EVN Future – Next Decade and Beyond

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Background

- Future vision needs a balance between realism and ambition
- Where were we in 2008?
- EVN decentralised structure makes it hard to 'steer' , hard to make big steps forward – but also impossible to destroy
- Relationship to other networks also makes planning harder; believe need stronger global collaboration in future for VLBI to continue to advance in age of SKA.

- Consider how best to exploit the collecting area we have or is soon on horizon

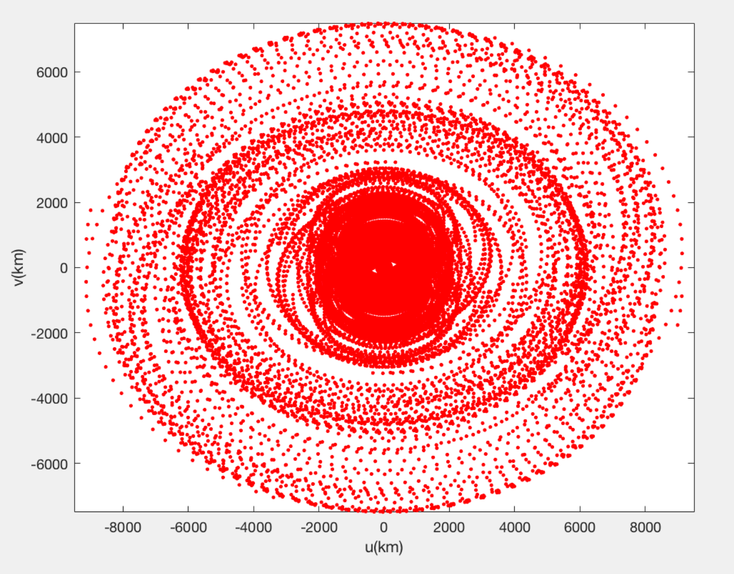
Dimensions of Improvement

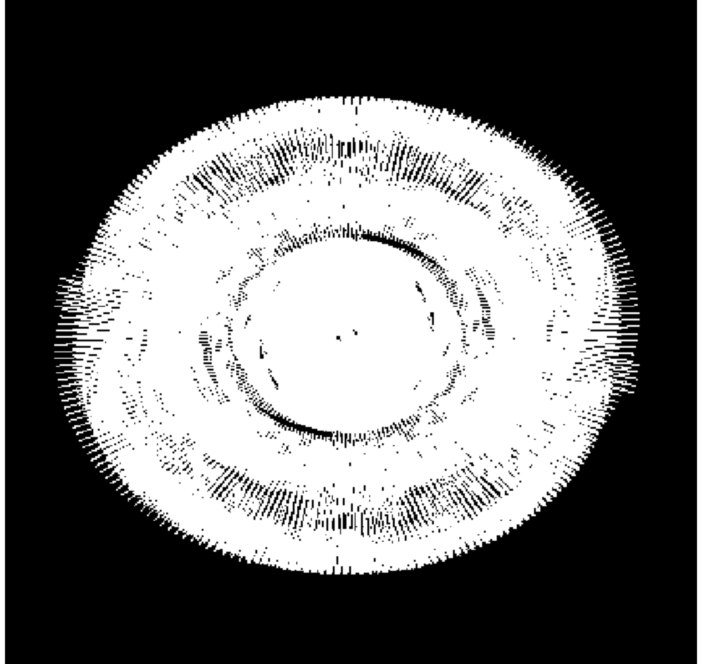
- Collecting area/uv coverage – FAST, SKA-mid, strategic places for new antennas Thailand, Middle East?
- Frequency Range - extend compatibility between networks, new frequencies (15GHz?)
- Bandwidth (2Gbps is 256 MHz spanned BW, SKA 512MHz L band 2GHz at C-band – VLBI 4 – 16 GHz (12GHz possible)
- Availability (EVN-light, more responsive)

- How to position/sell EVN/VLBI (as add on to SKA, or as SKA as add-on to VLBI) and as major facility in its own right. Also *VLBI as technology development beyond SKA1-mid.*

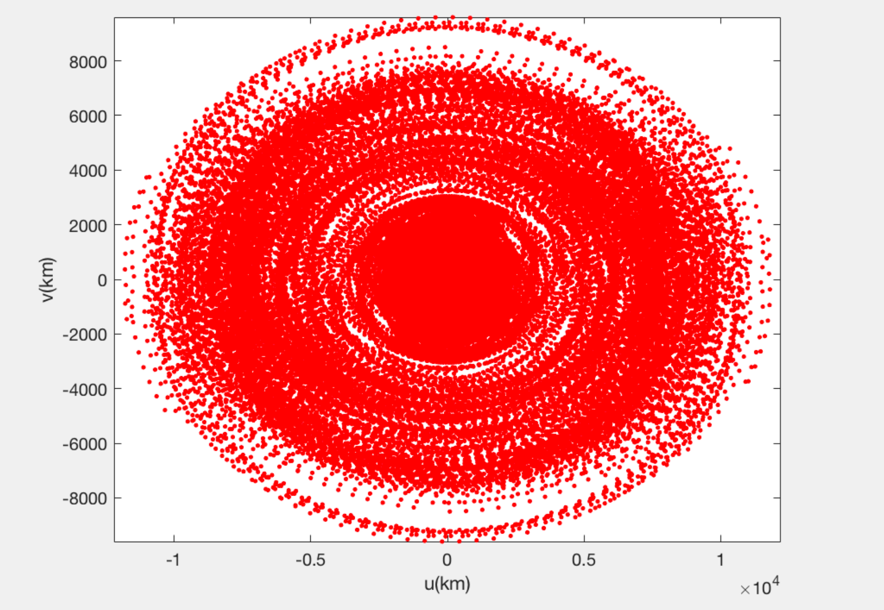
EVN today or soon(ish) uv coverage + sensitivity

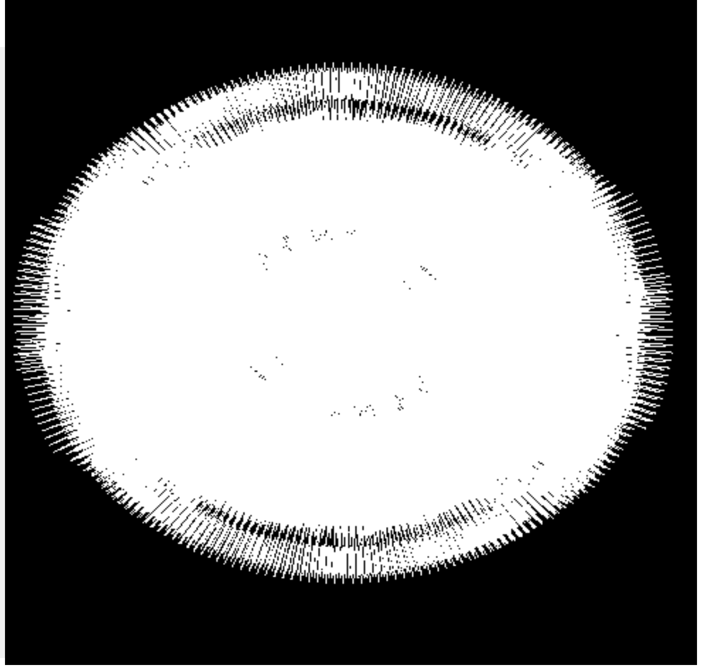
EVN C-band. + eMERLIN 18 stations Single frequency and 2Gbps (256MHz or 5% BW)

