

# (Approaching) 30 Years of Correlation at JIVE

## Bob Campbell, JIVE

- **The MkIV Data Processor**
- **The EVN Software Correlator at JIVE (SFXC)**
- **Evolution reflected in plots**
- **Support flowcharts**
- **People**

# The MkIV Data Processor

- XF-based; real-time at 32Msamp/s (channel BW  $\leq$  16MHz)
  - Various other “hard” limits:  $\leq$ 16-stations (at once);  $\leq$ 16 channels;  $\leq$ 2048 freq.pt per SB/pol; integrations  $\geq$  1/4s, ....
  - Correlated user experiments from 21 July 1999 (EL023) through 19 April 2012 (EM071D)
- A whirlwind tour through a sampling of highlights:
  - First fringe: 21 July 1997; First image: 7 April 1998
  - First publication: A&A, February (I) 2000 (van Langevelde et al.; NGC4261)
  - First 512 Mbps user experiment: session 3/2003 (EC020B)
  - Improved van Vleck correction: October 2004
  - First 1 Gbps user experiment: session 1/2005 (EP049B)
  - Shift to CALC10 for correlator model: December 2005
  - Better fractional-bit-shift (post-correlation) correction: March 2007
  - First recirculation in user experiment: session 1/2009 (methanol obs.)
- Real-time nature enabled e-VLBI (up to 1 Gbps)
  - First e-EVN user experiment: 16 March 2006 (RF001)
  - e-EVN procedures continually evolving
    - Proposal types: regular, triggered, ToO, short



# The EVN Software Correlator at JIVE (SFXC)

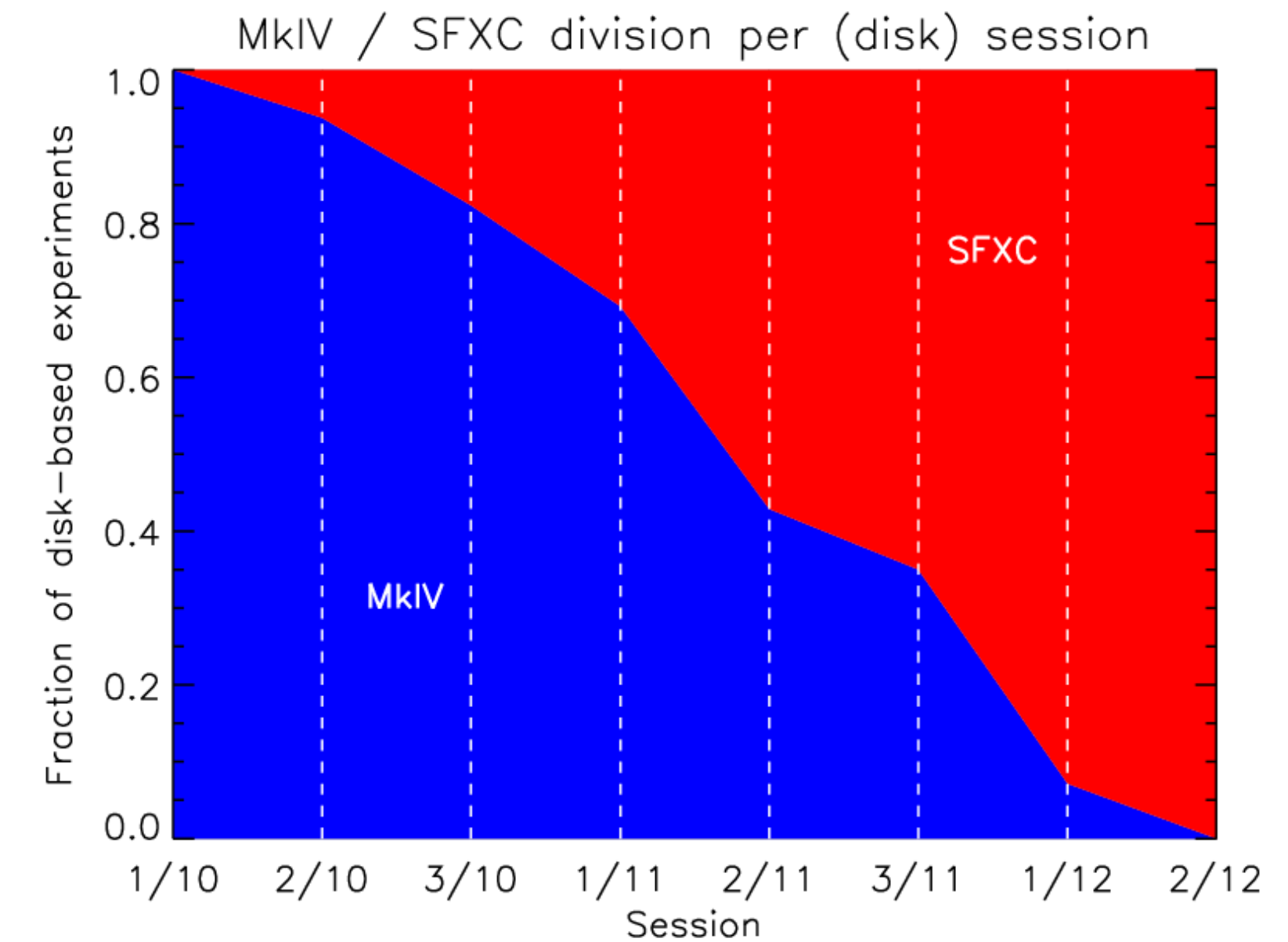
- MkIV  $\leftrightarrow$  SFXC transtion

