RSN4: audit of INAF-Schede

25 May 2021

Panchromatic studies of the Fast Radio Bursts (FRBs)

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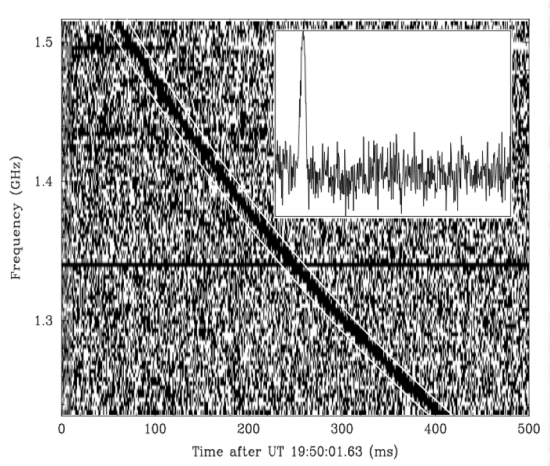
Science cornerstones



[Lorimer et al. 2007]

1: original discovery

First case of detection of an extragalactic dispersed (DM>DM_{mw}) radio burst

2: confirmation of the cosmic nature

A Population of Fast Radio Bursts at Cosmological Distances

D. Thornton,[1,2*] B. Stappers,[1] M. Bailes,[3,4] B. Barsdell,[3,4] S. Bates,[5] N. D. R. Bhat,[3,4,6] M. Burgay,[7] S. Burke-Spolaor,[8] D. J. Champion,[9] P. Coster,[2,3] N. D'Amico,[10,7] A. Jameson,[3,4] S. Johnston,[2] M. Keith,[2] M. Kramer,[9,1] L. Levin,[5] S. Milia,[7] C. Ng,[9] A. Possenti,[7] W. van Straten[3,4]

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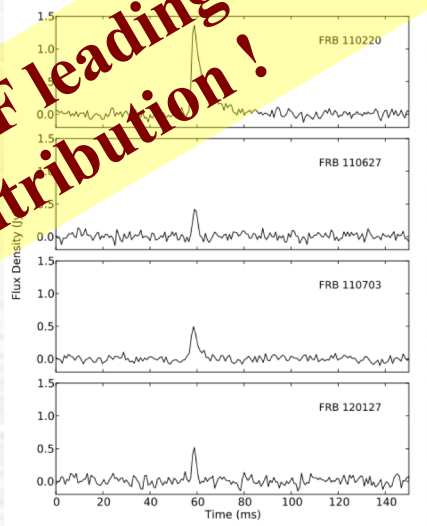
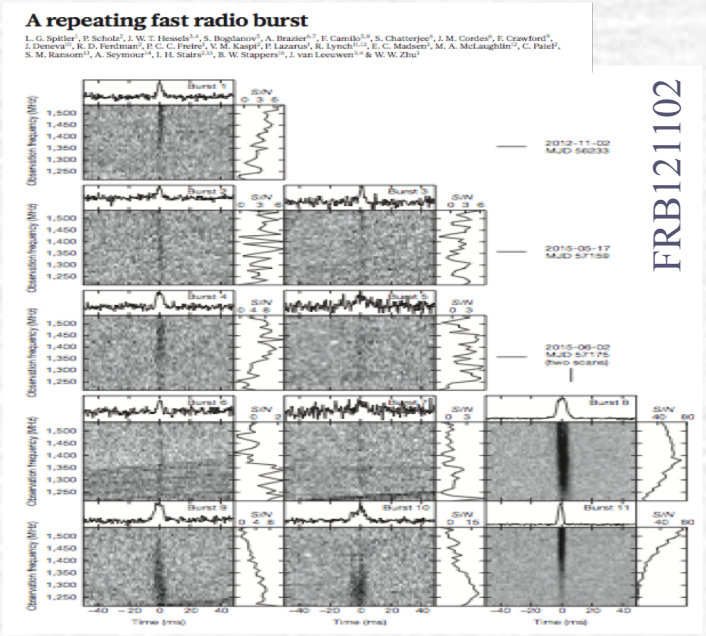
INAF leading contribution !



