Testing dark matter with Cherenkov light – prospects of H.E.S.S. and CTA for exploring minimal supersymmetry

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Erice 18/9/2019

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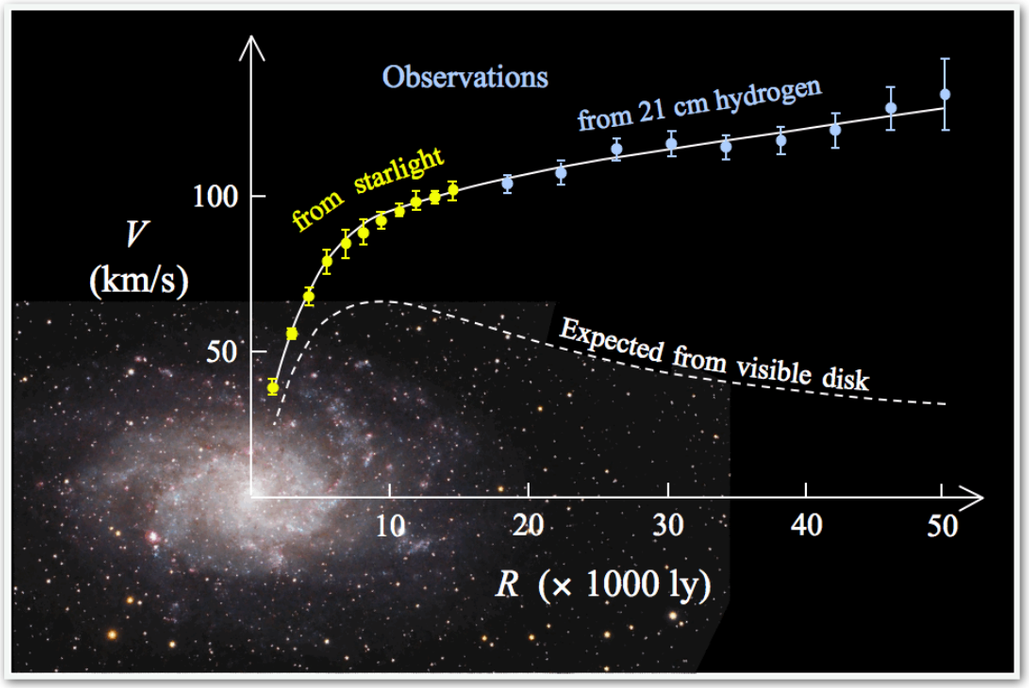
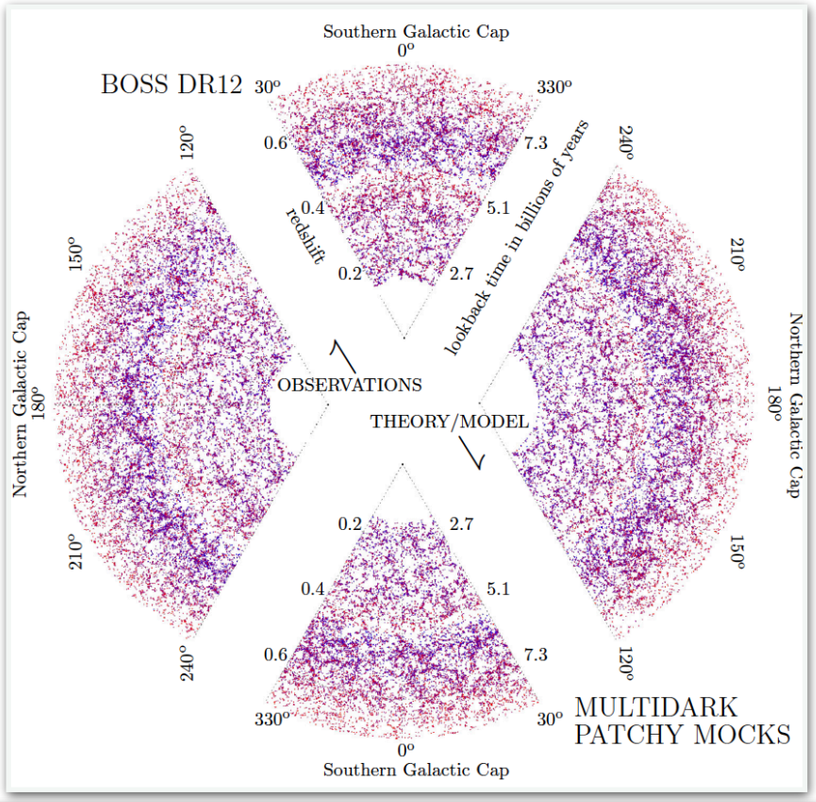
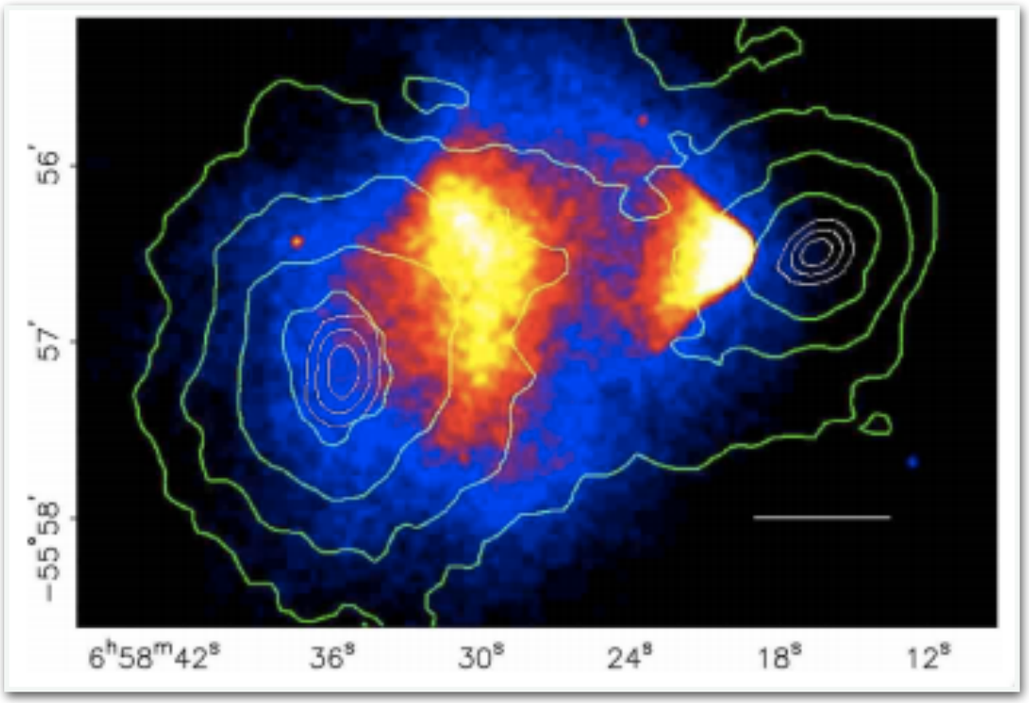
Based on: hep-ph/1905.00315 - accepted by JHEP

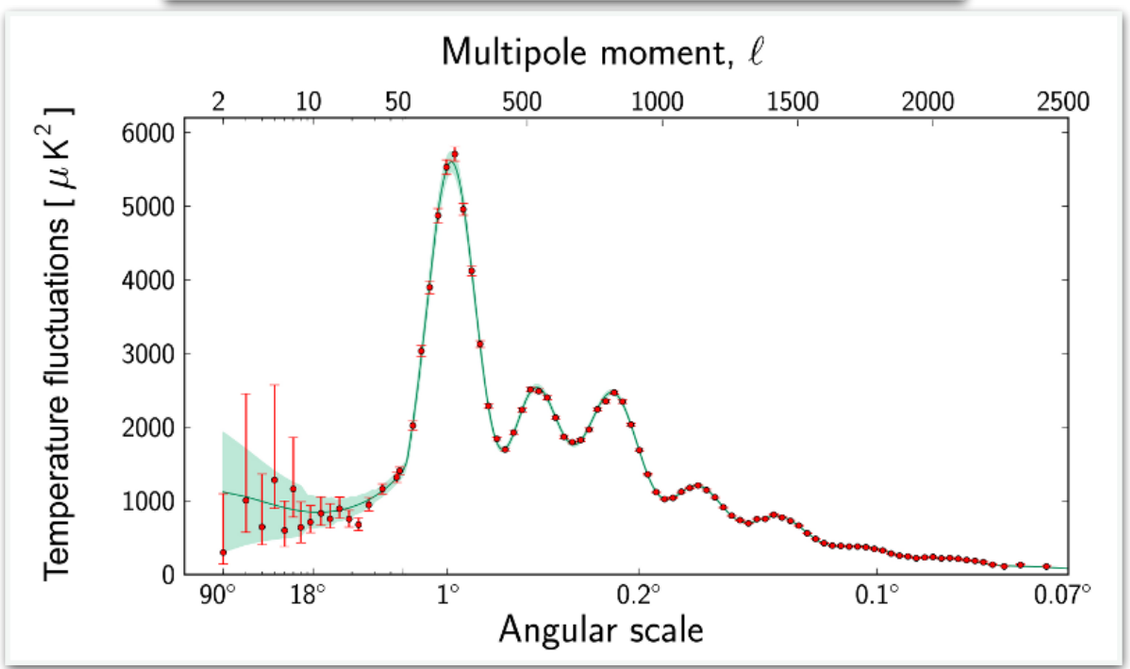
Dark Matter in the Universe

Evidence on multiple scales:







