Have mirror stars been observed?

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Abstract

Observations by the MACHO collaboration suggest that a significant proportion of the galactic halo dark matter is in the form of compact objects with typical masses $M \sim 0.5M_\odot$. One of the current mysteries is the nature and origin of these objects. We suggest that these objects are stars composed of mirror matter. This interpretation provides a plausible explanation for the inferred masses and abundance of the MACHO events. We also comment on the possibility of inferring the existence of mirror supernova’s by detecting the neutrino burst in existing underground detectors such as SuperKamiokande.

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A long standing mystery is the nature of the dark matter in the Universe. In order to shed light on the nature of the dark matter, the Australian - American MACHO collaboration has been searching for Massive Compact Halo objects (MACHO’s) in the halo of our galaxy using the gravitational microlensing technique suggested in Ref.\[1\]. By monitoring source stars in the Large Magellenic Cloud the MACHO collaboration have found 14 MACHO’s events\[2\]. These MACHO’s have typical masses $M \sim 0.5M_\odot$ and they are estimated to make up a large fraction of the galactic halo $f \sim 0.5\[2\]$. 

So what are the MACHO’s? Over the last few years several conventional candidates for the observed MACHO’s have been discussed, such as white dwarfs, brown dwarfs (i.e. Jupiter’s), neutron stars, etc. However all of these obvious candidates have either been excluded or appear to be disfavoured for one reason or another (for a recent discussion, see e.g. Ref.\[3\]). For example, if the MACHO’s are brown dwarfs, then it is difficult to understand the estimated mass of the MACHO events ($M \sim 0.5M_\odot$) because brown dwarfs are much lighter ($< \sim 0.08M_\odot$). In view of the estimated masses of the MACHO’s, the most likely conventional interpretation is that they are white dwarfs. However if the MACHO events are white dwarfs then it is very difficult to understand why there are so many of them in the halo of our galaxy. Furthermore there appears to be problems with overproduction of heavy elements and overproduction of light at high redshifts from the luminous stars which were the progenitors of the white dwarfs\[4\]. Thus, instead of solving the dark matter mystery the MACHO experiment has apparently deepened the mystery.

It is also apparently possible that the MACHO’s are not actually in the halo of our galaxy but are stars in the LMC. The situation will hopefully become better understood as more studies are done. If it turns out that the MACHO’s (or at least a significant proportion of them) are in the galactic halo then it may be possible that the observed MACHO’s are something more exotic. If this is the case what could they be? This is a quite nontrivial question, because the usual exotic dark matter candidates, such as the hypothetical neutralino, would not clump together to form MACHO’s. Are there any obvious particle physics dark matter candidates which have the required properties to form MACHO’s?

The purpose of this note is to suggest that the observed MACHO events are mirror stars composed of mirror atoms (i.e. mirror baryons and mirror electrons). The existence of a set of mirror particles is well motivated from a particle physics point of view, since these particles are predicted to exist if parity is an unbroken symmetry of nature\[5\] (the general idea was independently and earlier discussed a very long time ago by Lee and Yang\[6\] other historical details can be obtained from Ref.\[7\] and references there-in). The idea is that for each ordinary particle, such as the photon, electron, proton and neutron, there is a corresponding mirror particle, of exactly the same mass as the ordinary particle. For example, the mirror proton and the ordinary proton have exactly

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1 Of course this is not the only possibility, examples of other possibilities are that the MACHO’s are primordial black holes, see e.g. Refs\[2, 3\] and references there-in).
the same mass. Furthermore the mirror proton is stable for the same reason that the ordinary proton is stable, and that is, the interactions of the mirror particles conserve a mirror baryon number. The mirror particles are not produced in Laboratory experiments just because they do not couple to any of the ordinary particles. In the modern language of gauge theories, the mirror particles are all singlets under the standard $G \equiv SU(3) \otimes SU(2)_L \otimes U(1)_Y$ gauge interactions. Instead the mirror particles interact with a set of mirror gauge particles, so that the gauge symmetry of the theory is doubled, i.e. $G \otimes G$ (the ordinary particles are, of course, singlets under the mirror gauge symmetry). Parity is conserved because the mirror particles experience $V + A$ mirror weak interactions and the ordinary particles experience the usual $V - A$ weak interactions. The only force common to both ordinary and mirror matter is gravity.

