Effect of the cosmic neutrino background in radiative emission of neutrino pair

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arXiv:1409.3648 M. Yoshimura, N. Sasao (Okayama U.), MT

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Cosmic Neutrino Background (CNB)

Big bang cosmology

Standard model of particle physics

→ CNB

CNB at present: $f(\boldsymbol{p}) = [\exp(|\boldsymbol{p}|/T_\nu - \xi) + 1]^{-1}$

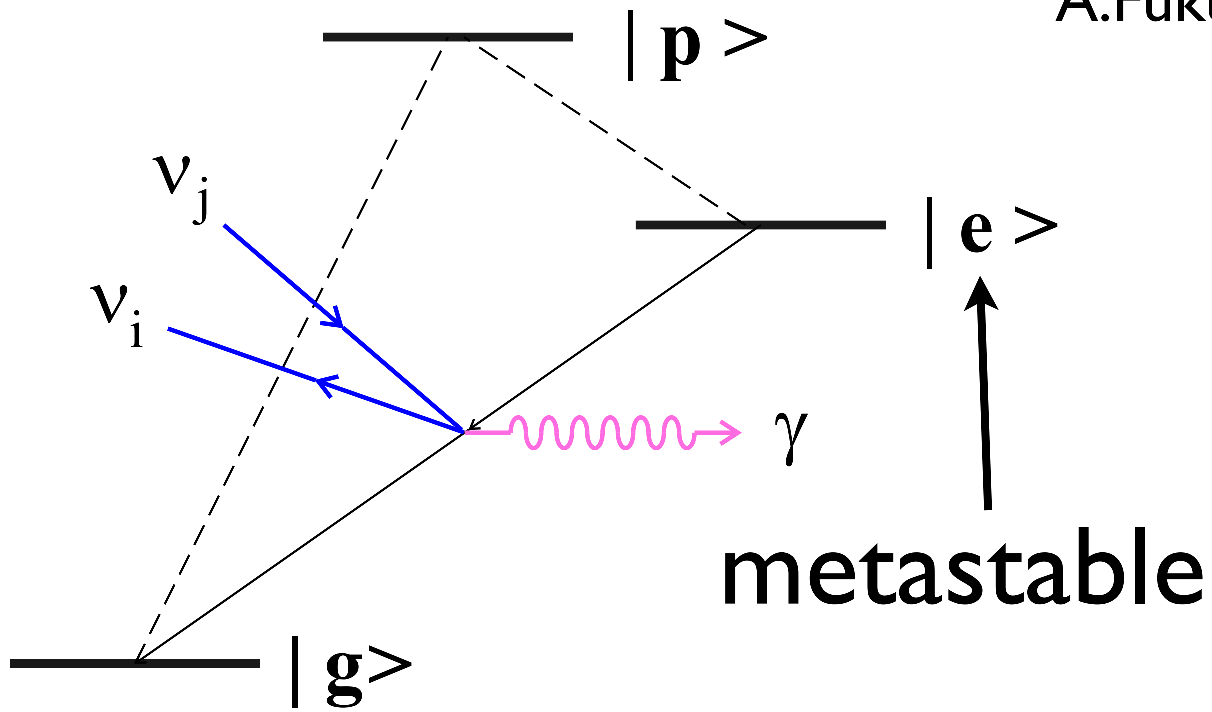
(not) Fermi-Dirac dist. $|\boldsymbol{p}| = \sqrt{E^2 - m_\nu^2}$

$$T_\nu = \left(\frac{4}{11}\right)^{1/3} T_\gamma \simeq 1.945 \text{ K} \simeq 0.17 \text{ meV}$$

→ $n_\nu \simeq 56 \text{ cm}^{-3}$ Detection?

Radiative Emission of Neutrino Pair (RENP)

A.Fukumi et al. PTEP (2012) 04D002, arXiv:1211.4904



Neutrino emission from

1. valence e spin current
2. nuclear weak charge (monopole)

