An overview on Fast Radio Busts

Principe Giacomo

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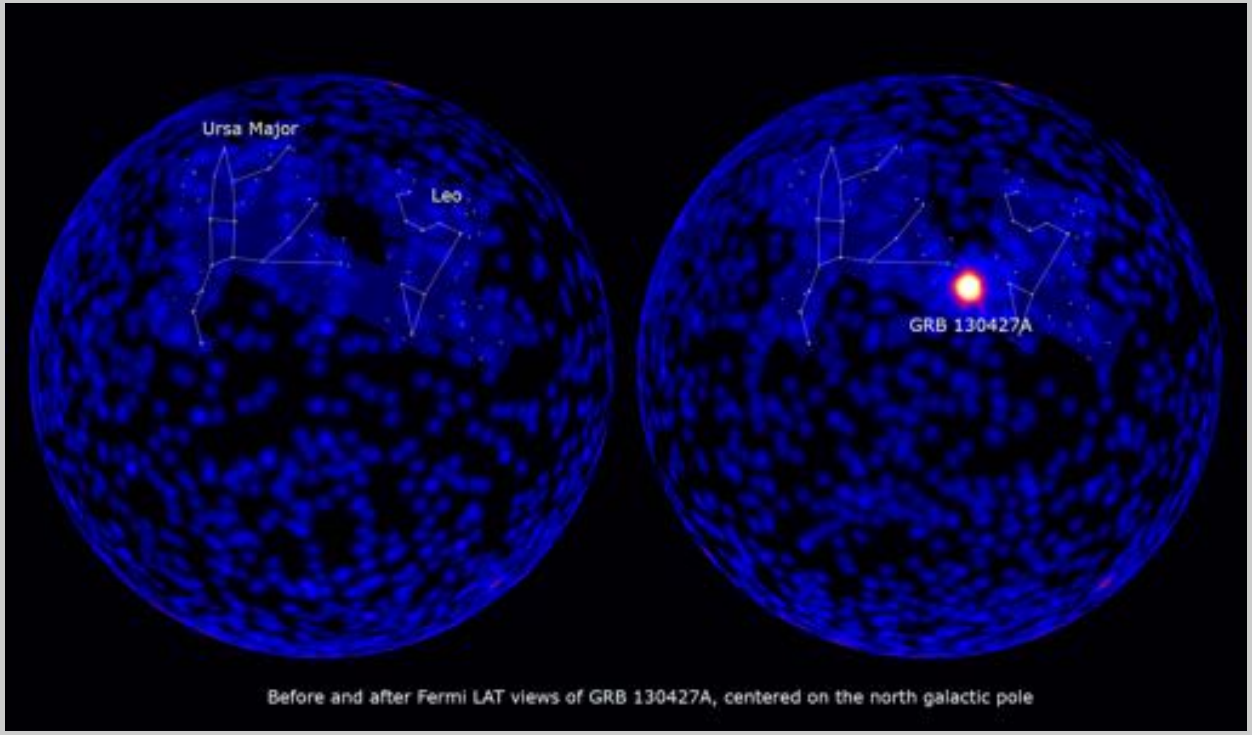
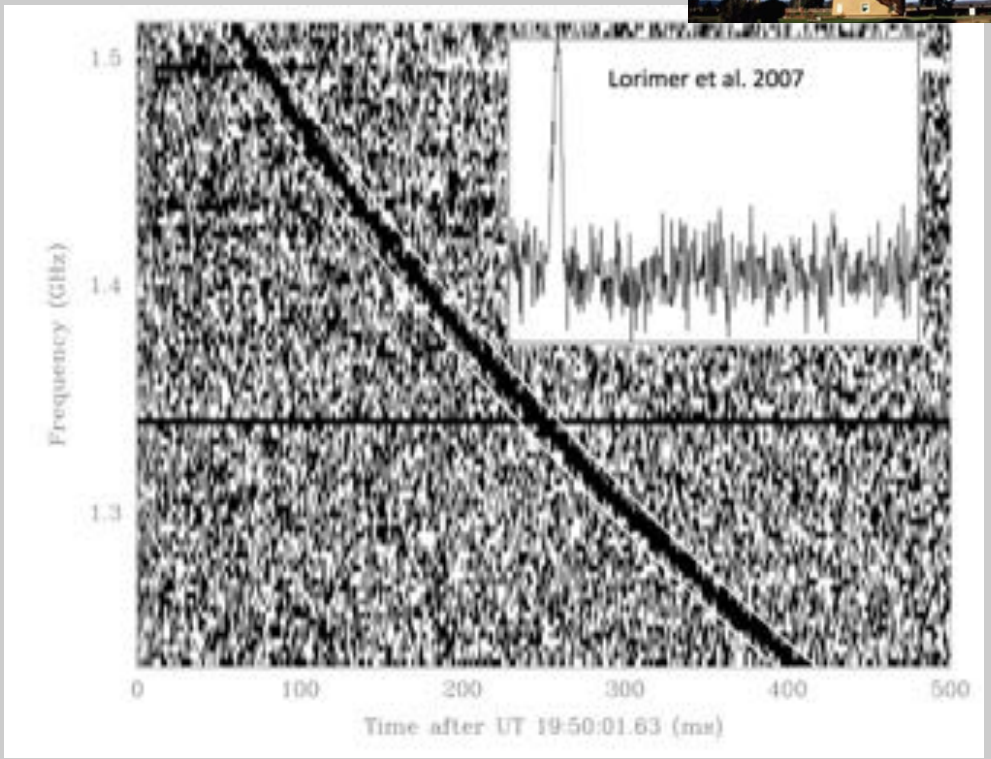
GRB vs FRB

GRB finder (e.g. Fermi-GBM)
Large field of view
(half of the sky)

FRB finder (previous state of the art)
Small field of view
typical value is < 1 sq. deg.



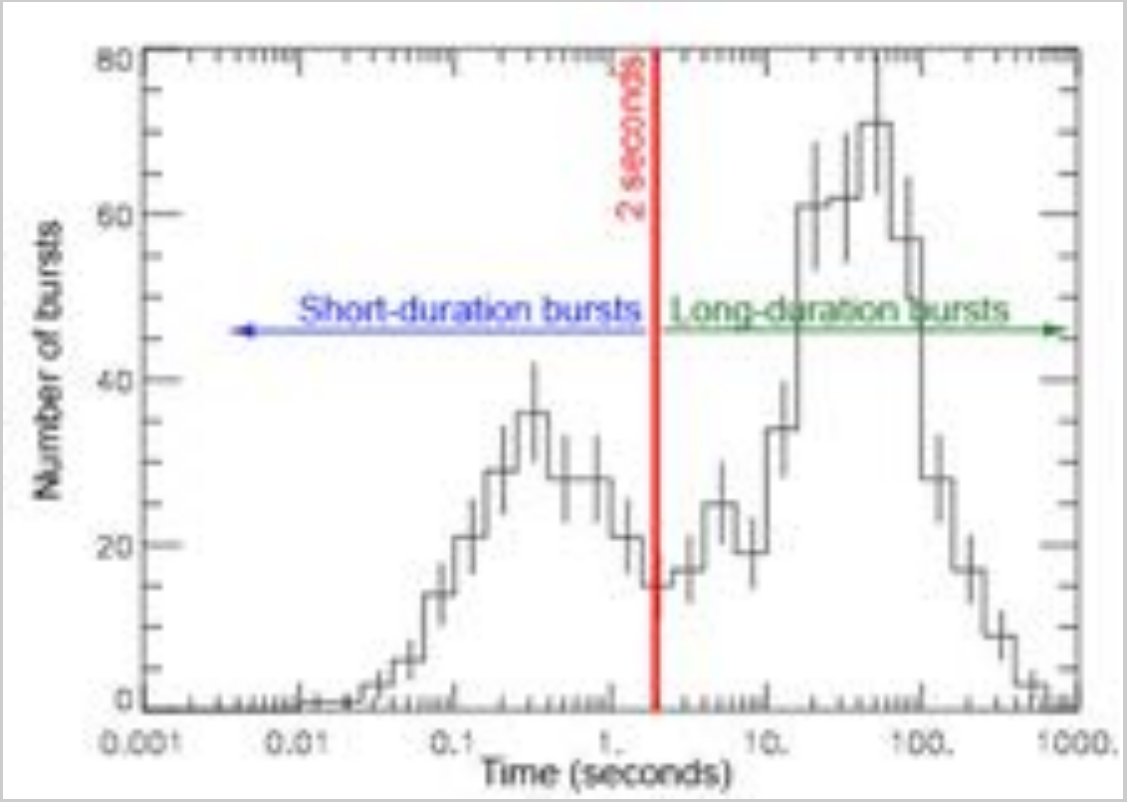


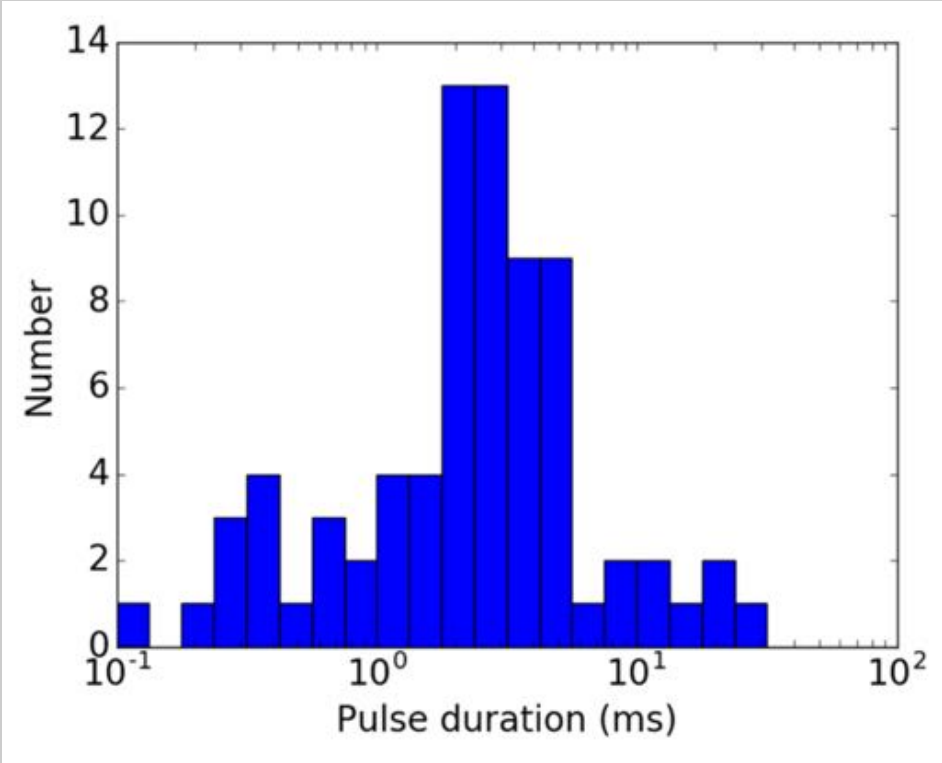
We need sufficiently sensitive *all-sky* radio monitors

