The EVN MkIV data processor at JIVE

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The highlight of the 4^{th} EVN/JIVE Symposium in Dwingeloo was the inauguration of the EVN MkIV data processor at JIVE. Since then, we have been increasing the capabilities, flexibility, and reliability of the correlator, and have now processed several test, pilot, and user experiments. Milestones include the first scientific publication resulting from data correlated at JIVE: detection of HI absorption within 20 light-years of the nucleus of NGC4261. We will discuss developments and accomplishments at the JIVE correlator since the last EVN Symposium — most importantly, focusing on how they relate to the astronomy that can be done.

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1. Introduction

A key item in the MkIV upgrade of the EVN was the construction of the EVN MkIV data processor at the Joint Institute for VLBI in Europe (JIVE). JIVE is hosted by ASTRON in Dwingeloo, the Netherlands, and is funded by science councils in a number of European countries. Special projects have been funded directly by the EU. The EVN MkIV data processor was constructed in the context of the International Advanced Correlator Consortium (see Casse 1999 for details of the IACC), with significant contributions, from European members, in hardware from CNR/IRA, control software from Jodrell Bank, and correlator software from ASTRON.

The first fringe on the EVN MkIV data processor was seen on 21 July 1997, and its official inauguration took place on 22 October 1998. Casse (1999) and Phillips & Van Langevelde (1999) provide a description of the correlator and the detection of fringes at that time. The "first science" resulting from data correlated on the EVN MkIV data processor detected HI absorption against the counterjet very close to the nucleus of NGC4261, providing the ability to see the transition from molecular to atomic gas in the disk, and hence to say something about its thermal structure (Van Langevelde *et al.* 2000; Pihlström 2000).

Since the previous EVN Symposium, we have made a great deal of improvements in the capability and operation of the JIVE correlator. This paper will concentrate on aspects of specific interest to you, the astronomer using the JIVE correlator: tools for planning observations with regard to the correlator's capabilities, current operational and communication flow between JIVE and the PI, and what we at JIVE do to get your data to you in a usable form. More information about using the EVN and JIVE can be found at the JIVE website: `www.jive.nl/jive`.

2. Capabilities

Basic characteristics of the design of the EVN MkIV data processor include:

- correlation of up to 16 stations, with 16 channels per station.
- 1 Gb/s recording (via 2 head-stacks × 32 heads × 16 Mb/s/track).
- use of either MkIV and VLBA format recordings.

The principal science drivers behind the development of the correlator and associated software include the ability to handle continuum dual-polarization observations, spectral

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line experiments (*i.e.,* providing lots of frequency points and narrow bandwidths), and phase-reference mapping.

Current capabilities include:

• 2-bit sampling.

• cross-polarization.

• up to 512 frequency points for correlation of up to 8 stations; up to 128 frequency points for 9–16 stations (see the discussion following equation 2.1).

• fan-out modes, where 1 channel was written onto 2 or 4 tracks, increasing bandwidth without using higher tape-speeds.

• processing of both MkIV and VLBA type recordings.

• sustained 256 Mb/s recordings, a capability that is currently unique to the EVN (see, *e.g.,* Garrett, Muxlow, Garrington, *et al.* 2000) — full 1 Gb/s awaits all stations being equipped with two heads and 320 ips recording.

Capabilities whose development is still underway or not yet fully tested include:

⊙ Oversampling at 2, 4, 8, or 16 times the Nyquist frequency in order to provide bandwidths down to 125 kHz.

⊙ MkIII modes.

⊙ Pulsar gating.

Capabilities that are yet to come include:

∘ Reading observations with barrel-rolling.

∘ Playback at tape speeds different than used in recording.

∘ Recirculation — achieving >2048 frequency points via time-sharing the correlator.

∘ Sub-netting.

∘ Multi-pass correlation (>16 stations).

∘ Phase-cal extraction.

∘ Space VLBI.

