FAST RADIO BURSTS

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15th EVN Symposium, Cork

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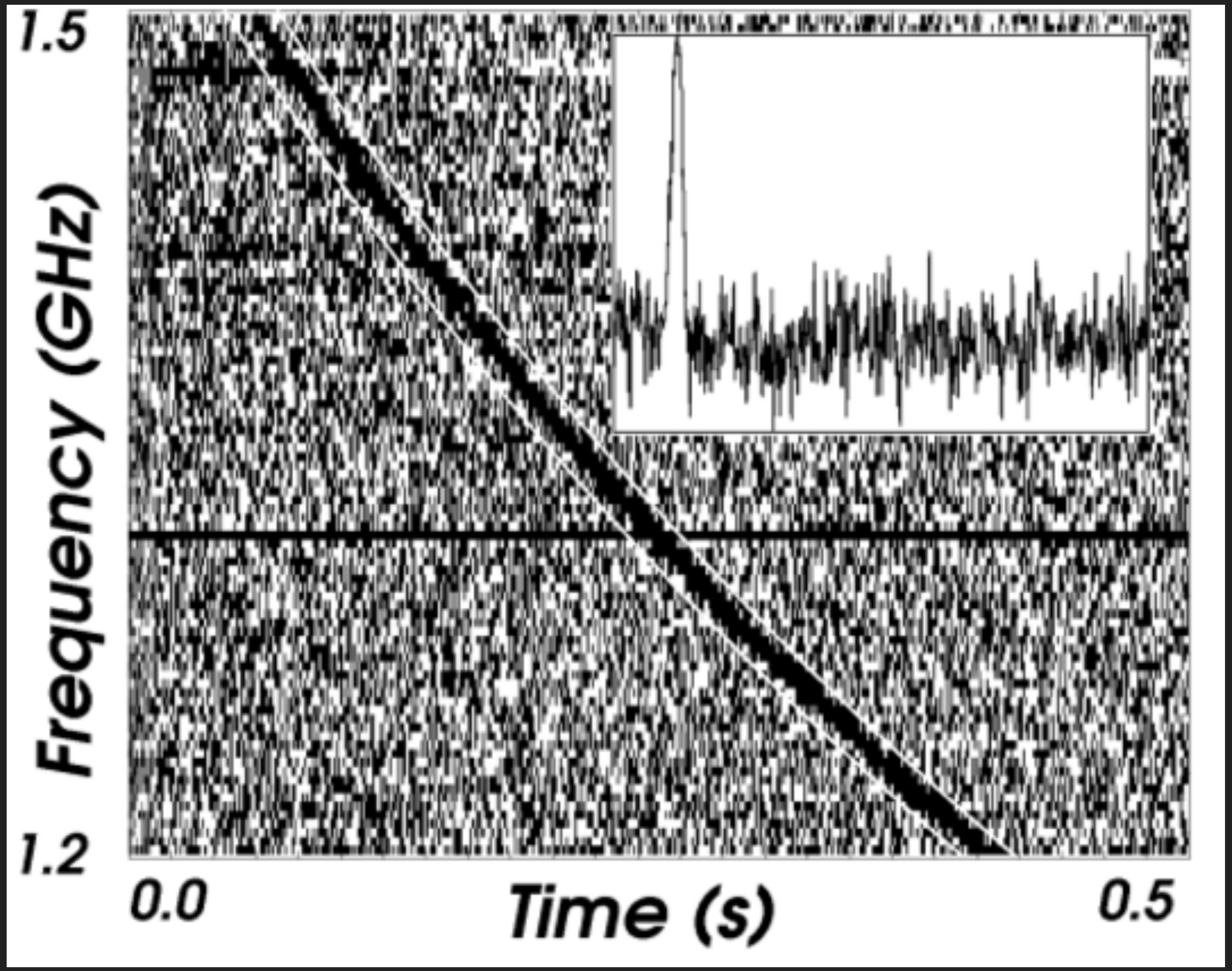
CAASTRO
ALL-SKY ASTROPHYSICS

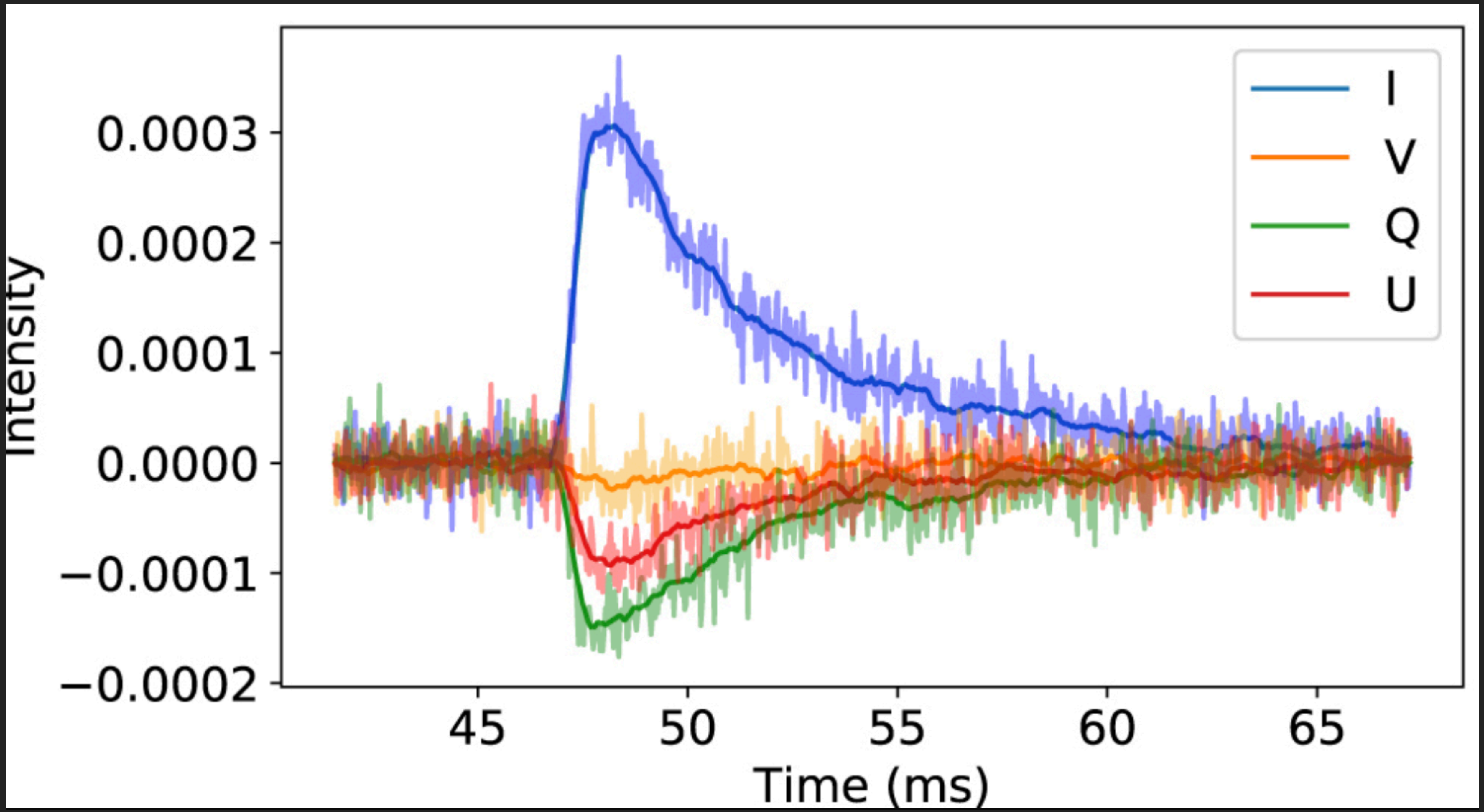
FAST RADIO BURSTS

- Fast: microseconds to milliseconds in duration
- Radio: detected at radio frequencies
- Bursts: appear and disappear in a flash; extremely energetic events.
- ~3000 events/sky/day
- Some repeat!; very sporadic in nature
- Unknown origin



Lorimer+07

FRB SIGNAL AND PROPAGATION EFFECTS



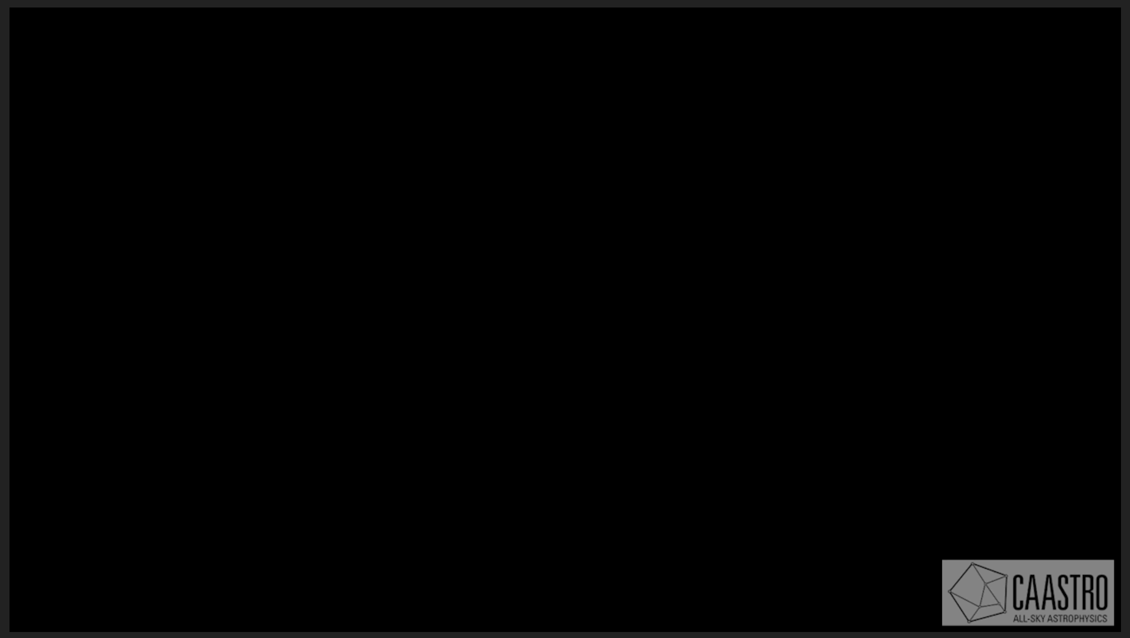
Bhandari+20b

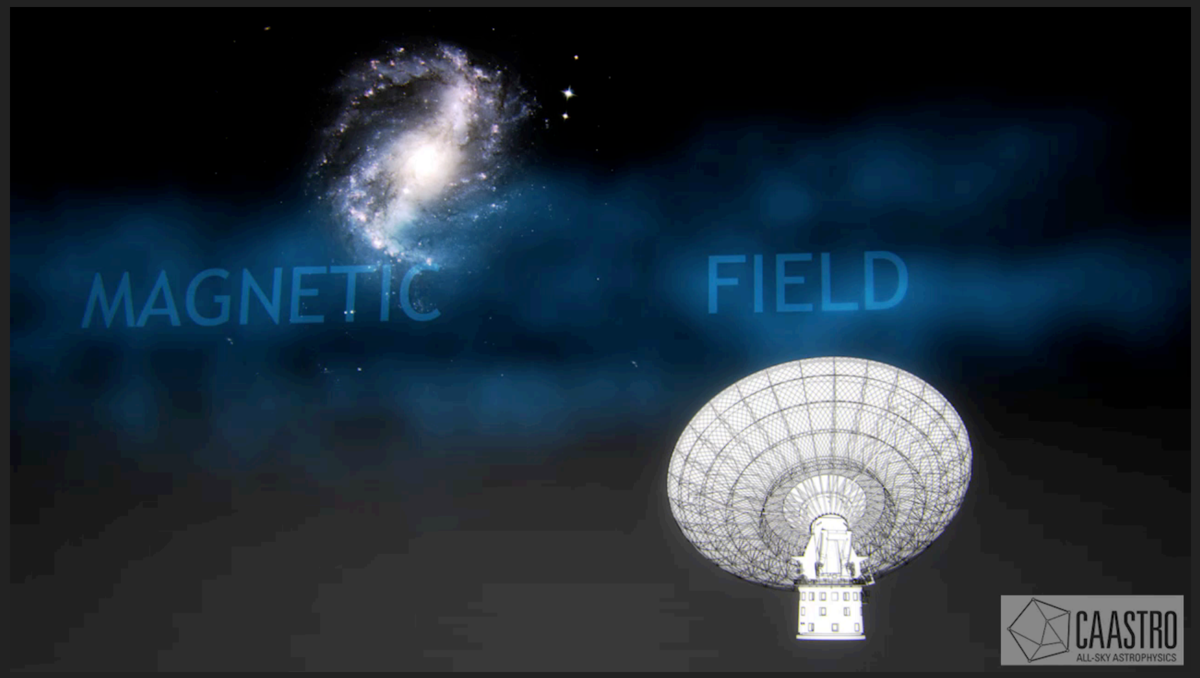
- Dispersion
- Faraday rotation
- Scattering

$$DM = \int_0^d n_e dl,$$

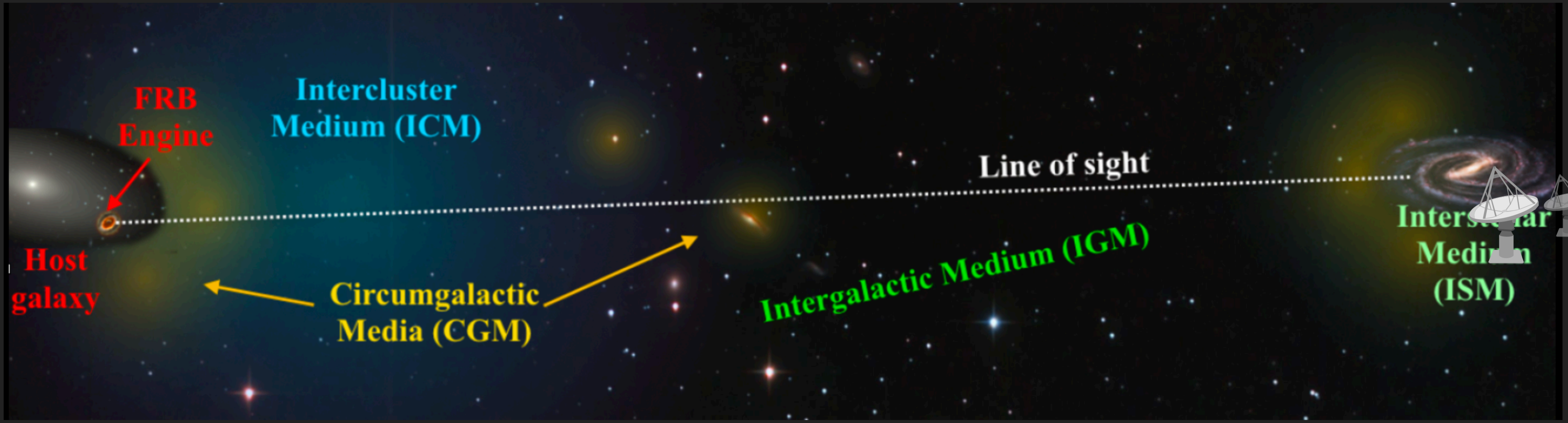
$$RM = \frac{e^3}{2\pi m_e^2 c^4} \int n_e B_{||} dl \ \mathrm{rad\,m^{-2}}$$

- Isotropic energy of FRBs: 10^{35} - few 10^{43} erg
- Width of the burst: few μs to ms





FRB DISPERSION MEASURES



Ravi+19

NE2001/YMW16

$$\mathrm{DM_{FRB}}(z) = \mathrm{DM_{MW,ISM}} + \mathrm{DM_{MW,halo}} + \mathrm{DM_{cosmic}}(z) + \mathrm{DM_{host}}(z)$$

Observed — Desired

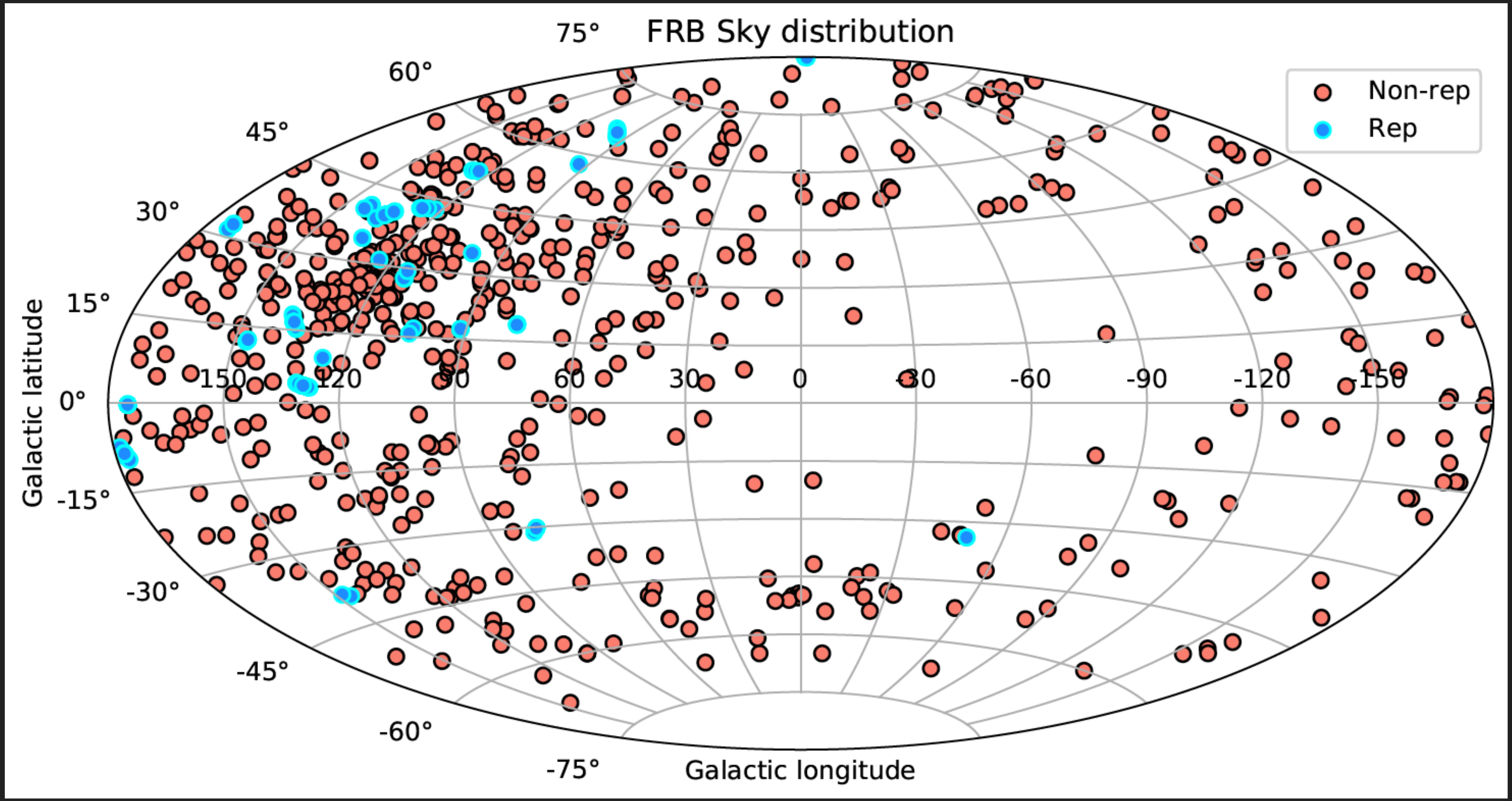
$\mathrm{DM_{MW,halo}} + \mathrm{DM_{host}} = 50 + 50/(1+z)$ pc cm^{-3}