GRB vs FRB

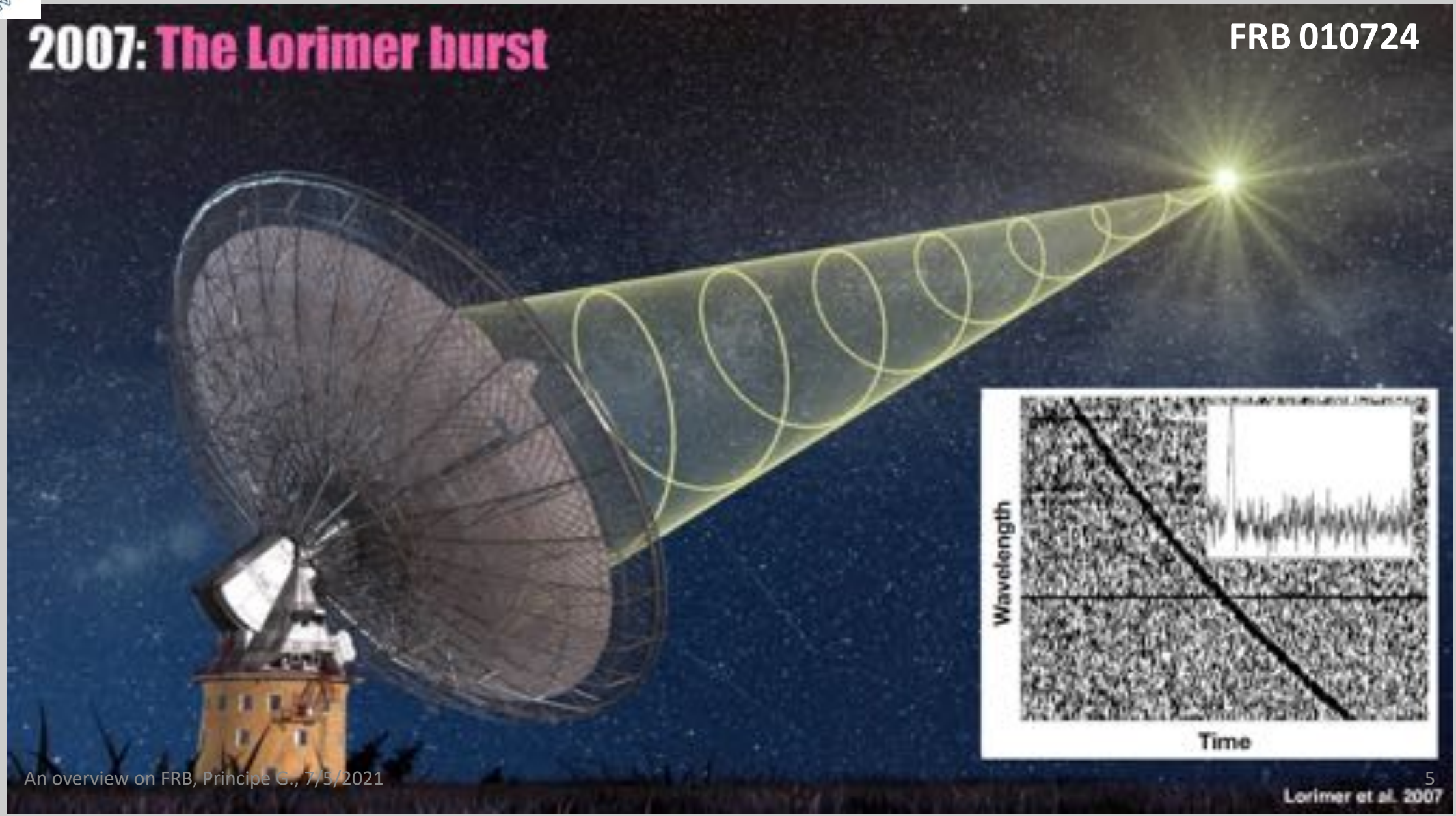
GRB duration
0.01 – 1000 s

FRB duration
0.1 - 30 ms

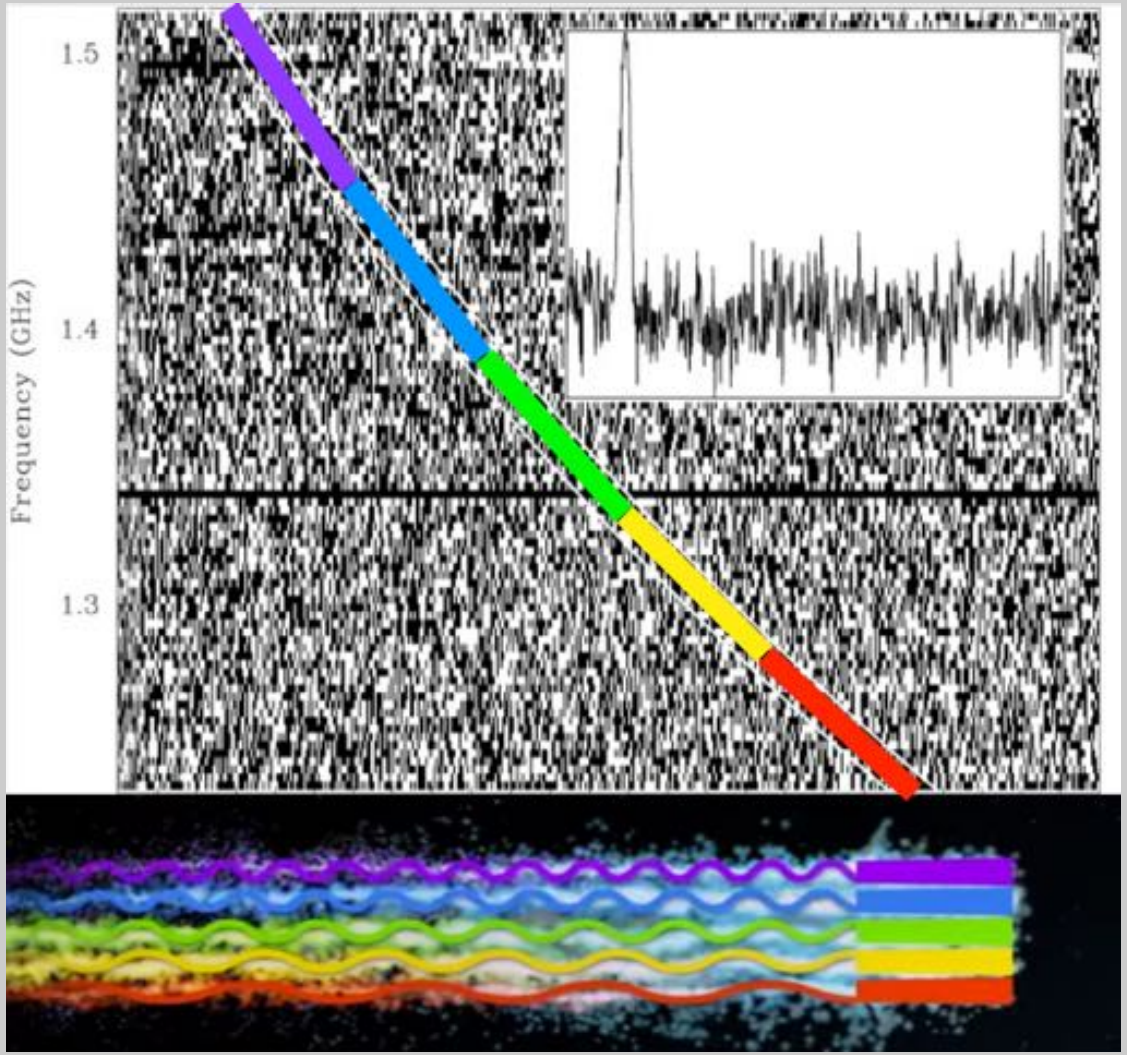




The Lorimer Burst

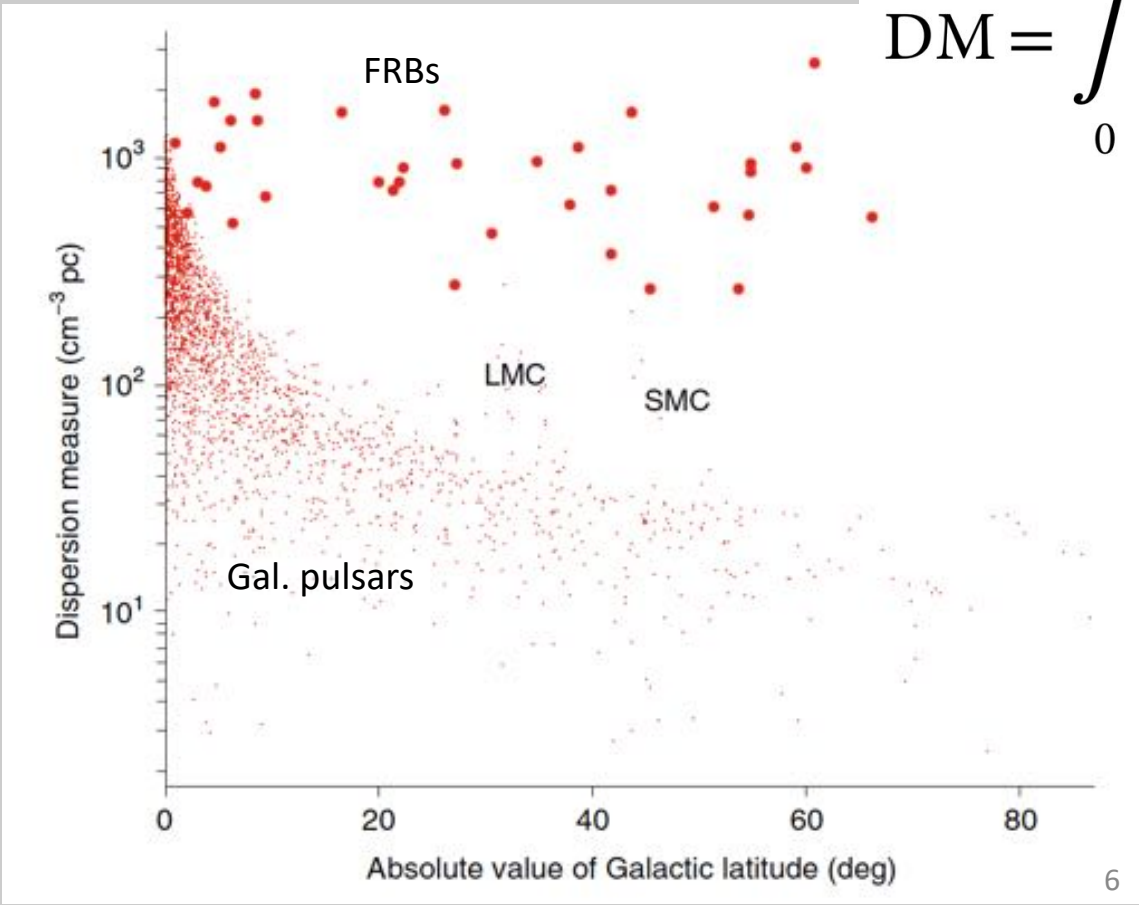


The Lorimer Burst

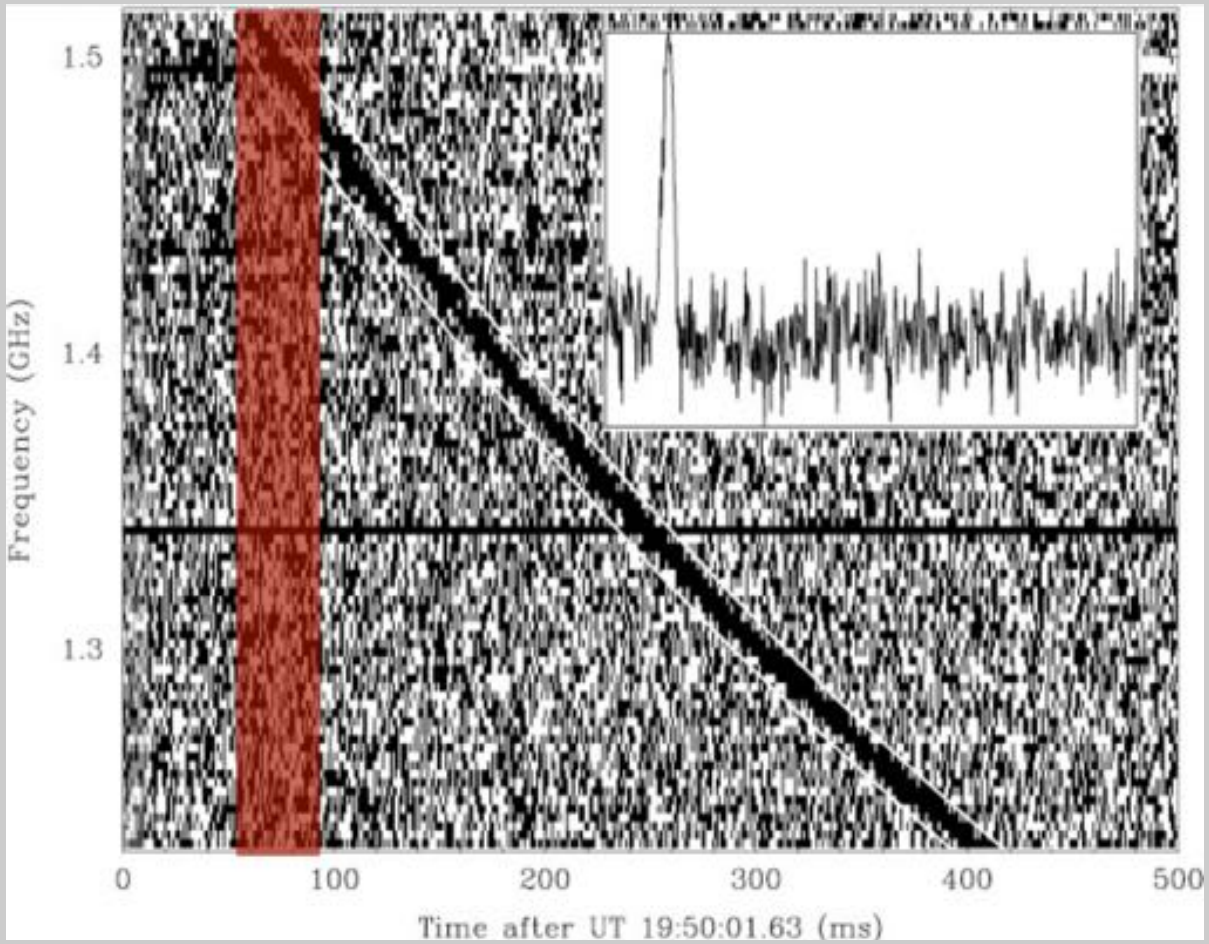


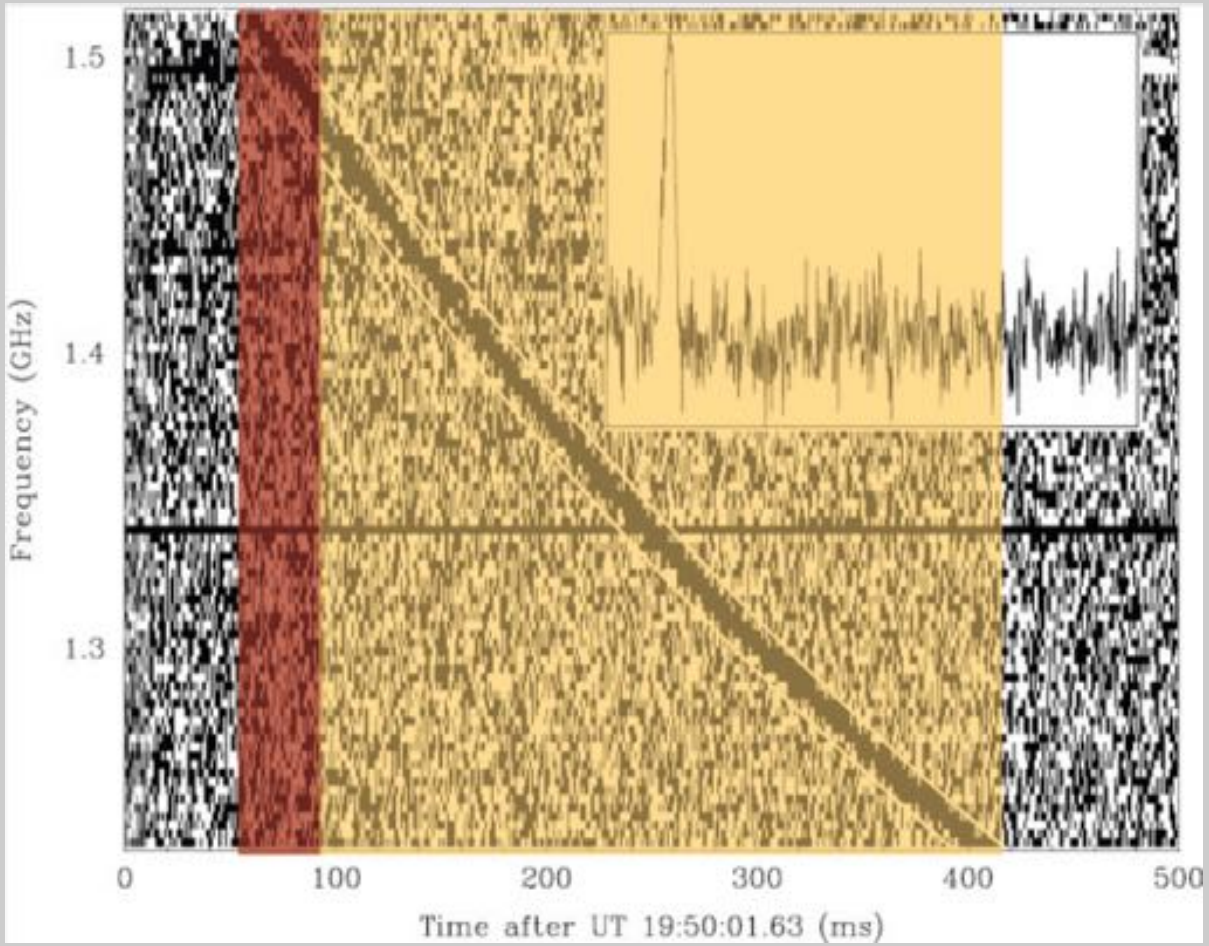
Due to the frequency-dependent refractive index of the ionized interstellar medium, the highest-frequency components of the signal travel faster than their lower-frequency counterparts and arrive earlier.

$$\mathrm{DM} = \int_0^d n_e \, dl$$



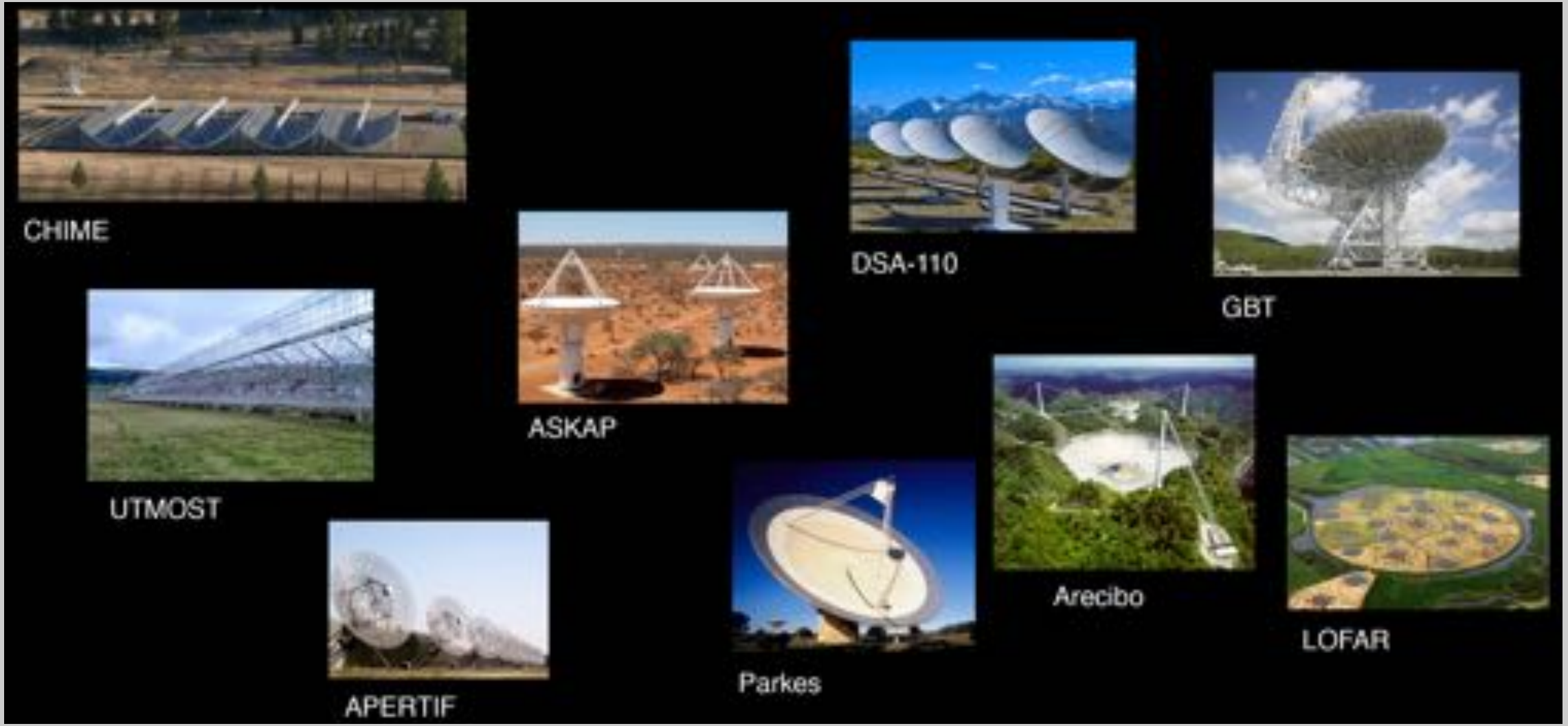
The Lorimer Burst



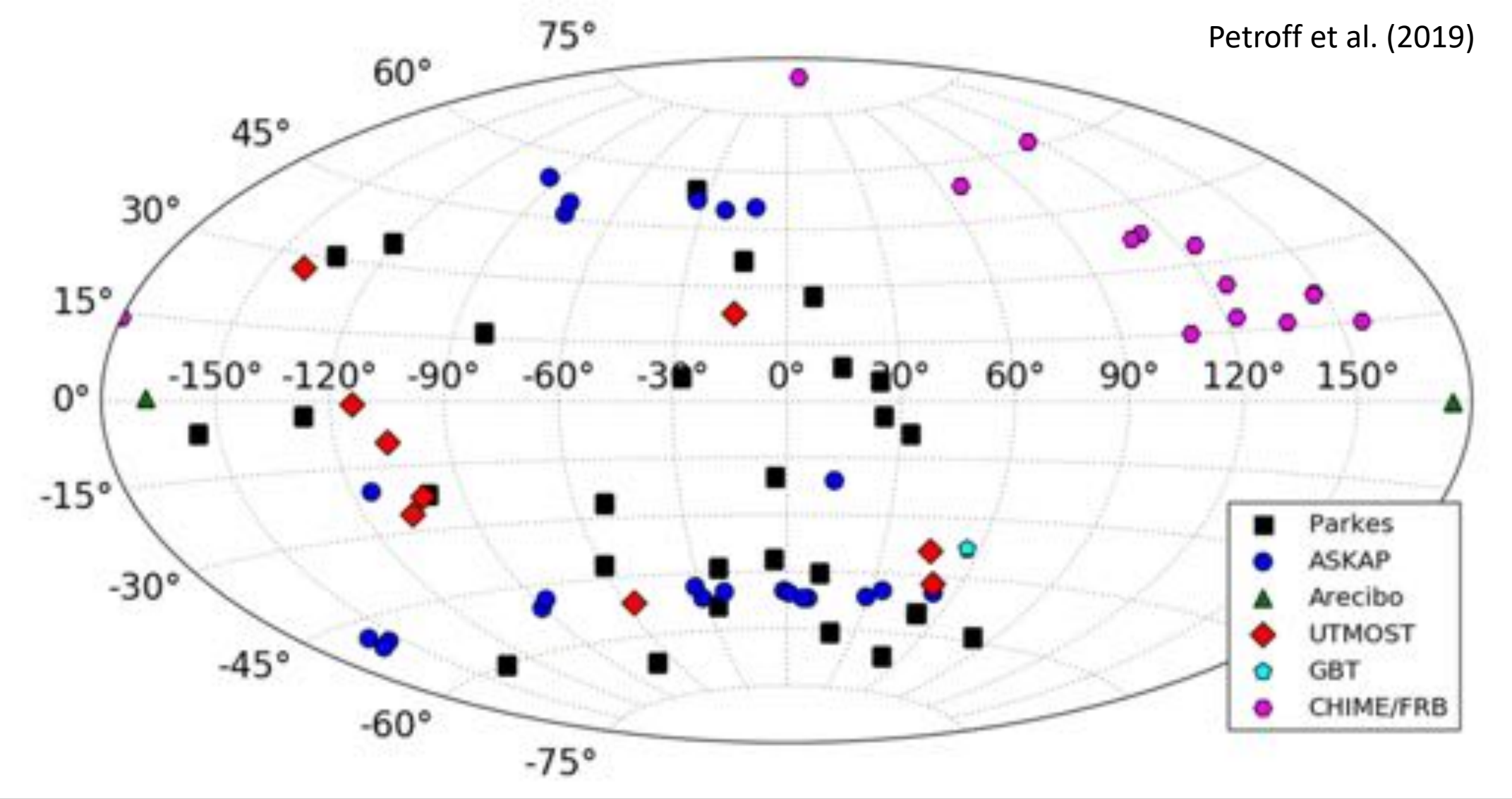


Clear extragalactic origin

Hundreds FRBs detected by many telescopes!!!!



Hundreds FRBs detected by many telescopes!!!!

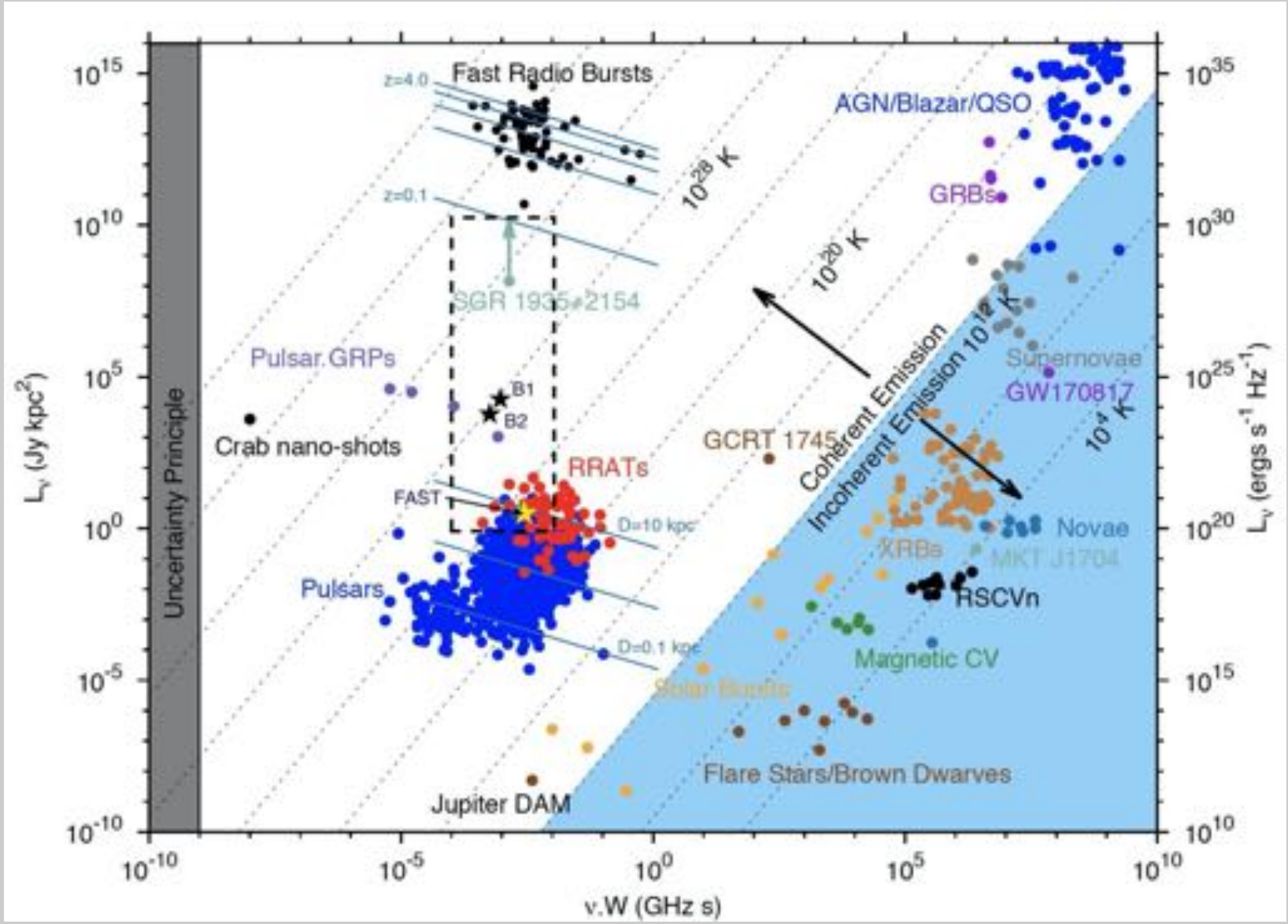


Some shocking facts on FRB origin

- **Last 100 times shorter than the blink of an eye.**
  -> milliseconds duration
- **Created long-long ago in galaxies far-far away.**
  -> DM > few + DM_{MW}
- **Same energy as the Sun emits in one day.**
  -> 0.05 – 150 Jy*ms

FRB origin

FRBs vs Pulsars



Cordes (2019)

