

Time-Domain Astronomy

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Fast Radio Bursts: recap

Search: Single-pulse Vs FFT for intermittent sources

RRATs: Sporadic neutron stars; long periods; magnetospheric switching

FRBs: ms bursts, extragalactic (DM excess), $L \sim 10^{42}$ erg/s, $T_B \sim 10^{35}$ K

Discovery milestones:

2007: Lorimer burst

2013: population established

2017+: localisation + repeaters

Host diversity: dwarf (young magnetars) → massive (delayed channels)

Propagation: DM, scattering (ν^{-4}), scintillation, spectral structure

Continuum: Pulsars → RRATs → Magnetars → FRBs

Takeaway: Multiple progenitors + probes of IGM & cosmology

Fast Radio Bursts: population

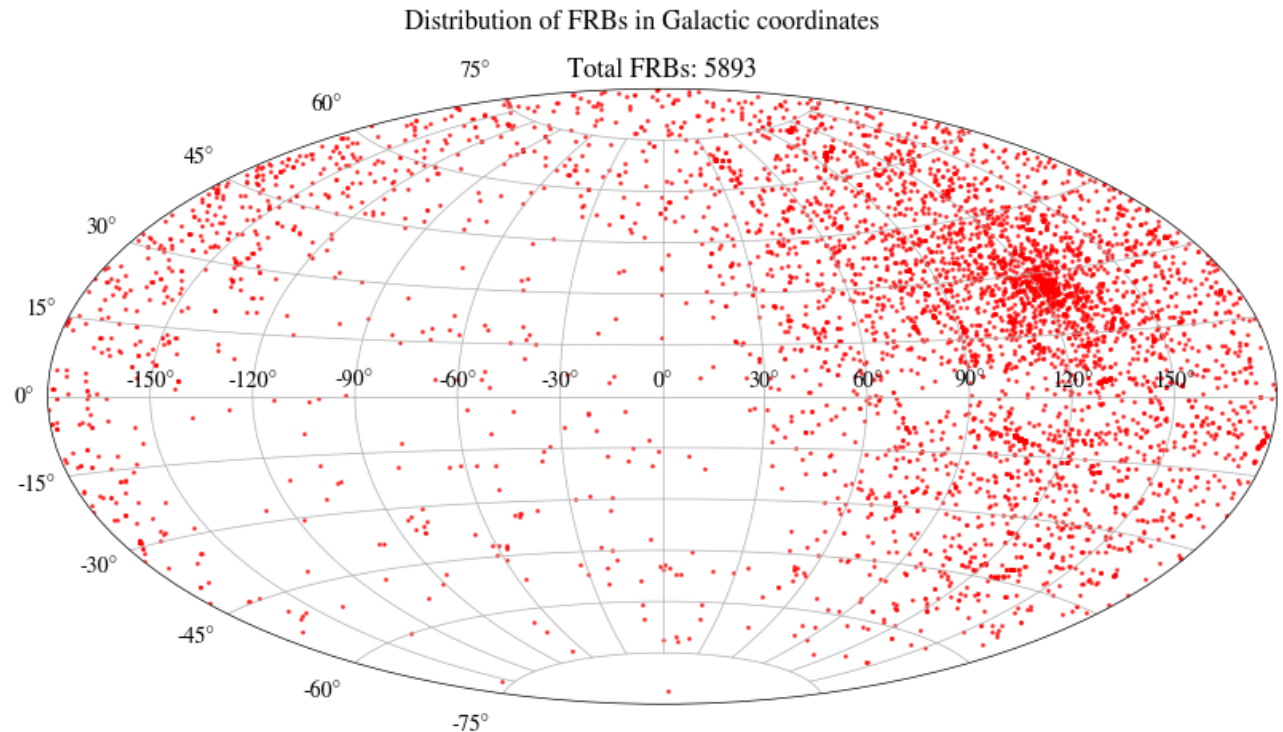
Total FRB discovered: 4500+

Repeaters: 93 (~1.6%)

Host galaxies: 119 (~2%)

