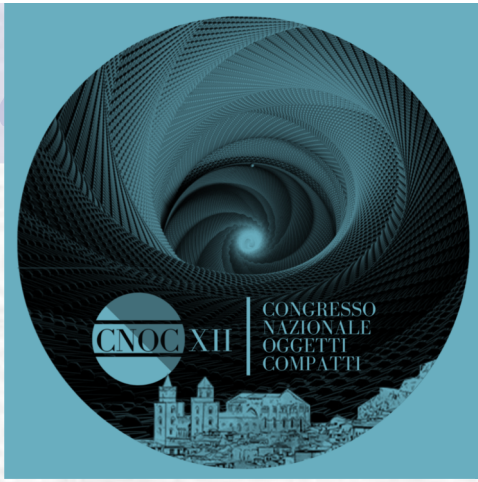


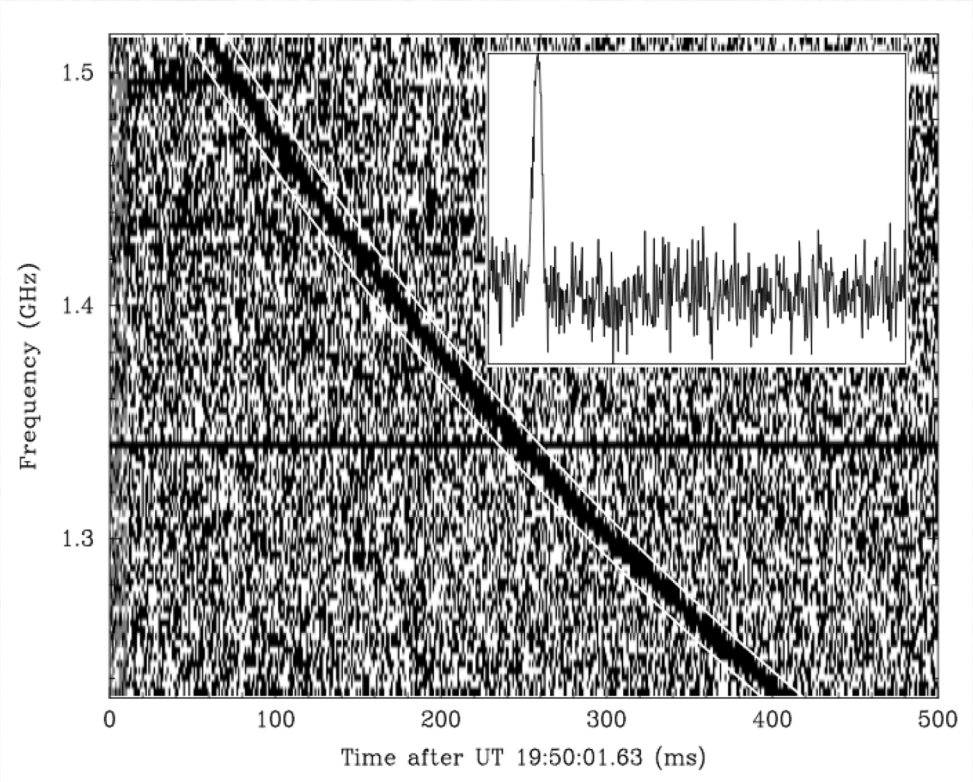
Congresso Nazionale Oggetti Compatti XII

The FRBs' saga: mysteries, suspects, and culprits

Andrea Possenti

Osservatorio Astronomico di Cagliari

FRBs' saga: 1st episode



[Lorimer et al 2007]

