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Detecting Exomoons Orbiting Pulsar Planets

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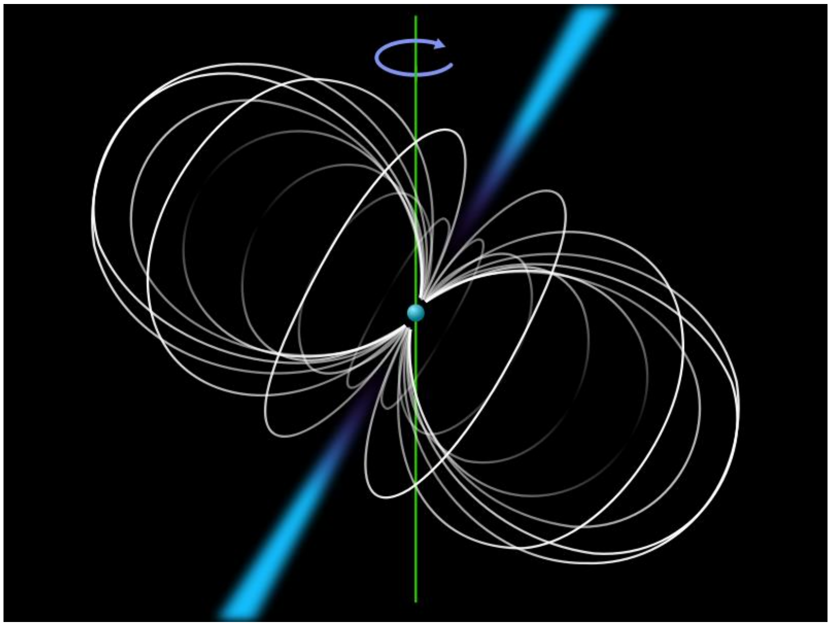

Figure 1: A neutron star (or pulsar), including the x-ray emitted shown in blue.

Although exomoons are difficult to detect, it may be possible to discover them when orbiting pulsar planets due to very regular pulses emitted by the neutron star. Not only is there possibility of life on such moons but it is also important to understand more about exoplanets and possible configurations of exomoons. This will provide useful and necessary information for space travel and finding hospitable planets

On February 25th, 2014 a research article titled the "Possibility of Detection of Exomoons with Inclined Orbits Orbiting Pulsar Planets Using the Time-of-Arrival Analysis" was published. This article not only provides useful information about exomoons and possibilities of life on other planets but it reaches into the deep mathematics necessary to find such planets. While the mathematics was done by Dr. Antonio Pasqua and Dr. Khudair Assaf, the data for this paper was collected from exoplanet.eu, a site that features all the parameters related to exoplanets known to date as well as relevant papers. Although it was found to be impossible to detect exomoons orbiting pulsar planets with the current knowledge, this paper invites further thought and promise for continuing research into this interesting and novel concept as well as a mathematical basis for related projects.

As mentioned, exomoons are satellites of exoplanets which are extrasolar planets orbiting a star. This could be any type of star, ranging from sun-like stars, through red giants, to exotic kinds such as neutron stars, otherwise known as pulsars. Neutron stars can form when a sufficiently massive star has burned up its fuel and ejecting any remaining matter, creating a supernova. This leaves behind a dense core, crushed by gravity. Until recently, it was believed that the supernova would destroy any planets in orbit. This however, even though the reason is not known, was proved wrong in 1992, when Wolszczan and Frail announced the discovery of the first exoplanetary system of two planets orbiting a neutron star. The existence of such exoplanets around neutron stars invites the study of these as possible sources of life. Since it is impossible to study them directly, it is necessary to do observations on these planets. Generally they can be studied using the light from the sun but this becomes impossible for exomoons since the change in intensity is not large enough to detect objects that have such small cross-sections. Neutron stars however, emit powerful x-rays at extremely regular intervals making it possible to observe even small changes in intensity. The Time of Arrival (TOA) model describes the frequency of the pulses emitted by a neutron star. Perturbations of the TOA of these pulses can be helpful in finding objects orbiting pulsars.

The goal of the research is to be able to detect exomoons for further research on their orbit and potential life on them. With the advances into space observation and even space travel, being able to further analyse and potentially even send objects and becomes necessary. Of course, before sending anything to another planet it is useful to know everything about the planet, including its moons.

