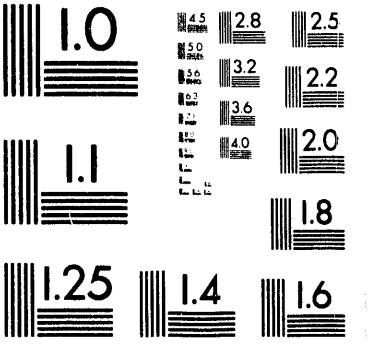

1.0
4.5
2.8
2.5
5.0
3.2
2.2
5.6
3.6
2.0
4.0
1.1
1.8
1.25
1.4
1.6

1 of 1

Conf-930293--4

UCRL-JC-113747
PREPRINT

RECEIVED
AUG 09 1993
OSTI

Weak Neutral Currents and Collapse Initiated Supernova

J. R. Wilson

This paper was prepared for submittal to the
History of Weak Neutral Currents
Santa Monica, CA
February 3–5, 1993

March 19, 1993

Lawrence Livermore National Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

Weak Neutral Currents and Collapse Initiated Supernova

J.R. Wilson

March 19, 1993

Since 1974 the neutrino processes mediated by neutral currents have been a part of supernova (SN) modeling calculations. In this report only present day SN calculations will be discussed.

First I will give brief description of the SN computer model and an outline of the explosion process as depicted by that model. The computer model assumes spherical symmetry and it follows the hydrodynamic evolution of the matter coupled to the neutrino spectral distributions. The mu and tau neutrinos (and their antiparticles) are assumed to have zero chemical potential and are represented by one distribution function. The ν_e and $\bar{\nu}_e$ distributions are each followed independently. The calculations are fully consistent with general relativity.

The SN explosion process proceeds as follows. Massive stars (mass between 12 and 30 $M_\odot$, solar masses) form central iron cores of about 1.4 $M_\odot$ which cool by neutrino emission and contract. After the central density

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

reaches about 10^{10} gm/cc electron capture becomes so large that the inner .5 to .7 $M_{\odot}$ collapses at almost free fall speed. The collapse is halted after the central density increases to about twice nuclear density. An outgoing shockwave is formed in the still infalling material. The shockwave proceeds out to about 300 Km where it slows. At around 0.3 seconds after bounce, conditions are such for the matter between 100 and 200 Km that the electron neutrino and antineutrino captures on neutron and protons are able to blow a bubble in that region which boosts the shock wave moving outward. This propitious situation arises because in the above radial interval there is just sufficient energy in the matter to decompose it to free baryons, and the temperature is low so the matter absorbs neutrinos well but does not emit neutrinos strongly. Neutrinos continue to heat the matter above the proto-neutron star for the following $\sim$ 10 seconds until a cold neutron star forms. The hot bubble formed by the neutrinos has enough energy to expel the outer portions of the star and produce the optical display observed. See figure for a graphic representation of the explosion process.

Next I will discuss the role weak neutral current (WNC) processes play in the explosion process. During the initial collapse phase, as reported long ago by Freedman, WNC induces coherent scattering in the heavy ions that constitute the infalling matter. This increase in neutrino transport cross section keeps the core from being as deleptonized as it would be if there were

no WNC. This lessened deleptonization produces a stronger core bounce.

After bounce the proto-neutron star (PNS) matter is hot enough that mu and tau neutrinos are produced sufficiently rapidly by WNC that the luminosities of all 6 neutrino species are almost equal. Mu neutrinos could just as well be produced by the charged current process of pion decay, but tau neutrinos are produced only by WNC (temperatures are always less then 100 MeV).

