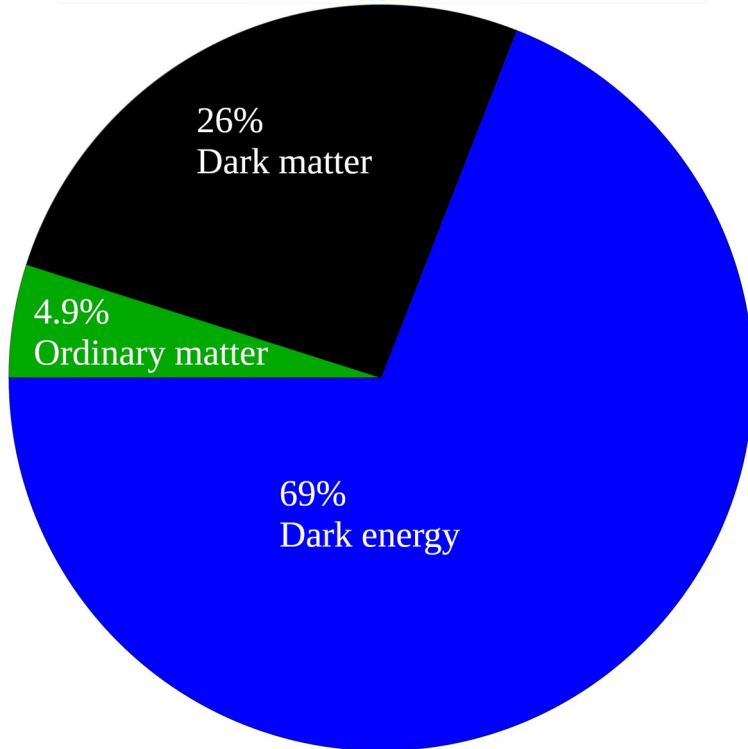
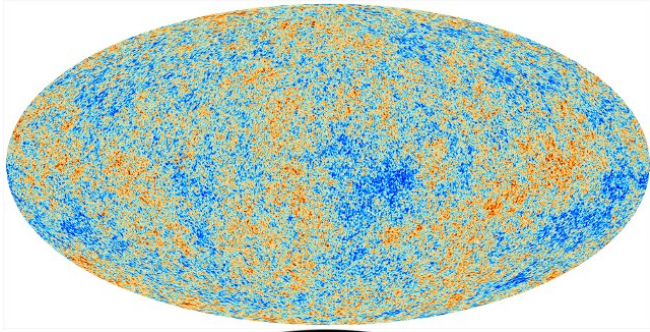


Multiwavelength detection prospects for annihilating heavy WIMP dark matter around M31*

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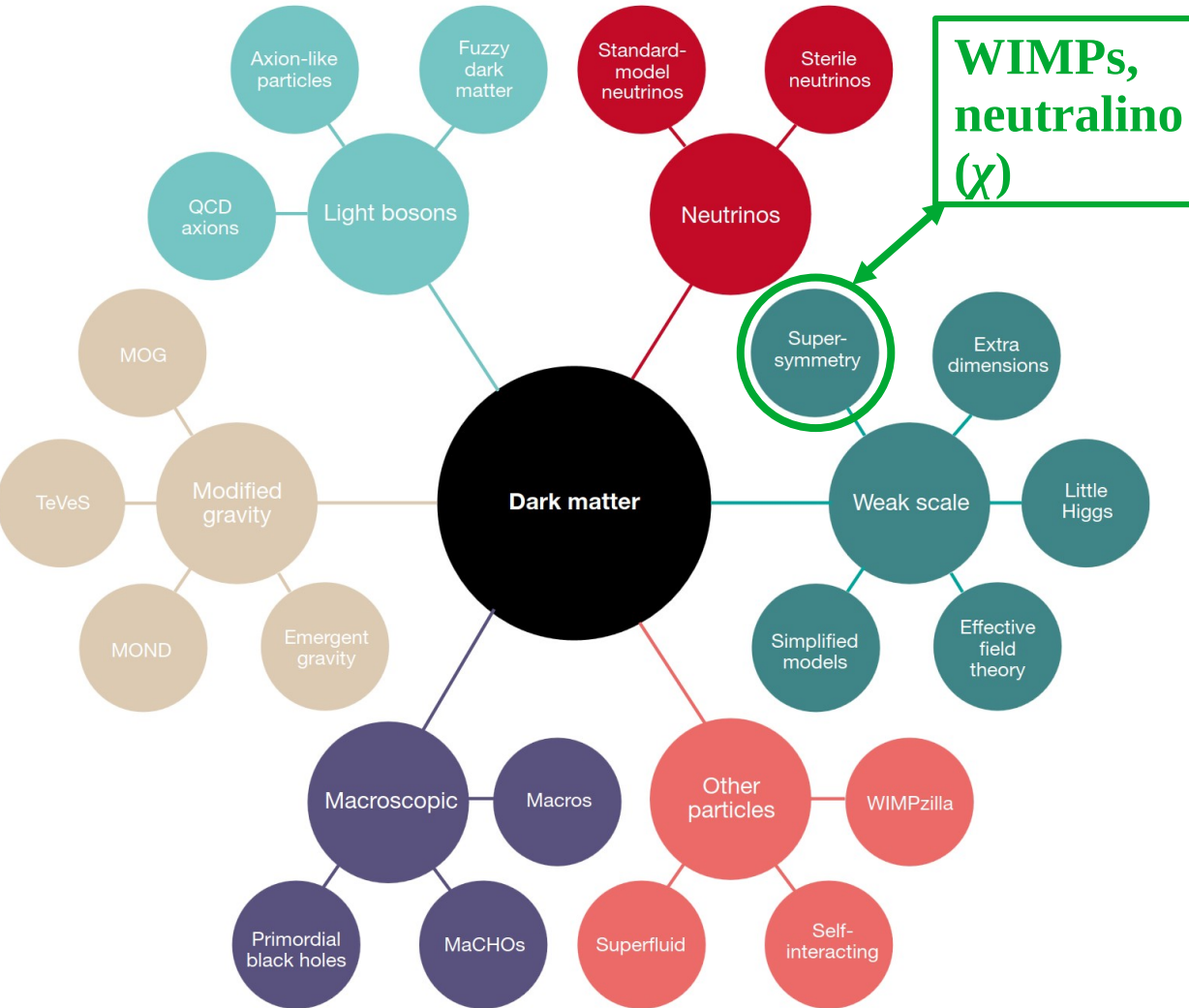
My talk is based on my publications: JCAP 04, 002 (2026)
(ArXiv:2512.10923) & ArXiv:2609.08771 (submitted to JCAP).

