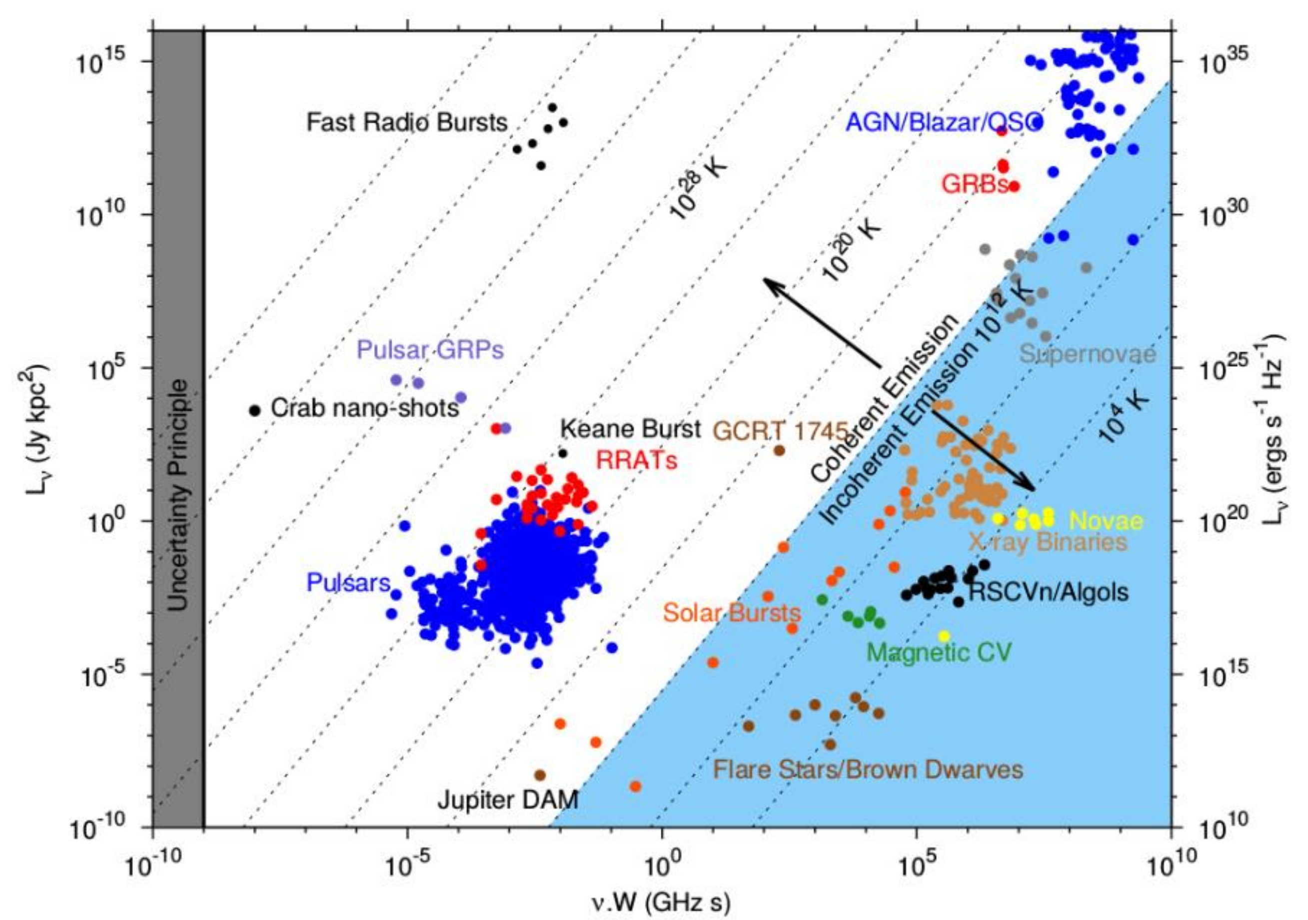
Fast radio bursts and magnetars

SERGEI POPOV (SAI MSU)

Radiotransients



Many different types of transient sources are already detected at radio wavelengths.

However, detection of very short and non-repeating flares of unknown sources without identification at other bands is a very complicated task.

Rotating Radio Transients (RRATs) – millisecond radio bursts from neutron stars, - have been identified in 2006.

In 2007 the first example of a new class of millisecond radio transients have been announced: the first extragalactic millisecond radio burst.

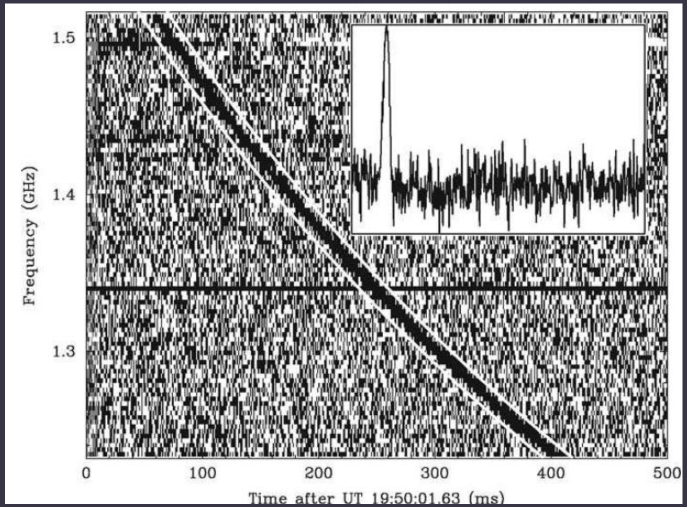
1507.00729, 1411.1067

Brief history of FRBs

2007 Lorimer et al. The first event announced.
2012 Keane et al. The second event.
2013 Thornton et al. Four events. The story really starts.

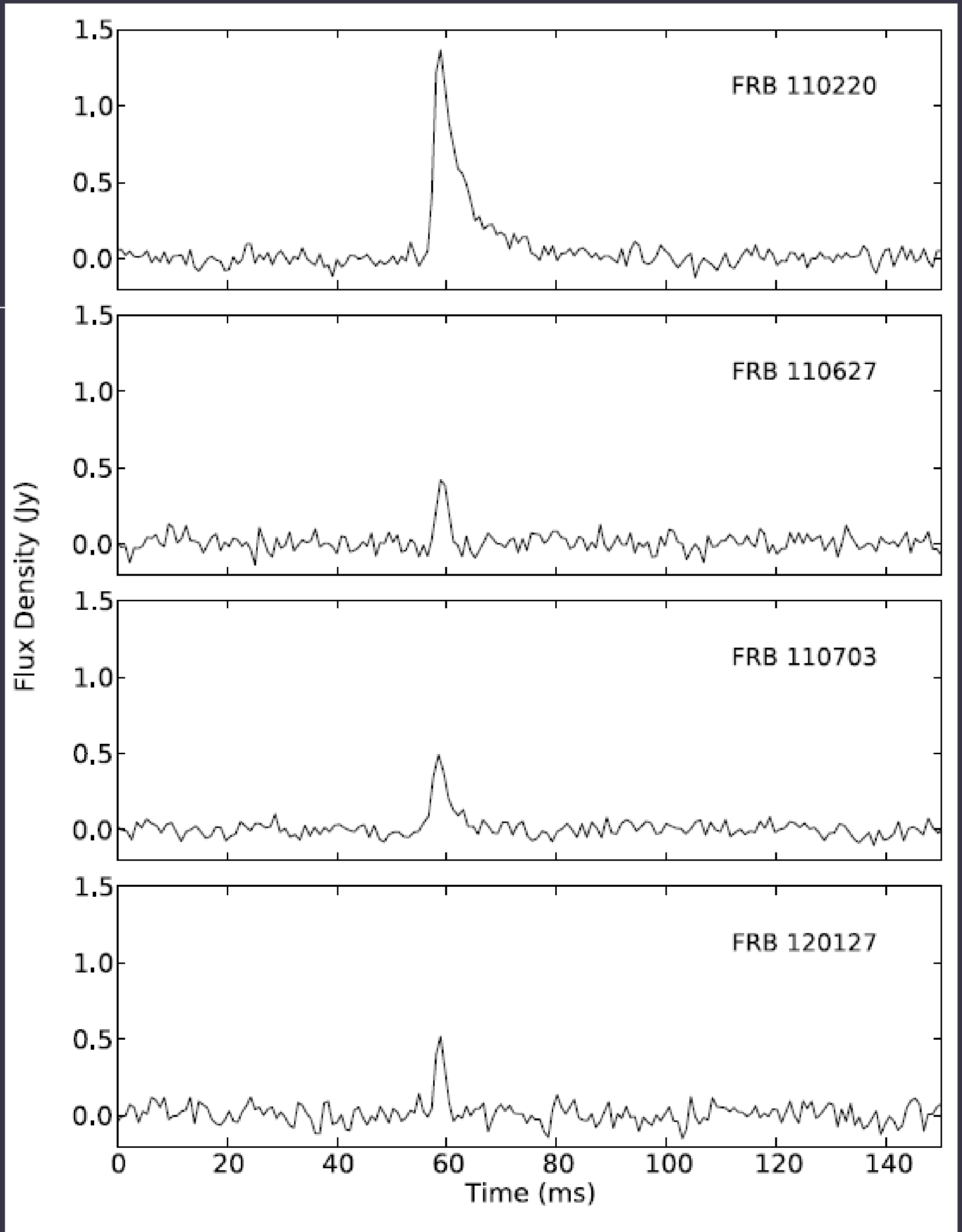
2016 Spitler et al. The first repeating source.
Chatterjee et al. Identification of the host galaxy

Lorimer et al.



Large dispersion measure points to extragalactic origin.

This is supported by isotropic sky distribution and many other considerations.



1307.1628

Catalogue

Parkes - ~30
UTMOST – ~10
ASKAP – ~30
CHIME - ~30
GBT – 2
FAST – 1
Apertif - 1
DSA-10 - 1
Arecibo – 2
Pushchino – ~10 (?)
VLA - 1

~120 FRBs
(several repeaters)

Many bursts are known,
but not yet included in the list.

Rate: several thousands
per day per sky

FRB Catalogue

This catalogue contains up to date information for the published population of Fast Radio Bursts (FRBs). This site is maintained by the FRBCAT team and is updated as new sources are published or refined numbers become available. Sources can now be added to the FRBCAT automatically via the VOEvent Network, details of this process are given in Petroff et al., 2017. FRBs confirmed via publication, or received with a high importance score over the VOEvent Network, are given 'Verified' status and are shown on the default homepage; to see all events (including unverified candidates received via the VOEvent Network) toggle the "Show all/Show verified" button below.

Information for each burst is divided into two categories: intrinsic properties measured using the available data, and derived parameters produced using a model. Cosmological values are obtained using the Cosmology Calculator (Wright, 2006). The intrinsic parameters should be taken as lower limits, as the position within the telescope beam may be uncertain. Where multiple fits or measurements of a burst have been made each one is provided as a separate sub-entry for the FRB.

You may use the data presented in this catalogue for publications; however, we ask that you cite the paper (Petroff et al., 2016) and provide the url (http://www.frbcat.org). Any issues relating to the use of the catalogue should be addressed to FRBCAT team (primary contact: Emily Petroff).

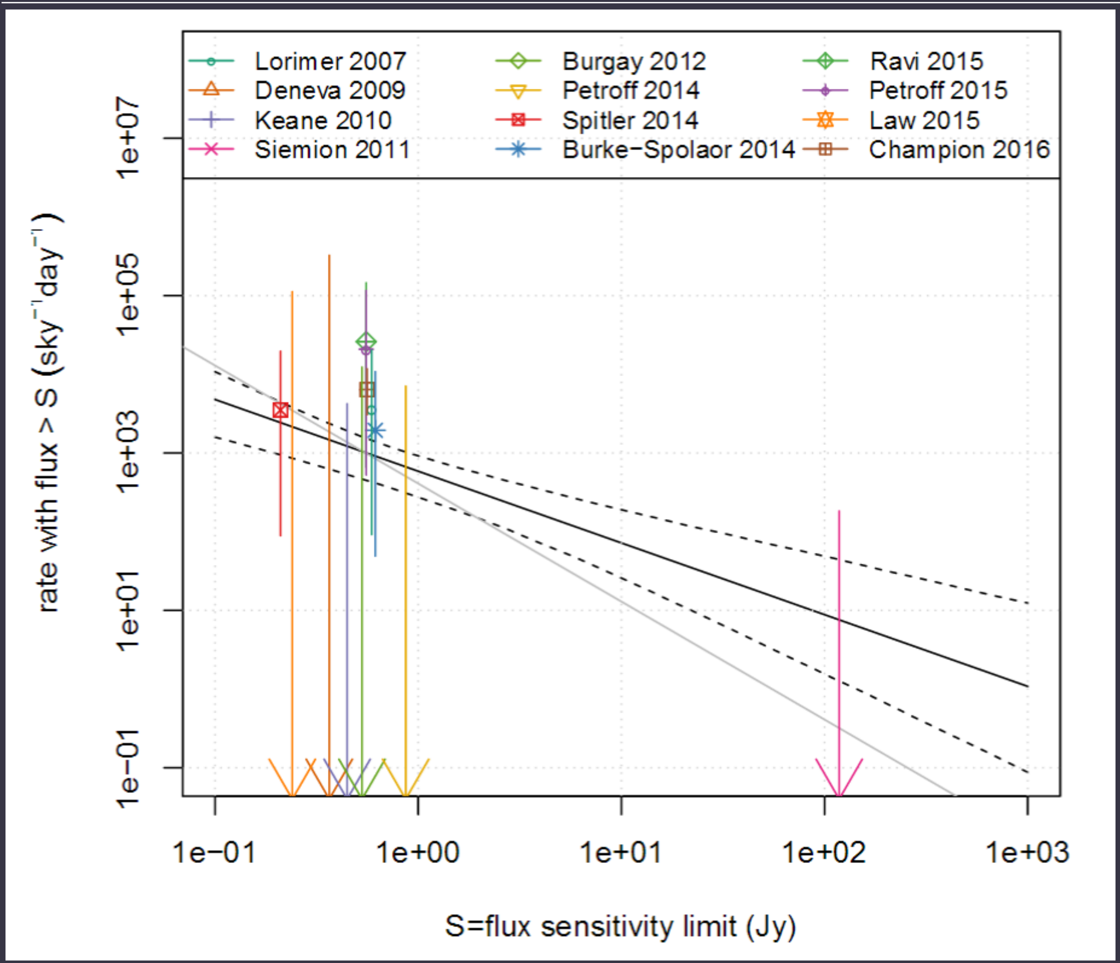
Visible columns | Show verified | Export to CSV | Search | Clear

	FRB	UTC	Telescope	RAJ	DECJ	GL	GB	DM	Width	SNR
+	FRB180311	2018/03/11 04:11:54.800	Parkes	21:31:33.42	-57:44:26.7	337.3	-43.7	1575.6	12	11.5
+	FRB180309	2018/03/09 02:49:32.990	Parkes	21:24:43.8	-33:58:44.5	10.9	-45.4	263.47	0.576	411
+	FRB180301	2018/03/01 07:34:19.760	Parkes	06:12:43.4	04:33:44.8	204.4	-6.4	520	3	16
+	FRB171209	2017/12/09 20:34:23.500	Parkes	15:50:25	-46:10:20	332.2	6.24	1458	2.5	40
+	FRB170922	2017/09/22 11:22:23.400	UTMOST	21:29:50.61	-07:59:40.49	45.1	-38.7	1111	26	22
+	FRB170827	2017/08/27 16:20:18.000	UTMOST	00:49:18.66	-65:33:02.3	303.2	-51.7	176.4±0	0.4	90

http://frbcat.org/

1601.03547

Statistical properties of FRBs



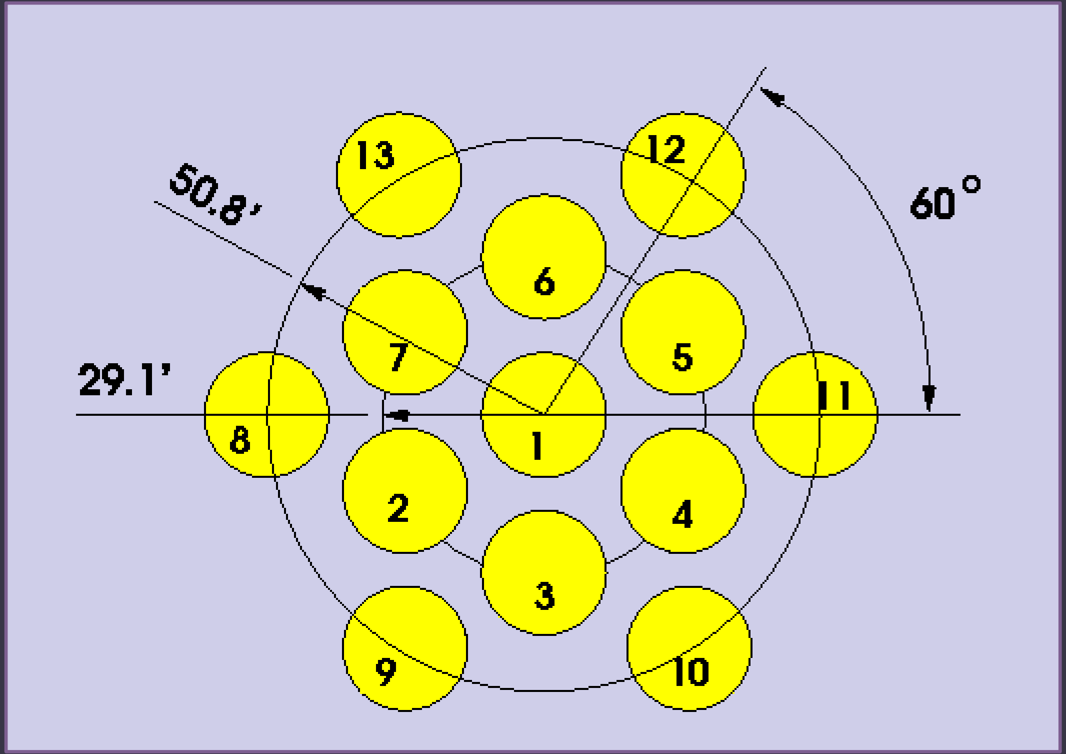
Black solid line –
new data.
Dotted lines –
95% uncertainty.

