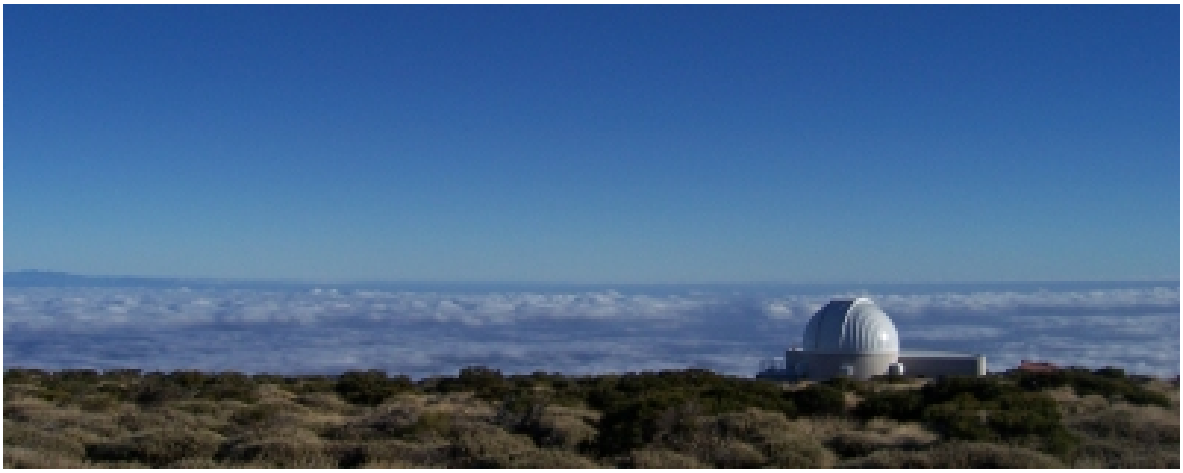
Stellar Winds above Atlantic Clouds

A collaboration between amateurs and professionals



Many amateur astronomers admire the professionals for their highly sophisticated equipment and their exclusive access to spectacular observing sites all over the world. Professional astronomy seems to be a league of its own. However, there are some fields in astronomy where amateurs can contribute reasonable scientific results even with small-size telescopes. One of these fields is spectroscopy of bright, massive stars. Today, high-resolution spectrographs which match professional requirements can be constructed by average skilled amateurs or bought off-the-shelf. On the other hand, professional astronomers who need long time-coverage of special targets find it difficult, if not impossible, to get extended observing runs at large instruments. They have to use small-size telescopes.

The idea

In 2006 I discussed the upcoming periastron passage in January 2009 of WR 140, a WR+O binary in the Cygnus constellation with a highly eccentric orbit and a period of about 8 years, together with my mentor and friend Tony Moffat at the Université de Montréal in Canada. The two stars would then come much closer together for an interval of several months, whereby their strong winds would collide with great force. Because the O-star wind is about ten times less intense than the WR wind, a shock-cone of dense and highly excited material wraps around the O star component as the two winds collide at supersonic velocities. WR140 has already been a target of previous observing campaigns but some important parameters (e.g. the opening

angle of the shock cone, the system inclination) remain poorly constrained. Beside the seldom opportunity for detailed investigations just every eight years, the periastron passage should be covered for more than just a few nights. An extended run of several months is required to do the job. This limits one to a smaller telescope at one or more observing sites, since large telescopes are rarely used this way. In any case, a group of observers would be essential to do the job: Who wants to spend four months non-stop observing? Another solution would be to use robotic telescopes, but then where's the hands-on fun?

I announced this idea in the forum of the section SPECTROSCOPY of the German Amateur Society VdS (spektroskopie.fg-vds.de) as well as in the forum of the ASTRONOMICAL RING FOR ACCESS TO SPECTROSCOPY (ARAS - http://astrosurf.com/aras) of our French colleagues and designed a respective webpage (http://www.stsci.de/wr140) to bring all parties to the same level of information.

Periastron passage of WR140 should be observable with a medium-resolution spectrograph on a small telescope and soon enough, a number of experienced observers from Germany, France, England, Portugal and Spain took notice of this information as important in the context of their own programs. It became clear that amateur involvement in spectroscopy could contribute to professional investigations. Furthermore, this campaign could bind together amateurs from different countries for further work in the field they love.