FRB origin

GRB: detected few per weeks
FRB: detected few per week but with a small FoV

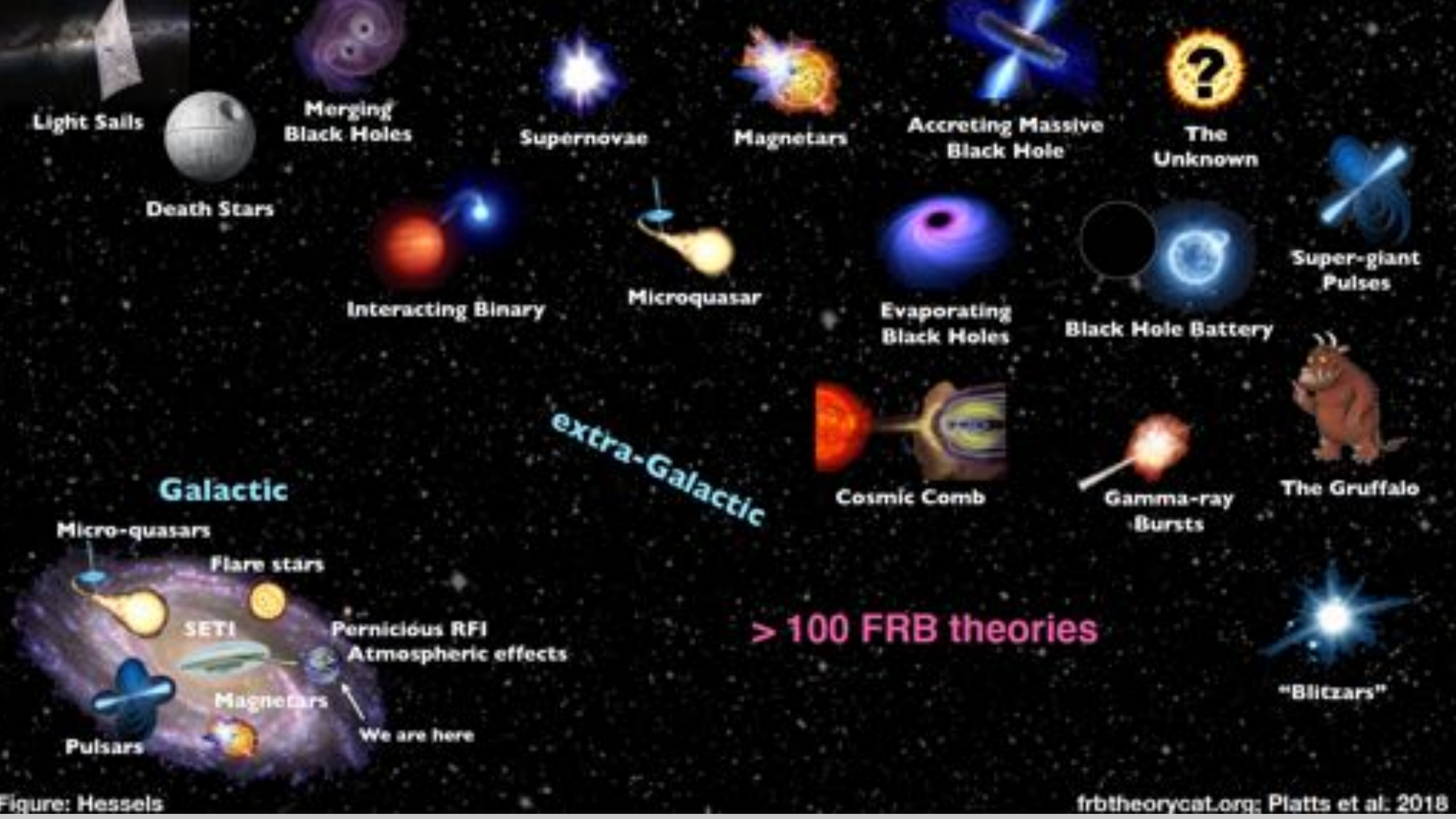
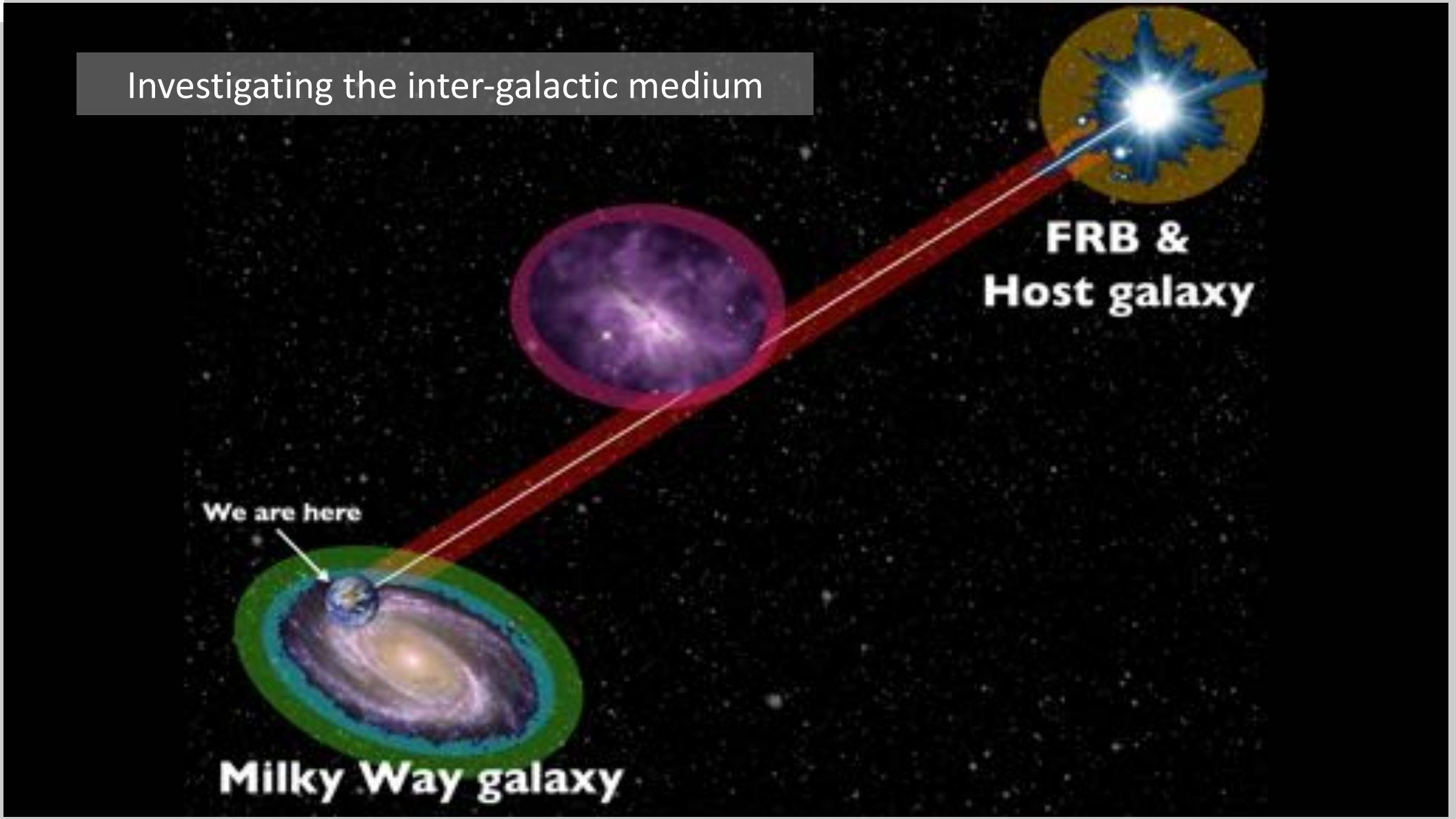


Figure: Hessels

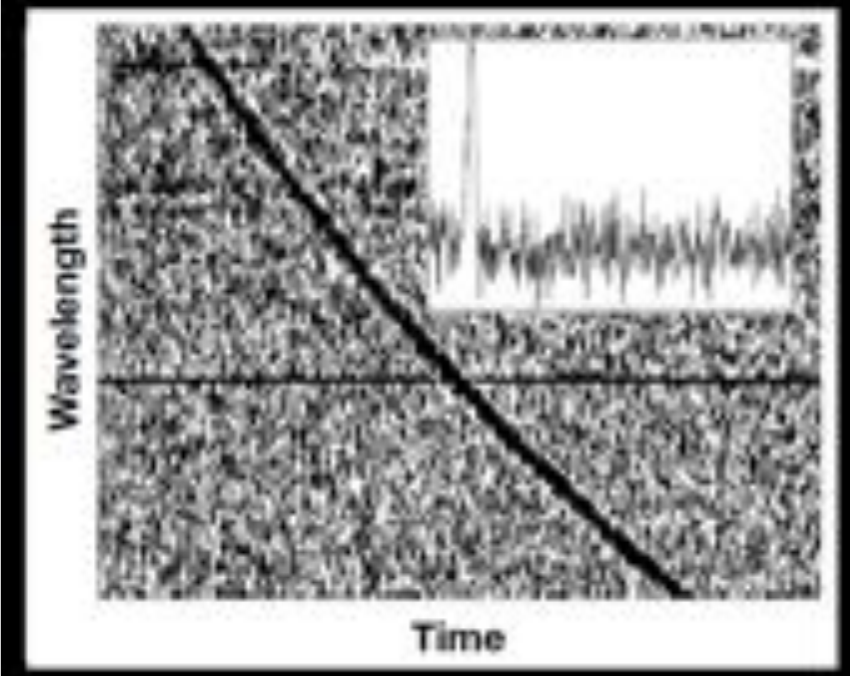
frbtheorycat.org; Platts et al. 2018

FRB as a cosmological probe



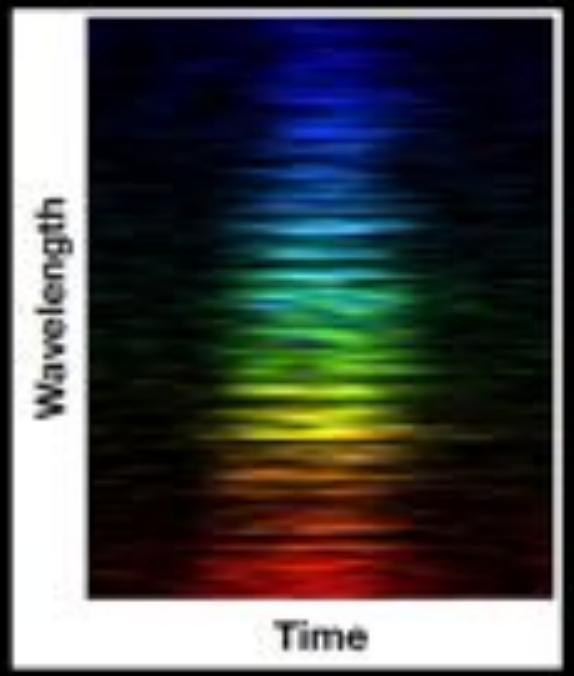
FRB as a cosmological probe

Dispersion



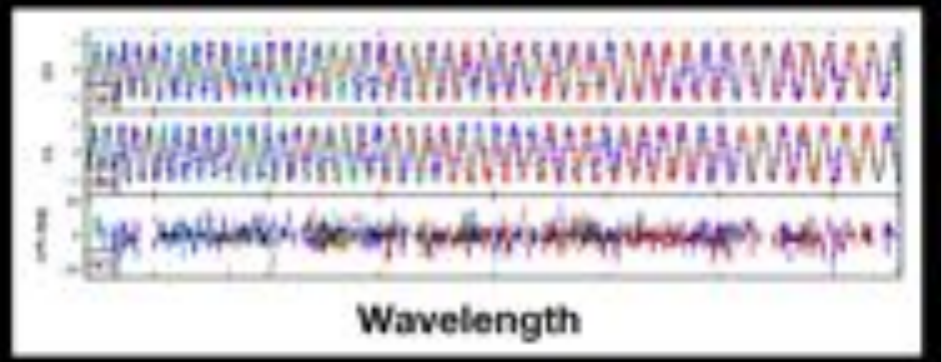
Total electron column density

Scintillation & Scattering



Clumpiness

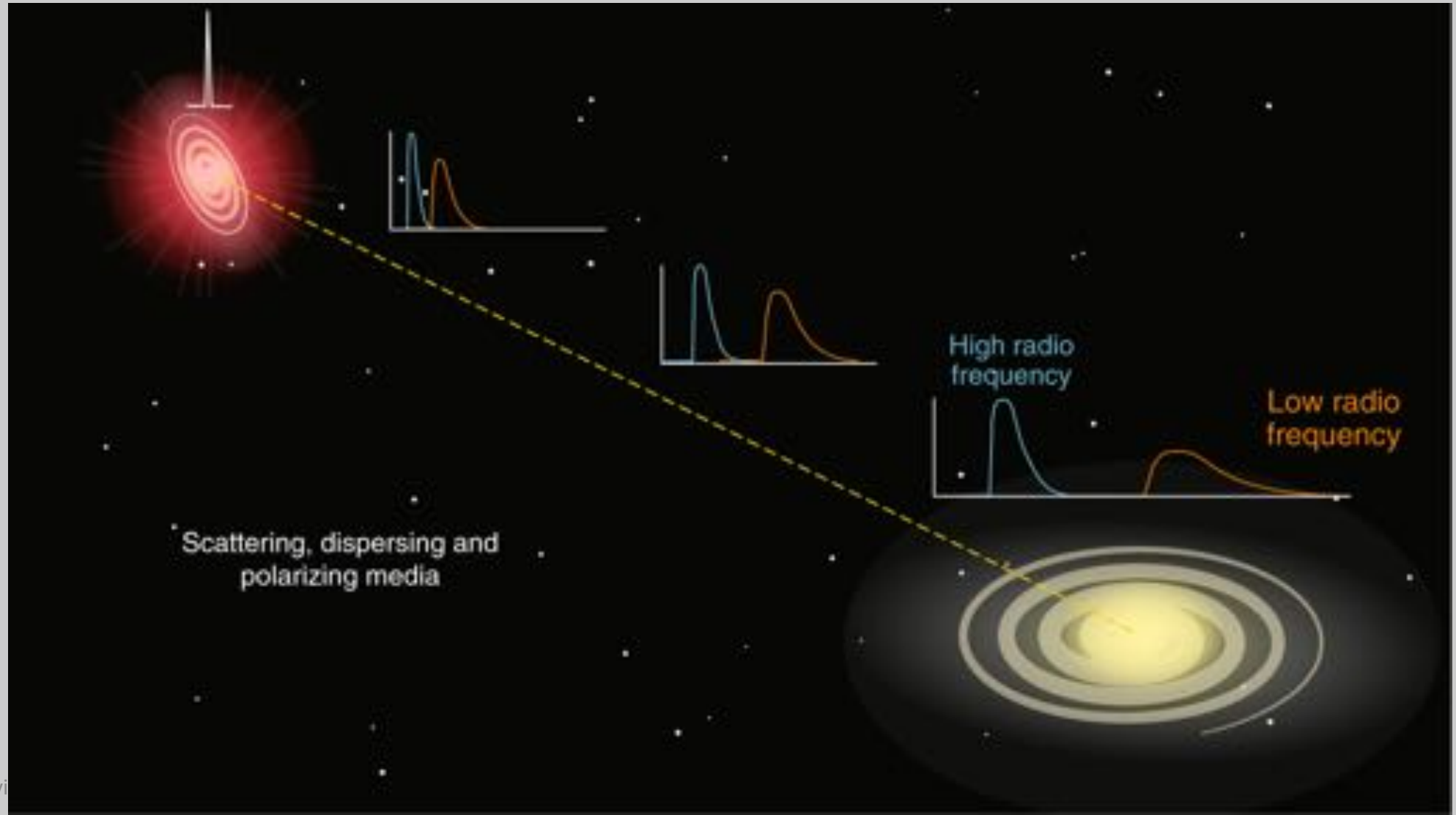
Faraday rotation



Line-of-sight magnetic field

Dispersion and scattering

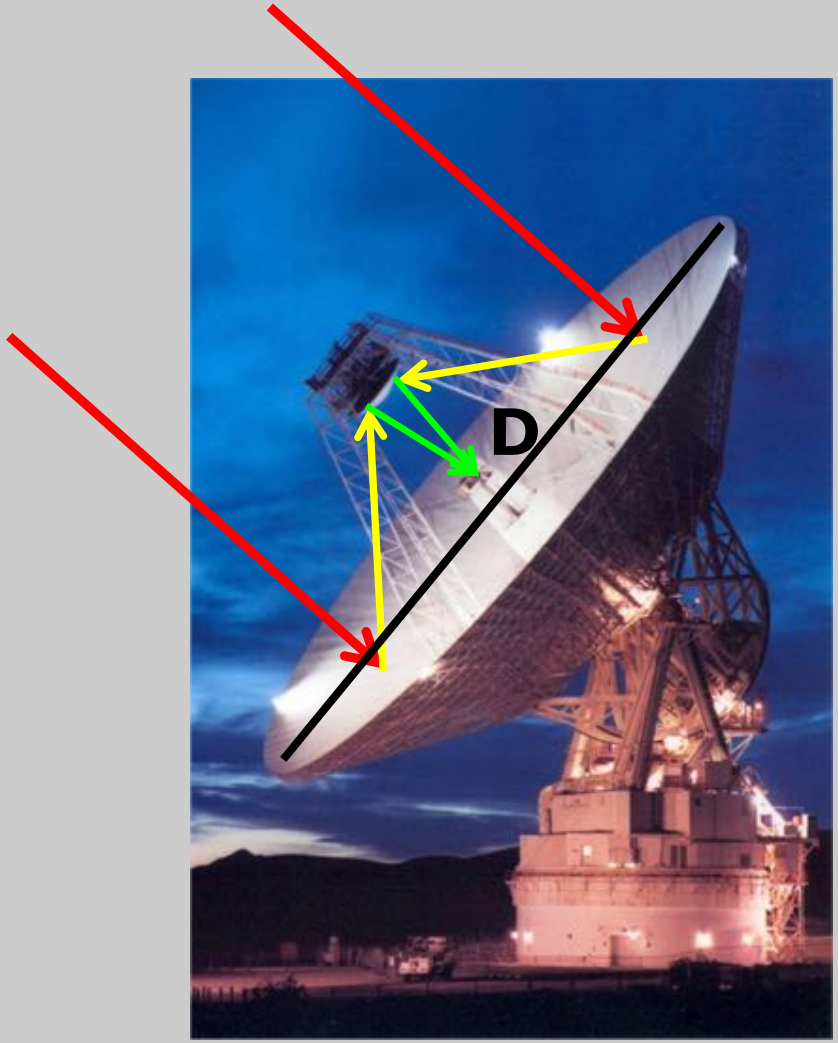
Dispersion (a time-dependent sweep from low to high frequency) and scattering (a greater broadening of the pulse at low frequencies). More pronounced with signal propagation over longer spatial scales.



Localizing a FRB

Only ~13 FRBs precisely localized to date

Localizing a FRB



How does a **single dish radio telescope** works?

Radio waves are extremely weak

1 Jansky (Jy)=10^{-26}W/(Hz m^2)

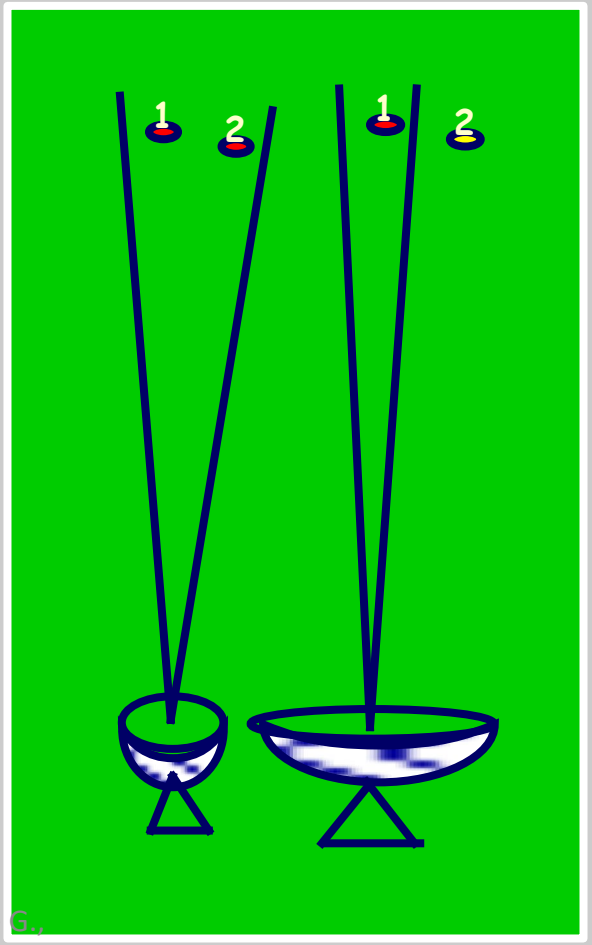
Sensitivity ~ Collection area ~ D^2

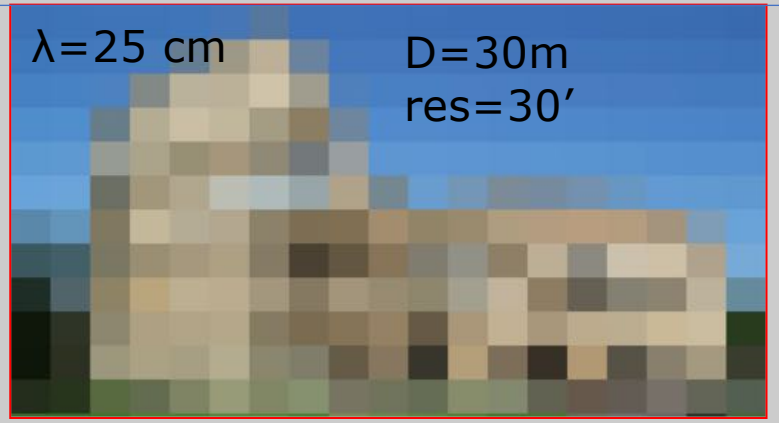
In 50 years, an antenna with D=32m bandwith of 2GHz collect an energy od 0.00003 J.
(Compared with 100J emitted by a common desk lamp in 1 second)

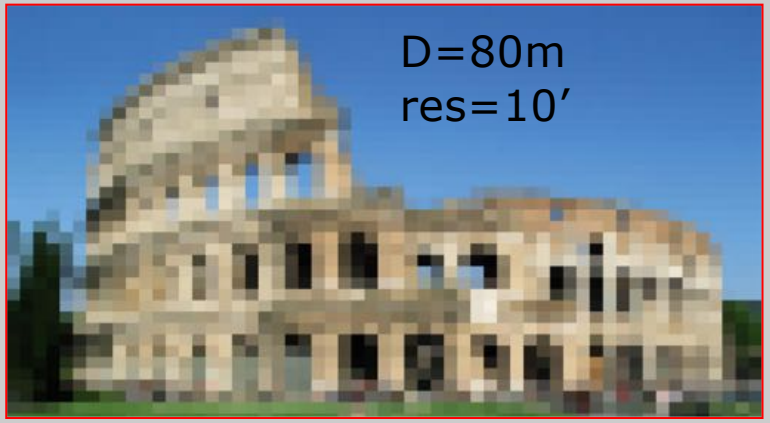
Localizing a FRB

How does a radio telescope work?

