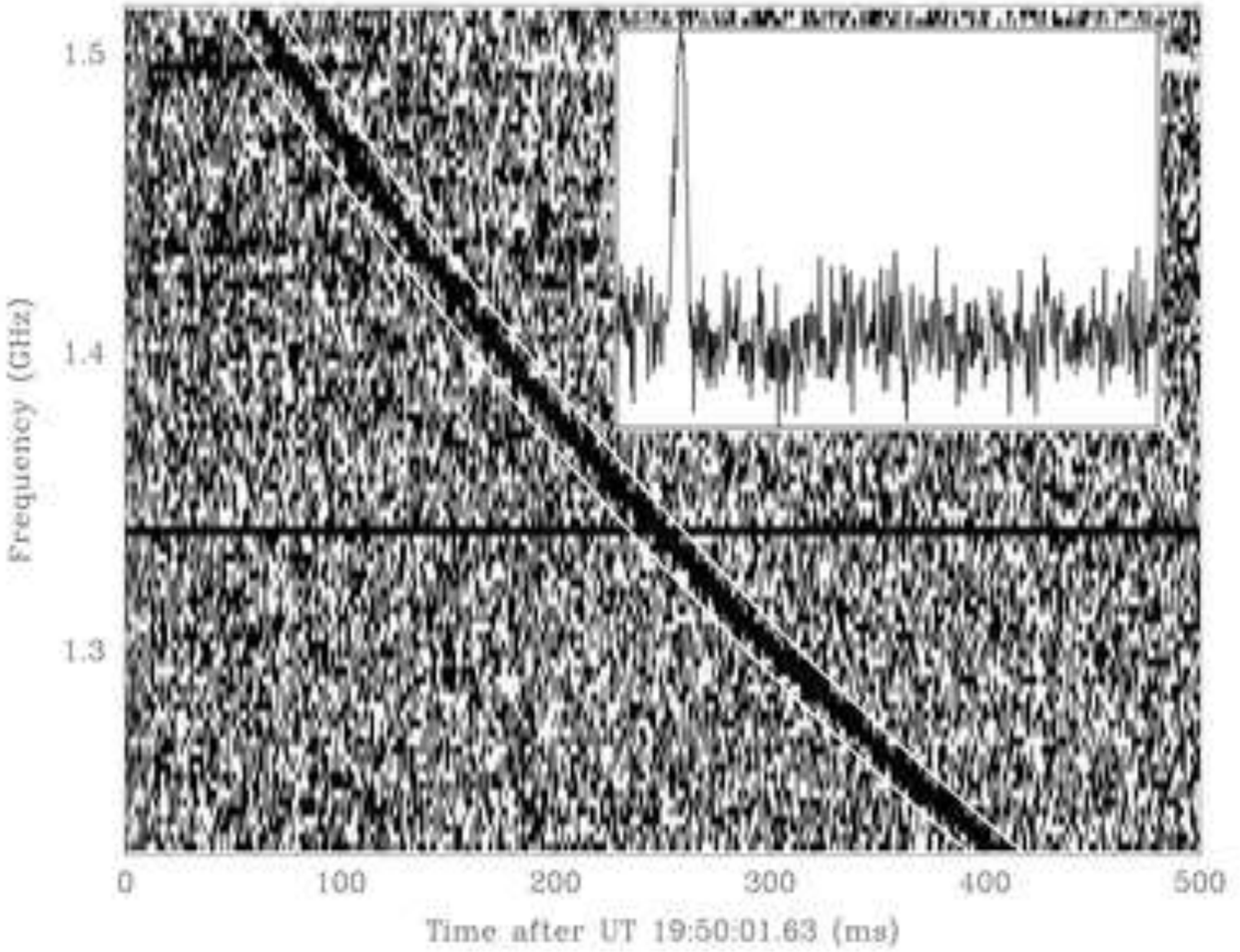
Multiwavelength FRBs: Challenge Accepted!

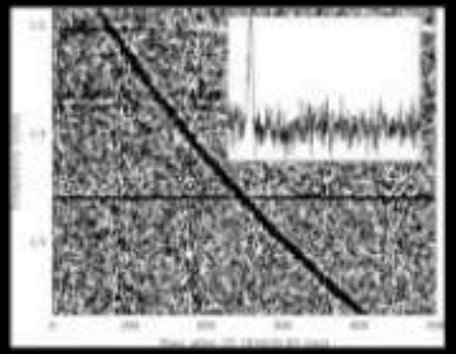
Maura Pilia

Photo Courtesy: Alessio Trois

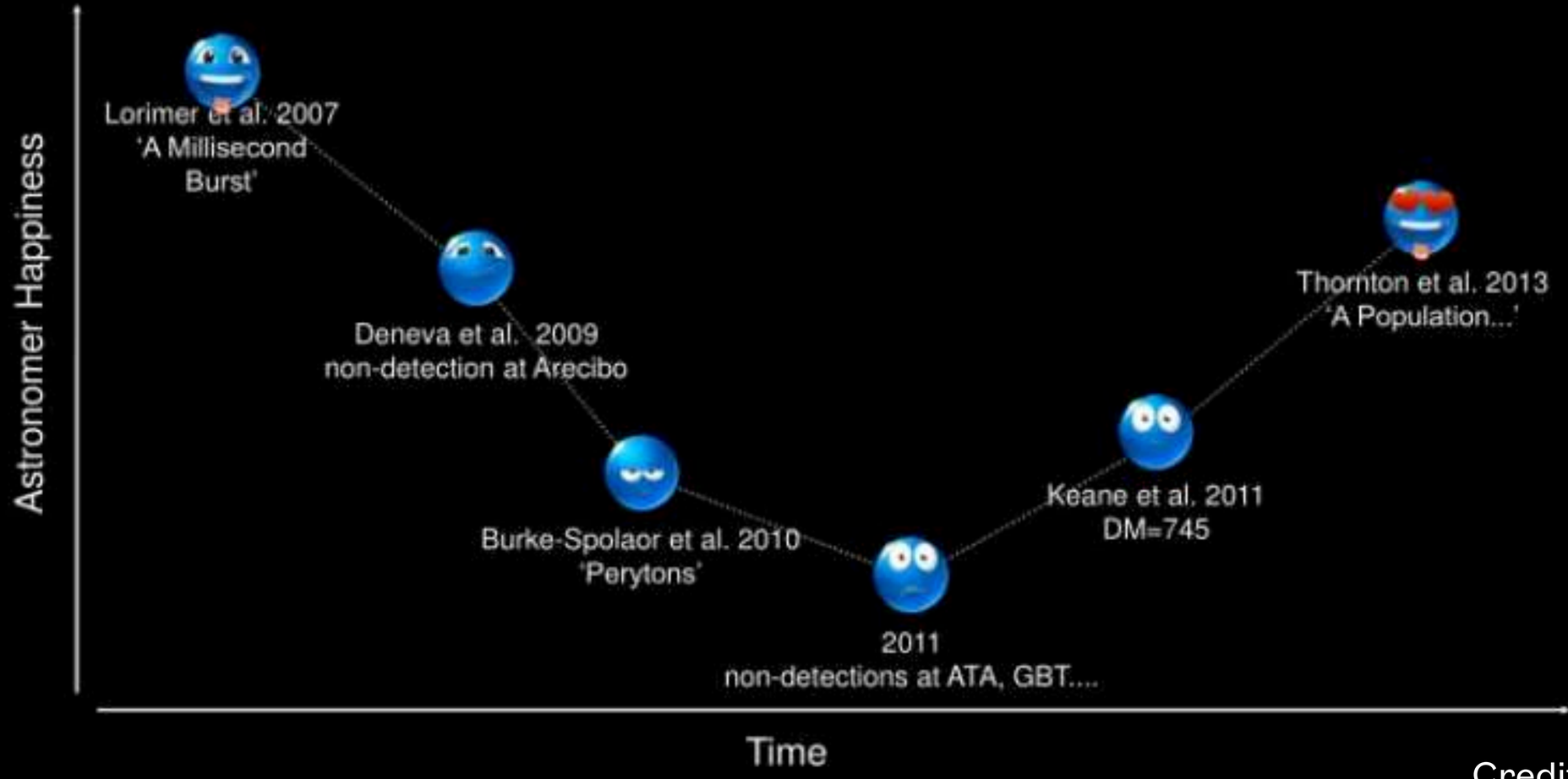
Fast Radio Bursts

- Lorimer Burst discovered in 2007
- A very bright signal lasting only a few milliseconds
- Its dispersion delay exceeded the one expected towards that region of the Milky Way



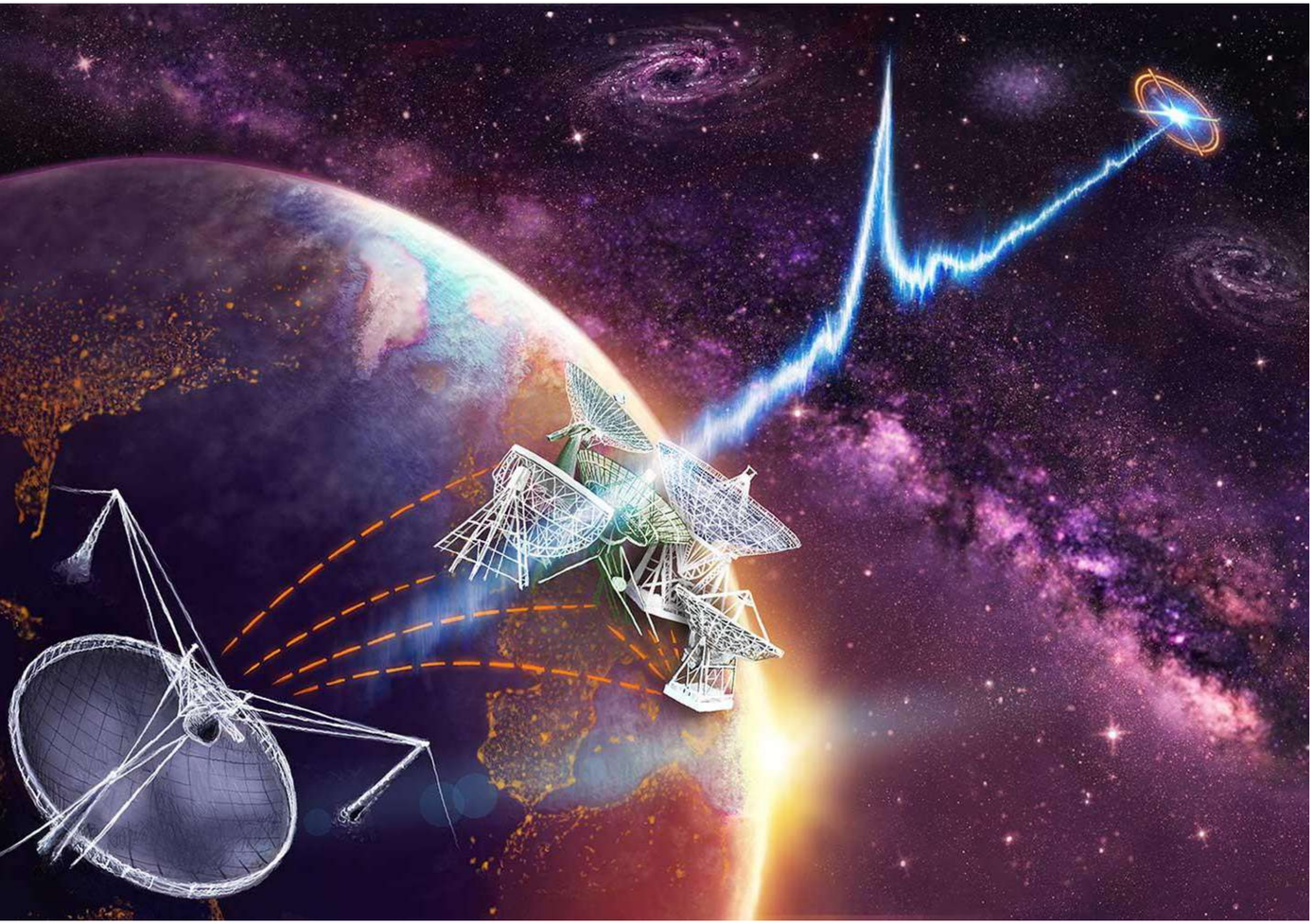


The Saga of the 'Lorimer Burst'



Credits: A. Siemion

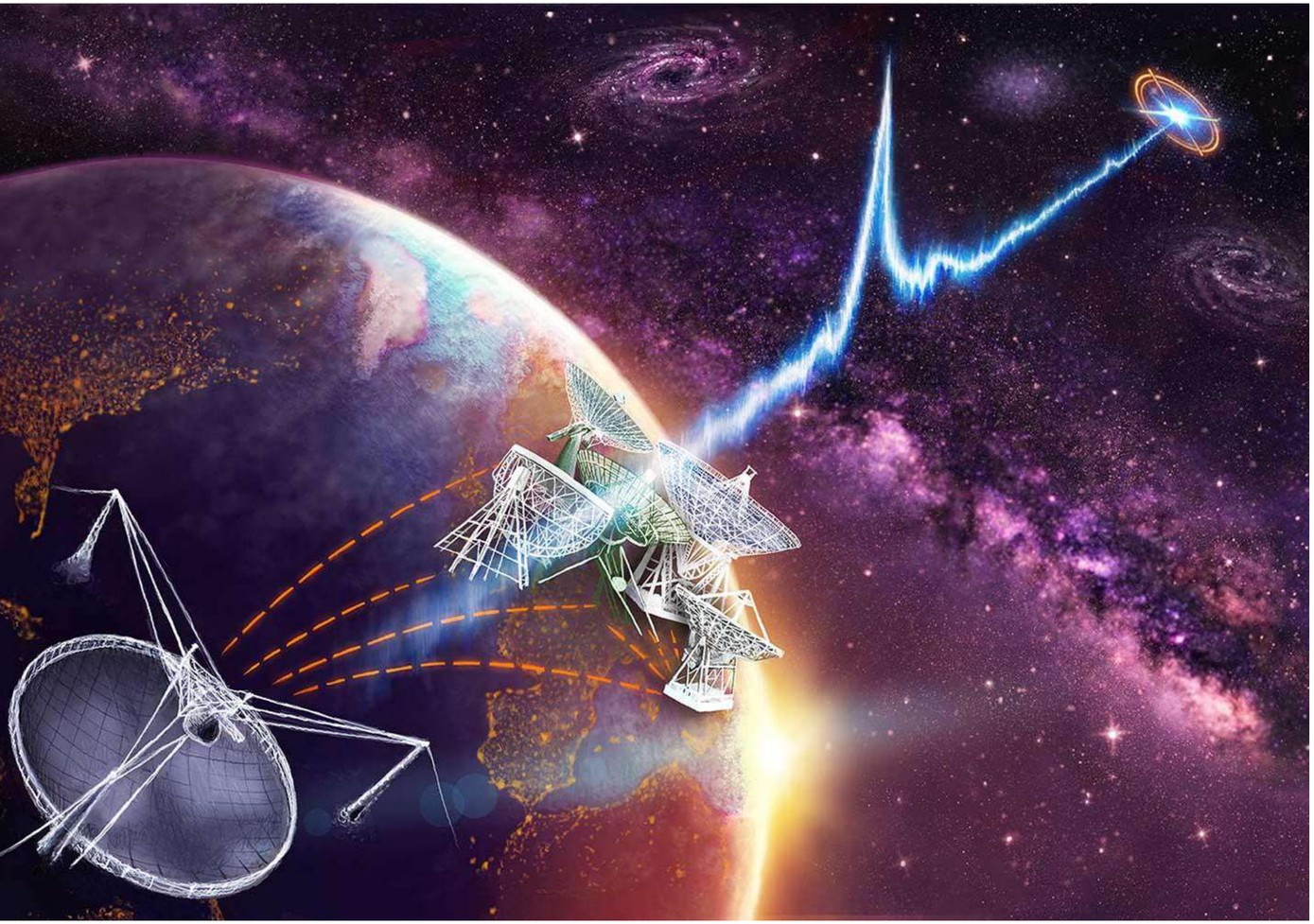
FRB 121102
How Everything Changed



- First FRB seen by a different telescope than Parkes:

  ⟶ They're astrophysical!

