Ultra-High Time Resolution Measurements of the Crab Nebula Pulsar “Giant” Pulses

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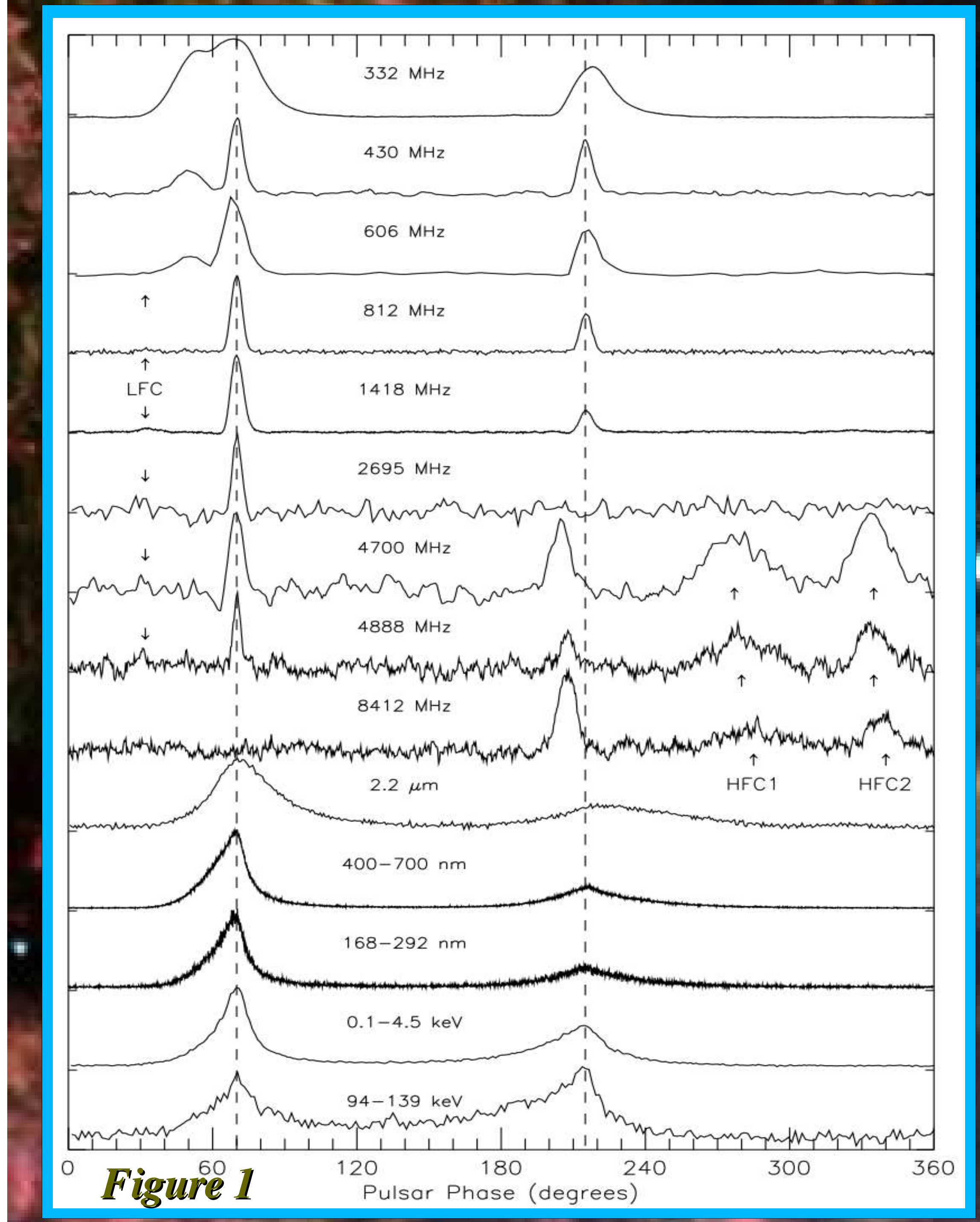

Figure 1

Figure 1: Mean profiles from the Crab pulsar, obtained by synchronously averaging its emission over many rotation periods, shows several frequency-dependent components. The main pulse and interpulse are shown by the dashed lines at 70 and 215 degrees of pulse phase. It is thought that the main and interpulse come from opposite magnetic poles on the star, which alternately rotate through our line of sight. (D. A. Moffett, Thesis, 1997)

