HBA monitoring of 3C196 (project LEA128)

Ionospheric effects above LOFAR:

Differential Faraday Rotation (DFR) and Amplitude Decorrelation due to large and rapidly variable ionospheric TEC gradients

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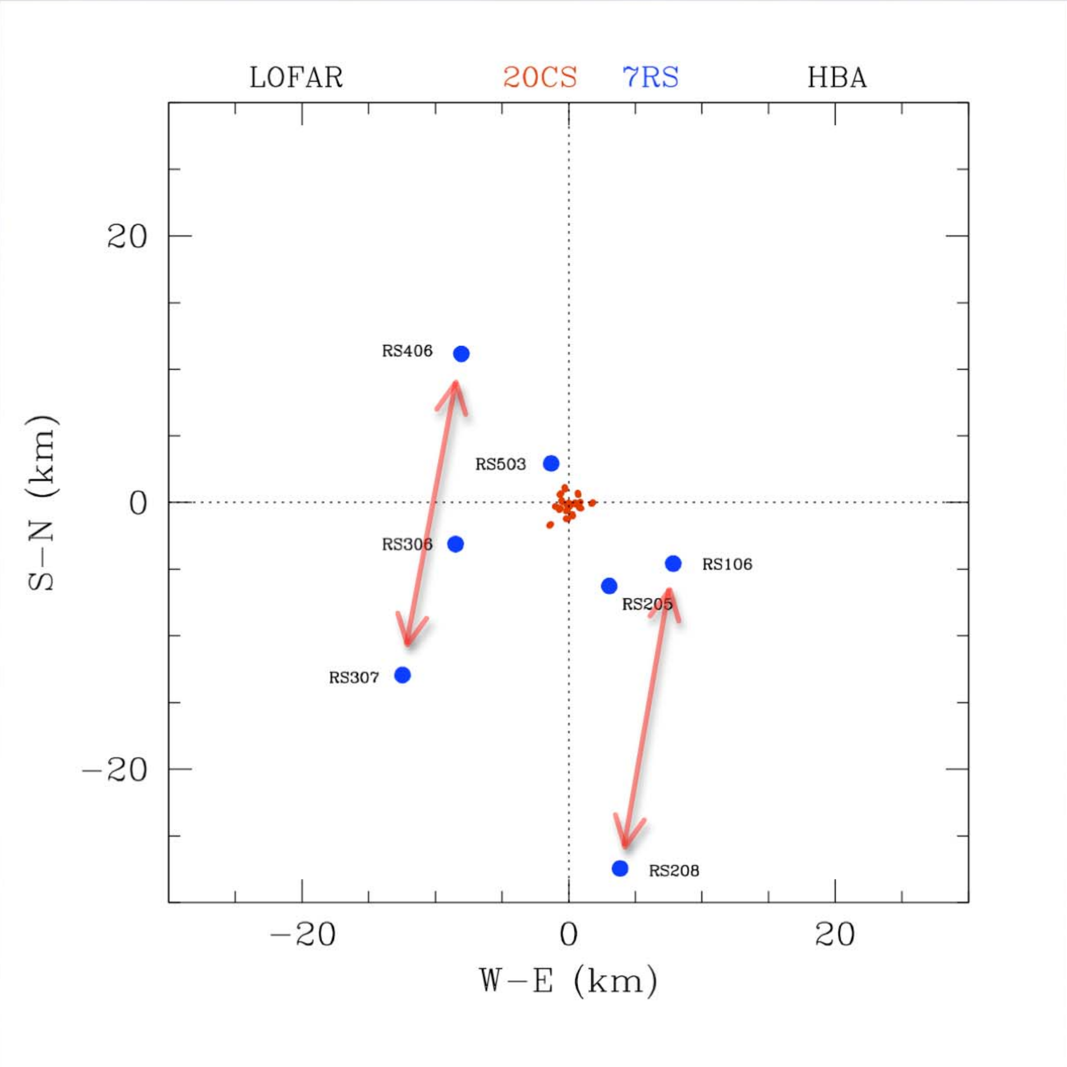
Project LEA128 3C196

L2011_23259 4 Feb 2011 (UT 1948-0148)
L2011_23927 11 Mar 2011 (UT 1730-2230)

HBA 115-163 MHz (244 subbands)

Data are shown for
SB009 (117 MHz)
SB039 (122 MHz)
SB100 (135 MHz)

