8.2.4 High Velocity Clouds and the Halo

A number of new observations of high velocity clouds has been made (39.131.042, 39.131.043, 37.155.063 39.131.044, 39.131.045), the last of which is interpreted as high velocity inflow of HI toward the Galaxy. Other more local interpretations were also presented (38.131.079, 38.155.015), the first of which shows components of the high velocity clouds in the spectra of nine stars. This important observation, if confirmed, would imply that a large fraction of the high velocity clouds are within 200 pc of the Sun. Another study (42.155.054) suggests distances of 1–3 kpc. Clearly, the problem of the high velocity clouds requires more observations. A theoretical investigation by Lacey and Fall suggests that the star formation history of the Milky Way requires either radial infall or inflow from the outer regions of the galactic disk.

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9. The Outer Galactic Environment

One of the highlights of the study of the galactic environment is the demonstration that companions and hydrogen clouds surrounding our Galaxy form a ring-like structure similar to that surrounding external polar-ring galaxies. Probably this feature is common in giant galaxies. Dwarf galaxies may possess their own dark coronas, which fact, if confirmed, puts severe constraints on the nature of dark matter. Available evidence confirms earlier suggestions that our Galaxy with its massive corona, companions, and surrounding gas forms a single system with many mutual interactions. Most companions of our Galaxy as well as the main hydrogen streams are located in a narrow strip inclined 70° to the galactic plane.

(042.155.108) suggested that nearby companions and hydrogen streams probably form a polar ring around the Galaxy. There are evidently two types of high-velocity clouds (HVC's) of neutral hydrogen: relatively nearby features, and clouds at large distances from the Sun.

The polar ring of the Milky Way is composed of high-velocity gas of the second type. It is rotating with a velocity of $\sim$ 200 km.s^{-1}, approximately equal to the rotation speed of the Galaxy in its main plane. A similar match is observed in external galaxies with polar rings (043.151.002). These results demonstrate that coronas are triaxial with axial ratios of their equipotentials $c/a \sim 0.96$. The mass of the dark corona was derived using a number of various test particles. RR Lyrae stars and globular clusters yield the mass within 20 – 25 kpc; the results lie in an interval $2.6 - 2.9 \times 10^{11} M_{\odot}$ (039.155.078; 040.122.159; 039.155.104); 039.155.113; 041.154.019; 040.154.015). The outer radius of the ring system is estimated to be $\sim$ 90 kpc. HVC's of the first type can be considered a consequence of interaction between the polar ring and galactic gas. Near the anticenter region accretion of the intergalactic gas to the Galaxy takes place. HVC streams, beginning there and smoothly merging to the polar ring structure may be the infalling hydrogen clouds. The infall of ring clouds into the galactic disk may give rise to the bending of the plane of the Milky Way, and may also trigger the formation of spiral structure, and thus explain a number of features in the kinematics of the population of young stars.

(039.151.016), (038.151.020), (038.151.070) and (038.157.165) discussed the stability of the galactic disk and the developing of its warp under the influence of the heavy halo. The infalling gas can also explain the constant scale height of the disk of Galaxy and the formation of HI loop structures. (039.155.054), (039.155.117), (040.131.283) and (042.155.087) reviewed the observations and theories involving the gaseous corona of the Milky Way.

(039.131.044), (039.131.045), (039.131.296), (040.156.008), (042.131.053), (039.131.043) and (039.131.042) describe recent observations of HVC's. (042.131.189) used *IRAS* observations to look for infrared emission from

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dust in HVCs. None of these clouds is detected. (043.155.002) detected no associated *IRAS* 100 μm flux in the Magellanic Stream, indicating that the Stream has a different dust content from that of the gas in the Galaxy. (039.156.006) and (041.156.003) suggested that the SMC approached the LMC as close as 3 to 7 kpc about 200 million years ago, and that the Magellanic Stream is due to the gravitational interaction among the triple system of the Galaxy, LMC and SMC. (042.151.055) present two-dimensional hydrodynamic simulations for the interaction of HVC's with a galactic disk. The calculations show the build-up of massive structures, able to retain for a significant time (043.155.003). General trends support the hypothesis that the mechanism of cloud-Galaxy interactions may be responsible for some of the most energetic structures in the Galaxy, such as supershells.

