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

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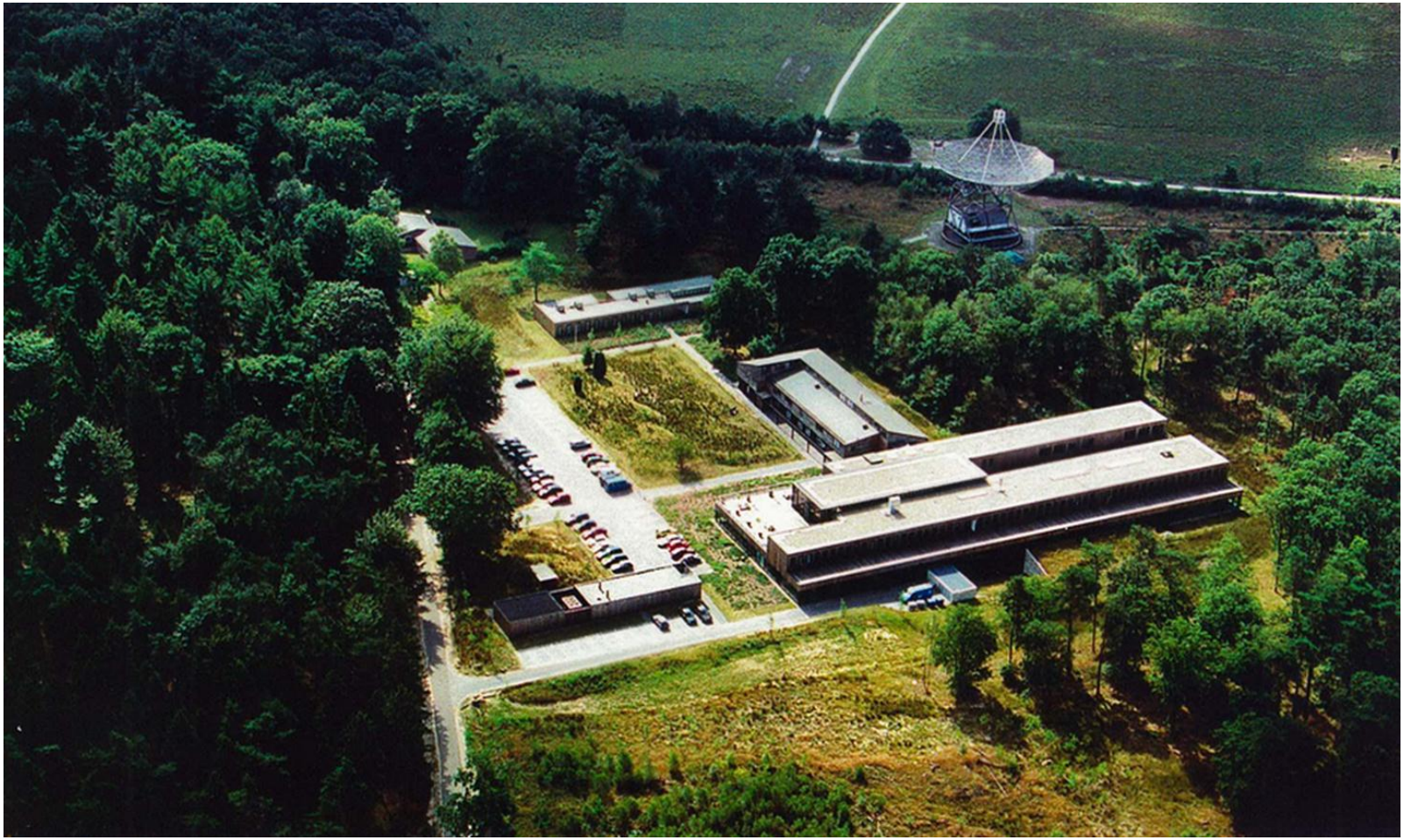
- Developments in Dwingeloo
- Real-time e-EVN Astronomy
- Software Correlation at JIVE (SFXC)
- UniBoard FPGA correlator
- Remote time-/frequency-control at Torun

