Wide-field Imaging with the DiFX Software Correlator

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Overview

1. **Wide-field VLBI**
   - Imaging
2. **Correlating, transforming and averaging**
   - Theory
   - Implementation
   - Results
3. **Conclusion**

VLBI has lots of megapixels!

For 2 telescope of diameter d separated by D the primary beam Θ and resolution θ are given by

$$\theta \approx \frac{\lambda}{D}, \Theta \approx \frac{\lambda}{d} \tag{1}$$

So the number of resolution elements across the primary beam is

$$\frac{\Theta}{\theta} = \frac{D}{d} \Rightarrow n_{pixel} \sim \left(\frac{D}{d}\right)^2 \tag{2}$$

This is before we start playing with space VLBI or imaging sources in the sidelobes

Image size of different arrays

Array	d (m)	D (km)	D/d	δ (kHz)	τ (s/GHz)
VLA	25	32	1 280	400	8
Merlin	32	217	8 680	80	1.5
EVN	100	10 180	101 800	5	0.1
VLBA	25	8 611	344 440	1.6	0.025

$\sim$100 000 megapixels for global VLBI with 25m dishes

How to Reduce Wide-field Data

Of course, not much of this image will contain real detections.
Depending on the *a priori* information it may be necessary to:-

- ⇒ Image the entire primary beam
- ⇒ Image several discrete sources

Correlator Model

⇒ The delay model controls how the different datastreams are aligned

⇒ The datastreams are shifted so that all of the antennas are on a plane

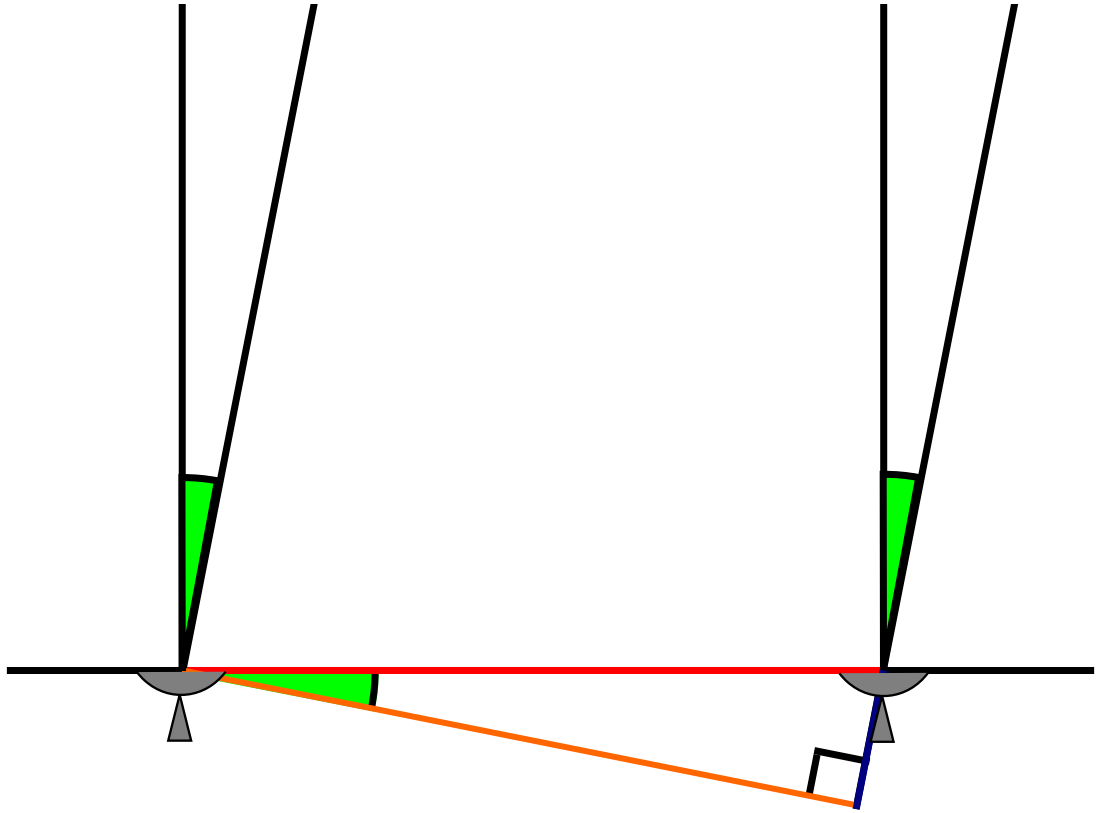
- → Perpendicular to the direction of the source
- → Passing through the centre of the Earth

⇒ It is this delay model that determines the centre of the image.

⇒ Although these models are exquisitely complex, they're not perfect, just *good enough*.

