mm-VLBI with Multiband Receivers and Frequency Phase Transfer

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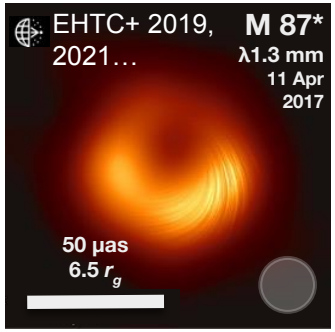
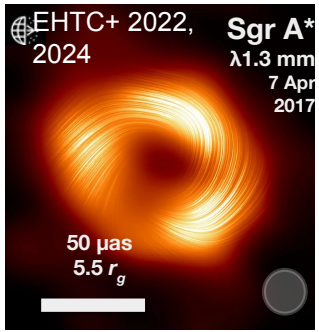
Outline

- Shared optical path (SOP) receivers & frequency phase transfer (FPT)
- An emerging global mm-VLBI network with triple-band receivers *at 22/43/86 GHz*
- Result from a pilot dual-band *(22/43 GHz)* observing campaign in 2018 with EAVN+Yebes
  - Dual-band images with eht-imaging library
  - Source-frequency phase-referencing (SFPR) & core-shift measurements
- Upcoming high-frequency FPT tests with APEX-IRAM 30m

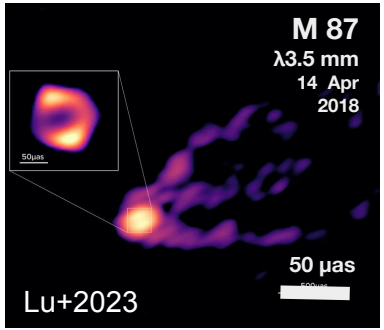
The quest for high resolution
Probe closer to the central engine

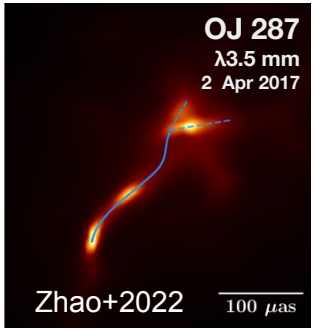
BH shadows





Innermost jets



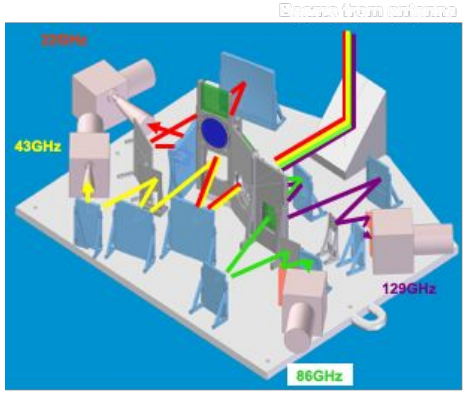


Challenges!!

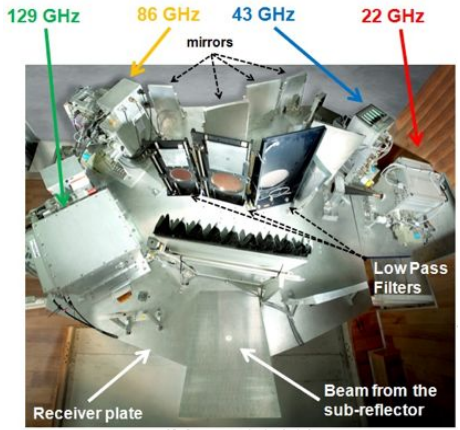
Frequency (GHz)	2	8	15	22	43	86	129
Coherence Time (sec)*	800	200	100	73	37	19	12

- **Turbulent** atmospheric conditions
  - **Shorter** coherence times
- **Limited** number of sites
  - **Sparse** (u,v) -coverages
- **Weaker** targets
  - Much **less** sources detectable

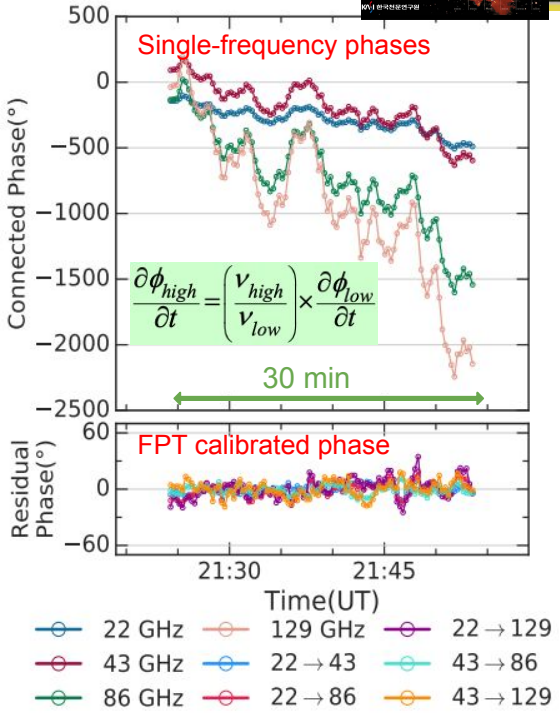
mm-VLBI: the KVN approach



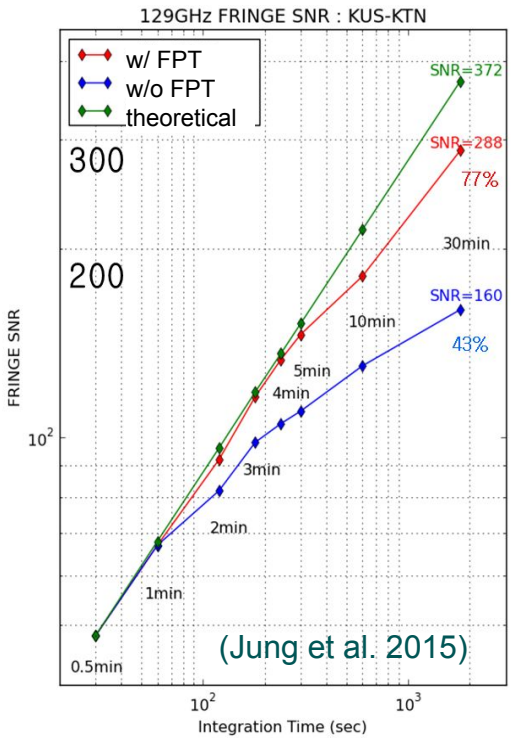
KVN Multi-Frequency System



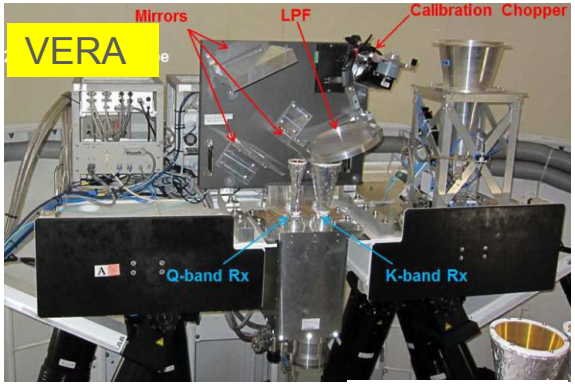
(Han+2013)



