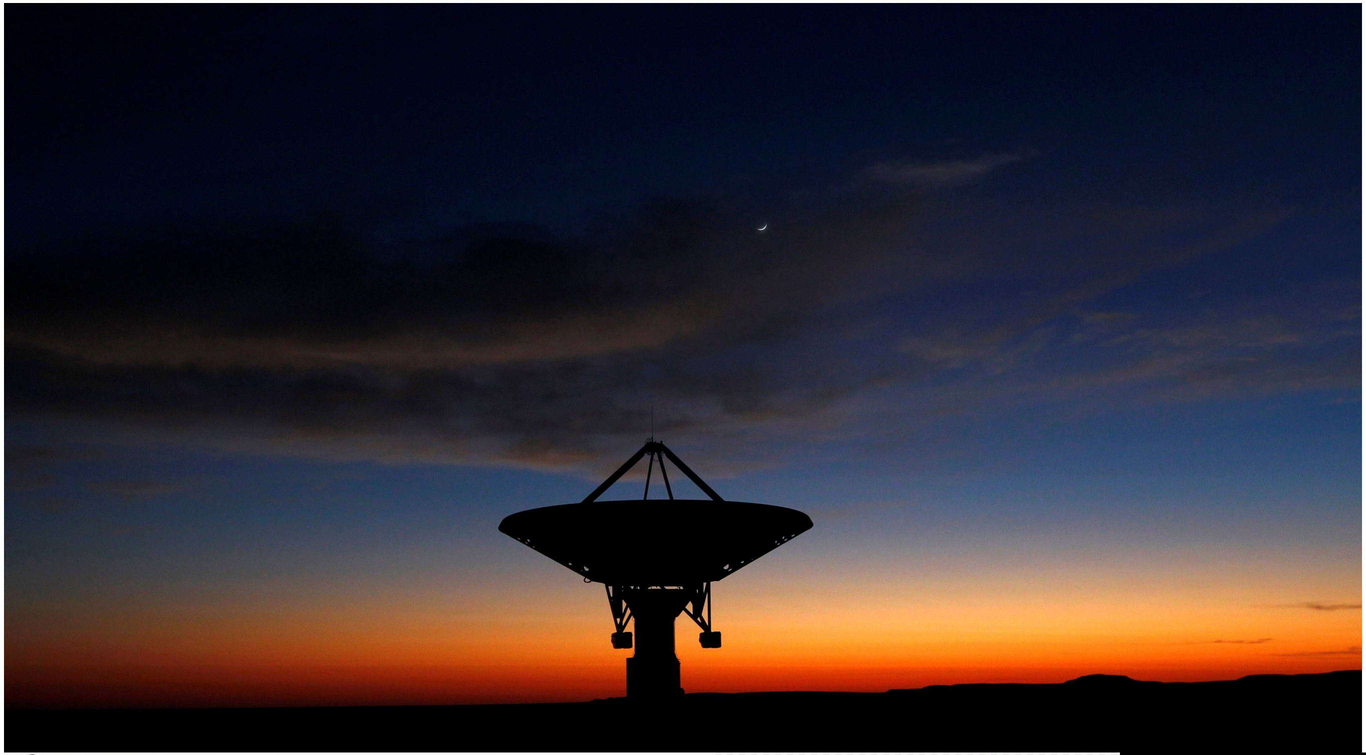
Particle dark matter searches with the Square Kilometre Array



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Outline

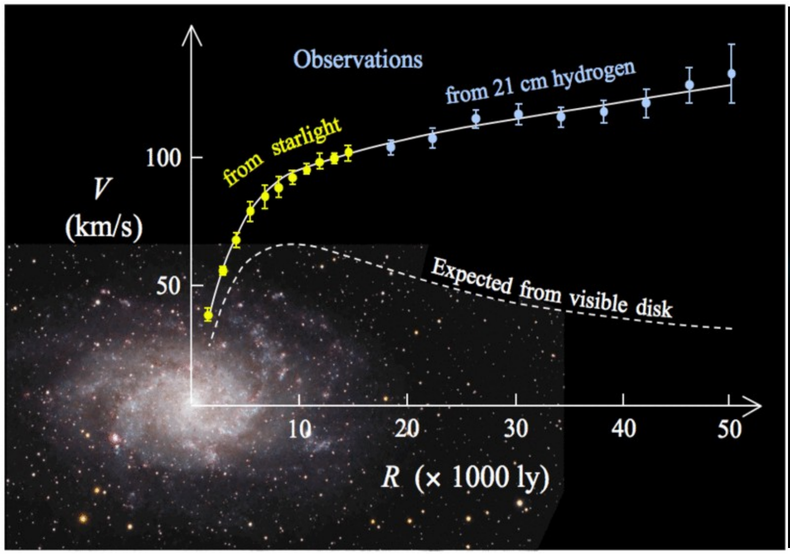
1. Brief introduction & Ingredients for Dark Matter detection

