Dark matter searches with the Cherenkov Telescope Array: the inner Galactic halo and dwarf galaxies

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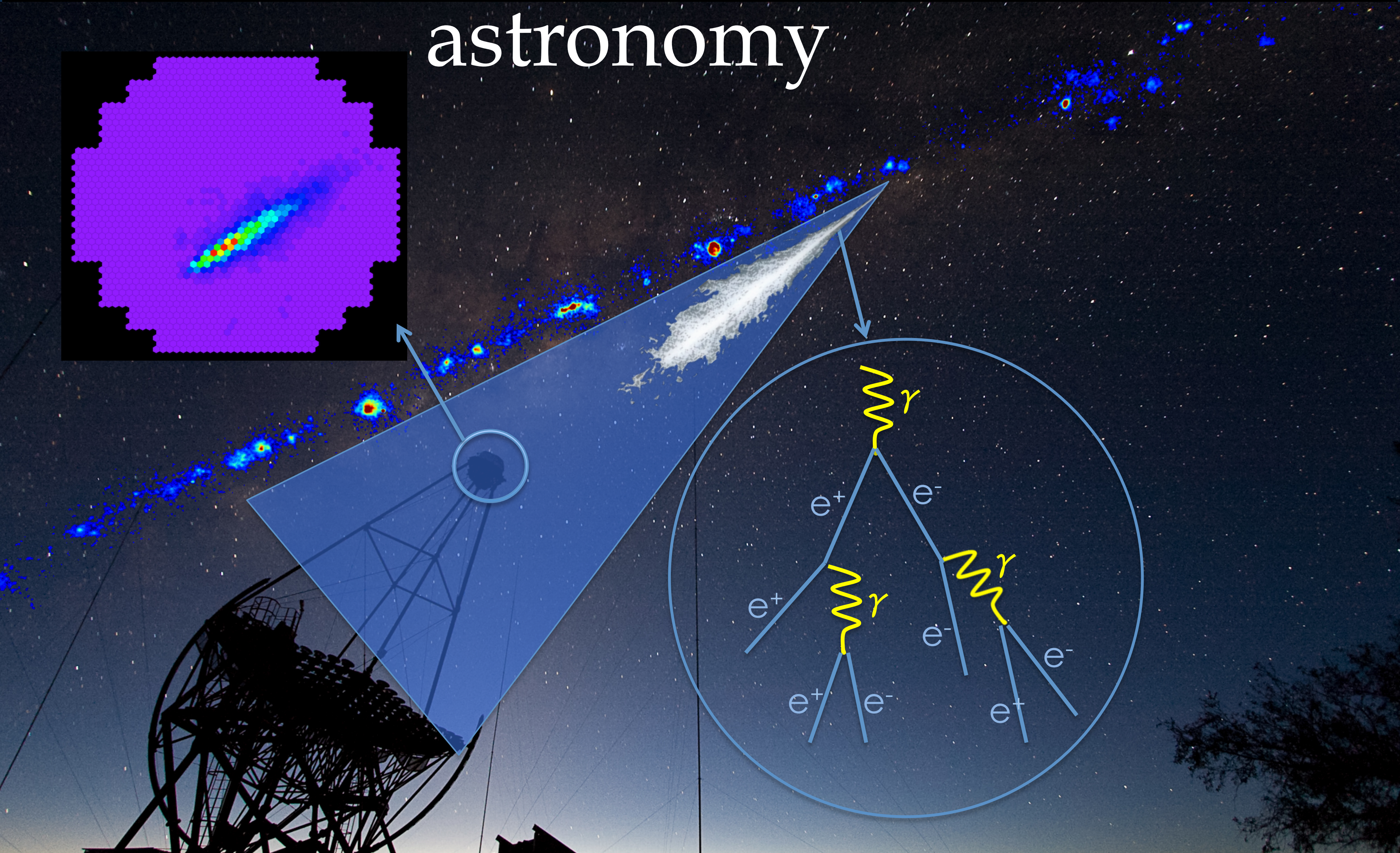
Based on work w/ E. Moulin, P. Panci, G. Mamon, J. Silk

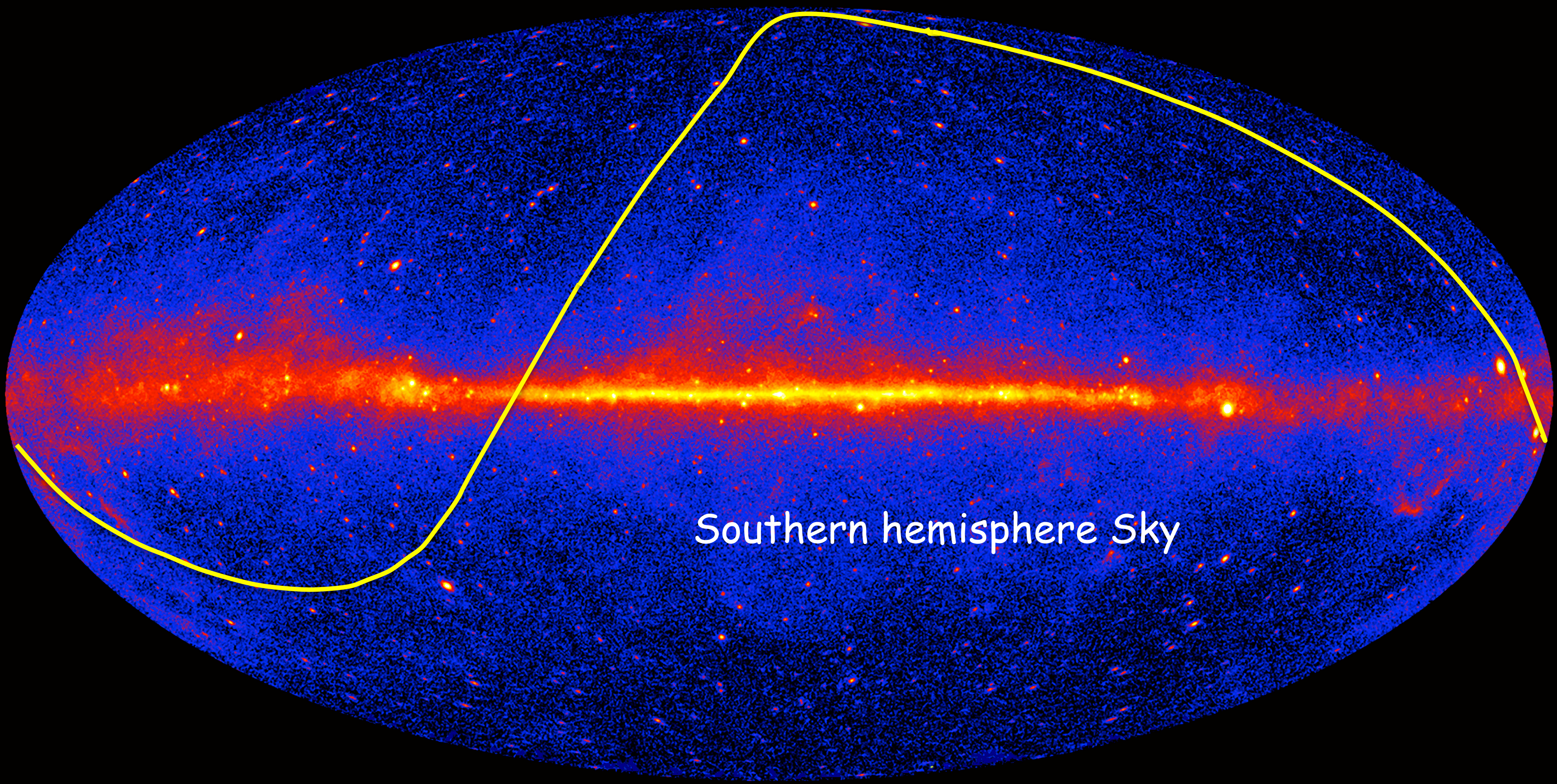
(c) F. Acero & H. Gast

Ground-based Gamma-ray astronomy



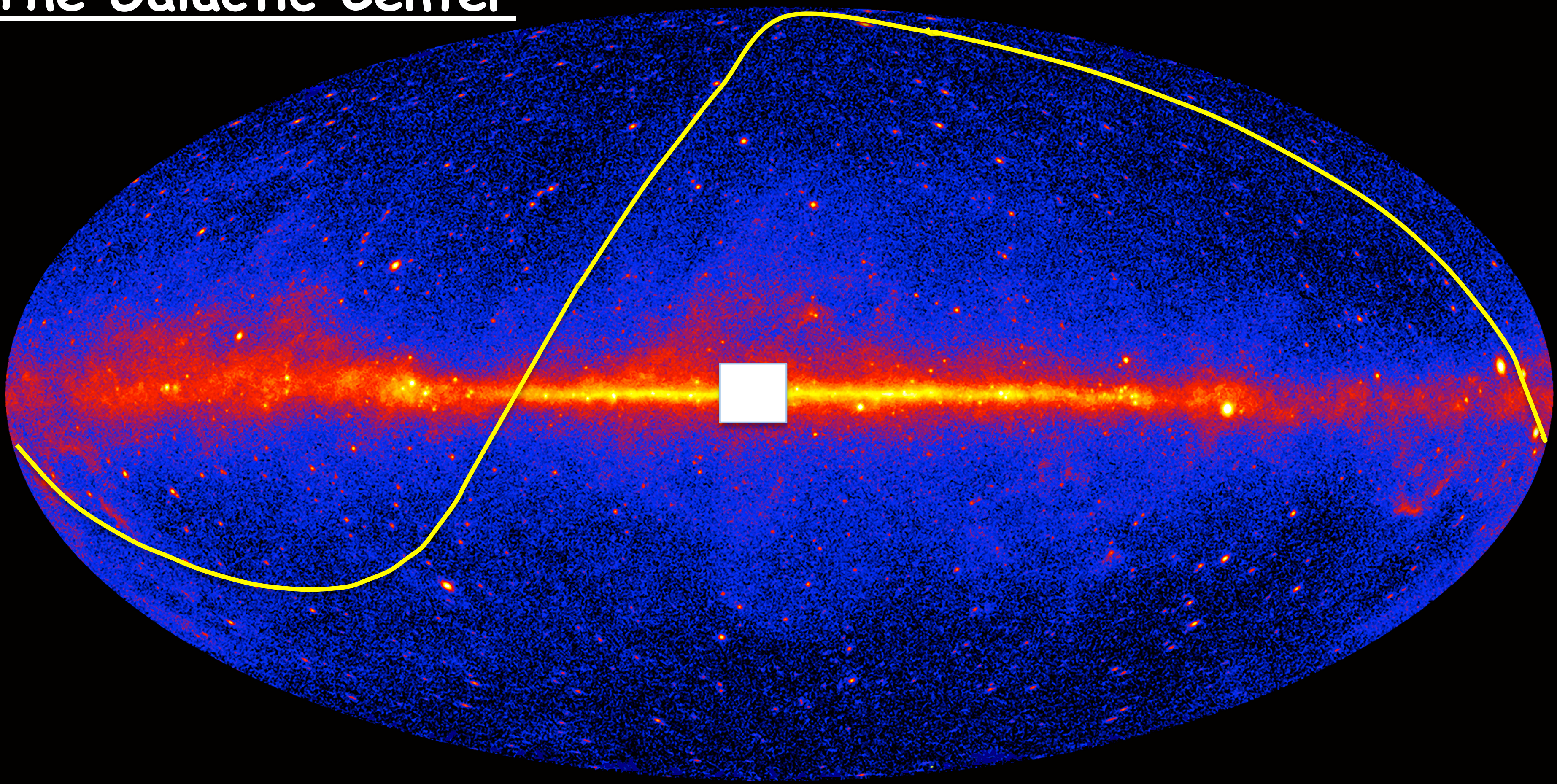
(c) F. Acero & H. Gast

Where to look for DM?



Where to look for DM?

