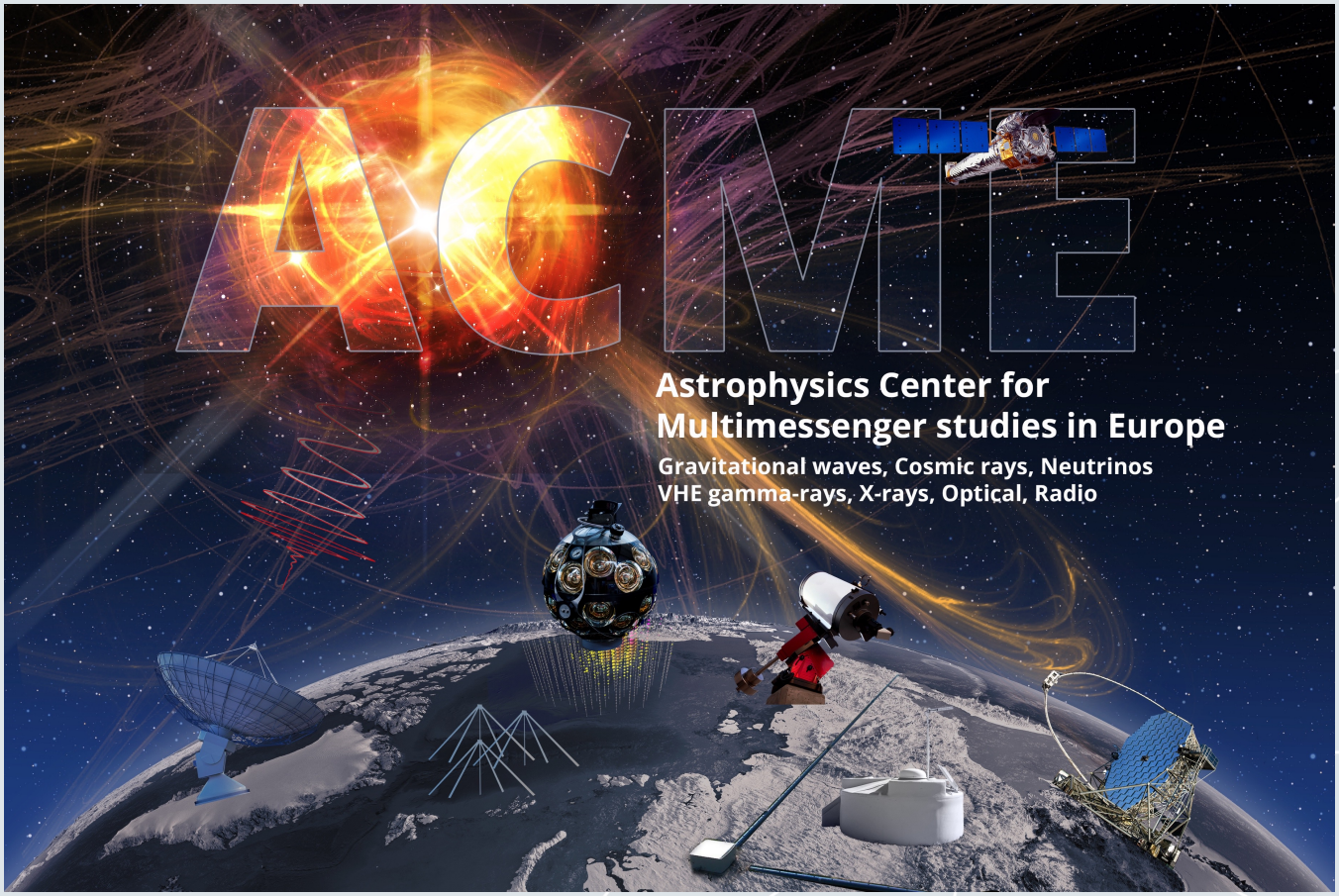
MM & Radio: challenges & significant results

Zsolt Paragi
JIVE

The ACME initiative



- **ACME aims to bring together astronomical and astroparticle observatories and their communities, to address the most powerful phenomena in the Universe**
- **This will open new horizons in High-energy Astrophysics research**

ACME science themes

- **High-energy astrophysics addresses phenomena related to powerful cosmic explosions or/and involve objects with relativistic equation of state**
  [these latter are often the consequence of the former]

