Optical Interferometry and Adaptive Optics of Bright Transients

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1 Introduction

Bright optical transients (i.e. transients typically visible with the naked eye) are populated mainly by novæ eruptions plus a few supernovæ (among which the SN1987a event). Indeed, usually one bright nova happens every two year, either in the Northern or the Southern hemisphere (see Fig. 1). It so happens that current interferometers have matching sensitivities, with typically visible or infrared limiting magnitudes in the range 5–7. The temporal development of the fireball, followed by a dust formation phase or the appearance of many coronal lines can be studied with the VLTI. The detailed geometry of the first phases of novæ in outburst remain virtually unexplored. This paper summarizes the work which has been done to date using mainly the Very Large Telescope Interferometer.

We invite the reader to have a look at the extensive review on the topic by Chesneau & Banerjee [1] for a complete description of the science on transients that can be achieved with optical/infrared long-baseline interferometers. We give a short summary of the content of this paper in the next section.

2 Why observing novæ with optical interferometers?

Optical interferometers represent a breakthrough in terms of spatial resolution, that can provide crucial information related to the nova phenomenon. All targets in the 3-5 kpc range can be potentially resolved by current interferometers (CHARA, VLTI, NPOI).

The VLT Interferometer can provide measurements of the angular diameters of the nova ejecta in continuum and lines, from the near-IR to the mid-IR in the very first moments of the outburst. The primary outcome of these observations is a direct

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estimate of the expansion parallax, thus the distance to novæ. Of importance is the possibility to spatially and spectrally resolve different near-IR emission lines to estimate the physical conditions throughout the wind and the ejecta. For those objectives, the medium spectral resolution of the near-IR instrument AMBER is an asset. If the nova appears to form dust (CO novæ), an in-depth study of the dust forming regions can be carried out with the MIDI instrument. Using a set of flexible observing runs, we shall follow the outburst from the first days up to several months.

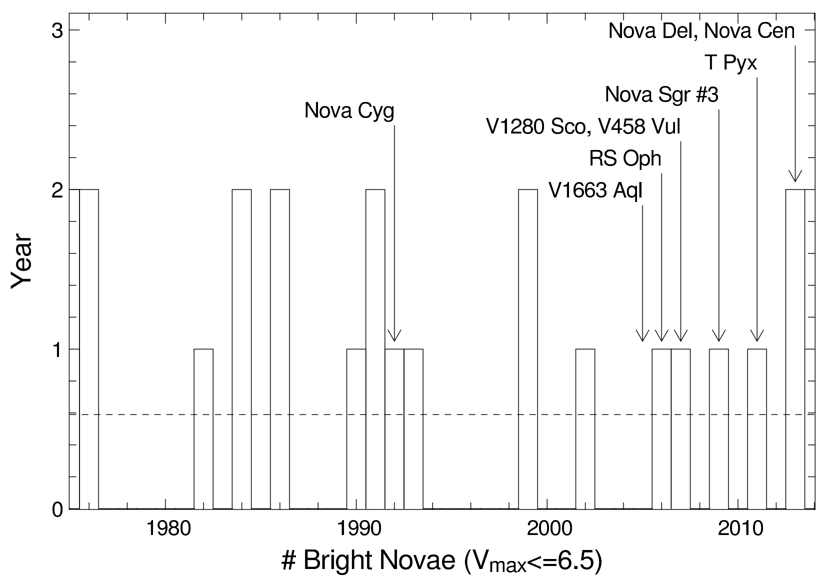

Figure 1: Typical frequency of bright novæ from 1975 to 2013. About one nova every two years occurs, either in the Northern on the Southern hemisphere (data from *http://www.cbat.eps.harvard.edu/nova_list.html*, complemented by data from *http://asd.gsfc.nasa.gov/Koji.Mukai/novae/novae.html*. Some peak magnitudes were corrected using AAVSO data). V1663 Aql & V458 Vul do not appear in this plot as they are too faint in V (but bright in K). The average rate per year is plotted as a dashed line. The arrows show Novæ observed with optical interferometers.

