

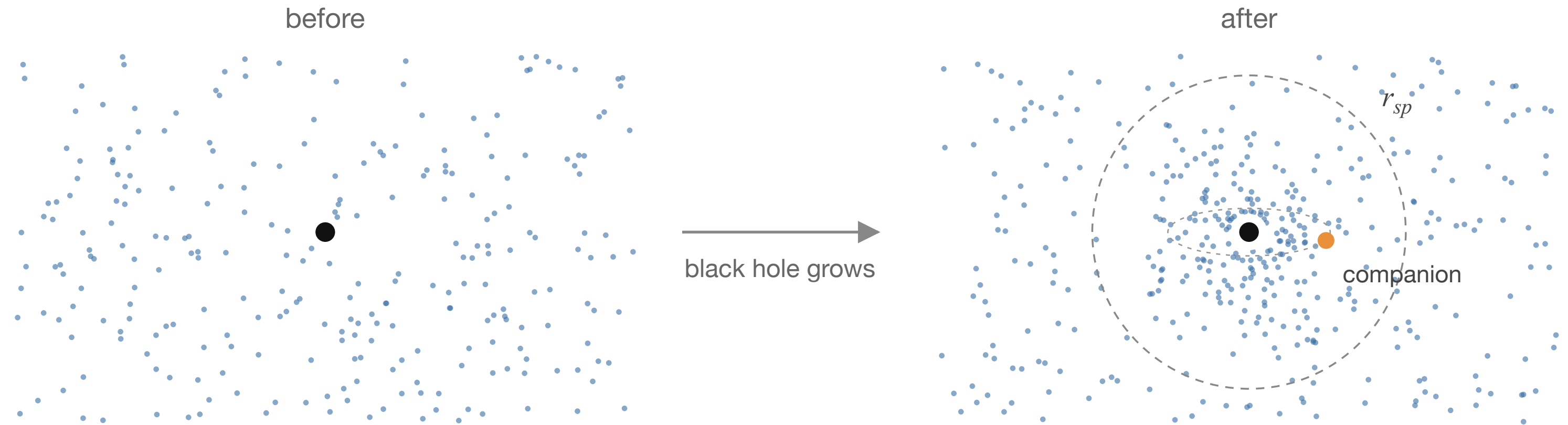
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Positron escape from dark matter spikes in black hole X-ray binaries

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Dark matter spikes



- A black hole growing inside the Galactic dark matter pulls the orbits inward (Gondolo & Silk 1999)
- Inside r_{sp} the density rises as $\rho \propto r^{-\gamma_{sp}}$, with γ_{sp} between about 1.5 and 2.3; empty inside $2R_s$
- Annihilation rate goes as ρ^2 , so a spike can make the black hole a bright source

The proposal of Chan & Lee

- The orbits of A0620–00 and XTE J1118+480 decay faster than expected
- Chan & Lee (2023): dynamical friction against a dark matter spike around each black hole
 - fitted spike index: $\gamma_{\text{sp}} = 1.71^{+0.01}_{-0.02}$ and $\gamma_{\text{sp}} = 1.85 \pm 0.04$
 - a few per cent precision; around Sgr A* the index is essentially unconstrained
- Chan & Lee (2025): annihilation in the same spikes produces the AMS-02 high-energy positron excess
 - best fit $m_{\text{DM}} \approx 8 \text{ TeV}$, W^+W^-

How the positron flux is calculated

The dark matter density around each black hole:

$$\rho_{\text{DM}}(r) = \begin{cases} 0, & r \leq 2R_s \\ \rho_0 \left(\frac{r}{r_{\text{sp}}} \right)^{-\gamma_{\text{sp}}}, & 2R_s < r \leq r_{\text{sp}} \\ \rho_0, & r > r_{\text{sp}} \end{cases}$$

