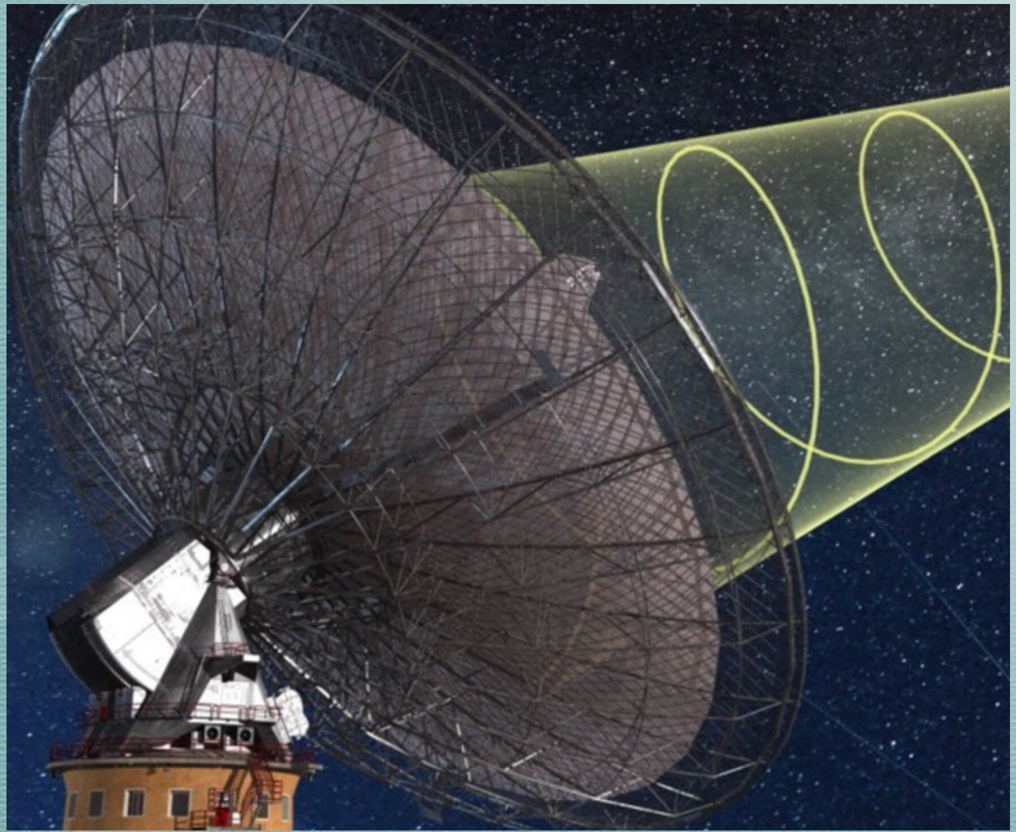
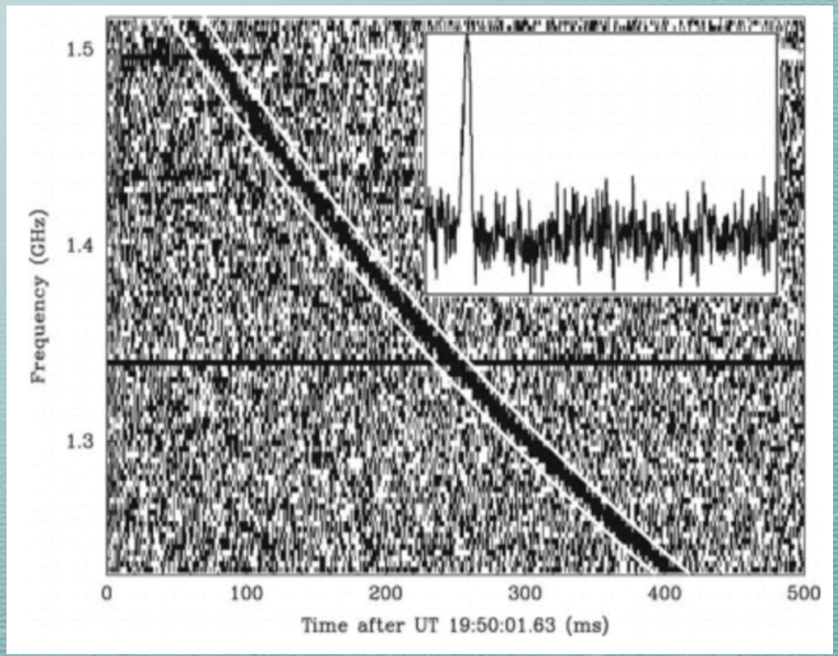
SEARCH FOR HIGH-ENERGY EMISSION FROM FAST RADIO BURSTS

TAM, Pak Hin (Sun Yat-sen University)

19/1/2017

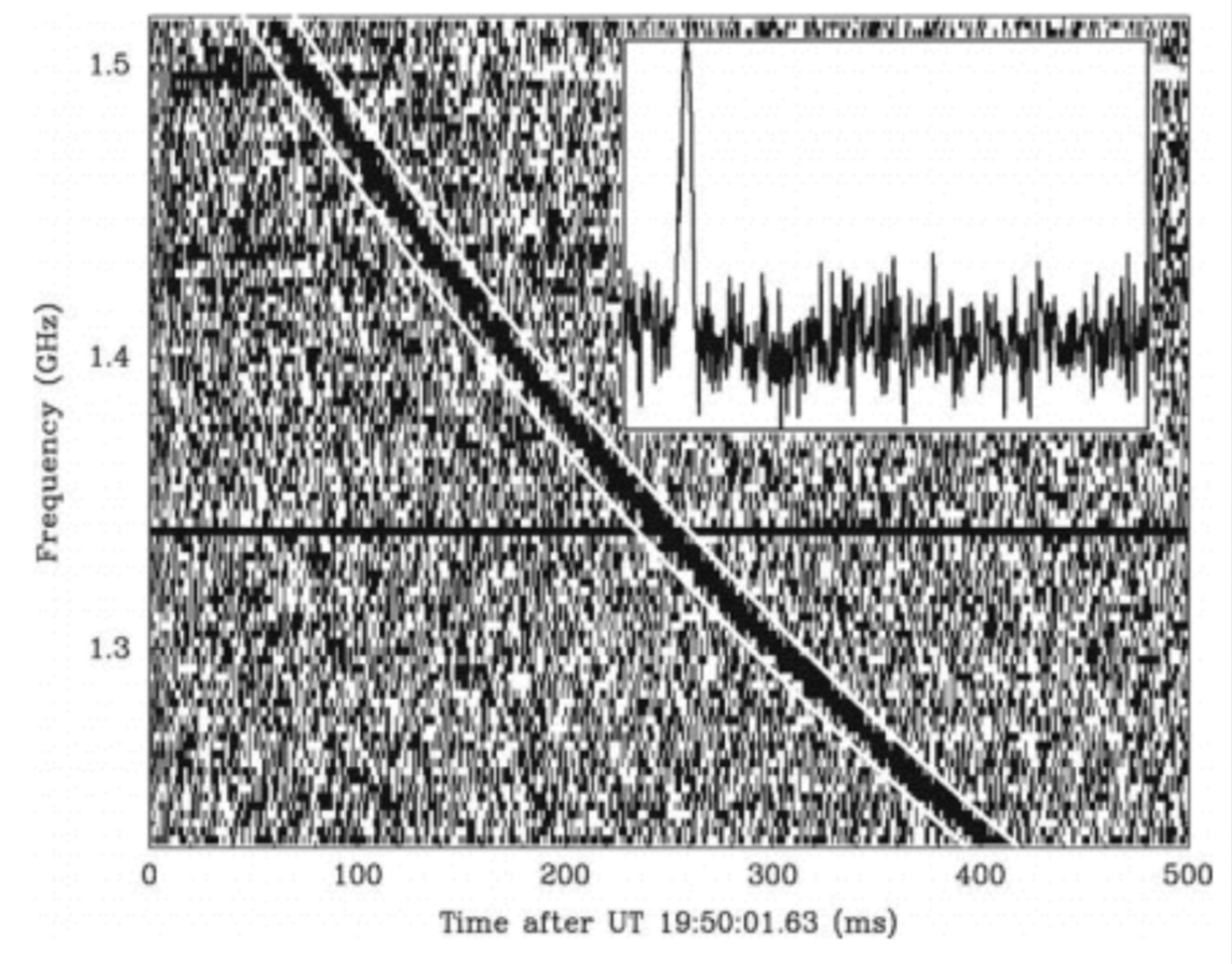




Fast Radio Bursts

Lorimer+ (2007)

- First FRB (010724) discovered in 2007 (Lorimer et al.)
- ms-duration
- Fluence: a few Jy-ms
- Rate ~ 5,000 sky^{-1} day^{-1}



Fast Radio Bursts

* Large dispersion measure (DM, >~ 200pc cm^{-3})

$$DM = \int_0^d n_e \, ds$$

* It's about 10 times the Milky Way contribution
* Some or all excess DM may come from inter-Galactic medium. Thus, they are likely extragalactic or cosmological sources.
* *These are strongly supported by the very recently discovered radio counterpart & host galaxy (~1 Gpc) of FRB 121102 (Chatterjee et al., Nature, 2017)*

The FRB catalog

(http://www.astronomy.swin.edu.au/pulsar/frbcat/)

