October 2000

Do “isolated” planetary mass objects orbit mirror stars?

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Abstract

We propose that the “isolated” planetary mass objects observed by Zapatero Osorio et al in the σ Orionis cluster might actually be in orbit around invisible stellar mass companions such as mirror stars. Mirror matter is expected to exist if parity is an unbroken symmetry of nature. Future observations can test this idea by looking for a periodic Doppler shift in the radiation emitted by the planets. The fact that the observations show an inverse dependence between the abundance of the these objects and their mass may argue in favour of the mirror matter hypothesis.

A variety of observations strongly suggests the presence of a significant amount of dark matter (DM) in the universe. Galactic rotation curves and cluster dynamics cannot be explained using standard Newtonian gravity unless non-luminous but gravitating matter exists. Arguments from Big Bang Nucleosynthesis and theories of large scale structure formation disfavour the simple possibility that all of the DM consists of ordinary baryons. Candidates for the required exotic component in the DM abound: WIMPS, axions and mirror matter are examples. The observation of microlensing events from the Small and Large Magellanic Clouds is consistent with the existence of Massive Compact Halo Objects (MACHOs) in the halo of the Milky Way [1]. The inferred average mass is about $0.5 M_{\odot}$, where $M_{\odot}$ is the mass of our sun. The most reasonable conventional identification sees MACHOs as white dwarfs, although there are several strong arguments against this [2]. For example, the heavy elements that would have been produced by their progenitors are not in evidence [2]. This argues against the conventional white dwarf scenario, and in favour of exotic compact objects. In summary, there is strong evidence for exotic DM which is capable of forming compact stellar mass objects.

Mirror matter [3] is an interesting candidate for some of the required exotic DM [4]. It can be independently motivated by the desire to see the full Poincaré Group, including improper transformations (parity and time reversal), as an exact symmetry group of nature. The basic postulate is that every ordinary particle (lepton, quark, photon, etc.) is related by an improper Lorentz transformation with an opposite parity partner (mirror lepton, mirror quark, mirror photon, etc.) of the same mass. Both material particles (leptons and quarks) and force carriers (photons, gluons, W and Z bosons) are doubled. Mirror matter interacts with itself via mirror weak, electromagnetic and strong interactions which have the same form and strength as their ordinary counterparts (except that mirror weak interactions couple to the opposite chirality). Because ordinary matter is known to clump into compact objects such as stars and planets, mirror matter will also form compact mirror stars and mirror planets. Since mirror matter does not feel ordinary electromagnetism, it will be dark. Gravitation, by contrast, is common to both sectors. Mirror matter therefore has the correct qualitative features: it is dark, it clumps, and it gravitates.[1] Later, we will explain why the observed inverse dependence between the abundance of the these objects and their mass may already argue in favour of the mirror matter hypothesis.

It has been speculated that MACHOs might be mirror stars [9], and one of us (RF) has proposed that the observed extrasolar planets [10] might be composed of mirror matter [11]. The former is well motivated by the aforementioned difficulties in identifying MACHOs as conventional stellar mass objects such as white dwarfs. The latter is motivated by the fact that the detected extrasolar planets are rather massive and orbit very closely to the star,

[1]There are several other interesting implications of the mirror matter model. In particular, oscillations between ordinary and mirror neutrinos have been proposed as a solution to the solar and atmospheric neutrino problems [5]. Ordinary - mirror neutrino oscillations also lead to interesting implications for early Universe cosmology [6]. Also photon-mirror photon kinetic mixing leads to potentially observable effects for orthopositronium [7] and can resolve the orthopositronium lifetime anomaly [8].

which are surprising characteristics. It is unlikely that ordinary planets of sufficient size could have condensed so close to the stars. If they are composed of ordinary matter, then they probably formed much further from the stars and then migrated in. Another possibility, though, is that they are composed of exotic material such as mirror matter. Because of the weak coupling between ordinary and mirror matter, there is no barrier to mirror planet condensation very close to an ordinary star. This idea should be testable by observing the opacity and albedo properties of the planets [12].

Zapatero Osorio et al. [13] have recently presented strong evidence for the existence of "isolated planetary mass objects" in the σ Orionis star cluster. These objects are more massive than Jupiter M_J, but not as massive as brown dwarfs ($\sim 5 - 15 M_J$ although there is some model dependence in the mass determination [13]). They appear to be gas giant planets which do not seem to be associated with any visible star. So far, eighteen such objects have been identified. Given that the σ Orionis cluster is estimated to be between 1 million and 5 million years old, the formation of these "isolated planets" must have occured within this time scale. Zapatero Osorio et al. argue that these findings pose a challenge to conventional theories of planet formation because standard theories of substellar body formation (as well as new theories inspired by previous claims of isolated planet discovery), are unable to explain the existence of numerous isolated planetary mass objects down to masses $\sim$ few M_J. See Ref. [13] and references therein for further discussion. It is possible therefore that non-standard particle physics may be required to understand their origin.

