CONF-8805142--7

Summary for Astrophysics and Non-Accelerator Physics

BNL--41423

S. H. Kahana

DE88 013782

Physics Department
Brookhaven National Laboratory
Upton, New York 11973

Invited summary talk

Intersections between Particle and Nuclear Physics (III)

Rockport, Maine

May 1988

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, 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 any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This manuscript has been authored under contract number DE-AC02-76CH00016 with the U.S. Department of Energy. Accordingly, the U.S. Government retains a non-exclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SUMMARY FOR ASTROPHYSICS AND NON-ACCELERATOR PHYSICS

Sidney H. Kahana

Brookhaven National Laboratory, Upton, NY 11973

INTRODUCTION

Summarising, in real time, a parallel session in a conference of this size and scope serves an obvious purpose. Committing such a summary to paper would appear of less value, since the several contributors to the session have themselves presented their offerings in writing. With this in mind, I will not overly detail the separate talks in this year's Non-Accelerator and Astrophysics section, but will instead reiterate the conclusions (or absence of conclusions) arrived at by these speakers and comment on these in light of their relevance to the theme of the Intersections Conference and to the scientific world at large. I will include within the scope of my comments the plenary talks on closely related topics.

SUPERNOVA 1987a

One group of speakers (Bethe, Brown, Kirshner, Baron, Masaike, and Penypacker) concentrated on the observation of, modelling of, or search for supernovae. SN1987a, of course, played a highly visible role in all of this, stimulating much activity in astrophysics, in the nuclear physics associated with gravitational collapse and in neutrino physics.

Kirshner displayed in graphic and entertaining fashion the output of a wide variety of detectors brought to bear on the electromagnetic radiation, optical, and otherwise, emitted by SN1987a. We have, uniquely, photographs and spectra from the progenitor [Sanduleak 69-202] of a type II (or any other type) supernova; a surprising progenitor at that, being a superblue rather than a superred giant. As Kirshner noted and Beier later expanded upon, this supernova was the first to be seen as a neutrino emitter^{1,2}. The detection of electron antineutrinos from 1987a, a most fortunate happening tied to the perspicacity of the nucleon decay watchers, opens a new and glorious phase in the evolution of neutrino astronomy. My former colleagues at Brookhaven, Ray Davis and collaborators³, were responsible for the first phase in this discipline. Paradoxically, their measurements have created puzzles, while 1987a has generated interesting limits on the neutrino mass, lifetime, magnetic moment, and other characteristics. At the very least 1987a has dramatically confirmed theoretical ideas about gravitational collapse.

Hans Bethe developed the physics of the extant theoretical mechanisms for producing supernovae subsequent to gravitational collapse (type II). Gerry Brown considered the role in the supernova, and the derivation, of the equation of state for hadronic matter of supranormal density. Baron presented the nature and status of the latest simulations of the prompt mechanism by a Brookhaven - Stony Brook collaboration⁴. Although the present evidence^{5,6} from the analysis of the light curve of SN1987a is not conclusive, it appears a vigorous explosion

occurred, with total energy near or above 1.5×10^{51} ergs. A prompt mechanism, i.e., direct explosion by the hydrodynamic shock generated during collapse, seems favoured.

Despite the many "moving parts" of these or any other similar calculations, our understanding of the input physics is such that the results are sensitive to a limited number of parameters. Indeed, one can say that if the initial "iron" core mass (i.e., at the instant before collapse) were known and the equation of state for matter up to 3 or 4 times normal saturation were specified, then the fate of the shock could be determined. Aside from these few physics inputs, the most uncertain part of the simulation is the technical treatment of neutrino transport. One can, presently, map out a region of parameter space for an equation of state for which the prompt mechanism will successfully generate supernova explosion. Improvements in the handling of neutrino transport will somewhat alter the boundaries of this region of viability.

