Understanding the origins of fast radio bursts through high resolution imaging

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Max-Planck-Institut
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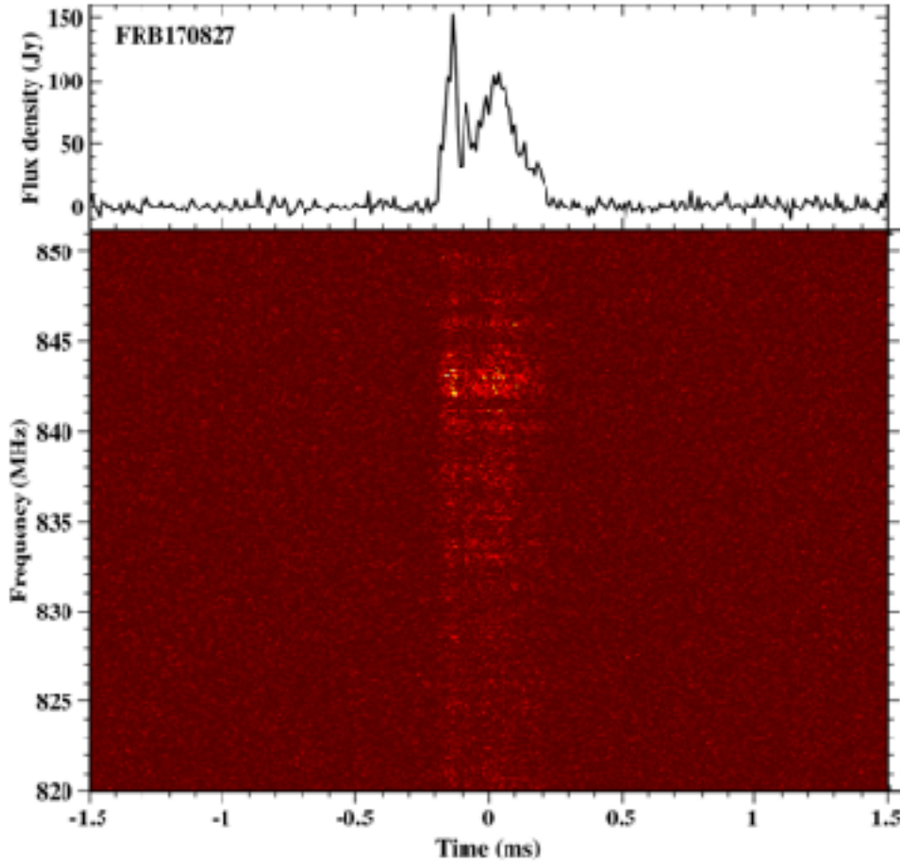
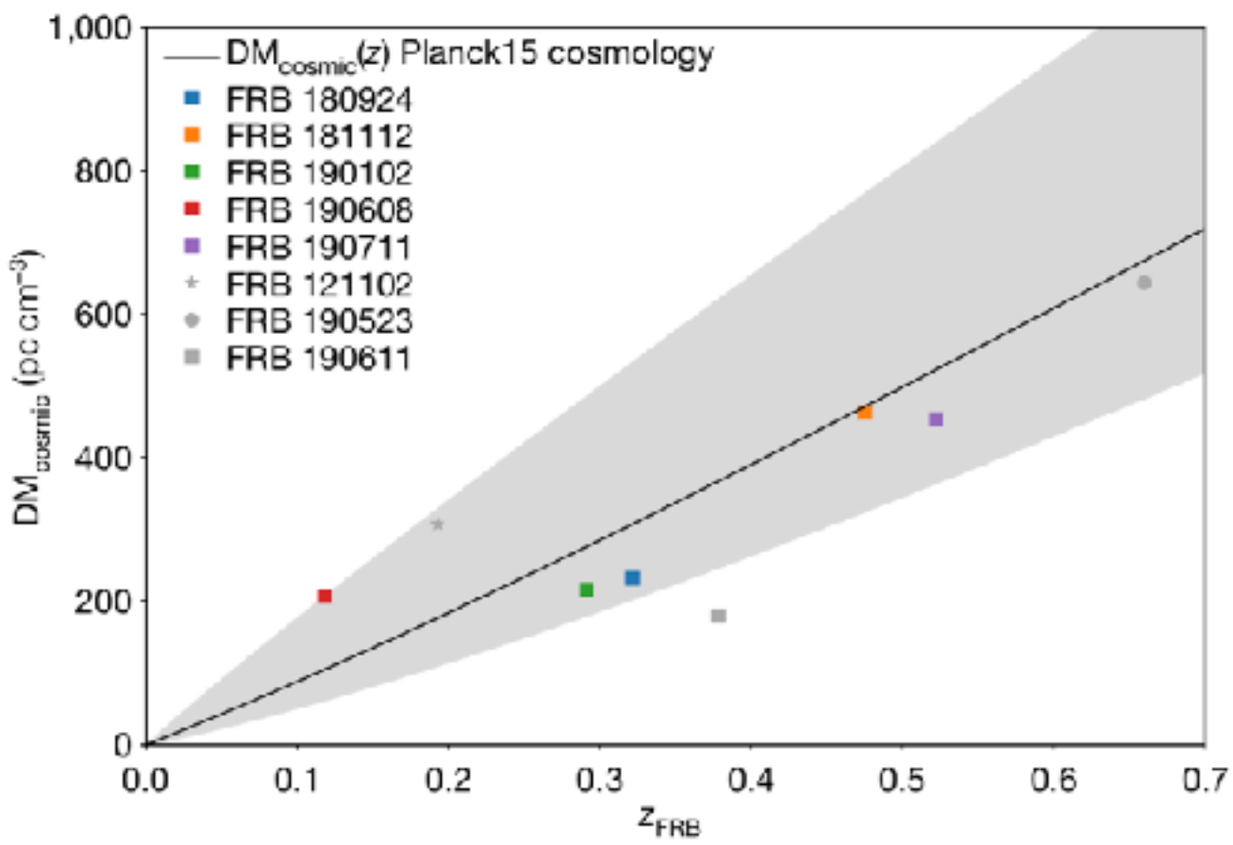
What are FRBs?

