Zooming in on fast radio bursts

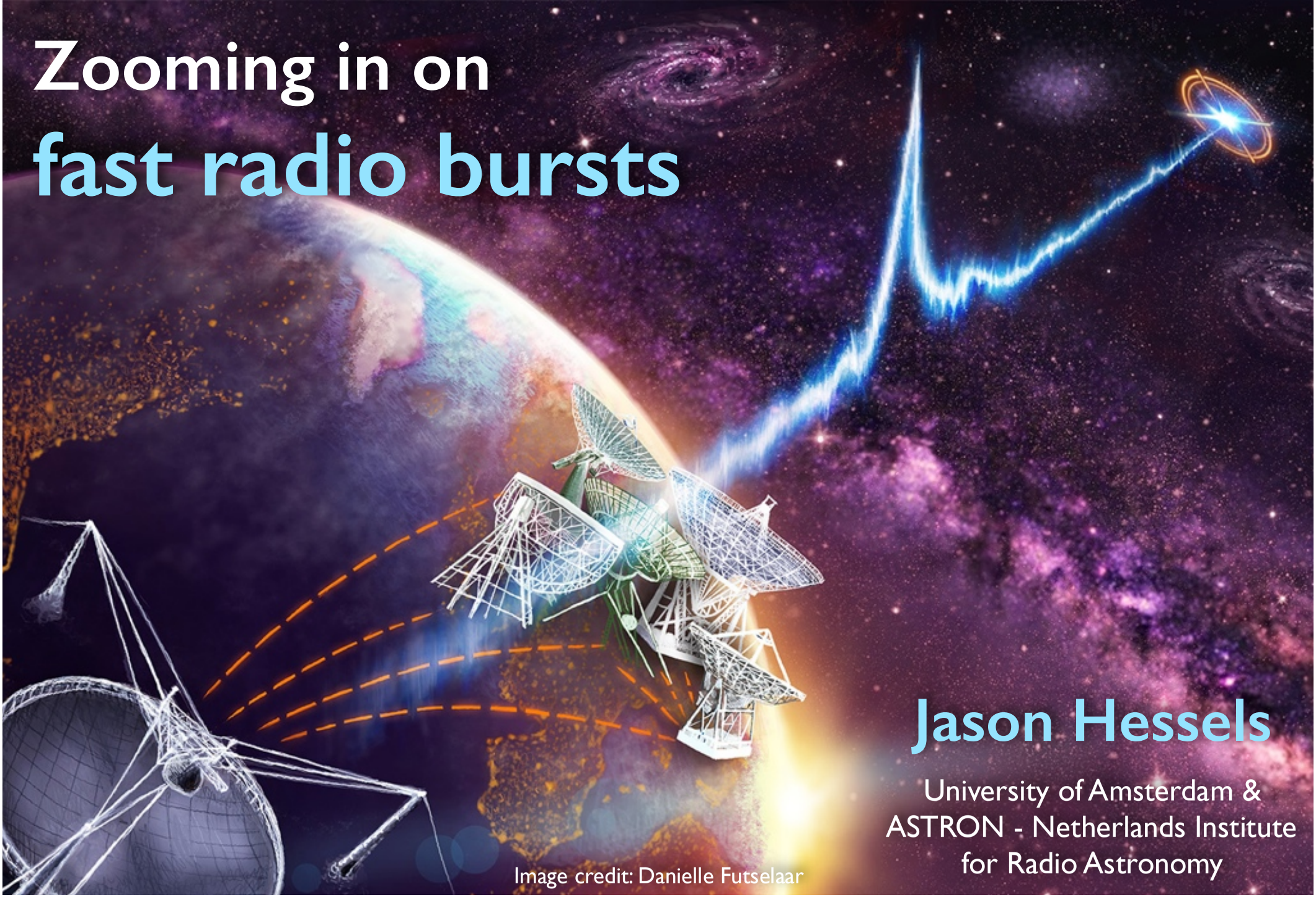


Image credit: Danielle Futselaar

Jason Hessels

University of Amsterdam &
ASTRON - Netherlands Institute
for Radio Astronomy

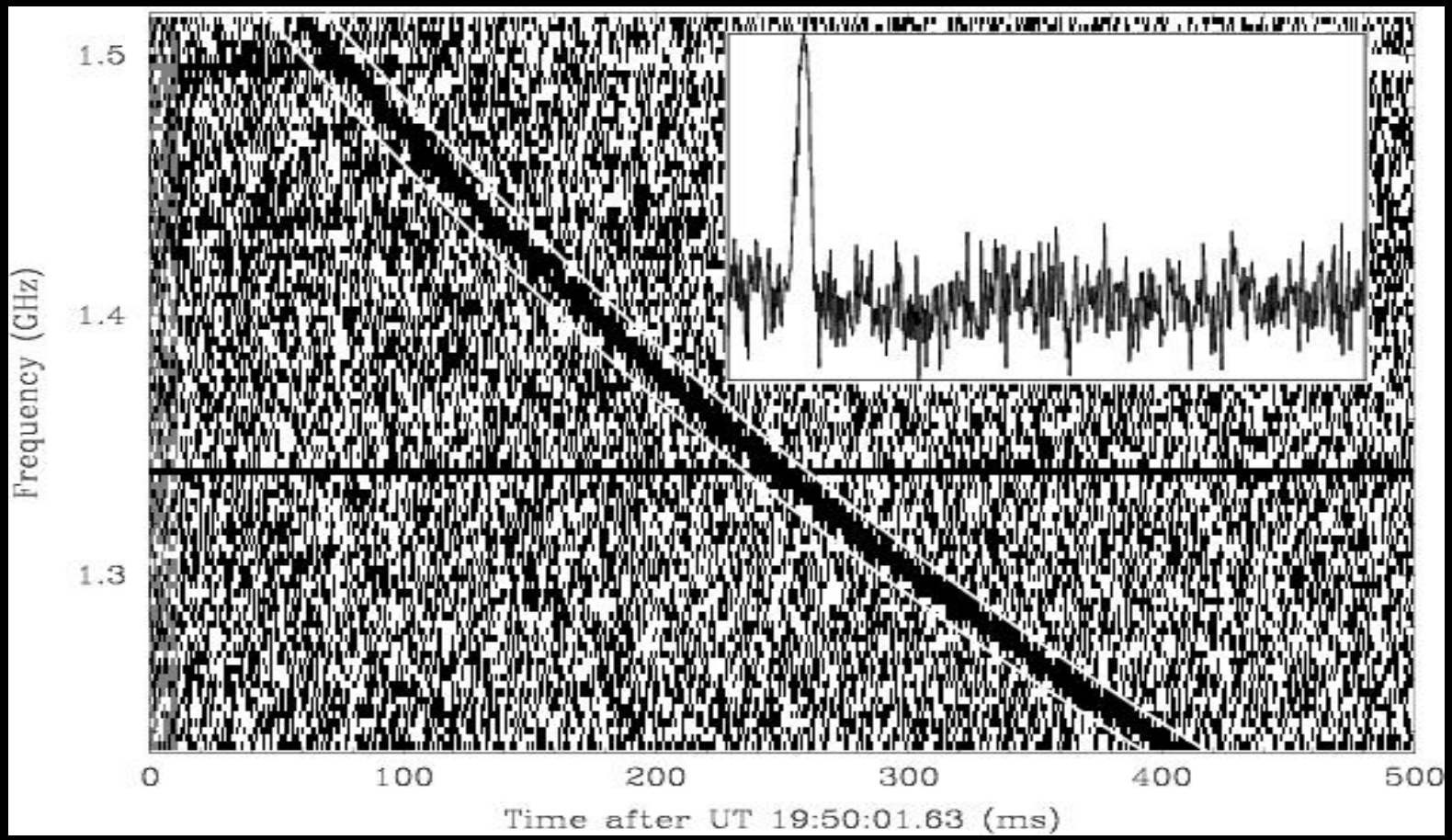
Universiteit van Amsterdam

European Research Council
Established by the European Commission

NWO
Netherlands Organisation
for Scientific Research

ASTRON
Netherlands Institute for Radio Astronomy

What are FRBs observationally?

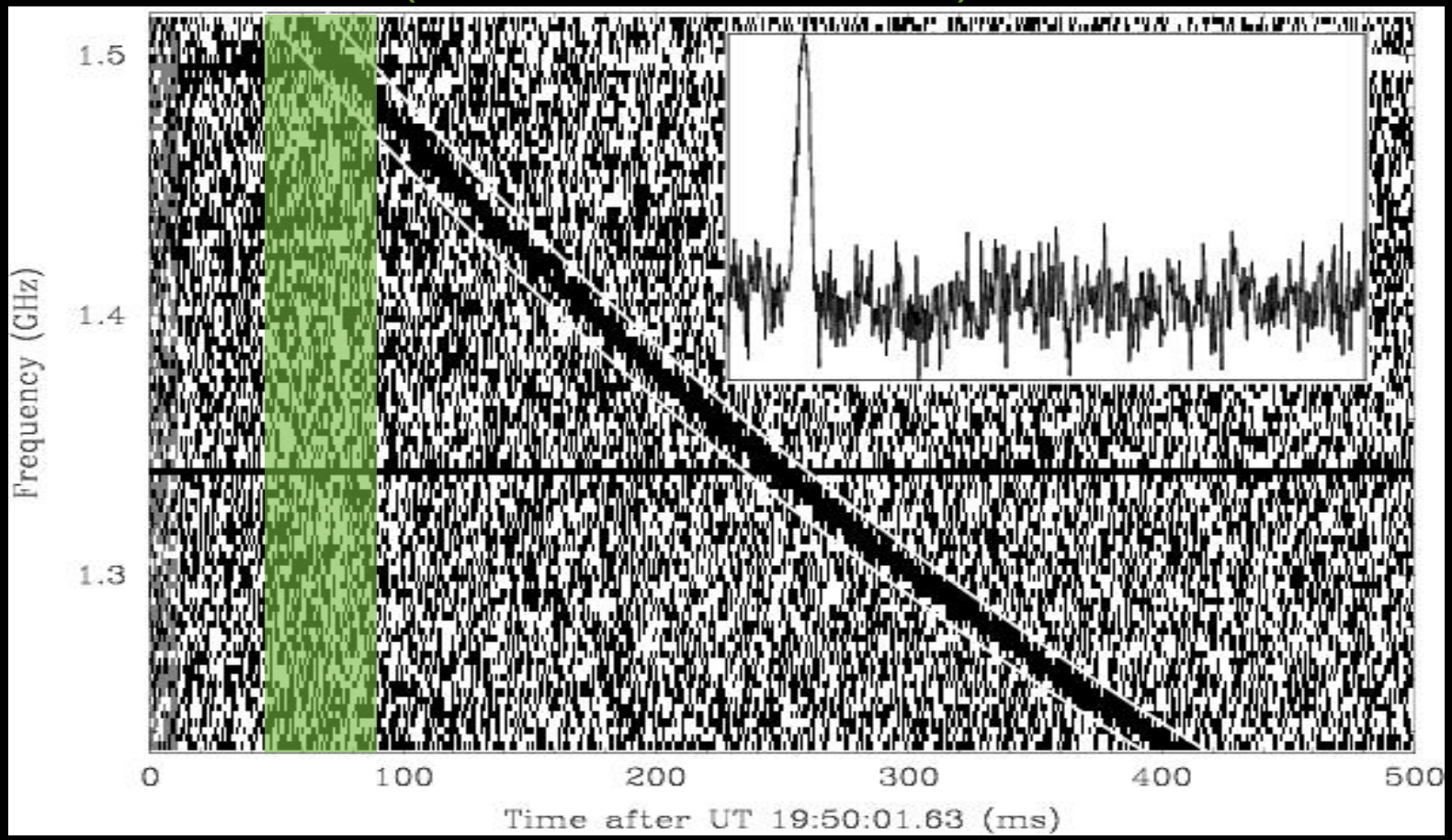


Lorimer et al. 2007

The "Lorimer Burst"

What are FRBs observationally?