Spitler et al. 14



FRB 121102
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- First FRB seen by a different telescope than Parkes:

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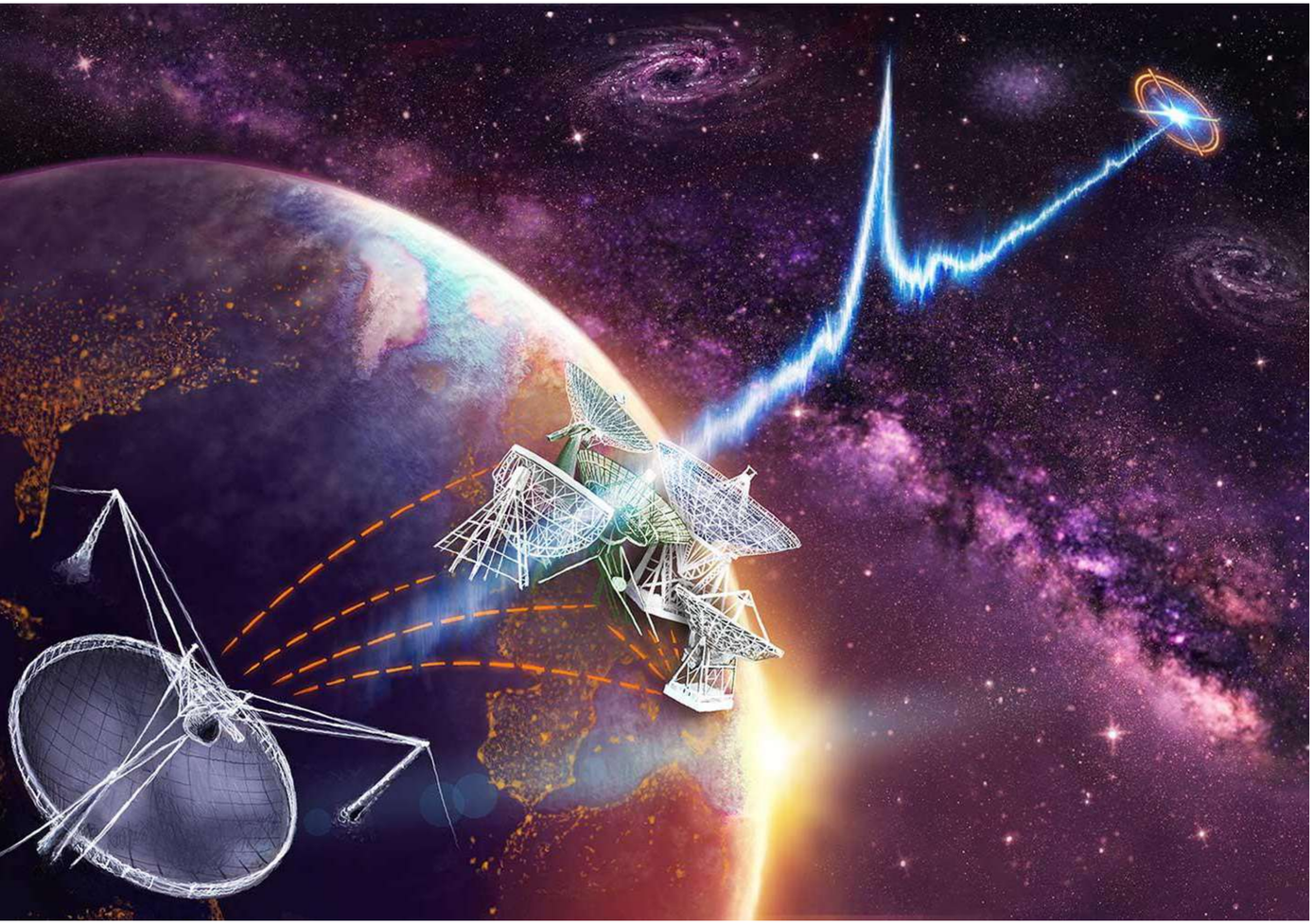
- First FRB seen to repeat:

  ⟶ They're not (all) produced by catastrophic events!

Spitler et al. 14, 16


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
Platts et al. 2019
Credit: Jason Hessels



FRB 121102
How Everything Changed

- First FRB seen by a different telescope than Parkes:

  ⟶ They're astrophysical!

- First FRB seen to repeat:

  ⟶ They're not (all) produced by catastrophic events!

- First localised FRB:

  ⟶ They're extragalactic!

Spitler et al. 14, 16, Chatterjee et al. 17, Marcote et al. 17

What have we learned

from FRB 121102?

- Located in a star forming region of a dwarf Galaxy.
- Persistent source coincident with the position of the FRB.
- Rapid variations in RM and DM.
- An extreme magneto-ionic environment.

What are FRBs?

Magnetars?

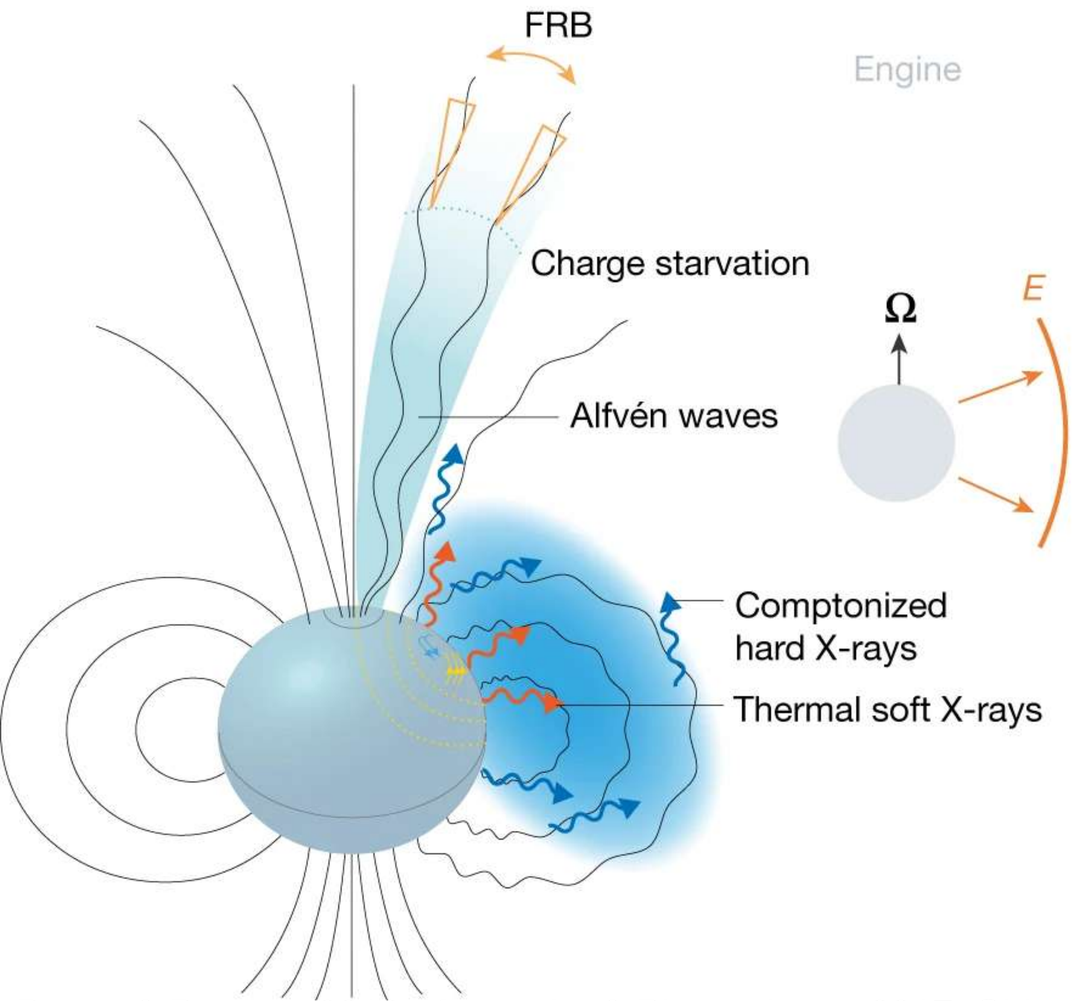
What mechanisms lie behind FRBs?

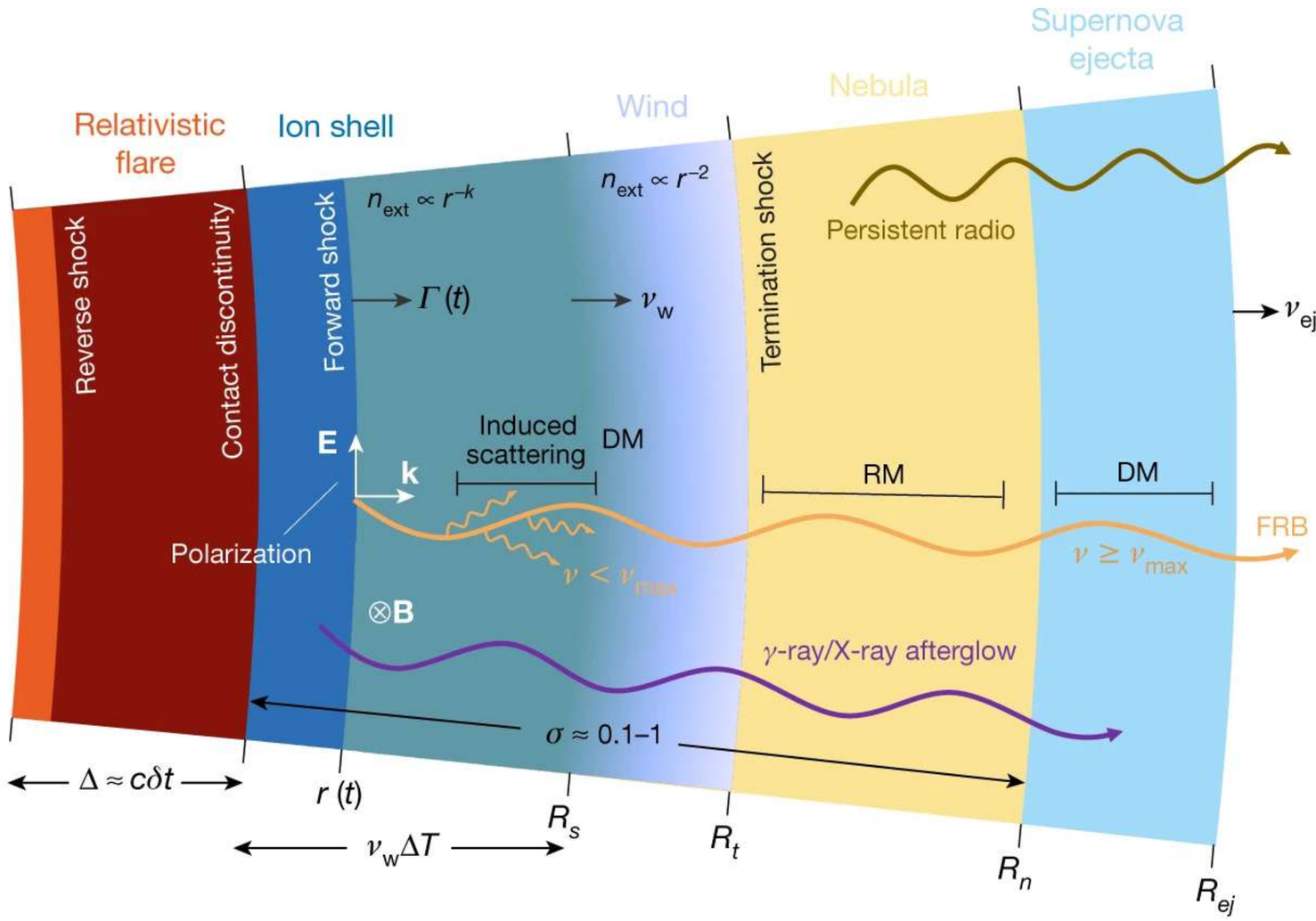
- Extragalactic nature
- Luminosities around 10^{43} erg s^{-1}
- Energetics of the order of 10^{40} erg

- Large flux,
- Short duration
- Cosmological distances
- Huge brightness temperature of the order of $T_B \sim 10^{34}$–10^{37} K

→ Coherent radiation process

Magnetars?

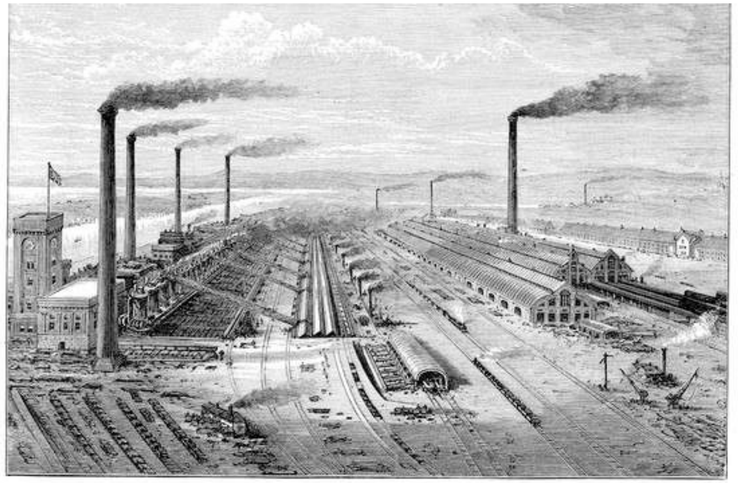




Popov & Postnov 2013, Kumar, Lu & Bhattacharya 2017; Ghisellini & Locatelli 2018; Lu, Kumar & Zhang 2020, Lyutikov 2021

Lyubarski 2014, Beloborodov 2017, Metzger, Margalit & Sironi 2020, Margalit et al 2021

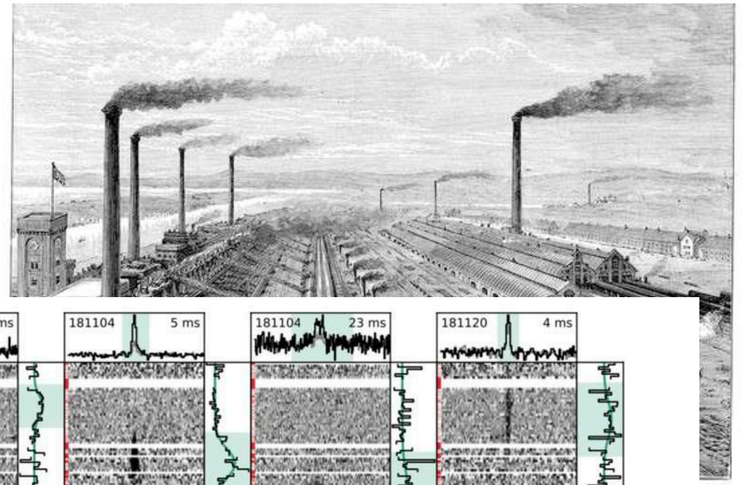
The industrial revolution: CHIME

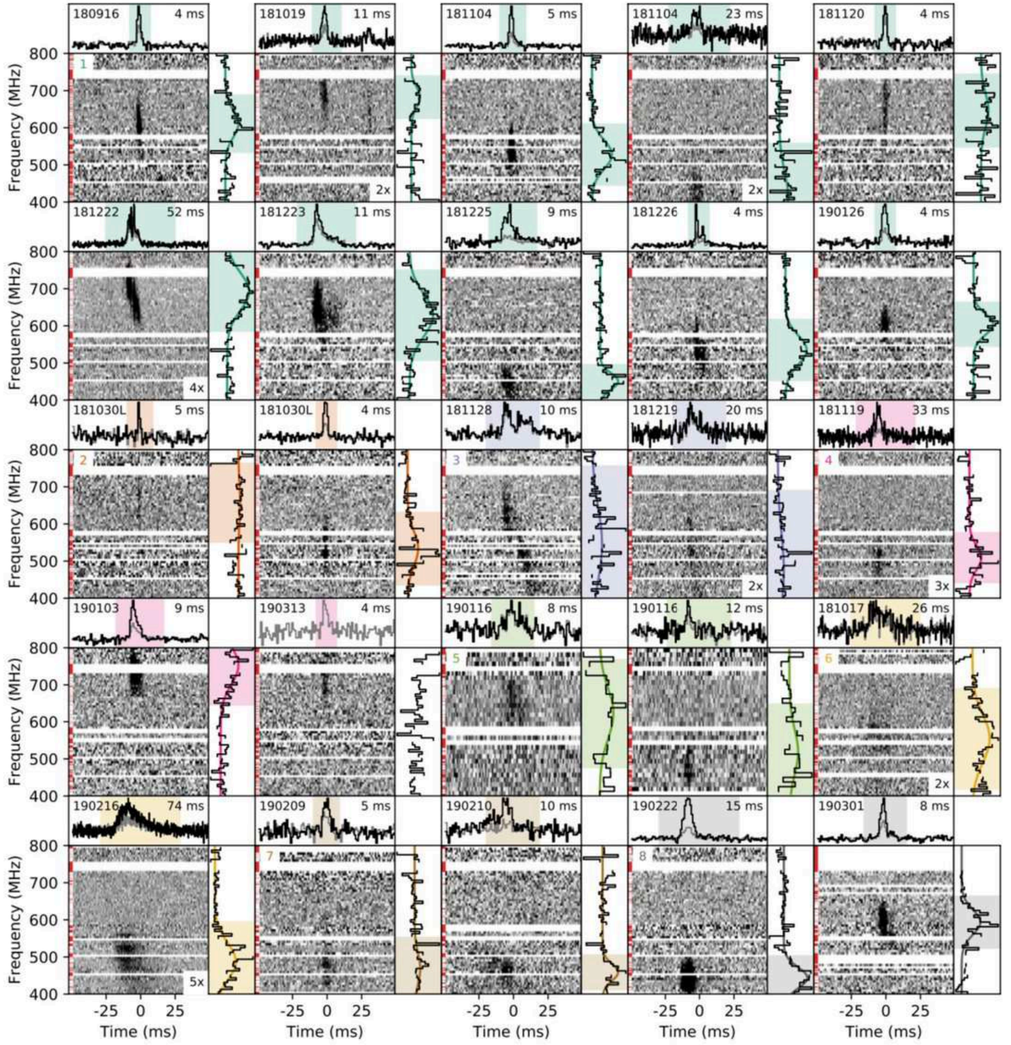


IRON AND STEEL WORKS, BARROW-IN-FURNESS.