Dark matter (DM) phenomenon in our Universe



- DM was discovered by F.Zwicky & S.Smith in 1930s as a hidden mass in Coma & Virgo clusters;
- bears $\approx 26\%$ of the total energy density of Universe;
- is composed by non-SM particles most likely;
- is stable over the age of Universe;
- gravitates as usual matter;
- does not interact much through other SM forces;
- must be cold enough to form structures in the early Universe $\rightarrow m_x > \text{few keV}$, if produced thermally;
- weakly interacting massive particles (WIMPs) are the most popular and probable candidate historically.

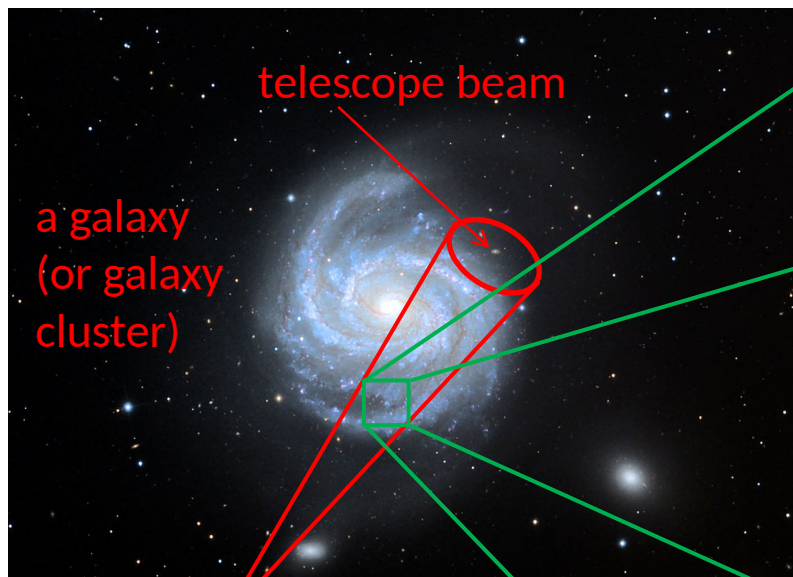
Main candidates for the role of DM



- $m_\chi \sim \text{few GeV} \div 100 \text{ TeV}$;
- thermal production in early Universe;
- self-annihilation $\chi + \chi \leftrightarrow SM + SM^*$;
- The annihilation cross section is usually treated as $\langle \sigma v \rangle$, since σv is supposed to be velocity-independent in the first approximation (s-wave: $\sigma \propto 1/v$).
- The cross section sets WIMP abundance $\Omega_\chi = 0.26$ in Universe:

$$\Omega_\chi \propto 1/\langle \sigma v \rangle \Leftrightarrow \langle \sigma v \rangle \approx 2 \cdot 10^{-26} \text{ cm}^3/\text{s}$$
- So-called **WIMP miracle**: weak interaction cross section (assumed for annihilation) $\sim$ necessary thermal production cross section!