The WR+O Binary System WR 140

The archetype of colliding-wind binary (CWB) systems is the 7.9-year orbiting WR+O binary system WR140 (HD193793), where the stellar separation varies between ~ 2 AU at periastron and ~ 30 AU at apastron. The binary is frequently considered a textbook example of the colliding-wind phenomenon. The binary consists of a moderately hot carbon-sequence Wolf-Rayet (WC7) star orbiting a more massive and luminous, evolved O5 companion. The system's high eccentricity and rather favorable inclination help to probe different regions of the Wolf-Rayet wind and, at the same time, the profound change of conditions in the wind-wind collision zone around the time of periastron passage. This change is mainly reflected in rapid formation of carbon-based dust and can be detected as gigantic IR outbursts occurring

on a strictly periodic (once per orbit) timescale. The system has a relatively long period and, despite the very high eccentricity (e = 0.88), even a long-lasting periastron passage. This poses a challenge for professional astronomers to obtain a lot of data during periastron passage. Due to WR140's brightness (visual magnitude 7.0) amateurs can indeed obtain reasonable data, providing a good opportunity to collaborate with the pros.

The spectrum of WR 140 is dominated by huge and broad emission lines like all Wolf-Rayet stars. The hydrostatic surface of the star is invisible due to a strong stellar wind and we can not MK-classify WR stars in the usual way as for normal absorption-line stars. As a consequence of the extremely broad emission-lines, it is difficult to define a clear continuum level between the lines, so a reliable spectroscopic rectification is difficult. Since WR 140 is a binary, we find a number of absorption lines from the O component superposed on its WR spectrum. Very narrow interstellar absorptions are also seen in the combined spectrum, with the Sodium D1 and D2 lines around 5900 Å being the most prominent in the optical spectrum. The orbit has an advantageous inclination to the line-of-sight, allowing relatively large Doppler motions to be measured for such a wide system. In Figure 1 this direction is defined by a projected straight line and one can see that the outflowing shock-cone material, produced by wind-wind interaction of the two components (see also Figs 2 and 3), changes its apparent flow direction from blue to red during periastron passage. Before periastron passage the material moves towards the observer and afterwards it moves away from the observer.

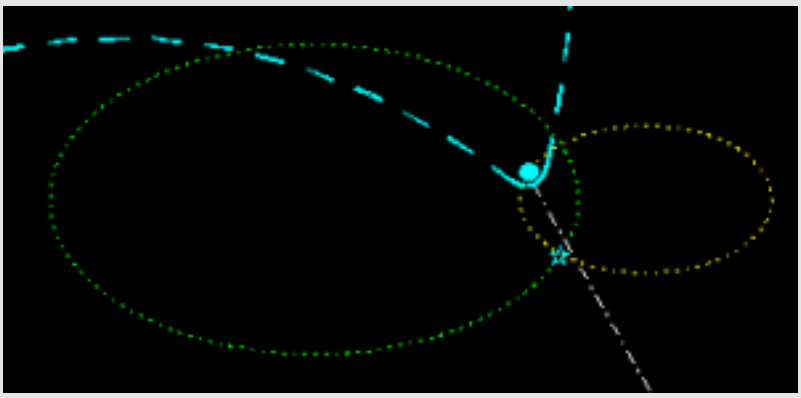


Fig 1: Orbit of WR 140 with the larger ellipse for the less-massive WR component indicated by an asterisk in one position in the orbit and the smaller ellipse for the O component indicated by a large dot. The orbital motion for each star is clockwise in this plot. The line-of-sight to the O star is indicated by a straight line.

This situation leads to spectra as illustrated in Figure 4. First, an average spectrum was computed (top) outside periastron, when wind-wind collision effects are not yet seen. By subtracting this average from individual spectra, the residual emission comes from hot,

compressed material which is produced within the shock cone (somewhere downstream from the head). In the lines observed to show an excess emission from the shock cone, those from CIII 5696A and (more difficult to see) He I 5876A, one can observe that the excess appears shortly before periastron, moves from blue to red and disappears after periastron. In addition, one can see in Figure 5 that the excess line emission quickly increases and decreases in strength during periastron passage.

