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Theoretical Study of Dark Matter and Energy in Galaxies and Why Scientists Closer to Observing Dark Matter

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Abstract: In this paper gives a rather theoretical introduction into particle physics aspects of the cosmological dark matter and energy puzzle. A fairly comprehensive list of possible candidates is given; in each case the production mechanism and possible way to detect them are described. I then describe detection of the dark matter, in my view, most promising candidates, dark matter in galaxies, scientists closer to observing dark matter, Higgs boson may unravel dark energy mystery, How do black holes get super massive? and How dark matter works? in slightly more detail. The main emphasis will be on recent developments.
Keywords: Dark matter, galaxy, boson, critical density, black holes etc.

INTRODUCTION

Dark Matter in Galaxies

The concept of dark matter didn't originate with Vera Rubin. In 1932, the Dutch astronomer Jan Hendrik Oort observed that stars in our galactic neighbourhood were moving more rapidly than calculations predicted. He used the term "dark matter" to describe the unidentified mass required to cause this surge in velocity. A year later, Fritz Zwicky began studying galaxies in the Coma cluster. Using luminosity measurements, he determined how much mass should be in the cluster and then, because mass and gravity are related, calculated how fast the galaxies should be moving. When he measured their actual velocities, however, he found that the galaxies were moving much, much faster than he expected. To explain the discrepancy, Zwicky suggested that more mass—two orders of magnitude more—lay hidden among the visible matter. Like Oort, Zwicky called this invisible stuff dark matter [source: Super CDMS at Queen's University].

Hubble's observations in 1920s clearly demonstrated that every galaxy was receding away from every other galaxy with velocities proportional to the distances between them. This observational result was most suitably modelled by the concept of the Expanding Universe [1]. Soon after, Abbe Lemaitre proposed the world model that all the matter in the present Universe was confined in a small volume at high temperature in the Primeval Atom as it was called, which exploded in a Big Bang throwing material at high speeds in all directions. Lemaitre's original concept, after some later modifications, developed into the present theory of Standard Big Bang for the universe which started some 10 to 20 billion years ago (depending on the value of H).

Dark matter (DM) is, by definition, stuff that does not emit detectable amounts of electromagnetic radiation. At present its existence can therefore only be inferred from the gravitational pull it exerts on other, visible, celestial bodies. The best evidence of this kind comes from the study of galactic rotation curves [2].

Calculations reveal that the expansion of the Universe will be halted if the mass density in the Universe be equal to the critical density, ρ_c given by

$$\frac{3H^2}{8\pi G} \cong 1 \times 10^{-29} gm\ cm^{-3} \qquad (1)$$

Where H = 70 km/s Mpc^{-1} has been used. The ratio of the observed density, $\rho_{obs,}$ and the critical density ρ_c is defined as

$$\Omega = \rho_{obs}/\rho_c \qquad (2)$$

The expansion of the Universe will be halted if $\Omega = 1$, the Universe then being called flat. But all current observations indicate that $\Omega = 0.20$ is an extreme upper limit. This is the baryonic mass detected by its gravitational effect. The remaining 80 percent of the matter is nonbaryonic, provided we like to cling to the concept of a flat Universe. The severe restriction on the amount of the baryonic matter is imposed by the present understanding of the Standard Big Bang Nucleosynthesis.

The limitations come principally from the observed abundance of ${H_e}^4$ which is about 24 percent, according to the best present determination. If all matter was baryonic, $H_e{}^4$ would have been about 30 percent, a value absolutely precluded by present observations.

What kind of matter contributes to the 80 percent nonbaryonic matter is not clearly known at present. Particle physicists have prepared a long shopping list of particles in search of the plausible matter. The Big Bang may not have left just baryons and radiation, but other species as well which may contribute to Ω . In the Standard Big Bang model neutrinos are almost as abundant as microwave background photons [3]. So if neutrinos have masses as small as about tens of electron volts, they are able to supply enough mass for the flat Universe. All recent experiments in these directions indicate that the neutrinos do possess such masses. Several other candidates have been proposed for the purpose by particle physicists. Light gravitations, quark nuggets, axioms and magnetic monopoles are a few such probable. But neutrinos are the most favoured candidate at the moment.