3 Nova as a spherical fireball

Up to now, the program of observations has focused on novæ with magnitudes reachable by the VLTI (South declination & K magnitude ≥ 7). Past observations and theoretical work on the nova phenomenon have provided a substantial knowledge about the physical nature of these binary systems and the outburst. However, these investigations are naturally limited by the difficulty of estimating the distance, which is usually inferred indirectly and with large errors. Spherical symmetry is a basic tenet adopted in the derivation of relationships that link the non-spatially resolved photometric and spectroscopic observations to the physical parameters of the system [2, Table 3]. Spherical symmetry is implicitly assumed when the *uv* coverage is not sufficient to perform a better analysis. This was the case for the Nova V1280 Sco [3] which was also observed exclusively using 2 telescope recombination. Two years after, observations with the AO system NACO mounted at the UT4 telescope revealed an impressive dusty bipolar nebula [4, see Fig. 2].

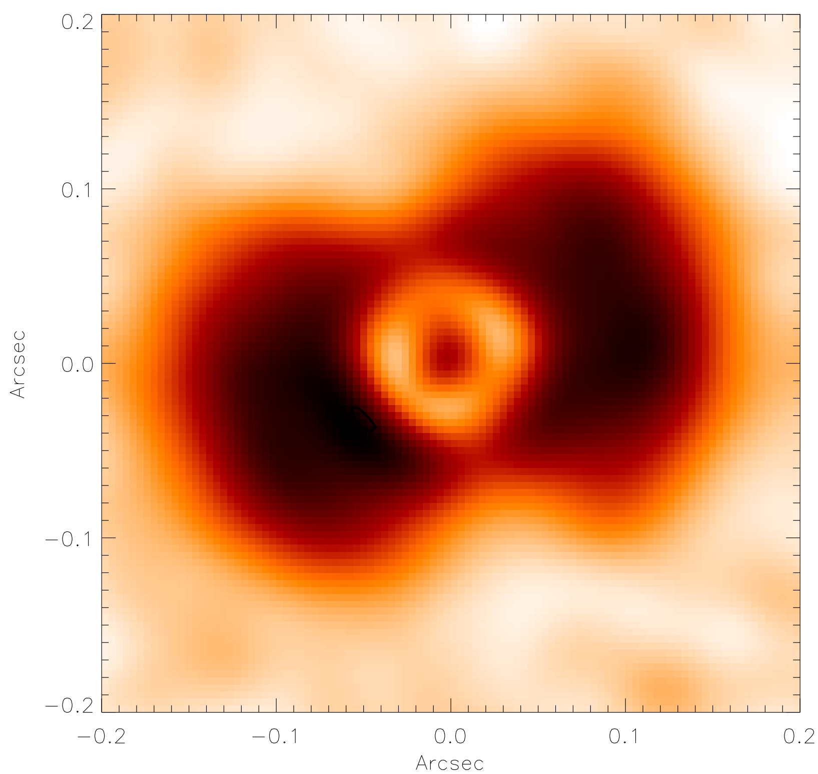

Figure 2: 2010 NACO K band image after a PSF subtraction revealing the impressive bipolar nebula. Mid-IR images also show that there is no dust emission in the equatorial plane.

4 A bipolar fireball from the first blink

An interferometer is mainly sensitive to the angular size of a nova in its early stages. Measuring the size of the fireball in different orientations on-sky allows us to infer the axis ratio and orientation of an individual nova shell. This is relatively easy to obtain for a 3–6-telescopes interferometer. This was the case for the outburst of the recurrent nova RS Oph [5].

The highly collimated outflow from the RS Ophiuchi has been imaged by the HST [6] and in the radio [7]. The AMBER observations showed that the jet was already in existance 5.5 days after the discovery, and provided a unique view of radial-velocities which could afterwards complement the expansion rates derived by the HST and radio images [8].