ISM (interstellar medium)



Frequency ↑

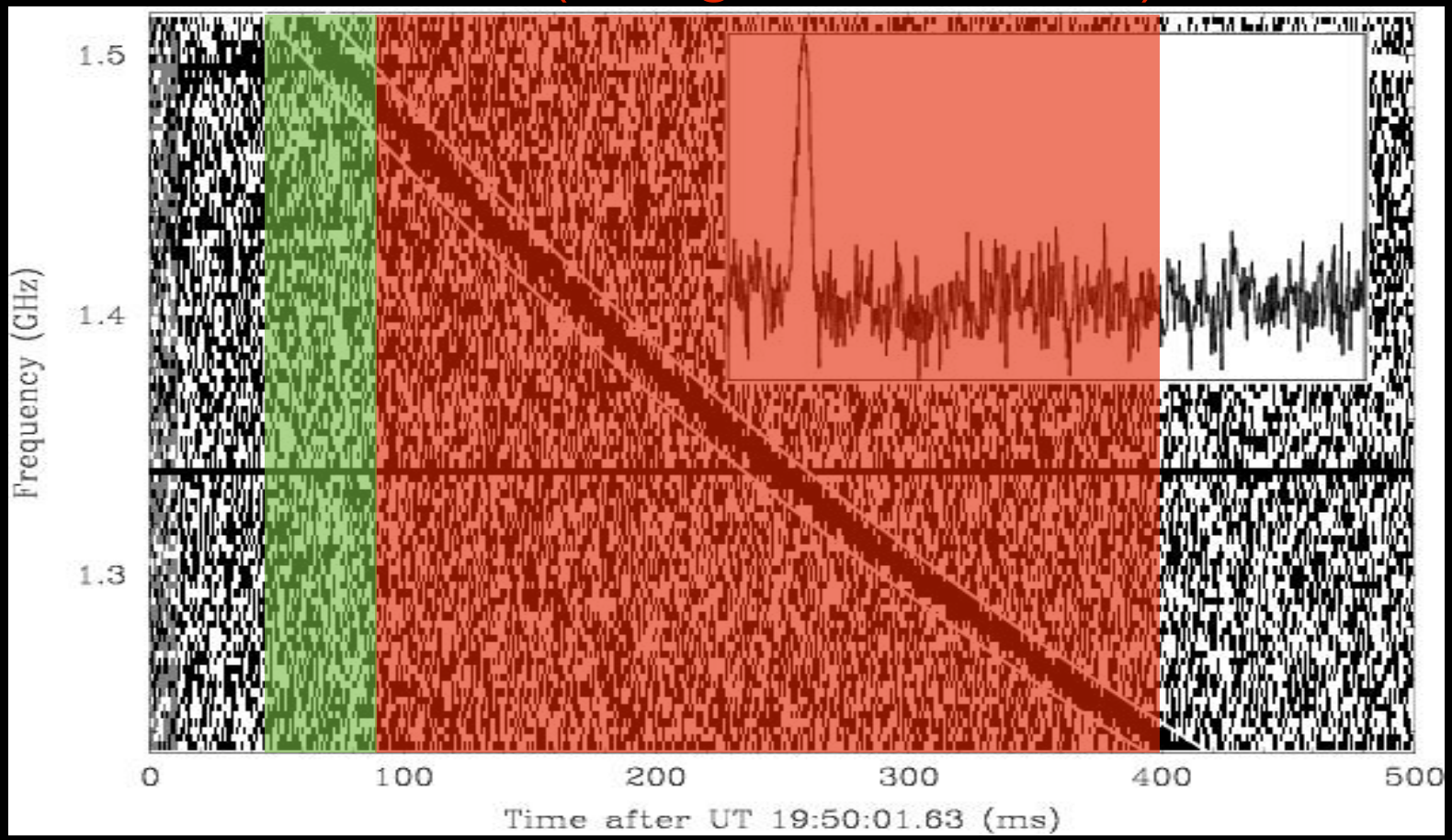
Time →

Lorimer et al. 2007

Delay too large to come from just the galaxy

What are FRBs observationally?

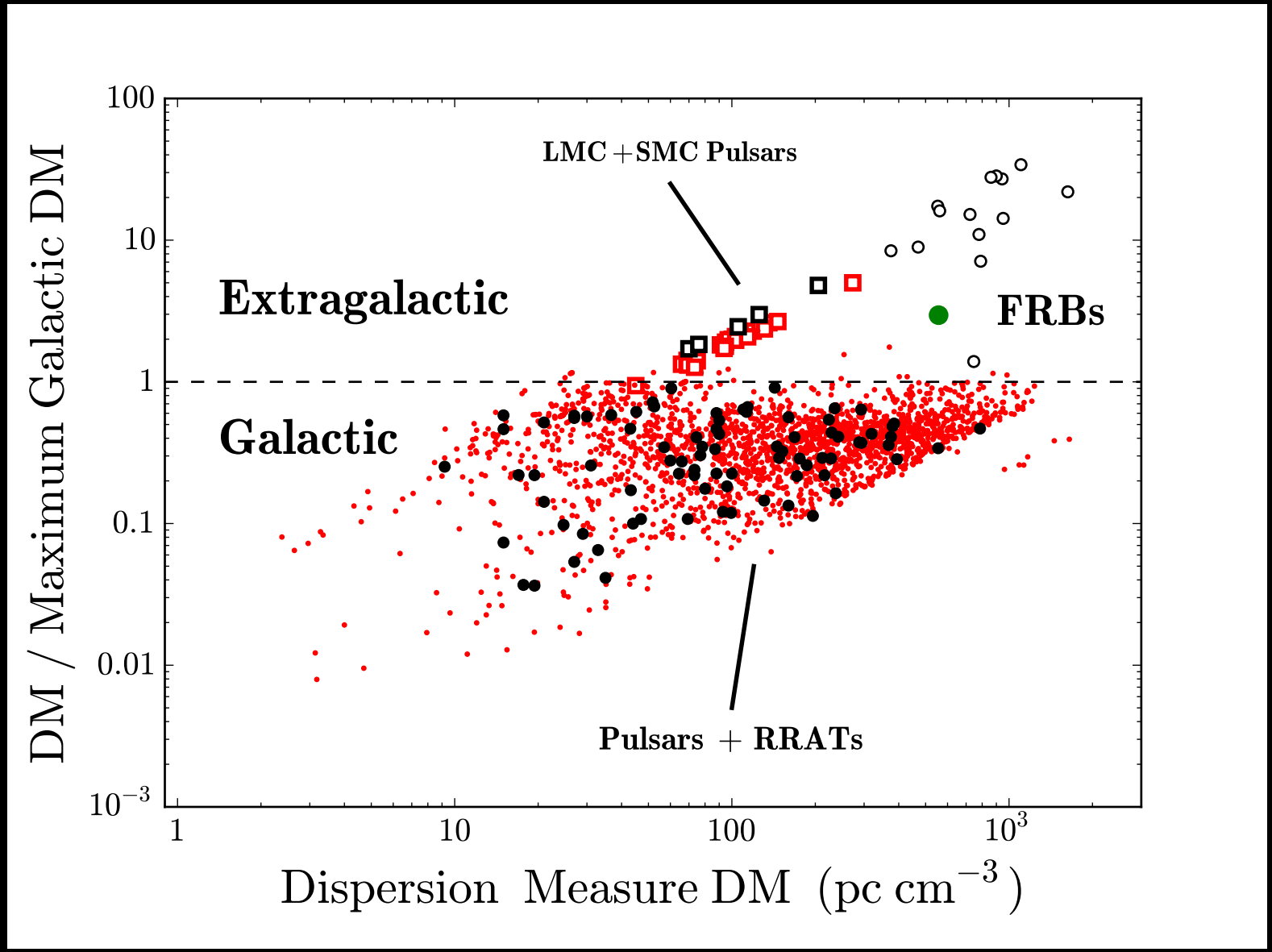
ISM IGM (intergalactic medium) + Host?