A high rate of events
$\gtrsim 10^3$ all-sky/day

Science cornerstones



[Spitler et al. 2016]

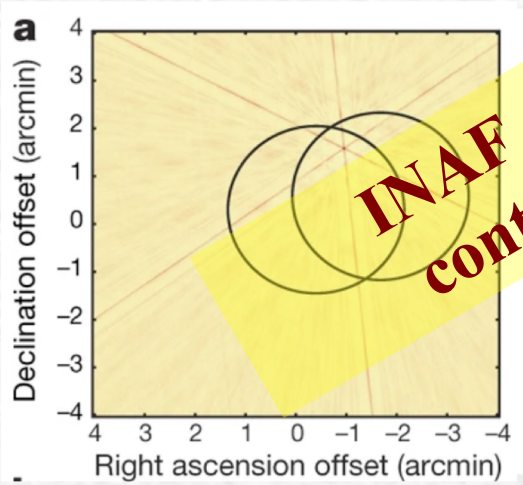
3° : discovery of the repeating FRBs

The **repeating** bursts usually show **wider** pulse widths **than one-off** bursts and different polarimetric and time-frequency properties

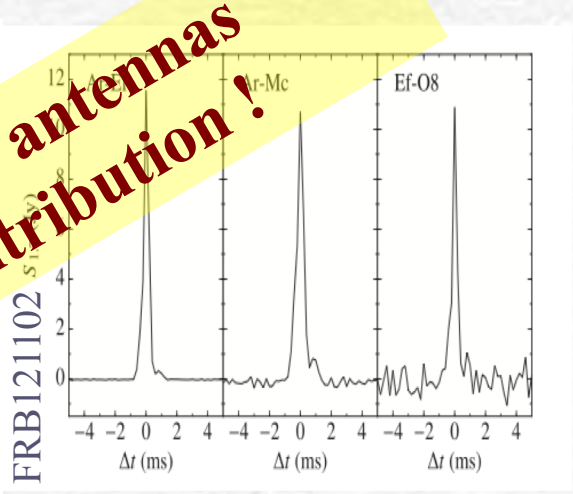
[Keane et al. 2016; … ; Nimmo et al. 2021]

4° : identifications of the host galaxies

Repeating and apparently nonrepeating, are found in a **variety of types** of host galaxies [Bhandari et al 2020] http://frbhosts.org/



[Chatterjee et al 17]



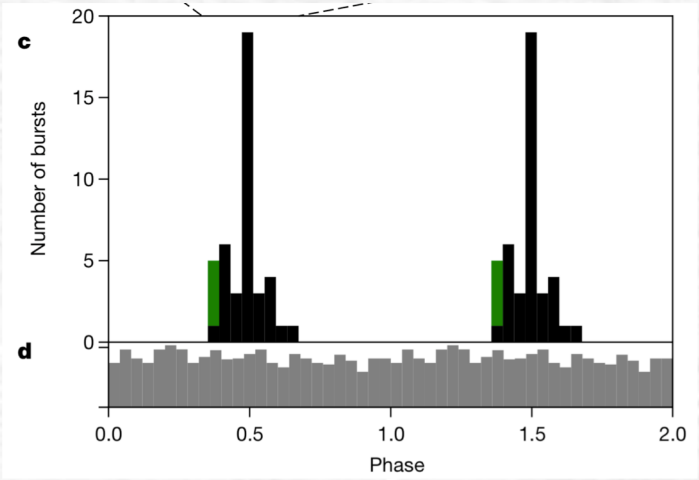
[Marcote et al 17]

INAF antennas contribution !

Are repeaters intrinsically different wrt one-off events ?

Science cornerstones

[Chime collaboration 2020]

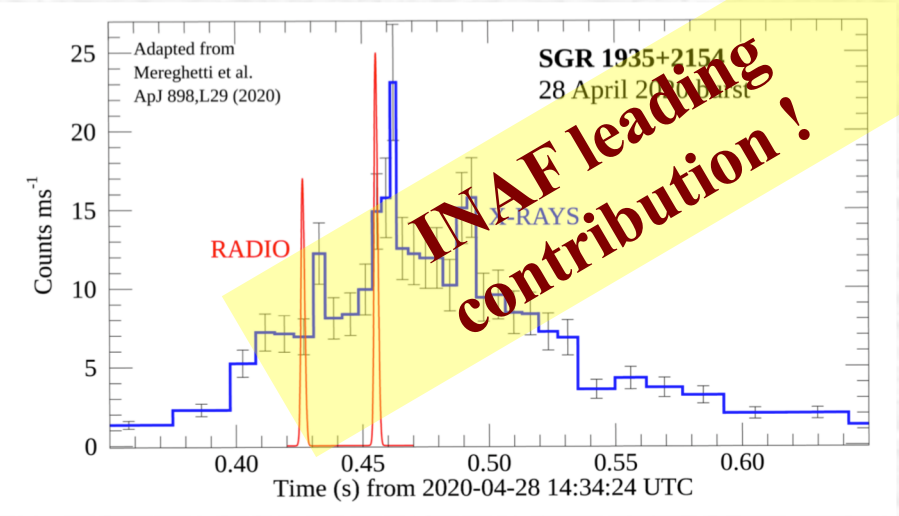


5° : periodicity in repeating FRBs

Looking at the repeater
FRB 180916

discovered a 16.35 day periodicity of the bursts

6° : a galactic FRB



What is the origin of the periodicity ? A link among the magnetars and repeating FRBs ?

