SYNERGIES WITH OTHER DOMAINS OF ASTROPHYSICS, GLOBAL COLLABORATIONS

Eduardo Ros (European GMVA Scheduler)
J. Anton Zensus, Andrei P. Lobanov, Yuri Y. Kovalev,
Thomas P. Krichbaum, et al.

Max-Planck-Institut für Radioastronomie

10 years ago – KSP meeting at MPIfR, December 2012

SYNERGIES IN THE ERA OF MULTI-MESSENGER ASTRONOMY FOR HIGH T_B SCIENCE

Single dish
Effelsberg. PV30m, MRO, OVRO

Radio interferometer
(ng)VLA, ALMA, SKA

cm-VLBI
VLBA, EVN, LBA

mm-VLBI
GMVA, EHT

X/γ rays
Chandra/XMM, Fermi/LAT, Cherenkov

Neutrino
IceCube, KM3net, Baikal

GW
LIGO/Virgo

Space VLBI

AGN
SMBH region

AGN
jet

PSR

Galactic molecules

Radio stars

ISM

Transients

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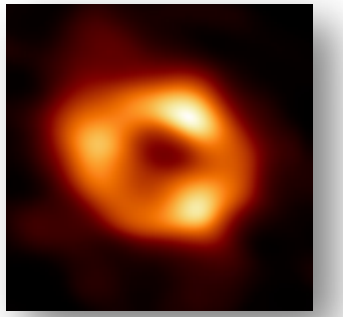
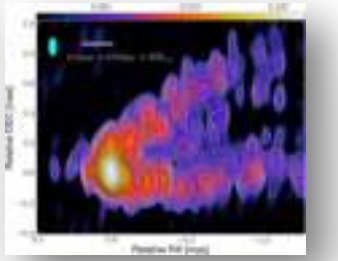
EHTC



