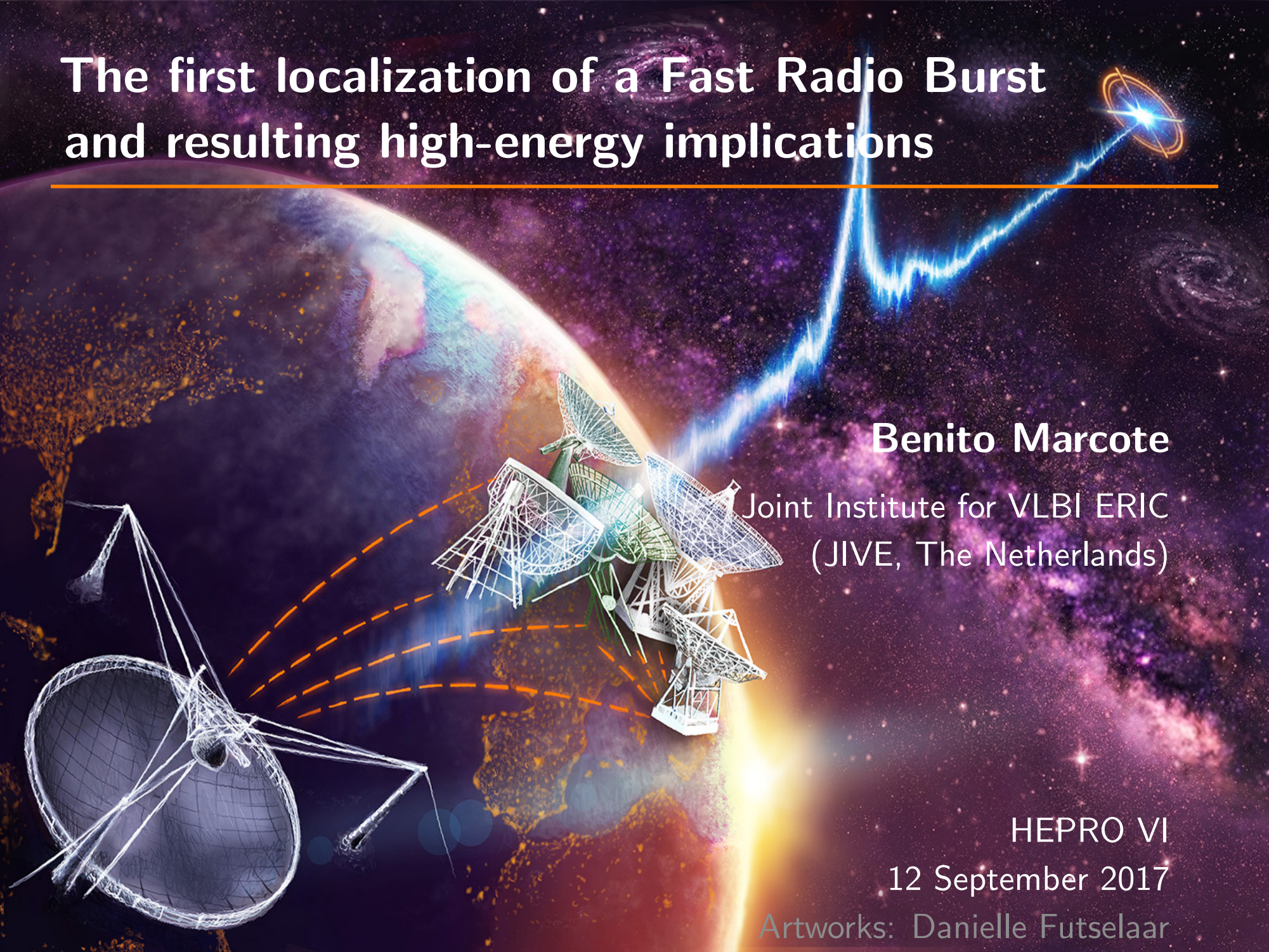
The first localization of a Fast Radio Burst and resulting high-energy implications



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HEPRO VI

12 September 2017

Artworks: Danielle Futselaar

Introduction

- Fast Radio Bursts
- Possible origins

The only repeater, FRB 121102

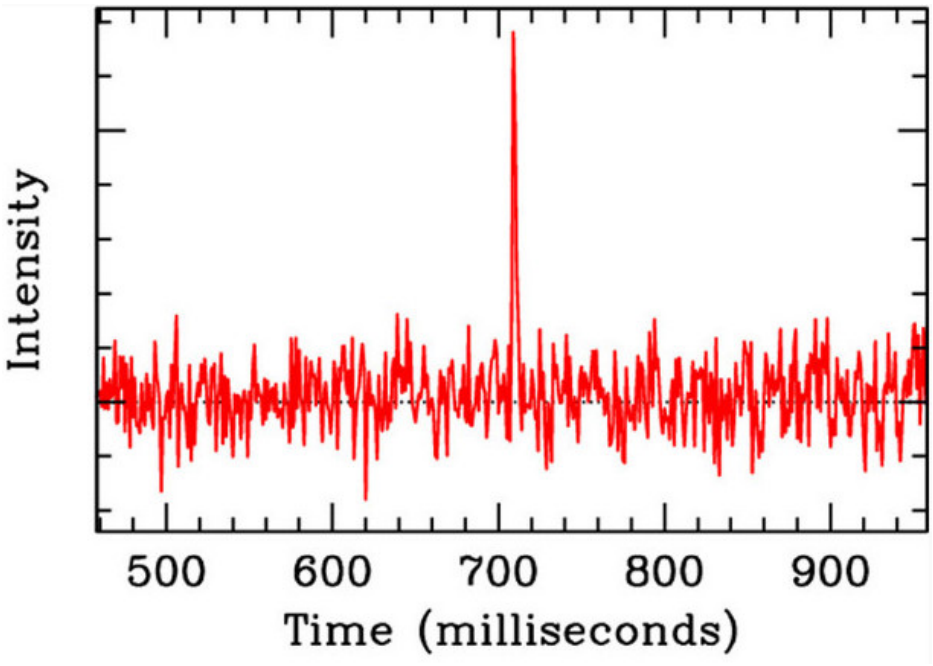
- The first localization of a FRB
- The radio counterpart
- The optical counterpart
- Possible origins for the bursts and the persistent counterpart
- Expectations at gamma-rays?

Conclusions and prospects

Introduction

Introduction: What is a Fast Radio Burst?

- **Fast and strong radio flashes**
- Duration of a few milliseconds
- Bright: $\sim$ 0.1–1 Jy
- Detected at radio freq. ($\sim$1 GHz)
- Discovered by Lorimer et al. (2007)
- Origin: completely unknown



FRB 140514

The known Fast Radio Bursts

Event	Telescope	gl [deg]	gb [deg]
FRB010125	parkes	356.641	-20.020
FRB010621	parkes	25.433	-4.003
FRB010724	parkes	300.653	-41.805
FRB090625	parkes	226.443	-60.030
FRB110220	parkes	50.828	-54.766
FRB110523	GBT	56.119	-37.819
FRB110626	parkes	355.861	-41.752
FRB110703	parkes	80.997	-59.019
FRB120127	parkes	49.287	-66.203
FRB121002	parkes	308.219	-26.264
FRB121102	arecibo	174.950	-0.225
FRB130626	parkes	7.450	27.420
FRB130628	parkes	225.955	30.655
FRB130729	parkes	324.787	54.744
FRB131104	parkes	260.549	-21.925
FRB140514	parkes	50.841	-54.611
FRB150418	parkes	232.665	-3.234
FRB150807	parkes	336.709	-54.400
FRB160317	UTMOST	246.050	-0.990
FRB160410	UTMOST	220.360	27.190
FRB160608	UTMOST	254.110	-9.539

Petroff et al. (2016)

- 24 FRBs have been reported to date Petroff et al. (2016)
- Single-dish obs. (poor resolution!)
- Typical observing frequency: 1.4 GHz
- No correlation with the Galactic Plane
- Rate: $\sim 10^{3\text{–}4}$ sky^{-1} day^{-1}
- More models than FRBs!!!

The Dispersion Measure

Light is dispersed by the material in the medium.

