

Time-Domain Astronomy

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Fast Radio Bursts: recap

~4500+ FRBs discovered

~1.6% are repeaters

Only ~2% have host galaxy associations

Distributed across the sky → cosmological origin confirmed

Downward frequency drift (“sad trombone”)

Common in repeaters

Suggests intrinsic emission physics rather than propagation

Repeaters:

Multiple sub-bursts

Narrow bandwidth

Frequency drift, Complex morphology

One-offs:

Single pulse

Broader bandwidth

Simpler structure

Waiting-time distributions show two peaks:

Local burst activity

Global activity cycles

Energy distributions:

Low-energy turnover → intrinsic

High-energy tail resembles one-offs

Fast Radio Bursts: recap

Galactic magnetar SGR 1935+2154 produced FRB-like burst

Bridges energy gap between:

Pulsars/magnetars/FRBs

16.35-day periodicity (FRB 180916)

Possible origins:

Binary systems (wind interaction, eclipses)

Magnetar precession/activity cycles

Strong linear polarisation (50–100%)

→ coherent, magnetospheric origin

Circular polarisation: 0–30%

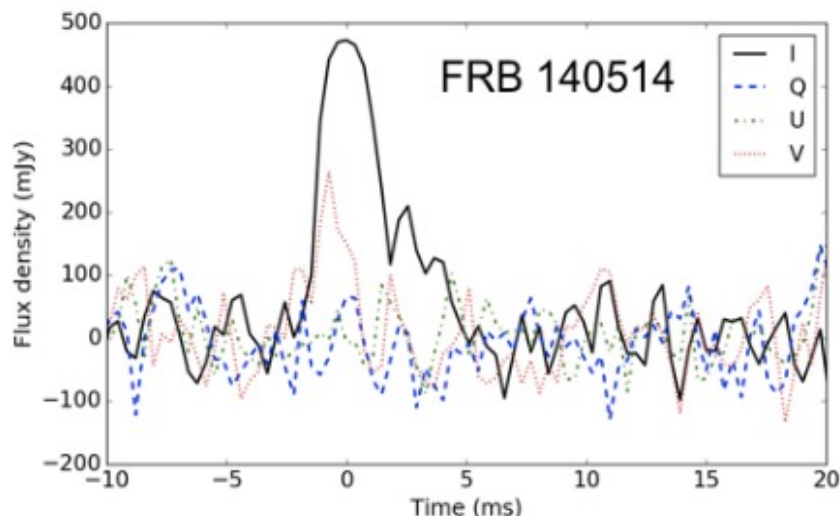
PA swings (S-shaped) → pulsar-like geometry

Faraday rotation:

RM probes magnetized plasma environment

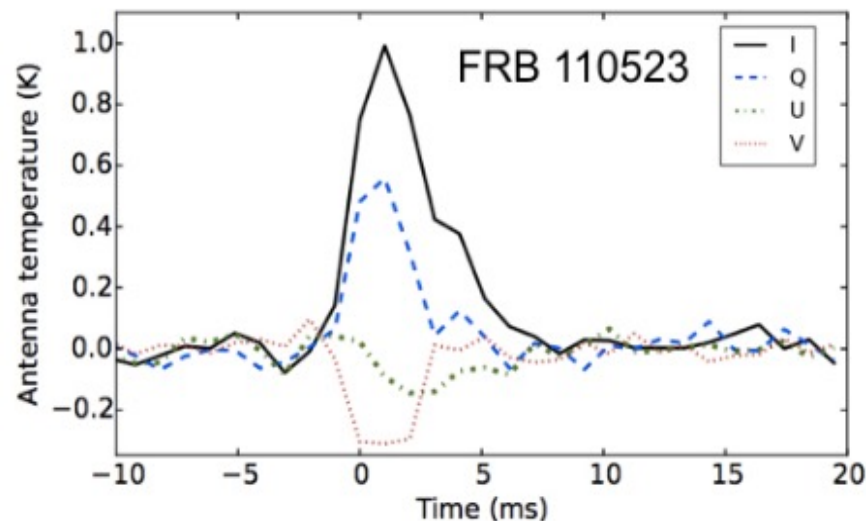
Fast Radio Bursts: polarisation

Petroff et al. 2015



FRB 140514: First one to show circular polarisation

Mausi et al. 2015



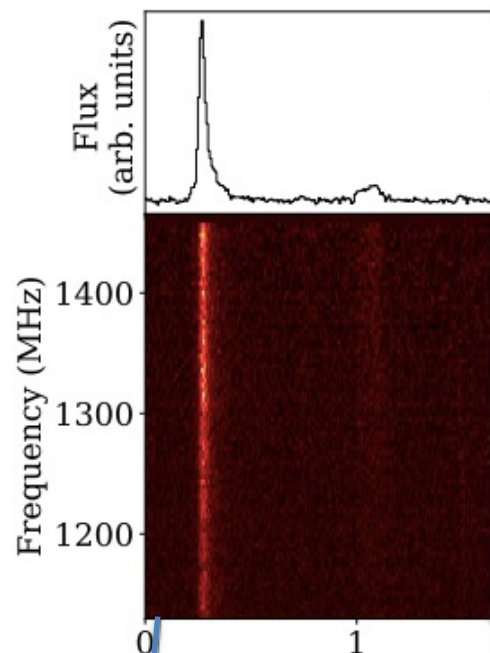
FRB 110523: First one to show linear polarisation

FRB polarisation can probe magnetic fields in the IGM and/or host environment

Change of polarisation angle with frequency $\rightarrow$ Faraday Rotation, measured by Rotation Measure (RM); FRB 121102 has $RM \sim 10^5 \text{ rad m}^{-2} \rightarrow$ highly magnetised dense local environment, not clean-sparse local environment

Only 9 FRBs are having polarimetric information $\rightarrow$ require real-time detection and triggering for full polarisation data dump