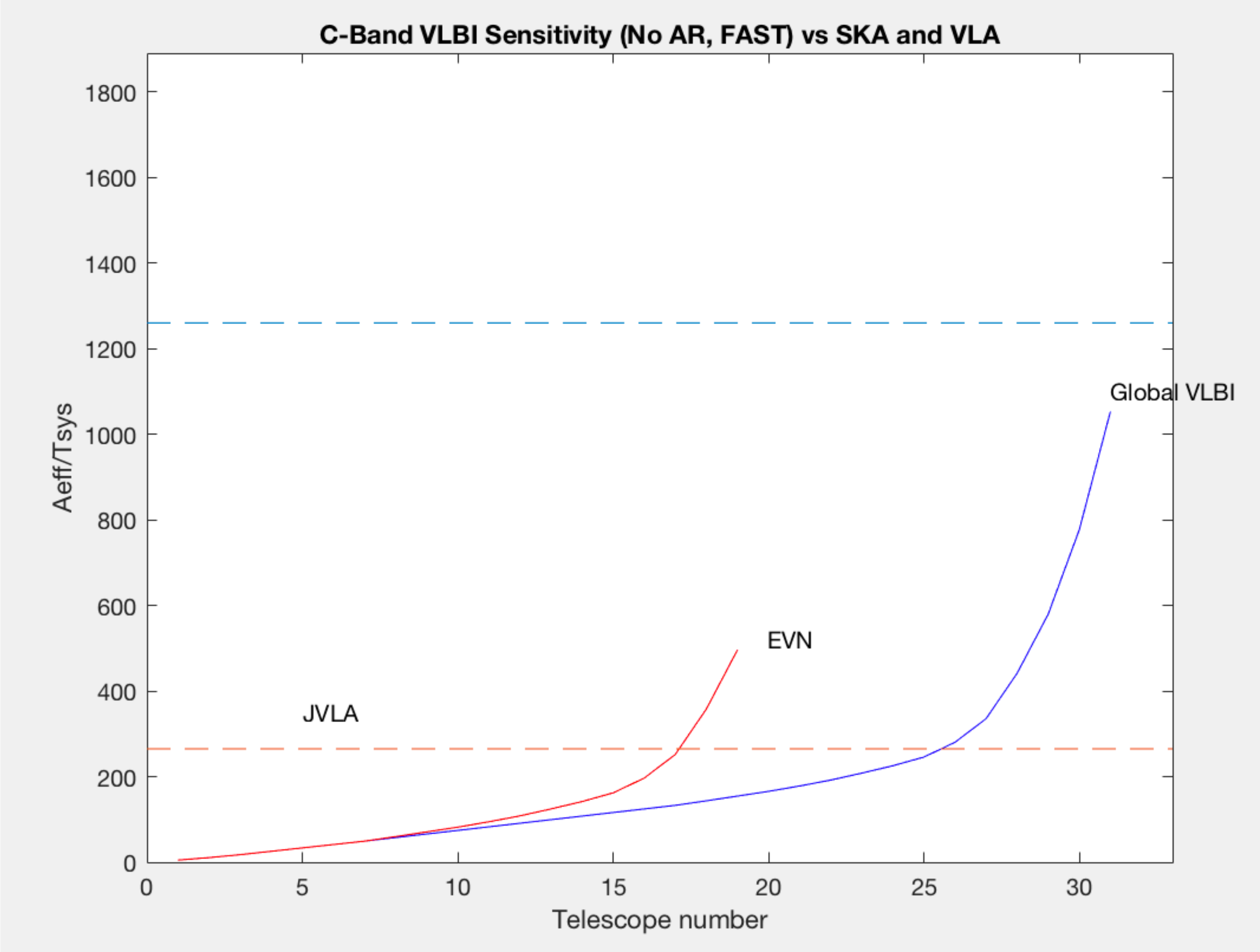




Global C-band. 30 station Single frequency and 2Gbps (256MHz or 5% BW)



