Radio transients: current status

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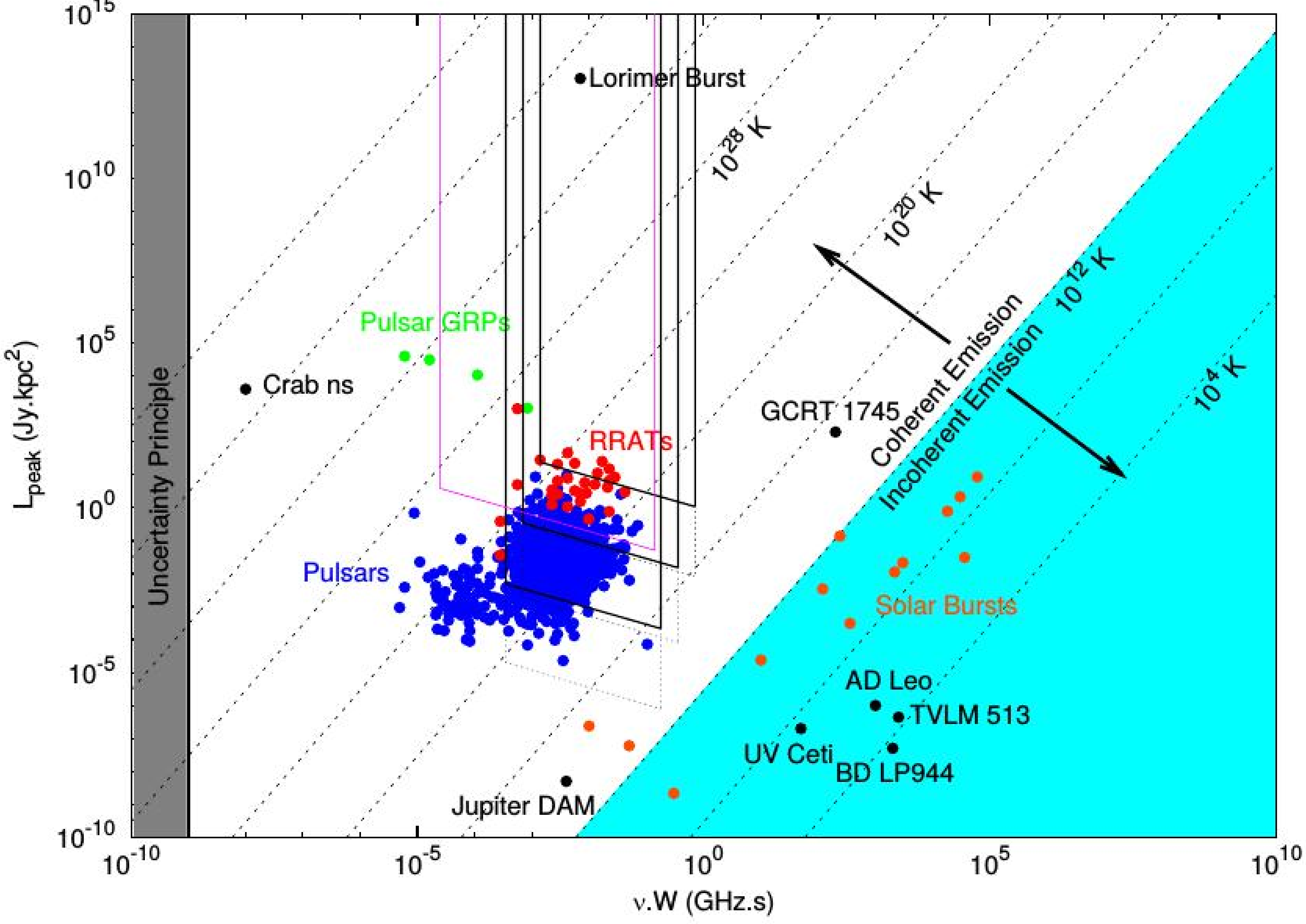
Overview

- Transient definition and parameter space
- Solar system -- Sun and Jupiter
- Galaxy -- stellar flares, pulsar-related.
- Extragalactic -- afterglows, AGNs
- FRBs
- Unknown

Radio transients

- First, they are detected in the radioband. I.e., we're dealing with low frequencies mostly around 1 GHz (0.1-10 GHz).
- Second, they are transients, so the fluxes vary with time. The time scales of the variation differs vastly: from ~ns in pulsars' giant pulses to years in AGNs flares

