

Time-Domain Astronomy

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21st April 2026

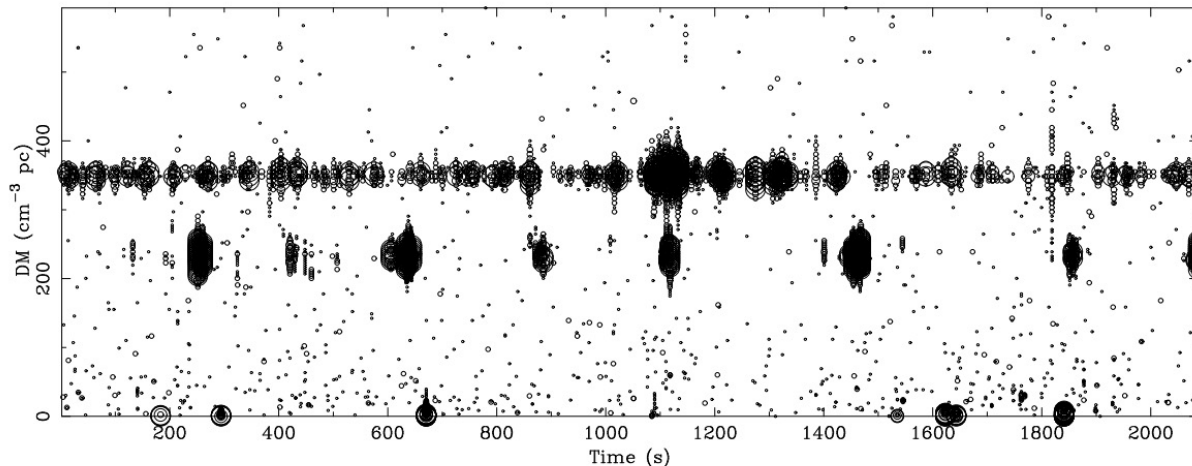
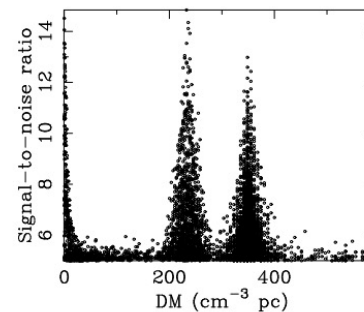
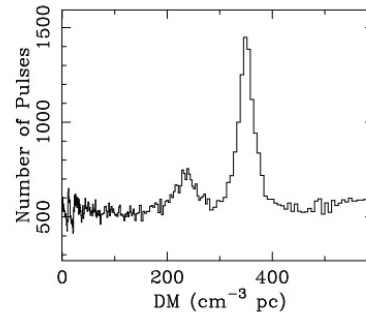
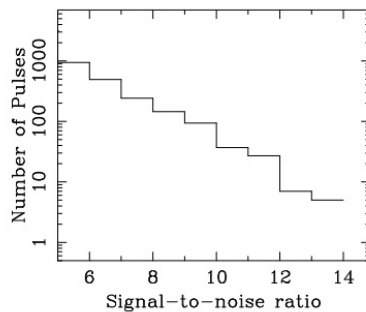
Single pulse Vs periodicity search

The ratio of signal-to-noise ratios of FFT and SP searches

$$r = \frac{(S/N)_{\text{SP}}}{(S/N)_{\text{FFT}}} = \frac{A}{\sqrt{N}} \frac{S_{\text{peak}}}{S_{\text{ave}}},$$

File: PM0089_00311.dat

5106 events. max S/N = 14.8. peak DM = 348.5 (cm⁻³ pc)



Radio pulses were detected at rates as low as once per three hours to as frequently as one every few minutes

Rotating RAdio Transients

Rotating RAdio Transients (RRATs, Keane & McLaughlin, [2011](#)),

Currently, RRATalog has 335 RRATs are known

RRATs may be normal pulsars with very high nulling fractions

The pulsar magnetosphere may have: multiple stable states
It switches between: radio-loud and radio-quiete

Some RRATs lie close to the pulsar death line

Intermittency is caused by material fallback from a supernova debris disk

Radio emission from infalling circumstellar material affecting the charge density in the magnetosphere

