# “The beginning: Finding errors in the *uv* plane”

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**Astron**

## “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

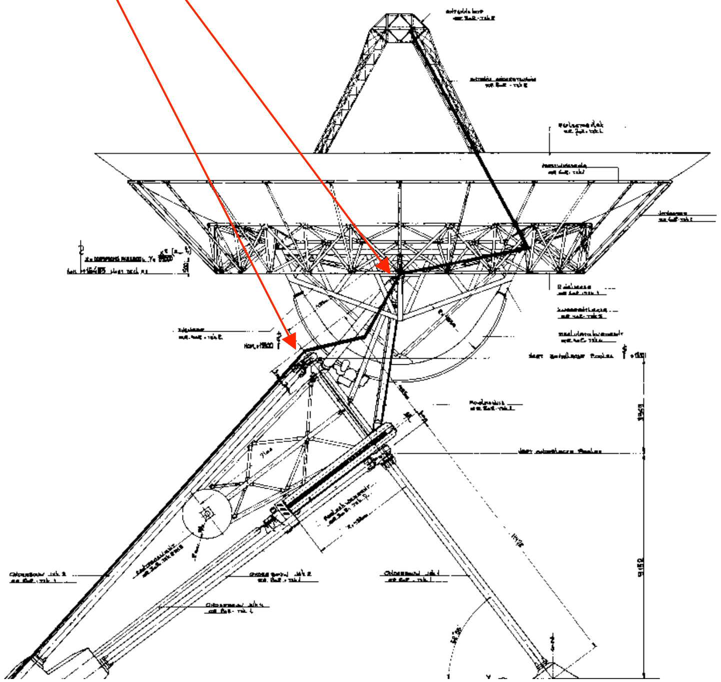
- Pilot signal
- Simultaneous with target observations

