Solar neutrino flux at keV energies

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Edoardo Vitagliano
edovita@mpp.mpg.de
Max Planck Institute for Physics, Munich

elusives
neutrinos, dark matter & dark energy physics

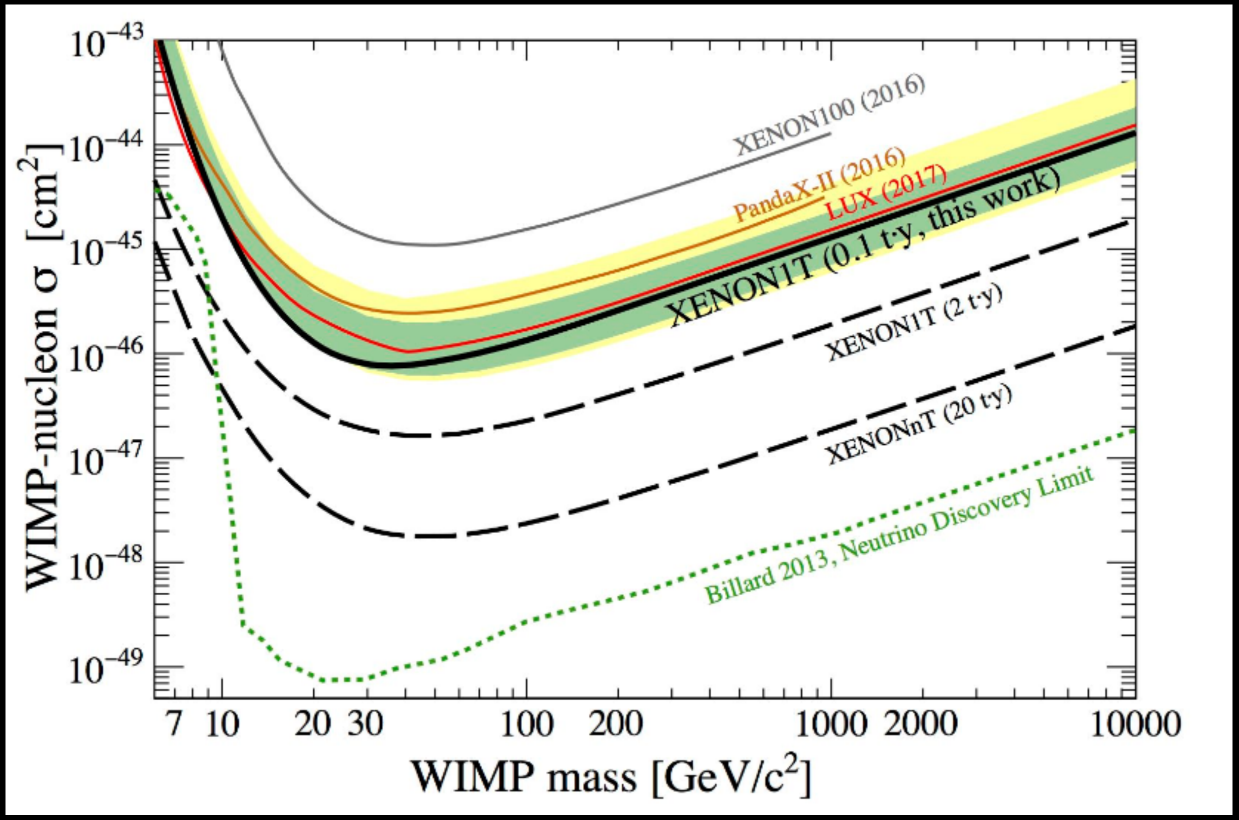
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Based on 1707.xxxx w/ J.Redondo & G. Raffelt

Beyond the WIMP paradigm

During the conference lot of discussion about several dark matter candidates (from axions to MACHOs…)

Time to discuss the possible background to the detection of these candidates



Sterile neutrino dark matter

- Gives mass to neutrinos
- With mass above 0.4 keV no Tremaine-Gunn bound
- Solves the cusp-core problem

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

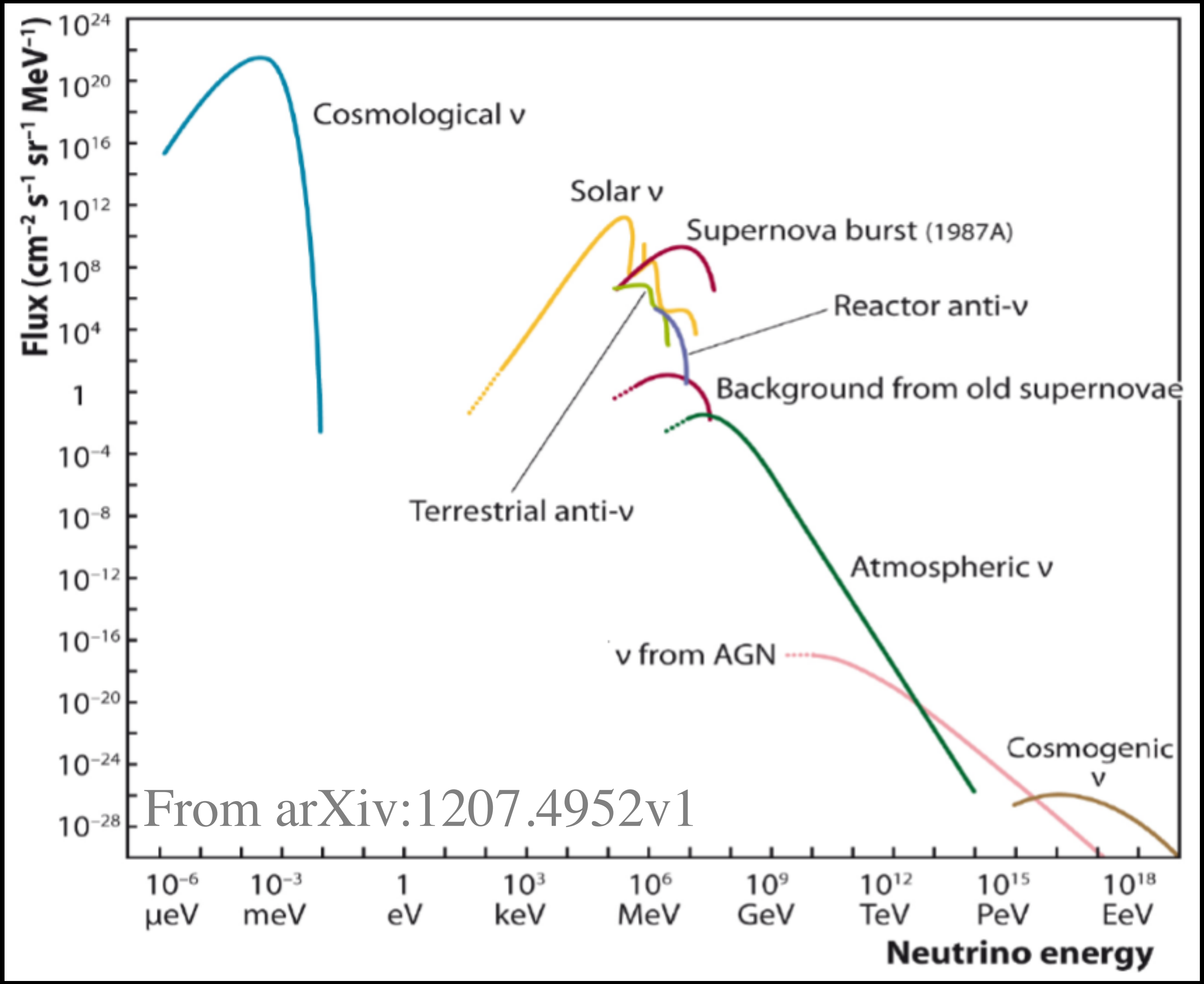
A White Paper on keV sterile neutrino Dark Matter