The Galactic Center



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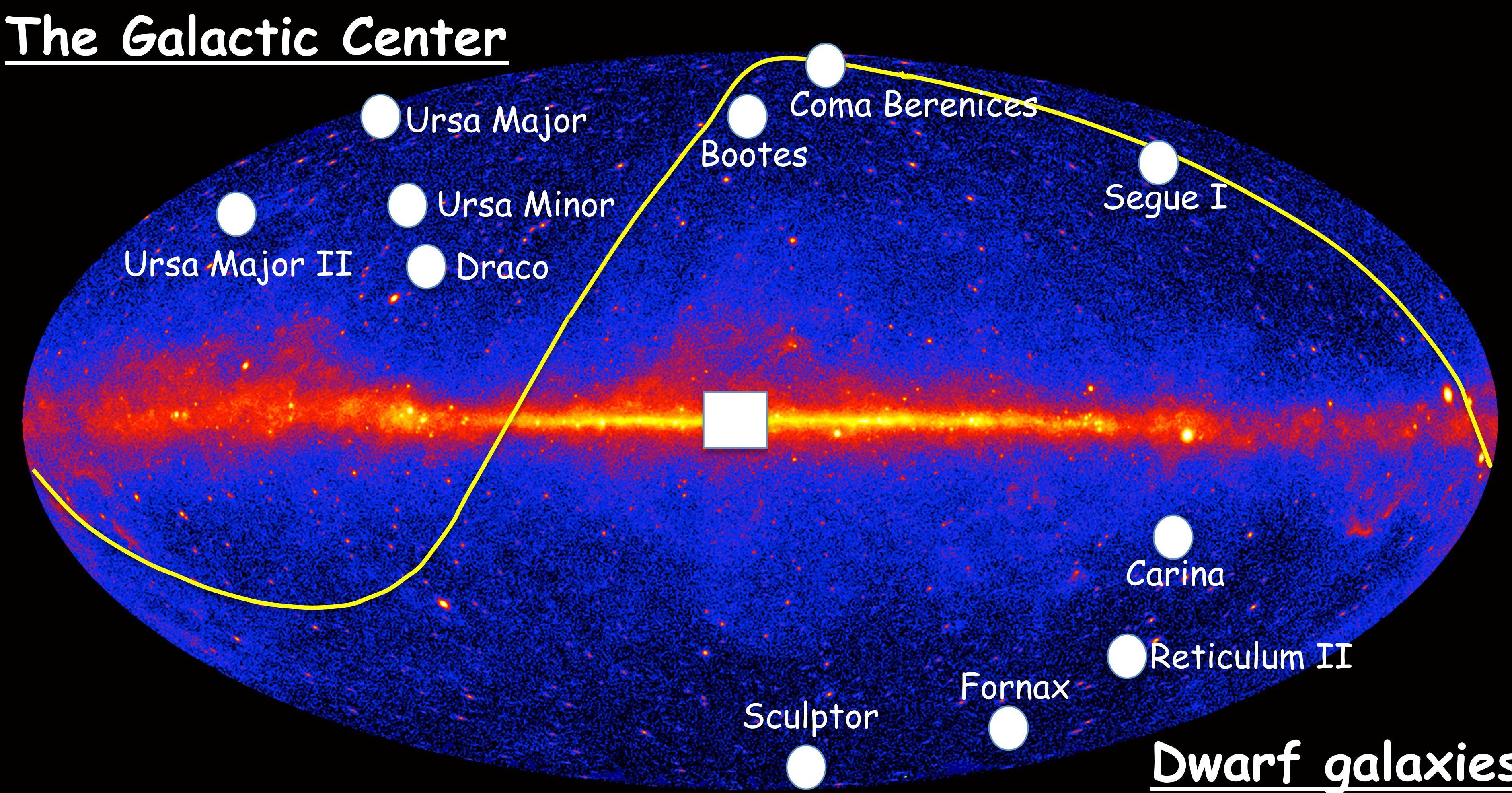


Strongest γ ray constraints

Up to 400 GeV

Fermi LAT telescope
Observation of the Milky way
Dwarf spheroïdale galaxies

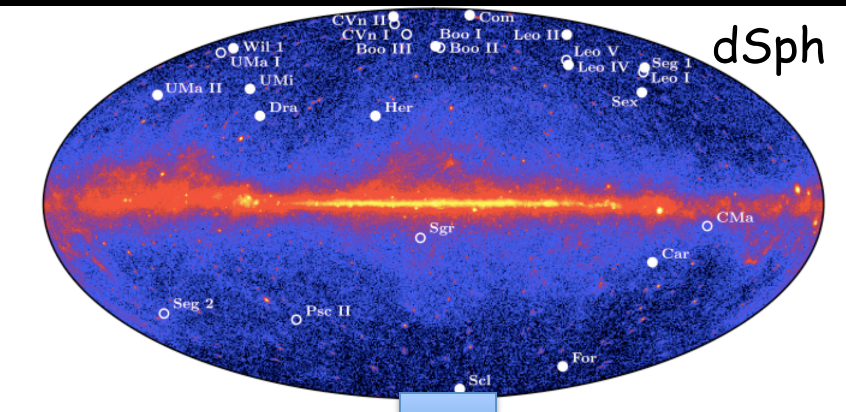
- Energy range 50 MeV - 500 GeV
- < 0.15° angular resolution at 1GeV
- Observation of all the sky every 3 hours

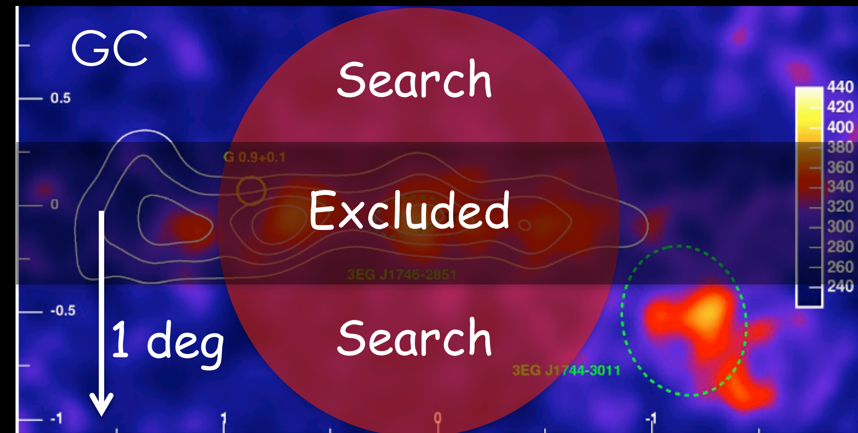
At the TeV Scale

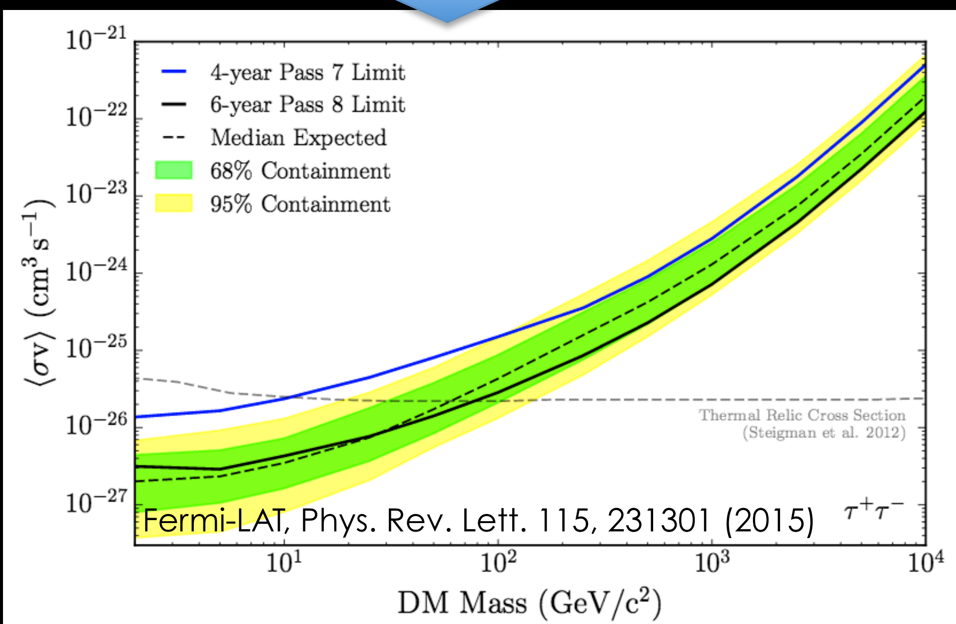
H.E.S.S. and the Galactic Center observations

- 3-5° Field of view
- ~0.1° angular resolution
- 15% energy resolution
- Sensitivity < 1% crab
- 30 GeV < E < 80 TeV

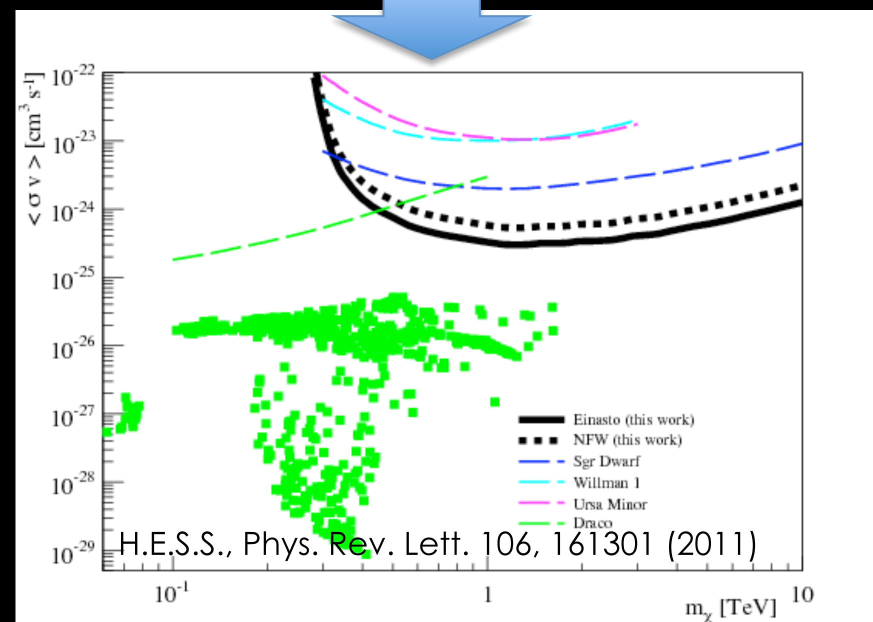
Strongest γ -ray constraints





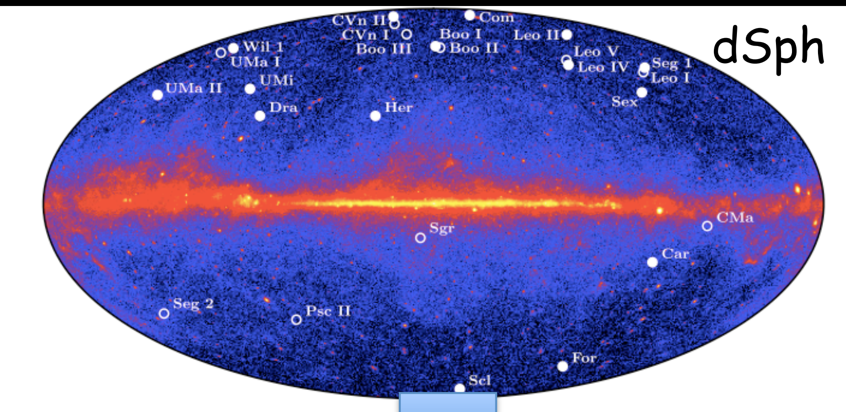


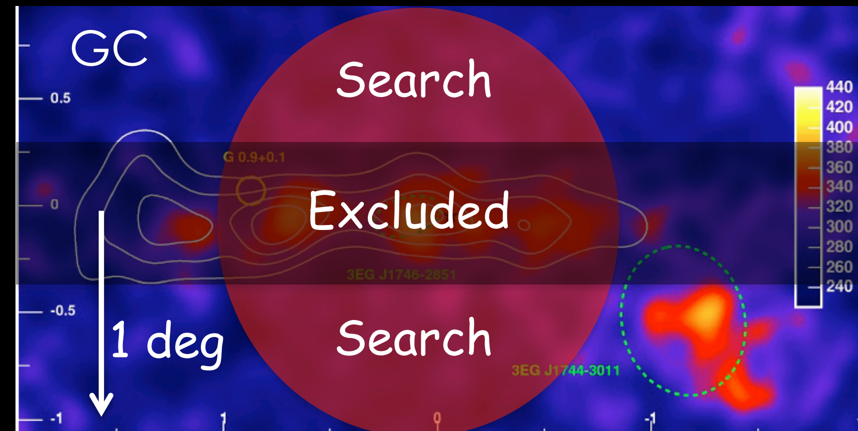
Fermi-LAT, Phys. Rev. Lett. 115, 231301 (2015)