Image: Andre Renard, Dunlap Institute; CHIME

The industrial revolution: CHIME

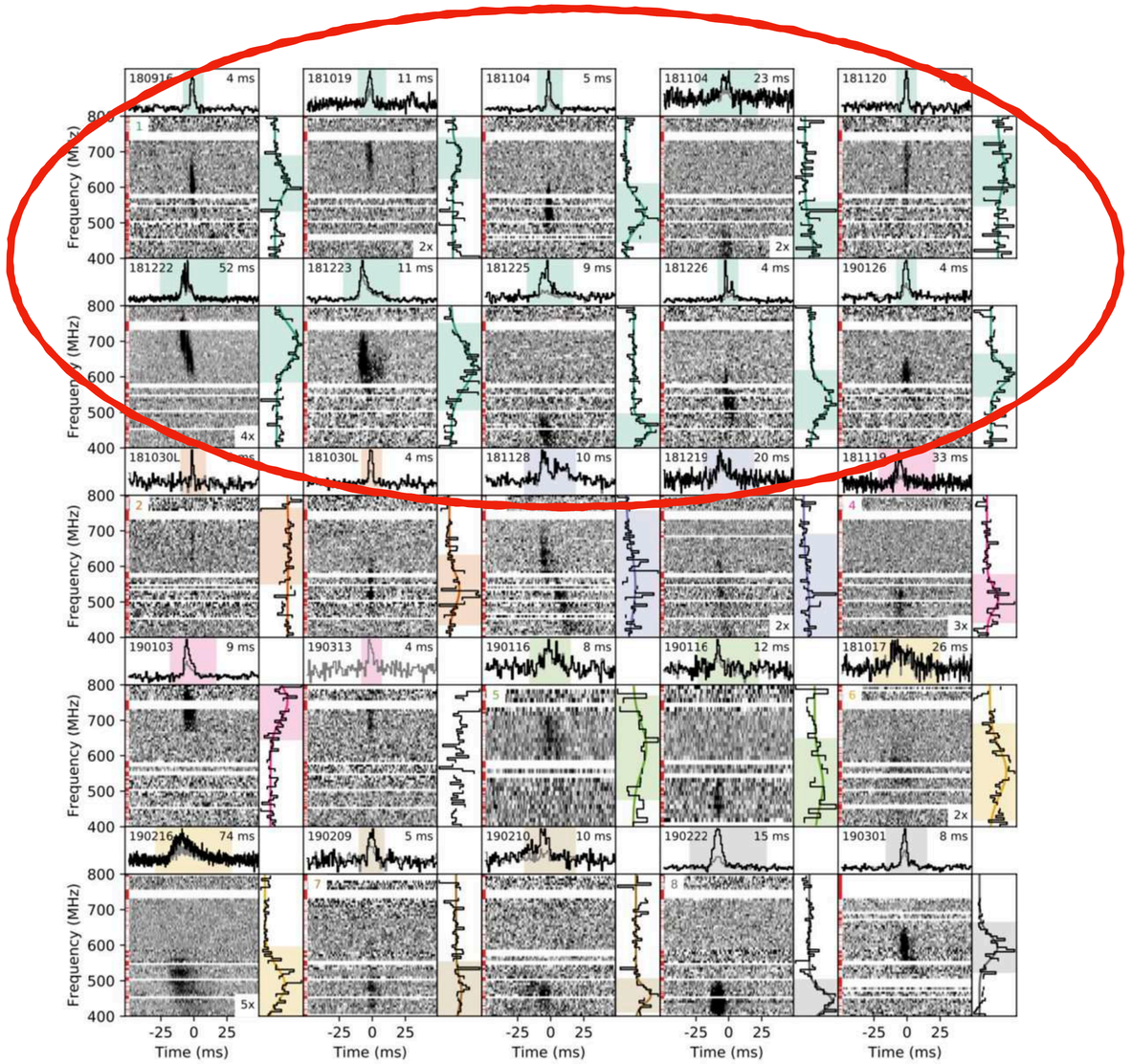




Chime/FRB Collaboration, Nature, 2019

FRB 180916

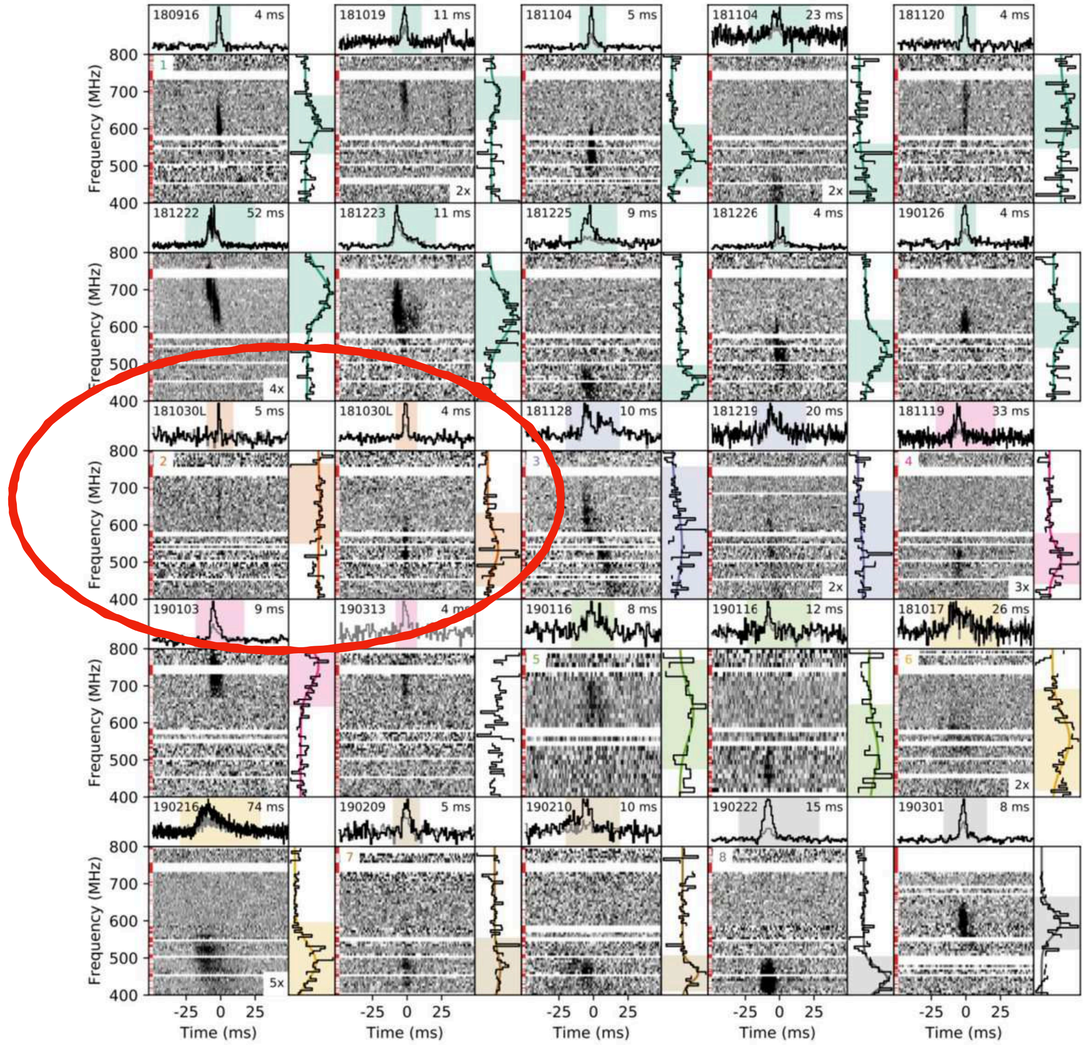
- 10 bursts
- Repeater with lowest extragalactic DM
- DM = 350 pc/cm3



Chime/FRB Collaboration, Nature, 2019

FRB 181030

- Repeater with lowest DM
- DM = 103.5 pc/cm3
- A possible association with a host galaxy



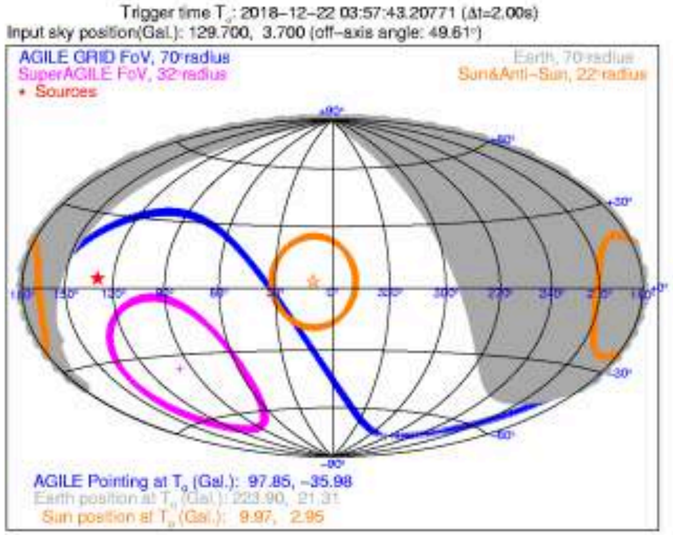
Chime/FRB Collaboration, Nature, 2019

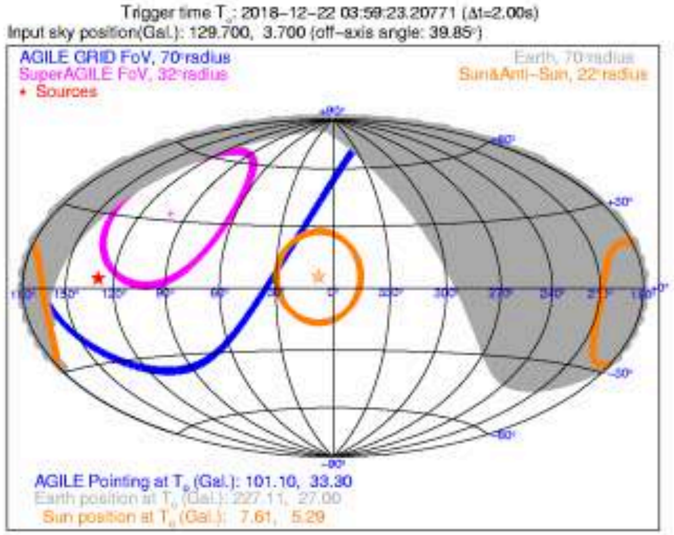
AGILE

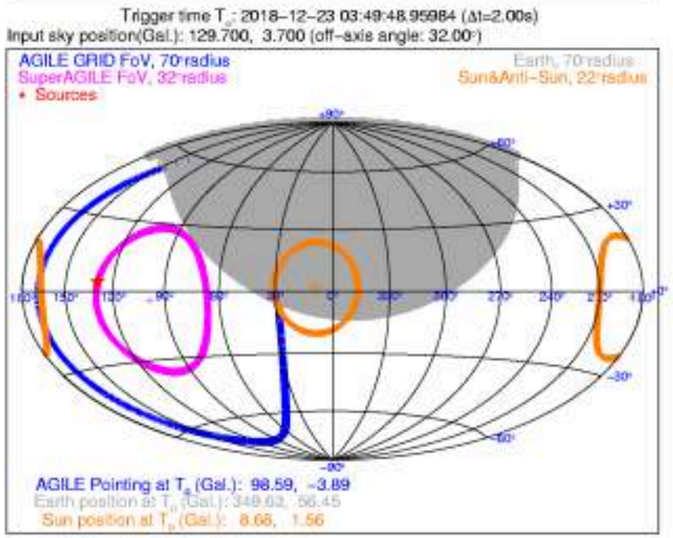
Astro-rivelatore Gamma a Immagini Leggero

AGILE coverage of the 12 events

Casentini et al. 2020







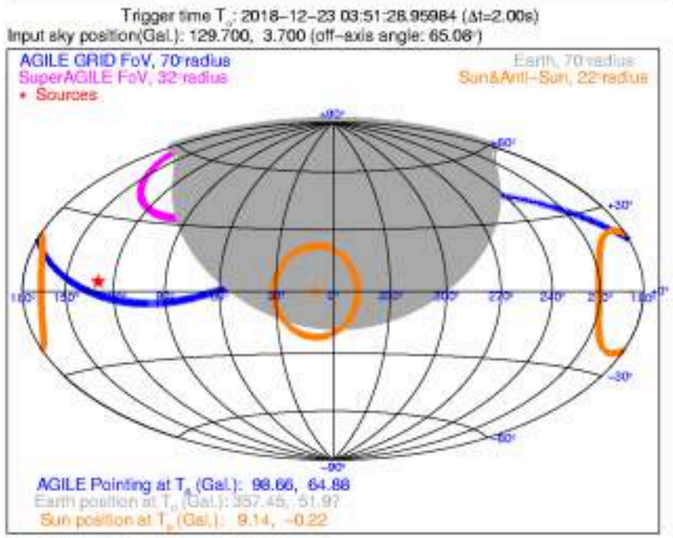
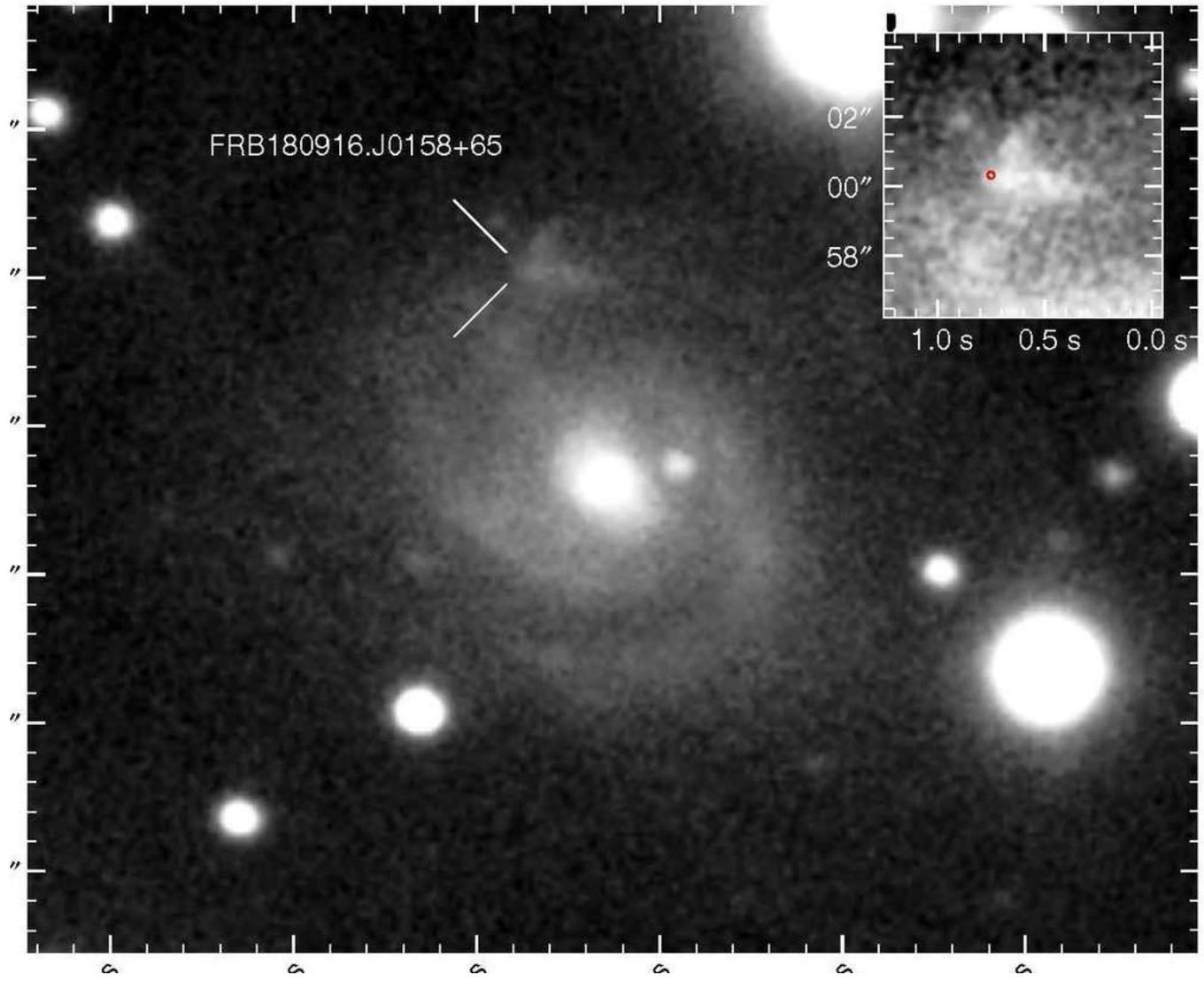


Table 1. Repeating FRBs and *AGILE* observations

FRB Radio Parameters				Event in the *AGILE* FoV		
Label	Day (yymmdd)	Arrival Time (UTC @ 400 MHz)	Fluence (Jy ms)	MCAL	GRID	Super-A
Source 1: FRB 180916.J0158+65						
A	180916	10:15:19.8021	2.3	NO	NO	NO
B	181019	08:13:22.7507	2.7	-	-	-
C	181104	06:57:18.58524	2.5	YES	NO	NO
D	181104	07:07:01.591	2.0	YES	NO	NO
E	181120	05:56:06.23243	1.8	YES	NO	NO
F	181222	03:59:23.2082	27	YES	YES	NO
G	181223	03:51:28.96040	8.1	YES	YES	NO
H	181225	03:53:03.9260	1.9	YES	NO	NO
I	181226	03:43:30.1074	3.8	YES	NO	NO
L	190126	01:32:45.3289	2.0	-	-	-
Source 2: FRB 181030.J1054+73						
A	181030	04:13:13.0255	7.3	YES	NO	NO
B	181030	04:16:21.6546	2.2	YES	NO	NO



FRB 180916

How Everything Changed ... AGAIN!

