Comments on recent XENON1T results and their theoretical interpretations

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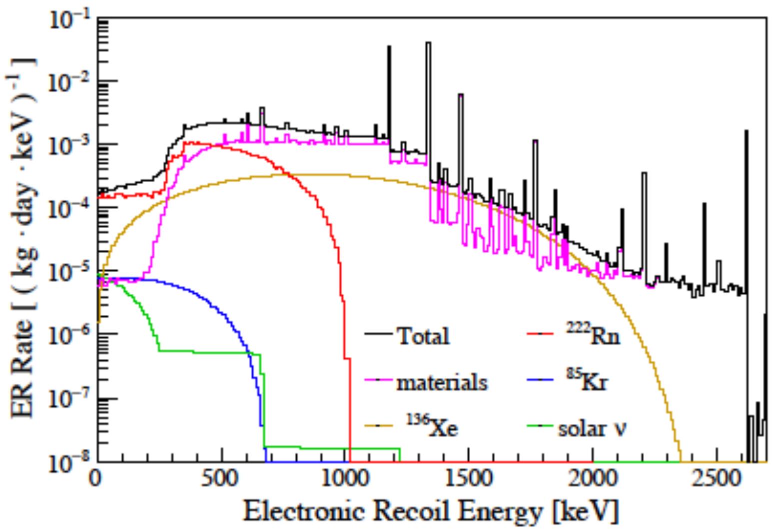
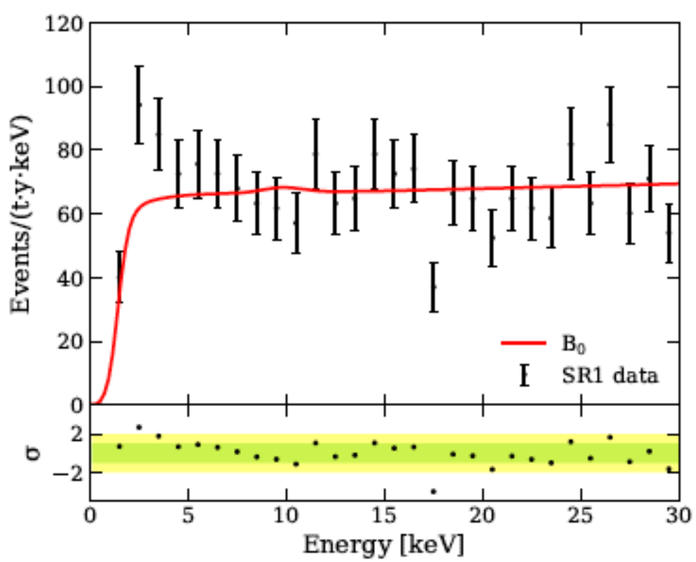
O(40) theoretical papers by many authors, several new ideas

Congratulations to the collaboration on achieving low backgrounds and high sensitivity



2015 projections, 1512.07501



2020 results, 2006.09721

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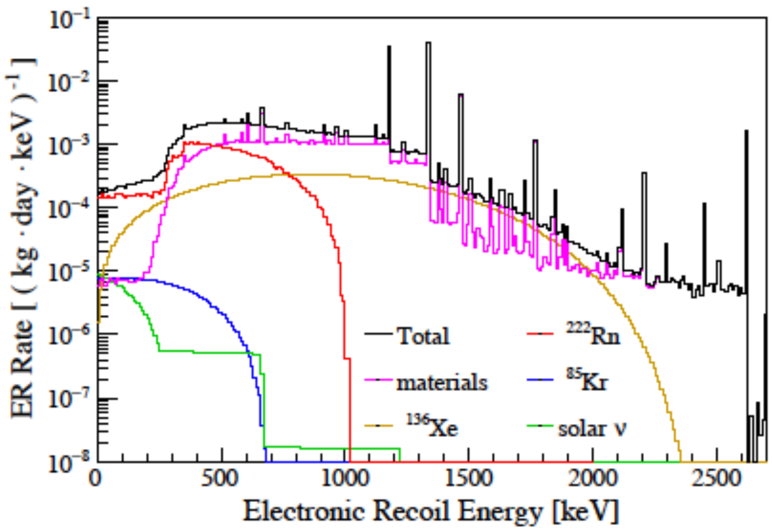
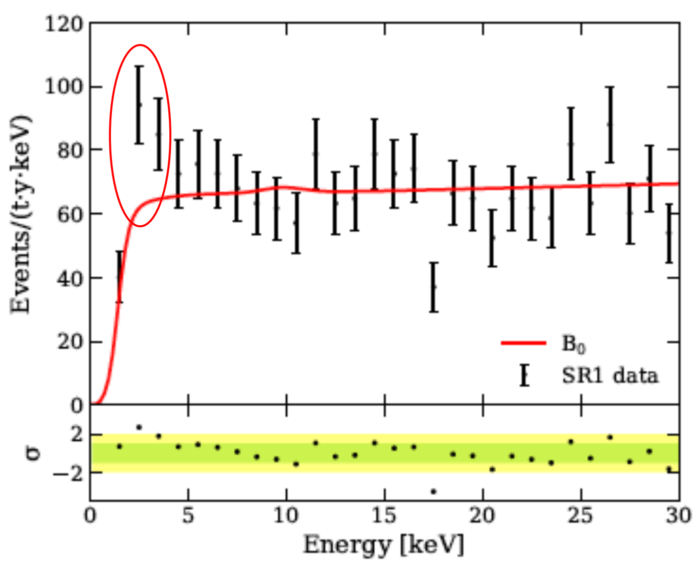