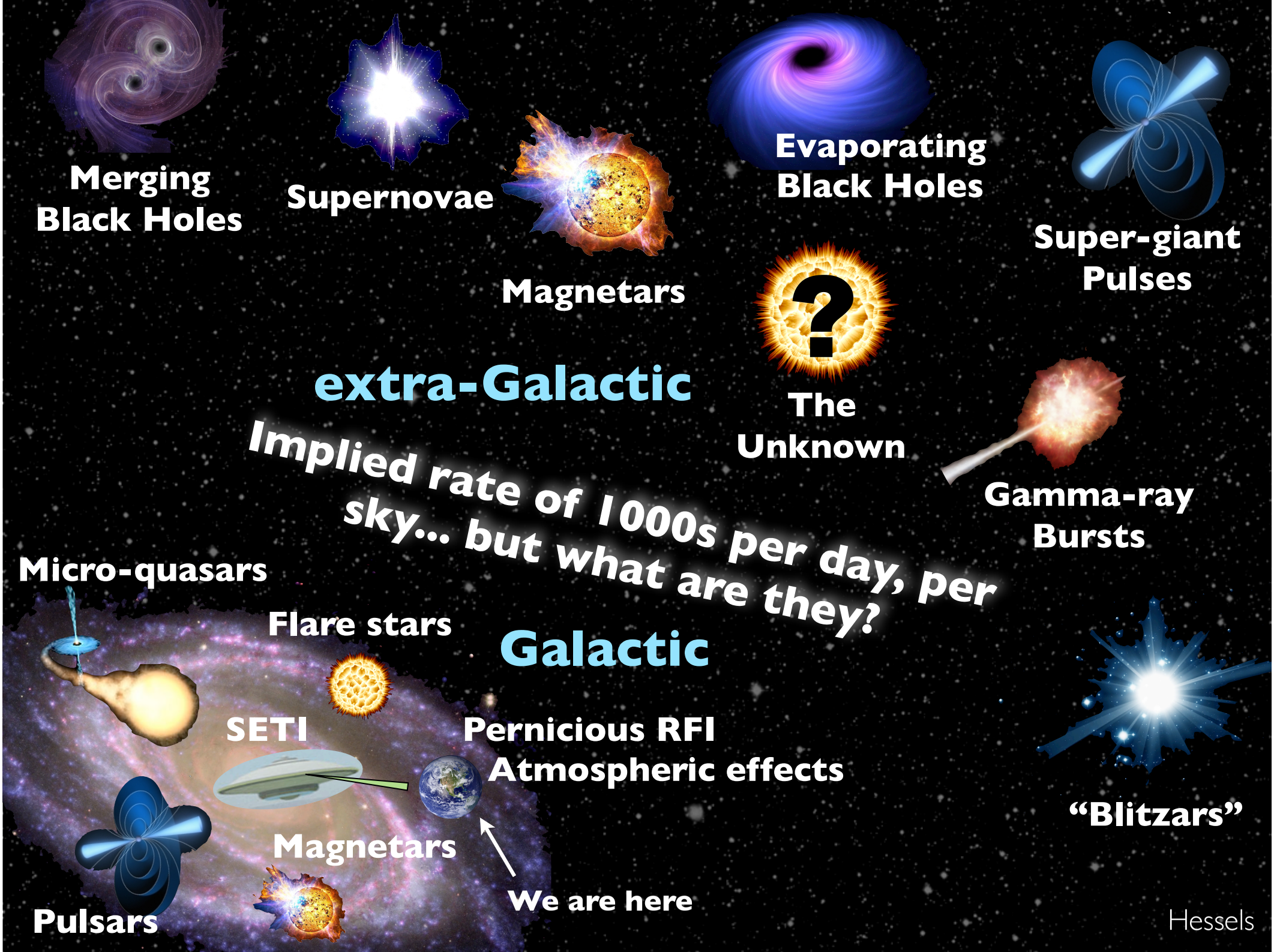
Lorimer et al. 2007

Delay too large to come from just the galaxy

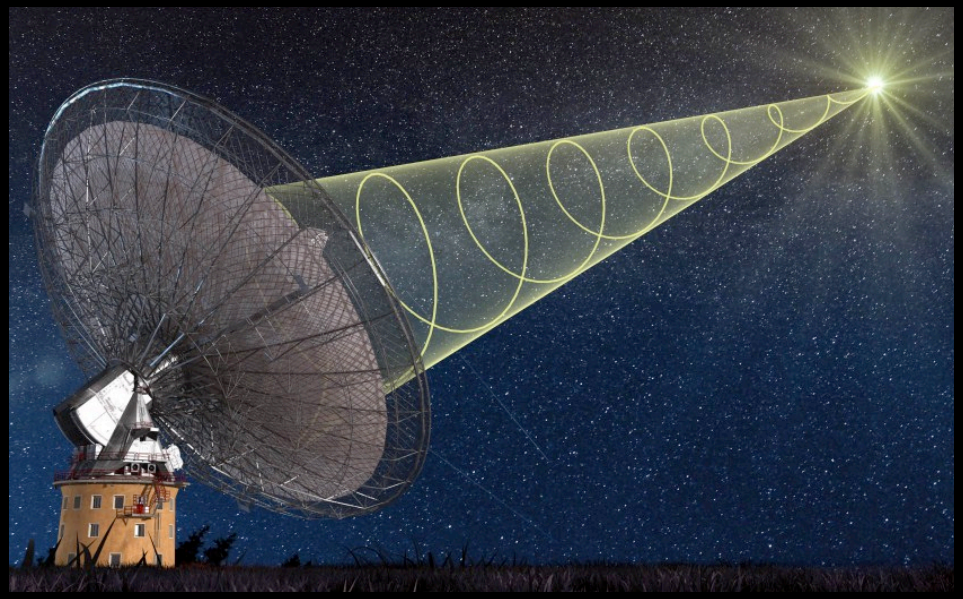
Pulsars versus FRBs



Cordes


Merging Black Holes
Supernovae
Magnetars
Evaporating Black Holes
Super-giant Pulses
?
The Unknown
extra-Galactic
Implied rate of 1000s per day, per sky... but what are they?
Gamma-ray Bursts
Micro-quasars
Flare stars
Galactic
SETI
Pernicious RFI
Atmospheric effects
"Blitzars"
Magnetars
We are here
Pulsars
Hessels

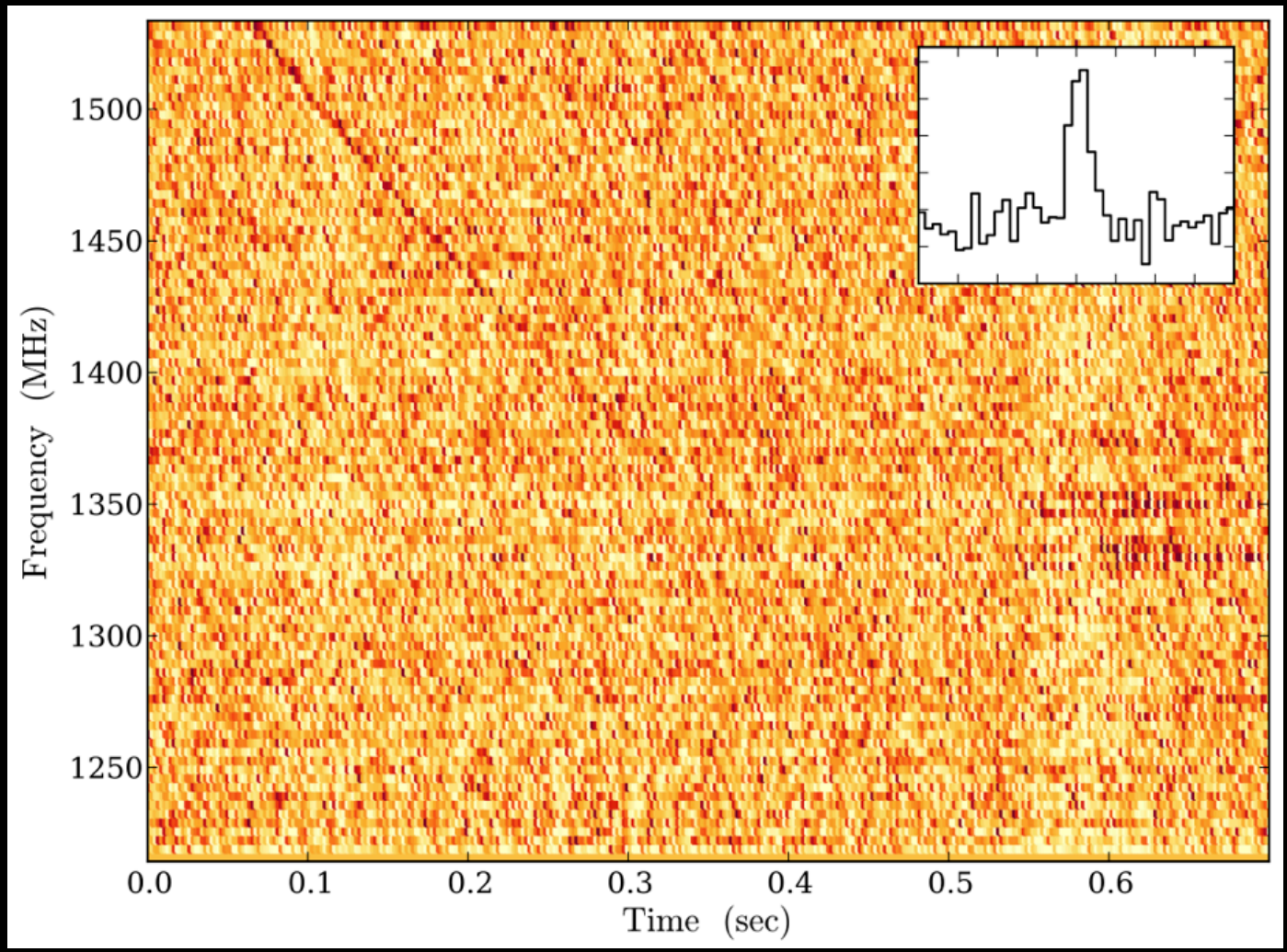
Why important?



- Sites of extreme energy density. Important probes of extreme (astro)physics?
- New type of astrophysical object?
- Probes of intervening material.

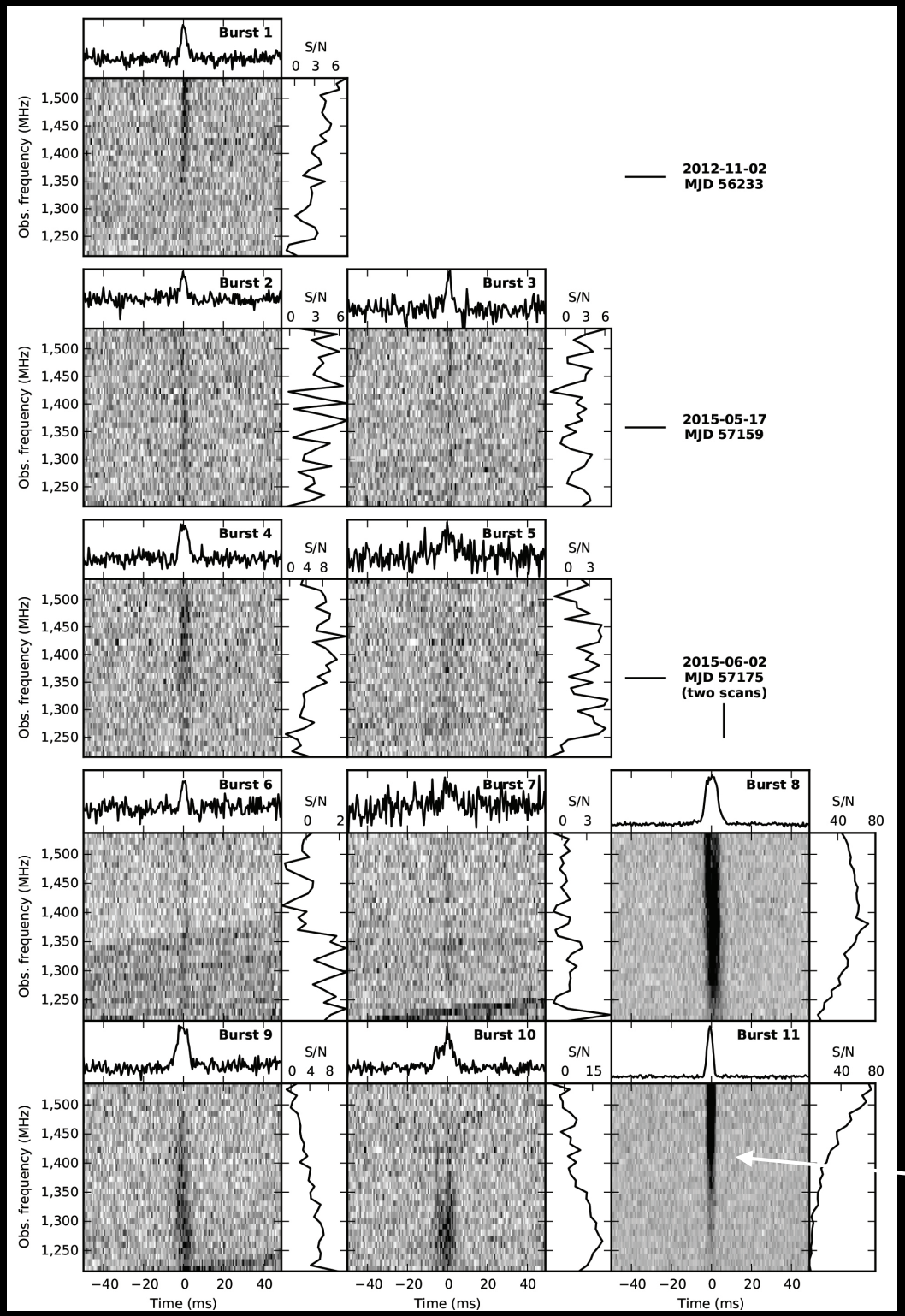
FRB 121102: the Arecibo burst

DM_{FRB} = 3x $DM_{Max\ Gal.}$



First non-Parkes FRB

Spitler, Cordes, Hessels et al. 2014



FRB 121102: First repeating Fast Radio Burst!

