International Journal of Astrobiology 15 (2): 127–132 (2016)
doi:10.1017/S1473550415000257

On the search for artificial Dyson-like structures around pulsars

Z. Osmanov

School of Physics, Free University of Tbilisi, 0183 Tbilisi, Georgia e-mail: z.osmanov@freeuni.edu.ge

Abstract: Assuming the possibility of existence of a supercivilization we extend the idea of Freeman Dyson considering pulsars instead of stars. It is shown that instead of a spherical shell the supercivilization must use ring-like constructions. We have found that a size of the 'ring' should be of the order of (10^{-4}–10^{-1}) AU with temperature interval (300–600) K for relatively slowly rotating pulsars and (10–350) AU with temperature interval (300–700) K for rapidly spinning neutron stars, respectively. Although for the latter the Dyson construction is unrealistically massive and cannot be considered seriously. Analyzing the stresses in terms of the radiation and wind flows it has been argued that they cannot significantly affect the ring construction. On the other hand, the ring in-plane unstable equilibrium can be restored by the energy which is small compared with the energy extracted from the star. This indicates that the search for infrared ring-like sources close to slowly rotating pulsars seems to be quite promising.

Received 20 May 2015, accepted 8 July 2015, first published online 6 August 2015

Key words: Dyson sphere, pulsars, SETI

Introduction

In the framework of search for extraterrestrial intelligence (SETI) one of the important projects was the search for the interstellar radio communication. A rather different and quite original method was proposed by the prominent physicist Freeman Dyson in 1960, who suggested that if an extraterrestrial intelligence has reached a level of supercivilization, it might consume an energy of its own star (Dyson 1960). For this purpose, to have the maximum efficiency of energy transformation, it would be better to construct a thin shell completely surrounding the star. In the framework of this approach the author assumes that the mentioned superintelligence observed by us will have been in existence for millions of years, having reached a technological level exceeding ours by many orders of magnitude. Kardashev in his famous article (Kardashev 1964), examining the problem of transmission of information by extraterrestrial civilizations, has classified them by a technological level they have already achieved: (I) – a technological level close to the level of the civilization on earth, consuming the energy of the order of 4×10^{19} ergs s^{-1}; (II) – a civilization consuming the energy of its own star –4×10^{33} ergs s^{-1} and (III) – a civilization capable of harnessing the energy accumulated in its own galaxy: 4×10^{44} ergs s^{-1}. In this classification Dyson's idea deals with the civilization of type-II, consuming the energy exceeding ours approximately $4 \times 10^{33}/4 \times 10^{19} = 10^{14}$ times (see the similar estimates by Dyson (1960)). If we assume that an average growth rate of 1% per year in industry is maintained, the level of type-II civilization might be achieved in ∼3000 years (Dyson 1960), being quite reasonable in the context of the assumption that a civilization exists millions of years.

Dyson has suggested that if such a civilization exists, then it is possible to detect it by observing the spherical shell surrounding the star. In particular, it is clear that energy radiated by the star must be absorbed by the inner surface of the sphere and might be consumed by the civilization. The author implied that the size of the sphere should be comparable with that of the Earth's orbit. It is clear that to have energy balance, the spherical shell must irradiate the energy, but in a different spectral interval: in the infrared domain, with the black body temperature of the order of (200–300) K (Dyson 1960).

The attempts to identify Dyson spheres on the sky were performed by several groups Slish (1985); Jugaku & Nishimura (2000); Timofeev *et al.* (2000) but no significant results were obtained. Recently an interest to such an ambitious idea has significantly increased: a couple of years ago Carrigan has published an article titled: 'IRAS-based whole sky upper limit on Dyson spheres' (Carrigan 2009), where he considered the results of the instrument The Infrared Astronomical Satellite (IRAS). This satellite covered almost 96% of the sky, implying that this is almost whole sky monitoring. According to the study, the searches have been conducted as for fully as for partially cloaked Dyson spheres. The search has revealed 16 Dyson sphere candidates, but the author pointed out that further investigation must have been required. Recently an interesting series of works has been presented (Wright *et al.* 2014a, b; Griffith *et al.* 2015) where the authors discuss a broad class of related problems starting from philosophical aspects of SETI (Wright *et al.* 2014a), also examining in detail the strategy of the search for the infrared galactic and extragalactic sources corresponding to Kardashev-II/III civilizations (Wright *et al.* 2014b; Griffith *et al.* 2015).

