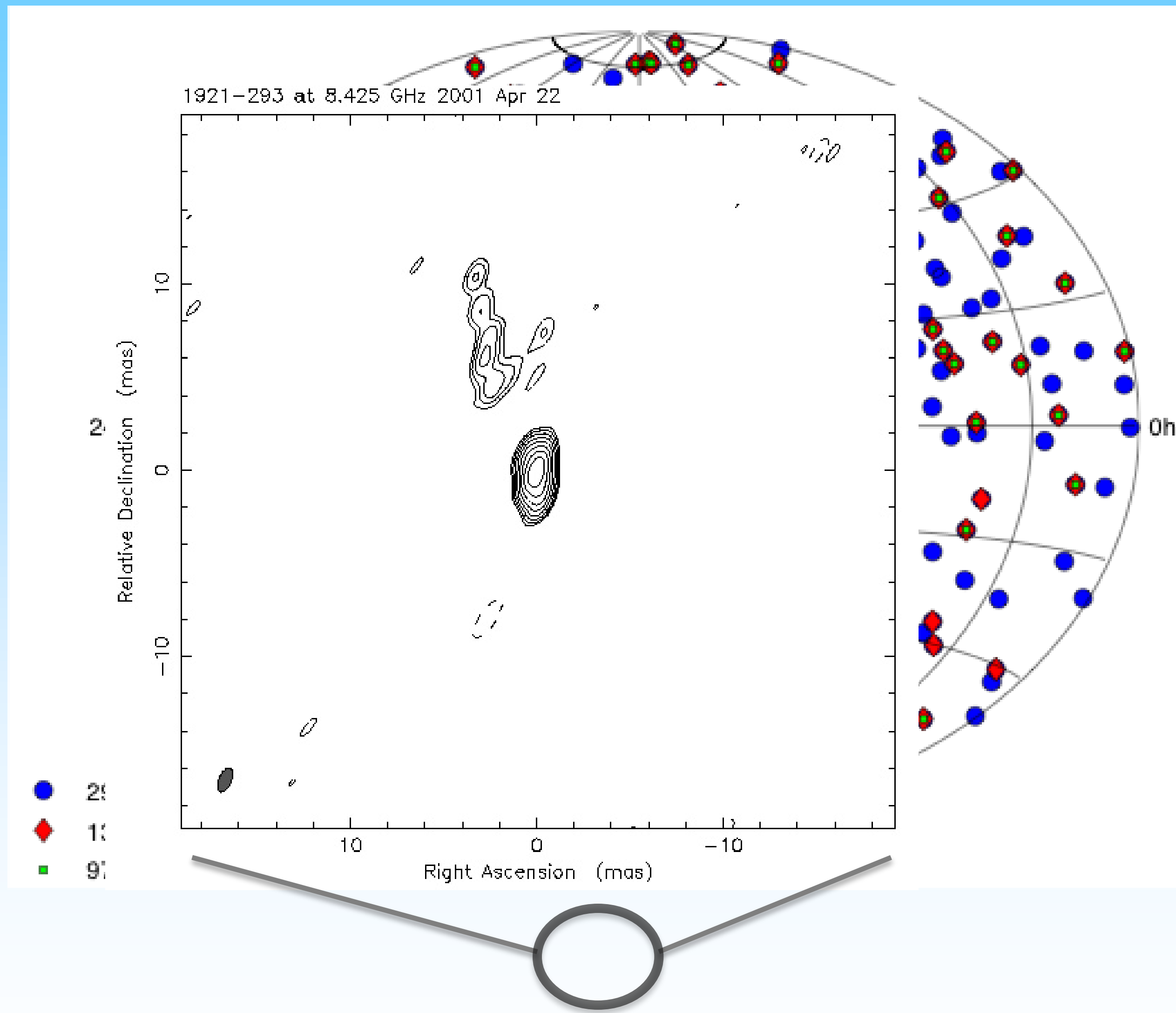
Enabling High Precision VLBI Relative Astrometry at the Highest Frequencies

Maria Rioja[1,2] and Richard Dodson[1]

ICRAR/UWA (Australia)
OAN (Spain)

