Multi-band receivers at Italian antennas

Marcello Giroletti
INAF Istituto di Radioastronomia

Science Enabled with Multi-Band Receivers and Frequency Phase Transfer
13 October 2022, MPIfR, Bonn

Outline

- short history of radio astronomy (and in particular VLBI) in Italy
- current status and recent results, on national and international grounds
- science interest for short λ - and issues with present instrumentation
- PON overview and status
- future plans at short and long wavelengths

History - before VLBI

1964, Northern Cross in Medicina, 408 MHz

1972, 1980 Bologna YERAC

History - VLBI in Italy

- 1980 IRA is one of five EVN founders
- 1983 Medicina VLBI dish opening and IAUS 110
- 1988 opening of VLBI dish in Noto
- 2008 EVN symposium in Bologna
- 2013 first VLBI tests in Sardinia
- 2014 EVN symposium in Cagliari
- 2018 MoA with KASI for joint INAF-KVN observations

EUROPEAN VLBI NETWORK

1983: VLBI and Compact Radio Sources

PREFACE

I.A.U. Symposium No. 110 on VLBI and Compact Radio Sources was held in Bologna, Italy from June 27 to July 1, 1983. 166 participants from 19 countries were registered and 106 invited and contributed papers were registered.

The scientific presentations and discussion concentrated on VLBI observation and interpretation of galactic and extragalactic radio sources, including topics as diverse as quasars and galactic nuclei, interstellar masers, pulsars, and astrometry. Geodetic applications and technical development were treated only briefly, as these topics have been the subject of other recent international symposia.

Since the first VLBI observations in 1967, sensitivity, resolution, and image quality have improved dramatically. Radio maps shown at the symposium were of comparable quality to conventional synthesis maps being made at the time of the first VLBI experiments 15 years ago, but with a resolution more than a factor of 1000 better.

We wanted to accommodate the large number of contributed papers in this rapidly developing field, but there was inadequate time for normal oral presentations and discussion. We therefore asked that all contributed papers be put on display for at least 24 hours prior to a brief oral summary. A question and discussion period followed groups of oral presentations on the same or similar topic. In this way the opportunity for interactive discussion, not available in conventional poster displays, was preserved.

The Symposium was sponsored by IAU and the National Research Council of Italy and to these bodies the organisers express their grateful thanks.

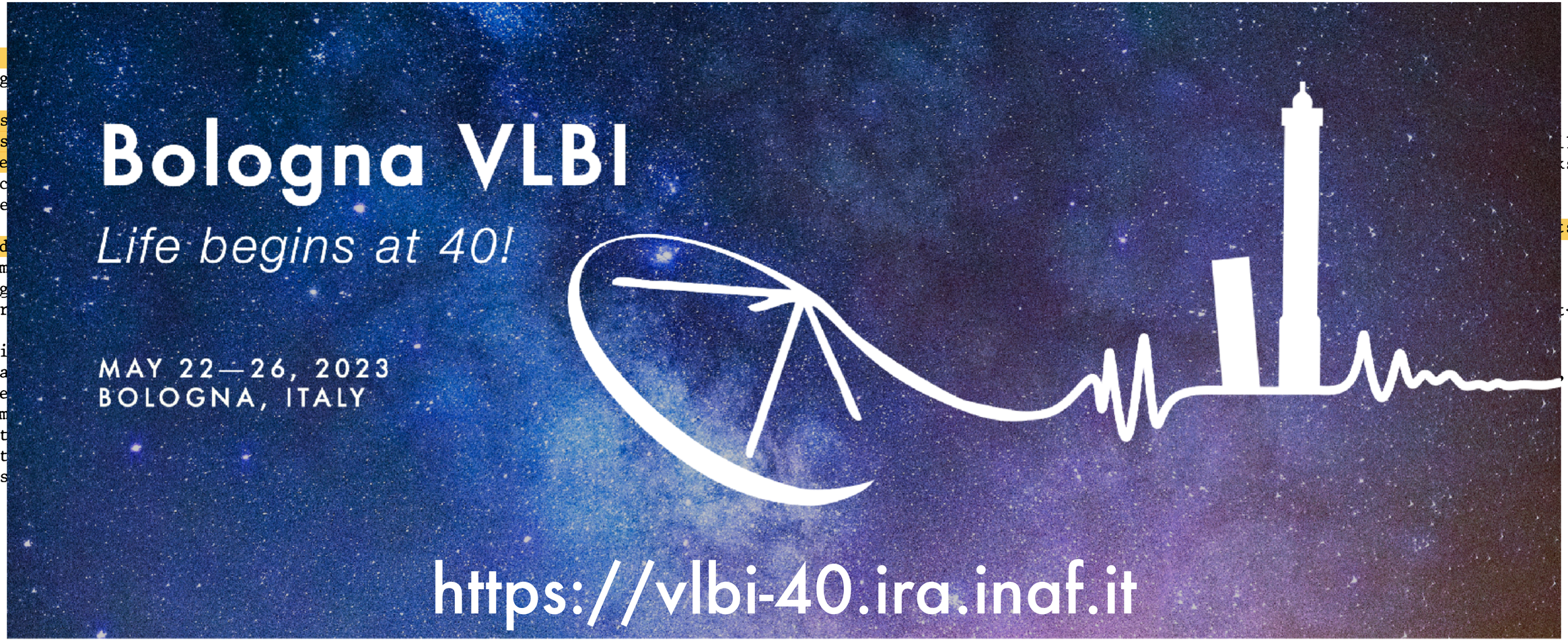
On June 29th the group had the opportunity to see the new 32 meter Italian antenna at Medicina - the first in the world dedicated to VLBI research. Following the observatory visit, more than 150 were the guests of the Mayor and village of Medicina for a never-to-be-forgotten "home-cooked dinner" followed by some hours of merriment.

We thank the authors and participants who have contributed to the symposium and to these proceedings. Special thanks go to the local participants who worked so hard to keep the symposium running smoothly.
We also wish to express our gratitude to the secretarial staff and, in particular, to Mrs. S. Buckley, to Mr. L. Baldeschi and to N. Primavera, of the Istituto di Radioastronomia, for their invaluable help.

R. Fanti
K.I. Kellermann
G. Setti

1983-2023… Life begins at 40!