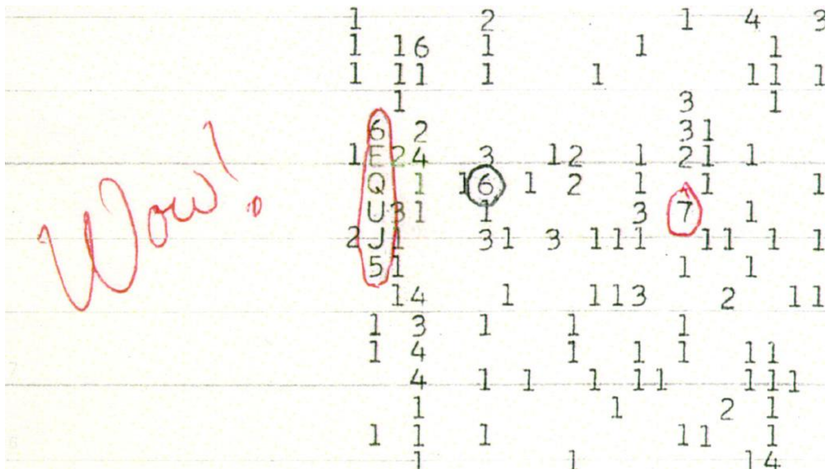
Radio transients: parameter space

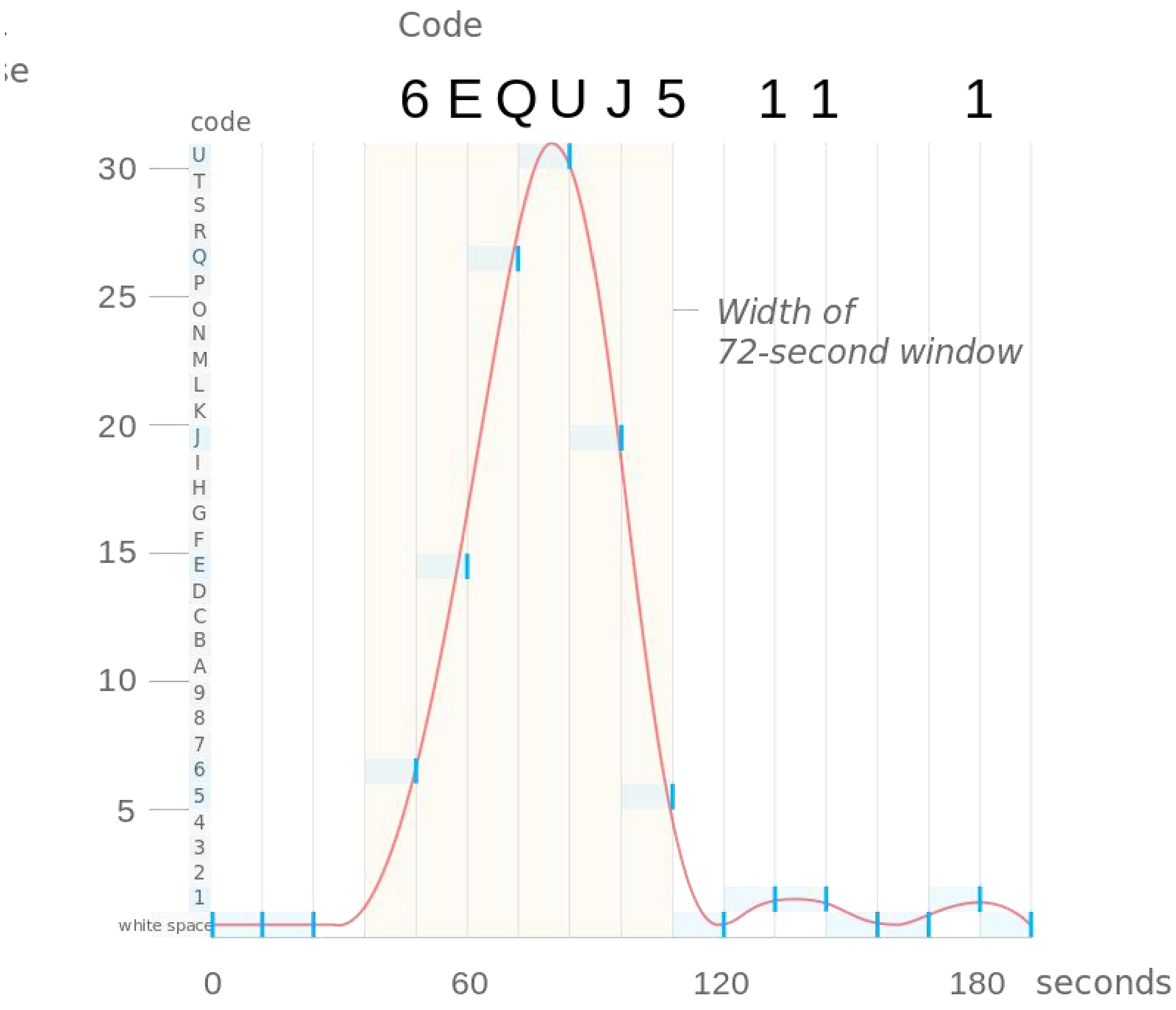


Keane 2010

What we are not going to discuss

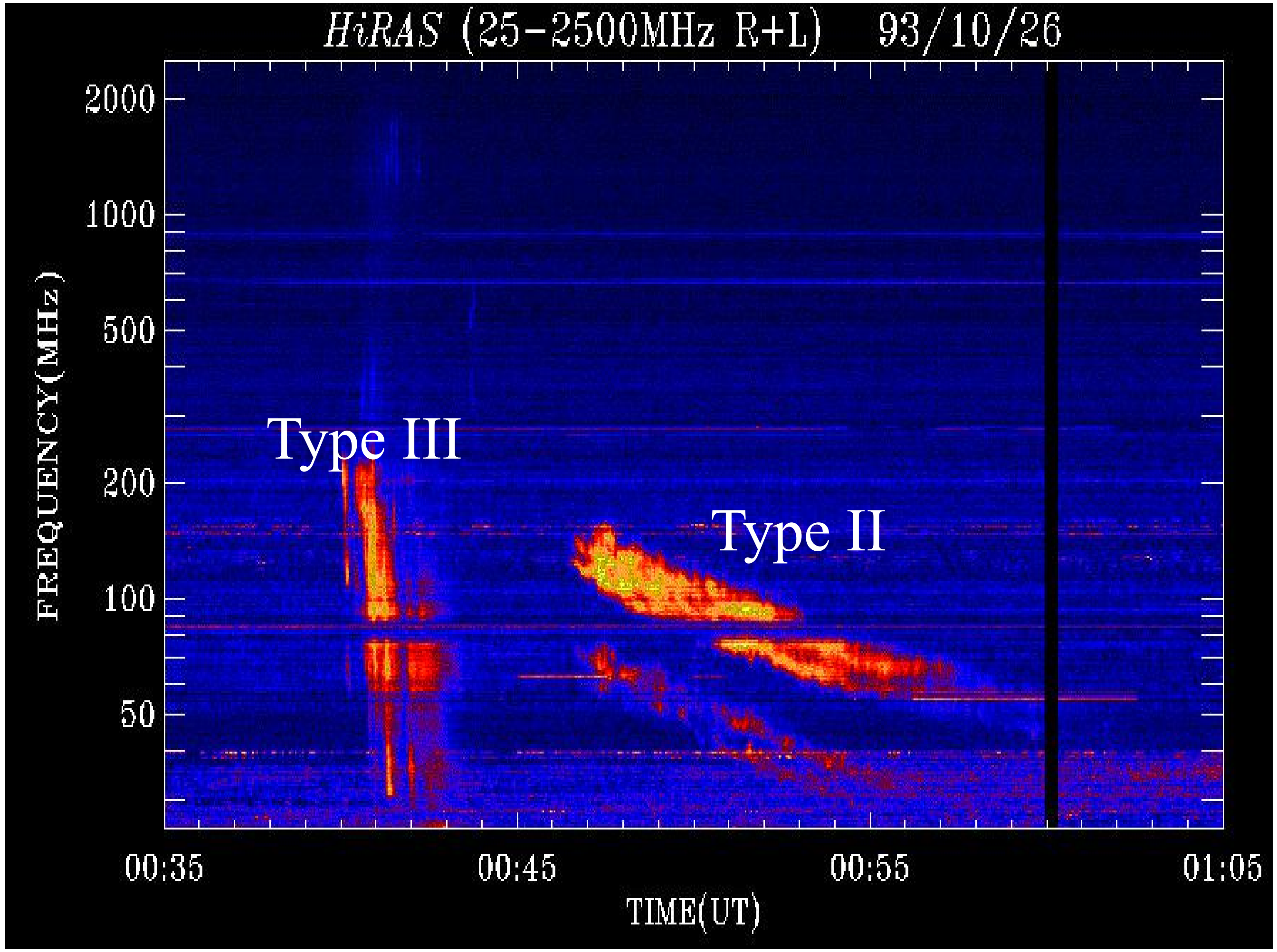
- SETI like Wow! signal and BLC1
- Still there are a lot of other interesting transients





