ICRAR

International Centre for Radio Astronomy Research

Fast Radio Bursts at Metre Wavelengths

Jean-Pierre Macquart
and the
CRAFT collaboration

Curtin University

THE UNIVERSITY OF WESTERN AUSTRALIA

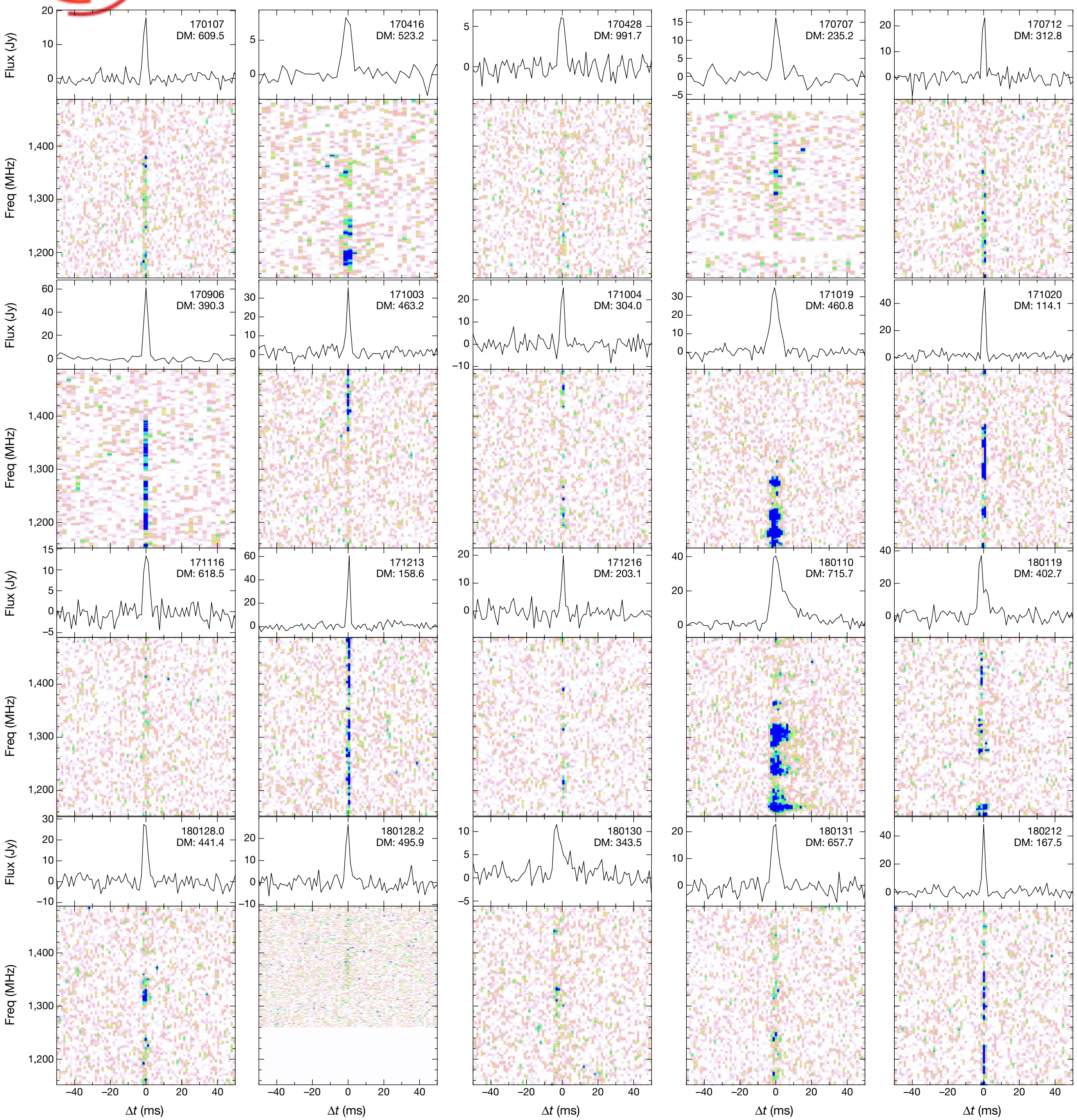
FRBs are an affront to astrophysics

- With brightness temperatures ~10^{35}K, emission must be coherent and outrageously luminous
- Energy estimation requires knowledge of:
    - spectral range (1st part of talk)
    - distances (2nd part of talk)
    - beaming (unknown)
  - For a typical bright burst of 20 Jy ms at z=0.47, the (isotropic) energy received in the 300 MHz detection band alone would be **6×10^{33}J**