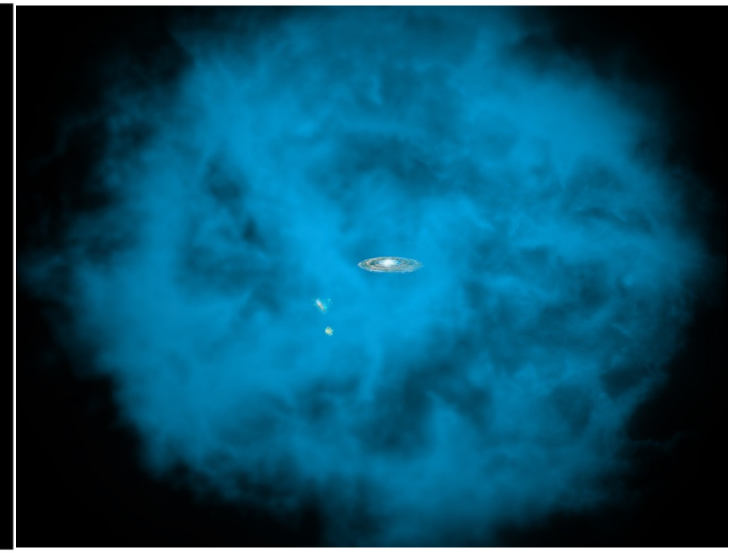
2. Dark Matter sensitivity prospects with SKA

Brief Introduction & Ingredients for Dark Matter detection

Brief Introduction

-Dark Matter halos:



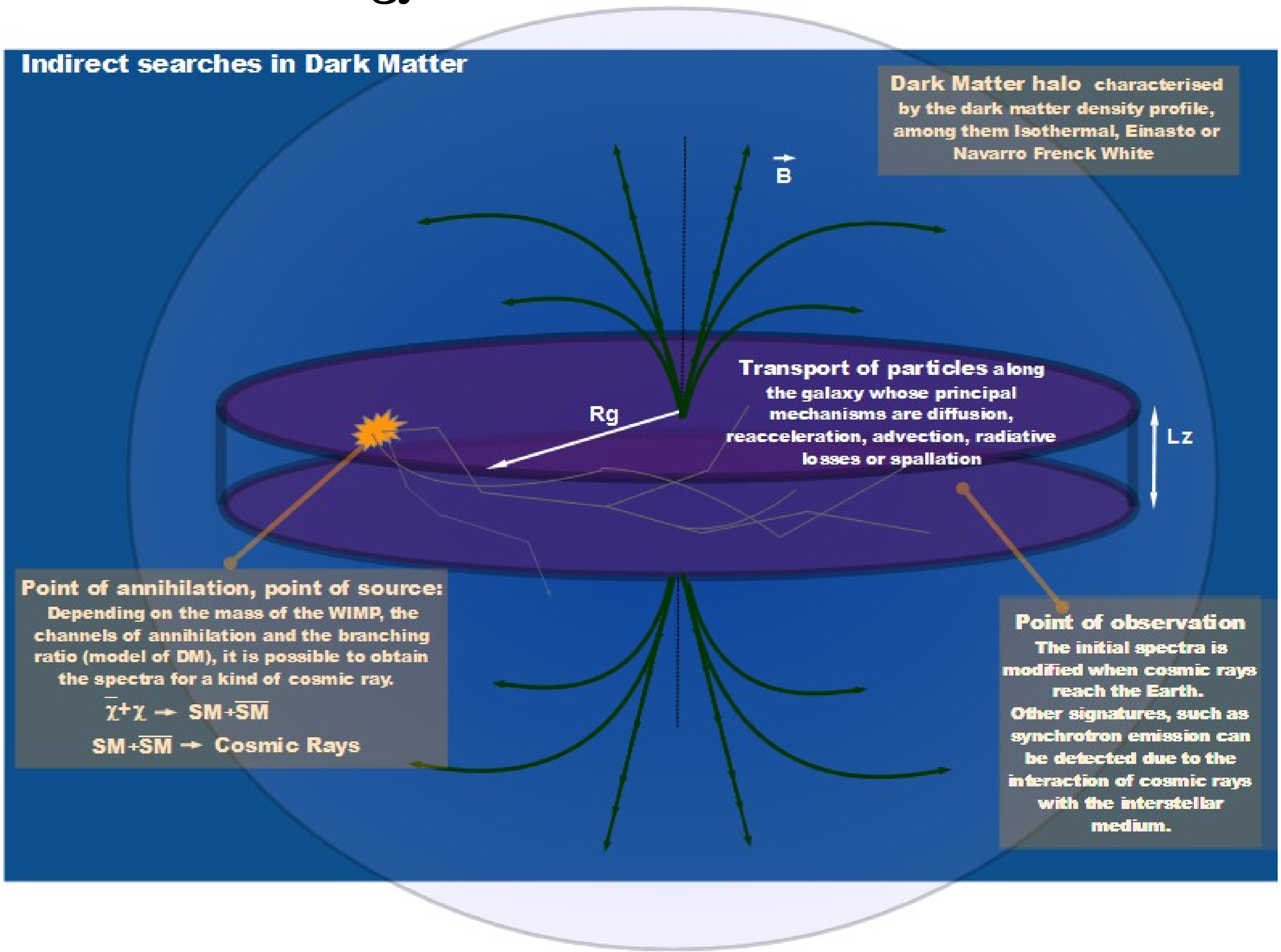


-Dark Matter decay and annihilation:

$$\mathrm{DM} \rightarrow \mathrm{SM} \rightarrow \text{Stable particles}$$

$$\mathrm{DM} + \overline{\mathrm{DM}} \rightarrow \mathrm{SM} + \overline{\mathrm{SM}} \rightarrow \text{Stable particles}$$

Phenomenology of Dark Matter Indirect Searches



1-DM density profile

2-Point of annihilation

Annihilation cross section

Injection spectra of annihilation products

3-Transport of products

-Diffusion

-Energy losses

4-Observation

In other words...

