Gamma rays from dark matter spikes in EAGLE simulations

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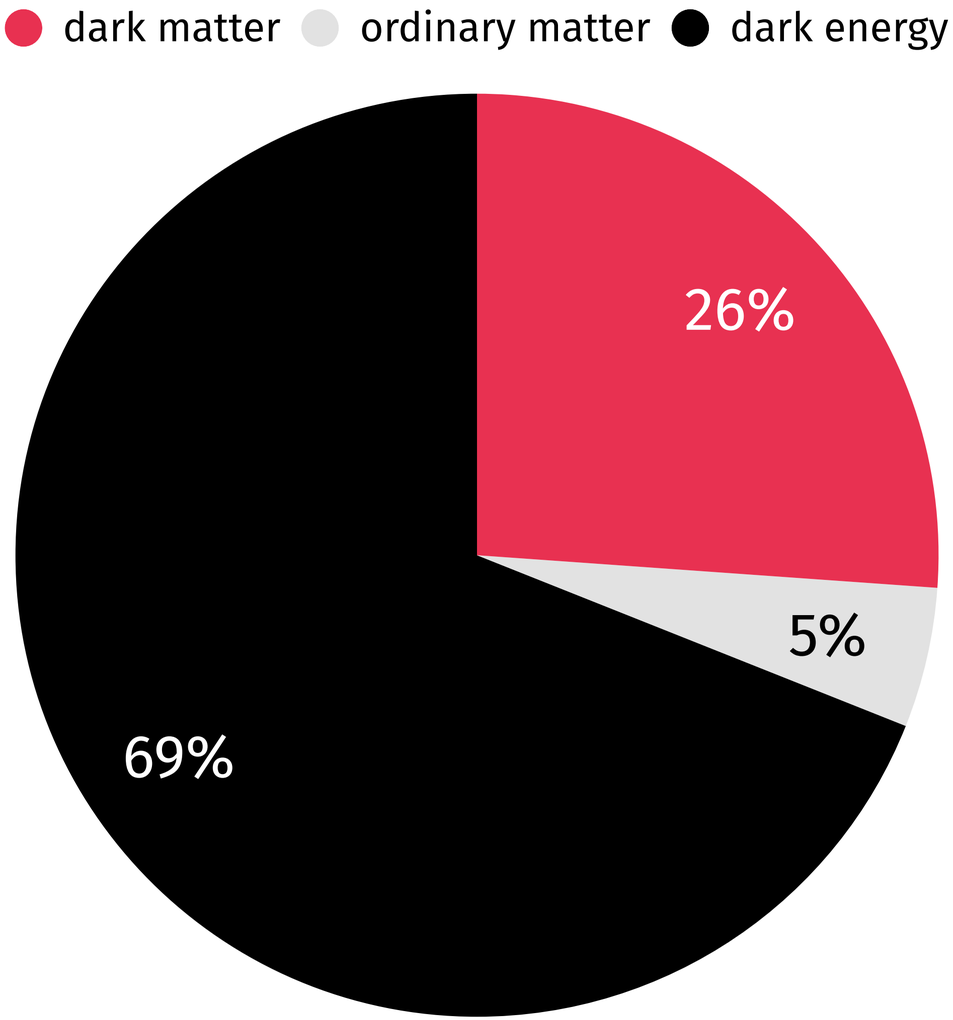
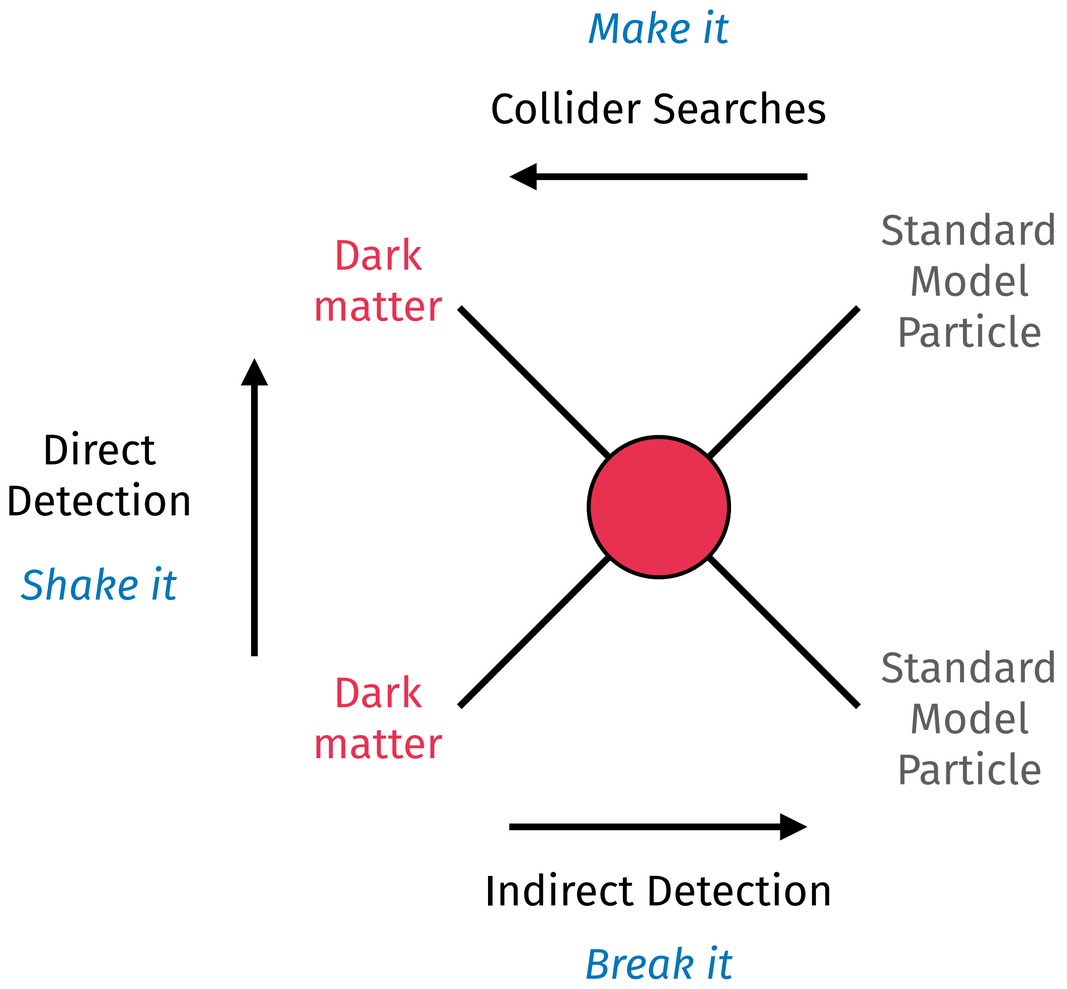
university of groningen

Dark matter





Credit: Planck Collaboration (2018)

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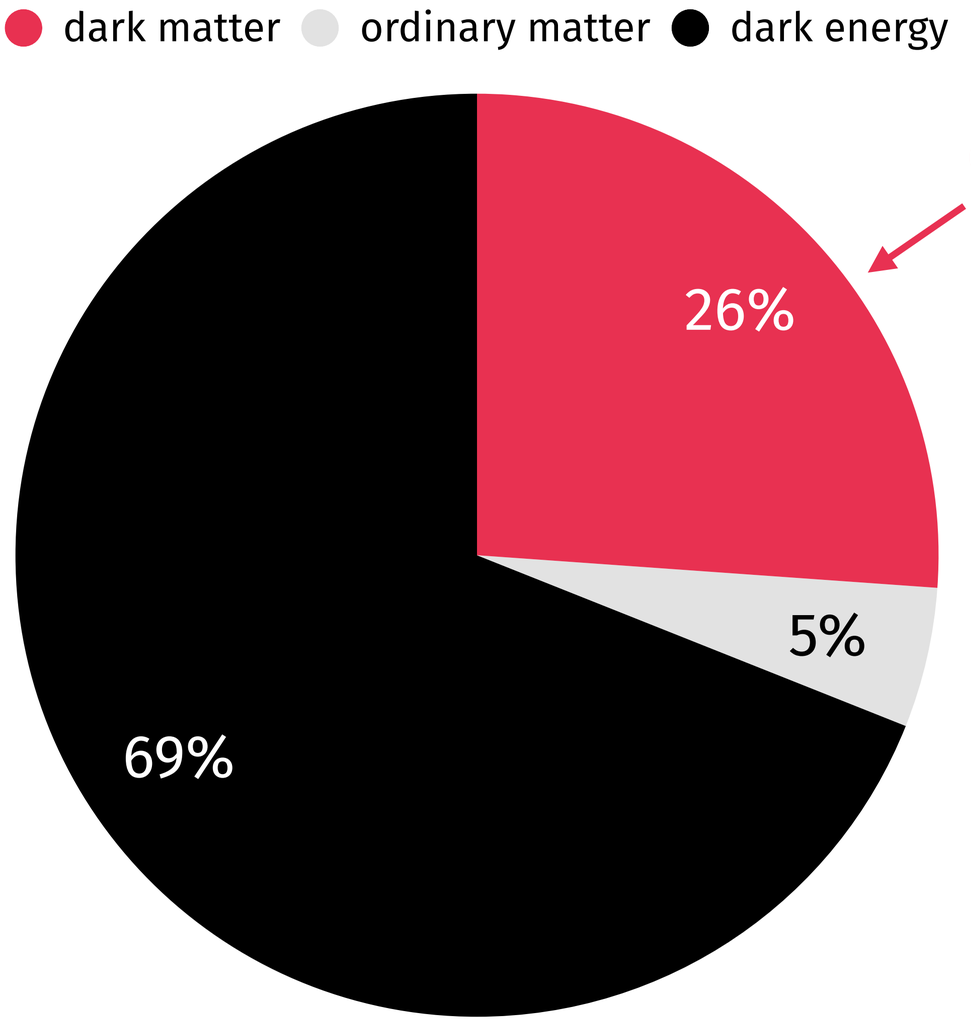
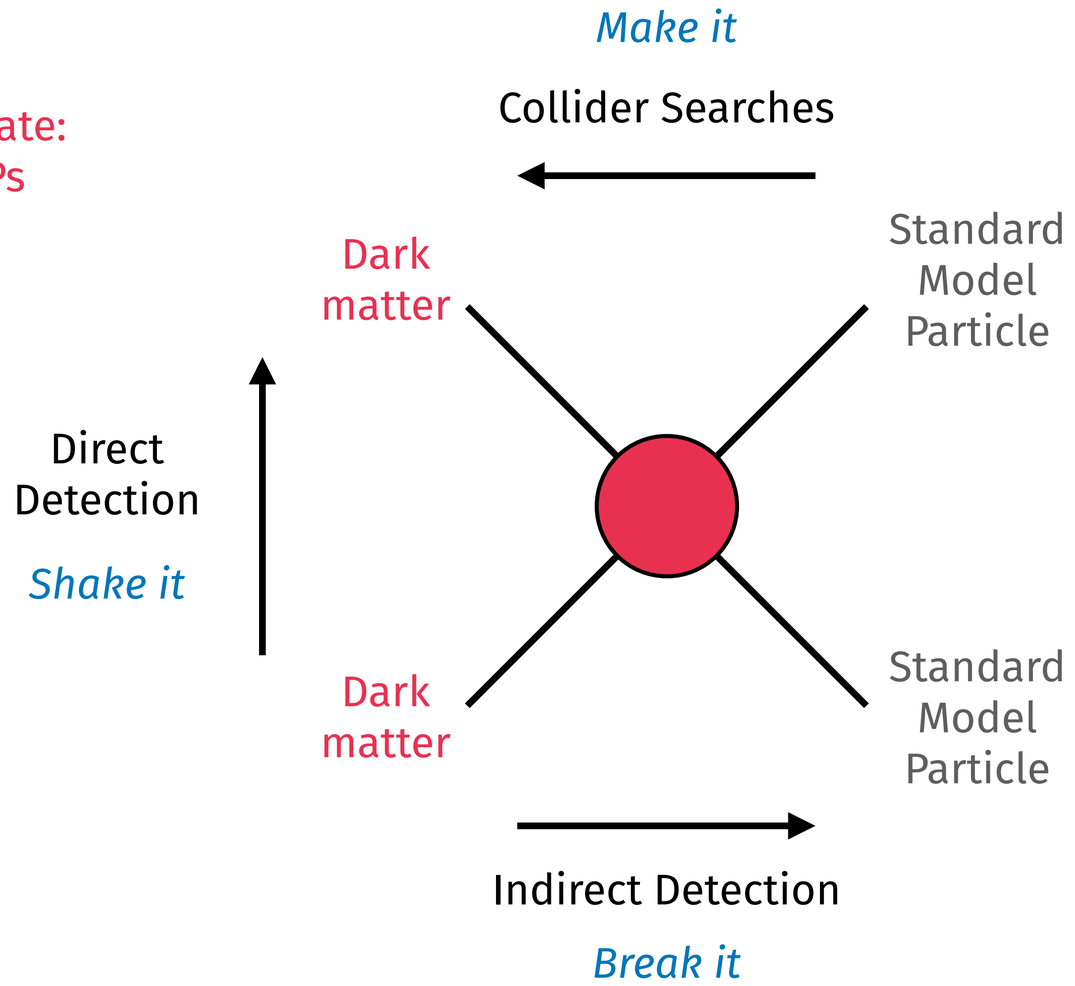


Candidate:
WIMPs



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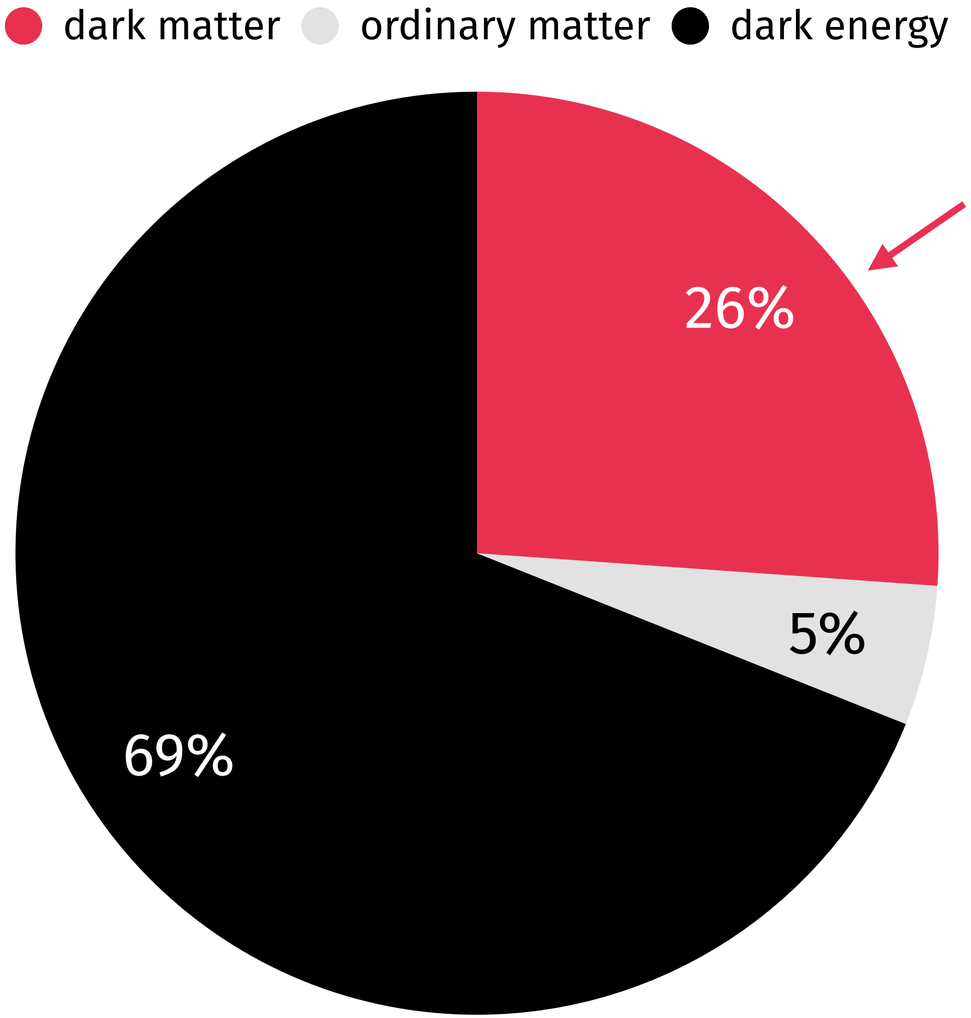