Configuration of 20 CS and 7 RS



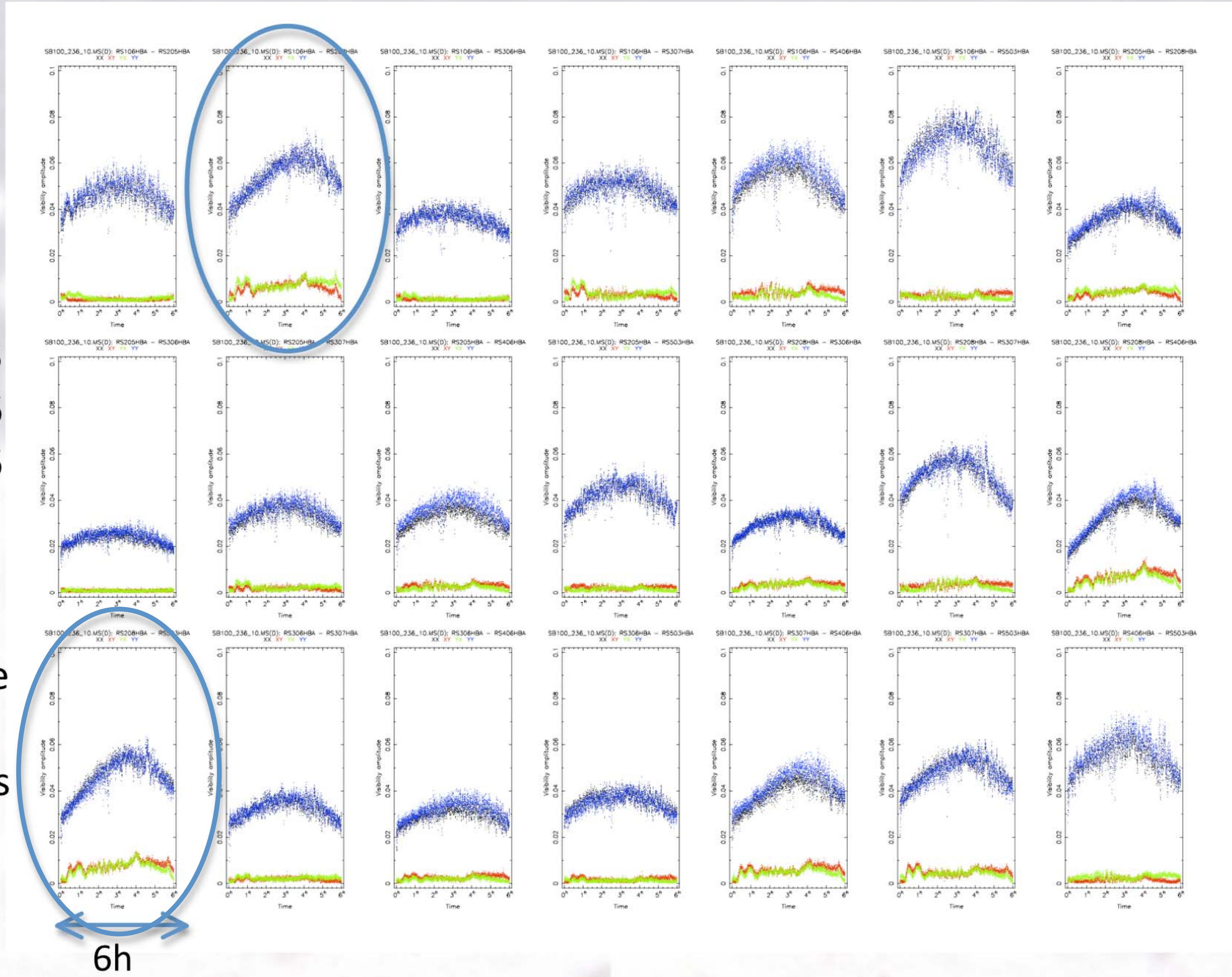
Note that baselines between
RS106-RS208 and
RS307-RS406
are very similar in length
(~ 25 km) and orientation

Visibilities (raw) between 7 Remote Stations (21 baselines)