  - Efficiency of coherent radio emission from pulsars is 10^{-11} to 10^{-4}:
    If similar efficiency to Crab giant pulses total FRB energy output is ~10^{42}J

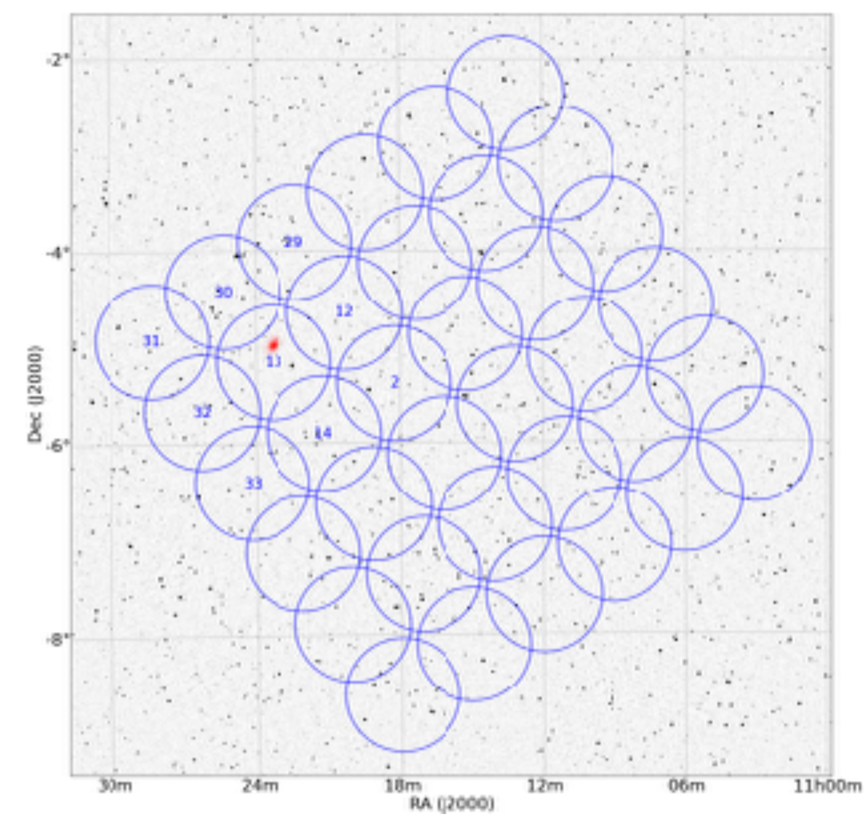
Get out clause: Energetics assume isotropic emission. If emission is tightly beamed, energetics lower by $\Omega_{beam}/4\pi$. But then event rate is $4\pi/\Omega_{beam}$ higher!

