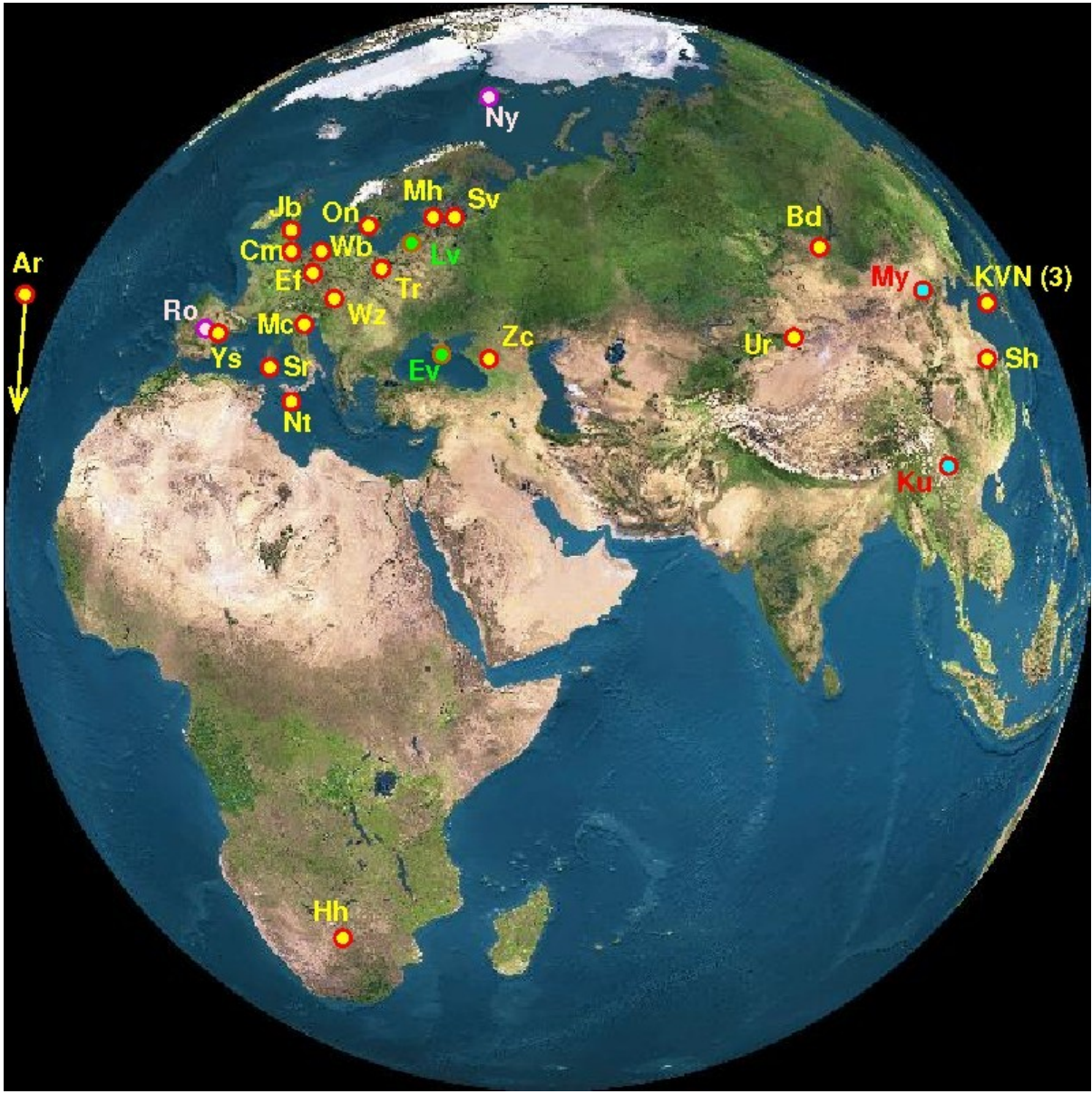
A potted outline of the EVN data

- What is the EVN
- What is a Network Monitoring Experiment
  - and what is in this one
- Before observation
- Correlation
- Calibration
- Imaging

Very Long Baseline Interferometry

- Join signals from radio telescopes internationally
- European VLBI Network includes dishes in Russia, China, Korea, SA...
- Works with USA, Australia, Japan etc. and satellite Radioastron