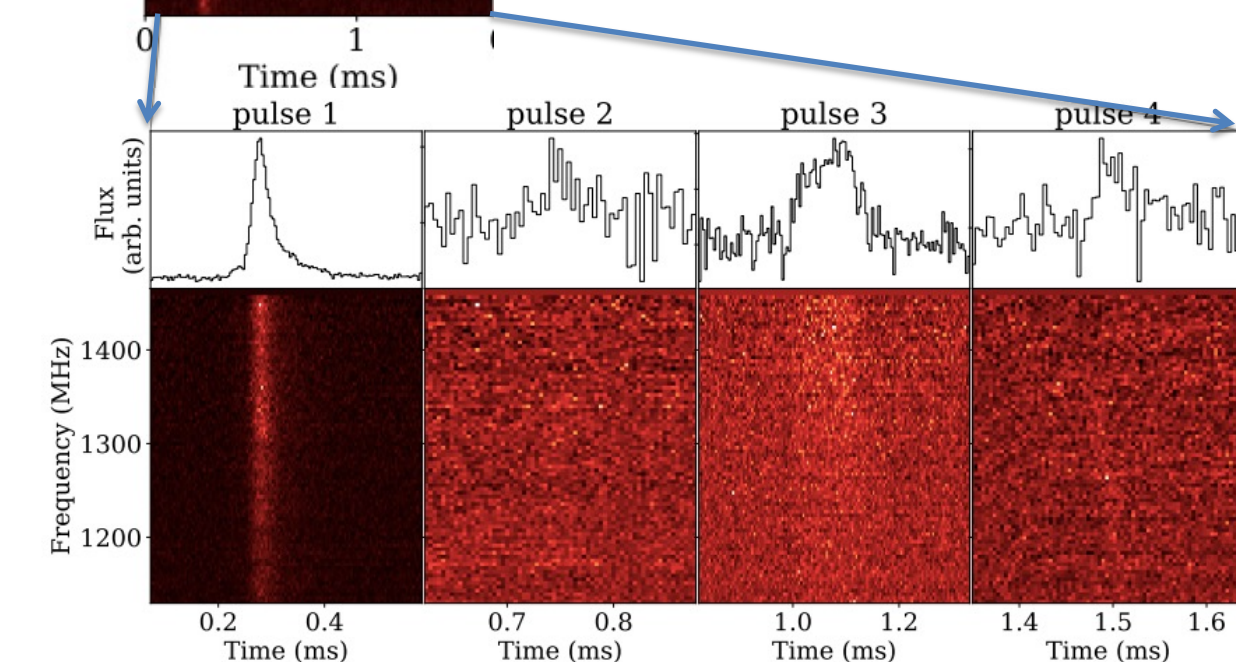
Fast Radio Bursts: micro-structure



A coherent dedispersion mode with ASKAP probe emission up to 3ns time-scale with full polarisation → **require real-time detection and triggering for Nyquist samples dump (increasing S/N from 20 to 220!)**

A single burst from FRB 181112 resolves into four narrow pulses at $\sim 15\mu\text{s}$ time-scale with DM and RM variations

No evidence of temporal broadening limits scattering and turbulence of the intervening halo

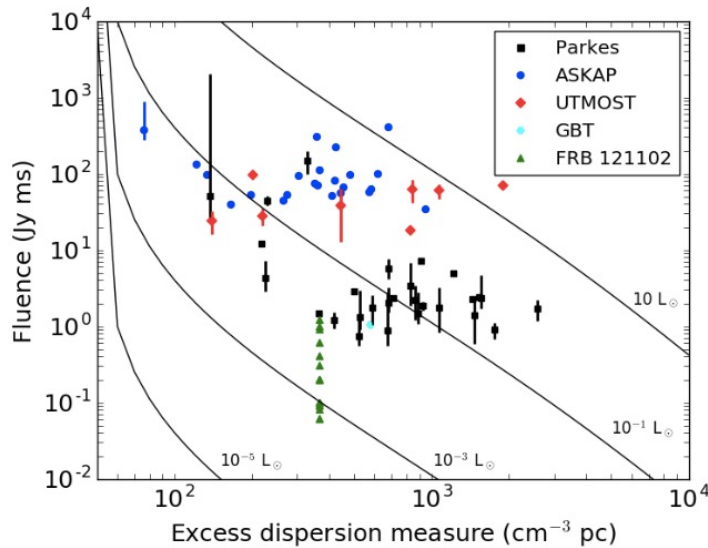


High-time resolution polarimetric study allows to probe burst emission process as well as propagation effects exists over the gigaparsec path

Cho et al. 2020

Fast Radio Bursts: event rates

Petroff et al. 2019



Newer bursts from ASKAP are brighter and closer than the previous Parkes bursts

An order of magnitude spread in the intrinsic luminosity

In addition to surveys (using FAST) to probe fainter high-DM end, we also *need to probe bright low-DM part.*

Rate (FRBs sky ⁻¹ day ⁻¹)	Range	CI (%)	$\mathcal{F}_{\text{lim}}$ (Jy ms)	Frequency (MHz)	Reference
~ 225	—	—	6.7	1400	(Lorimer <i>et al.</i> , 2007)
10000	5000 – 16000	68	3.0	1400	(Thornton <i>et al.</i> , 2013)
4400	1300 – 9600	99	4.4	1400	(Rane <i>et al.</i> , 2016)
7000	4000 – 12000	95	1.5	1400	(Champion <i>et al.</i> , 2016)
3300	1100 – 7000	99	3.8	1400	(Crawford <i>et al.</i> , 2016)
587	272 – 924	95	6.0	1400	(Lawrence <i>et al.</i> , 2017)
1700	800 – 3200	90	2.0	1400	(Bhandari <i>et al.</i> , 2018)
37	29 – 45	68	37	1400	(Shannon <i>et al.</i> , 2018)

On-average $> 10^3$ FRBs / sky every day above a $F > 1$ Jy-ms

Fast Radio Bursts: possible progenitors

Propose FRB sources based on energetic, time scale and event rate, but we have $N_{theory}/N_{FRB} > 1$

