Search For Infrared Emission From Disks Around Pulsars

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1 Introduction

The standard model for a pulsar is a rotating neutron star born in a supernova explosion. Radio pulsars are powered by rotation while most x-ray pulsars are powered by accretion from a companion. Here, we propose to search for infrared emission from pulsars due to passive illumination of a surrounding hypothetical fallback disk rather than from either dissipation of rotational energy or accretion from a companion.

While there is no current direct evidence for the existence of disks around pulsars, there is indirect evidence that such disks could exist. For example, planets were discovered orbiting the pulsar B1257+12 by Wolszczan and Frail (Foster and Fischer 1996). These detected planets with periods of $\tilde{9}0$ days, implying distances between 0.19 and 0.46 AU, could not have orbited the progenitor of the pulsar which was a red supergiant with a radius of 2 to 3 AU (Drilling and Landolt 1999). It is likely that the planets formed from a disk of material surrounding the pulsar that was created subsequent to the supernova explosion, a "fallback disk" that would radiate mainly in infrared wavelengths. Somewhat similar models have been examined to help explain infrared excess around white dwarfs (Jura 2003) and anomalous x-ray pulsars (Israel et al 2003).

Previous searches for infrared or sub-millimeter fluxes from disks around pulsars were performed by Phillips and Chandler (1994) at 99 GHz and 380 GHz, Koch-Miramond et al. (2002) at 15 μm and 90 μm, and Foster and Fischer (1996) at 10 μm, respectively finding upper limits on the flux from disks that 10^5, 10^4, and 10^3 times greater than predicted by the model described below. In the context of the proposed model, previous searches for infrared or sub-millimeter emission from pulsars lacked sufficient sensitivity to detect a circumpulsar disk. With its vastly greater sensitivity, we propose to use the IRAC on SIRTF to search for these hypothetical disks.

Consider the emission of a flat, opaque disk surrounding a pulsar. The disk absorbs energy released by the pulsar due to a loss of rotational kinetic energy, L_*. The disk temperature is controlled by thermal balance, which is achieved when the rate of emitting energy balances the rate of absorbing energy. At a distance, d, from the pulsar, the flat disk absorbs energy

$$E = \left(\frac{L_*}{4\pi d^2}\right)\cos\theta \tag{1}$$

where θ is the average angle of incidence of the radiation. Modifying the temperature expression used by Jura (2003) results in a disk temperature expression of

$$T_{disk} = \left(\frac{L_* R_*}{6\pi\sigma d^3}\right)^{1/4} \tag{2}$$

where R_* is the radius of the pulsar, typically 10 km. The maximum disk temperature is limited to $\tilde{1}000$ K because above this temperature the material of the disk would no longer be solid dust grains. This maximum temperature, along with limiting the inner radius of the disk, makes the flux drop off rapidly as the wavelength approaches optical wavelengths. The radius of the disk, represented by x, is modeled by the expression

$$x = \frac{h\nu}{kT_{disk}} \tag{3}$$

where ν is the frequency (Jura 2003). The energy flux from this disk is

$$F_\nu = \frac{16\pi}{3}\cos i\left(\frac{R_*}{D_*}\right)^2 \frac{h}{c^2}\nu^{1/3}\left(\frac{k}{h}\right)^{8/3}\left(\frac{L_*}{6\pi^2\sigma}\right)^{2/3} R_*^{-4/3}\int_{x_{in}}^{x_{out}}\frac{x^{5/3}}{e^x-1}dx \tag{4}$$

where D_* is the distance to the pulsar from the sun. Although this expression (4) is an idealized model, it can be used to successfully reproduce the infrared flux of the white dwarf G29-38 (Jura 2003).

2 Feasibility

Our sample of target pulsars is taken from a compilation of Taylor, Manchester, and Lyne (1993). We selected pulsars that have the highest values of

F_ν as given by equation (4). Using 2MASS data, we eliminated targets that lay in crowded fields due to the confusion problems these fields present. The Vela Pulsar and Crab Pulsar were also eliminated because they are young and may have intrinsic infrared emission.

To estimate the required exposure time for a target, the background level needs to be calculated. By entering the target pulsars in the SIRTF Planning Observation Tool (SPOT), we were able to find each targets background level at the four different wavelengths. Using these background levels and the IRAC sensitivity table, we calculated the approximate time for a 6σ detection at all four IRAC wavelengths. The total time requested for this proposal is 8370 seconds.

Table 1 – Predicted Infrared Fluxes

Target	Dist (kpc)	Log E (erg s^{-1})	F (3.6μm) (μJy)	F (4.5μm) (μJy)	F (5.8μm) (μJy)	F (8.0μm) (μJy)	Total Time (s)
J0633+1746	0.15	34.51	101	159	226	298	290
J0437-4715	0.14	34.39	96	152	216	284	290
J1932+1059	0.17	33.59	19	30	43	56	1730
J0953+0755	0.12	32.75	10	17	24	31	3030
J1952+3252	2.50	36.57	8	14	20	25	3030