-For the target we focus on:

$$-K_0 E^{\delta} \nabla^2 \psi - \frac{\partial}{\partial E}(b(E)\psi) = Q(\mathbf{r}, E)$$

-Two main mechanisms govern the propagation:

1-Diffusion → Two parameters, K_0 , δ

2- Energy losses → $b(E)$ →Magnetic field

-Source term: $$Q(\mathbf{r}, E) = \frac{1}{2}\langle\sigma v\rangle \left(\frac{\rho_{\rm DM}(\mathbf{r})}{M}\right)^2 \sum_j \beta_j \frac{\mathrm{d}N_e^j}{\mathrm{d}E}$$

where $\psi(\mathbf{r}, E)$ is the e^+ / e^- number density/ energy along the whole galaxy

Solution for the diffusion equation: Spherical case

- Target: dwarf spheroidals → Spherical diffusion assumed

Using the Green's method:

-The solution for the spherically symmetryc case:

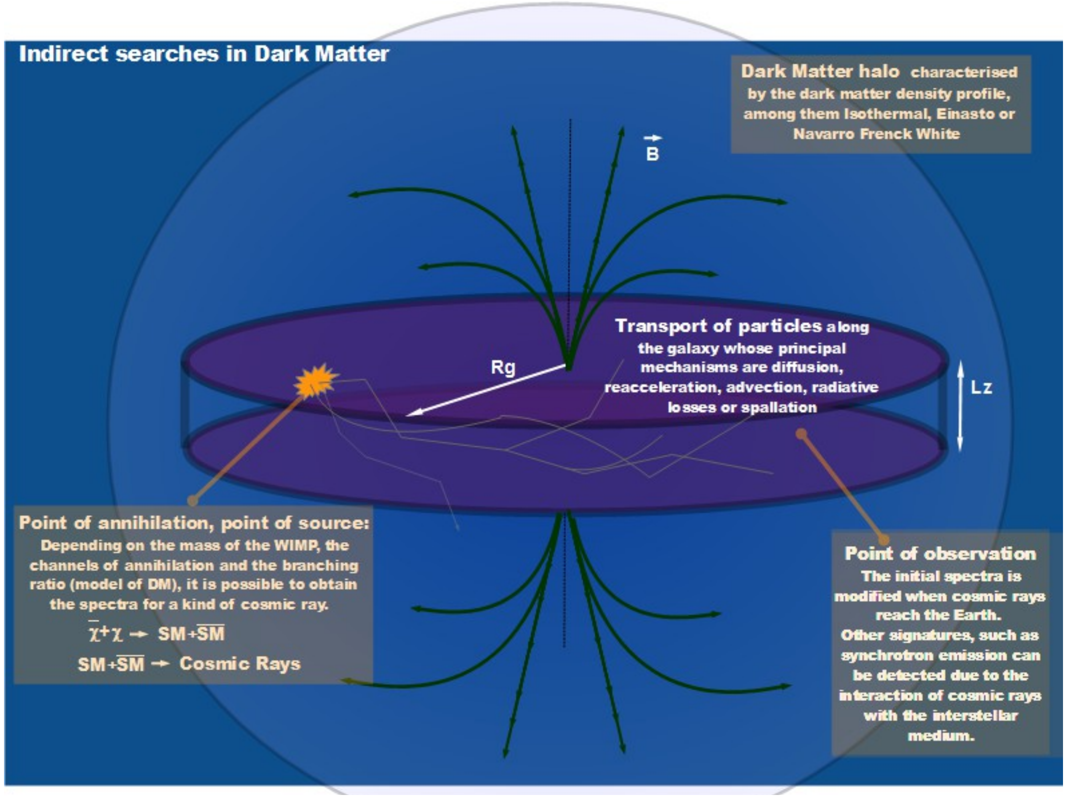
$$\psi(\mathbf{r},E) = \frac{1}{b(\mathbf{r},E)} \int_E^M \mathrm{d}E_s G\left(r,E,E_s\right) Q(\mathbf{r},E)$$

