Evidence for Highly Relativistic Motion for the Crab Giant Pulses

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ABOUT THE AUTHOR

My interests cover much of astronomy but a focus on compact objects, stars and binaries, their structure, formation, and evolution, and their use to infer fundamental physical properties. My research is grounded in observations, but includes interpretation, theory, and numerical modelling. I generally try to make progress using key observations and/or physical considerations of individual, carefully selected objects.

My major focus has been to use neutron stars to study high-density and high field-strength physics, in conditions out of reach of terrestrial experiment (and theory, as yet), and to solve associated astronomical puzzles. I've become particularly intrigued by the possibilities of pico-arcsec astrometry offered by pulsar scintillation. We have started to try to apply this technique on pulsars, both to resolve emission regions and measure pulsar orbits on the sky.

I am also hoping to contribute to solving the mystery of FRBs, for which it seems likely neutron stars, possibly in binaries, are responsible. The nearest ones offer the best hope, as they are most suitable for follow-up at other wavelengths. In an effort to obtain accurate enough positions, I'm helping build an array of small, wide-field antennas, to observe in concert with CHIME.

RELEVANT RESULTS

The Crab Pulsar's radio emission is unusual, consisting predominantly of giant pulses, with durations of about a micro-second but structure down to the nano-second level, and extreme brightness temperatures. It is unclear how giant pulses are produced, but they likely originate near the pulsar's light cylinder, where corotating plasma approaches the speed of light.

I discuss observations where we use scattering in the Crab nebula to resolve not just the emission region giant pulses originate in, but also the region their constituent nanoshots are formed. We suggest that the simplest explanation for being able to resolve the emission regions, despite the short duration of giant pulses, is (apparent) superluminal motion.

In a different set of observations, shown in the figure overleaf, we appear to see direct evidence for Doppler shifts during the scattering tail of a giant pulse. From those, we infer that the plasma producing the giant pulses likely moves highly relativistically, with a Lorentz factor $\gamma \sim 10^4$, consistent with what is required for resolving the emission regions.

The above results support models that appeal to highly relativistic plasma to transform ambient magnetic structures to coherent GHz radio emission, be it for giant pulses or for potentially related sources, such as fast radio bursts.

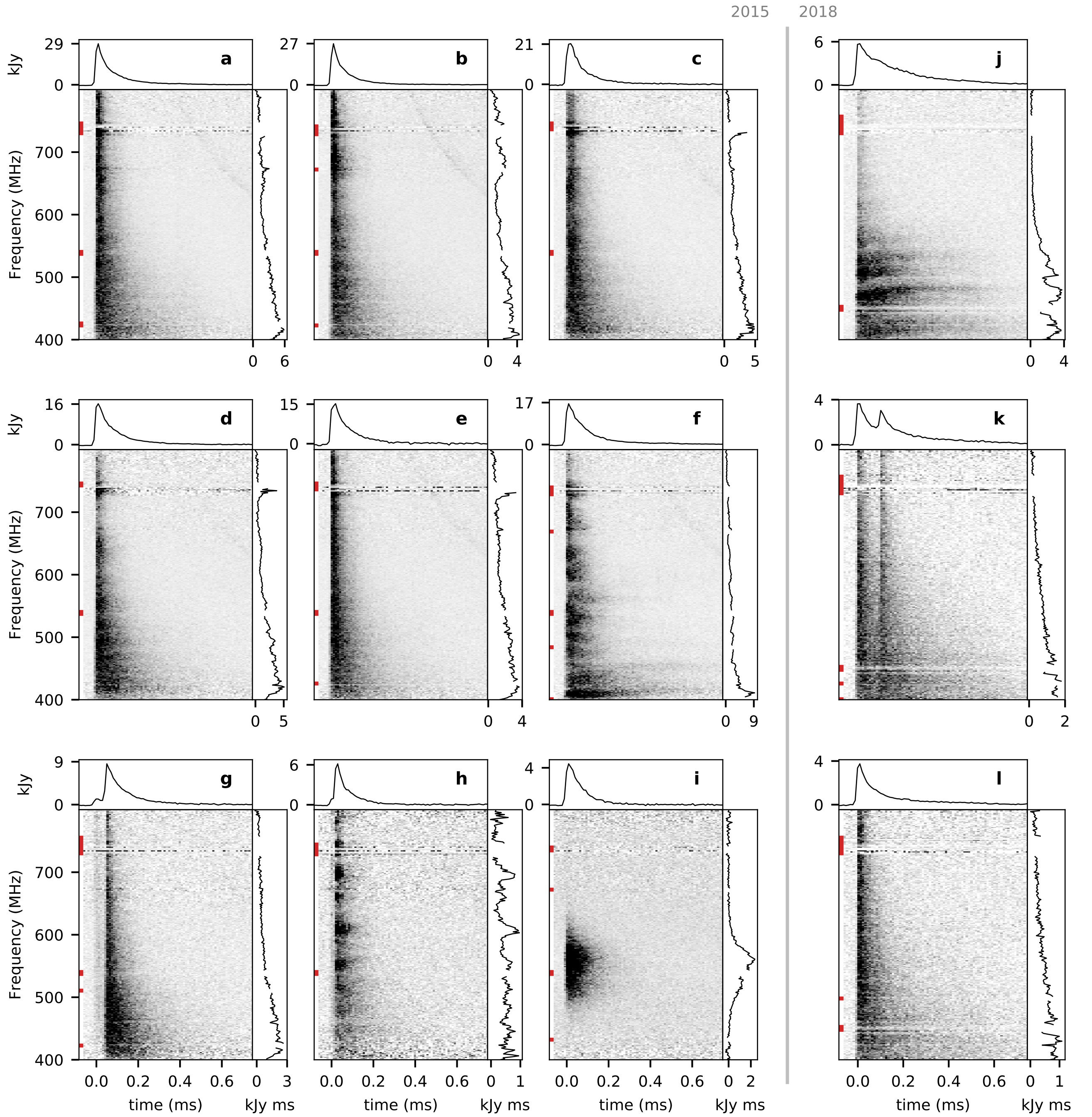

Figure 1. Dynamic spectra of 12 bright giant pulses of the Crab pulsar (taken from Bij et al., 2021, ApJ 920:38). Panels a–f and j–l are the brightest pulses in 2015 and 2018, respectively (ordered by descending brightness), while panels g–i are three further 2015 pulses chosen for their particular profiles. Pulse j stands out especially, with strong spectral bands that drift upward during the scattering tail. While the banding may simply reflect interference between nano-second scale giant pulse components, the variation is surprising, as in the scattering tail the only difference is that the source is observed via slightly longer paths, bent by about an arcsecond in the nebula. The corresponding small change in viewing angle could nevertheless reproduce the observed drift by a change in Doppler shift, if the plasma that emitted the giant pulses moved highly relativistically, with a Lorentz factor $\gamma \sim 10^4$ (and without much spread in γ).