Natural association with neutron stars due to high energy and short time-scale

Typically not coincident with the nucleus of their hosts (all the four ASKAP FRBs are at the outskirts of host galaxies)

Super giant pulses from extragalactic pulsars; nulling pulsars, RRATs at their extreme limits

Giant flares from Magnetar (in dense supernova environment), where the radiated energy is drawn from the neutron star's magnetostatic energy

Magnetars from core-collapse supernovae; young stellar population hosting repeating bursts from young magnetars

Cataclysmic model involves merger of NS-NS, WD-WD, NS-BH, BH-BH; possibly associated with old, intermediate age stellar population

FRB121102 is not a typical one; active star forming region in a dwarf galaxy → flaring magnetar embedded in an extreme magnetoionic environment

Fast Radio Bursts: localisation

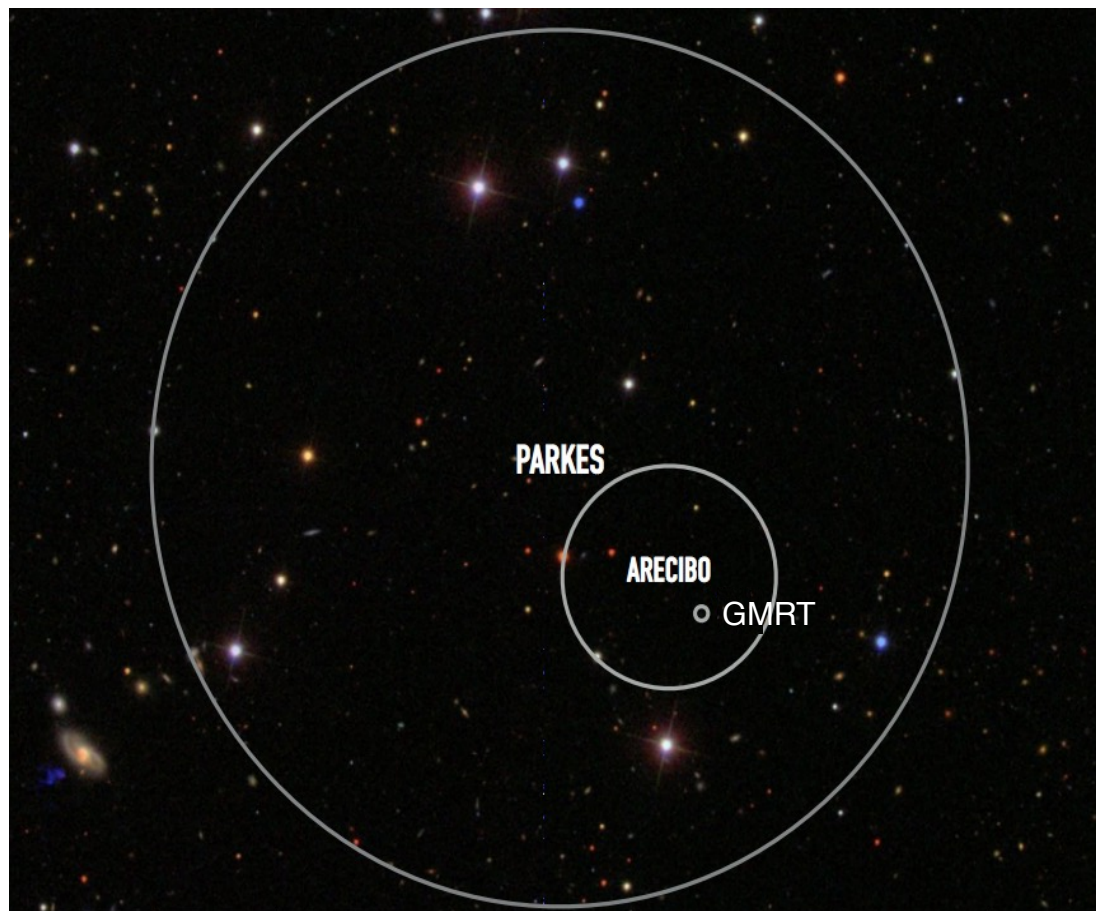
FRBs are localised to host galaxies → specific galaxies, distance from the center can be probed

Host galaxy population, local FRB environment → crucial for progenitor understanding

Independent redshift
Measurement → can be used
as cosmological probe

Search for multi-wavelength
prompt emission or
afterglow requires

*(real-time localisation
of FRBs (@ arc-sec)
triggered by real-time
detection)*



SPOTLIGHT: FRB detection+localisation



Fast Radio Bursts: cosmological tools

Nearby FRBs are good to study FRB progenitors

Localised FRBs spanning a wider range of redshift
→ good as cosmological probes

A large samples of FRBs with DM and Z
→ probe ionisation, density, magnetic properties of plasma on cosmological scale

ionised materials in IGM (missing baryons)

IGM to be fully ionised and homogeneous
→ approximately linear relations between DM and z for $z < 3$

Variation in the DM for a set of FRBs at similar redshifts

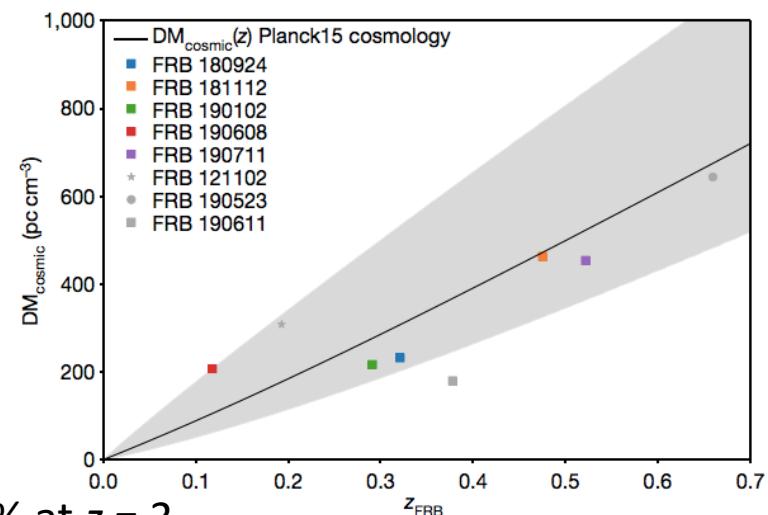
DM- z and the scatter due to inhomogeneous distribution of ionised gas in the IGM