Localised host galaxies across universe

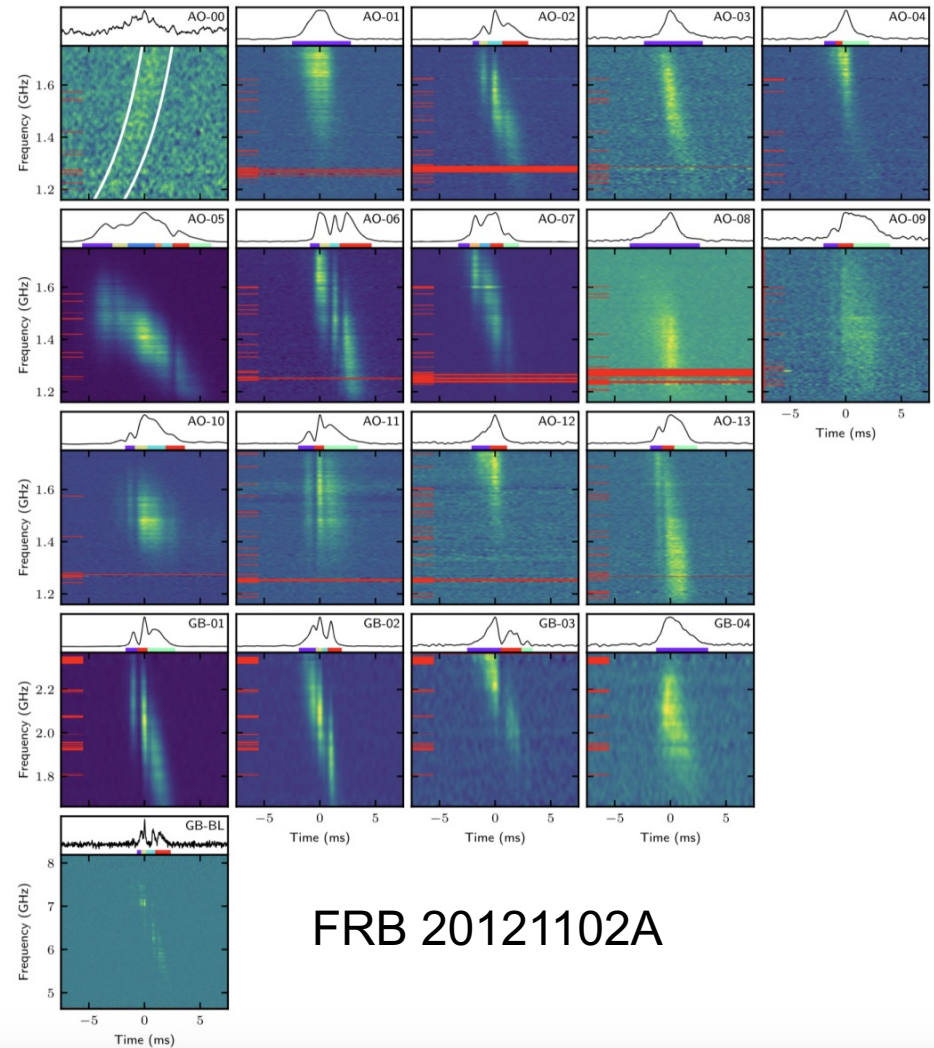
Still unknown origin



Fast Radio Bursts: spectral features

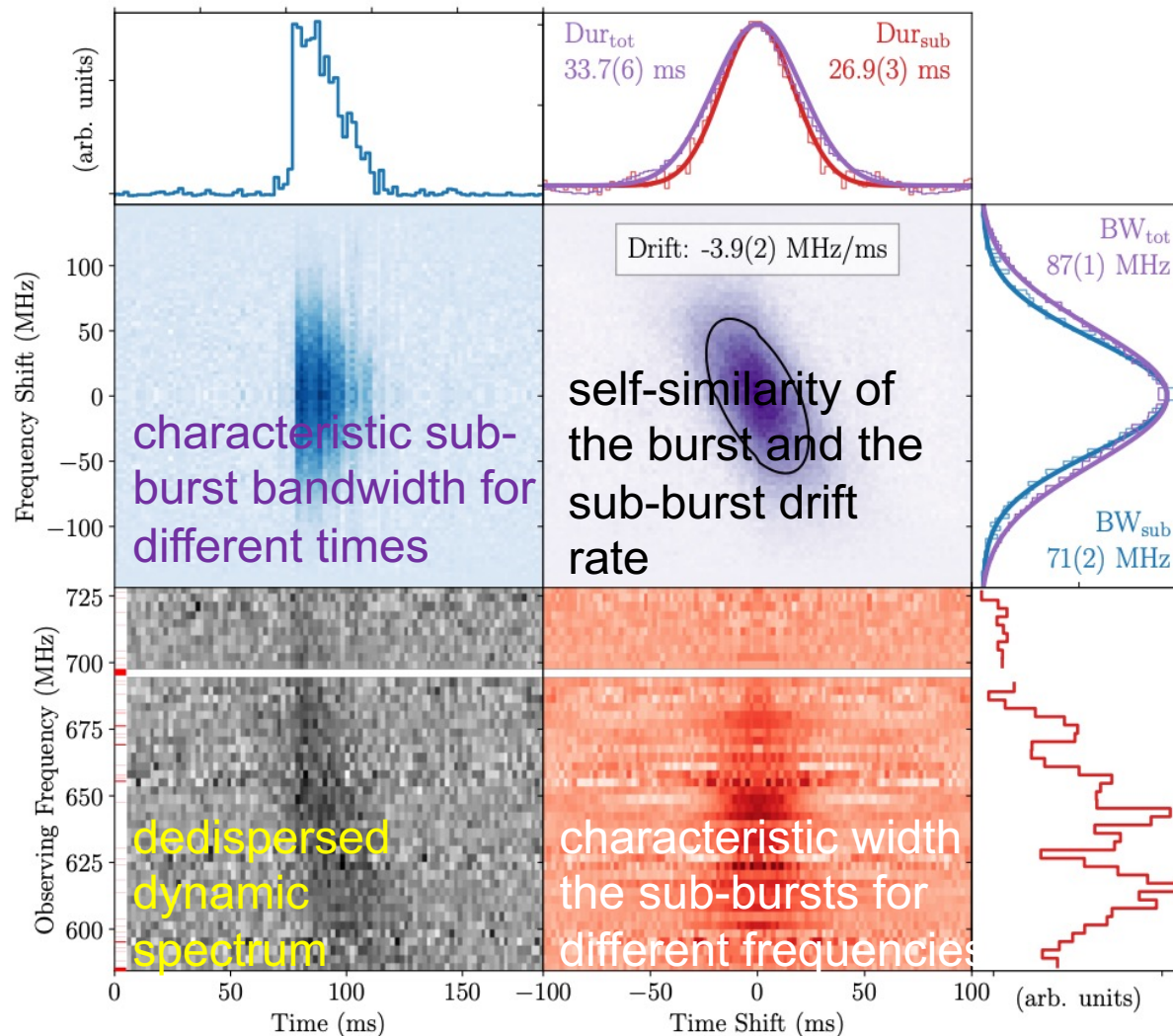
Down-drifting of pulses
("sad trombone" effect) with frequency

→ likely related to the intrinsic radiation
physics of FRBs
(magnetospheric Vs lensing)