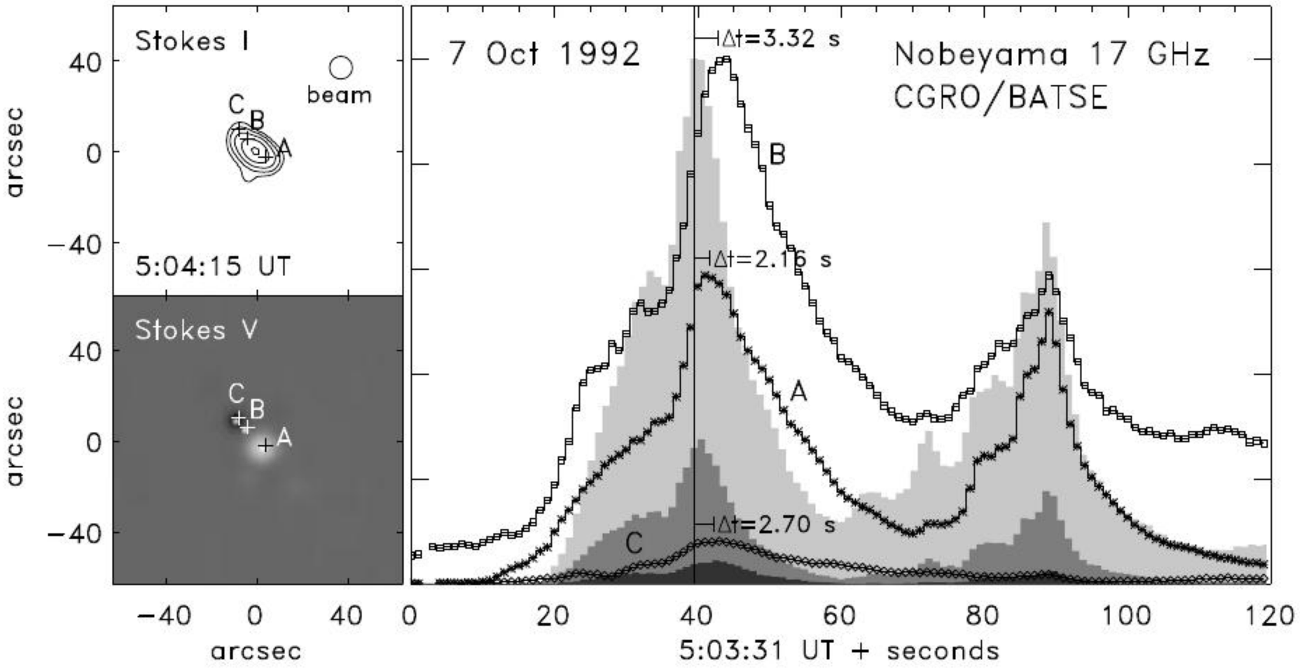
Radio transients: Solar system

- We'll start our tour from the immediate vicinity
- Two well-established sources of transients
- **Sun**: burst of several types
- Different duration and spectral evolution
- Originate due to magnetospheric processes (reconnection)
- X-ray counterparts (during Solar flares, Type II &III)



Radio transients: Solar system

- Coherent mechanism at low frequencies (<1 GHz). Plasma waves -> EM waves mostly at plasma frequency
- Incoherent, gyrosynchtotron at higher, so-called microwave bursts (~10 GHz)
- Electrons 100-1000 keV
- Tight correlation with X-ray



- **Jupiter**: magnetospheric <40 MHz, ms-s, interaction with Io

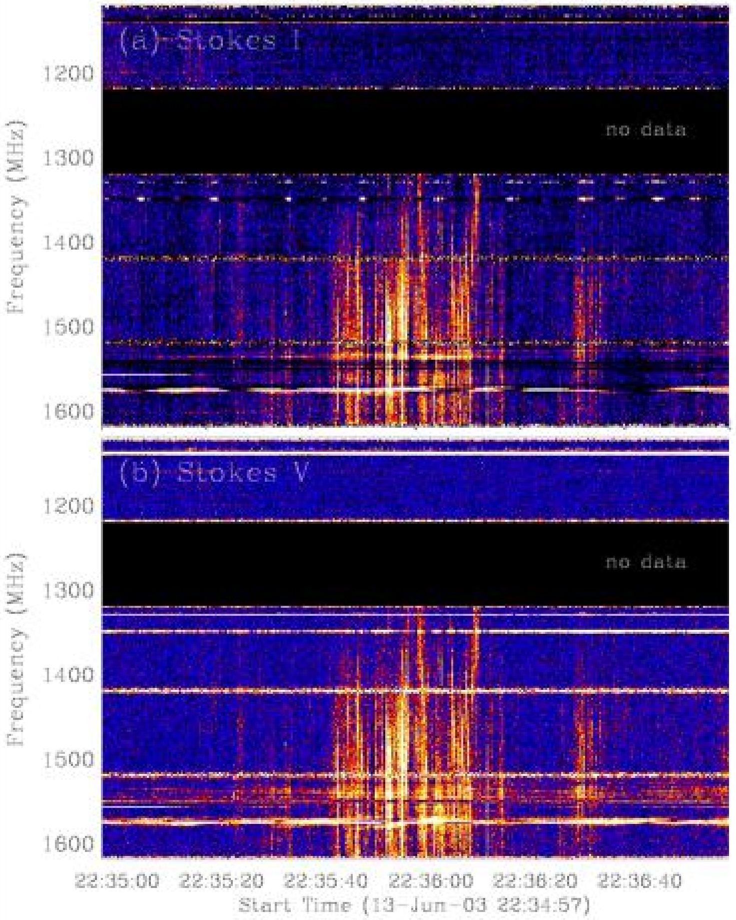
Bastian et al, 1998

Radio transients: moving to the Galaxy

- First, more of the same, **radiobursts from exoplanets**
- One would expect Jovian-like decametric bursts from exoplanets as well
- Extremely weak
- First and yet only tentative detection in 2020, from τ Boötis @ 15 pc distance (Turner et al, 2021)
- Used LOFAR LBA
- 14-21 MHz, 3σ, 900 mJy, ~20 s
- Origin is far from being clear, could have a stellar origin or very specific instance of RFI

Radio transients: moving to the Galaxy

- **Stellar flares**. Much better established, more than 50 years of observations.
- Analogue of solar flares (convective K, M and later stars)
- Also coherent (~O(100 MHz)) and non-coherent (>GHz)
- **Binary systems**: symbiotic binaries RS CVns, cataclysmic variables, X-ray binaries (μQSOs)
- **Young Stellar Objects**
- Caveat: duration of these transient spans from <seconds to many days (like flare of XRB SS433)



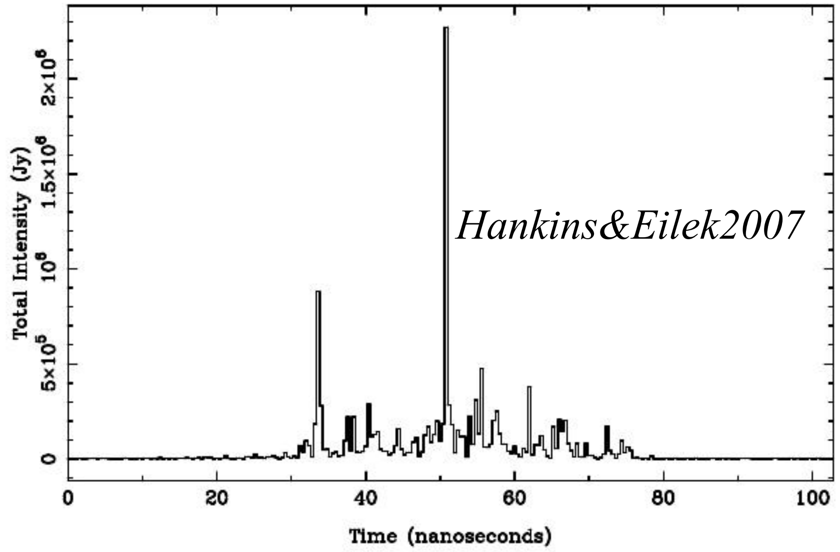
AD Leo flares observed by Arecibo with 10 ms resolution (Osten&Bastian, 2006)