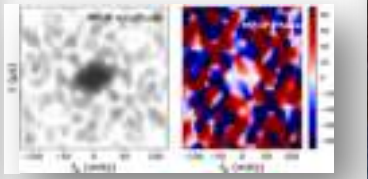
AGN
SMBH region

JY Kim +



AGN
jet

Main +

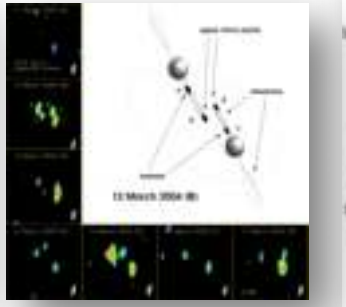


PSR

Bally +

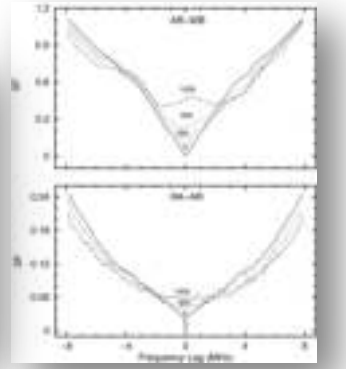
Galactic molecules

Massi +



Radio stars

Smirnova +

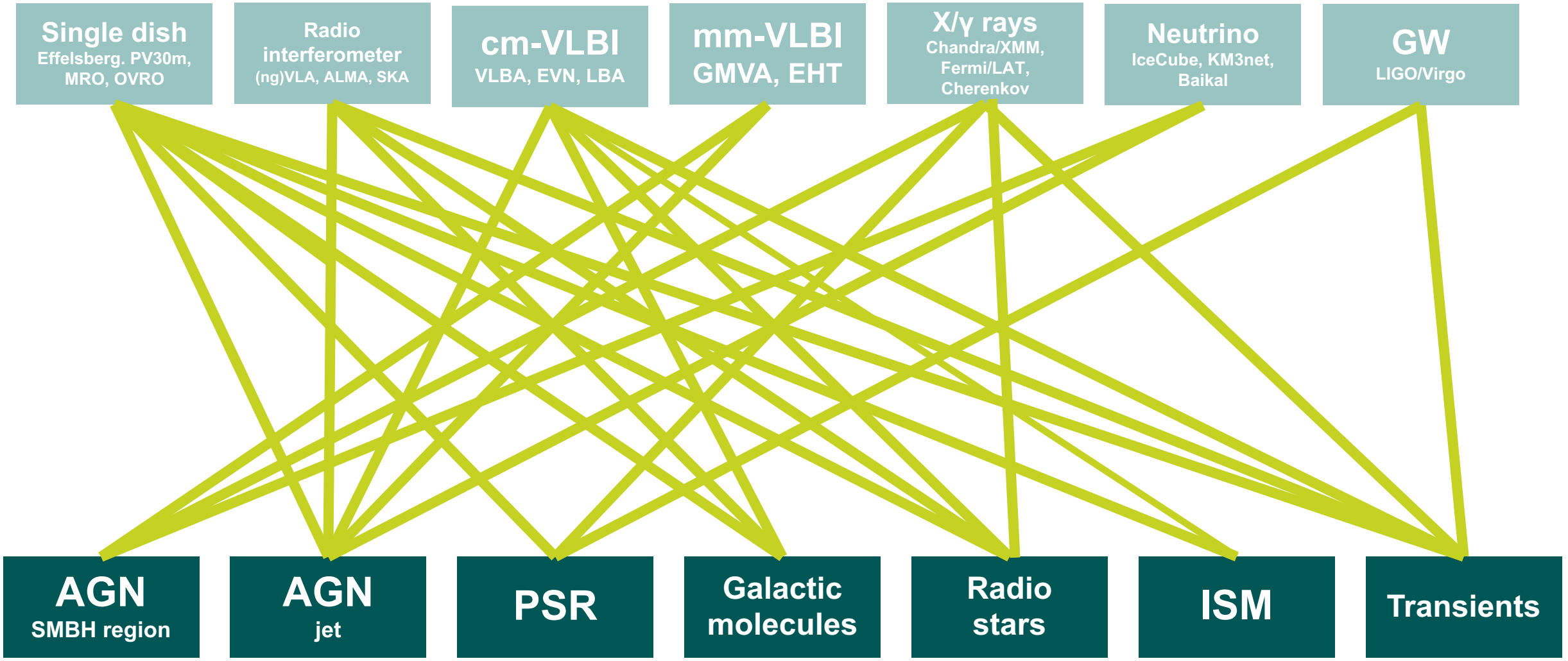


ISM

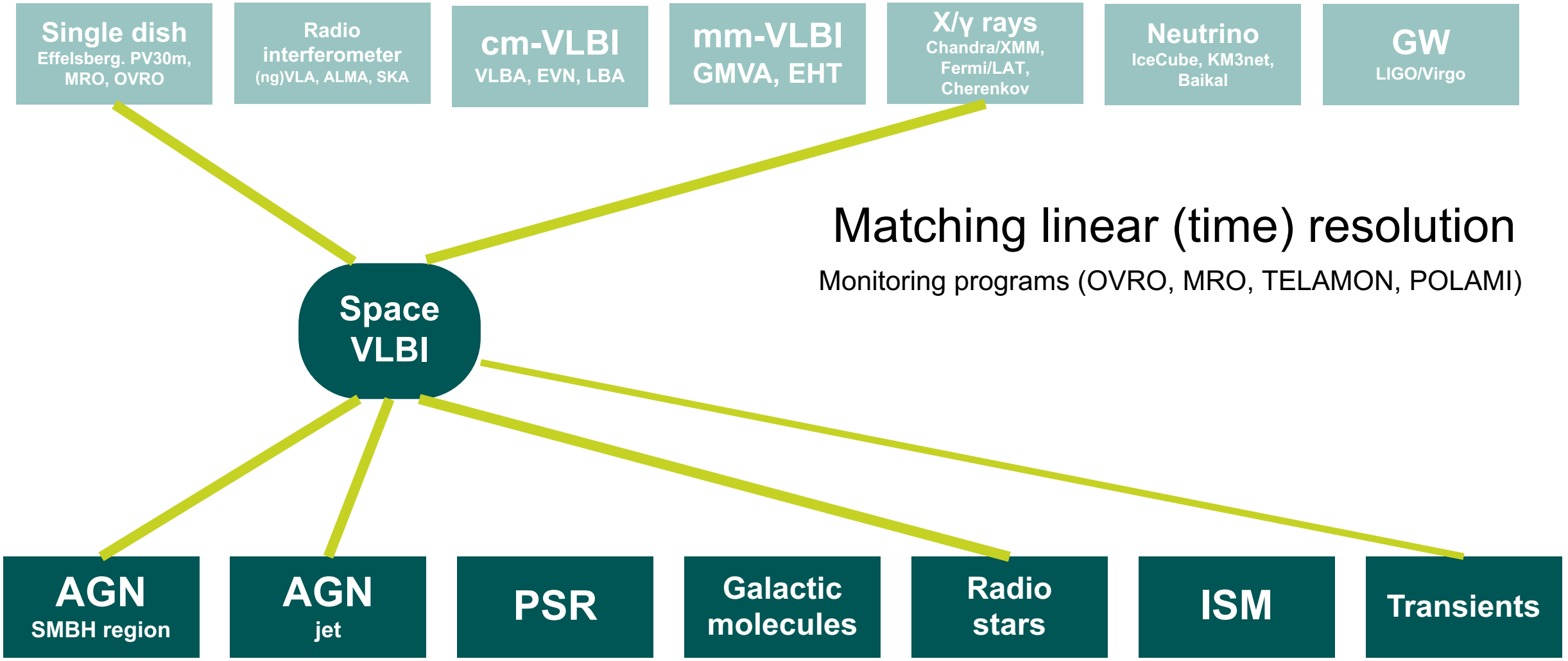
Caleb +

Transients

SYNERGIES IN THE ERA OF MULTI-MESSENGER ASTRONOMY FOR HIGH T_B SCIENCE



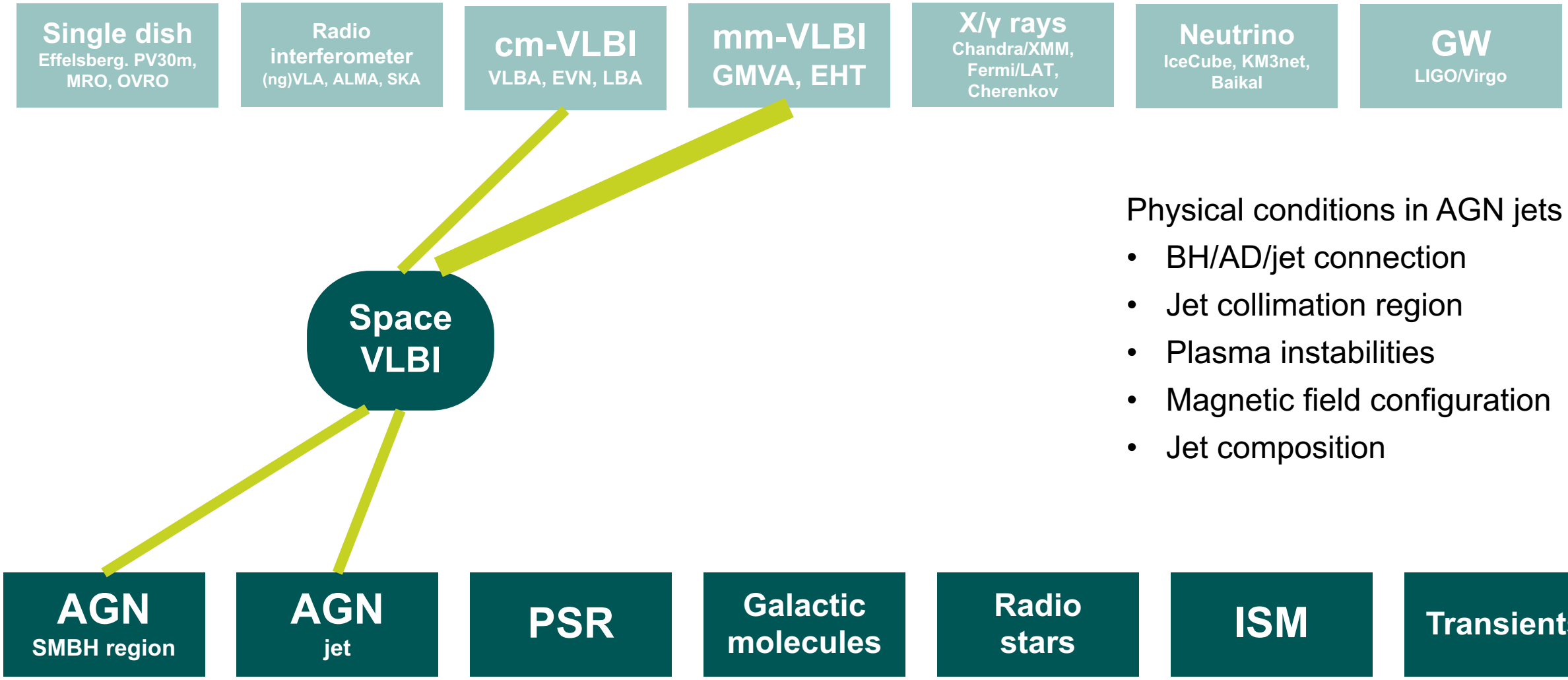
MATCHING LINEAR (TIME) RESOLUTION



Matching linear (time) resolution

Monitoring programs (OVRO, MRO, TELAMON, POLAMI)