Again, of the observed baryonic mass the luminous matter is only 20 percent. This luminous matter consists of bright stars and gas in different phases (molecules as well as neutral and ionized atoms) observed at various wavelength of the electromagnetic spectrum including X-rays, radio waves and microwaves [4]. In large clusters of galaxies about one half of the luminous matter consists of the X-ray emitting high temperature ionized intracluster gas in the central regions. Thus, an overall 20 percent of the detected matter is actually seen.

The remaining 80 percent remains unseen or invisible. Since this matter does not radiate in any wavelength of the electromagnetic spectrum it has been called dark matter.

At least 80% percent of the detected baryonic matter is dark because this comes from a comparison between the actually observed luminous matter and the gravitationally detected matter. In what form this dark matter exists? The possible forms are (a) black holes, (b) dead stars like white dwarfs and pulsars, and (c) sub stellar bodies like brown dwarfs and Jupiter.

Some astronomers believe that a massive black hole ($M > 10^6\ M_\odot$) lies at the centre of each normal galaxy. Also, there may be a sparse distribution of smaller black holes in a galaxy which probably manifest themselves as isolated X-ray sources. But there cannot exist many massive black holes in a galaxy, sufficient to compensate for the dark mass by them, as their presence would manifest observable physical and dynamical effects on their environment, the like of which are not seen at all. Also, the existence of a distribution of innumerable low mass black holes that may provide a fair compensation for the required dark matter appears very improbable [5]. It is difficult to see how most of the galactic mass can be converted into billions of tiny black holes. We therefore neglect the possibility of the presence of the galactic missing mass in the form of black holes.

Now consider the case for dead stars. From an extensive study of the distribution of pulsars in the local regions of the Galaxy, J. H. Taylor and R. N. Manchester have derived the birth rate of one pulsar in six years in the entire Galaxy assuming $< n_e > = 0.03 cm^{-3}$. If $< n_e > = 0.02 cm^{-3}$, the corresponding rate is one pulsar in forty years. We compromise with one pulsar in ten years, leading to the birth of 10^9 pulsars in the lifetime of the Galaxy [6]. Assuming an average mass of $1 M_\odot$ for pulsars, the total mass dumped as pulsars in the Galaxy is $10^9\ M_\odot$. A similar calculation can be made for the total mass in white dwarfs. Analyzing both theoretical and observational works on the formation rate of white dwarfs and planetary nebulae to be (4-10) x $10^9\ pc^{-2}\ yr^{-1}$ in the Galaxy. We compromise with $7x10^{-9}\ pc^{-2} yr^{-1}$ in the Galaxy. We compromise with $7\ x\ 10^{-9}\ pc^{-2} yr^{-1}$ as the birth rate; take 1000 kpc^2 as the effective area of the galactic disk and $0.7 M_\odot$ as the average mass of a white dwarf. This yields a mass $5\text{x}10^{10}\ M_\odot$ in white dwarfs. Thus the total mass in dead stars in our Galaxy may be $\sim 5 \times 10^{10} M_\odot$. This is at most ten percent of the total mass of the Galaxy. Almost an equal amount of mass is contained in luminous stars and gas and this is true for any normal spiral galaxy. The remaining 80 percent of mass of the galaxy consists of some other form of dark matter. On the other hand, the stellar evolution theory predicts that unless a body has a minimum mass of $0.08 M_\odot$, it cannot form star (nuclear fuel is not ignited at the centre) and will evolve as a sub stellar object, such as brown dwarf or Jupiter, Their evolution time is 10^9 years. These objects will therefore populate the galaxy contributing to its dark matter.

THEORETICAL OBSERVATIONS

(a) Scientists closer to observing dark matter:

A particle detector attached to the International space station has observed the potential signature of the elusive dark matter in the universe, scientists have claimed.

The international team running the Alpha Magnetic Spectrometer (AMS) announced the first results in its search for dark matter that is estimated to constitute 84.5 per cent of the total matter in the universe [7, 8].

They report the observation of an excess of positrons in the cosmic ray flux. The results, presented by AMS spokesperson Professor Samuel Ting in a seminar at CERN2, are to be published in the journal physical review letters.