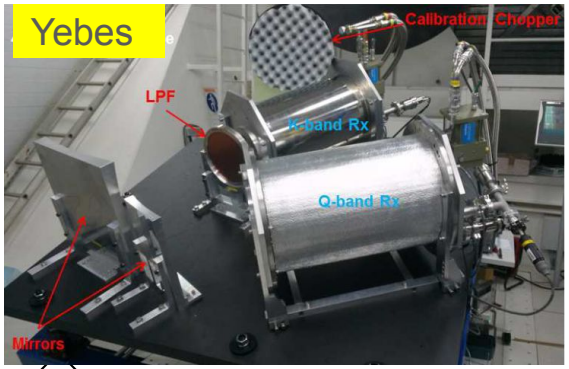
The non-dispersive nature of tropospheric effects



More VLBI facilities with shared optical path receivers

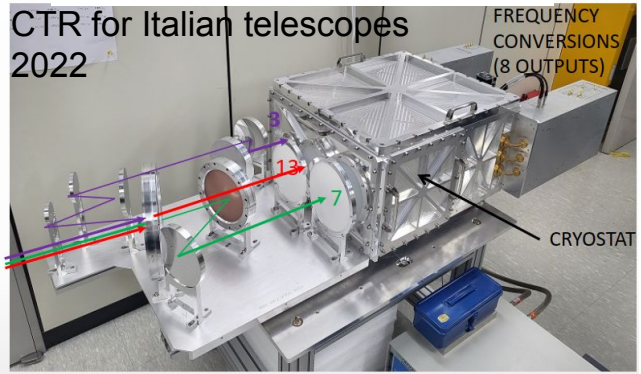


(Han S.T.)

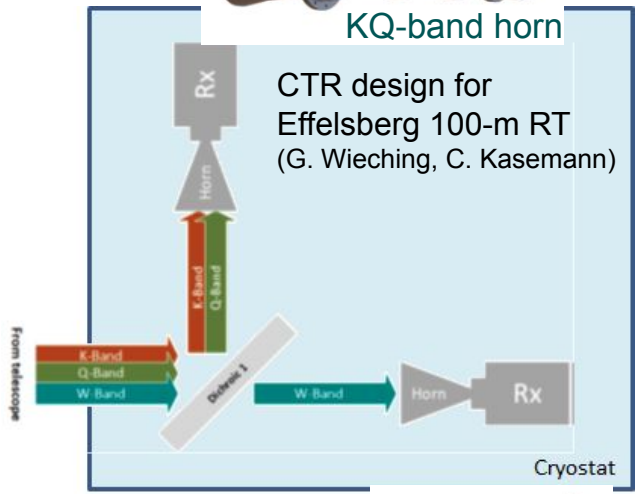


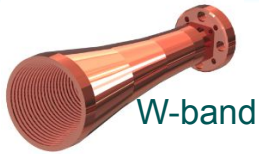
Compact Triple-band Receiver

(Han 2018)



KQ-band horn





W-band horn

(Eduardo's talk at 14:55)

Plans for triple-band receivers in Eurasia

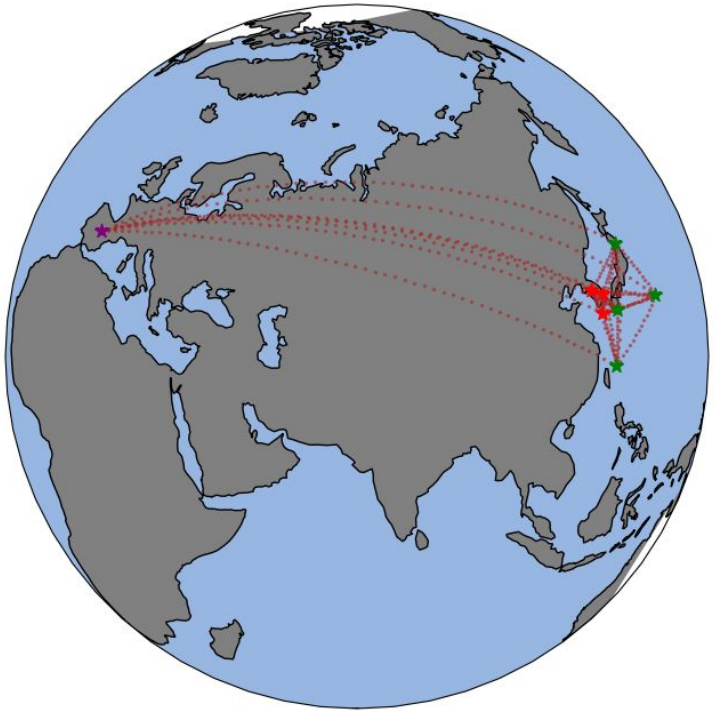
KQW
22/43/86 GHz

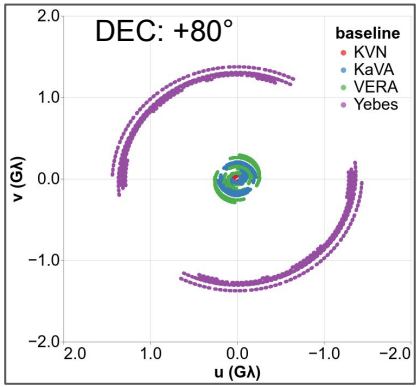
KQWD
22/43/86/129 GHz

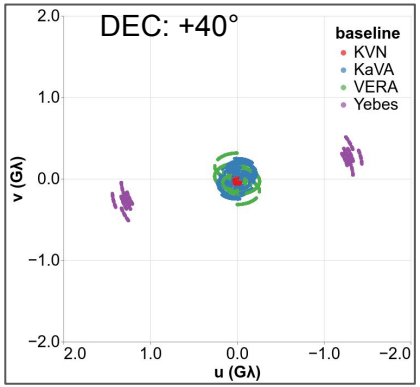
2022 workshop report: arXiv:2306.04516

A pilot observing campaign in 2018 with EAVN+Yebes:

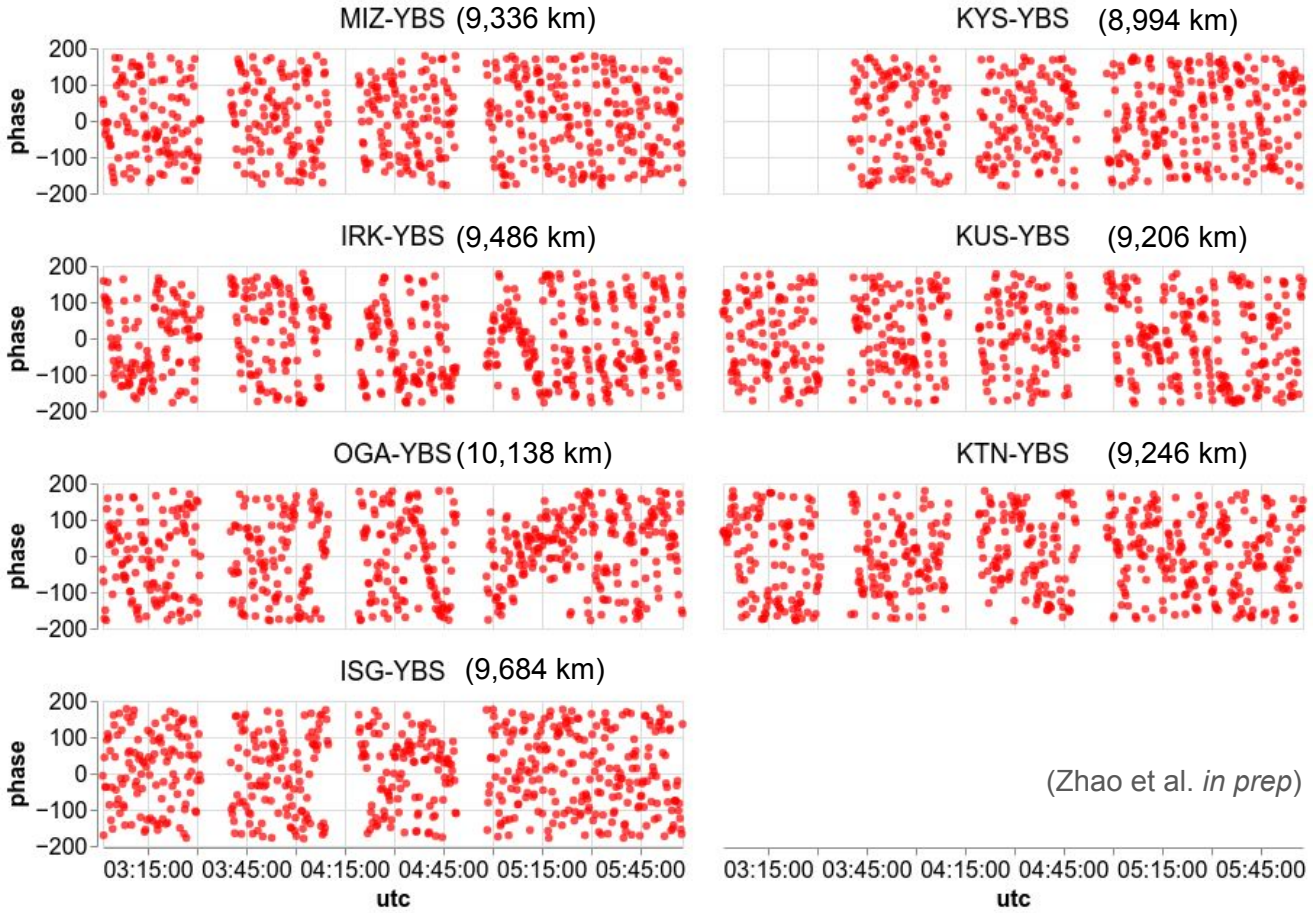
- Array:
  - ★ 3 KVN (KYS, KUS, KTN);
  - ★ 4 VERA (MIZ, IRK, OGA, ISG);
  - ★ Yebes 40-m RT
- Frequencies: 22.1 GHz (K), 42.8 GHz (Q)
- Bandwidth: 2 * 128 MHz; (1 Gbps, single pol)
- Dates: March 16-18, 2018
- Targets: 0716+714 & 0836+710; 4C39.25&0917+449&0945+408