- **The ACME science themes are the following:**

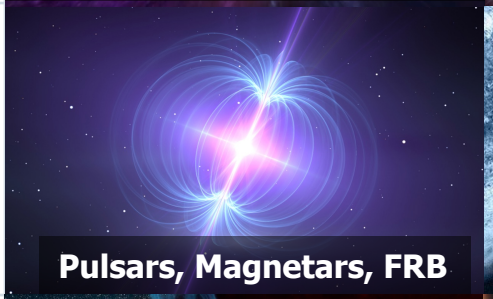
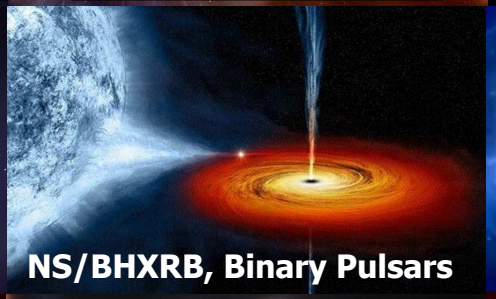
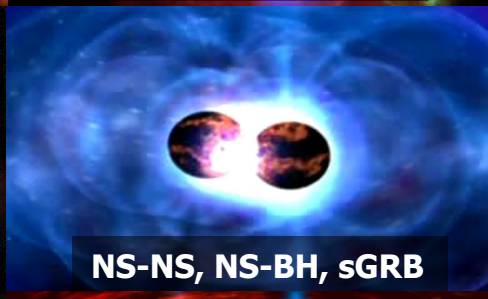
  - Stellar explosions
  - Relativistic stars & Magnetic Powerhouses
  - Stellar or/and Compact Object mergers
  - Active Galactic Nuclei

- **The above themes include a wide range of objects and phenomena (**see next slide**) that can be studied with a range of multi-messenger instruments:**

  - Radio arrays, single dish telescopes and interferometer networks
  - IR/Optical/UV telescopes and satellites
  - X-ray and γ-ray satellites
  - Cherenkov detectors
  - Low- and high-energy neutrino detectors
  - Gravitational wave interferometer detectors and networks

- **Access to these instruments, and to the know-how by the broad astronomy community is in the prime focus of ACME.**

ACME science targets & phenomena

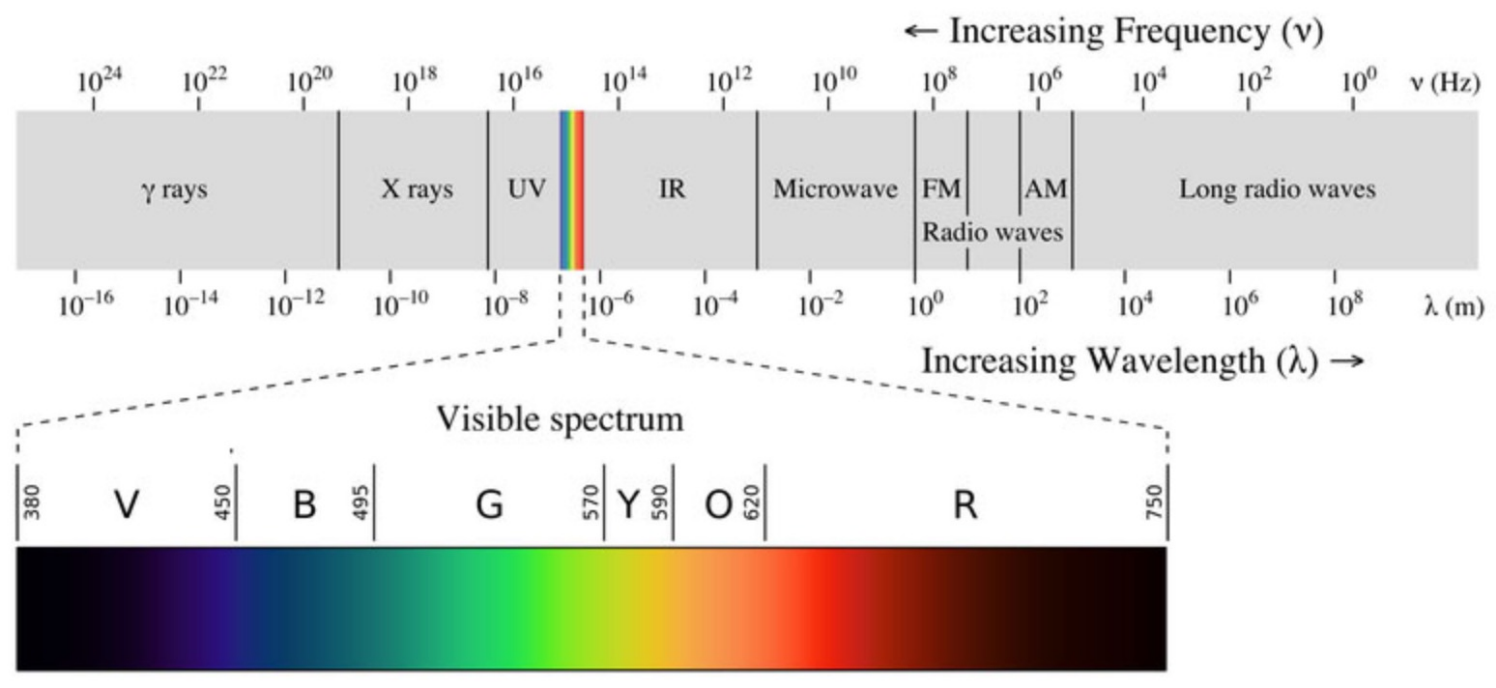
Type M/R $(\frac{M}{M_\odot} \times \frac{R_{Sch}}{R})$ \ Configuration	Single	Binary	Merger
Stellar $M/R \ll 1$	 Flare stars, SNe/SNR, lGRB	 Novae, Dwarf Novae	 Common Envelope
Relativistic Stellar $M/R \sim 1\text{-}10^3$	 Pulsars, Magnetars, FRB	 NS/BHXRB, Binary Pulsars	 NS-NS, NS-BH, sGRB
Massive BH $M/R \sim 10^4\text{–}10^{10}$	 Active Galactic Nuclei, TDE	 Dual/multiple AGN	 BSMBH mergers

