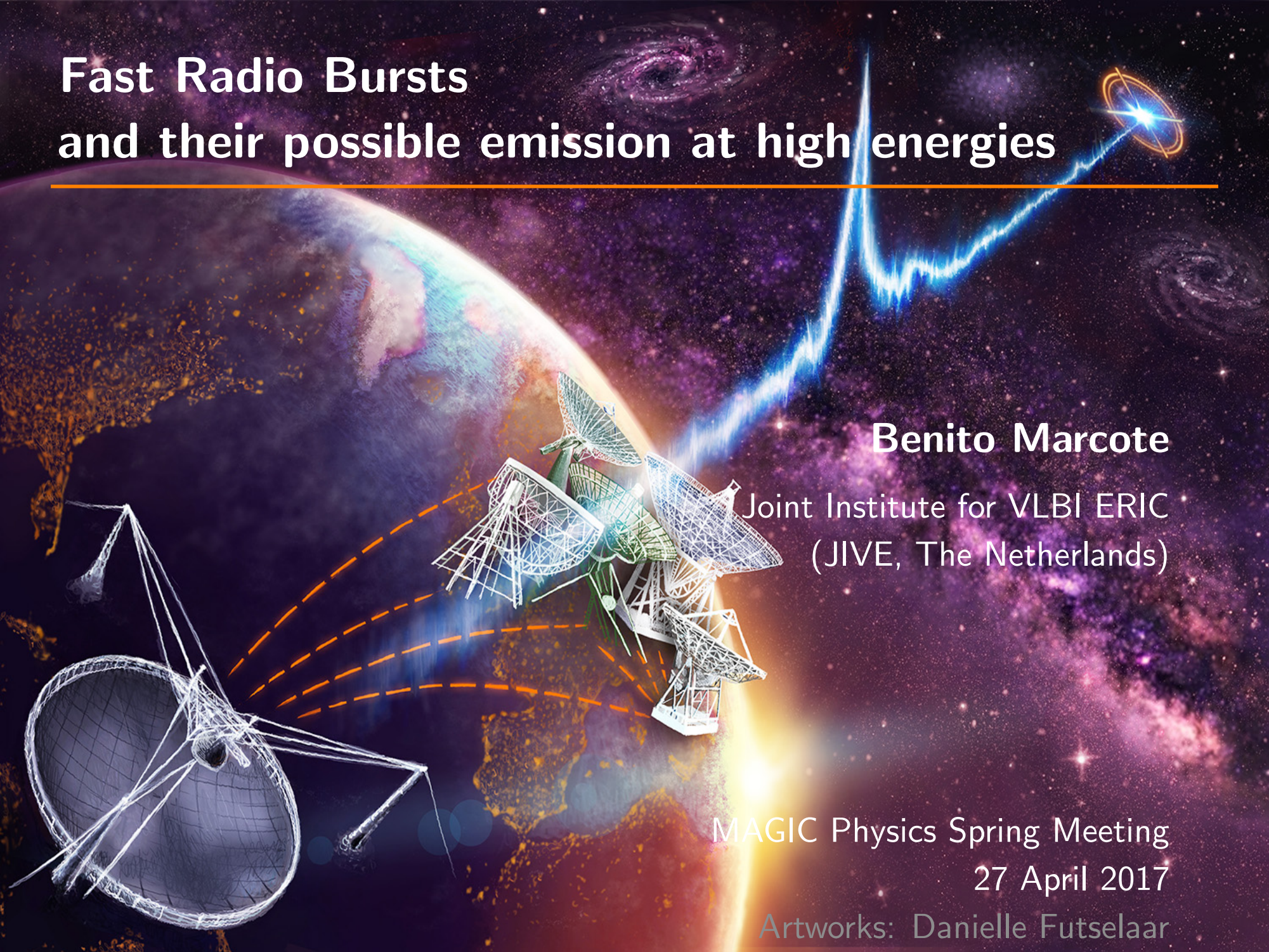
Fast Radio Bursts and their possible emission at high energies



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(JIVE, The Netherlands)

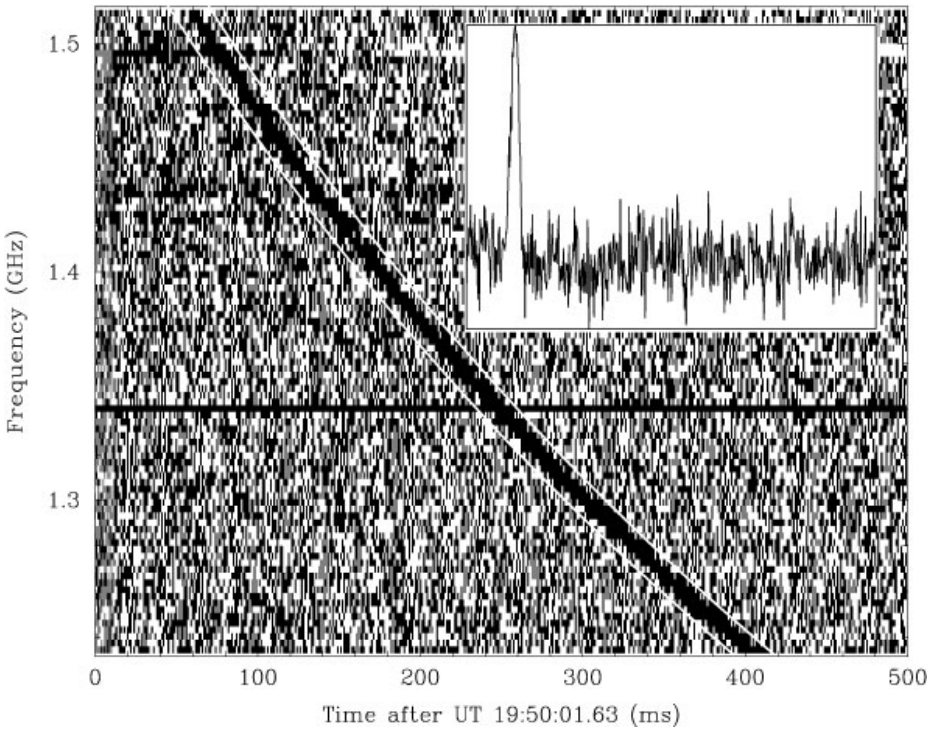
MAGIC Physics Spring Meeting
27 April 2017

Artworks: Danielle Futselaar

Introduction

Introduction: What is a Fast Radio Burst?

- **Fast and strong radio flashes**
- Duration of a few milliseconds
- Detected at radio freq. ($\sim$1 GHz)
- Bright: $\sim$ 0.1–1 Jy
- Discovered by Lorimer et al. (2007)
- Origin: completely unknown
- All possibilities are still open during these 10 yr



Lorimer et al. (2007)

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)

- 21 FRBs have been reported to date Petroff et al. (2016)
- Plus 3 detected in 2016/17
- No correlation with the Galactic Plane
- Almost all of them detected by Parkes
- 1 by Green Bank & 1 byArecibo
- UTMOST in the last year
- Rate: $\sim 10^{3-4}$ day^{-1} sky^{-1}

The Dispersion Measure

Light is dispersed by the material in the medium.

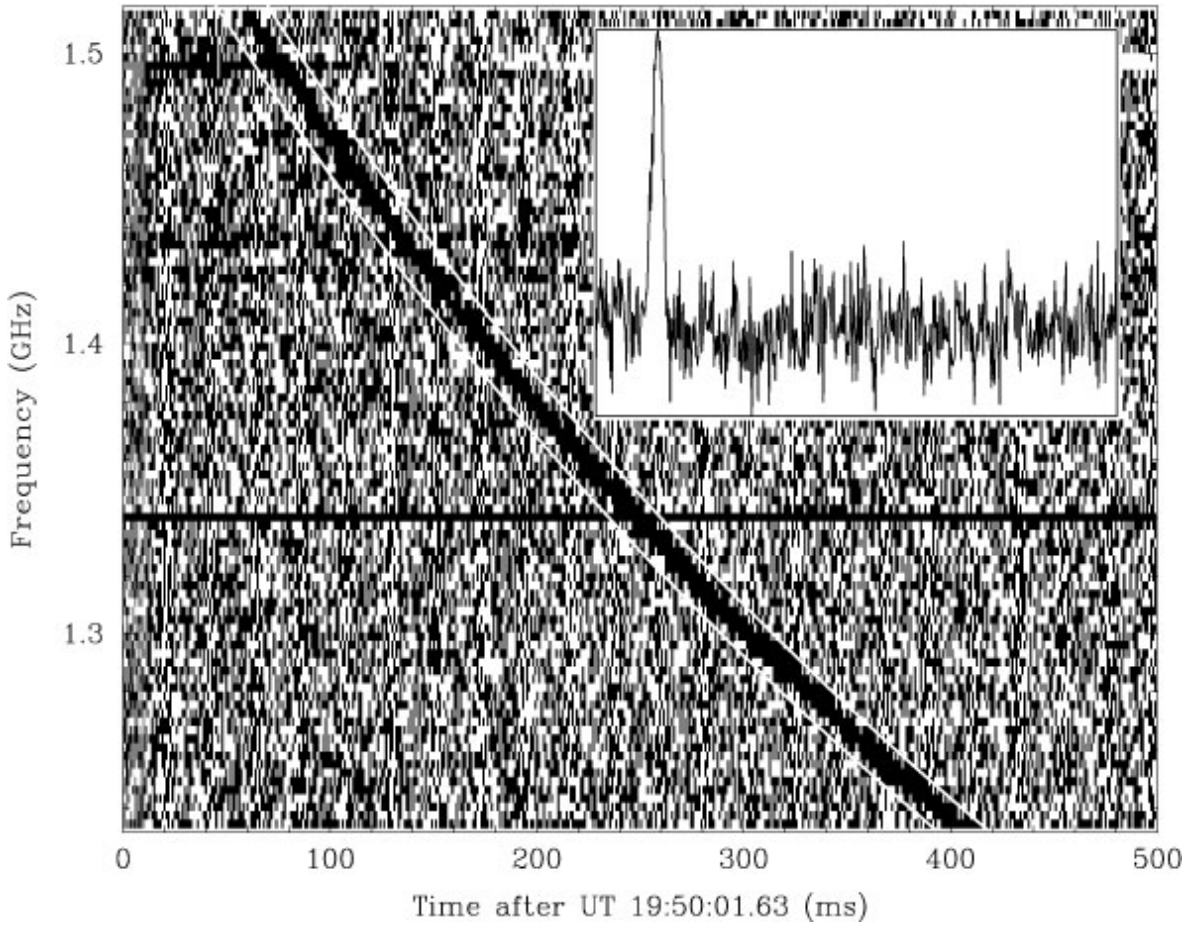
Dispersion Measure:

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

All FRBs show unexpected large DMs.