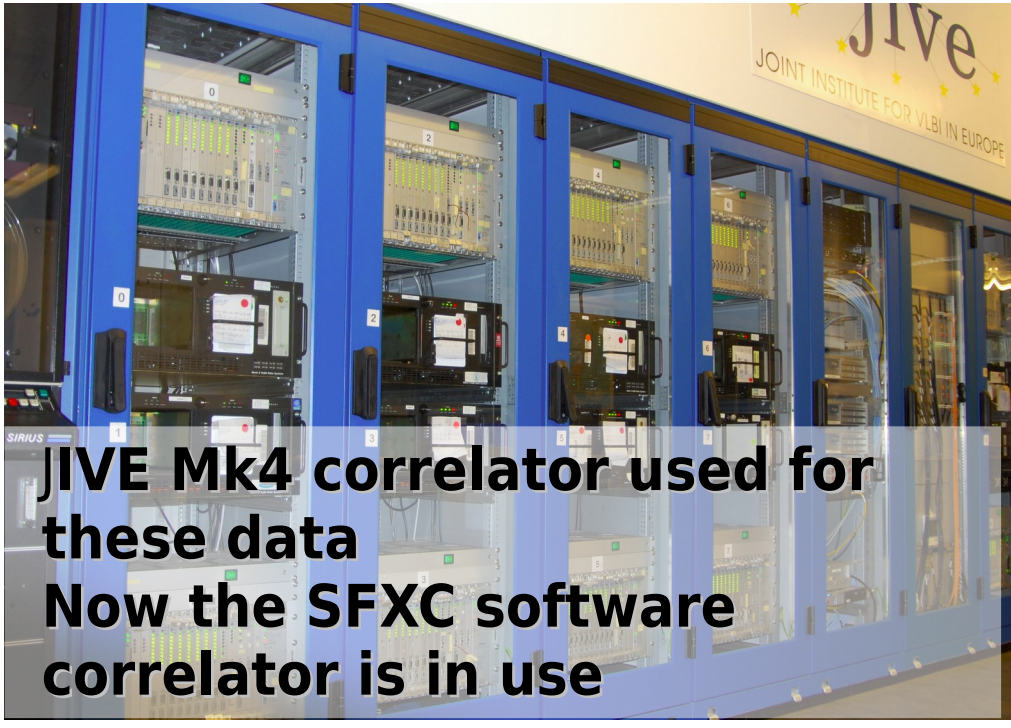


European VLBI Network

- Ad-hoc array of about ten regular members
  - 20 or so more participate from time to time
- Largest regular member 100-m Effelsberg
  - Arecibo (305 m) sometimes
    - Smallest <20m, still useful in an array
  - Phased arrays e.g. WSRT also have large effective areas
- 4 sessions per year, few weeks per session
  - Target of Opportunity observations any time with subset of antennas (e.g. for a new supernova)
- Antennas also used for single dish/national arrays the rest of the time

Data transport

- Most data recorded at each telescope onto computer disk packs (originally, tapes)
  - Shipped to JIVE correlator, The Netherlands
    - Data are correlated after observations
- EVN telescopes connected by the public internet
  - Used to transport short/ small bandwidth observations and correlated in real time
    - Sources needing rapid follow-up e.g. GRB
    - Tests at start of each session



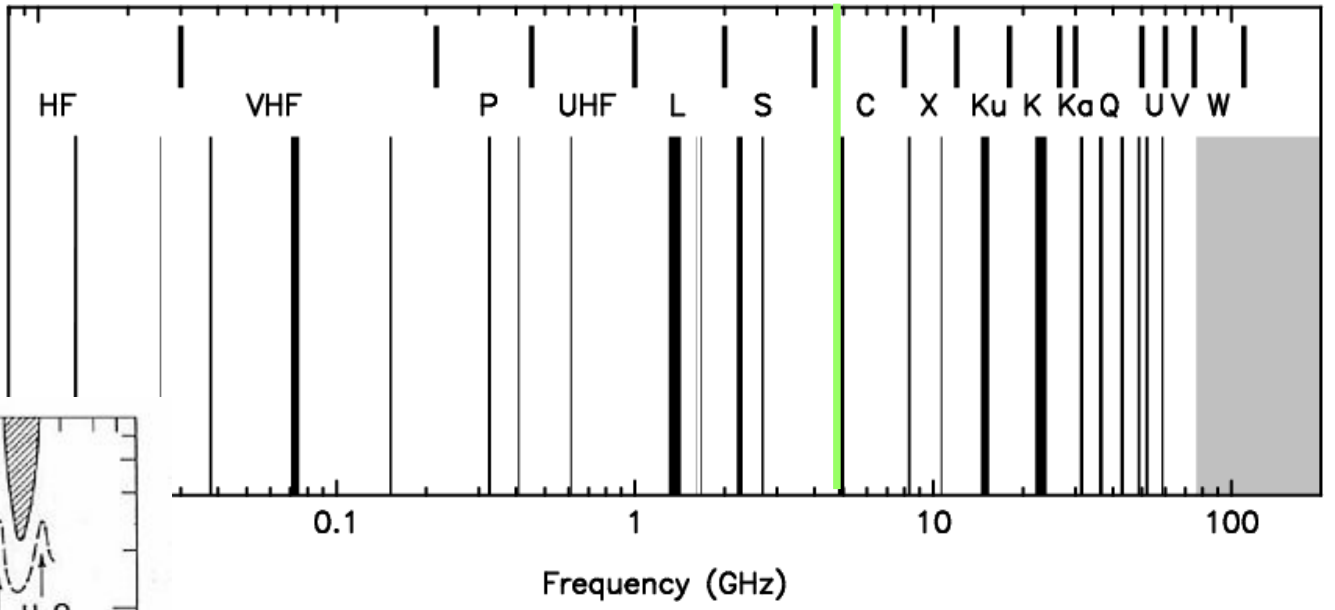
JIVE Mk4 correlator used for these data
Now the SFXC software correlator is in use

