Prospects for a dark matter annihilation signal towards the Sagittarius dwarf galaxy with ground based Cherenkov telecopes

Aion Viana
Based on arXiv:1103.2627

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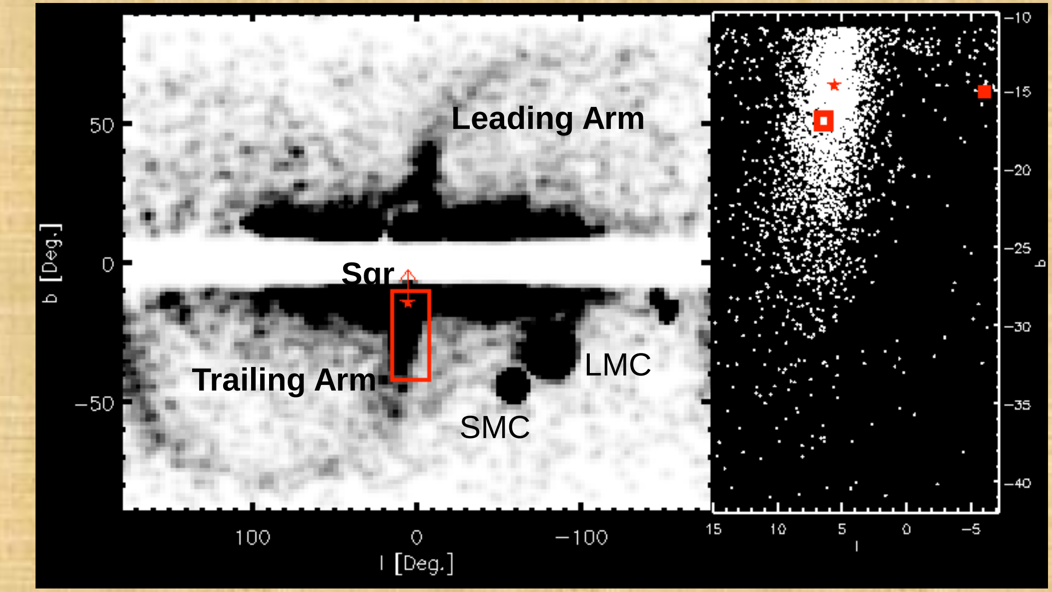
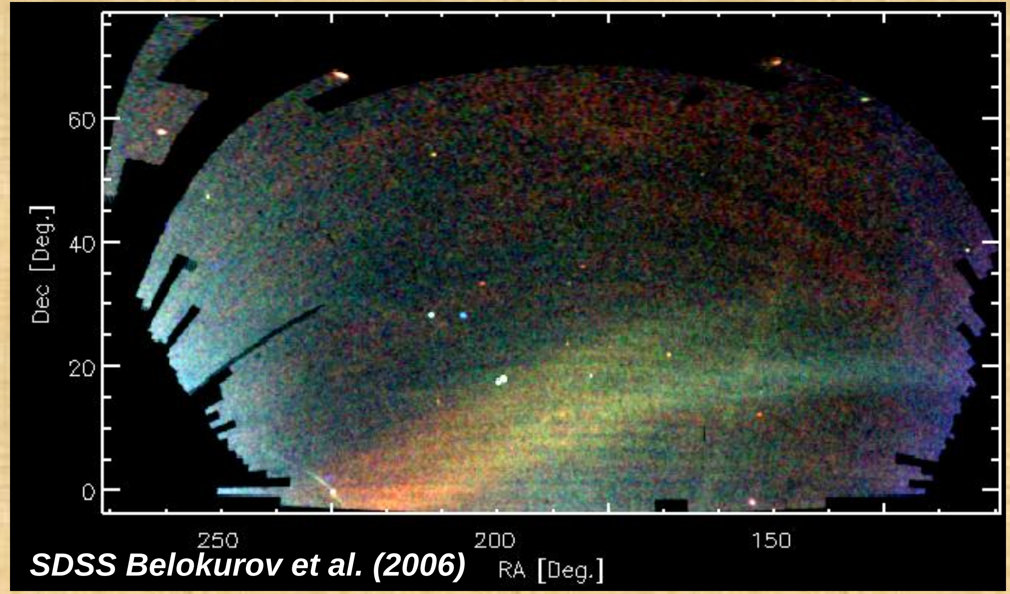
Outlines

- The Sagittarius dwarf galaxy
- Indirect Dark Matter search principle
- Sagittarius dwarf DM halo modelling
- Updated exclusion limits
- Next generation of IACTs: CTA
- Astrophysical backgrounds
- Summary

The Sagittarius dwarf spheroidal galaxy





SDSS Belokurov et al. (2006)

- Discovered by Ibata, Gilmore, Irwin (1994)
- Heliocentric distance 24 kpc; on the opposite side of the Galactic Centre
- Brightest known Galactic dwarf spheroidal MV = -13.3
- Shows clear evidence of ongoing tidal mass stripping in the form of an associated tidal stream => hard DM halo modelling
- Has been claimed to be among the best target for indirect DM seaches, because of its near location

Indirect dark matter searches through gamma-rays

DM self-annihilation rate :

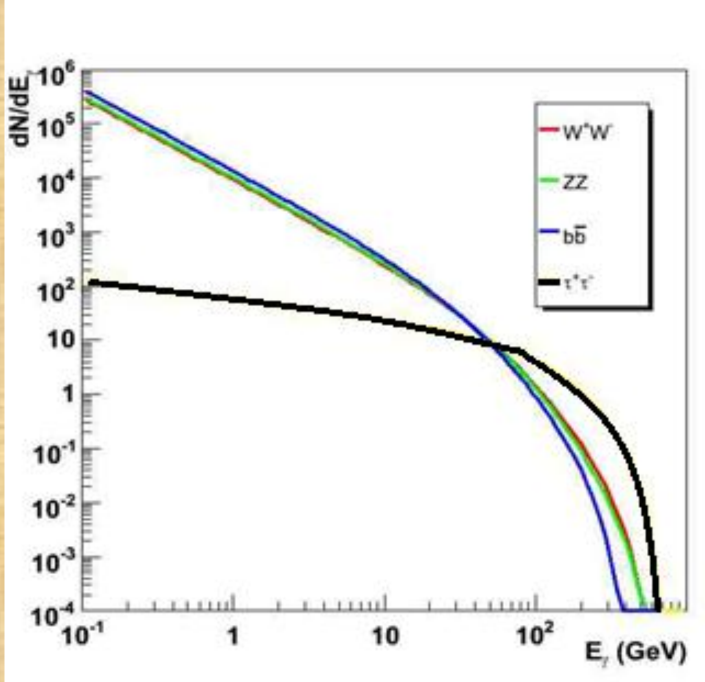
$$\Gamma_\chi \approx \sigma v \frac{\rho_\chi^2}{m_\chi^2}$$