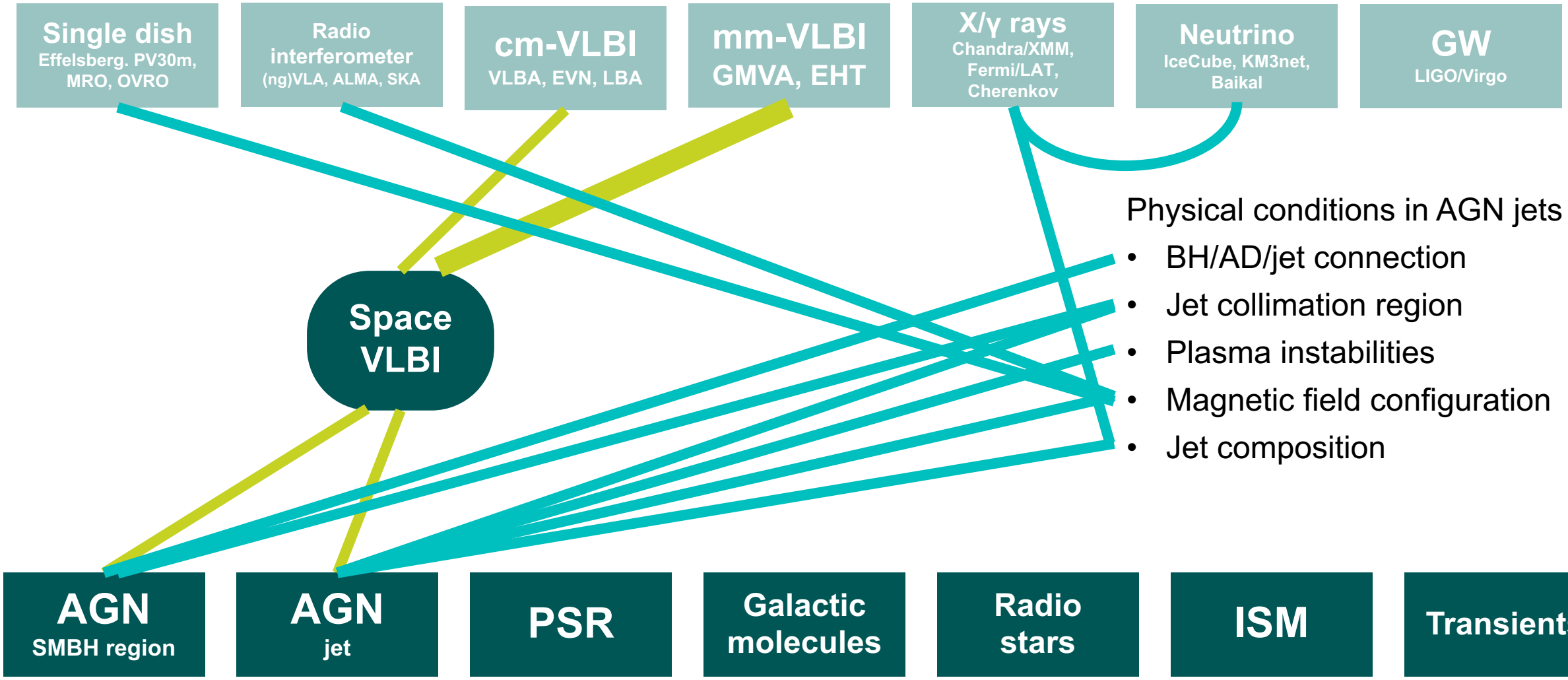
MATCHING ANGULAR RESOLUTION



Physical conditions in AGN jets

- BH/AD/jet connection
- Jet collimation region
- Plasma instabilities
- Magnetic field configuration
- Jet composition

MATCHING ANGULAR RESOLUTION



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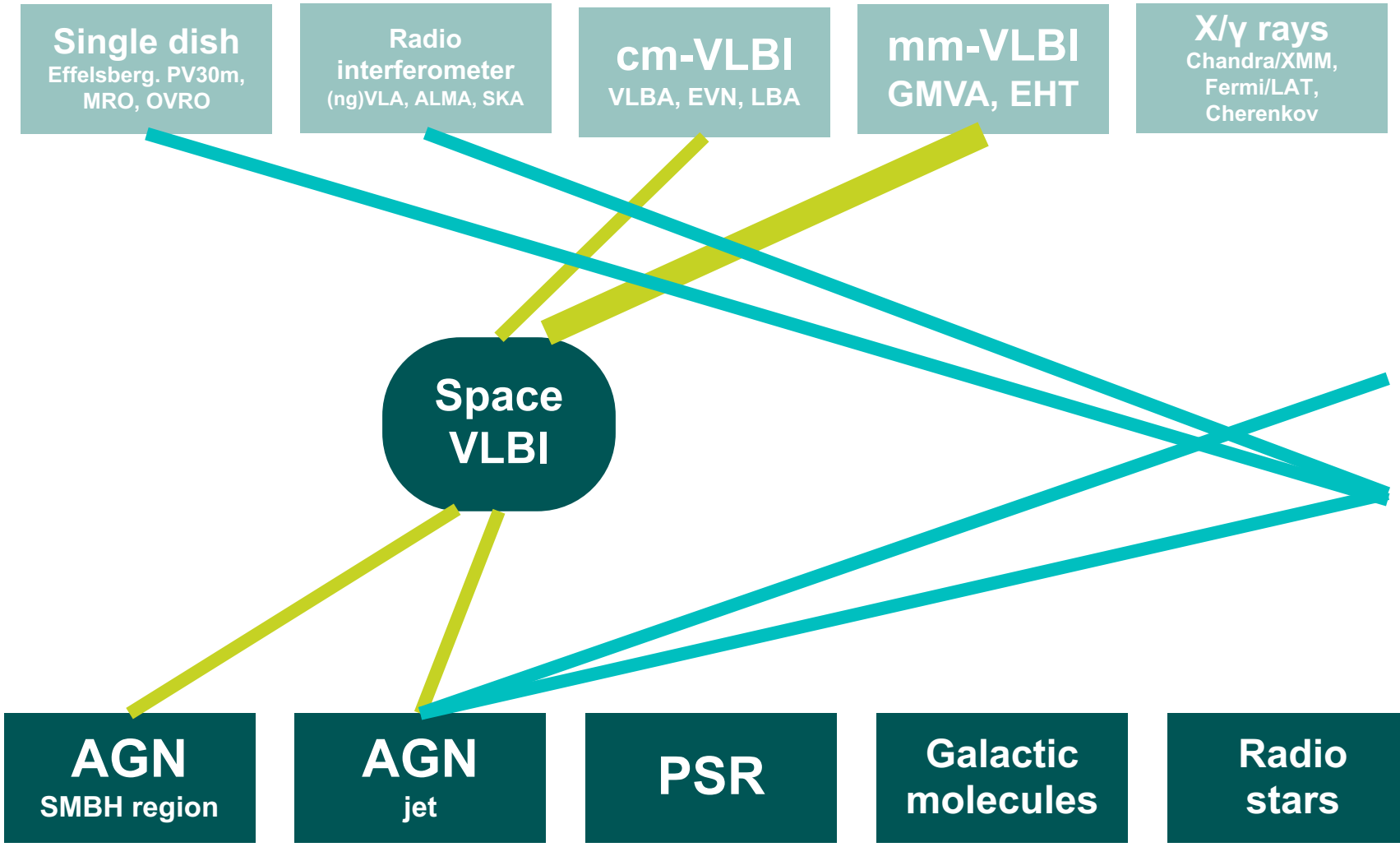