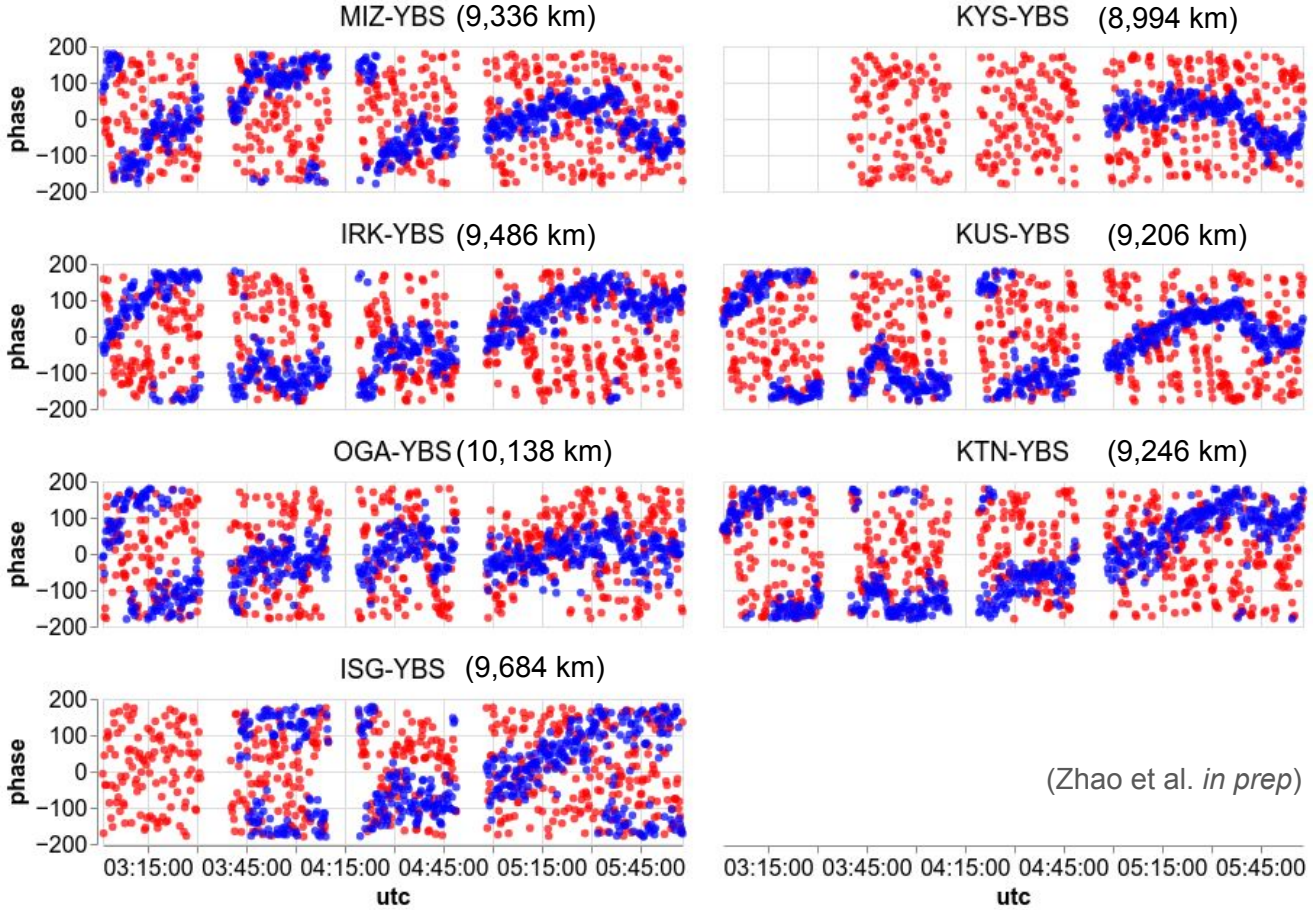
43 GHz phases on Yebes baselines



43 GHz (7 mm) phases of 0716+714 on Yebes beselines

(Zhao et al. *in prep*)

43 GHz phases on Yebes baselines



43 GHz (7 mm) phases of 0716+714 on Yebes beselines

(Zhao et al. *in prep*)

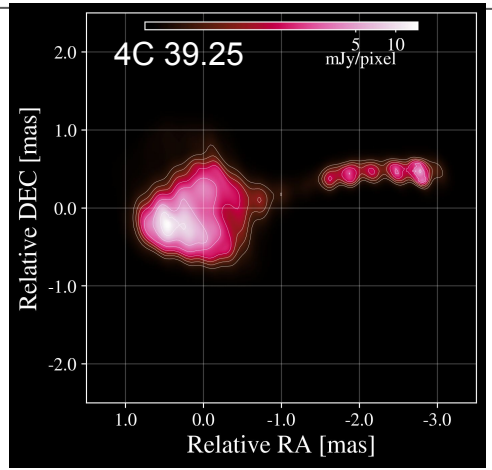
Dual-band images

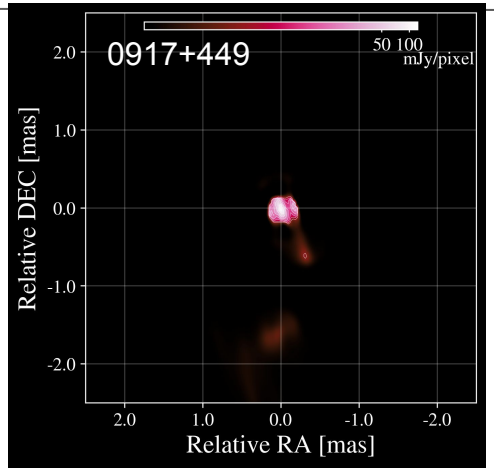
eht-imaging library

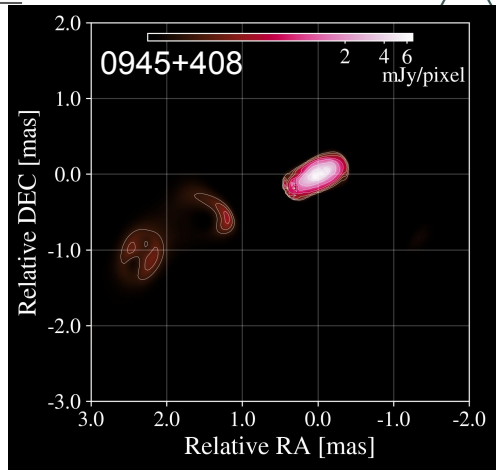
22.1 GHz (K)

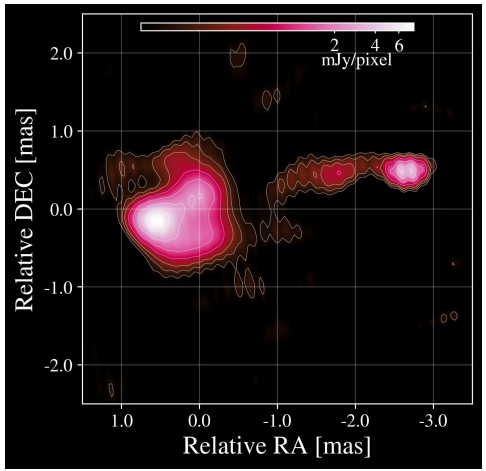
42.8 GHz (Q)

