Limits on WIMP Annihilation from the M87* EHT Observations

Ding Ran

Yuan Guan-Wen , Chen Zhan-Fang , Shen Zhao-Qiang , Guo Wen-Qing , DR,
Huang Xiaoyuan & Yuan Qiang, arXiv:2106.05901

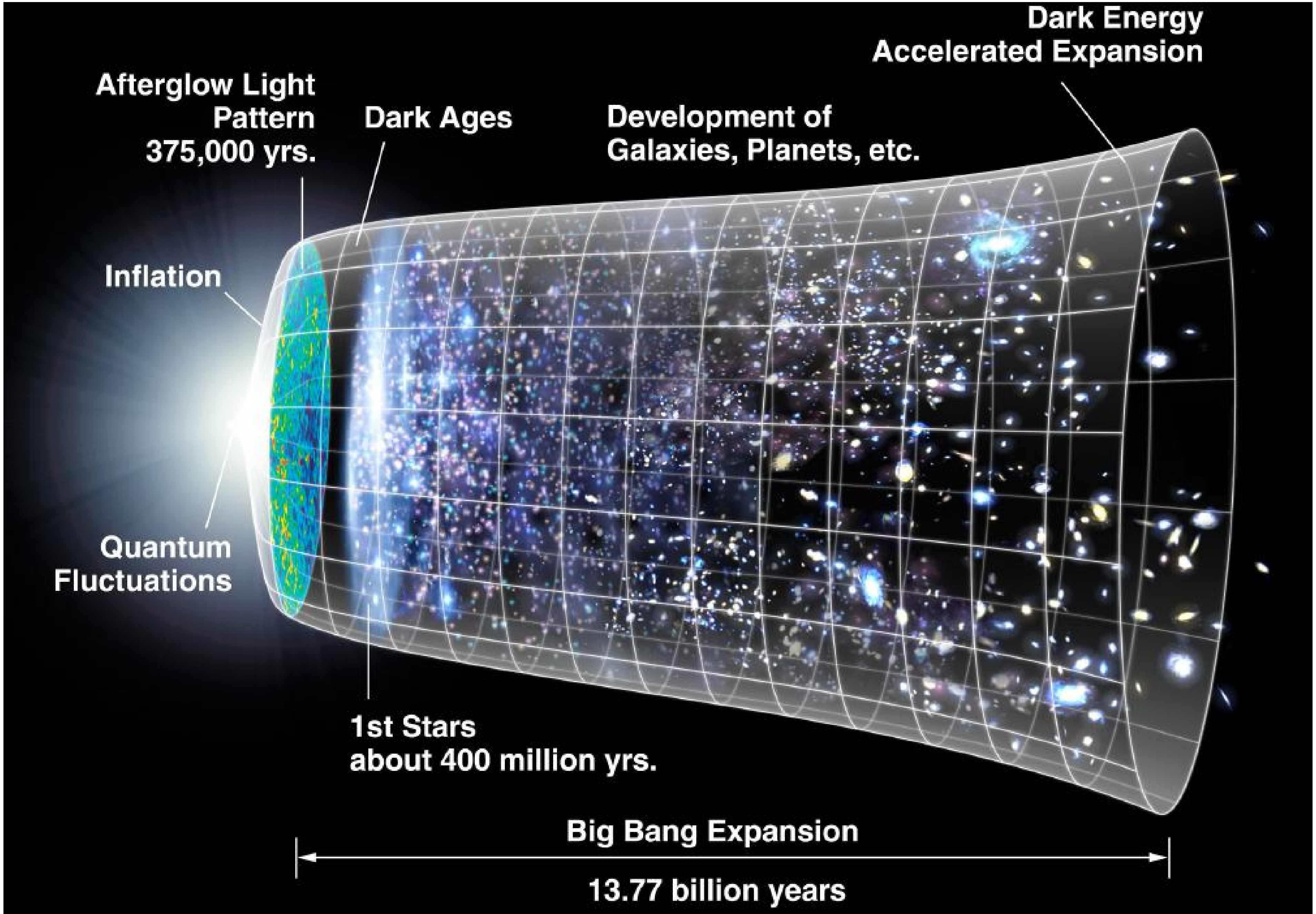
ITP, 2021.09.26

Outline

- Introduction
- Calculation framework
- Results & Discussion

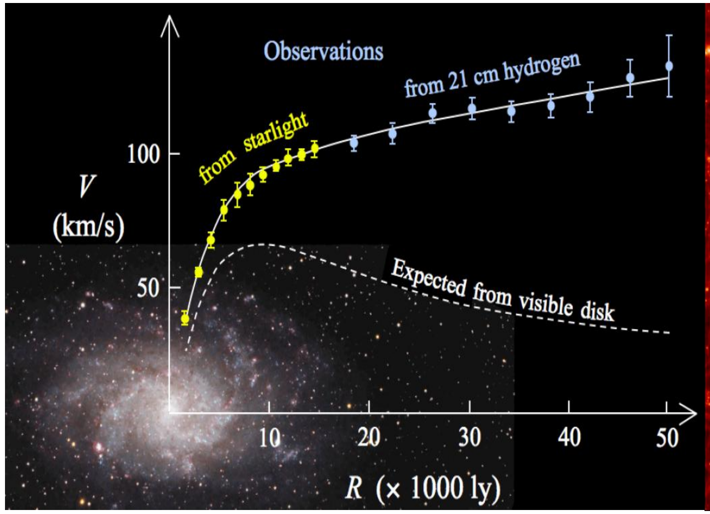
Introduction

- Chronology of the Universe