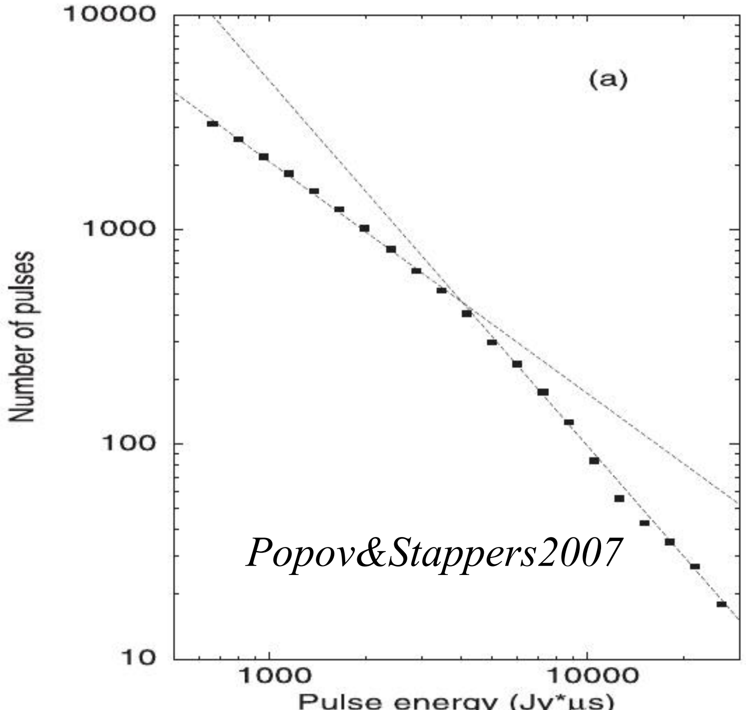
Radio transients: moving to the Galaxy

- **Pulsar** related, something new.
- Much shorter, reaching down to ns(!) -- even more interesting
- **RRATs**(Rotating radio transients) -- pulsars, that were discovered in single pulse searches. Most probably -- extreme nulling, i.e. >99% of periods PSR is in the 'silent mode'
- **Giant pulses** (GPs) from pulsars -- average pulses are very stable in shapes and quite stable in amplitude. Still, intensity of individual pulses could vary wildly. GP -- amplutude 10-30 times larger than average.
- Several pulsars (around 10) demonstrate them, both ordinary and MSPs
- The very best examples are the Crab pulsar and MSP B1937+21

Radio transients: moving to the Galaxy

- Crab: GPs are observed at the same phases as main pulse and interpulse
- Frequencies 0.1-10 GHz
  Apparently smooth pulse consists of stochastic microbursts. Some of them could be very strong -- GPs.
- Going further --nanoshots
- Shortest detected <0.4 ns
- T_b~10^{41} K
- BPL distribution, dN/dE



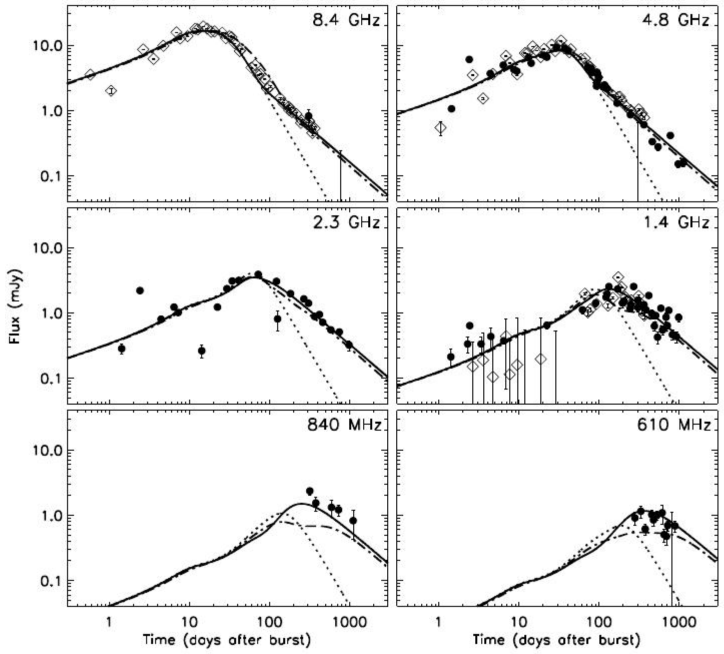


Radio transients: extragalactic

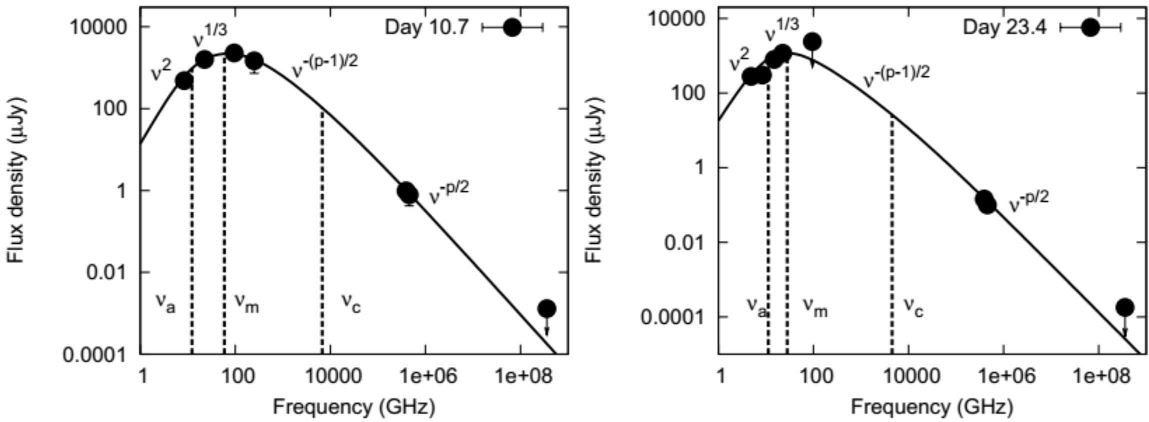
- Plethora of new phenomenae, rare by Galactic standards events also have radio transients as counterparts.
- First group -- ejecta from strong explosions interacts with surrounding medium, causing radio flares. Typical timescales 10-100 days.
- Second group -- AGN (or just SMBH) related

Radio transients: extragalactic

- **GRB afterglow.**
- Afterglow in all energy ranges from X-ray to radio
- Spectrum peak evolves to lower frequencies as time goes by, i.e. right after the burst it's in X-ray, but 10 days later it could be in radio
- Could last >1000 days



