An Overview and Update of the Repeating FRB

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Overview

• Brief background on FRB 121102 and update on single dish observations

• What can we learn about the system from observing the bursts?

• What can we learn about system from observing its environment?
FRB 121102: the first (and so far only) repeating FRB

Discovered in archival processing in pulsar survey data (PALFA) from the Arecibo Observatory...

... in the Galactic plane

AO Team
Jason Hessels (U van A)
Andrew Seymour (NAIC)
Daniele Michilli (U van A)
Kelly Gourdji (U van A)

Arecibo monitoring of the “repeater”

Daily VLA and AO observations

5 GHz detections
All other detections at 1.4 GHz

Sept 20: Hurricane Maria
Nov 7: first post-Maria observation
What can we learn from observing the bursts?

- Radio observations
  - ~200 detections from 1.2 to 9 GHz
  - No detections (simultaneous or otherwise) below 1 GHz
  - Simultaneous, multi-telescope detections are rare
  - Highly non-Poissonian detection rate
  - Bursts highly polarized

- Higher energy (optical/X-ray / gamma-ray)
  - No detectable simultaneous bursty emission:
    - Scholz et al. 2017, Hardy et al. 2017
“Weird bursts”

Arecibo
1.2-1.7 GHz

GBT
1.6-2.4 GHz

All bursts @ DM = 560.5 pc cc

Coherently dedispersed

S/N > 60

Detections during high-cadence Sept 2016 obs.
(Except AO-00, GBT-03, GBT-04)

(Hessels et al., in prep)
Models for 3D printers developed by Anne Archibald

https://www.thingiverse.com/thing:2723399
Burst component drift rates
Arecibo 5 GHz detections with PUPPI

25 Dec 2016
26 Dec 2016
19 Jan 2016

20 μs burst duration

Narrow freq. striping is Galactic scintillation

(Michilli et al 2018)
Bursts 100% linearly polarized

Once you can correct for the large rotation measure...

Constant polarization angle during a burst and between bursts

Arecibo Observatory

Green Bank Telescope (Breakthrough Listen) August 2017

(Michilli et al., 2018)
GBT Breakthrough Listen

Vishal Gajjar

4-8 GHz receiver

BL backend with baseband recording

August 2017

21 bursts detected

Observed the source to “turn off”

(I will return to polarization later)

(Gajjar et al., in prep)
What can we learn from observing the bursts?

- What we need to explain...
  - Complex time-frequency structure
  - 100% linear polarization and flat and constant polarization angle
  - Perhaps, variable detection rate

- Possibilities:
  - Intrinsic emission mechanism
  - Extrinsic effect, i.e. propagation
  - Some combination of the two

Exception: Periodicity!
Intrinsic process: when in doubt... invoke the Crab pulsar

High frequency interpulse giant pulses

Banded frequency structure

Separation of the bands increases linearly with frequency

(Hankins & Eilek 2007)

(Hankins, Eilek, Jones 2016)
Crab HF IP GP polarization

Main pulse giant pulse
Interpulse giant pulse

Jessner et al., 2010
Extrinsic process: Plasma Lensing

Cuspy frequency structure
Significant gain boosts

Multiple Images

Time delays between images

Known plasma lensing phenomenon:
Extreme scattering events
Echos in profile of Crab pulsar

What can we learn by observing the environment?

• Arguably, a lot more...

• (If you want to try to convince me the repeater comes from a different FRB population, show me the environments of “one-off” sources.)
**Bursting source:**
Localized to sub-milliarcsecond precision

**Persistent radio source:**
Compact (<0.7 pc)
Spatially coincident with bursting source

**Optical follow-up**
**Host galaxy:**
Redshift of 0.193
Low metallicity dwarf

Chatterjee et al, *Nature*, 2017
Marcote et al., *ApJL*, 2017
FRB 121102 located in large star formation region