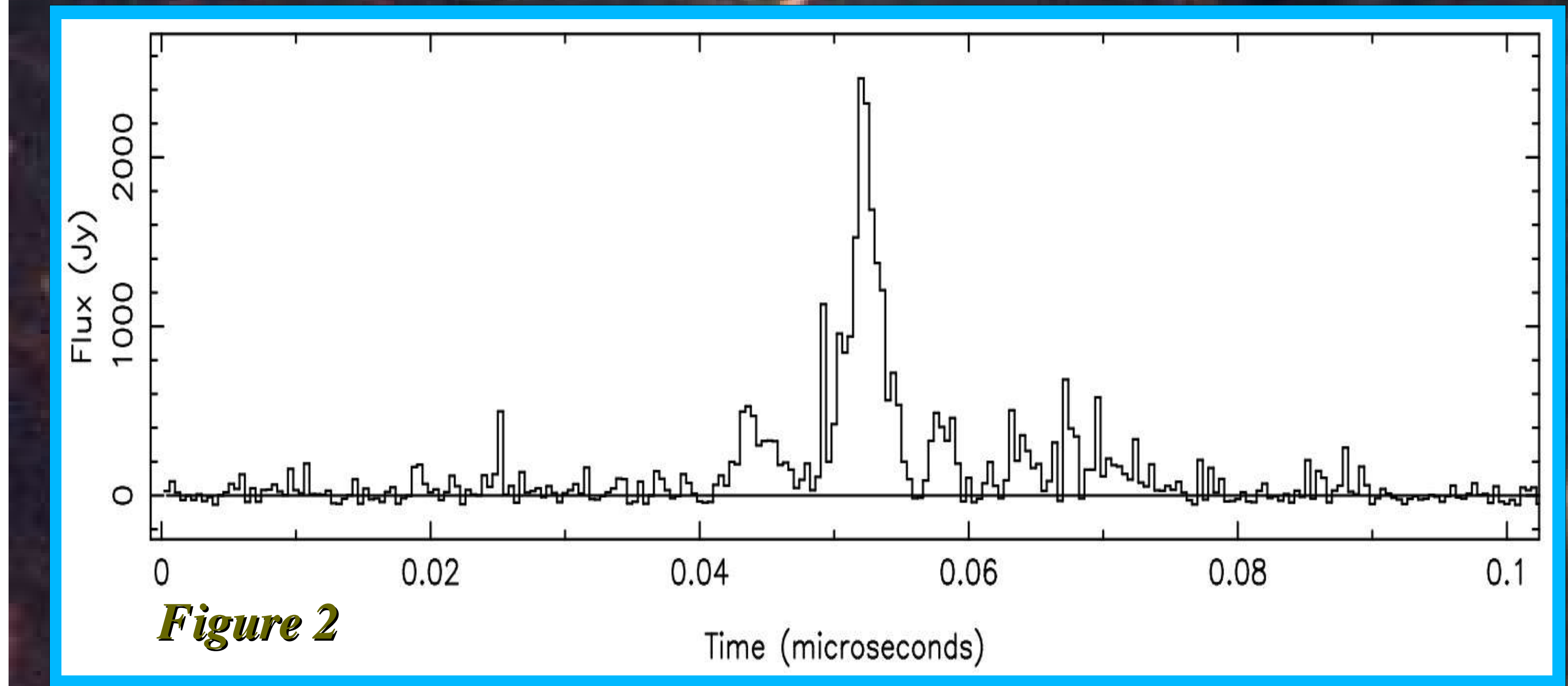

Figure 2

Figure 2: A portion of a giant main pulse from the Crab, recorded at the Arecibo Observatory, dedispersed, then smoothed and plotted with 0.4-nanosecond time resolution. This nanopulse is strikingly similar to the temporal structure predicted by the soliton collapse models of plasma emission; alternative models predict longer timescales. From this we conclude that strong plasma turbulence creates the coherent emission in the giant main pulses from this pulsar.

Figure 3: Total intensity and dynamic spectra of Crab giant pulses recorded within four minutes of each other, at a center frequency of 9.25 GHz, and bandwidth 2.5 Ghz. The total intensity is plotted with 6.4-ns time resolution. The dynamic spectra are plotted with time resolution of 100 ns and frequency resolution of 19.5 Mhz. The upper plot shows a giant interpulse; the lower plot shows a giant main pulse. Both of these pulses were processed identically. The temporal structure and frequency content of the main and interpulse are radically different, suggesting the emission physics is dissimilar at the two magnetic poles of this star. The temporal and frequency structure of the main pulse appears to be consistent with predictions of emission by strong plasma turbulence; but the banded frequency structure in the IP cannot be explained by any current radio emission model. Note that the onset of the pulse in the interpulse dynamic spectrum is frequency dependent, implying that the dispersion measures of the main and interpulse are slightly different. This implies that the interpulse originates deeper in the pulsar magnetosphere than the main pulse.

The goal of our pulsar research has been to understand the physics of the radio emission region. Because different models predict different time signatures, we developed high time resolution data acquisition systems in order to test these models. We use these systems to study the Crab pulsar, whose occasional “giant” pulses are bright enough to study the time structure down to the limit $1/B$ imposed by the observing bandwidth, B.

We initially studied the bright “main pulses” at nanosecond time resolution. We detected very short-lived “nanopulses” (as in Figure 2); causality suggests these pulses arise from plasma clouds no larger than beach balls -- the smallest objects ever detected outside the solar system. From these results we concluded that strong plasma turbulence is responsible for the coherent radio emission from the giant main pulses.