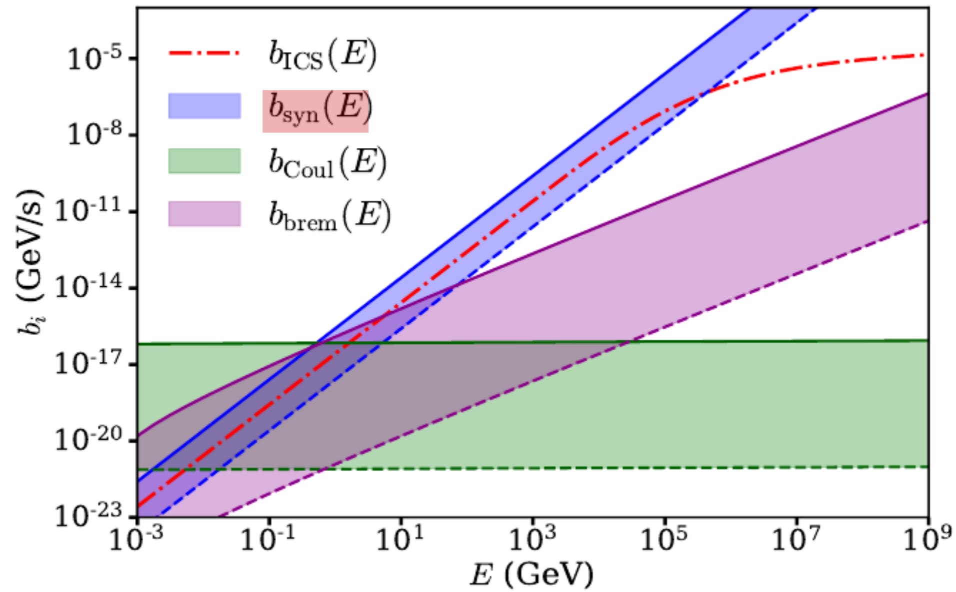
with

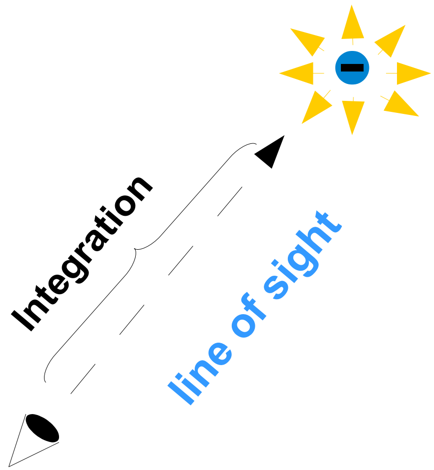
$$G\left(r,E,E_s\right) = \frac{1}{\sqrt{\pi \lambda_D^2(E,E_s)}} \sum_{n=-\infty}^{\infty} (-1)^n \int_0^{r_h} \mathrm{d}r' \frac{r'}{r_n} \left(\frac{\rho_{\mathrm{DM}}(r')}{\rho_{\mathrm{DM}}(r)} \right)^2 \left[\exp(-g_n^-) - \exp(-g_n^+)\right]$$

with $g_n^{\pm}(r',E,E_s) = \frac{(r' \pm r_n r)^2}{\lambda_D^2(E,E_s)}$

Energy losses







$$-K_0\epsilon^{\delta}\nabla^2\psi - \frac{\partial}{\partial E}(b(E)\psi) = Q(\mathbf{r}, E)$$

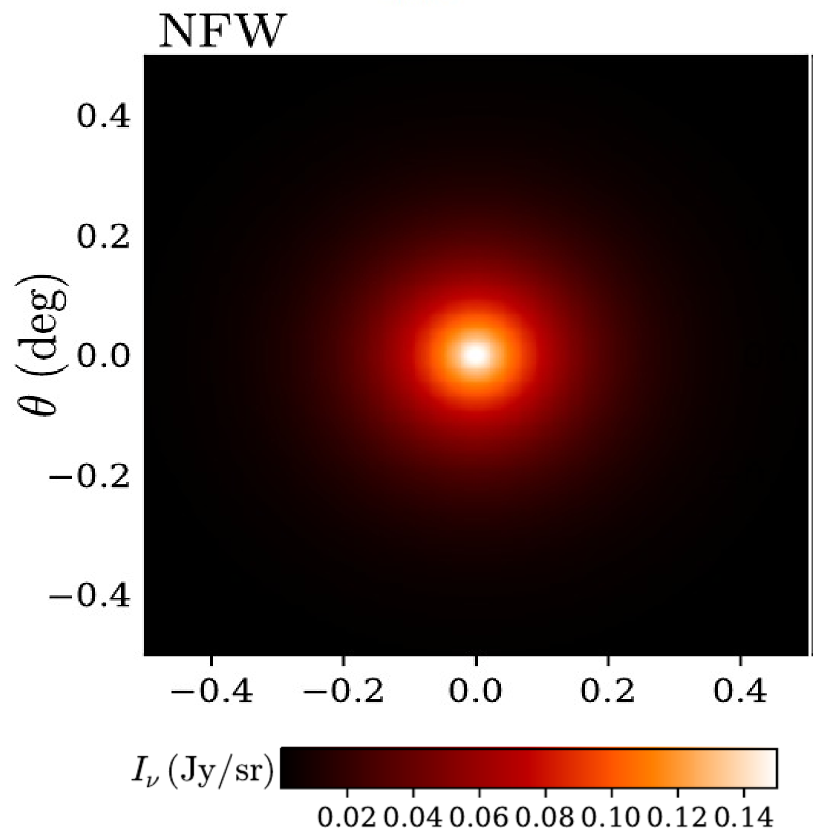
$$j_\nu(\mathbf{r}, z) = 2\int_E^M \mathrm{d}E\,\psi(\mathbf{r}, E)P_{\mathrm{syn}}(\nu, \mathbf{r}, E, z)$$