PREFACE



Today: astrophysics in Italy

- INAF = Istituto Nazionale di AstroFisica = National Institute for Astrophysics
- Nation-wide organisation with sub-structures in several cities: observatories, institutes, facilities
- Activities are also coordinated by central “units”, according e.g. to observing band
- Involved in several big projects for the future: SKA, CTA, ELT
- Links with several Universities and with national institute for particle physics (INFN, for MWL/MM synergy)

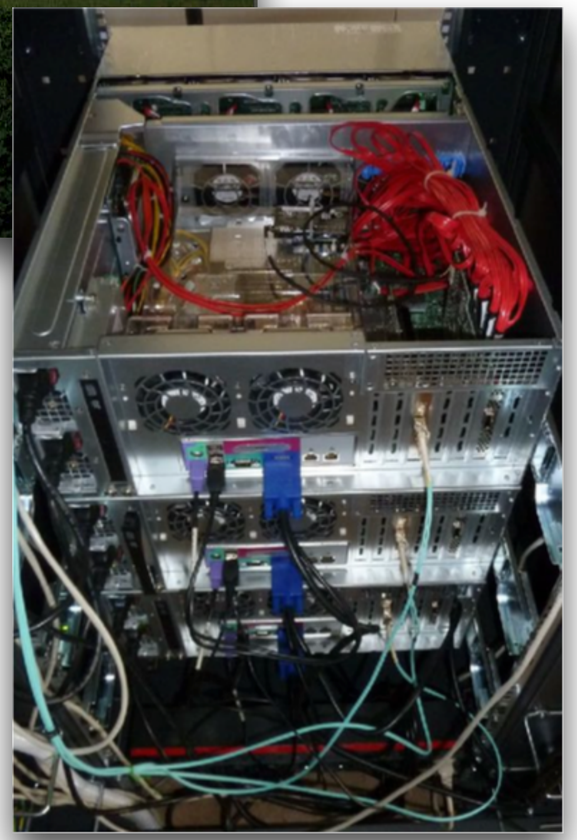
Today: VLBI in Italy

- IRA = Istituto di RadioAstronomia = Institute of radioastronomy: one of the several local INAF sub-structures
  - HQ in Bologna; previously part of the national research council (CNR)
  - operates two 32-m dishes in Medicina and Noto, and hosts data storage and software correlator facility (in Bologna)
  - involved in EHT and LOFAR-VLBI
- Cagliari observatory:
  - operates 64-m Sardinia radio telescope
- other important INAF structures for radio astronomy: Catania, Arcetri, Milan, Rome

Sardinia, 64m

Medicina, 32m

Noto, 32m



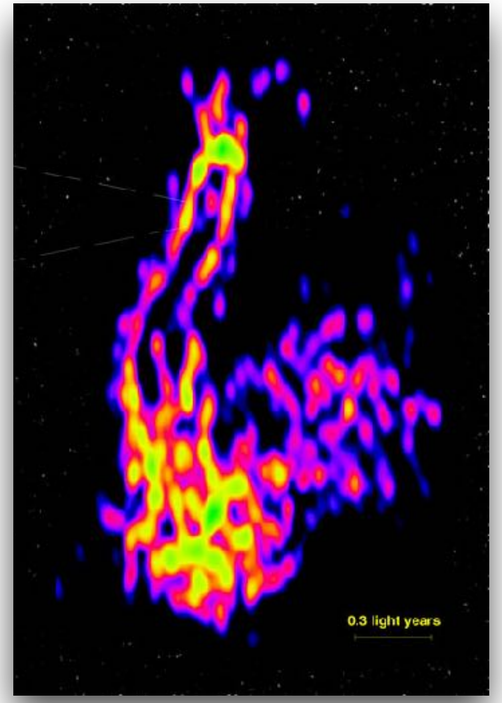
Bologna,
DiFX correlator

Besides VLBI

- Significant community interested in single-dish studies, primarily with the SRT but also with smaller dishes
  - diffuse galactic and extragalactic emission, pulsars/FRBs, transients, spectral line science, blazar/AGN monitoring
  - SKA!
  - ALMA - with regional centre in Bologna

A selection of recent VLBI papers from the Italian community - AGNs

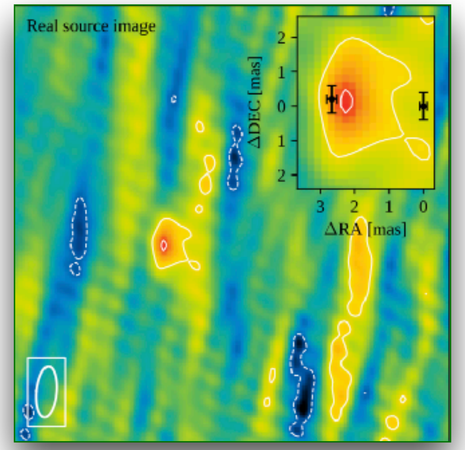
- Giovannini et al. 2018, Nature Ast., *A wide and collimated radio jet in 3C84 on the scale of a few hundred gravitational radii*
- Spingola et al. 2020, *Parsec-scale properties of the radio brightest jetted AGN at z > 6*
- Orienti & Dallacasa 2020, *Variability and parsec-scale radio structure of candidate compact symmetric objects*
- Nanci et al. 2022, *Observing the inner parsec-scale region of candidate neutrino-emitting blazars*

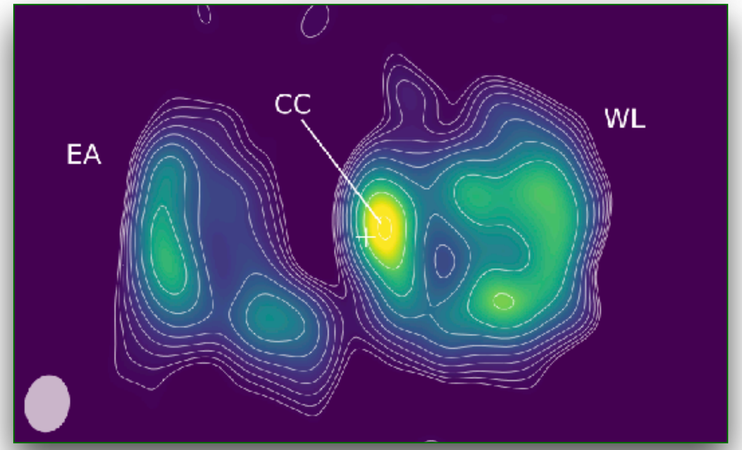


also gravitational lensing, studies of non-jetted AGNs, and participation in EHT

A selection of recent VLBI papers from the Italian community - transients

- Ghirlanda et al. 2019, Science, *Compact radio emission indicates a structured jet was produced by a binary neutron star merger*
- Munari, Giroletti, et al. 2022, *Radio interferometric imaging of RS Oph bipolar ejecta for the 2021 nova outburst**
- Piro et al. 2021, *The fast radio burst FRB 20201124A in a star-forming region: Constraints to the progenitor and multiwavelength counterparts***
- Egron et al. 2017, *Single-dish and VLBI observations of Cygnus X-3 during the 2016 giant flare episode*