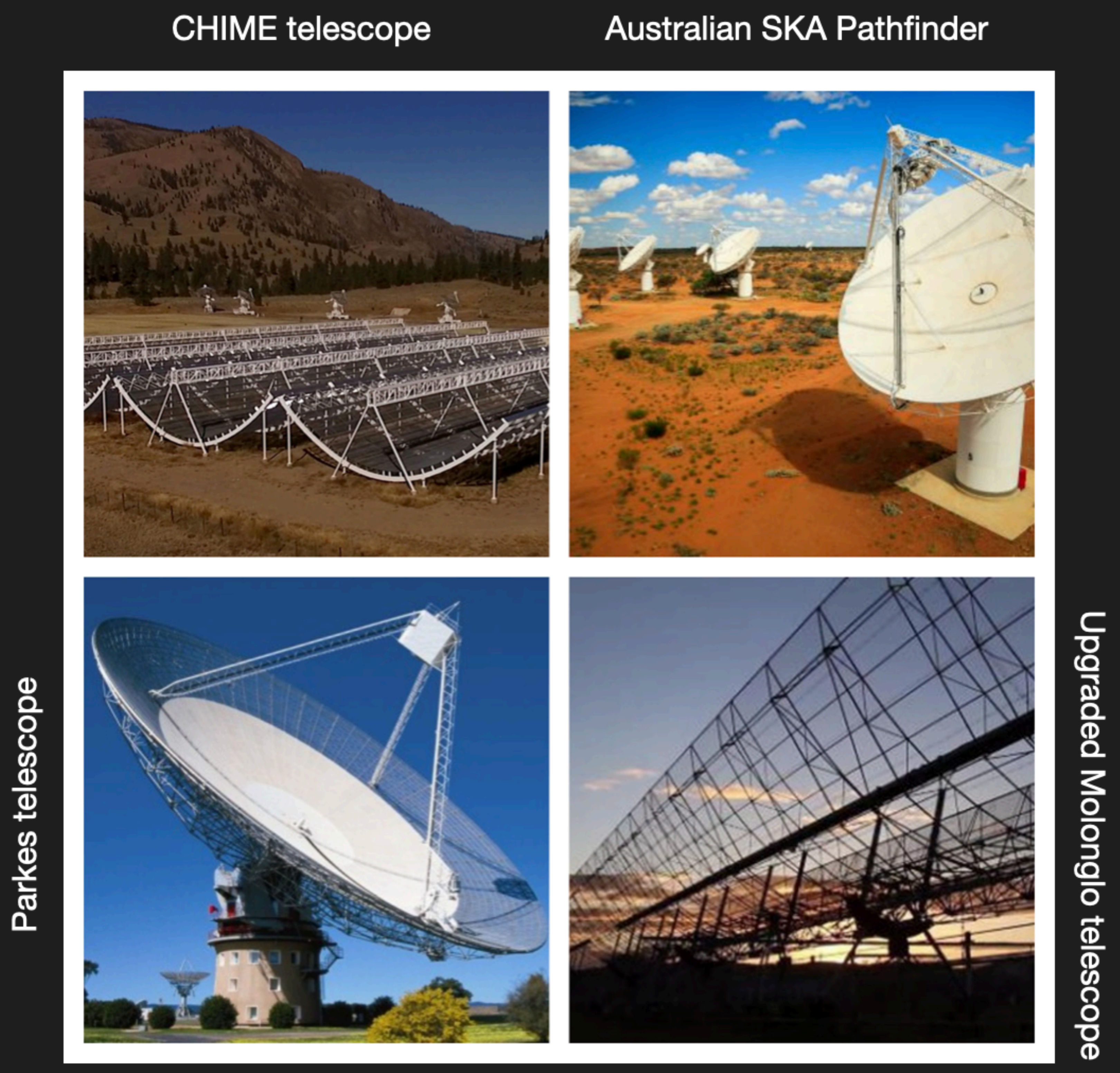
Prochaska+19, Macquart+20

APPROX. 4% OF PUBLISHED FRB SOURCES EMIT REPEATING BURSTS

Total FRB count: 623
Repeater FRB sources: 24
Host galaxies: 20

FRB POPULATION EXPLOSION

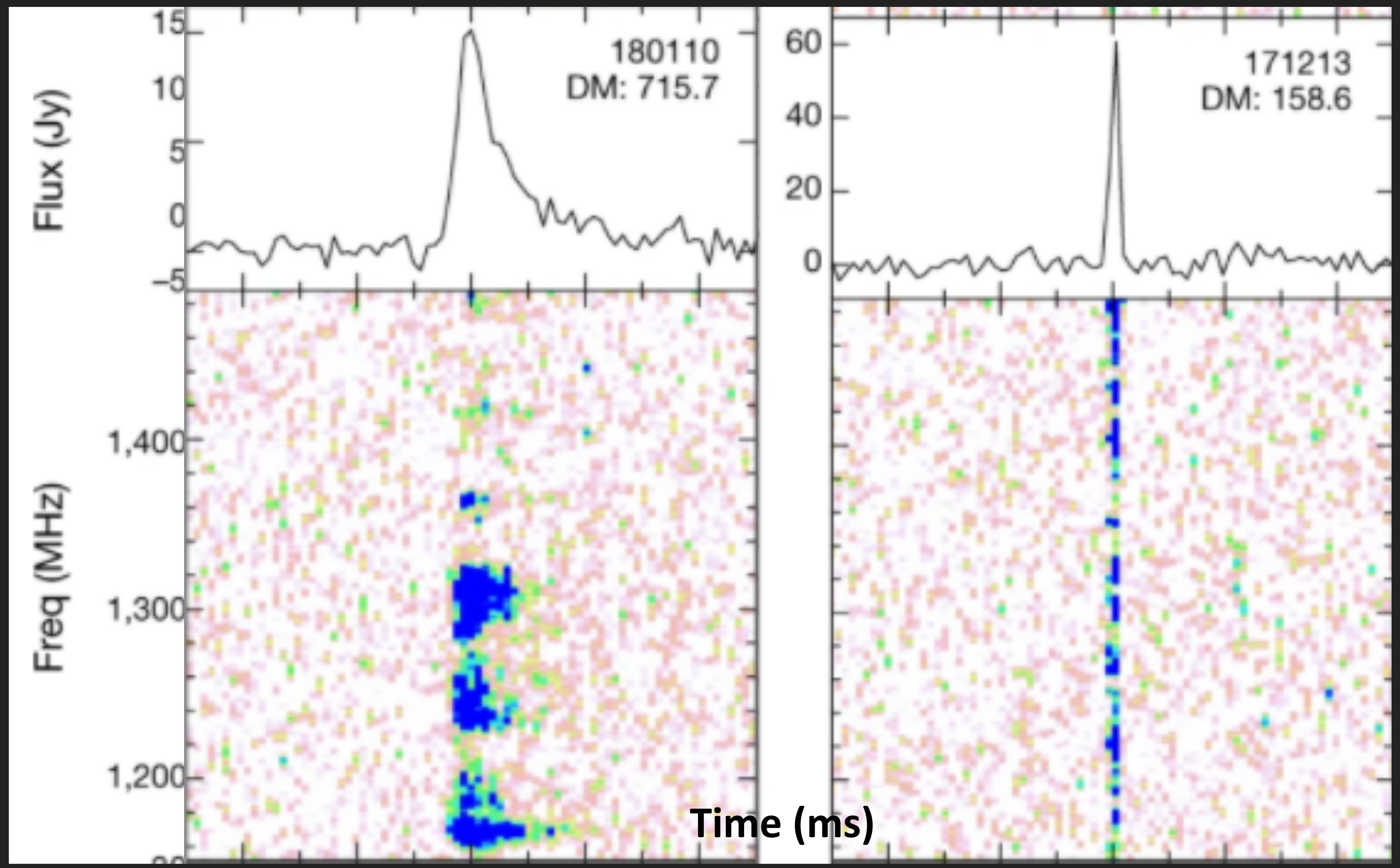




A subset of radio facilities implementing real-time search

BURST MORPHOLOGIES

Broadband emission

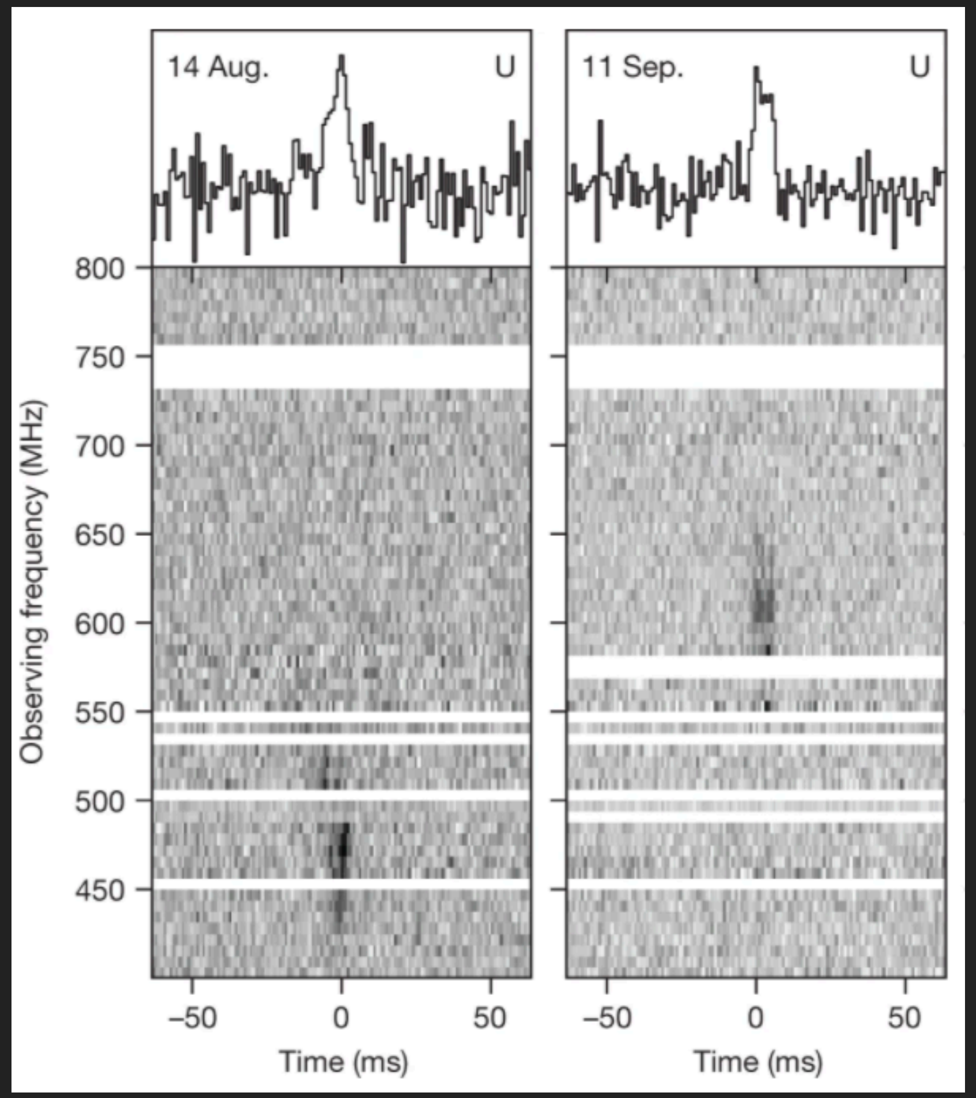


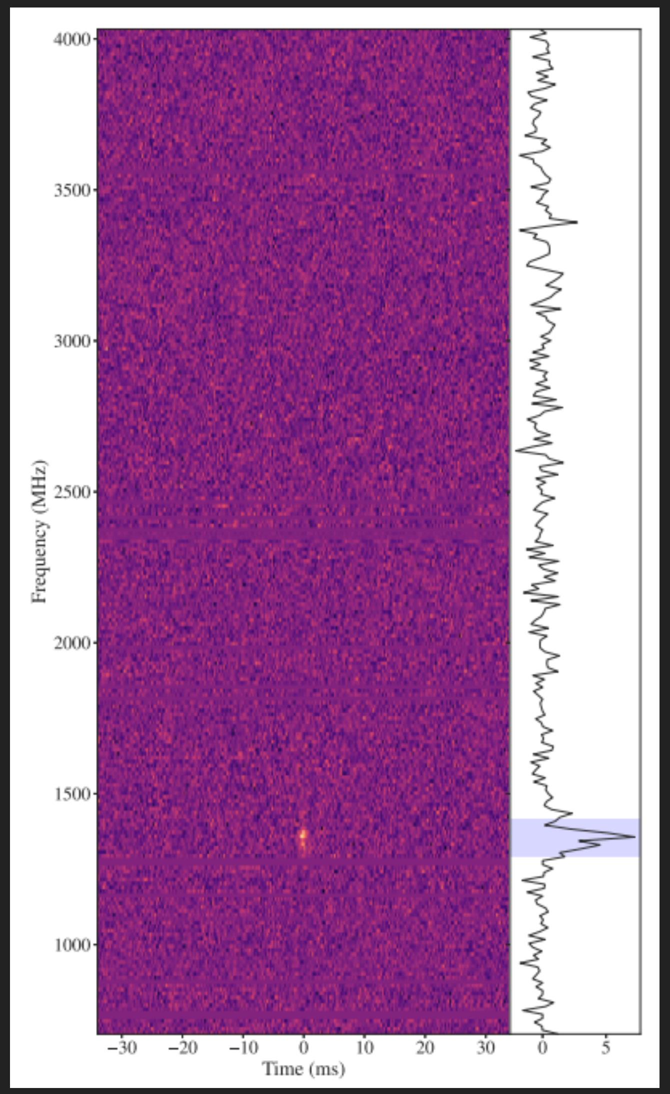
Shannon+18

Pleunis+21

Sub-band emission

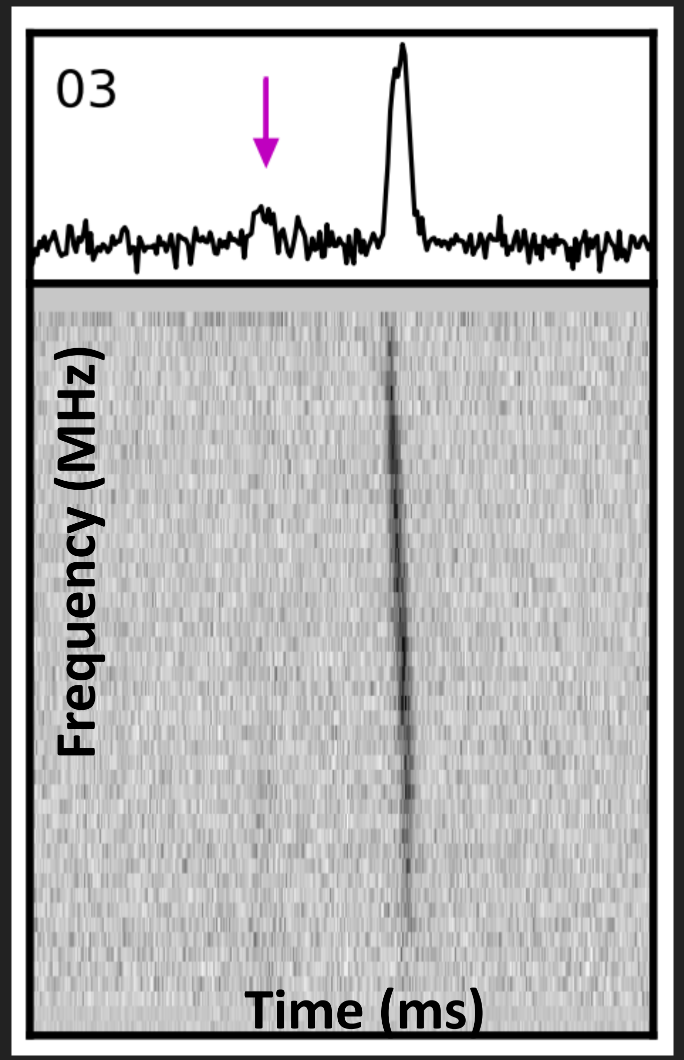
(CHIME/FRB Collaboration 2019)





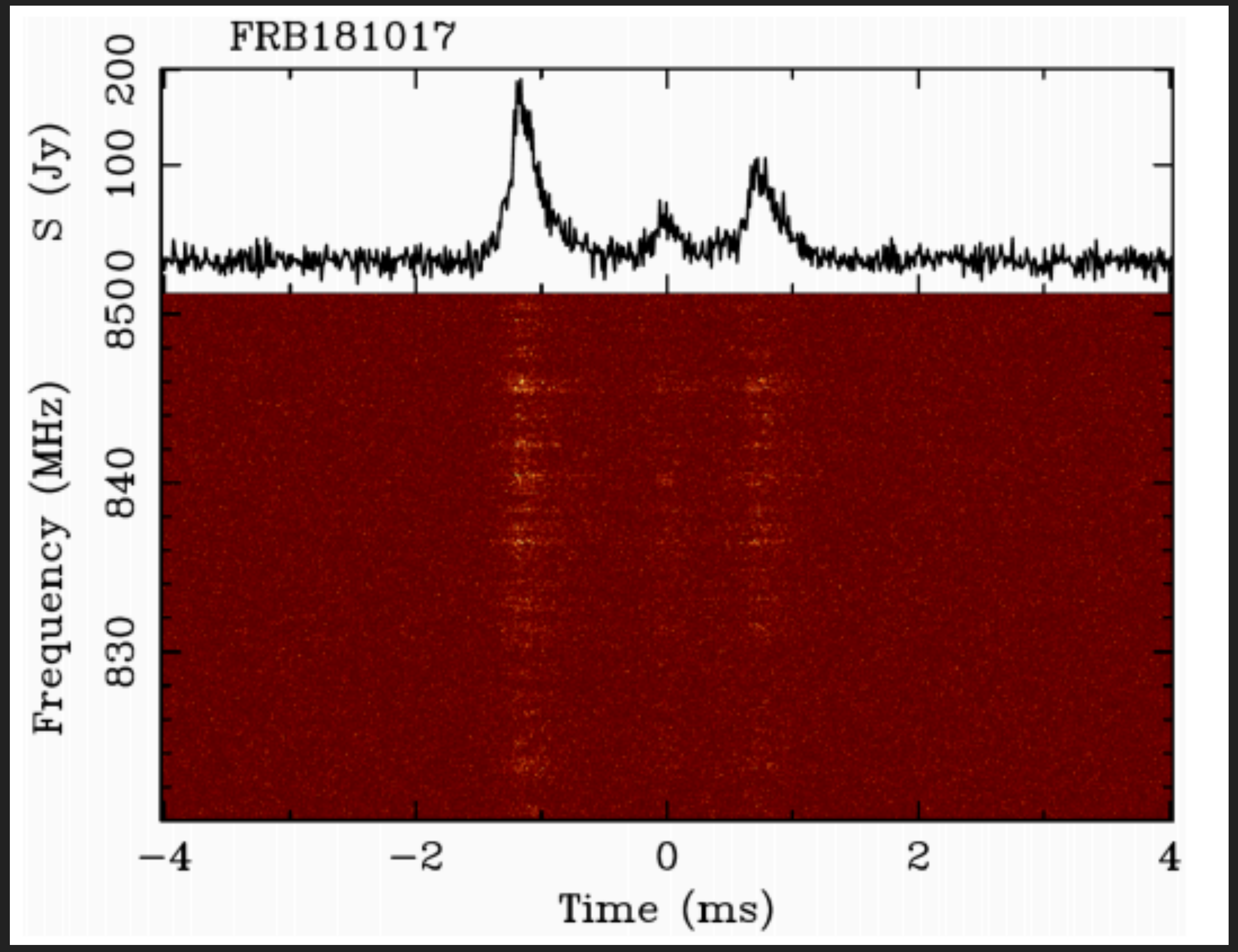
Kumar+21

Caleb+20

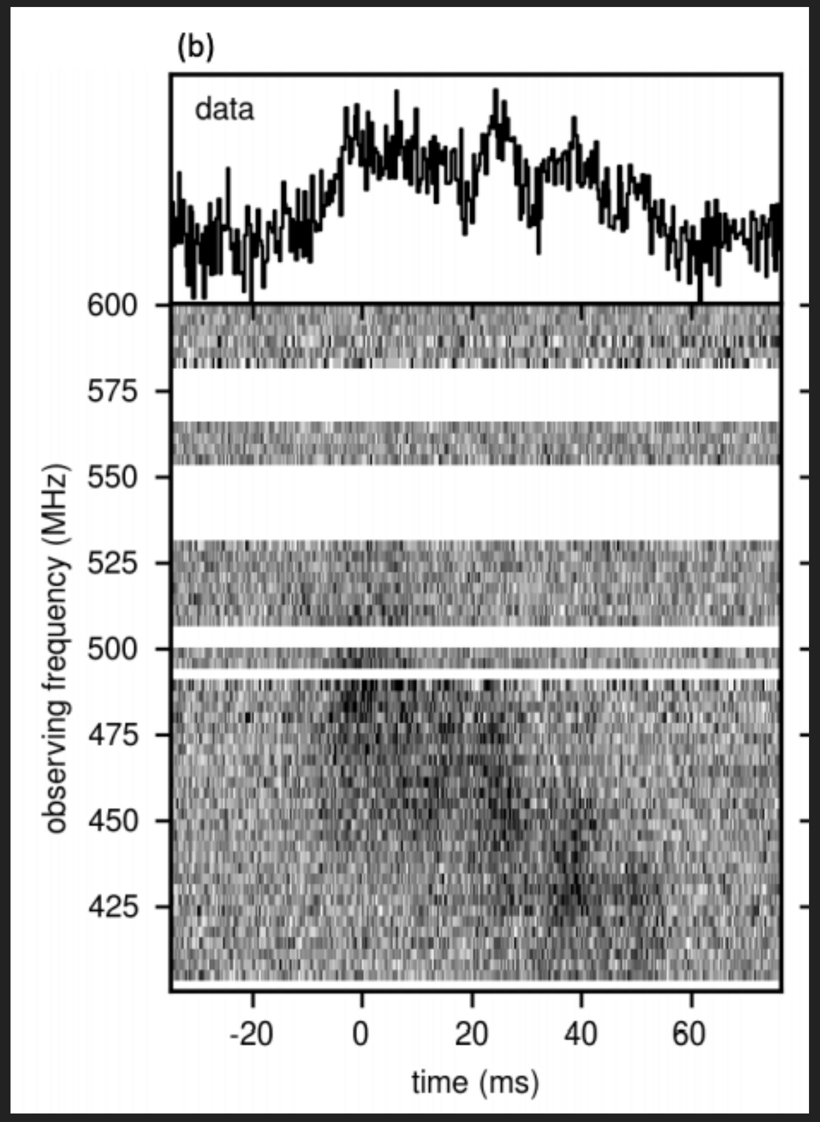


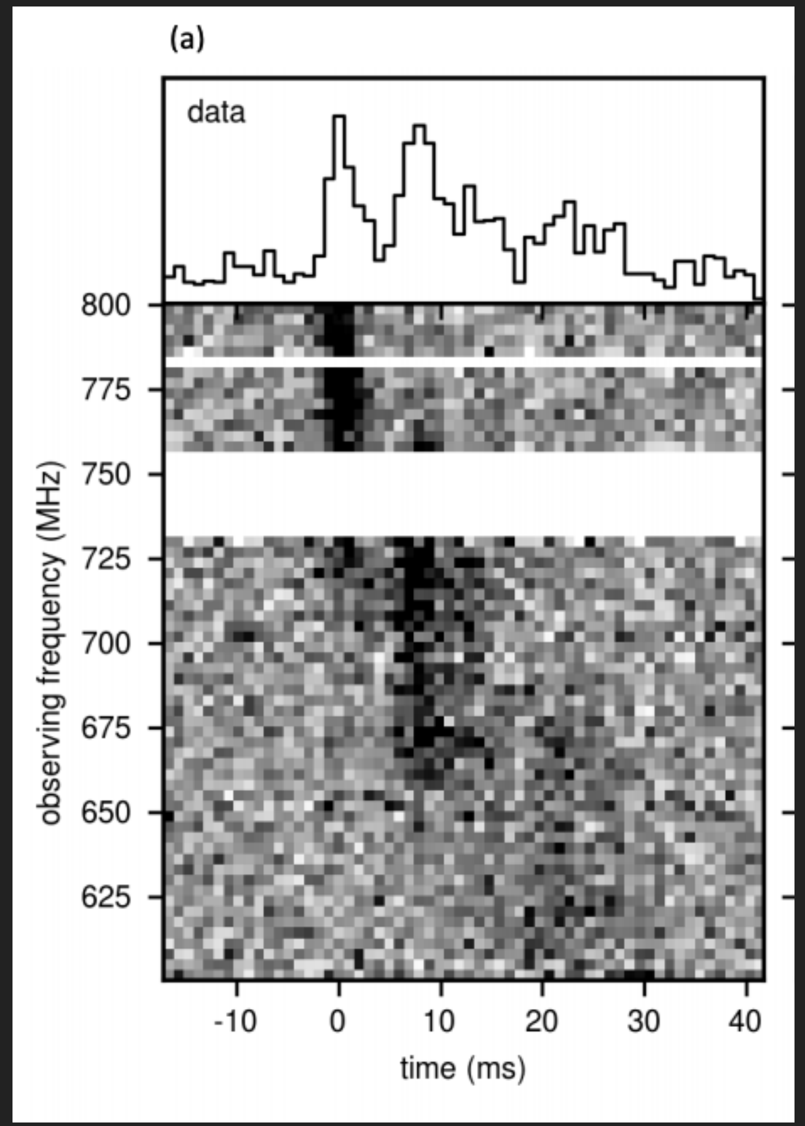
Precursor emission

Farah+19



Multiple components





(CHIME/FRB Collaboration 2019)

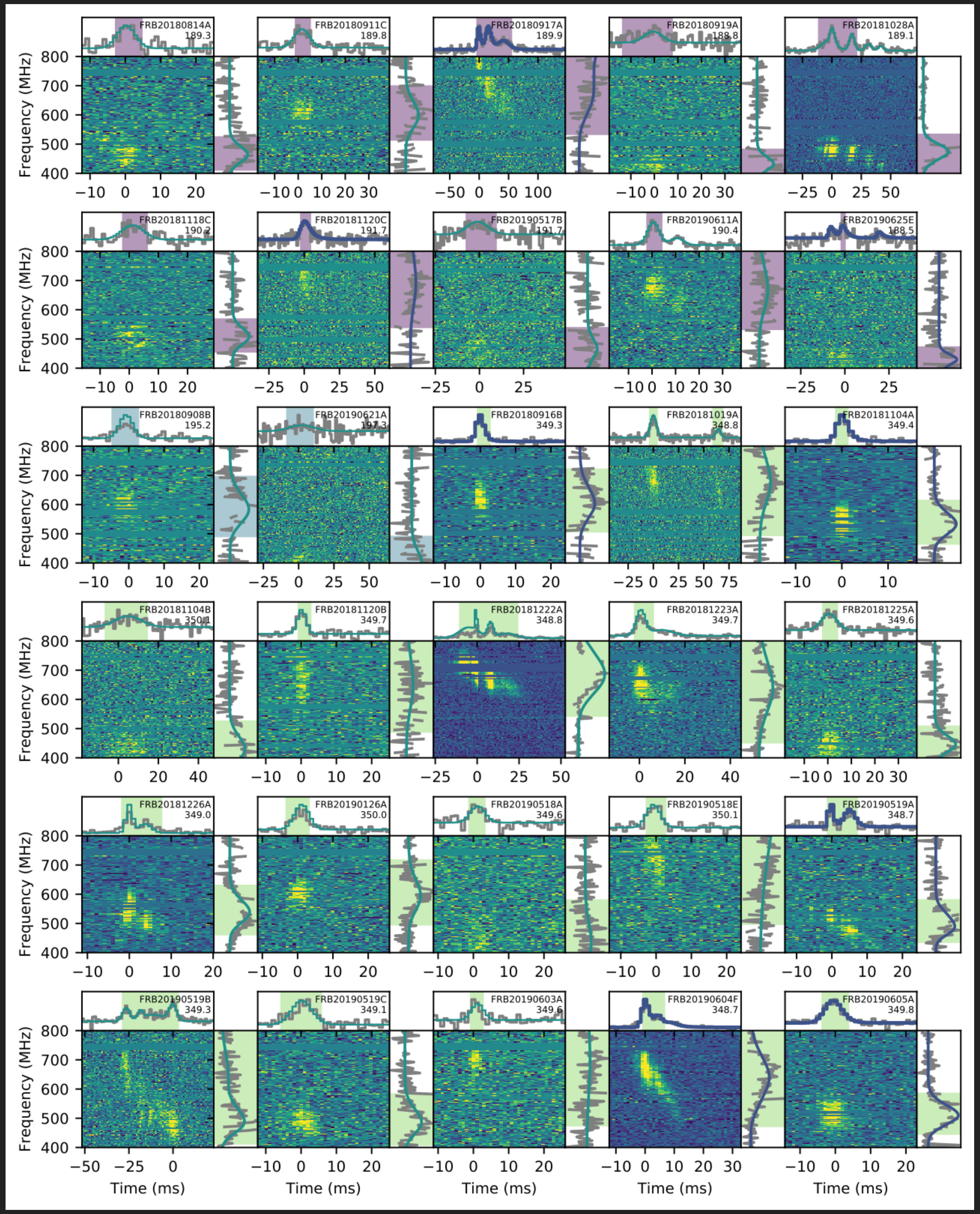
Frequency drifting

REPEATING FRBS ARE TEMPORALLY WIDER AND SPECTRALLY NARROWBAND

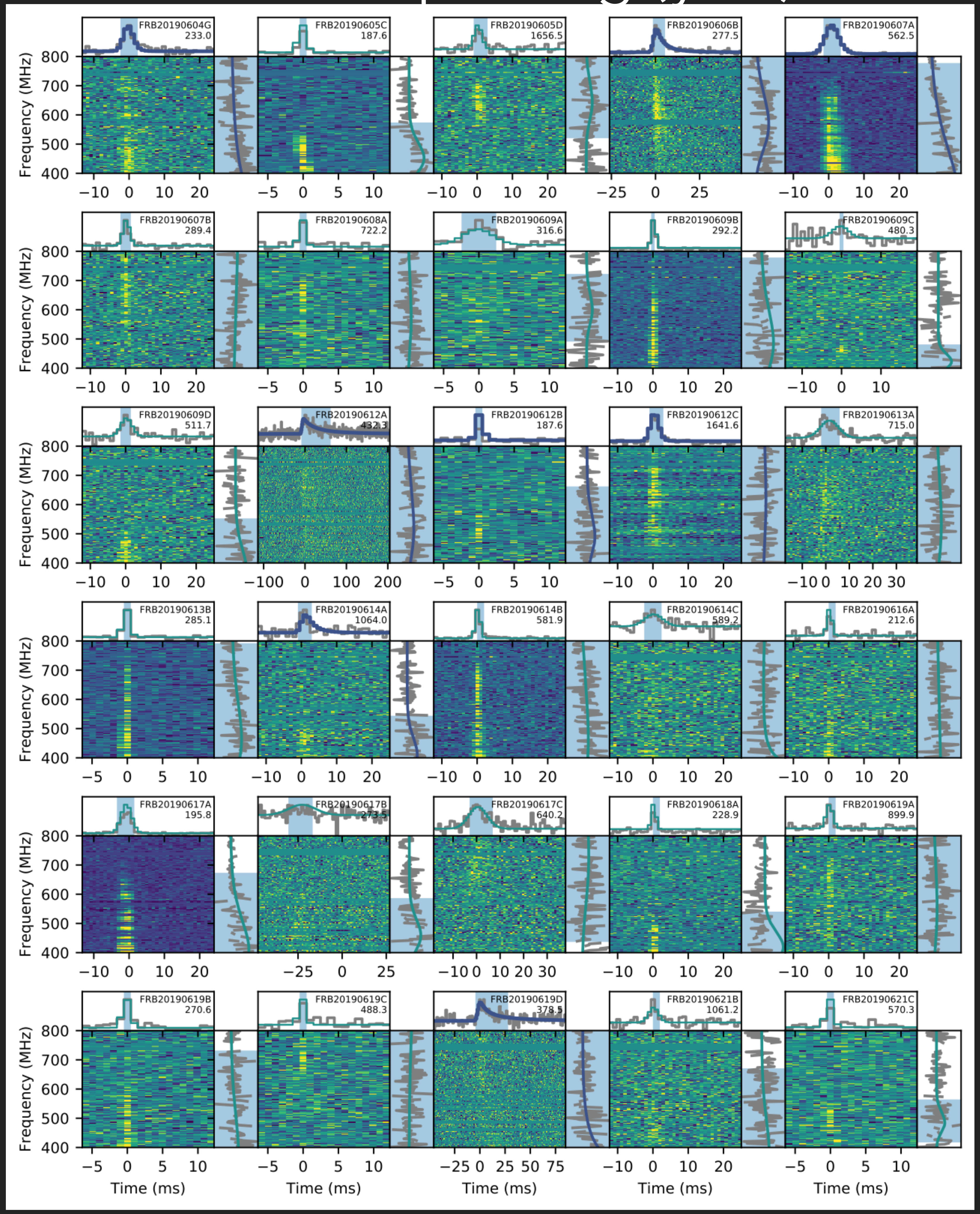
TWO CLASSES?

