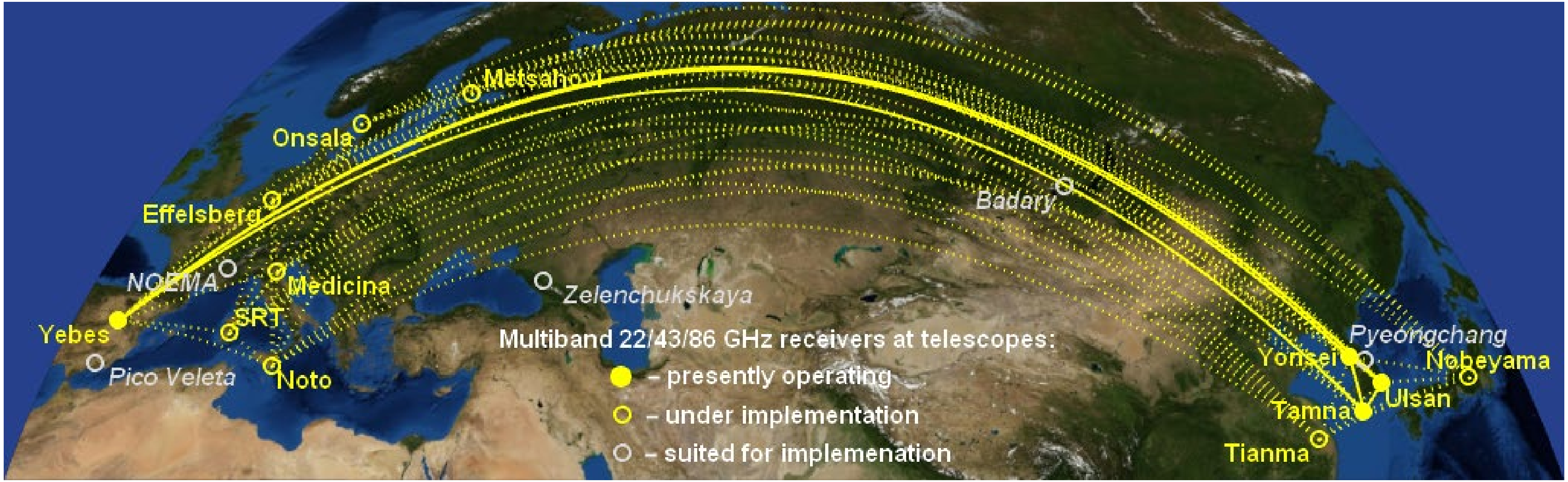
RADIO ASTRONOMY WITH MULTIBAND RECEIVERS AND FREQUENCY PHASE TRANSFER:

Scientific Perspectives

Report from Workshop held in Bonn on 12-14 October 2022



Richard Dodson[1], Cristina García-Miró[2], Marcello Giroletti[3], Taehyun Jung[4], Michael Lindqvist[5], Andrei Lobanov[6], Maria Rioja[7,1,2], Eduardo Ros[6], Tuomas Savolainen[8], Bong Won Sohn[4], Guang-Yao Zhao[9]

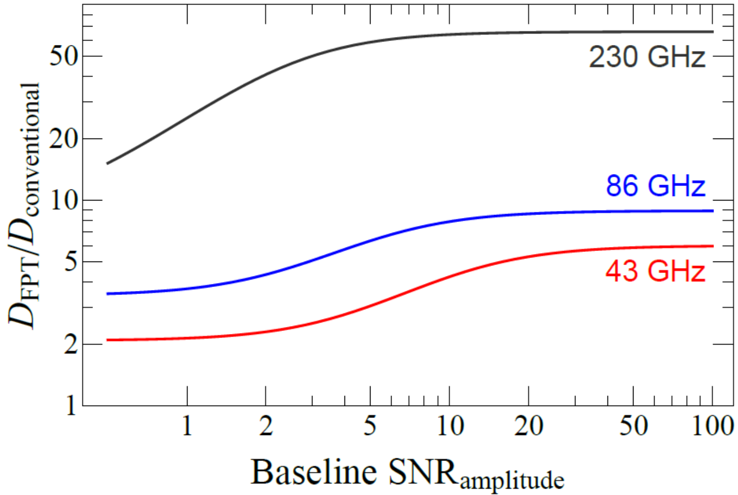
IMPACT OF FPT AND SFPR FOR VLBI AT 86 AND 230 GHZ

- **Frequency phase transfer should provide**
  - Arguably the most efficient way to achieve the required improvement of the dynamic range of the EHT and GMVA imaging
  - Strong imaging capability at 86 GHz with the KVN + (up to) 6 European antennas, surpassing image sensitivity of present day GMVA and reaching an effective image resolution of ~20 μas for M87
  - Astrometric accuracy of <10 μas, with SFPR

Phase noise in conventional and FPT (highlighted) VLBI

Major VLBI arrays operating at mm-wavelengths										
Array	43 GHz		86 GHz		132 GHz		230 GHz		345 GHz	
	SEFD	σ_{ph}	SEFD	σ_{ph}	SEFD	σ_{ph}	SEFD	σ_{ph}	SEFD	σ_{ph}
KVN	1110 Jy	5°	1862 Jy	10°	3436 Jy	15°		*30°*		*40°*
GVLBI	25 Jy	10°								
GMVA			86 Jy	30°						
GMVA+ALMA			50 Jy	20°						
EHT							675 Jy	100°	780 Jy	100°
EHT+ALMA							185 Jy	25°		