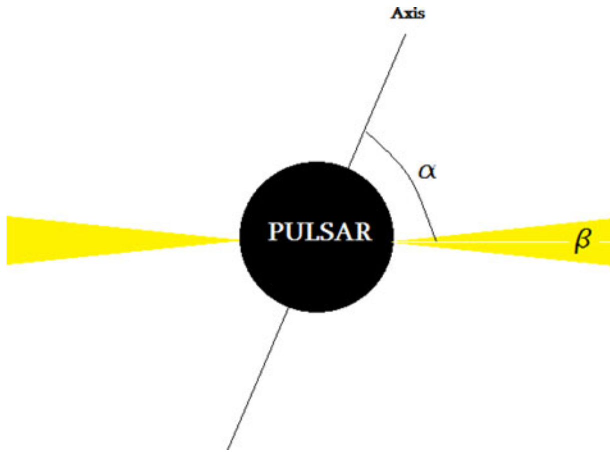

Fig. 1. In the picture we schematically show the pulsar, its axis of rotation and two emission channels with an opening angle β. It is worth noting that when α is close to 90°, the Dyson construction has to be located in the equatorial plane. Contrary to this, for relatively smaller angles, the emission channels will irradiate two different ring-like structures located in different planes parallel to that of the equator.

In this paper we present a rather different idea on how to search an advanced intelligence. In the framework of Dyson's idea, the spherical shroud (with radius of the order of (1–3) AU) is constructed around stars. It is clear that in order to consume almost the total energy radiated by the star, it must be imbedded inside a closed spherical shell, requiring enormous material to construct it. On the other hand, it is very well known that pulsars – rapidly rotating neutron stars – emit huge energy in narrow channels (see Fig. 1), therefore, if a supercivilization exists it can in principle utilize the energy of these objects. But in these cases, instead of sphere-like envelopes the super intelligence has to use ring-like structures around the pulsars. If the angle between the rotation axis and the direction of emission, α, is close to 90°, the ring will be located in the equatorial plane of the neutron star. As we will see later, in case of relatively slowly spinning pulsars (with periods of rotation of the order of 1 s) an advantage will be quite small sizes of these artificial constructions. Another class of neutron stars is the so-called X-ray pulsars, having a strong emission pattern in the X-ray band. Usually these objects are characterized by short periods of rotation with quite high values of slowdown rates, having luminosities exceeding those of normal pulsars by several orders of magnitude. It is worth noting that a habitable zone (HZ) around them might be further than around slowly spinning pulsars, implying that the possible size of the artificial 'ring' could be extremely large. Therefore, we can hardly believe that these objects can be interesting in the context of the search for extraterrestrial super advanced intelligence.

The organization of the paper is the following: after introducing the theoretical background we work out the details of the Dyson 'rings' surrounding the pulsars in the Section 'Theoretical background and results' and in the Section 'Conclusion' we summarize our results.

Theoretical background and results

In this section we consider the pulsars and estimate the corresponding physical parameters of artificial ring-like constructions surrounding the rotating neutron stars.

Generally speaking, any rotating neutron star, characterized by the slow down rate $\dot{P} \equiv dP/dt > 0$, where P is the rotation period, loses energy with the following power (called the slowdown luminosity, L_{sd}) $\dot{W} = I\Omega|\dot{\Omega}|$. Here by $I = 2MR_*^2/5$ we denote the moment of inertia of the neutron star, $M \approx 1.5 \times M_\odot$ and $M_\odot \approx 2 \times 10^{33}$ g are the pulsar's mass and the solar mass, respectively, $R_* \approx 10^6$ cm is the neutron star's radius, $\Omega \equiv 2\pi/P$ is its angular velocity and $\dot{\Omega} \equiv d\Omega/dt = -2\pi\dot{P}/P^2$. The slowdown luminosity for the relatively slowly spinning pulsars is of the order of

$$L_{sd} \approx 4.7 \times 10^{31} \times P^{-3} \times \left(\frac{\dot{P}}{10^{-15}\,\mathrm{ss}^{-1}}\right) \times \left(\frac{M}{1.5M_\odot}\right) \mathrm{ergs\ s}^{-1}, \quad (1)$$

where the parameters are normalized on their typical values. As it is clear from equation (1), the energy budget is very high forcing a supercivilization construct a 'ring' close to the host object. On the other hand, these sources exist during the time scale $P/\dot{P}$, which is long enough to colonize the star.

