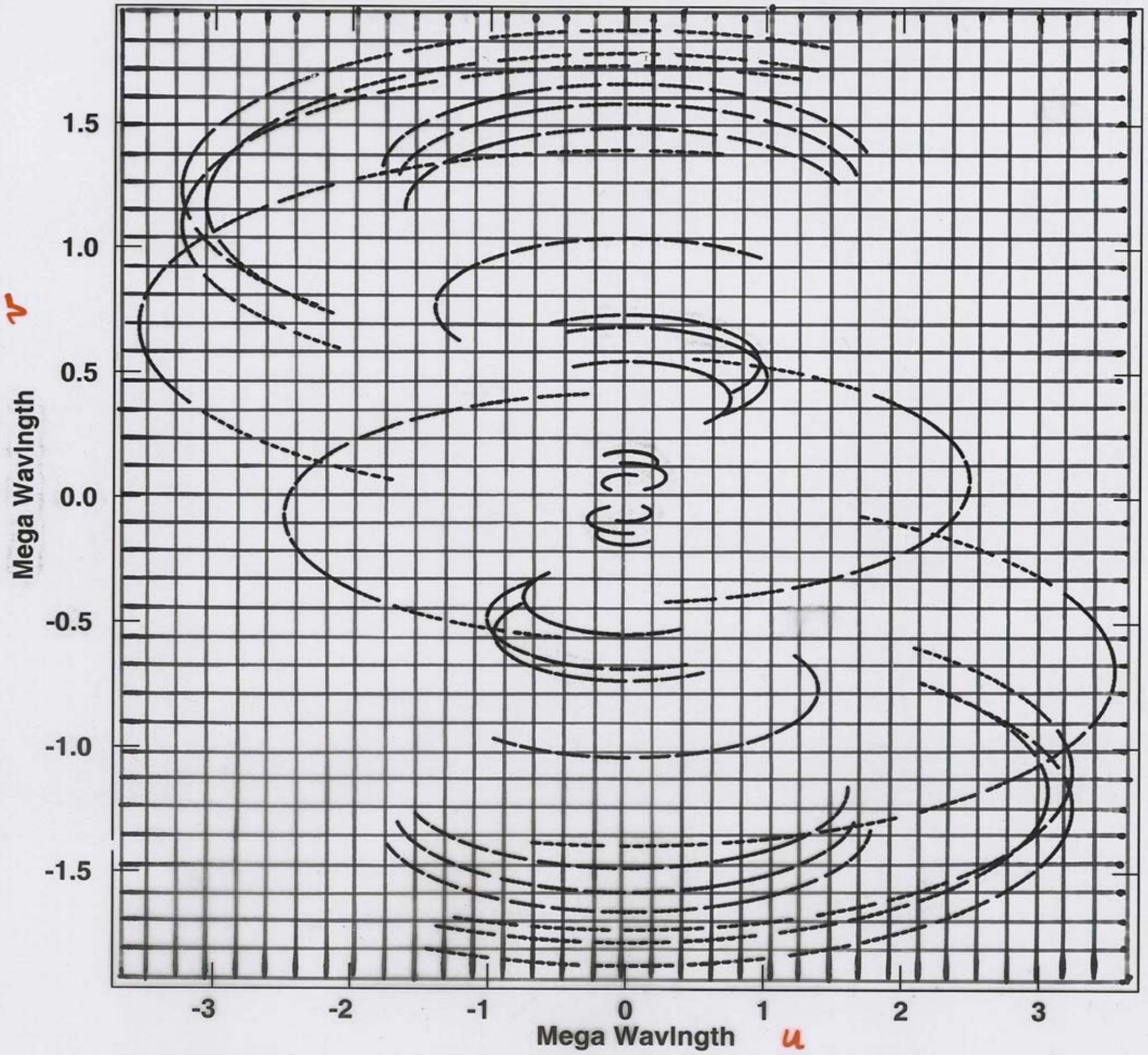
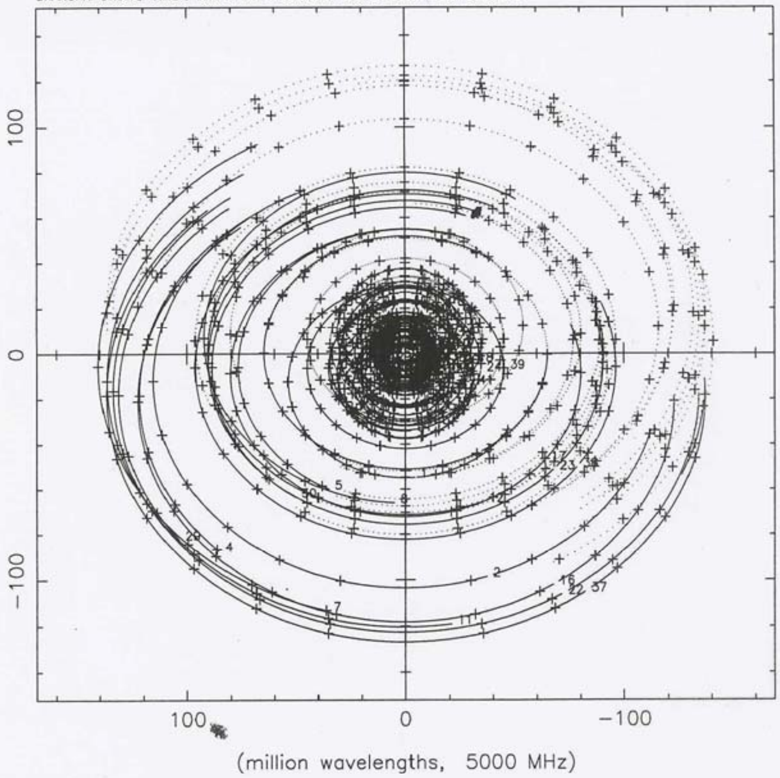
U,V COVERAGE SAMPLING FUNCTION