(and still only known)

Spitler, Scholz, Hessels et al. 2016

Open questions:

- Can all FRBs repeat?
- Do they all have the same physical origin?

Dispersion removed

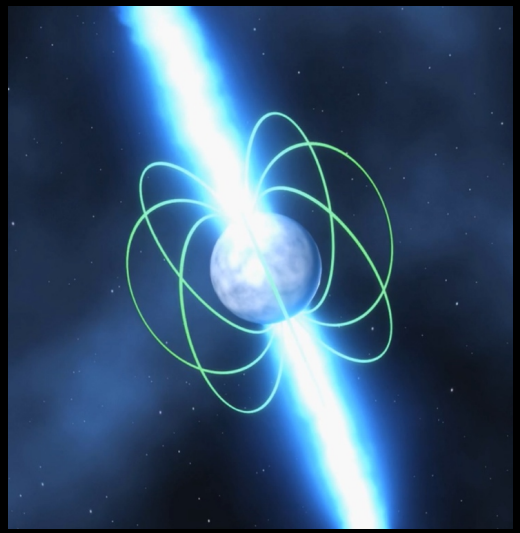
Scholz

Why important?

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

One-time-only explosion

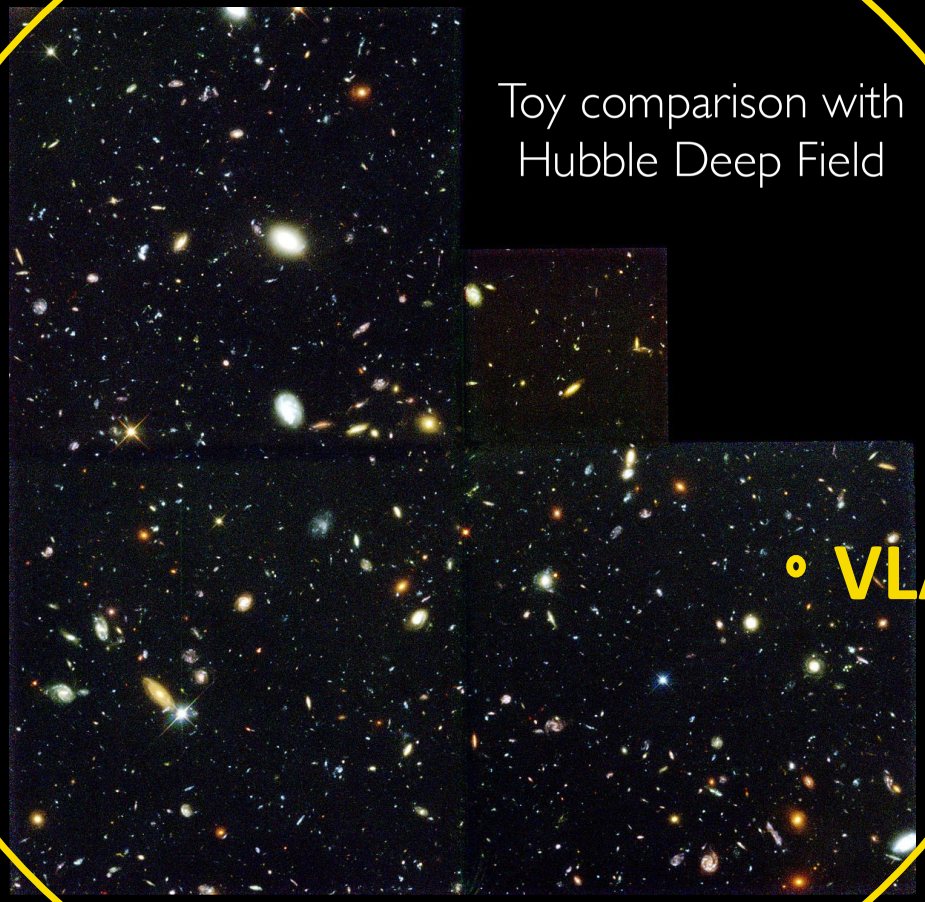
versus



Pulsar on steroids

Facilitates multi-wavelength follow-up

The need for localization

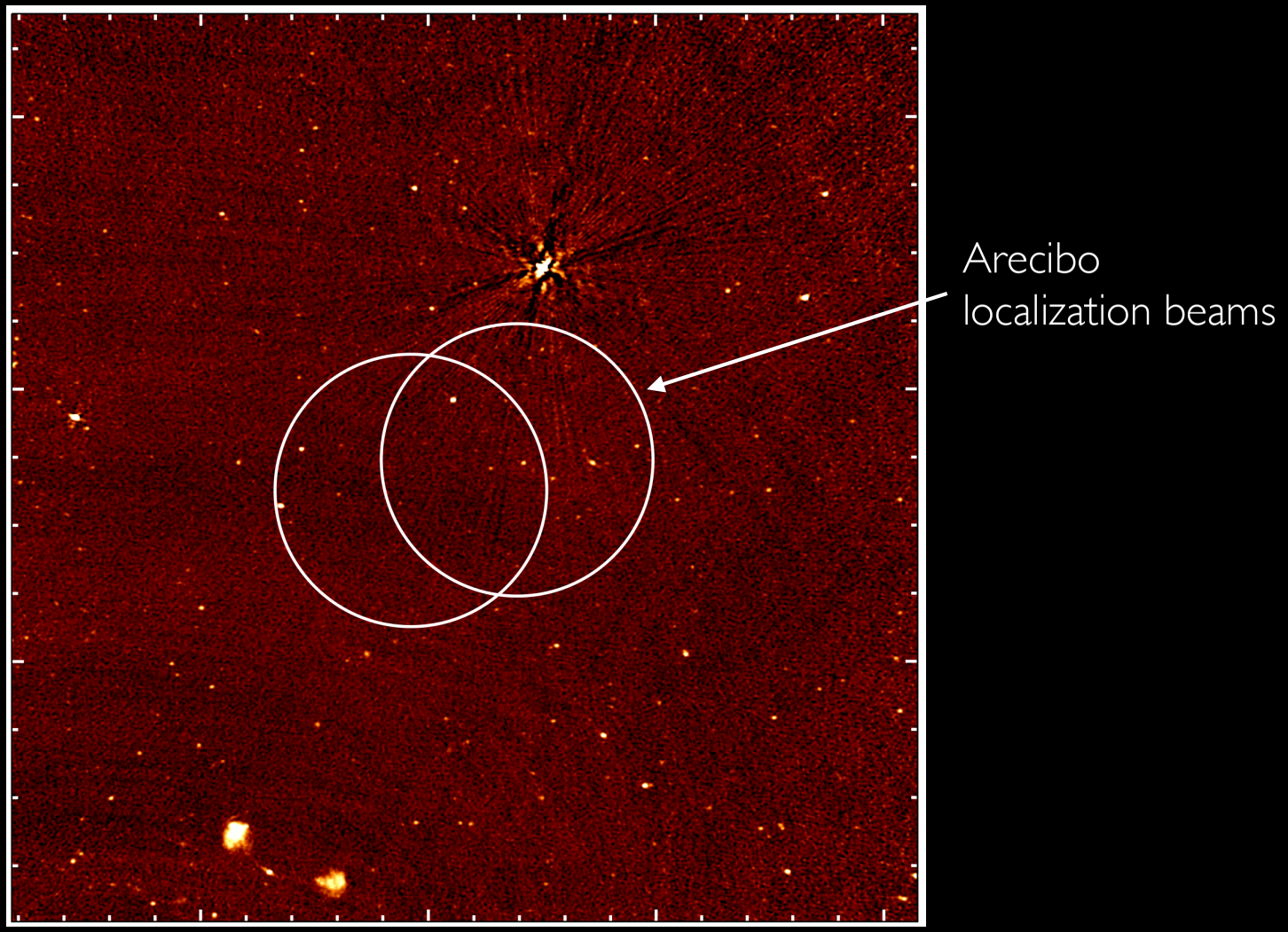


Arecibo localization

- **VLA localization**

Identifying host galaxy is critical

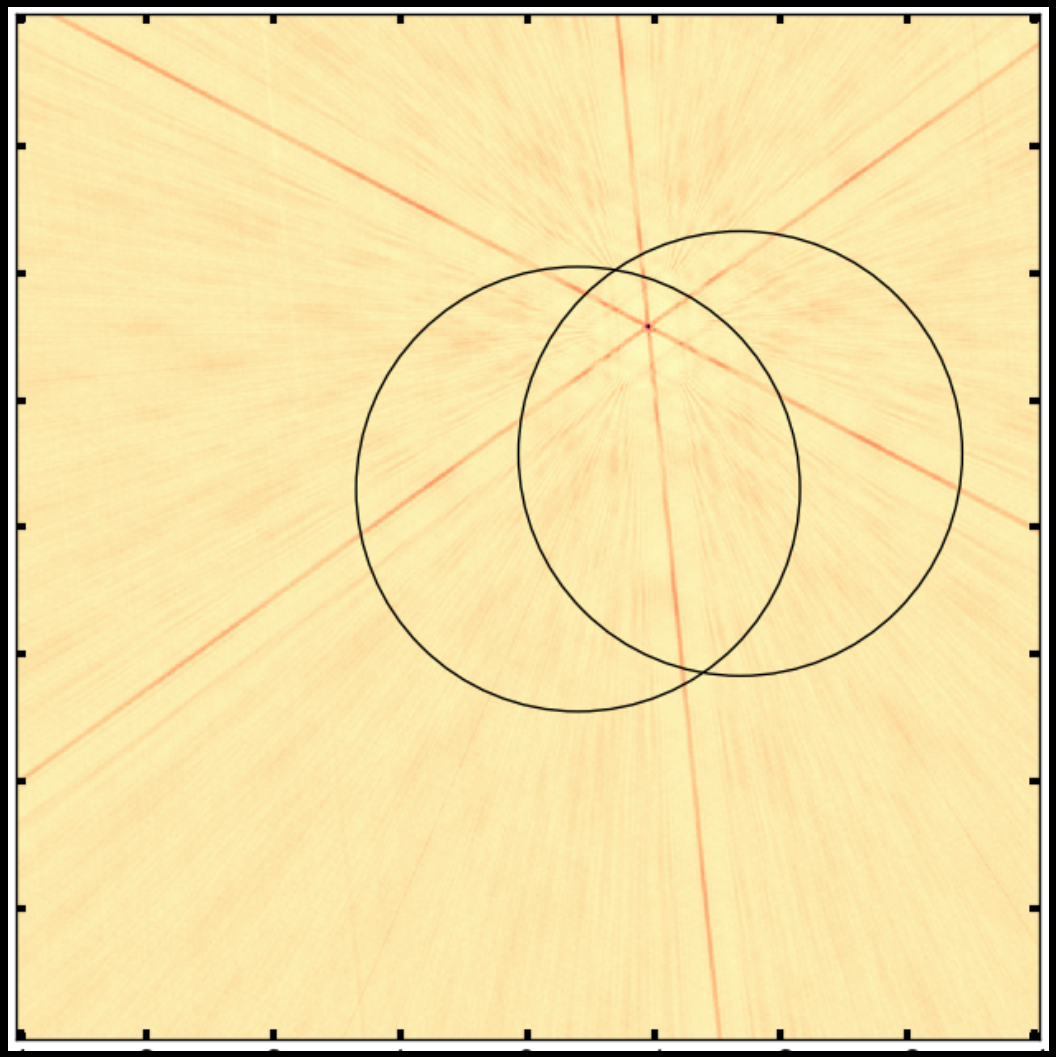
VLA localization



10s of radio sources in an ultra-deep (10s of hrs) VLA image

Chatterjee et al. 2017