Animation Removed: 1 of 2

New Building in Dwingeloo



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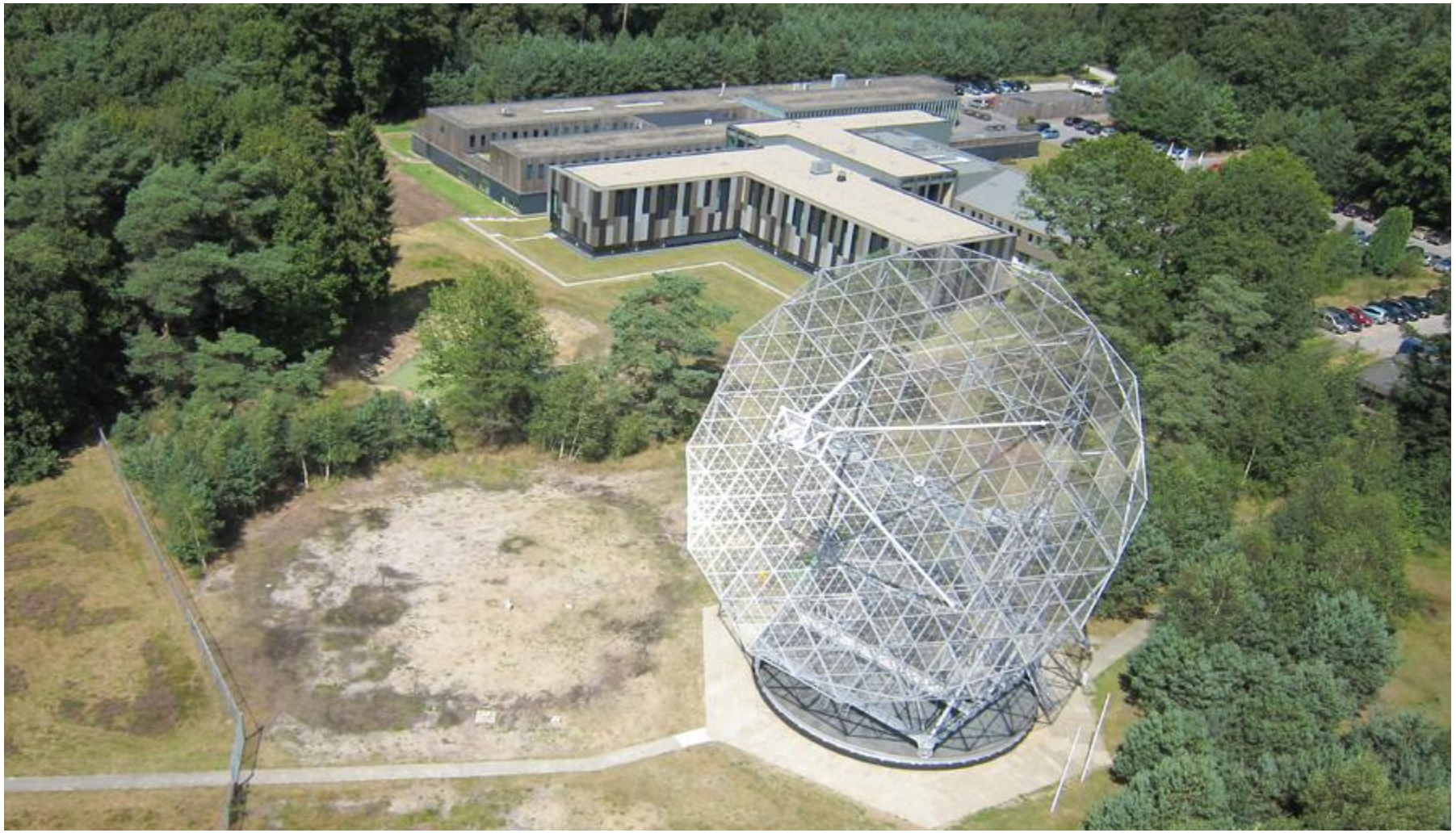


JIVE → JIV-ERIC

- "ERIC" = European Research Infrastructure Consortium
  - Change from Dutch "foundation" to ERIC: 21 Dec 2014
  - ERIC = full legal entity under EU law
- Practical consequences
  - `jive.nl` → `jive.eu` (URLs, e-mail)
  - Biennial reports → annual reports
  - Logos:

Real-time e-EVN Science

- Proposal-driven e-EVN science observations
  - Nowadays, a network of 10-11 stations at Gbps is routine
  - Typically ~23-30% of EVN observing time
  - 260 observations from 164 proposals; 68 different PIs
  - e-EVN network misses KVAZAR telescopes & Urumqi
- Evolution of e-EVN procedures
  - ~monthly 24-hour runs (+4hr prelim. test) on fixed dates
    - e-EVN also in ToO's & regular disk sessions (longer runs)
  - Proposals within standard proposal-submission cycles
    - Any EVN or GLOBAL proposal may contain e-VLBI observation(s)
    - **Target of Opportunity** Observations (54 since Sep'07; 39 props)
    - Proposal Class for "**triggered**" observations (12 since Apr'08)
    - New categories: **generic trigger**, **automatic-override trigger**

e-EVN Operational Bandwidth

Station	Connection
Effelsberg	2048 Mbps (2x in tests)
Westerbork	1024 Mbps
Jodrell Bank	1024 Mbps
Medicina	2048 Mbps
Noto	2048 Mbps
Onsala	2048 Mbps (2x in tests)
Torun	1024 Mbps
Yebes	2048 Mbps (2x in tests)
Sh / Tm65	1024 Mbps
HartRAO	2048 Mbps
Arecibo	512 Mbps
Metsahovi	1024 Mbps

ATNF: 1 Gbps (At,Mp,Pa)