There are two equations that are useful when planning observations that will be correlated on the EVN MkIV data processor. The first relates to total correlator capacity:

$$N_{\rm sta}^2 \cdot N_{\rm sb} \cdot N_{\rm pol} \cdot N_{\rm frq} \leq 131072 \quad (= 2^{17}). \tag{2.1}$$

We are currently limited to one-quarter of this capacity (*i.e.,* 32768 vice 131072) pending installation of local processing capacity (DSP's) onto all correlator boards, which we anticipate to be in place before the end of 2000. In equation (2.1), $N_{\rm pol}$ is the number of polarization combinations wanted in the correlation (1, 2, or 4). $N_{\rm sb}$ represents the number of different frequency subbands, counting lower- and upper-sidebands from the same BBC as distinct subbands, but not multiple polarizations in the same sideband (these enter via $N_{\rm pol}$). The value to use for $N_{\rm sta}$ is currently either 8 or 16: if you have 7 stations, use "8"; if you have 9, use "16". We plan in the future to reduce this granularity in $N_{\rm sta}$ from multiples of 8 to multiples of 4. When recirculation is operational, the constant term 131072 will be multiplied by the recirculation factor used. Equation (2.1) takes into account all correlator products, both cross- and auto-correlations. You should pick the various N parameters in designing your observation such that the equation holds, otherwise you will have to compromise on at least one of them when it's time to correlate.

The second equation relates to output capacity:

$$\frac{N_{\rm sta}^2/2 \cdot N_{\rm sb} \cdot N_{\rm pol} \cdot 2N_{\rm frq} \cdot 8\,\text{bytes}}{t_{\rm int}} = \text{OutputRate}. \tag{2.2}$$

