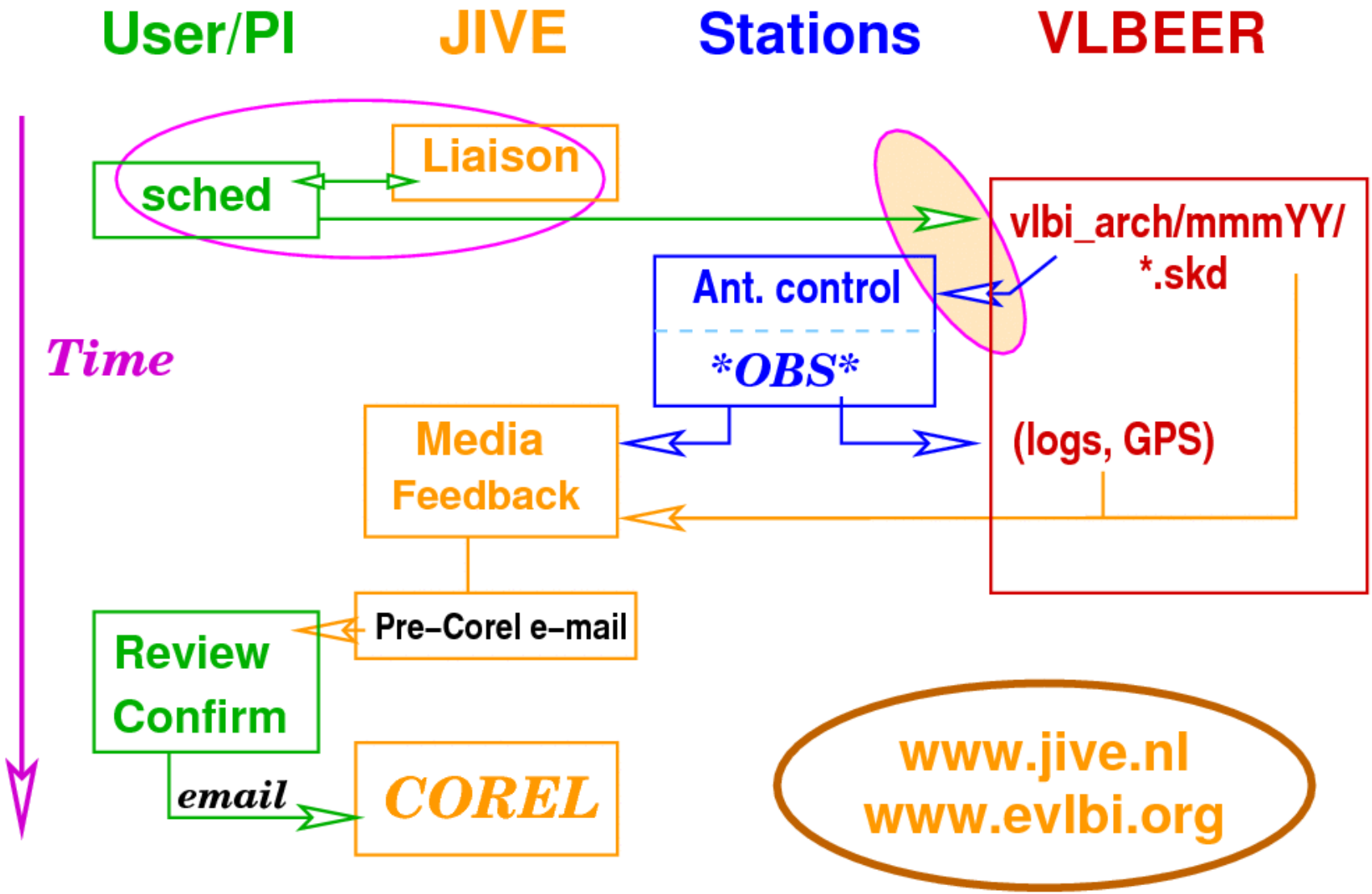
Software Correlation at JIVE & Real-time e-VLBI in the EVN