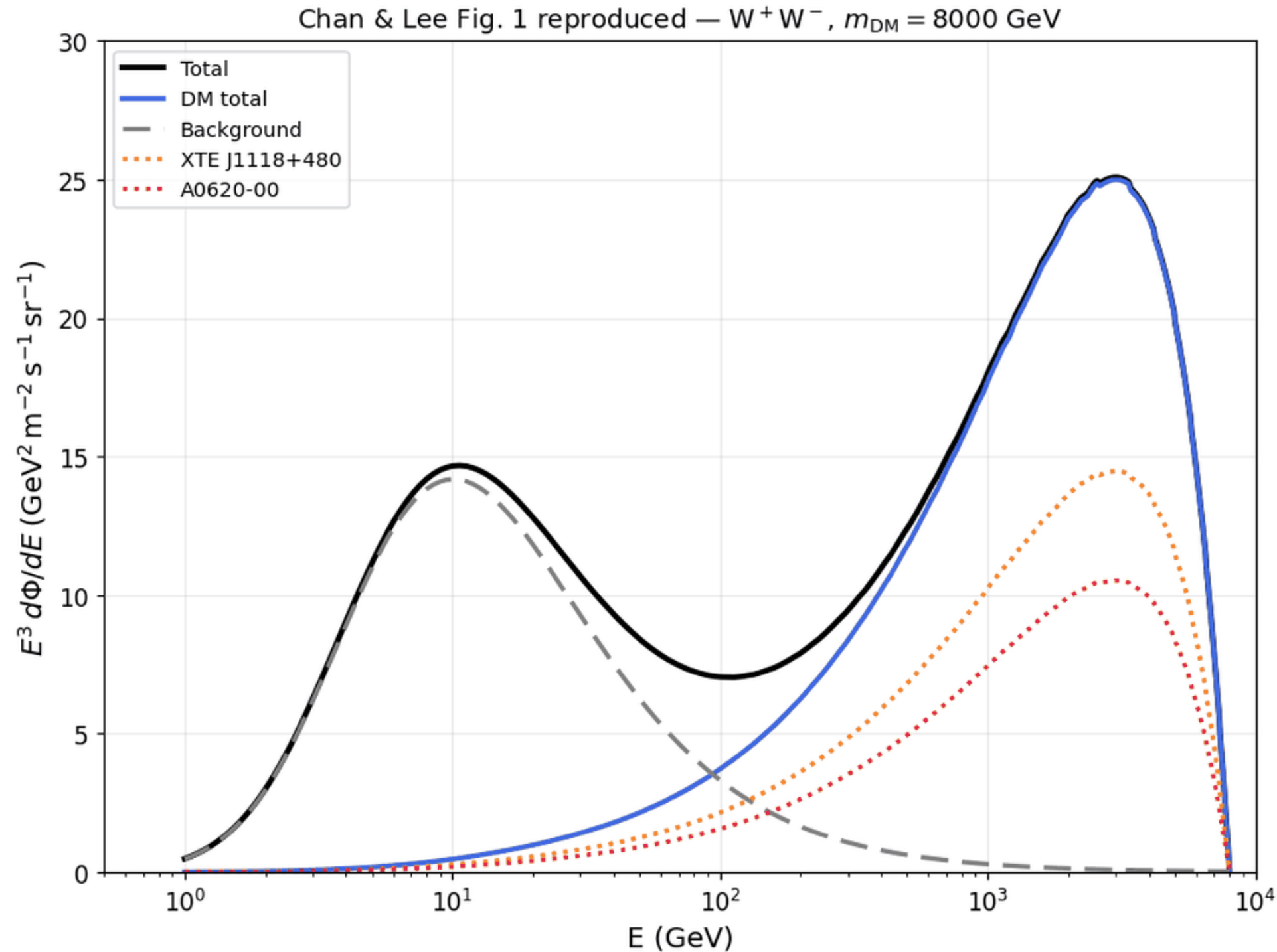
The rate at which annihilation injects positrons:

$$Q(E, r) = \frac{\langle \sigma v \rangle}{2 m_{\text{DM}}^2} \rho_{\text{DM}}^2(r) \frac{dN_e}{dE}$$

The positrons then diffuse outwards and lose energy:

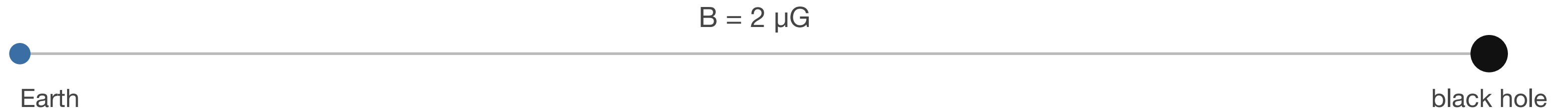
$$\frac{D(E)}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial n_e}{\partial r} \right) + \frac{\partial}{\partial E} (b(E) n_e) + Q(E, r) = 0$$

