Two components of dark matter in the DAMA data

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I. INTRODUCTION

The yearly variation observed in the DAMA experiment[1,2] extends for 12 years and the location of the maximum has been established with 8.9σ. Since the time at the maximum does not coincide with that when the Earth orbit approaches the GC or is tangential to a circular orbit around the GC, it is natural to assume that dark matter has two components, one that circulates around the GC and another that is emitted from the GC. This article computes the ratio of the two components. A possibility of the Migdal effect being a source that differentiates the results of the DAMA data and the CDMS data is discussed.

II. TWO DARK MATTER PARTICLE (DMP) COMPONENTS

If the GC is on the 18h of the RA coordinate, the Earth is moving towards it on March 22nd (81 days from January 1st) and moves tangentially to a circular orbit around the GC on June 22nd (173 days) and December 22. The real coordinates of the GC are?[3]

RA = 17°45′37″.1991 = 266°.40499625 (1)
DEC = −28°56′10″.221 = −28°.93617242 (2000)

then the time when the Earth is moving towards the GC is March 18.35 or

\[ t_{01} = 77.35 \text{ in days} \] (3)

and the time when the Earth is closest to the GC is

\[ t_{02} = 168.66 \text{ in days}. \] (4)

Since neither of these dates coincides with the observed time of maximum yearly variation[1],

\[ t_{0} = 145 \pm 7, \text{ (8.9σ)}, \] (5)

one has to assume that there are two dark matter components. Let us denote the yearly intensity variation of the component coming from the GC by \( A_1 \) and that of the component along a circular orbit by \( A_2 \). The total DMP intensity variation that yields \( A \) is given by

\[ A \cos(\omega(t - t_0)) = A_1 \cos(\omega(t - t_{01})) + A_2 \cos(\omega(t - t_{02})), \] (6)

which gives

\[ A \cos(\omega t_0) = A_1 \cos(\omega t_{01}) + A_2 \cos(\omega t_{02}) \] (7)

and

\[ A \sin(\omega t_0) = A_1 \sin(\omega t_{01}) + A_2 \sin(\omega t_{02}), \] (8)

where

\[ \omega = \frac{2\pi}{365.2422} \text{ (in days}^{-1}). \] (9)

From Eq. (7) and Eq. (8), one gets

\[ A^2 = A_1^2 + A_2^2 + 2A_1 A_2 \cos(\omega (t_{02} - t_{01})) \] (10)

\[ = A_1^2 + A_2^2, \] (11)

since

\[ \omega (t_{02} - t_{01}) = \frac{\pi}{2}, \] (12)

and

\[ \tan(\omega t_0) = \frac{A_1 \sin(\omega t_{01}) + A_2 \sin(\omega t_{02})}{A_1 \cos(\omega t_{01}) + A_2 \cos(\omega t_{02})}. \] (13)

Solving Eq. (13) for \( A_2/A_1 \), one obtains

\[ \frac{A_2}{A_1} = \frac{\sin(\omega (t_0 - t_{01}))}{\sin(\omega (t_{02} - t_0))}. \] (14)

From Eq. (13), one gets

\[ \frac{A_2}{A_1} = 2.35 \pm 1.04. \] (15)

The DMP component that circulates on a circular orbit around the GC is moving with the solar system and it creates a yearly variation due to a variation in the radial DMP distribution, as is described in the next section. This gives the \( A_2 \) component. In March, when the Earth is approaching the GC, it encounters DMP emitted from black holes at the GC with higher relative velocity than in September, when the earth is moving away from the GC, with smaller relative velocity. This gives the \( A_1 \) component. The details of the both components will be described in the following sections.
III. DMP CIRCULATING THE GC

The simplest assumption that gives the flat velocity distribution observed in most spiral galaxies is a spherically symmetric distribution of DMP. If one assumes that DMP are orbiting in all possible directions, no yearly variation is produced, since a summer-winter difference is cancelled by two DMP orbiting in the opposite directions. A yearly variation is produced by a radial distribution of DMP. If the DMP distribution is a decreasing function of distance from the GC, then the Earth encounters more DMP flux in the summer due to the fact that Earth is closer to the GC in the summer. This is consistent with the DAMA data in the previous section.

If the orbital motion of DMP is constrained so that the angular momentum component relative to that of the solar system or the visible spiral galactic plane, then the component of the orbital motion in the galactic plane contributes to the yearly variation, since the component vertical to the galactic plane cancels between orbits with opposite vertical components. Assuming that the average orbit is circular, its component in the galactic plane has opposite vertical components. Assuming that the average orbit is circular, its component in the galactic plane has a velocity less than that of the solar system. Then the maximum of yearly variation occurs in the winter, since the component vertical to the galactic plane cancels between orbits with opposite vertical components. In order to get a solution with a maximum in the summer, one has to have a contribution from a decreasing radial distribution compensating the effect of orbital motion.