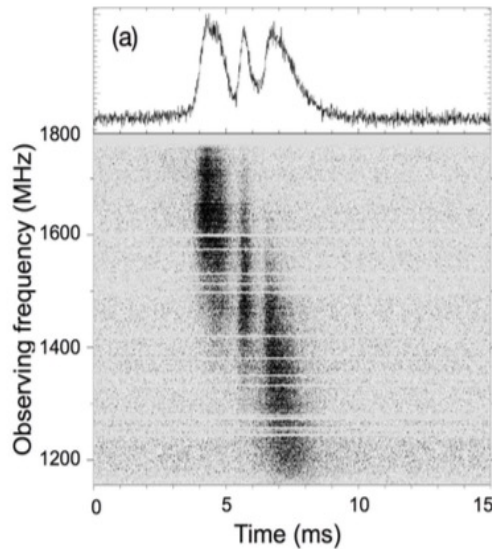
Fast Radio Bursts: propagation effects

Down-drifting of pulses: common in repeating FRBs unlike one-offs

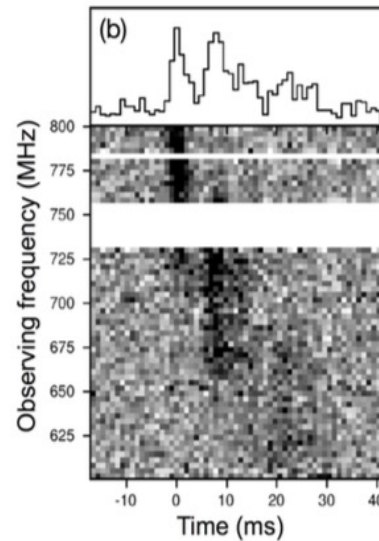


Repeaters with long-lived engines Vs One-offs with cleaner/variable environments

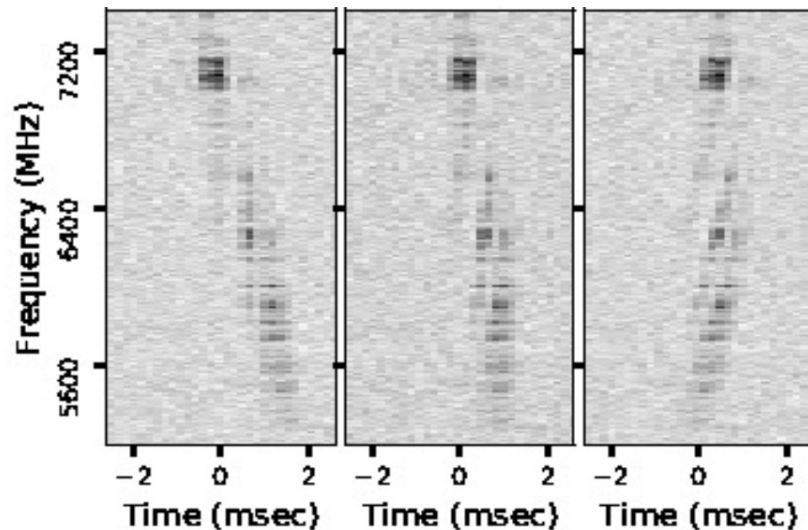
Fast Radio Bursts: Repeating ones



FRB 121102



FRB 180814.J0422+73



FRB 121102, Michilli et al. 2018

Sub-burst structures with descending centre frequencies over time

Frequency structure from propagation effect can not change in $\sim$ sub-ms time-scale

Scintillation can explain higher resolution (few MHz) spectral structures (narrow decorrelation bandwidth for FRBs)

Some repeaters have similar structure $\rightarrow$ Intrinsic to emission rather than propagation

Fast Radio Bursts: Repeaters Vs One-offs

Burst duration vs bandwidth

Repeaters tend to show longer durations and narrower emission bandwidths, while apparently non-repeaters are on average shorter and broader-band

Dynamic-spectrum morphology panels

Repeaters: multiple sub-bursts,
downward frequency drift (“sad trombone”),
complex time–frequency structure.

One-offs: Single component simple profile

Energy or fluence distribution plots

Cumulative distributions of burst energy can be used to compare the two classes. The energy distributions may even suggest a connection between repeaters and non-repeaters.

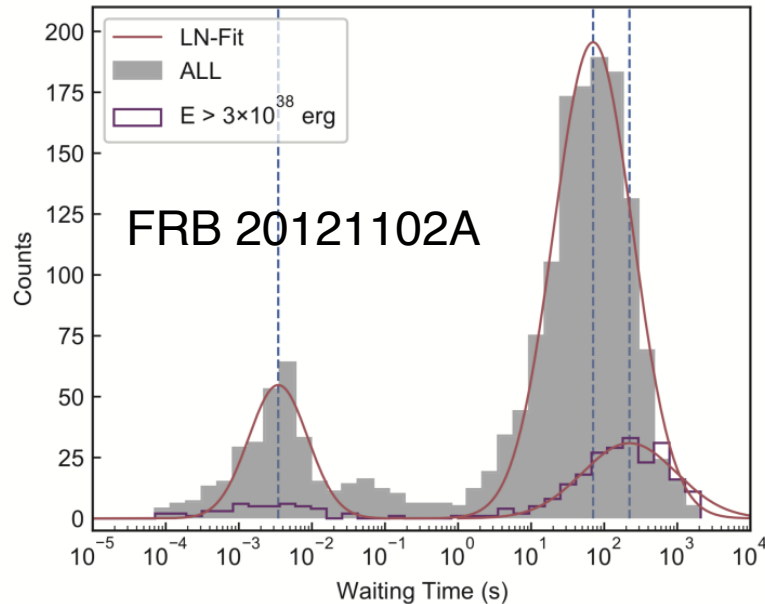
Host-galaxy parameter plots

Early localized repeaters and one-offs already showed that repeaters can live in dwarf star-forming environments, while some one-offs are found in more massive, quiescent hosts, although the full host picture is now broader than that simple split.

Repeater fraction vs observing time / censoring plots

These plots help show that “non-repeater” often really means not yet seen to repeat.

