Simplified Dark Matter Models - Update

Chris Chang

Paper 1: Scalar and fermionic models

Scalar DM:

$$\mathcal{L}_{BSM} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m_{DM}^2\phi^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}m_M^2 V_\mu V^\mu + g_q V_\mu \bar{q}\gamma^\mu q + i g_{DM}^V V_\mu \Big(\phi^\dagger(\partial^\mu\phi) - (\partial^\mu\phi^\dagger)\phi\Big)$$

Dirac fermion DM:

$$\mathcal{L}_{BSM} = i\bar{\chi}\gamma^\mu\partial_\mu\chi - m_{DM}\bar{\chi}\chi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}m_M^2 V_\mu V^\mu + g_q V_\mu \bar{q}\gamma^\mu q + V_\mu\bar{\chi}(g_{DM}^V + g_{DM}^A\gamma^5)\gamma^\mu\chi$$

Majorana fermion DM:

$$\mathcal{L}_{BSM} = \frac{1}{2}i\bar{\psi}\gamma^\mu\partial_\mu\psi - \frac{1}{2}m_{DM}\bar{\psi}\psi - \frac{1}{4}V_{\mu\nu}V^{\mu\nu} - \frac{1}{2}m_M^2 V_\mu V^\mu + g_q V_\mu \bar{q}\gamma^\mu q + \frac{1}{2}g_{DM}^A V_\mu\bar{\psi}\gamma^5\gamma^\mu\psi$$

Both Majorana and Dirac models face unitarity bounds.

Assumptions:

No lepton couplings

-> To avoid strong di-lepton searches.

No axial-vector quark couplings

-> To avoid strong electroweak precision tests.

Flavour universal couplings

-> To require minimal flavour violation.

Parameters	**Range**
DM mass, m_{DM}	$[50, 10000]$ GeV
Mediator mass, m_M	$[50, 10000]$ GeV
quark-mediator coupling, g_q	$[0.01, 1.0]$
mediator-DM coupling (vector), g_{DM}^V	$[0.01, 3.0]$
mediator-DM coupling (axial vector), g_{DM}^A	$[0.01, 3.0]$
Nuisance Parameters	
Pion-nucleon sigma term, $\sigma_{\pi N}$	$[5, 95]$ MeV
strange quark cont. to nucleon spin, Δ_s	$[-0.062, -0.008]$
strange quark nuclear tensor charge, g_T^s	$[-0.075, 0.021]$
strange quark proton charge radius, r_s^2	$[-0.22, -0.01]$ GeV^{-2}
Local DM density, ρ_0	$[0.2, 0.8]$ GeV cm^{-3}
Most probably speed, v_{esc}	$[216, 264]$ km s^{-1}
Galactic escape speed, v_{peak}	$[453, 603]$ km s^{-1}

Status: Scalar and Fermion DM

- **Scans:** Rerunning many of them due to a mistake in a likelihood that expands the allowed parameter space. Most of these are complete/close-to complete. A few require small region scans to neaten contours.
- **Paper:** The paper is largely written, it will just need the updated plots with some small tweaks to the text to match.
- **Code Merge:** Code review is very close.