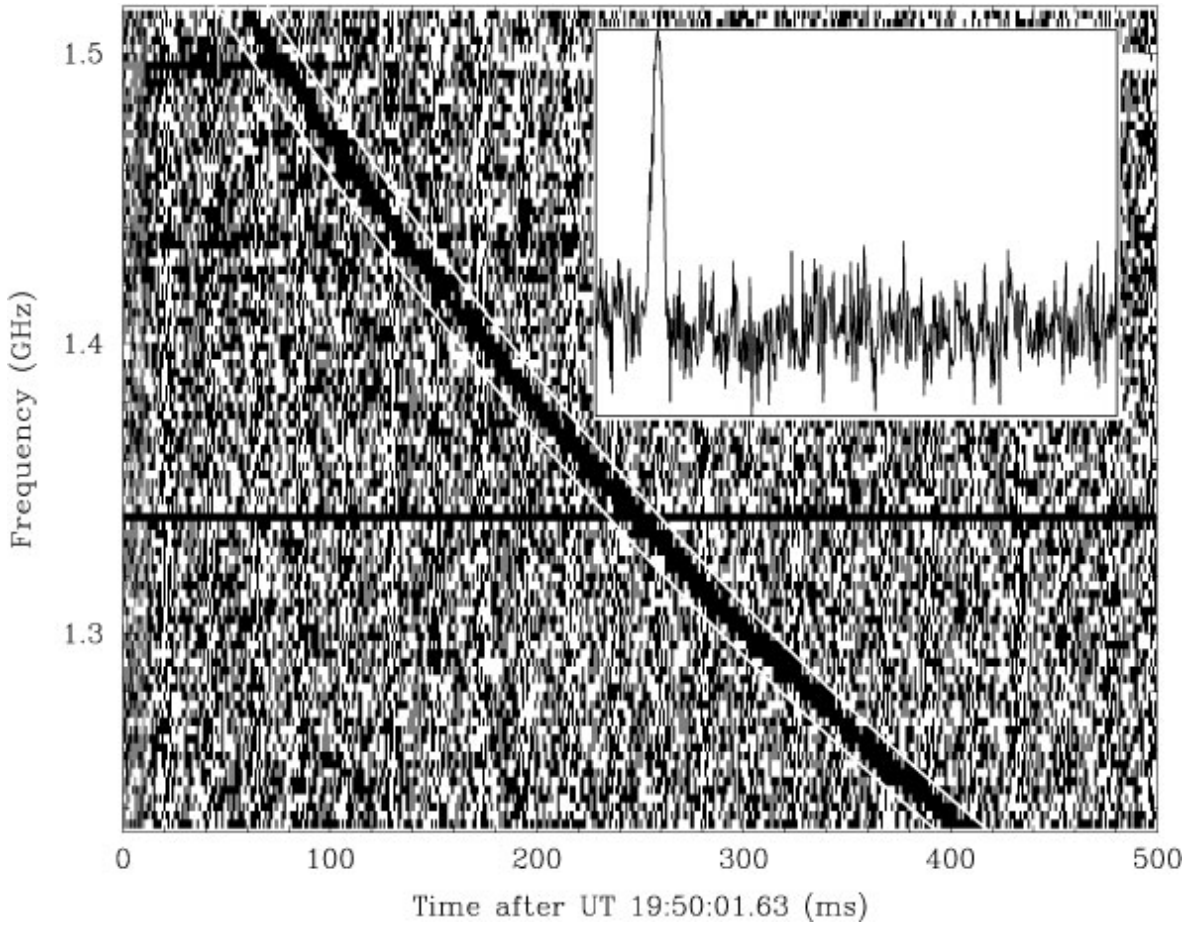
Dispersion Measure:

$$\mathrm{DM} = \int n_e \mathrm{d}l$$

All FRBs show unexpected large DMs.

Larger than the contribution of our Galaxy

Estimated $z \sim 0.16$–1.3



Lorimer et al. (2007)

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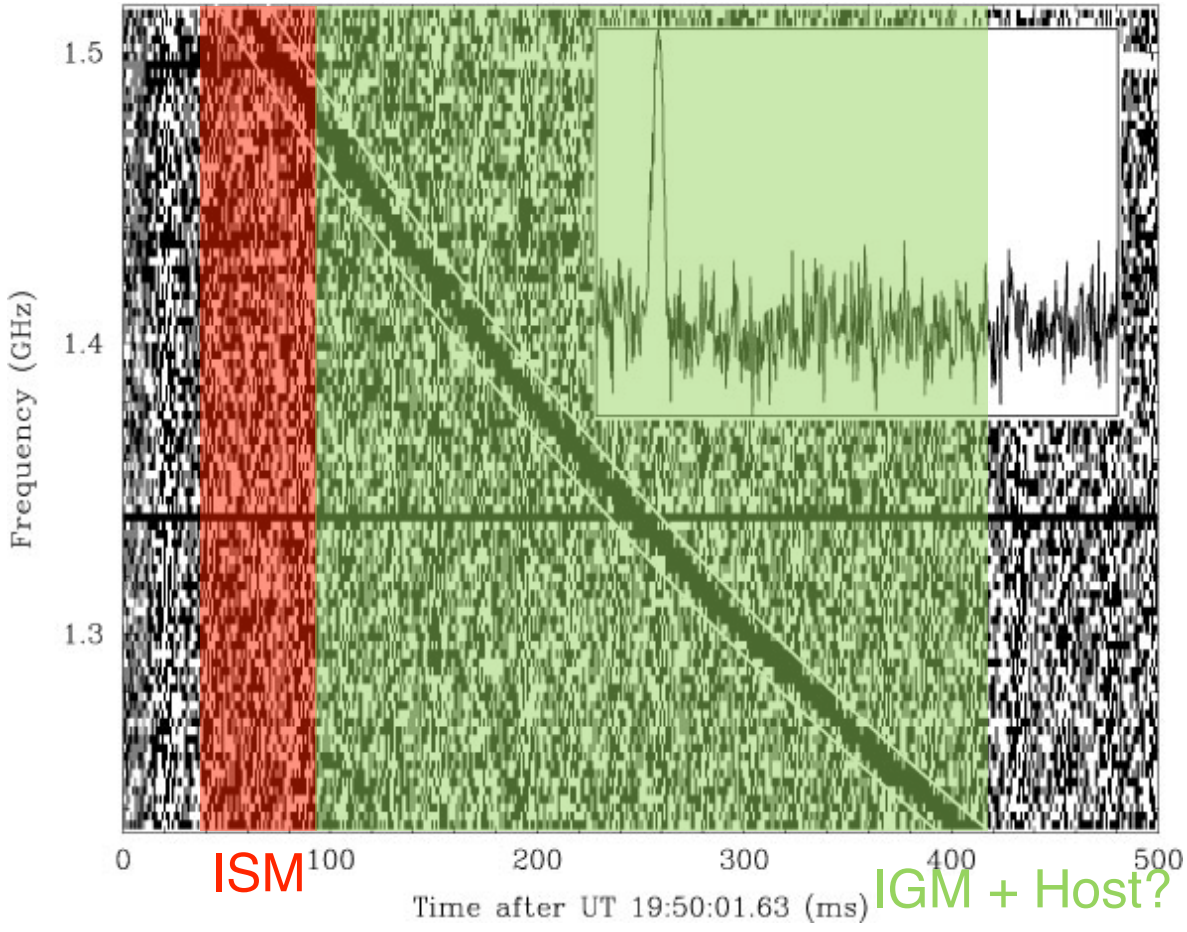
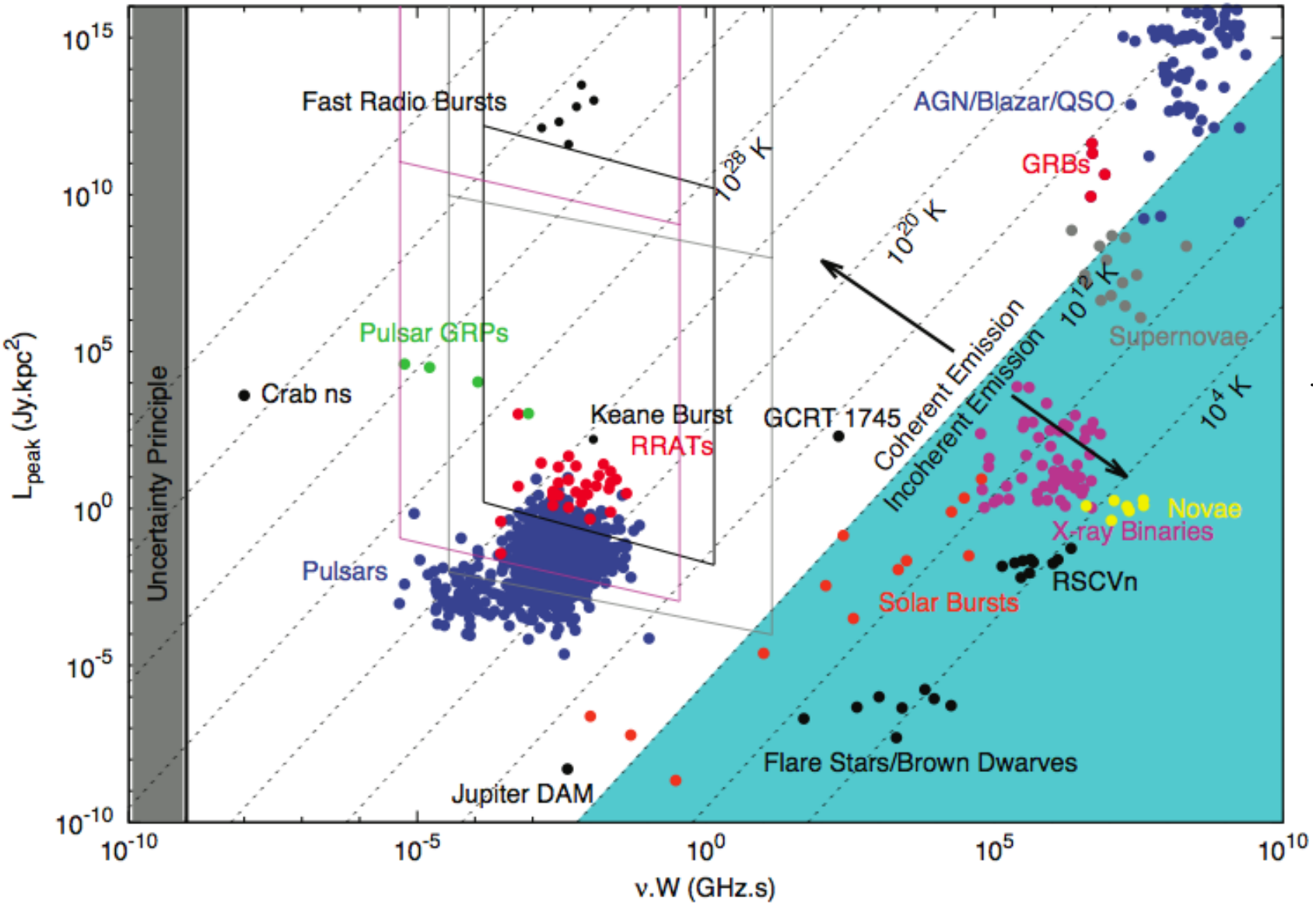


Lorimer et al. (2007)

What can FRBs be?