WIMP indirect (astrophysical) searches



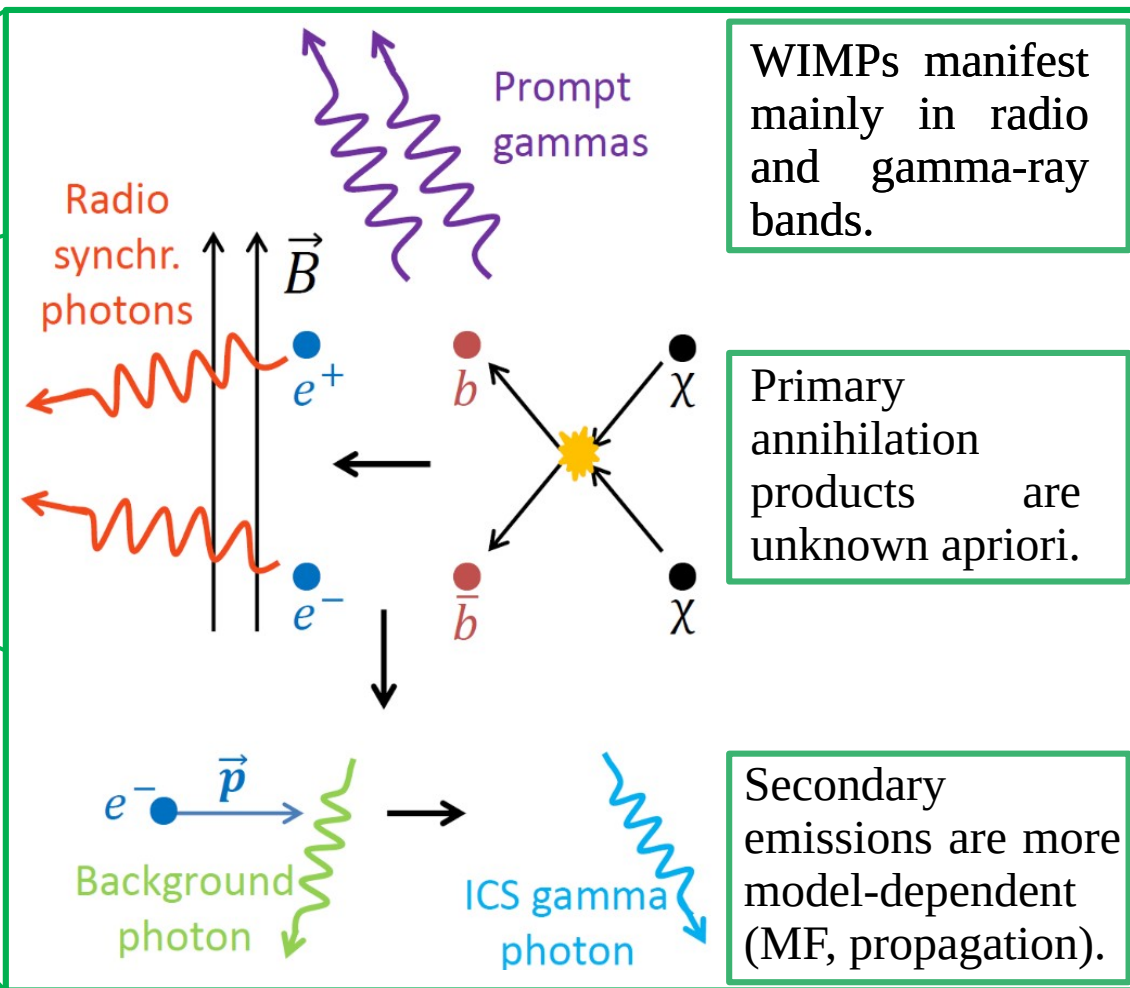
observer

- Emissivity:

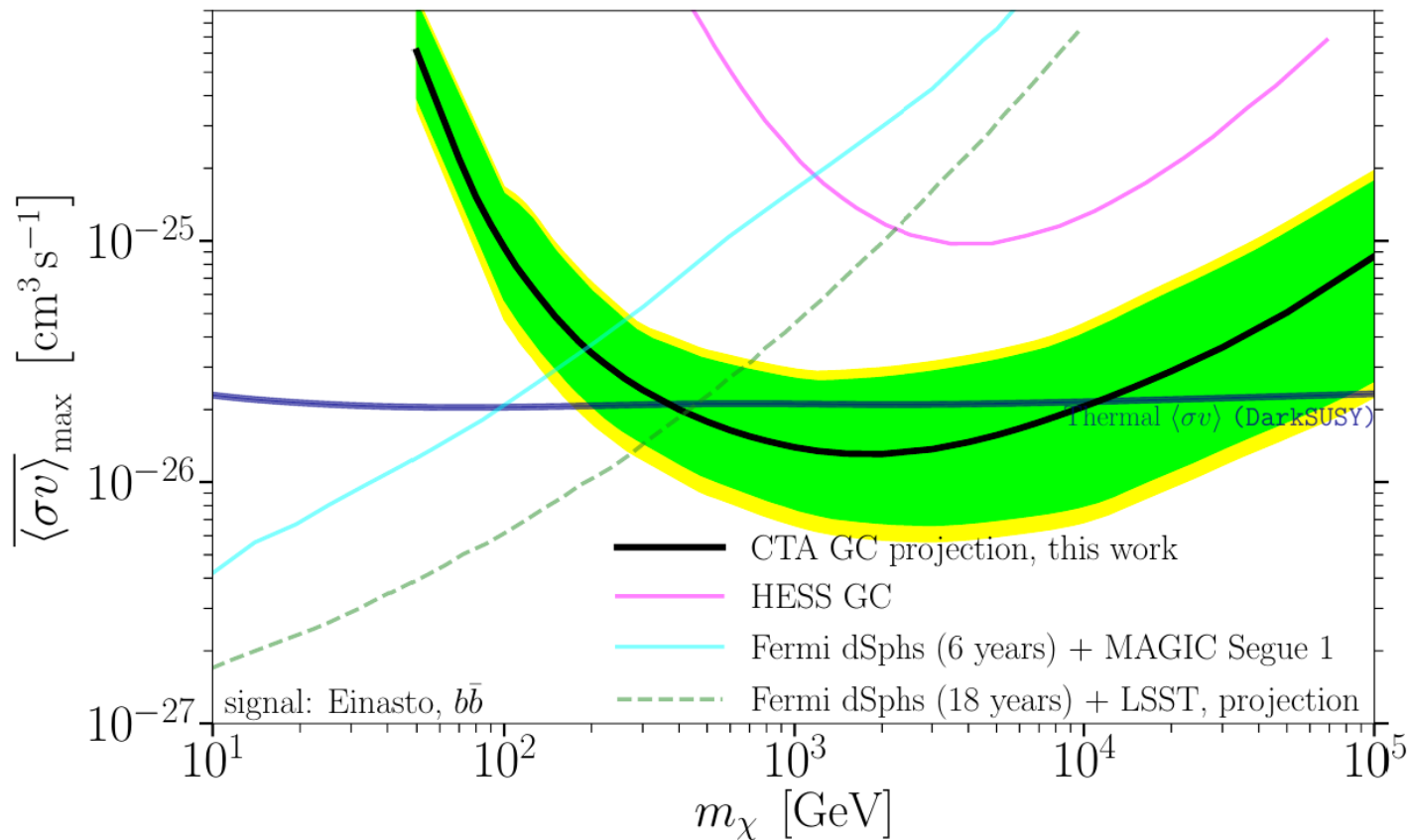
$$j \propto \langle \sigma v \rangle \left(\frac{\rho_{DM}}{m_x} \right)^2$$

- Intensity distribution on the sky:

$$S(\nu, \theta, \phi, \Delta\Omega) = \frac{1}{4\pi} \int_{\Delta\Omega} d\Omega \int_{l.o.s} j(\nu, l, \theta, \phi) dl$$



WIMP indirect searches: current status



- So far we have tested only light thermal s-wave annihilating WIMPs with $m_\chi \lesssim 0.1 \text{ TeV}$.
- CTA will observe Galactic center and probe the range $m_\chi \sim (0.1 \div 10) \text{ TeV}$ in good case scenario of cuspy profile.
- Only one alternative methodology, which may allow to probe *all heavy* WIMPs up to 100 TeV, is observations of DM density spikes around nearby SMBHs!