(039.155.100) located, from an automated objective-prism survey, a sample of over 150 K giants in the outer galactic halo. Radial velocities show that the outer halo is at most slowly rotating and the line-of-sight velocity dispersion, 101 km.s^{-1}, is approximately constant with distance from the Sun (039.111.012; 041.111.004).

(040.114.149) reviewed the determination of C, N, and O abundances in old stars of the halo field, globular clusters, and the seven dwarf spheroidal satellites of the Galaxy. Of crucial importance for the understanding of the nature of the dark matter is the possible presence of dark halos around dwarf galaxies. Observed and derived structure parameters are tabulated for 154 galactic globular clusters, 7 dwarf spheroidal satellites, and 6 globular clusters in the Fornax dwarf spheroidal by (039.154.069). Dwarf spheroidal companions can be divided into nearby (Carina, Draco, Sculptor and Ursa Minor) and distant ones (Fornax and Leo). In Carina accurate radial velocities have been obtained for six carbon stars (040.157.025). The observed rms velocity dispersion is $\sim$ 6 km.s^{-1}. The derived M/L is then 9.7. Accurate radial velocities have been obtained for 3 carbon stars in Sculptor by (040.157.025). (042.157.128) presented radial velocities for 16 K giants. The observed *rms* velocity dispersion is $\sim$ 6 km.s^{-1}, consistent with an M/L ratio of 6.0. Precise ($1-2$ km.s^{-1}) velocities have been obtained for three Fornax globulars (042.157.095). The observed *rms* velocity dispersion of five carbon stars is $\sim$ 6 km.s^{-1}(040.157.025). The derived M/L is then 0.5. These values indicate that both the Carina and Sculptor dwarfs contain a substantial amount of additional mass not found in globular clusters, but Fornax does not. Another possible explanation for the large velocity dispersion in nearby companions is that these galaxies are undergoing tidal disruption. *BV* and near-infrared photometry was done (041.156.012) for 161 Cepheids in the Small Magellanic Cloud to derive their relative distances. The line-of-sight distribution of the younger Cepheids splits into two components, each of depth of about 6 kpc and with centers 12 kpc apart.

Recent radial velocity measurements of stars and their interstellar CaII absorption lines show convincingly that the near and far components should be identified with the low and high-velocity portions in the SMC HI distribution respectively. The results demonstrate that SMC is in a stage of tidal disruption. (043.154.001) argued that the distribution of the globular clusters with respect to the galactocentric distance shows a gap around 30 – 40 kpc. The outer halo clusters are intrinsically faint ($M_V = -4$ to -6 against -7 to -8), with a very large core radius (5–20 kpc against 1–2 kpc).

10. Dark Matter in the Galaxy

10.1 Dark Matter

Following an early suggestion by Kahn and Woltjer (1959) and Oort (1970), Gunn (1974), Einasto *et al.* (1974) and Ostriker *et al.* (1974) suggested that our Galaxy as well as other giant galaxies are surrounded by a corona. These initial suggestions on the presence of massive coronas around galaxies were based on the observed flat rotation curves of galaxies. The present state of the evidence for dark matter galactic halos derived from rotation curves of spiral galaxies is summarized by Sancisi (1985). Properties of the "dark" matter component of the galactic halos have been inferred from the constancy of the rotation curves by Malagoli and Ruffini (1985). In order to detect the gravitational effect of the dark corona component of disk galaxies, it is necessary to have surface photometry and rotation data that extend well beyond three disk scale-lengths. The new observational data for such analysis were discussed by Freeman (1986), Kent (1986) and Athanassoula *et al.* (1987). From the analysis of the observations Carignan and Freeman (1985) concluded that the mean halo-to-disk mass ratio at the Holmberg radius is 1.0. Bahcall and Casertano (1985) mentioned that the unseen matter in a sample of spiral galaxies exhibits simple regularities and characteristic numerical values. Athanassoula *et al.* (1987) have made an analysis of the rotation curves of a sample of spiral galaxies for which both photometric and kinematical data of reasonable quality are available in the literature, assuming constant mass-to-light ratios for bulge and disk separately. They suggested that all galaxies need a halo to fit their rotation curve. The velocity dispersion of the isothermal sphere best