The downward evolution of iron core masses in the work of Hashimoto and Nomoto⁷ or of Woosley and Weaver⁸, makes certain the existence of progenitors with main sequence mass (M_{ms}) for which type II supernova will go by the prompt mechanism. In particular, the current Woosley-Weaver model for $M_{\text{ms}} = 18M_{\odot}$ possesses a core mass $\approx 1.36 M_{\odot}$, and such cores were found to "explode" in past calculations⁴, while the Nomoto-Hashimoto $13 M_{\odot}$ model for which $M_{\text{core}} = 1.18 M_{\odot}$ will certainly explode.

Bethe and Baron very clearly outlined the steps taken to place the simulations on a good footing. The more difficult problem of deriving a high density description of nuclear matter is still with us. Brown pointed out how high the stakes are and showed how one could reconcile⁹ the situation in stellar interiors with conclusions drawn from relativistic heavy ion collisions performed at LBL^{10,11}. Knowledge of the state of high density matter is also relevant to the expected transition [in the case of high density and low temperature probably a chiral-restoration] to quark-gluon matter. These two fields of study can usefully feed on each other.

NEUTRINOS FROM SN1987a

Probably the most unusual aspect of 1987a has been the actual observation of neutrinos. This remarkable eventuality was accomplished with detectors designed for other purposes and only fortuitously in place at the right instant. Nevertheless, the rewards have been many. E. Beier went over the setups and results at Kamioka and IMB and reminded us of the startling confirmation of the theories of collapse provided. He discussed the planned upgrade of KII and the possible heavy water detector at Sudbury in Canada (SNO)¹². Supernova neutrino observatories must likely find other things to do to justify their existence, and, for example, SNO's primary purpose is to examine solar neutrinos; perhaps disentangling the neutral and charged currents.

It is interesting to contrast the limits on neutrino mass discussed in other sessions of this meeting [see B. Kayser and J. Wilkerson in these Proceedings] with the limit deducible from SN1987a. The laboratory experiments suggest a neutrino mass presently no higher than 18 – 25 eV, while the limit obtained from the supernova is conservatively quoted as between 10 and 15 eV. No one in his right mind would discourage further terrestrial experiments on such a basis, but the advantages of a long flight path are evident.

Further limits established by the IMB and KII neutrinos include, quixotically, an equality to about a part in 10^9 between the "speed of light" for neutrino and that for photons, a limit on masses for neutrinos into which electron neutrinos can oscillate if any supernova mechanism is to be possible, and a whole host of others described elsewhere¹³.

Among all the fanciful imaginings produced by theorists examining the 19 neutrinos seen, there remains a hint of something unusual, tied to the final three late-time sightings by Kamiokande II. These neutrinos, labelled #10, 11, 12 are assigned relatively high energies and consequently are highly unlikely to have all been background (10^{-4} probability). The time sequence in KII alone puts a gap of seven seconds between an initial 1.92 second pulse and these last events. This gap is reduced to five seconds if the IMP and KII detections are joined together in the most straightforward fashion, but still leaves one with a bit of a puzzle. This is especially so when one combines these data with the theoretical difficulties in extending the neutrino-visible cooling period beyond several seconds. It is tempting to conclude the late time neutrinos are the result of an appreciable reheating in the proto-neutron star core. Again, the theoretical time scale for material falling back into the core is on the order of a few seconds. A phase transition from hadronic to quark-gluon matter could result in a change to higher core density, smaller radius and additional gravitational binding energy. The transition, if it were to, say, three-flavoured quark matter, might indeed require a time of the order of many seconds to be spread over the entire, dense core — a tantalizing possibility.

X-RAYS AND γ -RAYS FROM SN1987a

As I have pointed out, observations from SN1987a have by no means ceased. Kirshner mentioned the x-rays detected by GINGA¹⁴, and Masaike displayed very recent observations by this Japanese x-ray satellite. The initial x-ray observations in September showed two components — the harder part of the spectrum above 10 keV can be understood¹⁵ as down-scattering of the two cobalt γ -rays at 0.88 MeV and 1.23 MeV, while the softer x-rays might have arisen from collision between the exploding stellar atmosphere and previous circumstellar matter. Theorists have had a hard struggle with the data, suggesting first in September observations would not be made for several months and then having no easy explanation for the sudden rise (or fall) in intensity seen by GINGA in January.