Angular resolution $\theta_{min} \sim \lambda/D$







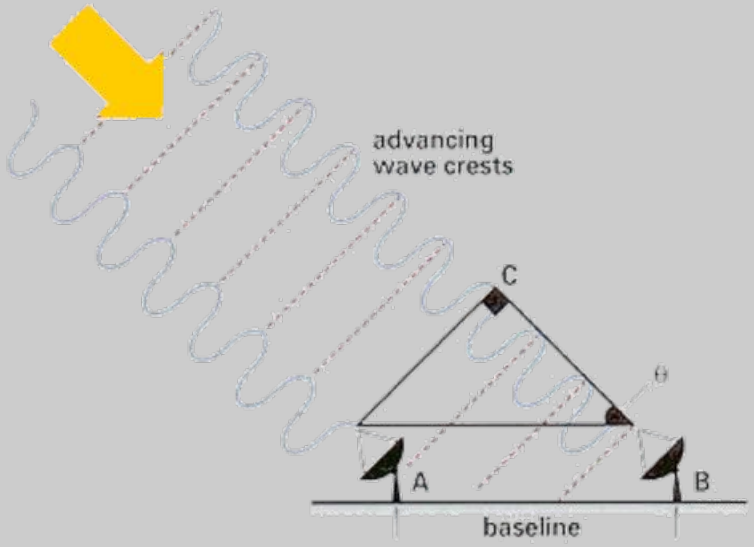
Localizing a FRB

FAST – China;
D=500 m

Localizing a FRB

Interferometry: D = maximum distance among the antennas (B_{max})

+ Angular resolution ~ λ/B_{max}



Jansky Very Large Array
New Mexico
27 antennas
D = 25 m
B_{max}= 30 km



JVLA
(New Mexico US)

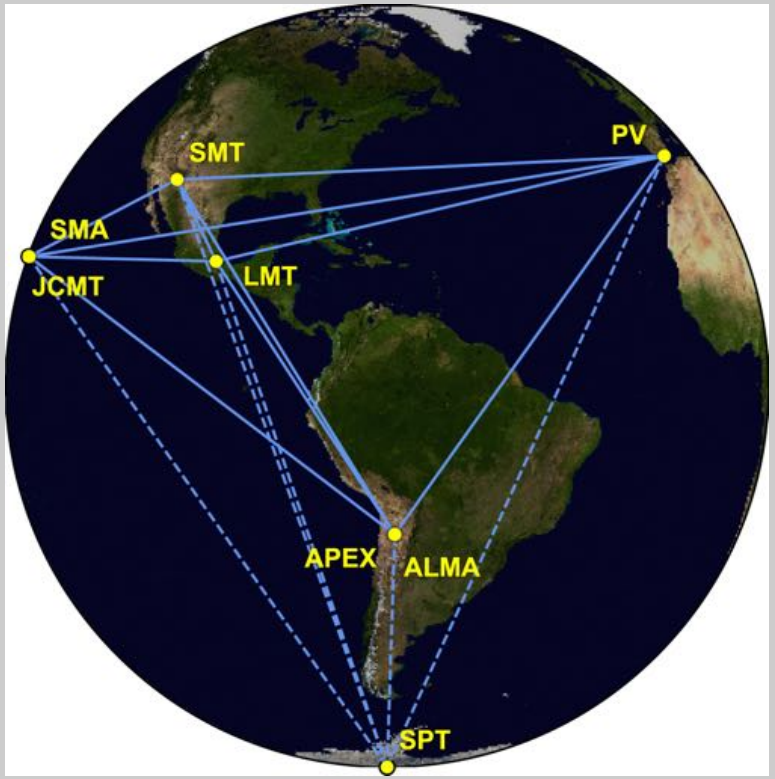
Jodrell Bank
(England)

Arecibo
(Puerto Rico)

Effelsberg
(Germany)

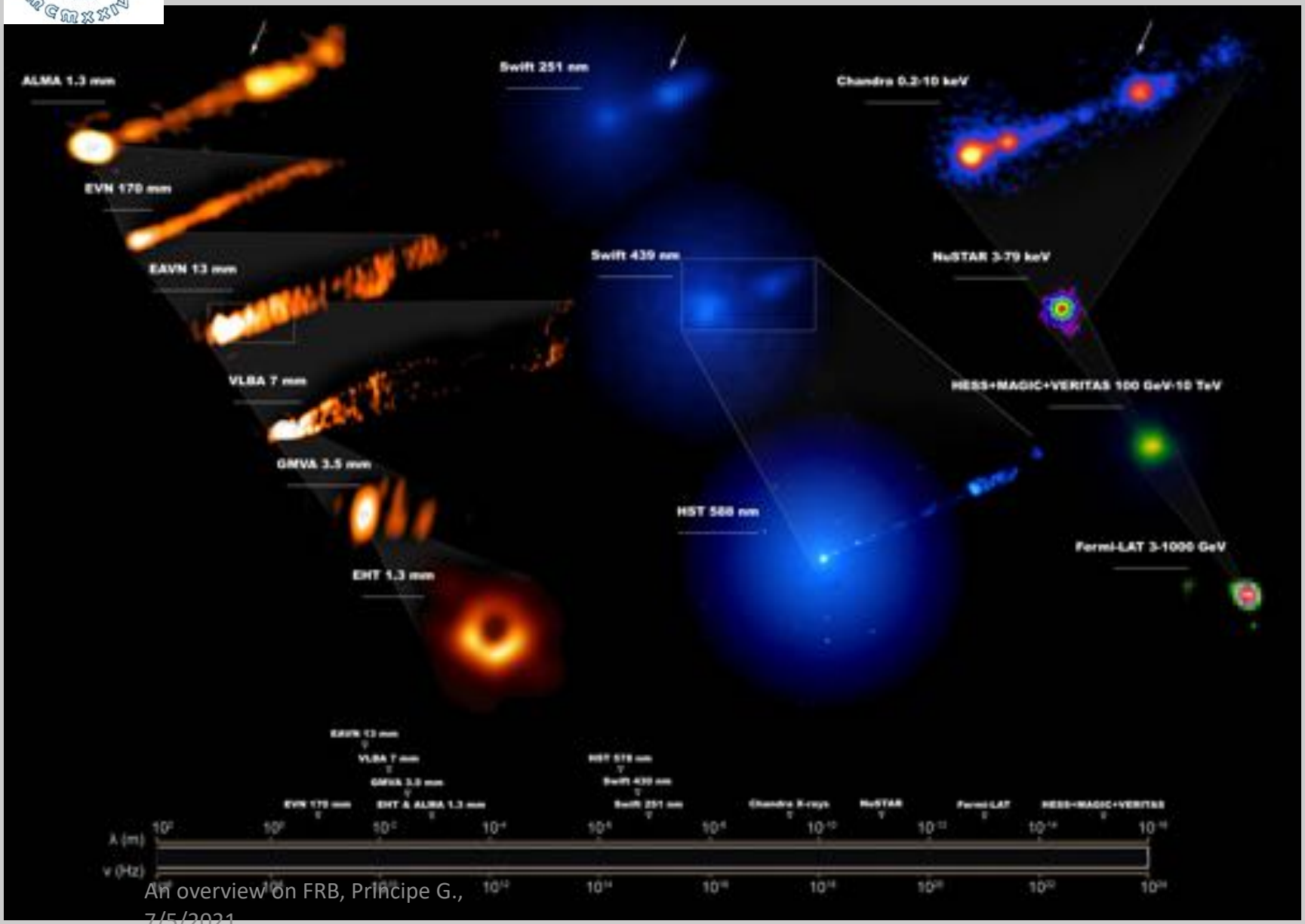
ALMA
(Chile)

Localizing a FRB

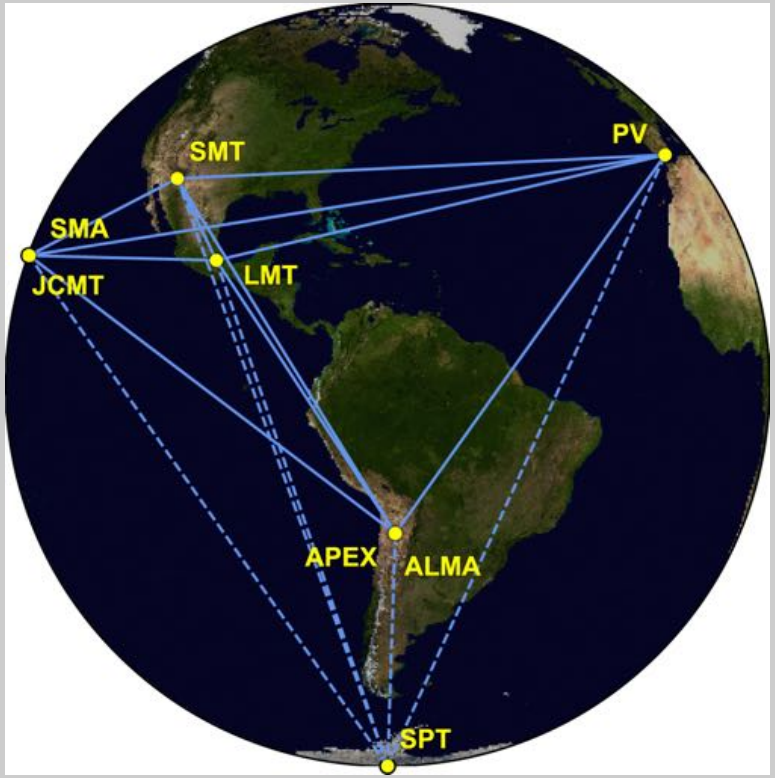


22 antennas spread among Europe (and the world) B_{max}= 10.000 km
Angular resolution 0.01 arcoseconds

An example of interferometry



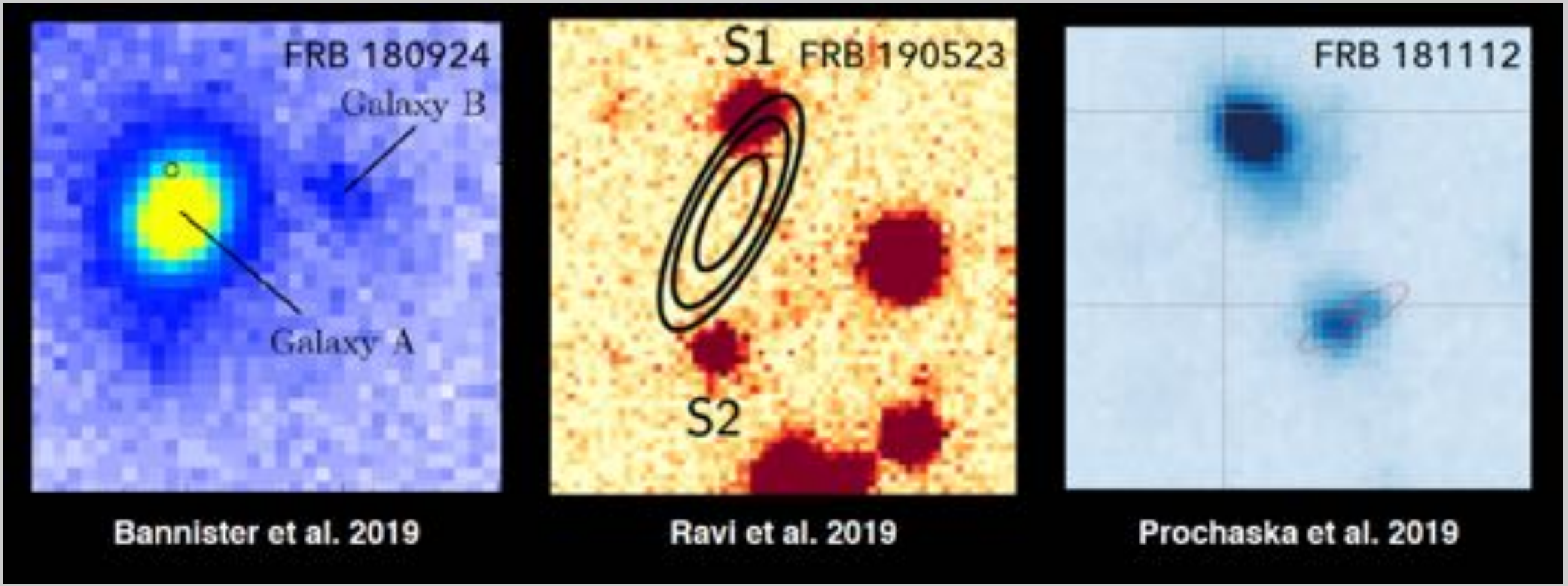
EHT



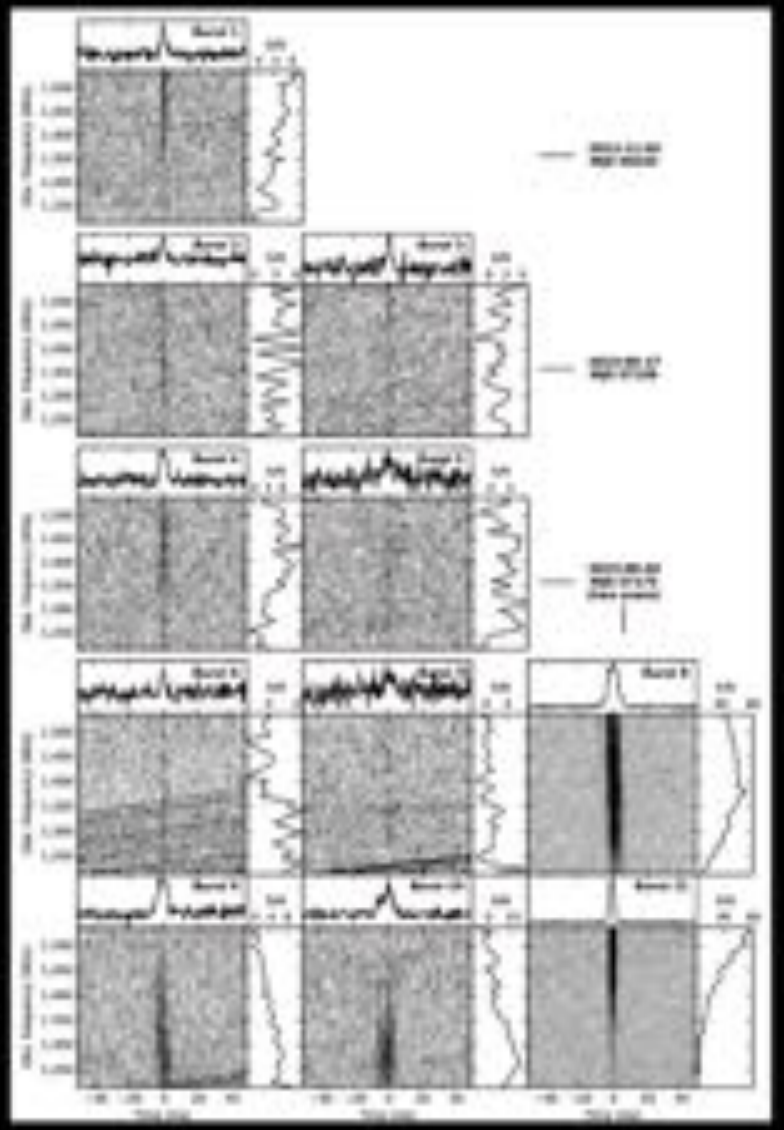
Localizing non-repeating FRBs

Non-Repeating FRBs

- Massive Galaxies
- No (or little) star formation
- No persistent radio source



FRB 121102 repeats!



Spitler, Scholz, JH et al. 2016
Scholz, Spitler, JH et al. 2016

FRB 121102: the first repeating FRB

Why important?

Rules out a cataclysmic source (at least for this FRB)

vs.

One-time-only explosion

Longer-lived energy source

Localizing repeating FRB

FRB 121102 localized

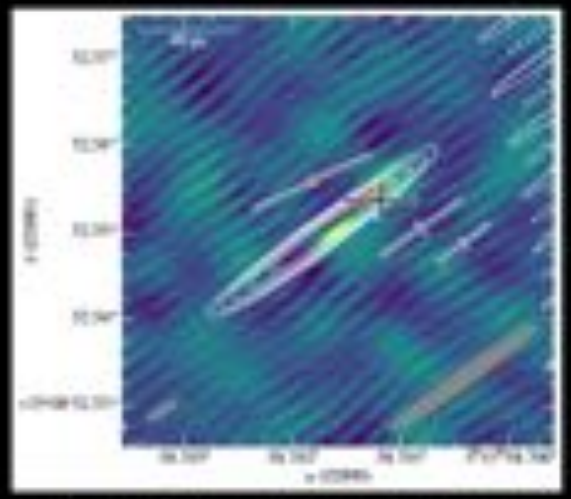
VLA

EVN

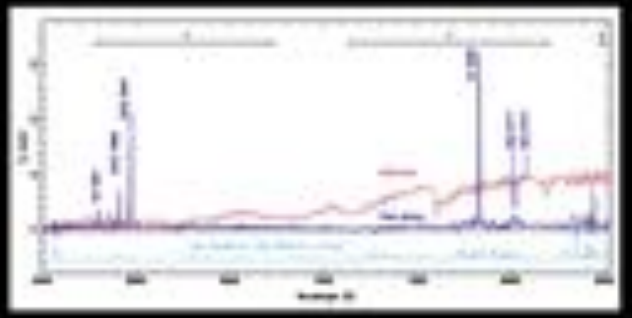
Gemini

HST

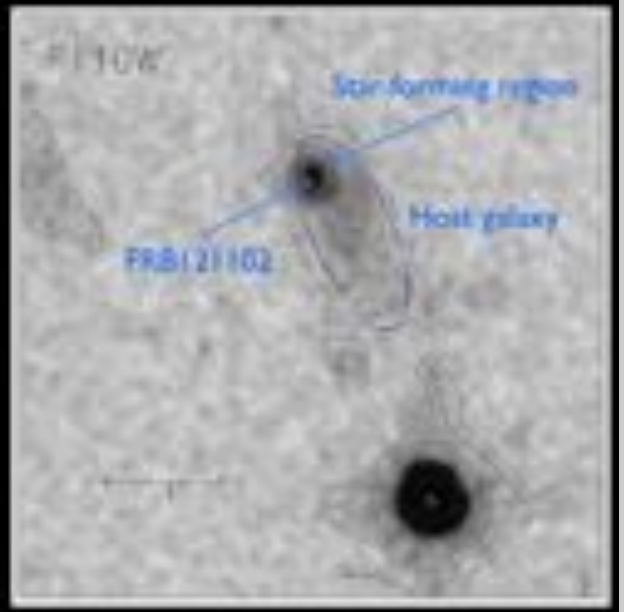
Chatterjee et al. (2017)



Marcote, Paragi, JH et al. (2017)



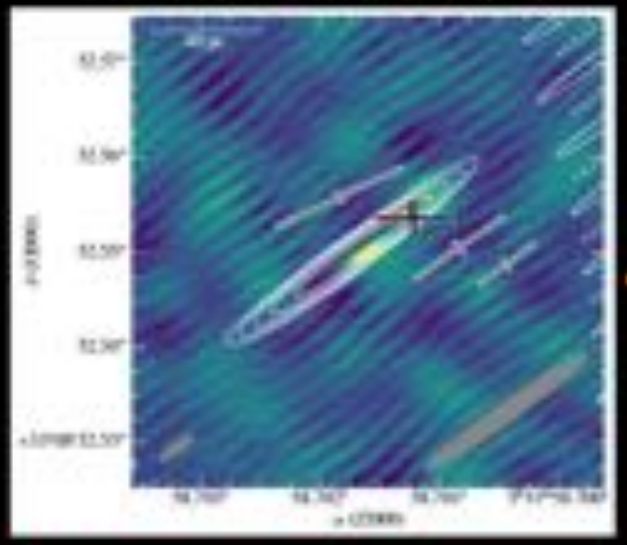
Tendulkar et al. (2017)



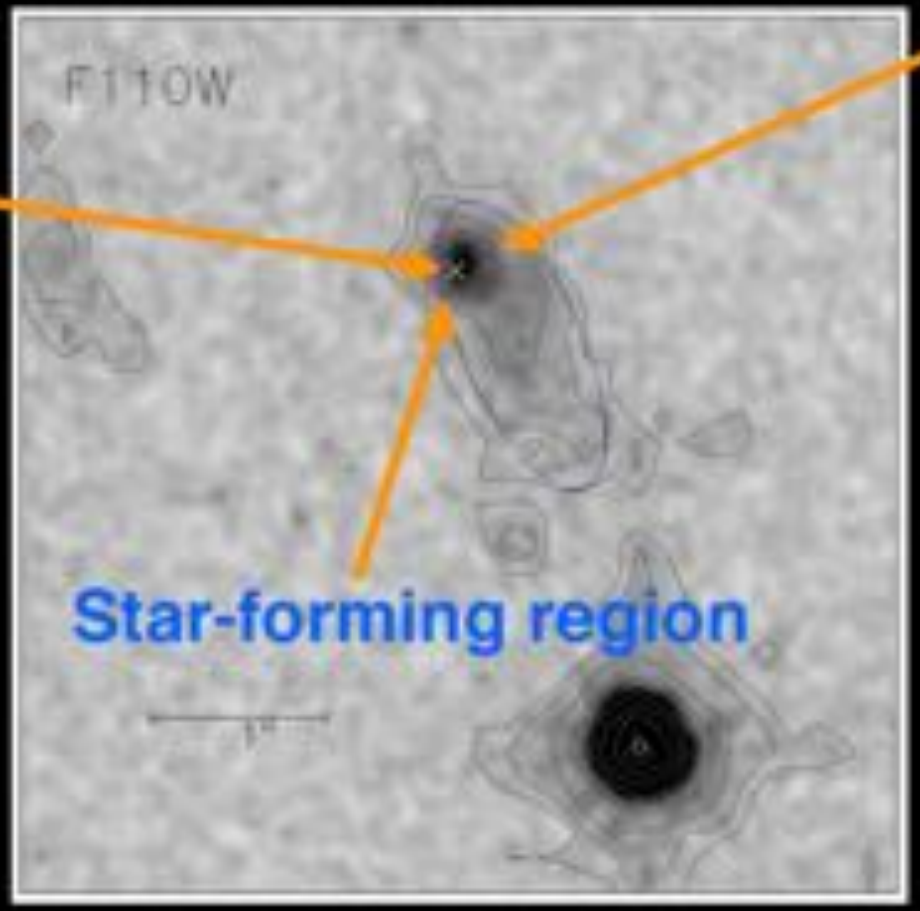
Bassa et al. (2017)