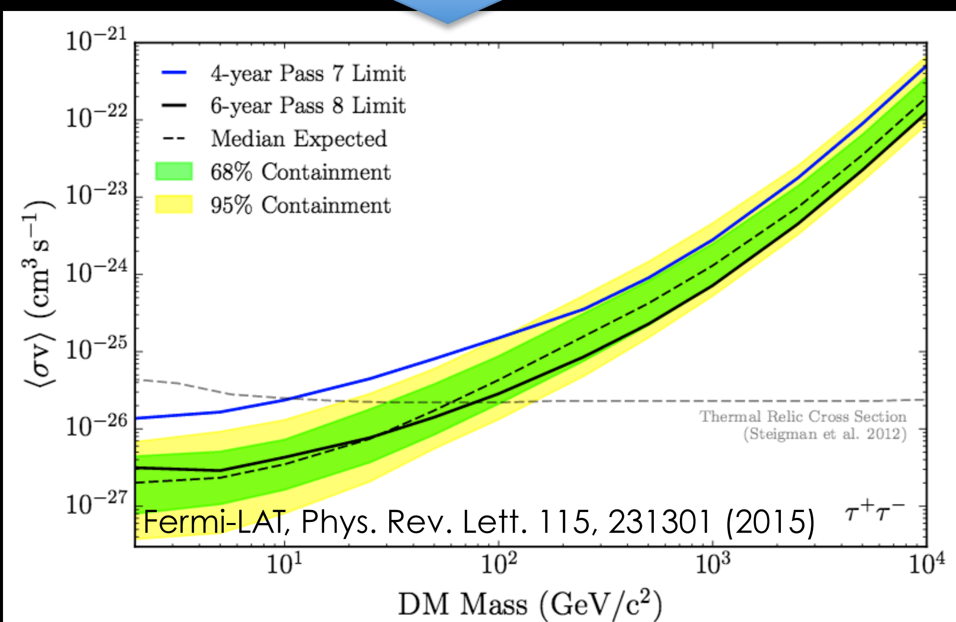


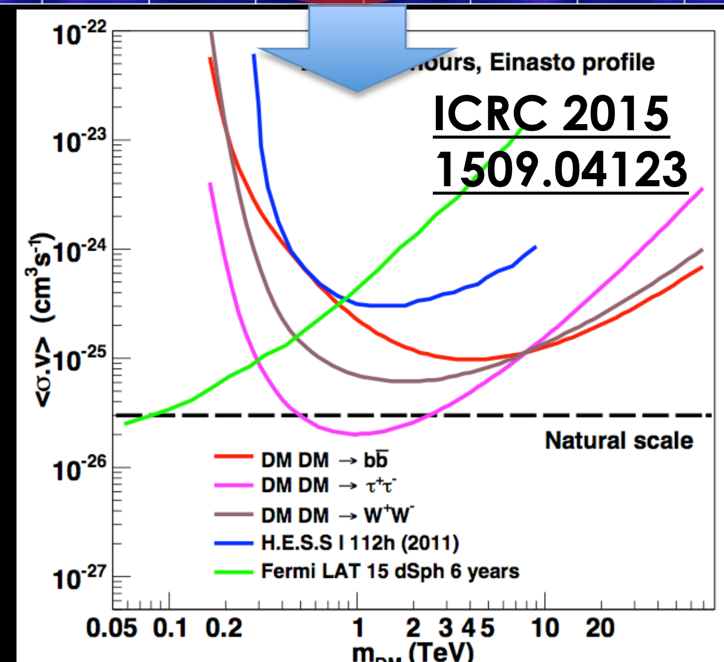
H.E.S.S., Phys. Rev. Lett. 106, 161301 (2011)

Strongest γ -ray constraints

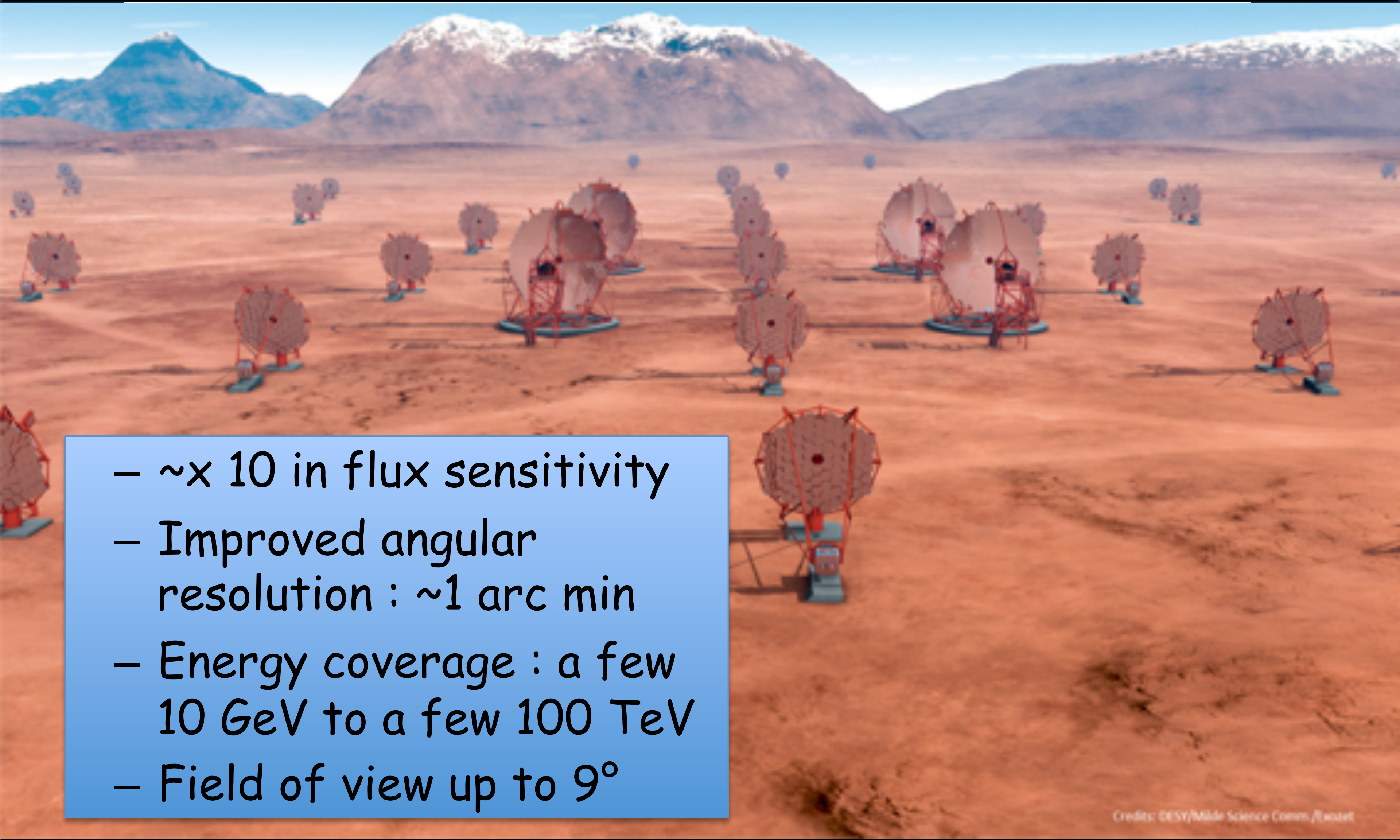








The Cherenkov Telescope Array



- ~x 10 in flux sensitivity
- Improved angular resolution : ~1 arc min
- Energy coverage : a few 10 GeV to a few 100 TeV
- Field of view up to 9°

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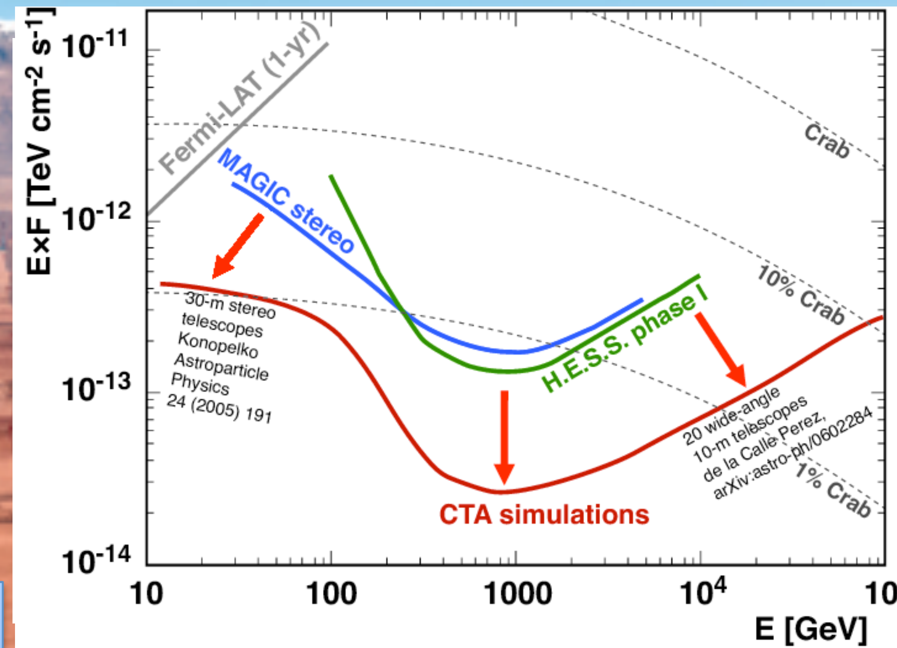

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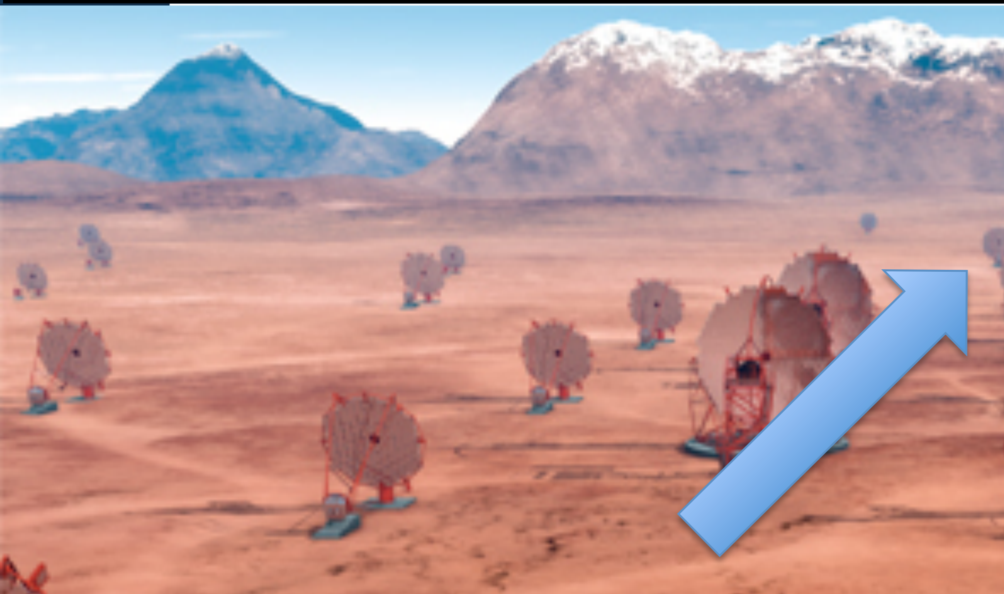

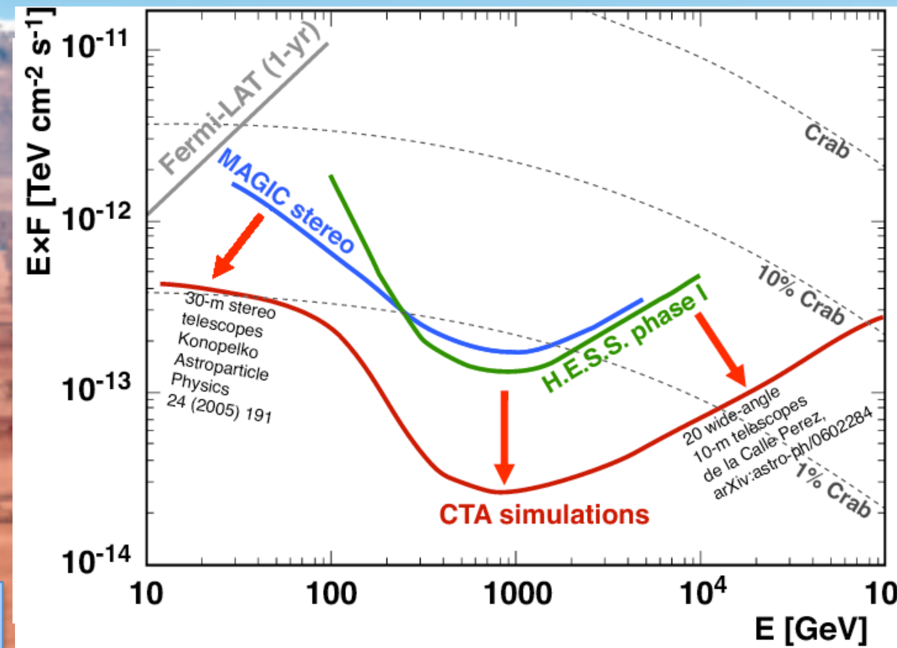

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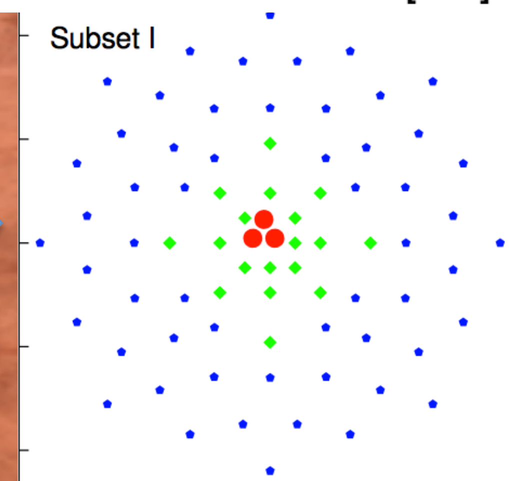
Candidate array