Credit: J. P. Macquart

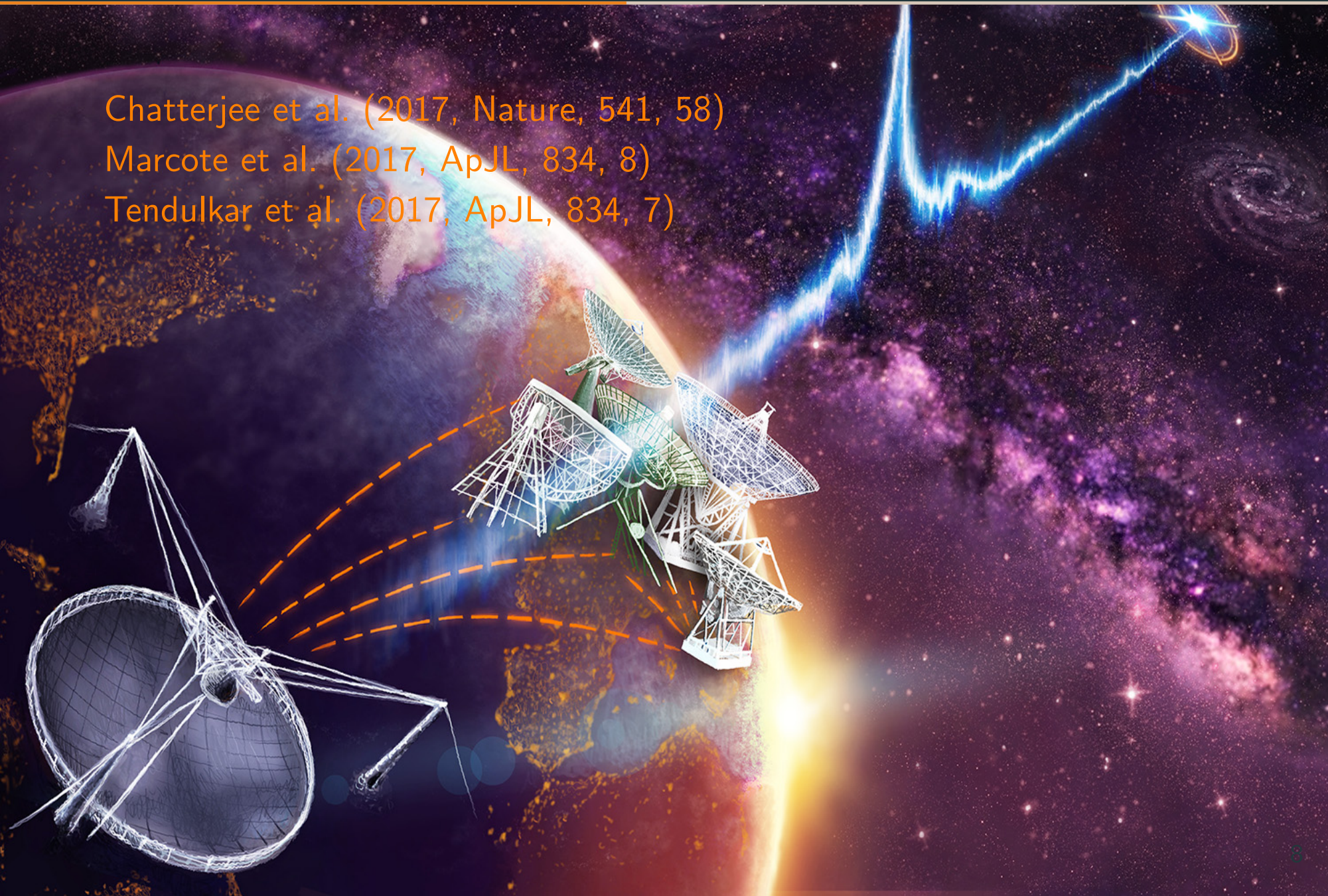

Merging Black Holes
Supernovae
Magnetars
Evaporating Black Holes
Super-giant Pulses
?
The Unknown
extra-Galactic
Implied rate of 1000s per day, per sky... but what are they?
Gamma-ray Bursts
Micro-quasars
Flare stars
Galactic
SETI
Pernicious RFI
Atmospheric effects
"Blitzars"
Magnetars
We are here
Pulsars
Credit: Jason Hessels

The only repeater, FRB 121102

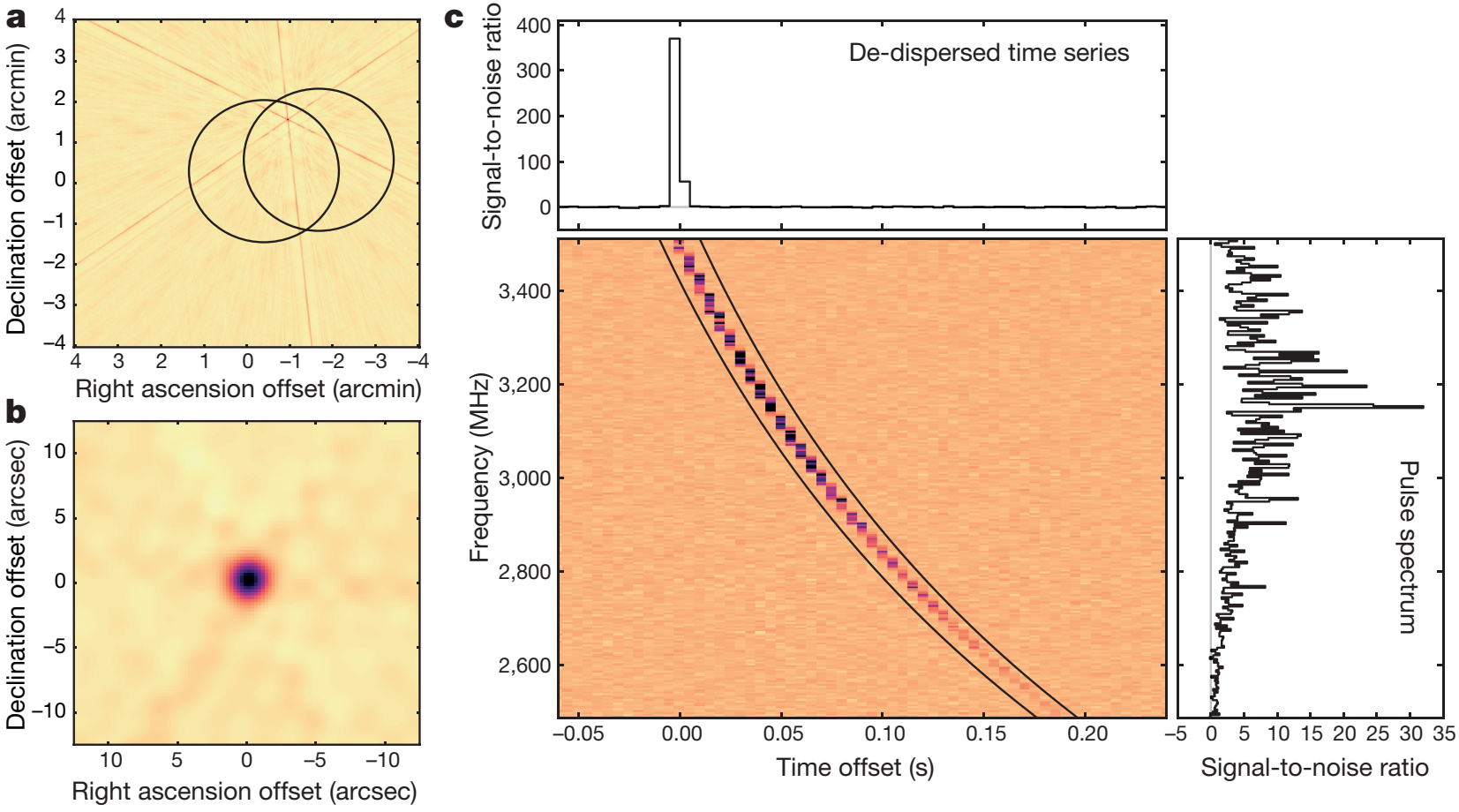
The repeating FRB 121102

- The only one discovered 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
- No periodicities at all
- One of the closest ones?
  ($\times$3 Galactic contribution)
- Two types of FRBs?

