Discovery of fast radio transients at very low frequencies

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June 02, 2015

Overview

Transient Searches at low frequencies: Motivations

In general

- Sporadic emission from unknown pulsars, RRATs, intermittent pulsars, etc.
- Radio flares from active stars, planets, Sun (and Sun-like stars)
- Low-DM counterparts of the high-DM FRBs/Lorimer-burst
- New class of transients

Specific to relevant data

Search for radio counterparts of gamma-ray pulsars via:

- Non-persistent/Transient emission
- Highly scattered bright pulses

Observations: Telescope

Observations using the Gauribidanur Radio Telescope (situated near Bangalore, India) in *phased-array (tied-array)* mode.

- East-West rows of single linear polarization dipoles (160×4; 1.4 km long)
- Centre Frequency: 34 MHz; Bandwidth: $\sim$1.5 MHz
- Beam-width: $0.35^\circ \times 21^\circ$ (RA$\times$DEC)
- Effective collecting area: 12,000 m^2
- A transit instrument with electronic transit capability

Observations: Target sources, duration, etc.

Observations and transient search towards J0633+1746/J0633+0632:

- Raw voltage sequence recorded at Nyquist rate
- Offline processing: Converting to filterbank format, RFI mitigation, etc.
- 131 observing sessions, each typically 30 minutes long, spread over $\sim$9 months (2012–2013)
- Data from 32 sessions were not usable due to severe RFI.
- From rest of the 99 sessions, strong, fast transient events were discovered in 2 sessions

Transient search: Methodology

Standard transient search methods, fine-tuned and optimized for transients expected at low frequencies, an in-house developed pipeline well tested and successfully used for last several years.

1. Dedispersion
2. Matched-filtering
3. Thresholding
4. Diagnostics
5. Scrutinizing

1. **Dedispersion**
   Frequency-dependent refractive index of the ISM

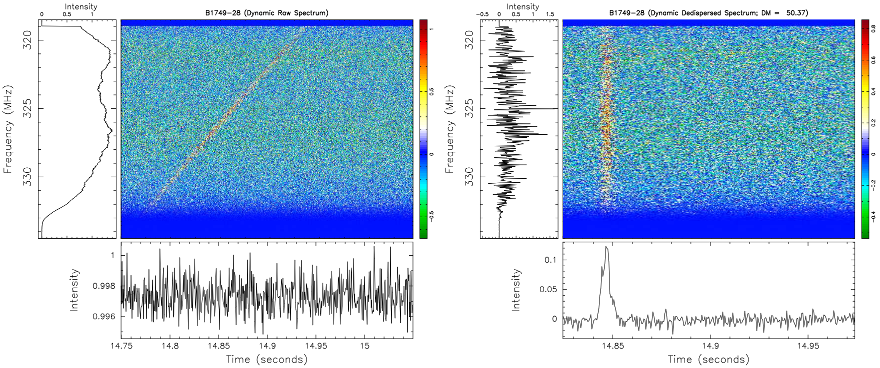
$$\mu = \sqrt{1 - \left(\frac{f_p}{f}\right)^2}$$

implies a frequency-depended time-of-arrival of a pulsed signal

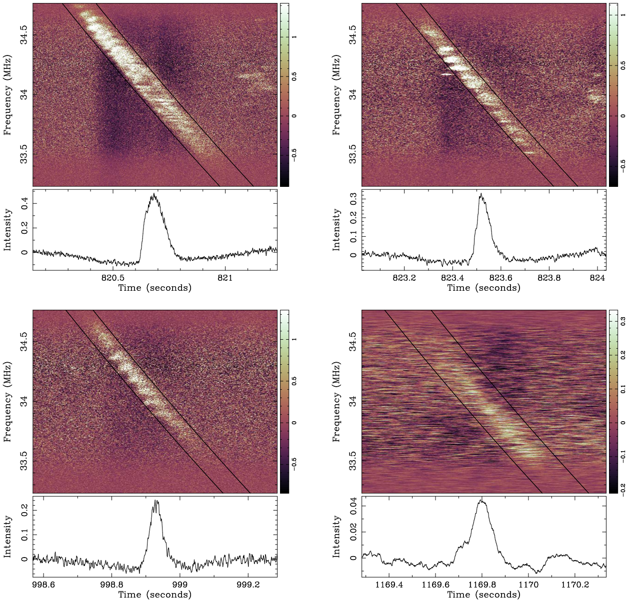
$$t = \frac{e^2}{2\pi m_e c} \frac{\int_0^d n_e \, \mathrm{d}l}{f^2}$$