RRAT burst rates on timescales ranging between ~ 0.5 hrs and ~ 5 yrs

Rotating RAdio Transients

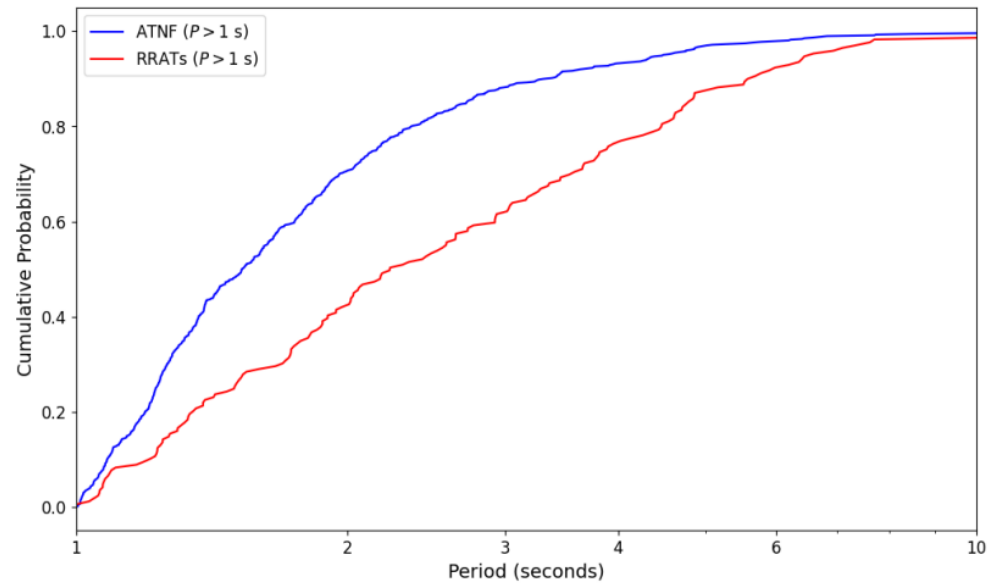
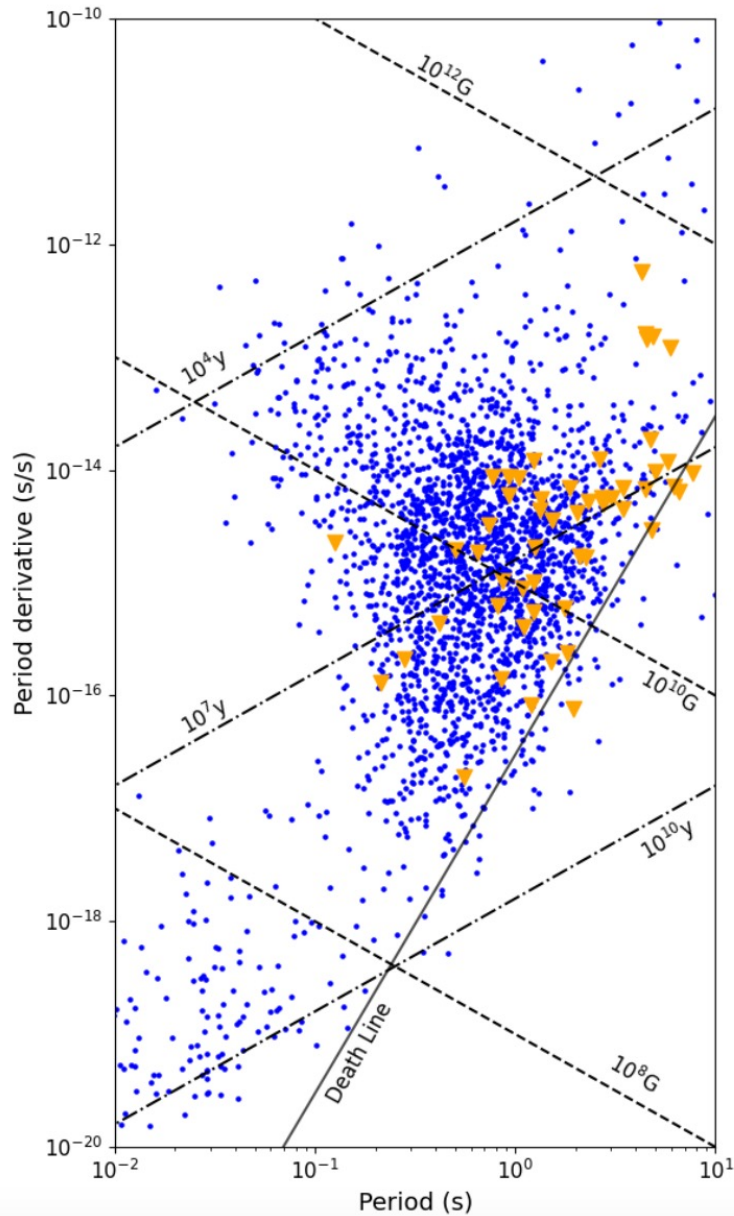
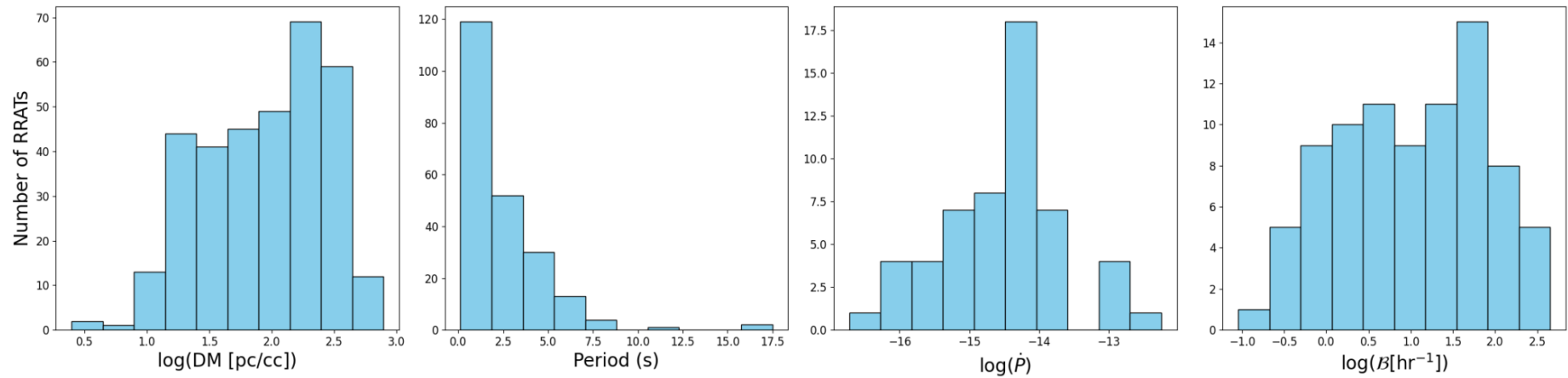
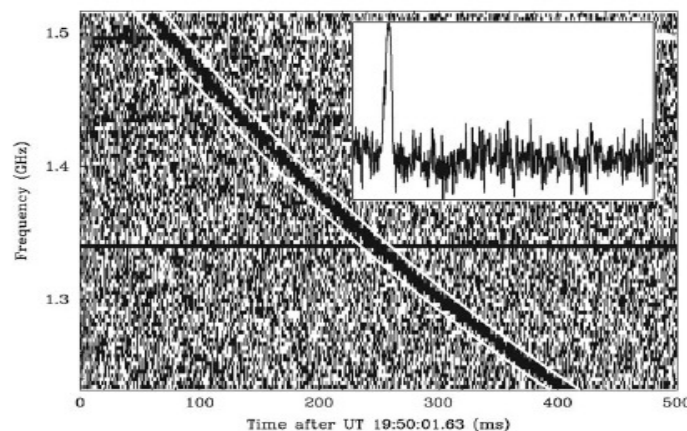
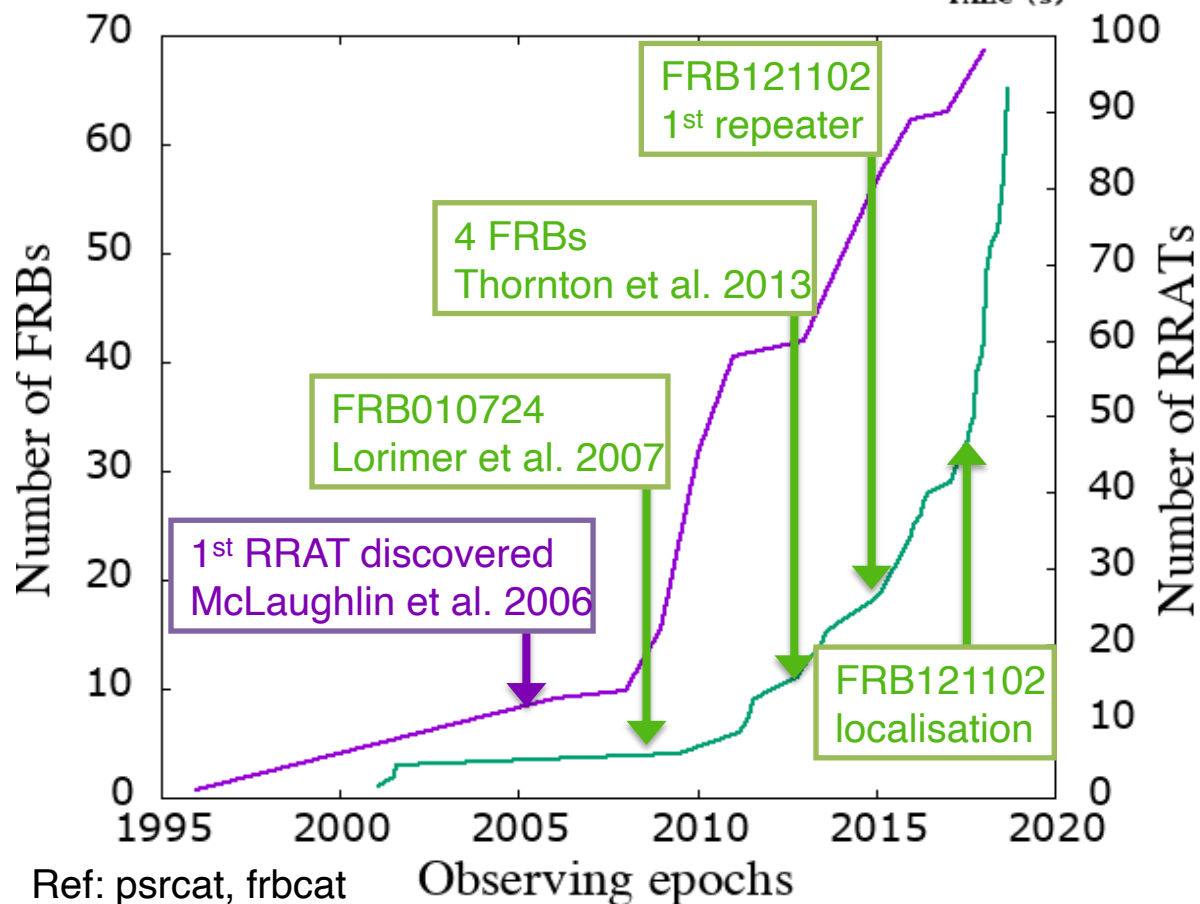
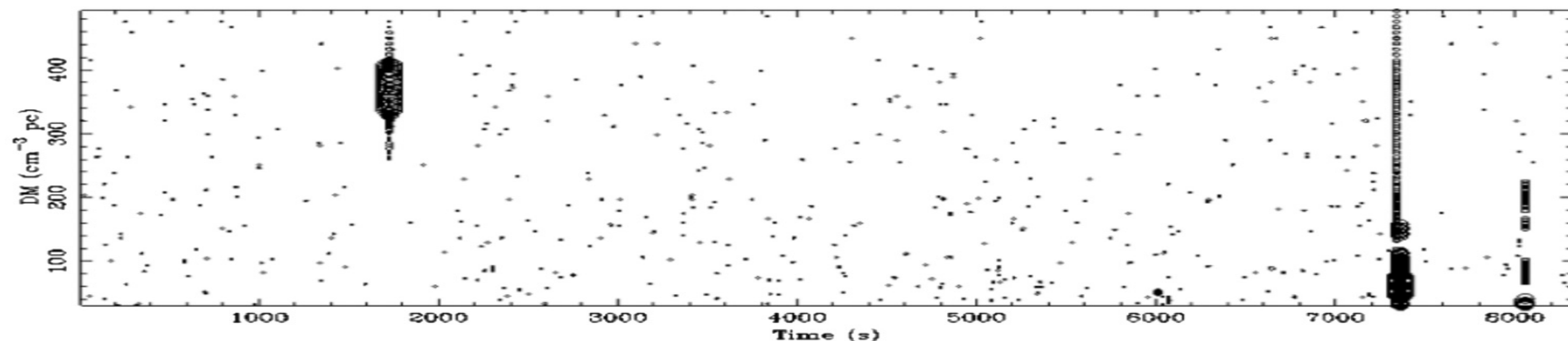