FRB20010724

Duration $\Delta t \approx 5$ ms

Dispersion Measure DM ≈ 375 pc/cm^3

First case of detection of an highly dispersed and bright radio burst

Contributions to the dispersion measure and distances

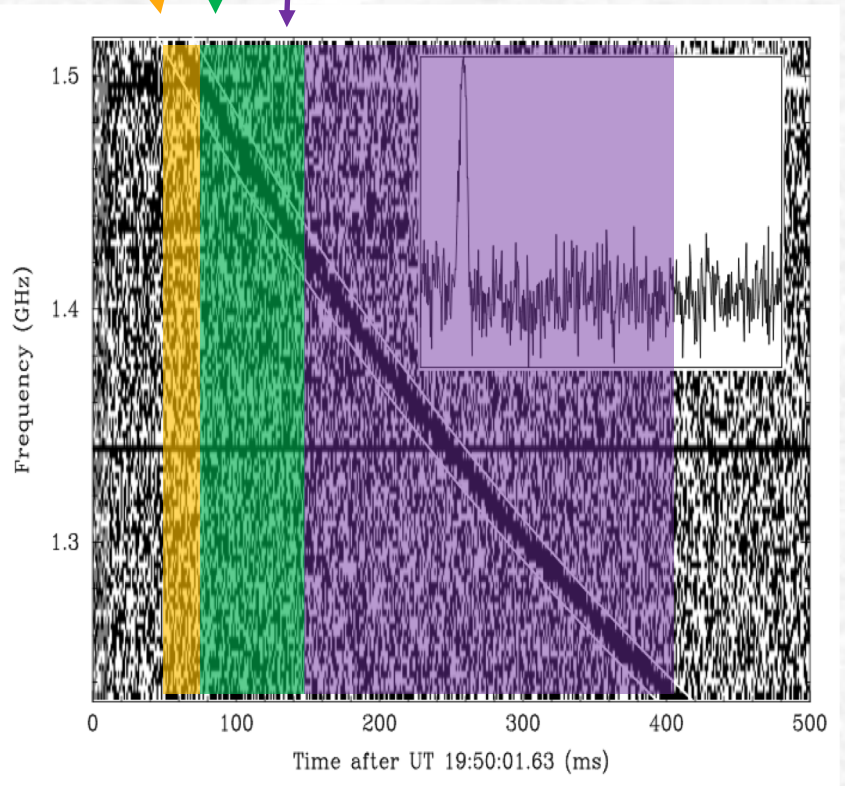
$$\mathrm{DM_{FRB}}(z) = \mathrm{DM_{MW,ISM}} + \mathrm{DM_{MW,halo}} + \mathrm{DM_{cosmic}}(z) + \mathrm{DM_{host}}(z)$$

$DM_{MW,ISM}$ = contribution of the Milky Way

$DM_{MW,halo}$ = contribution of the Milky Way Halo

DM_{host} = contribution of the host Galaxy

DM_{cosmic} = contribution of the Inter Galactic Medium



[courtesy Matteo Trudu]

Using the simplified formula of [Ioka 2003] or [Inoue 2004] for the redshift vs DM relationship (for $z < 1$), recently improved by [Mcquart et al 2020]

$$z \approx DM_{cosmic}\ (\mathrm{pc/cm^3}) / 1000$$

one can use DM_{cosmic} as a proxy for the distance of the source

Distance $D_L \approx$ **1 Gpc**

whence an **Extragalactic origin** !

… and also for the energy released in the event

$$E_{\mathrm{FRB}} = \frac{4\pi D_{\mathrm{L}}^2 \mathcal{F}_\nu \Delta\nu}{(1+z)},$$