The AMS results are based on some 25 billion recorded events, including 400,000 positrons with energies between 0.5 GeV and 350 GeV, recorded over a year and a half.

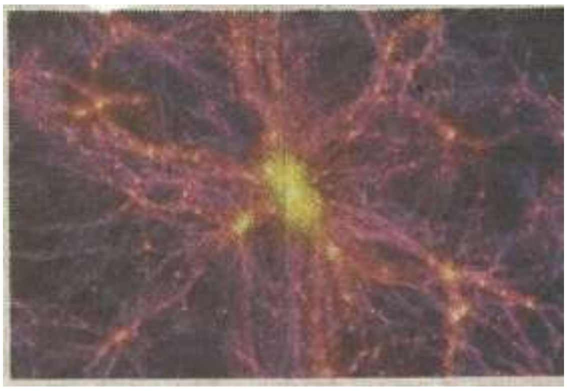

Fig-1: Dark matter

This represents the largest collection of antimatter particles recorded in space. The results are consistent with the positrons originating from the annihilation of dark matter particles in space, but not yet sufficiently conclusive to rule out other explanations. “As the most precise measurement of the cosmic ray positron flux to date, these results show clearly the power and capabilities of the AMS detector,” said Ting.

“Over the coming months, AMS will be able to tell us conclusively whether these positrons are a signal for dark matter, or whether they have some other origin,” Ting said in a statement issued by the European Organisation for Nuclear Research (CERN) [9].

Cosmic rays are charged high energy particles that permeate space. The AMS experiment, installed on the ISS, is designed to study them before they have a chance to interact with the Earth’s atmosphere. An excess of antimatter within the cosmic ray flux was first observed around two decades ago.

One possibility, predicted by a theory known as super symmetry, is that positrons could be produced when two particles of dark matter collide and annihilate.

(b) Higgs boson may unravel dark energy mystery:

The recently discovered Higgs boson could provide a possible “portal” to physics that may help explain some of the attributes of the enigmatic dark, scientists suggests. One of the biggest mysteries in contemporary particle physics and cosmology is why dark energy, which is observed to dominate energy density of the universe, has a remarkably small (but not zero) value, researches said. This value is so small, it is perhaps 120 orders of magnitude less than would be expected based on fundamental physics, they said.

Now physicists—Lawrence Krauss of Arizona State University and James Dent of the University of Louisiana-Lafayette-explore how a possible small coupling between the Higgs particle ,and possible new particles likely to be associated with what is conventionally called the Grand Unified Scale could result in the existence of another background field in Nature in addition to the ‘Higgs field’. This would contribute an energy density to empty space of precisely the correct scale to correspond to the observed energy density, researchers said.

Current observations of the universe show it is expanding at an accelerated rate. But this acceleration cannot be accounted for on the basis of matter alone, they said. Putting energy in empty space produces a repulsive gravitational force opposing the attractive force produced by matter, including the dark matter that is inferred to dominate the mass of essentially all galaxies, but which doesn’t interact directly with light and, therefore, can only be estimated by its gravitational influence [10]. Because of this phenomenon and what is observed in the universe, it is thought that such ‘dark energy’ contributes up to 70 percent of the total energy density in the universe, while observable matter contributes only 2 to 5 percent, with the remaining 25 per cent or so coming from dark matter. The source of this dark energy and the reason its magnitude matches the inferred magnitude of the energy in empty space is not currently understood, making it one of the leading outstanding problems in particle physics today.

“ Now that is Higgs boson has been discovered, it provides a possible ‘portal’ to physics at much higher energy scales through very small possible mixings and coupling to new scales fields which may operate at these scales,” said krauss.

“We demonstrate that the simplest small, mixing, related to the ratios of the scale at which electroweak physics operates, and a possible Grand Unified Scale, produces a possible contribution to the vacuum energy today of precisely the correct order of magnitude to account for the observed dark energy,” Krauss said [11].

(c) How do black holes get super massive?

A binary black hole pair with an accretion disk inclined at 45 degrees. One can see the concentric rings before they are accreted onto the black holes. Super massive black holes have always been deeply mysterious objects. Astronomers remain baffled as to how these super massive monsters become so massive.