- First user experiment correlated on SFXC: session 2/2010 (EV018A)
- ftp fringe-tests in Network Monitoring Experiments since 2007

- Much more flexible, but not necessarily real-time

- Astronomy Gains

- ~Arbitrary number of stations, total bit-rate, channel BW
- ~Arbitarily large freq.pt per SB/pol, small integrations ( $\rightarrow$  wider-field mapping)
- Multiple output phase centers per pointing (i.e., subset of wider field)
- Pulsar gating/binning (1 gate, N equally spaced bins)
- Spectral zooming
- Choice of spectral-windowing function
- Mixed input channel BWs
- External model files can be passed (e.g., near-field target or orbiting antenna)
- Pure station-based fringe rotation to CoE; consistent cross-pol handling





- MkIV considerations

- Velocity resolution ( $BW_{\text{chan}}$  &  $N_{\text{frq}}$ ) vs. continuum sensitivity ( $N_{\text{chan}}$  &  $BW_{\text{chan}}$ )

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

$$N_{\text{sta}} \in \{4, 8, 12, 16\}; \quad N_{\text{pol}} \in \{1, 2, 4\}; \quad N_{\text{chan}} \leq 16; \quad N_{\text{frq}} \leq 2048$$

$$\text{Recirculation: } \mathcal{R} \leq 16 \text{ MHz} / BW_{\text{chan}}$$

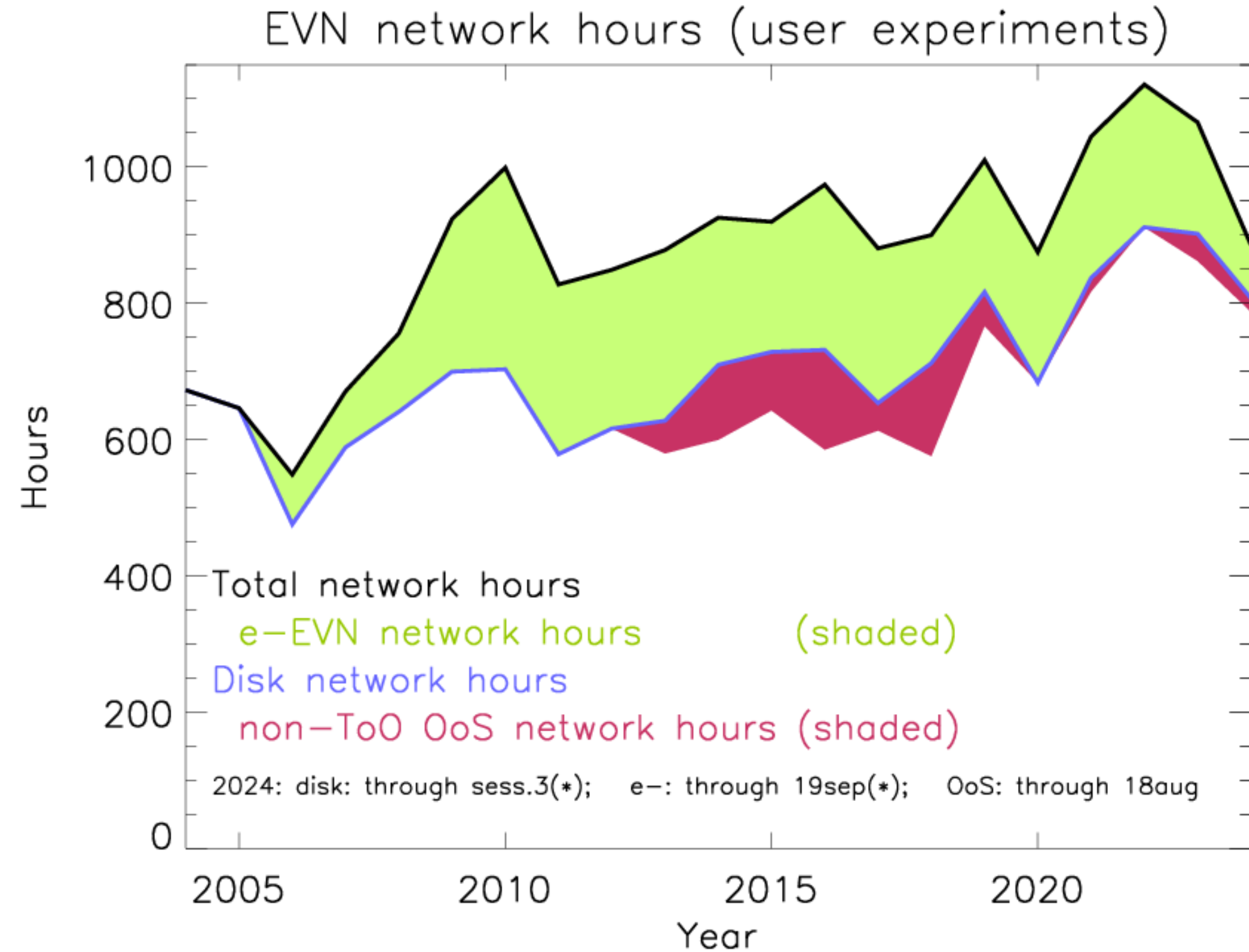
(if 16 MHz channels) 9—16 Sta 1 SB 2 Pol 256 Frq.pt (R=1)

(if 2 MHz channels) 9—16 Sta 1 SB 2 Pol 2048 Frq.pt (R=8)