Catalogue Version 1.0

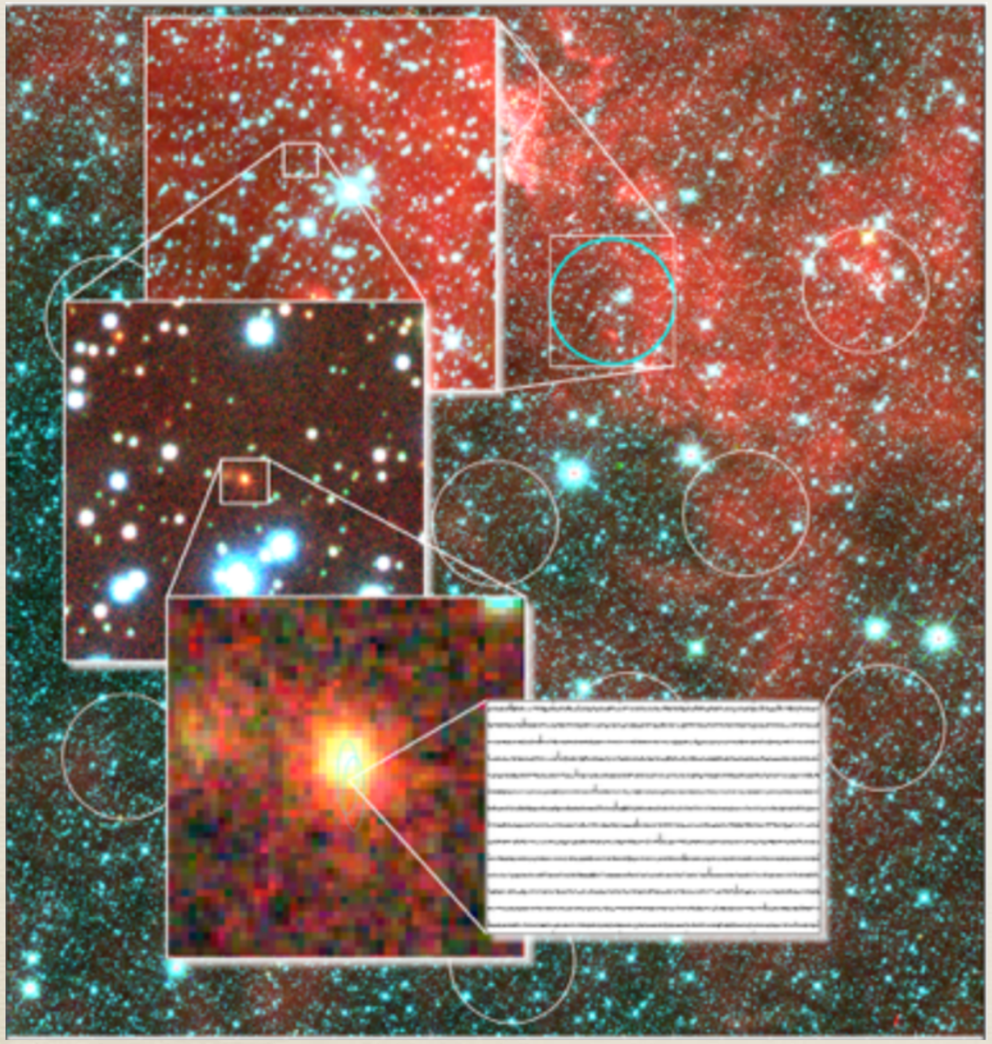
Event	Telescope	gl [deg]	gb [deg]	FWHM [deg]	DM [cm^{-3} pc]	S/N	W_{obs} [ms]	$S_{peak,obs}$ [Jy]	F_{obs} [Jy ms]	Ref
FRB010125	parkes	356.641	-20.020	0.25	790(3)	17	$9.40^{+0.20}_{-0.20}$	0.30	2.82	1
FRB010621	parkes	25.433	-4.003	0.25	745(10)		7.00	0.41	2.87	2
FRB010724	parkes	300.653	-41.805	0.25	375	23	5.00	$>30.00^{+10.00}_{-10.00}$	>150.00	3
FRB090625	parkes	226.443	-60.030	0.25	899.55(1)	30	$1.92^{+0.83}_{-0.77}$	$1.14^{+0.42}_{-0.21}$	$2.19^{+2.10}_{-1.12}$	4
FRB110220	parkes	50.828	-54.766	0.25	944.38(5)	49	$5.60^{+0.10}_{-0.10}$	$1.30^{+0.00}_{-0.00}$	$7.28^{+0.13}_{-0.13}$	5
FRB110523	GBT	56.119	-37.819	0.26	623.30(6)	42	$1.73^{+0.17}_{-0.17}$	0.60	1.04	6
FRB110626	parkes	355.861	-41.752	0.25	723.0(3)	11	1.40	0.40	0.56	5
FRB110703	parkes	80.997	-59.019	0.25	1103.6(7)	16	4.30	0.50	2.15	5
FRB120127	parkes	49.287	-66.203	0.25	553.3(3)	11	1.10	0.50	0.55	5
FRB121002	parkes	308.219	-26.264	0.25	1629.18(2)	16	$5.44^{+3.50}_{-1.20}$	$0.43^{+0.33}_{-0.06}$	$2.34^{+4.46}_{-0.77}$	4
FRB121102	arecibo	174.950	-0.225	0.05	557(2)	14	$3.00^{+0.50}_{-0.50}$	$0.40^{+0.40}_{-0.10}$	$1.20^{+1.60}_{-0.45}$	7
FRB130626	parkes	7.450	27.420	0.25	952.4(1)	21	$1.98^{+1.20}_{-0.44}$	$0.74^{+0.49}_{-0.11}$	$1.47^{+2.45}_{-0.50}$	4
FRB130628	parkes	225.955	30.655	0.25	469.88(1)	29	$0.64^{+0.13}_{-0.13}$	$1.91^{+0.29}_{-0.23}$	$1.22^{+0.47}_{-0.37}$	4
FRB130729	parkes	324.787	54.744	0.25	861(2)	14	$15.61^{+9.98}_{-6.27}$	$0.22^{+0.17}_{-0.05}$	$3.43^{+6.55}_{-1.81}$	4
FRB131104	parkes	260.549	-21.925	0.25	779(1)	30	2.08	1.12	2.33	8
FRB140514	parkes	50.841	-54.611	0.25	562.7(6)	16	$2.80^{+3.50}_{-0.70}$	$0.47^{+0.11}_{-0.08}$	$1.32^{+2.34}_{-0.50}$	9
FRB150418	parkes	232.665	-3.234	0.25	776.2(5)	39	$0.80^{+0.30}_{-0.30}$	$2.20^{+0.60}_{-0.30}$	$1.76^{+1.32}_{-0.81}$	10
FRB150807	parkes	336.709	-54.400	0.25	266.5(1)		$0.35^{+0.05}_{-0.05}$	$128.00^{+5.00}_{-5.00}$	$44.80^{+8.40}_{-7.90}$	11

Proposed models

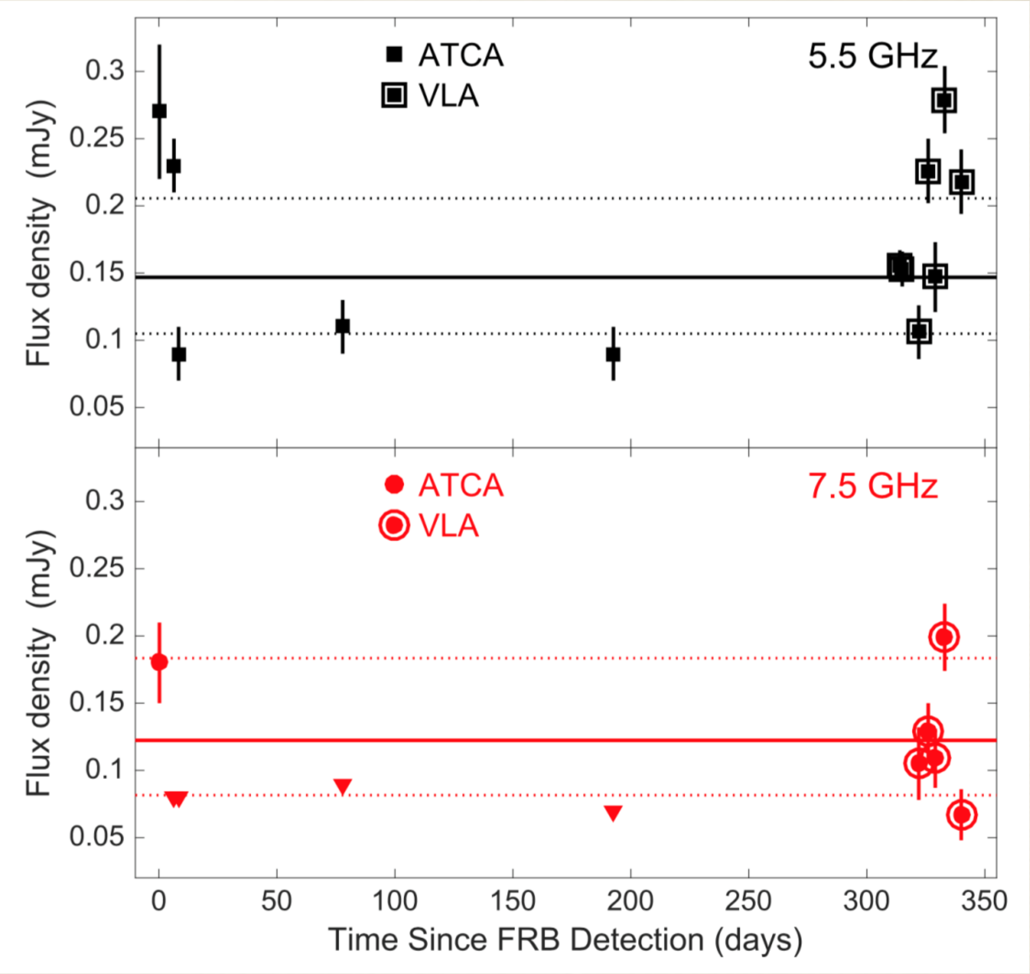
* Collapse of supra-massive neutron stars to black holes (Falcke & Rezzolla 2013; Zhang 2014)
* Magnetospheric activity after NS-NS mergers (Totani 2013)
* Mergers of binary white dwarfs (Kashiyama et al. 2013)
* Magnetar radio bursts (Popov et al. 2007, 2013; Kulkarni et al. 2014; Pen & Connor 2015)
* Cosmic sparks from superconducting strings (Vachaspati 2008; Yu et al. 2014)
* Evaporation of primordial black holes (Rees 1977; Keane et al. 2012)
* White holes (Barrau et al. 2014; Haggard)
* Flaring stars (Loeb et al. 2013; Maoz et al. 2015)
* Supergiant radio pulses (Cordes & Wasserman 2015; Connor et al. 2015; Pen & Connor 2015)
* Axion miniclusters, axion stars (Tkachev 2015; Iwazaki 2015)
* NS-Asteroid collisions (Geng & Huang 2015; Dai et al. 2016)
* Quark Nova (Shand et al. 2015)
* Dark matter-induced collapse of NSs (Fuller & Ott 2015)
* Higgs portals to pulsar collapse (Bramante & Elahi 2015)
* Soft gamma repeaters (Katz 2016)
* Giant pulse from rapid rotating pulsars (Lyutikov et al. 2016)
* Compact binary model (Gu et al. 2016)
* Mergers of neutron stars (Wang et al. 2016; Zhang 2016)

