PUBLICATIONS OF THE KOREAN ASTRONOMICAL SOCIETY
7:31~37, 1992

DARK MATTER IN THE UNIVERSE : BRIEF REVIEW

OH, KAP-SOO
Department of Astronomy and Space-Science, Chungnam National University

(received February 10, 1992)

ABSTRACT

Dark matter in various size of scales is reviewed briefly. The evidence of dark matter in dwarf spheroidal galaxies is still uncertain. However there is no doubt about the existence of dark matter in larger scales. Many proposed candidates for dark matter are still speculative. Several possibilities of direct detection of dark matter are proposed.

I. INTRODUCTION

About sixty years ago, from the study of Coma cluster, Zwicky (1933) concluded that the velocity dispersions in clusters of galaxies required 10 to 100 times more mass to keep them bound than could be accounted for by the luminous galaxies themselves. That was dramatic evidence for dark matter (hereafter, often DM) that is still among the best we have.

The beginning of the modern era of DM research was initated by Ostriker et al. (1974) and Einasto et al. (1974). They tabulated galaxy masses as a function of the radius to which they applied and found mass increasing linearly with radius out to at least 100 kpc and 10^{12} $M_\odot$ for normal sprials and ellipticals.

Since then, many observers and theoretists devoted to understand this unseen matter. Now regarded as at least a decent working hypothesis, DM has turned from nemesis to powerful ally : initially invoked merely to bind galaxies and clusters of galaxies, it is now called upon to form them and, by some, even to close the universe itself.

Stars, planets, comets, gas, dust, and stellar remnants can be dectected by their electromagnetic radiation. So these masses are called luminous or known masses. We also can deduce the mass from gravitational effect, which is referred as dynamical mass. Dynamical mass provides an estimate of the total mass. Therefore mass of DM is the rest of the substraction of known mass from dynamical mass. DM is any form of matter whose existence is inferred solely from gravitational effects.

We like to describe the status of the DM in various objects, from galaxy to clusters of the galaxies. We will also mention about the composition and the detection of DM.

II. DARK MATTER IN VARIOUS OBJECTS

1. Milky Way

a) Solar neighborhood

Dynamical mass around solar neighborhood can be calculated from the vertical pressure - gravity balance. So we can get the amount of dark matter in the disk. This is important because it constrains the shape of our Galaxy's DM distribution, and disklike DM will be baryonic, i.e. ordinary matter. However the current evidence of dark matter is ambiguous (Kuijken and Gilmore 1987). Dynamical mass from the surface density and volume density using K giants and old F stars shows little or no requirement of DM in either a thin or thick disk. But analysis from young F stars constrains the amount of dark matter less than two-third of dynamical mass. Therefore we need better data to justify the existence of DM in the solar neighborhood.

b) Milky Way rotation curve

If a rotation is balanced by gravity, then the circular orbit speeds of test particles at known distances from the center could be turned into a curve of $M(R)$ with only modest uncertainties arising from the difference between the gravitational potentials of spheres, ellipsoids, and thin disks.

Although there are some problems in this method due to uncertainties of distances to objects and our own distance from the Galactic center, the amount of DM is about half of dynamical mass inside R_o, and about two thirds out to about 2 R_o (Trimble 1987).

c) Milky Way halo

Visible tracers in the halo are RR Lyraes and field stars (Hawkins 1984, 1987 ; Kuijken and Gilmore 1989), globular clusters (Frenk and White 1983), satellite galaxies (Little and Tremaine 1987), Magellanic stream (Lin and Lynden-Bell 1982). The result of these investigations show that $M(R)$ gradually increases with radius to at least 10^{12} $M_{\odot}$at 100 kpc (implying $M/L \geq 30$), and fluctuations due to different choices of velocity distribution. However there are somewhat ambiguous about this in two ways. First, a nonstandard modeling of the the gravitational effects of the Magellanic Clouds (Valtonen et al. 1985) says that cluster and satellite velocities do not currently probe the gravitational potential very well. Second, the most extreme members of the stellar and cluster populations may not currently be bound to the Milky Way. Some stars with high positive velocities could be runawys from distrupted binary systems.