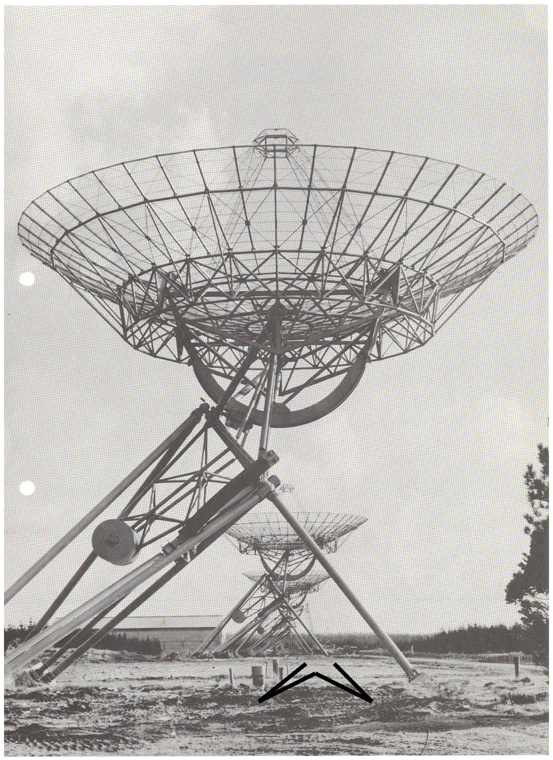
Natural

- Calibrator source
- Interleaved with target observations

# WSRT high-frequency  cables

Polar and declination
axis crossings

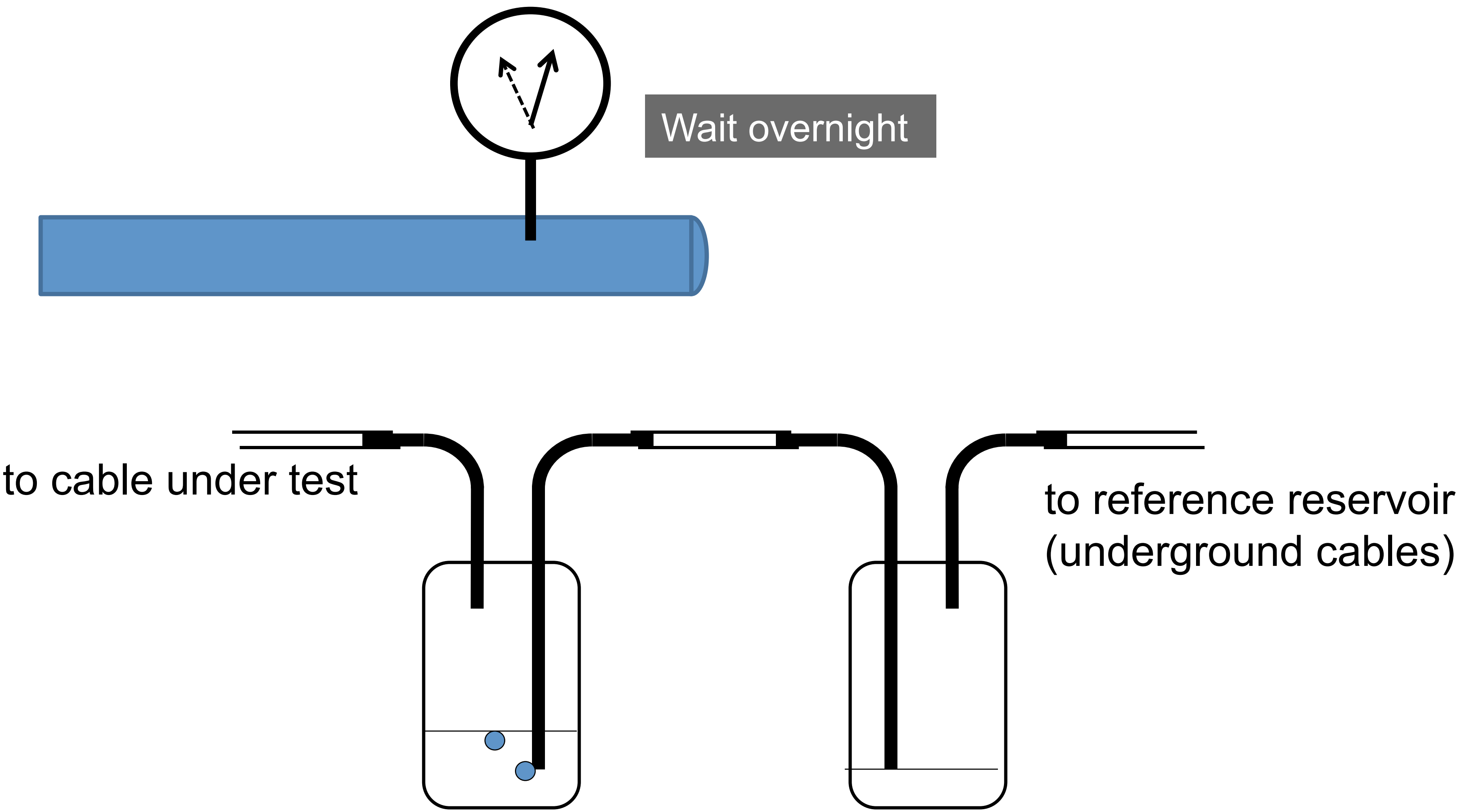




6 HF gas-filled coaxial
cables per telescope

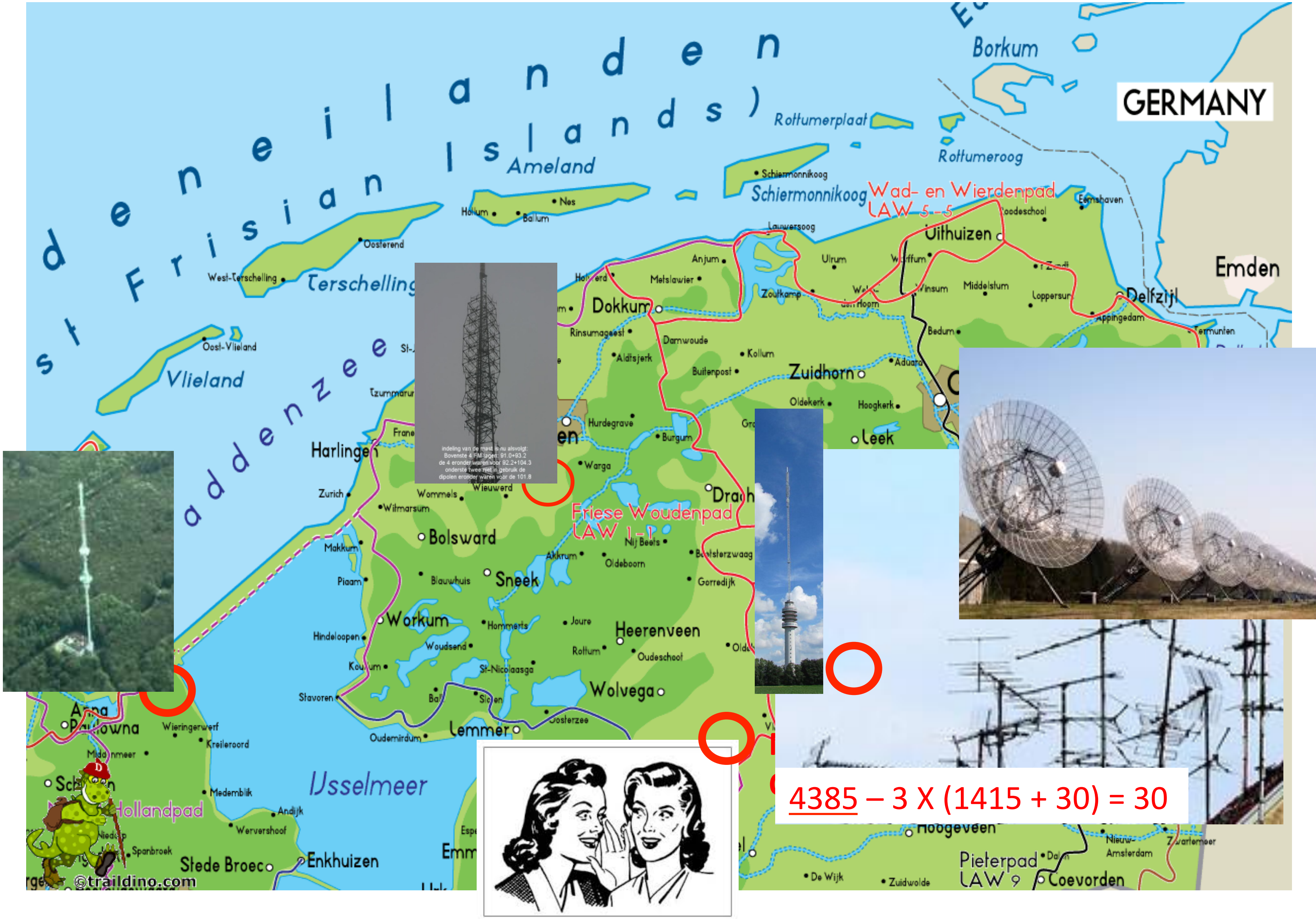
# Detecting gas leaks in the cable system

Hamaker, Katgert, Le Poole, autumn 1969




"Bellenvat" = Bubble Chamber
(a detector device used nuclear physics)

# Man-made interference




4385 – 3 X (1415 + 30) = 30

# WSRT calibration on cosmic reference sources

Primary, per week:

Several long (6-12 hour) runs on calibrators of various DEC

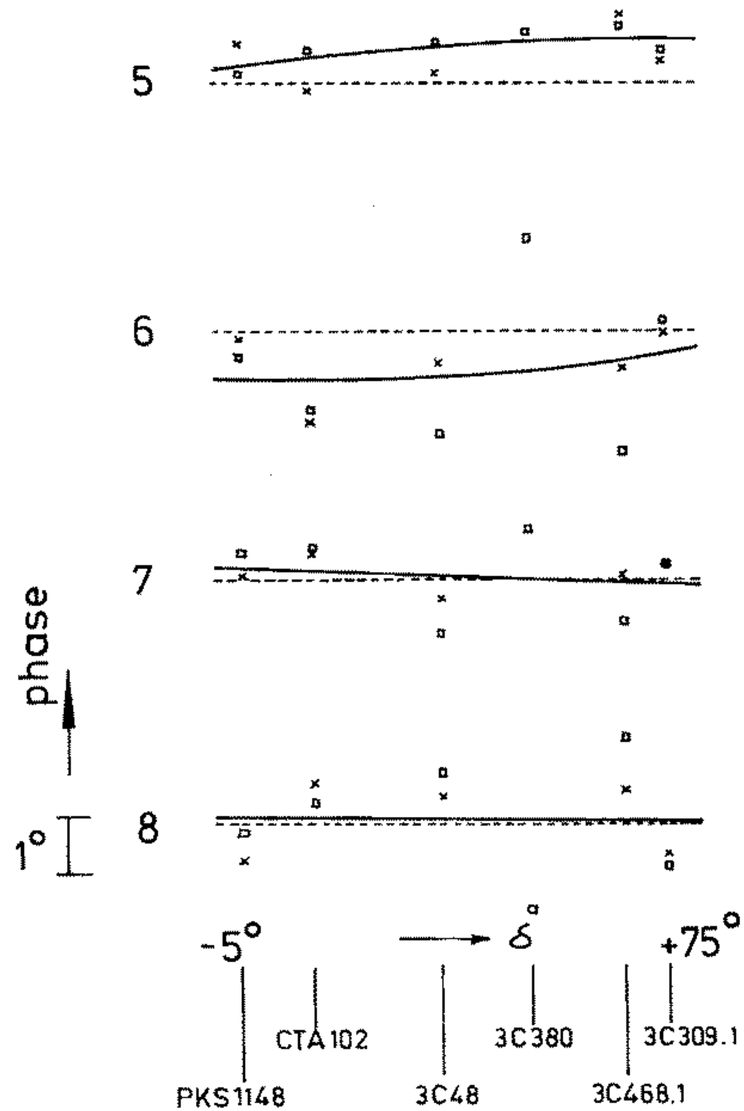
Fit model of baseline/telescope position

Secondary, per target source

Short (30-60 min) runs on one calibrator to measure

interferometer phases before and after

# Calibrating telescope positions




□ Relative to RT A

× Relative to RT B

1 deg = 0.6 mm

Drawn curves:

Best-fit *A* + *B sin* DEC

# 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

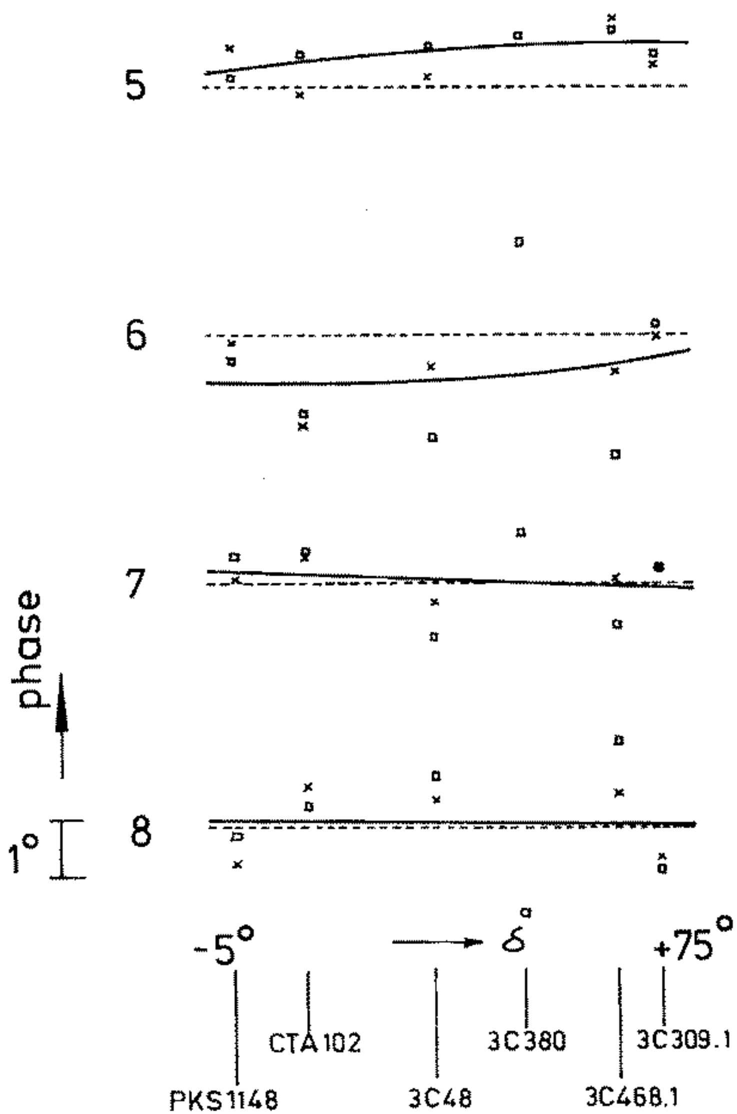
Some two FTE over seven years (1966-1972)

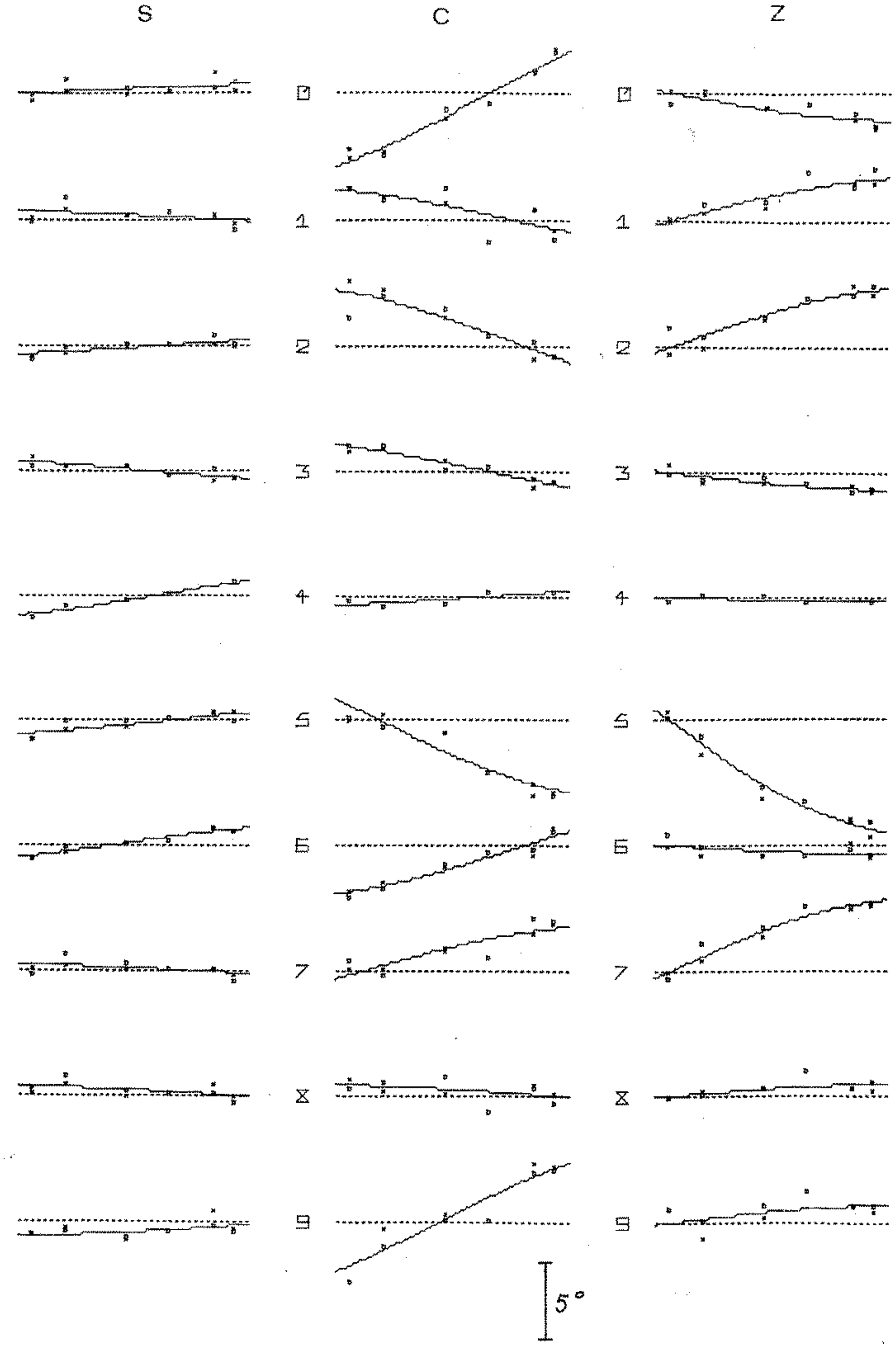
Interferometer phase measured with about 1 degree (.6 mm) accuracy (1973)

