We found that a cycle lasting 12 months was most prominent, although cycles of higher frequencies also exist. We subtracted the principal (12-month) cycle from the data shown in Fig. 2B to obtain

$$\overline{C}_{I^*}(T) = \overline{C}_i - C_P \cos\left(\frac{2\pi P}{T} - \theta_P\right)$$

where P indicates the principal 12-month cycles. The value of C_P is 34 parts per billion by volume (ppbv), $\theta_P = 1.5$ radians, and $P = 3$. The resulting data $\overline{C}_{i^*}(T)$ are shown in Fig. 2E. Once again, the increasing trend of CO is apparent, and we estimated its magnitude by standard and nonparametric (Theil) statistical analyses (*9*). The trend for 1980 to 1982 was found to be significantly positive ($\alpha = 0.05$) and about 6 percent per year (Table 1).

Our third method for overcoming the effects of seasonal cycles on long-term trends was to average our data (Fig. 2B) over each of the 3 years (1980, 1981, and 1982). Once again, the results (Fig. 2F) indicate an increase of about 6 percent per year. The three methods used to analyze long-term trends provide results in remarkable agreement with each other.

The full range of environmental effects from increased concentrations of CO is not known; however, CO is believed to control the concentrations of OH radicals in the troposphere. Increased CO may deplete tropospheric OH radicals, thereby reducing the yearly removal of dozens of natural and anthropogenic trace gases. In particular, this effect may add to the increase of CH_4, which in turn could further reduce OH concentrations (*10*). Increased CO may indirectly intensify global warming and perturb the stratospheric ozone layer by increasing the lifetimes of trace gases such as CH_4, CH_3Cl, CH_3CCl_3, and $CHClF_2$ (F-22).

Carbon monoxide may be included in the group consisting of CO_2, N_2O, and CH_4, all of which have probably been present in the earth's atmosphere for a long time and are now increasing as a result of the rapid rise in the human population over the past century. The natural and anthropogenic emissions of these gases as well as their annual losses may vary from year to year, depending on natural fluctuations in climate and other processes. For long-lived species such as CH_4, CO_2, and N_2O, random fluctuations of sources and sinks do not greatly affect the global concentration since their amounts in the atmosphere at any time far exceed the yearly emissions. The case for short-lived gases such as CO is entirely different. Natural fluctuations of sources and sinks may greatly affect the CO concentrations from year to year and even from place to place. Although we have extracted the leading mode and proposed that it represents the geophysical background concentration, long-term atmospheric measurements at other remote locations are needed to verify the global nature of the increase. It is difficult to define a firm global rate of increase for CO since it varies considerably from year to year, and it is not possible to unequivocally attribute the entire observed increase to human activities. With a longer span of observations, it should be possible to overcome these difficulties.

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7. Smoothing:

$$\overline{C}(\Delta, T) = \frac{1}{\Delta} \sum_{i=T}^{T+\Delta-1} \overline{C}_i$$

where $\overline{C}_i$ are the monthly average concentrations during month i, as shown in Fig. 2, A or B; Δ is the interval of averaging, here 12 months; T is the time in months and ranges from 1 to $(N - \Delta) + 1$, where N is the total time span of data, here 44 months.
8. Fourier series:

$$\overline{C}_i = \overline{C}_0 + bt_i + \sum_{k=1}^{\infty} C_k \cos(\omega_k t_i - \theta_k)$$

where $\overline{C}_i$ are monthly concentrations, $\omega_k = 2\pi k/T = 2\pi/\tau_k$, and $\theta_k = \arctan(b_k/a_k)$, $C_k = (a_k^2 + b_k^2)^{1/2}$, $t_i = i$, $i = 1, \ldots, N$; T is the length of months of the entire database, which for our analysis had to be confined to an integral number of years (January 1980 to December 1982) so that $T = 36$ months; a_k and b_k are the usual Fourier series coefficients.
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Detectability of Supernova Neutrinos with an Existing Proton Decay Detector

Abstract. *The 8000-ton water IMB nucleon decay detector has good sensitivity to the neutrino burst associated with the collapse of stars. It is particularly sensitive to the $\bar{\nu}_e$ charged current interactions with protons but can also record other neutrino interactions through νe scattering. Signal, noise, physics objectives, and detector modifications that would enhance burst detection are discussed. The objectives include astrophysical questions about the pulse structure and power. It also may be possible with a distant source to study neutrino masses and neutrino oscillations.*

Although the IMB nucleon decay detector was developed primarily for the study of baryon stability, this detector has features that make it an ideal instrument for other physics studies. For instance, it should be suitable for the observation of neutrinos emitted during the collapse of a massive star to a black hole or neutron star. Our understanding of these phenomena has grown in recent years through the study of astrophysical gamma-ray sources and radio pulsars (*1*). A large amount of theoretical work has also been done; including work on the effects of the weak neutral current (*2*) and, more recently, on the possibility of neutrino oscillations (*3*).