The official catalog of published FRBs

It is located at http://frbcat.org/ and https://wis-tns.weizmann.ac.il/

FRB Catalogue

A complete catalogue of fast radio bursts (FRBs) is now maintained at the Transient Name Se
information. This catalogue contains the population of fast radio bursts (FRBs) published up
actively updated. Information for each burst is divided into two categories: observed parame
model. Cosmological values are obtained using the Cosmology Calculator (Wright, 2006). Th
the limitations of the data acquisition systems. Where multiple fits or measurements of a burs

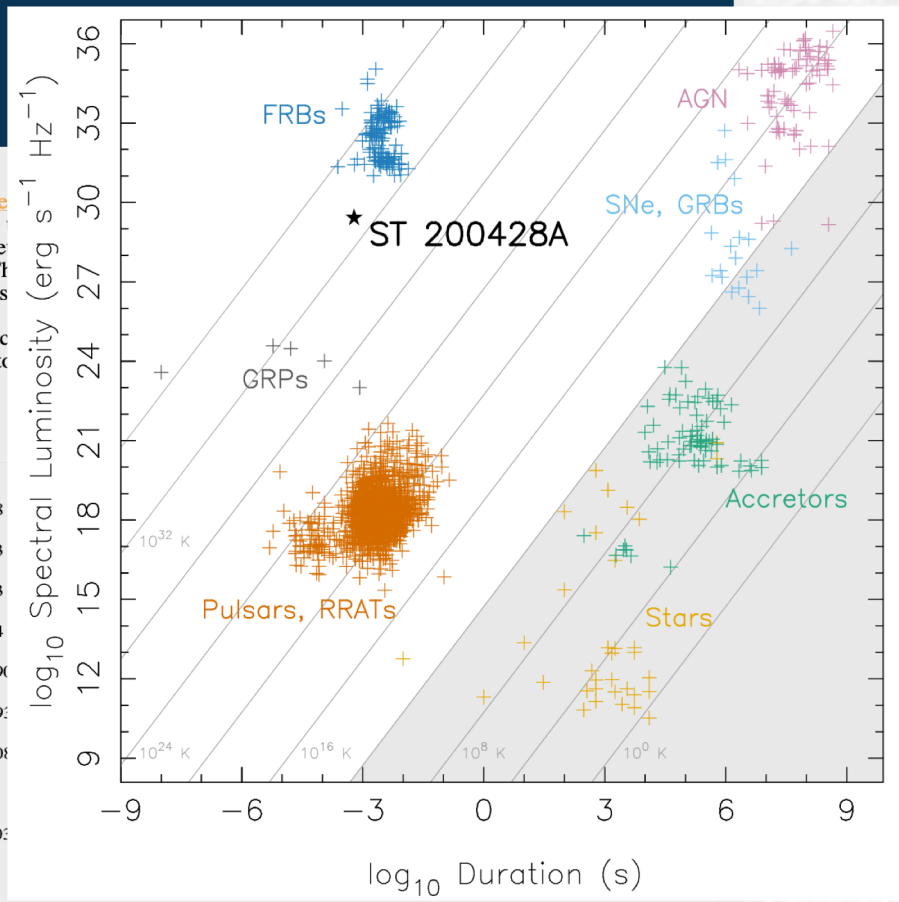
You may use the data presented in this catalogue for publications; however, we ask that you c
(http://www.frbcat.org). Any issues relating to the use of the catalogue should be addressed t

Visible columns | Verified events | Export to CSV

Search | Clear

FRB	UTC	Telescope	RAJ	DECJ	gl				
FRB20200125A	2020/01/25 12:15:19.600	GBT	14:36:31.580	+07:42:06.84	359.8				
FRB20190614D	2019/06/14 01:13:02.010	VLA	04:20:18.13	+73:42:24.3	136.3				
FRB191108	2019/11 19:3[illegible]:47.71	Apertif	01:33:47	+31:51:30	133.3				
FRB190907.J08+46	2019/09/07 17:02:43.311	CHIME/FRB	08:09	+46:16	173.4				
FRB19[illegible]11	2019/07/11 01:53:40.861	ASKAP	21:57:40.68	-80:21:28.8	310.9				
FRB[illegible]0611	2019/06/11 05:45:43.299	ASKAP	21:22:58.91	-79:23:51.3	312.9				
FRB190608	2019/06/08 22:48:12.883	ASKAP	22:16:04.75	-07:53:53.6	53.20				
FRB190604.J1435+53	2019/06/06 05:34:23.574	CHIME/FRB	14:35	+53:17	93.8				
FRB190523	2019/05/23 06:05:55.815	DSA-10	13:48:15.6	+72:28:11	117.0				
FRB190417.J1939+59	2019/04/17 13:55:44.814	CHIME/FRB	19:39	+59:24	91.5				
FRB190303.J1353+48	2019/07/02 03:14:39.762	CHIME/FRB	13:53	+48:15	97.5	65.7	222.4±0.2	4.5	0
	2019/02/22								

additional 500 in publication…



[Bochenek et al. 2020]