In the framework of the standard definition, a HZ is a region of space with favourable conditions for life based on complex carbon compounds and on availability of fluid water, etc. (Hanslmeier 2009). This means that the surface of the 'ring' must be irradiated by the same flux as the surface of the Earth (henceforth – the flux method). Therefore, the mean radius of the HZ, is defined as $R_{HZ} = (\kappa L_{sd}/L_\odot)^{1/2}$ AU, where $L_\odot \approx 3.83 \times 10^{33}$ ergs s^{-1} is the solar bolometric luminosity, is expressed as follows

$$R_{HZ} \approx 3.5 \times 10^{-2} \times P^{-3/2} \times \left(\frac{\kappa}{0.1}\right)^{1/2} \times \left(\frac{\dot{P}}{10^{-15}\,\mathrm{ss}^{-1}}\right)^{1/2} \times \left(\frac{M}{1.5M_\odot}\right)^{1/2} \mathrm{AU}, \quad (2)$$

where we have taken into account that the bolometric luminosity, L, of the pulsar is less than the slowdown luminosity and is expressed as κL_{sd}, $\kappa < 1$. As we see, the radius of the HZ for 1 s pulsars is very small compared with the radius of the typical Dyson sphere – 1 AU. The best option for the supercivilization could be to find a pulsar with an angle between the magnetic moment (direction of one of the channels) and the axis of rotation close to 90°, because in this case an artificial 'ring' has to be constructed in the equatorial plane. In case of relatively small inclination angles, there should be two rings, each of them shifted from the equatorial plane, although, in this case it is unclear how do the 'rings' keep staying in their planes, therefore, we focus only on pulsars with $\alpha \approx 90°$.

According to the standard model of pulsars it is believed that the radio emission is generated by means of the curvature radiation defining the opening angle of the emission channel

(Ruderman & Sutherland 1975)

$$\beta \approx 32^\circ \times P^{-13/21} \times \left(\frac{\rho}{10^6\,\mathrm{cm}}\right)^{2/21} \times \left(\frac{\dot{P}}{10^{-15}\mathrm{ss}^{-1}}\right)^{1/14} \times \left(\frac{\omega}{1.0\times 10^{10}\,\mathrm{Hz}}\right)^{-1/3}, \quad (3)$$

where the radius of curvature of magnetic field lines – ρ and the cyclic frequency of radio waves – ω, are normalized on their typical values (Ruderman & Sutherland 1975). One can straightforwardly check that the artificial 'ring' with equal radiuses of the spherical segment bases should have height in the following interval $(1-2)R_{HZ}\sin(\beta) \approx (0.006-0.06)$AU.

One of the significant parameters to search the 'rings' is their temperature, which can be estimated quite straightforwardly. In particular, if the aim of the super civilization is to consume the total energy radiated by the host pulsar, then albedo of the material the 'ring' has to be made of must be close to zero. For simplicity we consider $\alpha = 90°$, then it is clear that the inner surface of the 'ring', irradiated by the pulsar, every single second absorbs energy of the order of L. On the other hand, energy balance requires that the 'ring' must emit the same amount of energy in the same interval of time, $L = A_{ef}\sigma T^4$, leading to the following expression

$$T = \left(\frac{L}{A_{ef}\sigma}\right)^{1/4}, \quad (4)$$

where $\sigma \approx 5.67\times 10^{-5}$ erg/(cm^2 K^4) is the Stefan–Boltzmann constant, $A_{ef} = 8\pi R_{HZ}^2 \sin(\alpha/2)$ is the effective area of the spherical segment taking into account inner and outer surfaces and T is the average temperature of the 'ring'.

After applying equations (1)–(3), one can obtain T. In Fig. 2 (top panel) we plot the behaviour of temperature versus the period of rotation of a pulsar for different values of the slow down rate $\dot{P}$: $\dot{P} = 10^{-15}$ ss^{-1} (solid line); $\dot{P} = 10^{-14}$ ss^{-1} (dashed line); $\dot{P} = 2\times 10^{-14}$ ss^{-1} (dotted-dashed line). As we see from the graph, for relatively slowly spinning pulsars the typical values of the effective temperature of the artificial construction are in the following interval ~(400–500) K. The corresponding radius of the HZ varies from $\sim 10^{-2}$ to $\sim 10^{-1}$ AU (see the bottom panel).