The First Precise Localization of a Fast Radio Burst



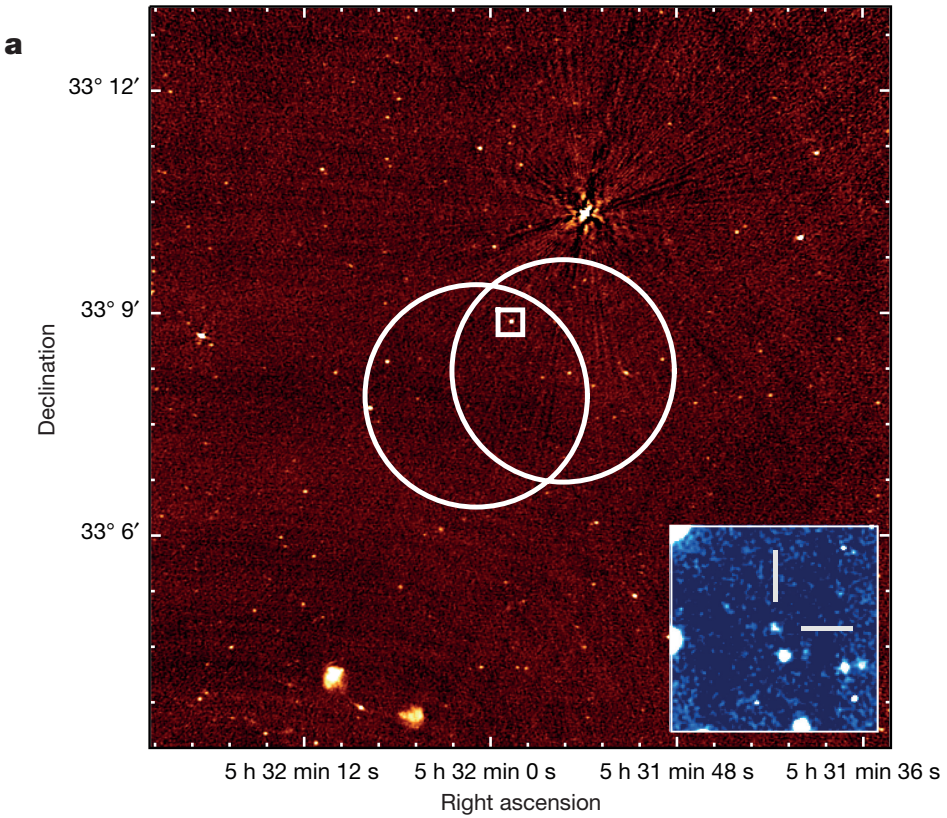
The VLA localization of FRB 121102

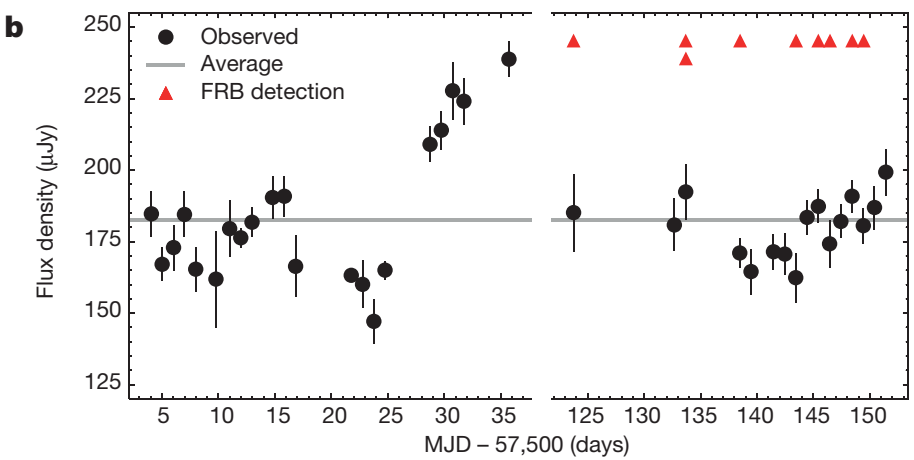


5-ms image (dispersion corrected) of one burst.

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

The VLA localization of FRB 121102



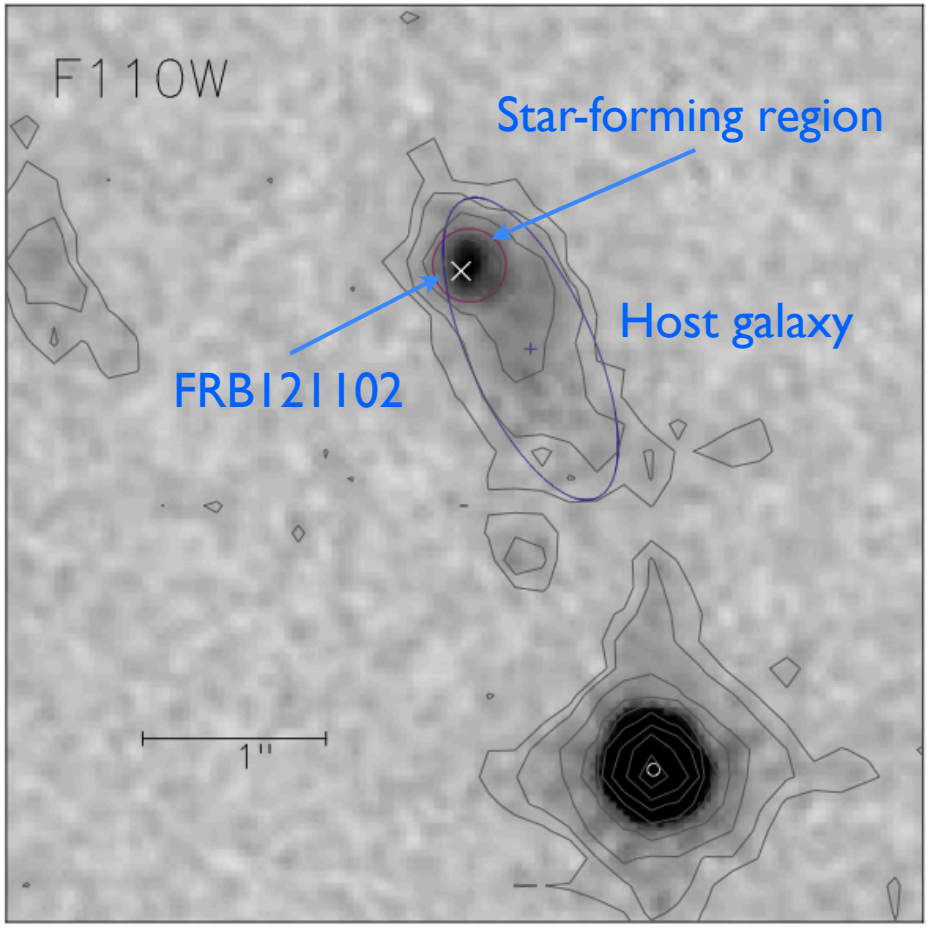


- Persistent radio counterpart
- Co-located within ~ 0.1 arcsec
- Variability $\sim 10\%$
- Variability uncorrelated with bursts
- $L_{\text{persistent}} = 3 \times 10^{38}$ erg s^{-1}
- $L_{\text{bursts}} \sim 10^{42}$ erg s^{-1}

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

The optical counterpart

- Archival Keck data from 2014
- Gemini observation (Oct 2016)
- *HST* data in early 2017
- Extended 25-mag counterpart
- $z = 0.19273(8) \Longrightarrow 972$ Mpc
- **Dwarf galaxy**:
  Diameter: $\lesssim$ 5–7 kpc
  Mass: 10^8 $M_\odot$
  Star Formation: ~ 0.4 $M_\odot$ yr^{-1}
- **Low-metallicity star-forming region**:
  Diameter of ~ 1.3 kpc



Tendulkar et al. (2017, ApJL, 834, 7)
Bassa et al. (2017, ApJL, 843, 8)

