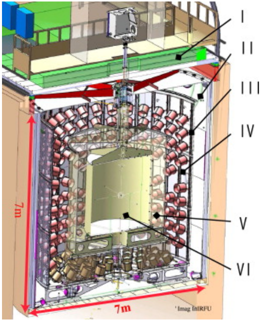
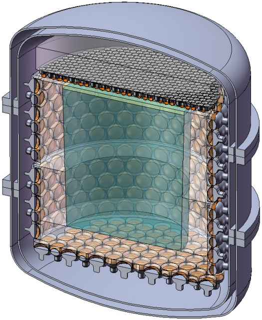
New signals in dark matter detectors

Joachim Kopp

(based on work done in collaboration with
Roni Harnik and Pedro Machado, arXiv:1202.6073)

Kaffeepalaver @ MPIK, November 08, 2012



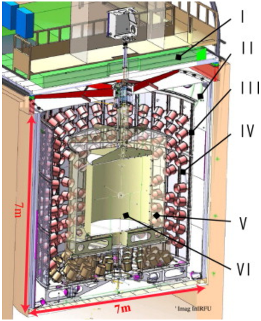


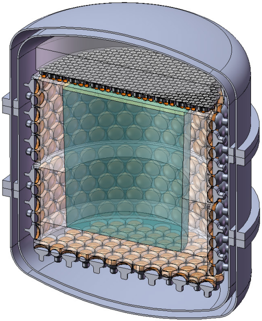
ν signals in dark matter detectors

Joachim Kopp

(based on work done in collaboration with
Roni Harnik and Pedro Machado, arXiv:1202.6073)

Kaffeepalaver @ MPIK, November 08, 2012





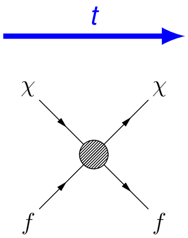
Outline

1. Direct Dark Matter detection
2. Standard Model neutrino backgrounds in DM detectors
3. Enhanced neutrino scattering from new physics
4. Temporal modulation of ν signals
5. Constraints on hidden photons and sterile neutrinos
6. Conclusions

Outline

Direct Dark Matter detection

Idea: A WIMP (Weakly Interacting Massive Particle) can scatter on an atomic nucleus.

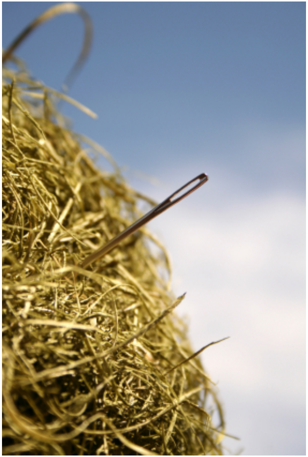


Strategy: Look for feeble nuclear recoil

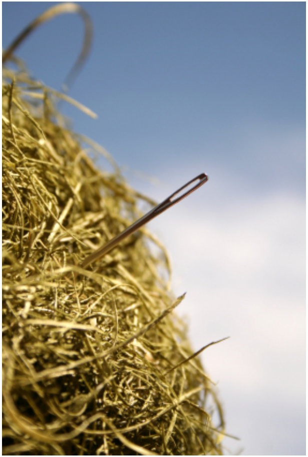
Problem: Many background processes can mimic the signal:

- Radioactive decays
- Cosmic rays
- Neutrinos $\rightarrow$ this talk
- …

Direct DM detection — The experimental challenge



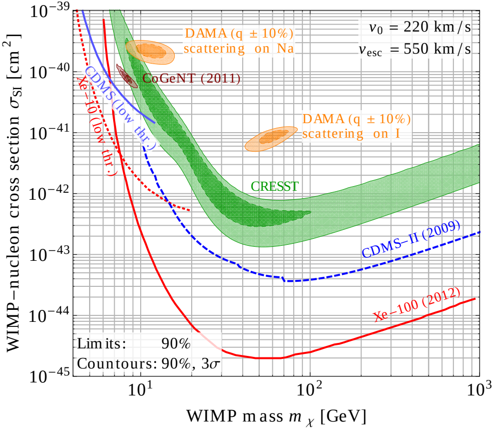
Direct DM detection — The experimental challenge



background

suppression

Direct detection results — Current status



updated version of plot from JK Schwetz Zupan 1110.2721
see also Freese Lisanti Savage 1209.3339

Assumptions here:

- Elastic DM scattering $\propto$ target mass

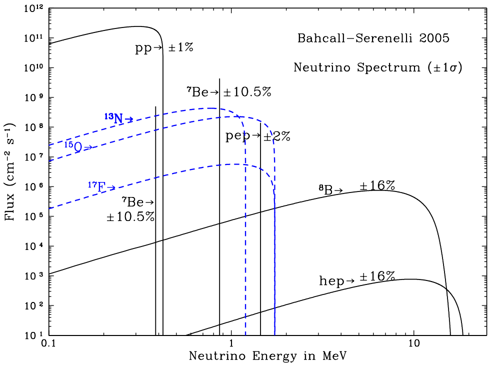
Outline

Standard Model neutrino backgrounds in DM detectors

Solar neutrinos are a well-known background to future direct DM searches:

see e.g. Gütlein et al. arXiv:1003.5530

$$\frac{d\sigma_{\rm SM}(\nu N \to \nu N)}{dE_r} = \frac{G_F^2 m_N F^2(E_r)}{2\pi E_\nu^2}\Big[A^2 E_\nu^2 + 2AZ(2E_\nu^2(s_w^2 - 1) - E_r m_N s_w^2) + 4Z^2(E_\nu^2 + s_w^4(2E_\nu^2 + E_r^2 - E_r(2E_\nu + m_N)) + s_w^2(E_r m_N - 2E_\nu^2))\Big],$$

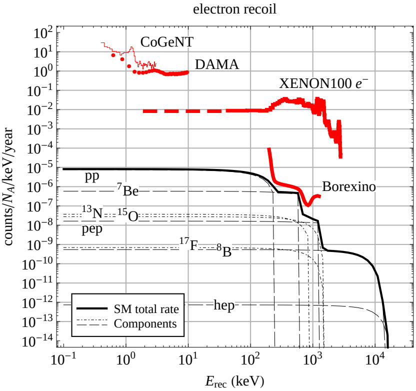


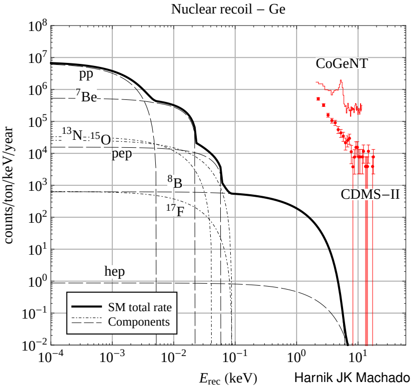
Standard Model neutrino backgrounds in DM detectors

Solar neutrinos are a well-known background to future direct DM searches:

see e.g. Gütlein et al. arXiv:1003.5530

$$\frac{d\sigma_{\rm SM}(\nu N \to \nu N)}{dE_r} = \frac{G_F^2 m_N F^2(E_r)}{2\pi E_\nu^2}\Big[A^2 E_\nu^2 + 2AZ(2E_\nu^2(s_w^2 - 1) - E_r m_N s_w^2) + 4Z^2(E_\nu^2 + s_w^4(2E_\nu^2 + E_r^2 - E_r(2E_\nu + m_N)) + s_w^2(E_r m_N - 2E_\nu^2))\Big],$$





Harnik JK Machado 1202.6073

Standard Model neutrino backgrounds in DM detectors

Solar neutrinos are a well-known background to future direct DM searches:

see e.g. Gütlein et al. arXiv:1003.5530

$$\frac{d\sigma_{\rm SM}(\nu N \to \nu N)}{dE_r} = \frac{G_F^2 m_N F^2(E_r)}{2\pi E_\nu^2} \Big[A^2 E_\nu^2 + 2AZ(2E_\nu^2(s_w^2 - 1) - E_r m_N s_w^2) + 4Z^2(E_\nu^2 + s_w^4(2E_\nu^2 + E_r^2 - E_r(2E_\nu + m_N)) + s_w^2(E_r m_N - 2E_\nu^2)) \Big] ,$$

SM signal will only become sizeable in multi-ton detectors

But: New physics can enhance the rate

Outline

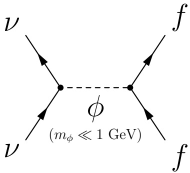
Enhanced neutrino scattering from new physics

Question:

- Can neutrino scattering be relevant already in the current generation of DM detectors?
- Can it explain some of the anomalous signals (CoGeNT, DAMA, CRESST)?