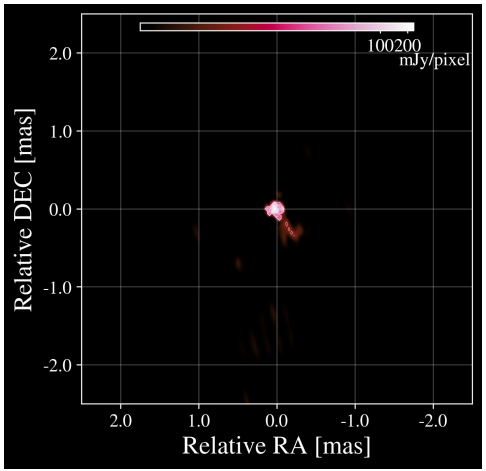
(Zhao, Jung et al. *in prep*)

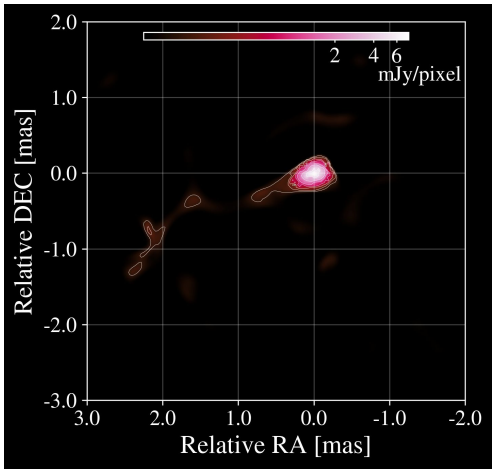




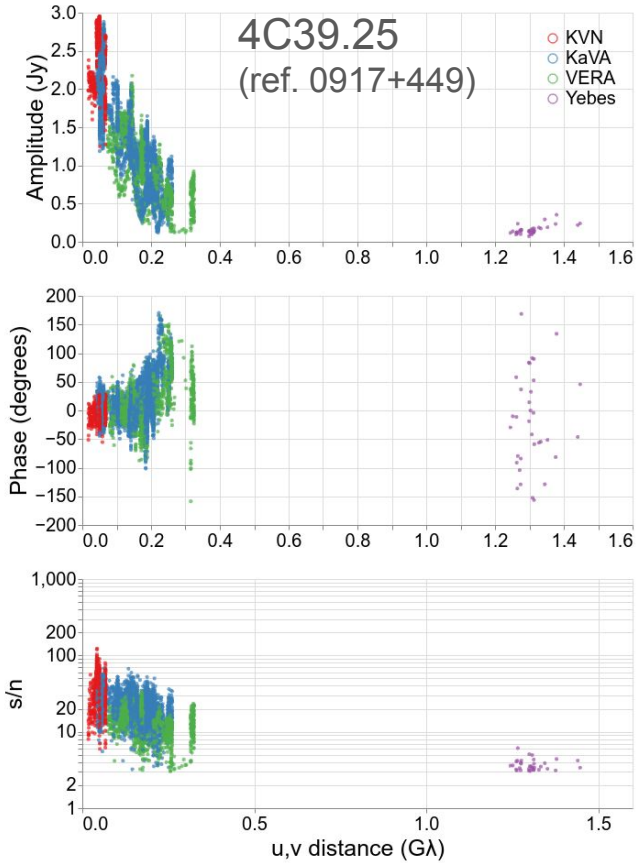








SFPRed visibilities



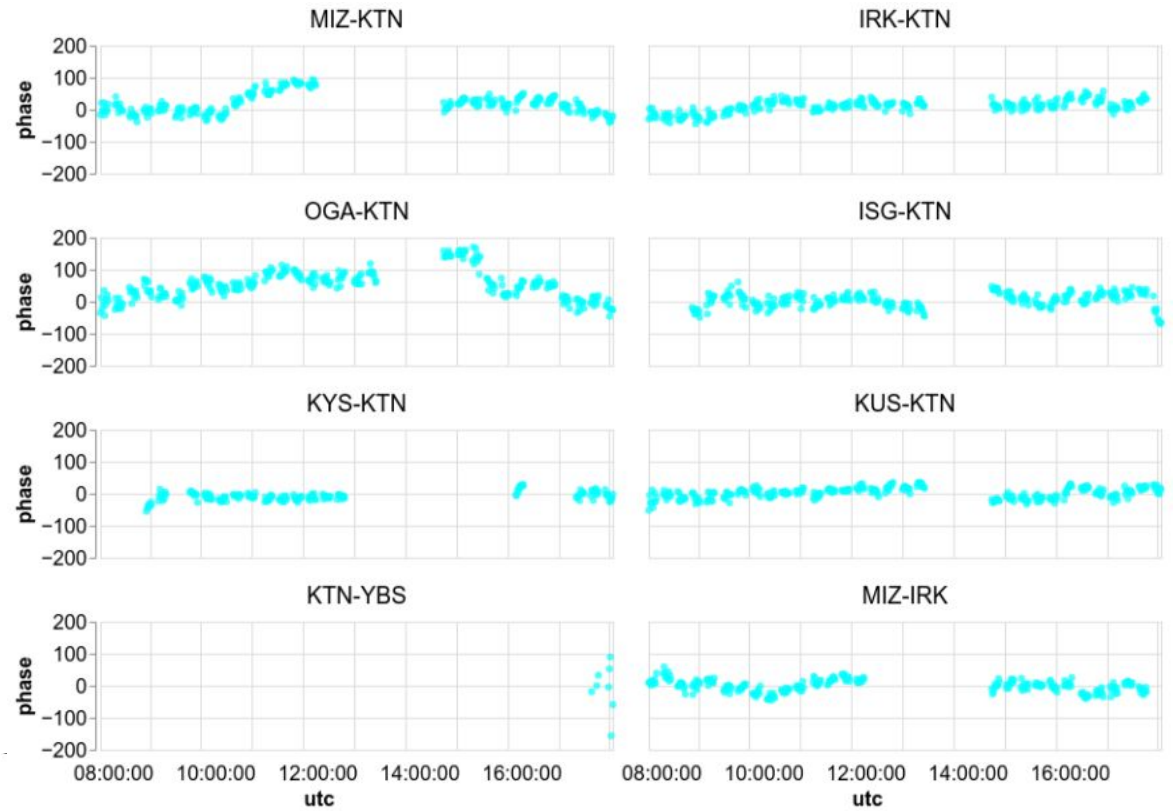