(CHIME/FRB Collaboration 2021)

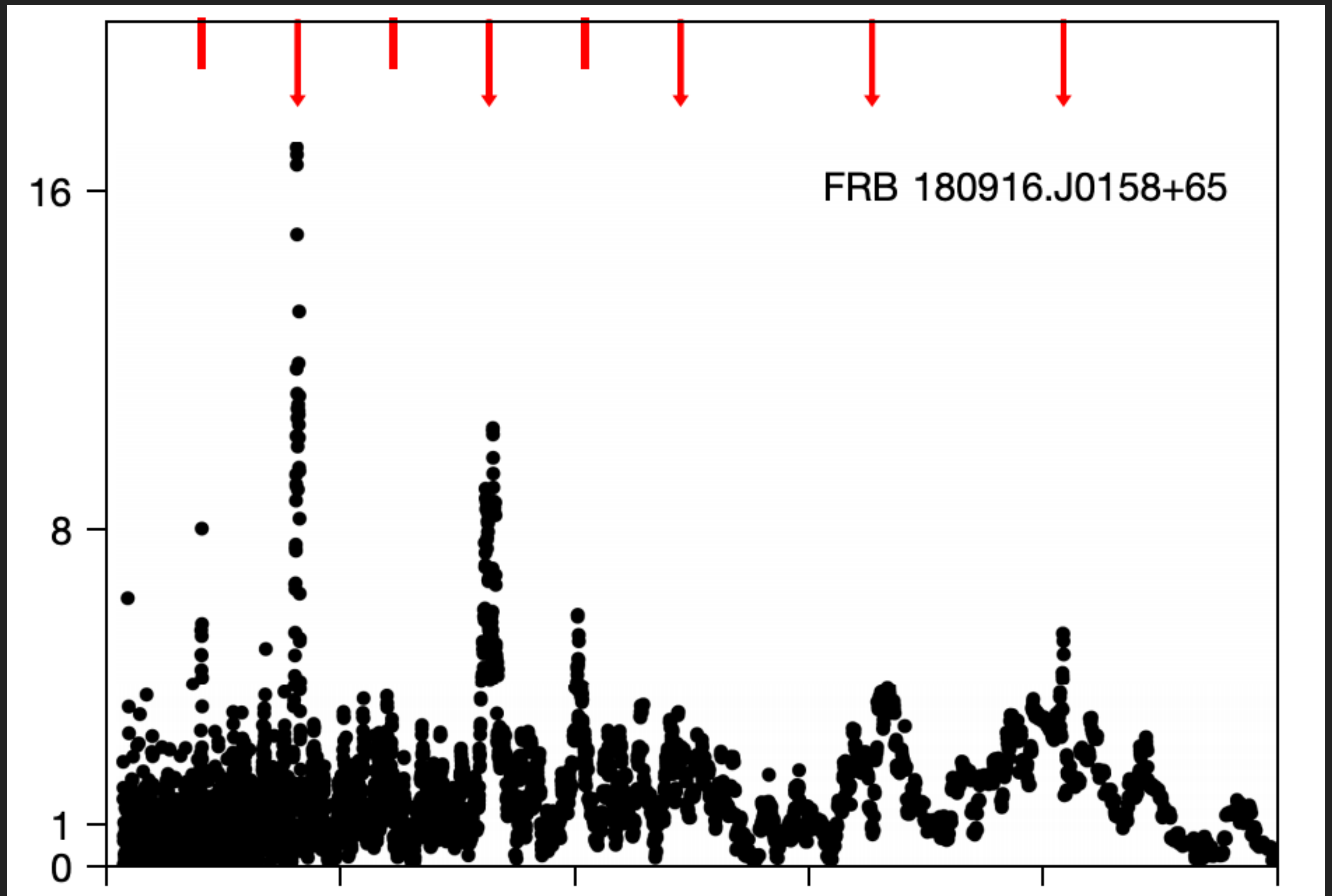
Repeating



Non- Repeating (yet!)



PERIODIC IN ACTIVITY

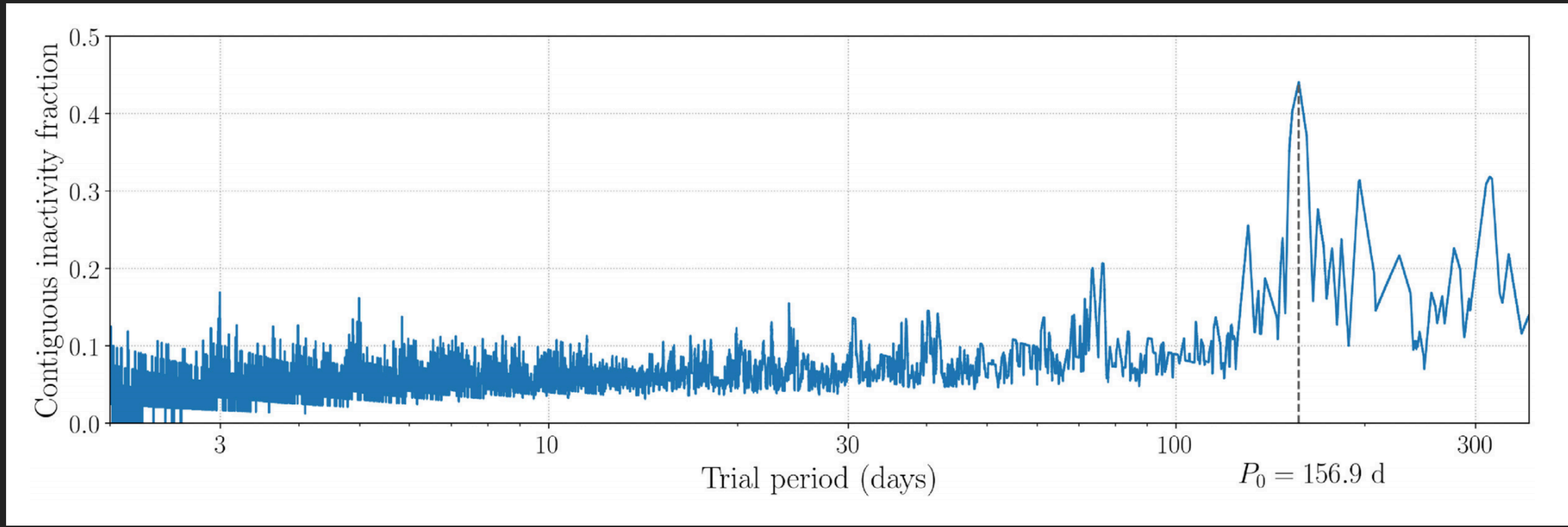


Period (days)

CHIME FRB collaboration 2020

FRB180916

- 16.35 day period in activity; ~5 day activity window
- Binary orbital motion: OB type star + NS?
- Classical binary precession?



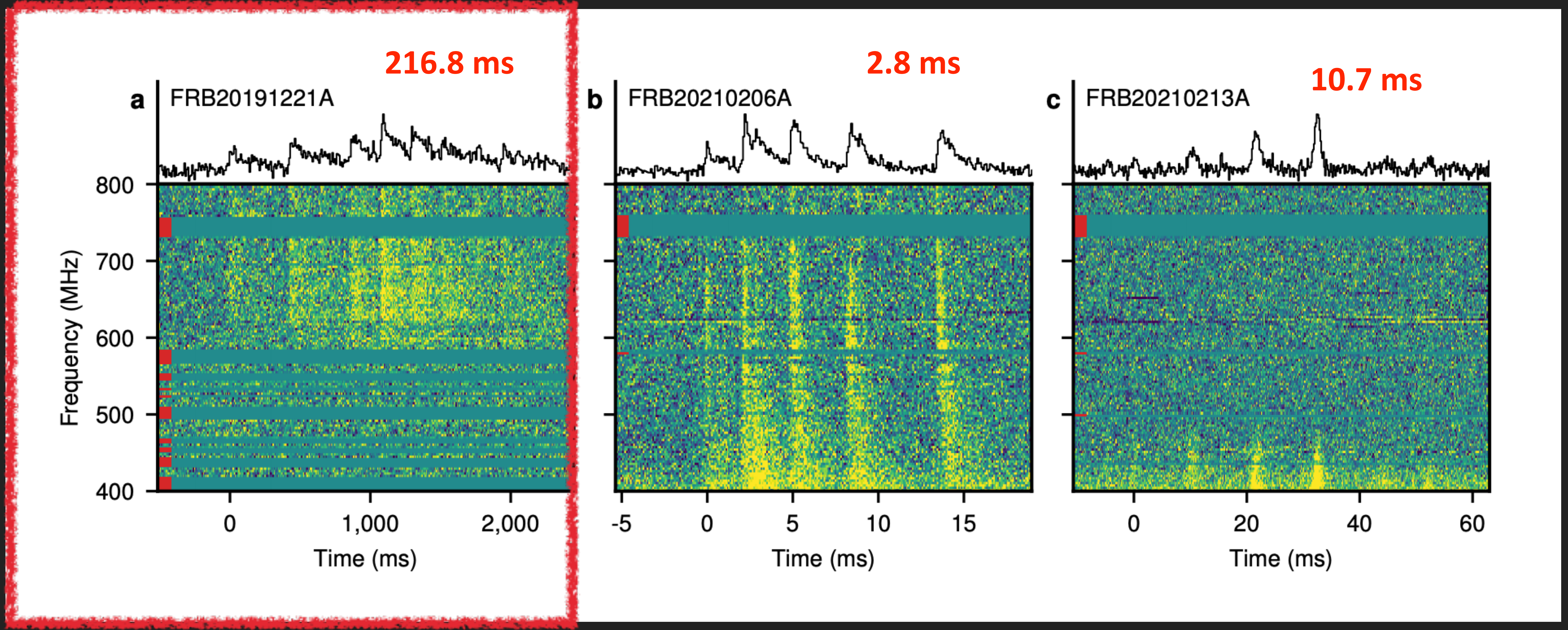
Rajwade et al. 2020

FRB121102

- 156.9 day period in activity; ~90 day window

SOME CHIME FRBS SHOW PERIODICITY/QUASI-PERIODICITY

- Periodic separation of 216.8ms between components with a significance of 6.5σ
- Long (~3 s) duration and nine or more components forming the pulse profile

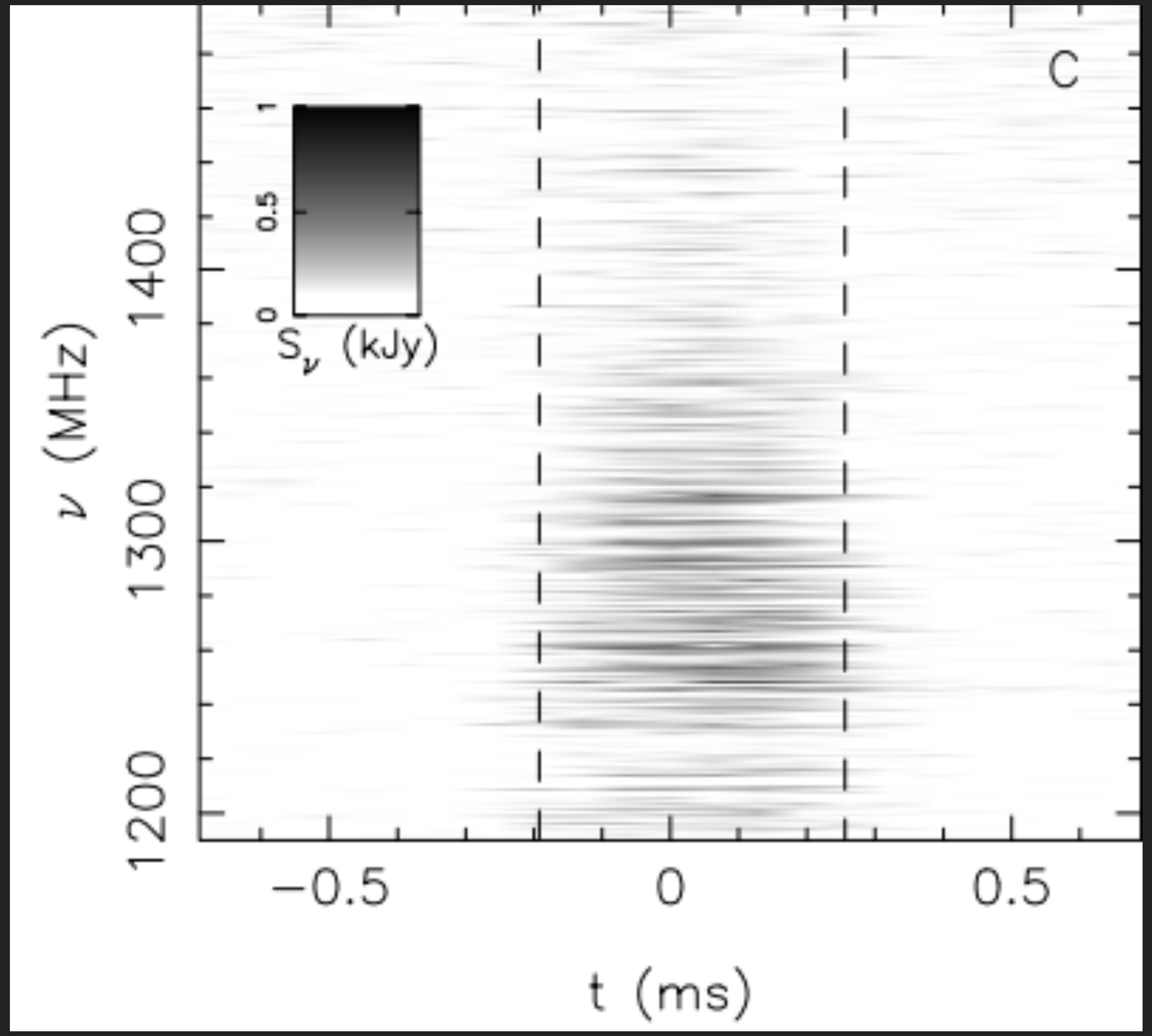


The CHIME FRB collaboration 2021

Strong evidence of NS origin!

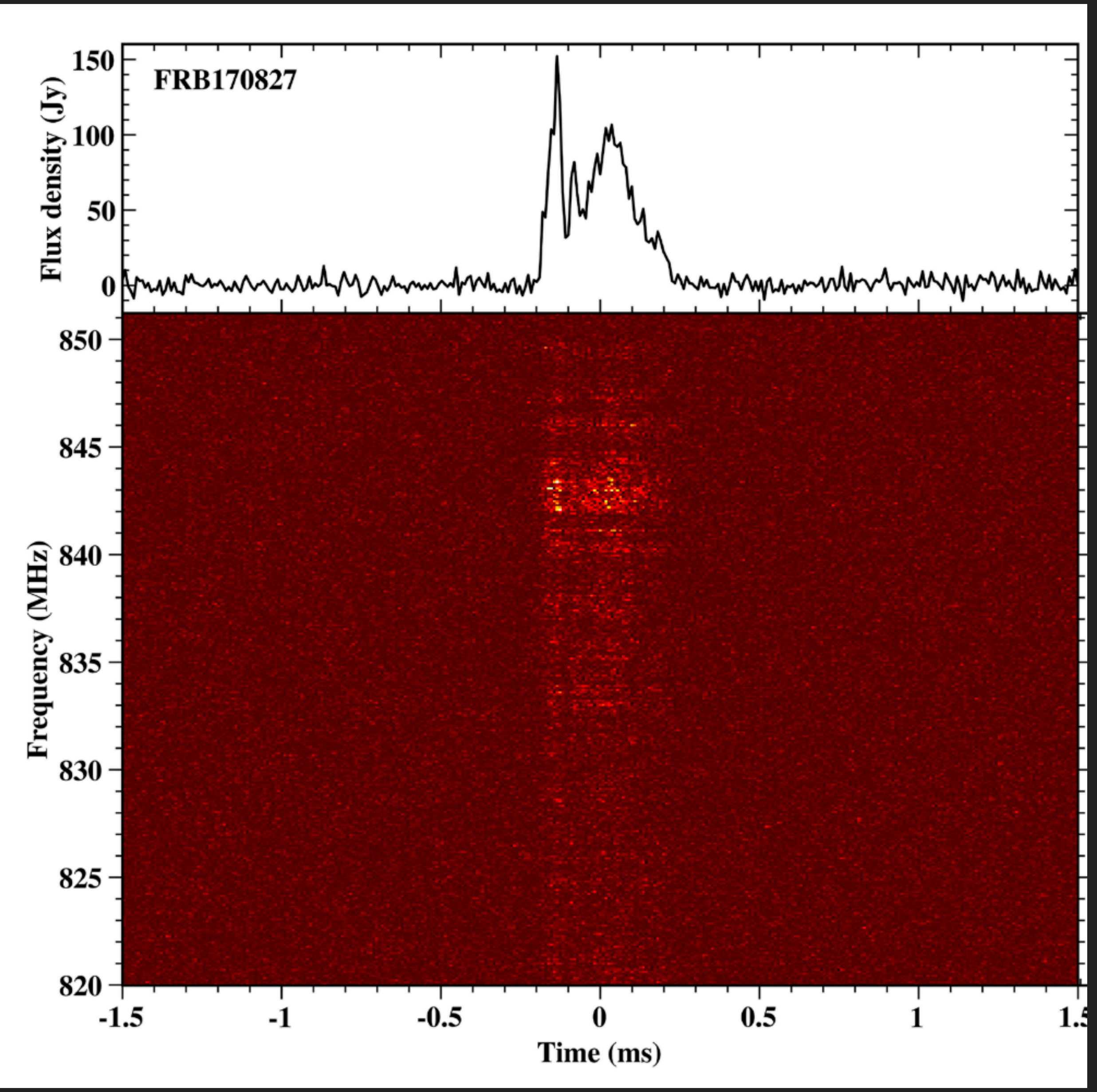
HIGH-TIME RESOLUTION STUDIES

Scintillating bursts



Ravi+16

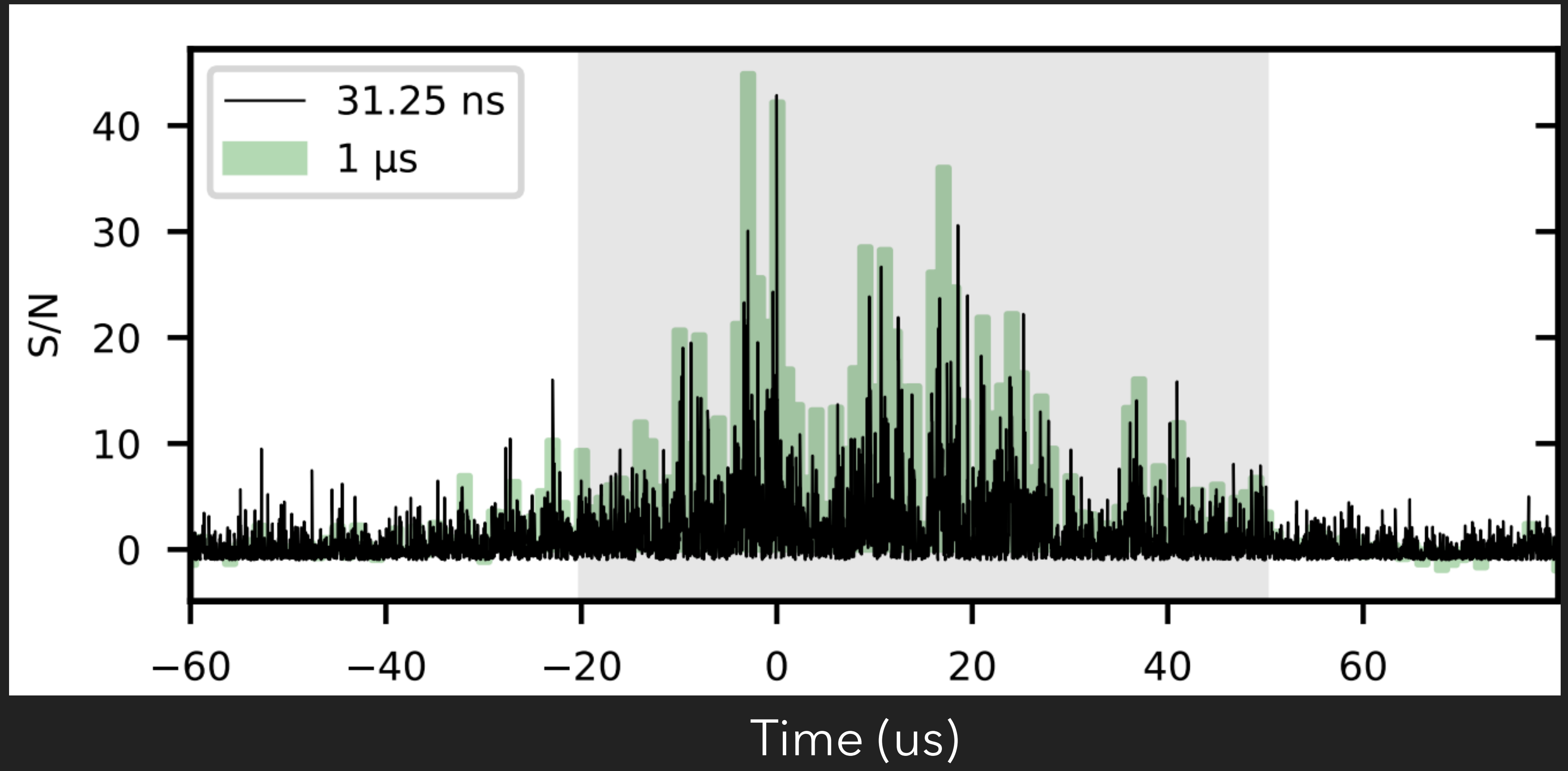
- FRBs show temporal structure on timescales of tens of μs to few μs to nanoseconds.
- Modulations in the dynamic spectrum – intrinsic or propagation effect
- On average FRBs are linearly polarised
- Most FRBs have RMs in the range zero to few hundreds rad m^{-2}
- FRBs show diverse polarisation position angle