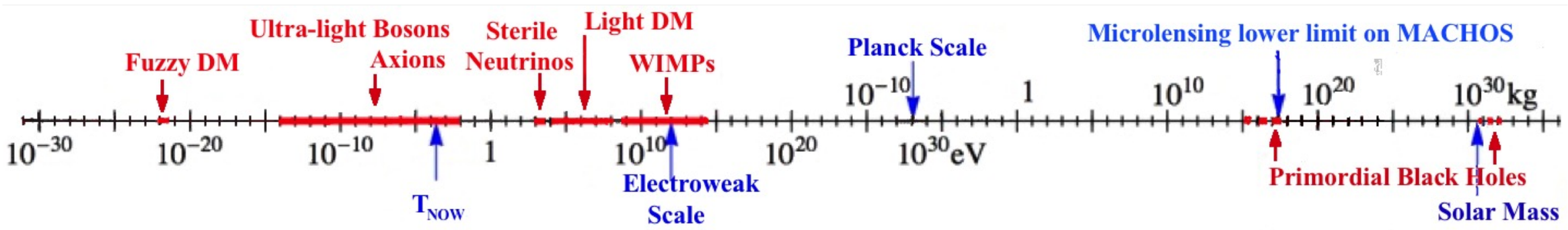


Particle DM

Standard Model is not complete description of Nature:

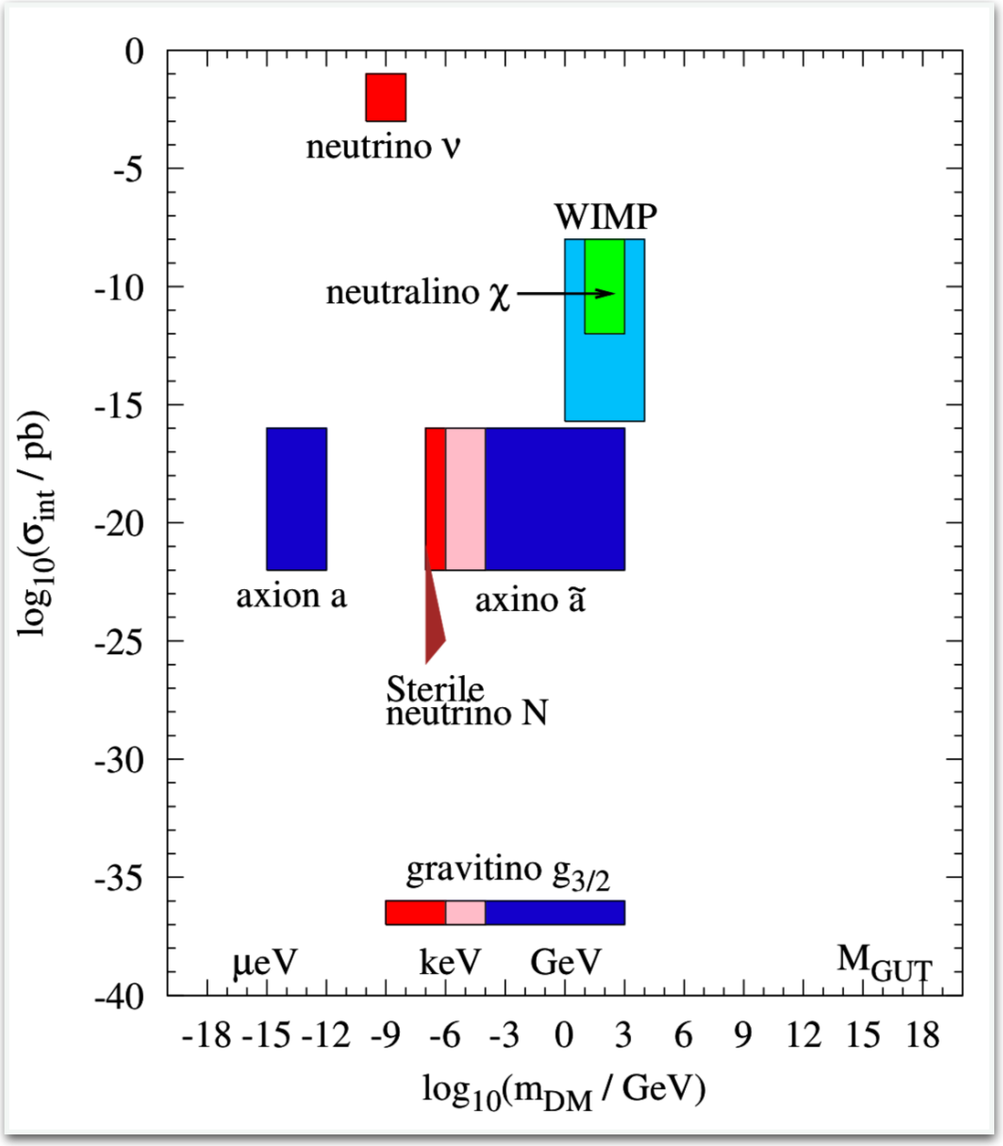
- Neutrino masses
- Baryogenesis
- Hierarchy problem
- Quantum gravity
- …

Physics BSM could take many forms - from minimal extensions to multiple hidden (dark) sectors



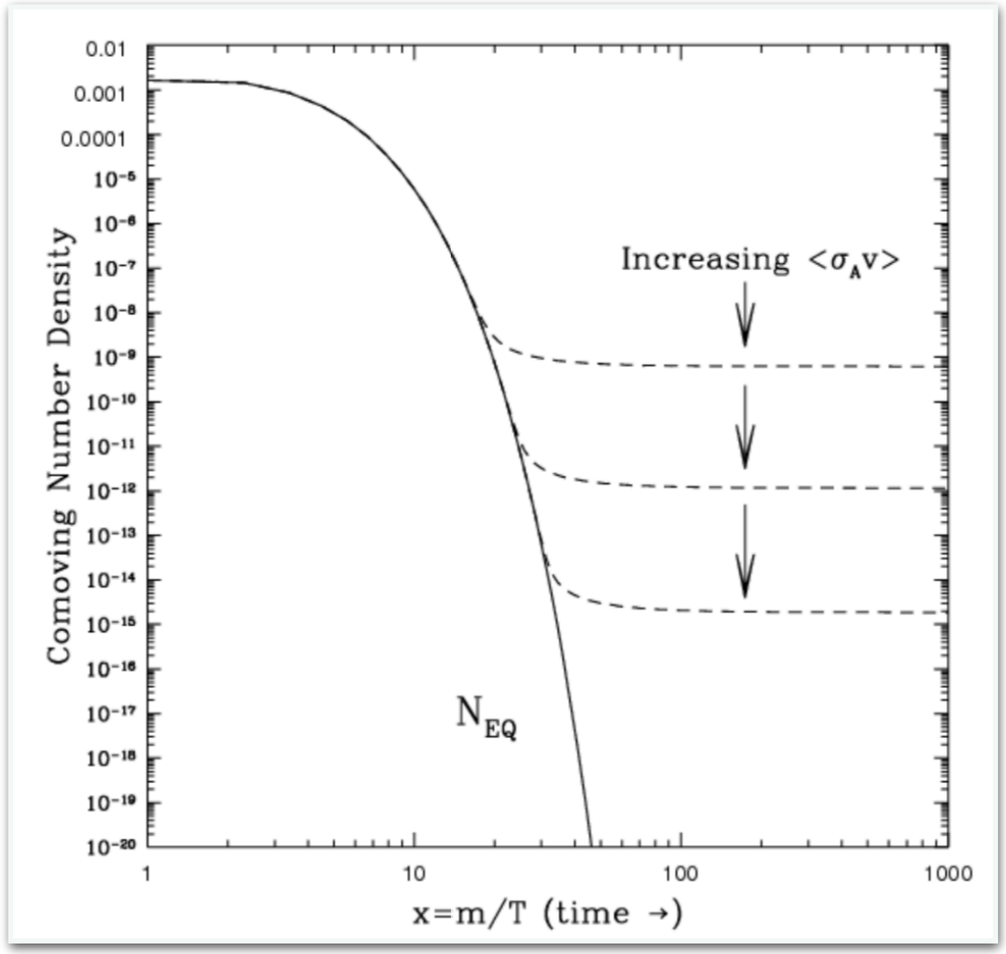
New, stable particle is generic prediction in models BSM

Particle DM



"WIMP miracle"

Since late 70's, its well known that particle with electroweak-scale mass and weak interaction with SM predicts observed relic density



$$\Omega_\chi h^2 \approx 0.1 \frac{3 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}}{\langle \sigma v \rangle}$$