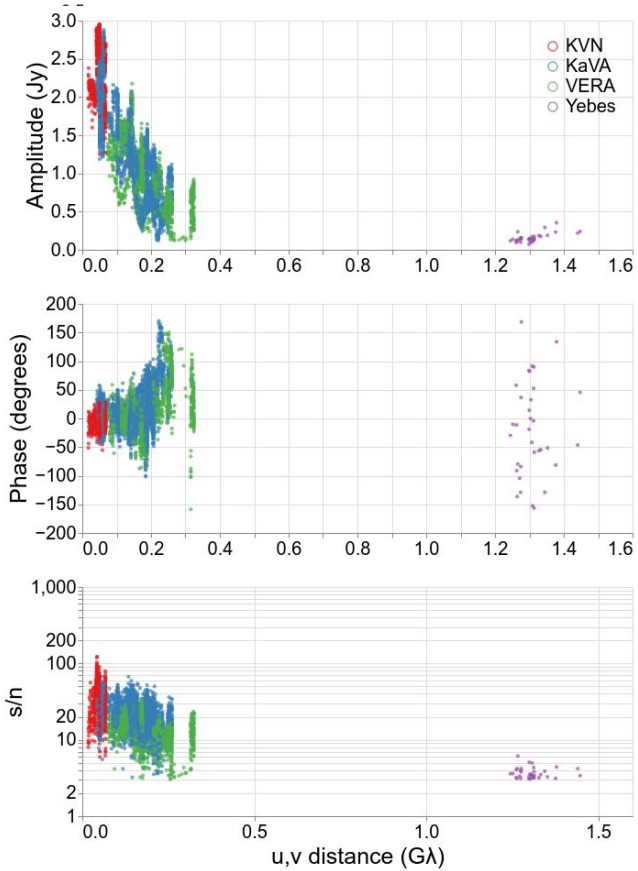
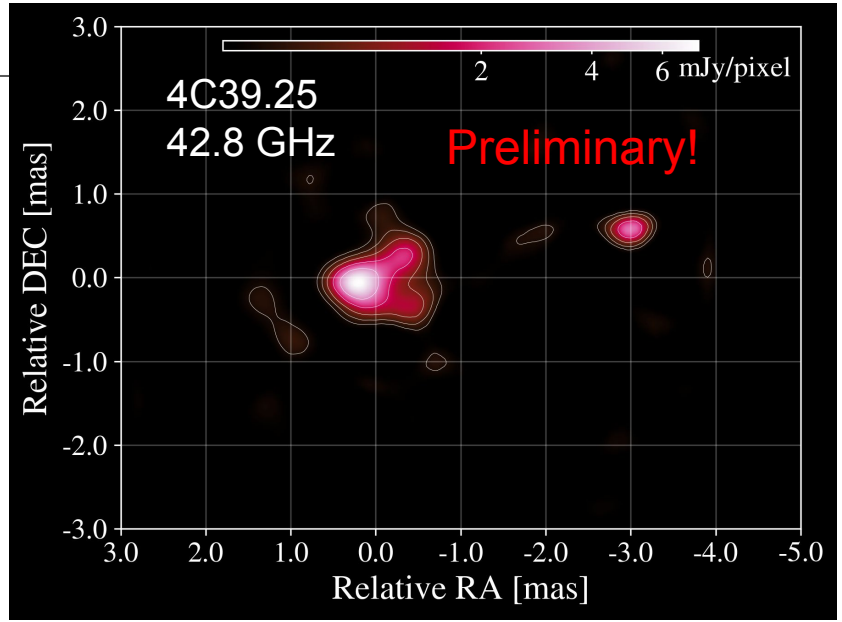


Image reconstructions





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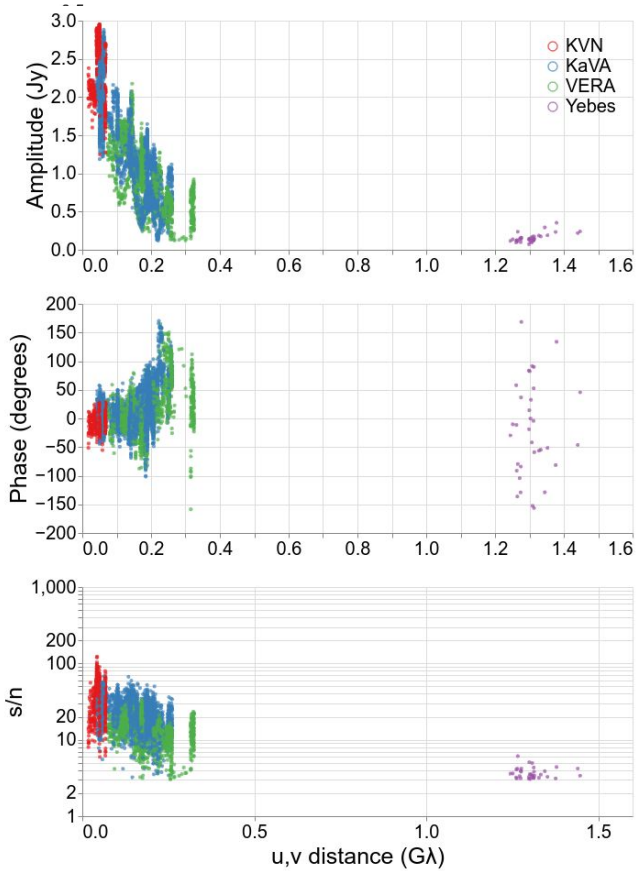