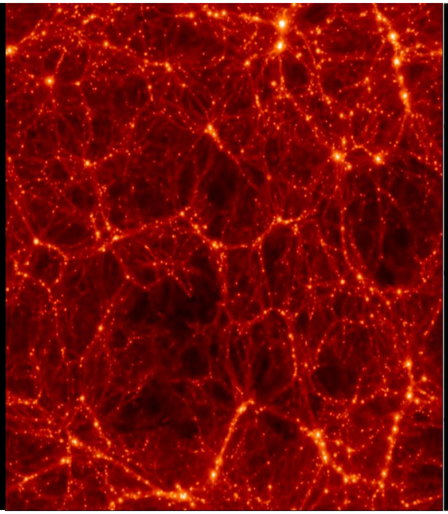


Evidences for DM

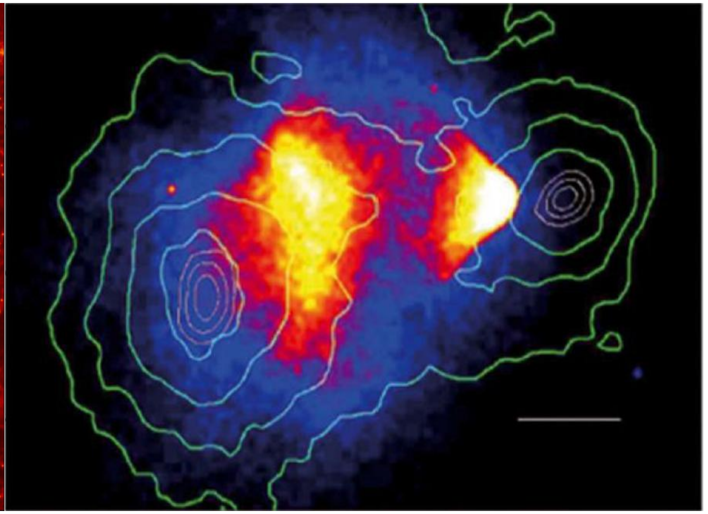
- Rotation curves



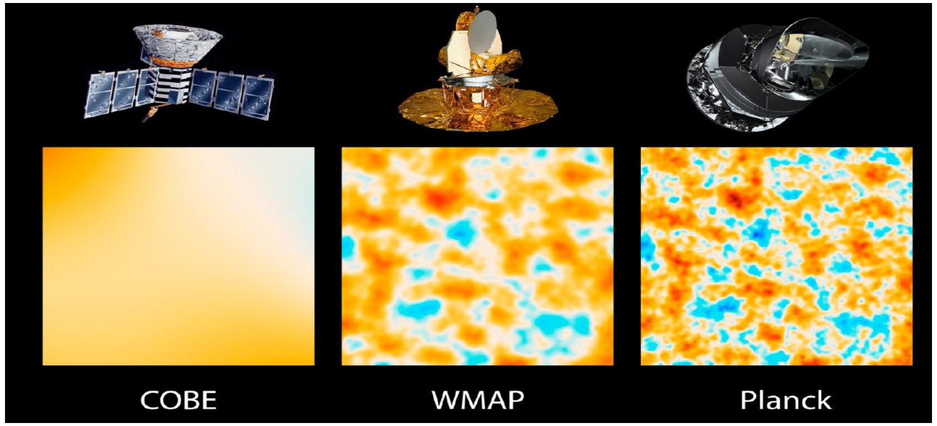
- LSS



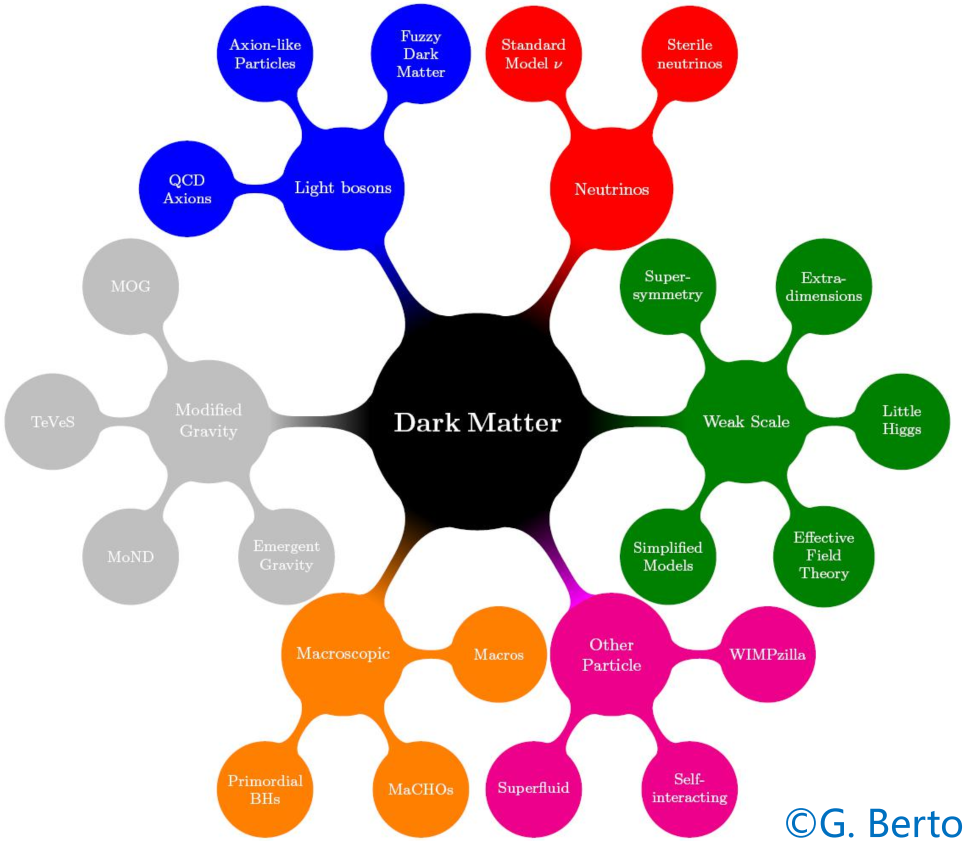
- Bullet cluster



- CMB



●DM candidates



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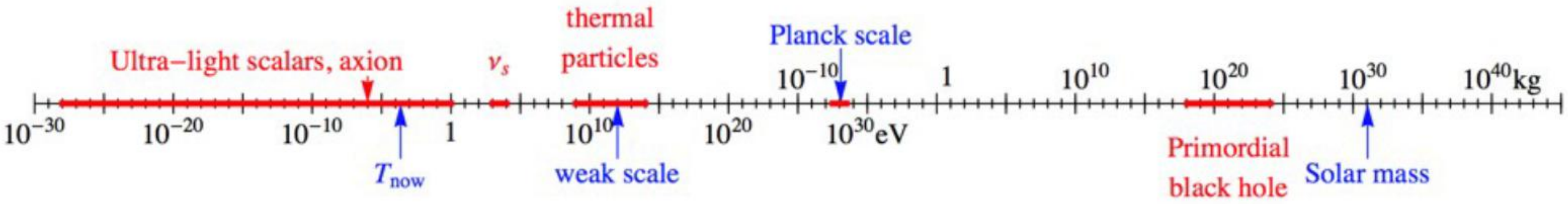
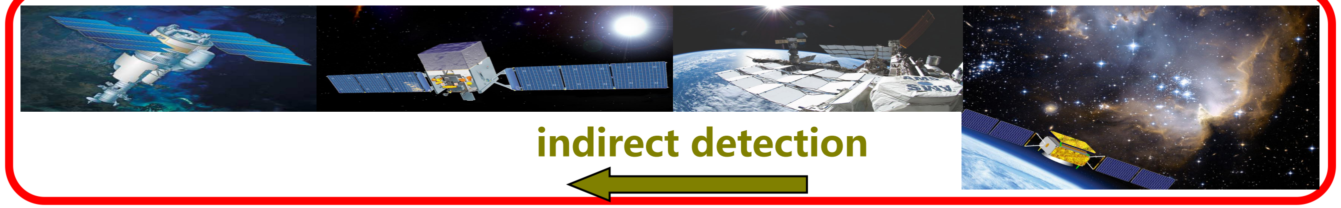