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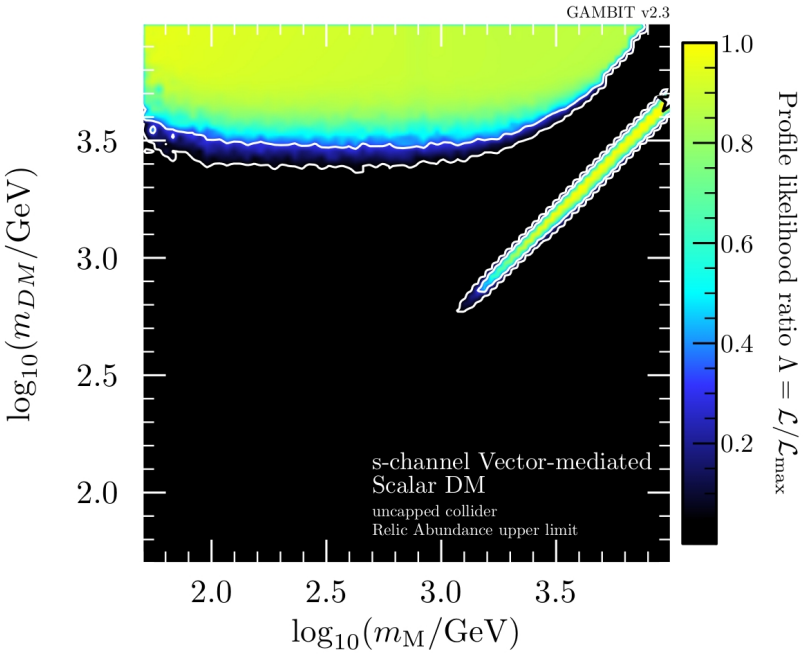
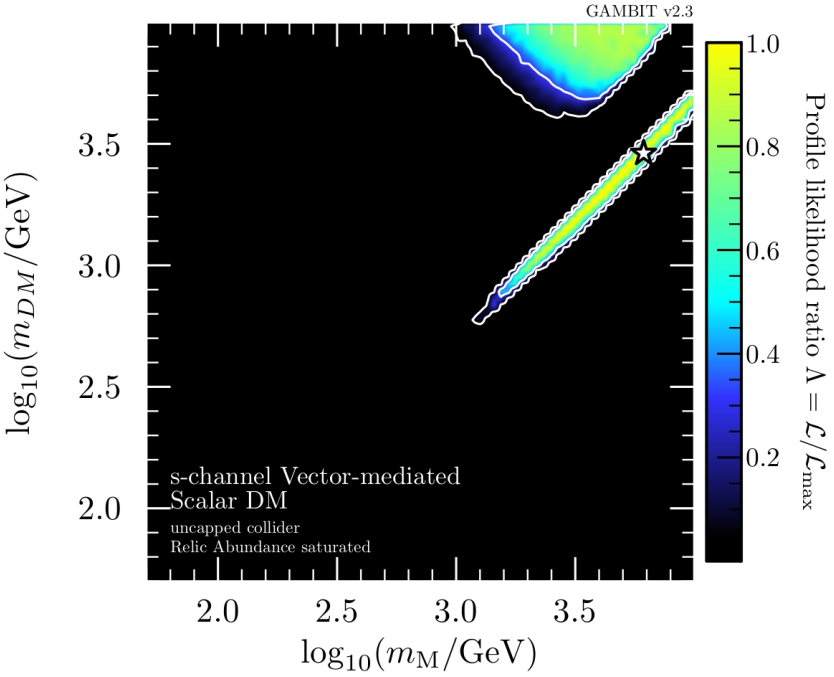
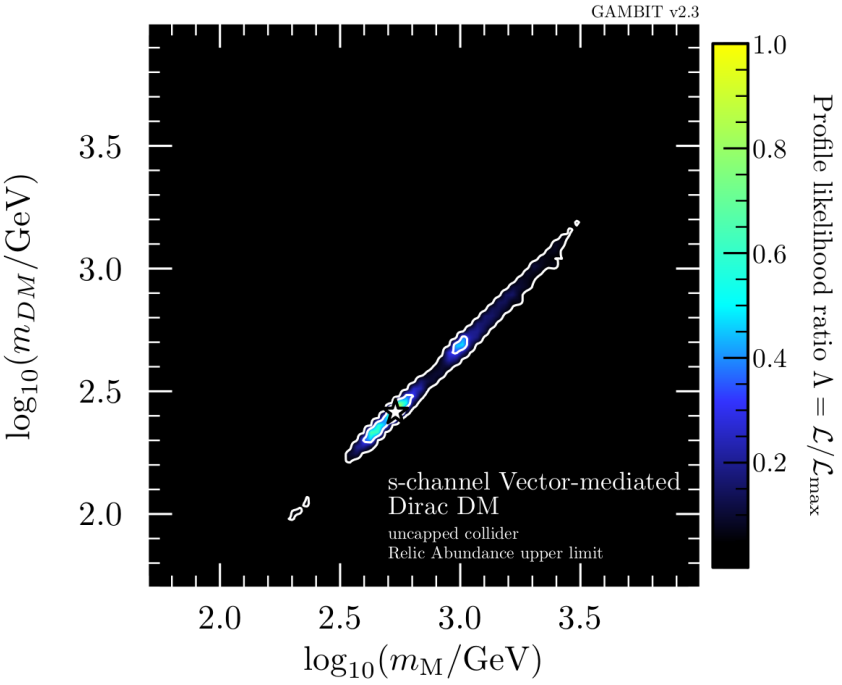
So forgive some slightly poorly sampled plots…