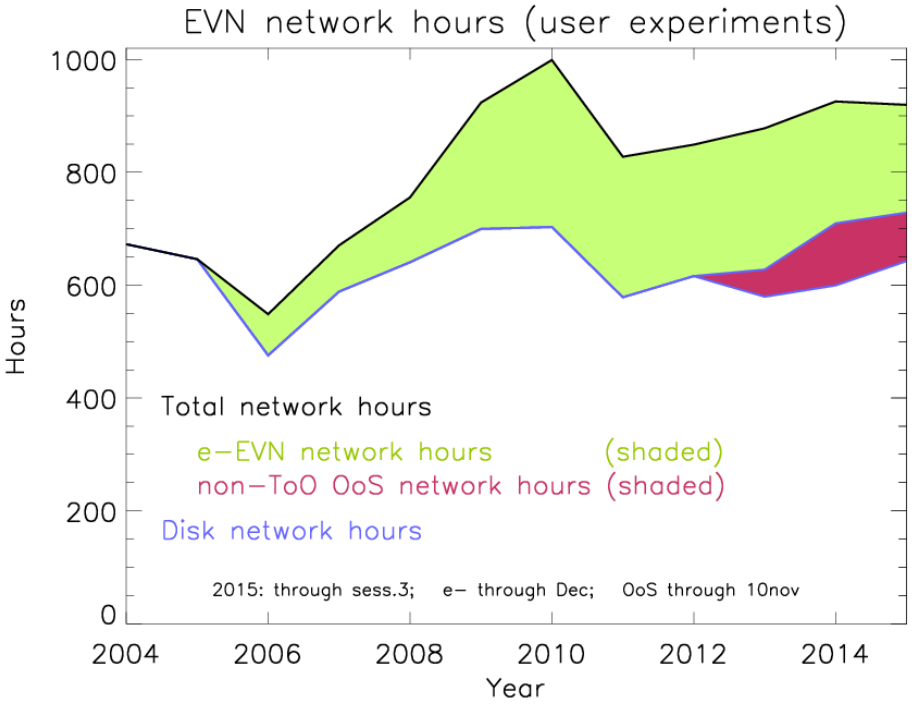
SRT expected soon

Robledo to start tests

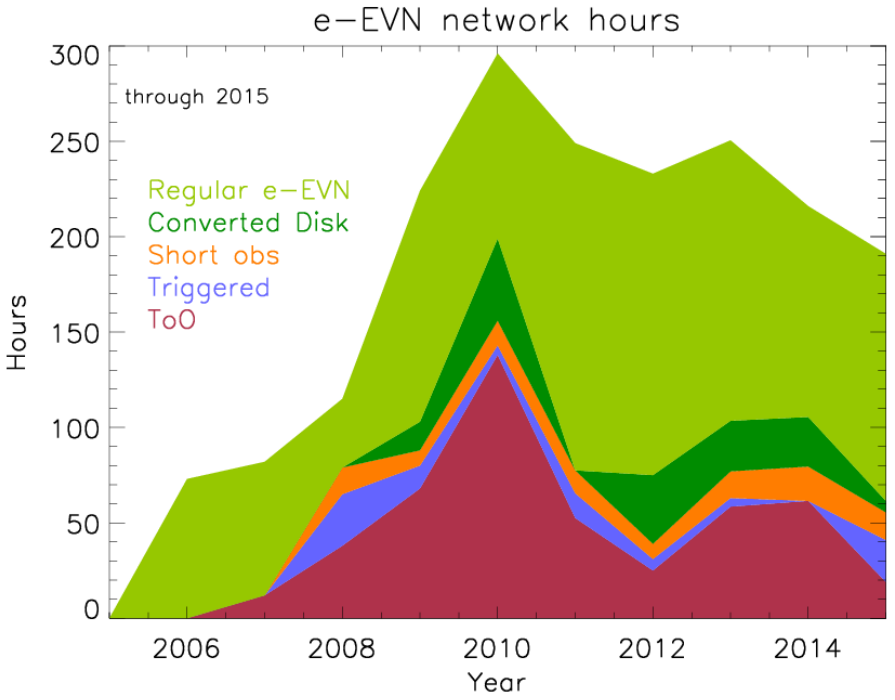
Irbene connection in place

Full operation with 2Gbps e-EVN needs better control over the fila10G
(in e-EVN, we control a station's Mark5)

EVN / e-EVN Network Hours



New category: non-ToO out-of-session (RadioAstron): ≤12 blocks of ≥12 hr per year; max 144 hr/yr



2016 so far: ToO = 25.5 hr
total = 75 hr

e- & Record // e-shipping

- Limitation: e-EVN had to be real-time correlation
- jive5ab → correlate real-time & record onto FlexBuff
  - Continuum-/Line-pass spectral-line observations
  - Torun remote-maser e-tests
- e-shipping
  - Data recorded onto "wrong" packs (*e.g.*, wrong target correlator)
  - Small data sets (*e.g.*, RadioAstron @ 256 Mbps)
- The Future is now: FlexBuff (sta) → FlexBuff (corr)
  - no pack shipments at all in either direction (**Ef**, **On**, soon **Ys**)
    - For context: typical EVN session = 60-70 TB/sta; max = 122 TB/sta
  - No limitation to N_{ant} because of the # of Mark5 play-back units

SFXC: Development / Config

- EVN software correlator at JIVE (SFXC)
  - Based on correlator for tracking Huygens descent (S. Pogrebenko)
  - VEX-driven + configuration file with correlation parameters
  - Mark 5A, Mark 5B, VDIF (single-, multi-thread) formats
  - Data sources: pack, e-VLBI, FlexBuff (local, remote), file, ……
  - Post-correlation processing: → MS → IDI-FITS
- Hardware
  - 46 nodes, 464 cores (Intel Xeon 5500/5600/E5-2600/E5-2630)
  - QDR Infini-band inter-connect (40 Mbps)
  - 12 nodes with 10 GbE (currently limited to 30 Gbps total)
  - 15-16 stations at 1 Gbps real-time; 8-9 at 2 Gbps

MkIV → SFXC: Astronomy Gains

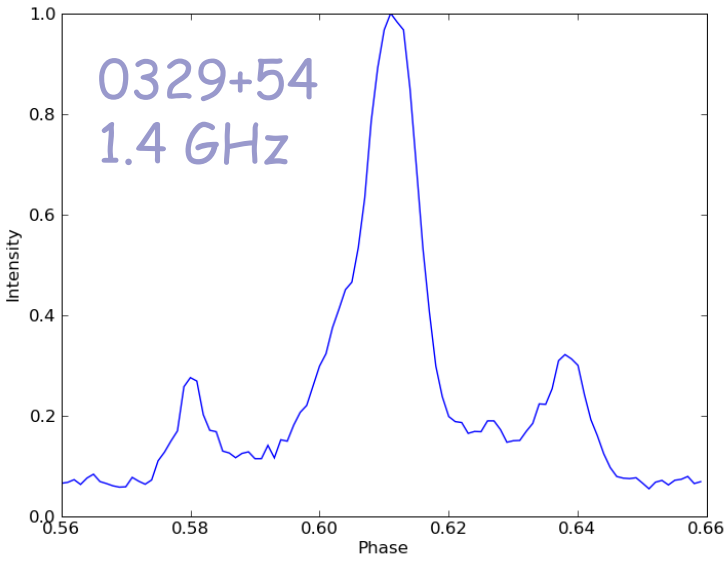
- N_{sta} limited only by available input devices (was 16)
- Arbitrary total bit-rate & BW_{SB} (was 1 Gbps & 16 MHz)
- ~arbitrarily large number of frequency points (was 2048)
  - Velocity resolution improvements w/o cont. sensitivity penalty
  - Selectable spectral windowing (Hanning, Hamming, cosine, tophat)
- ~arbitrarily small integration times (was $\frac{1}{4}$s)
- Large N_{frq} & small t_{int} together → wider-field mapping
- Improvements in correlated data
  - Pure station-based fringe rotation to center of earth
  - Decoupled correlation/delay-tracking FFT sizes
  - Consistent cross-polarization handling

