The Crab Pulsar From A Birr's Eye View

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We present the early results from a **40-hour observing campaign** of the **Crab Pulsar** between **110 and 190 MHz** using the Irish LOFAR station (**I-LOFAR**) at Birr Castle, 180 years on from the Crab Nebula's discovery with the Great Leviathan Telescope of Birr, a stone's throw from the station.

While scattering due to the nebula and ISM suppresses normal pulsed emission from the Crab pulsar at low frequencies, the large fractional bandwidth of I-LOFAR and ample observing time have allowed us to compile what we believe to be the largest catalogue of giant pulses at this frequency from 12 hours of fully processed data.

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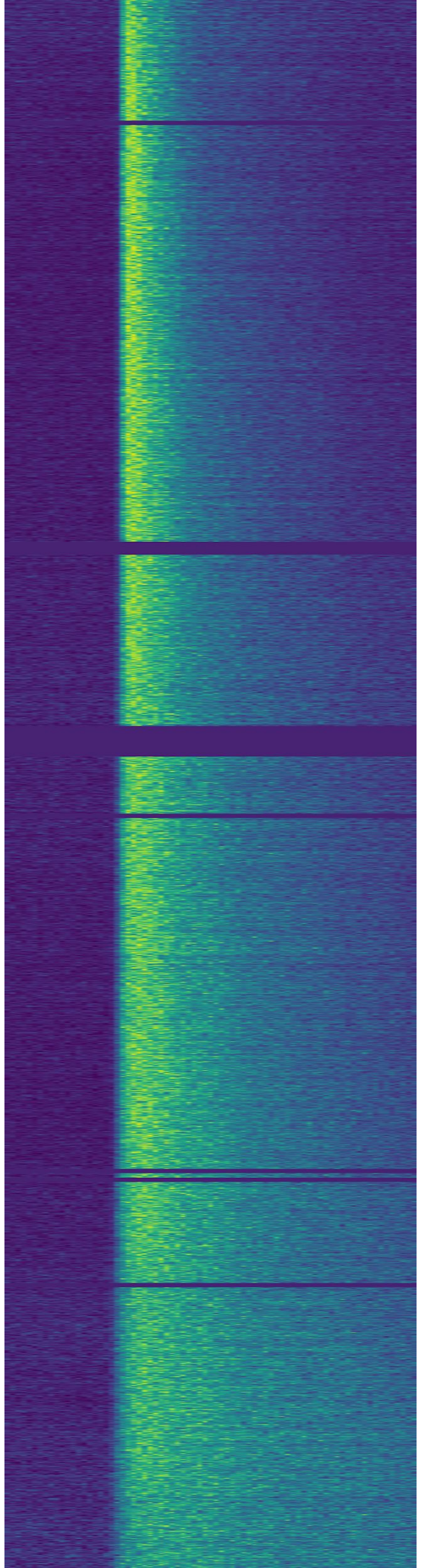
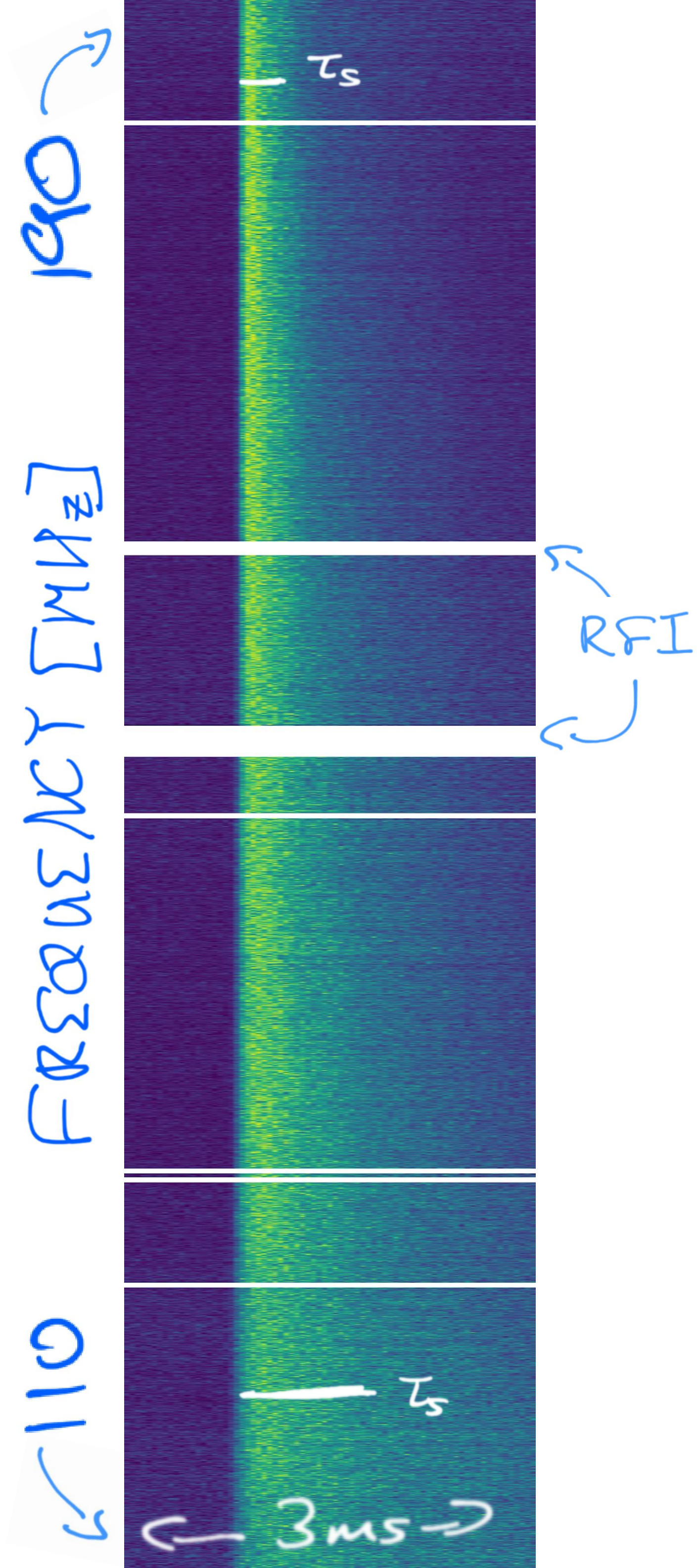