# Fitting telescope positions

uncorrected

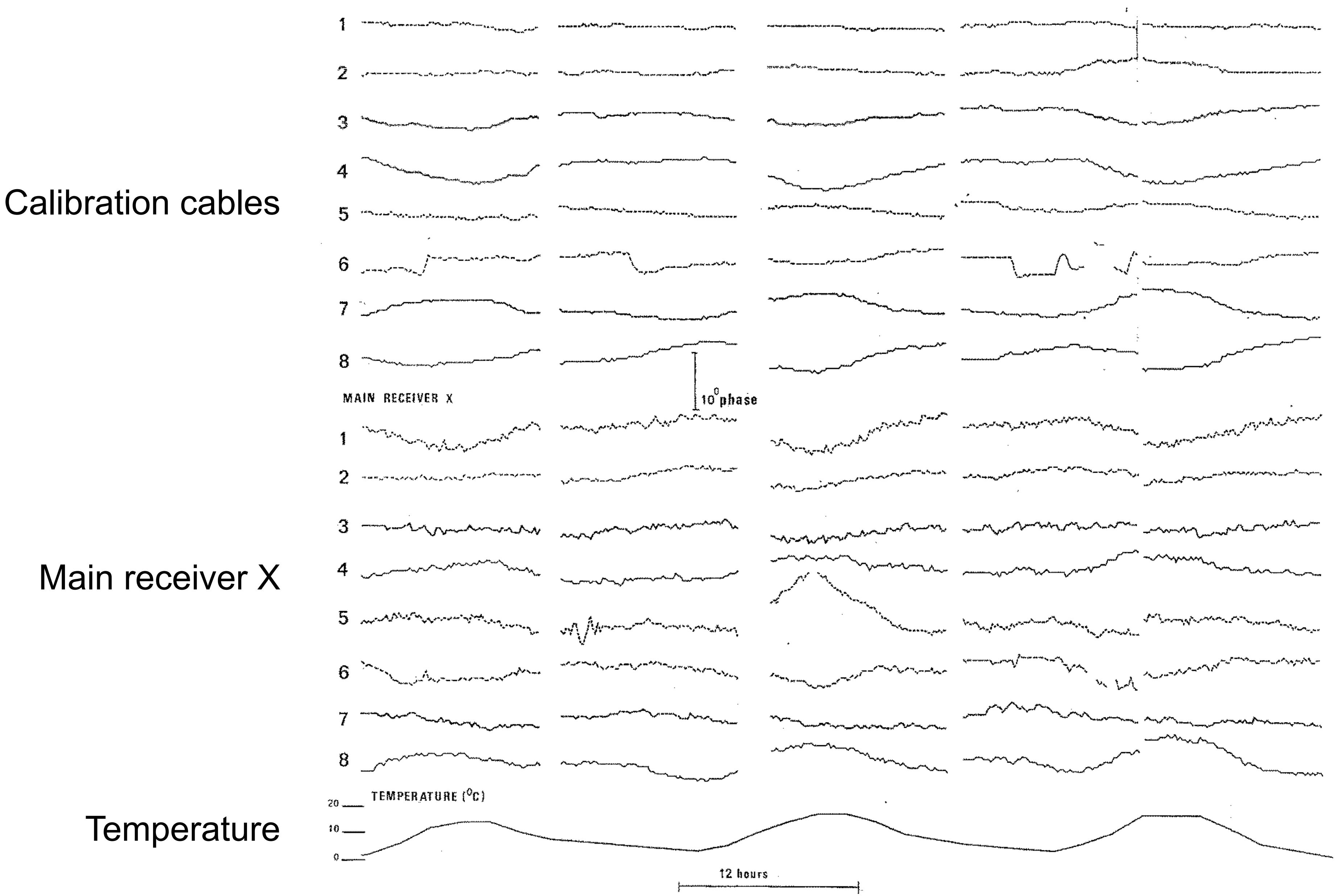
corrected





S
C
Z
0
1
2
3
4
5
6
7
8
9
5°

# 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

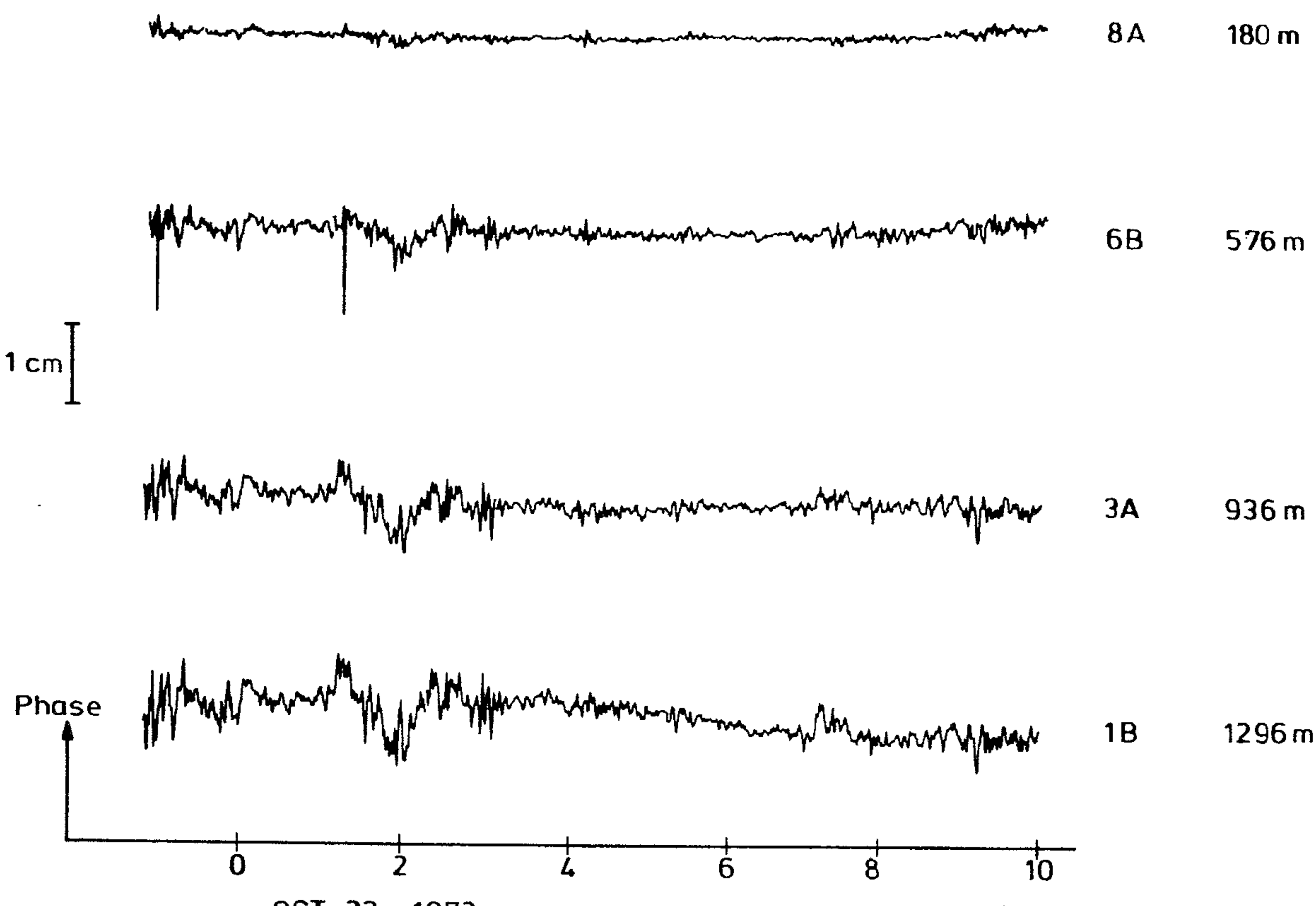



Fig. 3. The sequence of phase profiles over the array for the observation of Figure 2. Time progresses downward in 1 min intervals in each column and to the right from column to column. There is a 6 min overlap between successive columns. The major features of Figure 2 are readily identified.

