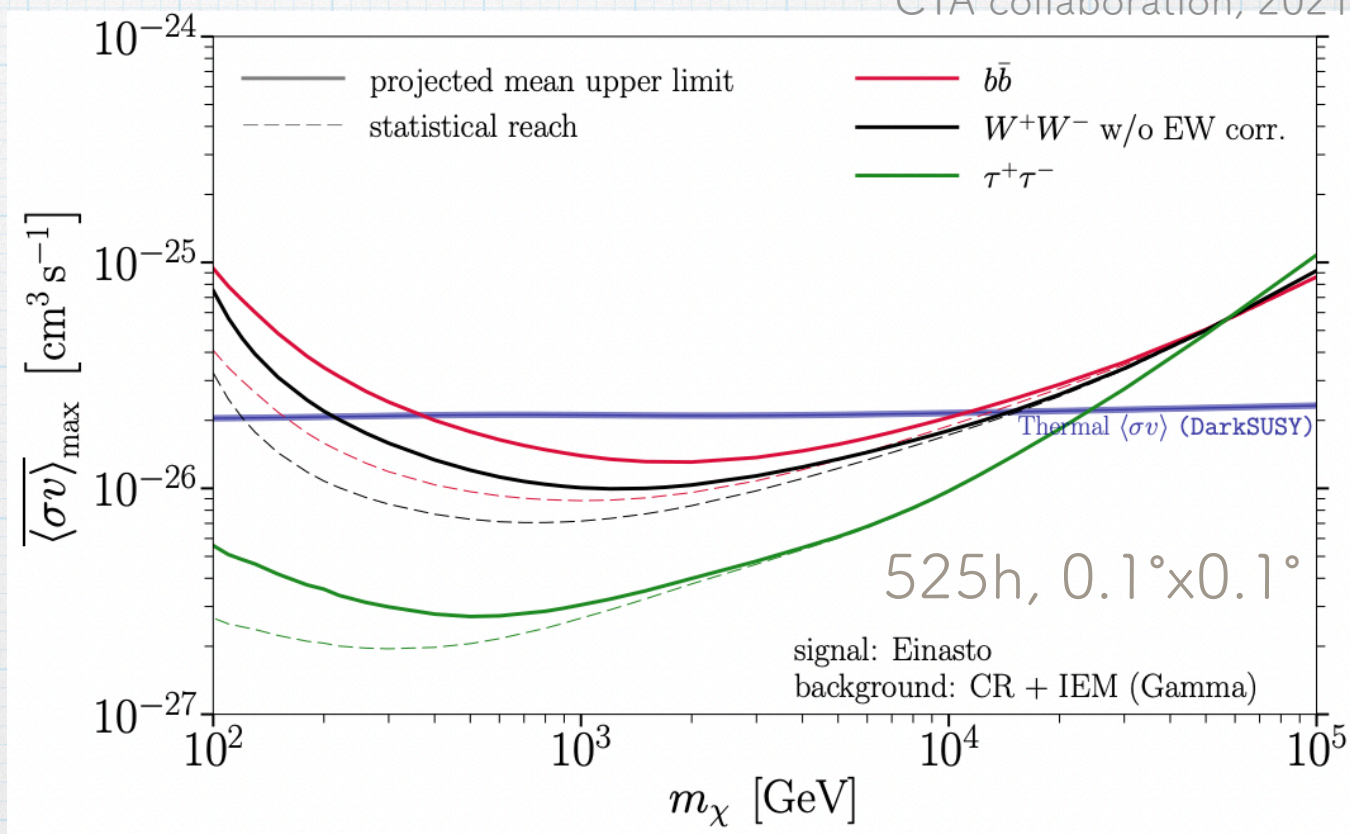
Galactic Center

- Einasto profile

$$\rho_{\text{DM}} = \rho_s \exp \left[-\frac{\alpha}{2} \left(\frac{r}{r_s} \right)^\alpha - 1 \right], \quad J \sim 7.1 \times 10^{22} \text{GeV}^2/\text{cm}^5$$

- background for DM signal sources, Fermi Bubble, interstellar γ , c.r. residuals