VLA localization

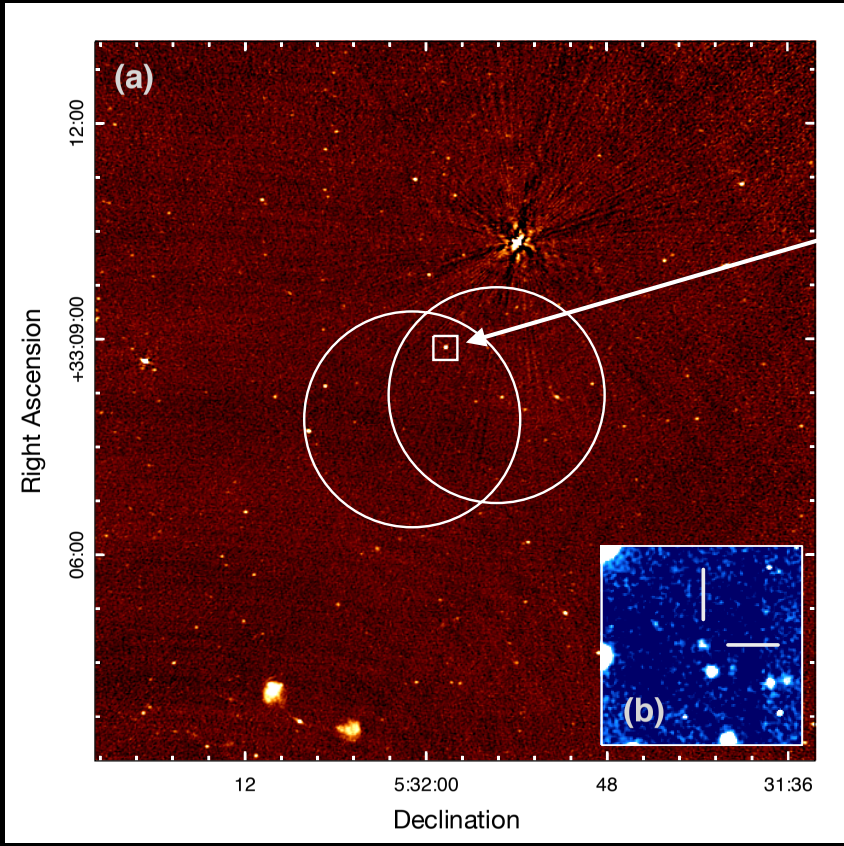


...and suddenly a burst
(this is a 5-ms snapshot)

Chatterjee et al. 2017

VLA localization

Association with persistent radio & optical sources



Coincident radio source (200 microJy)

Coincident optical source (25th mag.)

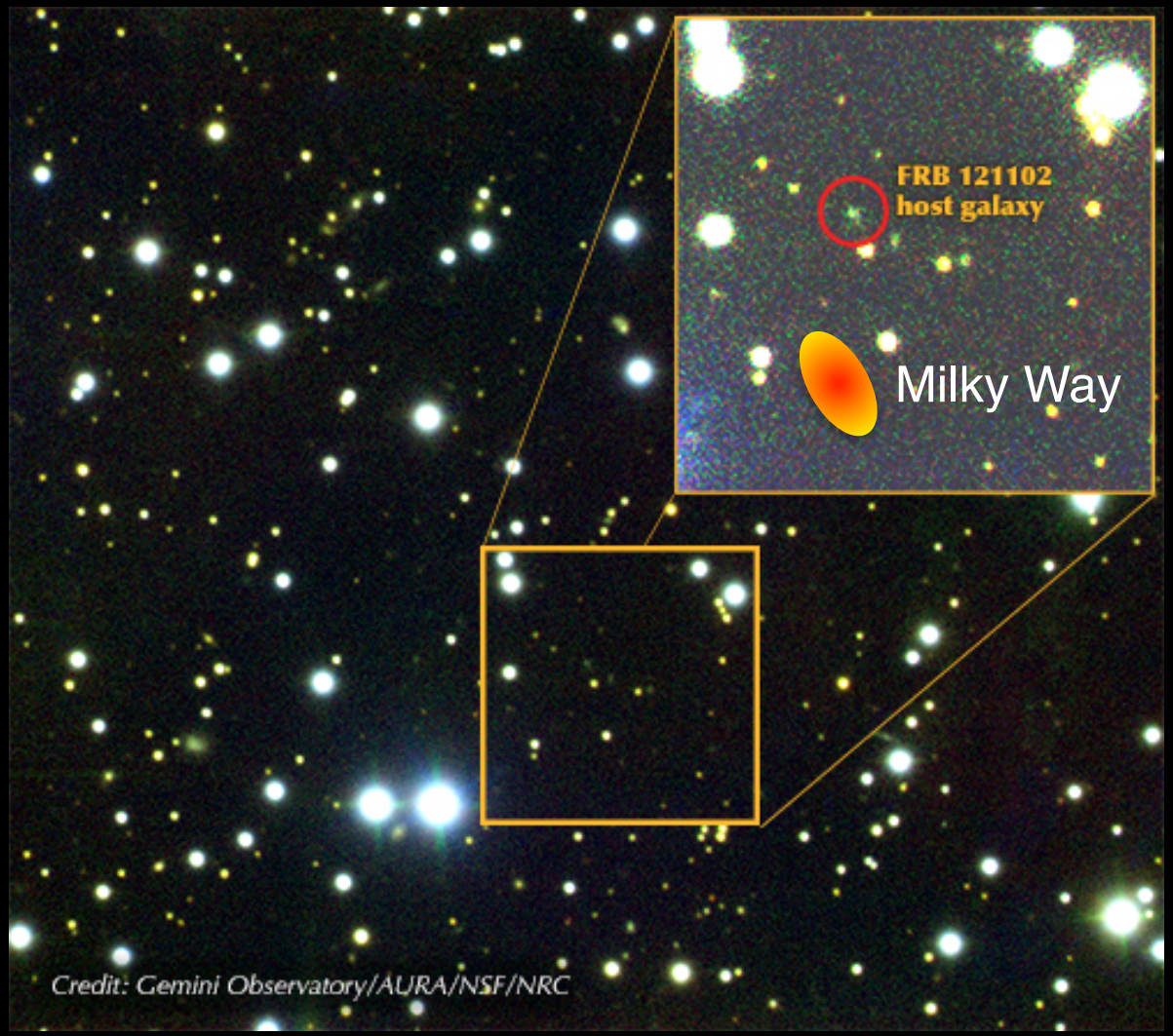
EVN and VLBA show that radio source is compact

From previously stored baseband data

Chatterjee et al. 2017

Host galaxy

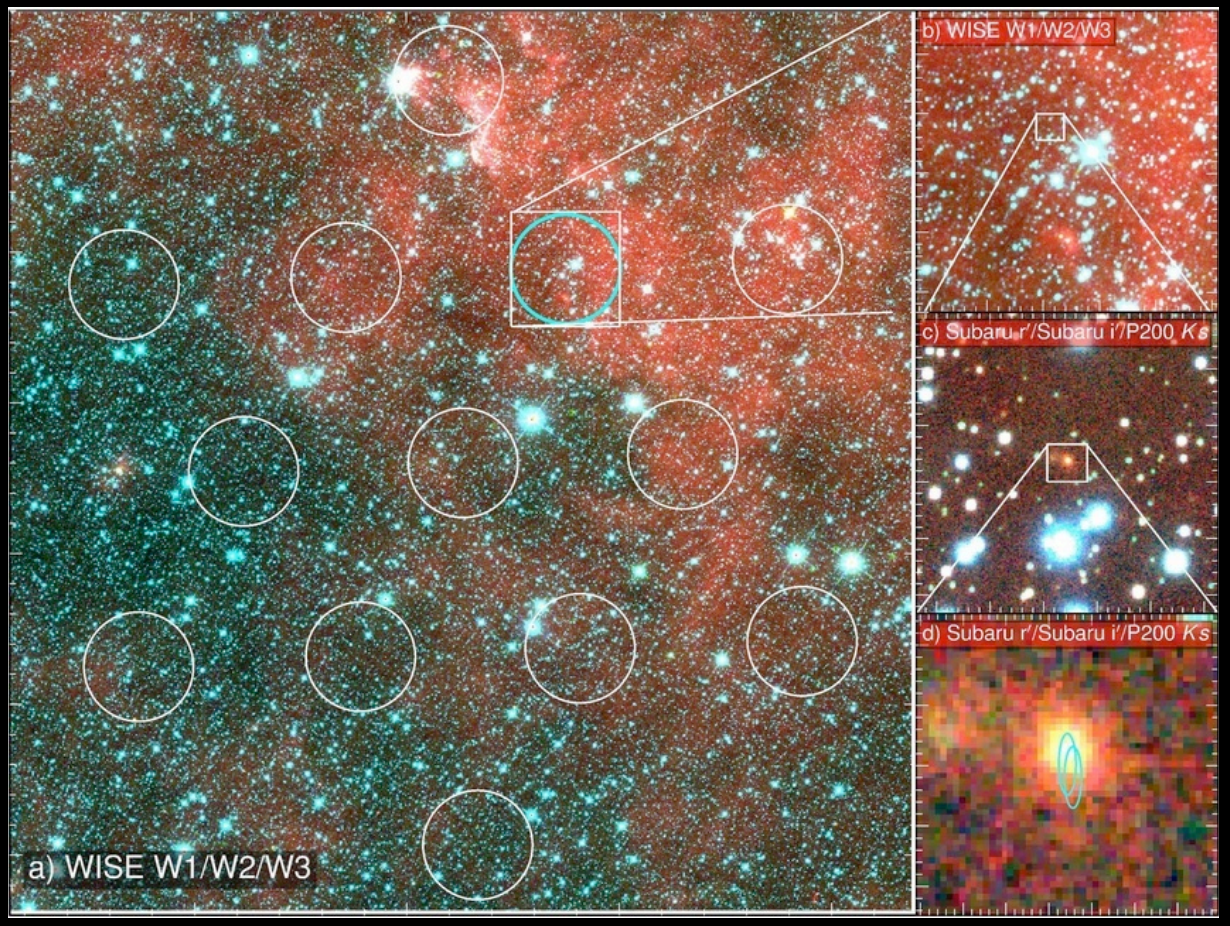
Extragalactic nature confirmed: z = 0.193



- 25th mag., roughly 100 million times fainter than the naked eye limit.
- Each burst (briefly) outshines all other stars in the galaxy!
- 1000x less massive than the Milky Way.