Gamma-ray flux from annihilation of a WIMP:

$$\frac{\mathrm{d}\Phi(\Delta\Omega, E_\gamma)}{\mathrm{d}E_\gamma} = \frac{1}{8\pi} \underbrace{\frac{\langle\sigma v\rangle}{m_\chi^2} \frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}}_{Particle\,Physics} \times \underbrace{\bar{J}(\Delta\Omega)\Delta\Omega}_{Astrophysics} \quad \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{GeV}^{-1}$$

where

Gamma spectrum: typically a continuum with an cut-off at the DM particle mass



and

$$\bar{J}(l,b) = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{los} \rho^2[r(s)]ds$$

Openning angle of obs.: $\Delta\Omega \approx 10^{-3} - 10^{-6}\,sr$

Strong dependence on dark matter density distribution modeling; halo density profile model is needed

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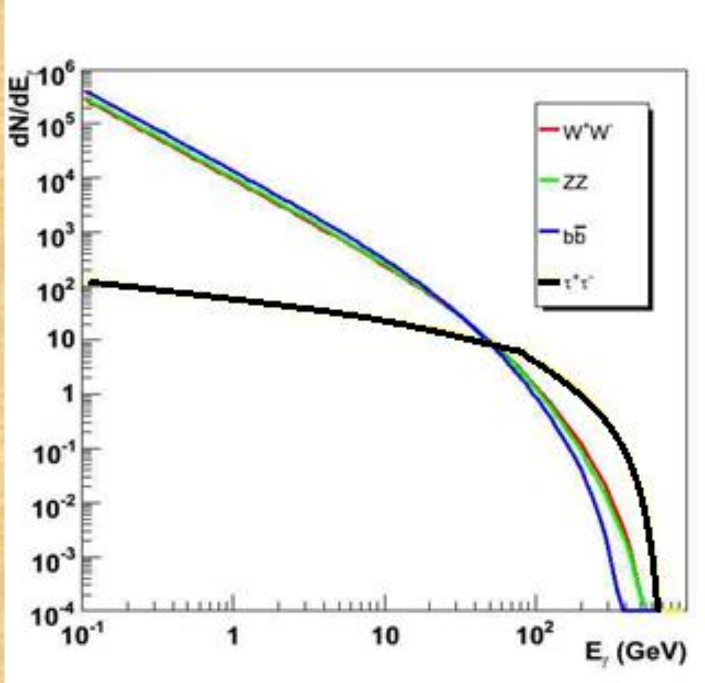

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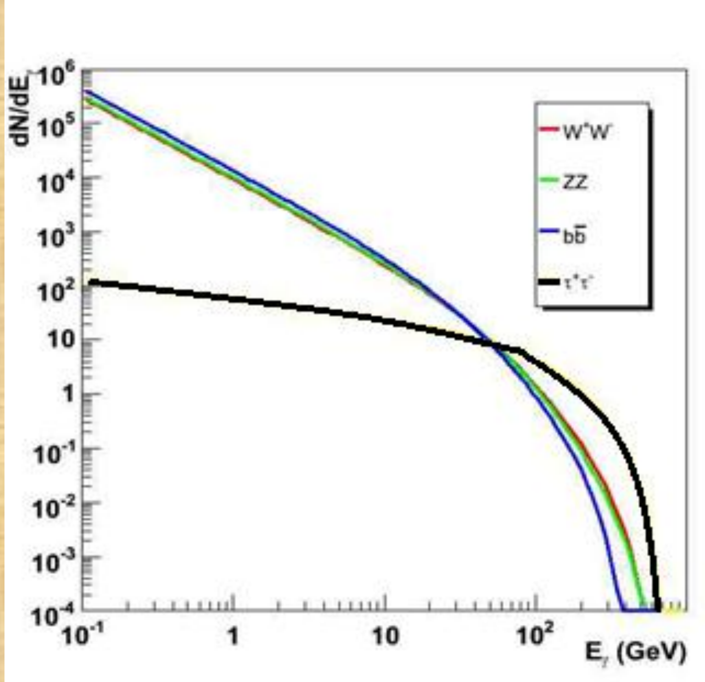

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Dark Matter halo modeling

$$\rho(r) \rightarrow ?$$

- Cosmological N-body numerical simulations => Cusp profile
- Analytical solutions of the Jeans equation(hydrodynamics) => Cored profile

•Two differents types of DM halo profiles are taken as examples:

-NFW profile: N-body simulations

-cored profile: analytic resolution of the Jeans equation

$$\begin{cases} \rho_{NFW}(r) = \dfrac{\rho_s}{(r/r_s)(1+r/r_s)^2} \\ \rho_{ISO}(r) = \dfrac{m_h \alpha}{2\pi^{3/2} r_{cut}} \dfrac{\exp[-(r/r_{cut})^2]}{(r_c^2+r^2)} \end{cases}$$

The parameters are found after solving the Jeans equation from observation of the stars dynamics(luminous density, velocity dispersion, velocity anisotropy…) inside the galaxy

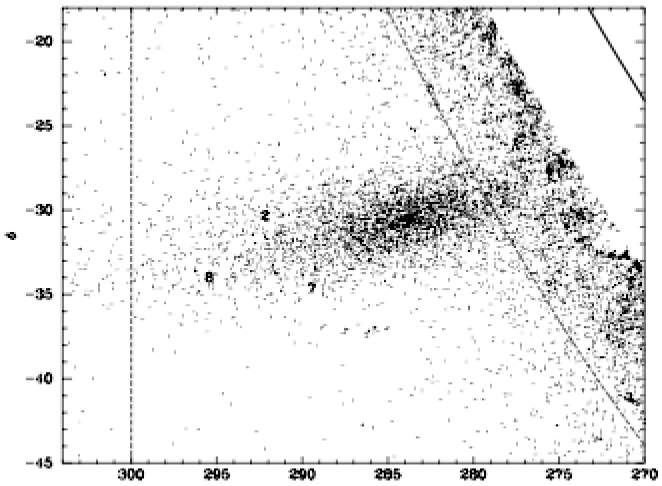
Problem: the distribution stars has been clearly altered from its original configuration by tidal mass stripping!

