

Localizing a Fast Radio Burst on milliarcsecond angular scales

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Artworks: Danielle Futselaar



The repeating FRB 121102

- The only one detected by Arecibo (305-m diameter)
- The only one detected more than once:
[Spitler et al. \(2014, 2016\)](#),
[Scholz et al. \(2016\)](#)
- In the Galactic anticenter
- One of the closest ones
 $DM = 557 \text{ pc cm}^{-3}$
- Is it like a strange pulsar?
Is it Galactic?
Two types of FRBs?





Merging Black Holes



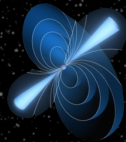
Supernovae



Magnetars



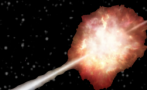
Evaporating Black Holes



Super-giant Pulses



The Unknown



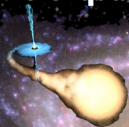
Gamma-ray Bursts

extra-Galactic

Implied rate of 1000s per day, per sky... but what are they?

Galactic

Micro-quasars



Flare stars



SETI

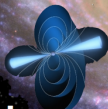


Pernicious RFI Atmospheric effects



We are here

Magnetars

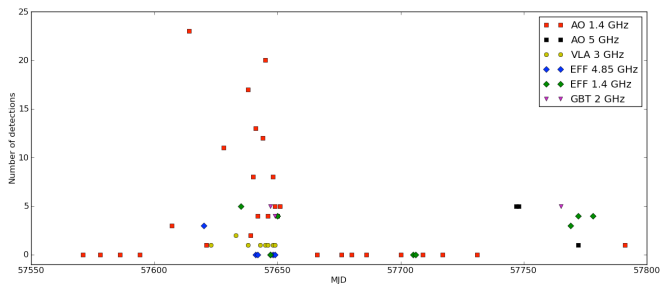


Pulsars



"Blitzars"

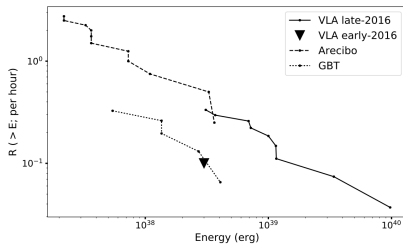
FRB 121102, burst statistics?



Credit: L. Spitler

Broadband bursts but:
many (most?) with $\Delta \sim 500$ MHz

Some bursts show “weird” structures



Law et al. (2017, arXiv:1705.07553)

The fundamental problem: poor localization

The main problem on FRBs is the lack of known counterparts

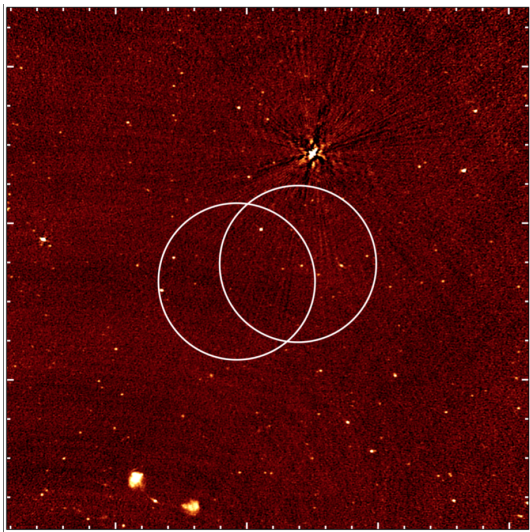
- We only have tentative distances
- Precision of several arcmin
- Hundreds/thousands of possible counterparts