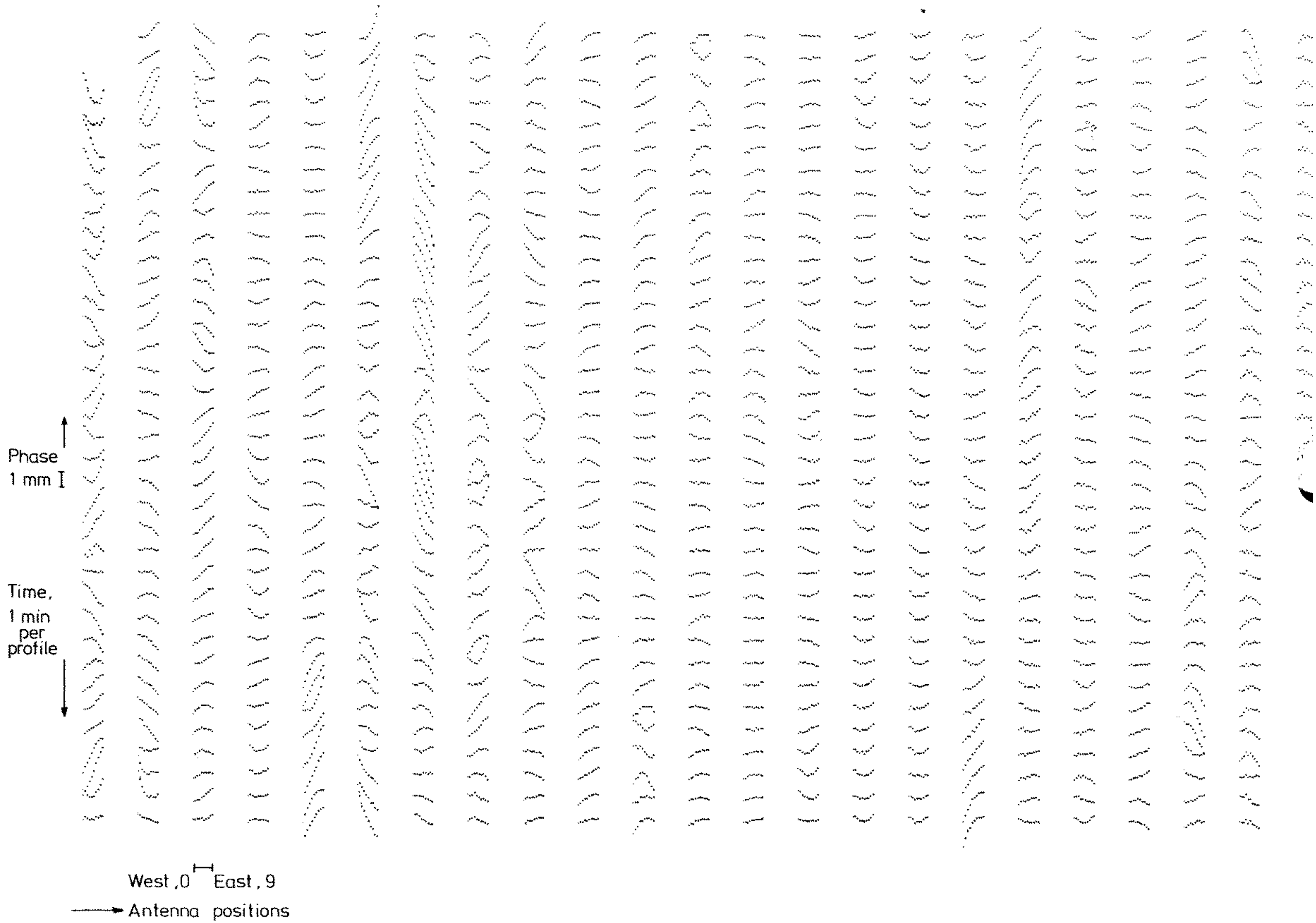



Fig. 3. The sequence of phase profiles over the array for the observation of Figure 2. Time progresses downward in 1 min intervals in each column and to the right from column to column. There is a 6 min overlap between successive columns. The major features of Figure 2 are readily identified.

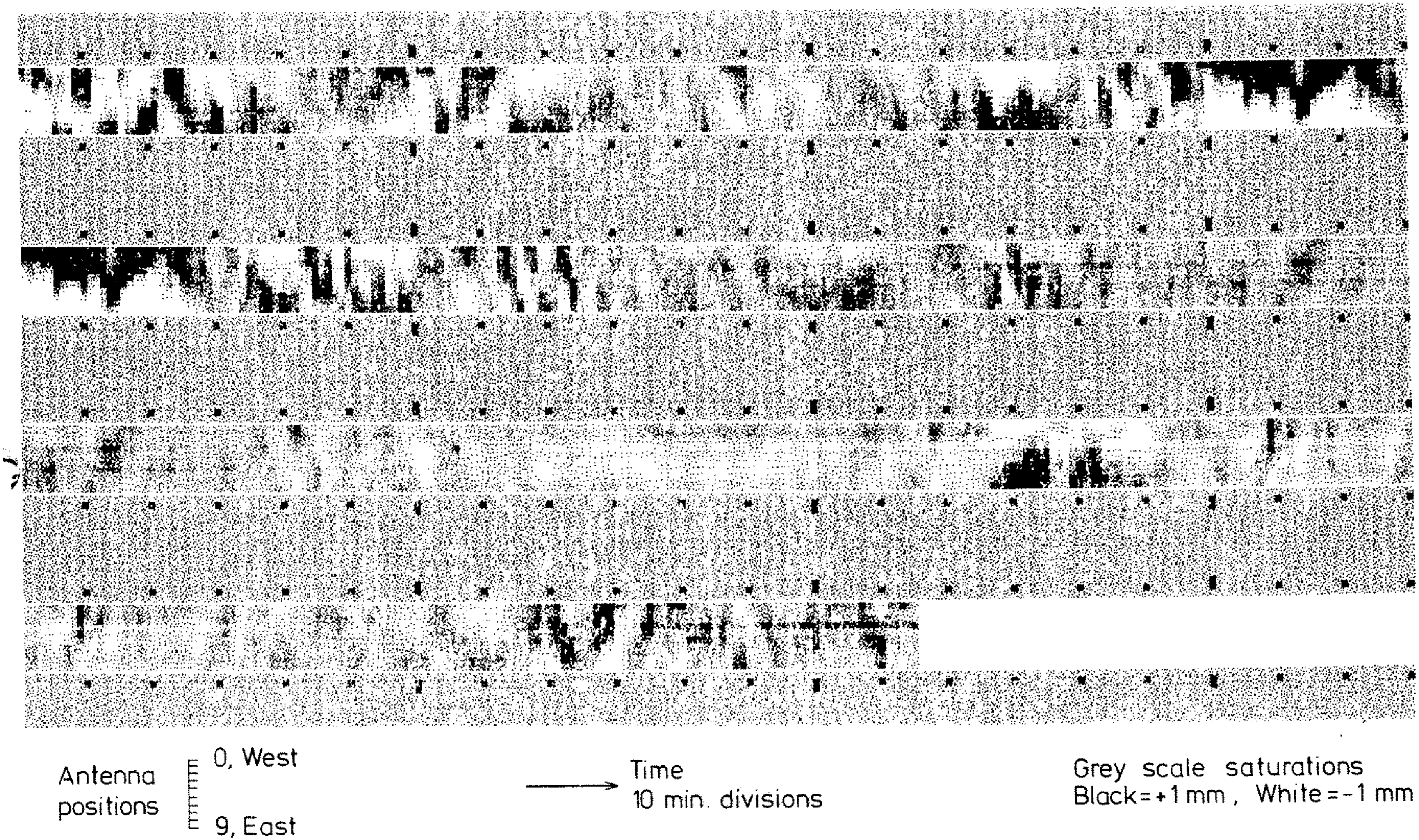
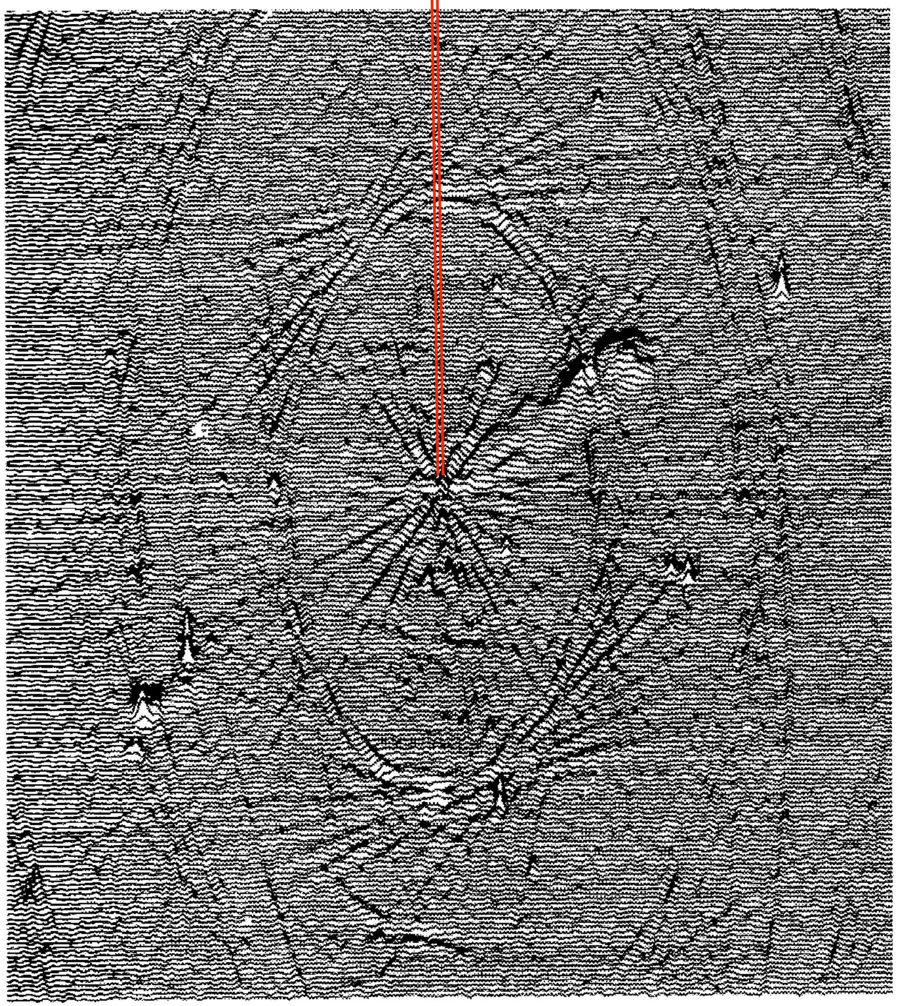