Conditions for large scattering cross sections:

- Large scattering rate at low energies, low scattering rate at high energies
  - High-*E* neutrino scattering well studied experimentally, consistent with SM
  - Possible realization: Scattering through a light (or massless) force carrier

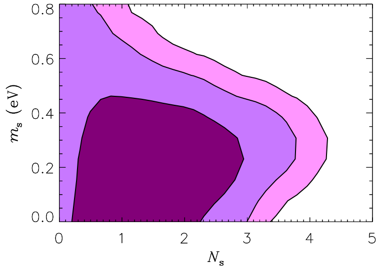


- Typically also: Existence sterile neutrinos
  - Active neutrinos in the same $SU(2)$ doublets as charged leptons
  - New physics in the charged lepton sector tightly constrained

Light force carriers: Motivation

- We know they exist! In particular the photon in electromagnetism.
- Top-down approaches to particle physics (Grand Unified Theories (GUTs), string theory, ...) usually have extra gauge groups
- $U(1)$ factors are often left over when gauge symmetries are broken
  - Example: $SU(2) \times U(1)_Y \to U(1)_{\text{em}}$
- No preferred mass scale for new gauge bosons (depending on BSM symmetry breaking mechanism)
- Couplings and masses naturally suppressed in extra-dimensional worlds

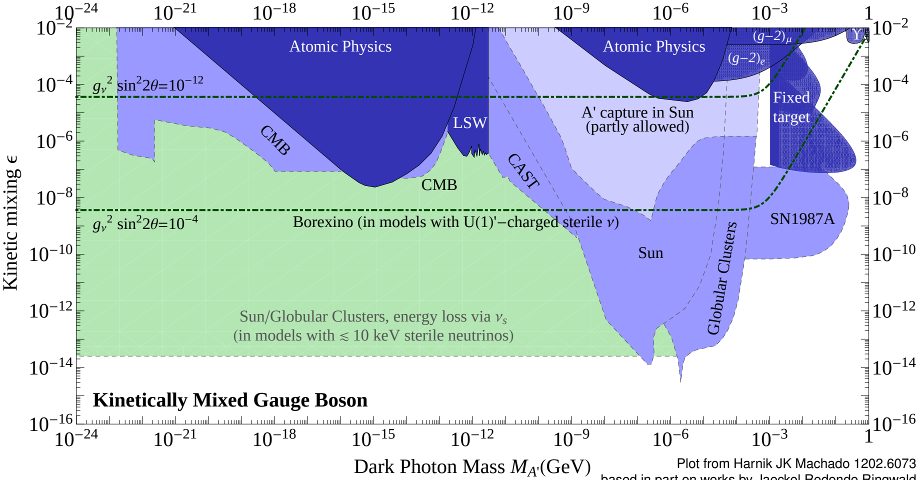
  see talks by Jörg Jäckel
- Slight cosmological preference for extra "radiation" (light particles)



Hamann Hannestad Raffelt Tamborra Wong 1006.5276

Light force carriers: Motivation (2)

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} - \frac{1}{2} \epsilon F'_{\mu\nu} F^{\mu\nu}$$



Plot from Harnik JK Machado 1202.6073
based in part on works by Jaeckel Redondo Ringwald

Lots of open parameter space ... more on this later

Sterile neutrinos: Theoretical motivation

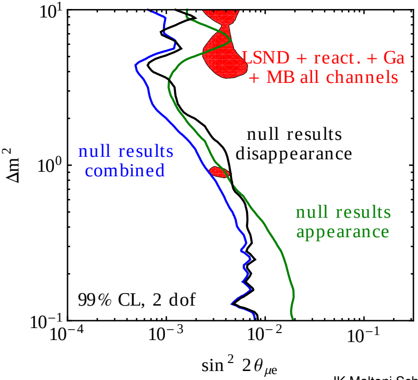
- Standard Model singlet fermions are a very generic feature of "new physics" models
  - Leftovers of extended gauge multiplets (e.g. GUT multiplets) (typically heavy)
  - Dark matter (keV . . . TeV or above)
- Neutrino–singlet mixing is one of the allowed "portals" between the SM and a hidden sector.
- SM singlet fermions can live at any mass scale
- Typical Lagrangian:

$$\mathcal{L}_{\text{mass}} \supset Y_\nu \bar{L} H^* N_R + m_s \bar{\nu}_s N_R + \frac{1}{2} M \overline{N_R^c} N_R + h.c.$$

$\Rightarrow$ mass mixing between active and sterile neutrinos

Sterile neutrinos: Experimental motivation

- Several experiments have seen hints for sterile neutrinos in $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ appearance and $\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e$ disappearance oscillations
- . . . but tension with other experiments ($\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$, $\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e$, $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$)



JK Maltoni Schwetz 1103.4570 and work in progress

see also Giunti Laveder 1107.1452 and 1109.4033; Mention et al. 1101.2755; Karagiorgi et al. 0906.1997 and 1110.3735

appearance: E776, ICARUS, KARMEN ($\bar{\nu}_e$), LSND ($\bar{\nu}_e$), MiniBooNE (ν_e, $\bar{\nu}_e$), NOMAD

disappearance: Atmospheric Neutrinos, CDHS, KARMEN ν_e–^{12}C, LSND ν_e–^{12}C, MiniBooNE (ν_μ, $\bar{\nu}_\mu$), MINOS, Reactor Neutrinos, Solar Neutrinos