Dark matter signal

- Prompt emission
  - Differential flux :

Particle physics

$$\frac{d\Phi^{P}_{\gamma}}{d\Omega E_{\gamma}} = \frac{1}{2}\frac{r_{\odot}}{4\pi}\frac{\rho^2_{\odot}}{m^2_{DM}} J(\theta) \sum_{f} < \sigma v >_{f} \frac{dN^{f}_{\gamma}}{dE_{\gamma}}(E_{\gamma})$$

$$J(\theta) = \int_{l.o.s.} \frac{ds}{r_{\odot}} \frac{\rho^2(r(s,\theta))}{\rho^2_{\odot}}$$

Astrophysics factor

$$\chi\chi \to b\bar{b}, t\bar{t}, W^{+}W^{-}, \tau^{+}\tau^{-}, \mu^{+}\mu^{-}, e^{+}e^{-}$$

Dark matter signal

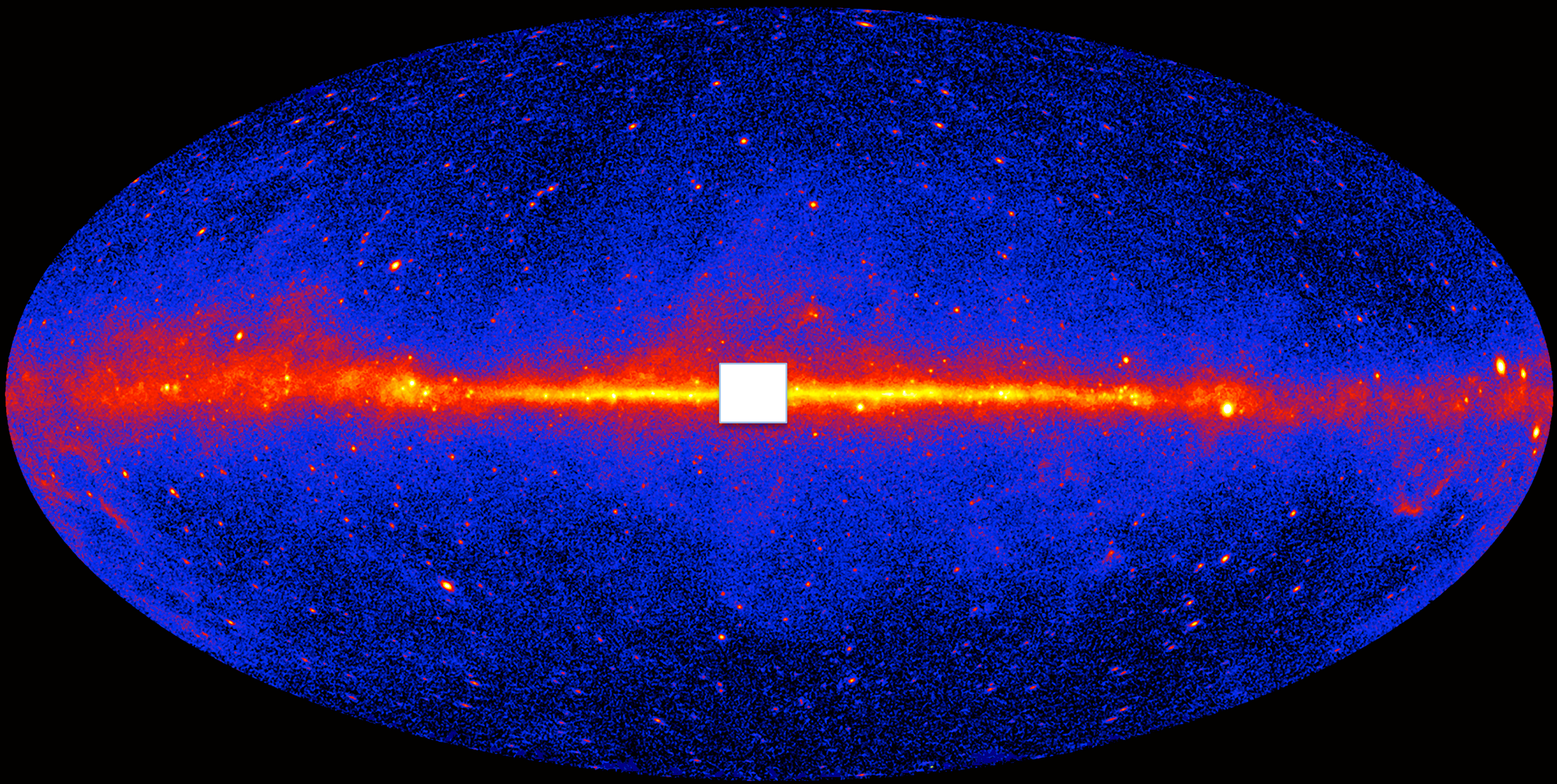
- Prompt emission
  - Differential flux :

$$\frac{d\Phi^{P}_{\gamma}}{d\Omega E_{\gamma}} = \frac{1}{2}\frac{r_{\odot}}{4\pi}\frac{\rho_{\odot}^{2}}{m_{DM}^{2}} J(\theta) \sum_{f} < \sigma v >_{f} \frac{dN^{f}_{\gamma}}{dE_{\gamma}}(E_{\gamma})$$

- Secondary emission (in the case of the GC)
  - differential γ-ray flux produced by the IC scattering of electrons on radiation fields: CMB, IR, Starlight

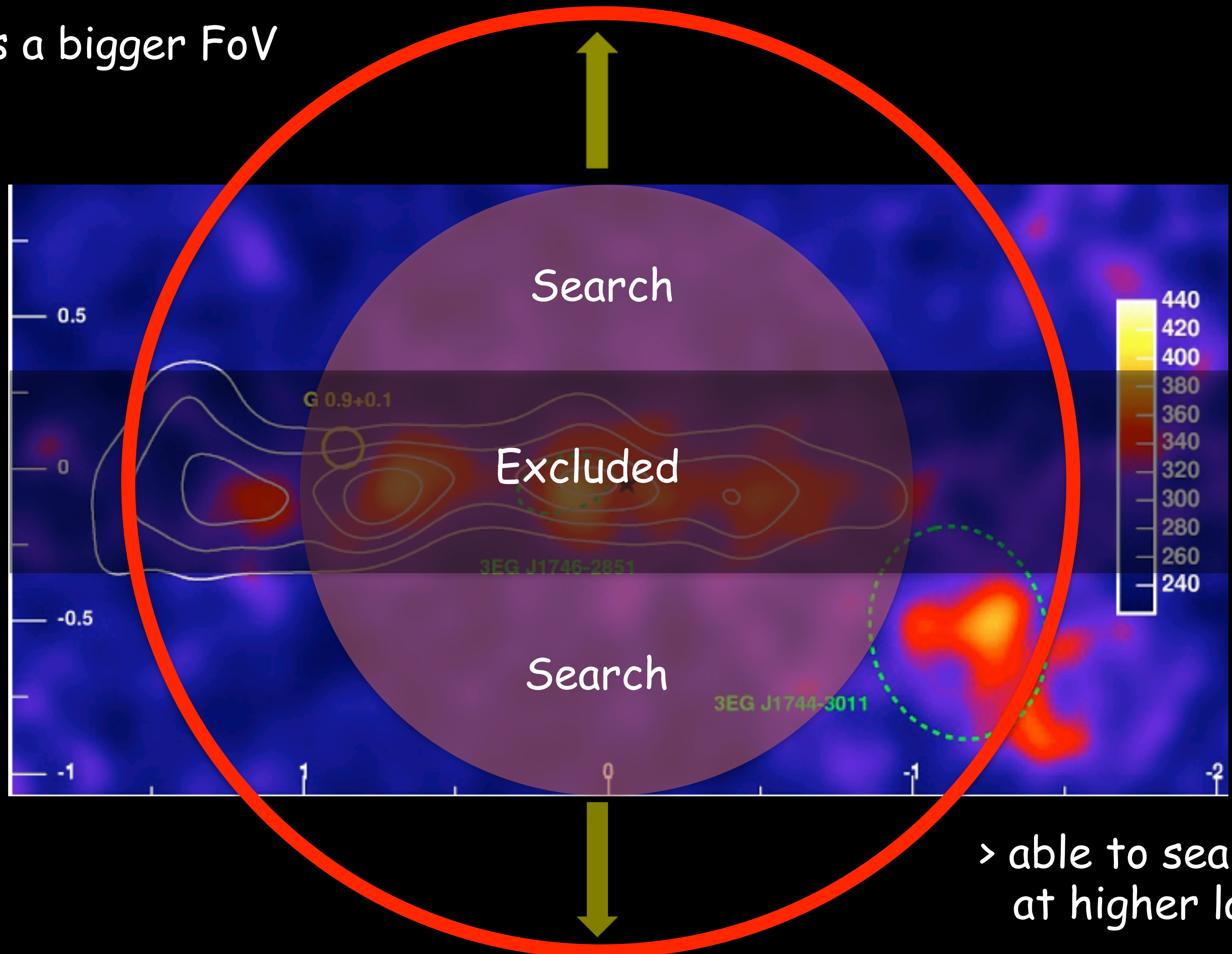
The Galactic Center

V.L., E. Moulin, P. Panci , J. Silk, Phys. Rev. D 91, 122003 (2015)



Galactic halo: region of interest

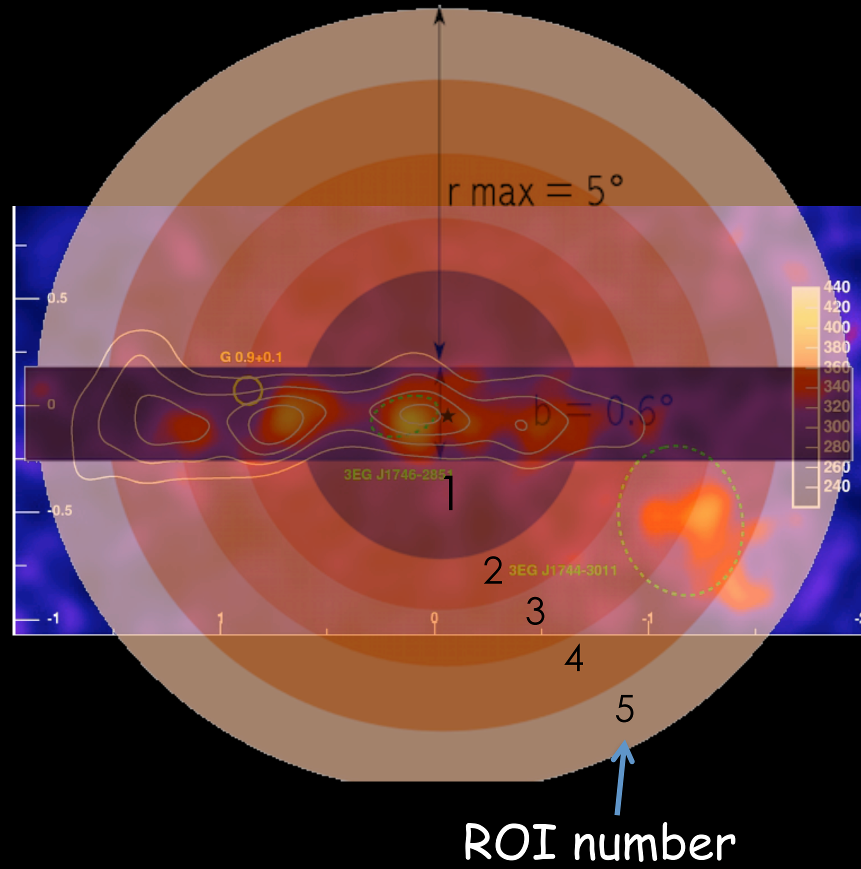
CTA has a bigger FoV



> able to search for DM at higher latitude

Analysis methodology

- 2D Likelihood approach
  - Spatial : sub ROIs
    - Different morphologies of signal and background rates.
  - Spectral
    - Different spectral features between signal and background



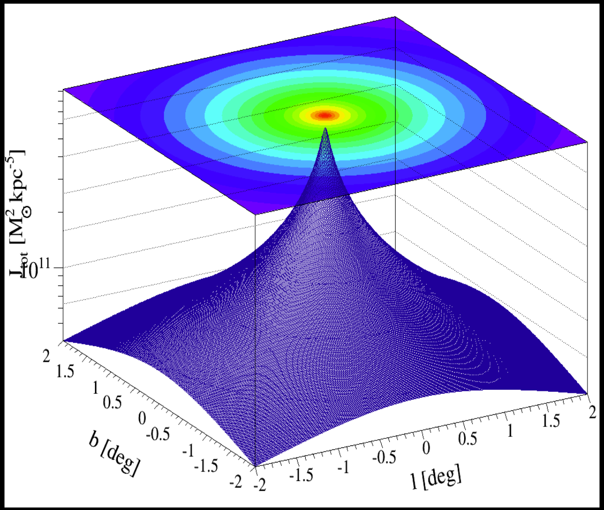
J-factor : GC

Dark matter halo : Einasto profile

$$\rho(\mathrm{r}) = \rho_{\mathrm{s}} \exp\left[-\frac{2}{\alpha_{\mathrm{s}}}\left(\left(\frac{\mathrm{r}}{\mathrm{r_s}}\right)^{\alpha_{\mathrm{s}}} - 1\right)\right]$$