Geometry

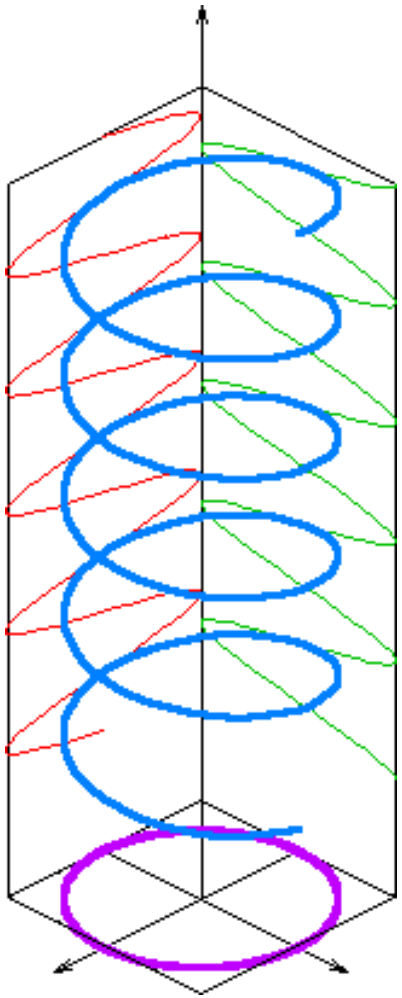
The correlator has already shifted the datastreams so that the two antennas are on a baseline perpendicular to the original phase centre:



Consider a source with an offset from this position.