The EVN localization of FRB 121102

colorscale: 5-GHz image

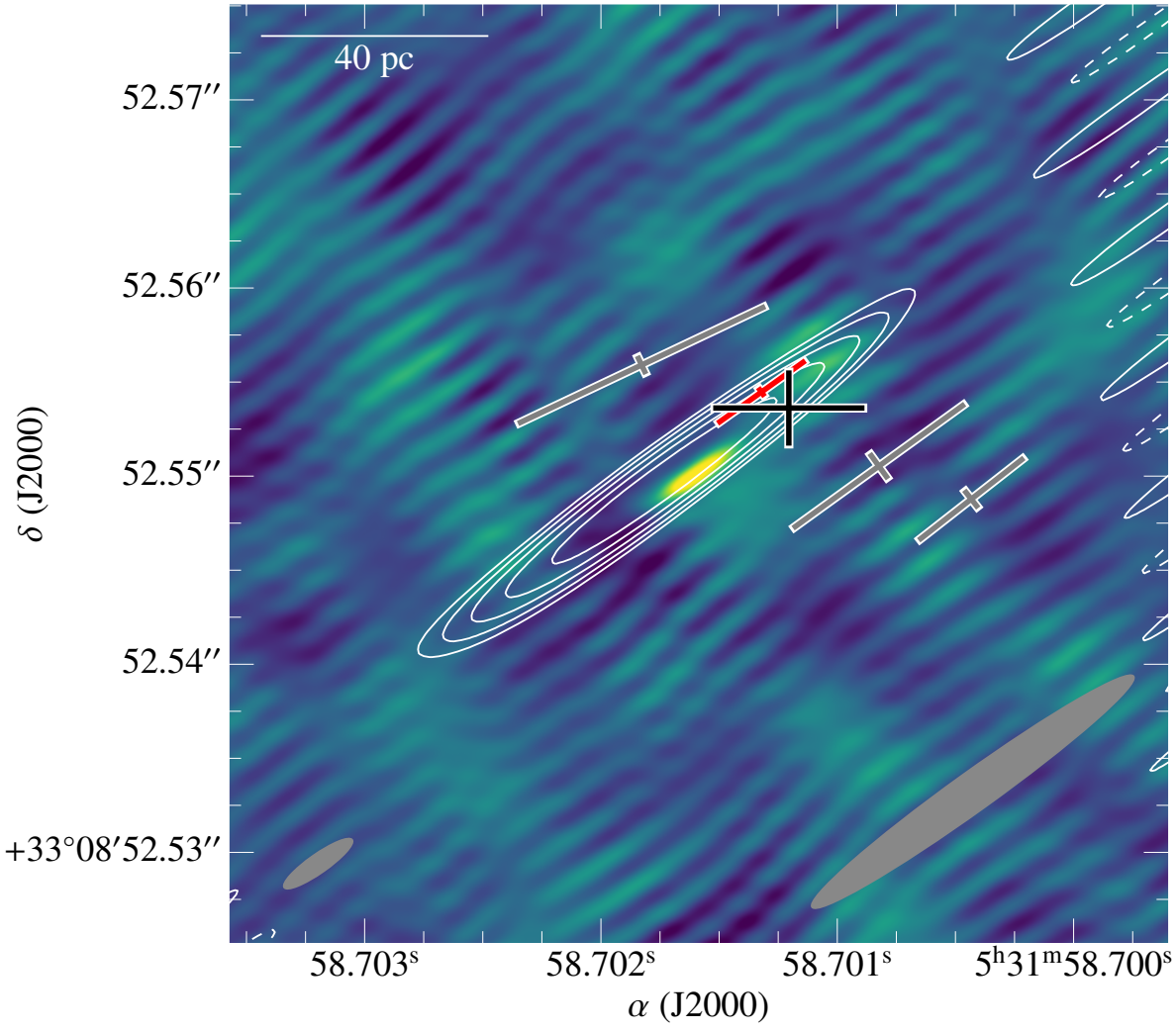
Contours: 1.7-GHz image

(Bursts observed at 1.7 GHz)

+: brightest burst

+: other bursts

+: average position



Source size $<$ 0.7 pc

Bursts coincident within 2σ:

$<$ 40 pc at 95% C.L.

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

Possible origins for FRB 121102

- The star-forming region resembles the hosts of long-duration GRBs and hydrogen-poor superluminous supernovae (SLSNe-I).

- Young (10–100 yr) superluminous supernovae powered by the spin-down power of a magnetar (e.g. Kashiyama & Murase 2017).

See next talk!

- Bursts produced by a strong plasma turbulence excited by the jet of a massive ($\sim 10^{5–6}$ $M_\odot$) black hole (Vieyro et al. in 2017).

- Magnetar interacting with the jet of a massive black hole (Pen & Connor 2015, Cordes & Wasserman 2016, Zhang 2017).

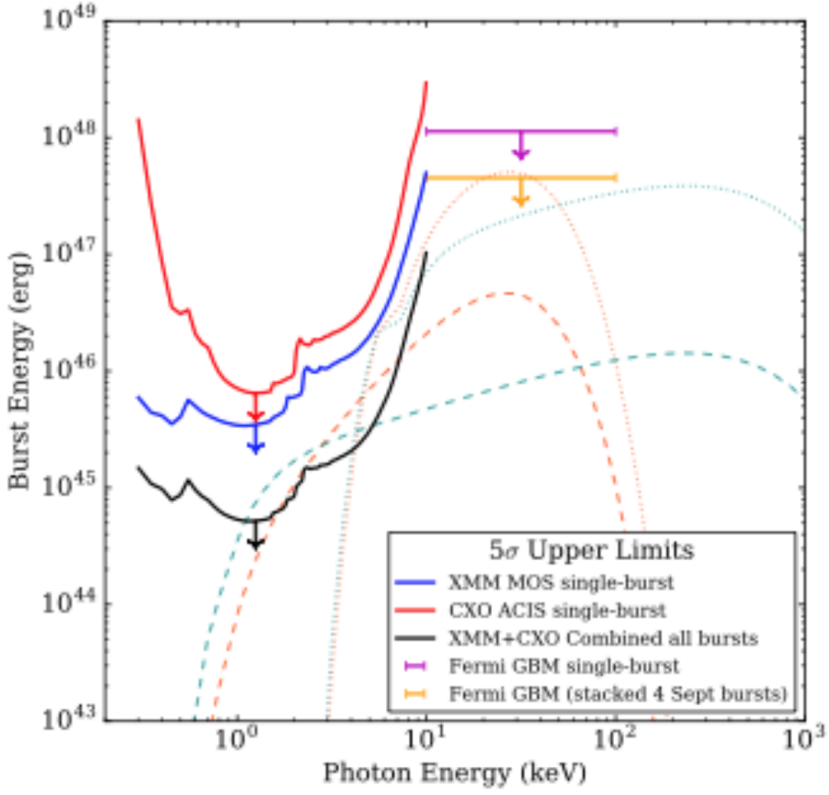
Is gamma-ray emission expected? Maybe no simultaneous!

- Magnetar + SLSNe: γ-ray flashes expected for < 100 Mpc (Murase et al. 2016)
- Analogous to X-ray bursts observed in Galactic magnetars (Luytikov 2002, Lyubarsky 2014)
- AGN/jet-related: could produce γ-ray emission on second-minute timescales (Vieyro et al. 2017)
- Possible emission if FRBs are GRB-like and nearby (Murase et al. 2017)
- γ-ray FRBs followed by radio afterglows in the magnetar scenario or mergers (Murase et al. 2017)
- Other scenarios do not support emission above radio frequencies (Ghisellini & Locatelli 2017)

Simultaneous radio and X-ray observations

- 12 radio bursts observed
- No X-ray photons at those times
  $< 3 \times 10^{-11}$ erg cm^{-2}
  or $\sim 4 \times 10^{45}$ erg
- No X-ray bursts at all
  $< 5 \times 10^{-10}$ erg cm^{-2}
- No *Fermi*/GBT detections:
  $< 4 \times 10^{-9}$ erg cm^{-2}
- X-ray Persistent emission?
  $L < 3 \times 10^{41}$ erg s^{-1}

Scholz et al. (2017, ApJ, 846, 80)



High-Energy counterparts

Bursts at other wavelengths:

- Simultaneous optical-radio observations:
  Optical upper-limits on burst fluence of < 0.046 Jy ms
  (Hardy et al. 2017)
- Simultaneous optical/TeV-radio observations with MAGIC:
  Coming soon

Concerning the persistent counterpart:

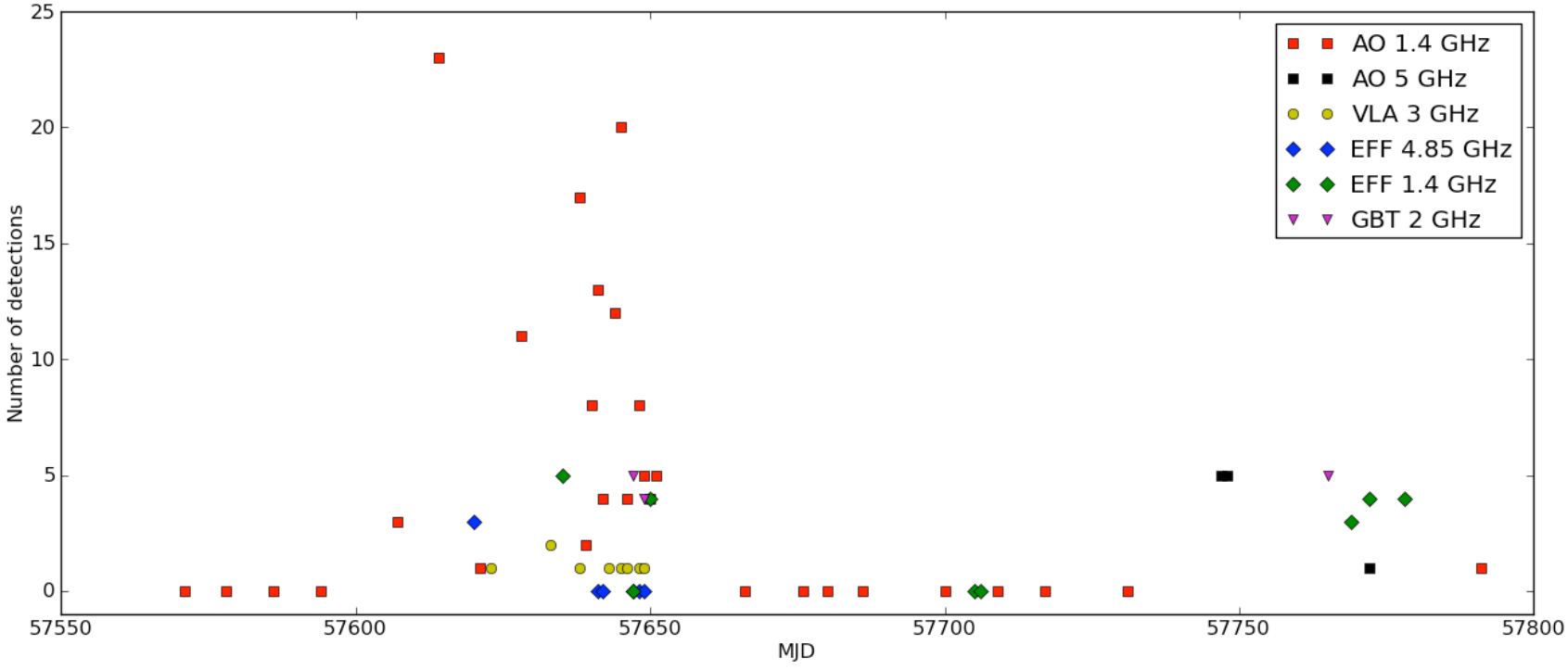
- Upper-limits from VERITAS of 5.2×10^{-12} cm^{-2} s^{-1} TeV^{-1} at 0.2 TeV (Bird et al. 2017)
- No significant *Fermi*/LAT emission: $\lesssim 4 \times 10^{44}$ erg s^{-1}
  (Zhang & Zhang 2017)