Larger than the contribution of our Galaxy

Estimated $z \sim 0.16$–1.3



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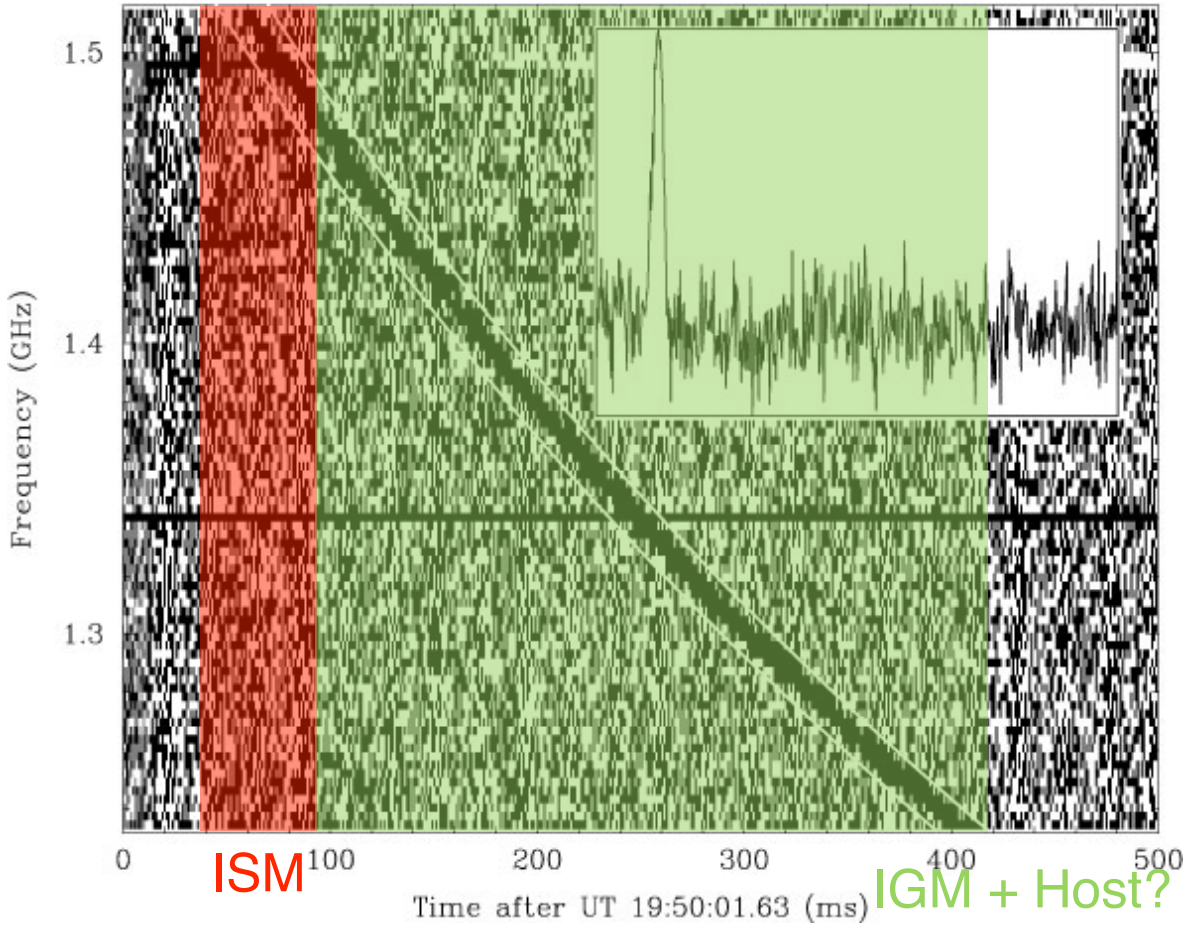
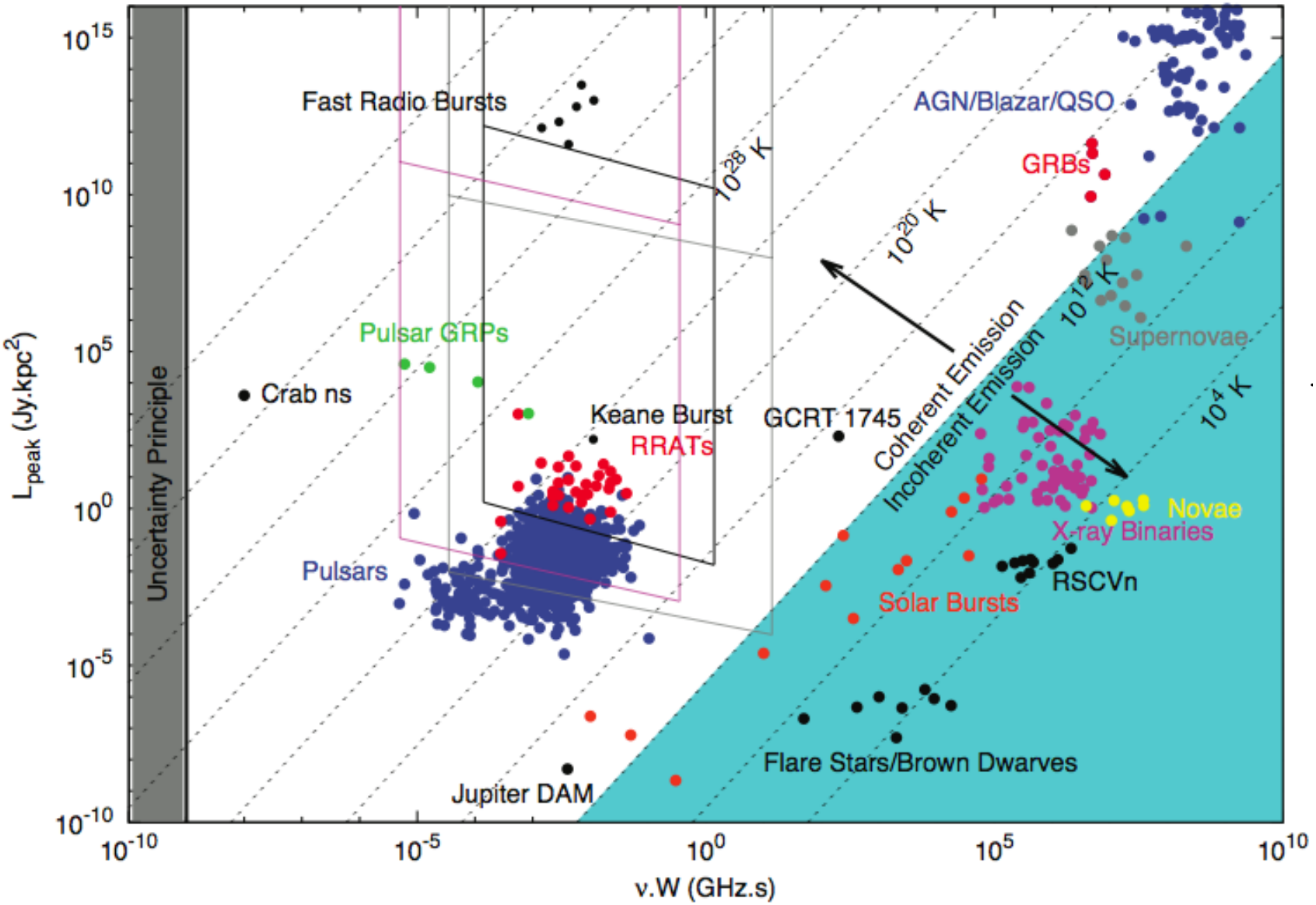


Lorimer et al. (2007)

What can FRBs be?



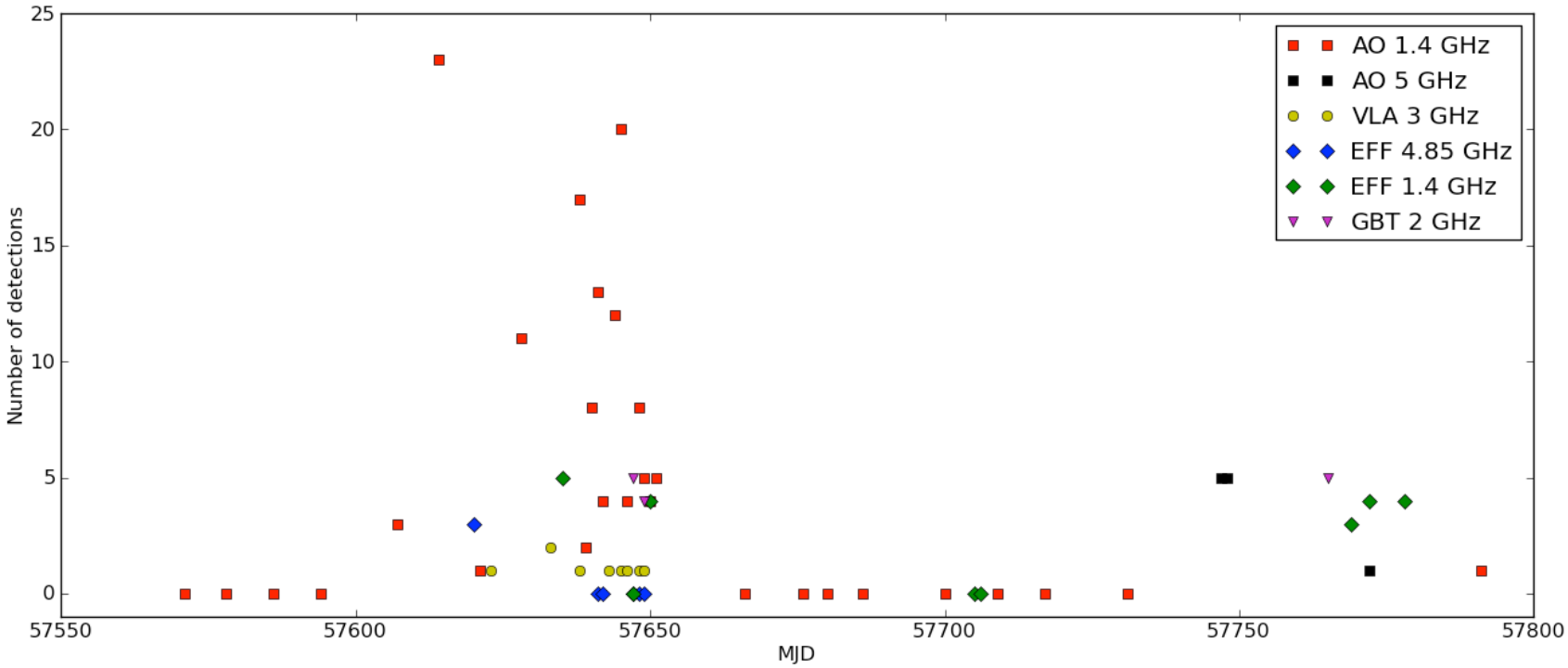
Credit: J. P. Macquart


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

The repeating FRB 121102

- The only one observed 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?
  ($\times$3 Galactic contribution)
- Two types of FRBs?