CTA collaboration, 2021



dwarf spheroidal galaxies

- target selection

 - J-factor value

 - J-factor quality

 - positions on the sky

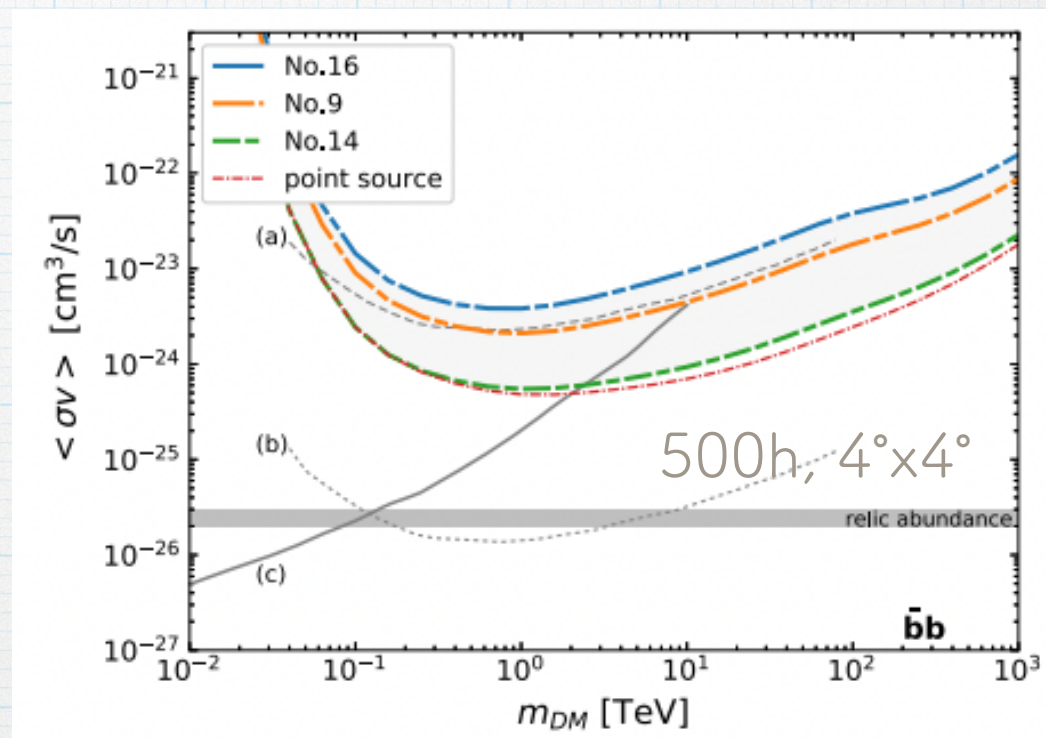
- J-factor calculation

 - caution!

 - different profile models

 - ↔ different J-factors

up-to-now publication: Hiroshima+, 2019



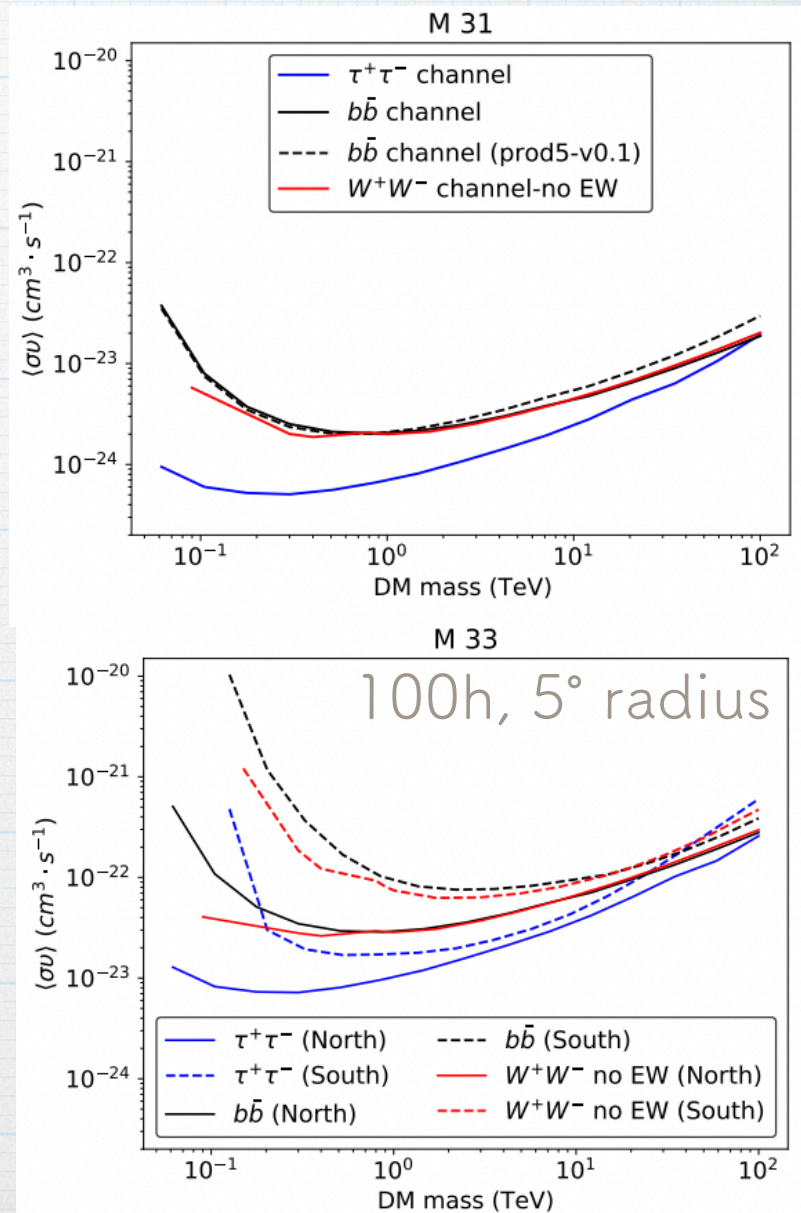
CTA Key Science Paper is now being prepared