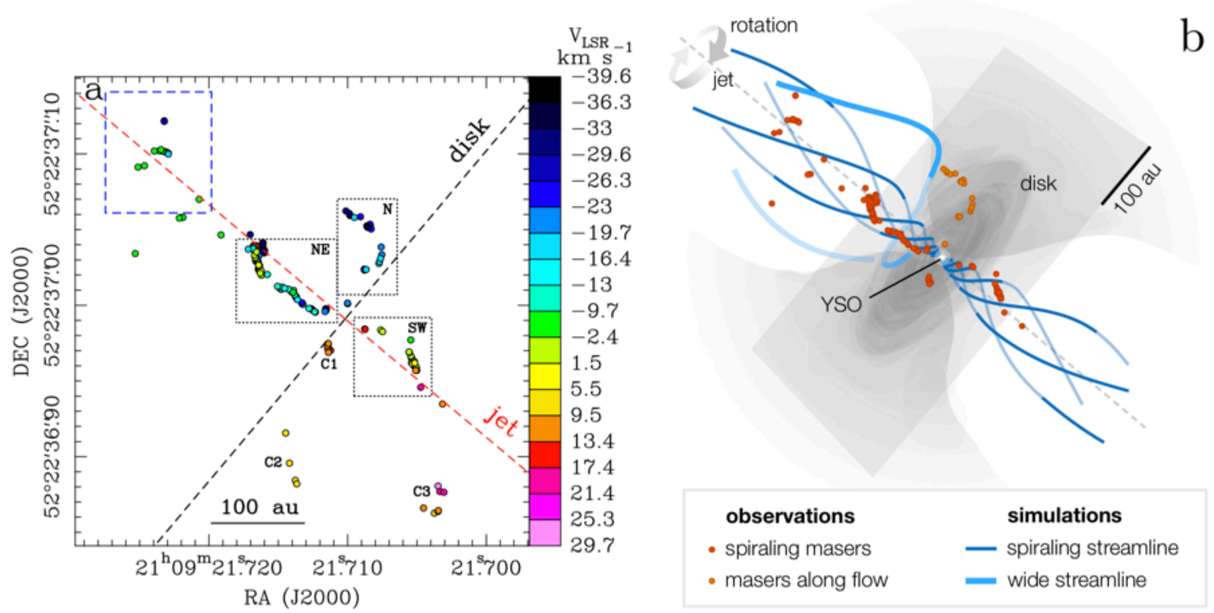


* on novae: see also Giroletti et al (2020) on V407 Cyg

** on FRBs: also participation in PRECISE observations/papers

A selection of recent VLBI papers from the Italian community - masers

- Moscadelli et al. 2022, Nature Ast., *Snapshot of a magnetohydrodynamic disk wind traced by water maser observations*



- Surcis et al. 2022, *EVN observations of 6.7 GHz methanol maser polarization in massive star-forming regions. V. Completion of the flux-limited sample*

Current status: Medicina&Noto

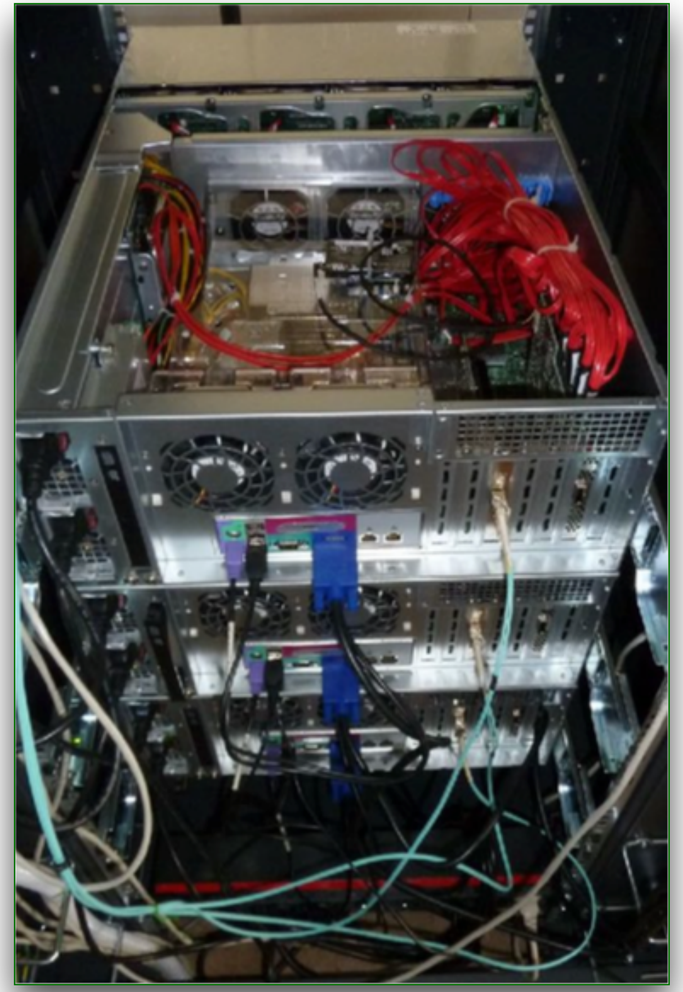
- Started operations in 1983 (Mc) and 1988 (Nt)
- 32m diameter, receivers: L/SX/C/C+/K
- Medicina: co-located with Northern Cross interferometer at 408 MHz
- Noto: active surface
- Observing time: EVN sessions, IVS, single dish, maintenance/testing
- Baseline length: 893 km

Current status: Sardinia

- Started operations in 2013
- 64 m diameter, three focal positions
- P-L/C+/K(multi-feed) receivers
- active surface
- observing time: EVN sessions, ASI time, single dish, maintenance/testing
- Baseline lengths: 592 km (Mc), 580 km (Nt)
- <u>currently under major upgrade</u>

Current status: the DiFX correlator

- Infiniband 40Gbit connection
- 10 Gbit network
- 5 nodes (2 computing, 3 mixed computing/storage)
- Now 150 TB available + 200 TB storage
- Stations can record directly to Bologna, or e-transfer
- Correlation of 1 Gbps data in half observing time
- Important for tests of national network and international collaborations



INAF telescope tables

Table 1. INAF radio telescopes.

Location	Code	Size	Year	Latitude	Longitude	Elevation	Operating receivers
Medicina	Mc	32 m	1983	44° 31′ 15″ N	11° 38′ 49″ E	25 m	L, S, C, C+, X, K
Noto	Nt	32 m	1988	36° 52′ 34″ N	14° 59′ 21″ E	78 m	P, L, C+, K
Sardinia	Sr	64 m	2011	39° 29′ 34″ N	9° 14′ 42″ E	600 m	L, S, C, C+, X, K

Table 2. INAF VLBI baseline length and sensitivity.

		Sensitivity (mJy min^{-1} Gbps^{-1})		
Baseline	Length (km)	L-band	C+-band	K-band
Mc-Nt	893	5.9	7.8	6.1
Mc-Sr	592	1.8	1.7	2.5
Nt-Sr	580	1.8	1.9	2.7

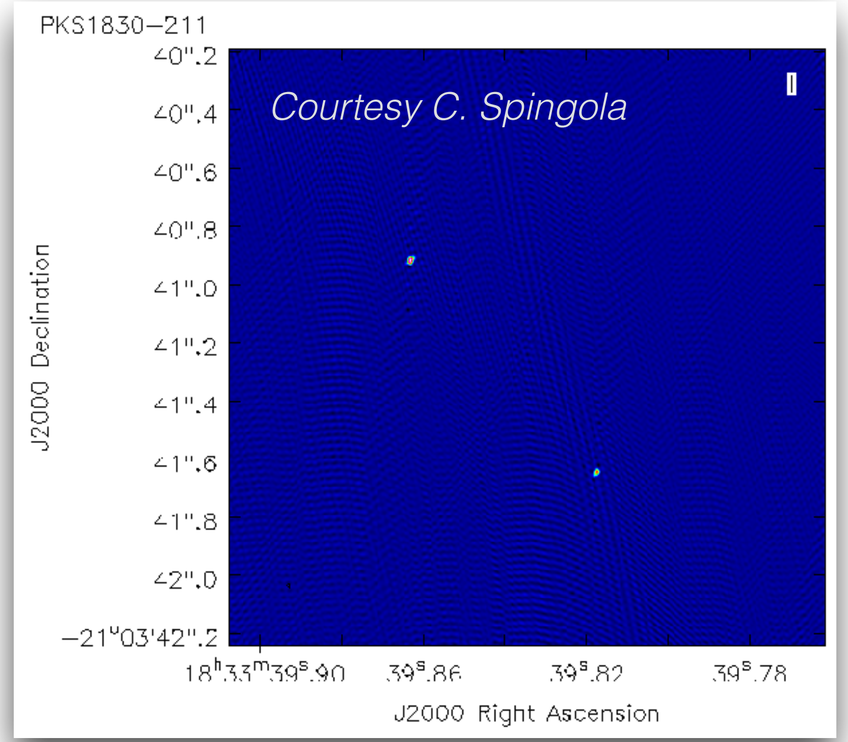
From Eating VLBI review (current draft)