Generally speaking, the distance to the HZ is not strictly defined, because our knowledge about life is very limited by the conditions we know on Earth. But even in the framework of life on Earth the radius of the HZ might be defined in a different way, assuming a distance enabling the effective temperature in the interval: (273–373) K where water can be in a liquid state (henceforth – the temperature method)[1]. From equation (4) one can show that

$$R_{HZ} = \left(\frac{L}{8\pi\sigma \sin[\beta/2]T^4}\right)^{1/2}. \quad (5)$$

In Fig. 2 (bottom panel) we plot the graphs of R_{HZ} versus T for the same values of $\dot{P}$. It is evident that in this case the distance to the HZ ranges from 2×10^{-4} to 1.3×10^{-2} AU.

[1] In reality the temperature range might be even narrower. For example the melting temperature of DNA is approximately 60 °C.

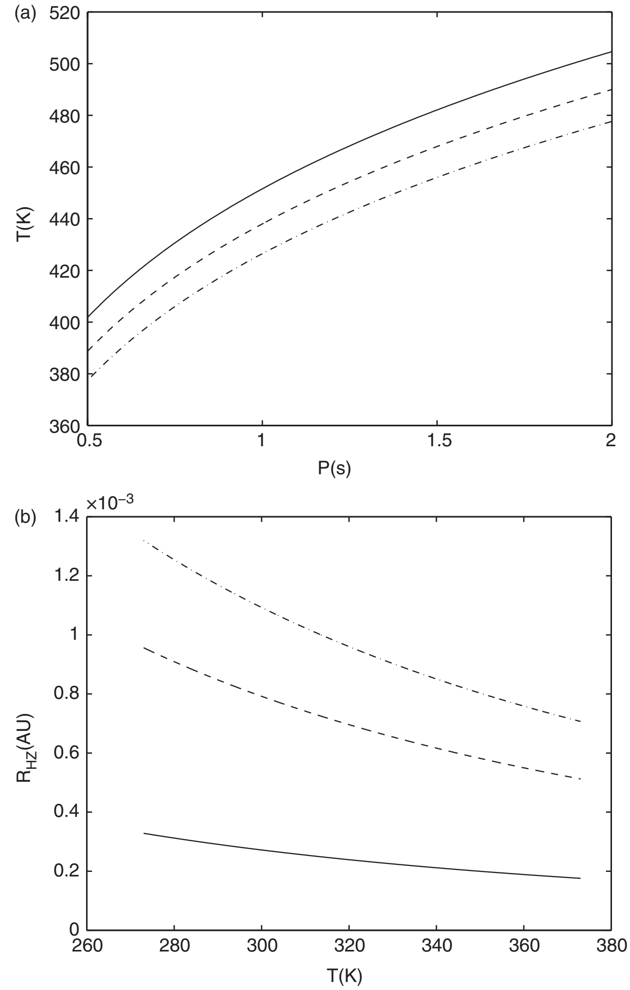

Fig. 2. On the top panel, in the framework of the flux method, we plot the dependence of T on P for three different values of $\dot{P}$: $\dot{P} = 10^{-15}$ ss^{-1} (solid line); $\dot{P} = 10^{-14}$ ss^{-1} (dashed line); $\dot{P} = 2\times 10^{-14}$ ss^{-1} (dotted-dashed line). As it is clear from the graph, for typical values of relatively slowly spinning pulsars the effective temperature of the artificial construction ranges from ~400 to ~500 K. On the bottom panel, in the framework of the temperature method, we show the dependence of R_{HZ} on T for the same values of $\dot{P}$. As we see the distance to the HZ ranges from 2×10^{-4} to 1.3×10^{-3} AU.

Another possibility for the supercivilization might be the 'colonization' of millisecond pulsars since these objects reveal extremely high values of luminosity. In particular, for the pulsar with $P = 0.01$ s and $\dot{P} = 10^{-13}$ ss^{-1} the slowdown luminosity is of the order of 9.5×10^{38} ergs s^{-1} and by taking into account $\kappa \approx 0.01$ (being quite common for millisecond pulsars), one can show that the bolometric luminosity

$$L \approx 9.5\times 10^{36} \times \left(\frac{P}{0.01\mathrm{s}}\right)^{-3} \times \left(\frac{\kappa}{0.01}\right) \times \left(\frac{\dot{P}}{10^{-13}\mathrm{ss}^{-1}}\right) \times \left(\frac{M}{1.5M_\odot}\right)\mathrm{ergs\ s}^{-1}, \quad (6)$$

is by several orders of magnitude higher than for relatively slowly rotating pulsars. Here the physical quantities are

https://doi.org/10.1017/S1473550415000257 Published online by Cambridge University Press

normalized on typical values of rapidly rotating neutron stars. It is clear that all rapidly spinning pulsars have extremely high energy output in the form of electromagnetic waves. As a result, a corresponding distance from the central object to the HZ must be much bigger than for slowly rotating pulsars.