As at April 2021: 147 FRBs, 24 Repeaters, 14 identified host galaxies

Summary of the basic observational features

Given the so far observed parameters:

- Burst of ≈ few microsecond to 10s of millisecond duration
- Dispersion measure > few x the expected Milky Way contribution
- Dispersion delay consistent with ν^{-2}
- When measurable, scattering time consistent with Kolmogorov spectral index, $\nu^{-4.4}$
- Peak Flux density at 1.4 GHz ≈ 0.1-100 Jansky

Assuming that the extra-DM is mainly due to the Inter Galactic Medium, one can derive the following additional parameters:

- **Red-shift** $0.001 \lesssim z \lesssim 2.0$ (IGM from [Ioka 2003;Inoue 2004])
- **Co-moving distance** $0.01 \lesssim D\,(\mathrm{Gpc}) \lesssim 3.5$
- **Isotropic emitted energy** $10^{36} \lesssim E_{iso}\,(\mathrm{erg}) \lesssim 10^{42}$
- **Brightness temperature** $10^{30} \lesssim T\,(\mathrm{K}) \lesssim 10^{37}$

The zoo of the published FRB's models

https://frbtheorycat.org/

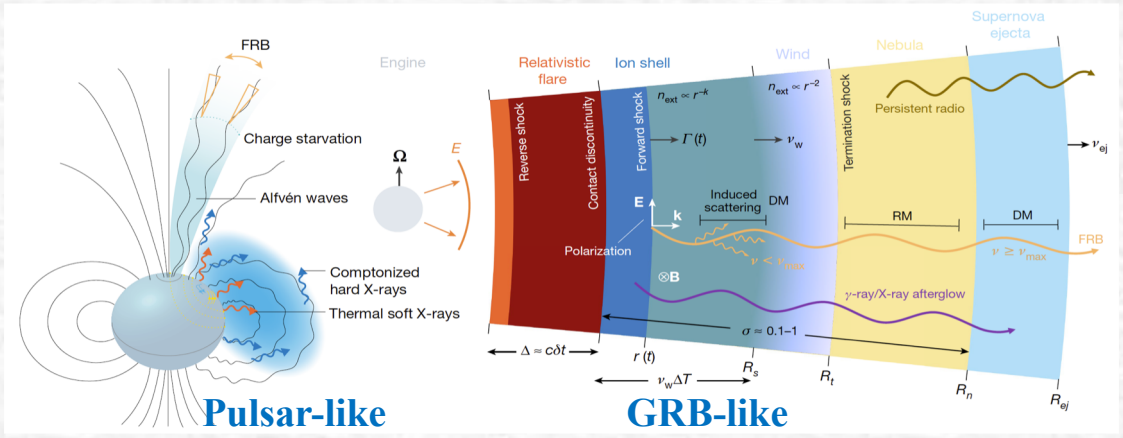
Hosted by the Institut Spatial de McGill / McGill Space Institute in collaboration with University of Cape Town, University of KwaZulu-Natal / INYUVESI YAKWAZULU-NATALI

See also [Platts et al. 2019]

Name	Category	Progenitor	Type	Energy Mechanism	Emission Mechanism	LF Radio Counterpart	HF Radio Counterpart	Microwave Counterpart	THz Counterpart	OIR Counterpart	X ray Counterpart	Gamma ray Counterpart	GW Counterpart	Neutrino Counterpart	References	Comments
NS-WD Accretion	Accretion	NS-WD	Repeat	Mag. reconnection	Curv.	Yes	--	--	--	--	--	Yes, but unlikely detectable	--	--	URL	None
AGN-KBH	AGN	AGN-KBH Interaction	Repeat	Maser	Synch.	Yes	--	--	--	Supernova	--	Yes	Yes	Yes	URL	Neutrinos from preceding SN and from collapse to BH.
AGN-SS	AGN	AGN-Strange Star Interaction	Repeat	Electron oscillation	--	Yes	--	--	--	Thermal		Yes	Yes	Yes	URL	Neutrinos from preceding SN and from collapse to BH. GW from collapse and persistent GWs from SS.
Jet-Caviton	AGN	Jet-Caviton Interaction	Both	Electron scattering	Bremsst.	Yes	Yes	--	--	--	--	Possible GRB	Yes	--	URL · URL	Persistent scintillating radio emission.
Wandering Beam	AGN	Wandering Beam	Repeat	--	Synch.	Yes	--	--	--	--	Yes	--	--	--	URL	None
NS to BH (DM-Induced)	Collapse	NS to BH	Single	Mag. reconnection	Curv.	Yes	--	--	--	--	--	--	Yes	--	URL	None
NS to KNBH	Collapse	NS to KNBH	Single	Mag. reconnection	Curv.	Yes	--	--	--	--	Possible afterglow	Possible GRB	Yes	--	URL · URL · URL	Possible X-ray afterglow and a short/long GRB created in NS birth prior to the FRB.
NS to Quark Star	Collapse	NS to Quark Star	Single	β-decay	Synch.	Yes	--	--	--	--	Yes	Yes	Yes	--	URL	The burst is predicted to be several seconds, explainable if the de-dispersion process that stacks f
SS Crust	Collapse	Strange Star	Single	Mag.	Curv.	Yes	--	--	--	--	--	--	Yes	--	URL	None