Relation to long GRBs and superluminous SNe?

This is a direct localization, not an afterglow



Keane et al. 2016

Avoids the ambiguity in localizing a burst based on time coincidence with a multi-wavelength event

Arecibo+EVN localization

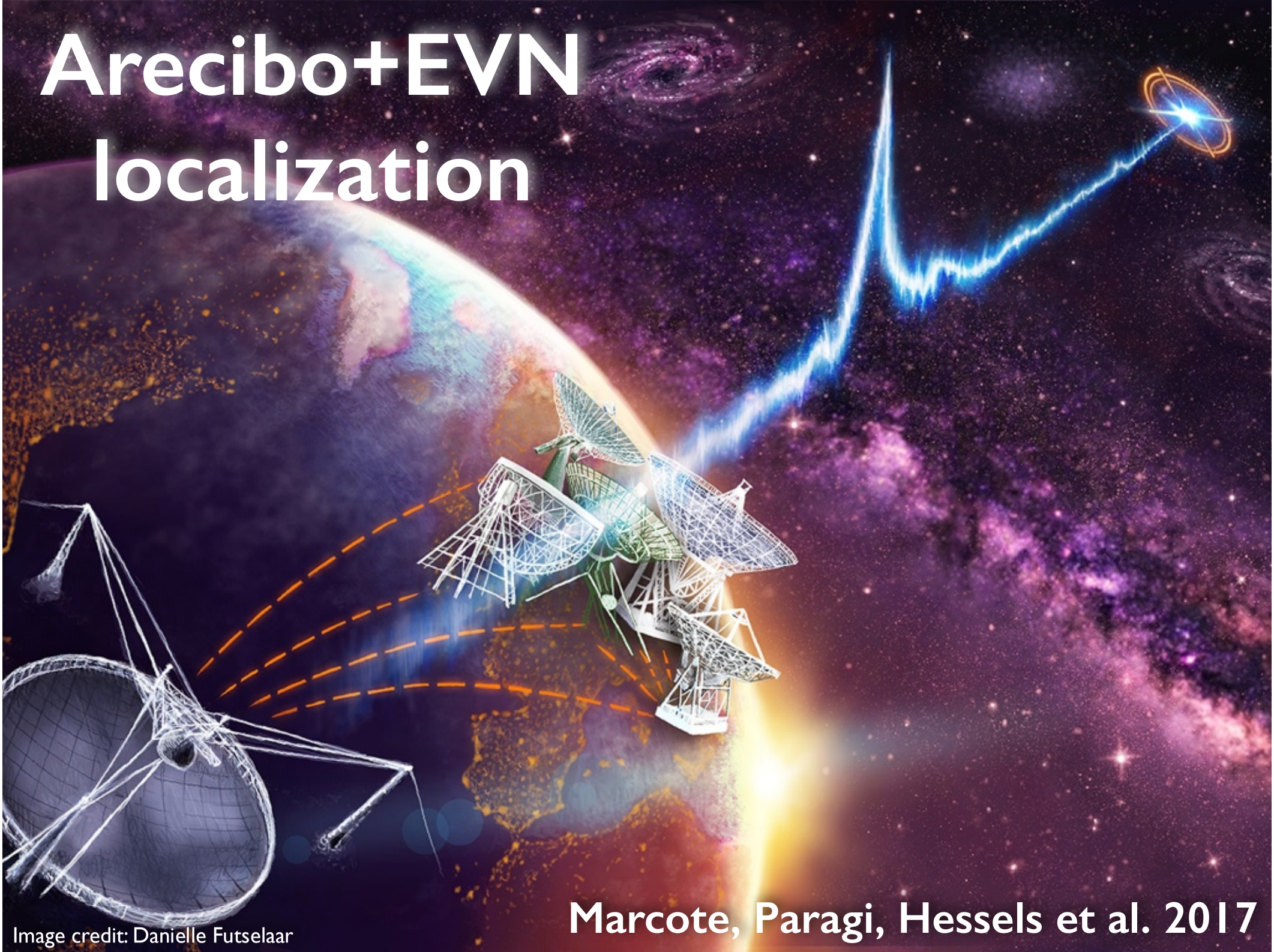


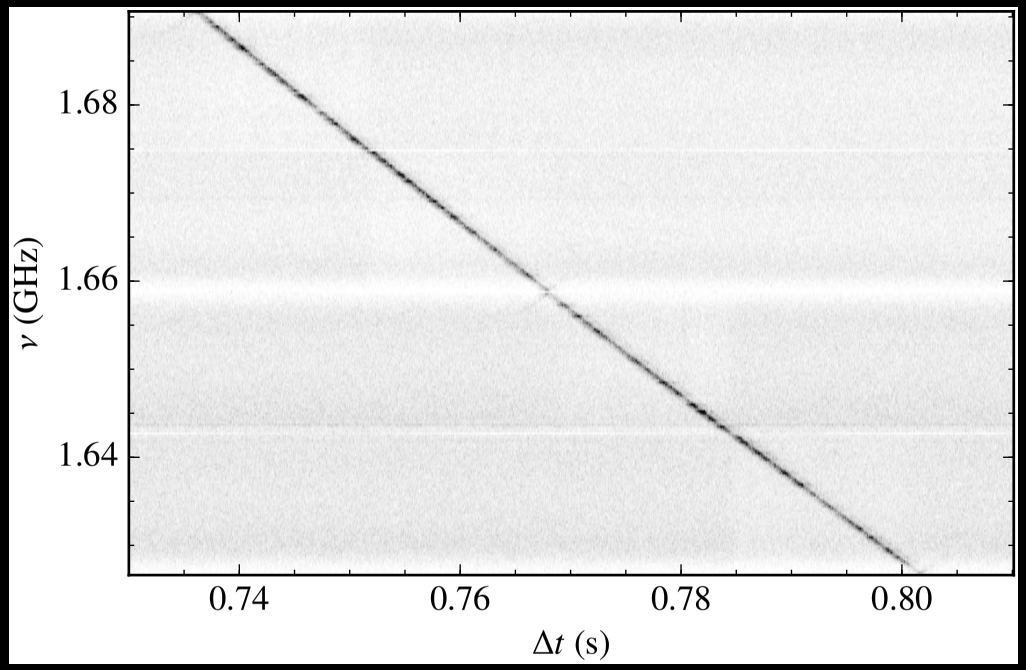
Image credit: Danielle Futselaar

Marcote, Paragi, Hessels et al. 2017

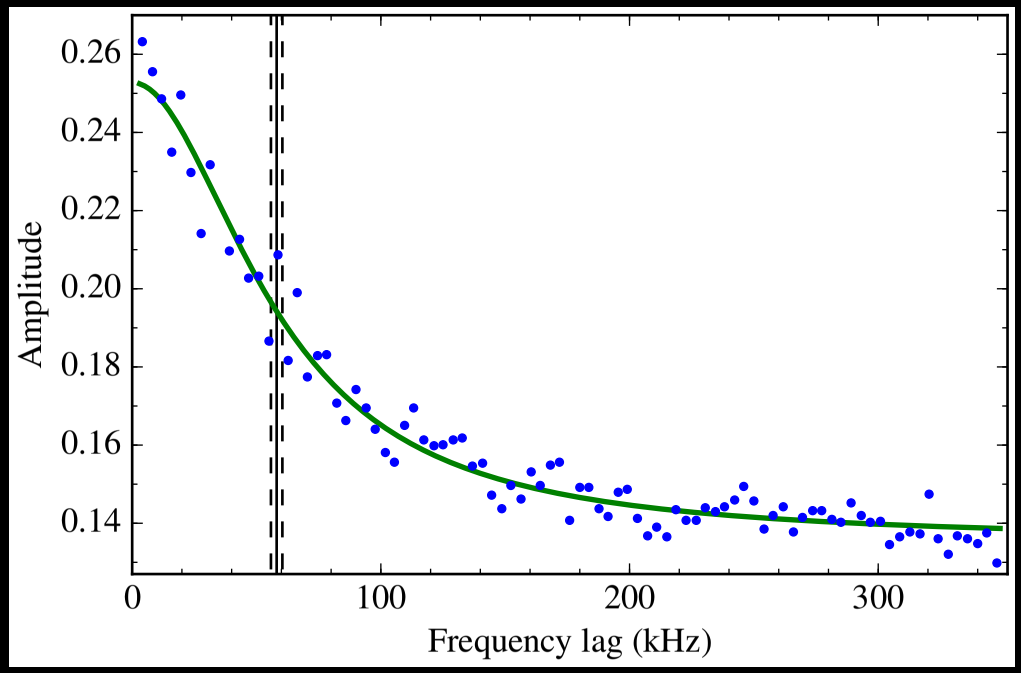
Why zoom-in even further?

- Do the bursts come from exactly the position of the persistent radio source?
- What is their physical relation?
- Are the bursts coming from the center or the outskirts of the host galaxy?

Arecibo+EVN detects a burst!



Dynamic spectrum from Arecibo auto-correlations

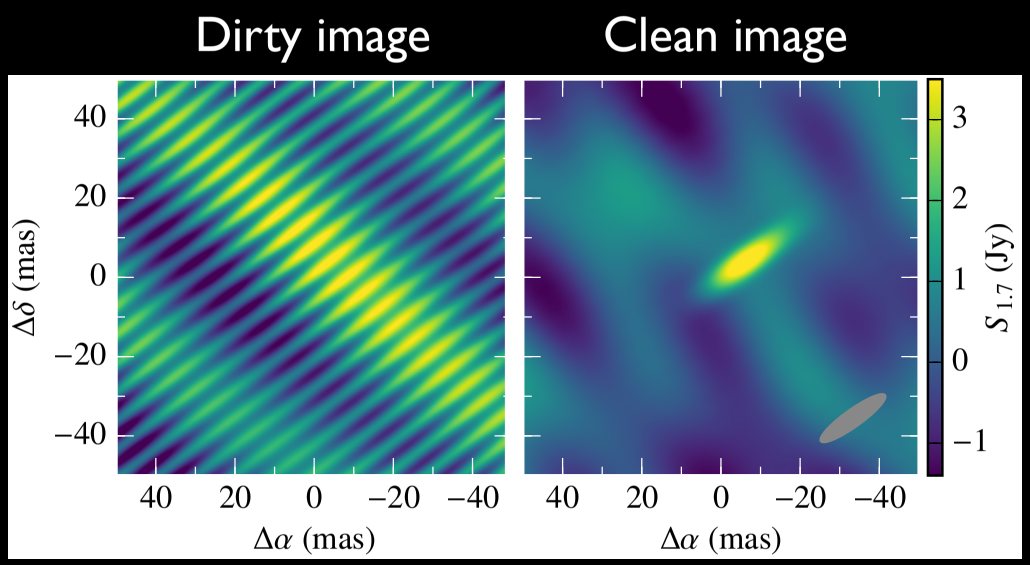


ACF in the frequency direction. Shows Galactic diffractive scintillation?