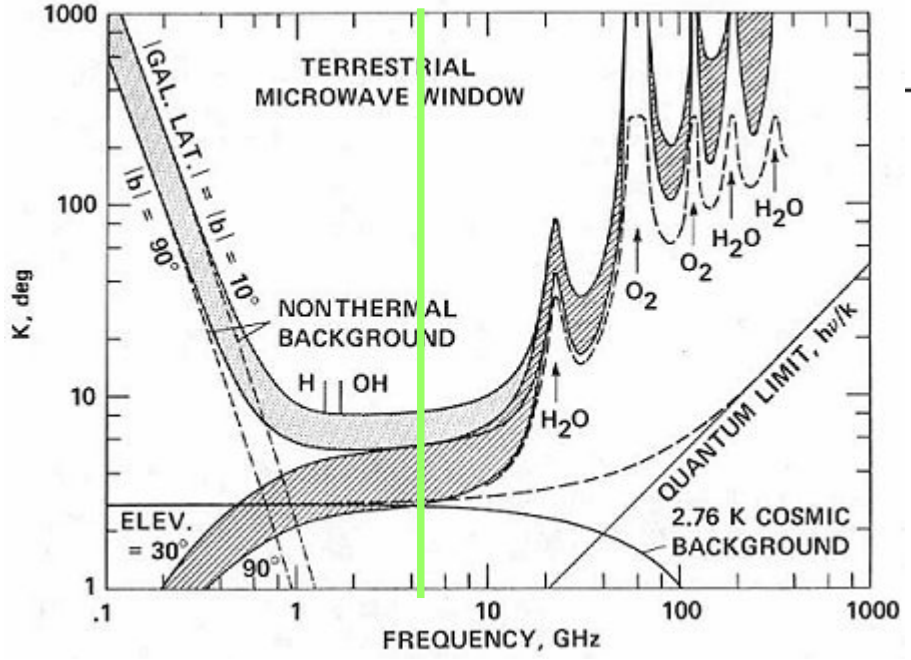
Network Monitoring

- Ad hoc array; telescopes are set up for different types of observation most of the year
  - Have to reconnect the spagetti just right....
    - Get the polarizations the right way round!
- Check at start of each session
  - Short burst test via internet
  - Few-hr Network Monitoring Experiments
    - Check Rx performance, correlation etc.