- **Bright, short duration flashes of coherent radio waves originating from so-far unidentified, extragalactic sources.**



Farah et al., MNRAS, 2018



Macquart et al., *Nature*, 2020

FRBs: the observational phenomenon

- The human experience is to expect a sky that is constant and predictable

- The FRB experience is a sky that is dynamic and almost entirely unpredictable

    - The sky is mostly empty

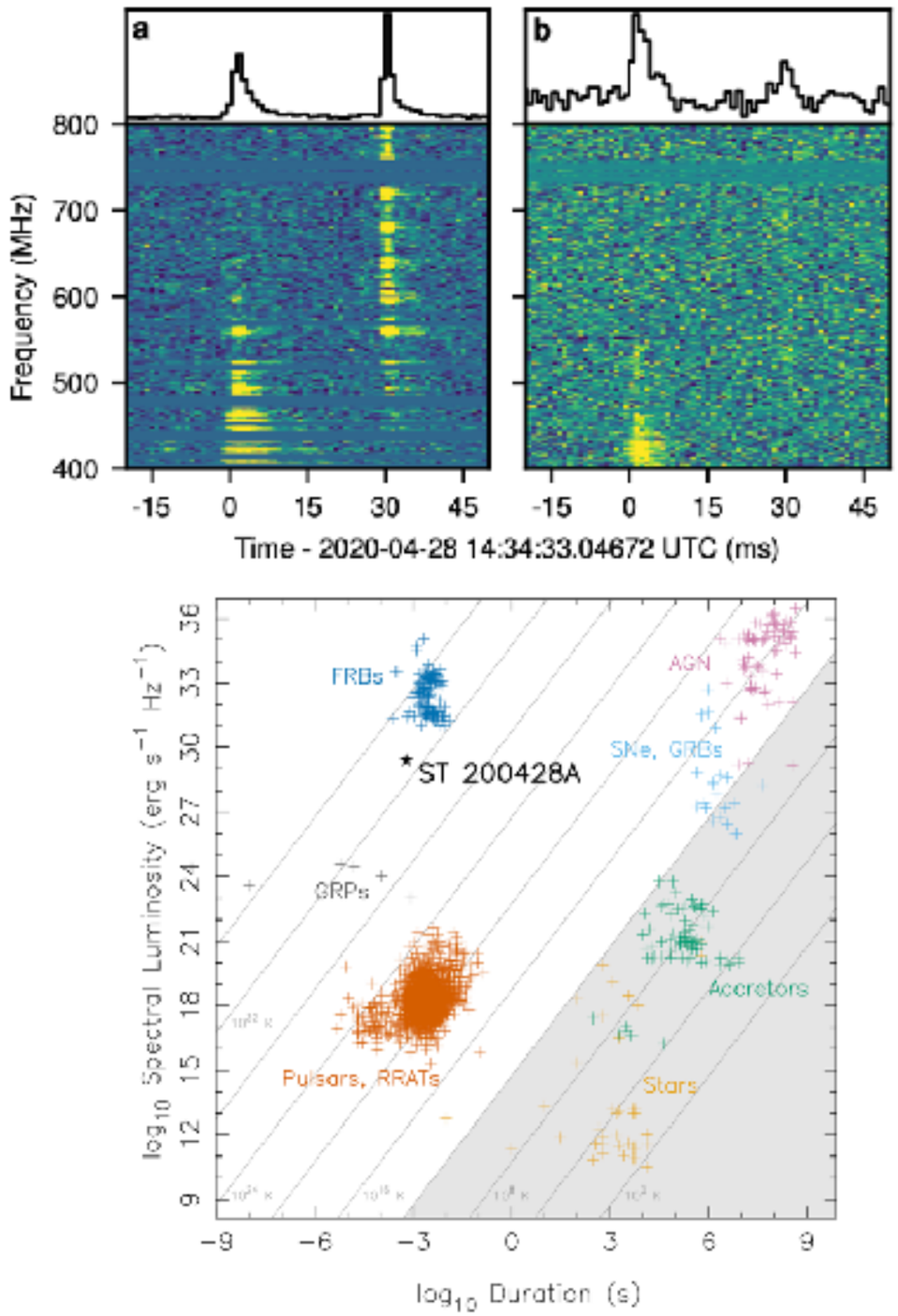
    - Most FRBs appear to be on-off events

    - Repeating sources are unusual and repeating sources with rhythm even rarer.

FRBs: Brief status update

- Over 100 published FRBs
- Roughly 20 repeaters
- Bursts detected between 330 MHz and 8 GHz
- No coincident bursts detected in optical, X-ray or gamma-ray
- **One possible Galactic FRB analog**

Galactic magnetar: SGR 1935+2154

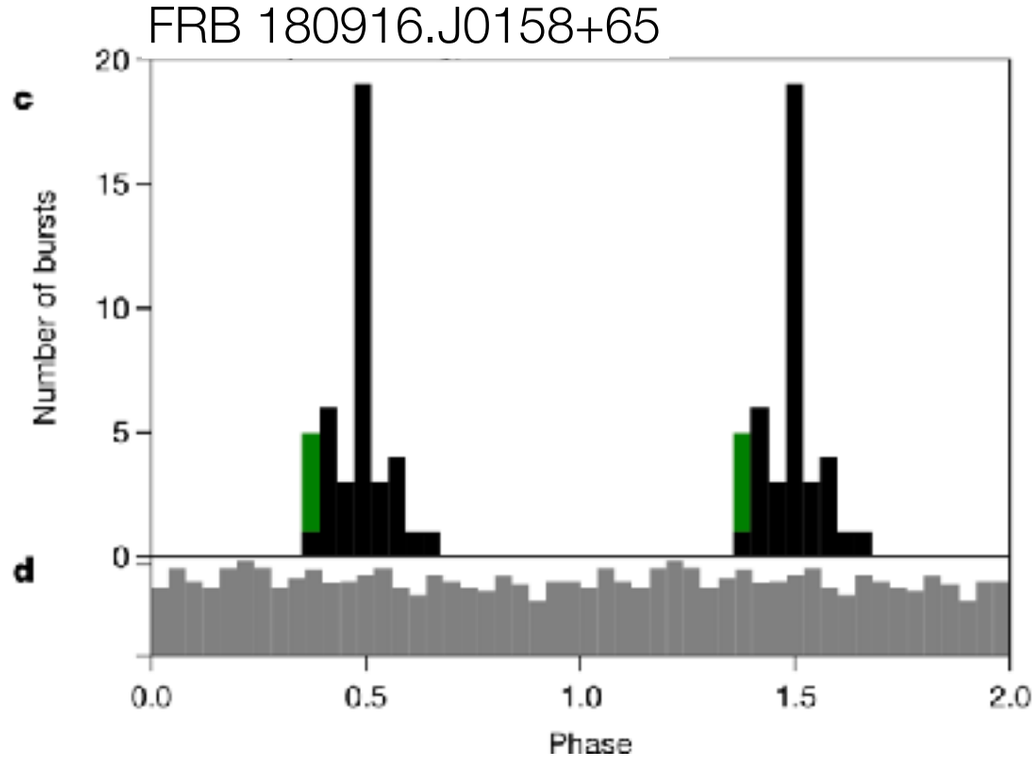


Top: CHIME/FRB collaboration, astro-ph: 2005.10324
Bottom: Bochenek et al., astro-ph: 2005.10828