PARKES

ARECIBO

VLA

FRB 121102: previous Arecibo detections



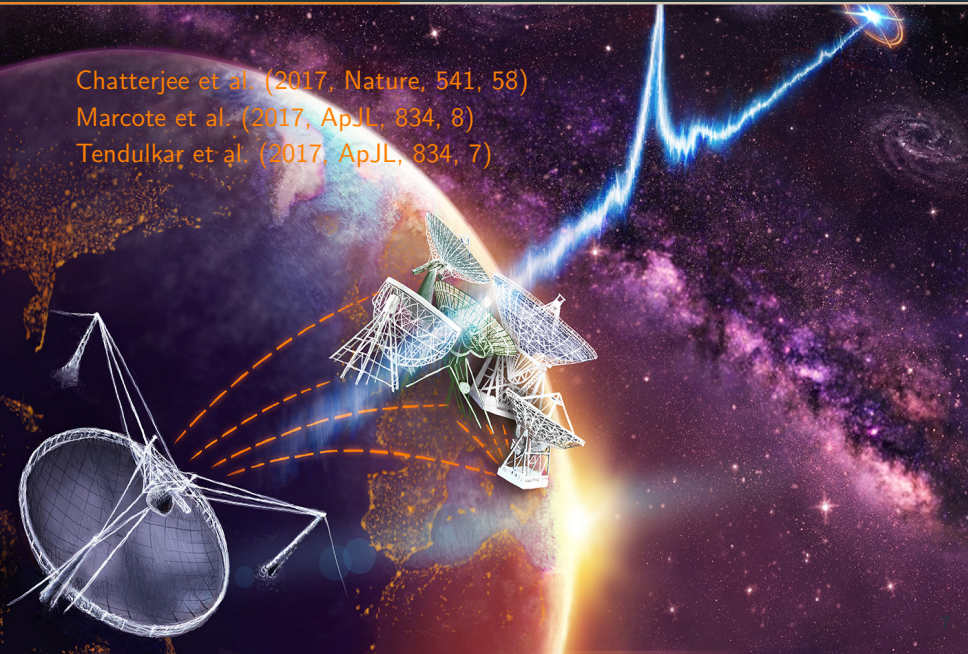
Chatterjee et al. (2017)

The First Precise Localization of a Fast Radio Burst

Chatterjee et al. (2017, *Nature*, 541, 58)

Marcote et al. (2017, *ApJL*, 834, 8)

Tendulkar et al. (2017, *ApJL*, 834, 7)



The localization of FRB 121102



Karl G. Very Large Array (VLA)

- From Nov 2015 to Sep 2016
- 83 h at 1.6 and 3 GHz
- One burst on 23 Aug 2016
- 8 more in Sep 2016

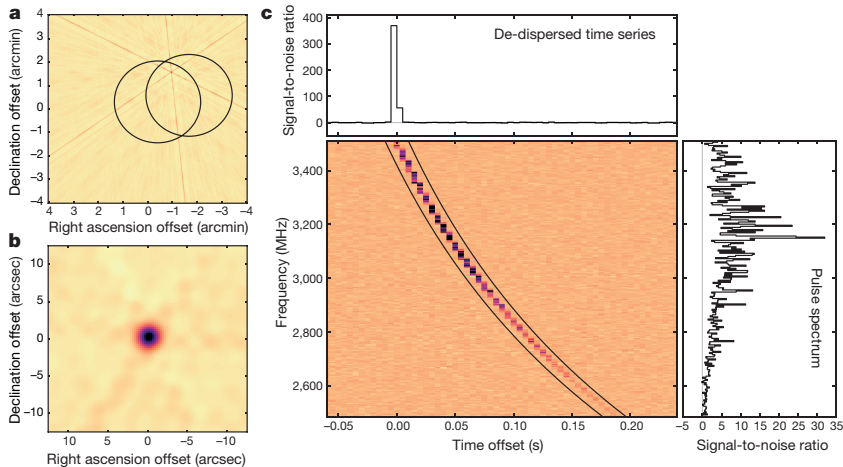


European VLBI Network (EVN)

- From Feb to Sep 2016
- 8 epochs at 1.6 and 5.0 GHz
- 4 bursts on 20 Sep 2016

Interferometric correlation + raw data buffering

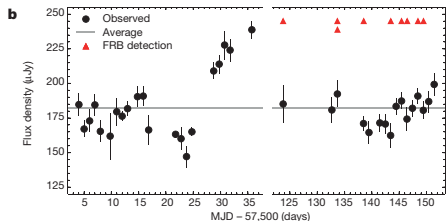
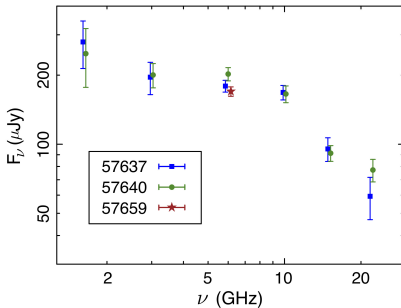
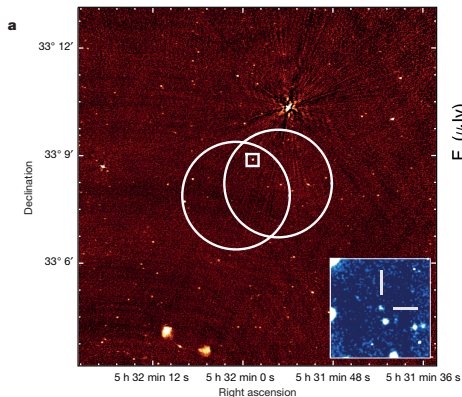
The VLA localization of FRB 121102



5-ms image (dispersion corrected) of one burst.