Grey line is plotted under assumption that index is the Log N – Log S distribution is equal to 3/2.

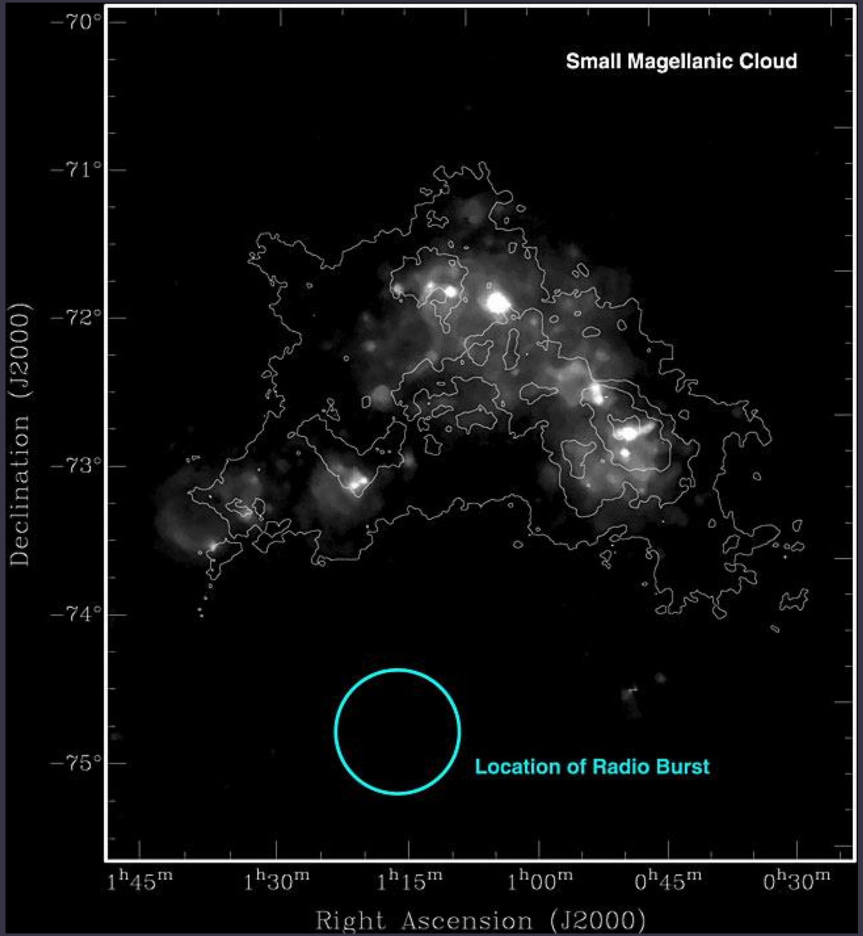
587 per day with flux above 1 Jy.

Localization

Radius of uncertainty circle ~10 arcmin



Usually FRBs are seen just in one beam.



Repeating bursts

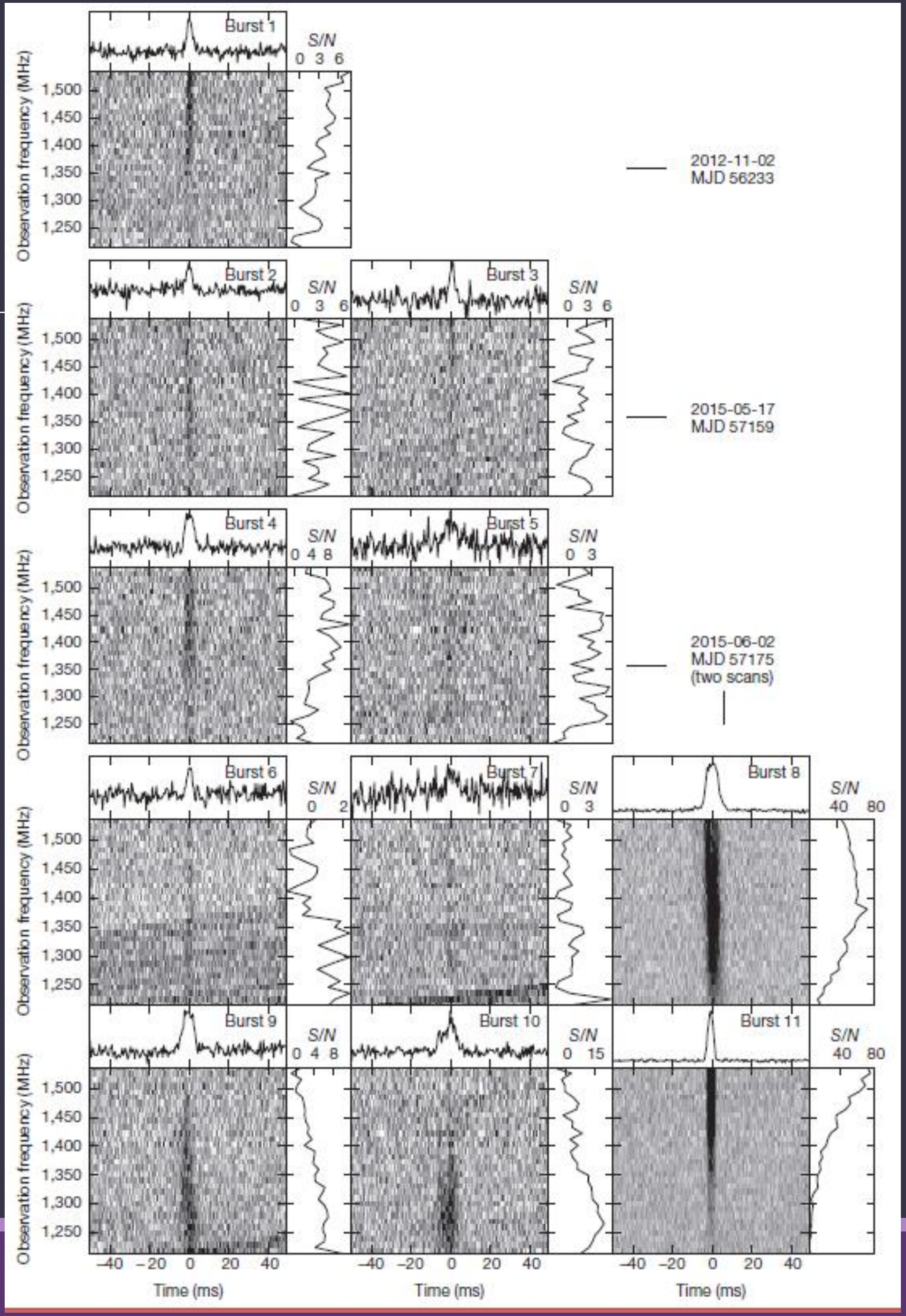
Repeating bursts are detected firstly from FRB 121102.

The source was found at Arecibo.

Initially 10 events reported.
Rate ~ 3/hour
Weak bursts (<0.02-0.3 Ян)

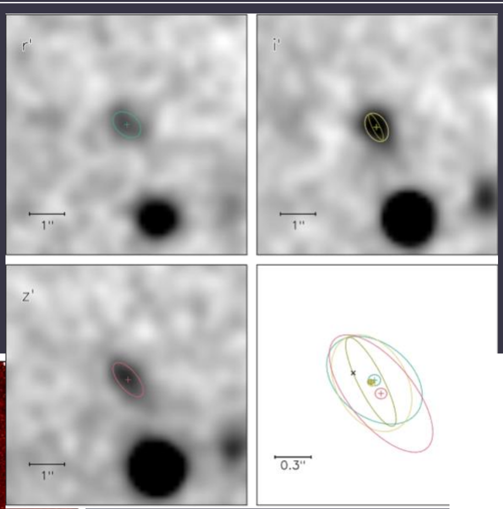
Variable spectral parameters.

Unclear if it is a unique source,
or it is a close relative of other FRBs.

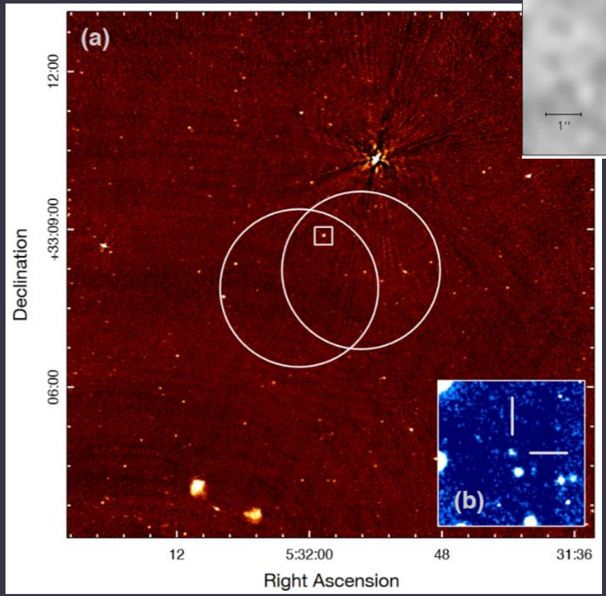


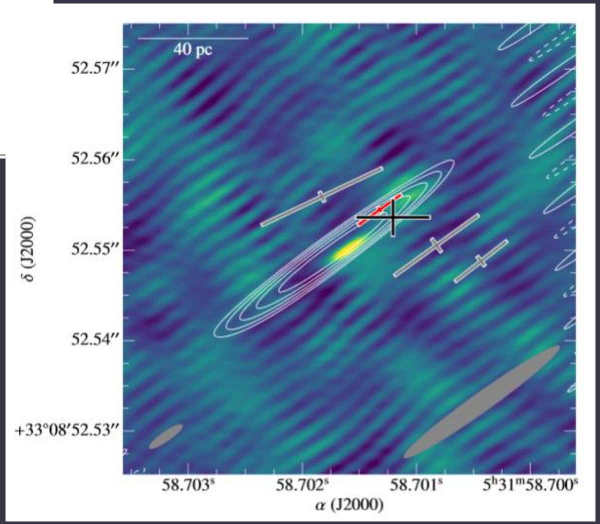
1603.00581

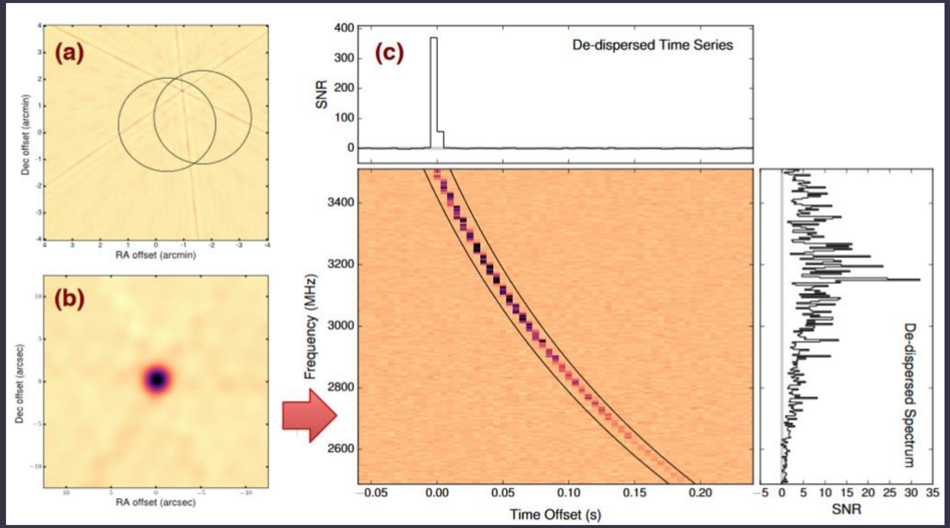
Host galaxy of the FRB



Thanks to precise localization of FRB 121102
it became possible to identify a host galaxy.
This a dwarf galaxy with high starformation rate
at z~0.2 (~1 Gpc).