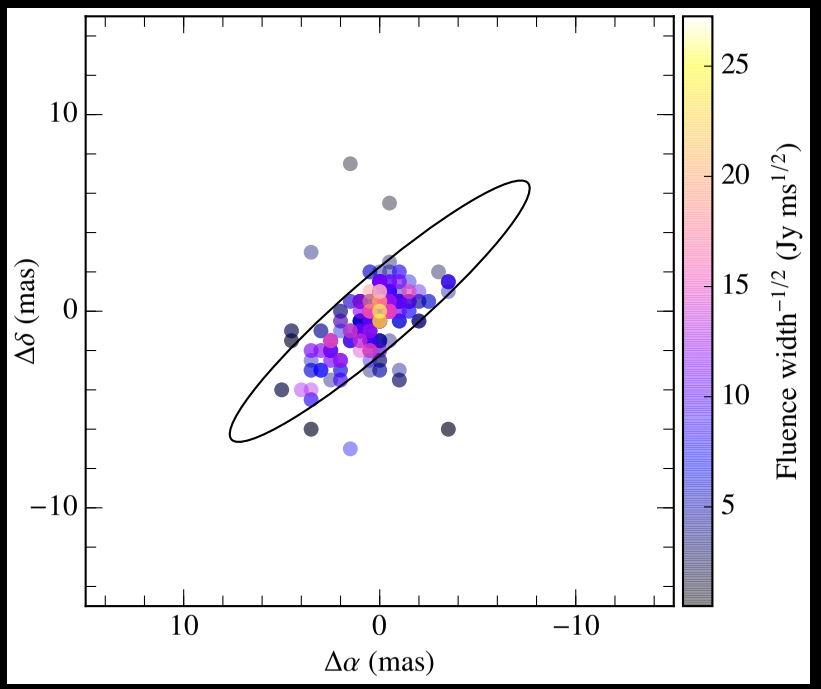
One bright & 3 weak bursts detected in a 2-hr observation

Marcote et al. 2017

Arecibo+EVN localization



Brightest FRB121102 burst seen by Arecibo+EVN



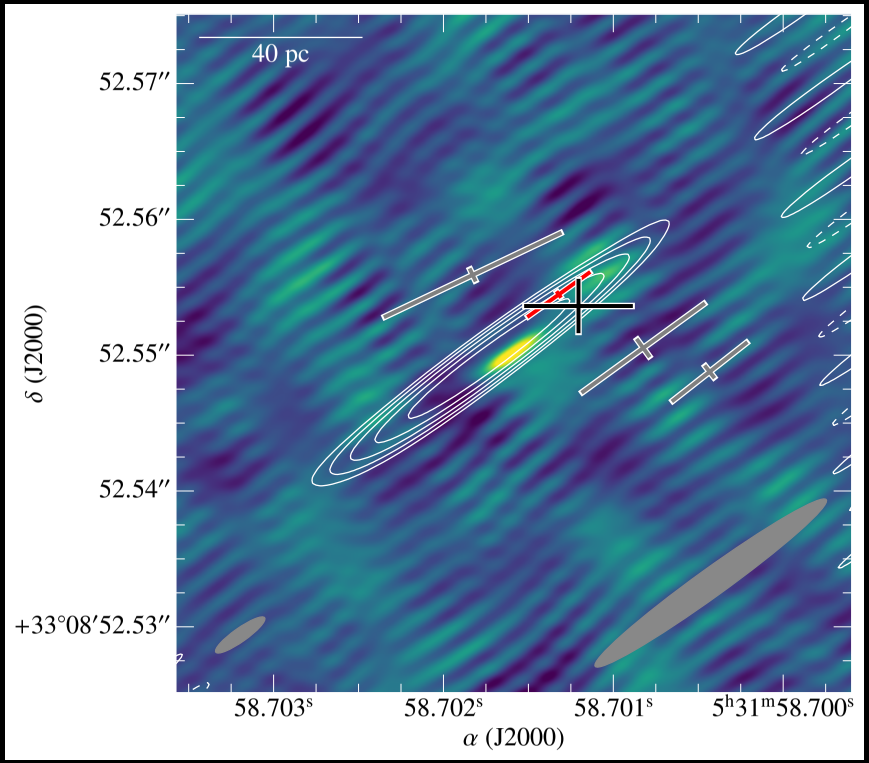
Localizations of pulses from test pulsar B0525+21

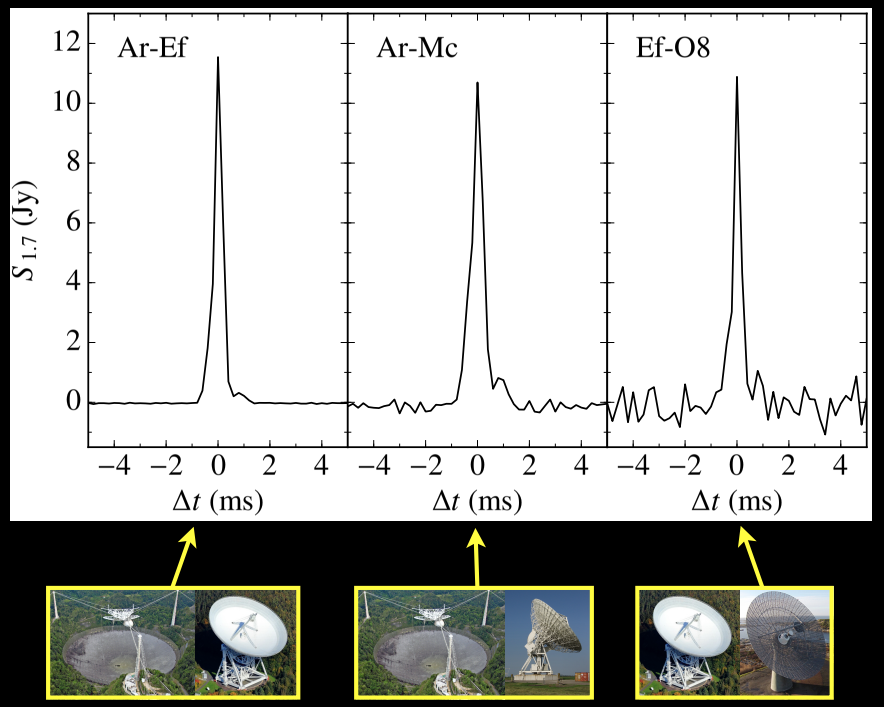
Quantifying systematic errors on the position

Marcote et al. 2017

Arecibo+EVN localization

Localization to ~10mas





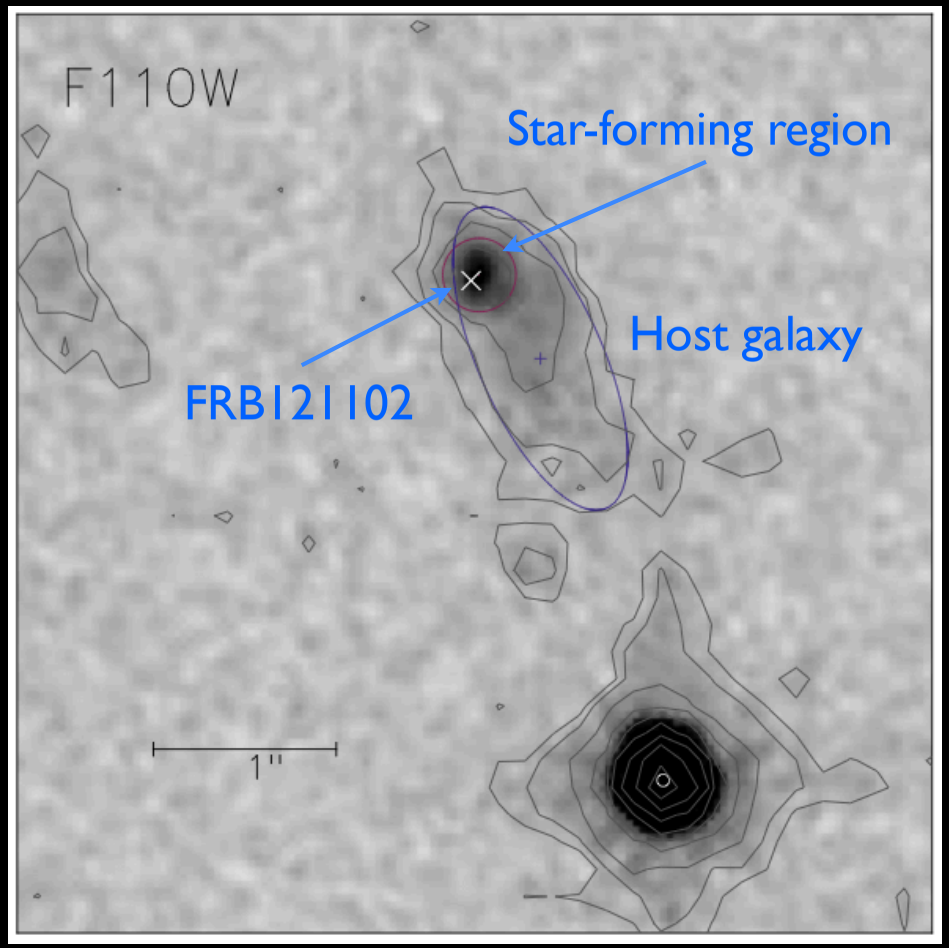
Bursts and persistent radio source are physically related

(coincident to within < 40 pc at 1Gpc)