The radio part of the EM spectrum

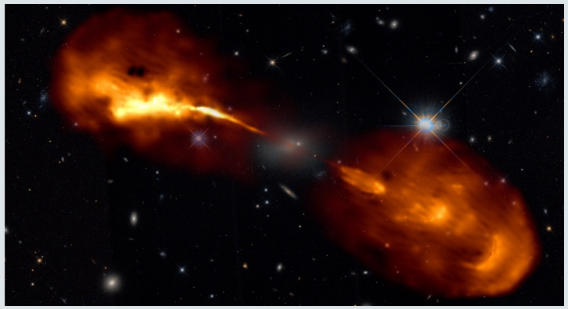
Type	Frequency	Wavelength
AM Radio	1 MHz	300 m
FM Radio	100 MHz	3 m
Wifi	2–6 GHz	15–5 cm
Microwave	300 MHz - 300 GHz	1 m - 1 mm
Green Light	5.54×10^{14}	0.55 μm

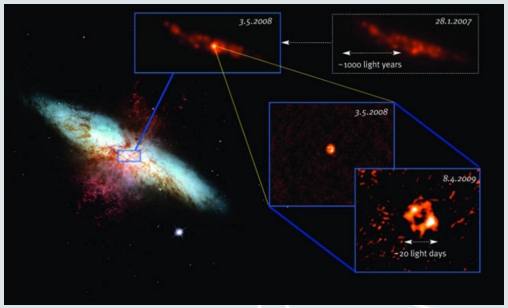
Radio domain

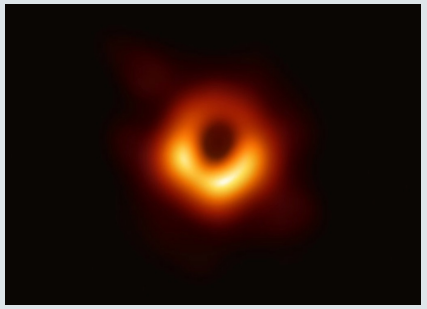
12 orders of mg. in photon energy!
➔ Range of physical processes