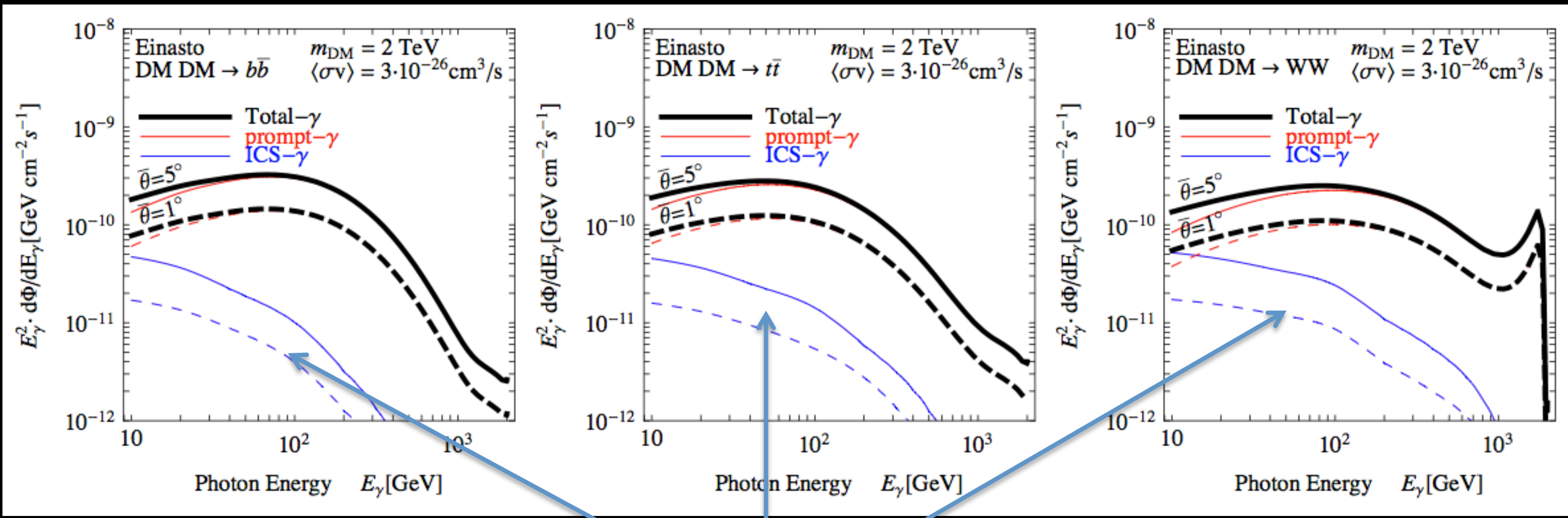
Normalisation parameters such as $\rho(r_{sun}) = 0.3$ GeV.cm^{-3}

$$\rho_{\mathrm{s}} = 0.033\ \mathrm{GeV/cm^3}$$
$$\alpha_{\mathrm{s}} = 0.17$$
$$\mathrm{r_s} = 28.44\ \mathrm{kpc}$$



Expected gamma-ray fluxes

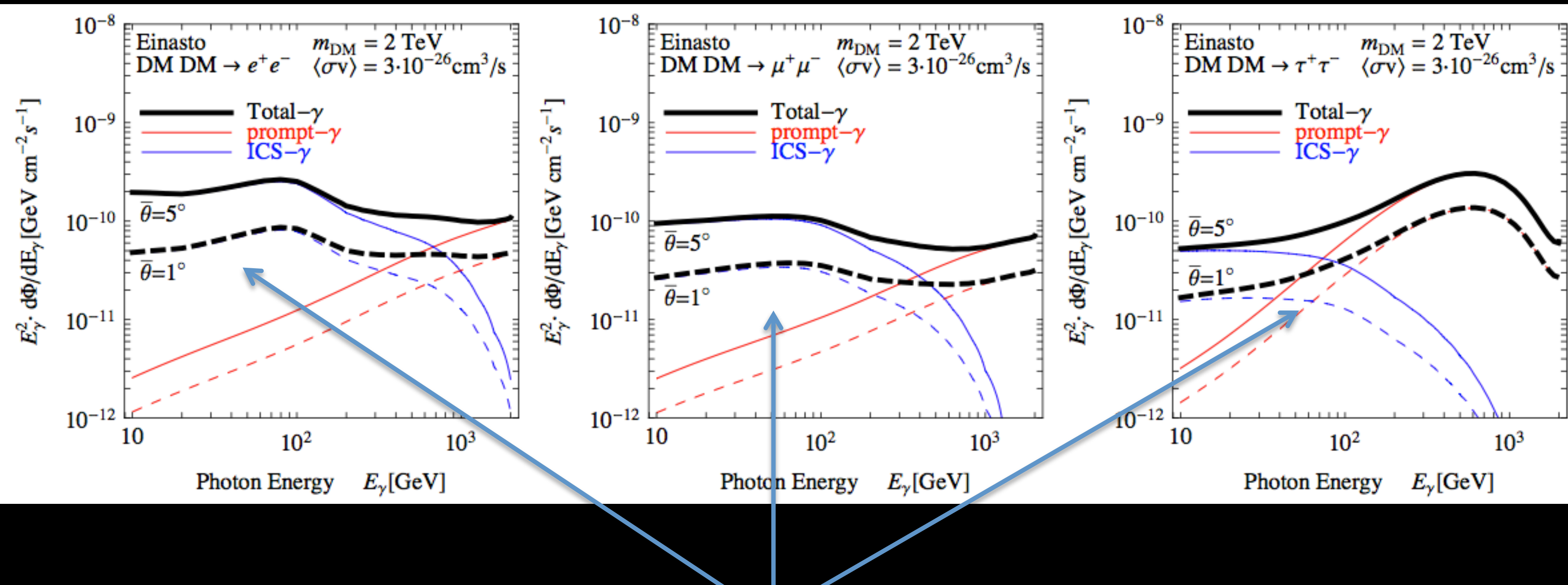
Hadronic channels



No significant contribution
From ICS

Expected gamma-ray fluxes

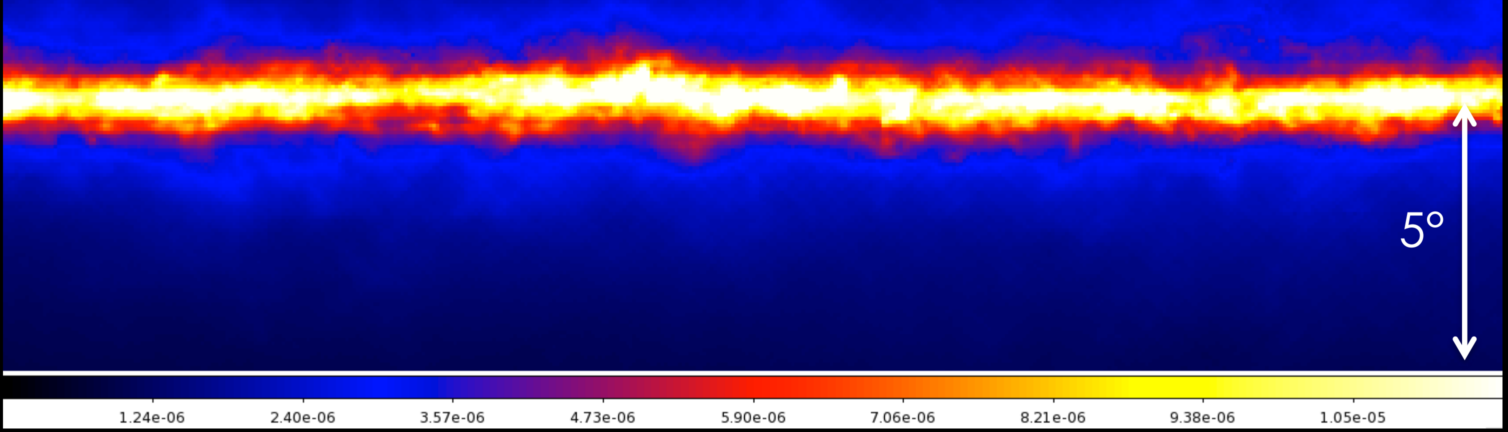
Leptonic channels



Important contribution from ICS processes, from 10 GeV to several hundred of GeV, well above CTA energy threshold

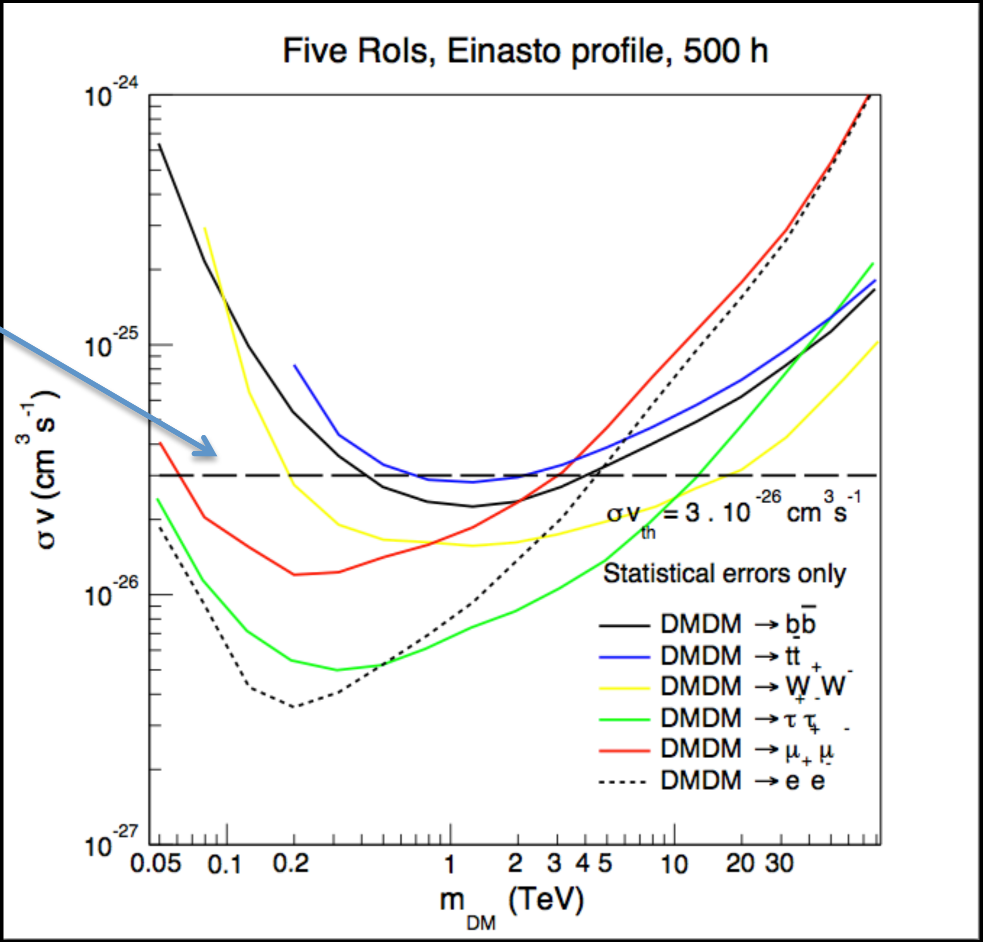
Background

- Cosmic proton
- Cosmic electron
- Galactic diffuse emission (GDE)
  - Extract from Fermi LAT data