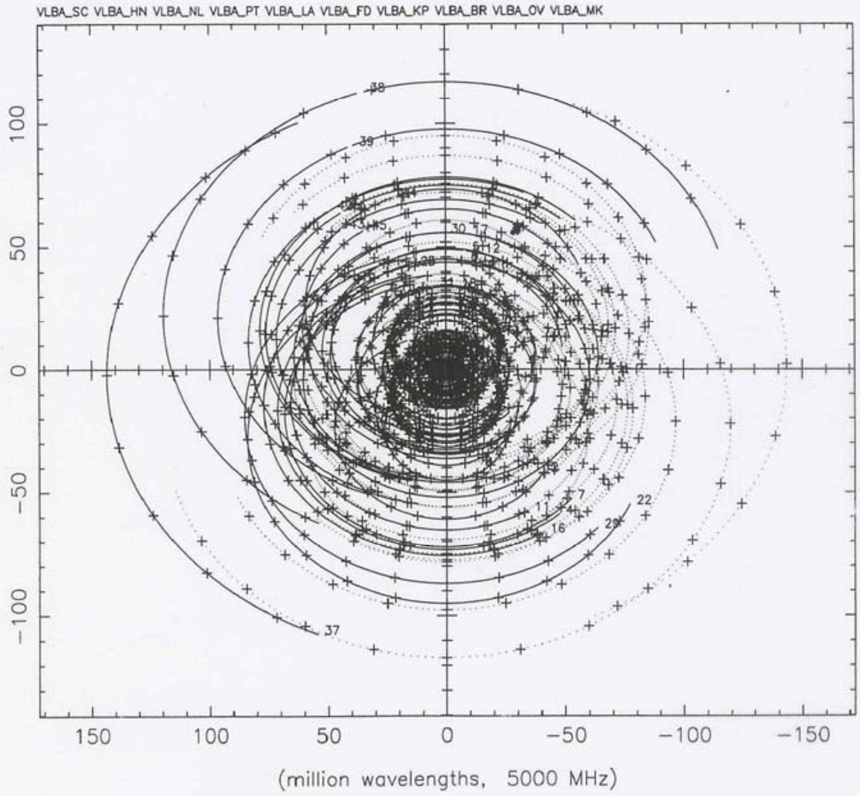
3C295 EVN

SHANGHAI URUMQI SIMEIZ TORUN NOTO BOLOGNA ONSALA BONN WSRT JODRELL

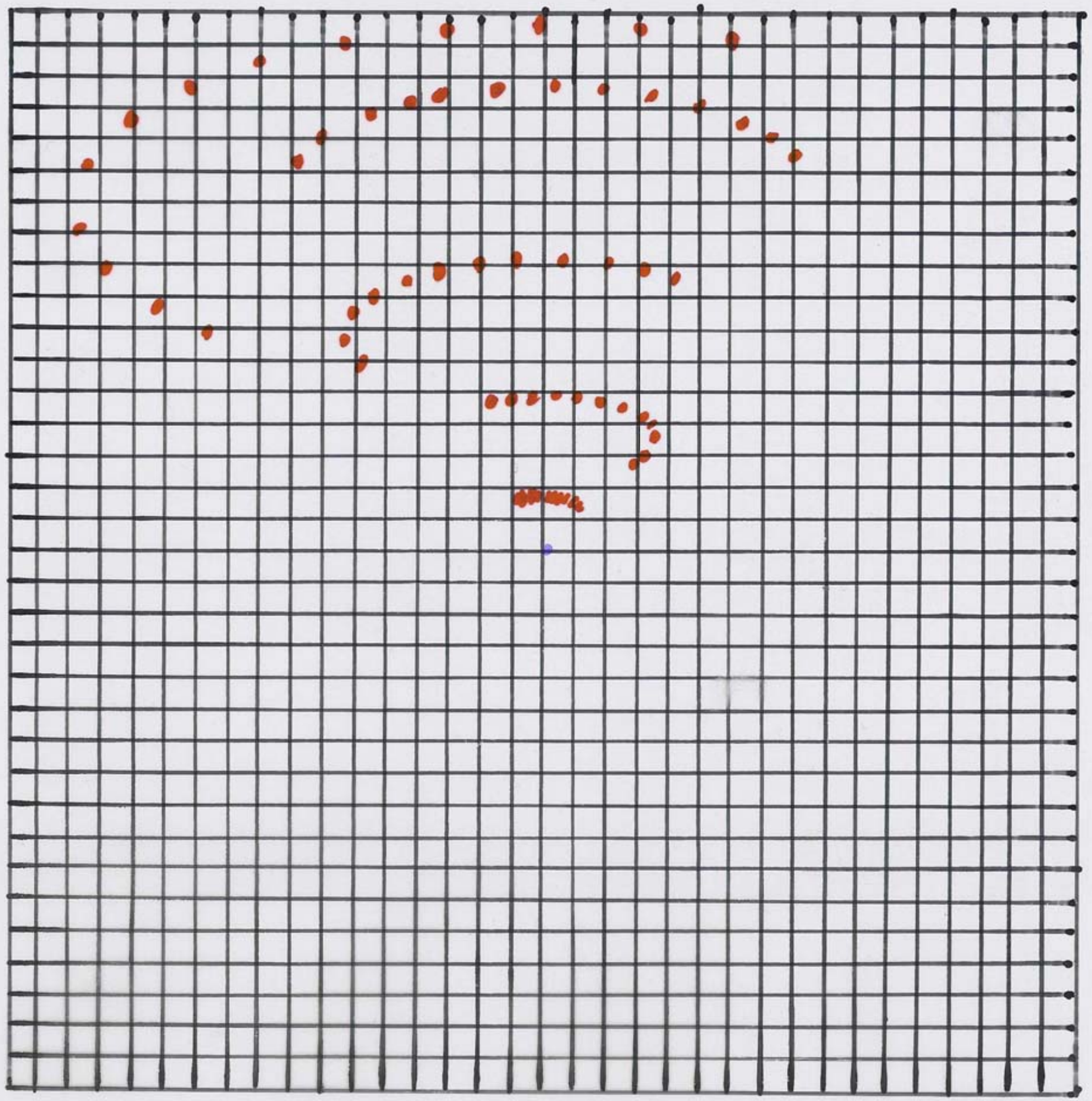


3C295 VLBA

VLBA_SC VLBA_HN VLBA_NL VLBA_PT VLBA_LA VLBA_FD VLBA_KP VLBA_BR VLBA_OV VLBA_MK



297
[+291]



WEIGHTING OF THE SAMPLING FUNCTION

"GRIDDING" WEIGHTS

UNIFORM

ALL SAMPLED AREAS OF THE (u,v)-PLANE HAVE EQUAL WEIGHTS

NATURAL

ALL DATA SAMPLES HAVE EQUAL WEIGHT

- HIGHEST S/N FOR POINT SOURCE (LOWEST RMS NOISE)
- GREATER WEIGHT TO LOW (u,v) VALUES
  ⇒ DECREASES RESOLUTION
  (INCREASES DIRTY BEAM WIDTH)