Figure 10. Cumulative distribution of Galactic pulsars with $P > 1$ s and $\dot{P} > 10^{-18}$ taken from the ATNF catalogue compared to the RRATs. There is a significantly higher fraction of high P objects in the RRAT sample.

Rotating RAdio Transients



Fast Transients: Fast Radio Bursts (FRBs)



Discovery of Lorimer Burst

Discovered in 2007 (Lorimer et al.) from Parkes archival data in a search of RRATs from SMC

Duration: ~ 5 ms | Flux: ~ 30 Jy | DM: ~ 375 pc cm $^{-3}$ ($DM_{MW} \sim 25$ pc cm $^{-3}$)

Excess DM

→ extragalactic origin

($\sim$ Gpc distance)

Extremely luminous:

Sun's decades of energy
in milliseconds

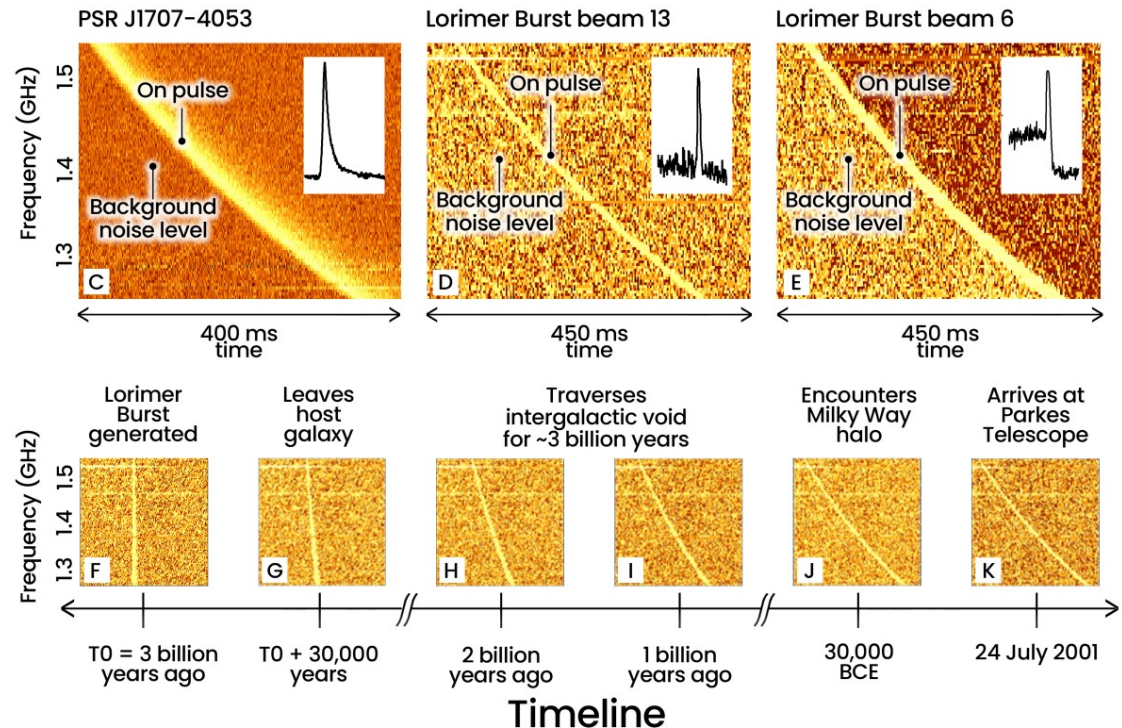
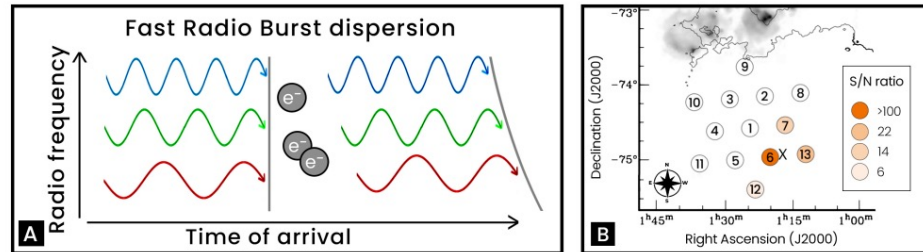
Initially debated

(RFI vs astrophysical)

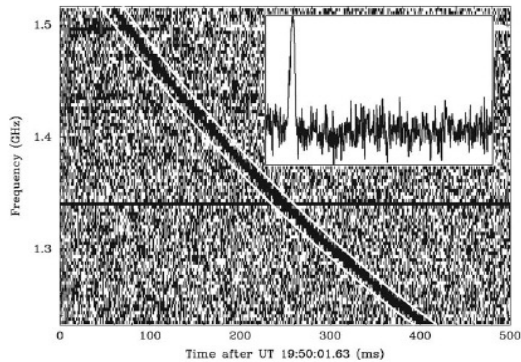
Led to discovery of

Fast Radio Bursts (FRBs)