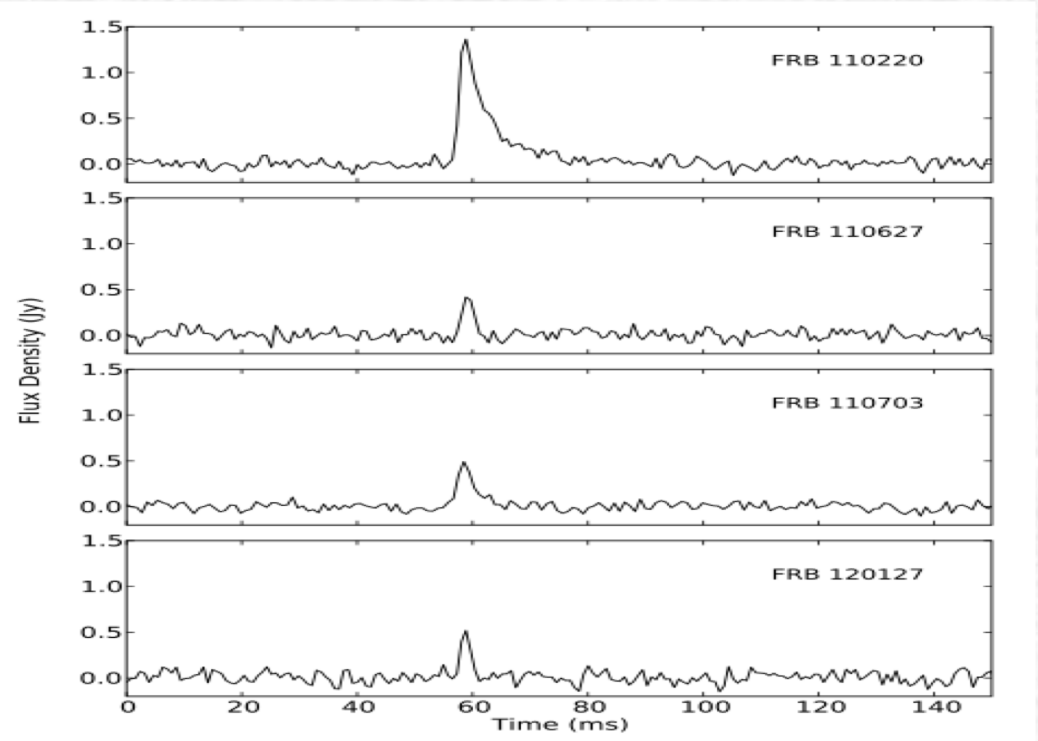
where $F_\nu = S_\nu W \approx 30$ Jy ms

$\Delta\nu \approx 10^9$ Hz

Energy released $\mathbf{E_{FRB}} \approx \mathbf{10^{40}}$ **erg** [Lorimer et al 2007]

Extragalactic and highly energetic events

FRBs' saga: 2nd episode



[Thornton et al 2013]

Discovery of a population of FRBs at Parkes

FRB20110220A, FRB20110627A, FRB20220703A, FRB20120127A

Saga's characters

It is located at https://www.wis-tns.org/

Search

Select time interval and FRBs population

Note that repeaters appear with various names, but are associated to the original one

ID	Name	Reps	Class	RA	DEC	Obj. Type	Repeater of Primary Burst	DM (Err)	Reporting Group/s	Discovery Data Source/s	Disc. Internal Name	Public
92669	FRB 20210407C	1		05:08:03.000	+26:03:39.00	FRB	FRB 20201124A	309 (4) pc/cc	CRAFT	CRAFT	FRB210407.381	Y
92668	FRB 20210407B	1		05:08:03.000	+26:03:39.00	FRB	FRB 20201124A	413 (3) pc/cc	CRAFT	CRAFT	FRB210407.260	Y

As today there are 630 catalogued FRBs

Estimates of the rate ...

≈ 2800 sky/day for fluence > 2.0 Jy * ms at 1.4 GHz from Parkes surveys "complete"
[Keane & Petroff 2015]

Nowadays the determination became much more sophisticated, trying to fully include observational biases:

≈ 10^5 sky/day for fluence > 0.0146 Jy * ms at 1.4 GHz for 1 ms event at 7σ [Niu et al 2021]

≈ 820 ±60 ±200 sky/day for fluence > 5 Jy * ms at 0.6 GHz [CHIME/FRB 2021]

which translates into a volumetric rate

≈ 7×10^4 in a Gpc^3/year [Shin et al 2022]

also compatible with **isotropic distribution**

Some comparison with rates of other cosmic events

≈ 2×10^5 in a Gpc^3/year for Core Collapse SNae [Li et al 2011]

≈ 10^5 in a Gpc^3/year for type Ia SNae [Scannapieco & Bildstein et al 2005]