Correlated data

For a radio source offset from the phase centre



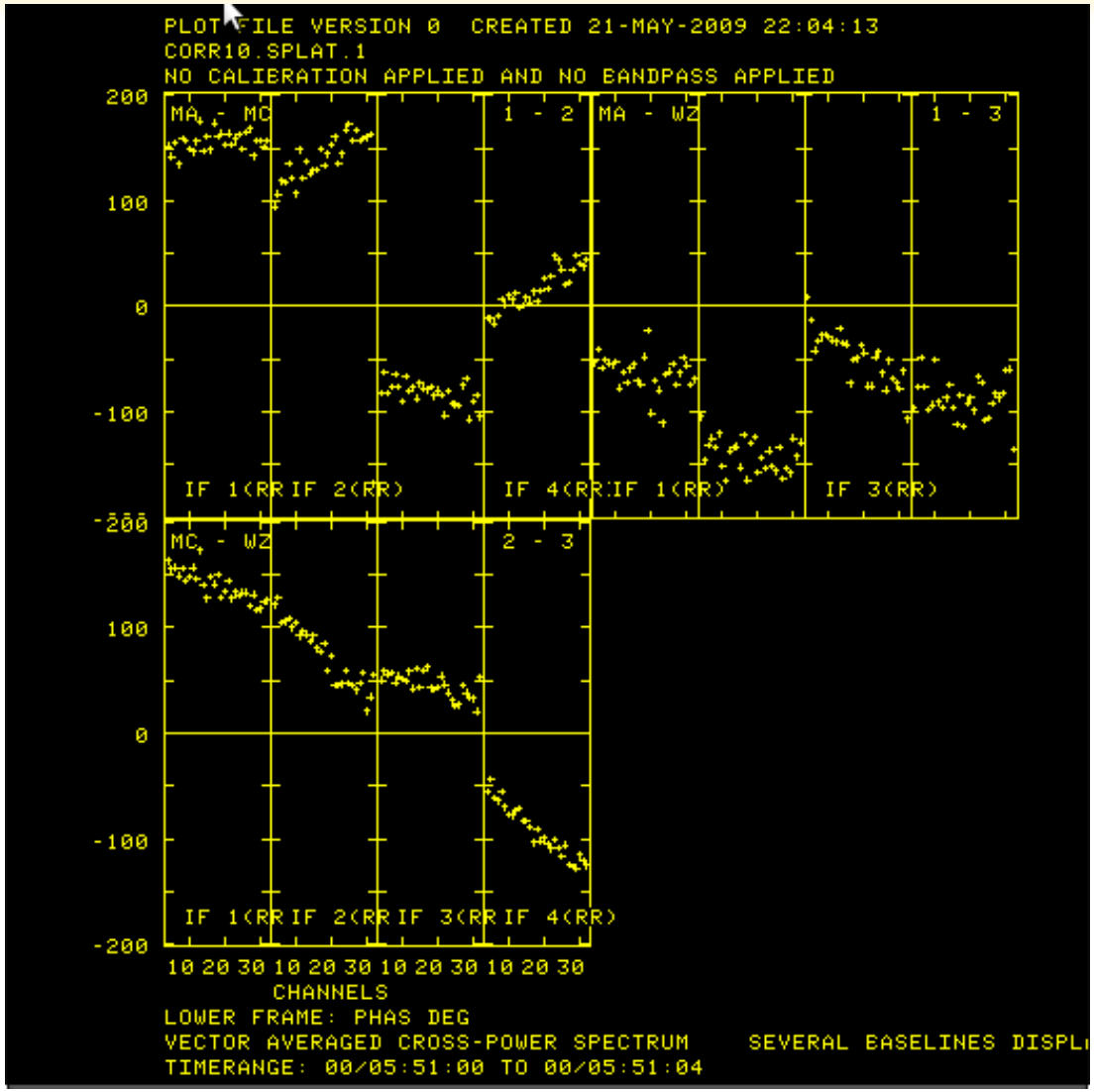
⇒ The phase is rotating

→ In time

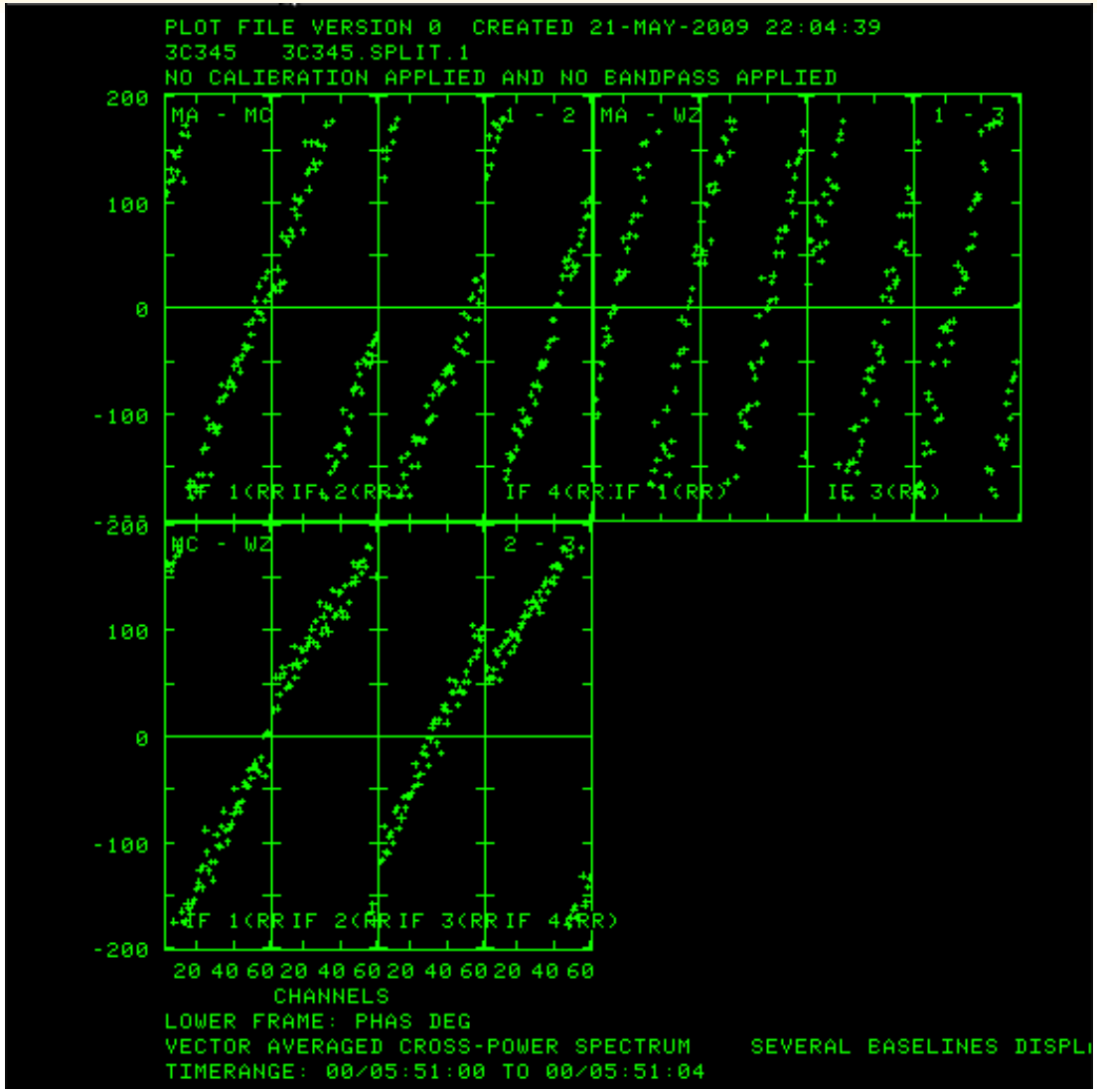
→ In frequency

⇒ Over-averaging will cancel flux to zero.