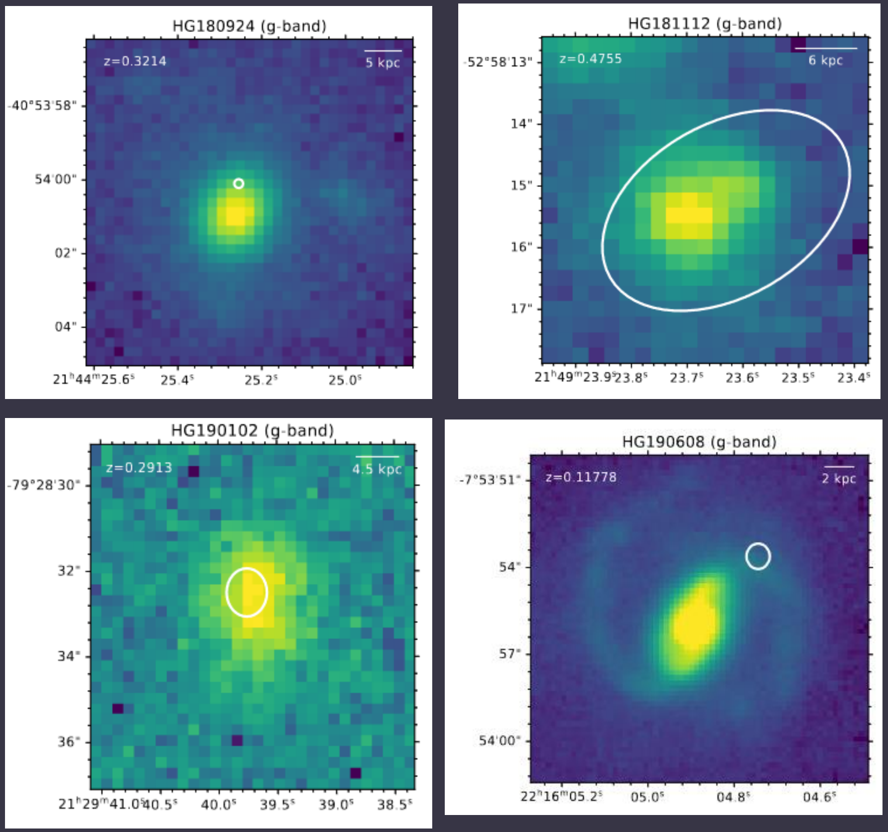


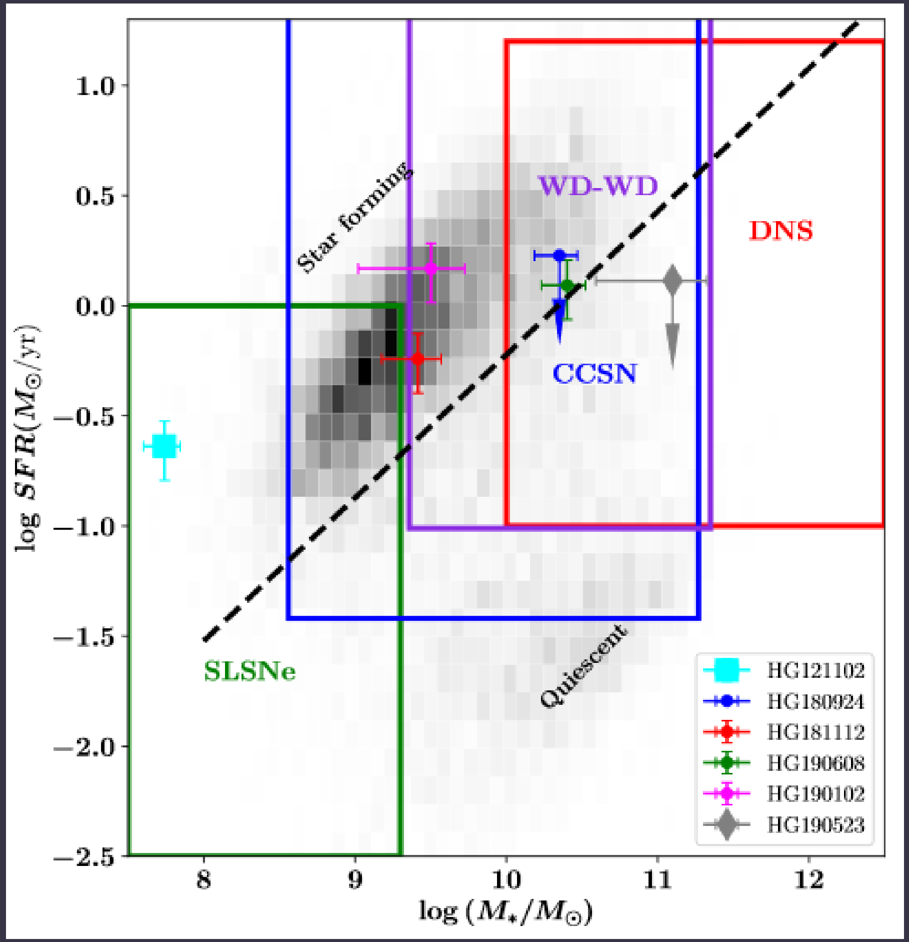


Many localizations by ASKAP

Four new localizations of non-repeating bursts

At the end of 2020 ~10 sources are well localized.

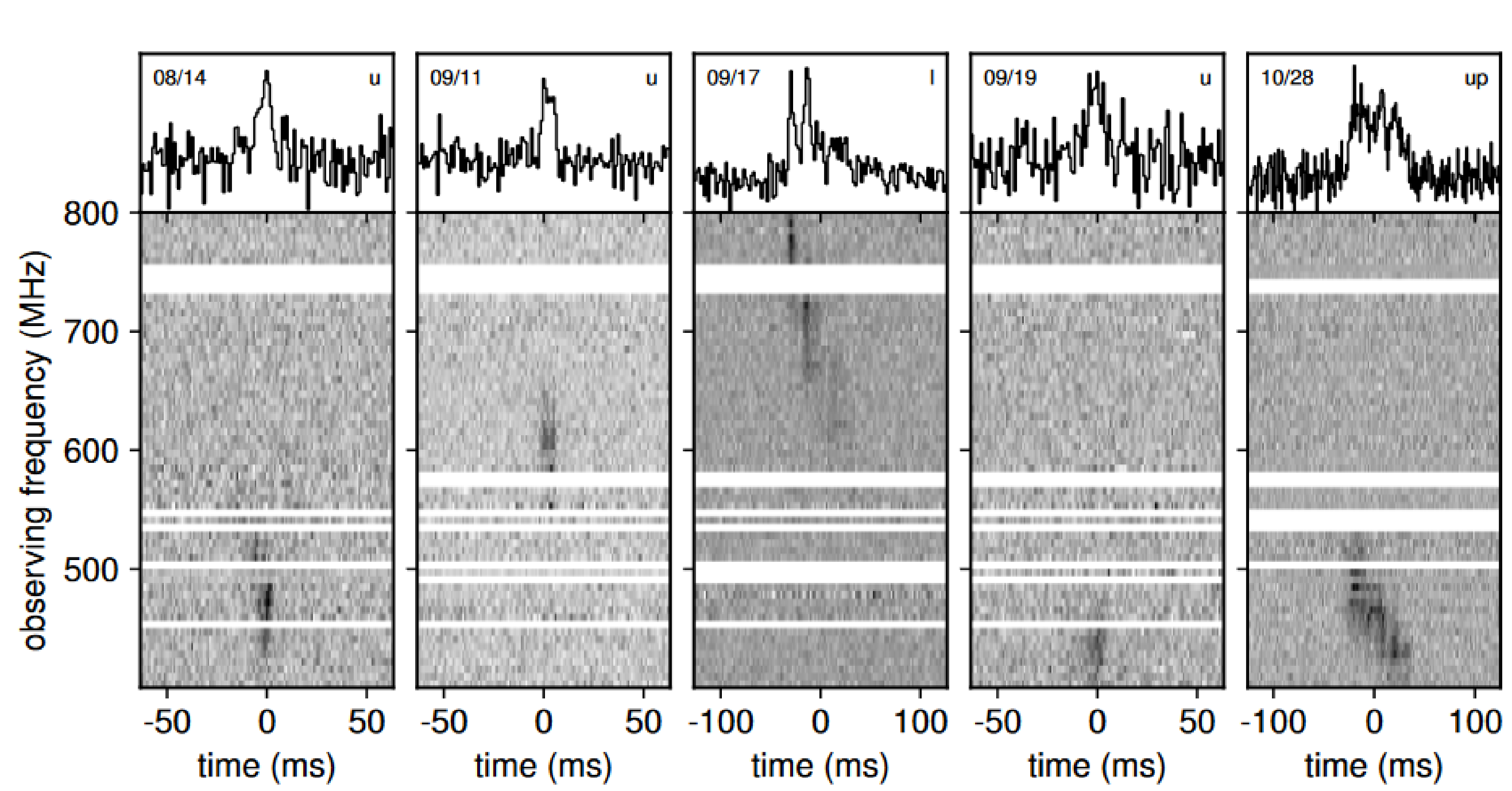




The second repeater

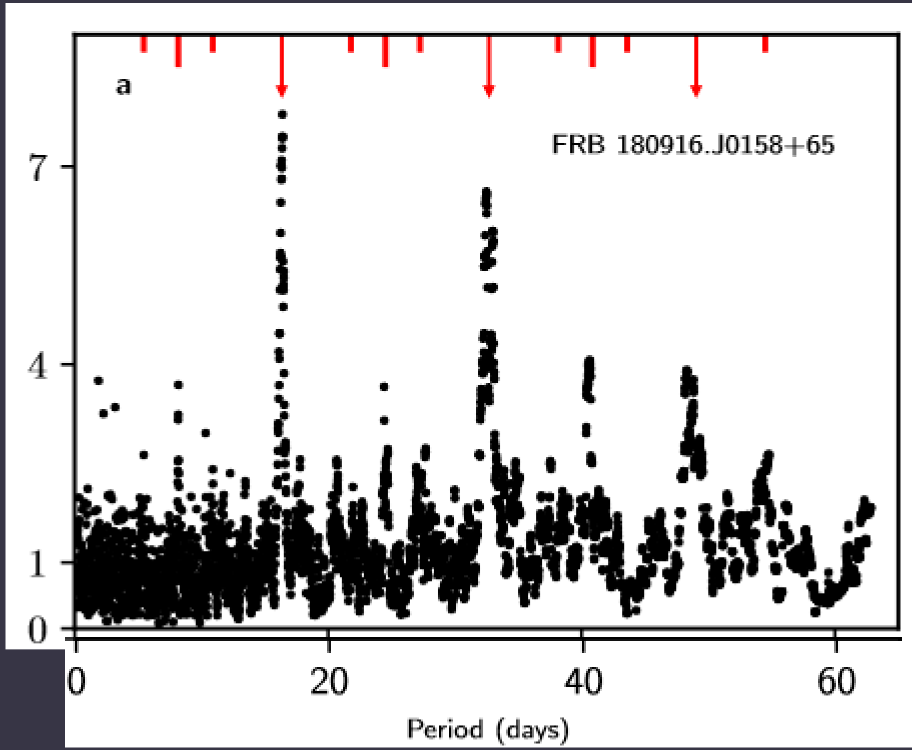
FRB 180814
CHIME

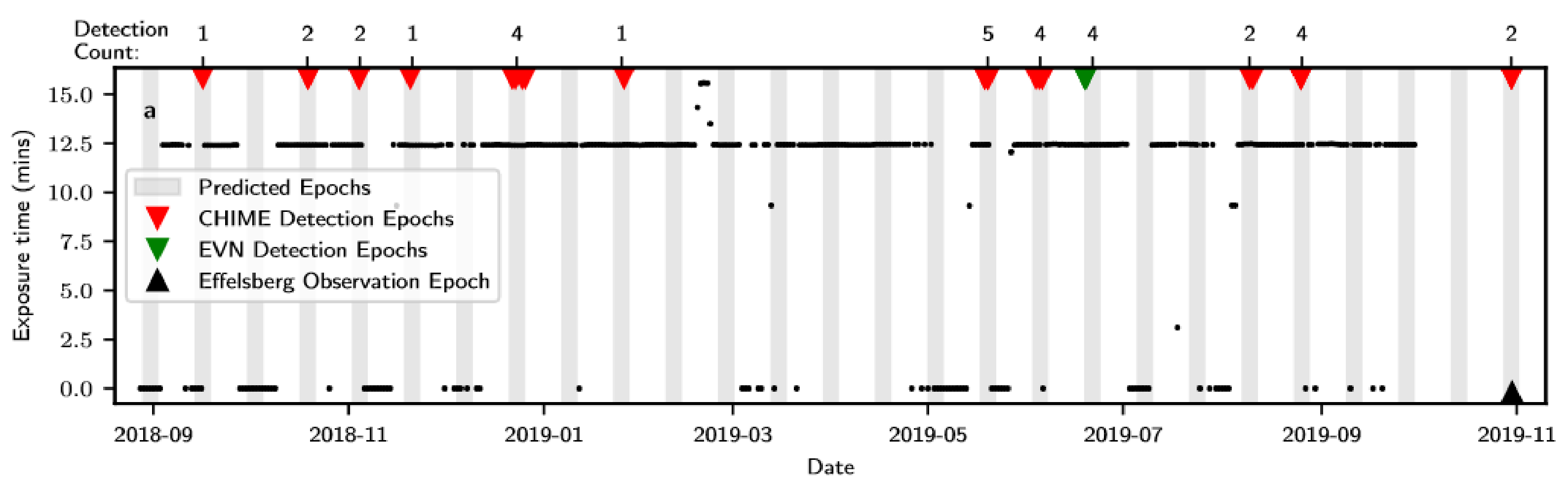
At the end of 2020
~20 repeaters are known.



Periodicity in FRB bursts

FRB 180916.J0158+65
CHIME (+Effelsberg)





The source is localized in a near-by massive spiral galaxy.
Period ~16.35 days

Polarization of FRB emission

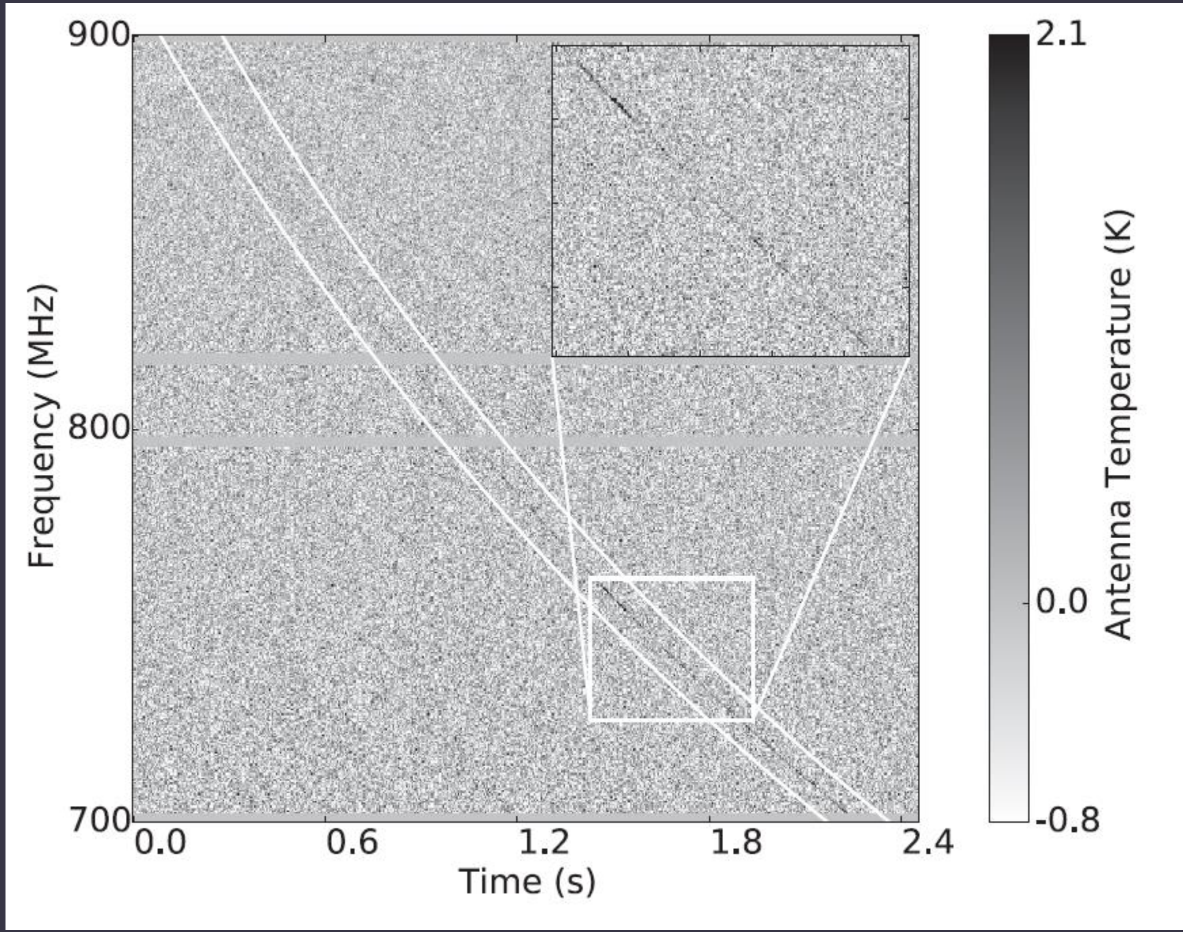
Petroff et al. (1412.0342) detected circular polarization of FRB 140514 at the level ~20%.

Later Masui et al. (2015) detected linear polarization of FRB 110523.

0.38 microGauss

This result fits models with a young NS in a SNR or PWN.

At the end of 2020 for ~20 sources polarization is measured.



Masui et al. 1512.00529

FRBs. Different hypotheses

Millisecond extragalactic radio bursts of that intensity without immediate identification with other bursts have not been predicted by earlier studies.