CHIME: expanding the population

- Canadian Hydrogen Intensity Mapping Experiment
- New telescope built in Penticton, British Columbia, Canada
- Collaboration of North American institutions
- Operates at 400-800 MHz
- Large field-of-view (~250 deg^2)
- 18 new repeaters!
  - One with periodicity activity (P=16.8 days)

Image credits: CHIME



CHIME/FRB collaboration, *Nature*, 2020

ASKAP: finding host galaxies

- Australian Square Kilometer Array Pathfinder
  - New interferometer built in Western Australia by CSIRO
  - 36 antennae with 12-m diameters
  - Equipped with 1.4 GHz phased array feeds that form 36 beams
  - 28 discoveries including six published localizations
  - Localization precision: ~0.5 arcsec

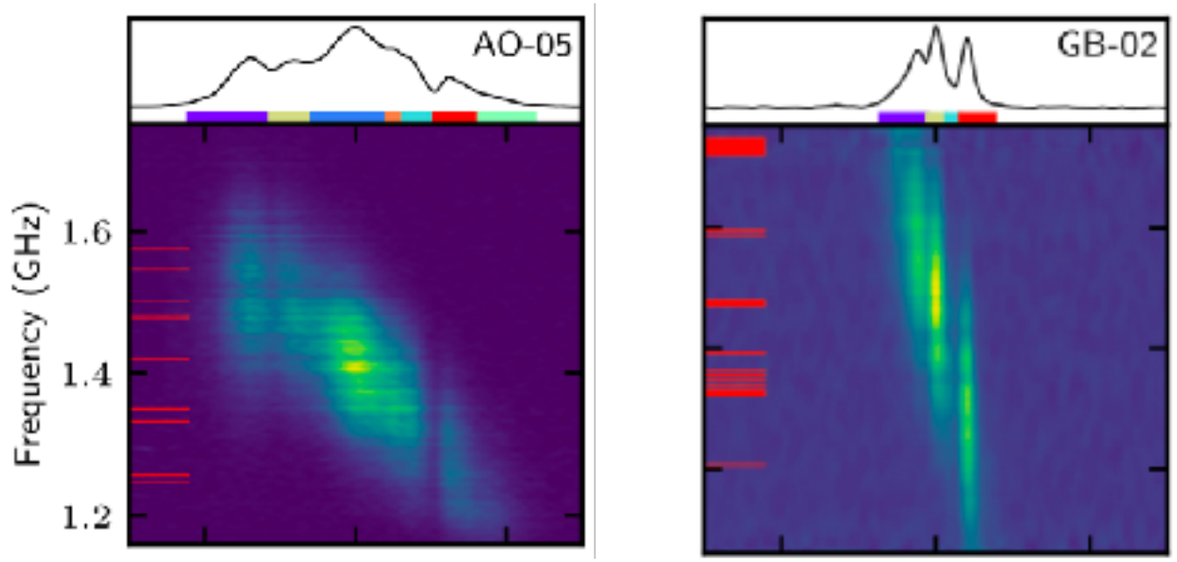
Image Credit: CSIRO

Key publications:
Shannon et al., *Nature*, 2018
Bannister et al., *Science*, 2019
Prochaska et al., *Science*, 2019
Macquart et al., *Nature*, 2020

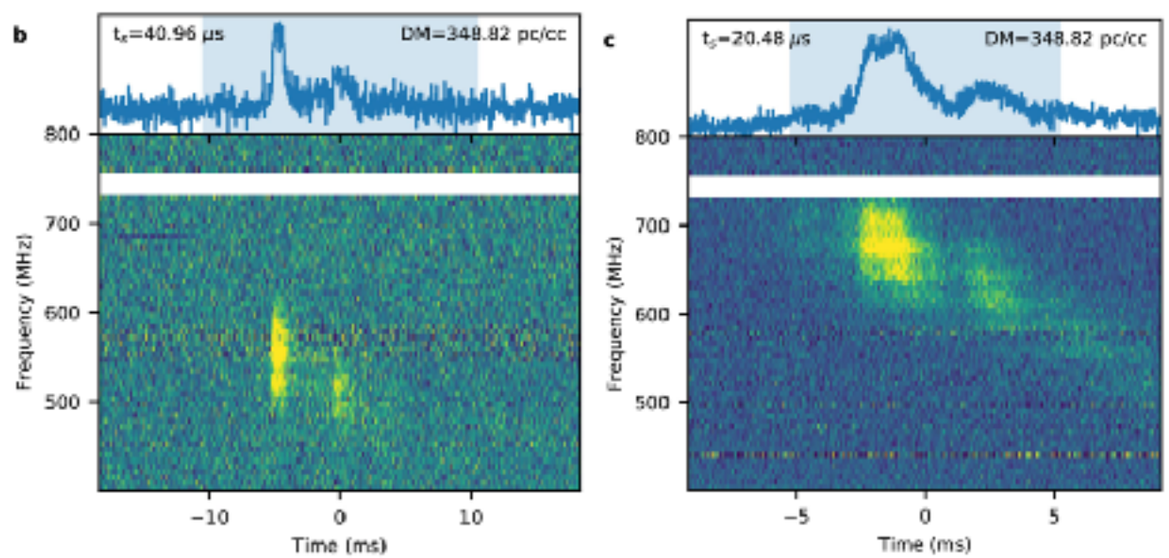
Repeating vs. non-repeating sources

- Roughly 20 published repeating sources
- Hallmark of repeaters is emission in a limited frequency band and “sad trombone” drift
- Two repeaters appear to exhibit periodic activity
- **Unclear whether all FRBs would repeat given enough follow-up time**