GRB030329, van der Horst et et al 2007



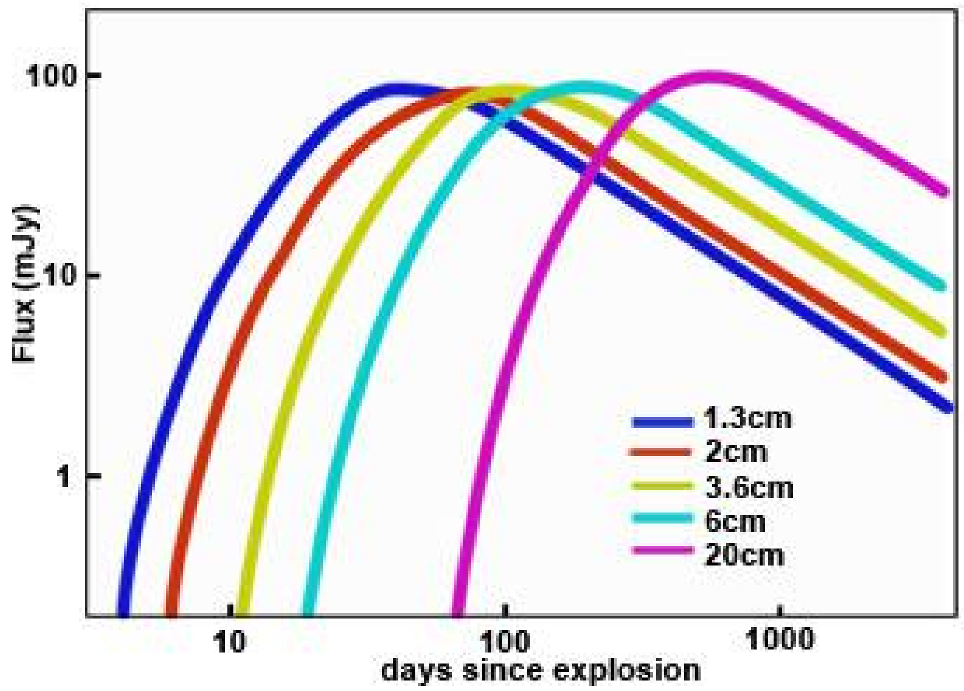
GRB070125, Chandra et al 2008

Radio transients: extragalactic

- **Radio Supernovae.**
-

  Scaled-down version of the previous. Detectable from <30 Mpc only

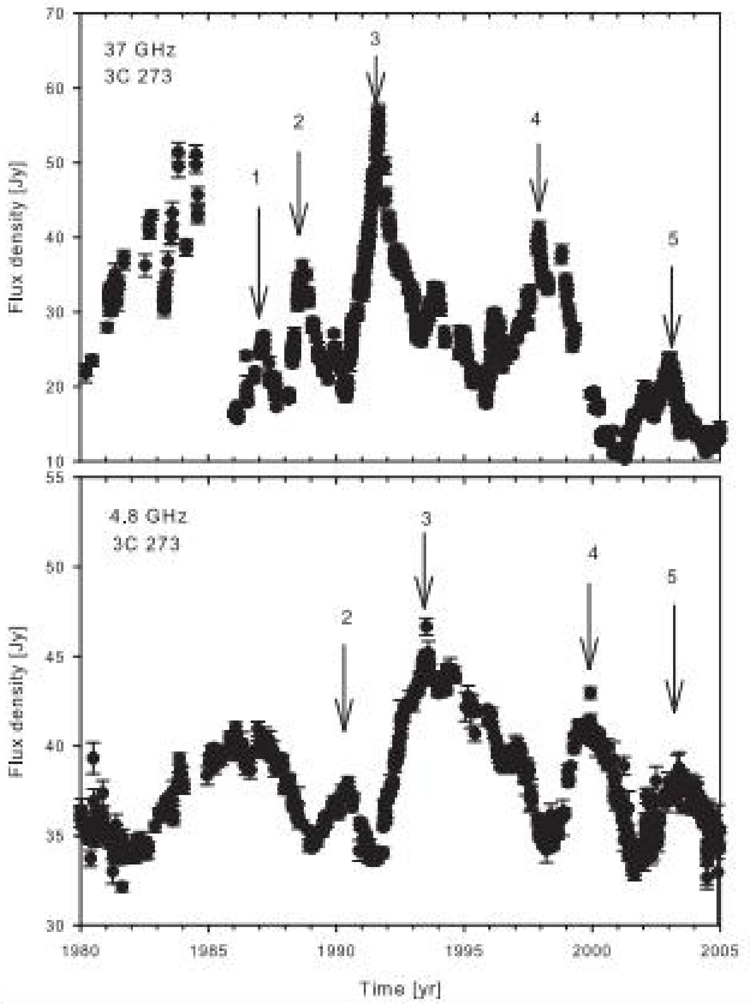
- Mildly relativistic ejecta
- Probe of circumexplosion medium and pre-explosion mass loss regime
- Duration -- O(100-1000 days)
- Galactic analogue: nova radio flares



Swinburne University of Technology Encyclopedia of Cosmos

Radio transients: extragalactic

- **AGN flares**
- Propagation of some perturbation in jet
- Duration in ~years range
- Observed at different frequencies, from ~GHz to >100 GHz
- **TDEs, tidal disruption events**
- Activity initiated by accretion of material from disrupted star onto a SMBH



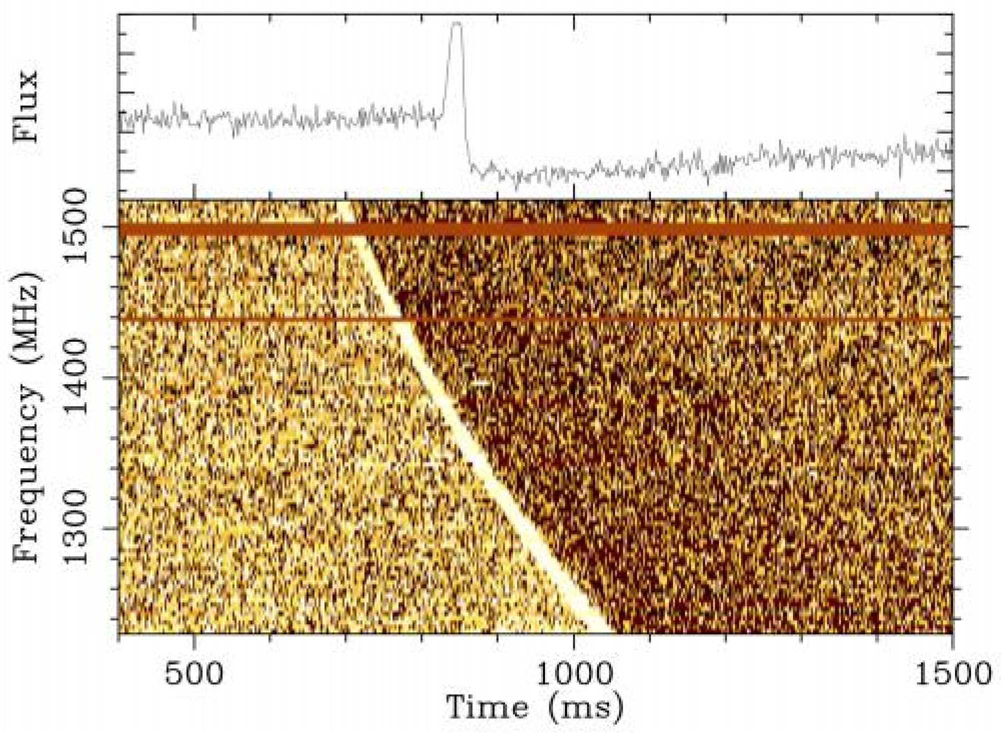
3C273, Hovatta et al, 2008

Radio transients: FRBs

- **Fast radio bursts (FRBs)**
- Timeline:
  - 2007 First FRB reported ('Lorimer burst', FRB 010724)
  - ---'dark ages'----
  - 2013 Thornton et al, +4 new bursts. Almost certainly extragalactic
  - 2015 Peryton mystery solved (MW oven as a culprit)
  - 2014-2017 FRB 121102 -- first non-Parkes FRB, first repeating burst, first precise localization and host identification
  - 2019 FRB 180814 -- second repeating source
  - 2020 first galactic FRB (FRB 200428) from magnetar SGR 1935+2154
  - 2021.04 ~120 FRBs, ~10 repeating FRBs *http://frbcat.org/*

FRBs: main characteristics

- short, burst duration ~ms
- bright 0.1-100 Jy
- large DM, implying extragalatic origin and correspondingly huge radio luminosities
- frequent, all-sky rate~10^4 day^{-1}