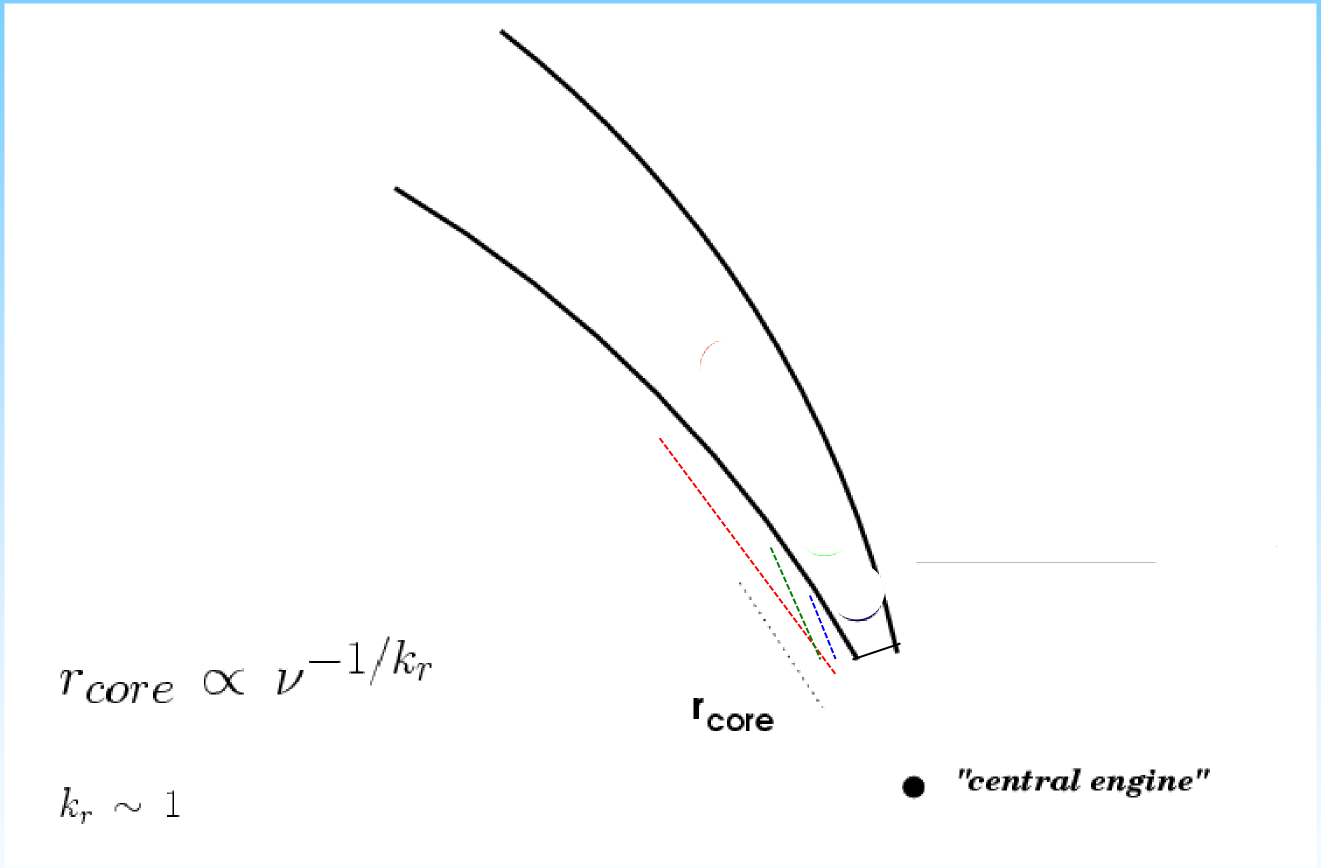
OUTLINE

- Characterization of Core-shifts
- Techniques to measure core-shifts: limitations
- A new technique to measure core-shifts at highest frequencies
- Applications of new technique



