Mapana–Journal of Sciences
2021, Vol. 20, No. 3, 17-21
ISSN 0975-3303/https://doi.org/10.12723/mjs.58.2

Planet Nine – Primordial Black Hole or a Dark Matter Object: A Comparative Study

Arun Kenath*, Kiren Othayoth Veetil† and Chandra Sivaram‡

Abstract

The study of Planet Nine has received a lot of attention of late. Recently it has been proposed that Planet Nine could be a Primordial Black Hole (PBH) lurking in our solar system. Earlier it was suggested by the present authors that Planet Nine could be degenerate object constituted mostly of dark matter (DM) particles, having their own distinct characteristic properties which were elaborated upon. Here we do a comparative study on whether the Planet Nine is a PBH or a DM Object, which would be relevant for future observations.

Keywords: Planet Nine, dark matter objects, primordial black hole

1. Introduction

Planet Nine is a hypothesized planet lurking in our solar system far beyond the orbit of Neptune and it was inferred by a peculiar clustering of six trans-Neptunian bodies (Trujillo and Sheppard, 2014). When the motions of these bodies were analysed, it was suggested that this object could be a massive planet (Batygin and Brown, 2016), which has been labelled as Planet Nine.

* Department of Physics and Electronics, CHRIST (Deemed to be University), Bangalore, Karnataka, India; kenath.arun@christuniversity.in
† Department of Physics and Electronics, CHRIST (Deemed to be University), Bangalore, Karnataka, India; kiren.ov@res.christuniversity.in
‡ Indian Institute of Astrophysics, Bangalore, Karnataka, India; sivaram@iiap.res.in

In an earlier paper (Sivaram et al., 2016) it was suggested that Planet Nine could be a degenerate object constituted of DM particles with its characteristic properties. The DM particles could form degenerate objects at earlier epochs (when local DM density was much higher) which provided a motivation to consider Planet Nine to be such a DM object. If made up of mostly DM particles, such objects (like Planet Nine) would not emit any radiation (at any wavelength) and therefore not be seen in the usual observational searches. It was also estimated that there could be one such object in the solar system volume (Oort cloud volume) and hence in our galaxy there could be as many as 10^{15}such objects (Sivaram et al., 2016).

Currently there is a lot of ongoing discussions as to whether this Planet Nine is actually a planet or possibly a primordial black hole (Scholtzand Unwin, 2020; Witten, 2020). Primordial black holes are black holes that are created in the early Universe right after the big bang and since they are not formed by the stellar gravitational collapse (Niemeyer and Jedamzik, 1999) their masses are much smaller compared to stellar mass black holes. So, for a definitive observation of Planet Nine we need instruments as in the Wide-field Infrared Survey Explorer (WISE) and Pan-STARRS (Meisner et al., 2017). Here we give a comparative study of the two different possibilities i.e., Planet Nine being either a PBH or a DM object.

2. Planet Nine as a PBH

The mass of the Planet Nine mass is estimated to be of the order of $10^{29}g$ (Batygin et al., 2019). Hence here we consider a corresponding PBH of the same mass. The radius, temperature and luminosity of a PBH of mass M is given by (Sivaram et al., 2014):

$$R = 10^{-33}\left(\frac{M}{M_{Pl}}\right)cm \quad (1)$$

$$T = 10^{32}\left(\frac{M_{Pl}}{M}\right)K \quad (2)$$

$$L = 10^{59}\left(\frac{M_{Pl}}{M}\right)^{2} ergs/s \quad (3)$$

where $M_{Pl} = 2.1 \times 10^{-5}g$ is the Planck mass.

For a PBH with mass the same as that of Planet Nine, the radius, temperature, and luminosity (from equations (1) to (3)) works out to be $10\ cm$, $3 \times 10^{-2} K$, and $10^{-8}\ ergs/s$ (fem to watt) respectively. The wavelength corresponding to the above temperature is$\sim 10\ cm$ which falls in the radio frequency range. At a distance of about 100 AU, the angular size of the Planet Nine mass PBH will be $\sim 10^{-10}$ arc seconds.

3. Planet Nine as a DM object

Dark matter could play a vital role in planetary formation. It has been pointed out (Arun et al., 2019) that local DM may have played a role in the formation of solar system and this raises the possibility of planets constituting DM particles. In a recent paper (Sivaram et al., 2019), it was suggested that DM particles, of several GeV rest mass, could form (gravitationally condense) degenerate objects of planetary mass. The typical mass of such objects, made up mostly of DM particles of mass m_D($\sim 60\ GeV$) is given by:

$$M = \frac{M_{Pl}^3}{m_D^2} \qquad (4)$$

for DM particles of mass $\sim 60\ GeV$ (Gelmini, 2006; Huang et al., 2016), this mass works out to be $10^{29} g$, typical mass of the hypothesized Planet Nine. If made up of mostly DM particles, such objects would not emit any radiation (at any wavelength) and therefore will not be seen in the usual observational searches. The radius of this DM object is given by:

$$R = \frac{92 \hbar^2}{G m_D^{8/3} M^{1/3}} \qquad (5)$$

which works out to be $10^5\ cm$.