The predicted positron spectrum at Earth



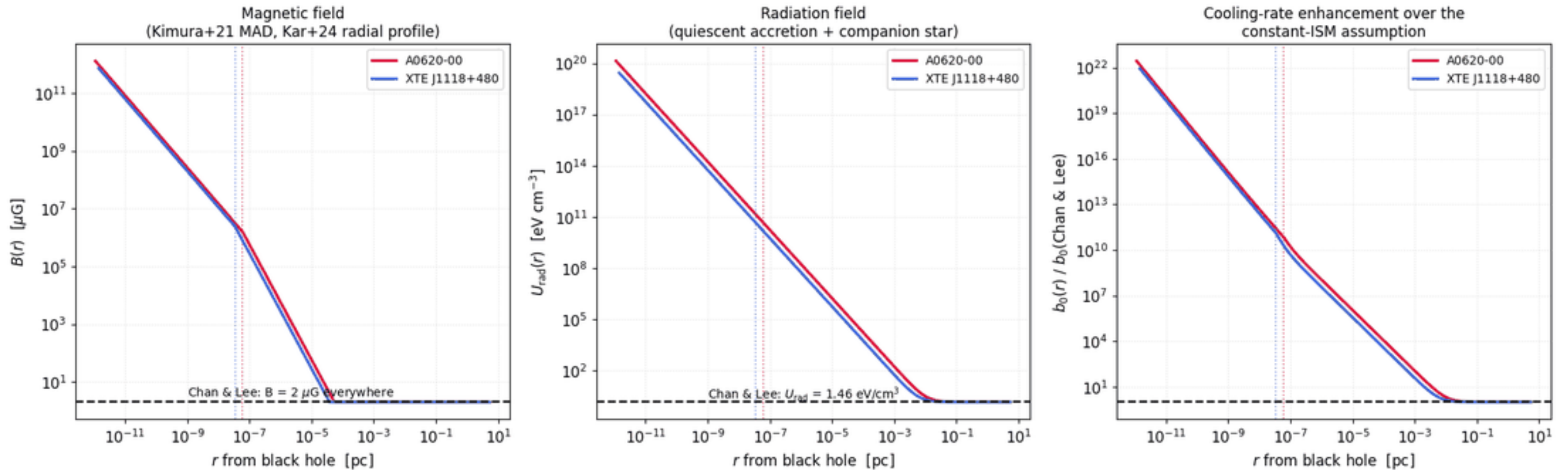
- The AMS-02 positron flux is described by two source terms
- Grey: the low-energy background, from ordinary cosmic rays colliding with interstellar gas (about 1 to 100 GeV)
- Blue: the unknown high-energy source, supplied by dark matter annihilating in the spikes of the two binaries (dotted)
- Best fit: $m_{\text{DM}} \approx 8 \text{ TeV}$, W^+W^- , with $\chi^2_{\text{red}} = 0.64$, better than pulsar models (≈ 1.0)

Their assumption: a homogeneous medium



- The positrons propagate in a constant $B = 2 \mu\text{G}$ from the black hole to Earth
- This includes the region a few Schwarzschild radii from the horizon, where they are produced

