

# #EUROFLASH#

**Jason Hessels**  
McGill / UvA / ASTRON

Image credit: Futselaar & Hessels



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Research team



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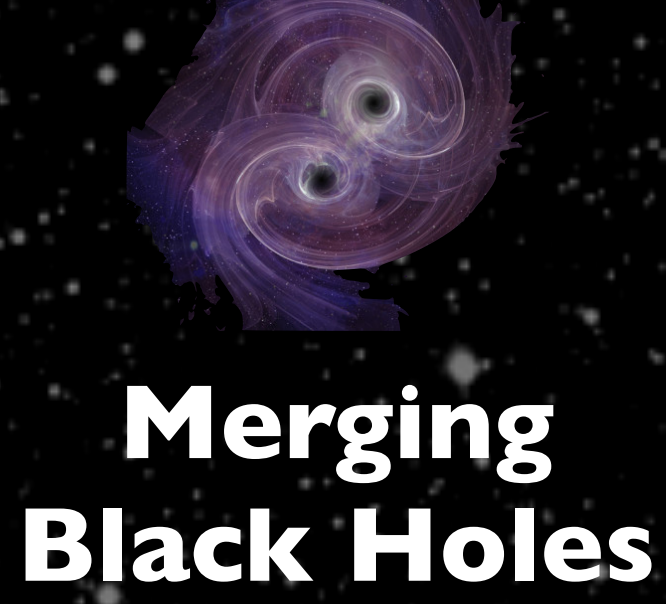


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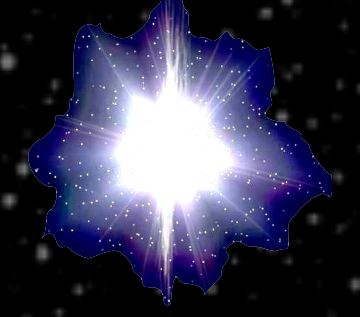


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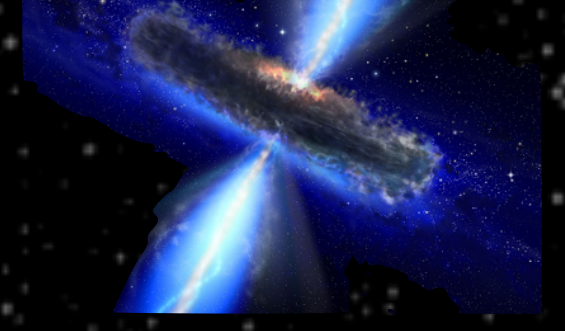
**Merging Black Holes**



**Supernovae**



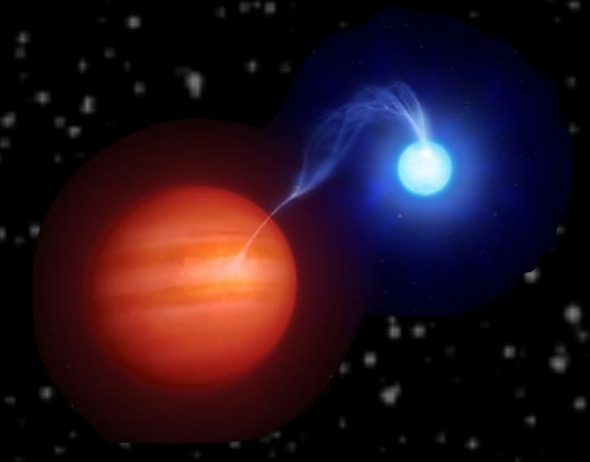
**Magnetars**



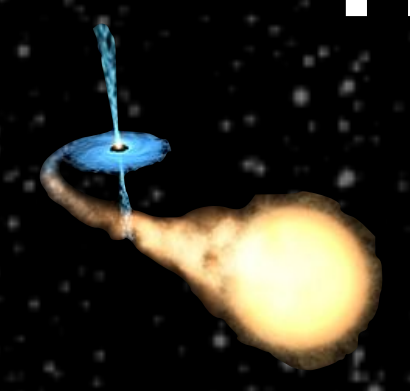
**Accreting Massive Black Hole**



**Super-giant Pulses**



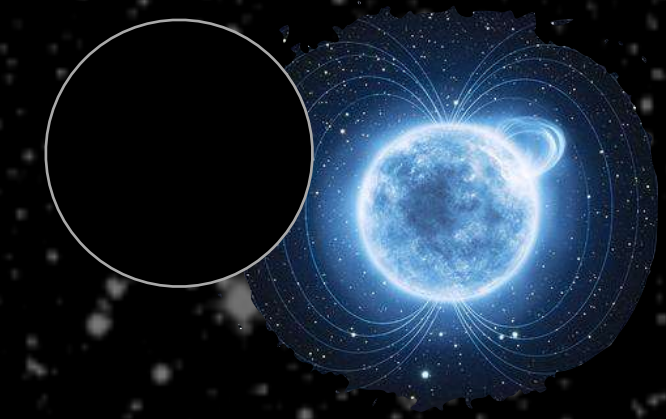
**Interacting Binary**



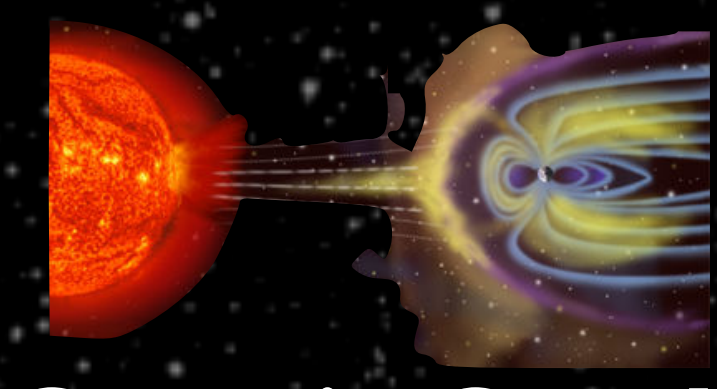
**Microquasar**



**Evaporating Black Holes**



**Black Hole Battery**



**Cosmic Comb**



**Gamma-ray Bursts**



**"Blitzars"**

**Galactic**

**Extragalactic**

**Micro-quasars**

**Flare stars**

**ETI**

**Magnetars**

**Pulsars**

**We are here**

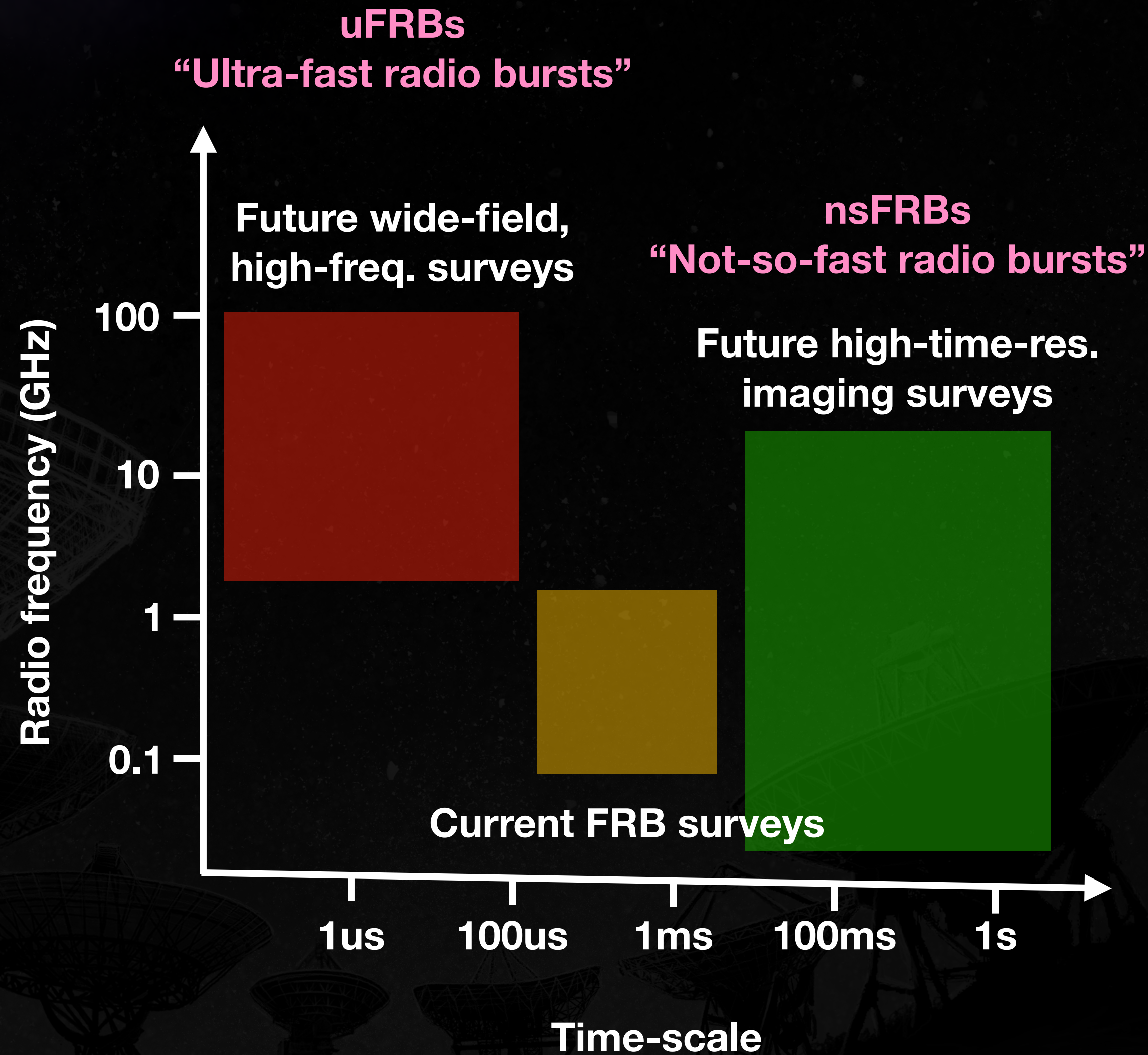
**(Potential) sources of coherent radio flashes**

**EUROFLASH**

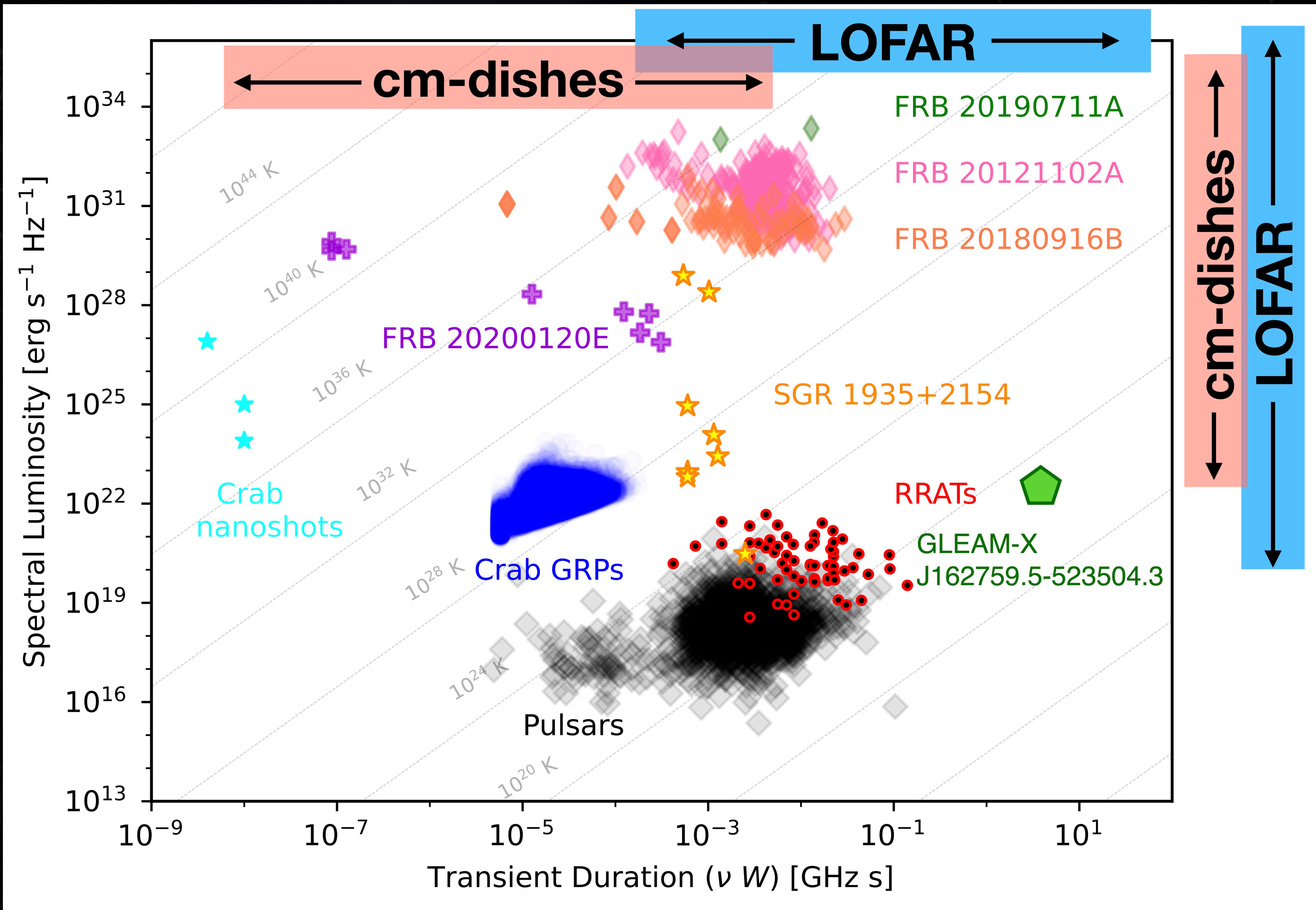
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# Boldly go where no telescope has gone before