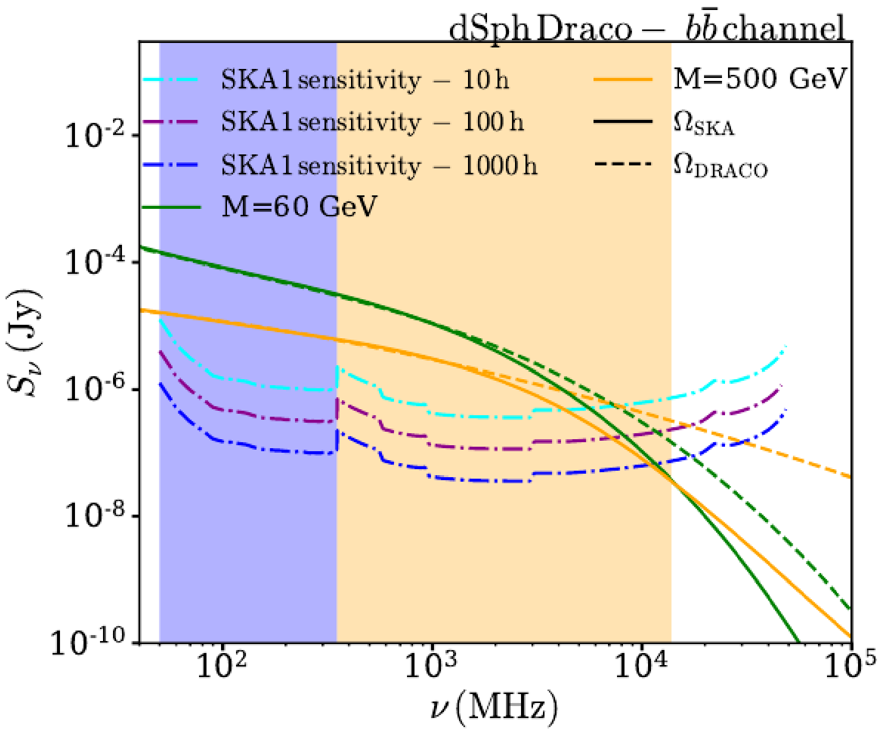
Dark Matter sensitivity prospects with SKA

Quantities to be measured

$$I_\nu(\theta, z) = \int_{\text{l.o.s.}} \mathrm{d}l \, \frac{j_\nu(l, \theta, z)}{4\pi}$$

