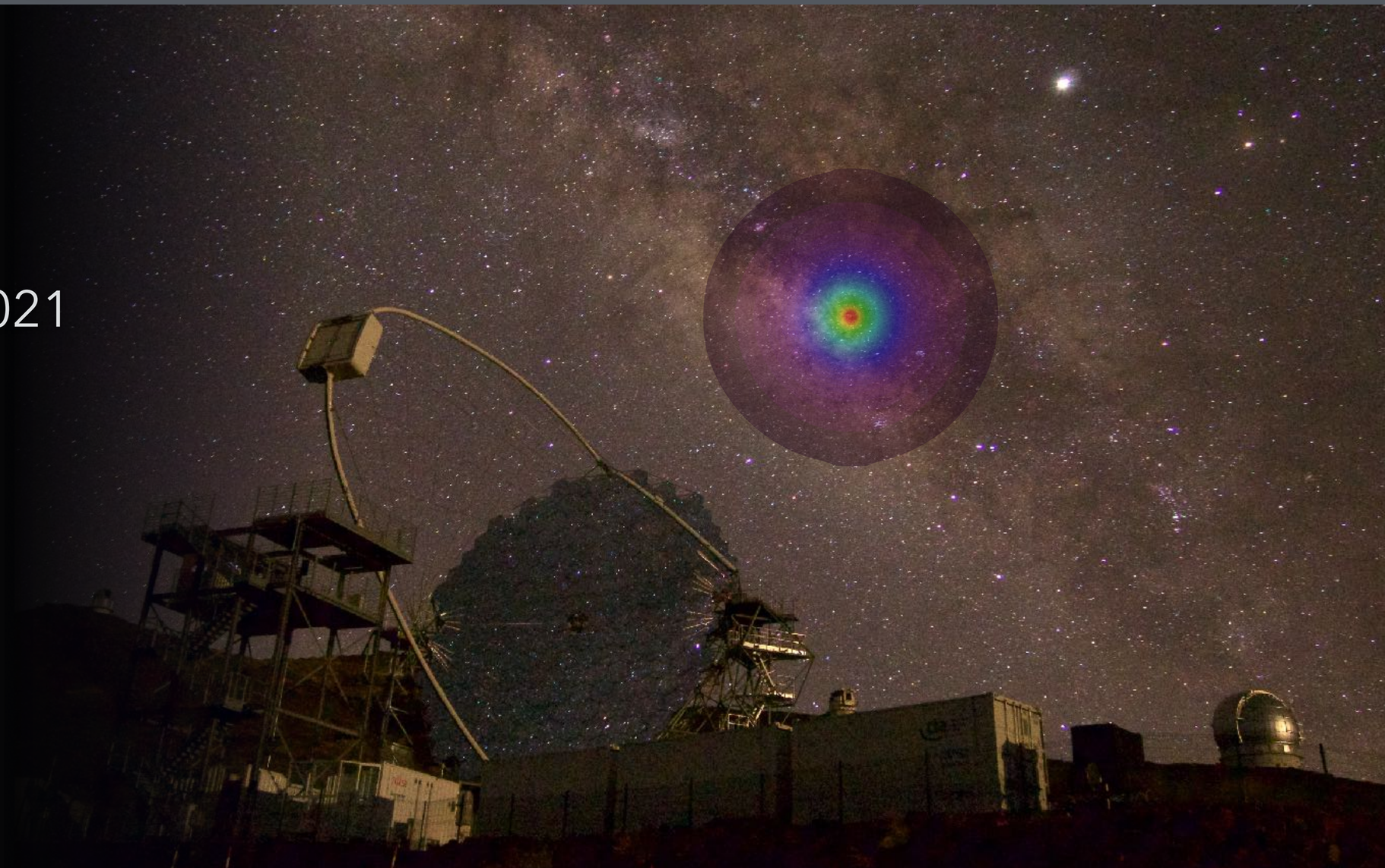
Probing Dark Matter in our Galaxy with the CTA Large Size Telescopes

Moritz Hütten

The extreme Universe viewed in very-high-energy gamma rays 2021

Feb. 22, 2022



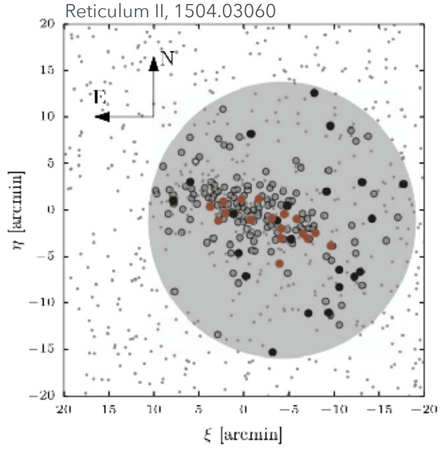
ICRR Institute for Cosmic Ray Research University of Tokyo

cta cherenkov telescope array

The compelling evidence for Dark Matter

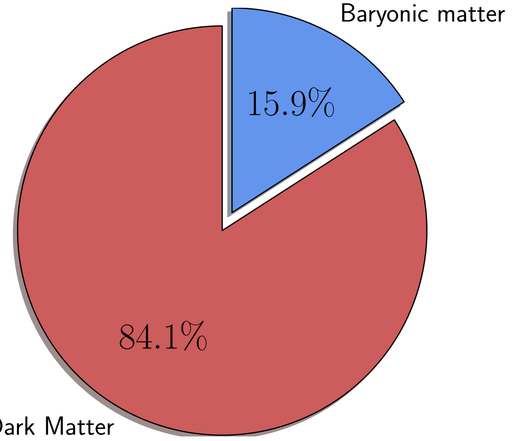
All evidence is gravitational

Reticulum II, 1504.03060



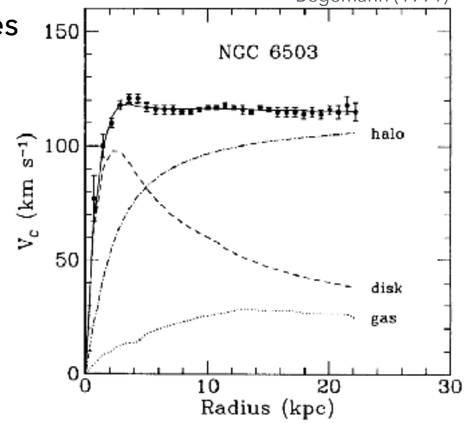
Dwarf spheroidal galaxies

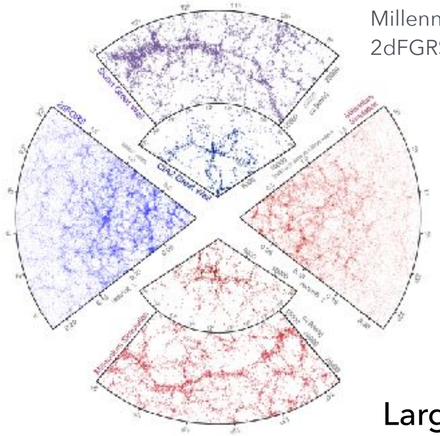
exhaustive review:
1001.0316



Spiral galaxies

Begemann (1991)