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fitting the halo correlates well with the maximum velocity of the disk component. The central density of the isothermal sphere correlates with the central disk surface density divided by a disk characteristic length. They considered both as manifestations of a disk halo conspiracy and noted that the halos of early type spiral galaxies are more concentrated than those of later types. Fabian *et al.* (1986) have shown that the average total binding mass associated with early-type galaxies is large, $\mathcal{M}_T \geq 5 \times 10^{12} \mathcal{M}_\odot$. This implies that the average mass-to-light ratio $(M/L_B) > 74$ and significant amounts of dark matter are present in early-type galaxies. The radial distribution of matter in three elliptical galaxies with extensive shell systems was investigated by Hernquist and Quinn (1987a). They reported that the form of the galactic potential can be constrained by several independent observable quantities: 1) the number of shells between two fixed radii; 2) the radial distribution of shells; 3) the location of the innermost shell; and 4) the velocity dispersion of the underlying elliptical galaxy. A simple argument was used to show that the luminous material in NGC 3923 cannot account for the number of shells surrounding this galaxy and that the potential must be dominated by an extended and massive dark component. The total mass-to-light ratio was $\sim 100 - 200$. In their next paper (Hernquist and Quinn, 1987b) the shell method was used to study the modified Newtonian dynamics introduced by Milgrom as an alternative to the existence of dark matter in galaxies. The results are in disagreement with both the observed number and radial distribution of shells around NGC 3923. The modified dynamics have been suggested as an alternative to the hidden mass hypothesis. Kuhn and Kruglyak (1987) mentioned that from an empirical perspective we could conclude that there are no significant constraints on possible spatial variations in Newton's constant at large distances. They considered a correction term in analogy to a power-law expansion. Milgrom (1984) considered self-gravitating isothermal spheres using dynamics that differ from the Newtonian in the limit of small accelerations. He found (Milgrom, 1986) that if the mass discrepancy in galactic systems is due to a break-down of Newtonian dynamics, it may be possible to find configurations in which the required "hidden mass" is negative. Sanders (1984, 1986ab) demonstrated that the modification of Newtonian gravitational attraction which arises in the context of modern attempts to unify gravity with other forces in nature can produce rotation curves for spiral galaxies which are nearly flat from 10 to 100 kpc, bind clusters of galaxies, and close the universe with the density of baryonic matter consistent with primordial nucleosynthesis. This is possible if a very low mass vector boson carries an effective anti-gravity force which on scales smaller than that of galaxies almost balances the normal attractive gravity force. At the same time Goldman (1986) showed that the strength of antigravity of a range $\gg 1$ *AU* is severely constrained by terrestrial and solar system experiments. The Eotvos-Dicke experiments impose $|\alpha| \leq 10^{-9}$; the gravitational redshift experiment yields $|\alpha| \leq 7 \times 10^{-5}$ and the Mercury perihelion shift measurement implies $|\alpha| \leq 10^{-2}$. These constraints rule out antigravity as a possible cause for the flat rotation curves of spiral galaxies. A brief outline of the conflicting determinations of galaxy masses based on observable luminous matter and those based on dynamical arguments is presented by Gallagher III (1986). Upper limits have been set by Skrutskie *et al.* (1985) to the luminosity from the massive halos of three late-type edge-on spiral galaxies: NGC 2683 (Sb), NGC 4244 (Scd), and NGC 5907 (Sc). The limits resulted from simultaneous photometry in the visual (V) and 2.2 μm (K) photometric bands. Valtonen and Byrd (1985) discussed the evidence for dark matter in different scales in the universe, from our Galaxy to large clusters of galaxies. They find that in spiral galaxies the mass-to-light ratio $M/L \leq 15$ in solar units ($H_\circ = 72$ km.s^{-1}.Mpc^{-1} is assumed). They have presented evidence pointing to the possibility that groups and large clusters of galaxies are not gravitationally bound units. Frenk and White (1985) reported on a symposium "Dark matter in the Universe", held at Princeton, 24–28 June 1985 and on a related meeting "Galaxy formation", held at Toronto, 19–21 June 1985. Some aspects of this question were reviewed by Miyamoto (1986). Carney (1984) discussed recent and continuing studies of the outer halo of our Galaxy. A brief inventory has been conducted of the stellar systems lying at distances exceeding 25 kpc from the galactic center. The spatial distributions of such systems and the field stars have been reviewed, as well as the galactic mass estimates that follow from considerations of their kinematics. The question of a gradient in the halo's metallicity has been addressed, plus the scant information available on the chemical abundance pattern of outer halo systems has been discussed.

