

Giant Pulses — A Brief Review

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Abstract. We briefly review observational manifestations of pulsars with giant pulse emission and consider quasi-giant pulse phenomena in other pulsars. We argue that power-law statistics give the best definition of giant pulses. Finally, we speculate as to the origin of the giant pulses and a possible link with high energy emission.

1. Introduction

Single pulses from radio pulsars come in a wide variety of shapes and sizes. Somewhat surprisingly however, the flux density of the single pulses rarely exceeds the mean flux density by more than a factor of 10 (excluding the effects of interstellar scintillation). Indeed, for over 25 years, only the Crab pulsar was known to emit giant pulses, whose emission exceeded the mean by large factors. In the last decade, giant pulse emission from a further four pulsars has been detected. Of the pulsars now known to emit giant pulses, three are millisecond pulsars and two are young pulsars. Their common features appear to be their hard, non-thermal, high-energy emission and their high magnetic field strength at the light cylinder. We summarize the recent literature on these pulsars below. We then discuss other examples of pulsars with “abnormal” single pulse behavior. Finally, we end with a speculation as to the origin of giant pulses.

2. Pulsars with Giant Pulses

2.1. The Crab pulsar

The Crab pulsar was initially detected through its giant pulse emission and for two decades was the only pulsar known to emit giant pulses. The giant pulses make up the bulk of the “main” and “interpulse” emission in the pulse profile, and align with the optical, X-ray and γ -ray pulses. Multi-frequency observations of the Crab giant pulses have shown them to be a broadband phenomenon (Sallmen et al. 1999). Most recently, Hankins et al. (2003) have detected bursts of giant pulse emission with a duration of only 2 ns, many of which have high levels of circular polarization. Shearer et al. (2003) have detected a correlation between optical emission and giant radio pulse emission. Their study found that optical pulses coincident with radio giant pulses were 3% brighter on average. In contrast, Lundgren et al. (1995) found no enhancement in γ -ray emission with giant radio pulse emission albeit with lower sensitivity to small fluctuations.

2.2. PSR B1937+21

Giant pulses from the fastest known pulsar were probably seen as early as 1984 (Wolszczan, Cordes & Stinebring 1984) but not recognized as such for 10 years (Sallmen & Backer 1995; Cognard et al. 1996). Giant pulses are seen from the trailing edges of both the main and interpulses. Kinkhabwala & Thorsett (2000) showed that the giant pulses were intrinsically narrow, with durations $< 1 \mu\text{s}$. The flux density is power-law distributed. Recently, Cusumano et al. (2003) have shown that the X-ray emission is in phase with the giant pulse emission.

2.3. PSR B1821-24

PSR B1821-24 is a 3.05 ms pulsar in the globular cluster M4. It has a complex pulse profile in the radio, with three main components and emission over the whole pulse period (Backer & Sallmen 1997). In the X-ray, there are two main components (Rots et al. 1998). The first lags the first radio component by $60 \mu\text{s}$ with the second component lagging the third radio component by $250 \mu\text{s}$. A total of 16 giant pulses were detected in 3 hr of Parkes data (Romani & Johnston 2001). The location of the giants was confined to the trailing edge of the first radio component and closely aligned with the X-ray component. There was some evidence that the flux of the giants was power-law distributed.

2.4. PSR B0540-69

PSR B0540-69 is a young pulsar in the LMC. It was discovered in X-rays (Seward, Harnden & Helfand 1984) and detected in the radio a decade later (Manchester et al. 1993). In both radio and hard X-rays the pulse profile appears to be a merged double. Giant pulses were detected by Johnston & Romani (2003) although they failed to detect the integrated profile at 1.4 GHz. The pulses were scatter-broadened even at this high frequency. Recent observations (Johnston et al. 2004) show that the X-ray profile and the radio giants are aligned.

2.5. PSR J0218+4232

Joshi et al. (these proceedings) have presented evidence for giant pulse emission from PSR J0218+4232. This is a millisecond pulsar with a high magnetic field strength and known high energy emission (Kuiper et al. 2002).