The magnetic field near the black hole

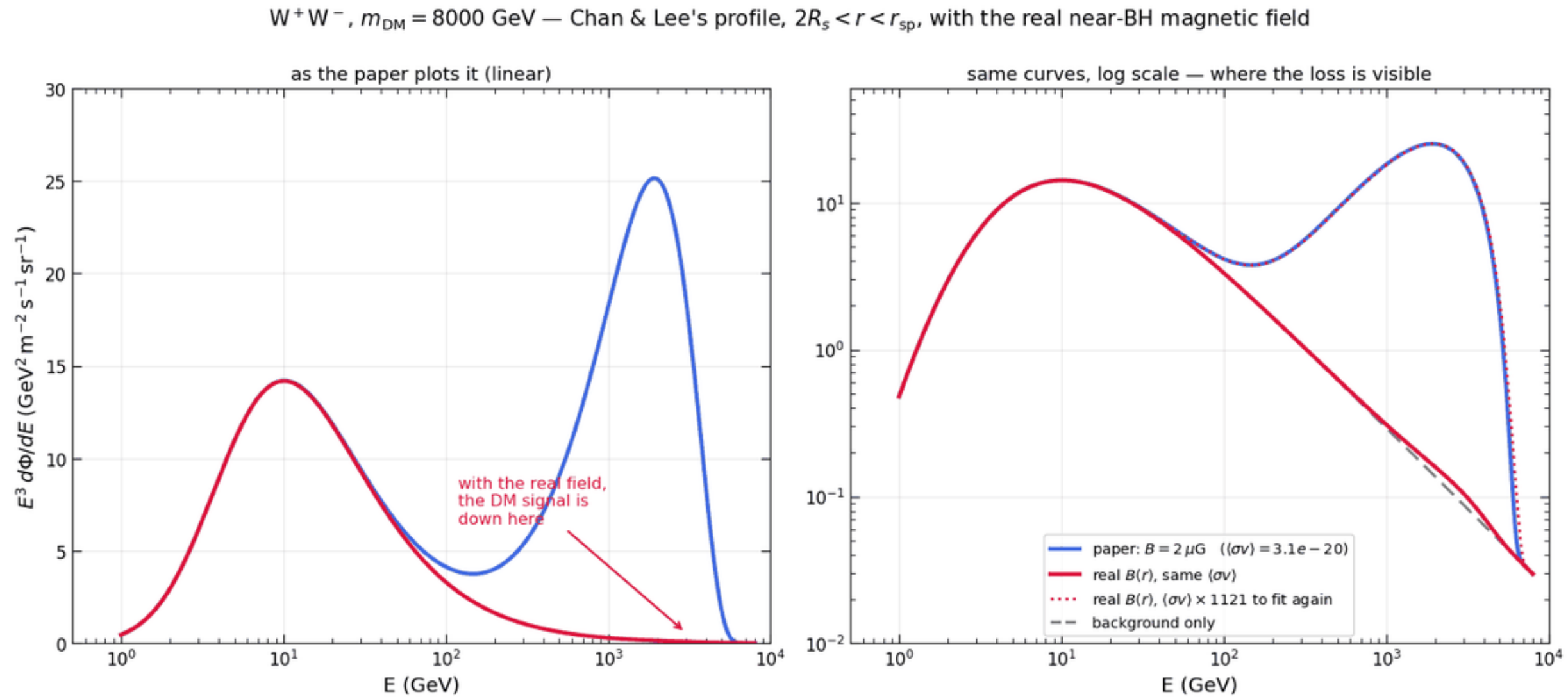


- Accretion-flow model of Kimura et al. (2021), fitted to these two binaries; consistent with Kar et al. (2024)
- About $4 \times 10^5 \text{ G}$ at $10 R_g$, against the $2 \mu\text{G}$ assumed

Does such a small region matter?

- The field is above 1 kG only within a few hundred R_s , a tiny fraction of the spike volume, so it is easy to neglect
- But the annihilation rate goes as ρ^2 , and the density is highest there
- In Chan & Lee's own profile, over 90% of the annihilations happen in this region