≈ 2.5×10^4 in a Gpc^3/year for Soft Gamma Repeaters [Ofek et al 2007]

≈ 2-20 $\times 10^2$ in a Gpc^3/year for Double Neutron Star mergers [Abbott et al 2020]

≈ 2-20 $\times 10^2$ in a Gpc^3/year for Long Gamma-Ray burst beamed everywhere [Kulkarni et al 2014]

≈ 5-20 $\times 10^2$ in a Gpc^3/year for Short Gamma-Ray burst beamed everywhere [Kulkarni et al 2014]

A remarkably high event rate! Suggestive to investigate the origin of the FRB

Frequency bands of observation

Telescope	Centre Frequency (MHz)	Bandwidth (MHz)	No. of Polarizations
WSRT	1370	300	2
ASKAP Incoherent	1272	336	2
ATCA	5500	2000	2
	7500	2000	2
CHIME	600	400	2
DSA	1400	220	2
DSN	2250	115	2
	8360	450	2
Effelsberg	1360	300	2
	6000	4000	2
EVN	1700	128	2
	5000	128	2
FAST	1250	500	2
GBT	350	100	2
GMRT	650	200	2
LOFAR	150	80	2
Lovell	1400	336	2
MeerKAT	1284	856	2
	816	544	2
MWA	185	30	2
Northern Cross	408	16	1
Parkes	2368	3300	2
SRT	328	64	2
	1400	500	2
STARE2	1400	188	1
UTMOST	834	16	1
VLA	1400	256	2
	6000	2048	2
VLA (VLASS)	3000	1500	2

A list of the main telescopes and radio bands which produced detections of FRBs

[Caleb & Kean 2021]

FRBs unambiguously detected from 110 MHz up to 8.5 GHz

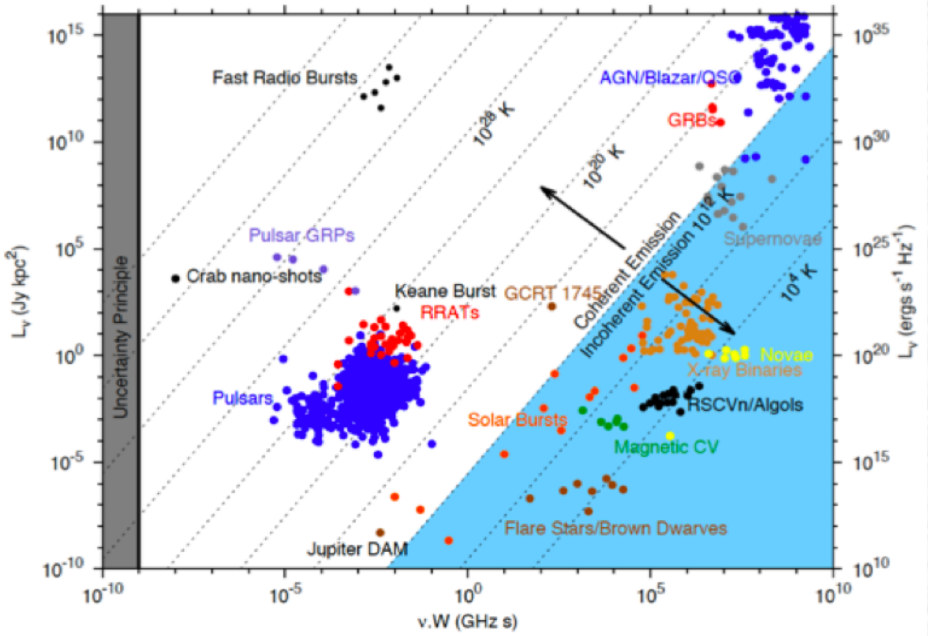
The nature of the emission process

- Burst timescale gives limit on source area
  $A \leqq (c\,\Delta t)^2 = (cW)^2 = (1500\ \mathrm{km})^2 \approx 10^{17}\ \mathrm{cm}^2$
- Source power is very large
  $\mathbf{P} = \mathbf{E}_{\mathrm{FRB}} / W \approx 10^{42}\ \mathrm{erg/sec}$
- Typically $\Delta\nu \approx \nu \approx 10^9\ \mathrm{Hz}$
- Brightness temperature T_b: equivalent black-body temperature in Rayleigh-Jeans limit