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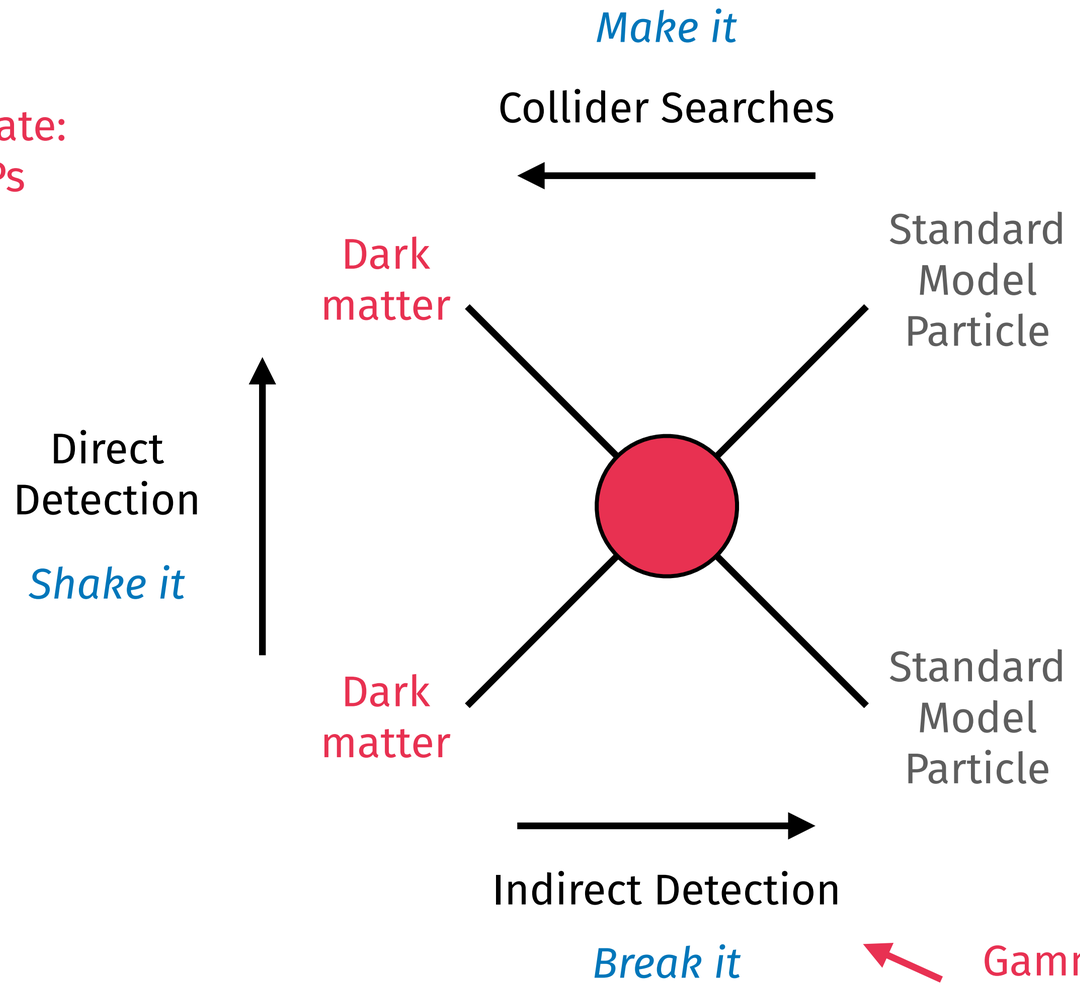


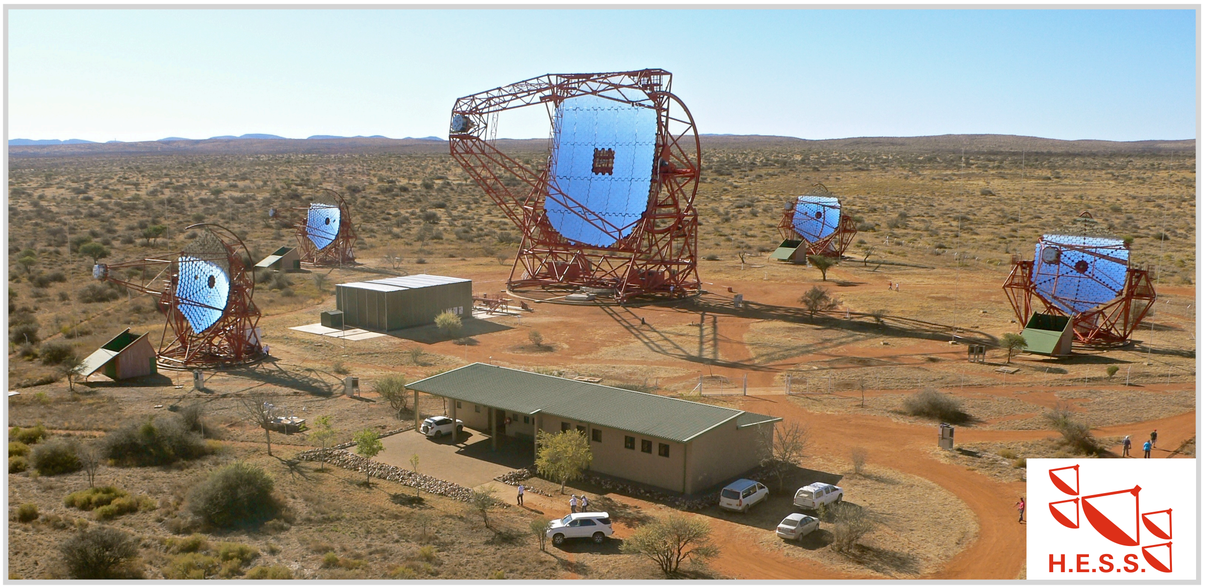
Credit: Planck Collaboration (2018)

Gamma-ray instruments

Space-based

- Direct detection
- Small collection area
- Energy range: ~ 10 MeV - 100 GeV

Ground-based

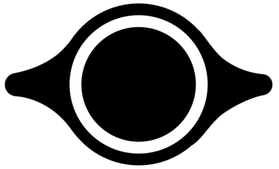


- Indirect detection
- Large collection area
- Energy range: ~ 20 GeV - 100 TeV

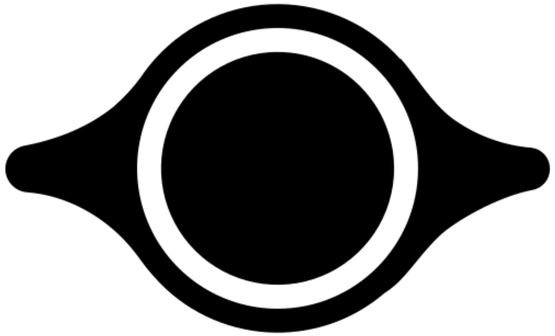
Credit: NASA/DOE/Fermi LAT Collaboration, HESS Collaboration

Intermediate mass black holes (IMBH)

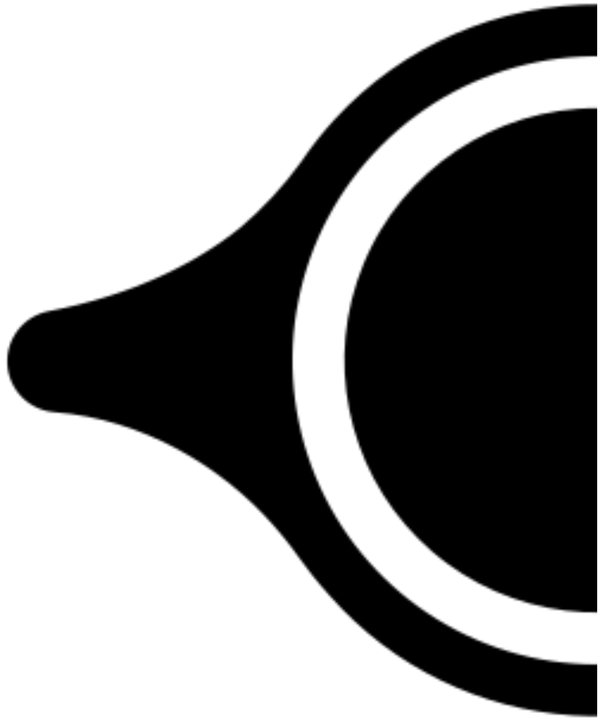
Stellar-mass black hole
$< 20 M_\odot$



Intermediate mass black hole
$20 - 10^6 M_\odot$



Supermassive black hole
$> 10^6 M_\odot$



Intermediate mass black holes (IMBH)

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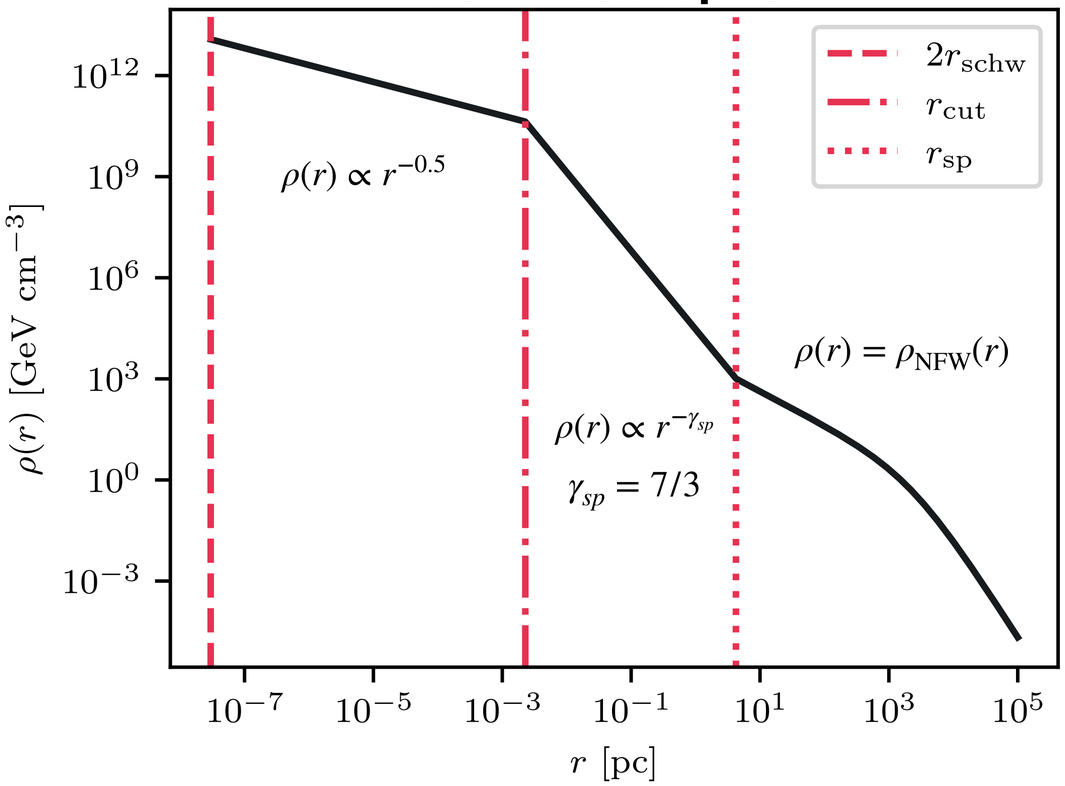
Dark matter spikes



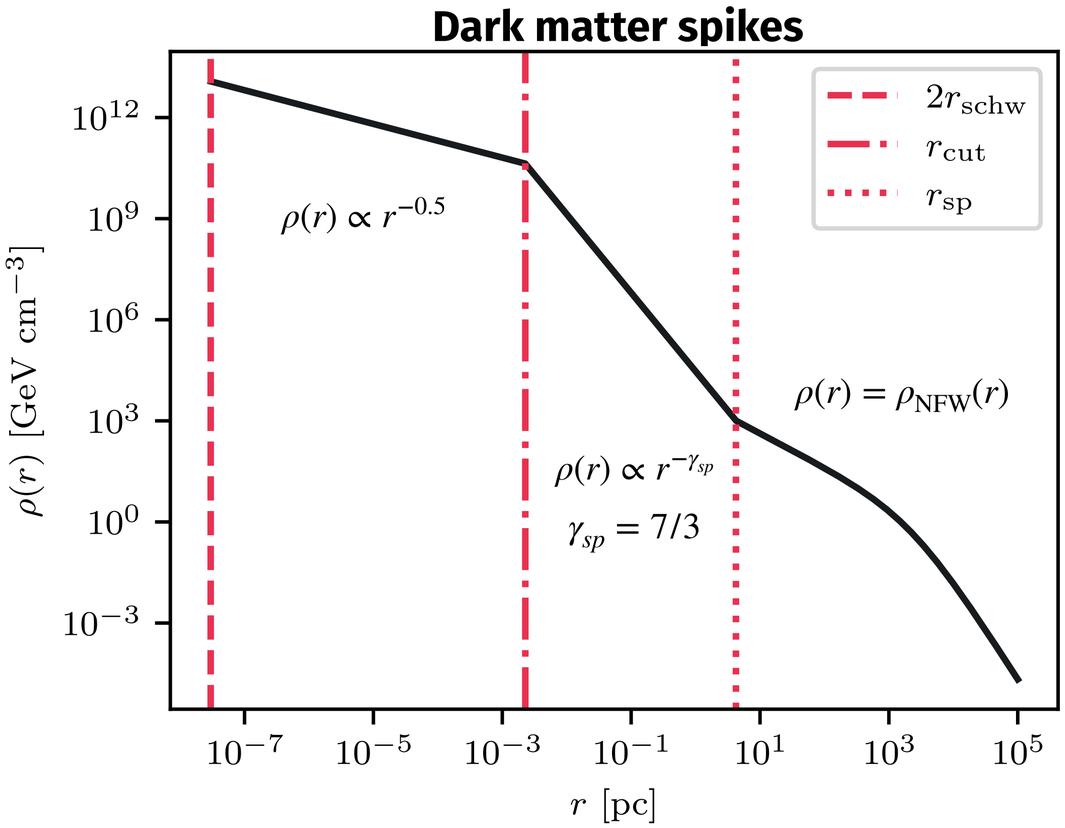
based on Bertone+ (2005), Zhao & Silk (2005), Vasiliev (2007)

Intermediate mass black holes (IMBH)

IMBHs are ideal targets for dark matter searches!

1. Unidentified point like sources
2. Identical energy spectra

→ smoking gun signature for dark matter!