# Boldly go where no telescope has gone before



**Timescale**

**10,000,000,000x**

**Luminosity**

**1,000,000,000,000,000x**

Adapted from Nimmo et al. 2022

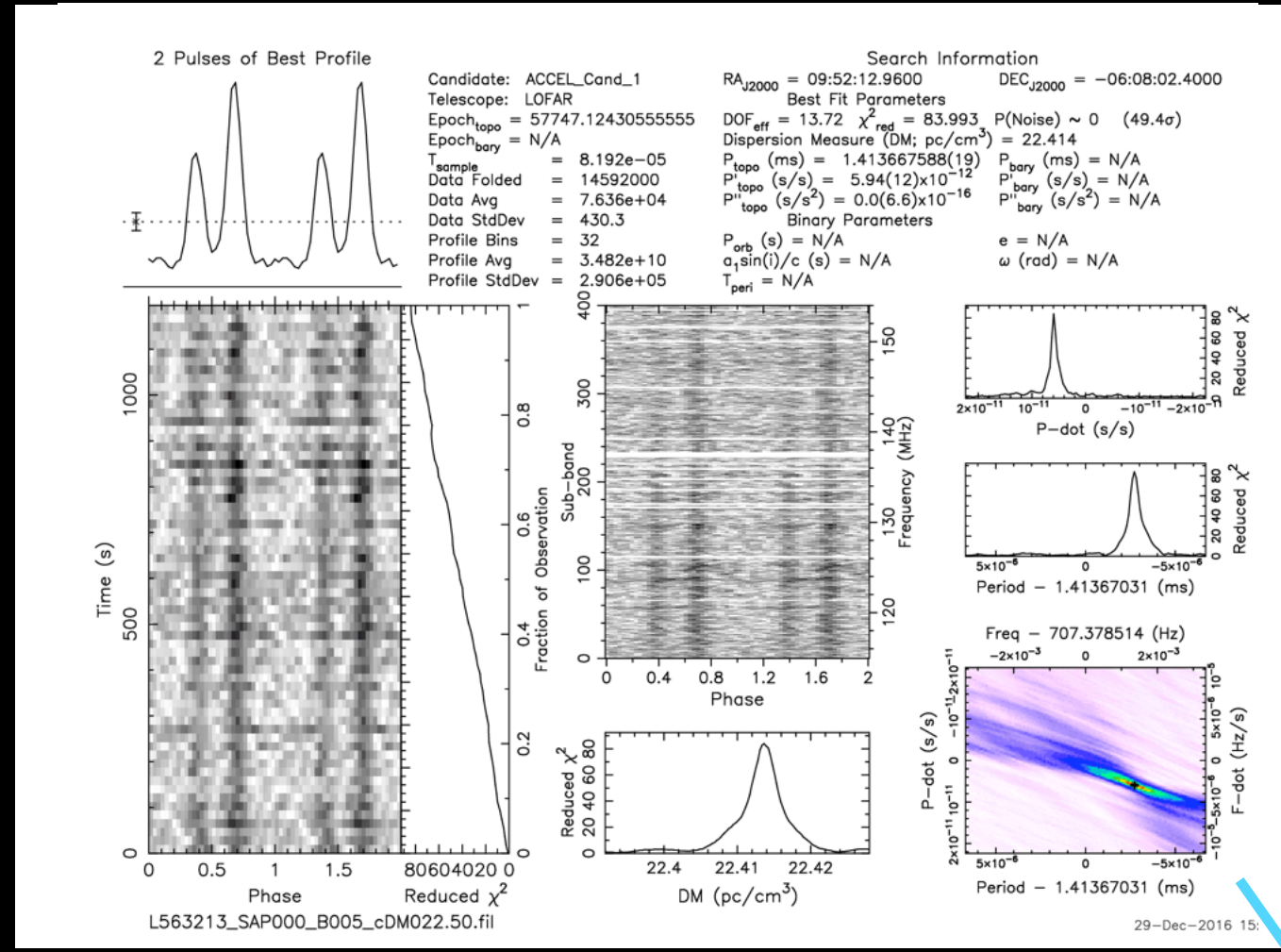
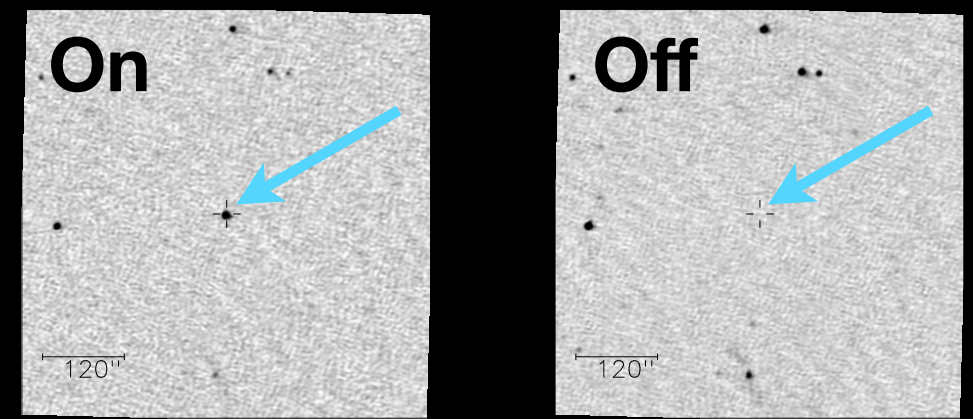
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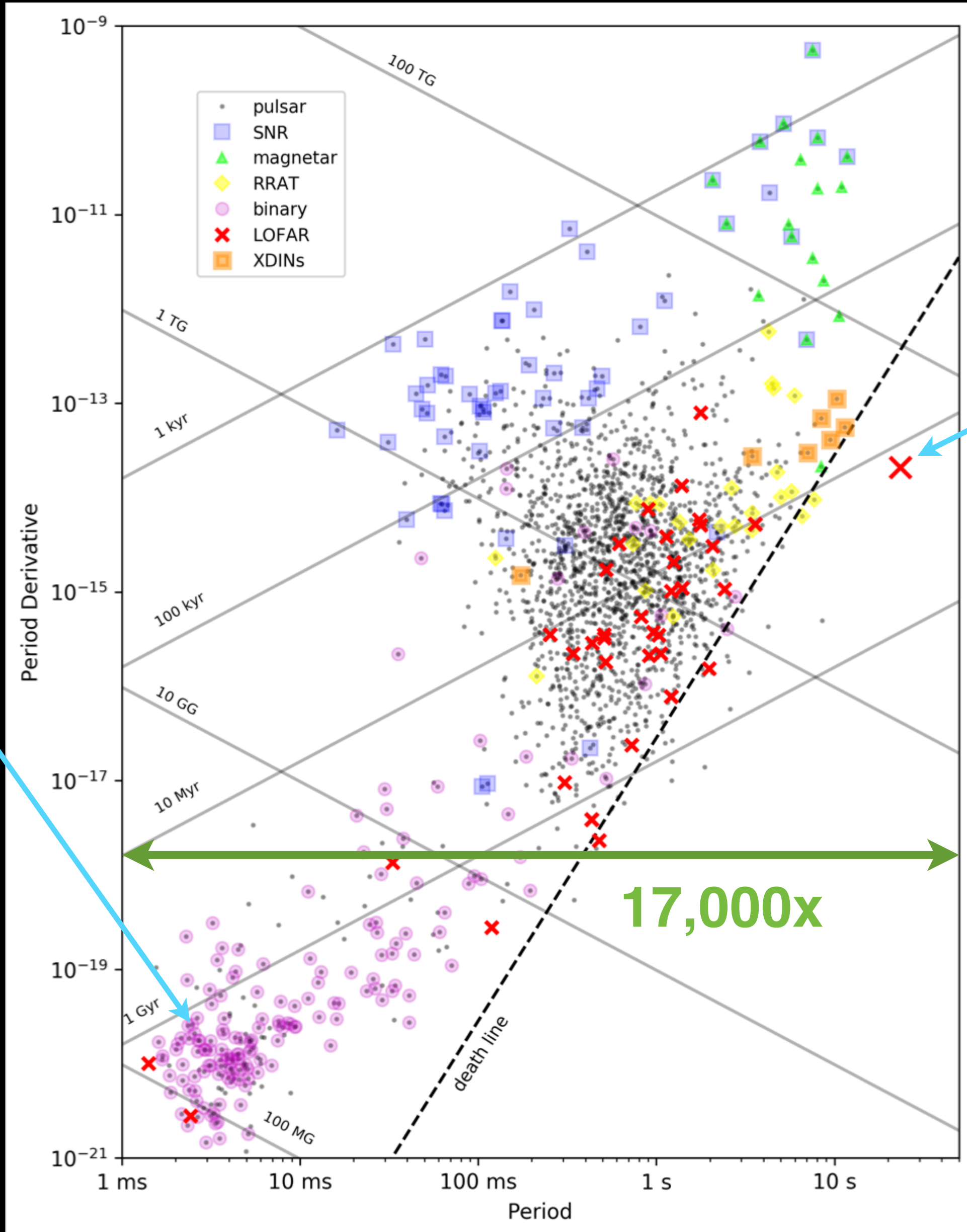
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# LOFAR on the P-Pdot