During the past decade, WR 140 has been a frequent target for long-term multiwavelength campaigns with subsequent state-of-the-art modeling of the colliding-wind phenomenon. In 1999–2002 we intensified our large optical campaign in an attempt to follow the system with shorter time steps through the February 2001 periastron passage. To our pleasant surprise, the ‘‘clockwork’’ behaviour of WR 140 dramatically emerged during this first truly intense campaign. (from Marchenko et al. 2003, The Astrophysical Journal, 596, 1295)

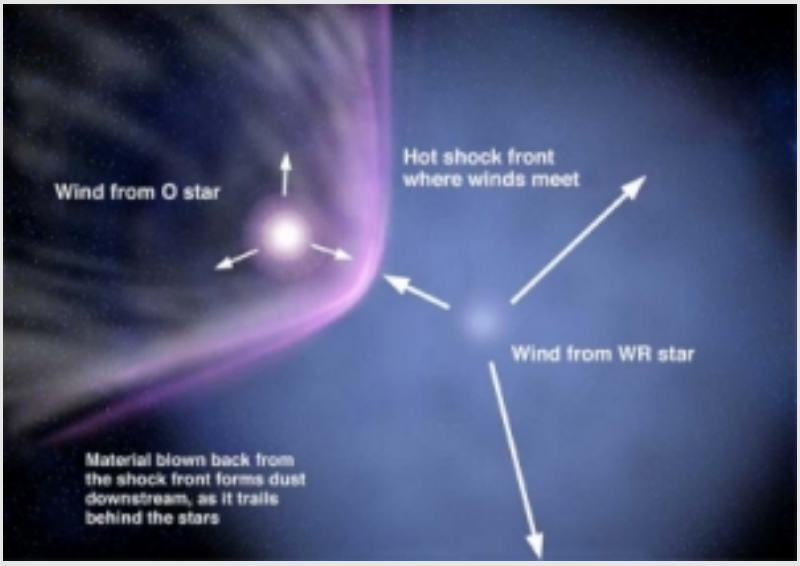


Fig. 2: The wind-wind interaction produces a shock cone.

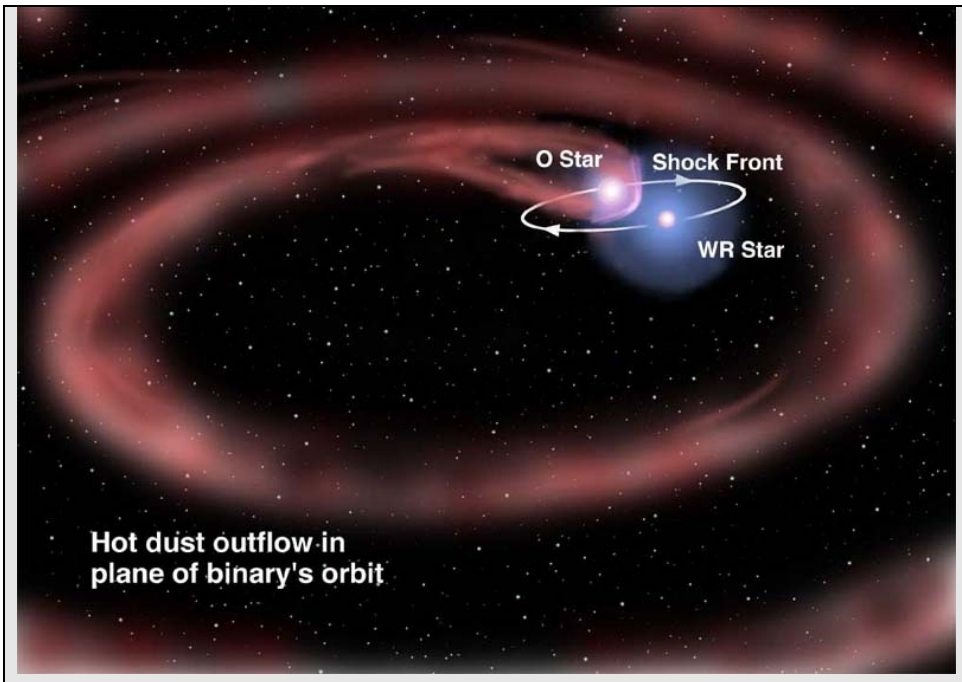


Fig. 3: The hot, excited material drifts along the shock front and creates a one-armed spiral due to the orbit of the two stellar components. The material radiatively cools, temperature drops and dust is created. In the case of WR140, with its highly elliptical orbit, dust formation does not occur uniformly around the orbit, but rather mostly around periastron.

