

A closer look at the pp -chain reaction in the Sun: Constraining the coupling of light mediators to protons

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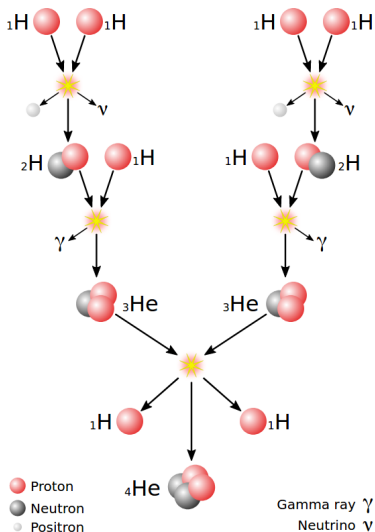


Why our sun is an interesting place to look at?



The Sun

- Closest star
- Well studied and well measured
- Better measurements will come
- *pp*-chain - primary channel (99.7%)



Non-standard mediators coupling to protons

vector boson (Z')

scalar (ϕ)

$$\mathcal{L}^{Z'} = gZ'_{\mu}\bar{p}\gamma^{\mu}p$$

$$\mathcal{L}^{\phi} = g\phi\bar{p}p$$

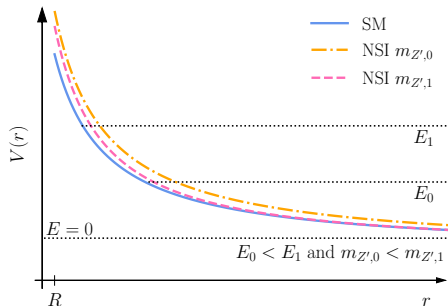
Interaction potential

$$V(r) = \frac{e^2}{r} \pm \frac{g^2}{r} \exp[-m_{\{Z',\phi\}}r]$$

Coulomb barrier penetration factor

$$P_{0,\text{SM}} \approx \frac{E_c}{E} \exp\left[-\frac{2\pi e^2}{\hbar v}\right] \approx \frac{E_c}{E} \exp[-W_{0,\text{SM}}]$$

$$\Delta \approx \frac{|W_{0,\text{NSI}}^{\frac{2}{3}} - W_{0,\text{SM}}^{\frac{2}{3}}|}{W_{0,\text{SM}}^{\frac{2}{3}}}$$

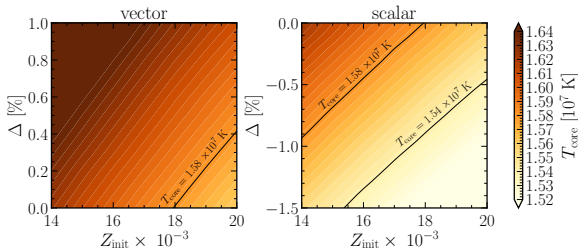


pp interaction rate

$$\Gamma_{pp} \propto \exp\left(-3.381(1 \pm \Delta) \left(\frac{T}{10^9 \text{ K}}\right)^{\frac{1}{3}}\right)$$

Changes in the solar parameters

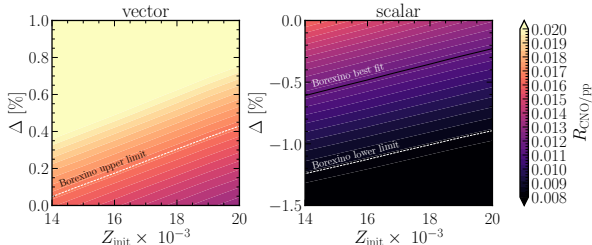
Sun's core temperature



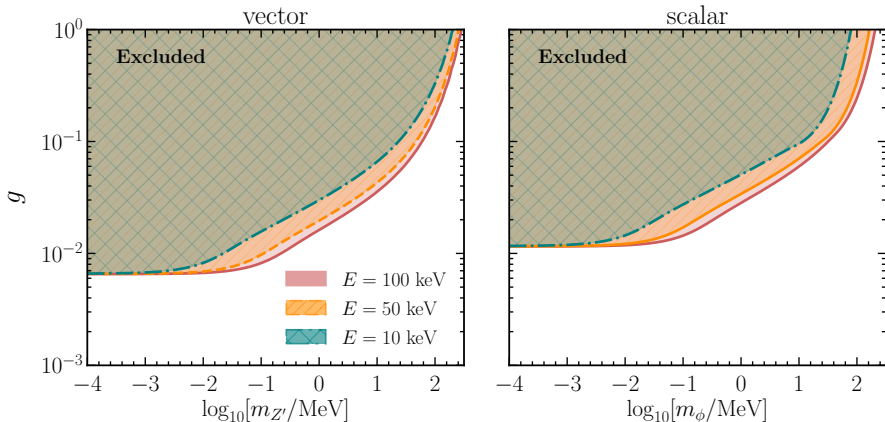
- **vector boson mediator**
temperature increase
- **scalar mediator**
temperature decrease

CNO to *pp* ratio, $R_{\text{CNO}/pp}$

- $R_{\text{CNO}/pp}$ – the same trends
- **degeneracy between**
initial metallicity and NSI



Sensitivity bounds on the non-standard mediators



- low mediator mass \rightarrow limits insensitive to the mediator mass
- higher proton energies \rightarrow the excluded region grows
- conservative bounds \rightarrow there is a room for an improvement

Conclusions

Non-standard mediators

- affect the Coulomb potential felt by the charge particles
- change the temperature of the core of the Sun
- can be constrained with the solar neutrino fluxes
- can affect nuclear reactions in more massive stars

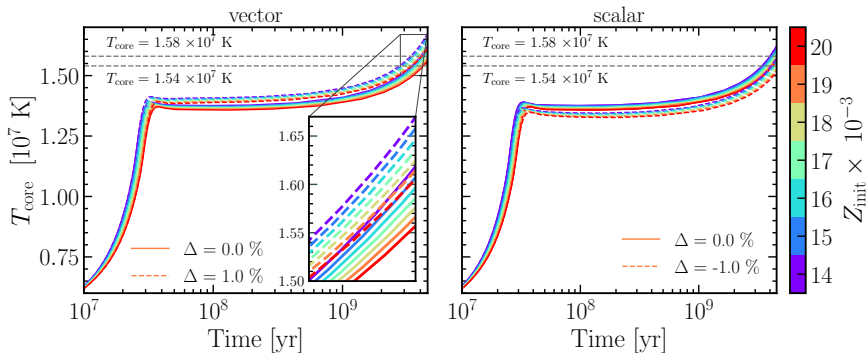
The calculated sensitivity bounds for protons

- most constraining for mediators with masses above 50 keV
- will improve with better measurements of the metallicity and CNO neutrinos

Thank you!

Backup slides

Temporal evolution of the solar core's temperature



- Modules for Experiments in Stellar Astrophysics *MESA*
- Evolution until the current solar age
- Changes in the barrier and metallicity affect the outcome