10.2 The Nature of Dark Matter

The principal particle candidates for galactic dark matter were discussed, and the detection methods available for each were summarized by Smith (1986). A review was given of the present status of two general classes of dark matter experiment: 1) the detection of light bosons (e.g. axions) by conversion of photons, and 2) the detection of new heavy particles (e.g. photinos) by measurement of nuclear recoil energy using low temperature calorimetric or photon detection techniques. The distinction between "hot" and "cold" varieties of dark matter was reviewed by Primack (1986), and the evidence against hot dark matter was briefly summarized. The hypothesis of cold dark matter with a Zel'dovich spectrum of primordial Gaussian fluctuations gives a picture of galaxy and cluster formation that is in reasonably good agreement with the available observations. However, this model appears to lead to less structure on very large scales than is observed. Possible remedies were discussed, including: 1) decaying dark matter, 2) an additional feature in the fluctuation spectrum on large scales, such as can arise in a hybrid

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model with more than one kind of dark matter, and 3) non-Gaussian fluctuations, for example those that arise from cosmic strings. The particle physics of the most popular cold dark matter candidates was reviewed, Sciama (1984b) illustrated recent development by brief discussions of the possible roles of massive neutrinos, photinos and gravitinos in providing the "missing" matter in the universe as a whole, in galaxy clusters and in individual galaxies. If these particles have non-sero rest-mass they might dominate the universe, providing it with the critical density, and also individual galaxies, providing them with their missing mass Sciama (1984a). This hypothesis might be tested by searching for the photons which these particles (except gravitinos) would be expected to emit. Srednicki *et al.* (1986) pointed out that if the galactic halo is composed heavy, weakly interacting particles then the pair annihilation can produce potentially observable sharp peaks in the diffuse cosmic γ-ray background. The possibility of detecting of heavy neutral fermions in the Galaxy was discussed by Wasserman (1986). The decaying dark matter cosmology postulates that a heavy elementary-particle species X first drives the formation of galaxies and clusters, and then decays non-radiatively, providing a smooth, undetected background of relativistic particles. It has been found (Flores *et al.* , 1986) that the observed flat rotation curves cannot be obtained in these decaying dark matter models. Thus, a relativistic, weakly interacting decay product cannot be dominant. Krauss (1985) demonstrated that dark matter consisting of any type or types of stable weakly interacting elementary particles is incompatible with the minimal predictions of inflation, based on present observations of galaxy clustering, and assuming galaxies are good traces of mass in the Universe. Datta *et al.* (1985) pointed out that several independent considerations rule out the hypothesis that the missing mass in galactic halos is dominated by massive neutral fermions such as neutrinos, gravitinos or photinos. The analysis of the data on the small-scale anisotropy of the relic electromagnetic radiation leads to a conclusion on the advantages of the models of the Universe with super-massive carriers of its "hidden mass" (Zabotin and Nasel'skij, 1985). The relations between micro-wave background anisotropy and decaying cold particle scenarios are analysed by Kolb *et al.* (1986). Ruffini and Song (1987) introduce a general theoretical framework which imposes constraints upon the spin, masses, and phase space densities of the cosmological "inos" forming the dark matter component of the Universe. Solar system constraints and signatures for dark matter candidates were analysed by Krauss *et al.* (1986b). A note on a lower limit to the rest mass of ions in the halo of our Galaxy was published by Fang and Gao (1984). Melnick and Terlevich (1986) discussed the nature of dark matter in dwarf galaxies. Fermions whose masses exceed $\sim$ 500 eV may cluster in these objects (Melott and Schramm, 1985), but they cannot provide the missing mass, as long as such dwarf galaxy halos constitute a small fraction of the dark matter in the Universe. Nasel'skij and Polnarev (1984, 1985) reviewed the possible forms of hidden mass in inflationary Universe models and Zee (1986) discussed the relations between fractional statistics, exceptional preons, scalar dark matter, lepton number violation, neutrino masses, and hidden gauge structure. Paczynski (1986) pointed out that if the halo is made of objects more massive than $\sim 10^{-8}\mathcal{M}_{\odot}$, then any star in a nearby galaxy has a probability of 10^{-6} to be strongly microlensed at any time. Monitoring the brightness of a few million stars in the Magellanic Clouds over a time scale between 2 hr and 2 yr may lead to the discovery of "dark halo" objects in the mass range $10^{-6} - 10^{2}\mathcal{M}_{\odot}$ or it may put strong upper limits on the number of such objects. Cremonesi (1986) presented limits on dark matter candidates calculated using the data of an experiment on double beta decay of ^{76}Ge carried out by the Milan group in the Mont Blanc laboratory using two big Ge(Li) detectors. The detectability of certain dark matter candidates was discussed also by Goodman and Witten (1985) and Drukier *et al.* (1986). Possible dark-matter candidates are discussed below.