Lee, Weinberg '77; Others

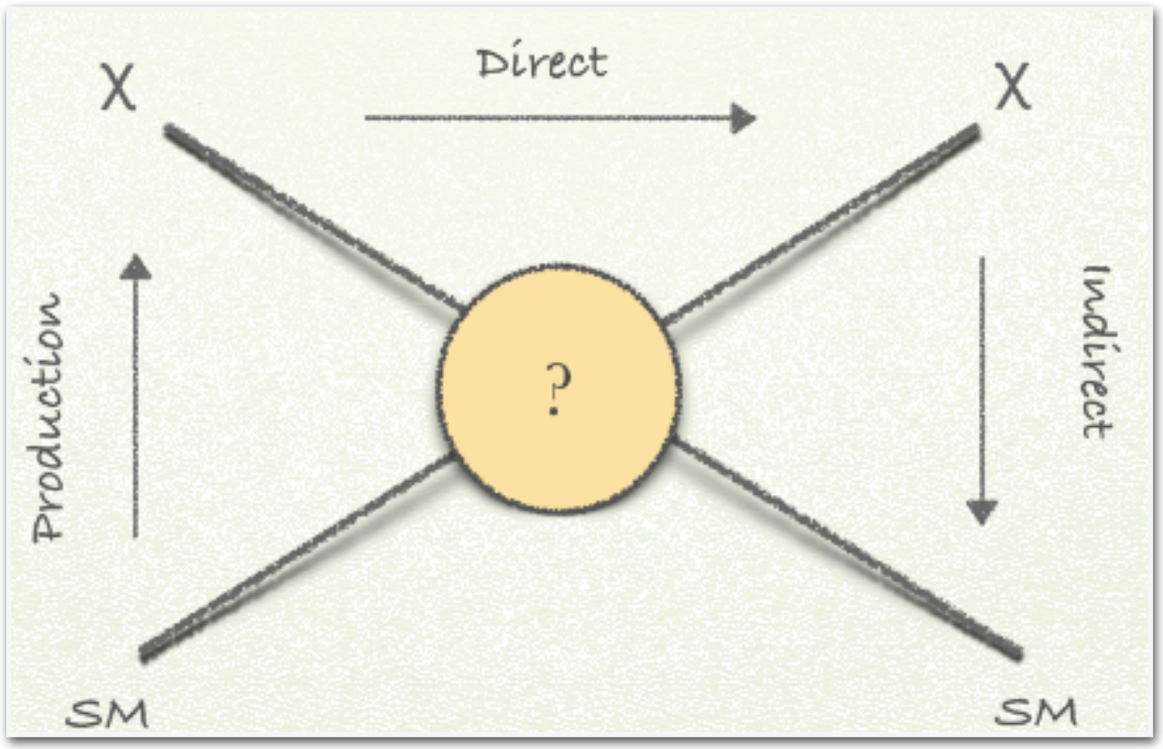
"WIMP miracle"

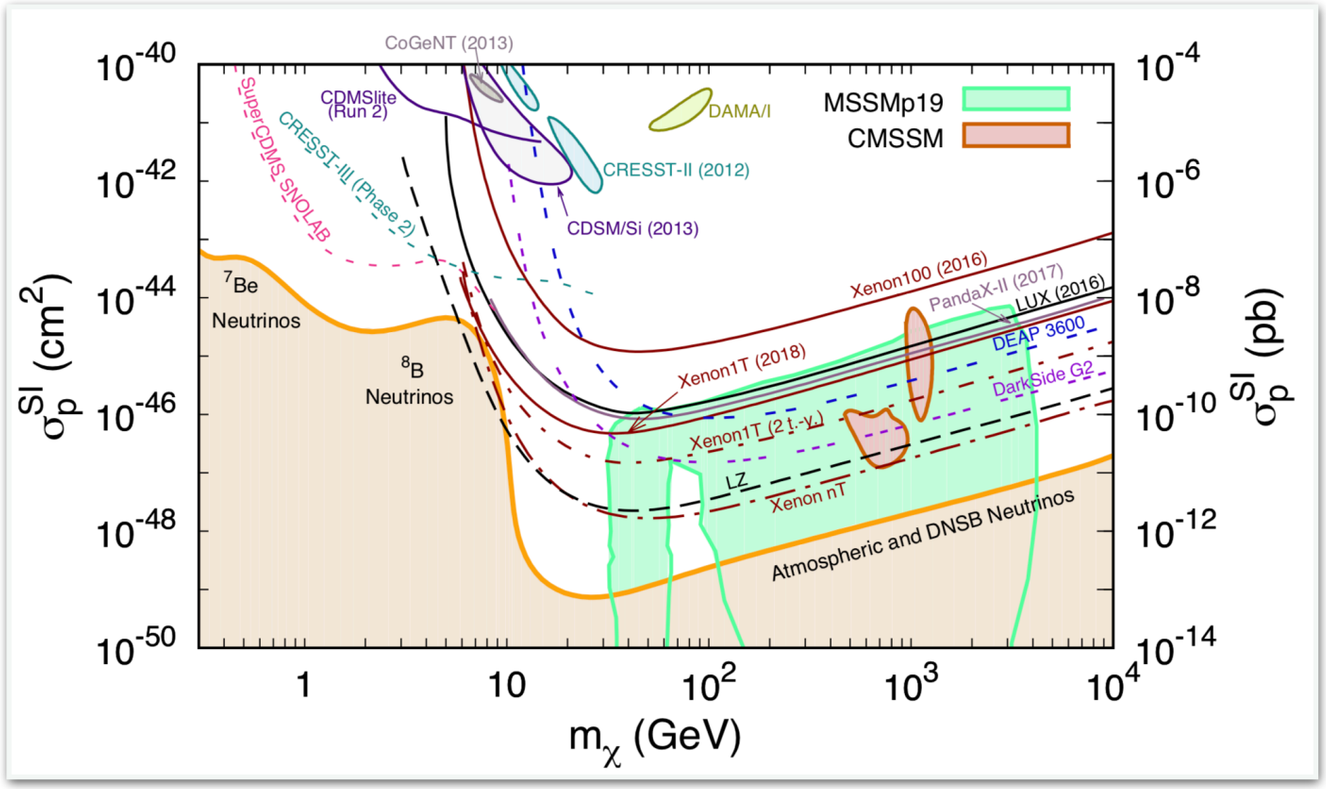
On dimensional grounds: $\sigma \propto \frac{g^4}{m_\chi^2}$ ⟶

Plenty of possibilities!

$\sim 1\text{GeV} \lesssim m_\chi \lesssim 100\text{TeV}$

Same energy scale is suggested by e.g. the hierarchy problem and currently being probed by LHC experiments



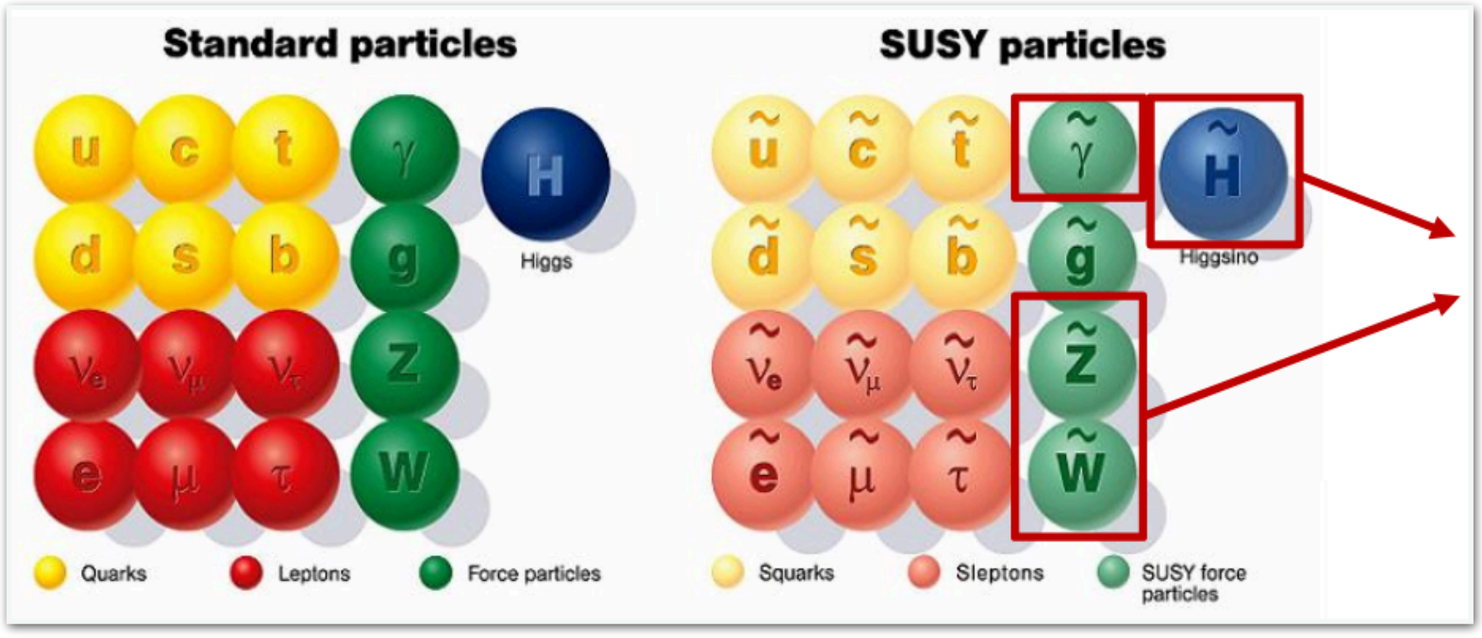


Impressive progress in DD searches both in spin-independent (coupling to nucleus mass) and spin-dependent (coupling to nucleus spin) elastic scattering

Goal: indirect detection prospects of ~TeV neutralino DM

SUSY is arguably the most popular Beyond Standard Model framework which solves e.g. the gauge-hierarchy problem and provides several promising DM candidates

We consider the lightest **neutralino** as DM



It is mixture of gauge eigenstates

- Higgsinos
- Wino
- Bino

Global Z_2 symmetry ⟶ stable

Null collider searches have generally pushed SUSY scale into a multi-TeV regime ⟶ find ID prospects of 0.1 - 5 TeV neutralino in **pMSSM**

