ATMOSPHERIC TURBULENCES IN WIDE-FIELD INTERFEROMETRIC IMAGES
(CASE OF THE SKA)

Ivan Marti-Vidal
Max-Planck-Institut fuer Radioastronomie (Bonn, Germany)

J.C. Guirado, S. Jiménez-Monferrer, & J.M. Marcaide Univ. Valencia (Spain)
POSITION-DEPENDENT PHASE GAIN

\[ V_{lm} = \sum_k F_k(\vec{B}_{lm}) \cdot \exp \left( i2\pi (\Delta \vec{\alpha}_k \cdot \vec{B}_{lm}) \right) \cdot \exp \left( i\phi_{lm}^k \right) \]

\[ V_{lm}^{\text{cal}} = V_{lm} \cdot \exp \left( -i\phi_{lm}^0 \right) \quad \phi_{lm}^0 = \phi_{i}^{\text{gain}} - \phi_{j}^{\text{gain}} \]
200 stations:

- 100 stations in an inner core of 10 km diameter.
- 100 stations in a square of 3000 km length.

- 5 equiangular spiral arms; logarithmic spacing.

- Sensitivities from Jones (2004) (SKA memo 45)
Ionosphere and wet troposphere follow Kolmogorov statistics.

- Ionosphere ($\nu^{-2}$):
  Fried length = 3 km @ 100 MHz

- Troposphere ($\nu$):
  Seeing at 5 GHz = 0.1 as

(See Thomson, Moran & Swenson 1991)

Kolmogorov screens are self-similar
MONTE-CARLO SIMULATIONS

- 13 frequencies (150 - 24000 MHz)
- Separation of 5 degrees
- 1,500 simulations at each frequency

-Astrometric uncertainty and dynamic range taken from statistics of image distributions.
- Dominance of ionosphere below 500 MHz.
- Window between 500 and 15000 MHz with good detections and high astrometric precision.
- Dominance of troposphere above 15000 MHz.
DEPENDENCE WITH FREQUENCY

SEPARATION = 5 deg. \hspace{1cm} \text{INT. TIME} = 60 \text{ s}

\[
\text{SNR} = \frac{S}{\sigma}
\]

\[
\sigma = \sqrt{\frac{\sigma_{th}^2}{S} + \sigma_{at}^2}
\]

\[
\sigma_{at} = K(\Delta \alpha, \nu) \cdot S
\]

\[
\text{SNR} = \frac{S}{\sqrt{\sigma_{th}^2 + K^2 S^2}}
\]

\[
S >> \sigma_{th} \rightarrow \text{SNR} \sim \frac{1}{K}
\]
DEPENDENCE WITH DISTANCE

FREQUENCY = 1420 MHz     INT. TIME = 60 s

“LARGE” FLUX DENSITY (0.01 mJy)

- Dynamic range and astrometric precision limited by atmosphere.
- Better for smaller images and/or longer integration times.
- No dependence on flux density nor antenna sensitivities!

\[ \sigma = \frac{\sigma_0}{D_0} (k\Delta \alpha + 1) \]

\[ SNR = \frac{D_0}{(k'\Delta \alpha + 1)} \]

Similar to Pradel, Charlot, & Lestrade (2006)
REAL DATA: PHASE REFERENCING WITH VLBA

THE S5 POLAR CAP SAMPLE

- Studied in MPIfR since 80s (Eckart et al., 1987, Witzel et al., 1988, etc.)
- Strong radiosources (0.25 - 3.5 Jy at 15GHz)
- Long term astrometry program

\[ V_{lm} = \sum_{k} F_k(\vec{B}_{lm}) \cdot \exp \left( i2\pi (\Delta \vec{a}_k \cdot \vec{B}_{lm}) \right) \cdot \exp \left( i\phi_{lm}^k \right) \]
REAL DATA:
PHASE REFERENCING WITH VLBA OBSERVATIONS @ 15 GHz
CONCLUSIONS

• Atmospheric turbulences generate position-dependent phase gains in wide-field images.

• We have generated a set of Monte Carlo simulations of a realization of the SKA under the effect of turbulent ionosphere and wet troposphere.

• The astrometric precision and image fidelity decrease as the distance to the image phase center increases.

• The maximum dynamic range (and, indirectly, astrometric precision) does not depend on station sensitivity nor source flux density and is strongly limited.

• These results are qualitatively similar to results obtained from real phase-reference observations with the VLBA.

Marti-Vidal et al. (in preparation) & Marti-Vidal et al. (2009) (SKA memo 112)
RECORD GUINNESS OF PHASE-REFERENCING!!

0212+735 w.r.t. 2007+777 - SEPARATION OF 20.8 deg!
- **LESS ANTENNAS:** Dynamic range and astrometric precision roughly modified by the ratio of the number of baselines.

- **LESS SENSITIVITY:** Lower dynamic ranges for weak sources, but similar dynamic ranges for strong sources (i.e., same atmospheric limitation).

- **SHORTER BASELINES:** Slightly higher SNR for good detections. Therefore, astrometric precision not exactly modified by the ratio of baseline lengths.