Mirror Sectors and Mirror Stars

Jack Setford
with David Curtin

University of Toronto

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Why mirror sectors?

- Mirror sectors are an (approximate) copy of the Standard Model.
- Some well motivated models (naturalness) predict mirror sectors, neutral naturalness, Mirror Twin Higgs.
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**Mirror Twin Higgs**

Mirror nuclear physics can be *similar* to SM nuclear physics.

Mirror sector mass scale $\sim v_B$
- Collider searches $\rightarrow v_B/v_A > 3$
- $\Delta N_{\text{eff}}$, asymmetric reheating $\rightarrow v_B/v_A > 5$.

Mirror sector is at most 10% of total dark matter density (self interaction and large scale structure bounds.)

Predictive framework for cosmology, e.g. Helium mass fraction $\rightarrow 75%$ (25% in SM).

[Chacko, Curtin, Geller, Tsai, arXiv:1803.03263]
Mirror Stars

- If physics of the mirror sector is similar enough to SM physics, it’s reasonable to suppose mirror stars might form.

- Mirror stars of an exact mirror sector have been discussed before.

- But no estimate of expected signal.

- We’re interested in a broad class of models with mirror nuclear physics – MTH model is a good benchmark.
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Mirror photons

As usual in models with a second $U(1)$ gauge boson we expect a kinetic mixing term:

$$\mathcal{L} \supset \frac{\epsilon}{2} F_{\mu\nu} F'_{\mu\nu}$$

Current bounds on $\epsilon$ are

$$\epsilon \lesssim 10^{-9}.$$  

In MTH, $\epsilon$ is forbidden at 1- and 2-loop, so small value arises naturally.

[Vogel, Redondo, arXiv:1311.2600]
How can we see a mirror star?

$\epsilon^2 L_{\text{star}}$ surface brightness:

Captured SM matter:

Captured SM matter is heated via $\epsilon^2$-suppressed processes: collisions with mirror nuclei, and photon conversion.
SM matter catalyzes mirror photon conversion:

\[ p, e^- \rightarrow \gamma' \]

Converted photons can heat up the captured material. There is an X-ray photosphere from which converted X-ray escape → potential signature.
**Calculation Program**

1. Obtain benchmark stellar profiles + star age (we assume SM-like).
2. Calculate total amount captured. Mirror capture, self capture, evaporation, different species.
3. Properties of captured matter: size of SM nugget (hydrostatic equilibrium), surface temperature of nugget (isothermal?), optical depth.
4. Calculate signal strength and shape.
# Optical Depth of Nugget

<table>
<thead>
<tr>
<th></th>
<th>Optically thin</th>
<th>Optically thick</th>
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</thead>
<tbody>
<tr>
<td>Thermal photons</td>
<td>Nugget cools via collisional processes e.g. bremsstrahlung</td>
<td>Nugget cools as blackbody with effective surface temperature</td>
</tr>
<tr>
<td>Converted X-rays</td>
<td>All X-rays escape</td>
<td>Most X-rays deposit energy as heating, while conversions in photosphere can escape.</td>
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</table>
Results: Spectrum

Overall luminosity (are under curve) is a robust prediction, although some uncertainty in the shape.

\[ \epsilon = 10^{-9} \]
\[ M = M_{\text{sun}} \]
RESULTS: LUMINOSITIES

Two distinct thermal spectra – can plot separately on a Hertzsprung-Russell diagram:
CONCLUSIONS

- Mirror sectors theoretically well-motivated.

- Mirror stars can efficiently capture interstellar matter, which leads to a signal in SM photons.

- Two thermal signatures: the temperature of the nugget and the temperature of the mirror star core.

Back-up slides
Profile of captured matter

Assume that the captured material is in isothermal hydrostatic equilibrium, in an *external* gravitational well.
Simplifying assumption, isothermal profile.

\[ kT \frac{dn}{dr} = - \frac{GM(r) mn(r)}{r^2} \]

(Ignores captured matter gravitational self-interactions)

Solution given by

\[ n(r) = Ce^{-\int A(r)dr}, \quad A(r) = \frac{GM(r)m}{kTr^2} \]  \hspace{1cm} (1)

Virial theorem, characteristic radius:

\[ r_{\text{capture}} = \sqrt{\frac{9kT}{4\pi G\rho_{\text{mirror}} m}} \]  \hspace{1cm} (2)
SIMULATING MIRROR STARS

How to simulate a mirror star:

- Starting point, assume star is composed of mirror hydrogen and mirror helium.
- Understand different reaction rates and energy output; weaker weak interaction, higher deuterium binding energy, etc.
- Solve equations of stellar structure:

\[
\frac{dP}{dr} = - \frac{GM(r) \rho(r)}{r^2} \quad \frac{dM}{dr} = 4\pi r^2 \rho(r)
\]

\[
\frac{dL}{dr} = 4\pi r^2 \rho(r) \epsilon(r) \quad \frac{dT}{dr} = - \frac{3}{4ac} \frac{\kappa(r) \rho(r)}{T(r)^3} \frac{L(r)}{4\pi r^2}
\]
- Understand mirror opacity in terms of fundamental parameters.
Mirror stars are SM-like, i.e. same opacity, same reaction rates and energy output.

Generate stellar profiles using MESA for different masses.
SM-like mirror stars

Benchmark star with $M = M_{\text{sun}}$.

Similarly have profiles for pressure, opacity, composition, etc.