~13% scatter ($1\text{-}\sigma$) in DM to a source at $z = 1$ and ~7% at $z = 3$



JP Maquart

First to probe missing baryons
Macquart et al, Nature, 2020



Fast Radio Bursts: cosmological tools

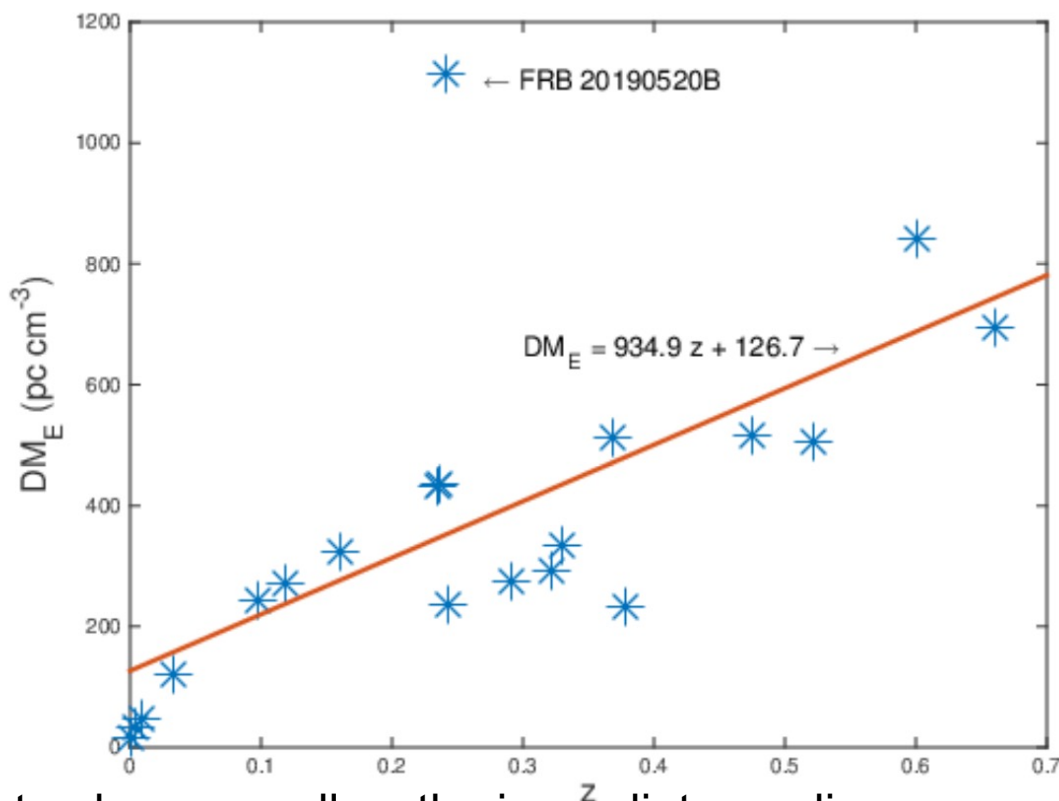
$$DM_E = DM - DM_{MW} - DM_{halo}$$

FRB 20190520B with huge $DM_{host} + DM_{src}$

Measured DM can be either greater or smaller than the theoretical value due to the inhomogeneity of the IGM

Consistent with indirectly inferred Baryon density from cosmic microwave background and Big Bang nucleosynthesis measurements

This solves the long-standing “missing baryon problem” and suggests that the majority of the missing baryons are in the intergalactic medium.



DM contribution from the FRB host galaxy as well as the immediate medium around the FRB source.

Fast Radio Bursts: cosmological tools

Study ionised and magnetised structures on cosmological scales.

Excellent probes to trace the ionised gas in galaxy halos, large-scale structure, and the intergalactic medium

At high redshift ($z > 2$), most of the expected baryons are found in the diffuse, ionised IGM

At low-redshifts, the observed baryons in stars, the cold interstellar medium

Hot gas in clusters of galaxies account for only $\sim 50\%$ of the baryons

The amount and the location of cosmic baryons in the CGM and IGM is crucial in understanding galaxy evolution via galaxy halo accretion and feedback models.

Majority of the missing baryons reside in the diffuse Warm-Hot Intergalactic Medium

WHIM is difficult to detect directly because of its extremely low density

Fast Radio Bursts: cosmological tools

DM contribution from the FRB host galaxy as well as the immediate medium around the FRB source.

$$RM = RM_{\text{ion}} + RM_{\text{MW}} + RM_{\text{IGM}} + \frac{RM_{\text{host}} + RM_{\text{src}}}{(1+z)^2},$$

The observed RM is likely dominated by the near-source medium, which is likely a dynamically evolving magnetized environment

The observed DM, on the other hand, is dominated by the IGM term.

Estimate the average line-of-sight magnetic field in the host and source (most likely in the source region)

$$B_{\parallel}^{\text{src}} \sim (1.23\mu\text{G})(1+z) \left| \frac{\Delta RM}{\Delta DM} \right|$$

FRBs enable measurements of the mean magnetic field of the IGM

Fast Radio Bursts: cosmological tools

At least 10^3 events occur over the sky each day to a fluence of a few Jy ms

CHIME (200 deg²) are already detecting FRBs at around 1 per day

Coherent ASKAP-CRAFT system localising one burst per day

MeerKAT telescope will also deliver a sample of high-DM FRBs

VLA Low-band Ionosphere and Transient (VLITE)-Fast experiment localise roughly 1 FRB per month

DSA-2000 will also detect and localise FRBs at a rate of $\sim 10^3$ – 10^4 FRBs per year

Square Kilometre Array (SKA) promises detection of 10^4 – 10^6 FRBs

SPOTLIGHT (1 deg²) is 10x more sensitive than CHIME, event rate?