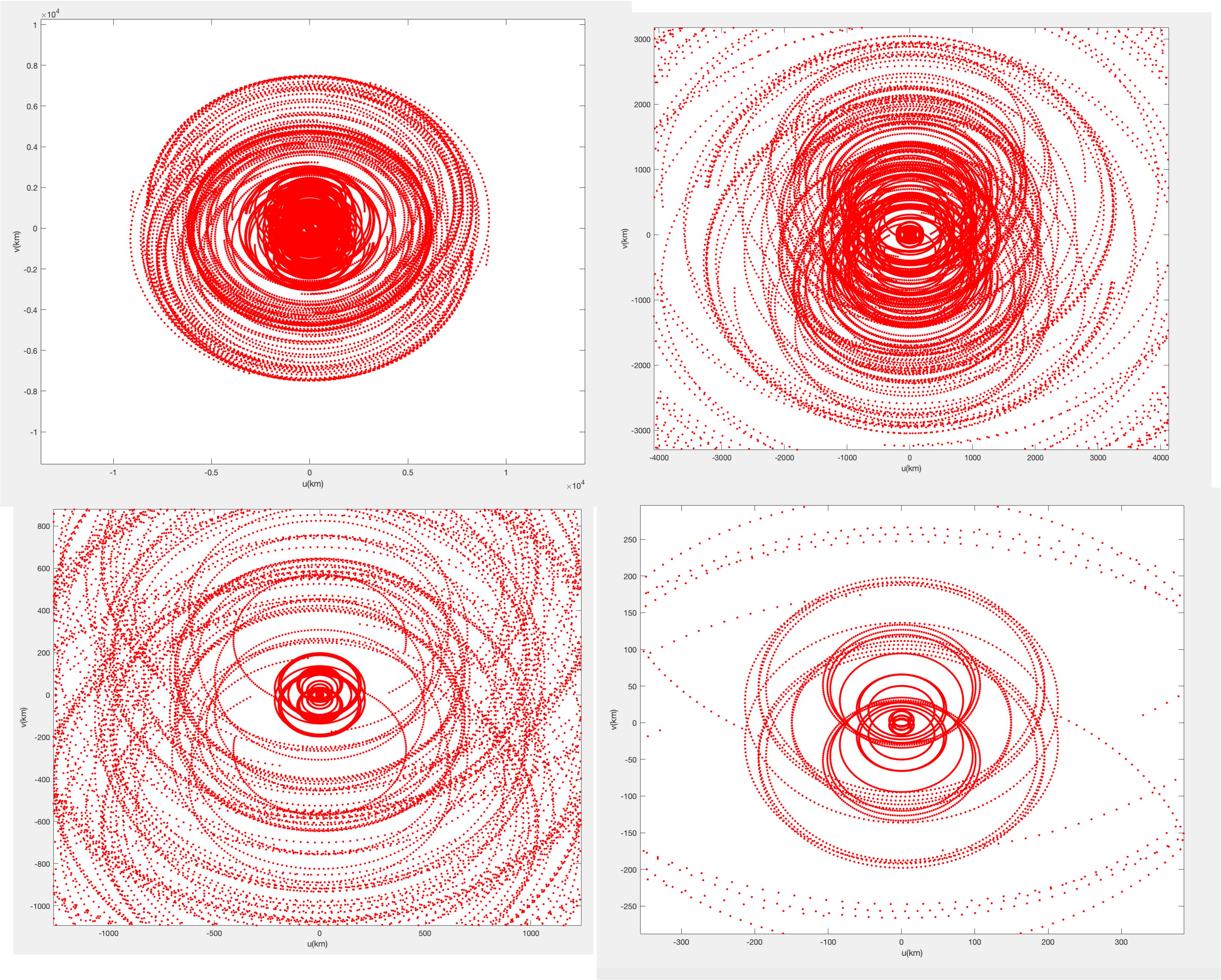




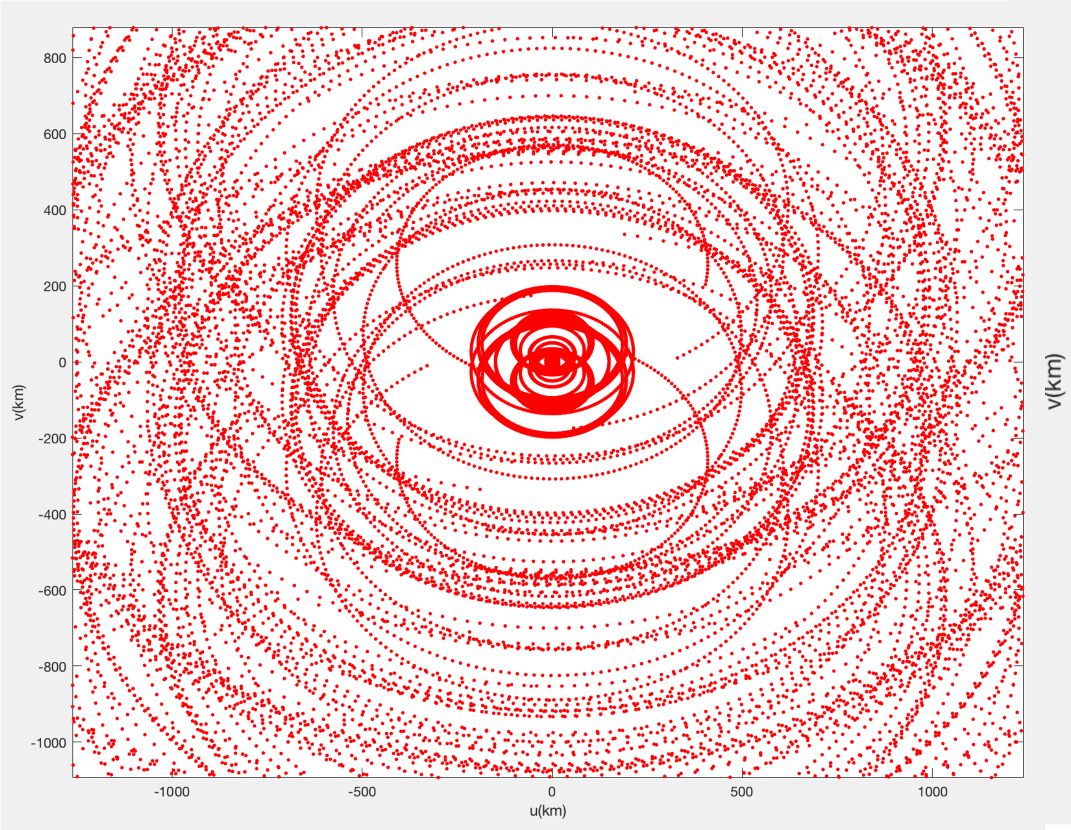
Sensitivity plot (no Ar or FAST) – simple summing of Aeff/Tsys future version to estimate 'effective Aeff/Tsys' taking into mutual visibility down-weighting of sensitive antennas for reasonable effective uv coverage.

EVN + e-MERLIN Excellent Spatial dynamic range 8000km to 6km i.e >1000:1

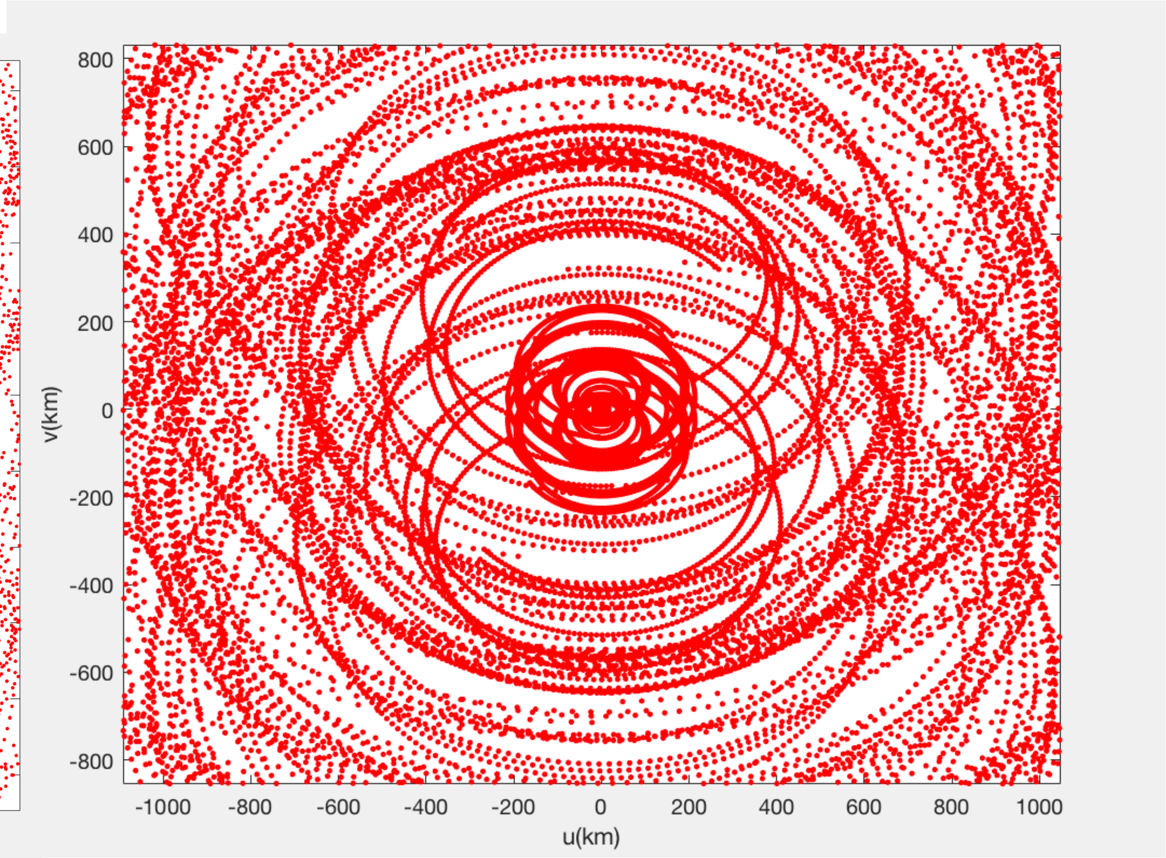
Like Multi array VLA (A+B+C) or SKA1.mid (check)



EVN+ MERLIN



Global (single freq, with MFS nearly complete)



Global VLBI promote as VLA-like coverage (25-30 station) but potentially with many times VLA sensitivity reaching within factor of 2 of SKA1-mid + spatial dynamic range of multi-configuration.

With MFS basically complete uv coverage(!). Change paradigm in peoples heads of VLBI being just sparse arrays! One thrust of my EWASS talk in Liverpool in April.

Growing Networks in Asia.

Recent Nature Astronomy Article on EAVN evolving out of KaVA

Future antennas i.e. Thailand will improve more.

Table 2 | Parameters of the EAVN telescopes

Subarray	Telescope name	Diameter of telescopes (m)	Frequency bands (GHz)								
			1.6	2.3	5	6.7	8.4	22	43	86	129
CVN	FAST	500	0.07-3								
	Kunming	40		●		●	●				
	Miyun	50		●			●				
	Sheshan	25	●	●	●	●	●	●			
	Tianma	65	1.25-50								
	Urumqi	26	●	●	●		●	●			
JVN	Gifu	11						●			
	Hitachi	32				●	●	●			
	Kashima	34	●	●			●	●	●		
	Takahagi	32				●	●	●			
	Usuda	64	●	●		●	●				
	Yamaguchi	32				●	●				
VERA	Iriki	20		●		●	●	●	●		
	Ishigakijima	20		●		●	●	●	●		
	Mizusawa	20		●		●	●	●	●		
	Ogasawara	20		●		●	●	●	●		
NRO	Nobeyama	45						●	●	●	
KVN, NGII	Sejong	22		●			●	●	●		
	Tamna	21						●	●	●	●
	Ulsan	21				6.4–9	●	●	●	●	●
	Yonsei	21						●	●	●	●