Instruments & science

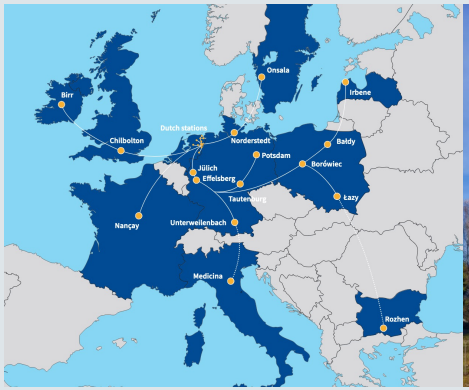


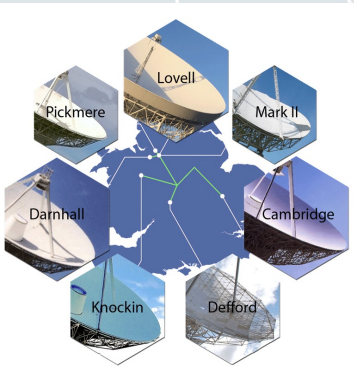




~1-6m | ***~1m – 1cm*** | ***~1mm***

LOFAR | **Eflsberg, e-MERLIN, EVN** | **(EHT)**



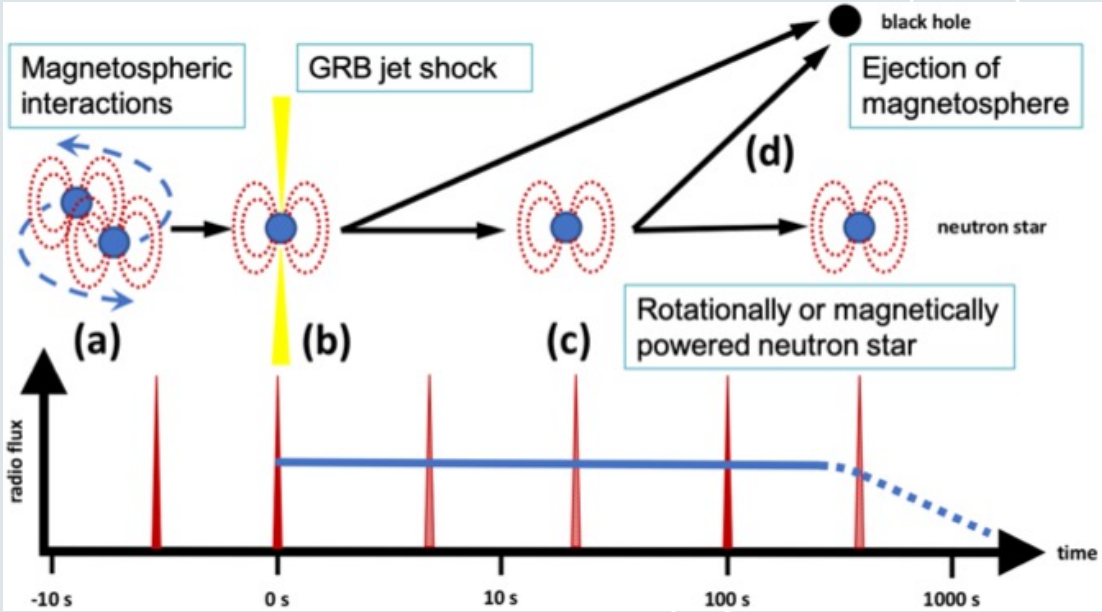


Megaparsecs | **Kiloparsecs** | **Parsecs** | ***R*** **Sch**

LOFAR

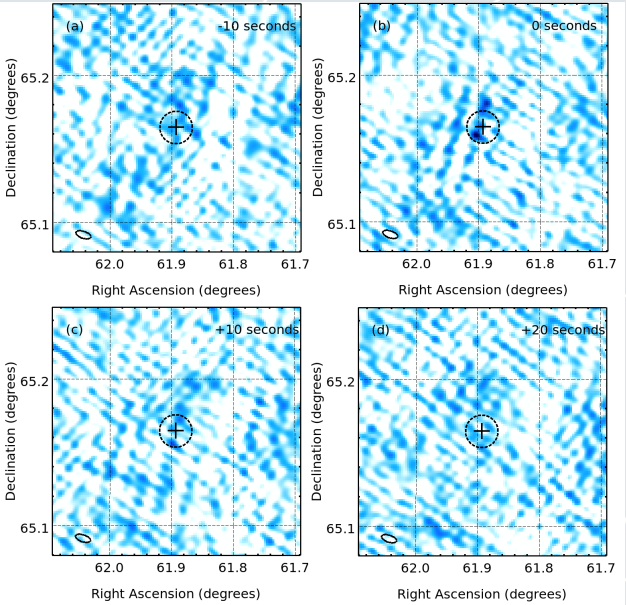
- **Currently in transition between LOFAR ➔ LOFAR 2.0**
- **Has had rapid response (4-5m) short GRB and GW program, a.w.a late-time for GWs** (and various other, like XRBs, RS Oph recurrent nova)
- **In ACME, main focus is on supporting MM astronomers using the instrument, and accessing archival data**

Coherent emission models



Rowlinson & Anderson (2019); see also Gourdji et al. (2020)