Dynamic range improvement expected for FPT VLBI



EXPECTED SCIENTIFIC IMPACT FROM FPT VLBI

- **FPT VLBI at 86/230 GHz will have a strong impact in a broad range of scientific areas:**

Science Area	Main Goals	Impact Level
Cosmology	Hubble constant measurements with local galaxies at distances up to ~100 Mpc	Unique
Galactic dynamics	Direct proper motion and parallax measurements at distances up ~100 kpc	Unique
Galactic dynamics	Most accurate determination of Solar motion inside the Galaxy and with respect to the CMB reference frame	Unique
Stellar astrophysics	Co-location and physics of different maser species	Unique
Black hole physics	Event horizon tests with magnetic field measurements	Critical
Black hole physics	Photon ring and disk-jet connection studies	Critical
Black hole physics	Dynamic imaging of photon-ring and inner jet in M87	Critical
Black hole physics	Hot spot motion in Sgr A*	Essential
GW and Transients	Localizations and followups of TDE, VHE flares and gravitational wave and neutrino detections	Essential
Binary SMBH	Orbital motion of radio loud companion in binary SMBH	Essential
AGN and jet studies	Synchrotron spectrum and rotation measure imaging	Essential

PRESENT STATUS OF MULTIBAND RECEIVERS FOR FPT VLBI

Antenna	Receiver Band				
	22 GHz	43 GHz	86 GHz	130 GHz	230 GHz
KVN: Yonsei	in operation	in operation	in operation	in operation	(clarify)
KVN: Ulsan	in operation	in operation	in operation	in operation	
KVN: Tamna	in operation	in operation	in operation	in operation	
KVN: Pyeongchang	*planned*	*planned*	*planned*	*planned*	*planned*
Yebes	in operation	in operation	*in operation*		
ATCA *	in operation	in operation	in operation		
Noto	*in 2023/Q2*	*in 2023/Q2*	*in 2023/Q2*		
SRT	*in 2023/Q2*	*in 2023/Q2*	*in 2023/Q2*		
Medicina	*in 2023/Q4*	*in 2023/Q4*	*in 2023/Q4*		
Effelsberg	*in 2024/Q2*	*in 2024/Q2*	*in 2024/Q2*		
Onsala	*design*	*design*	*design*		
Metsahovi	*proposed*	*proposed*	*proposed*		
Tianma	*planned*	*planned*	*planned*		
Nobeyama	*planned*	*planned*	*planned*		
Mopra	*planned*	*planned*	*planned*		
Pico Veleta	*possible*	*possible*	*under tests*	*possible*	*under tests*
NOEMA	*possible*	*possible*	*possible*	*possible*	*possible*
APEX	*possible*	*possible*	*possible*	*possible*	*possible*
Zelenchukskaya	*possible*	*possible*	*possible*		
Badary	*possible*	*possible*	*possible*		

* - limited frequency range

TECHNICAL IMPLEMENTATION OF FPT VLBI

- **Dedicated efforts at participating telescopes and observatories**
  - Compilation, assessment, and revision of technical specs of existing and planned triple band (22/43/86 GHz) receivers.
  - Special attention to band specifications (minimally accepted frequency ranges) and polarization performance.
- **Maximizing the common framework of receiver design**
  - Addressing all design aspects not affected by local factors (focal cabin dimensions, illiumination, etc.).
- **Recorders and backends**
  - Will strongly benefit from adopting a common approach. Coordination between EVN TOG and GMVA Technical Group is desired.

ORGANIZATIONAL IMPLEMENTATION OF FPT VLBI

- **FPT VLBI will move on from *ad hoc* experiments to regular observations**
  - FPT VLBI will likely become the standard mode of operation at frequencies above 43 GHz.
  - Provisions for carrying out regular FPT VLBI observations need to be jointly out of existing VLBI frameworks provided by the EVN, GMVA, and Global VLBI.
  - Enhanced flexibility of scheduling will be one of the prime issues to be addressed.
- **Data correlation and pipelining**
  - Continued access to a correlator facility and reliable pipelining of data will be critical.
  - The EVN and MPIfR correlator facilities can accommodate present needs. Dedicated effort and funding will be needed in the future.

CONCLUSIONS AND RECOMMENDATIONS

- **FPT VLBI presents ample scientific opportunities and it is important for the EVN institutes to engage in this area of research.**

- **Continued, active information exchange on all aspects of technical implementation is critical.**
  - Forming a dedicated Technical Working Group on FPT VLBI should be considered.
  - Initiating regular test observations would help optimizing the performance and bringing new telescopes into the forming FPT VLBI network.

- **Further developing the science case for FPT VLBI**
  - Science Working Group should be formed with the prime goal of exploiting the full scientific potential of FPT VLBI.
  - The SWG should work in close contact with the TWG (or EVN TOG, GMVA TG).