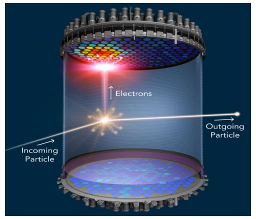
● WIMP detections

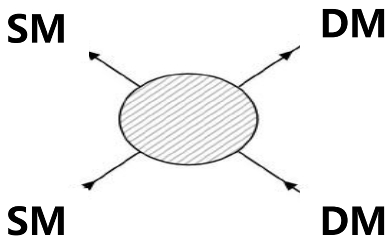
Cosmic-Ray (CR) physics



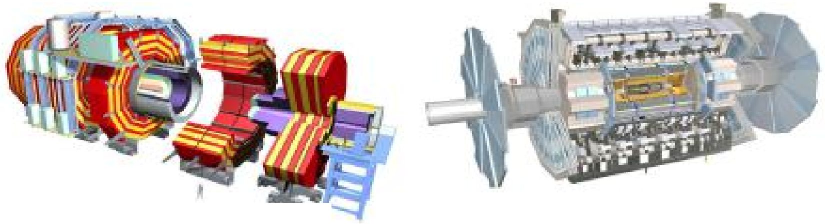
indirect detection

direct detection



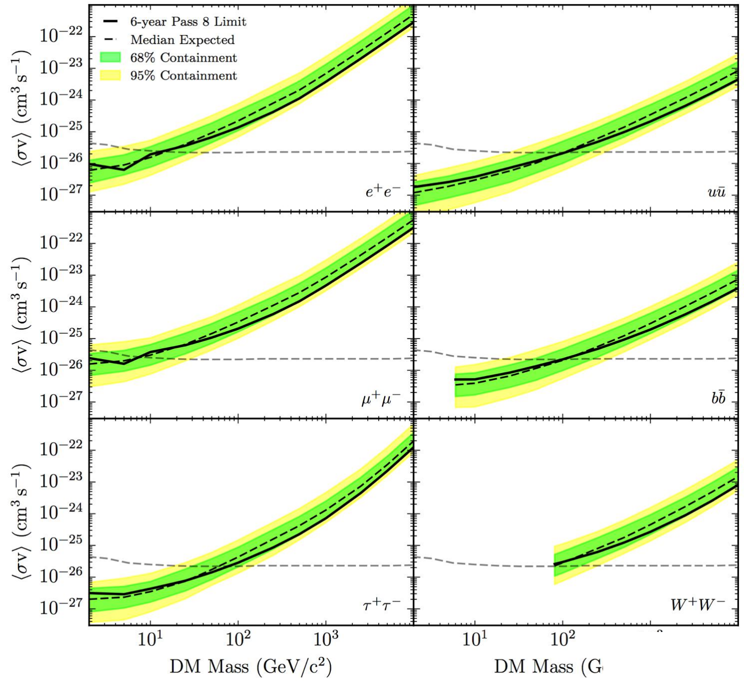


collider detection

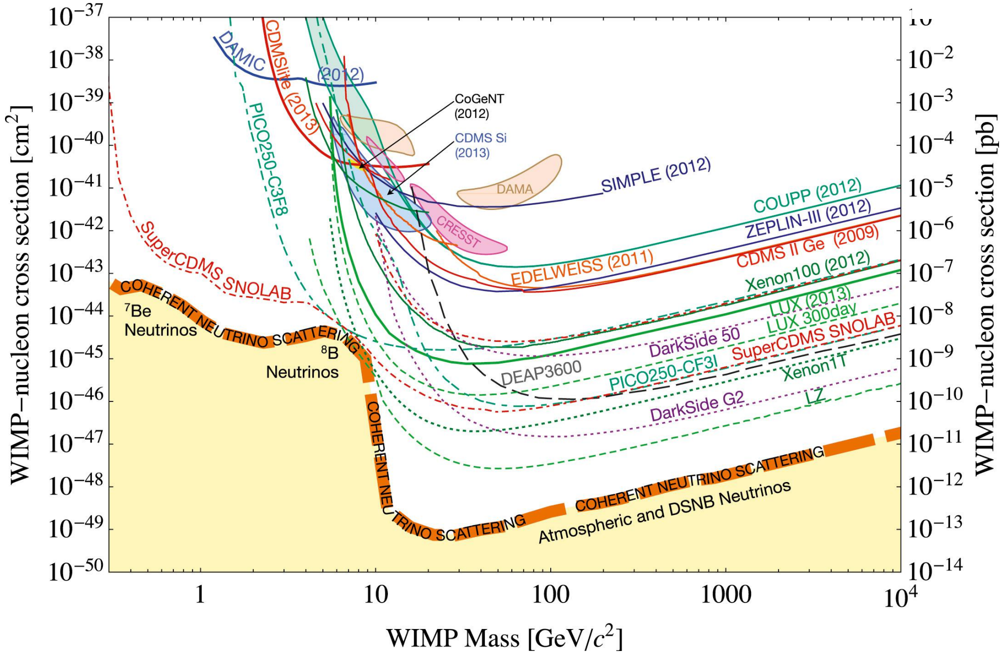


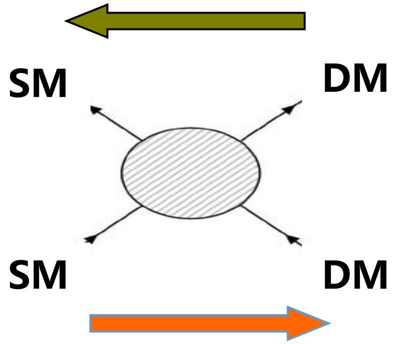
- WIMP Liimits

Indirect detection



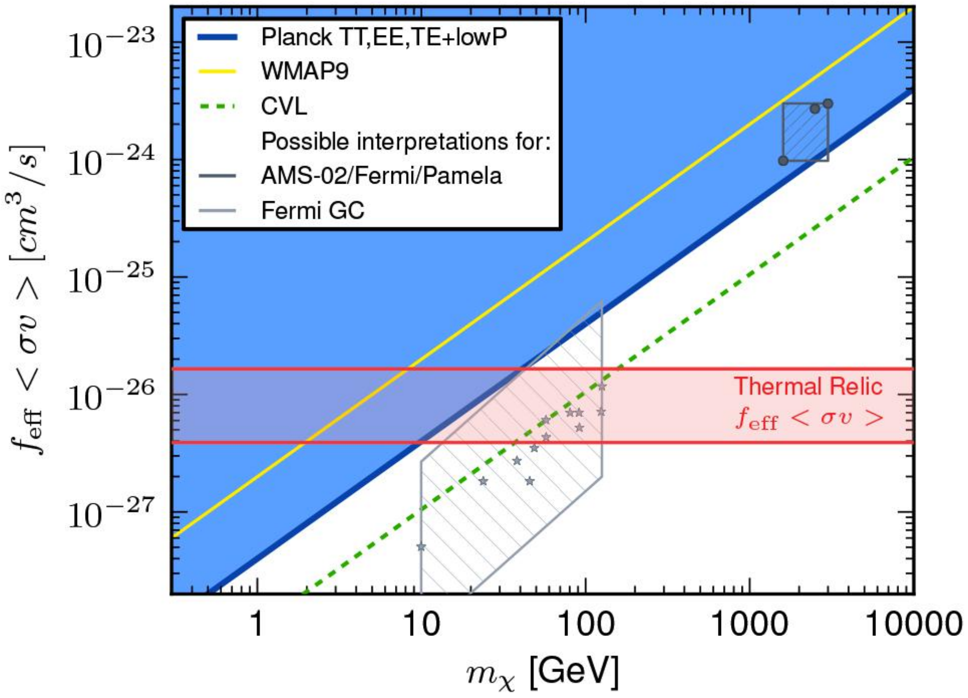
Direct detection





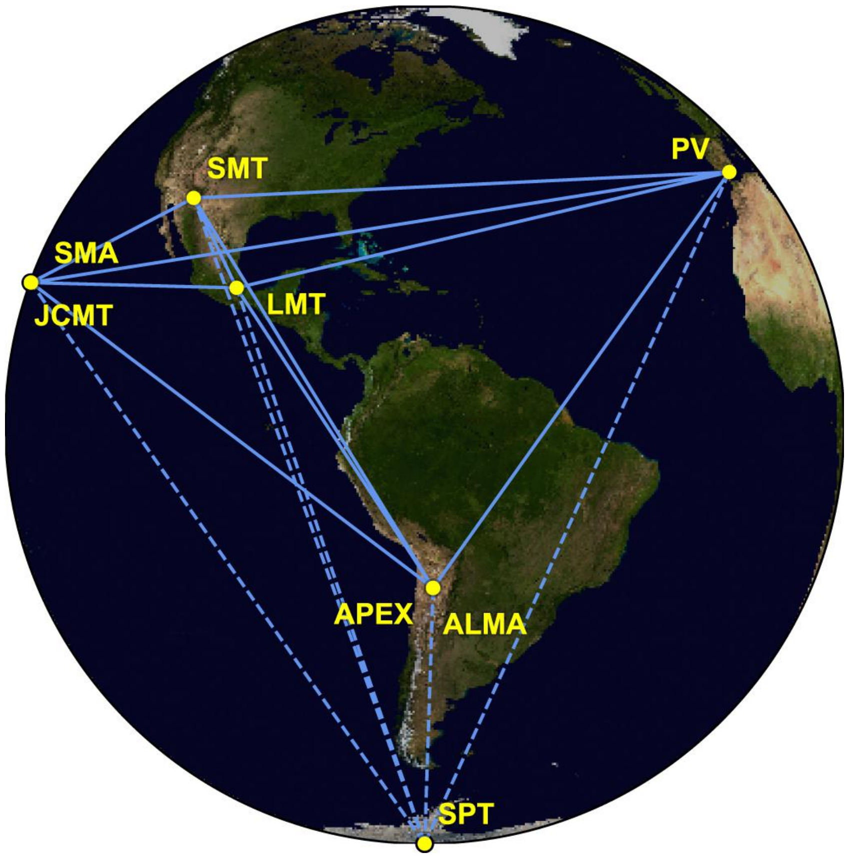
collider detection

CMB energy injection



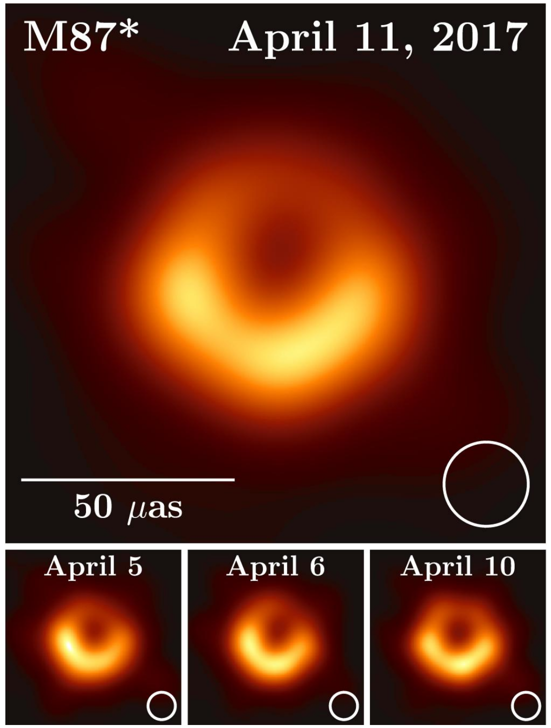