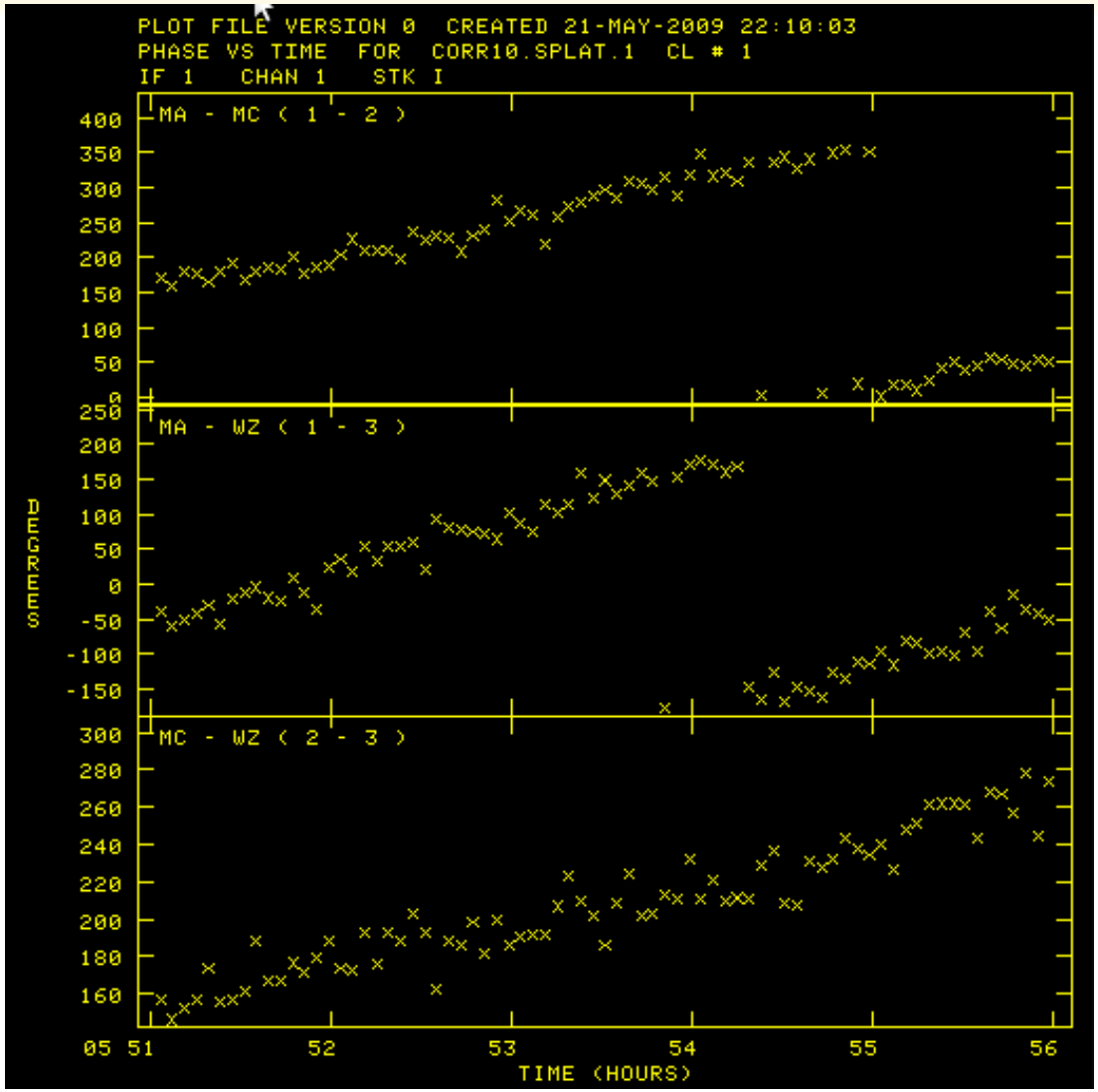
3C345: Normal correlation



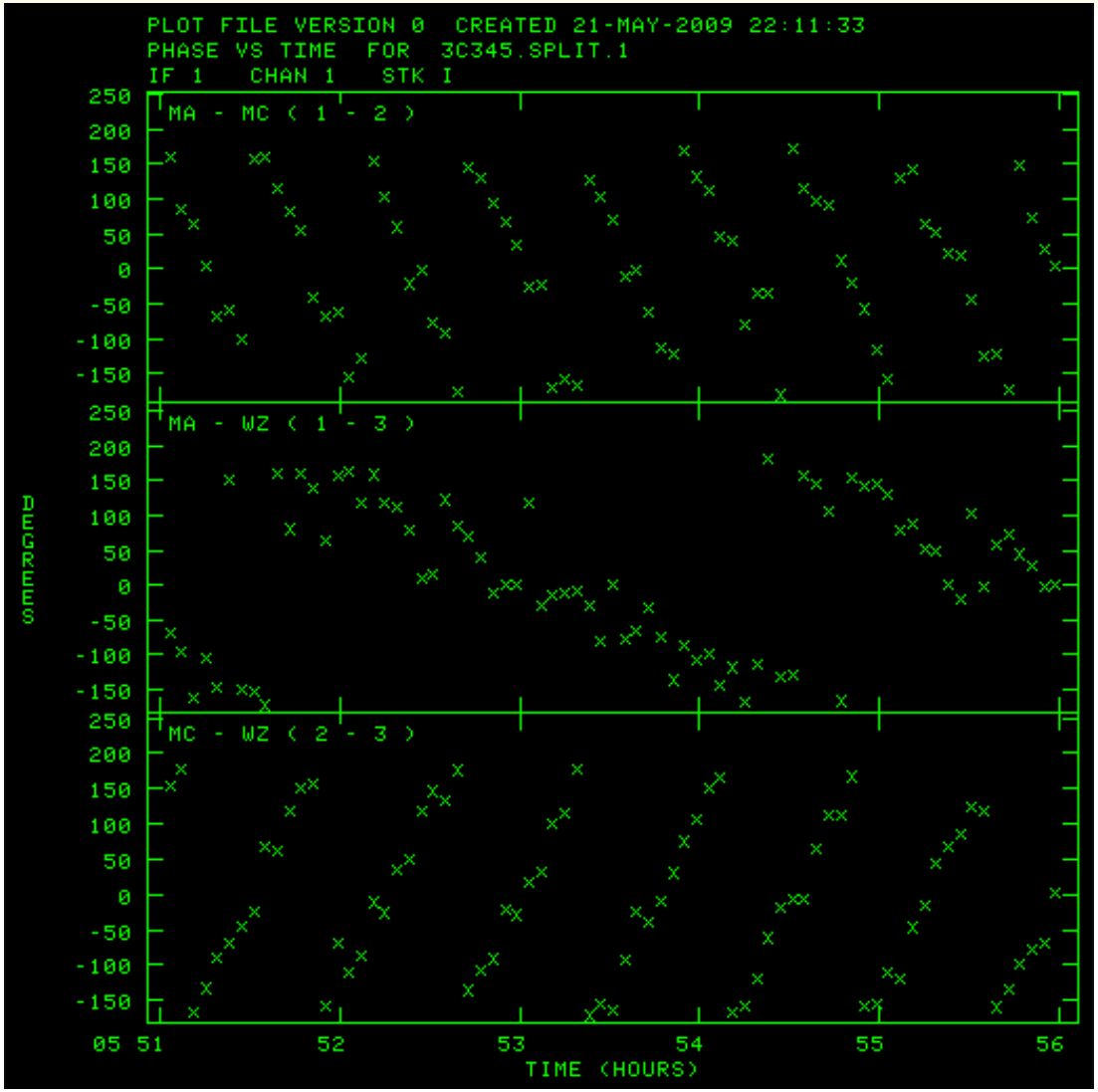
3C345: 10×10 arcsec offset



3C345: Normal correlation



3C345: 10×10 arcsec offset



Wide-field Imaging

Direct wide-field imaging

Very quickly becomes slow

⇒ Will quickly fill computer memory

⇒ Little to be gained from parallelisation

Correlating with different phase centres

⇒ Ties up correlator

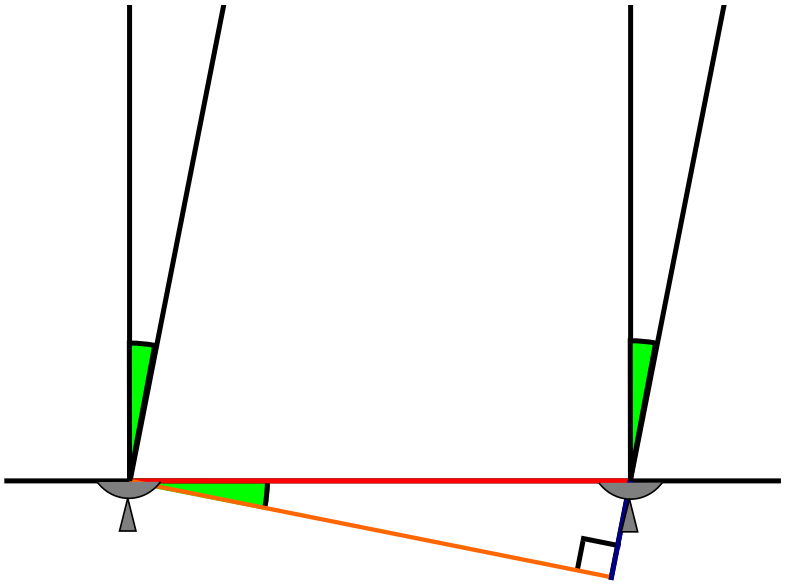
⇒ Ties up raw data (and media)

Correlating, transforming and averaging

⇒ Correlate to create one large dataset

⇒ Use this to generate several smaller datasets

Correlating, Transforming and Averaging



- ⇒ We start with the correlated data
- ⇒ Recalculate baseline vectors (UVW)
- ⇒ Apply a phase shift to each datum
  - → time dependent
  - → frequency dependent

We can then average in time and frequency.

We can repeat this, making several small datasets from one large one

Correlating, Transforming and Averaging

We can do it in AIPS (UVFIX). However:

- ⇒ It's laborious
  - → UVFIX only works on single-source datasets
- ⇒ There is limit on $n_{IF} \times n_{channel} \times n_{polarisations}$
- ⇒ It gives position errors

This is probably due to insufficient accuracy in AIPS's internal baseline model. (It could also be related to inaccurate UVW coordinates)

Accurate UV Shifting

- ⇒ We can use CALC/SOLVE to generate our UVW coordinates
- ⇒ Calculate the phase shift by calculating the difference in delay between our original model and the shifted model.
- ⇒ This can be done at the FITS conversion stage

This should give us an answer consistent with correlating at the new phase centre.
Preliminary results show a significant improvement in positional accuracy.

Implementation in difx2fits

- ⇒ Adding the shift easy-peasy
- ⇒ Spectral Averaging already supported
- ⇒ Time averaging tricky
  - → need to buffer entire time integration

This is done

Averaging in pulsar bins in difx2fits or concurrently writing out multiple fits files should now be fairly trivial modifications to make.