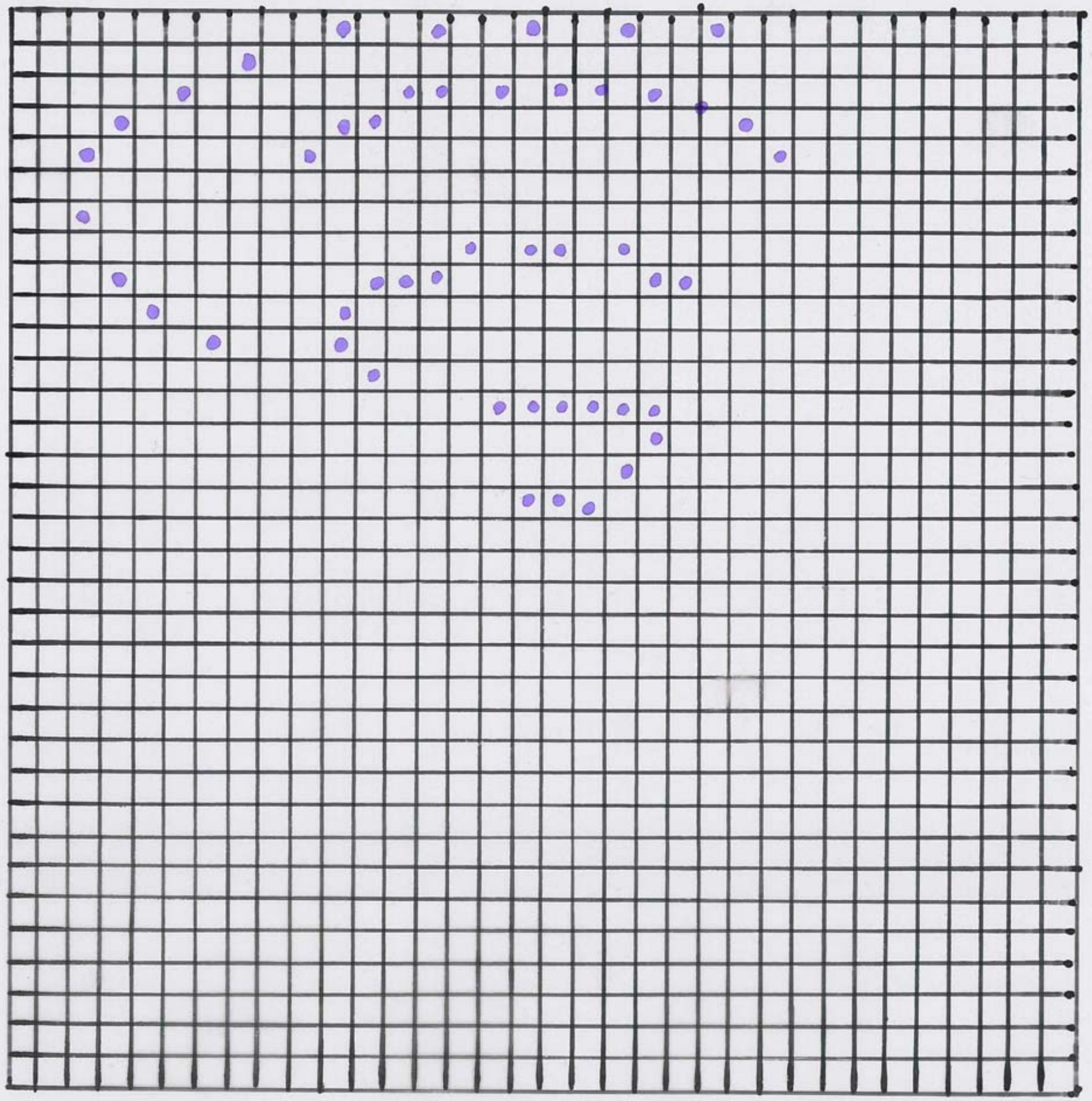
ROBUST

(u,v)-TAPER

- LOW WEIGHT TO HIGH (u,v) VALUES
  ⇒ DECREASES RESOLUTION
  ⇒ REDUCE SIDELOBES
  ("CLEANER" DIRTY BEAM)

29291
[+24]

UNIFORM
WEIGHTING

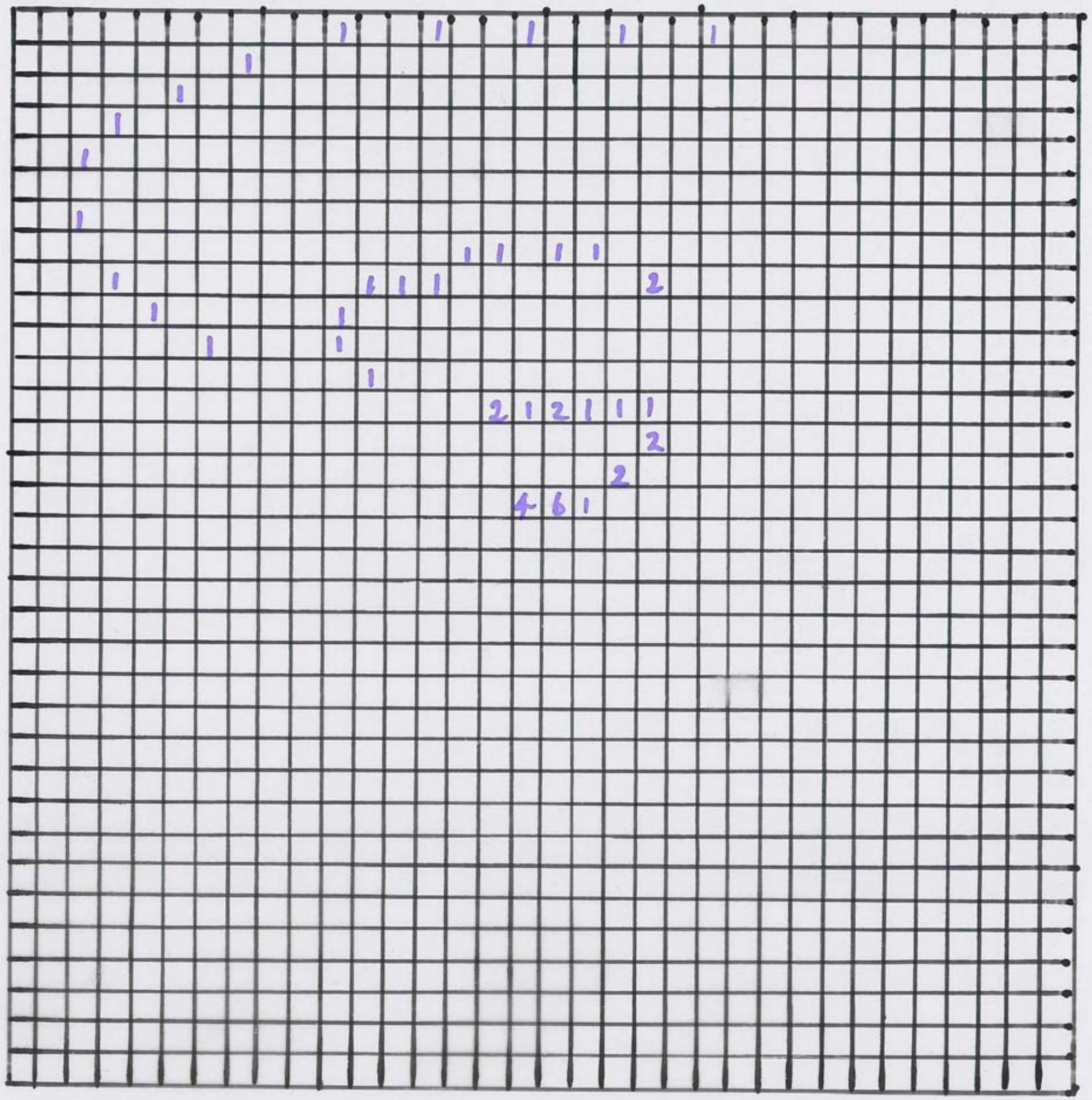


TK

2991
[+291]