New research, of course, explains that a super massive black hole might begin as a normal black hole, with tens to hundreds of solar masses, and slowly accrete more matter, becoming more massive over time [12]. The trick is in looking at a binary black hole system. When two galaxies collide, the two super massive black holes sink to the centre of the merged galaxy and form a pair. The accretion disk surrounding the two black holes becomes misaligned with respect to the orbit of the pair. It tears and falls onto the black hole pair, allowing it to become more massive.

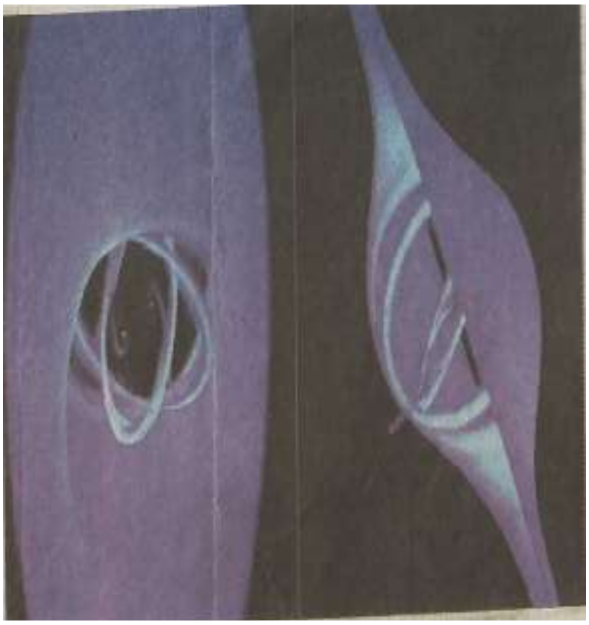

Fig-2: A binary black hole pair

(d) How Dark Matter Works?

Cosmologists working to decipher the origin and fate of the universe must identify completely with The Boss' sense of tragic yearning. These stargazing scientists have been facing their own darkness on the edge of town (or on the edge of galaxies) for a long time as they try to explain one of astronomy's greatest mysteries. It's known as dark matter, which is itself a placeholder- like the x or y used in algebra class-for something unknown and heretofore unseen. One day, it will enjoy a new name, but today we're stuck with the temporary label and its connotations of shadowy uncertainty. Just because scientists don't know what to call dark matter doesn't mean they don't know anything about it [13]. They know, for example, that dark matter behaves differently than "normal" matter, such as galaxies, stars, planets, asteroids and all of the living and nonliving things on Earth. Astronomers classify all of this stuff as baryonic matter, and they know its most fundamental unit is the atom, which itself is composed of even smaller subatomic particles, such as protons, neutrons and electrons.

Unlike baryonic matter, dark matter neither emits nor absorbs light or other forms of electromagnetic energy. Astronomers know it exists because something in the universe is exerting significant gravitational forces on things we can see[14]. When they measure the effects of this gravity, scientists estimate that dark matter adds up to 23 percent of the universe. Baryonic matter accounts for just 4.6 percent. And another cosmic mystery known as dark energy makes up the rest- a whopping 72 percent [source: NASA/WMAP]!

CONCLUSION

Most of the mass of the Universe is dark. Very likely most of this dark matter is non-baryonic, although baryonic dark matter should also exist, and may have been found in the form of MACHOs, Neutrinos, by themselves, do not appear to make good Dark matter candidates; the dark matter puzzle therefore strongly hints towards new physics. Unfortunately knowing the approximate DM density does not allow us to say much about the objects that form it. Even if we restrict ourselves to truly elementary particles, their mass could be anywhere between $10^{-5}\,eV$ and $\geq 10^{13}\,GeV$. Their interactions with normal (baryonic) matter could be anywhere between essentially non-existent (gravitations) and extremely violent (B-balls). Astronomers have been fascinated by galaxies for centuries. First came the realization that our solar system lay swaddled within the arms of a massive body of stars. Then came evidence that other galaxies existed beyond the Milky Way. By the 1920s, scientists like Edwin Hubble were cataloguing thousands of "island universities" and recording information about their sizes, rotations and distances from Earth. The implication of all of these results pointed to two possibilities: Something was fundamentally wrong with our understanding of gravity and rotation, which seemed unlikely given that Newton's law had withstood many tests for centuries. Or, more likely, galaxies and galactic clusters must contain an invisible form of matter- hello, dark matter- responsible for the observed gravitational effects. As astronomers focused their attention on dark matter, they began to collect additional evidence of its existence.