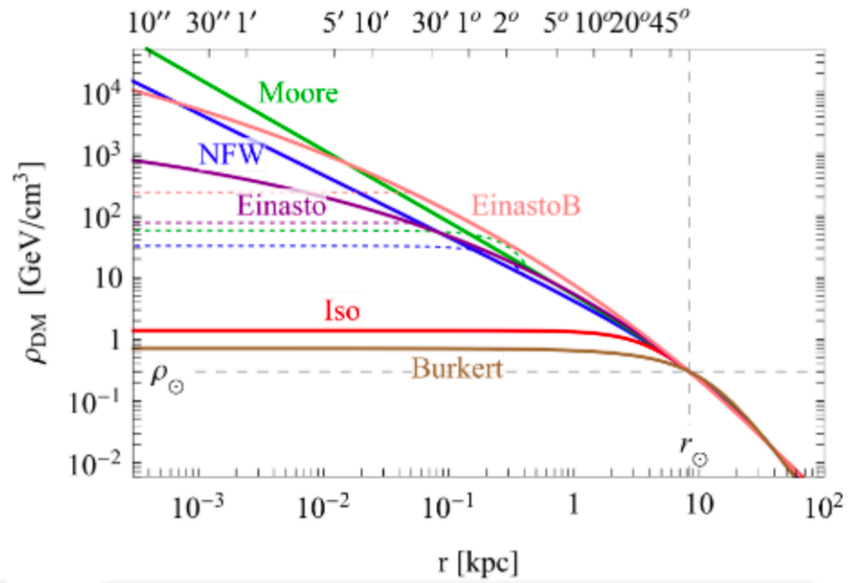
Indirect Detection

Expected photon flux from pair-annihilation of DM particles is:

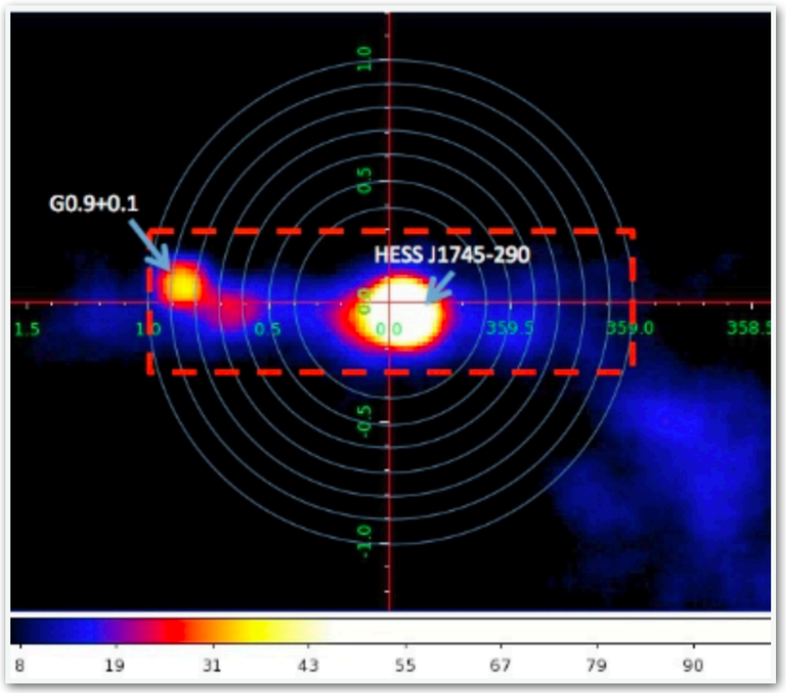
$$\frac{\mathrm{d}\Phi_\gamma^{\mathrm{DM}}}{\mathrm{d}E}(\Delta\Omega, E) = \frac{\sigma v_0}{8\pi m_{\mathrm{DM}}^2}\frac{\mathrm{d}N_\gamma(E)}{\mathrm{d}E} \times J(\Delta\Omega)$$

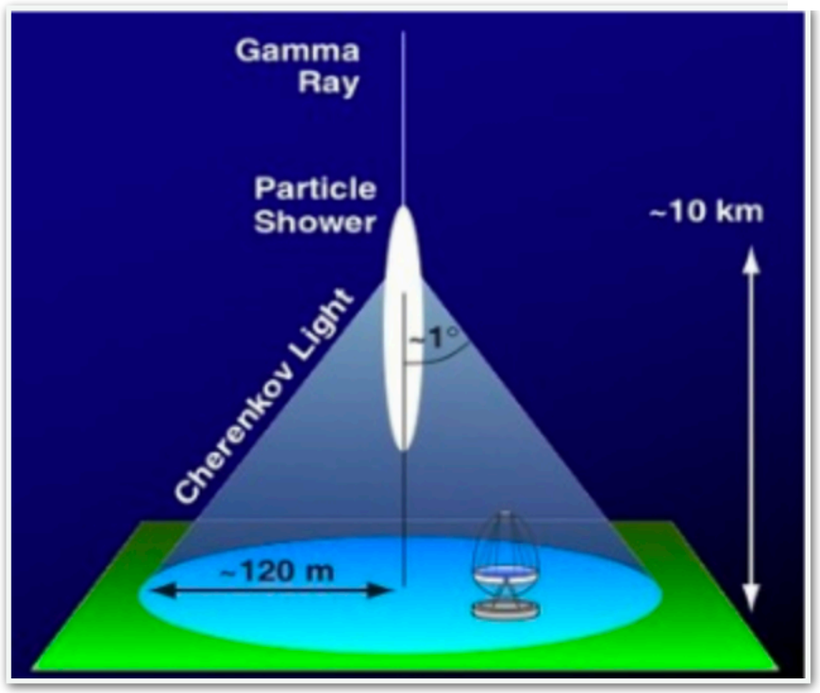
$$J(\Delta\Omega) \equiv \int_{\Delta\Omega} \mathrm{d}\Omega \int_0^\infty \mathrm{d}s \rho_{\mathrm{DM}}(r(s,\theta))^2$$

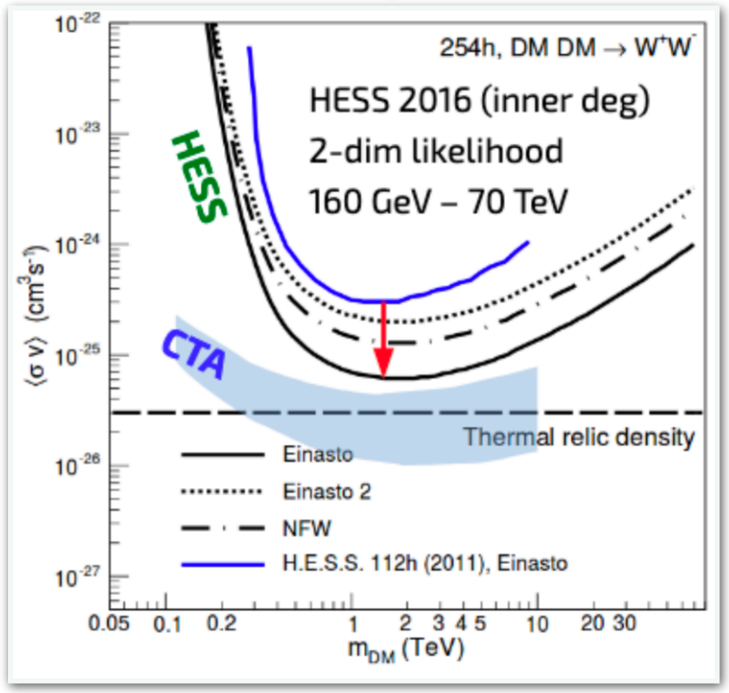
The DM distribution close to GC (<1kpc) is only poorly constrained