Long Period Transients (LPTs)

A newly identified class of radio transient sources in the time-domain sky

Characterised by periodic radio bursts lasting seconds to minutes

These bursts repeat with long periodicities ranging from minutes to hours

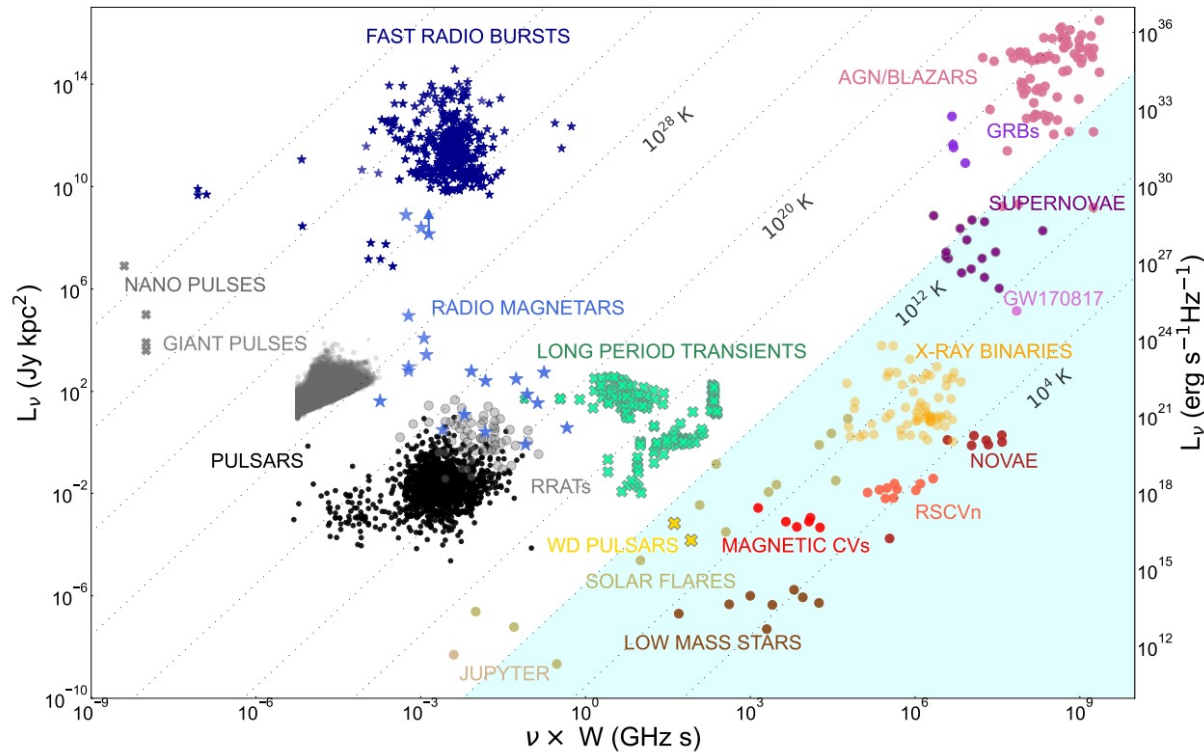
Emit bright radio pulses (up to tens of Jansky)

Show strong (often high) polarization, indicating coherent emission processes

Exhibit intermittent or episodic activity phases rather than continuous emission

Represent the slowest known radio-pulsing sources, with periods far longer than normal pulsars

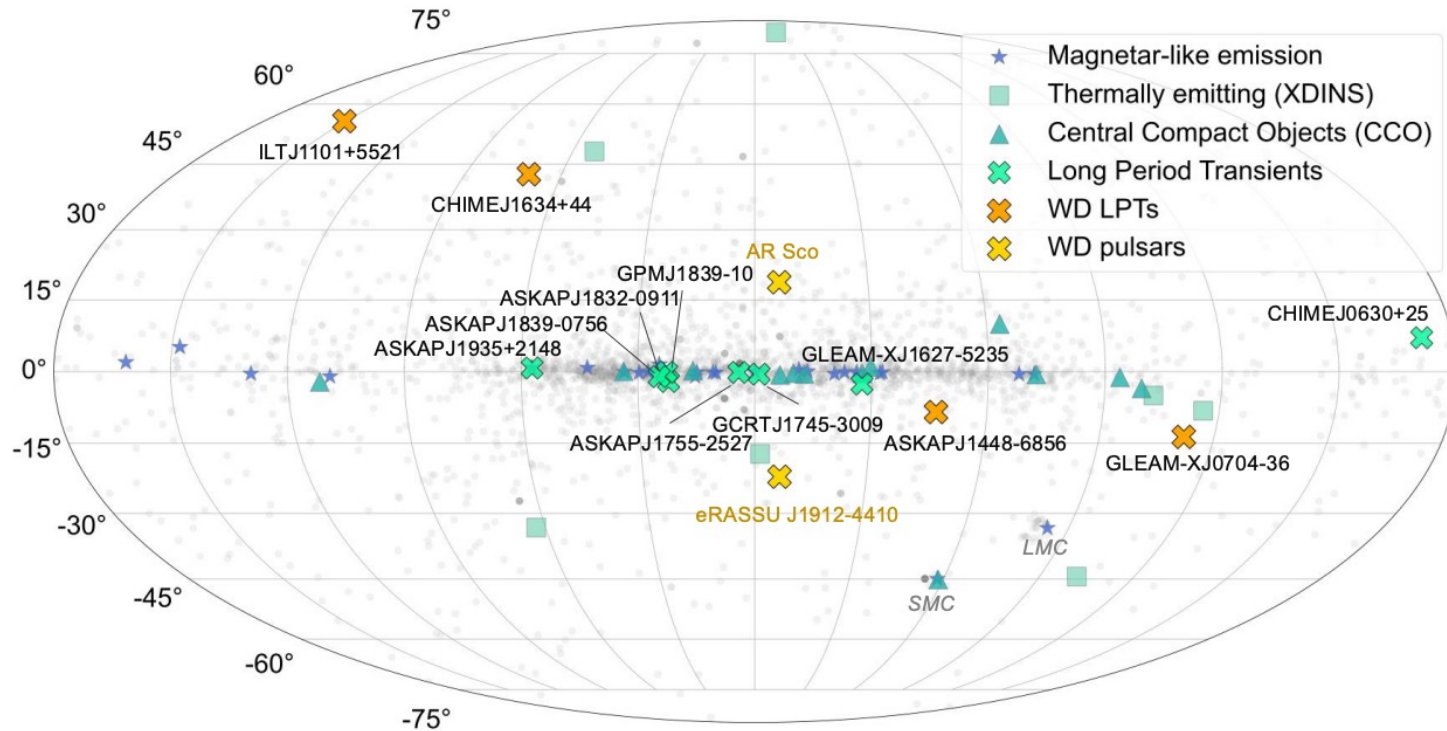
Long Period Transients (LPTs)



