Subject: Feasibility of Detecting Pulsars with Horns.
Memo: 25, Revision 2
From: Glen Langston,
Date: 2019 March 1

Summary: Detecting Radio Pulsars is difficult, but possible with a 32inch diameter horn. Bigger horns or more horns with signals averaged eases detection of Pulsars.

This note summarizes an approach to detecting radio pulsars with Science Aficionado horns. We summarize the properties of pulsars and the sensitivity of the horns, to estimate the observations required to detect pulsars. Note that detection is always possible with with any telescope, if the data are averaged long enough. The two main questions we answer are: First, how long of an observation is required to detect a normal brightness, say 10 Jansky, pulsar? Second can individual Crab Giant Pulses (> 40,000 Jy), be detected with a horn?

Background

Radio Pulsars have been known to exist for decades. However until recently detecting pulsars has been only possible using custom and expensive radio telescopes and receivers. The radio pulsars are brighter at low frequencies (< 300 MHz) but detection is difficult due to the dispersion of the pulses in frequency and time. The net effect of dispersion is that pulses arrive earlier at higher frequencies than at lower frequencies, making detection more difficult. Through some signal processing this effect can be corrected in software.

Horn Sensitivity

The event detection software is tested by observations of Giant Pulses from the Crab Pulsar. These pulses are as bright as 45,000 Jy at 1400 MHz.

We first calculate the sensitivity (i.e. Gain) of a 3-foot diameter horn for detection of pulses.

The 3-foot horn has an effective area of 0.5 m^2. We use Boltzmann's constant to convert the system temperature times area into a system equivalent flux density in Janskys. Jansky units are units of power in watt seconds per meter squared. 1 Jy = 10^{-26} Watts - seconds or 10^{-26} Watts-Hz/m^2.

Gain (K/Jy) = $A_e/2k$ = 0.5 $m^2 \times 10^{-26}$ / 2. x 1.38 x 10^{-23} J/K = 1.8 x 10^{-3} K/Jy = 0.0018 K/Jy

Therefore a typical brightness radio source, about a 1 Jy source, increases the system temperature by 0.0018K, a very small amount. A 1000 Jy source raises the system temperature by 1.8 K.

For our horns, the combination of amplifiers and feed probe has an effective system temperature of 120 K.