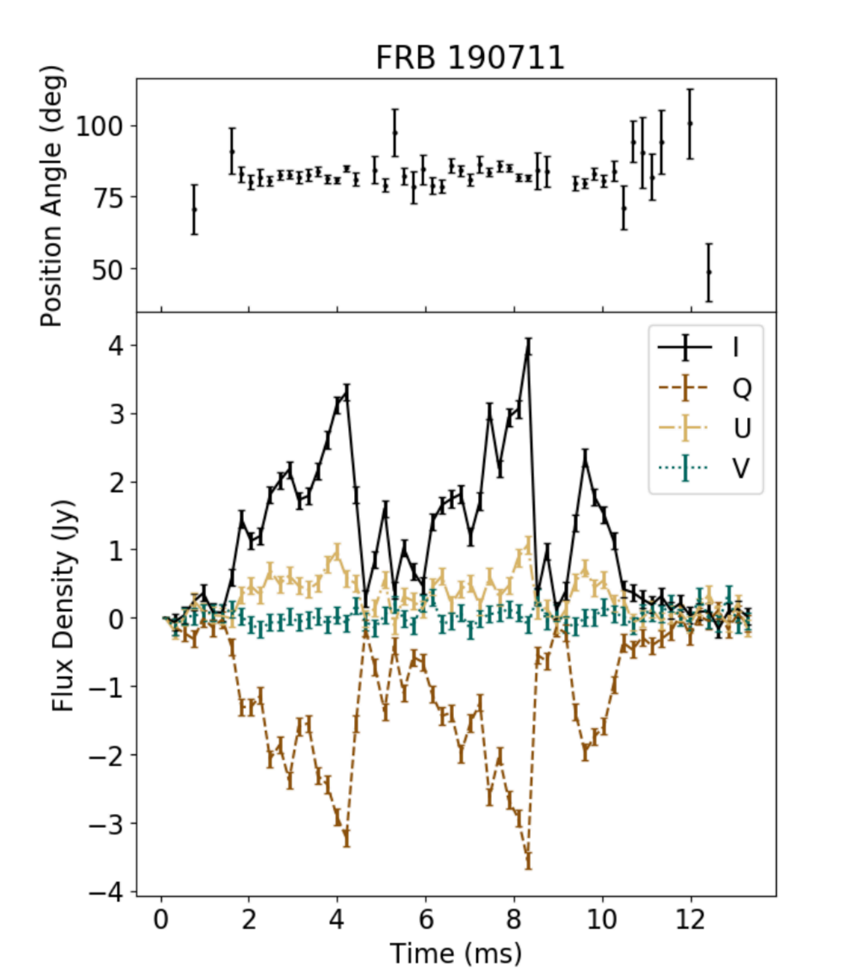
Farah+18

Forest of shots of emission

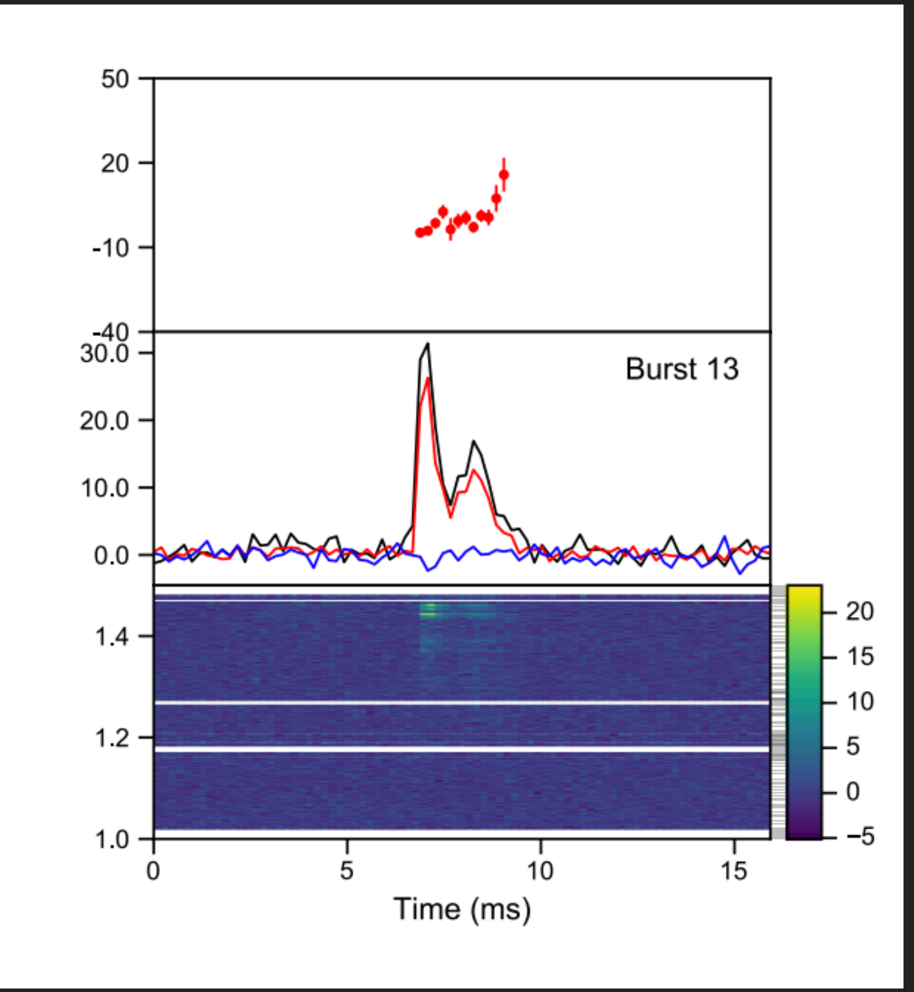
Nimmo+21



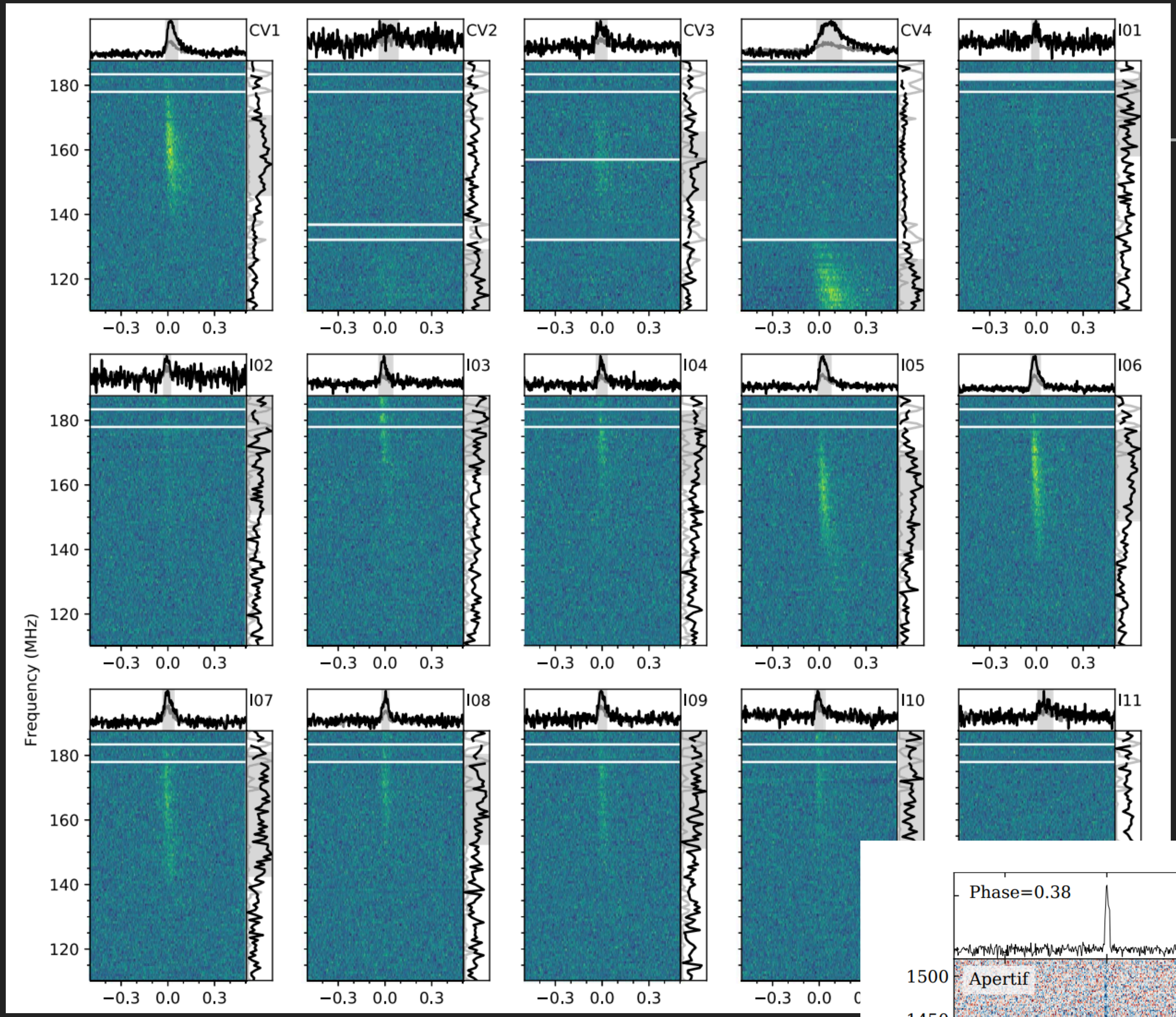
Day+20



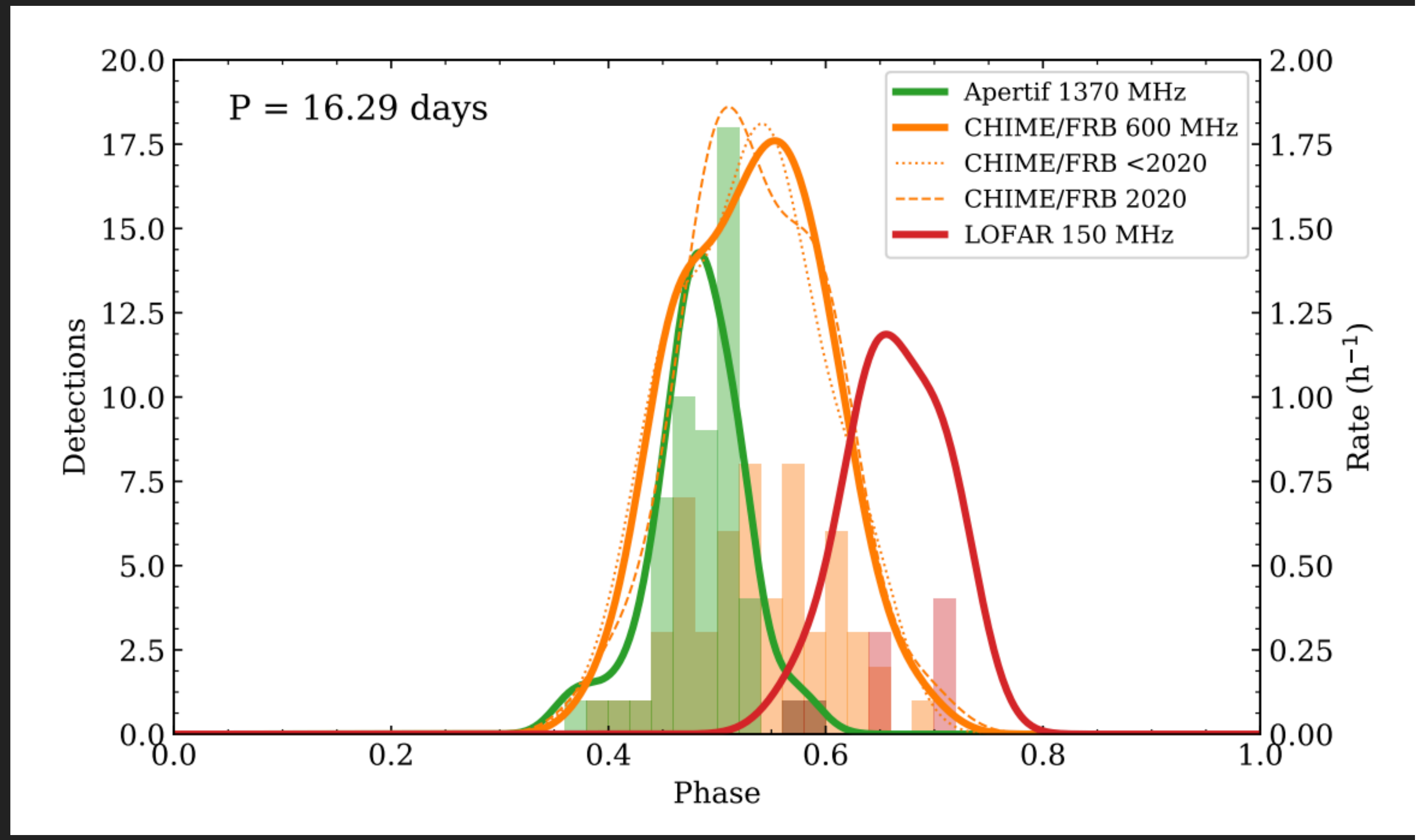
Luo+20

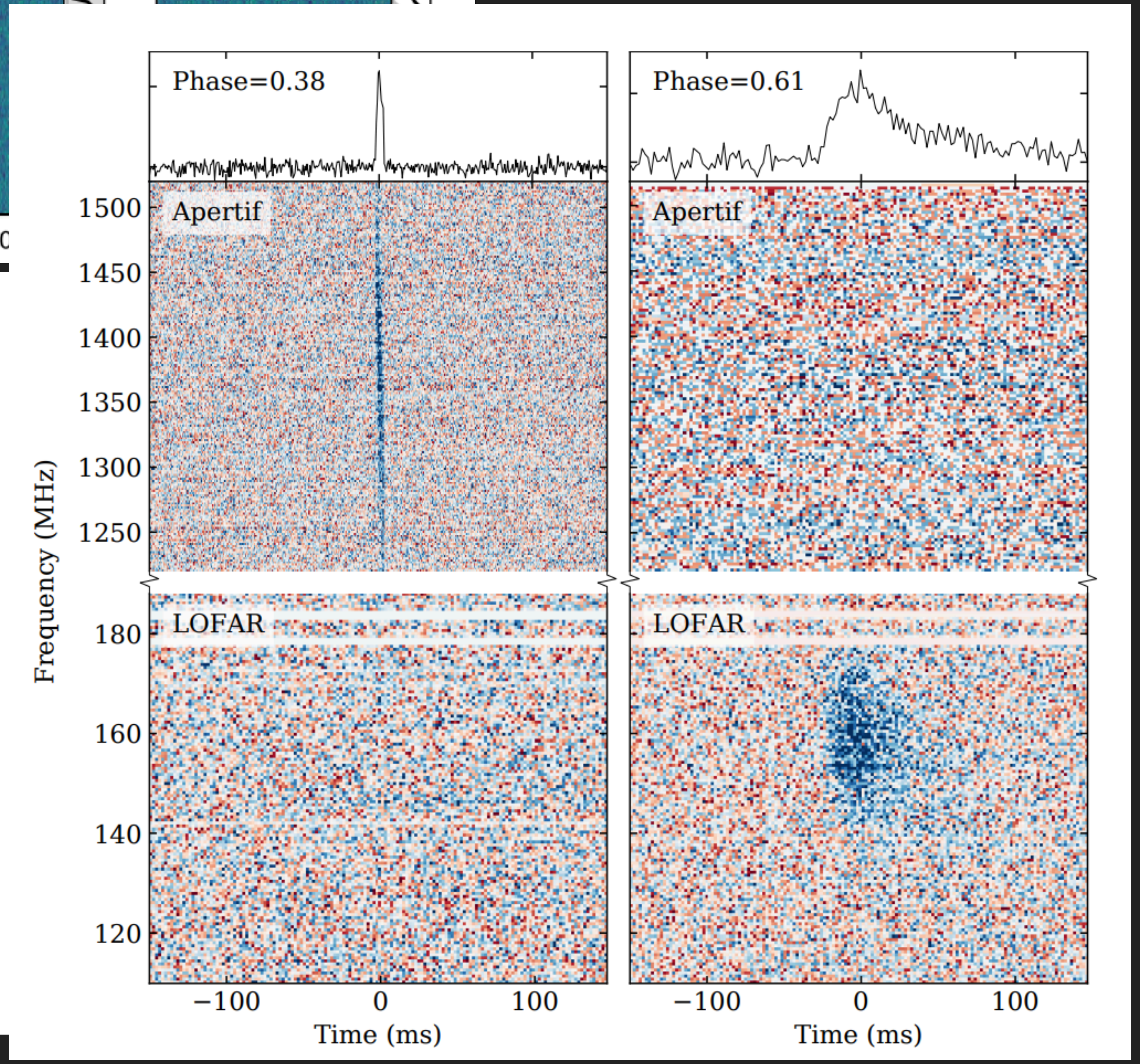


LOW-FREQUENCY DETECTIONS



Pleunis+21





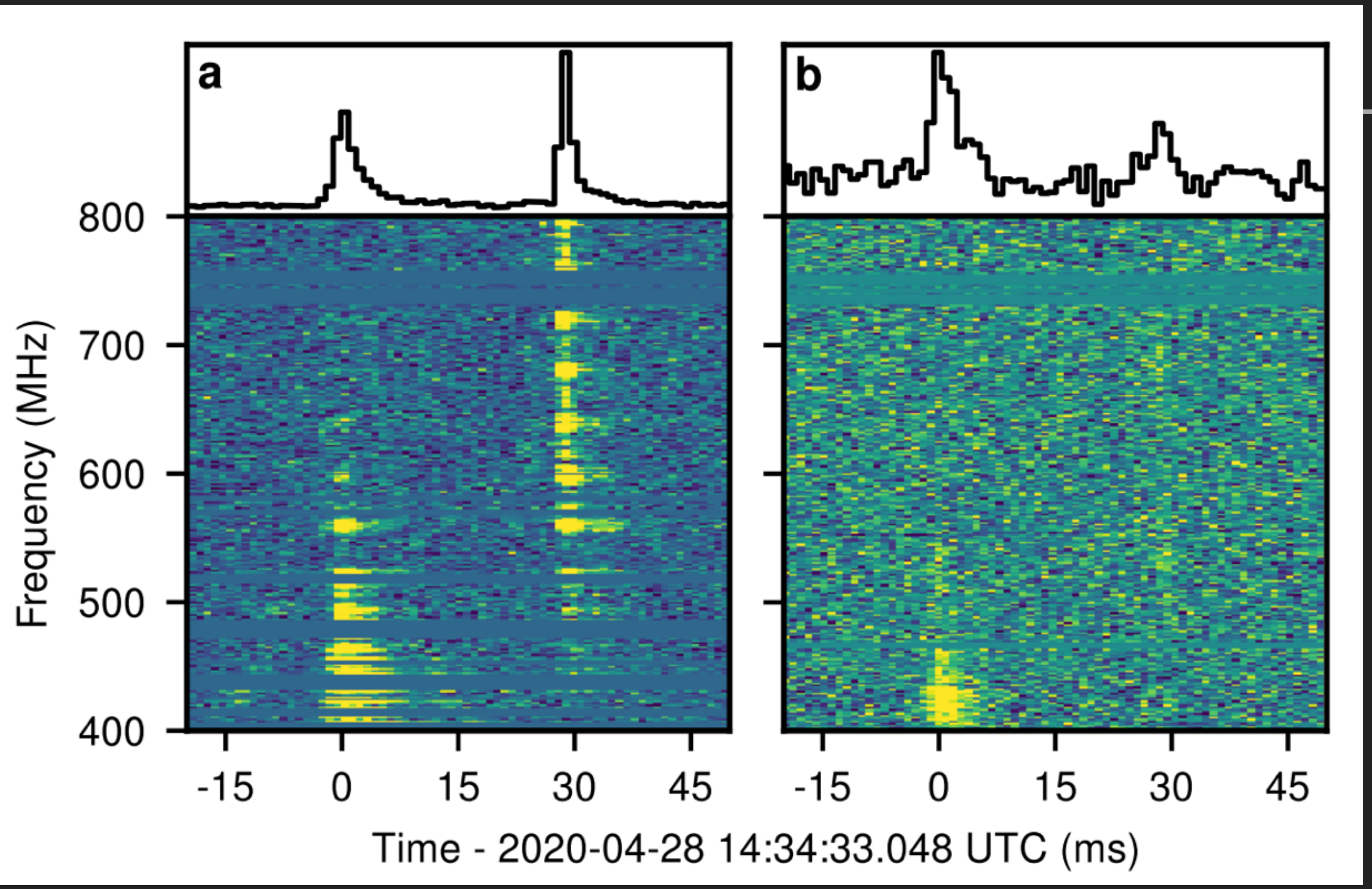
Pastor-Marazuela+21

- LOFAR detection of repeating FRB 180916 at 110-188 MHz
- Low frequency FRB emission can escape the local medium
- Activity window is narrower and earlier at higher frequencies

Some FRBs live in a cleaner environments!

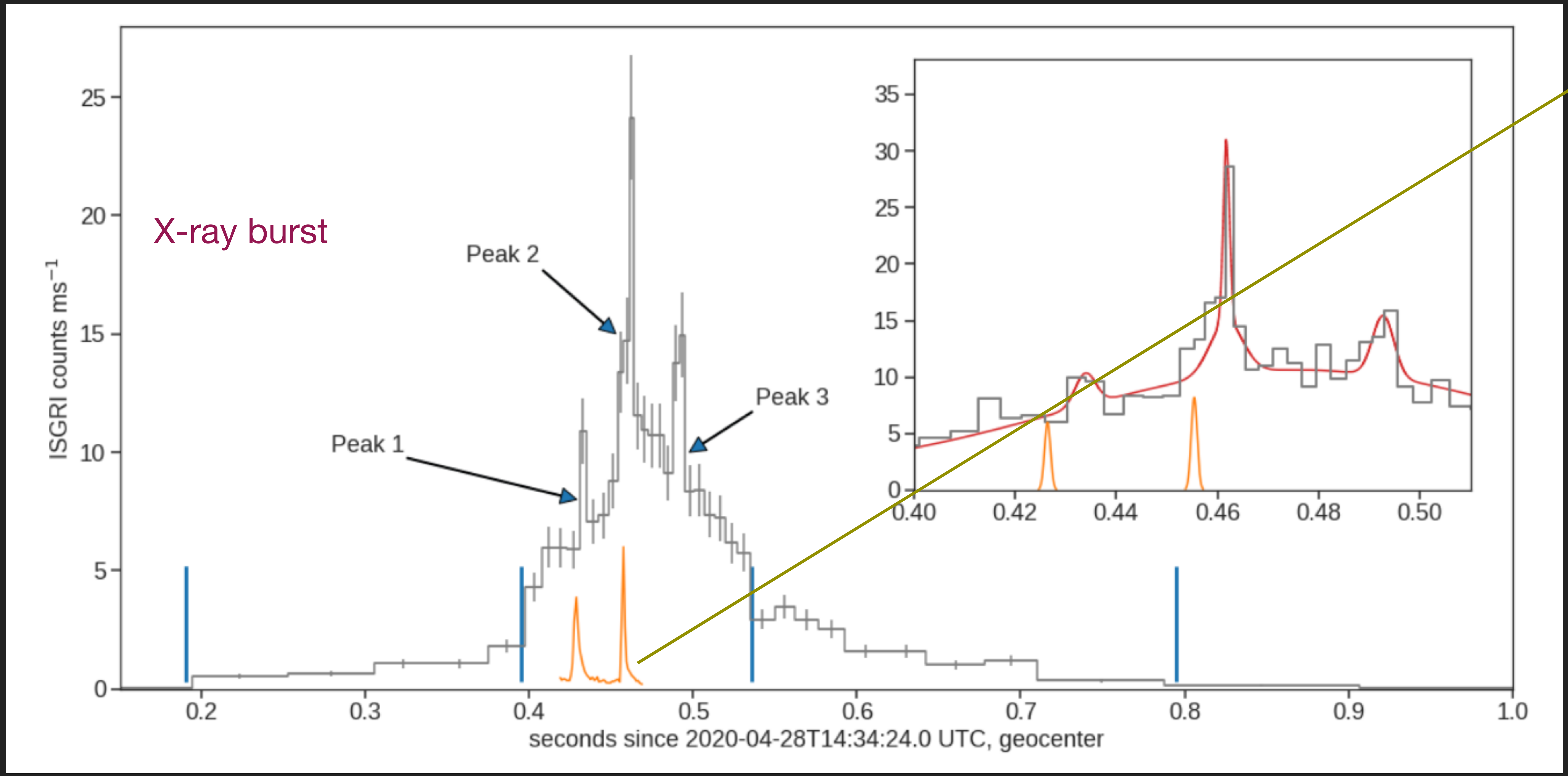
GALACTIC "FRB"

CHIME Collaboration 2020

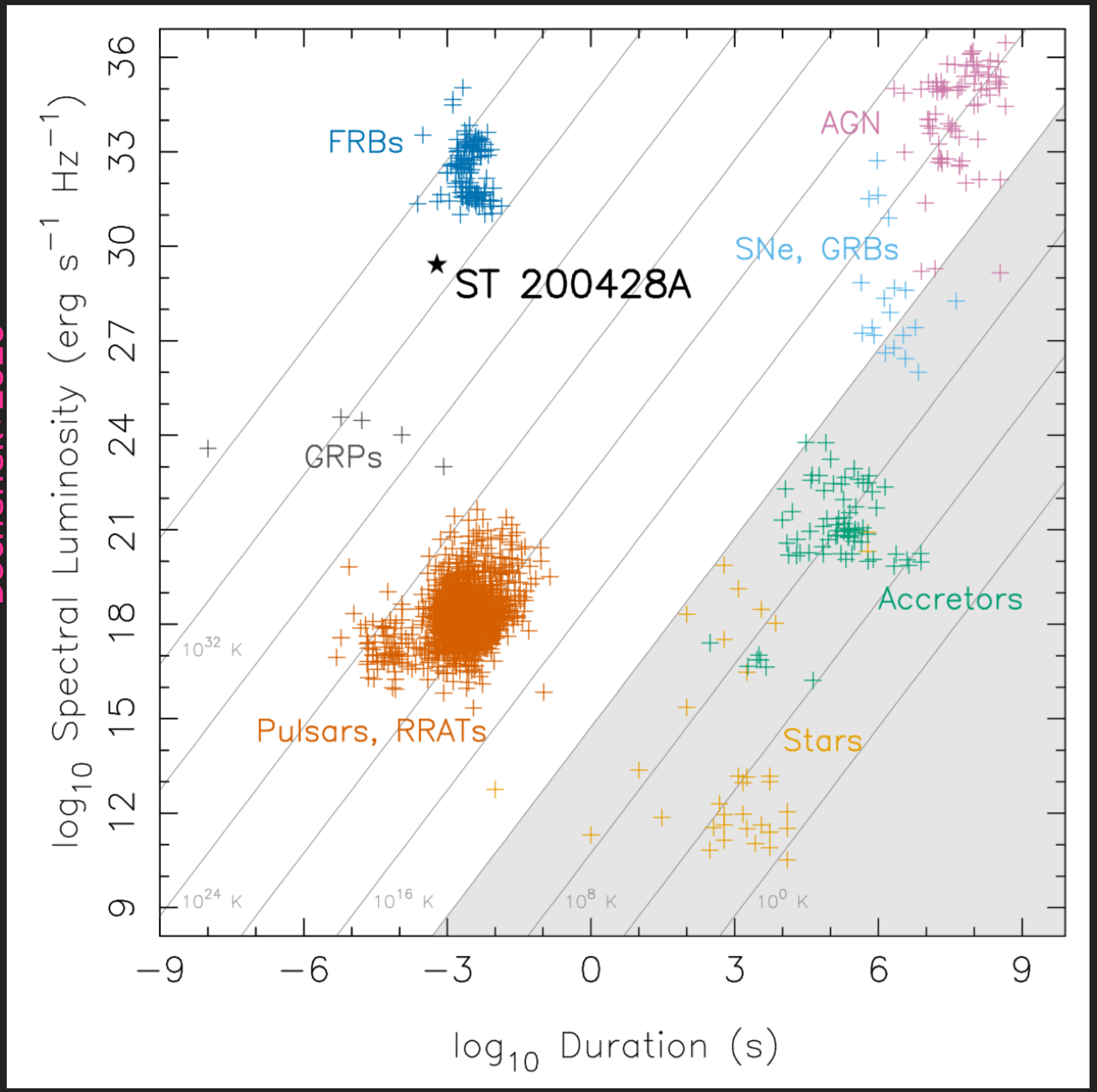


The discovery of a millisecond-duration radio burst from the Galactic magnetar SGR 1935+2154

Mereghetti+20



Bochenek+2020



INTEGRAL discovery of an X-ray burst (mostly) coincident with radio emission from the magnetar SGR 1935+2154

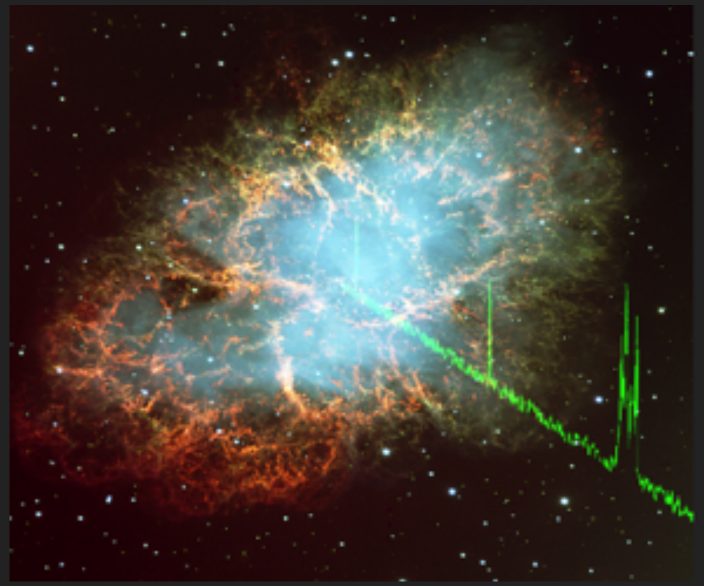
Image credits: ESA

POSSIBLY COMPACT OBJECTS WITH SUB-POPULATION

WHAT PRODUCES AN FRB?