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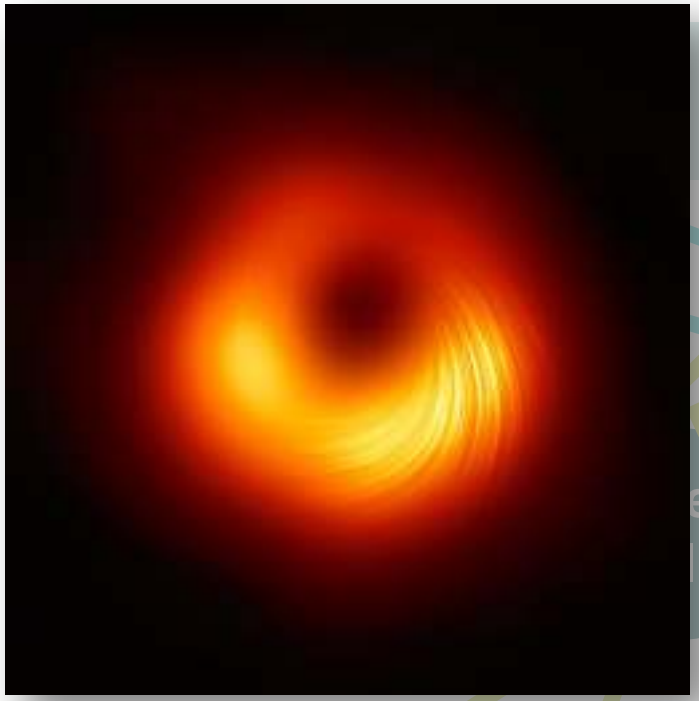
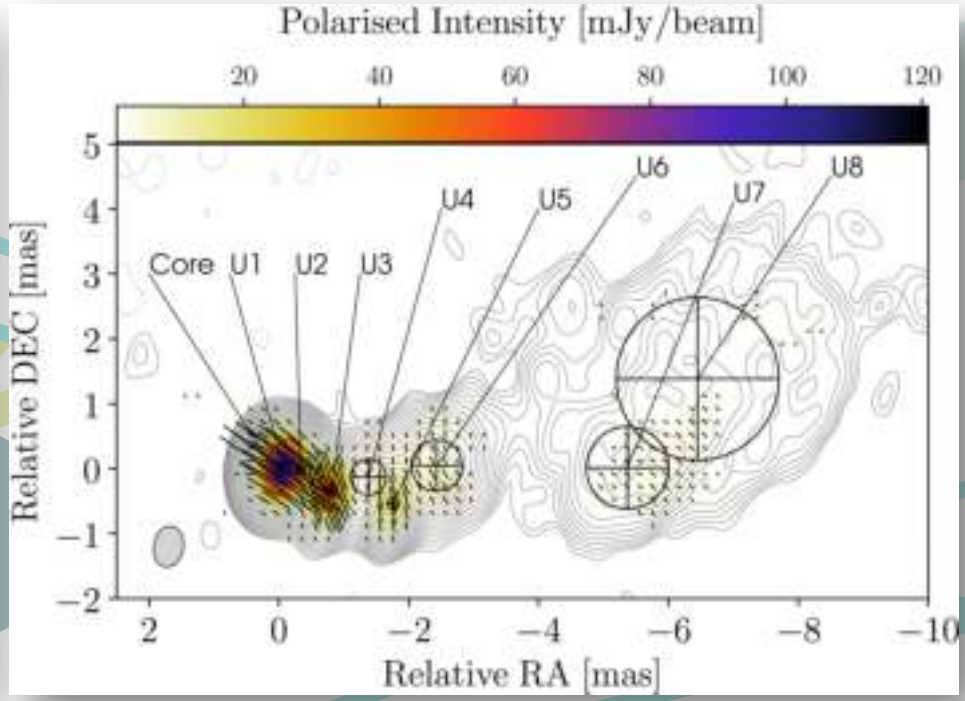
EHTC 2021