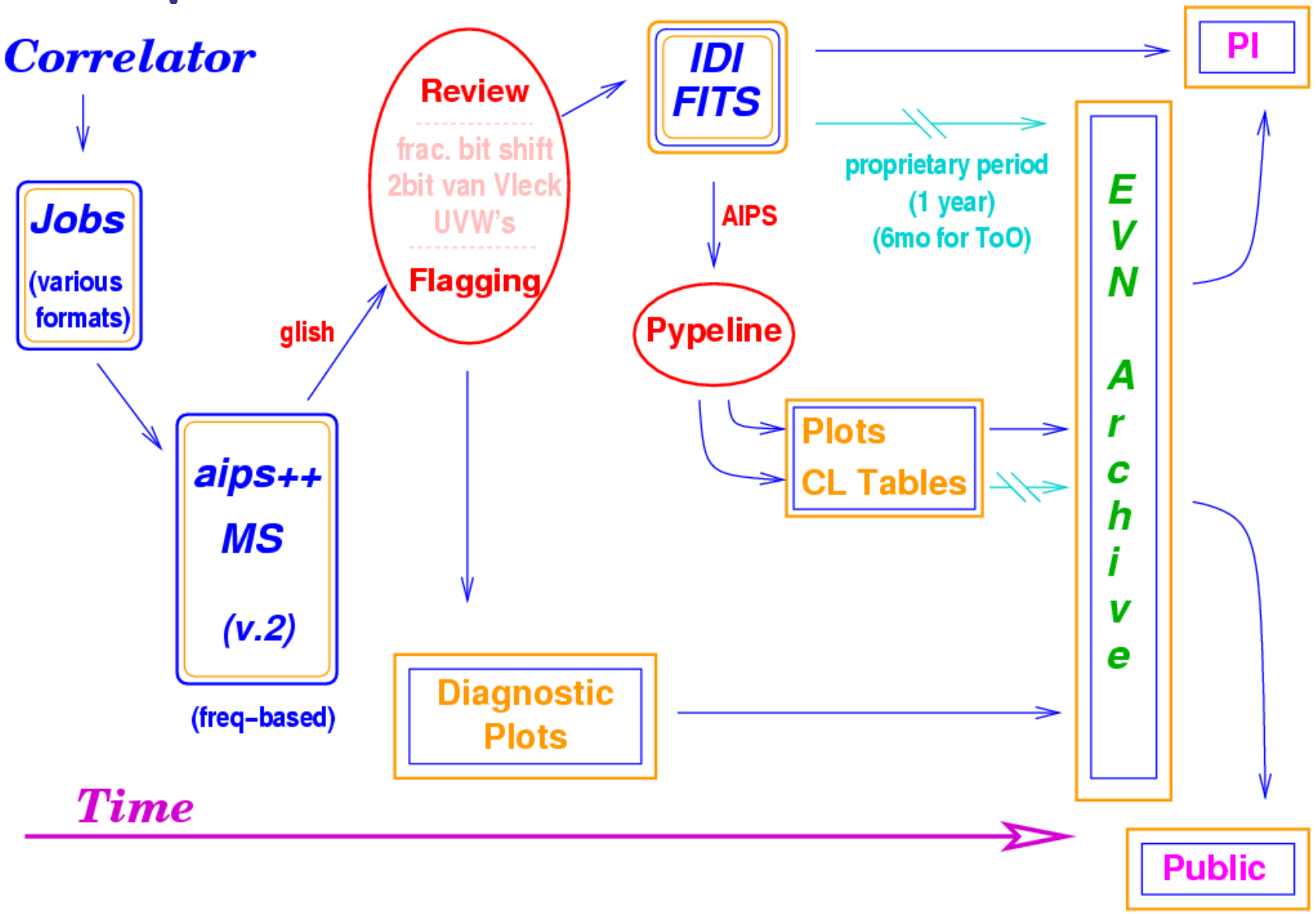
Bob Campbell, JIVE

- Operations and PI Interaction
- Software Correlation at JIVE
- Real-time e-EVN Astronomy
- ***RadioNet3 EVN Trans-National Access***

Ops Flowchart (≤ Correlation)



Ops Flowchart (> Correlation)



Software Correlation at JIVE

- SFXC (based on correlator for tracking Huygens descent*) *{Pstr}*
  - vex-driven + configuration file with correlation parameters
  - Mark 5A, 5B, VLBA, and VDIF support
  - Post-correlation processing → IDI-FITS (as for MkIV)
- Now running on a dedicated 256-core cluster (9.5 kW)
  - "Real-time" processing currently = 9 stations at 1 Gbps
  - Replacement of MkIV ~ 4x this; EVN2015 concept ~ 64x
- NEXPReS: integration of SFXC with e-EVN(+) *{Pstr}*
  - Globally distributed correlation (dynamic resource demand)
  - Bandwidth on demand
  - Data buffering (to blur the e-/disk-VLBI distinction)

•www.jive.nl/jive-research-notes (R.N #4, 5, 11)

•www.mrc.uidaho.edu/entryws/full/programme_detailed.html (C-4.6)

MkIV → SFXC: Astronomy Gains

- N_{sta} limited only by available input devices (was 16)
- Arbitrary total bit-rate & BW_{SB} (was 1 Gbps & 16 MHz)
- ~arbitrarily large number of frequency points (was 2048)
  - Velocity resolution improvements w/o cont. sensitivity penalty
- ~arbitrarily small integration times (was $\frac{1}{4}$s)
- Large N_{frq} & small t_{int} together → wider-field mapping
  - Multiple output phase centers within a wider field
- Pulsar Gating/Binning (was never available operationally)
- Near field model (was never available)
- Improvements in correlated data
  - Pure station-based fringe rotation to center of earth
  - Consistent cross-polarization handling
  - Control over spectral windowing function

MkIV → SFXC: as seen by user

MkIV

$$N_{sta}^2 \cdot N_{sb} \cdot N_{pol} \cdot N_{frq} \le 131072 \cdot \mathcal{R}$$

N_{sta} = (4,8,12,16); N_{pol} = (1,2,4); $N_{chan} \le 16$; N_{frqmax} = 2048

Recirculation: $\mathcal{R} \le 16\text{MHz}/BW_{sb}$; N_{frqmax} still 2048

(if 8 MHz SB) 9—16 Sta 1 SB 2 Pol 512 Frq ($\mathcal{R}$ = 2)

(if 2 MHz SB) 9—16 Sta 1 SB 2 Pol 2048 Frq ($\mathcal{R}$ = 8)

Maximal velocity spacings (N_{frq}=2048, Δv in [m/s])

BW_{sb} [MHz]	$\Delta\nu$ [Hz]	Δv_{1420}	Δv_{1665}	Δv_{6668}	Δv_{22235}
16	7813	**1651**	1408	351	**105**
2	977	206	**176**	**44**	13

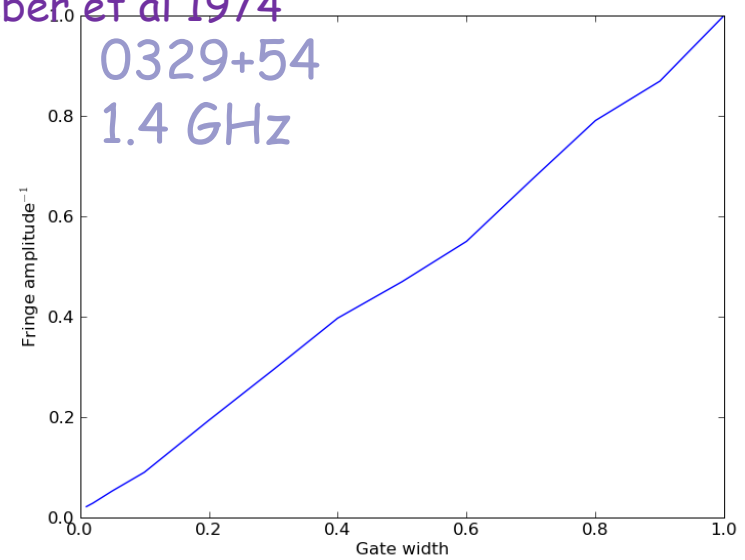
SFXC

Specify desired velocity spacing & required continuum sensitivity (set BW_{sb}, then N_{frq})