FRB 121102: host and local enviroment

Marcote, Paragi, JH et al. 2017

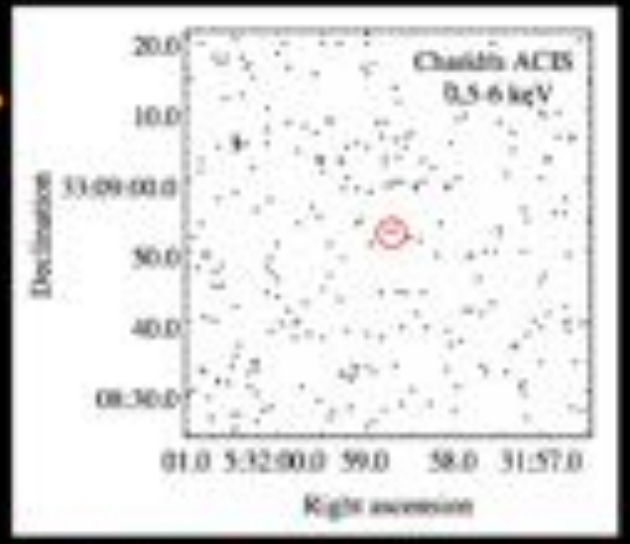


Compact radio source



Bassa et al. 2017

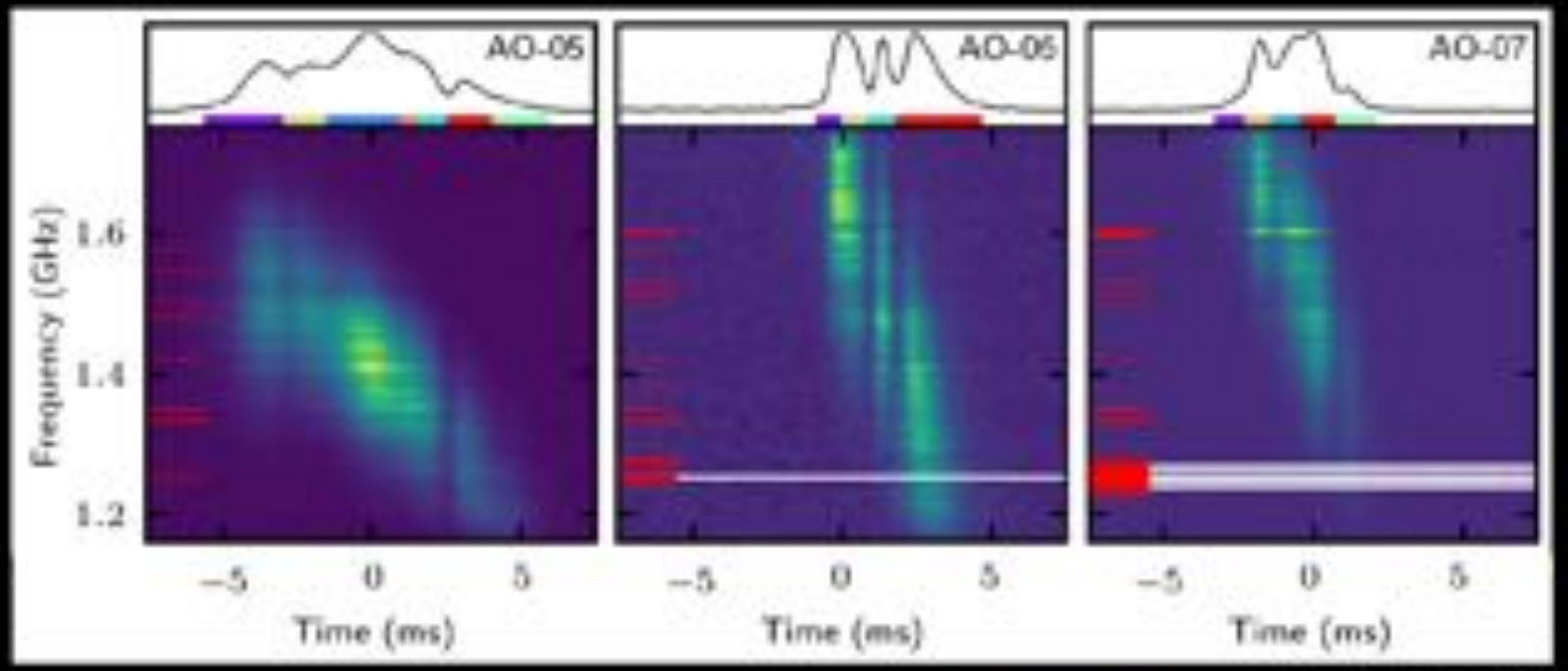
Scholz, Bogdanov, JH et al. 2017



No X-rays or gamma-rays

- Dwarf Galaxy
- High star formation
- Enigmatic persistent source

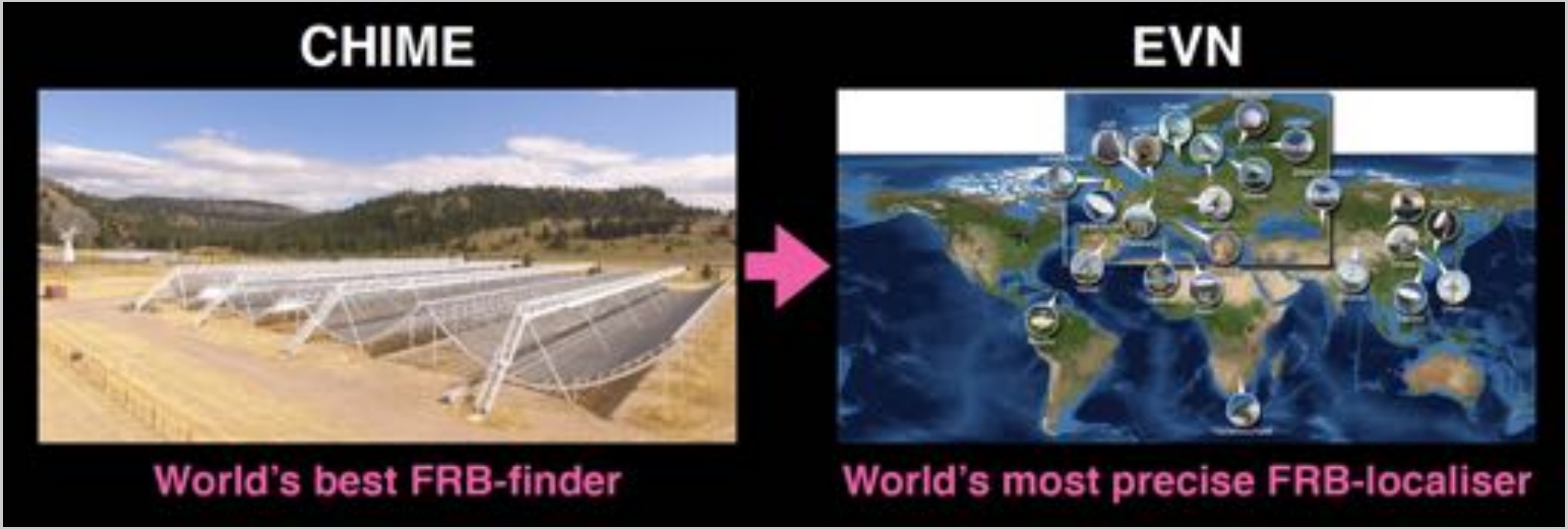
Burst show complex time-frequency structure

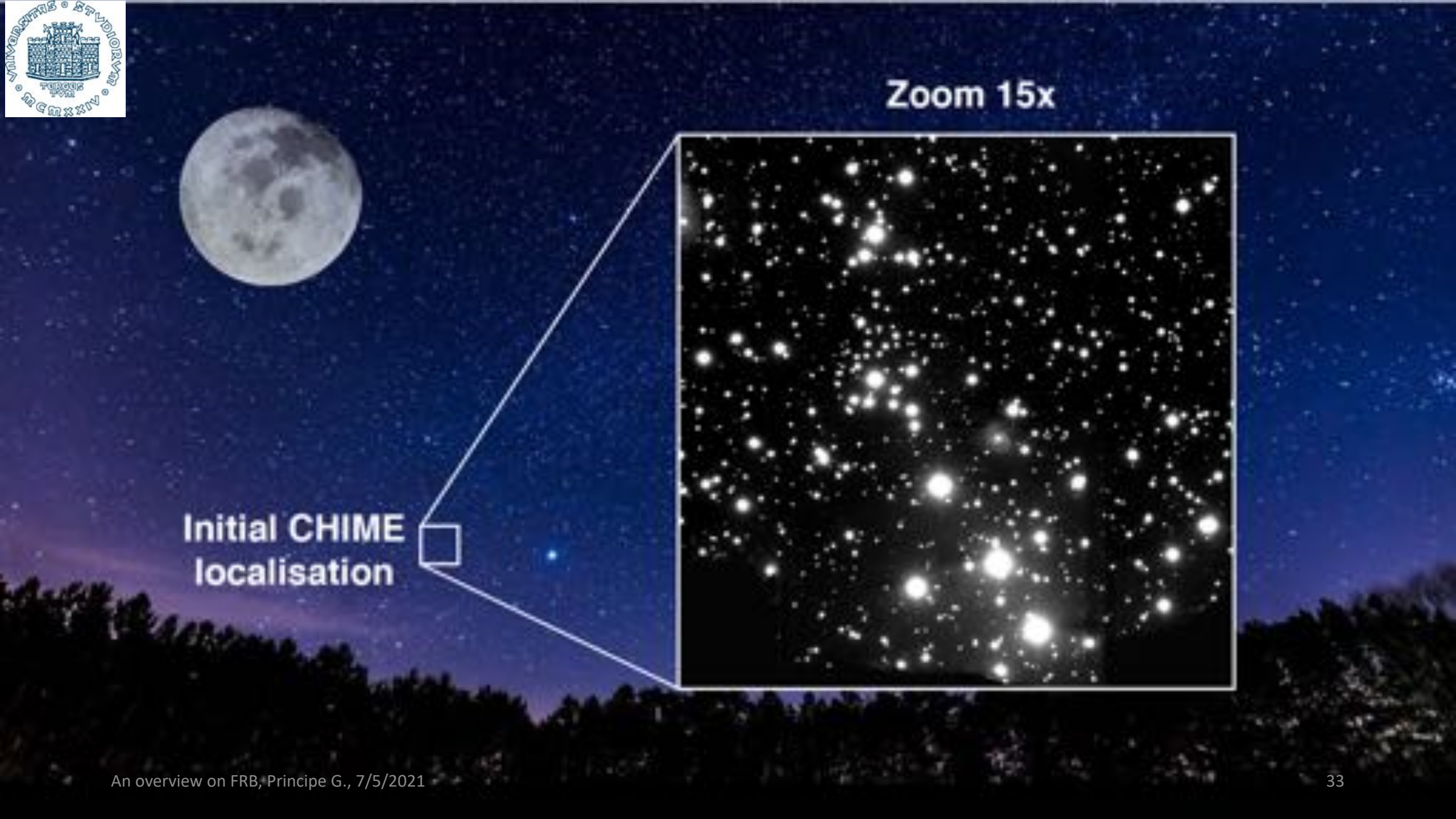


Hessels et al. 2019

Sad trombones

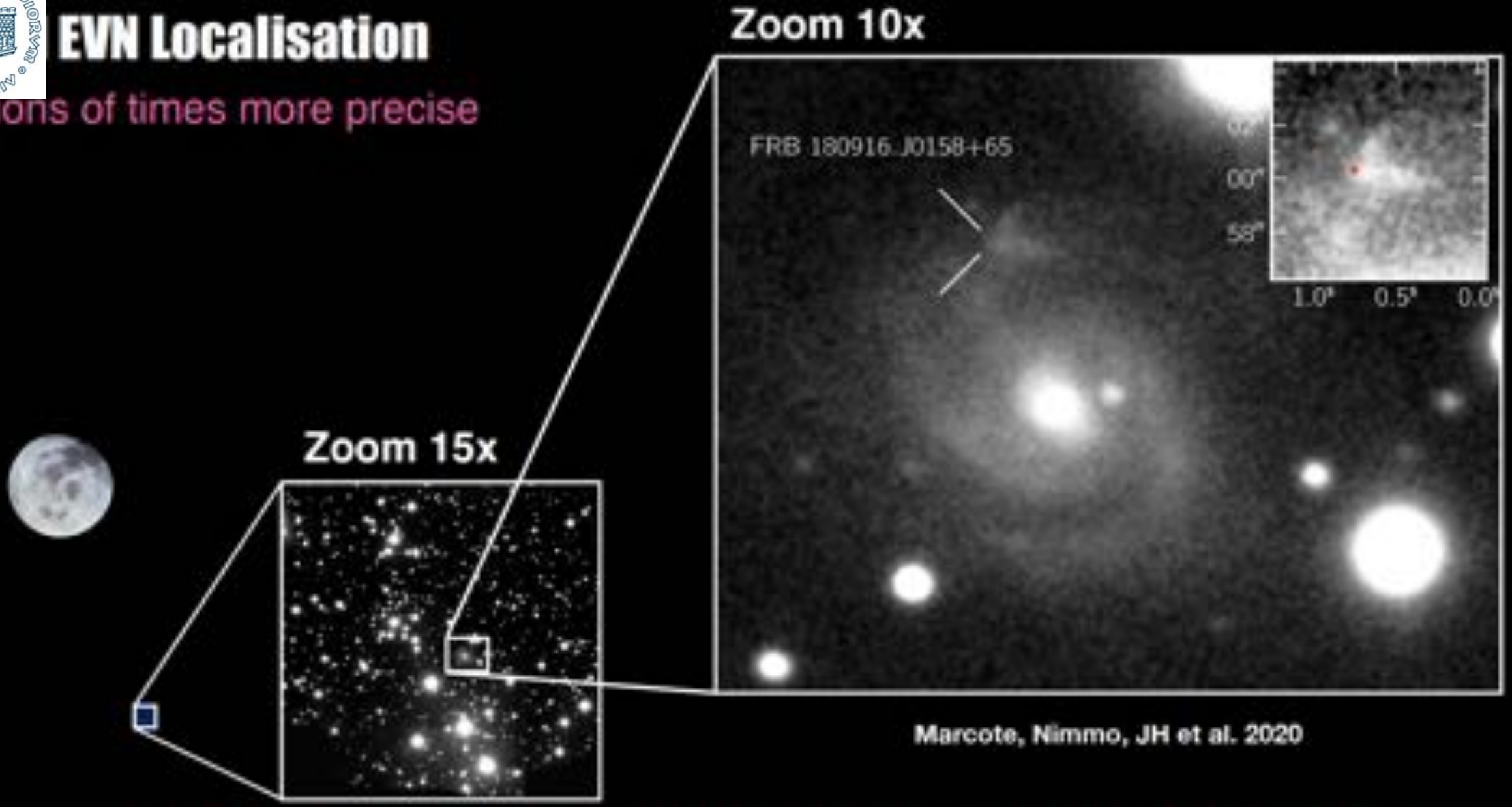
Let’s localise FRB 180916.J0158+65




Zoom 15x
Initial CHIME
localisation

EVN Localisation

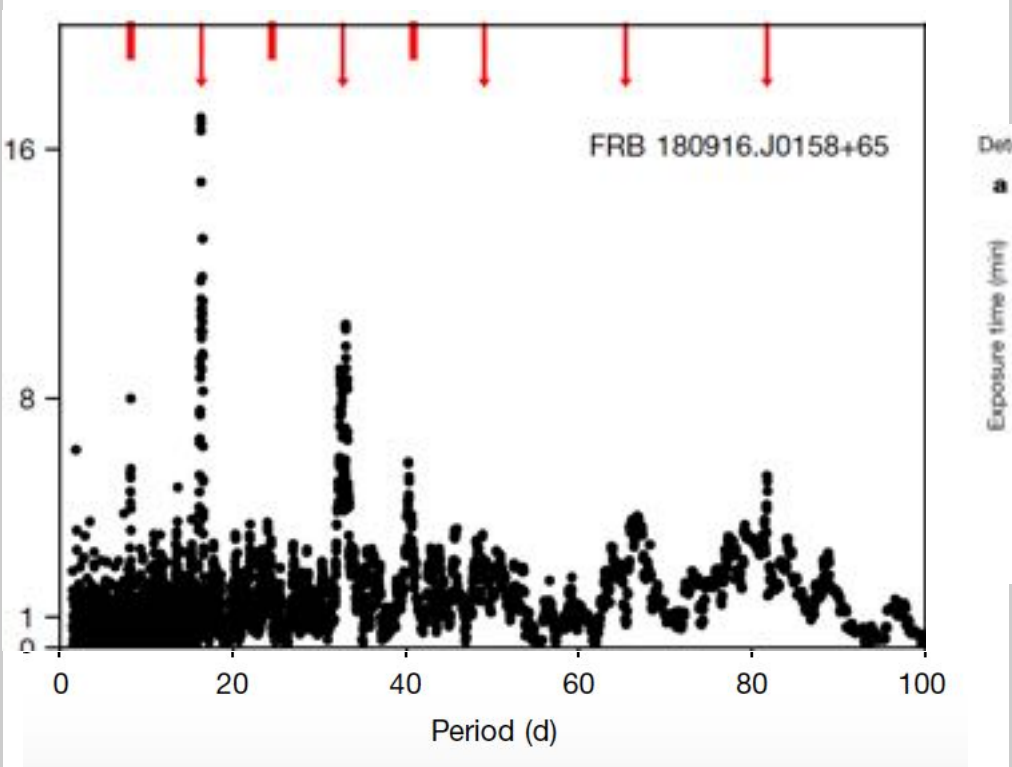
Billions of times more precise

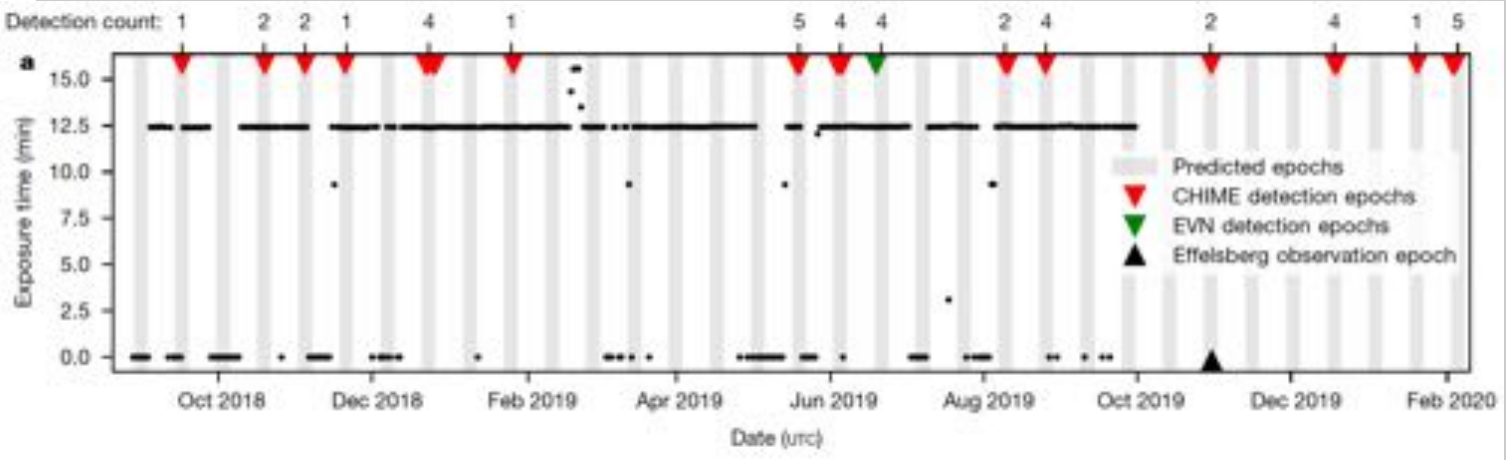


...and the source becomes active every 16.3 days?!

An observed periodicity

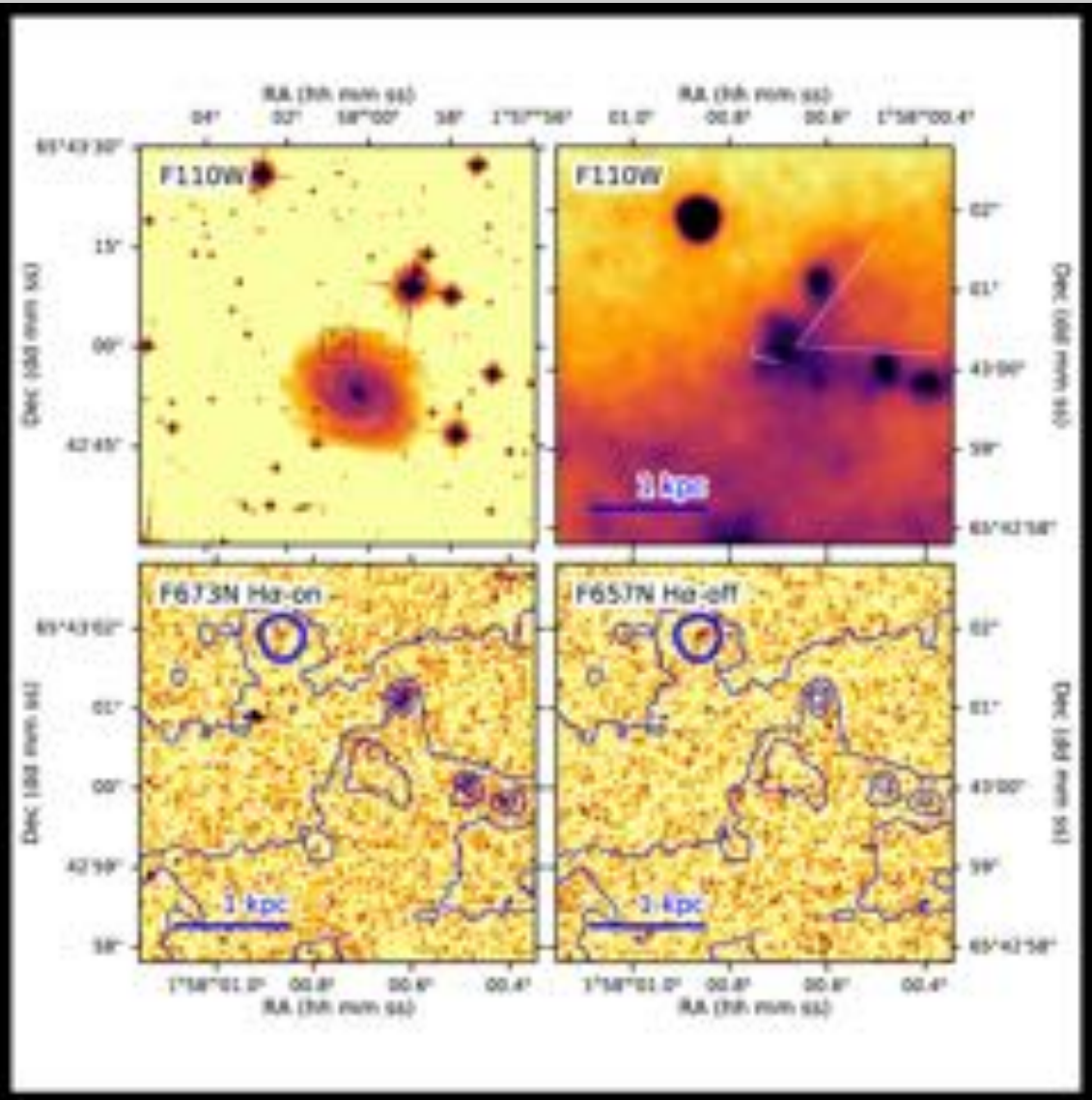
FRB 180916: detection of a 16.35 ± 0.15 day periodicity (or possibly higher frequencies). In 38bursts recorded from September 16th, 2018 through February 4th, 2020, we find that all bursts arrive in a 5-day phase window, and 50% of the bursts arrive in a 0.6-day phase window.