$$S_\nu(z) = \int_\Omega \mathrm{d}\Omega \, I_\nu(\theta, z)$$



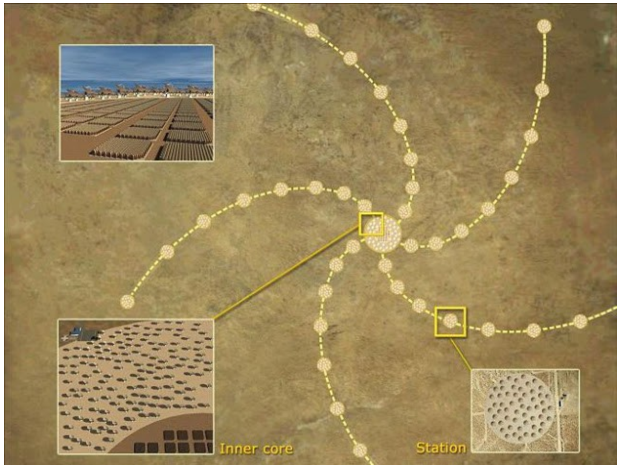


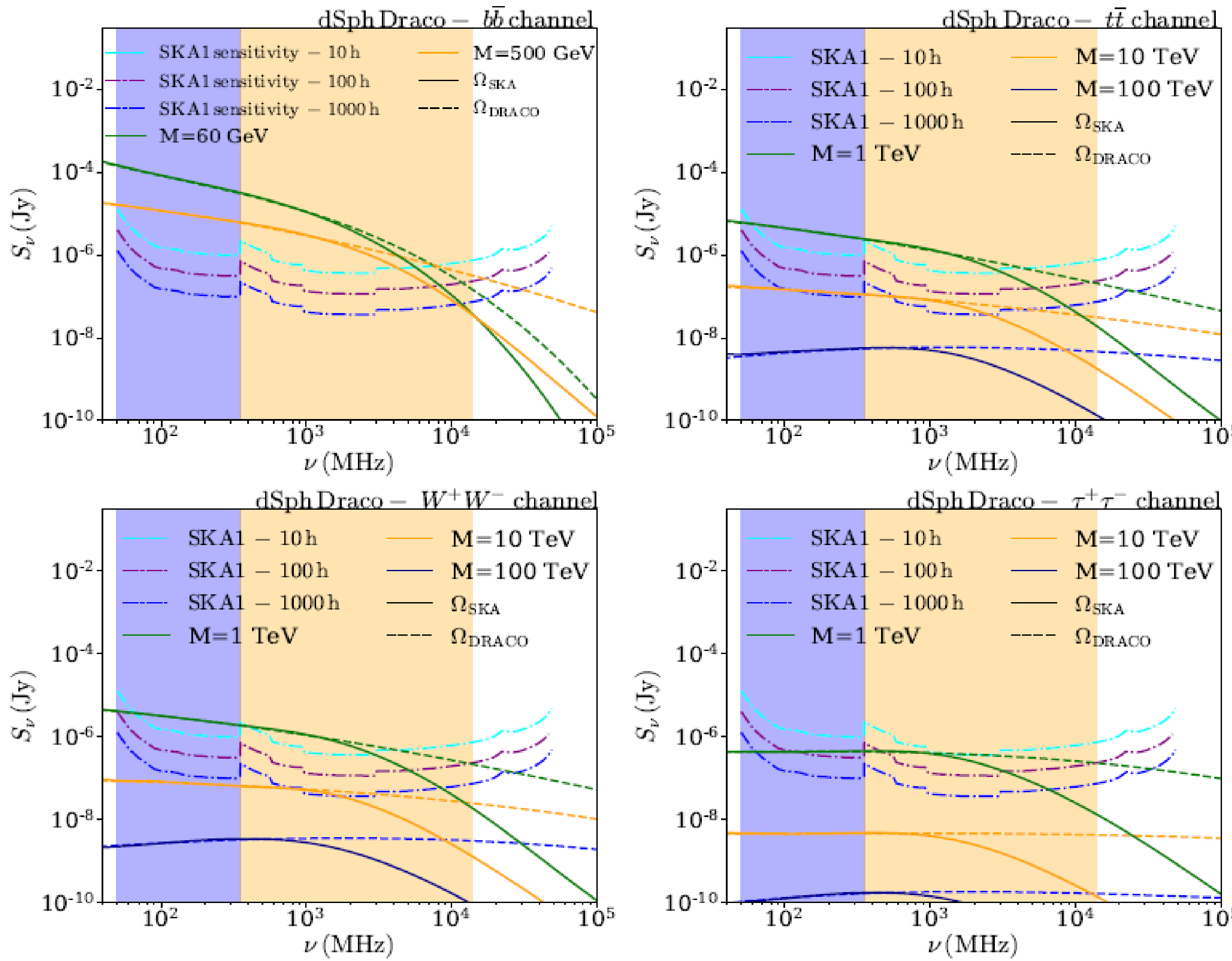
$$\nu = 150 \text{ MHz}$$

$$S_{\min} \propto \frac{1}{\sqrt{\tau \Delta\nu}}$$

Flux density from model independent DM

SKA - Phase 1





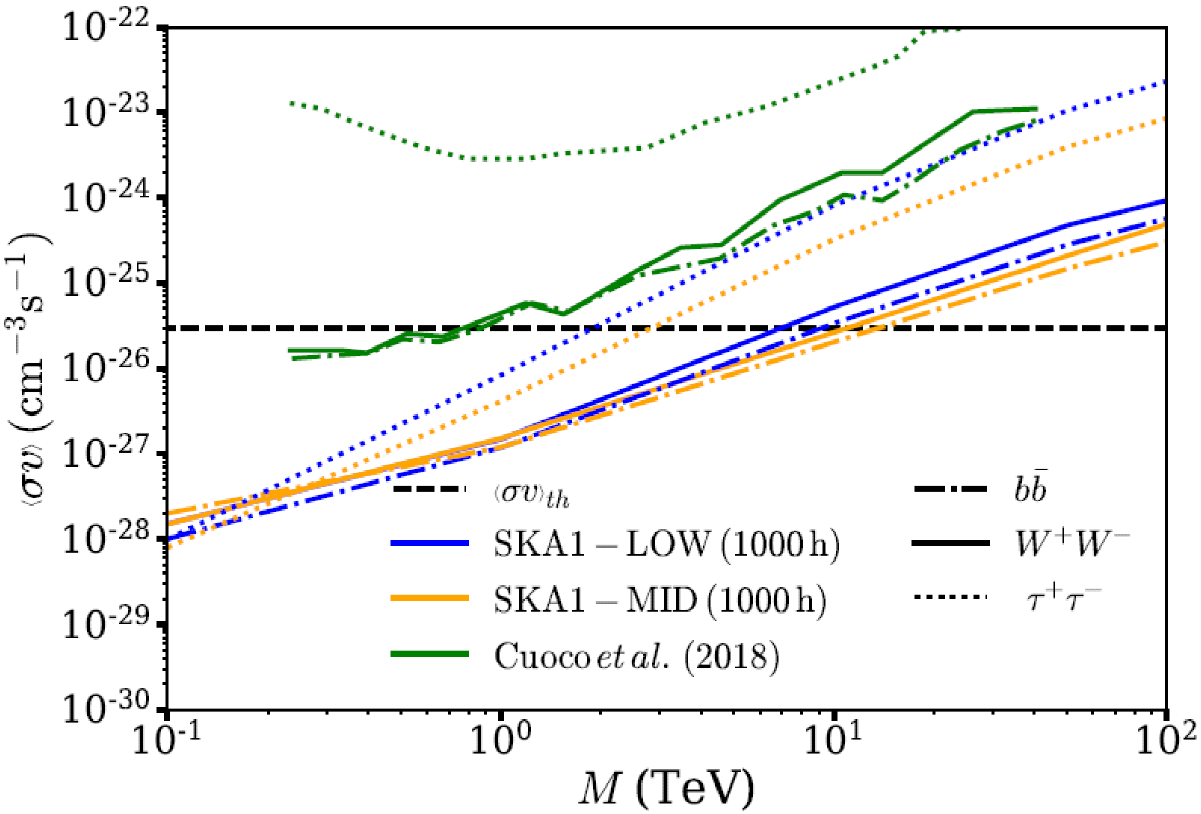
Draco dSph

$d \sim 80$ kpc

$$B(r) = B_0 \exp(-r/r_c)$$

$$\text{NFW:} \quad \rho(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)\left(1 + \frac{r}{r_s}\right)^2}$$