The EHT project

- VLBI: Very Long Baseline Interferometry, an Earth-sized interferometer.
- EHT collaboration: focus on improving the capability of VLBI at short wavelengths.



- First image of a SMBH

EHT collaboration, Astrophys. J. Lett. 875 (2019) L1, [1906.11238]

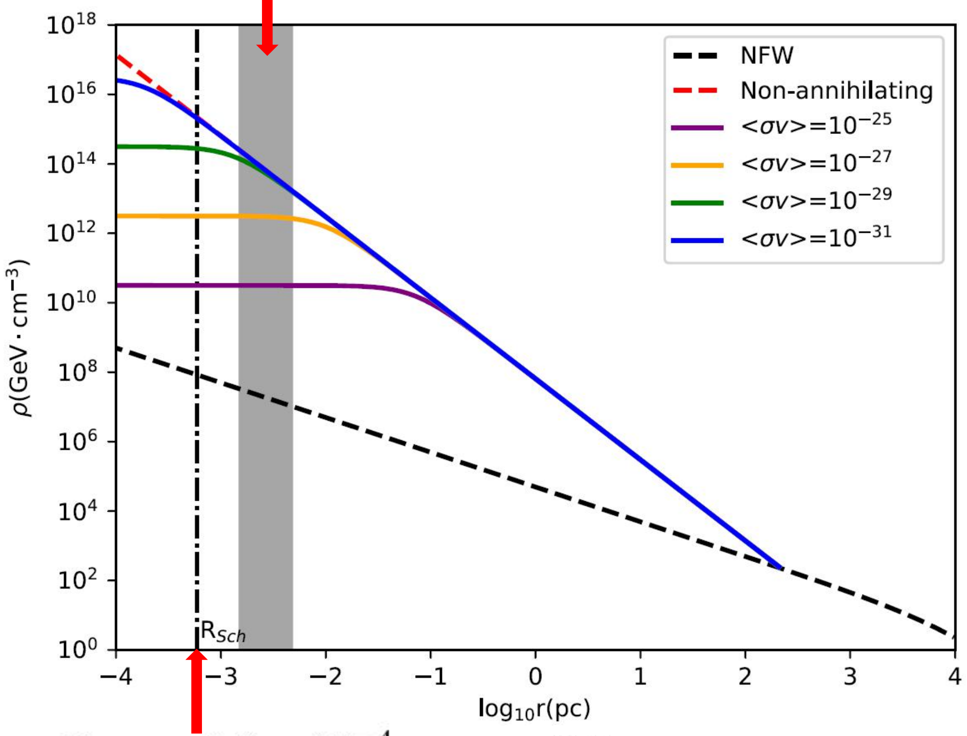


Symbol	Value	Property
M	$6.2 \times 10^9\ M_\odot$	Compact object mass
D	16.9 Mpc	Compact object distance
$\nu_{\mathrm{obs},0}$	230 GHz	Observing frequency

DM spike model

- Adiabatic growth of SMBH will significantly enhance the DM density and form a spike structure.