FRB121102



FRB 180916.J0158+65

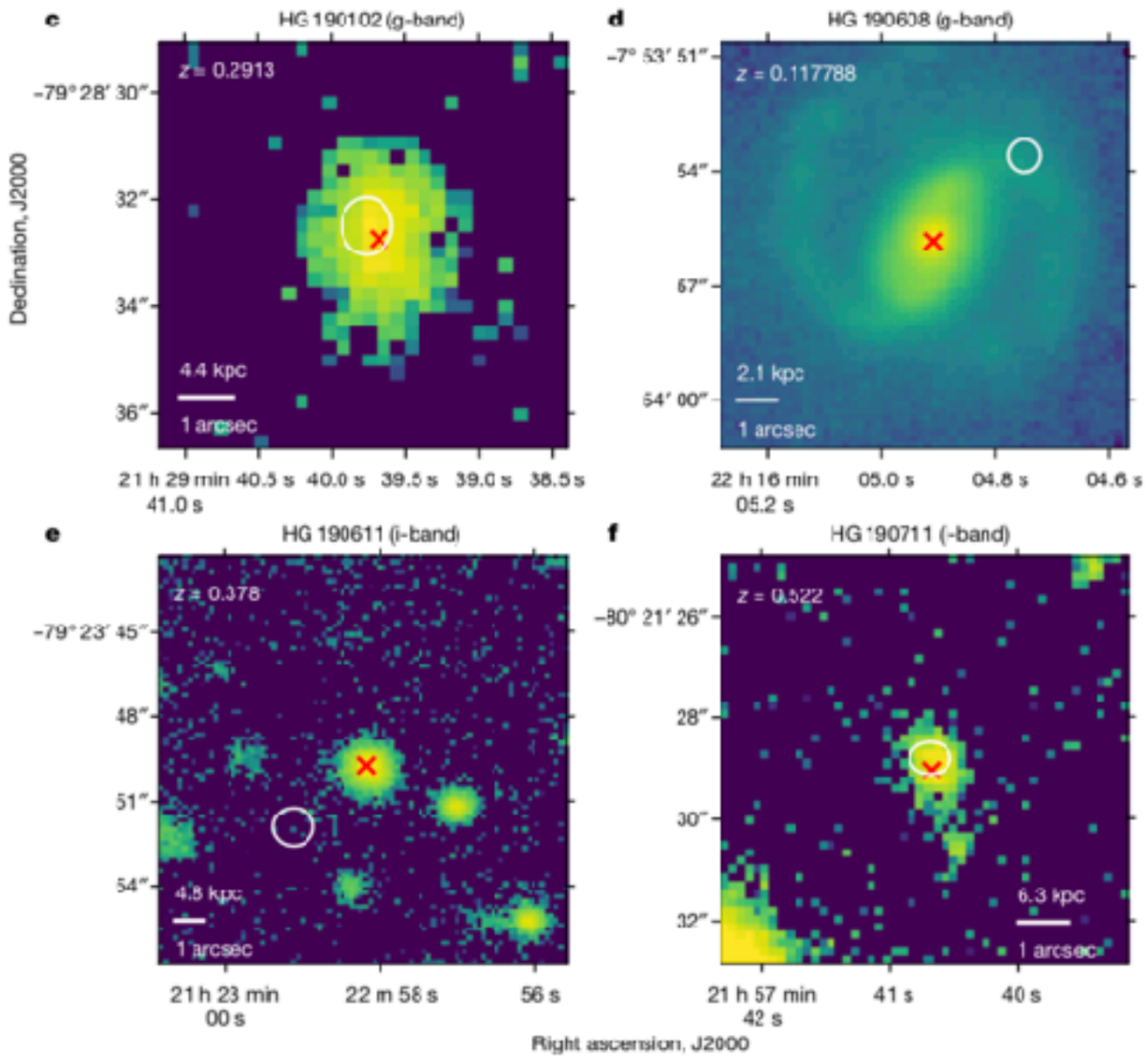


Top: Hessels et al., *ApJL*, 2019
Bottom: CHIME/FRB collaboration, *Nature*, 2020

Localized vs. non-localized

- FRB are localized if their positions are sufficiently well measured that a host galaxy can be unambiguously identified
- 9 localized FRBs
  - 7 directly localized
  - 2 repeaters localized after discovery
- **FRB hosts are diverse**