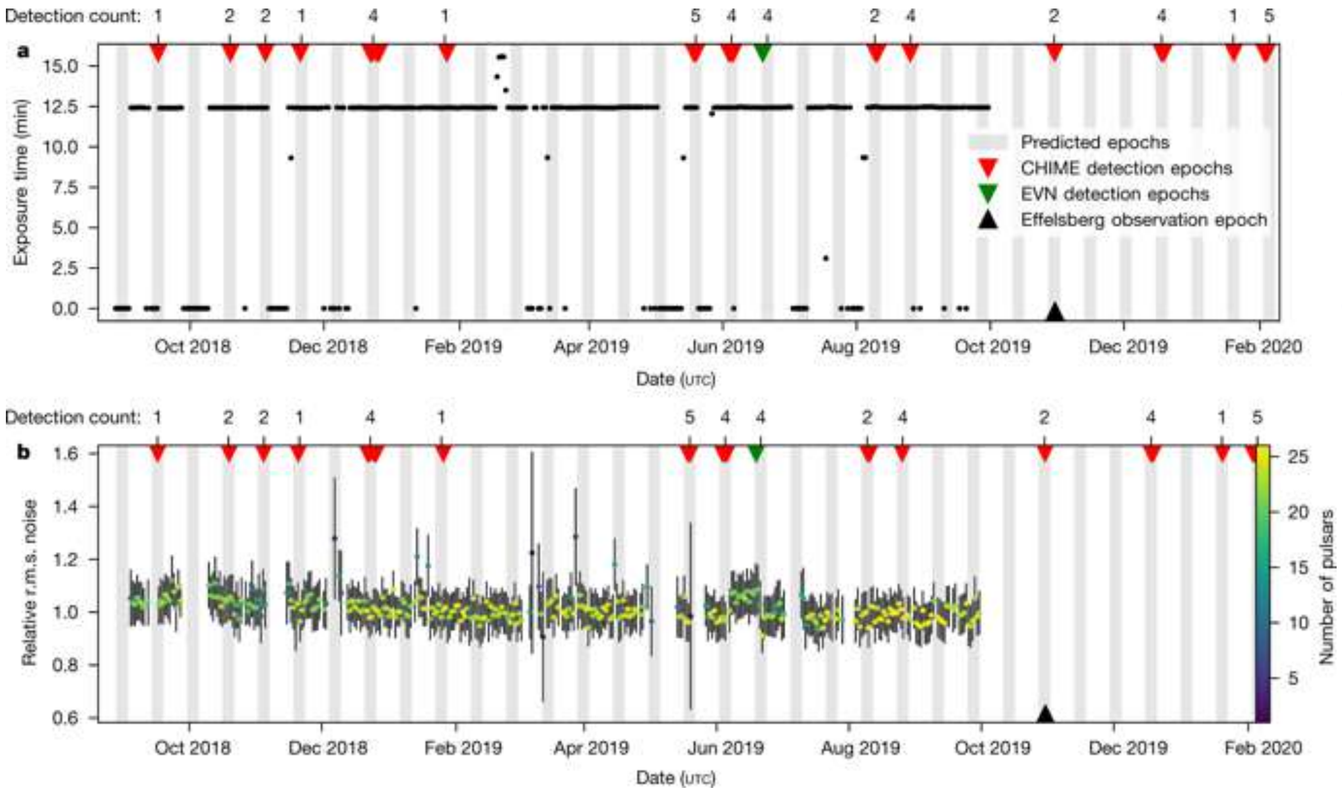
- Very close-by repeater:

  ⟶ Fast localisation!

Marcote et al. 2020, Tendulkar et al. 2021

FRB 180916

How Everything Changed ... AGAIN!

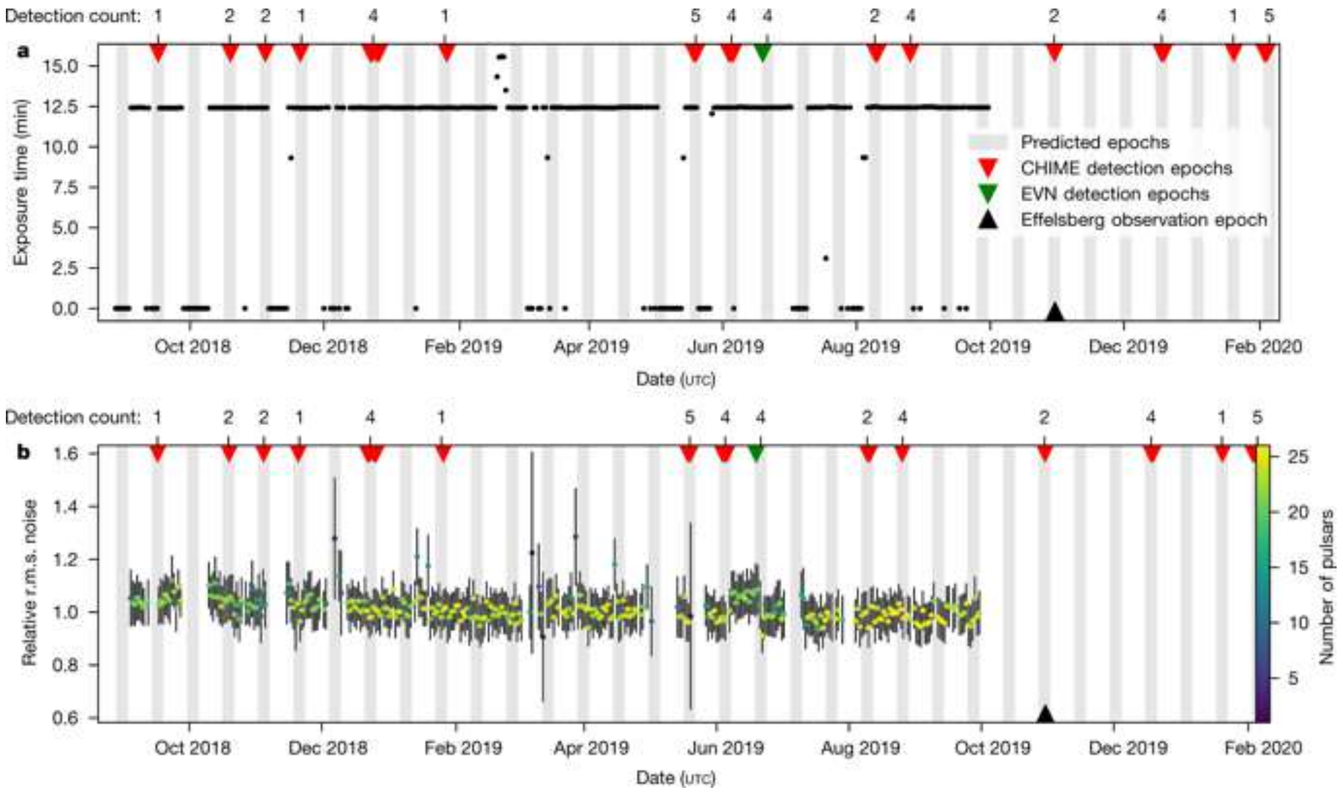


- Very close-by repeater:
  - ⟶ Fast localisation!
- First FRB seen to pulsate periodically:

Chime/FRB Collaboration, Nature, 2020

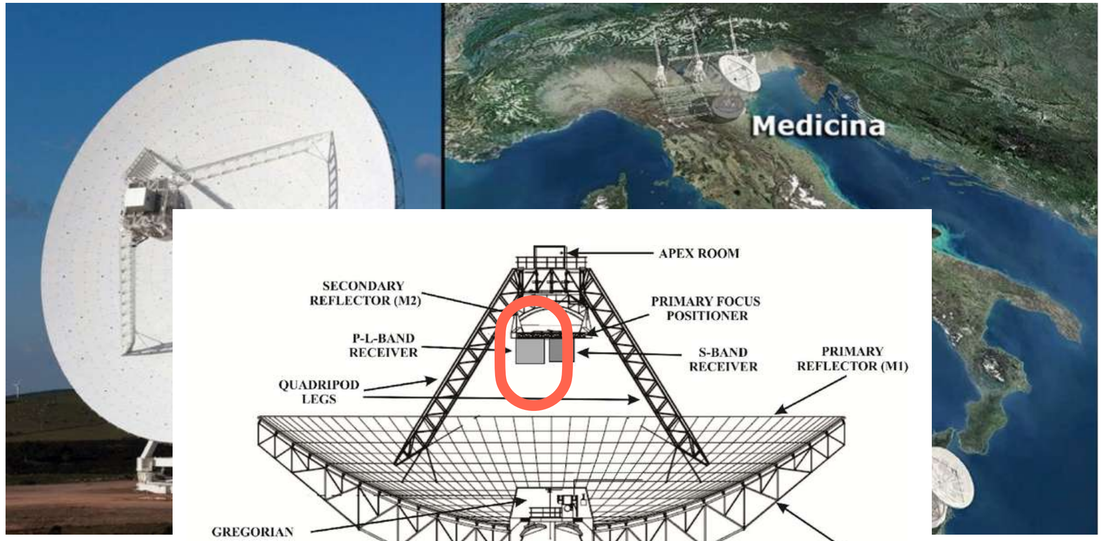
FRB 180916

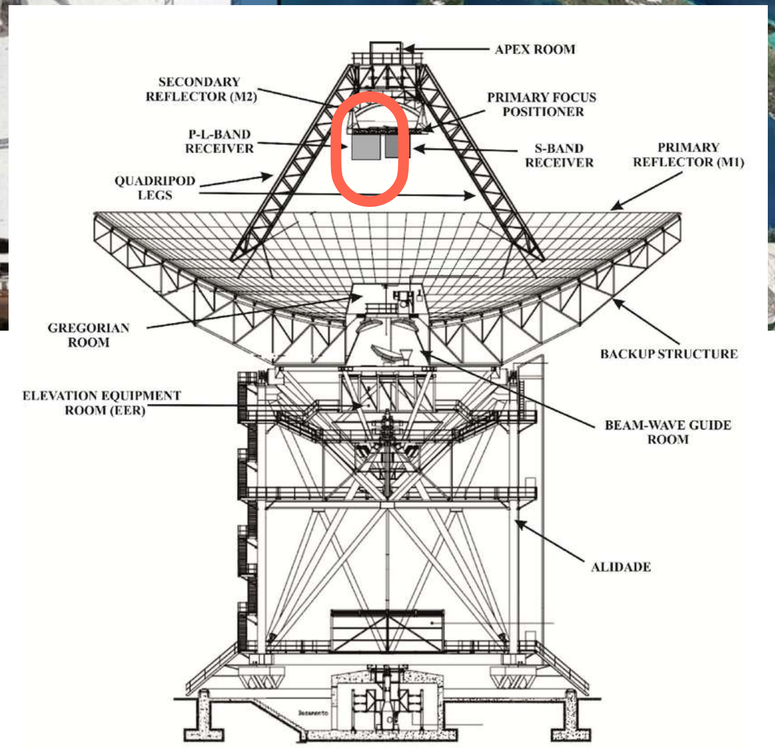
How Everything Changed ... AGAIN!



- Very close-by repeater:
  - ⟶ Fast localisation!
- First FRB seen to pulsate periodically:
  - ⟶ BUT period activity every 16.35 days
- Can FRBs still be magnetars?
  - ⟶ If so, there is something (Precession? Binary system?) to be added to the simple isolated magnetar model

Chime/FRB Collaboration, Nature, 2020





The Sardinia Radio Telescope

SRT

- 64-m dish located in Sardinia;
- Observations at C and K bands
- L/P dual band receiver:
  - 1300 - 1800 MHz
  - 300 - 400 MHz

M. Burgay, A. Possenti, A. Ridolfi, V. Gajjar, A. Corongiu, D. Perrodin, G. Bernardi, G. Naldi, G. Pupillo, F. Ambrosino, G. Bianchi, A. Burtovoi, P. Casella, C. Casentini, M. Cecconi, C. Ferrigno, M. Fiori, K. C. Gendreau, A. Ghedina, G. Naletto, L. Nicastro, P. Ochner, E. Palazzi, F. Panessa, A. Papitto, C. Pittori, N. Rea, G. A. Rodriguez Castillo, V. Savchenko, G. Setti, M. Tavani, A. Trois, M. Trudu, M. Turatto, A. Ursi, F. Verrecchia, L. Zampieri

Feb. 20-24, 2020

Ready to fire

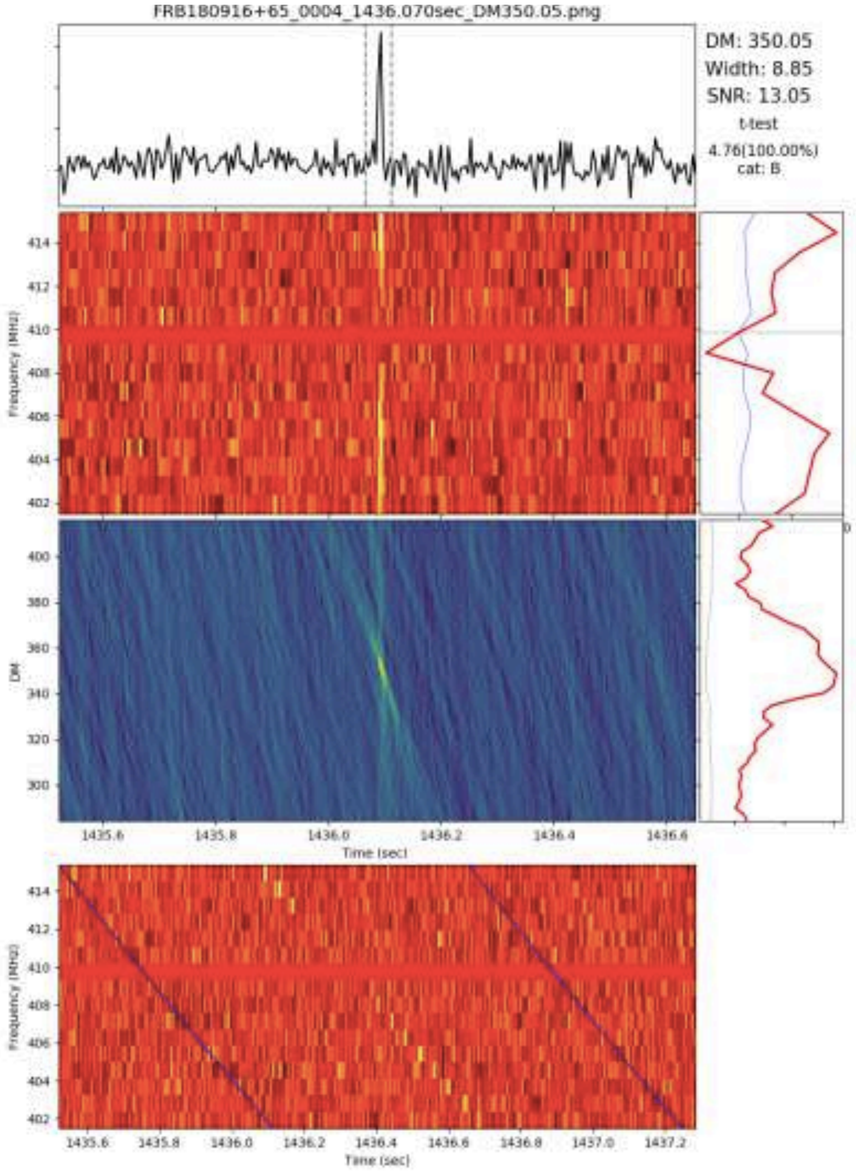
The SRT & Friends campaign

NORTHERN CROSS

- Locatelli et al. 2020
- Transit telescope observing at 408 MHz
- Commissioning FRB mode

The SRT & Friends campaign

NORTHERN CROSS



- Locatelli et al. 2020
- Transit telescope observing at 408 MHz
- Commissioning FRB mode
- Has now accumulated over 1 year of data on FRB 180916 (ATel #14480, Trudu et al. in preparation)

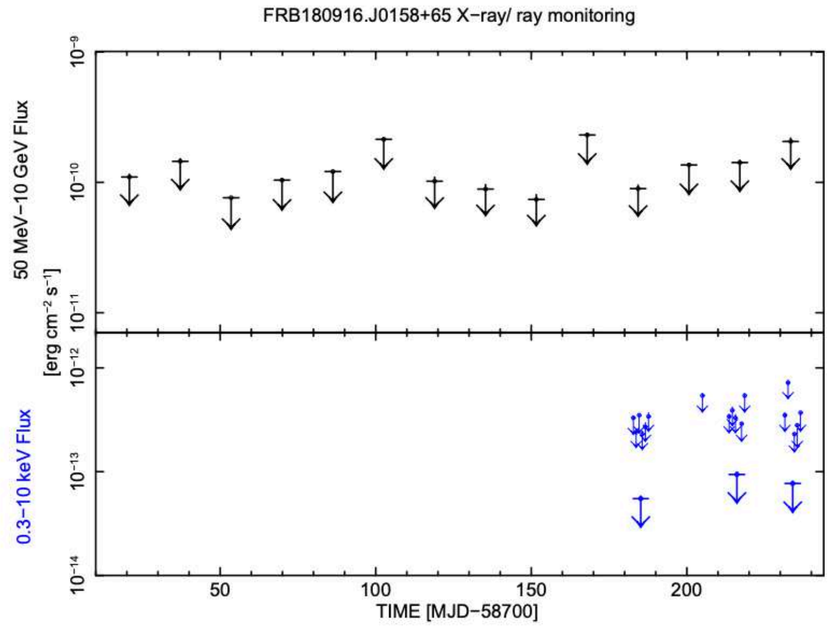
The SRT & Friends campaign

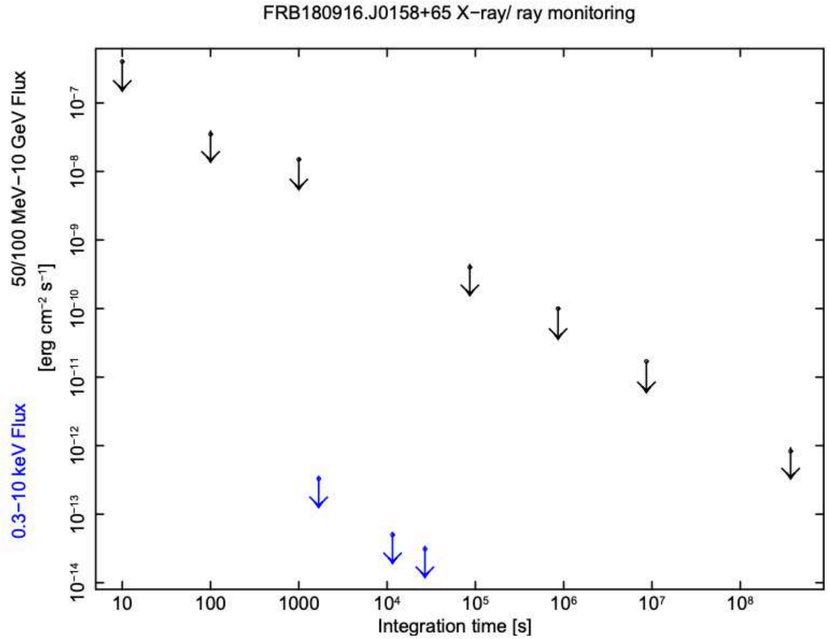
ASIAGO

- IFI+Iqueye fast optical photon counter
  - Redundant systems for background excision
  - 3 sigma upper limit corresponding to an instantaneous (1 ms) magnitude V~11 and a fluence ~0.151 Jy ms. (ATel #13493, Zampieri et al. 2020);