It is important to appreciate that compact objects like stars and planets would not be expected to contain equal amounts of ordinary and mirror matter. This is just because ordinary and mirror atoms cannot collide with each other and dissipate energy to become bound up in compact objects like stars. One naturally expects the formation of stars composed primarily of ordinary matter, and mirror stars composed primarily of mirror matter. Thus the segregation of ordinary and mirror matter in the Universe can be nicely explained without any additional assumptions. In particular it is not necessary to assume that the mirror baryon number of the Universe is much less than the ordinary baryon number. Indeed it is most natural for these two quantities to be comparable in magnitude. (Of course the origin of the baryon number of the Universe is not understood so no definite conclusions can be drawn). Note that in this respect mirror particles are quite different to antiparticles, a Universe with equal amounts of matter and anti-matter is known to be problematic.

If mirror stars exist (i.e. stars composed of mirror atoms), then they would certainly appear to us as dark matter. Such stars could only be observed by their gravitational effects (unless they explode, as we will discuss later on). Note that the typical masses of mirror stars should be similar to ordinary stars. This is just because the interactions of mirror atoms literally mirror those of ordinary atoms. Thus providing that the Universe contains a significant amount of mirror matter, the observed MACHO events can be nicely explained. They are mirror stars, being primarily composed of mirror hydrogen and mirror helium. The mirror stars would have masses of order of the solar mass and this is nicely consistent with the observed MACHO events, which indicate that $M \sim 0.5M_\odot$.

3 The mass degeneracy of ordinary and mirror matter is only valid provided that the parity symmetry is unbroken, which is the simplest and theoretically most attractive possibility. For some other possibilities, which invoke a mirror sector where parity is broken spontaneously (rather than being unbroken), see Ref. 8.

4 An important issue which we have not addressed is the distance scale of this segregation. The interpretation of the MACHO’s as mirror stars would suggest that this segregation distance is less than or of the order of the inferred diameter of our galaxy (i.e. of order 30 kpc). Whether or not this feature can be explained in simple models of galaxy formation in the early Universe is beyond the scope of the present paper.
Actually estimates of the contribution of MACHO’s to the mass density of the Universe suggest that the mass density of MACHO’s is of the same order of magnitude as the mass density of ordinary baryons\(^3\). This feature may be plausibly explained by this mirror matter interpretation of the data since it is quite natural to expect that the mirror baryon number of the Universe is comparable to the ordinary baryon number.

Note that the idea that mirror matter is the origin of some or all of the observed dark matter in the Universe has been proposed in earlier papers by a number of authors, see e.g. Ref.\(^4\), \(^1\). The point of the present paper is to point out that the gravitational effects of individual mirror stars may have already been observed in the MACHO experiments. We have argued above that the rough features of the MACHO events can be plausibly explained by this interpretation. Of course, there is already strong evidence for the existence of the mirror world coming from neutrino physics, since one of the main predictions of these models\(^7\), \(^1\) is that each ordinary neutrino oscillates maximally into its mirror partner if neutrinos have mass (this is just a consequence of the unbroken parity symmetry). This provides a very natural explanation for the maximal mixing \(\nu_\mu \rightarrow \nu_x\) \((\nu_e \rightarrow \nu_y)\) suggested by the atmospheric (solar neutrino experiments).