EHT observational areas



$R_{\rm Sch} = 5.9 \times 10^{-4}$ pc. ➡ $7.3\ \mu$as

P. Gondolo & J. Silk,PRL 83(1999) 1719{1722, [astro-ph/9906391]

O. Y. Gnedin & J. R. Primack, PRL 93 (2004) 061302, [astro-ph/0308385]

P. Ullio, H. Zhao & M. Kamionkowski, PRD 64 (2001) 043504, [astro-ph/0101481]

R. Aloisio, P. Blasi & A. V. Olinto, JCAP 05 (2004) 007, [astro-ph/0402588]

T. Lacroix, M. Karami, A. E. Broderick, J. Silk & C. Boehm, PRD 96 (2017) 063008,[1611.01961]

- DM density profile with Spike

$$\rho_\chi(r) = \begin{cases} 0 & r < R_{\rm Sch}, \\ \frac{\rho_{\rm sp}(r)\rho_{\rm sat}}{\rho_{\rm sp}(r)+\rho_{\rm sat}} & R_{\rm Sch} \le r < R_{\rm sp}, \\ \rho_{\rm NFW}(r) & r \ge R_{\rm sp}. \end{cases} \quad R_{\rm sp} \simeq 220 \text{ pc}$$

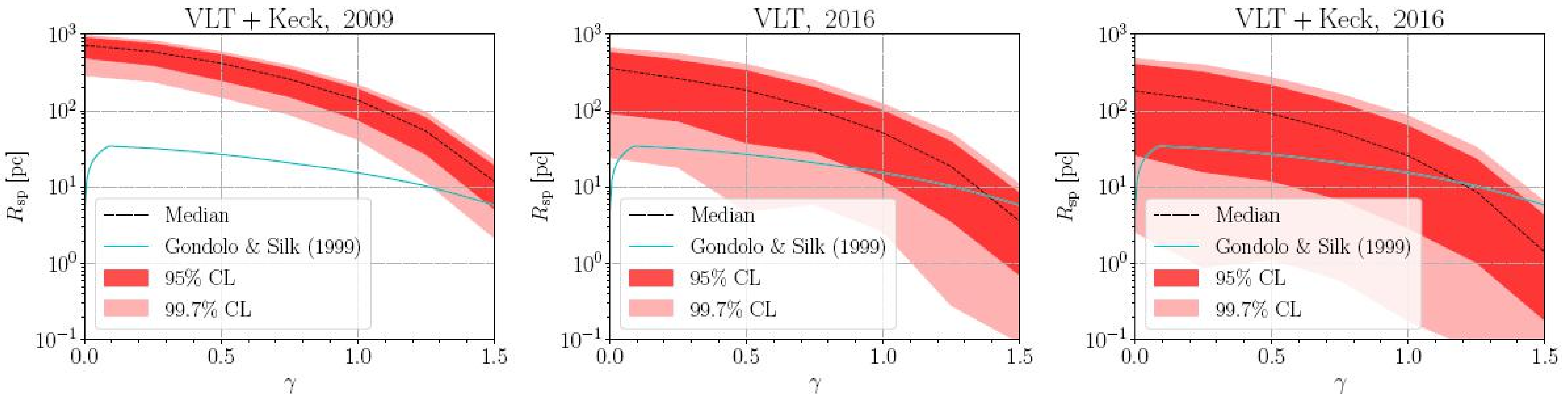
spike radius

- Saturate DM density

$$\rho_{\rm sat} = m_\chi / \langle \sigma v \rangle t_{\rm BH}$$

➡ age of SMBH $t_{\rm BH} = 10^9$ yr

- Constraints DM spike at the GC from stellar orbits



- Synchrotron emission due to WIMP annihilations can be stringently constrainted!

Calculation framework

R. Aloisio, P. Blasi & A. V. Olinto, JCAP 05 (2004) 007, [astro-ph/0402588]
T. Lacroix, M. Karami, A. E. Broderick, J. Silk & C. Boehm, PRD 96 (2017) 063008,[1611.01961]

$$S_{\rm syn}(\nu) = \int d\Omega_{\rm obs} \int_{l.o.s} dI_{\rm syn}(\nu)$$

Specific intensity: radiative transfer equation

$$\frac{dI_{\rm syn}(\nu,s)}{ds} = -\alpha(\nu,s) I_{\rm syn}(\nu,s) + \frac{j_{\rm syn}(\nu,s)}{4\pi}$$

relativistic Doppler effect and gravitational redshift

$$I_{\rm obs}(\nu_{\rm obs}) = \left(\frac{\nu_{\rm obs}}{\nu_{\rm em}}\right)^3 I_{\rm em}(\nu_{\rm em}) = g^3 I_{\rm em}(\nu_{\rm em})$$

emissivity

$$j_{\rm syn}(\nu,r) = 2\int_{m_e}^{M_\chi} dE \langle P_{\rm syn}\rangle(\nu,E_e,B)\, n_e(r,E_e)$$

$B \sim 1 - 30$ G

$$P_{\rm syn}(\nu,E_e,B,\theta_p) = \frac{\sqrt{3}e^3 B \sin\theta_p}{m_e c^2} F(\nu/\nu_c)$$

power of synchrotron emission

electron and positron energy spectrum

$$n_e(r,E) = \frac{4\pi p^2}{c} f_e(r,p)$$

outside accretion radius : propagation equation

$$-\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2 D \frac{\partial f_e}{\partial r}\right] + v\frac{\partial f_e}{\partial r} - \frac{1}{3r^2}\frac{\partial}{\partial r}(r^2 v)\, p\frac{\partial f_e}{\partial p} + \frac{1}{p^2}\frac{\partial}{\partial p}(\dot{p}p^2 f_e) = q(r,p)$$

source function

$$q(r,p) = \frac{c}{4\pi p^2} Q(r,E) = \frac{c}{4\pi p^2}\frac{\langle\sigma v\rangle \rho_\chi^2(r)}{2m_\chi^2}\sum_i {\rm BR}_i \frac{dN_{e^\pm}^{\rm inj}}{dE}(E)$$