Pötzl+ 2021



Neutrino
IceCube, KM3net, Baikal

GW
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AGN SMBH region

AGN jet

PSR

Galactic molecules

Radio stars

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Transients

MAGNETIC FIELDS: M2FINDERS ADVANCED GRANT

Mapping Magnetic Fields with INterferometry Down to Event hoRizon Scales

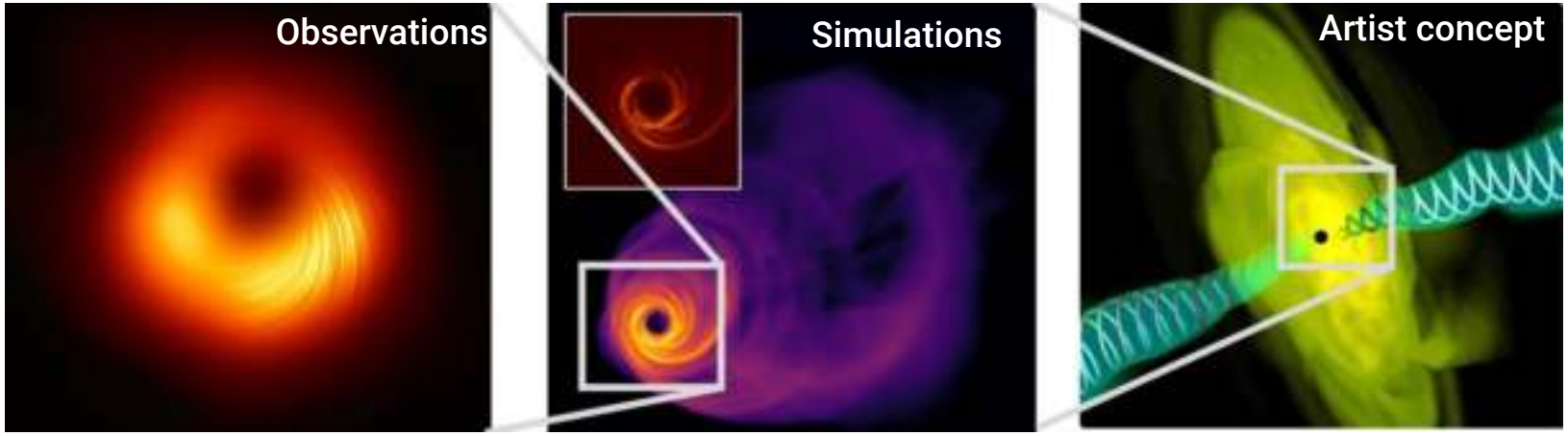


Image: Eduardo Ros © EHT Collaboration, Nakamura et al. 2020, Tchekhovskoy 2015

P.I.
J.A. Zensus

Three working packages to probe magnetic fields near black holes

Mapping magnetic fields through polarisation and astrometric VLBI

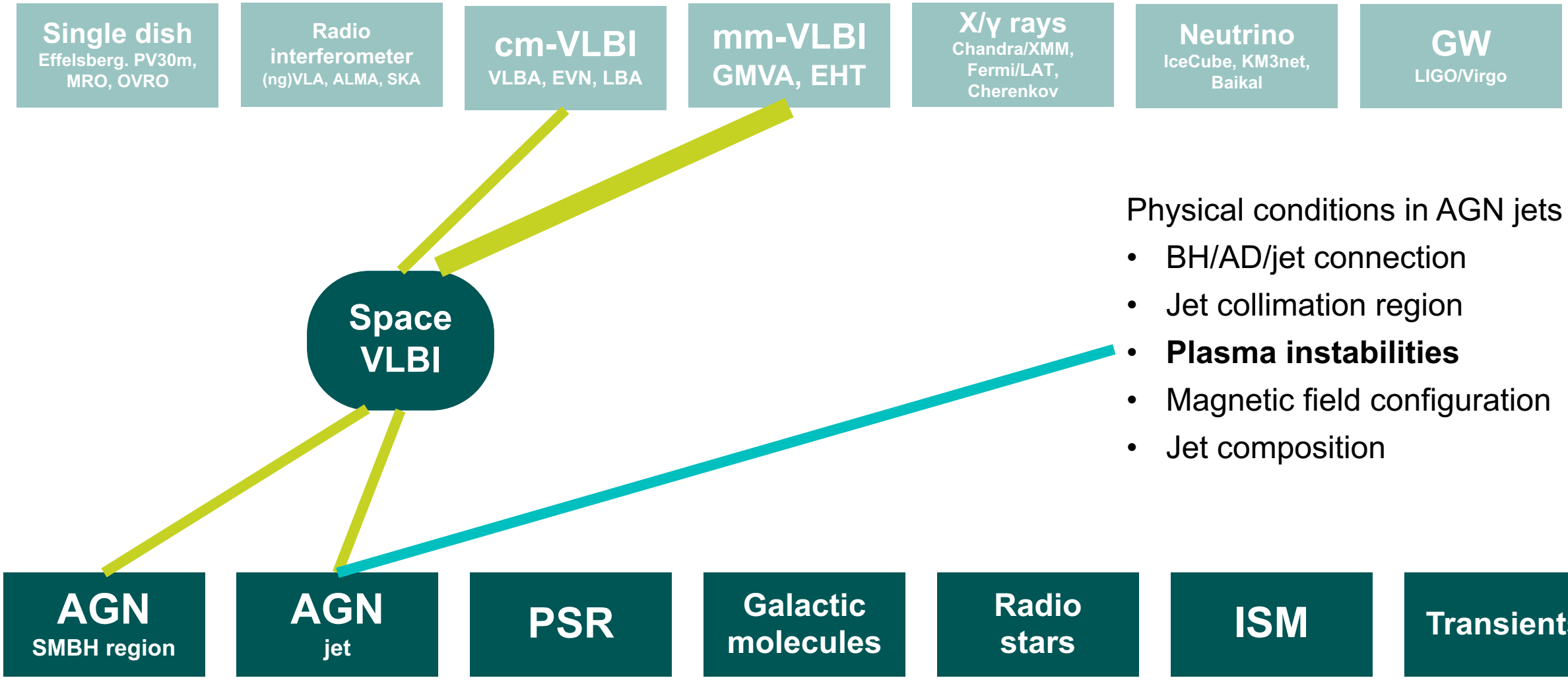
Developing VLBI interferometry techniques

Deriving robust magnetic field properties near the event horizon

↘ *2,5 M€ funded from the European Research Council*

Project started in November 2021

MATCHING ANGULAR RESOLUTION



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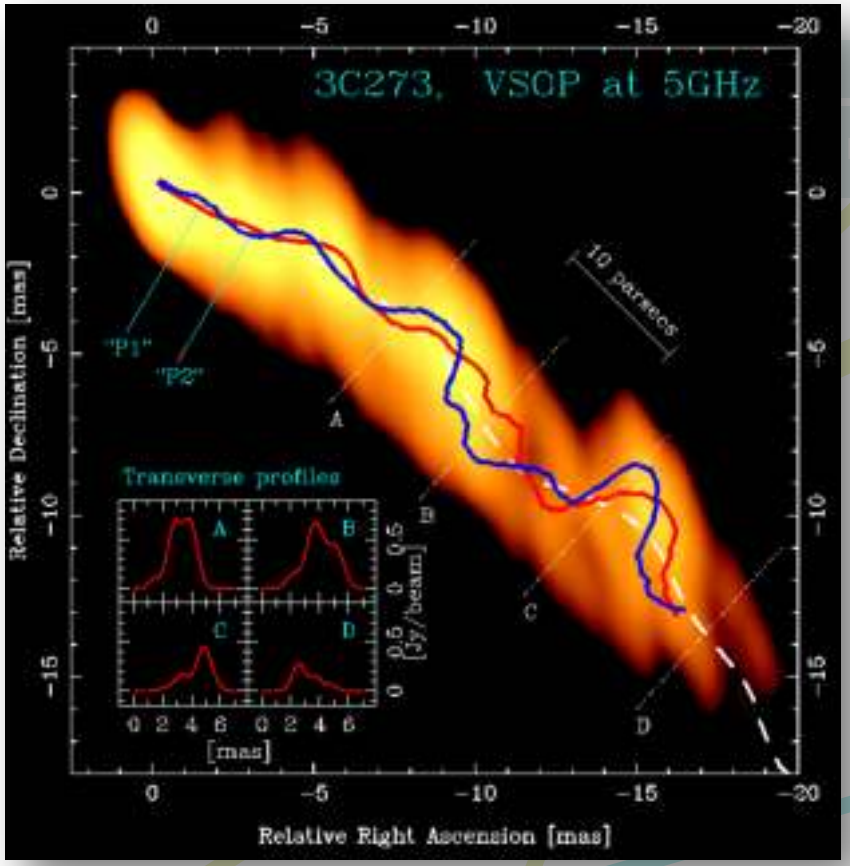
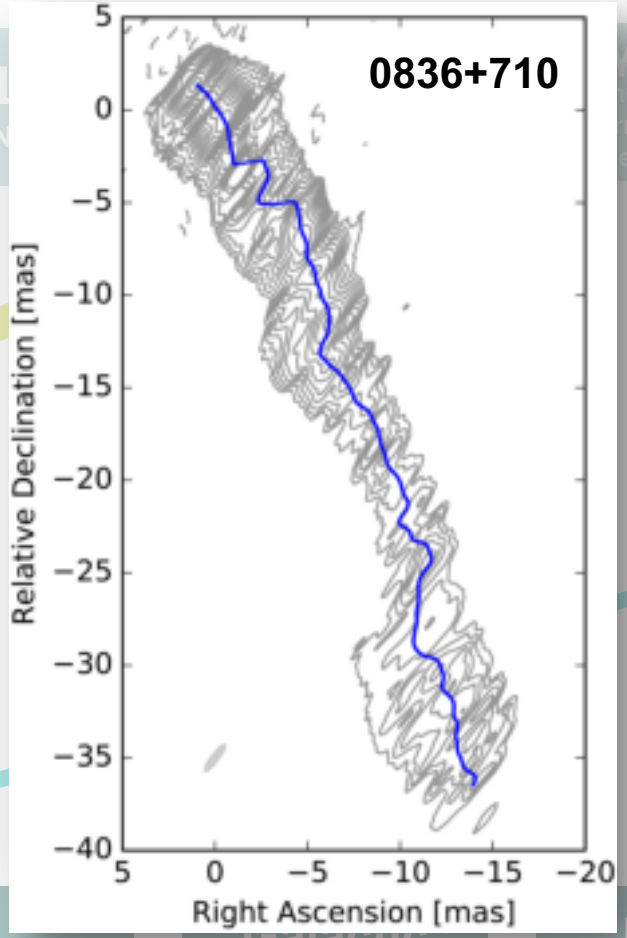
MATCHING ANGULAR RESOLUTION

Lobanov & Zensus (2001)



Vega-García et al. (2020)