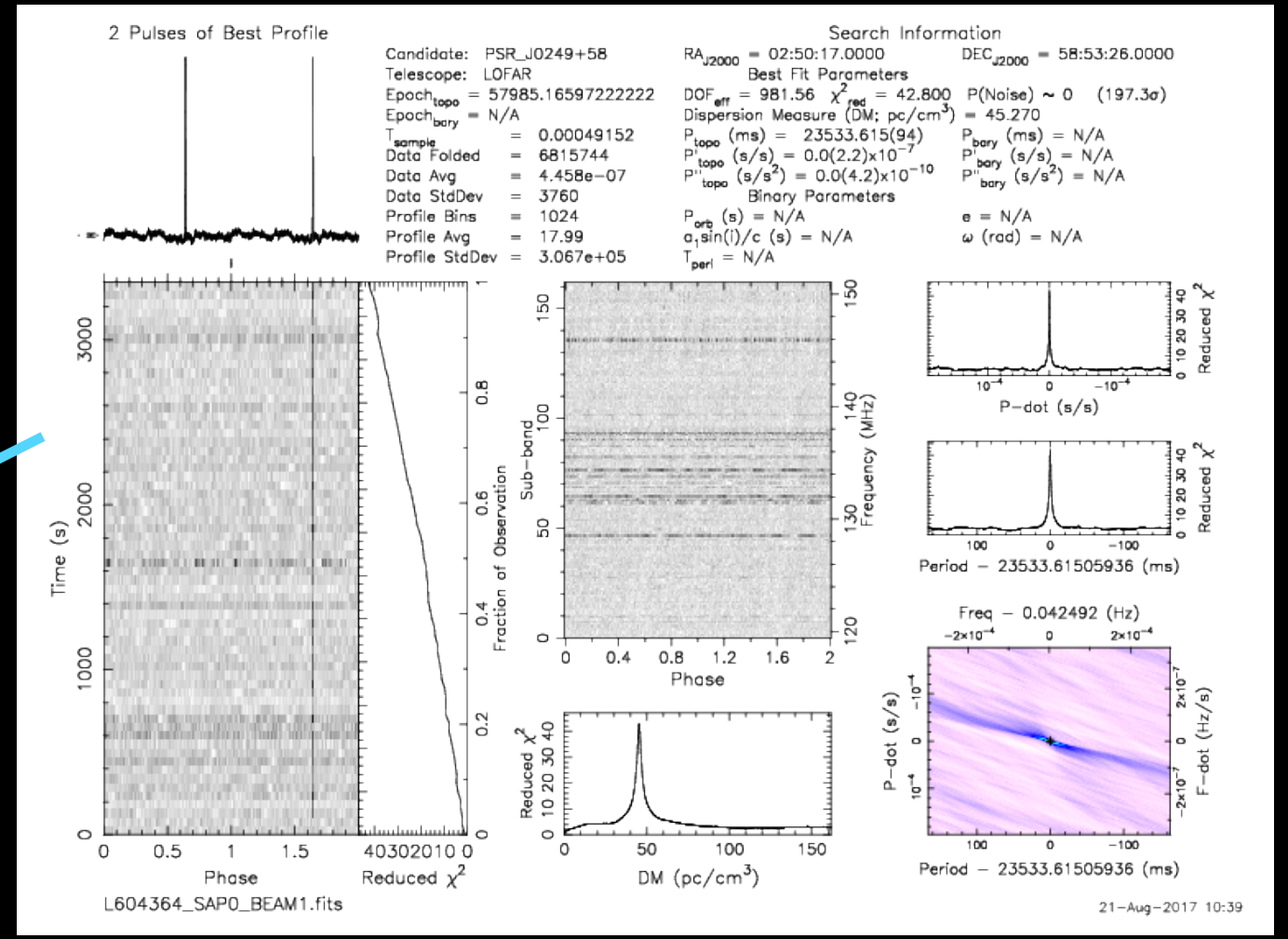


Bassa et al. 2017

707Hz  
1.41ms



Cooper - see also van der Wateren et al. 2023



Tan et al. 2018

0.042Hz  
23,533.6ms



# FRBs with LOFAR

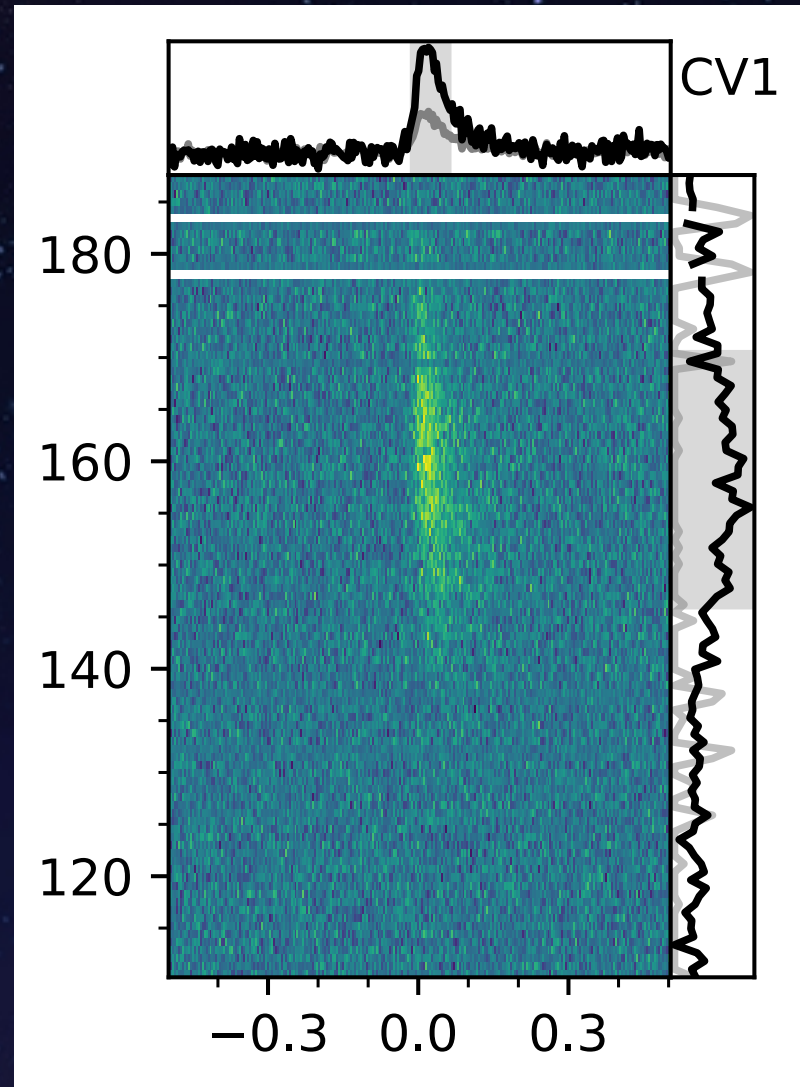


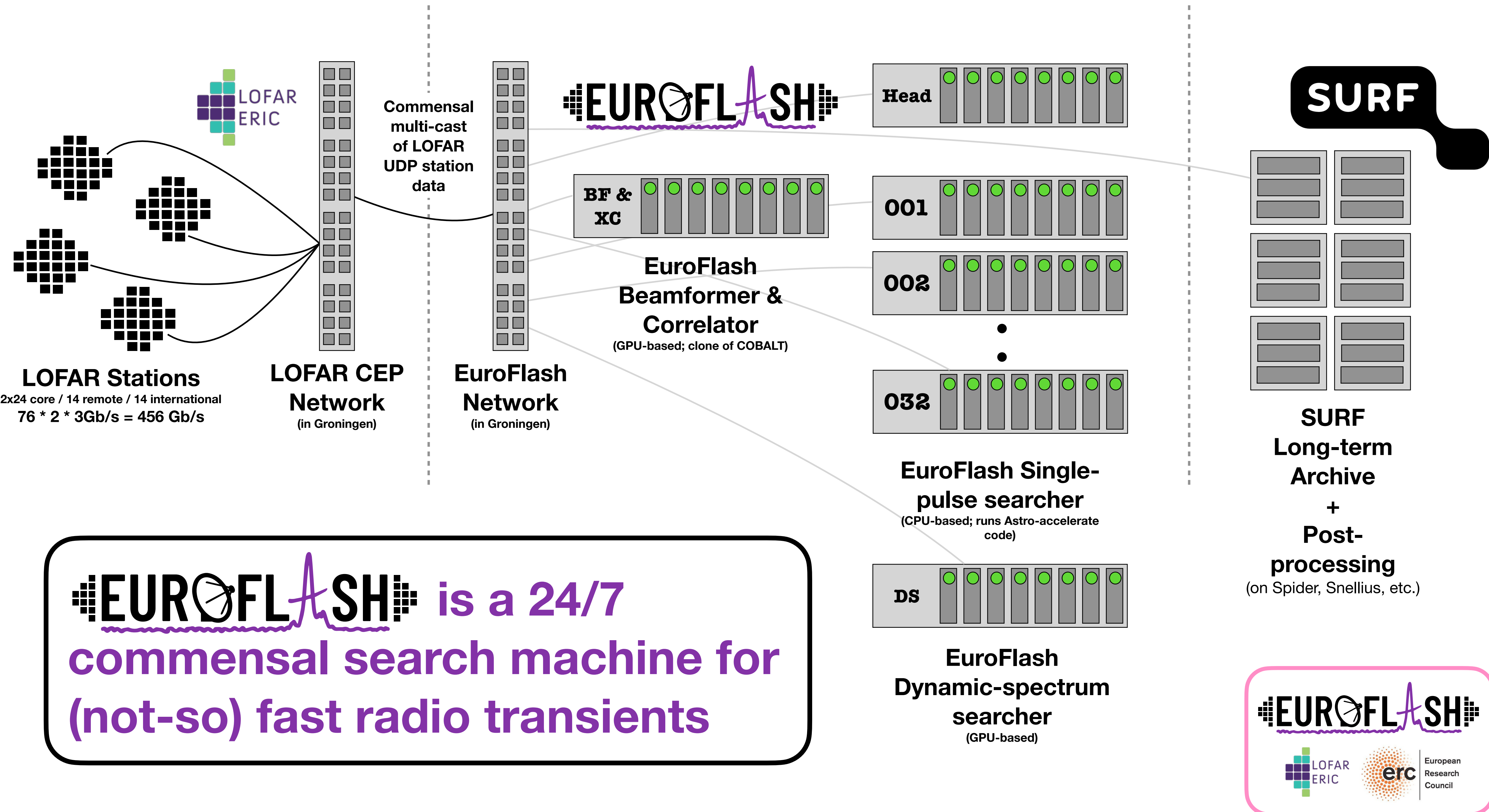
Figure credit:  
Pleunis et al. 2021



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Image credit: Daniëlle Futselaar / ASTRON



**EUROFLASH** is a 24/7 commensal search machine for (not-so) fast radio transients

**EUROFLASH**

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# LOFAR2.0 Large Programmes

## Transients

## Slow(er) Transients (LORAX)

Rowlinson, Wijers et al.



### Submission: LOFAR2.0 Large Programmes – Full proposal LOFAR2.0 Observations of Radio Astrophysical eXplosions (LORAX)

Antonia Rowlinson<sup>1,2</sup>, Ralph A.M.J. Wijers<sup>2</sup> and full team in Table 2

<sup>1</sup>ASTRON – Netherlands Institute for Radio Astronomy  
<sup>2</sup>Anton Pannekoek Institute for Astronomy, University of Amsterdam

#### Abstract

The low frequency radio sky has surprised us with elusive transient sources whose progenitor systems and/or physics remain unknown. These fascinating events are rare and require high quality observations to capture them. We will utilise commensal LOFAR2.0 survey observations to search for more of these unusual events. The vast wealth of data proposed from the LOFAR2.0 surveys teams will give an unprecedented view of the low frequency transient sky on timescales from seconds up to years. In addition to untargeted searches, we intend to make use of the significantly faster response time of LOFAR2.0 to search for predicted low frequency radio emission from multi-messenger transient sources. We request 70 rapid response triggers to gravitational wave events, gamma-ray bursts and magnetars over the 5 year period, corresponding to 152 hours of HBA interferometric and beam formed data. We will also use LOFAR2.0 to monitor known multi-messenger transient and variable sources. We request 34 targeted late time follow-up campaigns over the 5 year period to use on sources including X-ray binaries, recurrent novae and LOFAR transients. These follow-up observations correspond to 755 hours of HBA interferometric data and 72 hours of LBA interferometric data. Finally, with the increased capacity of LOFAR2.0 AARTFAAC-12 will be able to provide near-continuous and real-time monitoring of the low frequency radio sky to find the rarest and brightest events and thus zero-latency and precursor observations of rare transients.

**Keywords**  
transients, surveys, radio astronomy, coherent radiation

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## Pulsar & Fast Transient Surveys (PFTS)

Hessels, Bassa, Pilia, Sobey, Stappers et al.