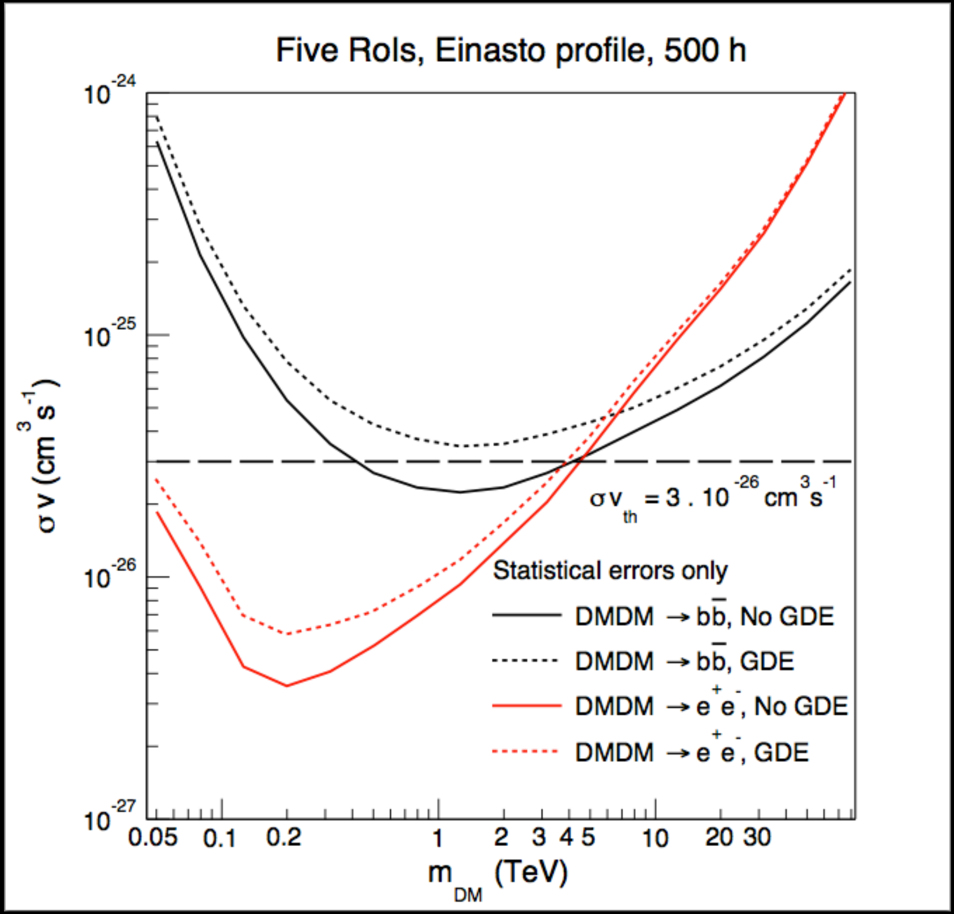
CTA Sensitivity: channels

- Thermally produced DM can be probe with all channels in 500 h
- Strong constraints for the leptonic channel from the ICS contribution



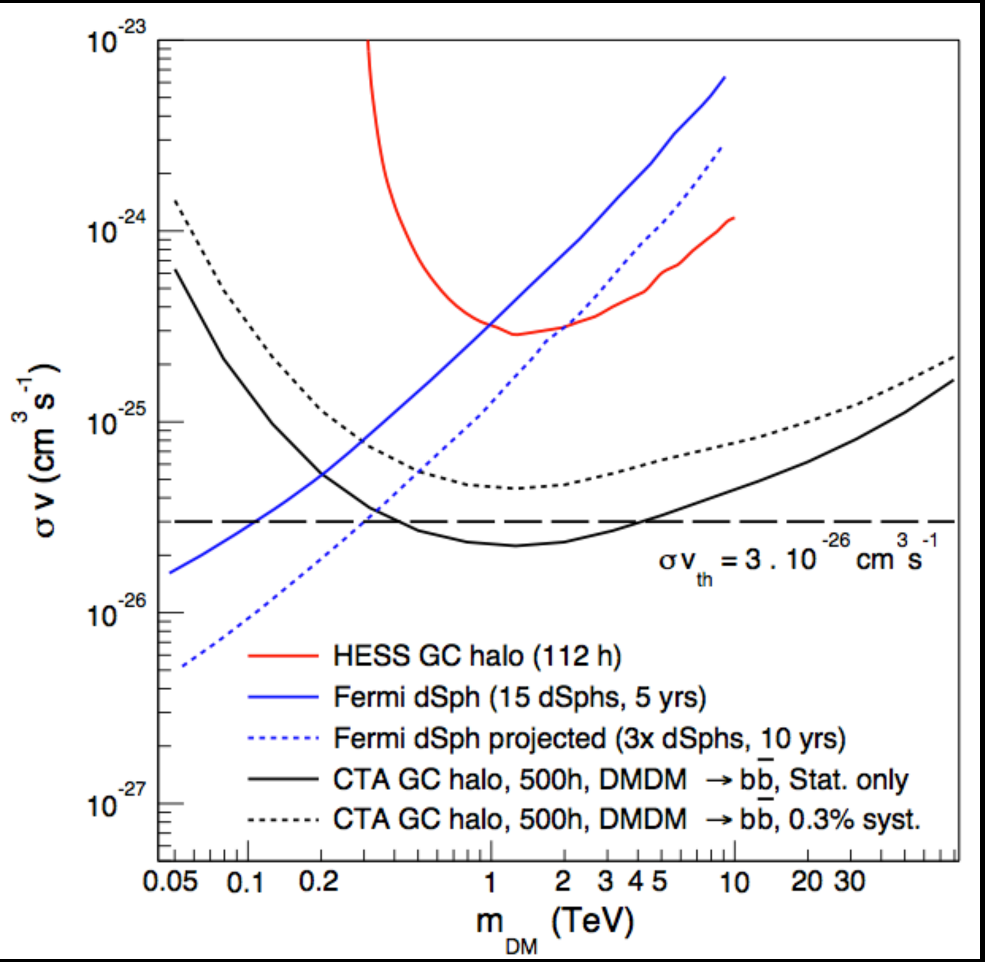
Impact of the GDE

- Incertitude on the GDE is big
- We used max GDE from Fermi LAT sky map
  - ➜ results are conservative



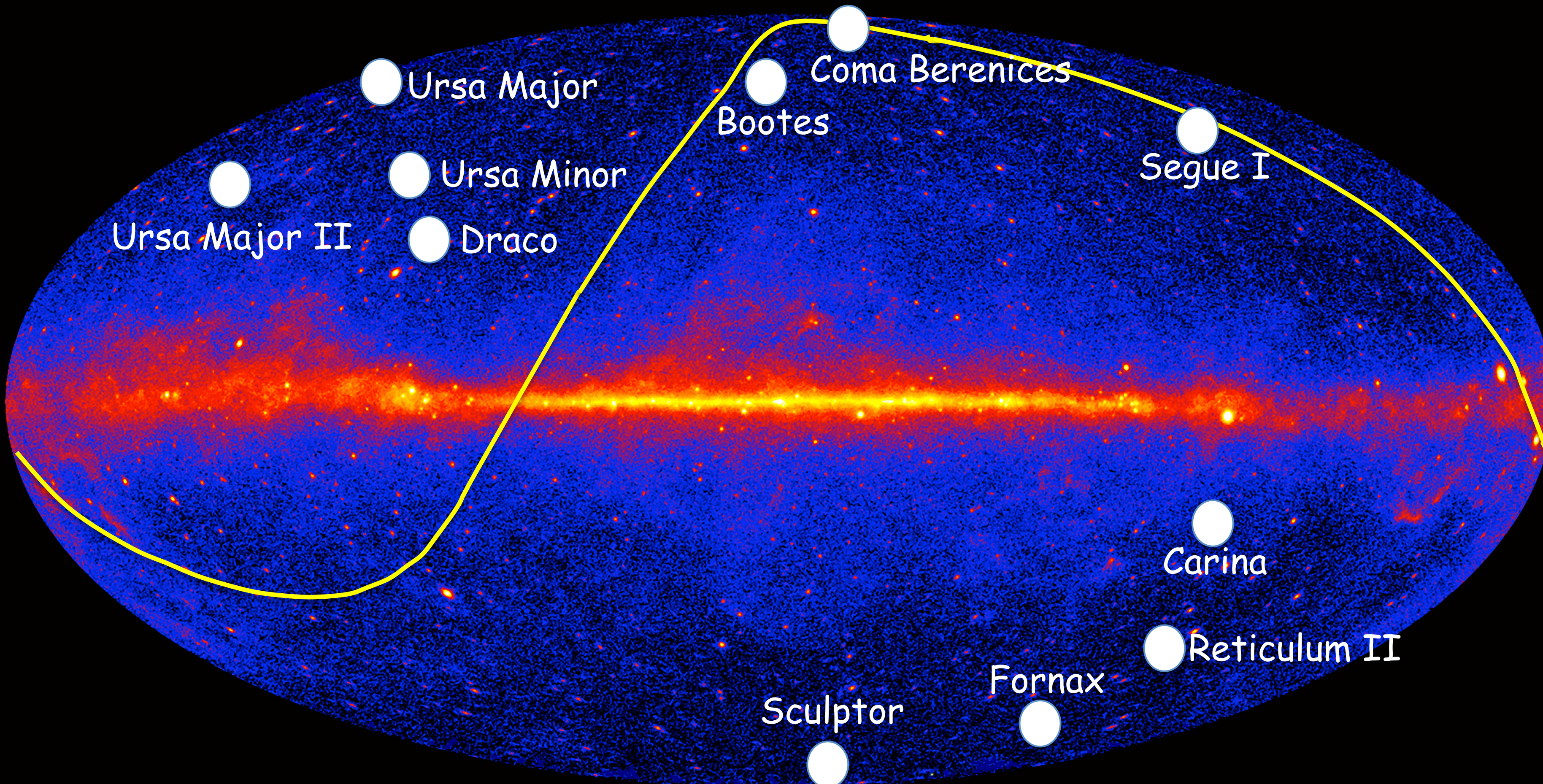
Results : comparison

- A factor of ~10 can be expected compare to H.E.S.S.
- Complementarity with Fermi LAT Limits above a few 100 GeV



Dwarfs spheroïdal galaxies

V.L., E. Moulin, G. Mamon, P. Panci , J. Silk, in prep (2015)



Choice of the targets

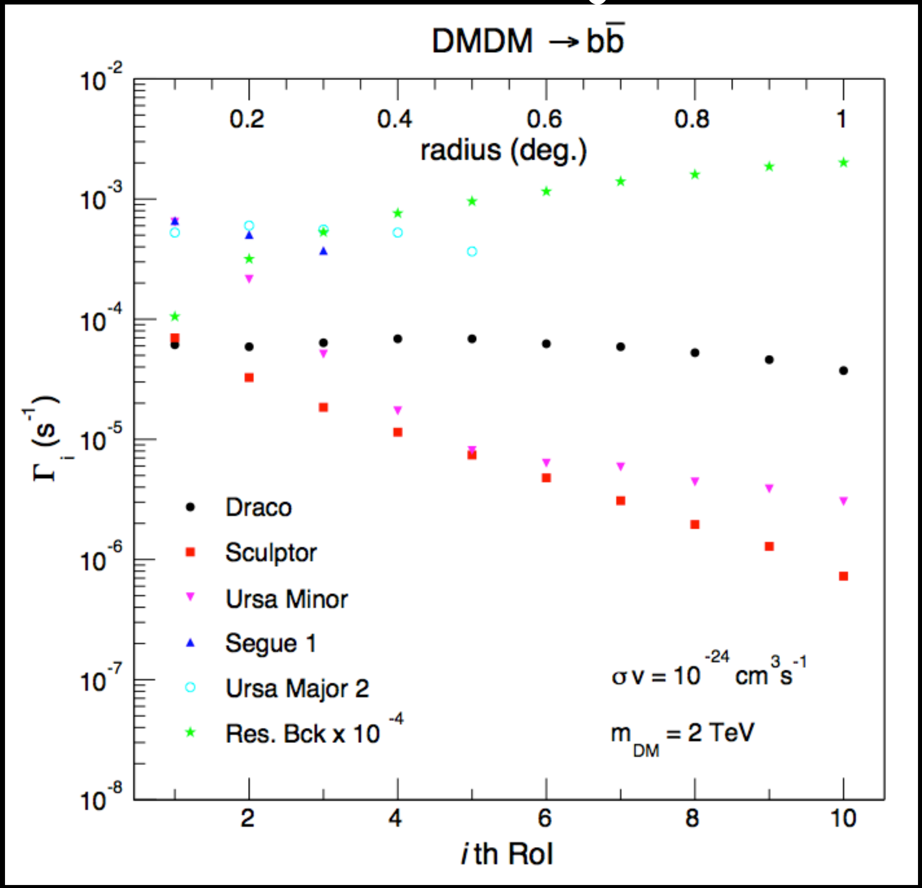
- 10 dSph : 5 « Classical » & 5 Ultra-Faint + the recently discovered Reticulum II
- The signal integration size is wisely according to the extention of the DM halo
- Sub-RoIs: rings of 0.1° width