An important ingredient necessary for an explosion to occur is neutron finger convection inside the proto-neutron star. Neutron finger instability arises because the outer portions of the PNS are much more deleptonized than the inner portions and hence if the outer material is put at the same temperature and pressure but with no composition change, the deleptonized matter is less buoyant even though it may have a higher entropy. As the neutron fingers descend the composition difference is reduced by the electron neutrino flow, but that is more than made up by the fact all neutron species transport energy and at the same radius the neutrino flows almost equalize the temperature but leave most of the composition difference. The neutron finger convection increases the overall neutrino luminosity so that the neutrino heating in the heating region, $\sim$ 150 Km is strong enough to revive the outward motion of the shockwave.

During the first half of a second, except for assisting the neutron finger

convection, mu and tau neutrinos (via WNC) are just a loss to the system and do not contribute to the explosion. After about one second mu and tau neutrinos begin to play a helpful role in the explosion. As the PNS shrinks and the density outside the PNS (the outside is defined as the radius outside of which neutrinos on the average will have one collision before completely escaping the star) falls off more and more rapidly with density. Neutrinos and anti-neutrinos close to the outside of the PNS if not too colinear in motion may annihilate to form electron pairs. This produces heating on the face of the PNS in addition to the heating by electron neutrino capture on baryons. Material ablated off the PNS continues to be heated and when its entropy rises to $\sim$ 100 the number of electron-positron pairs per baryon becomes large enough that neutrino-electron scattering becomes the dominant heating mechanism. Of course mu and tau neutrinos participate in this heating by WNC. The entropy rises to a peak of several hundred which may provide the long sought after conditions for heavy element nucleosynthesis.

If the tau neutrino has mass then other interesting effects can occur. for example massive neutrinos may be turned into right handed neutrinos and escape almost unimpeded from the PNS. Right handed neutrinos can be formed by neutrino-nucleon scattering. by nucleon-nuclear-neutrino bremsstrahlung. and by pion annihilation producing pairs of right handed neutrinos. The latter process is the dominant one and all these processes are WNC mediated.