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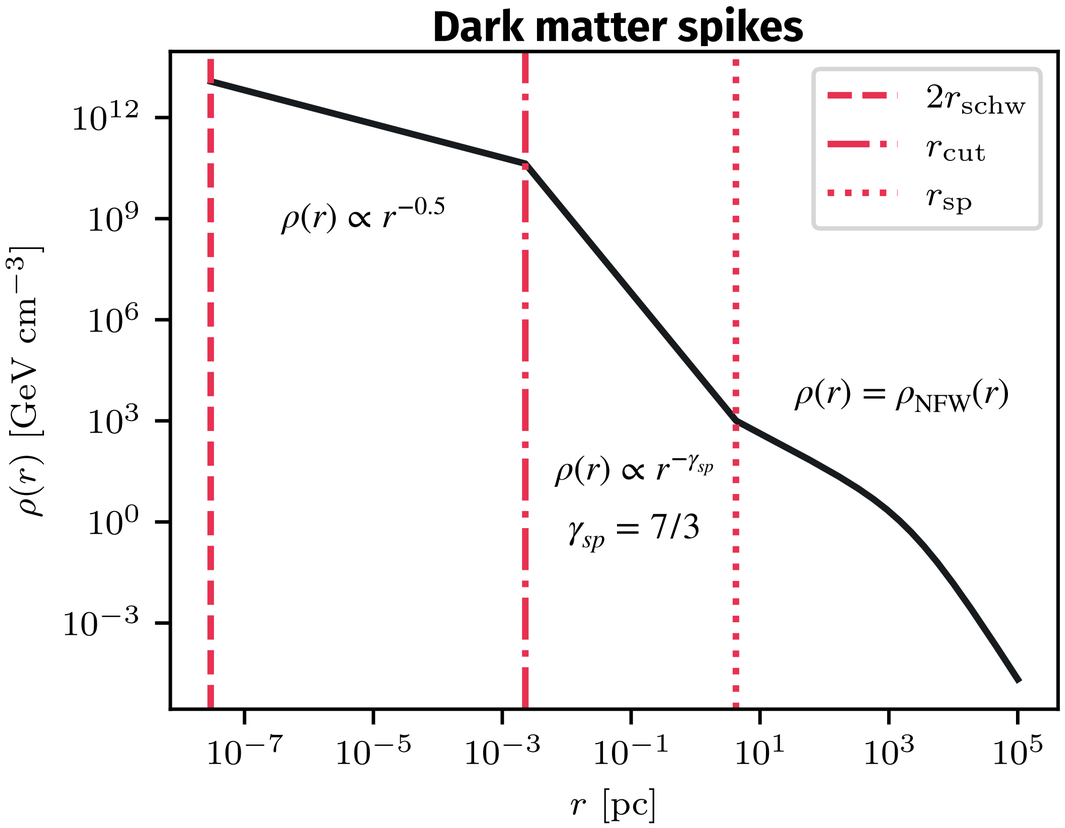


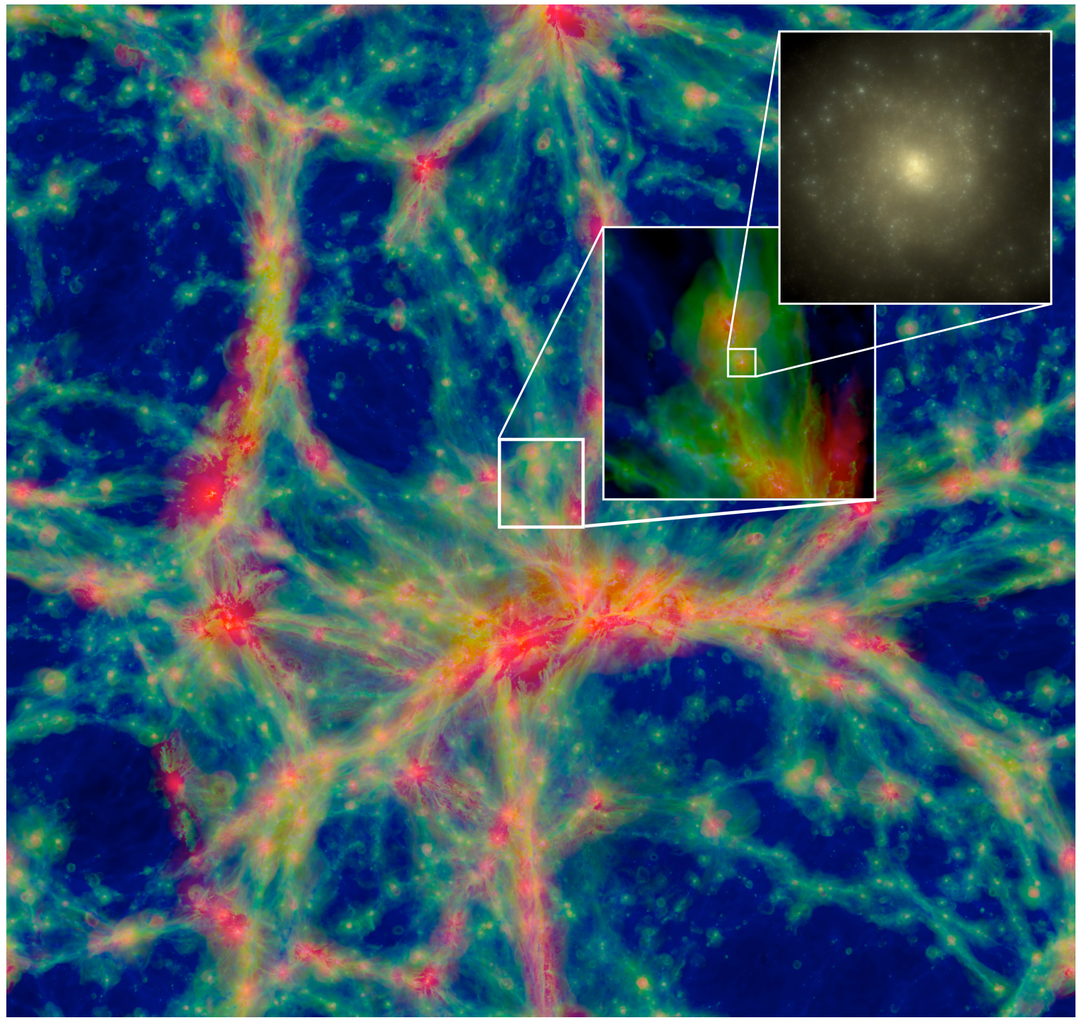
Problem: Number and spatial distribution of IMBHs in the Milky Way is unknown

→ Cosmological simulations

based on Bertone+ (2005), Zhao & Silk (2005), Vasiliev (2007)

EAGLE cosmological simulation

- **E**volution and **A**ssembly of **G**a**L**axies and their **E**nvironments
- Calibrated to reproduce observables at z = 0
- Contains dark matter, gas, stellar and black hole particles
- Seed black holes with $M_{bh} \approx 10^5$ $M_\odot$



Credit: Schaye et al. 2014

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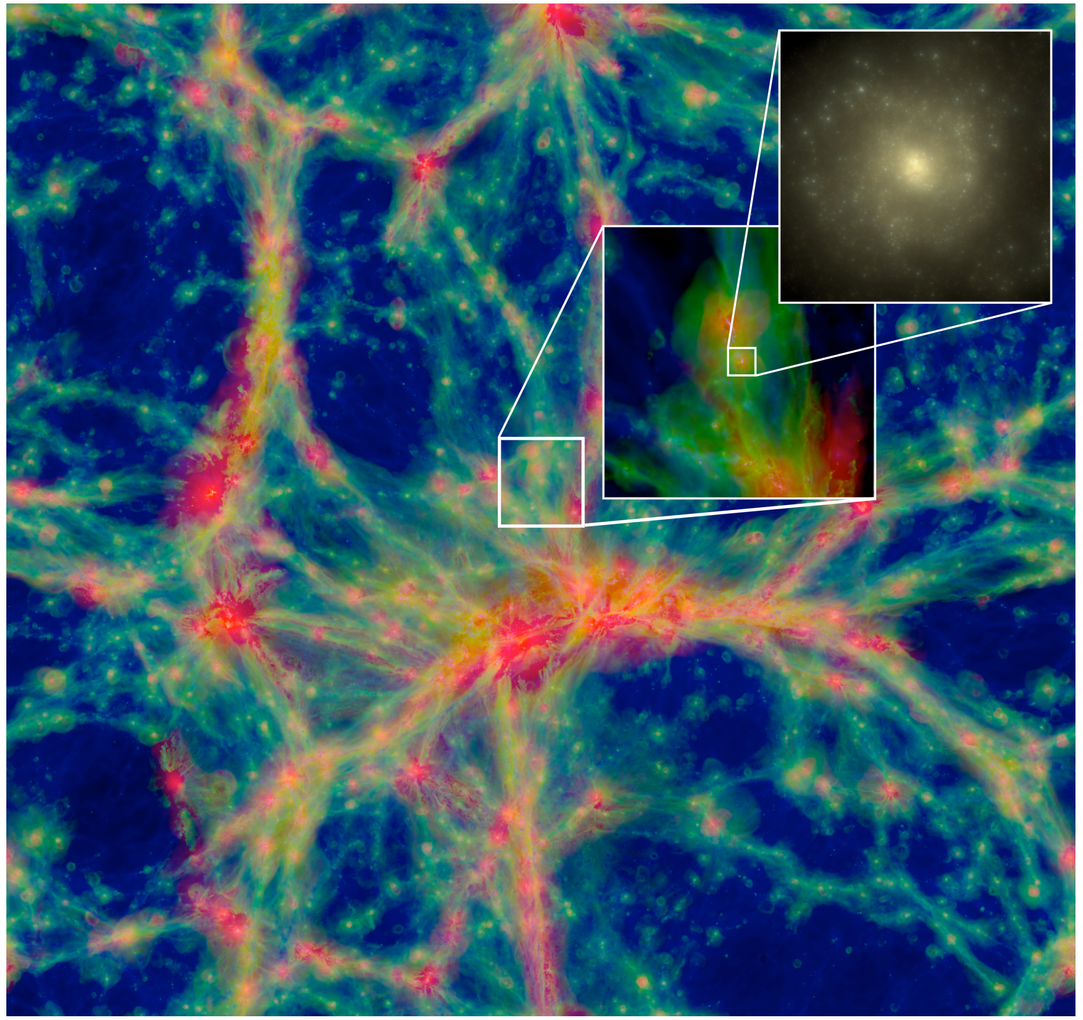

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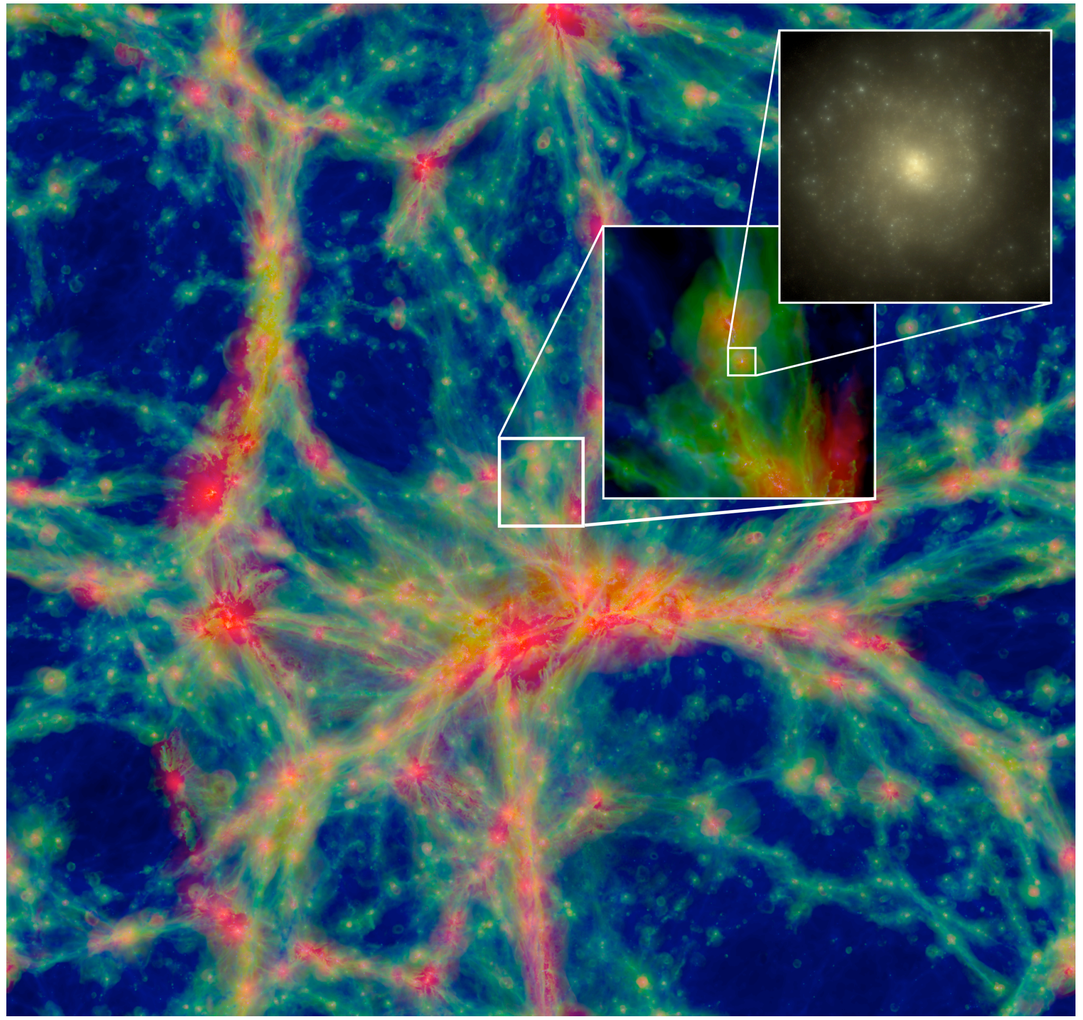