Editors: M. Drewes, T. Lasserre, A. Merle and S. Mertens

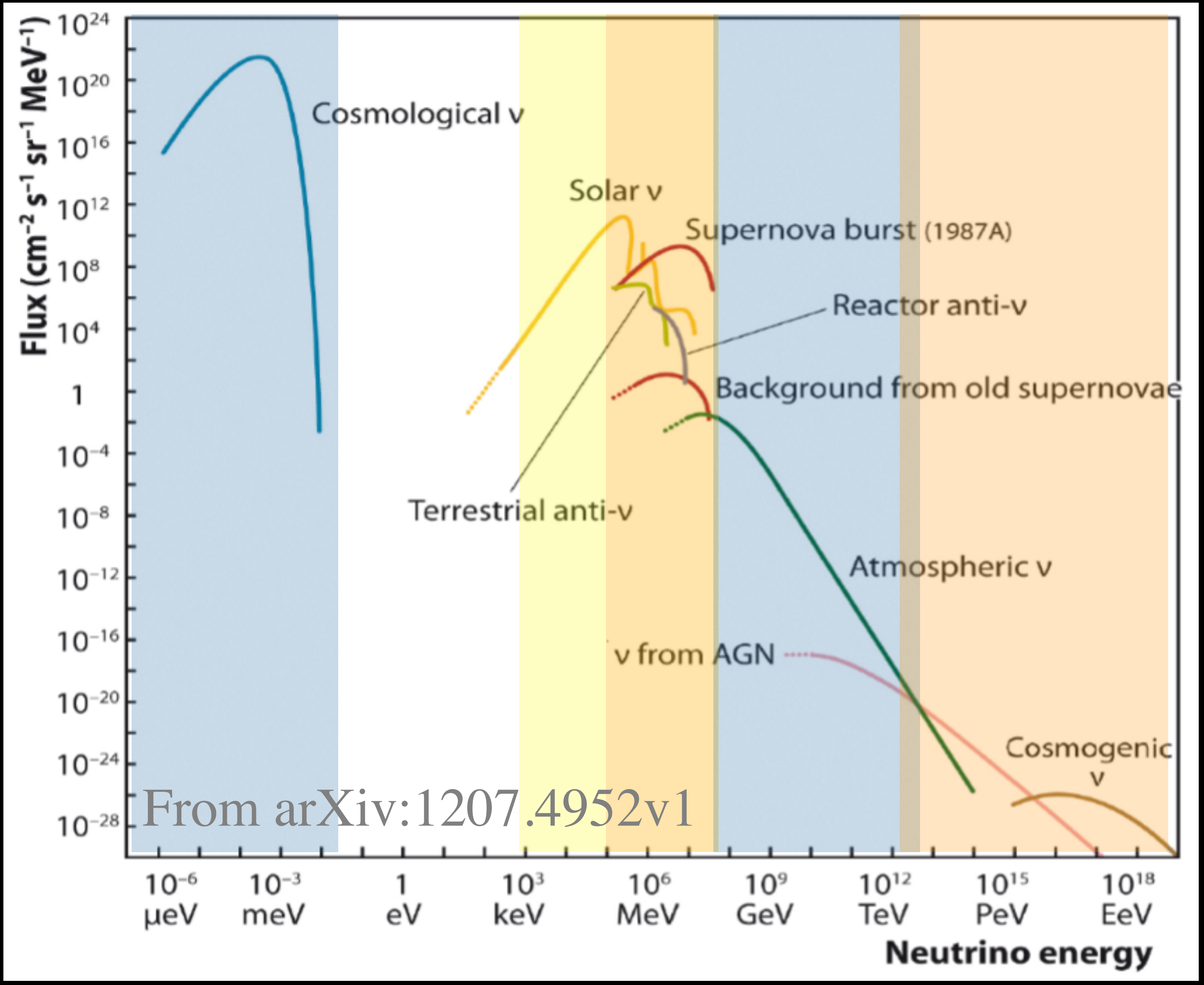
arXiv:1602.04816

A very good candidate

The neutrino spectrum at all energies



The neutrino spectrum at all energies



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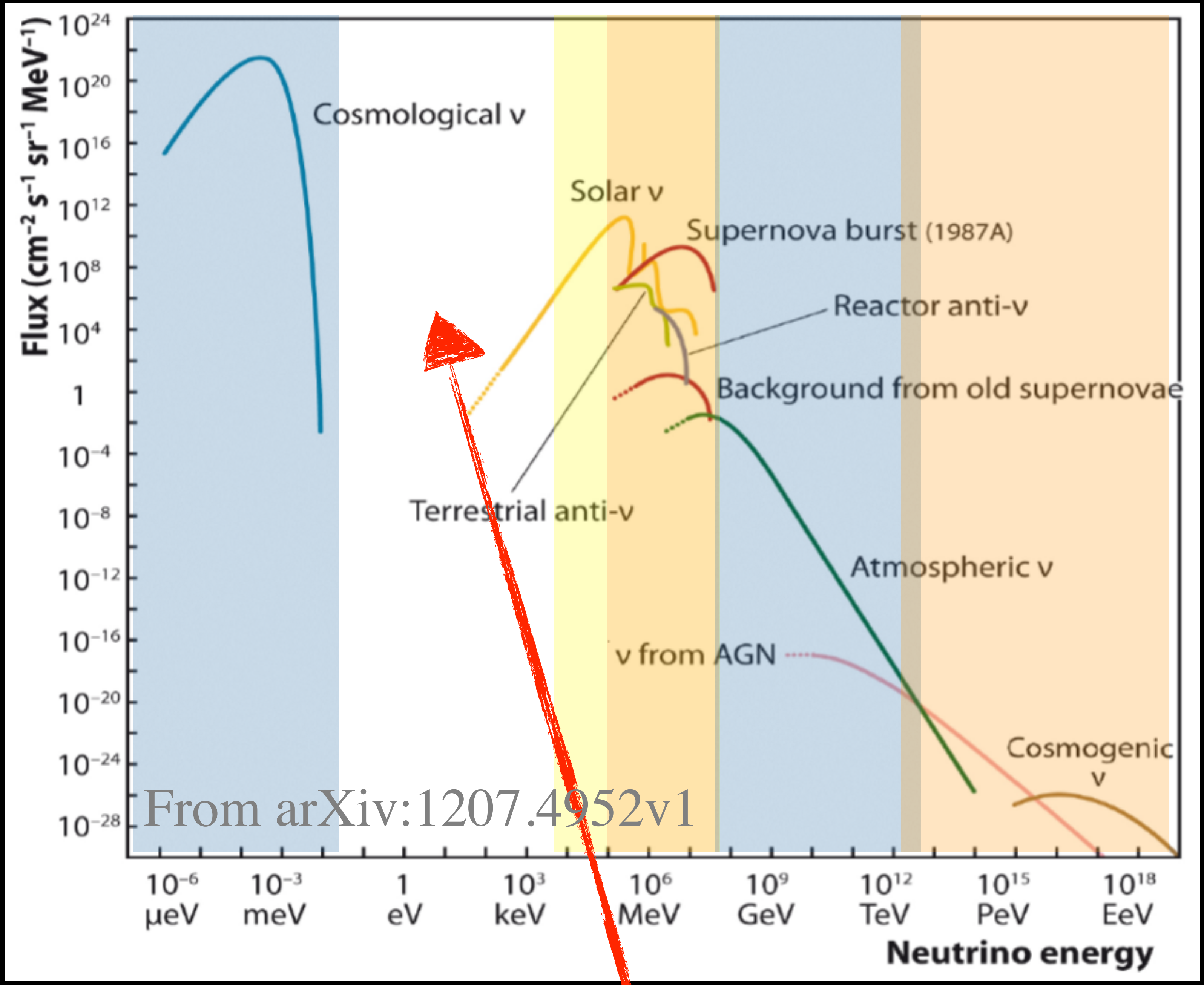
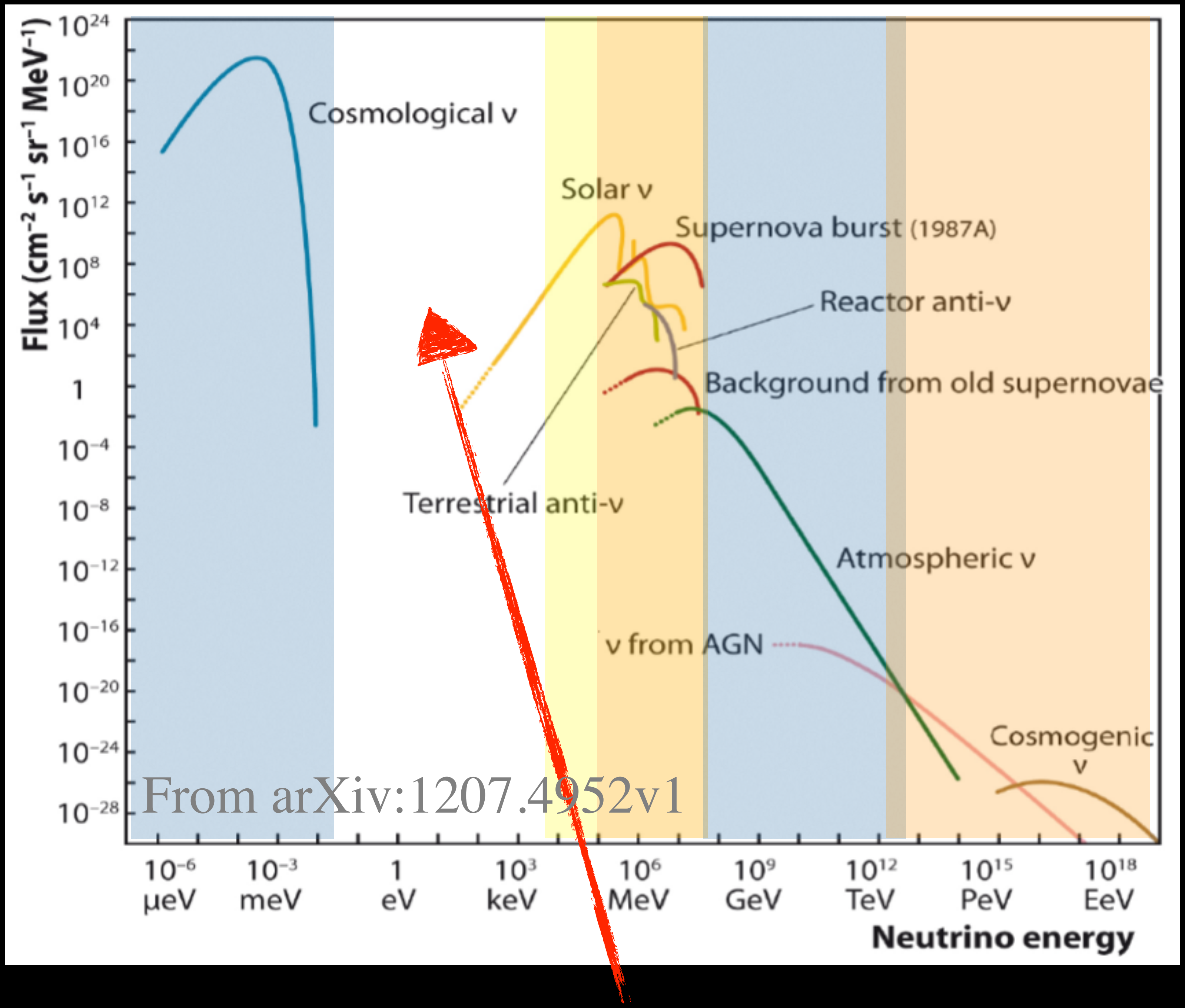


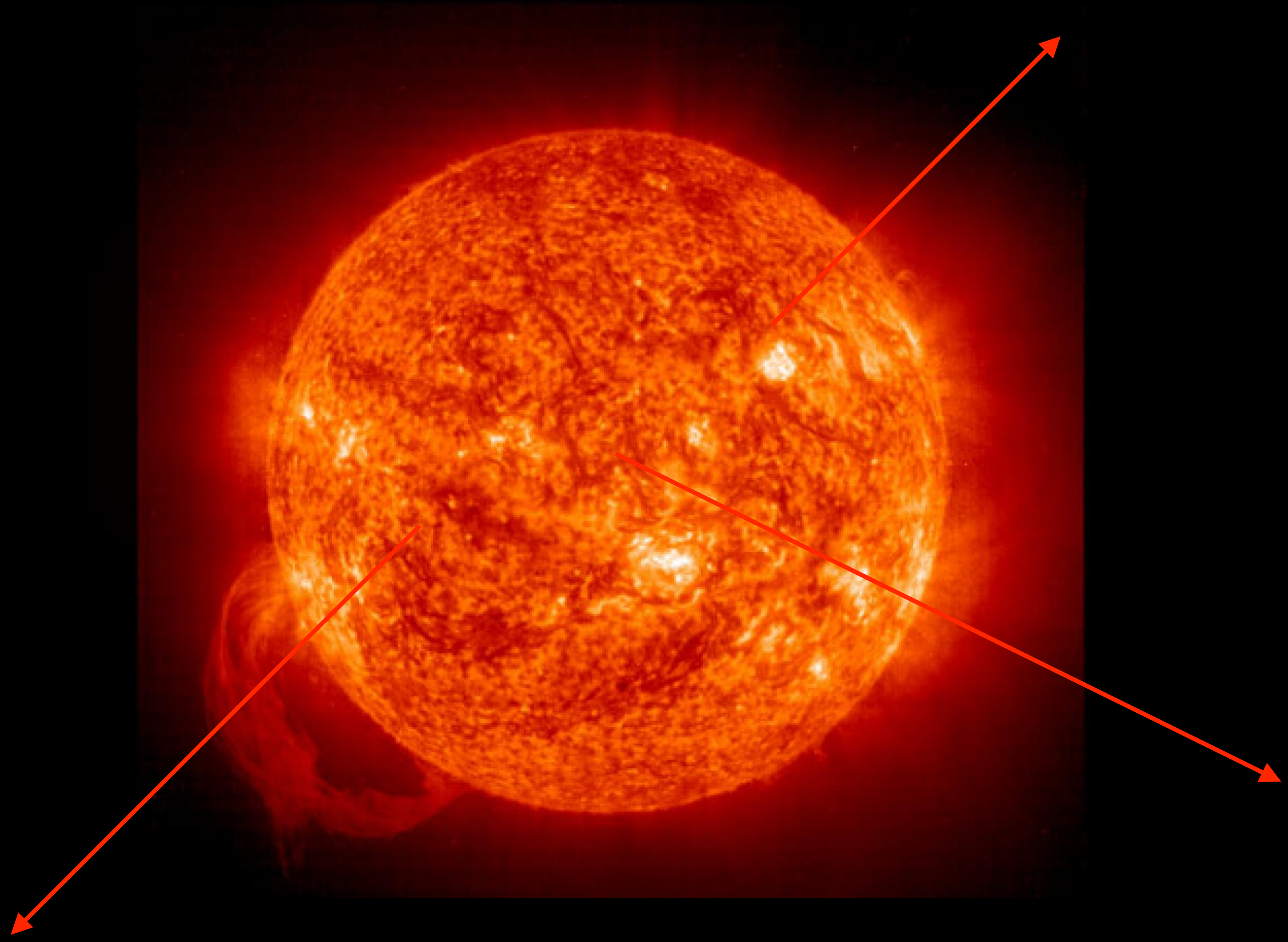
???