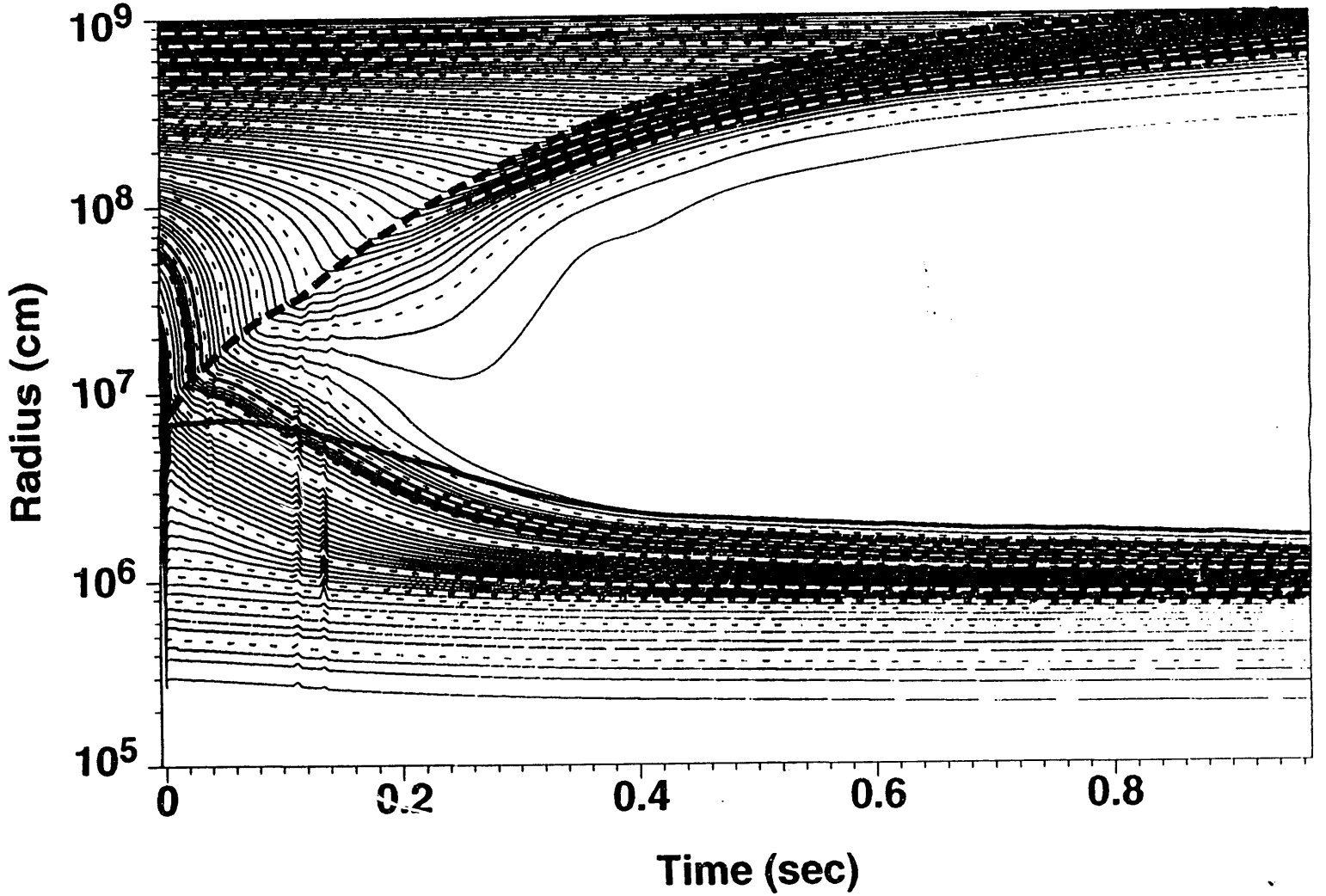
Putting the effects into the numerical model and comparing to the neutrino signal from SN1987A yields an upper limit on the tau neutrino of 3 KeV. If the tau neutrino has mass in the tens of eV range (the cosmologically interesting range) then neutrino oscillation (MSW effect) may be important. If tau neutrinos oscillate into electron neutrinos a more energetic explosion occurs since the tau neutrinos have highter energies than the original electron neutrinos. Most of the energy of the explosion comes from electron neutrino capture on nucleons hence the higher energy electron neutrinos formed by this oscillation will interact more strongly with the matter in the bubble. However, the energetic electron neutrinos formed from the tau neutrinos have a deleterious effect on nucleosynthesis. The electron neutrinos destroy the neutron excess in the bubble. The repeated capture of neutrons on heavy nuclei is thought to produce the heavy elements. Neutrino oscillation could prevent SN from being the source of heavy elements, however a small mixing angle alleviates this difficulty.

Finally, inelastic scattering of tau neutrinos by heavy elements via WNC on Earth opens up a possible mechanism for measuring the mass of the tau neutrino. For sufficiently high energy neutrinos enough energy is deposited by the scattering from a large nucleus that a neutron is boiled off the nucleus. Tau and mu neutrinos are much more energetic than electron neutrinos so most neutrons produced would arise from mu, tau neutrinos. It is proposed

to put a BF_3 counter array deep underground to detect these neutrinos in the event of a galactic SN. Neutrino mass would be inferred by the difference in signal times from such counters and from the Kamiokande signal which measures predominantly electron neutrinos.

Figure Caption: Radius-time trajectories for selected mass points for the first 0.9 seconds of the SN explosion. Bounce time is the zero of time. The dash line is the shockwave position. The shock is seen to go out to about 4×10^7 cm and slow down. Material underneath the shock for the first 0.3 seconds is cooling by neutrinos and continuing to fall onto the proto-neutron star. The heavy line is the neutrino photo-sphere. Between 0.3 and 0.7 seconds the first phase of neutrino heating starts. After about 0.7 seconds neutrino pairs annihilate and neutrino-electron pair heating becomes important. The heating of the hot bubble then continues for many seconds.

Radius vs time



UB4-26420-01

DATE
FILMED
10/13/93

END