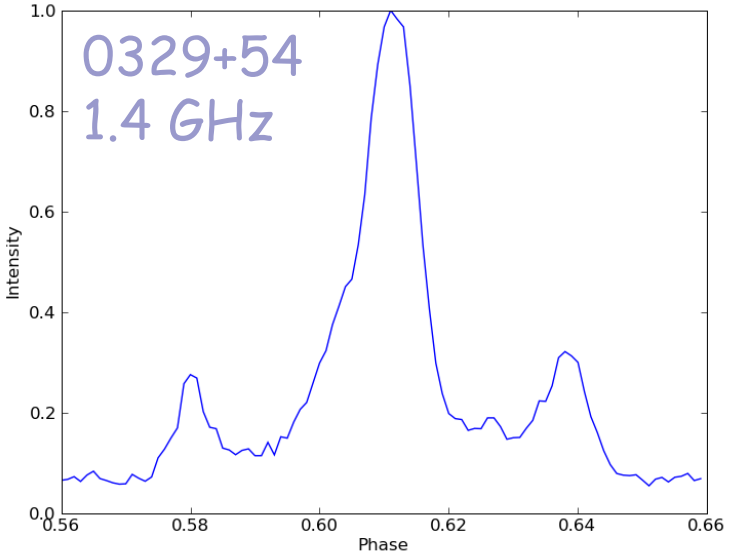
SFXC: Pulsar Gating/Binning

- Gating = arbitrary interval within a PSR period
- Binning = arbitrary number of bins within the gate
  - Each bin → separate correlation / output IDI-FITS file

Sieber et al 1974



Expected inverse relation between amp & gate-width (y-axis = 1/amp)



Pulse profile (1 gate [0.1 Per], 100 bins)

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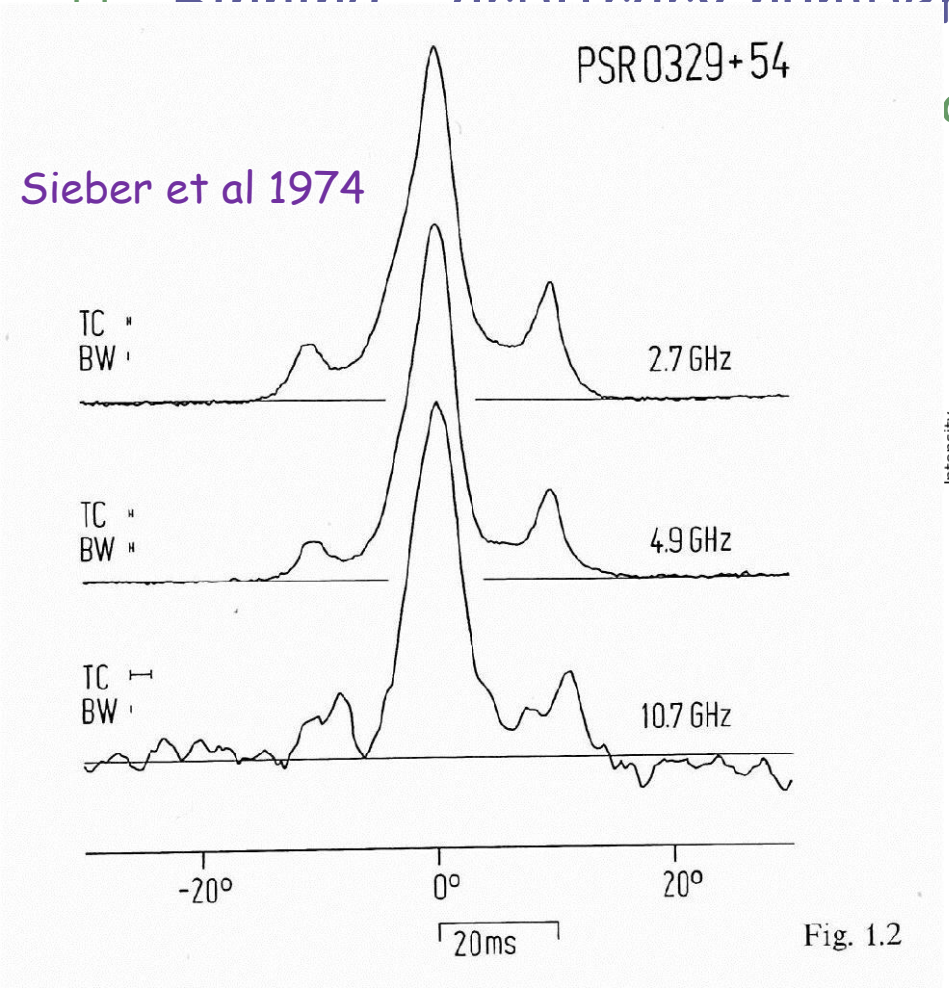

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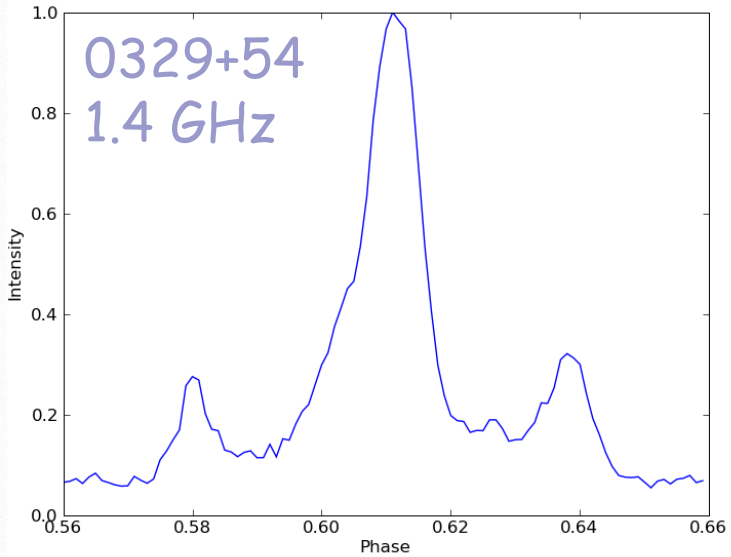
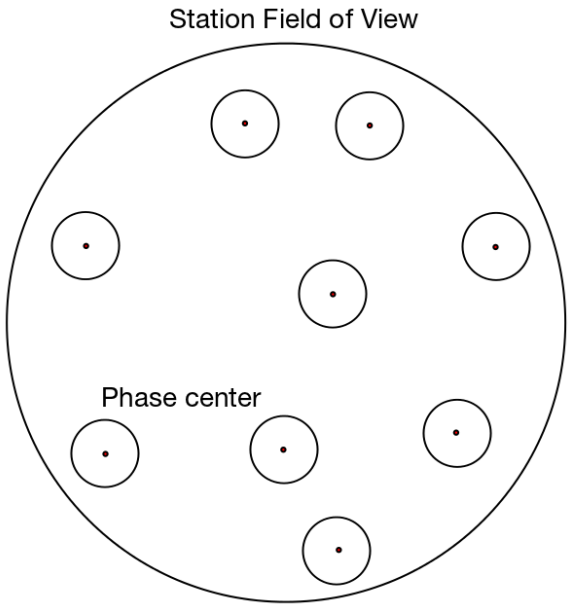