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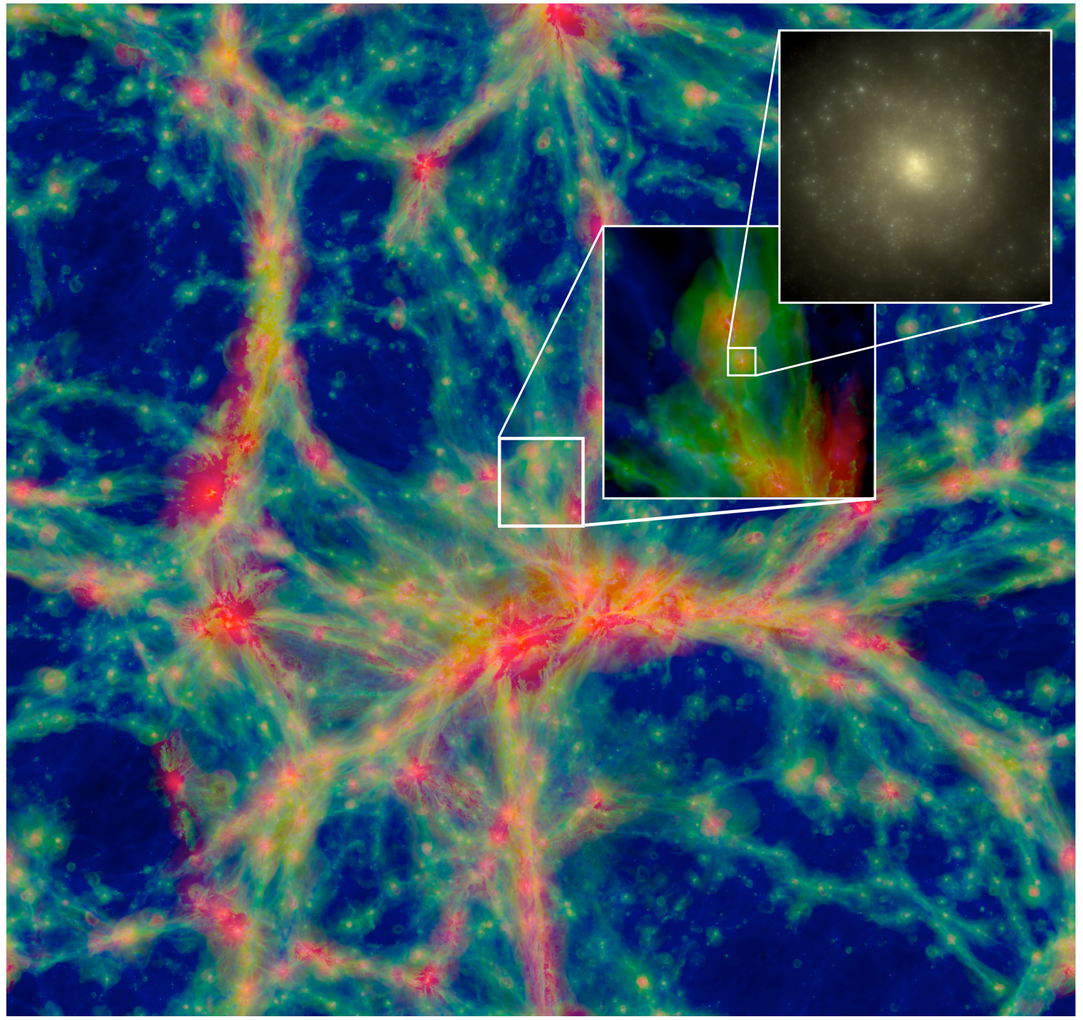
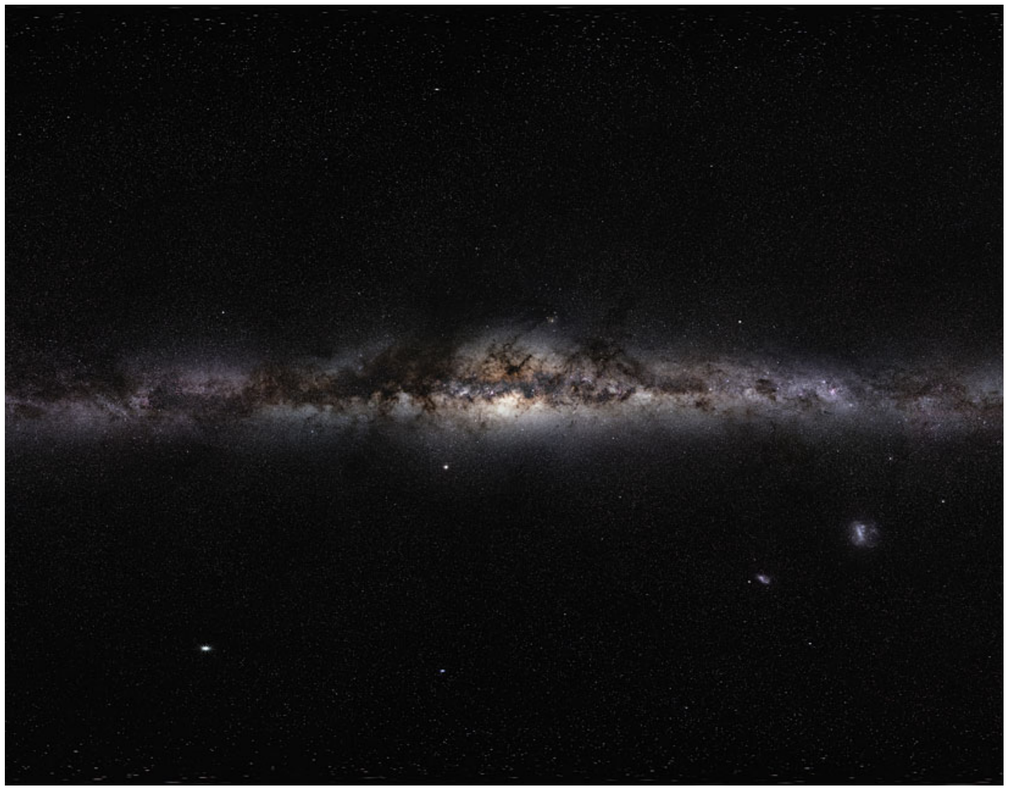


Credit: Schaye et al. 2014

How to get an IMBH catalogue?

1. Select Milky Way-like galaxies
2. Select unmerged IMBHs within galaxies
3. Determine IMBH coordinates
4. Determine dark matter spike parameters
5. Calculate expected gamma-ray flux



Credit: ESO/S. Brunier

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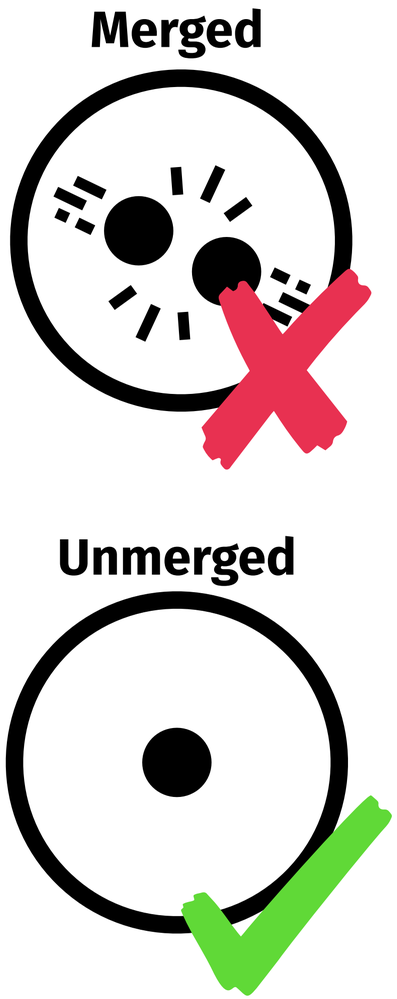

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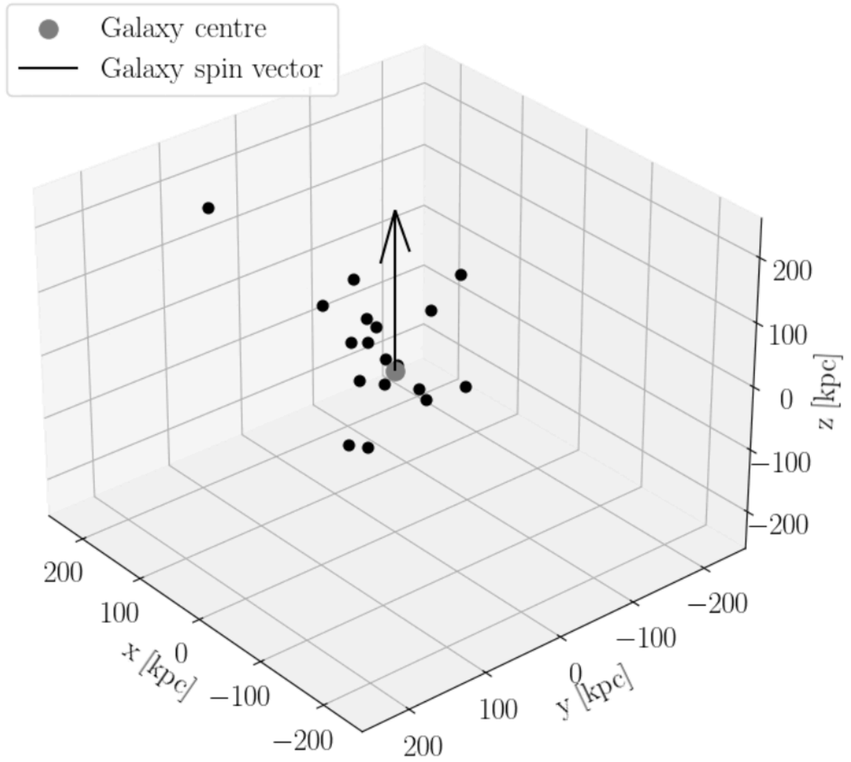

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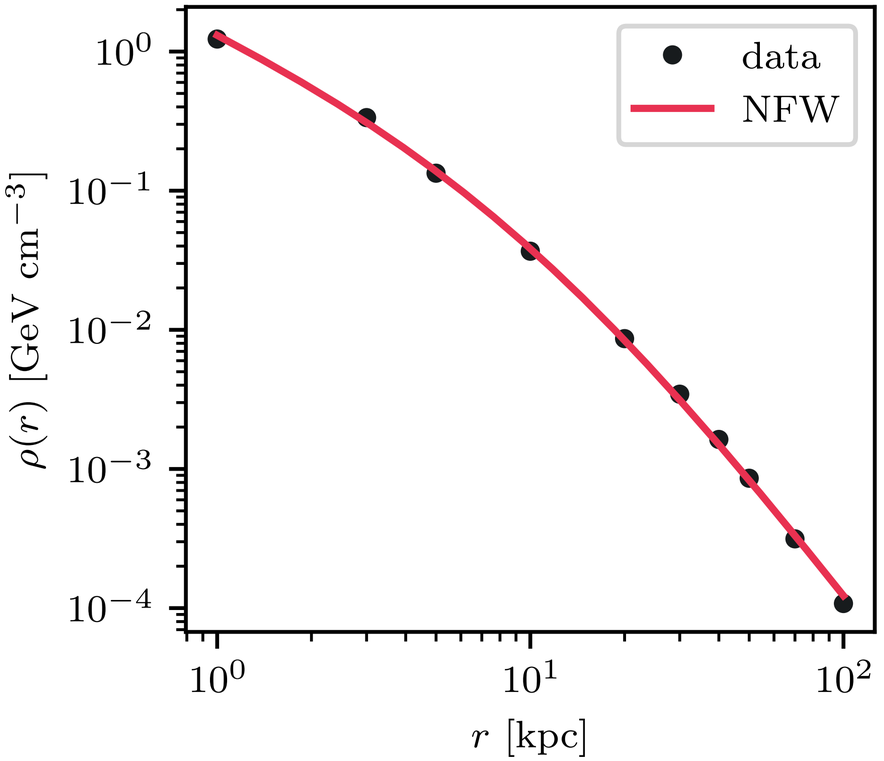
Formation halo of IMBH



$\rightarrow r_{\rm sp}, \rho(r_{\rm sp}), r_{\rm cut}$

How to get an IMBH catalogue?

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3. Determine IMBH coordinates
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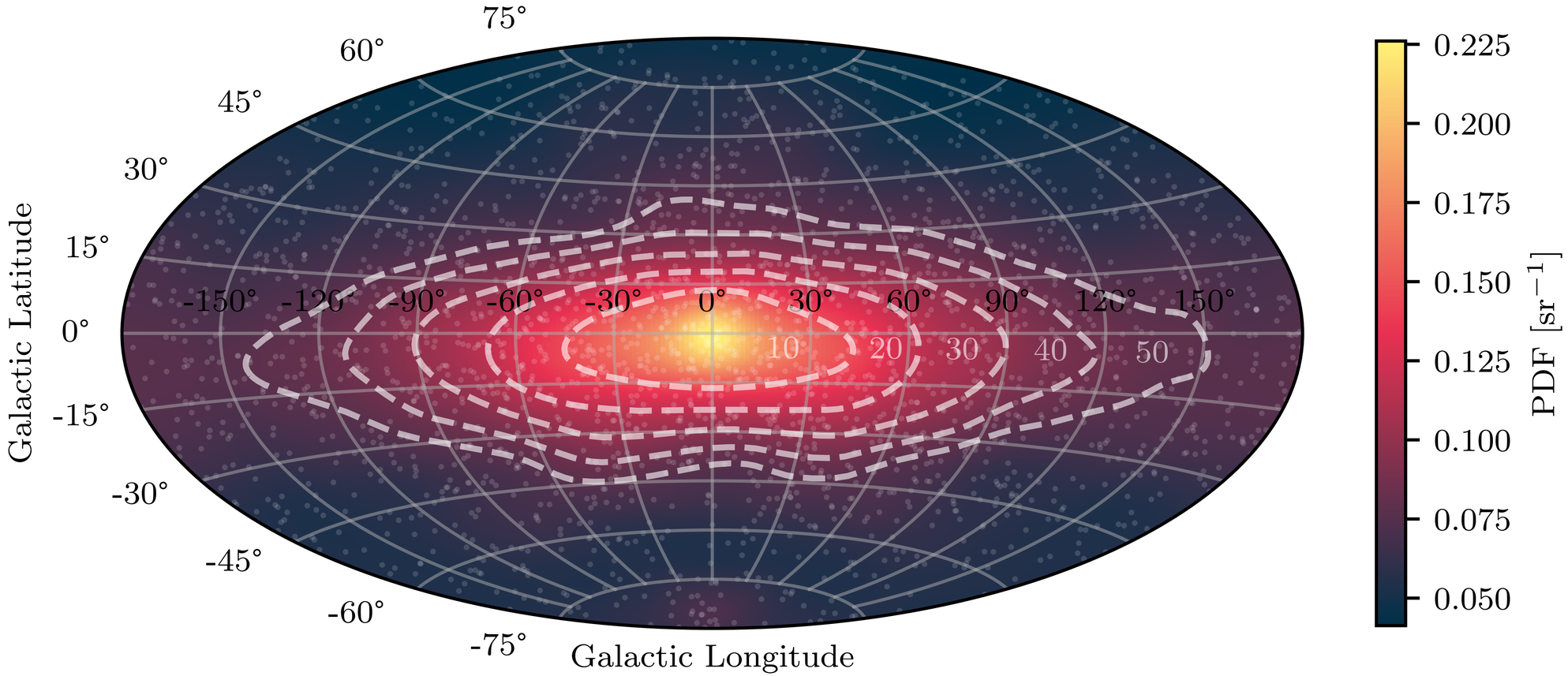
$$\Phi(E, D) = \frac{11}{20}\frac{1}{D^2}\underbrace{\frac{\mathrm{d}N}{\mathrm{d}E}\frac{\langle\sigma v\rangle}{m_\chi^2}}_{\text{dark matter properties}}\underbrace{\rho(r_{\mathrm{sp}})^2 r_{\mathrm{sp}}^3\left(\frac{r_{\mathrm{cut}}}{r_{\mathrm{sp}}}\right)^{-5/3}}_{\text{dark matter spike parameters}}$$