DM density spikes around SMBHs

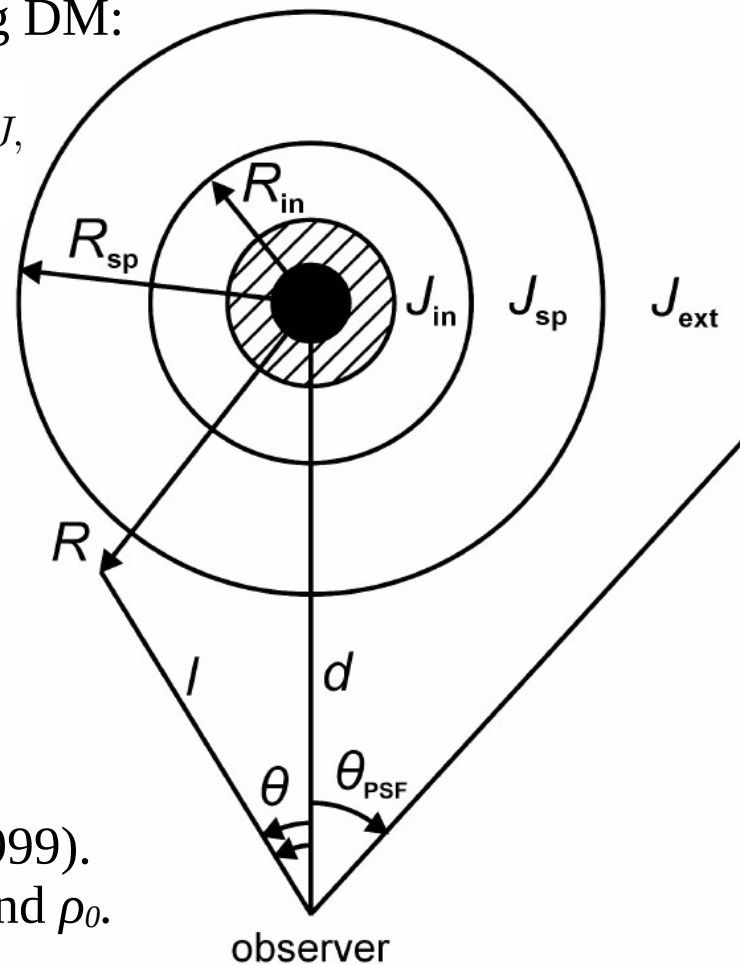
- SMBH should form very dense DM spike in its local sphere of gravitational influence.
- Prompt gamma-ray emission flux density due to annihilating DM:

$$\frac{d\Phi}{dE} = \frac{\langle\sigma v\rangle}{8\pi m_x^2} \frac{dN_\gamma}{dE}(E, m_x) \times \int_{\Omega_{\text{PSF}}} \int_{\text{LoS}} \rho^2(R) d\Omega dl \equiv \frac{\langle\sigma v\rangle}{8\pi m_x^2} \frac{dN_\gamma}{dE}(E, m_x) \times J,$$

- DM density distribution around SMBH:

$$\rho(R) = \begin{cases} 0, & R < 2R_\bullet = 4GM/c^2; \\ \rho_{in}(R/R_{in})^{-\gamma_{in}}, & 2R_\bullet \leq R < R_{in}; \\ \rho_0(R/R_{sp})^{-\gamma}, & R_{in} \leq R < R_{sp}; \\ \rho_{ext}(R), & R \geq R_{sp}. \end{cases}$$

- Spike radius: $R_{sp} = \langle bGM/v^2 \rangle = bGM/\sigma_c^2$, $b \sim 1$
- Pioneering work: Gondolo & Silk, Phys. Rev. Lett. 83, 9 (1999).
- But: huge model systematic uncertainties due to those in γ and ρ_0 .



Comparison of nearby SMBHs

SMBH host	d [Mpc][52]	M [$M_\odot$]	σ_c [km/s][53]	ρ_0 [GeV/cm ³]	J_{sp} [GeV ² /cm ⁵]
MW	0.0083 [54]	$4.3 \cdot 10^6$ [54]	130 [55]	110 [9]	$2.6 \cdot 10^{16}$
M31	0.76 [56]	$1.4 \cdot 10^8$ [57]	150	47 [47]	$8.2 \cdot 10^{15}$
NGC 3115	10	$9.6 \cdot 10^8$ [58]	260	27 [50, 59, 60]	$1.7 \cdot 10^{14}$
M104	11	$1.0 \cdot 10^9$ [61]	230	13 [62]	$7.8 \cdot 10^{13}$
M60	17	$2.1 \cdot 10^9$ [58]	330	11 [59]	$2.3 \cdot 10^{13}$
M87	17	$6.5 \cdot 10^9$ [63]	450 [51]	0.52 [64, 65]	$2.3 \cdot 10^{11}$
M84	17	$1.5 \cdot 10^9$ [58]	280	6.8 [59]	$9.0 \cdot 10^{12}$
NGC 4889	97	$2.0 \cdot 10^{10}$ [66]	390	4.7 [67]	$4.0 \cdot 10^{13}$
NGC 3842	100	$1.0 \cdot 10^{10}$ [66]	310	14 [66]	$1.7 \cdot 10^{14}$

Table 1. The list of potentially promising nearby and massive SMBHs arranged by distance. The second column contains distance, the third – mass, the fourth – stellar velocity dispersion in the center of host galaxy, the fifth – employed DM halo density at the spike border and the sixth – calculated spike J -factor. The origin of all data is provided (the first row contains default data source). MED model parameter values were used in calculation: $\gamma = 1.5$, $b = 0.6$, medium density ρ_0 .

My conclusion: only MW* and M31* are worthwhile targets for WIMP searches. However, M31* has never been studied before, which is unfair. And popular M87* is the faintest source.

And M31* is expected to provide even better sensitivity for WIMP signal due too much fainter nucleus!