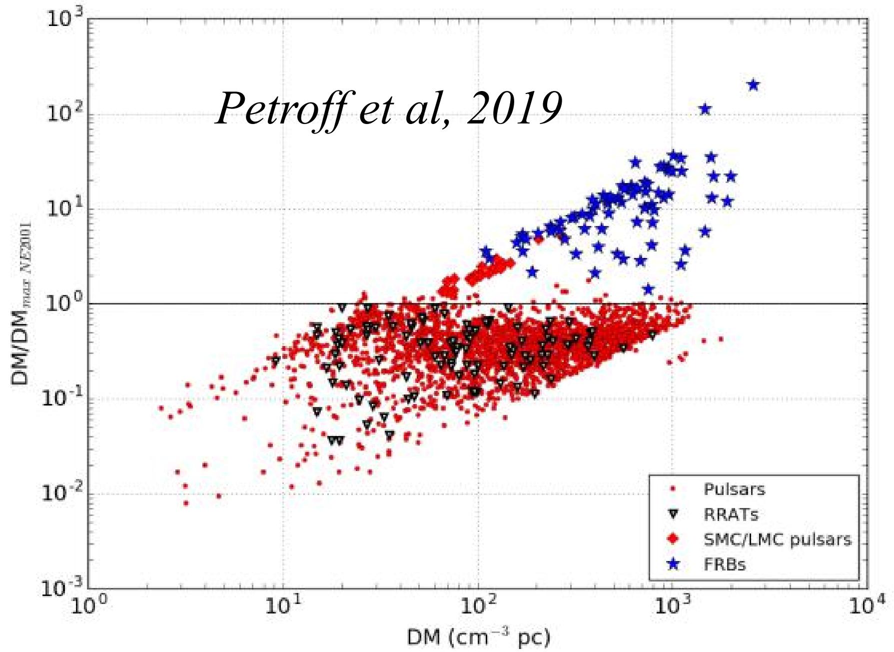
"Lorimer burst' FRB010724
DM=375 pc cm-3.
Inferred distance D~1 Gpc

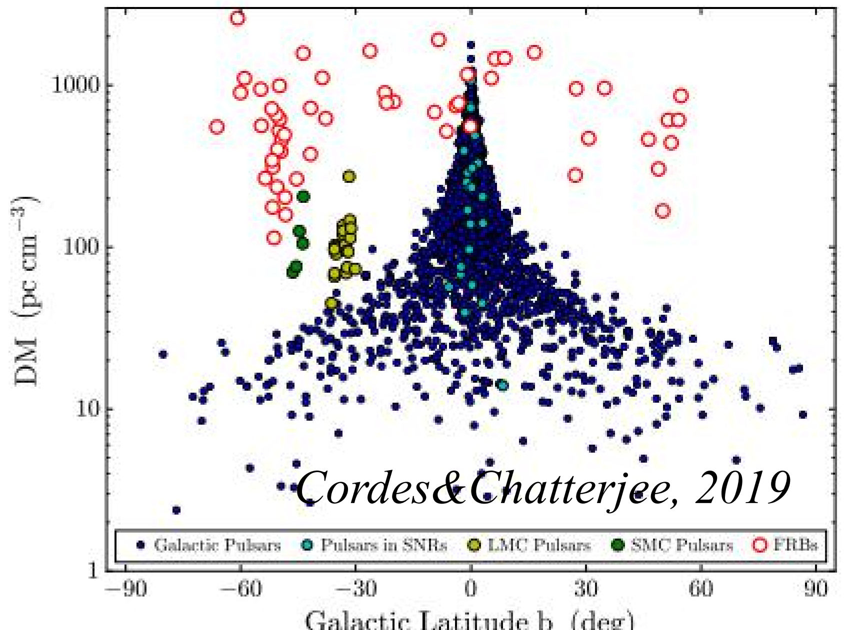
- DM -- dispersion measure: $\mathrm{DM} = \int_0^d n_\mathrm{e}\,\mathrm{d}l$
  [DM]=pc cm^{-3}
- Causes time delay between f_1 and f_2 (GHz)

$$\Delta t_{12} = 4.15\ \mathrm{ms}\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right) DM$$

FRBs: DM

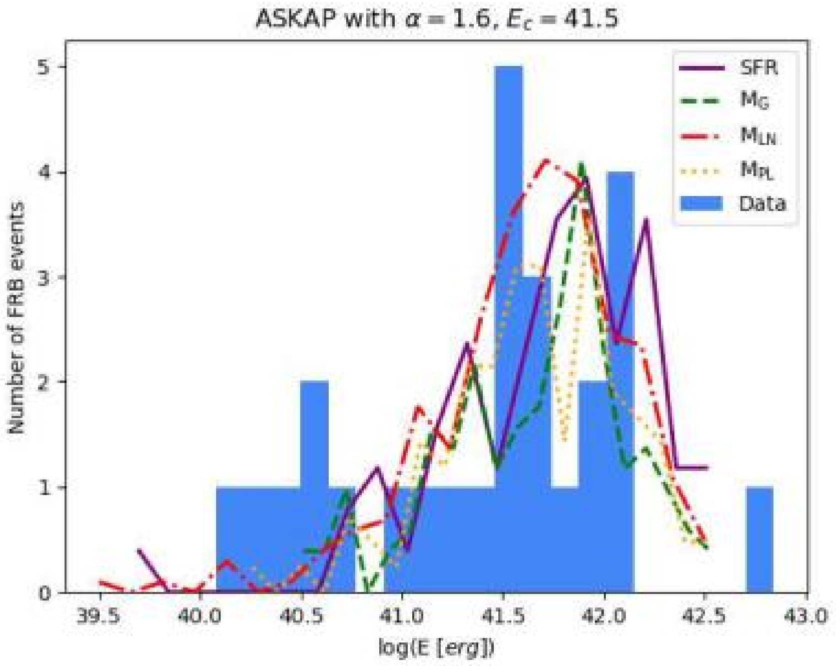
- Large DM is the primary selection criterion.
- What is large?
- 100 pc cm^{-3}<DM_{FRB}<2600 pc cm^{-3}
- There 20+ Galactic PSRs
  with DM>1000 pc cm^{-3}
- Highest Galactic DM~1800 pc cm^{-3}
- So why extragalactic?
- Large *excess* DM_x = DM-DM_{MW}.
- Galactic contribution is estimated using models for electron density in the Milky Way (NE2001, YMW16)



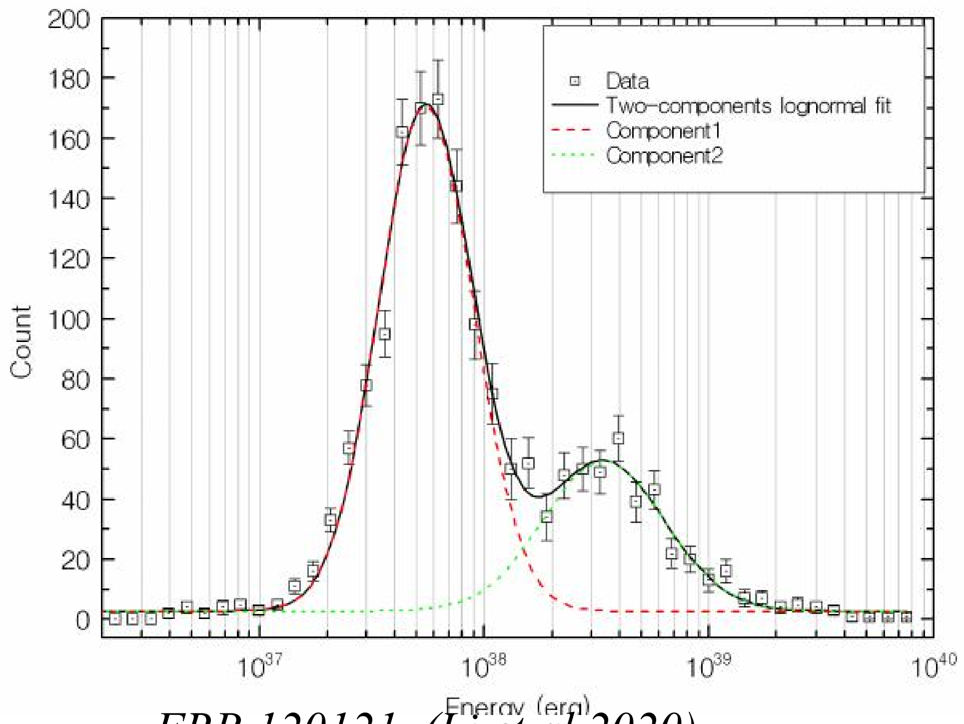


FRBs: luminosities and energetics

- DM_x allows to estimate luminosity distance and from that convert observed luminosities into intrinsic luminosities
- S: 0.04-140 Jy, F: 0.1-400 Jy ms
- Extremely bright, T_b~10^{35} K
- L~10^{44} erg/s, E~10^{42} erg