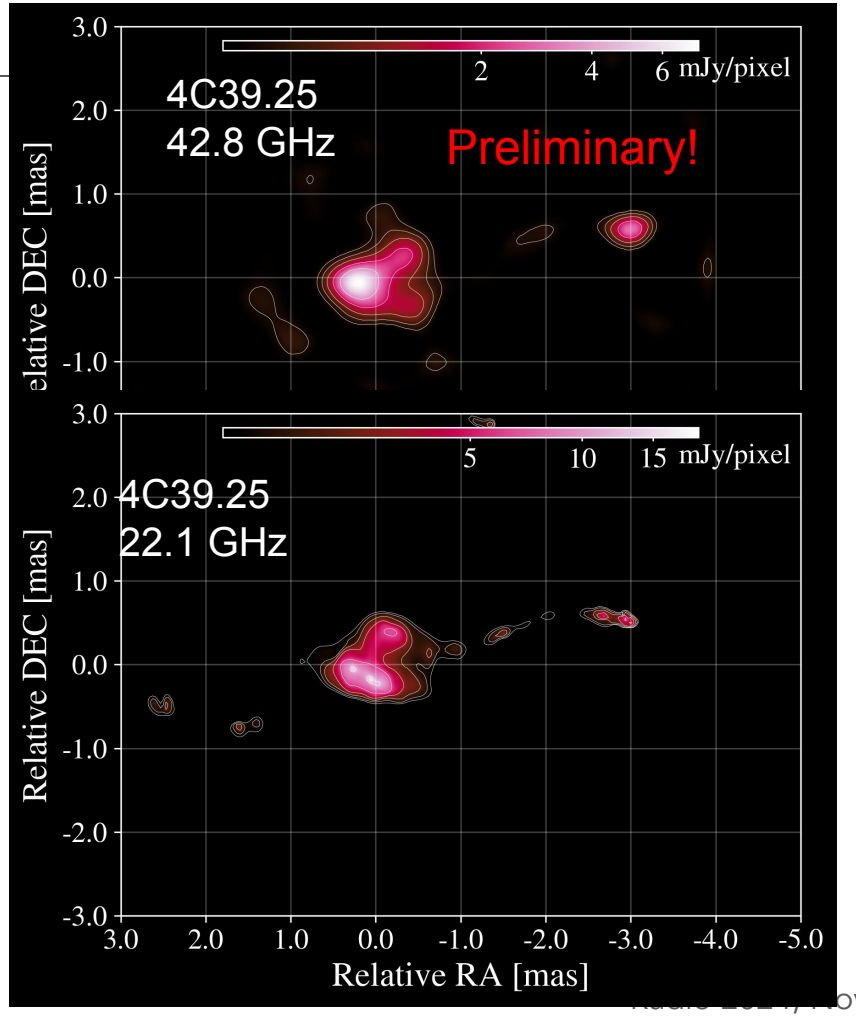

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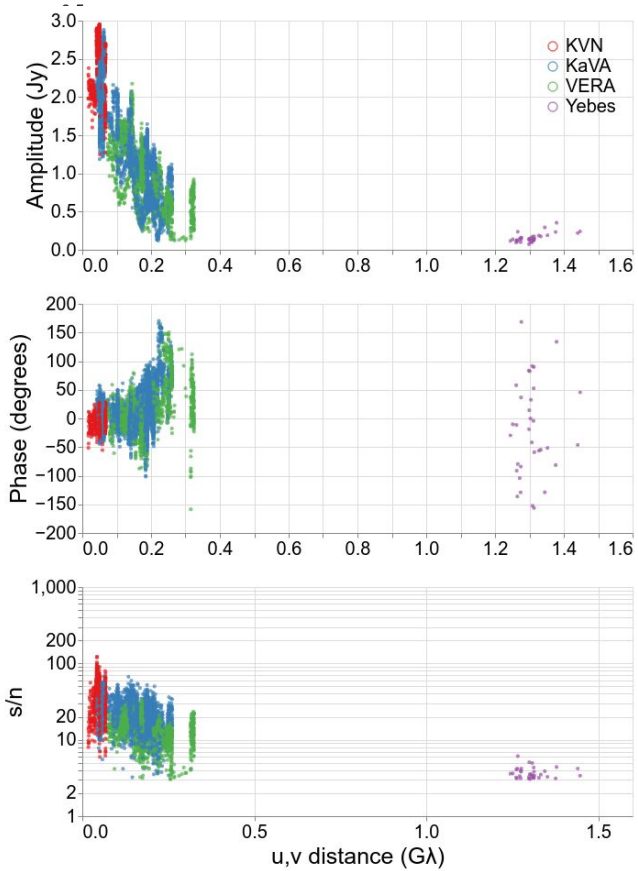
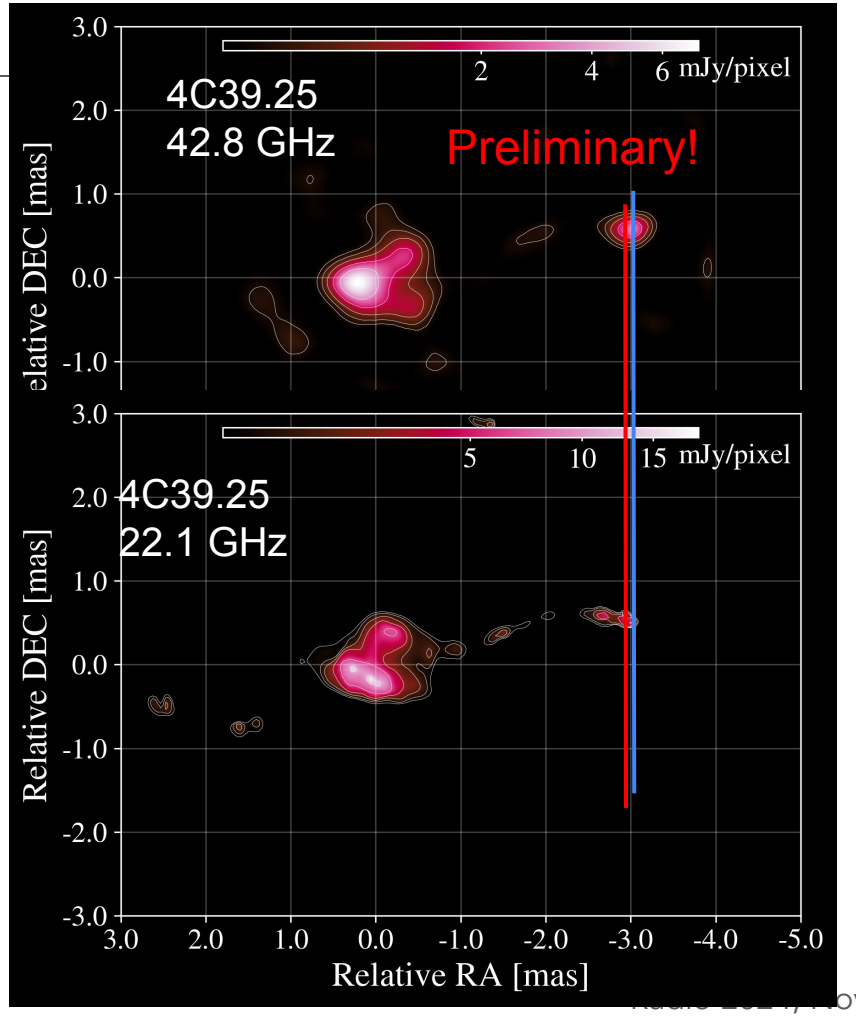
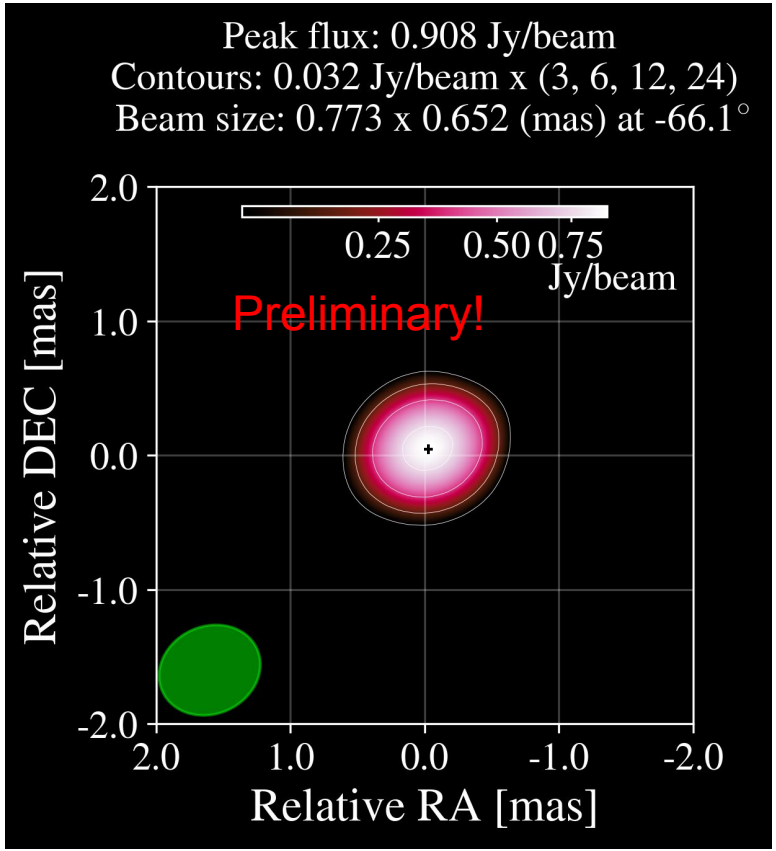




