Highlights of Astronomy, Vol. 13
International Astronomical Union, 2003
O. Engvold, ed.

DARK MATTER: Astronomical Aspects

Virginia Trimble

Department of Physics and Astronomy, University of California, Irvine CA 92697 USA, and Astronomy Department, University of Maryland, College Park MD 20742 USA

Abstract. The chief evidence for appreciable dark matter in the universe comes from the monotonic increase in mass to light ratios measured for various astronomical systems as one looks on larger and larger length scales. Though the evidence comes from photons, most of the dark matter is non-photonic, and, for that matter, non-baryonic. There remain several questions about the nature and behavior of dark matter to which conventional astronomical observations are (probably) relevant. The most germain to this JD is whether astronomers have seen decay or annihilation products from dark matter particles, to which the current answer seems to be no. We look at a few of the others.

Single stars and clusters have mass-to-light ratios of order unity, in solar units, while the largest scale structures and global values reach about 300, corresponding to a matter density of about 30% of closure density. If you think of this as a graph with a nearly straight line sloping from lower left to upper right, then the standard points on it pertain to the solar neighborhood (and inner bright parts of other galaxies), the outskirts of galaxies (rotation curves, globular cluster velocities, etc), binary galaxies and small groups, rich clusters, superclusters, and the universe as a whole. Curiously, by giving a little thought to the assorted distances scales in use at various times, you could have drawn this line before World War II, using the solar neighborhood numbers of Kapteyn (1922) and Jeans (1922), the Babcock (1939) rotation curve for M31, the binary galaxies of Holmberg (1937), and the work on the Coma and Virgo clusters by, respectively, Zwicky (1933) and Smith (1936). Holmberg drew attention to this qualitatively, by saying he thought it reasonable that his typical mass for a galaxy should come somewhere between those found by Hubble (for visible parts) and those found by Zwicky and Smith if you divide the mass of the whole clusters by the number of galaxies you see.

Most astronomers working in extragalactic astronomy would endorse the previous paragraph. There remain, however, three sorts of alternatives. The first is that gravity might not behave as described by the equations of Newton and Einstein. Two examples are the MOdified Newtonian Dynamics (MOND) of Milgrom (2002) and the conformal gravity of Mannheim (2001). The second goes further, with non-standard contributions to the velocities we observe as well as to the forces exerted by matter. The quasi-steady state theory (Narlikar et al. 2003) is the best-known example in this class. Third is something that none of us has thought of yet, for which there are necessarily no references except to the speaker who was originally scheduled to give this talk.

In the absence of direct laboratory detection of dark matter particles, most of the evidence we have for their properties comes from astronomical observations. Many of the results have been around for long enough to be well known: the universe is not closed by primordial black holes (or Hawking radiation does not exist, or both); the universe is not closed by billion solar mass black holes (or many more QSOs and GRBs would be lensed); the universe is not closed by gravitational radiation in a subset of possible wavelength bands (or pulsar timings would be much more erratic); the Milky Way is not dominated by MAssive Compact Halo Objects (or there would be more microlensing of LMC stars); the universe is not closed by hot (neutrino-ish) dark matter (or galaxies would not have formed in time). My own earlier views on these and related topics can be found in Trimble (1987, 2003) and annual updates (Trimble and Aschwanden 2003, plus earlier, and probably later, papers in the same series)

An assortment of other astronomical questions are still open, and may turn out to have answers that bear on the nature of dark matter. Here is a subset:

Where are the missing satellite galaxies? The three classes of answers floating around are not mutually exclusive. (A) They were unable to accrete gas because of re-ionization, but show up as lumps in lensing studies of halos, (B) They accreted gas but made no stars and are the high velocity HI clouds, and (C) They accreted gas and made stars, but were later damaged, with the dwarf spheroidal galaxies being the tip of the mass distribution and globular clusters being the stripped cores of the others.

Do halos (galaxies or clusters) have cusps or cores at their center? The observers' answers look much more like isothermal cores than like singular cusps, so the question goes back to the theory team to see if they can modify the CDM prediction by adding other sorts of DM, including baryons.

Are most halos fairly round? Yes, probably, with the structure of polar ring galaxies the traditional supporting evidence, Iodice et al. (2003) and mild triaxiality implied by disk flaring (Bekki and Freeman 2002).

Could the Milky Way have a significant disk dark matter component? If each paper in the past two years gets one vote, than it is about 7:1 against, but take a look at the minority view (Kalberla 2003) before the refutation (Drake and Cook 2003)

Have we seen decay, annihilation, or collision products from dark matter candidates? A fascinating (but apparently wrong) suggestion was the Sciama neutrino, whose mass was just a bit more than twice the Lyman limit energy, so that the decaying particles made a large contribution to intergalactic and galactic fringe ionization. Recent ultraviolet observations have not found the predicted photons. Still open is whether the highest energy "cosmic rays" might actually be produced in the galactic halo by something (presumably very high energy neutrinos) coming from very far away but not subject to the ZKG limit hitting something that has been here all along (presumably the dark matter particles in the halo).

Is there a real, significant discrepancy between global values of the total density of dark matter, which tend to fall around or above 0.3 of closure and the values derived from clusters of galaxies, which tend to fall around or below 0.2? This turns out to be an enormously over-simplified version of a broader question about whether the various determinations of all the cosmological parameters (the good ones anyhow) are mutually consistent. The answer is clearly no (Bridle et al. 2003). As always, "further observations are needed" to decide whether it will eventually all come together, or the situations will become serious but not desperate (as the German general said to the Austrian general) or desperate but not serious (as the Austrian general said to the German general).

Acknowledgments. I am grateful to the Harry Messel International Science School and the Peter Gruber Foundation for contributions to travel expenses to the IAU GA and distinctly ungrateful to Sir Martin Rees for deciding not to come. One version of his own views on the subject should appear next year (Rees 2004).

References

Babcock, H.W. 1939 Lick Observator Bulletin 19, 41

Bekki, K. & Freeman, K.C. 2002. ApJ 566, 245

Bridle, W.L. et al. 2003. Science 299, 1532

Drake, A.J. & Cook, K.H. 2003. ApJ 589, 281

Holmberg, E. 1937. Lund Annals 6, 1

Iodice, E. et al. 2003. ApJ 585, 730

Jeans, J.H. 1922. MNRAS 82, 122

Kalberla, P.M.W. 2003. ApJ 588, 805

Kapteyn, J.C. 1922 ApJ 55, 302

Mannheim, P. D. 2001. ApJ 561, 1

Milgrom, M. 2002. ApJ 571, L81

Narlikar, J. et al. 2002. ApJ 585, 1

Rees, M.J. 2004. Discover Magazine, to appear

Smith, S. 1936. ApJ 83, 23

Trimble, V. 1987. ARA&A 25, 425

Trimble, V. 2003 in W. Freedman ed. Measuring and Modeling the Universe. Cambridge University Press

Trimble , V. & Aschwanden, M. 2003. PASP 115, 514

Zwicky, F. 1933. Helv. Phys. Acta 6, 110