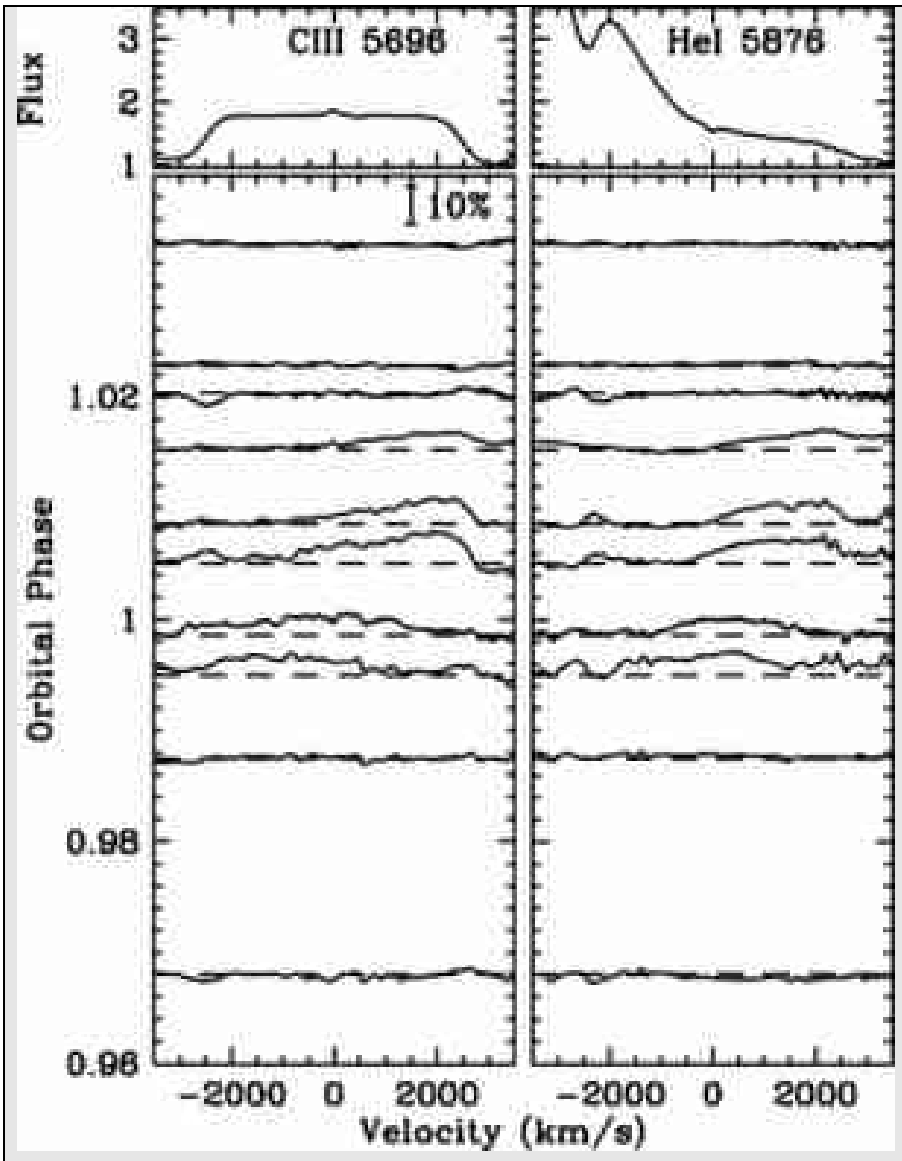


Fig. 4. Excess emission of CIII and HeI moving in wavelength during periastron passage.