Candidate coherent flash in GRB 201006A @ 144 MHz

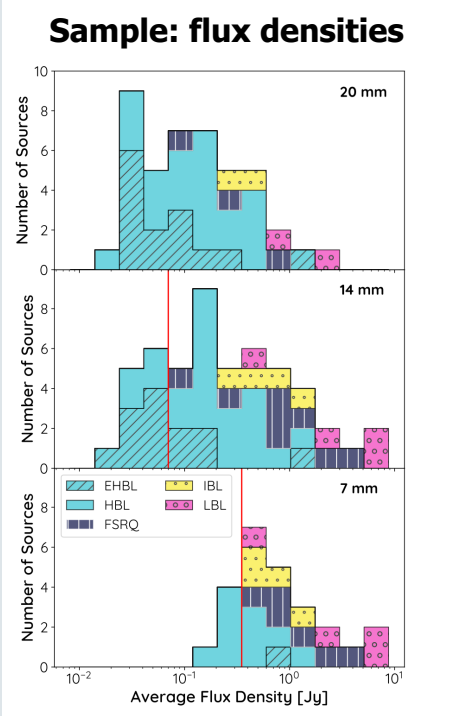


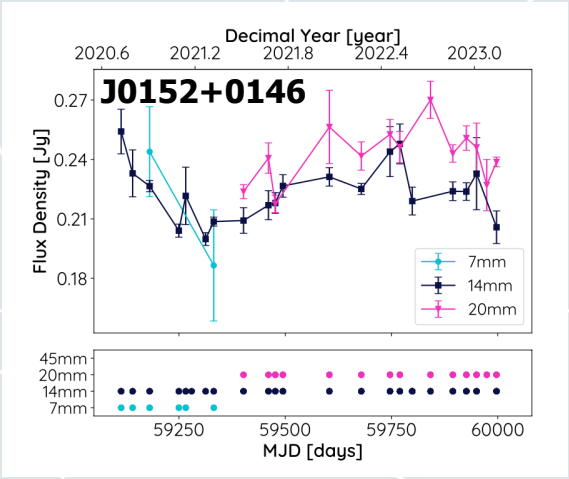
Rowlinson et al. (2023)

Effelsberg

- **Largest fully stearable dish in Europe (100m); repainting of the dish is finishing**
  Available as single dish or as part of VLBI networks; pulsar backend; FRB detection
- **Great sensitivity, broad frequency coverage, frequency agility**
  In secondary focus nearly continuous 2.5-50 GHz, switching time ~30s
- **Various transient programs, but not flexible re fast reaction time/scheduling**

TELAMON project: multi-band monotoring of ν-associated/TeV blazars





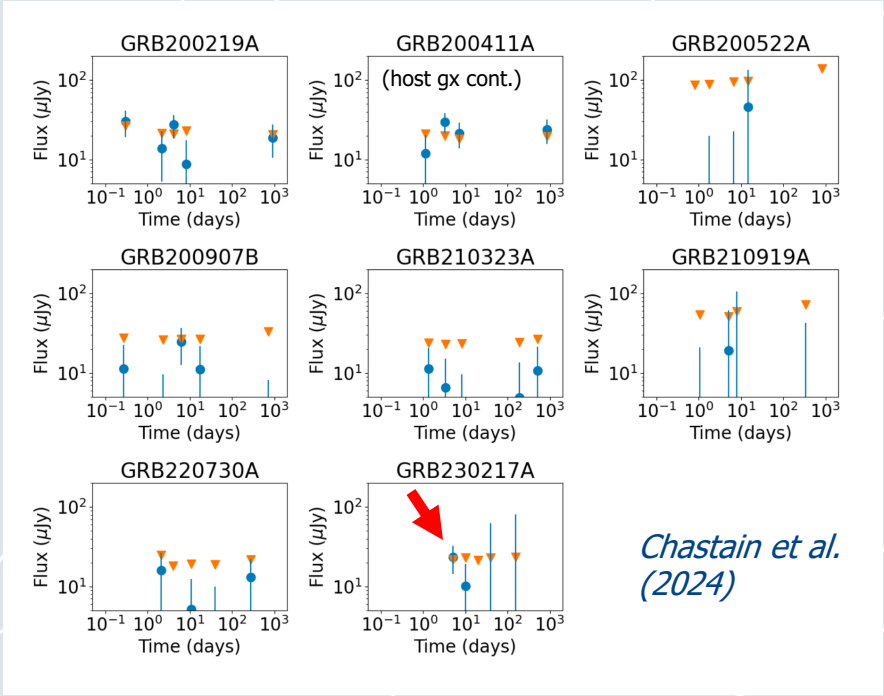
Eppel et al. (2020) – project

Eppel et al. (2023), Atel#16399
(**Radio flare in PKS0446+11, coincident w. IceCube-240105A**)

e-MERLIN

- **Flexible imaging interferometer array**
  10s of pc to kpc; ~$10^{15\text{-}17}$ cm in MW; 18-21cm, 5-6cm, 1cm
- **Open instrument, ideal for multi-band monitoring campaings**
  Centrally scheduled; pipeline provides (near-)science ready data
- **Various transient programs, e.g. Einstein Probe & Swift follow-up**

