ICRAR

International Centre for Radio Astronomy Research

Astrometry with Space VLBI

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The Government of Western Australia

The University of Western Australia

Overview

Astrometry with a free-floating Space Platform

Four papers with demonstrations

- Porcas & Rioja, 2000, S-VLBI Symp, 245
- Porcas & Rioja, 2000, Ad. Sp. R., 26, 673
- Guirado etal 2001, A&A, 371, 766
- Rioja, Porcas etal 2009, S-VLBI Symp, 402, 486

Two papers on simulations

- Rioja, Dodson etal 2011, 142, 157
- Dodson & Rioja 2013, 145, 147

Mission Solutions

- VSOP-2
- THEZA
- Millimetron

Astrometry in 3 lines

Calibrate against a `reference' separated by $\Delta\phi$

At wavelength λ and maximum baseline B

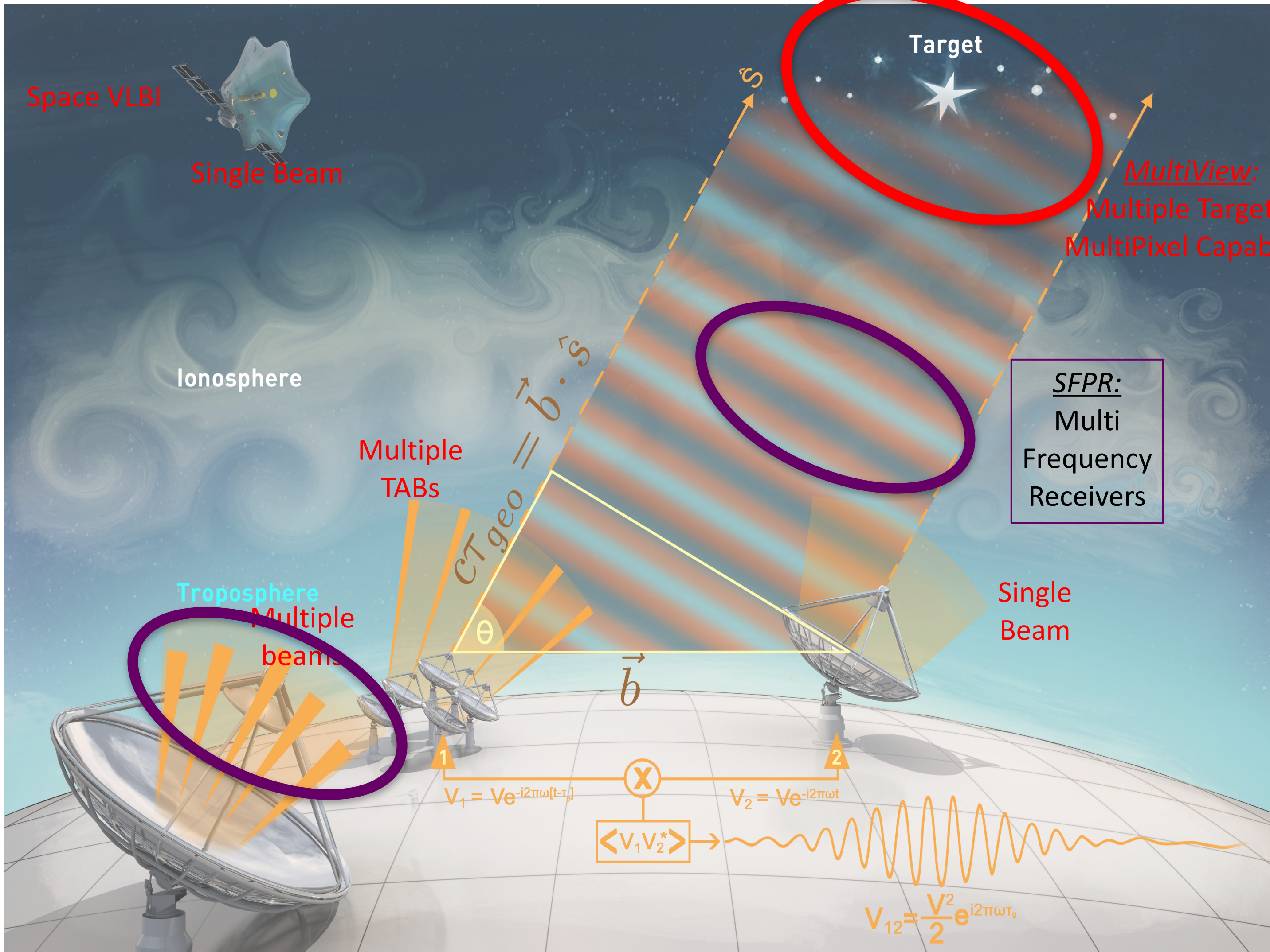
Error Limits are:

Thermal (λ/B/DR) (dynamic errors reduce DR)

Orbit Det. ($\propto \Delta B/B*\Delta\phi$) (ODDA error)

Ionospheric ($\propto \Delta TEC*\lambda^2/B*\Delta\phi$) (static TEC error)

Astrometry in 1 picture



From Rioja & Dodson AARv 2020

Precise radio astrometry and new developments for the next generation of instruments