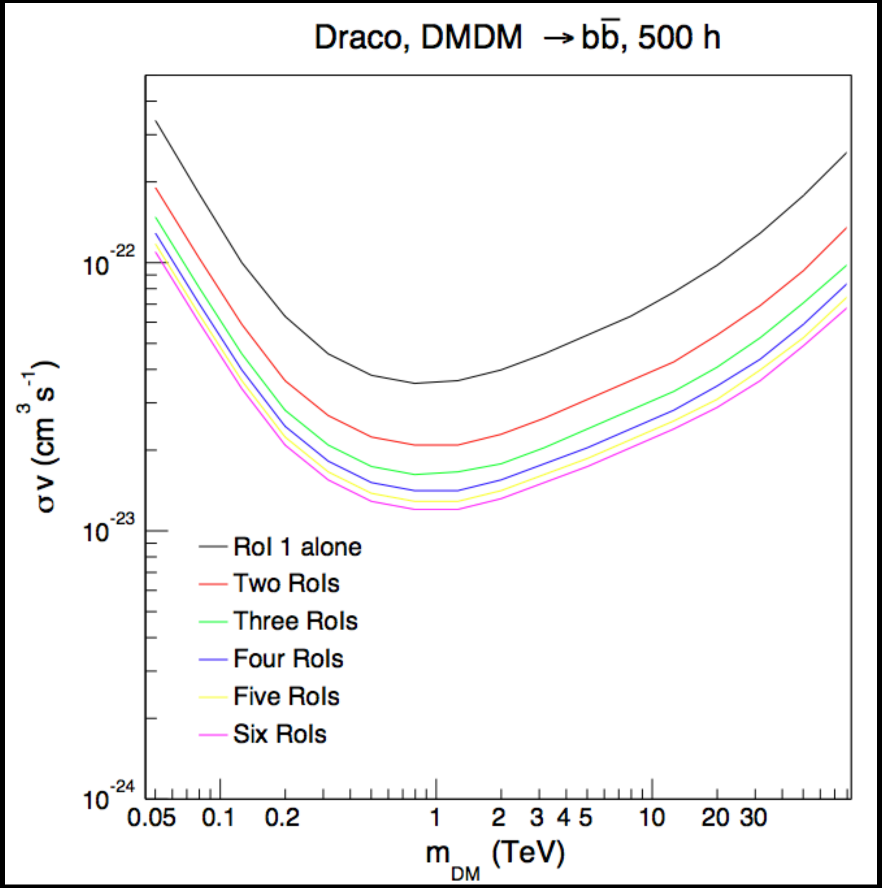
Target	Hemisphere	Distance [kpc]	Angular size [deg]	Number of RoIs	$\log_{10}(J_{all}\ [\mathrm{GeV}^2\,\mathrm{cm}^{-5}])$
Carina	S	101	1.26	4	$17.84^{+0.08}_{-0.08}$
Draco	N	82	1.30	6	$18.89^{+0.14}_{-0.14}$
Fornax	S	138	2.61	3	$17.78^{+0.13}_{-0.08}$
Sculptor	S	79	1.94	3	$18.45^{+0.07}_{-0.06}$
Ursa Minor	N	66	1.37	2	$18.89^{+0.30}_{-0.30}$
Bootes I	N	66	0.47	4	$18.20^{+0.40}_{-0.36}$
Coma Berenices	N	44	0.31	3	$19.02^{+0.37}_{-0.40}$
Segue I	N	23	0.35	3	$19.33^{+0.32}_{-0.34}$
Ursa Major I	N	97	0.43	4	$17.86^{+0.56}_{-0.33}$
Ursa Major II	N	30	0.53	4	$19.36^{+0.42}_{-0.41}$
Reticulum II	S	32	—	5	$19.30^{+0.40}_{-0.40}$

J-factors extracted from Geringer-Sameth et al. PRL 115, 081101
For Reticulum II, Bonnivard et al. 1504.03309

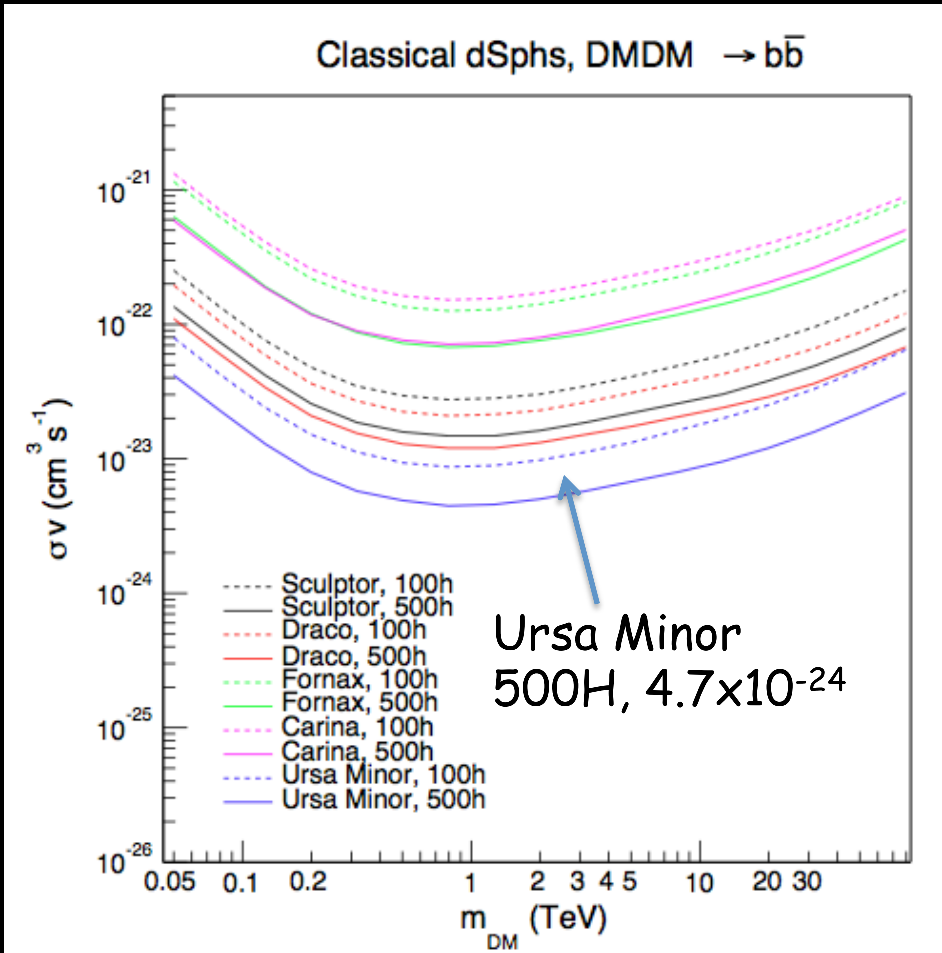
Dark matter halo extension

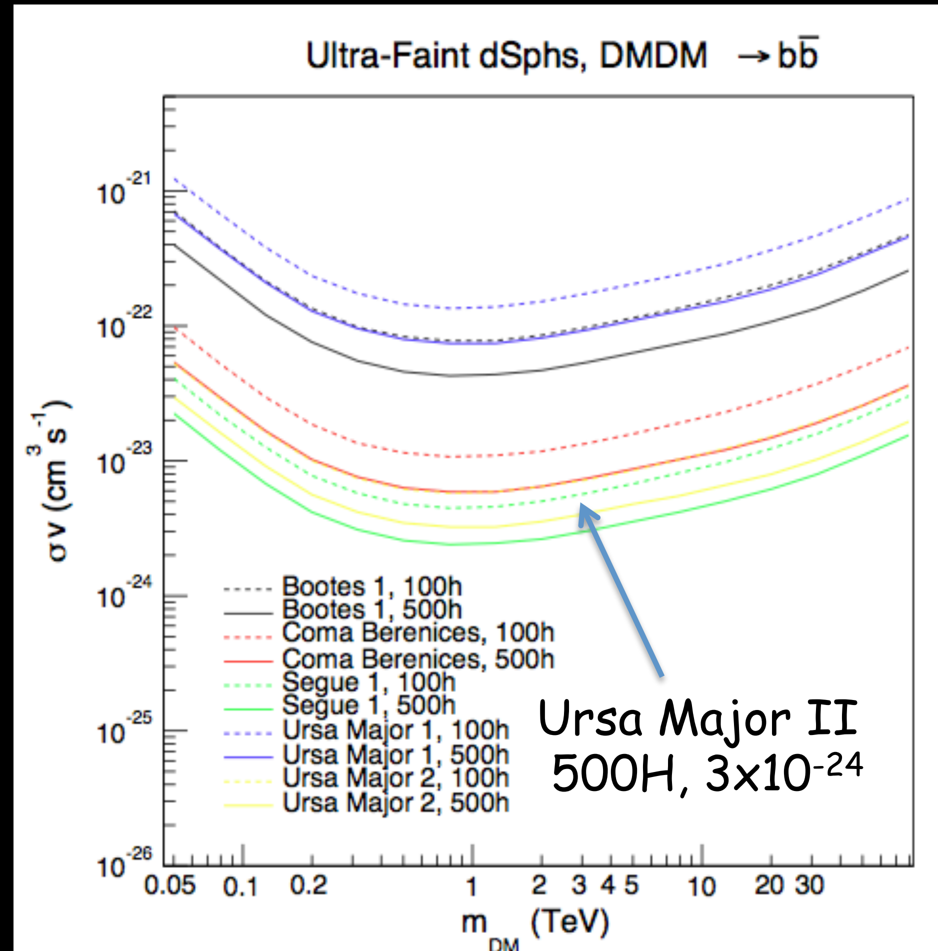
- DM halos of dSphs need to be considered as extended object !





Results

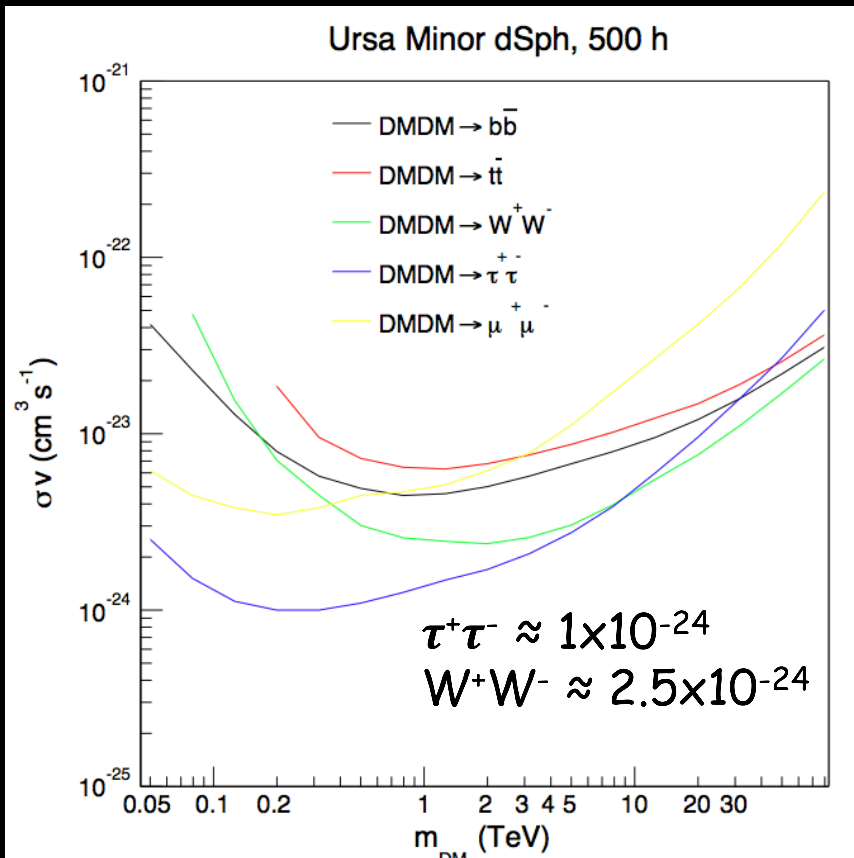




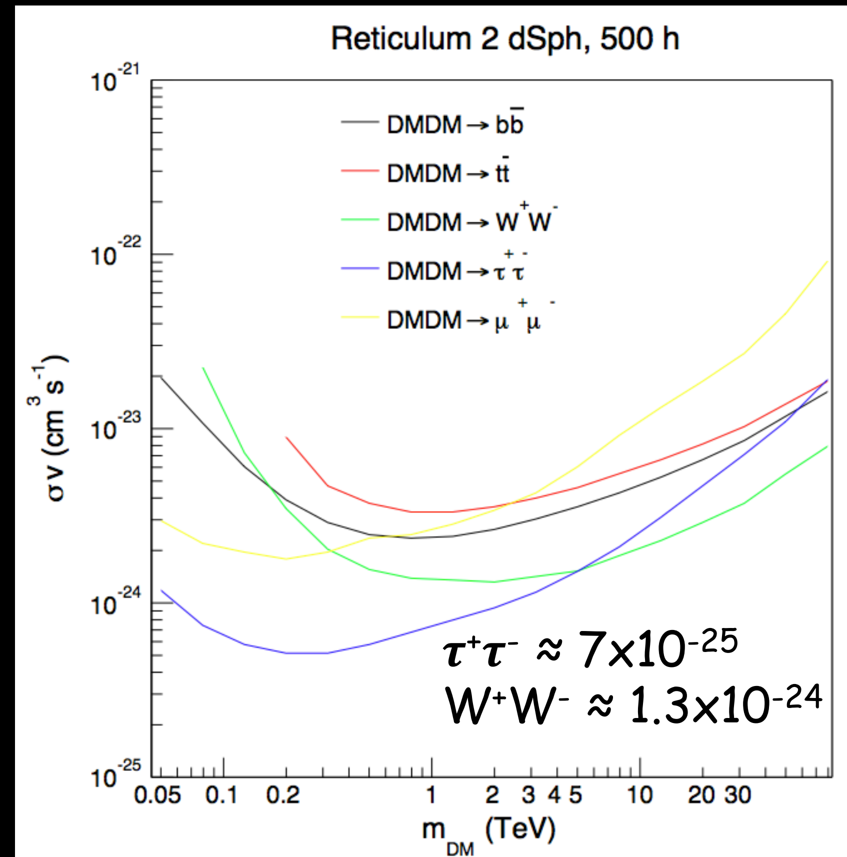
Caveat: Segue I J-factor may be overestimated by a factor 100
See Bonnivard et al. 1504.02048