annihilation rate

injection spectrum

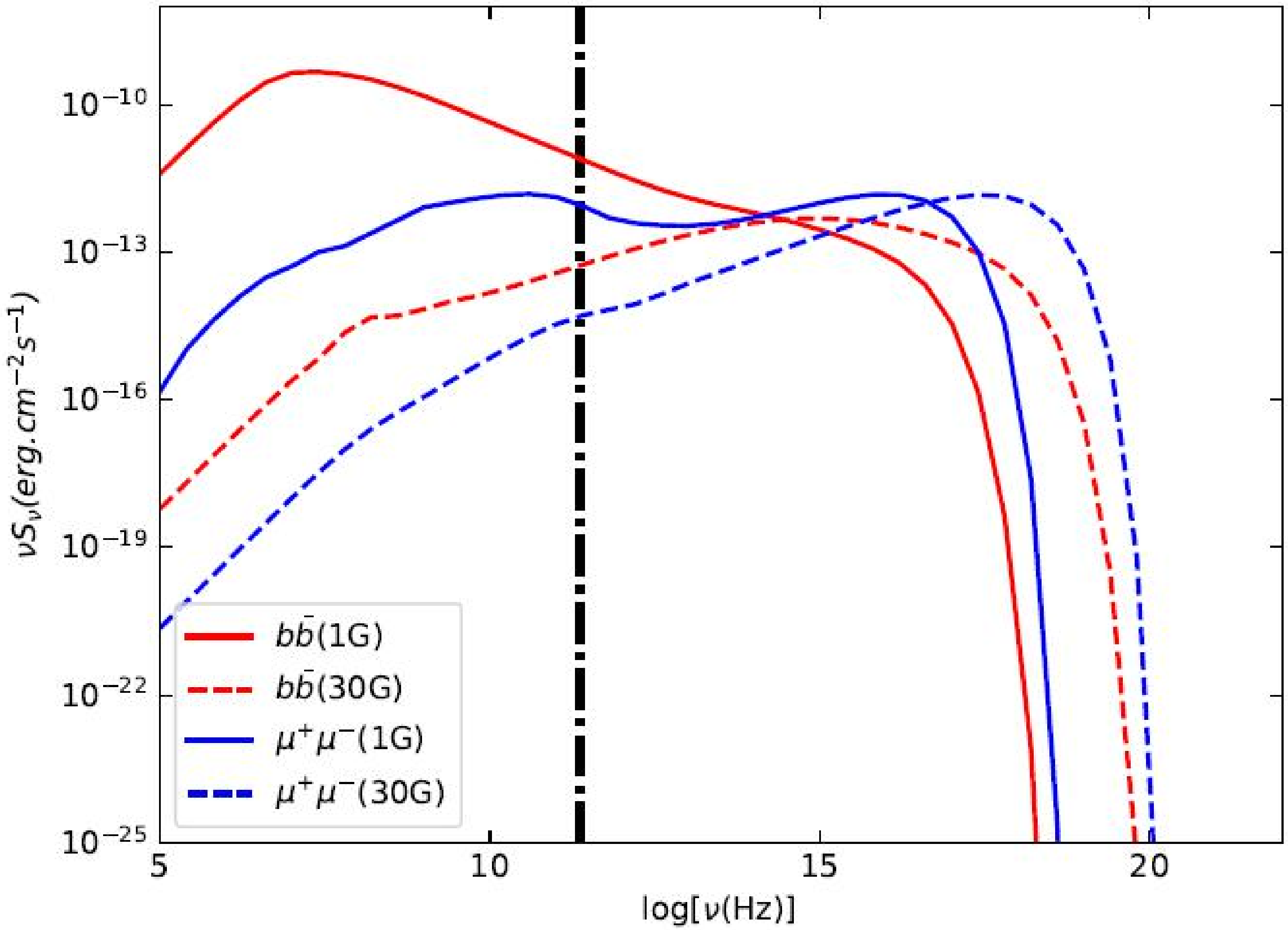
inside accretion radius: integral analytic solution

$$f_e(r,p) = \int_r^{r_{\rm acc}} \frac{Q_i(R_{\rm inj},p_{\rm inj})}{v(R_{\rm inj})}\left(\frac{R_{\rm inj}}{R_{\rm Sch}}\right)^{\frac{5}{2}}\left(\frac{p_{\rm inj}}{p}\right)^4 {\rm d}R_{\rm inj}$$

injection momentum

$$p_{\rm inj}(R_{\rm inj};r,p) = p\left[\frac{k_0 R_{\rm Sch}^{-\frac{1}{2}}}{c} R_{\rm inj}^{\frac{3}{2}} p\left(\frac{r}{R_{\rm inj}} - 1\right) + \left(\frac{R_{\rm inj}}{r}\right)^{\frac{1}{2}}\right]^{-1}$$

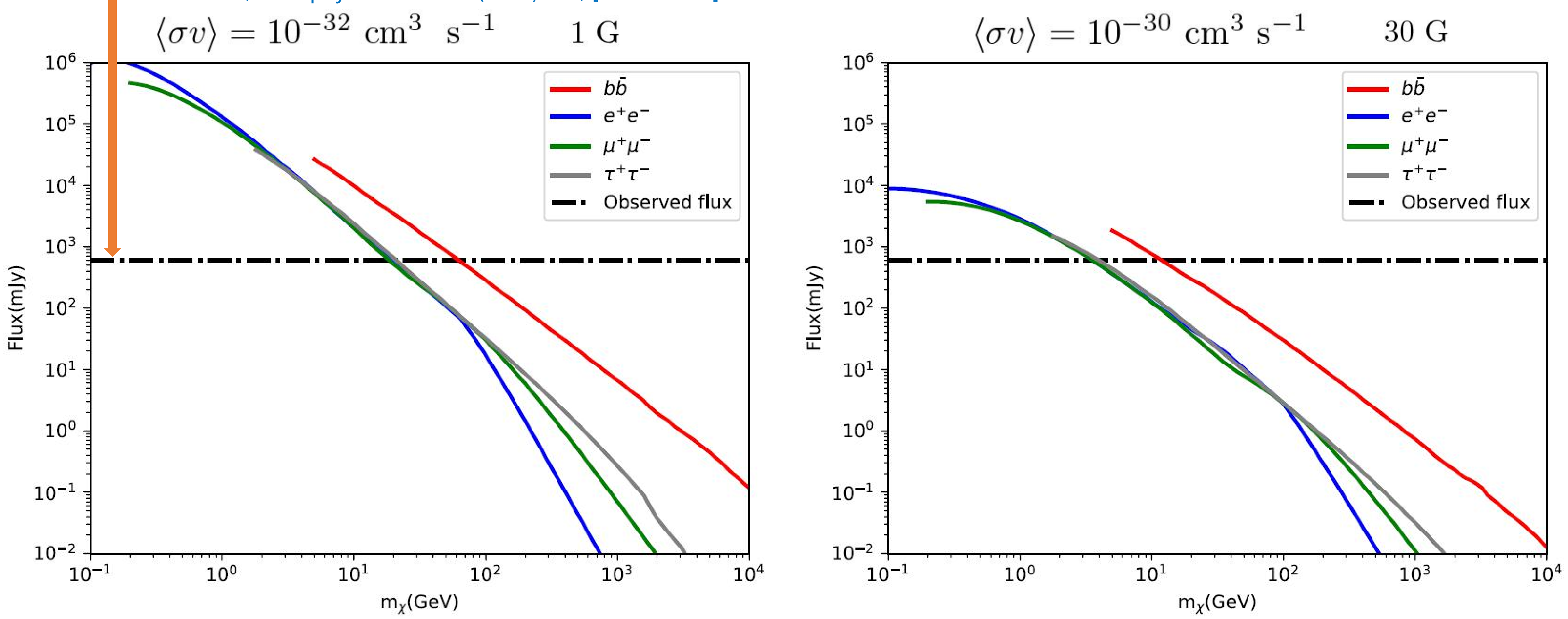
- Spectra of synchrotron emission from DM annihilation



