Mirror Sectors and Mirror Stars

Jack Setford
with David Curtin

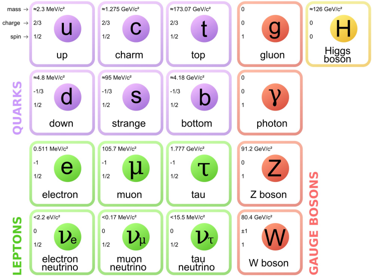
University of Toronto

PHENO 2019

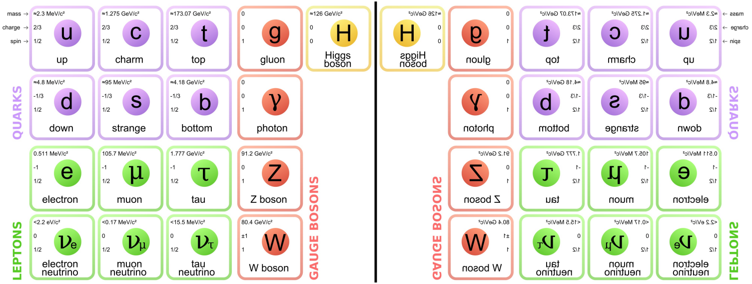
7th May 2019

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.



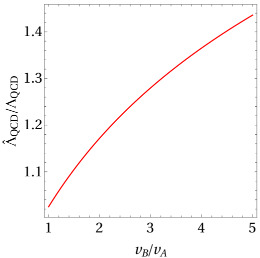
- Mirror sectors are an (approximate) copy of the Standard Model.
- Some well motivated models (naturalness) predict mirror sectors, neutral naturalness, Mirror Twin Higgs.



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

Mirror sector mass scale $\sim v_B$

- Collider searches $\rightarrow v_B/v_A > 3$
- ΔN_{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 → 75% (25% in SM).

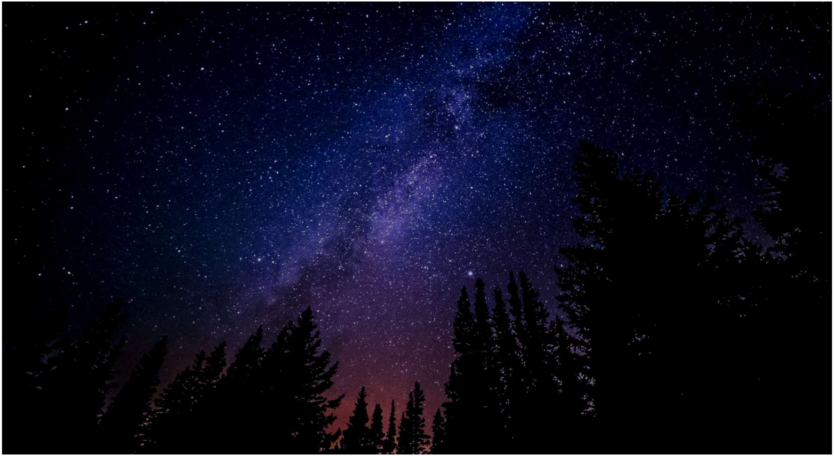
[Chacko, Curtin, Geller, Tsai, arXiv:1803.03263]

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.
  [Foot, Ignatiev, Volkas, arXiv:astro-ph/9902065, arXiv:astro-ph/0011156]
- 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.

STARS!

Standard Model stars were a particularly easy scientific discovery.



STARS!

Standard Model stars were a particularly easy scientific discovery.