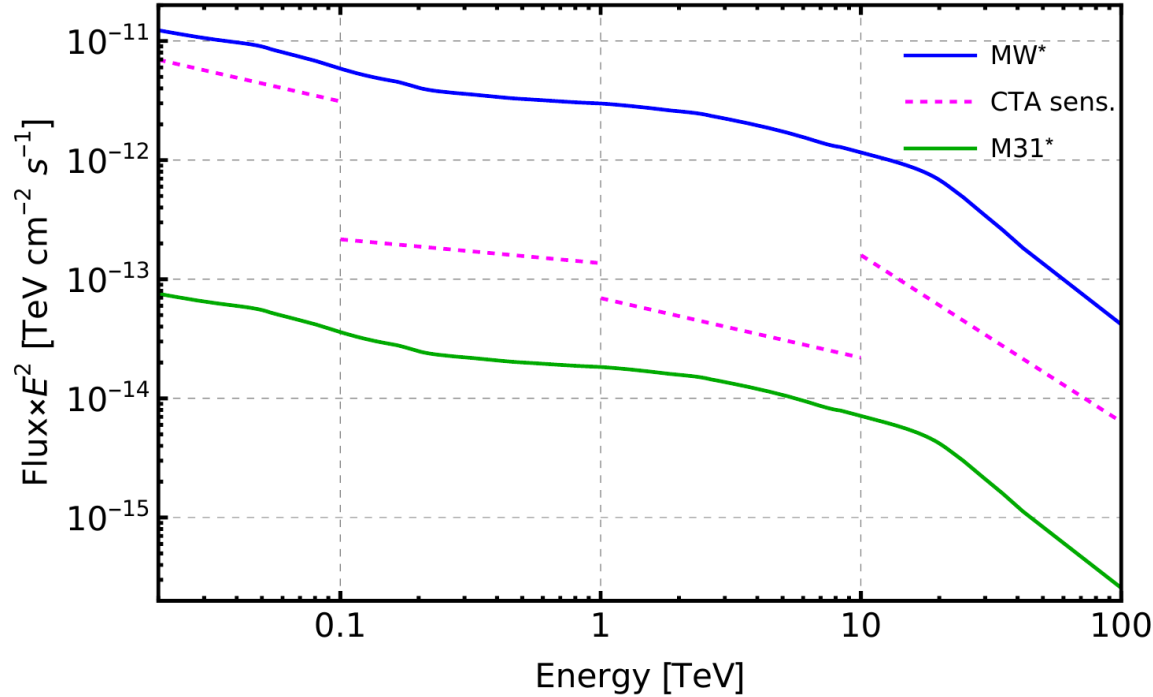


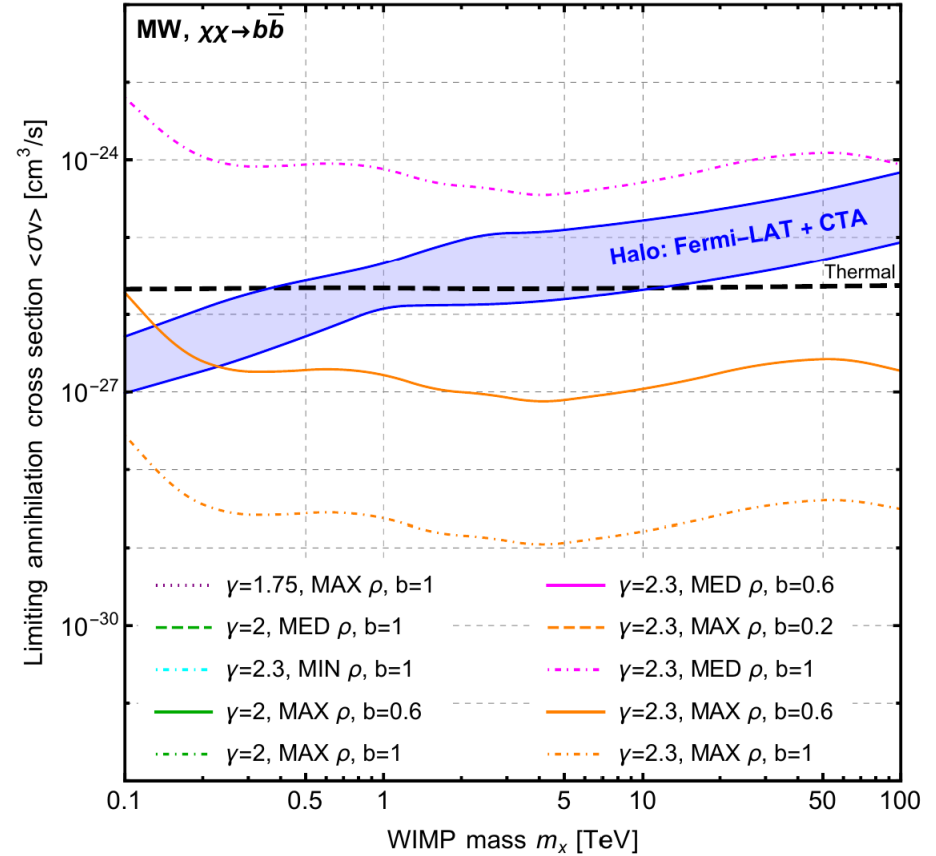
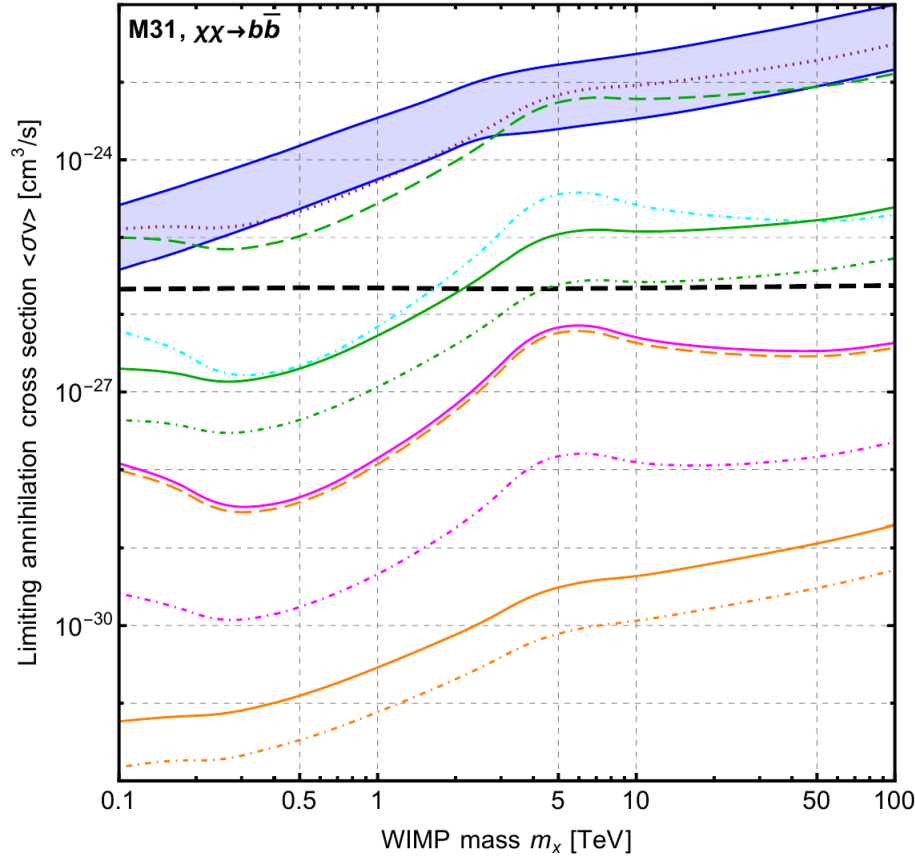
Figure 3. The blue line shows the spectrum of J1745–290 source taken from [69, figure 3] and extrapolated to 100 TeV by power law. The green line shows the same spectrum assigned to M31 center by rescaling to M31 gamma-ray flux measured at ≈ 0.01 TeV. The dashed line shows approximate CTA sensitivity to a point source with relevant power-law spectrum in the chosen wide energy bins for $T = 100$ h. More details are in section 4.