The Space VLBI mission VSOP

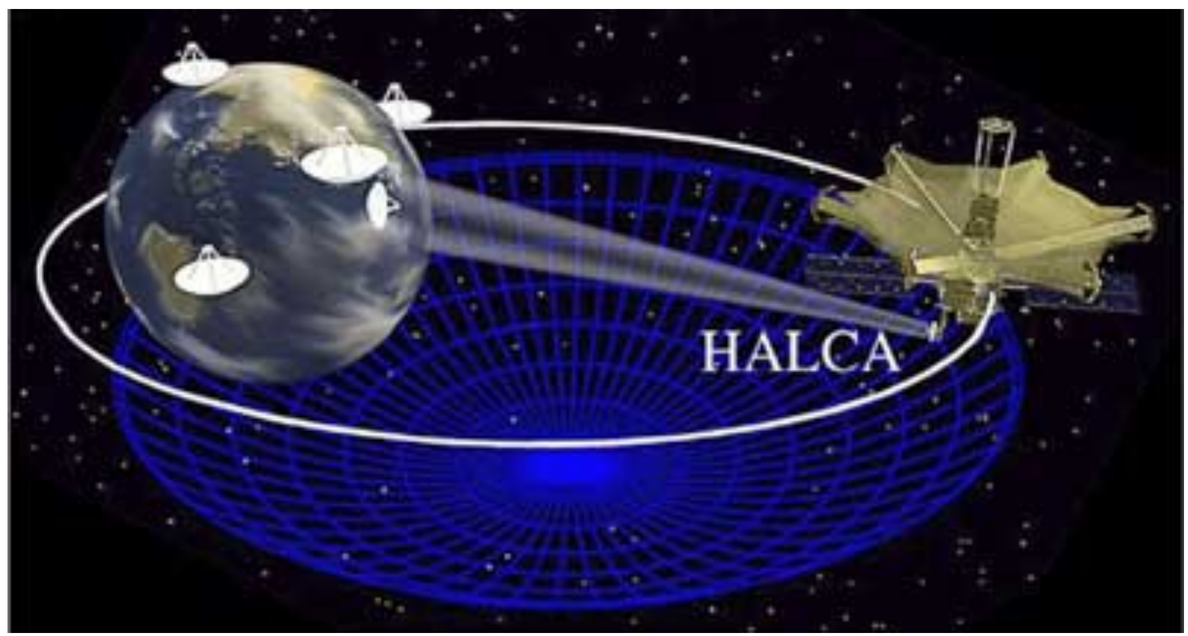
VSOP mission will be reported on by Hagiwara-san
Minimal information is:

8m dish
In 25,000km orbit
At 1.6, 5 (& 22) GHz

Launched in 1997 - worked for 7 years

Not designed as astrometric mission

Engineering testbed

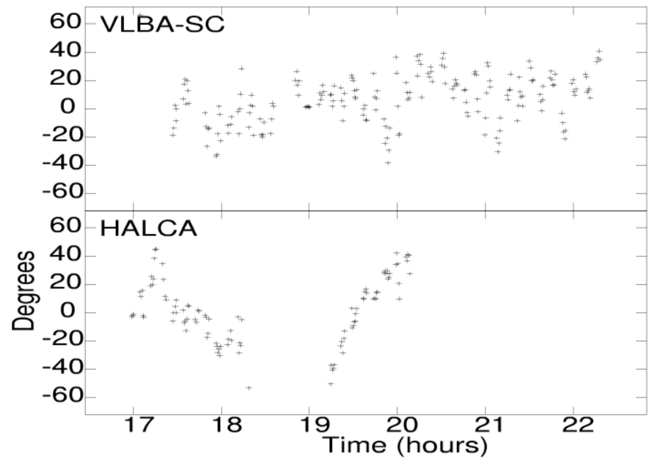


Demonstrations with VSOP

The Space VLBI mission
VSOP has a number of Astrometric demonstrations for sources that can be co-observed in the VSOP beam

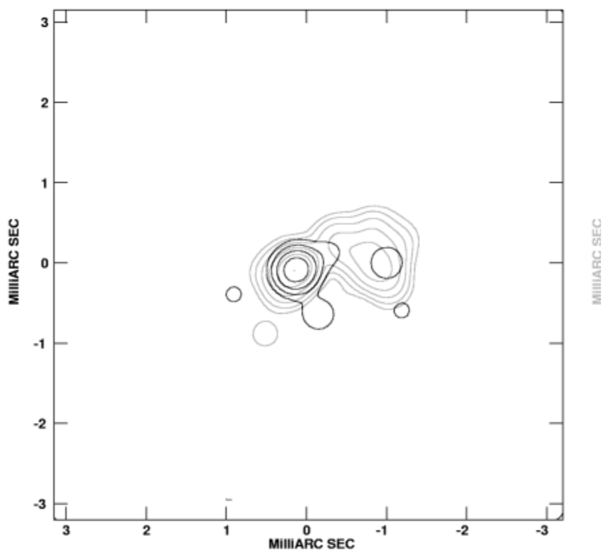
1038+52A,B,1308+326&8 and 1342+662/3

$\Delta\phi = 2\pi(\Delta B/\lambda)\theta$ ODDA error
$\theta \leq \lambda/D$ in-beam req.



Orbit determination of HALCA was accurate to 2-5m

1308+326



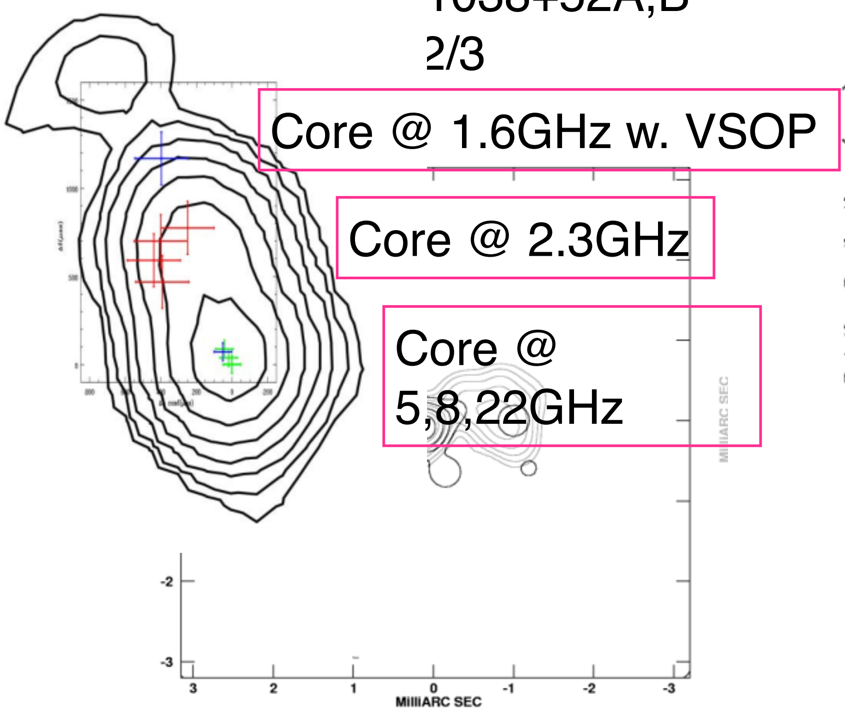
VSOP only baselines show the core of the source with the jet resolved