The surface temperature of DM object (for example with a layer of H gas) is $30\ K$ and the luminosity is $10^{11}\ ergs/s$ (10KW) (due to solar radiation at 100 AU). The wavelength of the radiation emitted by the object is $10^{-2} cm$ which falls in the IR spectrum and its angular size seen over a distance of 100 AU will be~ 10 micro arc seconds.

The relativistic time dilation factor associated with an object of mass M at a distance r from its centre is given by:

$$\Delta = 1 - \frac{GM}{rc^2} \qquad (6)$$

where G is the gravitational constant and c is speed of light.

For the PBH of radius $10\,cm$, the time dilation factor at a distance of two times its radius will be $\Delta = 0.75$. Similarly at a distance of 2 km from the centre of DM object (i.e., twice the radius of the DM object) the time dilation factor $\Delta = 0.99$. This gravitational time dilation will in turn affect the frequency of the signal coming from, say an atomic clock placed inside the space probe investigating Planet Nine as detected by an observer at a very large distance (say from Earth). At the same distance of 2 km from the PBH, the time dilation factor will be the same as that with DM object, i.e., 0.99. Hence for this effect on the signals from the atomic clock (in the probe) to be seen (and distinguishable between DM object and PBH), we have to approach within two times the radius (about $10\,cm$) of PBH, which is a practical impossibility. So, it is impossible to distinguish the nature of the object using time dilation at a distance of say 2 km from the centre of the object.

The tidal force acting on a probe of mass m, radius r by an object of mass M at a distance d is given as:

$$F_T = \frac{2GMmr}{d^3} \qquad (7)$$

If a space probe of mass 1 ton ($10^3\,kg$), radius $10^2\,cm$, and a typical breaking stress of $200\,GPa$ is approaching the object of mass $10^{29}\,g$, then the force required to break this probe would be $2 \times 10^{16}\,dyne$. The distance from the centre of the object at which the break up will occur is $4 \times 10^4\,cm$ (from equation (7)). Thus, a space probe approaching twice the distance of PBH (i.e.,$\sim 20\,cm$) will be torn apart by the tidal force. Whereas this won't be a concern for a probe approaching the DM object.

4. Conclusion

In light of the recent discussions on the nature of Planet Nine (with the possibility of it being a PBH) we have done a comparative study of Planet Nine being either a PBH or a DM object (which was proposed earlier). This would be relevant for future observations of Planet Nine. We have shown that if Planet Nine is a PBH, it will be extremely difficult to detect it due to its small size, angular size, luminosity, etc. On the other hand, the signature of the corresponding DM object would be more easily evident.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Arun, K., Gudennavar, S. B, Prasad, A. and Sivaram, C. 2019, Astrophysics and Space Science, 364, 24.

Batygin, K. and Brown, M. E. 2016, Astronomical Journal, 151, 22.

Batygin, K., Adams, F. C., Brown, M. E. and Becker, J. C. 2019, Physics Reports, 805, 1.

Gelmini, G. B. 2006, In: Journal of Physics: Conference Series (IOP Publishing), Vol. 39, p. 166.

Huang, X. J., Zhang, W. H. and Zhou, Y. F. 2016, Physical Review D, 93, 115006.

Meisner, A. M. et al. 2017, Astronomical Journal, 153, 65.

Niemeyer, J. C. and Jedamzik, K. 1999, Physical Review D, 59, 124013.

Scholtz, J. and Unwin, J. 2020, Physical Review Letters, 125, 051103.

Sivaram, C. and Arun, K. 2011, Open Astronomy Journal, 4, 57.

Sivaram, C., Arun, K. and Kiren, O. V. 2019, Earth, Moon, and Planets, 122, 115.

Sivaram, C., Arun, K. and Kiren, O. V. 2014, Astrophysics and Space Science, 351, 407.

Sivaram, C., Arun, K. and Kiren, O. V. 2016, Astrophysics and Space Science, 361, 230.

Switzer, E. R. and Hirata, C. M. 2008, Physical Review D, 77, 083008.

Trujillo, C. A. and Sheppard, S. S. 2014, Nature, 507, 471, 2014.

Witten, E. 2020, arXiv: 2004. 14192 [astro-ph.EP]