In order to reach still higher time resolution, we observed at higher frequencies (7 and 9 Ghz) to obtain 2-GHz bandwidth. We first chose to observe at the phase of the interpulse, where giant pulses are more common at high frequencies; we later carried out identical observations of giant main pulses. We were astounded by what we found -- emission from the main pulse and interpulse differ dramatically in both temporal structure and frequency content, as shown in Figure 3. The main pulse contains several micropulses which are narrow in time and broadband in frequency. The interpulse, on the other hand, is temporally broad but has a striking “banded” frequency spectrum. This banded structure was totally unexpected, and was not anticipated by any model of pulsar emission.

While we remain perplexed by the dramatic banded structure seen in the giant interpulses, we are considering some possible toy models. One idea is that the interpulse emission reaches us by two emission paths, which interfere constructively at regularly spaced frequencies. This suggests that an unusual, nondipolar magnetic field controls the interpulse emission region; but why *two* particular and stable signal paths are favored is far from clear. Another idea is that a long set of well-organized, regularly spaced charge bunches create such an impulse train. Such a structure might develop in the nonlinear phase of a beam instability; but such regularity over such a long charge-bunch train is not consistent with current models of such instabilities.

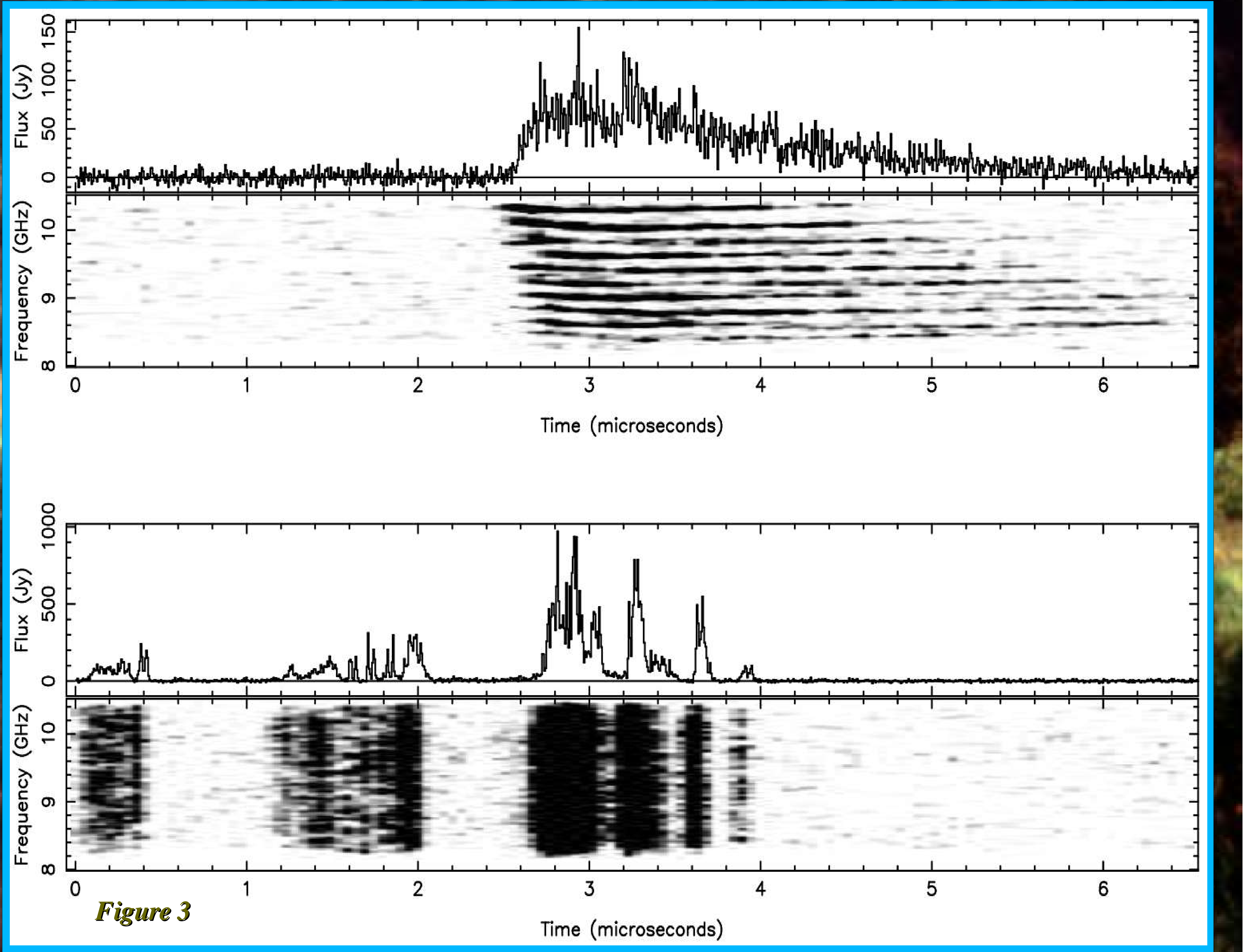

Figure 3

This work has been supported by NSF grant AST-0139641. The Arecibo Observatory is operated by Cornell University under contract from the NSF. The Very Large Array is operated by Associated Universities Incorporated under contract from the NSF. The background photograph of the inner Crab Nebula: NASA and The Hubble Heritage Team (STScI/AURA), `http://heritage.stsci.edu/2000/15/`