Rationale for the IRA/INAF contribution to JIVE

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Introduction

This document was prepared in the process of defining the MoU between the JIVE partners for the period 2008-2012. It describes the current level of participation of IRA/INAF in JIVE, and the return that Italian astronomy enjoys from this investment. It shows that the current level of participation of Italy in the EVN and JIVE is easily justifiable. In fact, through the European projects that JIVE raises and carries out on behalf of the EVN, this investment has at least double return. Italian astronomers are leading the EVN in getting science out of this facility and IRA staff members are intensively involved in the technical projects to further enhance the EVN and JIVE.

Background

The European VLBI Network (EVN) is an array of radio telescopes located within Europe (and beyond) that conducts Very Long Baseline Interferometry (VLBI) observations of cosmic radio sources. EVN data are processed (correlated) centrally at the Joint Institute for VLBI in Europe (JIVE), located in Dwingeloo, the Netherlands. JIVE was originally funded by 7 different international organisations (ASTRON-NL, IRA/INAF-IT; IGN-ES, MPIfR-DE, NWO-NL, STFC-UK and OSO-SE) to which recently Chinese (in 2006) and French (from 2008) agencies have joined. It also receives support from European Space Agency and various EC programmes, including RadioNet and EXPReS. This latter programme focuses on the introduction of e-VLBI and JIVE is the coordinator of this high profile activity.

The EVN operates 12 weeks per year (split into 3 block sessions) with the Italian radio telescopes at Medicina and Noto playing a major role. Additionally, the Medicina telescope is one of the corner stones of the e-VLBI project and participates very prominently in tests and science observing runs of this new facility. The EVN is the most sensitive VLBI array in the world with the regular participation of three of the largest radio telescopes in the world. This position will be strengthened considerably with the addition of the 64m Sardinia Radio Telescope. The EVN often co-observes with the MERLIN array, the NRAO Very Long Baseline Array and other large antennas around the world (so called Global VLBI). Besides the Sardinia Radio Telescope three EVN telescopes are currently under construction (Yebes 40-m, Spain; Miyun 50-m and Kunming 40-m, both China). With the upgrade to disk based recording systems, the EVN is now routinely offering Gbit/s recording for optimal sensitivity. Moreover, through enhanced monitoring enabled by direct connections, the current VLBI network is operating much more robustly than ever before. A typical 12 hour EVN observation reaches 1-sigma r.m.s. noise levels of a few μJy per beam. On top of this the EVN has recently started to offer e-VLBI as an operational facility, giving the user the unique option to do real-time VLBI and have access to the user output immediately after (or during) the experiment. The EVN is an open facility in which observing time is made available purely on the basis of scientific merit. JIVE provides comprehensive support to all astronomers that wish to use the instrument, including an on-line pipelining facility for fast data assessment.

IRA/INAF's share of the operating costs amounts to 240 k€ per year. This is equal to the UK contribution and only topped by the Dutch, who host JIVE. The Italian contribution amounts to about 14% of the base budget. The base budget covers all the permanent staff and provides for the core operational support of running and maintaining the correlator, as well as providing basic access to the data. From a variety of sources JIVE has acquired additional funding to carry out technical, software and scientific projects. Amongst this is the EC Trans-National Access programme that allows comprehensive support for the European VLBI Network and its users. All of this almost doubles the JIVE budget and therefore the Italian contribution amounts to only 8% of the total budget of ≈3M€. Below it is shown that Italian astronomers successfully claim about 20% of the total observing capacity. Moreover, Italian telescopes deliver about 25% of the raw data input, which is turned into an astronomical product by the central facility at JIVE.

Key Science Objectives

The EVN and JIVE facility address a very broad range of astronomical research, ranging from unique dynamical studies of methanol maser emission – tracing the earliest stages of massive star formation in our own galaxy; high resolution observations of the transient SNe and SNR that can be detected and monitored in local Starburst galaxies (e.g., M82 and Arp 220); discriminating between AGN and star forming processes as the source of the very faint radio emission seen in highly obscured and distant sub-millimeter Galaxies; understanding the physics of the relativistic jet outflows and probing the local ISM of AGN via HI absorption features; measuring the scale of the Universe and the nature of dark matter via detailed milli-arcsecond scale imaging of gravitationally lensed radio sources. The introduction of e-VLBI has provided a new dimension for investigations of transient objects in both the local and distant Universe (e.g., X-ray binaries, flare stars, SNe & GRBs) by offering a rapid response option. Since the highly successful tracking with VLBI of the Huygens descent there is a growing interest to invest in this technique for future planetary missions.