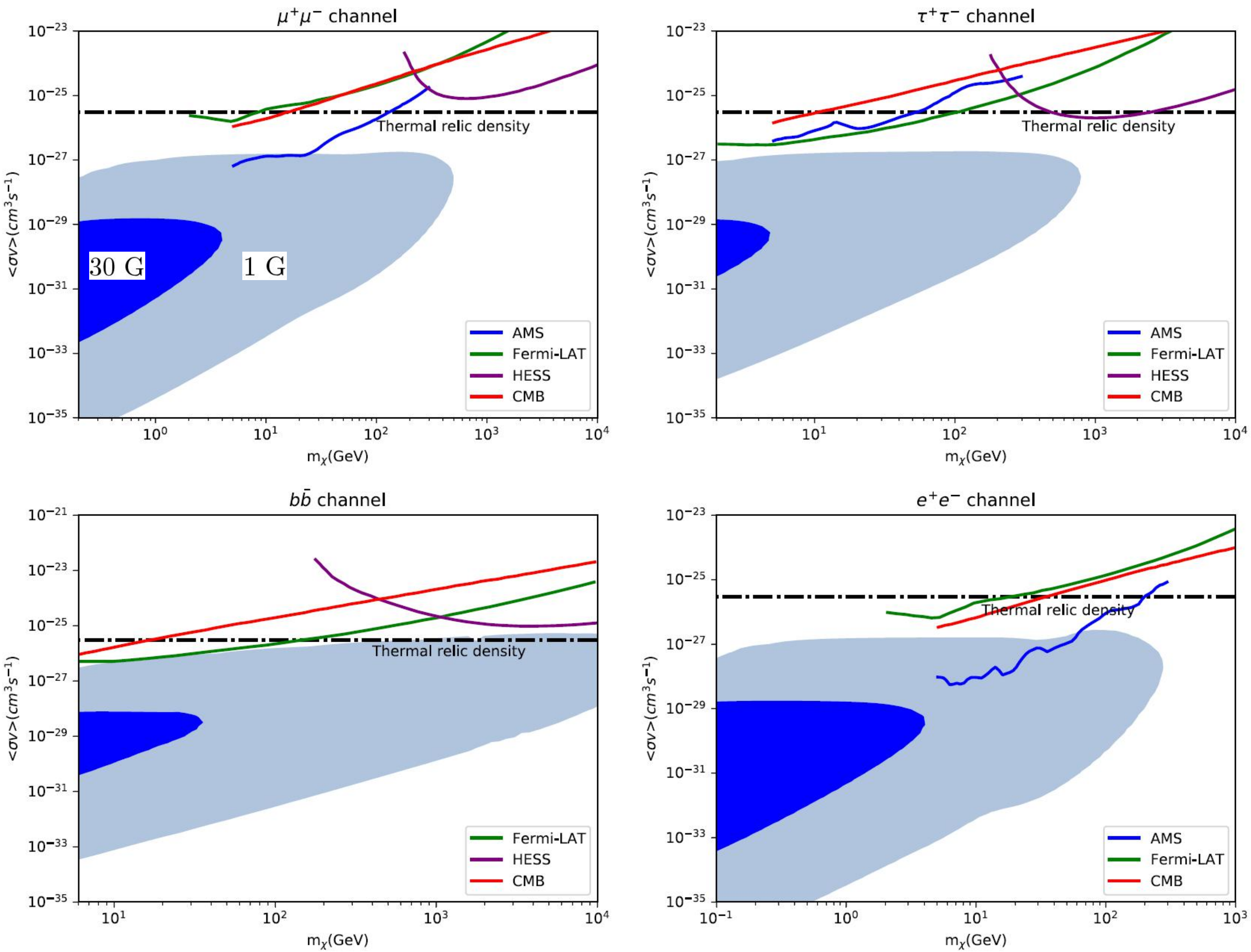
● Bnechmark flux for four annihilation channels

EHT collaboration, Astrophys. J. Lett. 910 (2021) L12,[2105.01169]

EHT collaboration, Astrophys. J. Lett. 910 (2021) L13, [2105.01173]



Limits on WIMP annihilation cross sections



Future work for improvement

R. A. Battye,B. Garbrecht, J. I. McDonald S. Srinivasan [hep-ph/2104.08290]

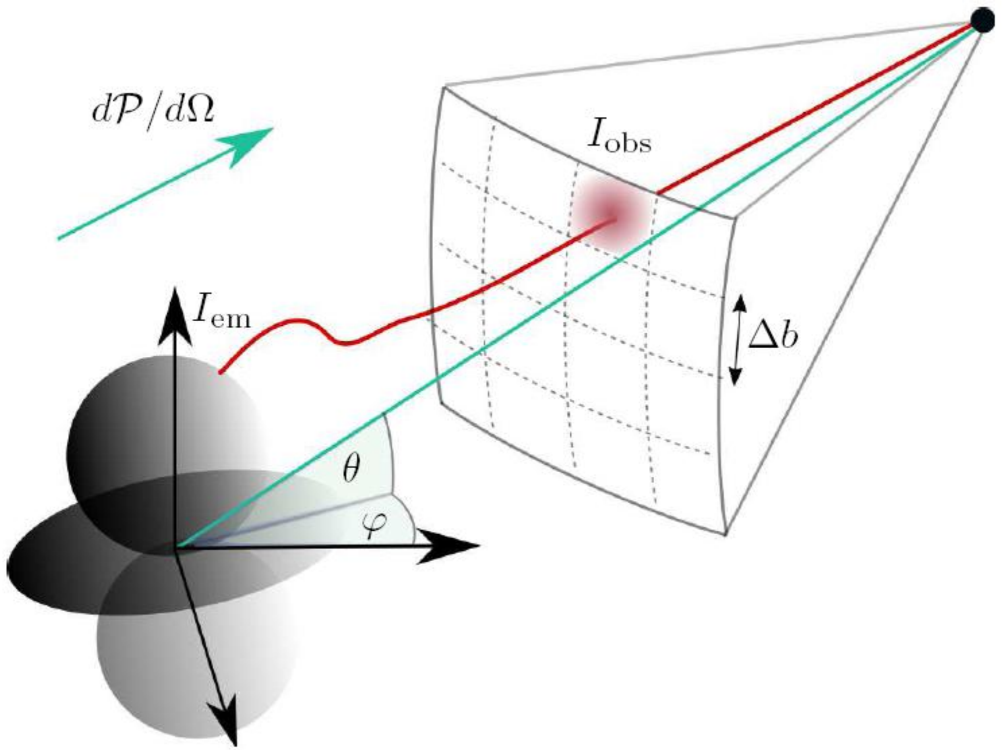
- Ray-tracing geometry & plasma effect
- Geodesic equation with plasma sources