The repeating FRB 121102



Credit: L. Spitler

No periodicities are observed **at all**.

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)

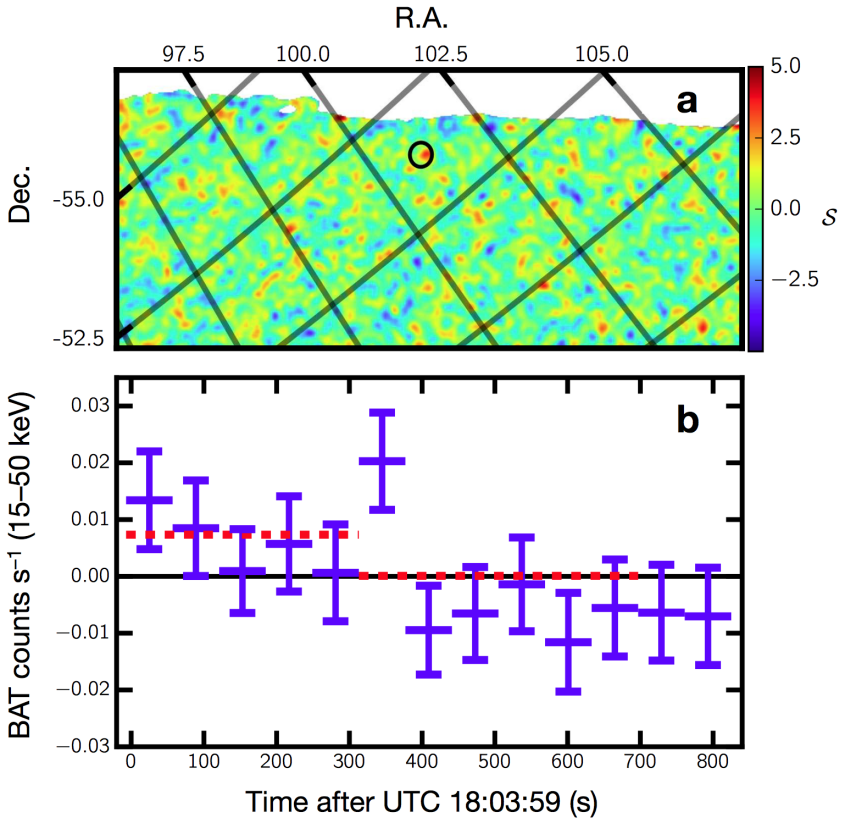
FRB 131104 also observed at X-rays ("gamma")?

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

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

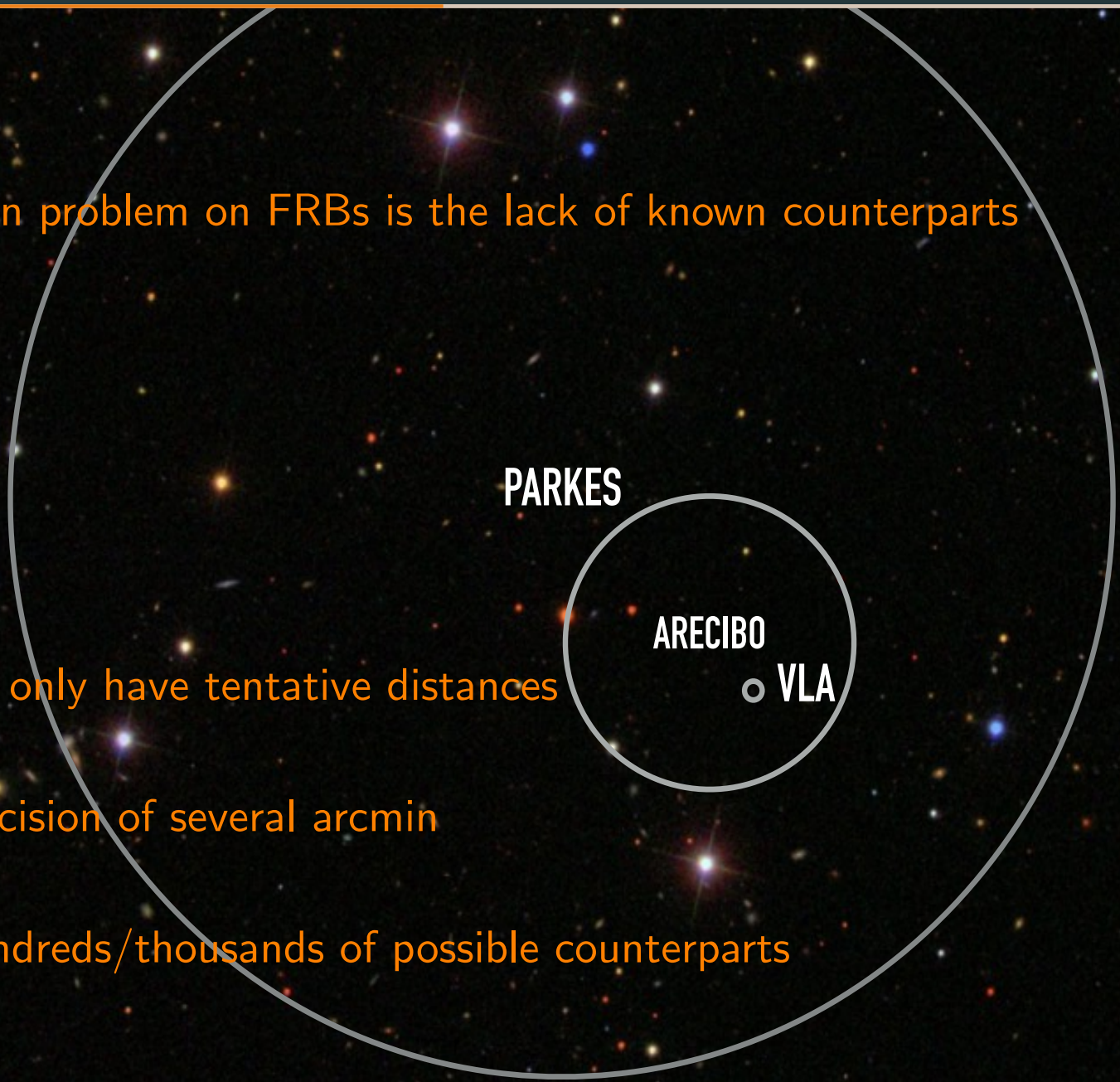
However,

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



Next step: find counterparts (higher resolution)

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

How can we better localize Fast Radio Bursts?

Direct detection.

The only unambiguous approach.

High resolution $\Longrightarrow$ limited field of view

Requires imaging on ms scales

Extremely challenging (technically and operationally)

Looking for afterglows.

When a FRB occurs, look at the field with higher resolution telescopes.

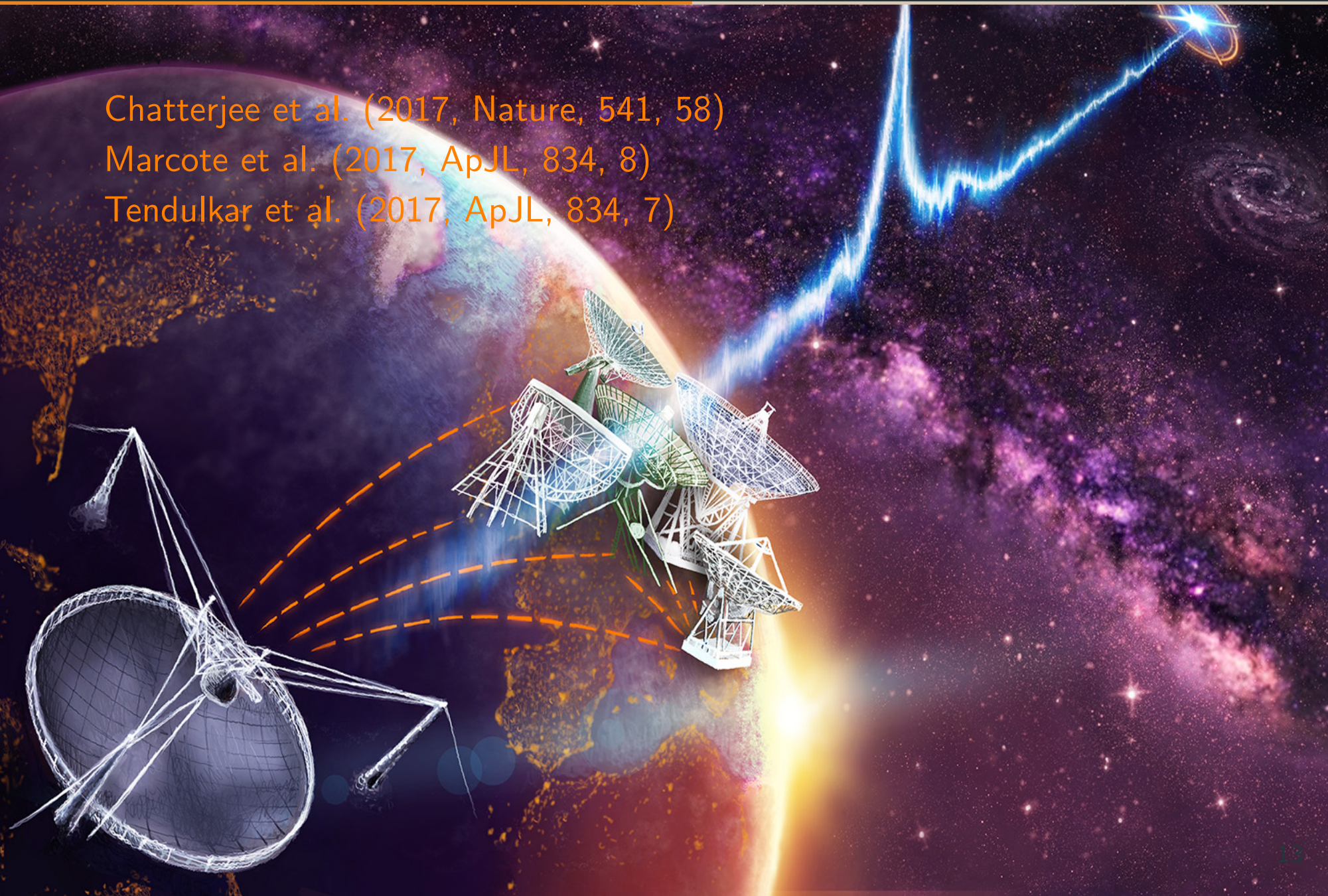
If they are cataclysmic $\Longrightarrow$ should be an afterglow