Italian astronomers are making use of the EVN facility in a wide range of topics. In particular, strong groups are involved in studies of the AGN phenomena, making more use of statistical methods and multi-wavelengths approaches recently. Also strong is the interest in Young Stellar Objects and ambitious work has been done to study the dynamics of these objects on very small scale by monitoring different maser species. Recently, more different university groups have started to use the EVN facility.

Future capabilities

The introduction of the e-VLBI service is revolutionizing the VLBI practice. It has demonstrated to be a powerful tool for rapid response science, especially of transient sources. Its current success is remarkable, as not yet all of the EVN telescopes are in the system; apparently the rapid feedback is proving to be of great value to both users and participating telescopes. In 2008 the e-VLBI capability will be much more powerful with the inclusion of the big Yebes and Effelsberg dishes and the routine inclusion of more e-MERLIN telescopes. The investment in e-VLBI will really pay off when close collaborations start with a number of monitoring facilities that are currently being developed (GLAST, LOFAR). Recently e-VLBI has been demonstrated to be a valid approach for global VLBI as well, with telescope data from China and Australia streaming to JIVE in real-time.

The great promise of e-VLBI is to enhance the sensitivity of the EVN further by sampling larger bandwidth. This is complementary to the introduction of several new (high-frequency) telescopes amongst which the Sardinia Radio Telescope features most prominently. The users will benefit from this extra sensitivity, but also from the enhanced imaging capabilities that the new telescope elements offer. These enhancements are beneficial to all VLBI science topics. Continuum observations, such as the deep cosmological fields, will obviously benefit from the improved sensitivity. Even wider field of views will be enabled by the next generation correlator, bringing also better spectral flexibility to spectral line observations. But also the sensitivity for spectral line observing will improve; not only will more antennas bring more collecting area especially at the frequencies of water and SiO masers, but the improved continuum sensitivity will also add to the precision of phase referencing and astrometric observing modes.

Around the EVN various steps are being made to define the new observing modes for VLBI. The dBBC data acquisition system, developed in Italy, will play a prominent role in flexibly capturing more bandwidth and thus providing more sensitivity. It is also vital for introducing more telescopes to the network, as the current, operational components are no longer on the market. Some work on 10Gbps data transfer is carried out in the EXPReS research activity "FABRIC". And more initiatives are being prepared for the RadioNet FP7 project, with considerable participation from Italy.

JIVE staff is concentrating on the definition of a next generation correlator to match the enhanced data acquisition. This correlator is also required to accommodate the growing number of telescopes. Not only are there currently four telescopes under construction, but in various Eastern European countries telescopes are being outfitted for VLBI. Additional plans exist for new telescopes in other countries (Ireland, Portugal and Middle East). The current effort is focusing on developing a software correlator based on Grid technology in which Italian groups have also expressed interest. The reasoning is that this can serve as an intermediate solution, but that in the long run a "hybrid" correlator, based on FPGA technology is required. Funding for exploration of this technology is sought through the RadioNet FP7 proposal and local funding options. The development is planned to run parallel with the preparatory studies for the SKA correlator. For the construction of the new correlator, contributions will have to come from all the JIVE and EVN partners. The most attractive option for this is to raise the overall JIVE budget by inviting new partners to join the collaboration. The science case for this upgrade ("EVN2015") is being discussed in the EVN. Other future capabilities include increased sensitivity at high frequencies and the option of using feed arrays for multiple beam astrometry.

There is no doubt that this way the EVN, and its global collaboration with American telescopes, will result in a competitive facility during the time that the SKA pathfinders are coming on-line. In fact, the e-EVN is recognized as a SKA pathfinder for high resolution astronomy and real-time long baseline connectivity. Even if the SKA is realized by the end of the next decade there may be a valid science case to maintain the VLBI capability in the Northern Hemisphere. In collaboration with the American and Chinese antennas VLBI is providing much longer baselines and higher resolution than will be available from the SKA

To this we can add the science case for Spacecraft Navigation. JIVE has led the global array of radio telescopes that tracked (and successfully detected) the ESA Huygens probe as it descended through the atmosphere of Titan earlier. ESA support for JIVE in the use of VLBI as a precision navigation tool is expected to continue in the future, for planetary missions or for example in support of the BepiColombo mission. In the latter case precision VLBI orbit determination of the spacecraft may permit extremely tight constraints to be placed on theories of gravitation, including general relativity. It is possible that ESA might be interested in collaborating in the development of e-VLBI and the next generation VLBI correlator project.

