Echoes of Crab Pulsar Giant Radio Pulses

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Introduction

Occasional anomalous scattering of the Crab nebula pulsar radio pulses has been attributed to refraction from nebular plasma passing near the line of sight to the star. The scattered emission has been termed a pulse “echo” or “ghost”. We present here two days of high time resolution observations of individual giant radio pulses taken using the Very Large Array. The observations reveal echo emission at shorter time lags than has been seen before. An analysis of the characteristics of our echo component leads us to believe this phenomenon to be of a different nature than previously reported echo events.

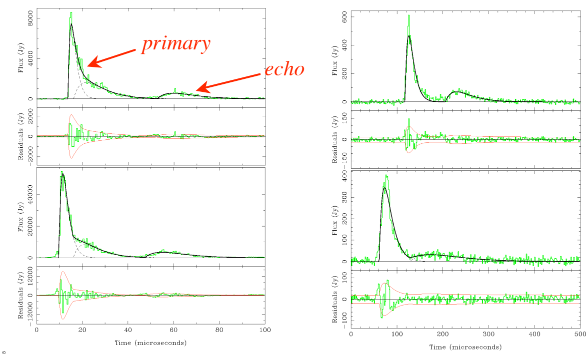
Data

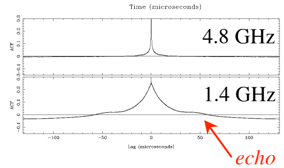
- We analyzed 38 Crab giant single pulse data sets spanning dates from 1993 to 1998; **only two data sets contain echo emission**.
- Echoes are **clearly visible in 45 of 77** pulses at 1.4 GHz on 1996 Oct 14 and 1997 Nov 26 (see examples, right). The other 32 pulses contain low signal to noise, complex microstructure, and/or a weak or absent echo component.
- The 1996 echo event is **constrained in time** by observations 2 days before and after where no echo is present.
- **No echo is seen in simultaneous 4.8 GHz data** of the 1996 event -- we searched for both geometric and dispersive delays (see ACFs, right).
- Primary and echo microstructure components have been fitted with one or two instances of an exponential scattering function,

$$s(t) = at\,e^{-t/\tau}.$$

1996 Oct 14 — 1.4 GHz, 500 ns resolution

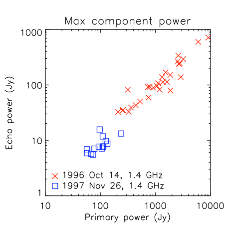
1997 Nov 26 — 1.4 GHz, 1.5 μs resolution



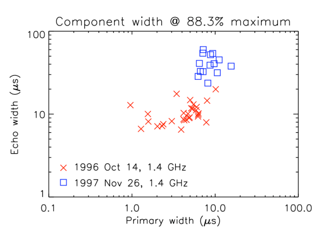


Average autocorrelation of all 1996 Oct 14 single giant pulses. Note the echo is visible at 1.4 but not 4.8 GHz.

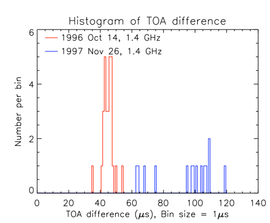
Analysis



Maximum **echo power is consistently 10%** that of the primary component.



All echoes are 1 to 10 times wider than the primary component.



Echo time lag is consistently 45 μs for 1996. Lag ranges from 60 to 120 μs for 1997.

- The above plots show measurements from 43 single giant pulses for which primary and echo components were successfully fitted with exponential scattering functions.
- No echo characteristics show consistent evolution over the time of our observations.
- Echo time delay does not vary with the pulsar phase of the primary component.

Interpretation

Other authors (Backer et al. 2000, Lyne et al. 2001) have explained echo emission by refraction from evolving plasma structures in the nebula surrounding the pulsar. This explanation seems plausible for the events we present here. However, our echoes differ in several ways from previously reported echoes.

- Our echoes lag behind the primary pulse component by less than 120 μs, a length of time unresolvable in previous studies where echoes were found to lag by 1 to 4 ms.
- The 1996 Oct 14 event lasted no more than 4 days. Previous studies reported echo lifetimes of 6 to 50 days.
- We find our echo emission to be frequency dependent -- present at 1.4 but not 4.8 GHz.

Assuming the echo emission is produced by small angle reflection from plasma structure in the Crab nebula, and noting the frequency dependence, we are able to estimate an allowable range for the product of the change in electron number density, Δn_e, at the boundary of the plasma structure and distance from the pulsar to the plasma structure, R:

$$10^{16}\mathrm{cm}^{-2} \le R\cdot\Delta n_e \le 10^{17}\mathrm{cm}^{-2}.$$

Estimated properties of the filaments in the outer region of the Crab nebula (Backer et al., 2000) are inconsistent with this range. We note that the rapidly evolving wisp-like structure associated with the pulsar wind shock is a possible alternative location for refraction.

Conclusions

- Crab pulsar giant pulse data from 1996 Oct and 1997 Nov show a transient echo-like microstructure component following the normal primary component.
- This echo emission differs from other echo emission reported previously.
- We think it improbable that these refraction events occurred in the emission-line nebular filaments, and propose refraction may have been caused by the wisp-like structures associated with the pulsar wind shock.

This work was partially supported by NSF grant AST-0139641. The Very Large Array is an instrument of the National Radio Astronomy Observatory, a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.