A variey of progenitors: in most cases compact objects

in binaries, ULX etc to account for periodicity



[Metzger et al. 2019]

[Zhang 2020]

Many emission models …

Vacuum synchrotron maser, plasma synchrotron maser and synchrotron maser from magnetized shocks, coherent curvature emission, are among the most invoked mechanisms ...

The long standing bottom-line questions ...

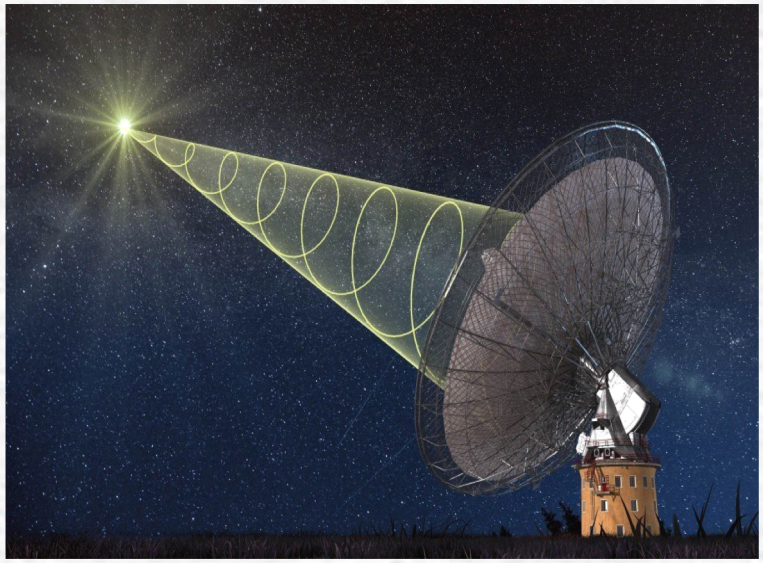
① What is(are) the FRBs' origin(s) ?

② How can we use them ?

Interlaced questions...

key factors for responding:

- ✓ **understanding the radio emission process**
- ✓ **detecting a counterpart at other wavelengths and get constraints on the progenitor and its distance**



The INAF approach: the Team ...

Le strutture INAF coinvolte

Bologna	Osservatorio Astronomico di Bologna (OAS), Istituto di RadioAstronomia (IRA)
Cagliari	Osservatorio Astronomico di Cagliari (OAC)
Milano	Osservatorio Astronomico di Brera (Brera), Istituto di Astrofisica Spaziale e Fisica cosmica (IASF)
Napoli	Osservatorio Astronomico di Capodimonte (OACN)
Padova	Osservatorio Astronomico di Padova (OAPD)
Roma	Osservatorio Astronomico di Roma (OAR), Istituto di Astrofisica e Planetologia Spaziali (IAPS)

