

# High output data rates with PCInt on the EVN MkIV data processor

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**Abstract.** The EVN MkIV data processor is being equipped with a high data output capability, called PCInt. In its next phase it will allow very high data output rates, up to 160 Mb/s. This functionality is required for the high spectral resolution that will be offered with recirculation. Moreover, VLBI observations traditionally focus on a small patch of sky and image typically a few 100 mas around a bright source. High spectral and time resolution is needed to image a larger area of the sky, up to the primary beam of the individual telescopes. After the upgrade such high resolution data will become the standard product. From the archive of high resolution data it will be possible to image many sources in each field of view around the original targets.

## 1. Introduction

The output data rate of a VLBI processor determines how accurately the correlation product can be sampled in frequency and time. The frequency resolution is important for various spectral line applications, but it also limits the field of view (FoV) that can be imaged before bandwidth smearing sets in. The spectral resolution of a VLBI correlator is usually determined by the computing power built into its hardware, e.g. the number of available lags per baseline. Furthermore, the product over all available telescope pairs of spectral resolution and short visibility integration time combines into the total output rate. There is generally a maximum data rate, determined by how fast the data can be flushed to a standard computing environment and saved to disk. This limits not only the spectral sampling but also the temporal sampling, constraining the FoV further through time smearing, which scales with baseline length and distance from the field centre.

Both the spectral capabilities and the output bandwidth of the EVN data processor at JIVE are being upgraded. The first by introducing recirculation and the latter by the PCInt project.

In this paper we discuss the scientific motivation and the future data handling of this system. We consider the possibility to operate the EVN correlator in wide field mode for all experiments in order to build up an archive with large sky coverage, containing a fantastic number of faint sources.

## 2. Scientific Justification

A VLBI dataset, if properly calibrated, has flat phase response, both in time and frequency, for the target position. Positional offsets from the phase centre introduce increasingly steep phase slopes in frequency and time. As long as these are properly sampled, sources at the primary beam edge can still be imaged. Both effects scale with baseline length (and are therefore particularly severe for VLBI); time smearing also scales with frequency (Wrobel 1995). The resulting limits on the FoV for typical VLBI experiments can be seen in Table 1. Although the original recordings of a single VLBI experiment hold information over the whole field, typically only  $10^3$  out of  $10^8$  beams are imaged.

**Table 1.** The resulting data volume and field of view (by time and bandwidth smearing) for a rather modest VLBI recording at 18cm on 8 EVN antennas with a total bandwidth of 64 MHz (2 bit sampled). The primary beam of a 25m telescope measures  $27'$ . The requirements become even more severe at higher spatial resolution (global baselines, or higher frequency).

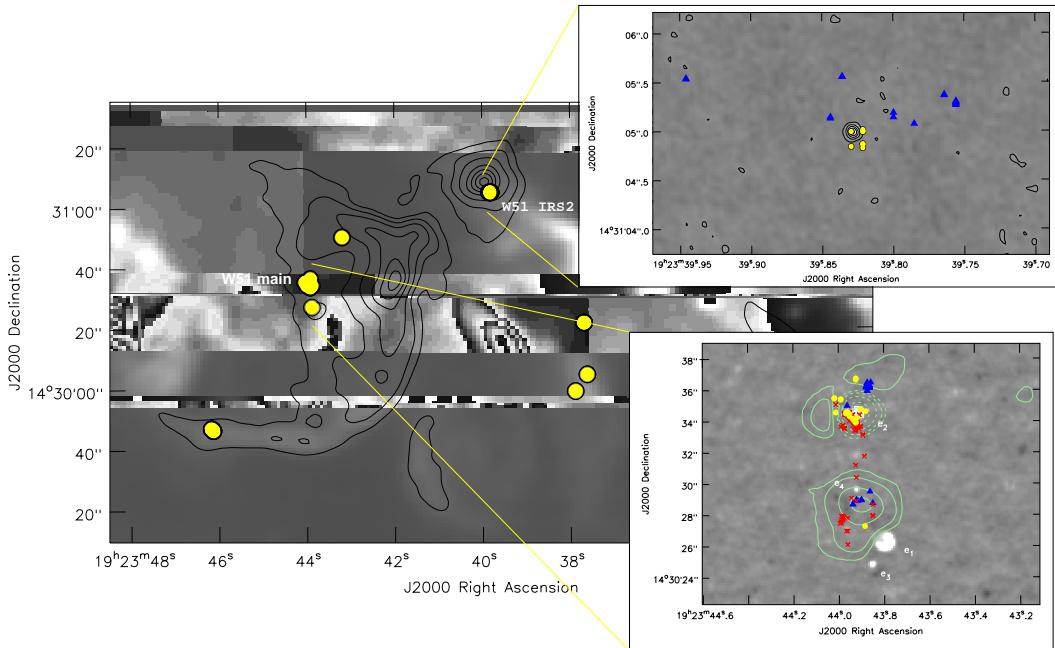
Application	$N_{sp}$	$t_{int}$ [s]	Output [MB/s]	$FoV_t$ [']	$FoV_{bw}$ [']	$V_{12hr}$ [GB]
Traditional	128	4.000	0.02	0.70	0.82	1
Operational max	1024	0.500	1.50	5.57	6.59	63
Phase 0	2048	0.250	6.00	11.14	13.19	253
Full system	4096	0.031	96.00	89.11	26.36	4050