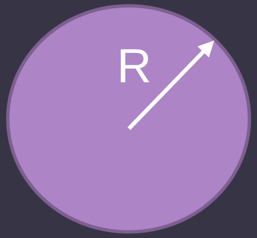
Since 2007 many hypotheses have been proposed.

A real flow started in late summer of 2013 after the paper by Thornton et al.

- Magnetars
- Super radio pulsars
- Evaporating black holes
- Coalescing NSs
- Coalescing WDs
- Coalescing NS+BH
- Supramassive NSs
- Deconfinement of a NS
- Axion clouds and NSs
- Cosmic strings
- Charged BHs
- NS collapse

bestiary.ca/

Neutron stars and exotics



A neutron star has mass ~solar and
radius ~10 km.
This gives free fall velocity $v=(2GM/R)^{1/2}$ ~0.5 c
Free fall time scale $t=R/v< 0.1$ msec
Thus, it is easy to get very short events.
The same is true for BHs.

Absence of counterparts and, in general, shortage of data allows to propose very exotics scenarios for explanation of Fast Radio Bursts.

In addition, NSs have strong magnetic fields
and they are known sources of strong short radio bursts.

So, model of FRBs can divided into two parts:
neutron stars and exotics.

Early ideas

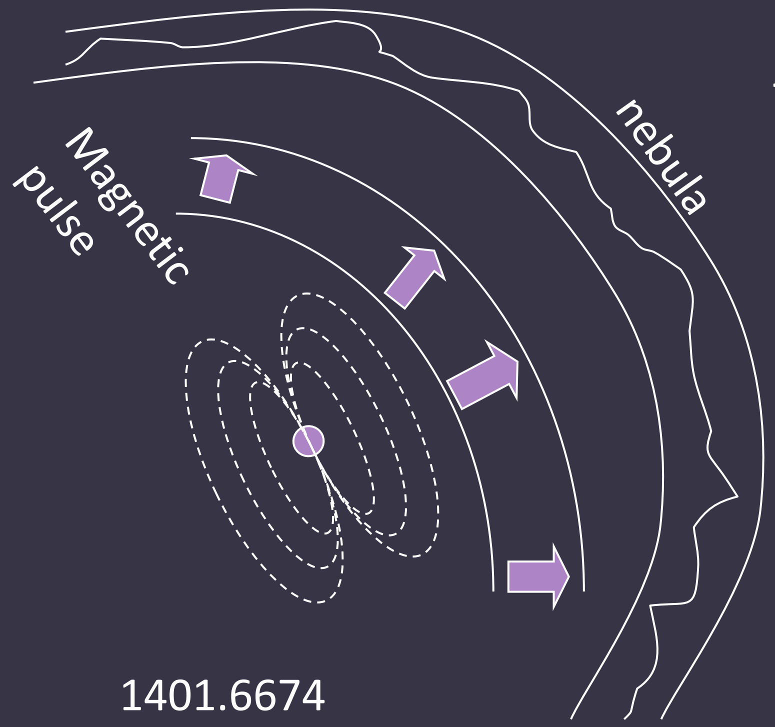
~~Exotics: strings, axions, white holes, etc.~~

~~Catastrophic events: SN, GRBs, coalescence, …~~

~~Compact objects + smth.: asteroids on NSs, etc.~~

Mainstream: magnetars and pulsars

Magnetar model



1401.6674

The first idea of possible connection between FRBs and magnetars has been proposed already in 2007: arXiv 0710.2006.

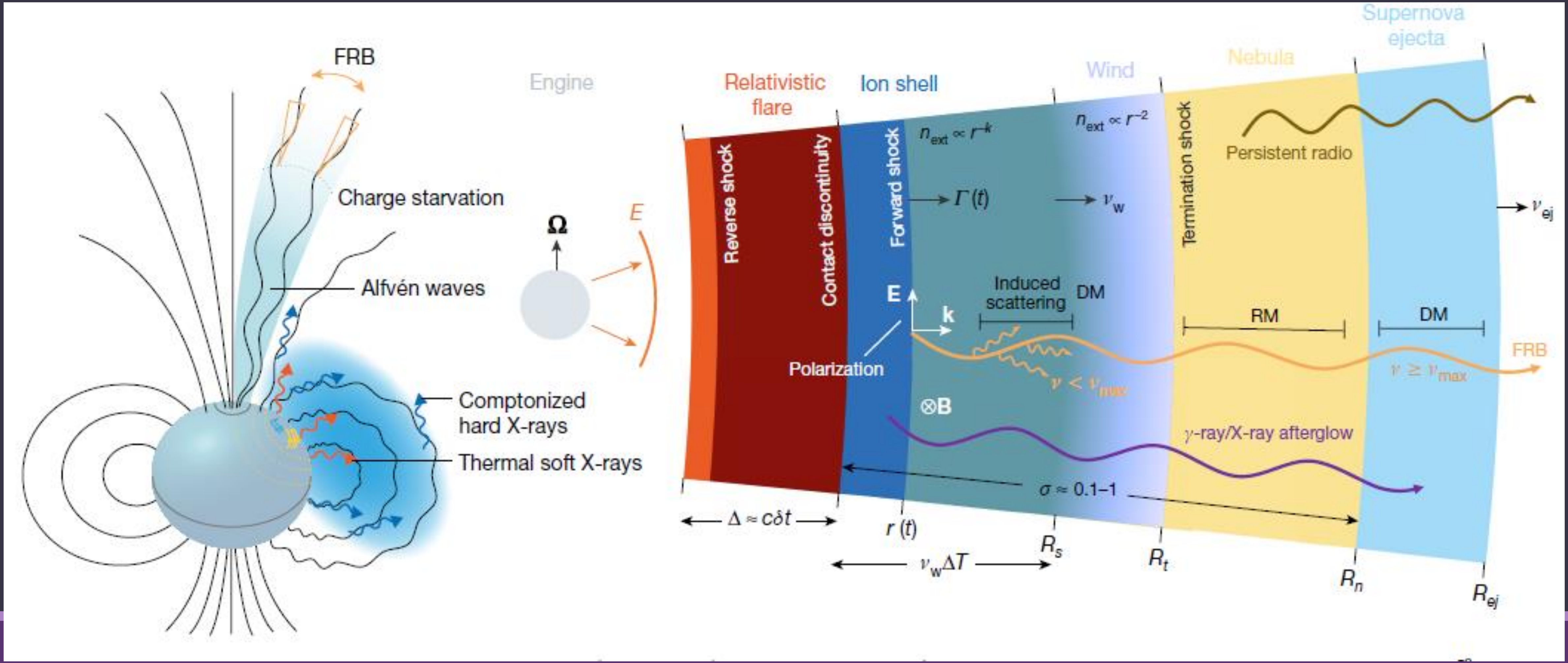
This hypothesis has been based on rate and energetics considerations, mainly.

FRB bursts might be related to giant flares of magnetars

Later this approach was developed by Lyubarsky (2014).

In the model by Lyubarsky the radio burst happens
due to synchrotron maser emission
after interaction between a magnetic pulse after
a giant flare of a magnetar with surrounding nebula.

Магнитосфера или внешние ударные волны?

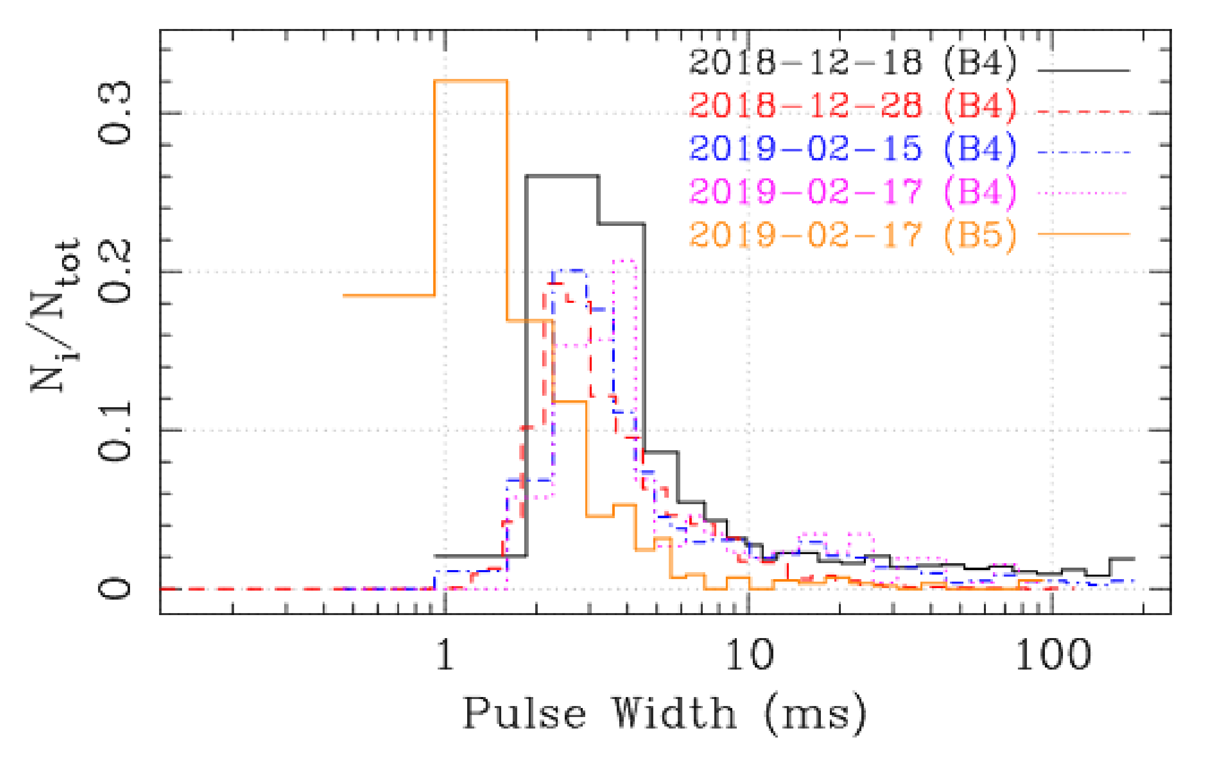


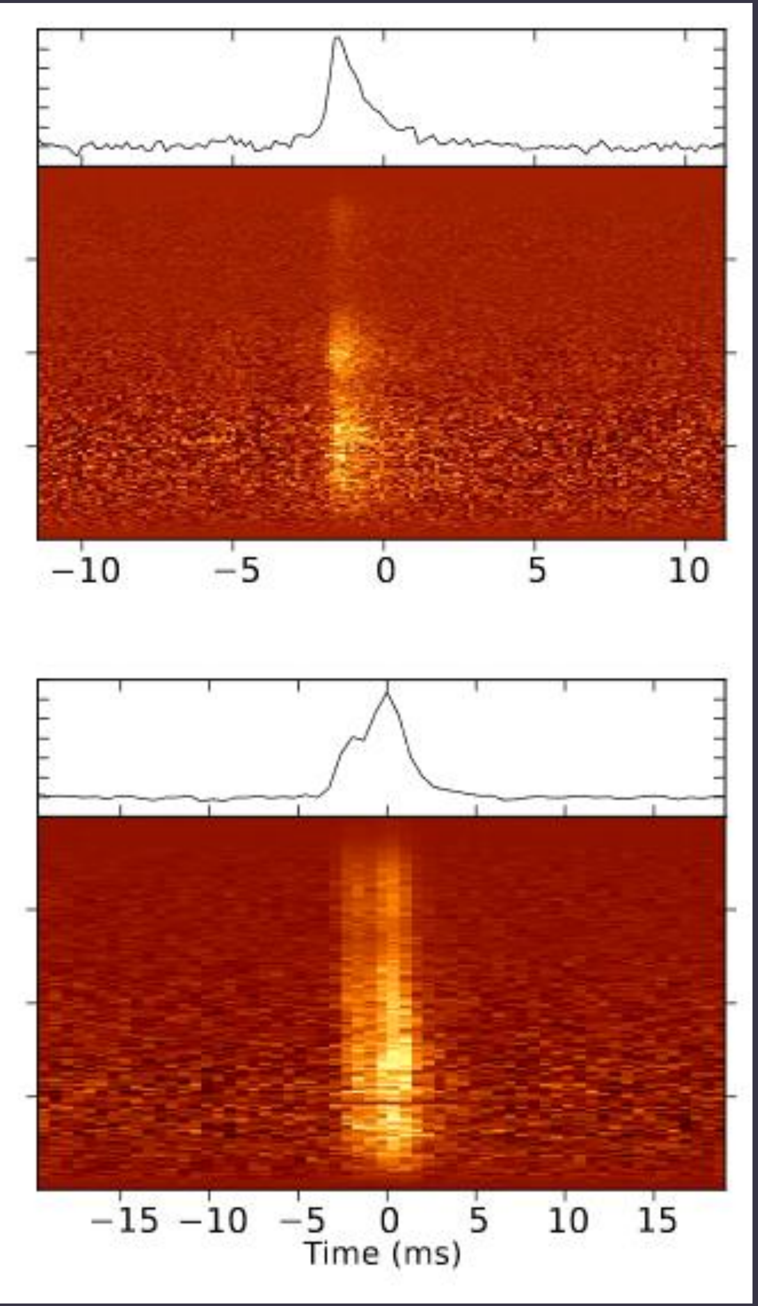
Zhang 2020 (Nature)

Bursts from a magnetar

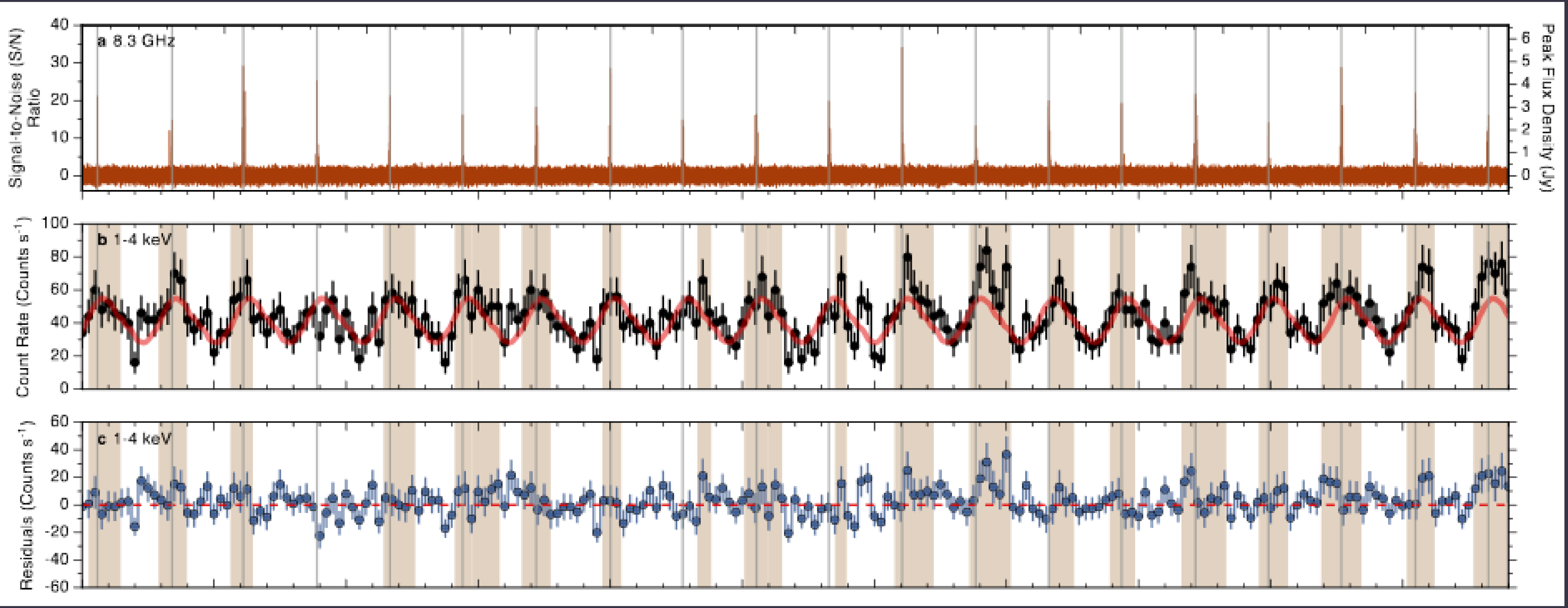
XTE J1810−197
Second period of activity with radio emission: 2018-2019.