In order to estimate the height of the 'ring' one has to define the opening angle of a radiation cone for millisecond pulsars radiating in the X-ray spectrum. According to the classical paper (Machabeli & Usov 1979), the X-ray emission of pulsars has the synchrotron origin, maintained by the quasi-linear diffusion. As it was shown by Machabeli & Usov (1979) the corresponding angle of the radiation cone is given by

$$\beta \approx 8^{\circ} \times \left(\frac{0.01\,\mathrm{s}}{P}\right)^{1/2} \times \left(\frac{R_{\mathrm{st}}}{10^6\,\mathrm{cm}}\right)^{1/2}, \tag{7}$$

which automatically gives an interval of height of the artificial construction: (0.02–0.15) AU.

After combining Equations (4) and (7), like the previous case of slowly rotating neutron stars, one can estimate the effective temperature for millisecond pulsars. In particular, in Fig. 3 (top panel) in the framework of the flux method, we show the behaviour of temperature of the 'ring' as a function of P and as we see, for the following interval of rotation periods: (0.01–0.05) s the temperature ranges from ~ 540 K to approximately 660 K. The size of the HZ ranges from 30 to 350 AU. Contrary to this, by applying the temperature method, in Fig. 3 (bottom panel) we show the behaviour of R_{HZ} versus T for three different values of $\dot{P}$: $\dot{P} = 10^{-13}$ ss^{-1} (solid line); $\dot{P} = 2\times10^{-13}$ ss^{-1} (dashed line); $\dot{P} = 4\times10^{-13}$ ss^{-1} (dotted-dashed line). From the figure it is clear that the distance to the HZ ranges from 10 to 30 AU.

To understand how realistic are these constructions it is interesting to estimate their masses. Let us assume that the material the rings are made of has the density of the order of the Earth, $\rho \sim 5.5$ g cm^{-3}. Then it is straightforward to show that the expression of mass is given by

$$M_{\mathrm{ring}} \approx 4\pi\rho R_{\mathrm{HZ}}^2 \Delta R \sin(\beta/2), \tag{8}$$

where ΔR is the average thickness of the ring. If we consider slowly rotating pulsars, by assuming $\Delta R \sim 10$ m and $R_{\mathrm{HZ}} \sim 10^{-3}$ AU (see Fig. 2), one can show that $M_{\mathrm{ring}} \approx 4\times10^{24}$ g, that is three orders of magnitude less than the mass of the Earth. Therefore, in the planetary system the material could be quite enough to construct the ring-like structure around 1 s pulsars.

The similar analysis for millisecond pulsars, shows that the mass of the ring, 4×10^{32} kg, exceeds the total mass of all planets, planetoids, asteroids, comets, centaurs and interplanetary dust in the solar system by three orders of magnitude. This means that nearby regions of millisecond pulsars hardly can be considered as attractive sites for colonization.

Another issue one has to address is the force acting on the structure by means of the radiation. By assuming that half of the total energy is radiated in each of the radiation cones, the corresponding force can be estimated as follows