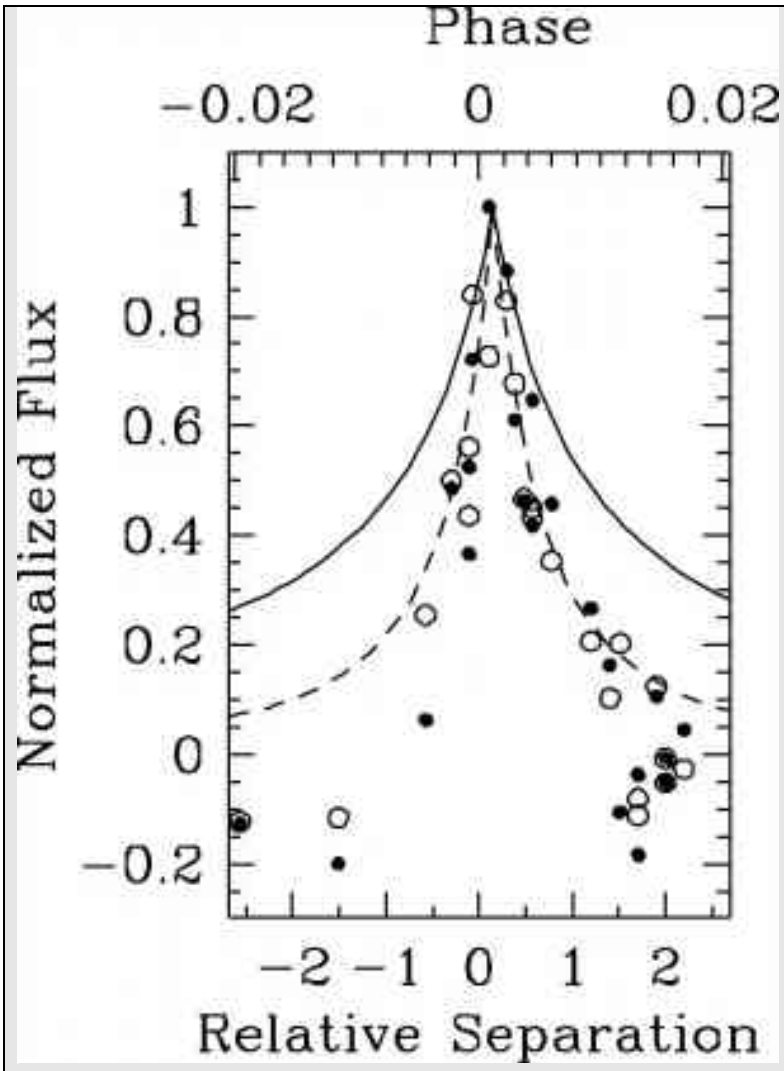


Fig. 5: Normalized excess flux at closed approach.

Major parameters of WR 140

- Type: WR+O binary (actual types: WC7pd + O5I)
- Visual Magnitude = 7.07 mag
- Periastron passage at = HJD 2 446 147.4 ± 3.7 (1985)
- Period P = 2899.0 ± 1.3 days
- Inclination i = 50° +/- 15°
- Half opening angle of the shock cone θ = 40° +/- 15°
- Orbital Eccentricity e = 0.881 +/- 0.005
- Coordinates RA (2000) 20h 20m 27.98s, DEC (2000) +43° 51' 16.3"

Within some days a number of amateur spectroscopists in Germany, France, Portugal, England and Spain announced their interest in participating in a coordinated campaign. In addition, some simultaneous professional campaigns were initiated in France, Finland, India, Canada and the USA, as well as for the X-ray space telescopes Rossi X-Ray Timing Explorer (RXTE) and Chandra.

Some weeks later I took the airplane to the island of Tenerife together with my girl-friend Britta to visit my long-time friend Johan Knapen, now professor at the local astrophysical institute which runs the famous observatories on La Palma and Tenerife. When approaching the island, I peered through the airplane window at the Teide mountain high above the clouds and immediately recognized the local astronomical observatory Izaña. Izaña is a first-class site with respect to atmospheric conditions. It made me think... it obviously would be better to have a private telescope and run the WR 140 campaign here on the island and not from the cloudy mess in central Europe. That is what I told Johan one evening over a beer in a local pub. Johan calmly replied: "We have such a telescope up at Izaña and I believe you can use it." I was thrilled and Johan ordered the next beer. The next weekend we visited the MONS telescope on the mountain. It is an f/15 Cassegrain of 50cm aperture. The infrastructure is not as good as some advanced amateur telescopes but one can use it for research. It has electronic guiding but no GoTo pointing . It has an SBIG ST8 camera and can be used by students and visitors as a toy not to disturb other scientists working at other larger telescopes on the mountain.