2015 projections, 1512.07501

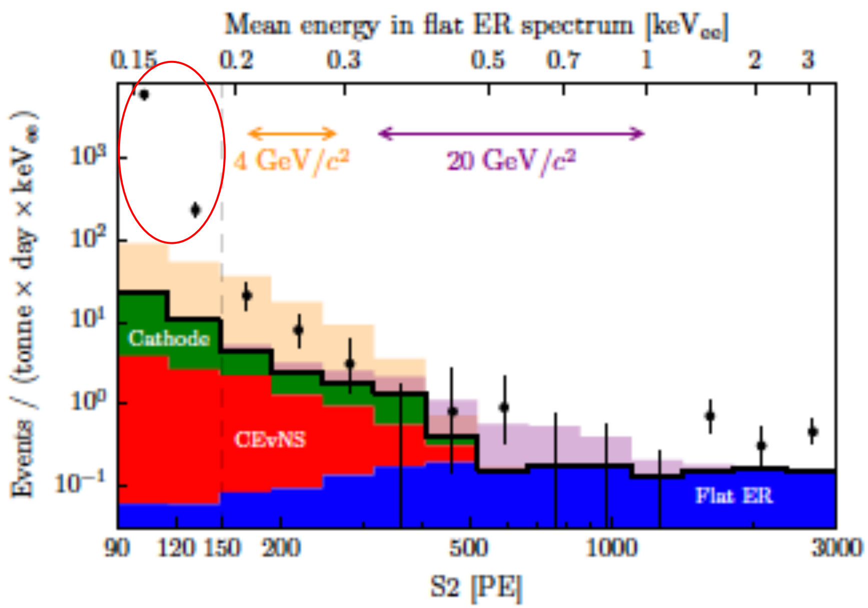


2020 results, 2006.09721

There is a slight excess in low-energy bins →lots of attempts to explain it

There are other puzzles in Xenon experiment

- S2-only signal also has an excess: many events with low number of photo-electrons. Origin = probably not necessarily exotic physics.



- Low Q-value beta emitters, such as tritium, or some e-capture elements in small numbers could cause an excess at 2-4 keV.

- Time-stability or time-variability of the excess needs to be studied. (Many sources of putative signal, i.e. solar core, do not vary much)

What if it is a signal of new physics?

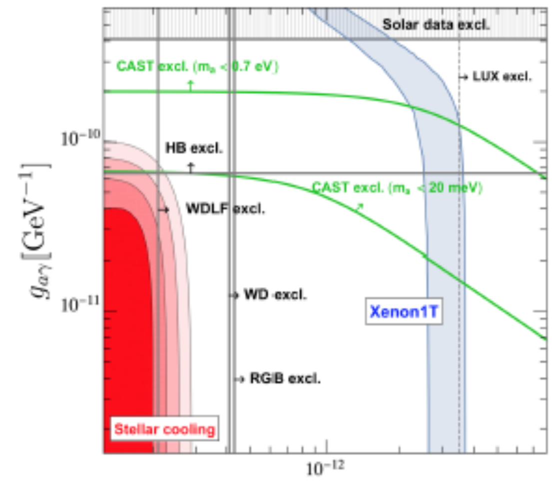
- Is it a sign of thermal emission from the Sun?
- Is this a sign of non-trivial interactions of light SM neutrinos?
- Is it a sign of some new keV energy scale "built-into" dark matter physics, i.e. mass or mass splitting?
- Is it a sign of new "fast" particles: dark radiation, boosted dark matter? What are the possible sources?