SFXC: Completely New Astronomy

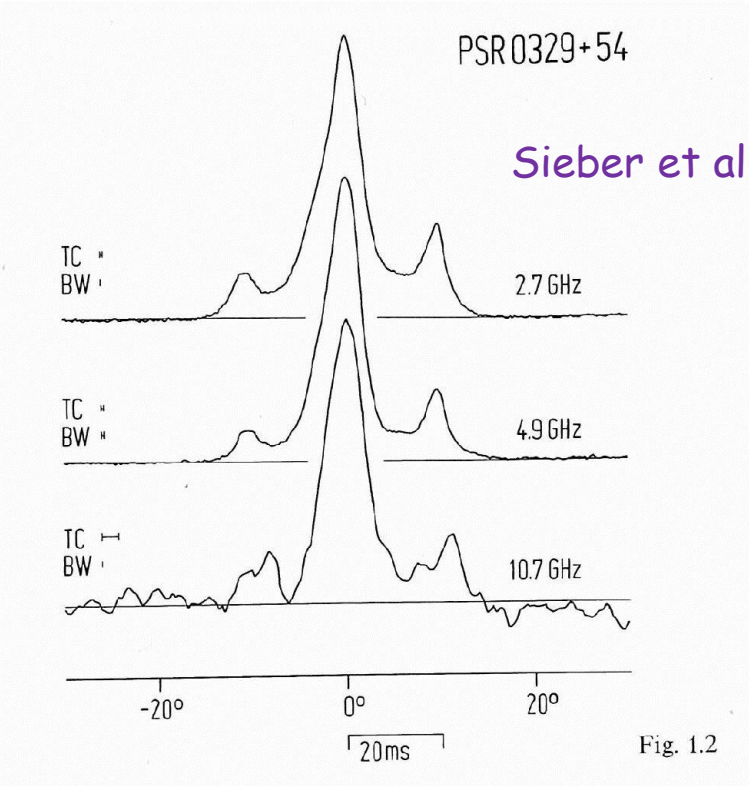
- Pulsar Gating/Binning
  - Both incoherent and (new) coherent de-dispersion
- Multiple output phase centers within a wider field
- Mixed-bandwidth, mismatched-sideband correlation
  - (enables inclusion of a wider set of heterogeneous back-ends)
- "Phasing up" the EVN
- Space VLBI
  - Near-field target (*e.g.*, solar-system spacecraft)
  - Orbiting antenna (*e.g.*, RadioAstron)

SFXC: Pulsar Gating/Binning

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



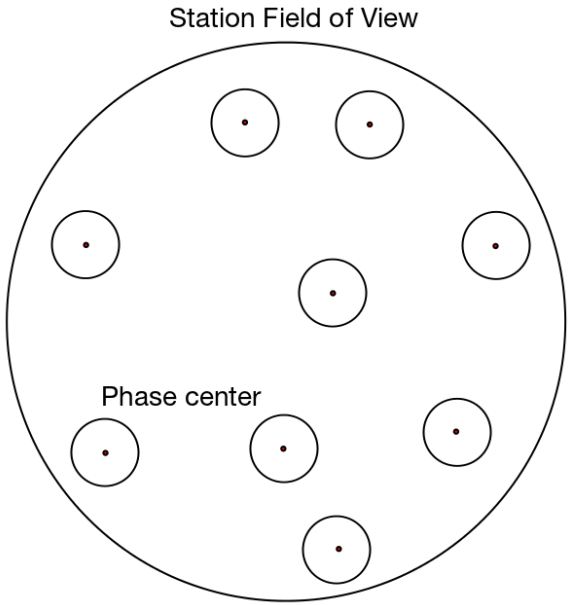
Pulse profile (1 gate, 100 bins)