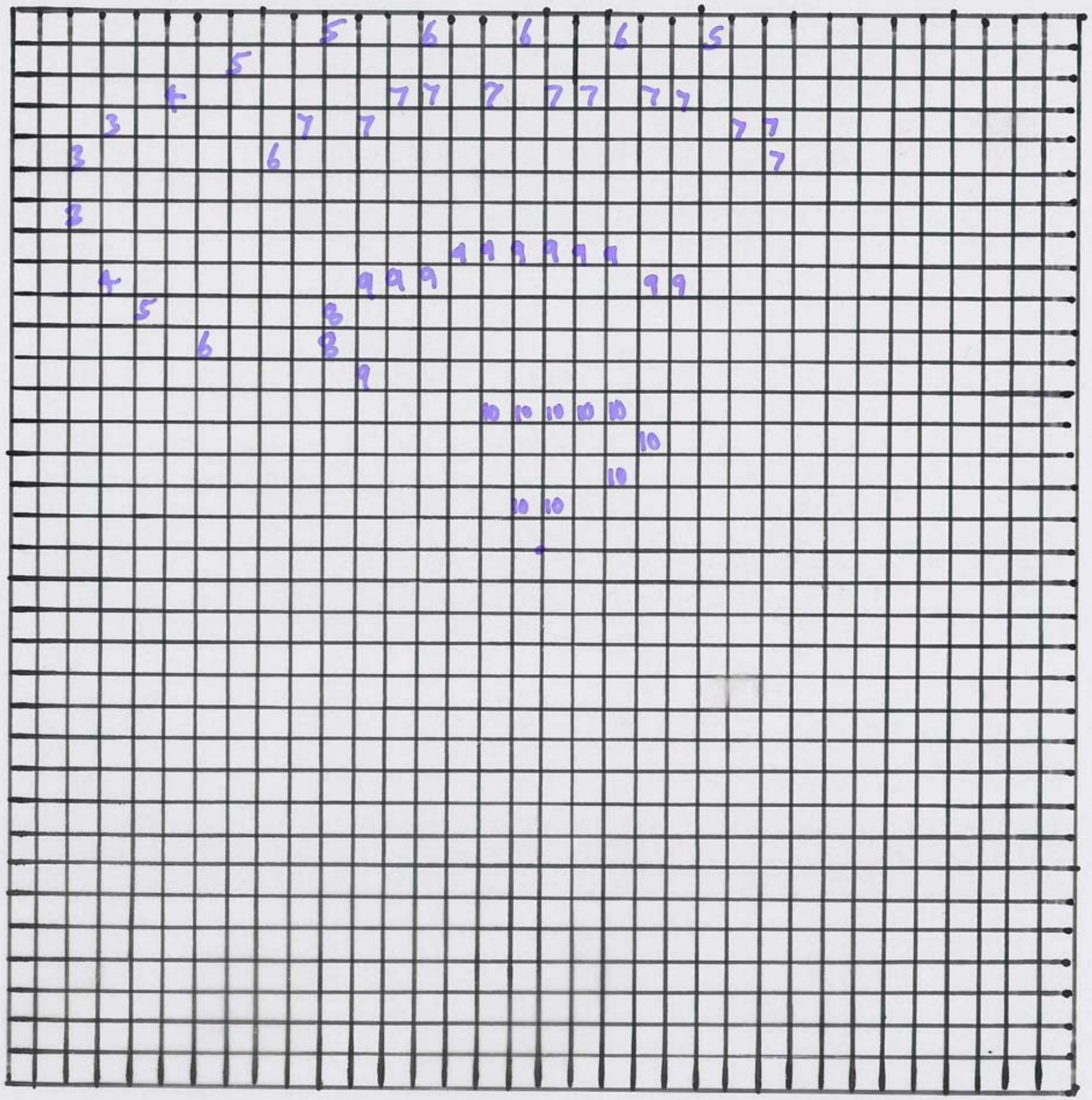
NATURAL

WEIGHTING



TK

29291
[+29u]
u,v TAPER



"DATA WEIGHTS"

NOISE ERROR

$$\sigma_{AB} = \sqrt{\frac{J_A . J_B}{\Delta t \times b}}$$

FOR VLA, WSRT, VLBA:

ALL ANTENNAS AND SYSTEMS ROUGHLY THE SAME

$$J_A = J_B = J_C = J_D = \ldots\ldots$$

$$\sigma_{AB} = \sigma_{BC} = \sigma_{AC} = \sigma_{AD} = \ldots\ldots$$

FOR EVN, GLOBAL VLBI, VSOP, ...

A WIDE RANGE OF ANTENNA SIZES, SENSITIVITIES, etc

$$J_{MC} = 10 \times J_{EB}$$

$$\sigma_{MC-X} = 3.3 \ \sigma_{EB-X}$$

$\Rightarrow$ CAN INCREASE WEIGHT OF EB BASELINES

$$W_{AB} = \frac{1}{(\sigma_{AB})^2}$$

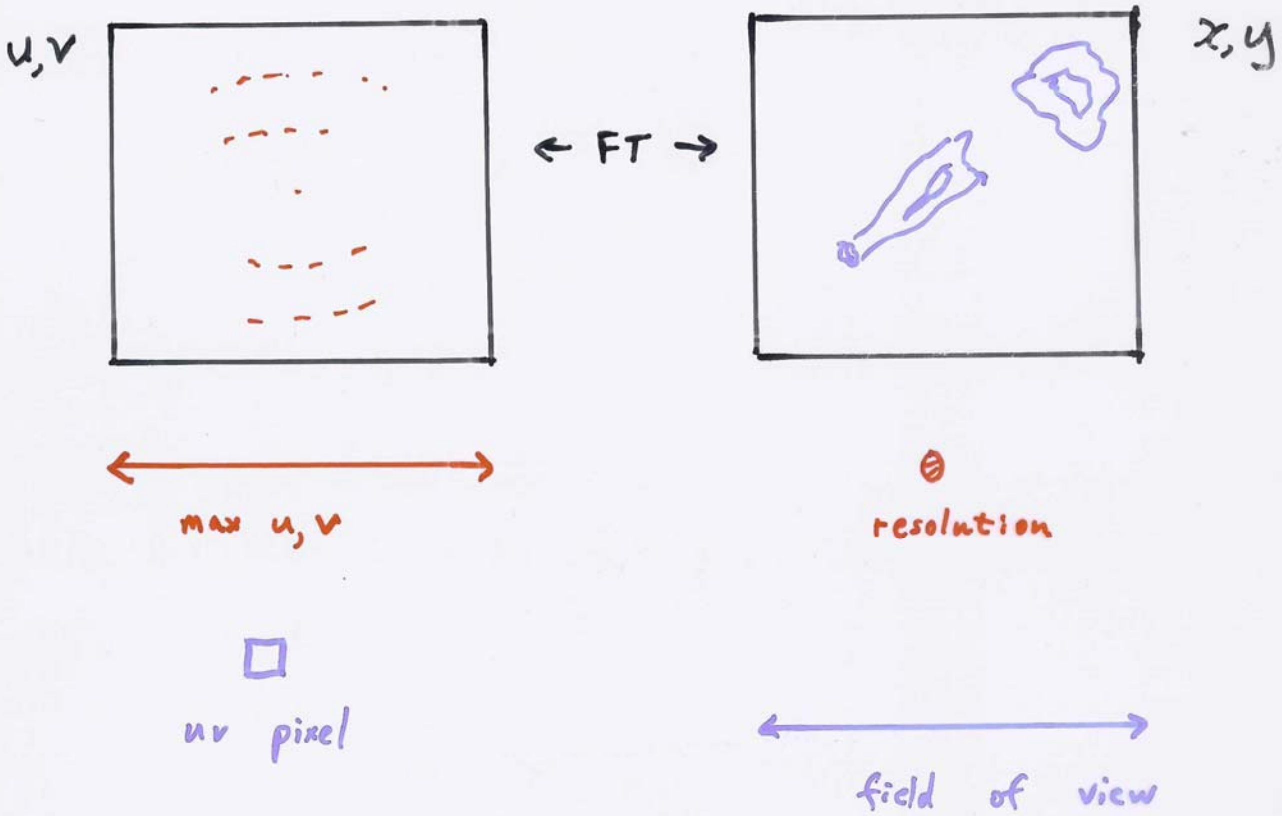
[AIPS: "CALIBRATE THE WEIGHTS"]

BUT: NOT WITH HALCA ....

...... IT WILL END UP WITH WEIGHT ≈ 0 !

FIELD OF VIEW

IMAGE SIZE, PIXEL SIZE, U,V SAMPLING



RESOLUTION: BEAM (FWHM)

PIXELS / FWHM > 2

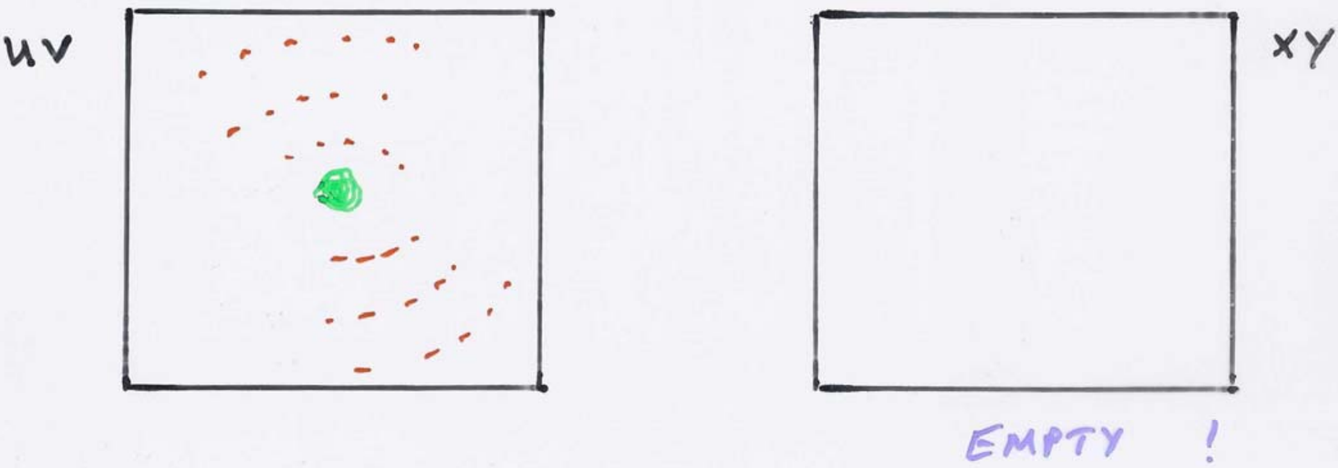
FIELD OF VIEW: $\Delta u, \Delta v$ LOWEST SPATIAL FREQUENCIES THAT COULD BE PRESENT

$$\approx \frac{1}{\mathrm{FOV}}$$

MAPS: PIXEL SIZE, MAP SIZE IN PIXELS (2^n)

SOURCES CAN BE "RESOLVED OUT" !