$$DM = \int_0^d n_e \, \mathrm{d}l$$

1. **Dedispersion**
   Effect of, and correction for, the dispersion in the ISM:



Discovery of transients/radio-bursts



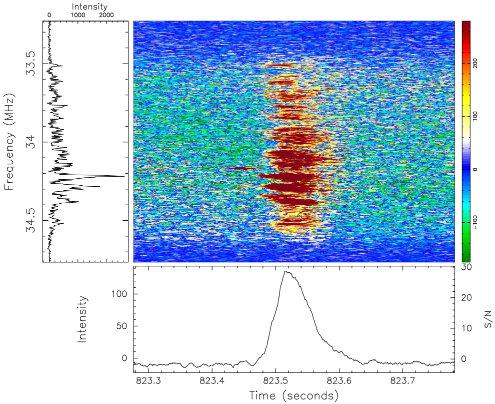
Radio-bursts: Basic parameters

S.no.	DM (pc cm^{-3})	Width (ms)	S/N
1	2.16±0.07	110	323
2	2.01±0.04	75	172
3	2.08±0.06	85	148
4	2.62±0.13	140	58
5	1.42±0.04	55	102
6	1.40±0.08	90	54
7	2.30±0.15	95	19
8	2.09±0.20	180	37
0	1.45±0.11	50	26
10	1.42±0.10	40	37
11	1.47±0.07	45	47
12	2.59±0.40	170	12
13	1.74±0.27	195	17

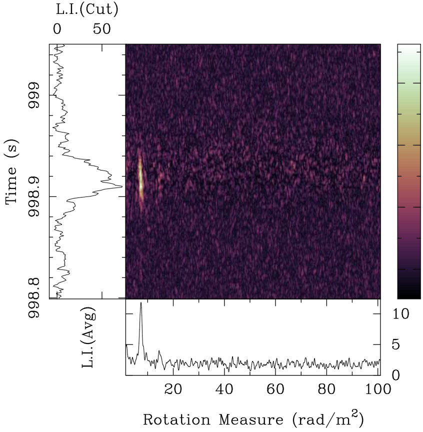
Table : Properties of the detected transients

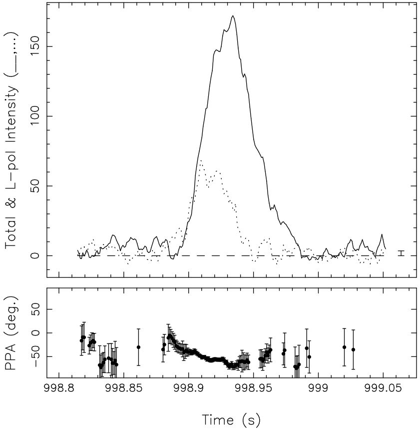
Origin of the bursts: Terrestrial or Astronomical ?

Signature of Faraday Rotation?