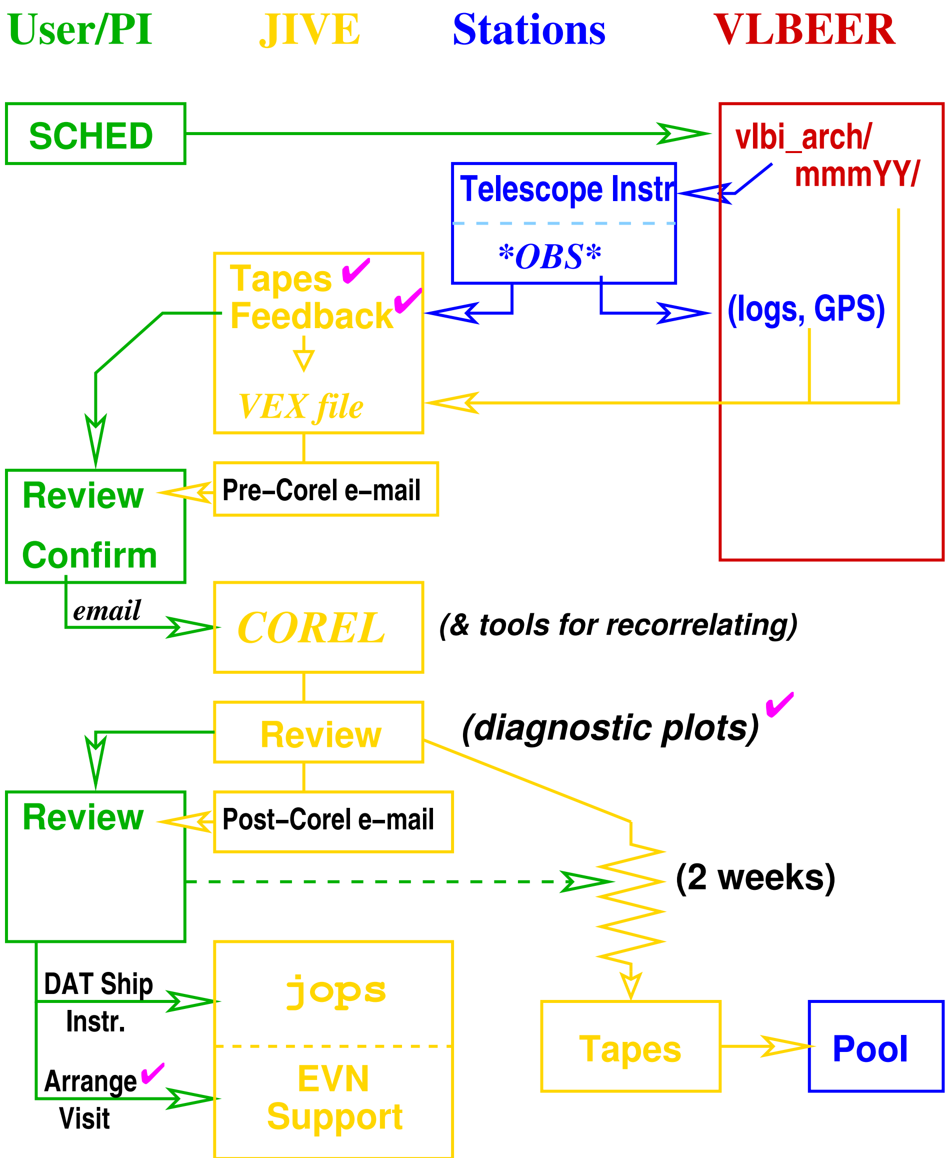

FIGURE 1. Operational flow for the observation and correlation of an experiment.

Our current peak output rate is ~250 kB/s (which puts a lower limit to integrations times for experiments using the full correlator of ~4 s). In the future, with the Post-Correlator Integrator operational, the output rate may go as high as 40 MB/s.

3. Operational Concerns

Figure 1 summarizes operational and communication flow between the PI, JIVE, and the various EVN assets during an experiment (this figure is available in color, clarifying the lines of data/communication flow, in the actual postscript version available on the web). The user deposits `SCHED` output on `VLBEER`, from which individual stations draw their observing instructions. Help from JIVE of course may be requested during the scheduling process. Following the observations, the stations deposit logs and GPS data on `VLBEER`, send tapes to JIVE, and post comments to the JIVE website. We pull necessary information off `VLBEER`, prepare files that will drive the correlation, and send e-mail to the PI describing what we envision the correlation of the experiment to entail. The PI has the opportunity to review the parameters in our e-mail and all other available information (items with a check in figure 1 are available on the JIVE website), and writes back to pass along any requests for changes (*e.g.,* improved source coordinates, *etc.*) and/or confirm that correlation can go ahead.

We operate the correlator 80 hours per week, from which time system testing and development must also come. When correlation of the experiment is finished we review the output, make diagnostic plots (which we put on our anonymous FTP server), and send post-correlation e-mail to the PI summarizing the results of the correlation. After reviewing the e-mail and plots, and after any further discussions with the responsible JIVE support scientist if necessary, the PI can then arrange for the shipment of the FITS-file DAT and also for visiting the EVN support group at JIVE for help in data reduction if desired. We usually request that you let us know by a certain date whether it's okay to release the tape back into the pool. It greatly benefits the whole network if PIs could give us this authorization in a timely fashion, especially for thin tapes.

Our internal data review process begins by transforming the lag-based correlator output into lag- and frequency-based `AIPS++` Measurement Sets (MS). These MS contain a data-cube of the real & imaginary components of the correlation-function per subband per baseline/autocorrelation. We can then investigate slices of the correlation functions in time and lag/frequency channel, allowing us to detect and diagnose various problems with the recorded data or the correlation itself, and to determine any scans for which recorrelation would be profitable. There are also various plots more suited to providing feedback to the stations rather than to the PI. We usually flag subsets of the data for low weights or other known problems resulting in spurious correlation amplitudes and phases. The last step is converting the final MS into a FITS file, which can be read into AIPS directly using `FITLD`.

As of 4 September 2000, we have completed correlation of 22 user and 14 test experiments. A further 9 user and 1 test experiments were then in the process of running or in the queue. Nine user experiments were on hold awaiting either further PI liaison (6) or specific correlator features (3). We have so far processed and distributed data from experiments having goals including:

- continuum mapping (including a global experiment).
- HI absorption (1420 MHz & UHF).
- OH megamasers.
- Phase-reference mapping.

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