(UNLIKE FILLED APERTURES)



MINIMUM BRIGHTNESS TEMPERATURE DETECTABLE DETERMINED BY SHORTEST BASELINE IN ARRAY

THERMAL EMISSION OF 10^5 K NOT DETECTABLE WITH VLBI !

LIMITS OF F. O. V.

1. INDIVIDUAL ANTENNA PRIMARY BEAMS

BEAM $\sim \frac{\lambda}{D}$

INTERFEROMETER $\sim \frac{\lambda}{L}$

FIELD LIMITED TO N beams × N beams

$$N \approx \frac{L}{D}$$

A FWHM(A)

B  FWHM(B)

$$\Rightarrow \sqrt{\mathrm{FWHM}(A) \times \mathrm{FWHM}(B)}$$

2 BANDWIDTH LIMIT

UNCOMPENSATED PATH FOR A SOURCE FAR AWAY FROM THE (PATH COMPENSATED) FIELD CENTRE

UNCOMPENSATED DELAY

$$\Delta\tau = \frac{L\cos\theta_0}{c} \cdot \Delta\theta > \frac{1}{b}$$

LOSS OF COHERENCE

$$\Delta\tau = \frac{q}{\nu} \cdot \Delta\theta > \frac{1}{b}$$

MUST HAVE

$$\frac{\nu}{b} > q \cdot \Delta\theta$$

$$\frac{\nu}{b} > N$$

(no. beams)

VLBI $\sim$ 1"

3. "FRINGE RATE" LIMIT

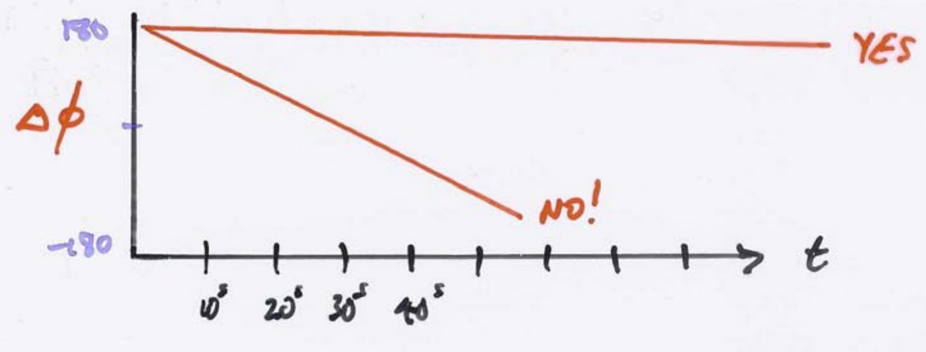
UNCOMPENSATED PHASE FOR A SOURCE FAR AWAY FROM FIELD CENTRE

$$\Delta\phi = \frac{2\pi L}{\lambda} \cos\theta_0 \cdot \Delta\theta$$

DUE TO EARTH ROTATION

$$\frac{d\,\Delta\phi}{dt} = \frac{-2\pi L}{\lambda} \sin\theta_0 \cdot \left[\frac{d\theta_0}{dt}\right] \cdot \Delta\theta$$

$$\frac{d\Delta\phi}{dt} \ll \frac{1}{\Delta t} \qquad [\Delta t = \text{avg. time}]$$



$$N \lesssim \cancel{\frac{t(s)}{20{,}000}} \quad \frac{20{,}000}{t(s)}$$

VLBI: λ6cm, US-Eu $\Delta\theta = 6''$ $\frac{d\Delta\phi}{dt} = 200$ mHz

[1 turn in 5^s]

SOME SOLUTIONS

Smaller b Δt

lose S/N $> 0.1^s$?

1 BANDWIDTH

SUB-DIVIDE b INTO SMALLER PIECES

"SPECTRAL LINE CORRELATION"

[ALWAYS USED FOR VLBI]

$\langle V_1 . V_2 \rangle$ S (visibility function)

$\langle V_1(t) . V_2(t) \rangle$

FORM BAND SPECTRUM BY FORMING $CCF(\tau)$

AND F.T. COBE FIRAS

$$\left.\begin{array}{l} \vdots \\ V_1(t) . V_2(t) \\ V_1(t) . V_2(t+\frac{1}{2b}) \\ V_1(t) . V_2(t+\frac{2}{2b}) \\ \vdots \end{array}\right\} S(\nu)$$

$n = 16 \ldots$

16 visibility functions, each with F.O.V. 16 × Larger!

BUT AVERAGING THEM REDUCES F.O.V. AGAIN!

2. FRINGE RATE

Δt limit 10^s 1^s 0.1^s

MULTIPLE FIELD CENTRE CORRELATION

VLBI MULTIPLE "PASSES"

e.g. Multiple image gravitational lenses

B0218+357 IMAGE A PdB – VLBA_LA

90 GHz

9.7 σ

260^s 512 Mbps [128 MHz]

$\Delta\theta = 0.3''$ $\Delta t = 1^s$ Bonn Correlator

PHASE ERRORS

INSTRUMENTAL

UNEQUAL ELECTRONIC PATHS

LO PHASE (VLBI)

$$\phi_i = \phi_i(t)$$

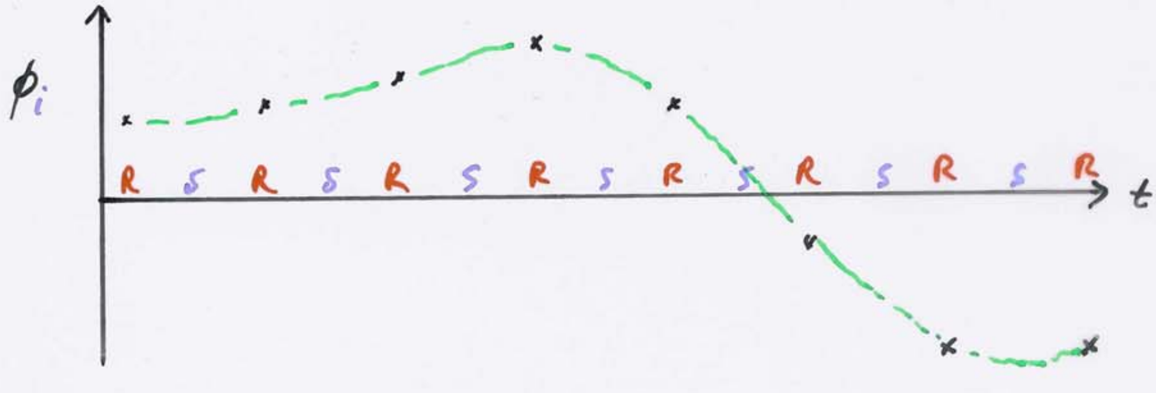
CALIBRATE SUFFICIENTLY OFTEN

MULTI-CHANNEL DATA [AIPS: "MULTIPLE IFs"]