NME n14c3

- n14c3 observed 2014 Oct 22 at C-band
  - ~5 GHz





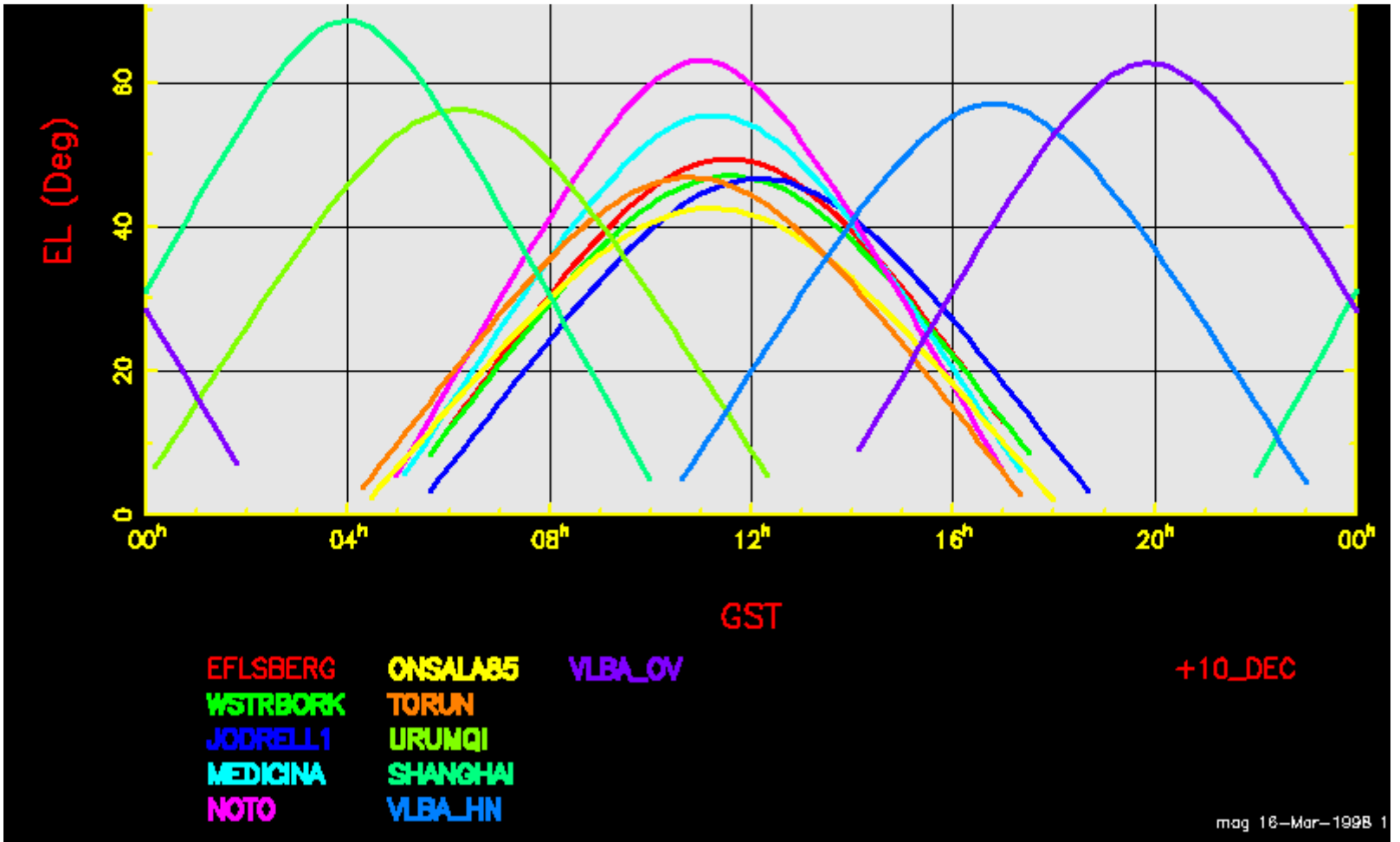
- Sweet spot where neither ionosphere nor troposphere are too bad
- Receivers are very sensitive

NME n14c3

- Observe two sets of phase-reference target pairs
  - <~3^{o} separation to allow fast (1-min) switching
    - Sources known to be 'compact' and bright (~Jy)
  - Max. baseline ~10,000 km, λ 6cm
    - Resolution 1 – 2 mas – most sources slightly resolved!
      - Will need to check/map all calibrators
- Bandpass calibrator
  - In this case we use one of the phase-refs
- Theoretical sensitivity reaches 0.025 mJy in 30 min
  - VLBI usually dynamic-range limited

Sources must be visible!

- Telescopes almost on opposite sides of Earth
  - Sources only above all horizons for few hr at best



Observations

EVN OBSERVATORIES	TELESCOPE	
	Code	Diameter(m)
Jodrell Bank (UK)	Jb-1 Lovell	76
	Jb-2 Mk2	25
Cambridge (UK)	Cm	32
Westerbork (NL)	Wb	25
Effelsberg (DE)	Ef/Eb	100
Medicina (IT)	Mc	32
Noto (IT)	Nt	32
Sardinia (IT)	Sr	65
Onsala (SE)	On-85	25
	On-60	20
Sheshan(Shanghai,CN)	Sh	25
Tianma(Shanghai,CN)	Tm65 (T6)	65
Nanshan(Urumqi,CN)	Ur	25
Torun (PL)	Tr	32
Metsaehovi (FI)	Mh	14
Yebes (ES)	Ys	40
Arecibo (USA)	Ar	305
Hartebeesthoek (SA)	Hh	26
	Ht	15
Wettzell (DE)	Wz	20
Svetloe (RU)	Sv	32
Zelenchukskaya (RU)	Zc	32
Badary (RU)	Bd	32

- 12 antennas used
- Data recorded on disc
- Tsys measurements recorded separately
  - Gain-elevation curves also separately available
- Data correlated at JIVE, stored in FITS IDI format

Summary of observation status

Network Monitoring Report: **C-band** N14C3

Source: 3C345, 1848+283, 2023+336, J1640+3946, J1849+3024
Reference antenna: Effelsberg
Experiment code: N14C3