One immediate implication of this interpretation of the observed MACHO’s as mirror stars is that there is a significant population of mirror stars in or near our galaxy. It is possible that mirror supernova also occur. If this is the case then it may be possible to detect the neutrino burst from such explosions. The reason is that the mirror supernova should release a significant amount of their energy into mirror electron neutrinos. The mirror model interpretation\(^7\), \(^1\) of the solar neutrino anomaly indicates that the electron neutrinos oscillate into mirror electron neutrinos with oscillation length less than about 1 astronomical unit. Thus, we would expect half of the mirror electron neutrinos from a mirror supernova explosion to have oscillated into electron neutrinos. If the mirror supernova explosion occurs in or near our galaxy then these electron neutrinos should be detectable in various existing underground neutrino experiments such as SuperKamiokande (just as the neutrino burst from SN1987 was observed). The obvious distinguishing signature of such explosions is that there will be no observed photon burst. The discovery of such events would add further evidence for the existence of a mirror world\(^5\). The typical energies of supernova neutrinos are in the range 10 to 25 MeV. It is tempting to speculate that the small observed excess of solar neutrinos with energies greater than about 13 MeV\(^1\) may be due to electron neutrinos emitted from distant

\(^3\) It should be pointed out that the properties of mirror supernova may not be as similar to ordinary supernova as one might naively expect. (For example, the rate at which mirror stars explode may be different to the rate at which ordinary stars explode). One reason for this is that the primordial chemical compositions of ordinary and mirror stars may be somewhat different. This is possible because the ratio of primordial mirror hydrogen to mirror helium may not be identical to the ratio of ordinary hydrogen to helium even if the baryon and mirror baryon numbers of the Universe are equal in magnitude. Indeed big bang nucleosynthesis arguments suggest that the temperature of the mirror particles in the early Universe should be less than the ordinary particles. In this case the ordinary light element abundances and the mirror light element abundances would not be expected to be exactly same.
mirror supernova. However, there is no reason for their direction to be correlated with the direction of the sun so that this explanation is probably not viable (although this conclusion may depend on the details of the background subtraction). Of course if the mirror supernova is close enough (i.e. in our galaxy or in a nearby galaxy) then there should be several detected events in a very short period of time (typically of order 10 seconds). The inferred direction of the detected neutrino events should also be correlated. This should be enough information to infer the existence of a mirror supernova even if no photon burst is observed.

We conclude this paper with the following general summary of the implications of a mirror world. There seems to be essentially three distinct ways to test this idea\(^6\). First, if neutrinos have mass then ordinary and mirror neutrinos should maximally mix with each other\(^7\)[11]. There is already strong experimental evidence that this mixing has already been observed in the solar and atmospheric neutrino experiments (the additional evidence for neutrino oscillations obtained by the LSND collaboration is also compatible with the mirror models\(^7\)). This interpretation of these experiments will be tested more rigorously in the near future as more data is analysed and more experiments come on-line. Second, the mirror sector will have important implications for early Universe cosmology. In general the predictions of the mirror model will be distinct from the standard model due to the creation of lepton number asymmetries due to ordinary - mirror neutrino oscillations\(^15\). Early Universe cosmology will be stringently tested in the future by the MAP and PLANCK experiments and by improved estimations of the primordial light element abundances. Finally, the existence of mirror stars and perhaps mirror galaxies is a natural consequence of the existence of a mirror sector. Such objects may help explain the inferred dark matter of the Universe. Indeed, we have argued in this paper that upto 14 mirror stars have already been ‘observed’ by the MACHO collaboration. We await with interest for future experiments and for a mirror star to explode so that we can further test the existence of a mirror world.

**Note added**

After submitting this paper, S. Blinnikov has informed me that he has already discussed the possibility that the MACHO events are mirror stars. See astro-ph/9801015. Also, after my paper was submitted, R. Mohapatra and V. Teplitz (astro-ph/9902085) have also discussed MACHO’s as mirror stars in the context of a model with mirror symmetry spontaneously broken.

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\(^6\) There are two other possibilities which have also been discussed in the literature, i.e. photon-mirror photon mixing and higgs - mirror higgs mixing\(^3\). However, big bang nucleosynthesis arguments suggest that such interactions are probably not observable experimentally\[^3\][14].
on this paper. The author also thanks N. F. Bell for explaining to me something about black holes which I should have known. The author is an Australian Research Fellow.

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