Conclusions and the future: SKA–VLBI in transients

- The nature of FRBs still remains unknown.
- Pick your model!
- FRB 121102 is the only one precisely localized
- Is FRB 121102 representative of FRBs?
- Other wavelengths rather than radio?

Thank you!

The repeating FRB 121102



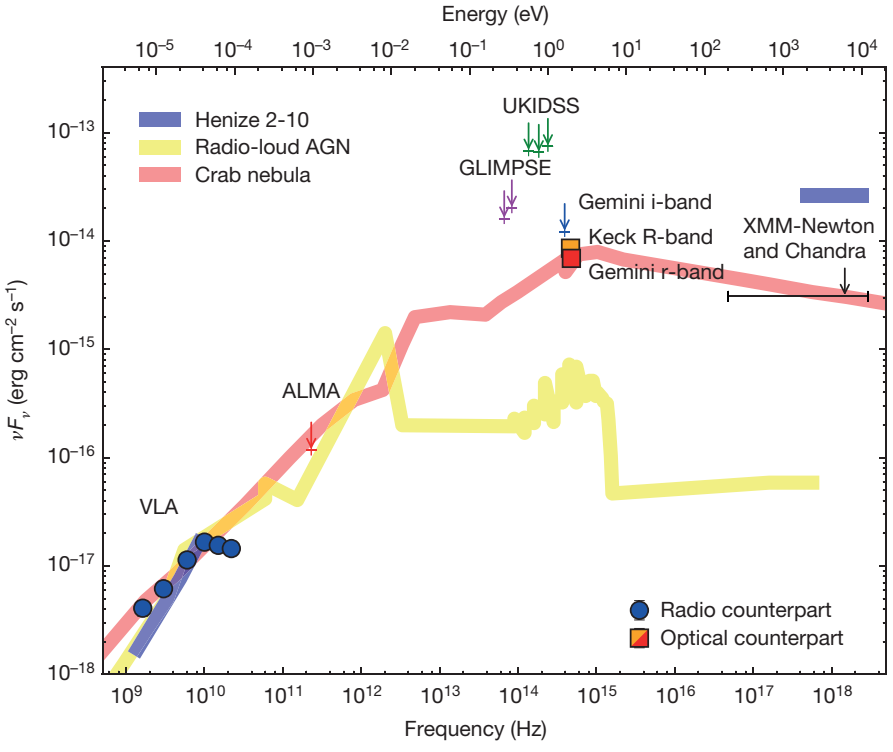
Credit: L. Spitler (preliminary data)

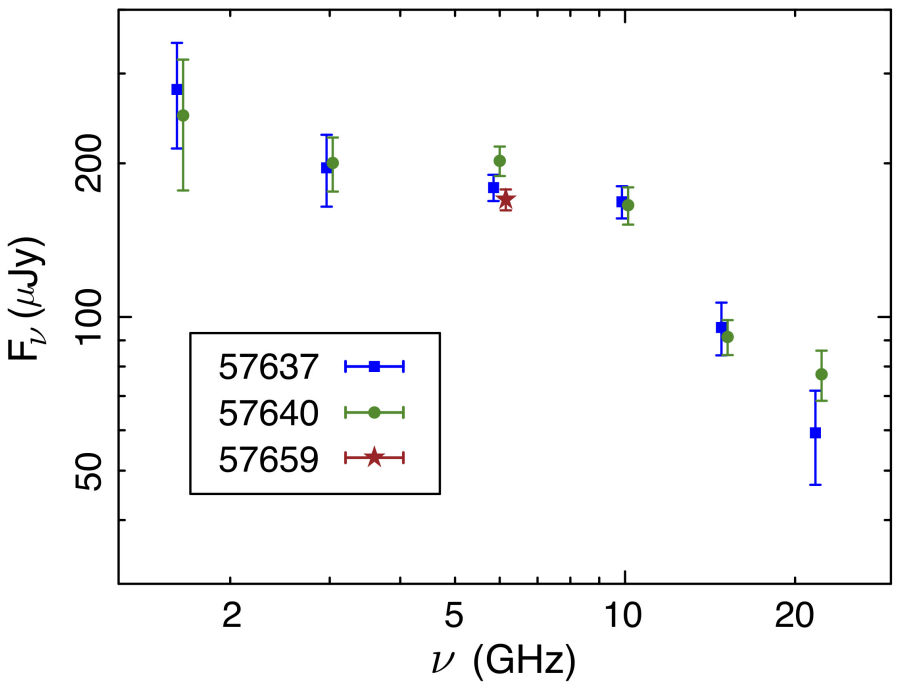
No periodicities are observed **at all**.

Bursts exhibit short bandwidths ($\sim$ 500 MHz)