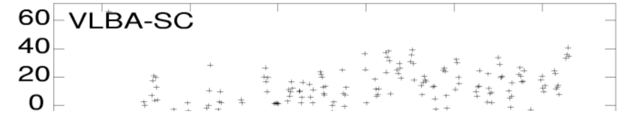
Rioja, etal., 2009, S-VLBI Symp.
Porcas & Rioja, 2000, S-VLBI Symp.
Porcas & Rioja, 2000, Ad.Sp.R.
Guirado J., 2001, A&A
Rioja, Porcas, Dodson etal 2009, S-

Demonstrations with VSOP

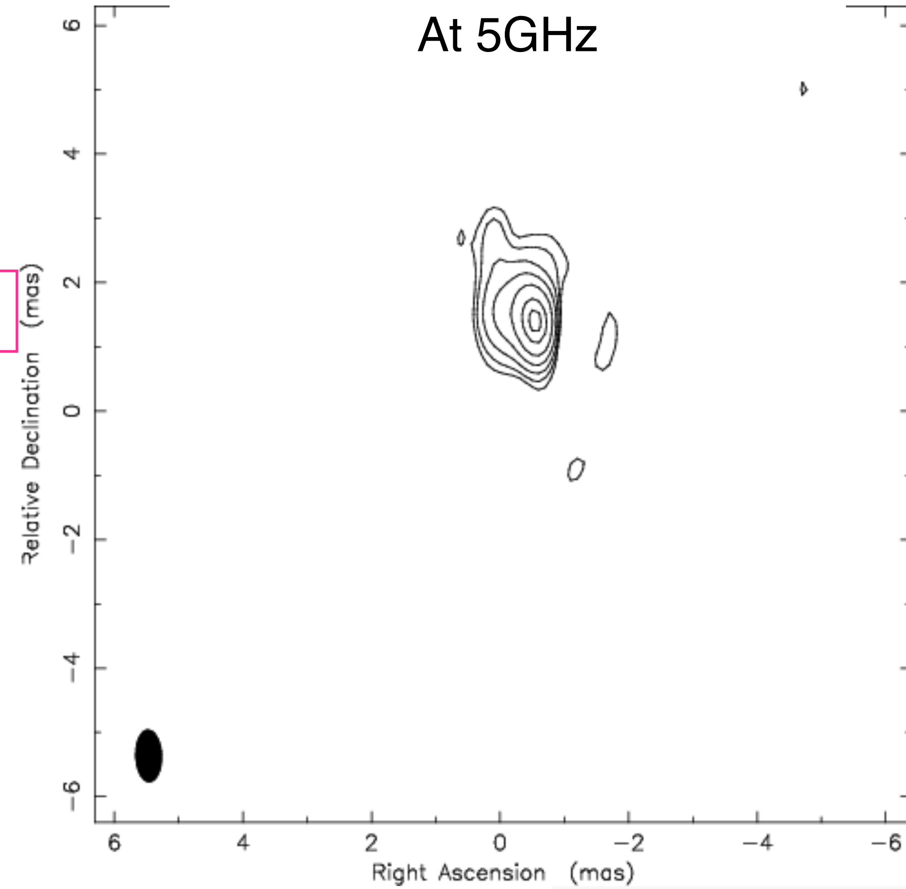
The Space VLBI mission VSOP has a number of Astrometric demonstrations for sources that can be co-observed in the VSOP beam

1038+52A,B
2/3





B1342+662 PR to B1342+663
At 5GHz



Guirado J., 2001, A&A

Rioja, Porcas, Dodson eta

Mission: Approach of VSOP-2

Longer baselines means improved astrometry — as long as the errors are not equally increased. Residual tropospheric errors ~1cm with care

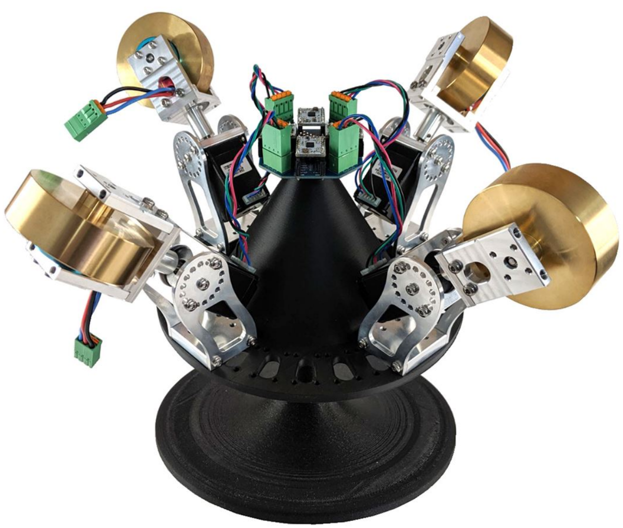
Space craft baseline errors need to be about equal

Two key pieces of highly complex technologies to provide astrometry:

- Massive Moment Wheels, to allow rapid source switching (1 min cycle)
- Precise Orbit Determination with on-board GPS transmitter, SLR ranging and accelerometers