$$T_b = \frac{c^2}{2k\nu^2} B_\nu(T) = \frac{c^2}{2k\nu^2} \frac{4\pi D_{\mathrm{L}}^2 S_\nu}{A}$$

$$= \frac{c^2}{2k\nu^2} \frac{E_{\mathrm{FRB}}}{A\,W\Delta\nu} \geq 10^{35}\ \mathrm{K}$$

The radio transient "phase space"

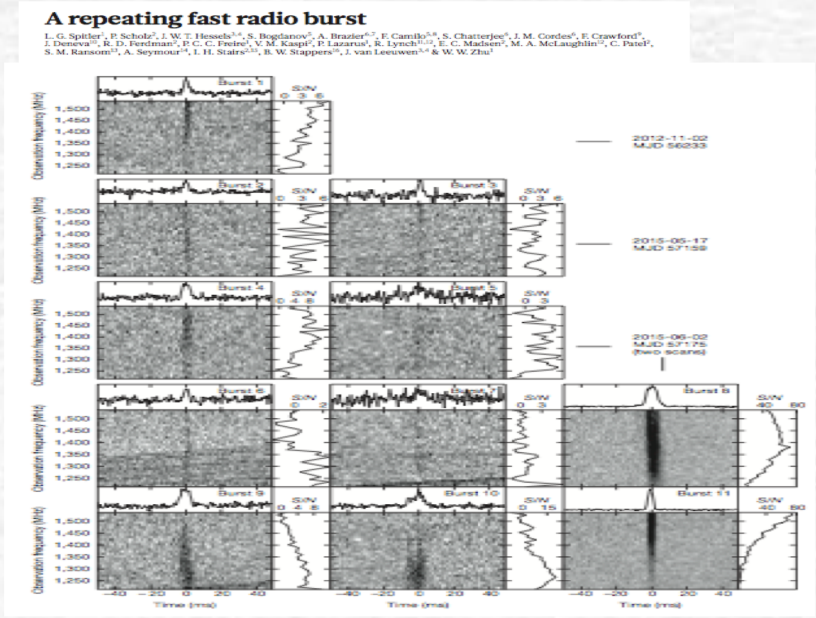


[Pietka et al. 2015]

Since $L_\nu = 4\pi D_{\mathrm{L}}^2 S_\nu$ one can rewrite the relation to obtain $T_b = \dfrac{L_\nu}{2k\,(\nu\,W)^2}$ and hence the plot…

Coherent emitters!

FRBs' saga: 3rd and 4th episodes



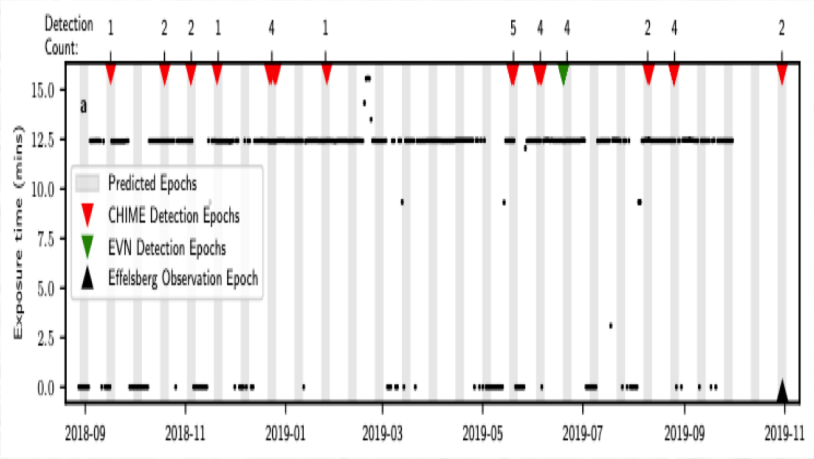
[Spitler et al 2015]

FRB20121102A

Discovery of repeating FRBs (repeaters: rFRB)

FRB20180916B

Discovery of periodicity in some repeating FRBs



[CHIME collaboration 2020]

A great observational advantage for characterizing and localizing the source !