Opened new field in
time-domain radio
astronomy

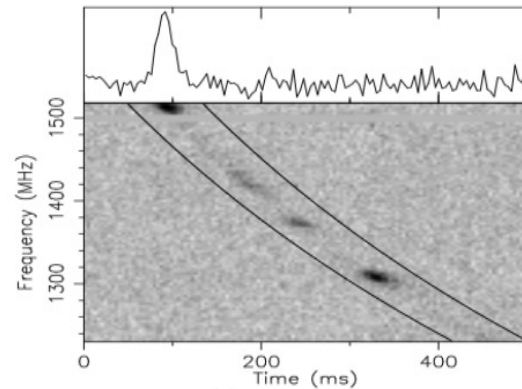


Fast Radio Bursts: first decadal journey



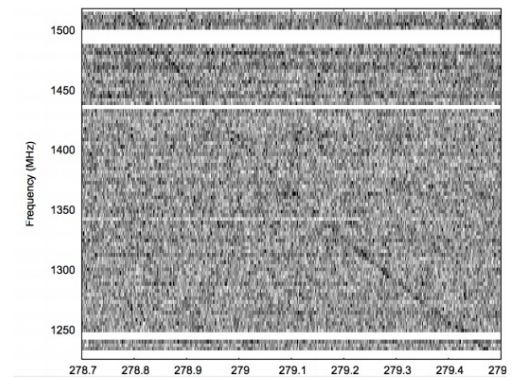
2007

Lorimer burst @ 375 pc cm^{-3}



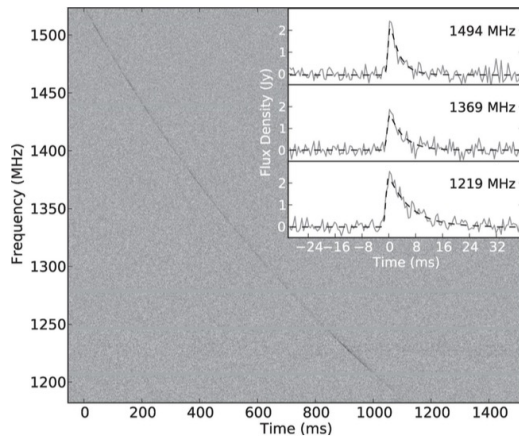
2011

Perytons @ Parkes



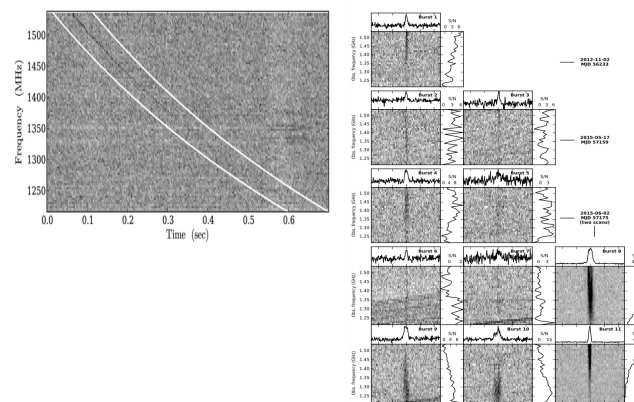
2013

Keane burst @ 746 pc cm^{-3}



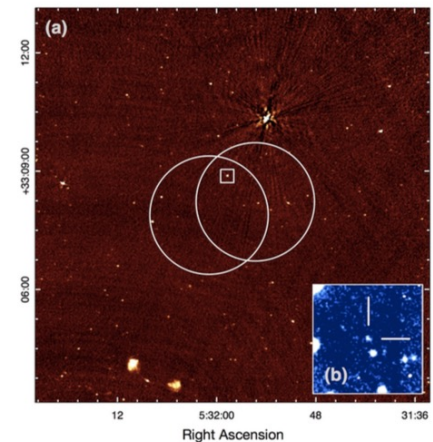
2013

4 bursts by Thornton et al.



2014, 2016

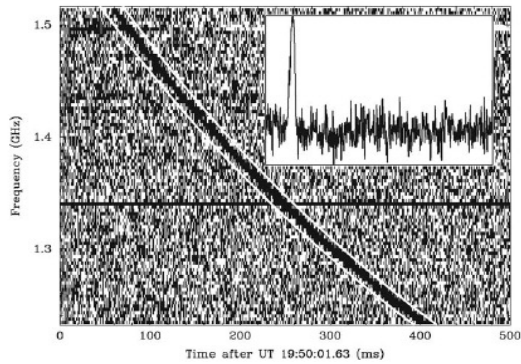
Arecibo bursts by Spitler et al.



2017

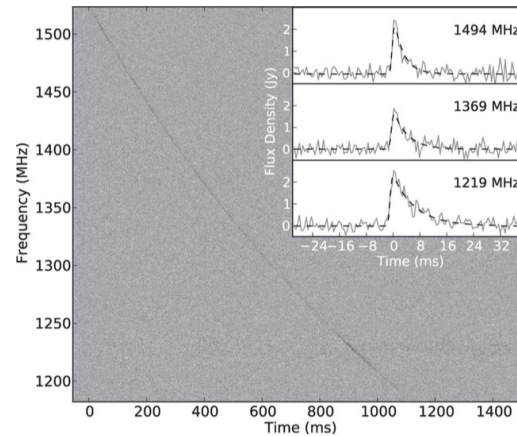
Localisation by Chatterjee et al.

Fast Radio Bursts: milestones



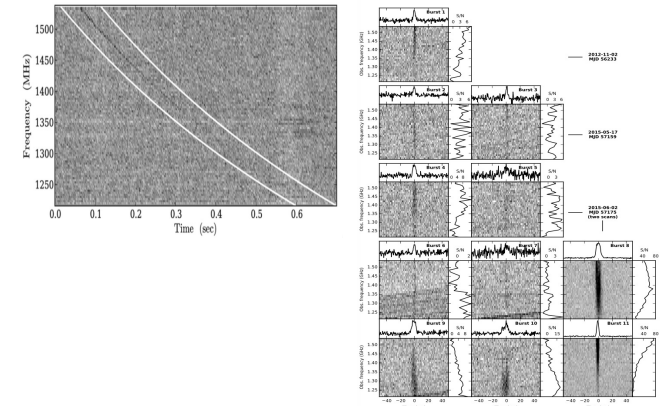
2007

Lorimer burst @ 375 pc cm^{-3}



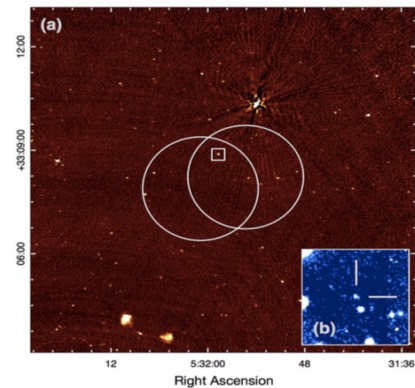
2013

4 bursts by Thornton et al.

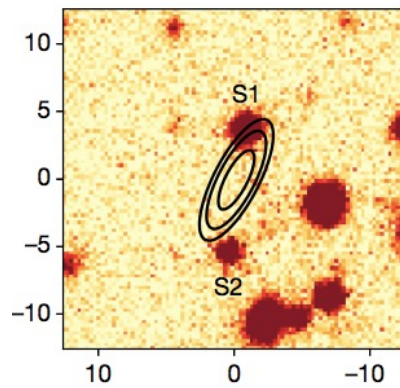


2014, 2016

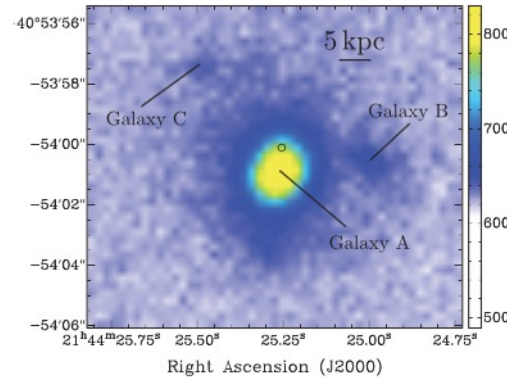
Arecibo repeater by Spitler et al.