Derivation of sensitivity to WIMP parameters

$$\frac{d\Phi}{dE} = \frac{\langle\sigma v\rangle}{8\pi m_x^2} J(\langle\sigma v\rangle, m_x, M, t_\bullet, \sigma_c, d, \rho_0, \gamma_{in}, \gamma, b) \frac{dN_\gamma}{dE}(E, m_x) \leq$$

$$\leq \left\{ \begin{array}{l} \text{observed flux density for MW*}, \\ \text{observed flux upper limit by Fermi-LAT AND future sensitivity reach by CTA for M31*} \end{array} \right.$$

Fermi-LAT + CTA WIMP sensitivity limits in DM spikes



Deep M31* observations in very high energy band may allow to probe the basic thermal s-wave annihilating WIMPs up to the highest possible mass = 100 TeV. However, it's possible only in the case of optimistic spike parameter configurations ($\gamma \gtrsim 2$).

Synchrotron emission from DM density spike

- WIMP annihilation produces relativistic electrons and positrons, which emit synchrotron in the strong magnetic field (MF) of SMBH accretion flow at microwave frequencies.
- General equation for the calculation of synchrotron emission flux density:

$$F(\nu) = \frac{1}{4\pi d^2} \iiint j(\nu, R) d^3 R = \frac{2}{d^2} \int_{3R_\bullet}^{R_m} \int_{E_0}^{m_x c^2} \psi(R, E) P_e(\nu, R, E) R^2 dE dR$$

