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%)

Pictures: Kurzgesagt, Wikipedia
Non-standard mediators coupling to protons

vector boson ($Z'$)
\[ \mathcal{L}_{Z'} = g Z'_{\mu} \bar{p} \gamma^\mu p \]

scalar ($\phi$)
\[ \mathcal{L}_{\phi} = g \phi \bar{p} p \]

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

Coulomb barrier penetration factor
\[ P_{0,SM} \approx \frac{E_c}{E} \exp\left[-\frac{2\pi e^2}{\hbar \nu}\right] \approx \frac{E_c}{E} \exp[-W_{0,SM}] \]

\[ \Delta \approx \left| \frac{W_{0,NSI}^2}{W_{0,SM}^{2/3}} - W_{0,SM}^{2/3} \right| \]

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

D. D. Clayton, *Principles of stellar evolution and nucleosynthesis* (1968)
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
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