Millisecond scale bursts and spectral properties similar to FRBs.



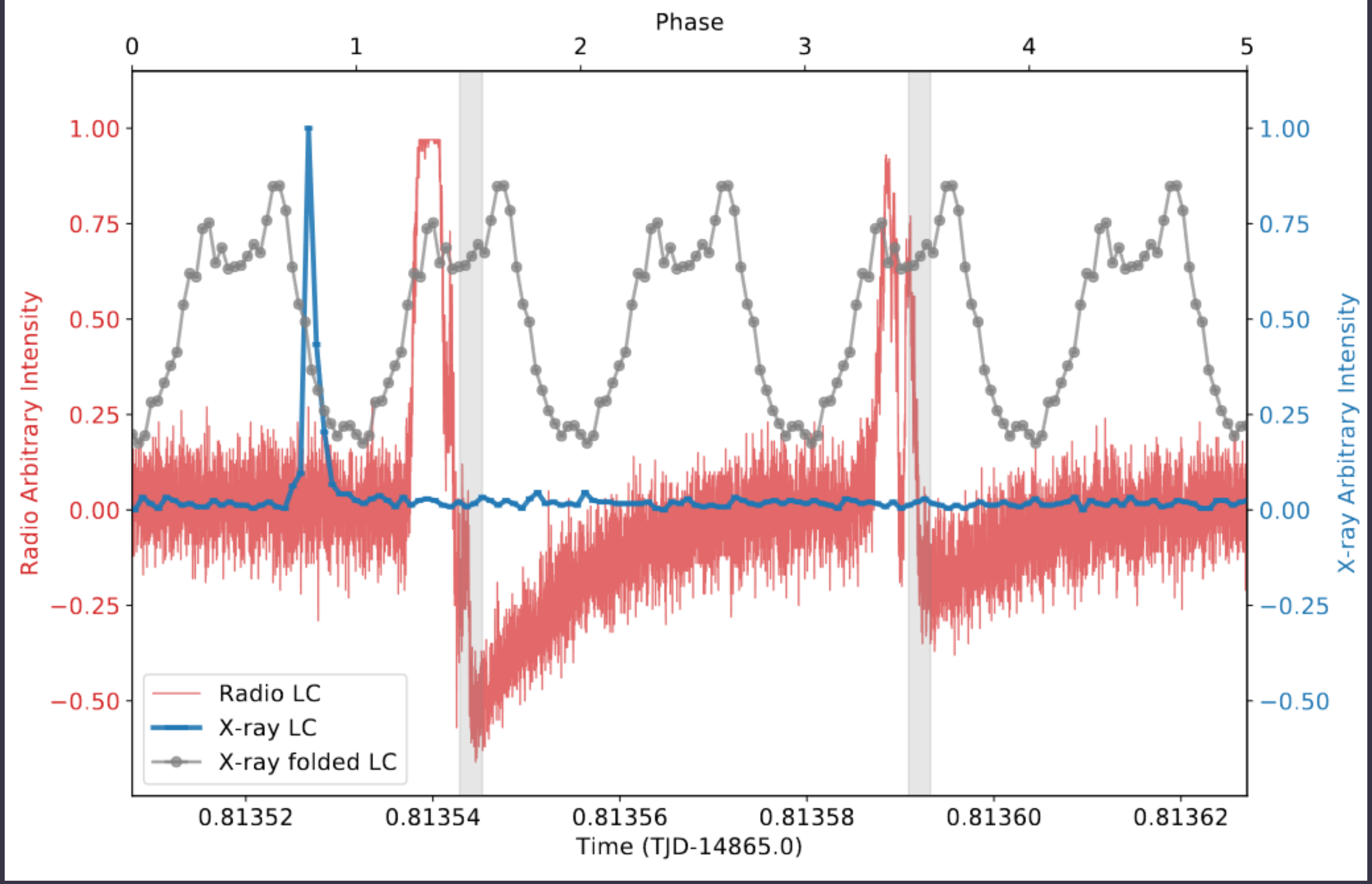


Bursts from XTE 1810



2005.08410

1E 1547.0–5408

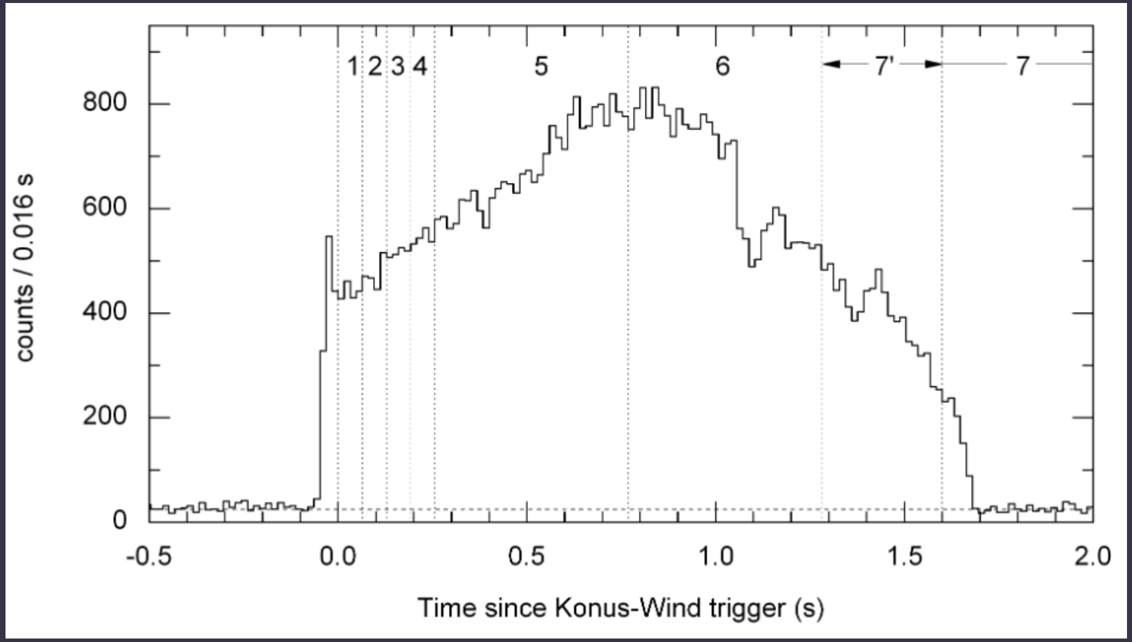


Old observations: 2009

Chandra+Swift+Konus-Wind
And Parkes in radio

SGR 1935+2154

Discovered in 2014 (see, Israel et al. 2016).
P=3.25 sec
Distance ~7-12 kpc (2005.03517)
Intermediate flare (Kozlova et l. 2016)



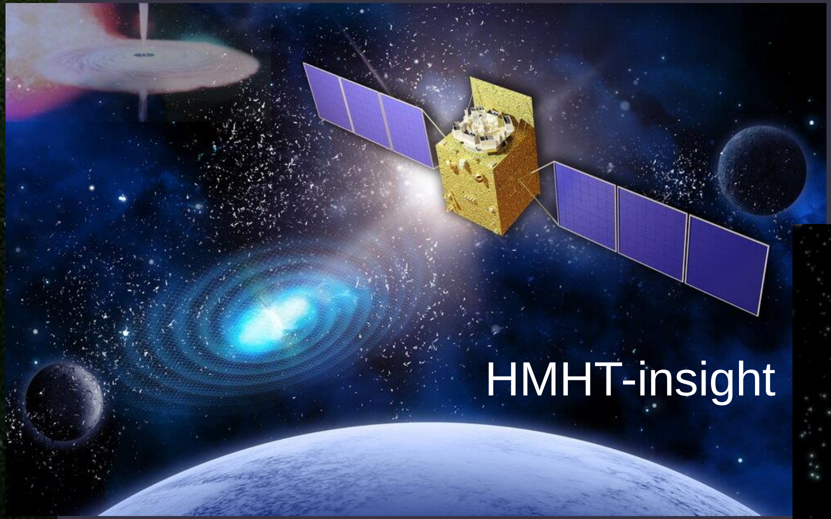
Activated in April 2020.
Finally, on April, 28 2020
A simultaneous burst
in radio and X/gamma
was detected.

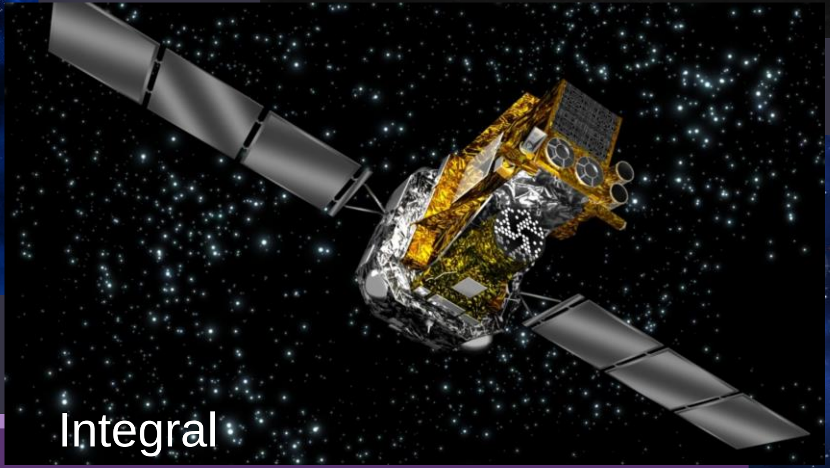
astronomerstelegram: 13681-13769

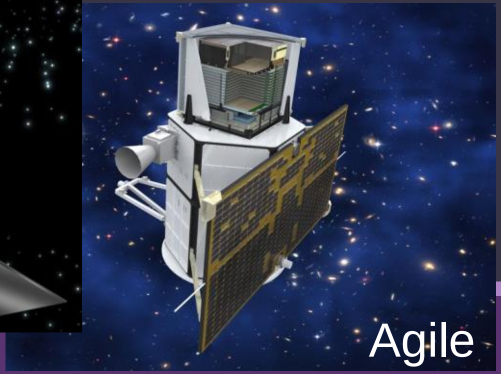
GCN: 27666-27669

FRB from a Galactic magnetar

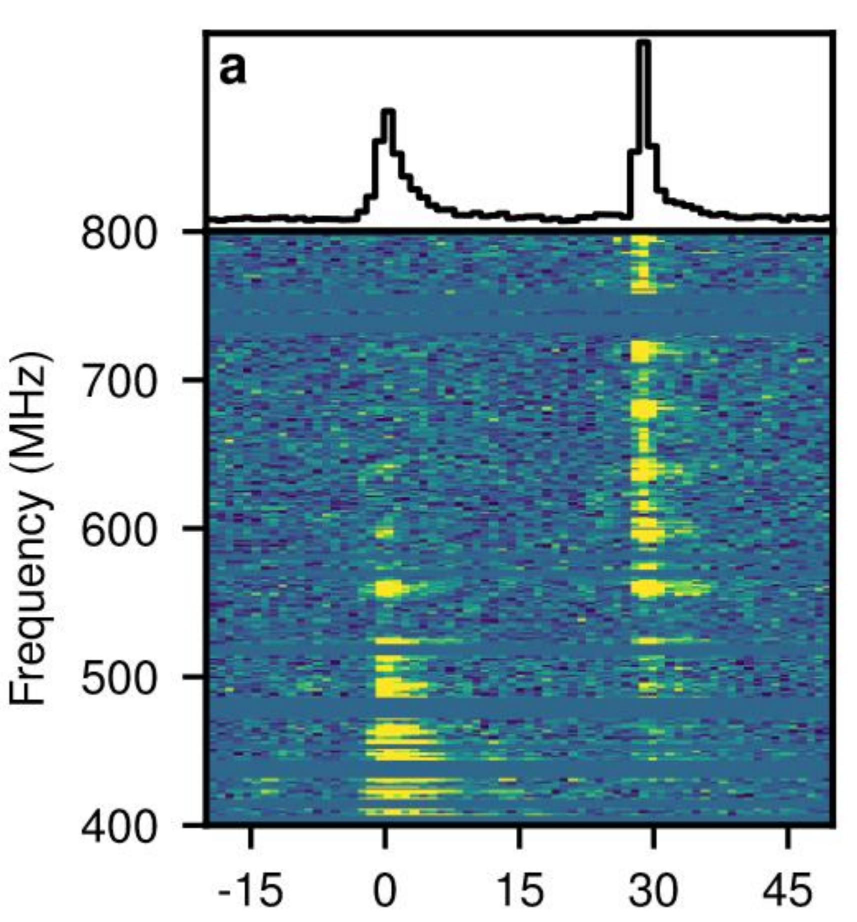
April 28 2020. The first simultaneous detection of short radio and high energy bursts from the Galactic magnetar SGR 1935+2154.