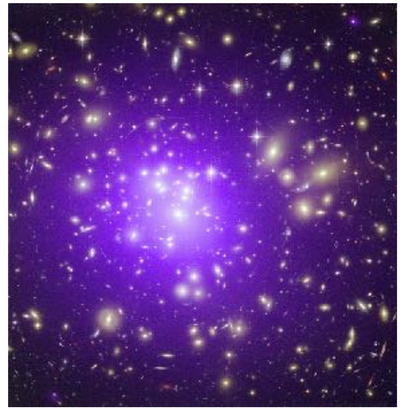




Millennium ΛCDM simulation vs. 2dFGRS survey

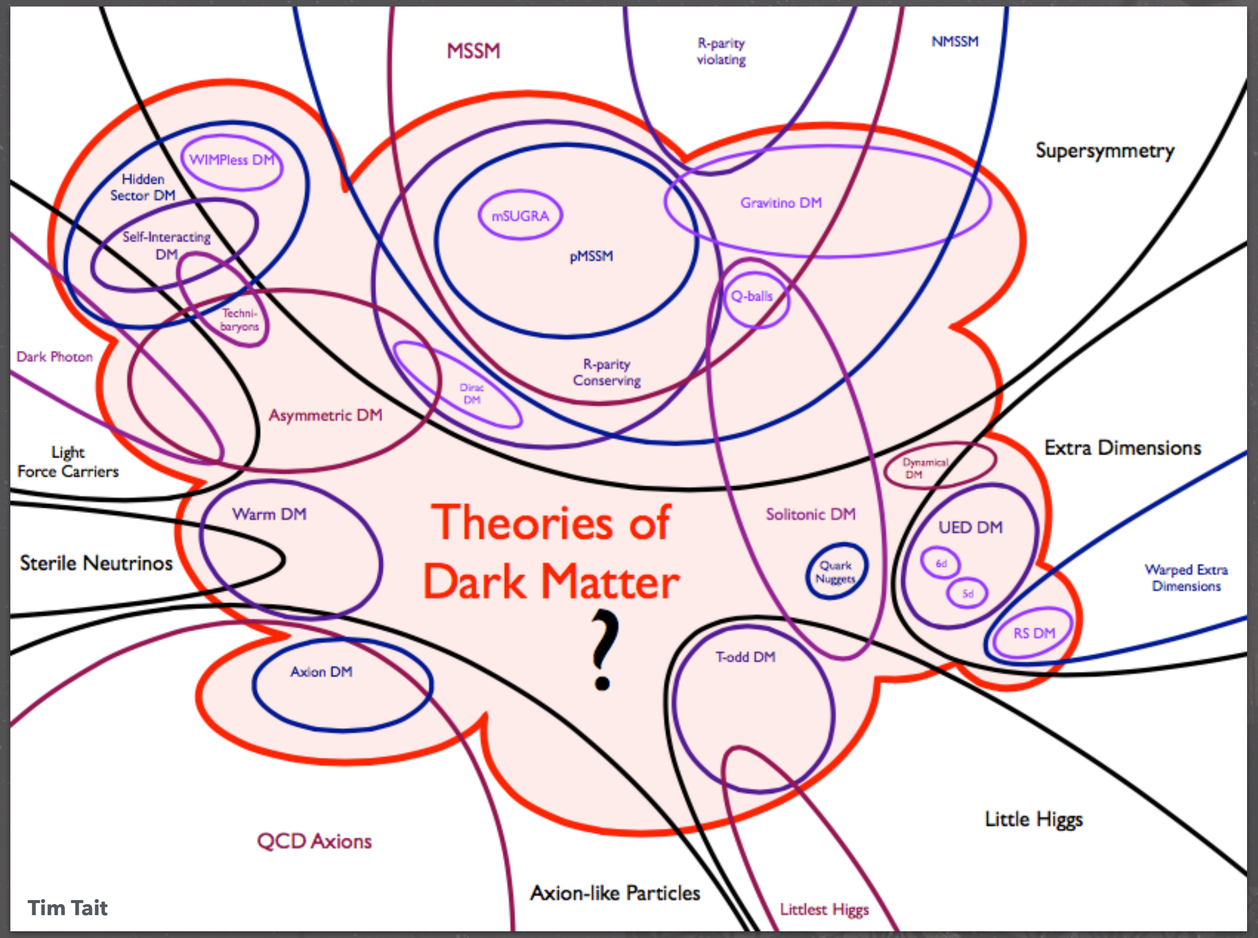
Large Scale Structure

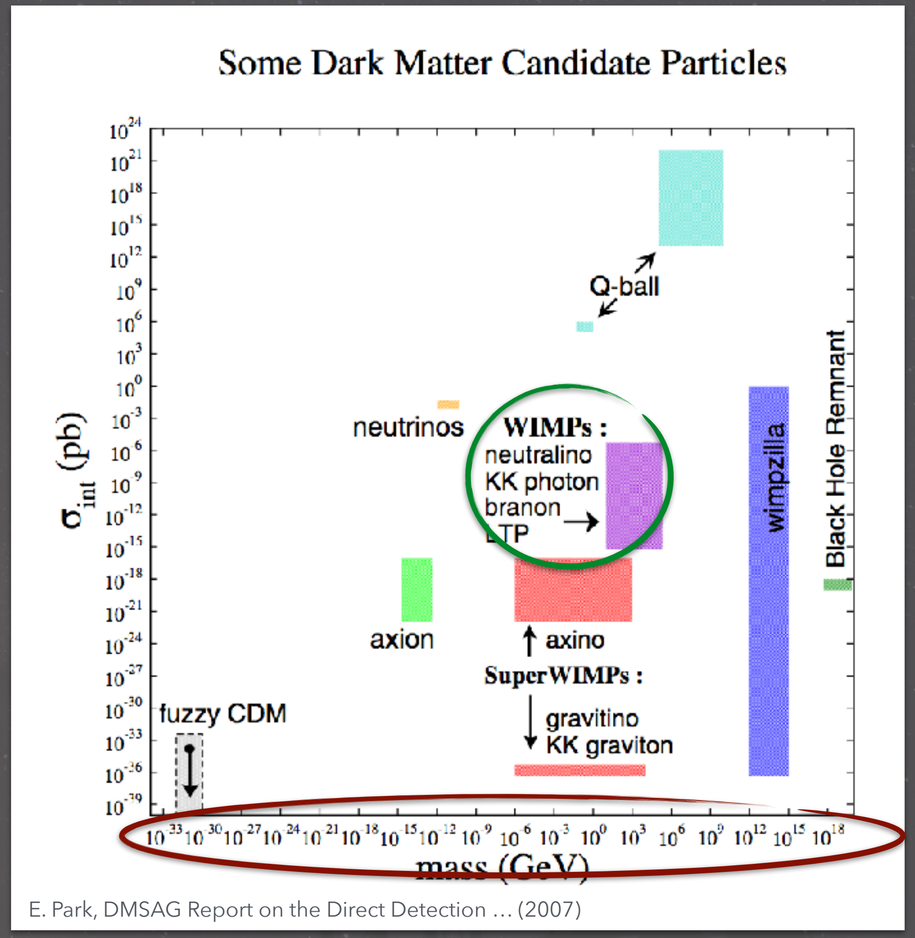
Chandra/HST image of Abell 1689



Galaxy clusters

The Dark Matter theory jungle



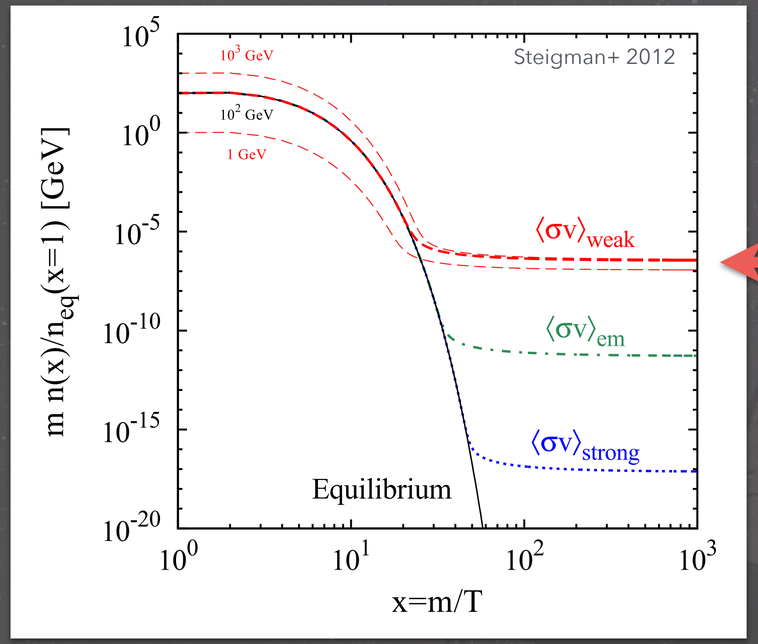


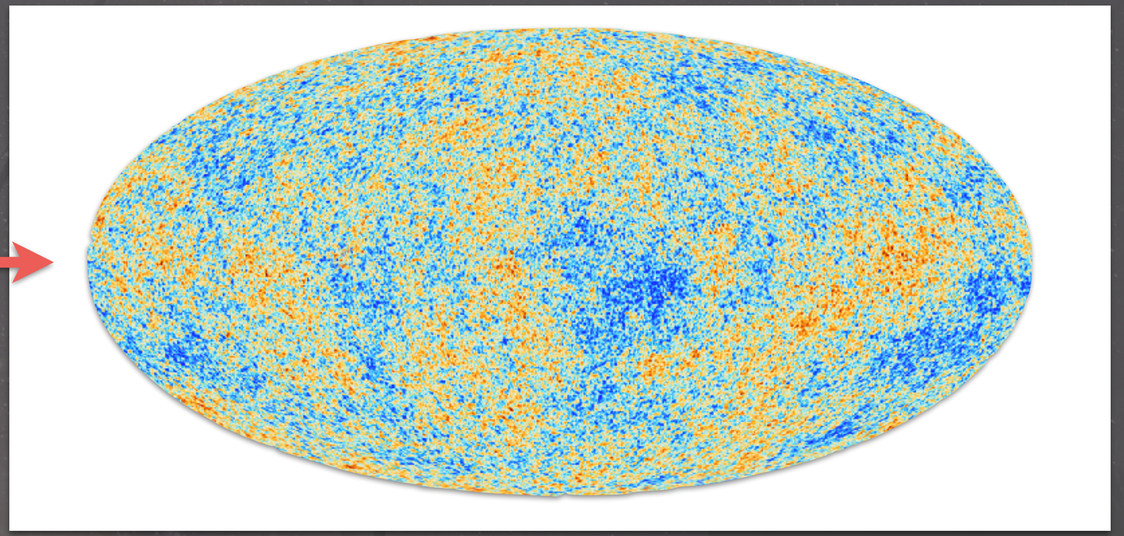
E. Park, DMSAG Report on the Direct Detection … (2007)

51 orders of magnitude

Appeal of the WIMP paradigm

"Weakly interacting massive particle" (WIMP) miracle:



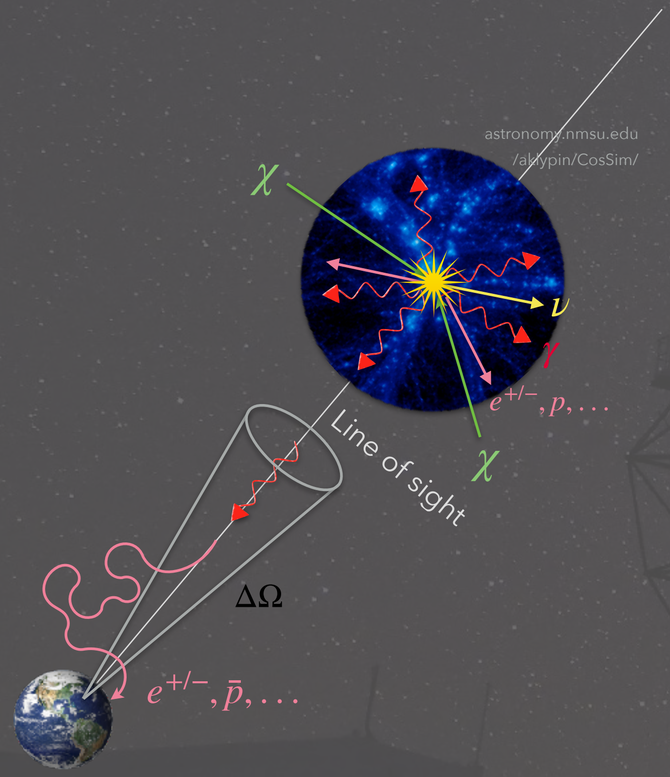


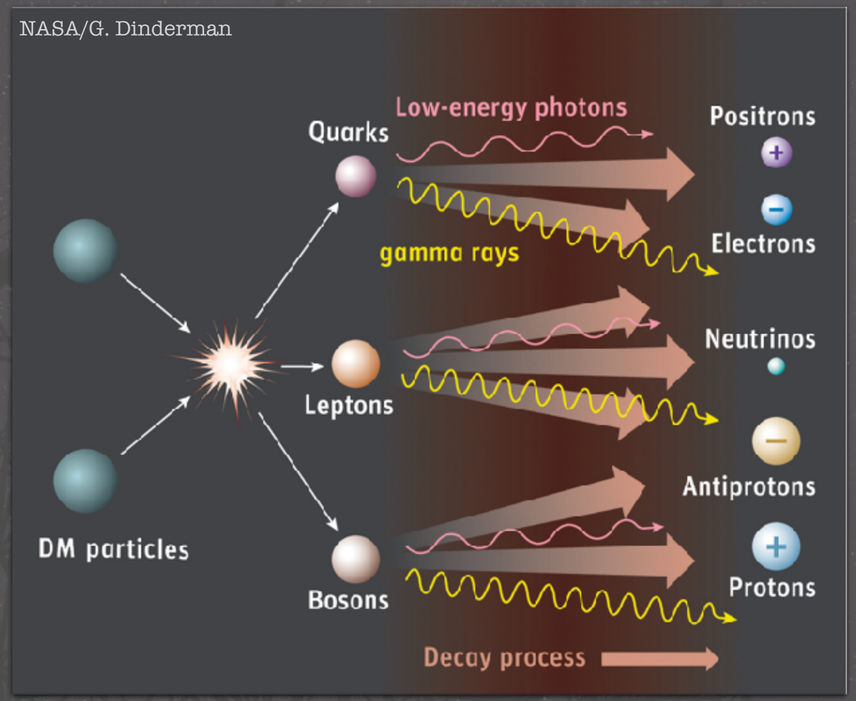
$$\rho_\chi\, h^2 \simeq 0.12 \rho_{crit} \left(\frac{80}{g^*}\right)^{1/2} \left(\frac{m_\chi}{25\, T_F}\right) \left(\frac{2.2 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}}{\langle \sigma v \rangle}\right)$$

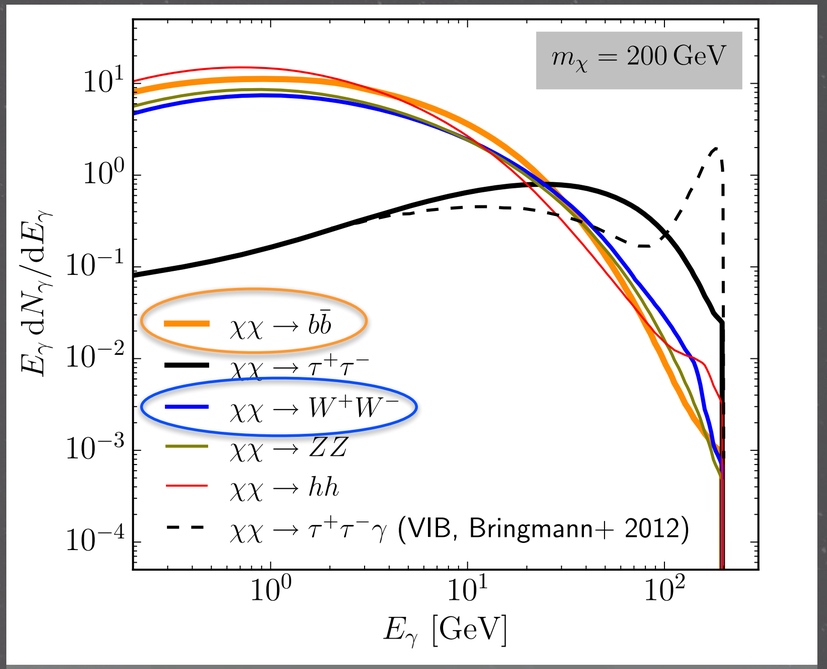
Non-relativistic **GeV to TeV particle** with weak-scale cross section gives relic abundance matching observed cosmic DM density

Indirect searches for WIMP Dark Matter

$$\frac{\mathrm{d}N_{\gamma,\nu,e,\ldots}}{\mathrm{d}A\mathrm{d}t} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{\delta\, m_\chi^2} \times \int \frac{\mathrm{d}N^{\text{per interact.}}_{\gamma,\nu,e,\ldots}}{\mathrm{d}E}\,\mathrm{d}E \times \int_{\Delta\Omega}\int_{l.o.s.} \rho_\chi^2\,\mathrm{d}l\mathrm{d}\Omega$$





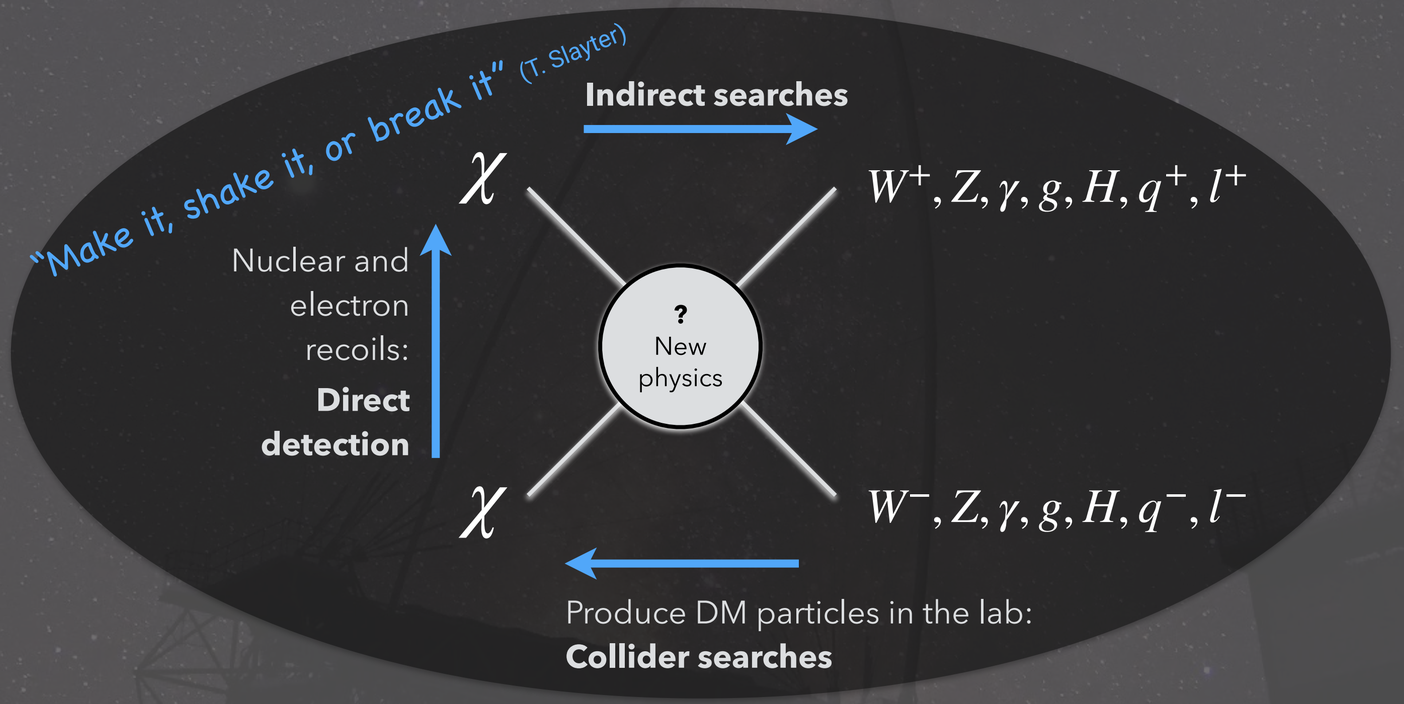


Role of thumb:

TeV DM particles: most energy deposited in GeV-TeV final state particles:

High energy astronomy

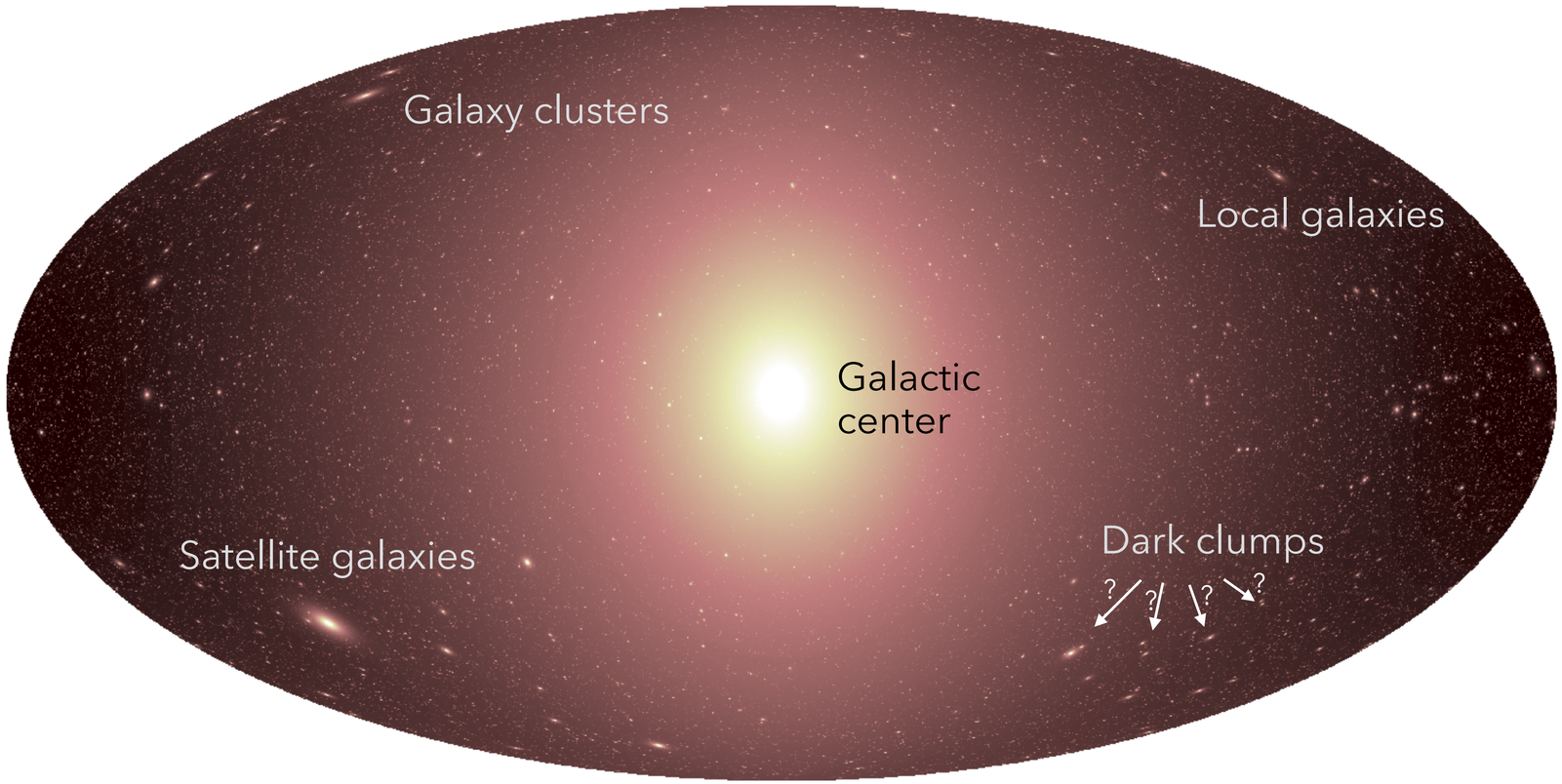
Appeal of indirect dark matter searches



Indirect WIMP searches:

- Probing the **same mass budgets** which provide DM gravitational evidence
- Probing the **same interaction** (annihilation) explaining DM thermal relic abundance

Where to search? Different Dark matter targets

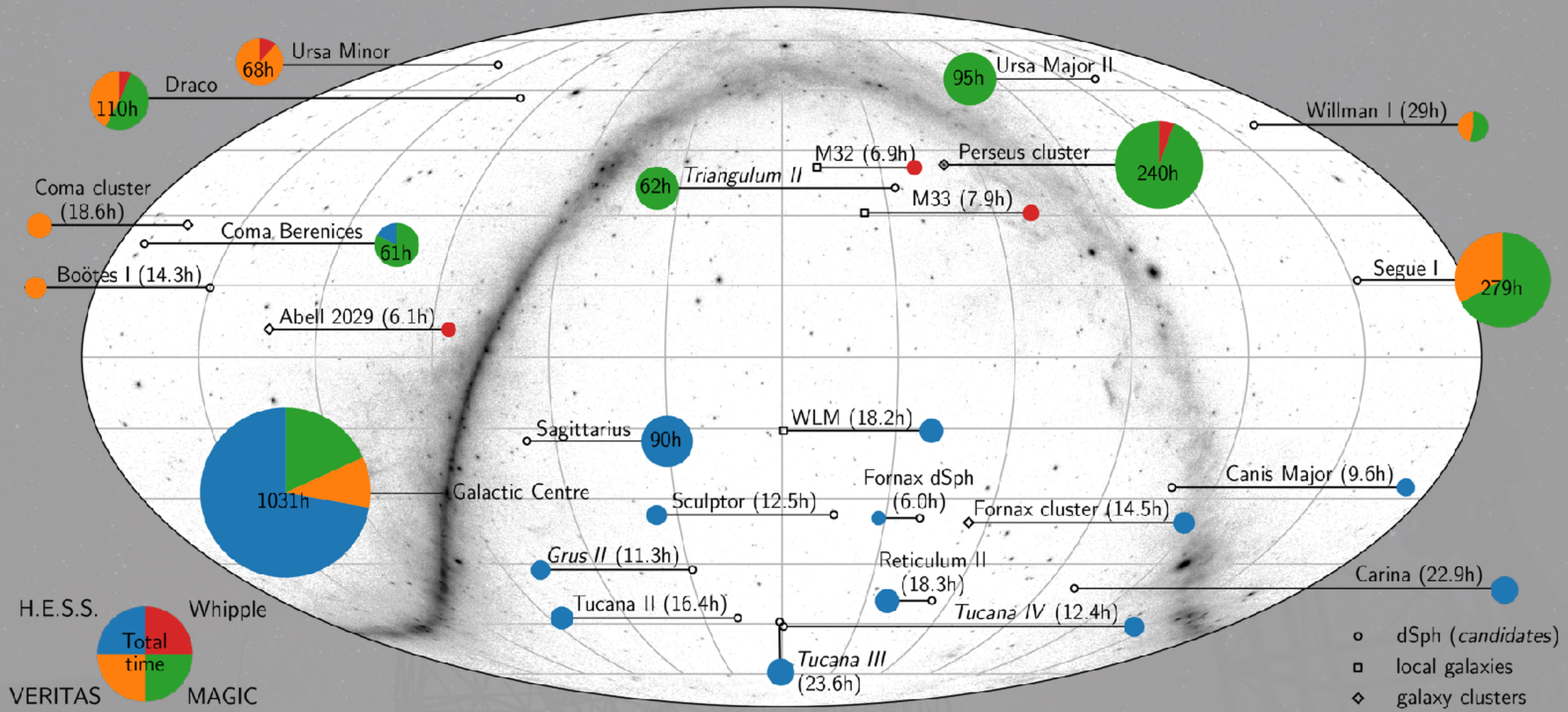


log (γ-ray intensity from DM annihilation), **MH** et al., 1806.08639

So far no detection after 20+ years

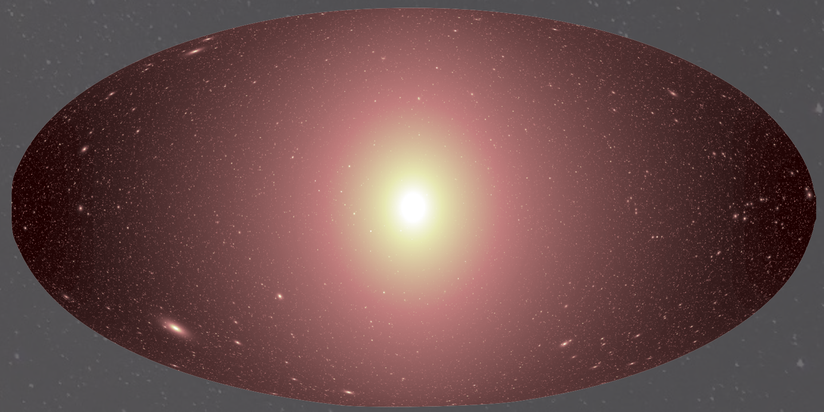
(M. Doro, M. Sánchez-Conde, MH, 2111.01198)

Dark Matter searches with Imaging Air Cherenkov Telescopes:

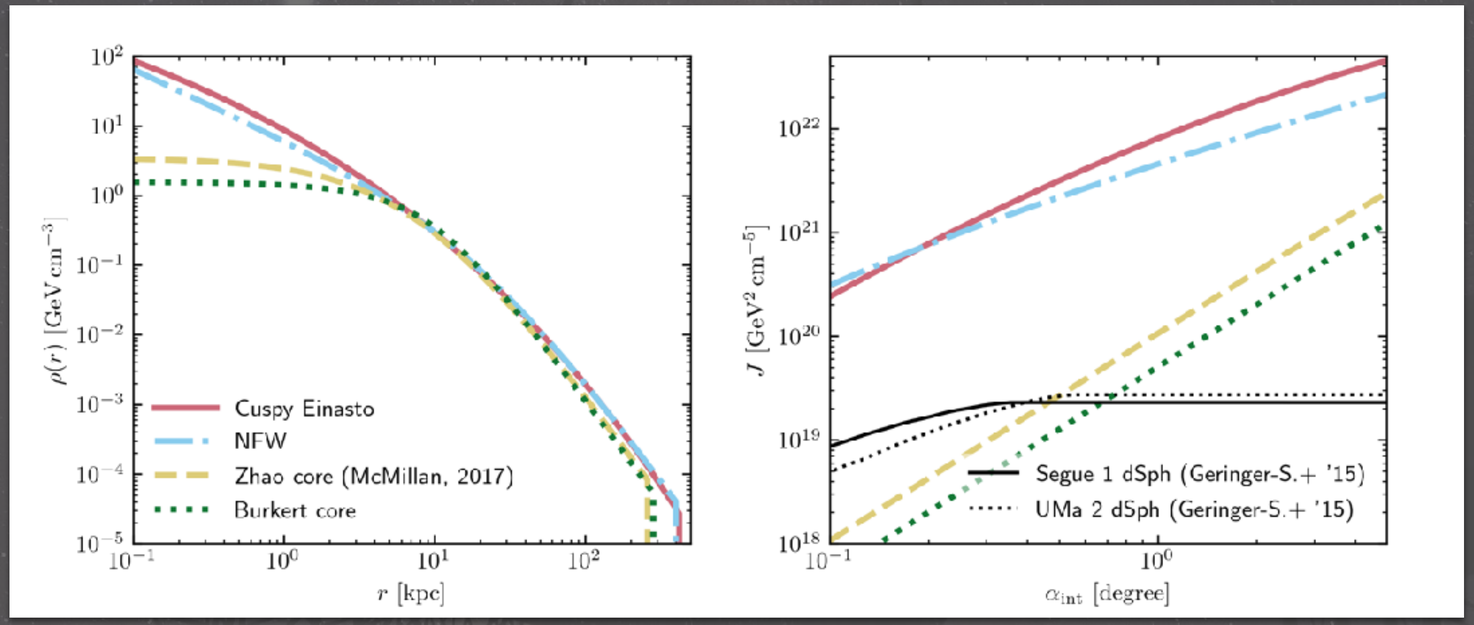


Why the Galactic Centre?

Why the Galactic Centre?



$$\frac{\mathrm{d}N_{\gamma,\nu,e,\ldots}}{\mathrm{d}A\mathrm{d}t} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{\delta\, m_\chi^2} \times \int \frac{\mathrm{d}N^{\text{per interact.}}_{\gamma,\nu,e,\ldots}}{\mathrm{d}E}\,\mathrm{d}E \times \underbrace{\int_{\Delta\Omega}\int_{l.o.s.} \rho_\chi^2\,\mathrm{d}l\mathrm{d}\Omega}_{= J}$$



- Flux expected orders of magnitude larger than from dSph galaxies
- Even comparably promising in most pessimistic case

Galactic Centre Challenges I: the DM uncertainty

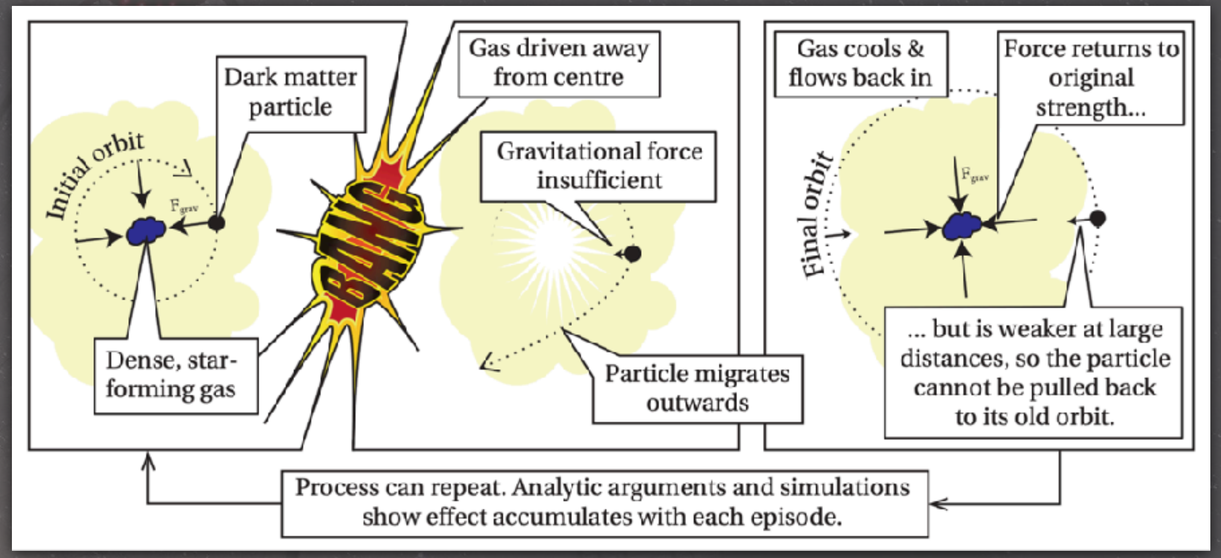
1. Possible flattening of the inner DM profile due to supernova feedback

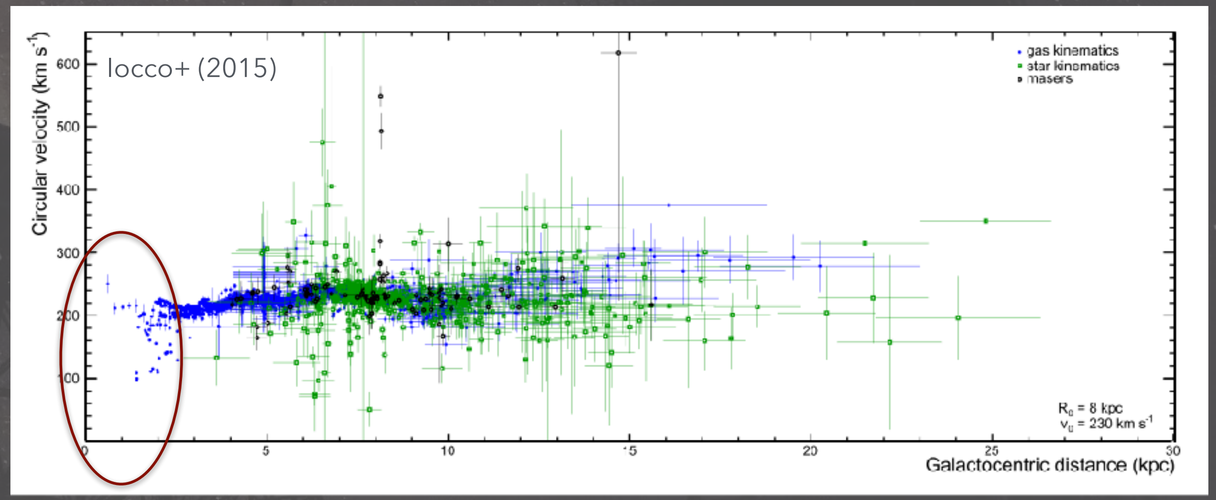
   (e.g., Pontzen & Governato, 2012)