Dark Matter halo modeling

NFW profile

- Tightly bound dark matter cusp is more resilient to disruption
- The kinematics of stars that locate the central regions of the dwarf are not influenced by external tidal field

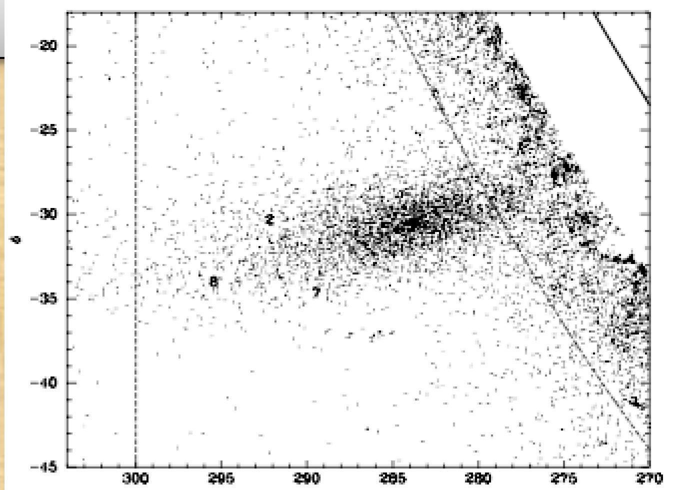
Jeans equations to search the DM halo parameters that best fit the observed stellar kinematics



Majewski (2003)

Dark Matter halo modeling

NFW profile



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Isothermal cored profile

Leading and trailing tails show the future and past location of the progenitor system

Peñarrubia, J. et al. (2010). MNRAS, 408, L26

Streams trace orbits

Orbits depend on DM halo potential

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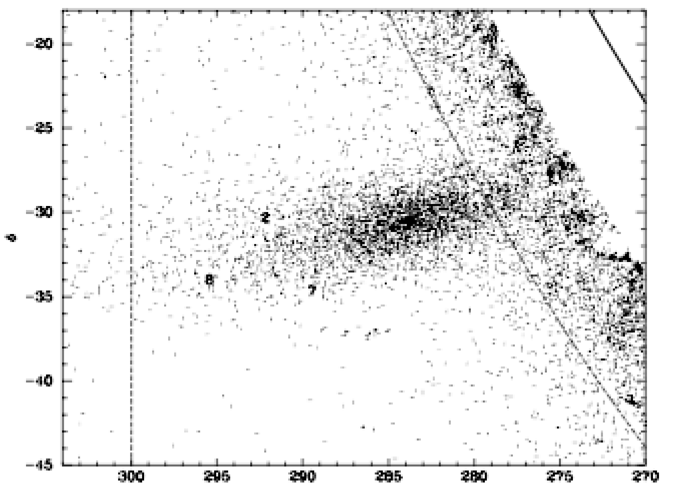

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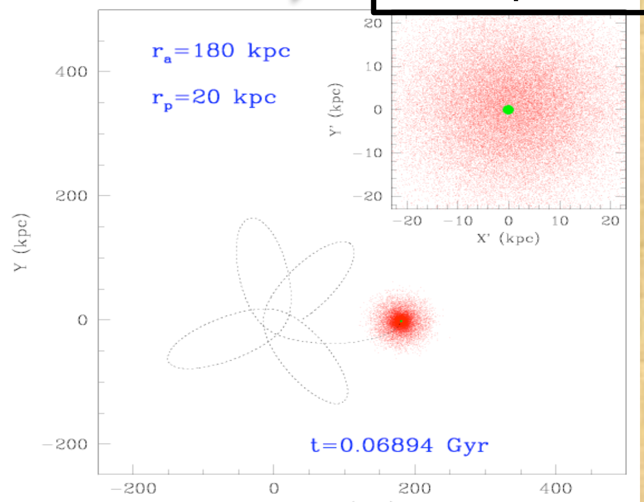

Peñarrubia, Navarro & McConnachie (2008)

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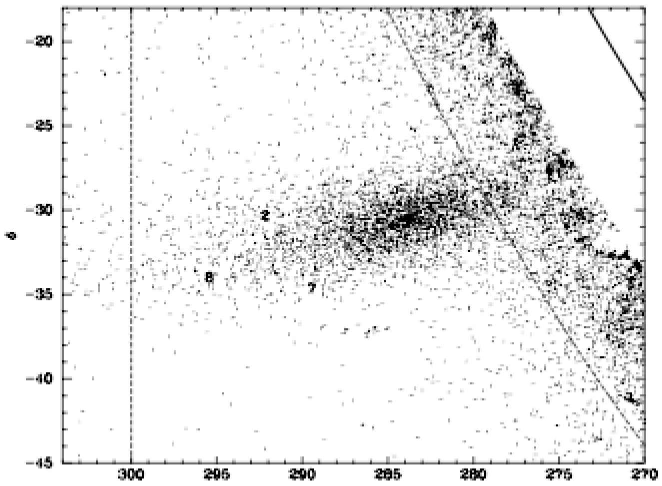