Atomic/molecular energy scale ~ eV or less

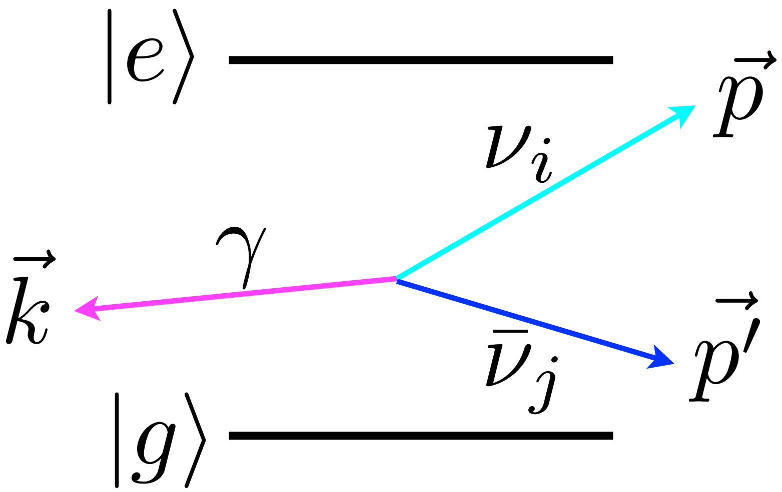
close to the neutrino mass scale

Rate $\sim \alpha G_F^2 E^5 \sim 1/(10^{33}\,\mathrm{s})$

enhancement by macrocoherence

Macrocoherence

Yoshimura et al. (2008)



position of atom

$$\propto e^{-i(\vec{k}+\vec{p}+\vec{p'})\cdot\vec{x}_a}(2\pi)\delta(\epsilon_{eg}-\omega-E_p-E_{p'})$$

$$(\epsilon_{eg}=\epsilon_e-\epsilon_g,\ \omega=|\vec{k}|)$$

Macroscopic target of N atoms, volume V (n=N/V)

total amp. $\propto \sum_a e^{-i(\vec{k}+\vec{p}+\vec{p'})\cdot\vec{x}_a} \simeq \frac{N}{V}(2\pi)^3\delta^3(\vec{k}+\vec{p}+\vec{p'})$

$$d\Gamma \propto n^2V(2\pi)^4\delta^4(q-p-p') \qquad q^\mu=(\epsilon_{eg}-\omega,-\vec{k})$$