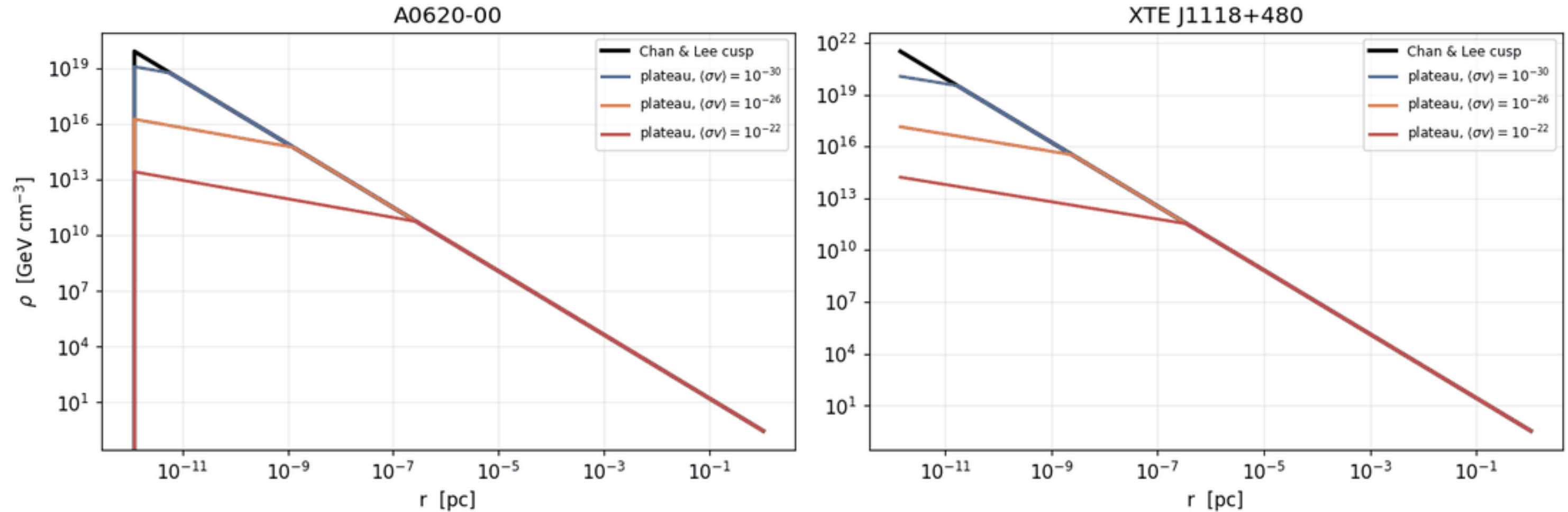
Effect on the positron flux



- Same calculation, only B changed. Synchrotron losses $b(E) \propto B^2 E^2$: the positrons still escape, but at low energy
- At the same $\langle\sigma v\rangle$ the peak falls by about three orders of magnitude

The annihilation plateau

The plateau eats the inner spike



- Annihilation caps the density at $\rho_{\text{sat}} = m_{\text{DM}}/(\langle\sigma v\rangle t_{\text{BH}})$, with the spike age $t_{\text{BH}} \leq P/\dot{P}$
- This lowers the annihilation rate by roughly two (A0620–00) to four (XTE J1118+480) orders of magnitude, independent of B