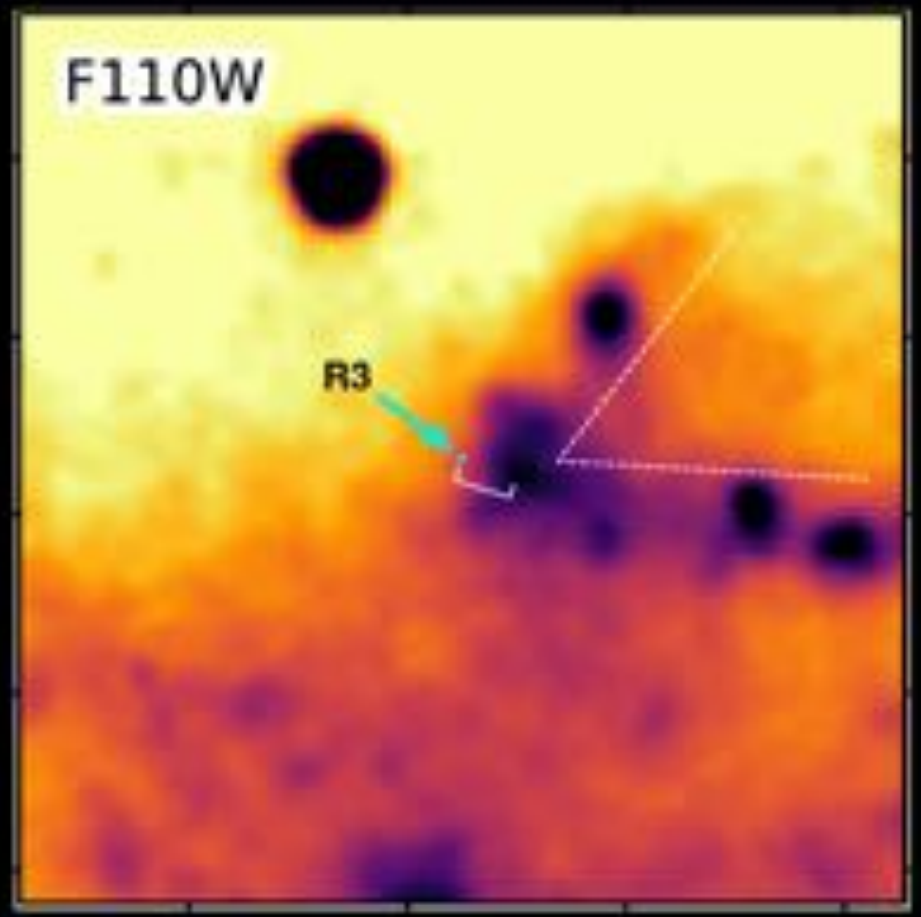




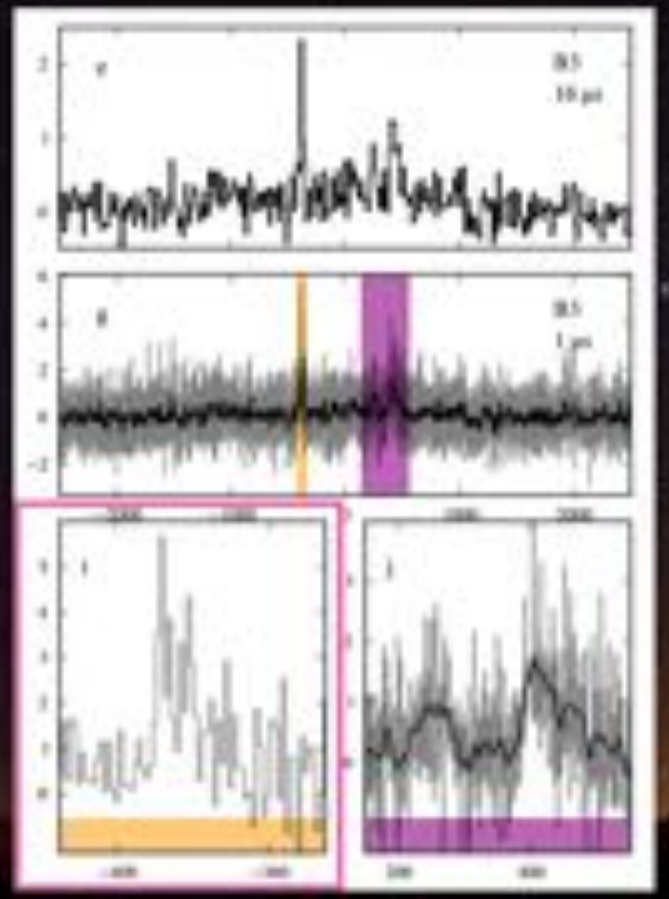
CHIME Collaboration, Nature; June 2020

HST 60-90 mas imaging of an FRB host





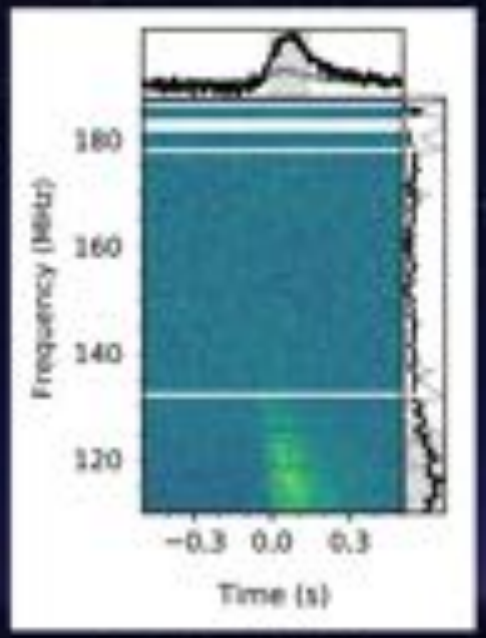
Tendulkar, Gil de Paz, Kirichenko, JH et al. 2021



Nimmo, JH et al. 2021

Zooming in at microsecond resolution

Probe ultra-low frequencies



Pleunis et al. 2021
(see also Pastor-Marazuela et al.)

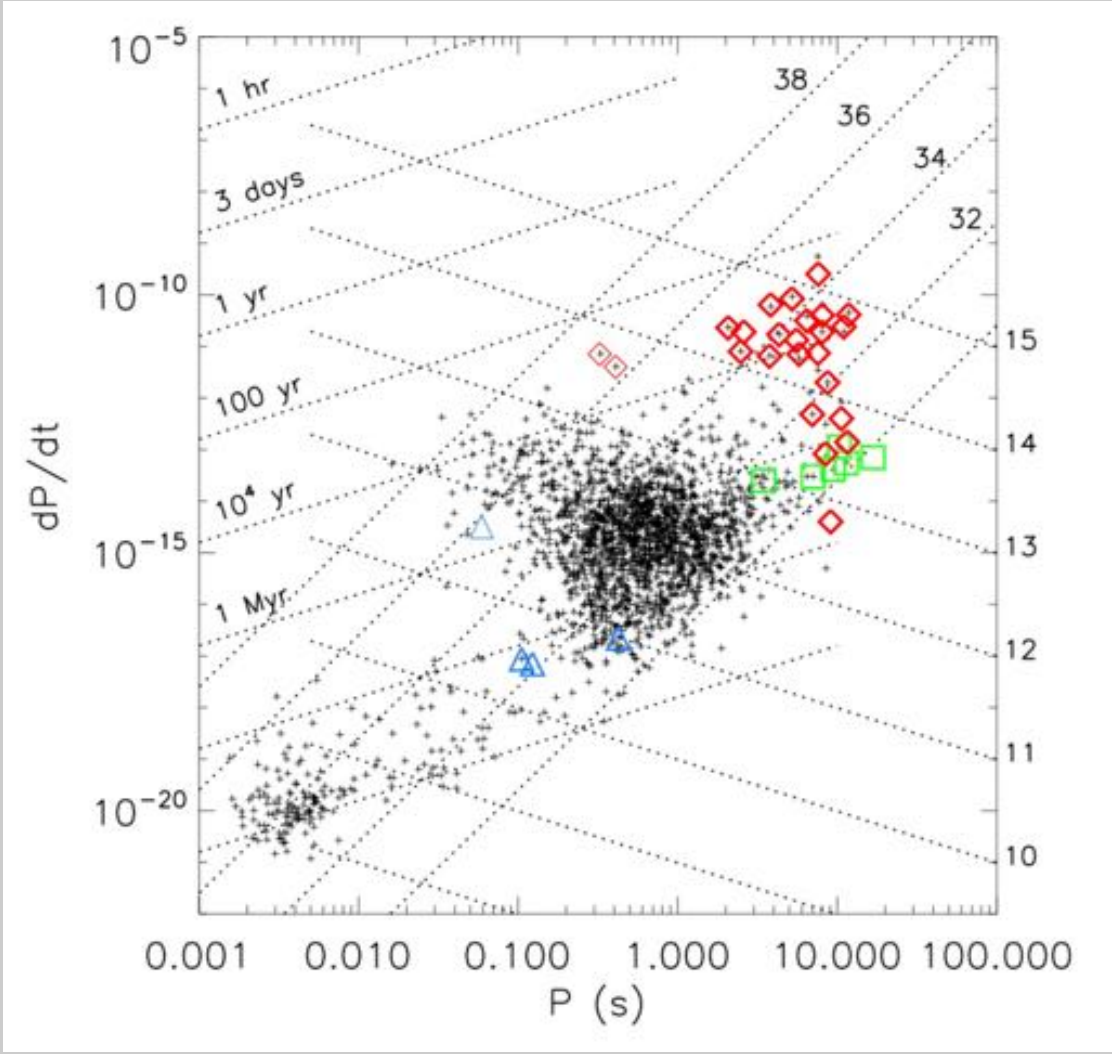
Image credit: Danielle Futselaar

A Galactic FRB

Magnetar – Fast Radio Burst connection ??

Magnetars

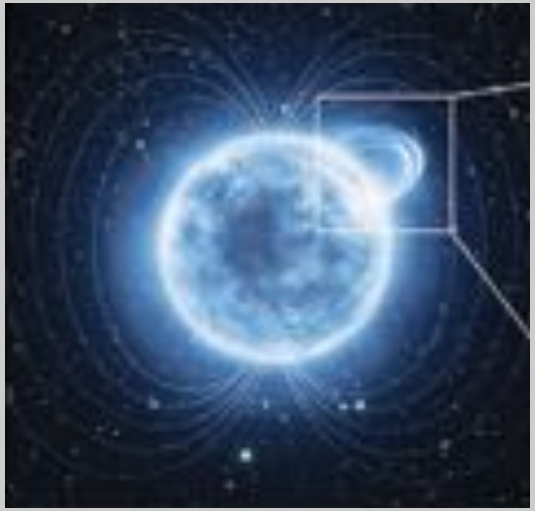
- (Isolated) *neutron stars powered by magnetic energy* (B~10^{15} G)
- *Slowly rotating* (P ~ 1-12 s),
  and fast spin-down (dP/dt ~10^{-10} –10^{-11} s/s)
- $dE_{rot}/dt < L_x \approx$ 1034-1036 erg/s
- many are transients ($L_{QUIESC} \approx 10^{32-33}$ erg/s)
- emit short hard X-ray bursts and (rare) Giant Flares
- ~30 known in Milky Way and Mag.Clouds



Kaspi+Beloborodov 2017; Mereghetti+ 2015; Turolla+ 2015

A Galactic FRBc

Magnetar



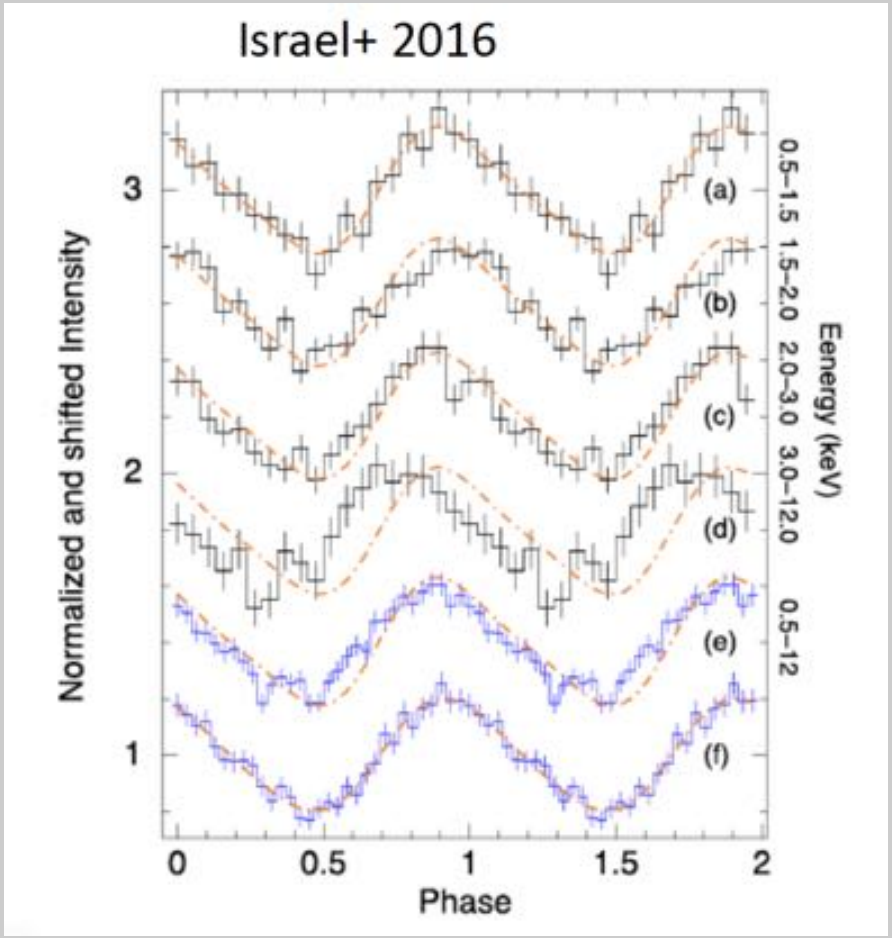
?

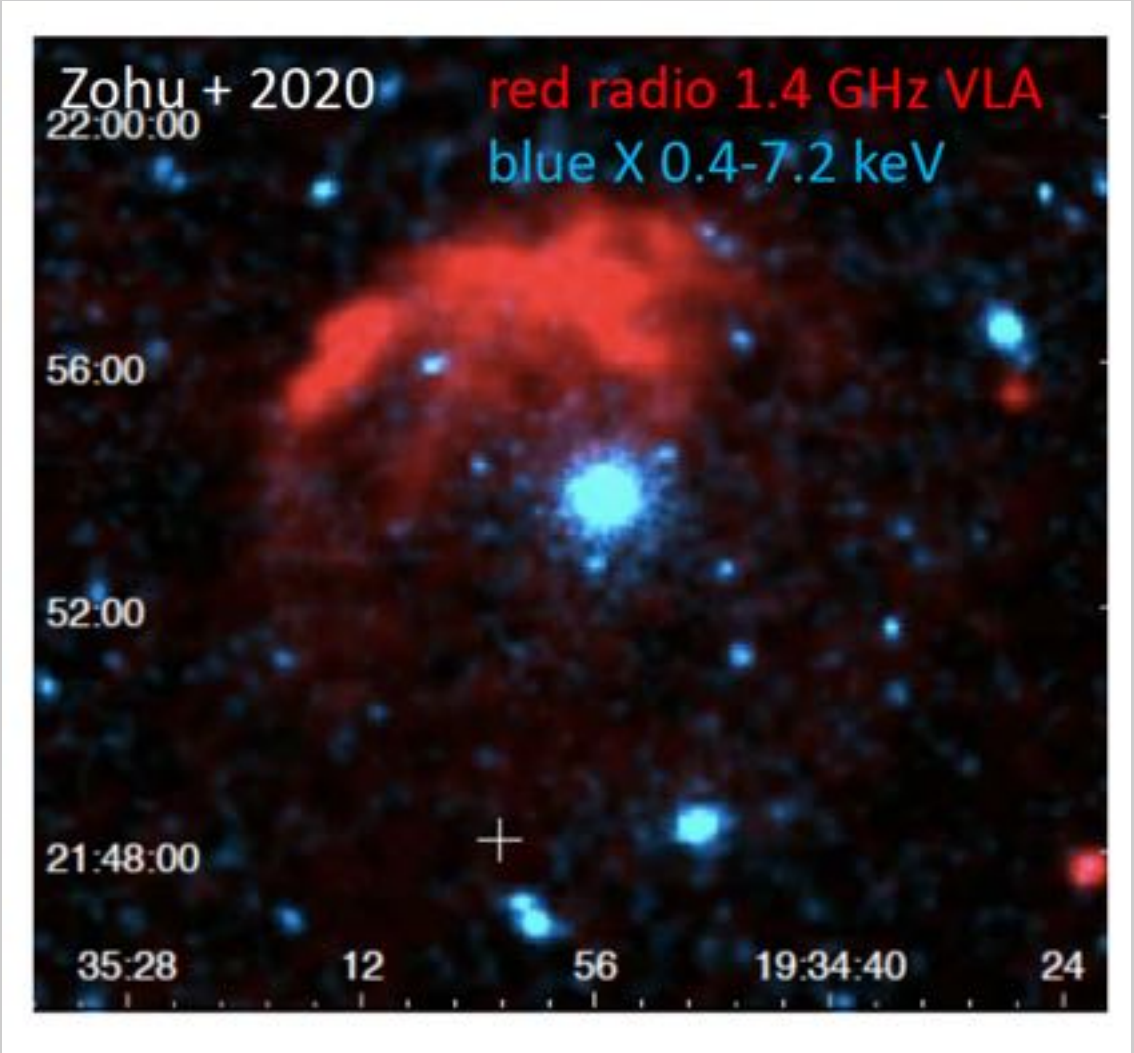
FRB

- Several indirect indications
- No direct observational evidence, until recently…

SGR 1935+2154: an ``ordinary'' magnetar....