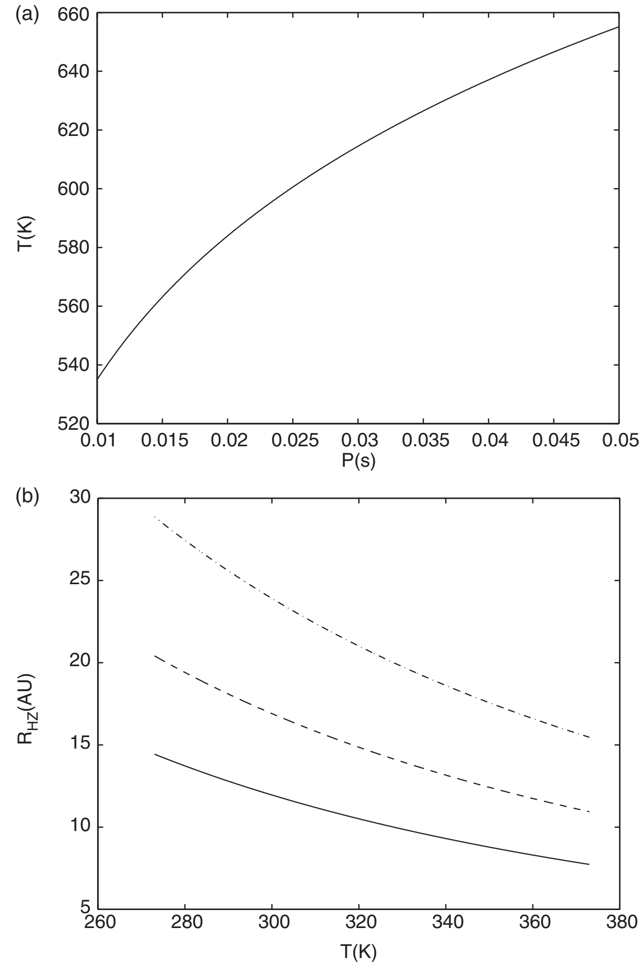

Fig. 3. On the top panel we present the behaviour of T versus P in the framework of the flux method. It is evident that for rapidly spinning pulsars the effective temperature of the 'ring' is in the following interval: (540–660) K. On the bottom panel, in the framework of the temperature method, we show the dependence of R_{HZ} on T for three different values of $\dot{P}$: $\dot{P} = 10^{-13}$ ss^{-1} (solid line); $\dot{P} = 2\times10^{-13}$ ss^{-1} (dashed line); $\dot{P} = 4\times10^{-13}$ ss^{-1} (dashed-dotted line). As we see the distance to the HZ ranges from 10 to 30 AU.

$$F_{\mathrm{rad}} \approx \frac{L}{2c}. \tag{9}$$

On the other hand, the stress forces in the ring, caused by gravitational forces should be of the order of the gravitational force acting on the mentioned area of the ring. This force is given by

$$F_{\mathrm{g}} \approx \frac{GM\lambda A}{R_{\mathrm{HZ}}^2}, \tag{10}$$

where λ is the mass area density of the ring and $A = 2\pi R_{\mathrm{HZ}}^2(1-\cos(\beta/2))$ is the area of the ring, irradiated by the pulsar. It is clear that for maintaining stability of the structure the radiation force should be small compared with the gravitational force. By imposing this condition equations (9) and (10) lead to $\lambda \gg L/(4\pi GMc(1-\cos(\beta/2)))$, which

https://doi.org/10.1017/S1473550415000257 Published online by Cambridge University Press

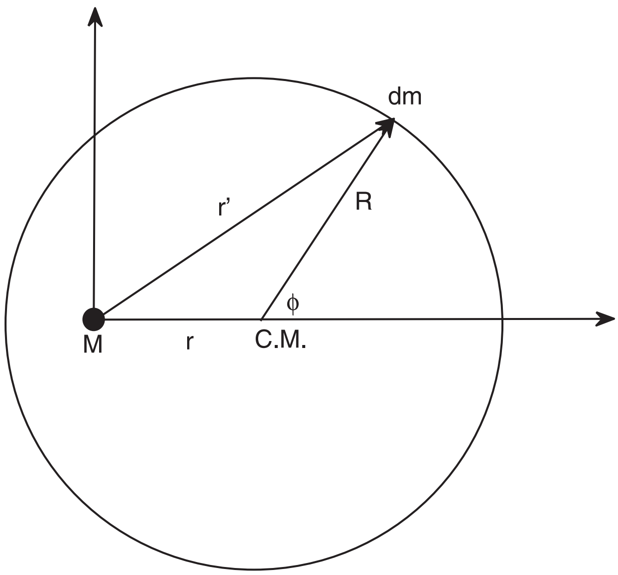

Fig. 4. Here we show the in-plane displaced ring with respect to the pulsar, denoted by M.

for $\beta = 32°$ reduces to

$$\lambda \gg 3.4 \times 10^{-6} \frac{L_{31}}{M_{1.5}} \mathrm{g\ cm^{-2}}, \tag{11}$$

where $L_{31} \equiv 10^{31}$ ergs s^{-1} and $M_{1.5} \equiv M/(1.5M_{\odot})$. As we see from the aforementioned estimate, for realistic scenarios the emission cannot significantly perturb the Dyson construction.