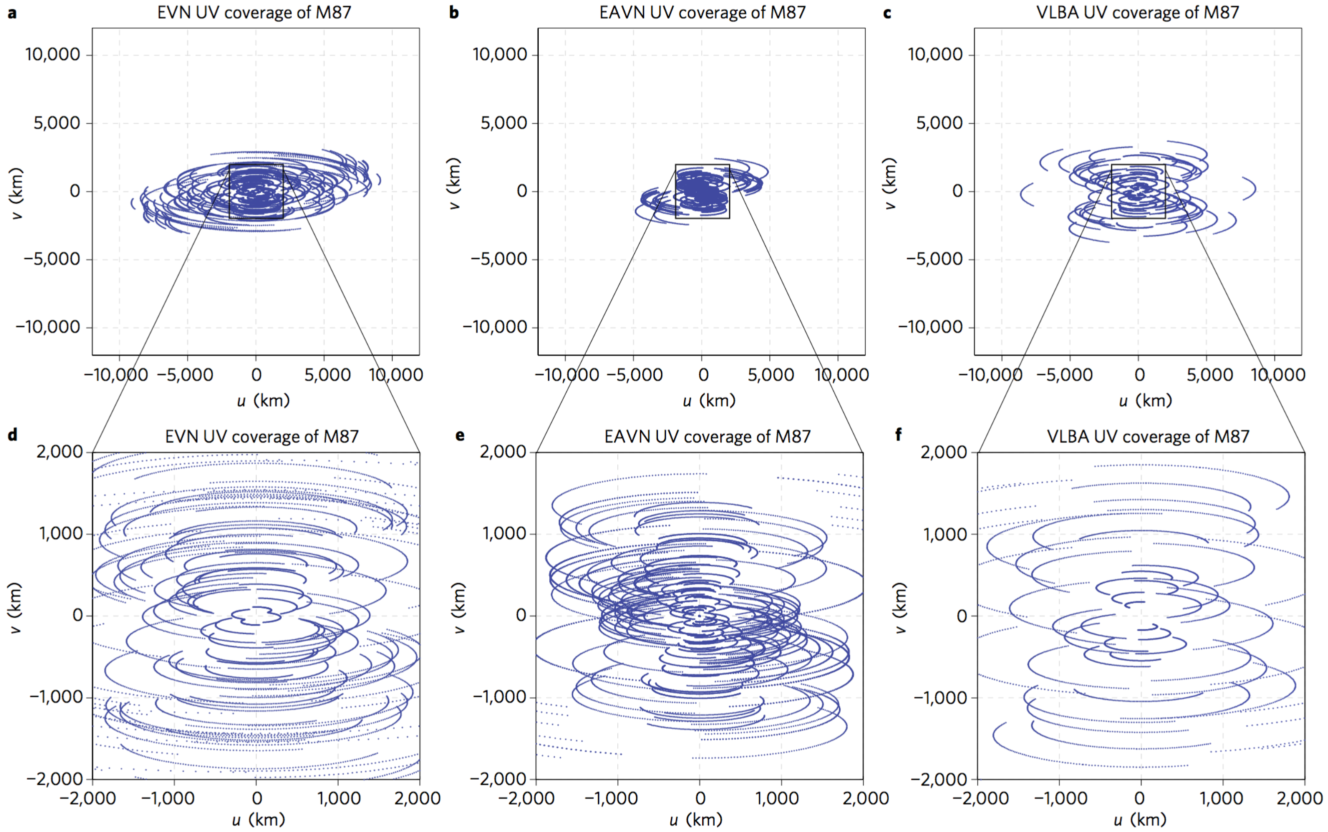
The operational frequency bands are marked with solid dots. The available frequency coverage in the early science phase of FAST is 0.07–3 GHz. The frequency coverage of the Tianma telescope is continuous from 1.25 up to 50 GHz. The Ulsan telescope has a broadband receiver at the 6.4-9 GHz frequency range.

Best overlap with EVN at 22GHz, 2.3GHz, 8GHz, 6.7GH – not so much overlap at 1.6 or 5GHz

An et al EAVN Paper

1.3cm uv coverages

Dec = +12



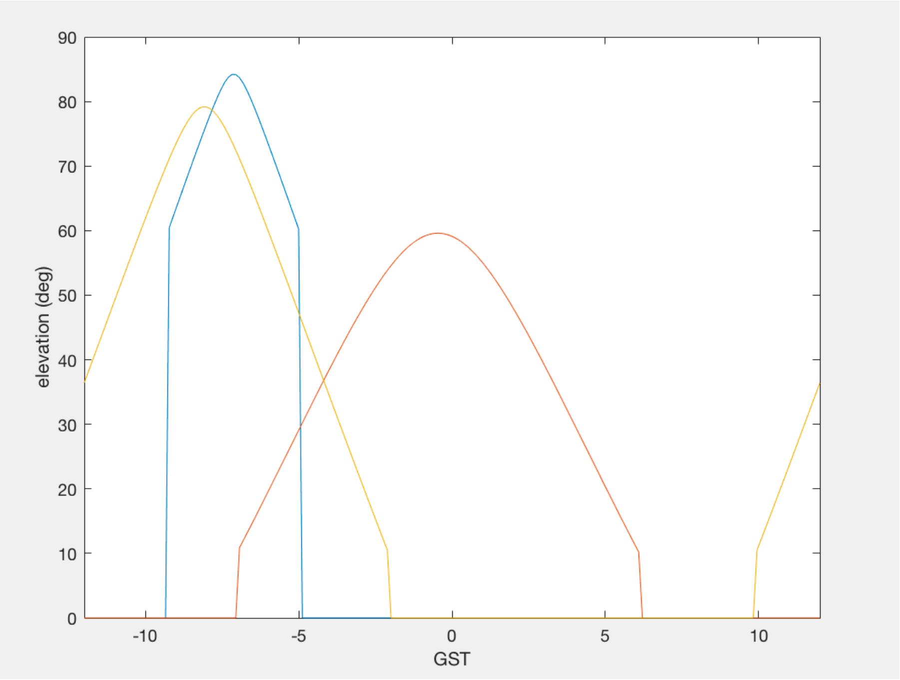
Idea of new mode of sub-array Global - separately observed/correlated for EVN, VLBA, EAVN combine later. If simultaneous some stations correlated as part of two arrays (some VLBA stations correlated with EVN) - and existing joint EVN/EAVN.

Relative to true global just lose some inter network (very long) baselines For dec <40 these anyway mosty in EW direction only. More manageable logistics/correlation than true global.

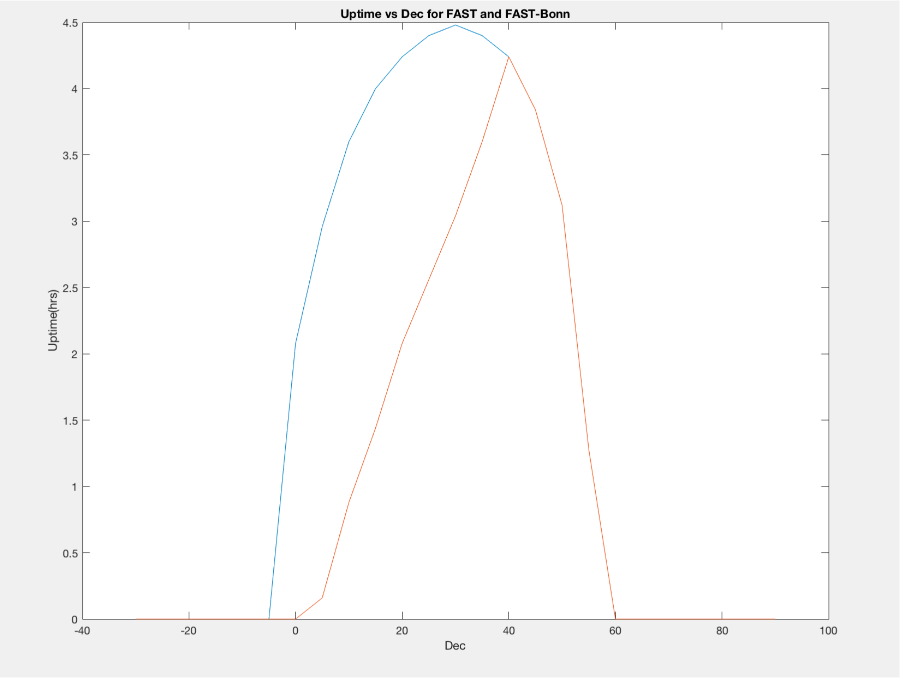
Advantage 3 times the uv coverges, **Disadvantage** 3 times fewer obs, what is tradefoff for VLBI science output? Probably Globals (traditional or subarray-type will only for small fraction of highest prority observations?)