Struttura INAF	Componenti	Competenze
OAS	Pian, Nicastro, Palazzi, Orlandini, Amati, Rossi, Stratta, Guidorzi, Frontera, Gardini	Contributo nell'analisi dati multi-frequenza e sviluppo software; analisi di dati X e ottici
IRA	Bernardi, Naldi, Stagni, Stanghellini, Pupillo, Orlati, Giroletti	Calibrazione ed analisi delle osservazioni tramite la Croce del Nord; analisi scientifica e tecnica delle osservazioni VLBI
OAC	**Possenti (Coordinatore)**, Pilia, Burgay, Corongiu, Perrodin, Ridolfi, Trudu	Coordinamento delle campagne osservative; osservazione ed interpretazione dei dati in radio e sviluppo software
Brera	Ghisellini	Sviluppo modelli teorici
IASF	Mereghetti, Mignani, Esposito	Implementazione di nuovi modelli teorici e la loro applicazione a dati X/radio
OACN	Savaglio, della Valle	Osservazione e analisi dati di possibili transienti nell'ottico e galassie ospitanti
OAPD	Zampieri, Turatto	Osservazioni fotometriche veloci; analisi dati e ricerca di controparti nell'ottico mediante sviluppo di nuovi software; comparazione tra osservazioni e modelli teorici
OAR	Papitto, Ambrosino, Casella, Verrecchia, Perri, Stella, Nucita, De Paolis, Strafella, Israel, Pittori	Esecuzione di osservazioni nell'ottico e analisi dati; ricerca di controparti ottiche; analisi dati X e ricerca di controparti nelle alte energie
IAPS	Panessa, Tavani, Ursi, Casentini	Ricerca di burst nelle alte energie in nuove osservazioni e dati di archivio

39 INAF people + 8 associated ≈ 3.2 FTE per year now

The INAF approach: Two science headlines ...

- **What will we learn from the detection of an FRB outside the radio band?**

A detection outside the radio band would be transformational for rFRB science: planned radio/optical/X-ray/gamma-ray "simultaneous" observations to try to detect (or constrain) the burst fluence outside the radio band. Systematic searches for activity associated with rFRBs will be undertaken in archival data as well.

One immediate goal is also to localize one or more repeating FRBs at sub-arcsecond level with the Italian VLBI array, and search for persistent radio emission in the associated galaxy. Characterization of the host galaxies at the repeating FRB site will involve both archival data and dedicated MWL observations. Deep observations will be performed to investigate any persistent emission, too.

The INAF approach: Two science headlines ...

- **What is the relation between the FRBs and the radio pulses from magnetars?**

Are all rFRBs periodic? What is the nature of the periodicity? Do radio-active magnetars in our Galaxy also have periodic ultra-strong bursting activity?

Are rFRB emission properties resembling those of Galactic magnetars? What "repeating" engine can produce the fluences observed from the rFRBs? Is the emission intrinsically narrow-band or does lensing favor some spectral emission regions selectively? Is absorption playing a major role? How could this happen in a somewhat regular fashion in the periodic rFRBs? Have rFRBs and non-repeating FRBs intrinsically distinct radio emission properties and distinct origins?

Which are the properties of a magnetar releasing FRB-like bursts? Is the rate of occurrence of fainter bursts supporting the extrapolation to FRB distances? Are magnetars also emitting optical bursts?

The INAF approach: Two science headlines ...

- **What will we learn from the detection of an FRB outside the radio band?**
- **What is the relation between the FRBs and the radio pulses from magnetars?**

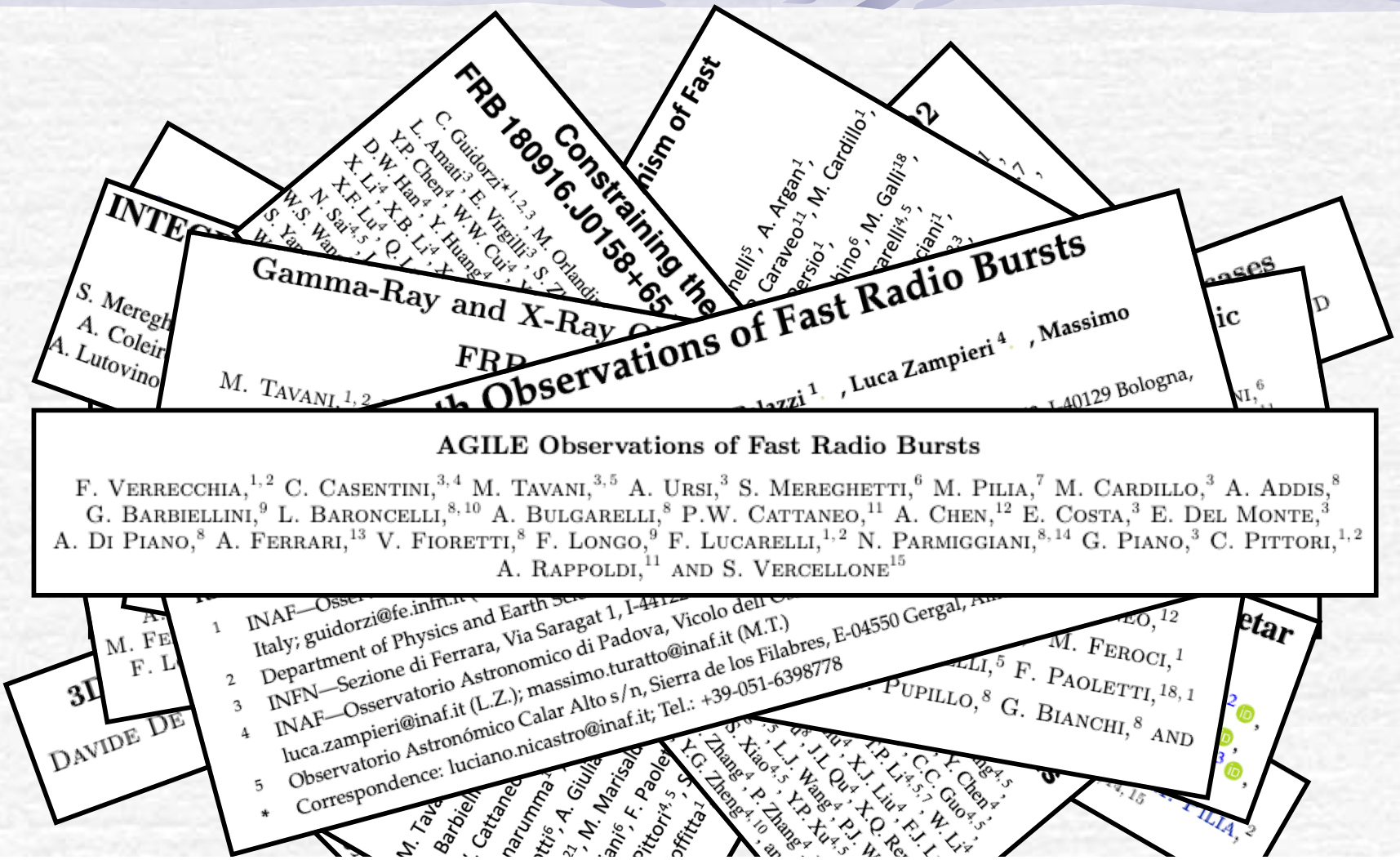
These two lines of investigation are also allowing us …