Generally speaking, rotation of pulsars drives high energy outflows of plasma particles around the star (Gudavadze *et al.* 2015) and the influence of these particles deserves to be considered as well. The similar result can be obtained by considering the interaction of the pulsar wind with the ring. In particular, in equation (11) instead of the radiation term, $L/2$, one should apply the pulsar wind's kinematic luminosity, that cannot exceed the slowdown luminosity. After considering the maximum possible kinematic wind luminosity, L_{sd}, the critical surface density will be of the same order of magnitude. Therefore, the Dyson structure can survive such an extreme pulsar environment.

On the other hand, it is clear that gravitationally such a system might not be stable. In particular, McInnes (2003) has considered a point mass and a thin solid ring having initially coincident centers of masses, thus being in the equilibrium state. Although, it has been shown that this equilibrium configuration is stable due to the perturbations normal to the plane of the ring and is unstable for perturbations within the mentioned plane.

In Fig. 4 we schematically show the in-plane displaced ring with respect to the pulsar. The gravitational force between the pulsar and the ring element with mass dm

$$df = G\frac{Mdm}{r'^2}, \tag{12}$$

projected on the r line and integrated over the hole ring (McInnes 2003)

$$f_r(\zeta) = G\frac{MM_{\mathrm{ring}}}{2\pi R^2}\int_0^{2\pi}\frac{\zeta + \cos\phi}{\left(1+2\zeta\cos\phi+\zeta^2\right)^{3/2}}d\phi, \tag{13}$$

for small values of $\zeta \equiv r/R$, leads to the equation describing the in-plane dynamics (McInnes 2003)

$$\frac{d^2\zeta}{dt^2} - \frac{1}{\tau^2}\zeta = 0, \tag{14}$$

where $\tau \equiv \sqrt{2R^3/(GM)}$ is the timescale of the process. This equation has the following solution

$$\zeta(t) = \zeta_0 e^{t/\tau}, \tag{15}$$

indicating that the equilibrium configuration is unstable against in-plane perturbations. Here, ζ_0 is the initial nondimensional perturbation. By means of this process the ring gains the kinetic energy with the following power

$$W = M_{\mathrm{ring}}R^2\frac{d\zeta}{dt}\frac{d^2\zeta}{dt^2}, \tag{16}$$

therefore, in order to restore the equilibrium state of the ring, one should utilize the same amount of energy from the pulsar corresponding to the instability timescale. On the other hand, it is evident that such constructions may have sense only if the power needed to maintain stability is small compared with the bolometric luminosity of the pulsar. By taking into account this fact, one can straightforwardly show that the initial declination from the equilibrium position must satisfy the condition

$$\zeta_0 \ll \frac{0.37}{R}\left(\frac{L_b}{M_{\mathrm{ring}}}\right)^{1/2}\left(\frac{2R^3}{GM}\right)^{3/4}, \tag{17}$$

which for the parameters presented in Fig. 3 leads to $\zeta_0 \ll (10^{-5} - 10^{-4})$. It is worth noting that such a precision of measurement of distance for supercivilization cannot be a problem. For instance, in the Lunar laser ranging experiment[2] the distance is measured with the precision of the order of 10^{-10}.

In the vicinity of pulsars radiation protection could be one of the important challenges facing the super advanced civilization. In particular, the radiation intensity

$$I = \frac{L_b}{4\pi R^2\left(1-\cos(\beta/2)\right)}, \tag{18}$$

for the shortest ring radius 2×10^{-4} AU is of the order of 10^{12} erg s^{-1} cm^{-2} and therefore, it should be of great importance to protect the civilization from high energy gamma rays. For this purpose one can use special shields made of certain material, efficiently absorbing the radiation, which in turn, might significantly reduce the corresponding intensity. If one uses half-value layer, *HVL*, which is the thickness of the material at which the intensity is reduced by one half we can estimate if the thickness of the ring is enough to make a strong protection from extremely high level of emission. If as an example we

[2] The corresponding data is available from the Paris Observatory Lunar Analysis Center: http://polac.obspm.fr/llrdatae.html

https://doi.org/10.1017/S1473550415000257 Published online by Cambridge University Press

examine concrete with $HVL = 6.1$, one can show that a layer of thickness 2.5 m reduces the intensity by 10^{12} orders of magnitude, being even more than enough for radiation protection.