Shortest separation between bursts: $\sim$ 34 and 37 ms

The VLA localization of FRB 121102

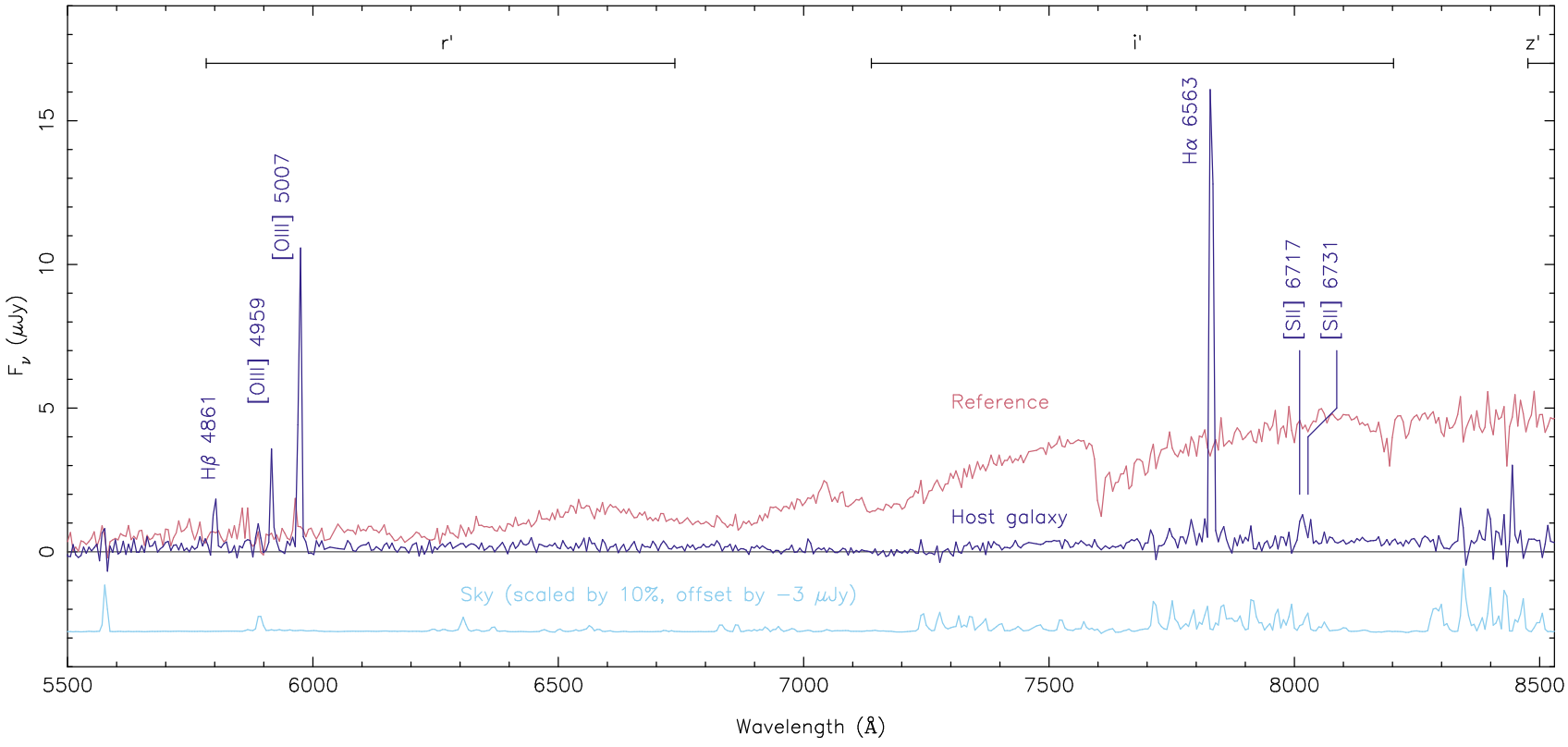




SED and radio spectrum of FRB 121102

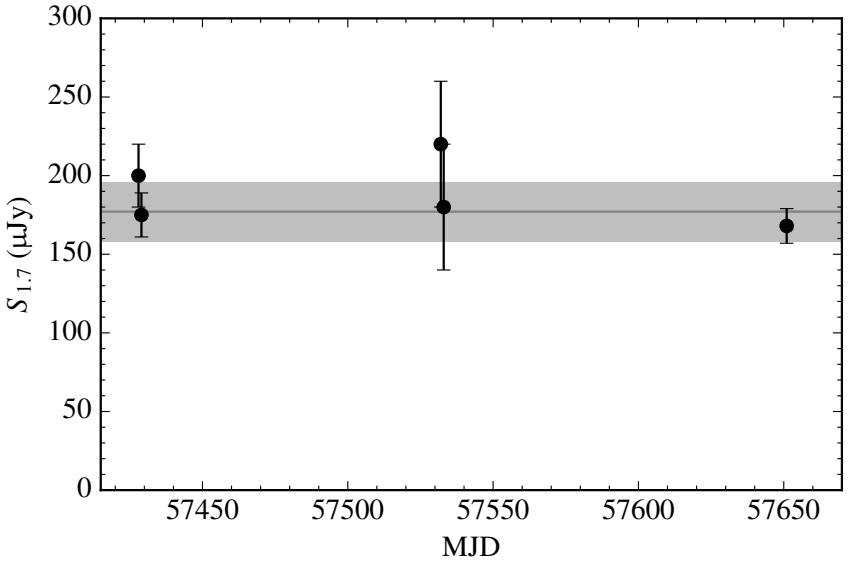
(Chatterjee et al. 2017, Nature, 541, 58)

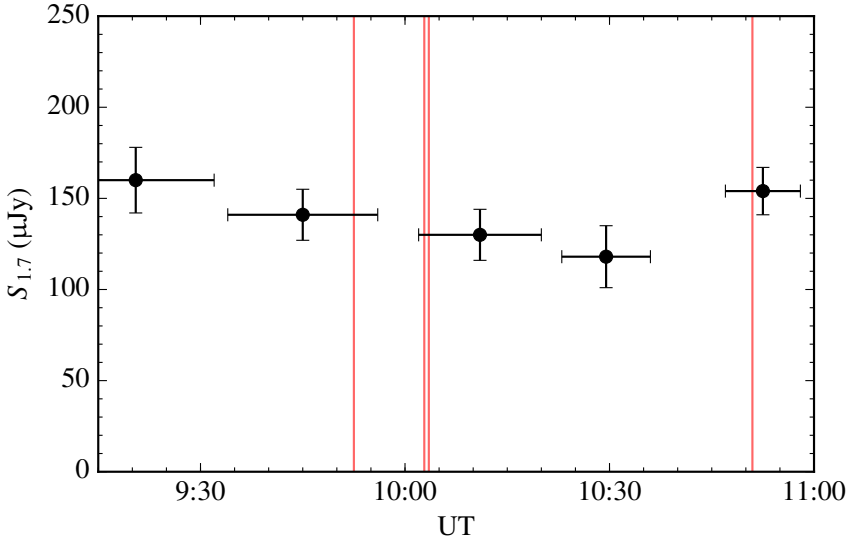
Optical spectrum



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

Localizing FRB 121102 on milliarcsecond scales





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

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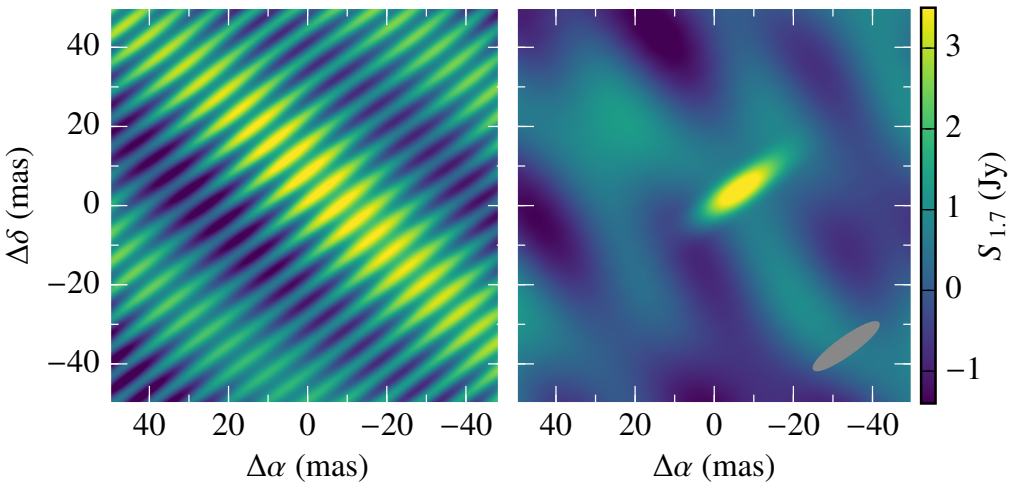
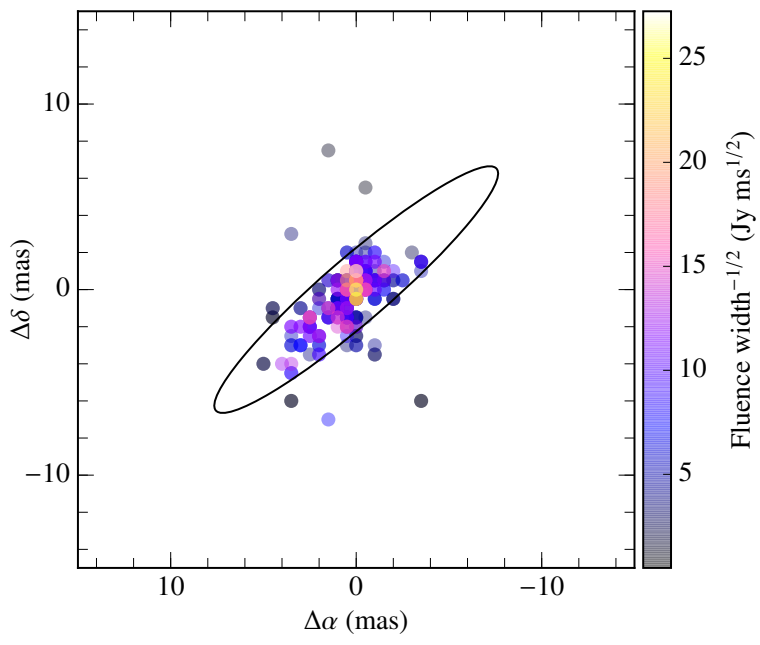


Dirty and clean image from FRB 121102.

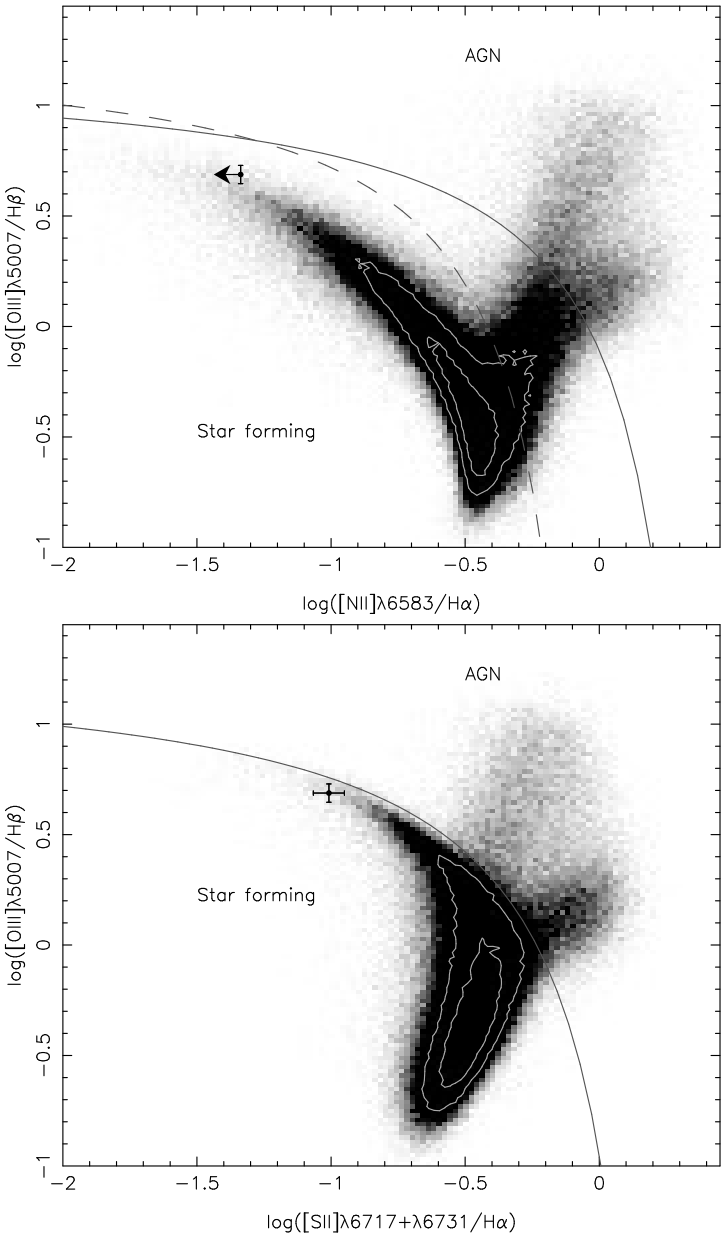
Astrometry limited by signal-to-noise ratio