Results: spatial distribution

On average: ~15 IMBHs within a Milky Way-like galaxy



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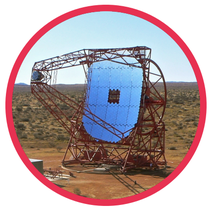
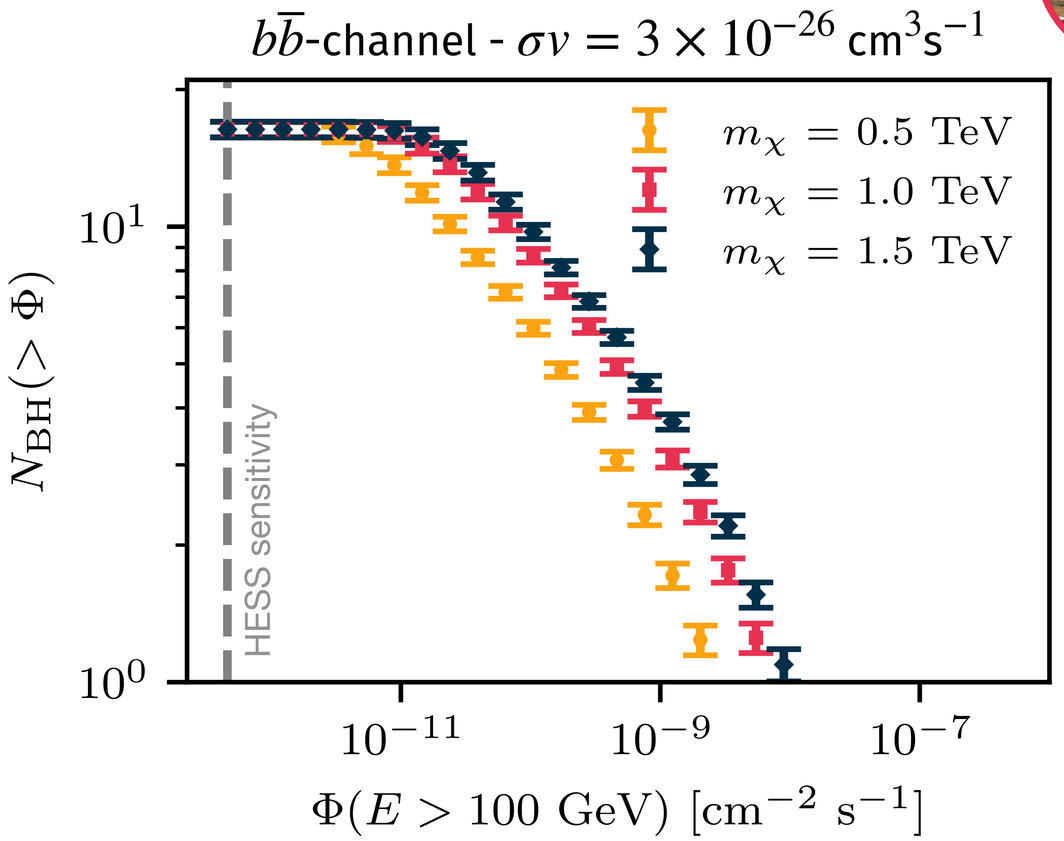
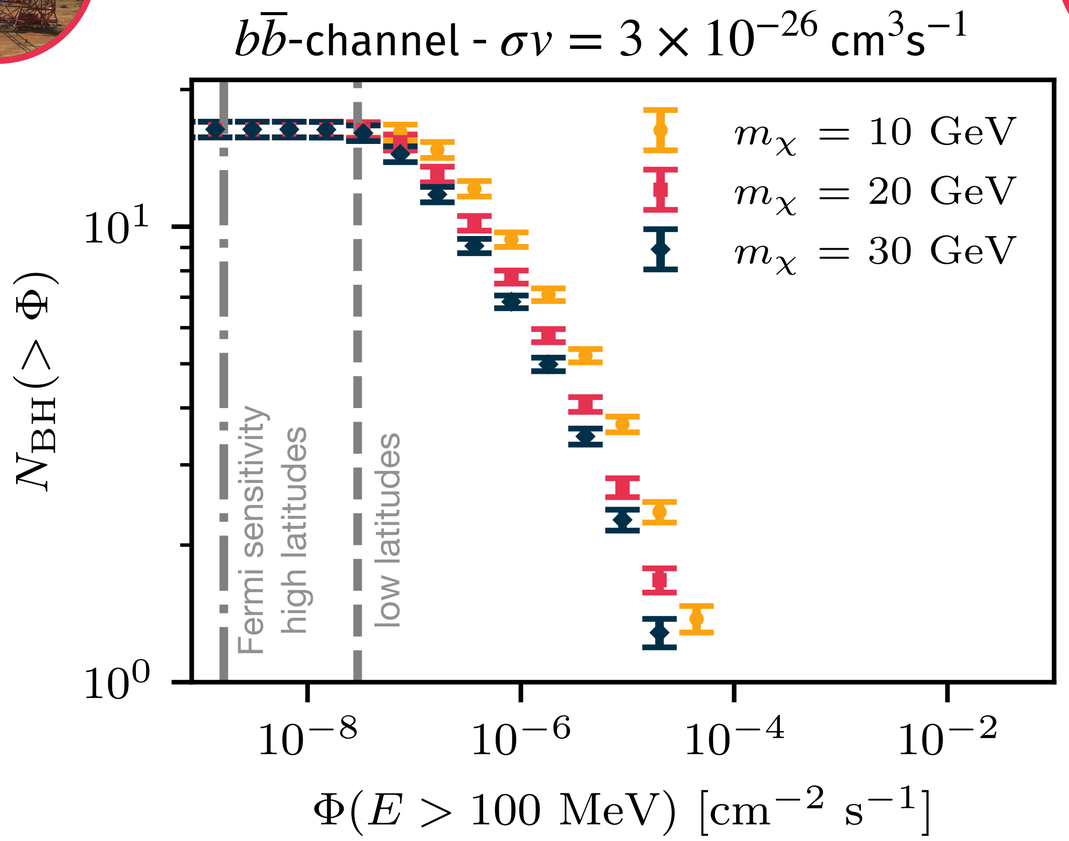
Results: expected gamma-ray flux







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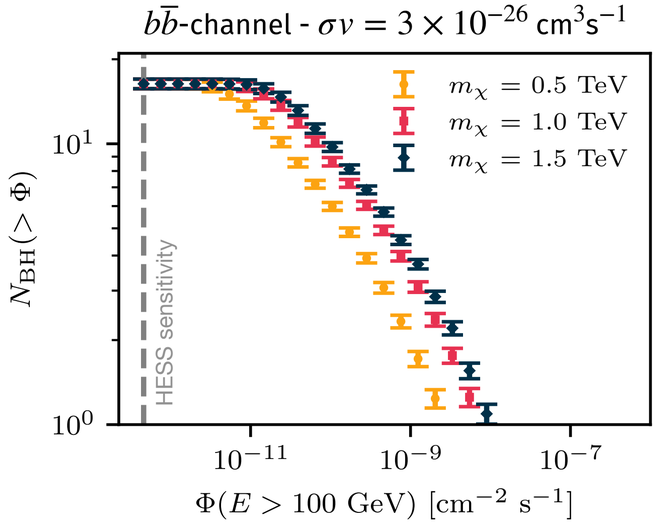
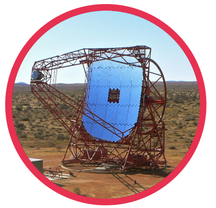
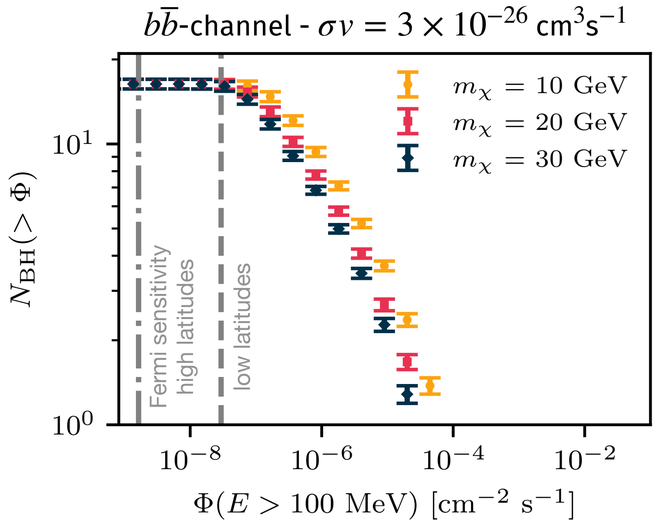
Conclusions & Outlook

- Smoking gun dark matter signature from IMBHs
- ~15 unmerged IMBHs with $M_{bh} \gtrsim 10^5\ \mathrm{M}_\odot$ expected within our Milky Way
- Gamma-ray observatories could detect dark matter around IMBHs!
- Future: Search for dark matter signal around IMBHs with H.E.S.S.







DAMSPI

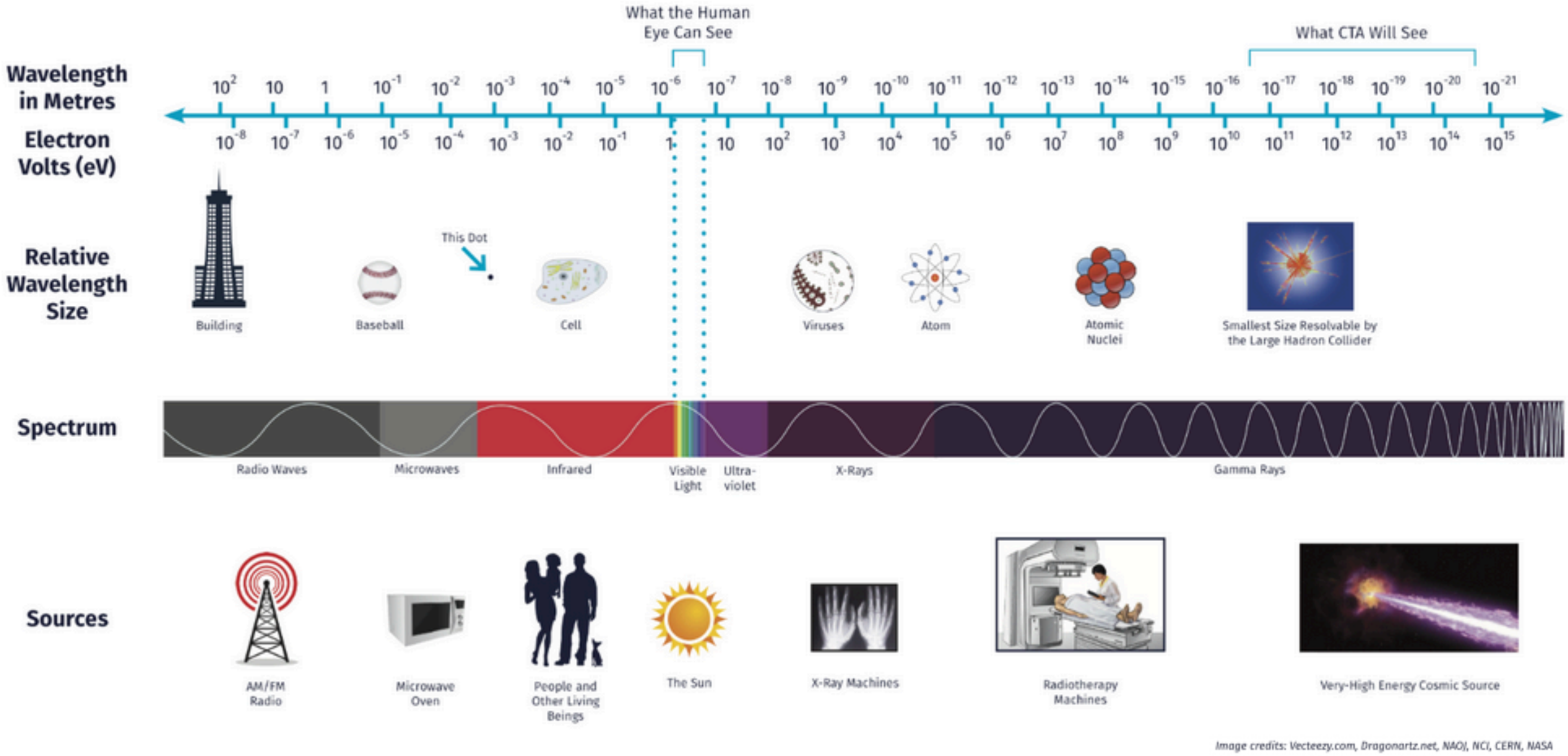
Paper

GitHub

Thanks for your attention!

Attachment

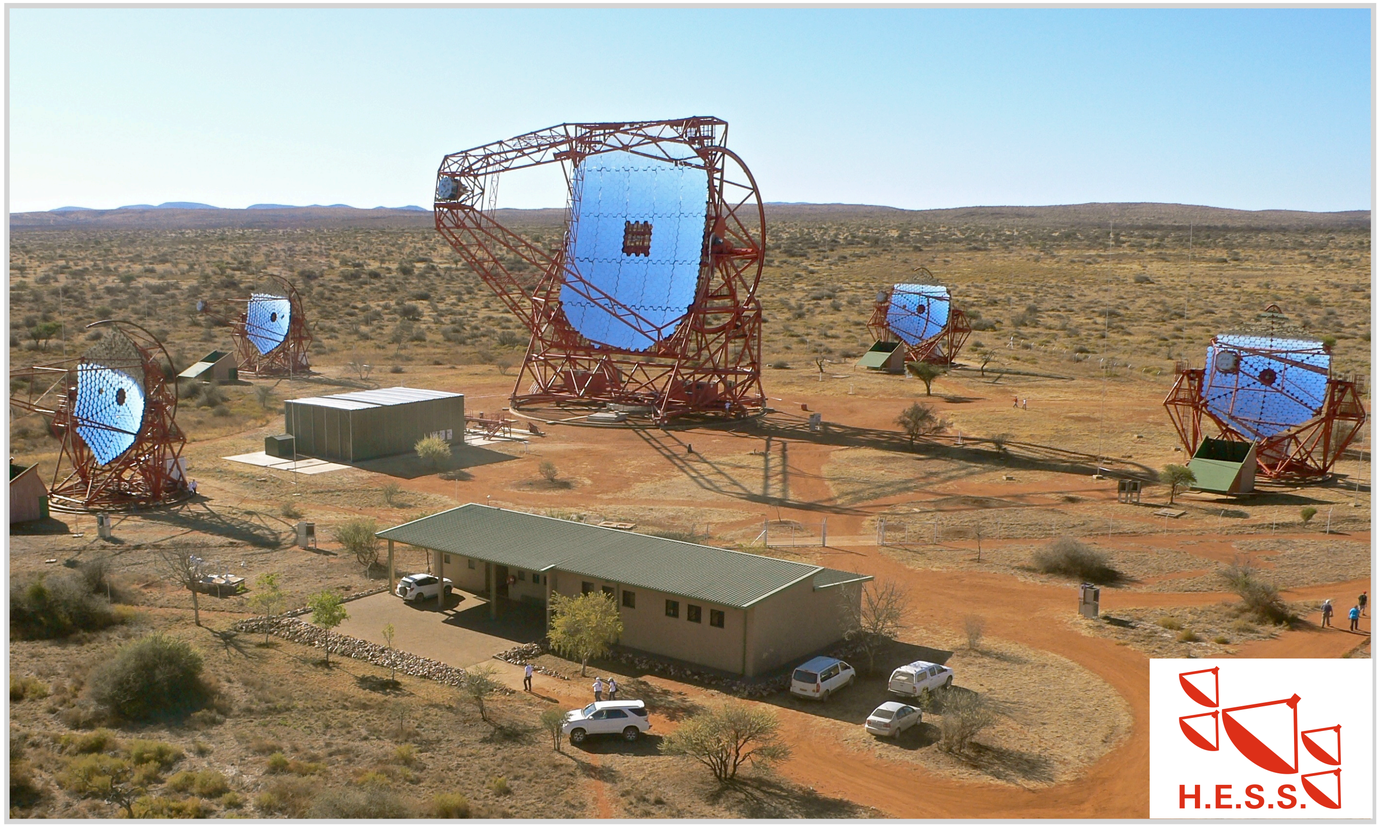
Gamma-ray astronomy



Credit: CTA Collaboration

HESS

- Gamma-ray observatory
- Located in Namibia
- 30 GeV - 100 TeV energy range
- Consisting of 5 telescopes
  - 4 small telescopes
  - 1 large telescope