135 MHz
11 Mar 2011

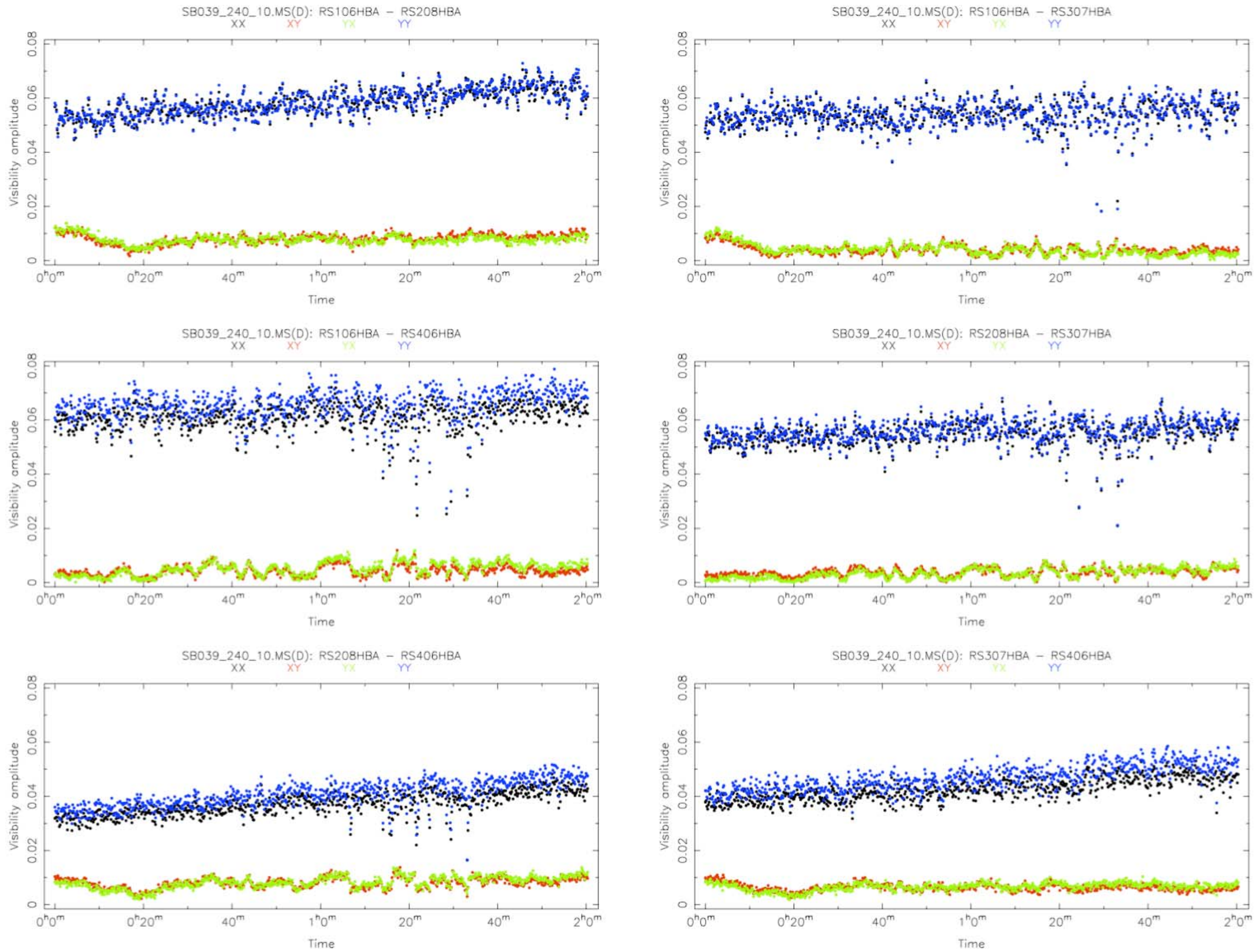
RS106, RS205
RS208, RS306
RS307, RS406
RS503