The ongoing enhancements of the scientific capabilities also require attention for the upgrade of the user tools to process the data. As the bandwidth, number of telescopes and especially the field-of-view of the EVN increases, the users are facing more and more complicated data processing tasks. Through the RadioNet programme, JIVE has taken the lead to innovate the existing user tools for data processing, and the first product, called ParselTongue, has successfully been introduced to the community. This scripting environment enables users to streamline large and non-standard data processing tasks and has rapidly been adopted by a number of PhD students around Europe, including Italy. Enhancing the accessibility of the EVN is also a continuous area of attention. JIVE has implemented an on-line archive of all the EVN data, which provides calibration data to the user transparently. Applying the same scripting environment, a pipeline has been invoked that provides the users with preliminary images from the archive.

Italian participation in the EVN

Italy, as a major player in the EVN, has an important role in JIVE. Without JIVE the EVN would be set back to a dubious level. Without its main correlator, user support or the support for monitoring the Network performance, it will be impossible to offer the EVN as an astronomical service. There are various ways to rationalize the Italian level of contribution to JIVE. We can try to measure its scientific use by Italian astronomers, but it is probably even more fundamental to estimate the fractional participation of Italian telescopes, because without the JIVE infrastructure they cannot be employed for astronomical VLBI.

With the Medicina and Noto telescopes, Italy is the most prominent partner of the EVN in number of elements and contributes critically to the EVN's imaging capability. In this sense it is directly comparable to the UK. The table below shows the participation of the Italian telescopes in EVN observations. The main reason for not participating in a particular experiment is when a telescope does not have the desired receiver for that experiment. In general the Italian telescopes are extremely agile. Estimating the average number of telescopes in EVN experiments as 7, this implies that Noto and Medicina are generating at least 25% of the EVN raw data. We note that the Italian telescopes also have a proven track record for operational reliability.

	2004	2005	2006	2007 (so far)
Total EVN observing time (hr)	668	646	539	661
Fraction of experiments that include Medicina	75%	88%	88%	97%
Fraction of experiments that included Noto	77%	73%	90%	96%

But also in astronomical usage the Italian community are very prominent in the EVN. We list below the number of Italian users that successfully applied for EVN observing time, where we distinguish the projects that have an Italy based PI. The total number of Italian participants is the total sum of all Italian proposers across all projects, including those with a PI from outside Italy. The observing time is for all projects that had Italian participation.

	2004	2005	2006	2007 (so far)
Italian led projects	5	4	5	10
Total number of Italian co-I's	14	9	9	11
Number of observing hours	166	166	90	103

Note that on average 50 experiments are done every year, for a total of approximately 600 hours. This counting includes participation by non-European astronomers. From this analysis it is clear that the Italian astronomers participate in at least 20% of the total EVN observing.

Italy is not only participating at high level in the scientific productivity of JIVE and the EVN. Besides this relation to JIVE's core mission, the IRA staff has played a major role in the innovation of the EVN and JIVE. Staff technicians at the Italian telescopes have been actively involved in the distributed effort to maintain the telescopes throughout the EVN and train staff at telescopes that wish to join. A highlight is the development of the dBBC system, which will allow the EVN to flexibly observe more bandwidth enhancing the sensitivity. The Medicina telescope is a key element in the testing and commissioning of the e-VLBI concept. As was the case for the current correlator, it is expected that specialists from IRA will play a role in the definition of the new EVN data processor. Italy is a very keen party in the development of the various space related VLBI programmes.

We note that Italian astronomers are also making a lot of use of the American VLBA network that offers complementary capabilities. Although this may appear as an alternative for the EVN, it should be noted that in radio-astronomy the principle of open skies is successfully applied globally. This principle of openly sharing resources can only continue to work if there is a global balance in consumption and availability of resources.