Two independent problems

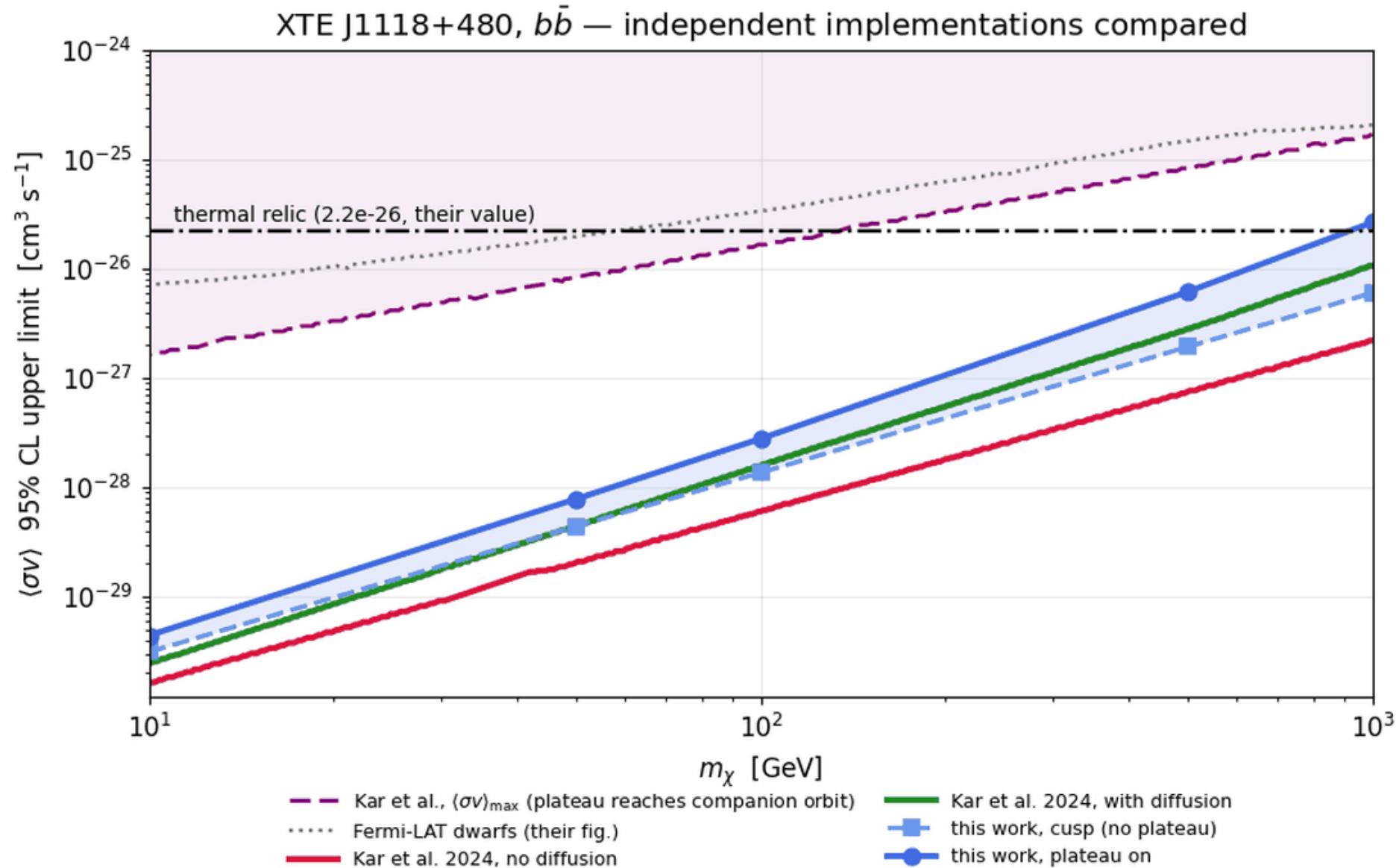
1. At the source: the spike cannot hold the density the proposal needs
2. In transport: the near-horizon field takes the positrons' energy

Either one alone rules out the proposed explanation of the AMS-02 excess.

Limits on $\langle \sigma v \rangle$ from the measured spectra

- The same field makes these binaries efficient synchrotron emitters
- Compare the predicted emission with the measured quiescent radio and X-ray fluxes (Gallo et al. 2006, 2014)
- Exclude models that over-predict the data, $\Delta\chi^2 = 2.71$; a model below the data can hide under the jet
- The plateau makes the flux non-monotonic in $\langle \sigma v \rangle$, so the excluded region is a band
- Checked with χ^2 , an exact posterior, and MCMC under two priors

Radio limits for XTE J1118+480



- Annihilation $e^\pm$ radiate synchrotron in the near-horizon field; the radio flux they predict cannot exceed the measured quiescent flux
- Each curve is a 95% upper limit on $\langle\sigma v\rangle$; everything above it is excluded
- Heavier particles are fewer at the same density, so the limit weakens with m_χ
- Below the dashed line a thermal relic is excluded, up to $m_\chi \approx 900$ GeV for our curve
- Shaded: above Kar et al.'s ceiling the plateau reaches the companion's orbit, so no spike survives
- The gap to Kar et al. comes from two unstated inputs, the spike radius (limit $\propto r_{\text{sp}}^{-4}$) and the accretion rate; matching both puts us between their curves

Summary and future work

1. The near-horizon field cannot be neglected: the positrons lose their energy before escaping, and the predicted peak falls by about three orders of magnitude.
2. Annihilation caps the spike density, lowering the rate by two to four orders of magnitude, independent of the field.
3. Either effect alone rules out the proposed explanation of the AMS-02 excess.
4. The measured quiescent fluxes constrain $\langle\sigma v\rangle$; for $b\bar{b}$ the bound is below thermal for $m_\chi \lesssim 900$ GeV.
5. Matching the two input choices reproduces the Kar et al. bound to within a factor of two.

Future work

- The radio limits come from electrons with Lorentz factors of only 5 to 13, where the standard synchrotron kernel is not justified; compute the gyro-synchrotron emission directly
- Model the jet, and check our X-ray flux conversion against the published spectra
- Forecast what SKA can do for these binaries