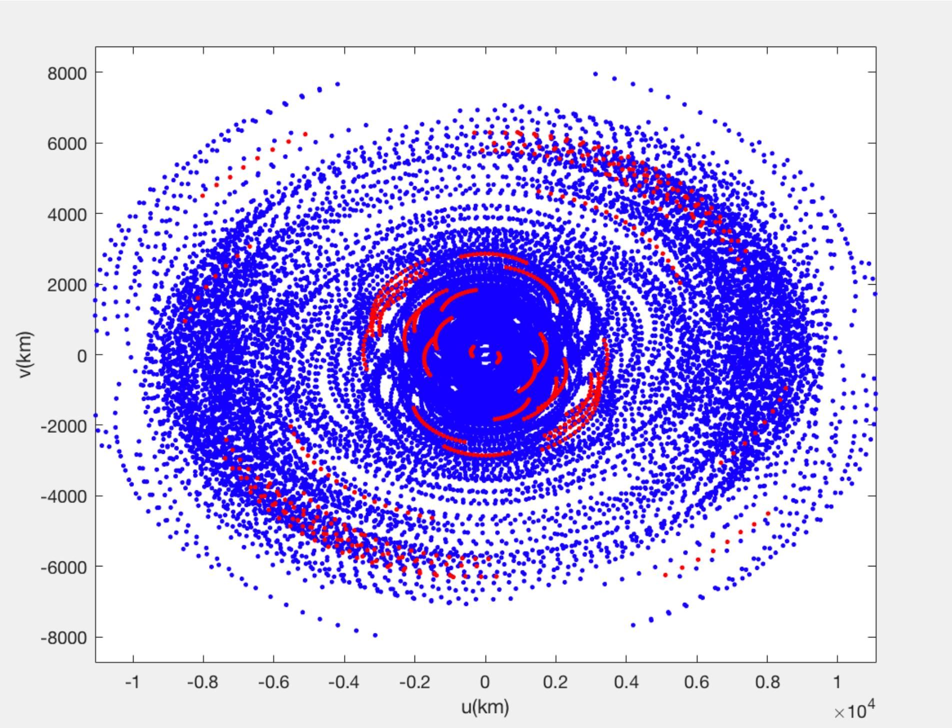
Impact of FAST

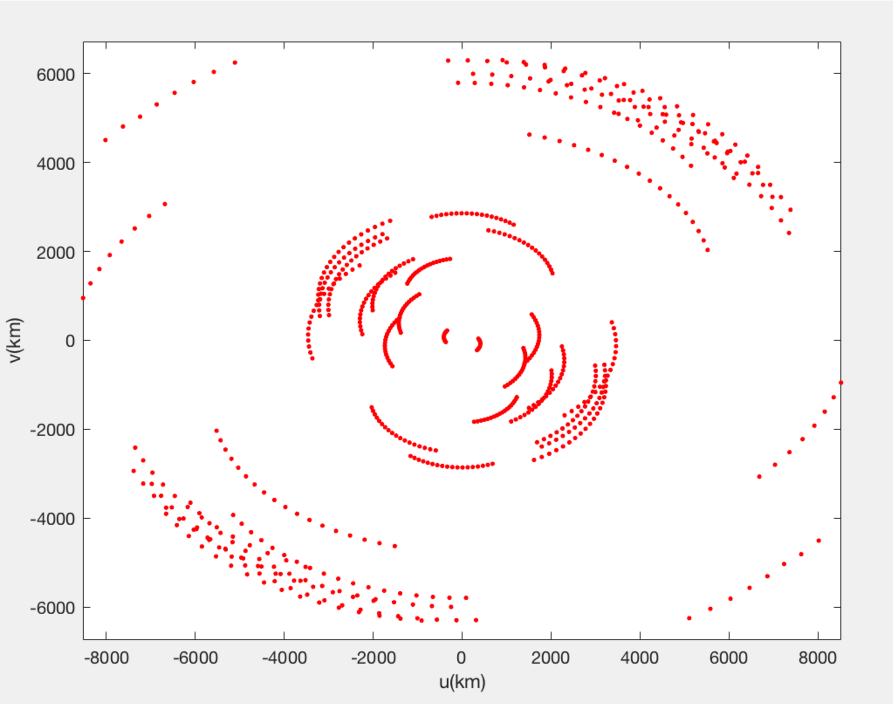
Elevation vs Time at Dec=20, FAST Shanghai, Bonn. FAST elev limit 50 deg others 10 deg



Uptime for FAST only and FAST - Bonn Versus Dec







2.3GHz array Dec=+35 deg – including EAVN, Russia, Europe + Mk, Br, Ov. Baselines to FAST in red

Just the baseline to FAST

Conclusion from deg +15 to +40 deg worthwhile for resolution/imaging to add non EA antennas.

Should check effect of Thai antennas or a Mid-East antenna

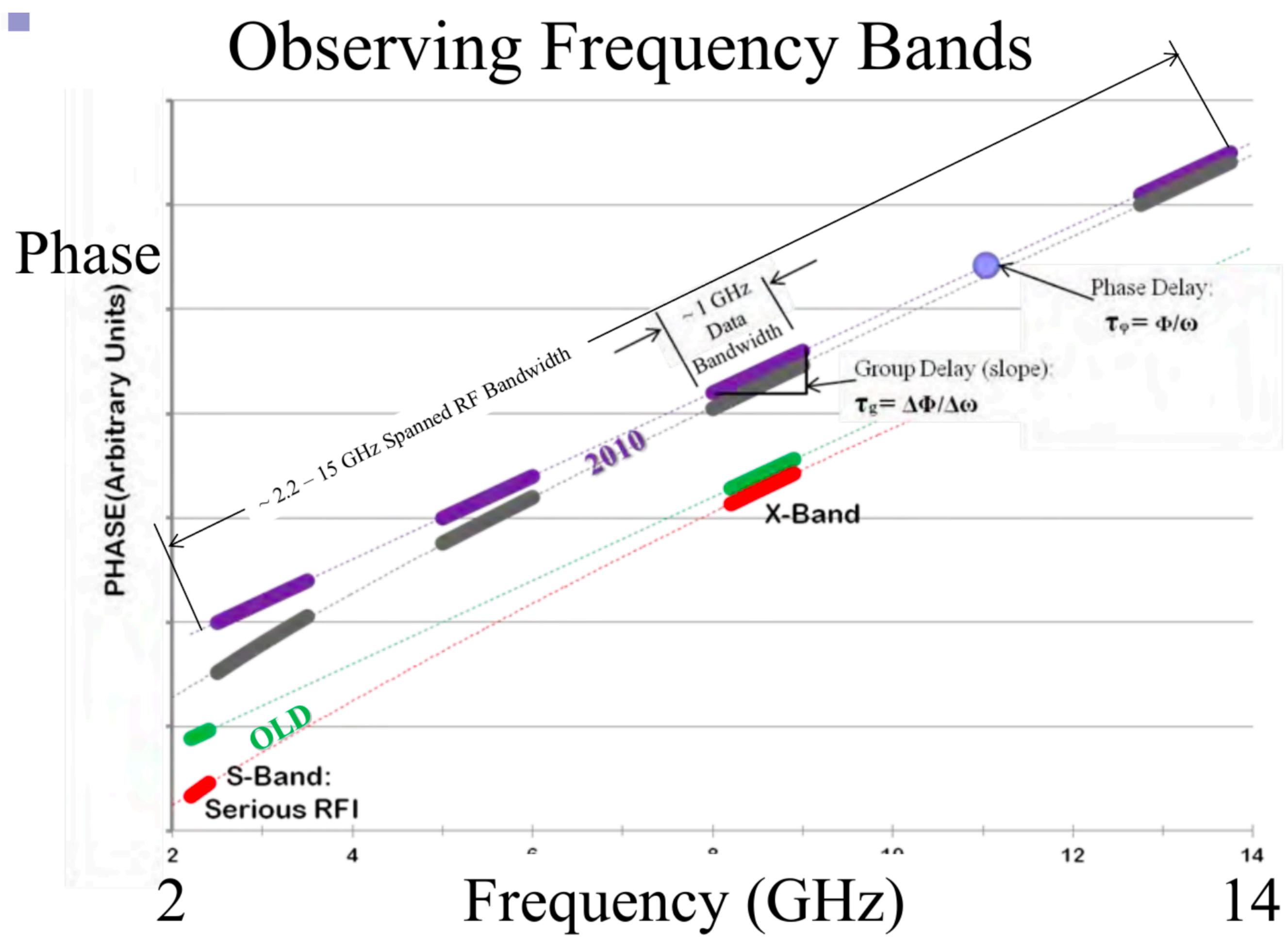
SKA in VLBI

- Will be great of course (1.6GHz and 5GHz at start) ….
- But - Most of high sensitivity added on Long baselines and most N-S, unlike N-hemisphere without SKA non-complete uv coverage
- Planned AVN antenna will help but still a ‘North African’ gap
- Careful handling of message N-hemisphere VLBI without SKA powerful in own right – don’t forget other synergies SKA as finder telescope for VLBI.