Submission: LOFAR2.0 Large Programmes – Full proposal

### LOFAR2.0 Pulsar & Fast Transient Surveys

Jason Hessels<sup>1,2</sup>, Cees Bassa<sup>1</sup>, Maura Pilia<sup>3</sup>, Charlotte Sobey<sup>4</sup>, Ben Stappers<sup>5</sup>, Shivani Bhandari<sup>2,6</sup>, Leszek Blaszkiwicz<sup>7</sup>, Marta Burgay<sup>8</sup>, Manisha Caleb<sup>9</sup>, Jesus Alberto Cázares<sup>9</sup>, Pragma Chawla<sup>2</sup>, Alessandro Corongiu<sup>1</sup>, Marcin Gawronski<sup>10</sup>, Aaron Golden<sup>11</sup>, J.-M. Griessmeier<sup>12,13</sup>, Akshatha Gopinath<sup>2</sup>, Gemma Janssen<sup>1,14</sup>, Aris Karastergiou<sup>15</sup>, Evan Keane<sup>16</sup>, Mark Kennedy<sup>17</sup>, Franz Kirsten<sup>18</sup>, Vladislav Kondratiev<sup>1</sup>, Kamen Kozarev<sup>19</sup>, Michael Kramer<sup>20,5</sup>, David McKenna<sup>21,16</sup>, Daniele Michilli<sup>22,23</sup>, Leah Morabito<sup>24,25</sup>, Rouhin Nag<sup>2</sup>, Cherry Ng<sup>26</sup>, Kenzie Nimmo<sup>22</sup>, Aditya Parthasarathy<sup>1</sup>, Ziggy Pleunis<sup>26</sup>, Andrea Possenti<sup>2</sup>, Harry Qiu<sup>27</sup>, Kaustubh Rajwade<sup>1,5</sup>, Alessandro Ridolfi<sup>3</sup>, Antonia Rowlinson<sup>1,2</sup>, Maciej Serylak<sup>27,28</sup>, Xiaoxi Song<sup>1</sup>, Laura Spitler<sup>22</sup>, Chia Min Tan<sup>29</sup>, Caterina Tiburzi<sup>1</sup>, Sander ter Veen<sup>1</sup>, Dany Vohl<sup>2,1</sup>, Jun Wang<sup>30</sup>, Emma van der Wateren<sup>1,14</sup>, Patrick Weltevrede<sup>3</sup> and Ziwei Wu<sup>31</sup>

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<sup>2</sup>Anton Pannekoek Institute for Astronomy, University of Amsterdam  
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<sup>6</sup>JIVE – Joint Institute for VLBI ERIC  
<sup>7</sup>University of Warmia and Mazury in Olsztyn, Olsztyn, Poland  
<sup>8</sup>Sydney Institute for Astronomy, School of Physics, The University of Sydney, NSW 2006, Australia  
<sup>9</sup>Ventspils International Radio Astronomy Centre, Ventspils University of Applied Sciences, Ventspils, LV-3601, Latvia  
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<sup>11</sup>University of Galway, University Road, Galway, H91 TK33, Ireland  
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## Galactic Plane Survey (L2GPS)

Arias, Rajwade, Hajduk et al.

### Submission: LOFAR2.0 Large Programmes – Full proposal The LOFAR 2.0 Galactic Plane Survey (L2GPS)

Maria Arias<sup>1</sup>, Kaustubh Rajwade<sup>2</sup>, Marcin Hajduk<sup>3</sup> and the L2GPS collaboration<sup>4</sup>

<sup>1</sup>Leiden Observatory, Niels Bohrweg 2, 2333 CA, Leiden, NL  
<sup>2</sup>ASTRON, Oude Hoogevensdijk, Dwingelo 7991 PD, NL  
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<sup>4</sup>The entire author list is provided in the Appendix

#### Abstract

The LOFAR 2.0 Galactic Plane Survey (L2GPS) is a proposed wide-area survey that will cover the Northern Milky Way from 30° – 210° in Galactic longitude and ±10° in Galactic latitude at 150 MHz and 40 MHz, i.e. the LOFAR 2.0 High Band and Low-Band Antennas (HBA and LBA, respectively). The survey will consist of multiple observations of the same field in order to enable transient science. We will provide the astronomical community with science-ready images at 6'' resolution and 80 – 300 μJy beam<sup>-1</sup> sensitivity at 150 MHz, and at 15'' resolution and ~ 800 μJy beam<sup>-1</sup> sensitivity at 40 MHz. We will also provide high-resolution (0.3'' – 1'') 150 MHz images of ~ 60% of the Survey area. In order to do this, we request a total of 1833 observing hours.

The L2GPS will enable a plethora of science results in the field of Galactic astronomy, including the possibility of finding a new source class of ultra-long period sources. Discoveries and studies of ultra-long period sources will potentially revise our understanding of radio emission from compact objects. The survey will also be key for understanding the role of magnetic fields in the formation of massive stars, and the relation between the different components of the interstellar medium (ISM). It will probe thermal and non-thermal phases of the ISM, and help assess the link between H II regions, the warm ionised medium, and the cosmic ray density of the Galaxy. It will allow us to conduct a complete census of the supernova remnant population of the Northern sky, and trace the local magnetic field through Faraday rotation. Moreover, it will support a series of ancillary science goals like discoveries of peculiar transients and cosmological source counts and become a legacy dataset for the broader astronomical community. Conducting this survey will require that we observe, store and process 4.1 PB of data, and we will achieve this by coordinating closely with other proposals. We will develop dedicated data reduction techniques and strategies in order to conduct direction-dependent imaging in regions that present many technical complexities, in particular, due to the large range of spatial scales of emission, and the large number of very bright sources that are located in the Galactic plane.

The L2GPS Collaboration is a diverse, international team of researchers, with a mix of technical and scientific experts, and of early-, mid-, and late-career contributors. We will encourage science participation and exploitation in a collaborative and respectful manner, and will have a policy whereby early career researchers are encouraged to lead science projects, and any interested scientist, from any country, will have the option to join the collaboration.

**Keywords**  
Milky Way, Galactic Plane Survey, interstellar medium, ultra-long period sources, young stellar objects, H II regions, planetary nebulae, supernova remnants, scattering, transients, cosmic dipole

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## Pulsar & Fast Transient Monitoring (PURR)

Tiburzi, Bassa, Hessels, Janssen, Keane et al.

Submission: LOFAR2.0 Large Programmes – Full proposal

### PURR – PULsars and Repeaters Research, a Pulsar and Fast Transient Monitoring Project

C. Tiburzi<sup>1</sup>, C. G. Bassa<sup>2</sup>, J. W. T. Hessels<sup>2,3</sup>, G. H. Janssen<sup>2,4</sup>, E. F. Keane<sup>5</sup>, M. A. Krishnakumar<sup>6,7</sup>, L. S. Oswald<sup>8,9</sup>, M. Pilia<sup>3</sup>, C. Sobey<sup>10,11</sup>, X. Song<sup>2</sup>, M. Trudu<sup>1</sup>, J. P. W. Verbiest<sup>12</sup>, P. Weltevrede<sup>13</sup>, F. Abbate<sup>14,5</sup>, J. Antoniadis<sup>14,6</sup>, A. Antonova<sup>15</sup>, A. Basu<sup>16</sup>, R. Basu<sup>16</sup>, A. V. Bilous<sup>17</sup>, C. Blanchard<sup>18</sup>, L. Blaszkiwicz<sup>19</sup>, M. Brionne<sup>18</sup>, M. Burgay<sup>1</sup>, M. Brüggen<sup>20</sup>, J. A. Cázares<sup>21</sup>, A. Chalumeau<sup>22,23</sup>, B. Ciardi<sup>24</sup>, A. Corongiu<sup>1</sup>, P. Flisek<sup>19</sup>, M. P. Gawronski<sup>25</sup>, A. Golden<sup>26</sup>, J.-M. Grießmeier<sup>18,27</sup>, M. Hoeft<sup>28</sup>, H. Hu<sup>8</sup>, F. Iraci<sup>1,29</sup>, F. Jankowski<sup>18,13</sup>, O. A. Johnson<sup>5</sup>, A. Karastergiou<sup>8</sup>, M. R. Kennedy<sup>30</sup>, J. Kijak<sup>18</sup>, V. I. Kondratiev<sup>1</sup>, K. Kozarev<sup>15</sup>, M. Kramer<sup>13</sup>, A. Kravkovski<sup>31</sup>, J. van Leeuwen<sup>32</sup>, W. Lewandowski<sup>33</sup>, G. A. Lowes<sup>34,35</sup>, K. Liu<sup>36</sup>, Y. Liu<sup>37,38</sup>, R. A. Main<sup>39,36</sup>, J. W. McKee<sup>39,32</sup>, D. McKenna<sup>32</sup>, R. Mitchev<sup>40</sup>, R. Nag<sup>41</sup>, S. Odzowski<sup>42</sup>, D. Perrodin<sup>43</sup>, A. Parthasarathy<sup>44</sup>, A. Possenti<sup>45</sup>, N. K. Porayko<sup>46,47</sup>, H. Qiu<sup>48</sup>, A. Ridolfi<sup>49</sup>, K. M. Rajwade<sup>50</sup>, A. Rowlinson<sup>51</sup>, K. Rozko<sup>49</sup>, D. J. Schwarz<sup>7</sup>, M. Serylak<sup>38,39</sup>, G. M. Shaifullah<sup>22,51</sup>, M. Soida<sup>52</sup>, S. C. Susarla<sup>35</sup>, B. W. Stappers<sup>17</sup>, A. Szary<sup>48</sup>, P. Tarafdar<sup>41</sup>, G. Theureau<sup>18,27,42</sup>, S. ter Veen<sup>7</sup>, C. Vocks<sup>41</sup>, E. van der Wateren<sup>24</sup>, J. Wang<sup>44,7</sup>, Z. Wu<sup>41</sup> and O. Wucknitz<sup>6</sup>

<sup>1</sup>INAF - Osservatorio Astronomico di Cagliari, via della Scienza 5, 09047 Selargius (CA), Italy  
<sup>2</sup>ASTRON, Netherlands Institute for Radio Astronomy, Oude Hoogevensdijk 4, 7991 PD Dwingelo, The Netherlands  
<sup>3</sup>Anton Pannekoek Institute for Astronomy, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands  
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# Goals

Uncover origin(s) of fast radio bursts (FRBs)

Discover new FRB-like transients

Probe extreme astrophysical processes

Probe intervening magneto-ionised medium



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# Goals

Uncover origin(s) of fast radio bursts (FRBs)

Discover new FRB-like transients





Probe extreme astrophysical processes

Probe intervening magneto-ionised medium



# Goals

- Uncover origin(s) of fast radio bursts (FRBs)
- Discover new FRB-like transients
- Probe extreme astrophysical processes
- Probe intervening magneto-ionised medium



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# Observing modes

## Localisation in time

**20  $\mu$ s - 10 ms:**

targeted searches using semi-coherent dedispersion

**1ms - 100 ms:**

incoherent sum of  $\sim 14$  International stations

**10ms - 1000 ms:**

$\sim 1000$  tied-array beams from Core

**1s - 100 s:**

fast difference imaging from Core

## Localisation in space

buffer Remote + International station data

$\Delta t \sim 100,000$



Image credit: Classy Girl Cupcakes

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# Observing modes

## Localisation in time

20  $\mu$ s - 10 ms:

targeted searches using semi-coherent dedispersion

1ms - 100 ms:

incoherent sum of ~14 International stations

10ms - 1000 ms:

~1000 tied-array beams from Core

1s - 100 s:

fast difference imaging from Core

## Localisation in space

buffer Remote + International station data

At ~ 100,000



Image credit: Classy Girl Cupcakes

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# Observing modes

## Localisation in time

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## Localisation in space

buffer Remote + International station data

At  $\sim 100,000$



Image credit: Classy Girl Cupcakes

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10ms - 1000 ms:

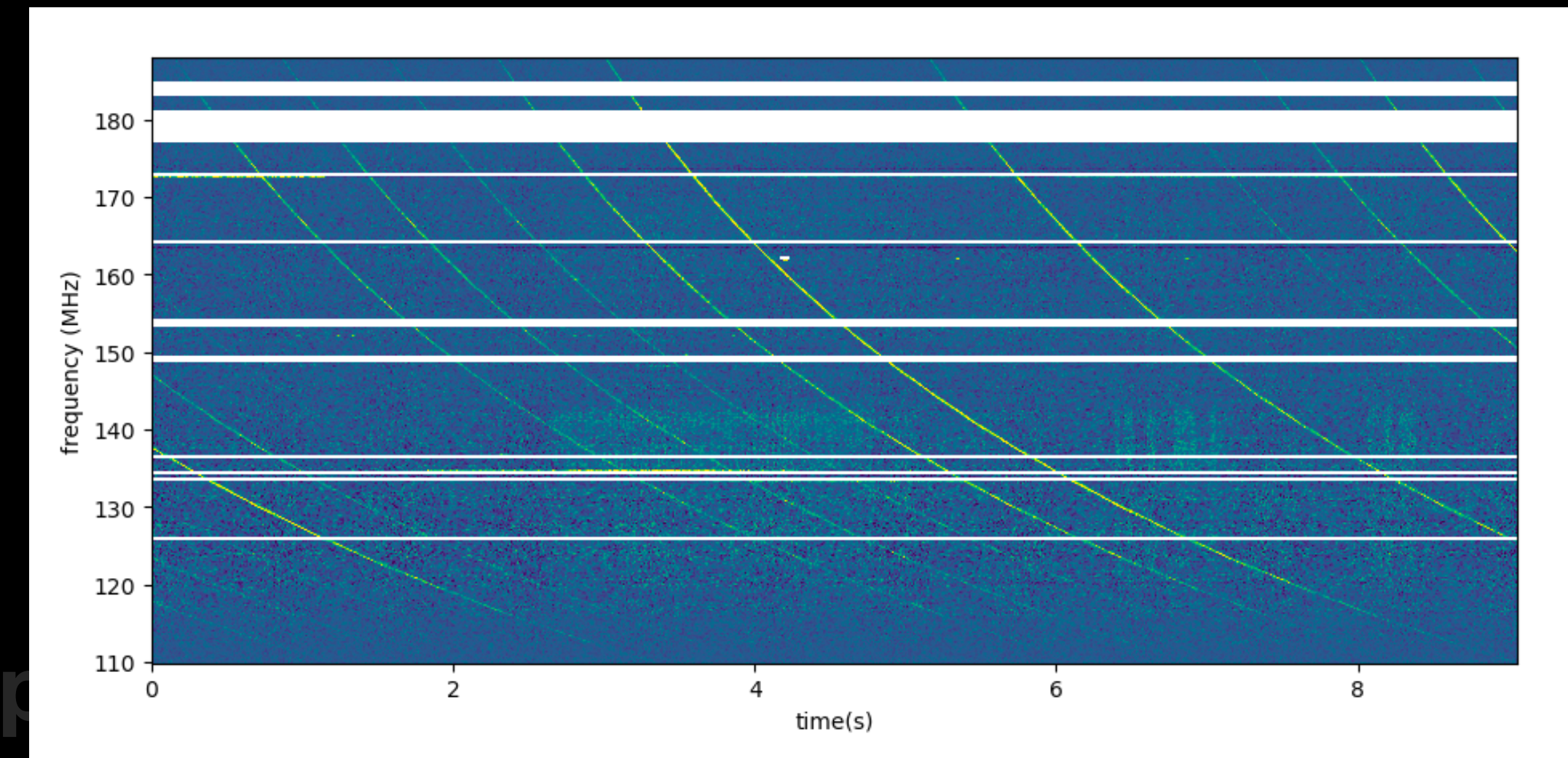
$\sim 1000$  tied-array beams from Core

**1s - 100 s:**

**fast difference imaging from Core**

## Localisation in space

buffer Remote + International station data



**10-ms visibilities from COBALT2.0!**

Figure credit: Akshatha Gopinath



# Observing modes

## Localisation in time

20  $\mu$ s - 10 ms:

targeted searches using semi-coherent dedispersion

1ms - 100 ms:

incoherent sum of  $\sim 14$  International stations

10ms - 1000 ms:

$\sim 1000$  tied-array beams from Core

1s - 100 s:

fast difference imaging from Core

## Localisation in space

buffer Remote + International station data

At  $\sim 100,000$



Image credit: Classy Girl Cupcakes

EUROFLASH

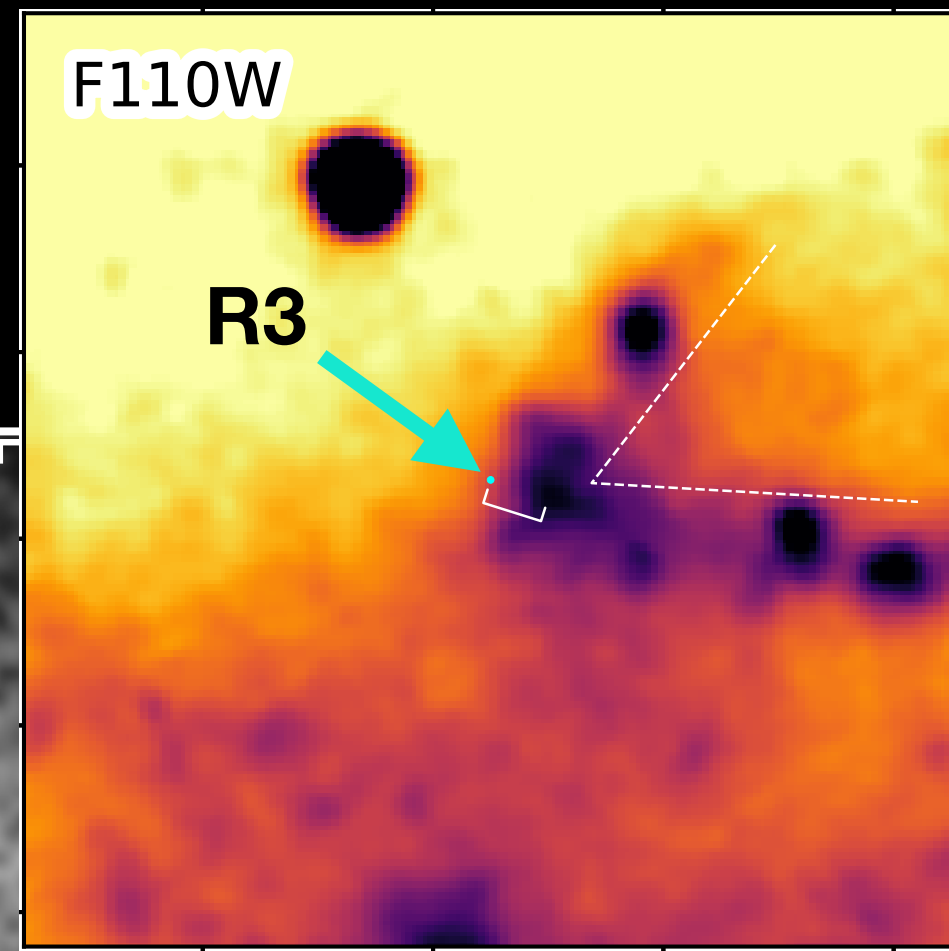
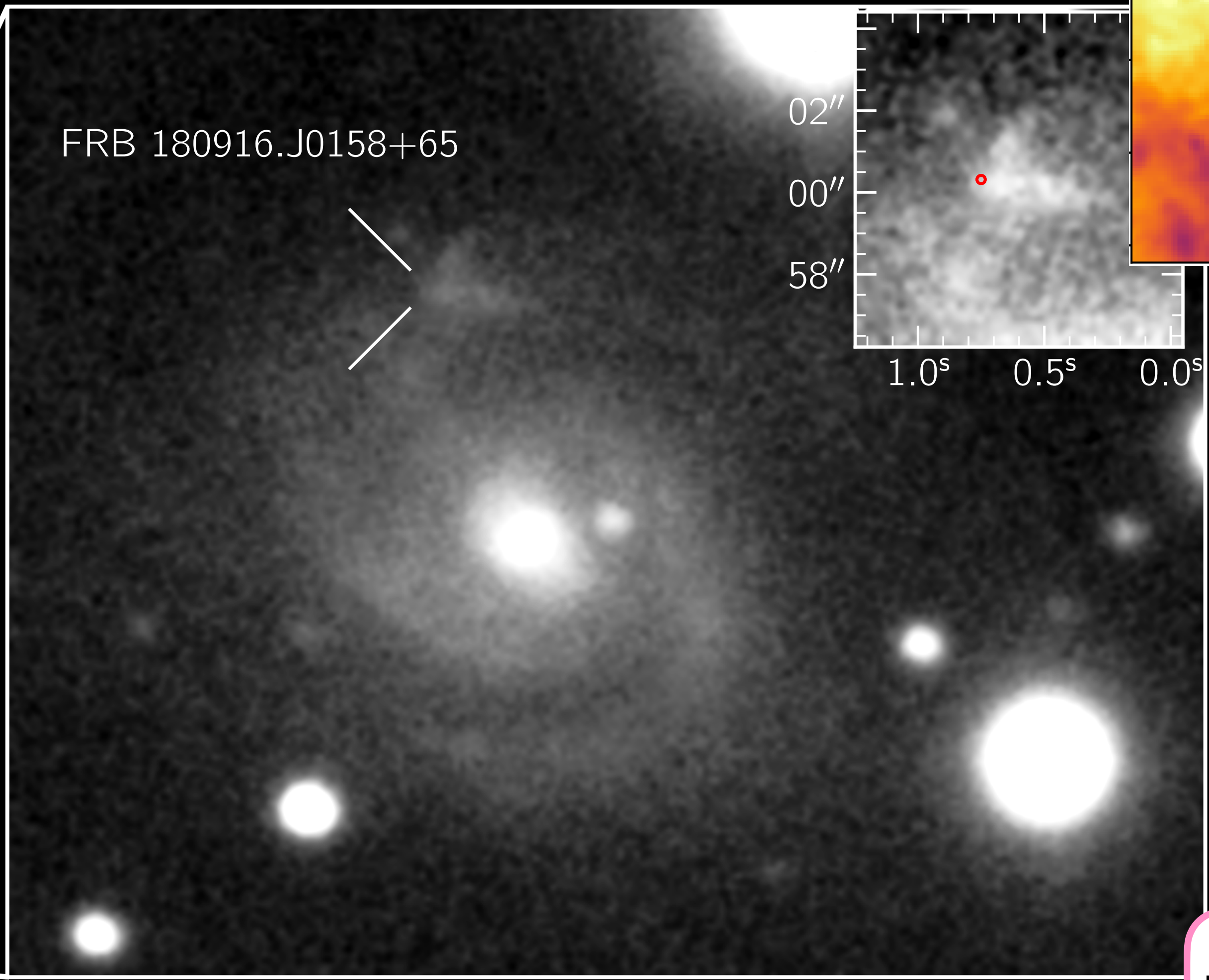
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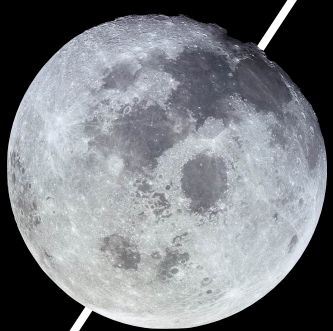
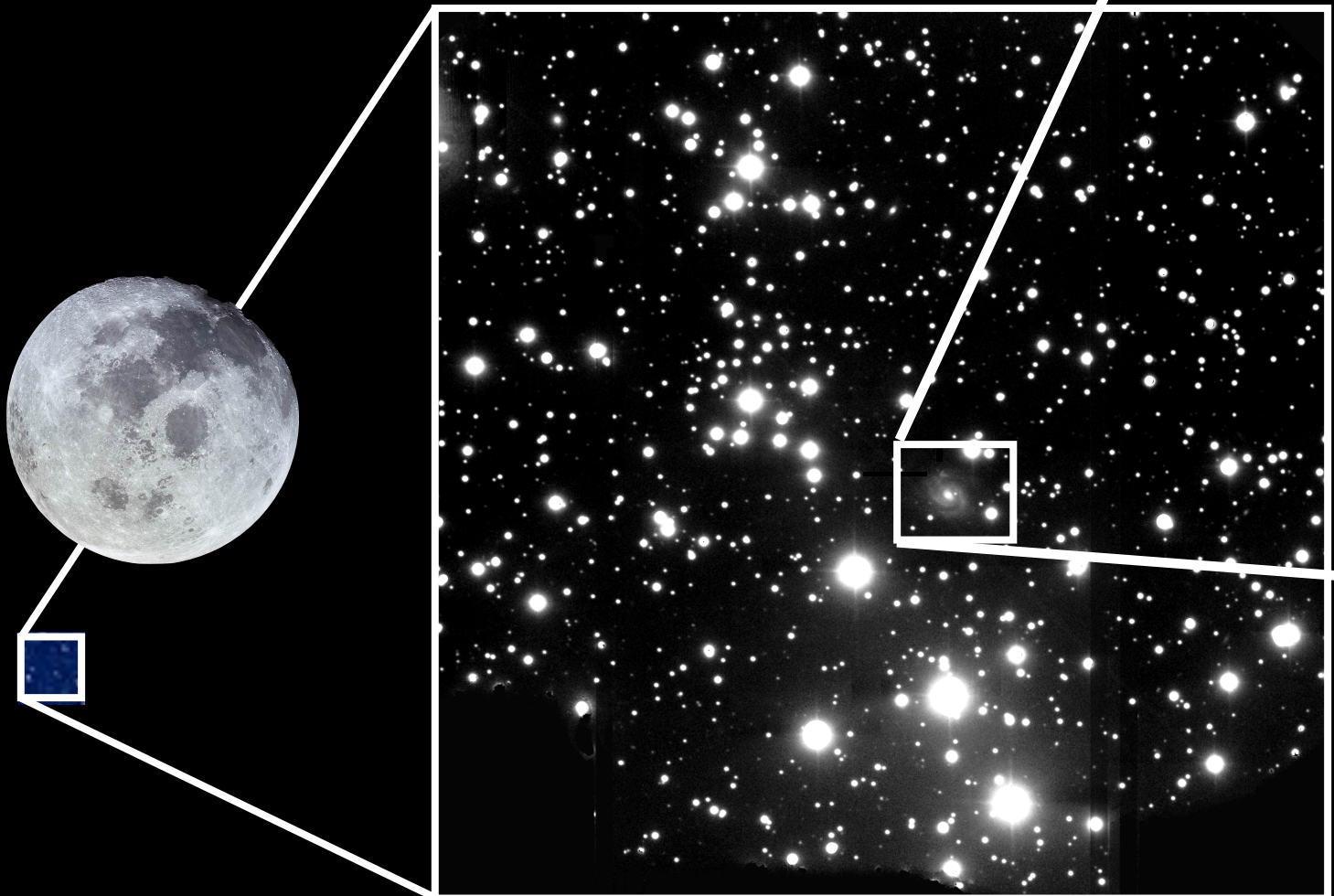
# FRB Localisation