Length: 180 min.
Date of observations: 22/10/14
Date of report: 28/01/15

Observing mode: Mk V, mode 512-8-2, dual pol.
Reference date: 22/10/14; 295d 12h 00m
by: Gabriele Surcis

⊗ According to expectation, no special remarks
■ Problem occured - see enclosed footnote(s)
⬚ Station did not observe (not scheduled)
○ Entry not applicable/investigated

	Ef	Wb	Jb	On	Nt	Tr	Ys	Sv	Bd	Zc	Sh	Hh
Station has observed	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Station produced fringes (ftp)	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Station produced fringes (disk)	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Filled in TRACK	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Logs are available (within 72 hours)	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
GPS data available (within 7 days)	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Disks are available (within 7 days)	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Feedback on www (within 7 days)	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
GPS clock estimate gives fringes	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Clock offset in μsec	−23.511	1.333	−6.779	9.665	−9.222	171.560	7.984	215.926	215.730	213.622	25.426	4.091
Clock rate in psec/sec	−0.139	0.174	0.086	0.105	0.080	−18.000	0.428	0	0	0	0.773	0.181
Recording okay	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Polarization setup okay	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Strong signal amplitude	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Phase cal aligns phases	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Sampler statistics okay	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Please check VC number(s):												
Previous reported problem(s) corrected												
Problem(s) first reported												
See enclosed footnote(s):								a				

Enclosure: Footnotes C-band N14C3

Data processing

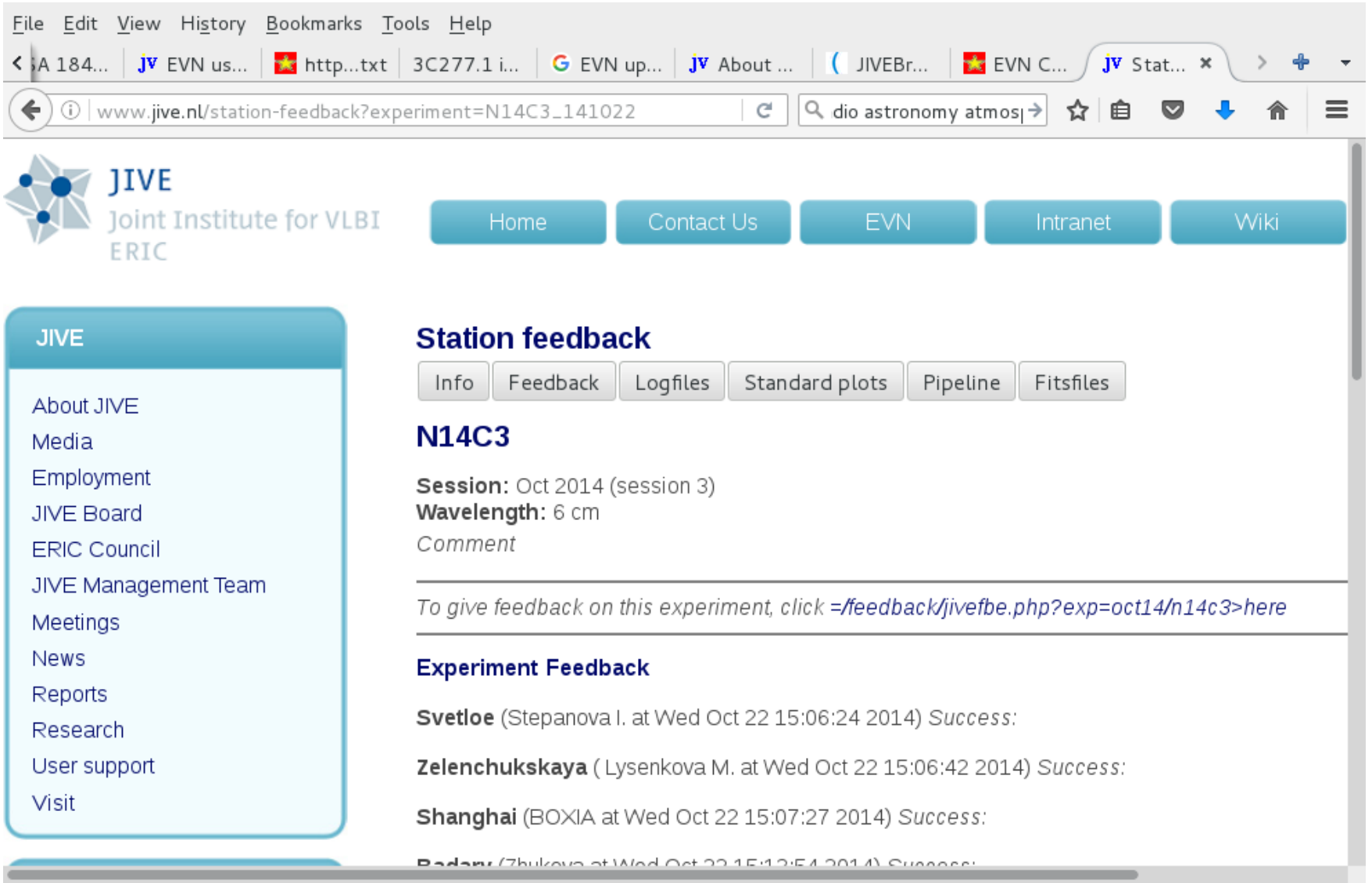
- During correlation, delay can be adjusted to ensure 'fringes' on bright source
  - i.e. timing corrected to provide constructive interference
    - Residual delay errors likely