The Anatomy of Crab Giant Pulses

Before we can find a pulse, our data must be **dedispersed**. While the Crab pulsar rotates once every 33 milliseconds, the signal is delayed by up to 6 seconds between the top and bottom of our bandwidth due to free electrons between Birr and the Crab Nebula.

Then after travelling 6,523 light years to Earth, we **zap** some of the light due to local **radio frequency interference**, as many communications applications operate at the same radio frequencies that we observe at.

Now we can analyze the **energies** and **scattering timescales** **(τ_s)**, which are unique for every pulse and frequency we observe.

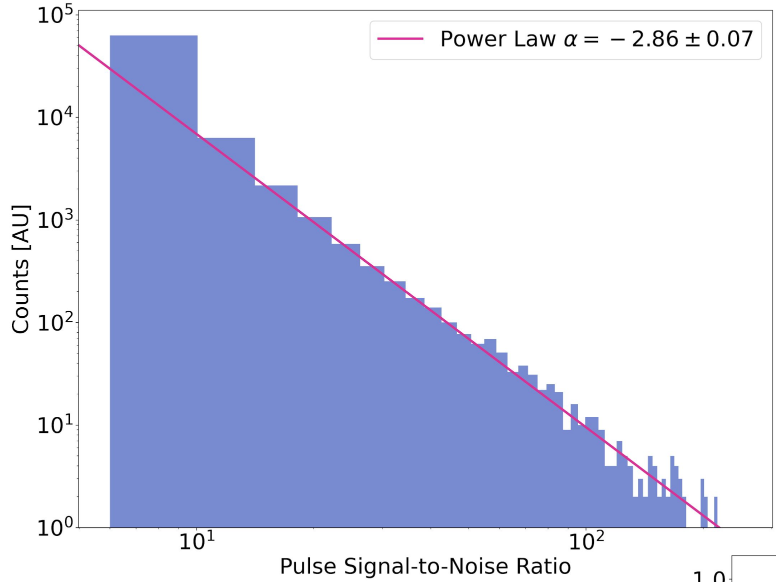
To analyze scattering timescales, we **fit a pulse broadening function (PBF)** to each pulse to describe the (in)homogeneity of the free electrons along the line of sight, we found the model for a **thick scattering screen (1)**[0] had the best fit to our data.