Note the time variable XY and YX signals



3C196 122 MHz 11 Mar 2011

6 Baselines between stations RS106, RS208, RS307 & RS406



2h at 10s resolution

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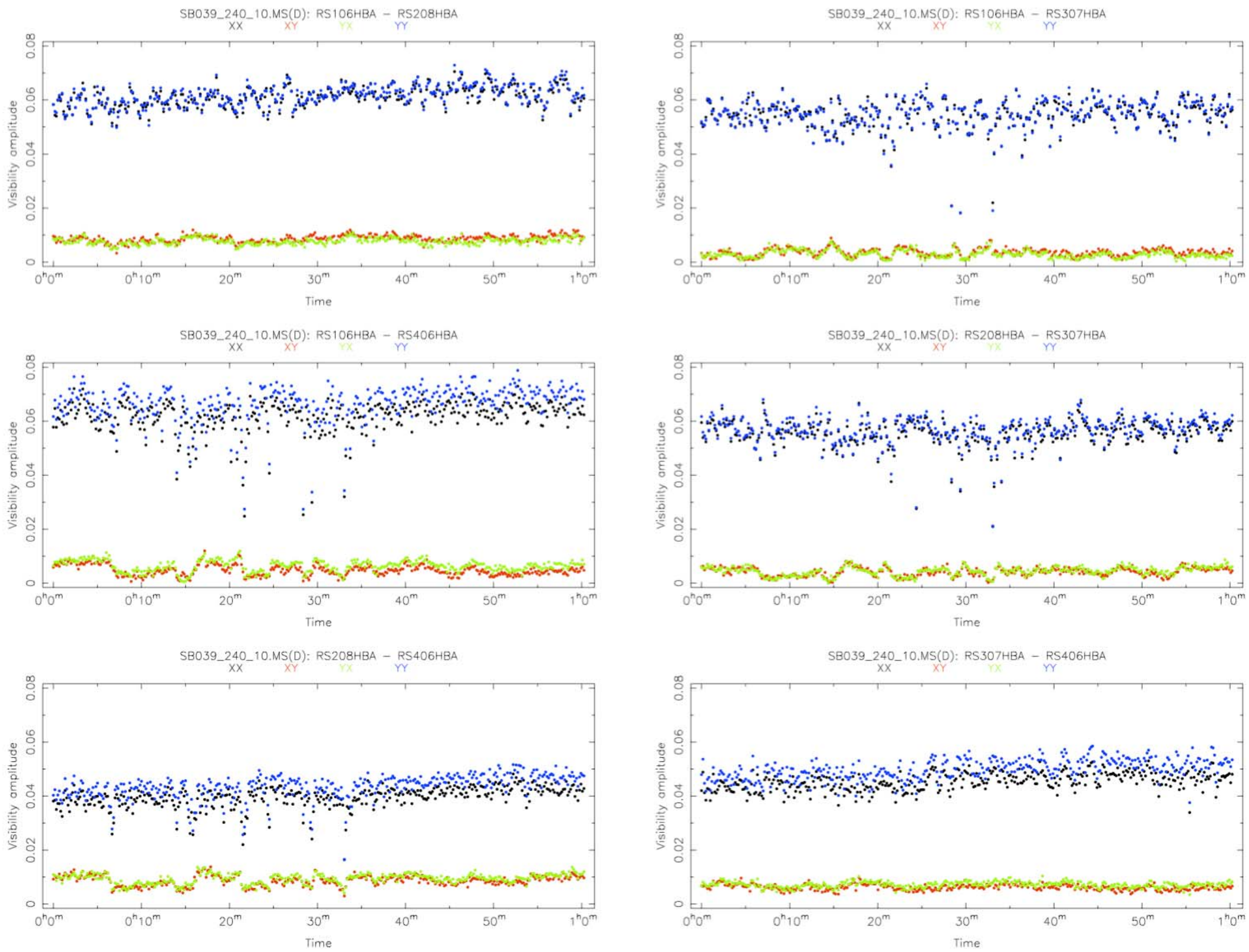
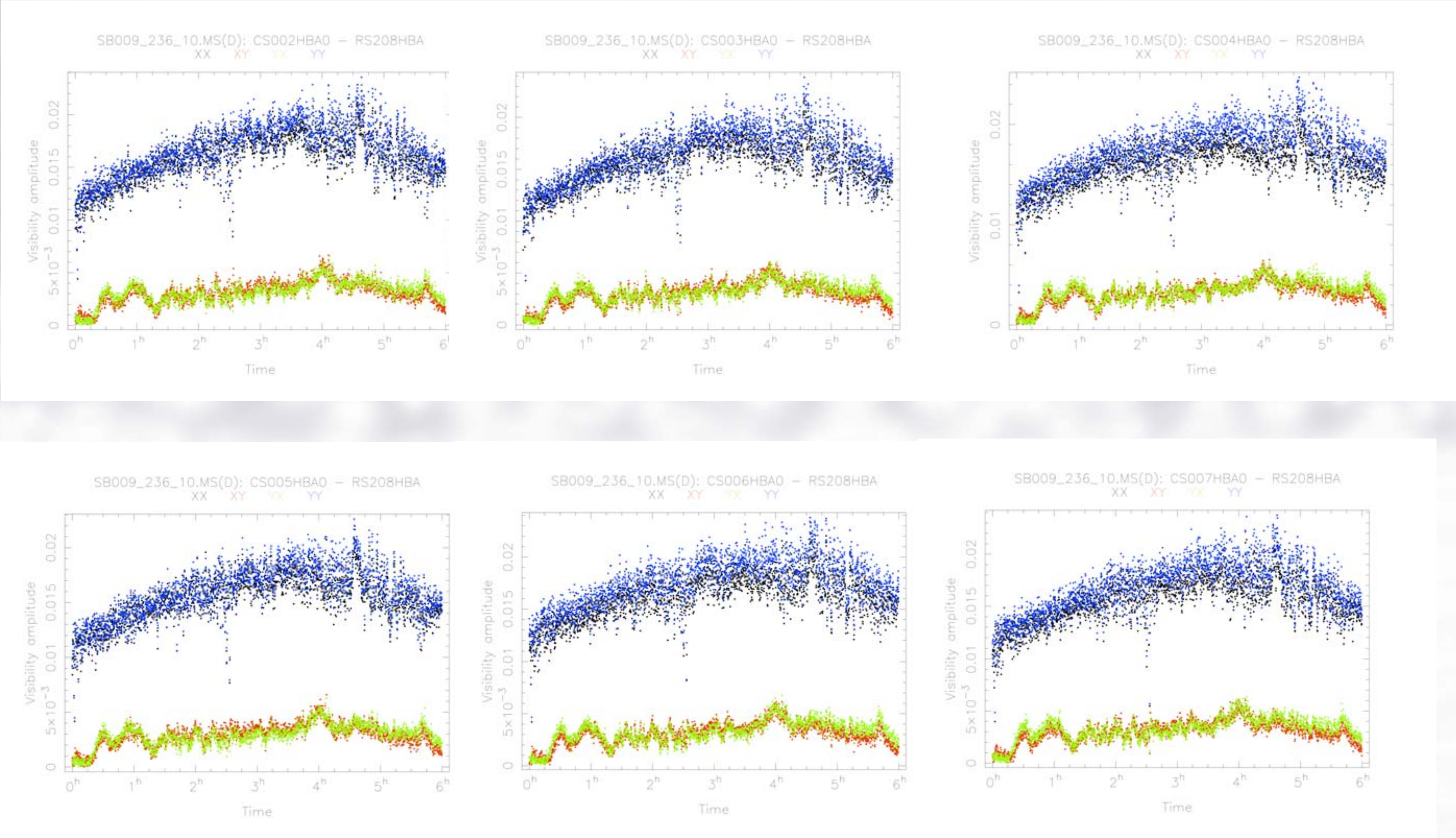
Note the rapid changes of the XY and YX signals and the associated amplitude decorrelation dips