FRB 150418: first evidence of a (radio) afterglow

Keane et al. (2016, Nature, 530, 453): host galaxy, z=0.492±0.008



this might be an AGN-like activity (Williams & Berger 2016)



非常有爭議性

FRB 131104/ SwJ0644.5-5111

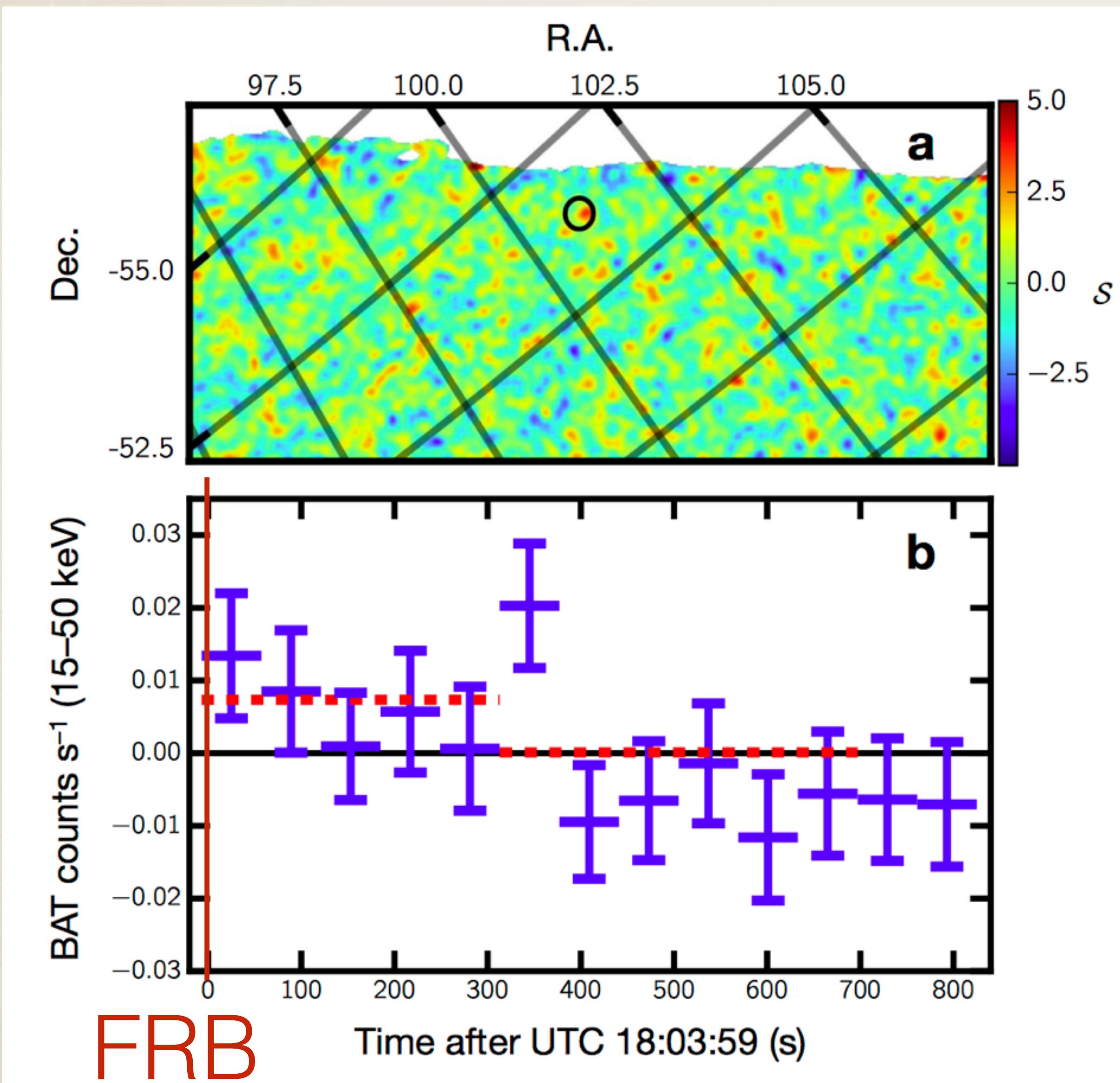


Table 2. Properties of FRB 131104

Joint	R.A.	$06^{h}\ 44^{m}\ 27\overset{s}{.}06$
	Dec.	$-51°\ 12'\ 54\overset{''}{.}0$
	r_{90}	$5\overset{'}{.}78$
Radio	UTC	18:03:59
	S_{GHz}	2.33 Jy ms
	DM	779 ± 1 pc cm^{-3}
	z_{max}	0.55
γ-ray	T_{90}	377 ± 24 s (1σ)
		>100 s (90%-c.l.)
PL	Γ	$1.16^{+0.68}_{-0.78}$
	$S_{\gamma,-6}$	4.0 ± 1.8
TB	kT	$200^{+\infty}_{-125}$ keV
	$S_{\gamma,-6}$	3.4 ± 1.5

Significance of association~3.2 sigma

DeLaunay+ (2016)

Echoes..

* The low-significance event triggers a lot of discussion
* It quickly points to something involving relativistic shocks, even to GRBs
* The non-detection from radio, optical to X-rays has been used to constrain the density of the medium to be very tenuous, i.e., n<~ 10^{-3} cm^{-3} (Murase +2016, Gao&Zhang 2016, Dai+ 2016)
* But GeV emission resulting from the synchrotron electrons in the shock is independent of the ISM density

$$F_\nu = 0.2\mathrm{mJy} E_{55}^{(p+2)/4} \epsilon_e^{p-1} \epsilon_{B,-2}^{(p-2)/4} t_1^{-(3p-2)/4} \times \nu_8^{-p/2} (1+Y)^{-1} (1+z)^{(p+2)/4} d_{L28}^{-2},$$

* This motivated us to search for GeV emission from FRBs (Xi, Tam, Peng, Wang, submitted)

Search for GeV counterparts to fast radio bursts with *Fermi*

Shao-Qiang Xi[1,3], Pak-Hin Thomas Tam[2], Fang-Kun Peng[1,3] and Xiang-Yu Wang[1,3]

[1] *School of Astronomy and Space Science, Nanjing University, China; xywang@nju.edu.cn*

[2] *School of Physics and Astronomy, Sun Yat-sen University, Zhuhai 519082, China; tanbxuan@mail.sysu.edu.cn*

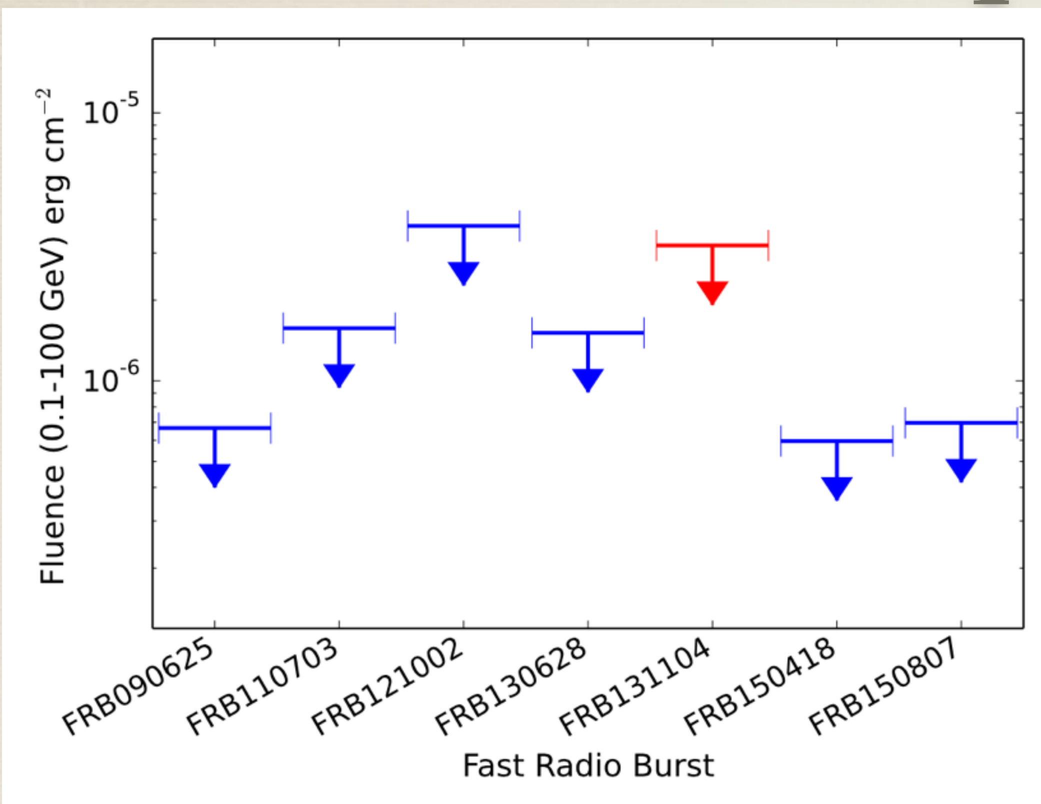
[3] *Key laboratory of Modern Astronomy and Astrophysics, Nanjing University, Ministry of Education, Nanjing 210093, China*