Pulse profile (1 gate [0.1 Per], 100 bins)

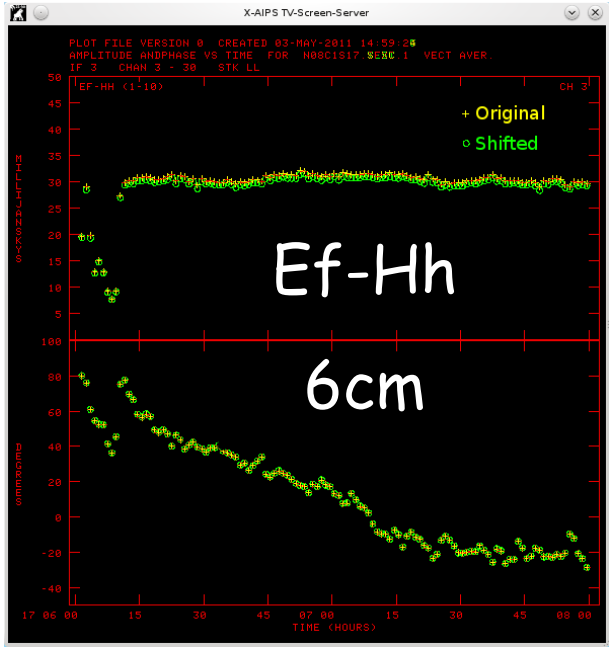
SFXC: Wide-Field Mapping

- Essentially unlimited max-N_{frq}, min-t_{int}: can map area on the sky ~single-dish beam w/ minimal smearing
  - Price = huge output data sets
- Multiple phase-center correlation: outputs only subsets of the full area (user exps. so far up to 50 phs. centers)



Typical initial correlation:
N_{frq} ~16k; t_{int} ~ 4—15 ms
Further processing-factor "penalty" small

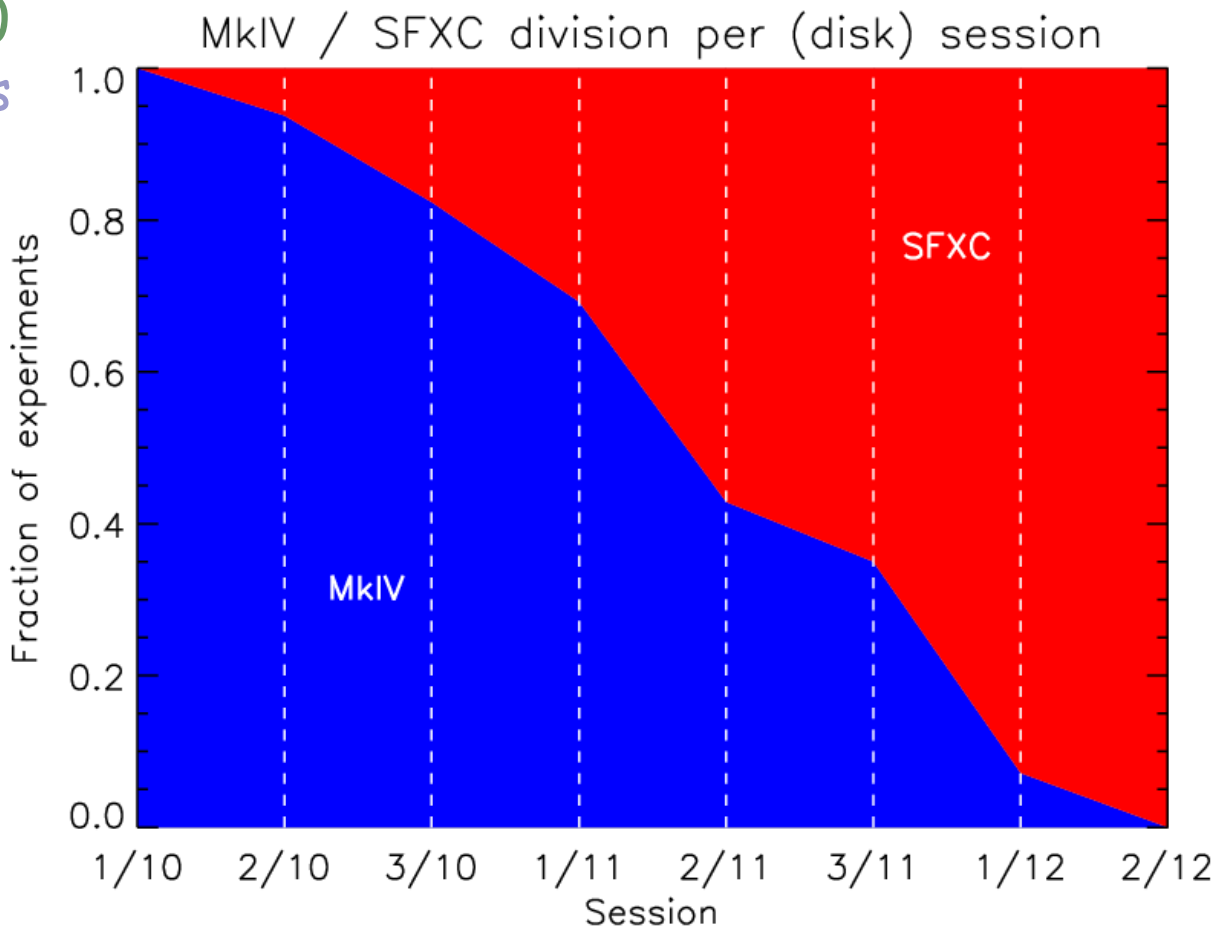
Example validation run: same source correlated at two positions 1.4′ apart; $|\Delta\varphi|_{Ef\text{-}Hh}$ = 0.3° pk-to-pk.