Mirror photons

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

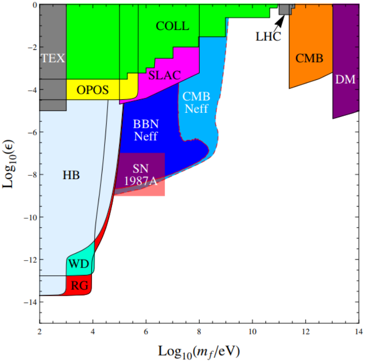
$$\mathscr{L} \supset \frac{\epsilon}{2} F_{\mu\nu} F'^{\mu\nu}$$

Current bounds on ϵ are

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

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

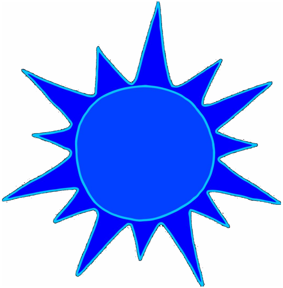
[Vogel, Redondo, arXiv:1311.2600]



Signals from a Mirror Star

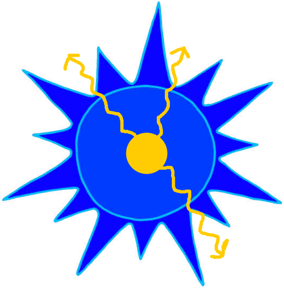
How can we see a mirror star?

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



$\times \epsilon^2$

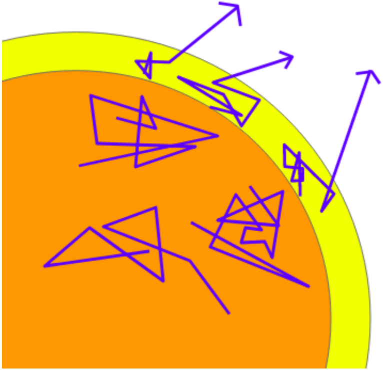
Captured SM matter:

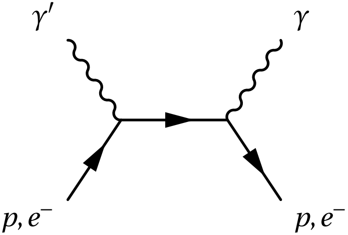


Captured SM matter is heated via ϵ^2-suppressed processes: collisions with mirror nuclei, and photon conversion.

Photon conversion, X-ray signature

SM matter *catalyzes* mirror photon conversion:





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

Calculation program

Obtain benchmark stellar profiles + star age (we assume SM-like).

↓

Calculate total amount captured. Mirror capture, self capture, evaporation, different species.

↓

Properties of captured matter: size of SM nugget (hydrostatic equilibrium), surface temperature of nugget (isothermal?), optical depth.

↓

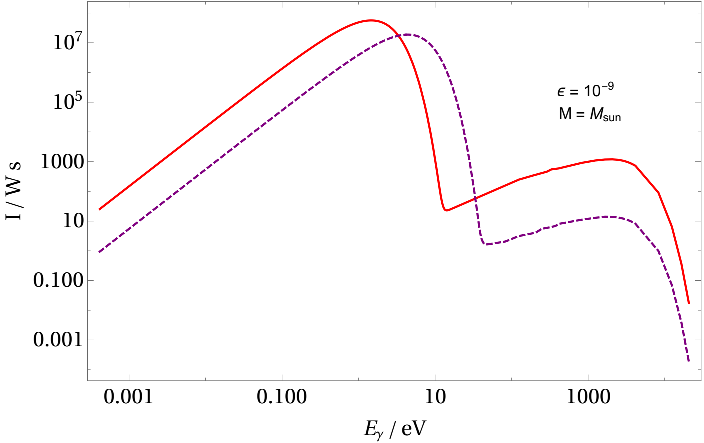
Calculate signal strength and shape.

Optical depth of nugget

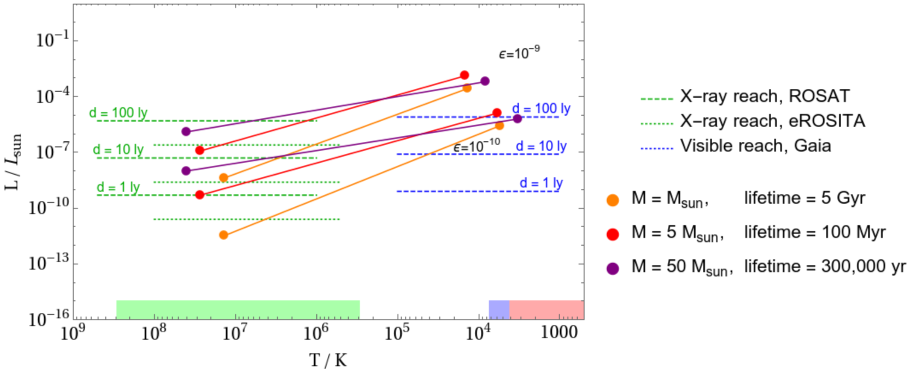
	Optically thin	Optically thick
Thermal photons	Nugget cools via collisional processes e.g. bremsstrahlung	Nugget cools as blackbody with effective surface temperature
Converted X-rays	All X-rays escape	Most X-rays deposit energy as heating, while conversions in photosphere can escape.