1h at 10s resolution

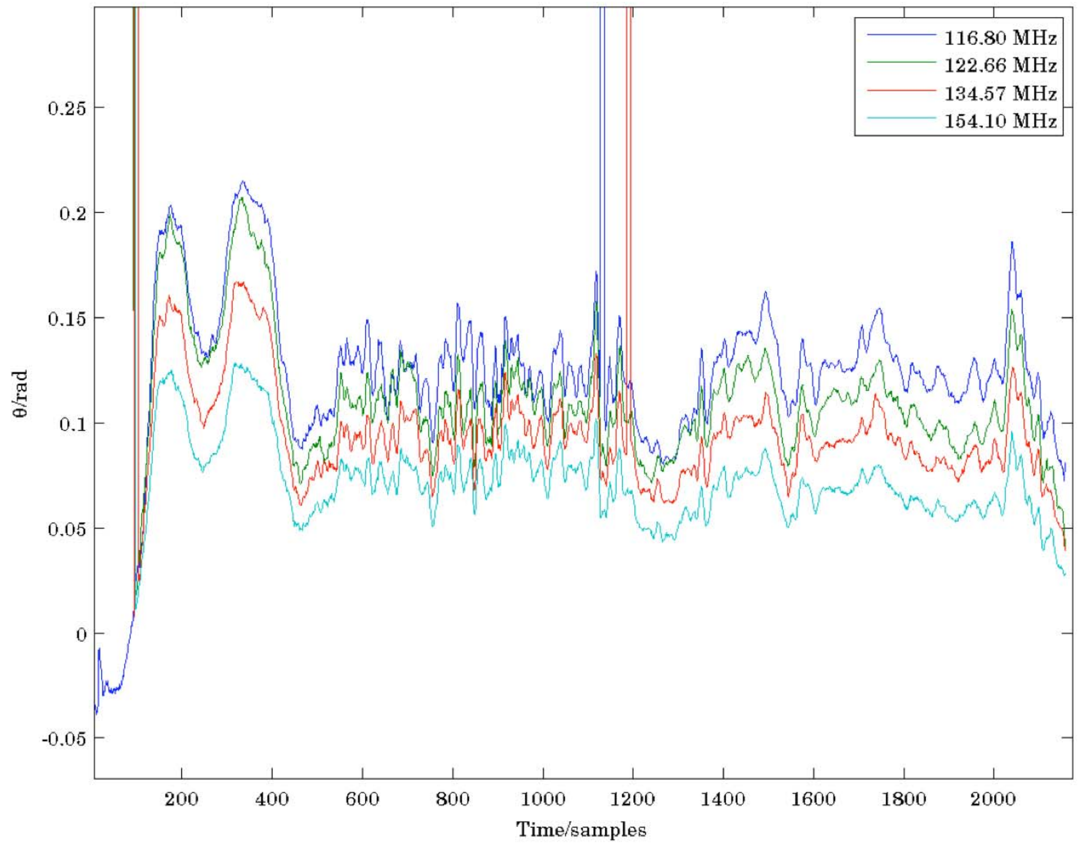
Identical DFR between RS208 and 6 superterp stations