Zoom 10x



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

Zoom 15x



Marcote, Nimmo, JH et al. 2020

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# Challenges

**RFI & baseline variations:**  
beam 'flat-fielding'

False positives & completeness:  
machine learning classifiers &  
injections

Dispersive delay:  
for  $DM = 1000 \text{ pc/cc}$ ,  $\Delta t = 141 \text{ s}$

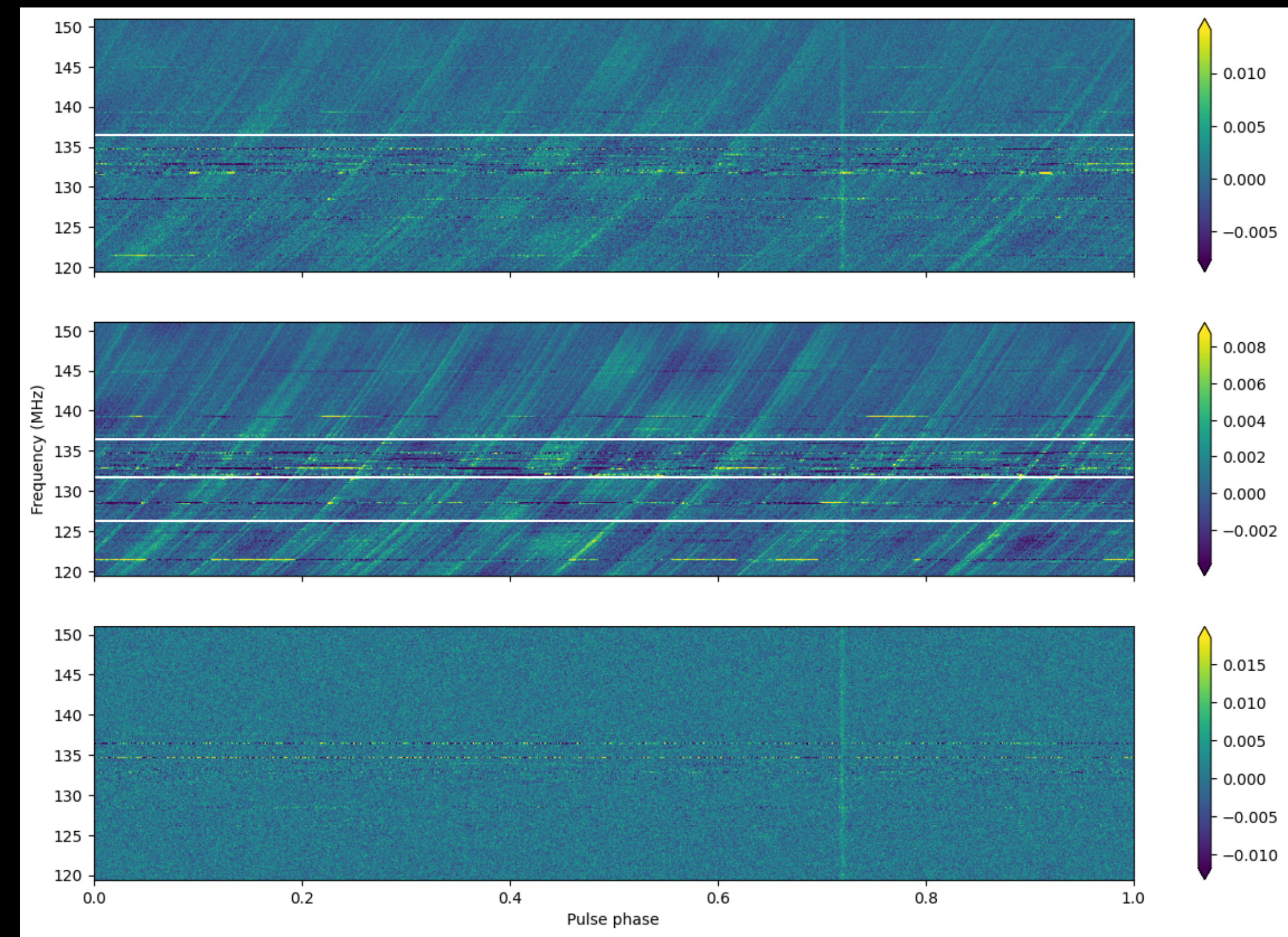


Figure credit: Cees Bassa

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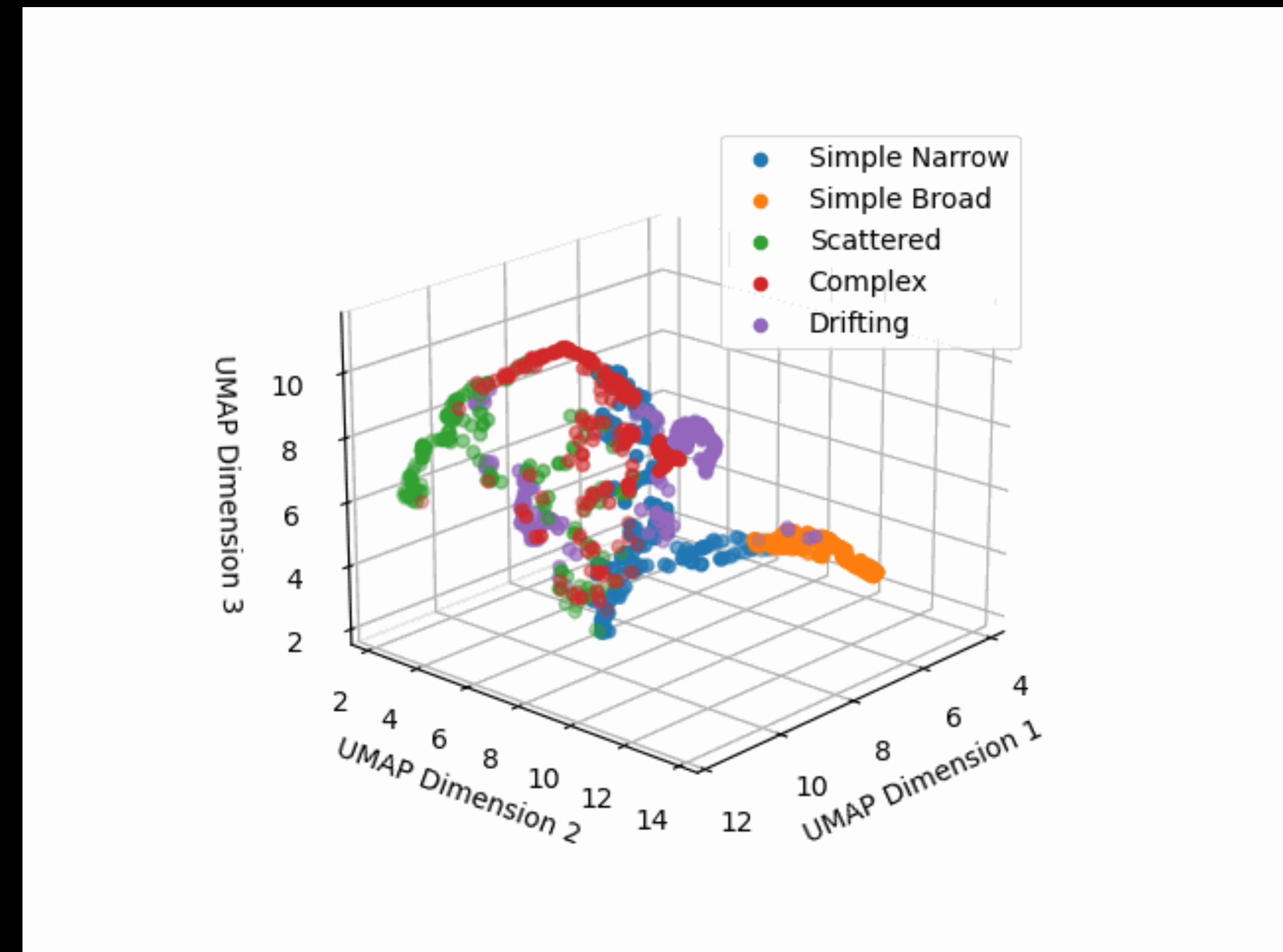


