OLIVIER CHESNEAU’S WORK ON LOW MASS STARS

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Abstract. During his too short career, Olivier Chesneau pioneered the study of the circumstellar environments of low mass evolved stars using very high angular resolution techniques. He applied state of the art high angular resolution techniques, such as optical interferometry and adaptive optics imaging, to the study of a variety of objects, from AGB stars to Planetary Nebulae, via e.g. Born Again stars, RCB stars and Novae. I present here an overview of this work and most important results by focusing on the paths he followed and key encounters he made to reach these results. Olivier liked to work in teams and was very strong at linking people with complementary expertises to whom he would communicate his enthusiasm and sharp ideas. His legacy will live on through the many people he inspired.

1 Introduction

During the late stages of their evolution, low to intermediate mass (between $\sim 0.8$ and $8 M_\odot$) stars develop a large mass-loss (up to $10^{-4} M_\odot \text{yr}^{-1}$) that plays a key role in the chemical evolution of galaxies by enriching the interstellar medium with newly formed elements. This mass loss often leads to the formation of non spherical circumstellar envelopes. Olivier Chesneau became a world leader in the study of these circumstellar envelopes using the most advanced high angular resolution techniques, in order to understand this departure from spherical symmetry. His work and enthusiastic personality inspired many young scientist, as it was clearly shown during the conference dedicated to his memory. I will review his main contributions to the field of evolved low mass star.

2 Binaries and bipolar nebulae

Low mass stars appears more or less spherical in shape on the main sequence. When they reach the planetary nebula (PN) phase, the circumstellar envelope of
gas and dust that was formed during the Asymptotic Giant Branch (AGB phase), and then ejected, gets ionised by the central star. A wide variety of shapes is observed during this PN phase, nebulae being round, elliptical, bipolar or even multipolar. One of Olivier’s main interest was to try and understand this observed symmetry break.

For decades, meetings devoted to the study of the shaping of planetary nebulae where the stage of friendly fights between magnetic fields and binary people. Defenders of magnetic fields could model the formation of the observed collimated jets, while binary systems could lead to the formation of equatorial over densities such as disks and torus, that would favour a polar ejection of matter. To settle the debate, a football game was even organised at the Asymmetrical Planetary Nebulae IV in La Palma (2007). Olivier took part to the game, but his most important contribution to the community remains scientific.

Two key papers had an important impact for his research:

- Soker (2006) showed that a single star can not supply enough energy and angular momentum to shape those nebulae.
- Nordhaus et al. (2006) demonstrated that magnetic fields can play an important role but isolated stars can not sustain a magnetic field for long enough.

Binaries had to play a key role in the shaping of PNe, and Olivier really wanted to directly detect binaries using high angular resolution techniques, such as interferometry or adaptive optics imaging. Unfortunately, a given interferometric observation with two telescopes only probes a given spatial scale and orientation. To probe different spatial scales, one needs many baselines (i.e. different projected lengths and angles on the sky of the line formed by the two telescopes) to fill the so-called UV plane. This makes it very difficult to detect binaries with interferometry. For adaptive optics, the difficulties are due to the limited angular resolution at the time (∼50mas with NACO/VLT in the K band). Olivier thus realised it would be very difficult to directly detect binary companions with these techniques (at least with state of the art instruments around 2005) and decided to look for indirect evidences for binaries.

3 Discs and bipolar nebulae

Most of the scenarios proposed to explain the shaping of PNe rely on the presence of an equatorial disk (see e.g. the review by Balick & Frank (2002)). Disks can indeed either channel the mass loss toward the poles or lead to the formation of bipolar jets. The presence of such disks in the core of planetary nebulae can be indirectly observed by the presence of dark equatorial lanes in optical observations or via their polarimetric signatures. However, to better understand the impact of disks on the shaping of the nebulae, one needs to measure its mass, size, geometry and angular momentum. This can also give us information about the formation process of the disks. Binary companion can indeed provide the extra angular momentum necessary for the stability of a disk. Olivier decided to combine high
Fig. 1. Sketch of Olivier’s technique to look for disks in the core of PNe using interferometry with 2 telescopes. Left: two perpendicular baselines (in white) as projected on the HST image of the PN Menzel 3. Right: visibilities obtained for different baselines orientations. The main idea is to obtain interferometric measurements along different projection angles of the interferometer baseline (the line between the two telescopes) on the sky. An interferometer measures visibilities, which is the Fourier transform of the 2D flux integrated perpendicular to the baseline. To translate this to people who do not live in the Fourier space (like Olivier), it means that, for a given baseline, if the visibility is large, then the measured object is small, and vice versa. The MIDI/VLTI observations of the planetary nebula Menzel 3 presented here show a clear interferometric detection of a disc, as the visibilities reveal the presence of a structure flattened in the polar direction.

angular resolution observations and radiative transfer modeling to measure the mass and kinematics of such disks.