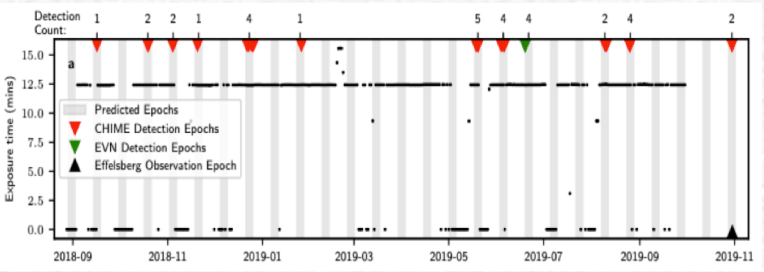
Repeaters (rFRB) family

24 repeaters known so far (≅ 4% of the whole published population)

[Zhang et al 22]

TNS Name	ν_c [a] MHz	DM (pc cm^{-3})	DM_{MW} (pc cm^{-3})	DM_E [b] (pc cm^{-3})	W_{obs} (ms)	S_{peak} (Jy)	F_{obs} (Jy ms)	z	E (10^{39} erg)	$\overline{F}$ [d] (Jy ms)
FRB 20121102A	1375	557.00 ± 2.00	188.00	369.00	3.00 ± 0.50	$0.40^{+0.40}_{-0.10}$	$1.20^{+1.60}_{-0.55}$	0.31	0.13	0.36
FRB 20171019A	1297	460.80 ± 1.10	37.00	423.80	5.40 ± 0.30	40.50	219.00	0.35	34.01	101.62
FRB 20180814A	600	189.38 ± 0.09	87.00	102.38	2.60 ± 0.20	8.08 [c]	21.00	0.09	0.13	22.57
FRB 20180908B	600	195.70 ± 0.90	38.00	157.70	1.91 ± 0.10	0.60 ± 0.40	2.70	0.13	0.04	2.03
FRB 20180916B	600	349.70 ± 0.70	200.00	149.70	1.06 ± 0.05	7.64 [c]	8.10	0.12	0.12	10.26
FRB 20181017A	600	1281.00 ± 0.60	43.00	1238.00	20.20 ± 1.70	0.79 [c]	16.00	1.03	60.07	8.50
FRB 20181030A	600	103.50 ± 0.70	40.00	63.50	0.59 ± 0.08	12.37 [c]	7.30	0.05	0.02	4.75
FRB 20181119A	600	364.00 ± 0.30	34.00	330.00	2.66 ± 0.10	0.94 [c]	2.50	0.28	0.24	1.77
FRB 20181128A	600	450.20 ± 0.30	112.00	338.20	2.43 ± 0.16	1.81 [c]	4.40	0.28	0.46	3.45
FRB 20190116B	600	443.60 ± 0.80	20.00	423.60	1.50 ± 0.30	1.87 [c]	2.80	0.35	0.52	1.80
FRB20190117A	600	393.30 ± 0.10	48.00	345.30	1.44 ± 0.03	1.70 ± 0.60	5.90	0.29	0.64	6.36
FRB 20190208A	600	580.20 ± 0.20	72.00	508.20	1.31 ± 0.14	0.60 ± 0.30	2.00	0.42	0.60	1.70
FRB 20190209A	600	424.60 ± 0.60	46.00	378.60	3.70 ± 0.50	0.54 [c]	2.00	0.32	0.28	1.25
FRB 20190213A	600	651.50 ± 0.40	43.00	608.50	4.00	0.50 ± 0.30	3.00	0.51	1.46	1.80
FRB 20190212A	600	301.40 ± 0.20	49.00	252.40	2.10 ± 0.30	1.10 ± 0.60	2.50	0.21	0.13	2.67
FRB 20190222A	600	460.60 ± 0.10	87.00	373.60	2.97 ± 0.90	2.53 [c]	7.50	0.31	1.00	5.45
FRB 20190303A	600	221.80 ± 0.50	29.00	192.80	2.00 ± 0.30	0.50 ± 0.30	2.30	0.16	0.06	2.47
FRB 20190417A	600	1378.50 ± 0.30	78.00	1300.50	1.19 ± 0.02	0.70 ± 0.20	1.70	1.08	7.40	3.10
FRB 20190604A	600	552.60 ± 0.20	32.00	520.60	3.00 ± 0.40	0.90 ± 0.40	8.30	0.43	2.64	5.00
FRB 20190711A	23.8	593.10 ± 0.40	56.40	536.70	6.50 ± 0.50	5.23 [c]	34.00	0.45	9.88	17.70
FRB 20190907A	600	309.50 ± 0.30	53.00	256.50	0.54 ± 0.14	0.40 ± 0.20	0.90	0.21	0.05	1.10