$$\tau_{obs} = \tau_{geom} + \tau_{rot} + \tau_{str} + \tau_{tropo} + \tau_{iono} + \tau_{insts} + \varepsilon_{noise}$$

  - Source orientation wrt. position of telescope, Earth rotation
  - Source structure
  - Atmospheric refraction
  - Instrumental electronic path effects

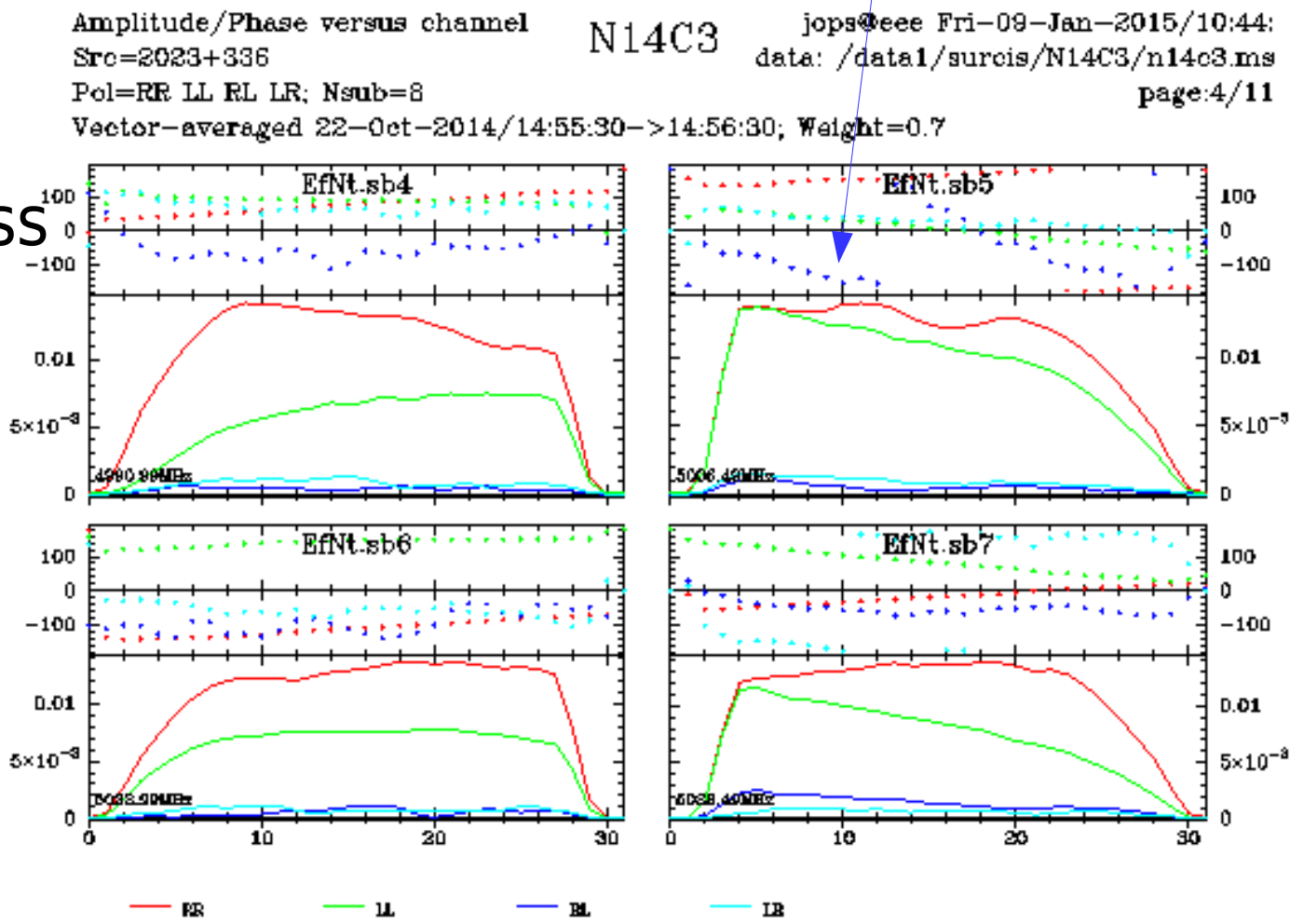
EVN archive report

- Reports, diagnostic plots, pipeline script, files



Delay (phase v. frequency)