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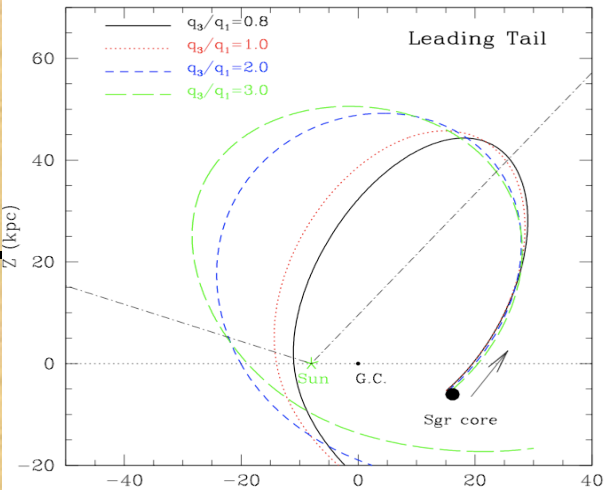
Evolution code assuming a initial ISO profile

Fit the known stream with semi-analytic orbits

Allows to recover the actual DM profile



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Sensitivity curves to DM annihilation

In case of no gamma-ray signal, a limit on the number of gamma rays can be derived by:

- Numbers of gamma-ray in the signal region (N_{ON}) and background events (N_{OFF}) from measurements in a observation

- Assuming $N_{ON} = N_{OFF}$ for a known background (model) in the sensitivities calculations

- **The 95% C.L. limit on Nγ provides a 95% C.L. limit on the velocity-weighted cross section for a given DM profile:**

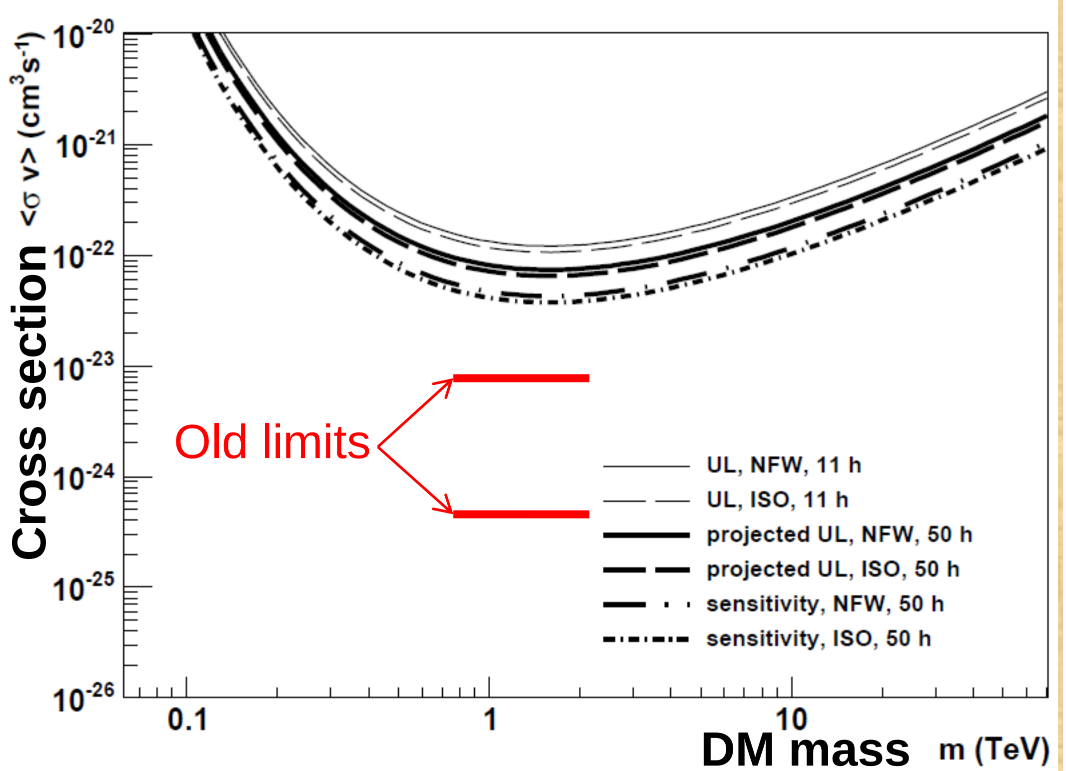
$$\langle \sigma v \rangle^{95\%\,C.L.}_{\mathrm{min}} = \frac{8\pi}{\bar{J}(\Delta\Omega)\Delta\Omega} \times \frac{m_\chi^2\, N^{95\%\,C.L.}_{\gamma,tot}}{T_{\mathrm{obs}} \int_0^{m_\chi} A_{eff}(E_\gamma)\,\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}(E_\gamma)\,\mathrm{d}E_\gamma}$$

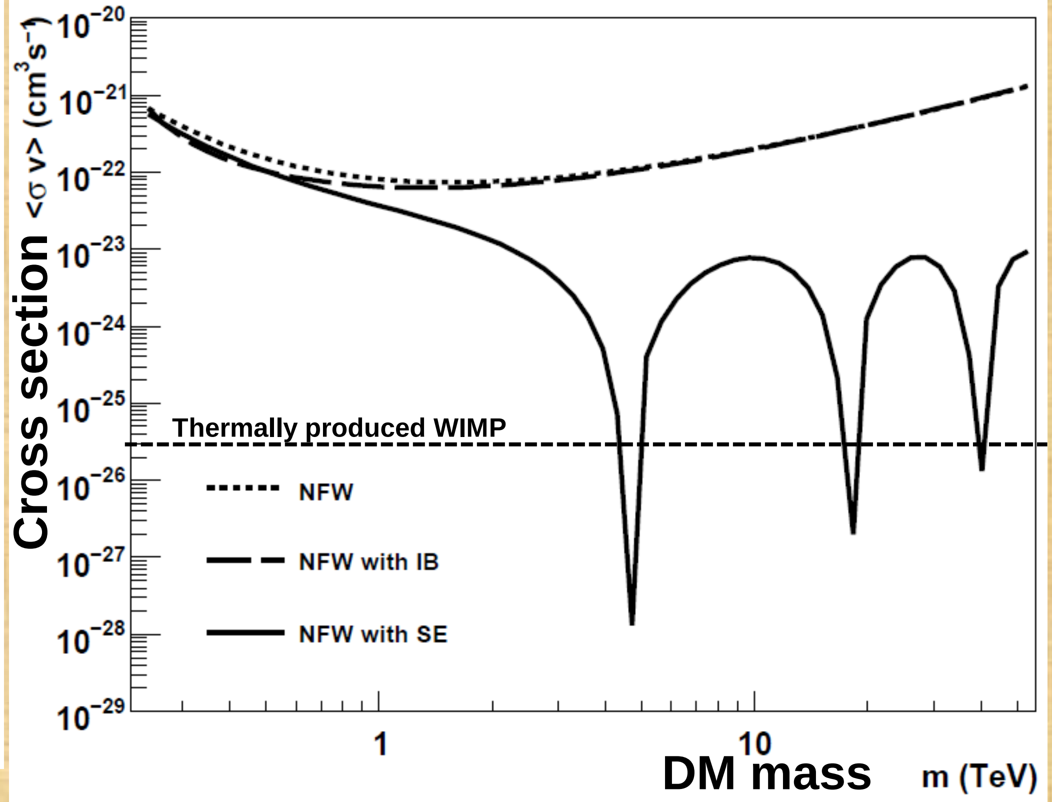
➢ **the velocity-weighted cross-section is then calculated as function of the DM particle mass**