Cherenkov detectors





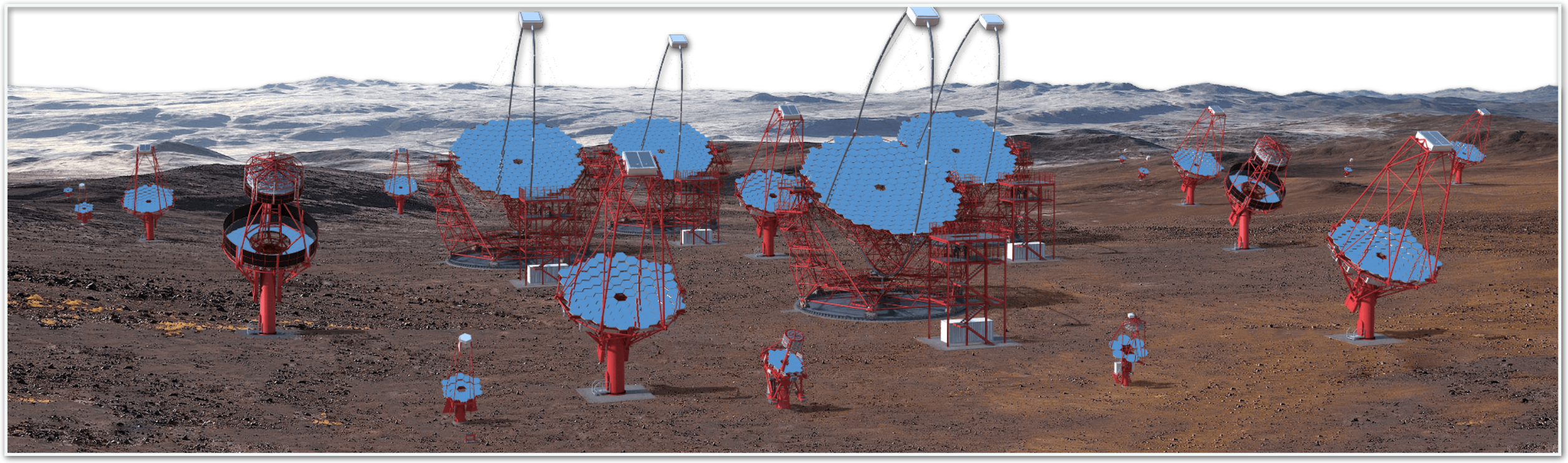


Science with CTA, 1709.07997; Hinton, Hoffmann 2009

Cherenkov Telescope Array

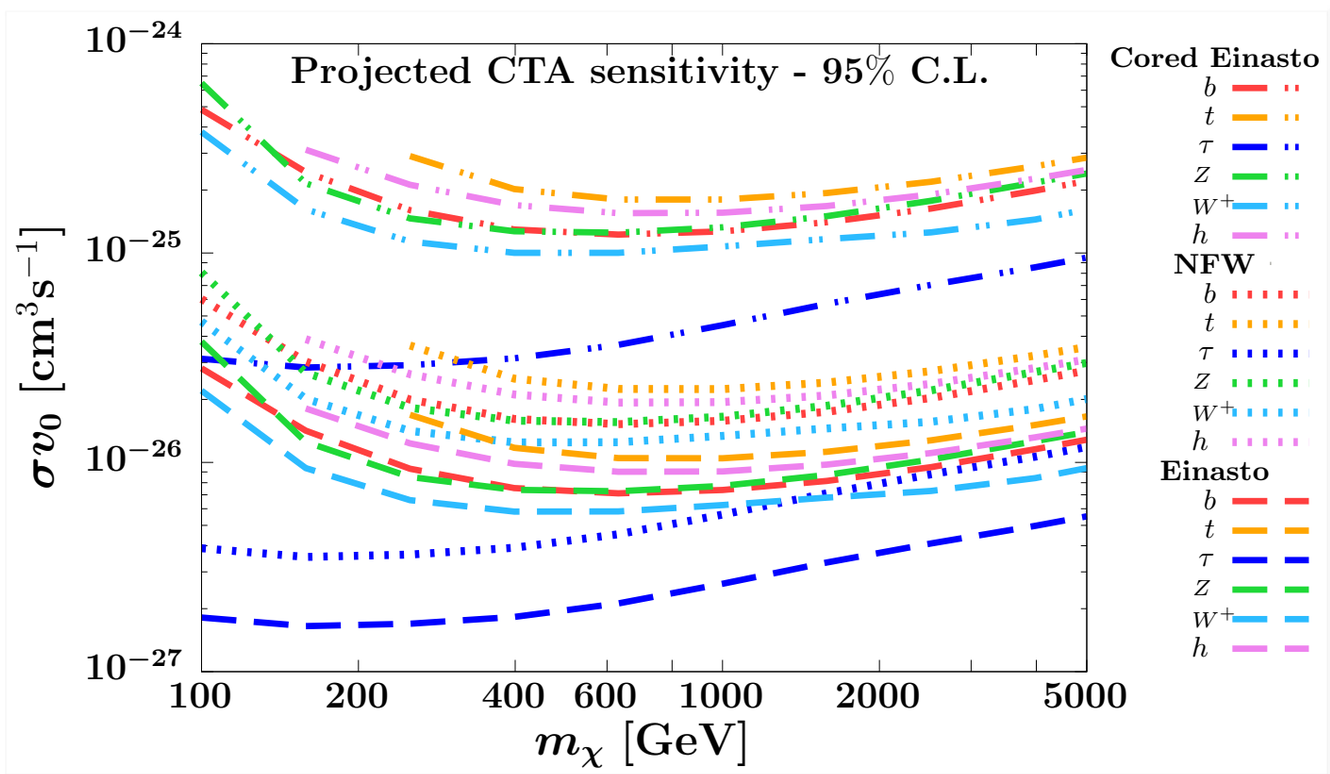
- Major observatory for very high energy (**20 GeV to 300 TeV**) γ ray astronomy
- Telescopes located on both hemispheres - covers the whole sky
- In advanced stage of pre-construction - with production beginning in 2021
- Medium and small-sized telescopes already achieved ‘first light’
- Dedicated DM programme with 500 h of observations already planned
- Principal target is the Galactic halo within several degrees of the GC

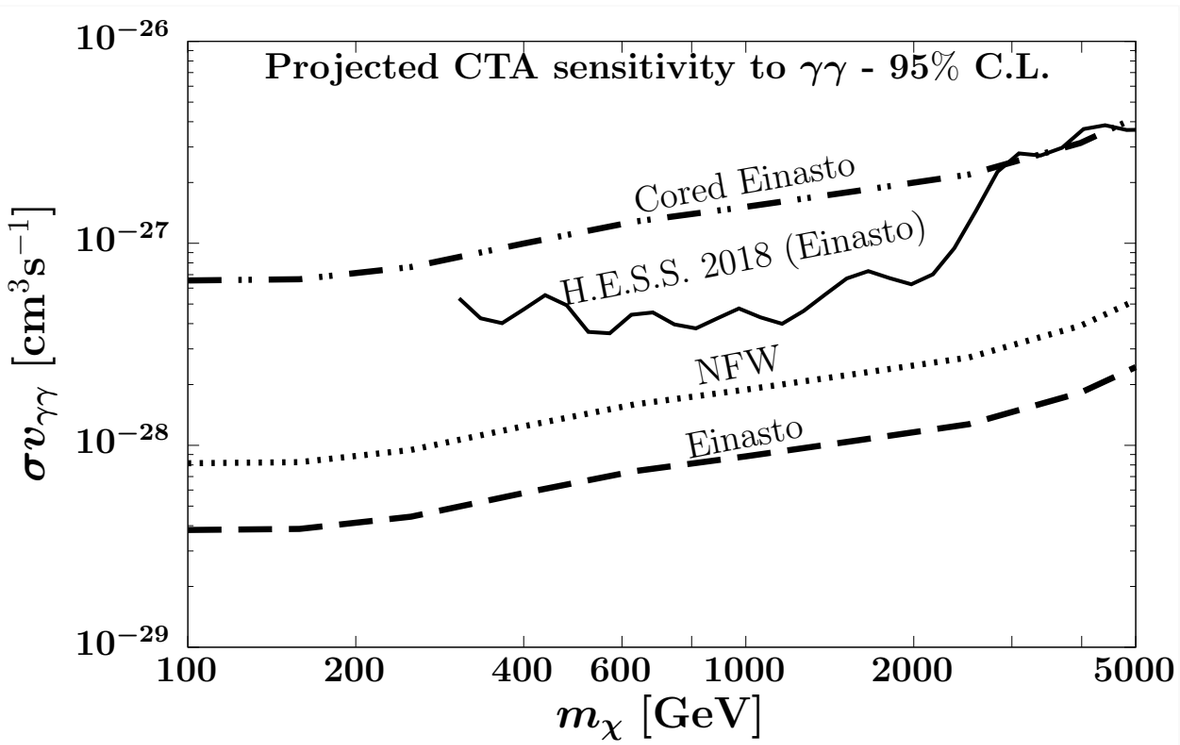
Cherenkov Telescope Array Consortium, 1709.07997



Projected CTA limits

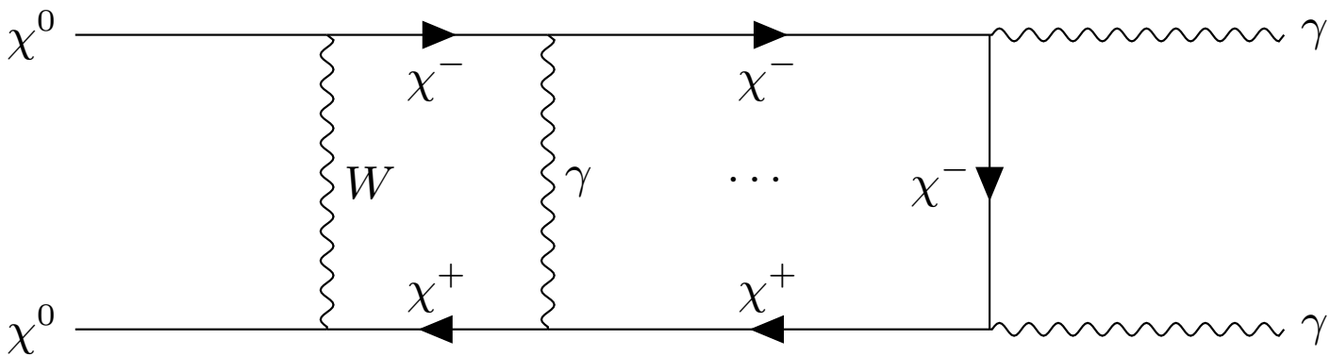
- ROI extends up to $\pm 5^\circ$ from the GC both in longitude and latitude
- We derived CTA Southern array sensitivity using:
  - latest instrument response functions
  - 3-dim. log likelihood ratio test statistics
- Three different choices of the DM Galactic halo profile: **Einasto**, **NFW and Cored Einasto** (r_{core} = 3 kpc)

