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Pulsar Scintillation Measurements: Is there any evidence for a Local Bubble Shell or effects from pulsar bow shocks?

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Abstract. Bhat et al. (1998) presented a model in which they explain the increase in scintillation bandwidth with decreasing pulsar distance as being due to a shell of scattering material associated with the Local Bubble. However, Britton et al. (1998) concluded that the scattering material for local pulsars is nearer to the pulsar (i.e. possibly in a bow shock or shell near the pulsar). We have investigated the effects of the local bubble shell and pulsar bow shocks on the scintillation bandwidth, the scintillation timescales and the angular broadening of pulsars. We find that a) there is no evidence for a shell of scattering material associated with the Local Bubble because the scintillation timescale data do not fit the Bhat et al. model and the angular broadening measurements do not suggest a scattering screen near the Sun, and b) that pulsar bow shocks cannot produce any enhanced scintillations.

1. Introduction

Bhat et al. (1998) suggested that a shell of scattering material near the Sun (and possibly associated with the local bubble) could explain the observed scintillation bandwidths of nearby pulsars. Britton et al. (1998) compared the scintillation bandwidths (pulse delays) with the observed angular broadening and concluded that any scattering screens must be located closer to the pulsars than to the observers. These two conclusions are obviously in conflict with one another.

In this paper we use other scintillation parameters to explore whether the Bhat model is correct and if pulsar bow shocks play an important role. By using the scintillation bandwidths and timescales as well as the angular broadening of pulsars we use different "lever-arms" for the relative distance to the scattering material (see Figure 1) which allows us to constrain models of the distribution of scattering material to a much higher degree of accuracy.

2. The Models

First, we should note that Bhat et al. (1998) used only the scintillation bandwidths (τ_{d}, ν) in determining their model. This leads to an ambiguity that can not be eliminated. Since the weighting function for the scintillation bandwidth is symmetric (see Figure 1), a scattering screen 100 pc from the observer and

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the same scattering screen 100 pc from the pulsar will give the same result. This means that the Bhat model could be mis-identifying scattering screens that should be near the pulsar as actually being near the Sun. Secondly, we note that Bhat et al. (1998) used the wrong constant of proportionality in their equation 12, $(A_\alpha f_{\rm obs}^\alpha)^{-1}$ rather than $(A_\alpha f_{\rm obs}^\alpha)^{2/(\alpha-2)}$. This error explains the difference in the scintillation bandwidth from the Bhat model and the actual data in Figure 2.

We use the following parameters for the local bubble shell model (derived from the values in Bhat et al. 1998): $\mathrm{C_n^2(shell)} = 10^{-2.14}\ \mathrm{m^{-20/3}}$, $\mathrm{r_1} = .06$ kpc and $\mathrm{r_2} = 0.075$ kpc are the "average" distances to the shell edges from the Sun, $\mathrm{C_n^2(ISM)} = 10^{-4.5}\ \mathrm{m^{-20/3}}$ and the average perpendicular component of the pulsar velocity (to the line of sight) relative to the ISM as 50 km/s. The pulsar bow shock model has the following properties: $\mathrm{C_n^2(bow\ shock)} = 10^{-3.8}\ \mathrm{m^{-20/3}}$, $\mathrm{r_1} = .000005$ kpc and $\mathrm{r_2} = 0.000009$ kpc are the "average" distances to the bow shock edges from the pulsar and the average perpendicular component of the pulsar velocity relative to the ISM as < 50 km/s.

In Figure 2 we plot the Bhat model and the pulsar bow shock model versus the various observables. Equations 5, 7 and 42 from Rickett and Cordes (1998) were used to determine the model values. In the upper right panel of Figure 2 we see that the scintillation timescales for the Bhat et al. model are three orders of magnitude too large for distant pulsars. We also note that the shape of the scintillation timescale versus distance curve is functionally different from the data. The pulsar velocities assumed here could be off by a factor of ten and the determination of the pulsar scintillation timescales can be off by factors of three. However this cannot explain the discrepancies mentioned above. We also note that the pulsar bow shock model produces scintillation timescales that are too long. This discrepancy may arise because the relative velocities between the bow shock material and the pulsar are very close to zero (so that we get refractive but not diffractive effects) or because the ISM material is not in the bow shock long enough to become fully ionized (as is assumed). Finally, the time that the material spends in the pulsar bow shock may be shorter than the eddy turnover time for turbulence so that the turbulence never develops in the bow shock.