2. Little data constraints on the innermost DM profile slope

   (e.g., Benito et al. 2019, 2020)

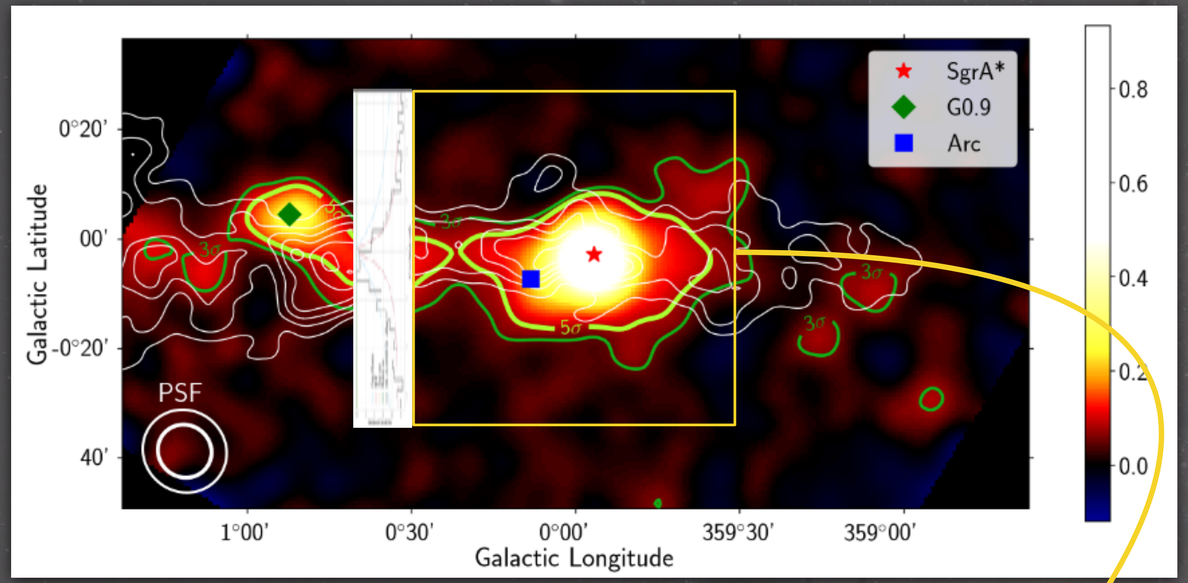
Figure by A. Genina (Kashiwa DM 2021)

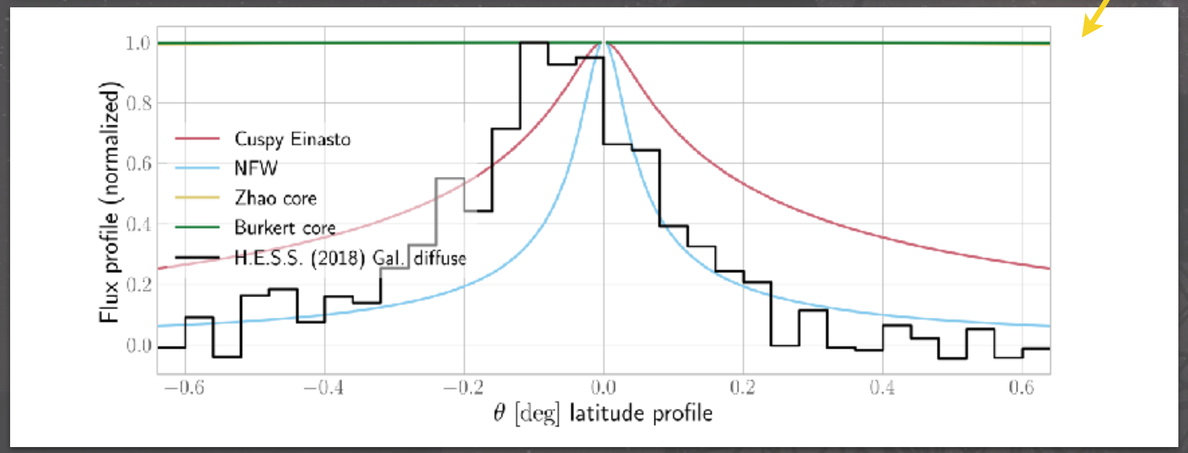


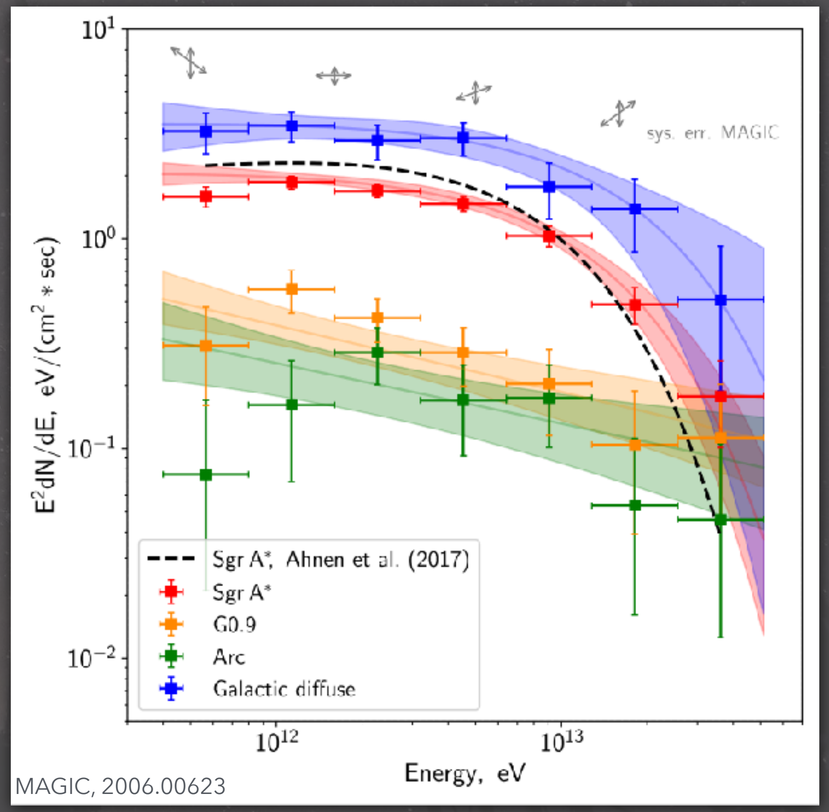


Galactic Centre Challenges II: the backgrounds

MAGIC, 2006.00623







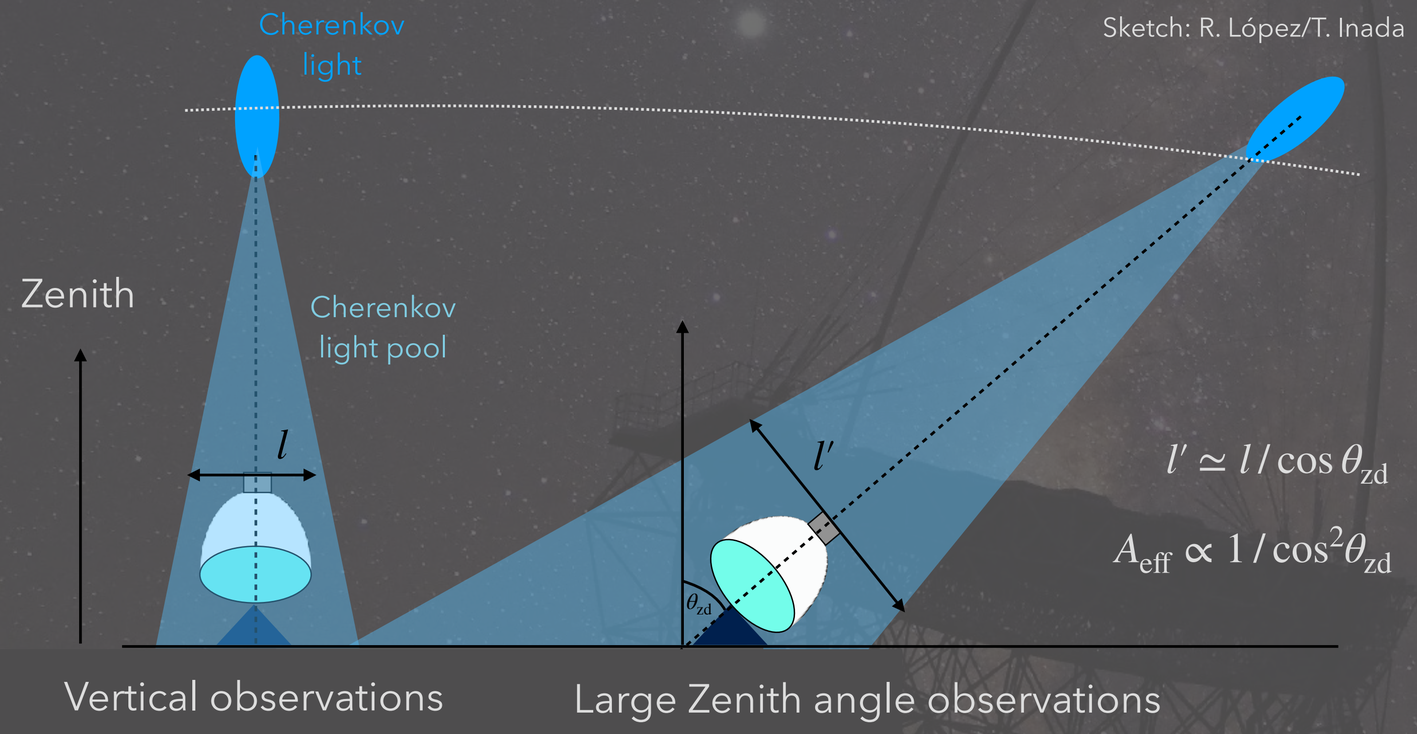
Galactic center active region with diverse known γ-ray emitters

Galactic Centre Challenges III: low elevation in the North

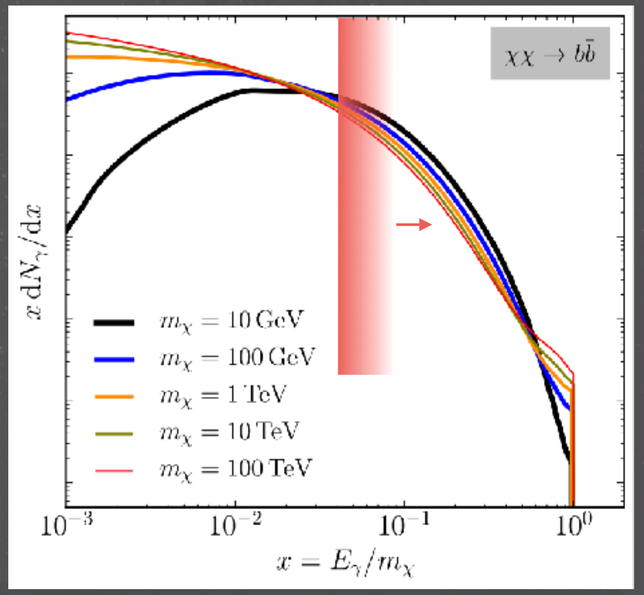
Picture credit: D. López

Galactic Centre Challenges III: low elevation in the North

58° - 70° distance from zenith: large zenith angle observation (LZA)

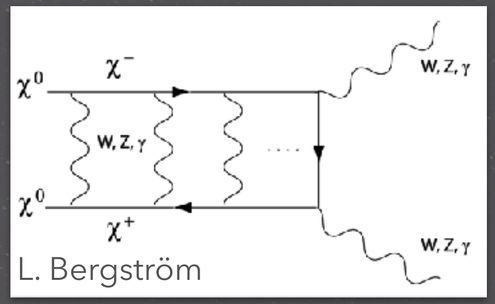


+	Increased γ-ray detection area: larger statistics at TeV energies
-	Increased energy threshold

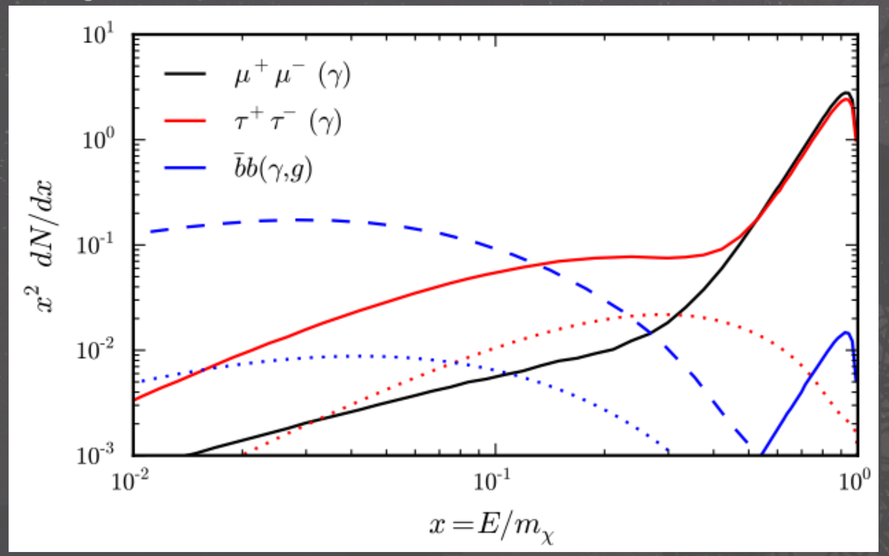


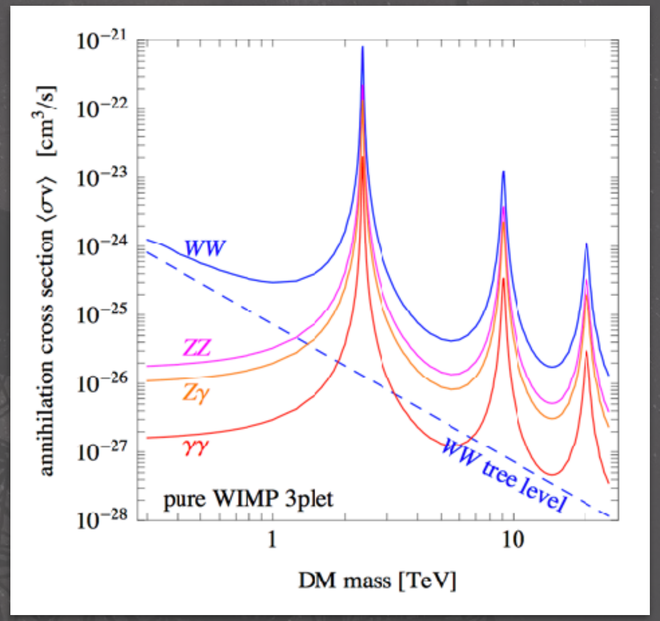
Less threshold constraints: Search for DM line emission