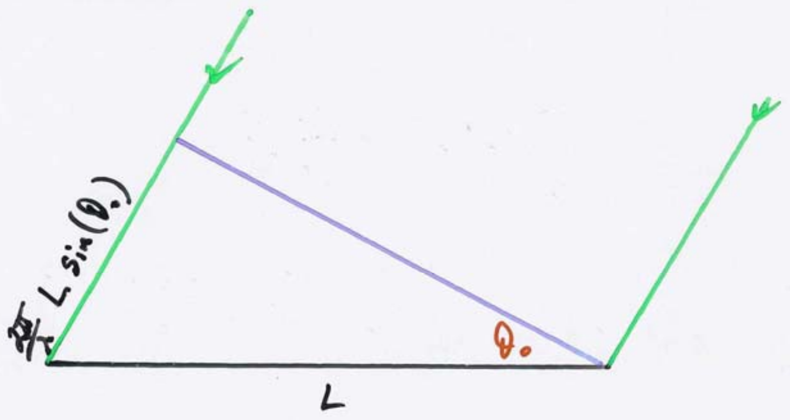
$$\phi_i = \phi_i(ch)$$

PHASE CAL (PULSE CAL) FOR VLBI

PHASE CALIBRATION ON A POINT SOURCE



GEOMETRICAL ERRORS



ACCURACY OF $\frac{2\pi L}{\lambda}$ $\qquad\qquad$ $\delta L \ll \lambda$

ACCURACY OF $\sin(\theta_0)$ $\qquad\qquad$ $\delta \theta_0 \ll \frac{\lambda}{L}$

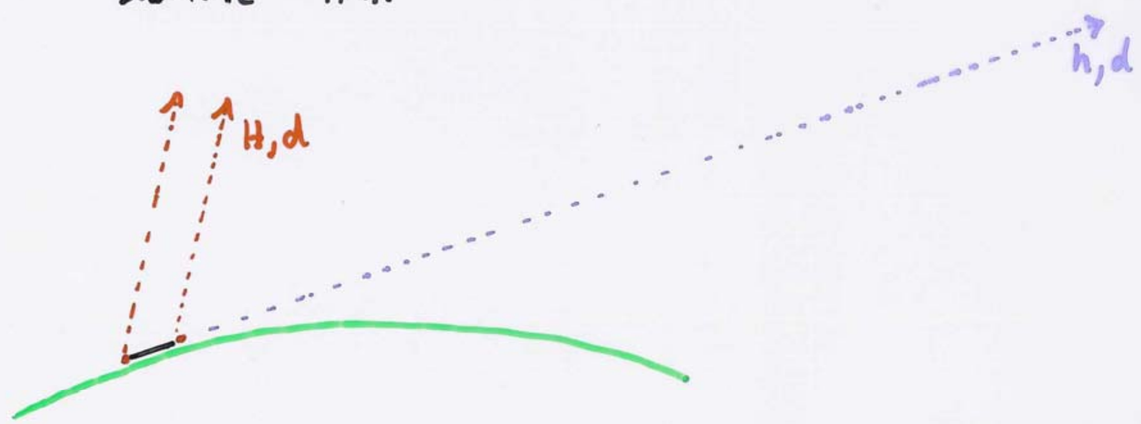
$$\sin \theta_0 = \sin D . \sin d + \cos D . \cos d . \cos(H-h)$$

D source declination

H source H.A [S.T. - RA]

d baseline declination

h baseline H.A.



$$\phi_g = \phi_g(RA, D, t)$$

Effect of errors in model

$$d\phi = d\left[\frac{2\pi L}{\lambda}\sin\theta_0\right]$$

$$\sim \frac{2\pi L}{\lambda}\left[dRA,\ dD,\ d(ST),\ dh,\ dd\right]$$

"DILUTION" of errors with reference source

$$d\phi \sim \frac{2\pi L}{\lambda}\, dh$$

$$d\phi^R \sim \frac{2\pi L}{\lambda}\, dh$$

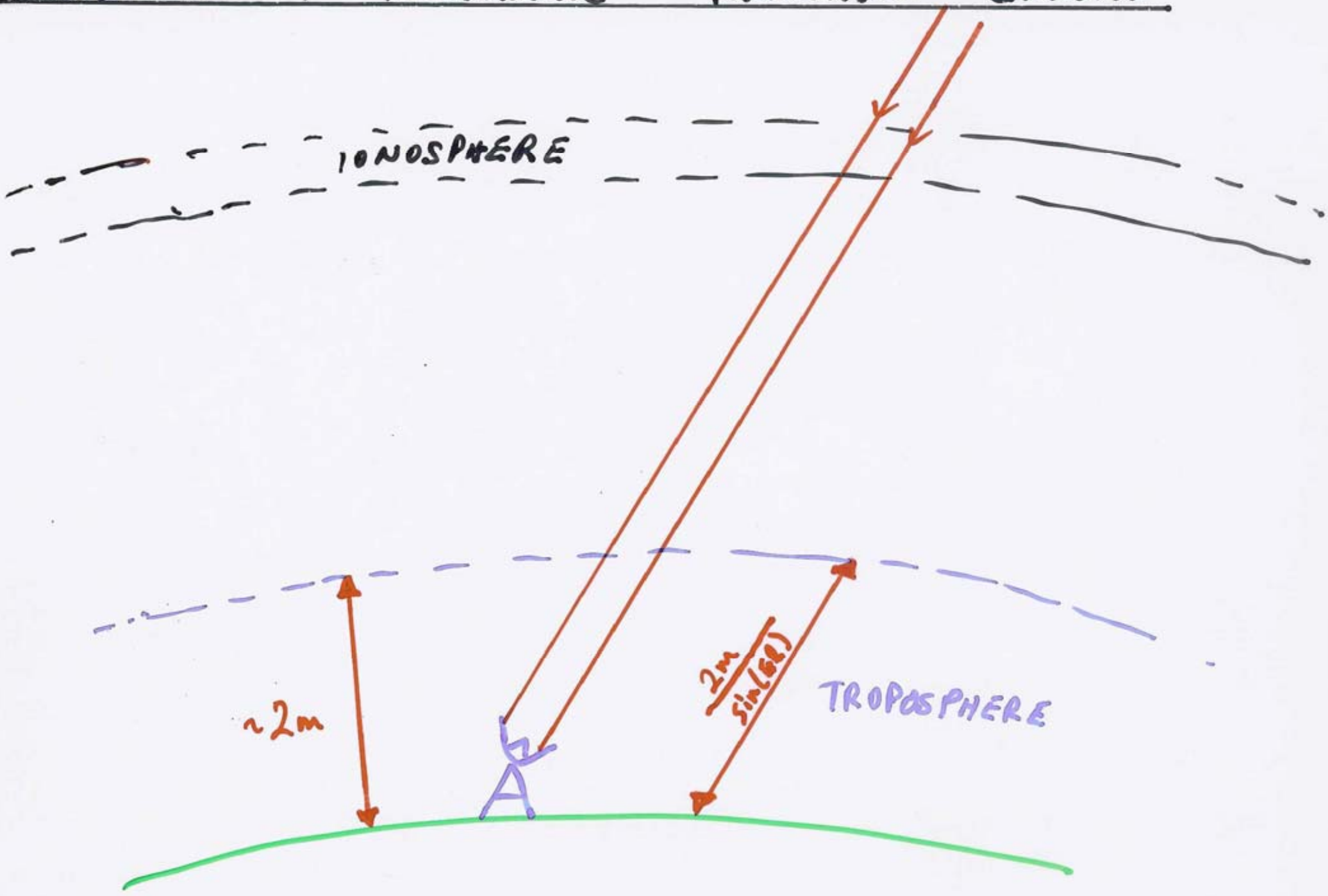
$$d(\phi-\phi^R) \sim \frac{2\pi L}{\lambda}\, dh \cdot \Delta\theta$$