Despite the uncertainties, it seems safe to conclude that (a) within R_o, there is about as much mass in a spheroidal (mostly dark) halo as within the luminous disk, and (b) outside R_o, there is much more matter, probably 3 - 10 times, than inside.

2. Other Disk Galaxies

a) Rotation curves

Optical rotation curves have been obtained for ~ 60 galaxies from H II observations. The median extent of optical rotation curves before 1976 was only 30% of Holmberg radius (R_H). Today it's about 0.5 R_H. While known matter dominates inside 80% of optical radius, some optical rotation curves require no DM. Could do without DM altogether, if there's a modest change in stellar population with radius, such that M/L of disk increases with radius. However, the consensus is that mass of DM is about the half of the total mass inside the optical radius.

Giant H I envelopes occur in one third of all galatic disks. Extended rotation curves have been obtained for about 20 galaxies from 21 cm observations. Their median extent is about 1.5 R_H (Salucci and Frenk 1989). Maximum disk method show that M/L is about 20 and 80% of total mass is the form of DM inside 2 R_H.

b) Shape of the dark matter distribution

For external spiral galaxies as well as Milky Way, evidence favoring a spheroidal rather than flat dark component comes from H I flaring, H I warps, disk stability and polar ring galaxies. However less centrally condensed distribution of globular clusters highly suggest triaxiality of the shape of DM halo (Ostriker et al. 1989).

3. Elliptical Galaxies

a) Central velocity dispersions

After velocity dispersions measured from the absorption-line profile, it can be deconvolved to density profile using some standard model. Although there is uncertainty in deconvolution of absorption-line profiles, M/L in visible part of most normal ellipticals is 7 - 14 (Bacon et al. 1985; Jarvis and Freeman 1985).

b) Radio data

Most ellipticals have very little gas, and cases showing a coherent gas velocity field are even rarer. Results in NGC 4278, NGC 5666, NGC 7097 are 7 - 40 of M/L.

c) X-ray data

Recent observations have shown that most ellipticals possess extensive halos of hot gas. Samples from Forman et al. (1985) show M/L is ~ 40 inside 50 kpc. The best studied case is M87, for which M/L is about 150 inside 300 kpc, which leads that DM is 96% of total mass. This is the largest scale associated with individual galaxies for which there is evidence of DM.

4. Dwarf Galaxies

The dwarf irregular galaxies are believed to be the low mass end of the family of disk galaxies. In most case, the observed rotation curve from H I is flat or rising in the outer parts of the galaxy. The galaxies, with $-19.8 < M_B < -14.5$, give strong evidence of DM ($M/L \sim 8 - 15$). For smaller dwarf irregulars, it is more difficult to study their DM distributions. Because the rotational velocities are low and support from random gas motions become significant (Freeman 1987).

The central velocity dispersions of spheroidals give very large values of $M/L(\geq 50)$ in Ursa Minor and Draco (Freeman 1987). This is the smallest scale on which there is an evidence of DM. However this evidence may be uncertain because the large velocity dispersion may reflect the tidal disruption phase of dwarf spheroidal galaxies, and after stars become gravitationally unbound to these galaxies, stars beyond the tidal radius may comove with dwarf spheroidal galaxies for some time. Thus, the large M/L inferred from kinematic data remains to be suggestive rather than affirmative (Oh et al.1992).

5. Binary Galaxies

The measurement of binary galaxy masses uses velocity differences and projected separations. Once differences in assumed values of Hubble constant, orbital eccentricity, and wave band for luminosity have been reconciled, M/L can be calculated for assumed orbits. Circular orbits give higher values than isotropic case, and radial orbit give least value. Result from 48 pairs of galaxies show M/L 21 ± 5 for sprials and 39 ± 9 for ellipticals.

6. Gravitational Lenses

Any mass concentration bends the path of light travelling nearby, and thus acts as a gravitational lens. Analysis of multiple images of qusar show $M/L \sim 100$ within 10 kpc, though several cases of qusar-galaxy association with no lensed image suggest M/L less than 10.