3. Other High Intensity Phenomena

In a high time resolution study of the Vela pulsar, Johnston et al. (2001) discovered short-duration, high intensity emission on the leading edge of the pulse profile. They dubbed this emission “giant micro-pulses” as they appeared to be more akin to microstructure rather than true giant pulses. Similar emission has subsequently been found in PSRs B1706-44 (Johnston & Romani 2002) and B0950+08 (Cairns, Johnston & Das 2004). Again, this emission only arises in a small range of pulse phase and has power-law statistics.

In a study of PSR B1133+16, Kramer et al. (2003) show that the spectral index of the brightest single pulses is significantly flatter than the mean spectral index. This means that many pulses at 4.8 GHz exceed the mean flux by more than a factor of 10. However, the flux distribution does not appear to be power

law. Whether this is seen in other pulsars at high frequency is not clear. Sallmen & Backer (1995) showed that some pulses from the millisecond pulsar B1534+12 exceeded the mean flux density by a factor 10–15. It remains unclear if these are true giant pulses. Finally, Ershov & Kuzmin (2003) have reported several consecutive large amplitude pulses from PSR B1112+50 at 110 MHz. This might be a propagation phenomenon rather than giant pulse behavior.

4. Discussion

We believe a good working definition of giant pulses is that (a) the flux density distribution of giant pulses has power-law statistics and (b) that they appear associated with non-thermal high energy emission. Such a definition would then encompass all the pulsars described in §2 but rule out those in §3. In particular, the alignment of the X-ray pulses with the giant radio pulses is secure for four objects and the correlation between the optical pulses and the giant radio pulses in the Crab is a significant result.

The five pulsars with known giant pulse emission are among the highest when ranked by their magnetic field at the light cylinder, B_{lc} . In the outer-gap model of high-energy emission, the X-ray and γ -ray pulses are believed to arise in an outer magnetosphere acceleration gap along the boundary of the open zone (Cheng, Ho & Ruderman 1986; Romani & Yadigaroglu 1995). These Crab-type outer gaps are believed to have $\gamma - \gamma$ pair production maintained by a dense bath of target soft synchrotron photons from the gap itself. High magnetic fields (especially near the null charge surface) should enhance synchrotron emissivity, and hence the rate of secondary $e^\pm$ production. This dense pair plasma produces the narrow hard X-ray pulses, and we can speculate that the high densities promote the instabilities that create enhancements in the particle coherence and hence the giant radio pulses. The detailed dependence of giant pulse occurrence on B_{lc} is not clear. If the critical quantity is the field near the outer gap base at the null charge surface, where pair production is expected to be most intense, then magnetic inclination α should play a strong role in the detectability.

Let us assume that giant pulses have a duration of $\sim 1 \mu\text{s}$ and we normalize the fluxes to a distance of 1 kpc and an observing frequency of 1.4 GHz. Then, after 10^6 rotations the peak fluxes are 130, 11, 0.03 and 0.02 MJy for the Crab, PSRs B0540–69, B1821–24 and B1937+21 which makes for a striking difference between the young pulsars and the millisecond pulsars (Johnston & Romani 2003). In principle, therefore, current telescopes are capable of detecting giant pulses from young pulsars at distances of ~ 1 Mpc, and millisecond pulsars out to ~ 50 kpc. In practice, however, lack of knowledge of the DM and scatter broadening both serve to weaken these limits and a recent survey of M33 with the Arecibo telescope failed to detect giants (McLaughlin & Cordes 2003).

The prospects for future generation radio telescopes are excellent however. Even if giant pulses only occur over the first ~ 2000 yr of a pulsar's life, one might then expect to see ~ 20 pulsars emitting giant pulses per large galaxy and more in the nearby starburst galaxies. For millisecond pulsars, the fastest objects which have the highest magnetic fields at the light cylinder, will produce giant pulses for a Hubble time. Therefore, there may be a large population of millisecond pulsars which produce giant pulses, enhancing the prospects for targeted searches

of globular clusters in external galaxies. Detection of extra-galactic pulsars will yield the electron density content of the inter-galactic medium, important in understanding the nature of dark matter (Maloney & Bland-Hawthorn 2001).

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