Chatterjee et al. (2017, *Nature*, 541, 58)

The VLA localization of FRB 121102



- Persistent radio counterpart
- Variability $\sim 10\%$
- Variability uncorrelated with the bursts

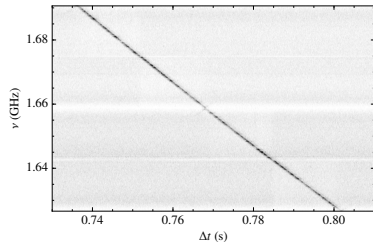
Chatterjee et al. (2017, *Nature*, 541, 58)

but... are FRB 121102 and the persistent radio counterparts
physically related?

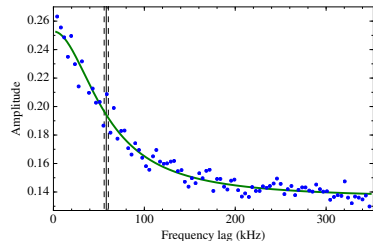
Localizing FRB 121102 on milliarcsecond scales

The EVN observations

- 4 bursts on 20 Sep 2016
 - The brightest one: ~ 4 Jy
 - The other three ~ 0.2 – 0.5 Jy
- Arrival times from Ar data
- ACF: Galactic diffractive scintillation
- Images of bursts and persistent source on mas scales



Marcote et al. (2017, ApJL, 834, 8)



Localizing FRB 121102 on milliarcsecond scales

colors: 5-GHz EVN image

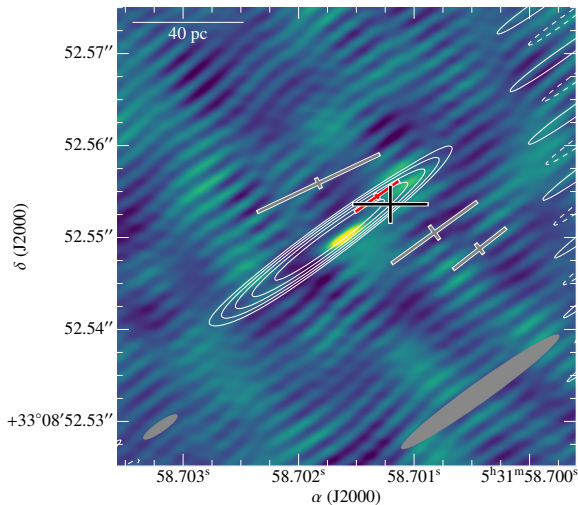
Cont.: 1.7-GHz image

(same as bursts)

Black cross: average burst position.

Coincidence within 2σ :
< 40 pc at 95% C.L.

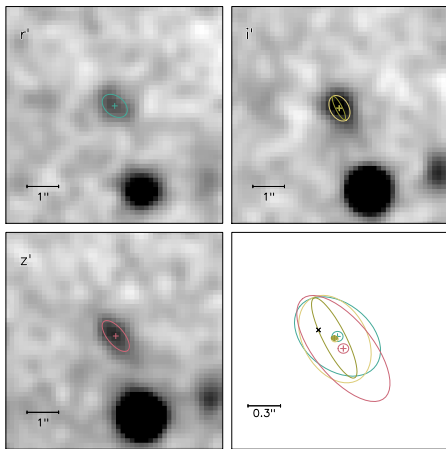
Persistent source < 0.7 pc



Marcote et al. (2017, ApJL, 834, 8)

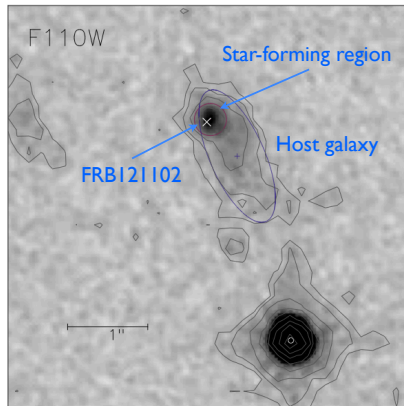
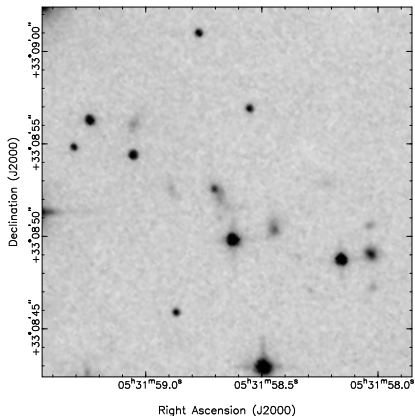
The optical counterpart

