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Interferometry in radio and infrared

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Abstract

In this paper I give three brief examples, two astrophysical applications and an image reconstruction study for a future instrument, of interferometric projects in which Hungarian groups are involved.

Keywords: *technique: interferometric, galaxies: active, stars: individual: V1647 Ori*

1 The Deep Extragalactic VLBI-Optical Survey

Pilot results of an ambitious programme, the Deep Extragalactic VLBI-Optical Survey (DEVOS, Mosoni et al. 2006) is presented first. Our ultimate aim is to collect information on compact structures in a large sample of extragalactic radio sources ($\sim 10^4$ objects) up to two orders of magnitude fainter than those studied in typical imaging Very Long Baseline Interferometry (VLBI) surveys up until now. In order to place the objects in the cosmological context, DEVOS will match the sky coverage of large optical surveys (e.g. the Sloan Digital Sky Survey, SDSS, Abazajian et al. 2004) which provide the necessary redshifts. This would lead to an unprecedented data base for various applications: 1. Study the cosmological evolution of radio-loud active galaxy population, 2. Study gravitational lensing, 3. Estimate fundamental cosmological parameters, such as the density parameters Ω_m and Ω_Λ (Gurvits 2003 and references therein), 4. Position of μJy-sources (Garrett et al. 2005) can be determined, 5. Provides an essential supplement to and basis for future development of the astrometric VLBI data bases (e.g. Ma et al. 1998). The sensitive next-generation space-borne optical astrometry missions (e.g. Gaia) would provide a possibility to directly link the radio and optical reference frames using a large number of AGNs observed also with VLBI (Frey et al. and references therein, in these proceedings).

The primary goal of the DEVOS pilot project was to verify and adjust sample selection criteria, observing strategies and data reduction procedures before the full survey has started. We conducted MERLIN (Multi-Element Radio Linked Interferometer Network) and global VLBI observations of a sample of 47 radio sources selected from the FIRST (Faint Images of the Radio Sky at Twenty-centimeters, White et al. 1997) survey with integrated flux density $S > 30$ mJy and angular size $\theta < 5"$, within 2° separation from the phase-reference calibrator source J1257+3229. We detected 37 sources at 5 GHz with MERLIN observations at a peak brightness of at least ~ 2 mJy/beam, filtering out extended radio structures not detected with MERLIN. Subsequent 5-GHz observations with the global VLBI network revealed that 19 of the sources are stronger than ~ 1 mJy at an angular resolution of ~ 1 mas. Tools are available for efficient data reduction in a highly automated way for the full survey. We were able to identify 34% of the pilot source sample with SDSS-detected sources. All of these sources were detected with MERLIN and 11 with VLBI. All sources with unresolved optical structure were detected with VLBI.

With the typically $0.3 - 0.7$ mJy/beam (3σ) VLBI image noise achieved, we could determine the mas-scale brightness distribution of sources with rest-frame brightness temperatures of at least $\sim 5 \times 10^6$ K. Hence the objects detected are likely to be powered by AGN rather than starburst activity (e.g. Condon 1992). In DEVOS, we are probing the same AGN population, but one or two orders of magnitude fainter than traditionally surveyed with imaging VLBI. The results of this pilot study can already be valuable in their own right since there are a couple of individual sources that may be worth studying further (e.g. J125858.6+325738 and J130129.1+333700).

DEVOS is a very demanding project in terms of network resources. With a detection rate of $\sim 40\%$, VLBI imaging of 10 000 objects implies 25 000 sources in the parent FIRST-based sample to be observed with MERLIN. The full SDSS-FIRST spectroscopic quasar sample will contain ~ 15000 objects (Ivezić et al. 2002). Our experience shows that a significant fraction of these is expected to have compact radio structure and could be detected with VLBI. With the technical capabilities available for the pilot experiment presented here, such a full survey would require approximately 600 days of MERLIN and 450 days of VLBI time. The time required can be significantly reduced with the perspective of further developments in the radio interferometric technique and an increased detection rate of the VLBI observations by "fine-tuning" the selection and filter criteria based on our pilot experience. After completing this pilot study, we initiated further VLBI and target-finding filter observations.

2 First AU-scale observations of V1647 Ori

In January 2004 a new reflection nebula (McNeil's Nebula) appeared in the LDN 1640 dark cloud of the Orion B molecular cloud complex (McNeil et al. 2004). V1647 Ori, whose outburst apparently caused the appearance of McNeil's Nebula, is a low-mass pre-main sequence object. Near-infrared colour maps show that the source is embedded in an elongated disk-like structure, whose size is approximately 7000 AU (Acosta-Pulido et al., in prep.). Since the object had been gradually fading until Oct 2005, when the eruption rapidly ended (Kóspál et al. 2005), it seems to be pausible that V1647 Ori is an intermediate-type object between FU Orionis and EX Lupi-type (Muzerolle et al. 2005 and references therein).