P = 3.24 s
B = 2.2 x 10^{14} Gauss
t = 3600 years
Spin-down lum. = 2 x 10^{34} erg/s

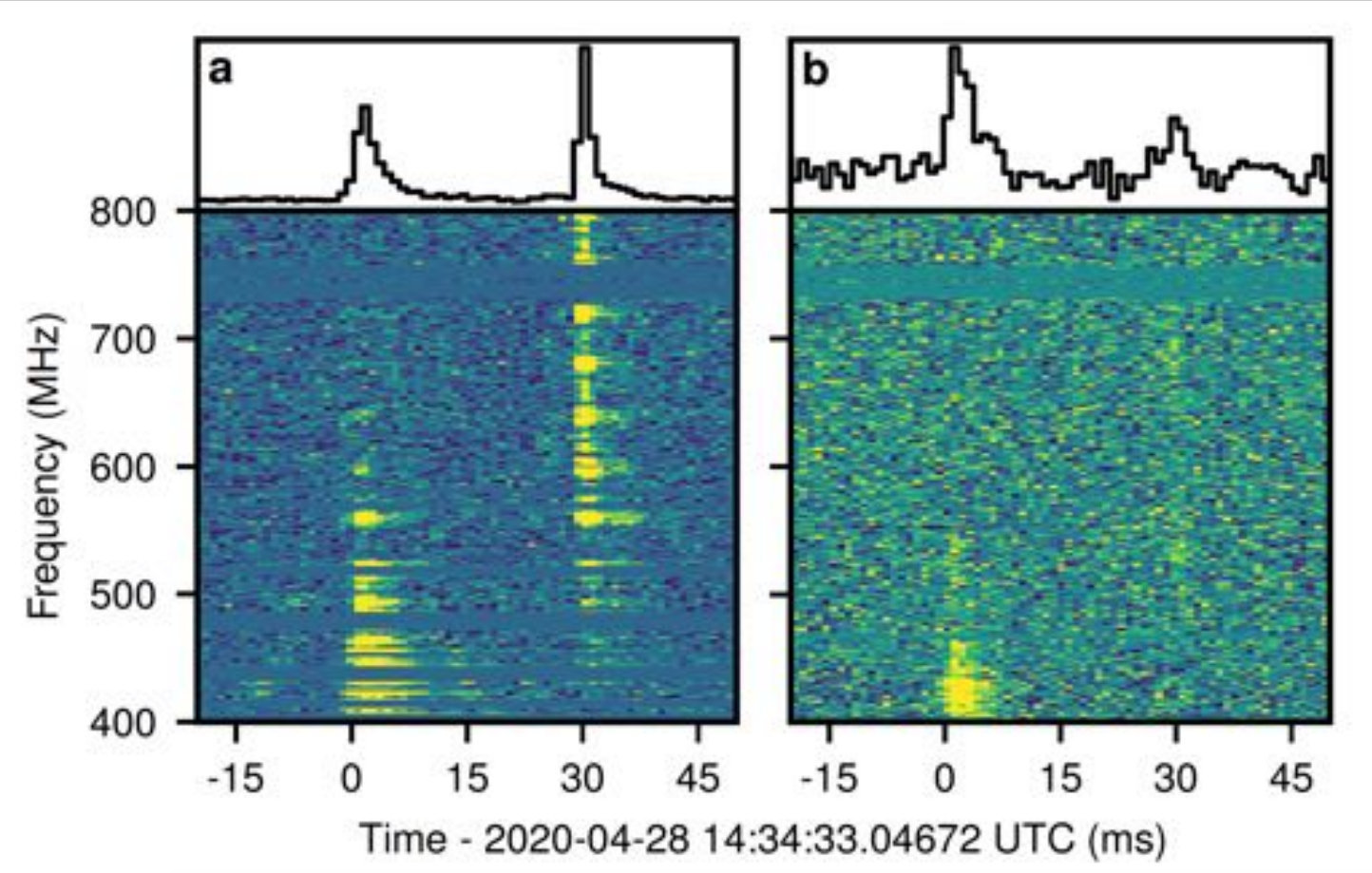




``FRB-like'' radio burst of April 28, 2020

CHIME 400-800 MHz:
two pulses (0.6, 0.3 ms) separated by 29 ms
Fluence 480 and 220 kilo-Jansky ms

STARE2 1.4 GHz:
one pulse (= 2nd CHIME pulse)
Fluence 1.5 +/-0.3 Mega-Jansky ms



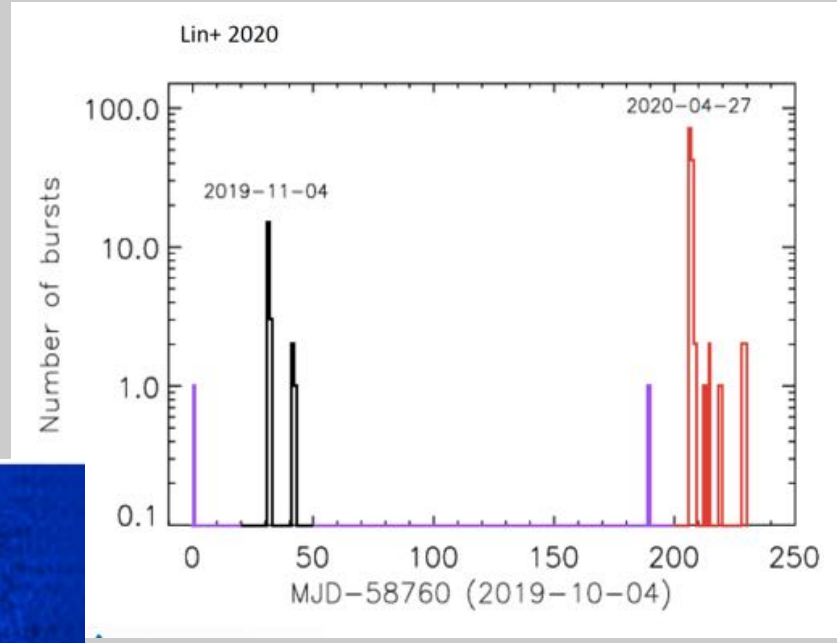
Localized with ~1 deg accuracy at position of SGR 1935+2154

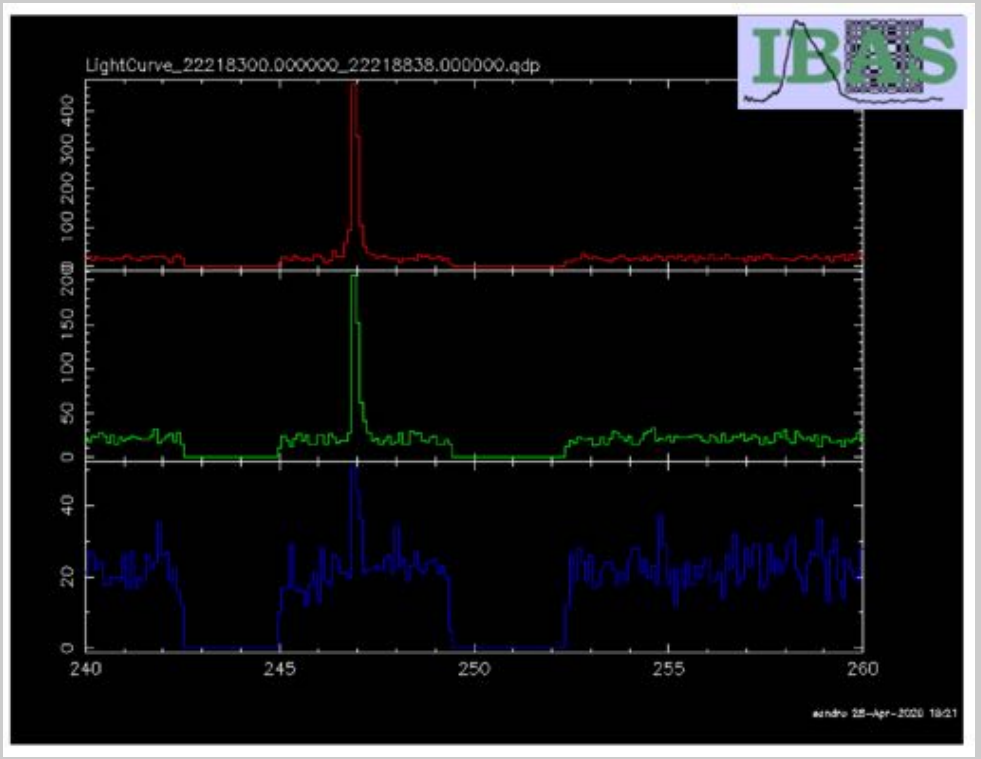
DM = 332.7 pc/cm3 < $DM_{Milky\ Way}$ (= 500-700 pc/cm3)

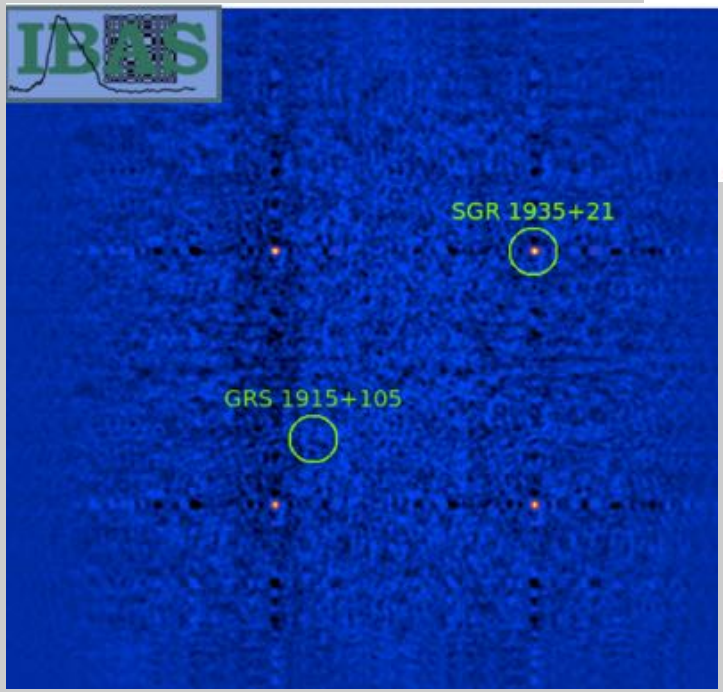
X-ray observations

SGR 1935+2154 was very active in April 2020
observed by several X/ (low energy) gamma satellites

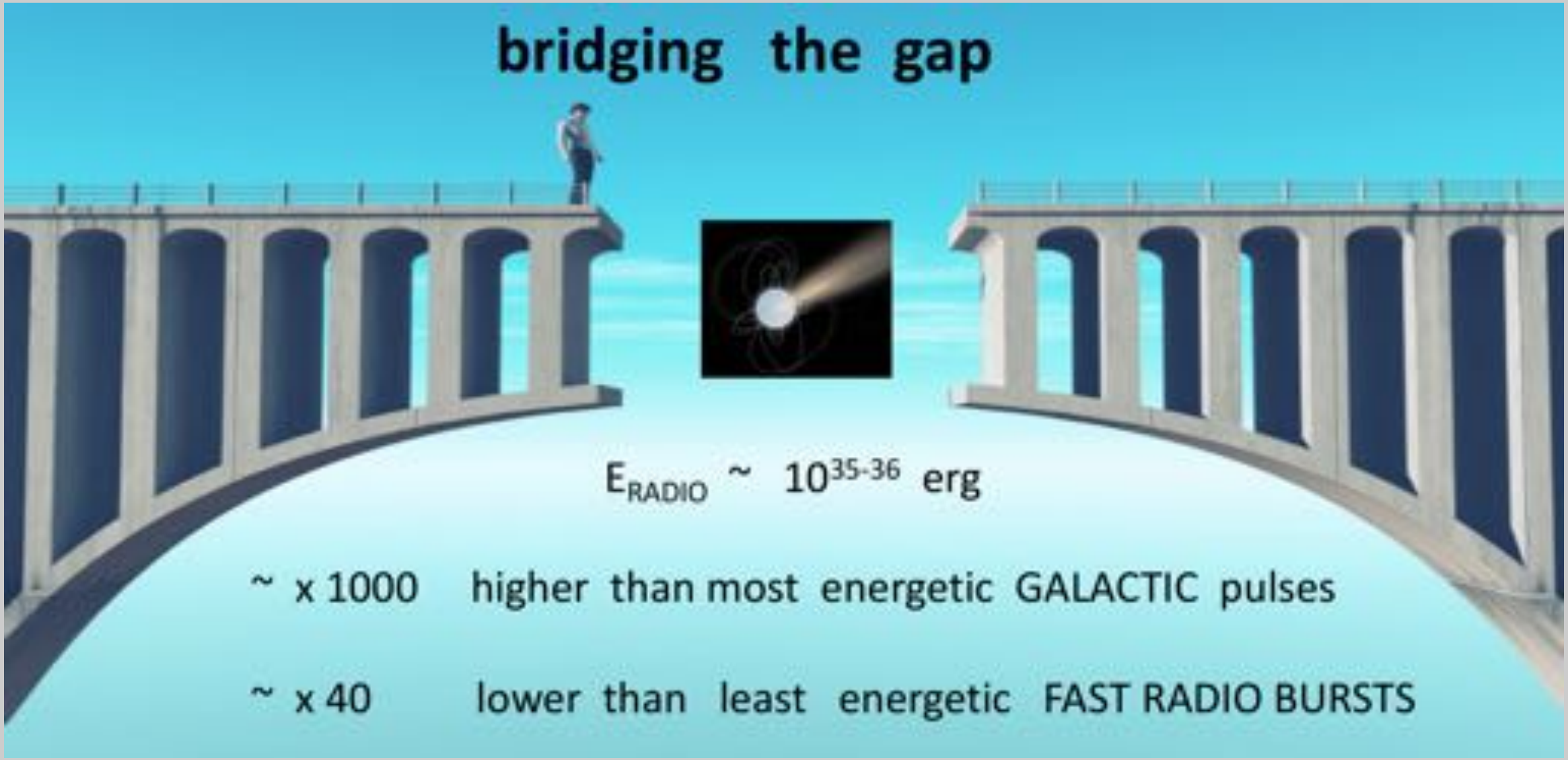
… an extraordinary event on April 28, 2020
INTEGRAL Burst Alert system (IBAS) Alert distributed after ~ 5 s with correct source identification







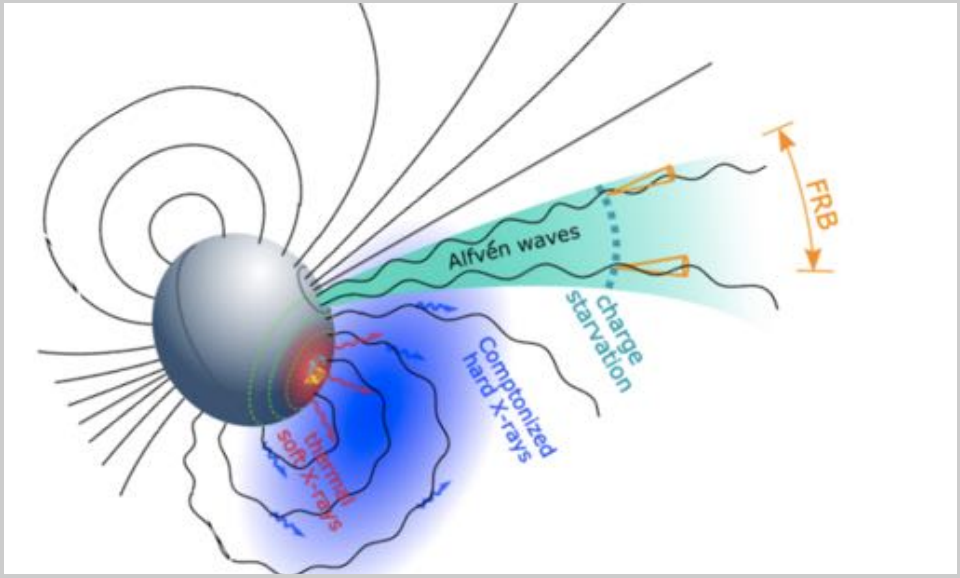
SGR 1935+2154 - Magnetar vs FRB



Two main classes of models

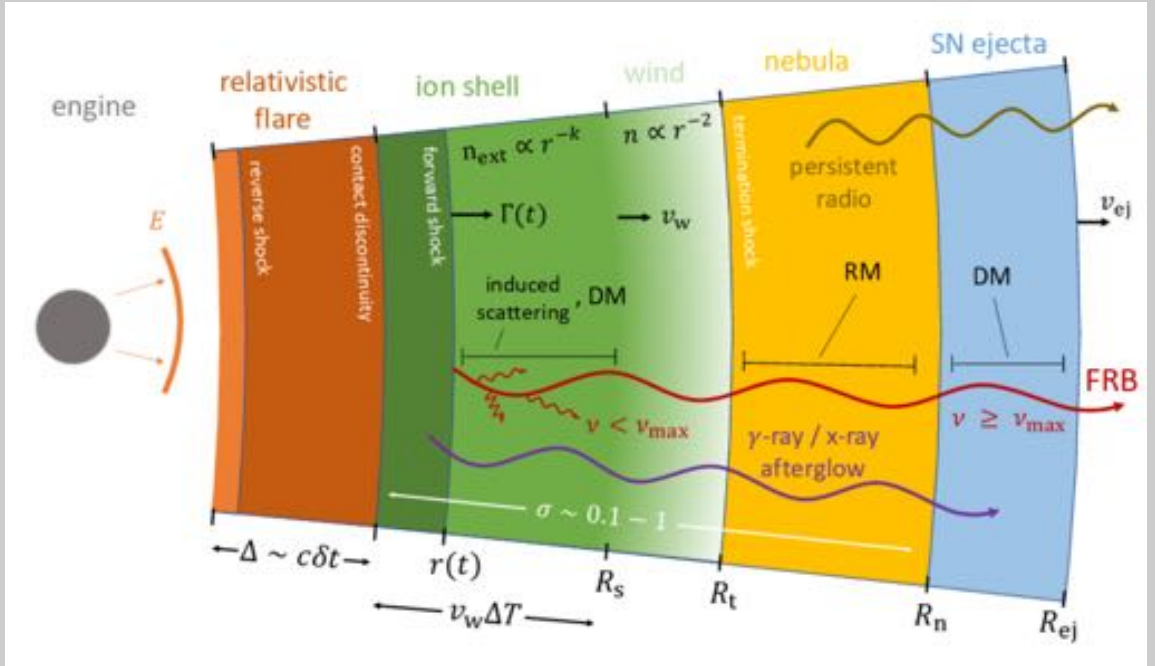
$R < R_{LC}$ - emission in magnetosphere

[e.g., Pen & Connor 2015; Cordes & Wasserman 2016; Lyutikov + 2016; Kumar+ 2017; Zhang 2017; Lu & Kumar 2018; Yang & Zhang 2018; Kumar & Bosnjak 2020]



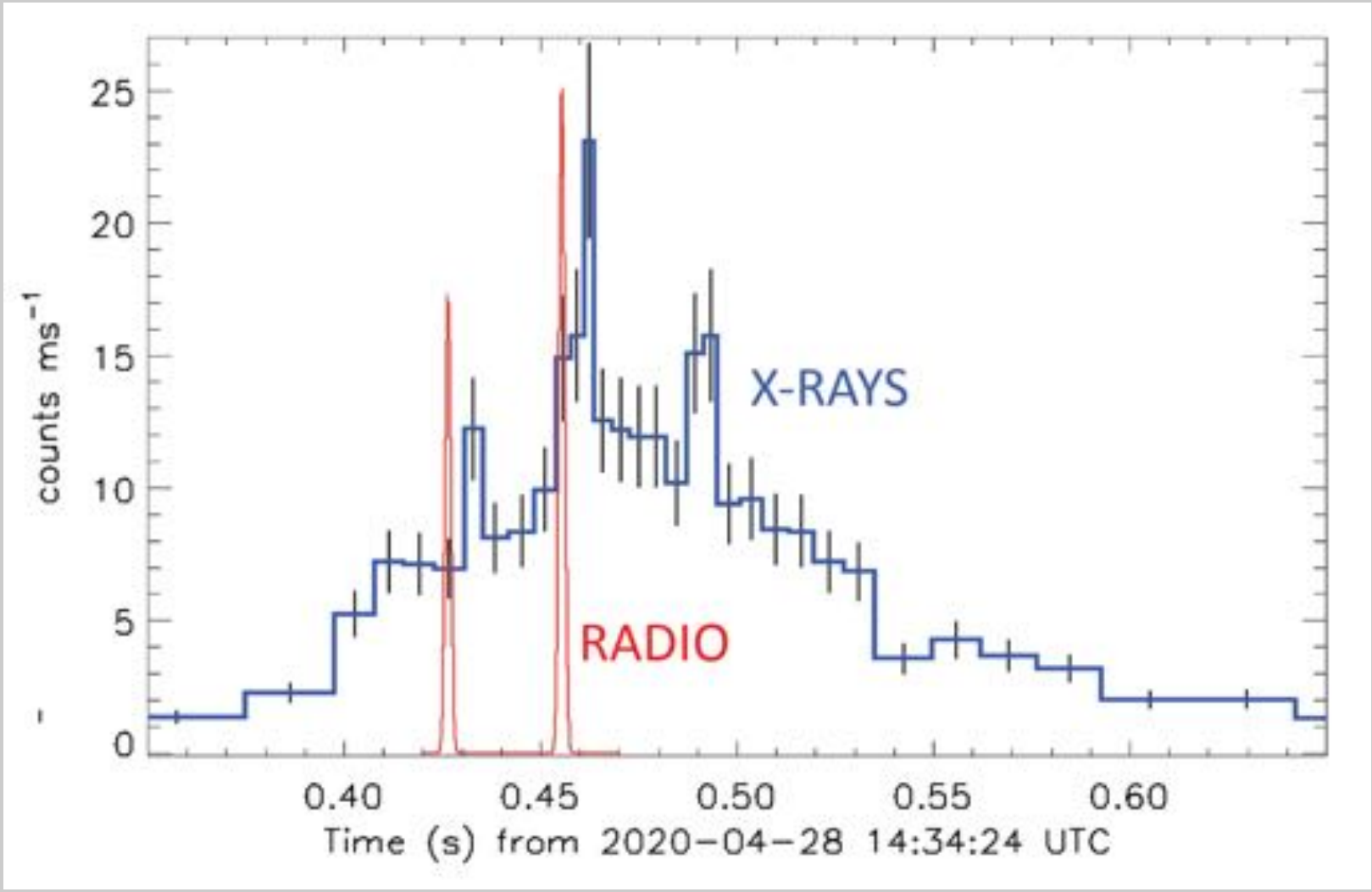
$R >> R_{LC}$ - emission in relativistic outflow interacting with surrounding medium at R ~$10^{13\text{-}15}$ cm

[e.g. Lyubarsky 2014; Waxman 2017; Beloborodov 2017, 2019; Metzger+ 2019; Margalit+ 2020]



FRB origin

INTEGRAL 20-200 keV light curve



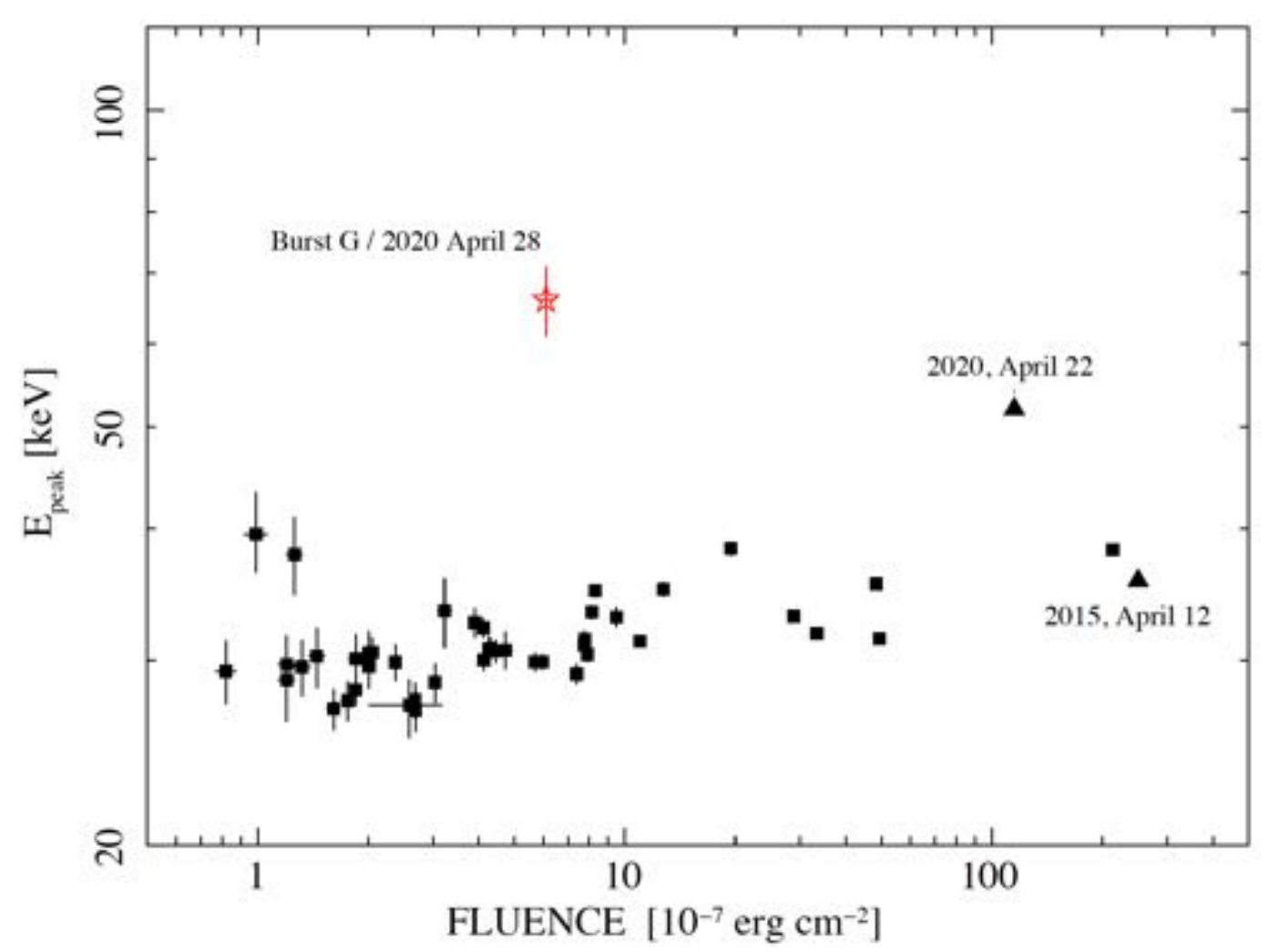
Broad X-ray pulse starts before the radio