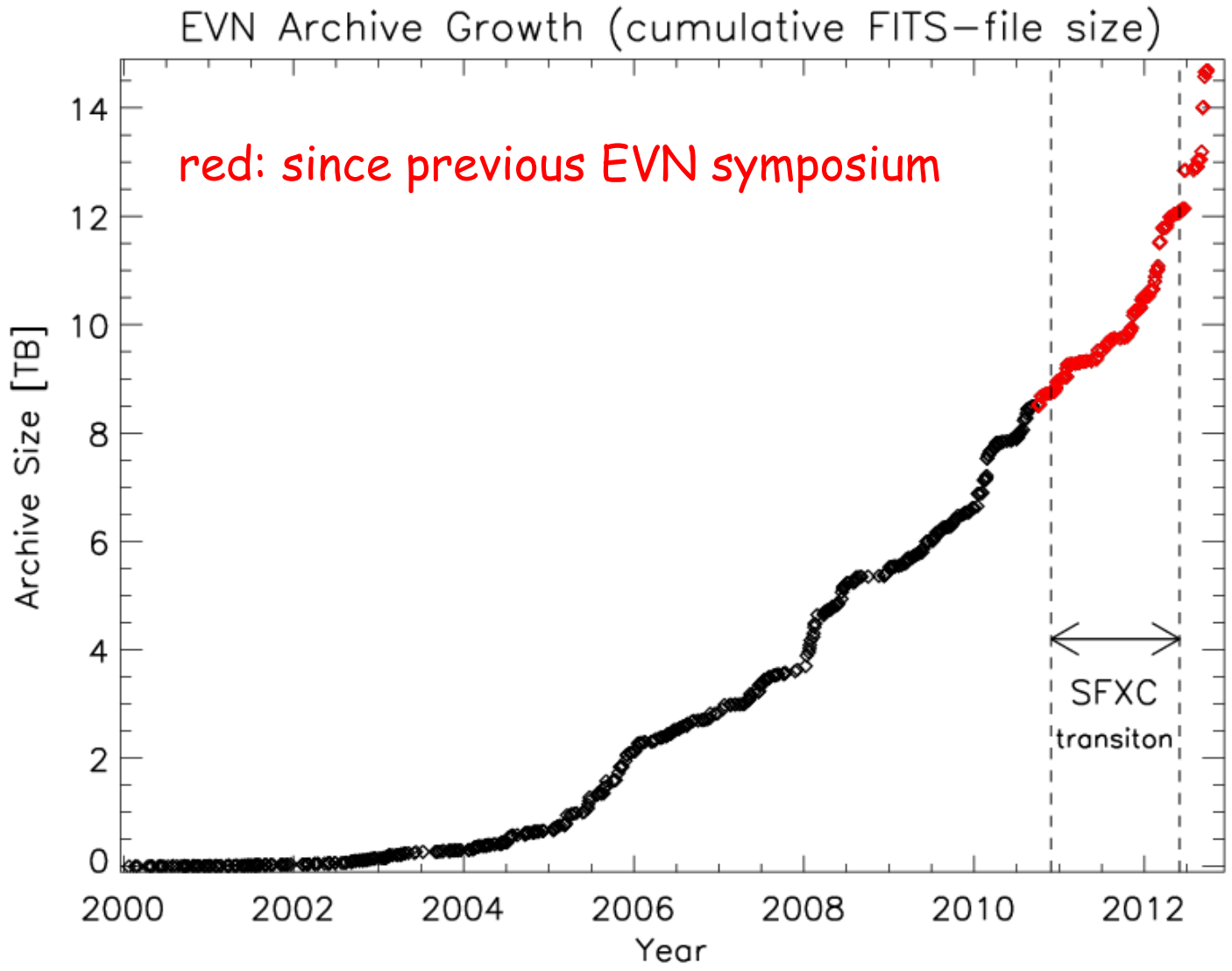
Transition: MkIV→SFXC

SFXC-correlated observations impossible on MkIV:

- Multiple φ-centers: 10
  - mixed fixed/slewing skds
- Pulsar gating: 7
- >2048 frq.pts: 4
  - record to date: 8192
- >16 stations: 3
  - rtd: 20, sess.3 exp: 24
- other >MkIV: 17
  - $\{N_{sta}, N_{sb}, N_{pol}, N_v\}$ too big
- X-pol spectral line: 13



MkIV→SFXC: Archive Growth



Real-time e-EVN Science

- Proposal-driven e-VLBI science observations (stats thru 9-10 Oct)
  - 1st observation = 16 Mar 2006 (6 stations at 128 Mb/s)
  - Nowadays, network of 8-9 stations at Gbps is routine
  - 158 observations from 105 proposals (1226.5 network hours)
  - 46 different PI's
- Evolution of e-EVN procedures
  - ~monthly 24-hour runs (+4hr prelim. test) on fixed dates
  - Proposals now within standard proposal-submission cycles
    - Proposal Class for "**triggered**" observations (9 since Apr'08)
  - Proposal Class for "**short**" observations (25 since May'08)
  - Target of Opportunity Observations (36 since Sep'07)
  - e-EVN in regular disk sessions also now common (runs of >24hr)
  - NorthStar proposal tool modifications