- Sharp peak at DM mass
- $\chi\chi \rightarrow \gamma\gamma$ channel loop-suppressed by α^2 (Some TeV DM models expected with Sommerfeld enhanced σv)
- Line-like features also by three-body annihilations (virtual internal bremsstrahlung)



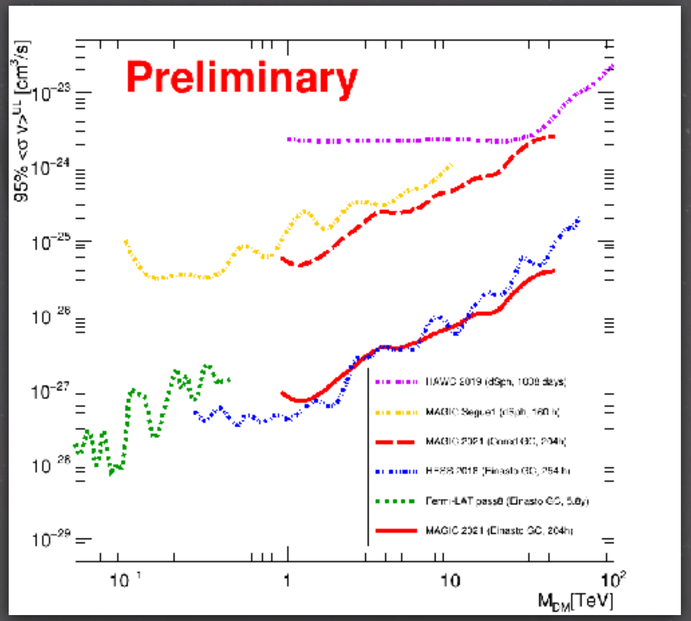
T. Bringmann et al. JCAP07(2012)



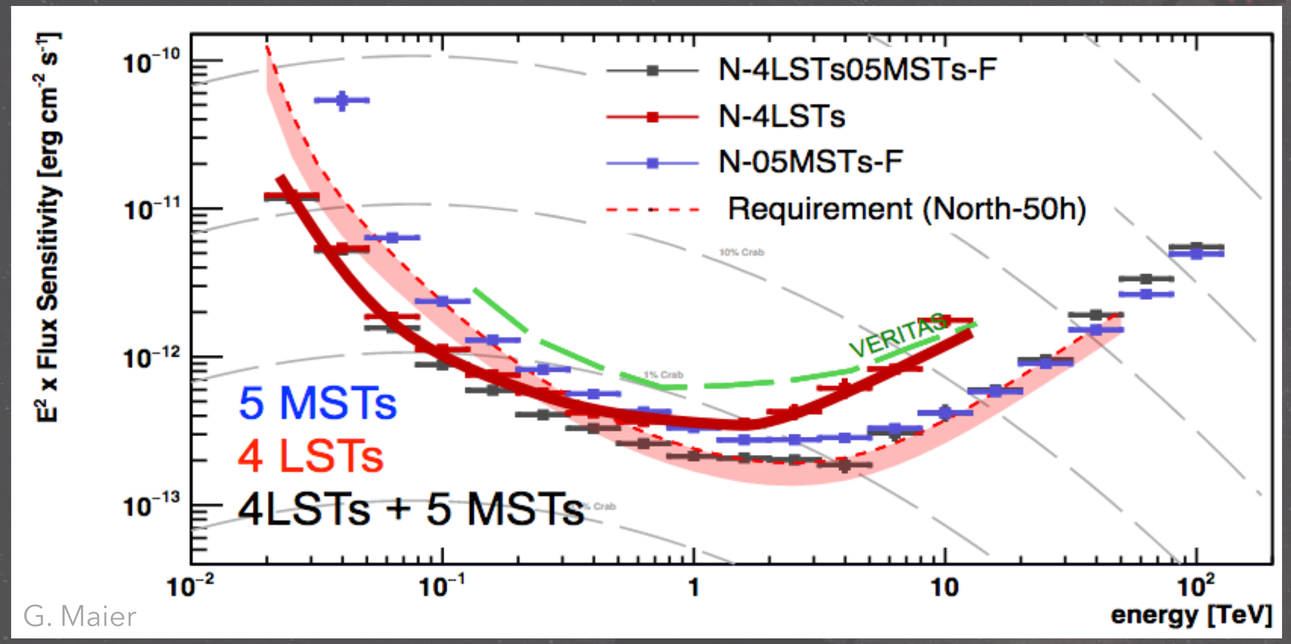


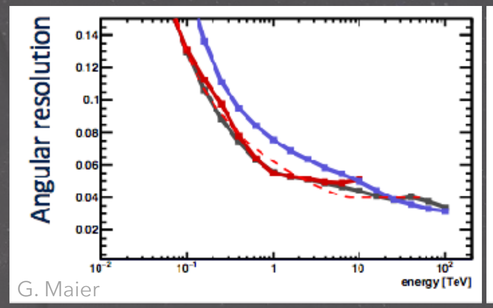
H.E.S.S. collaboration JCAP11(2018)

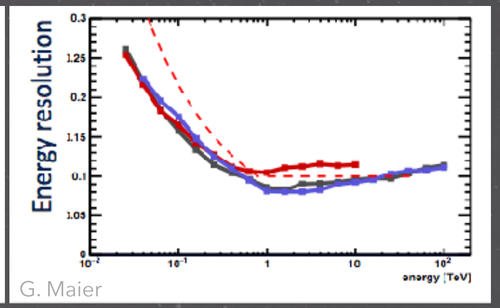
Ongoing project: T. Inada (ICRR), D. Kerszberg (IFAE), MH for MAGIC, ICRC 2021

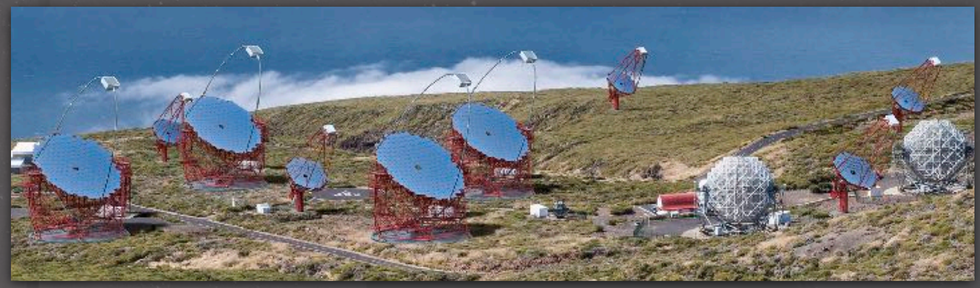


LST performance (low zenith)





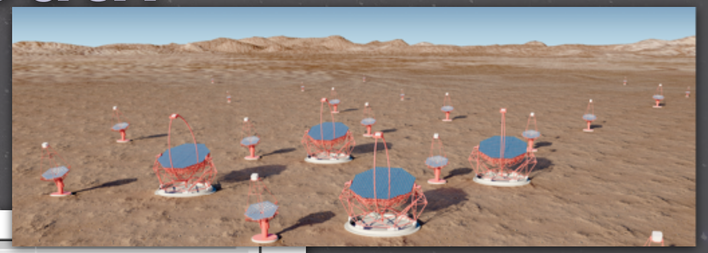


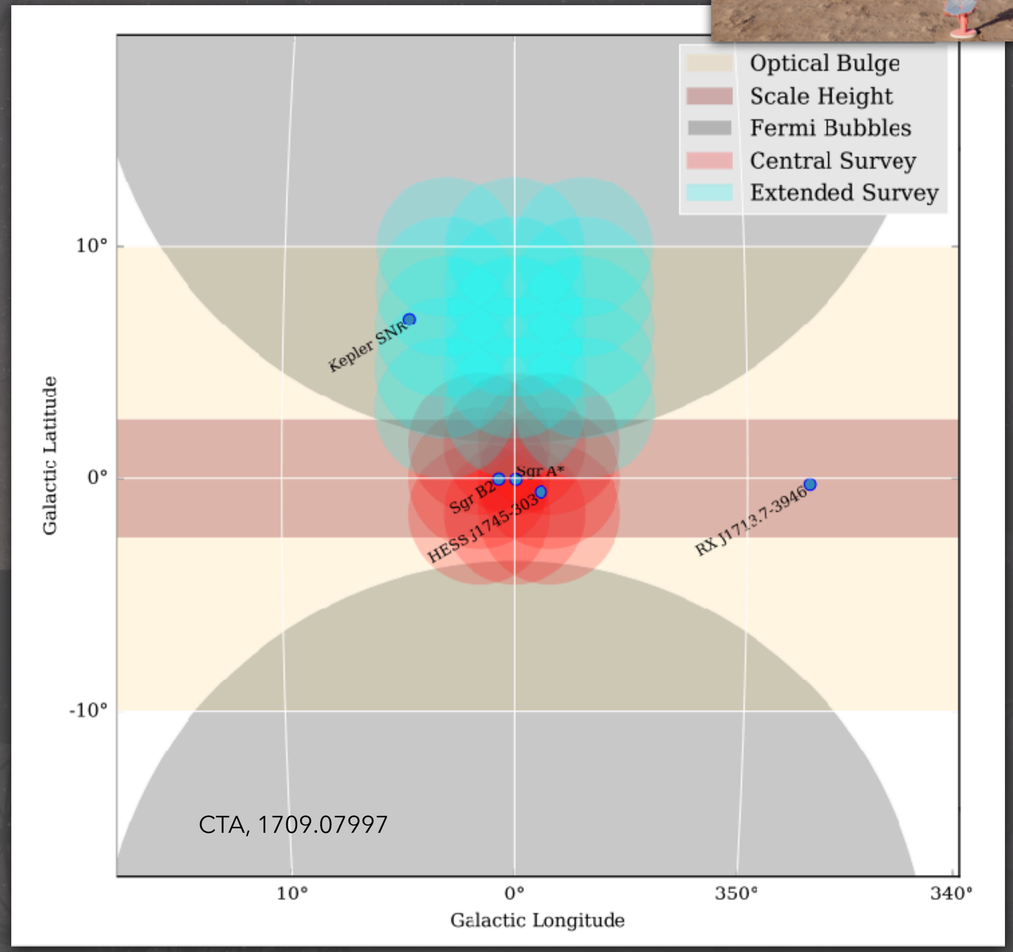


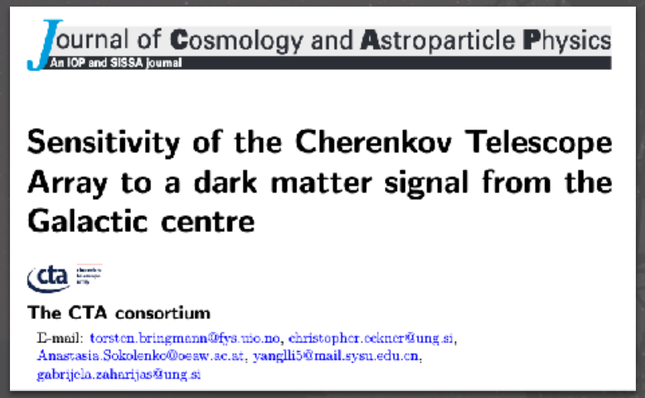
4 LSTs: Differential sensitivity factor 2 to 3 better than MAGIC/VERITAS/H.E.S.S.
+ lowered energy threshold

Galactic Centre DM searches with CTA South

- Galactic Center survey Key Science project with CTA: 525h + 300h in 1st decade
- Detailed sensitivity study published last year (2007.16129)






Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

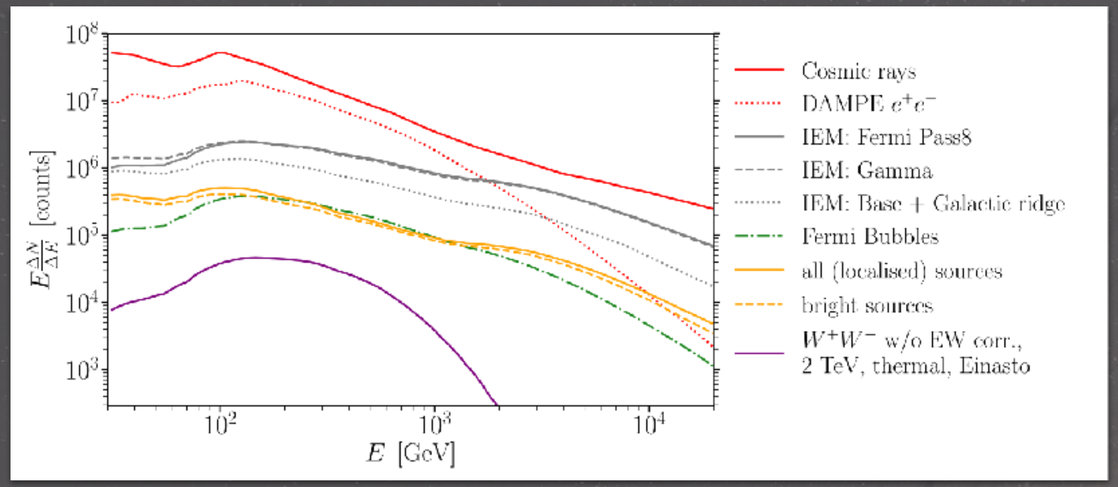
Sensitivity of the Cherenkov Telescope Array to a dark matter signal from the Galactic centre