Fast Radio Bursts: Burst waiting time

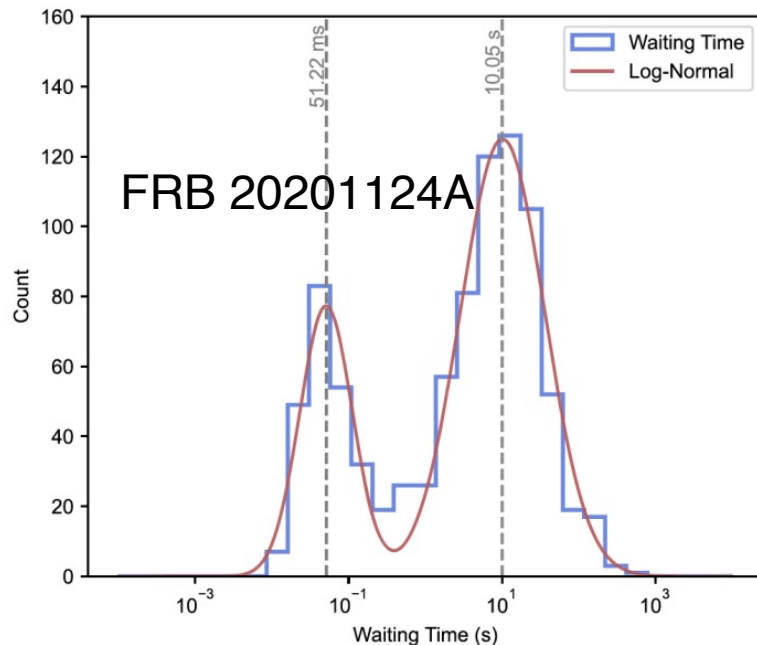


Waiting time distributions of active repeaters show two active peaks

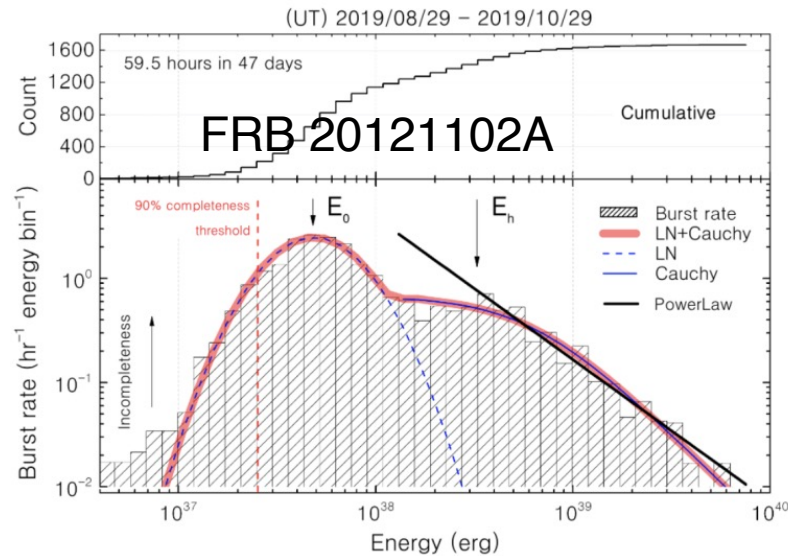
First peak: how distinct the bursts are; related to continuous activity

Second peak: global activity level of the source

Local Vs global periodicity of FRBs



Fast Radio Bursts: Burst waiting time



Burst rates as a function of energy have been reported for several repeating FRBs

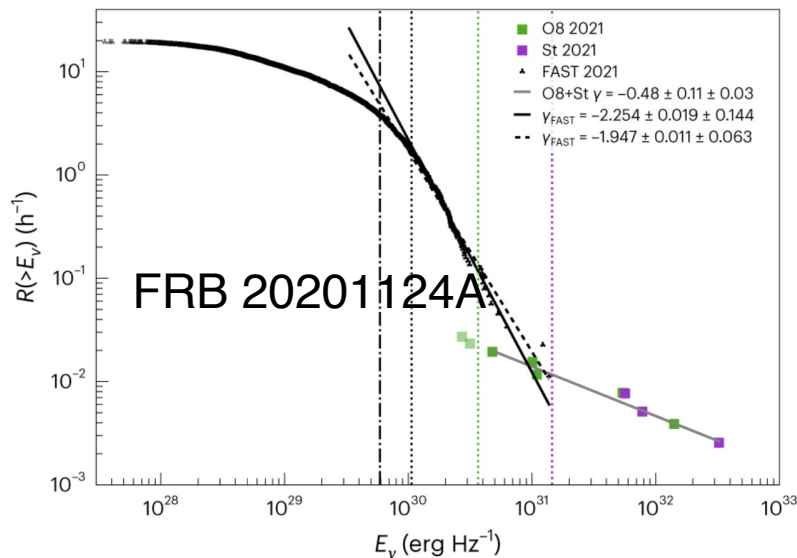
The low-energy turnover appears to be intrinsic to the emission process

The slope usually steepens towards the high-energy end

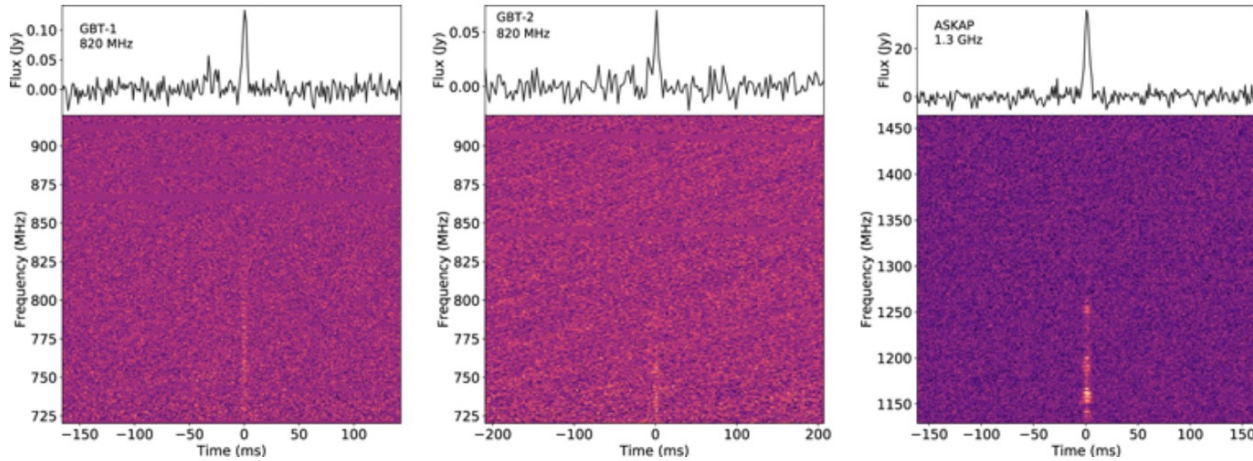
Gradual flattening of the burst rates for very high-energy bursts

The distribution of the ultra-high-energy tail resembles that of non-repeaters

For apparently non-repeating FRBs, we may be observing bursts from a similar high-energy tail.