SFPR error estimation

- Subtract the model from visibility data
- Add phase noise
  (using equations in Rioja&Dodson 2011)
  - *Tropospheric* **~0°**
  - *Dynamic ionospheric* $\propto \theta_{separation} * T_{switch}$ **~ 10°**
  - *Static ionospheric* $\propto \theta_{separation} * \Delta TECU$ **~ 35°**
  - *Instrumental* **< 5°**
  - *Thermal noise* **~ 4°**
- Model-fitting with a point source,and calculate the error with *beam/SNR:*
  62±26 μas



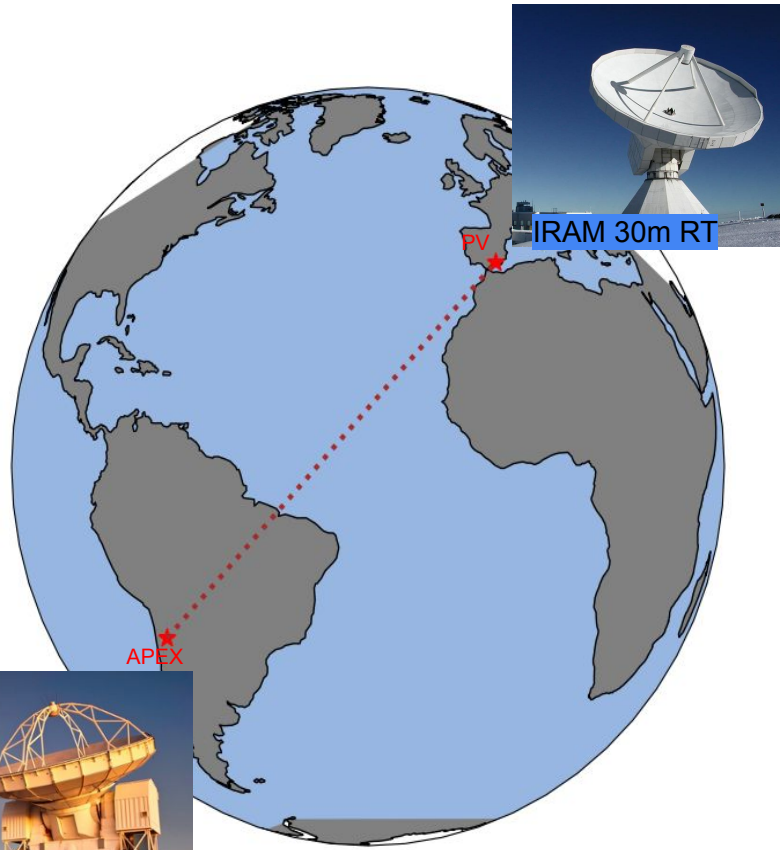
(Zhao, Jung et al. *in prep*)

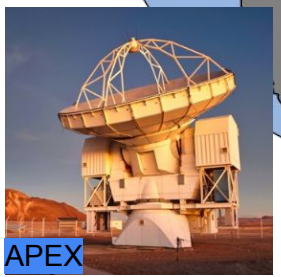
Upcoming FPT test with APEX-PV at 86/258 GHz

- 4 hours during Nov. 19-22, 21:00-01:00 UT
- Simultaneous dual-band receiving systems
- Integer ratio (=3) between frequencies
- 7.5 Gλ (25 μas) at 258 GHz
- Targets: 3C 454.3, BL Lac, CTA 102 …

Pilot study for future dual-band observations with more EHT stations (e.g., NOEMA, OVRO, …)

- Improve the dynamic range of BH shadow images/movies
- Follow-up observations of transients (GRB, TDE, GW EM counterparts, radio SNe)





Take home messages

- FPT works on 10,000 km baselines (0.8 D_{Earth})!
- A global network of VLBI stations with triple-band receivers is being formed
- Pilot observations with a prototype array yield promising results
  - High-resolution images with eht-imaging library
  - Astrometric accuracy of 26 μas achieved
- FPT will soon be available at the highest frequencies for VLBI