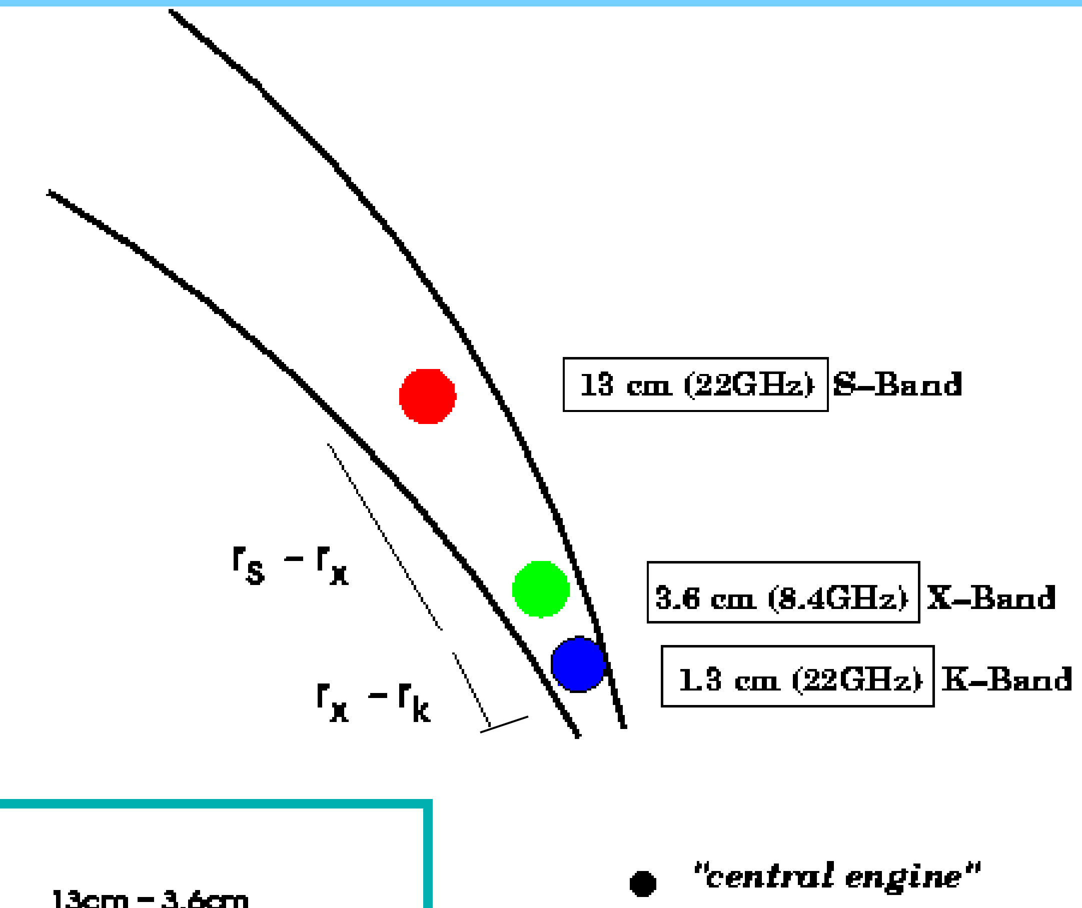
Images: Boboltz uas astronomy-2009
Ojha ATNF-newsletter 2002

Standard Model for Extragalactic Radiosources



Central engine powering jets of plasma

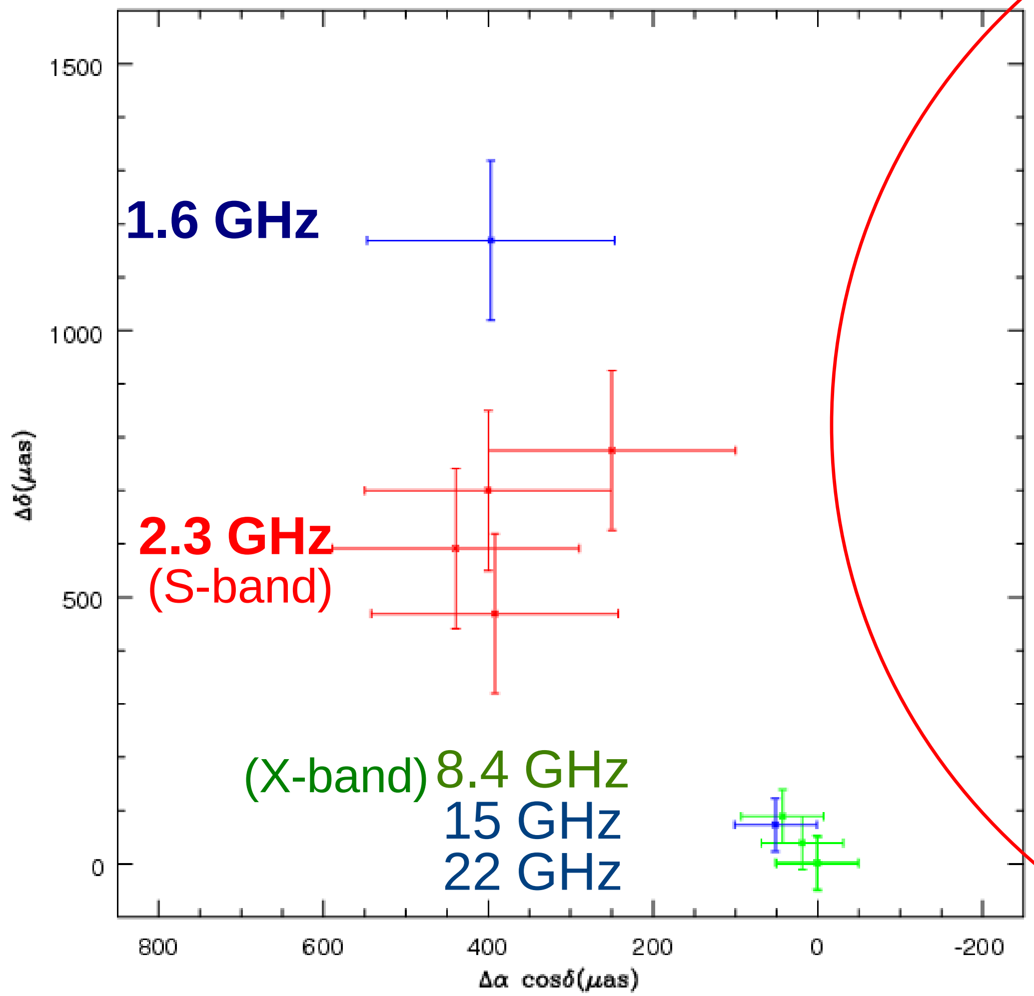
Standard Model for Extragalactic Radiosources