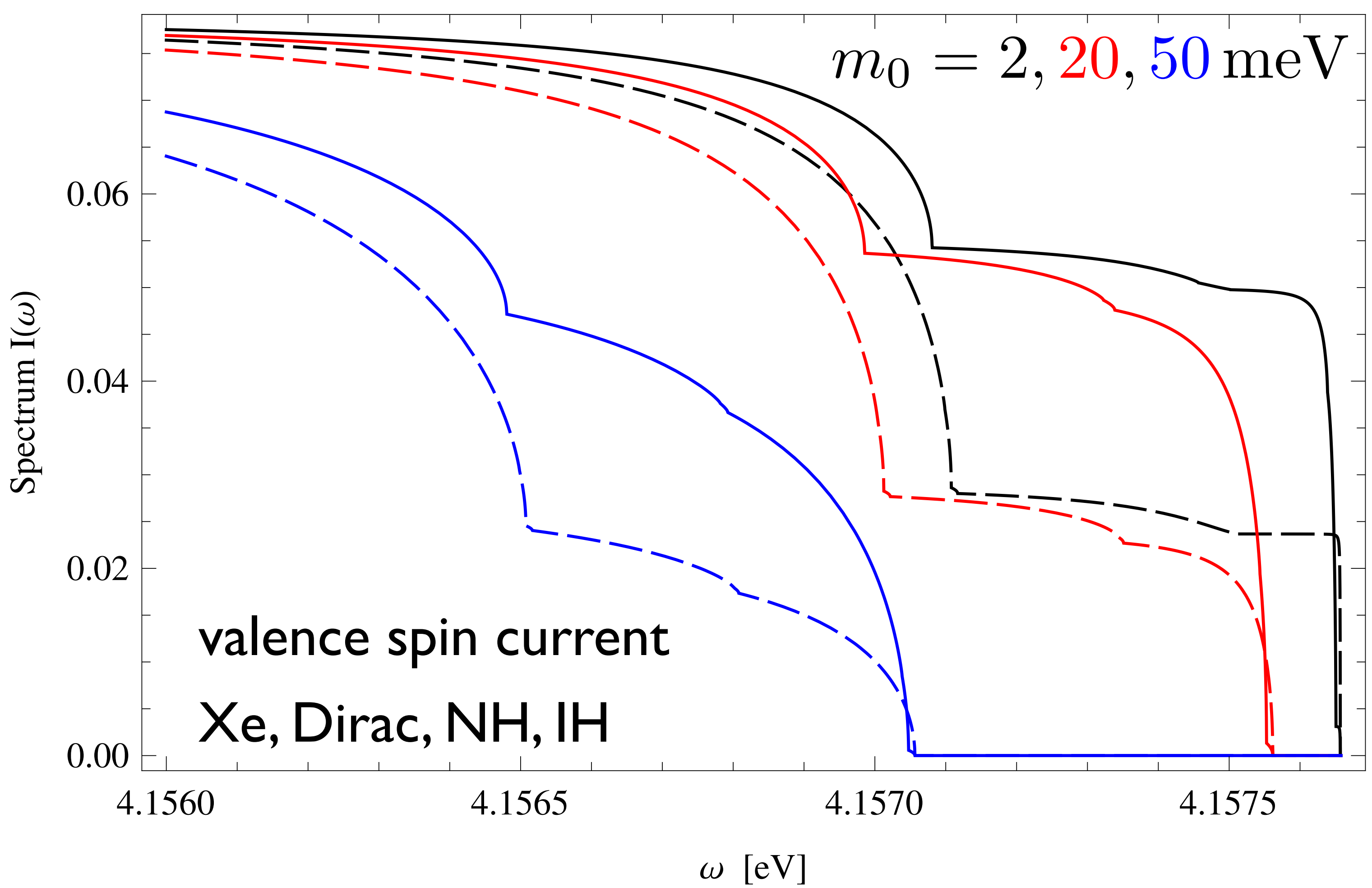
macrocoherent amplification

RENP spectrum

D.N. Dinh, S.T. Petcov, N. Sasao, M.T., M. Yoshimura
PLB719(2013)154, arXiv:1209.4808

Energy-momentum conservation
due to the macrocoherence
→ familiar 3-body decay kinematics

Six (three) thresholds for valence (nucleus)



RENP in CNB

$$|e\rangle \to |g\rangle + \gamma + \nu_i \bar{\nu}_j$$

Pauli exclusion → spectral distortion

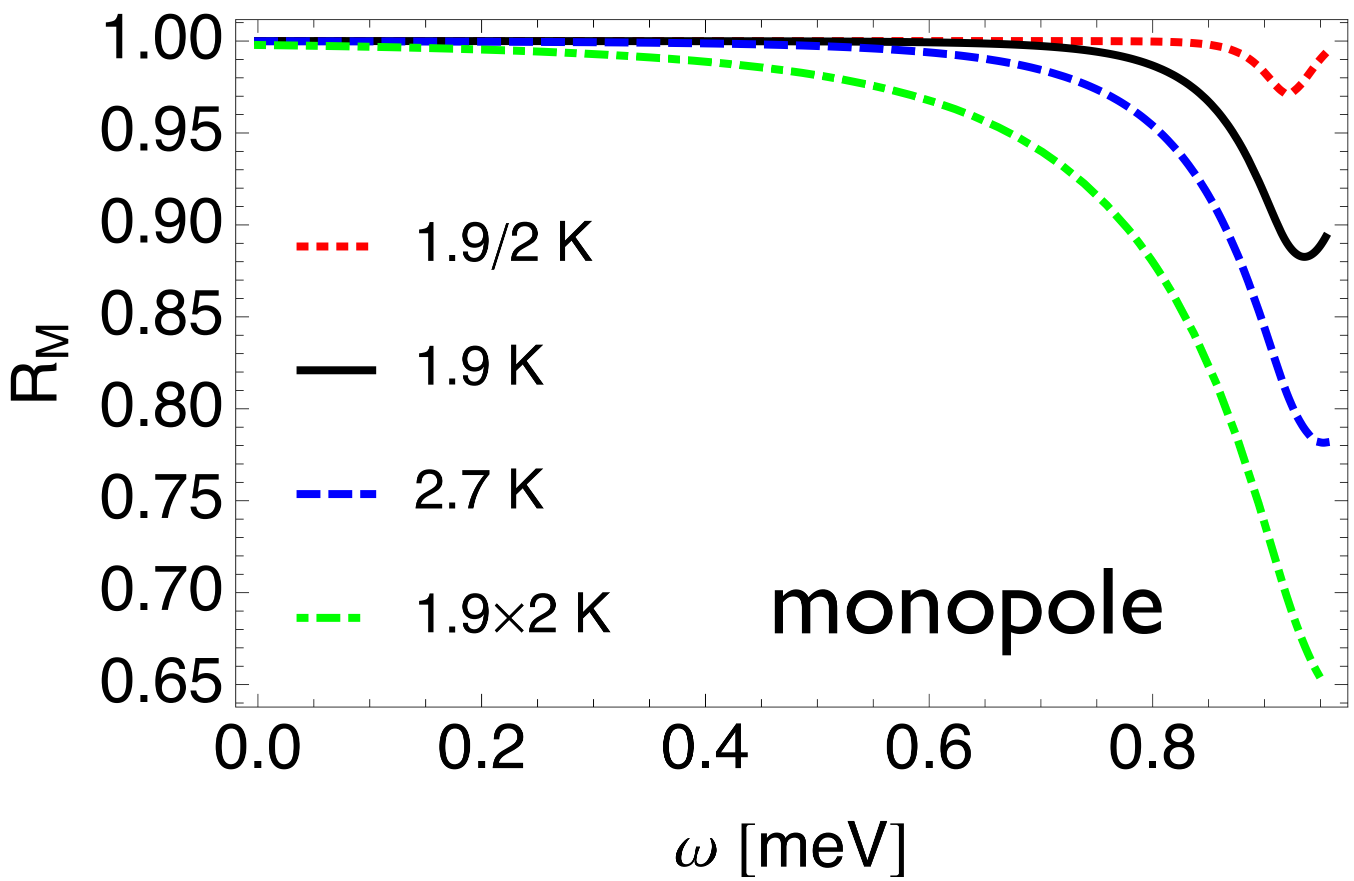
$$d\Gamma \propto |\mathcal{M}|^2 [1 - f_i(p)] [1 - \bar{f}_j(p')]$$