Four ASKAP host galaxies

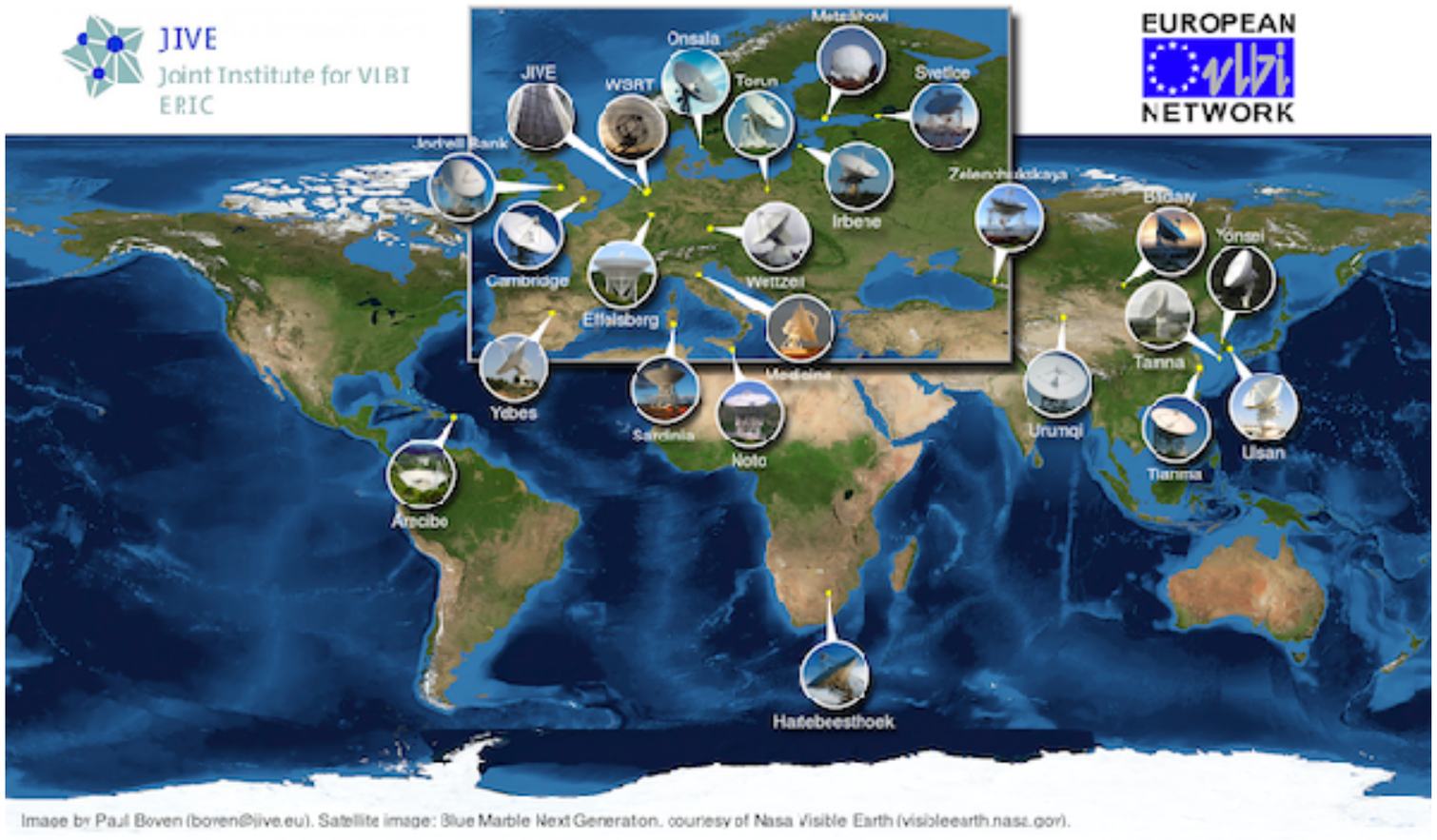


Macquart et al., *Nature*, 2020

Fast radio bursts and high spatial resolution

- The two localized repeaters have positions and images from the European VLBI Network

- Value added from VLBI:
  - Placement within the host galaxy
  - Associated persistent radio emission on ~pc scales