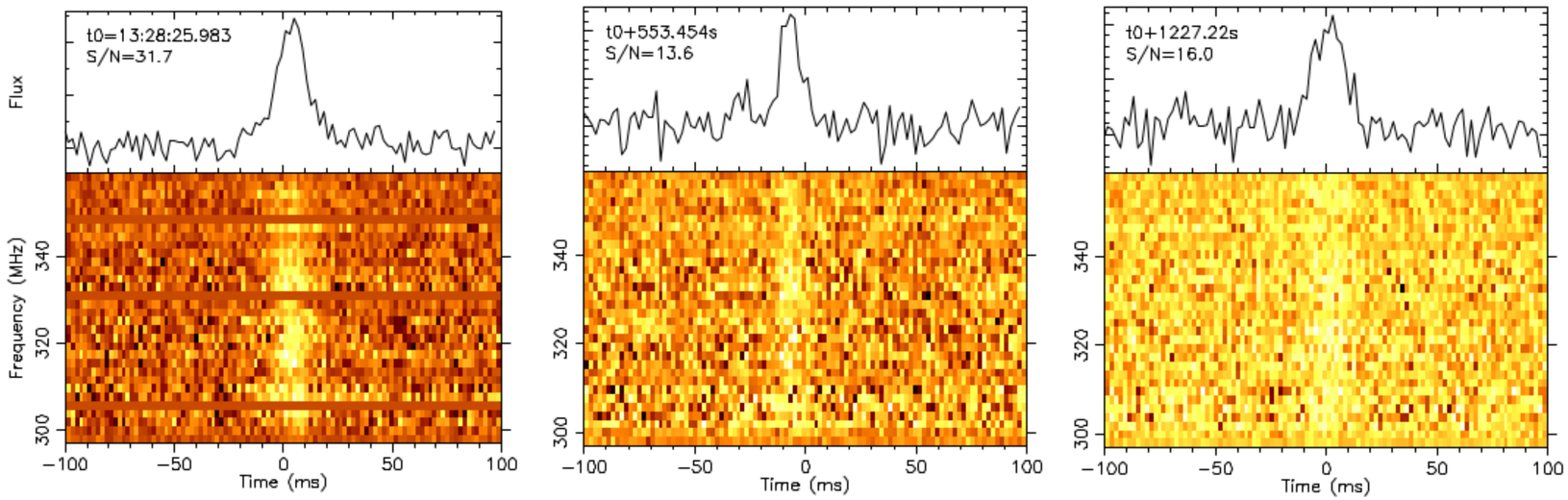
The SRT & Friends campaign

AGILE + SWIFT





The three bursts



Time (UT)	Time (MJD)	Width (ms)	S/N (-)	Peak flux (Jy)	Fluence (Jy ms)	DM (pc cm^{-3})
13:28:25.983(8)	58899.56141184	13(4)	31.7	2.8(9)	37(16)	349.8(1)
13:37:39.437(7)	58899.56781756	9(4)	13.6	1.5(7)	13(8)	349.4(1)
13:48:53.20(1)	58899.57561573	14(4)	16.0	1.4(4)	19(8)	350.1(1)

Pilia et al. 2020, ApJL

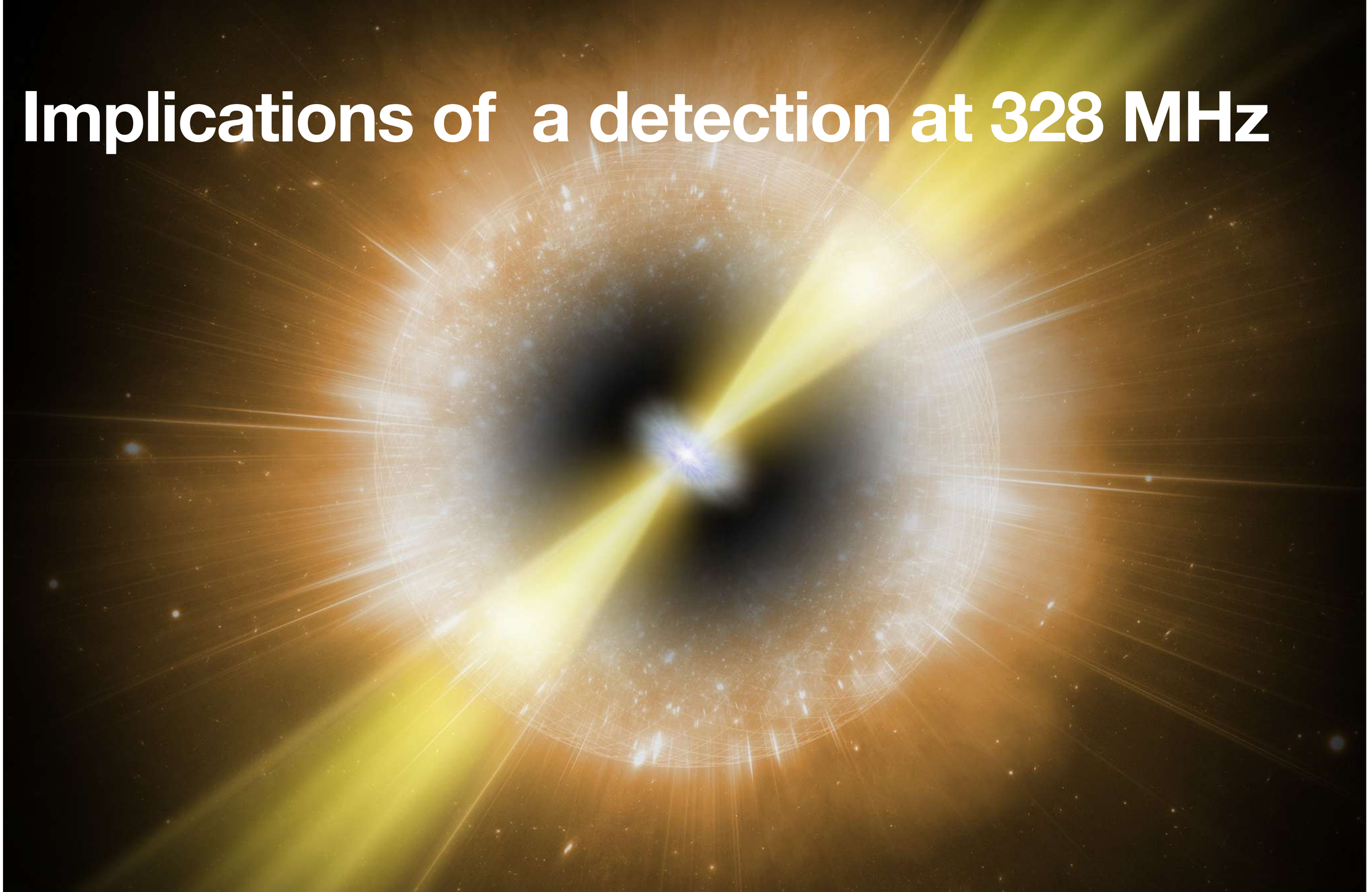
Implications of a detection at 328 MHz

Implications of a detection at 328 MHz

Coenen et al. 2014;
Tingay et al. 2015;
Karastergiou et al. 2015;
Sokolowski et al. 2018;
Chawla et al. 2020

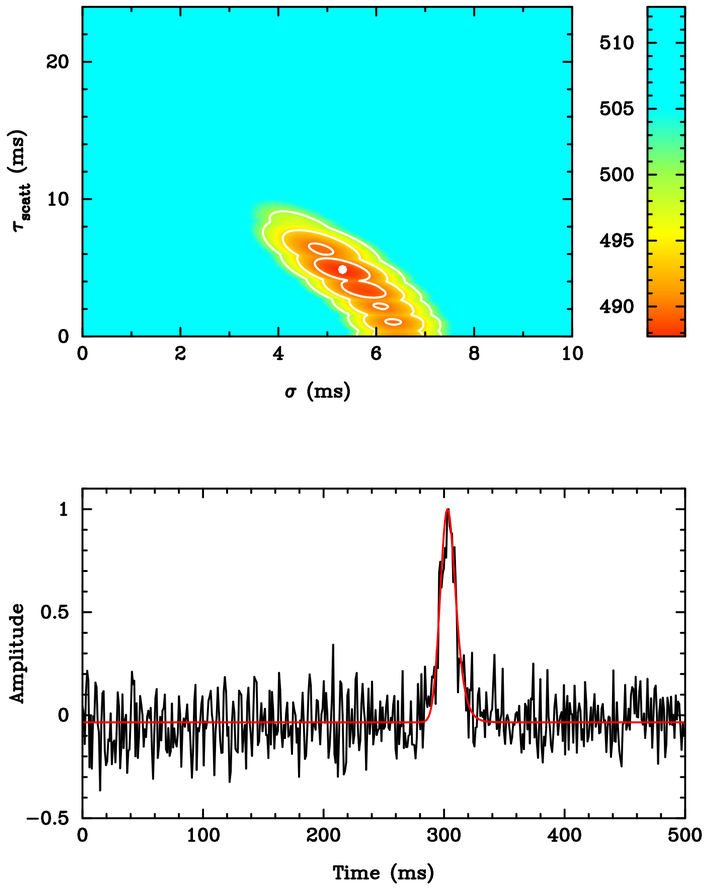
Rajwade et al. 2020

Implications of a detection at 328 MHz



Radio properties of bursts

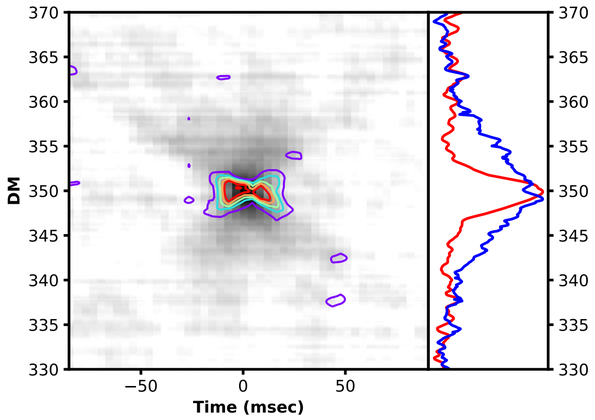
Scattering



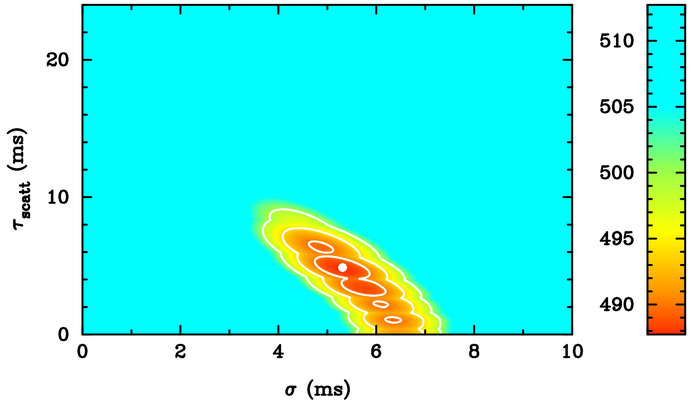
Pilia et al. 2020, ApJL

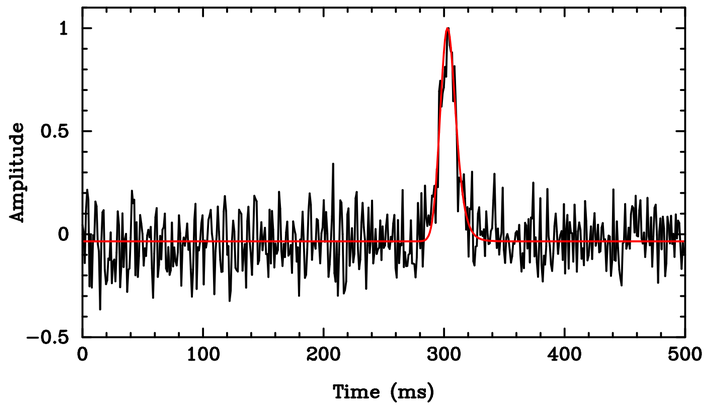
Radio properties of bursts

Structure



Scattering





Pilia et al. 2020, ApJL

Radio properties of bursts

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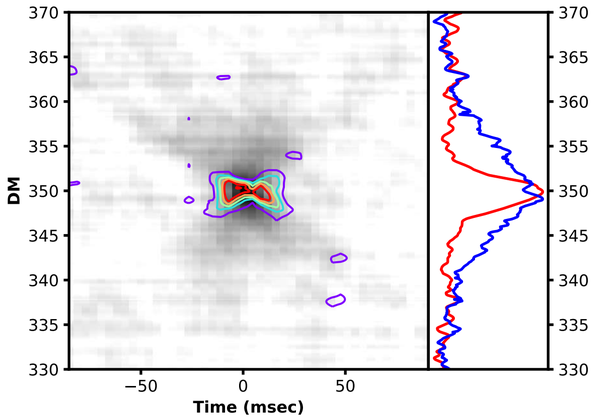
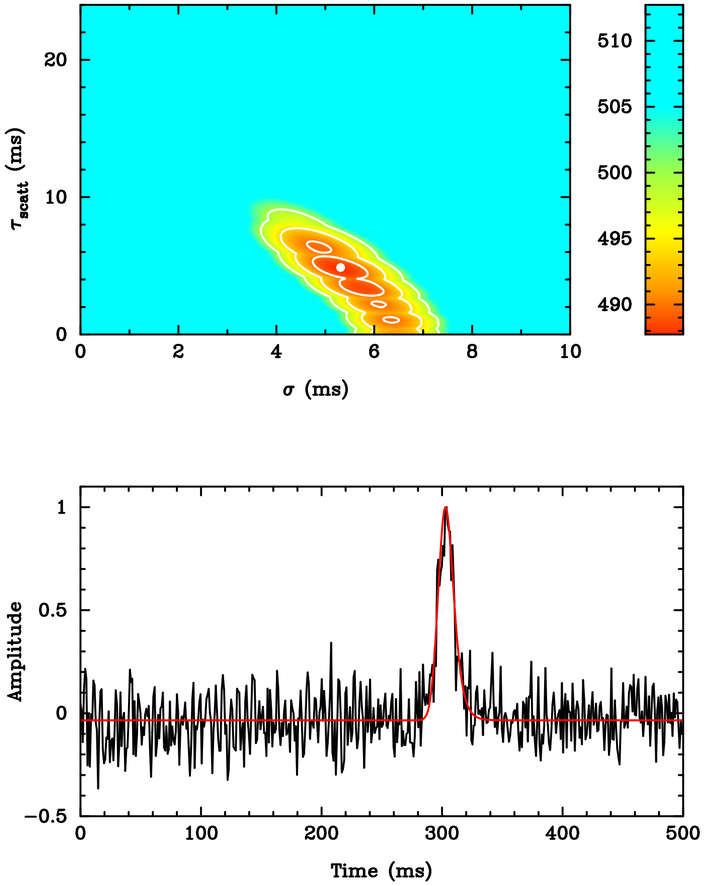
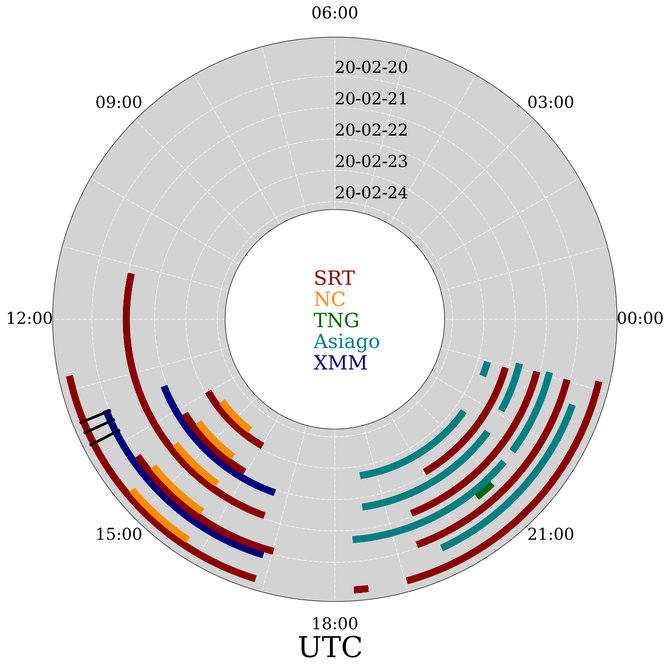