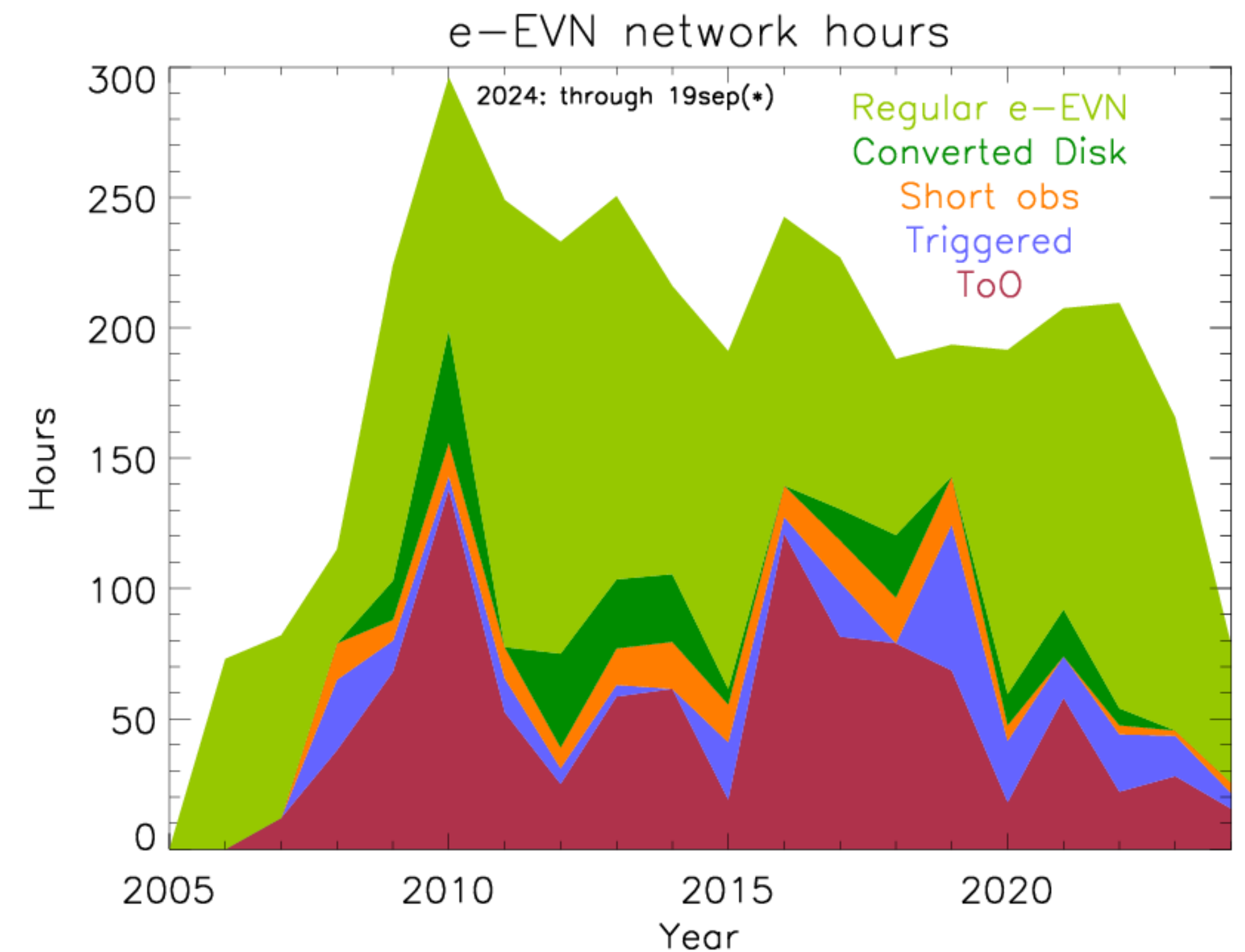
- SFXC considerations

- Required continuum sensitivity ( $N_{\text{chan}}$  &  $BW_{\text{chan}}$ ), then desired velocity resolution ( $N_{\text{frq}}$ )
- With spectral zooming, don't even need to worry about  $BW_{\text{chan}}$  being wider than your line(s) need