➢ **A spectrum of a typical Dark Matter particle annihilating into W and Z pairs is used (e.g. SUSY neutralino)**

Sensitivity curves to DM annihilation: Updated H.E.S.S. upper-limits

Using published H.E.S.S. data on Sagittarius dwarf:





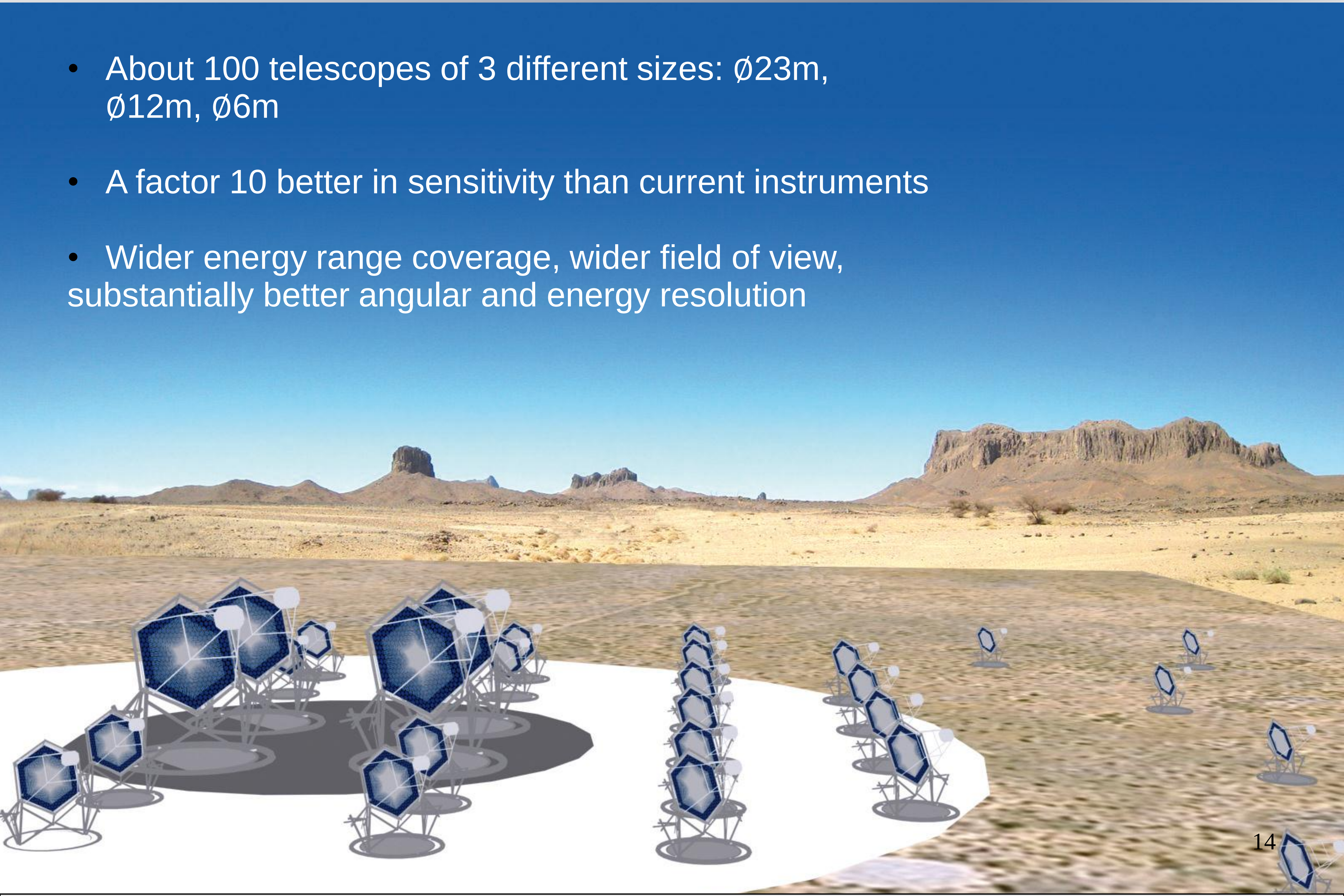
- Updated limits with new halos models
- Old limits overestimate the DM gamma-ray flux
- Unrealistic DM halo models due to lack of accurate modelling of SgrDw at that time
- Projected upper limits and sensitivity for 50h