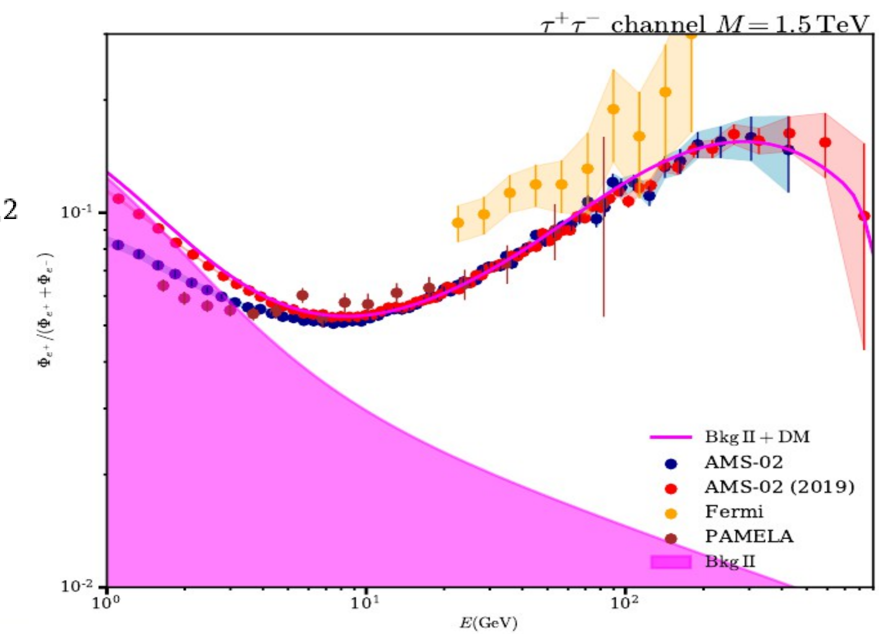
Sensitivity constraints with SKA



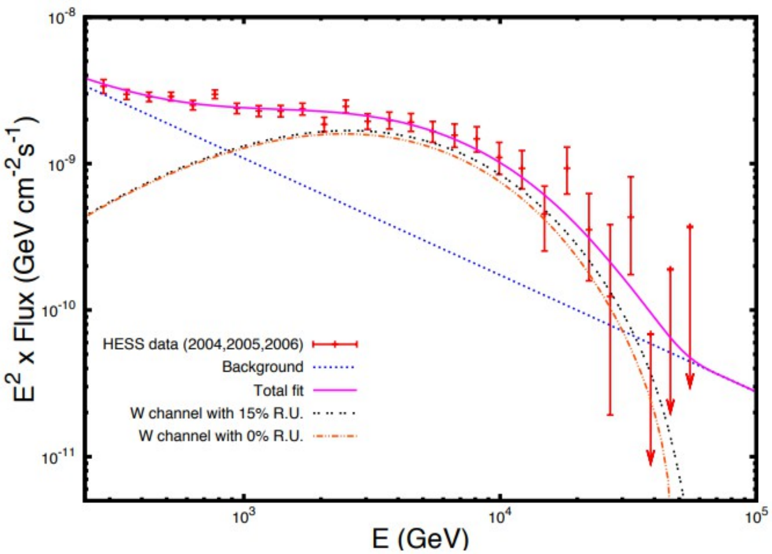
AMS-02 DM candidate at around 1.5 TeV?

$$\langle\sigma v\rangle_{th} = 3 \cdot 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$$

Detector	Magnetic field	Channel	M (TeV)
SKA1-LOW	Exponential	$\tau^+\tau^-$	1.90
		W^+W^-	7.09
		$b\bar{b}$	9.36
SKA1-MID	Exponential	$\tau^+\tau^-$	2.87
		W^+W^-	11.07
		$b\bar{b}$	13.83