# EVN Observing

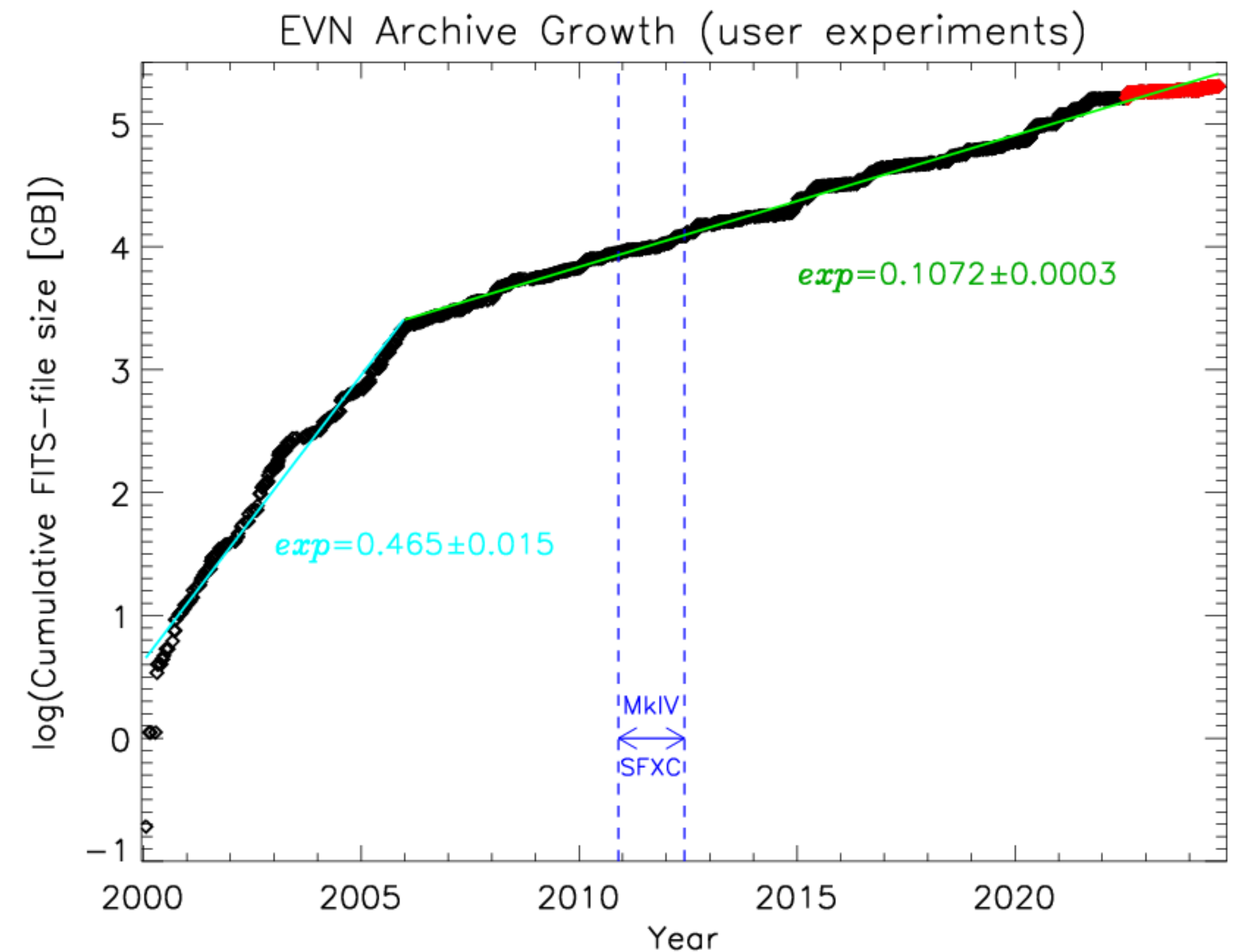
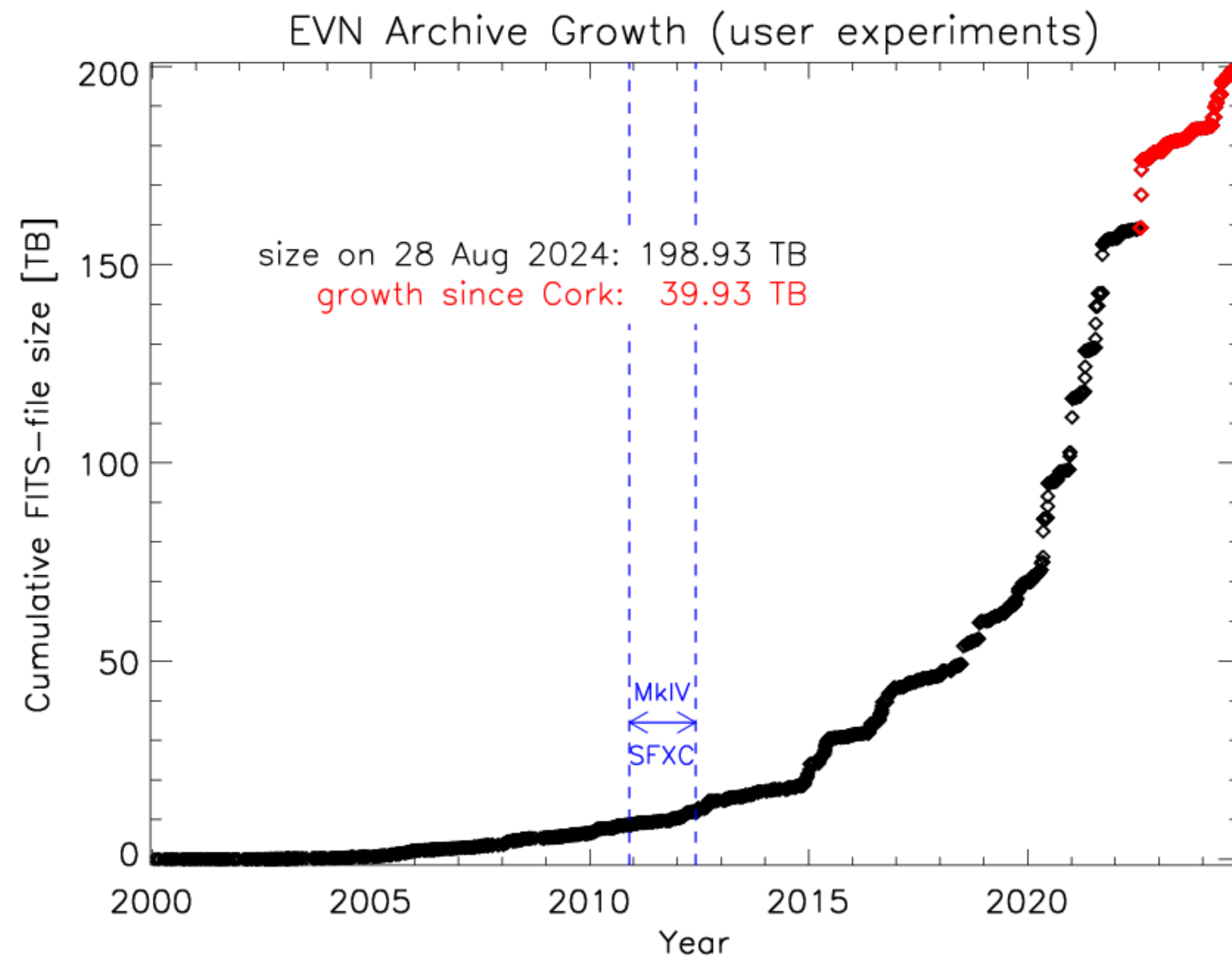


- Generally increasing trend observing hours
- 2019, 2021—23 exceeded 1000 network hours  
(2020 = COVID effects on May/June session)
- 2022 = current record at 1121 network hours



- Can simultaneously correlate e-EVN in real-time and record incoming data onto local FlexBufs; enables running multiple correlator passes.