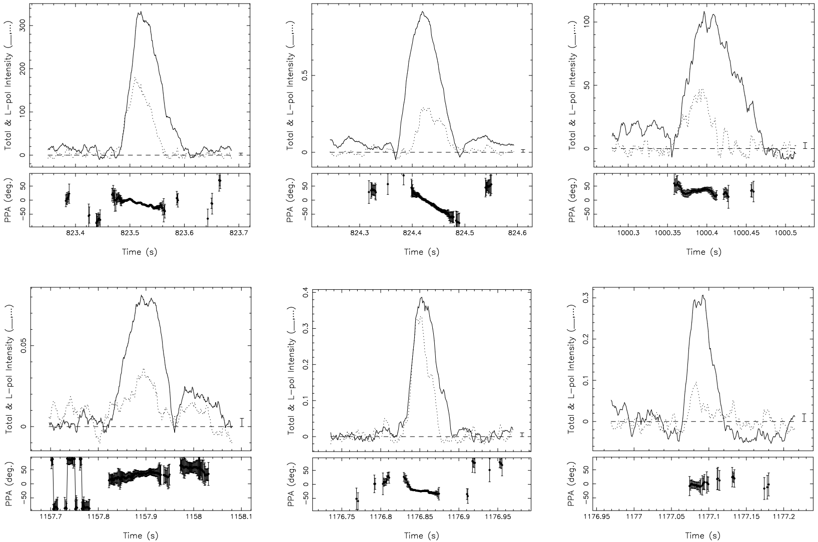
Time-resolved Rotation Measure Synthesis



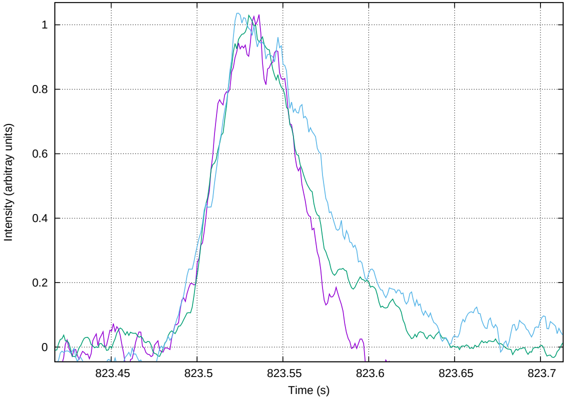


Maximum contribution from ionosphere : 2 rad m^{-2}

Polarization properties of radio bursts



...and possible hints of interstellar scattering



⇒ **Almost certain that the transients are not of terrestrial origin.**

Transients: summary of properties

Table : Summary of properties

Sr. No.	Arrival Time (seconds)	Pulse width (ms)	Pulse Energy (Jy.ms)		Dispersion Measure (pc cm^{-3})	Rotation Measure† (Rad. m^{-2})
Session A						
1	820.69 ± 0.03	110	403000	[556900]	2.16 ± 0.07	—
2	823.53 ± 0.02	75	174000	[240500]	2.01 ± 0.04	9.4 ± 0.8
3	824.42 ± 0.03	85	159700	[220700]	2.08 ± 0.06	12.6 ± 2.8‡
4	944.11 ± 0.03	140	81000	[111900]	2.62 ± 0.13	—
5	998.93 ± 0.02	55	89600	[123800]	1.42 ± 0.04	7.3 ± 0.4
6	1000.41 ± 0.02	90	60300	[83400]	1.40 ± 0.08	7.0 ± 0.7
7	1157.89 ± 0.03	95	22200	[30600]	2.30 ± 0.15	6.3 ± 1.1
8	1169.80 ± 0.03	180	58600	[81000]	2.09 ± 0.20	—
9	1172.50 ± 0.01	50	21600	[29800]	1.45 ± 0.11	—
10	1176.86 ± 0.01	35	26600	[36800]	1.42 ± 0.10	10.6 ± 1.3
11	1177.07 ± 0.01	30	26400	[36400]	1.47 ± 0.07	10.7 ± 1.1
12	1186.41 ± 0.04	170	18500	[25500]	2.59 ± 0.40	—
13	1187.39 ± 0.02	195	28300	[39000]	1.74 ± 0.27	—
Session B						
14	713.10 ± 0.04	130	57100	[79000]	3.62 ± 0.17	—
15	1345.99 ± 0.07	270	91300	[126200]	2.91 ± 0.17	—
16	1518.90 ± 0.05	150	106600	[147300]	3.41 ± 0.11	—