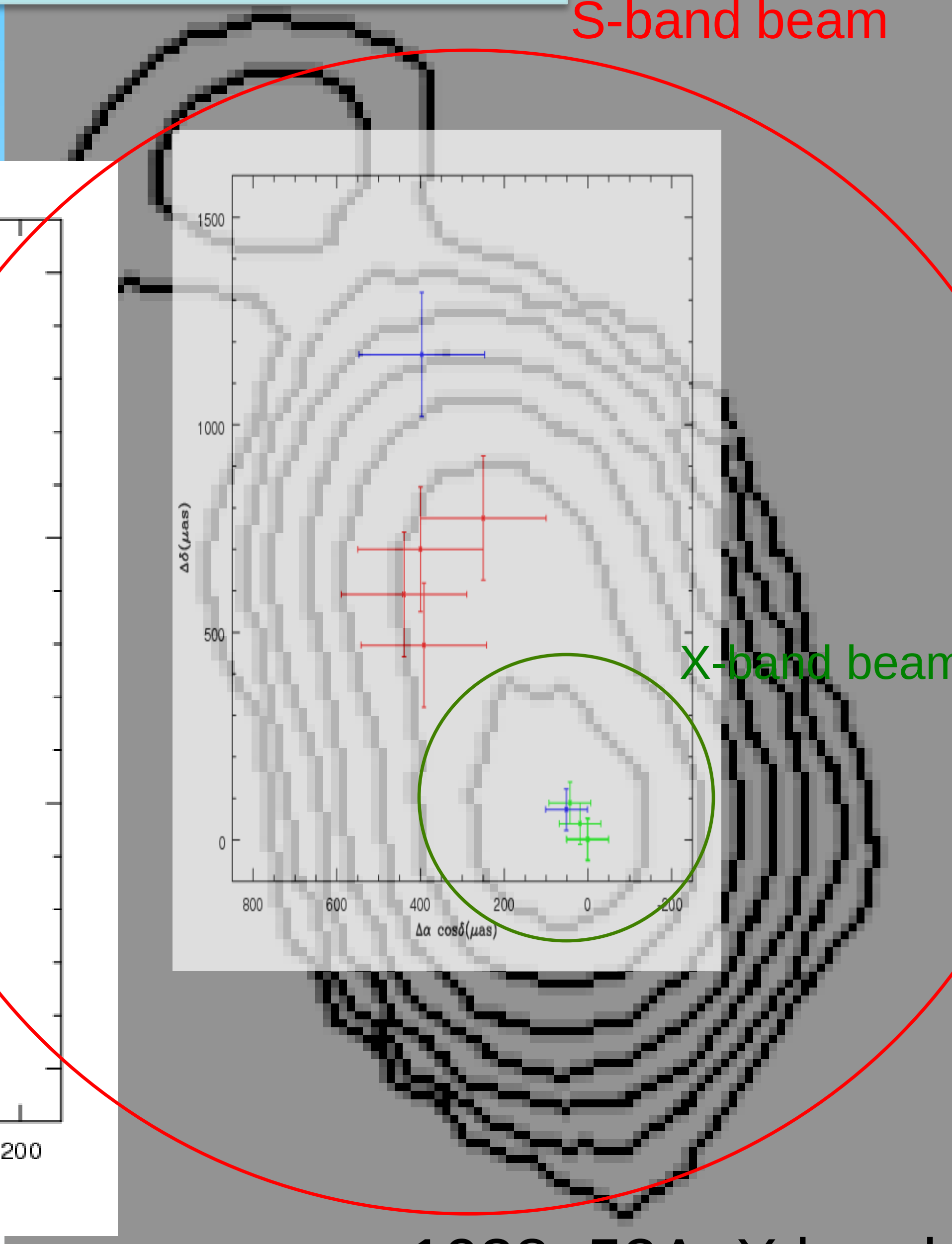


$$\frac{r_S - r_X}{r_X - r_K} = \frac{13cm - 3.6cm}{3.6cm - 1.3cm} \sim 4$$

Observational evidence of "core-shifts"