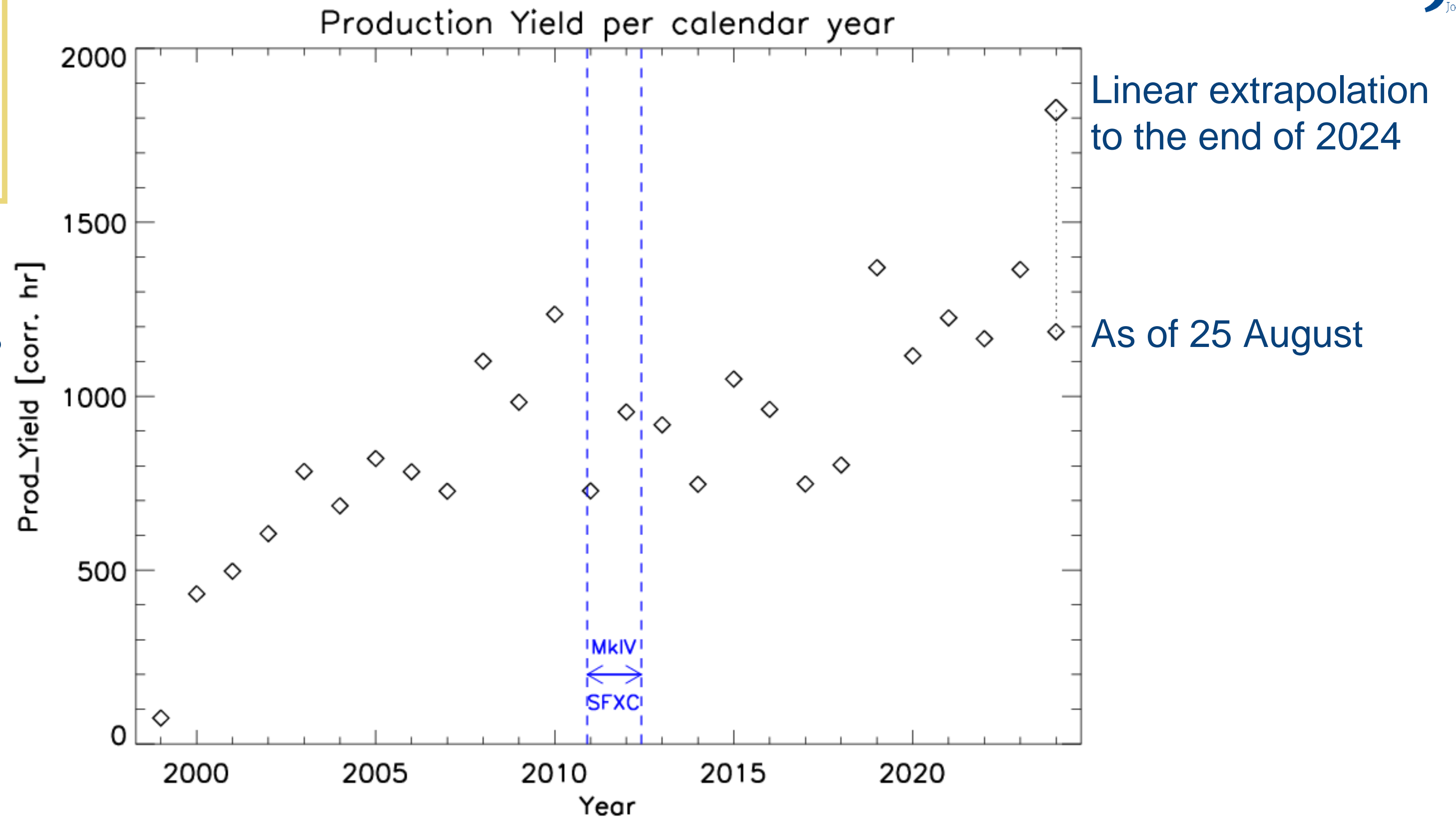
- Indexed by experiment; searchable with FITS-finder tool; abstracts now archived
- Growth reflects enhanced SFXC capabilities; VO presence implemented