7. Clusters of Galaxies

a) Cluster cores

A dynamical study of Virgo (Zwicky 1933) was among the first indicators of dark matter in the universe. Virial theorem is the common method to get the dynamical mass in clusters of galaxies. Virial M/L's of 100 or more have been derived for Virgo (Giraud 1986; Huchra 1985), Coma (Millongton and Peach 1986), Perseus (Kent and Sargent 1983), and a number of other rich clusters. Uncertainty in virial method such as constant M/L with radius, effect of faint galaxy in averaging luminosity function could lead a factor of 2 - 4.

The X-ray emission of hot gas in rich clusters also can give mass estimate. The standard assumptions of hydrostatic isothermal gas lead to M/L values of 100 or more (Fabricant 1986; Ulmer et al. 1985). And the distribution of DM belong communally to the cluster, not individually to the galaxies.

b) Superclusters

Results on these large scales are usually given in terms of the ratio Ω of density in a particular component to the density needed to close the universe. A component with a particular value of $(M/L)h$ will contribute $\Omega = (M/L)h/1000h$ toward closure. The results shows $\Omega = 0.2 \pm 0.1$ out to scales of 30 - 50 Mpc.

III. COMPOSITION OF DARK MATTER

1. Baryonic Dark Matter

The candidates of baryonic DM are brown dwarfs, white dwarfs, and massive black holes. Brown dwarfs are substellar objects whose only energy source is contraction. These could be the source of disk DM or halo DM. White dwarfs are normal remnants of stars and can fade below detectability in less than the age of the Galaxy. One model of galactic chemical evolution poist an early generation of intermediate-mass stars whose white-dwarf remnants might account for the dynamical mass in the disk and probably the halo as well (Larson 1986; Olive 1986). Massive black holes might have formed in the early universe. Black holes with 10^6 $M_{\odot}$can contribute the increase of stellar velocity dispersion or spiral arms. These black holes in halos should reveal themselves by gravitationally lensing radiation from objects behind them. Observations of those effect may be possible in radio and space optical interferometer. Diffuse baryonic halos are seen in several galaxies such as M87, the Sombrero galaxy, and several heavy-metal qusar absorption line systems. Thus baryonic matter definitely cannot be ruled out and even has some advantages at least up to the $\Omega \sim 0.15$ level, consistant with conventional nucleosynthesis.

2. Nonbaryonic Dark Matter

The agreement between the standard primodial nucleosynthesis calculations and the observed abundances of the light nuclides (H, D, ^{3}He, ^{4}He, ^{6}Li, ^{7}Li) has generally been regarded as a pillar of the standard hot big bang model and a triump for theoretical cosmology. But this works well only if the upper limit of the density Ω_b of baryonic matter is less than 0.14. If $\Omega = 1$ then the majority must be nonbaryonic (Primack et al. 1988). Theory favors $\Omega = 1$ based on three reasons. First, $\Omega = 1$ the uniquely stable value for Friedmann cosmologies. If Ω is larger or smaller than unity at early times, it deviates increasingly as time goes on. Second, the hypothesis of cosmic inflation - that the universe underwent exponential expansion during an early brief phase when the vacuum energy dominated - leads to the prediction of vanishing curvature. Third, if galaxies and clusters arose from density fluctuations in the early universe as is commonly supposed, this implies lower limitson the amplitude of these density fluctuations at the era of recombination, which in turn imply model-dependent lower limits on the magnitude of the fluctuations $\delta T/T$ in the cosmic background radiation on the angular scale of a few arcminutes. Because the fluctuation amplitude grows more slowly with time in a low-density universe, for models such as cold DM these lower limits on $\delta T/T$ are in serious conflict with the latest upper limits on $\delta T/T$ if $\Omega_o \approx 0.2$, but not (yet) in trouble if $\Omega_o = 1$.

The candidates of nonbaryonic DM are usefully classified - according to their mass - as hot, warm, or cold, this determining the scale on which they can cluster. The lightest superpartner (LSP) and the axion are two particle physics DM candidates that are well motivated, in the sense that they are needed in particle theories that were invented to solve problems entirely unrelated to the cosmology of DM. Not only is there no direct evidence that the LSP or axion actually exists; even if one or both do exist, they might not have the right mass and interaction strength to be comologically dominant. Other elementary particle possibilities for DM have also been proposed, including neutrinos both light ($m_\nu \leq 30$ eV) and massive ($m_\nu \geq 3$ MeV). Some additional DM candidate particles ; called "cosmions", have been proposed specifically to solve the solar neutrino puzzle. Finally, there are several hypothetical particles. All possibilities are still speculative.