In this paper, perturbations of the TOA model are used to detect exomoons. To do this, the maximum amplitude of the perturbation of the TOA is found to be

$$\max\left(\mathrm{TOA}_{\mathrm{pert,pm}}\right) = \frac{9\sin I}{16}\frac{M_m M_p}{\left(M_m + M_p\right)^2}\frac{R}{c}\left(\frac{r}{R}\right)^5 \times \left(\frac{5\sin^2\alpha}{3} - \frac{2\sin\alpha}{3} - \frac{2\cos^2\alpha}{9}\right),$$

where M_m is the mass of the moon, M_P is the mass of the planet, R is the distance between pulsar and planet, r is the distance between planet and moon, I is the angle between the normal of the planet-pulsar orbit and the line-of-sight of the pulsar and the moon, c is the speed of light and α is the angle between the planes of the planet-moon orbit and the star-planet orbit. The limiting case of a binary system, where M_m and M_p are equal, and the case that the pulsar-planet and planet-moon planes are coplanar are considered. In the first of these cases, the equation reduces to

$$\max\left(\mathrm{TOA}_{\mathrm{pert,pm}}\right) = \frac{9\sin I}{64}\frac{R}{c}\left(\frac{r}{R}\right)^5,$$

and when α is 90° the equation reduces to zero. When α is 90° the orbital planes are the same. Since systems where the mass of moon and planet are the same have not yet been found orbiting a neutron star, contrary to the hypothesis, there is no noticeable perturbative contribution from the exoplanet. This shows that the only detectable signal is produced by the planet.

From the above, it can be seen that TOA is not a viable technique for observing exomoons at this point. To be able to do so, all other objects producing similar perturbations would have to be found and their signals eliminated from the overall TOA. Such objects and processes could be the presence of other minor planets or pulsar precession which is the change in spin axis of the pulsar. Another issue is noise in the signal of the pulsar. This could be for example due to the phase changing slightly over time. Future work to improve the results would include using elliptical orbits instead of strictly circular orbits.

In conclusion, even though the time-of-arrival technique was promising for the detection of exomoons orbiting pulsar planets, it turned out to be non-viable in the presence of noise due to other factors. Since new technology will continuously bring new information, it is likely that some of these issues will be resolved or new methods of detecting exomoons will be determined. Not only does this research provide a mathematical analysis for a binary system orbiting a pulsar but it can also be used to delve into related fields.

Transcript:

Is all the data from exoplanets.eu?

Our data is from exoplanet.eu. You can find all the parameters related to all exoplanets known to date and you can also find some relevant papers.

How long do you think it took to collect the data you used?

I did not take them, I just used the values of the parameters already available. I think you can find more information about the data taken for pulsar planets in the relevant papers. You can find them cited in my paper or on the website. If you want more details, try to contact the people involved in the discovery of these planets. They can surely give you some good hints.

How long did it take to write the paper?

That's hard to say. I had the main idea to write this paper about 2 years ago, but I started to effectively work on it about one year ago and in about two months me and my other colleague finished it.

What are applications of this research?

There are a lot of things we need to learn about exoplanets. It's a really new field and one of the things we know even less about is exomoons. We want to have more ideas about them and hopefully detect them in the near future. Many people believe exomoons orbiting sun-like stars can harbour life so it is important to study them. Pulsar timing is the most promising model in order to detect exomoons since it is the most sensible among the available models. We wrote this paper in order to better understand which the possible configurations and limits are, we have in order to detect moons around pulsar planets. That's if they exist.

How much more difficult do you think it would be to do these calculations for elliptical orbits?

For elliptical orbits, the work becomes harder from a mathematical point of view. The main problem is that most of the equations used are only valid for circular orbits. When you consider elliptical orbits you start to have more complications. First of all, you'll find that the final equations of the work will depend on the ellipticity of the orbit. Often the eccentricity is not known. Moreover, in planetary science it is not easy to solve equations related to elliptical orbits. For example, very often you find elliptical integrals which cannot be solved so approximations are necessary. Also, the quantities which involve the distances between planet and moon become more difficult to evaluate since there are more parameters involved. If I need to make an estimate I think it is at least three times more difficult to work with elliptical orbits since it is required to use more difficult equations and to make longer calculations. You must also consider that the order of magnitude of the final result will be the same with elliptical orbits so considering this case does not give many more details about the physical phenomenon.

In your experience, what is the best thing about publishing?

That you can give a contribution to scientific knowledge with your effort made in order to make the paper.

What is the most frustrating?

In my opinion, the most frustrating thing is all the procedure there is for paper review. You need to pay attention to all the small details and sometimes people who need to correct your paper pay more attention to the style than the real scientific content. And sometimes, if you are unlucky you can find a Referee of your paper who send you really silly comments which are almost impossible to answer so it makes you lose time because you need to submit your work to other journals.

What kind of silly responses have you received from referees?

Most of my papers are on modified gravity and sometimes referees ask to give evidence that modified gravity is a correct theory. But there is no such evidence. Up to now it’s just a theory.

How old wereyou when you published oyur first paper?

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