Nearby galaxies (M31 & M33)

Michailidis et al., 2023

- astrophysical emissions
 - 6 (4) catalogued sources in the FoV of M31 (M33)
 - extended emission in M31
- negligible Galactic diffuse contribution
- residual cosmic-ray background

Possibility with LMC is also discussed



Galaxy cluster (Perseus)

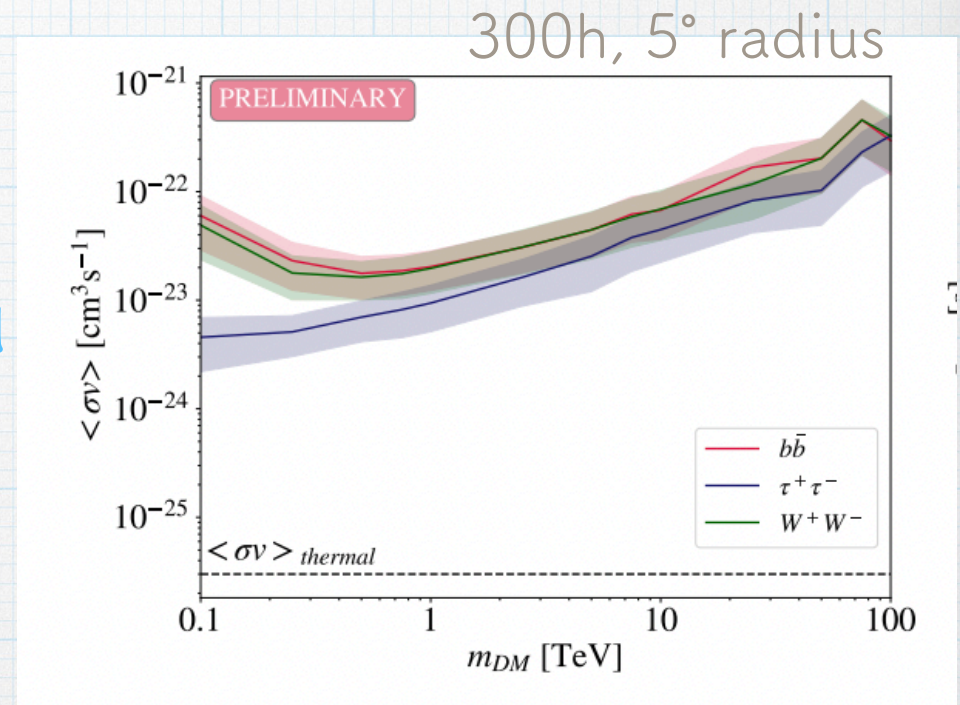
- properties:

- $M \sim \mathcal{O}(10^{14} - 10^{15})M_{\odot}$
- the brightest in X-ray
- cool-cored, dynamically relaxed
- with 2 AGN (variable)