ASKAP FRBs (Zhang et al 2021)



FRB 120121 (Li et al 2020)

FRBs: rates

- Rate of FRBs depends on the sensitivity limit
- At benchmark 1 Jy·ms it is safe to claim several thousand per day

Table 3 A summary of the various estimates for the all-sky FRB rate based on various surveys and analyses. Rates and ranges are quoted with confidence intervals (CI) above a fluence threshold ($\mathcal{F}_{\rm lim}$) for observations at a given reference frequency.

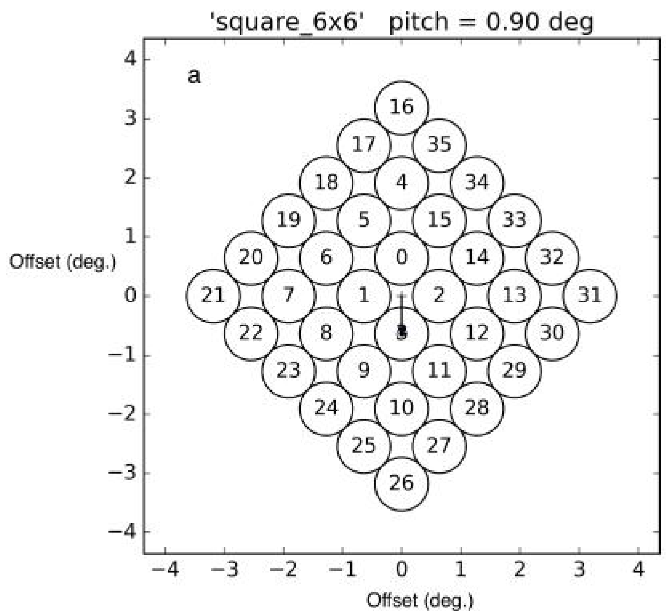
Rate (FRBs sky^{-1}	Range day^{-1})	CI (%)	$\mathcal{F}_{\rm lim}$ (Jy ms)	Frequency (MHz)	Reference
$\sim$ 225	—	—	6.7	1400	(Lorimer *et al.*, 2007)
10000	5000 – 16000	68	3.0	1400	(Thornton *et al.*, 2013)
4400	1300 – 9600	99	4.4	1400	(Rane *et al.*, 2016)
7000	4000 – 12000	95	1.5	1400	(Champion *et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

Petroff et al, 2019

- dN/dS~$S^{-\gamma}$, but exponent value is still highly uncertain, maybe breaks.
- In a couple of years we'll have more definite answer

FRBs: repeating bursts.

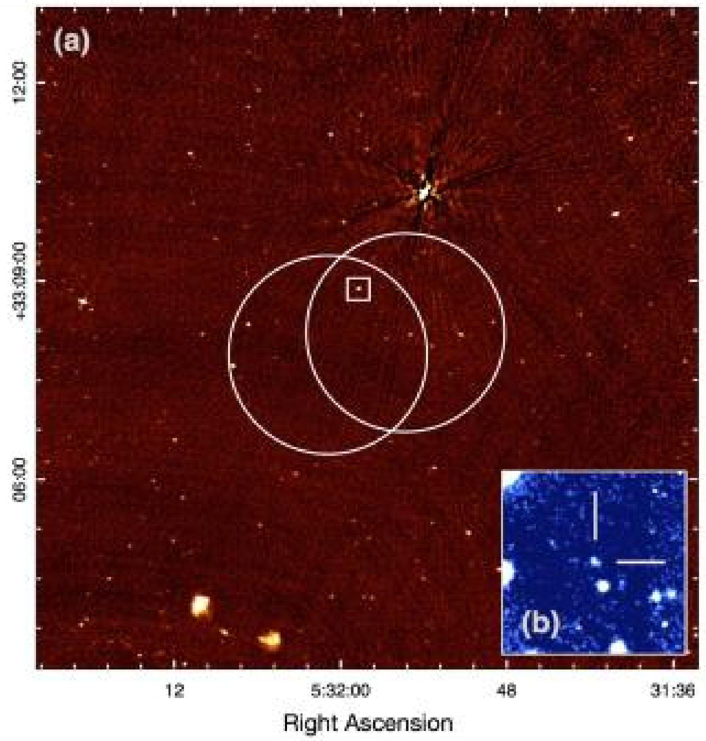
- FRB121102 discovered at Arecibo was huge boost for the field
- You can allocate much more observational time, when you know that eventually there must be a burst.
- Usual localization for non-repeating bursts constrained by the beamsize ~10'
- Not enough for host identification
- Repeaters allow to use VLA and get much better localization



ASKAP beams
(from Shannon et al 2018)

FRBs: repeating bursts.

- FRB121102: DM=557 pc cm^{-3} (3xDM$_{NE2001}$)
- VLA+EVN observations localize better than 0.1"
- VLBI -- 0.012"
- Coincides with persistent (but variable) source with average flux ~0.2 mJy
- This allowed to use large optical telescopes (Gemini-North) and get host identification!
- Dwarf galaxy with active star-formation at z=0.193 (D=972 Mpc)