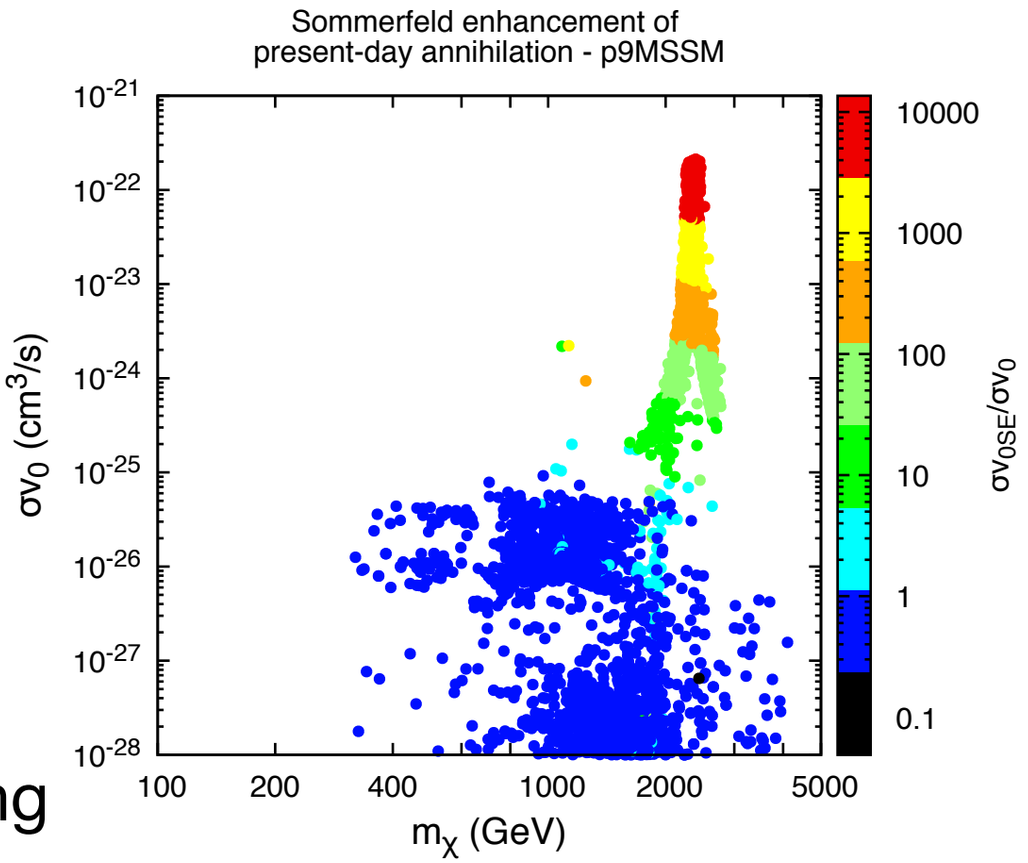




Sommerfeld enhancement

Sommerfeld, ’31
Hisano, 0610249





Non-relativistic, non-perturbative effect modifying the annihilation cross section due to long range force acting between slowly moving particles

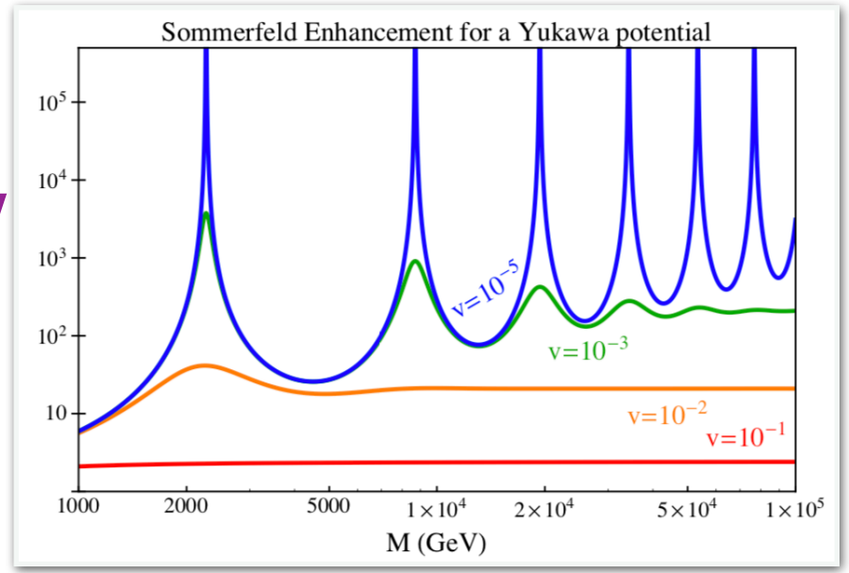
Based on **DarkSE** code
Hryczuk, 1102.4295

Important for **precise determination** of both relic density and present-day annihilation

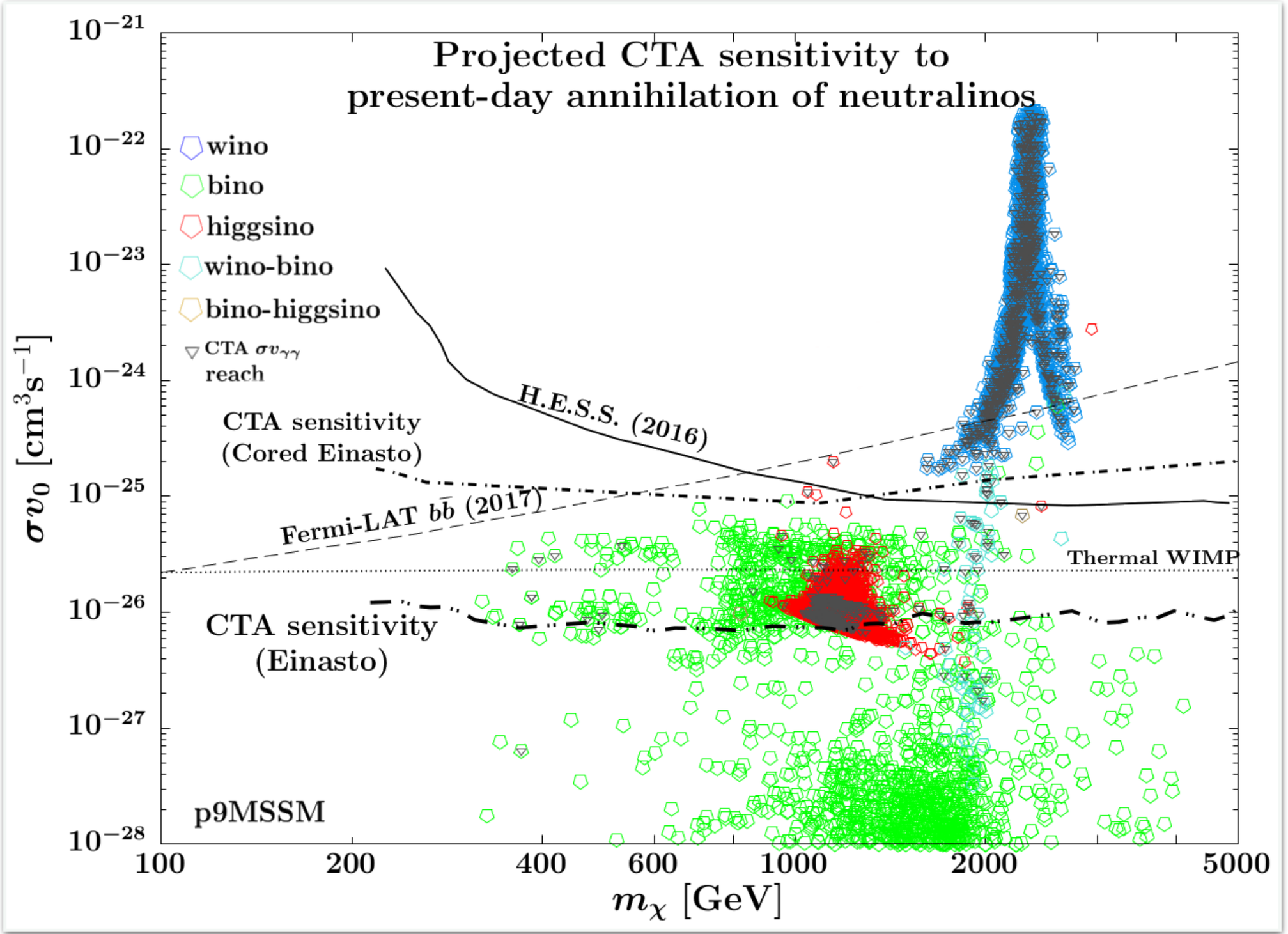
SE crucial for **wino** DM - note **resonance at ~ 2.4 TeV**

Impact on relic density:

- Factor ~ 5 for mixed states with wino.
- ~10% for pure higgsino
- ~1% for pure bino