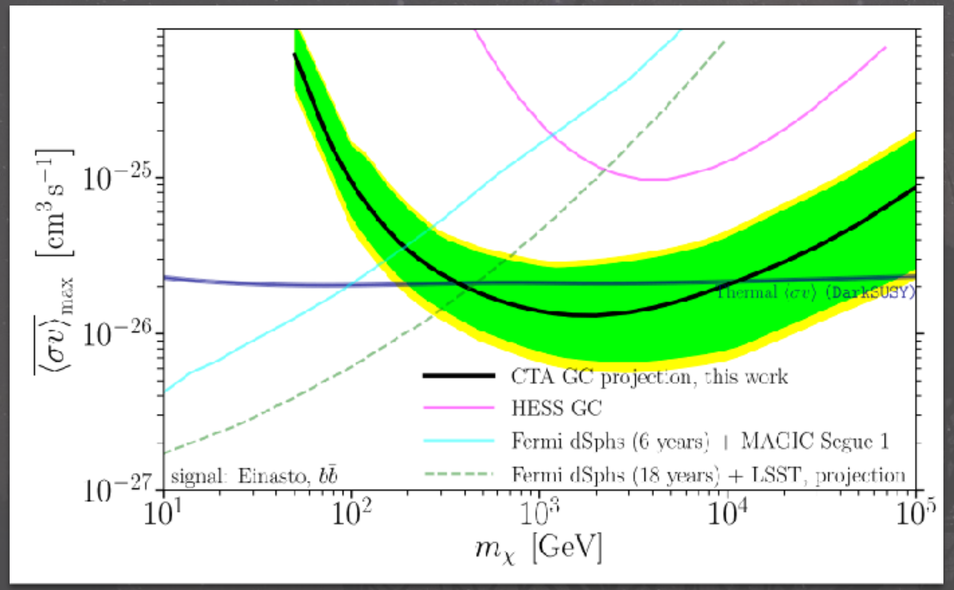
cta

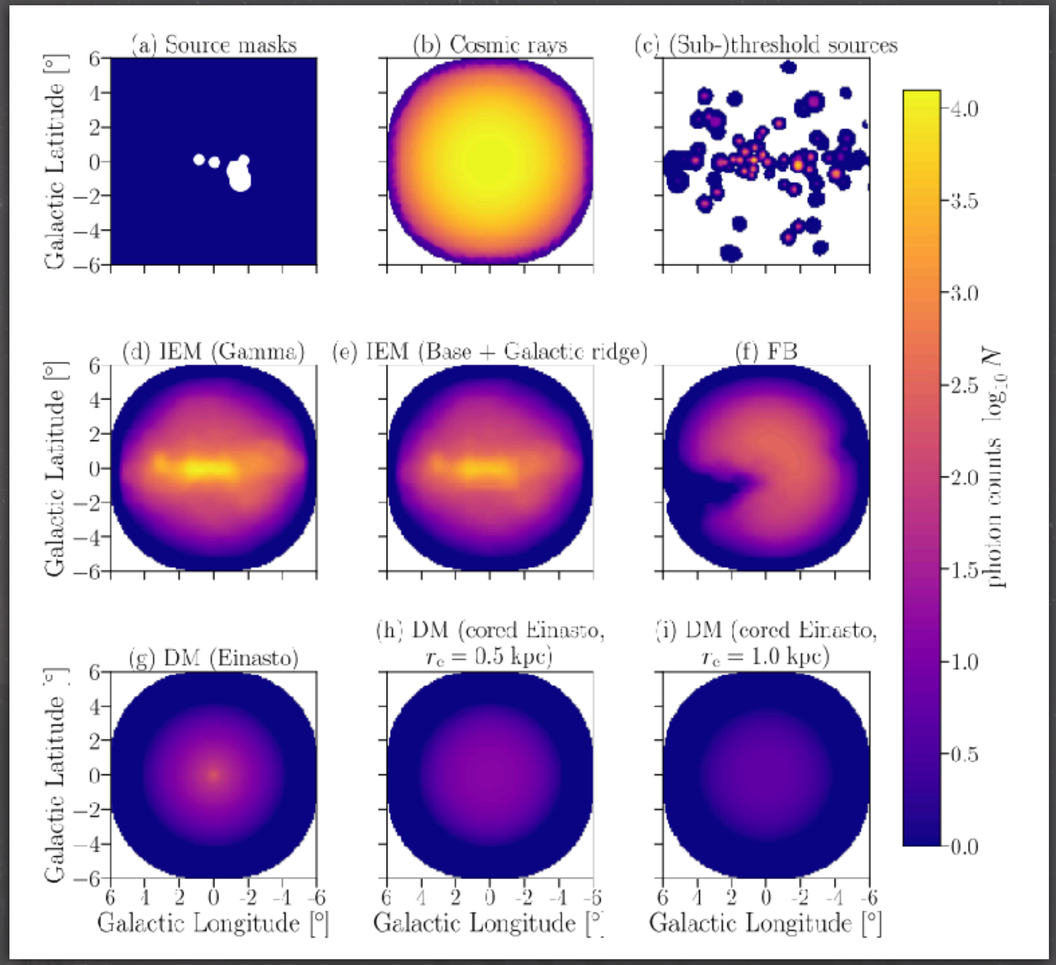
The CTA consortium

E-mail: torsten.bringmann@fys.uio.no, christopher.eckner@ung.si, Anastasia.Sokolenko@oeaw.ac.at, yanglli5@mail.sysu.edu.cn, gabrijela.zaharijas@ung.si

Galactic Centre DM searches with CTA South

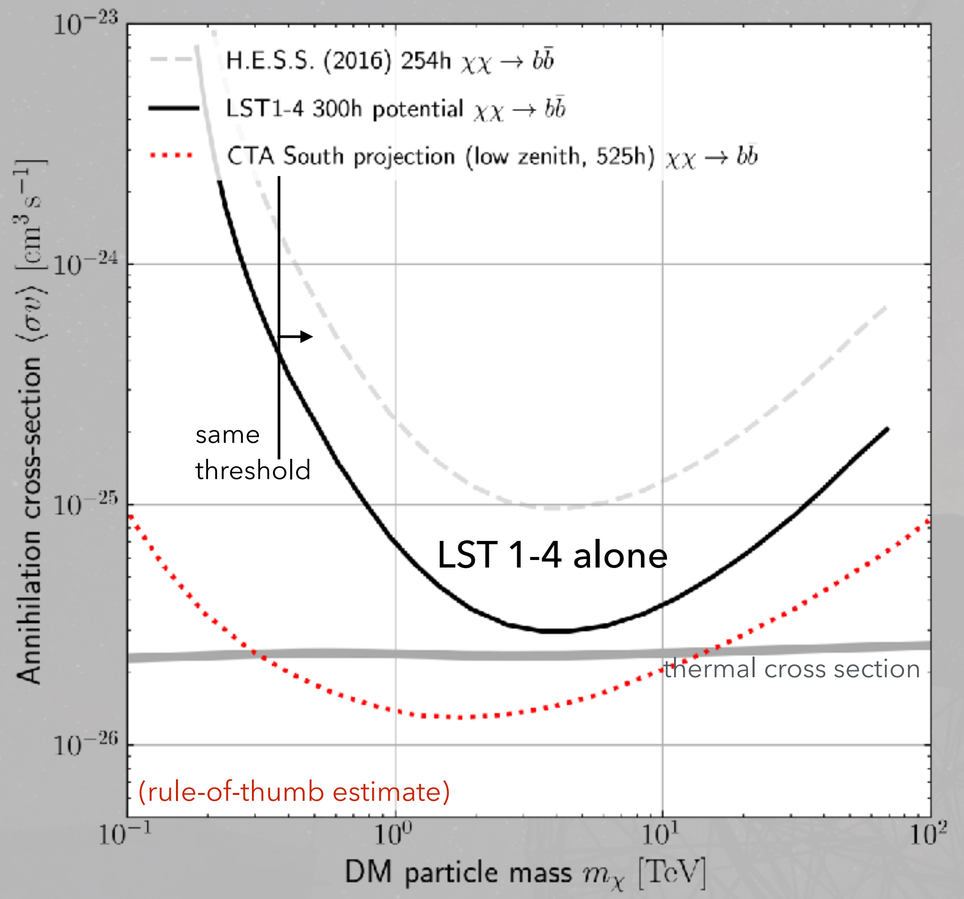


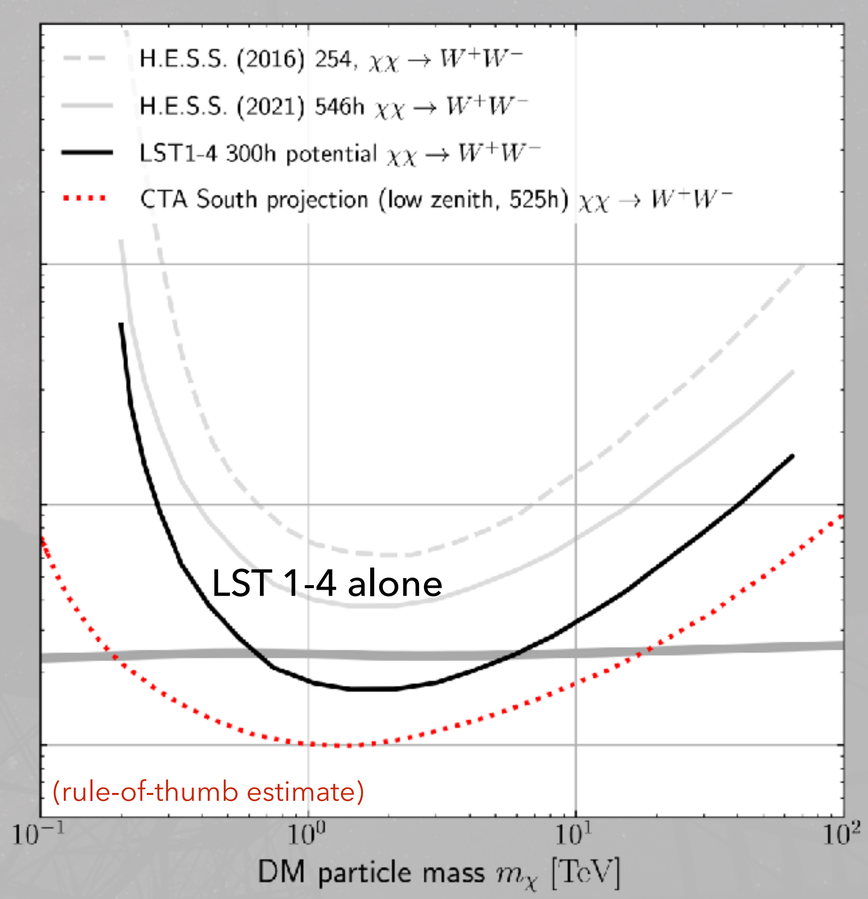




DM detection potential with 4-LST array (300h)

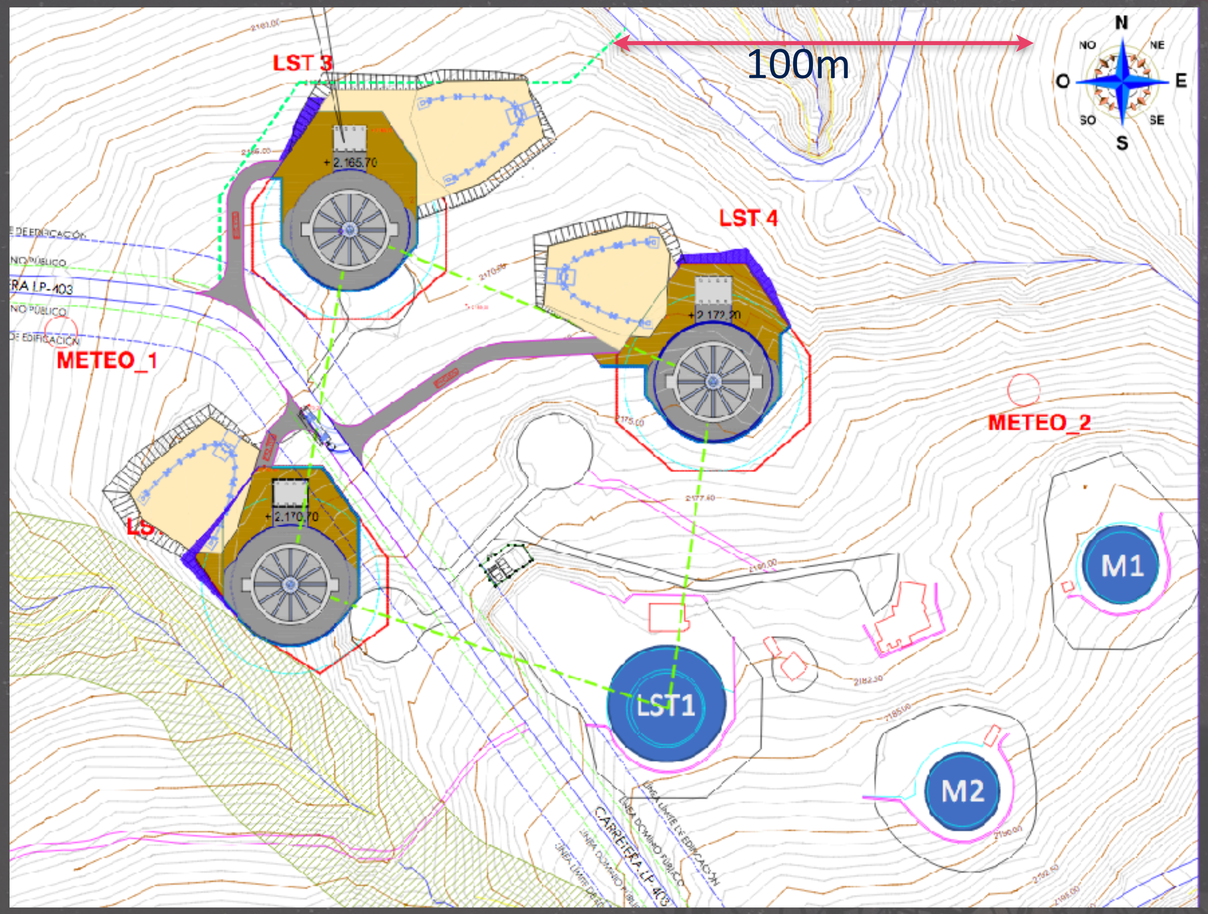
3x better integral sensitivity and high-zd threshold = low-zd threshold of current IACTs

