Art preceding science: auroras on pulsar planets

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Auroras on Planets around Pulsars

Ruchi Mishra[1], Miljenko Čemeljić[1,2,3], Jacobo Varela[4], and Maurizio Falanga[5,6]
[1] Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences, Bartycka 18, 00-716 Warsaw, Poland
[2] Research Centre for Computational Physics and Data Processing, Institute of Physics, Silesian University in Opava, Bezručovo nám. 13, CZ-746 01 Opava, Czech Republic
[3] Academia Sinica, Institute of Astronomy and Astrophysics, P.O. Box 23-141, Taipei 106, Taiwan
[4] Universidad Carlos III de Madrid, Leganes, E-28911, Spain
[5] International Space Science Institute, Hallerstrasse 6, 3012 Bern, Switzerland
[6] Physikalisches Institut, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland
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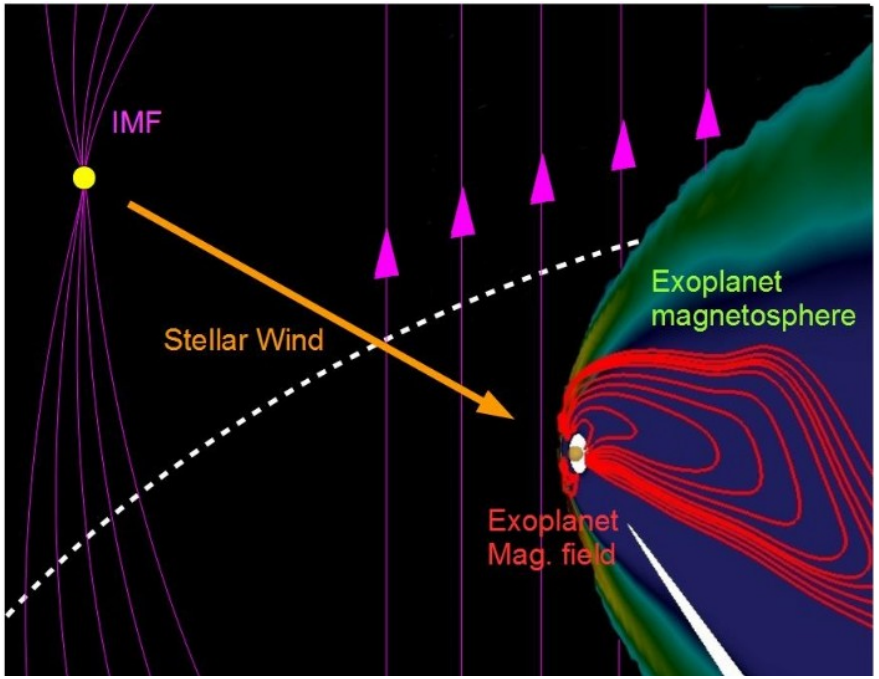
Abstract

The first extrasolar planets were discovered serendipitously, by finding the slight variation in otherwise highly regular timing of the pulses, caused by the planets orbiting a millisecond pulsar. In analogy with the solar system planets, we predict the existence of aurora on planets around millisecond pulsars. We perform the first magnetohydrodynamic simulations of magnetospheric pulsar–planet interaction and estimate the radio emission from such systems. We find that the radio emission from aurora on pulsar planets could be observable with the current instruments. We provide parameters for such a detection, which would be the first radio detection of an extrasolar planet. In addition to probing the atmosphere of planets in such extreme conditions, of great interest is also the prospect of the first direct probe into the pulsar wind.

Unified Astronomy Thesaurus concepts: Pulsar planets (1304); Magnetohydrodynamics (1964); Aurorae (2192)

Numerical simulations of star-exoplanet interaction

In a direct analogy with solar system planets and exoplanets around main sequence stars, we performed simulations for planets around pulsars. Radio emission from aurora is proportional to the magnetic field, so the emission should be the largest for the pulsar planets! This is important when our instruments are barely reaching needed sensitivity for the known exoplanets. For pulsars, we set a challenge: it is observable!