Dimensions of Improvement

- Collecting area/uv coverage – excellent N-hemisphere coverage + FAST, SKA-mid, AVN
- Frequency Range - extend compatibility between networks– Is adding 15GHz a priority? Possible promote simultaneous 22/43/86 GHz,
- Bandwidth (EVN 2Gbps is 256 MHz spanned BW - SKA 512MHz L band 2GHz at C-band – VLBI 4 – 16 GHz (12GHz possible) *EVN needs to keep pace with VLBA catch up to SKA and then surpass it*
- Availability (EVN-light, more responsive)
- *How to position/sell EVN/VLBI (as add on to SKA, or as SKA as add-on to VLBI) and as major facility in its own right*

2) Leveraging existing technical developments for geodetic -VLBI + SKA



VLBI Geodesy Observing System (VGOS) observing concept

- need ultra-wide band to get accurate group delays- = derivative of phase versus frequency – needs large lever arm in frequency

VGOS Fast Slewing Telescopes

Wetzell, Germany

Onsala Twin Telescopes

Ishioka (JP)   Courtesy Y. Fukuzaki

Yebes (Spain)
(August 2013) Courtesy:
J.A. Lopez

Santa Maria (Eastern Azores)
(Sep. 2014) Courtesy: F. Colomer

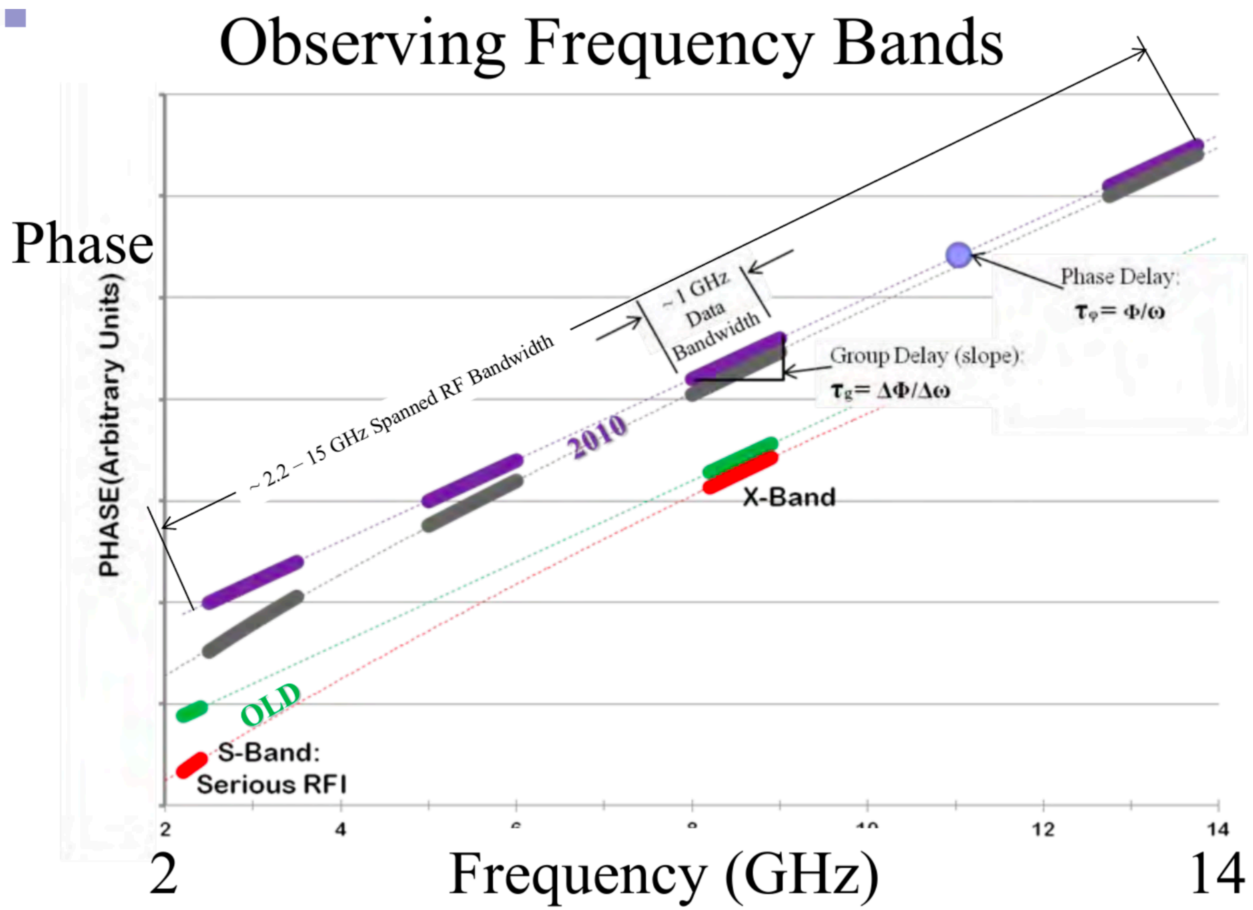
Badary (RU)

Zelenchukskaya (RU)

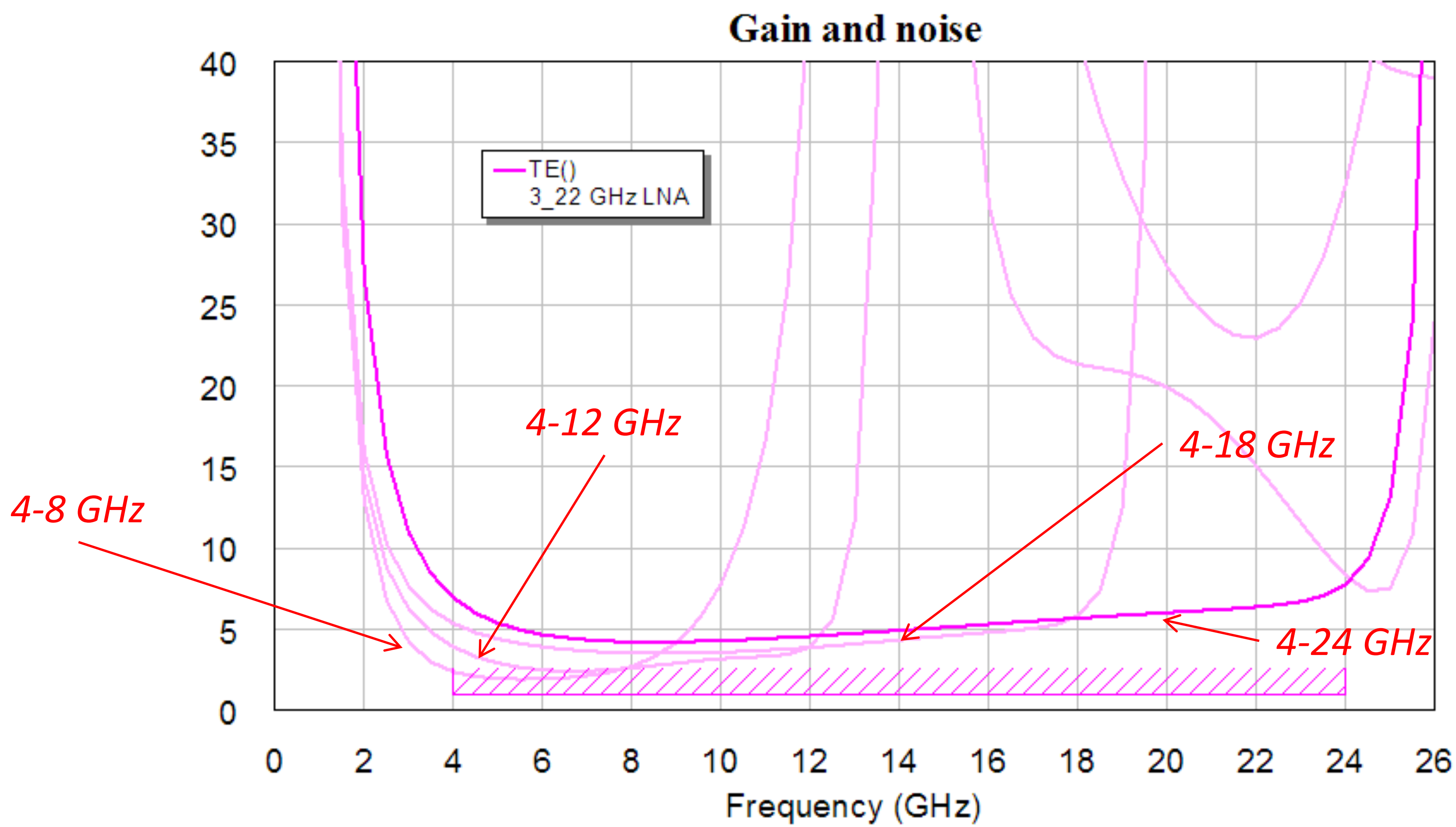
GGAO (US)