10.3 Baryonic Halos

Skrutskie *et al.* (1985) set upper limits to the luminosities from the massive halos of three late-type edge-on spiral galaxies. The limits resulted from simultaneous photometry in the visual (V) and 2.2 μm (K) photometric bands. The results virtually eliminate the possibility that hydrogen-burning stars comprise more than a fraction of the halo masses. Gursadyan (1986) obtained an upper limit on the mass of the objects the hidden mass consists of, which seems to exclude the possibility that the hidden mass is constituted of stars being on the late stages of their evolution. Theoretical considerations would predict that sub-stellar masses have formed more frequently under the metal-poor conditions in the early Galaxy (Zinnecker, 1986). Thus the missing mass in the galactic halo and in the dark halos around other spirals may well reside in these metal-poor Population II brown dwarfs. Some of the major observational and theoretical issues in the study of brown dwarfs were reviewed by Bahcall (1986). It was concluded that all of the unseen local disk matter could be in the form of brown dwarfs without conflicting with any available observations. Nelson *et al.* (1985) presented the results of the first numerical evolutionary calculations for very low-mass stars (masses in the range of $0.01 - 0.1\mathcal{M}_{\odot}$). Tayler (1985) commented on new stellar evolution calculations for low-mass sub-luminous stars. The study of such objects may be directly relevant to the development of an understanding of the dark-matter problem in our Galaxy and many extragalactic systems. A survey for low-luminosity M-dwarfs from deep UK Schmidt plates was described by Hawkins (1986). The resulting luminosity function shows a decrease in space density in the range $M_R = 12 - 15$; thereafter the space density rises again. On the basis of stellar evolution models for low-mass stars, the turnover in the luminosity function is associated with