... back to ν signals in dark matter detectors

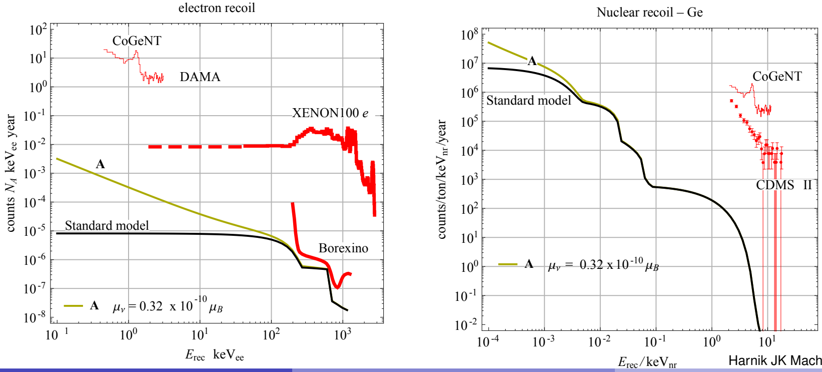
Model 1: Neutrino magnetic moments

Assume neutrinos carry an enhanced magnetic moment (e.g. for composite neutrinos)

$$\mathcal{L}_{\mu_\nu} \supset \mu_\nu \, \bar{\nu}\sigma^{\alpha\beta}\partial_\beta A_\alpha \nu \,, \qquad \mu_{\nu,\mathrm{SM}} = 3.2 \times 10^{-19}$$

Cross section large at low energies due to photon propagator $\propto q^{-2}$

$$\frac{d\sigma_\mu(\nu e \to \nu e)}{dE_r} = \mu_\nu^2 \alpha \left(\frac{1}{E_r} - \frac{1}{E_\nu} \right) ,$$



Harnik JK Machado 1202.6073

Model 2: A hidden photon + sterile neutrinos

Introduce a hidden photon A' and a sterile neutrino ν_s

Related model with gauged $U(1)_B$ first discussed in Pospelov 1103.3261
detailed studies in Harnik JK Machado 1202:6073 and Pospelov Pradler 1203.0545

- ν_s charged under $U(1)' \to$ direct coupling to A'
- SM particles couple to A' only through kinetic mixing

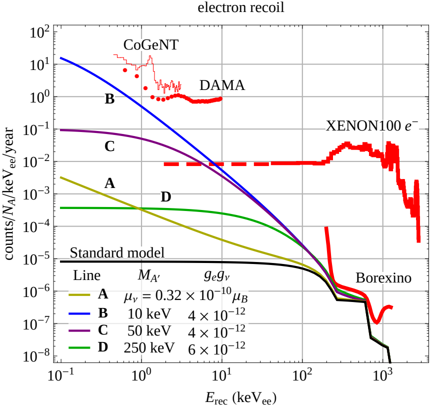
$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\epsilon F'_{\mu\nu}F^{\mu\nu} + \bar{\nu}_s i\partial\!\!\!/ \nu_s + g'\bar{\nu}_s\gamma^\mu\nu_s A'_\mu$$
$$- \overline{(\nu_L)^c} m_{\nu_L}\nu_L - \overline{(\nu_s)^c} m_{\nu_s}\nu_s - \overline{(\nu_L)^c} m_{\mathrm{mix}}\nu_s$$

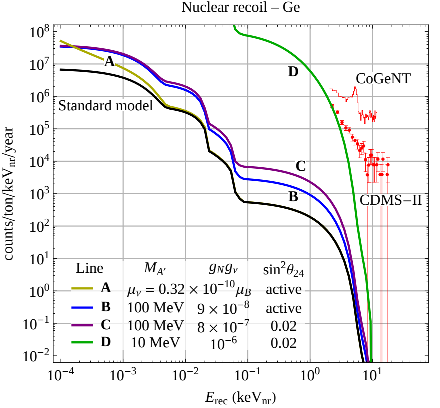
A small fraction of solar neutrinos can oscillate into ν_s

ν_s scattering cross section in the detector given by

$$\frac{d\sigma_{A'}(\nu_s e \to \nu_s e)}{dE_r} = \frac{\epsilon^2 e^2 g'^2 m_e}{4\pi p_\nu^2 (M_{A'}^2 + 2E_r m_e)^2}\left[2E_\nu^2 + E_r^2 - 2E_r E_\nu - E_r m_e - m_\nu^2\right]$$