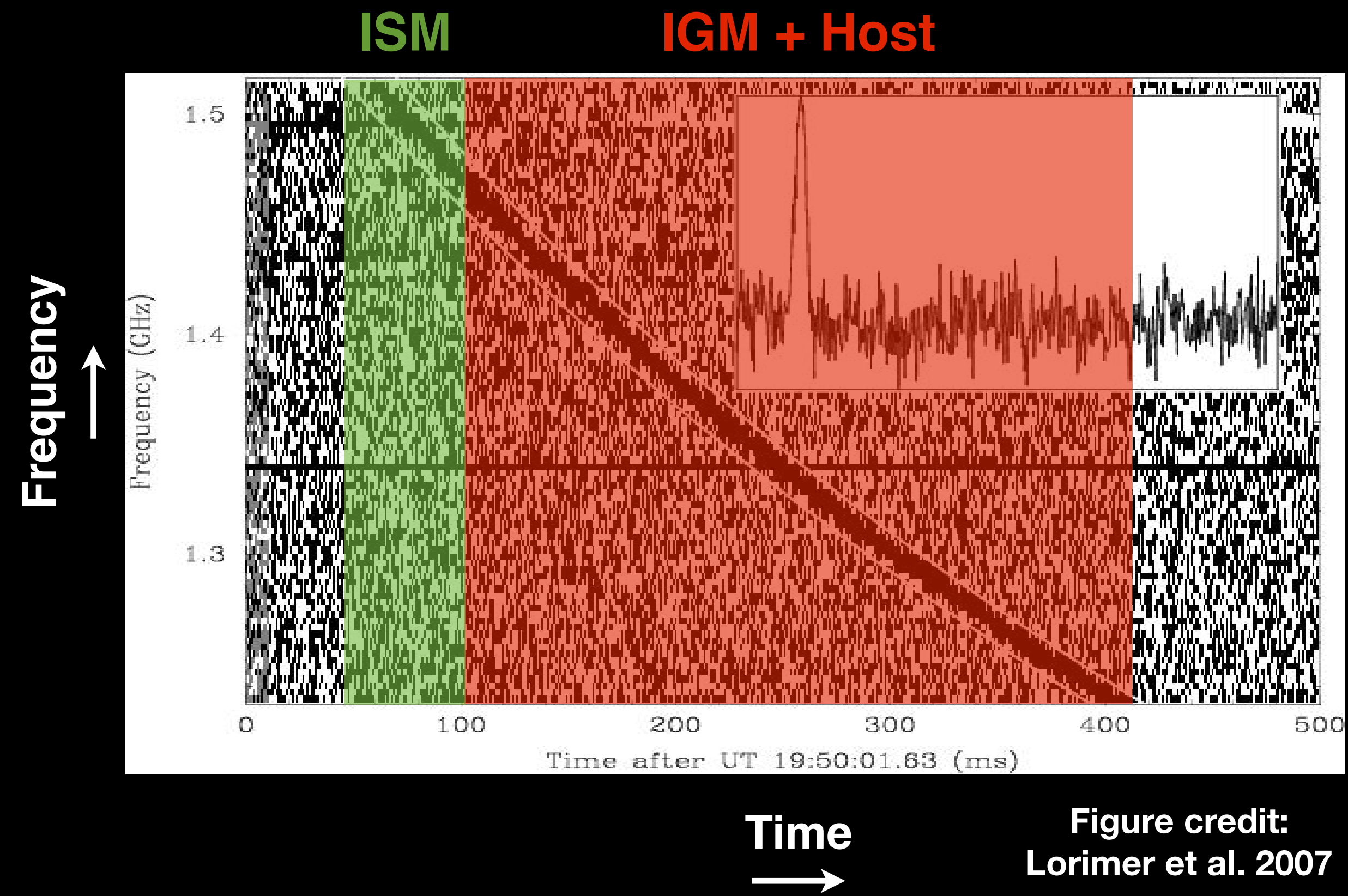
Figure credit: Dirk Kuiper

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# LOFAR FRB Rates

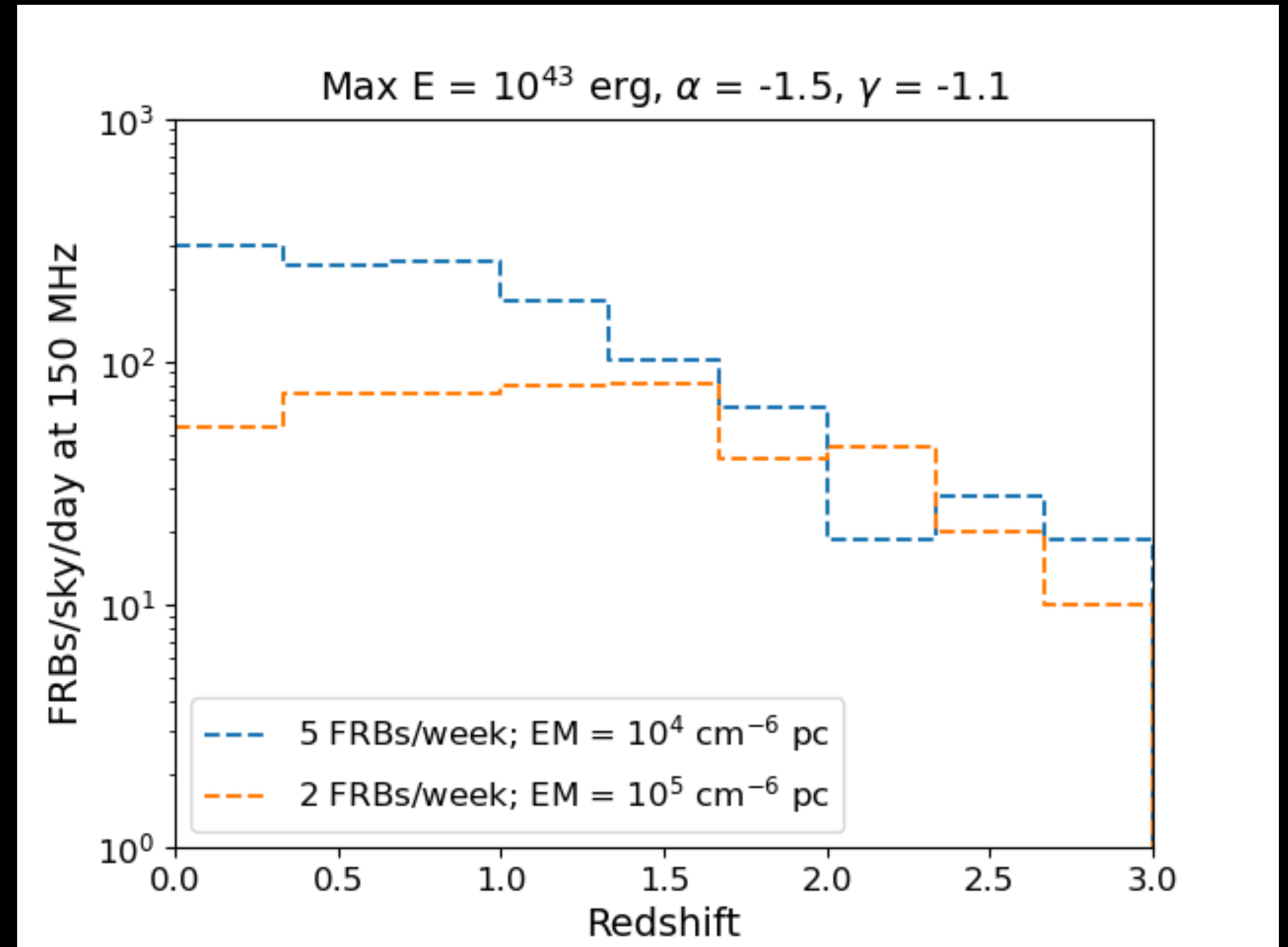
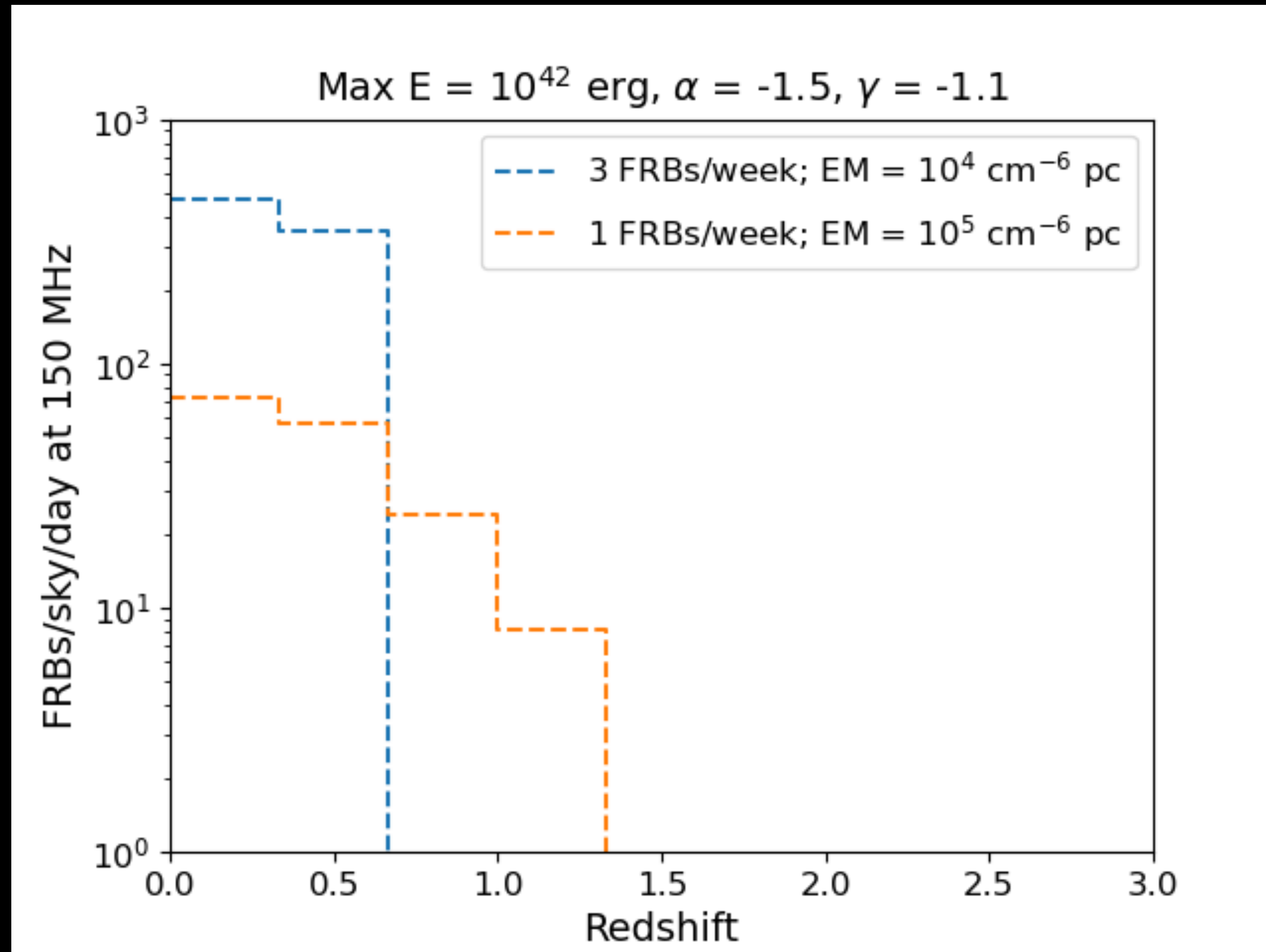