- Magnetospheric origin
- Shock wave model

Magnetars	Pulsars	White dwarfs	Compact object mergers
‣ Young magnetar from SLSNe ‣ Magnetar from CCSNe ‣ Magnetar from DNS merger	‣ Pulse giant flares ‣ Young SNR pulsars	‣ WD from WD-WD mergers ‣ Accretion induced collapse (AIC) of WD	‣ NS-NS merger ‣ WD-WD merger ‣ NS-BH merger ‣ BH-BH merger



www.frbtheorycat.org

Host identifications are the most urgent observational priority for FRB science — Cordes & Chatterjee 2019

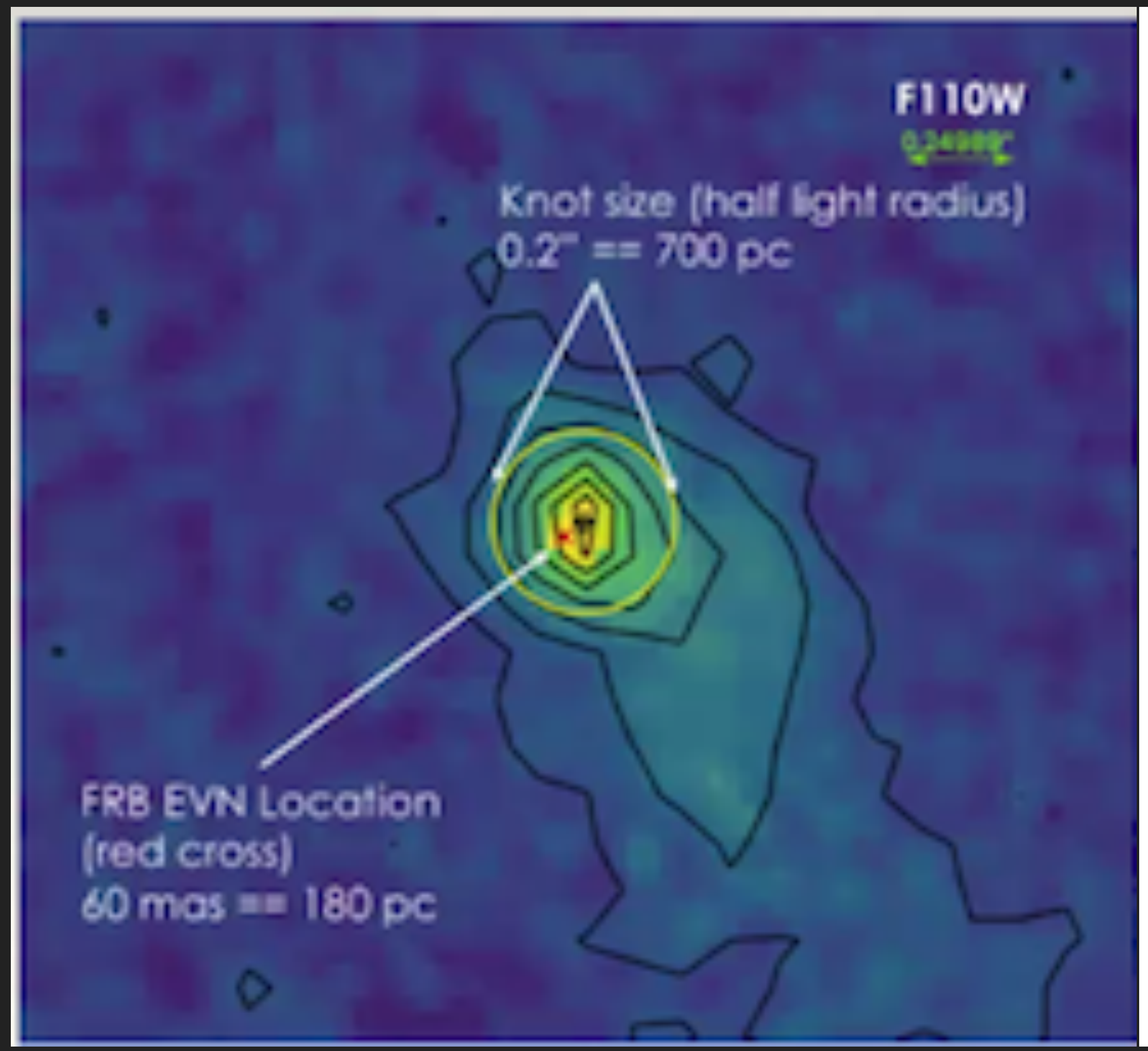
Credits: Daniëlle Futselaar

VLBI IS KEY TO IDENTIFYING PROGENITORS AND COMPREHENDING LOCAL ENVIRONMENTS

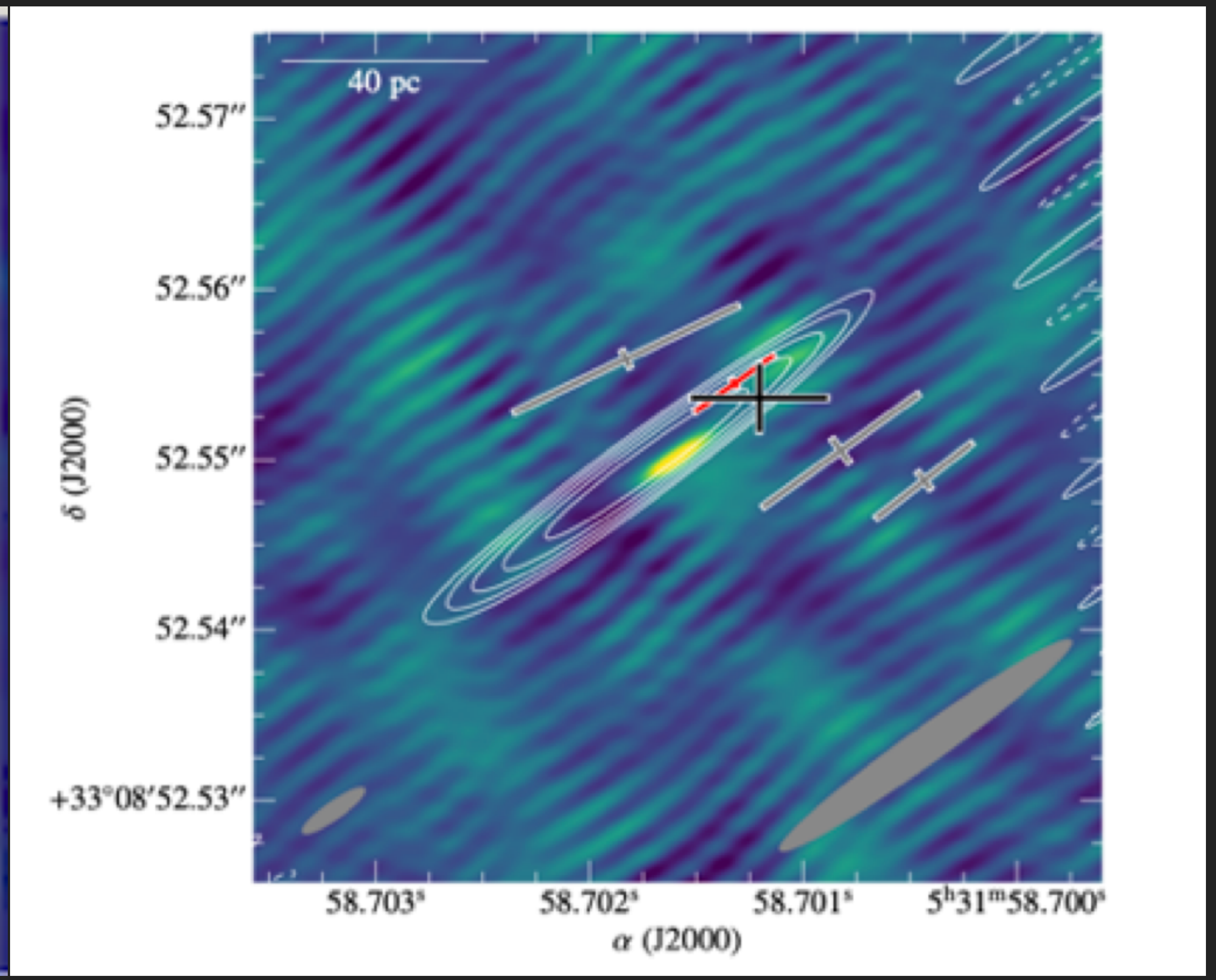
REPEATER HOST GALAXIES

FRB 121102

Tendulkar+17



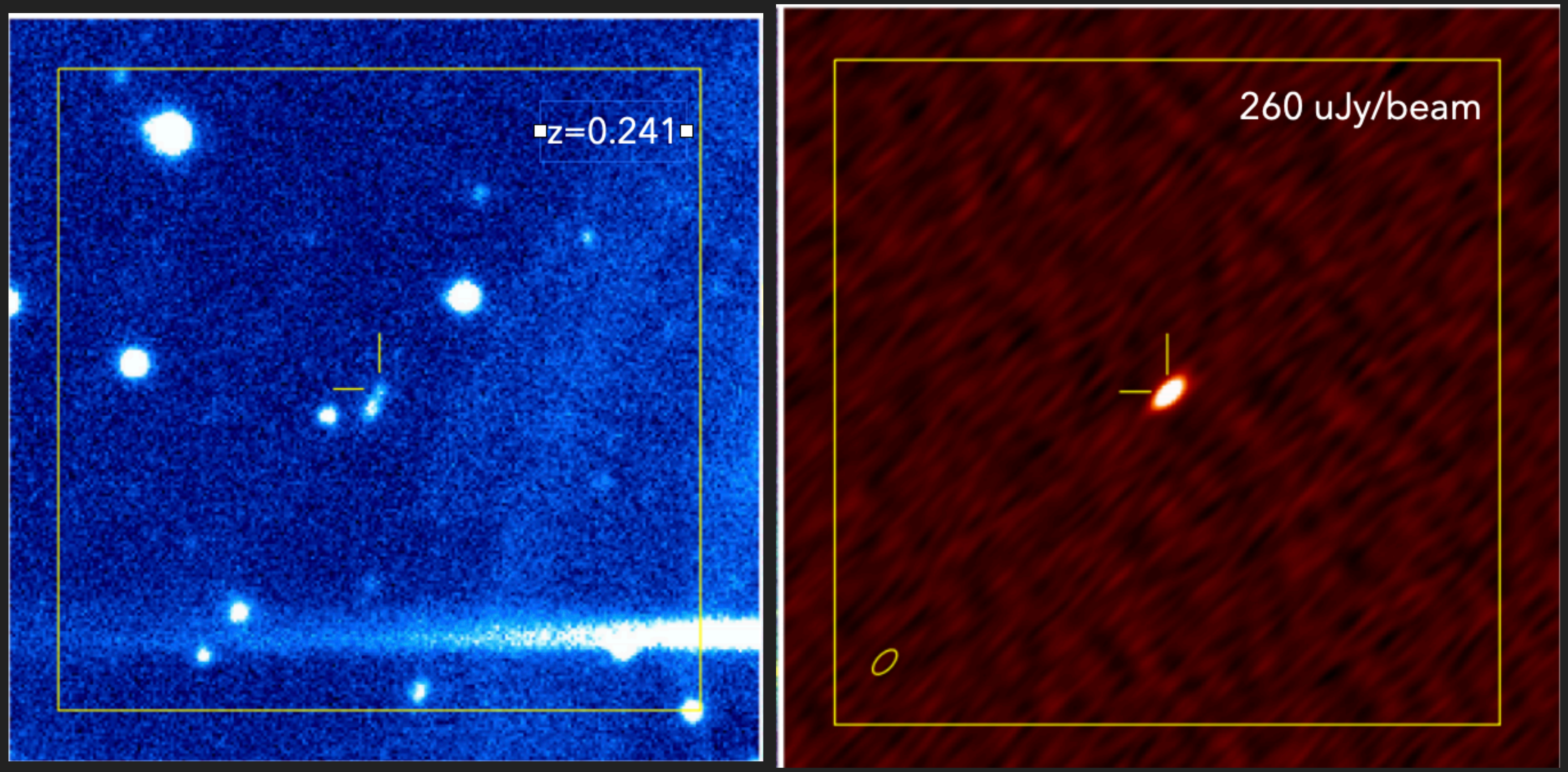
Marcote+17



- Localised to a dwarf galaxy at z= 0.192
- Persistent radio emission on mas scales (<0.7 pc)
- Either associated with low-luminosity AGN or a young NS energising a supernova remnant.
- Extreme magneto-ionic environment (RM = 10^5 rad m^{-2})
- Flaring magnetar embedded in a magnetised wind nebula

FRB 190520

Niu+22

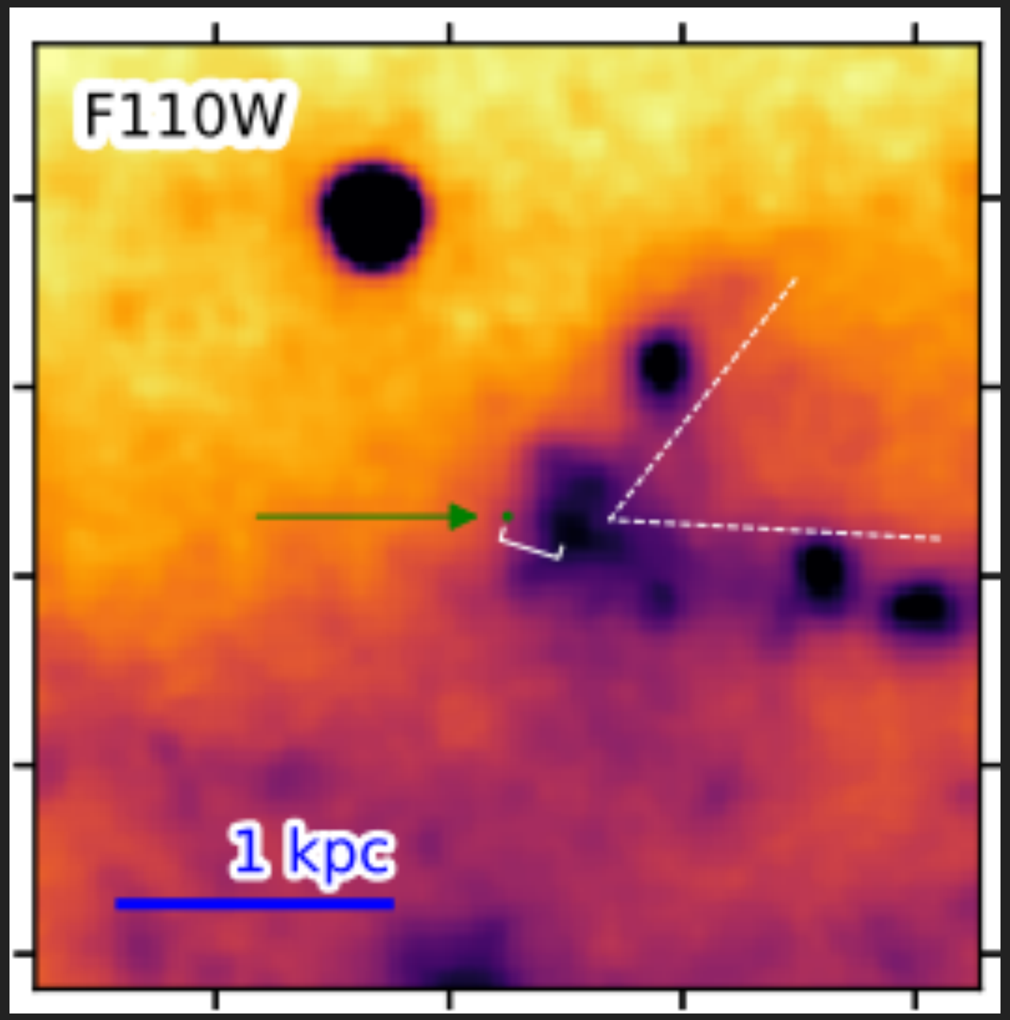


- Localised to a dwarf galaxy at z= 0.241
- Persistent radio emission
- Excess host DM contribution (912 pc/cc)
- RM ~ few 10^4 rad m^{-2}
- Young stellar population

VLBI IS KEY TO IDENTIFYING PROGENITORS AND COMPREHENDING LOCAL ENVIRONMENTS

FRB 180916

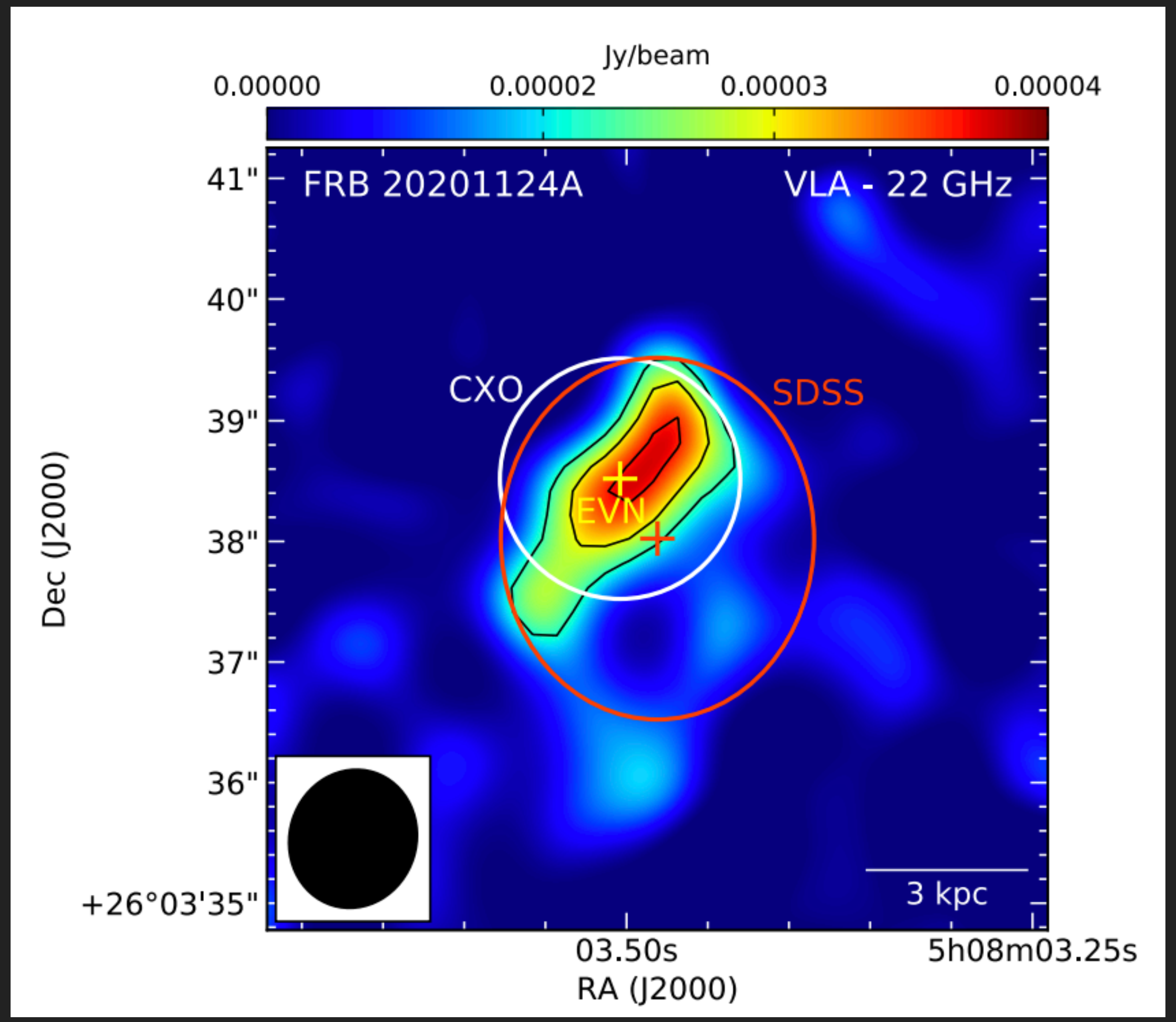
Tendulkar+20



- Localised to a star-forming region in a massive spiral galaxy
- No radio persistent source
- No extreme magnetic fields
- Low frequency detection
- Burst is offset from a star forming region
- Age of the progenitor is compatible with the ages of high-mass X-ray binaries

FRB 20201124A

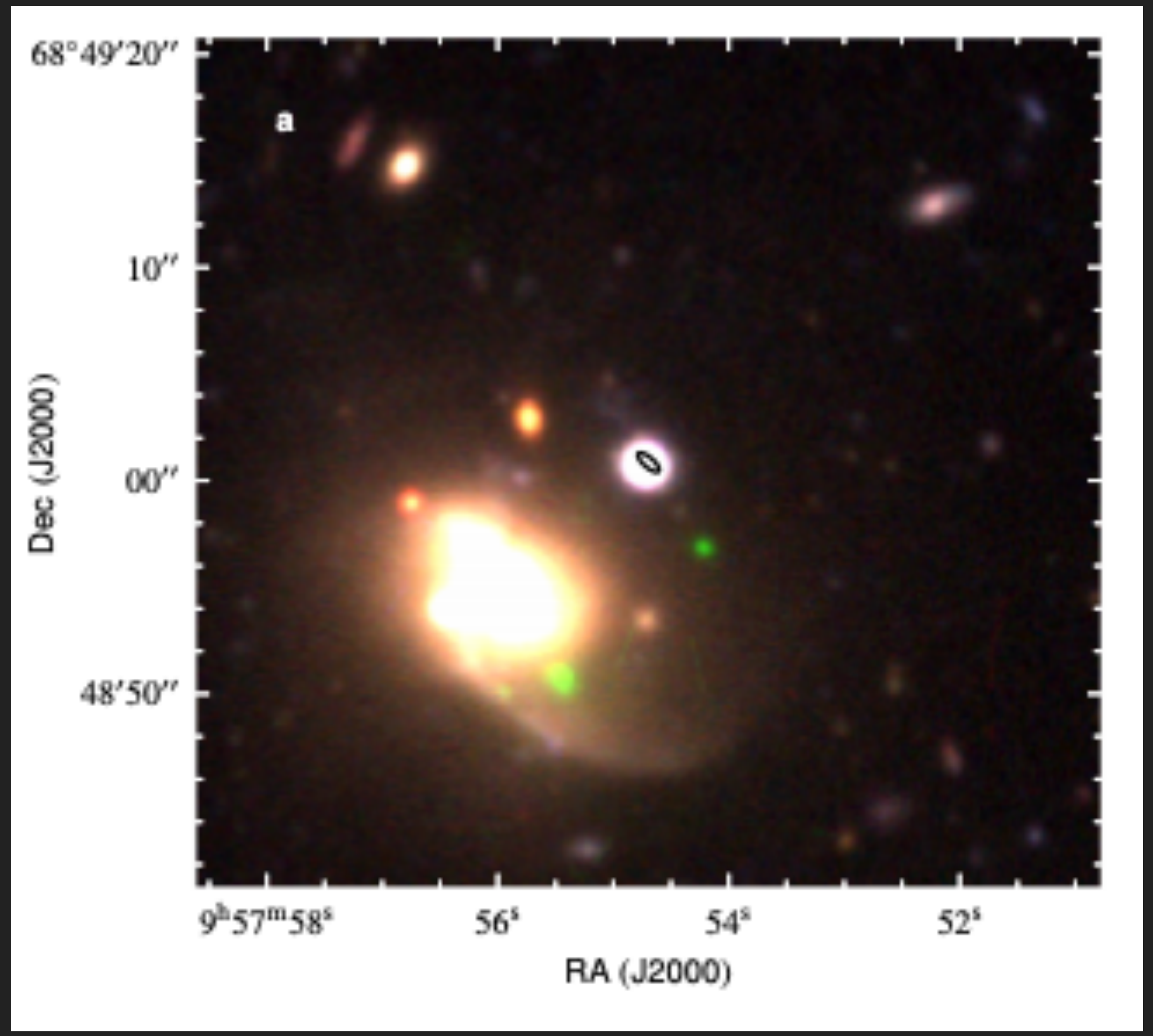
Piro+21



- Typical star forming, massive and dusty galaxy
- Radio emission due to star formation
- Old stellar population (5-6 Gyr)
- Progenitors that have longer delay times