Model 2: A hidden photon + sterile neutrinos





A: ν magnetic moment
B, C, D: kinetically mixed A' + sterile ν_s

A: ν magnetic moment
B: $U(1)_{B-L}$ boson
C: kinetically mixed $U(1)'$ + sterile ν
D: $U(1)_B$ + sterile ν charged under $U(1)_B$

proposed in Pospelov 1103.3261, details in Pospelov Pradler 1203.0545

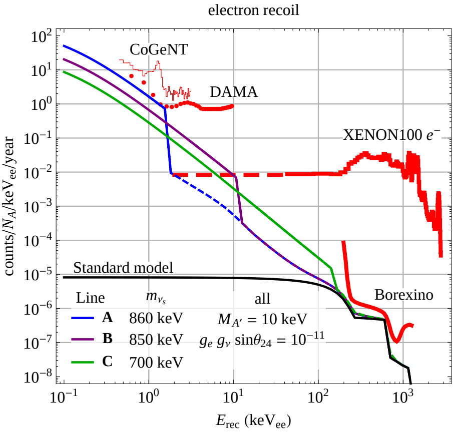
- Enhanced scattering at low E_r for light A'
- Negligible compared to SM scattering ($\sim g^4 m_T / M_W^4$) at energies probed in dedicated neutrino experiments

Harnik JK Machado 1202.6073

Heavier sterile neutrinos

Sterile neutrinos with mass close to a kinematic threshold in the Sun lead to different recoil spectra

Example: $m_{\nu_s} \sim 861$ keV (energy of solar Be-7 line: $^7\text{Be} + e^- \to {}^7\text{Li} + \nu$)

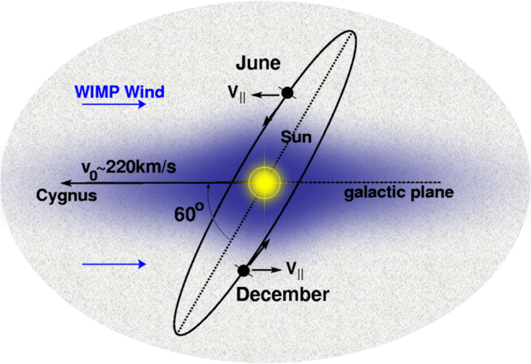


Plot from Harnik JK Machado 1202.6073

Outline

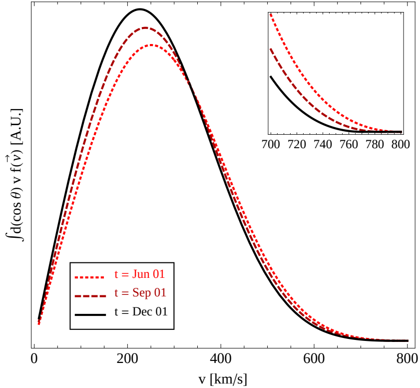
Annual modulation as a “smoking gun” DM signature

- An annually modulation signal is considered very robust evidence for DM.
  Freese Frieman Gould 1988
- Earth’s velocity relative to the Milky Way’s DM halo is different in summer and in winter



Annual modulation as a "smoking gun" DM signature

- An annually modulation signal is considered very robust evidence for DM.
  Freese Frieman Gould 1988
- Earth's velocity relative to the Milky Way's DM halo is different in summer and in winter
  - Expect annually modulating scattering rates
  - Low recoil energy, heavy DM: Peak in summer
    High recoil energy, light DM: Peak in winter



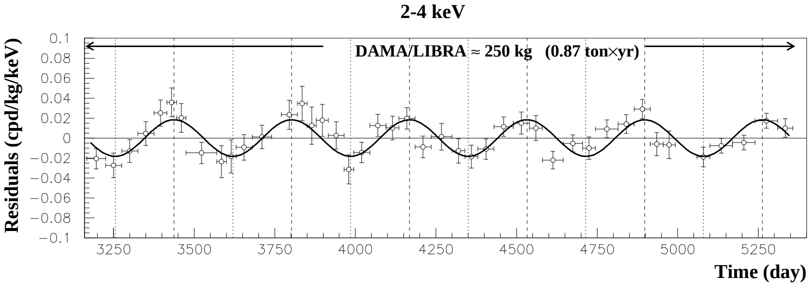
DM scattering rate:

$$\frac{dR}{dE_r} \propto \int_{v_{\min}} d^3v \, \frac{f(\vec{v} + \vec{v}_\oplus)}{v}$$

$$v_{\min} = \frac{m_N + m_\chi}{m_N m_\chi} \sqrt{\frac{E_r m_N}{2}}$$

Annual modulation as a "smoking gun" DM signature

- An annually modulation signal is considered very robust evidence for DM.
  Freese Frieman Gould 1988
- Earth's velocity relative to the Milky Way's DM halo is different in summer and in winter
  - Expect annually modulating scattering rates
  - Low recoil energy, heavy DM: Peak in summer
    High recoil energy, light DM: Peak in winter
- The DAMA signal
  - Highly controversial evidence for annual modulation in nuclear or electron recoils from NaI detectors