Sieber et al 1974

SFXC: Wide-Field Mapping

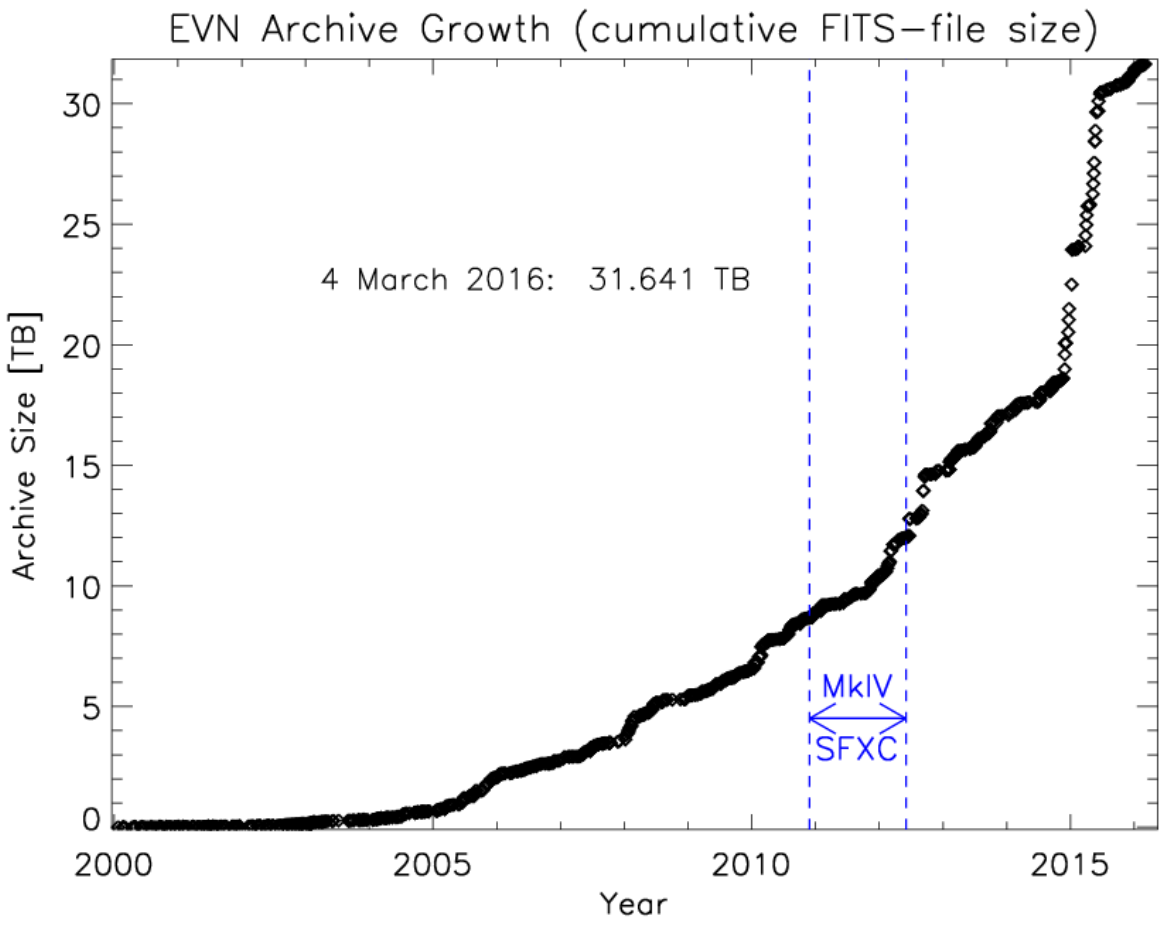
- Essentially unlimited max-N_{frq}, min-t_{int} → can map an area on the sky ~single-dish beam w/ minimal smearing
  - Price = huge output data sets (record = 5.3 TB of FITS files)
- Multiple phase-center correlation: outputs only subsets of the full area (record = 699 phase centers)



Typical "internal" correlation: N_{frq}~16k; t_{int}~ 4-15 ms

Further processing-factor "penalty" per phase center small (for a reasonable N phase centers) — multiplications vs. Fourier transforms