Distortion factor

$$R_X(\omega) \equiv \frac{\Gamma_X(\omega, T_\nu)}{\Gamma_X(\omega, 0)}$$

$$X = \begin{cases} M & \text{nuclear monopole} \\ S & \text{valence } e \text{ spin current} \end{cases}$$

larger rate $i = j$



level splitting

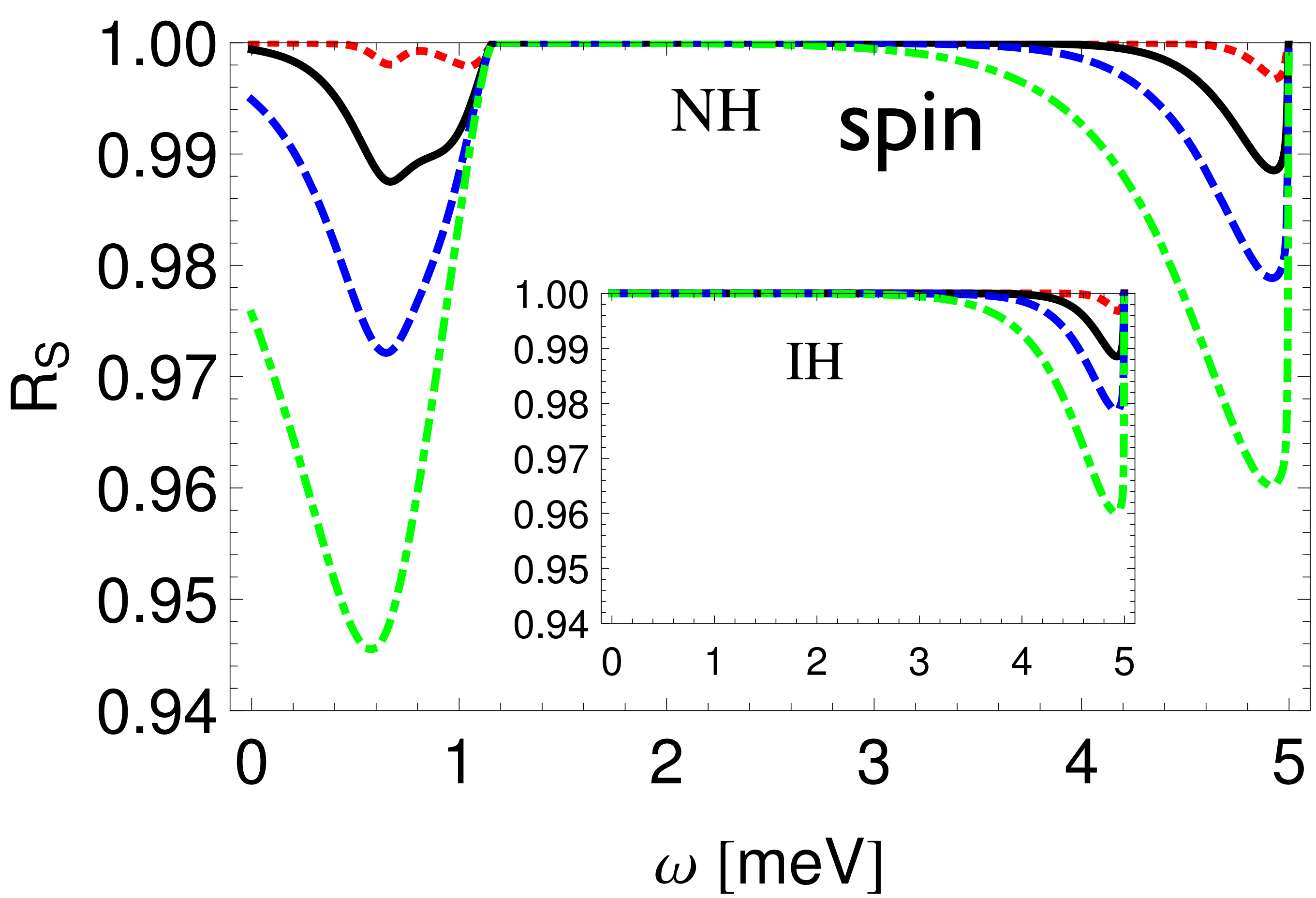
$\epsilon_{eg} = 11\ \mathrm{meV}$

smallest neutrino mass

$m_0 = 5\ \mathrm{meV}$

chemical potential

$\xi_i \equiv \mu_i / T_\nu = 0$

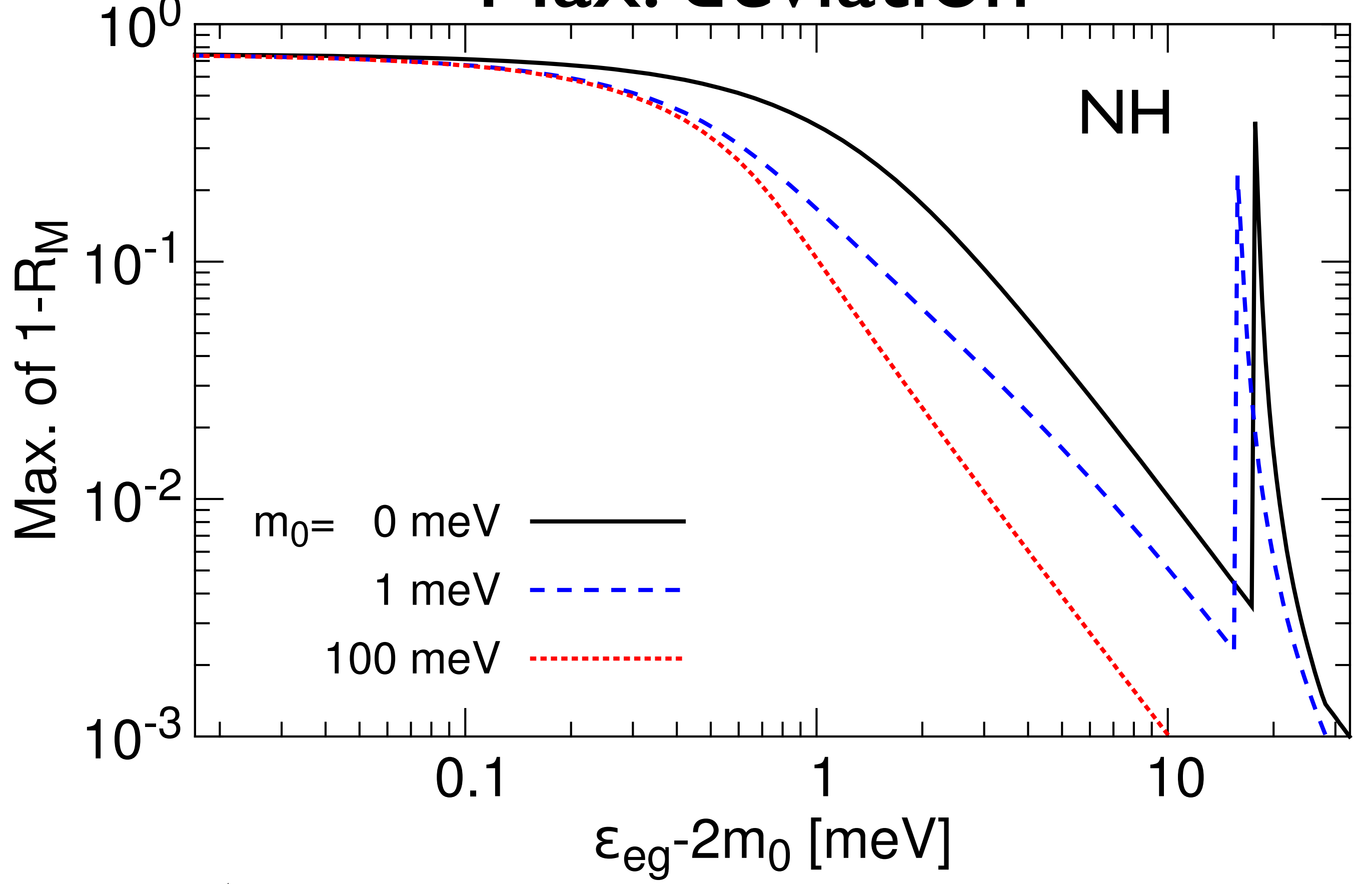


$\epsilon_{eg} = 1\ \mathrm{meV}$