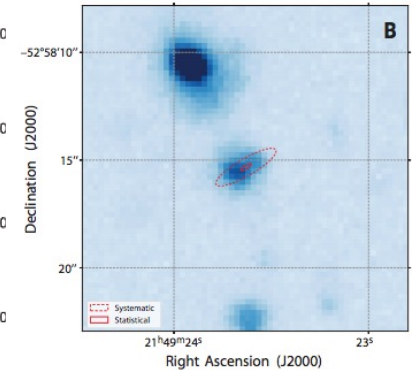
FRB 121102 (2017)
Chatterjee et al.



FRB 190523 (2019)
Ravi et al.



FRB 180924 (2019)
Bannister et al.

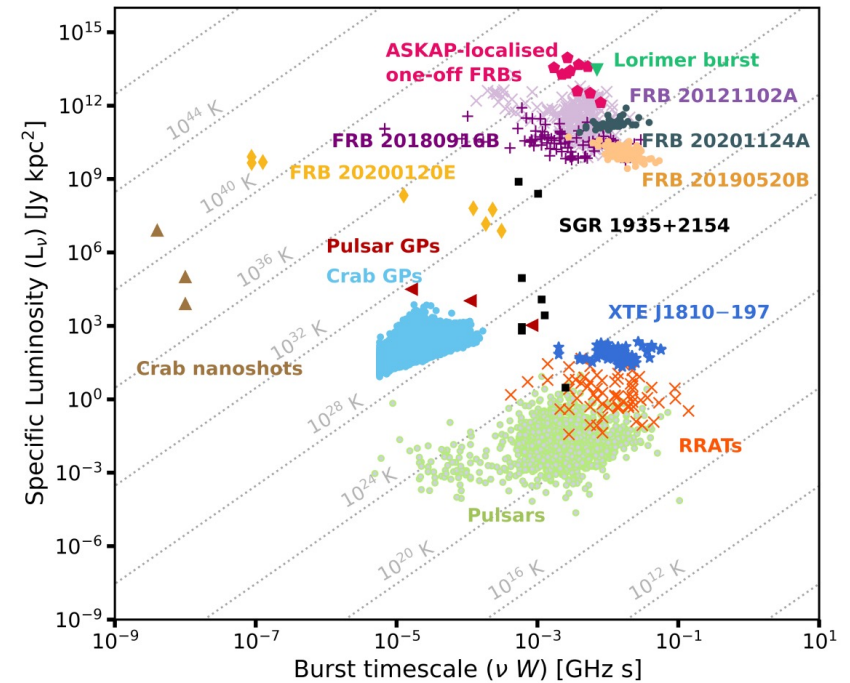
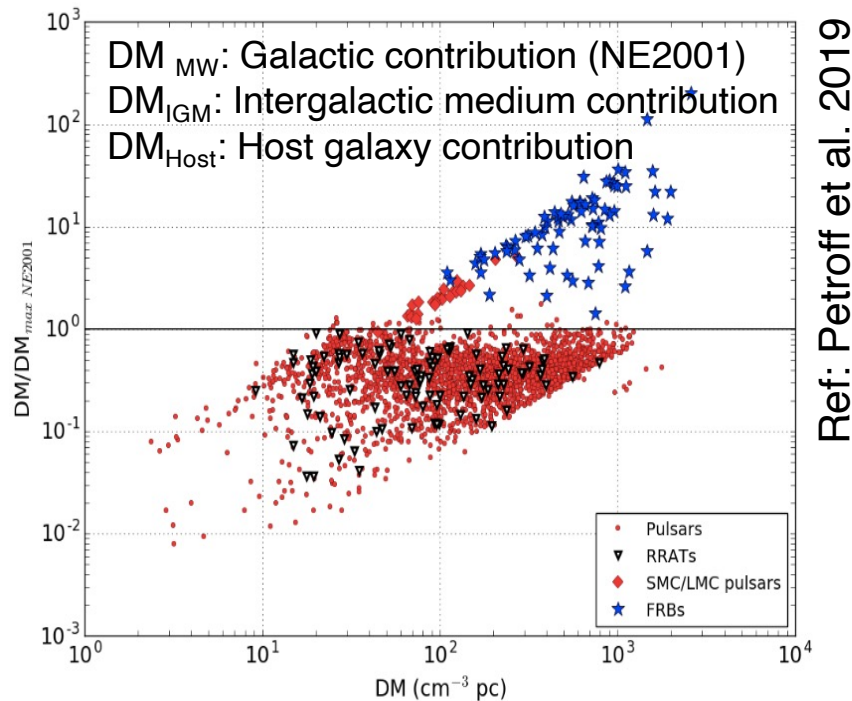


FRB 181112 (2019)
Prochaska et al.

Fast Radio Bursts: milestones

Property	FRB 121102	FRB 190523	FRB 180924	FRB 181112
Host type	Dwarf, starburst	Massive, quiescent	Massive, early-type spiral	Moderate-mass, star-forming
Redshift	0.193	0.66	0.321	0.47
Metallicity	Low	Moderate–high	Moderate–high	Moderate
Stellar population	Young, active SF	Older, evolved	Older, low SF	Mixed / moderate SF
Star-formation rate	High (starburst)	Very low	Low	Moderate (~main-sequence)
Local environment	Dense + persistent radio src	Clean	Clean	Clean
Offset from galaxy	Near SF region	kpc-scale	~4 kpc	kpc-scale
Repetition	Yes (repeater)	No (so far)	No	No
Special feature	First repeater + PRS	First massive host (D=0.66)	First precise ASKAP localisation	Probed foreground galaxy halo
Physical picture	Young magnetar (active)	Older/delayed channel	Older/delayed channel	Intermediate / mixed channel

Fast Radio Bursts: extragalactic origin



For a FRB at DM of 563 pc cm^{-3} with peak flux density of 1 Jy, luminosity distance $d_L < 3.3 \text{ Gpc}$