Another test of the Bhat et al. model is to compare the angular broadening of nearby pulsars with the angular broadening of extra-galactic radio sources along nearby lines of sight. Assuming that one screen dominates the scattering (for all lines of sight as in the Bhat et al. model) or that there is a smooth medium and a screen, we can determine the distance of any scattering screen. For the thin screen case the ratio of the extra-galactic angular broadening to the pulsar angular broadening (r) is given by $\mathrm{r} = 1 - \frac{\mathrm{d_s}}{\mathrm{D}}$ where D is the distance to the pulsar and $\mathrm{d_s}$ is the distance from the Sun to the scattering screen. If there is a uniform scattering medium and a thin screen then we have $\mathrm{r}^2 = \left(\frac{\mathrm{D}}{3} + \frac{\mathrm{SM_s}}{\mathrm{SM_u}}(\mathrm{D} - \mathrm{d_s})\right) / \left(\mathrm{d_u} + \frac{\mathrm{SM_s}}{\mathrm{SM_u}}\mathrm{d_u}\right)$ where $\mathrm{d_u}$ is the total extent away from the Sun of the uniform medium, $\mathrm{SM_s}$ is the scattering measure of the screen and $\mathrm{SM_u}$ is the scattering measure of the uniform medium.

In Table 1 we present the results of comparing pulsar and extra-galactic angular broadening measurements. In Table 1 the first column gives the pulsar name, the second gives the extra-galactic source name. The angular separation

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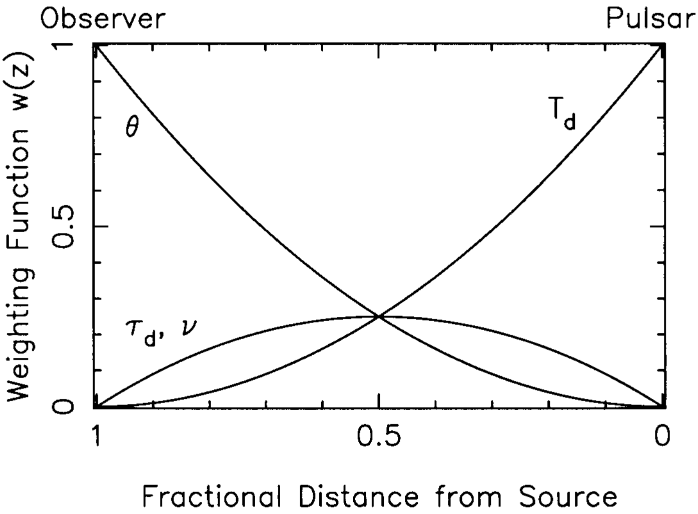

Figure 1. The weighting functions (lever arms) for different interstellar scattering observables: scintillation bandwidth/pulse delay (ν, τ_d), scintillation timescale (T_d) and angular broadening (θ). Note the symmetry of the scintillation bandwidth/pulse delay weighting function.

between sources is given in the third column while the distance to the pulsar is given in the fourth. The ratio of the angular broadening at 1 GHz is given in the fifth column, the distance to the scattering screen (from the Sun) in the screen only model is given in the sixth column while the seventh column gives the distance (from the Sun) of the screen in the screen plus uniform scattering model. None of the results in Table 1 are consistent with a nearby scattering screen as proposed by Bhat et al.

3. Results

We find that both pulsar scintillation timescale measurements and the comparison of angular broadening of pulsars and extra-galactic sources present results which are inconsistent with the Bhat et al. model of a shell of scattering material associated with the local bubble. We also find no evidence for pulsar bow shocks having any detectable effects on the observed scintillation properties.

References

Bhat, N.D.R., Gupta, Y. and Rao, A.P. 1998, ApJ, 500, 262
Britton, M.C., Gwinn, C.R. and Ojeda, M.J. 1998, ApJ, 501, L101
Cordes, J.M. and Rickett, B.J. 1998, ApJ, 507, 846.