Intermediate mass black holes

Formation scenarios:

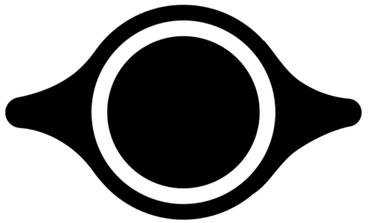
A. Collapse of Population III stars
B. Collapse of primordial gas
C. Gravitational runaway
D. Primordial black holes
E. BH-BH merger

Stellar-mass black hole

$< 20 M_\odot$

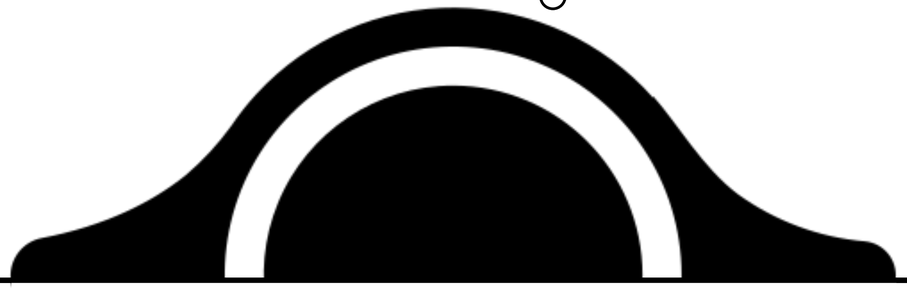
Intermediate mass black hole

$20 - 10^6 M_\odot$



Supermassive black hole

$> 10^6 M_\odot$

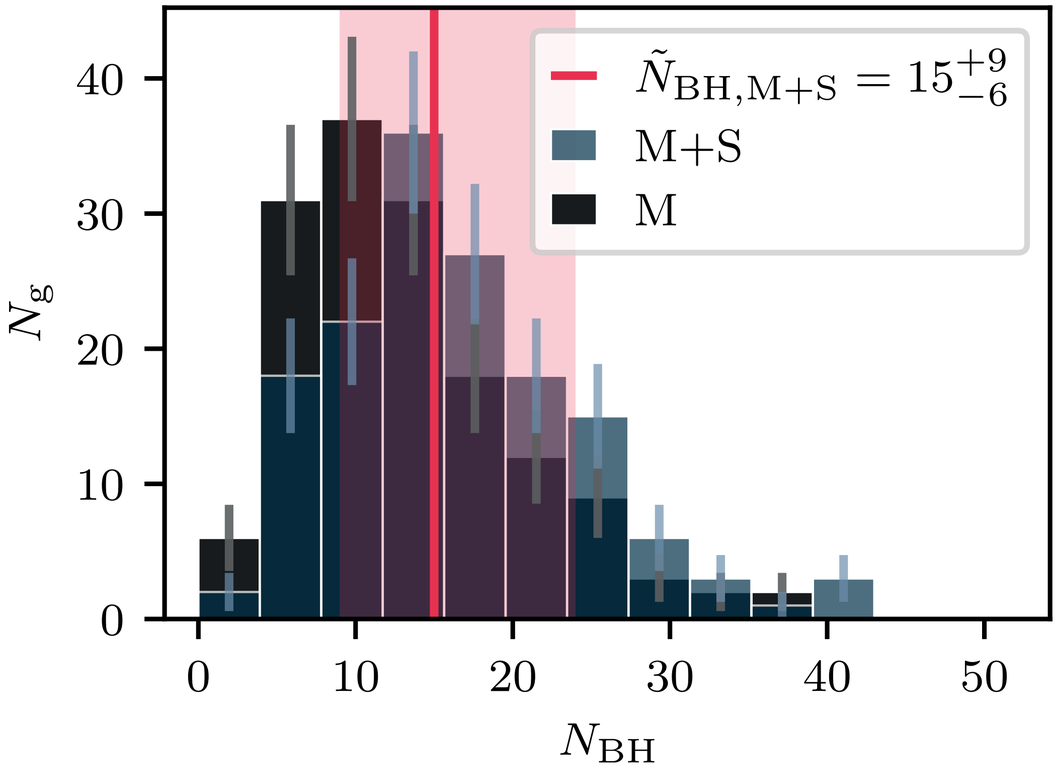


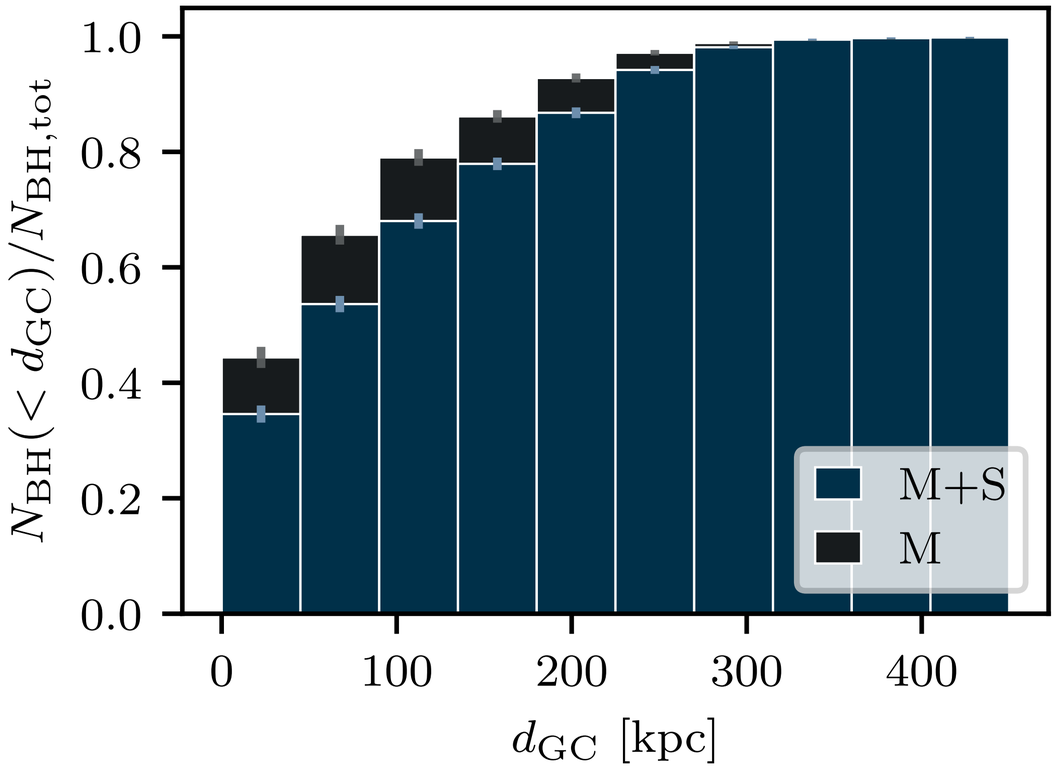
Milky-Way like selection

- Selection criteria for host halo
  - Halo mass M_{200} range: $0.5 - 2.0 \times 10^{12} M_{\odot}$
  - Stellar mass $M_{*}(r < 30$ kpc) range: $10^{10.4} - 10^{11.2} M_{\odot}$
  - Star formation rate range: $0.1 - 3.0 M_{\odot}$/yr
  - Stellar disk-to-total mass ratio f_{disk} larger than 0.4
  - Distance between the centre of mass and the centre of potential of the galaxy is less than $0.07 R_{200}$
  - Total mass in substructures is less than $10\,\%$ of the total mass of the galaxy
- Selection criteria for satellite galaxies:
  - Distance from halo centre $r$in the range: 40 kpc $< r' < 300$ kpc with $r' = r(10^{12} M / M_{200})^{1/3}$

Number & cumulative radial distribution

EAGLE: ~150 Milky Way-like galaxies with ~2500 IMBHs





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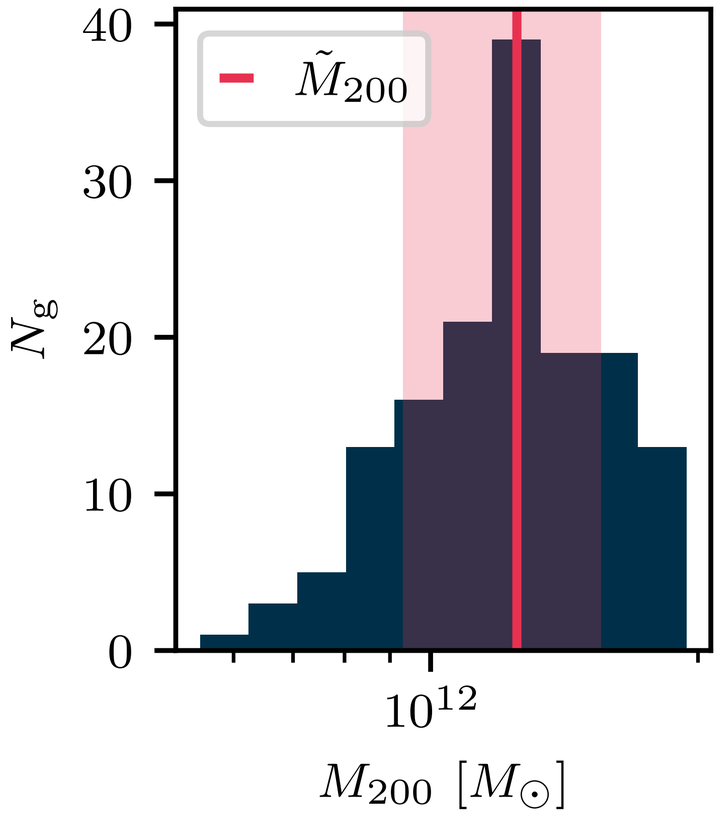

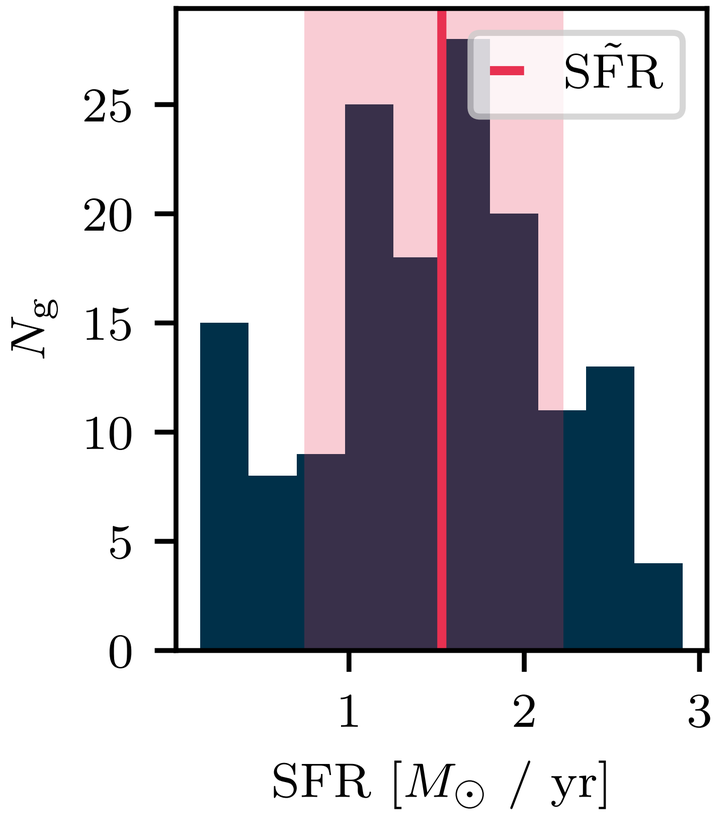

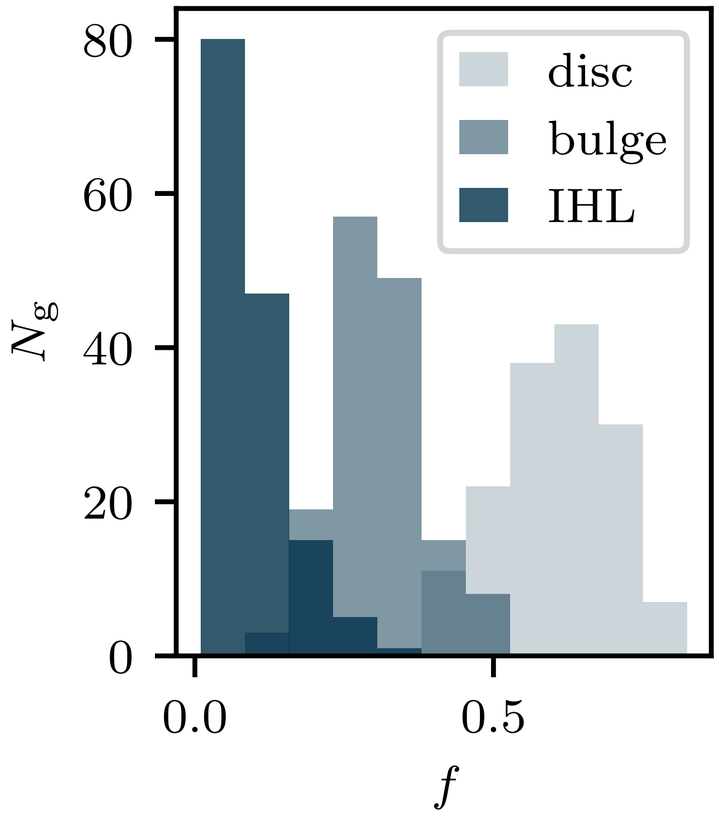

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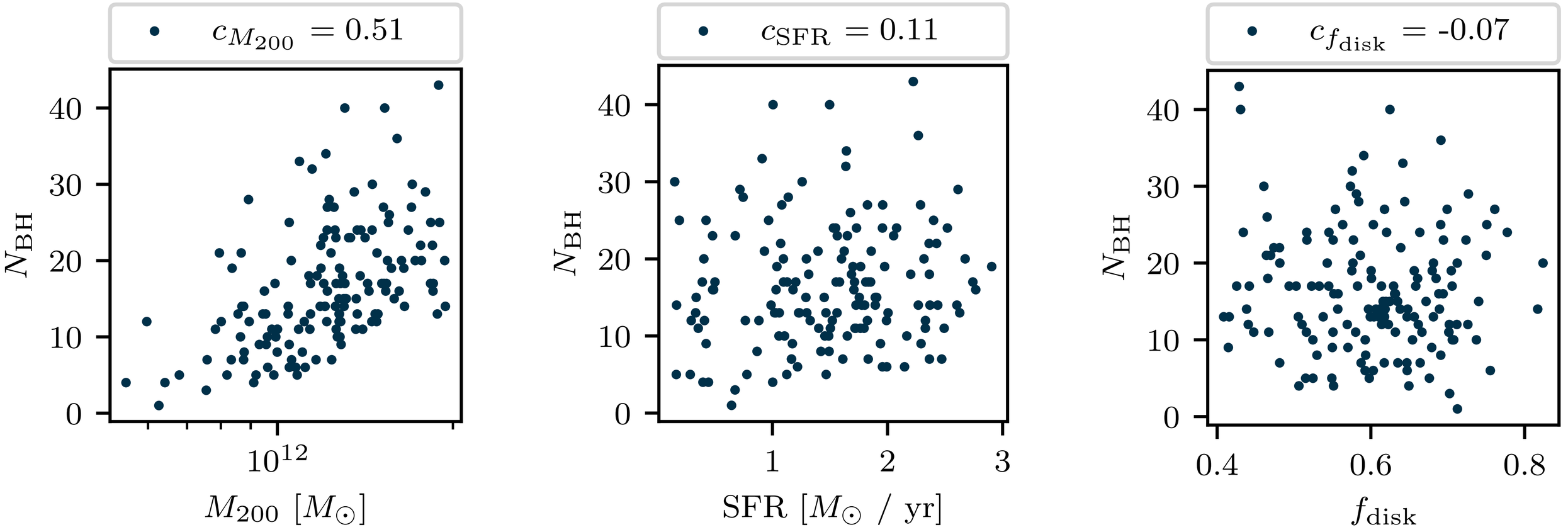