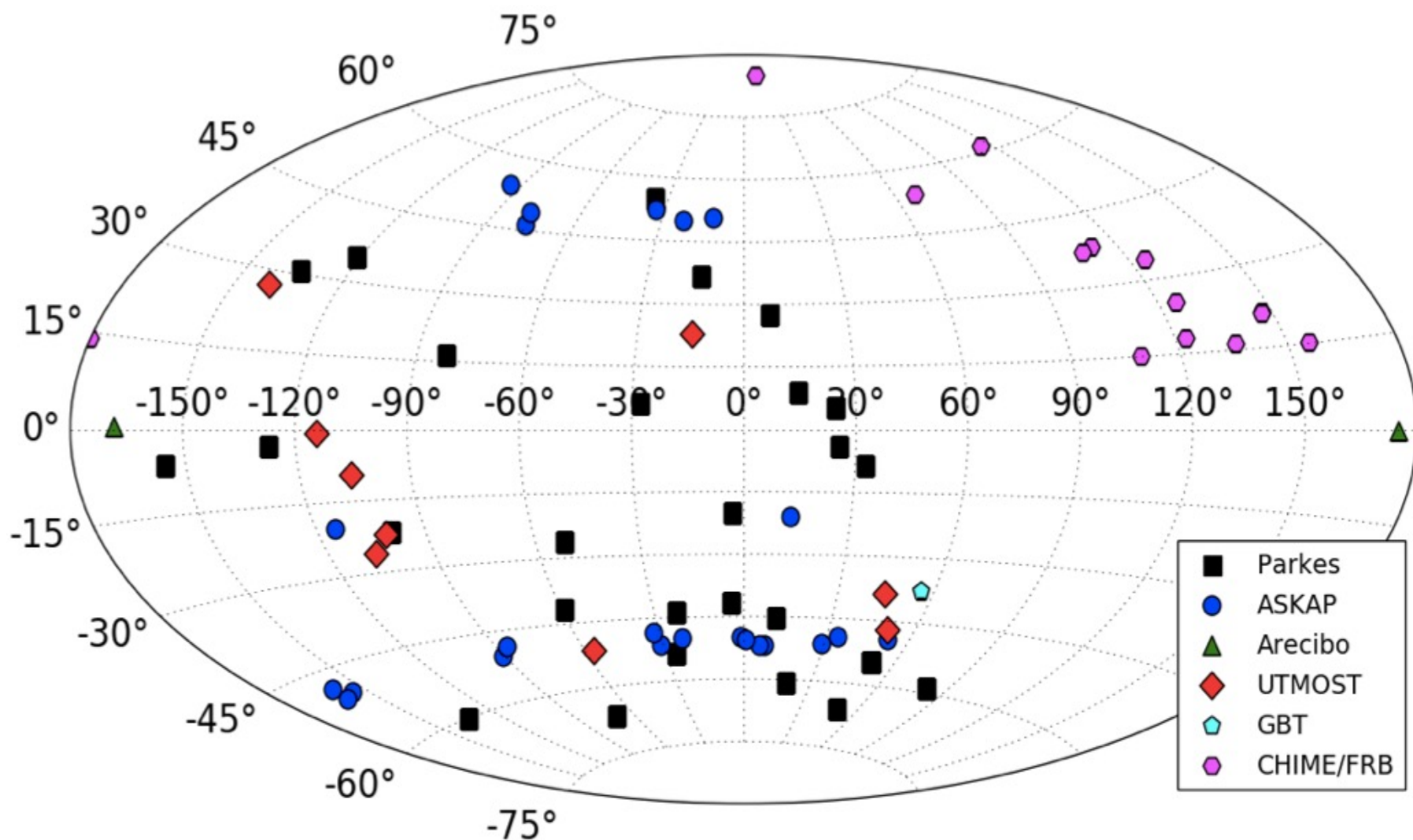
for $z < 0.56$; luminosity limit over 300 MHz band bandwidth $\sim O(10^{42}) \text{ erg/s}$

Normal Radio pulses with $\sim \text{ms}$ to 10 s μs duration having energy $\sim O(10^{30}) \text{ erg/s}$

Giant pulses from Crab with $\sim \mu\text{s}$ duration having energy $\sim O(10^{36}) \text{ erg/s}$

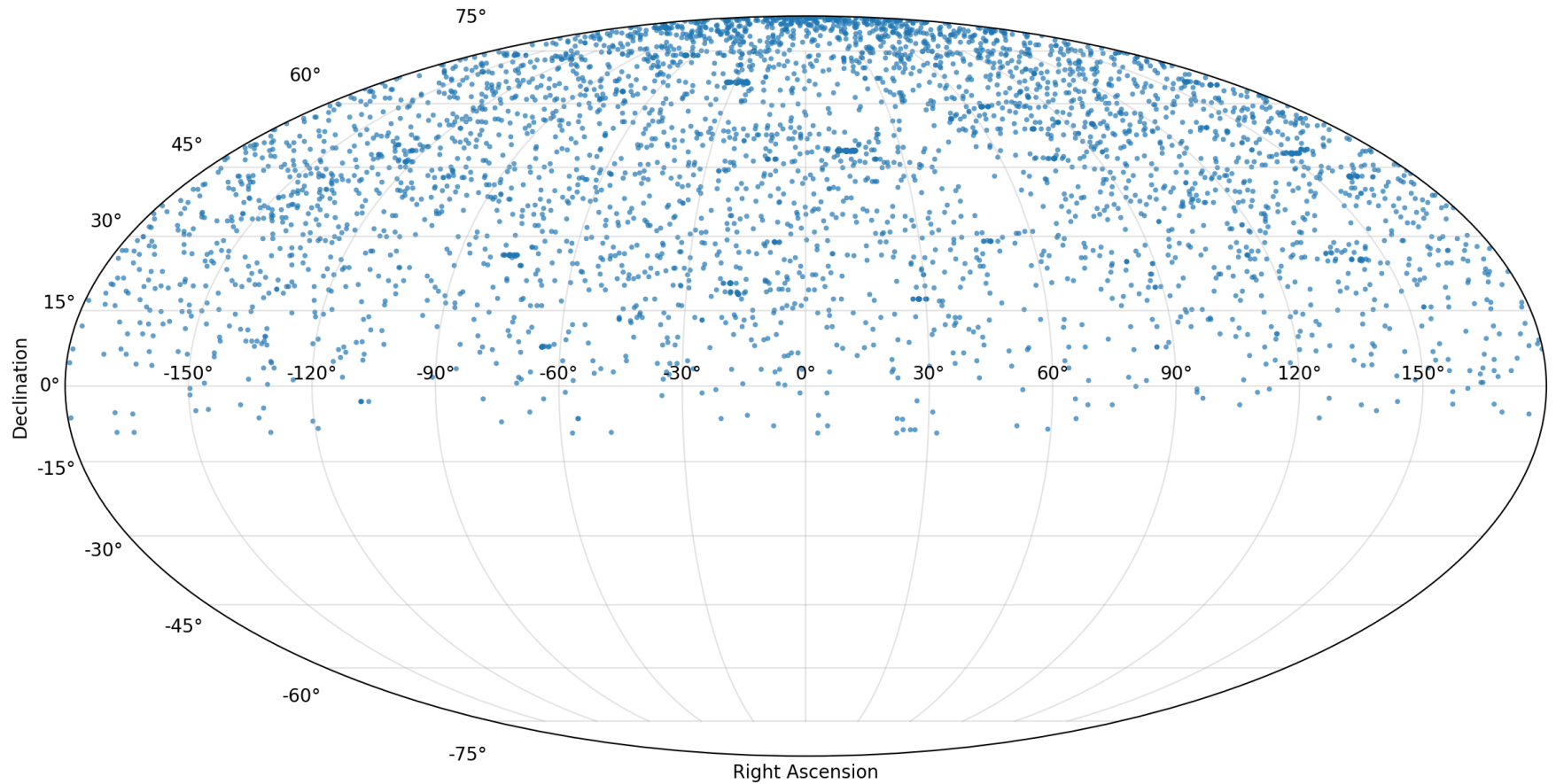
FRBs are at $T_B \sim 10^{35} \text{ K}$; Radio Pulsars are at 10^{26} K

