Fast radio bursts: a new exotic puzzle in astrophysics

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Radiotransients

Many different types of transient sources are already detected at radio wavelengths.

However, detection of very short and non-repeating flares of unknown sources without identification at other bands is a very complicated task.

Rotating Radio Transients (RRATs) – millisecond radio bursts from neutron stars, - have been identified in 2006.

In 2007 the first example of a new class of millisecond radio transients have been announced: the first extragalactic millisecond radio burst.
History of FRBs

2007 Lorimer et al.      The first event announced.
2012 Keane et al.         The second event.
2013 Thornton et al.    Four events. The story really starts.
2016 Spitler et al.        The first repeating source.
                          Chatterjee et al. Identification of the host galaxy

Large dispersion measure points to extragalactic origin.

This is supported by isotropic sky distribution and many other considerations.
Catalogue

22 FRBs
+ one repeater

Rate: several thousands per day per sky

<table>
<thead>
<tr>
<th>Event</th>
<th>Telescope</th>
<th>$gl$ [deg]</th>
<th>$gb$ [deg]</th>
<th>FWHM [deg]</th>
<th>DM $[\text{cm}^{-3}\text{pc}]$</th>
<th>S/N</th>
<th>$W_{\text{obs}}$ [ms]</th>
<th>$S_{\text{peak,obs}}$ [Jy]</th>
<th>$F_{\text{obs}}$ [Jy ms]</th>
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<tr>
<td>FRB010125</td>
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<td>356.641</td>
<td>-20.020</td>
<td>0.25</td>
<td>790(3)</td>
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<td>2.60</td>
<td>22.30</td>
<td>57.96</td>
</tr>
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</table>

http://www.astronomy.swin.edu.au/pulsar/frbcat/
Localization

Radius of uncertainty circle ~10 arcmin

Usually FRBs are seen just in one beam.
Statistical properties of FRBs

\[ \frac{dN}{dF_{\text{obs}}} = (4.4 \pm 0.4) \times 10^3 F_{\text{obs}}^{-1.18 \pm 0.15} \text{ sky}^{-1} \text{ day}^{-1} \]
FRBs. Different hypotheses

Millisecond extragalactic radio bursts of that intensity without immediate identification with other bursts have not been predicted by earlier studies.

Since 2007 many hypotheses have been proposed.

A real flow started in late summer of 2013 after the paper by Thornton et al.

- Magnetars
- Super radio pulsars
- Evaporating black holes
- Coalescing NSs
- Coalescing WDs
- Coalescing NS+BH
- Supramassive NSs
- Deconfinement of a NS
- Axion clouds and NSs
- Cosmic strings
- Charged BHs
- NS collapse
The first idea of possible connection between FRBs and magnetars has been proposed already in 2007 by Popov, Postnov: arXiv 0710.2006.

This hypothesis has been based on rate and energetics considerations, mainly. **FRB bursts might be related to giant flares of magnetars**

Later this approach was developed by Lyubarsky (2014).

In the model by Lyubarsky the radio burst happens due to synchrotron maser emission after interaction between a magnetic pulse after a giant flare of a magnetar with surrounding nebula.
Nebula emission

The model of a nebular emission after a huge energy release in a central source was developed by several authors.
Nebulae around magnetars

There are examples of nebulae around magnetars and highly magnetized radio pulsars.

About formation of pulsar nebulae around magnetars see 1606.01391
Radio flares from M31

Rubio-Herrera et al. (2013) discovered millisecond radio bursts from the Andromeda galaxy.

It looks like a scaled version of FRBs. In the magnetar model such (more frequent) bursts can be related to weaker flares of magnetars.

Note, that Frederiks et al. (2005) proposed a candidate for a giant magnetar flare in M31.
Radio pulsar model

In the case of the Crab pulsar so-called giant pulses are known.

It has been suggested (1501.00753, 1505.05535) that young pulsars with large $E_{\text{dot}}$ can rarely produce much more energetic events.

Scaling allows to reproduce energetics of FRBs.
FRBs as supergiant pulses

Estimates are done via scaling of parameters of the Crab. Rather normal magnetic field but rapid rotation formally can explain FRB energetics.