FRB 121102: the first repeating FRB

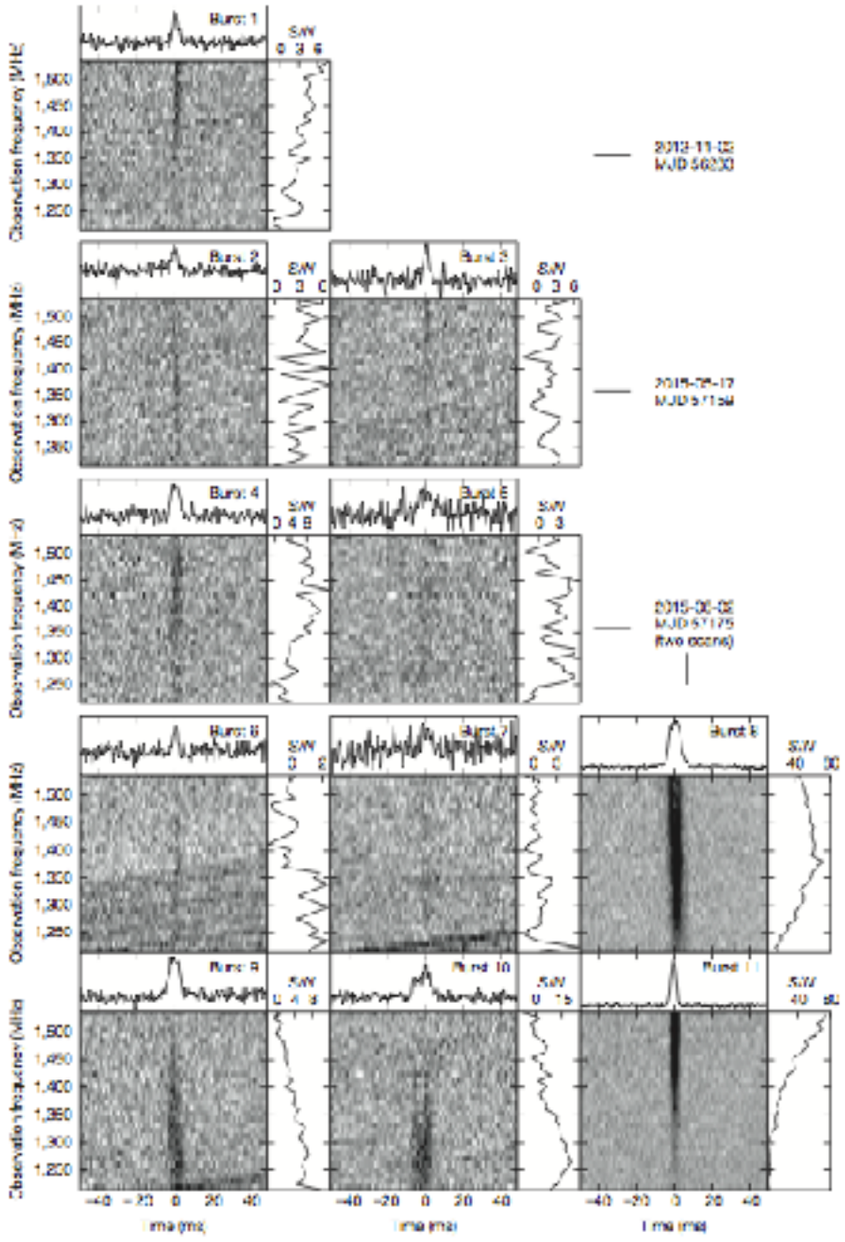
2014: Discovery burst

Archival processing of pulsar survey data (PALFA) from the Arecibo Observatory

Credit: NAIC

Spitler et al, *ApJ*, 2014

2016: Discovery of repetitions

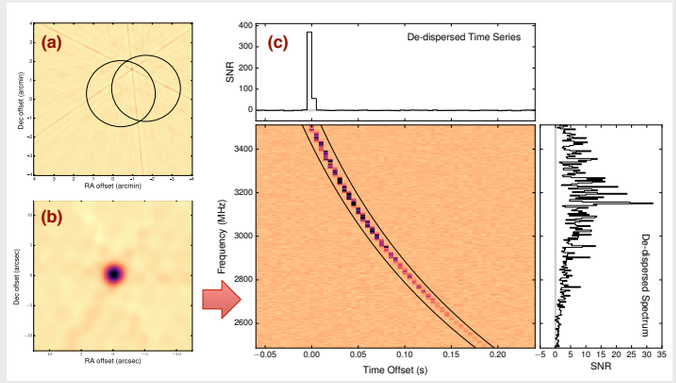


Spitler et al, *Nature*, 2016

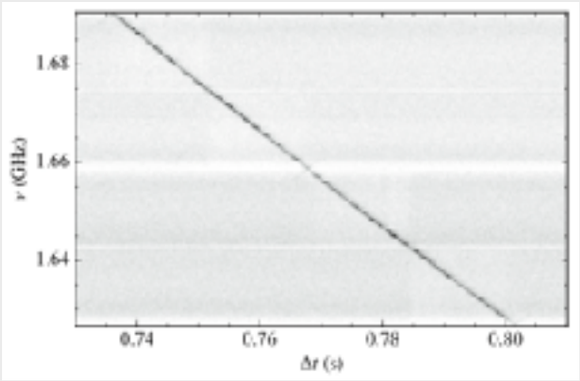
Radio localization

Bursting source:
Localized to sub-milliarcsecond precision

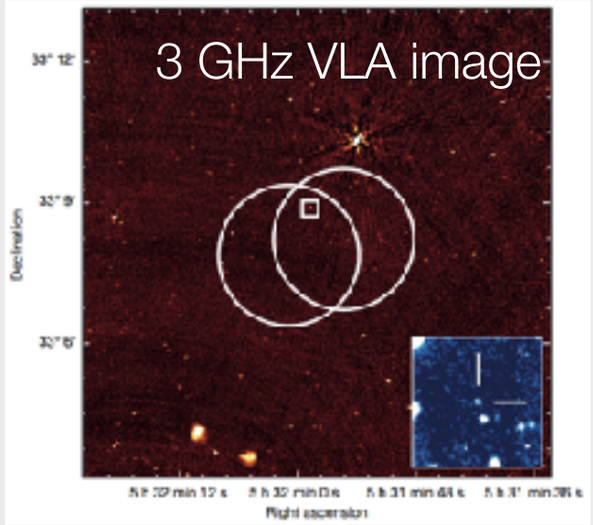
Very Large Array



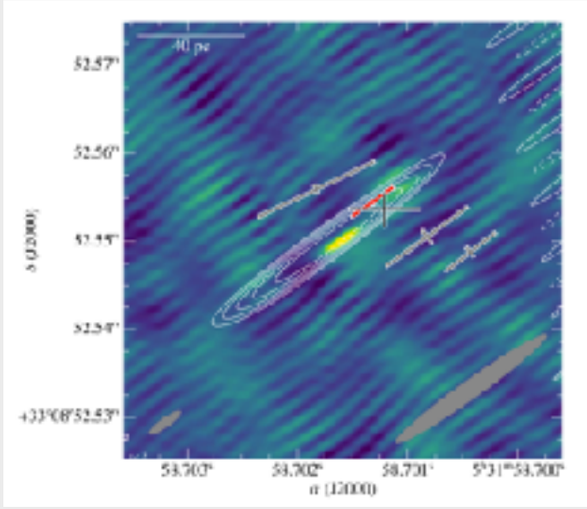
European VLBI Network



Persistent radio source:
Compact (<0.7 pc)
Spatially coincident with bursting source