Next generation of IACTs : the CTA case

- About 100 telescopes of 3 different sizes: ø23m, ø12m, ø6m

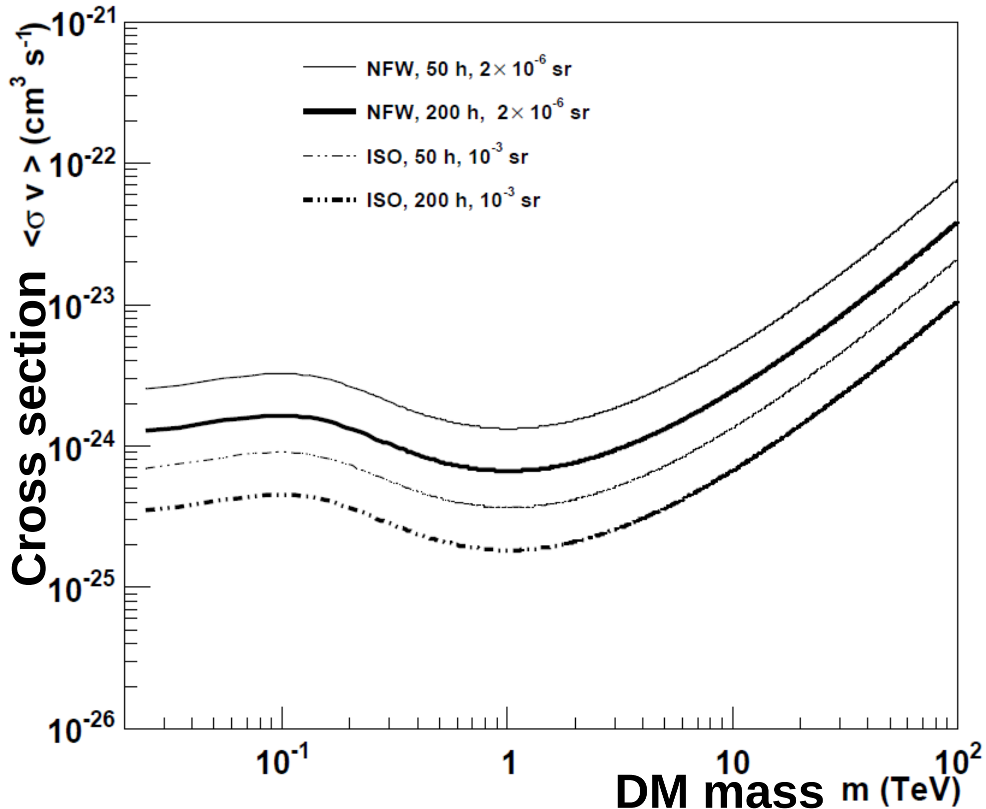
- A factor 10 better in sensitivity than current instruments

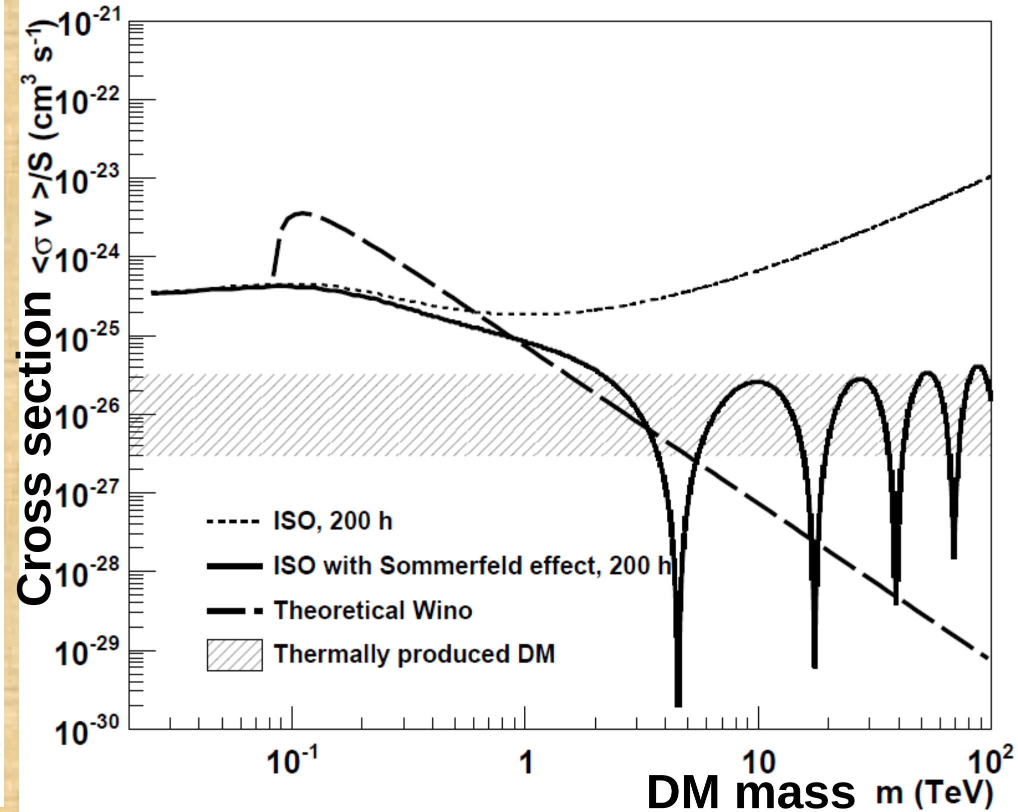
- Wider energy range coverage, wider field of view, substantially better angular and energy resolution



Sensitivity curves to DM annihilation: CTA sensitivities

Using public CTA effective area:





- sensitivities are improved by more than one order of magnitude for DM masses above 1 TeV

- thermally-produced DM can be tested for specific wino masses in the resonance regions of the Sommerfeld effect

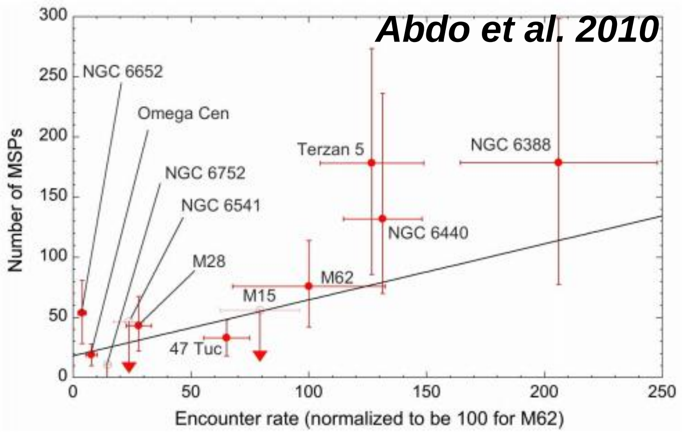
Astrophysical background emission

- Although are generally believed to contain very little background emission from conventional astrophysical sources, some gamma-ray emitting sources may still exist