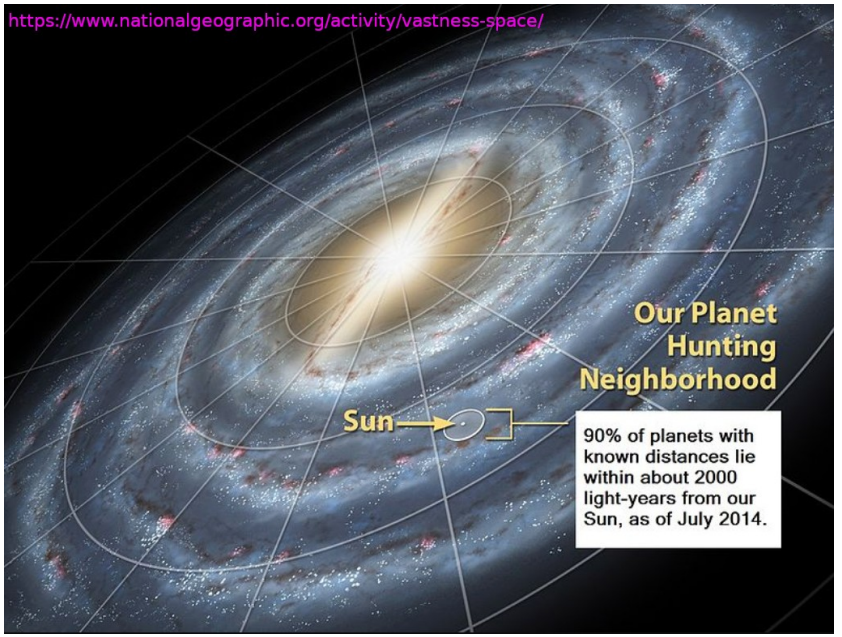


Table 2. Predicted and tentative intensity of the radio emission flux Φ for an observer on Earth in our two simulations with non-magnetized pulsar planet with conducting and ferromagnetic planetary surfaces, at different distances (in parsecs) from us. In the last three columns we check if the predicted values are above the frequency limit *AND* sensitivity of the currently most sensitive instruments, LOFAR and MeerKAT, and the future SKA. We also estimate the tentative realistic results in each of the cases, which indicate that such objects could be observable today.

Set-up	$\Phi_a(750)$ (mJy)	$\Phi_b(250)$ (mJy)	$\Phi_c(100)$ (mJy)	P_{radio} (Wm^{-2})	B_{sw} (G)	$\Delta\nu$ MHz	LOFAR	MeerKAT	SKA
Pulsar-planet (cond.)	0.60	5.4	33.75	3.65×10^{12}	0.0025	0.007	NO	NO	NO
Tentative	>	>	>	>	7.4	20.1	YES	YES	YES
Pulsar-planet (ferrom.)	0.47	4.23	26.43	1.14×10^{13}	0.01	0.028	NO	NO	NO
Tentative	>	>	>	>	13	36.4	YES	YES	YES

Previous works on the topic

-Referee informed us that Mottez & Heyvaerts (2011a,b) worked on planets around pulsars in the context of theory of electromagnetic interaction of stars and planets or small bodies. They extended the theory of Alfven wings to relativistic winds. Mostly-in fact all 15-citations from FRB community. The only other mention of pulsar planet aurora was in the abstract of a conference paper from 2017, just a scientific wish without any following:

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Feasibility and benefits of pulsar planet characterization

J. Nekola Novakova (1,2) and T. Petrasek (1,3)
(1) Charles University, Czech Republic: Faculty of Mathematics and Physics, Department of Geophysics, (2) Charles University, Czech Republic: Faculty of Science, (3) Academy of Sciences, Czech Republic; (julie.novakova@natur.cuni.cz)

Abstract

Planet orbiting neutron stars seem to be rare, but all the more interesting for science due to their origins. Characterizing the composition of pulsar planets could elucidate processes involved in supernova fallback disks, accretion of companion star material, potential survival of planetary cores in the post-MS phase of their stars, and more. However, the small size and unusual spectral distribution of neutron stars (NS) make any spectroscopic measurements very difficult if not impossible in the near future. In this work, we set to estimate the feasibility of spectroscopy of planets orbiting specifically pulsars, and to review other possible methods of characterization of the planets, such as emissions caused by aurorae.

circumstellar disk of the magnetar 4U 0142+61 [9], and a tentative asteroid belt around the millisecond pulsar B1937+21 [7]. PSR B1620-26 b is a circumbinary planet orbiting a pulsar and a white dwarf, and likely formed around the white dwarf precursor, with its system later captured by the pulsar, giving rise to a binary, while the pulsar's original stellar companion was ejected [8]. In a globular cluster with high star density, where this system is present, such an event is more likely than in the galactic disk. Finally, the PSR J1719-1438 system contains most likely a remnant of a disrupted WD companion that narrowly avoided its complete destruction, based on its minimum density [1].