Can produce spurious identifications

as in Keane's localization of FRB 150418

Localizing FRB 121102

The First Precise Localization of a Fast Radio Burst



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

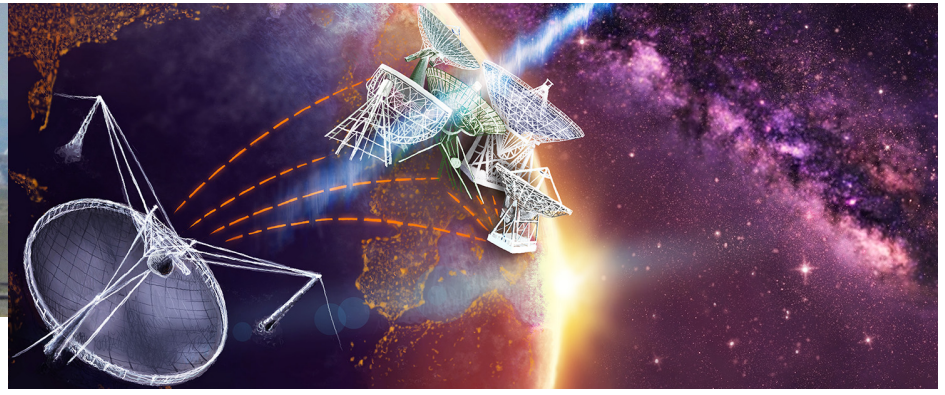
Marcote et al. (2017, ApJL, 834, 8)

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

The last crusade: the 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

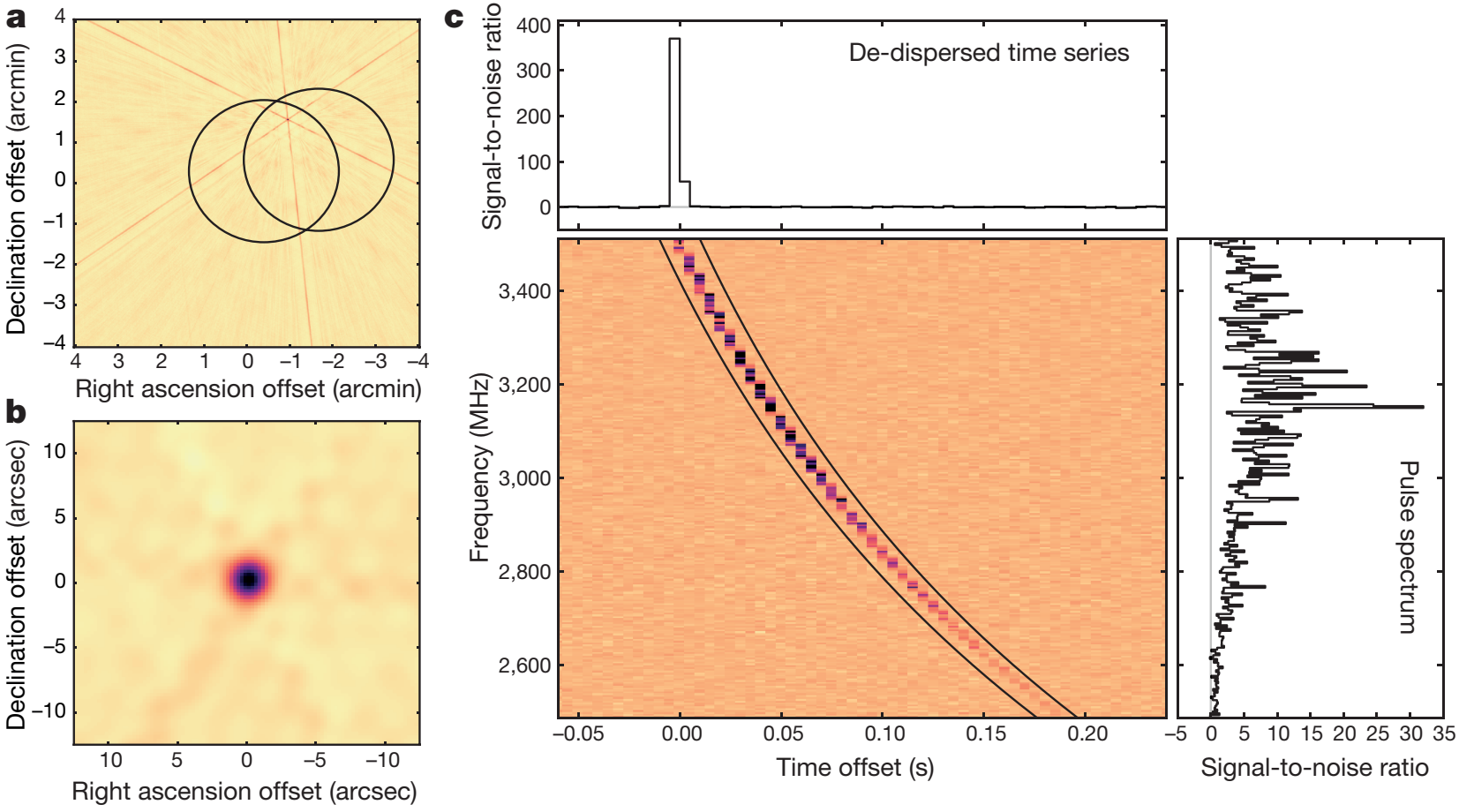


European VLBI Network (EVN)

- 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

Real-time correlation + raw data buffering to search for pulses
(techniques developed just during the last years)

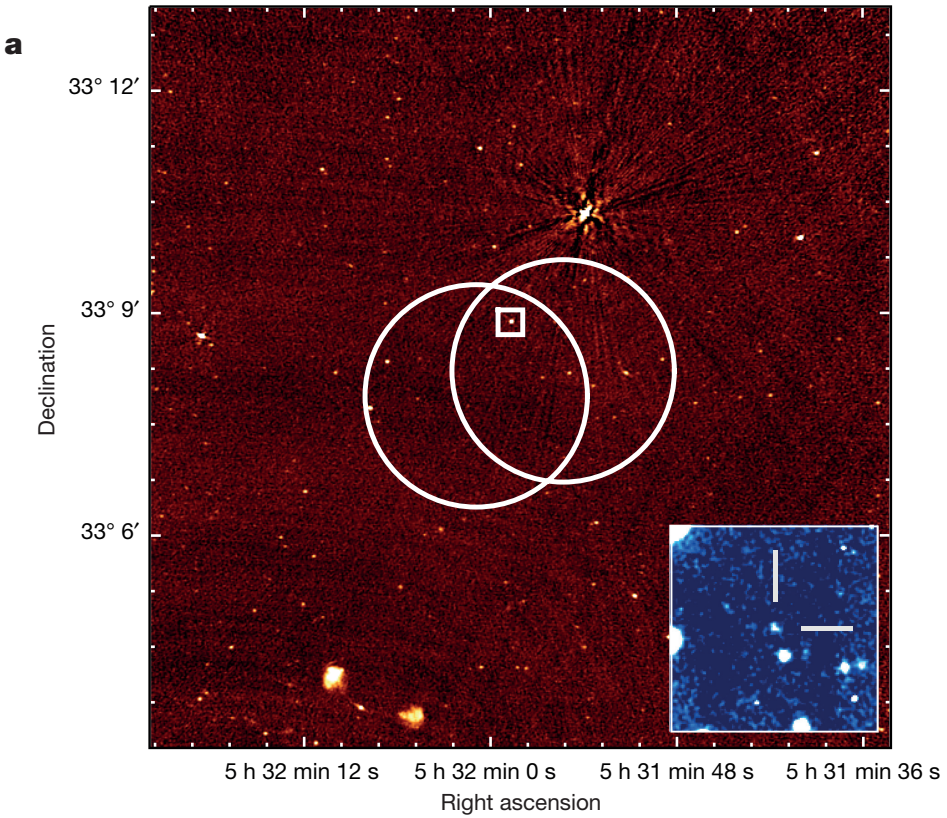
The VLA localization of FRB 121102

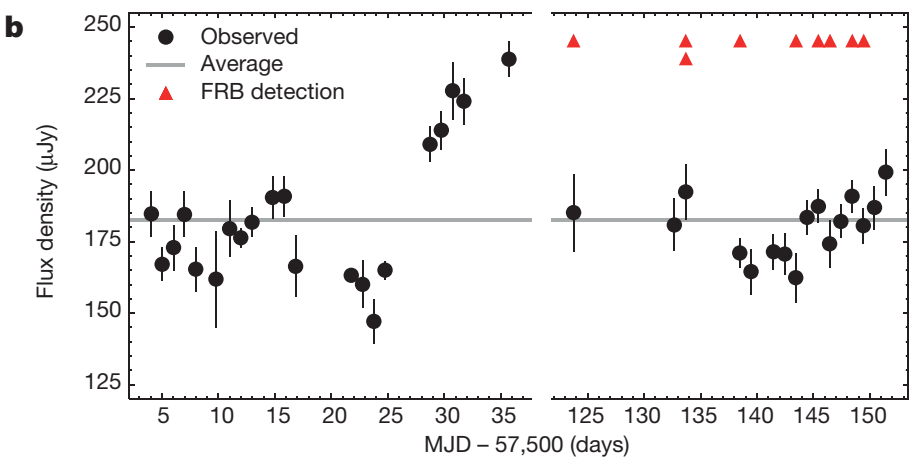


5-ms image (dispersion corrected) of one burst.