The neutrino spectrum at all energies



Is there a source for keV neutrinos?

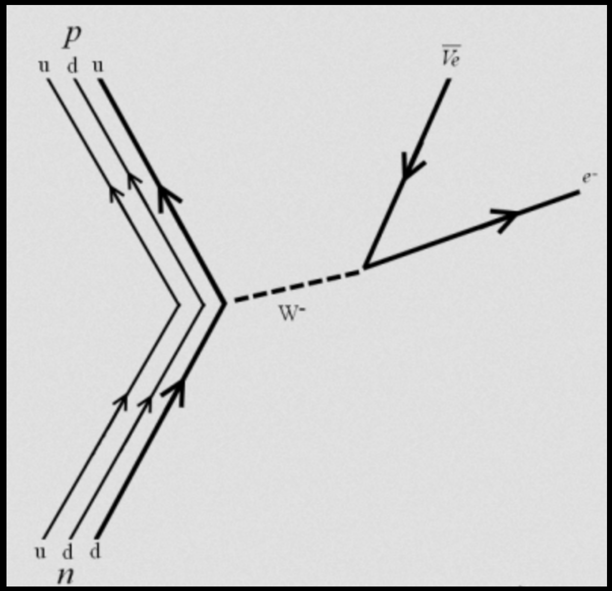
Yes! Directly from our domestic star…



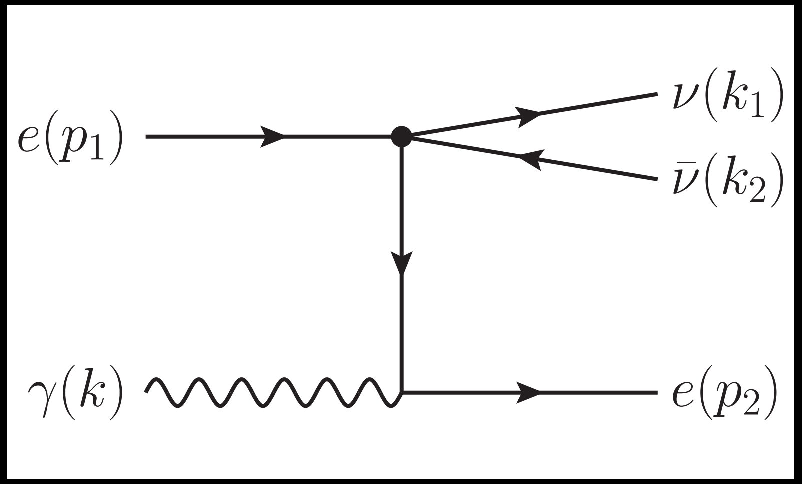
…keV neutrinos

Neutrino Solar production

Nuclear processes:
- well known
- beta decay like processes



Thermal processes:
- less analysed
- processes involving mostly photons and/or electrons



How - neutrino Solar production

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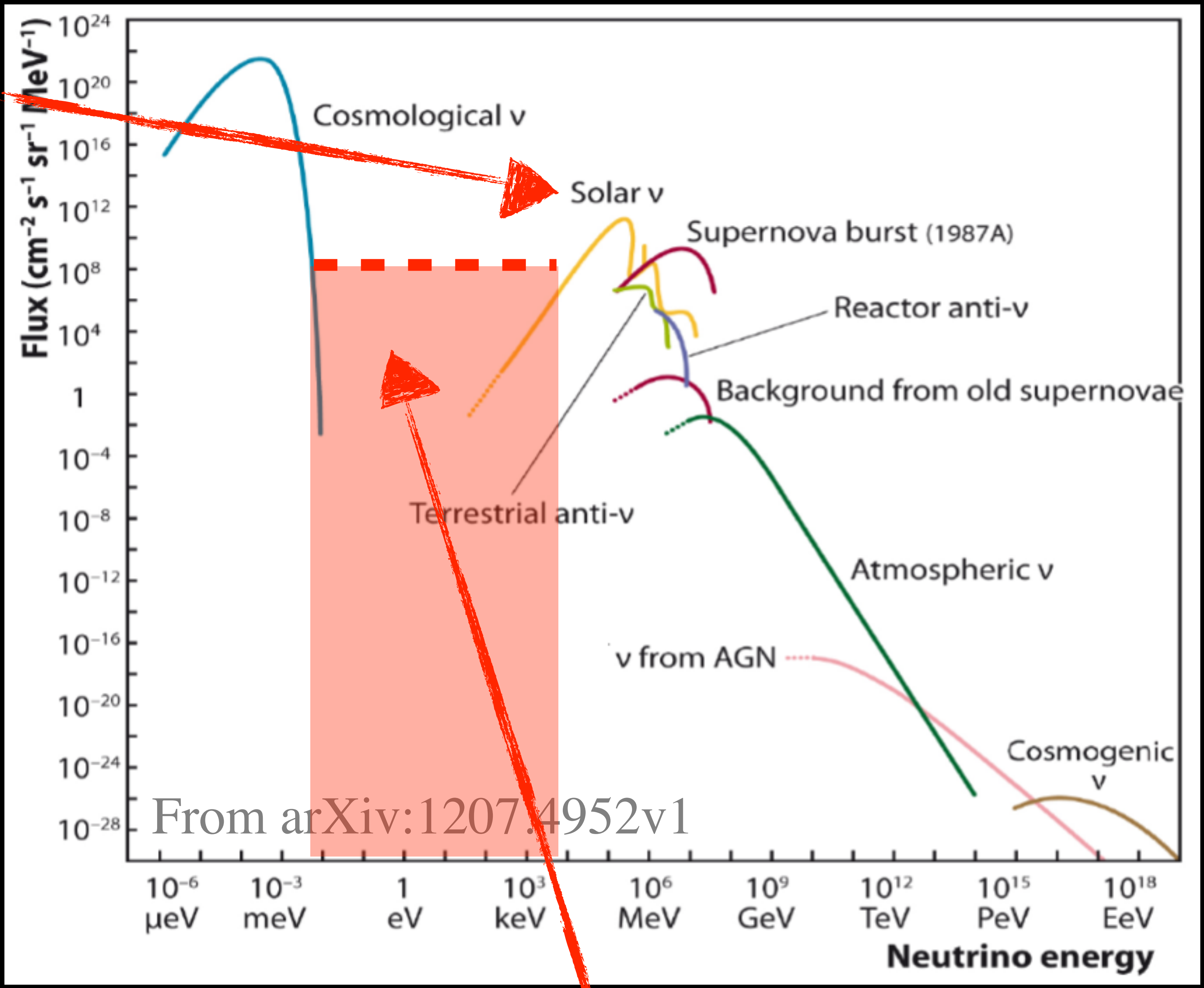

!!!

What-Why-How

We have a “What”, computing (and detecting…) the neutrino flux produced in the Sun at keV energies. But why and how?

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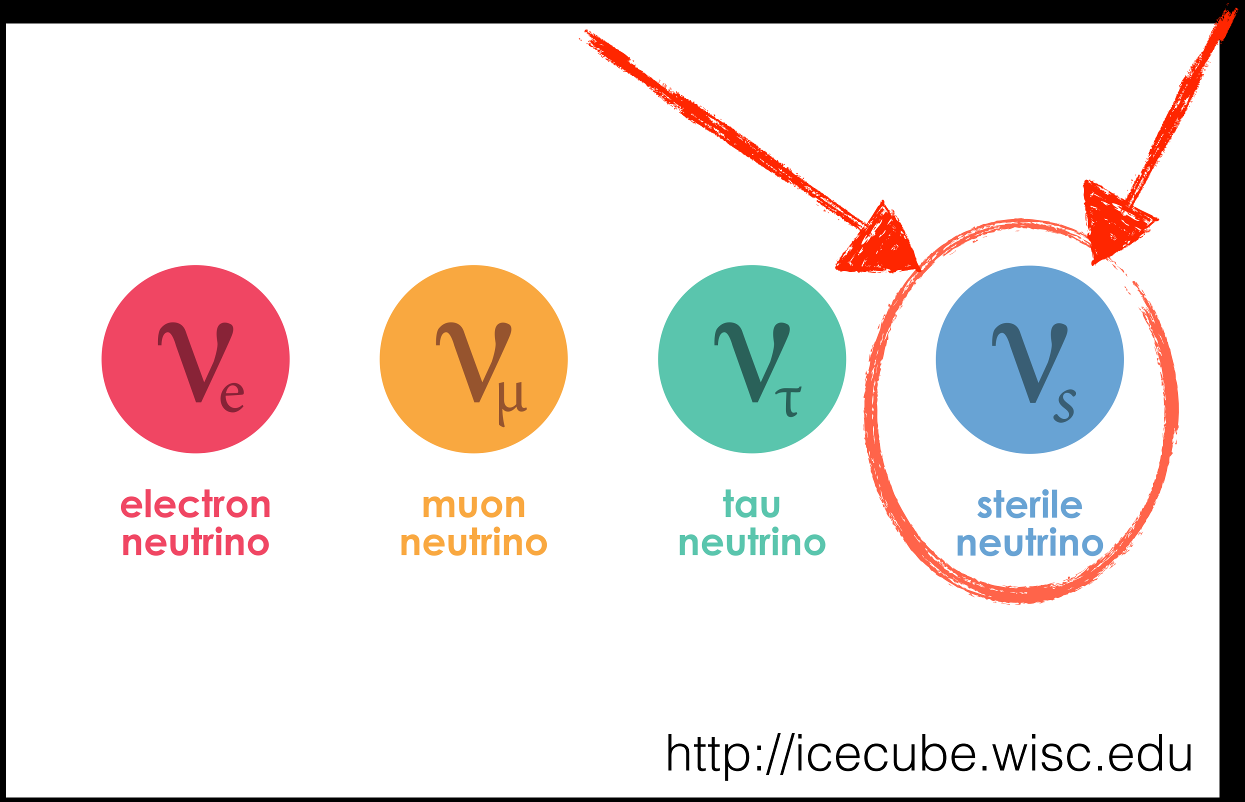