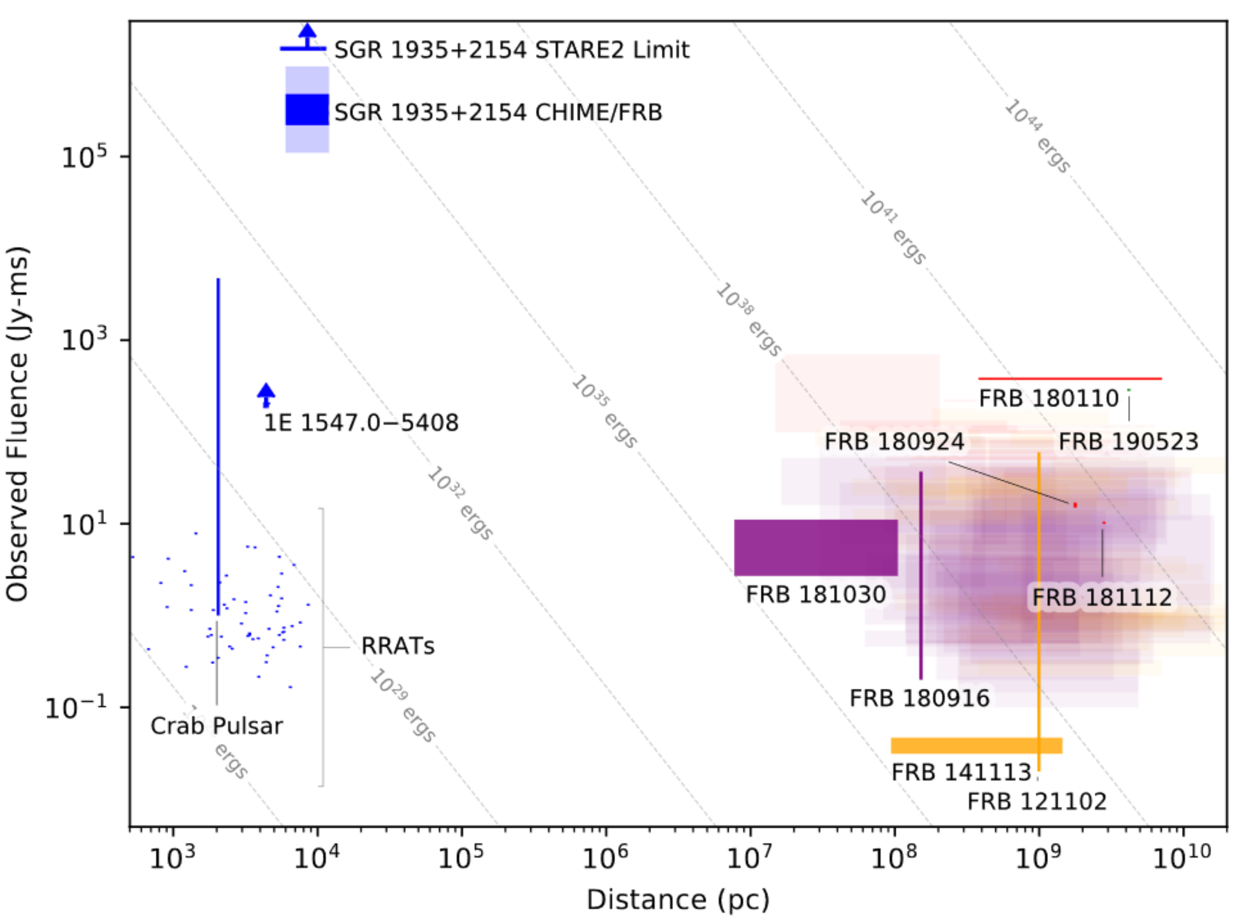






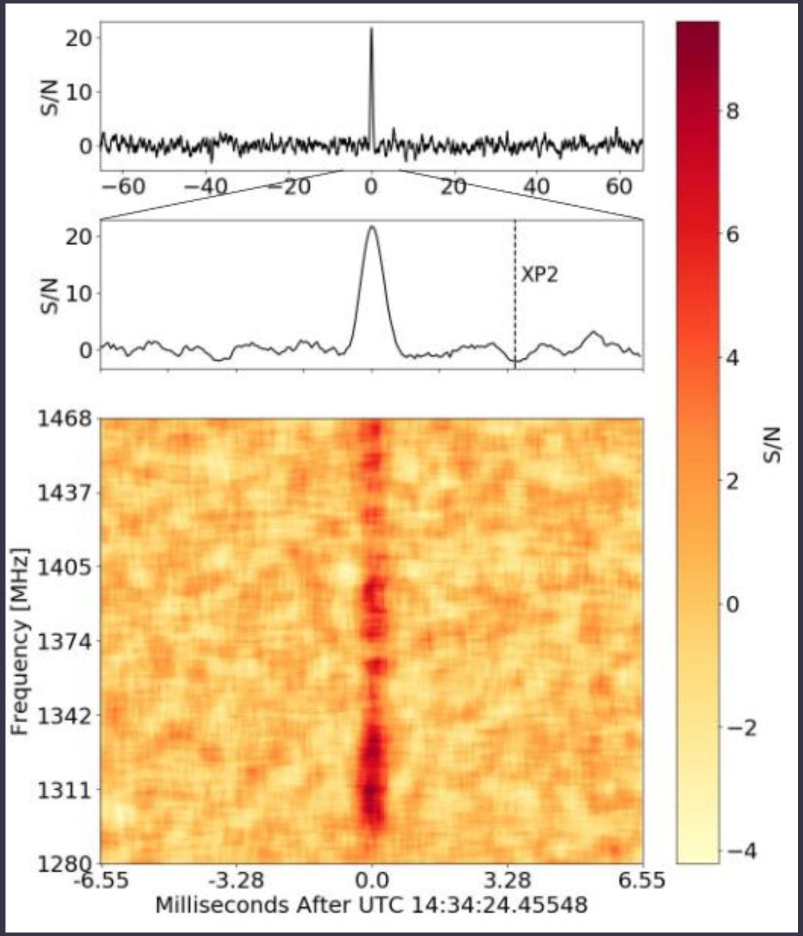
CHIME data

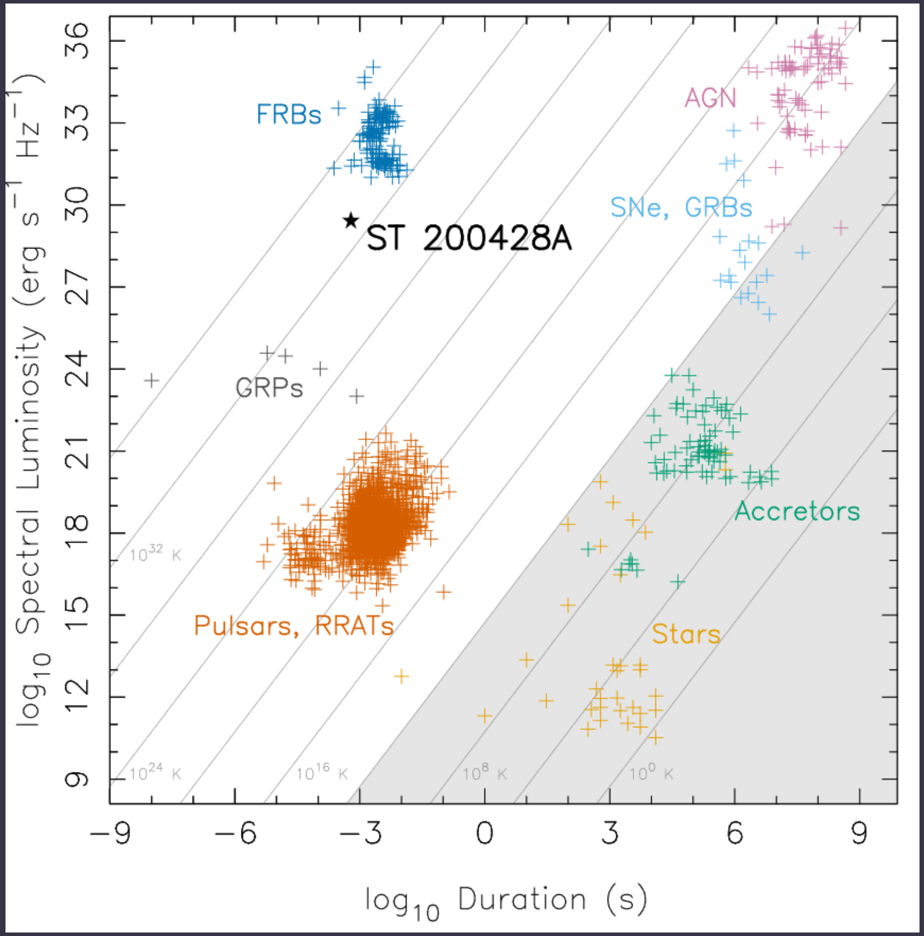

a
800
700
600
500
400
Frequency (MHz)
-15
0
15
30
45


SGR 1935+2154 STARE2 Limit
SGR 1935+2154 CHIME/FRB
1E 1547.0−5408
RRATs
Crab Pulsar
FRB 180110
FRB 190523
FRB 180924
FRB 181030
FRB 181112
FRB 180916
FRB 141113
FRB 121102
10^{44} ergs
10^{41} ergs
10^{38} ergs
10^{35} ergs
10^{32} ergs
10^{29} ergs
Observed Fluence (Jy-ms)
10^5
10^3
10^1
10^{-1}
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
Distance (pc)

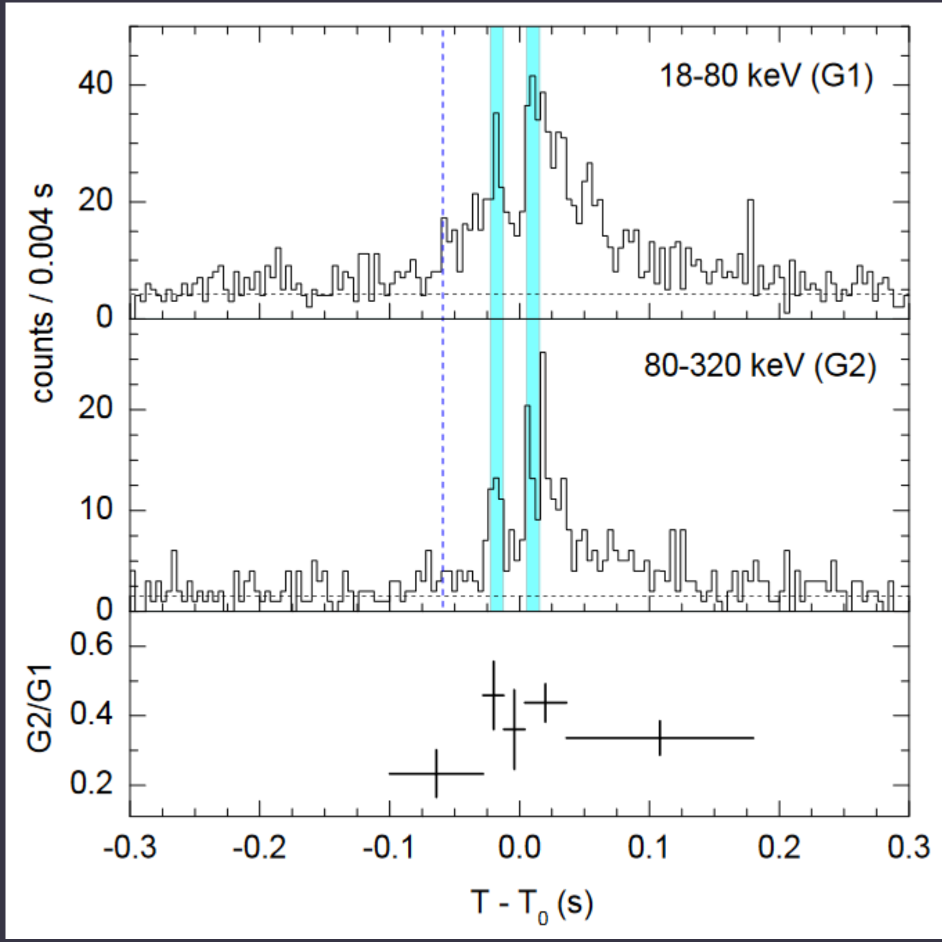
STARE2 data

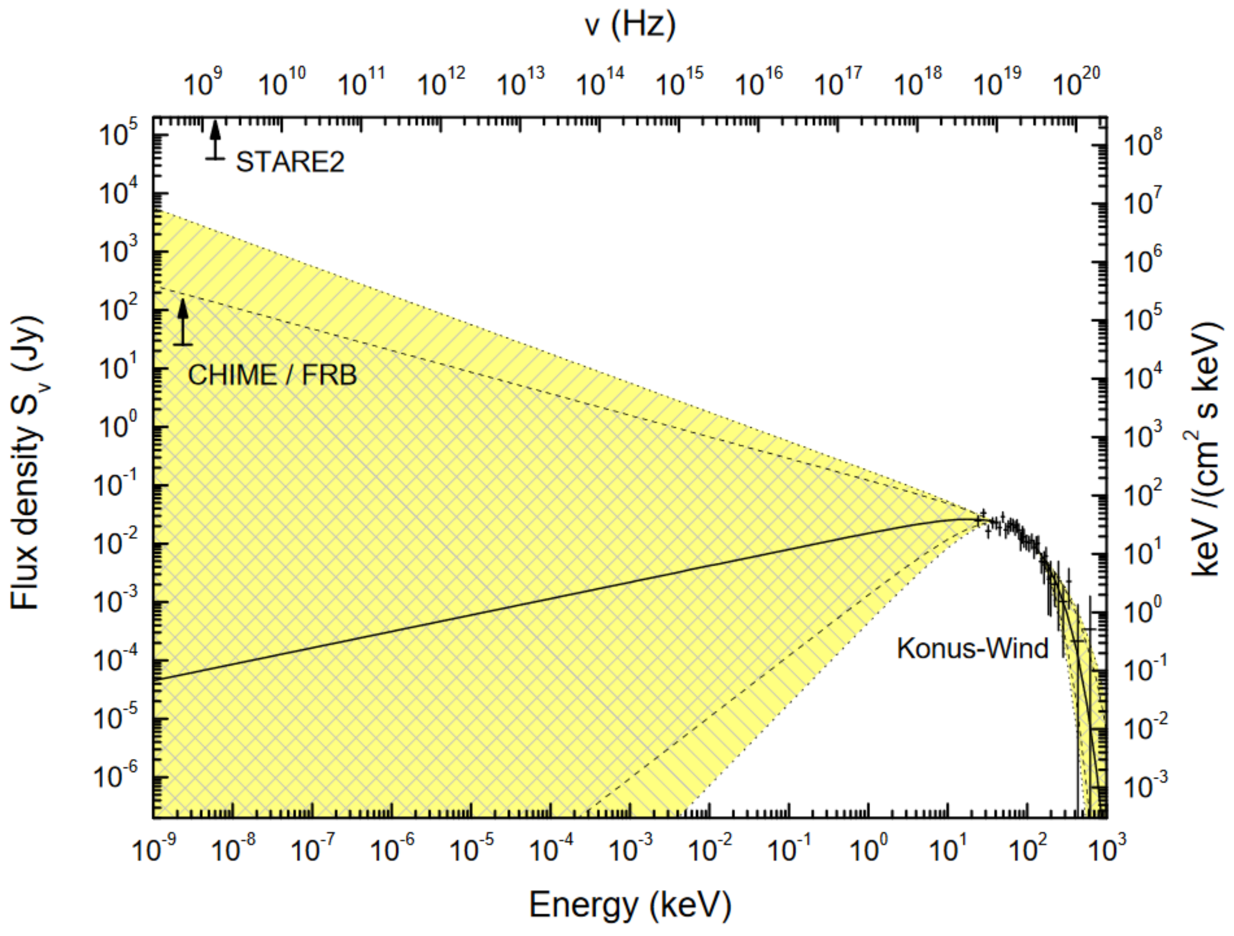

Delta
OVRO
Goldstone
Pie Town
1.80 ms
2.27 ms
0.86 ms
2.62 ms
Las Vegas


S/N
XP2
Frequency [MHz]
1468
1437
1405
1374
1342
1311
1280
-6.55
-3.28
0.0
3.28
6.55
Milliseconds After UTC 14:34:24.45548


FRBs
AGN
SNe, GRBs
ST 200428A
GRPs
Accretors
Pulsars, RRATs
Stars
$\log_{10}$ Spectral Luminosity (erg s^{-1} Hz^{-1})
$\log_{10}$ Duration (s)