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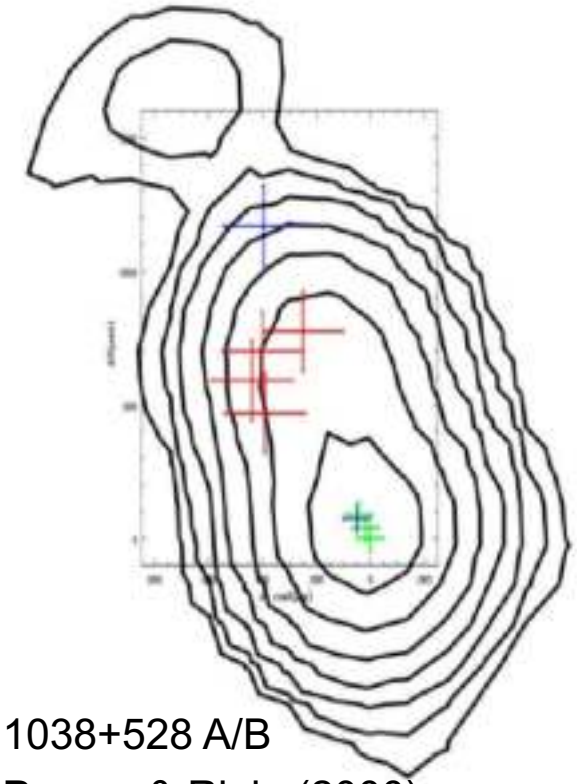
See also Gómez talk on 3C279

AGN SMBH region | **AGN** jet | **PSR** | Galactic molecules | Radio stars | **ISM** | **Transients**

Neutrino: IceCube, KM3net, Baikal

GW: LIGO/Virgo

MATCHING ANGULAR RESOLUTION: ASTROMETRY



1038+528 A/B

Porcas & Rioja (2000)

cm-VLBI
VLBA, EVN, LBA

mm-VLBI
GMVA, EHT

X/γ rays
Chandra/XMM, Fermi/LAT, Cherenkov

Neutrino
IceCube, KM3net, Baikal

GW
LIGO/Virgo

Astrometry of jets

- In-beam astrometry for gravitational lenses
- Core-shift studies with enhanced resoulution

Directly related to orbit determination

See also Rioja's talk on astrometry

AGN
SMBH region

AGN
jet

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mm-VLBI PRESENT ARRAYS AND SPACE MISSIONS

Millimetre VLBI

Continental and global arrays

D up to Earth size (10^7 m)

Recent boost in sensitivity by phased ALMA, offered both for GMVA at 3.5 mm and EHT at 1.3/0.8 mm

Space VLBI

Ground array supporting space baselines

D up to 3x or 10x Earth size (10^7 m)

High resolution for Tb determination, not necessarily for imaging

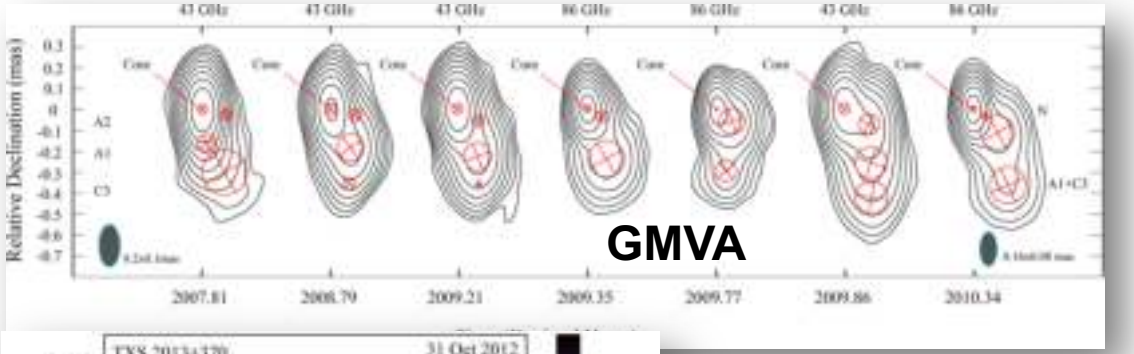
Array	ν [GHz]	D [km]	D [Mλ]	Θ [mas]
VSOP	1.65/4.8/*22.1*	33000	175/528/*2432*	1.17/0.39/*0.085*
Ground global	22	11600	893	0.231
RadioAstron	0.33/1.66/ 4.8/22	350000	7230/8500/ 24230/99600	0.540/0.106/ 0.037/0.009
Ground global	43	11600	1660	0.124
GMVA	86	11045	3680	0.056
EHT	230/345	11045	8500/12300	0.024/0.017

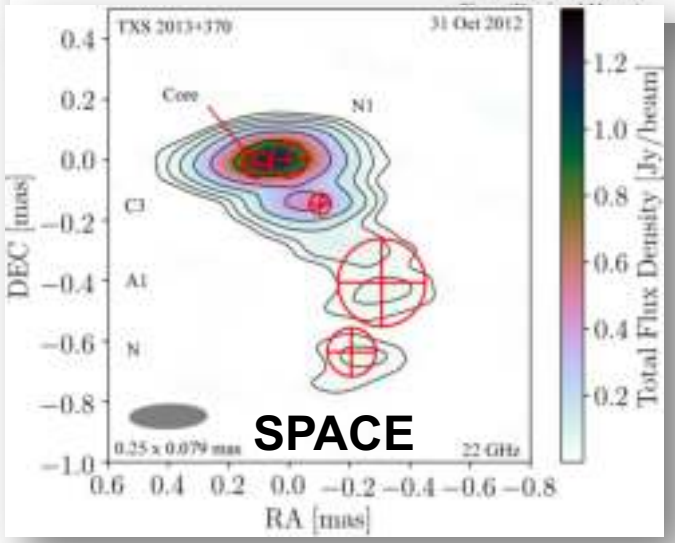
$$\Theta = 1.22\, c/(\nu\, D)$$

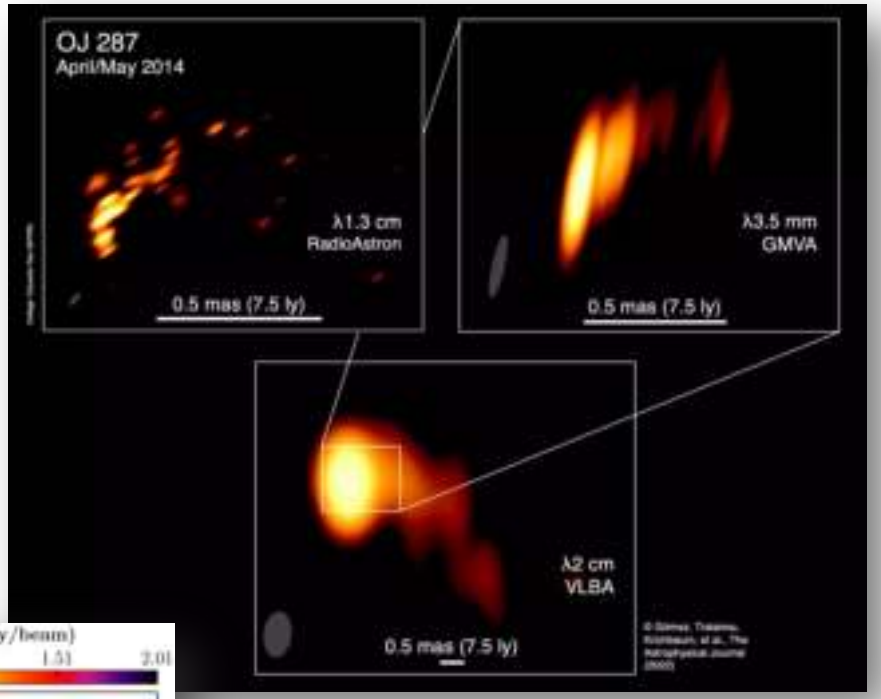

GMVA
GLOBAL MILLIMETER VLBI ARRAY
VLBA – Los Alamos
VLBA – North Liberty
NRAO – GBT 100m
MPIfR – Effelsberg 100m
Onsala 20m
Metsähovi 14m
KVN – Yonsei
VLBA – Brewster
KVN – Ulsan
VLBA – Mauna Kea
KVN – Tamna
VLBA – Owens Valley
INAF- Noto
VLBA – Kitt Peak
VLBA – Pie Town
VLBA – Fort Davis
joint observations
Phased-ALMA
IRAM – Pico Veleta 30m
OAN – Yebes 40m
IRAM - NOEMA