$$\frac{d^2x^\mu}{d\lambda^2} + \Gamma^\mu_{\nu\rho}\frac{dx^\nu}{d\rho}\frac{dx^\rho}{d\lambda} = -\frac{1}{2}\partial^\mu \omega_\mathrm{p}^2$$

$$F_\mathrm{obs}(\theta,\varphi) = \frac{1}{D^2}\sum_i (\Delta b)^2 I^i_\mathrm{obs}(\theta^i_\mathrm{obs},\varphi^i_\mathrm{obs})$$

$$\frac{I_\mathrm{obs}}{n^2_\mathrm{obs}\omega^3_\mathrm{obs}} = \frac{I_\mathrm{em}}{n^2_\mathrm{em}\omega^3_\mathrm{em}}$$

$$F = \frac{1}{D^2}\sum_i \frac{(\Delta b)^2}{(n^i_\mathrm{em})^2}\tilde{f}(r_\mathrm{em}, r_\mathrm{s})\frac{\rho_\mathrm{DM}(\mathbf{x}^i_\mathrm{em})v^a_\mathrm{em}P_{\mathrm{a}\to\gamma}}{4\pi}$$



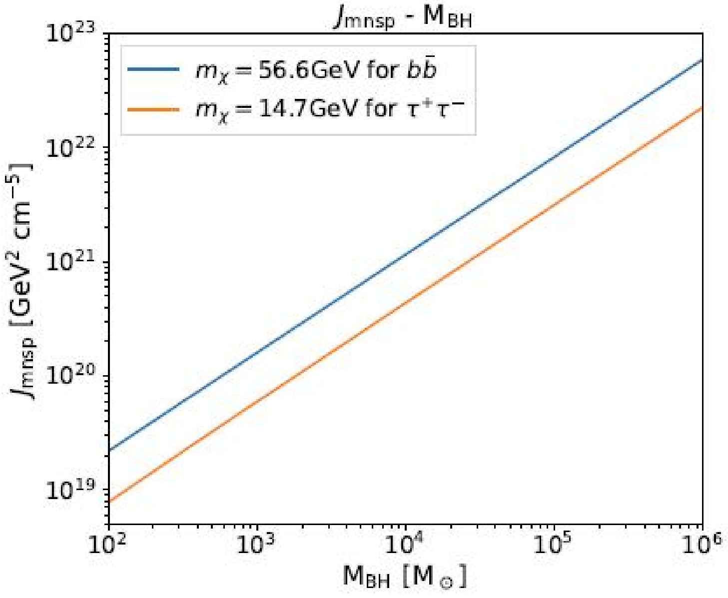
Investigating the dark matter minispikes with the gamma-ray signal from the halo of M31

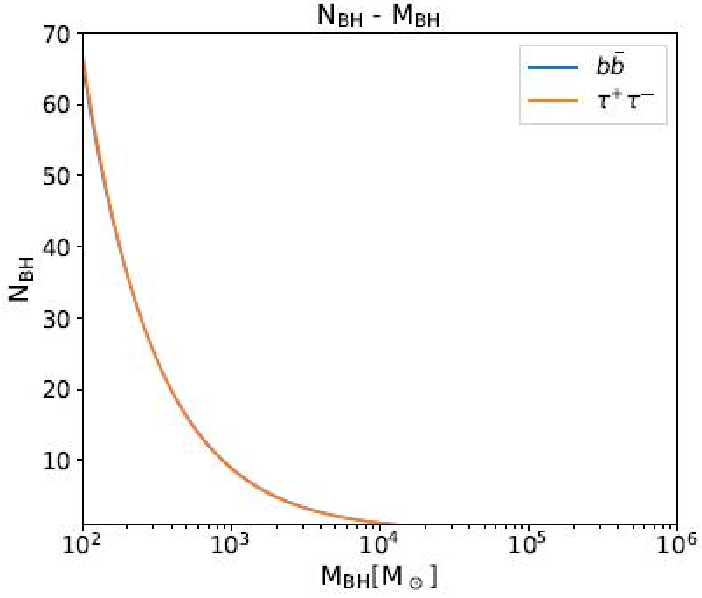
astro-ph/2108.09204

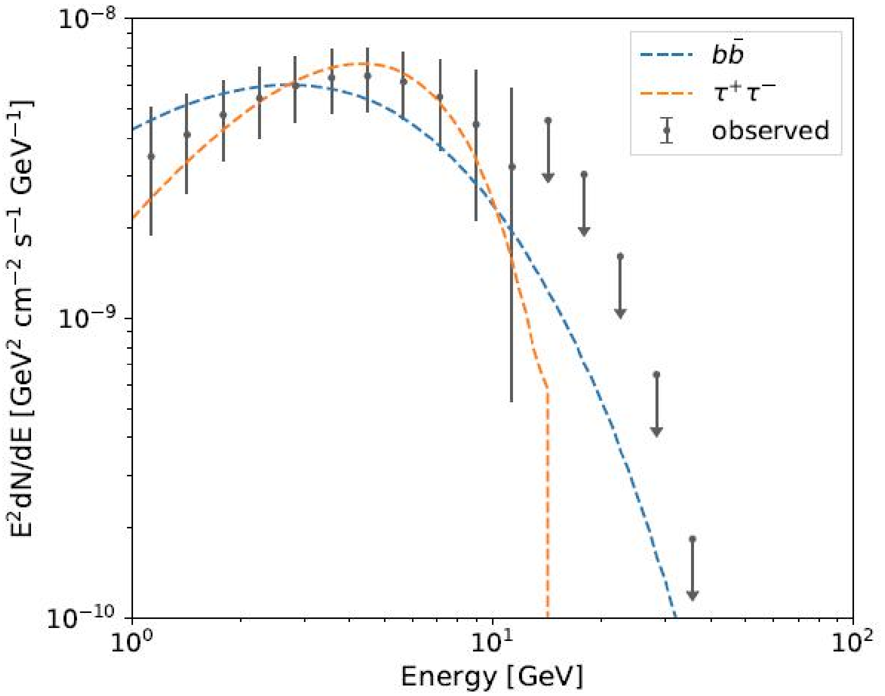
Zi-Qing Xia, Zhao-Qiang Shen, Xu Pan Lei Feng, Yi-Zhong Fan

$$\frac{d\Phi}{dE_\gamma}(E_\gamma) = \frac{\langle \sigma v \rangle}{8\pi m_\chi^2} \frac{dN_\gamma}{dE_\gamma} \times J_{\rm factor}$$

$$J_{\rm factor} = J_{\rm NFW} + {\rm N_{BH}} \times J_{\rm mnsp}$$







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