Fast Radio Bursts: Burst waiting time

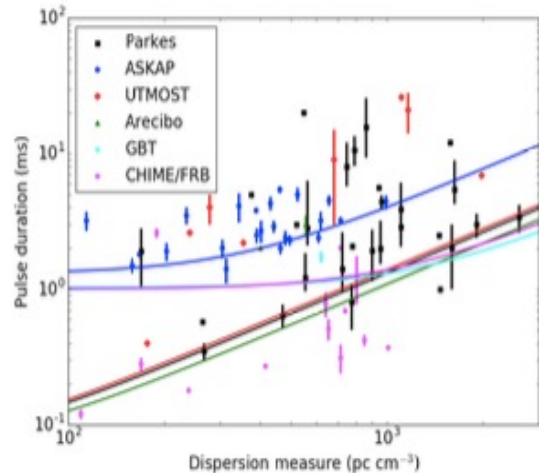


The repetitions are a factor of ~ 590 fainter than the ASKAP-discovered burst

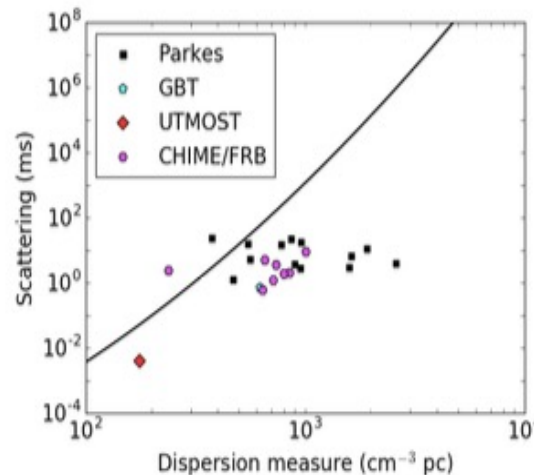
No.	Telescope	TOA ^a	Fluence ^b	Gaussian FWHM	Integrated S/N ^c	Spectral Index ^d	DM ^e
		(MJD)	(Jy ms)	(ms)			(pc cm ⁻³)
0	ASKAP	58045.56061371(2)	219 ± 5	5.4 ± 0.3	24.8	-12.6 ± 1.4	461 ± 1
			388 ± 12	5.2 ± 0.2	32.4	-9.9 ± 2.0	
1	GBT	58319.356770492(1)	0.60 ± 0.04	4.0 ± 0.3	15.2	-7.8 ± 1.2	456.1 ± 0.4
			1.11 ± 0.07	4.2 ± 0.3	16.7	-0.9 ± 1.8	
2	GBT	58643.321088777(1)	0.37 ± 0.05	5.2 ± 0.8	7.9	-13.2 ± 2.8	457 ± 1
			0.61 ± 0.07	3.7 ± 0.5	9.1	-9.6 ± 3.3	

The detection of faint pulses from FRB 171019 shows that at least some FRBs selected from bright samples will repeat if follow-up observations are conducted with more sensitive telescopes

Fast Radio Bursts: Width and Scattering



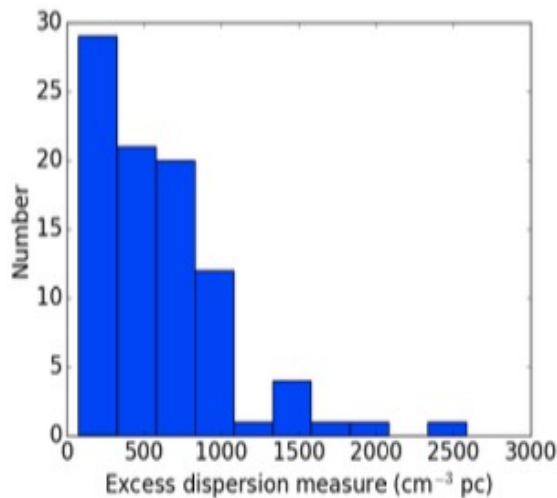
(a) Width vs. DM



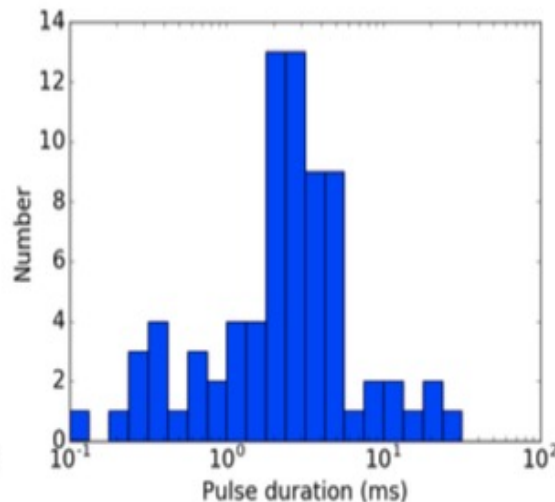
(b) Scattering vs. DM

Widths of FRBs as function of DMs along with the predictions from DM smearing

Scattering of FRBs as function of DMs $\rightarrow$ FRBs are under-scatter than the Galactic pulsars at similar DMs $\rightarrow$ IGM plays minor role in scattering