$$\mathrm{PFB}(t, \tau_s) = \sqrt{\frac{\pi \tau_s}{4t^3}} \exp\left[-\frac{\pi^2 \tau_s}{16t}\right] \quad (1)$$

The Bigger Picture

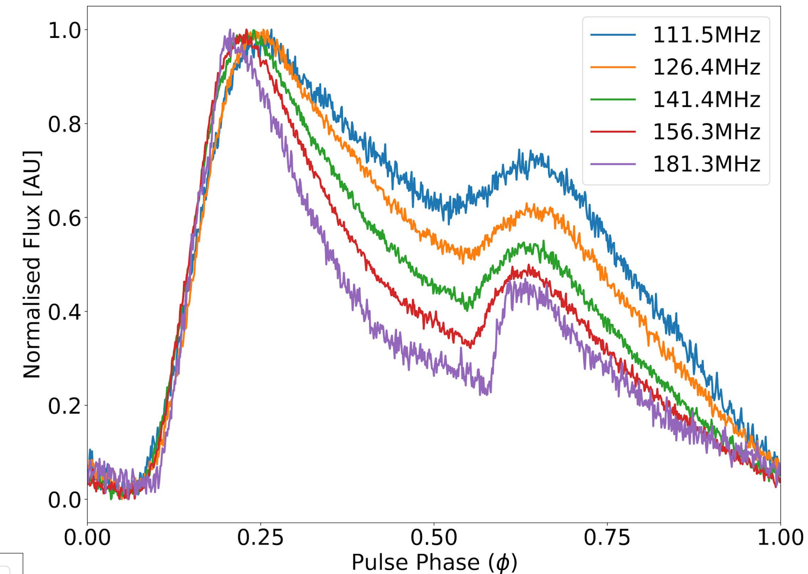
While each pulse is unique, we can take a look at the ensemble statistics to get a grasp on the behaviour of the Crab's giant pulses.

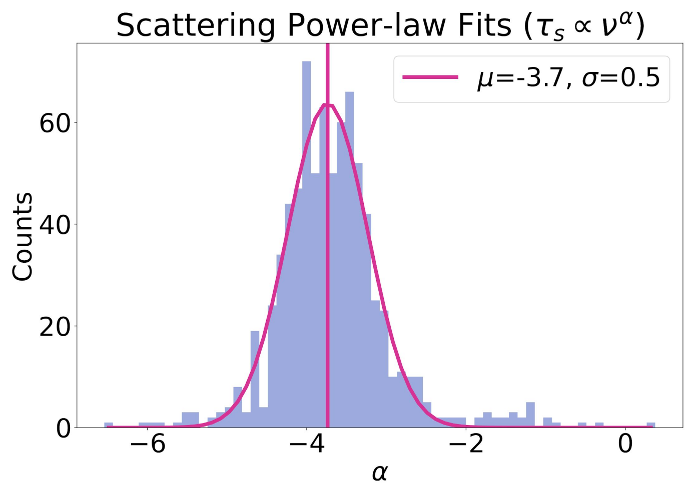
Analysis can be performed on the main pulse and interpulse separately, but have been combined here as the populations have not been separated.



Giant pulses form a fluence (integrated energy) **spectrum**, and while we fit lower a **power law exponent of −2.86** compared to -3.1 at the MWA[1] and LOFAR core[2], additional data has been trending us toward the value seen with the Lovell of -2.4 [3] as we fill out the tail of the spectrum.