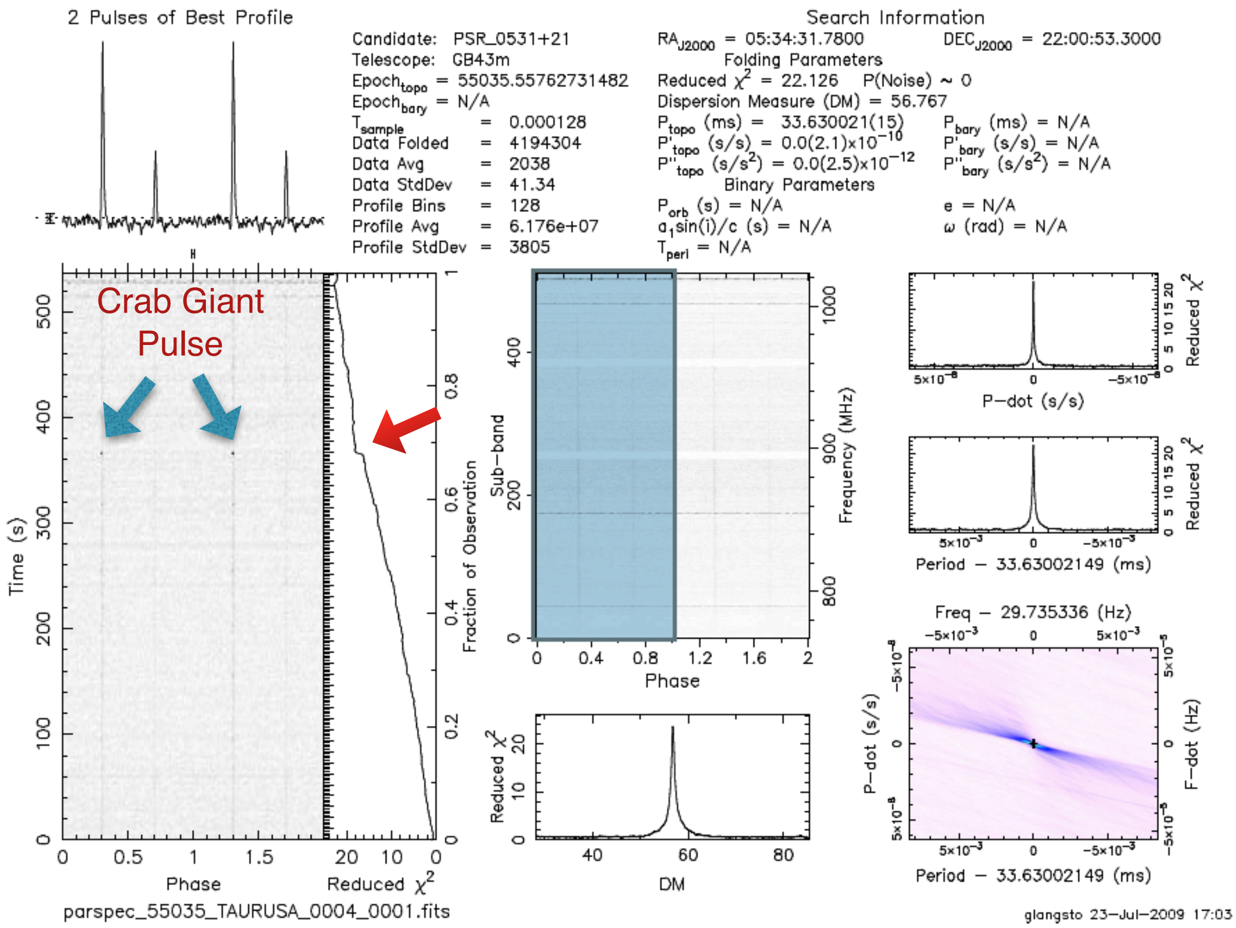

Figure 1: Crab Pulsar Observations with the GBO 43m (140ft) telescope. *This figure shows the results of observation and folding of a 10 minute (600 second) observation. The observations were made over a wide frequency range 700 to 1000 MHz. The top left plot, showing 4 peaks is the average of all observations, after pulsar "De-dispersion". The Crab pulsar has a main peak and a secondary, weaker, peak. The profile is shown twice. Below that plot, the time versus pulsar Phase image shows vertical stripes, where the pulsar is seen in individual, few second observations. At 370 seconds, a Crab giant pulse is seen. These giant pulses occur fairly frequently in the Crab pulsar. The two copies of the same giant pulse are shows black dots in the plot, marked with blue arrows. At the right of the giant pulses is yet another plot, a plot of increasing signal to noise (labeled Reduced X^2). The plot stars at zero on the bottom, and increases with averaging of data. The plot shows the jump in signal-to-noise when the Giant Pulse is detected. This is marked with the red arrow. The remainder of the plots show many important measurements, including the pulse period and DM found.*

Fast Sampling == Lots of Time Samples

Our observations of the radio sky are possible because low cost, but modern. devices can sample the radio signals very very fast. The devices have sampling rates ranging from a million times a second (1 MHz), to 50 million times a second. Our initial tests used an AIRSPY mini, which has a bandwidth of 6 MHz, meaning that the device samples at a rate of 12 million samples a second. Recording all data at this rate is possible, but takes a lot of storage space.

Since the AIRSPY has 12 bit samples and we write the data as ascii, for our convenience, this requires about 10 bytes per sample. A second of observations requires 10 bytes/second x 12 x 10^6 samples in a second= 120 Mega Bytes per second. So 1 Giga Byte of storage is used in 8.5 seconds. It is possible to use smarter data recording methods to reduce the space usage, but the point is: ***lots of storage space is needed to record all data samples.***

Crab Giant Pulses

An extremely bright sources, such as one of the most extreme Crab giant pulses (>40,000 Jy), would increase the system temperature by about 80 K. This is comparable with the system temperature for our horn, 120 K. The total brightness temperature, 200K, is 1.4 times the average system temperature. This seems like an ideal test target for horn observations of detecting events. However there are some issues we need to face.

The event detection software is tested by observations of Giant Pulses from the Crab Pulsar. These pulses brighter than 40,000 Jy are seen at 1400 MHz.

Dispersion Measure

We next need to talk about some data processing required to detect pulsars. This processing is needed to compensate for the fact that the radio signals from the pulsar must travel through the space between the stars. The space between the stars is mostly empty, but still contains a very think gas of ionized particles, mostly hydrogen atoms that have lost their electrons. This thin gas is called the *interstellar medium,* an ionized plasma. This plasma has the effect of slowing down radio waves as they pass from distant objects to our telescopes. The delay in the signal is not constant, but instead depends on the frequency of observations.

The amount of plasma along the line of sight is related to a measurement we can make with our radio telescopes. The bigger delay, the bigger the amount of *Dispersion Measure* (DM). For the Crab Pulsar the measured DM is 56.767. The total delay in a 6 MHz band at 1.420 GHz is t = 8.3 6. 56.5 /1.42^3 = 982.7 microseconds or 0.0009827 seconds.

The crab pulsar has a period of 0.033089 seconds. So the pulsar is on for about 3% of the time at 1.420 GHz, with a 6 MHz bandwidth.

At 6 MHz bandwidth (12 MHz samples), the total time a giant pulse is present is 12 * 10^6 * 0.0009827 = 11,792 samples. If the band was divided into 128 channels, a pulse would be seen in 92 spectra.

=

Conclusion

Thanks to my family and friends for their support for this work.