Echoes of Crab Pulsar Giant Radio Pulses

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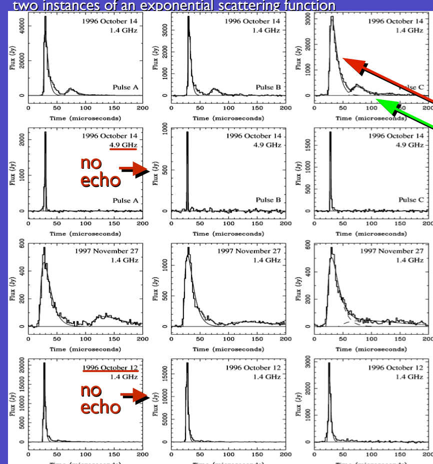
Introduction

Occasional "echoes" of Crab pulsar radio pulses have been seen on several occasions, and have been attributed to refraction/reflection from plasma structures in the outer Crab nebula. We report here the first observations of echoes from Crab pulsar giant radio pulses. The strength of Crab giant pulses (>1000 × average flux) provides us with sensitivity to study the echoes at shorter time scales and higher radio frequencies than have been used previously. The echo frequency and time dependence lead us to believe that our echoes originate from pulse refraction in the wisp-like plasma structures close to the pulsar, near the pulsar wind shock. Observed wisp structures have sizes 0.1" to 0.4" ~ 200 to 800 AU (at 2 kpc distance).

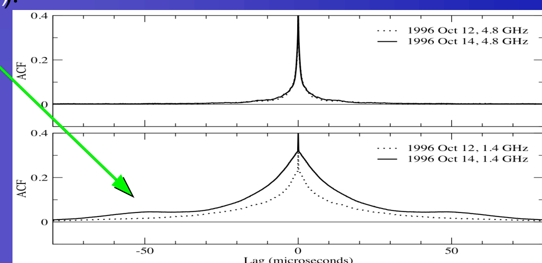
Data

- We observed Crab giant pulses with the VLA on 20 days between 1993 and 1998; **only two days contain echo emission**.
- Echoes are **clearly visible in 42 of 78** pulses at **1.4 GHz** on 1996 Oct 14 and 1997 Nov 26 (see examples, right). The other 36 pulses contain low signal to noise, complex microstructure, and/or a weak or absent echo component.
- The 1996 echo event is **constrained in time to ≤4 days** by observations 2 days before and after where no echo is present.

Pulses with and without echoes, 2 μs resolution. Primary and echo microstructure components have been fitted with one or two instances of an exponential scattering function



- **No echo is seen in simultaneous 4.8 GHz data** of the 1996 event -- we searched for both geometric and dispersive delays (see average autocorrelation functions, below).

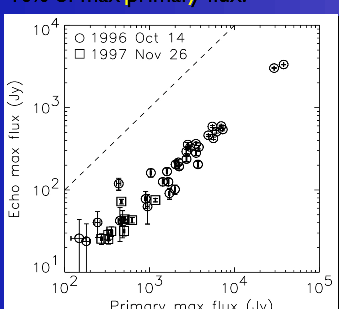


- Average degree of polarization is ~(17±5)% in both the primary and echo components.

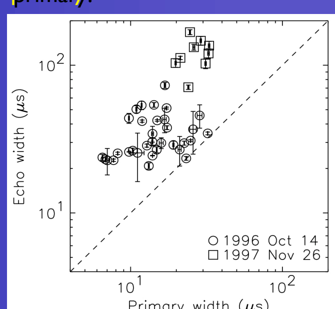
Analysis

Pulse components (primary and echo) were each fitted with an exponential scattering function: $F_i(t) = A_i(t - t_{0i})\, e^{-(t-t_{0i})/\tau_i}$. The fitted functions were then used to analyze component properties.

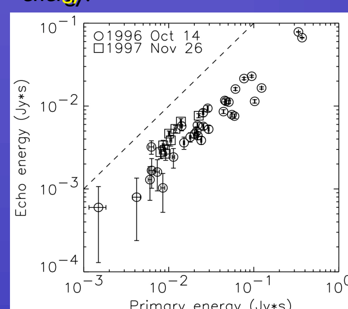
Maximum echo flux is consistently 10% of max primary flux.



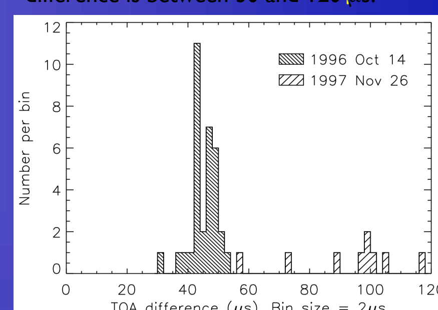
Echoes are ~3× wider than the primary.



Echoes have ~0.3× the primary energy.



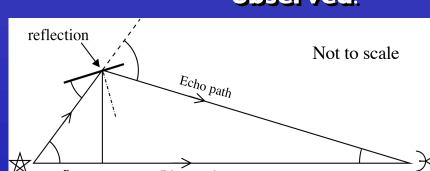
Primary-to-echo time of arrival difference is between 30 and 120 μs.



Results

- The 1996 Oct echo event has the shortest lifetime (≤4 days) of any Crab echo event yet observed. This is the **expected transit time for a Crab wisp** (velocity ~ 0.3c).
- We searched for but found **no echo in simultaneously recorded 4.8-GHz pulses**.
- The echo frequency dependence allows us to place a range on the product of the pulsar-reflection distance, R, and the change in the electron number density, ΔN_e, at the reflecting plasma boundary:

$$10^{16}\,\mathrm{cm}^{-2} \leq R\,\Delta N_e \leq 10^{17}\,\mathrm{cm}^{-2}.$$



- Synchrotron analysis leads us to believe that reflection from **an exceptionally dense wisp may have caused the echoes we observed**.
- The echo components are consistently broader than primary components; this is likely due to enhanced scattering within nebular plasma.
- The echoes are less energetic than the primary components. Possible causes of energy loss are: *partial* reflection of the pulse from nebular plasma, reflection of only part of the pulsar beam cross-section by small plasma structure, or reflection from a curved plasma surface.

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