(c) DM excess histogram



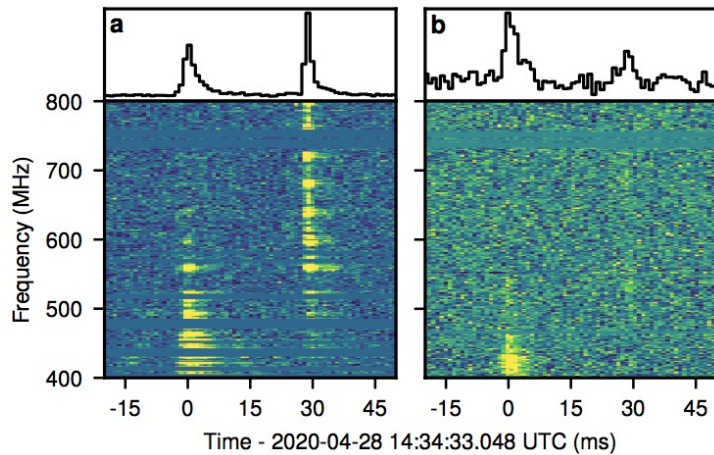
(d) Pulse duration histogram

The largest DM observed is $2596 \text{ pc cm}^{-3} \rightarrow$ redshift of 2.1

FRB pulse width of $10 \mu\text{s}$ (limit on emitting region) to 26 ms (limit on propagation effects).

$\rightarrow$ require real-time detection and triggering for Nyquist resolution data dump

Fast Radio Bursts: Galactic Magnetar

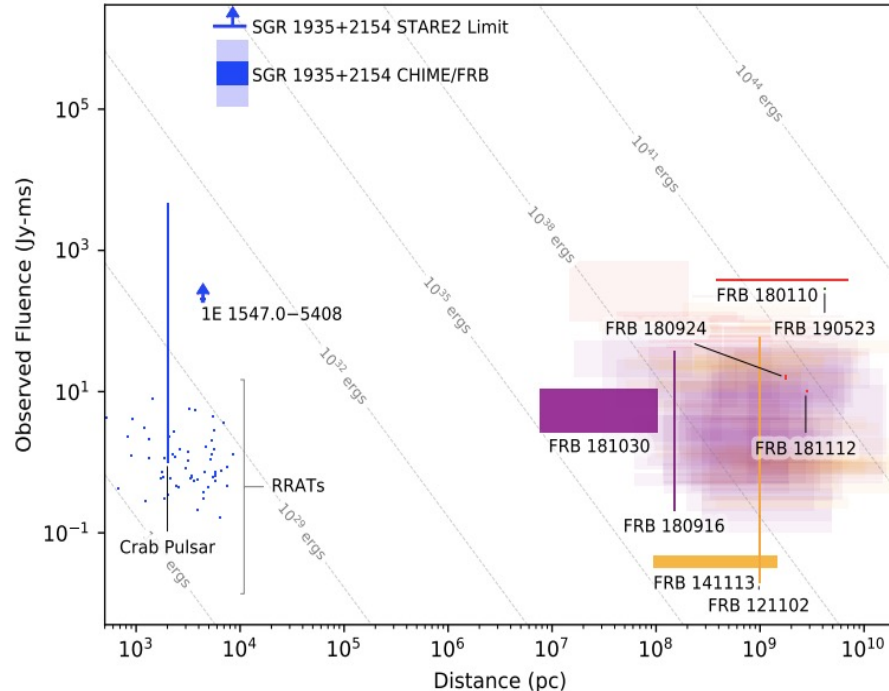


A millisecond burst seen from Galactic magnetar SGR 1935+2154 using CHIME and STARE2

Peak luminosity at 400-800 MHz is $\sim 10^{35}$ erg/s

The SGR 1935+2154 radio burst is by far the most radio-luminous such event detected from any Galactic magnetar