Positions derived from 406 pulses from the pulsar B0525+21

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

FRB 121102, optical emission



Emission lines dominated by Star Formation

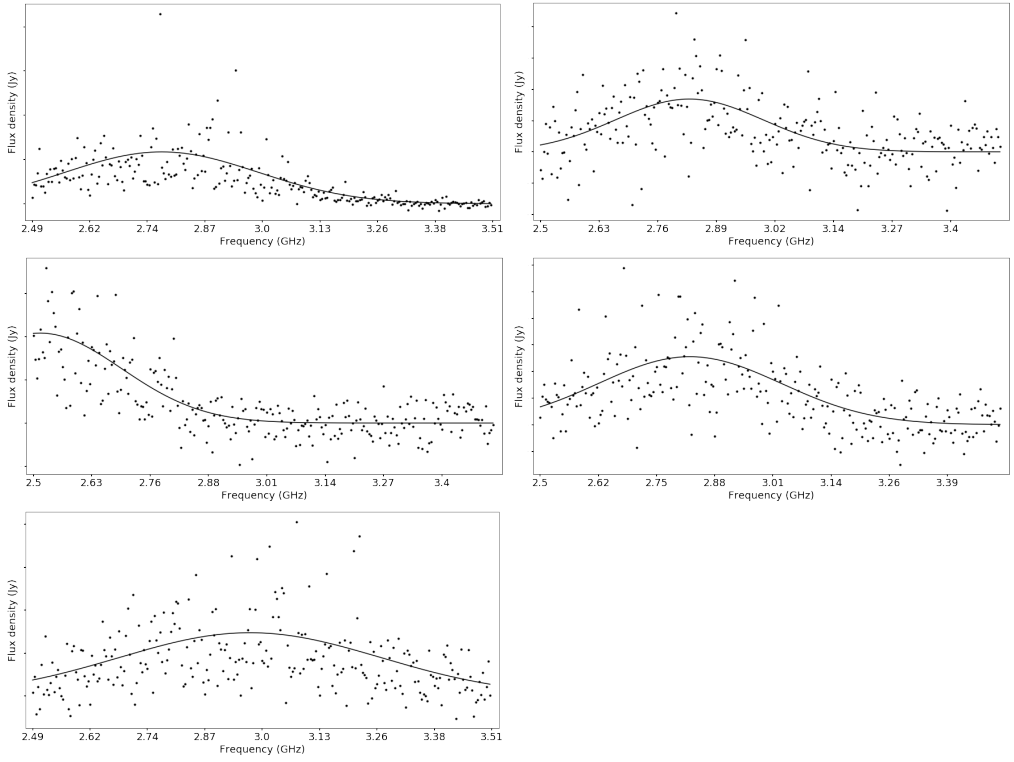
No emission detected at:

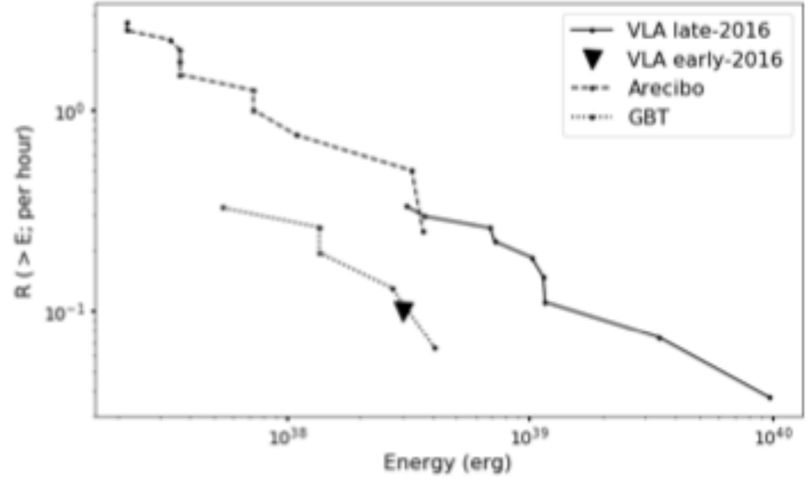
- sub-mm (ALMA)
  rms of 17 μJy
- X-rays (*Chandra*, *XMM*)
  $< 5 \times 10^{41}$ erg s^{-1} (5σ)
- γ-rays (*Fermi*/LAT)

Understanding the radio bursts

- The bursts seem to be localized in freq.
- Width of hundreds of MHz
- Rate vs E: power-law
- Different normalization depending on the "epoch"

Law et al. (arXiv:1705.07553)





The precise localization of FRB 121102

Karl G. Very Large Array (VLA)

- 27 25-m dishes
- ∼100 km apart
- 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

Real-time correlation + raw data buffering to search for pulses

European VLBI Network (EVN)

- 6–10 stations
  (Europe, Asia, Africa)
- ∼10 000 km apart
- From Feb to Sep 2016
- 8 epochs at 1.6 and 5.0 GHz
- 4 bursts on 20 Sep 2016

Other possible repeaters?

FRB 110220 and FRB 140514 were detected within 9 arcmin and 3-yr apart.

- FRB 110220. DM $= 944.4$ pc cm^{-3} (Thornton et al. 2013)
- FRB 140514. DM $= 562.7$ pc cm^{-3} (Petroff et al. 2015)

Probability of chance coincidence: 1–32%

Possible explanations: DM dominated by SNR (young and expanding) (Piro & Burke-Spolaor 2017)

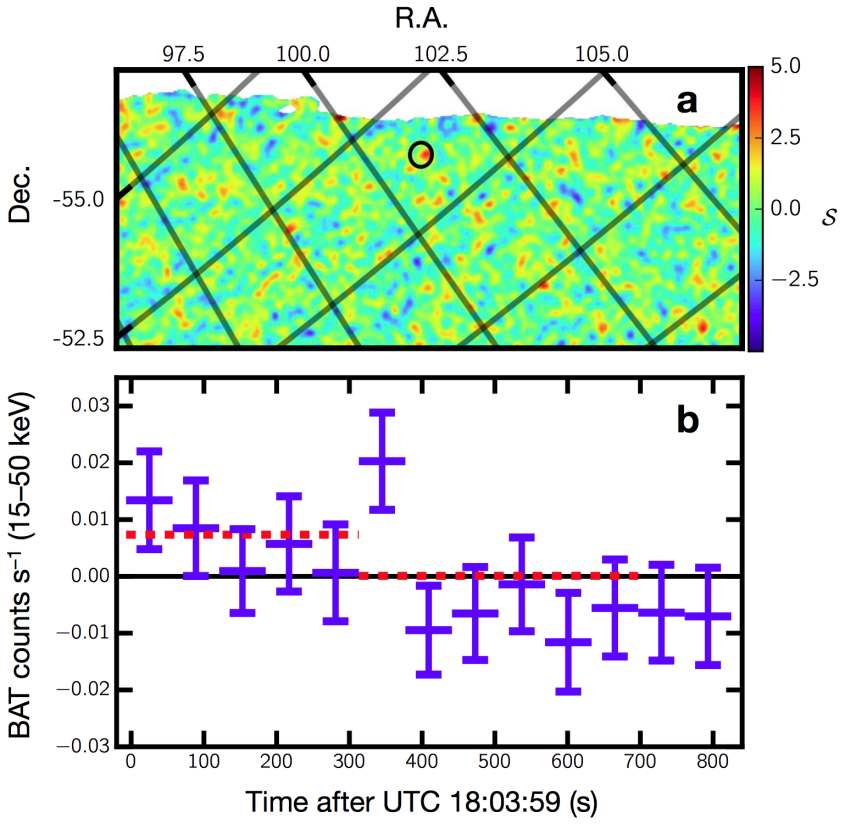
FRB 131104 also observed at X-rays ("gamma")?

Swift detected a 100-s transient coincident with FRB 131104 (DeLaunay et al. 2016)

- 15–200 keV
- $E \sim 5 \times 10^{51}$ erg

However,

- 3-σ detection
- Change coincidence subestimated (Shannon & Ravi 2017)
- Would point out to a much different (and close) distance (Gal & Zhang 2017)



FRB 150418: The first announced association

Keane et al. (2016, Nature, 530, 453)

Parkes detection
ATCA follow-up 2-hr later.

Association with a transient source
Early-type galaxy at $z \sim 0.5$

. . . or just an unassociated AGN?

Williams & Berger (2016)
Vedanthan et al. (2016)
Giroletti et al. (2016)
Bassa et al. (2016)