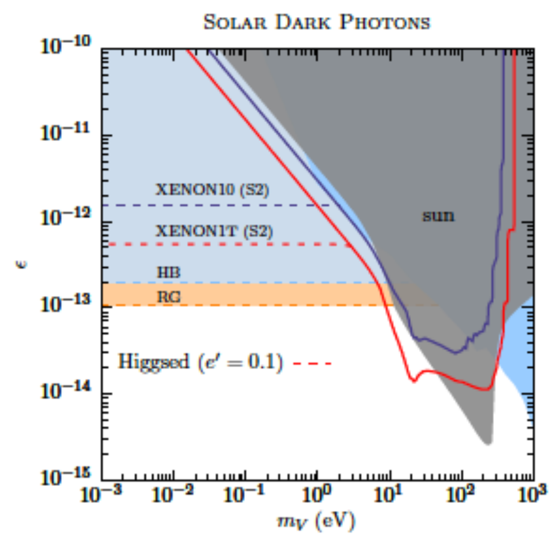
New particles with dim=5 and lower interactions could be generated by thermal processes in the Sun

- Axions or ALPs? Too large a coupling needed –in conflict with other energy loss constraints.

Since detector signal goes as coupling^4, (and stars go as coupling^2), a factor of 100 gain in sensitivity is needed if XENON experiment is to catch up with bounds that are factor of 3 apart. 2006.12487

Inverse Primakoff needs to be included, 2006.14598, .15118
Maybe it is time to revisit more calculations.





- Dark photons? Emission from the Sun provides leading constraints on sub-keV dark photons, but the spectrum is too soft. 2006.13929

Question: is there ANY model of sub-keV dark sectors that could give an excess and evade other bounds?

- *More complicated dark sectors? Examples that may soon be analyzed:* $\mathcal{L} = -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}_{\mu\nu} - \frac{1}{4} g'_{a\gamma\gamma} a F'_{\mu\nu} \tilde{F}'_{\mu\nu} - \frac{1}{2} \epsilon F_{\mu\nu} \tilde{F}'_{\mu\nu} + \frac{1}{2} m_a^2 a^2 - \frac{1}{2} m_{A'}^2 (A')^2$

Sun produces ~ few keV mass ALP, it decays to 2 transverse dark photons of few 10's eV mass (g'>> g), that then get absorbed by XENON. ($g_{a\gamma\gamma} \sim 10^{-10}$ GeV $^{-1}$, $\varepsilon \sim$ few 10^{-14} may work – work in progress)

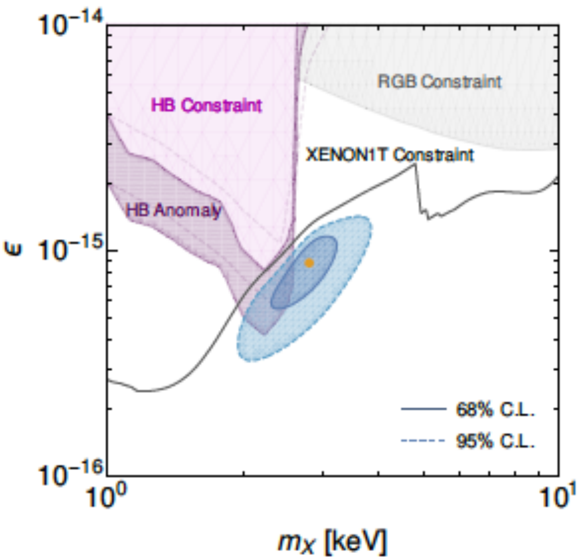
- *Mass/coupling change as function of environment (aka chameleons)? Due to additional interactions e.g. solar mass "renormalizes" m_a to be in 10's of keV or heavier to evade constraints*. [Strong sense of deja-vu, discussed in connection with "PVLAS anomaly"]. 2006.14521, 2006.15112