Scattering



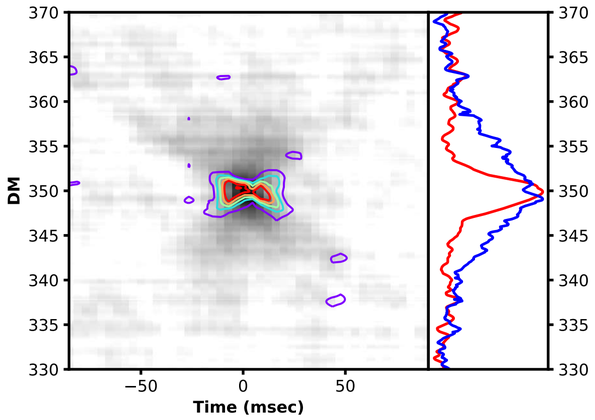
Distribution



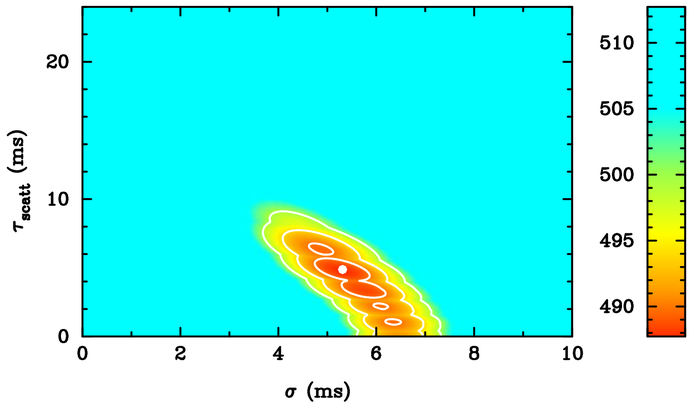
Pilia et al. 2020, ApJL

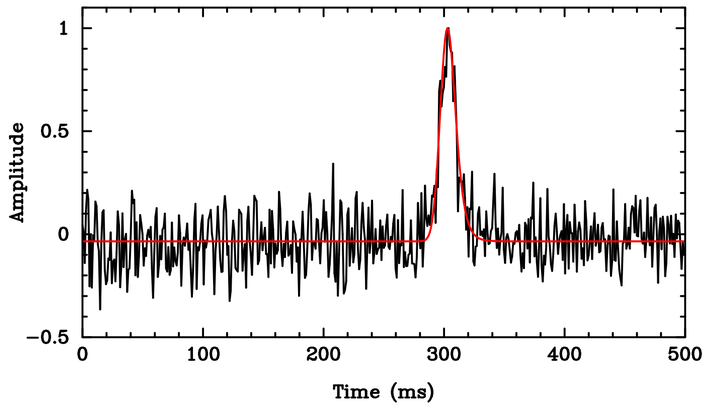
Radio properties of bursts

Structure



Scattering





Distribution

No other detection at P-band

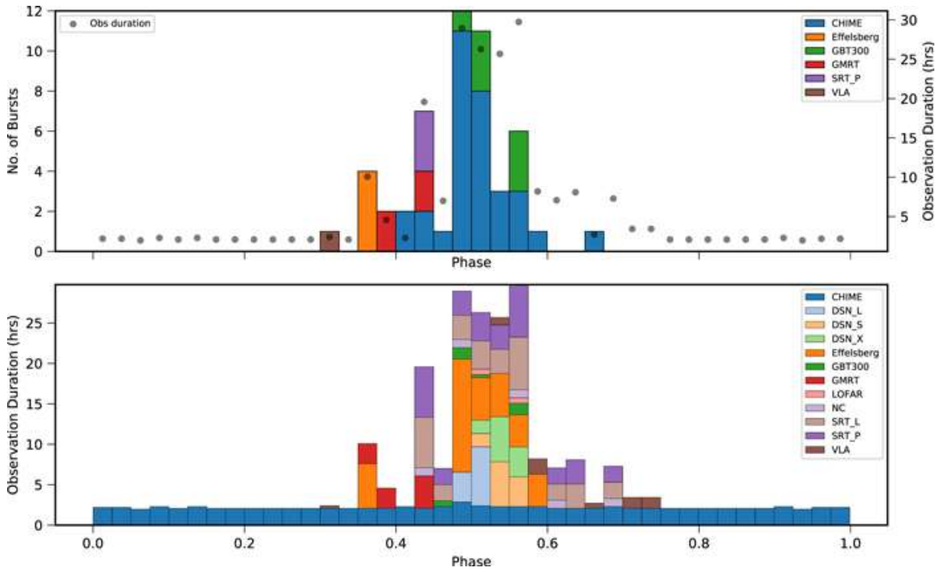
No detections at L-band

No detections with the Northern Cross at 408 MHz

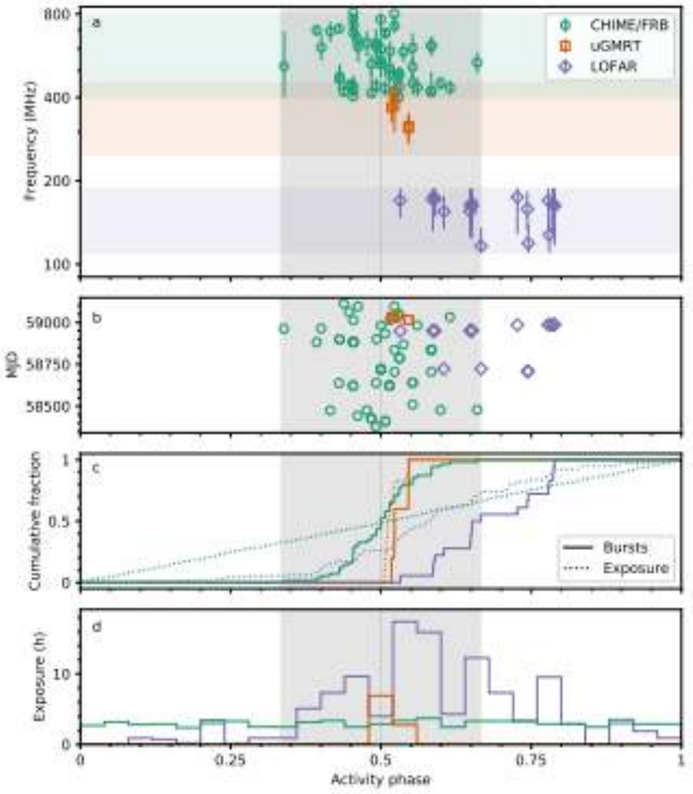
Clustering

Pilia et al. 2020, ApJL

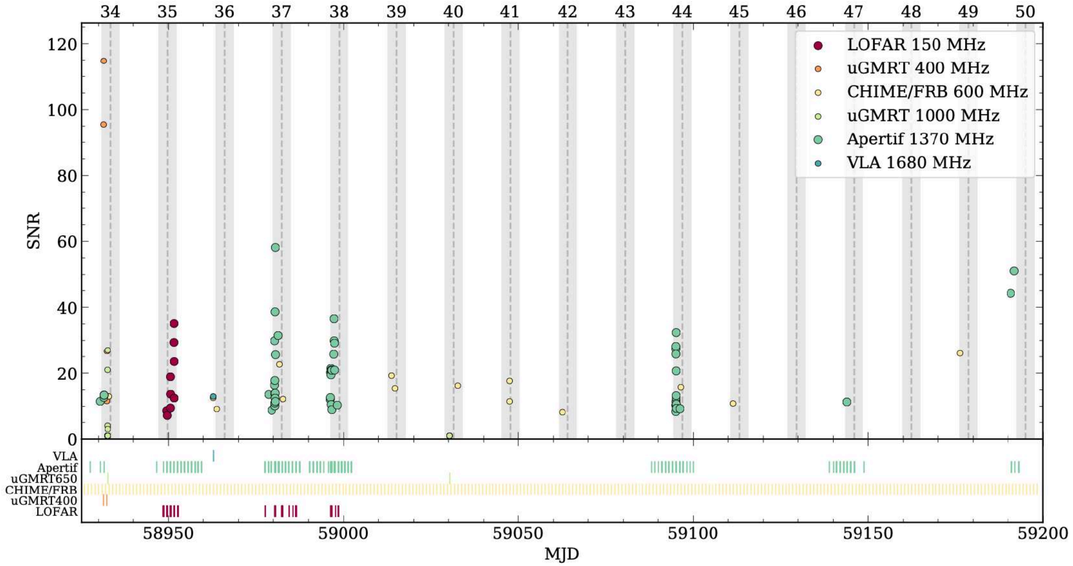
Frequency-dependent periodicity



Aggarwal et al. 2020

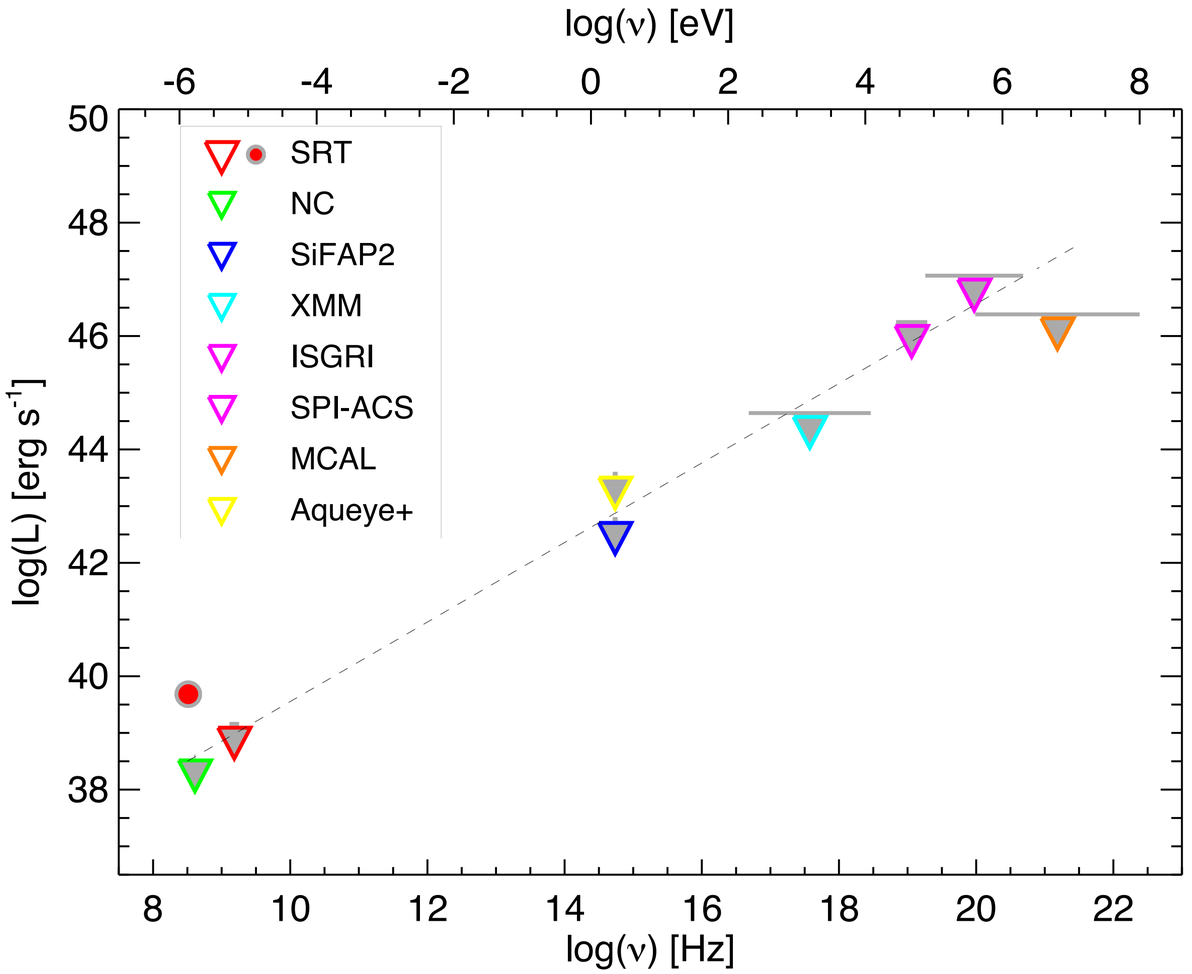


Pleunis et al. 2020



Pastor-Marazuela et al. 2020

Multiwavelength campaign

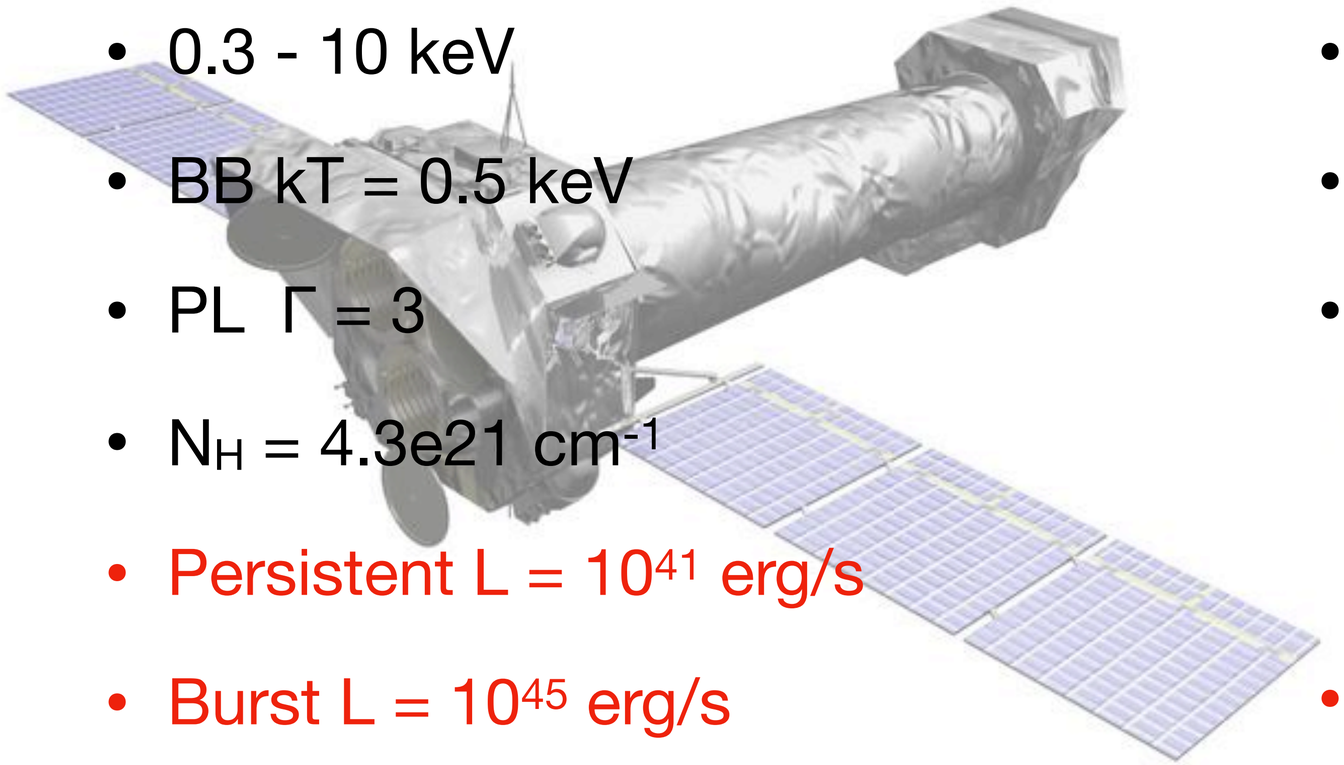


Pilia et al. 2020, ApJL

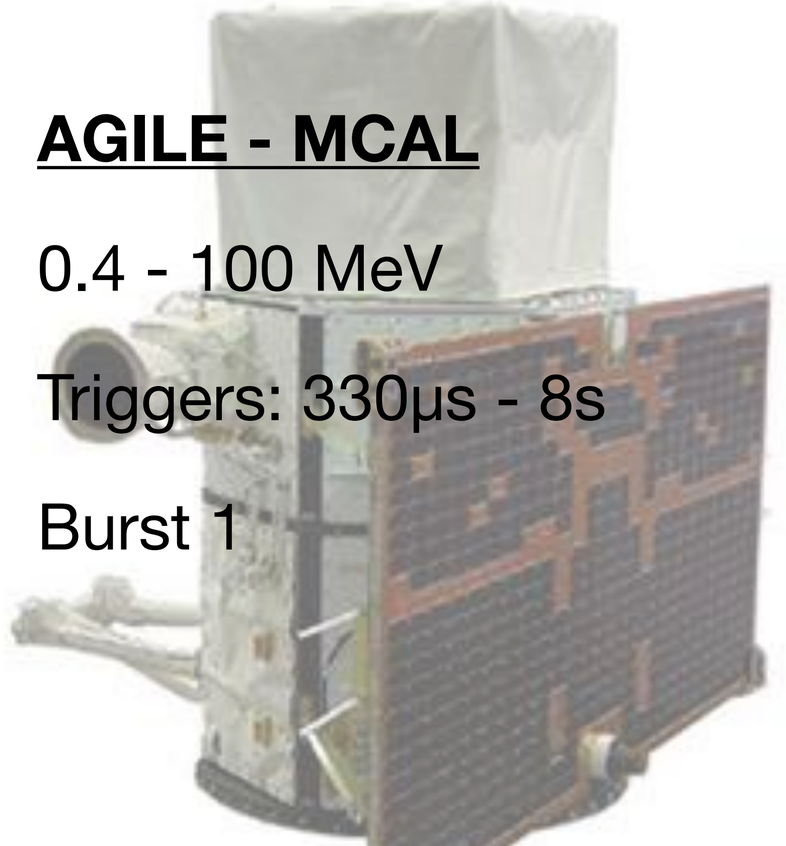
Simultaneous multi-wavelength coverage

$E_{r,i} = 6.3 \times 10^{37}$erg

- **<u>XMM-Newton</u>**
- 0.3 - 10 keV
- BB kT = 0.5 keV
- PL $\Gamma = 3$
- N_H = 4.3e21 cm^{-1}
- Persistent L = 10^{41} erg/s
- Burst L = 10^{45} erg/s



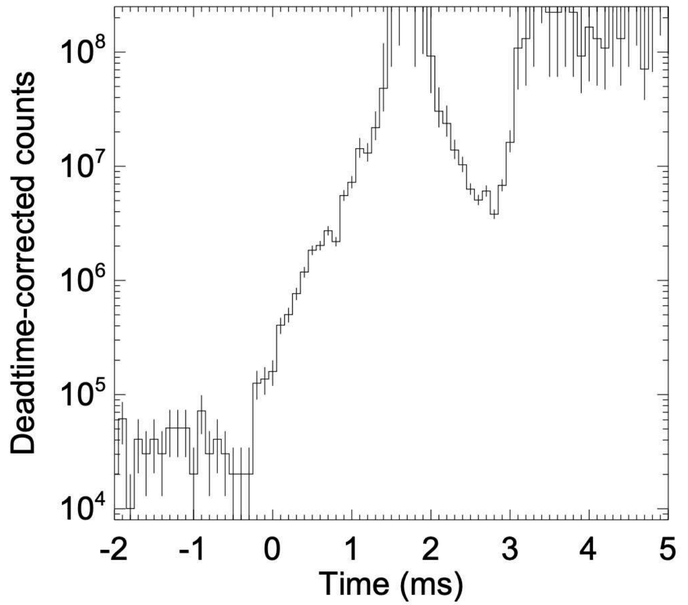
- **<u>AGILE - MCAL</u>**
- 0.4 - 100 MeV
- Triggers: 330μs - 8s
- Burst 1
- Isotropic E = 2.2x10^{46} erg



Implications of the high-energy upper limits

And comparisons with SGRs

- XMM persistent ULs are not so constraining, given the typical magnetar luminosity < 10^{38}erg/s
- AGILE MCAL UL on isotropic energy is close to the energy release that was observed for SGR1806-20 during its famous giant burst of 2004 (E = 2x10^{46} erg)
- $$\frac{E_X}{E_{radio}} \sim 5 \times 10^8$$



Palmer et al. 2005

Further X/gamma -ray upper limits

AGILE + SWIFT

Table 2. Average *AGILE*/MCAL fluence ULs in erg cm^{-2}

sub-ms	1 ms	16 ms	64 ms	256 ms	1024 ms	8192 ms
1.13×10^{-8}	1.29×10^{-8}	3.72×10^{-8}	4.97×10^{-8}	7.95×10^{-8}	1.59×10^{-7}	4.49×10^{-7}

Table 3. Average *AGILE*/GRID flux ULs in erg cm^{-2} s^{-1}.