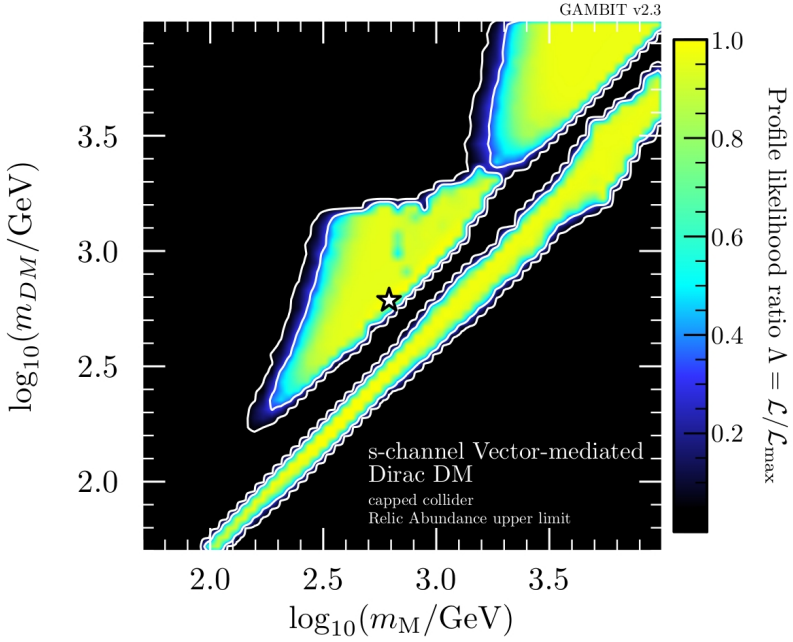
Results: Scalar DM



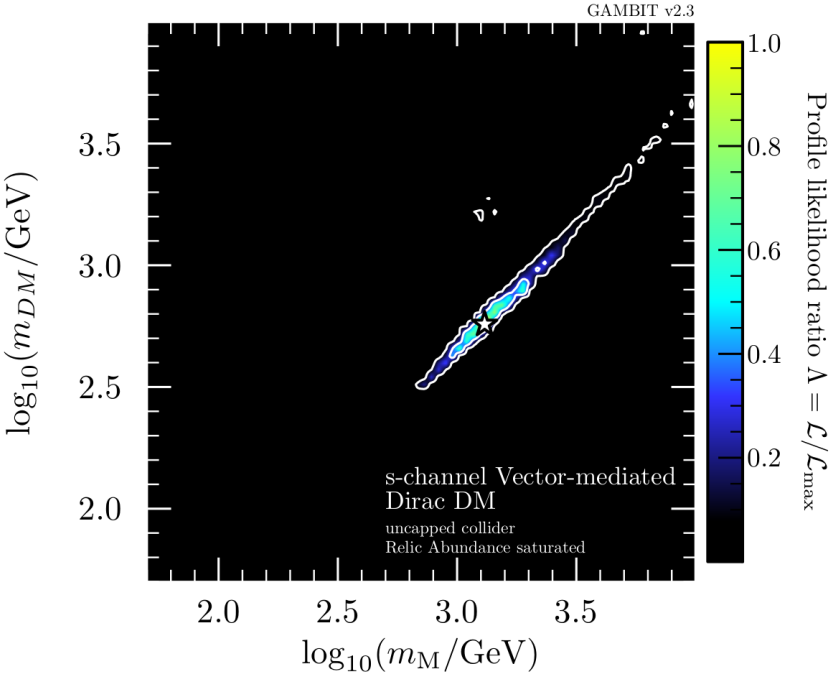


Results: Dirac Fermion DM



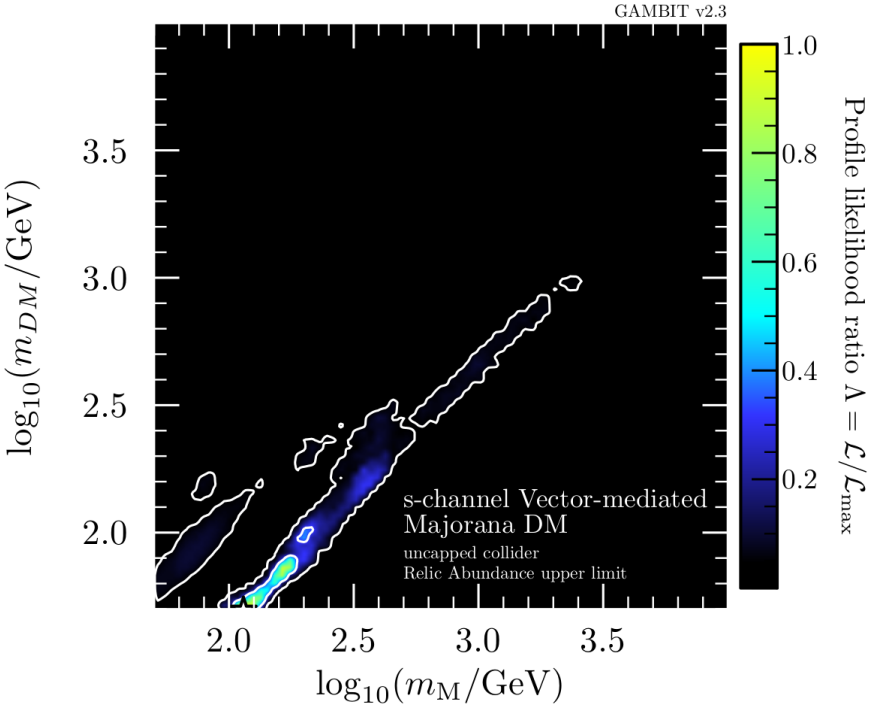


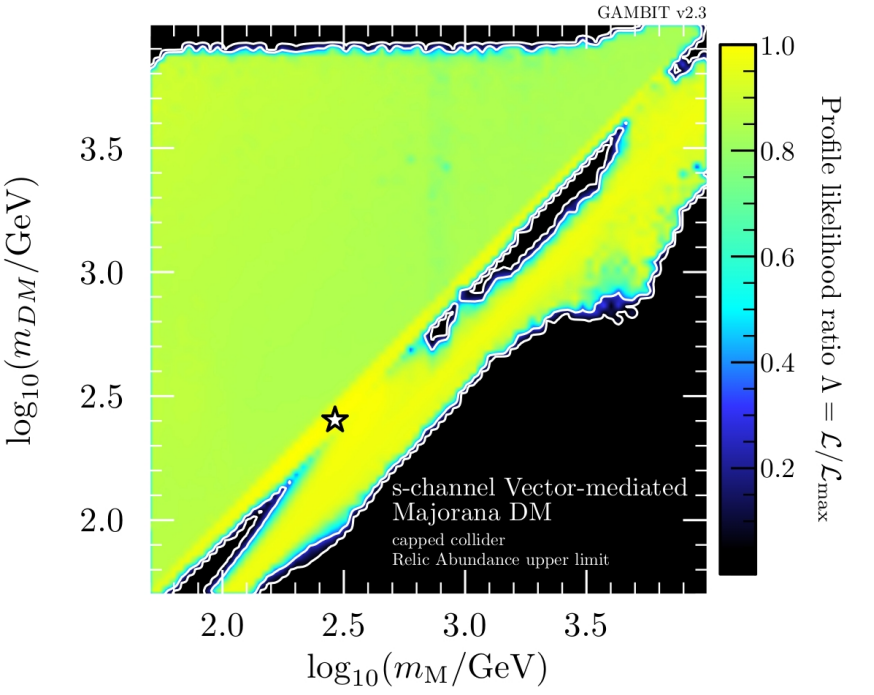
Results: Dirac Fermion DM - RD exact



Capped not yet re-run…

Results: Majorana Fermion DM