Both complex and heavy. Not good things on a space craft

54 *Takeuchi, VSOP-2 Orbit Determination SWG*



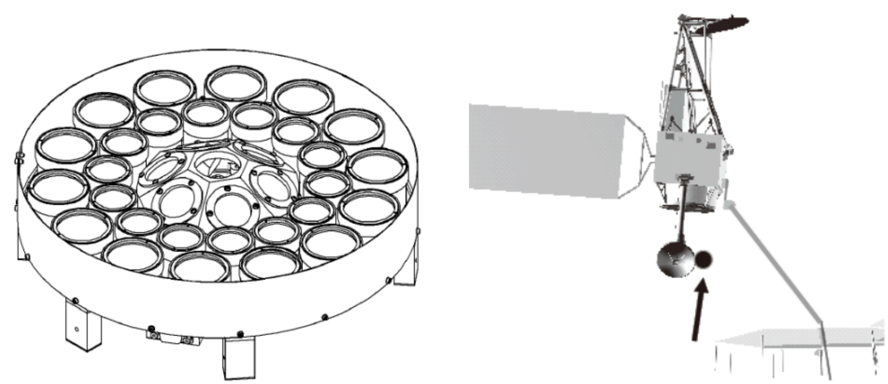
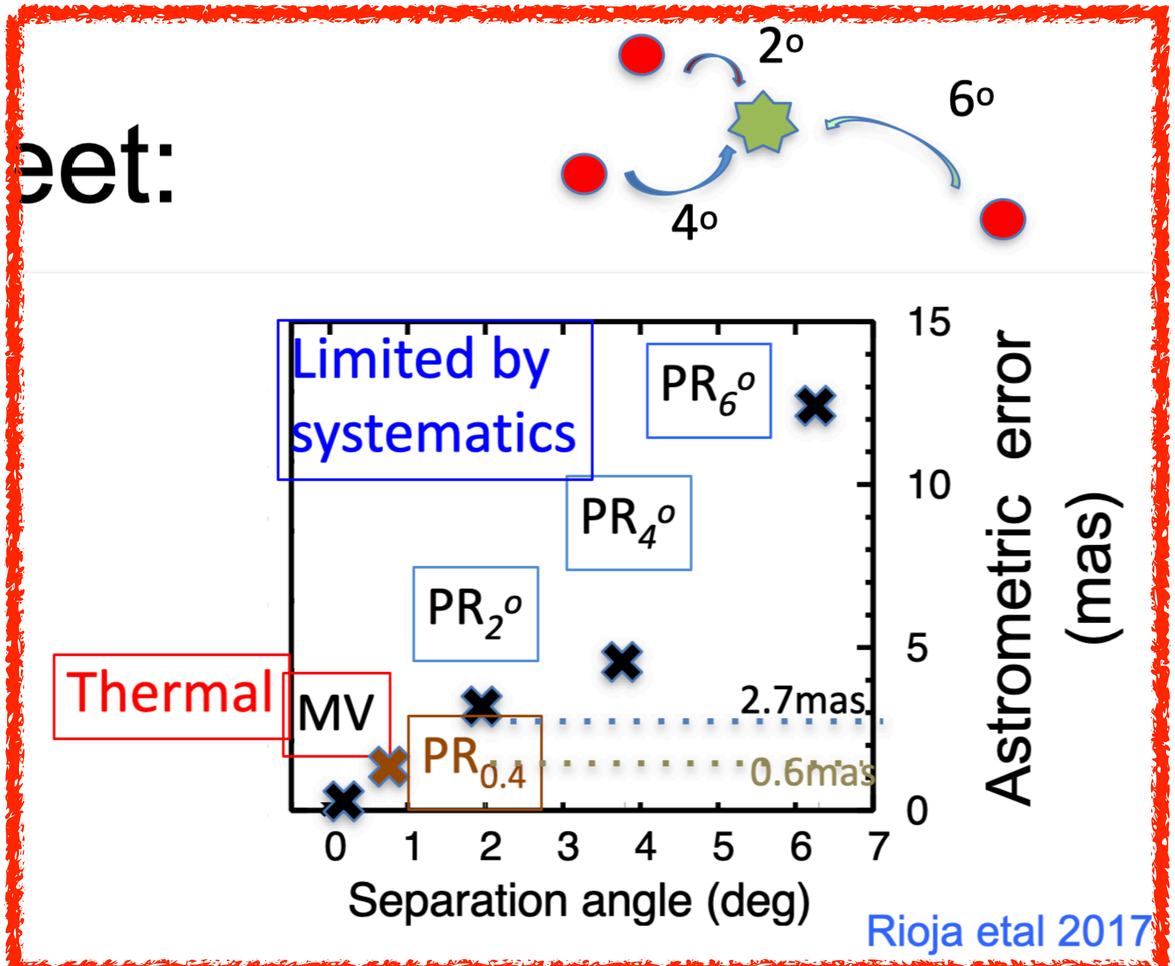


Figure 2. Developed retroreflector array optimized for the Astro-G's highly-elliptical orbit. The inner pyramid-shaped array for the low altitude supports wide range of incident angles. Outer surrounding flat retroreflectors for the high altitude contribute to increase the effective aperture area.

Method: MultiView astrometry

Maria introduced MultiView astrometry



MV corrects for all errors by generating a virtual calibrator at zero angular offset

i.e. orbit errors would be cancelled

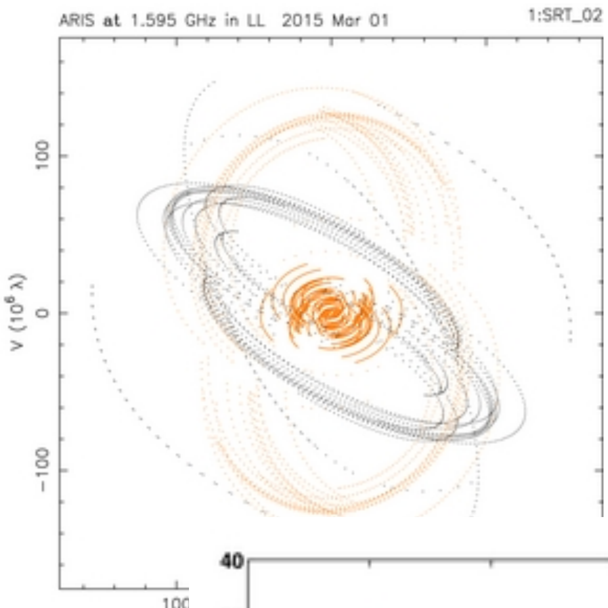
Proposed for lower freq to correct for ionosphere.