Possible source(s) of the radio bursts

1. Sun

- Varying DM, and no significant departure from dispersion law — **needs too much of a coincidence**
- Linear Polarization — **Unprecendented**
- Observed Rotation Measure values — **Possible**
- Pulse-widths — **Unlikely**
- Sun's position Offset from the pointing center: $\approx 18^\circ$ — **possible**
- *Archival solar data show no radio bursts at the epochs of radio bursts*

$\Rightarrow$ **Sun is unlikely to be the origin.**

Possible source(s) of the radio bursts

2. **Pulsar(s)**

- Varying DM — **Unprecedented, needs to explain the physical mechanism**
- Linear Polarization — **Okay**
- Observed RM values — **Okay**
- Polarization position angle sweeps — **Okay**
- Pulse energy — **Okay; Giant Pulses have similar energy at these wavelengths**
- Pulse widths — **Okay**

$\Rightarrow$ **A pulsar with variable Dispersion Measure ?**

Possible source(s) of the bursts: Known Pulsars in the field (J0633+1746 and J0633+0632)

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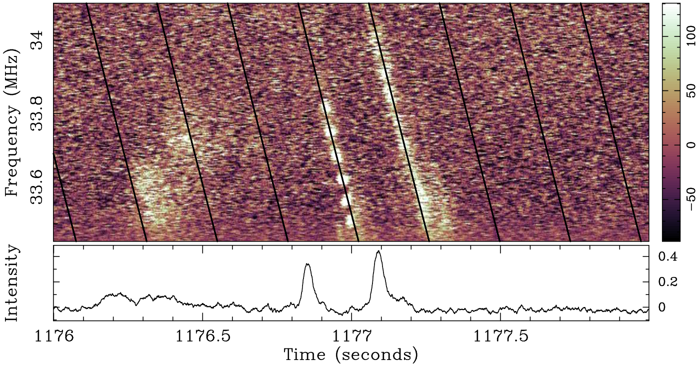
Possible source(s) of the bursts: Known Pulsars in the field (J0633+1746 and J0633+0632)

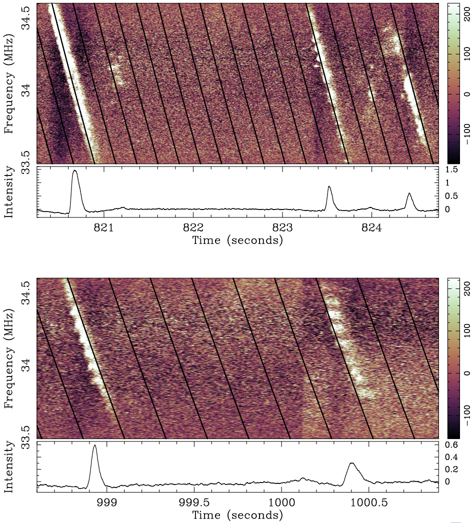
1. J0633+1746 (Geminga)

Arrival times of radio bursts and the Geminga's periodicity.



Possible source of the bursts: Geminga pulsar

Arrival times of radio bursts and the Geminga's periodicity.



Discovery of radio bursts at 34 MHz: Inferences and Summary

- Detection of several highly energetic radio bursts.
- Arrival times of the bursts suggest these to be originated from the gamma-ray pulsar Geminga.
- Pulse-energies of the bursts are comparable to those of giant pulses from Crab pulsar, and might suggest an emission mechanism similar to that of giant pulses.
- The short timescale (as small as a minute) variation in DM indicates that the underlying cause of the variation is most likely associated with the pulsar.
- The short timescale variation in DM together with non-persistent radio emission may explain why the pulsar has been detected only occasionally.