About 3×10^{53} ergs of energy are dissipated in the form of neutrinos during a collapse. This corresponds to the emission of 3.4×10^{57} ν_e neutrinos and comparable numbers of $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$, ν_τ, and $\bar{\nu}_\tau$ neutrinos. These neutrinos have a spectrum and time structure that characterizes their source. The $\bar{\nu}_e$ spectrum (*4*) extends from 5 to 20 MeV with a mean energy of 13.3 MeV. The neutrino flux falls as $1/r^2$. At a distance of 1 kpc (3.1×10^{21} cm) from the source the ν_e flux is 2.8×10^{13} cm^{-2}. The $\bar{\nu}_e$ flux is 1.7×10^{13} cm^{-2}.

Our detector consists of 8000 tons of water. The oxygen in the water is virtually inert to neutrinos of this energy. The protons in hydrogen are excellent $\bar{\nu}_e$ detectors, and the electrons in the detector present a substantial cross section for νe scattering from all forms of neutrinos. The detector has 5.4×10^{32} free protons and 2.7×10^{33} electrons. The protons present an effective cross section (cross section times number of particles) for 14-MeV $\bar{\nu}_e$'s of 5.9×10^{-9} cm^2. The electrons have a slightly different cross section for ν_e and $\bar{\nu}_e$ because of the presence of the charged current channel. Values of the cross section, σ, are:

$$\sigma(\nu_e + e) = 3.6 \times 10^{-10} \text{ cm}^2$$
$$\sigma(\bar{\nu}_e + e) = 1.5 \times 10^{-10} \text{ cm}^2$$
$$\sigma(\nu_{\mu,\tau} + e) = \sigma(\bar{\nu}_{\mu,\tau} + e) = 5.3 \times 10^{-11} \text{ cm}^2$$

For a typical supernova at a distance of 1 kpc the event rates are:

$$N(\bar{\nu}_e + p) = 10^5$$
$$N(\nu_e + e) = 10^4$$
$$N(\bar{\nu}_e + e) = 2.5 \times 10^3$$
$$N(\nu_{\mu,\tau...} + e) = 1.1 \times 10^3 \text{ (each neutrino type)}$$
$$= 4.5 \times 10^3 \text{ (total for all non-e neutrinos)}$$

The total event rate is 1.2×10^5 interactions. This rate falls as $1/r^2$ as the distance to the source increases.

It is interesting to compare this rate to the rate from possible terrestrial sources of neutrinos. A 2×10^9 W nuclear power plant at a distance of 5 km will produce only about 0.6 $\bar{\nu}_e$ events per day.

The kinematics of the $\bar{\nu}_e$p reaction are such that the final-state positron will have an isotropic distribution but will have an energy close to the initial neutrino energy. The νe scattering events will be much more directional, $<\cos \vartheta>$ = 0.93, but the energy of the recoil electron is a function of the scattering angle. In general, only one third to one half of the initial neutrino energy will be transferred to the electron.

Particle detection in the IMB detector is accomplished through the Cerenkov effect. Light produced by relativistic charged particles is detected by an array of photomultipliers arranged on the surface of a 20-m cube. The technique provides high sensitivity, allows for momentum reconstruction, and is insensitive to low energy backgrounds. It is optimal for studying baryon decay. Unfortunately, the light output of low-energy neutrino interactions is much more difficult to detect.

A typical 13-MeV electron or positron produces 3650 photons. Only 2 percent of the surface of the detector is photosensitive, and because of attenuation and phototube inefficiency only 6 percent of the light is captured. These factors lead to the observation of about 4 photoelectrons for the average 13-MeV positron. This rather small signal does not permit the present detector to reconstruct the burst event by event.

The 1.2×10^5 interactions from a stellar collapse at 1 kpc would produce a signal in the detector of 4.3×10^5 photoelectrons. Of this light, 7.3 percent would come from νe scattering and would preserve some directional information. Scaling these results, we find that a collapse at the galactic center, 10 kpc, would produce 1.2×10^3 interactions and a signal of 4.3×10^3 photoelectrons.

In principle one would like to see and measure individual interactions, but because of noise constraints the detector cannot be triggered at the four-tube level. The detector operates well with a six-tube trigger (*5*), corresponding to about 20 MeV, but reconstruction is not very reliable until many more tubes fire.

One can detect neutrino bursts by integrating the summed output of all phototubes and recording this sum as a function of time on a waveform digitizer. A d-c component of noise is always present, and an a-c component represents the signal or fluctuations in the tube noise. In addition to summing the entire detector, summing sections will provide directional information and somewhat better noise immunity.