INAF telescope activities

- ~70 days yr are devoted to EVN observations
  - 3x~20 days disk-based session and 10 monthly e-VLBI days
- other commitments:
  - single dish observations
  - maintenance and development
  - IVS observations for Geodesy (Mc, Nt), ASI support for space (Sardinia)
- other VLBI observations (national, ad-hoc) on a best-effort/PI-led basis

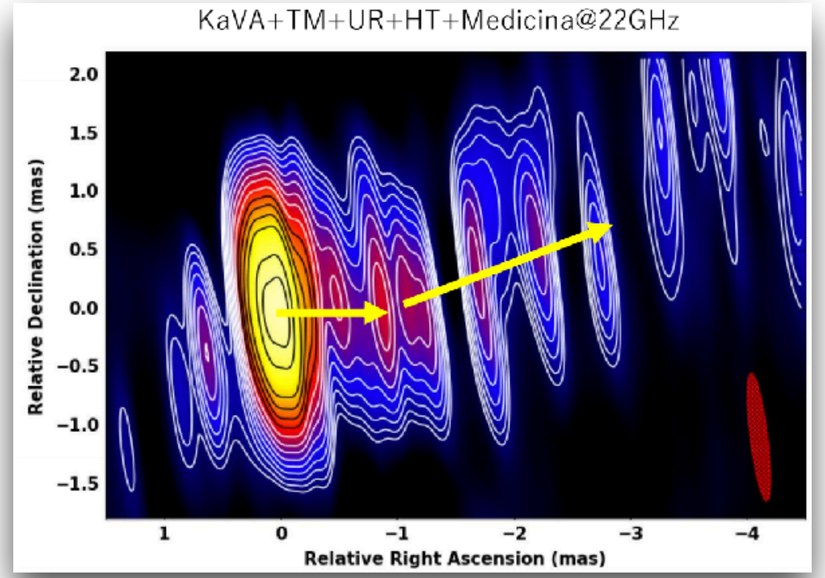
Challenges and opportunities

- Stations active primarily in regular EVN activity and as single dish: <u>primary development driver</u>
- Few resources for coordination and support of nation-wide scale activities
- Other limits: three stations, low-mid frequency
- Science opportunities: mostly non-imaging (surveys, transients, alerts)
- Great potential in sensitivity and angular resolution to be combined with other stations/networks:
  - PRECISE, Eating VLBI, Radioastron



East Asia To Italy: Nearly Global VLBI

- 2011, activities started with a bilateral Italy-Japan project aimed at VSOP2
- Gradual involvement of other East Asian countries
- Exchanges, joint tests (from one baseline to dozens!), outreach activities



“Eating VLBI” meetings

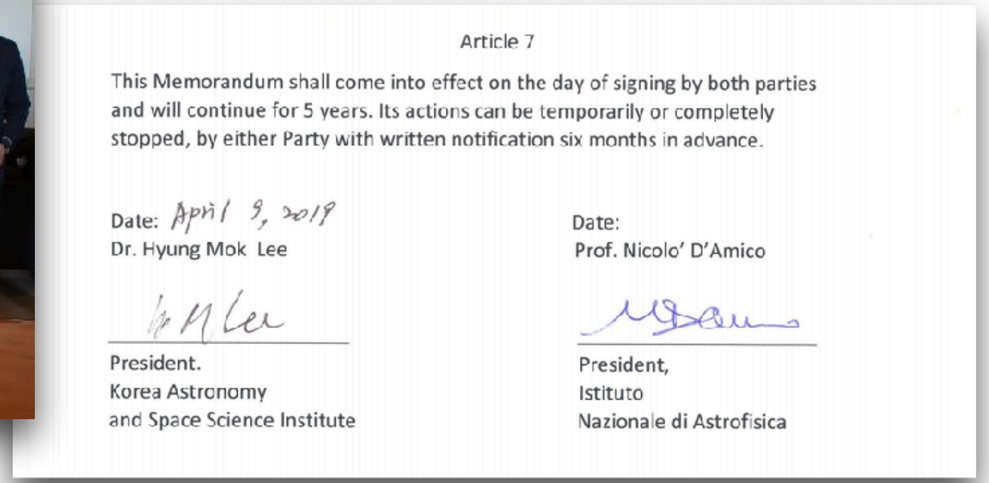
- 2012, 2014, 2017, 2019, 2022
- increased attendance and gender representation
- growing diversity in age, provenance, and science interests

Eating VLBI legacy

- MoA between INAF and KASI for joint observations
  - signed in 2018, 30 hours per semester, with I/K PI
  - proposals to be sent to both TACs separately
  - scheduling negotiated on a case-by-case basis (manageable so far)
- significant boost to mm-VLBI interest in Italy

MEMORANDUM of AGREEMENT
BETWEEN
THE ISTITUTO NAZIONALE DI ASTROFISICA
AND
THE KOREA ASTRONOMY AND SPACE SCIENCE INSTITUTE
ON JOINT VLBI OBSERVATIONS

The Istituto Nazionale di Astrofisica (hereafter referred to as INAF) headquartered at Viale del Parco Mellini n.84, 00136 Roma, Italy and represented by its President, Prof. Nicolo' D'Amico, and the Korea Astronomy and Space Science Institute (hereafter referred to as KASI), headquartered at 776 Daedeoke-daero, Yuseong-gu, Daejeon 34055, the Republic of Korea and represented by its President, Dr. Hyung Mok Lee,



Article 7

This Memorandum shall come into effect on the day of signing by both parties and will continue for 5 years. Its actions can be temporarily or completely stopped, by either Party with written notification six months in advance.

Date: April 9, 2019
Dr. Hyung Mok Lee

President.
Korea Astronomy
and Space Science Institute

Date:
Prof. Nicolo' D'Amico

President,
Istituto
Nazionale di Astrofisica

Status tables, 2017

	Medicina (Mc)	Noto (Nt)	Sardinia (Sr)
diameter	32m	32m	64m
active surface	N	Y	Y
L	Y	Y/N (not operational)	Y
S/X	Y	Y	N
C	Y	Y	N/Y (designed)
C - high	Y (not cooled)	Y (not cooled)	Y
K	**Y (2-beam)**	**Y**	**Y (7-beam)**
Q	N	Y/N (not operational)	N/Y (designed)
W	N	N (being considered)	N (being considered)
e-VLBI	Y	Y	almost!