Fast Radio Bursts



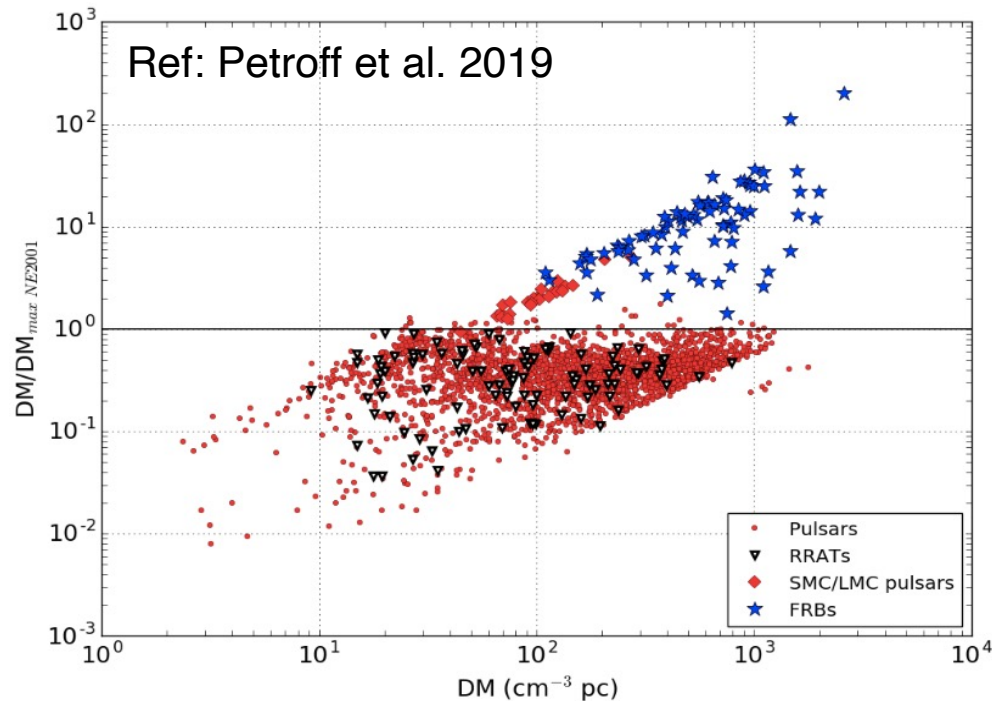
Fast Radio Bursts

All-sky distribution of 4,539 FRBs from CHIME/FRB Catalog 2



Source: official CHIME/FRB Catalog 2 public CSV (one point per burst)

Fast Radio Bursts: extragalactic origin



Excess DM

$$DM_E = DM - DM_{MW} = DM_{IGM} + \left(\frac{DM_{Host}}{1+z} \right)$$

DM_{MW}: Galactic contribution (NE2001)

DM_{IGM}: Intergalactic medium contribution

DM_{Host}: Host galaxy contribution

Redshift estimation from DM

$$z < DM/1000 \text{ cm}^{-3} \text{ pc}$$

Source luminosity
$$L = \frac{4\pi d_L^2 S_\nu \Delta\nu}{(1+z)}$$

For a FRB at DM of 563 pc cm⁻³ with peak flux density of 1 Jy, luminosity distance $d_L < 3.3$ Gpc

for $z < 0.56$; luminosity limit over 300 MHz band bandwidth $\sim O(10^{42})$ erg/s

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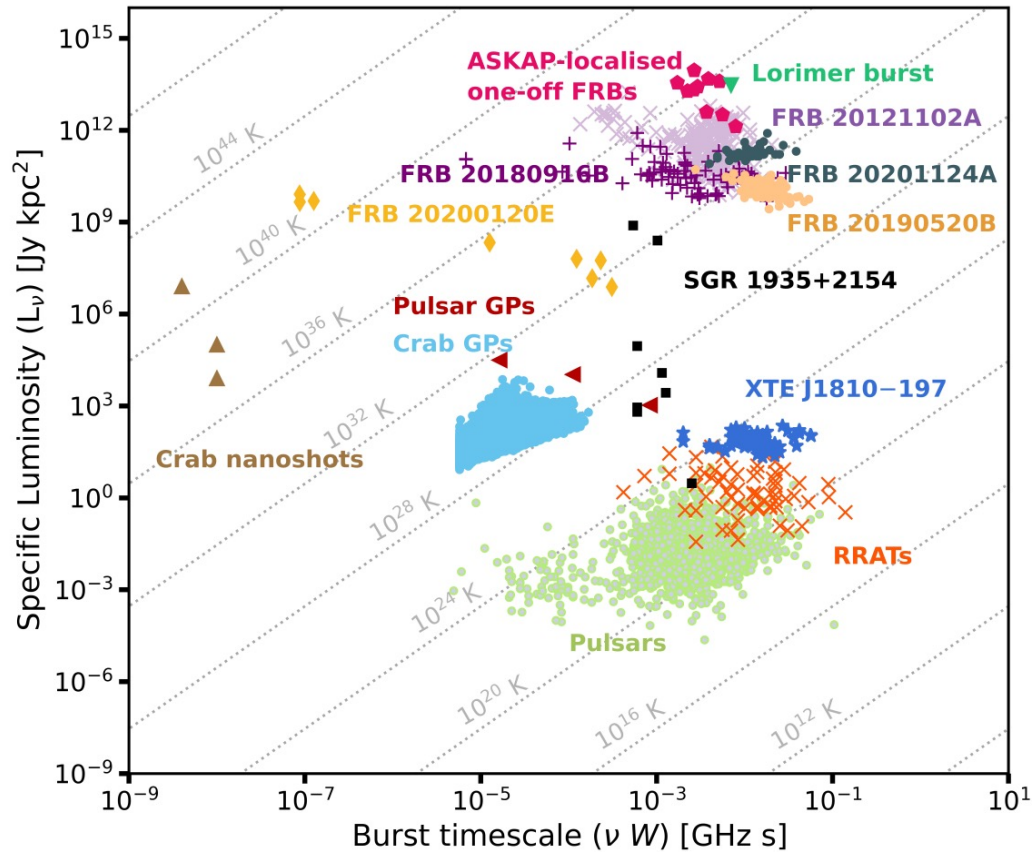
GRBs with $\sim$ sec duration having energy $\sim O(10^{51})$ erg/s