Figure credit: Pragya Chawla

# LOFAR FRB Rates

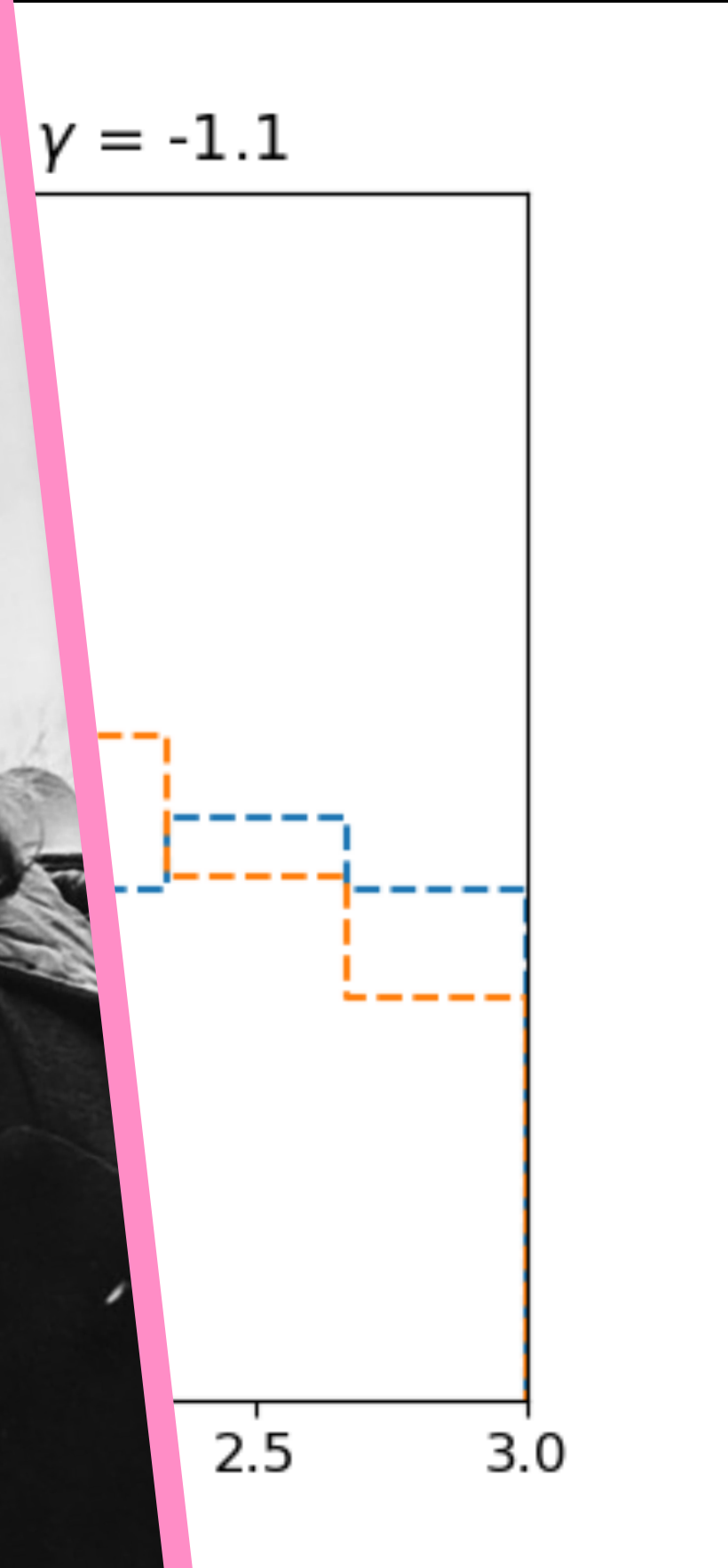
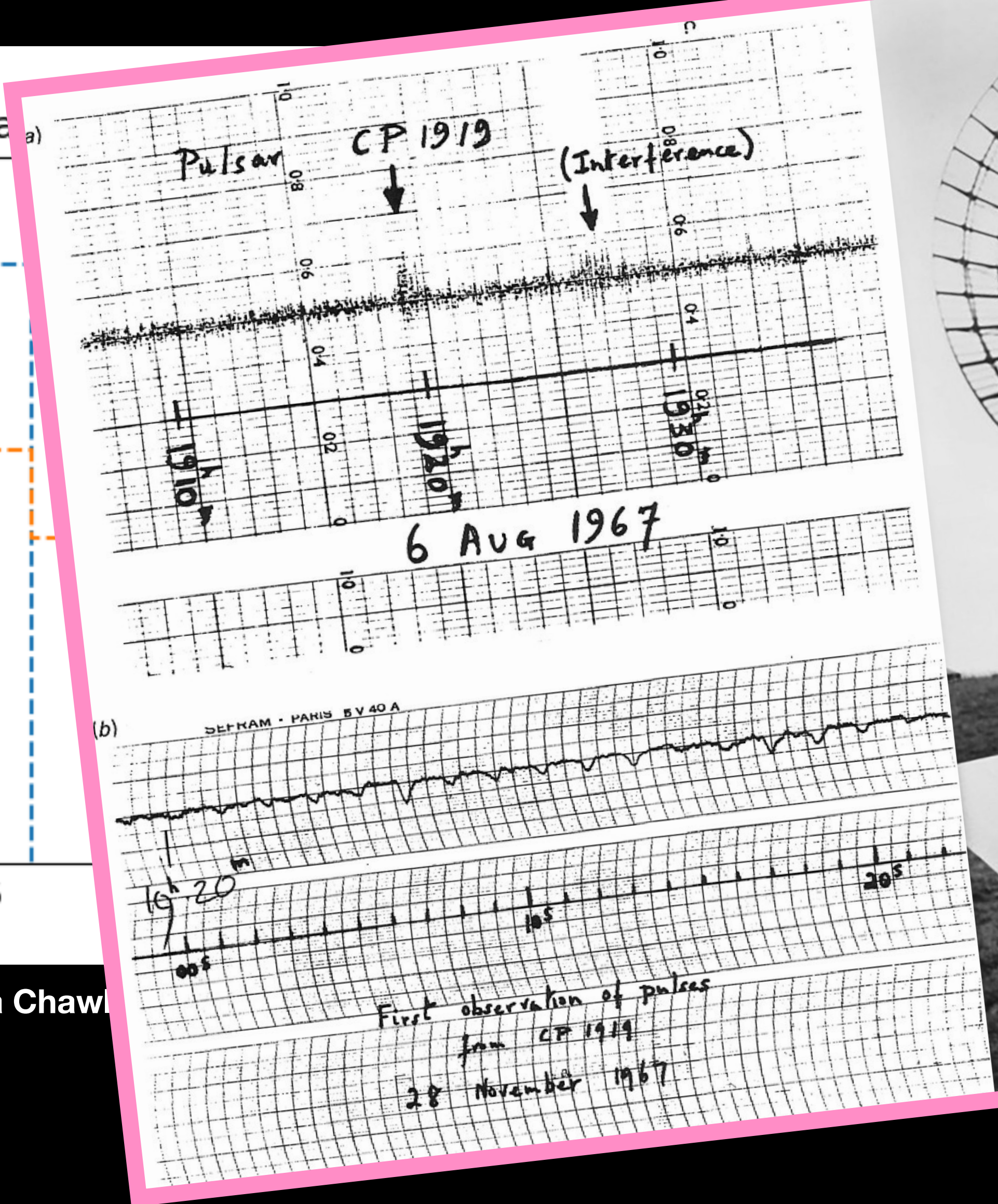
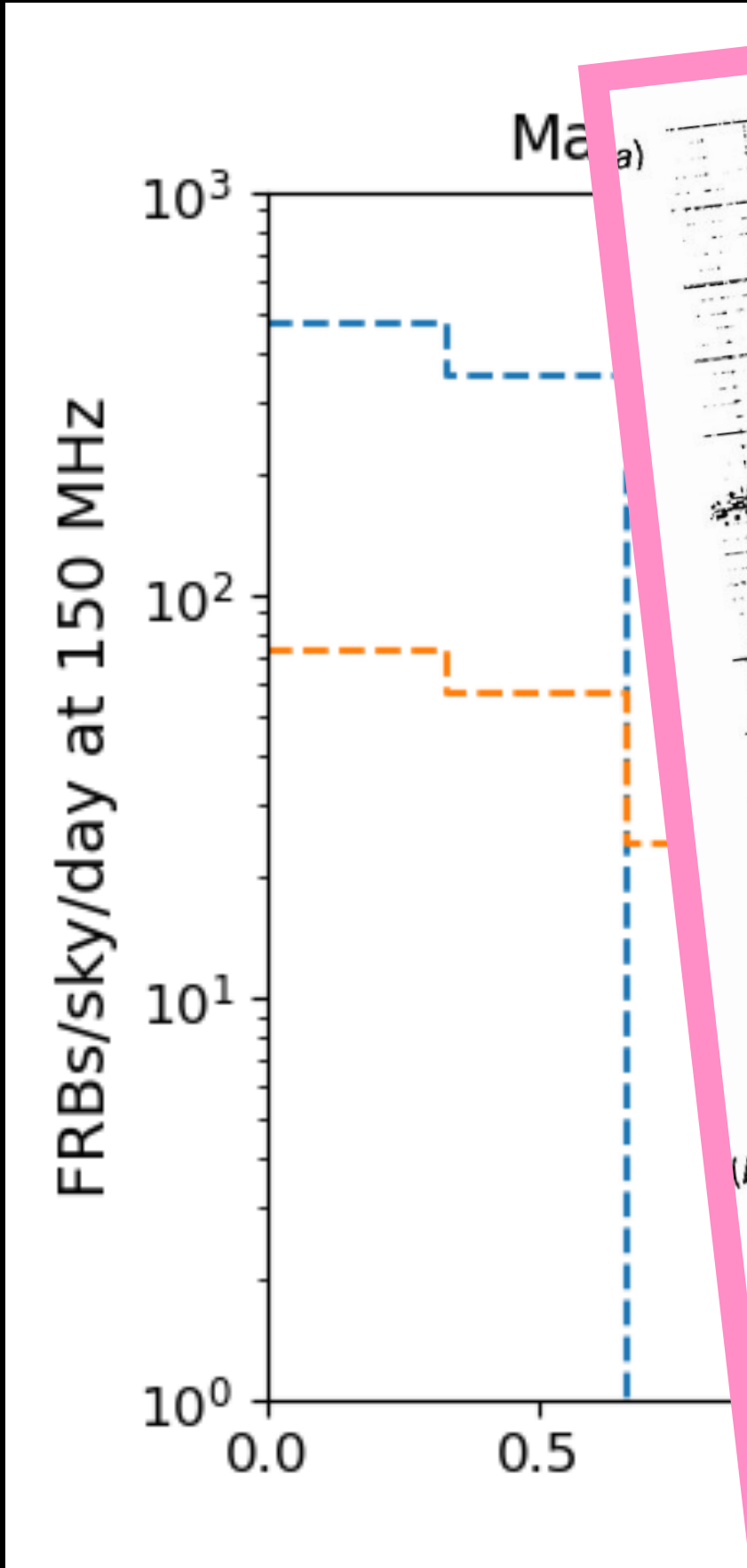


Figure credit: Pragma Chawla

# Summary

**EuroFlash is a 24/7 search for pulsars & fast radio transients**

- **Dedicated search machine in the LOFAR central network**



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# Summary

**EuroFlash is a 24/7 search for pulsars & fast radio transients**

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- Search on timescales from  $20 \mu\text{s}$  -  $100 \text{ s}$  ( $10^7\times$ )



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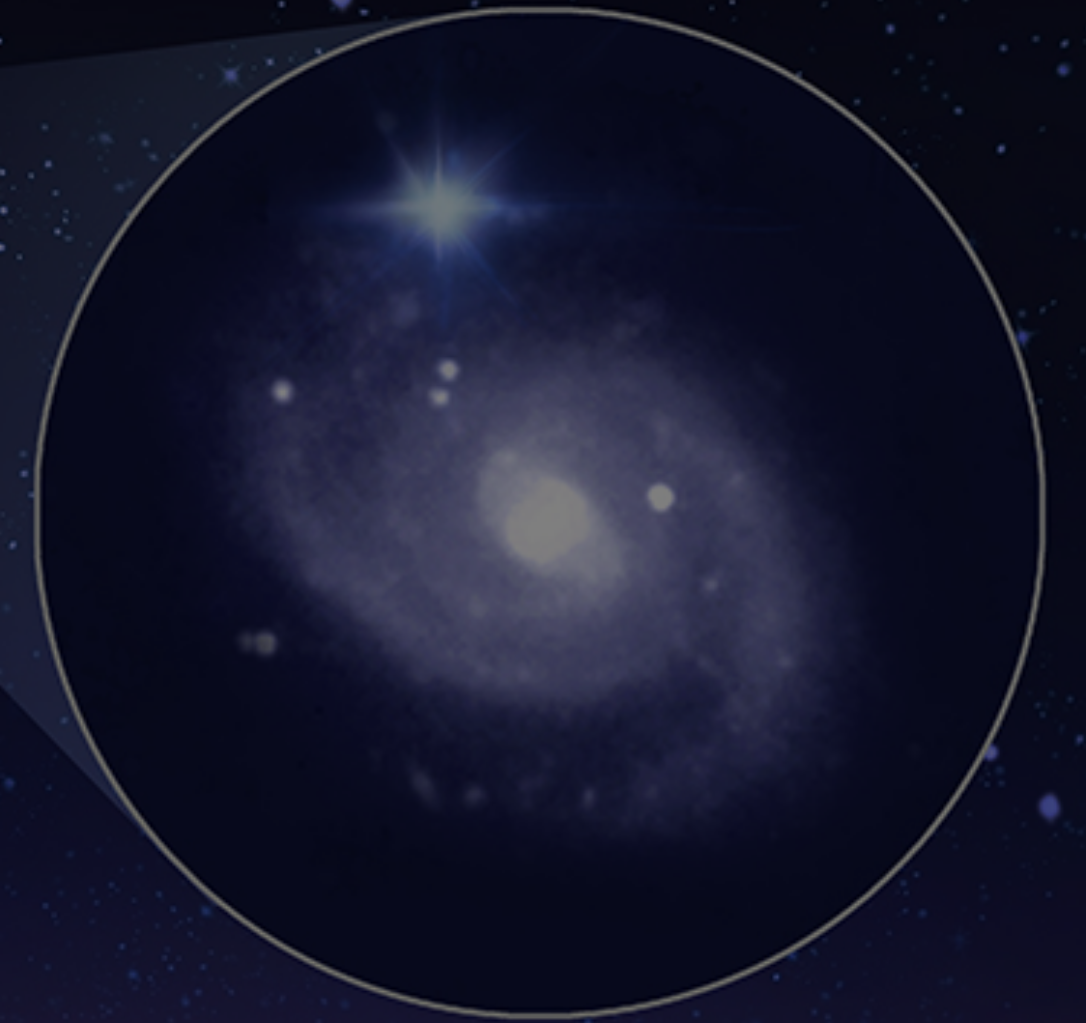


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# Summary

**EuroFlash is a 24/7 search for pulsars & fast radio transients**

- Dedicated search machine in the LOFAR central network
- Search on timescales from  $20 \mu\text{s}$  -  $100 \text{ s}$  ( $10^7\times$ )
- Decipher the extreme astrophysics of these sources and use them as precision probes



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