REFERENCES

1. Bœhm, C., & Silk, J. (2008). A new test for dark matter particles of low mass. *Physics Letters B*, *661*(4), 287-289.
2. Spergel, D. N., Bean, R., Doré, O., Nolta, M. R., Bennett, C. L., Dunkley, J., ... & Peiris, H. V. (2007). Three-year Wilkinson Microwave Anisotropy Probe (WMAP) observations: implications for cosmology. *The Astrophysical Journal Supplement Series*, *170*(2), 377.
3. Aubourg, E., Bareyre, P., Brehin, S., Gros, M., Lachieze-Rey, M., Laurent, B., ... & Queinnec, F. (1993). Evidence for gravitational microlensing by dark objects in the Galactic halo. *Nature*, *365*, 623-625.
4. For a brief but delightful history of DM, see V Trimble, in Proceedings of the First International Symposium on Sources of Dark Matter in the Universe, Bel Air, California, 1994, published by World Scientific, Singapore edited by D B Cline. For an up-to-date introduction into the dark matter problem, see J Primack, hep-ph/9707285, to be

published in the Proceedings of the 1996 Jerusalem Winter School (edited by A Dekel and J P Ostriker)

5. Pagels, H., & Primack, J. R. (1982). Supersymmetry, cosmology, and new physics at teraelectronvolt energies. *Physical Review Letters*, *48*(4), 223.
6. Rood, H. J., Page, T. L., Kintner, E. C., & King, I. R. (1972). The structure of the coma cluster of galaxies. *The Astrophysical Journal*, *175*, 627.
7. Drees, M. (1998). Particle dark matter physics: An update. *Pramana*, *51*(1-2), 87-106.
8. Primack, J. R., & Blumenthal, G. R. (1984). *"What is the Dark matter?" In Formation and Evolution of Galaxies and Large Structure in the Universe*, ed. By J. Audouze and J. Tran Thanh Van Reidel, Dordrecht, 163-183.
9. Alcock, C., Akerlof, C. W., Allsman, R. A., Axelrod, T. S., Bennett, D. P., Chan, S., ... & Park, H. S. (1993). Possible gravitational microlensing of a star in the Large Magellanic Cloud. *arXiv preprint astro-ph/9309052*.
10. Brandenberger, R. (1996). hep-ph/9701276, Lectures at the 15th Symposium on Field Theoretical Methods in Fundamental Physics, Seoul, August 1996 edited by C K Lee R Brandenberger, these Proceedings
11. Bernabei, R., Belli, P., Cerulli, R., Montecchia, F., Amato, M., Ignesti, G., ... & Kuang, H. H. (2000). Search for WIMP annual modulation signature: Results from DAMA/NaI-3 and DAMA/NaI-4 and the global combined analysis. *Physics Letters B*, *480*(1), 23-31.
12. Abusaidi, R., Akerib, D. S., Barnes Jr, P. D., Bauer, D. A., Bolozdynya, A., Brink, P. L., ... & Clarke, R. M. (2000). Exclusion limits on the WIMP-nucleon cross section from the cryogenic dark matter search. *Physical Review Letters*, *84*(25), 5699.
13. Bilenky, S. M., Giunti, C., & Grimus, W. (1997). Constraints on long-baseline neutrino oscillation probabilities and CP asymmetries from neutrino oscillation data. *arXiv preprint hep-ph/9705300*.
14. Sutherland, W., Alcock, C., Allsman, R., Axelrod, T., Bennett, D., Chan, S., ... & Perlmutter, S. (1995). Gravitational microlensing results from MACHO. *Nuclear Physics B-Proceedings Supplements*, *38*(1), 379-386.