- Correlated data have residual timing errors
  - These data are pretty good!
- Need to correct before averaging across band to avoid decorrelation
  - Fit slope to delay first



Manual processing of n14c3 I

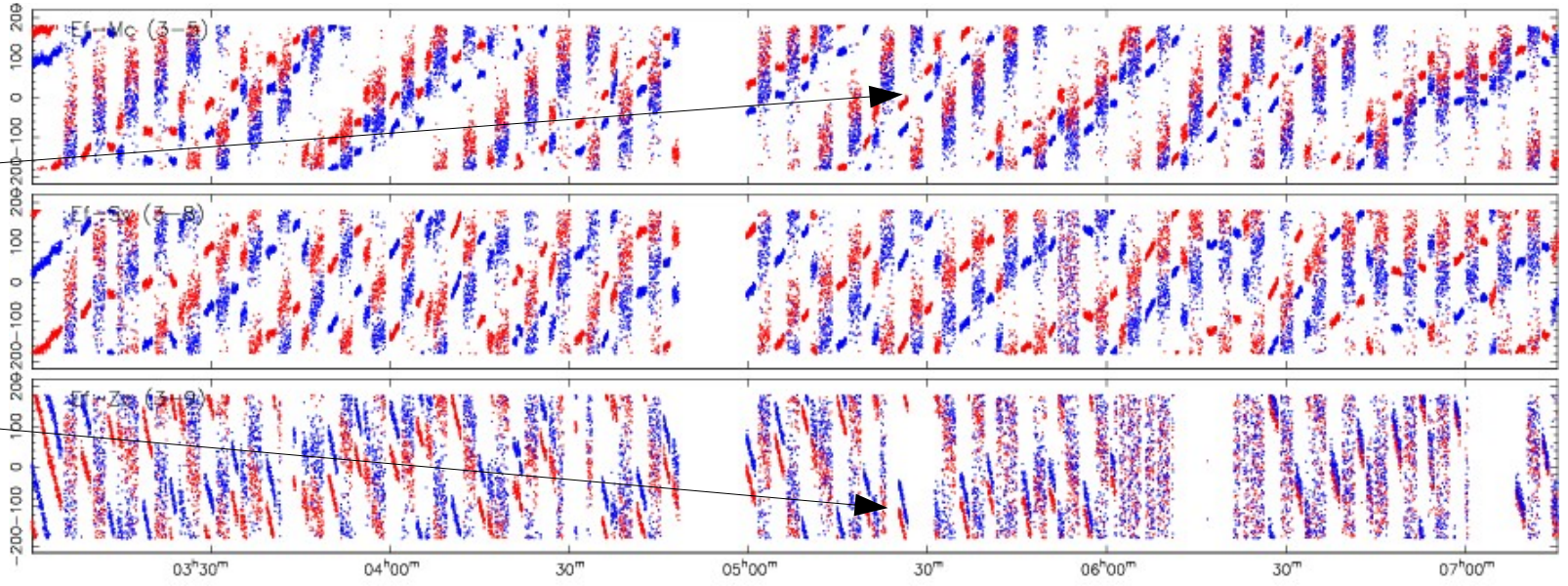
- Apply $T_{\rm sys}$ and gain-elevation corrections
  - Provides approximate flux scale by using SEFDs
    - (emission in Jy equivalent to system temperature)
- Inspect brightest compact source in data (BP cal)
- Select ~2 min good data to derive delay corrections
  - Short period to avoid time-variable decorrelation
  - Assume clock errors constant, apply correction to all data
- Iteratively correct phase and amp v. time and freq to derive a bandpass correction table, apply to all data

Phase rate (NOT needed for n14c3)

- The longer the baseline, the faster the phase rate v. time
  - Sources most resolved – fainter – on longest baselines
    - Data noisiest
- Need to correct on scale of phase-change <~10^{o}
  - Too short an interval for good S/N?
    - Fit first derivative (rate) – see later talk.