4 MIDI/VLTI to peer in the core of Planetary Nebulae

The disks in the core of planetary nebulae are compact (inner radius ~ a few AU at 1kpc or more) and dusty. The best way to directly peer into their centre and measure their size and geometry is achieved by using the highest angular resolution techniques. Probing their dust emission is also best done in the mid-infrared regime. Olivier thus used his favourite technique, namely optical/infrared interferometry to hunt for disks in the core of planetary nebulae. The best tool available when he started doing it was MIDI, the mid-infrared combiner of the Very Large Telescope Interferometer (VLTI). Olivier quickly turned MIDI, a two telescope combiner, into a disk hunting machine.

Optical/infrared interferometry can sound scary to non-interferometrist, but Olivier quickly managed to convince the PN community that it was a great disc
hunting tool. His observing techniques is quite easy to describe, but more complicated to apply. The MIDI instruments measures visibilities along the baselines formed by the two telescopes it is using. To make it simple, the visibilities provides an estimate of the size of the emitting region the interferometer is probing. Thus, for a given baseline, if a visibility is small, the object is large and vice-versa. Using different baseline’s orientation (this can be achieved using different telescopes and the earth’s rotation), one can thus measure the size of emitting regions in the core of PNe along different directions. Fig.1 shows the interferometric signature of a disk obtained using this technique with MIDI.

5 Olivier the disk hunter

Applying his observing technique with MIDI/VLTI, Olivier became a disk hunter. A key point of this work was to combine interferometric observations (to peer into the core of PNe) with high angular resolution imaging (to study the larger scale distribution of gas and dust). Having an idea of the larger scale distribution of gas and dust is indeed very important to interpret the interferometric signals. His first target was CPD-568302, a PN with a [WR] central star, for which the presence of an edge-on disk was hinted via HST spectroscopic observations showing an equatorial obscuration (De Marco et al., 2002). He decided to observe this promising target, together with Hen 2-113, its sibling PN, sharing many spectral and spectroscopic properties. As he was new in the PN field, he contacted Orsola De Marco who was an expert in the field and had indirectly proven the presence of a disk in the core of CPD-568032. One of Olivier’s main qualities was to build and lead teams of scientists from different horizons. For this project he built a strong and enthusiastic team comprising one of his former PhD supervisor Agnes Acker, Bruce Balick and Albert Zijlstra. He could find collaborators at any time and in any situation. I thus joined this project, which ended up being one of the key points of my career, after meeting Olivier in the restaurant of the Observatoire de la Côte d’Azur in Nice (which is arguably one of the best restaurant in an astronomical institute worldwide). I was a PhD student, and Olivier had just been hired as a tenure astronomer. We quickly realised we both had ESO data on Hen 2-113 and decided to work together. I then discovered the Chesneau Method, defined by three words: enthusiasm, curiosity and passion. After a month of long days and short (very short) nights, our first paper together was out. An equatorial torus was resolved in Hen 2-113 (Fig.2, left; Lagadec et al., 2006) from the adaptive optics images obtained with NACO/VLT. A disk was resolved in the core of CPD-568032 with the MIDI/VLTI observations. Interpreting those observations was a real headache for Olivier and his student Arnaud Collioud, as the structure of CPD-568032 (Fig.2) is very complex. The nebula is made of many jets with different orientations, and obtaining the geometry of the disk was a real challenge that Olivier overcame (Chesneau et al., 2006). He combined these observations with 3D radiative transfer modeling to estimate the mass of the disk and its dimensions.

Olivier’s main lesson from these first successful observations was that it would
be simpler to observe edge-on PNe with clearly defined bipolar structure. It would then be more straightforward to determine the orientation of the central disks. He got inspired by observation by Smith & Gehrz (2005) to observe M2-9 (the Butterfly nebula) and Menzel 3 (the Ant Nebula), a work that he did together with his student Clarie Lykou. From these VLTI observations, he discovered a disk in the core of Menzel 3 (Chesneau et al., 2007) and M2-9 (Lykou et al., 2011). The disk in the core of M2-9 appeared denser and more extended than the others, so that it was observable with the IRAM interferometer at plateau de Bure in the millimeter domain. Olivier started working with Arancha Castro-Carrizo and showed there was a great synergy between infrared and millimeter interferometry observations (Castro-Carrizo et al., 2012).