- components:

DM + c.r. in cluster
+ AGN + c.r. residuals

- on-off analysis & template fitting test

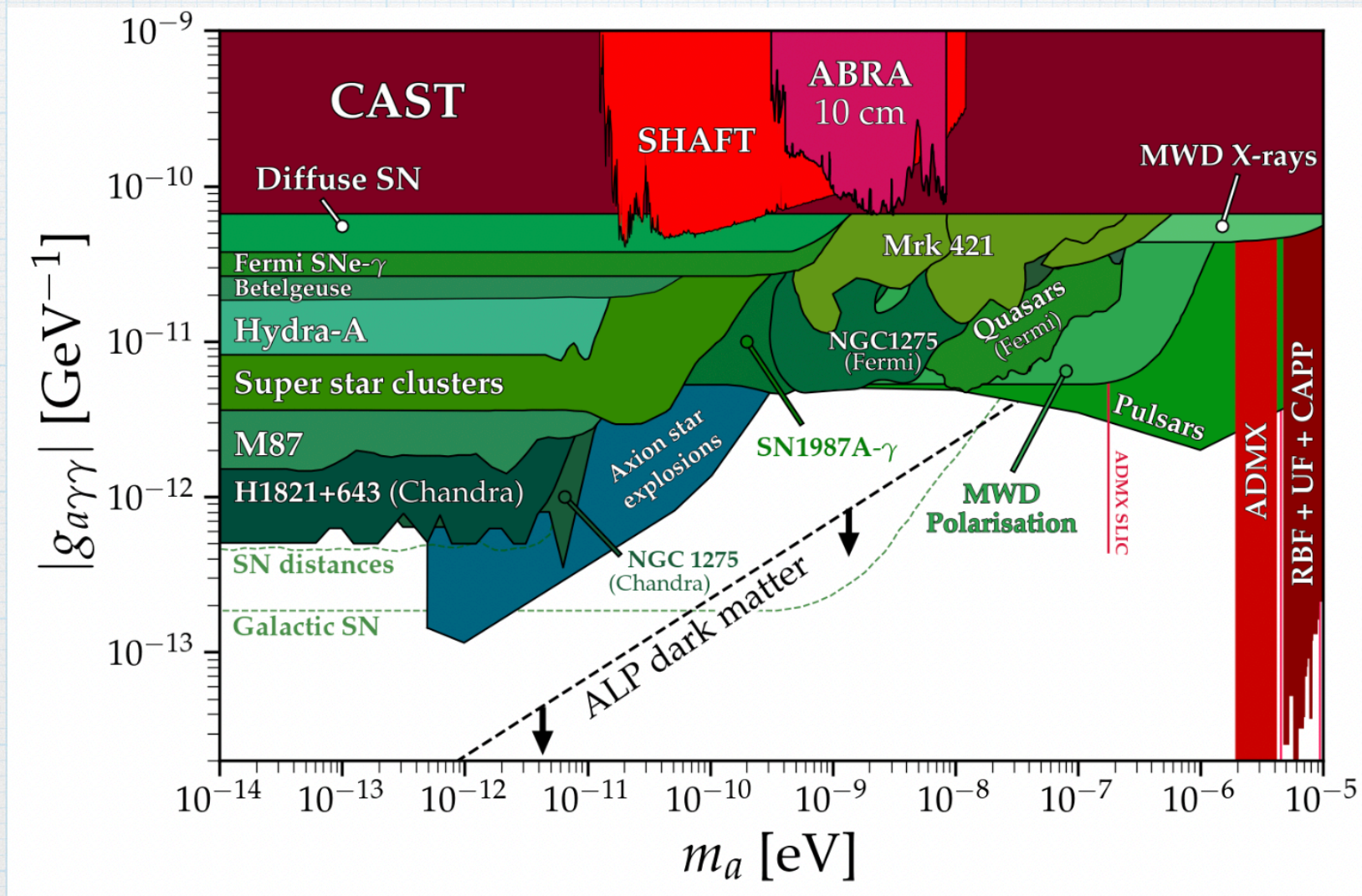


Perez-Romero+ 2021, ICRC2021 PoS 546
(CTA consortium paper in prep.)