Chatterjee et al, *Nature*, 2017

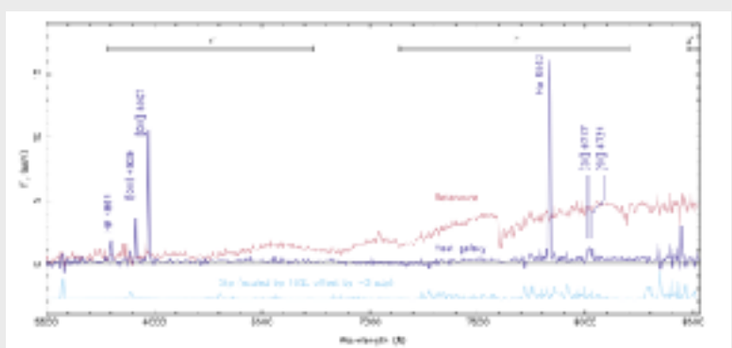


Marcote et al., *ApJL*, 2017

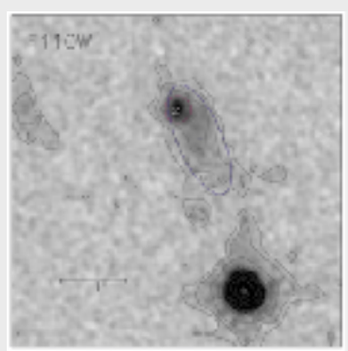
Optical follow-up

Host galaxy:
Redshift of 0.193
Low metallicity dwarf

Gemini North & HST



Tendulkar et al, *ApJL*, 2017

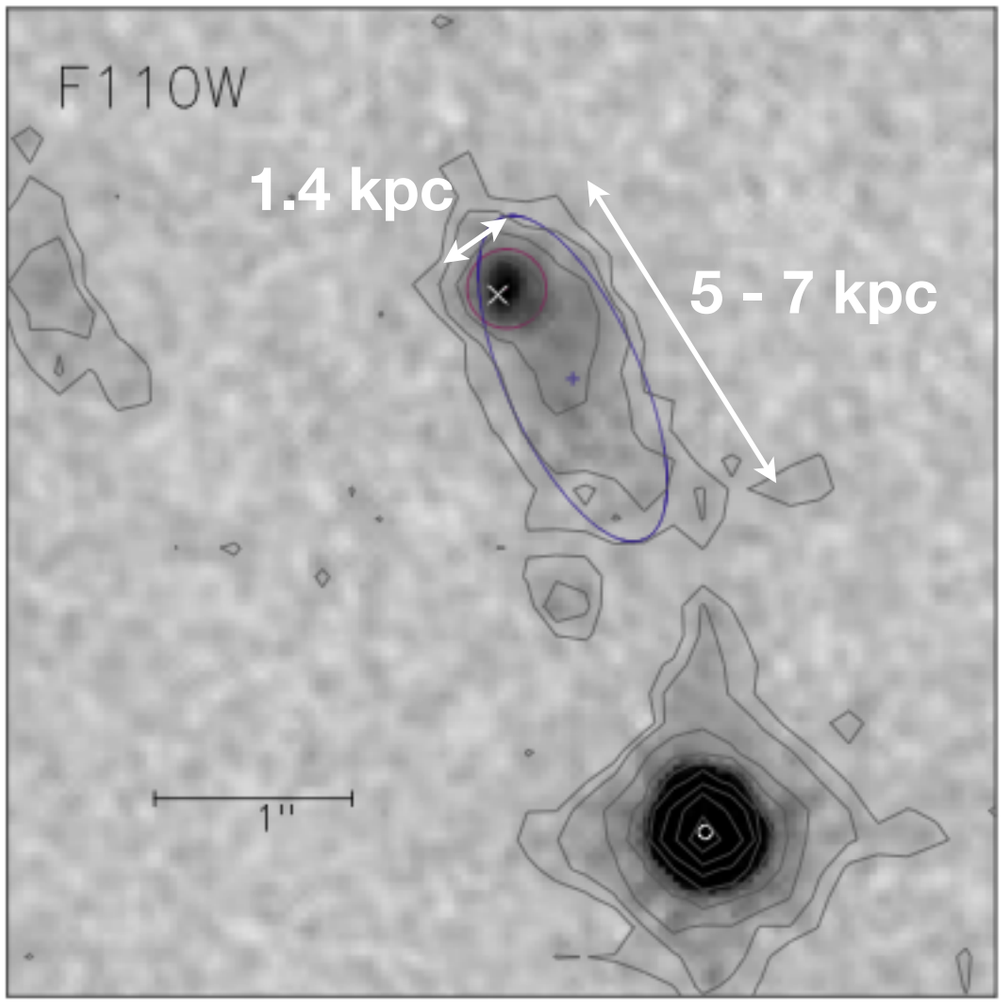


Bassa et al, *ApJL*, 2017

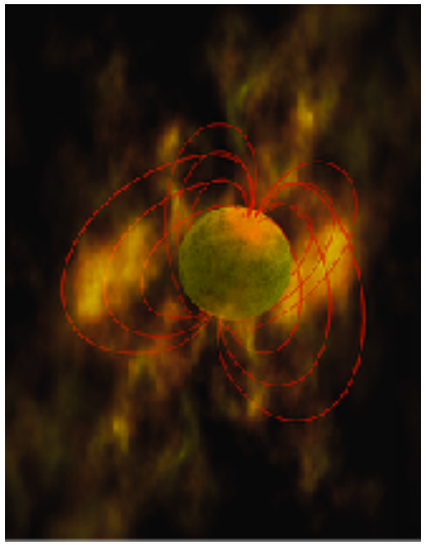
FRB 121102 located in large star formation region

- Host galaxy is a low metallicity dwarf
  - $M_\star \sim 10^8\ M_\odot$
  - Metallicity:
    $12 + \log_{10}(O/H) = 8 \pm 0.2$
  - SFR: 0.23 - 0.4 $M_\odot yr^{-1}$
- Persistent+bursting source sitting in a large HII region
- Similar to extreme emission line galaxies (EELGs)

HST image



Bassa et al, ApJL, 843, 2017



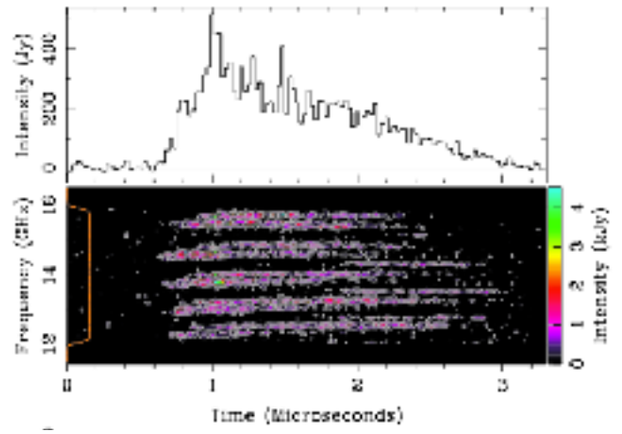
Several decades ago a **ms-magnetar** was born in a SLSNe/LGRB.

Today it is powering a **magnetar wind nebula** in an expanding relativistic shell of ejecta.

e.g. Metzger et al. 2017, Margalit et al. 2018

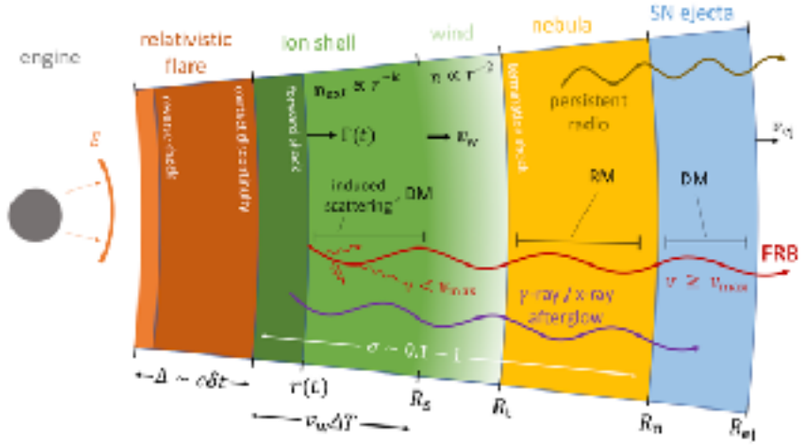
Bursts generated in…

… magnetosphere



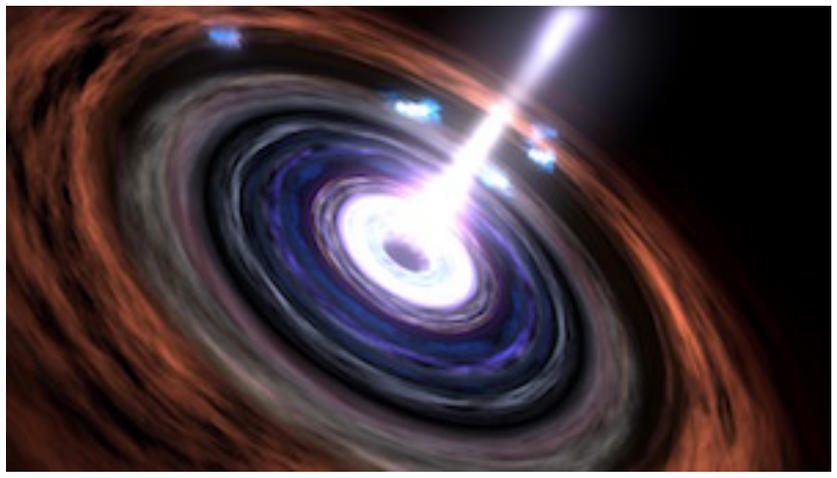
e.g. Crab: Hankins et al. 2016; Cordes & Wasserman 2016