e-EVN Operational Bandwidth

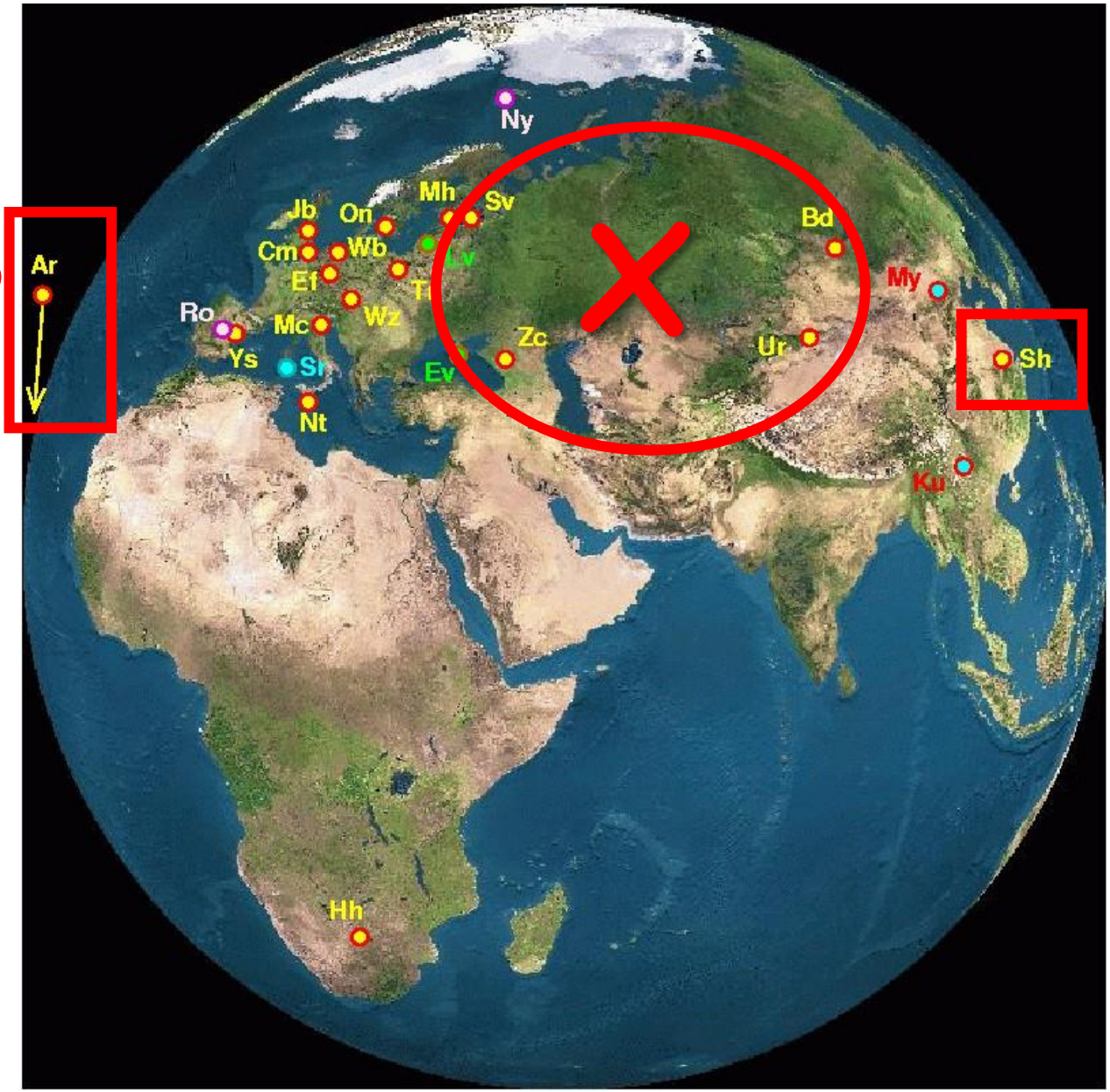
Station	Connection
Effelsberg	1024 Mbps (4x in tests)
Westerbork	1024 Mbps
Jodrell Bank	1024 Mbps
Medicina	1024 Mbps
Noto	896 Mbps (channel dropping)
Onsala	1024 Mbps (4x in tests)
Torun	1024 Mbps
Yebes	1024 Mbps (4x in tests)
Sheshan	256 Mbps
HartRAO	1024 Mbps
Arecibo	256 Mbps (512 from 04-10 UT)
Metsahovi	1024 Mbps

ATNF: 1 Gbps (At,Mp,Pa)

SRT expected soon

Robledo to start tests

Irbene connection in place



Gbps EVN:

current exceptions for e-EVN observations annotated

Real-time e-EVN Science Topics

- Rapid turn-around; urgency; denser time-sampling:
  - X-ray, γ-ray binaries in flaring states (including novae)
  - AGN γ-ray outbursts — locus of VHE emission
  - Other high-energy flaring (e.g., Crab)
  - Outbursts in Mira variables (spectral-line)
  - Just-exploded GRBs, SNe
  - Binaries (incl. novae, XRBs) at specific orbital/outburst phases
  - Exo-planet searches
  - Monitoring SNe population/birth in starburst galaxies
  - Monitoring HST-1 jet component in M87
  - Binary-AGN candidates
  - AGN vs. starburst contributions in high-z sources
  - Seeking IMBH via compact radio emission in ULX

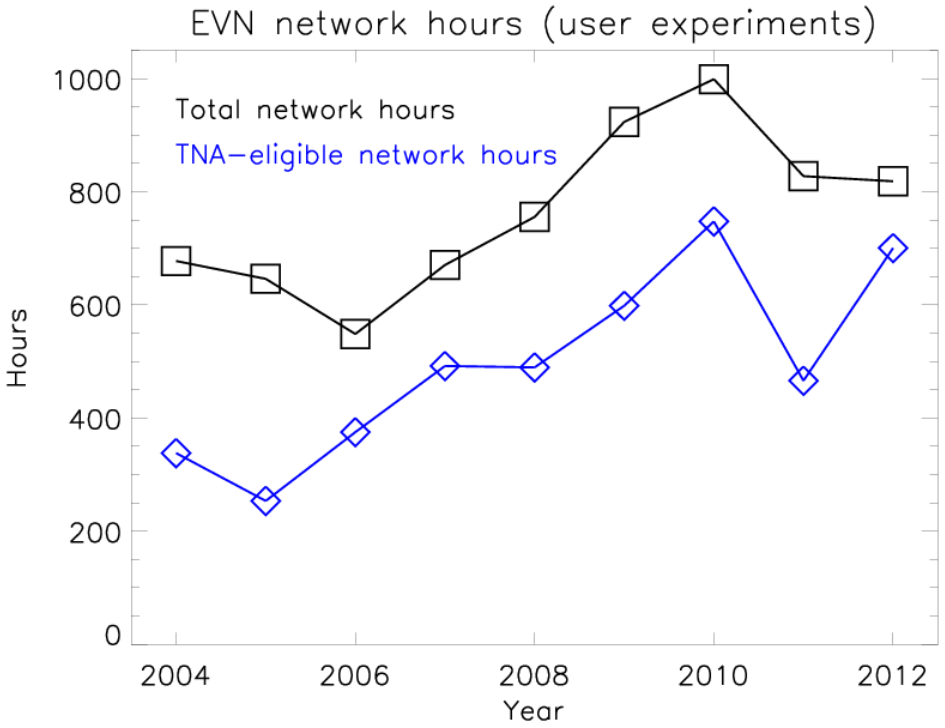
- Pre-proposal detection exp. / reference-source search

EVN Transnational Access (I)

- RadioNet3 EVN TNA eligibility rule:
  - {PI && ≥½ team members} from institutes in {EU+}
- TNA "bennies": reimbursement of travel costs to JIVE or other EVN institute(s) for a member of the team