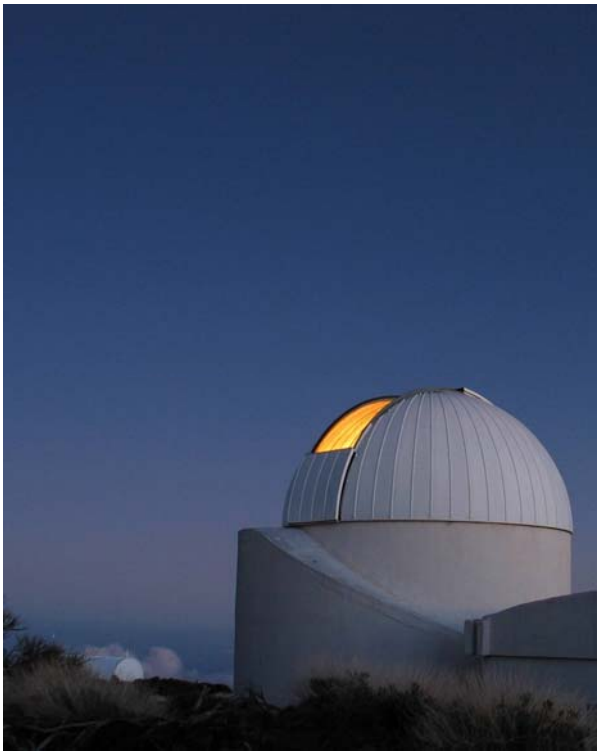
Teide Observatory in snow and lava.

Johan got excited as well and promised to give local support (at this point Britta was convinced that we had gone nuts). A quick cost calculation for a campaign of 3.5 months with eight teams of 2-4 observers for two weeks each at the telescope resulted in 700 Euro per person (including charter flight, team rental car and accommodation at the observatory). Meals were extra but very cheap at the residence. Back in Europe I spoke to Gregor Rauw and Thierry Morel at the Université de Liège in Belgium about additional program stars. They chose some Oe and B-stars to investigateperiodic phenomena in their winds. With time-scales of 3 – 15 days they matched our campaign well. I announced the idea again in the German and French spectroscopy discussion-forums and 15 amateur astronomers (ranging from a high-school student to a physician) from Germany, Portugal and Holland wanted to join this campaign and work on the mountain.

Tony Moffat became our main scientific partner. His PhD student Rémi Fahed came on board as well (on the mountain, he was coached by José Gallego from the IAC = Instituto de Astronomia de las Canarias). Perfect! The next question was about other targets. WR 140, a summer object in Cygnus to be observed in winter when periastron occurred , was terribly placed in the sky , close to the horizon and setting even at sunset (or later, rising at sunrise). We had plenty of time left over during the

nights, so we convinced Thierry Morel and Gregor Rauw to join us with their favourite targets. The run would start on Dec 1, 2008 and end on March 23, 2009. In addition, amateur Robin Leadbeater in England participated with his own observations in Cumbria (as well as some other “MONSters” at their own private observatories) and Otmar Stahl from the Landessternwarte in Heidelberg gave regular technical and scientific support via email. Rémi would reduce the WR data while Gregor and Thierry would look after the Oe and B stars. Hence, we could expect three publications in refereed scientific journals. All participants would sign as co-authors.

Tony and I started writing the proposal *STELLAR WIND TANGO* (see our project webpage) and iterated it together with Gregor and Thierry and especially with Johan at the IAC. It was a success and the IAC panel assigned sixteen weeks to it at MONS.



MONS telescope at Izaña Observatory.

Technical preparations

First we decided to completely use our own equipment, since we quickly learned that MONS has low support priority by the local technical staff. There was a CCD and a control room with an internet connection but no further computer control for the telescope. No GoTo technique (*fine, we could find the stars by hand*), no

spectrograph (*OK, we will bring our own*) and no other equipment for our goal (*great, a challenge*). The biggest penalty was the position of WR 140 in the sky. In twilight it would quickly drop to the horizon and would vanish after an hour or so (*wow, a risky job*). It was almost impossible to work under such conditions but we all loved the challenge! .