GMVA-RADIOASTRON RESULTS

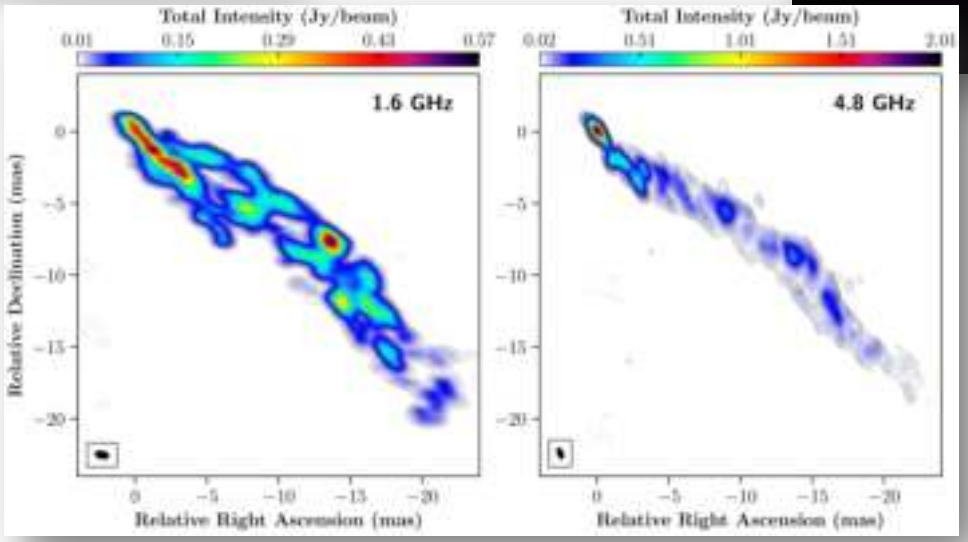
Traianou et al. (2020) TXS 2013+370





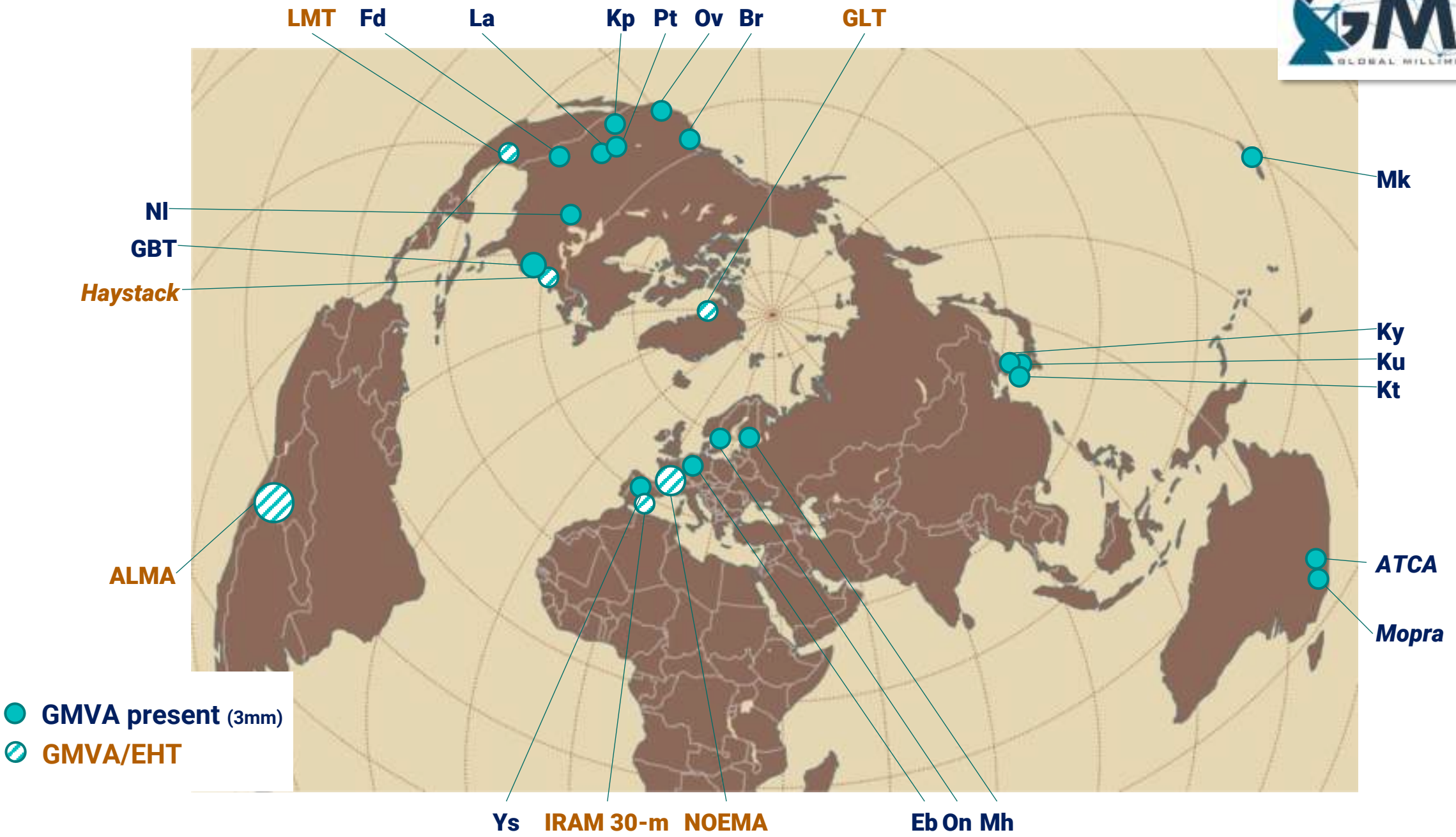


Gómez et al. (2022) OJ 287



Bruni et al. (2021) 3C 273

Forthcoming: 3C 84 (Savolainen, Giovannini, J.Y. Kim, et al.),
M 87 (J.Y. Kim et al.), 0615+820 (Ros et al.), 3C 279 (Fuentes, Gómez et al.)