	Mc	Nt	Sr	KVN-Ta
Mc		893*	592	8401
Nt	13,5		580	8639
Sr	5,5	6		8783
KVN-Ta	17	18	7,5	

baseline length (km)

** same as T6-Ky!*

K-band 5σ sensitivity (mJy) [5min @1Gbps]

Upgrades: “PON”

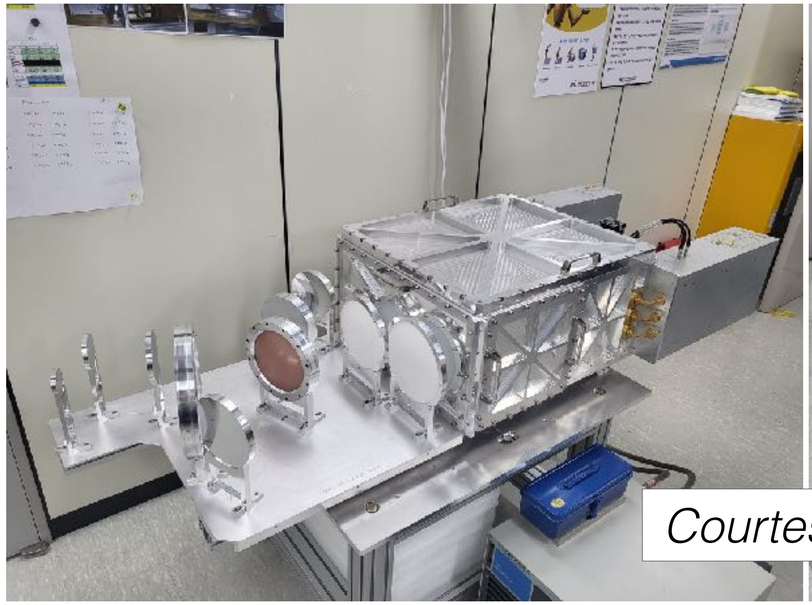
- “Enhancement of the SRT for the study of the Universe at high radio frequencies”
- Scientific coordinator: Federica Govoni
- Time scale: 36 months from kick-off (June ’19), with extensions due to Covid
- Budget: 18.7 M€ (15% outside Sardinia)
- Additional 1.4 M€ funding for personnel allocated in late 2020

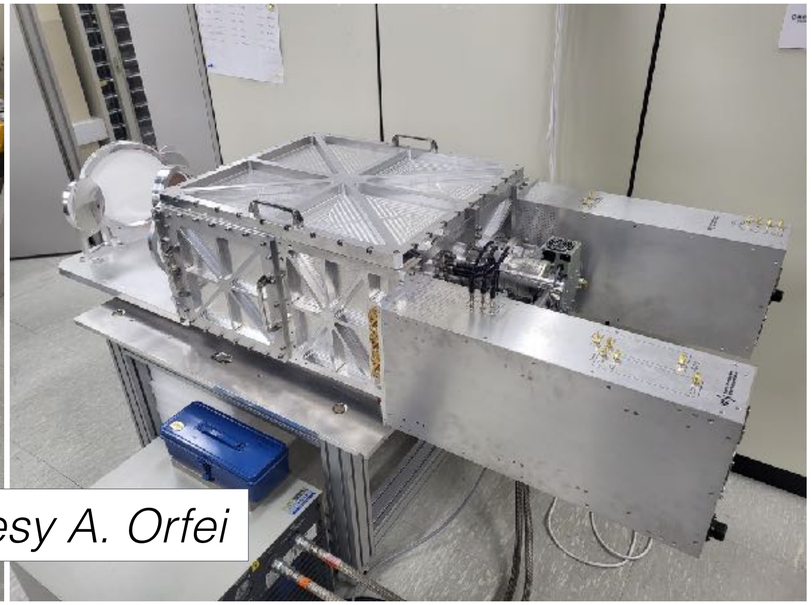
PON WPs

- WP1-3: multi-beam, single-frequency, Q and W band receivers
- WP4: Simultaneous microwave compact triple-Band receiving system for the three Italian radio telescopes (18-26 ; 35-50; 85-116 GHz)
  - Coordinator: Pietro Bolli
- WP5-9: backends, HPC, labs, etc.

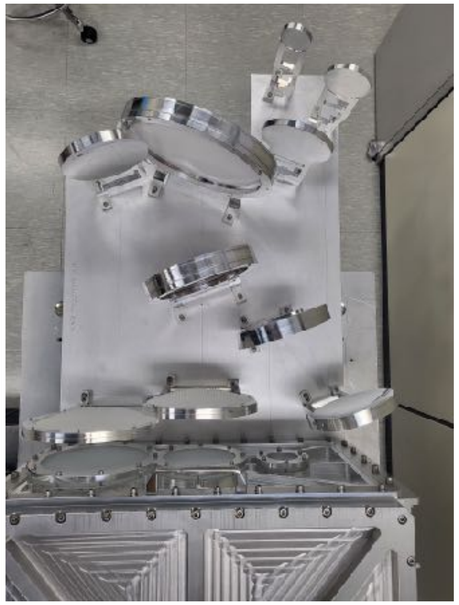
WP4: Simultaneous CTR system for the three INAF radio telescopes

- Receiver specifications by INAF
- Design and construction by KASI
- 3 years development
- 3 CTR delivered to Italy on August 29th, 2022