Rogues' gallery of ASKAP FRBs @ 1.4 GHz



Shannon et al. 2018

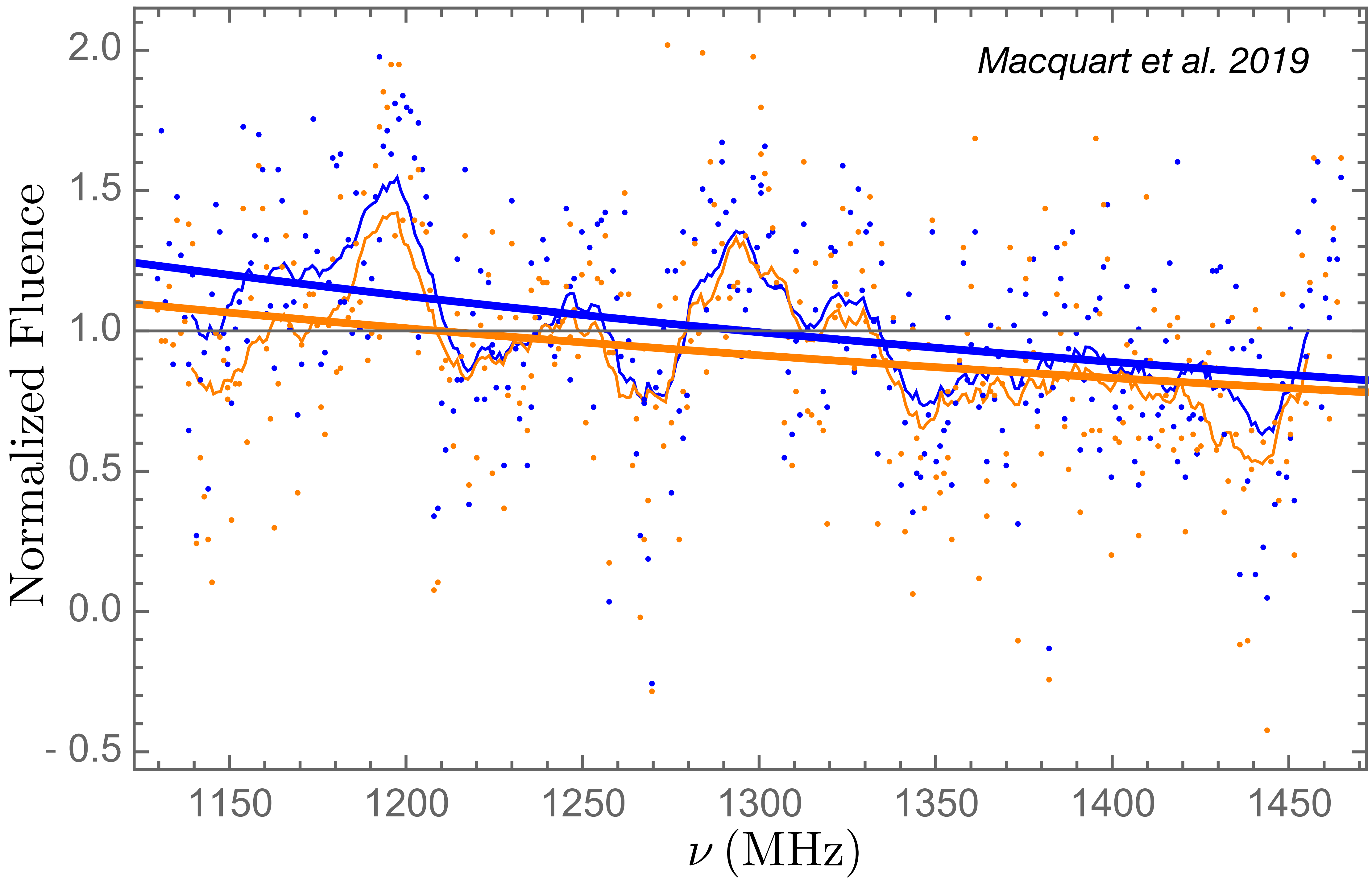
Phased Array feed enables accurate determination of burst fluence and spectrum



Spectral properties of CRAFT FRBs

Equal-weight mean fluence of 23 bursts

Spectral index (-1.2 to -1.8) close to that of ordinary spin-powered pulsars (-1.4 to -1.6)



FRBs at <300 MHz?

FRB emission is patchy but mean spectrum, averaged over 23 well-calibrated burst spectra (ASKAP) at 1.4 GHz is

$$F_\nu \propto \nu^{-1.5\pm0.3}$$

Macquart et al. 2019

This immediately implies

- The low frequency emission is crucial to understand the burst energetics
- Bursts should, on average, be more readily detectable at frequencies below 1.4 GHz

To date the lowest detections have been at 400 MHz

Are present lower-frequency surveys constraining on the emission physics?