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

The VLA localization of FRB 121102





- Persistent radio counterpart
- Co-located within ~ 0.1 arcsec
- $\langle S_{3\ \mathrm{GHz}} \rangle \sim 180\ \mu\mathrm{Jy}$
- Variability $\sim 10\%$
- Variability uncorrelated with the bursts

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

The EVN localization of FRB 121102

colorscale: 5-GHz image

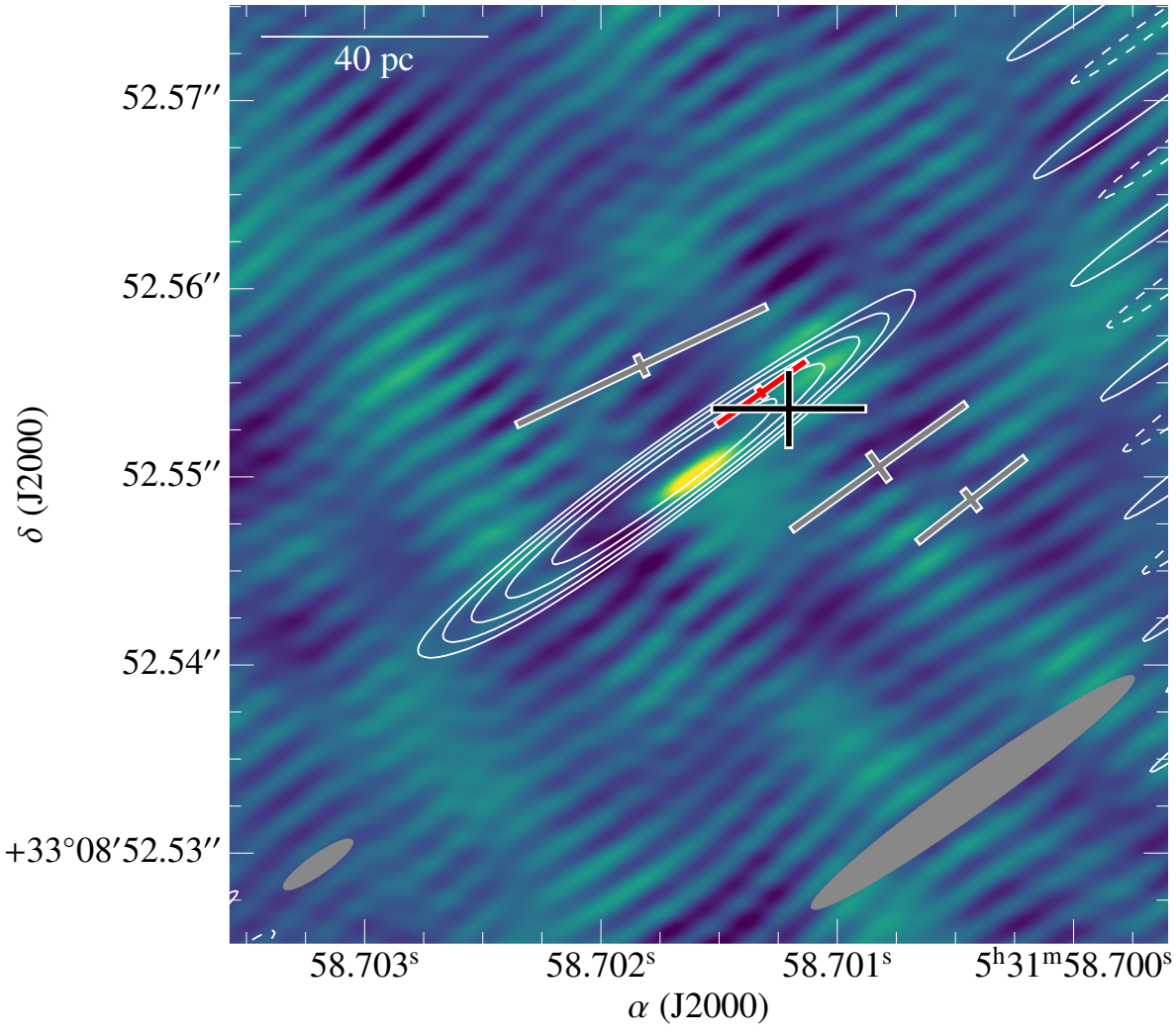
Contours: 1.7-GHz image

(Bursts observed at 1.7 GHz)

+: brightest burst
+: other bursts
+: average position

Source size < 0.7 pc

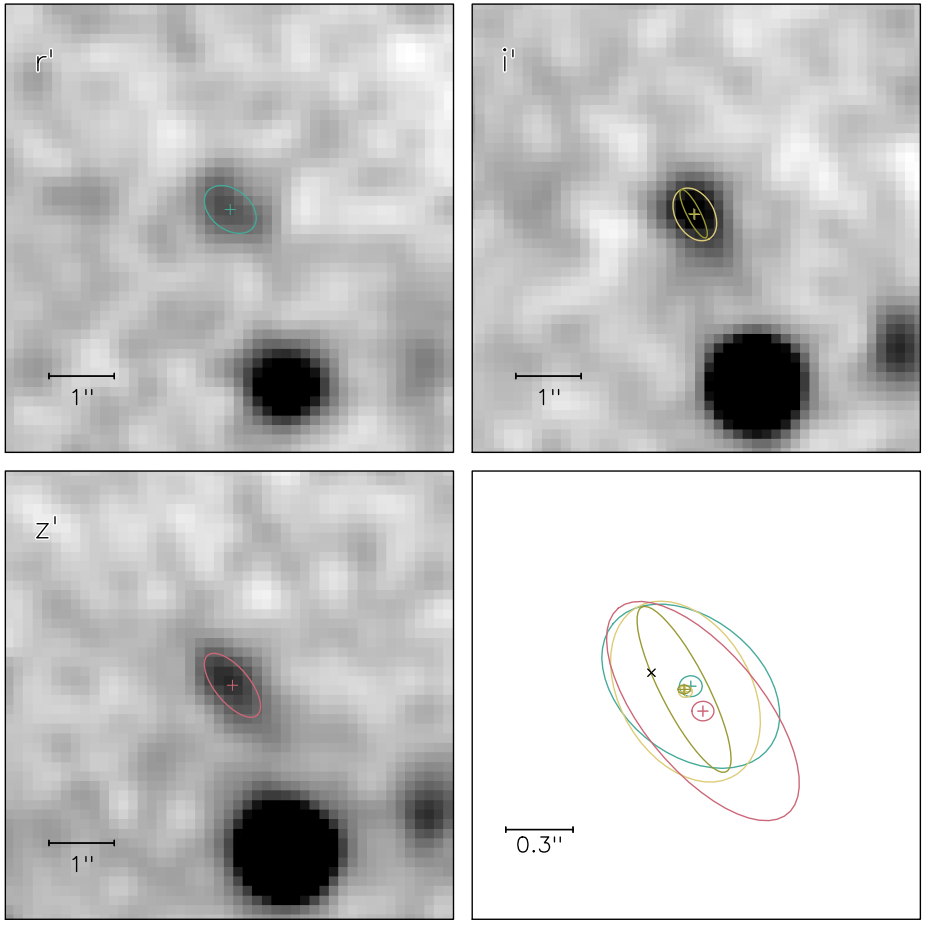
Coincidence within 2σ:
< 40 pc at 95% C.L.



