SOURCES AND DETECTION OF DARK MATTER IN THE UNIVERSE*

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The 2nd Symposium on Dark Matter in the Universe, organized by UCLA, was held in Santa Monica, California, February 14-16, 1996 with 100 participants. It was an exciting meeting, not only because of the new observations presented but also because of the expectations of major clarification of the nature of the Universe in the near future.

The Symposium started with an overview of the current status of the Hubble Constant by V. Trimble (UM, UCI) and the Age of the Universe by B. Chaboyer (U. Toronto). While H_0 is still greatly uncertain, the age of the Universe seems to be firmly greater than or equal to 12 billion years. Contrary to all of the recent press reports, there is no real "age crisis" yet.

One of the most exciting results was the announcement of the observation of seven very distant type-Ia supernovas (with a total of 11 more to be analyzed) by the LBNL-led collaboration by S. Perlmutter (LBNL). There is a real possibility of measuring q_0, the deceleration parameter of the Universe, and to determine the cosmological parameters, Ω and H_0, by using this technique. On the same note, the future detailed study of the CBR angular fluctuations with a new generation of detectors on new satellites can also give H_0 and Ω_0, *etc.* This subject was reviewed by A. Lange (Caltech) and E. Wright (UCLA).

An excellent, lucid review of this theory was provided by J. Silk (UC Berkeley). Following the pioneering work of COBE, the asymmetry in the CBR has now been measured at the 1-degree angle scale with important new data that arrived in 1996, which is already providing

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important clues to the cosmological parameters of the Universe. (At the same meeting two years earlier, the COBE data was still very novel.)

The discovery of a Brown Dwarf and more evidence for MACHOs indicate at least two concrete sources of dark matter in our Galaxy. Both topics were represented at the meeting by S. Kulkarni (Caltech), who presented the brown dwarf discovery, whereas members of the MACHO team [D. Bennett (LLNL) and others] discussed the MACHO search status. They reported a total of eight events for two years of observation. The mass of the MACHO candidates are from 1/4 to 1/2 of a solar mass, leading to the obvious question of whether these are stars, white dwarfs, or whatnot!

On the large scale of the Universe, the use of gravitational lensing to measure the total mass of galactic clusters is now becoming a reality. R. Blanford (Caltech) presented an overview of this exciting field. In the next few years, the comparison of the mass determined by lensing and conventional techniques could shed "light on the nature of the dark matter."

There were detailed discussions of the nucleosynthesis of light elements (theory in good shape, although one group still claims discrepancies) and of the large scale structure of the Universe, which still implies hot dark matter suggesting a neutrino mass from 2–5 eV [results presented by J. Primack (UCSC) and C. Ma (Caltech)]. There are still suggestions that the cosmological constant, Λ, first introduced by A. Einstein, may be nonzero; however, it was clear from the discussions at this meeting that such conclusions are premature.

One of the interesting discussions at the meeting was the search for indirect signals from dark matter annihilation. Perhaps the most interesting result was given by S. McKee (U. Michigan), who showed that the previously reported excess of cosmic e^+ and $\bar{p}$ have gone away. The cosmic $\bar{p}$ yield is now fully consistent with being a secondary product of energetic cosmic rays.

The search for particle dark matter is entering a new, intense phase with major experiments to search for axions, WIMPs, and neutrino mass coming on line all over the world. F. Boehm (Caltech) gave a general overview of the current search for neutrino mass and oscillations. The key experiments to search for a neutrino mass in the few-eV range are LSND (LANL), Karman (ISIS), Chorus (CERN), and Nomad (CERN). Reports from all of these detector groups were given at the meeting. While the positive signal from LSND has not been

confirmed (by themselves or others), the hope is still high that one of these experiments [as well as the COSMOS (FNAL) experiment] will be able to demonstrate neutrino oscillations in this mass range. While there is much progress, it is clear that this will be a long drawn-out process.

The major progress in the search for axions comes from the LLNL group, where an experiment is just getting started. The most promising form of WIMP is the supersymmetric neutralino. Unfortunately, the expected rates for SUSY WIMPs now falls into the $10^0 - 10^{-5}$ events/kg/day range, as was discussed by G. Kane (U. Michigan) and R. Arnowitt (Texas A&M).

Perhaps the most exciting news from the meeting is that various detectors are now about to start a real search for supersymmetric WIMPs in several underground laboratories. It was generally agreed that it requires at least a 1-kg detector to start this search. There are three different methods behind these detectors, described by P. Smith (RAL) for detectors with T > 100°K, including NaI, B. Cabrera (Stanford) for low temperature detection, and D. Cline (UCLA) for discriminating liquid-xenon detectors at the meeting. A new limit from the NaI detectors of <10 events/kg/day was reported (at the edge of the expectations for SUSY WIMPs). The low temperature and discriminating liquid-xenon detectors may be able to go to the $10^{-1} - 10^{-2}$ event/kg/day rate in the next few years.

As a summary of the meeting, it is possible to order the important new measurements to be made: (A) a new satellite to make precise studies of the CBR, (B) more observations of the distant supernova Ia's to measure q_0, (C) WIMP detectors in the 100-kg mass range, and (D) resolution of the issue of the few eV neutrino mass.

It is hard to imagine a more exciting discovery than that of SUSY WIMPs, implying that particle physics can once again be done in our own (basement) laboratories. The proceedings of the symposium will appear in *Nuclear Physics B* in the summer 1996. The third meeting in this series will be held in Santa Monica, CA, February 1998.