In both cases, the effect of the radial distribution has to dominate the yearly variation.

IV. EMISSION OF DMP FROM GC BLACK HOLES

The existence of DMP in orbital motion around the GC is quite natural. It is also natural to assume that its distribution is a decreasing function of distance from the GC at the location of the solar system, in order to get a flat velocity distribution around the GC. However, the existence of DMP emitted from the GC requires an explanation. That is related to a recent discovery by the Pierre Auger Project concerning the correlation between high energy cosmic rays and the location of AGN (Active Galactic Nuclei) and a model of the author which predicted the Auger data since 1985.

The Pierre Auger Project data suggest that high energy cosmic rays are emitted from AGN, massive black holes. In a series of articles, the author has presented a model for the emission of high energy particles from AGN. The following is a summary of the model.

1) Quantum effects on gravity yield repulsive forces at short distances.
2) The collapse of black holes results in explosive bounce back motion with the emission of high energy particles.
3) Consideration of the Penrose diagram eliminates the horizon problem for black holes. Black holes are not black anymore.
4) The knee energy for high energy cosmic rays can be understood as a split between a radiation-dominated region and a matter-dominated region, not unlike that in the expansion of the universe. (See page 10 of the lecture notes.)
5) Neutrinos and gamma rays as well as cosmic rays should have the same spectral index for each AGN. They should show a knee energy phenomenon, a break in the energy spectral index, similar to that for the cosmic ray energy spectrum.
6) The recent announcement by Hawking rescinding an earlier claim about the information paradox is consistent with this model.

Further discussion of the knee energy in the model predicts the existence of a new mass scale in the knee energy range, in order to have the knee energy phenomenon in cosmic rays. The following are additional features of the model.

7) If the proposed new particle with mass in the knee energy range (0.1 PeV~2 PeV) is stable and weakly interacting with ordinary particles, then it becomes a candidate for a DMP. It does not necessarily have to be a supersymmetric particle. That is an open question. However, if it is supersymmetric, then it is easy to make a model for a weakly interacting DMP. The only requirement is that such particles must be present in AGN or black holes so that the knee energy is observed when cosmic rays are emitted from AGN. A suggested name for the particle is sion (xion), using the Chinese/Japanese word for knee, si (xì).

8) If the particle is weakly interacting, then it does not obey the GZK cutoff, since its interaction with photons in cosmic background radiation is weak, as was pointed out earlier. This is a possible resolution of the GZK puzzle.

In summary, this model predicted the Pierre Auger Project data. Moreover it suggests the existence of a new particle in the PeV mass range, in order to explain the knee energy phenomenon in the cosmic ray spectrum. The author has suggested that this new particle is a candidate for DMP.

V. AGN AND GC EMITS DMP

We assume that the incident particles above the GZK cutoff observed by the Akeno-AGASA detector are weakly interacting particles at the PeV mass scale, which are required to exist in order to explain the cosmic ray knee energy in the model. In a model where the acceleration takes place by gravity such as that proposed by the author, there is no difficulty in accelerating a weakly interacting and neutral DMP by gravity.

Then AGASA and DAMA data present a consistent picture for DMP emission from black holes. The only dif-
ference is the AGASA data captures the high energy end of the DMP spectrum, while the DAMA data captures the lower end: In the latter, the cross section increases linearly with energy and the energy spectrum of the particle distribution decreases with energy, \( E^{-2.5} \) \( E^{-3} \), so that the lower end of the spectrum contributes to the DAMA data.

The discussion in the previous section and this section provides a basis for the DMP component emitted from the GC that is implied by the DAMA data. Due to the nature of weak interactions, where cross sections are an increasing function of energy, March has a higher probability of encountering with the dark matter than September.

VI. THE MIGDAL EFFECT AND THE DAMA DATA

An important question is why other experiments such as CDMS have not observed a yearly variation of DMP.

It was suggested that enhancement by the Migdal effect might be a key factor. In ref. [22], the Migdal effect is computed for a NaI detector and it is shown that there is a large ionization effect for the inner electron. The Migdal effect is known to give a smaller effect for targets with large atomic number \( Z \), since the Coulomb binding is proportional to \((Ze)^2\) and therefore the Migdal effect is proportional to \(1/Z^2\). The Migdal effect on the Ge target of CDMS is 1/10 of that of Na target of DAMA. That might explain the different results for the two detectors.

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