Results: Spectrum

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



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.
- Weird signal – faint, nearby, hot object with an X-ray signal. Close → parallax.

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.

$$kT\frac{dn}{dr} = -\frac{GM(r)\,m\,n(r)}{r^2}$$

(Ignores captured matter gravitational self-interactions)

Solution given by

$$n(r) = Ce^{-\int A(r)\,dr}, \quad A(r) = \frac{GM(r)\,m}{kTr^2} \tag{1}$$

Virial theorem, characteristic radius:

$$r_{capture} = \sqrt{\frac{9kT}{4\pi G\rho_{mirror}m}} \tag{2}$$

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:

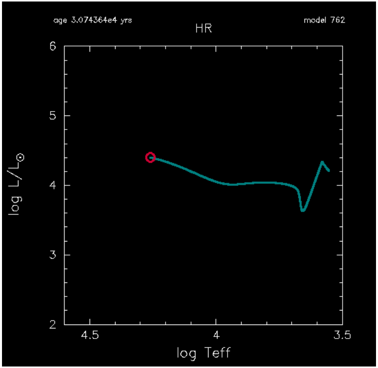
$$\frac{dP}{dr} = -\frac{GM(r)\rho(r)}{r^2} \qquad \frac{dM}{dr} = 4\pi r^2 \rho(r)$$

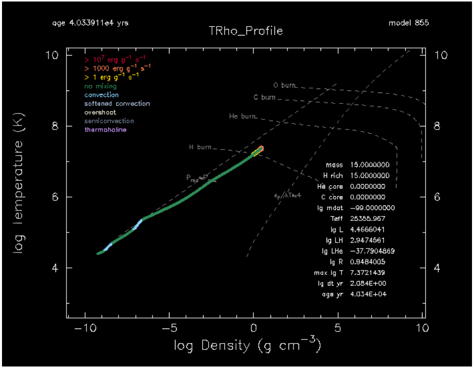
$$\frac{dL}{dr} = 4\pi r^2 \rho(r)\epsilon(r) \qquad \frac{dT}{dr} = -\frac{3}{4ac}\frac{\kappa(r)\rho(r)}{T(r)^3}\frac{L(r)}{4\pi r^2}$$

- Understand mirror opacity in terms of fundamental parameters.

SM-like mirror stars

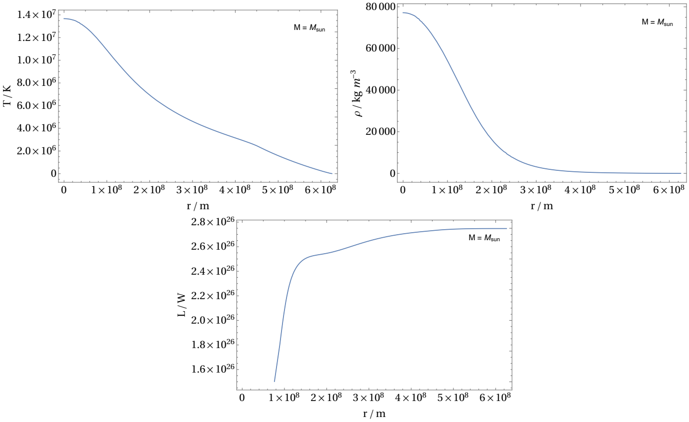
- Mirror stars are SM-like, i.e. same opacity, same reaction rates and energy output.
- Generate stellar profiles using MESA for different masses.





SM-like mirror stars

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



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