Problems with using new interactions of SM ν

- *The Sun provides up to $10^{11}/cm^2/sec$ neutrinos with sub-MeV energy.*
- It is tempting to use lower dimension interactions (magnetic moments, EDMs), to have a slightly infrared-enhanced effects, and no sensitivity to E_ν. Faces challenging stellar bounds due to $\gamma^* \to \nu\nu$.
- *New light Z' for neutrinos (E.g. below keV scale), that can give Rutherford like ~ dE_{recoil}/E^2_{recoil} cross sections, and be cutoff by Z' mass. The shape of the signal can be fit well. Unfortunately one needs to "reinvent" early cosmology, and face stellar production of Z'. 2006.11250*
- More complicated sterile ν sector? E.g. few MeV scale sterile neutrinos (from Boron flux, and/or Earth) with magnetic moments?

keV could be "intrinsic" scale built into dark matter

- *3 keV dark matter has 10^5 cm^{-3} concentration, and $10^{12}/cm^2/sec$ flux. If it is quasi-stable it can get absorbed by atoms, avoiding stellar bounds (!)*



- Dark photons with mixing in the few*10^{-16} range, ~ 3keV mass, 2006.11243, .13929, .14521
- ALPs, same mass, coupling to electron axial vector current, 2006.10035
- Dim=5 coupled vectors, 2006.13929

- Mass splitting in the dark sector allows the process of de-excitation: X2+e → X1 +e + few keV. Advantage: mass can be ~ GeV, outside the immediate astro/cosmo reach. 2006.13918
- *Problem: ad-hoc ~2 keV scale built-in by hand. Lower signifance.*

Fast dark particles?

- *Recoil electrons go with $v_{recoil}/c \sim 0.1$. It is suggestive that the particles that caused such a recoil are as fast. 2006.10735 (Or else it could be a true photon, "built-into" interaction, 2006.12462)*
- It is possible that "fast dark particles" can be created out of reflection from the solar electrons, due to collisions with other fast particles (cosmic rays), due to annihilation or semi-annihilation, and from the *decays* of existing particles.
- One can quantify maximum fluxes:

$\Phi_{\text{reflected from Sun}} \sim (R_{sun}/AU)^2\, \Phi_{DM} \sim 10^{-5}\, \Phi_{DM}$ [softer than needed, if mass is in few MeV]

$\Phi_{\text{reflected from CR}} < 10^{-4}\, \Phi_{CR}$ [less than $10^{-4}/cm^2/sec$]

Decays giving rise to fast particles

$$\Phi^{\rm global+MW}_{\rm DM\ decay} \sim 10^4\ {\rm cm^{-2}s^{-1}} \left(\frac{10\,\tau_{\rm U}}{\tau_{\rm DM}}\right)\left(\frac{1\,{\rm GeV}}{m_{\rm DM}}\right),$$

$$\Phi^{\odot}_{\rm proton\ decay} \sim 10^{-8}\ {\rm cm^{-2}s^{-1}} \left(\frac{10^{30}\,{\rm yr}}{\tau_{\rm p}}\right),$$

$$\Phi^{\odot}_{\rm H\ decay} \sim 10^{3}\ {\rm cm^{-2}s^{-1}} \left(\frac{10^{28}\,{\rm s}}{\tau_{\rm H}}\right),$$

2006.15140
1711.04531

- Dark matter decays can give rise to fast fluxes that are relatively large. Take a GeV decaying dark matter. Interactions of daughter products (e.g. magn moment) with electrons can give a good fit to XENON excess.
- Proton decay does not work. But e+p → dark sector [i.e. hydrogen decay] can give an excess (provided that the mass of daughter products match m_H within a couple of MeV)

Conclusions

- *New breakthrough sensitivity to keV -scale energy deposition, achieved by Xenon collaboration is a welcome development! We are all looking forward to see more results.*
- Strong limits can be imposed on many scenarios. Excess is tantalizing but is not yet amounting to "evidence for new physics"
- *Connection to thermal keV-scale emission from the Sun is the most exciting possibility. Axions/ALPs or dark photons do not seem to be able to fit the excess while escaping other constraints. Can more complicated dark sectors be at play?*
- An ad-hoc keV scale built into dark matter seems to be a generic possibility (mass, or mass splitting).
- *Decaying dark matter (and other sources) can give rise to "fast dark particles" that could fit the excess well. Certain interactions (millicharged particles, particles with magn moment) have a degree of universality somewhat mitigating model-dependence.*