- Keck & Gemini data
- Extended 25-mag counterpart
- $z = 0.19273(8) \implies 972 \text{ Mpc}$
Extragalactic!
- Emission lines
 \implies low-metallicity star-formation
- Dwarf galaxy!
Diameter: $\lesssim 4 \text{ kpc}$
Mass: $4\text{--}7 \times 10^7 M_{\odot}$
Star Formation: $\sim 0.4 M_{\odot} \text{ yr}^{-1}$



Tendulkar et al. (2017, ApJL, 834, 7)

FRB 121102 inside a star-forming region

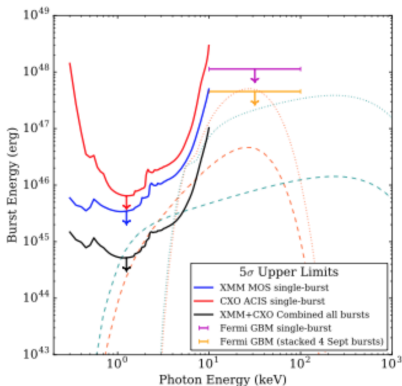


HST images: Bassa et al. (2017, arXiv:1705.07698)

Searching for bursts at other wavelengths

Simultaneous radio and X-ray observations (with *XMM* and *Chandra*)

- Nine bursts observed
- No X-ray photons at those times ($< 4 \times 10^{-11}$ erg cm $^{-2}$)
- No X-ray bursts at all ($< 5 \times 10^{-10}$ erg cm $^{-2}$)
- Persistent emission?
 $L_{0.5-6\text{keV}} < 3 \times 10^{41}$ erg s $^{-1}$



Scholz et al. (2017, arXiv:1705.07824)

Simultaneous optical & TeV observations coming soon

Summary & Conclusions

Facts about FRB 121102:

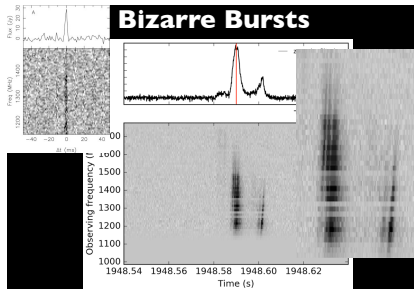
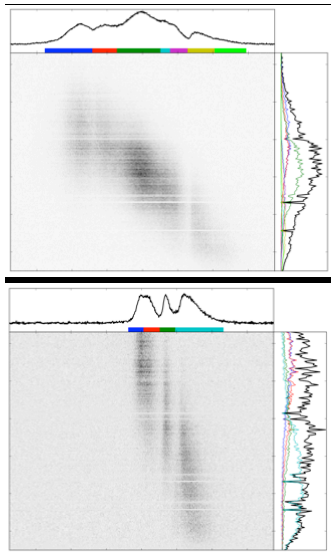
- FRB 121102 is associated with a persistent radio source < 0.7 pc
- This source is inside a low-metallicity star-forming region
- The SFR dominates the optical emission from the galaxy
- Dwarf galaxy $\lesssim 4$ kpc
- No X-ray bursts have been observed so far

What FRB 121102 is (can be):

- Magnetar powering a superluminous supernova?
- Magnetar associated with a massive black hole?
- ... any other suggestion?

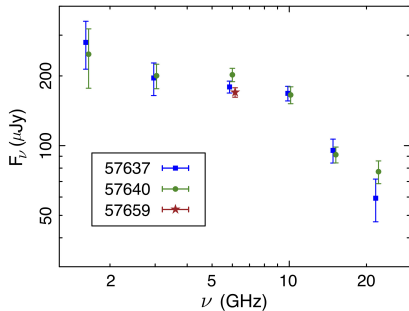
Thank you!