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the end of hydrogen burning, and its subsequent rise with the appearance of a population of degenerate brown dwarfs. An astrophysically plausible brown dwarf population was defined by Probst (1986) and yields a dark mass density ~ 0.5 times the observed density. Near infrared imaging of 60 nearby stars and 8 stars in the young Pleiades cluster revealed no substellar companions down to a limit corresponding to a mass of $\sim 0.04\ \mathcal{M}_\odot$ (Skrutskie *et al.* , 1986). The authors concluded that the dark matter in the galactic disk cannot reside solely in sub-stellar companions unless it is largely in objects less massive than the survey limit. Hills (1986) ruled out any appreciable fraction of the mass in the disk being in solid objects with masses less than about 10^{22} g. The corresponding limit for the galactic halo is about 10^{21} g. Halos composed of snowballs, dust and rocks, planets, stars, dead stellar remnants, and hot and cold gas were considered by Hegyi and Olive (1986). The serious problems that would arise for each of these types of matter lead to the conclusion that halos cannot plausibly contain substantial amounts of such matter. Olive and Hegyi (1986) reviewed a number of arguments which indicate that it is very unlikely that galactic halos contain substantial amounts of baryonic matter.

10.4 Black Holes

Lacey and Ostriker (1985) considered the idea that galaxy halos are composed of massive black holes as a possible solution of two problems: the composition of dark halos, and the heating of stellar disks. It is found that in order to account for the disk heating, the black holes must have masses $\sim 10^6 \mathcal{M}_\odot$. This heating mechanism makes predictions for the dependence of the velocity ellipsoid, that are in good agreement with observations. Kamahori and Fujimoto (1986) found that when the whole halo mass is attributed to black holes, the mean mass of the halo black holes must be smaller than $2 \times 10^6 \mathcal{M}_\odot$. McDowell (1985) provided independent constraints on black holes, by the requirement that their radiation due to accretion from the ISM should not make the nearest ones directly observable as optical objects. He showed that halo black holes must be less massive than about $10^3 \mathcal{M}_\odot$, and that the dark matter in the galactic disc cannot be made up of black holes of mass more than 10 $\mathcal{M}_\odot$. Carr (1985) considered the various constraints on the form of the dark matter and concluded that black holes could have a significant cosmological density only if they were of primordial origin or remnants of a population of pre-galactic stars.

10.5 Massive Neutrinos

Cowsik and Vasanthi (1986) concluded that neutrino condensates with $M \sim 10^{16} \mathcal{M}_\odot$ were the first objects to be formed in the Universe at a redshift of $\sim 10^4$. Subsequent to formation they expanded much slower than the rest of the Universe and fluctuations in the density of baryonic matter grew effectively with the formation of the galaxies. Assuming that neutrinos have a rest mass of $\sim 10\ c^{-2}$ eV details of the dynamical motions of galaxies and stars can be understood quantitatively. Ruffini and Stella (1983) investigated the properties of self-gravitating massive neutrino halos in structures ranging from galaxies to clusters of galaxies and attempted to obtain testable predictions. Assuming that massive neutrinos dominate the dark matter in galactic halos, Paganini *et al.* (1986, 1987) calculated the mass-radius relations and rotational curves for an isothermal neutrino distribution as well as for a distribution with a spatial cutoff (King model). For $M_\nu \geq 40$ eV, galaxies between 10 and 100 kpc radius can be reproduced with satisfactory (flat) rotational curves in the isothermal model. The authors also included baryons in the galactic core. The King model fails to give acceptable rotational curves for all baryon distributions considered. Chau and Stone (1985) reported on attempts to fit the observed rotation curves of spiral galaxies out to ~ 60 kpc assuming the required dark matter to be made up of neutrinos. The results indicate that the isothermal assumption made has to be relaxed in this "inner" region of a galaxy for a really good fit. Lower limits for the neutrino mass were obtained by Madsen and Epstein (1985), if one flavor of neutrino is predominantly responsible for the dark matter in galaxies. From rotation curves of spiral galaxies, it is found that the neutrino mass must exceed 35 $h^{1/2}$ eV (where h is the Hubble constant in units of 100 km.s^{-1}.Mpc^{-1}) if the velocity distribution of halo neutrinos is isotropic. If radial dispersion dominates, limits are slightly weakened. Madsen and Epstein (1984) found from the well studied galaxies M87 and M31 that the neutrino mass must exceed 8 eV. The preliminary reports of dark matter in dwarf galaxies would imply that the neutrino mass exceeds 125 eV. Phase-space considerations would require $M_\nu > 50$ eV if neutrinos dominate the missing mass in halos of large spiral galaxies and moreover $M_\nu > 200$ eV is implied in the case of dwarf spheroidals (Sivaram, 1985). These larger neutrino masses would be in conflict with observed constraints on the age of the Universe unless a cosmological constant is invoked. In order to investigate the mass-to-light ratio in irregular Magellanic galaxies, a sample of 21 Sdm, Sm, Im objects has been selected by Comte (1985). Implications for the particle mass of hypothetical massive neutrinos have been discussed. Neutral hydrogen observations were used to measure the total mass of dwarf galaxies by Davies (1984a). The dimensions and velocity fields of dwarfs would require a neutrino mass of ~ 150 eV. The observed luminosity profiles of dwarf spheroidals imply densities for the dark matter in the range 10^{-26} to 10^{-25} g.cm^{-3}, and mass-to-luminosity ratios which are typically an order of magnitude greater than