We speculate that rather than being isolated, these ordinary matter planets actually orbit invisible mirror stars. These systems could be, in a sense, just the mirror images of those ordinary star systems which have been speculated to feature large Jovian mirror planets in close orbit. Indeed, if there really are mirror planets in orbit around ordinary stars, then it is very natural to also expect mirror solar systems to sometimes contain large ordinary planets.

It should be possible to test this idea by searching for a periodic Doppler shift in spectral lines emanating from these planets. We have that

$$\frac{\Delta\lambda}{\lambda} = 2\frac{v_r}{c}, \tag{1}$$

where λ is wavelength, $\Delta\lambda$ is the difference between the peak and trough of the periodic Doppler modulation of λ, v_r is the maximum value of the component of the planet's orbital velocity in the direction of the Earth, and c is the speed of light. Suppose that a given planet is in a circular orbit of radius r around a mirror star of mass M. Let I be the inclination of the plane of the orbit relative to the normal direction defined by the Earth - mirror star line. Then

$$v_r = \sqrt{\frac{GM}{r}} \sin I, \tag{2}$$

where G is Newton's constant. Combining these equations we obtain

$$\frac{\Delta\lambda}{\lambda} \simeq 10^{-3} \sqrt{\frac{M}{M_\odot}} \sqrt{\frac{0.04\ A.U.}{r}} \sin I \tag{3}$$

as the level of spectral resolution required. Note that this is a few orders of magnitude larger than the Doppler shifts observed in extrasolar planet detection. However it is certainly true that the isolated planets are much fainter sources of light than the stars whose Doppler shifts have been measured so such a measurement may not be completely straightforward. However, it is worth noting that for the case of close orbiting ordinary planets where $r \sim 0.04$ *A.U.* (analogous to the close-in extra solar planets), the Doppler shift is quite large ($\sim 10^{-3}$) with a period of only a few days which should make this interesting region of parameter space relatively easy to test. Indeed, Zapatero Osorio et al. [13] have taken optical and near infrared low resolution spectra of three young isolated planet candidates (S Ori 52, S Ori 56, and S Ori 47). They have obtained absorption lines (at wavelengths ~ 900 nm), however their resolution was 1.9 nm [13] which is just below that needed to test our hypothesis. The higher resolution required has been achieved in the case of brown dwarfs [14] so we anticipate that it should be possible to test our hypothesis in the near future.

One would also expect some ordinary matter to have accumulated in the centre of the mirror star. It is possible, but not inevitable, that this ordinary matter also observably radiates. If so, one would expect this radiation to experience a much smaller Doppler modulation compared to that from the planet. Because the planet and mirror star would not be spatially resolved, one observational signature would be that some of the spectral lines are modulated (those from the planet), while a different set are not (those from the ordinary matter pollutants in the mirror star).

If the mirror star is invisible but opaque, then one would expect to see periodic planetary eclipses for some of these systems (those with $\sin I \simeq 1$). The eclipses should of course occur once per Doppler cycle, around one of the points of zero Doppler shift within a cycle. Obviously, such eclipses (along with the information provided by Doppler shift measurements) will be useful in distinguishing a mirror star from alternatives such as faint white dwarfs or neutron stars. However, it should be mentioned that standard objects such as white dwarfs and neutron stars are extremely unlikely candidates, because the age of the σ Orionis cluser is estimated to be only 1 million to 5 million years old, while white dwarfs and neutron stars are typically billions of years old.

Before concluding, we would like to point out an intriguing systematic in both the extrasolar planet and the Zapatero Osorio et al. data that may argue in favour of the mirror matter hypothesis. One envisages a universe that contained some admixture of ordinary and mirror matter from the earliest moments after the Big Bang. Eventually, both the smooth ordinary fluid and the mirror fluid condensed into large scale structures, stars and planets. Because gravitational condensation must be aided by non-gravitational dissipative effects to carry off kinetic energy, one does not expect the ordinary and mirror matter to have condensed in congruent locations, despite their common gravitational interaction. One expects instead a nonzero "segregation scale" ℓ to quantify the degree of spatial separation of condensed ordinary and mirror matter clouds or clumps. While we have too little information to theoretically calculate ℓ, the qualitative expectation is a universe of cells of scale ℓ, with a given cell being dominated either by ordinary matter or mirror matter. Provided that ℓ