DAMA collaboration, Bernabei et al. 1002.1028

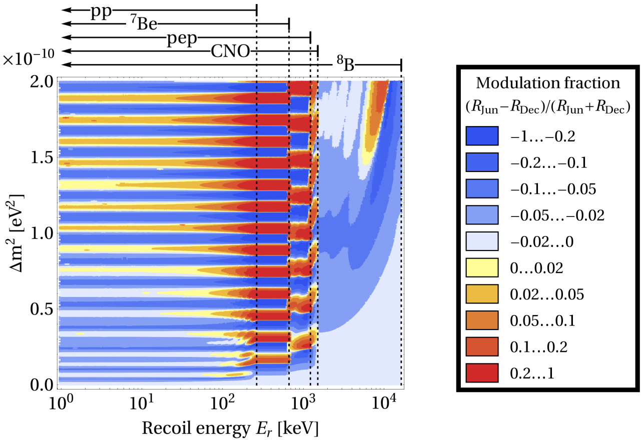
Annual modulation from ellipticity of the Earth orbit

- Earth–Sun distance is 3.4% larger in summer than in winter
- Thus, the solar neutrino count rate is generically $\sim$ 7% larger in winter than in summer
- This modulation is opposite to the DAMA modulation . . .
- . . . but can mimic signals of $\mathcal{O}$(100 GeV) dark matter Freese Frieman Gould 1988

Annual modulation from active–sterile oscillations

For active–sterile oscillations with oscillation lengths $\lesssim$ 1 AU, sterile neutrino appearance depends on the time of year.

Pospelov 1103.3261, Harnik JK Machado 1202.6073, Pospelov Pradler 1203.0545



This does not require extreme fine-tuning

More modulation mechanisms

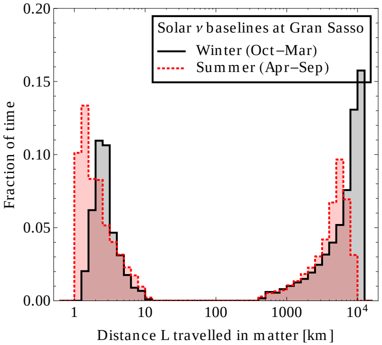
- Sterile neutrino absorption: For strong ν_s–A' couplings and not-too-weak A'–SM couplings, sterile neutrino cannot traverse the Earth.
  $\rightarrow$ lower flux at night. And nights are longer in winter.

More modulation mechanisms

- Sterile neutrino absorption: For strong ν_s–A' couplings and not-too-weak A'–SM couplings, sterile neutrino cannot traverse the Earth.
  $\rightarrow$ lower flux at night. And nights are longer in winter.
- Earth matter effects: An MSW-type resonance can lead to modified flux of certain neutrino flavors at night. And nights are longer in winter.

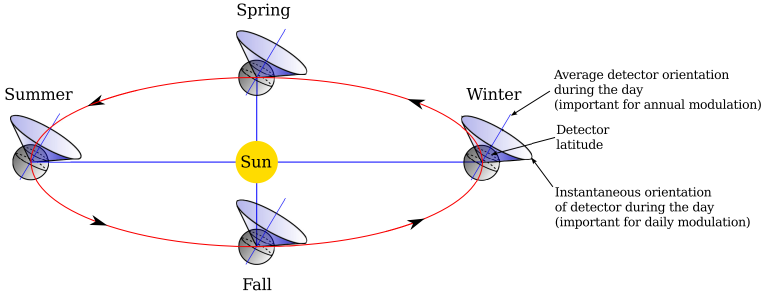
More modulation mechanisms

- Sterile neutrino absorption: For strong ν_s–A' couplings and not-too-weak A'–SM couplings, sterile neutrino cannot traverse the Earth.
  $\rightarrow$ lower flux at night. And nights are longer in winter.
- Earth matter effects: An MSW-type resonance can lead to modified flux of certain neutrino flavors at night. And nights are longer in winter.
  - A special case: Oscillation lengths comparable to $2R_\oplus$ or $\sim$ 1 km (thickness of rock overburden)