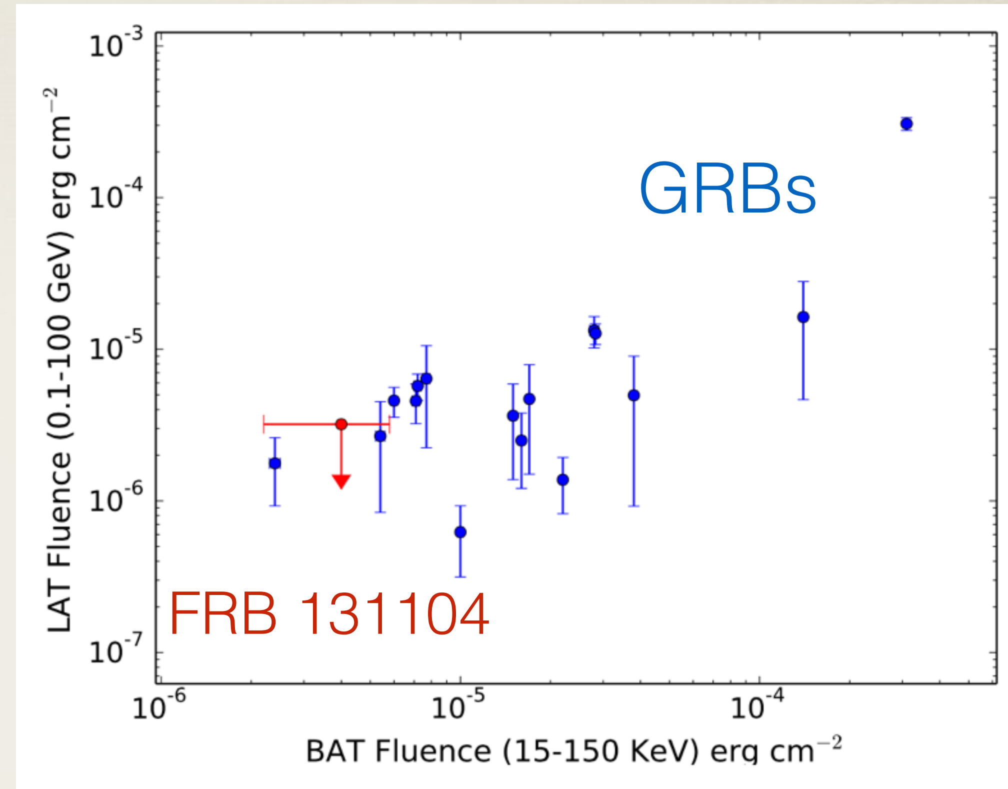
Results

Name	(l,b)[a] (°)	$T+T_0$[b] (s)	Fluence limit ($\times10^{-7}$ erg cm^{-2})	E_K limit ($\times10^{52}$ ergs)	DM(z)[a] cm^{-3}pc
FRB131104	(260.549,-21.925)	[5417,11142]	32.0	246.60	779.0(0.59)
FRB090625	(226.443,-60.030)	[0,595]	6.66	33.89	899.55(0.72)
FRB110703	(80.997,-59.019)	[0,1660]	15.73	42.49	1103.6(0.89)
FRB121002	(308.219,-26.264)	[0,5119]	37.82	65.15	1629.18(1.3)
FRB130628	(225.955,30.655)	[0,305]	15.10	34.78	469.88(0.35)
FRB150418	(232.665,-3.234)	[0,1193]	5.96	8.06	776.2(0.49)
FRB150807	(336.709,-54.400)	[0,4946]	6.97	0.32	266.5(0.16)

No significant detection

What do the upper limits mean?

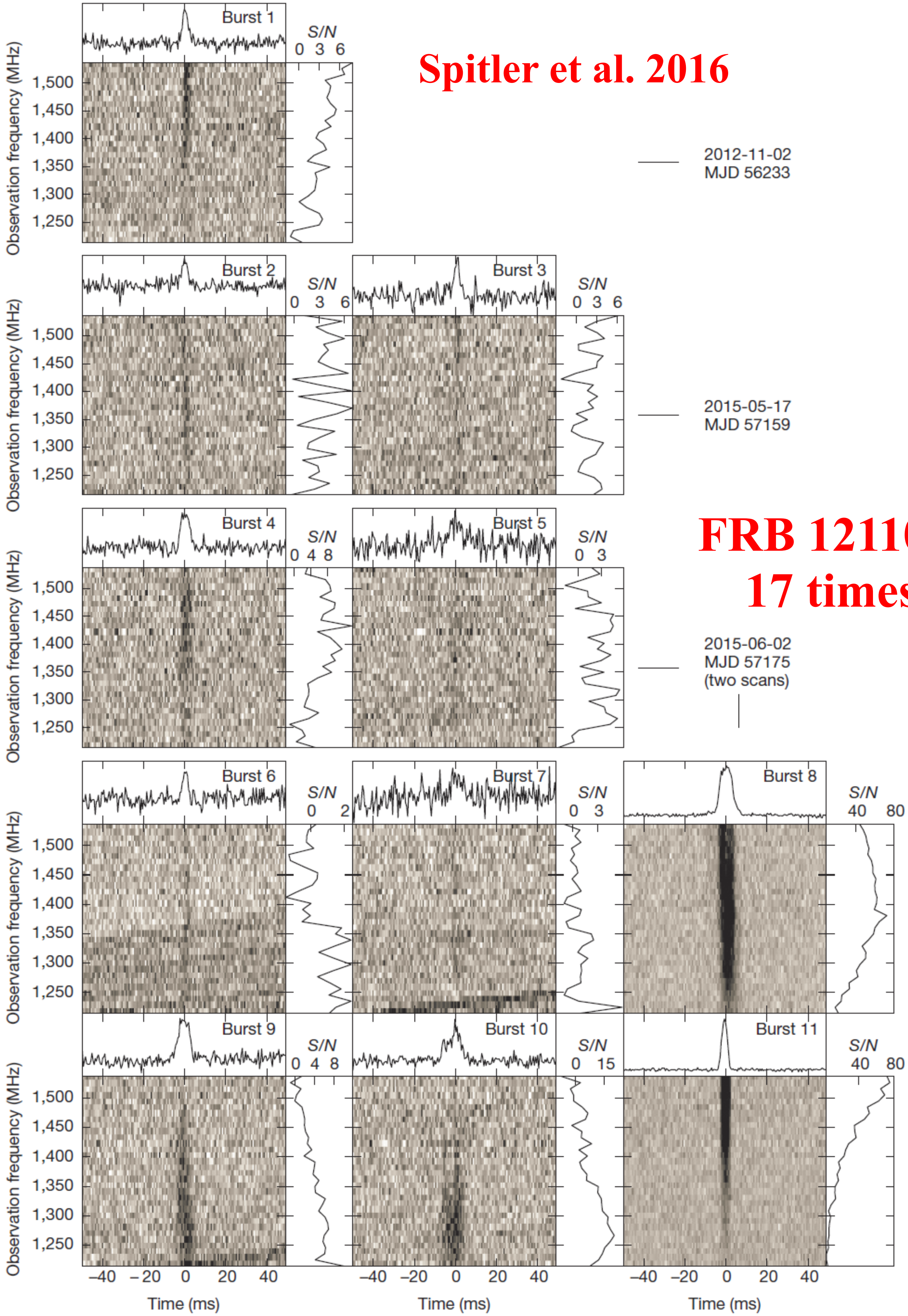




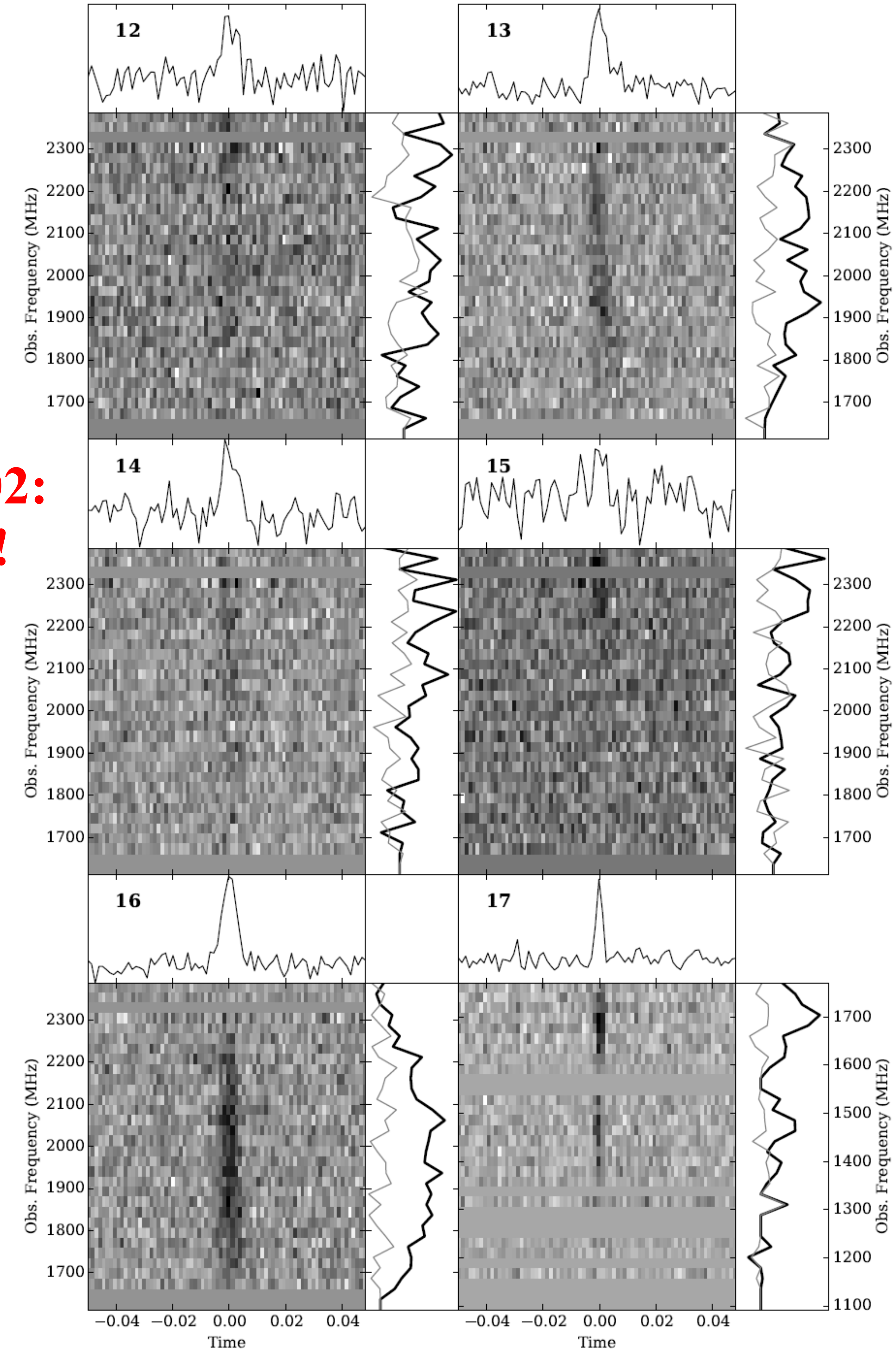
- The Swift/BAT fluence of 4×10^{-6} erg cm^{-2} is not weak, some GRBs with such fluence emit GeV emission, e.g., GRBs 110731A, 120729A, 150512A.
- We are able to constrain the kinetic energy of the relativistic blast wave to $E_k <\sim 10^{52} - 10^{54}$ erg.

