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Multiple Scintillation Arcs in Six Pulsars

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Abstract Low-intensity scattering in discrete screens gives rise to parabolic scintillation arcs in pulsar secondary spectra. The curvature of the arc boundary is uniquely determined by the location of the screen along the line of sight, the distance to the pulsar, and the relative velocity of pulsar and Earth (assuming the transverse screen velocity to be small). This information is usually available for the strong pulsars needed to exhibit clear scintillation arcs. Early studies reported single arcs along most lines of sight. This seemed puzzling given the variety of distances and sight lines being probed. We report new, higher sensitivity observations that show up to four scintillation arcs for a particular sight line.

Key words: ISM — pulsars: individual (B0329+54, B0823+26, B0919+06, B1133+16, B1642–03, B1929+10) — pulsars: general — scattering

1 INTRODUCTION

Pulsar scintillation studies have undergone rapid development in the past several years with the discovery of scintillation arcs (Stinebring et al. 2001), parabolic features in the secondary spectrum of pulsars. These arcs are a valuable tool for studying turbulence and discrete structures in the warm ionized interstellar medium (WIM) on size scales of 1 AU and larger. Both observations and theory (Hill et al. 2003; Walker et al. 2004; Walker and Stinebring 2005; Cordes et al. 2006) have developed to the point where detailed studies along particular sight lines are fruitful. As described in the previously cited papers, a simple model (Fig. 1) explains many of the basic features of scintillation arcs: 1) scattering in a thin screen of material and 2) interference between a "halo" of low level intensity and the core of the scattered image. One puzzling feature of early observations was the presence of only a single arc in most observations. It seemed implausible that along different sight lines there was only a single dominant scattering screen.

2 OBSERVATIONS

We show here that higher sensitivity observations display multiple arcs in at least half of the pulsars we have studied in detail (they are probably present, but still undetectable, in the rest of the sample). As detailed in Figure 1, the curvature of a scintillation arc – accompanied by a distance estimate and a measured proper motion for the pulsar – allows the location of the scattering screen to be determined.

In Figure 2 we show secondary spectra for six pulsars that exhibit multiple scintillation arcs. Note that most of these observations are about 1 hour long. Deeper integrations or co-added secondary spectra could show more details. In Figure 3 we summarize the location of the detected scattering screens as projected onto the Galactic plane.

3 CALCULATIONS

The determination of fractional screen location s can be re-expressed as $s = A/(1 + A)$ where $A = 2c\mu^2 D\eta/\lambda^2$, and where we have assumed, for simplicity, that $V_{\rm p} \gg V_{\rm obs}$. If the screen is located at the pulsar, $s = 0$, and if the screen is located at the observer, $s = 1$. For the six pulsars studied here, the proper

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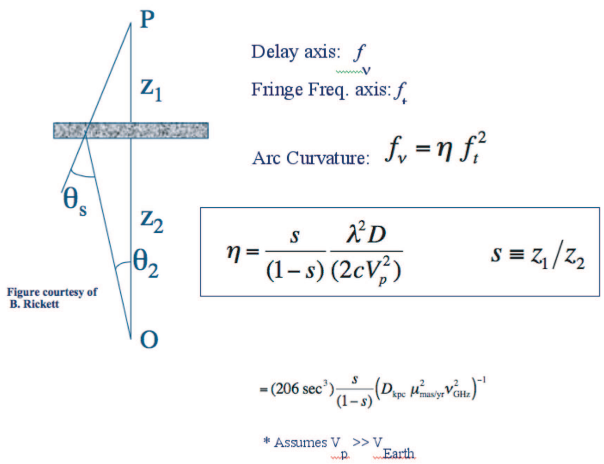

Fig. 1 Geometrical relationships between scattering parameters and scintillation arc curvature.