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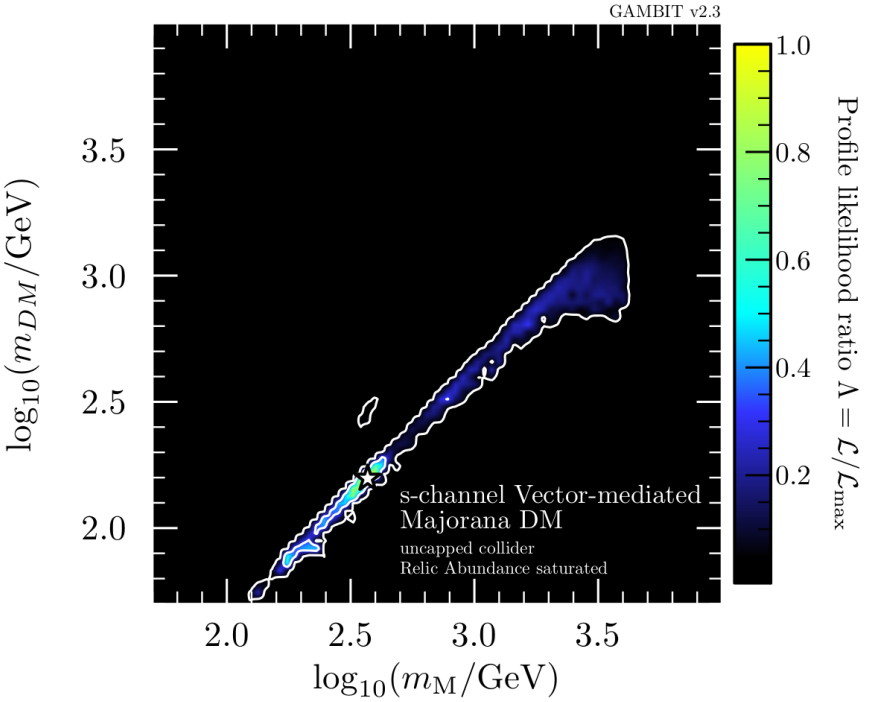

Capped not yet re-run…

Paper 2: Vector dark matter

Lagrangian:

$$\mathcal{L}_{BSM} = -\frac{1}{2}X^{\dagger}_{\mu\nu}X^{\mu\nu} + m^2_{DM}X^{\dagger}_{\mu}X^{\mu} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}m^2_M V_\mu V^\mu$$