FRB 121102: 17 times!

Spitler et al. 2016



Scholz et al. 2016



The repeating Fast Radio Burst FRB 121102 3

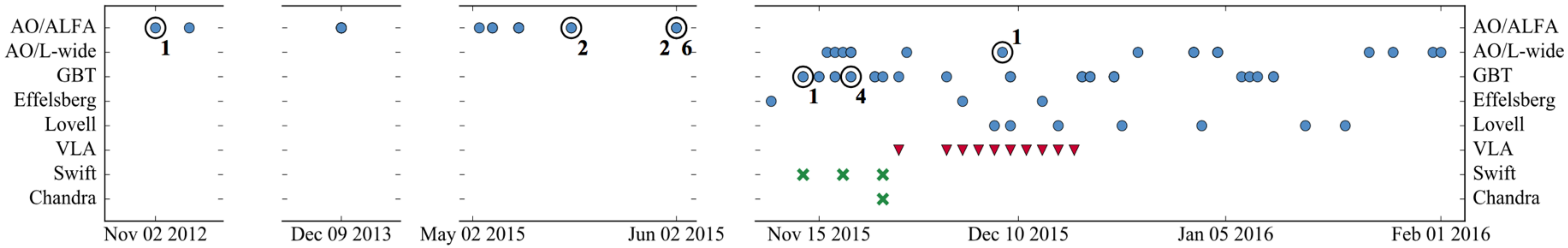


Figure 1. Timeline of radio and X-ray observations of FRB 121102 from discovery in 2012 November to 2016 January. Each row represents a set of observations from a given telescope (and receiver in the case of Arecibo observations). Blue circles represent single-dish radio observations, red triangles denote radio interferometer observations and green crosses are X-ray observations. Observations with bursts are encircled and marked with the numbers of bursts discovered. Note that bursts were discovered on 2015 June 2 in two separate observations.

Table 1
Summary of Radio Telescope Observations

Telescope	Receiver	Gain (K/Jy)	T_{sys} (K)	Bandwidth (MHz)	Central Frequency (MHz)	Beam FWHM (′)	Total Time on-source (hr)	Sensitivity[i] (Jy)
Arecibo	ALFA[a]	8.5	30	322	1375	3.4	4.4	0.02
Arecibo	L-Wide[b]	10	30	700[h]	1430	3.1	18.3	0.01
GBT	S-band[c]	2.0	20	800[h]	2000	5.8	15.3	0.04
GBT	820 MHz[c]	2.0	25	200	820	15	7.4	0.09
Effelsberg	S60mm[d]	1.55	27	500	4850	2.4	9.7	0.08
Lovell	L-band	0.9	27	400	1532	12	14.0	0.15
Jansky VLA	L-band[e]	2.15	35	2 × 128	1436, 1800	0.5–0.75[g]	10.0	0.1
Parkes	MB20[f]	0.9	27	400	1380	14	-	0.15

No counterpart in any other wavelengths (Scholz+ 2016)

FRB models based on magnetars

- giant flares from magnetars (Kulkarni et al. 2014),
- Sudden release of magnetic energy in a neutron star magnetosphere (Katz 2016)
- supergiant pulses from fast rotating young neutron stars or magnetars (Lyutikov et al. 2016)
- Asteroids encountering with highly magnetized pulsar (Dai et al. 2016)

- Magnetars can produce high-energy emission, X-rays, gamma-rays..

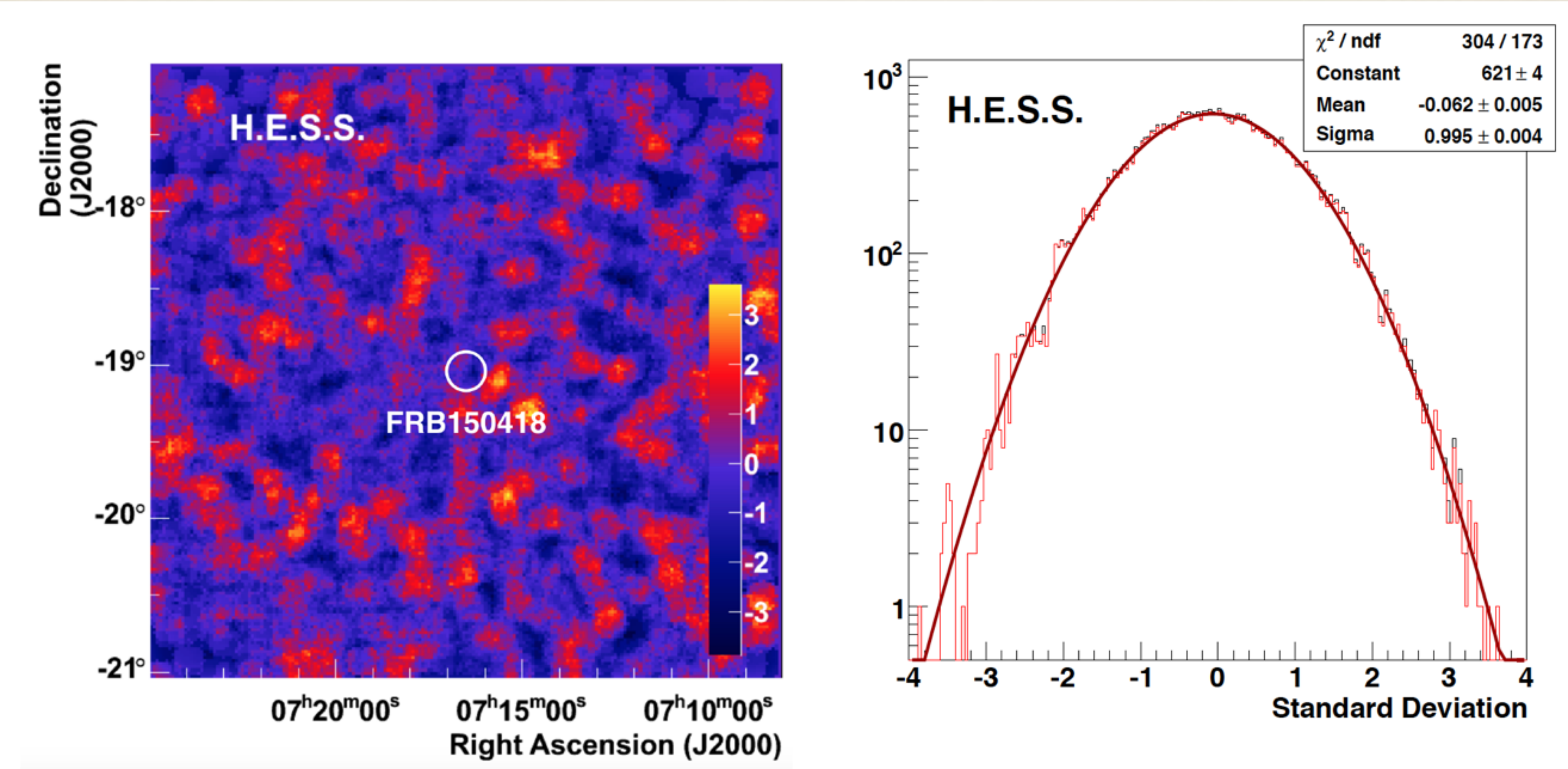
Searching Gamma Rays With Fermi LAT (He, Tam, in preparation)

17 Bursts' Peak time:

No.	Barycentric Peak Time (MJD)[a]	Peak Flux Density (Jy)[b]	Fluence (Jy ms)[b]	Gaussian Width[c] (ms)	Spectral Index[d]	DM ($pc\,cm^{-3}$)[e]
1	56233.282837008	0.04	0.1	3.3±0.3	8.8±1.9	553±5±2
2	57159.737600835	0.03	0.1	3.8±0.4	2.5±1.7	560±2±2
3	57159.744223619	0.03	0.1	3.3±0.4	0.9±2.0	566±5±2
4	57175.693143232	0.04	0.2	4.6±0.3	5.8±1.4	555±1±2
5	57175.699727826	0.02	0.09	8.7±1.5	1.6±2.5	558±6±4
6	57175.742576706	0.02	0.06	2.8±0.4		559±9±1
7	57175.742839344	0.02	0.06	6.1±1.4	-3.7±1.8	
8	57175.743510388	0.14	0.9	6.6±0.1		556.5±0.7±3
9	57175.745665832	0.05	0.3	6.0±0.3	-10.4±1.1	557.4±0.7±3
10	57175.747624851	0.05	0.2	8.0±0.5		558.7±0.9±4
11	57175.748287265	0.31	1.0	3.06±0.04	13.6±0.4	556.5±0.1±1

No.	Peak Time (MJD)	Peak Flux Density (Jy)	Fluence (Jy ms)	Gaussian FWHM (ms)	DM ($pc\,cm^{-3}$)
12	57339.356046005567	0.04	0.2	6.73 ± 1.12	$559.9 \pm 3.4 \pm 3.7$
13	57345.447691250090	0.06	0.4	6.10 ± 0.57	$565.1 \pm 1.8 \pm 3.4$
14	57345.452487925162	0.04	0.2	6.14 ± 1.00	$568.8 \pm 3.2 \pm 3.4$
15	57345.457595303807	0.02	0.08	4.30 ± 1.40	–
16	57345.462413106565	0.09	0.6	5.97 ± 0.35	$560.0 \pm 3.1 \pm 3.3$
17	57364.204632665605	0.03	0.09	2.50 ± 0.23	$558.6 \pm 0.3 \pm 1.4$