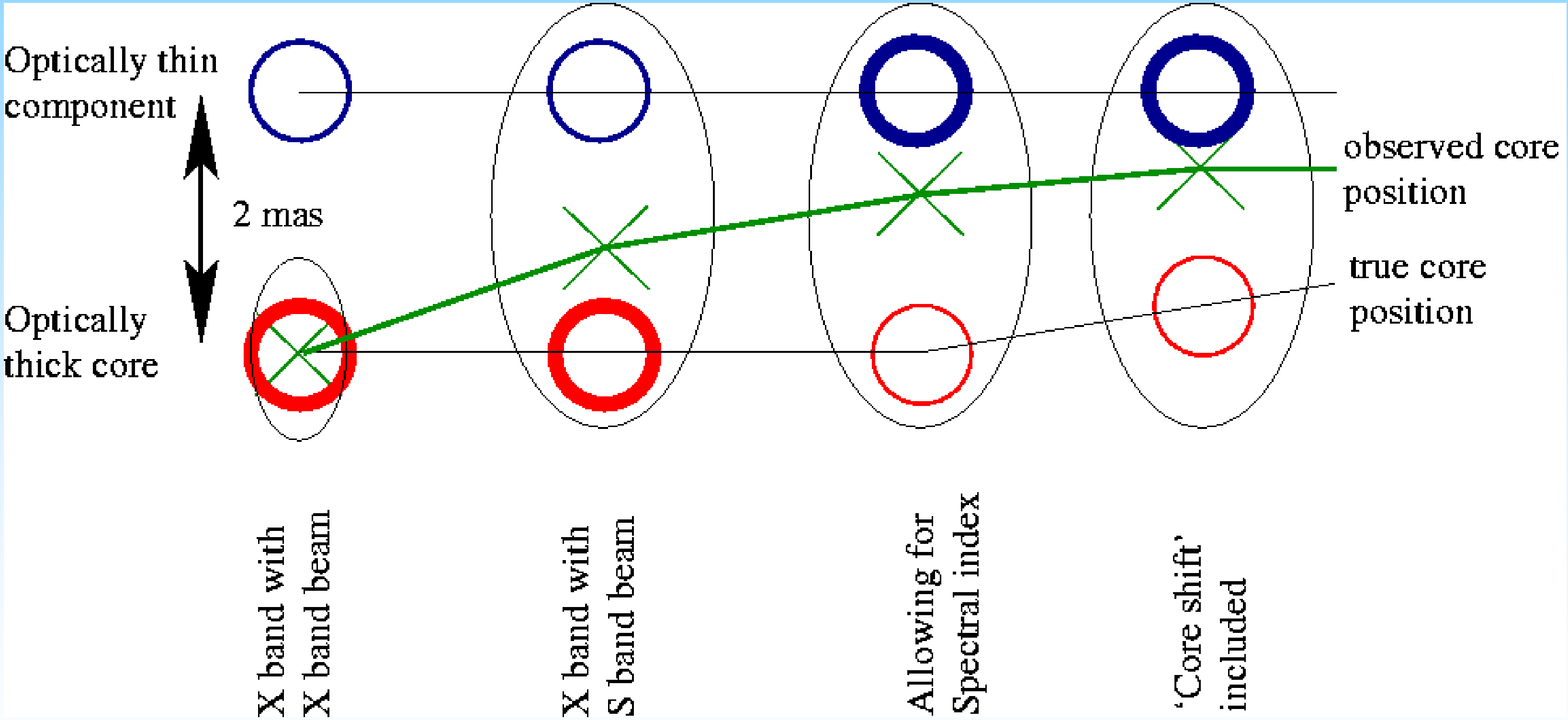
1038+528AB, 33"
Core-shifts in 1038+528A





(Rioja et al.)

Interpreting observed "core-shift": "opacity" + "instrumental"



Not predictable, can change in time

Magnitude of expected "core-shifts"

	"Opacity" core shift	"Instrumental" core shift	Measured core shift
2.2/8.4 GHz	0 – 1 mas	0 – 2 mas	0 – 1400 micro-as
8.4/30 GHz	0 – 0.25 mas	0 – 0.5 mas	0 – 300 micro-as

“core-shifts” in Geodesy, some facts…

- Group delay measurements result in a reduced “core shift” (Porcas, 2009)
  (for opacity shifts)

Exponent equal to 1, all frequencies measure same position

For other values, the deviation of exponent from 1 gives the multiplicative reduction factor.

Need to include also “instrumental” core-shift

“core-shifts” in Geodesy, some facts…

- ❖ Group delay measurements result in a reduced “core shift” (Porcas, 2009)
  (for opacity shifts)

- ❖ Core-shifts interact with dual-frequency group delay ionospheric correction

➡ **Shift in measured Source positions**

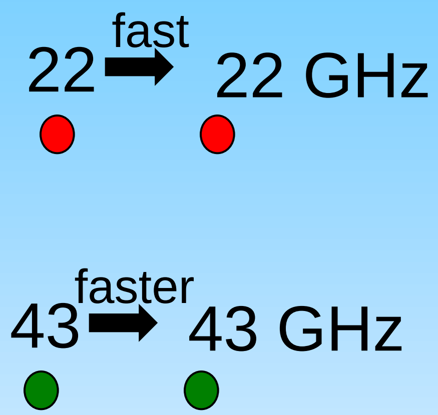
- ❖ VLBI2010: Core shifts might disturb phase Connection across frequency bands (by adding Phase ambiguities(?)