Acknowledgement for RadioNet on "Access to the EVN" web-page

People do seem to be learning the system……



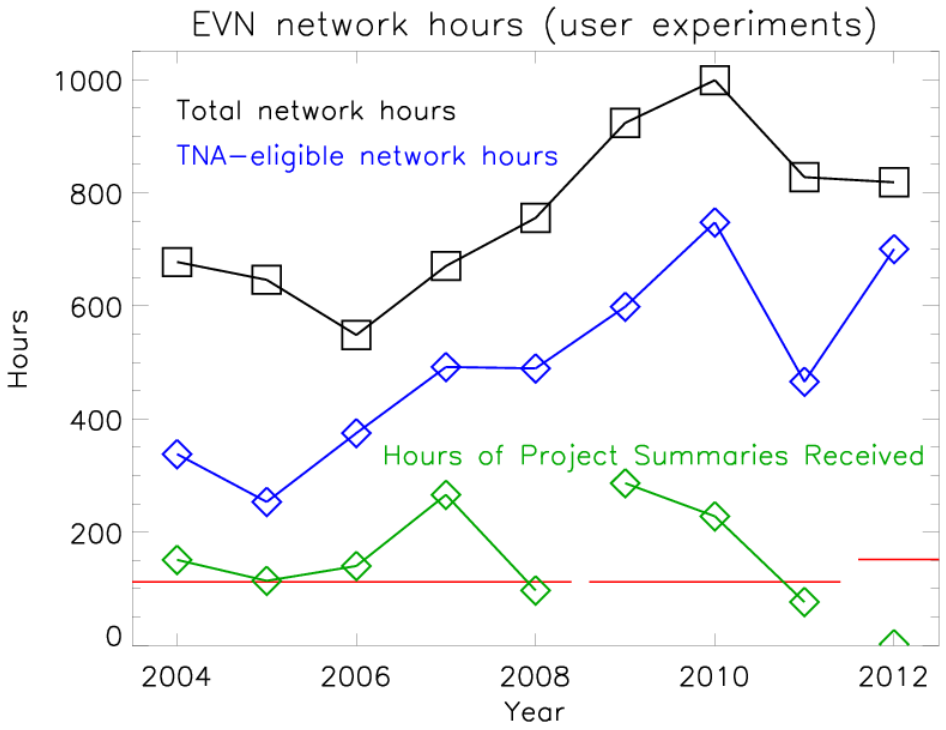
EVN Transnational Access (II)

- TNA responsibilities:
  - Project Summary (prior to travel reimbursement)
  - Questionnaires (1 each for RadioNet3 office & EC)

Ideally, **all** eligible projects submit their reports
→**Must have enough to account for contracted number of acces hours**

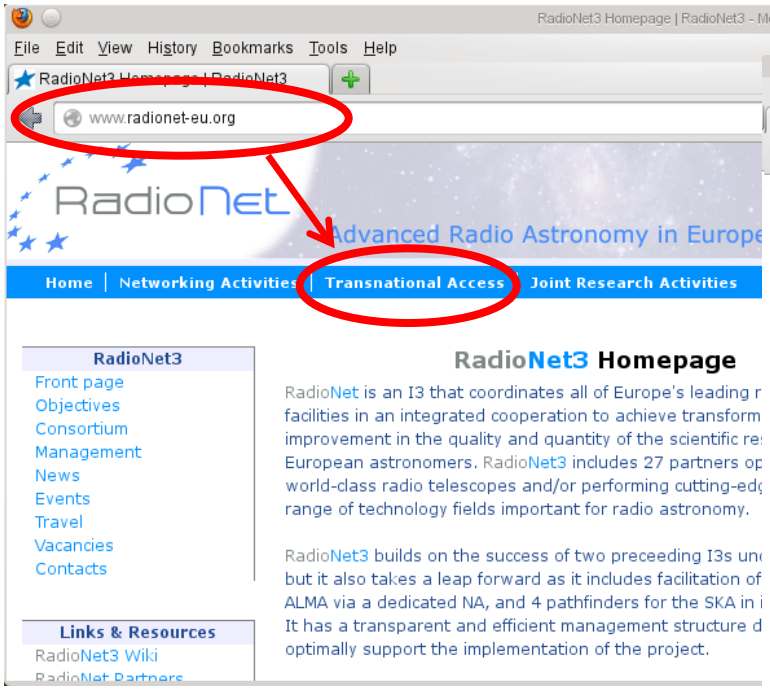
FP6: 2004—2008
FP7 : 2009—2011
RN3: 2012—2015 (still "in" FP7)

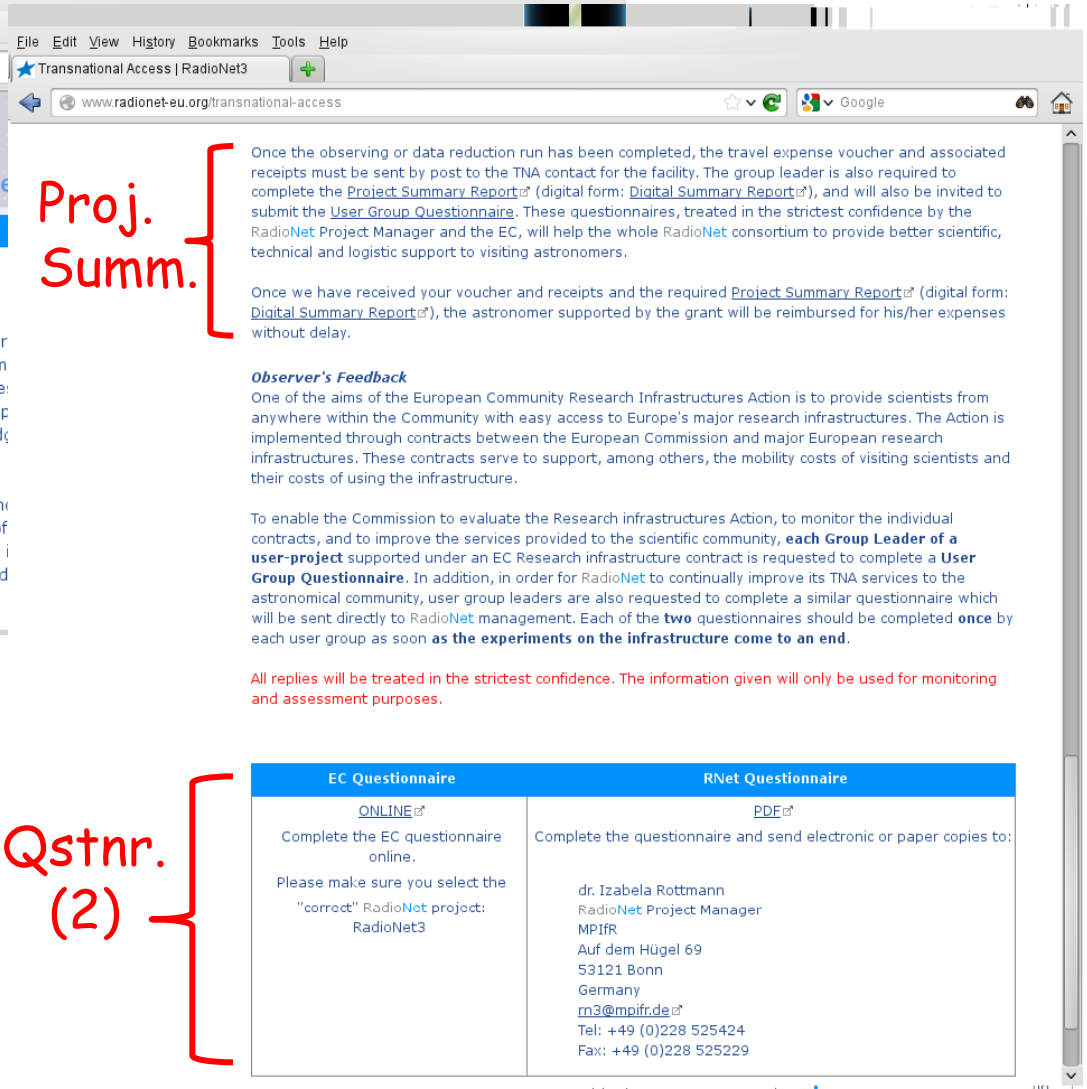
-> KEEP BRUSSELS HAPPY!!