- For instance, dwarf spheroidal galaxies can habours **globular clusters (M54 in the center of SgrDw), and globular cluster can host:**

➢ Milisecond pulsars population

- Collective emission of HE and VHE gamma-rays
- After 200h => 4σ - 60σ signal with reasonable assumption
- After 200h a thermally produced DM would give a 0.1σ signal


Abdo et al. 2010

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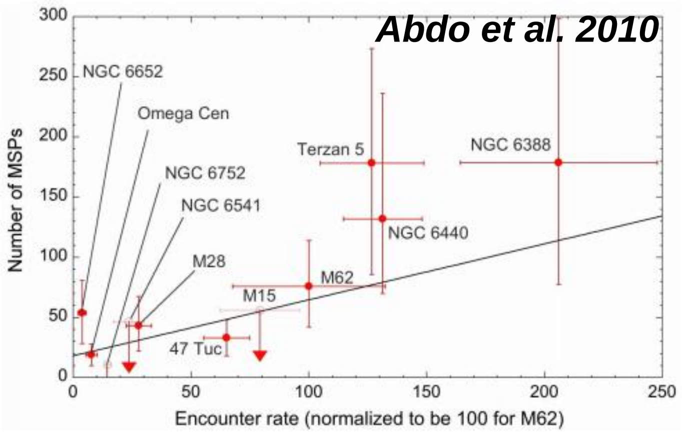
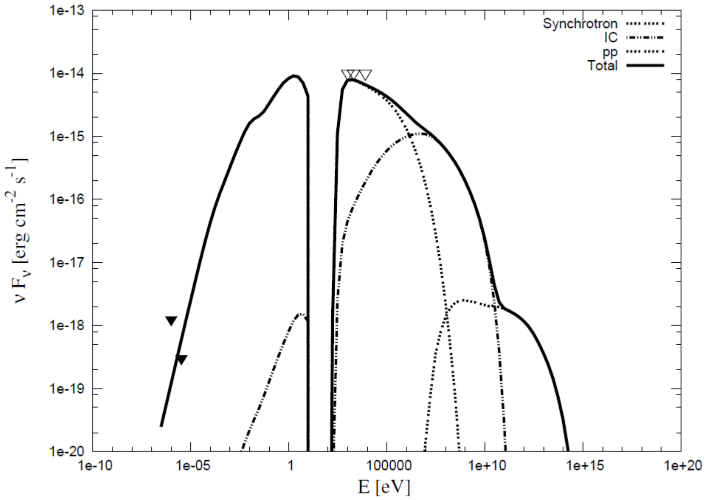

Abdo et al. 2010

➢ Intermediate mass black hole

- Gamma-ray emission of relativistic jets
- Signal is not detectable
- Jet inclination angle = 45° => conservative estimation
- If jet is aligned with the line-of-sight it might be detectable



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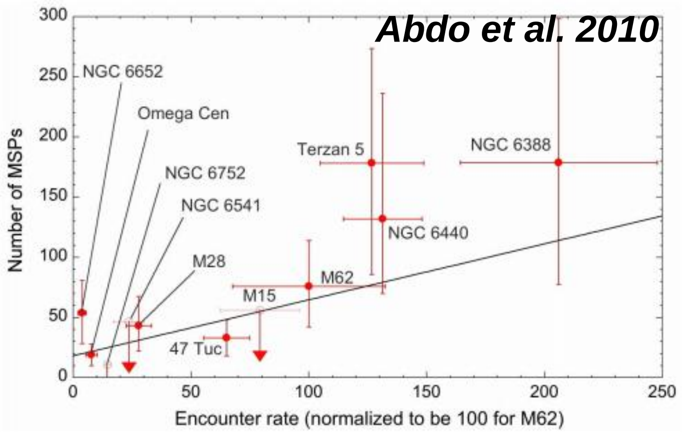
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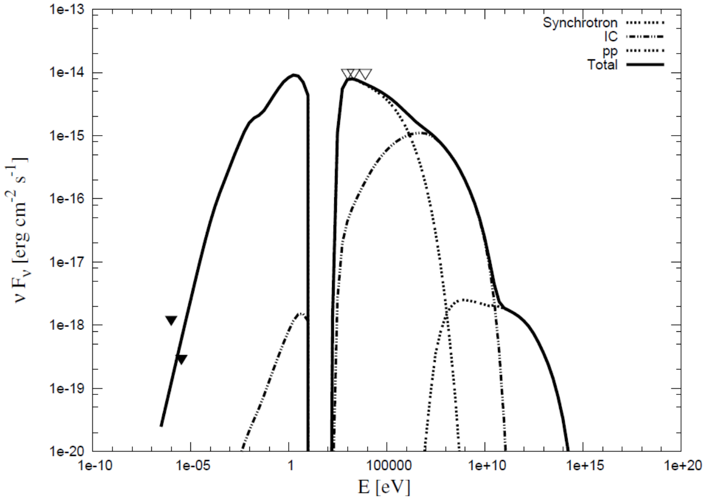

The collective MSP signal would be a few orders of magnitude stronger than a thermally produced DM annihilation signal.

Summary and conclusions

- Older publications on DM searches towards SgrDw gave too optimistic constraints on particle dark matter self-annihilation cross sections => lack of accurate modelling of SgrDw at that time (still the case for several galaxies)

- Realistic models are now published => loosen the existing constraints by more than one order of magnitude

- The future CTA array will be sensitive to $<\sigma v>$ values around a few 10^{-25} cm^3 s^{-1}.