$\Delta T = 10^1$ s	$\Delta T = 10^2$ s	$\Delta T = 10^3$ s	$\Delta T = 10^0$ d	$\Delta T = 10^1$ d	$\Delta T = 10^2$ d
4.0×10^{-7}	3.5×10^{-8}	1.5×10^{-8}	4.0×10^{-10}	1.0×10^{-10}	1.7×10^{-11}

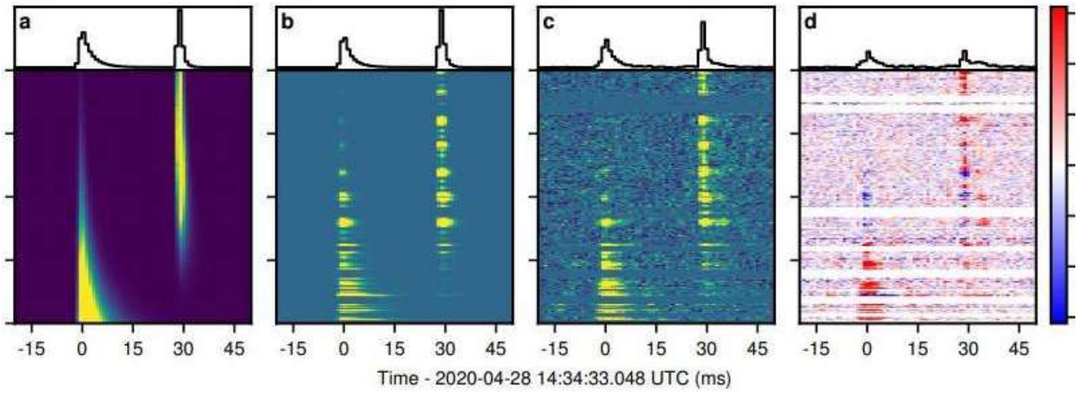
Tavani et al. 2020

Table 5. *Swift*/XRT 3-σ flux ULs.

Start Date (UTC)	Effect.Exposure (s)	0.3–10 keV UL value ($\times10^{-13}$ erg cm^{-2} s^{-1})
2020-02-03 18:43:55	1677	3.3
2020-02-04 15:43:59	1966	2.4
2020-02-05 15:23:58	1304	3.5
2020-02-06 15:29:51	2006	2.3
2020-02-07 15:23:35	2016	2.7
2020-02-08 15:16:35	1264	3.4
2020-02-25 14:00:01	920	5.4
2020-03-05 13:08:00	1828	3.4
2020-03-06 14:23:00	1241	3.9
2020-03-07 14:16:00	1392	3.3
2020-03-08 14:12:13	303	15.0
2020-03-09 14:04:46	1597	2.9
2020-03-10 13:57:52	920	5.4
2020-03-23 12:20:41	1795	3.5
2020-03-24 12:40:46	727	7.2
2020-03-25 12:40:34	318	18.0
2020-03-26 12:20:14	1938	2.3
2020-03-27 11:53:55	1738	2.8
2020-03-28 11:48:08	1254	3.7

A smoking gun
SGR 1935+2154

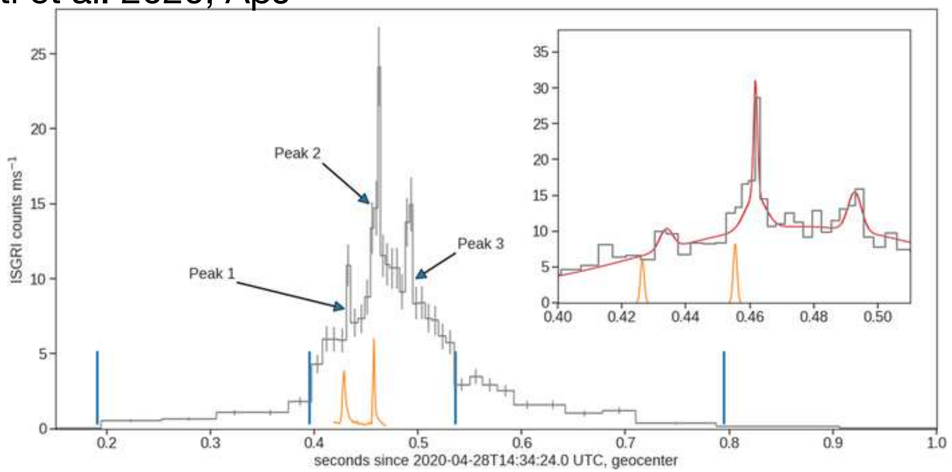
- P = 3.24 s, B ~ 2.2 × 10^{14} G (Israel+16)
- A forest of X-ray bursts started on April 24th
- A double burst seen by CHIME on April 28th with fluence 700 kJy ms
- A single burst independently seen by STARE2 at L-band with fluence 1.5 MJy ms



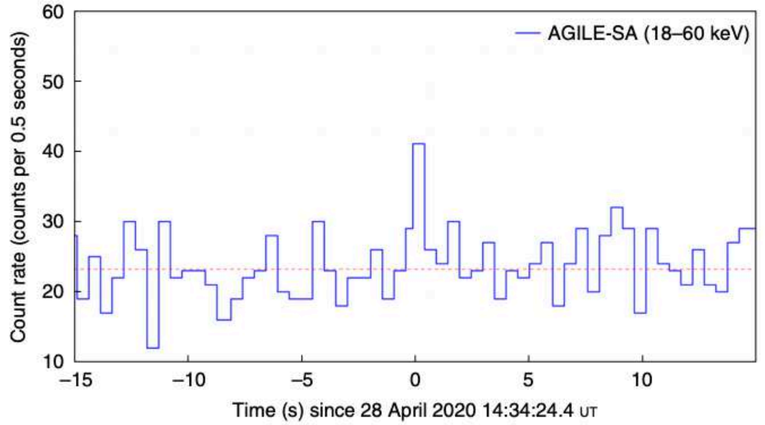
CHIME/FRB & STARE2, 2020, Nature

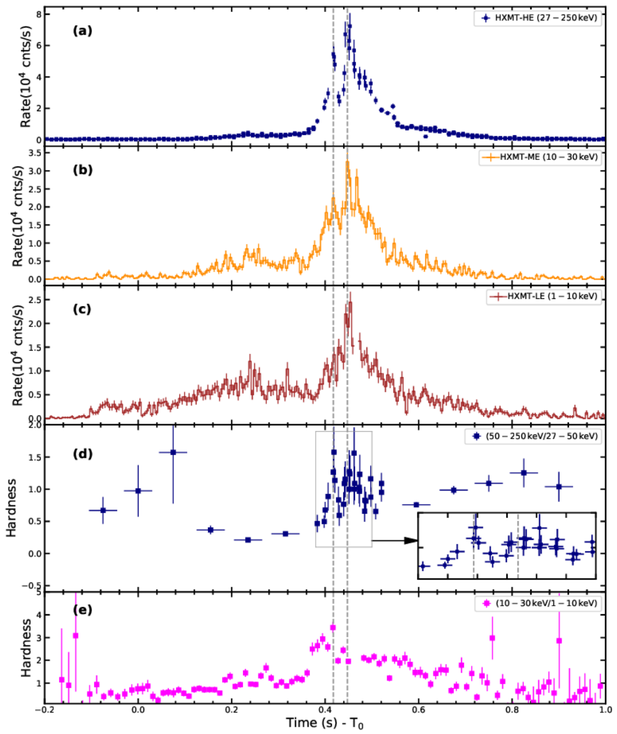
Plus Hard X-ray Emission!

Mereghetti et al. 2020, ApJ

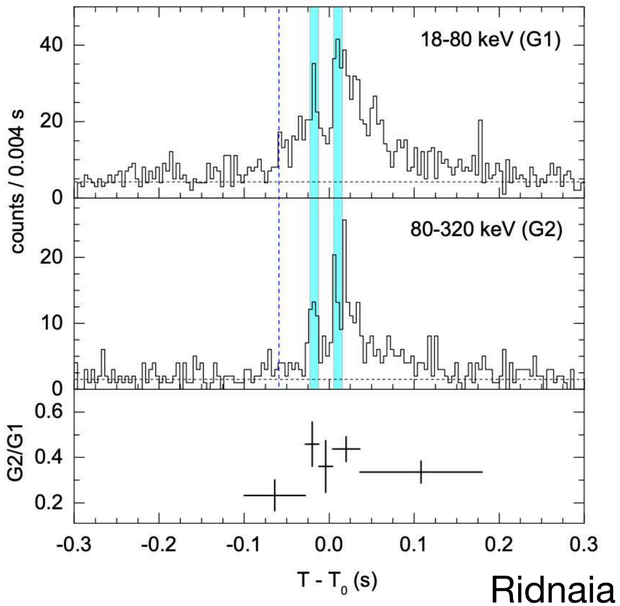


Tavani et al. 2020, NatAstro





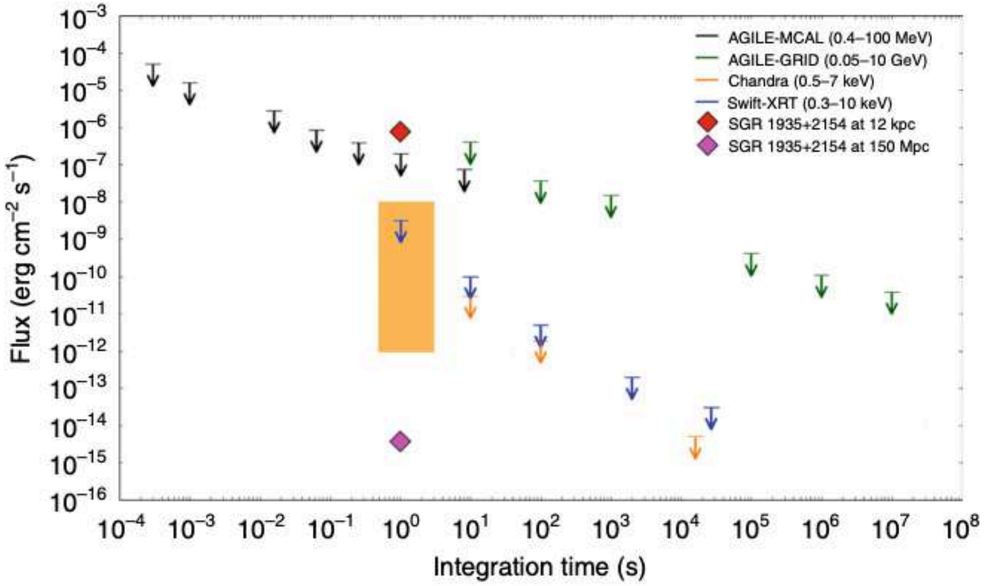
HXMT Coll. 2020, NatAstro

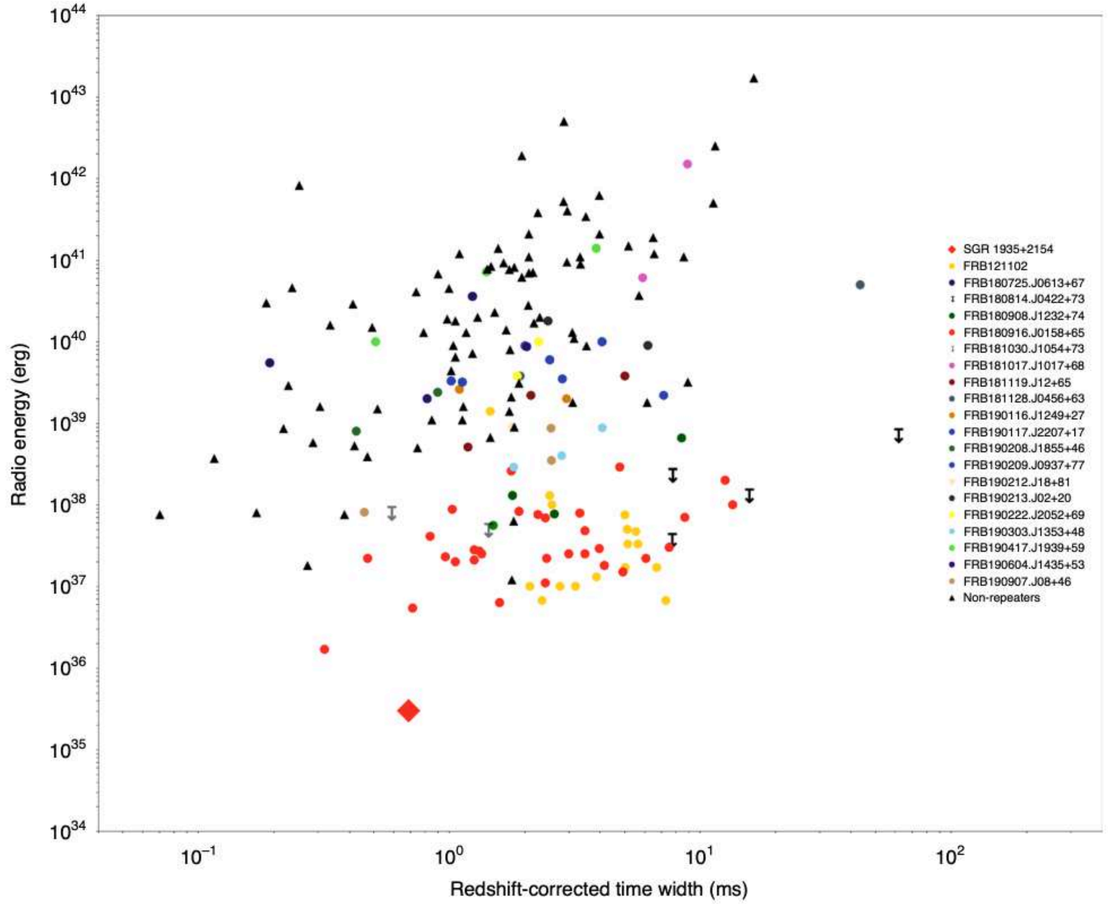


Ridnaia et al. 2020, NatAstro

FRB 200428?

Tavani et al. 2021 (+ Verrecchia et al. submitted)





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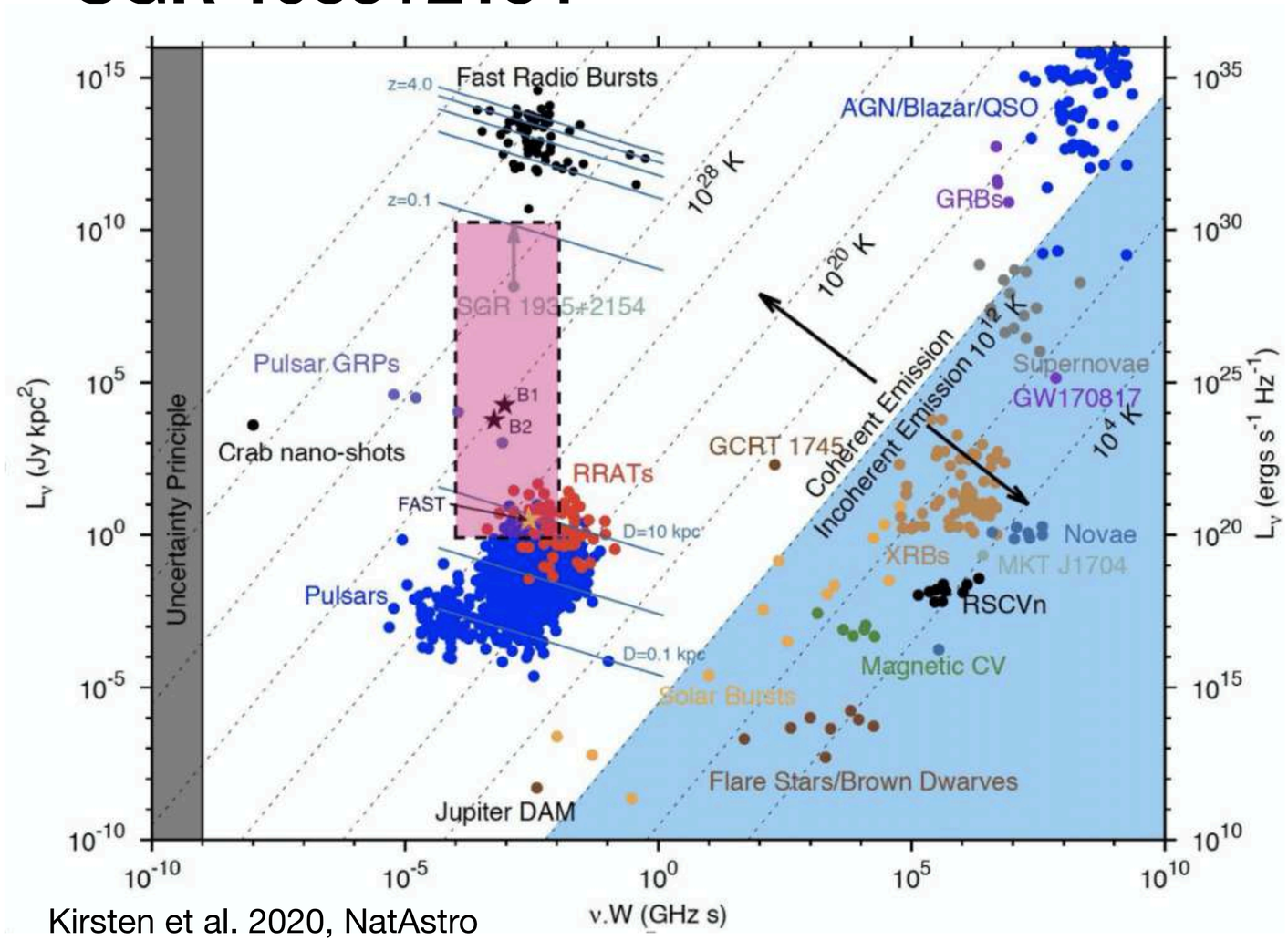
- $\frac{E_X}{E_{radio}} \sim 5 \times 10^8$ while it was ~10^5 for SGR 1935+2154
- SGR 1935+2154 emitted 1.4x10^{39} erg in the INTEGRAL band on April 28$_{th}$, 2020

A continuum of radio bursts?