Constraints on sGRB physics and their host GX (MeerKAT, ATCA, e-MERLIN)

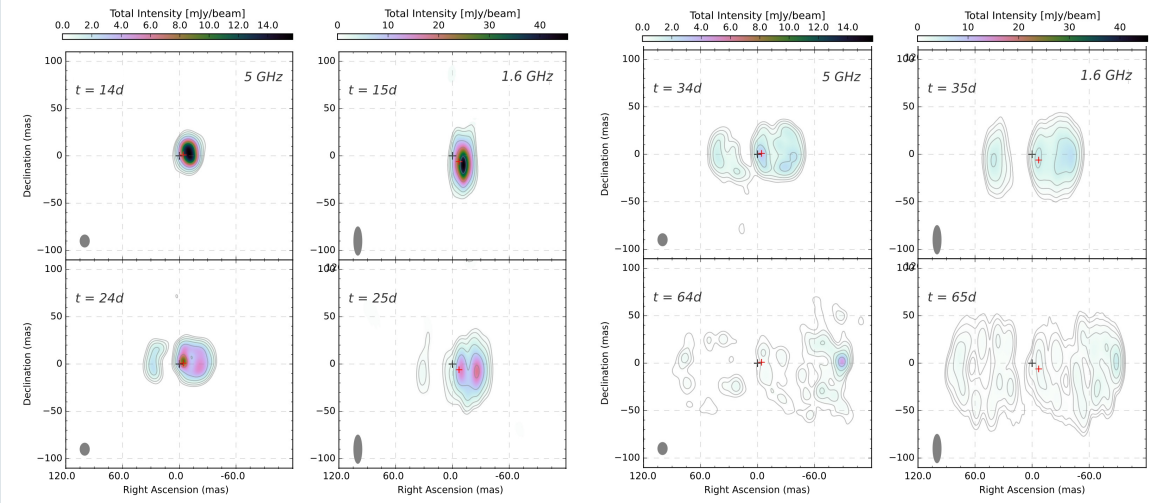


Chastain et al. (2024)

European VLBI Network (EVN)

- **Extending over Europe-Asia-South Africa; global-VLBI/GVA initiative**
  (sub-)pc to 100s of pc; ~$10^{14\text{-}16}$ cm in MW; Main bands: 18-21cm, 5-6cm, 1cm
- **Open instrument; somewhat flexible for transients (ToO,e-EVN, EVN-lite)**
  Supporting non-expert PIs/teams; (near-)science ready products is the ultimate goal
- **The most powerful probe of synchrotron and coherent transients (FRB)**
  (especially when part of MM campaigns, as combined e-MERLIN+EVN and/or in a global array)

RS Oph in 2021: first nova eruption detected in the VHE (>100 GeV) regime



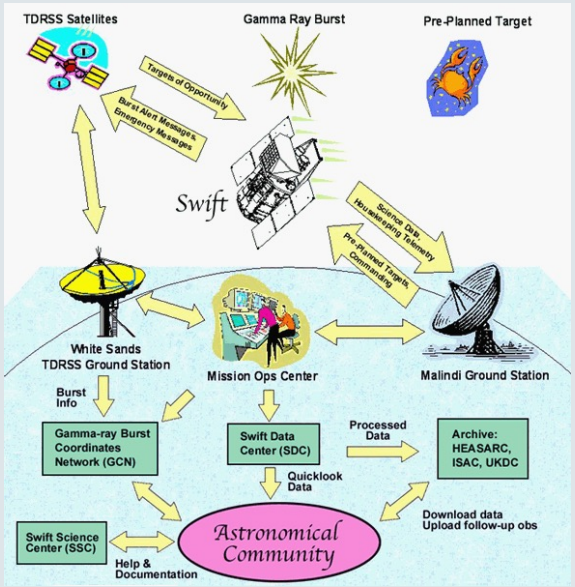
"We conclude that most of the mass lost by the red giant companion goes in the DEOP [orbital plane…], and in the circumstellar region, while only a small fraction (about one-tenth) is accreted by the white dwarf."