Fast Radio Bursts: brightness

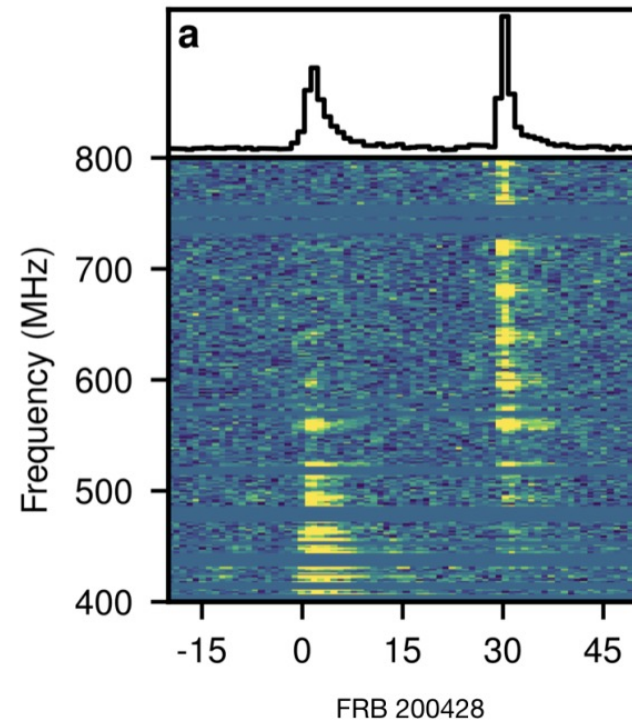
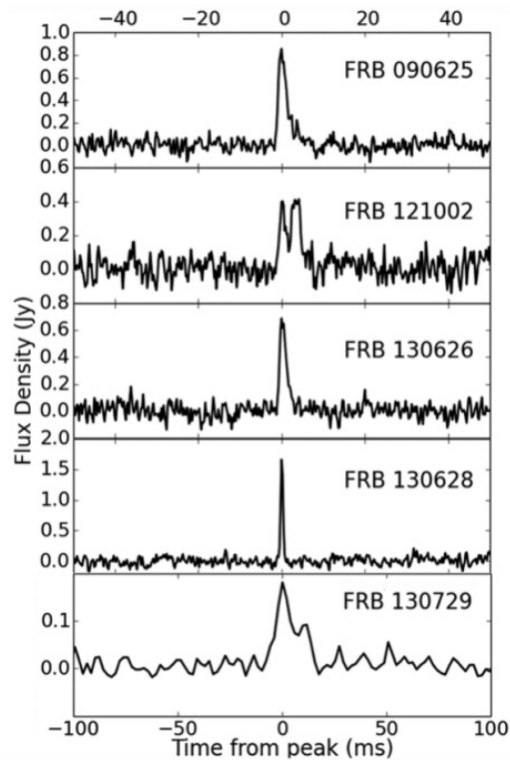
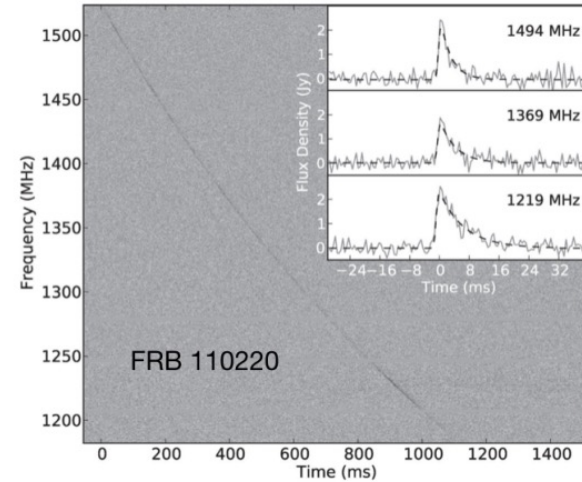
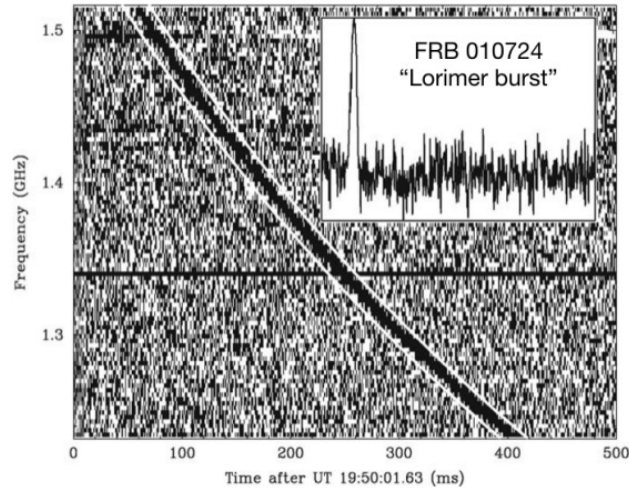
Brightness temperature is an indicator of non-thermal origin of the emission

$$T_B \simeq 10^{36} \text{ K} \left(\frac{S_{\text{peak}}}{\text{Jy}} \right) \left(\frac{\nu}{\text{GHz}} \right)^{-2} \left(\frac{W}{\text{ms}} \right)^{-2} \left(\frac{d_L}{\text{Gpc}} \right)^2$$

FRBs are at $T_B \sim 10^{35}$ K; Radio Pulsars are at 10^{26} K; Crab nanoshots are at $\sim 10^{37}$ K

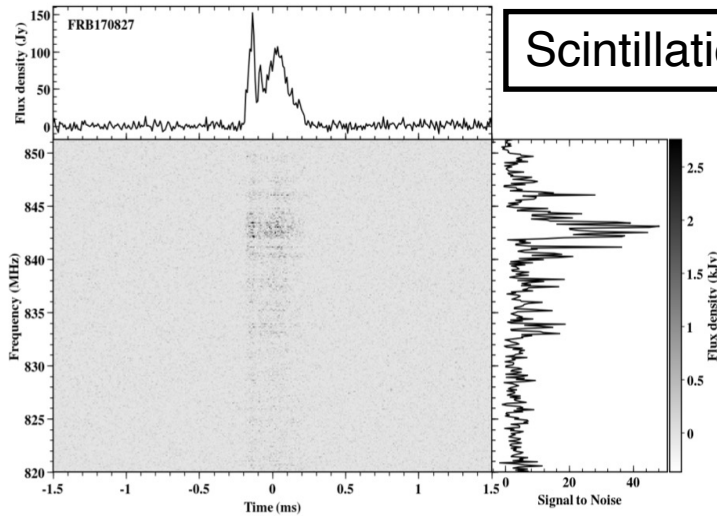


Fast Radio Bursts: Light curves



Fast Radio Bursts: propagation effects

Farah et al. 2018



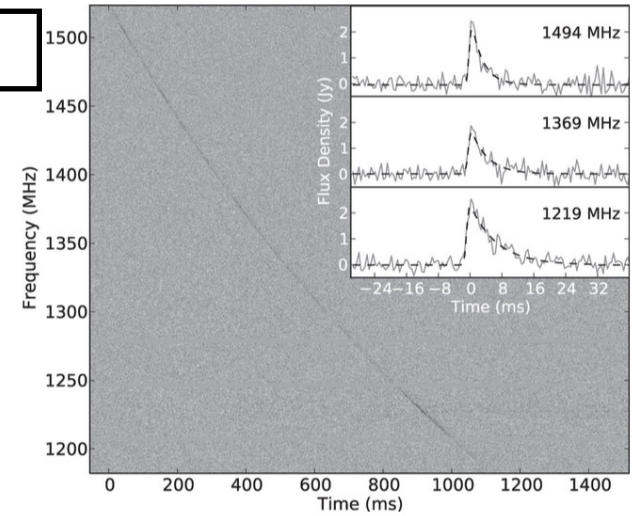
Scintillation

Scattering

Scintillation caused by diffraction and refraction of the incoming signal through clumpy, turbulent medium

The characteristic frequency scale of scintillation strongly frequency-dependent

Spectral feature seen in FRBs:
propagation effect or intrinsic: narrow-spectral structure Vs broad spectral structure



Thronton et al. 2013

FRB signals temporally broadened by scattering caused by multi-path propagation

Scattering time-scale $\propto \nu^{-4}$

Fast Radio Bursts: propagation effects

Since FRBs are from cosmological distances, the DM can be most generally written

$$\text{DM} = \int_0^{D_z} \frac{n_e(l)}{1+z(l)} dl,$$

The observed DM is usually split into multiple terms

$$\text{DM} = \text{DM}_{\text{MW}} + \text{DM}_{\text{halo}} + \text{DM}_{\text{IGM}} + \frac{\text{DM}_{\text{host}} + \text{DM}_{\text{src}}}{1+z},$$

the observed width

$$W = [W_i^2(1+z)^2 + \tau_{\text{sc}}^2 + t_{\text{ins}}^2]^{1/2},$$

the scattering time

$$\tau_{\text{sc}} = [\tau_{\text{MW}}^2 + \tau_{\text{IGM}}^2 + \tau_{\text{HG}}^2(1+z)^2]^{1/2}$$

instrumental broadening

$$t_{\text{ins}} = (t_{\text{samp}}^2 + \Delta t_{\text{DM}}^2 + \Delta t_{\delta\text{DM}}^2 + \Delta t_{\delta\nu}^2)^{1/2}$$

Fast Radio Bursts: propagation effects

The frequency dependent smearing due to dispersion measure

$$\Delta t_{\text{DM}} = (8.3 \mu\text{s}) \text{DM} \Delta \nu_{\text{MHz}} \nu_{\text{GHz}}^{-3},$$

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

→ likely related to the intrinsic radiation physics of FRBs