- to build on the recognized INAF leadership in the multi-wavelength studies and follow-ups of transient events. We will focus in particular on the case of the relatively nearby and repetitive targets, now being discovered in a larger number by several experiment e.g. 20200120E (in M81; 3.2 Mpc) e 20210402A (z=0.098). This will allow us to put strong constraints to the nature of this kind of FRBs;

- to exploit the top-level INAF role in the study of the magnetars, in order to support (or dismiss) the association among the magnetars and (at least a subclass of) the FRBs;

- to orchestrate the synergy among the various INAF groups involved in the study of the FRBs, in order to support the INAF role in this young and vibrant field of research, as well as to optimally coordinate with our research collaborators worldwide.

The INAF approach: the results (since 2020) …



11 Papers already published!

The INAF approach: the infrastructures ...

	Facility	Camera/Receiver/Detector	Observation Type
Radio	SRT - VLBI	0.3 / 1.4 / 7.0 / 18 GHz	Tracking-filterbank
	Medicina - Northern Cross	0.408 GHz	Transit
	Medicina - VLBI	1.4 GHz	VLBI
	Noto - VLBI	1.4 GHz	VLBI
	Parkes	0.3 / 0.8 / 1.4 GHz	Tracking-filterbank
	GMRT	0.3 / 0.6 / 1.4 GHz	Tracking-filterbank
	MeerKAT	0.8 / 1.4 GHz	Tracking-filterbank
Optical	Copernicus	Aqueye+	Fast-photometry
	Galileo	IFI-Iqueye	Fast-photometry
	TNG	SiFAP 2	Fast-photometry; Polarimetry
	LBT	LBC/Lucifer/MODS	Multi-filter photometry; Spectroscopy
	CAHA-2.2	AstraLux	Fast-photometry
	REM	ROS2/REMIR	Sub-s multi-filter monitoring
	VST	OMEGACAM	Multi-filter; Deep photometry
	NTT	EFOSC2/SOX	Deep photometry; Spectroscopy
	Schmidt 67/92	CCD	Wild field photometric monitoring; Calibration for fast-
	Savelli	CCD	Multi-filter
	NOT	CCD	Multi-filter
X-Gamma	Insight-HXMT	LE/ME/HE	Event mode (timing accuracy < 10 μs)
	AGILE	GRID/MCAL/SA	Event mode (MC 4 μs,GR 2 μs); ratemeters (MC/GR 1s, SA
	INTEGRAL	IBIS/ISGRI/SPI-ACS/JEM-X	High time resolution (~10 ms) ISGRI lightcurve; Spectral
	Swift	BAT/XRT	Event mode (~ 2ms)
	XMM-Newton	EPIC	Soft X-ray imaging for spectral and timing studies
	Chandra	ACIS	Soft X-ray imaging for spectral and timing studies
	NICER	XTI	Soft X-ray spectral and timing studies
	Fermi	LAT/GBM	Gamma-ray imaging; High time resolution (~ 1ms)