Further possibilities

axion/axion-like particle

current astrophysical limits: $\gamma + B \rightarrow a + B \rightarrow \gamma' + \dots$



test case: NGC 1275

CTA consortium, 2021

$$\gamma + B \rightarrow a + B \rightarrow \gamma' + \dots$$

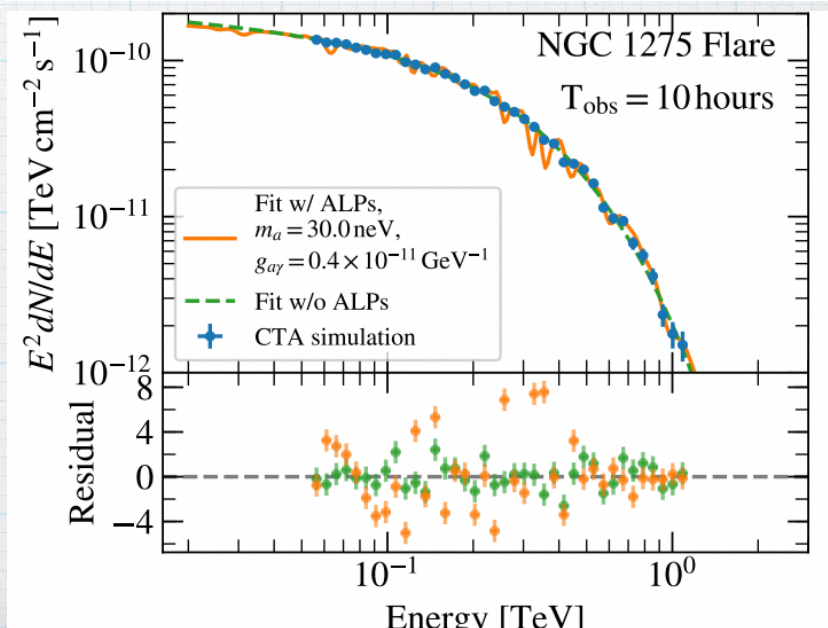
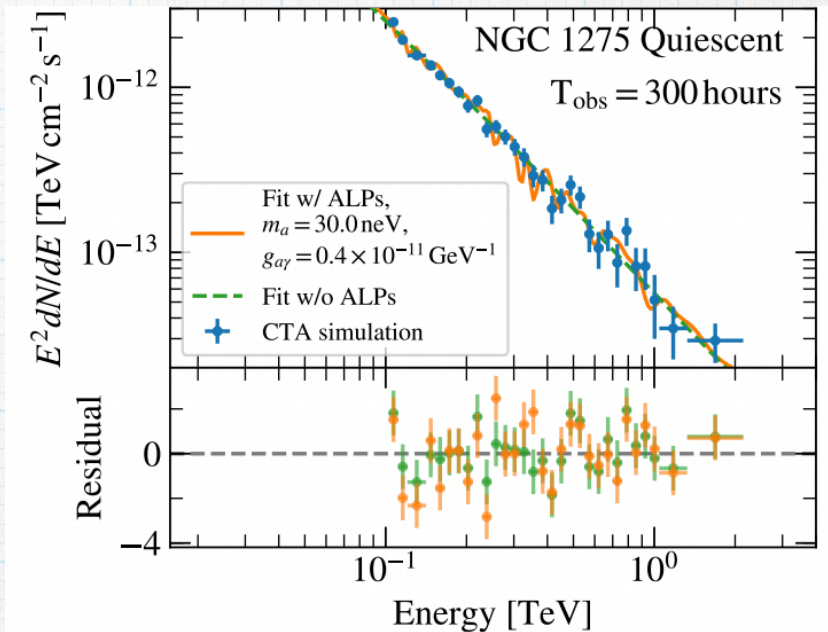
- conversion probability ($E > E_{\text{crit}}$)