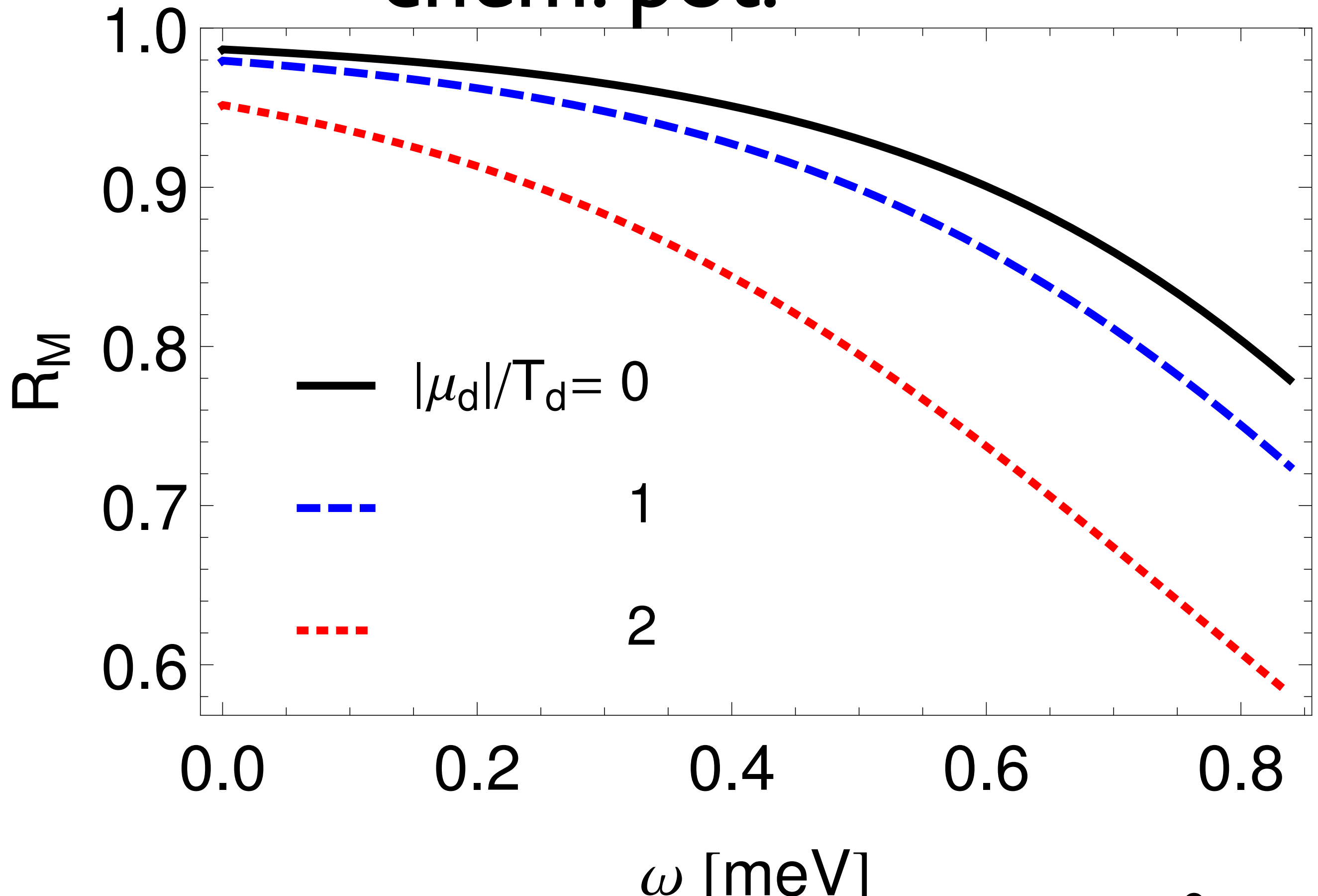
$m_0 = 0.1\ \mathrm{meV}$

$\xi_i = 0$

Max. deviation



chem. pot.

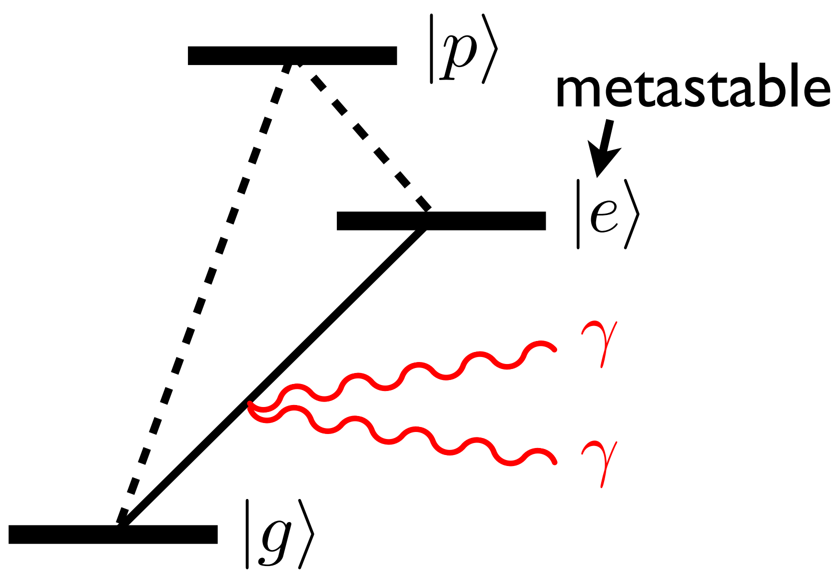


$$\epsilon_{eg} = 10T_\nu \simeq 1.7 \text{ meV}$$

$$m_0 = 0$$

Paired Super-Radiance (PSR)