↓

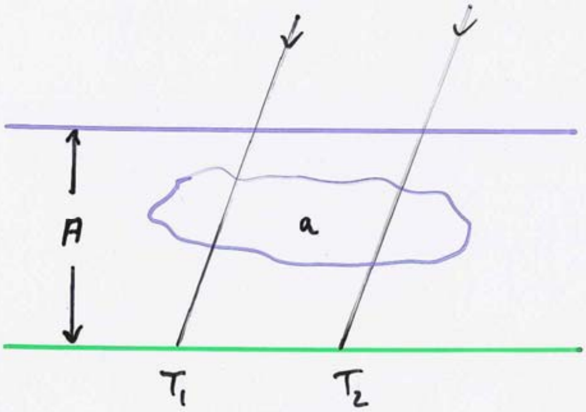
angular separation of target and ref. sources (in radians)

$\Rightarrow$ NEED CLOSE CALIBRATION SOURCE

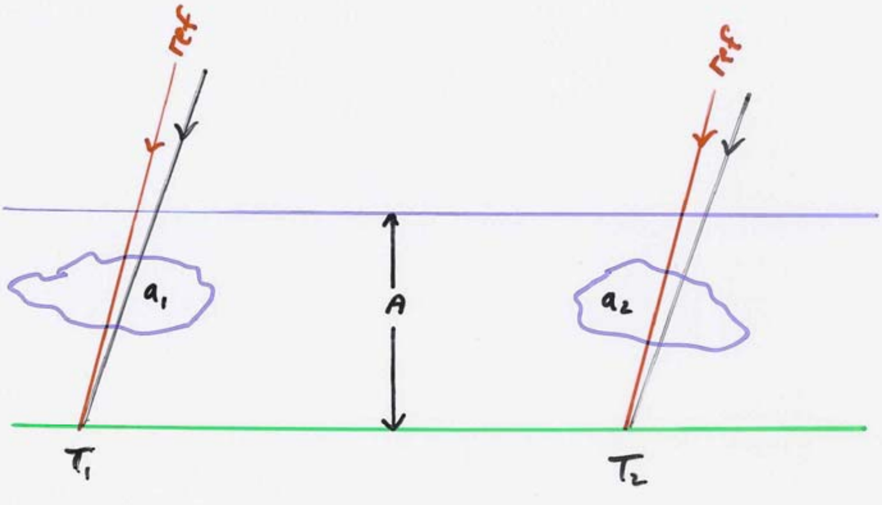
TROPOSPHERIC + IONOSPHERIC PROPAGATION ERRORS



$\phi_a = \phi_a(t, \epsilon)$



$\leq$ 5 Km



VLA (A) 35 Km

(1) $< 5\,km$

$$T_1 \quad : \quad \frac{A}{\sin E} + a$$

$$T_2 \quad : \quad \frac{A}{\sin E} + a$$

$$T_1 - T_2 \quad \simeq \quad 0$$

(2) VLA (35 km)

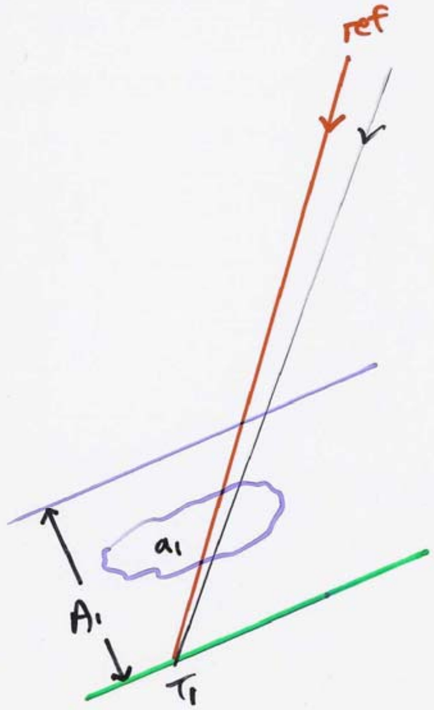
$$T_1 \quad : \quad \frac{A}{\sin E} + a_1$$

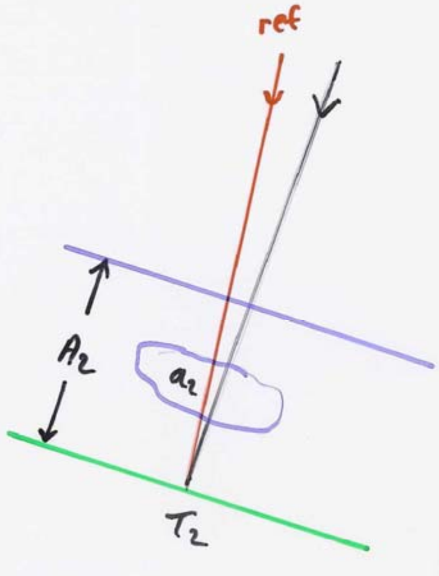
$$T_2 \quad = \quad \frac{A}{\sin E} + a_2$$

$$T_1 - T_2 \quad = \quad \underset{\{\sim cm\}}{a_1 - a_2} \quad \Rightarrow \quad \phi_a$$

Ref. Source

$$T_1^R - T_2^R \quad = \quad a_1 - a_2 \quad = \quad \phi_a$$





VLBI (5000 km)

③ VLBI (5000 km)

T_1 : $\dfrac{A_1}{\sin E_1} + a_1$

T_2 : $\dfrac{A_2}{\sin E_2} + a_2$

$T_1 - T_2$ $\quad \dfrac{A_1}{\sin E_1} - \dfrac{A_2}{\sin E_2} + a_1 - a_2$

{Large ~2m} {Small ~cm}

Ref source

$T_1^R - T_2^R \quad \dfrac{A_1}{\sin E_1^R} - \dfrac{A_2}{\sin E_2^R} + a_1 - a_2$

Source - Ref

$$A_1\left[\frac{1}{\sin E_1} - \frac{1}{\sin E_1^R}\right] - A_2\left[\frac{1}{\sin E_2} - \frac{1}{\sin E_2^R}\right]$$

⇒ Must have A_1 A_2 in model

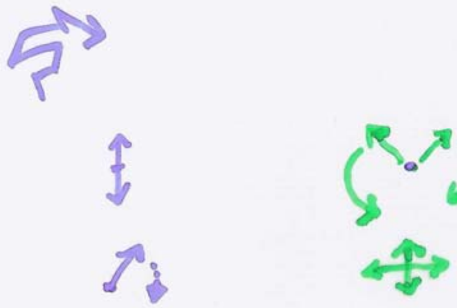
⇝ NEED CLOSE REFERENCE SOURCE

POLARIZATION

$\underline{E} \cos(2\pi f t)$

$V_y \cos(2\pi f t + \phi_y)$

$V_x \cos(2\pi f t + \phi_x)$



UNPOLARIZED

LINEAR

CIRCULAR

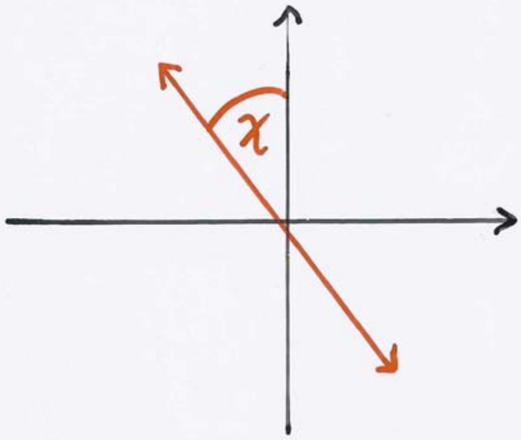
ELLIPTICAL

STOKES PARAMETERS

I	Total Power
Q, U	Linearly polarised power, (angle)
V	Excess of RHC over LHC

Linearly polarized flux density

$$p = \sqrt{Q^2 + U^2}$$

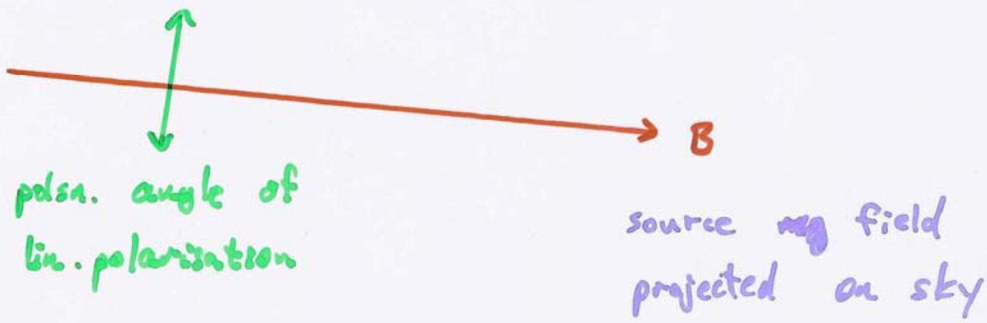


$$\left.\begin{aligned} Q &= p \cos 2\chi \\ U &= p \sin 2\chi \end{aligned}\right\} \quad \chi = \frac{1}{2} \tan^{-1}\left[\frac{Q}{U}\right]$$