On the long term, the SKA may offer far superior capabilities for radio-astronomy on a global scale. Above it was argued that the EVN may continue for certain niche science applications, but clearly the advent of the SKA will revolutionize the field and will force changes to the EVN. However, it is important for the vitality of the radio-astronomy community in Italy and Europe, that the excellent scientific capabilities of the EVN are maintained during the design and construction of the SKA. Without front-line instruments in the next decade, a risk could be that the leading position in this discipline is lost and we fail to train scientists to explore the scientific promise of the SKA.

A Memorandum of Understanding for the 2008 – 2012 period

Currently, there is no doubt that in VLBI the EVN and JIVE offer Italian astronomers access to a world-class VLBI facility. This was the conclusion of the ESF review committee in its review of JIVE in early 2006. It was also noted that the EVN and JIVE were establishing themselves as the world leaders in innovating VLBI. A next generation correlator must be established to continue this role. This ESF review was initiated by the JIVE board as a first step in the process of establishing a new MoU.

With this report, the commitment of the EVN partners to JIVE is strong and a new MoU for JIVE is expected to be finalized soon, entering into force over a 5 year period (2008-2012). This provides basic, operational funding for JIVE. In addition, the partners are negotiating a 10% increase of the budget, compensating the inflation over the last five years. This gives JIVE the flexibility to acquire new R&D projects related to the development of a new correlator. Other traditional sources of funding for JIVE include the European Commission. Preparations have started to continue this programme in FP7; it is important for JIVE that this is successful, in order to ensure various development programmes continue and to maintain a comprehensive level of EVN user support. FP7 is also an opportunity to start work on the next generation VLBI correlator. Beyond EXPReS there are opportunities to scale up e-VLBI to automatically switched light paths on 10 Gb/s infrastructure and to make more use of Grid fabric for both correlation and user data processing.

IRA/INAF has signed the multi-lateral MoU with the other funding partners of JIVE. This MoU will expire on 31 December 2007. With the current project development time of the SKA and the lack of long baseline facilities among the other SKA pathfinders, the expected lifetime of the EVN and JIVE facility is therefore at least 10-15 years. A reduction of IRA/INAF’s participation in JIVE seems hard to imagine while the SRT is under construction.

A concern for the current MoU implementation is the wide distribution of funding levels between the various JIVE partners. Italy, the Netherlands and the UK are providing first class support, the Swedish and Spanish contributions are mid-level, and China and France have started to make smaller contributions. The contribution from the German Max Planck Institute is between the last two categories. This distribution is largely historic. For example, in the German case it seems to have been based on the argument that they had their local correlator capacity. Also it is notable that a few EVN partners are missing from the JIVE collaboration. It is our view that this situation cannot continue during the entirety of the upcoming period. In the future it will be necessary to level the contributions to ideally one or two different levels of participation. New members will have to join in order to raise the budget for the construction of a new correlator. We propose to make these changes a part of the process which is necessary to make JIVE ready for the EVN2015 ambitions for the next decade.

Outreach and spin-off

Together the EVN and JIVE form a distributed radio telescope of continental and inter-continental dimensions. The technique of VLBI and the broad international collaboration that forms the foundation of its success, cannot fail to capture the imagination of the public at large. Perhaps the most interesting feature of VLBI to the layman is the ultra high resolution that can be attained – in many ways this brings a unique view to what is otherwise a fairly static Universe. In particular, changes in the structure of the radio emission associated with supernovae and jets can be experienced and observed on human timescales. The practical applications of VLBI are also well appreciated by the wider-public. The role of radio-astronomy in the ESA Huygens mission reached many popular media.

The evolution of this planet-sized radio telescope towards a real-time e-VLBI capability brings together further elements that are of interest to all and have their roots in fundamental science and global communication (networking) applications. The general public are already interested in the Internet, via developments such as e-VLBI they are also beginning to understand the crucial role high-speed optical fibre research networks can play in realising distributed facilities like the EVN and JIVE. Press releases on the e-VLBI project have been widely distributed.

The Italian scientists are actively involved in defining the digital components for the VLBI of the future, through their involvement in digital data systems and their possible role in future correlator development. This may have some impact for Italian industry, especially as the SKA will deploy similar techniques. The EXPReS project is setting some of the standards for wide bandwidth communication across the world. The use of light paths is exercised widely for the use of e-VLBI. The group at Medicina plays a role in defining this and important expertise is built up for future Internet connectivity applications.