More modulation mechanisms

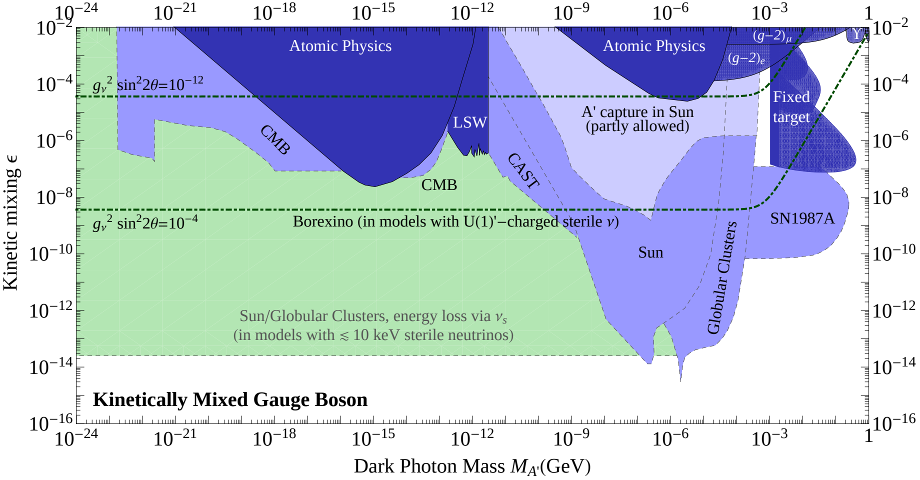
- Sterile neutrino absorption: For strong ν_s–A' couplings and not-too-weak A'–SM couplings, sterile neutrino cannot traverse the Earth.
  $\rightarrow$ lower flux at night. And nights are longer in winter.
- Earth matter effects: An MSW-type resonance can lead to modified flux of certain neutrino flavors at night. And nights are longer in winter.
- Direction-dependent detection efficiencies: If channeling effects are non-negligible, detection rates depend on the position of the Sun.



Outline

Hidden photons

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\epsilon F'_{\mu\nu}F^{\mu\nu} + \bar{\nu}_s i\partial\!\!\!/ \nu_s + g'\bar{\nu}_s\gamma^\mu\nu_s A'_\mu$$



Constraints from Jaeckel Ringwald 1002.0329, Redondo 0801.1527, Bjorken Essig Schuster Toro 0906.0580, Dent Ferrer Krauss 1201.2683, Harnik JK Machado 1202.6073

Anomalous energy loss in stars and supernovae

- A' bosons can be produced by plasmon oscillations in stars + supernovae

see e.g. Redondo 0801.1527 and references therein

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\epsilon F'_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m_{A'}^2 A'_\mu A'^\mu + A_\mu j^\mu$$
$$= -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$
$$+ \frac{1}{2}m_{A'}^2 A'_\mu A'^\mu - \epsilon m_{A'}^2 A'_\mu A^\mu + \frac{1}{2}\epsilon^2 m_{A'}^2 A_\mu A^\mu + A_\mu j^\mu$$

Equations of motion:

$$(k^2 g^{\mu\nu} - \Pi^{\mu\nu}(k) - \epsilon^2 m_{A'}^2)A_\nu + \epsilon m_{A'}^2 A'^\mu = 0$$
$$(k^2 g^{\mu\nu} - m_{A'}^2)A'^\mu + \epsilon m_{A'}^2 A^\mu = 0$$

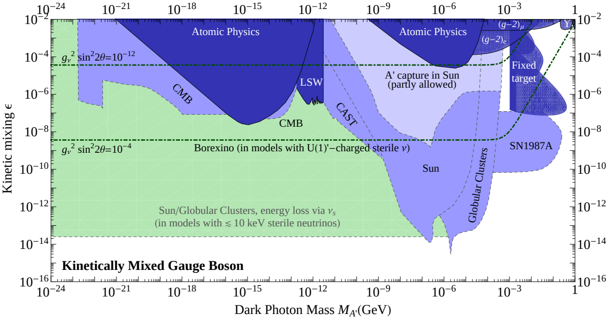
($\Pi^{\mu\nu}(k)$ = polarization tensor, depends on plasma frequency ω_P and on the inverse bremsstrahlung and Compton scattering rates)

Three regimes

- Low $m_{A'}$: A' production suppressed by small effective mixing $\sim m_{A'}^4/\omega_P^4$
- $m_{A'} \sim \omega_P$: Resonant A' production
- High $m_{A'}$: Thermal A' production

Anomalous energy loss in stars and supernovae

- A' bosons can be produced by plasmon oscillations in stars + supernovae
  see e.g. Redondo 0801.1527 and references therein
- Interesting features:
  - Resonant enhancement when $M_{A'} \sim$ plasmon mass
  - In general: Non-resonant A' production everywhere in the star (not just in the outer photosphere)
  - But: For very large ϵ, small optical depth even for A' $\rightarrow$ reduced production, weaker limit
- Limit based on requirement $P_{\text{invisible}} < P_{\text{visible}}$ (P = energy loss rate)