$\eta = \frac{L_{GP}}{\dot{E}_{\text{Crab}}} = \frac{\nu c^3 d_{\text{Crab}}^2 S_\nu P_{NS}^4}{4\pi^3 B_{NS}^2 R_{NS}^6} \approx 10^{-2},$

$L_{FRB} = \eta \dot{E} \rightarrow B_{NS} = \frac{c^{3/2} d\sqrt{(\nu F_\nu)} P_{NS}^2}{2\pi^{3/2} R_{NS}^{3/2}\sqrt{\eta}} = 2 \times 10^{13} d_{100\text{Mpc}} F_{30\text{Jy}}^{1/2} \tau_{5\text{ms}}^2 \sqrt{\nu_9 \eta_{-2}}^{-1/2} \text{ G}.$

$\tau_{SD} = \frac{\pi \eta I_{NS}}{d^2 F_\nu \mu P^2} \sim \text{few years.}$

With magnetic field and spin period it is possible to estimate the characteristic spin-down time.
Supergiant pulses of young radio pulsars in dense supernova remnants

Age 30-100 years
Uniform distribution in $E_{\text{dot}}$ in logarithmic scale
Absorption of low-frequency radiation in the remnant
Repeating bursts
Bursts are uniformly distributed in distance

Steady state solution for magneto-dipole spindown and

\[
f(\dot{E}) \propto \frac{\ln(\dot{E}_0/\dot{E})}{\dot{E}^{3/2}}, \beta = 1
\]

\[
\dot{f}_{\text{inj}}(\dot{E}) \propto \dot{E}^{-\beta}
\]
Dispersion in a dense supernova remnant

\[ DM \approx \frac{M_{ej}}{m_p r^2} \]

\[ r = \sqrt{\frac{M_{ej}}{m_p} \frac{1}{\sqrt{DM}}} = 0.34 \text{pc} \sqrt{m_\odot DM_{375}^{-1/2}} \]

\[ \frac{M_{swept}}{M_{ej}} = \sqrt{\frac{M_{ej}}{m_p}} \frac{n_{ISM}}{\text{DM}^{3/2} \text{pc}^{3/2}} = 4.5 \times 10^{-4} n_{ISM} \sqrt{m_\odot} \ll 1, \]

\[ v_{ej} = \sqrt{\frac{2E_{ej}}{M_{ej}}} \]

\[ t = \frac{M_{ej}}{\sqrt{2DME_{ej} m_p}} = 35 \text{yrs} m_\odot \]

\[ \tau = 8 \times 10^{-2} n^2 \nu^{-2.1} r T^{-1.35} = 0.05 \text{DM}_{375}^{5/2} m_\odot^{-1/2} \nu_9^{-2.1} \]

Dispersion in a dense SNR might explain observed DM of FRBs in the model when they are near-by at distances \(\sim 100-200 \text{ Mpc}\).
Burst rate

SN rate $\sim 3 \times 10^{-4}\text{ yr}^{-1}\text{ Mpc}^{-3}$ (Dahlen et al. 2012).
This gives $\sim 1$ SN per day in 100 Mpc.
Ages and typical lifetime of our sources $\sim 30\text{-}100$ years.
Thus, we have $\sim 10\,000$ – $30\,000$ sources in 100 Mpc.
The observed rate of FRBs $\sim 3 \times 10^3$ per day.
Then, each source might give a flare per few days.
If we increase the distance up to 200 Mpc then we can use just 10% of most energetic neutron stars.

Giant pulses of the Crab with fluence 100-200 kJy for $E_{\dot{E}_{\text{tot}}}$ increase by factor 100 000
are scaled to flares with the flux $\sim 1$ Jy from 100-200 Mpc.

Number of giant pulsars depends on flux as $\sim S^{-3}$.
For FRBs we then obtain that most bright event might be observed once per few months.
Monte Carlo simulations

\[ f_{inj} \propto \dot{E}^{-1} \]

\[ \partial_t \dot{E} \propto -\dot{E}^{-3/2} \]

\[ S \propto \dot{E}/r^2. \]
Dispersion measure does not correlate with fluence or peak luminosity.

This is in correspondence with the model.
In the model of supergiant pulses it is natural to expect that at distances 100-200 Mpc young energetic PSRs might be strong X-ray sources, similar to ULXs.

\[ L_X \approx 2 \times 10^{42} \left( \frac{\dot{E}}{10^{43} \text{ erg s}^{-1}} \right)^{1.34} \text{ erg s}^{-1}, \]

(Possenti et al. 2002)

Searches for possible counterparts of FRBs in X-ray in near-by (100-200 Mpc) galaxies can confirm or falsify the model.
Future observations

FAST – burst per week
1602.06099

SKA – burst per hour!
1602.05165, 1501.07535
Near future

Observation at other telescopes, especially for the repeating source.
Attempts to identify something at other wavelengths.

Observations at Parkes with a new monitoring system.

New system ALFABURST at Arecibo. 1511.04132

http://astronomy.swin.edu.au/research/utmost/
Burst per week, see 1601.02444
Special projects partly dedicated to FRBs

https://sites.google.com/site/publicsuperb/

CHIME – burst per day!
1601.02444

HIRAX.
South variant of CHIME

1607.02059
ASKAP and Apertif

Few bursts per week. 1709.02189

Northern sky. Doubling the number? Rapid on-line identification – follow-up