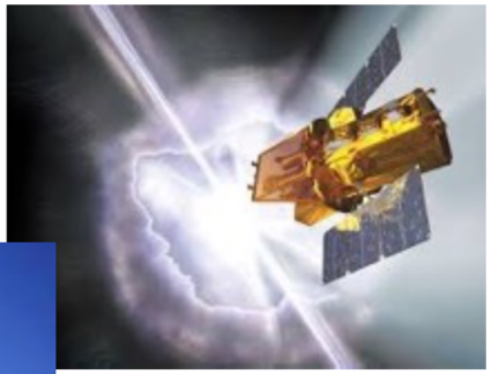
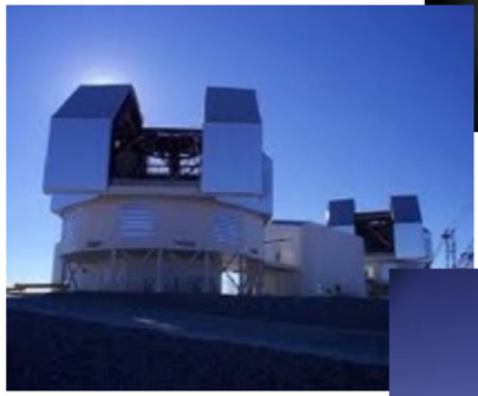
H.E.S.S. observation of FRB150418



* Observations started 14.5 hr after the FRB, lasting for 1.1 hr
* No detection

Multiwavelength follow-ups

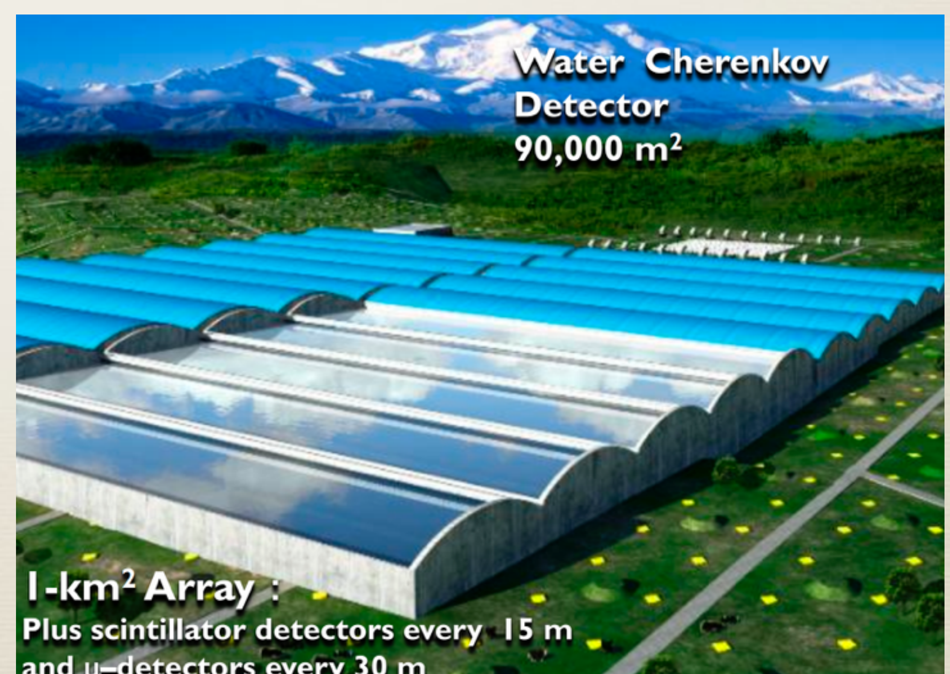
* e.g., SUPERB/Parkes
* agreements with a network of telescopes
* Aim: to provide a follow-up trigger within minutes of a detection
* Search for variable/fading source association


FAST & LHAASO

* Simultaneous observations of FRBs in the nearby geographical locations!
* Sky visibility largely overlaps （发挥地区优势）
* Also optical, radio facilities in China
* FAST/25-m radio telescope can detect the first FRB!
* FRB search strategy can be similar to GRB search (both need external trigger).

2016
貴州

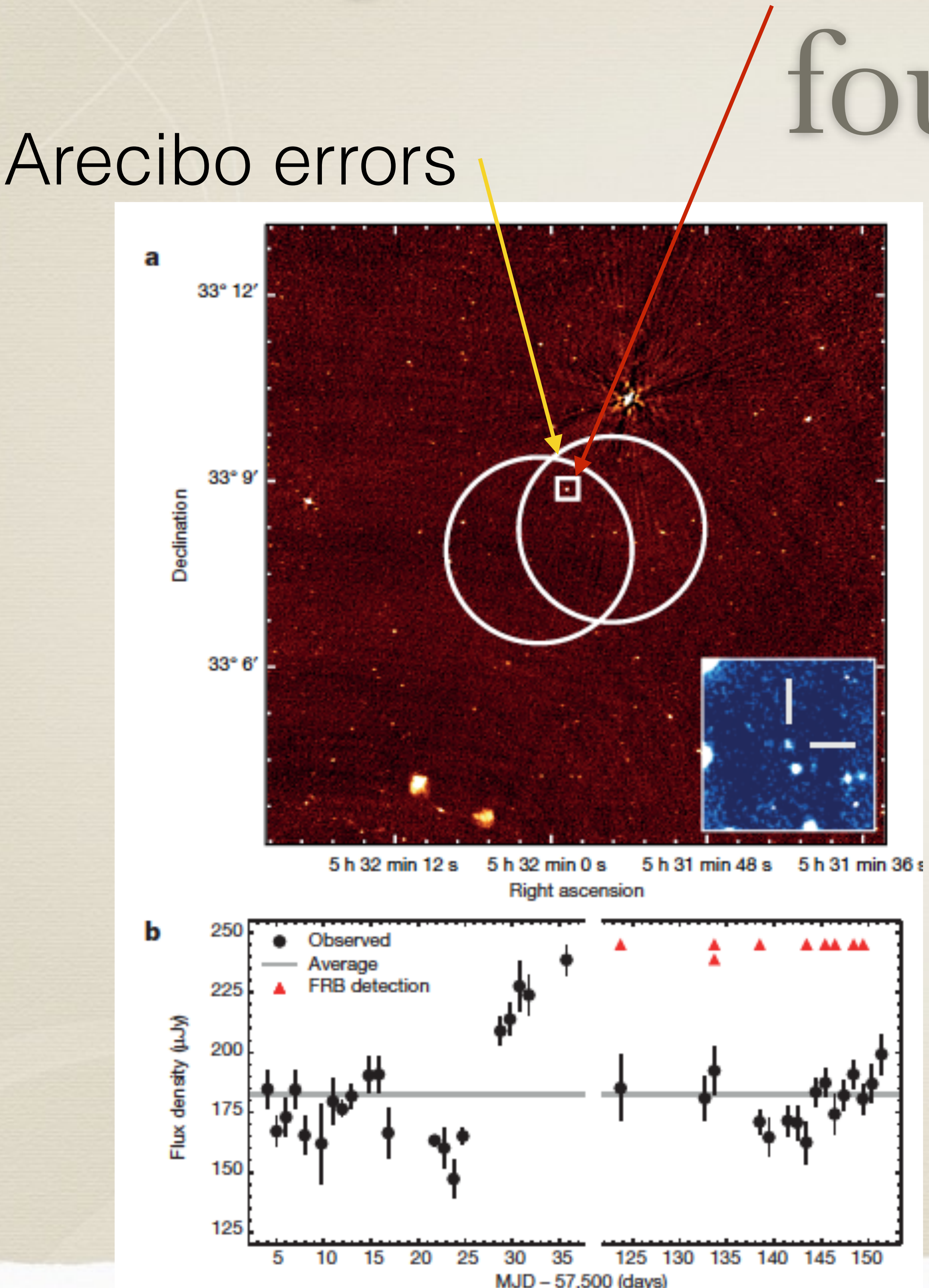


2017-
四川

Conclusions

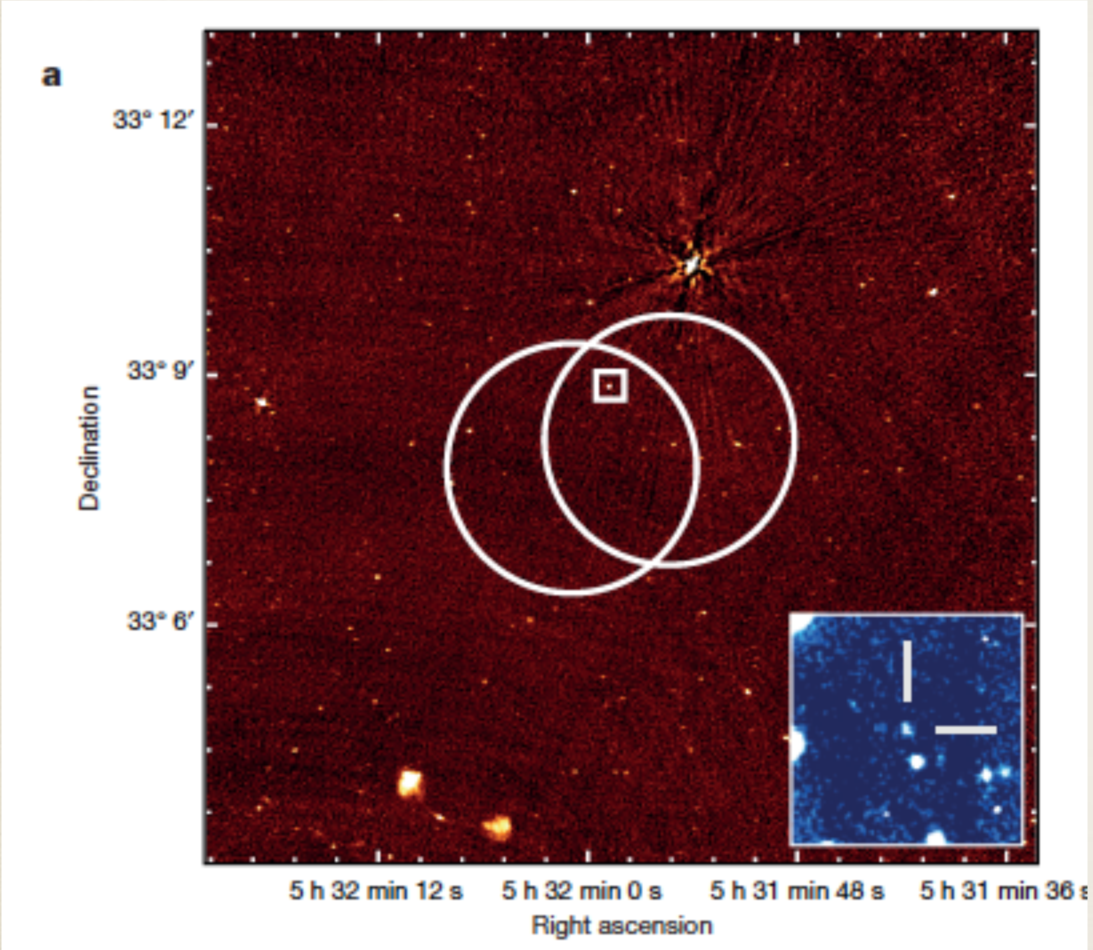
* Fast Radio Bursts are cosmological objects
* They are likely related to compact objects
* At least one FRB is repeating