$$+g_q V_\mu \bar{q}\gamma^\mu q - ig^V_{DM}\Big(X^{\dagger}_{\nu}\partial_\mu X^\nu - (\partial_\mu X^{\dagger\nu})X_\nu\Big)V^\mu$$

There is a more general possible coupling structure, but we fix many of these couplings to zero.

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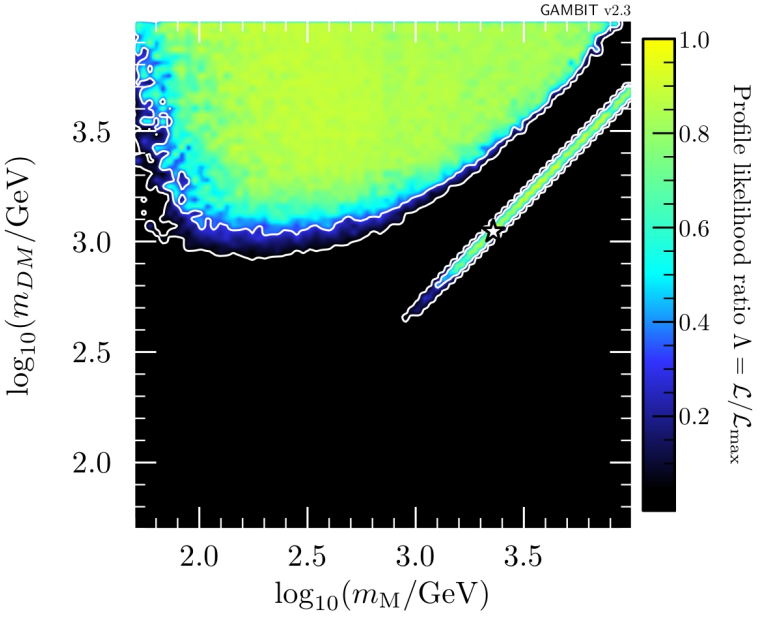
Unitarity Bound:

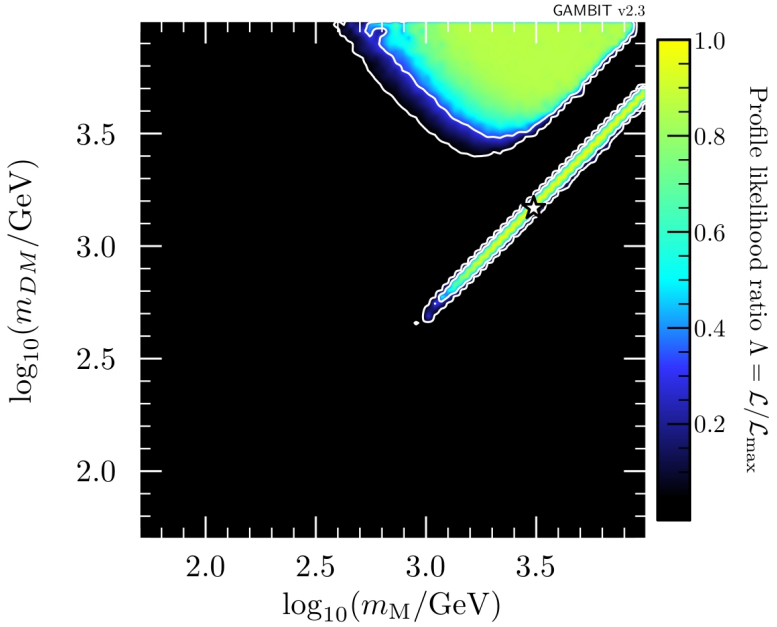
$$s \lesssim min\left(4\sqrt[3]{\pi}\frac{m^{4/3}_{DM}m^{2/3}_M}{g^{2/3}_{DM}}, \frac{\sqrt{96\pi}m^2_{DM}}{g_{DM}}\right)$$

Status: Vector DM

- Derived Unitarity bound for the model and applied it to collider events.
- **Scans:** Performed initial scans (need to do a small targeted scan to improve sampling). I also want to do a little more investigation of large decay widths.
- **Paper:** Largely empty.
- **Code Merge:** Will require very little beyond current code merge.

Results - Vector DM

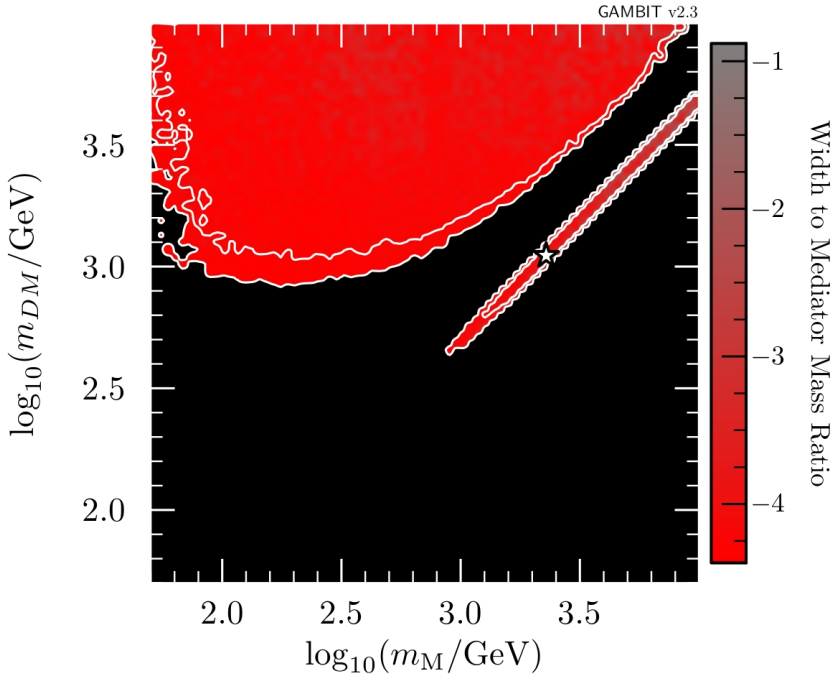




I still need to run a targeted scan for mediator masses below ~100 GeV.

High Decay Widths

If the decay width becomes much larger than the mediator mass, the narrow width approximation would break down (calling into question applicability of some likelihoods).



Even though Width/Mediator mass ratio can be very large in this scan, no surviving parameter points have a ratio above ~0.15

What’s Left to Do:

Paper 1: Scalar and Fermion DM:

- Finish running last scans (should be within the next 1-2 weeks).
- Paper: Update the paper with new plots, and tweak text changes to match.
- Code Merge: Push the changes to the di-jet likelihood and address the last few requested changes.

Paper 2: Vector DM:

- Do a little more investigation of large decay widths.
- Write…

So Paper 1 is very close, Paper 2 isn’t too far off.