Conclusion

We extended the idea of Freeman Dyson about the search for supercivilization and considered neutron stars. As a first example we examined relatively slowly rotating pulsars, considering the parameters $P = (0.5-2)$ s; $\dot{P} = 10^{-15}\ \mathrm{ss}^{-1}$; $\dot{P} = 2 \times 10^{-14}\ \mathrm{ss}^{-1}$; $\dot{P} = 2 \times 10^{-14}\ \mathrm{ss}^{-1}$. It has been shown that size of the 'ring' must be by (1–4) orders of magnitude less than those of the Dyson sphere, which is thought to be of the order of 1 AU. The corresponding temperatures of the artificial construction should be in the following interval (300–600) K.

By considering the parameters of millisecond pulsars, $P = (0.01–0.05)$ s; $\dot{P} = 10^{-13}\ \mathrm{ss}^{-1}$; $\dot{P} = 2 \times 10^{-13}\ \mathrm{ss}^{-1}$; $\dot{P} = 4 \times 10^{-13}\ \mathrm{ss}^{-1}$ we found that the radius of the 'ring' should be of the order of (10–350) AU with an enormous mass 10^{32} g exceeding the total planetary mass (except the central star) by several orders of magnitude. Therefore, it is clear that millisecond pulsars become less interesting in the context of the search for extraterrestrial superintelligence. Contrary to this class of objects, for slowly rotating pulsars the corresponding masses of the Dyson structures should be three orders of magnitude less than the Earth mass. We have also examined the tidal stresses in terms of radiation and pulsar winds and it has been shown that they will not significantly perturb the Dyson construction located in the HZ if the area density of the ring satisfies a quite realistic condition $\lambda > 3.4 \times 10^{-6}$ g cm^{-2}. We have examined the stability problem of the ring's in-plane dynamics and it has been shown that under certain conditions the power required to restore the equilibrium position might be much less than the power extracted from the pulsar. Also considering the problem of radiation protection we have found that it is quite realistic to reduce the high level of emission by many orders of magnitude.

It is worth noting that in the framework of the paper we do not suggest that an advanced civilization would arise around a massive star, surviving its supernova. On the contrary, we consider the possibility to colonize the nearby regions of pulsars building large-scale Dyson structures.

Generally speaking, the total luminosity budget of a pulsar is emitted over a broad range of wavelengths, that can be harvested by means of the Faraday's law of induction, transmitting electromagnetic energy into that of electricity.

As we see, the pulsars seem to be attractive sites for super advanced cosmic intelligence and therefore, the corresponding search of relatively small (0.0001–0.1 AU) infrared 'rings' (with the temperature interval (300–600) K) might be quite promising.

Acknowledgements

The research was partially supported by the Shota Rustaveli National Science Foundation grant (N31/49).

References

Carrigan, R.A. (2009). *ApJ* **698**, 2075.

Dyson, F. (1960). *Science* **131**, 1667.

Griffith, R.L., Wright, J.T., Maldonaldo, J., Povich, M.S., Sigurdsson, S. & Mullan, B. (2015). *ApJ* **217**, 25.

Gudavadze, I., Osmanov, Z. & Rogava, A. (2015). *Int. J. Mod. Phys. D* **24**, 1550042.

Hanslmeier, A. (2009). On the role of rotation in the outflows of the Crab pulsar. In *Habitability and Cosmic Catastrophes*, ed. p. 3. Springer-Verlag, Berlin, Heidelberg.

Jugaku, J. & Nishimura, S. (2000). A search for Dyson Spheres around late type stars in the Solar neighbourhood III, in *A New Era in Bioastronomy*, ASP Conference Series **213**, G. Lemarchand and K. Meech (eds), 581.

Kardashev, N.S. (1964). *AJ* **8**, 217.

Machabeli, G.Z. & Usov, V.V. (1979). *Sov. Astr. L* **5**, 238.

McInnes, C.R. (2003). *J. Br. Interplanet. Soc.* **56**, 308.

Ruderman, M.A. & Sutherland, P.G. (1975). *ApJ* **196**, 51.

Slish, V.I. (1985). In *The Search for Extraterrestrial Life: Recent Developments*, ed. Papagiannis, M.D., p. 315. Reidel Pub. Co., Boston, MA.

Timofeev, M.Y., Kardashev, N.S. & Promyslov, V.G. (2000). *Acta Astronautica J* **46**, 655.

Wright, J.T., Mullan, B., Sigurdsson, S. & Povich, M.S. (2014a). *ApJ* **792**, 26.

Wright, J.T., Griffith, R.L., Sigurdsson, S., Povich, M.S. & Mullan, B. (2014b). *ApJ* **792**, 27.