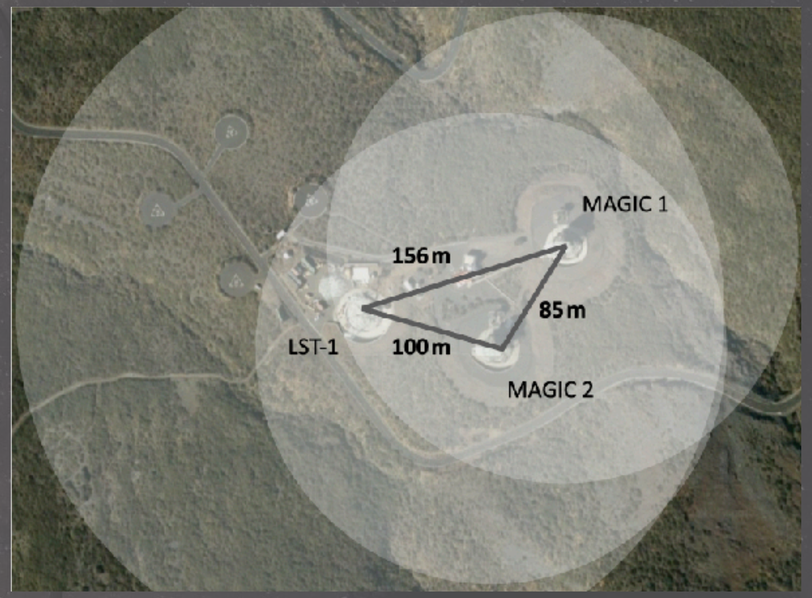




Caution! No proper sensitivity calculation, only rule-of-thumb extrapolation

DM detection potential with LST-1 + MAGIC

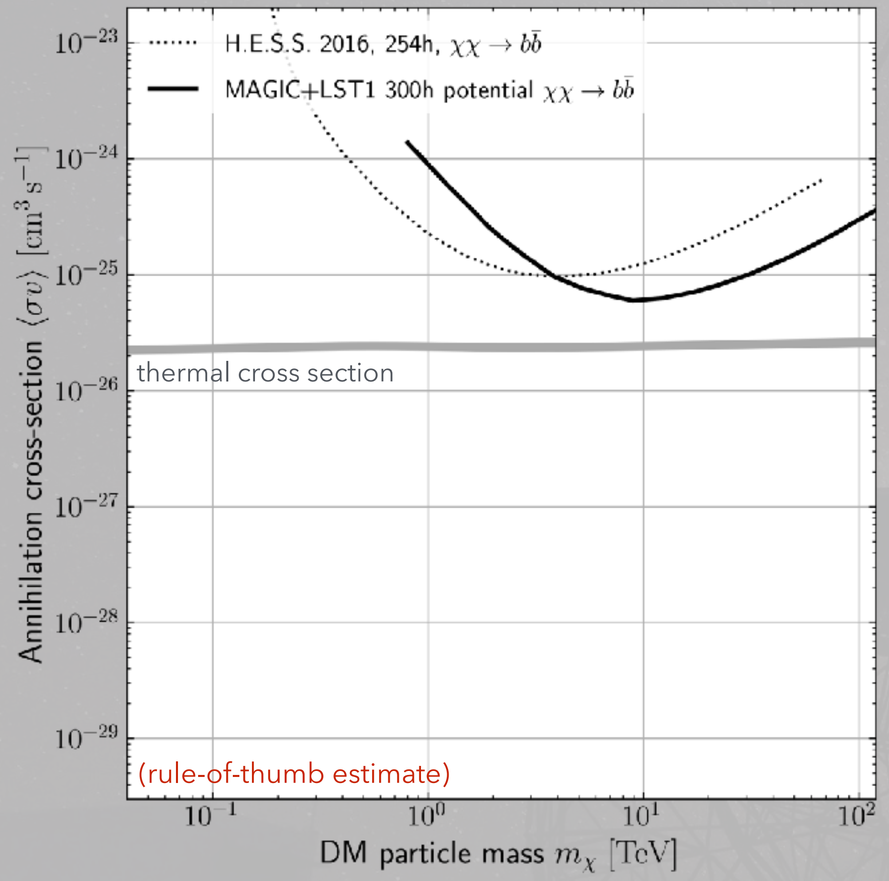


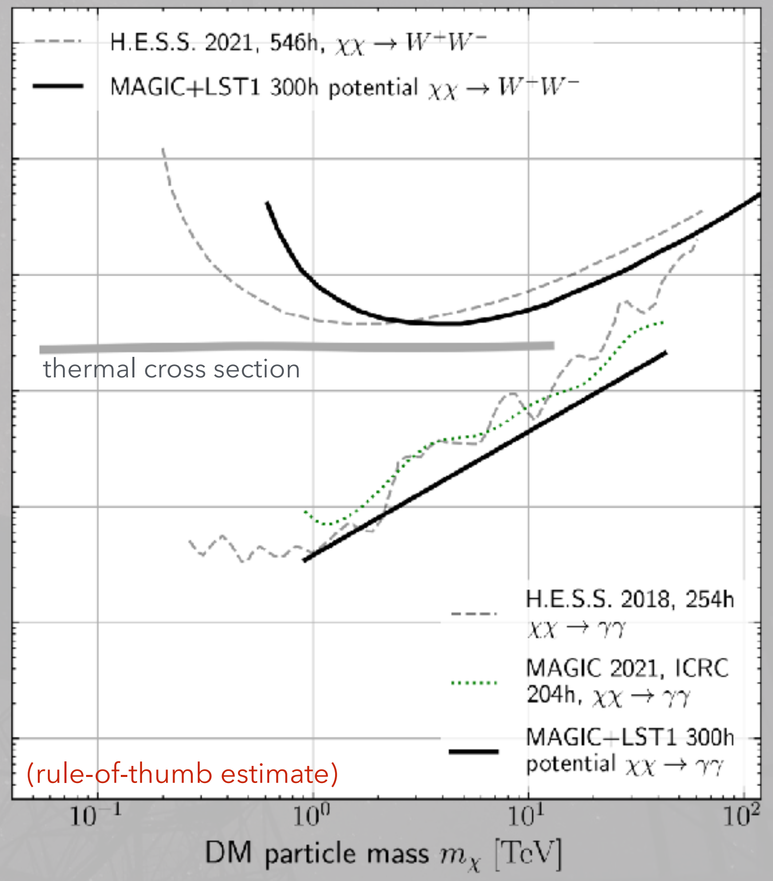


- Improved gamma-hadron separation, angular and energy resolutions
- Any-of-two trigger: increased effective area
- MAGIC+LST1 Hardware trigger to improve threshold

DM detection potential LST1+MAGIC array (300h)

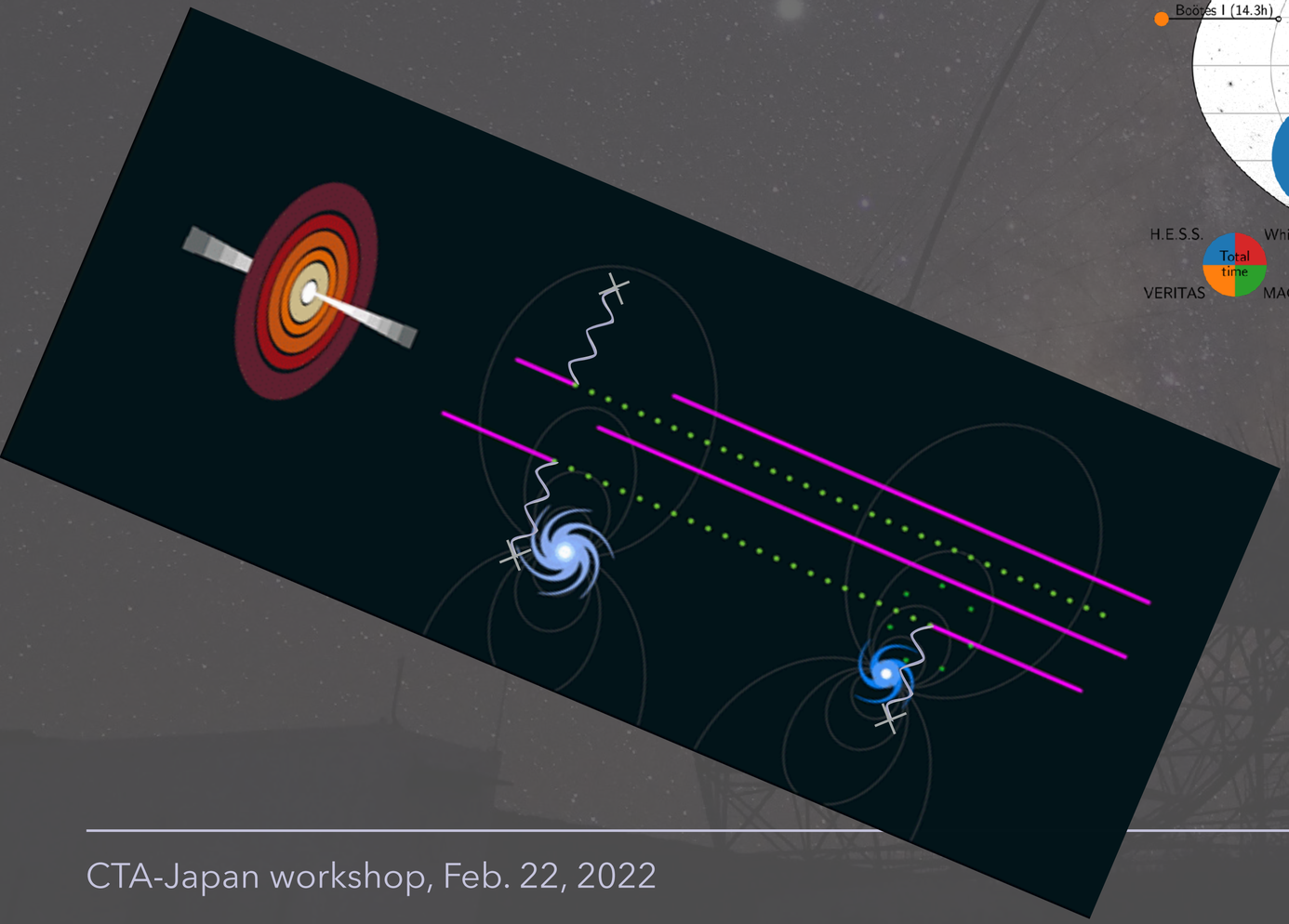
Assume 50% better sensitivity at high-zd threshold of current IACTs

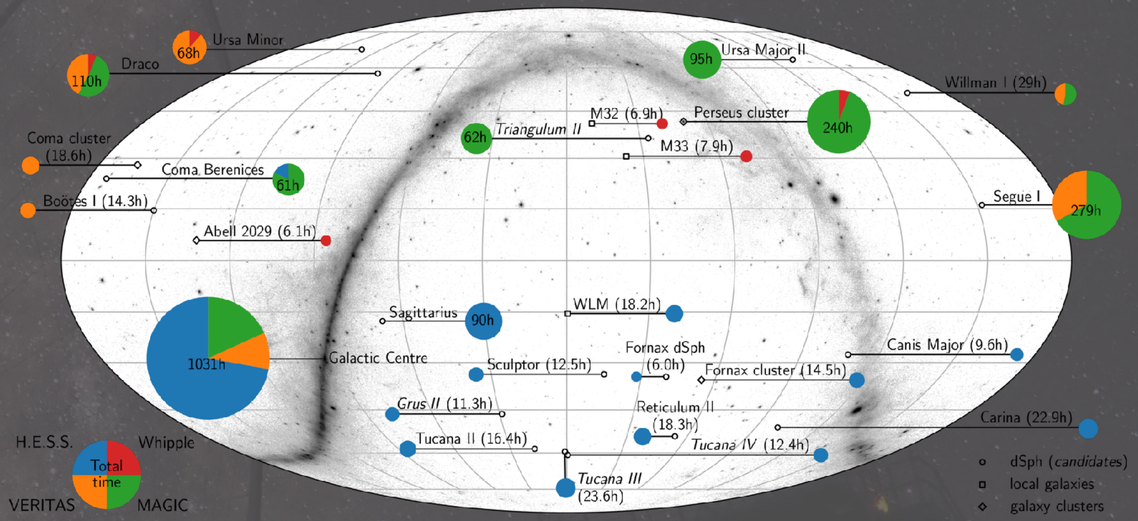




Caution! No proper sensitivity calculation, only rule-of-thumb extrapolation

Outlook: Other searches and candidates

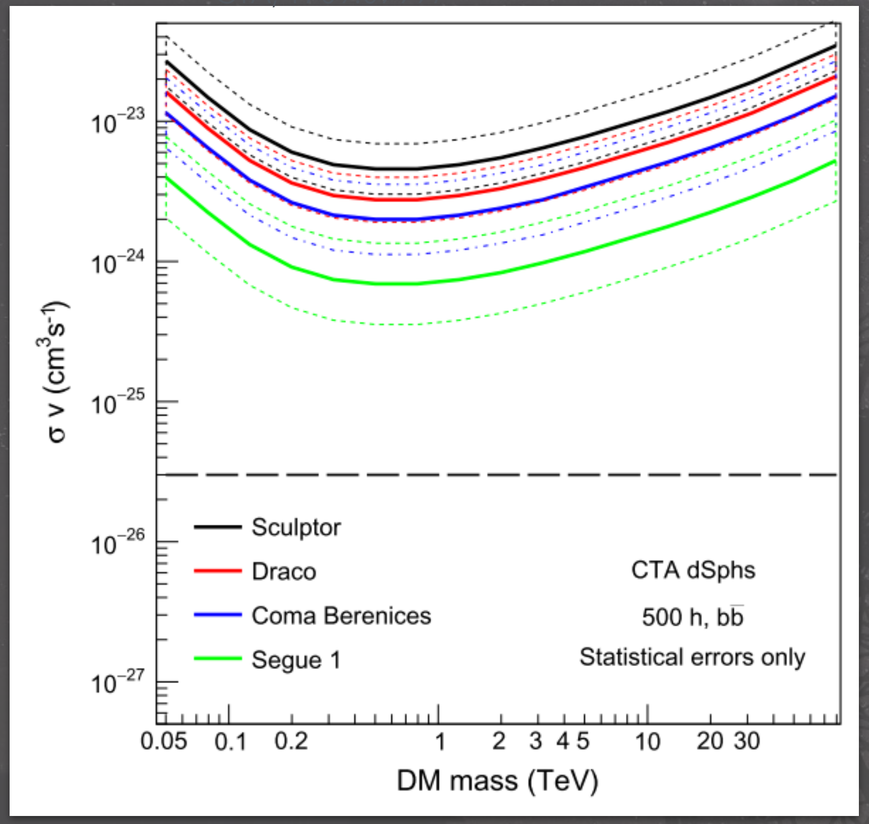




What to reach with dSph galaxies or clusters

CTA Key Science Projects: 300h allocated for best dSph target at that time

300h allocated for Perseus galaxy cluster



Use dSph observations to confirm DM origin of a signal detected at Galactic Center:

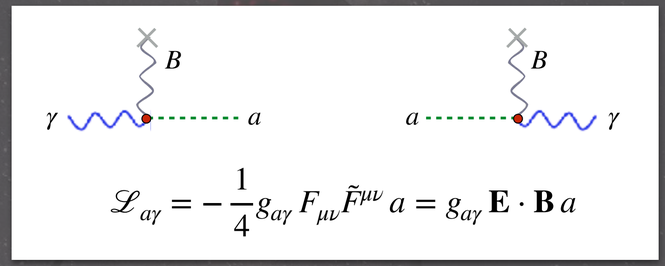
Year	1	2	3	4	5	6	7	8	9	10
Galactic halo	175 h	175 h	175 h							
Best dSph	100 h	100 h	100 h							
				in case of detection at GC, large σv						
Best dSph				150 h	150 h	150 h	150 h	150 h	150 h	150 h
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of detection at GC, small σv						
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 observation strategy (1709.07997)