Legend: Italian Facility; International Facility

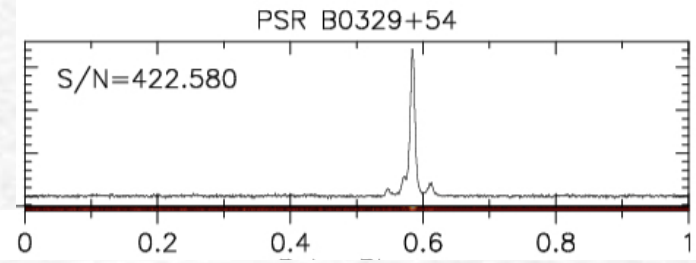
The INAF approach: the infrastructures ... Northern Cross

- 8 cylinders currently used for FRB observations, one single beam;
- Each source is observed for ~1 hour around transit (limitation due to the FoV);
- Bandwidth of 16 MHz, with channels of ~14 kHz, and 135 μs time resolution

Aerial view of the Northern Cross North-South arm

See Scheda FRB_NC (coord G. Bernardi)

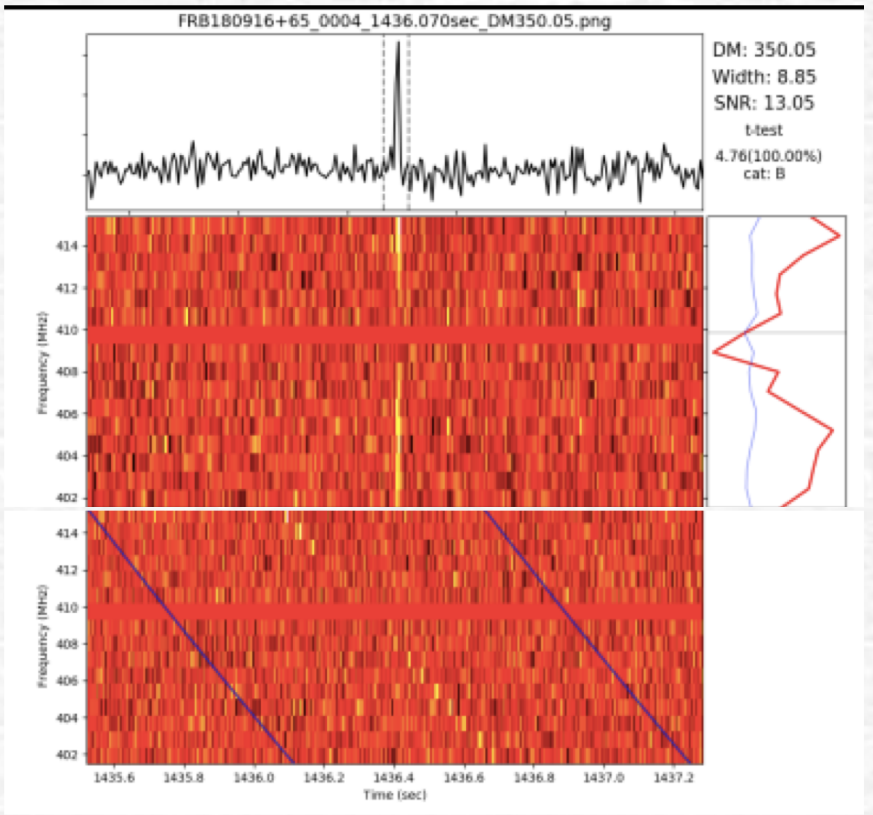
The INAF approach: the infrastructures ... Northern Cross



Profile of PSR B0329+54 [Locatelli et al. 2020]

Future developments:

- Multiple source (>3) daily monitoring (now till July 2021);
- 32 cylinders by the end of 2021; completion (64) by the end of 2022;
- Multi-beam capabilities (~25 beams in the field of view) by the end of 2022;
- FRB galore…



First burst observed by the Northern Cross produced by FRB 180916

[http://www.astronomerstelegram.org/?read=14480]

See Scheda FRB_NC (coord G. Bernardi)

The INAF approach: critical points (funds & people)

Given the elusivity of the target, a large multi-wavelength observational campaign is needed

↓

up to **30 instruments** might be used, most of them in parallel

↓

so far, FTEs from permanent INAF staff used, but
several "dedicated" wo/men power resources are needed to fully deploy the program and keeping the INAF leadership

no specific fund so far

↙ ↘

a PRIN-MIUR proposal submitted

other actions needed to grow a young community in INAF with state-of-art expertise in the "Astrophysics of the Transients"

↓

key for instruments alike SKAO-Vera Rubin-CTA

Thank you