SGR 1935+2154

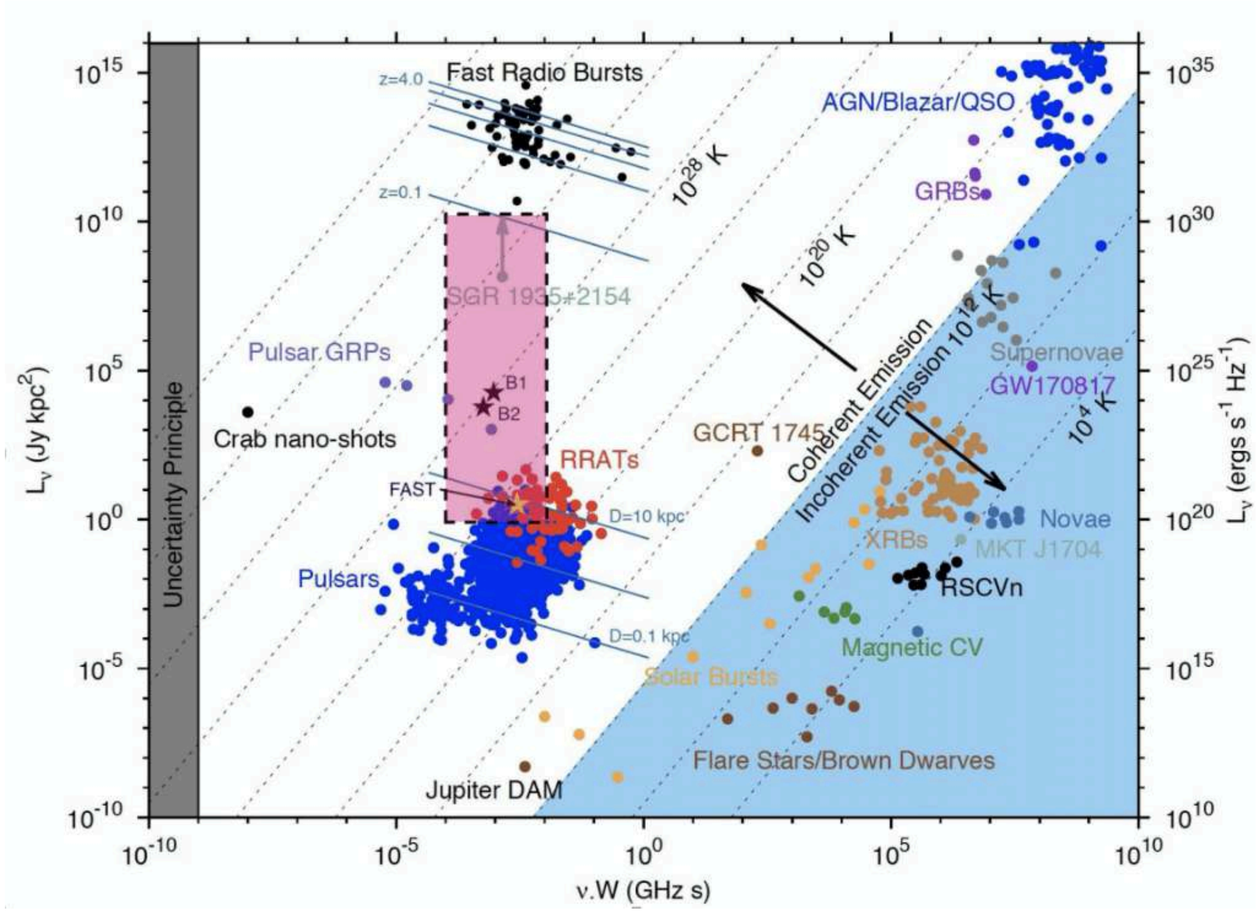


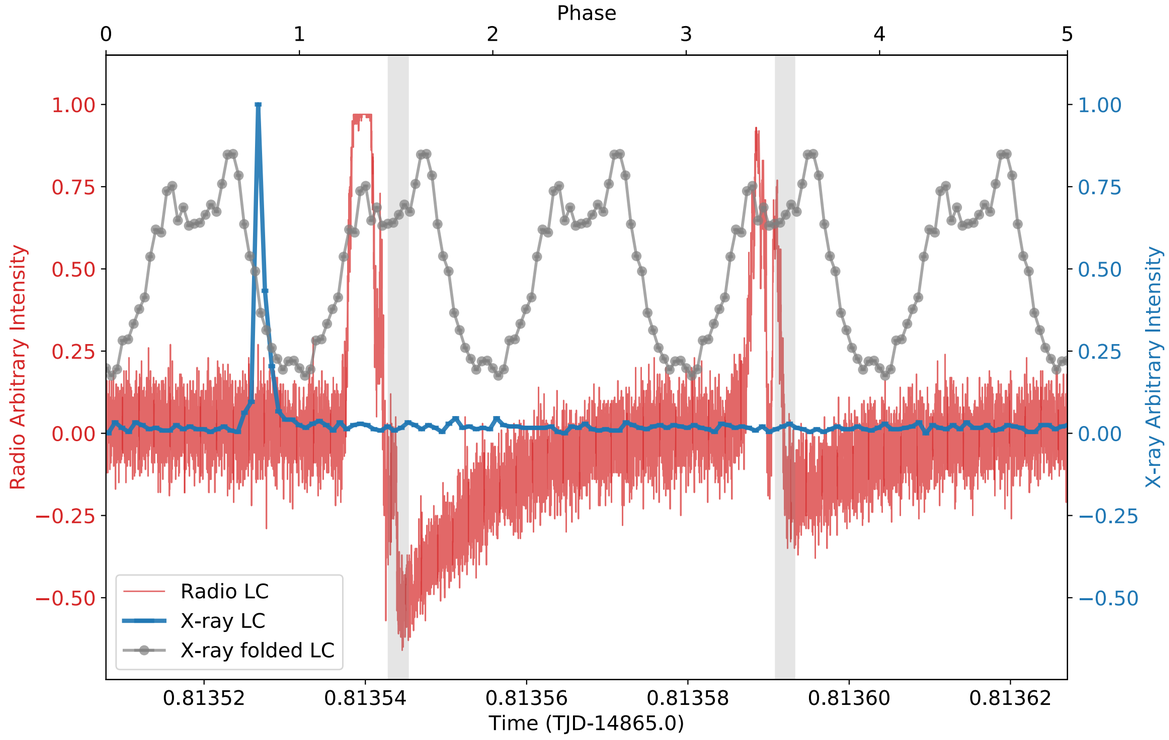
Kirsten et al. 2020, NatAstro

A continuum of radio bursts?

SGR 1935+2154

1E 1547.0-5408





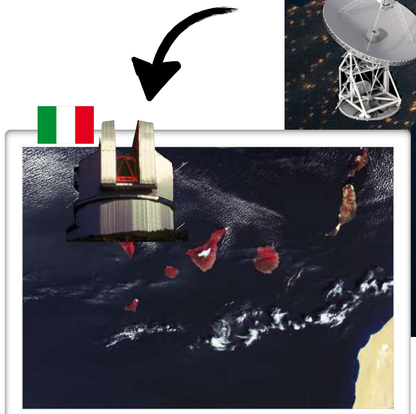
Kirsten et al. 2020, NatAstro

Israel et al. 2020, ApJ

Bright times ahead

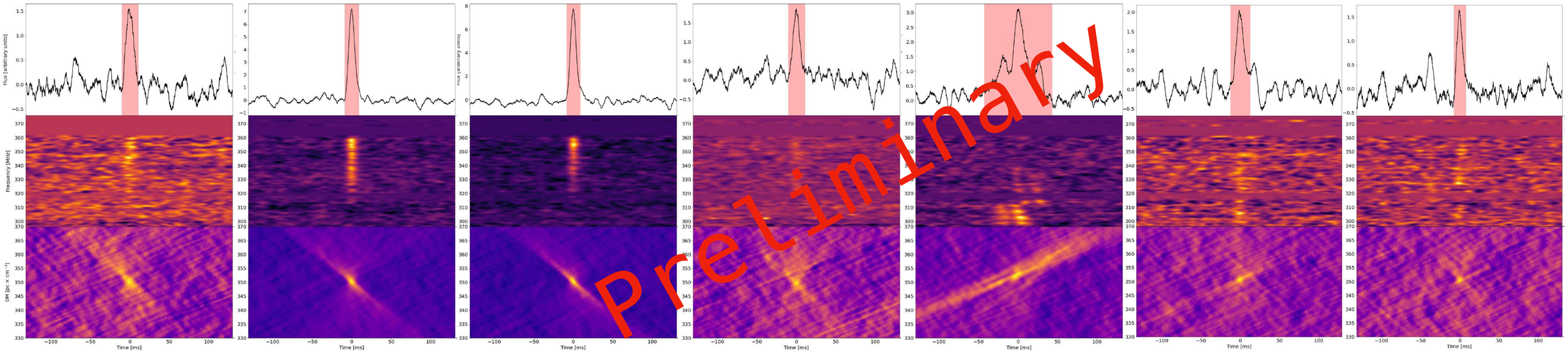
New campaigns

New telescopes



New campaigns

New bursts



Credits M. Trudu

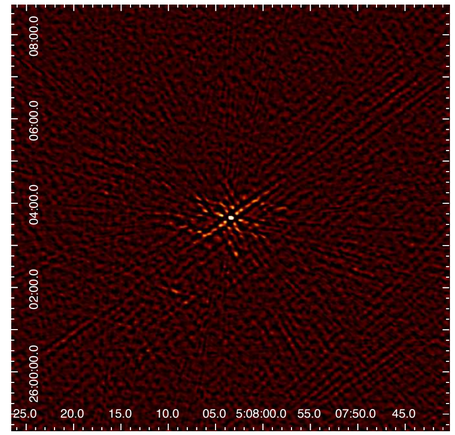
New nearby/active repeaters

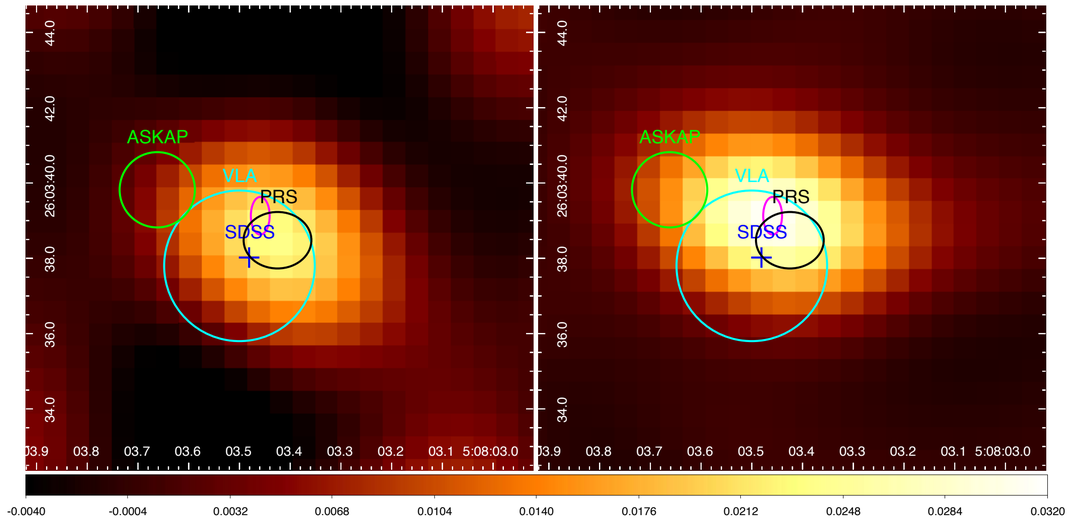
FRB 20200120E & FRB 20201124A

Table 2. Major Observables of FRB 20200120E.

Parameter	Value
R.A.(J2000)[a]	$09^{h}57^{m}56^{s}.7 \pm 12^{s}.5$
Dec. (J2000)[a]	$68°49'32'' \pm 01'24''$
l, b[b]	$142.°19, +41.°22$
DM[c]	87.818 ± 0.007 pc cm^{-3}
$\mathrm{DM}^{d}_{\mathrm{MW,NE2001}}$	40 pc cm^{-3}
$\mathrm{DM}^{d}_{\mathrm{MW,YMW16}}$	35 pc cm^{-3}
$\mathrm{DM}^{e}_{\mathrm{MW,WIM}}$	10–40 pc cm^{-3}
$\mathrm{DM}^{f}_{\mathrm{MW,N_H}}$	14–28 pc cm^{-3}
$\mathrm{DM}^{g}_{\mathrm{MW,halo}}$	30 pc cm^{-3}
Max. distance[h]	$\lesssim 135$ Mpc
RM[i]	$-28.3 \pm 0.6 \pm 1.0$ rad m^{-2}

Bhardwaj et al. 2021





ATels #14497, 14502, 14508, 14515, 14518, 14523, 14525, 14526, 14529, 14532, 14538

Summary and Conclusions

- **SRT:**
- 328 MHz detection of FRBs
- Clustering, Spectral selectivity, No scattering

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- **Northern Cross:**
- important asset for monitoring of nearby FRBs or Galactic magnetars

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- Northern Cross important asset for monitoring
- **Multiwavelength campaign:**
- New FRB repeaters seem encouraging to constrain high energy emission not only from giant flares
- Active, radio-loud, magnetars are optimal targets to look for a missing link with FRBs

Nicastro L. et al. 2021

Summary and Conclusions

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- Northern Cross important asset for monitoring
- Multiwavelength campaign:
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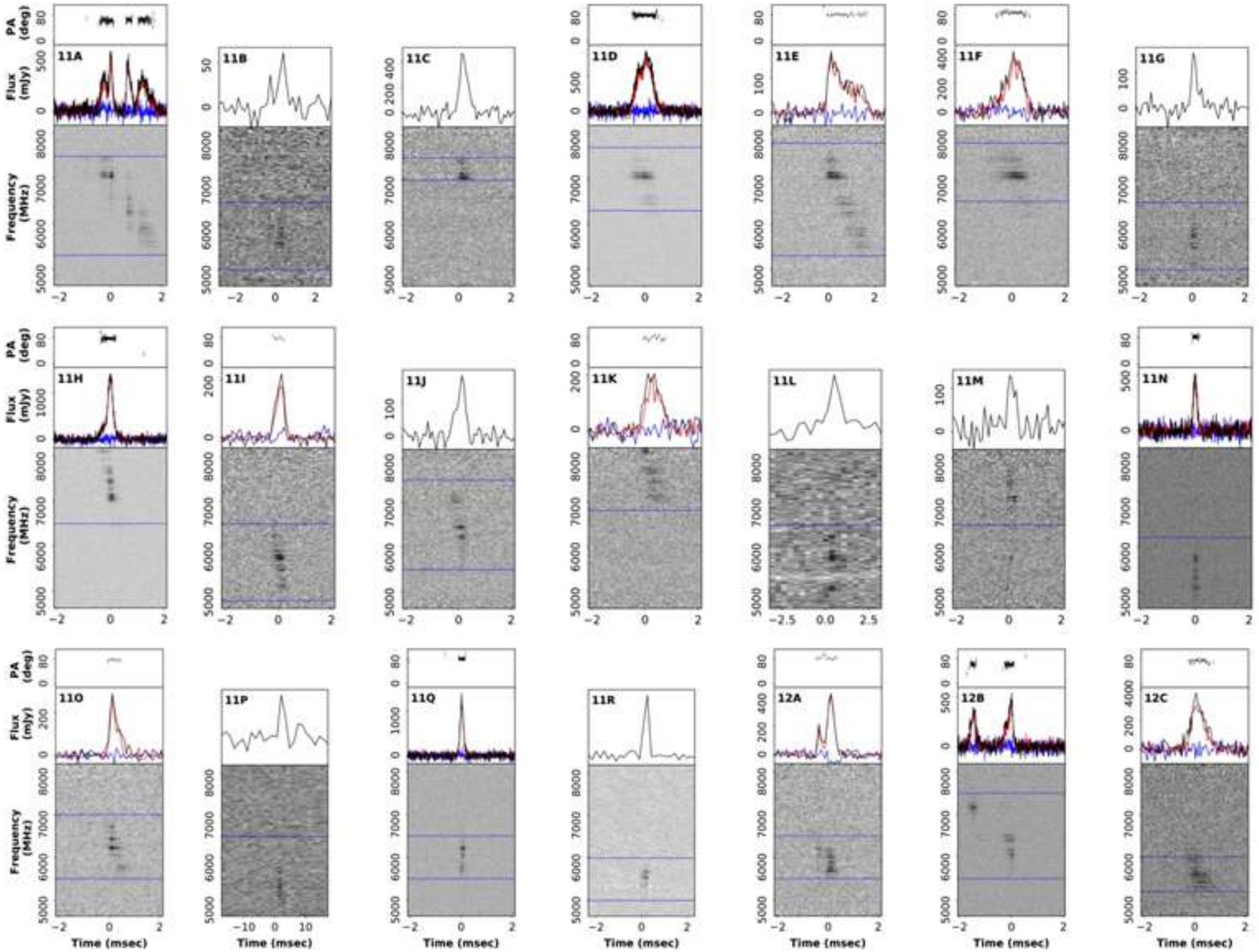
- Active, radio-loud, magnetars are optimal targets to look for a missing link with FRBs
- Proposals active at most facilities for future terms: **we are ready!**

THANK YOU!

How are FRBs?



Gajjar et al. 2018