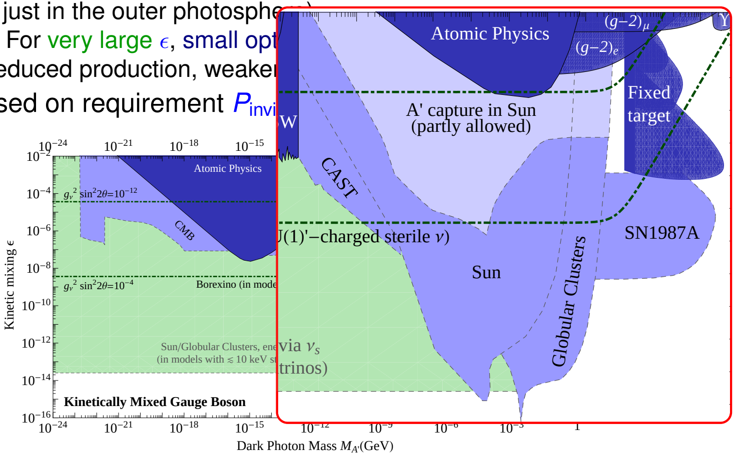


Anomalous energy loss in stars and supernovae

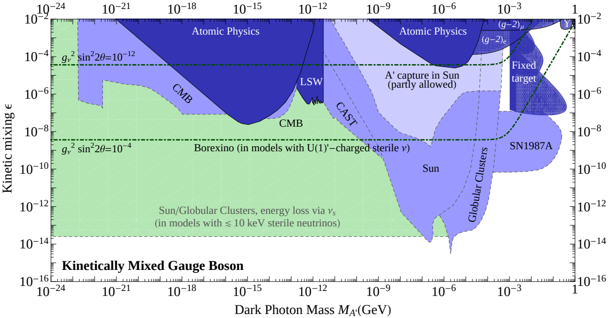
- A' bosons can be produced by plasmon oscillations in stars + supernovae

  see e.g. Redondo 0801.1527 and references therein

- Interesting features:
  - Resonant enhancement when $M_{A'} \sim$ plasmon mass
  - In general: Non-resonant A' production everywhere in the star (not just in the outer photosphe
  - But: For very large ϵ, small opt
    $\rightarrow$ reduced production, weake
- Limit based on requirement P_{invi}

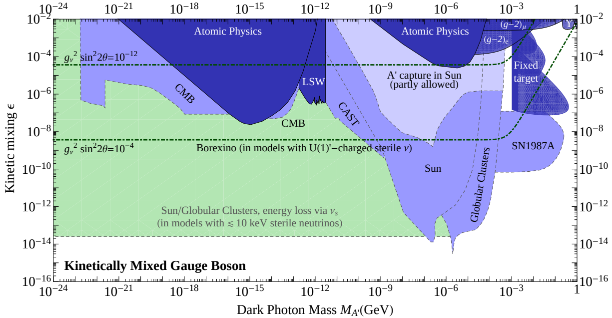


Other constraints (1)



- Muon and electron $g-2$
- Atomic physics: Test $1/r^2$ scaling of electromagnetic force
- Light shining through walls
- Fixed target experiments: A' production in beam dump, decay to SM
  - Expect significant improvement from APEX

Other constraints (2)



- CMB: Distortions to the black body spectrum
- Axion telescopes (e.g. CAST): Look for A' from the Sun oscillating to A
- B-factories: $e^+e^- \to A' +$ something, A' detected as $\not{E}$ or via its decay products
- In models with light sterile neutrinos:
  - ν_s production in stars + supernovae
  - $\nu_s e$ scattering in Borexino

Outline

Conclusions

- Neutrino detection and DM detection are closely related (experimentally and theoretically)
- Low-E solar neutrino spectrum only accessible in DM detectors
- Well-motivated new physics could show up at low E.
- Models with hidden photons and sterile neutrinos can lead to interesting phenomena in dark matter detectors
  - Enhanced neutrino–electron scattering
  - Enhanced neutrino–nucleus scattering
  - Possibility of annual and daily modulation

Thank you!

Palaver, das

Wortart: Substantiv, Neutrum
Häufigkeit:

Rechtschreibung
↑ Nach oben

Worttrennung:
Pa | la | ver

Bedeutungsübersicht
↑ Nach oben

1. (umgangssprachlich abwertend) endloses wortreiches, meist überflüssiges Gerede; nicht enden wollendes Verhandeln, Hin-und-her-Gerede
2. (landschaftlich) Geschrei, Gelärme

Synonyme zu *Palaver*
↑ Nach oben

Rederei, Schwadronade; (umgangssprachlich) Gerede, Hickhack, Sums; (umgangssprachlich, oft abwertend) Gelaber, Geplapper, Zeug; (abwertend) Gefabel, Hin-und-her-Gerede, Phrasen[drescherei]; (umgangssprachlich abwertend) Blabla, Geschwätz, Gewäsch, Heckmeck, Schwafelei; (landschaftlich, oft abwertend) Gebabbel

www.duden.de