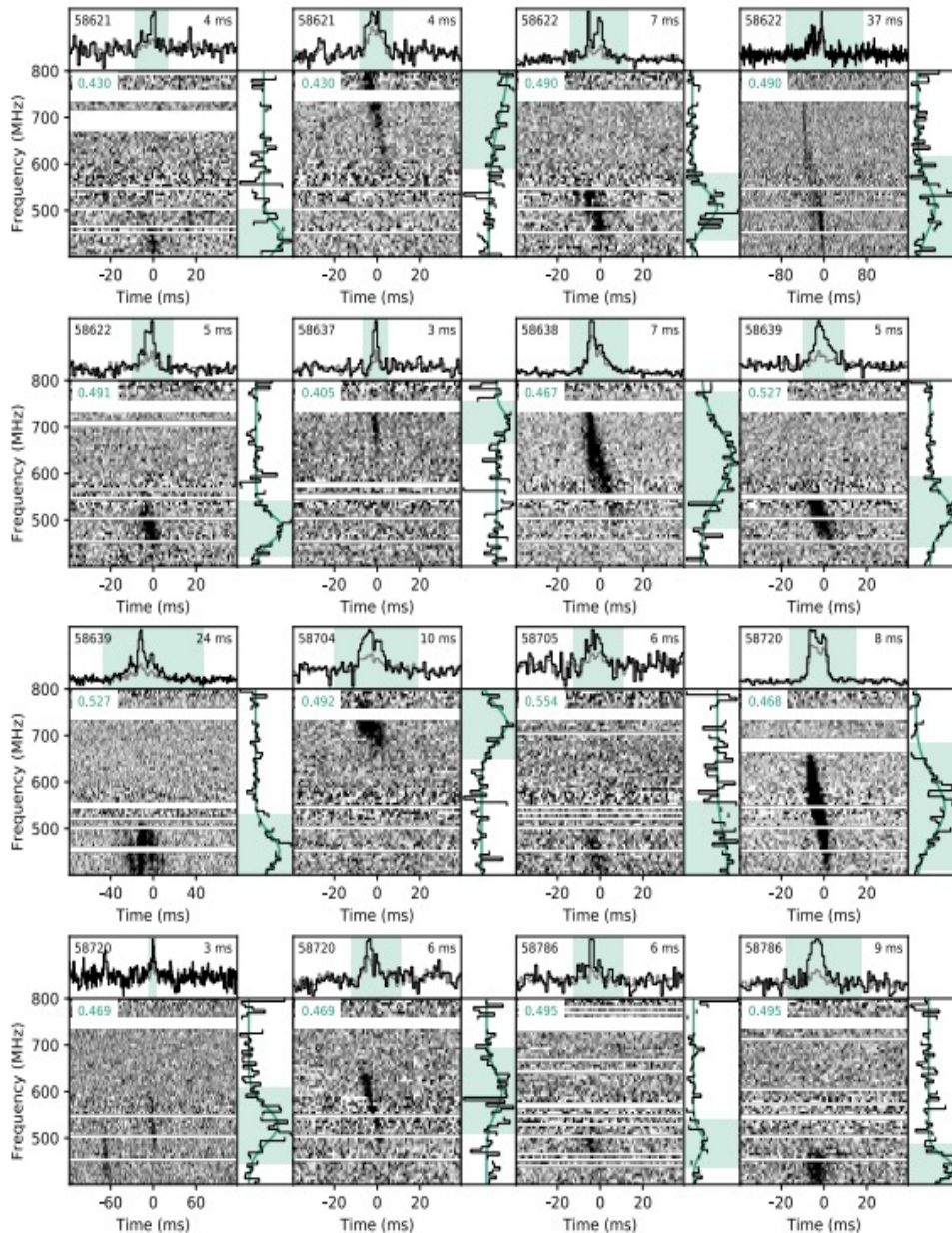
Andersen et al. 2020



Burst energy bridges the radio energy gap between Galactic magnetars and FRBs; SGR 1935+2154 is at 1-2 order magnitude below than burst energies from typical FRBs.

Extragalactic analogues of current Galactic magnetars could explain some of the FRB population, but not frequent burst like from FRB 121102