V1647 Ori was observed with MIDI, the mid-infrared interferometric instrument at the Very Large Telescope Interferometer (VLTI) with two 8-m Unit Telescopes (UT3 nd UT4), in Dec 2004 and March 2005 (Ábrahám et al. 2006). The obtained data set consists of acquisition images, 8–13 μm low resolution spectra (R=30), and interferometric measurements. Some of our results are summarised in the following.

1. The calibrated visibilities (Fig. 1) show that the source is resolved by MIDI on the UT3-UT4 baseline. The visibility curve suggests a non-uniform temperature distribution of the emitting material. The size of the mid-infrared emitting region is $\approx$7 AU at 10 μm.

2. The $8-13\,\mu$m spectrum *i*) exhibit no obvious spectral features thus cannot support models consisting of optically thin components; *ii*) the source faded in the N-band significantly between March (Andrews et al. 2004) and December 2004 but afterwards it exhibited an approximately constant spectral shape between December 2004 and March 2005; *iii*) the main fraction of the mid-infrared flux ($\approx$ 70%) is emitted in the innermost regions.

3. A simple disk model is able to fit both the spectral energy distribution and the observed visibility values simultaneously (Fig. 1). Model parameters for the disk were the following: $T(1\,\mathrm{AU}) = 680\,\mathrm{K}$ and $T{\sim}r^{-0.53}$, inner and

outer disk radii $7R_\odot$ and 100 AU, respectively, surface density $\Sigma{\sim}r^{-1.5}$, disk mass $M_d = 0.05\,\mathrm{M}_\odot$, inclination angle 60°.

3 Image reconstruction in the mid-infrared

The *Multi-AperTure mid-Infrared SpectroScopic Experiment* (*MATISSE*), designed as a beam combiner for 3 and 4-telescope arrays, will enable image reconstruction in the mid-infrared wavelength regime at the VLTI. It will overcome the ambiguities often existing in the interpretation of simple visibility measurements. We investigated image reconstruction methods of the Very Long Baseline Interferometry (VLBI) and the possible gains for *MATISSE* (Mosoni et al. 2005). The *MATISSE* image reconstruction studies show that 3-7 nights of observations with 3-4 ATs (1.8-m Auxiliary Telescopes) at varying locations will result in an uv-coverage which is sufficient in order to reconstruct images which allow to address profound science questions.

Different methods have been developed to handle the image reconstruction problem, e.g. deficiencies of the Fourier-plane sampling and the limited phase information. We applied phase self-calibartion algorithms and compared the results to the reconstructed images obtained with a bispectrum algorithm (i.e. Building Block Method, Hofmann & Weigelt 1993). We considered two different scenarios for our image reconstruction study: The availability of 1. closure phases and 2. Fourier-phases.

In the first case, phase self-calibration methods, which correct the Fourier-phases taking the measured closure phases into account, need a starting model. In some cases, even with complex source structure, this model can be a point source and so the procedure is model-independent. But in general, the starting model consists of some model components (point source, Gaussian distribution, etc.) in order to obtain a reconstructed image which fits to the visibility data well. In this case, the model-independent Building Block Method is more favourable. But in some cases, the bispectrum or the closure phase information were not sufficient for succesful image reconstruction. In most of these cases, the image reconstruction was succesful with radio interferometric techniques because the Fourier-phase information can be considered. In a 3 or 4-telescope configuration the closure-phases and the bispectrum contain much less information on the source structure than the Fourier-phases.

Bispectrum and phase self-calibration methods are available, the image reconstruction will depend on the VLTI infrastructure and instrumentation – what observables will be measured.

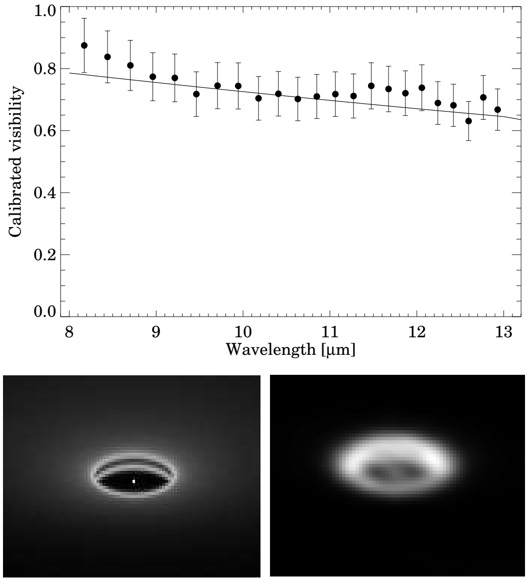

Figure 1: *A comparison of the outputs of present and future infrared interferometers. On the top panel the calibrated visibilities obtained with MIDI for V1647 Ori are plotted as a function of wavelength. The uniform error bars of 10% reflect our conservative estimate of the uncertainties. The solid line represents the model visibility curve of V1647 Ori. An example of MATISSE image reconstruction test results is shown below: the model image (bottom left) and a reconstructed image (bottom right). The model image, created with the radiative transfer code MC3D (Wolf et al. 1999), is a circumstellar disk around a T Tauri star with an inner hole up to 4 AU at the distance of 140 pc.*

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