"The beginning: Finding errors in the uv plane"



"The Beginning"

From the inauguration of the WSRT (1970) to the advent of Self-calibration (1980) (the Dark Ages B.G.)

"The *uv* plane" The entire path from source to telescope projected onto the Equatorial plane

"Errors"

Everything that gets in our way

Errors in the *uv* plane

- High-frequency cables
- Man-made interference
- Calibration on cosmic sources
- Earth-based calibration
- Atmospheric phase variations
- The first (primitive) self-calibration ever

Encore: Analogue Fourier Transformations

Errors in the uv plane

Prevention Layout: Surveying with astrometric precision Stable components Shielding from environment Electronics: Supply voltage, temperature Cables: Temperature, gas pressure Avoid differential effects Interferometer symmetry Interference, cross-talk Tag signals through modulation

Calibration

Determine instrumental effects by observing a known reference

Man-made

Pilot signal Simultaneous with target observations

Natural

Calibrator source Interleaved with target observations

WSRT high-frequency cables

Polar and declination axis crossings





6 HF gas-filled coaxial cables per telescope



Man-made interference



WSRT calibration on cosmic reference sources

Primary, per week: Several long (6-12 hour) runs on calibrators of various DEC Fit model of baseline/telescope position

Secondary, per target source Short (30-60 min) runs on one calibrator to measure interferometer phases before and after

Calibrating telescope positions



Earth-based 1415 MHz phase calibration system

Per interferometer:

Inject 1415 MHz CW reference signals tagged by modulation into both frontends Compare the reference signals in the correlator, using the modulation to separate them from the astronomy signals

Who calibrates the calibrator?

Use another modulation to tag signals reflected from the ends of the injection cables Compare the reflected signals to determine the phase difference of the signals injected

130 dB two-way loss over the injection cables: 0.1 pW returned from a 1W oscillator

Some two FTE over seven years (1966-1972)

Interferometer phase measured with about 1 degree (.6 mm) accuracy (1973)

Fitting telescope positions





Electrical lengths and ambient temperature over a 5-day period



Results

Electric cable lengths depend strongly on ambient temperature Large differences between cables

Difference in thermal expansion between fixed and movable telescopes (Asymmetry in mechanical foundations) Misalignments of polar axes

Not scalable to higher frequencies

BUT

Integration into the data processing system not straightforward

The WSRT was the best instrument on Earth anyway The priority was to add more frequencies The VLA was not taken seriously as a competitor

About 1980 Selfcal revolutionised the Rules of the game

Atmospheric phase variations





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----- Antenna positions

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Fig. 4. Phases displayed as grey levels versus antenna positions (vertical) and time (horizontal). Time progresses to the right in each strip and downward from strip to strip. There is a 30 min overlap between successive strips. The background grey level represents zero phase. Skew bands running across the strips represent irregularities moving over the array with a velocity component along its east-west direction. Several different east-west velocities are seen to occur in the course of the observation. The "horizontal" features visible mainly in the second half of the observation show that slowly drifting offsets in individual antennas have not been completely suppressed by the filtering.

## 3C236: One of the giant sources discovered by WSRT in 1974

Core source subtracted (unresolved, several slides high)



The radial stripes correspond to variable phase gradients over the WSRT

These can be removed by fitting and subtracting per hour-angle scan in the *uv* data.

## **3C236:** The first (primitive) self-calibration ever!

Raw

#### Corrected



"Finding errors in the uv plane"?

Interference ( if strong enough )

Major equipment malfunctions

Equipment inaccuracies, including large-scale atmospheric effects To some extent for the highly ordered 2-D *uv* plane of the WSRT Only for strong, compact sources

# Alternative: Fourier-transform the data! **BUT**

The FT is demanding Computing is very expensive, price/performance is slow in coming down

How about analogue Fourier Transformations? (1975)

#### Free from nature: A massively-parallel Fourier Transformer



#### Simplicity of the core operation versus unwieldy format mismatches at its input and output

NRAO seriously considered a proposal and eventually rejected it (1977)



Accumulation on a Scan Converter CRT

## ² A Moire' Fourier-transformer of sorts







# G.A. – the Golden Age a.k.a. A.G.

#### From a 1994 overview of NEWSTAR

Acknowledgements

NEWSTAR's history dates back to the pioneering work on Redundancy by J.E. Noordam in the early 1980s. W.N. Brouw systematised and expanded his work in subsequent years, in a suite of programs known as the 'R-series'. In 1990-1991, this series served as the prototype for an entirely new collection of programs that eventually became NEWSTAR.

During this entire development, A.G.de Bruyn played an indispensable role as an active and stimulating user.