Marcote et al. 2017

FRB121102 with HST

Clearly associated with a star-forming region

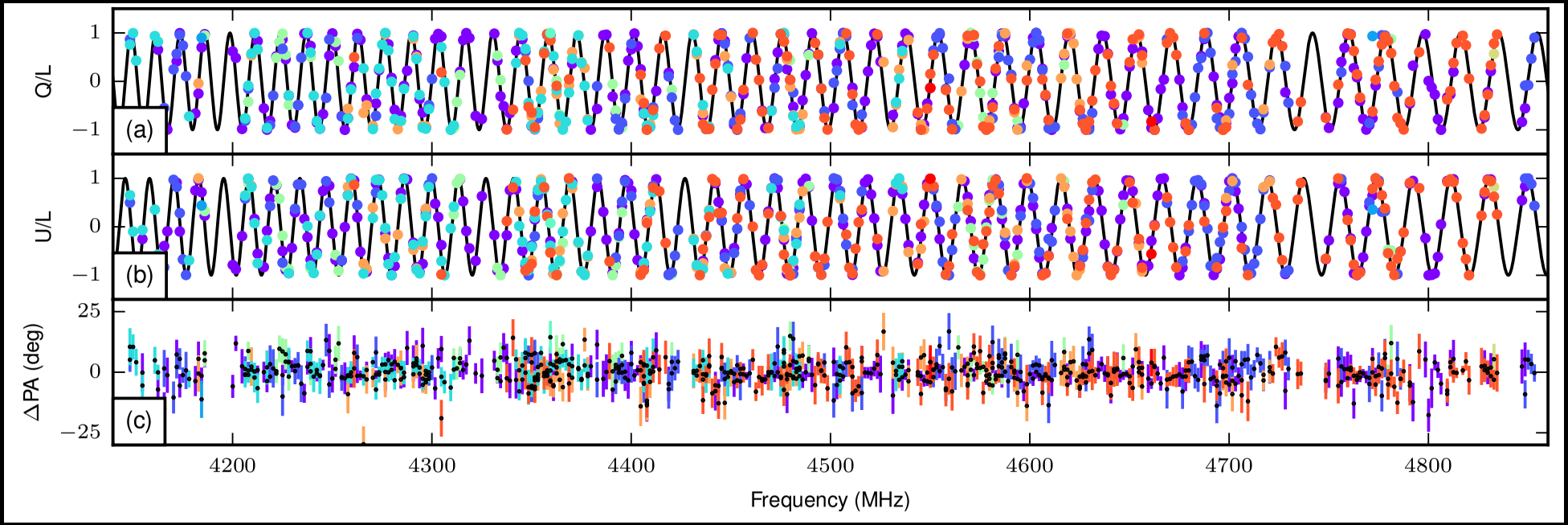


Bassa et al. 2017

EVN localization within galaxy is vital

Rotation measure of FRB 121102

(also shows that bursts are detectable at 5-10 GHz)



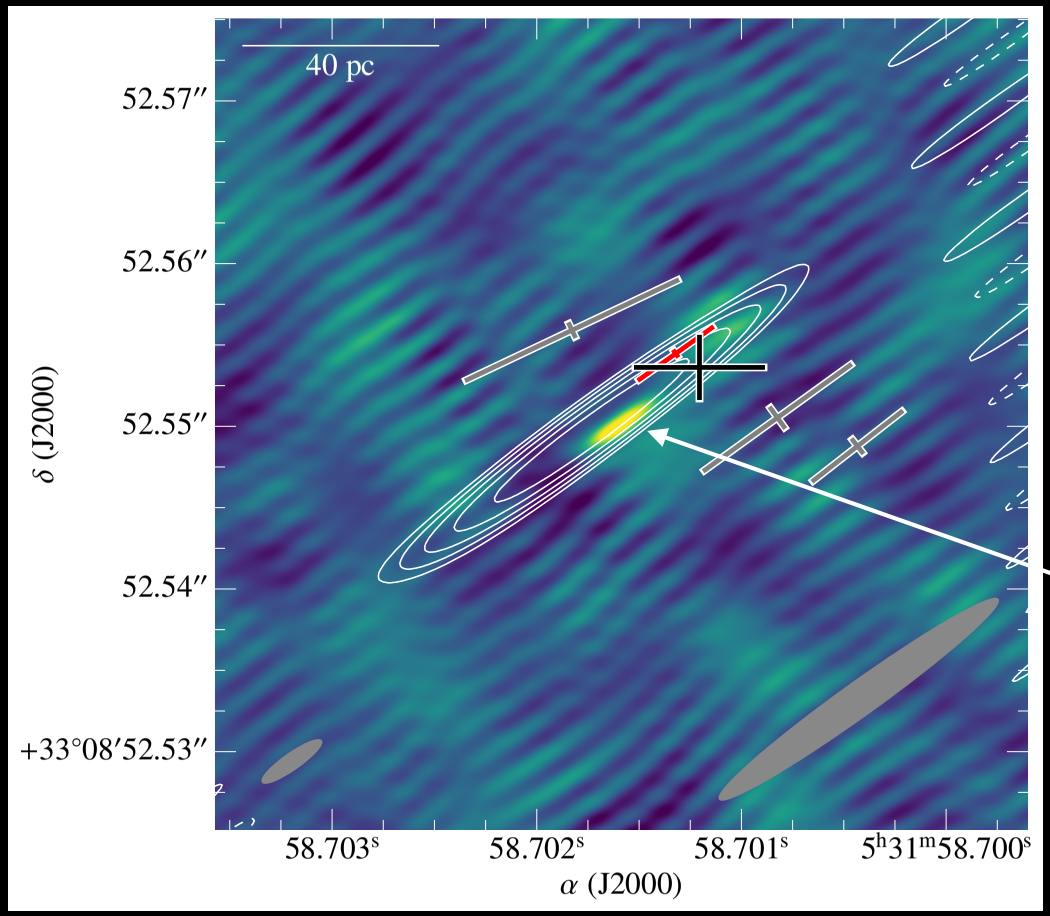
Michilli, Seymour, Hessels et al. 2018

Variable rotation measure ~ 140,000 rad m^{-2} in the source reference frame:

- Extreme and dynamic magneto-ionic environment.
- Persistent source a massive black hole or a dense nebula?

Next step for EVN

Resolve the persistent source?



5GHz EVN detection of persistent source (color map)

Marcote, Paragi, Hessels et al. 2017

Prospects for EVN

CHIME

ASKAP

- Discovery rate of FRBs expected to increase to several per day thanks to CHIME, ASKAP, Apertif, UTMOST, etc.

- Discovery localizations on the order of arcminutes.

- EVN can be an important follow-up instrument.

- Can EVN also be a competitive discovery machine?

FRB follow-up with EVN

- Partly predicated on the assumption that other FRBs will repeat.

- All FRBs associated with a compact persistent source? These are relatively rare (e.g. Eftekhari et al. 2018).

EVN can further differentiate between candidate persistent radio sources by finding the compact sources.
(only ~20% of sub-mJy radio sources are compact on mas scales)

- Need big dishes (Arecibo, Effelsberg, Lovell, GBT, FAST) *and* lots of smaller ones (instantaneous *uv* coverage).

- Rapid follow-up is best.

FRB follow-up with EVN

FRB121102 can be "blindly" localized in this way.

- Routinely Buffer baseband data from individual dishes (10s of TBs) for at least a week and ideally save for a year.

- Use biggest dish as a burst finder. Ideally also use a local broadband pulsar recorder with coherent dedispersion.

- Use delay mapping to get from arcminute to 10s of mas before correlating at burst time(s).

- Image all VLA and ATCA point sources in error box to find potential persistent radio counterparts.

FRB discovery with EVN

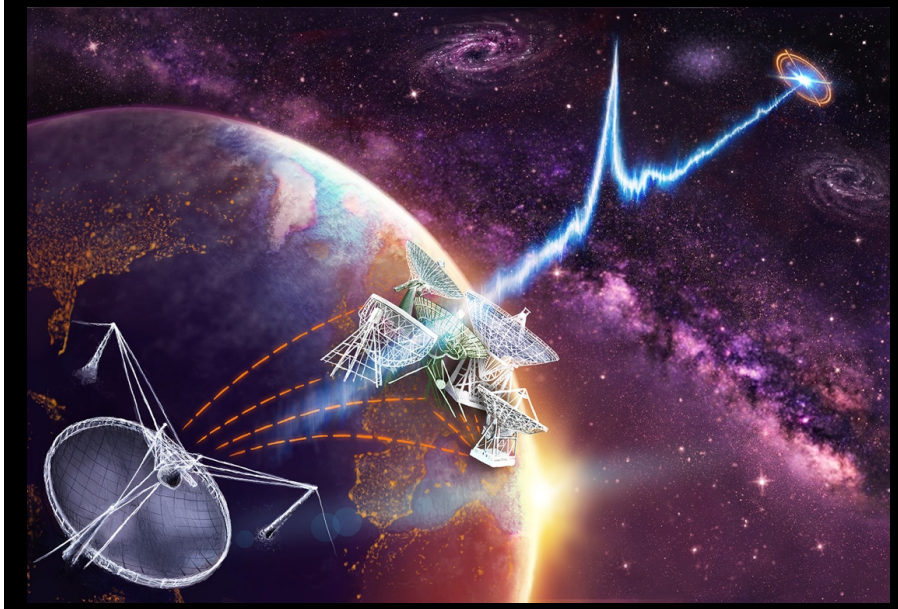
- EVN field-of-view is too small - even for the small dishes and even in a "fly's eye" mode.

- Would require a major investment to equip ~10 dishes with focal plane arrays and the necessary real-time processing backends.

- Direct, precision localization is the goal. "Just finding" a new FRB is not so interesting anymore.

But what about having the small EVN dishes continuously shadow Effelsberg PAF observations in order to provide direct localizations?

Summary



- FRB 121102 demonstrates the importance of VLBI for understanding FRBs (this was a pleasant surprise!).

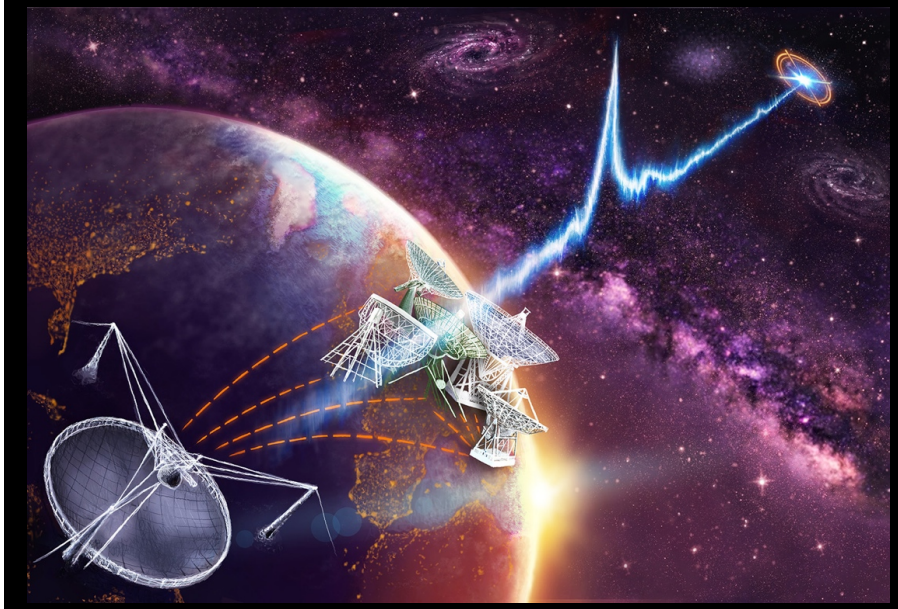
- Obtaining more precision localizations remains critical.

- With a modest investment, the EVN can be an important follow-up machine and enable precision burst localizations and identify potential persistent radio counterparts.

- Discovering new FRBs with EVN would require a major investment and effort.

Wisest short-term investments

(in my opinion)



- Greatly expand the capacity for buffering individual telescope data and imaging a large fraction of the primary field-of-view (make EVN images around all > 0.1 mJy point sources).

- Use the small dishes to continuously shadow an instrument capable of discovering FRBs at a reasonable rate.