M. Yoshimura, N. Sasao, MT, PRA86, 013812 (2012)



$$|e\rangle \to |g\rangle + \gamma + \gamma$$

Prototype for RENP

proof-of-concept for the macrocoherence

Preparation of initial state for RENP

coherence generation ρ_{eg}

Theoretical description to be tested

Maxwell-Bloch equation

Para-hydrogen gas PSR experiment

@ Okayama U

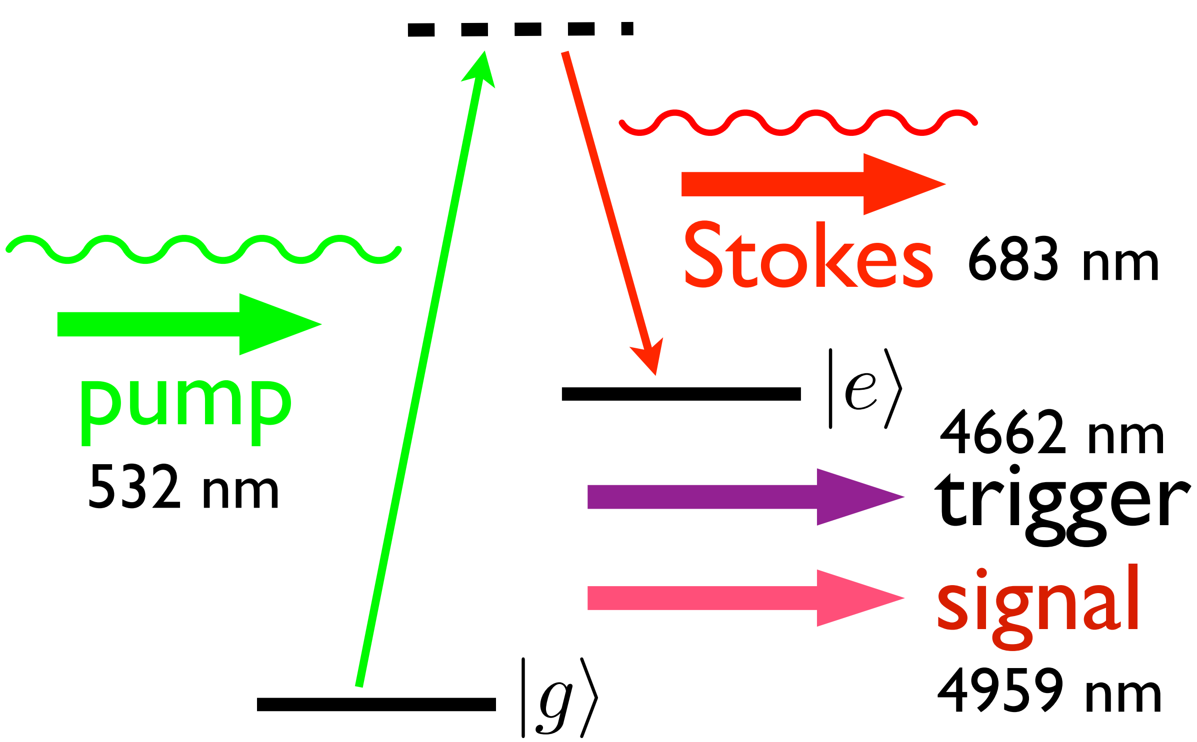
to be published in PTEP

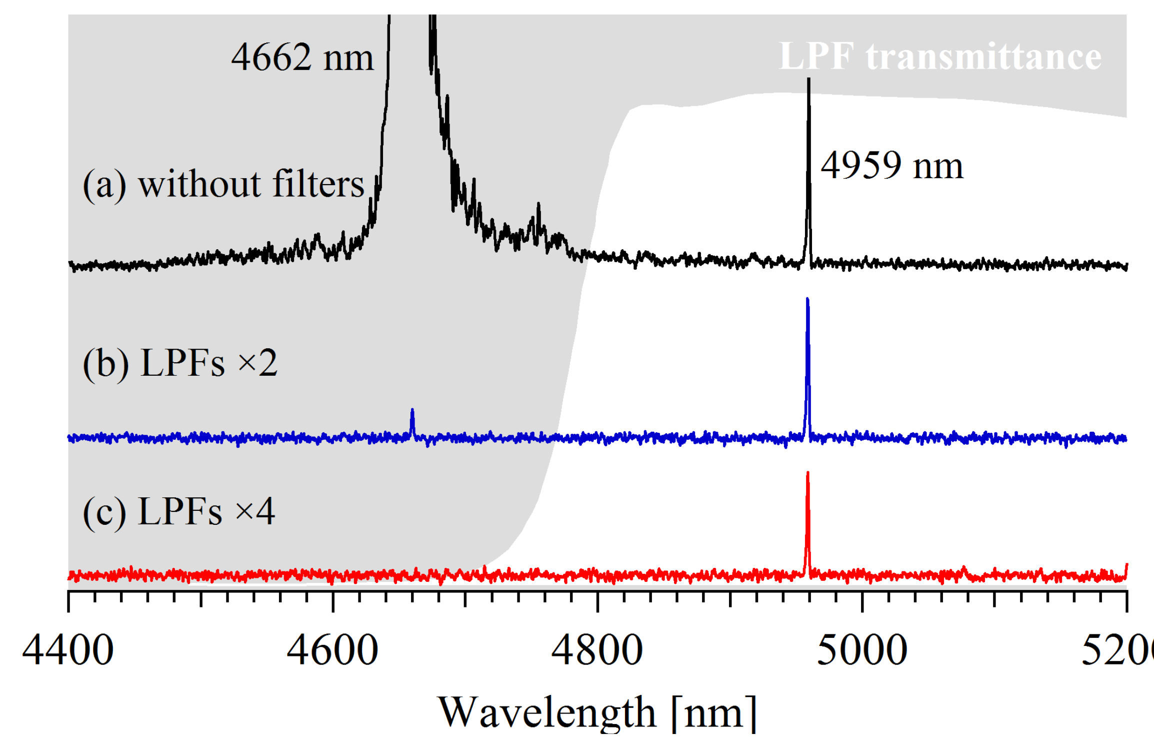
vibrational transition of p-H2

$$|e\rangle = |Xv=1\rangle \longrightarrow |g\rangle = |Xv=0\rangle$$

target cell: length 15cm, diameter 2cm, 78K, 60kPa

$$n = 5.6\times 10^{19}\ \mathrm{cm}^{-3} \qquad 1/T_2 = 130\ \mathrm{MHz}$$





$O(10^{16})$ enhancement

Summary

- ✸ RENP spectra are sensitive to the cosmic neutrino background.

  temperature, chemical potential.

- ✸ Macrocoherent rate amplification is essential.

  demonstrated by a QED process, PSR.

- ✸ More to be studied.

  target selection, background,
  other precesses, etc.

Neutrino physics with atoms

Backup Slides