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Dark matter spike parameters

$$\rho(r) = \begin{cases} 0 & r \leq 2r_{\rm schw} \\ \rho_{\rm wcusp}(r) & 2r_{\rm schw} < r \leq r_{\rm cut} \\ \rho_{\rm sp}(r) & r_{\rm cut} < r \leq r_{\rm sp} \\ \rho_{\rm halo}(r) & r > r_{\rm sp} \end{cases}$$

$$M(< r_h) = 4\pi \int_0^{r_{\rm h}} \rho_{\rm NFW}(r) r^2 dr = 2m_{\rm BH} \qquad r_{\rm sp} = 0.2 r_{\rm h}$$

$$\rho_{\rm halo}(r) = \rho_{\rm NFW}(r) = \rho_0 \left(\frac{r}{r_{\rm s}}\right)^{-1} \left(1 + \frac{r}{r_{\rm s}}\right)^{-2}$$

$$\rho_{\rm sp}(r) = \rho_{\rm NFW}(r_{\rm sp}) \left(\frac{r}{r_{\rm sp}}\right)^{-\gamma_{\rm sp}} \qquad \gamma_{\rm sp} = \frac{9 - 2\gamma}{4 - \gamma}$$

$$\rho_{\rm wcusp}(r) = \rho_{\rm sp}(r_{\rm sat}) \cdot \left(\frac{r}{r_{\rm sat}}\right)^{-0.5}$$

$$\rho_{\rm sp}(r_{\rm sat}) = \frac{m_\chi}{\langle \sigma v \rangle \cdot (t_0 - t_{\rm f})} \qquad r_{\rm cut} = \max[2r_{\rm schw}, r_{\rm sat}]$$

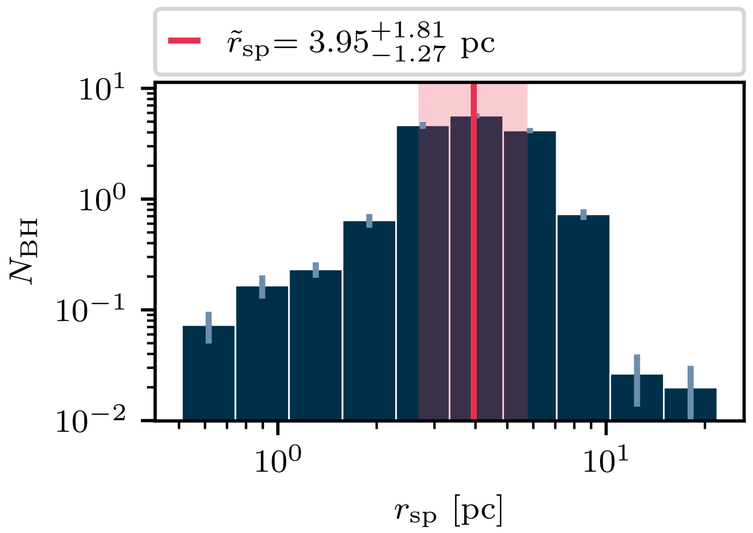
Gamma-ray flux

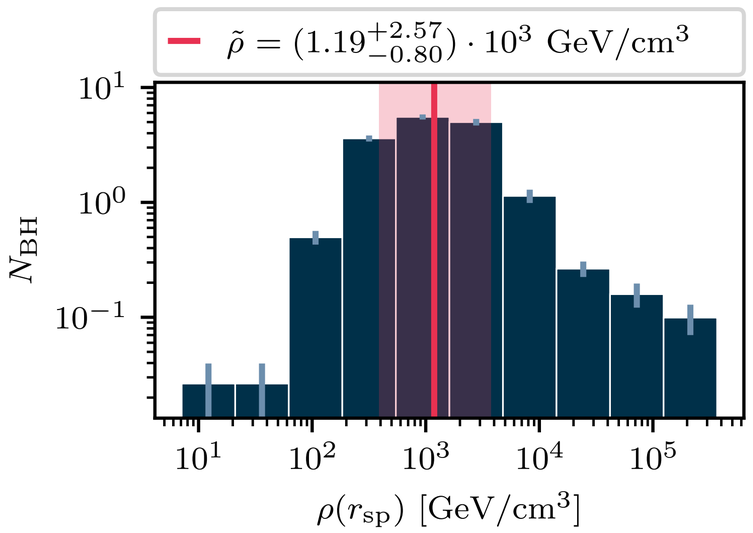
$$\Phi(E, D) = \frac{1}{2}\frac{\langle\sigma v\rangle}{m_\chi^2}\frac{1}{D^2}\frac{\mathrm{d}N}{\mathrm{d}E}\int_{2r_{\mathrm{schw}}}^{r_{\mathrm{sp}}} \rho^2(r) r^2 dr$$

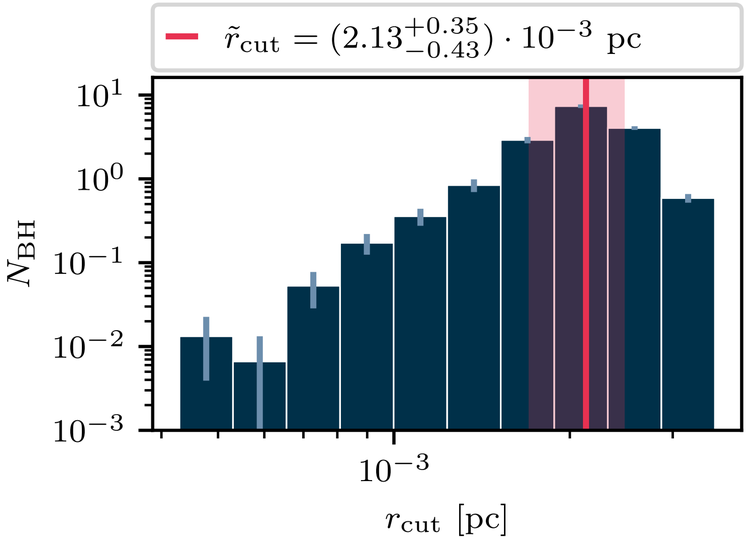
$$\approx \frac{\mathrm{d}N}{\mathrm{d}E}\frac{\langle\sigma v\rangle}{m_\chi^2 D^2}\rho(r_{\mathrm{sp}})^2 r_{\mathrm{sp}}^3 \frac{2\gamma_{\mathrm{sp}} - 1}{8\gamma_{\mathrm{sp}} - 12}\left(\frac{r_{\mathrm{cut}}}{r_{\mathrm{sp}}}\right)^{3-2\gamma_{\mathrm{sp}}}$$

$$r_{\mathrm{cut}} \propto \langle\sigma v\rangle^{3/7} m_\chi^{-9/7} \qquad \rightarrow \phi \propto \langle\sigma v\rangle^{2/7} m_\chi^{-9/7}$$

Dark matter spike parameters







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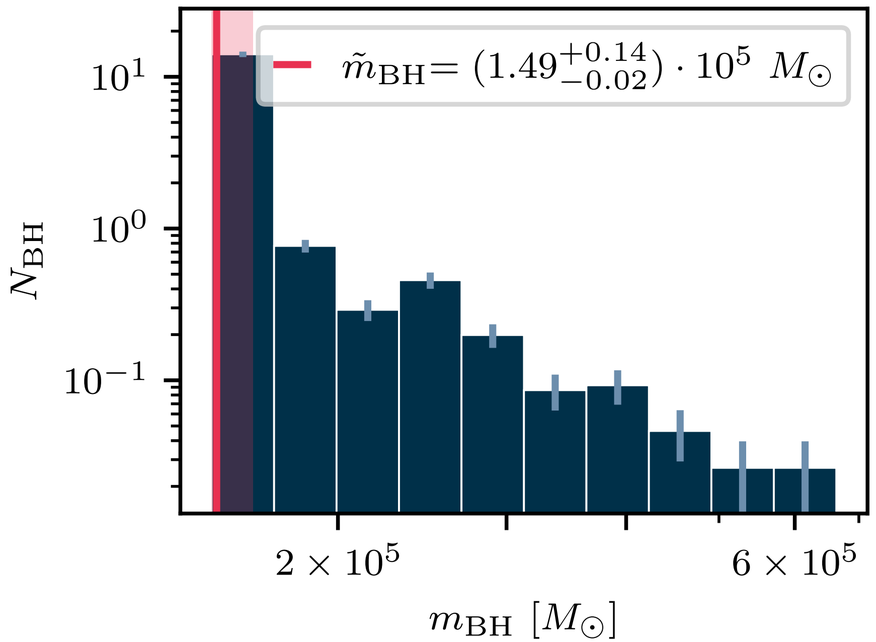
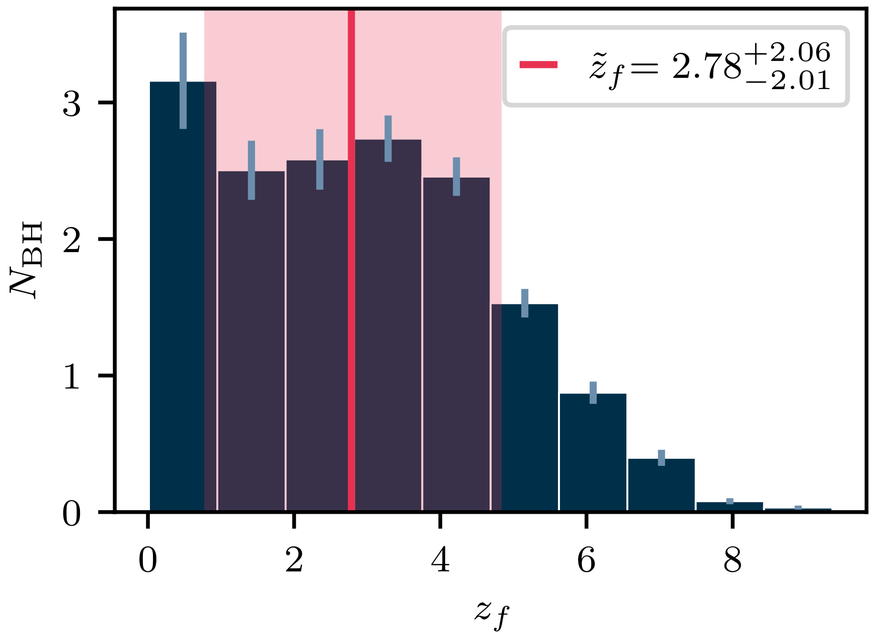
Mass and formation redshift





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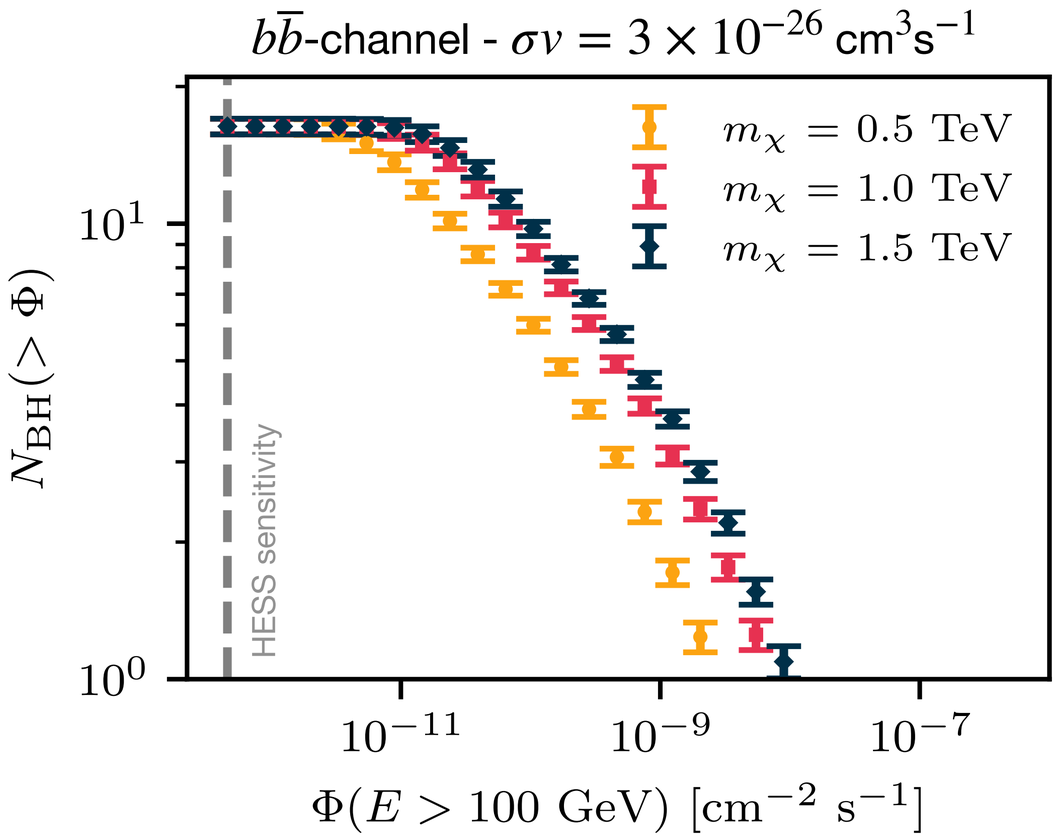
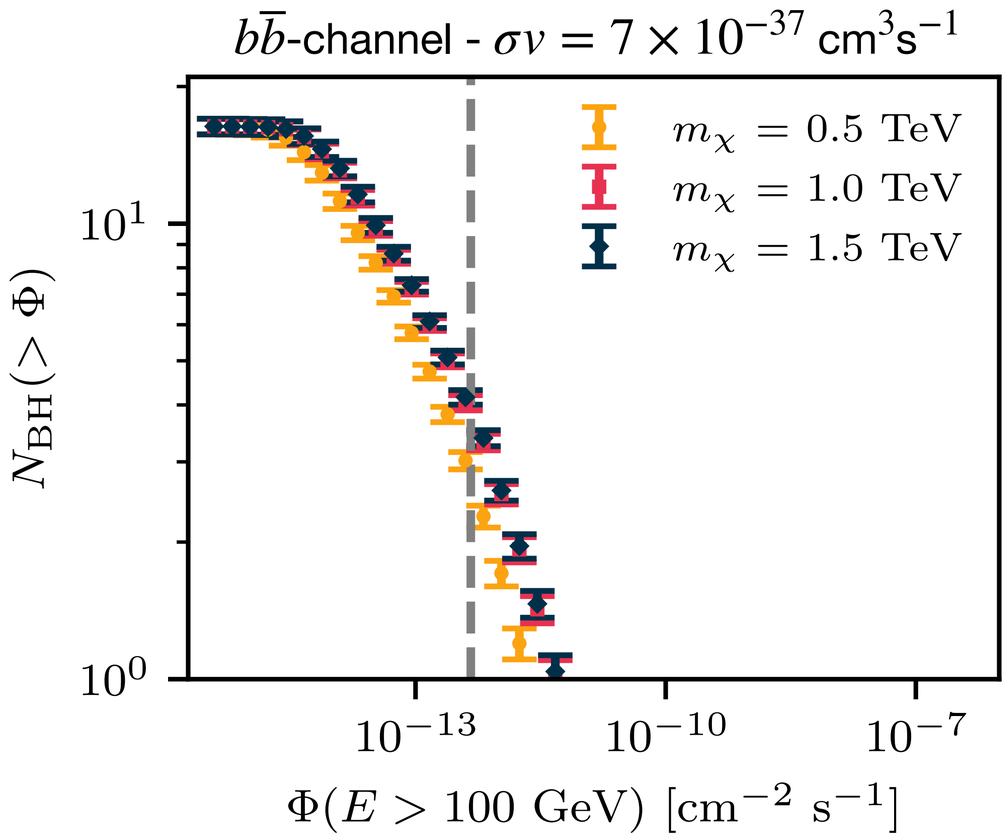
Integrated luminosity