Lico et al. (2024)

Challenges – for the field (radio)

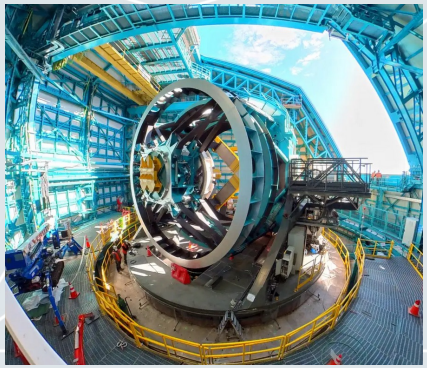
- **Lack of dedicated radio transient search/follow-up instruments**

Swift [X-rays]



swift.gsfc.nasa.com

Vera Rubin [optical]



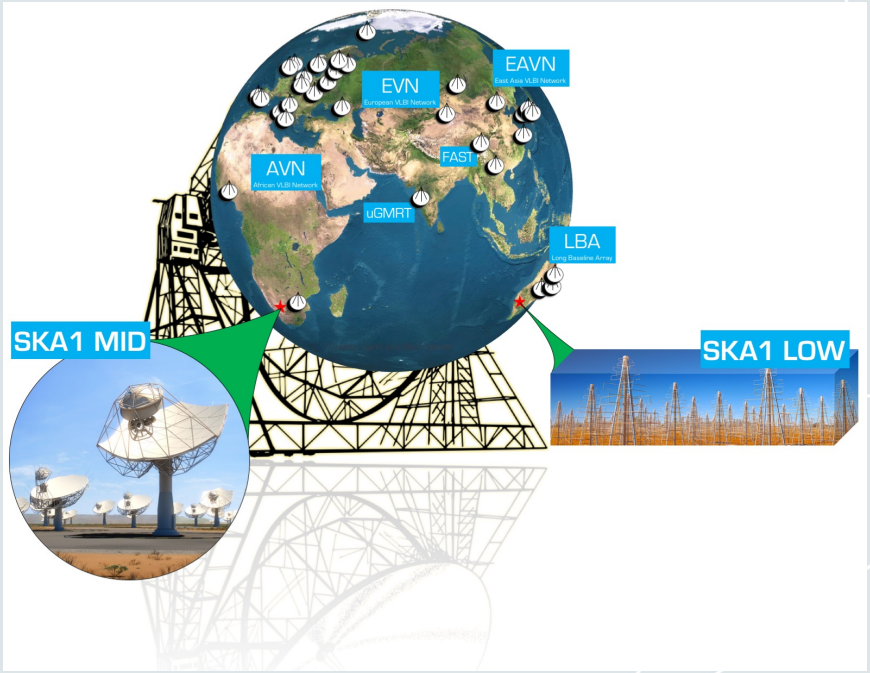
Radio – no trigger instruments!
For other triggers:

- Fast response projects difficult to arrange
- No central scheduling for distributed networks (observing schedule!)
- Manpower running the observations

Challenges – for the radio community

- **Future funding of radio facilities and support in general**

The SKA (&SKA-VLBI) is an opportunity – and a challenge

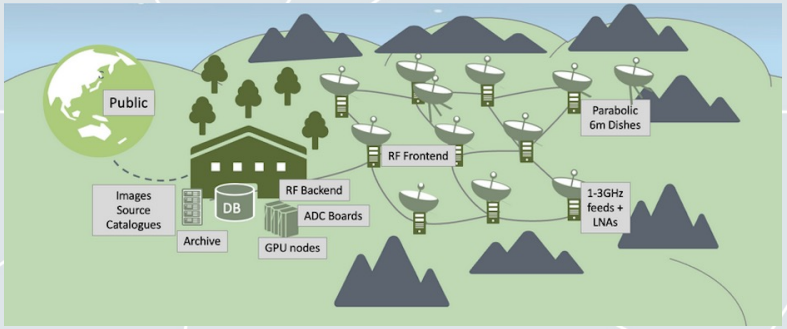


Courtesy of Garcia-Miro

European initiatives:

