CONSTRAINTS ON THE NEUTRINO MAGNETIC MOMENT FROM STELLAR EVOLUTION AND SUPERNOVAE TYPE Ia

C.SIVARAM
INDIAN INSTITUTE OF ASTROPHYSICS
BANGALORE 560034
INDIA

ABSTRACT

There are several interesting consequences of a neutrino magnetic moment (NMM) such as possibility of a time varying solar neutrino signal (ENS), increased cooling of red giants and enhanced evolution of horizontal branch stars. Earlier SN 1987A was used to put constraints on NMM. Here we use effects of NMM in preventing carbon-oxygen deflagrations that cause SN Type Ia to give $\mu_\nu < 10^{-13}\mu_B$. Constraints on CP-violating weak interactions are also put).

INTRODUCTION

NMM has suggested as a possible solution to the solar neutrino puzzle. However, this requires μ_ν 10 μ , a value just within current experimental limits on ν-e scattering but however ruled out by other astrophysical constraints among them being the consequnces for the detection of SN 1987A neutrinos. Theoretical lifetimes of cooling white dwarfs give $\mu_\nu < 10^{-11}\mu_B$. The increased cooling in the cores of red giants increases the mass of the He core at the onset of central He burning. This can affect the evolution of low mass stars. The temperature of the He core is governed by heating by gravitational contraction and the cooling by neutrinos, the larger the cooling (NMM enhances cooling) and the more delayed is the He ignition and the larger the core mass at this ignition. The Detectable increase in the luminosity of HB stars can then be used to constrain NMM thus giving $\mu_\nu < 10^{-12}\mu_B$. Also this gives larger luminosities and effective temperatures for He burning giants, i.e. for a $\mu_\nu > 10^{-11}\mu_B$ core mass excess is so large that the luminosity of stars at the REB tip is about 1 mag. higher than in standard calibrations and is thus ruled out. Pulsational properties of RR Lyrae variables give same constraint of $10^{-12}\mu_B$. In general, the helium burning phase for $\mu_\nu \sim 10^{-11}\mu_B$ is reduced by a factor of two. However, if there is a 17 KeV mass neutrino (either μ or tau), plasma production occurs in a region around the centre where the plasma frequency

$$\omega_o \approx \left(\frac{4\pi ne^2}{me}\right)^{\frac{1}{2}} > 17 \text{ KeV}.$$

This would increase the constraint to $\mu_\nu > 10^{-9}\mu_B$. Next we consider the effects on carbon-oxygen (C-O) deflagrations in degenerate white dwarf (WD) matter that are believed to cause SN Type Ia.

2. EFFECTS ON C-O DEFLAGRATION

As is known plasma neutrino losses through (where is a plasmon) are enhanced for a NMM, through an emission rate density:

$$\dot{E}_\nu = \frac{\mu_\nu^2 \omega_o^4}{c^3} \int_{\omega_o}^{\infty} \frac{\omega(\omega^2 - \omega_o^2)\, d\omega}{e^{\hbar\omega/kT} - 1} \quad \text{....(1)}$$

Runaway C-O deflagrations can occur in dense degenerate matter of WD's accreting matter and collapsing and this is supposed to power SN Ia explosions. The nuclear heating time is

$$t_N = \frac{CvT}{\dot{E}_N} \quad \text{....(2)}$$

where $\dot{E}_N$ the nuclear energy generation rate can be written as:

$$\dot{E}_N \approx Q \langle \sigma v \rangle n_1 n_2 T^{-A} \exp[-(T_o/T)^B] \quad \text{....(3)}$$

Q = energy released per reaction, $n_1 n_2$ are no. densities, A,B are constants. Typically for the explosion to occur, t must be shorter than the hydrodynamic time scale

$$t_H \sim (24\pi G \langle P \rangle)^{-\frac{1}{2}}$$

in which the gravitational energy is liberated at a rate

$$\dot{E}_G = \frac{d}{dt}\left(\frac{3}{5}\frac{GM^2}{R}\right) = \frac{7}{5}\frac{G}{K^{1/3}} M^{4/3} \dot{M} \quad \text{....(4)}$$

However, if the neutrino loss E given by eq. (1) is sufficiently rapid, then we can define a time scale, $t_\nu = CvT/\dot{E}_\nu$, with $\dot{E}_\nu$ as given in eq.(1). Thus if $t_\nu < t_N < t_H$, then the material would fail to detonate and we would not end up with enough energy for a type Ia SN. thus the inequality:

$$t_\nu < t_N \quad \text{....(5)}$$

given by eq.(5), with the various values for $\dot{E}_\nu$, $\dot{E}_N$, etc. from eqs (1) (3), etc. would now constrain μ_ν. Also from the requirement

$$\dot{E}_\nu < \dot{E}_N < \dot{E}_G \quad \text{....(6)}$$

Thus if SN of type Ia must occur with the observed blast energy of few x 10^{51} ergs, then $\mu_\nu < 10^{-13} \mu_B$.

3. CONSTRAINT ON CP VIOLATING WEAK INTERACTIONS

We have an interaction term of the type

$\sqrt{2}G_T(\bar{\nu}\sigma^{\alpha\beta}\nu)\ (\bar{l}\sigma_{\alpha\beta}l)$, where $\sigma^{\alpha\beta}\rightarrow i\gamma_5\sigma^{\alpha\beta}$ implies maximal CP violation. This gives an electric dipole moment for the neutrino (also contributing to E_ν by $\gamma_p\rightarrow\nu\bar{\nu}$) of:

$$\mu_\nu = \sqrt{2}\, eG_T\, m_\tau\, \ln\left(\frac{\Lambda}{m_\tau}\right) \qquad ....(7)$$

(m_τ is the τ-lepton mass, $\ln\left(\frac{\Lambda}{m_\tau}\right)\sim 1$).
The above constraint on the μ_ν, then implies that the CP-violating tensor coupling is $G_T < 10^{-6} G_F$ ....(8)
where G_F is the univeral Fermi constant.

CONCLUSION

Using the inequalities (5) and (6) and that C-O deflagration is necessary to have a SN Type Ia explosion we find that μ_ν is constrained to be below $10^{-13}\mu_B$. This then also constrains any CP-violating weak interactions to be of strength $<10^{-6}G_F$.

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