Courtesy A. Orfei

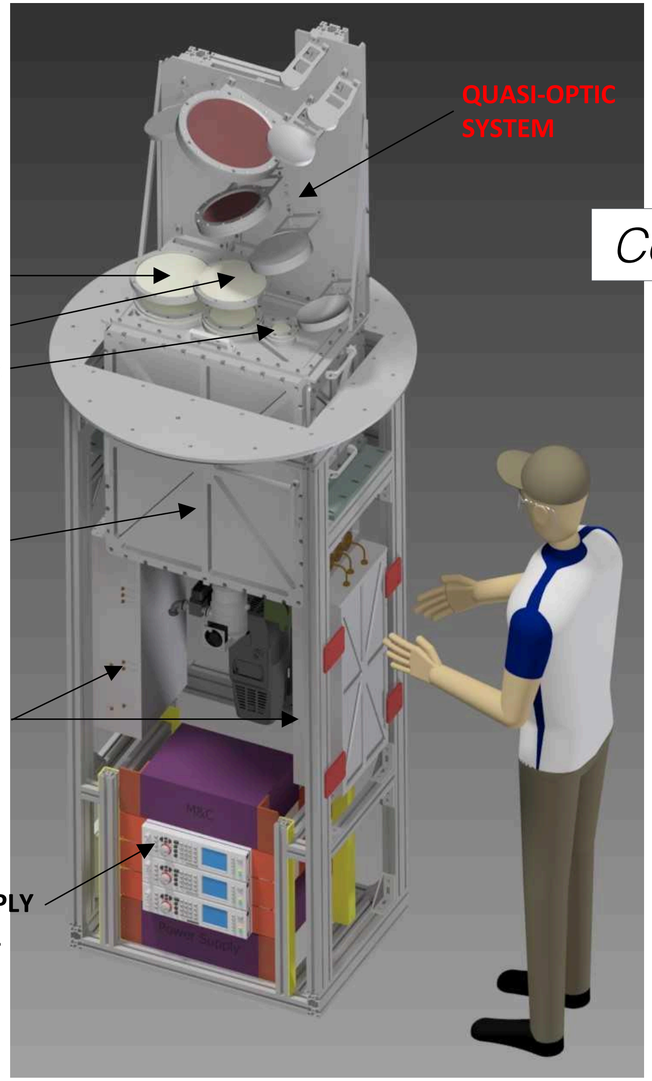


Specifications

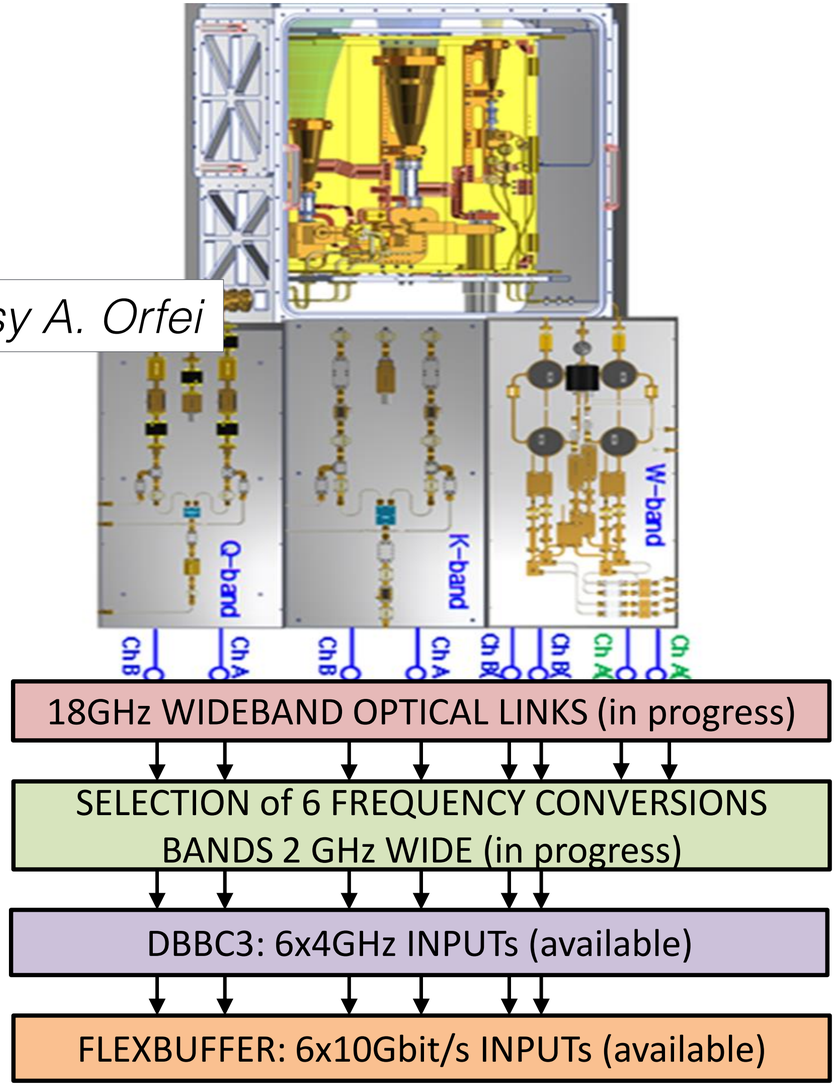
- Simultaneous LCP+RCP 8 bands: 18-26GHz; 34-50GHz; 80-96GHz + 100-116GHz
- Sky band tunability via local oscillator to cover the 96-100GHz gap
- Simultaneous LCP+RCP SSB bands: K-band 4-12GHz; Q, W_{low}, W_{high} 2-18GHz
- Measured receiver noise: K-band <60K; Q-band <70K; Wlow, Whigh <130K
- Measured overall crosspol: < -22dB
- Measured image rejection: >25dB
- ≥80Hz synchronous noise mark injection in the 3 bands
- Measured power consumption: 460W
- Weight: 300Kg
- Size: fit Mc/Nt/SRT secondary focus constraints (≈ 2.7 x 1 x 0.7 m)

Courtesy A. Orfei

INAF mm-VLBI: from receiver to the DBBC3



Courtesy A. Orfei



Status tables, 2017-> 2022

	Medicina (Mc)	Noto (Nt)	Sardinia (Sr)
diameter	32m	32m	64m
active surface	N	Y	Y
L	Y	Y/N (not operational)	Y
S/X	Y	Y	N
C	Y	Y	N/Y (designed)
C - high	Y (not cooled)	Y (not cooled)	Y
K	**Y (2-beam)**	**Y**	**Y (7-beam)**
Q	N	Y/N (not operational)	N/Y (designed)
W	N	N (being considered)	N (being considered)
e-VLBI	Y	Y	almost!

	Medicina (Mc)	Noto (Nt)	Sardinia (Sr)
diameter	32m	32m	64m
active surface	N/Y (funded)	Y	Y
L	**Y**	**Y**	**Y**
S/X	Y	Y	N
C	Y	Y	N/Y (designed)
C - high	Y (not cooled)	Y (not cooled)	**Y**
K	**Y (2-beam)**	**Y**	**Y (7-beam)**
Q	CTR	CTR	CTR
W	CTR	CTR	CTR
e-VLBI	Y	Y	Y

What's left

- Noto and Medicina don't provide surface accuracy to observe at 3mm
- Work in progress:
  - SRT: completion of the integration of new equipments on antenna - active surface available
  - Noto: new sub-reflector surface (50 μm) - active surface available
  - Medicina: installing active surface system and new sub-reflector surface
- Timetable
  - SRT, Noto: Spring/Summer 2023
  - Medicina: end 2023