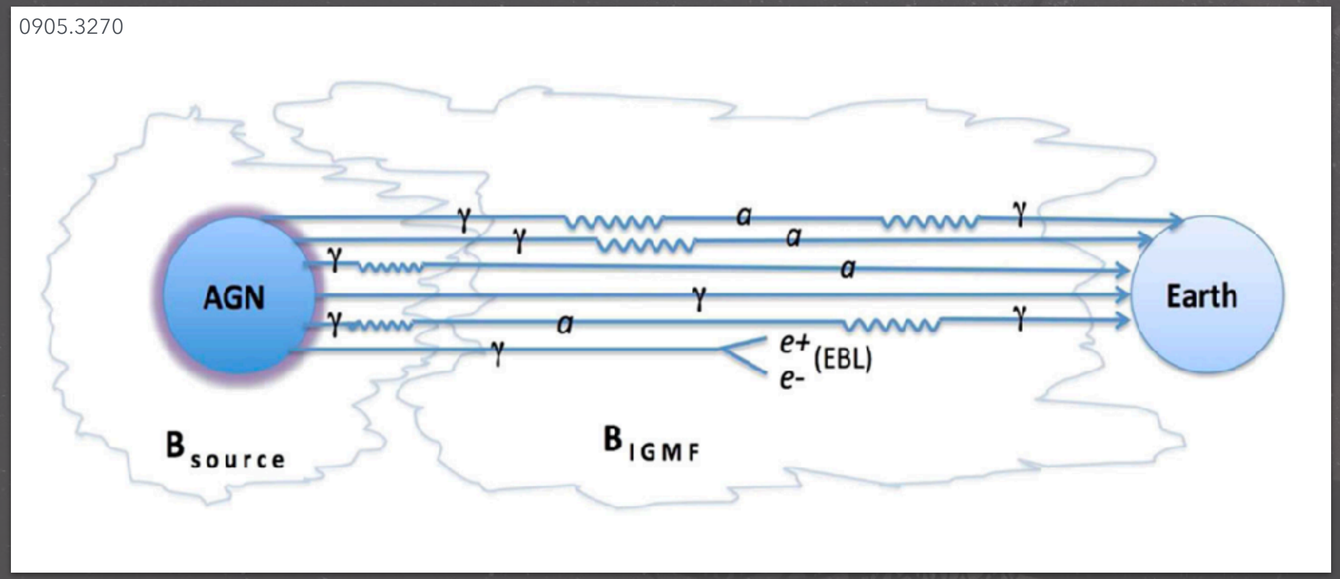
Refined analyses ongoing

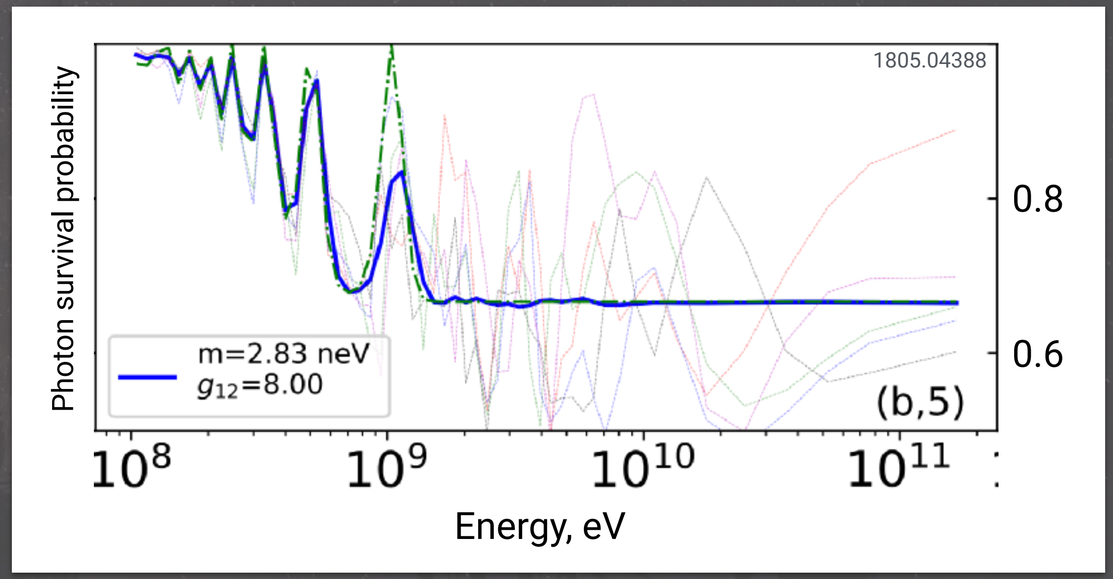
Astrophysical signatures from Axion-like particles (ALPs)

Conversion/oscillation in the presence of magnetic fields



$$\mathcal{L}_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a = g_{a\gamma} \mathbf{E} \cdot \mathbf{B}\, a$$





ALPs: a dark matter candidate (Preskill et al., 1983; Abbott and Sikivie, 1983; Arias et al., 2012, 1201.5902):

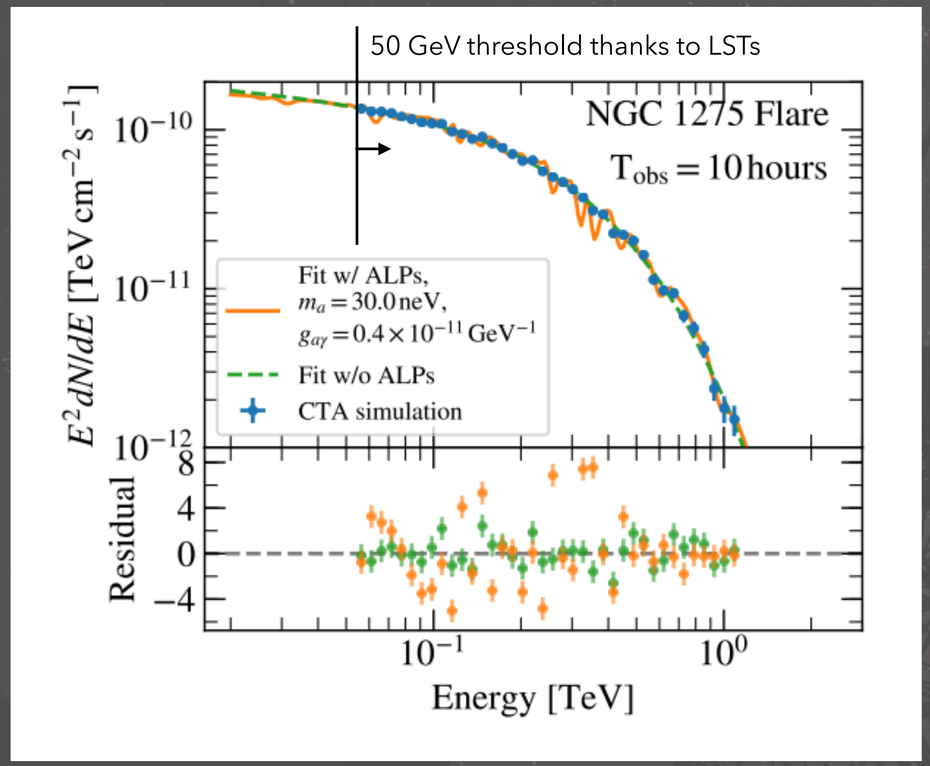
$$g_{a\gamma} < \frac{10^{-12}}{\mathrm{GeV}} \sqrt{\frac{m_a}{\mathrm{neV}}}$$

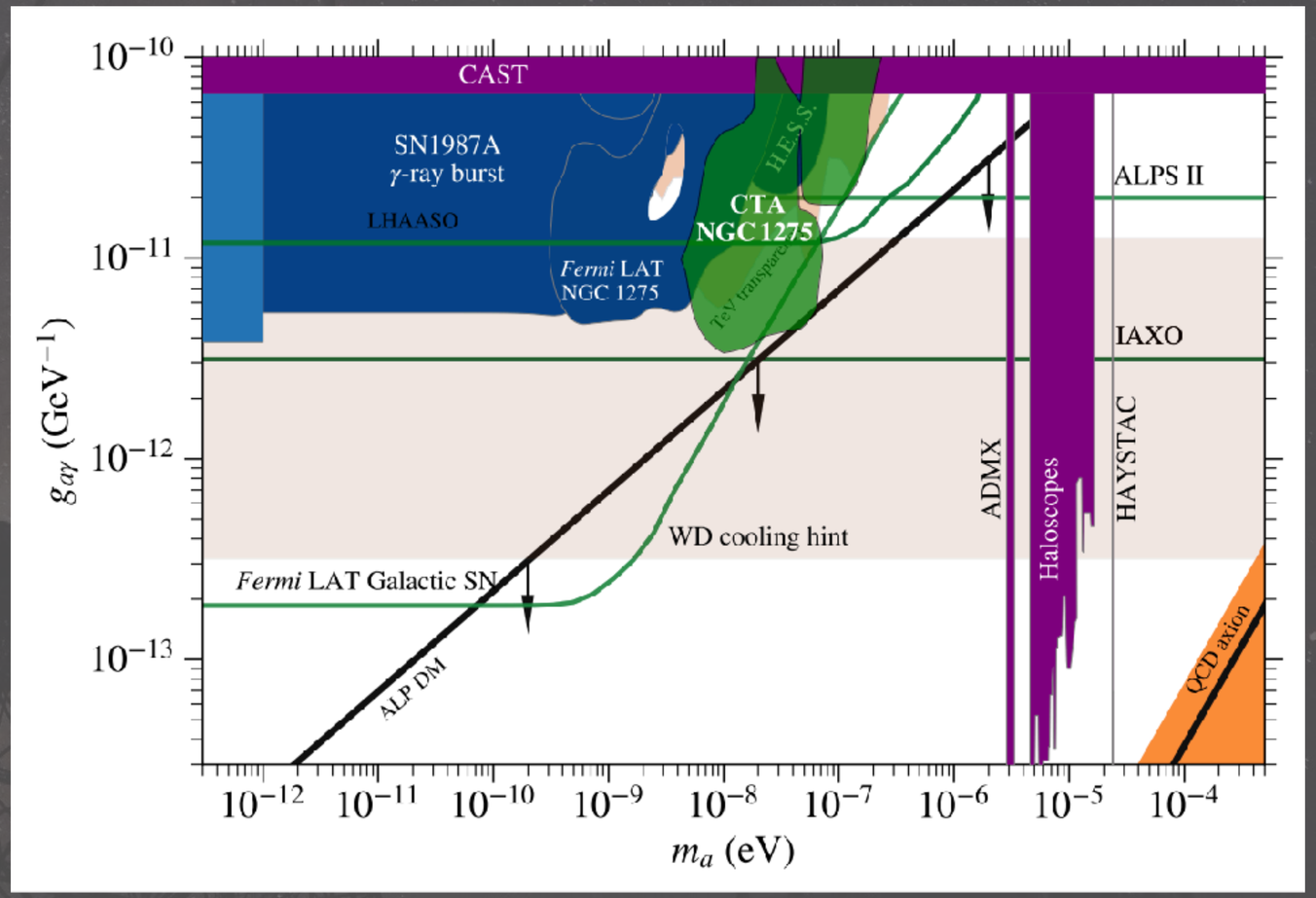
ALP searches towards NGC 1275 (Perseus) with CTA

Assume $300\,\mathrm{h}$ observations with CTA North, among them $10\,\mathrm{h}$ in flaring state

Sensitivity driven by flaring state

CTA, 2010.01349





Conclusions

Rich prospects for Dark matter searches with CTA and CTA-LST

Galactic Centre: 300h+ large-zenith angle observations with 4 LSTs from the North **could probe the canonic thermal relic cross section for DM masses around a few TeV**.

Galactic Centre: Combined observations of LST-1 and MAGIC with 300h+ half as sensitive, but **close to canonic cross section for** $\chi\chi \rightarrow W^+W^-$ **annihilations** and DM masses around a few TeV.

Conclusions

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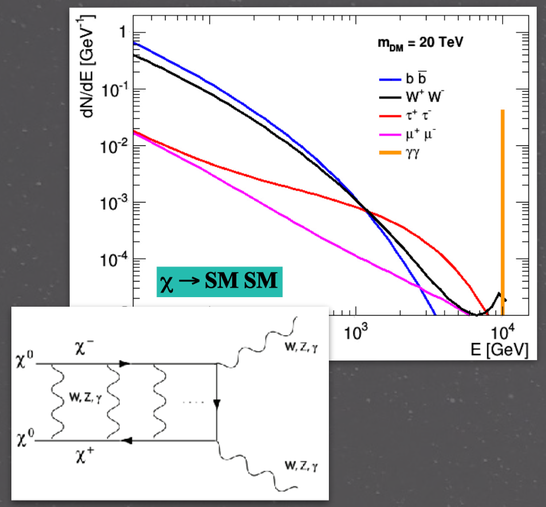
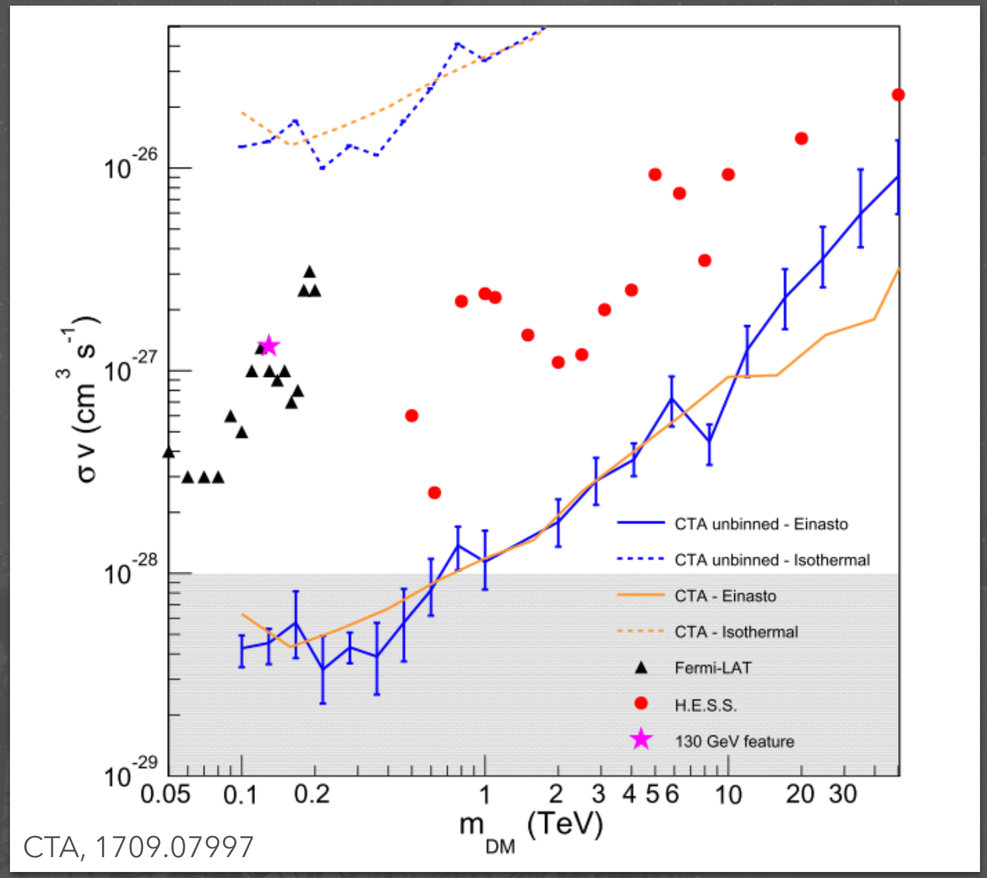
Thank you for your attention

CTA sensitivity to Line DM signal from Galactic Centre





Refined analysis ongoing (separate publication)