- Host galaxy is a low metallicity dwarf
  - $M_{\star} \sim 10^8 \, M_{\odot}$
  - Metallicity: $12 + \log_{10}(O/H) = 8 \pm 0.2$
  - SFR: $0.23 - 0.4 \, M_{\odot}\,yr^{-1}$
- Persistent+bursting source sitting in a large HII region
- Similar to extreme emission line galaxies (EELGs)

Two models

The burst source is a young magnetar in an energetic nebula

The bursting source (neutron star?) is in the vicinity of an intermediate massive black hole

Credit: NASA/Hubble

Credit: NASA/Goddard Space Flight Center Conceptual Image Lab
# Model scoreboard

<table>
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<th>Source of luminous bursts</th>
<th>millisecond magnetar (SLSNe/long GRB)</th>
<th>Intermediate mass black hole</th>
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<td>NS in vicinity?</td>
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✔ = easily explainable

✗ = less easily explainable
Rotation Measure

\[ \theta_p = \frac{c^2}{\nu^2} \text{RM} \]

\[ \text{RM} = \int_0^D n_e(l) B_{\parallel} dl \]

\[ n_e = \text{electron density} \quad B_{\parallel} = \text{magnetic field along the line of sight} \]

\[ \text{RM}_{\text{source}} = (1 + z)^2 \text{RM}_{\text{obs}} \]

\[ \text{RM}_{\text{source}} \sim 145,000 \text{ rad m}^{-2} \text{ (AO)} \]
\[ \text{RM}_{\text{source}} \sim 133,000 \text{ rad m}^{-2} \text{ (GBT)} \]

Explains why the bursts at 1.4 GHz show no polarization.

(Michilli et al 2018)
RM is time variable

\[ B_{\parallel} = \left( \frac{\text{RM}_{\text{src}}}{0.81 \text{ DM}_{\text{host}}} \right) \text{ mG} \]

\( \text{RM}_{\text{source}} \sim 145,000 \text{ rad m}^{-2} \)
\( \text{DM}_{\text{host}} = 70 - 270 \text{ pc cm}^{-3} \)
\( \text{B-field} \sim 0.6 - 2.4 \text{ mG} \)

We argue that the magnetized plasma local to the source is responsible for the RM is local to the source.

(Michilli et al 2018)
Interesting Galactic analog: Galactic center

Six “GC” pulsars

J1745-2900 (aka the “GC magnetar”)  
~0.1 pc from Sgr A*  

RM$_{\text{Sgr A*}}$ $\sim 4 \times 10^5$ rad m$^{-2}$

RM of J1745-2900 also variable  
DM is consistent with no variation

(Schnitzeler et al. 2016)  
(Michilli et al. 2018)  
(Desvignes et al., ApJL, 852, 2018)
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<td>✗ RM $\approx 10^5$ rad m$^{-2}$ have never been observed from a SNe/PWNe</td>
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✓ Maybe SLSNe/LGRBs simply different
Luminosity of persistent radio source

FRB 121102:

$L_{\text{Radio,PS}} \sim 10^{38} \text{ erg s}^{-1}$

$L_{\text{X-ray,PS}} < 10^{41} \text{ erg s}^{-1}$

SED of Crab nebula

“Fundamental plane” for AGN


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Host galaxy properties

Host of FRB 121102 typical for hosts of SLSNe/LGRBs

Low luminosity AGNs are rare in dwarf galaxies

Optically selected (Reines et al 2013): 0.5%

X-ray selected (Mezcua et al 2018): 0.2%; only ~8% had radio emission

Radio / X-ray luminosities don’t into the “fundamental plane”

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Conclusions

• The repeating FRB has been an interesting case study in FRB localization

  • We know the source is associated with a compact, persistent radio source in a low-metallicity dwarf galaxy at z=0.193. It is embedded in a region of strong star formation and in an environment similar to the center of our galaxy.

  • Bursts show a complex phenomenology

  • Observing the source’s environment did more to narrow down astrophysical models: young neutron star + SNe or NS in the vicinity of a low-luminosity AGN