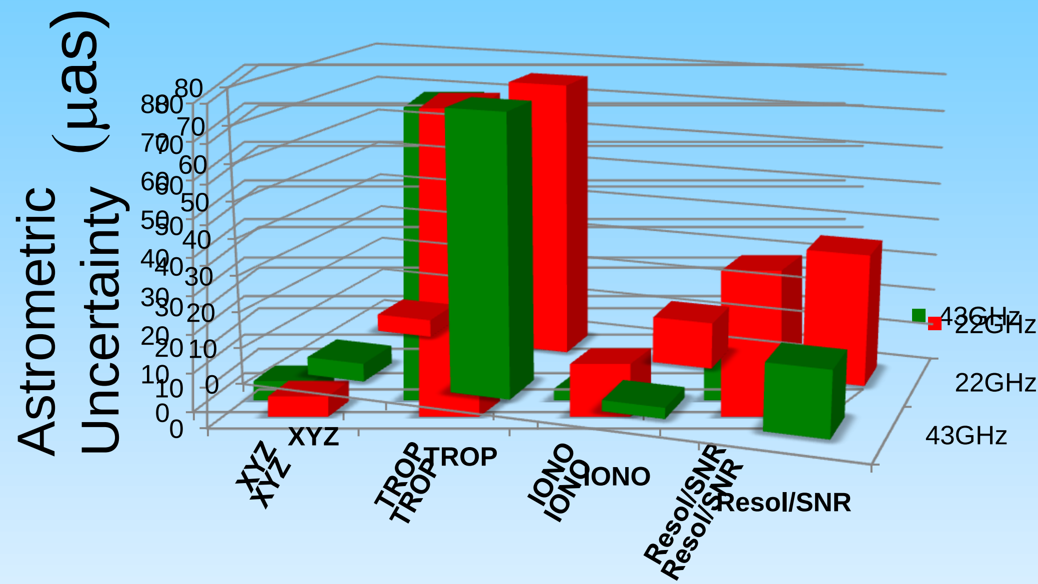
"core-shifts" can be measured

Phase referencing/Differential Astrometry

- Use interleaving observations of a nearby calibrator to eliminate residual errors in the target source
  (not direct modeling: high precision, relative separation)
- Prerequisite success: strong, compact nearby reference source
- Successful application regime: > 2 GHz, < 43 GHz

Astrometric Errors with Conventional Phase Referencing





Troposphere limits precision
(advanced methods include geodetic-setup)

And eventually prevents mm-astrometry

Alternative Tropospheric Calibration in mm-VLBI

Conventional Phase referencing to a calibrator source

(requirements difficult to meet)

fast

43 ➡ 43 GHz

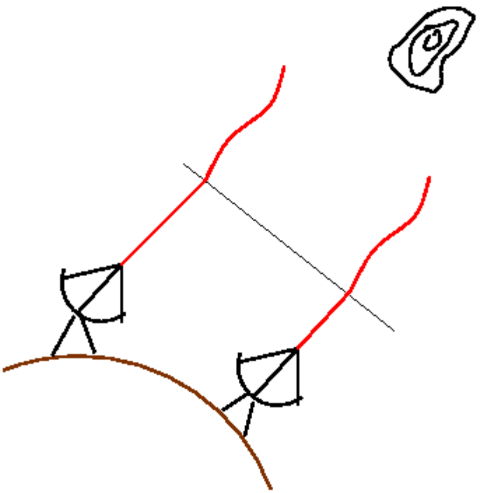
Different source

Multi-frequency: phase ref. to a lower frequency

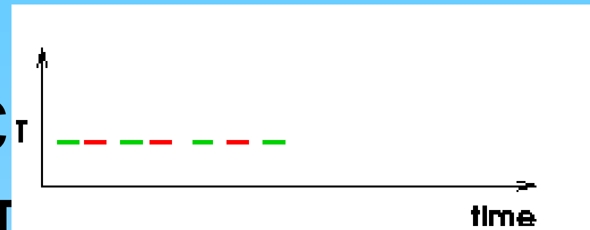
- **Observe at lower band (e.g. 21.5 GHz)**
- **Apply to higher band (e.g. 43 GHz)**

⬆ fast

Same source



Basic … od: CE/FREQ. phase referencing



fast slow slo w

$$\phi_A = \phi_{A,GEO} + \phi_{A,TRO} + \phi_{A,ION} + \phi_{A,INST} + \phi_{A,STR} + 2\pi n_A$$