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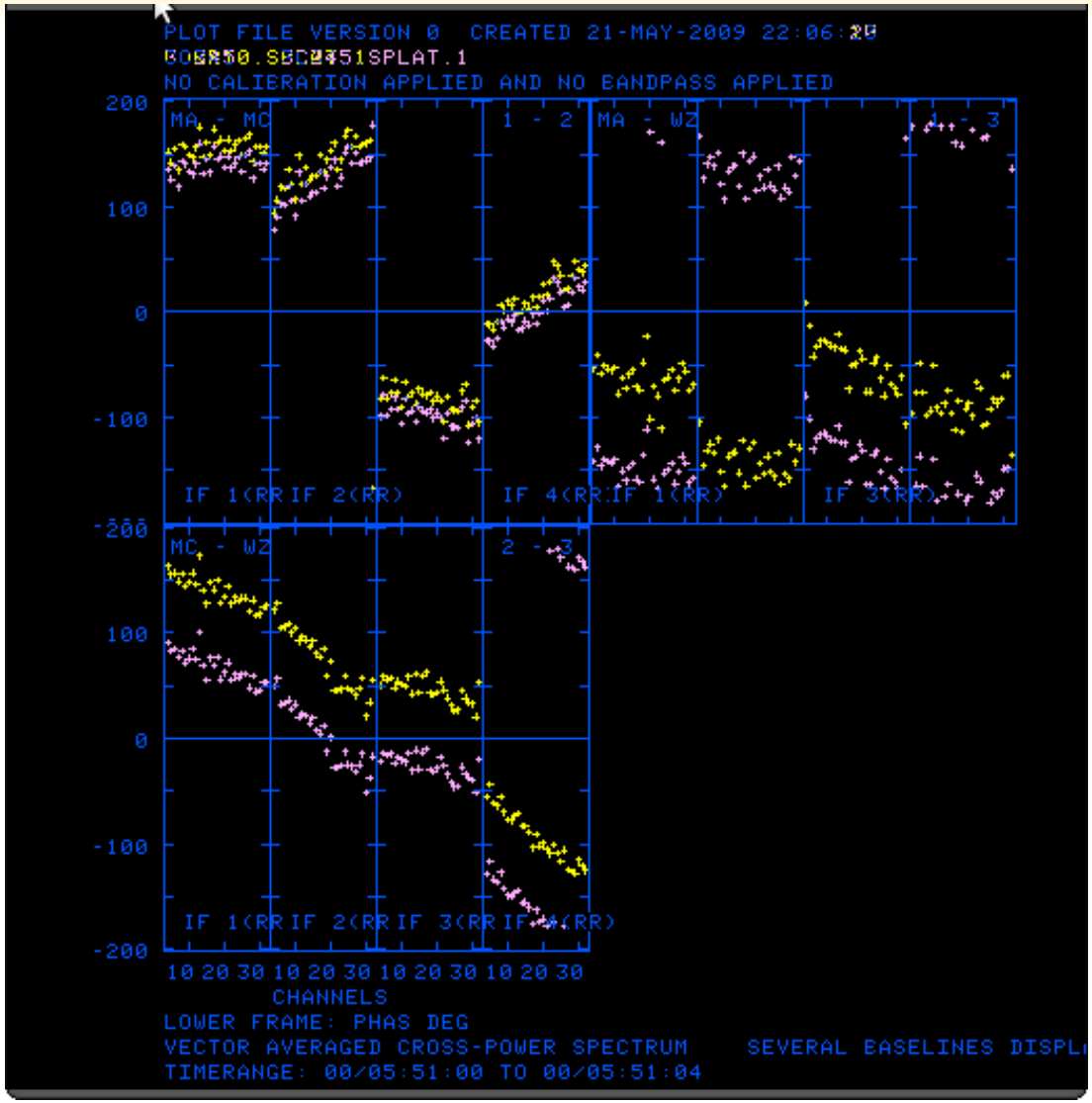