These three known systems represent three of the possible means of origin of pulsar planets. Formation in disks from WD-NS mergers as opposed to

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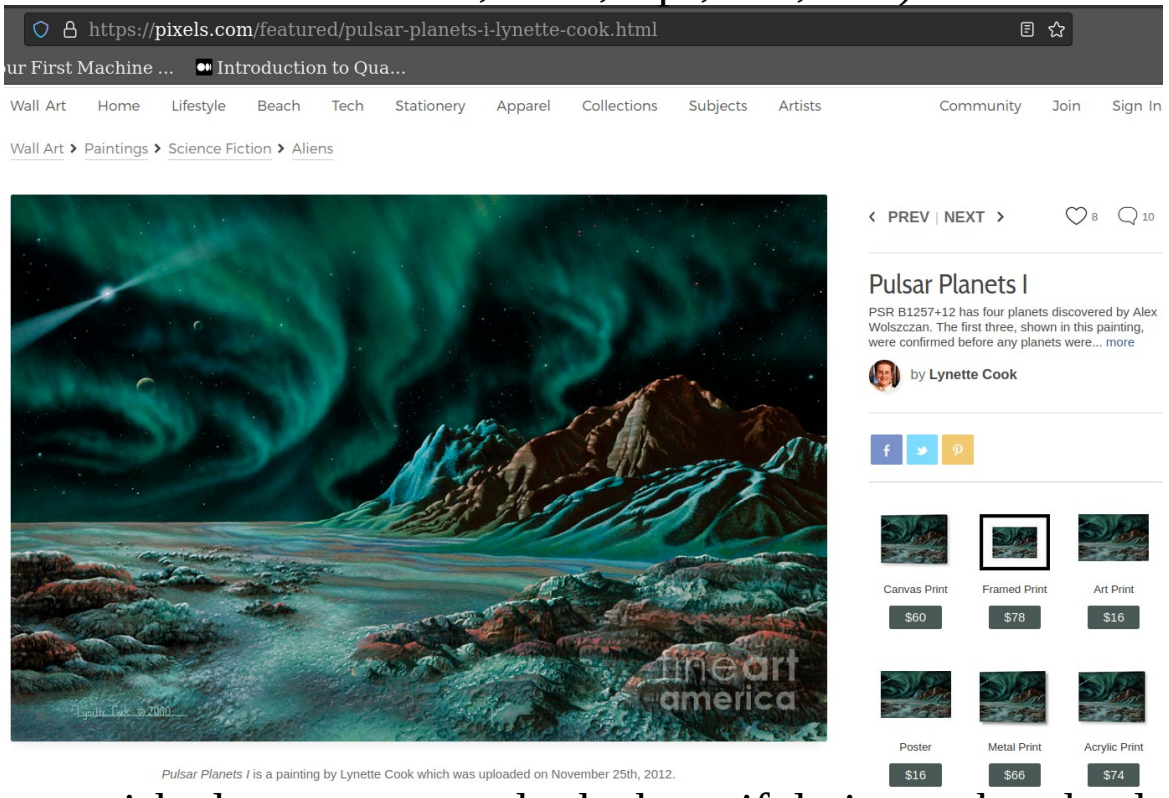
In the EAS 2024 meeting in Cracow in July 2023, where Ruchi Mishra, who worked with us on the article, had a poster with our results, I met Alex Wolszczan and asked him what he thinks of our idea. He listened carefully and commented: “I did not come to such idea. Give numbers!” Exactly this is what we did in the paper, making a challenge to the observers. But there was an interesting twist to the story. Browsing for “pulsar planets aurora” for a content related to our published paper (Mishra et al., “Auroras on Planets Around Pulsars”, 2023, ApJ, 959, L13) I was stunned to find the following picture:



What astonished me was not only the beautiful picture, but the date: 2012. And, on closer inspection, an even earlier date, 2000, near its bottom left corner. I already told you the timeline of the idea of such auroras, and this artist pictured it in 2000!? I could not leave it like this, and contacted the artist, Lynette Cook, asking if she just made it by analogy with Earth? She answered that she asked Alex Wolszczan back in 1999 about the scientific plausibility of the painting, and he suggested her to add an aurora! So, he did have, after all, an artistic idea of it, but it did not pass into the scientific work. Ours is the first where it is computed...25 years after the painting! Even the number of planets is correct, 3, not 4!