A persistent radio source found



- chance prob. < 1e-5
- variable at 10% on day time scales
- No correlation between radio flux & bursts

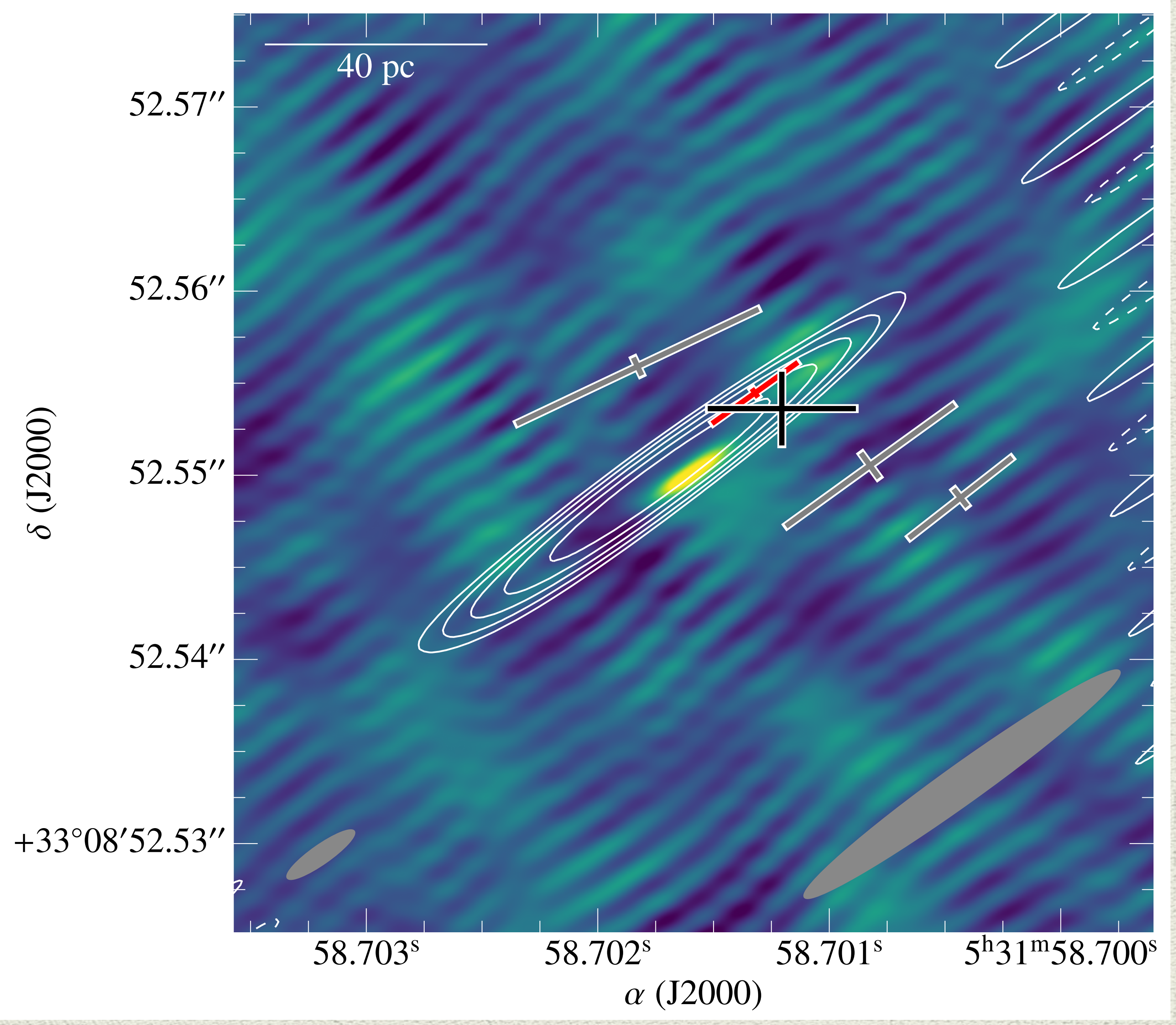
the coincident faint, unresolved optical source



- archival Keck data @2014, m_R(AB)=24.9+-0.1
- recent Gemini data, m_r(AB)=25.1+-0.1
- undetected in IR, ALMA's 230GHz, nor XMM/Chandra

EVN image of bursts & persistent source

- Red cross - strongest burst
- Gray crosses - other 3 bursts
- Black cross - average burst position
- White contours - persistent source at 1.7 GHz
- Color scale - persistent source at 5 GHz
- Burst - persistent source separation < 40 pc at 95% CL.



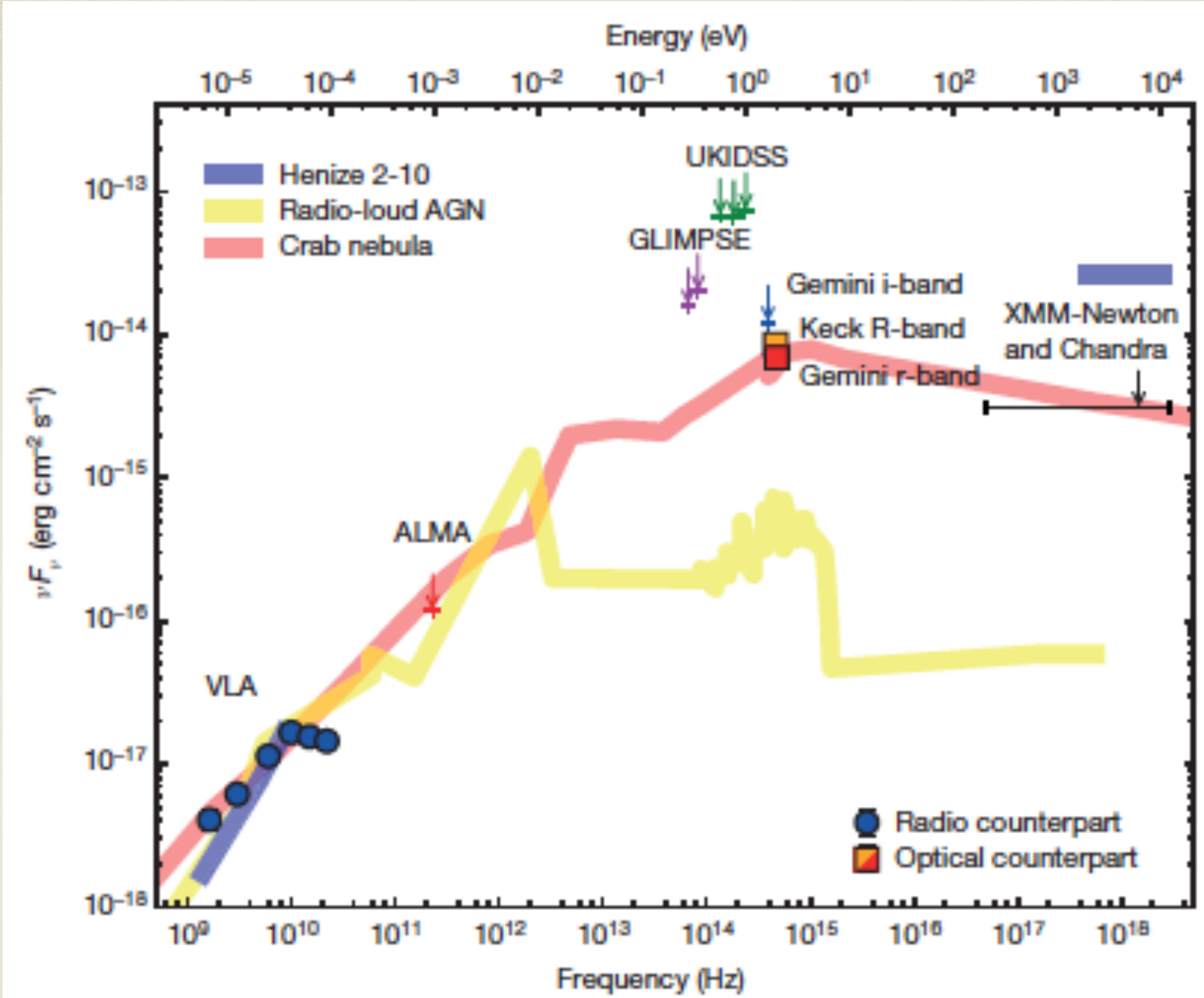


Figure 3 | Broadband spectral energy distribution of the counterpart. Detections of the persistent radio source (blue circles), the optical counterpart (red and orange squares) and 5σ upper limits at various frequency bands (arrows) are shown; see Methods for details. Spectral energy distributions of other radio point sources are scaled to match the radio flux density at 10 GHz and overlaid for comparison: low-luminosity AGN in Henize 2-10, a star-forming dwarf galaxy[28] placed at 25 Mpc (blue); radio-loud AGN QSO 2128−123[29] scaled by $10^{-4.3}$ to simulate a lower-luminosity AGN and placed at 3 Gpc (yellow); and the Crab nebula[30] at 4 Mpc (red). F_ν is the flux density and νF_ν is the flux density weighted by photon energy.