Constraints below 300MHz

LOFAR (Pilot pulsar survey) (Coenen et al 2014)

- Survey exposure 14,000 deg^{2}h at 140 MHz
- Fluence cutoff 2750 $(\Delta T/1s)^{1/2}$Jy ms ΔT=0.66ms to 1.26s

ARTEMIS @ 150 MHz (Karastergiou et al. 2015)

- Searched DM<310 pc cm^{-3} to fluences >4470 $(\Delta T/1s)^{1/2}$Jy ms
- Sensitive to burst durations shorter than 21ms

MWA (Tingay et al. 2015)

- Limiting fluence 700 Jy ms but only on 2s images
- Exposure 4700 deg^{2}h

MWA-ASKAP shadowing

Sokolowski et al. 2018

We used the MWA to shadow the CRAFT fly's eye survey

Telescopes well-matched in field of view and fluence sensitivity

170-200 MHz with 0.5s cadence imaging at 40 kHz resolution

Not a blind search — knowledge of the burst time and approximation position allows us to search to 5σ

- The 37±8 events $day^{-1}sky^{-1}$ burst rate measured by ASKAP at F>26 Jy ms is equivalent to an event every 27,000 deg^2h
- Previous surveys could not have detected even a single counterpart to these bursts!

No 200 MHz FRB emission

We shadowed 7 FRBs, including a 420 Jy ms event

For spectral indices steeper than -1.5 we should have detected the bursts at 15-25σ

We saw nothing

What we should've seen **Our limit**

FRB	UTC Detection	DM_{tot} [a] (pc/cm^3)	DM_{mw} [a] (pc/cm^3)	t_{arr} [b] (s)	t_{sweep} [c] (s)	τ_{scat} [d] (ms)	$\mathcal{F}_{1.4\,GHz}$ [e] (Jy ms)	$\mathcal{F}_{185MHz}$ (Jy ms) Expected [f] $\alpha = -1$	$\alpha = -2$	$\alpha = -1.8$ [g]	$\mathcal{U}_{5\sigma}$ [h] (Jy ms)
171020	10:27:59.00	114.1	38.4	11.7	4.5	1.7	200^{+500}_{-100}	1500^{+4000}_{-800}	11400^{+30000}_{-6000}	7600^{+19000}_{-4000}	2200
180110	07:34:34.95	715.7	38.8	73.0	28.0	4.5	420^{+20}_{-20}	3200^{+150}_{-150}	23900^{+1100}_{-1100}	16000^{+800}_{-800}	3350[i] or 6500[j]
180128.0	00:59:37.97	441.4	31.5	45.0	17.3	2.9	51^{+2}_{-2}	380^{+15}_{-15}	2900^{+110}_{-110}	1940^{+80}_{-80}	GL[k]
180128.2	04:53:26.80	495.9	41.0	50.6	19.40	2.3	66^{+4}_{-4}	500^{+30}_{-30}	3800^{+230}_{-230}	2500^{+150}_{-150}	SL[k]
180130	04:55:29.99	343.5	39.0	34.90	13.35	6.0	95^{+3}_{-3}	720^{+20}_{-20}	5400^{+170}_{-170}	3600^{+110}_{-110}	SL[k]
180315	05:05:30.99	479.0	101.7	48.66	18.63	2.4	56^{+4}_{-4}	420^{+30}_{-30}	3200^{+230}_{-230}	2100^{+150}_{-150}	SL[k]
180324	09:31:46.70	431.0	64.0	43.79	16.75	4.3	71^{+3}_{-3}	540^{+20}_{-20}	4000^{+170}_{-170}	2700^{+110}_{-110}	450[i]

What does it mean?

Pulse broadening alone cannot explain the non-detections — fluence preserved under scattering

There must be a spectral turnover above 200 MHz

Of the three most likely spectral break mechanisms:

Low DM of 171020 makes it hard to explain away with free-free absorption

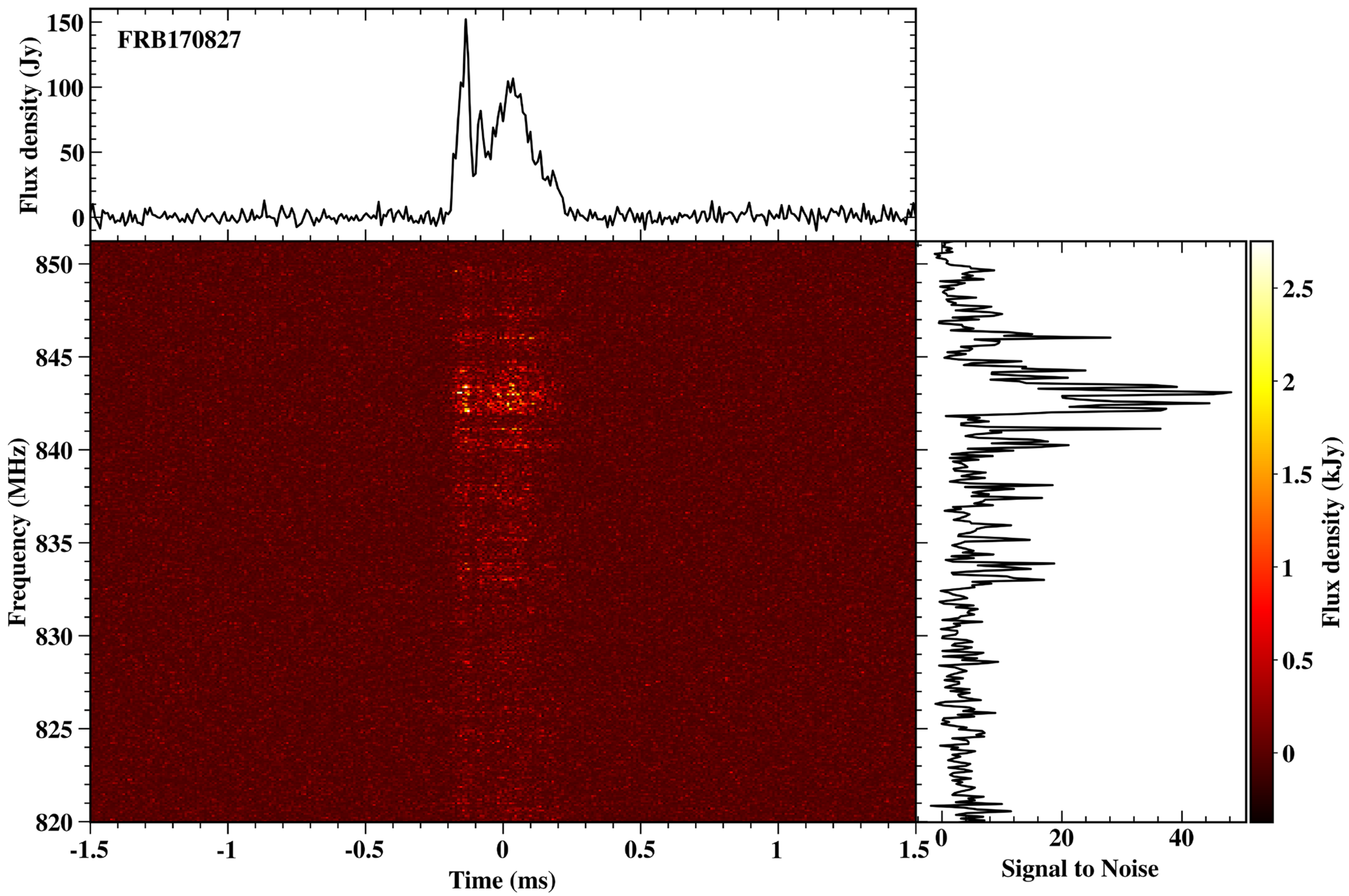
- Free-free? If you suppose ALL of DM_{EG} is in a shell:
  - Constrain thickness of absorbing medium of FRB171020 to $<0.03\ (T_e/10^4\ K)^{-1.35}$ pc
- Intrinsic spectral turnover?
- Magnification at ASKAP frequencies by lensing caustics or scintillation? — possible for individual events but not a large number (source counts arguments)

What is the spectral structure at low frequency?

All but one CRAFT FRB shows a mottled appearance

Fine spectral structure in an UTMOST FRB at 843 MHz

W. Farah et al.



Diffractive scintillation?