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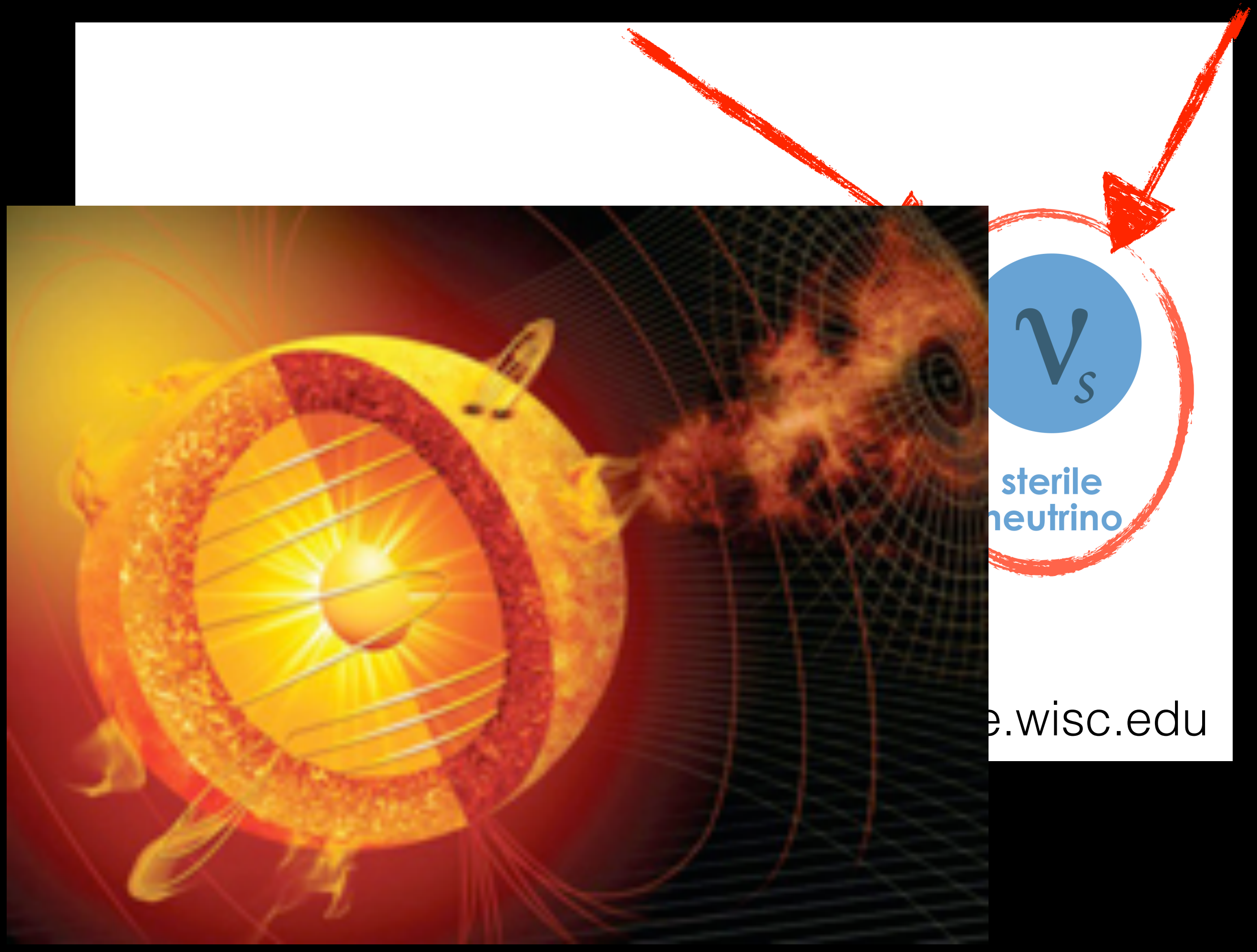
- Why 2: if detected, these neutrinos would give information about the Sun (abundances, T profile etc.)



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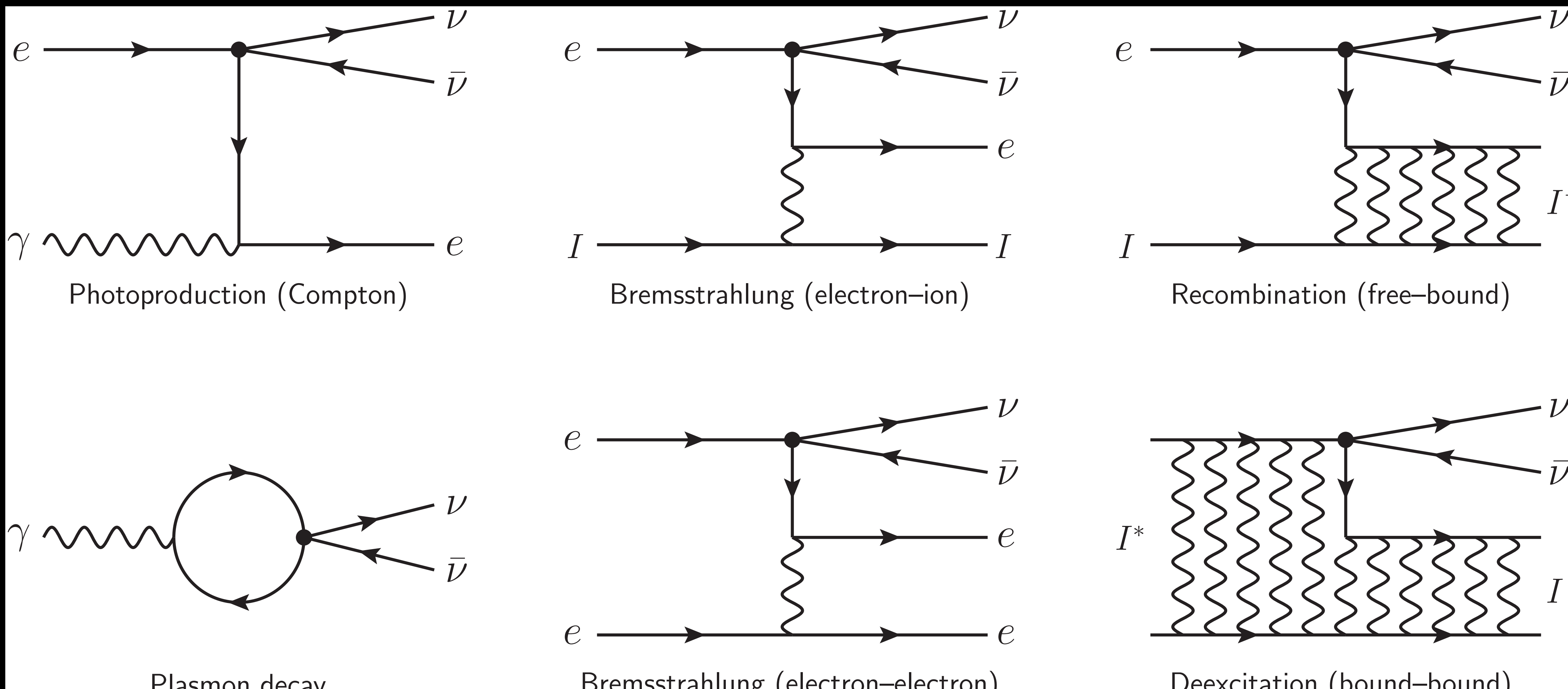
- Why 1: these neutrinos will be background to experiments searching for keV sterile neutrino
- Why 2: if detected, these neutrinos would give information about the Sun (abundances, T profile etc.)
- aka the signal of today is the background of tomorrow (or vice versa)

How - the ABCD processes



- Atomic recombination (fb) and deexcitation (bb)
- Bremsstrahlung (ff)
- Compton process
- Decay of a plasmon

Previous attempts

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The very low energy solar flux of electron and heavy-flavor neutrinos and antineutrinos

W.C. Haxton [a], Wei Lin [b,1]

[a] *Institute for Nuclear Theory, Box 351550, and Department of Physics University of Washington, Seattle, Washington 98195-1550, USA*

[b] *Center for Theoretical Physics and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139-4307, USA*

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Abstract

We calculate the thermal flux of low-energy solar neutrinos and antineutrinos of all flavors arising from a variety of neutrino pair processes: Compton production (including plasmon-pole diagrams), neutral current decay of thermally populated nuclear states, plasmon decay, and electron transitions from free to atomic bound states. The resulting flux density per flavor is significant (10^8–10^9/cm^2/sec/MeV) below $\sim$ 5 keV, and the distributions fill much of the valley between the high-energy edge of the cosmic background neutrino spectrum and the low energy tails of the pp-chain electron neutrino and terrestrial electron antineutrino spectra. Thermal neutrinos carry information on the solar core temperature distribution and on heavy flavor neutrino masses for m_{ν_μ} or $m_{\nu_\tau} \gtrsim$ 1 keV. The detection of these neutrinos is a daunting but interesting challenge.