Fig. 4. Phases displayed as grey levels versus antenna positions (vertical) and time (horizontal). Time progresses to the right in each strip and downward from strip to strip. There is a 30 min overlap between successive strips. The background grey level represents zero phase. Skew bands running across 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)

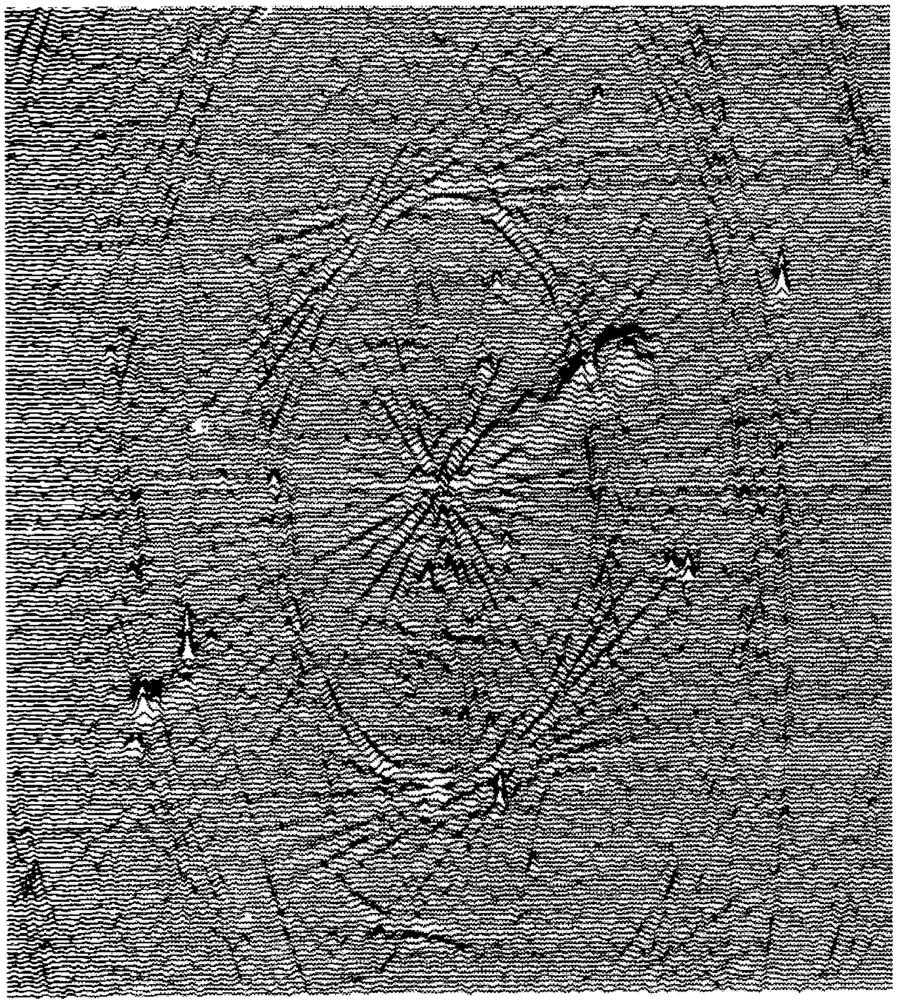


The radial stripes correspond to variable phase gradients over the WSRT

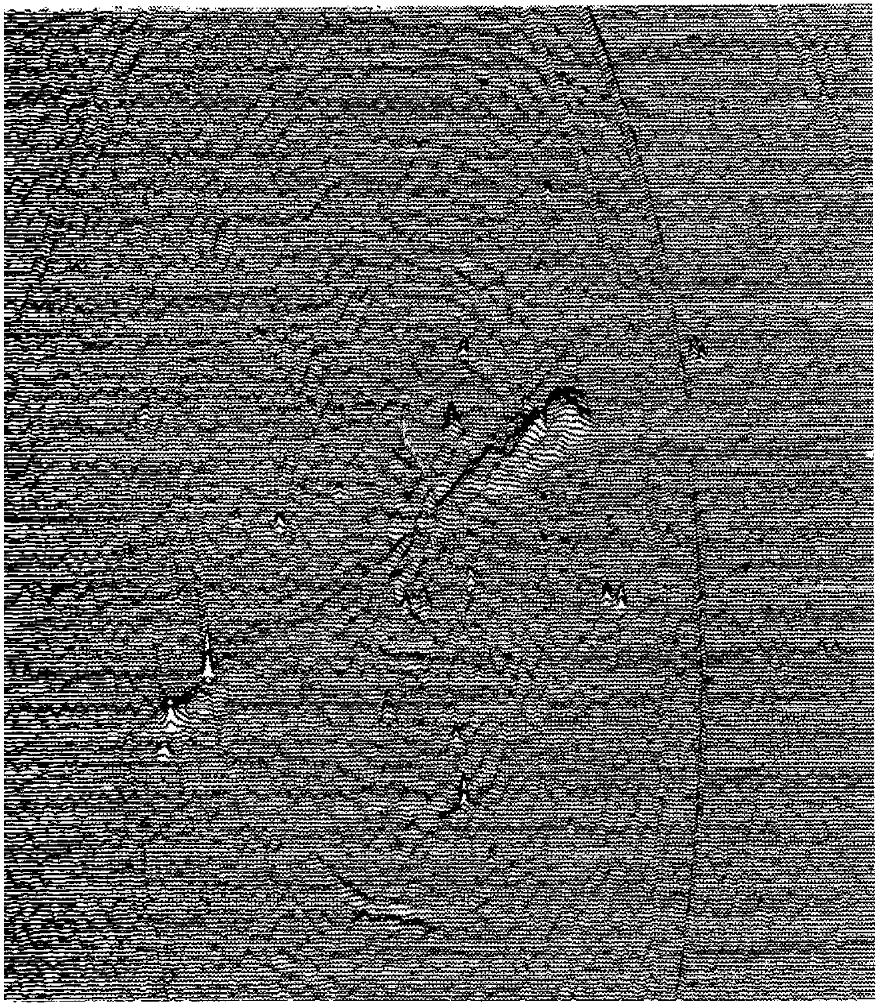
These can be removed by fitting and subtracting per hour-angle scan in the *uv* data.