… nebula



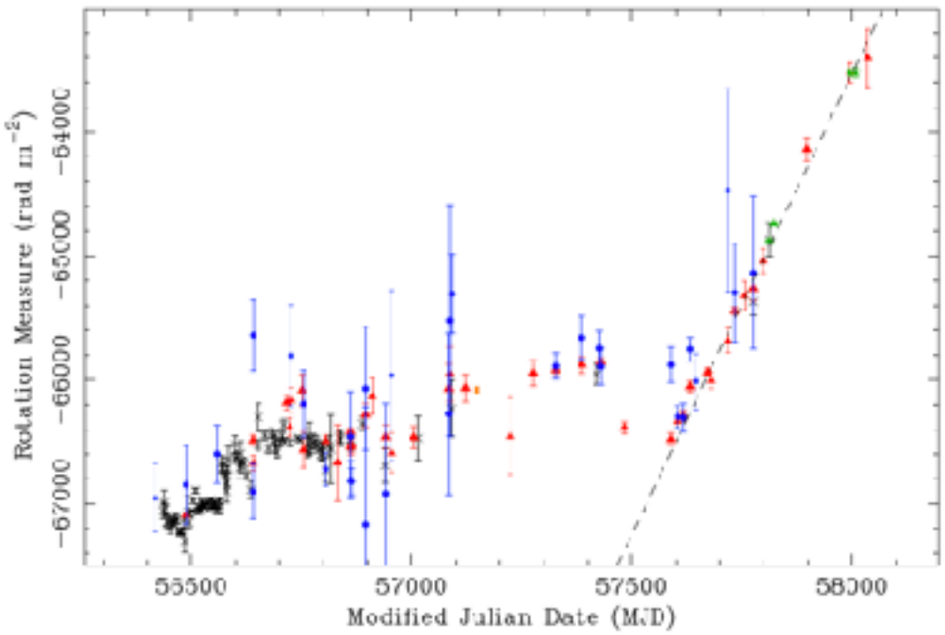
e.g. Waxman et al. 2017, Metzger et al. 2019

Low-luminosity active galactic nuclei



e.g. Marcote et al., 2017, Michilli et al. 2018

J1745-2900: Galactic center magnetar

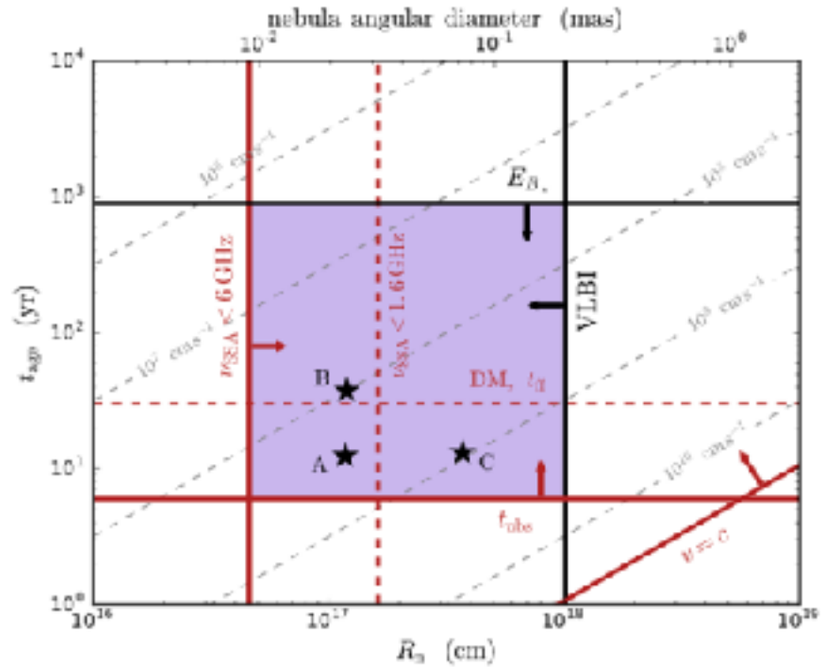


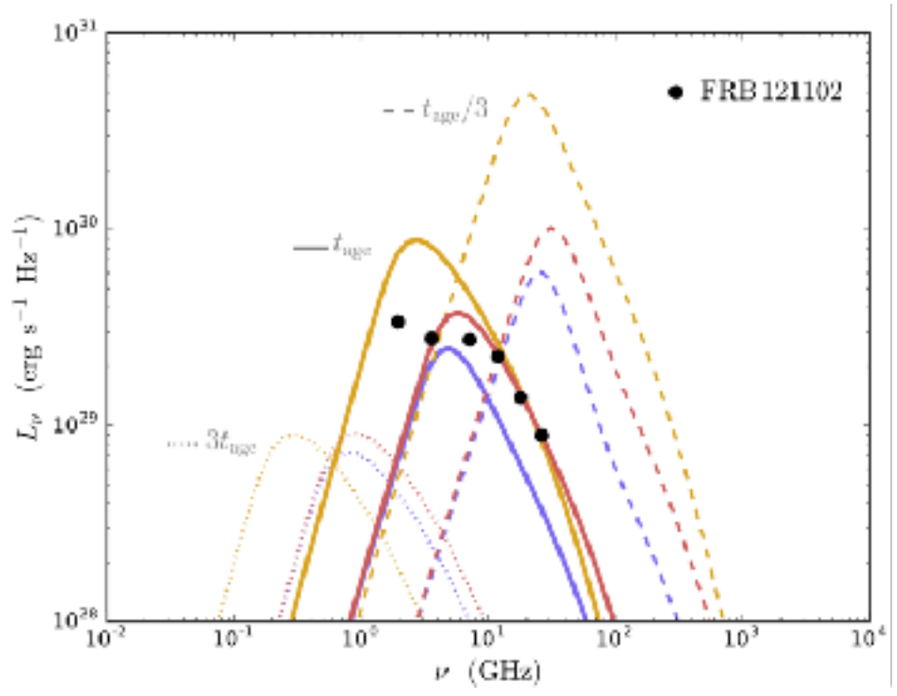
Desvignes et al., ApJ, 2018

FRB 121102: persistent radio source

- VLBI constrains on the luminosity and spatial size of the coincident persistent radio source was key input ms-magnetar models

- **Persistent radio emission is not universal to all FRBs**





Margalit & Metzger, ApJL, 2018

Conclusions

- Very long baseline interferometry is key for understanding the nature of FRBs in two ways:
    - What is going on in the vicinity of the FRB within the host galaxy?
    - What, if any, pc-scale radio emission is present (i.e. ejecta shell, nebula, afterglow, AGN, etc)?