Candidates for γ – ray source HESS J1745 – 290 at the GC

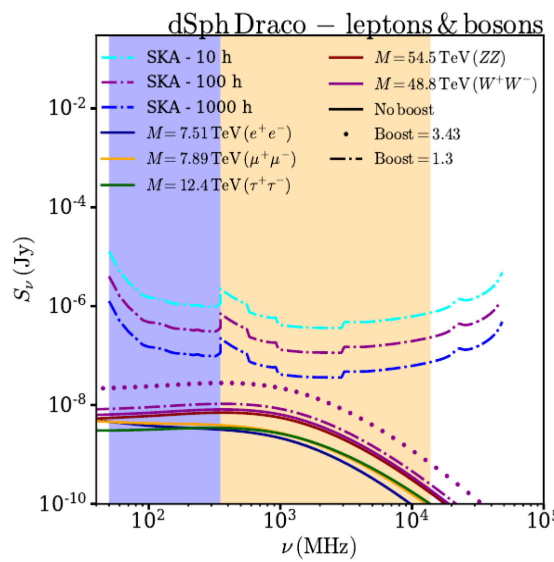


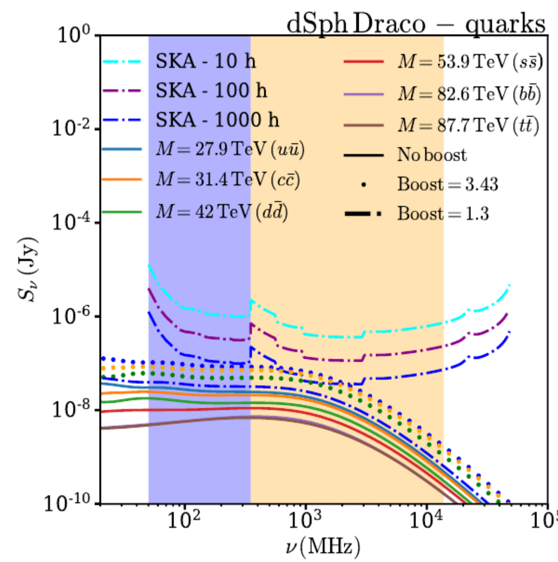
Cembranos et al arXiv:1302.6871

Annihilation channel	M (TeV)	Boost = 3.43	Boost = 1.3	Detector
e^+e^-	7.51 ± 0.11	No	No	-
$\mu^+\mu^-$	7.89 ± 0.21	No	No	-
$\tau^+\tau^-$	12.4 ± 1.3	No	No	-
$u\bar{u}$	27.9 ± 1.8	Yes	No	SKA1-MID
$d\bar{d}$	42.0 ± 4.4	Yes	No	SKA1-MID
$s\bar{s}$	53.9 ± 6.2	No	No	-
$c\bar{c}$	31.4 ± 6.0	Yes	No	SKA1-MID
$b\bar{b}$	82.0 ± 12.8	No	No	-
$t\bar{t}$	87.7 ± 8.2	No	No	-
W^+W^-	48.8 ± 4.3	No	No	-
ZZ	54.5 ± 4.9	No	No	-

Boost=3.43

Colafrancesco et al arXiv:1508.01386





Boost=1.3
(Tidal effects on DM halos)

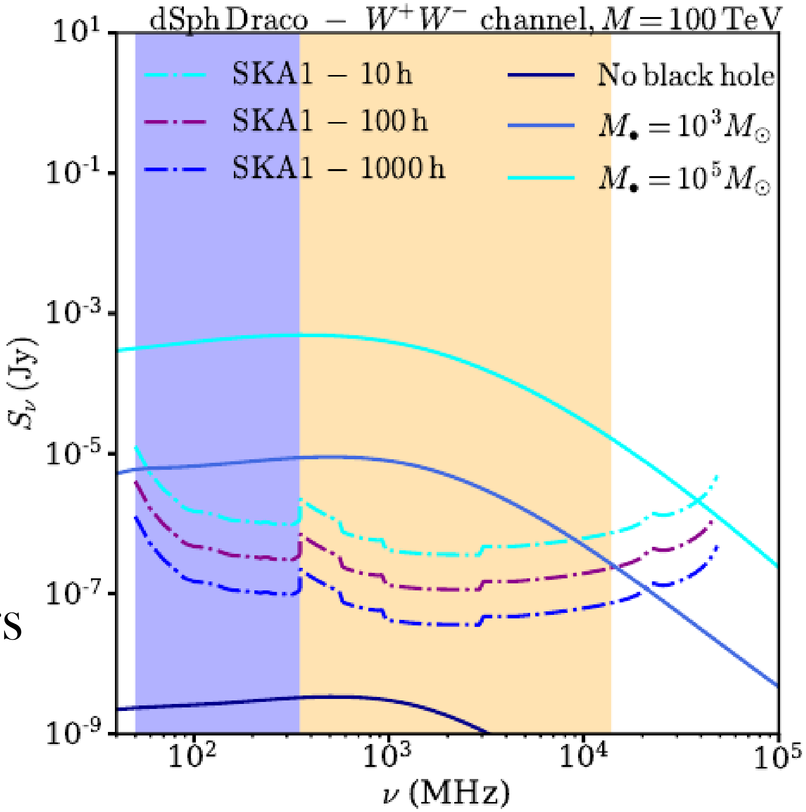
Moliné et al arXiv:1603.04057

Black holes

- No evidences of BH in dSphs
- Evidence of BH in dwarf galaxies with low luminosity (AGN tracers)

- Treatment? Change of the DM density profile

$$\rho_{\mathrm{DM+BH}}(r) = \begin{cases} \frac{M}{\langle\sigma v\rangle(t-t_f)} & \text{if } r < r_{cut} \\ \rho_{\mathrm{DM}}(r_{sp}) \left(\frac{r}{r_{sp}}\right)^{-\gamma_{sp}} & \text{if } r_{cut} \leq r < r_{sp} \\ \rho_{\mathrm{DM}}(r) & \text{if } r \geq r_{sp} \,, \end{cases}$$



Increase of the signal in more than two orders of magnitude!

Conclusions

1- In this work we have set sensitivity constraints for model-independent DM with the SKA–Phase 1.

2- The maximum masses detected by SKA-1 for thermal relics lie close to a few TeV. Candidates in agreement with the AMS positron fraction should leave observable signatures in Draco dSph.

3- DM candidates in agreement with HESS J1745-290 are hard to detect in dSphs. Galaxies hosting BH may open the possibility to measure them.

4- Alternative targets would improve the constraints we set in this work together with the sensitivity expected by SKA-Phase 2.

Further information : 1905.11154

Thank you

Other dwarf spheroidals

Target	Distance (kpc)	M/L	DM profile	B_0 (μG)
Draco	80	320	NFW‡	1
Ursa Minor	66	580	NFW	1
Segue 1	23	>1000	Einasto	2
Willman 1	38	700	NFW	1