VGOS also Requires

1) Broad Band LNAs
2) Wide band data acquisition and recorders
3) Wide band feeds



Broad Band LNA, only modest Tsys penalty for wide bands



- Modelling of Low Noise Factory LNA’s made in Chalmers University clean room. Four different designs for four different bandwidth- the noise for 4-12 GHz only about 0.5 K - 1.0 K higher than for 4 – 8GHz.

Backend

- DBBC3 in production – **can already cover 4 x 1GHz bands dual polarization.** → output 32 Gbps

- Units deployed at Onsala and other VGOS antennas and at Event Horizon Telescope (EHT) telescopes

- Development has been funded by VGOS and EHT – can be exploited for cm VLBI needs

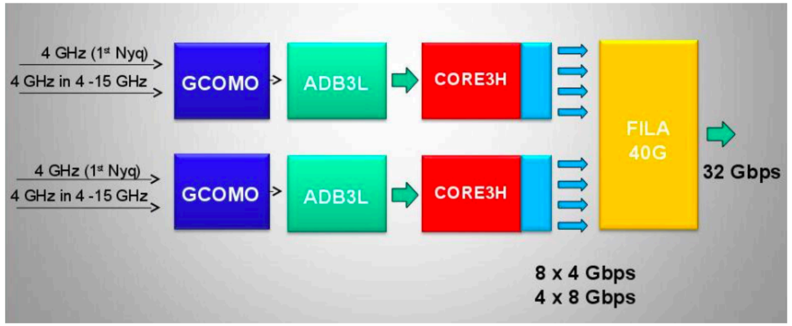


Fig. 1 DBBC3 block diagram.

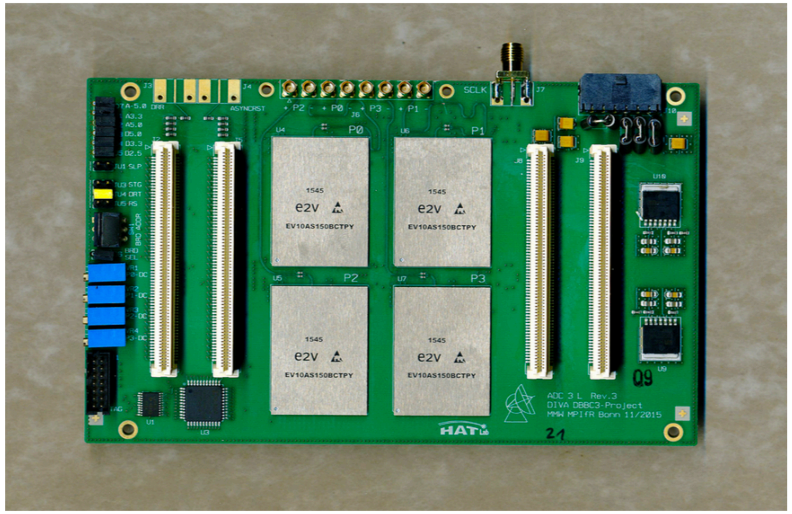
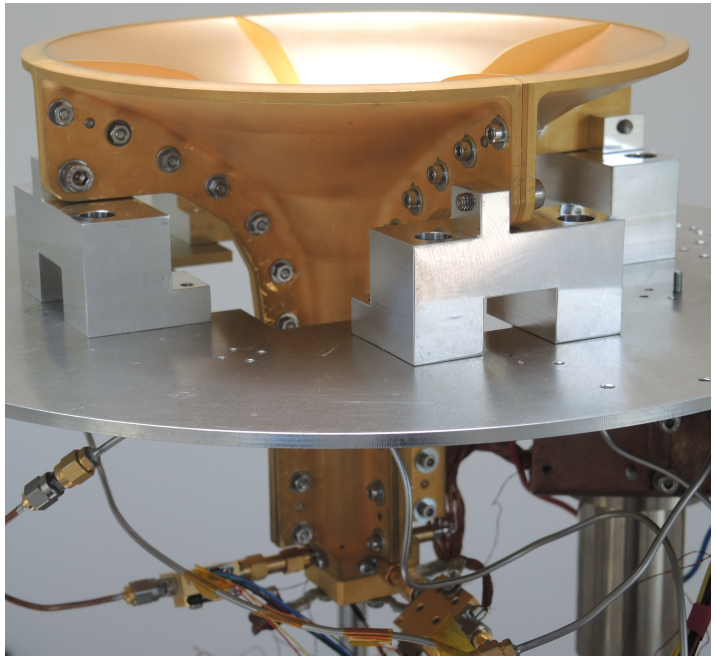