# Correlation Throughput

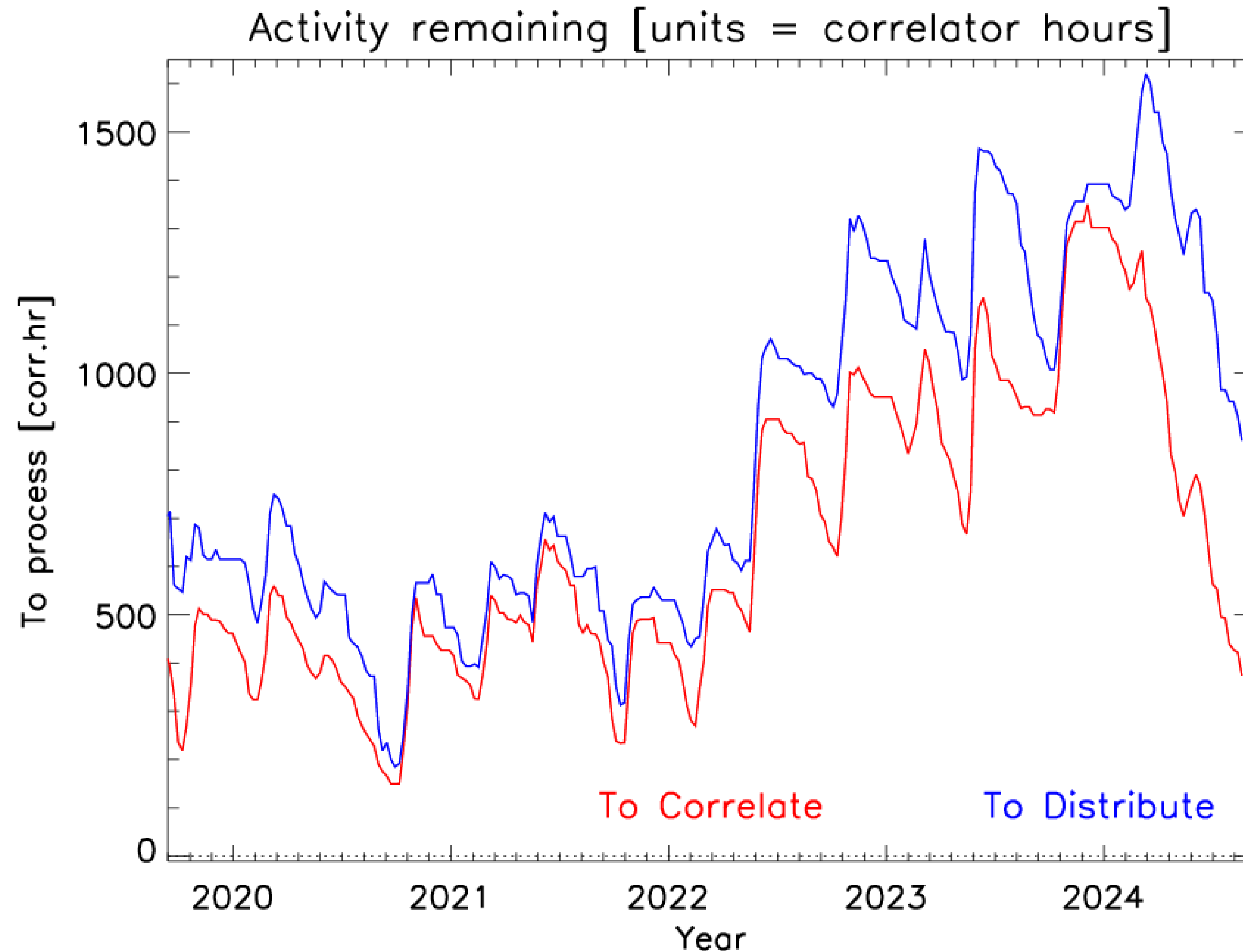
2029 User experiments  
23076 Correlator hours  
18321.5 Network hours

Correlator hours = Network hours multiplied by the number of passes required (e.g., continuum / line)



- Each year since 2019 has more output correlator hours than any SFXC year  $\leq 2018$
- SFXC not necessarily real-time (low bit-rate faster; high bit-rate, fancy features slower)  
 $\Rightarrow$  “Processing Factors” now range from  $<1$  to  $\sim 9$ , weighted mean since 2016 = 2.1