But works just as well for troposphere and higher freq

MultiView S-VLBI Simulations

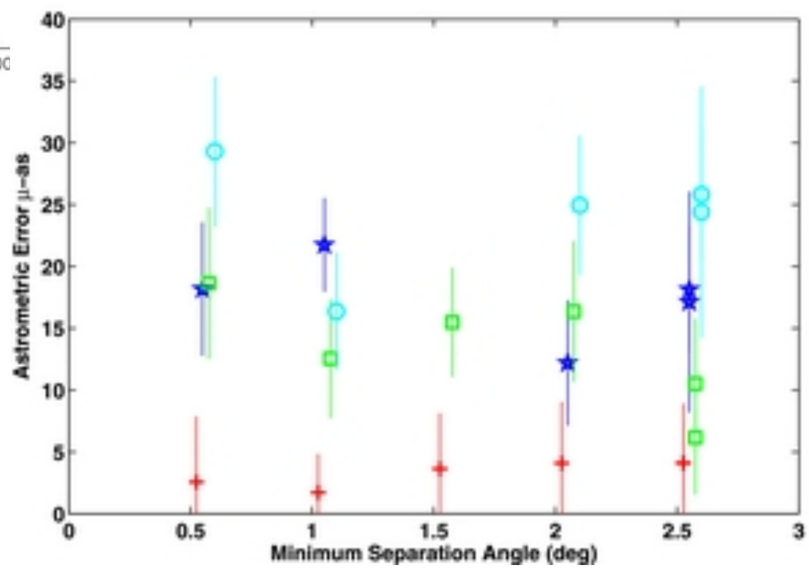
Maria introduced MultiView astrometry

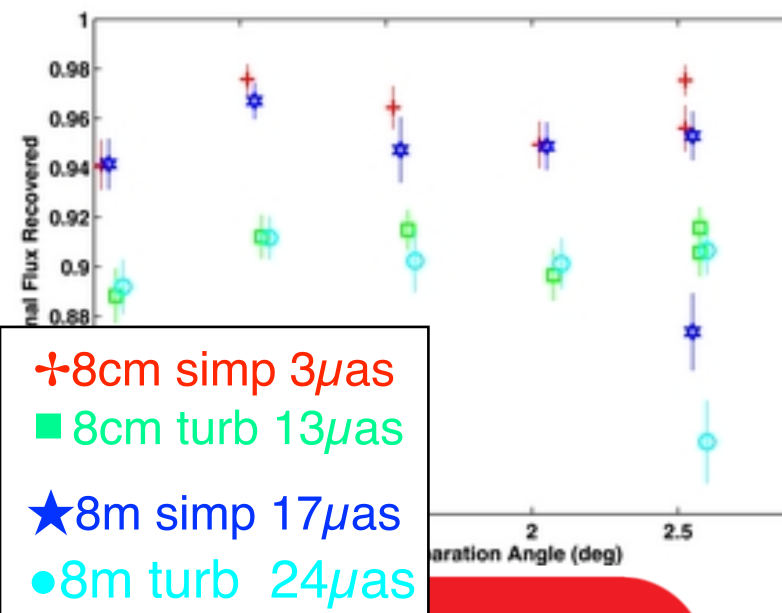
Dodson & Rioja, 2013, AJ, 145, 147



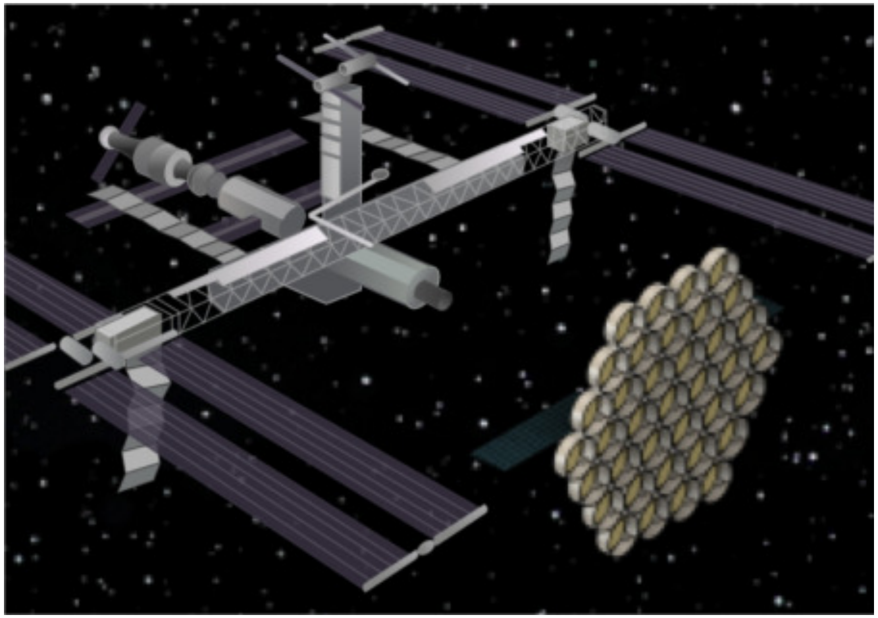
Simulated a L-band
dual space-craft with
multi-beam capabilities

Excellent astrometric accuracies in a range of weathers (turbulent ones worse than simple), and orbit errors (more or less consistent)





Mission: MultiView THEZA



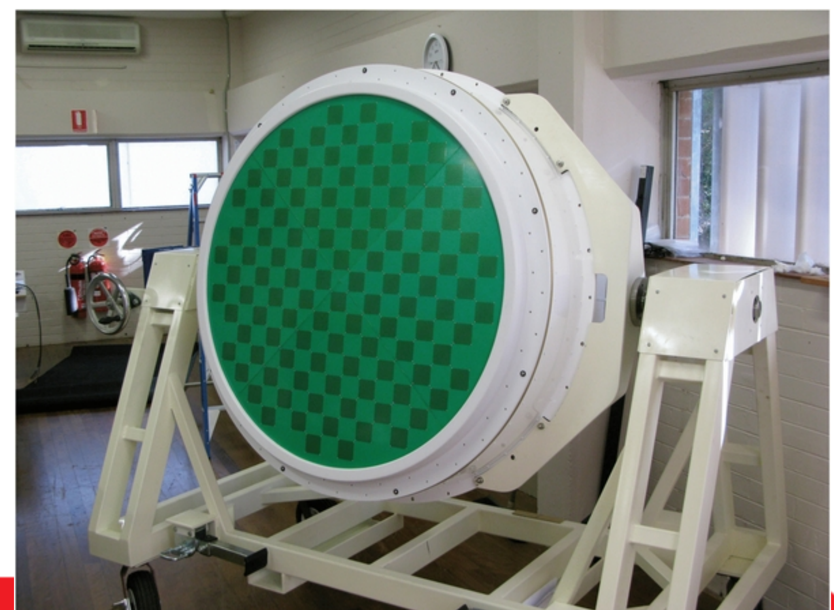
The THEZA proposal is for a mm to sub-mm Space Radio Antenna

Constructed from smaller elements

Such a system would allow multiple beams to be formed.