FRB 20200120E

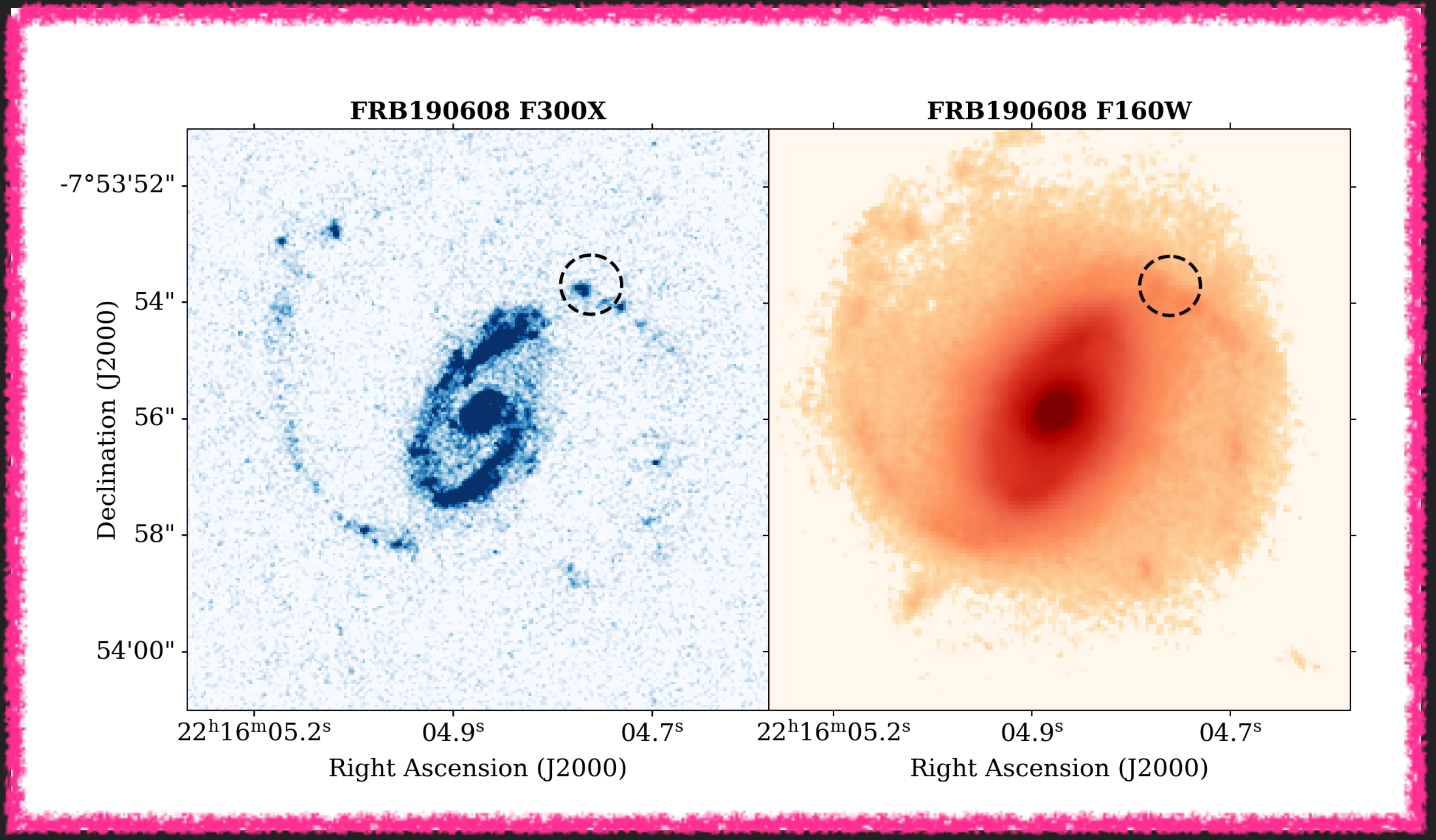
Kirsten+21

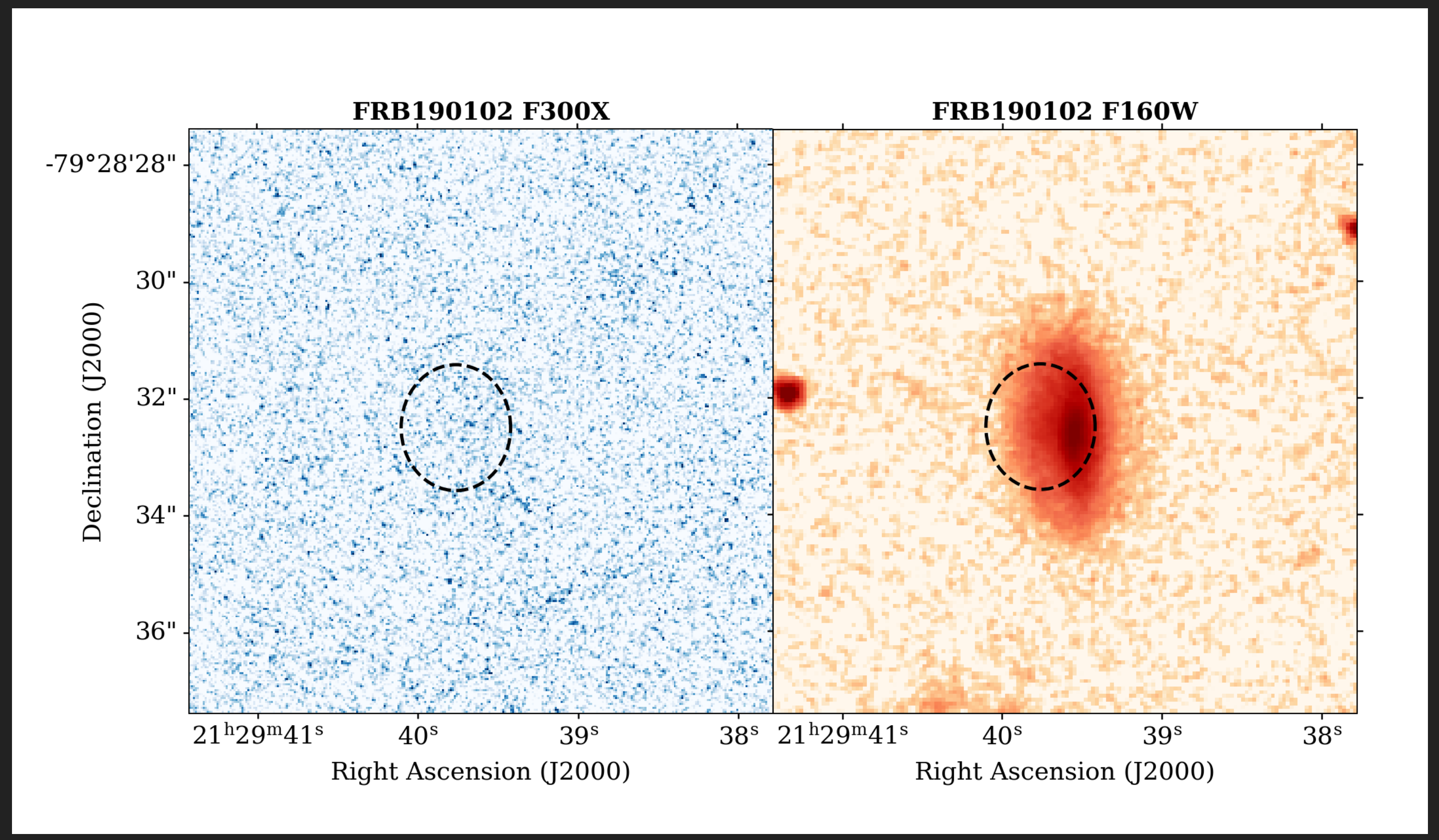


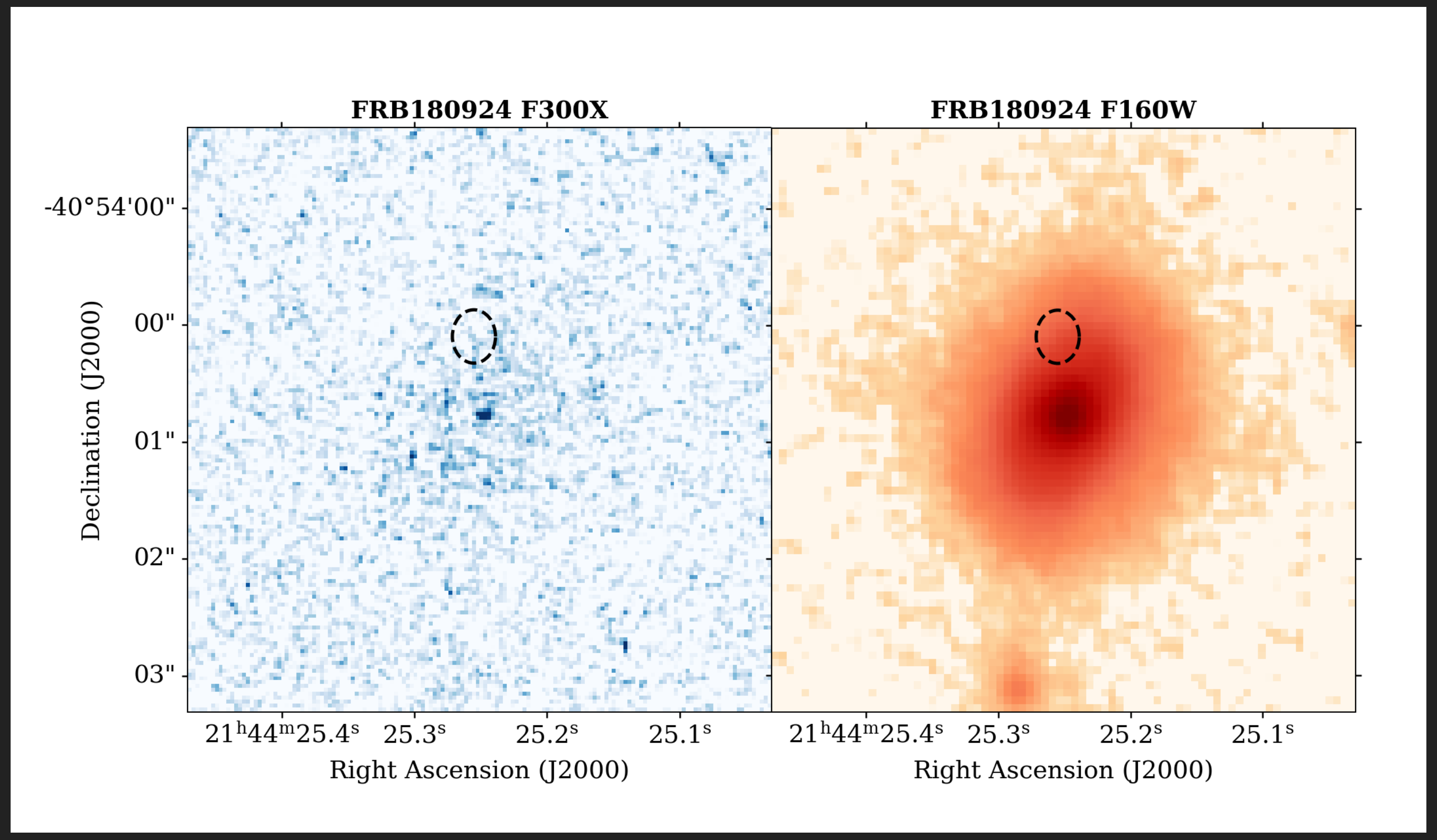
- Globular cluster near M81
- No persistent radio emission
- No extreme magneto-ionic environment
- Old stellar population; AIC of WD or merger of compact sources

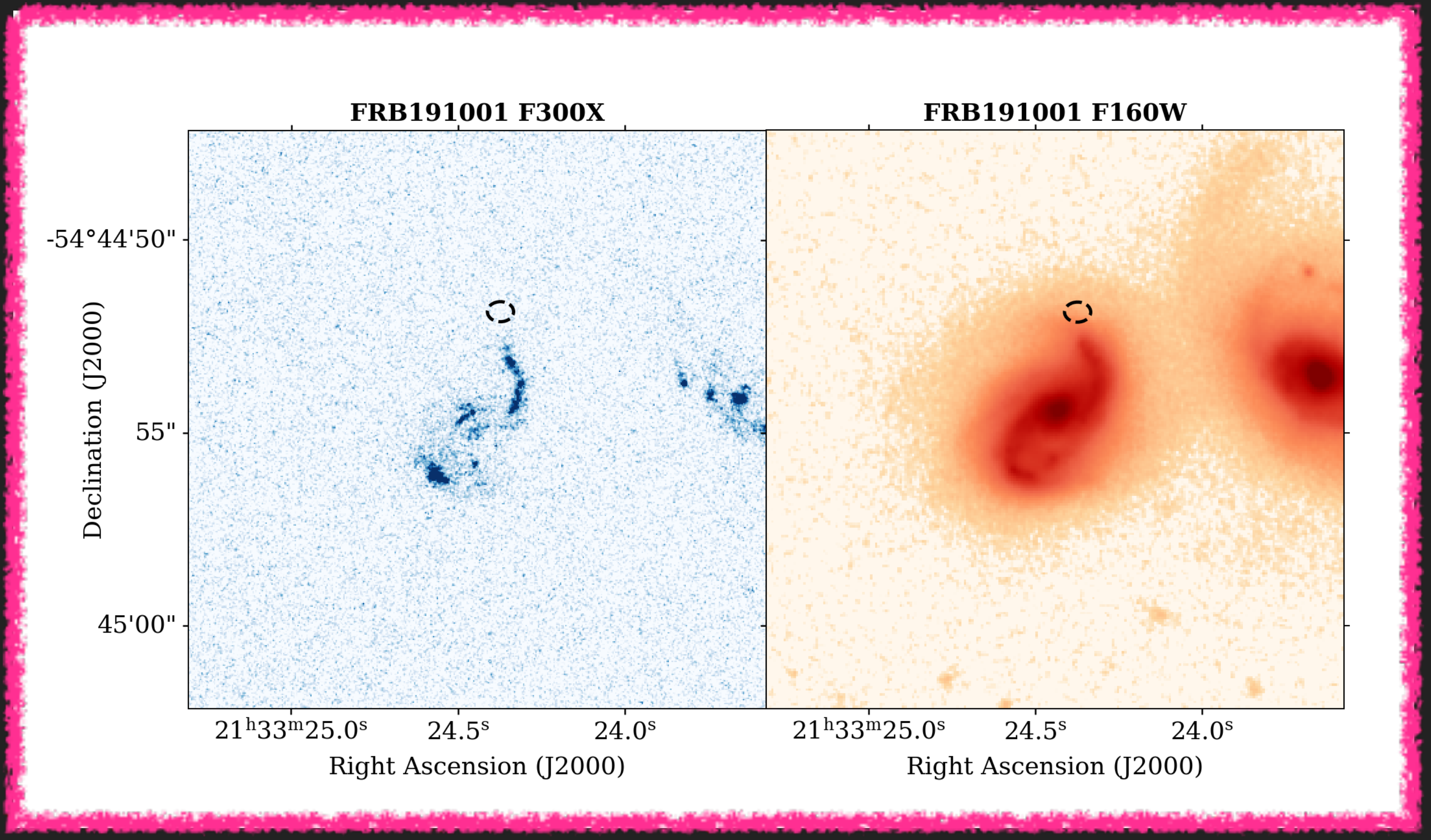
FRB (NON-REP) HOST GALAXIES

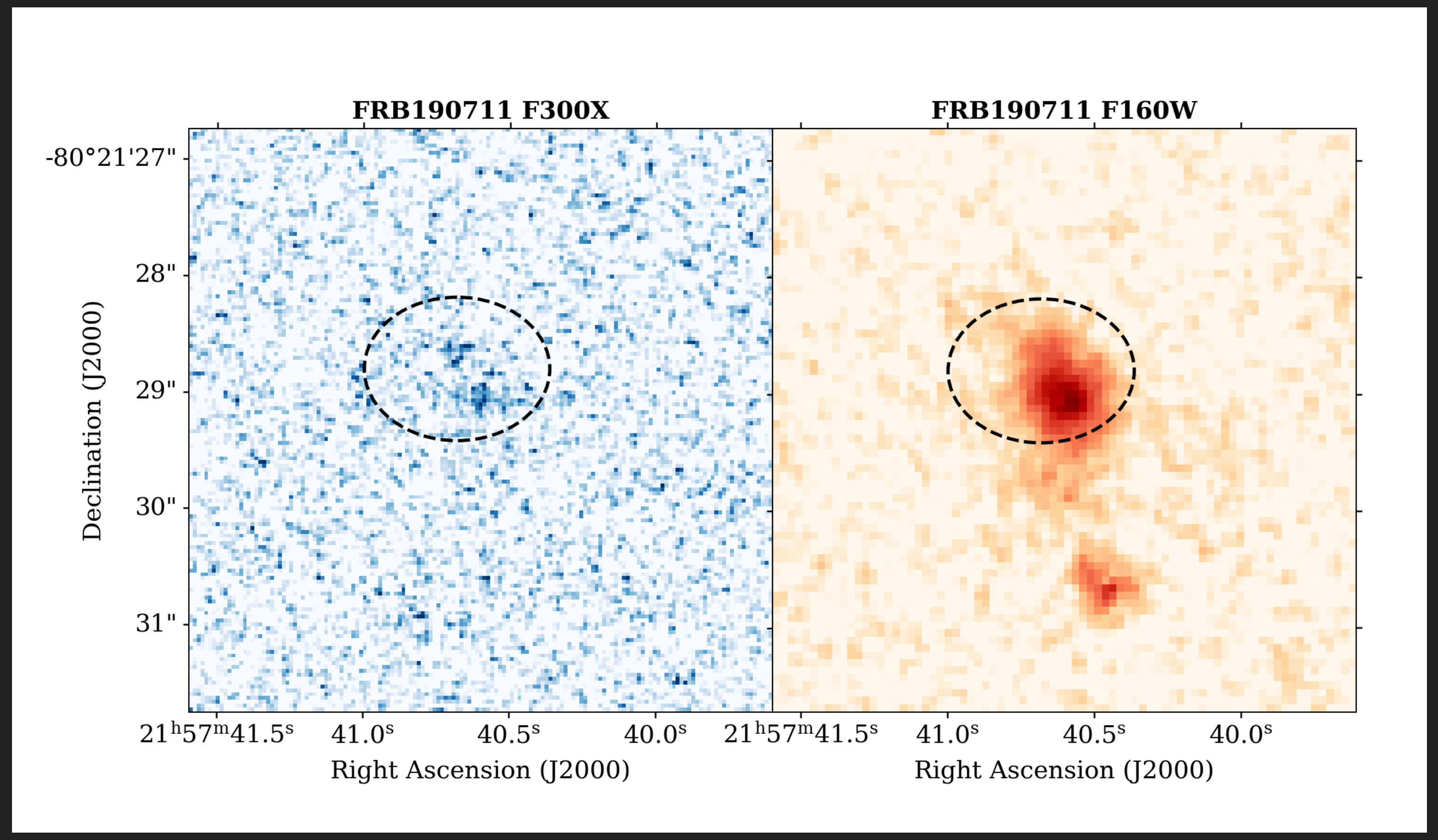
Mannings+21

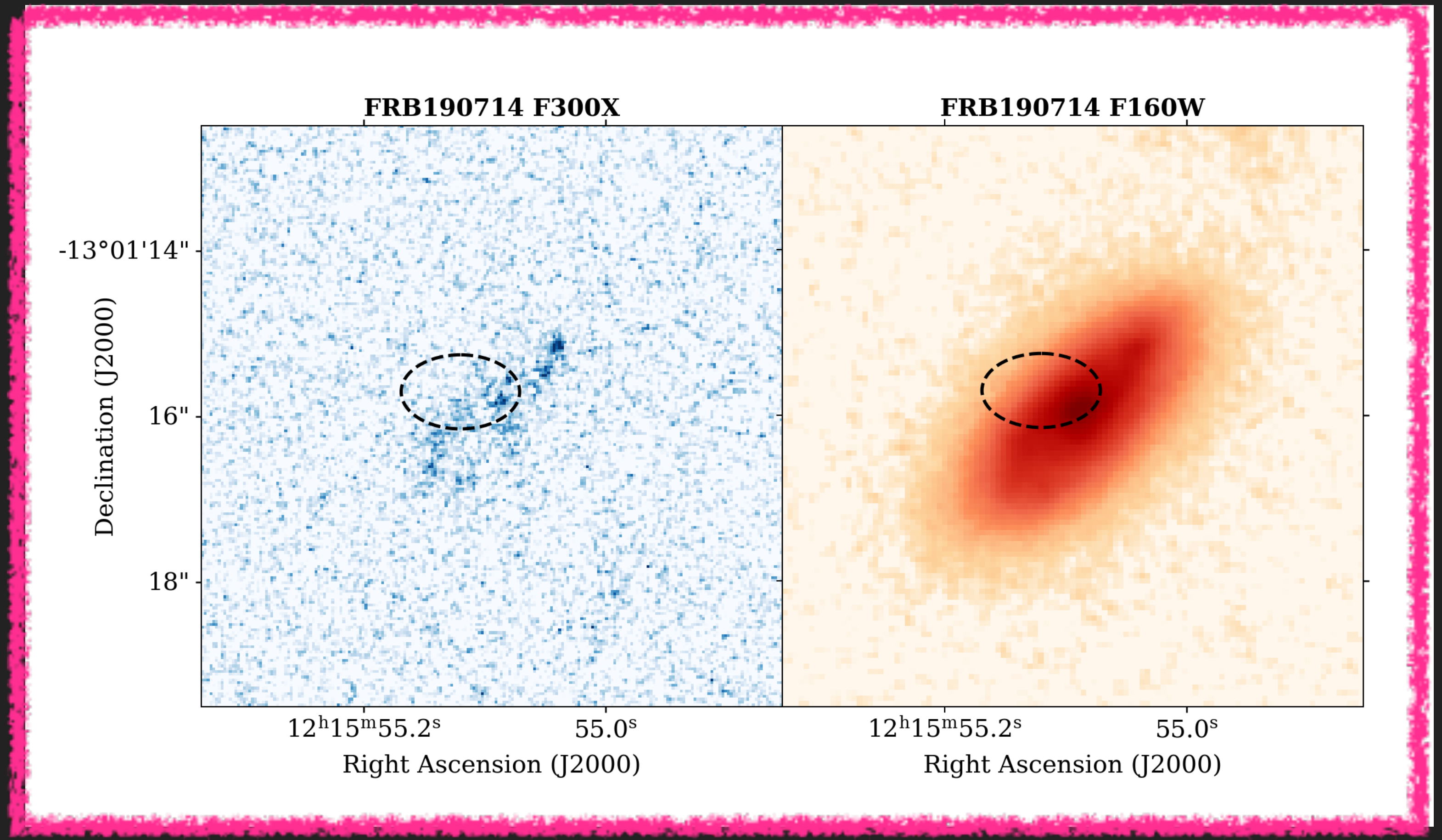








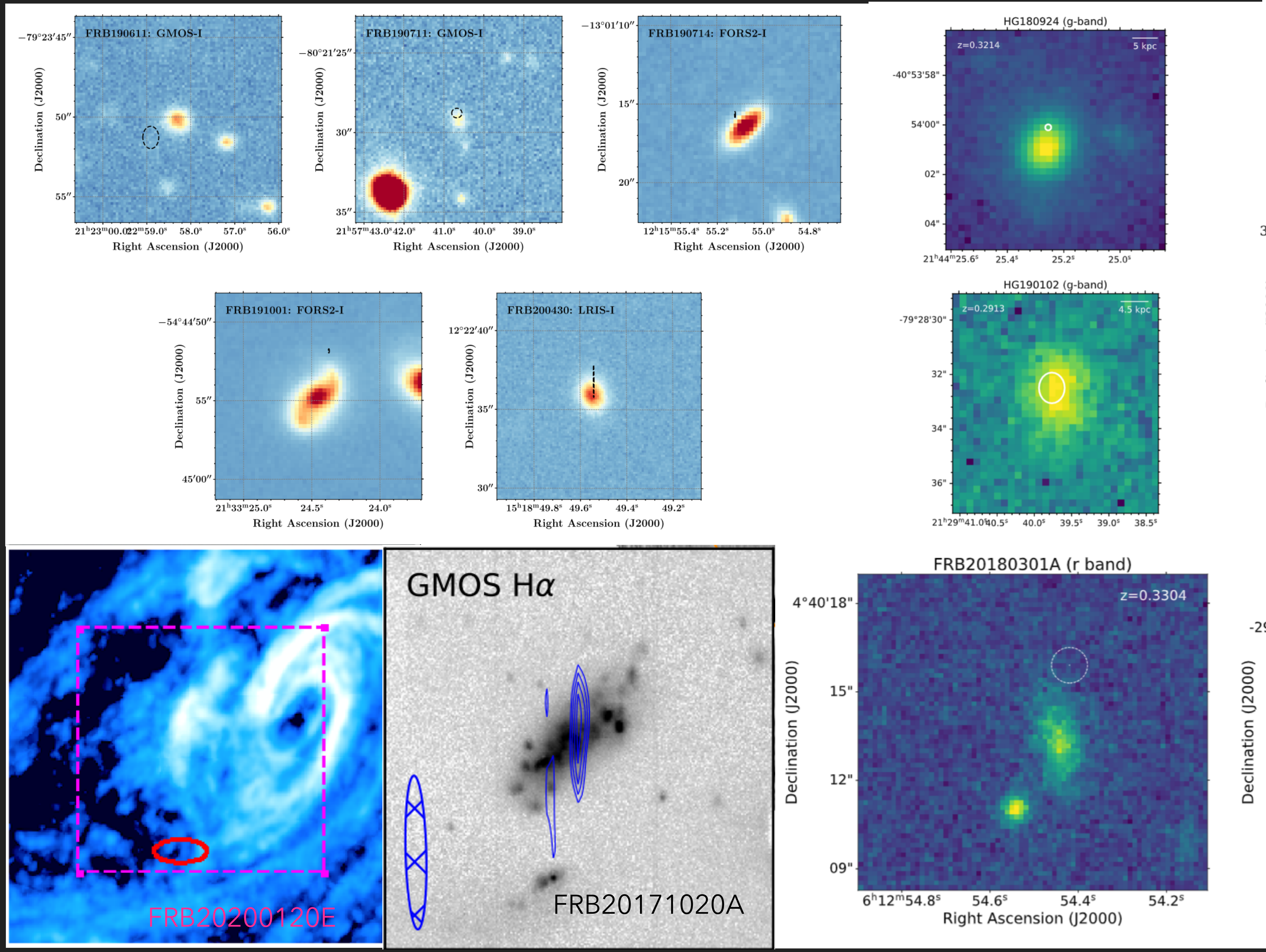


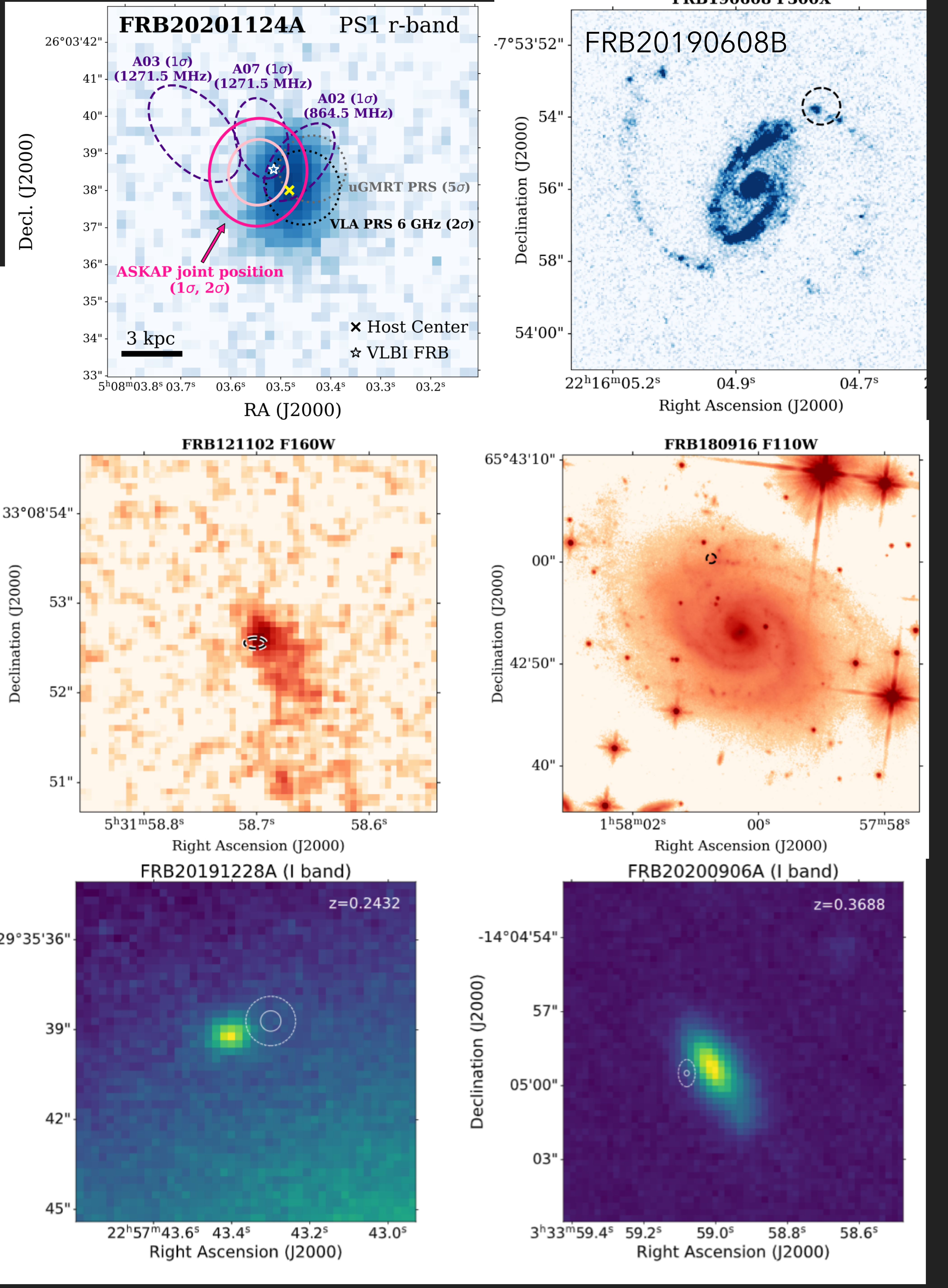


FRBs are offset from their host galaxy centres which
are a mix of spirals and more lenticular systems.