From arXiv:nucl-th/0006055

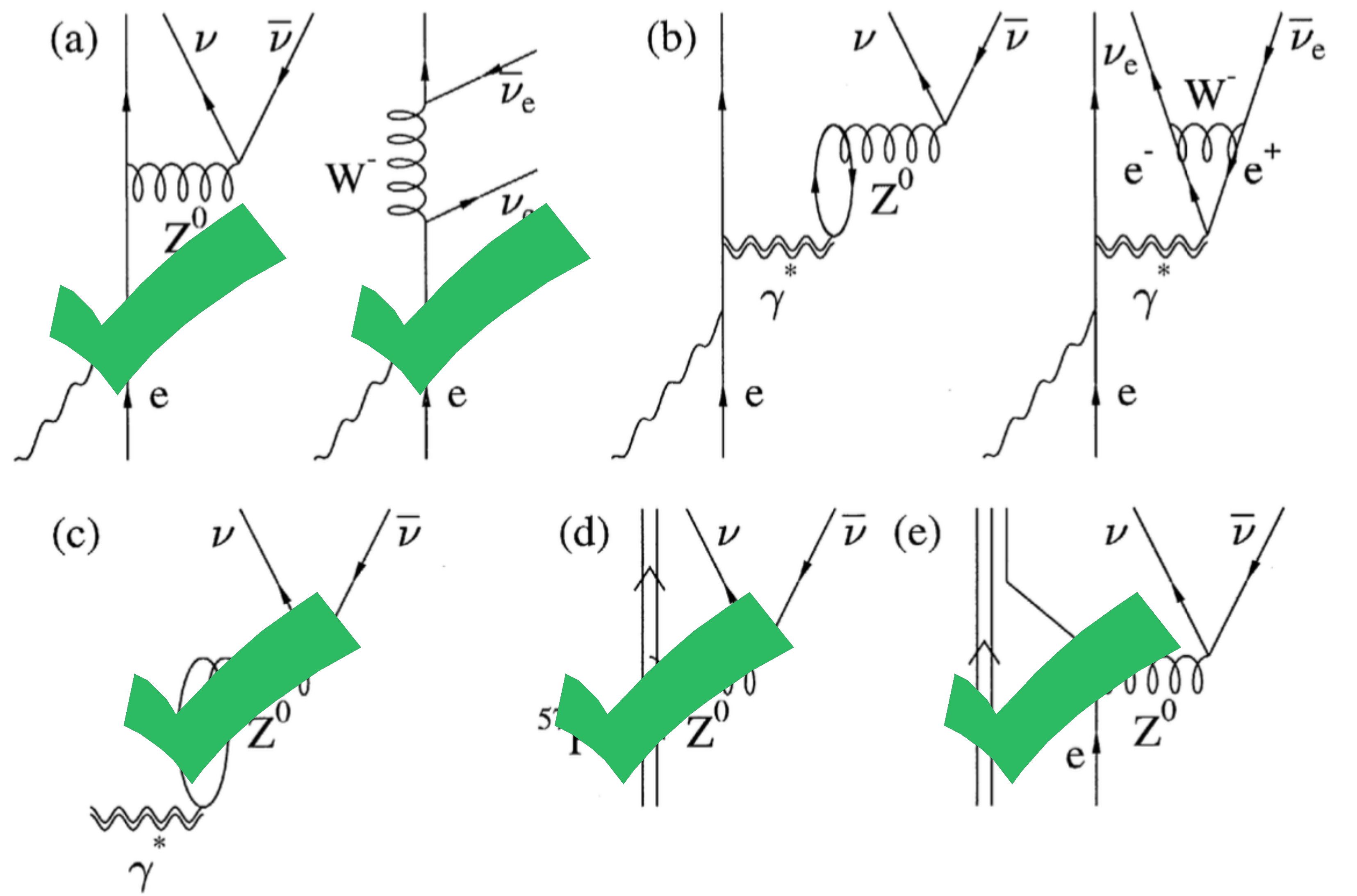

Fig. 1. Representative diagrams for the various thermal neutrino pair processes considered here: a) Compton process; b) plasmon pole contribution to the Compton process; c) transverse plasmon decay; d) nuclear Z^0 emission; and e) pair production in free-bound atomic transitions.

How - the ABCD processes

- Write down the term in the Boltzmann equation due to the specific process
- Account for correlation effects
- Do it for the BCD processes

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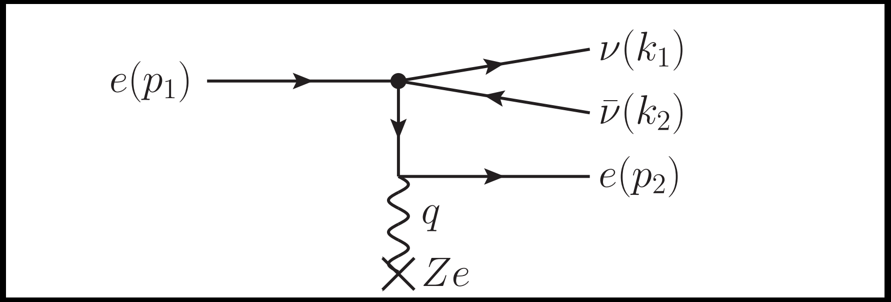
- Example: bremsstrahlung



$$\dot{n}_\nu = n_Z \int \frac{d^3\mathbf{p}_1}{(2\pi)^3}\frac{d^3\mathbf{p}_2}{(2\pi)^3}\frac{d^3\mathbf{k}_1}{(2\pi)^3}\frac{d^3\mathbf{k}_2}{(2\pi)^3} f_1(1-f_2)\frac{\sum_{s_1,s_2}|\mathcal{M}|^2}{(2m_e)^2 2\omega_1 2\omega_2} 2\pi\delta(E_1-E_2-\omega)$$

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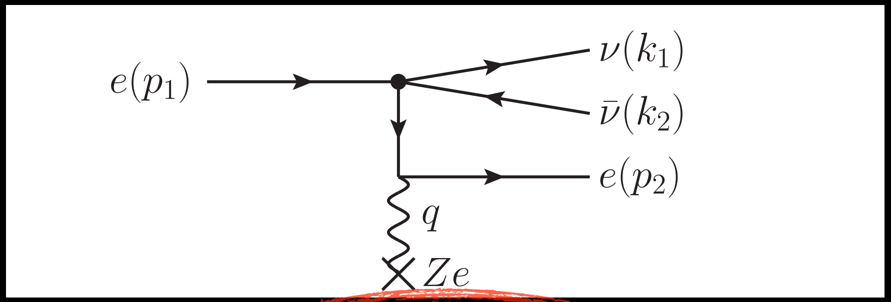

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Statistical physics: solar model (Saclay+GS98)

Particle physics

Long wavelength approximation

$$\mathcal{L}_{\rm int} = \frac{G_{\rm F}}{\sqrt{2}}\,\bar{\psi}_e\gamma^\mu(C_{\rm V}-C_{\rm A}\gamma_5)\psi_e\,\bar{\psi}_\nu\gamma_\mu(1-\gamma_5)\psi_\nu$$

Bremsstrahlung

Structure function (encoding medium properties)

$$\mathcal{S}(\omega) = \frac{(4\pi)^2}{(2m_e)^2}\frac{1}{n_e}\int \frac{d^3\mathbf{p}_1}{(2\pi)^3}\frac{d^3\mathbf{p}_2}{(2\pi)^3} f_1(1-f_2)\,\frac{1}{\mathbf{q}^2}\,2\pi\delta(E_1 - E_2 - \omega)$$

ν flux

$$\frac{d\dot{n}_\nu}{d\omega_\nu} = n_Z n_e \frac{8\,Z^2\alpha^2}{3}\left(\frac{G_\mathrm{F}}{\sqrt{2}}\right)^2 \frac{1}{3\pi^4}\int_{\omega_\nu}^{\infty} d\omega\, \mathcal{S}(\omega)\frac{\omega_\nu^2(\omega-\omega_\nu)^2}{\omega^4}$$
$$\times\left[C_\mathrm{V}^2\left(3\omega^2 - 2\omega\omega_\nu + 2\omega_\nu^2\right) + 2C_\mathrm{A}^2\left(3\omega^2 - 5\omega\omega_\nu + 5\omega_\nu^2\right)\right]$$

photon flux

$$\frac{d\dot{n}_\gamma}{d\omega} = n_Z n_e \frac{8\,Z^2\alpha^2}{3}\,\frac{\alpha}{\pi}\,\frac{\mathcal{S}(\omega)}{\omega}$$

$$\frac{d\dot{n}_\nu}{d\omega_\nu} = \frac{G_\mathrm{F}^2}{6\pi^3\alpha}\int_{\omega_\nu}^{\infty} d\omega\left(\frac{d\dot{n}_\gamma}{d\omega}\right)\frac{\omega_\nu^2(\omega-\omega_\nu)^2}{\omega^3}$$
$$\times\left[C_\mathrm{V}^2\left(3\omega^2 - 2\omega\omega_\nu + 2\omega_\nu^2\right) + 2C_\mathrm{A}^2\left(3\omega^2 - 5\omega\omega_\nu + 5\omega_\nu^2\right)\right]$$

ν flux in terms of the photon flux

Atomic processes

- A-processes are difficult (lot of atomic physics)
- But thanks to long wavelength approximation+detailed balance principle (relating absorption and emission) we can use photon opacities!
- We can take advantage from stars' axion and photon production calculation (axial current and vector current)

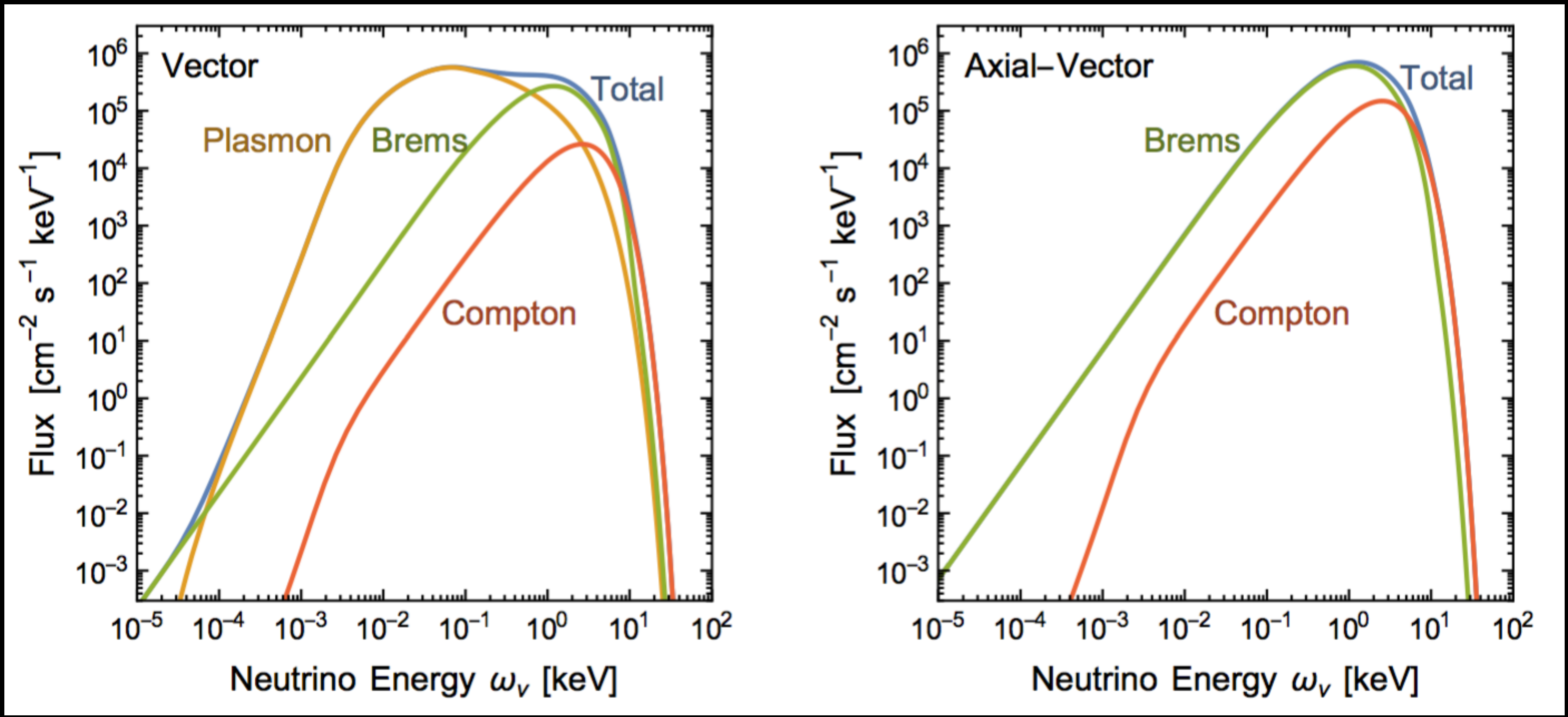
The Opacity Project - The Iron Project

The names Opacity Project (OP) and Iron Project (OP) refer to an international collaboration that was formed in 1984 to calculate the extensive atomic data required to estimate stellar envelope opacities and to compute Rosseland mean opacities and other related quantities. It