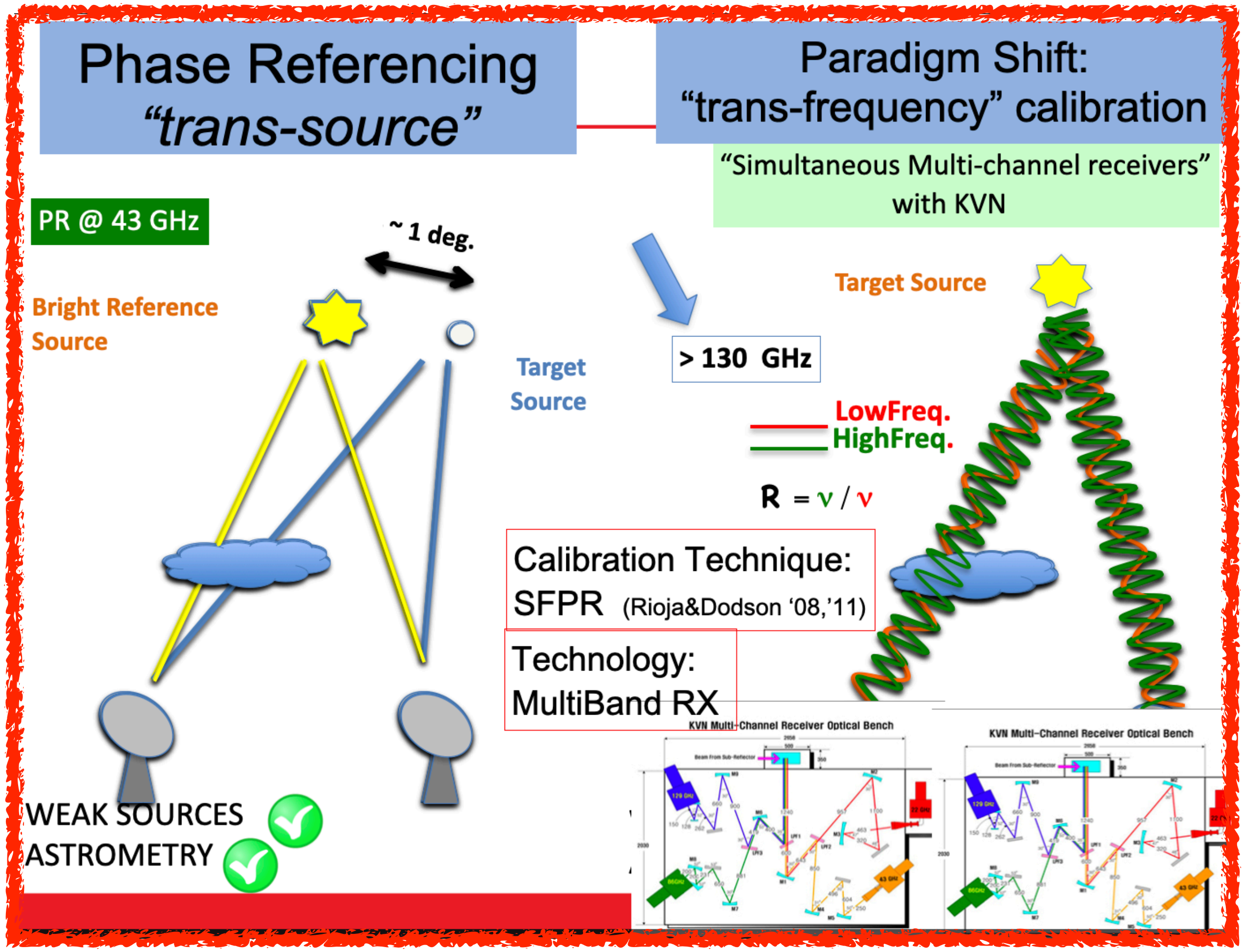
Perfect for Multi-Beam VLBI

Both conventional and MultiView astrometry would be possible



Method: Frequency Phase Transfer astrometry

Maria introduced Frequency Phase Transfer (FPT) and the astrometric extensions, SFPR and MFPR



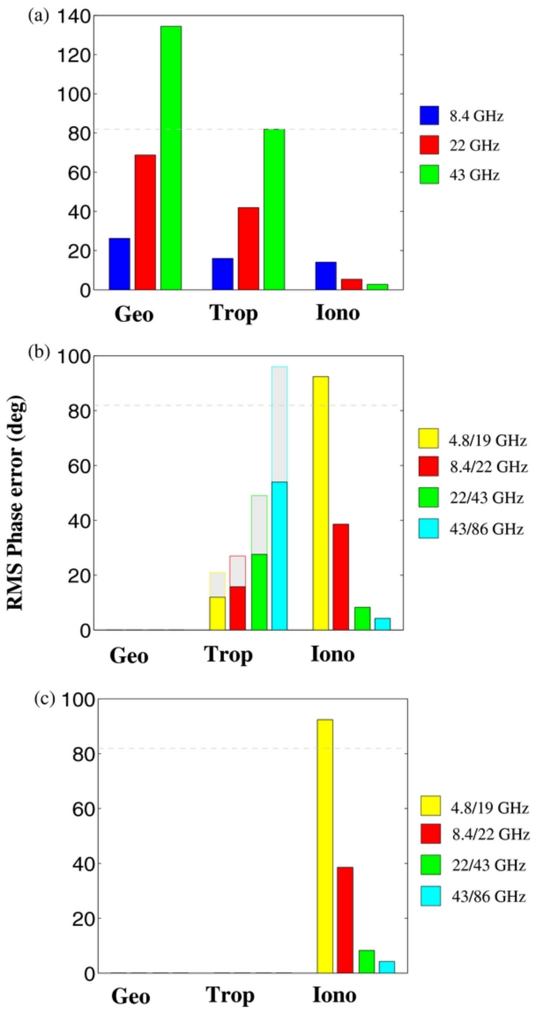
FTP solves for non-dispersive delays, including positional i.e. orbit errors

Mainly for the higher frequencies where troposphere dominates.