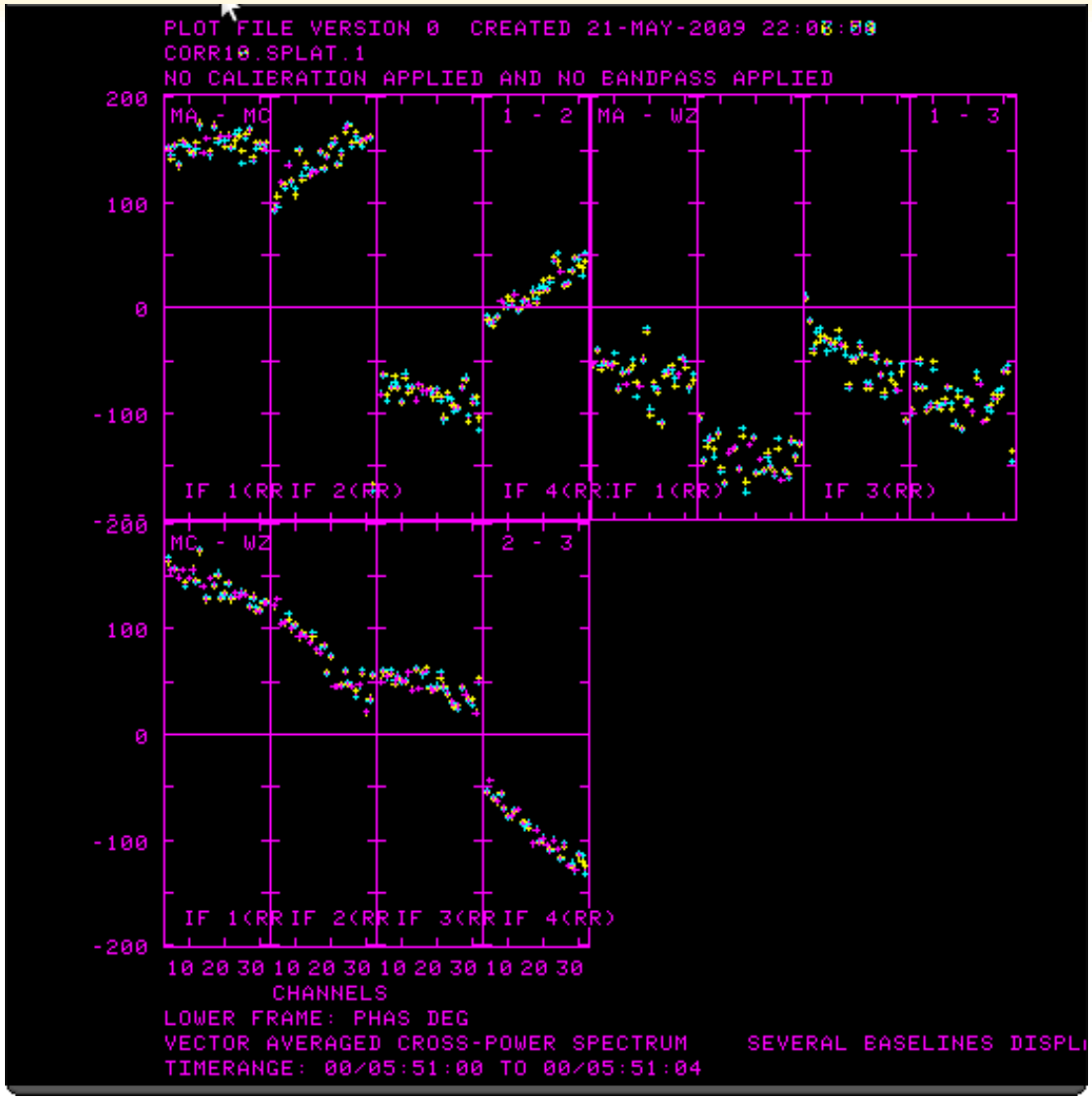
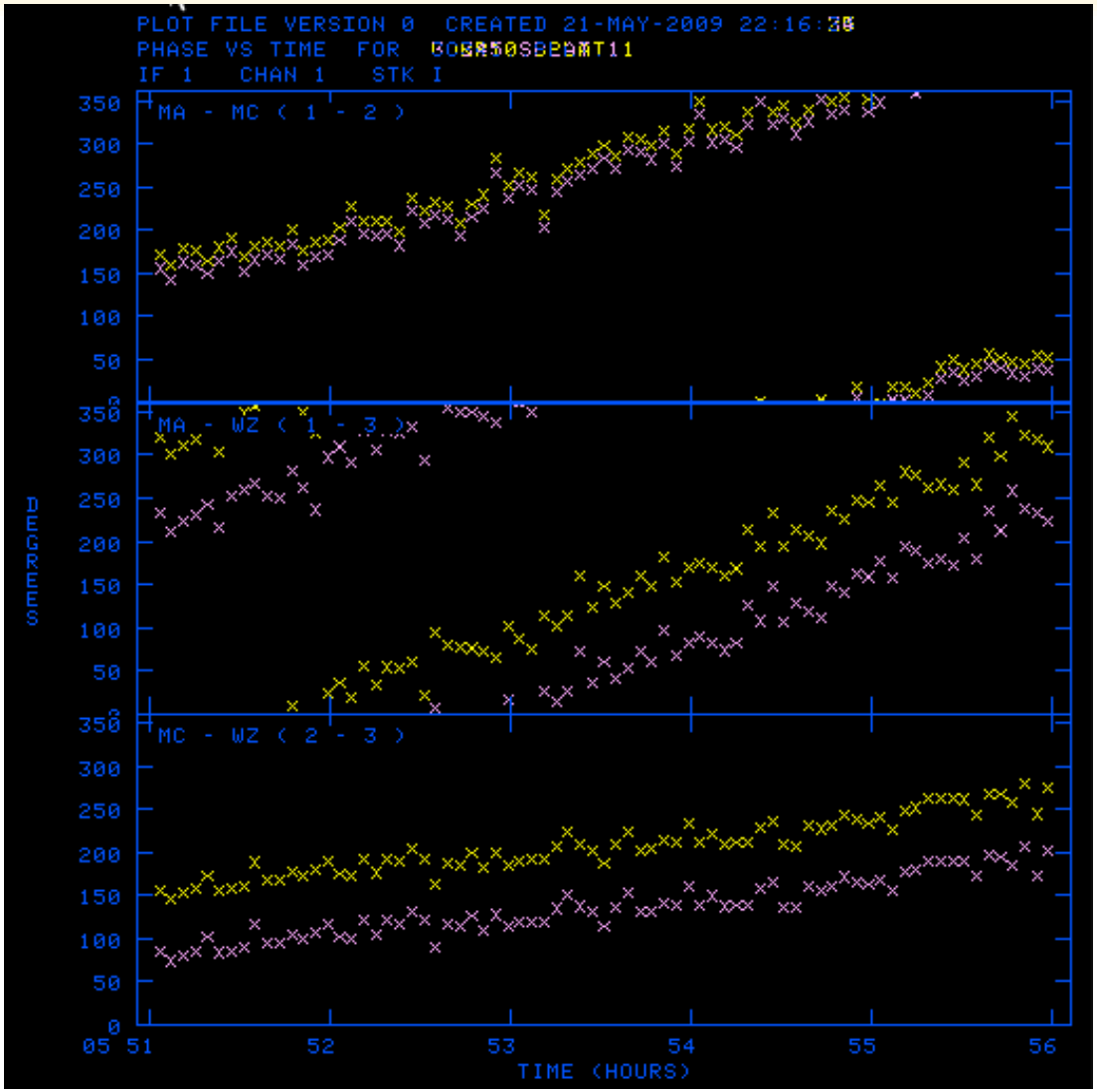
3C345: UVFIXed