As Olivier’s technique to look for disks in the core of PNe turned out to be very successful, he decided to apply it to new type of objects. Together with Geoff Clayton, he decided to peer into the core of Sakurai’s object, a Born-Again Star, i.e. a PN in which the central star underwent a so called Very Late Thermal Pulse that reignited nuclear reaction. His observations led to the detection of a dense equatorial structure (Fig. 3 left; Chesneau et al., 2009), that he could not fit with a stratified disk model, as in the case of PNe. This is certainly due to the fact that this disk is really young (∼ 15 years). An interesting point of these observations is that the main axis of the disk is orientated perpendicularly to an asymmetry observed in the old PN (Fig. 3 right). This indicates that the disk/torus shaping mechanism was also in action when the AGB star’s envelope got ejected. A few scenarios are possible to explain it, but Olivier was convinced it was due to the influence of a close binary companion.

His final work was a study of a RCB star, V854 Cen. Those stars are F-G type supergiants experiencing unpredictable episodes of deep obscuration (up to
8 magnitudes in V). Two scenarios have been proposed for the formation of RCB stars. They could be the produce of the merger of two white dwarfs or due to final helium flash (a bit like the Born-Again stars) in a PN central star. Olivier wanted to look for a disk in the core of V854, which would favour the double degenerate scenario, as a disk is very likely to be formed around a binary system. He thus applied his disk hunting technique to V854 Cen. With observations obtained in 2013, he resolved a structure in the core of this RCB star, but the measurements were all made with baselines with similar orientation. He needed visibilities measurements with other orientations to determine whether this structure was spherical or not. While in hospital, he prepared these observations and we discussed about observations I had obtained with the mid-infrared imager VISIR/VLT (Lagadec et al., 2011). The VISIR images were showing the presence of a weak, non spherical, circumstellar structure. However, it was difficult to convince him that the structure seen in the VISIR images was real and not due to a bad background subtraction. Together with Djamel Mekarnia, we worked on a careful re-reduction of the data, until we convincingly showed the presence of an elongated dusty structure around V854 Cen. Olivier became very enthusiastic, as the structures seen in the VISIR data were similar to the one hinted in his MIDI/VLTI data. He just needed data taken with new baselines to confirm it. He had a VLTI visitor run the week after, but he could not go to Chile, as he was already in palliative care. Florentin Millour prepared the observations with an over-enthusiastic Olivier. We recieved a great support from ESO staff in Chile (and particularly from Willem-Jan de Witt) who helped us obtaining data without being able to travel to Chile. The data, reduced within a few hours by Alain Spang, confirmed Olivier’s prediction, who then certainly broke a world record by submitting a paper based on VLTI data obtained less than 48h before (Chesneau et al., 2014a).
The same week, Olivier worked very actively with Florentin Millour on data he had just obtained of V838 Mon, the iconic nova-like object that erupted in 2002. The eruption was very likely due to a merger event. Olivier’s VLTI observations showed that this merger event lead to the formation of a disk. He submitted this paper (Chesneau et al., 2014b) a few hours before leaving us to get closer to his stars.

6 Conclusion

Olivier Chesneau played a key role for the understanding of the shaping of bipolar nebulae around low mass stars via his study of disks in the core of these objects. His dream was to directly image the binaries that are certainly responsible for the formation of disks and the shaping of these objects. To achieve this, Olivier was very involved in the science team of the SPHERE/VLT project. This new generation instrument of the VLT uses an extreme adaptive optics system to obtain diffraction limited images in the optical with a resolution down to \( \sim 15 \) mas. Olivier was leading the Other Science group for the SPHERE GTO Guaranteed Time Observations team and his main interest in this project was to map the innermost parts of evolved stars to study their morphologies, dust formation and hopefully detect binary companions. Since the first semester of 2015, this instrument is now offered at the VLT, and one of the first results it delivered was the detection of a binary companion around the binary star L2 Pup (Kervella et al., 2015 and this volume). Working with Olivier, Pierre Kervella had identified the presence of a disk around the AGB star using NACO/VLT imaging (Kervella et al., 2014). The detection of this binary companion of an AGB star was presented during this meeting honouring Olivier’s memory. It was quite symbolic to see one of Olivier’s dream being presented there.

Summarizing all the contribution of Olivier Chesneau to the field of low mass evolved stars was not an easy task, but his main contribution was to bring a huge leap forward in the study of the innermost part of circumstellar environment around these stars. Before Olivier’s work, people were talking about sub-arcsec astronomy, and Olivier brought the milliarcsec to the community.

Olivier not only brought state-of-the-art high angular resolution observations to the community, but also ideas about how to make the best use of these techniques to understand the physics of these objects. Olivier was also very good at bringing people with complementary expertise to work together and tackle important problems. His passion and dynamism was a key for that and was immensely communicative. His main legacy will be this passion and enthusiasm he gave to a whole generation of young astronomers in Nice and all over the world.

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