Fill a previously sparsely populated region in the diagram (missing population!)

LPTs sit between classical pulsars/RRATs and high-energy transients (FRBs/magnetars)

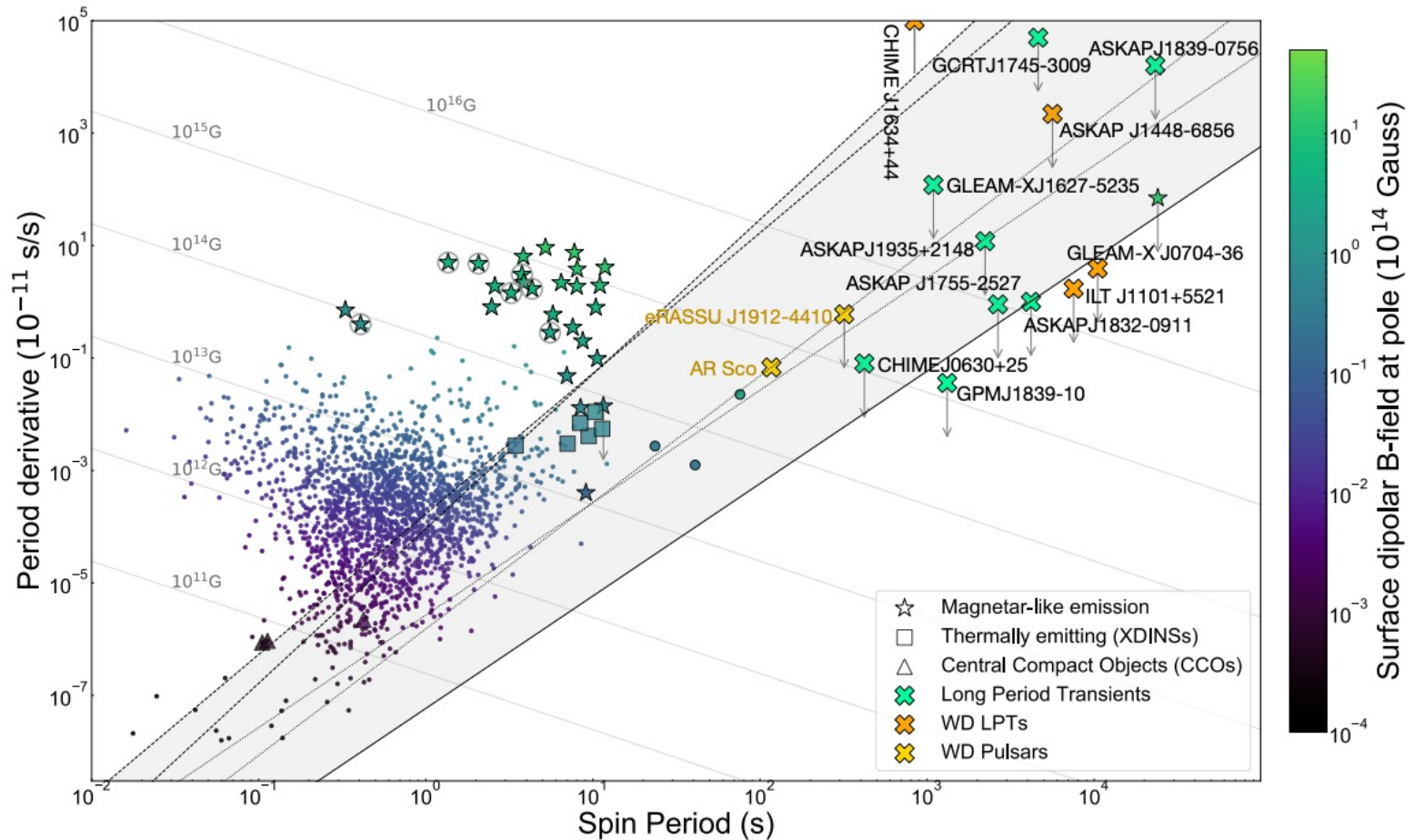
Long Period Transients (LPTs)



Most LPTs (green crosses) are clustered near Galactic latitude $b \approx 0^\circ$

LPTs are most likely a Galactic population of compact objects (neutron stars and/or white dwarf systems), with emission tied to magnetospheric or binary interaction processes

Long Period Transients (LPTs)



An unexplored regime of the P – $\dot{P}$ diagram, not sufficient to power emission via rotation alone $\rightarrow$ Magnetic energy, Binary interaction

Long Period Transients (LPTs)