Neutrino emission rate as a function of photon absorption rate

see also arXiv:1310.0823, same approach but for axions

ABCD processes



to be multiplied by C_V^2 and C_A^2

Total flux on Earth - with oscillation

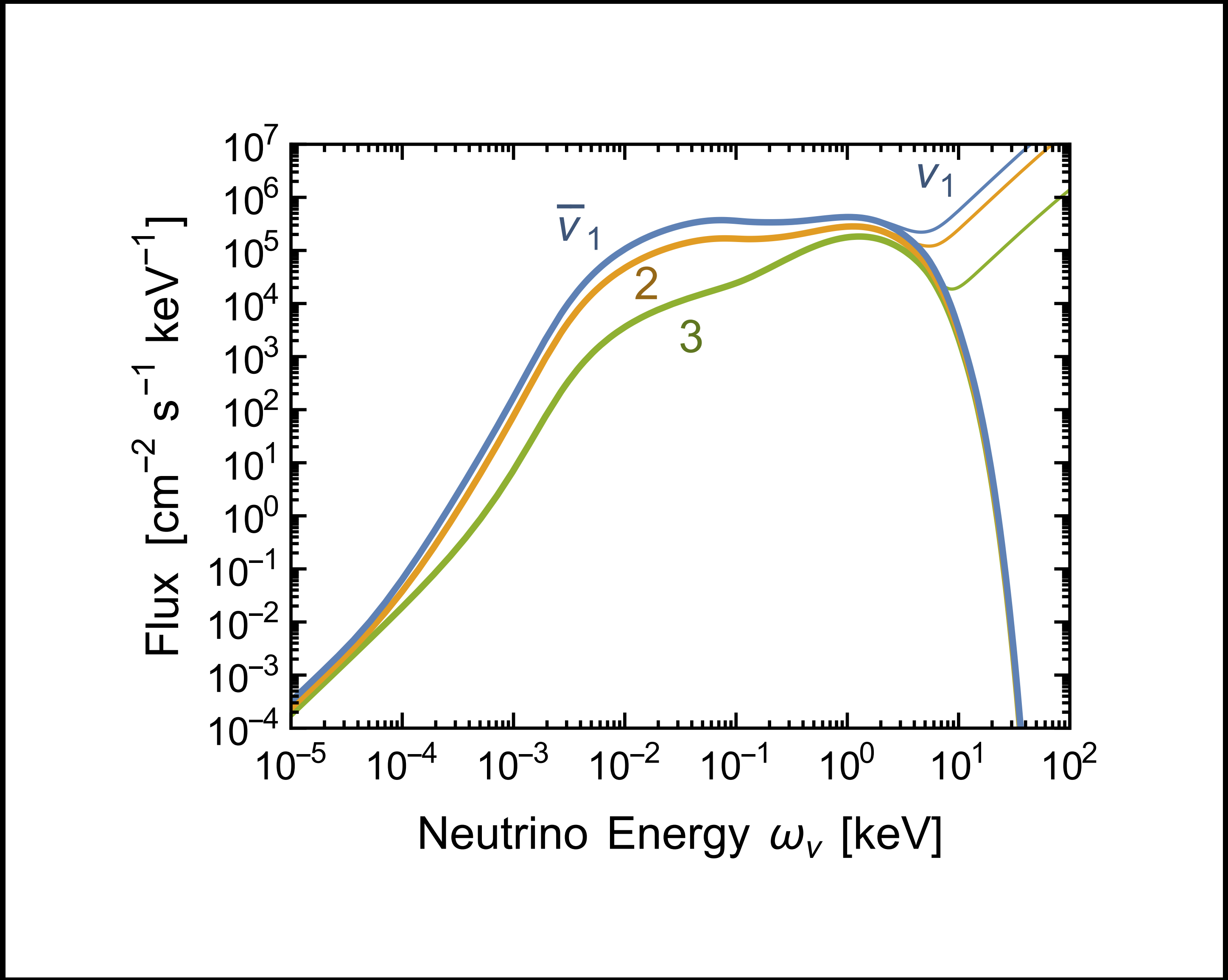
Flux of mass eigenstates, no matter effect for keV neutrinos

$$\Delta V = \sqrt{2} G_F n_e = 7.6 \times 10^{-12} \text{ eV}$$

$$\omega_{osc} = \Delta m^2 / 2E = 3.8 \times 10^{-8} \text{ eV} / E_{keV}$$

$$\omega_{osc} = 1.25 \times 10^{-3} \text{ eV} / E_{keV}$$

$$E_{keV} = E / \text{keV}$$



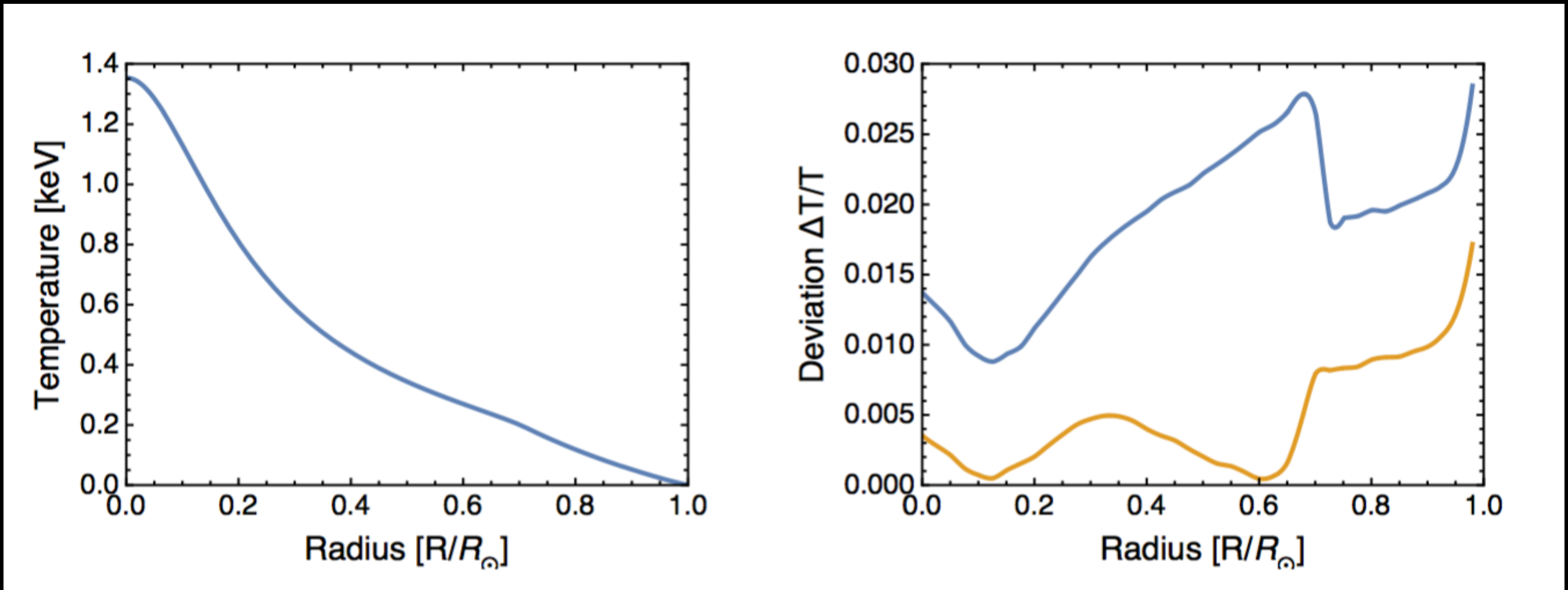
to be seen in a detector

Summary

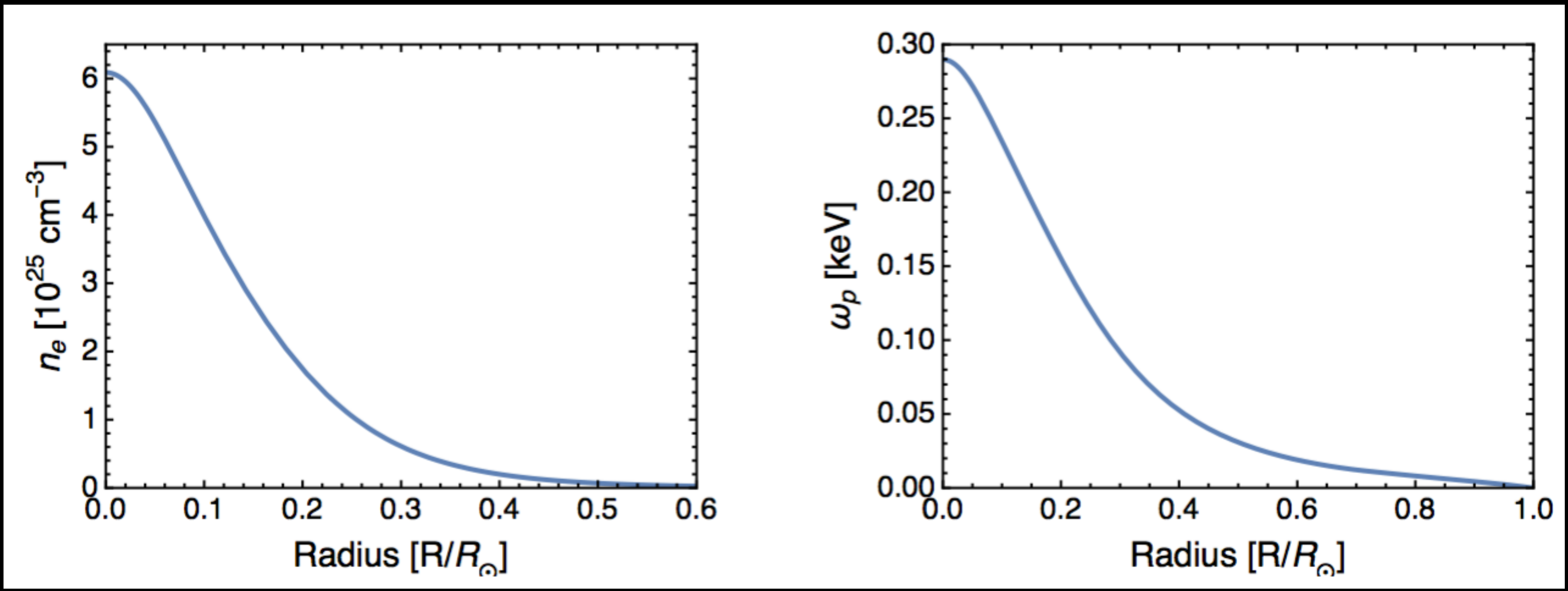
- For energies smaller than few keV, the dominant source is the Sun via thermal processes (ABCD)
- This flux will be the background of sterile neutrinos direct detection experiments
- Moreover, we can gain information about the temperature and electrons density profiles in the Sun, as well as about metallicity of outskirts and core