X

$$R*\phi_A = R*(\phi_{A,GEO} + \phi_{A,TRO} + \phi_{A,ION} + \phi_{A,INST} + 2\pi n_A)$$

$R = \nu / \nu$

$$\phi_{A,TRO} - R * \phi_{A,TRO} = 0$$

$\phi_{A,XYZ} - R * \phi_{A,XYZ} = 0$, **Antenna errors cancel!**

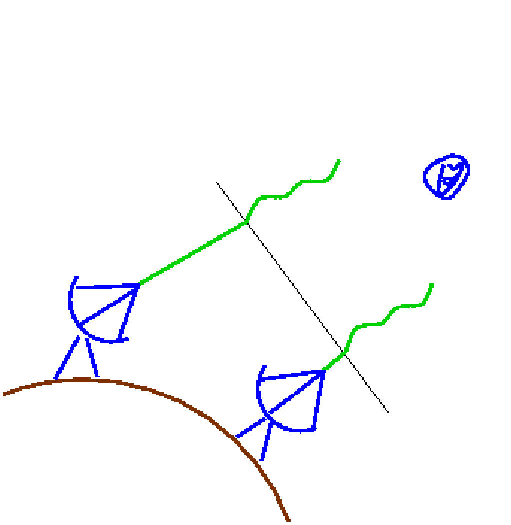
$$\phi_{□□□□□} - R * \phi_{□□□□□} = (R-1/R) * \phi_{A,ION}$$

⋮

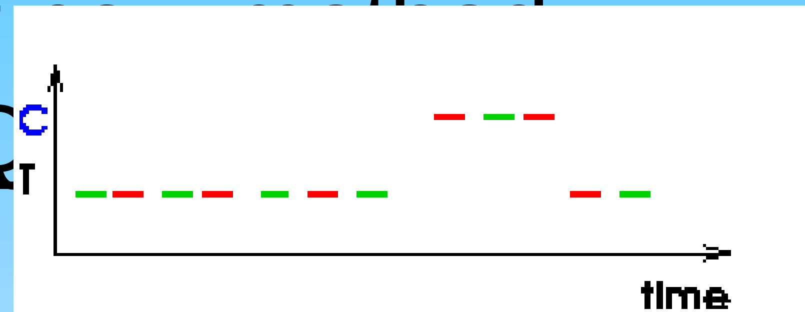
slow slow

$$\phi_A - R*\phi_A = \phi_{A,STR} + 2\pi\nu/c\,(\bar{D} \cdot \bar{\theta}_{A,shift}) + ION + INST$$