Note the close agreement of the XY & YX signals on these 6 almost identical baselines !

Solving for DFR (t) using MeqTrees Sarod Yatawatta

Solution of DFR for RS208 (relative to CS001) using all baselines



Note the scaling with wavelength**2 as expected

6 hours

Quantitative understanding of the effects of DFR

DFR converts (unpolarized) signals into circularly polarized signals visible in XY and YX.
DFR arises when we encounter large TEC gradients. Let us look at this quantitatively.

(Absolute) Ionospheric Phase Delay:

$\Delta\phi$ = - 50 TEC (λ/2m) radians where TEC is in TECU (=$1\text{x}10^{12}$ el/cm^2)

(Absolute) Faraday Rotation of polarisation angle:

$\Delta\theta$ = RM. λ^2 = 0.81 10^6 $B_{//}$ n_e.dl λ^2 radians where $B_{//}$ in Gauss and dl in pc

Differential Phase Delay (DPD) between two stations i and j :

$\Delta_{ij}(\Delta\phi)$ = - 50 Δ_{ij} (TEC) (λ/2m) radians

Differential Faraday Rotation (DFR) between two stations i and j

$\Delta_{ij}(\Delta\theta)$ ~ 1.04 $B_{//}$ Δ_{ij} (TEC) $(\lambda/2\text{m})^2$

Hence: **DPD/DFR ~ 48 $(B_{//}.\ \lambda/2\text{m})^{-1}$** independent of the Δ(TEC) !

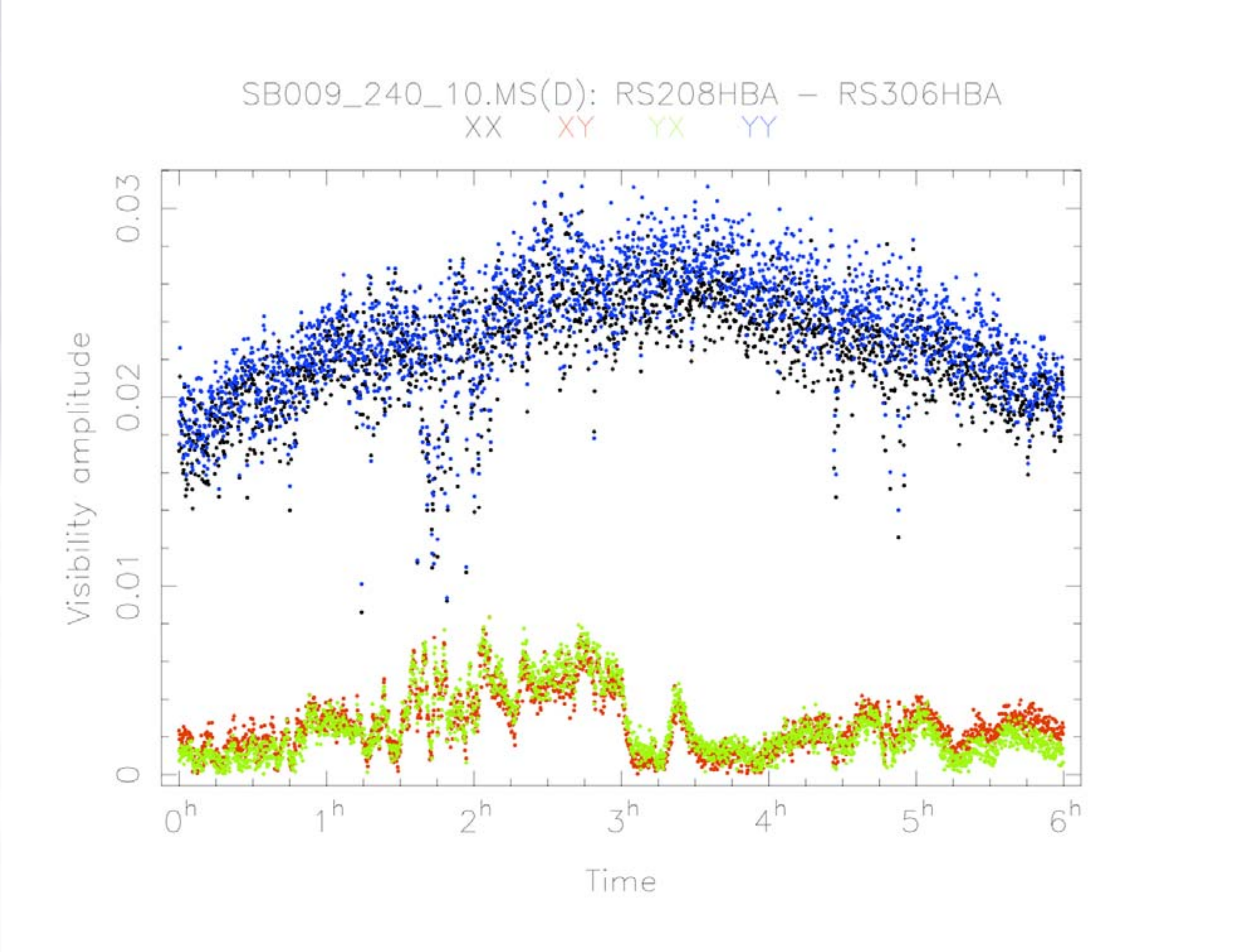
For a typical $B_{//}$ ~ 0.4 Gauss and a frequency of 122 MHz ➔ **DPD/DFR ~ 100**