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those of globular clusters (Cowsik and Ghosh, 1986). Neutrinos of mass $\sim$ 10 eV and $< V > \sim$ 1000 km.s^{-1}can provide this requisite density for the background. The theoretical expectation of the high mass of $\geq$ 400 eV for the particles constituting the dark matter in dwarf-spheroidals is an artifact of the implicit assumption that the density of particles vanishes at the visible edge (Cowsik, 1986). On the contrary, if dwarf-spheroidals are embedded in a neutrino condensation of the dimensions of the cluster, then M_ν = 10 eV can accommodate all the observations. The determinations of the neutrino mass were reviewed also by Huang *et al.* (1983), Ho (1984), Sciulli (1986), Madsen and Epstein (1986) and Press (1986). Some results of astrophysical importance on neutrino physics have been published in physical journals (Fukugita and Yanagida, 1984; Ching and Ho, 1984; Mößbauer, 1985; Galeotti and Gallino, 1985; Freese, 1986; Grifols *et al.* , 1986; Takahara and Sato, 1986).

10.6 Photinos

Observational tests of the hypothesis that the Universe is flat and dominated by dark matter in the form of massive photinos include the production of significant fluxes of cosmic rays and gamma rays in the galactic halo (Silk and Srednicki, 1984). Specification of the cosmological photino density and the masses of scalar quarks and leptons determines the present annihilation rate. The predicted number of low-energy cosmic-ray antiprotons is comparable to the observed flux. So, the stable photinos can explain both the "missing mass" in galactic halos and the cosmic-ray antiproton spectrum up to the highest energies observed so far. This requires a photino mass around 15 GeV (Stecker *et al.* , 1985a). As a consequence, the observed cosmic-ray antiproton-to-proton ratio is predicted to decrease abruptly just above the measured energy range, at $E = M_{\overline{\gamma}}$. Stecker *et al.* (1985b) considered the physics of the annihilation of photinos ($\overline{\gamma}$) as a function of mass, in order to obtain the energy spectra of the cosmic-ray $\overline{p}$'s produced under the assumption that $\overline{\gamma}$'s make up the missing mass in the galactic halo. The authors then compared the modulated spectrum at 1 *AU* with the cosmic-ray $\overline{p}$ data. A very intriguing fit is obtained to all of the present $\overline{p}$ up to 13.4 GeV data for $M_{\overline{\gamma}} \sim$ 15 GeV. A cutoff in the $\overline{p}$ spectrum is predicted at $E = M_{\overline{\gamma}}$ above which only a small flux from secondary production should remain. Silk *et al.* (1985) reported that if the Universe contains a nearly critical density of photinos, then gravitational trapping by the Sun and ensuing annihilation in the solar core yields a significant flux of $\sim$ 250 MeV neutrinos.