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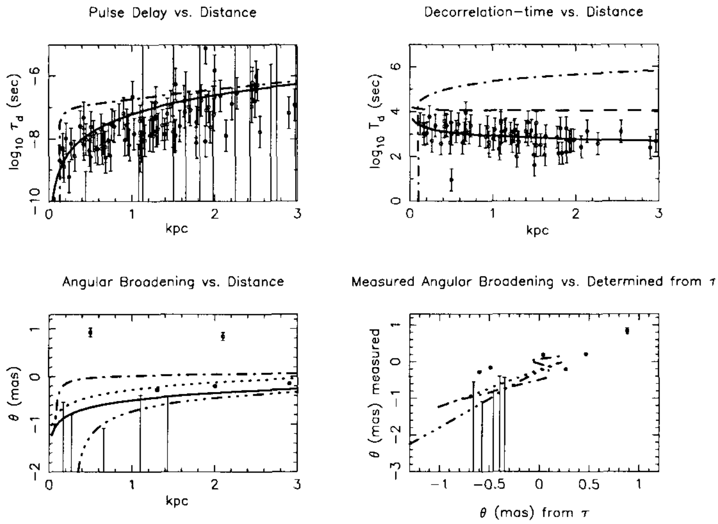

Figure 2. Model fits to the data. Solid line - uniform scattering. Dashed line - pulsar bow shock. Dash-dot line - Bhat et al. model. Dot-dot-dot line - angular broadening determined from scintillation bandwidth. Dot-dot-dot-dash line - uniform scattering beyond local bubble (no shell or scattering in the local bubble).

Table 1. Location of a scattering screen from comparing pulsar angular broadening to extra-galactic source angular broadening.

Pulsar Name	Extra-galactic Source Name	Angular Separation (degrees)	Pulsar Distance (kpc)	Angular Broadening Ratio	d_s (kpc)	d_u (kpc)
B0329+54	0241+622	9.70	1.43	< 0.0003	< 1.43	< 3.0
B1919+21	1922+155	5.57	0.66	< 0.0039	< 0.66	< 8.7
B1919+21	1932+204	1.93	0.66	< 0.0059	< 0.66	< 8.4
B1919+21	1954+282	9.70	0.66	< 0.0092	< 0.65	< 7.9
B1929+10	1905+079	6.16	0.17	< 0.0004	< 0.17	< 8.6
B1929+10	1922+155	4.11	0.17	< 0.0137	< 0.17	< 7.3
B1929+10	1932+204	9.04	0.17	< 0.0205	< 0.17	< 6.1
B1933+16	1909-161	4.16	7.94	> 1.4292	> -3.41	> -3.8
B1933+16	1922+155	2.22	7.94	0.0769	7.33	15.4
B1933+16	1932+174	1.26	7.94	> 0.8167	> 1.46	> -2.2
B1933+16	1923+210	4.08	7.94	> 0.1010	> 7.14	> 9.5
B1933+16	1932+204	3.86	7.94	0.1154	7.02	14.5
B1937+21	1909-161	8.03	3.60	> 1.3727	> -1.34	> -21.7
B1937+21	1922+155	6.89	3.60	0.0739	3.33	10.4
B1937+21	1932+174	3.95	3.60	> 0.7844	> 0.78	> -20.2
B1937+21	1923+210	2.38	3.60	> 0.0970	> 3.25	> 5.1
B1937+21	1932+204	1.44	3.60	0.1108	3.20	8.8
B1937+21	1954+282	7.80	3.60	0.1724	2.98	5.3
B2016+28	1954+282	3.16	1.10	< 0.0449	< 1.05	< 7.2
B2016+28	2008+33D	3.35	1.10	< 0.0031	< 1.10	< 8.1
B2016+28	2021+317	3.32	1.10	< 0.0155	< 1.08	< 2.3
B2016+28	2023+336	5.03	1.10	< 0.0059	< 1.09	< 2.7
B2016+28	CL4	6.63	1.10	< 0.0001	< 1.10	< 1.6
B2016+28	2048+313	6.62	1.10	< 0.0062	< 1.09	< 1.6
B2016+28	2013+370	6.99	1.10	< 0.0096	< 1.09	< 4.3
B2016+28	2005+403	9.03	1.10	< 0.0051	< 1.09	< 2.0

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