# 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

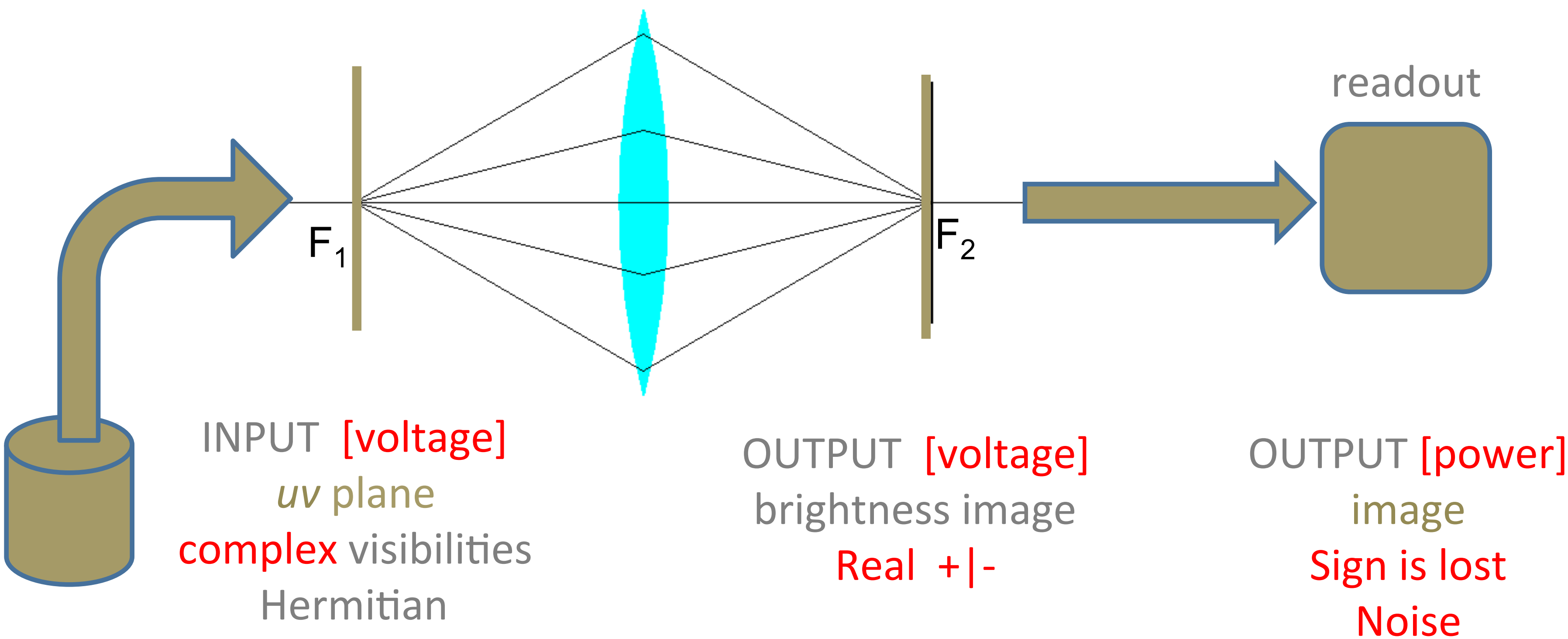
Computing is very expensive,

price/performance is slow in coming down

## How about analogue Fourier Transformations?

## (1975)

# Free from nature: A massively-parallel Fourier Transformer



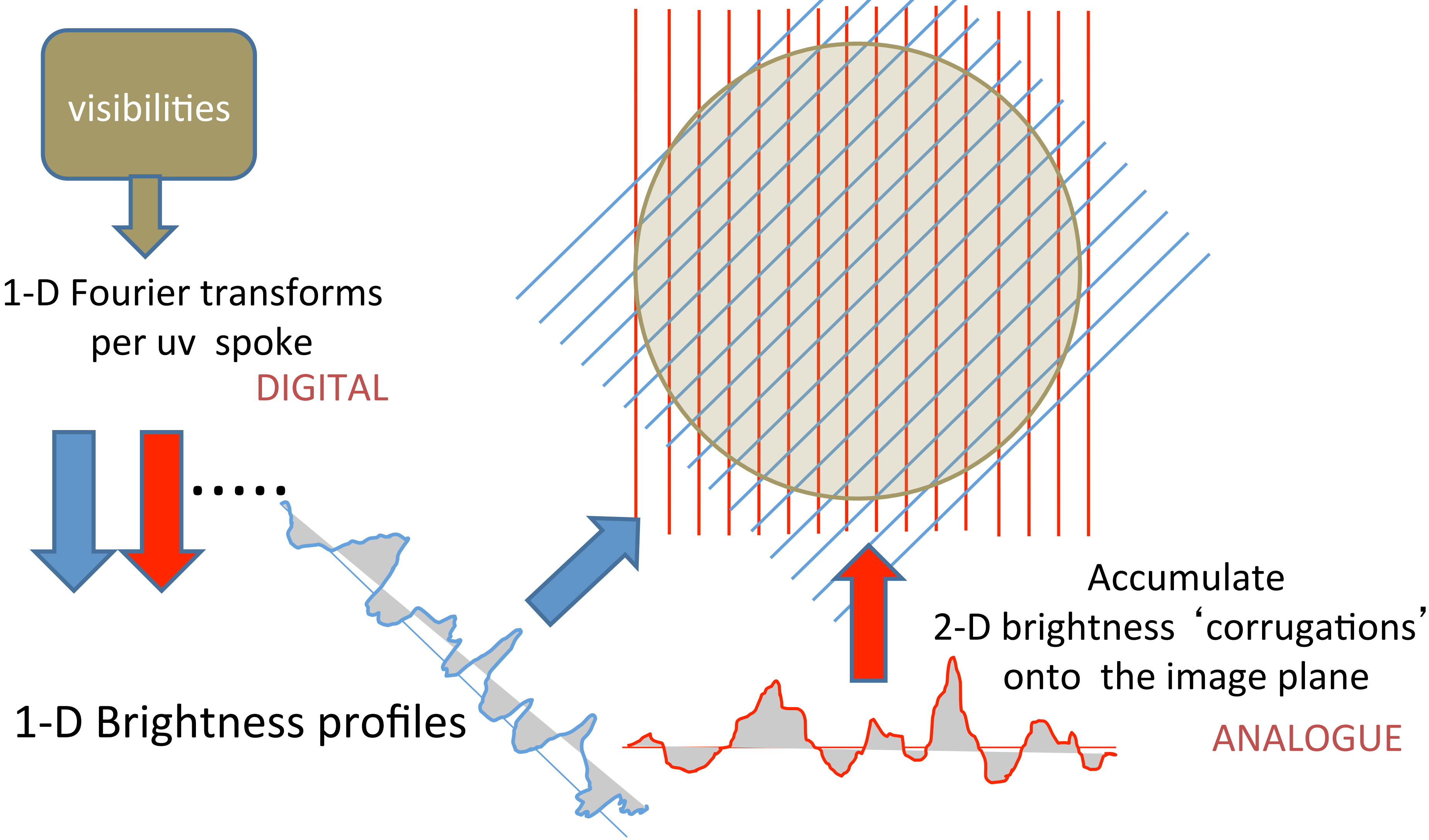

Simplicity of the core operation

versus