Backup slides

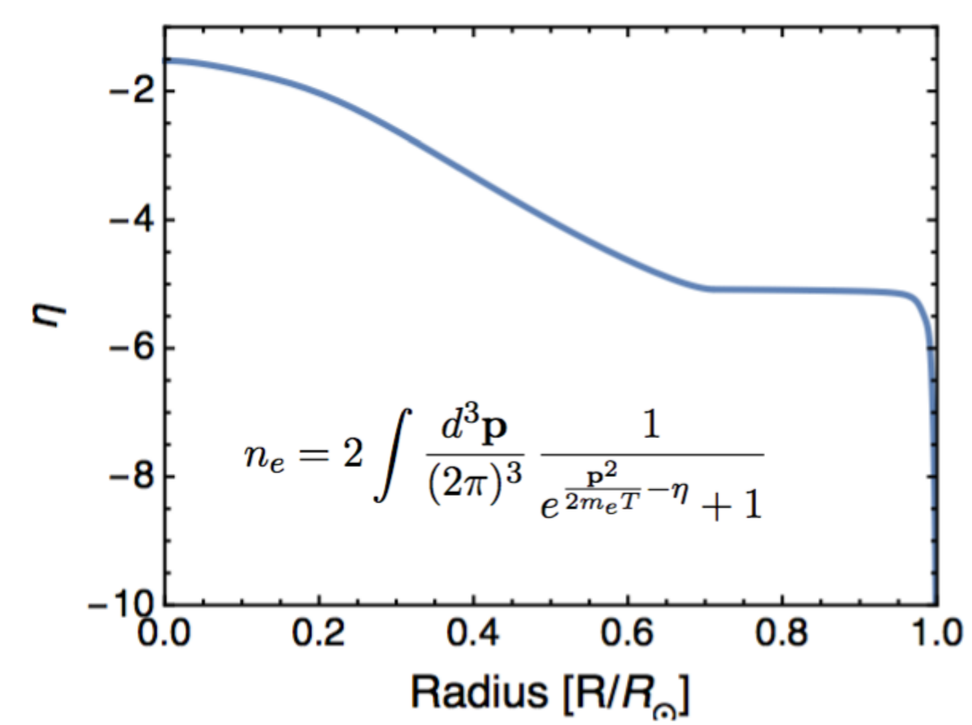
Temperature profile

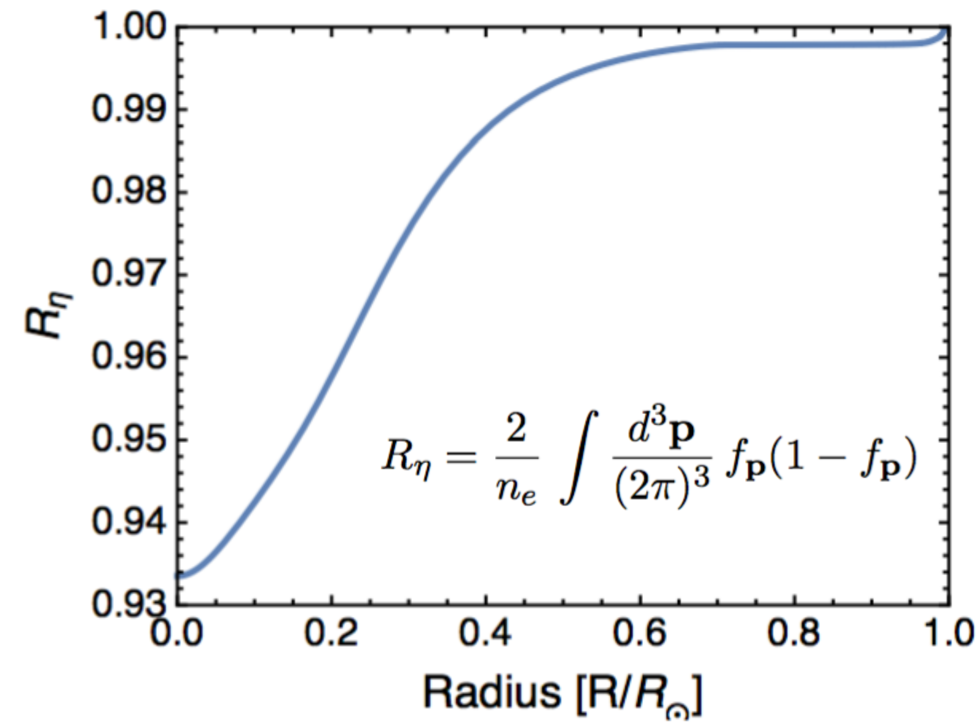


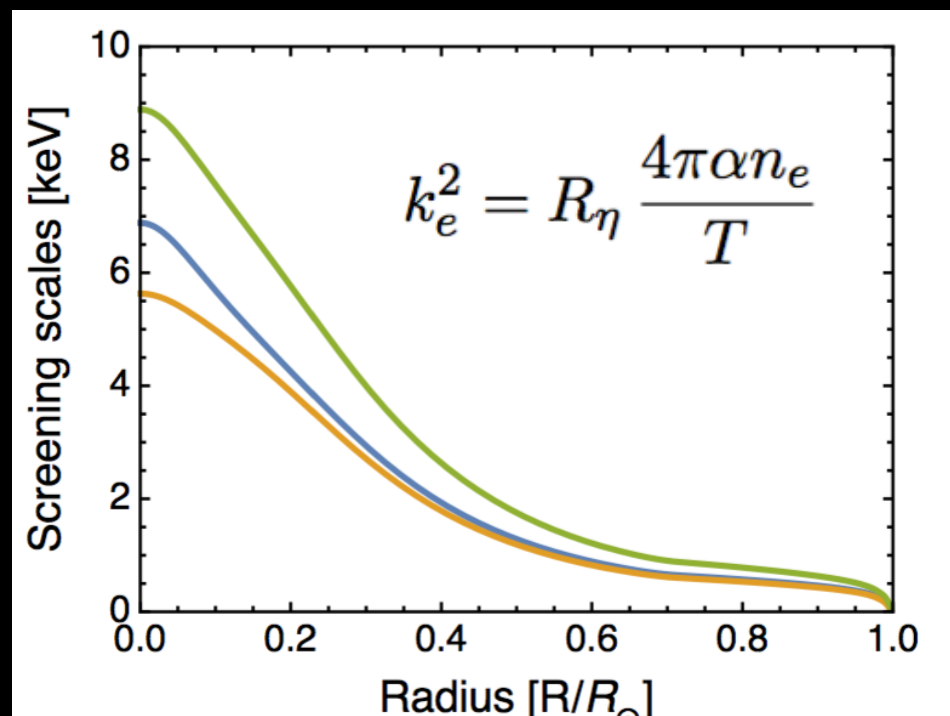
Electron density and plasma frequency profile



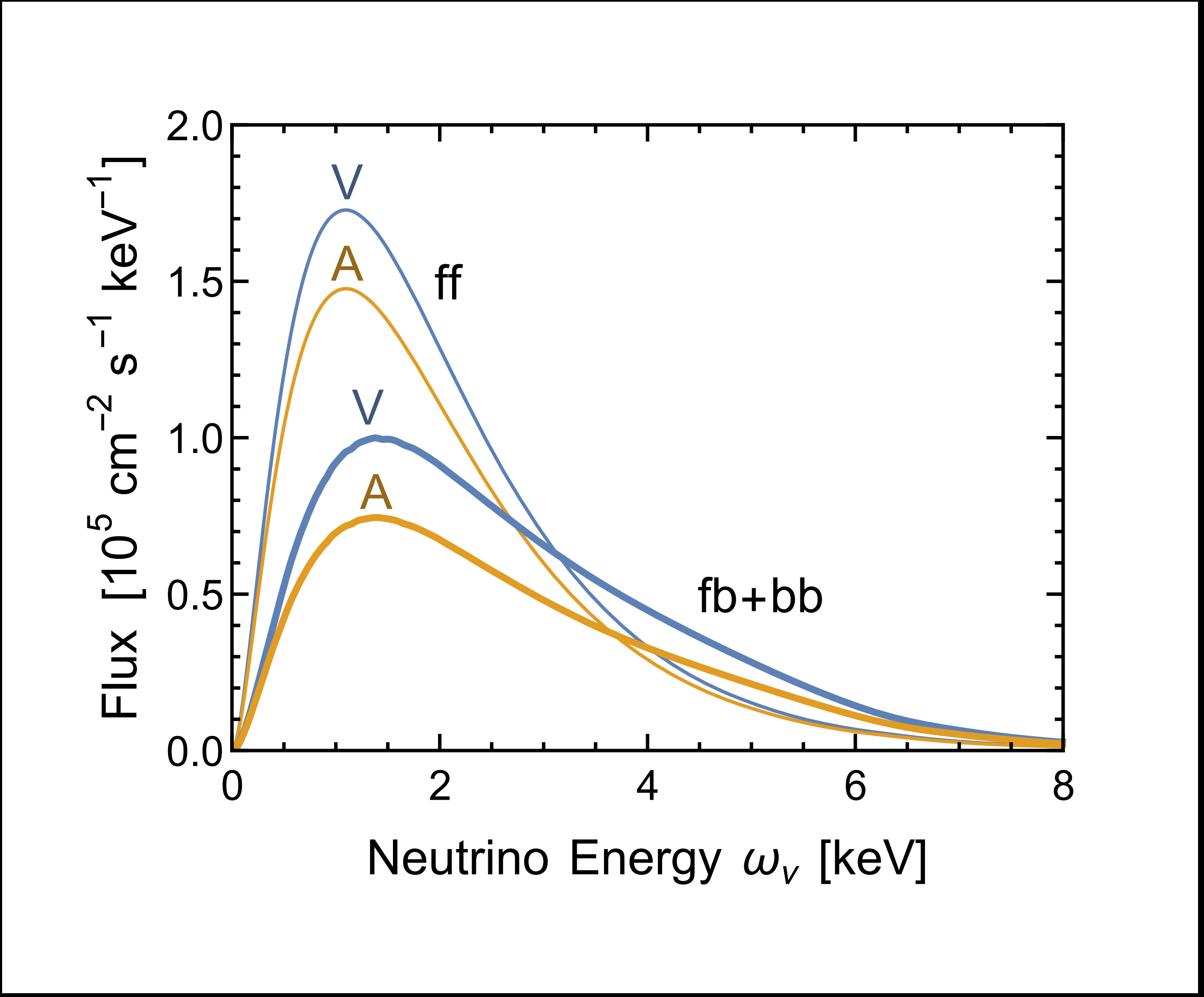
Degeneracy


η
Radius [R/$R_\odot$]
$n_e = 2\int \frac{d^3\mathbf{p}}{(2\pi)^3}\,\frac{1}{e^{\frac{\mathbf{p}^2}{2m_eT}-\eta}+1}$