- Some models could be excluded after 200 hours of observation, if boosts factors are taken into account

- VHE emission of milisecond pulsars population could give an observable signal for long-enough observation times and be a challenging astrophysical gamma ray background to overcome

- The candidate IMBH located at the center is not expected to give an observable signal => Under favorable circumstances (active black hole and jet aligned towards the line of sight), it might nevertheless be detectable in observations of SgrDw.

Backup slides

Dark Matter halo modeling

- From Jeans Equation: $$M(r) = r\left\langle v_r^2 \right\rangle\left(\frac{d\ln\rho}{d\ln r} + \frac{d\ln\left\langle v_r^2 \right\rangle}{d\ln r} - 2\beta\right)$$

$<v^2_r>$: radial velocity dispersion
ρ: luminous density
observed

M: luminous + dark mass
β: anisotropy
unknown

- Assumed ⟶ $\beta(r)$
  - solve for M(r) to get ρ_{dark}
  OR
  - fit DM halo parameters to $<v^2_r>$

- Two differents types of DM halo profiles are produced:

-NFW profile: fit of (ρ_s,r_s) parameters to $<v^2_r>$

-cored profile : evolution code of the stellar profile ⇒ analytic resolution of the Jeans equation

$$\rho_{NFW}(r) = \frac{\rho_s}{(r/r_s)(1 + r/r_s)^2}$$

$$\rho_{ISO}(r) = \frac{m_h\alpha}{2\pi^{3/2}r_{cut}} \frac{\exp[-(r/r_{cut})^2}{(r_c^2 + r^2)}$$

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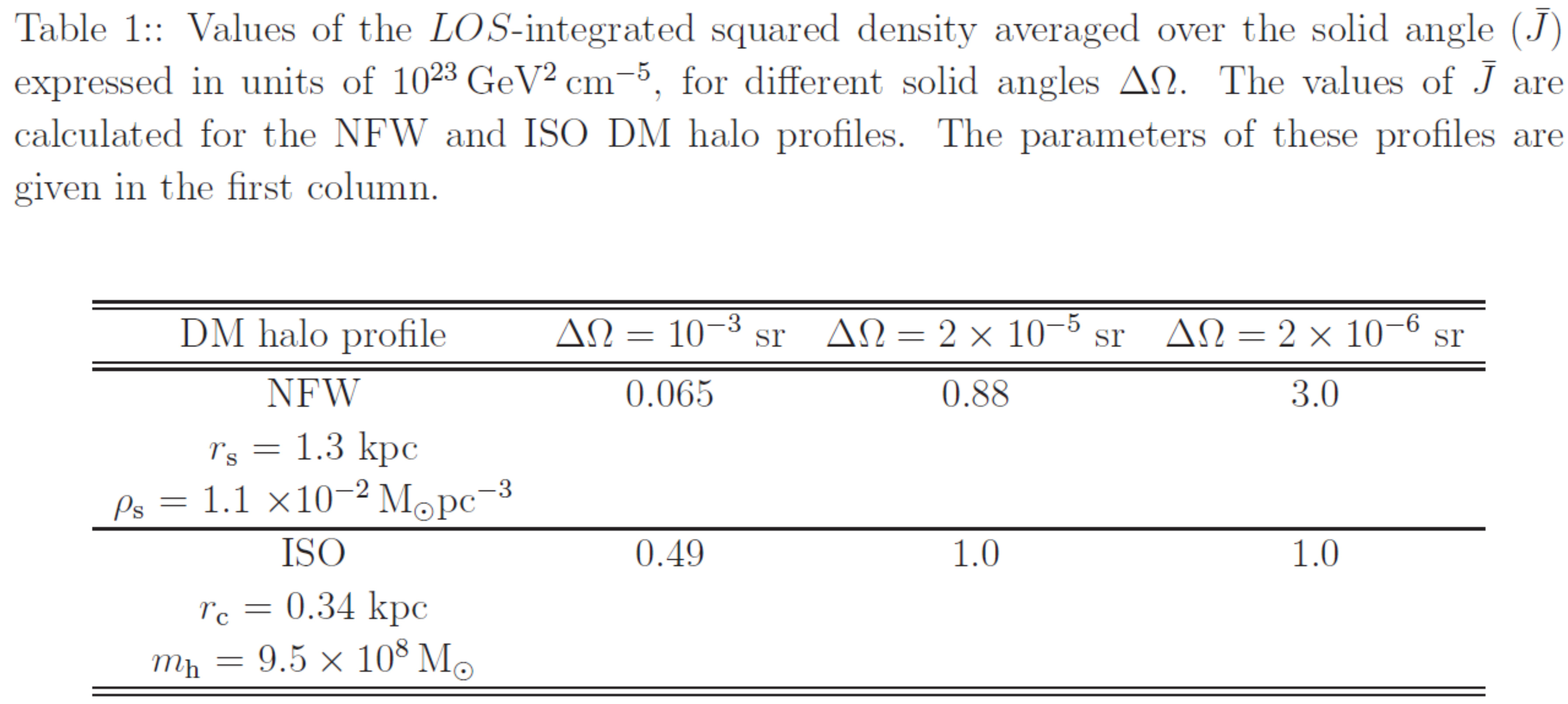

Table 1:: Values of the LOS-integrated squared density averaged over the solid angle ($\bar{J}$) expressed in units of $10^{23}\,\mathrm{GeV}^2\,\mathrm{cm}^{-5}$, for different solid angles $\Delta\Omega$. The values of $\bar{J}$ are calculated for the NFW and ISO DM halo profiles. The parameters of these profiles are given in the first column.

DM halo profile	$\Delta\Omega = 10^{-3}$ sr	$\Delta\Omega = 2 \times 10^{-5}$ sr	$\Delta\Omega = 2 \times 10^{-6}$ sr
NFW $r_s = 1.3$ kpc $\rho_s = 1.1 \times 10^{-2}\,M_\odot \mathrm{pc}^{-3}$	0.065	0.88	3.0
ISO $r_c = 0.34$ kpc $m_h = 9.5 \times 10^8\,M_\odot$	0.49	1.0	1.0