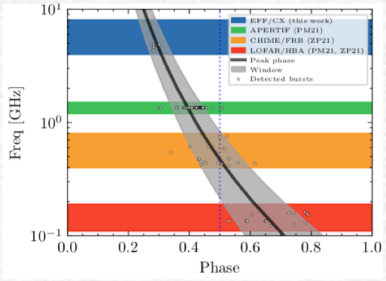
Periodic repeaters



Discovered on 2018 by CHIME, it later showed that its **repeated bursts follows a periodic pattern, with a periodicity ~ 16 days and an active phas of ~ 5 days**
[CHIME collaboration 2020]

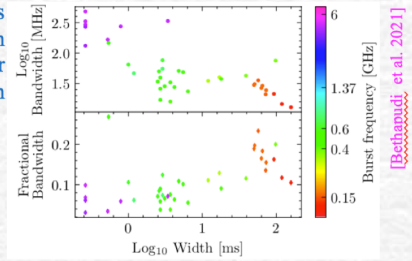
The first example: FRB20180916B

[Bethapudi et al. 2021]

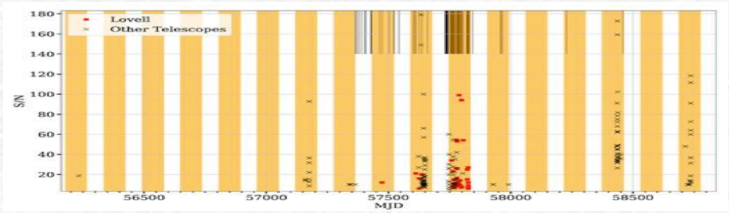


Higher frequency bursts are narrower, larger in bandwidth and lower fractional bandwidth

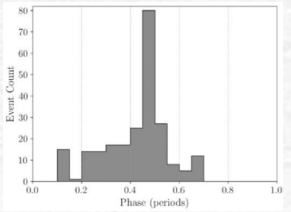
Detected **chromaticity** in the phases of insurgence of the bursts
[Pleunis et al. 2021][Pastor-Marazuela et al. 2021]
[Bethapudi et al 2021]



[Bethapudi et al. 2021]



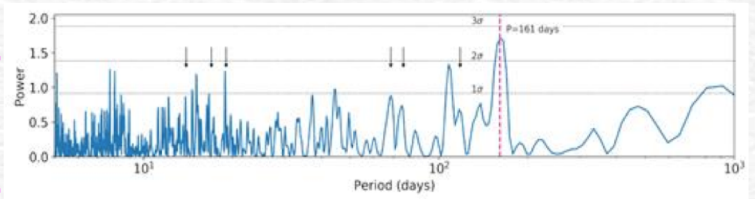
[Raiwade et al 2020]



The second known case: FRB20121102A

The second known case is FRB20121102A
which shows a periodicity ~ 161 days with an active phase of ~ 55% of the cycle

[Cruces et al 2020]



An additional great bonus for planning multi-messenger observations !