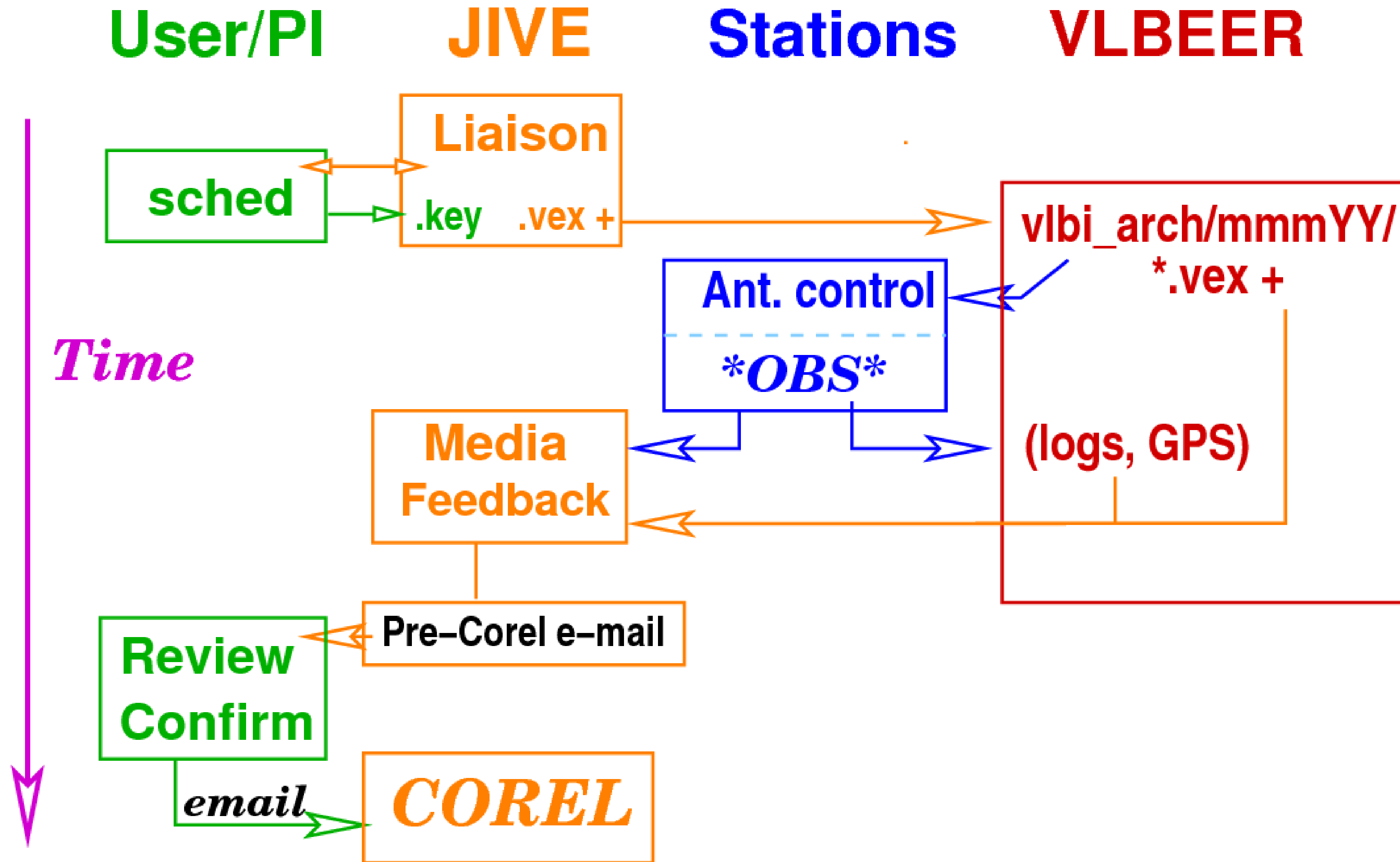




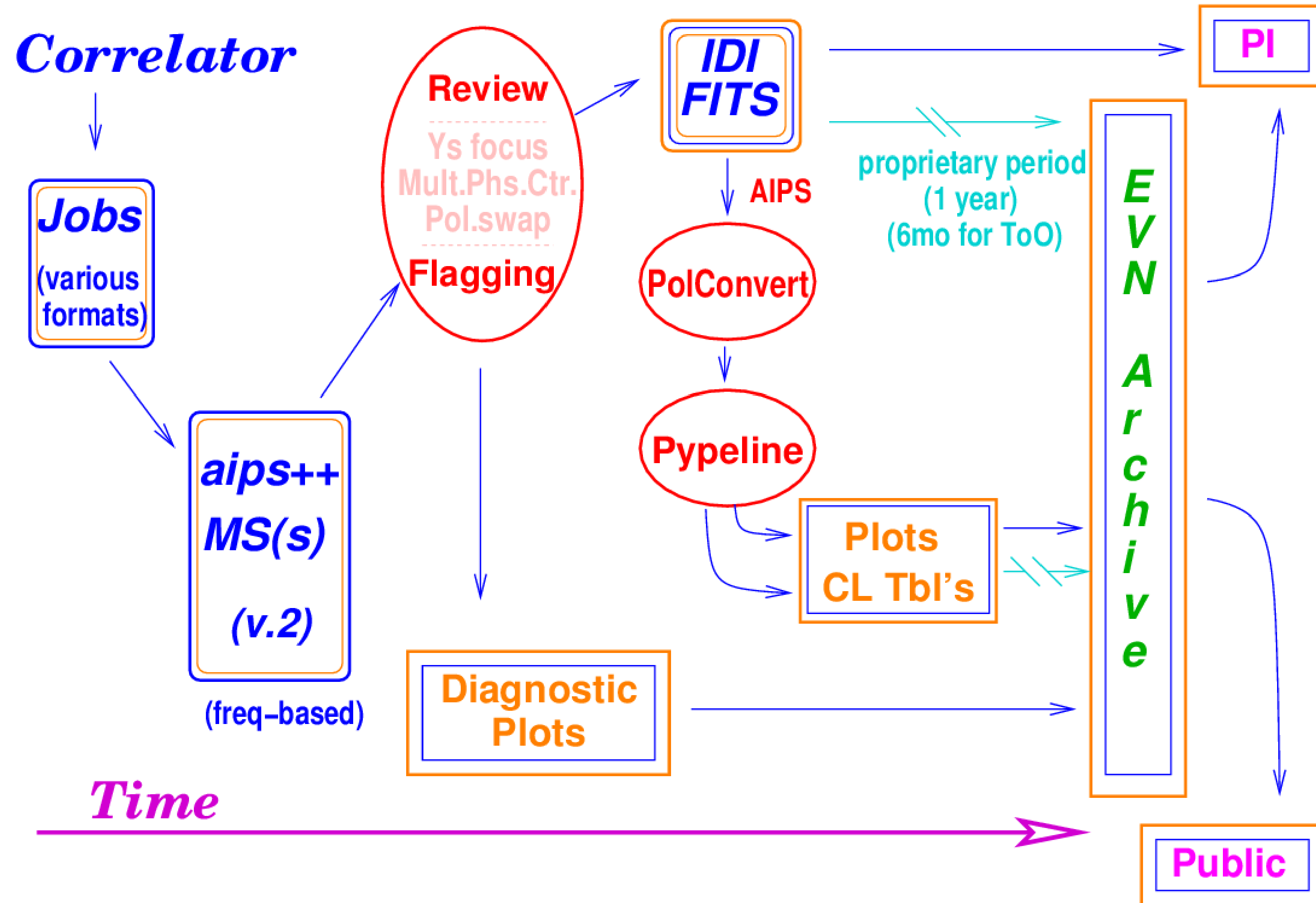
- **SFXC: increasing capabilities**
  - More complicated correlations possible
  - Not necessarily real-time
- **Shifting bottlenecks**
  - Pre-correlation preparation / data arrival
    - Individual station e-shipping rates
    - Investigating stations not showing fringes
  - Correlator run time
  - Post-correlation processing
    - PoConvert; multiple outputs; pipelining (e.g., compiling `antab` files, etc.)
- **Increasing load of station tests**