A DFR of 0.1 radian (as observed on ~ 25 km baselines) therefore also implies large ionospheric phase differences (~ 10 radians or ΔTEC ~ 0.2 TECU) !! On the previous slides one can see that this occurs quite often ! If ionospheric phase rates are very fast (say within 10s) they also cause **amplitude decorrelation** !

3C196 2011 — 117 MHz — 4 Feb

Another observation with strong variable DFR

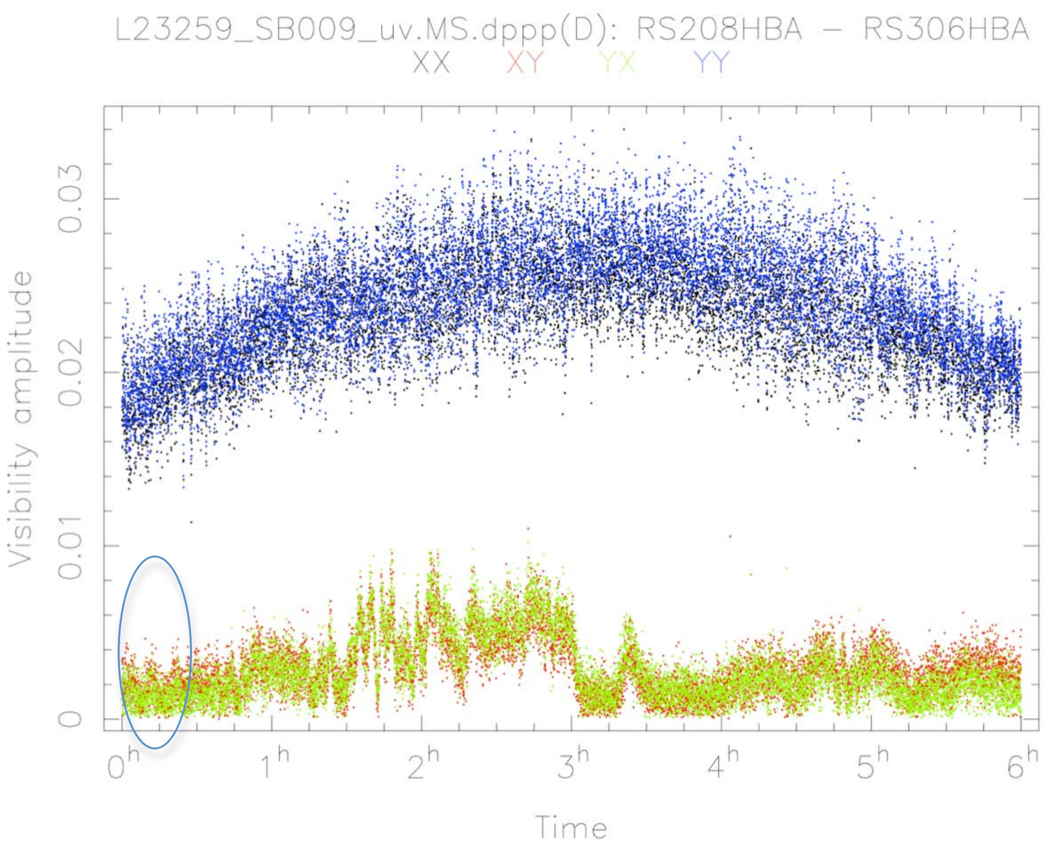
and strong associated amplitude decorrelation