10.7 Magnetic Monopoles

The lifetime of monopolonium was used by Stein and Schabes (1985) to put limits on the mass of the monopole. The author found that in order to be in accord with observations of the energy density of the Universe, the isotropy of the radiation backgrounds and the abundance of primordial light elements, the mass of the monopolonium cannot be greater than 10^{16} GeV, so making it very difficult to accommodate super-heavy monopoles in our observable Universe. The author investigated also the possibility of identifying monopolonium with the heavy particle recently proposed to solve the Ω-problem i.e. how to reconcile Universe with $\Omega = 1$ and a cold dark matter scenario capable of predicting the right large-scale structure of the Universe. It has been found that by choosing the radius of monopolonium, it is possible to solve the Ω-problem. The halo models are consistent with monopole masses $M_M \leq 7 \times 10^{19}$ GeV, and monopole fluxes in the range $F_M \geq 3 \times 10^{-13}$ cm^{-2}.s^{-1} (Farouki *et al.* , 1984). Some aspects of monopoles in astrophysics were discussed by Turner (1983).

10.8 Other Particles

Recent work on superstring theories has prompted interest in "shadow matter", exotic matter which interacts only gravitationally with normal matter (Krauss *et al.* , 1986a). Such a theory could result, at low energies, in the existence of two sectors: an 'observed' sector associated with all familiar particles and interactions, and another Universe. Of the particles whose mass may account for the missing mass of the Universe, those known as axions are the most shadowy (Maddox, 1986). What is known of stellar evolution helps to define their properties. Some effects of the axion halo on bound electrons were discussed by Slonczewski (1985). It has been recently proposed by Witten (1984) that dark matter in the Universe might consist of nuggets of quarks which could populate the "nuclear desert" between nucleons and neutron star matter. Audouze *et al.* (1985) examined a consequence of Witten's proposal and showed that the production of relativistic quark nuggets was accompanied by a substantial flux of potentially observable high energy neutrinos. The gravitinos as the cold dark matter in an $\Omega = 1$ Universe has been discussed by Olive *et al.* (1985).

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11. Galactic Dynamics : Stellar Orbits

11.1 General Problems

The interest in stellar orbits focussed on two areas: Firstly, on the existence of non-classical integrals of motion ("third integral") and on the occurence of stochastic or chaotic motions in systems with two or three degrees of freedom. While the case of three degrees of freedom is the more realistic one, results on systems with only two degrees of freedom can be applied to situations such as the motions of stars in the co-moving meridional plane of axisymmetric galaxies or in the equatorial plane of spiral or barred galaxies. Secondly, there is continuing interest in the orbital motions of stars in triaxial systems, which may represent either triaxial elliptical galaxies or galactic bars. The ultimate aim of many of the studies on stellar orbits is to build self-consistent models of stellar systems on the basis of the individual orbits of the stars.

A review of stellar dynamics has been given by Dejonghe (41.151.112). Orbital theory and the existence of non-classical integrals of motion have been reviewed or generally discussed by Antonov (40.042.118), Binney (38.151.018), Cleary (43.151.068), and Contopoulos (38.151.075).

Best approximations for quadratic integrals have been discussed by de Zeeuw and Lynden-Bell (40.151.158). The number of effective integrals in galactic models was studied by Magnenat (39.151.158). Models of stellar systems with third integrals have been constructed by Petrou (40.151.061), Vandervoort (38.151.106), and Villumsen and Binney (40.151.033). Non-isolating integrals were studied by Genkin and Genkina (43.151.048).

Periodic orbits in systems with two or three degrees of freedom have been investigated by Barbanis (40.151.063), Caranicolas, Diplas and Varvoglis (38.151.064, 41.151.105, 42.151.104), Cartigny, Desolneux and Hayli (38.042.028), and Hadjidemetriou (39.042.028). Resonant orbits were studied especially by Andrle (39.151.046), Caranicolas (38.151.042, 39.151.099, 40.151.050), and Contopoulos and Barbanis (40.151.078).

The consequences of bifurcations of families of periodic orbits, the collisions of bifurcations and complex instability in systems with three degrees of freedom have been studied by Contopoulos (39.151,073, 40.151.098, 41.151.087,

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