DIVERSE HOST ENVIRONMENTS

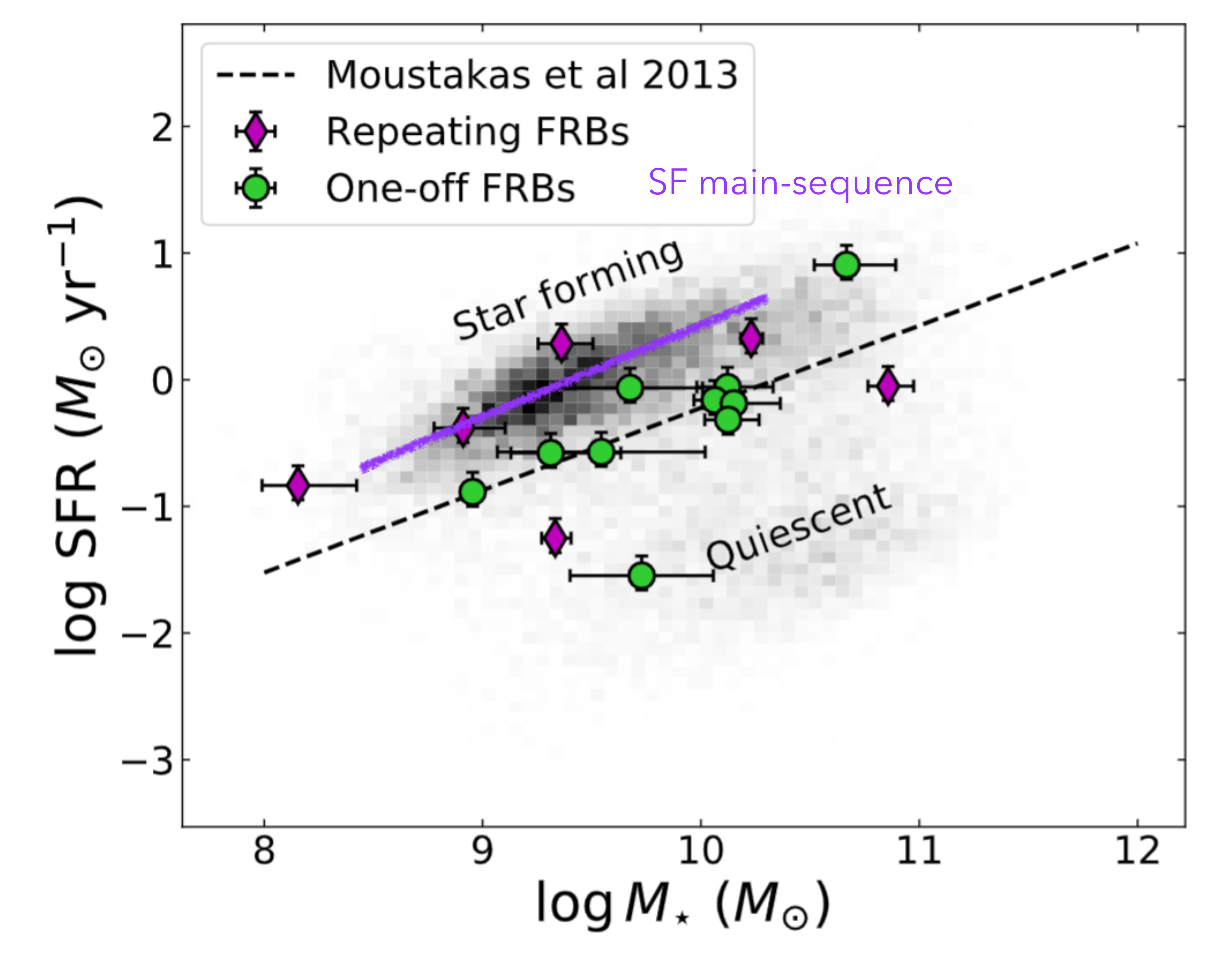
Mahony+18, Bhandari+20, Heintz+20, Mannings+21, Bhardwaj+21, Fong+21, Bhandari+21

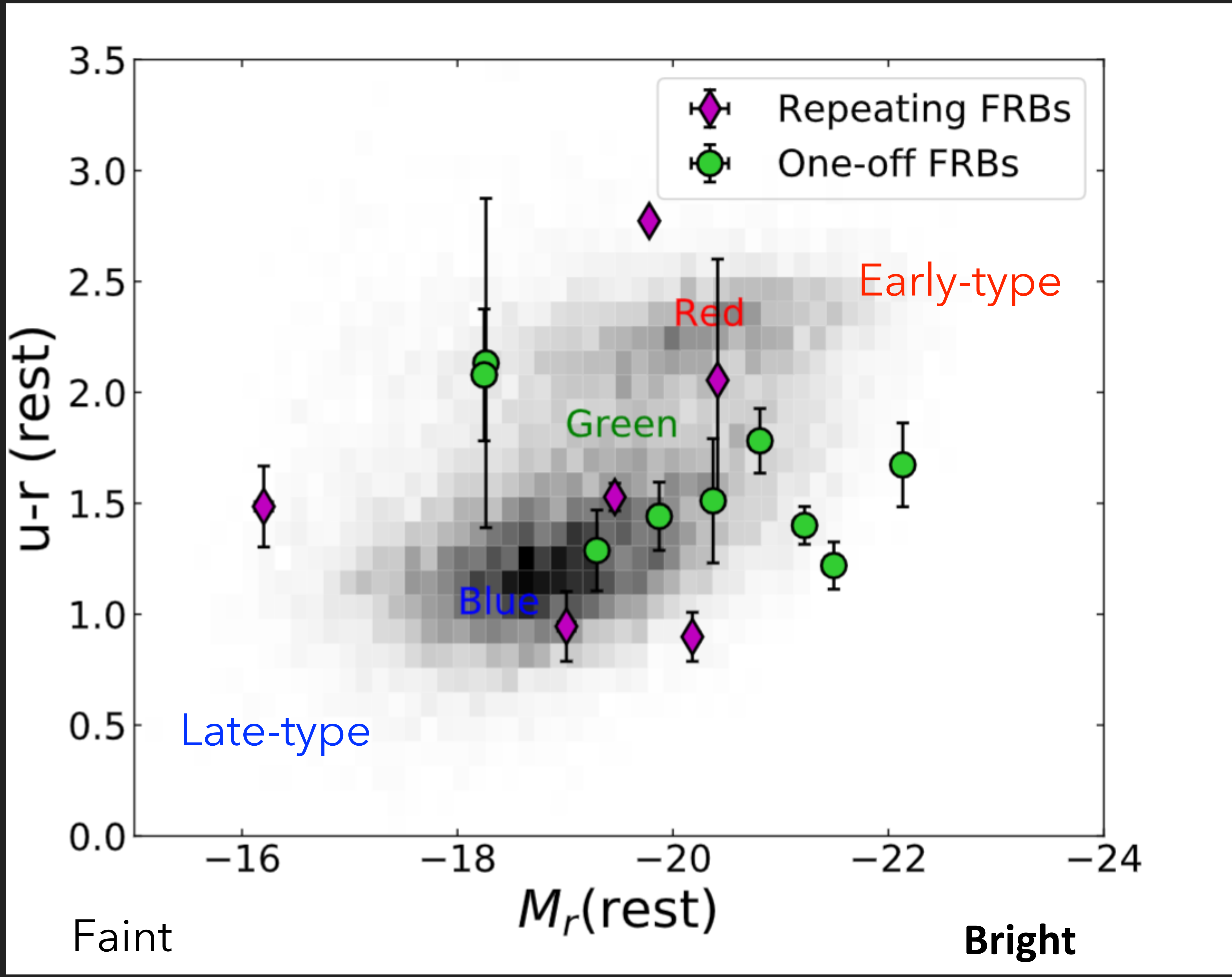




Stellar mass - Star formation rate

Colour - Magnitude Diagram



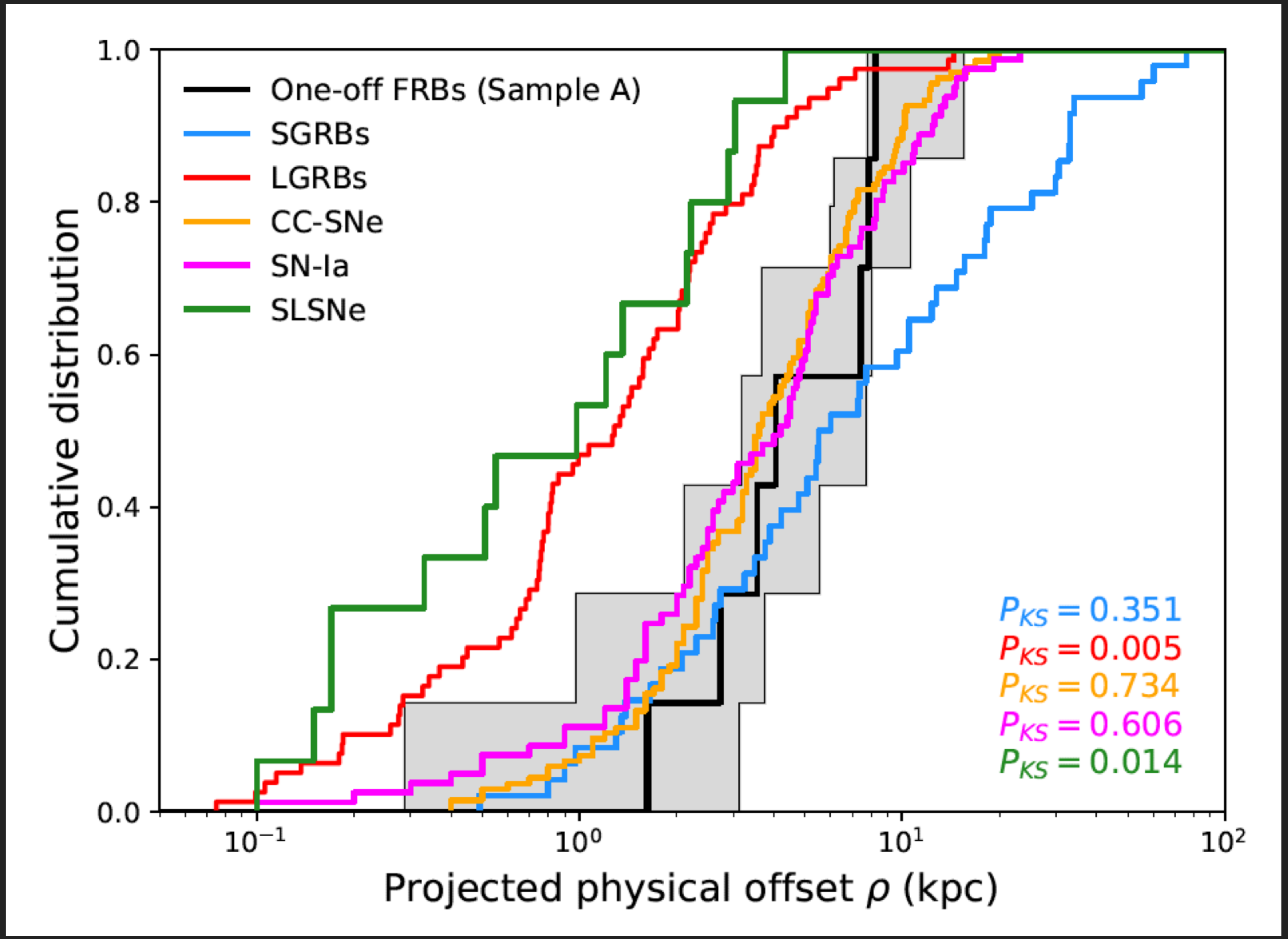


Bhandari+22

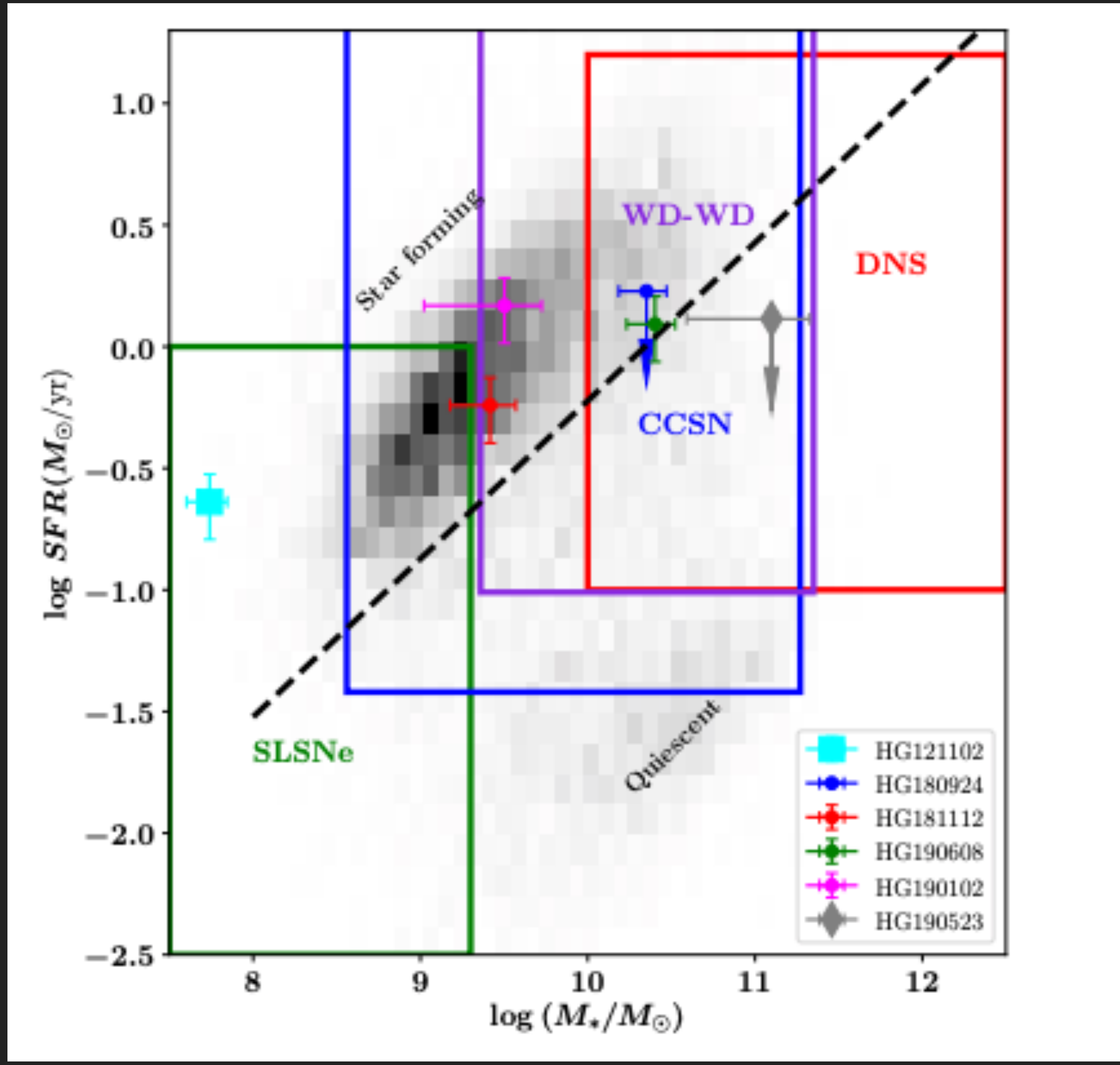
- Massive and moderately star forming galaxies with masses offset from the star-forming main-sequence
- Mostly lie on the luminous side of magnitude distribution mostly near blue cloud-green valley region.
- Dearth of red galaxies is observed: FRB progenitor production not dominated by “delayed channels”.

PROGENITOR IMPLICATIONS

Heintz+20



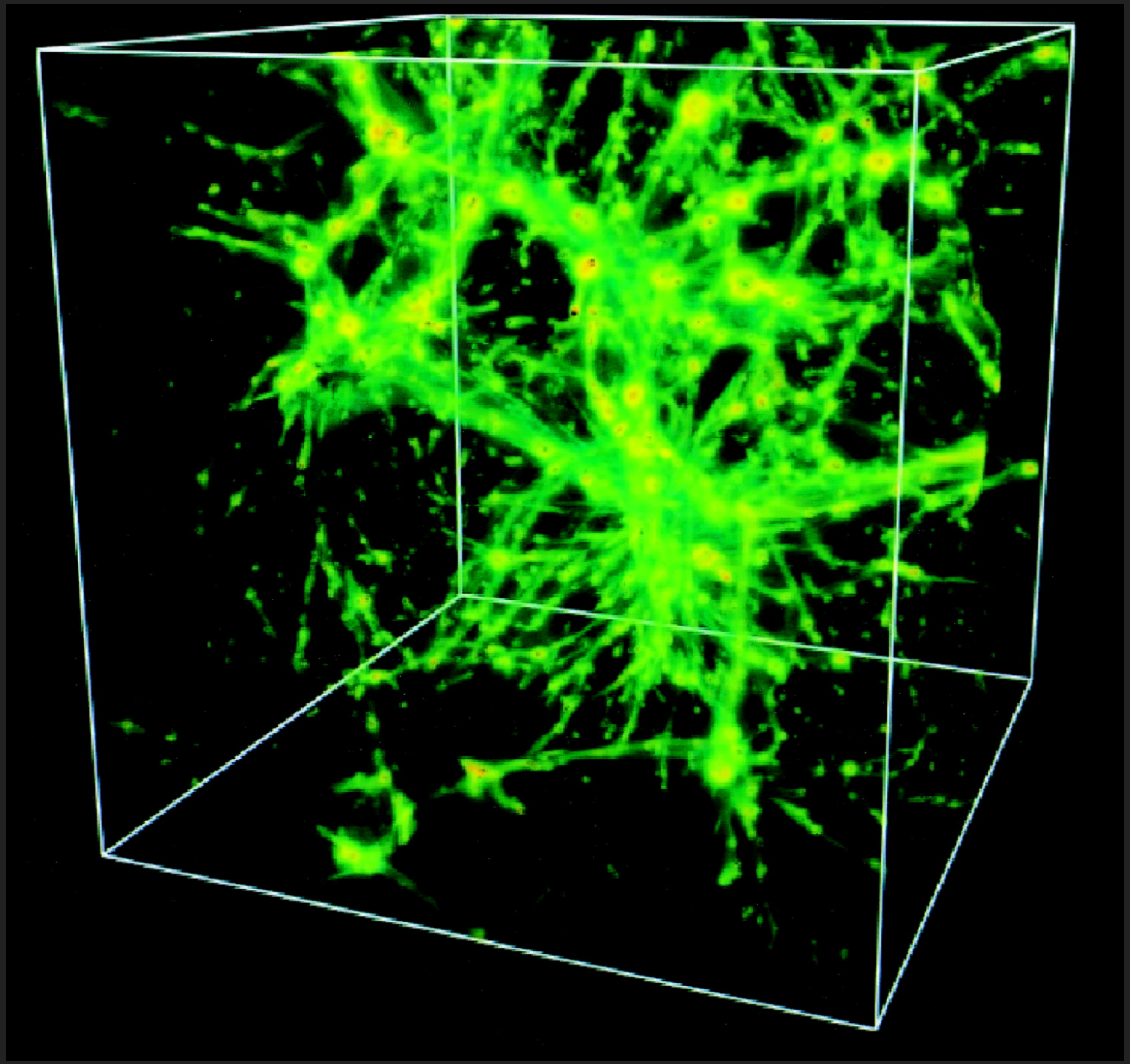
Bhandari+20



Host offset distributions of FRBs suggest galaxies hosting long gamma-ray bursts (LGRBs) are less likely to be common FRB hosts

Global properties of the FRBs suggests that compact merger events [White dwarfs (WD), Neutron stars (NS)], accretion-induced WD collapse and core-collapse SNe seem to be plausible progenitor channels for the FRBs