Narrow X-ray spikes delayed by ~6 ms

The lightcurve shows three narrow peaks separated by 29 ms time intervals, superimposed on a broad pulse lasting 0.6 s. The brightest peak had a delay of 6.51.0 ms with respect to the 1.4 GHz radio pulse

FRB origin

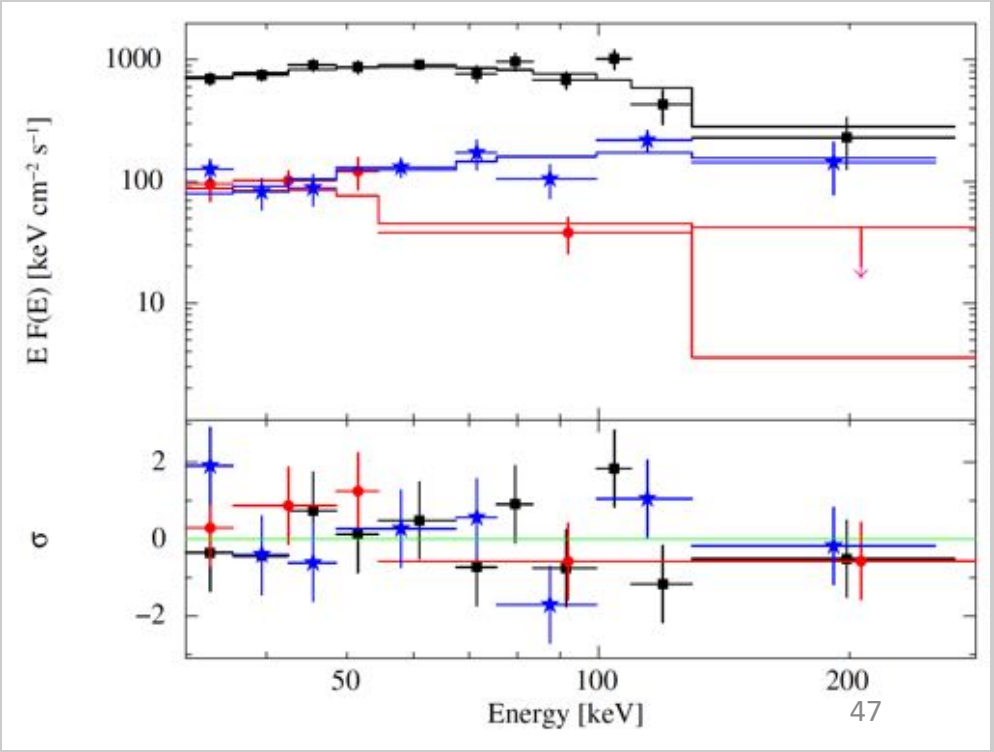
Mereghetti et al. (2020)



Not particularly energetic but significantly harder than 'normal' bursts from SGR 1935+2154

Exponentially cut-off power law
(G = 0.7 +/- 0.3 E_{peak} = 65 +/- 5 keV)

Peak luminosity ~ 10^{40} erg /s
isotropic en. emission ~ 1.4 10^{39} erg (@ 4.4 kpc)



Lesson learnt with SGR 1935+2154

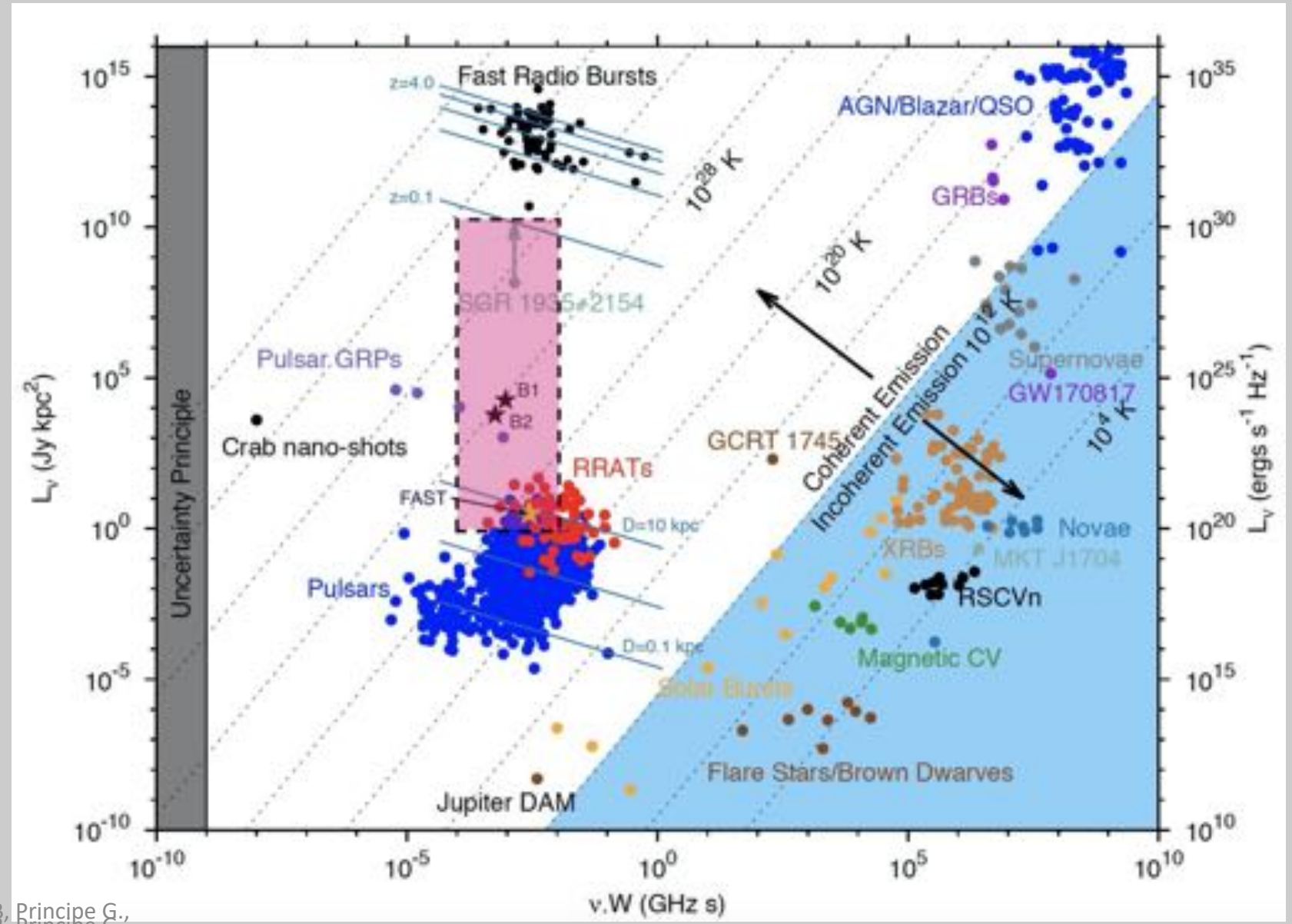
First detection of a ''FRB-like'' radio burst from a magnetar

- X-ray luminosity not exceptional , but harder spectrum
- Two types of bursts? Radio loud / radio quiet - beaming effects ?
- Upper limits for other events imply a large range of LRADIO / LX

Radio luminosity exceptionally high for a Galactic source, but not far from that of the closest FRB

- Strong support to magnetar models for FRB

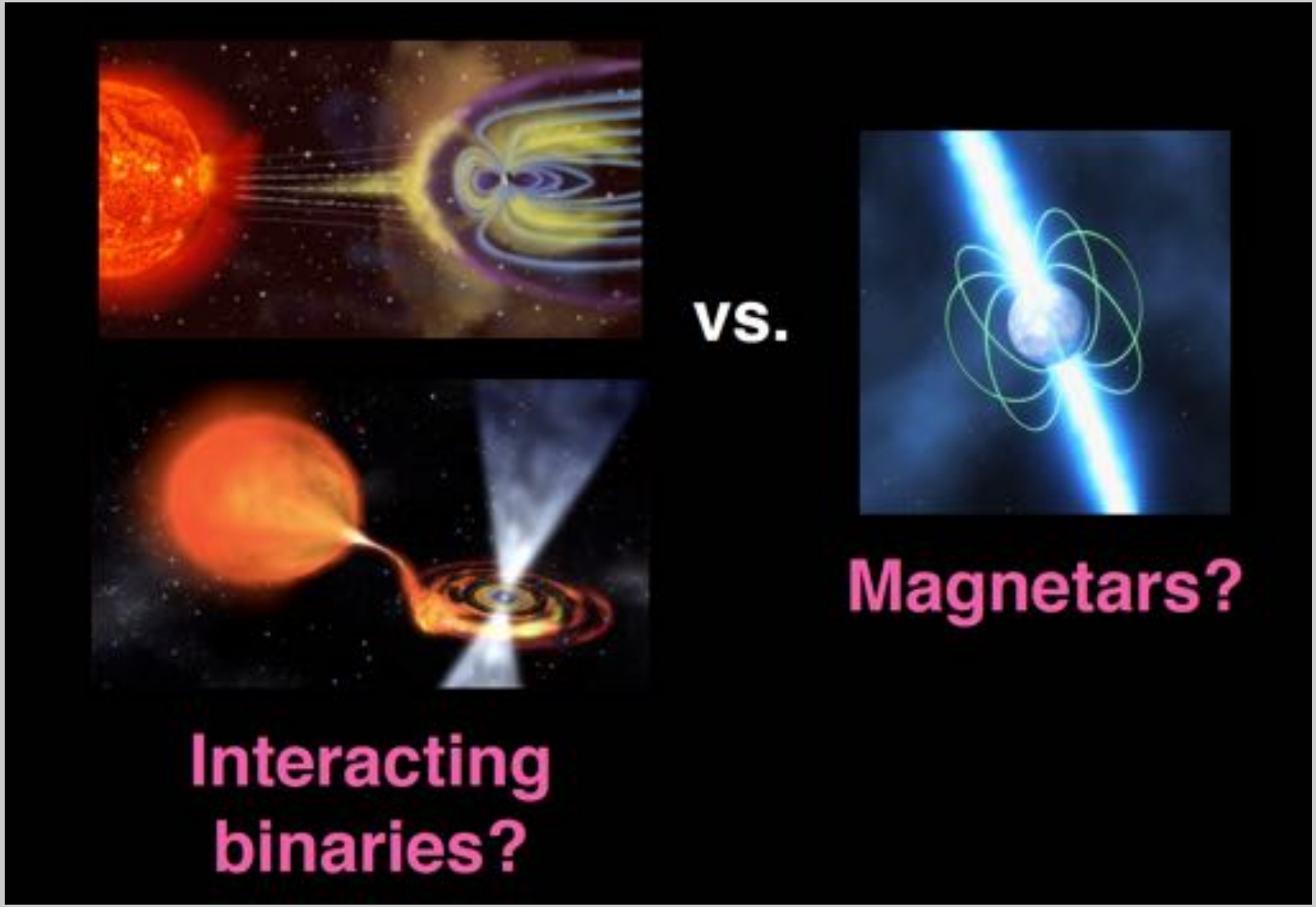
Bursts span 7 orders-of-magnitude in fluence



Jerskin+ (2020), Cordes+ (2019)

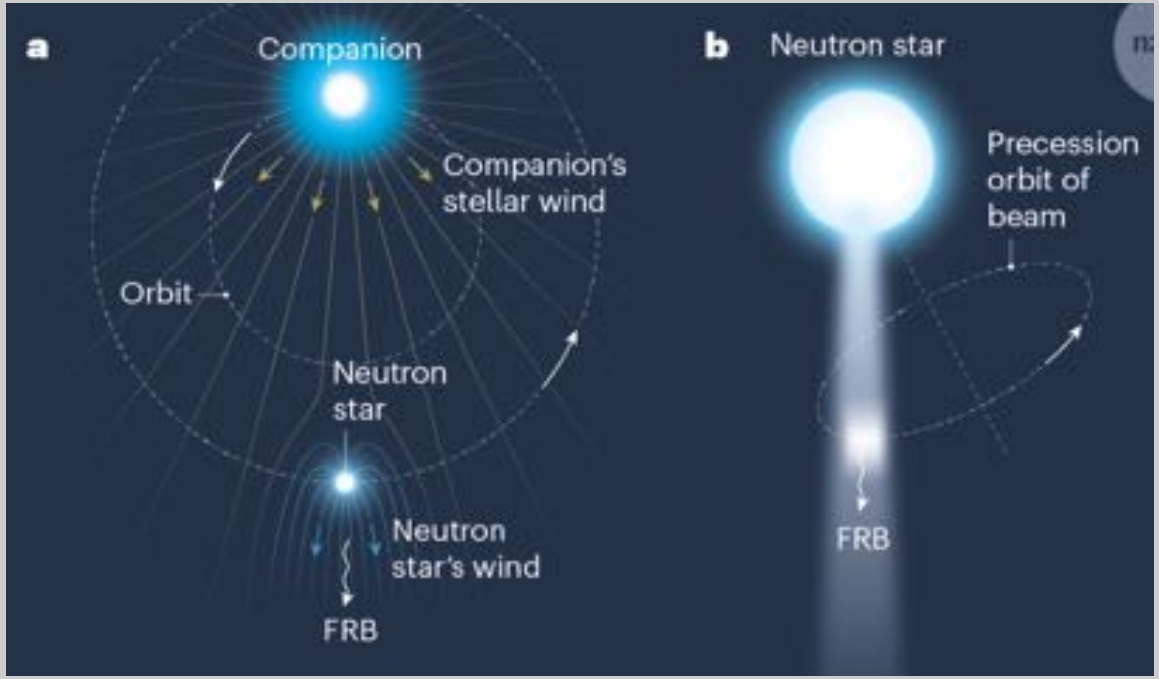
An overview on FRB, Principe G.

Repeaters vs non-repeaters

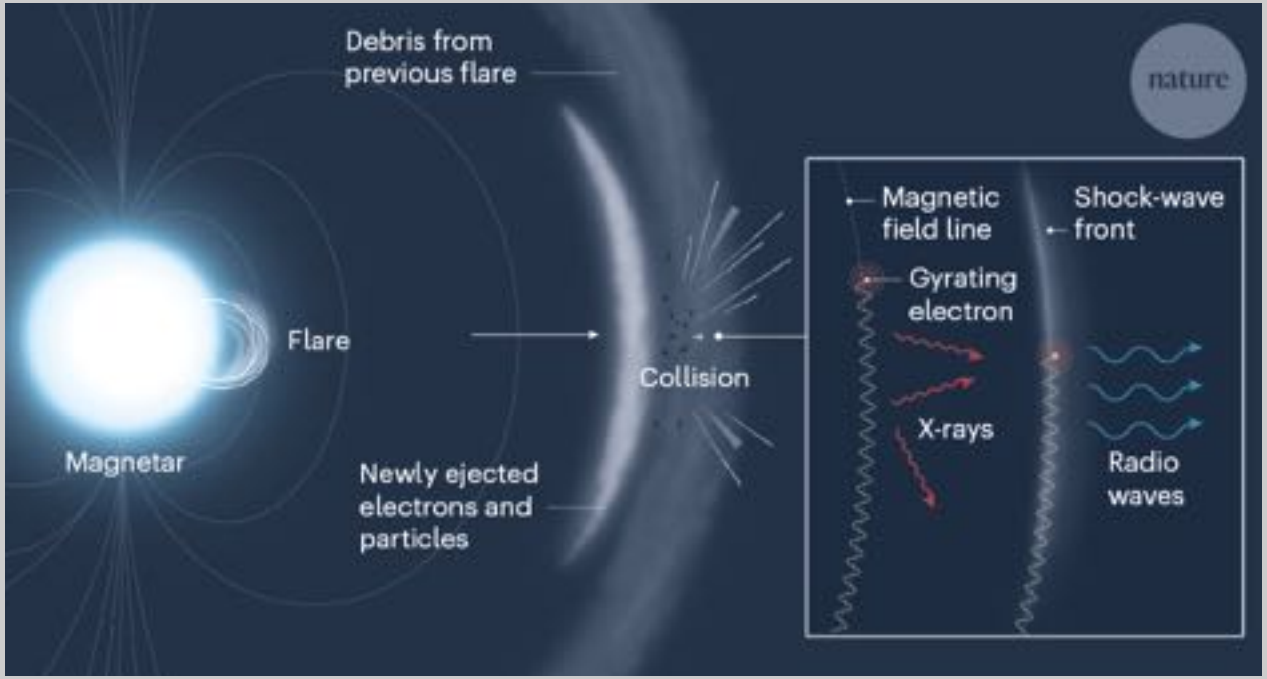


Repeaters vs non-repeaters

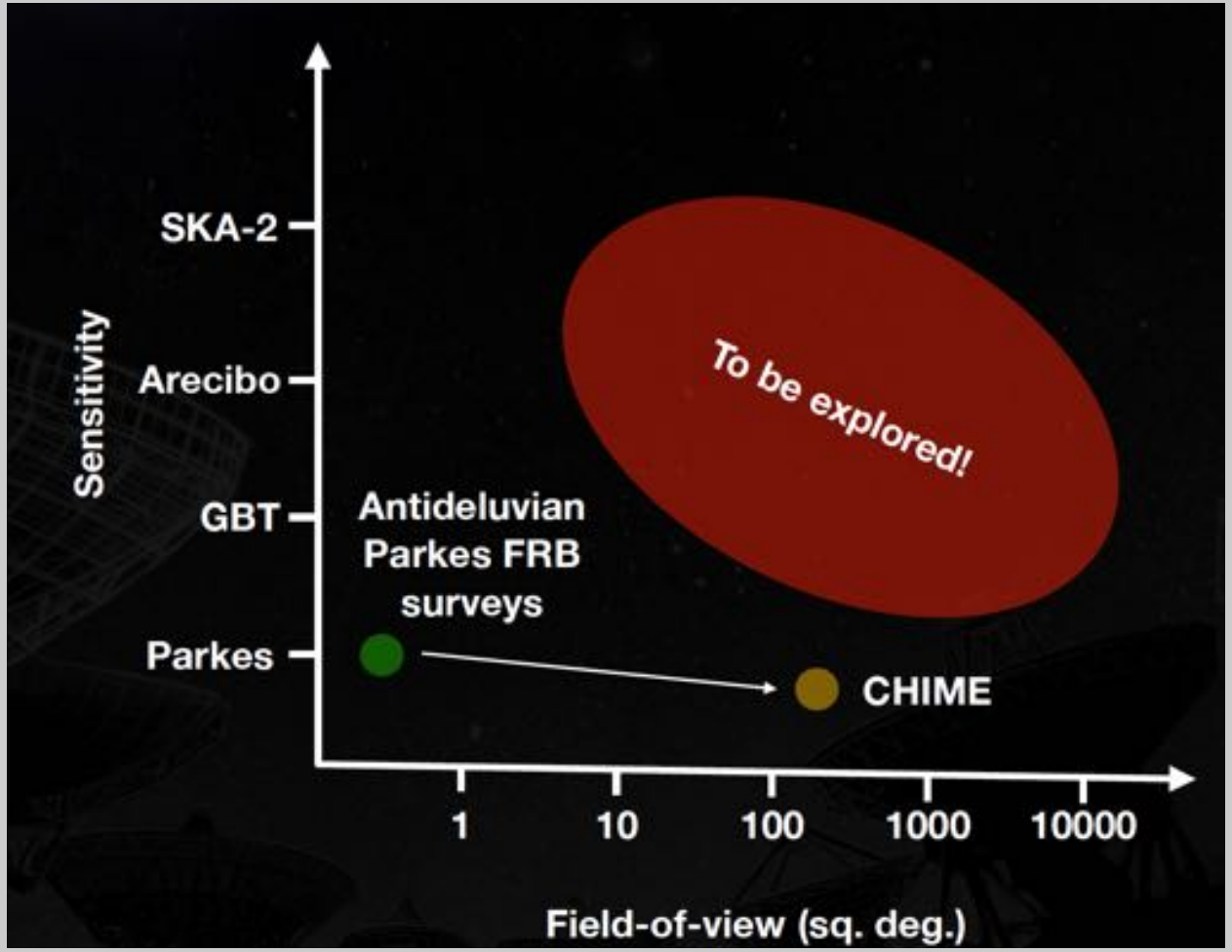
Interacting binaries



Magnetars



A look to the future



SKA

SKA:
high event rate
provides exceptional localisation precision.

Outlook

"Radio bursts are cheap!"
"FRB telescopes are cheap!"

A bright future for FRB is expected ;)