First half of an animated slide

Where are these TNA Reports?





Second half of an animated slide

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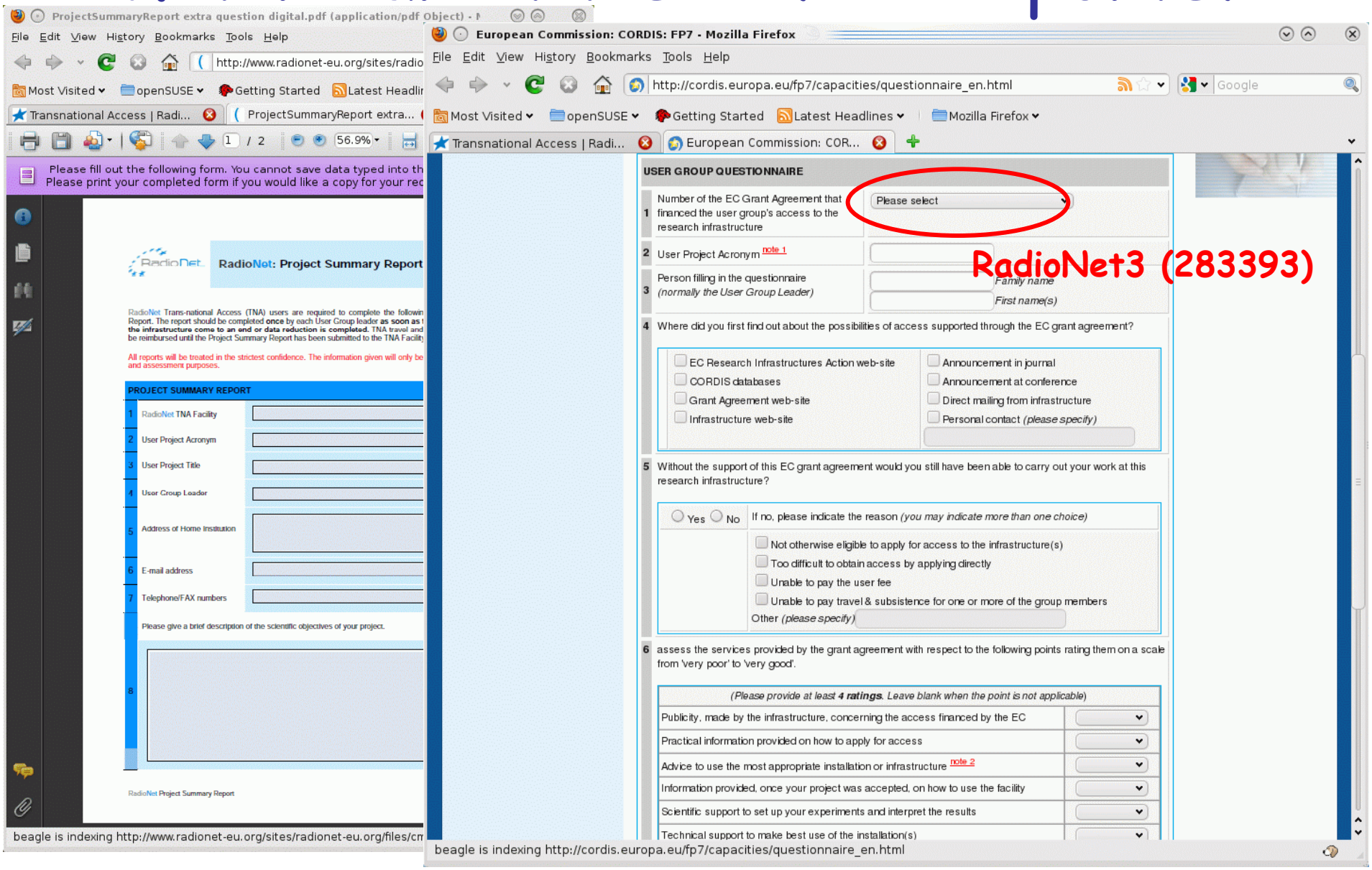

Topics being worked on

- New stations: e-MERLIN, KVN, Irbene 32m;
  Sardinia 64m, Shanghai 65m, Urumqi 110m
- New digital back-ends (→ beyond 1 Gbps)
- e-EVN via SFXC
- Primary beam corrections
  - TOG discussion — gathering information from stations
- SFXC & AIPS
  - Array vs. Correlator (CVEL, BPASS)
  - IM/MC tables
- SFXC Documentation: Web pages / paper

Summary

- Pre-/Post-correlation PI Support
  - Help available — don't have to wait until last minute
  - Archive: FITS, pipeline, standard plots, feedback
  - RadioNet3 EVN Trans-National Access program
- EVN Software Correlator at JIVE (SFXC)
  - Astronomical applications beyond the MkIV correlator
  - More straightforward capacity limitations
- e-VLBI now standard/indispensable facet of EVN
  - New kinds of astronomy enabled
  - 25—30% of network observing hours over last 4 yr