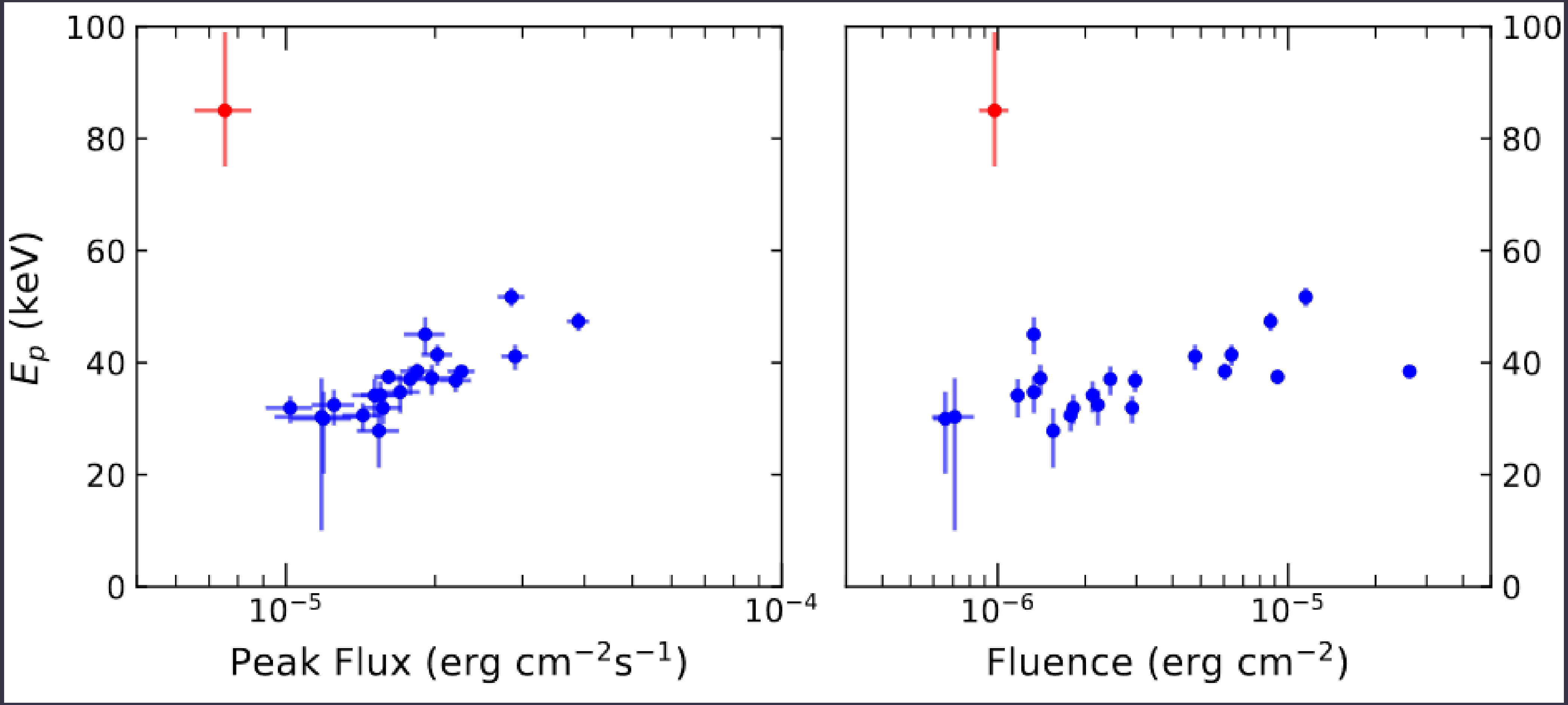
Konus-Wind data





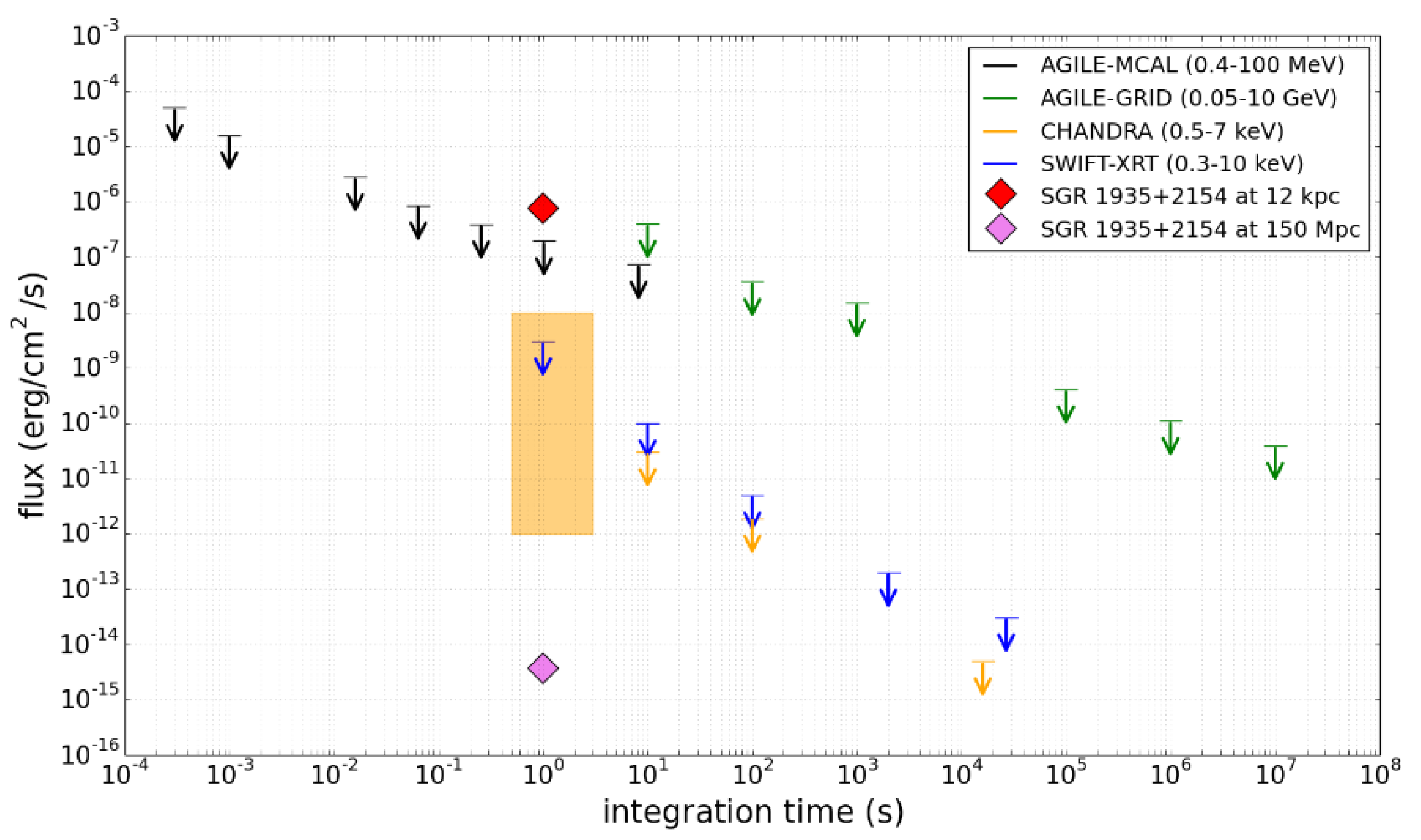
2005.11178

Konus-Wind data

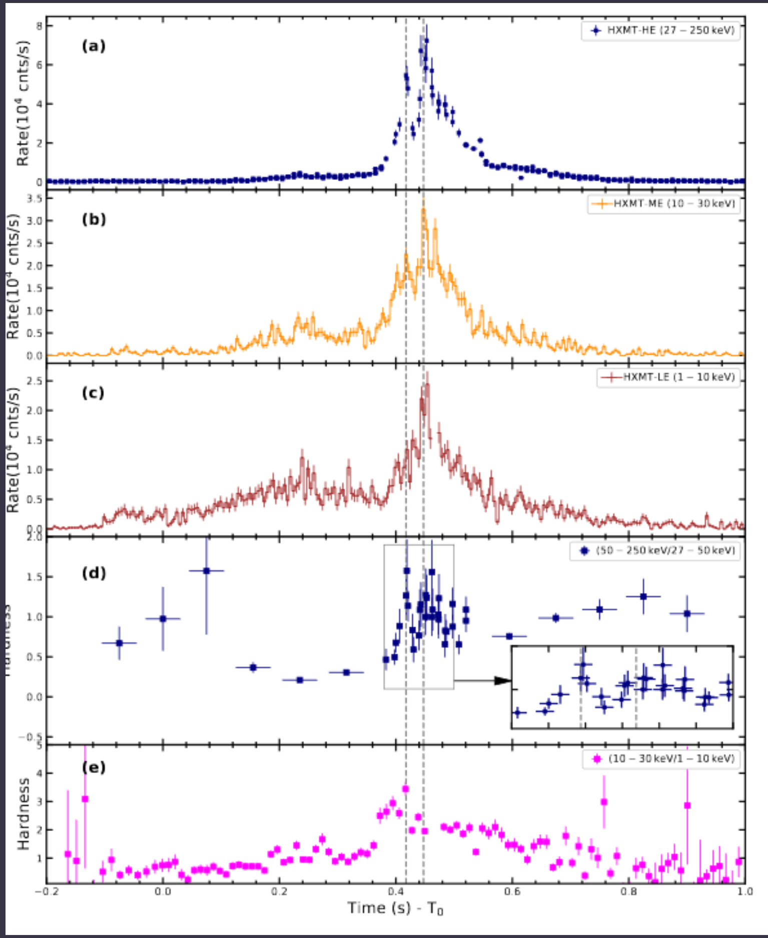


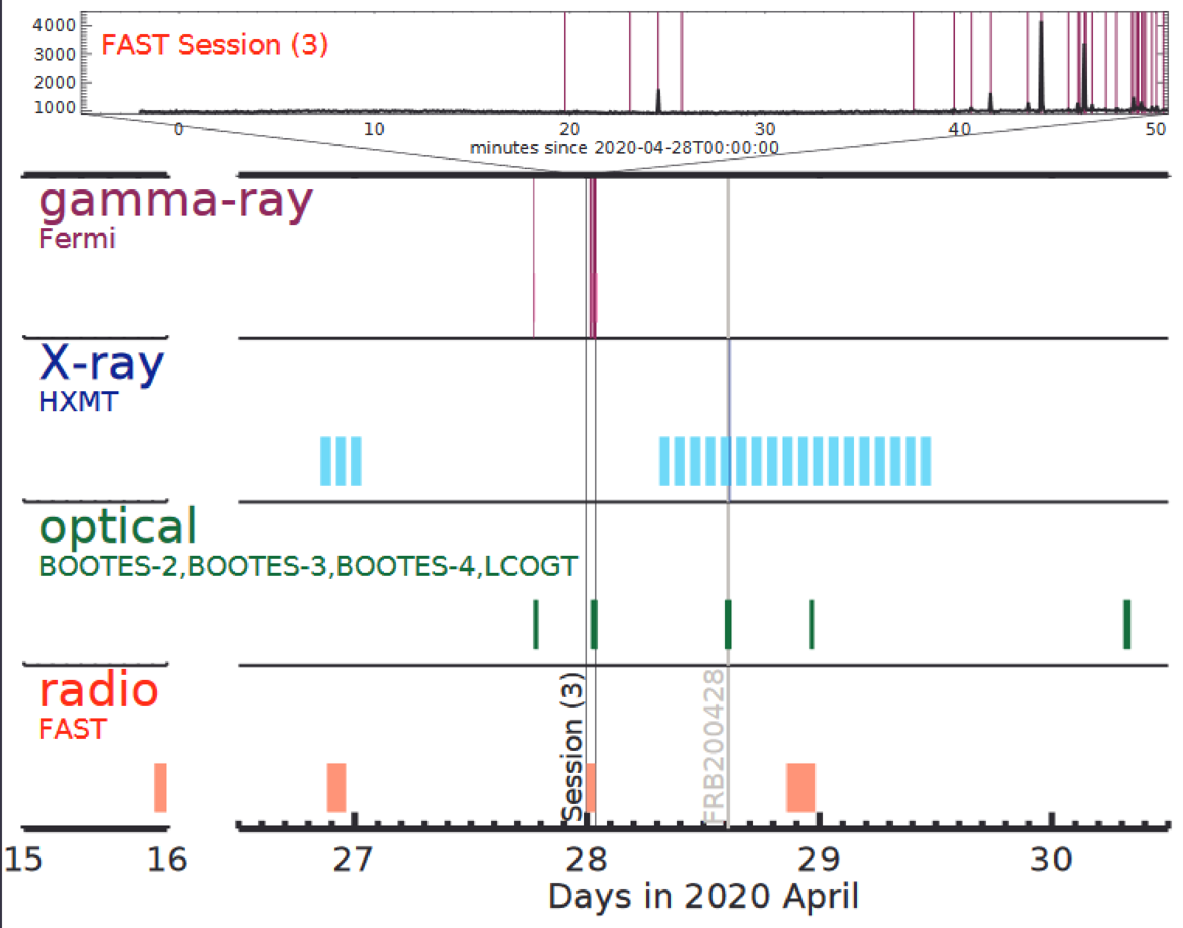
AGILE data

Comparison of SGR 1935 detection with monitoring of the repeating source FRB 180916 (at 149 Mpc)