Masaike made a claim for observation of extremely high energy γ -rays from SN1987a on two days in January also, by a combined Japanese - New Zealand team working with scintillation arrays and Cerenkov mirrors at a site in New Zealand. With respect to the x-ray seen by GINGA, Kirshner warned of the existence of a nearby, perhaps unresolved, source, Cygnus X-1. This variable source might be a problem for the γ -ray experiment as well. In any case, the reader can judge for himself by examining Masaike's figures showing the x-ray flux seen by JANZOS during a 42-hour period in January and the excess over background they extract, with apparent maxima on January 14 and 15. Surely, these courageous experiments must eventually give fruit, but the ability of the neutron star to produce such high energy particles relies on the existence of a pulsar or at least of a strong magnetic field. Just when this happens we are not sure. Kirshner did tell us that the optical light curve is dropping away from the exponential decay driven by Cobalt-56 decay and that there is little enough time till at least the Cobalt γ -rays are directly visible. The direct observation of these γ -rays and subsequently of, say, iron x-rays from the surface of the neutron star are eagerly anticipated. Accurate measurement of red shifts of Fe x-ray lines would contain a wealth of information about neutron star sizes and hence about the hadronic equation of state at high density.

AUTOMATED, OPTICAL SUPERNOVA SEARCHES

The optical supernova searches by the Berkeley group, reported on here by Carl Pennypacker, are part of another effort to be sustained over a longish time, with admirable goals and several presently interesting results. The differential observation of large numbers of galaxies, automated with a system including a PC to control the telescope and principal collector, and an eventual analysis by a microvax has already produced eight supernova discoveries, six not seen by other observers. Eventually the group expects to see more than fifty supernovae per year. The two present best discoveries, 1986i and 1987k, speak to the recent sightings of more than just 1987a. A most interesting result is the preliminary evaluation of the Hubble constant at 70 km/sec/MPC by using the observed supernovae as distance measures.

ULTRA HIGH ENERGY COSMIC RAYS; FLY'S EYE

From Masaike on γ -rays from pulsars to Loh on high energy γ -rays from anywhere in the galaxy is only a small step. The FLY'S EYE detector in Utah is a massive undertaking, directed towards a fundamentally interesting question, the sources of very high and ultra high energy gamma rays. The detector itself and the analysis used by this group of scientists are both unusual and can be followed in detail in Loh's contribution to these sessions. Loh's presentation of data at this meeting spoke to a momentous observation if sustained, the detection of γ -rays (or other neutrals) at energies $\sim 5 \times 10^{17}$ ev and apparently from the direction of Cygnus X-3. At such an energy even the short-lived neutrons might arrive relatively unscathed over the 40,000 or so light years from

Cygnus X-3, in fact 14% of neutrons at this energy survive. Once again the data is more tantalizing than conclusive, but with time must acquire considerable significance.

MONOPOLES, PRIMORDIAL NUCLEOSYNTHESIS, FIFTH FORCES and ELECTRIC DIPOLE MOMENT

In this final group of talks, we certainly move away from the subject of supernova or of cosmic rays from remnants of supernovae. Magnetic monopoles, quantized by Dirac, seen by some and not by others, are an inevitable result of GUT theories but perhaps in very small unobservable numbers. Groom, who is himself involved with one group of monopole gazers, presented us with an entertaining and succinct picture of such searches. His most important message was that limits set on monopole fluxes are strongly linked to assumed properties, i.e., aside from the obvious magnetic charge. Only induction detectors are free from bias. The best hope for the future seems to focus on the MACRO detector of Gran Sasso to be started up in part this summer. Again, this detector will give good flux limits for monopoles possibly possessing electric charge but which do not catalyse nucleon decay.

Applegate's indication that a first order QCD phase transition in the early universe, at 10^{-4} seconds in the evolution, might be observable as a relic in the footprint of r-process elements is certainly worthy of careful consideration. An important feature of his collaborative work with Hogan and Scherrer is the possibility of closing the universe mainly with baryons while still achieving the observed deuterium to helium-4 ratio. The criticism of this work by some on its prediction for primordial ${}^7\text{Li}$ is weakened somewhat by the fragility of this element in almost any environment. A preliminary assay of r-process elements in galactic-halo stars has not as yet uncovered any evidence of the phase transition.