6h at 10s resolution

3C196 117 MHz 4 Feb 2011

The amplitude decorrelation is reduced or absent at 2s time resolution



6h at 2s resolution

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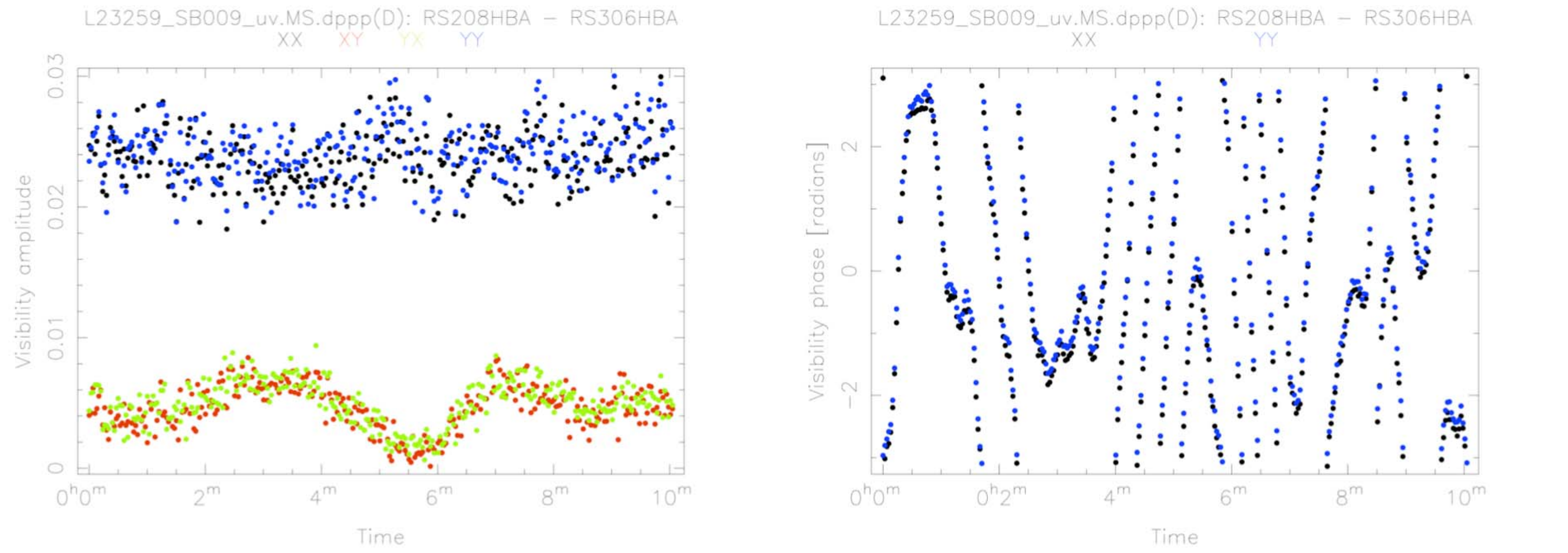

Amplitude

10m at 2s resolution

Phase

10m at 2s resolution

DFR ~ 0.2 rad in 100s → DPD ~ 20 radians phase

Conclusions

- Differential Faraday Rotation at low frequencies is well-known in VLBI world (hence RCP or LCP recording)

- DFR was first observed with LOFAR between Effelsberg and Exloo (~ 250 km) at LBA frequencies (see de Bruyn/Yatawatta, Lofar Status Meeting, 23 Sep 2009)

- In about 20% of the LEA128 data significant DFR effects occur at HBA frequencies on baselines as short as 20-30 km, especially around sunset ! This therefore occurs more frequently than ionospheric scintillation !

- On fields with weak sources DFR will not be noticeable. High quality imaging will require integration times down to 2 s at HBA and probably 1s at LBA !!

-DFR will seriously effect polarization calibration. Efforts to solve for DFR are ongoing. and calibration of DFR will become an integral part of LOFAR polarization calibration.

-Note: stable spatial TEC gradients only lead to DFR, but changes in them also cause signal decorrelation

- DFR effects will be used to constrain ionospheric mapping on large and small scales.