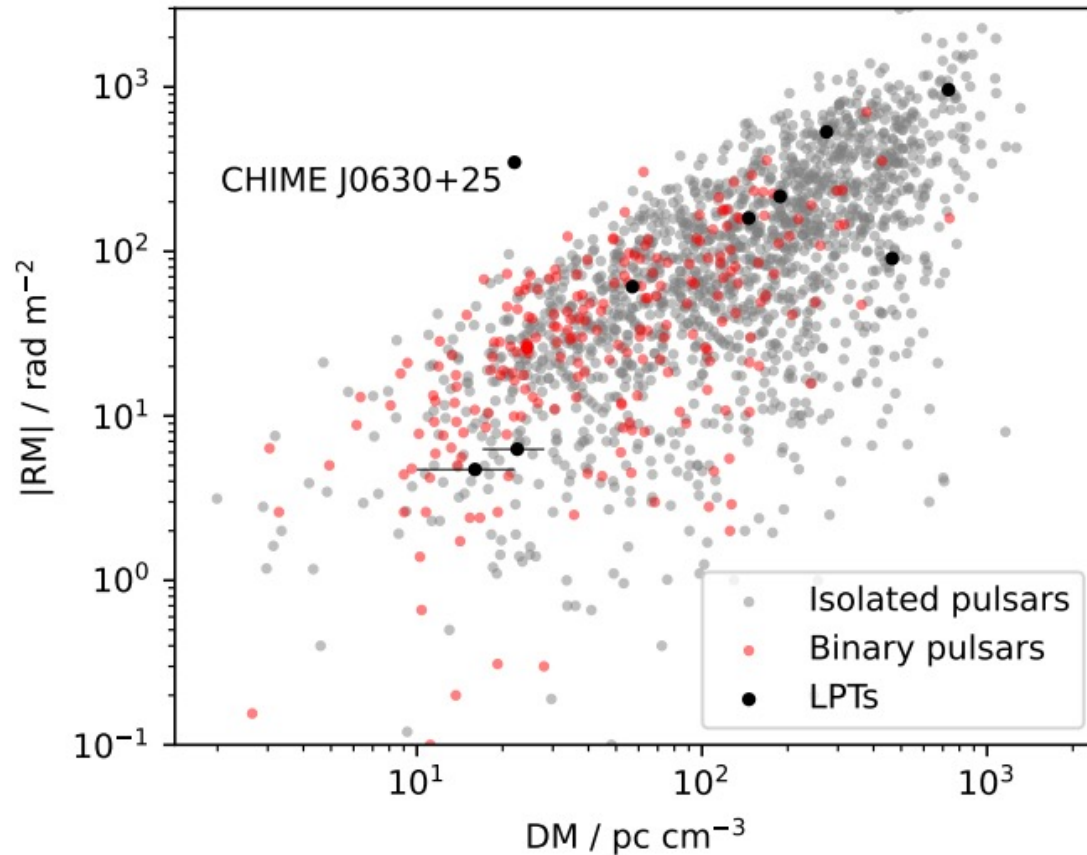
Source	Radio Flux (mJy)	Pulse Duty Cycle	Activity (months)	Polarization (total)	Spectral index α	Distance (kpc)
GCRT J1745–3009	500-1000	15%	< 1	60–100%	-(13.5–6.5)	–
GLEAM-X J1627–5235	5000-40000	6%	< 3	88%	-1.16	1.3±0.5
GPM J1839–10	100-10000	12%	>420	10–100%	-3.17	5.7±2.9
ASKAP J1935+2148	9-234	0.01–1.5%	< 12	90%	+0.4/-1.2	4.3
CHIME J0630+25	0.4-1.9	0.06–2.3%	< 1	–	-(5.1–0.05)	0.170 ^{+0.31} _{-0.10}
ASKAP/DART J1832–0911	60–1800	5–10%	> 12	92%	-1.5	4.5±1.5
ILT J1101+5521	41–256	2%	< 1	51%	-4.1	0.50±0.15
GLEAM-X J0704–36	25–100	0.5–2%	>120	10–50%	-6.2	1.5±0.5
ASKAP J1839–0756	2–1200	1.4–3.1%	>1	30–90%	-(2.7–2.9)	4.0±1.2
ASKAP J1448–6856	3–12	15–70%	>13	35–100%	-2.5	–
CHIME/ILT J1634+44	400–9000	1.2%	>54	100%	–	1–4.3
ASKAP J1755–2527	1–3000	0.5-3%	>21	25%	-2.4	–

LPTs are a highly diverse population of Galactic radio transients with:
 Wide luminosity range; Variable duty cycles, Long and short activity timescales, Strong polarization

Proposed models: slow-spinning magnetars, binary systems with a white dwarf and a low-mass star companion

Radio pulses are produced by an M dwarf+WD binary system with an orbital period that matches within errors the observed radio periodicity, with pulses produced when the two stars are in conjunction