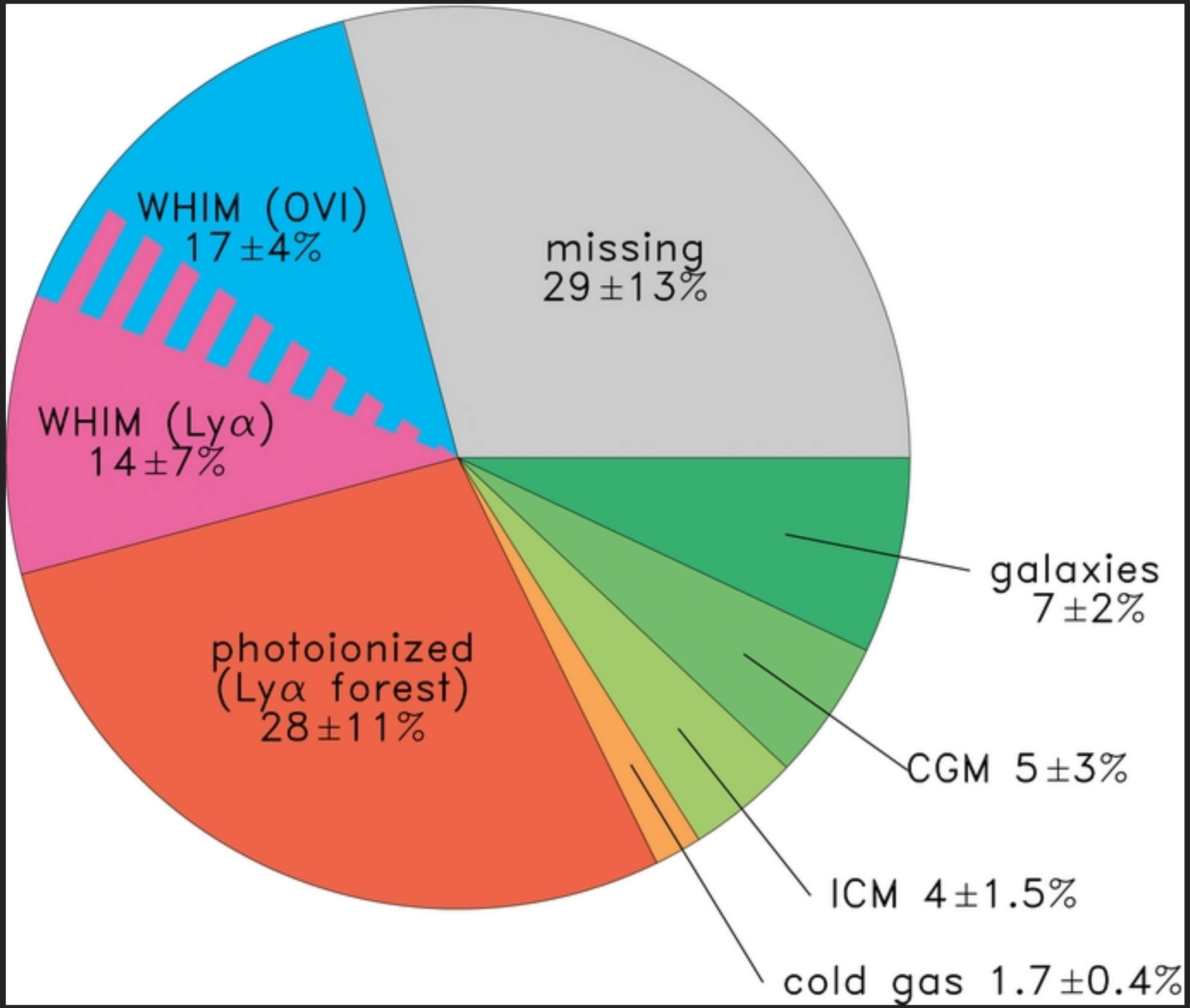
THE MISSING BARYON PROBLEM



Dave+01

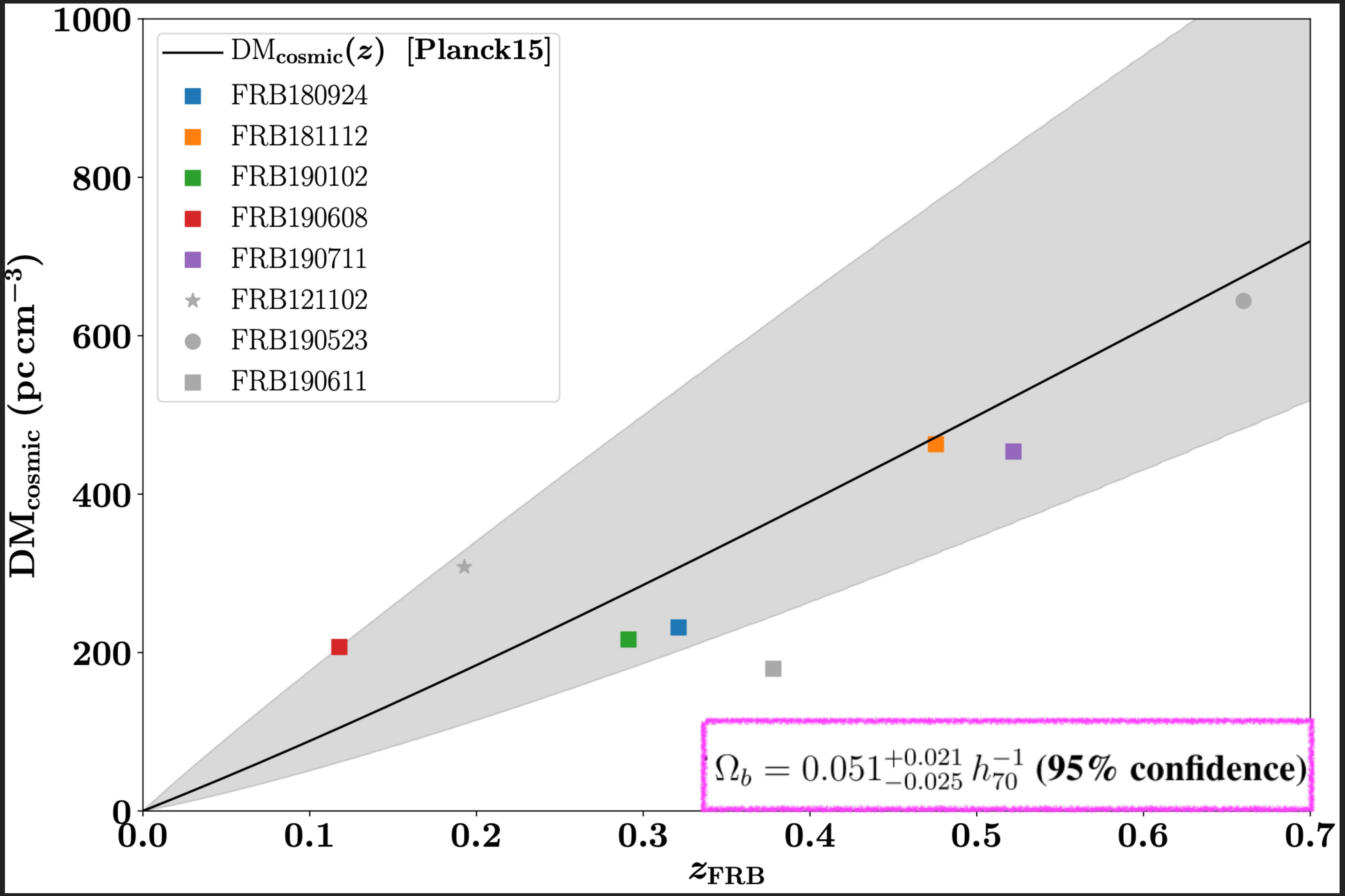
Low-z baryon consensus

Shull+12



DIRECT DETECTION OF THE MISSING BARYONS

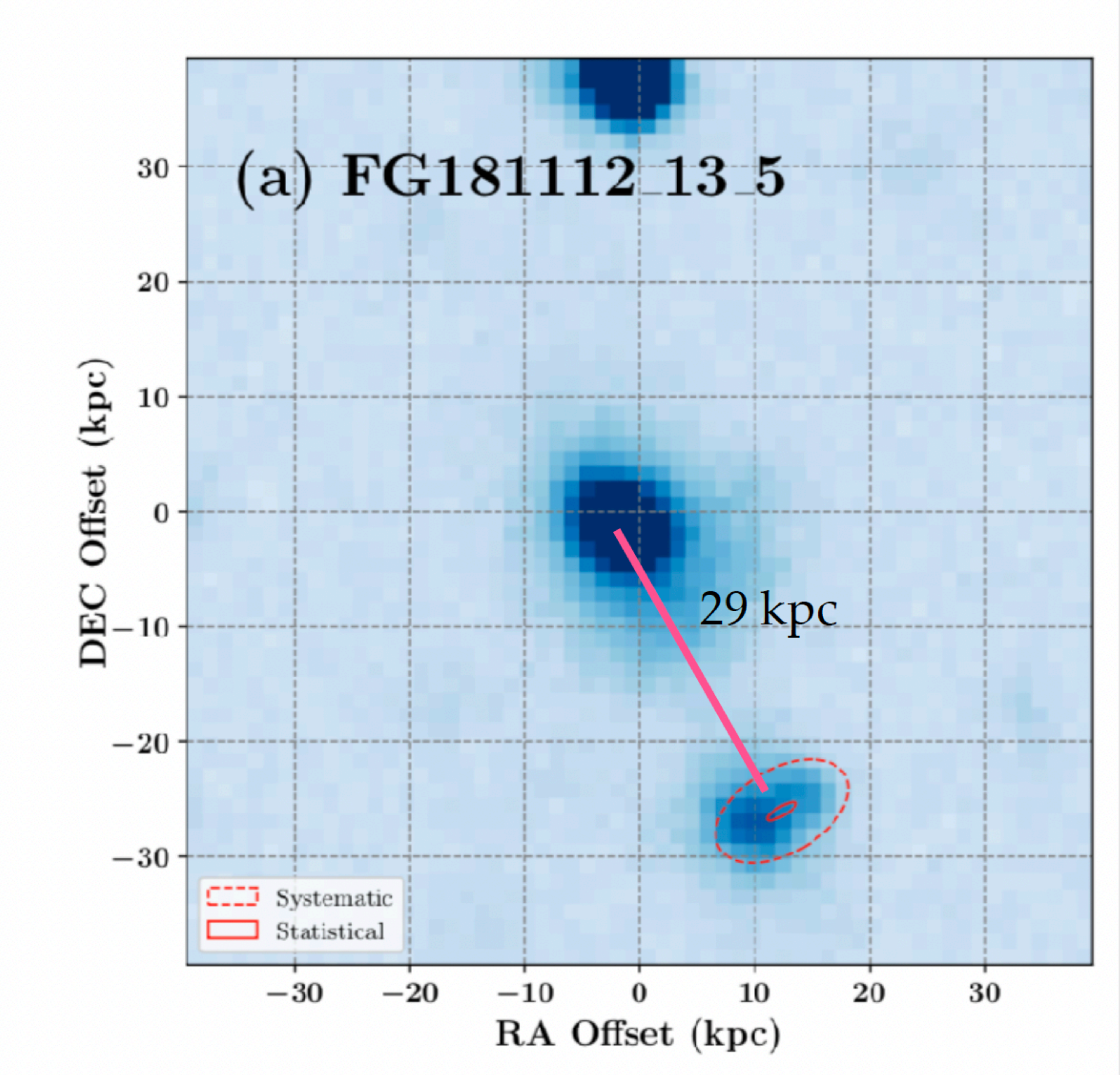
Macquart+20



- Direct detection of the missing baryons using the Macquart relation
- Consistent with cosmological expectations
- Scatter in relation will constrain gas in extragalactic halos

$$\langle \mathrm{DM_{cosmic}} \rangle = \int_0^{z_{\mathrm{FRB}}} \frac{c \bar{n}_e(z) dz}{H_0 (1+z)^2 \sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}}$$

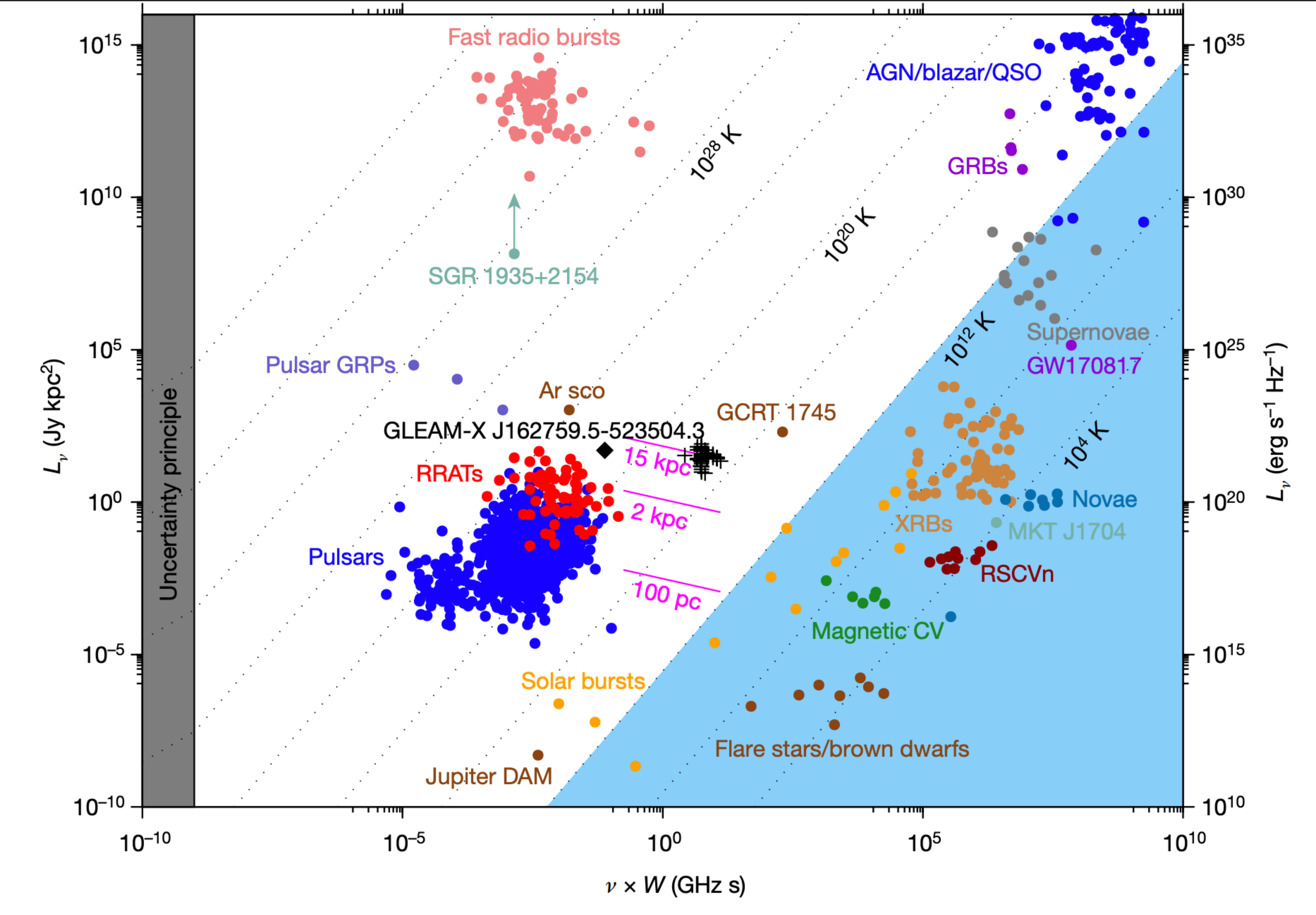
PROBING FOREGROUND HALOS



- FRB 181112 sightline intersects the halo of a massive foreground galaxy
- Scattering and polarisation properties probe the magnetic field, turbulence and density of the halo gas
- The gas in the galactic halo (CGM) is diffuse, and has low net magnetisation and turbulence.

Prochaska+19

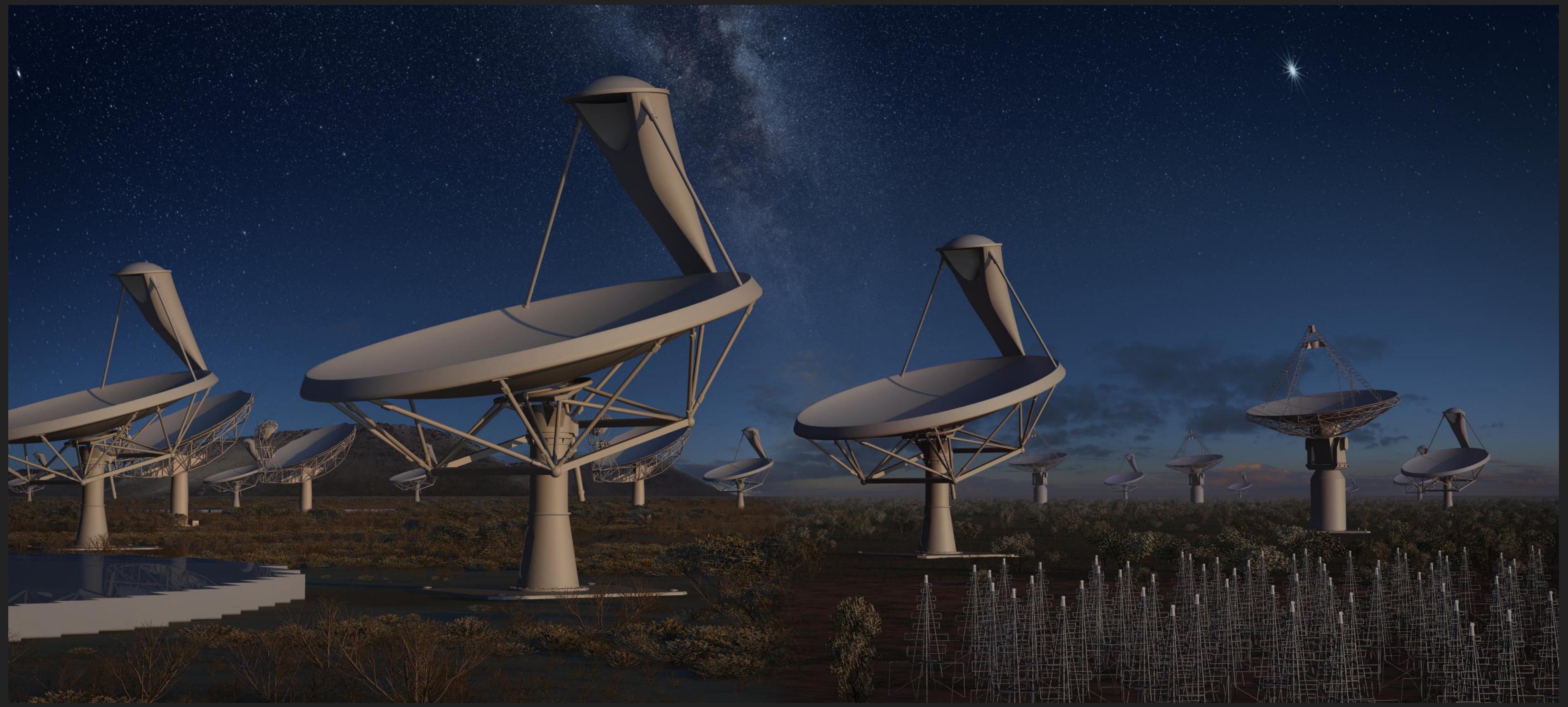
TRANSIENT PHASE SPACE



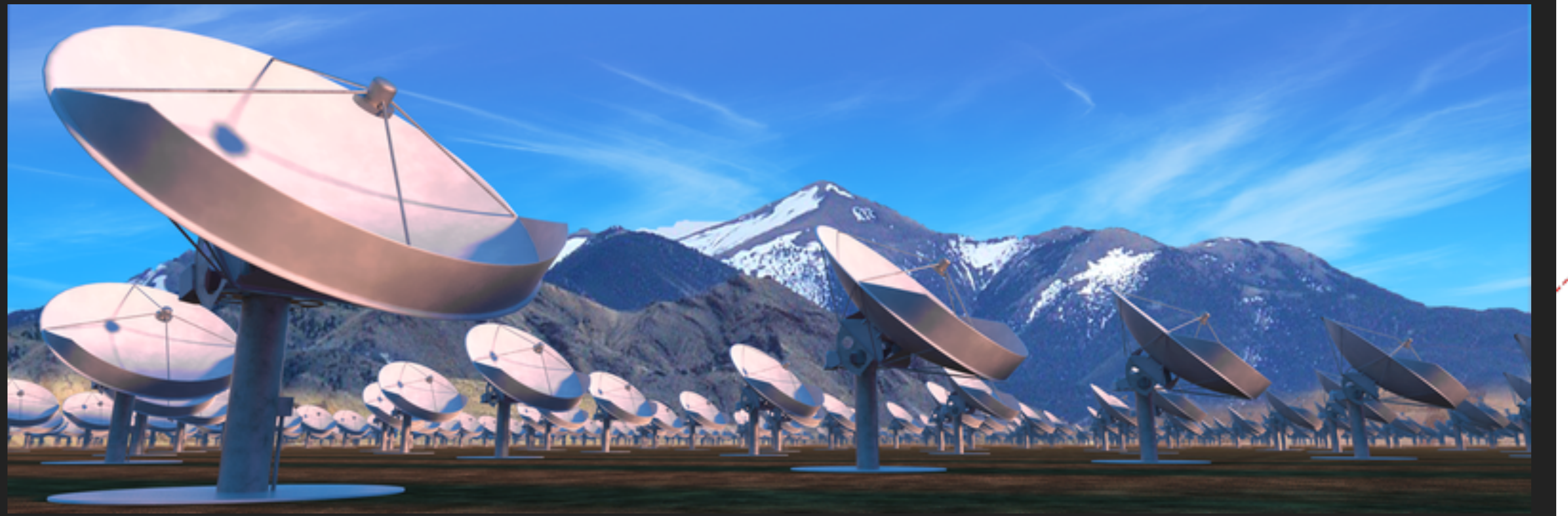
Hurley-Walker+22

FRBS HAVE BRIGHT FUTURE

Hallinan+19, Newburg+16, Vanderlinde+19, Fialkov+17



Meerkat

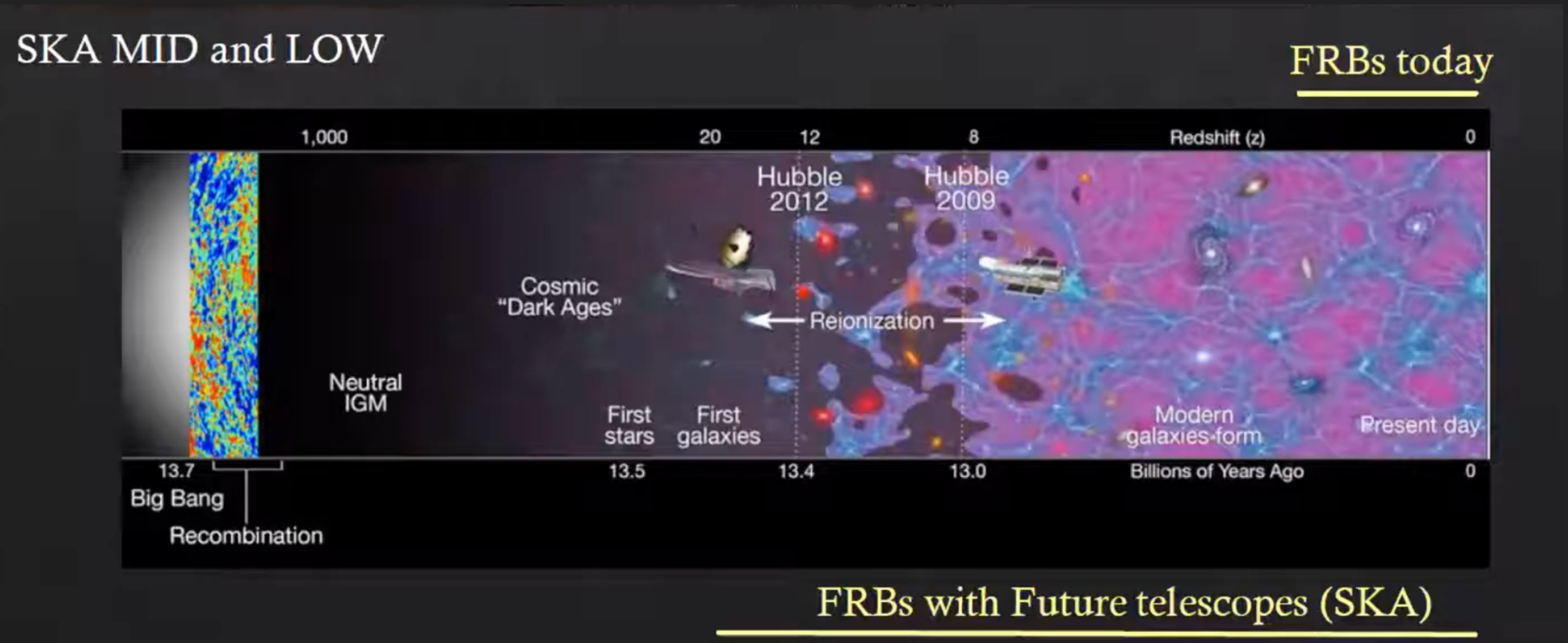


DSA-2000

CHIME-CHORD

HIRAX Instrument

LOFAR 2.0 (ASTRON)

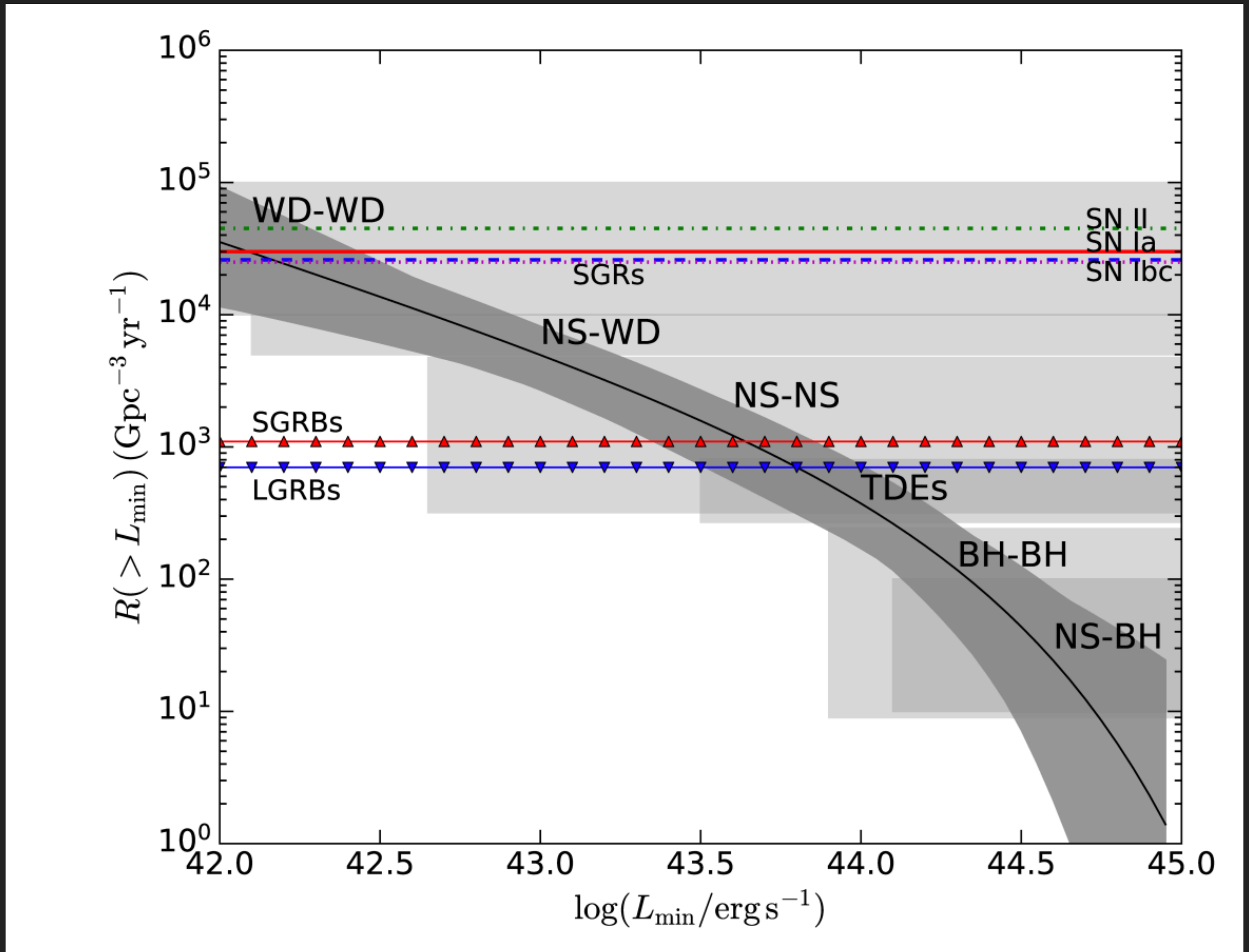


SUMMARY

- FRBs have different burst morphologies
- High time resolution analysis is crucial to study propagation effects and emission mechanisms
- Emerging differences between bursts from repeaters and non-repeaters
- FRBs reside in diverse environments
- Some FRBs may be in binary systems
- Some FRBs may be produced by magnetars
- FRBs are excellent probes of cosmology

FRB ALL-SKY RATES

- 10^5 sky^{-1} day^{-1} above a fluence of 0.0146 Jyms at 1.4 GHz
- ~820 sky^{-1} day^{-1} above a fluence of 5 Jyms at 600 MHz (CHIME catalog 1)
- Volumetric rate: 2^4 events Gpc^{-3} yr^{-1},similar to that of SGRs and within an order of magnitude of CCSNe (Type II).
- If FRBs are produced by binary NS mergers, they will produce only a very small fraction of special FRBs.
- If FRBs are produced by repeating sources (pulsars, magnetars), the sources responsible for the observed rate of FRBs may be far less abundant and easier to account for.



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