unwieldy format mismatches at its input and output

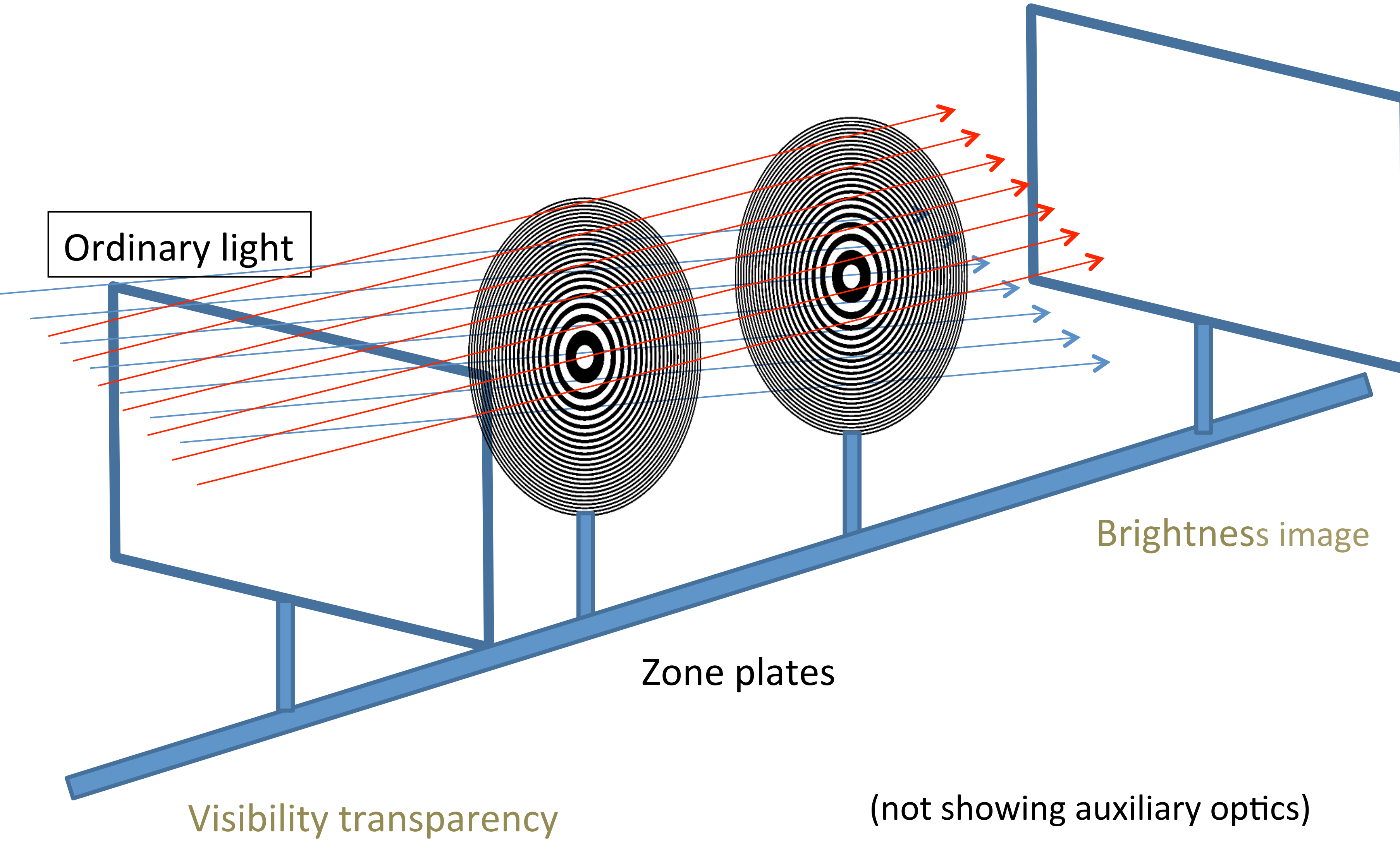
NRAO seriously considered a proposal and eventually rejected it (1977)

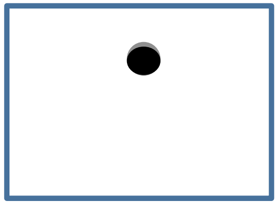
# A hybrid digital/analogue Fourier transformer

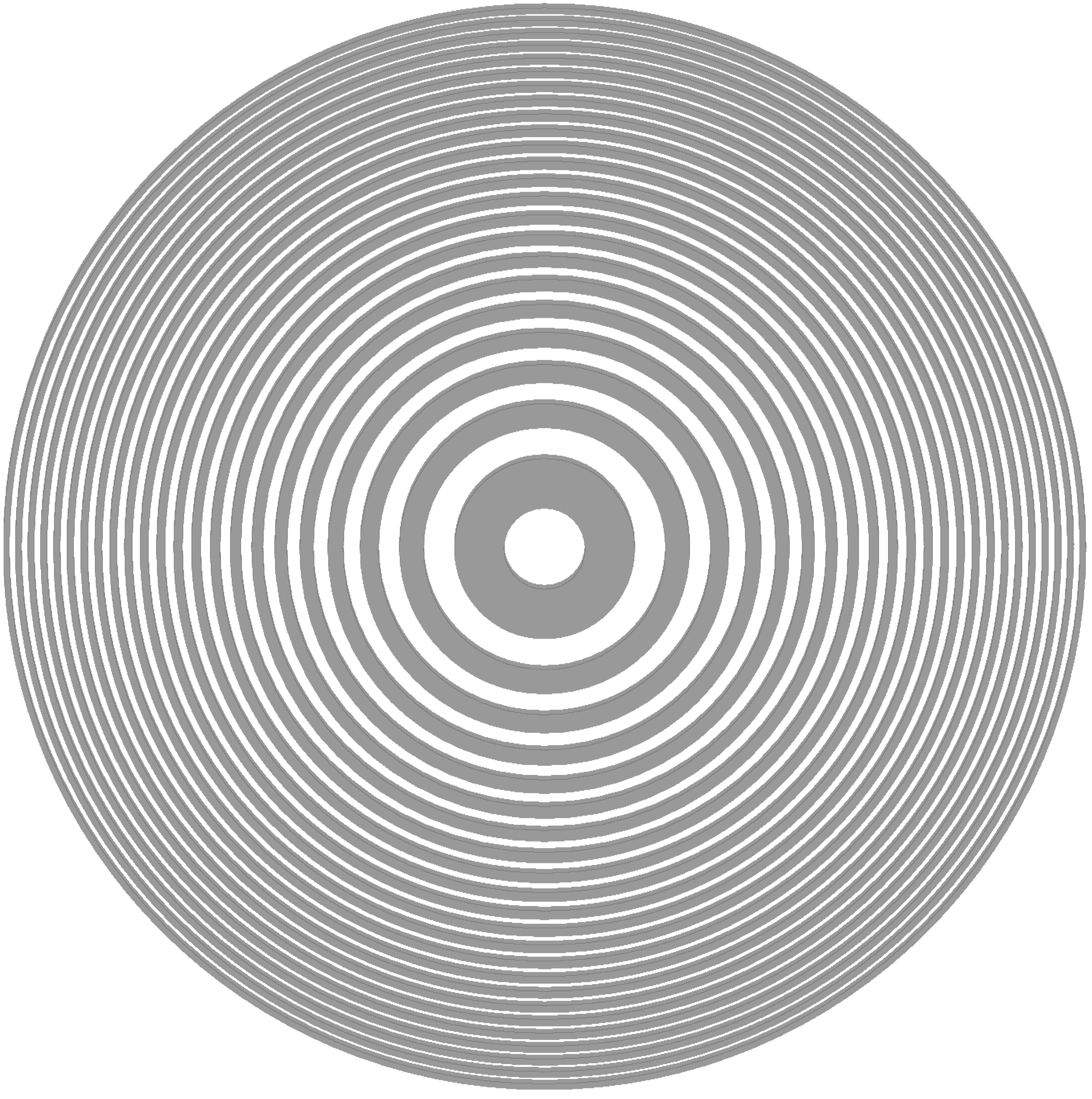



Accumulation on a **Scan Converter** CRT

# 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.