WFM: Effect on the Archive



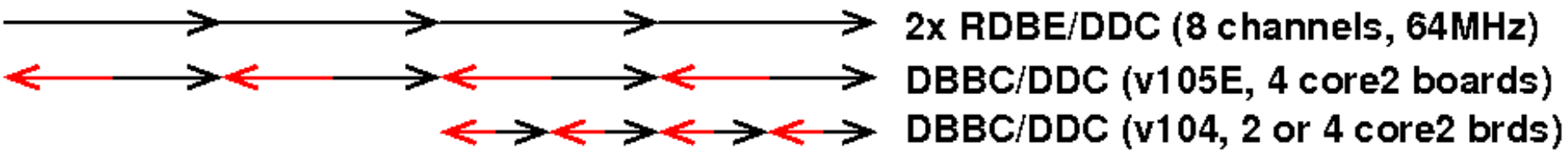
Transition period MkIV→SFXC annotated.

Exps. with an additional 5.8TB "in the headlights" (correlated or observed).

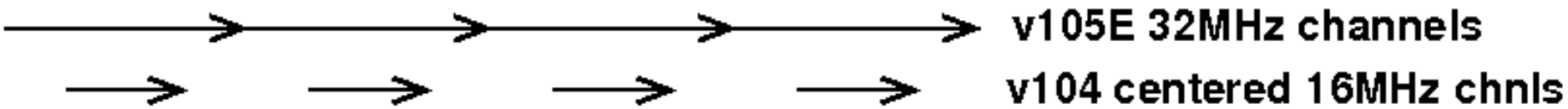
One proposal in Feb'16 implies an output = 85TB of FITS files.

SFXC: Mixed-BW

- K-band global obs: up to 6 different back-ends
- 2 Gbps global:



- Wide-band spectral line (*e.g.*, HI absorption):



- e-EVN with Arecibo:

SFXC: "Phasing up" the EVN

- Most applicable to pulsar observations
- Correlate phase-reference obs. "normally"
- Obtain fringe solutions for as many sources as possible
- Apply fringe solutions back into model for each station
- Re-correlate with new model
  - SFXC model allows an additional phase column, besides τ_{geom}
- Output as single (CoE) station in PSR-FITS
  - a.k.a. filter-bank data
  - run through PRESTO to fit for pulsar P, dP/dt, *etc.*

UniBoard: FPGA-based correlator

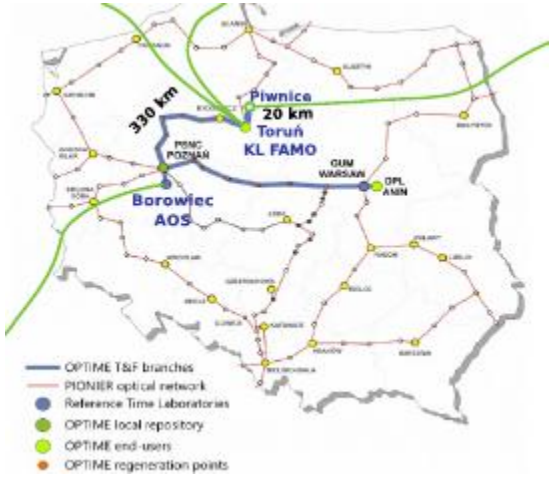
- Software: flexibility, "easy" to modify
- FPGA: power efficient, speed for limited modes
- UniBoard:
  - EC-funded multi-application astronomical SP board
  - As correlator: 32 MHz sub-band modes almost ready
- To contemplate real-time 16 stations at 4 Gbps:

	Power (kW)	Investment (keuro)
SFXC	30	Now + 550
UniBoard	1	Now + 30

SFXC & UniBoard

Torun: remote maser

- H-maser at Torun has had large rate (≥15 ps/s)
- Tests Dec/Jan using remote maser
  - Borweic → Torun → Piwnice (330 + 20 km)



  - Tests using remote optical-lattice clock continue
- Remote H-maser in operational use since January

Summary

- Real-time e-EVN an indispensable aspect of EVN
  - New proposal categories to exploit responsiveness
  - Connectivity improvements (only Ar not ≥ 1 Gbps)
  - jive5ab blurs the lines between e- & disk-VLBI
- EVN Software Correlator at JIVE (SFXC)
  - New astronomical applications / flexibility
  - Higher-rate, larger-N_{sta} e-EVN → UniBoard (FPGA)
- Tr remote H-maser operational
- **JIVE now an ERIC**