Frequency Phase Transfer S-VLBI Simulations

Maria introduced FTP astrometry   Rioja, Dodson etal 2011, AJ, 142, 157

Bar graph quantifies errors in deg



Conventional PR — dominated by Orbit

Switched FTP PR
dominated by Ionosphere for 5GHz pair
dominated by Troposphere for 43GHz pair

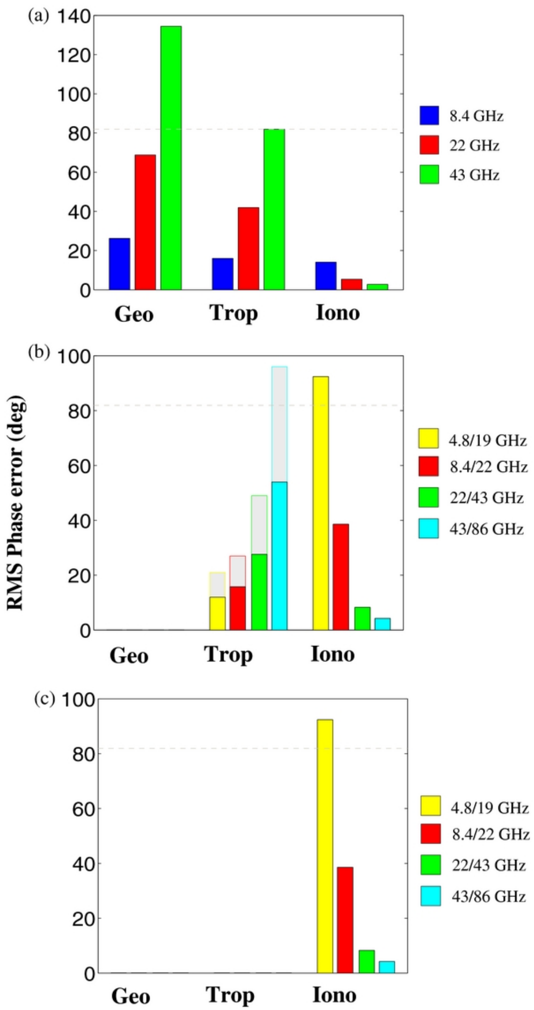
Simultaneous FTP PR
Only Ionosphere remains
Largest for 5GHz pair

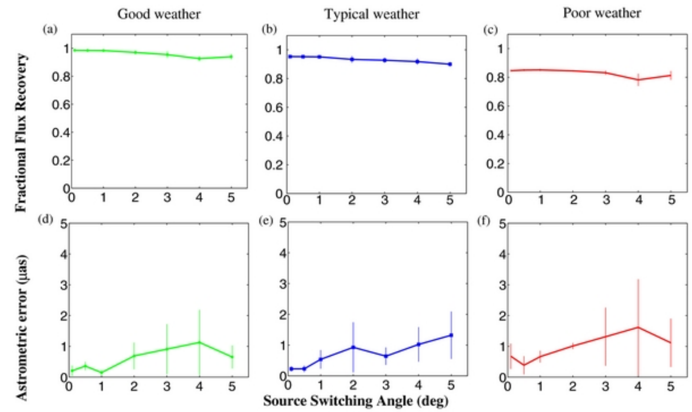
Frequency Phase Transfer S-VLBI Simulations

Maria introduced FTP astrometry

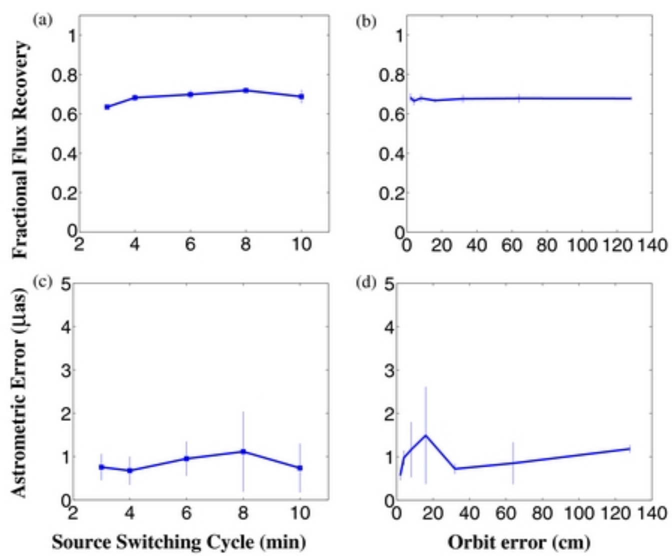
Rioja, Dodson etal 2011, AJ, 142, 157

Bar graph quantifies errors





Excellent performance in all weathers



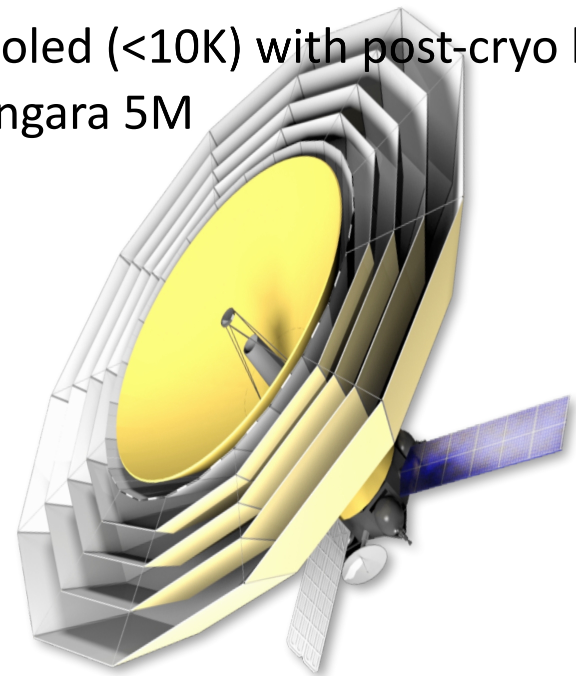
Excellent performance as a function of all orbit & other errors

Mission: Millimetron Space Observatory

The first 10-m deployable and cooled space Sub-mm and FIR telescope.