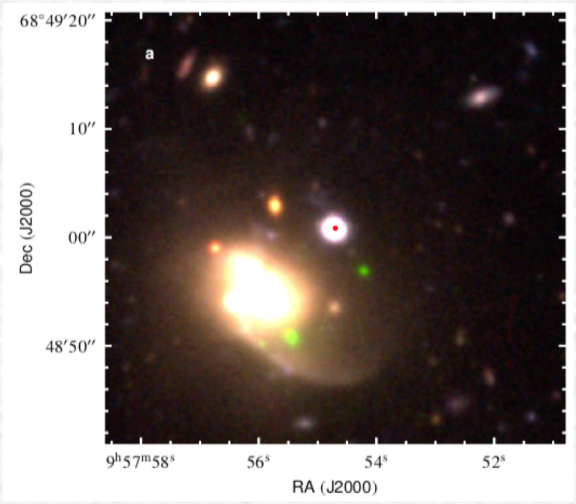
The lair of the culprits

20 FRBs to date have an **host galaxy** securely identified at $0.0001 < z < 0.66$ [Nicastro, Guidorzi et al 21 for a review]

- **Via interferometric imaging of repeaters (à la FRB20121102A)**
- **Imaging of one-off event via triggered accumulation of buffered raw voltages data**

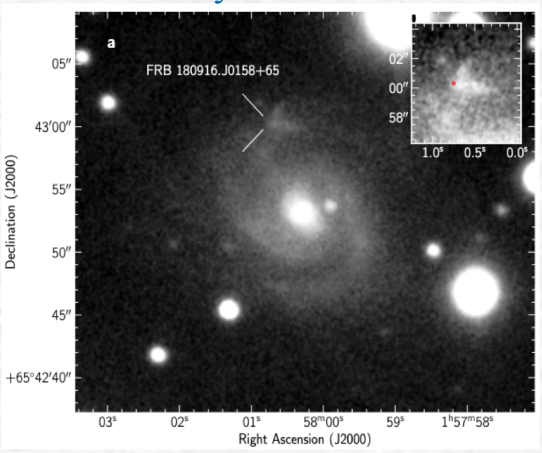
Some remarkable case:

rFRB20200120E in a Globular cluster of M81 at ~3 Mpc



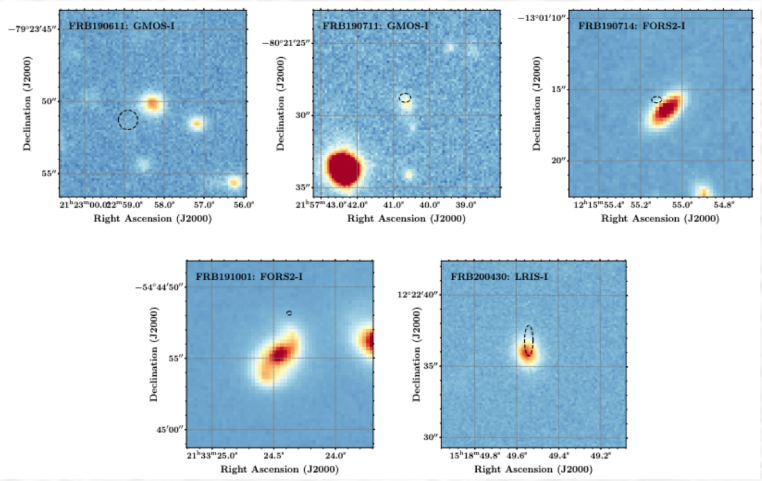
[Kirsten et al 22]

rFRB20180916B in a V shaped region at the outskirt of a spiral Galaxy at z =0.00337



[Marcote et al 20]

5 one-off FRBs and their associated host Galaxies



[Heintz et al 20]

Very diverse properties of the host Galaxies