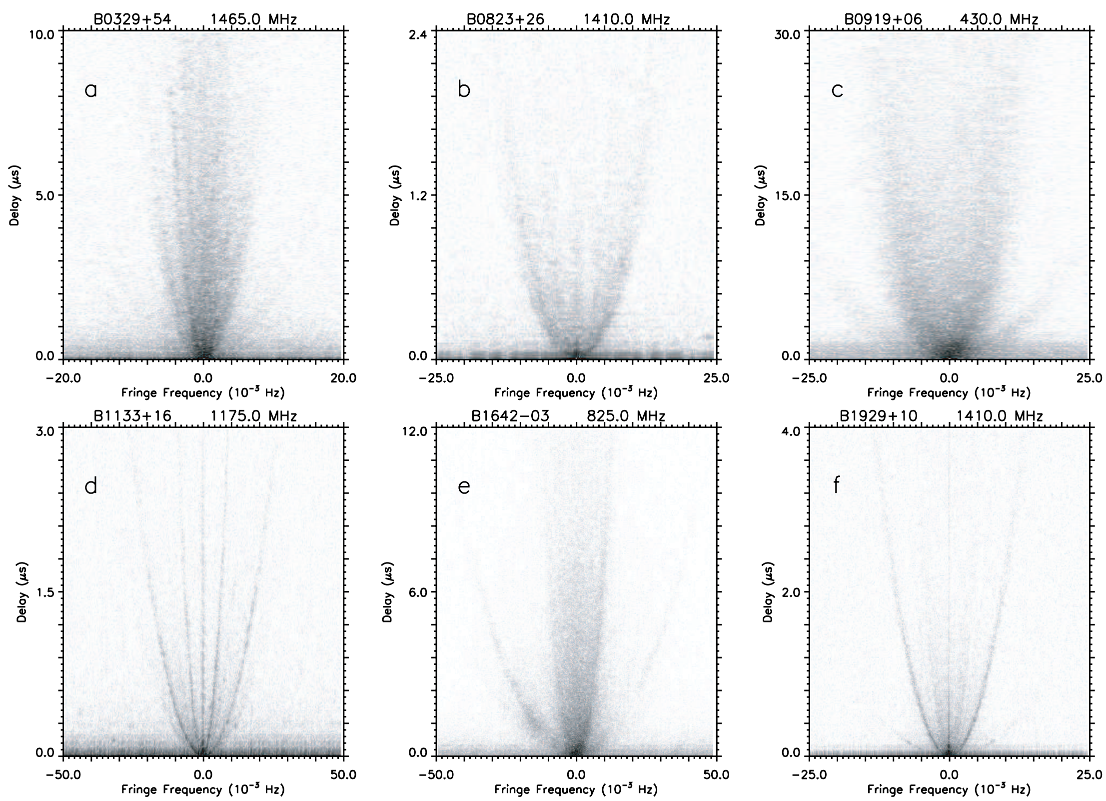

Fig. 2 Secondary spectra of six pulsars. Pulsars B0329+54 and B1642–03 were observed with the NRAO GBT. All others were observed with the NAIC Arecibo telescope. The observations were conducted on MJDs: 53445, 52630, 53371, 52448, 53642 and 52608 for objects a–f, respectively.

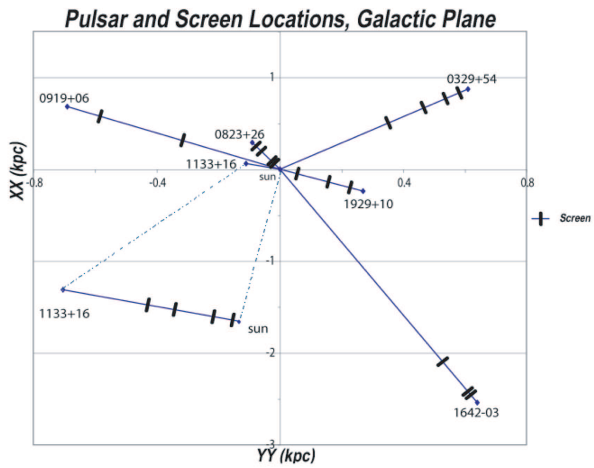

Fig. 3 A projection onto the Galactic plane of the six sight lines explored. Detected scattering screens are indicated with a short line perpendicular to the sight line. Projections onto the Galactic plane are significantly foreshortened for pulsars B0823+26, B0919+06, B1133+16, and B1642–03 which have galactic latitudes of 32, 36, 29 and 26 degrees, respectively. The other two pulsars lie close to the Galactic plane.

motion, μ, is known to better than 5 percent. The arc curvature, η, is a consistent, well-measured quantity as well. Thus, the distance D is the only quantity with substantial uncertainty. It is clear from the expression for s that an underestimate of D will bias s values downward, and conversely for an overestimate of D. We use the distance and proper motion information plus the measured arc curvature values to solve for detected screen locations. Our results are summarized in Table 1.

Table 1 Summary of the Scattering Screen Detections Along Six Sight Lines Through the Galaxy

Pulsar	S_{400} (mJy)	Distance (kpc)	s_a	s_b	s_c	s_d
B0329+54	1500	1.06	0.03	0.09	0.22	0.40
B0823+26	70	0.36	0.06	0.25	0.62	0.72
B0919+06	50	1.2	0.14	0.52		
B1133+16	260	0.36	0.46	0.61	0.84	0.94
B1642–03	390	2.91	0.02	0.03	0.16	
B1929+10	300	0.39	0.09	0.39	0.78	

4 DISCUSSION

Turning to the preliminary results shown in Figure 3, we see a number of new and interesting things. There are two pulsars (B0823+26 and B1929+10) for which the inferred screen locations span the entire distance from observer to pulsar. In three cases (B0329+54, B0919+06, and B1642–03) the screen locations are all in the more distant half of the sight line. These are also the more distant pulsars in the sample. It may be that multiple screens broaden the size of the image core to such an extent that the formation of a scintillation arc is hampered. For all but B0823+26 and B1642–03, the distance to these pulsars is known to better than 10% through parallax measurements.

We are interested in the average spacing between these screens. The various sight lines do not yield a consistent number, however. For B0823+26 and B1133+16 the average spacing is somewhere between 20–40 pc. It approaches 100 pc for B0329+54 and B1929+10 and is greater than 200 pc for B0919+06.

5 CONCLUSIONS

We are still in the early stages of studying filamentary or planar structure in the WIM with multiple scintillation arcs. The signal they produce in the secondary spectrum, although not strong, is clear and easily analyzed. The advent of telescopes with greater collecting area, particularly at low frequencies, will allow for significant improvements over these early results.

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