Frequency-referenced Visibility phase



Basics of ... method ... CE/FREQ ... g



$\psi_B - R * \phi_B = 2\pi\nu/c\ (D\ .\ \theta_{B,shift}) + ION$

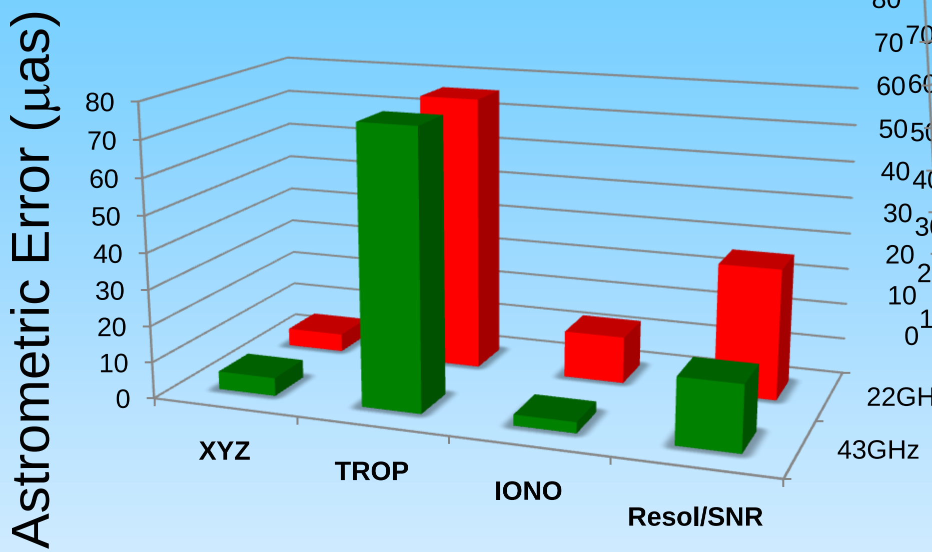
□□□NST□

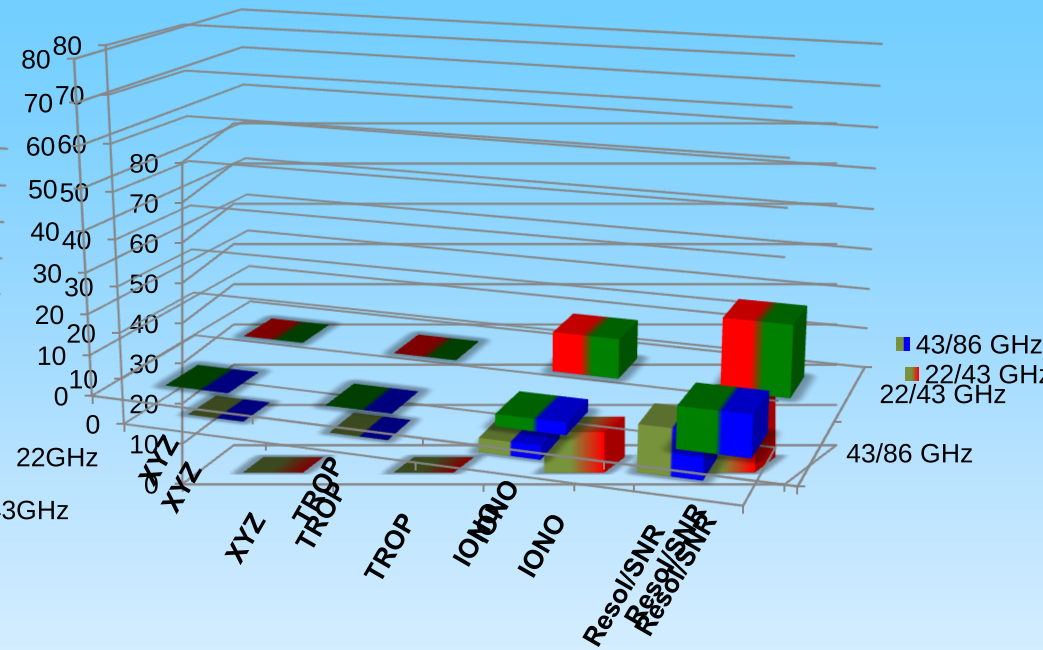
Source/freq. referenced Visibility phase:

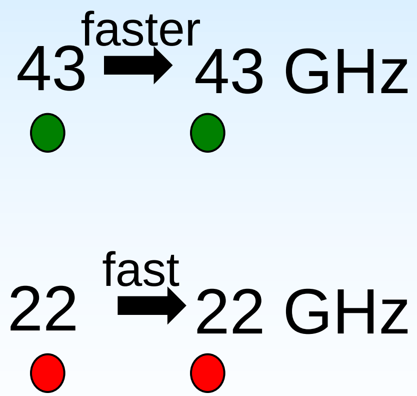
$$\phi_{A,STR} + 2\pi\nu/c * \bar{D}\ (\bar{\theta}_{A,shift} - \bar{\theta}_{B,shift})$$

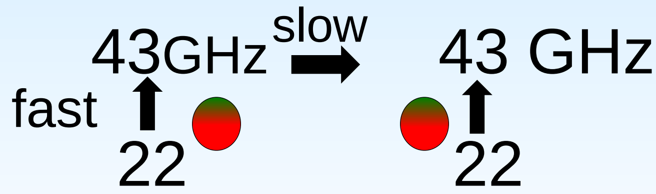
Conventional Phase-Ref.

Source/Freq. Phase Ref.









Successful demonstration
Using VLBA @43/86GHz

Important points

- “Perfect” Tropospheric calibration

- Frequency agility crucial: VLBA (switching);
  Best simultaneous observations: KVN, Yebes-40m

- Direct Astrometric measurement of “core-shifts”, even at the highest frequencies, > 43 GHz

- Errors in station coordinates no problem

- Non-integer ratio between frequencies problematic
  (Introduces phase jumps related to phase ambiguities)

$$\ldots\ldots\ 2\pi\,(n_A - n_B + R(n_A - n_B))$$

Applications

◆ HIGH PRECISION ASTROMETRY @ HIGHEST FREQ.:

✓ Core-shift science with “bona fide” astrometric positions

✓ Improve radio-optical reference frame alignment

✓ Astrometric alignment of molecular maser emission (e.g. SiO at 43 - 86 - 129 GHz in AGB stars)

◆ DIRECT COMPENSATION OF STATION COORD. ERRORS

✓ Enable VSOP-2 astrometry @ 43-GHz:

Orbit accuracy (orbit errors cancel!)

Lack of nearby calibrators (wider separations possible)

Summary

- Core-shifts exist, can vary, and can be measured with high precision.

- Characterization of core-shifts, hints for its existance

- Core-shifts should be accounted for in 1-mm precision geodesy, along with the source structure

- New calibrations strategies for mm-VLBI --
  extend astrometry beyond conventional phase ref. limits