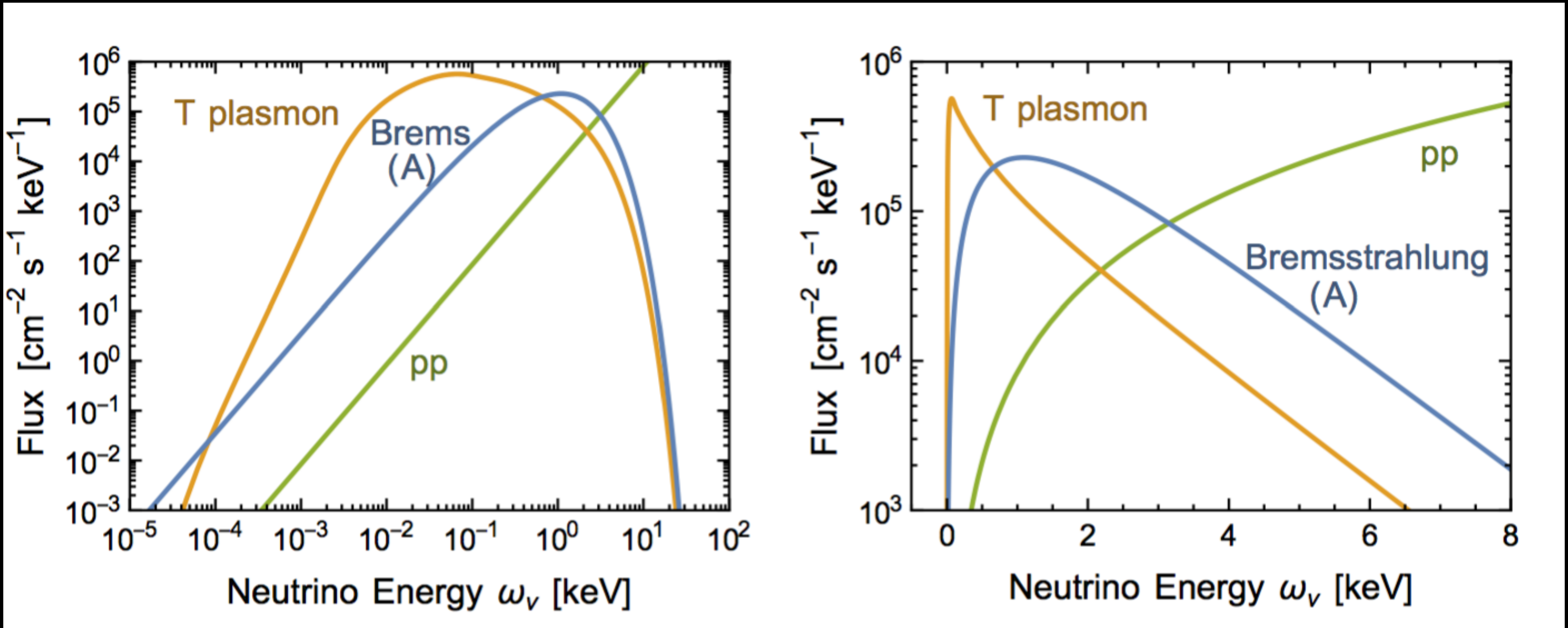

R_η
Radius [R/$R_\odot$]
$R_\eta = \frac{2}{n_e}\int \frac{d^3\mathbf{p}}{(2\pi)^3} f_\mathbf{p}(1-f_\mathbf{p})$


Screening scales [keV]
Radius [R/$R_\odot$]
$k_e^2 = R_\eta\,\frac{4\pi\alpha n_e}{T}$

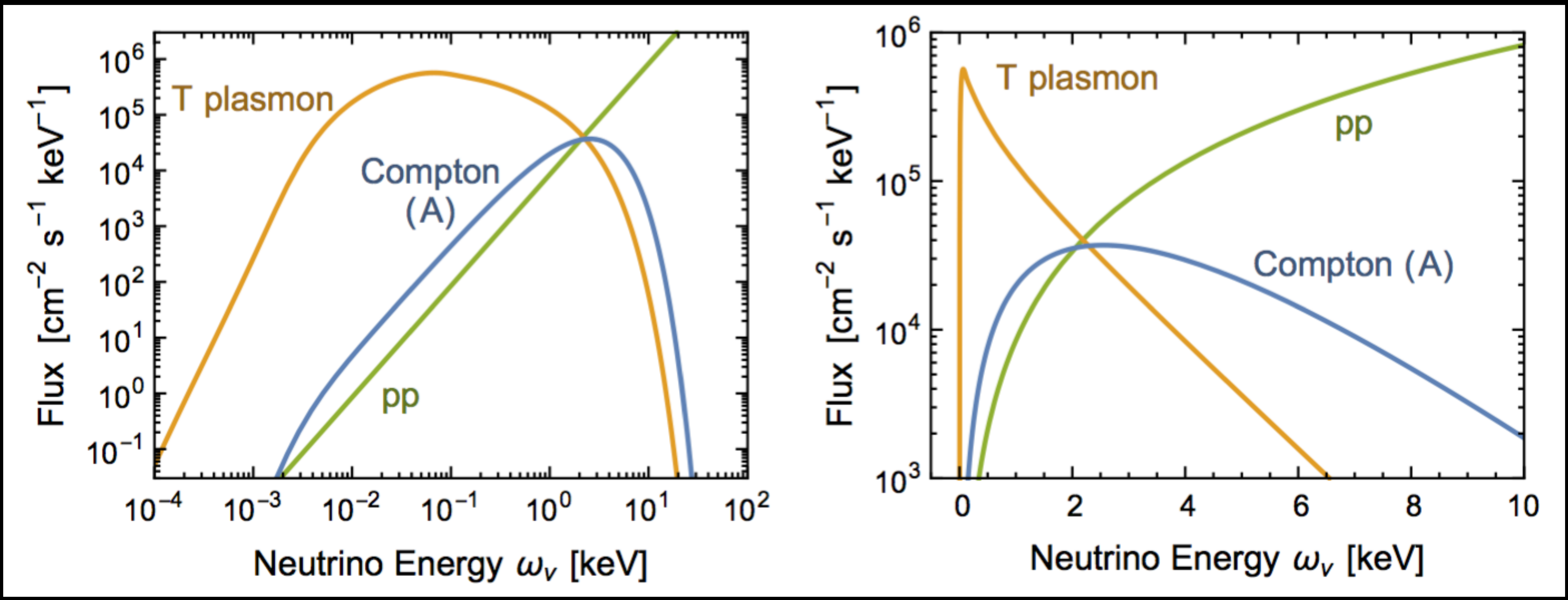
Atomic vs Bremsstrahlung (free-free) transitions



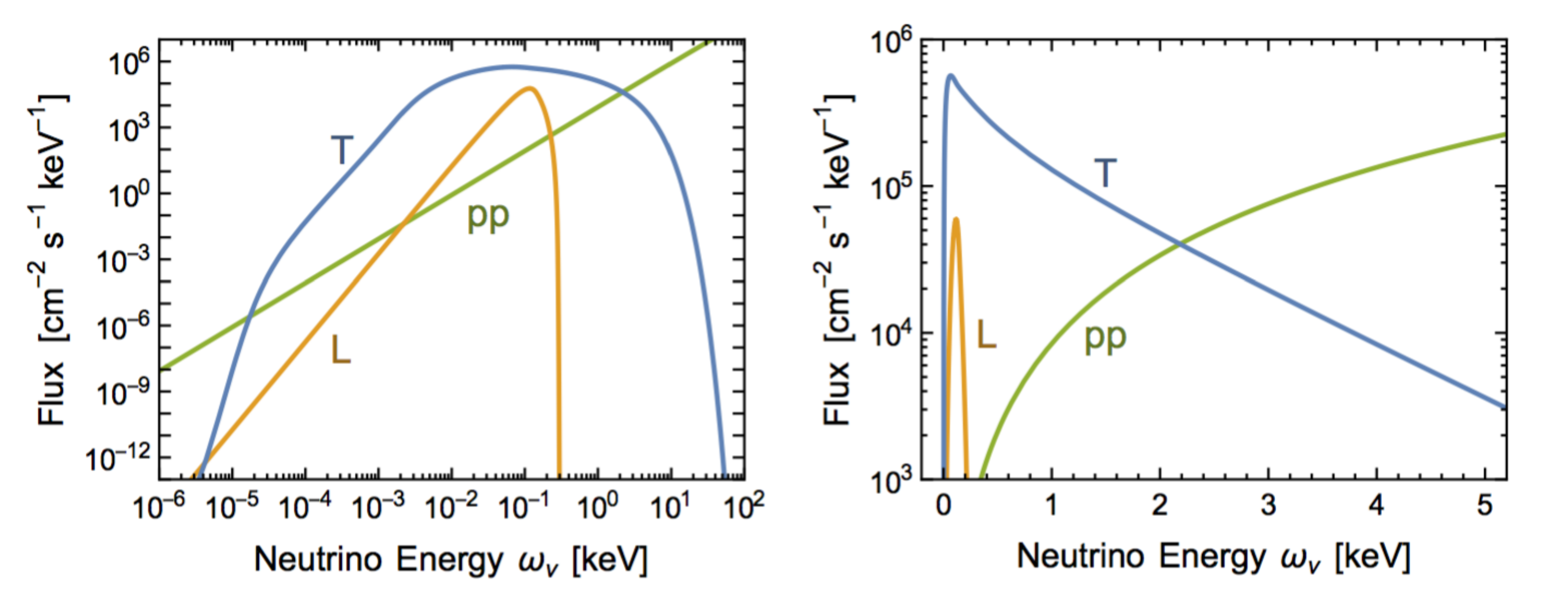
Bremsstrahlung process flux



Compton process flux



Plasmon decay process flux



Total flux on Earth - no oscillation

- Electron anti(neutrinos) produced by vector current
- All flavor produced by axial current
- electron neutrinos from pp