Courtesy A. Orfei

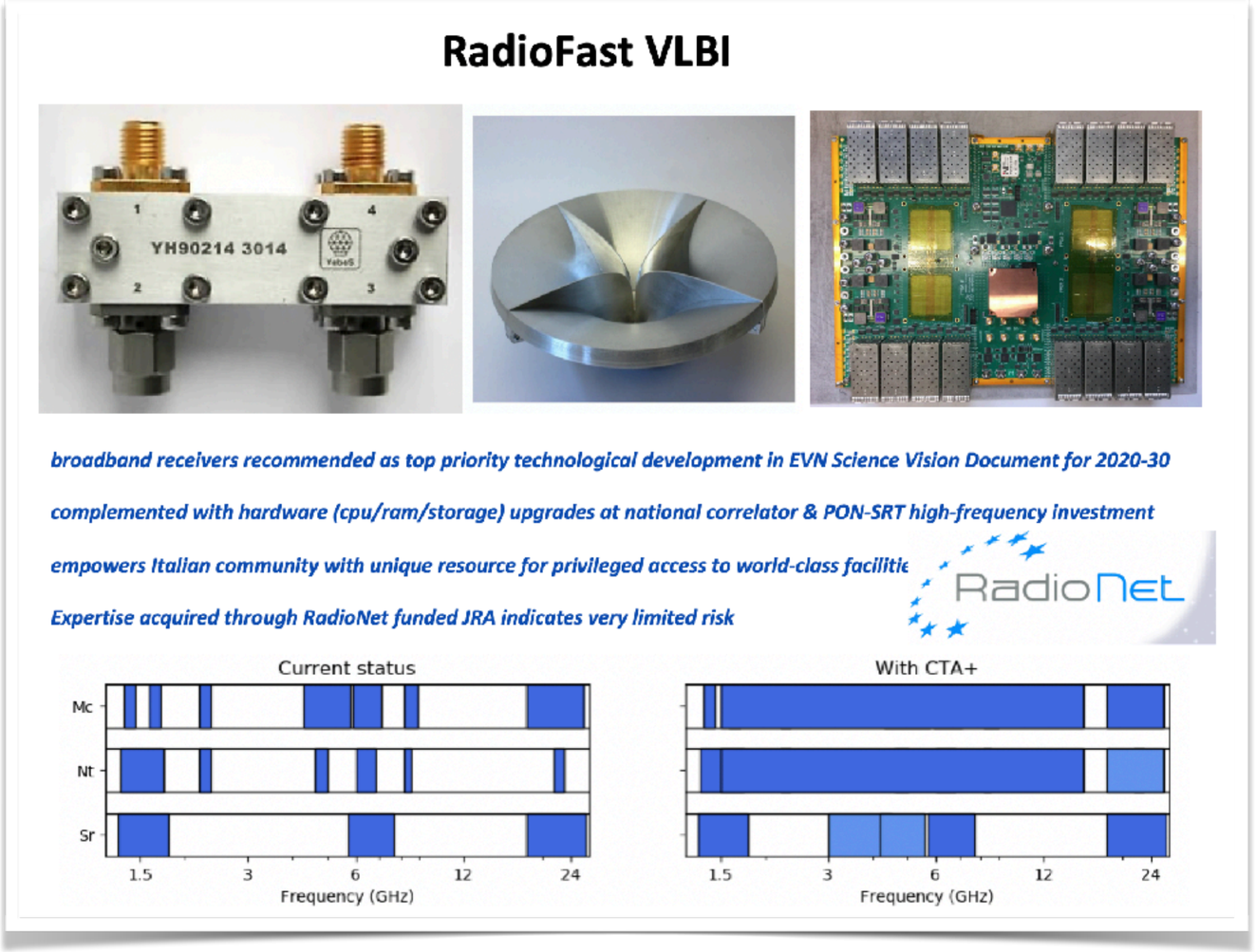
Status tables, 2017-> 2024

	Medicina (Mc)	Noto (Nt)	Sardinia (Sr)
diameter	32m	32m	64m
active surface	N	Y	Y
L	Y	Y/N (not operational)	Y
S/X	Y	Y	N
C	Y	Y	N/Y (designed)
C - high	Y (not cooled)	Y (not cooled)	Y
K	**Y (2-beam)**	**Y**	**Y (7-beam)**
Q	N	Y/N (not operational)	N/Y (designed)
W	N	N (being considered)	N (being considered)
e-VLBI	Y	Y	almost!

	Medicina (Mc)	Noto (Nt)	Sardinia (Sr)
diameter	32m	32m	64m
active surface	Y	Y	Y
L	**Y**	**Y**	**Y**
S/X	Y	Y	N
C	Y	Y	N/Y (designed)
C - high	Y (not cooled)	Y (not cooled)	Y
K	**Y (2-beam)**	**Y**	**Y (7-beam)**
Q	**Y**	**Y**	**Y**
W	**Y**	**Y**	**Y**
e-VLBI	**Y**	**Y**	**Y**

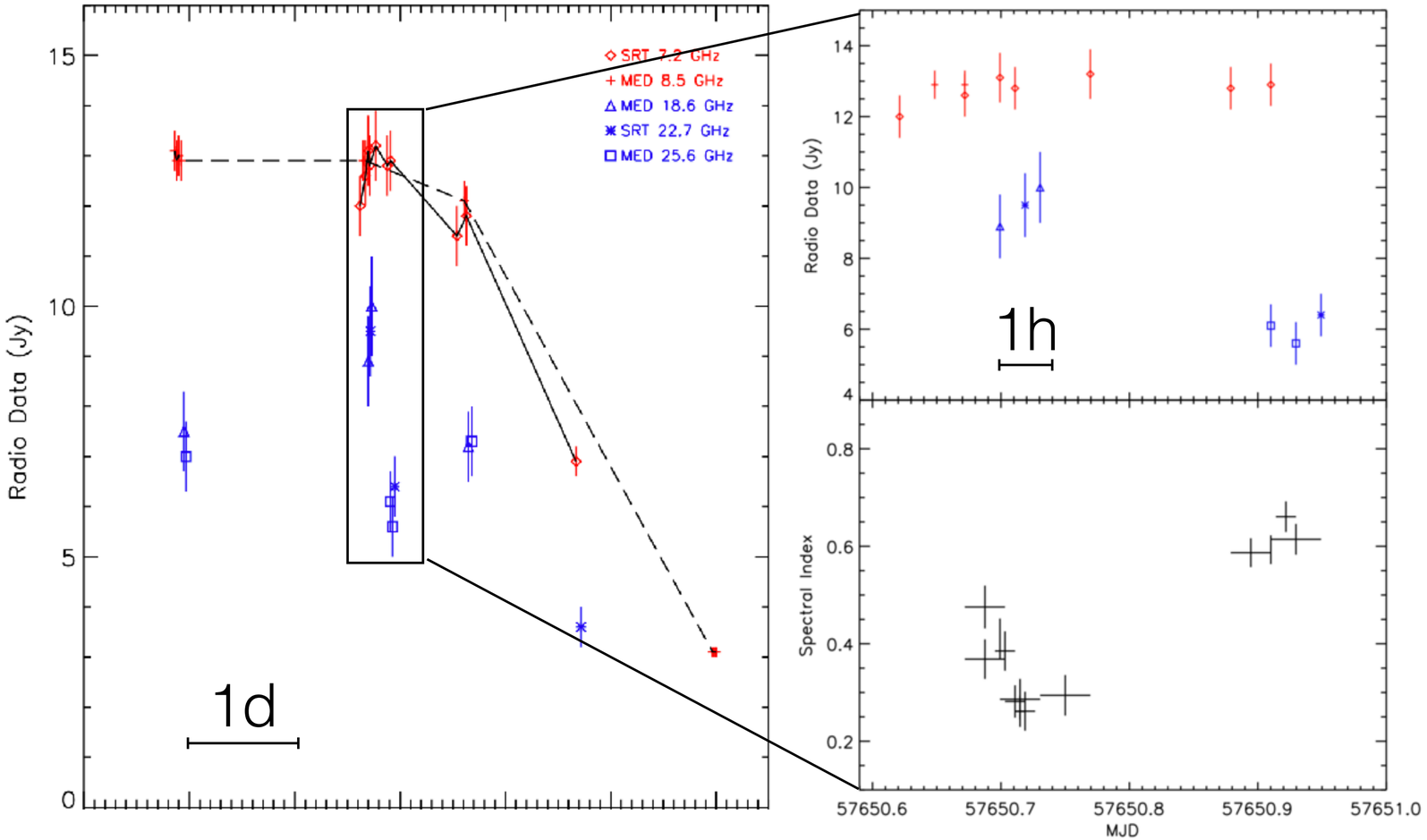
Further upgrades: “CTA+”