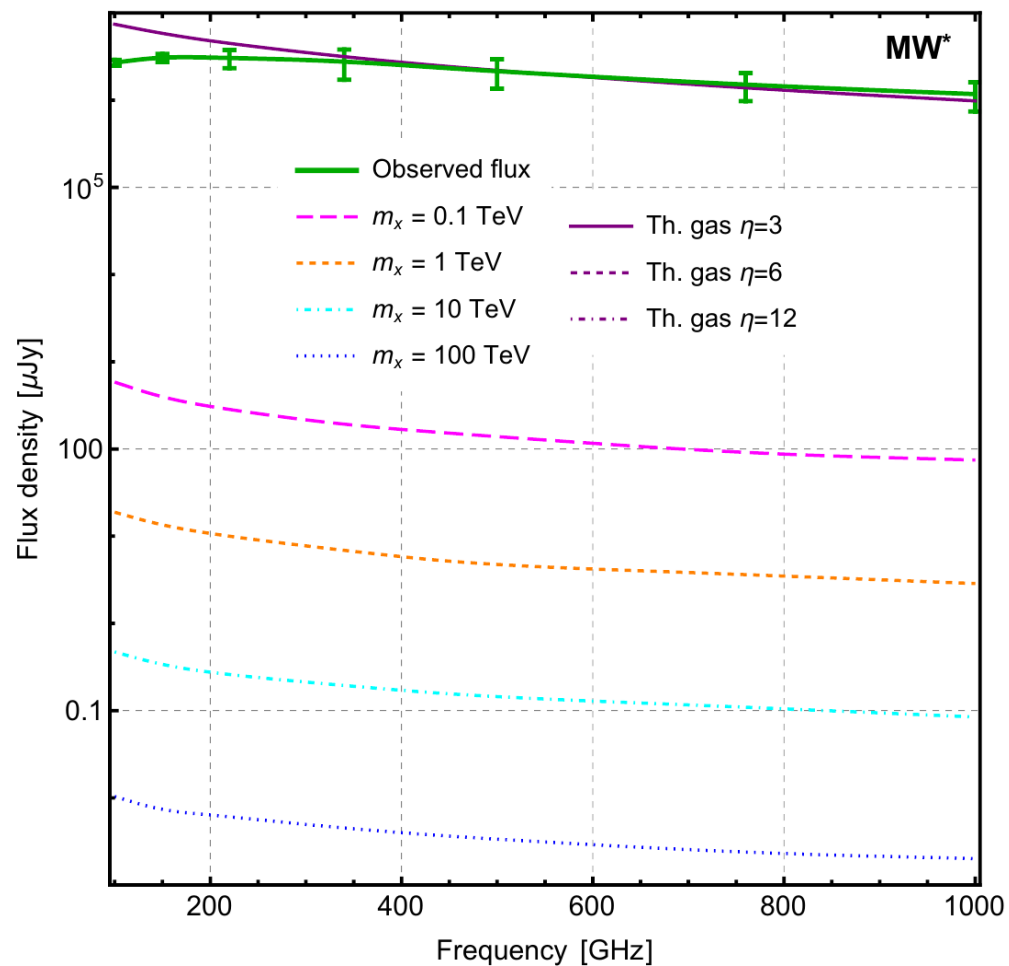
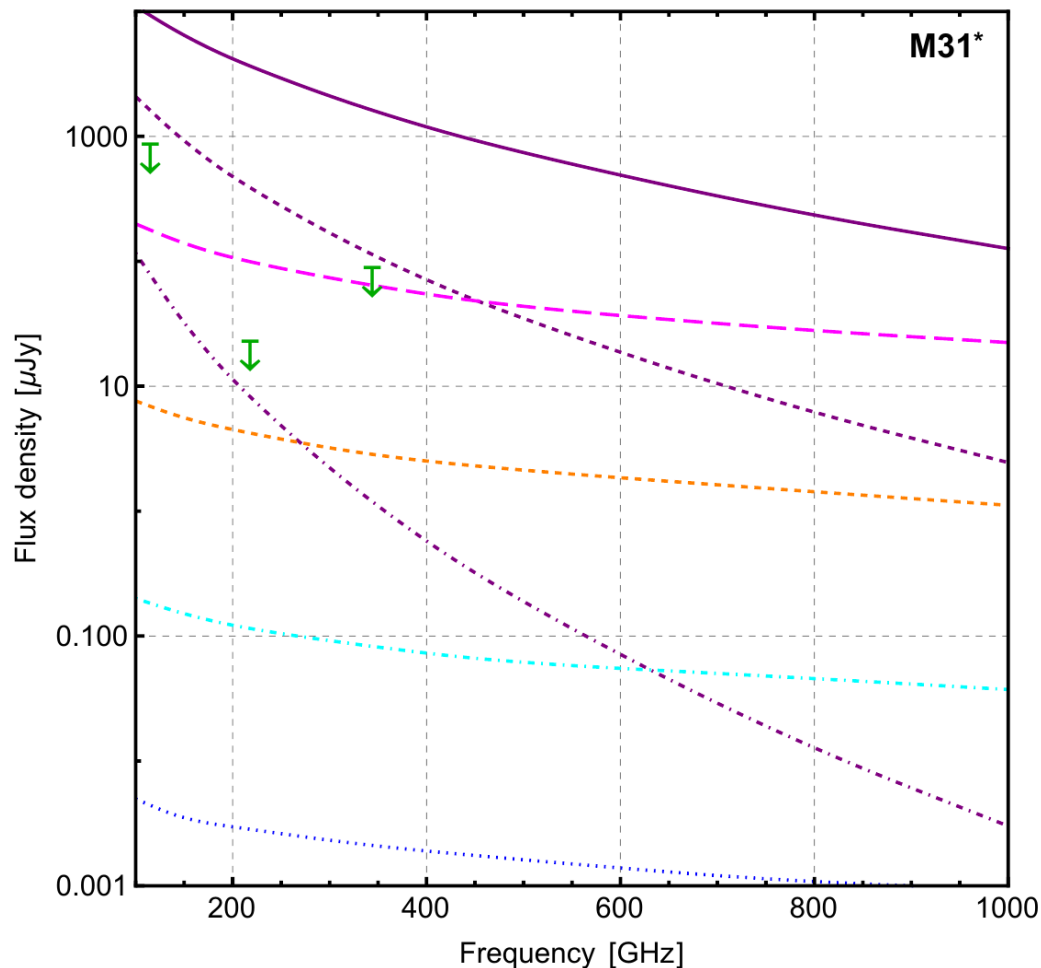
- The synchrotron emission power of single electron:

$$P_e(\nu, R, E) = \frac{2\pi m_e^2 c^3 e^2 \nu}{\sqrt{3} E^2} \int_0^\pi d\theta \sin \theta \int_{x/\sin \theta}^\infty dy K_{5/3}(y) \approx \frac{2\pi^2 m_e^2 c^3 e^2 \nu}{\sqrt{3} E^2 (0.869 x^{2/3} + x \exp(x))},$$
$$x = 4\pi m_e^3 c^5 \nu / (3e E^2 B(R))$$

- Equilibrium spectral concentration of $e^\pm$ comes as solution of transport equation ($E=pc$):

$$\nabla(\vec{V} f) + \nabla_{\vec{p}}(\vec{p} f) - \nabla(D \nabla f) - \nabla_{\vec{p}}(D_{pp} \nabla_{\vec{p}} f) = q_p(R, p) = \frac{\langle \sigma v \rangle \rho^2(R)}{2m_x^2} \frac{dN_e}{d^3 p}(p, m_x)$$