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

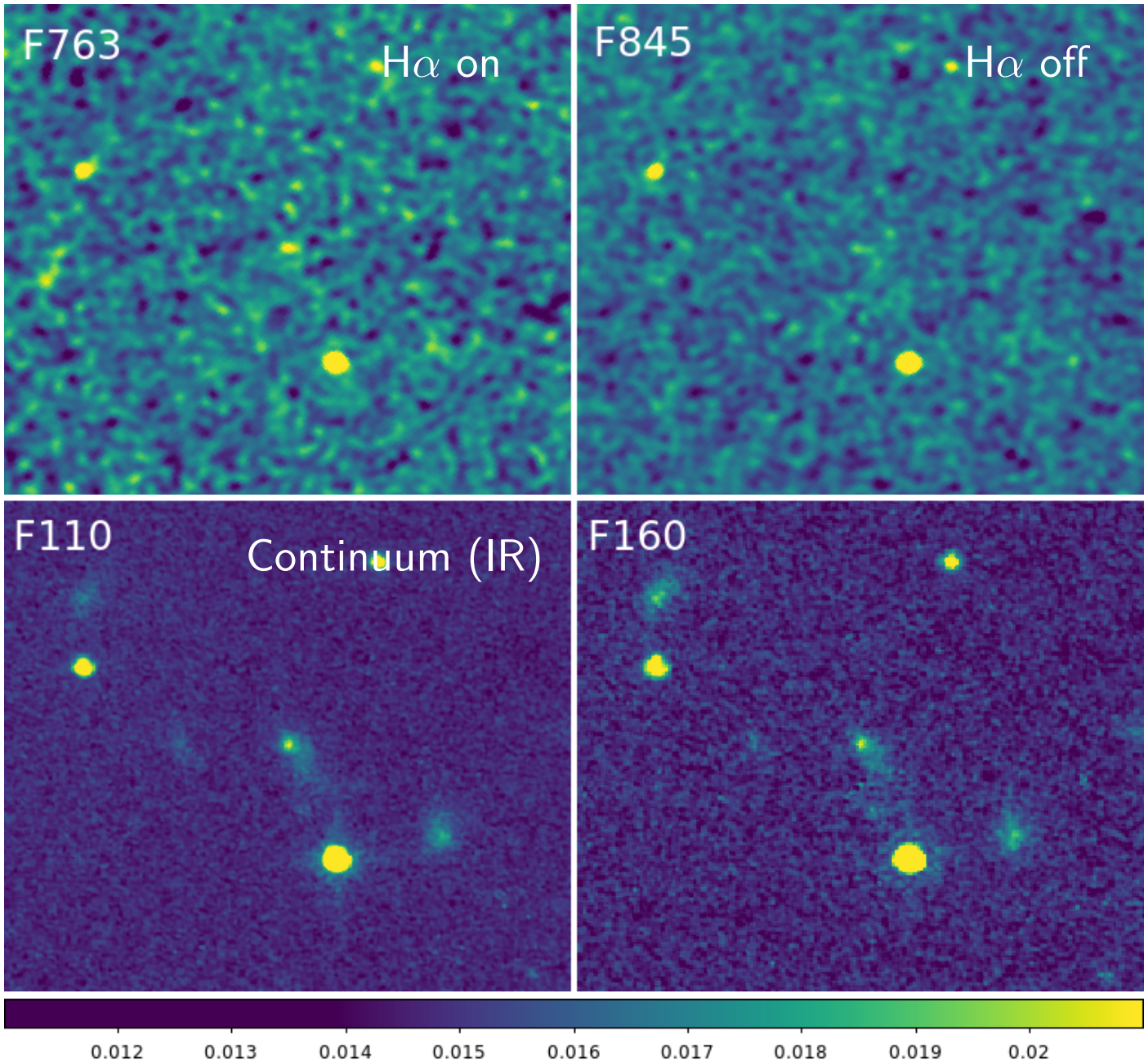
The optical counterpart

- Archival Keck data from 2014
- Gemini observation (Oct 2016)
- Extended 25-mag counterpart
- $z = 0.19273(8) \Longrightarrow 972$ Mpc
  Extragalactic!
- Emission lines
  $\Rightarrow$ low-metallicity star-formation
- Dwarf galaxy!
  Diameter: $\lesssim 4$ kpc
  Mass: 4–7$\times 10^7$ $\mathrm{M}_\odot$
  Star Formation: ~ 0.4 $\mathrm{M}_\odot$ yr^{-1}

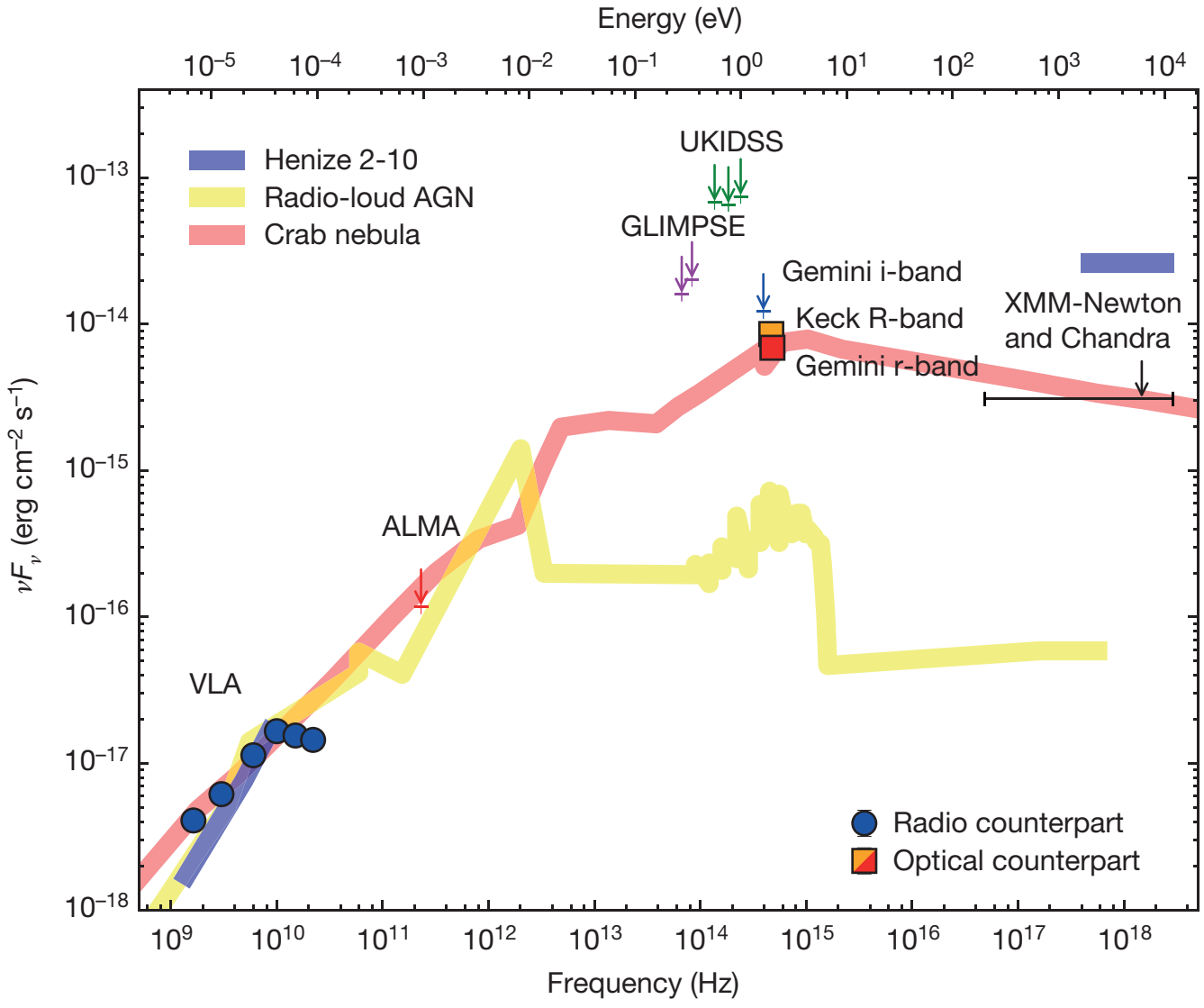


Tendulkar et al. (2017, ApJL, 834, 7)

Preliminary HST data! (Bassa et al. in prep)



The VLA localization of FRB 121102

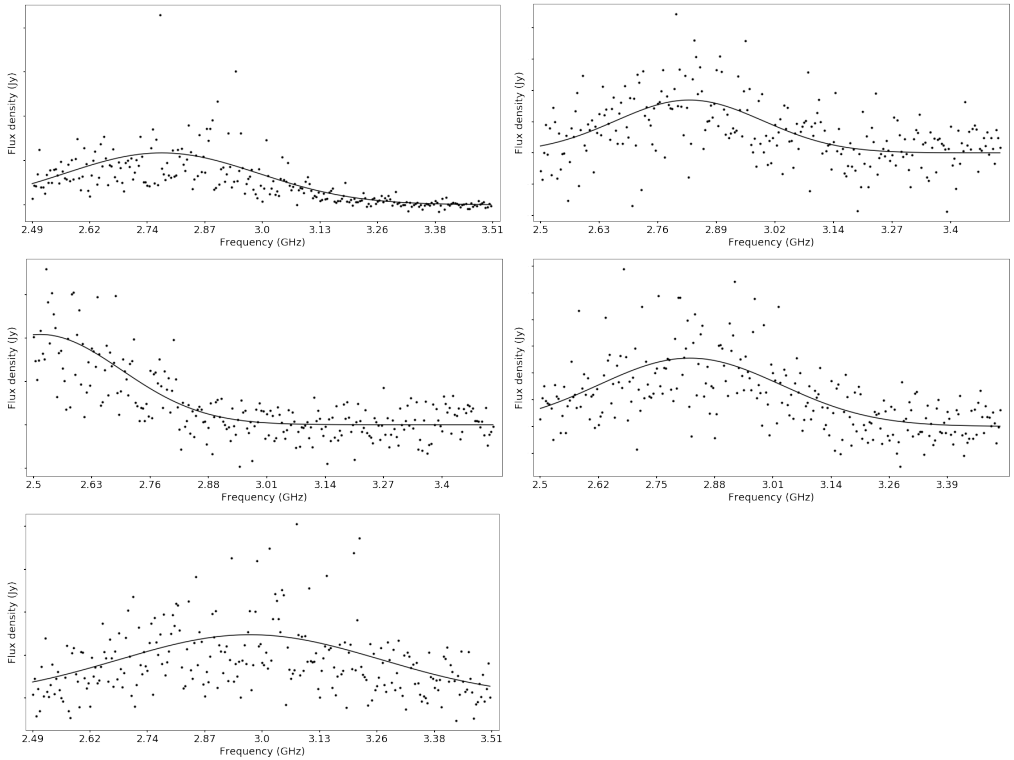


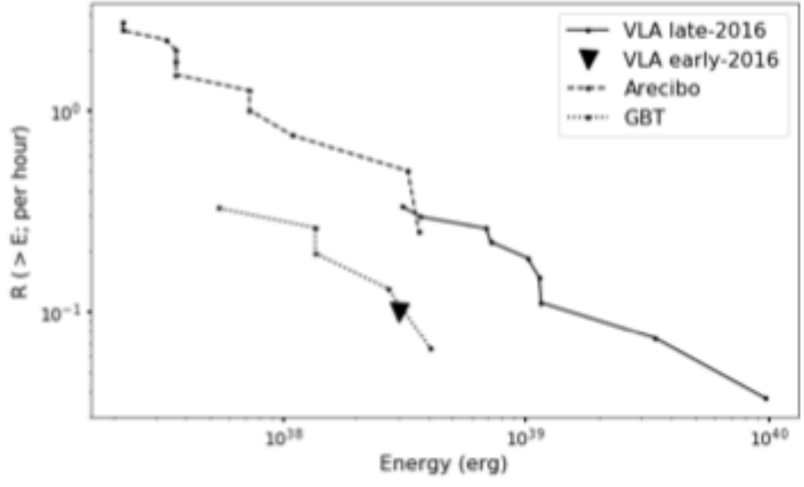
SED of FRB 121102 (Chatterjee et al. 2017, Nature, 541, 58)

Understanding the radio bursts (PRELIMINARY)

- 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. (in prep)