Insight-HXMT data and FAST

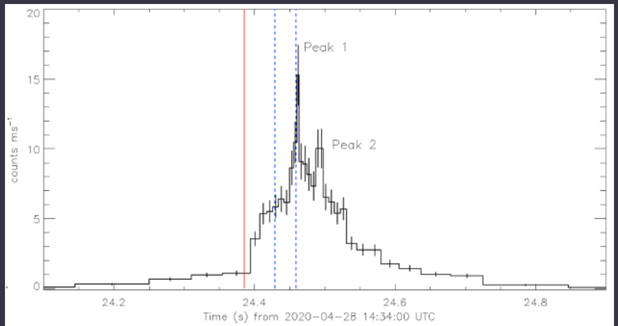


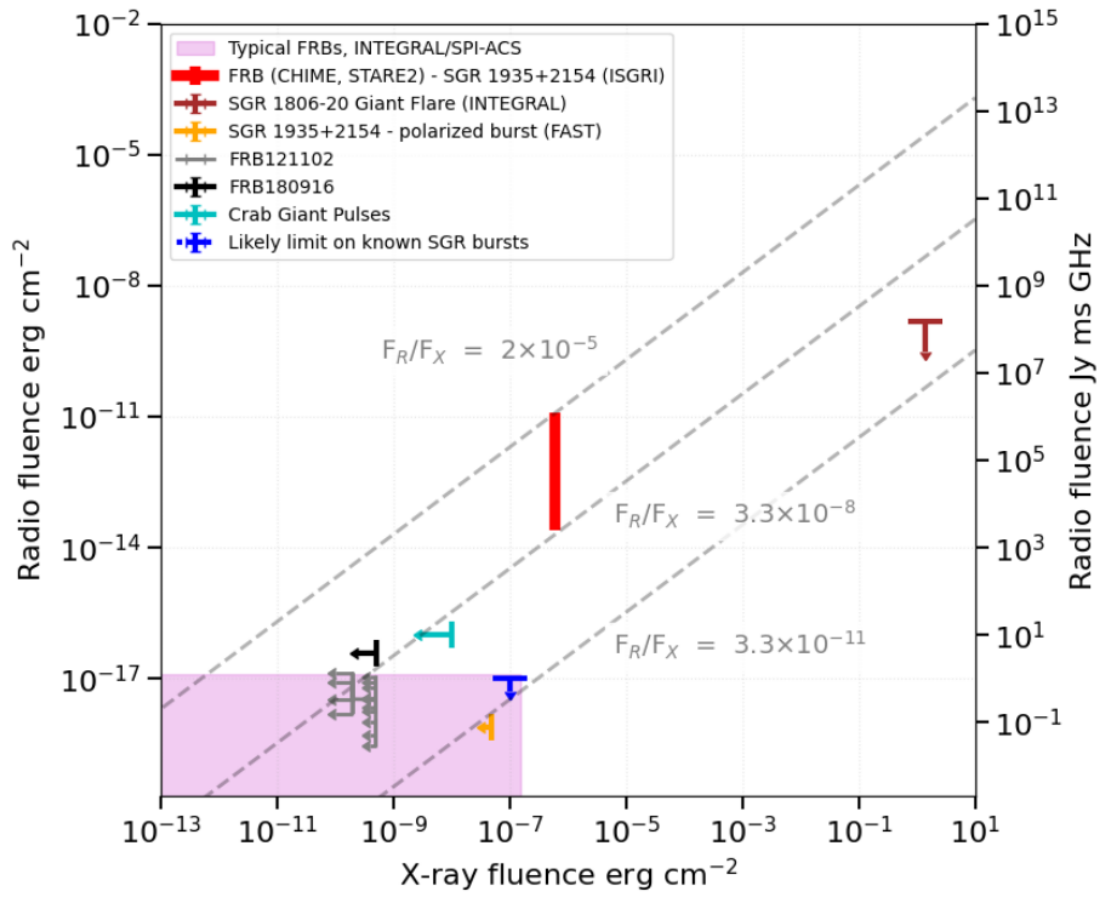


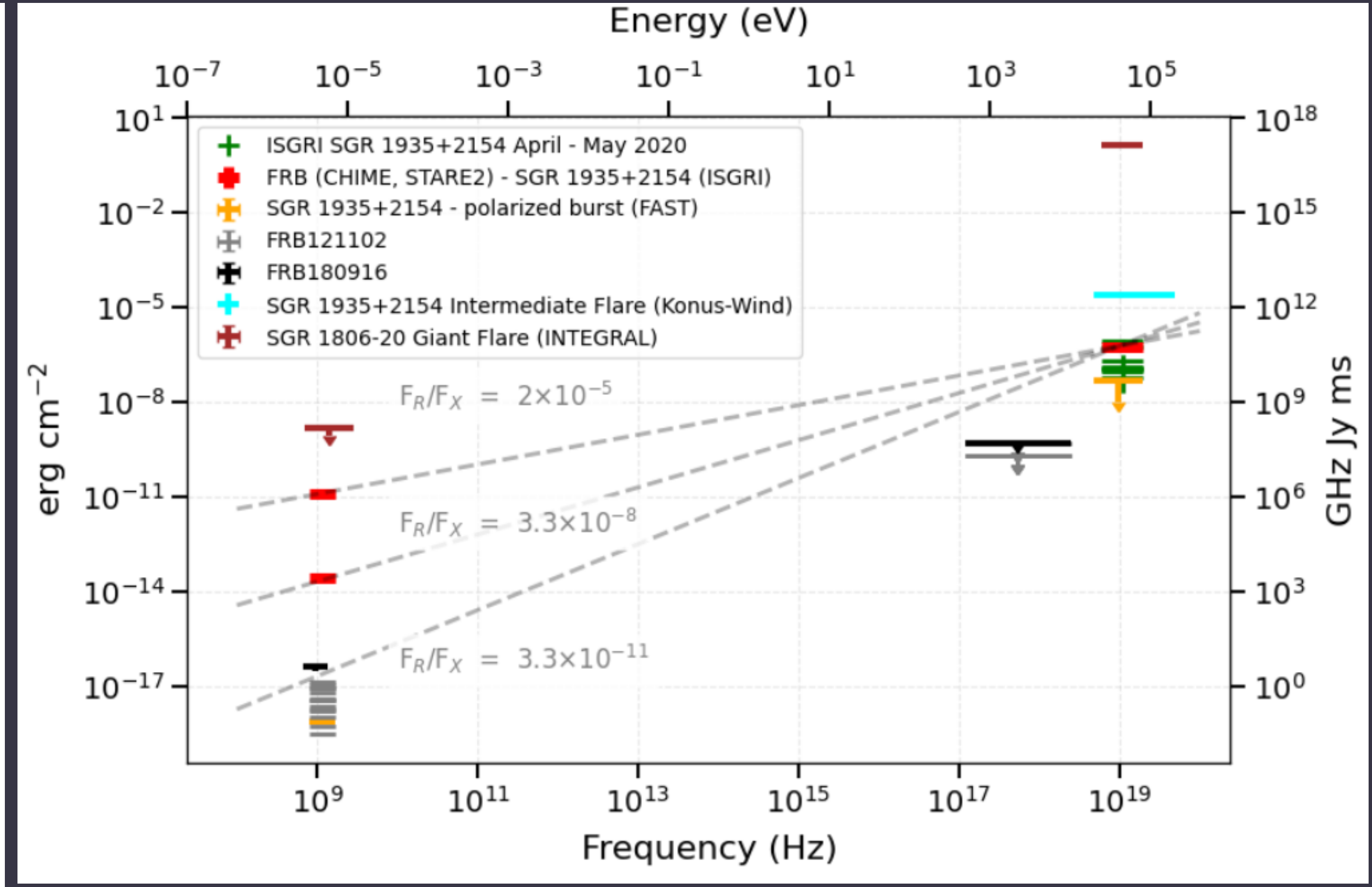
2005.11071

2005.11479

SGR 1935. INTEGRAL data





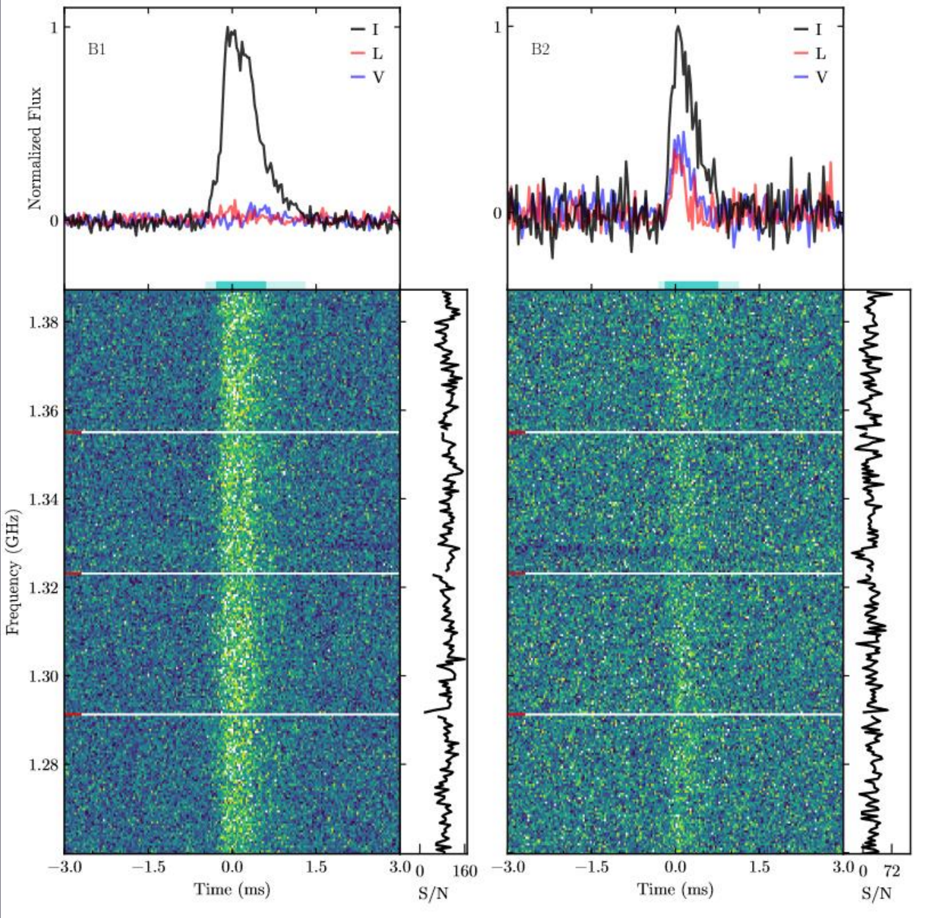


2005.06335

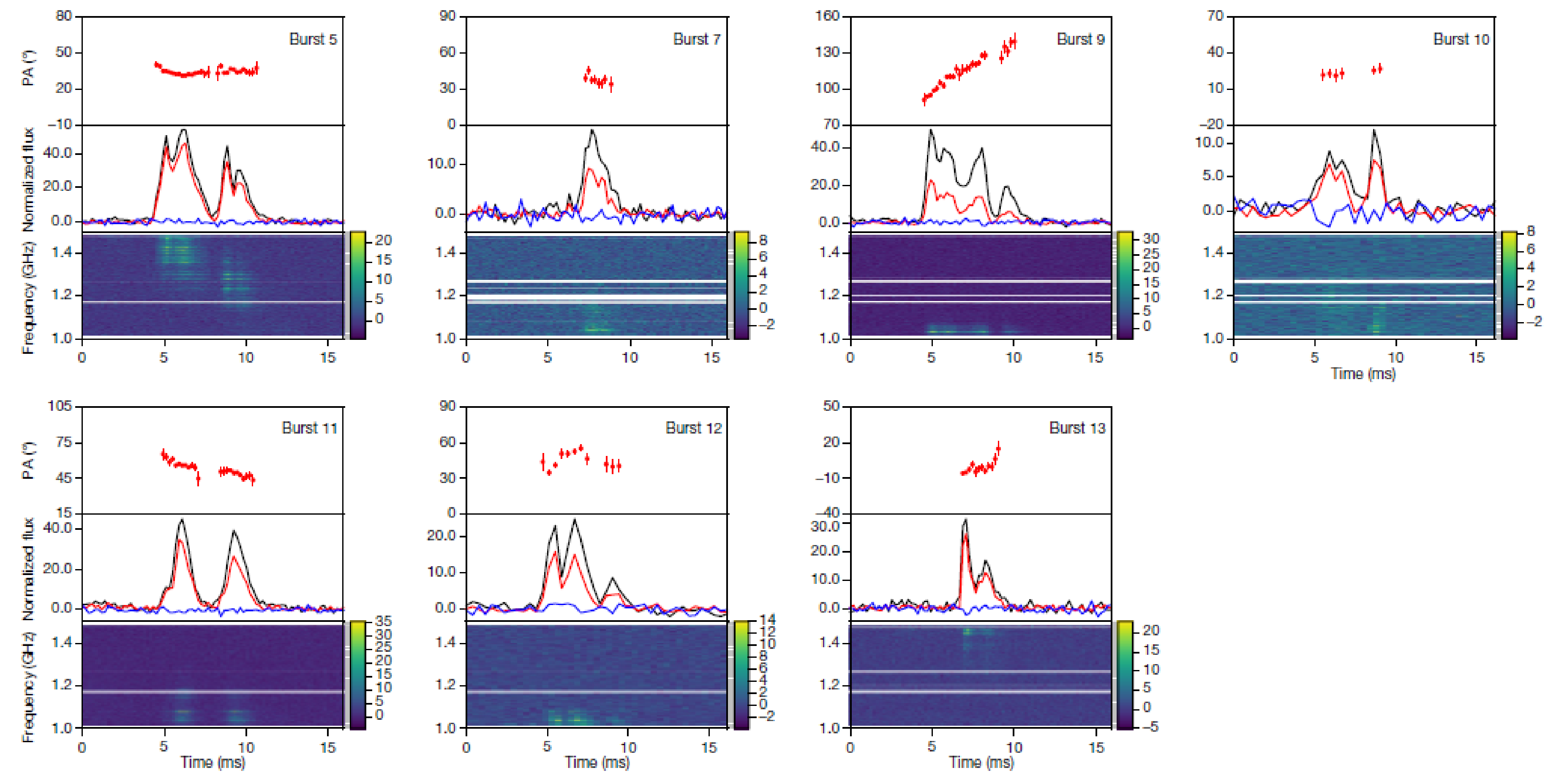
Weak radio bursts from SGR1935

~1 month of monitoring with 4 antennas.
Two bursts detected.
Flux intermediate between STARE2/CHIME strong flare and weak bursts detected by FAST.

	B1	B2
Barycentric arrival time [MJD][a]	58993.93008882	58993.93010498
Dispersion measure [pc cm^{-3}][b]	332.85 ± 0.21	332.94 ± 0.21
Fluence [Jy ms][c,d]	112 ± 22	24 ± 5
Peak flux density [Jy][c]	170 ± 34	64 ± 13
Spectral energy density [erg/Hz][c,e]	$(1.1^{+1.0}_{-0.6}) \times 10^{22}$	$(2.3^{+2.2}_{-1.3}) \times 10^{21}$
Intrinsic pulse width [μs][f]	427 ± 33[g]	219 ± 27
Observed burst width [μs][h]	866 ± 43	961 ± 48
Scattering time scale [μs]	315 ± 12	299 ± 29
Decorrelation bandwidth [kHz]	< 500 Hz	< 500 Hz
Linear polarisation L/I [%]	~ 5.9	~ 24
Circular polarisation |V|/I [%]	~ 6.6	~ 34



Polarization variation points towards magnetospheric origin?



Models with synchrotron mazers require ordered magnetic field in the shock wave to reach conditions for coherent emission.
Such models predict that the angle of polarization might not vary significantly from pulse to pulse.

Magnetospheric models do not have such restriction.

Luo et al. 2020, 2011.00171

Current ratings of hypothesis

- Discovery of repeating bursts with high rate provides arguments in favour of the models of activity of young magnetars
- Identification of a dwarf galaxy with high star formation rate as a host galaxy of the source of the repeating burster is a strong argument in favour of models involving young neutron stars.
  However, some other identified host galaxies are much different!
- Dissipation of magnetic energy seems to be more reliable.
- Discovery of a FRB-like burst from a known Galactic magnetar is a strong support in favour of the magnetar model.
  We are sure that at least some FRBs are produced my extragalactic magnetars.

- Population of FRBs can be non-uniform, i.e. more than one scenario can realize in Nature

More observations

Observation with many telescopes,
especially for the repeating source.

FAST – burst per week

1602.06099

Attempts to identify something
at other wavelengths.

http://astronomy.swin.edu.au/research/utmost/

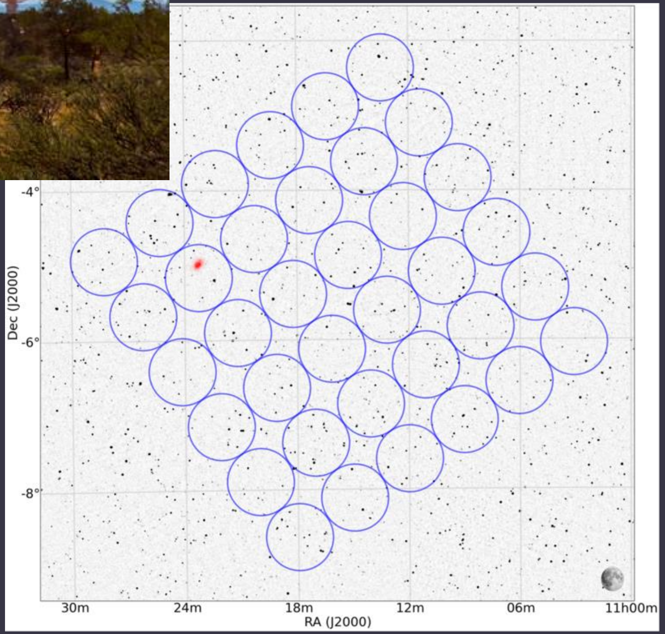
Burst per week, see 1601.02444

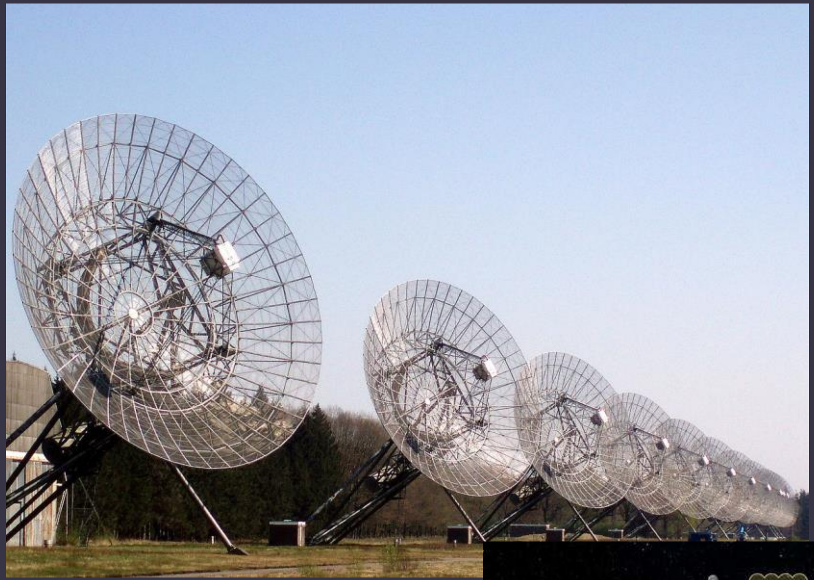
Observations at Parkes
with a new monitoring system.

ASKAP and Apertif

ASKAP

Few bursts per week.
1709.02189

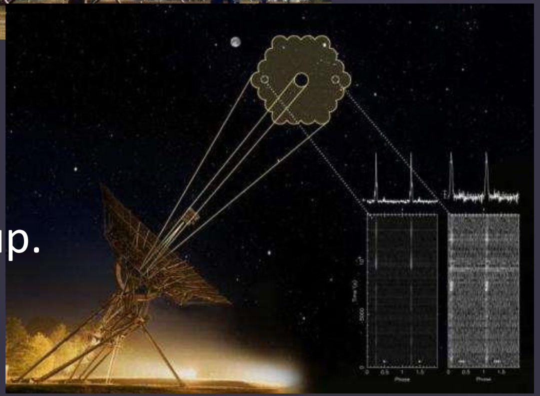




Westerbork

Northern sky.
Doubling the number?
Rapid on-line identification – follow-up.
FRB per week.

1709.06104



Future observations

SKA

SKA – burst per hour!

1602.05165, 1501.07535

Summary of observations

Main reviews: 1806.03628, 1810.05836,
1906.05878, 1904.07947
+ *2011.03500*

In catalogue (16/12/2020) frbcat.org
≥120 bursts (~20 repeaters), ~10 localized.

~20 with polarization data (11 – linear, 6 – circular)
RM for ~15 (+3 consistent with 0 within errors)
Max flux: ~160 Jy
DM max: 2600; DM min: 100

>50% detected at ~1.4 GHz.
~10 at ~800-840 MHz (~10 at UTMOST, 1 at GBT)
~30 at ~600 MHz (CHIME), 1 at 350 MHz (GBT),
and ~10 (?) at 111 MHz (Puschino)