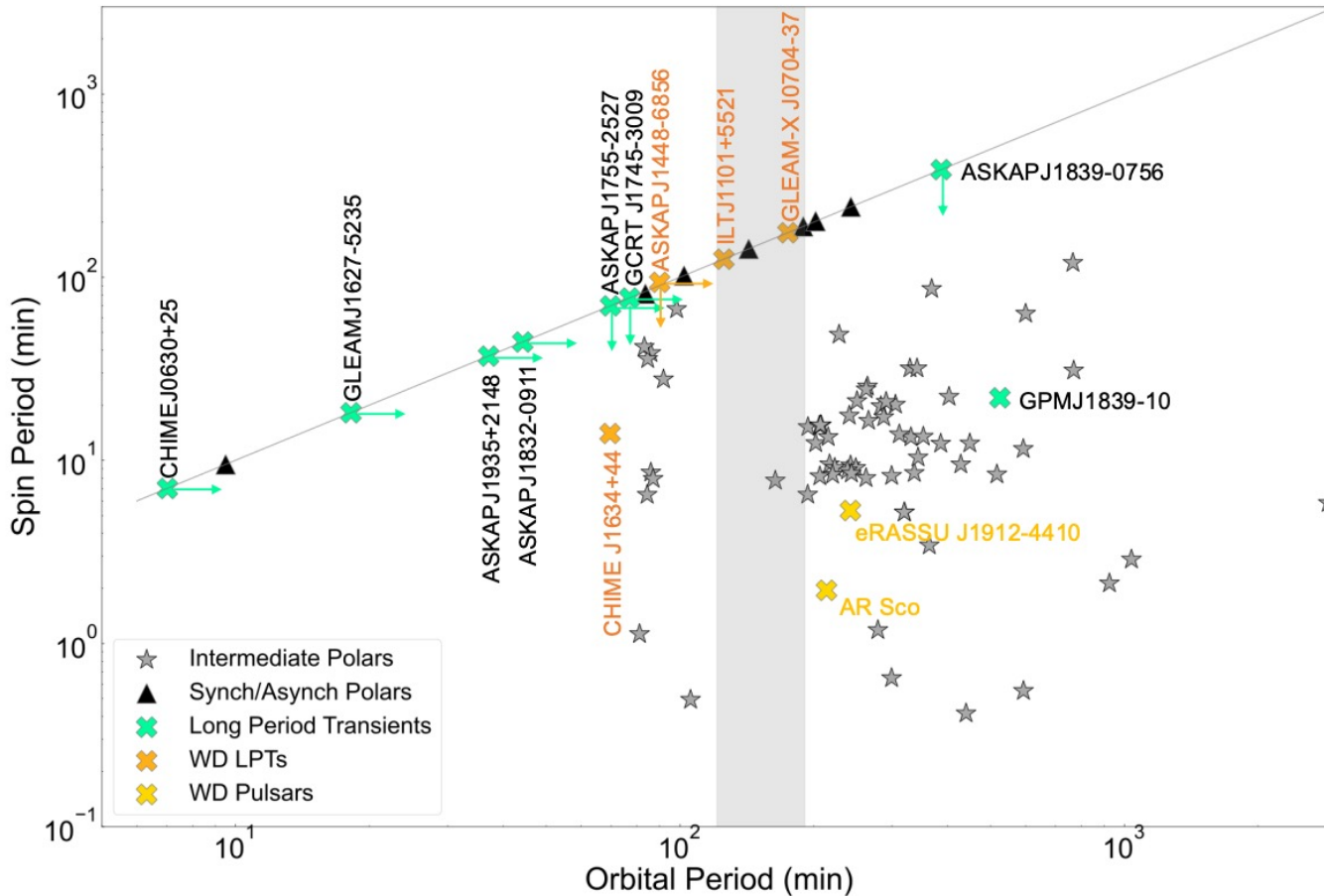
Long Period Transients (LPTs)



RM–DM relationship tends to be consistent with the general pulsar population

CHIME J0630+25 is embedded in locally magnetized plasma, either in a compact magnetosphere or in a surrounding nebula or binary environment

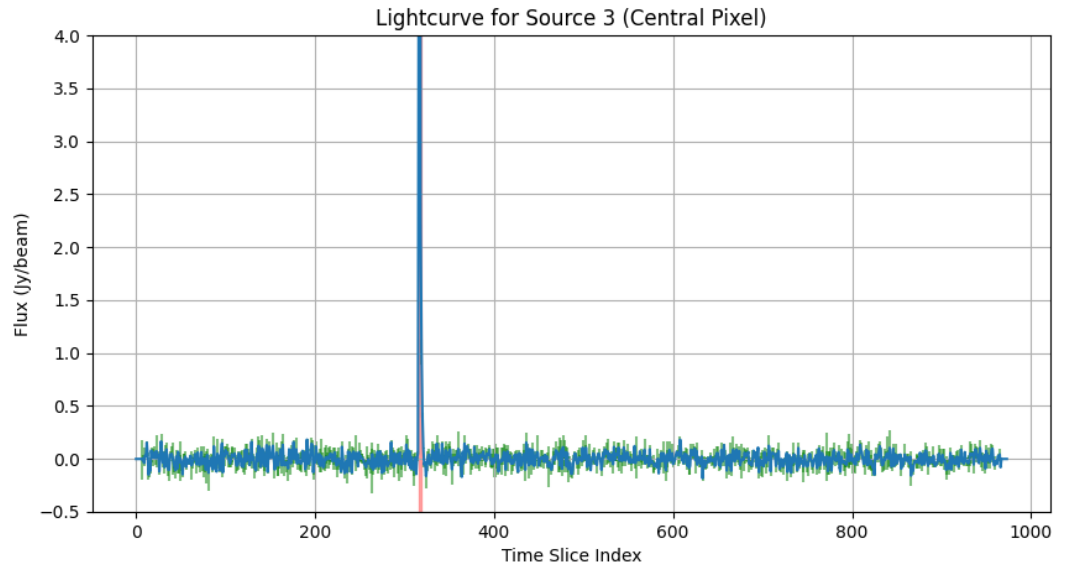
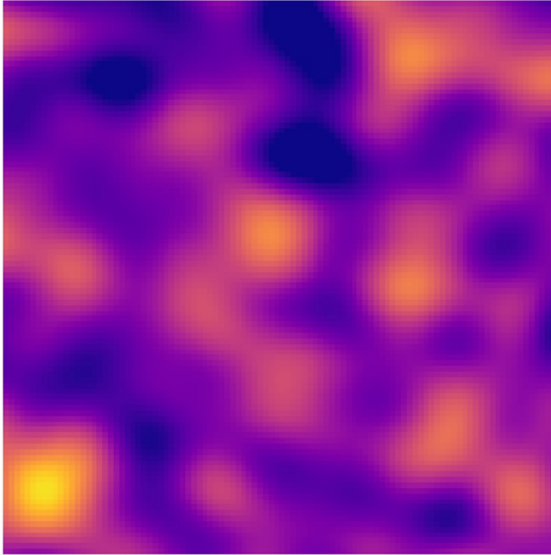
Long Period Transients (LPTs)



For most LPTs, the nature of the radio periods is unknown, and the arrows indicate their probable location if the systems are WD binaries

Long Period Transients (LPTs)

Source 3 - Slice 306



CHIME J1634+44 (14 mins)

Fast imaging search triggered time-domain detection