The obtained thermal and DM $e^\pm$ emission spectra



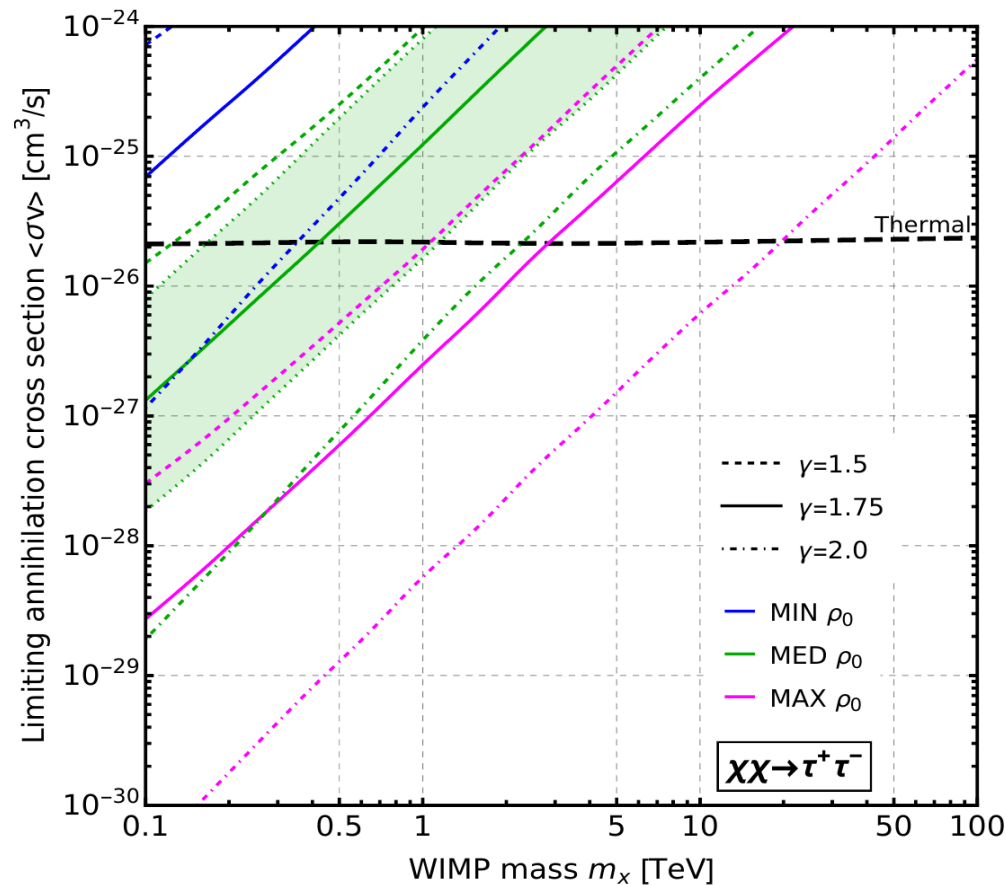
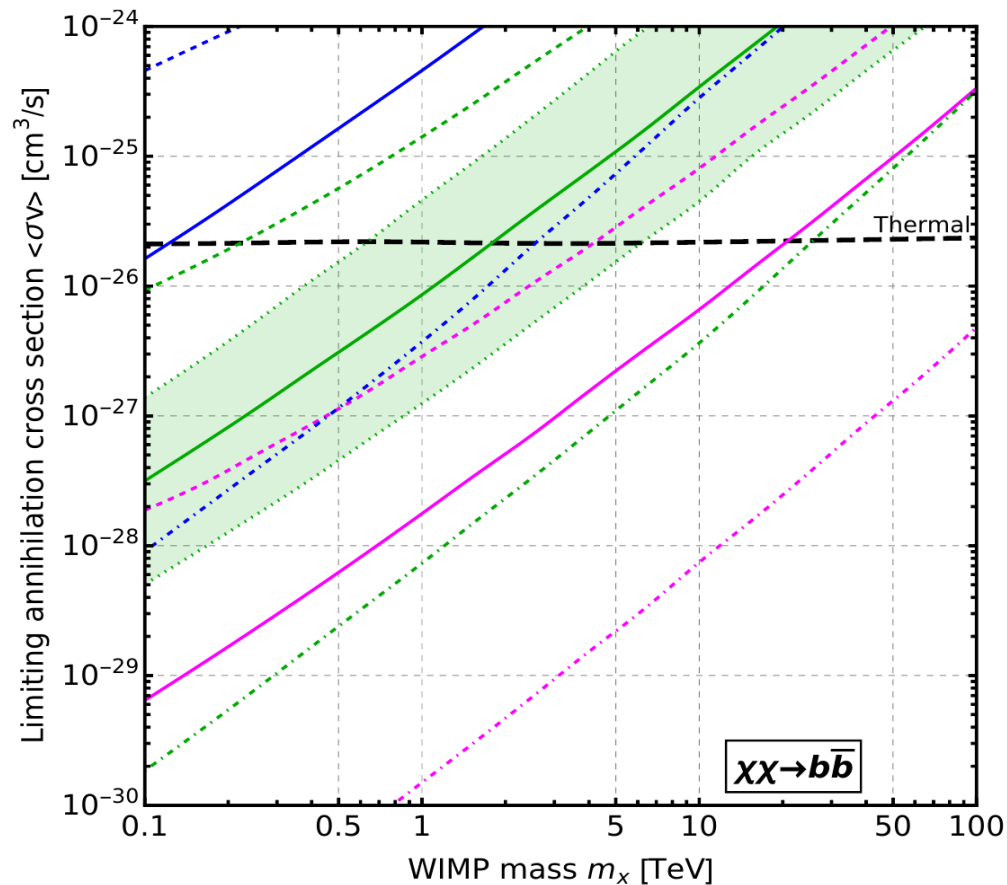
WIMP signal to thermal background ratio in M31* is larger than that in MW* by $\sim 10^5$ times!

Atacama Large Millimeter Array (ALMA)



Interferometer with 50 main antennas, subarcsecond imaging, covers 30-1000 GHz!

Final results: ALMA sensitivity to WIMP signal in M31*



Observational frequency = 100 GHz, exposure time = 24 hours.

Summary with a broad vision

- Despite of almost a century of research, exact DM nature remains still unknown.
- Easily accessible candidate parameter ranges had been already tested.
- The remaining parameter regions are hard to reach due to weakness of signals in comparison with natural astrophysical backgrounds.
- Thus, WIMPs are ruled out for $m_\chi \lesssim 0.1$ TeV, but 0.1÷100 TeV range is still unexplored.
- DM density spikes around the closest SMBHs may provide a progress. However, so far the community has been considering unrealistically high spike densities.
- M31* in microwave band represents the unique target, where heavy WIMPs might be reached in the case of physically realistic spike with $\gamma \approx 1.75$. Only one competitive methodology in the whole field is probably CTA observations of the Galactic center region.
- I propose to conduct deep dedicated observations of M31* by ALMA.
- From the most general point of view, DM may not manifest at all beyond gravity.
- I bet on DM discovery either in ~10 years or never.