The digitizer integrates and samples N times in a period T. The interval T/N is long enough so that the quantum nature of the signal and noise are not noticeable. Expanding the noise function, we obtain

$$n(t) = a_0 + \sum_{j=1}^{N} a_j \cos(k_j t + \vartheta_j)$$
$$k_j = \frac{N}{N+1} \frac{j\pi}{T}$$
$$\overline{n(t)} = a_0$$
$$\overline{[\bar{n}(t) - \overline{n(t)}]^2} = \sum_{j=1}^{N} \frac{a_j^2}{2} = RT$$

where R is the overall noise rate. The last line follows from Poisson statistics. The noise comes from 2000 independent photomultiplier tubes, each with a dark count rate in excess of 1 kHz. Since the noise is uncorrelated each mode will contribute equally:

$$\sum_{j=1}^{N} \frac{a_j^2}{2} = N\frac{a^2}{2} = RT$$
$$a = \sqrt{2R\frac{T}{N}}$$

where a is the noise amplitude per mode. For R = 2 MHz, T = 10 seconds, and N = 1000, then a = 200 counts.

The signal to be observed can also be expanded:

$$s(t) = \sum_{j=1}^{N} s_j \cos(k_j t + \phi_j)$$

In general, the first few terms will dominate this series. Detection is accomplished by examining the leading Fourier components, in real time.

If we assume that all of the signal is present in the lowest mode, the amplitude, s_1, is half the total counts. For the 4300 counts expected from a collapse at 10 kpc we get a signal-to-noise ratio of 10.8 for a 10-second pulse (*6*) with 10-msec sampling.

Better noise immunity can be accomplished by sampling more frequently, by applying an optimum filter (*7*), and by looking for coincidences in detector segments. Since the signal increases rapidly for closer events, the signal-to-noise ratio will rise and more details of the pulse structure should be evident. At 1 kpc the unfiltered signal-to-noise ratio is 96. Even at a distance of 5 kpc only modest filtering is necessary.

Even the simple process of observing a neutrino burst will be highly significant. At present, the rate of occurrence of stellar collapse and the ultimate final state are controversial (*2*). It may well be that many stars collapse with little, if any, other signal but the neutrino pulse. The number of supernova remnants seems to be inconsistent with the number of pulsars, yet they are both results of collapse. An optimistic estimate (*1*) for the rate of pulsar formation in our galaxy is one every 6 years, but this could represent a lower limit for collapses of all types.

If a collapse has occurred, our detector can yield two valuable pieces of information. The early time structure of the burst (*8*) tells a great deal about the shock mechanism and thermalization during the collapse. The total power, or power as a function of time, is important in understanding the nuclear physics of the collapse and the energy flow and transfer in the star.

Because the $\bar{\nu}_e$ component produces isotropic light while all other neutrinos interact through the directional νe scattering channel, one can hope to learn two things. By comparing the isotropic light to the directional light one can, in principle, separate the $\bar{\nu}_e$ flux from all other types. One can also use the asymmetry as a crude direction indicator. Multiple scattering limits the resolutions to 30°, but since the signal comes from an ensemble of events all peaked in the same direction, we may be able to do better.

If accurate time records are kept, one can perform a time-of-flight experiment with neutrinos (*9*). This can be done by comparing the neutrino time to optical or gamma observation times, or by comparing peaks in the time distribution. In principle, if the neutrino has a mass its time-of-flight difference will be

$$\Delta t = \frac{1}{2}\,\frac{m_1^2 - m_2^2}{p^2}\,t$$

Where m_1 and m_2 are the two masses to be compared and t is the total travel time. For $m = 10$ eV and $p = 10$ MeV at 1 kpc = 10^{11} seconds, one gets $\Delta t = 50$ msec. With modest timing accuracy one can compare the arrival with signals observed at gravitational-wave detectors (*10*) and perhaps gamma-ray satellites.

Since the neutrinos have a continuous energy spectrum this may not be distinct. To some extent the situation is helped by the E_ν^2 dependence of the cross section, which tends to narrow the effective spectrum for interacting neutrinos.

If separate neutrino mass peaks are observed, it may be possible to combine this information with the asymmetry information and measure the $\bar{\nu}_e$ component of the neutrino mass eigenstates—that is, $\langle \bar{\nu}_e \mid \nu_1 \rangle$, $\langle \bar{\nu}_e \mid \nu_2 \rangle$, and so on.

Although the signal from individual neutrino interactions is too weak to be detected, some of these will activate the proton decay electronics and be recorded. From these one can hope to learn something about the neutrino energy spectrum itself, which is related to the temperature in the star at the time it became transparent to neutrinos.