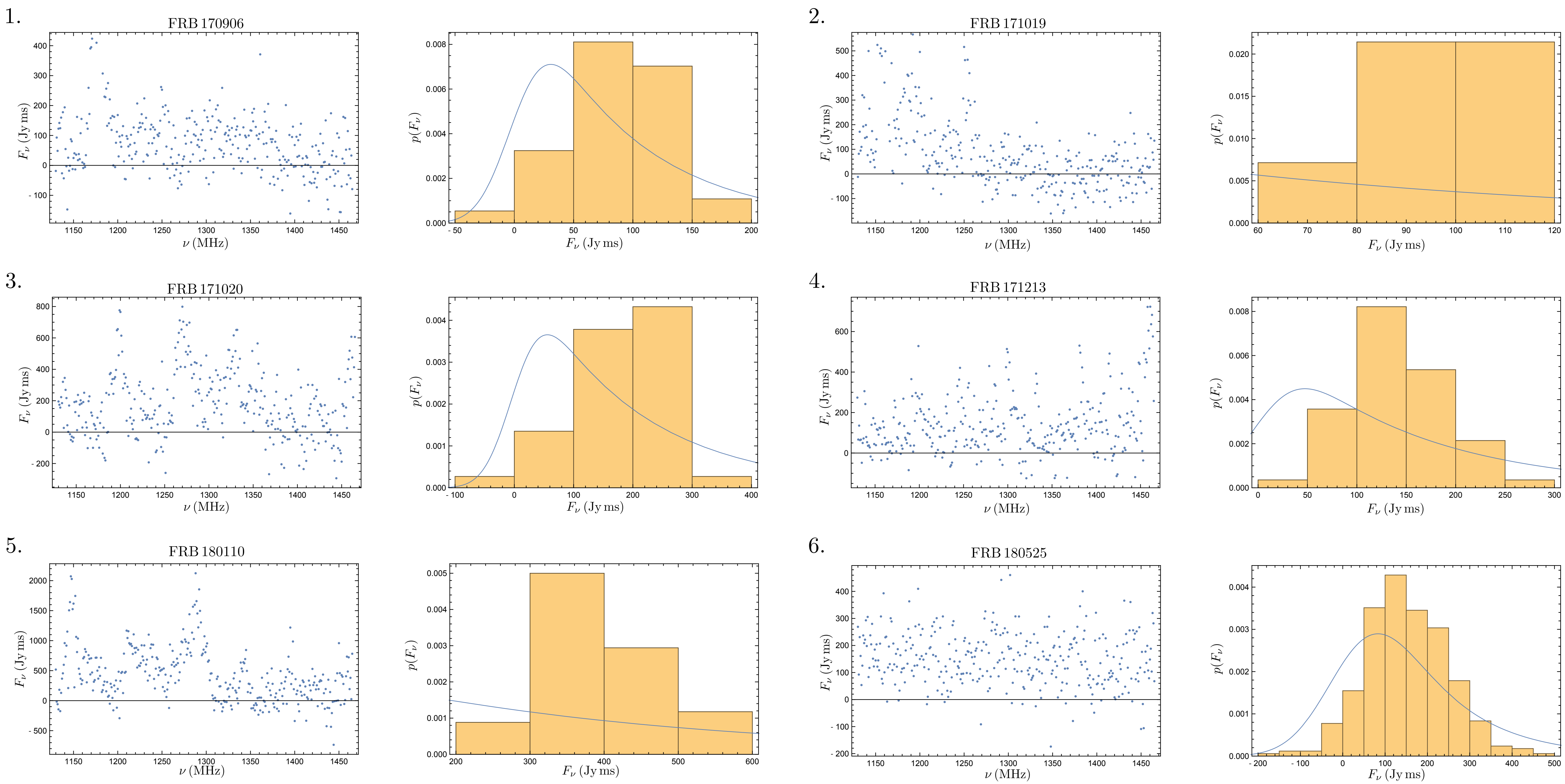
Bandwidth of spectral structure in UTMOST bursts at 843 MHz consistent with ASKAP bursts using ν^4 scaling

But the intensity statistics do NOT match the predictions of point-source diffractive scintillation

What else is going on?

Spectral properties of FRBs

Fully-modulated diffractive scintillation model doesn't fit in detail



Energetics Part II: distances