Results

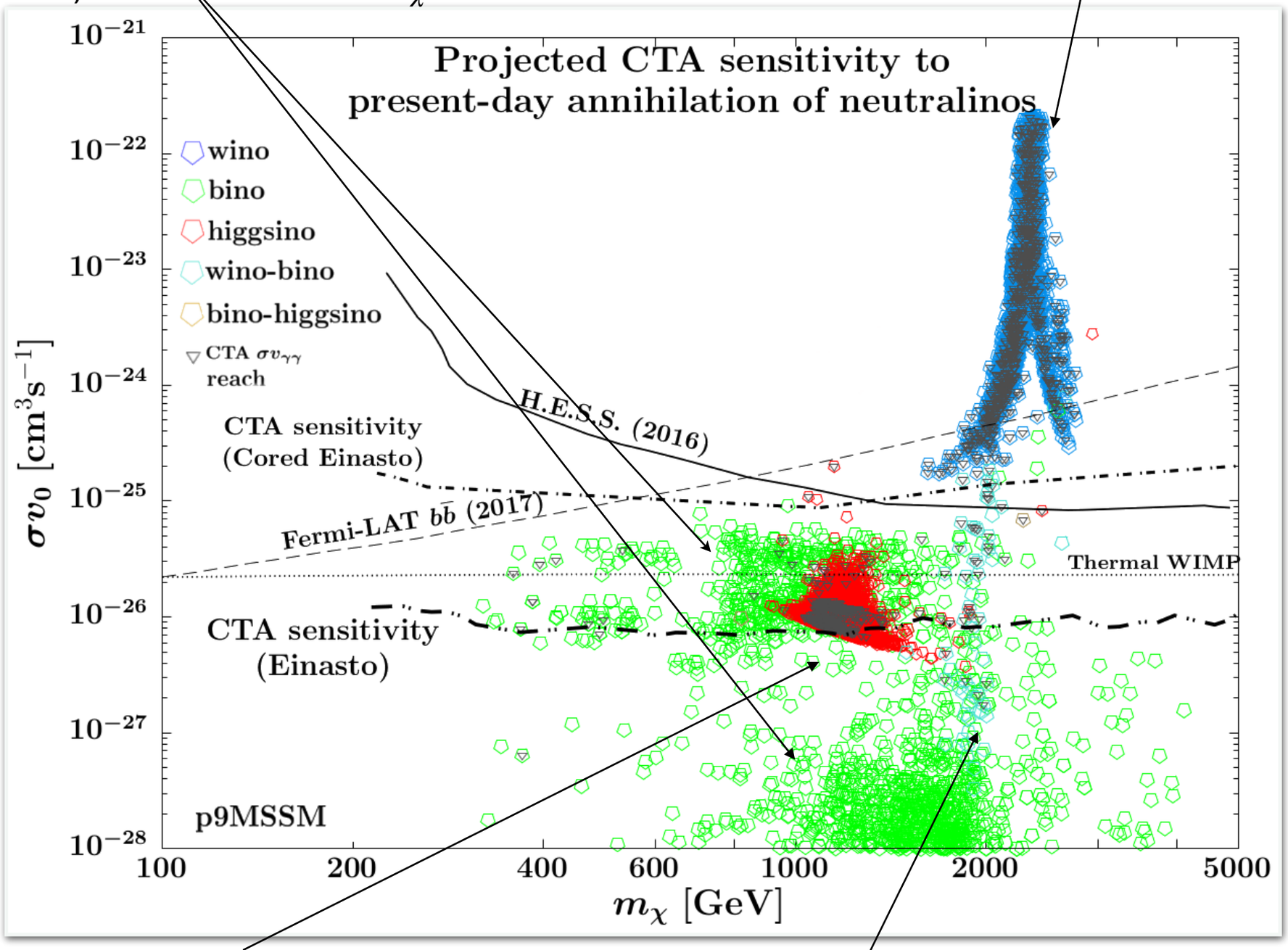

Projected CTA sensitivity to
present-day annihilation of neutralinos
wino
bino
higgsino
wino-bino
bino-higgsino
CTA $\sigma v_{\gamma\gamma}$ reach
CTA sensitivity (Cored Einasto)
H.E.S.S. (2016)
Fermi-LAT $b\bar{b}$ (2017)
Thermal WIMP
CTA sensitivity (Einasto)
p9MSSM
σv_0 [cm^{3}s^{-1}]
m_χ [GeV]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
100
200
400
600
1000
2000
5000

Results

Bino

Require additional mechanism (e.g. coannihilation) to obtain correct $\Omega_\chi h^2$

Wino - already excluded (?)