is much greater than a typical solar system scale, which is in fact observationally required,[2] then the majority of hybrid ordinary-mirror systems should have disparate components: large ordinary objects with small mirror objects, or the other way around. The ordinary star plus mirror planet systems, and our proposed mirror star plus ordinary planet systems, have exactly this characteristic. Indeed one might expect the number of hybrid systems to increase as a function of the disparity between the components. Intriguingly, the observed extrasolar planets increase in number as their mass decreases. Even more interestingly, the Zapatero Osorio et al. objects also increase in number with decreasing mass: from Fig.2 of Ref. [13] we see that there are about as many objects between $8M_J$ and $10M_J$ as there are between $10M_J$ and $20M_J$ (taking 5 million years as the relevant lifetime). We predict, therefore, that an extended search would find greater numbers of these objects at even smaller masses. Of course if the "isolated planets" do orbit mirror stars then this suggests that the star forming region near σ Orionis could also be a region of mirror star formation. This is certainly possible and was already envisaged many years ago by Khlopov et al. [16] where they argued that large molecular clouds (made of ordinary matter) could merge with large mirror molecular clouds in which case the formation of mixed systems (i.e. containing both ordinary and mirror matter) is enhanced.

In conclusion, we have proposed that the "isolated" planetary mass objects observed by Zapatero Osorio et al. might actually be planets orbiting invisible mirror stars. This idea can be tested by searching for a Doppler modulation at the level of $10^{-3} - 10^{-4}$ in amplitude.

ACKNOWLEDGMENTS

This work was supported by the Australian Research Council. R.F. is an Australian Research Fellow.

[2] For instance, one can deduce an upper bound of about 10^{-3} for the mirror matter content of the Earth [15].

REFERENCES

[1] C. Alcock et al., MACHO Coll., Ap. J. **486**, 697 (1997); **542**, 000 (2000); T. Lasserre et al., EROS Coll., astro-ph/9909505.

[2] See, for example, B. D. Fields, K. Freese, D. S. Graff, Ap. J. **534**, 265 (2000).

[3] T. D. Lee, C. N. Yang, Phys. Rev. **104**, 254 (1956); R. Foot, H. Lew, R. R. Volkas, Phys. Lett. B **272**, 67 (1991).

[4] S. Blinnikov, M. Yu. Khlopov, Sov. Astron. **27**, 371 (1983); E. W. Kolb, D. Seckel, M. S. Turner, Nature **514**, 415 (1985); M. Yu. Khlopov et al., Soviet Astronomy. 35, 21 (1991); H. M. Hodges, Phys. Rev. D **47**, 456 (1993); Z. G. Berezhiani, D. Comelli, F. L. Villante, hep-ph/0008265.

[5] R. Foot, H. Lew, R. R. Volkas, Mod. Phys. Lett. A **7**, 2567 (1992); R. Foot, Mod. Phys. Lett. A **9**, 169 (1994); R. Foot, R. R. Volkas, Phys. Rev. D **52**, 6595 (1995); see also, Z. G. Berezhiani, R. N. Mohapatra, Phys. Rev. D **52**, 6607 (1995).

[6] R. Foot and R. R. Volkas, Astropart. Phys. **7**, 283 (1997); Phys. Rev. D**61**, 043507 (2000).

[7] S. L. Glashow, Phys. Lett. B **167**, 35 (1986); see also B. Holdom, Phys. Lett. B **166**, 196 (1986).

[8] R. Foot, S. N. Gninenko, Phys. Lett. B **480**,171 (2000).

[9] Z. Silagadze, Phys. At. Nucl. **60**, 272 (1997); S. Blinnikov, Talk at "Baryonic Matter in the Universe and its Spectroscopic Studies", Atami, Japan, 22-24 Nov. 1996, astro-ph/9801015; R. Foot, Phys. Lett. B **452**, 83 (1999).

[10] For a review and references see the extrasolar planet encyclopaedia, http://cfa-www.harvard.edu/planets/encycl.html.

[11] R. Foot, Phys. Lett. B **471**, 191 (1999).

[12] R. Foot, astro-ph/0101055.

[13] M. R. Zapatero Osorio et al., Science **290**, 103 (2000). See also, M. Tamura et al., Science **282**, 1095 (1998); P. W. Lucas. P. F. Roche, Mon. Not. R. Astron. Soc. **314**, 858 (2000).

[14] A. Thakrah, H. Jones and M. Hawkins, MNRAS, **284**, 507 (1997).

[15] A. Yu. Ignatiev, R. R. Volkas, Phys. Rev. D **62**, 023508 (2000).

[16] M. Yu. Khlopov et al., in Ref. [4]