There are several astronomical applications for which larger fields of view are useful. Galactic masers may extend over rather large areas, especially in star formation complexes (Fig. 2). Gravitational lenses are another case where VLBI sources may extend over a large FoV.

Moreover, studies of the faint radio source population may be done more efficiently when a large instantaneous field of view is available. A long integration at the full recording bandwidth can then be employed to study many weak sources simultaneously. This technique was explored with the EVN at 1.6 GHz and the VLBA correlator by Garrett et al. (2001). Even at the moderate resolution of EVN only observations at 18cm, the FoV is a fraction of the Effelsberg beam, and barely covers the Hubble Deep field. Studies like this will benefit greatly from the upgrades ongoing in the EVN, both in recording and correlator capacity.

## 3. Correlator data flow

The EVN MkIV data processor correlates inputs from 16 stations simultaneously (Schilizzi et al. 2001). Each telescope input can handle up to 1 Gbit/s, from Mk4 tape, Mk5 disk playback or fiber connections. Its computing power is based on 32



**Fig. 1.** The methanol masers in the massive star formation complex W51 span arc-minutes on the sky. Imaging these accurately over the primary beam of the contributing telescopes requires high spectral and temporal resolution. The high resolution data can be compared with other tracers of star formation with milli-arcsecond accuracy (Phillips & van Langevelde 2003).

boards, each equipped with 32 custom made chips, each producing 256 complex lags. This yields sufficient spectral capacity to attribute 512 spectral channels to every baseline between 16 telescopes. With the introduction of recirculation the number of spectral channels scales up when the bandwidth of individual sub-bands is below the maximum of 16 MHz.

In its original configuration the data was flushed out on 4 parallel 10Mb/s Ethernet lines. The first improvement to this system has been implemented by upgrading the system with 8 Single Board Computers (SBC), which handle the data-streams and are outfitted with 100 Mb/s Ethernet to flush the data (Phase 0). In the final PCInt configuration each rack will have two Single Board Computers running Linux, which read the data from DSP powered serial ports. A total of  $8 \times 1$  Gb/s Ethernet connections are then available. The software is modified in order to process the output data in parallel by a cluster of workstations. Special hardware is procured to provide the required IO bandwidth to disk. In table 1 the Field of View (FoV) limits set by the bandwidth sampling (bw) and time smearing (t) in various stages of the project are shown.

This system will also be crucial for future spectral line studies. Currently, spectral resolution often has to be traded for the number of telescopes, polarization products and time resolution, resulting sometimes in multiple-pass correlation for large spectral line projects. With recirculation the spectral capacity could increase by a factor 8 for some projects (for example OH lines that can be observed with 2 MHz bandwidth). PCInt will be indispensable for handling such projects.

#### 4. User products

With the enhanced data rates it is anticipated that all correlation will one day run at full resolution in order to build up an archive which covers a substantial area of the sky. Already considerable effort has gone into making the archive of user products and diagnostic plots accessible through a web interface: <http://archive.jive.nl/>. The data is public after the original proposers grace period. In the future one can imagine that if the archive contains large FoV data, it may be interesting for studying e.g. the faint source population. While the output data will be at full resolution, the user may prefer the data at a coarser resolution, one that is optimal for the scientific goal of his study. An interface to the archive will be designed in order to allow users to make a selection and create a dataset at a lower resolution, possibly by averaging for a new target position. The goal is to have sufficient (parallel) computing infrastructure, in order to make such products available in an almost interactive manner. It is thought that wide field of view VLBI images will be made as an integral part of the data processor product. Such a solution would fit in with the Virtual Observatory paradigm. Some of the effort for this, including the streamlining of calibration, is part of the RadioNet software project ALBUS.

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