LMT
Fd
La
Kp
Pt
Ov
Br
GLT
Nl
GBT
Haystack
Mk
Ky
Ku
Kt
ALMA
ATCA
Mopra
Ys
IRAM 30-m
NOEMA
Eb
On
Mh
GMVA present (3mm)
GMVA/EHT

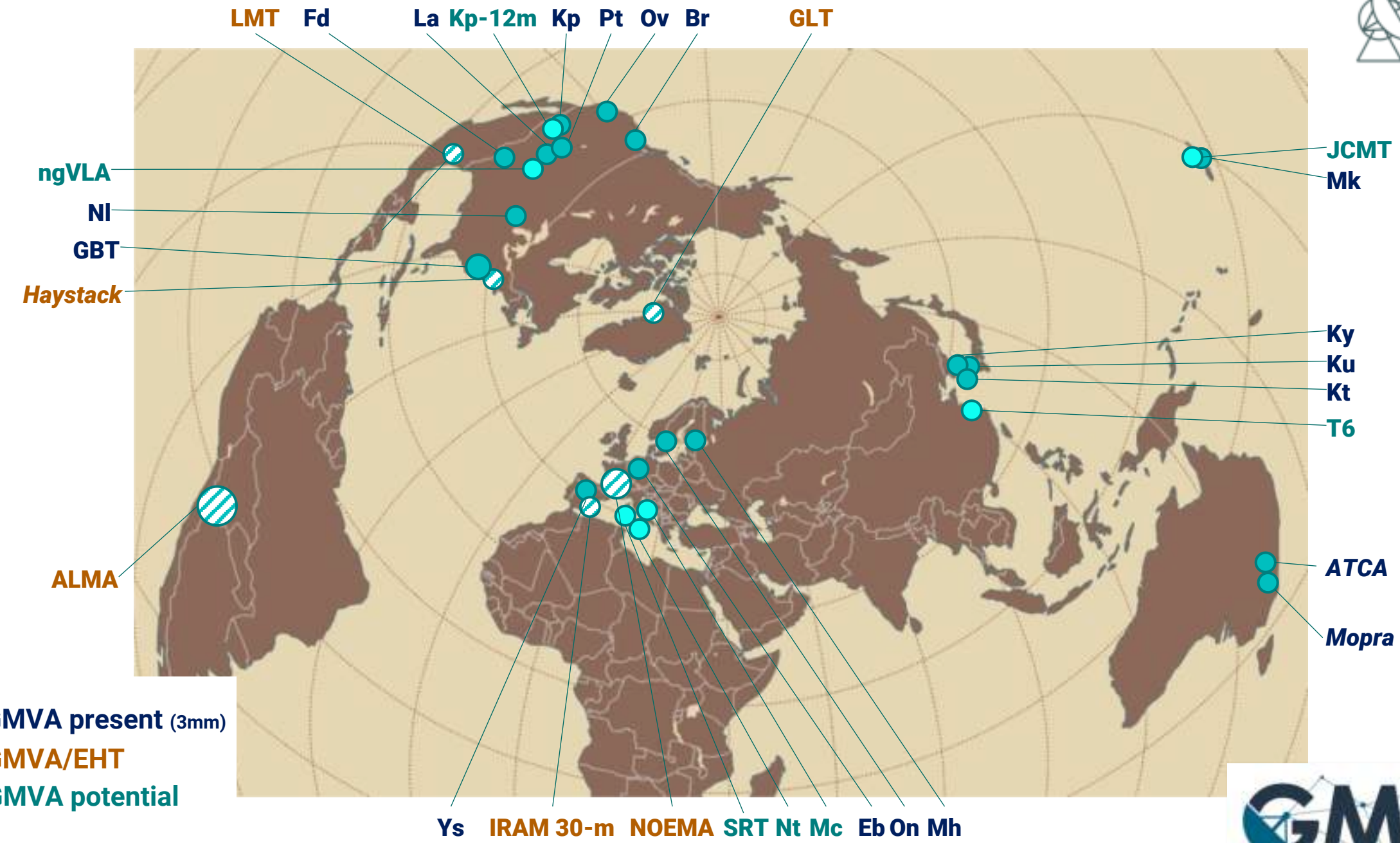
GMVA: PRESENT STATUS

- **Operations based on a Memorandum of Understanding**
  - 4 Gbps obs. at VLBA8+IRAM*+Eb+Mh+On+Ys*+KVN* + GBT (limited time) +GLT*+ALMA*
  - Temporary additions: LMT*, Haystack*, Mopra*, ATCA
  - Correlation at MPIfR
- **Open-sky policy, proposals via NRAO-PST (01feb, 01aug)**
  - Proprietary period of 1yr, data archived at MPIfR and NRAO
- **Two sessions per year (apr+oct)**
- **No dedicated funding, in-kind contribution by partners**
  - Media provision, session planning, scheduling by MPIfR
- **Moderate frequency agility (85-90 GHz) & 43 GHz interleaved (VLBA+Nt)**

*: 16 Gbps available

FORTHCOMING IMPROVEMENTS OF THE ARRAY: COVERAGE & BANDWIDTH

- **Improved (u,v) coverage (antennas)**
  - MoU stations: VLBA8+IRAM+Eb+Mh+On+Ys+KVN + GBT (limited access)
  - ALMA appointed GMVA for Band 3 (one session per year)
  - Temporary additions on best-effort basis: LMT, Haystack, Mopra, ATCA
  - Potentially: JCMT, KP12m, Taeduk, Nobeyama, Purple Mountain, OVRO, APEX, VERA
- **Higher bandwidth already available for a subset of antennas (check GMVA webpage)**
  - 16 Gbps available in IRAM-30m, NOEMA, GLT, Ys, KVN, *Mopra, Haystack, LMT, JCMT, KP12m*


LMT
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Kp-12m
Kp
Pt
Ov
Br
GLT
ngVLA
Nl
GBT
Haystack
ALMA
JCMT
Mk
Ky
Ku
Kt
T6
ATCA
Mopra
Ys
IRAM 30-m
NOEMA
SRT
Nt
Mc
Eb
On
Mh
GMVA present (3mm)
GMVA/EHT
GMVA potential

GMVA IMPROVEMENTS: CALIBRATION, TIME COVERAGE, MULTI-BAND OPTIONS

- **User friendliness: calibration and pipeline data reduction**
- **Improvement of observation cadence (more sessions per year) – costly option**
- **Multi-band receivers (Frequency-Phase-Transfer and Source-Frequency-Reference-Transfer observing modes) for a subset of the array, expansion of frequency coverage (bands KQWD)**
  - Current: KVN^{KQWD} +Yebes^{QW}
  - Future: KVN4^{KQWD} +On^{KQW}+Mh^{KQW}+Eb^{KQW} + SRT^{KQW}+Nt^{KQW}+Mc^{KQW}+T6^{KQW}
  - Following ngVLA^{KQWD} development (covers until D-band)

ROLE OF BIG COLLABORATIONS, EXPERTISE

Ground arrays and correlator with experienced teams

Examples: orbit determination of VSOP and correlation teams, revision of DiFX correlation for RadioAstron

Pre-launch survey and connection to large collaborations addresing the same objects (e.g., Fermi/LAT collaboration, MAGIC collaboration, MOJAVE team)

Building new structures

e.g., Global VLBI Working Group for VSOP

Addressing logistical issues

e.g., out-of-session observations needed for the arrays to match space missions

Success story: formation of Key Science Project teams at RadioAstron (e.g., Polarisation, Nearby Galaxies, Scattering, Pulsars), building on existing expertise

ROLE OF BIG COLLABORATIONS, EXPERTISE

teams

ation teams, revision of DiFX correlation for RadioAstron

aborations addresing the same objects (e.g., MOJAVE team)

e.g., out-of-session observations needed for the arr

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FINAL REMARKS

Successful space VLBI builds in the decade-long expertise in VLBI operations, both for ground support and operations, and for organization

Different astronomical techniques, and especially (but not only) mm-VLBI (i.e., GMVA and EHT) address the high (and extreme) T_b science