One can contemplate major improvements in the detector for studying stellar collapse. The use of more and larger photomultiplier tubes would increase the detector's range and aid in reconstructing more events but would be very expensive. One can increase the light collection by a factor of 3 inexpensively through the use of reflecting walls and wavelength shifters. While this would increase the range of sensitivity, it would destroy the structure of the Cerenkov light and prevent reconstruction and would make the detector unsuitable for studying proton decay.

Our signal is dominated by the charged current reaction $\bar{\nu}_e p \rightarrow e^+ n$. It may be possible to dissolve a good ν_e detector in water and boost the detector's sensitivity to other components of the burst. Other advantages of adding a salt to the detector are that the density would increase, giving greater sensitivity to proton decay, and the index of refraction would go up, yielding more Cerenkov photons per centimeter. This effect would be offset by the increase in dE/dx, resulting in a shorter range.

For example, it is known that NaCl does not adversely affect the attenuation length of light in water. It is highly soluble: 8000 tons of water dissolve 3200 tons of NaCl. This yields 3.3×10^{31} ion pairs. The chlorine has a modest cross section for ν_e interactions (*11*):

$$\sigma(\nu_e \times {}^{37}\text{Cl}) = 8.1 \times 10^{-41}\ \text{cm}^2$$

The natural abundance is 25 percent ^{37}Cl. For a collapse at 1 kpc, this yields 1.1×10^4 ν_e-Cl interactions. This rate is small compared to the 1.2×10^5 from the water but is comparable to the number of νe scatterings. The observed signal in this case is dominated by the excitation and subsequent decay of a low-lying argon state.

It is concluded that the 8000-ton water IMB detector would be an effective stellar collapse detector. It has a large mass of hydrogen, which gives it a large $\bar{\nu}_e$ cross section. Detector noise would not be a problem for signals originating in a large portion of our galaxy.

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12. The IMB detector is a collaborative effort of the University of California at Irvine, the University of Michigan, Brookhaven National Laboratory, the California Institute of Technology, Cleveland State University, the University of Hawaii, University College London, and the Tata Institute of Fundamental Research. The members of the collaboration are R. M. Bionta, G. Blewitt, C. B. Bratton, B. G. Cortez, S. Errede, G. W. Foster, W. Gajewski, M. Goldhaber, T. Haines, T. W. Jones, W. R. Kropp, J. Learned, E. Lehmann, J. M. LoSecco, P. V. Ramana Murthy, F. Reines, J. Schültz, E. Shumard, D. Sinclair, D. W. Smith, H. Sobel, J. L. Stone, L. R. Sulak, R. Svoboda, J. C. van der Velde, and C. Wuest. This work has benefited from the combined efforts of the members of the IMB collaboration. In particular, E. Shumard has made contributions to the detector implementation. Discussions with H. Bethe, A. Yahil, A. Burrows, J. Applegate, and J. Wilson are gratefully acknowledged. Supported in part by the Department of Energy under contract DE-AC03-81-ER40050 and by the Research Corporation.

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Major Carbon-14 Deficiency in Modern Snail Shells from Southern Nevada Springs

Abstract. *Carbon-14 contents as low as 3.3 ± 0.2 percent modern (apparent age, 27,000 years) measured from the shells of snails* Melanoides tuberculatus *living in artesian springs in southern Nevada are attributed to fixation of dissolved* HCO_3^- *with which the shells are in carbon isotope equilibrium. Recognition of the existence of such extreme deficiencies is necessary so that erroneous ages are not attributed to freshwater biogenic carbonates.*

Carbon-14 dating is a useful and precise technique only in cases where both the initial ^{14}C concentration of the sample and the magnitude of postdepositional changes in isotope ratio unrelated to radioactive decay are known. Wood has played an important role in ^{14}C dating because of its ubiquity on land, its incorporation of ^{14}C in near equilibrium with the atmospheric pool, and its relative resistance to alteration. Interpretation of the ^{14}C contents of other materials is not as simple, and many attempts have been made to define and compensate for the range of processes that affect isotopic composition. For example, studies of freshwater biogenic carbonates should account for the possible effects of contamination, fractionation, reservoir deficiencies including hard water effect (*1*), exchange, and measurement and sampling errors. Despite this range of processes, most measurements of modern freshwater biogenic carbon are at least 70 percent modern ^{14}C, although the largest reported deficiency is in *Potamageton illinoensis*, a living subaquatic plant with 4.72 ± 0.2 percent modern ^{14}C (*2*). Carbon-14 concentrations as low as 3.3 ± 0.2 percent modern, measured in shells of the aquatic snail *Melanoides tuberculatus* (Müller) collected live from three springs in Nevada, are the lowest recorded.

Crystal Pool, Big Spring, and King Spring, three major artesian springs, are