- A big INAF-led project to improve Cherenkov Telescope Array performance, and supporting instrumentation
- VLBI key for transient physics
- Complements “PON” at low frequency: ~0.9 M€ for ~1.5 “BRAND” receivers
- Activity start: 2023

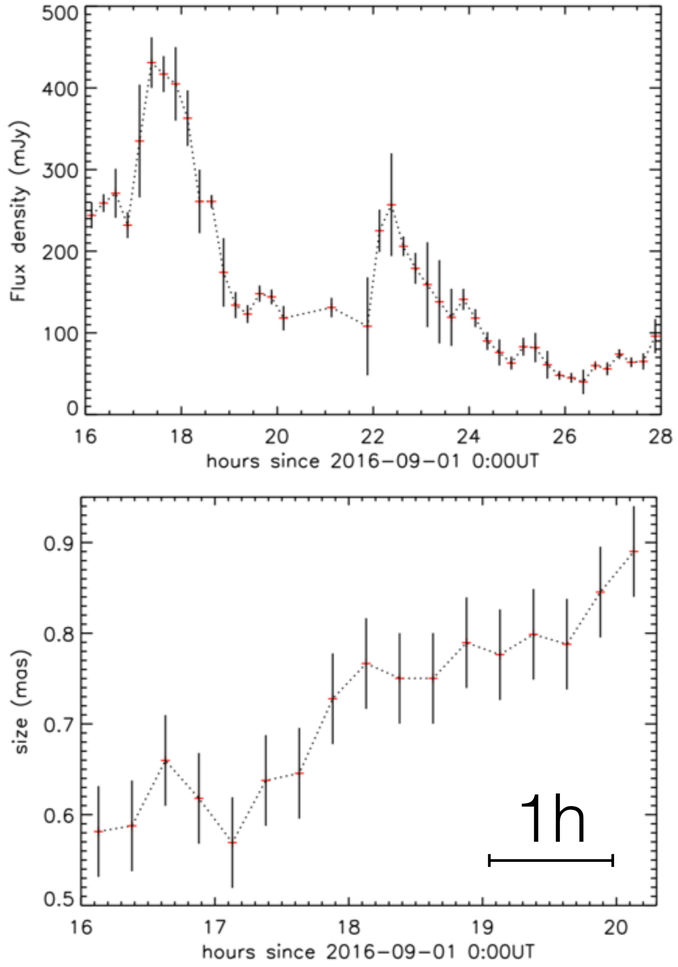


Further thoughts: transients (I)

Egron et al. 2017 - first Italian VLBI paper (with Ys, On, Tr)



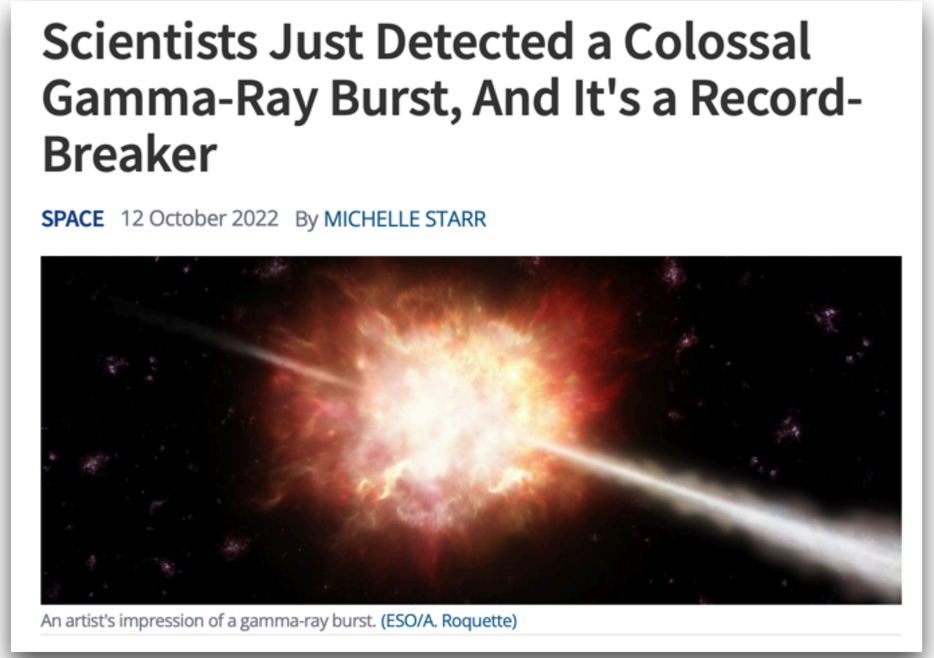
single dish 8-18-26 GHz light curve and spectral index



22 GHz VLBI light curve and expansion

Further thoughts: transients (II) & AGN

- Rapid response can be critical for some science cases; gamma-ray burst afterglows (also considering GW triggers!)
  - NB: EVN is doing great ToO-wise (RS Oph, GRB 221009A)
- But mm-emission will fade eventually, and we need good low frequency astrometry to compare to



Scientists Just Detected a Colossal Gamma-Ray Burst, And It's a Record-Breaker

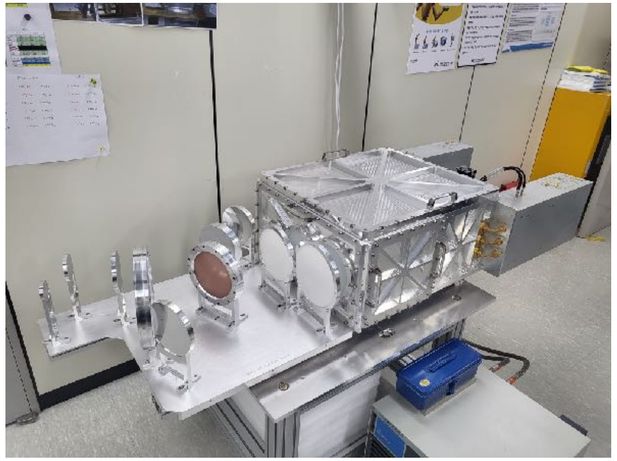
SPACE 12 October 2022 By MICHELLE STARR

An artist's impression of a gamma-ray burst. (ESO/A. Roquette)

- Multi-l comparisons: how critical is uv-sampling? [for AGNs, besides alignment]
- More science cases: thermal emission from radio-quiet/low-luminosity AGNs? [ADAF, etc.]

Take home messages

1. CTRs have reached Italy and we expect tests in 2023, operations in 2024
2. ERATec was great but Dodson et al. 2017 didn't get enough visibility (not just me! 3 cit.)
   - a lot has changed in the meanwhile (EHT images, GW+light, mwl wide field & transients)
3. We look forward to meeting you in May for BO-VLBI-40
   - start booking your accommodation!



- *Also: we will soon start looking for a postdoc!*