$$m = \frac{p}{I} = \text{"degree of lin. pol."}$$

SOURCES OF POLARIZED RADIATION

SYNCHROTRON RADIATION



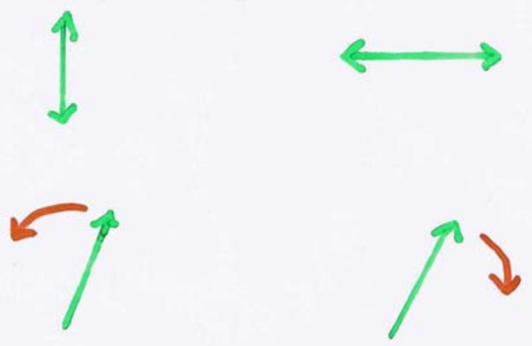
BUT FARADAY ROTATION

BY MAGNETO-IONIC PLASMA

$$\Delta \chi = RM. \ \lambda^2$$

FEEDS DETECTING CIRCULAR POL. MODES

NEED 2 ORTHOGANAL "MODES"



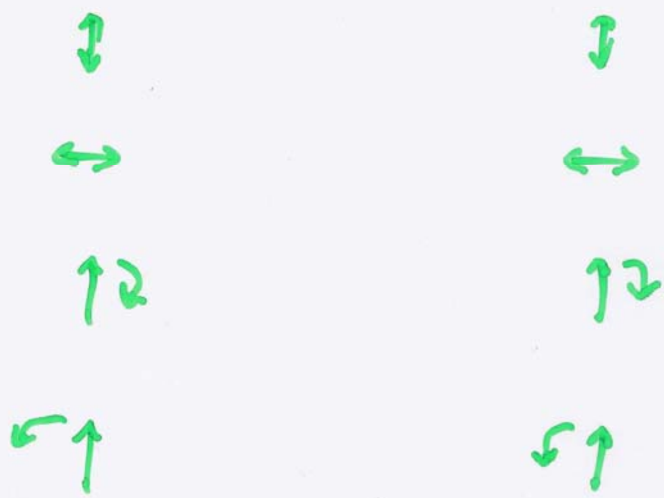
orth. lin.

LHC / RHC.

FOR UNPOLARISED SOURCE, ALL 4 FEEDS ARE EQUIVALENT → ½ THE POWER

FOR INTERFEROMETRY OF NOISE SIGNALS,

$V_1 \times V_2$ MUST BE FROM THE SAME "MODE"



Y.Y

X.X

R.R

L.L

DUAL POLARIZATION FEEDS

LHC + RHC signals from each telescope.

$< V_1^L . V_2^L >$ S^{LL} ($\propto I$ if $V=0$)

$< V_1^R . V_2^R >$ S^{RR} ($\propto I$)

$< V_1^R . V_2^L >$ S^{RL} $Q + iU$

$< V_1^L . V_2^R >$ S^{LR} $Q - iU$

IMAGING

$\left.\begin{matrix} S^{LL} \\ S^{RR} \end{matrix}\right\} \rightarrow$ I image

$\left.\begin{matrix} S^{RL} \\ S^{LR} \end{matrix}\right\} \rightarrow$ Q image
U image

NB Q, U can be negative!

$\rightarrow$ p image
m image
χ "image"

THE POLARIZATION "STICKS" show magnitude and direction of p (or m) and χ

BEAM DILUTION – a special resolution problem

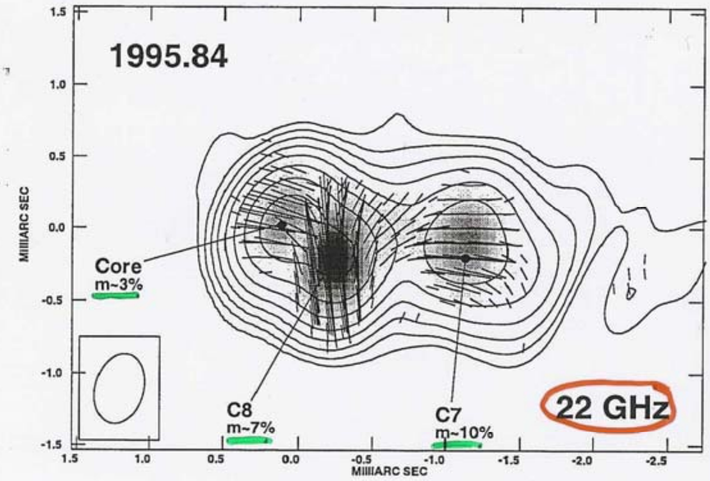


Fig. 9. VLBA I, p and χ images of 3C345 at 22 GHz, epoch 1995.84. The total intensity I is represented with contours (value of 6 mJy/beam$\times$ $-1, 1, 2.24, 5, 11.18, 25, \ldots$), superimposed over a grey scale polarized intensity map (peak of brightness of 112.4 mJy) and the superimposed electric vectors (χ, length proportional to p, 1 mas in the map is equivalent to 100 mJy/beam).

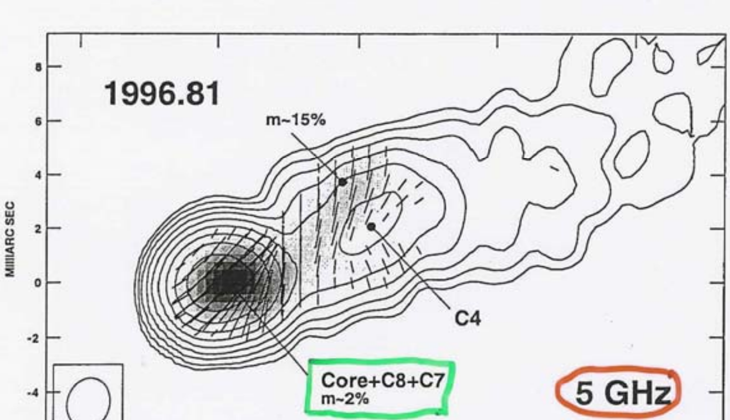


Fig. 12. Polarized intensity electric vectors (χ, length proportional to p, 1 mas in the map is equivalent to 10 mJy/beam) overlaid on total intensity (I) contours (3 mJy/beam$\times$ $-1, 1, 2.24, 5, 11.18, 25, \ldots$) and grey scale polarized intensity (p, grey scale up to the peak of brightness, 40.5 mJy/beam) images for 3C345 at 5 GHz, epoch 1996.81. It is obvious that the electric vector is almost perpendicular to the jet at core separations from 3 to 7 mas.

IF ONLY ONE HAND OF C.P. AVAILABLE

CANNOT FORM Q
U VISIBILITY FUNCTIONS

FOR THAT ANTENNA

HALCA

ACPS: "COMPLEX CLEAN"