Thermal history of cosmic neutrinos

$T \gtrsim 3.2\ \mathrm{MeV}$ $\quad \nu_{e,\mu,\tau}$ in equilibrium

$T \simeq 3.2\ \mathrm{MeV}$ $\quad \nu_{\mu,\tau}$ decoupling

$T \simeq 1.9\ \mathrm{MeV}$ $\quad \nu_{e}$ decoupling

$$f_D(\boldsymbol{p}) = \left[\exp\left(\frac{\sqrt{\boldsymbol{p}^2 + m^2}}{T_D} - \xi\right) + 1\right]^{-1}$$

$T \lesssim 1.9\ \mathrm{MeV}$ $\quad$ free propagation

Present $\quad a = 1 \quad f(\boldsymbol{p}) = f_D(\boldsymbol{p}/a_D)$

$$f(\boldsymbol{p}) = \left[\exp\left(\frac{\sqrt{\boldsymbol{p}^2 + (m a_D)^2}}{T_D a_D} - \xi\right) + 1\right]^{-1}$$

$T_\nu = T_D a_D \qquad m a_D \ll m$

Coherences in RENP

Atomic coherence $(|g\rangle + |e\rangle)/\sqrt{2}\,,\ \rho_{eg} = 1/2$

Target coherence $\left[\frac{1}{\sqrt{2}}(|g\rangle + |e\rangle)\right]^N$

$$\xrightarrow[J_-]{} \frac{1}{\sqrt{2^N}}[|g\rangle(|g\rangle + |e\rangle)\cdots(|g\rangle + |e\rangle) \\ +(|g\rangle + |e\rangle)|g\rangle\cdots(|g\rangle + |e\rangle) \\ +\cdots\cdots]$$

$$\Gamma \propto N^2$$

Macro-coherence

$$\Gamma \propto N^2/V = n^2 V$$