Phase-ref: small phase scatter on short baseline
Scans alternate with noisier target

Long baseline: very fast-changing phase



Manual processing of n14c3 II

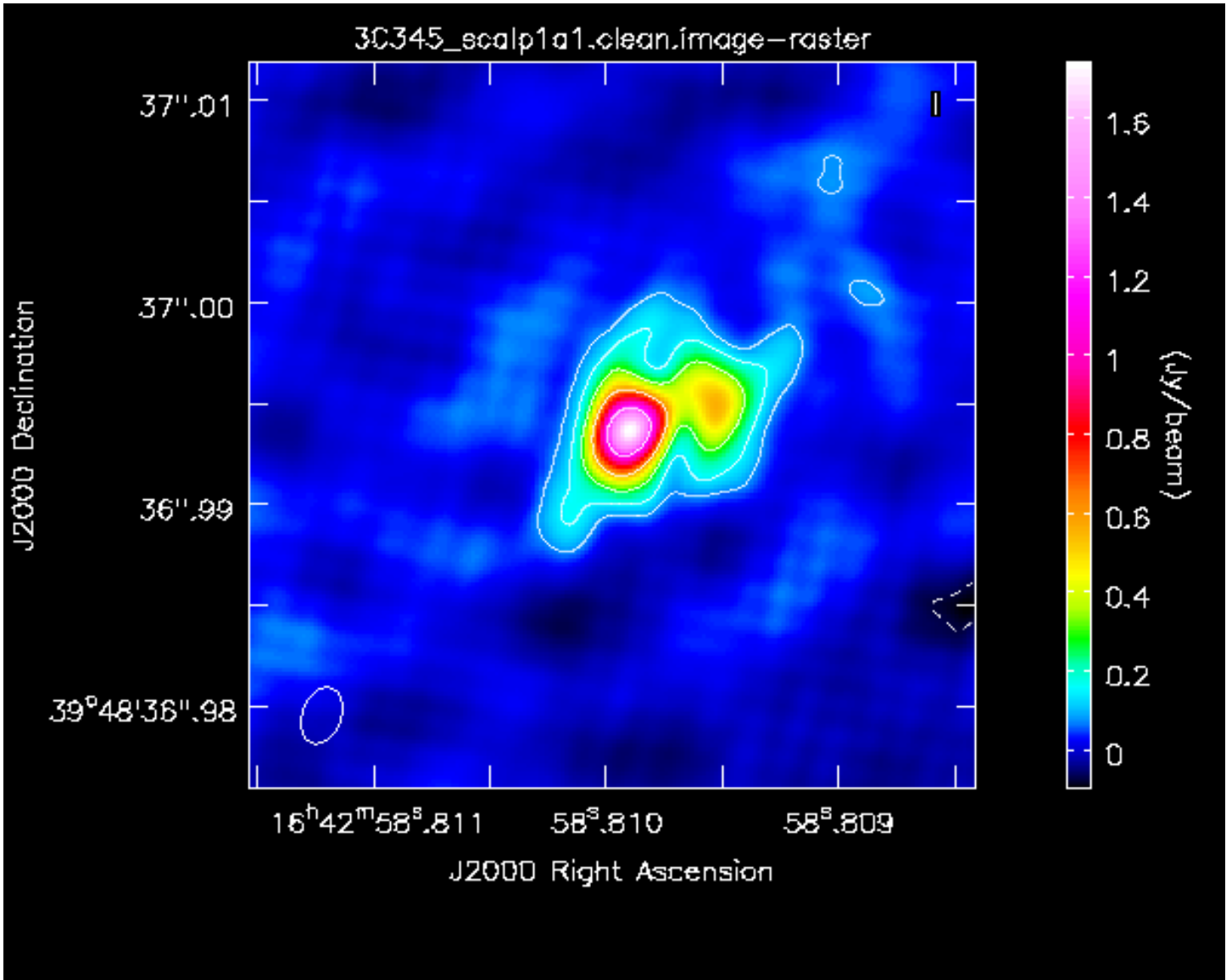
- At several stages:
  - In each calibration step, apply parallactic angle correction, i.e. compensate for different effects on L and R feeds as Alt-Az antennas rotate on the sky
  - Flag brightest source first, flag other sources as calibration is applied (easier to see bad data)
  - Check amplitude v. uv distance for signs of resolution
- Split out each phase-ref – target pair
  - Bandpass amplitude and phase are calibrated to allow averaging of all channels
  - Calibrate phase reference source phase assuming a point model

Manual processing of n14c3 III

- Apply calibration to phase ref and image
- Use image CC as model for phase & amp calibration of phase-reference
  - If very resolved, repeat until good model is achieved
- Apply phase and amplitude solutions derived from the phase ref to the target
  - (bandpass solutions already applied)
- Image target
  - Self calibrate target if bright enough
- Do some science! (in the real world)

The result....

n14c3 image of 3C345



MOJAVE image of 3C345 at higher frequency (different angle due to jet precession)