I come now to the eminently clear talk by Boynton on a subject which many of us wish (unscientifically) had been left dormant. Fifth, sixth, and other fundamental forces may one day emerge from the primordial slime, and surely our experimental science must be able to withstand these tests, but the present situation is more muddled than ever, surely than before elevators and Eötvös. Boynton described in detail essentially two experiments, one by Eckhardt et al on little g measured up television towers, and the other INDEX I (and II) by his own group at a site near Seattle. Eckhardt has anomalous results for g at various altitudes above the ground, disagreeing to parts in 10^7 with values predicted by numerical continuation of measurements on a surface grid around the tower. Boynton, in INDEX I, using a torsion balance near a 130 meter cliff, obtains $\xi\lambda = -0.023 \pm 0.007$ meters for the product of non-gravitational coupling and range. The sign of this result is inconsistent with the new force being proportional in strength to baryon number alone, and requires a dependence on isotopic spin as well. The positive results of INDEX I and of

Thieberger are seemingly close to being contradicted by the conclusions of Fitch and collaborators. Neither positive result here provides any simple explanation for Eckhardt.

Finally, Bruce McKellar outlined calculations of non-vanishing neutron electric dipole moment from several models. I refer you to his talk for a description of the consequences to both standard and other models from different scales of edm's .

On behalf of Gene Beier and myself I would at the end like to thank all of the speakers who contributed so vigorously and creatively to our sessions. For a more complete list of references on these subjects I refer you to the specific talks in these Proceedings.

REFERENCES

1. K.Hirata et al., Phys. Rev. Lett. 58, 1490 (1987).
2. R. M. Bionta et al., Phys. Rev. Lett. 58, 1494 (1987).
3. J. K. Rowley, B. T. Cleveland, R. Davis Jr., American Inst. Phys. Conf. Proc. 126, 1 (1985).
4. E. Baron, J. Cooperstein, and S. H. Kahana, Phys. Rev. Lett. 55, 126 (1985);
E. Baron, H. A. Bethe, G. E. Brown, J. Cooperstein, and S. H. Kahana, Phys. Rev. Lett. 59, 736 (1987).
5. S. E. Woosley, P. A. Pinto, and L. Ensman, Astrophys. J. (in press).
6. T. Shigeyama, K. Nomoto, M. Hashimoto, and D. Sugimoto, Nature 328, 320 (1987);
T. Shigeyama, K. Nomoto, and M. Hashimoto, Astronomy and Astrophys. (in press, Nov. 1987).
7. K. Nomoto and M. Hashimoto, private communication.
8. S. E. Woosley, P. A. Pinto, P. G. Morton, and T. A. Weaver (in press);
S. E. Woosley, private communication.
9. T. L. Ainsworth, E. Baron, G. E. Brown, J. Cooperstein, and M. Prakash, Nucl. Phys. A464, 740 (1987).
10. D. W. Harris et al., Phys. Lett. 153 (1982);
H. A. Gustafsson et al., Phys. Rev. Lett. 52, 1590 (1984).
11. J. T. Molitoris and H. Stöcker, Phys. Rev. C32, 346 (1985);
J. Aichelin, A. Rosenhauer, G. Peilert, H. Stöcker, and W. Greiner, Phys. Rev. Lett. 58, 1926 (1987).
12. G. Aardsma et al., (Sudbury Neutrino Observatory Collaboration) Phys. Lett. 194B, 321 (1987).
13. J. M. Lattimer and J. Cooperstein, Astrophys. J. (in press);
A. Burrows and J. Lattimer, "Neutrinos from SN1987a", University of Arizona preprint (April 1987);
S. H. Kahana, J. Cooperstein, and E. Baron, Phys. Lett. B196, 254 (1987);
M. J. Turner, Phys. Rev. Lett., 1797 (1988).
14. T. Dotani et al., Nature 330, 6145 (1987).
15. M. Ioh, S. Kumagi, T. Shigeyama, K. Nomoto, and J. Nishimura, (preprint).