- ARGOS
- LEVERAGE
- EVNCam
- EVN-lite, e-MERLIN upgrade…

ARGOS

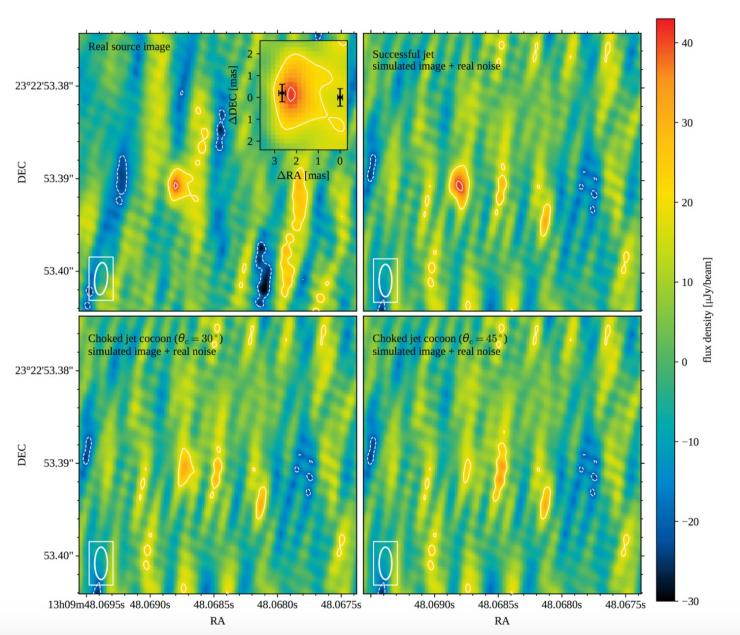


From John Antoniadis

Challenges – for the observations

- **Sensitivity of follow-up instruments (especially Radio!)**

GW1708178 counterpart:
Global VLBI vs. simulated maps



Ghirlanda et al. (2019) Science, 363, 968

Wide range of phenomena within easy reach, but:

- GW events barely or non-detectable on cosmological scales
- How to support next-generation GW instruments with EM facilities, especially radio!???
- ACME to keep this on the agenda?

Challenges – for the astronomers

- **"Radio astronomy is hard"**

Visitors at JIVE

Photo: ZP

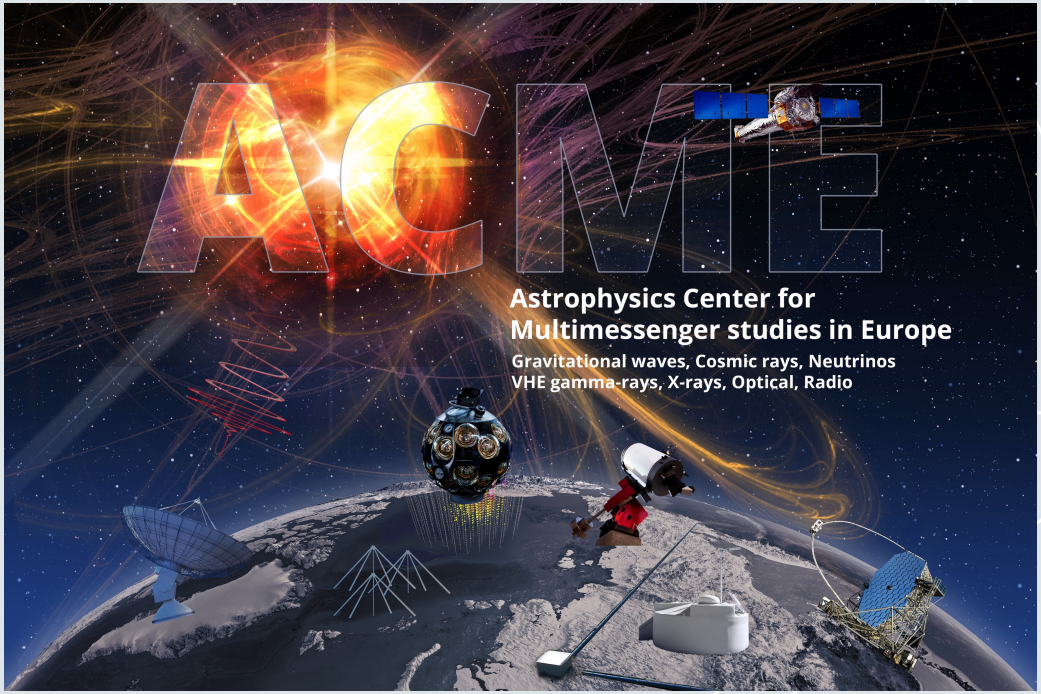
ERIS 2022

How to support astronomers [TA/VA]?

- Radio/VLBI data analysis reportedly most difficult for students (compared to other bands)
- Non-expert PI support, training, documentation, data reduction tools/recipes – very important
- Providing science-ready data is not trivial
- We must engage the broader astronomical community

Challenges – for the project

- **ACME to find solutions, lower barriers, form community!**



Beabudai Design

In our focus

- Find the best ways to meet all challenges!
- How to coordinate efforts between different facilities/fields?
- How to create long-term solutions?
- How to lower cross-field barriers, and nurture a community with MM in mind?