Size and energetics constraints

	Burst	Source	Burst-source separation
Angular (mas)	~2	~0.2	<~12
Physical	<~7 pc	<~0.7 pc	<~40 pc
Size from variability	<~3×10^{7} cm	<~3×10^{15} cm?	—
L_{Radio} (erg/s)	~10^{43}	~10^{39}	—
L_X (erg/s)	—	<5×10^{41}	—

→ Bursts and persistent source are probably physically associated.

→ Compare Cassiopeia A: brightest radio SNR, L_{Radio}~ 4×10^{34} erg/s, R~5 pc.

Possible origins of persistent source

- Young ($10^{2\text{-}3}$ yr old) SNR powered by spin-down of a central pulsar.
- Host similarity to SLSNe & LGRBs.
- Alternative: LL-AGN with a compact, loud, radio counterpart?

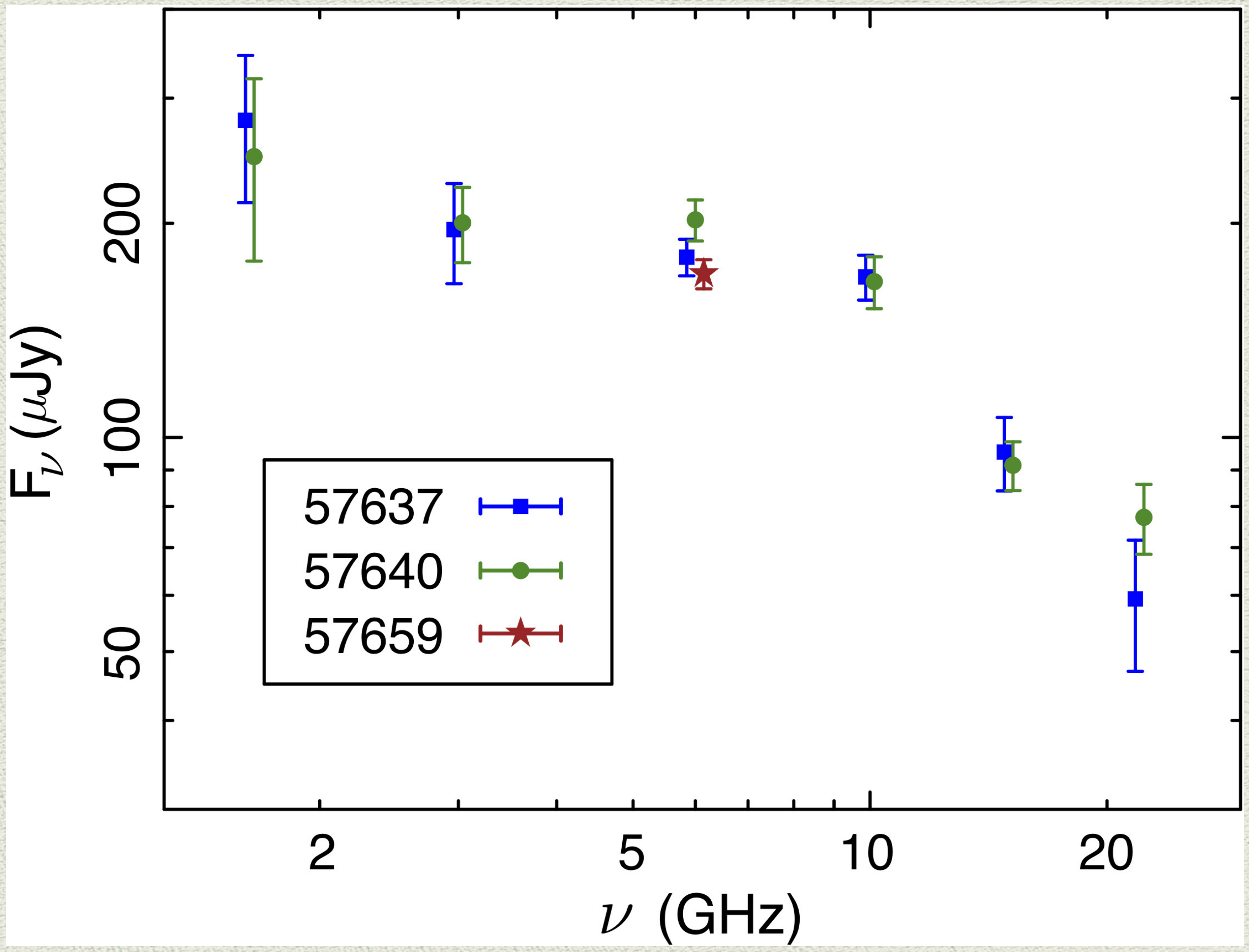
Further constraints:

- DM contribution from the nebula?

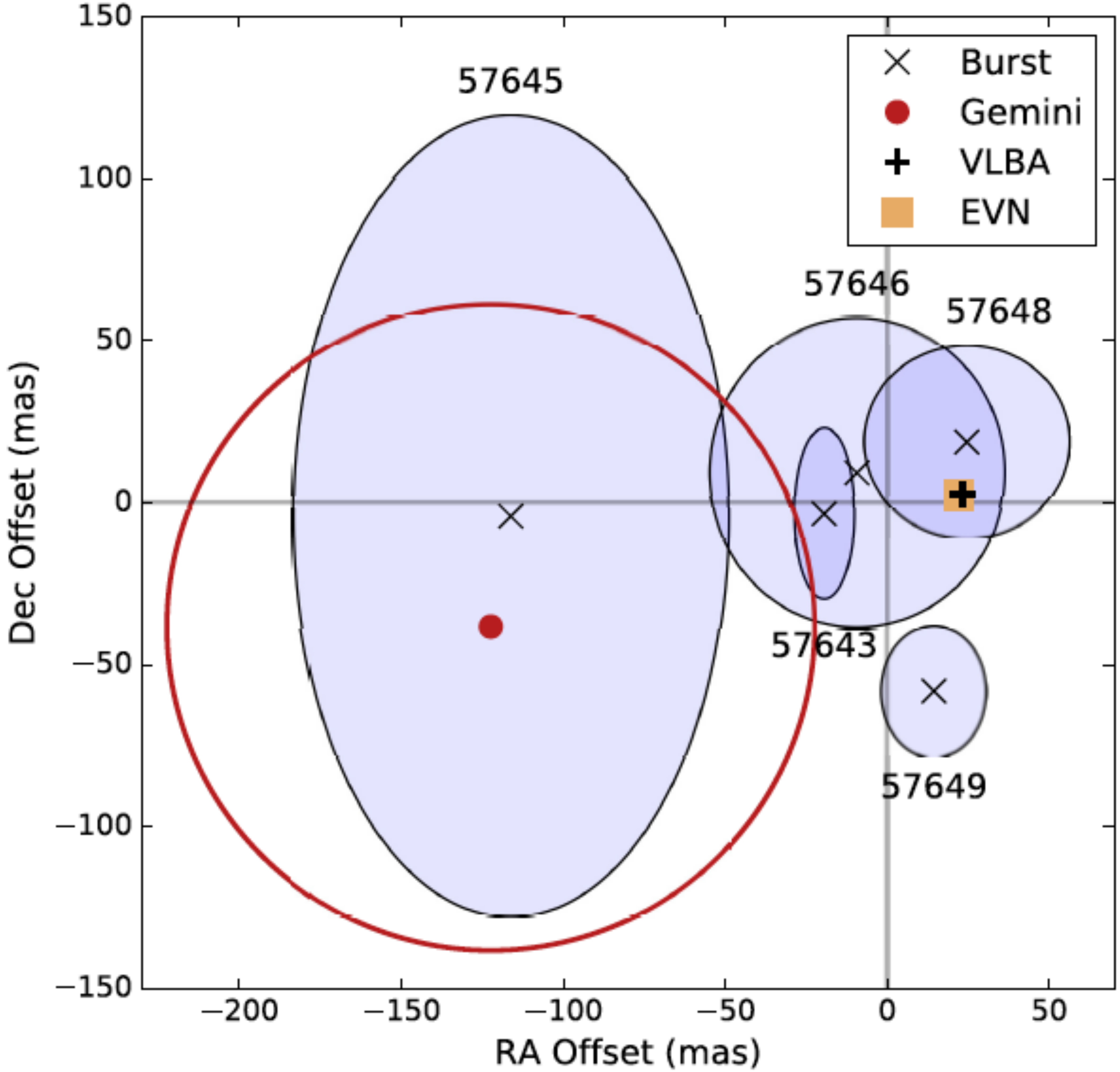
$$DM_{\rm SNR} \simeq 10 \left(\frac{M_{\rm SNR}}{M_\odot}\right) \left(\frac{R_{\rm SNR}}{\rm pc}\right)^{-2} {\rm pc\ cm^{-3}}$$

- Persistent source: synchrotron emission of SNR shock-heated ISM + PWN

VLA spectrum of persistent source



(Chatterjee et al. 2017)



Extended Data Figure 1 | The offset of FRB 121102 from the persistent counterpart. Five bursts detected at the VLA with the highest resolution (A-array, 3 GHz) are plotted (crosses), with epoch indicated by MJD values. The (right ascension (RA), declination (Dec)) coordinate difference (burst relative to counterpart) is shown with an ellipse indicating the 1σ error calculated as the quadrature sum of errors in the two sources. VLBA and EVN positions are indicated, with 1σ errors smaller than the symbols. The centroid of the Gemini optical counterpart is shown (red dot) with an estimated 1σ error circle of 100 mas (red) from fitting and radio-optical frame tie uncertainties.

- z<=0.32, ~1.7 Gpc
- faint optical and no-detection at 230GHz => low star formation rate host galaxy, ~0.06-19 M_{sun} yr^{-1}
- absolute M~-16@z=0.32 similar to SMC, 10^9 M_{sun}

* compactness of radio source implies size<8pc
* Not consistent with extended galaxy or star-forming region
* Young SNR?
* projected distance of the burst source and persistent <500 pc
* What are their relation?