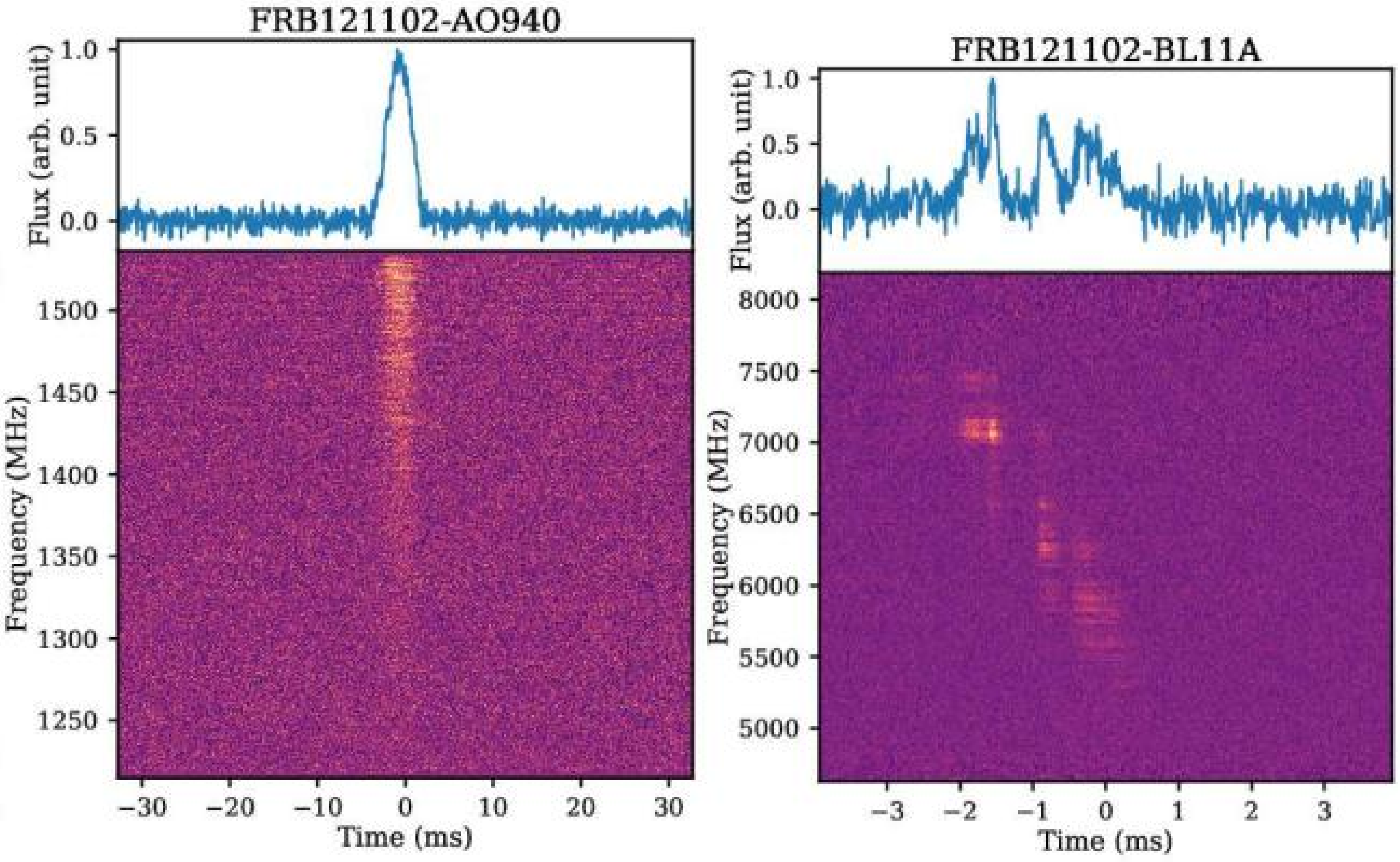


Chatterjee et al, 2017

FRBs: repeating bursts.

- Huge amount of dedicated observational time got some key facts (from ~2000 bursts):
    - No periodicity observed as yet.
    - No counterparts at other frequencies (from optics to TeV)
    - Complicated behaviour -- not just simple Poisson
    - Variable spectral shape -- wide (hundreds MHz) burst can emerge anywhere from <GHz to 10 GHz
    - Fine temporal and spectral structure of the bursts (shares with some other FRBs)
    - Extremely high RM~10^5 rad m^{-2}, which is evolving fast. There are only few other FRBs with detected polarization and for all of them RM values are modest (|RM|<1000)

FRBs: repeating bursts.



from Cordes&Chatterjee, 2019

FRBs: models

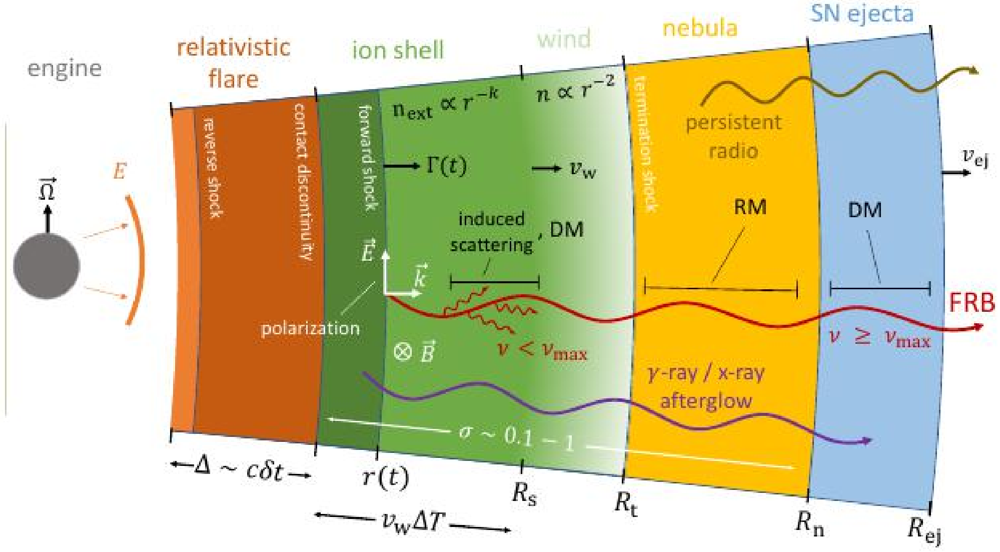
- Models must account for observational properties -- large energetics, high rate, short duration.

- Exotic: strings, evaporating BHs, axion stars
- More realistic almost inevitably use neutron stars.
- There are a lot of models with NSs, but two classes of them are most appealing at the moment:
    - Extreme giant pulses from very young energetic pulsars (like Crab but <100 years old)
    - Flares from magnetars

- The second one is the most popular at the moment.

FRBs: coming from magnetars?

- FRB-magnetar connection first proposed by Popov&Postnov, 2007.
- Theoretical models (e.g. Lyubarski, 2014; Metzger et al, 2019)
- Magnetar flare initiate ultra-relativistic magnetic outflow
- It interacts with wind nebula
- Synchrotron burst
- Strong corroboration of model: FRB200428
- This burst was detected by CHIME (and STARE2).
- Most importantly, coincided both spatially and temporally with X-ray burst from SGR 1935+2154, detected by many X-ray telescopes!

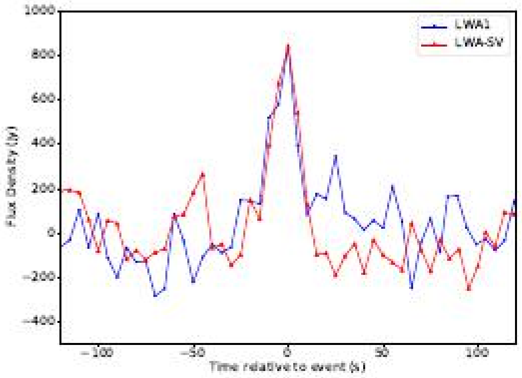


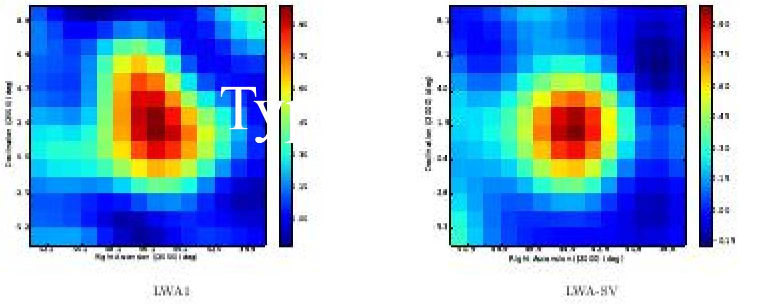
Metzger et al, 2019

Radio transients: unknown

- GCRT J1745−3009
  - VLA and GMRT: flares 2-10 minutes long, 77 min periodicity at 330 MHz.
  - Flaring star?

- Non-repeating transients.
  - LOFAR at 60 MHz -- 20 Jy flare for several minutes (Stewart et al, 2016)
  - LWA at 34 MHz, 100 sec, peaking at 1 kJy
  - At higher frequencies VLA surveys: several mJy level minute+ long transients (Bower et al, 2007), (Ofek et al, 2011)





LWAT10118, from Varghese et al, 2019

THANK YOU!