Results Channels

Ursa Minor



Reticulum II



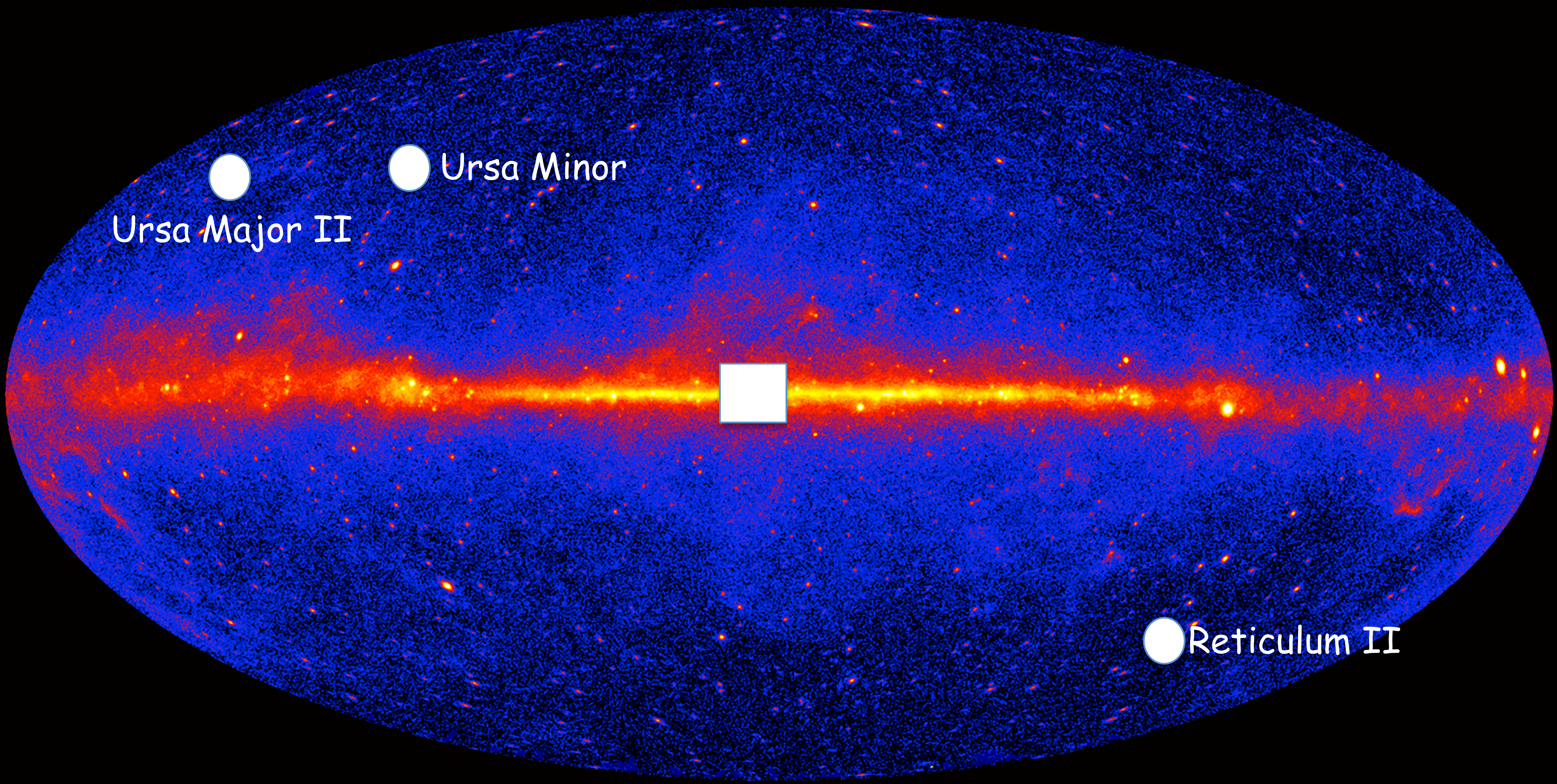
dSph J-factor modeling

Estimate of the systematics is crucial and further work is needed

- Confusion of stars with milky way stars
- Spherical symmetry assumed
- Differents star populations
- Data Binning
- Constant velocity anisotropy
- Exact position of the center of the dSph
- Tidal stripping
- Supermassive black hole …

Dark matter lines

V.L., E.Moulin, P.Panci, F.Sala, J.Silk, in prep



Dark matter lines

- Galactic Center :

J factor can be degraded by several orders of magnitude depending on the DM distibution.

(core vs cuspy profile)

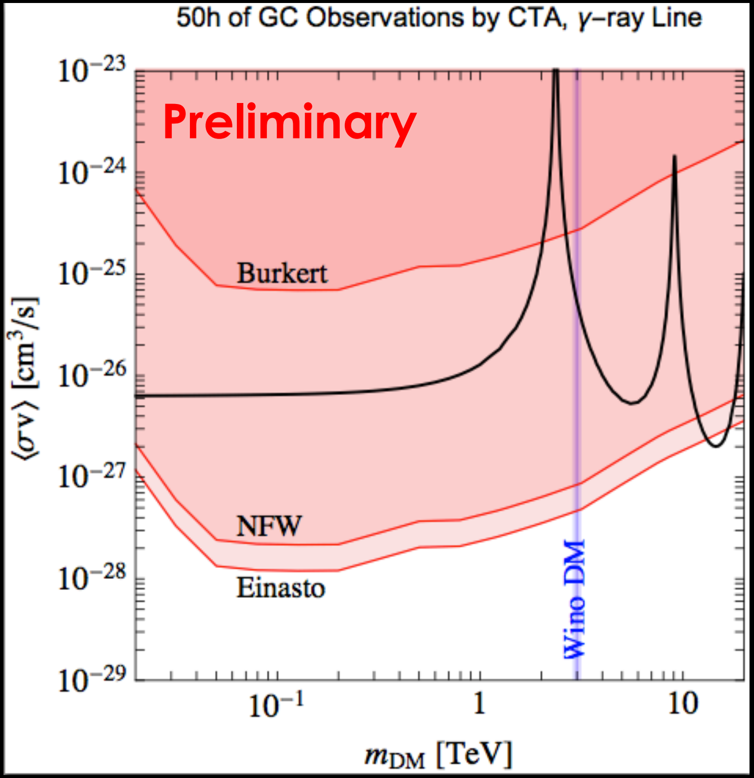
- Dwarfs galaxies :

Sommerfeld enhancement expected due to low velocities

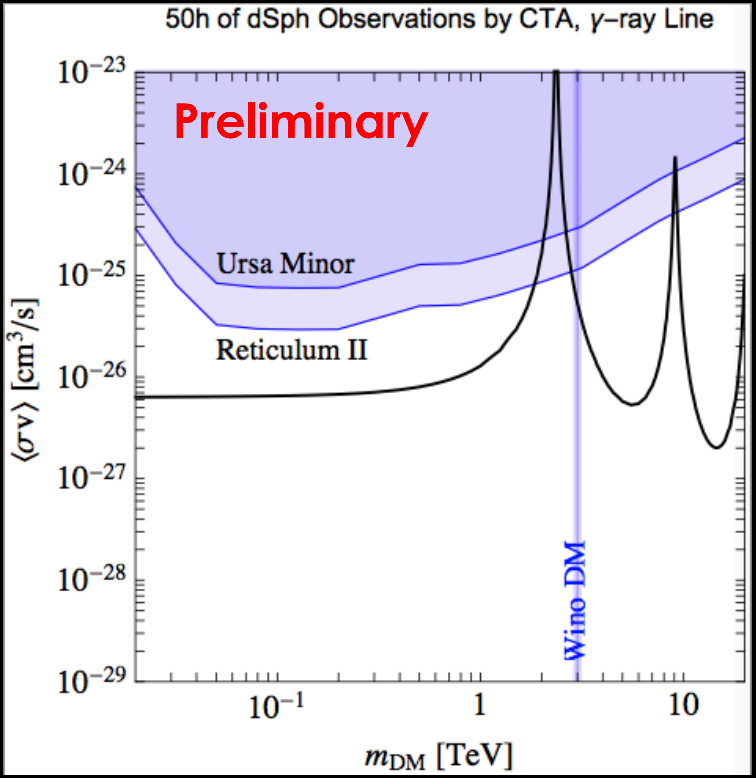
  - Well-motivated models with EW interactions can be probed with ~100 hours of observation on the best dSph targets

Dark matter lines

Galactic Center

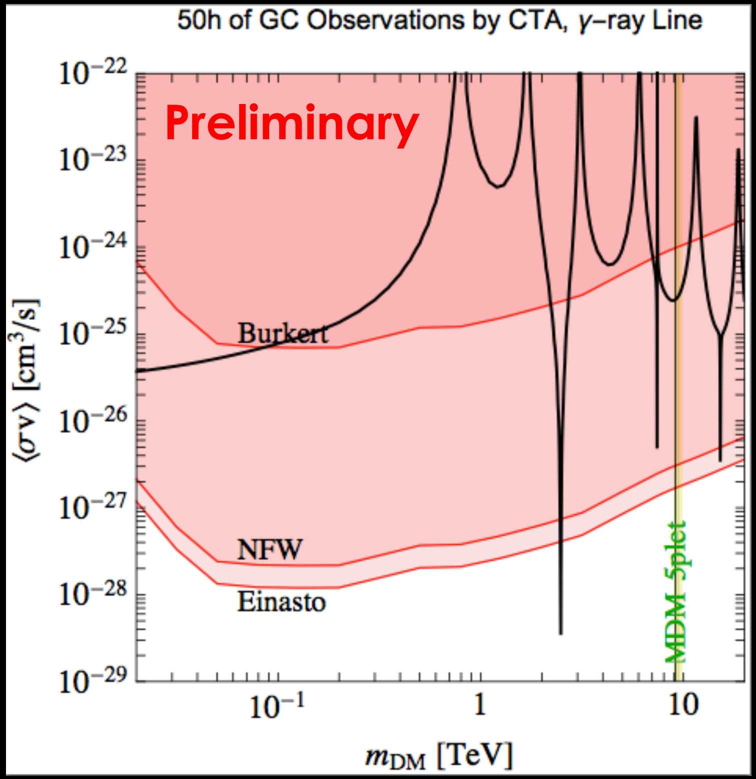


Dwarfs spheroïdal



Dark matter lines

Galactic Center



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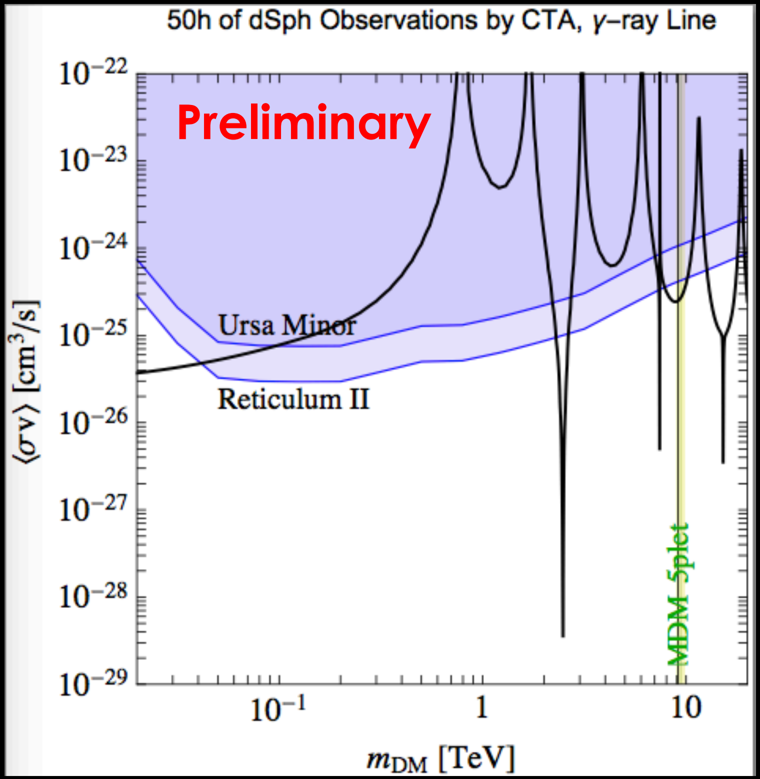

Summary

- Galactic halo will be a primary target for CTA
  - First time that thermal cross section can be probed by IACTs for cuspy DM distribution
  - Significant contribution from ICS emission for the leptonic channel

- Given current knowledge, dwarf galaxies observations should focus on Ursa Minor, Ursa Major II and Reticulum II.
  - Exclusion Well-motivated models with EW interactions in case of line.