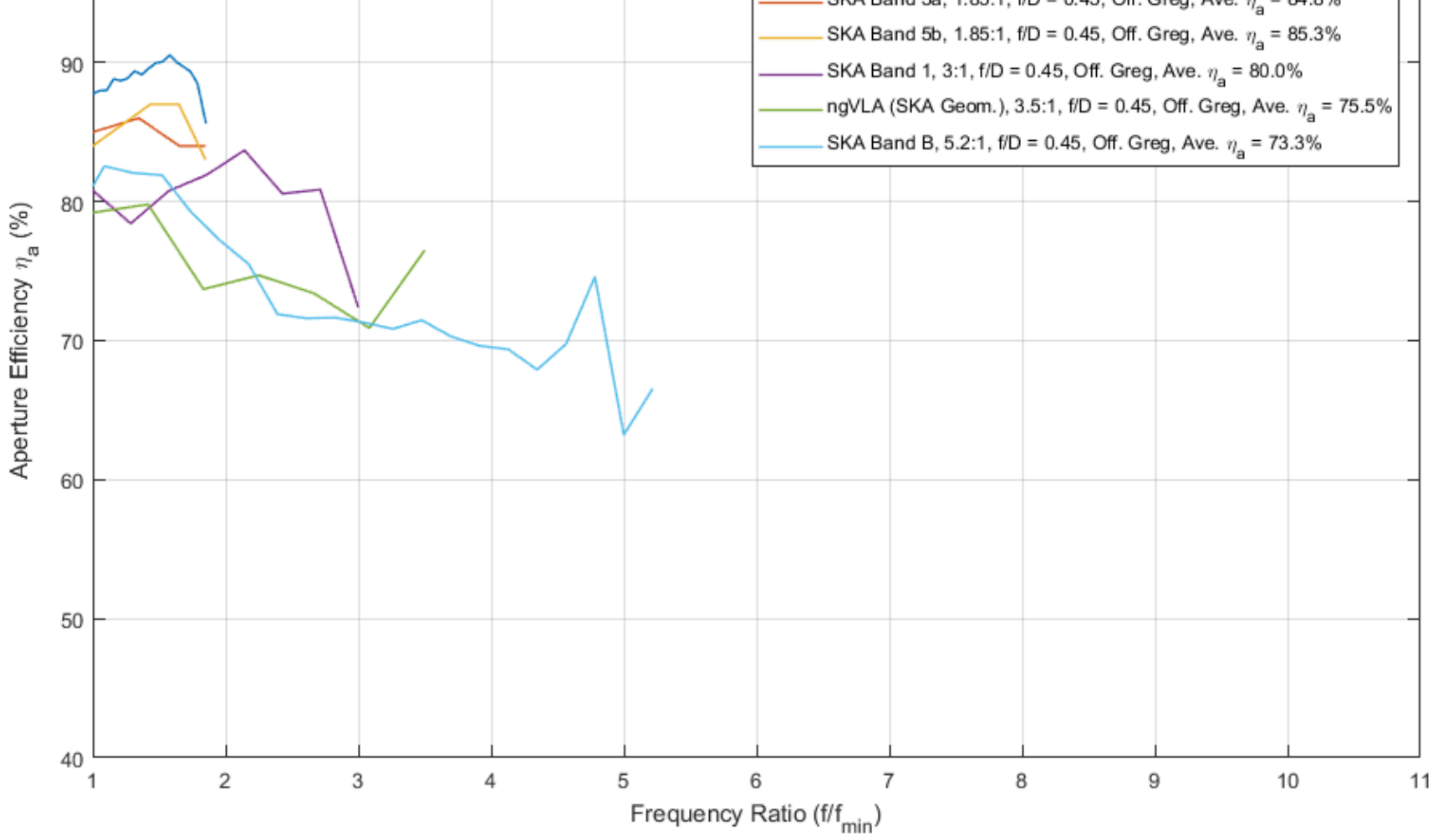
Fig. 2 ADB3L sampling board.In the centre the four sampling chips can be seen.

Broad Illumination Angle Broad Band Feeds - Quad-Ridge Flared Horns

Caltech feed – deployed on OTT telescope.



4.6 – 24GHz feed developed for SKA WBSPF AIP



Trade-off between bandwidth and aperture efficiency. Compared to Corrugated horns (1.8:1) lose 10% going to 3:1 and 20% going to 5:1 maybe 30- 35% for 10:1 BRAND feed. Worry this may push too far –

Are we interested in beyond octave receivers? Can world VLBI converge on strategy for frequency coverage.?

Multi three Band Receivers for 22GHz – 86GHz

At high frequency very broad sensitive LNA's covering 22- 115GHz don't present exist (probably could but needs development) – can't in any case sample all the BW in forseeable future.

Given smaller physical scales at high frequencies can instead separate frequencies by dichroic mirrors

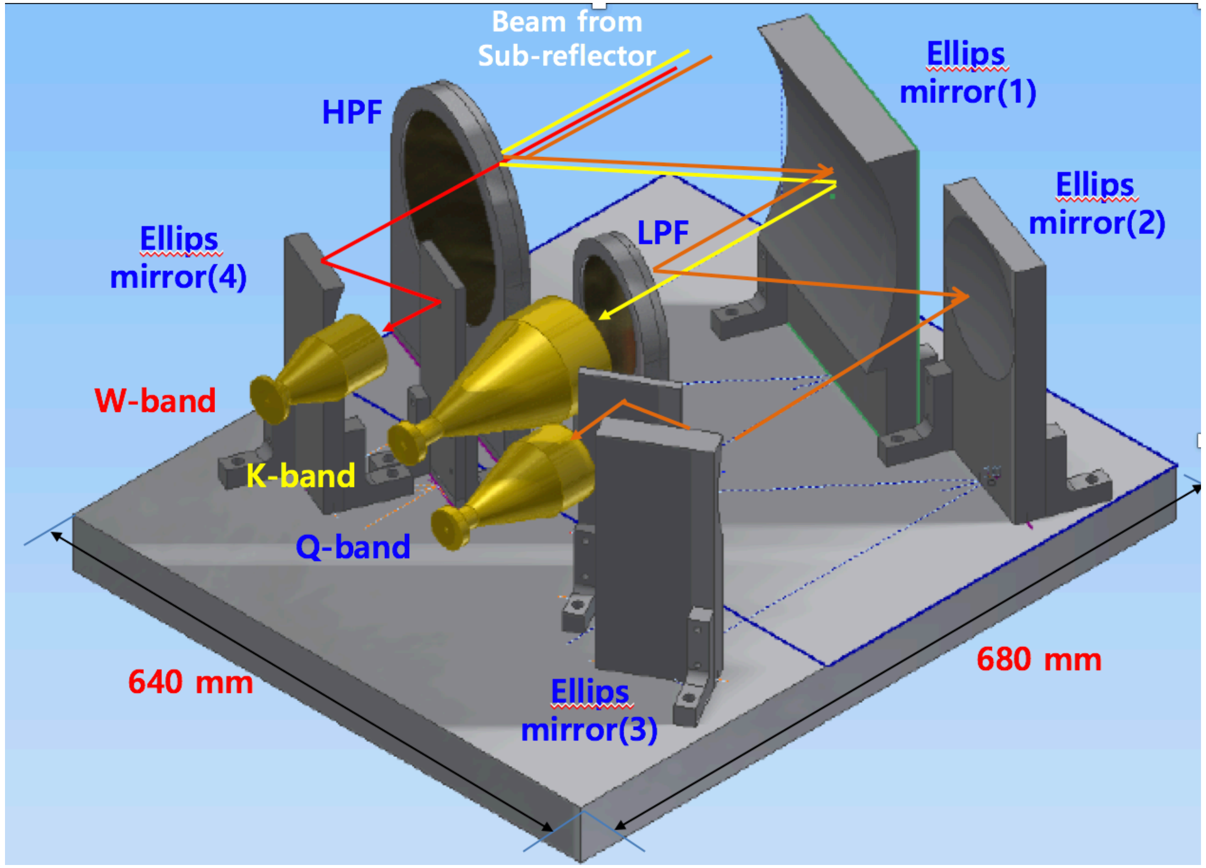
Seog-Tae Han, KVN, compact 3 band system

Yebes similar three band system and OSO/Bonn interested in this idea.

Observe multiple maser line simultaneous.

Position Registration of multifrequency line/continuum maps.

Use 22 and 43 GHz to get atmosphere phase, extend 86 GHz coherence time to look at weaker sources.



- Just one Possible target for EVN future, even without demonstrating 10:1 frequency range.

- **A)** Replace current L band (1.6GHz) systems with octave 1.2 - 2.3 GHz. (overlap MERLIN L and S Band or eMERLIN wide band))

- **B)** Replace current octave C band (5GHz) systems with 4 – 16 GHz systems (i.e. VGOS technology) . i.e 4:1 ratio (linear polarization) system with target 10% -15% loss in aperture efficiency wrt octave) - overlap eMERLIN C, X, U bands or broad band,

Several motivations for an **Old station** to accept 10% -15% loss in sensitivity at any given frequency on replacing C-band with a 4:1 system.

- Increase total BW around desired frequencies to more than compensate for continuum sensitivity
- get MFS uv coverage around each desired image frequency.
- Get spectral index information.
- Determine instantaneous broad band spectral properties of transients.
- Observe multiple bands at once (EVN frequency agility)
- Create aligned multi-frequency images for spectral index
- Access to new frequency regions such as 15GHz.
- Compatible with VGOS antennas.
- Lower running costs for fewer receivers – including less time consuming to calibrate.

On **New antennas** cheaper to build one receiver than three (C,X,U)

No problem with collecting data(!) Receivers and sampling is in good shape. 100Gbit/s link available (VGOS stations installed)

The only Limitation is requirement for massive correlator and media transfer!

Need to aim for big central investment >>10 M€ before <<2028. To implement 12GHz BW and 100 Gbit/s/station

Not pie in sky VGOS would also like 64 Gbit/s/station correlation for full capacity.