# Pre-Correlation Flowchart



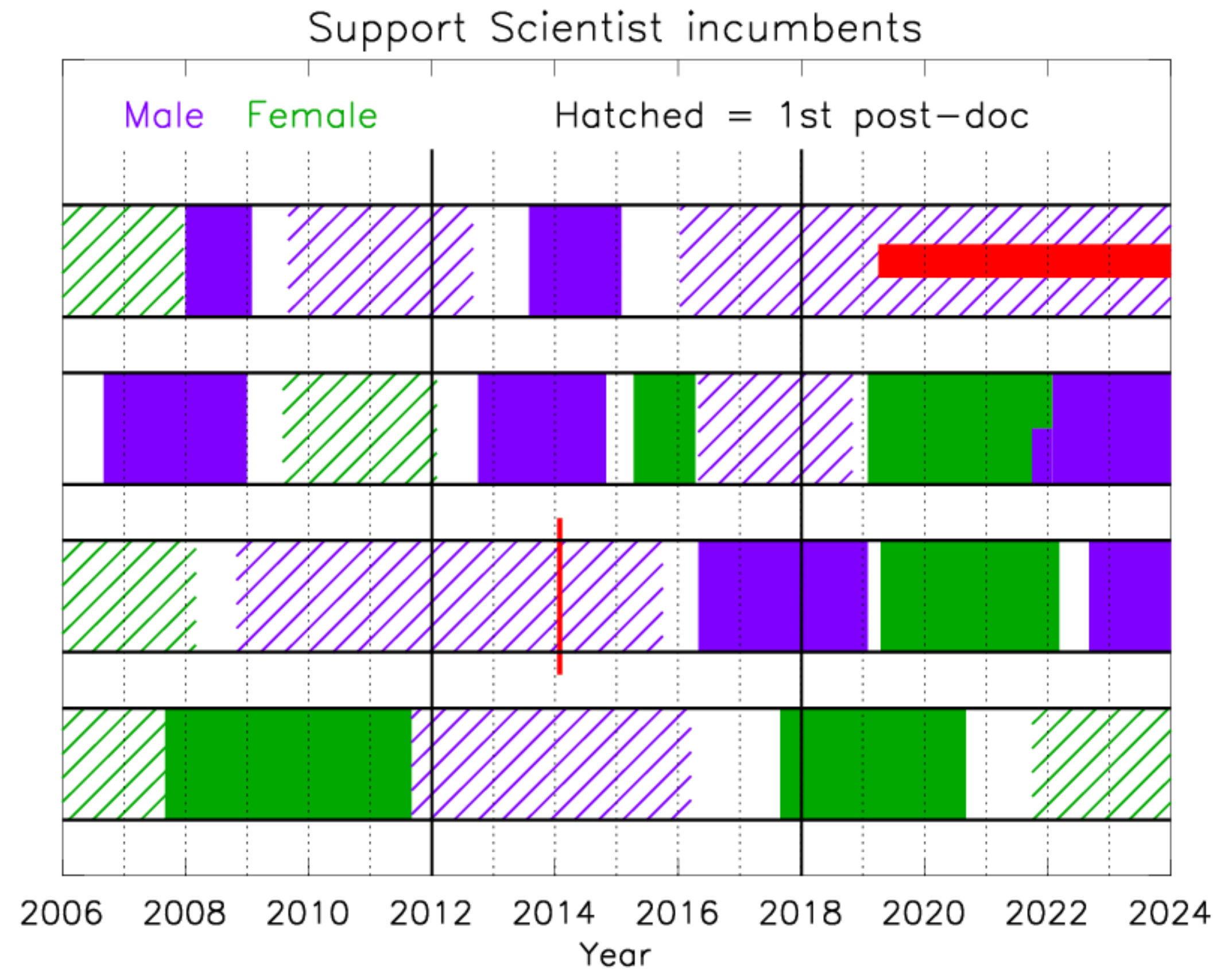
# Post-Correlation Flowchart



# People are the key

- Aim to have four support scientists
  - 50% support / 50% own science

- Support-scientist tenures since 2006 



- 44 people have been JIVE support scientists

- $\leq 2000$ , some (7) were hosted full-time at other EVN institutes
- 30 men, 14 women (for those starting  $\geq 2004$ : 13 men, 9 women)
- 26 people from 11 EU countries & 18 people from 9 non-EU countries
  - EU  $\in \{IT, UK (5), ES (4), DE (3), HU, NL (2), FI, FR, GR, IE, SE (1)\}$ ; non-EU  $\in \{US (5), AU (4), IN, RU (2), CN, JP, KR, PK, UA (1)\}$
- for those starting  $\geq 2004$ , 12 people from 5 EU countries & 10 people from 7 non-EU countries
  - EU  $\in \{DE, ES, IT (3), IT (2), HU (1)\}$ ; non-EU  $\in \{AU, IN, RU (2), CN, KR, PK, UA (1)\}$