$$P_{a\gamma} \sim \sin^2 \left(\frac{g_{a\gamma} B l}{2} \right),$$

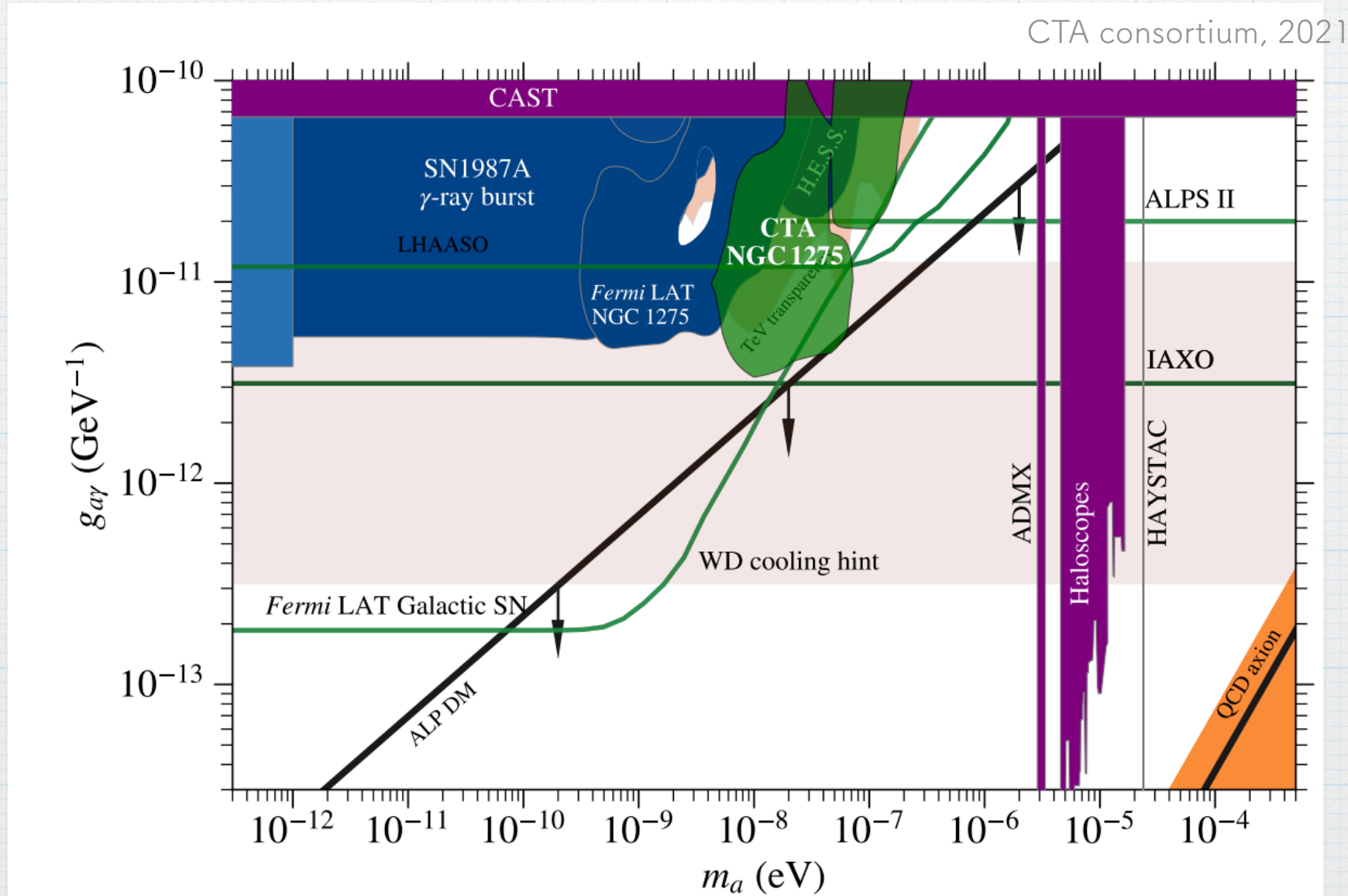
$$E_{\text{crit}} \sim 2.5 \text{ GeV}$$

$$\times \left(\frac{|m_a - \omega_{\text{pl}}|}{1 \text{ neV}} \right)^2 \left(\frac{B}{1 \mu\text{G}} \right)^{-1} \left(\frac{g_{a\gamma}}{10^{-11} \text{ GeV}^{-1}} \right)^{-1}$$

- blazar spectra
smooth PL (quiescent)
PL + exp. cutoff (flare)
→ wiggly structures in spectra
from $a \leftrightarrow \gamma$ conversion



Prospects with CTA



Summary

Summary

- CTA should be capable of probing various dark matter(DM) candidates.
- Several target objects are considered for WIMPs, such as the Galactic Center, dwarf spheroidal and// or nearby galaxies, galaxy clusters.
- Careful treatments of the astrophysical emissions and DM density profiles are needed.
- Understandings of DM candidates other than WIMPs and beyond the Standard Model physics will also be updated with CTA observations.