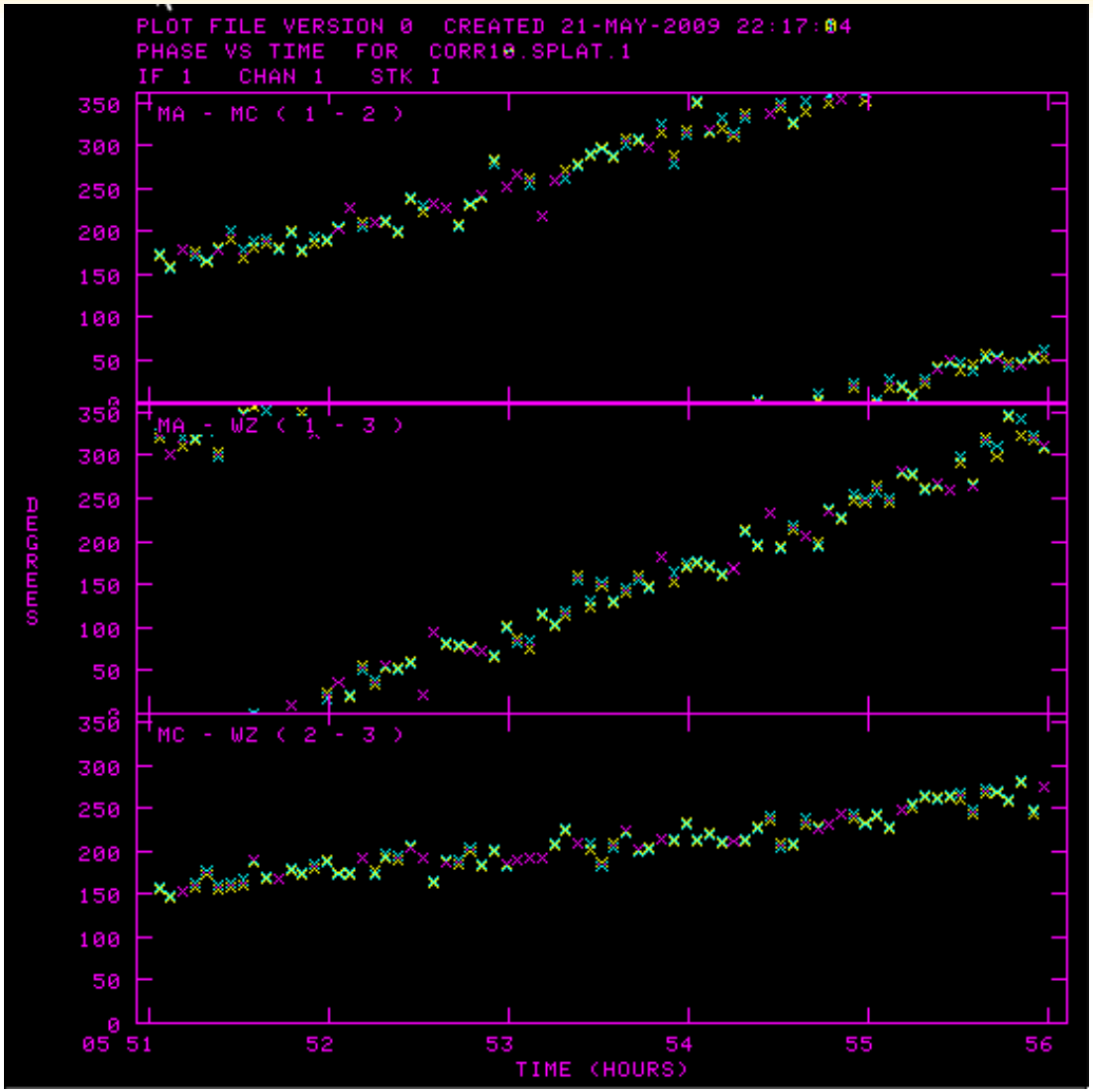
3C345: CALC shifted



3C345: UVFIXed



3C345: CALC shifted



Summary

⇒ Correlate one large dataset

⇒ Run the fits convertor several times

⇒ Each run results in a small independent dataset

Using this technique:-

⇒ We break the huge VLBI dataset into smaller pieces

⇒ Each of these datasets can be calibrated and imaged separately

⇒ This is separate from the correlation