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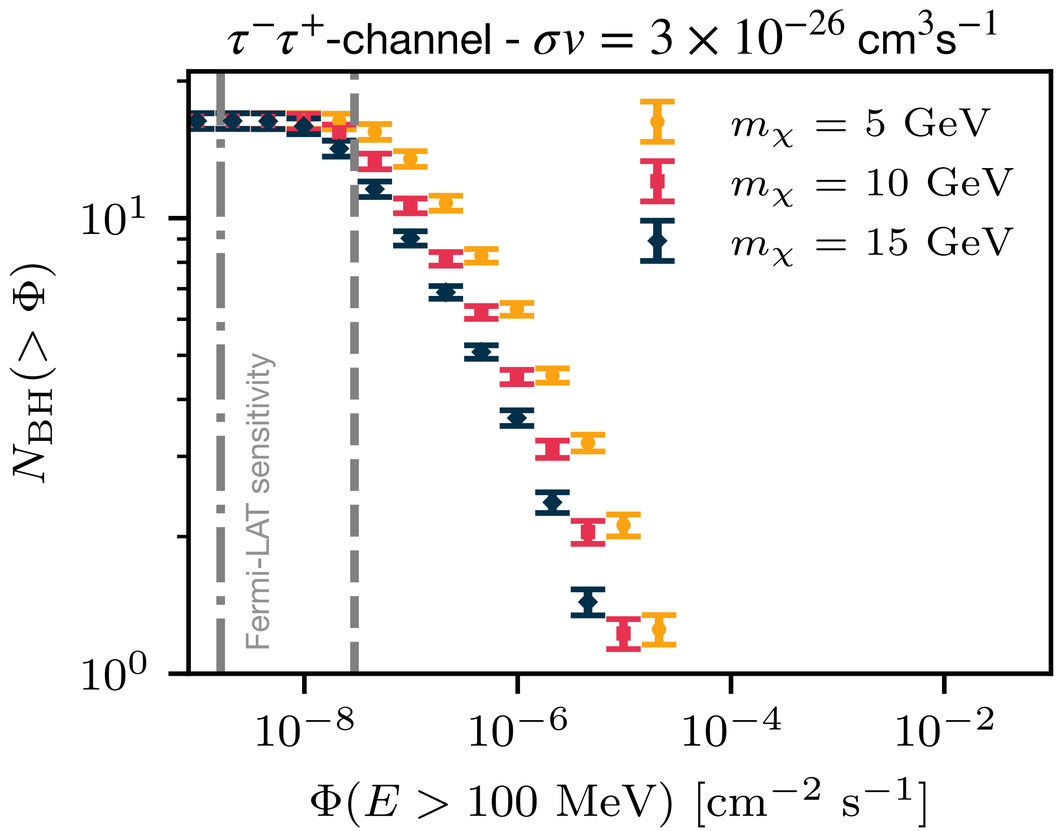
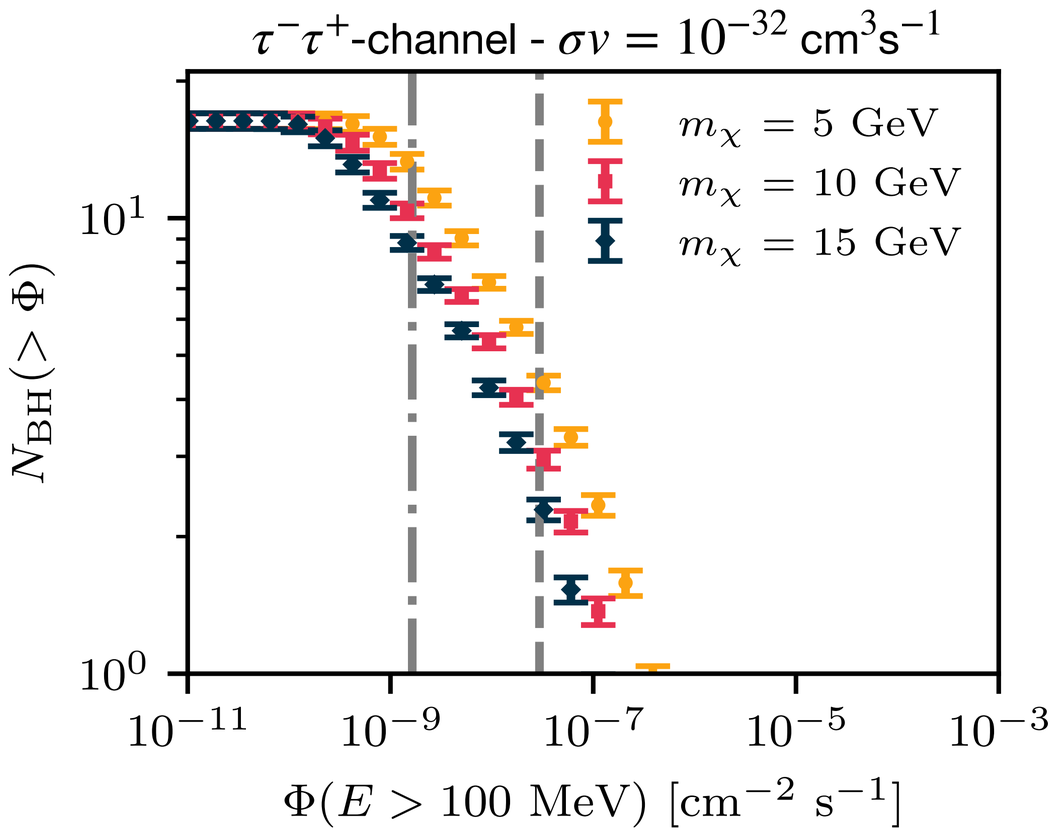
Integrated luminosity





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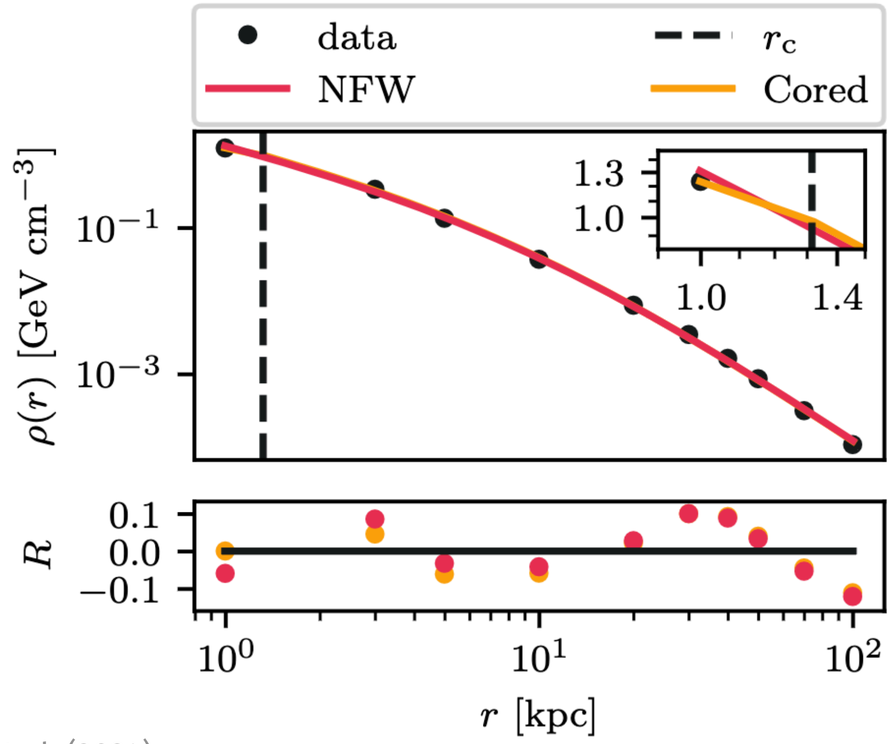
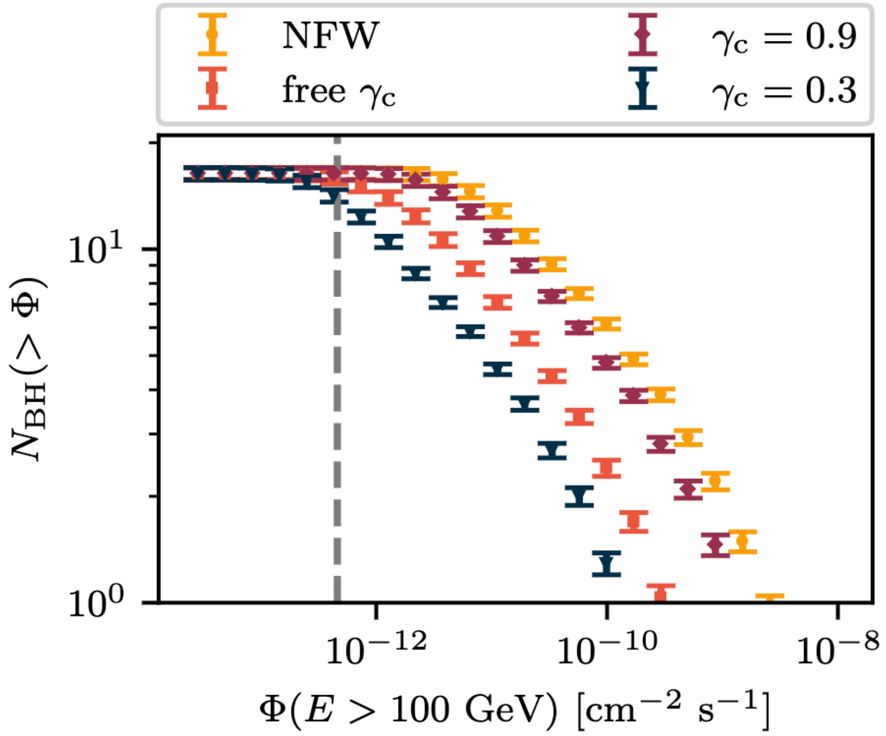
Cored dark matter profile

$$\rho_{\mathrm{cored}}(r) = \begin{cases} \rho_{\mathrm{NFW}}(r_{\mathrm{c}}) \left(\dfrac{r}{r_{\mathrm{c}}}\right)^{-\gamma_{\mathrm{c}}} & r < r_{\mathrm{c}} \\ \rho_{\mathrm{NFW}}(r) & r \geq r_{\mathrm{c}} \end{cases}$$





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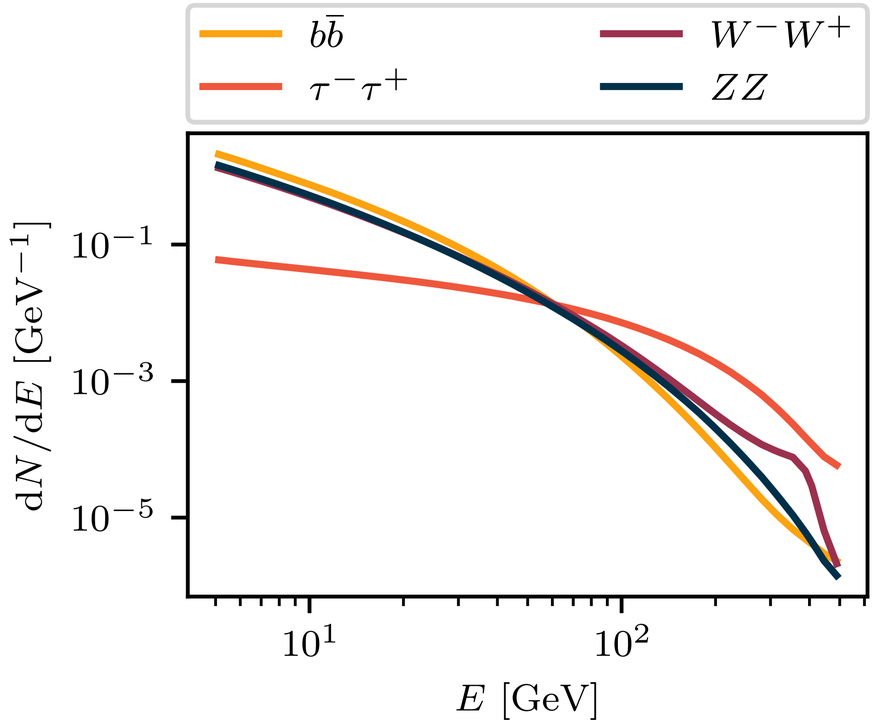
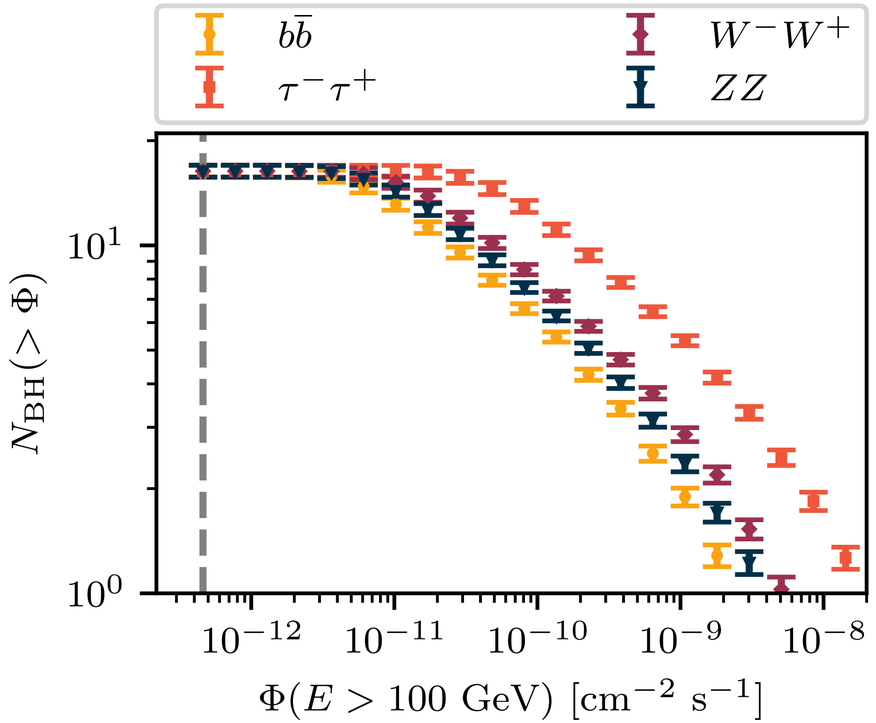
Annihilation channels





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