Bizarre bursts

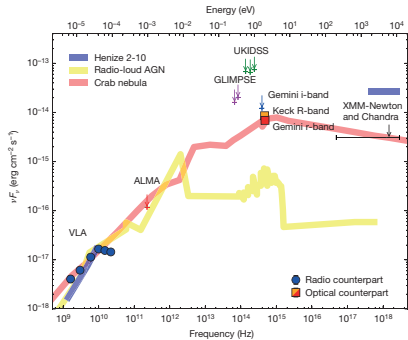


Hessels et al. (in prep)

The VLA localization of FRB 121102



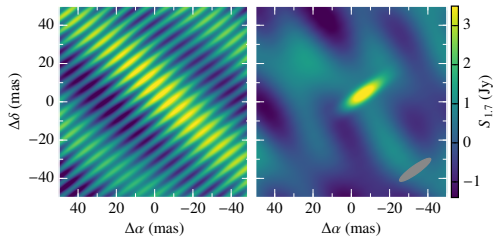
Spectrum of FRB 121102



SED of FRB 121102

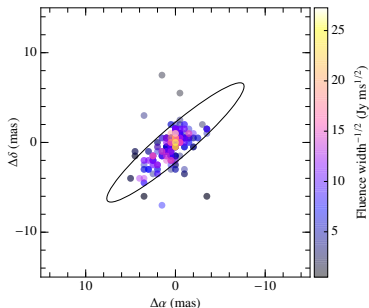
Chatterjee et al. (2017, Nature, 541, 58)

Localizing FRB 121102 on milliarcsecond scales



Dirty and clean image from FRB 121102.

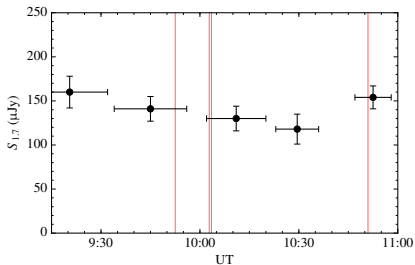
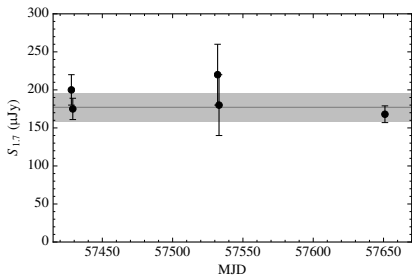
Astrometry limited by signal-to-noise ratio



Positions derived from 406 pulses from the pulsar B0525+21

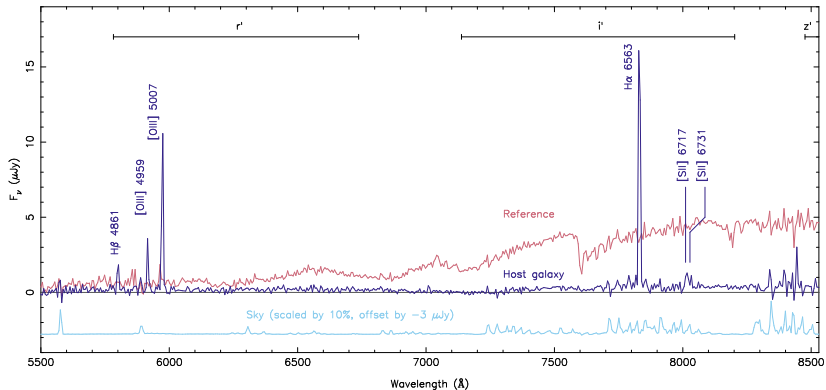
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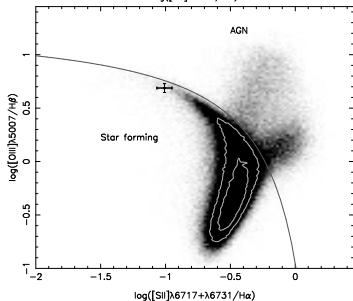
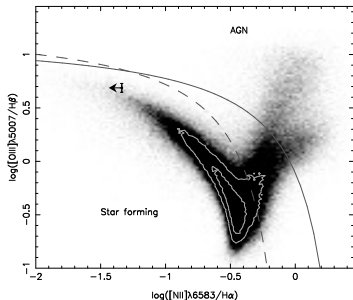
Marcote et al. (2017, ApJL, 834, 8)

The optical counterpart



Tendulkar et al. (2017, ApJL, 834, 7)

The optical counterpart



Emission lines dominated by SF

No emission detected at:

- sub-mm (ALMA)
rms of $17 \mu\text{Jy}$
- X-rays (*Chandra*, *XMM*)
 $< 5 \times 10^{41} \text{ erg s}^{-1} (5\sigma)$
- γ -rays (*Fermi*/LAT)