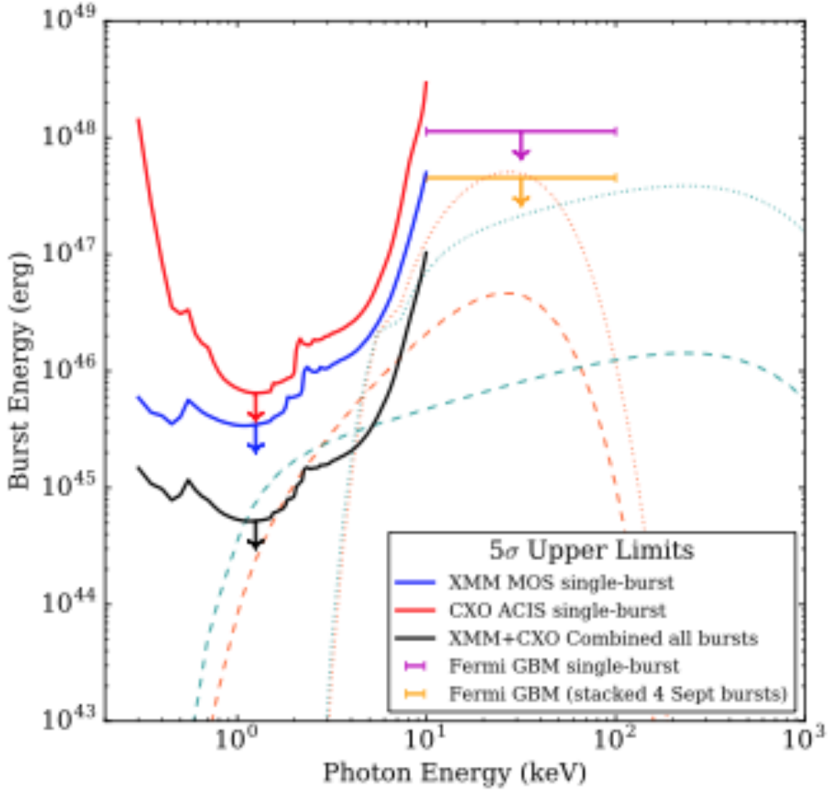


No X-ray bursts (PRELIMINARY)

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?
  $L_{0.5-6\mathrm{keV}} < 3 \times 10^{41}$ erg s^{-1}

Scholz et al. (*almost* submitted)



Possible origins for FRB 121102

- What it is not:
  - A standard pulsar / RRAT / flare star / ...
  - Supernova remnant, as Cas A (at least 4 orders of magnitude fainter)
  - Compact star-forming regions, as Arp 220 (similar luminosity but would need a much larger region and SFR)
  - IMBH, X-ray binary, ultraluminous X-ray nebula, ...

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- What it could be:
  - Young superluminous supernovae powered by the spin-down power of a neutron star or magnetar (e.g. Murase et al., Piro et al. 2016)
  - Bursts produced by a strong plasma turbulence excited by the jet of a massive black hole (Romero et al. 2016, Vieyro et al. in press)
  - Neutron star interacting with the jet of a massive black hole (Pen & Connor 2015, Cordes & Wasserman 2016, Zhang 2017)
  - Synchrotron maser activity from an AGN? (Ghisellini 2017)
  - Possibly new suggestions coming!

Is gamma-ray emission expected?

- Pulsar + SLSNe: γ-ray flashes expected for < 100 Mpc (Murase et al. 2016)
- AGN/jet-related: could produce γ-ray emission on second-minute timescales (on-going work) (Vieyro et al. A&A in press)
- 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)

Conclusions

- Origin of FRBs still widely discussed
- FRB 121102 is extragalactic
- We do not see afterglows in FRB 121102
- Is FRB 121102 representative?
  Are FRBs located in dwarf galaxies?
- Localization of more FRBs is still needed
- Coming soon: many observations from radio to TeV...

  Detection with MAGIC soon (either optical or TeV)? :-)

Thank you!

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 $z \sim 0.5$

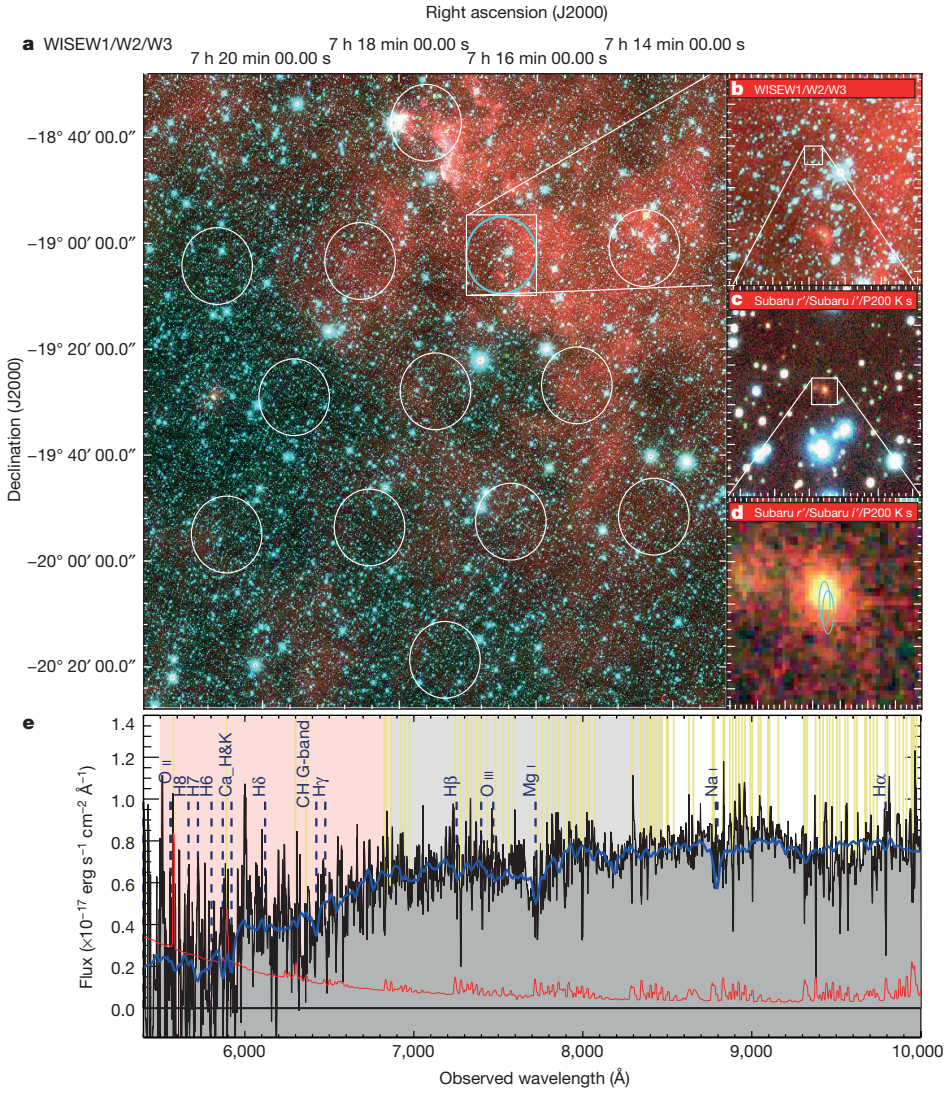
. . . or just an unassociated AGN?

Williams & Berger (2016)

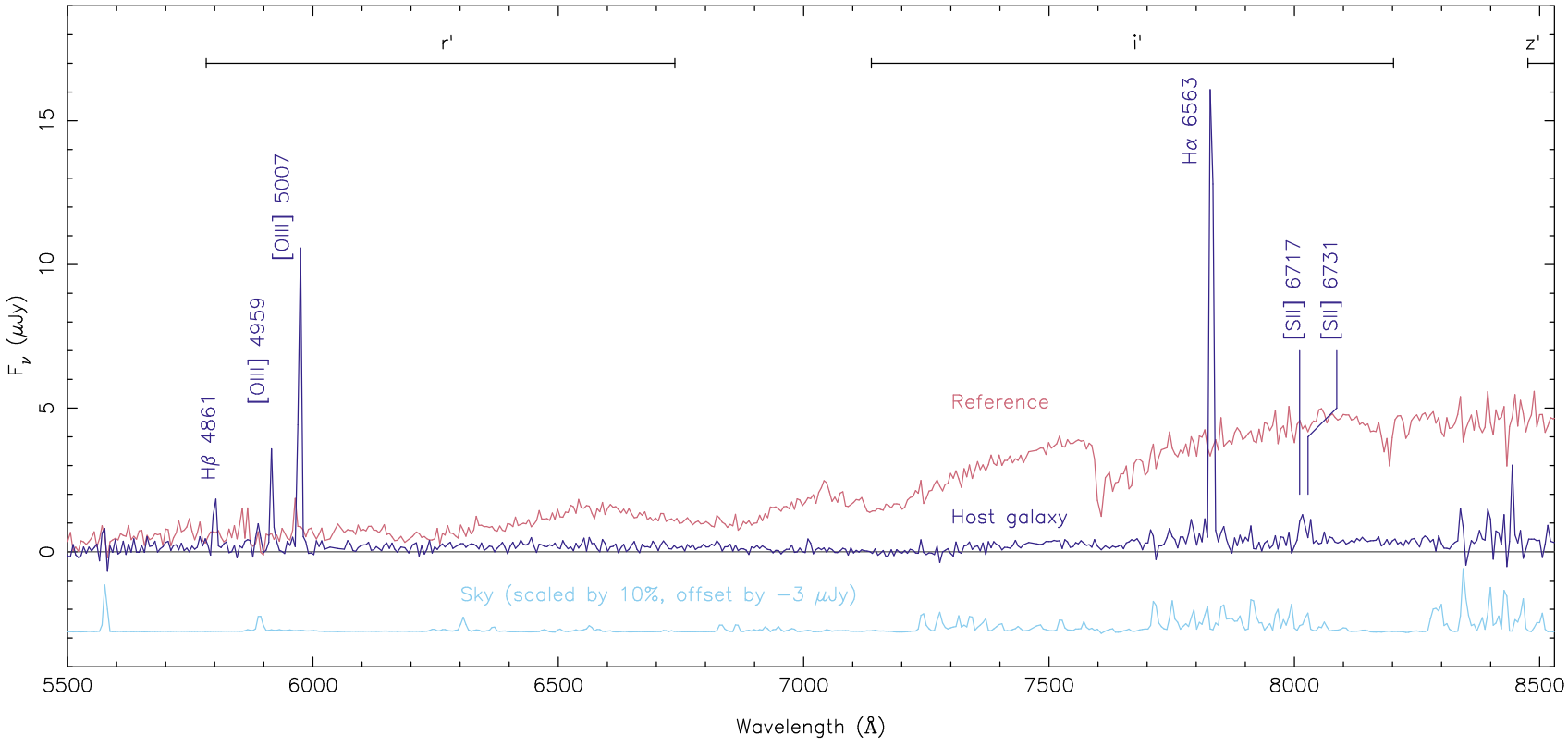
Vedanthan et al. (2016)