It is natural to assume that DM is invisible and has negligible electromagnetic interactions because it is composed of electrically neutral particles. Thus a broad category of DM candidates is known as weakly interacting massive particles (WIMPS). These particles generally have masses in the range of 1 - 100 GeV and weak strength interactions. There are several possibilities for direct detection, including the measurement of a non-zero neutrino mass, watching axions interact with a magnetic field, or detecting phonons as DM particles collide with a crystal lattice at the weak interaction rate. Details of detection method are well reviewed by Primack et al. (1988) and Smith and Lewin (1990).

IV. CONCLUDING REMARK

In the inner parts of most galaxies, DM is not required by the observations. However in the outer parts of most galaxies, DM dominates known matter. The study of DM is important to understand not only the current structure of galaxies, but also : how galaxies formed, and structure developed in the universe, the ultimate fate of the universe, the nature of the matter.

REFERENCES

Bacon, R., Monnet, G., and Simien, F. 1985, *Astron. Ap.*, **152**, 315.

Einasto, J. 1974, *Nature*, **250**, 309.

Fabricant, D., *et al.* 1986, *Ap. J.*, **308**, 530.

Forman, W., Jones, C., and Tucker, W. 1985, *Ap. J.*, **293**, 102.

Freeman, K. C. 1987, in *Nearly Normal Galaxies*, ed. S. Faber (New York : Springer), p. 317.

Frenk, C. S., and White, S. D. M. 1983, in *Kinematics, dynamics, and structure of the Milky Way*, ed. W. L. H. Shuter (Dordrecht : Reidel), p. 335.

Giraud, E. 1986, *Astron. Ap.*, **167**, 41.

Hawkins, M. R. S. 1984, *M.N.R.A.S.*, **206**, 433.

Hawkins, M. R. S. 1987, *M.N.R.A.S.*, **223**, 845.

Huchra, J. 1985, in *Clusters and Groups of Galaxies*, ed. F. Mardirossian, *et al.* (Dordrecht : Reidel), p. 79

Jarvis, B. J., and Freeman, K. C. 1985, *Ap. J.*, **295**, 246.

Kent, S. M., and Sargent, W. L. W. 1983, *A. J.*, **88**, 697.

Kuijken, K., and Gilmore, G. 1987, *Bull. Am. Astron. Soc.*, **19**, 1108.
Kuijken, K., and Gilmore, G. 1989, *M.N.R.A.S.*, **239**, 571.
Larson, R. B. 1986, *M.N.R.A.S.*, **218**, 400.
Lin, D. N. C., and Lynden-Bell, D. 1982, *M.N.R.A.S.*, **198**, 707.
Little, B., and Tremaine, S. 1987, *Ap. J.*, **320**, 493.
Millington, S. J. C., and Peach, J. V. 1986, *M.N.R.A.S.*, **221**, 15.
Olive, K. A. 1986, *Ap. J.*, **309**, 210.
Oh, K.-S., Lin, D. N. C., and Aarseth, S. J. 1992, in preparation.
Ostriker, J. P., Binney, J., and Saha, P. 1989, *M.N.R.A.S.*, **241**, 849.
Ostriker, J. P., Peebles, P. J. E., and Yahil, A. 1974, *Ap. J. (Letters)*, **193**, L1.
Primack, J. R., Seckel, D., and Sadoulet, B. 1988, *Ann. Rev. Nucl. Part. Sci.*, **38**, 751.
Salucci, P., and Frenk, C. S. 1989, *M.N.R.A.S.*, **237**, 247.
Smith, P.F., and Lewin, J. D. 1990, *Phys. Rept.*, **187**, 203.
Trimble, V. 1987, *Ann. Rev. Astron. Astrophys.*, **25**, 425.
Ulmer, M. P., Cruddace, R. G., and Kowalski, M. P. 1985, *Ap. J.*, **290**, 551.
Valtonen, M. J. and Innanen, K. A. 1985, *Astrophys. Space Sci.*, **107**, 209.
Zwicky, F. 1933, *Helv. Phys. Acta.*, **6**, 110.