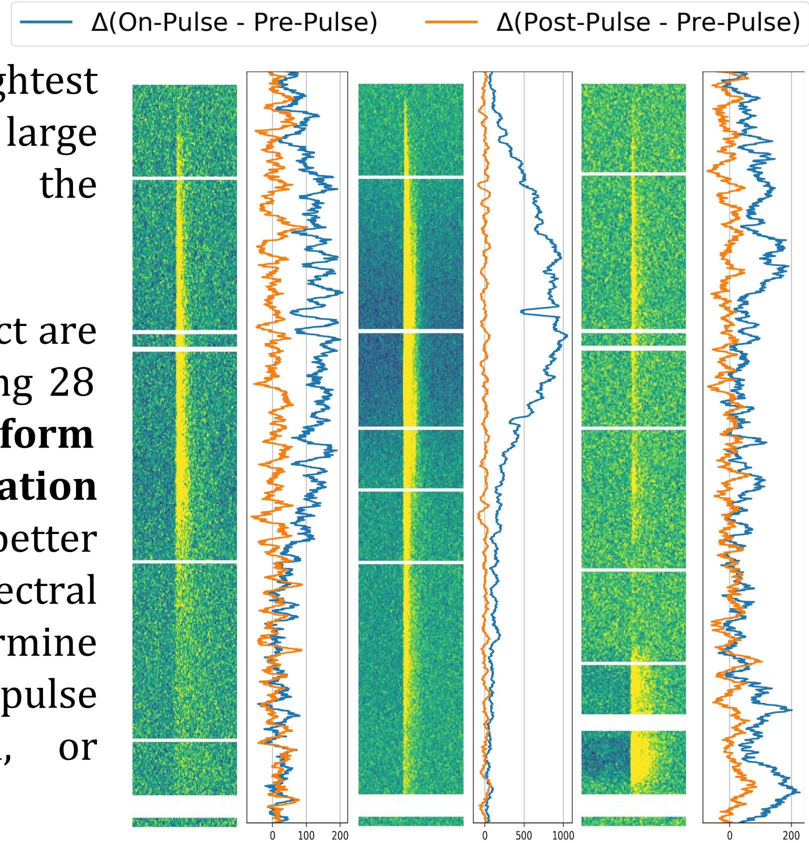
Averaged pulse profiles from a 4-hour observation in March offer a visual representation of the pulse broadening with increased scattering times at lower frequencies for both the main (ϕ=0.25) and interpulse (ϕ=0.66).





Fitting a power law to the scattering observed in 15 MHz channels, we find the pulses scatter with a **Gaussian fit of −3.7±0.5**, similar to previous results at −3.9±0.5 [4], −3.6 [5], which fall in the range expected for thin-screen scattering between -4.4 (Kolmogorov) and -4.

Oddities & Future Work



A significant number the brightest pulses (SNR > 50) have shown large spectral variability across the bandwidth of our observations.

Our short-term goals for the project are to **finish processing** the remaining 28 hours of observations and to **perform absolute flux density calibration** across the observed data to get a better grasp of the fluences and spectral variability of the pulses and determine if some of the abnormal pulse morphologies are instrumental, or intrinsic to the pulses themselves.

Beyond the scope of this project, the software developed to analyse our raw data and detect and analyse single pulses is already being put to work on a range of topics on the I-LOFAR **REAL**time **T**ransient **A**cquisition Cluster (REALTA, https://lofar.ie/realta/) to push forward the use cases for the telescope.

I-LOFAR now regularly points towards the **CHIME R3 repeating fast radio burst**, sources in the **RRatalog** and **CHIME Galactic Sources** Catalogue, with hopes of seeing pulses similar to those presented here.

Further work will also be dedicated to helping the REALTA cluster live up to its name, to perform **online processing** of the raw data and to provide a live feed of the ever-transient low frequency sky to the station's observers.

References

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