Giroletti et al. (2016)

Bassa et al. (2016)

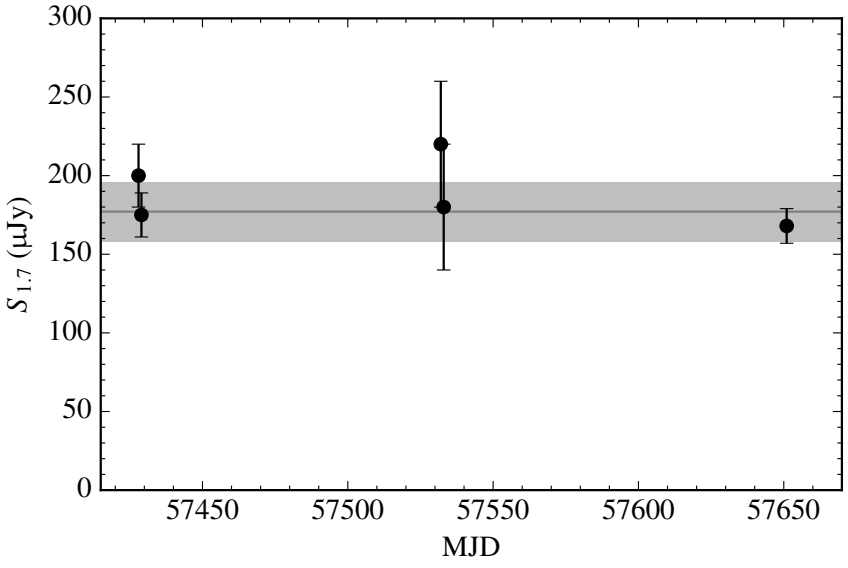


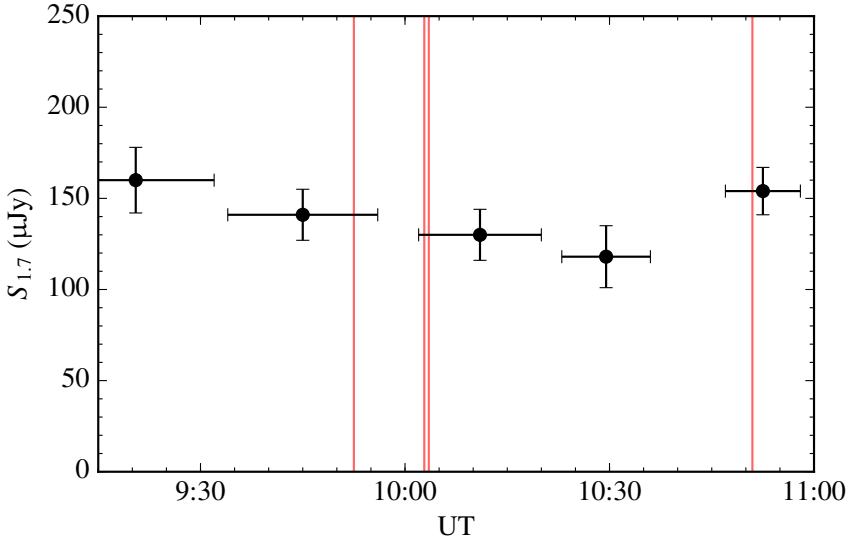
Optical spectrum



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

Localizing FRB 121102 on milliarcsecond scales





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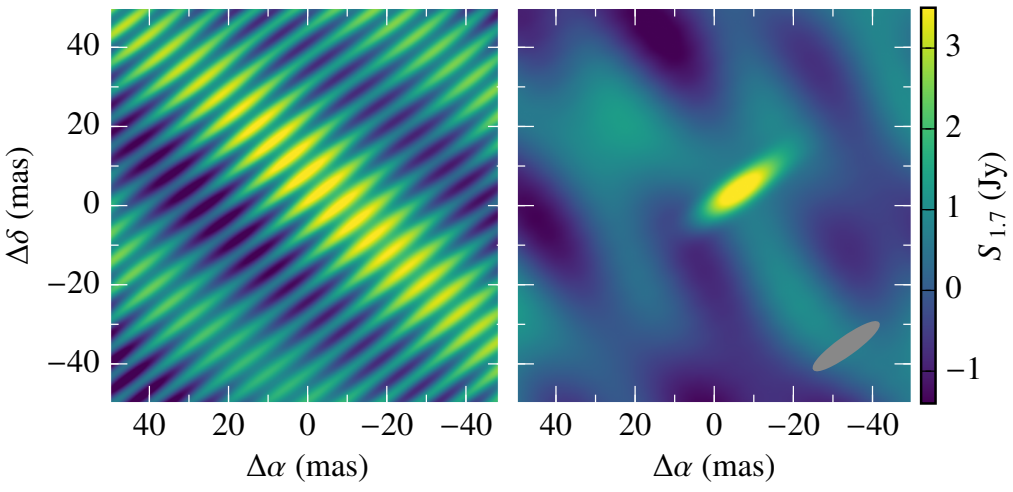
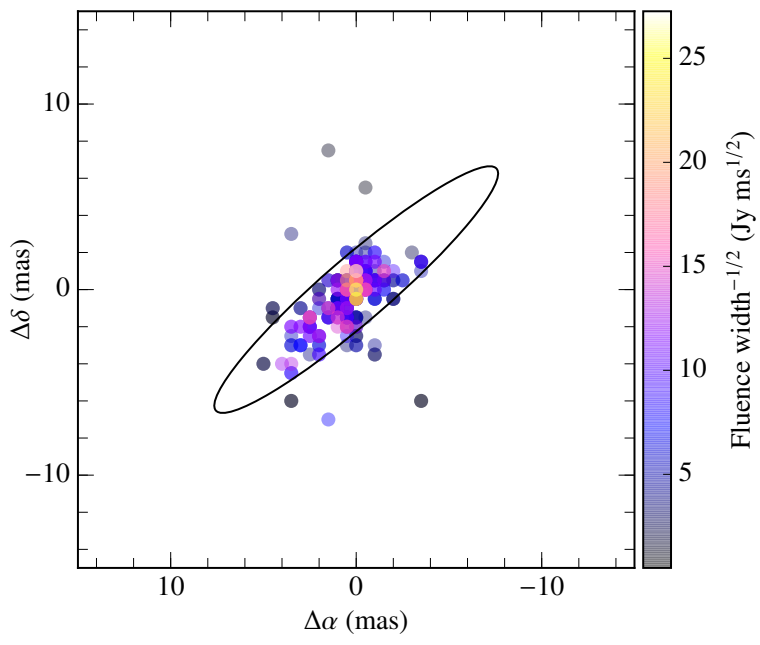


Dirty and clean image from FRB 121102.

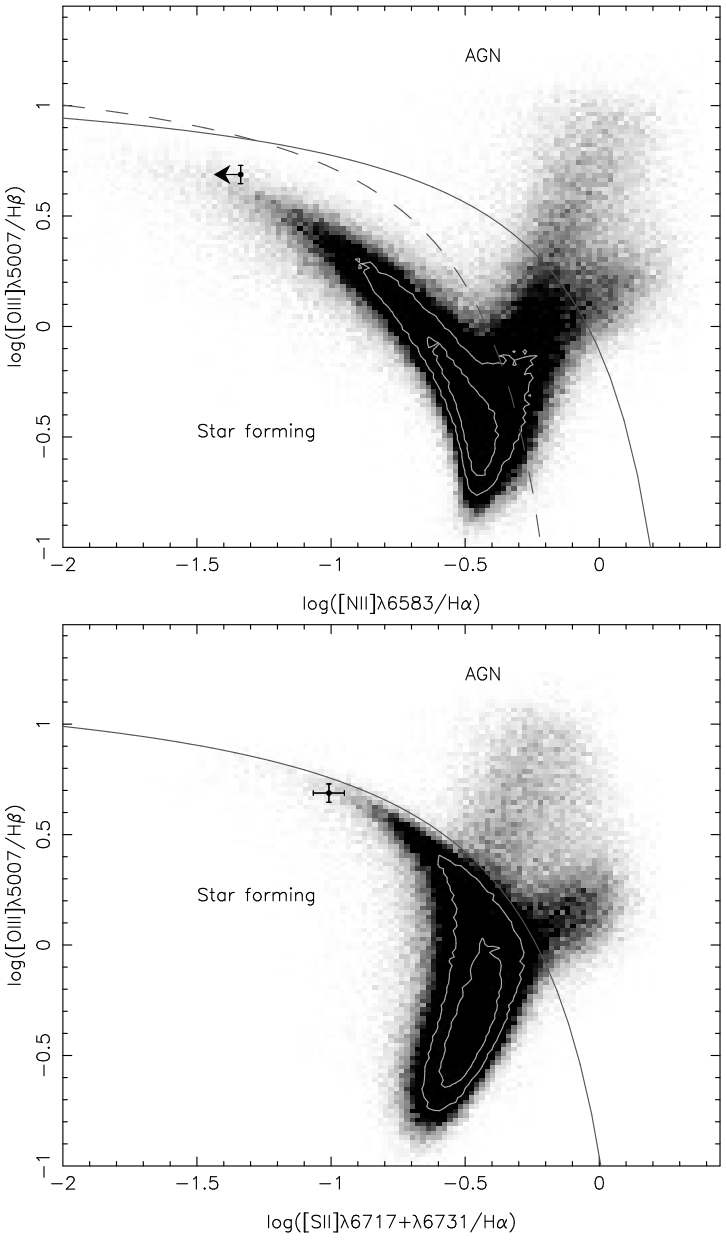
Astrometry limited by signal-to-noise ratio



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)