Fast Radio Bursts: periodic activities

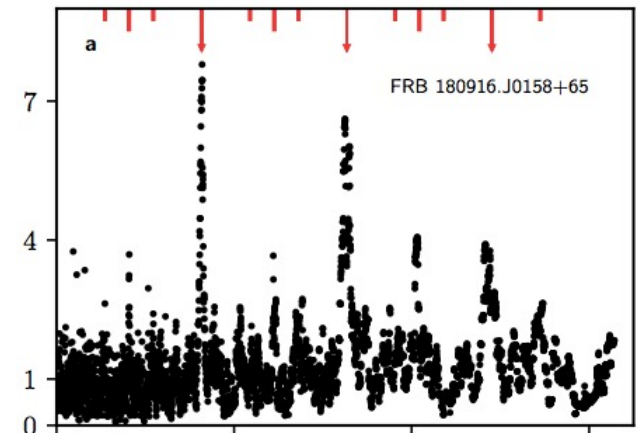


16.35 days periodicity seen in FRB 180916 from CHIME

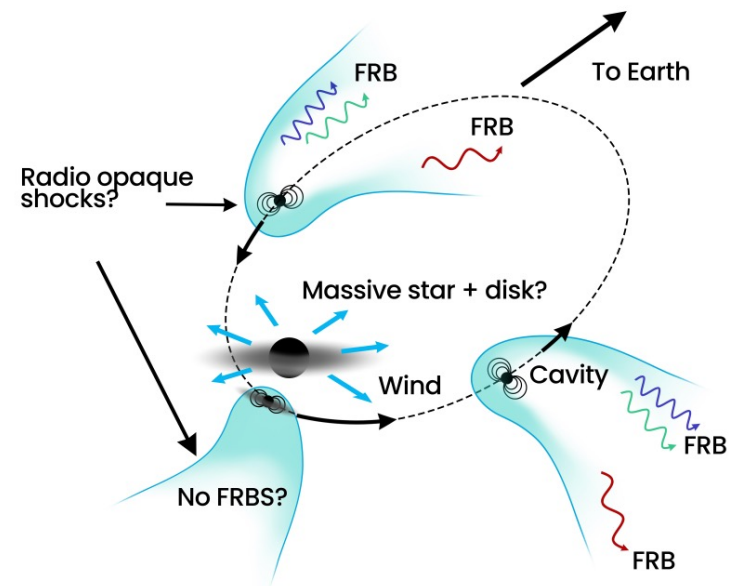
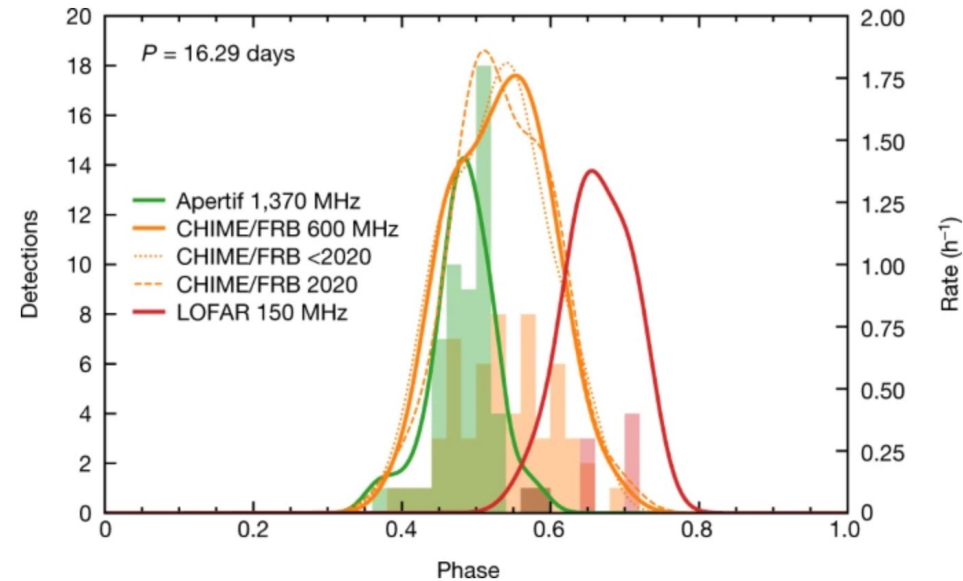
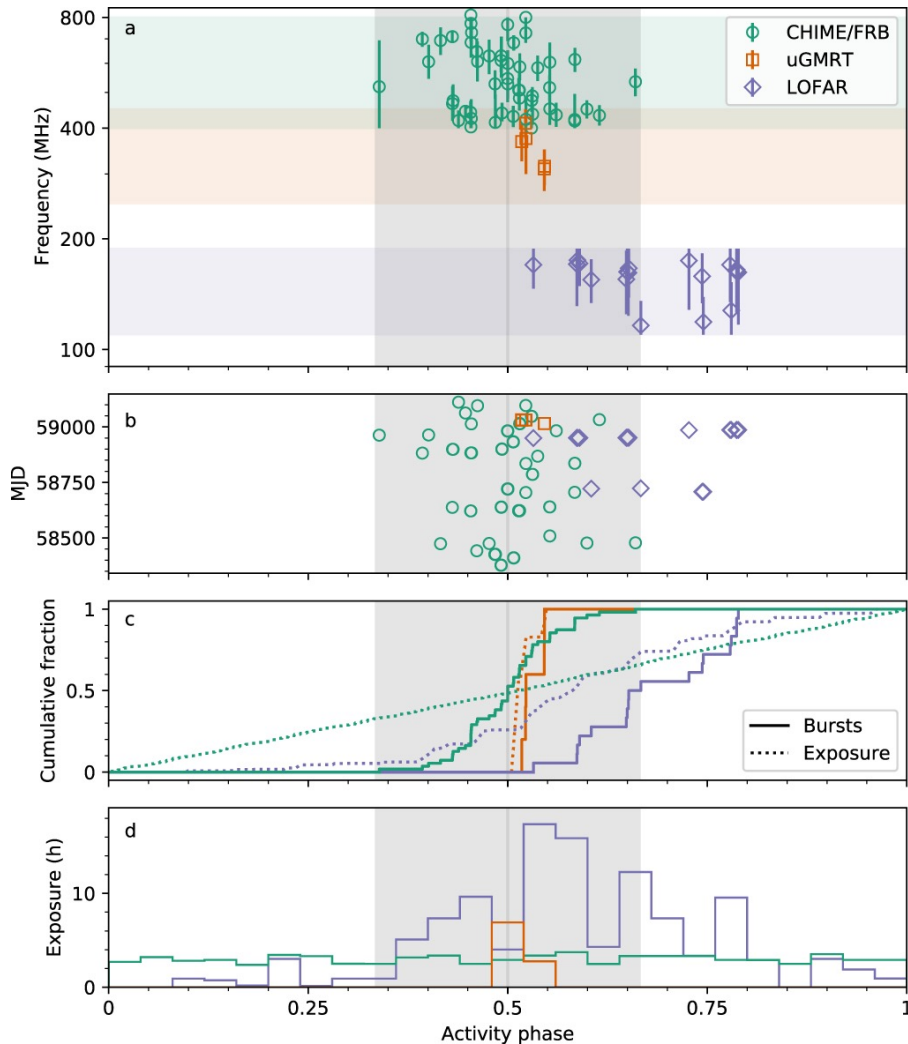
Orbital motion with either stellar or compact object companion; black-widow like binaries to massive O/B stars with highly eccentric systems

Strong plasma lensing/eclipse by companion wind

Isolated magnetar: intermittent, quasi-periodic emission in radio pulsars



Fast Radio Bursts: periodic activities



Activity window depends on frequency:
 High frequencies $\rightarrow$ earlier phase
 Low frequencies $\rightarrow$ later phase

Fast Radio Bursts: polarisation

Strong linear polarisation

FRBs show ~50–100% linear polarization: coherent emission, magnetospheric

Circular polarisation

Typically 0–30%: emission mechanism, propagation effects (mode conversion)

Polarisation angle (PA)

Smooth PA swings similar to pulsars: magnetospheric emission, stable geometry
burst-to-burst variation (repeaters): changing emission regions or propagation effects

Faraday rotation

As the wave propagates through magnetized plasma:

$$\psi(\lambda) = \psi_0 + \text{RM} \lambda^2$$

where RM = **Rotation Measure**:

$$\text{RM} \propto \int n_e B_{\parallel} dl$$

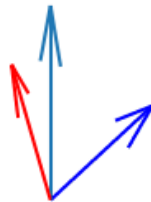
Magnetic field strength along the line of sight, Environment near the FRB

PA deviates from λ^2 : PA jumps across sub-bursts, PA varies within burst, PA varies across frequency bands

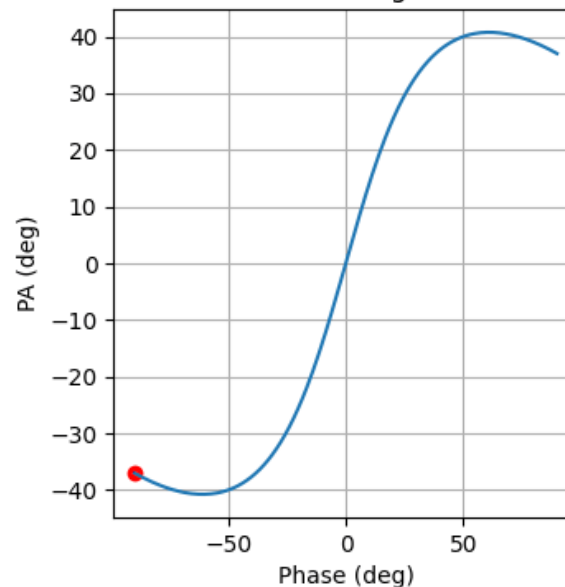
Fast Radio Bursts: polarisation

Property	Repeaters	One-offs
Linear polarisation	Often very high	High but more varied
RM	Can be extreme / variable	Usually moderate
PA behavior	Complex / evolving	Often simpler

Geometry



PA Swing



S-shaped PA swing expected when the line of sight cuts across dipolar field lines in a neutron-star magnetosphere.