DISTRIBUTION OF NEUTRINO FLUXES FROM PULSAR SHELLS

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ABSTRACT

Young pulsars apparently have a distribution of initial power outputs $N(> P_0^{-\gamma})$, with $\frac{1}{2} < \gamma < 1$ and $P_0 \geq 10^{38}$ ergs/sec. Assuming that ultra-high-energy ($E \gtrsim 10^{15}$ eV) cosmic-ray nuclei are accelerated at the central pulsar, a young, dense supernova shell can be a powerful source of high-energy neutrinos (Berezinsky, 1976). With an optical array placed in a volume of one km^3 at great ocean depths, as proposed for the DUMAND detector, it is likely that $\gtrsim 10^3$ hadronic and electromagnetic cascades induced by neutrinos would be recorded for a stellar collapse within our Galaxy. Such supernovae occur about 8 times per century (Tammann, 1976). Neutrinos from young supernova shells in the Virgo supercluster would be marginally detectable via neutrinos with $N(> P_0) \propto P_0^{-\frac{1}{2}}$, but unobservable if $N(> P_0) \propto P_0^{-1}$.

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A young, dense supernova shell can be a powerful source of high-energy neutrinos (Berezinsky and Prilutsky 1976, and Berezinsky 1976). In this model, ultra-high energy ($E \geq 10^{15}$ eV) protons and other nuclei are accelerated at the central pulsar. The protons interact in the supernova shell and generate cascades of mesons, which in turn yield neutrinos upon decay.

One essential problem in the estimate of neutrino fluxes is the initial rate of energy loss P_0 of the pulsar. The observed radio luminosity function of pulsars follows a power law, and has a broad distribution of values. Probably P_0, too, has a broad range of values.

Consider the pulsar luminosity function based on all the observed Galactic pulsars. Taylor and Manchester (1977) find that the power output distribution among pulsars is $N(\geq P) \propto P^{-\gamma}$, where $\gamma \approx 1.0$. However, pulsars with large radio luminosities are relatively young; if these are subtracted out from the luminosity distribution, one gets a steeper ($\gamma > 1.0$) distribution for the old pulsars. Conversely, for young (or initial) pulsars, $\gamma < 1.0$. We shall assume that the frequency of supernovae with an initial power output greater than P_0 is $N(> P_0) \propto P_0^{-\frac{1}{2}}$ or P_0^{-1}, where P_0 ranges from 10^{38} to 10^{44} ergs/sec.

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The efficiency of energy conversion into relativistic particles is high near a pulsar. Finzi and Wolf (1969) estimate that $\sim$ 1/3 of the rotational energy loss of the Crab pulsar is converted into energy of relativistic particles and magnetic fields, observed through synchrotron radiation. We shall assume that the power input into relativistic protons is similar, i.e. 0.3 P_0.

Let us adopt the supernova frequencies expected by Tammann (1976), i.e. $\sim$ 8 per century in our Galaxy (within a factor of two), and $\sim$ 1800 per century in the Virgo supercluster at distances $\leqslant$ 20 Mpc. Table 1 shows the estimated frequency of supernovae per century as a function of the number of neutrino events for the exponents γ_0 = 0.5 and 1.0.

TABLE 1
Estimated Numbers of Neutrinos (E $\geqslant$ 4 TeV) Detected in 10^{10} tons of water, in 4 months

	Initial rate of energy loss (ergs/sec)	Number of neutrino events	Frequency per century $N(\geq P_0) \propto$ $P_0^{-1/2}$	P_0^{-1}
Supernova in our Galaxy (at $\sim$ 10 Kpc)	10^{38} - 10^{39}	10^3	$\sim$ 6	$\sim$ 7
	10^{39} - 10^{40}	10^4	$\sim$ 2	$\sim$ 1
	10^{40} - 10^{41}	10^5	$\sim$ 0.5	$\sim$ 0.1
Supernova in the Supercluster (at $\sim$ 20 Mpc)	10^{41} - 10^{42}	0.1	40	1.3
	10^{42} - 10^{43}	1	13	0.1
	10^{43} - 10^{44}	10	4	0.01

We note from Table 1 that the high-energy neutrinos from supernovae in our Galaxy should be readily detectable, and with the assumptions stated earlier, the corresponding pulsars would have initial energy loss rates of 10^{38} to 10^{39} ergs/sec, i.e. they would be relatively low-powered pulsars. However, the neutrinos from the supernovae in the supercluster would be detectable with the DUMAND array only if $P_0 > 10^{42}$ ergs/sec (i.e. exceptionally high-powered pulsars), and if the power output distribution for young pulsars goes as $N(\geq P_0) \propto P_0^{-1/2}$.

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