The signature of a bipolar jet in interferometric data is now well identified provided that the emission lines are spectrally resolved (R$\sim$1500). The famous nova T Pyx exhibited a spherical appearance in broadband PIONIER data, but the signature of bipolar kinematics was clearly detected in our spectrally resolved AMBER data [9]. The numerous peculiarities of the T Pyx eruptions can be explained in the frame of recurrent nearly face-on eruptions that launch fast material in the line-of-sight and slow material perpendicular to it, building up the slow expansion shell imaged by the HST.

5 Intermediate Luminosity Optical Transients

Intermediate-Luminosity Optical Transients (ILOTs), are eruptive stars with peak luminosity between those of novæ and supernovæ that have been also called Red Novæ or red Transient. The powering processes and whether they are due to binary interaction or are formed through single star evolution is debated. High angular resolution techniques can play a role by tracking bipolarity and the formation of disks. Furthermore, one can also study the remaining central star when a merger is highly suspected, for instance by detecting the deformation due to very high rotational rate.

5.1 Sakurai's object

In 1996, Sakurai's object (V4334 Sgr) suddenly brightened in the center of a faint Planetary Nebula (PN). This very rare event was interpreted as being the reignition of a hot white dwarf that caused a rapid evolution back to the cool giant phase. From 1998 on, copious amount of dust has formed continuously, screening out the star that remained embedded in this expanding high optical-depth envelope. Mid-IR interferometry performed in 2008 with the MIDI/VLTI instrument discovered an unexpectedly compact (30 40 milli-arc-second, 105 140 AU assuming a distance of 3.5 kpc), highly inclined, dust disk [10]. The major axis of the disk is aligned with an asymmetry seen in the old PN. This implies that the mechanism responsible for shaping the dust envelope surrounding Sakurai's object was already at work when the old PN formed, a strong argument for binary interaction.

5.2 V 838 Mon

V838 Monocerotis erupted in 2002, brightening by 9 magnitudes in a series of outbursts, and eventually developed a spectacular light echo. A very red star emerged surrounded by copious amount of new dust that condensed from the expanding ejecta of the outbursts. V838 Mon is the close-by archetype of the ILOT sources which are triggering very active research currently. MIDI/VLTI observations obtained over the last few months showed that the dust resides in the form of a flattened structure (∼15-50 mas from 8 to 13 μm), i.e. a 90x300 AU flattened structure for a distance of 6.2 kpc (Sparks et al. 2008). The modelling of this extended structure is in progress but it is incomplete without a much better knowledge of the central source which is seen as a very cool M-L type super-giant. AMBER observations were also obtained in 2013 to measure the size of the central source, its shape (since it has potential to be a fast rotator) and study the cool photosphere/dusty disk transition. The AMBER data were essentially acquired with small baselines ($\leq$ 30 m) and are quite noisy ($\sigma V^2 \approx 0.05$), leading to an angular size of 3 mas, but with a large uncertainty. We can basically only set an upper limit to the diameter of the HK-bands object, of 4.7 mas. This would make the HK-bands object smaller than 30 AU. This size (and shape) difference between the HK-bands and N band is striking and reminiscent of super-giant stars dusty disks [11, 12]. Further AMBER observations would enable us to pinpoint more precise properties of this intriguing object.

6 Conclusion and prospectives

We have presented here a few results from the VLTI campaigns on Novæ and ILOTs. These campaigns present a challenge in terms of scheduling and observatory response but provide unique insights on the early processes at stake when a nova explodes. With the upcoming infrared instruments like MATISSE [13] or GRAVITY [14], getting a finer idea of the geometry will be much faster than with current instruments. The development of visible interferometric instruments at the CHARA array or at the VLTI would also be an asset to get the sharpest multi-wavelength picture of these objects a few days after outburst before the advent of the ELT in the mid-2030s which will enable direct snapshot pictures of the fireball at tens of milli-arc-seconds resolution for a much larger number of novæ.

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