The mission is approved and supported by Russian Space Agency (ROSCOSMOS)

- FIR, sub-mm and mm range
- In orbit deployable and adjustable antenna
- Antenna and focal plane instruments mechanically cooled (<10K) with post-cryo life
- Orbit around L2 Lagrange point; with new launcher Angara 5M
- Lifetime: goal 10 years; at cryo >3 years



Two operation modes:

Space-VLBI at 0.8 – 3 mm (EHT & ALMA Bands+)

Single dish at 0.08 – 3 mm

Sensitivity: 10^{-22} W/m^2 for spectroscopy

and 0.5 μJy for photometry (single dish)

- **Spacecraft bus and instruments in Phase-A**
- **Antenna in Phase-B**
- **Launch date : 2029**

More information: http://millimetron.ru/

Courtesy: Alexey Rudnitskiy

Frequency Phase Transfer Millimetron

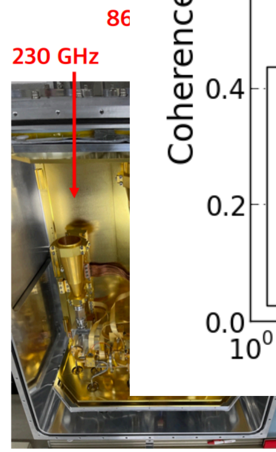
Millimetron plans to use the next-generation Compact Triple-band Receiver from KASI

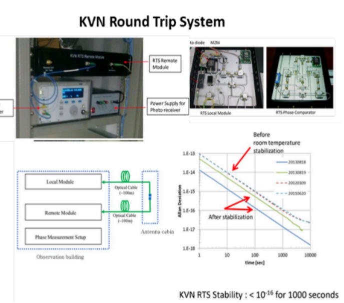
i.e. 80-115, 215-240, 330-350 GHz
(3mm, 1.3mm, 0.9mm)

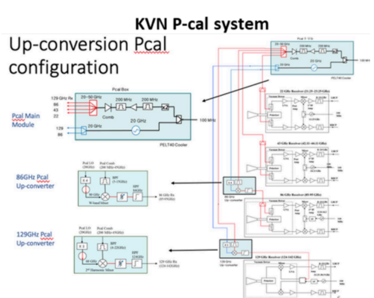
A new proposal for s-CTR development @ KASI

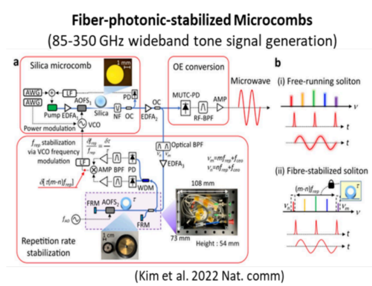
[Objective & Deliverables]

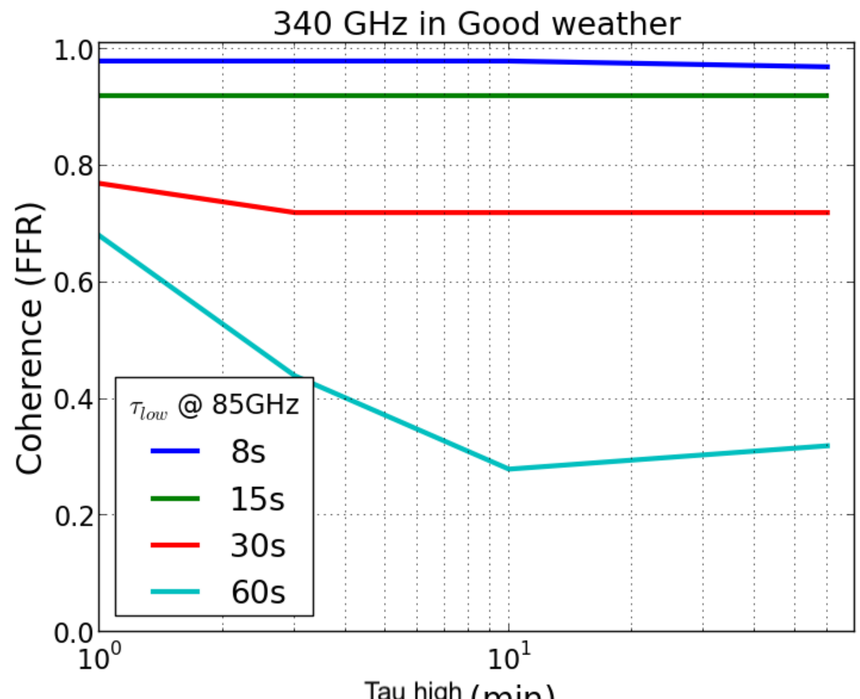
- to demonstrate VLBI phase correction (FPT) and astrometry in mm/submm frequency range
- to develop and deploy two receivers to two candidate telescopes
  - 86 GHz LNA-based (COTS device available)
  - 230/345 GHz : SIS mixer-based (in-house design)
  - LO generation and phase stabilization systems (in-house development)
  - Low crosspol quasioptical dichroic filters (in-house design, outsourced fab)
- **Testing:** photonic-based LO & P-cal tone generation for ultra-wideband (85-350GHz) instrumental phase calibration
- Applied for a new project of KASI (2024~) & under review [PI: Jung-Won Lee]









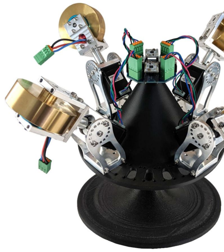


Coherence Simulations for Ground to Ground

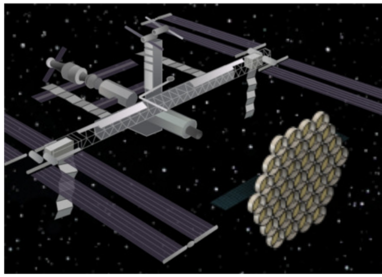
Taehyun Jung
last week Bonn

Conclusions

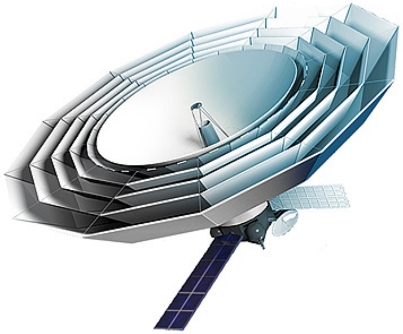
Astrometry with Space VLBI has been demonstrated
At 1.6 and 5GHz: In-beam observations with VSOP



Conventional Astrometry with Space VLBI is very hard
requires obit precision to match atmospheric precision of ~1cm
requires fast switching between sources



Multi Beam Astrometry with Space VLBI
requires PAF so multiple beams and observe sources
reduces obit precision requirement
Provides spatial astrometry



Multi Frequency Astrometry with Space VLBI
requires CTR (or similar) so multiple frequencies
are observed
reduces obit precision requirement
Provides lambda astrometry