Higgsino

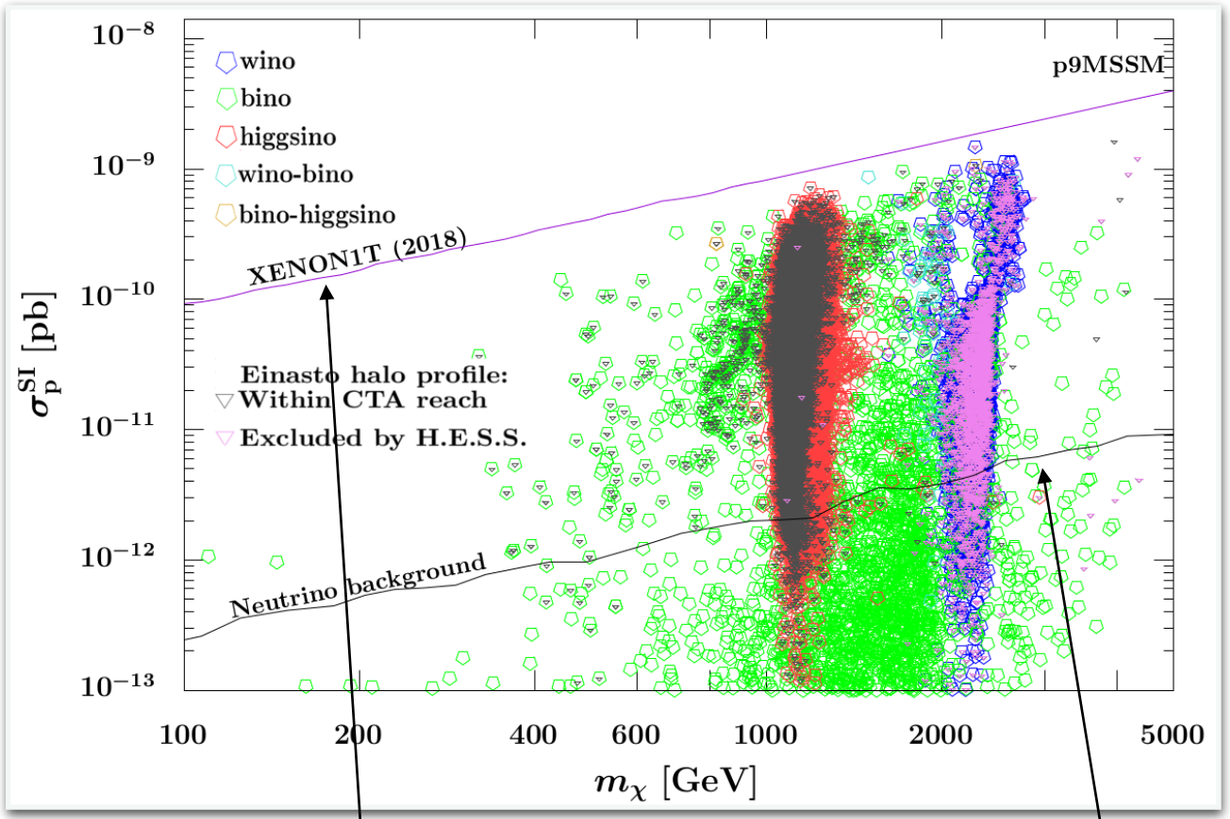
~ 1 TeV region

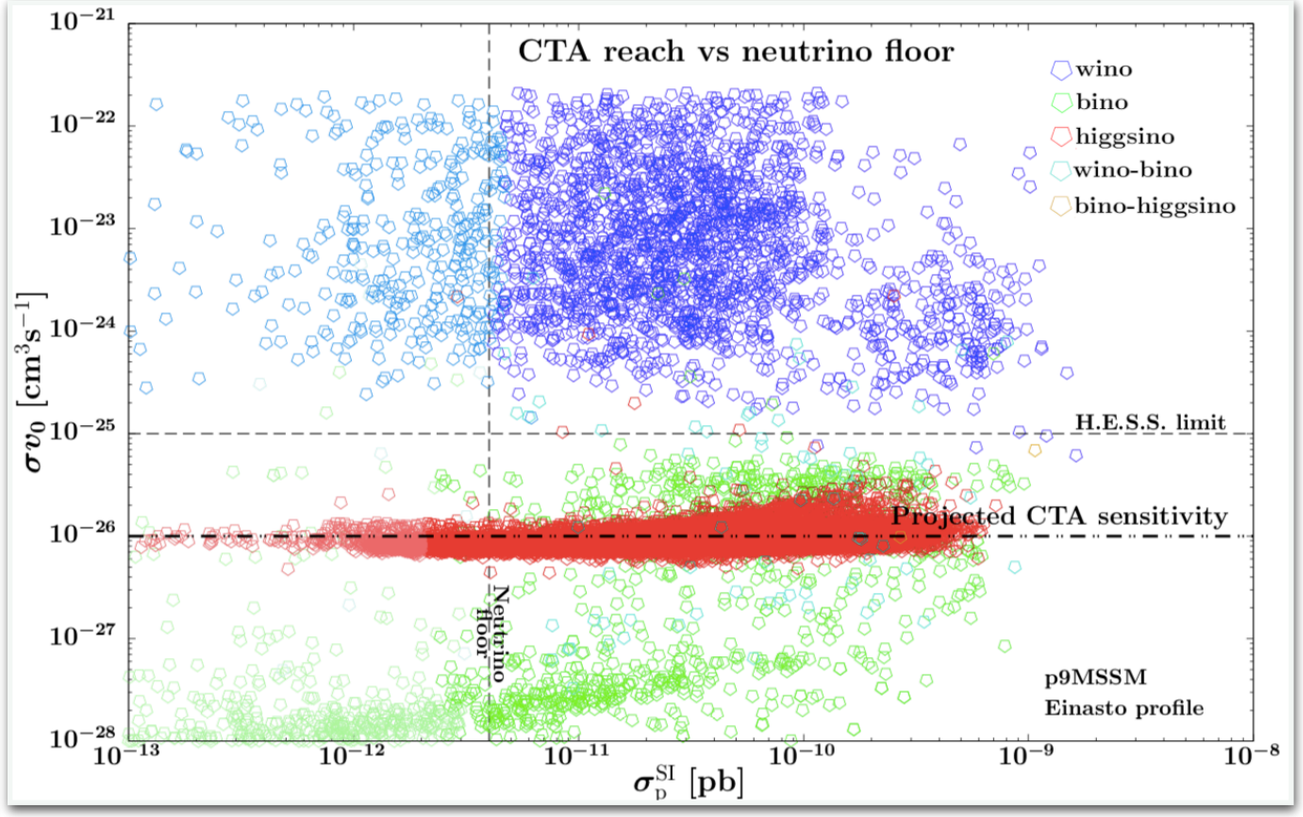
most promising candidate

Bino-wino

In reach of monochromatic γ line search

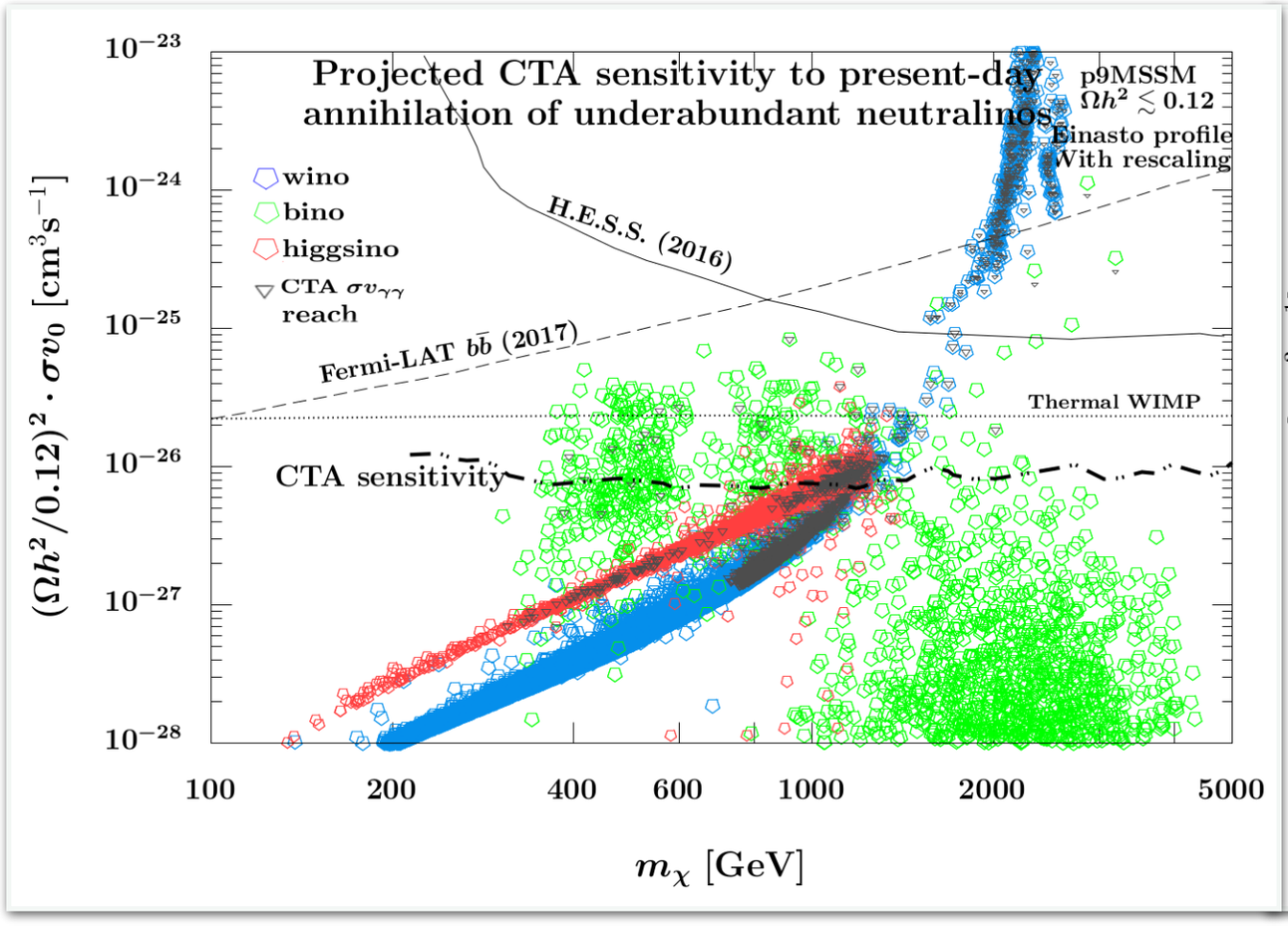
Complementarity with DD

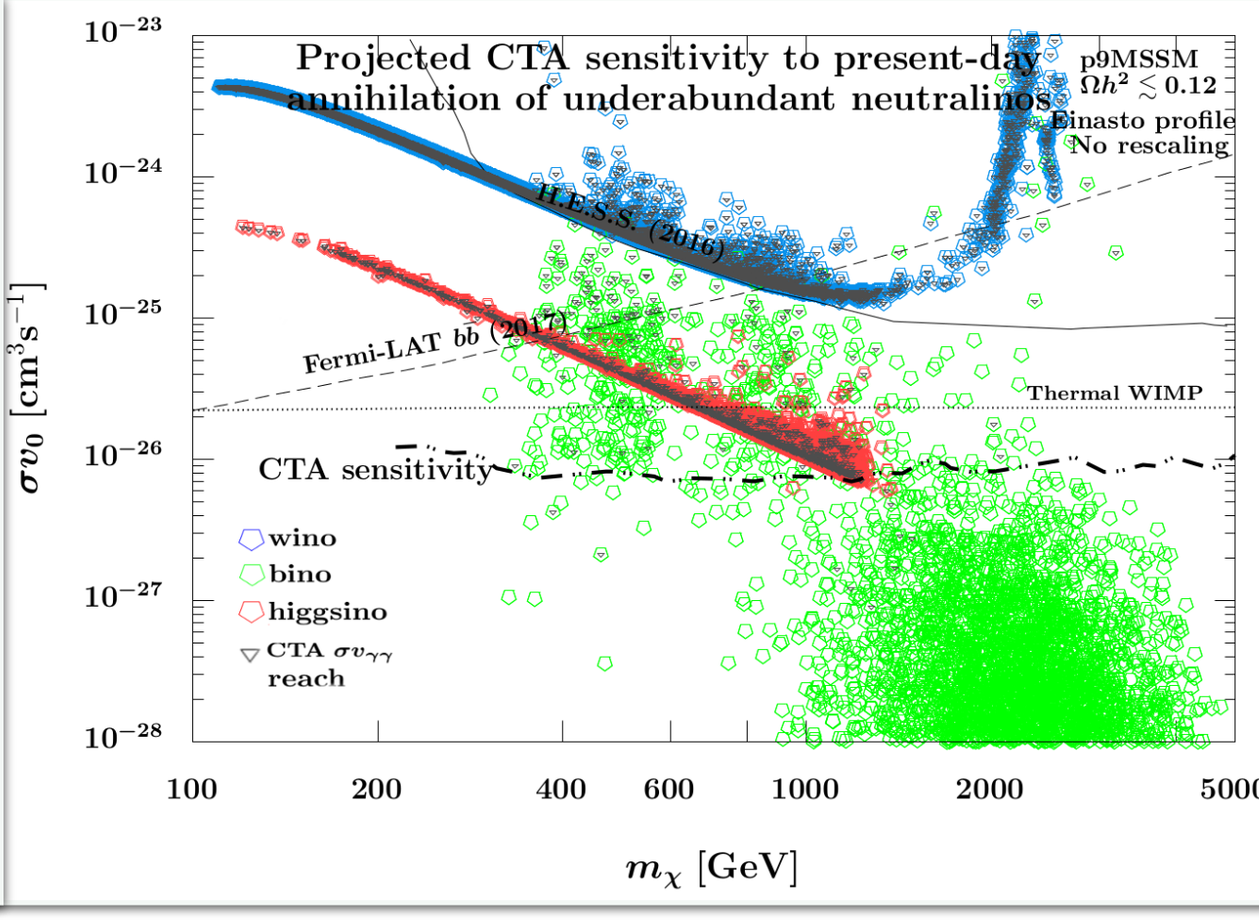




- Wino and higgsino region will be probed in the majority of cases, corresponding to:
  - spin-independent scattering cross section below the reach of 1-tonne underground detector searches
  - even well below the irreducible neutrino background
- Higgsinos in the ~1 TeV region are good thermal DM candidates
  - Not directly constrained by collider and DD searches → complementarity

Underabundant neutralinos - impact of γ line search





- The neutralino can be a good DM candidate even when its thermally produced relic abundance is different from the total DM relic density in the Universe
- It can then either be one of several DM components, or might even remain the only DM particle but in non-standard cosmological scenarios

Conclusions

- We updated and improved study of the reach of CTA in testing neutralino DM in minimal supersymmetric scenarios
- Sfermion co-annihilations for the first time were considered with Sommerfeld effect included in a scanning framework
- Cored Einasto profile leads to substantially weaker current bounds and in this case, the H.E.S.S. limits do not completely exclude the region of the parameter space with wino-like neutralino DM. Instead, CTA will be able to fully probe this important scenario
- CTA will be sensitive to several cases for which direct detection cross section will be below the so-called neutrino floor, covering a large fraction of the **~ 1 TeV higgsino region**
- CTA sensitivity will be further improved in the monochromatic photon search mode for both single-component and underabundant DM