German amateurs Berthold Stober and Lothar Schanne are experienced in mechanics and instrument design and took responsibility for the technical aspects. They managed to fix all major questions with respect to the spectrograph (donated by another German amateur colleague Wolfgang Arnold) and the CCD (on loan from the German manufacturer Gerhard Fischer). They even constructed a flip-mirror design for guiding and implemented a Shapley lens as a focal reducer for our set-up. It became clear that they should be the first team at MONS with the most difficult part, the set-up of the whole system.

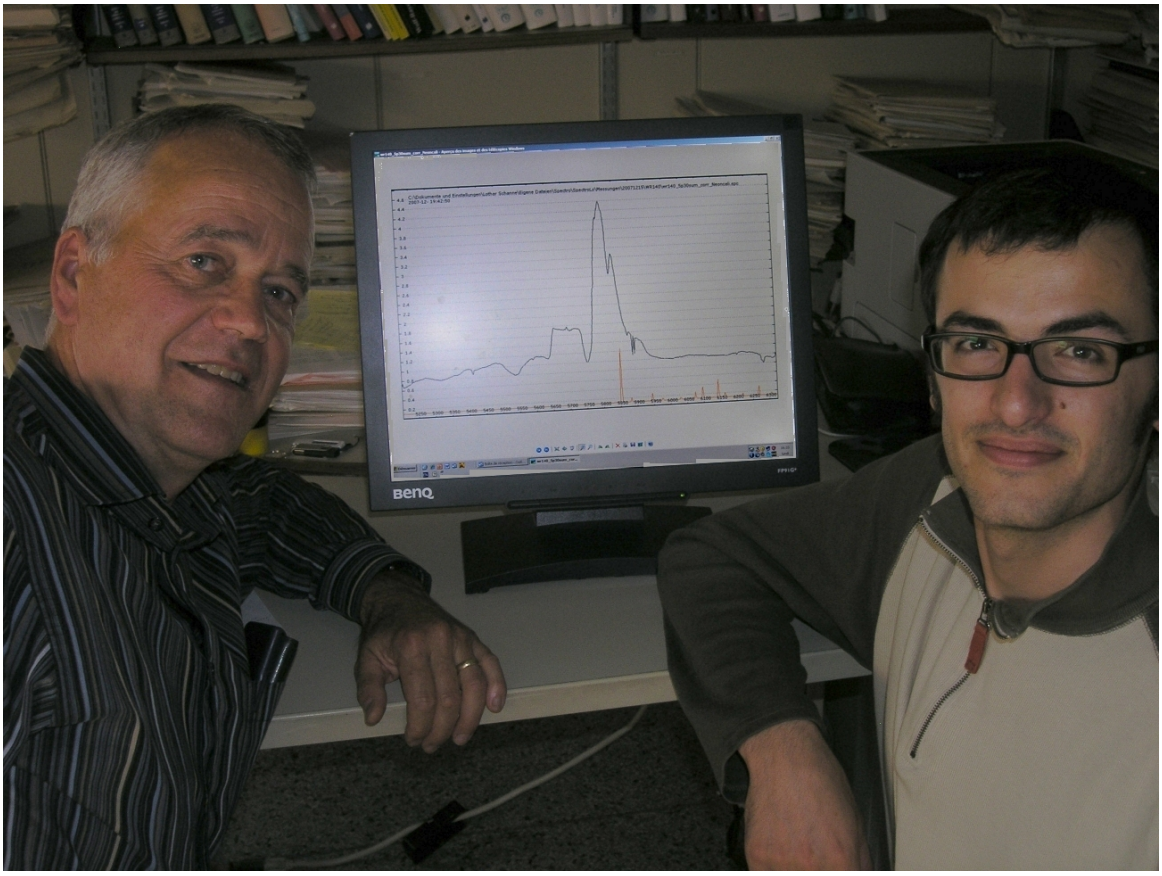
To start the ball rolling well in advance of the mission, , we organized two workshops in Berthold's house. All German amateur team members plus Otmar Stahl from Heidelberg Observatory participated (Portugal and Canada were too far away). Berthold runs a doctor's practice and had been on call during the whole weekend. For the rest of the gang this was quite fine and we all offered extensive support for any heart operation. At a certain point it is better to meet in person instead of using email for complicated problems. Best ideas come when coffee and cake are served (e.g. from Berthold's personal pastry cook Barbara). We discussed bias-, flatfield- and dark-correction images, finding charts, shock fronts, refraction, guiding problems, telluric lines, excitation levels, ftp-servers, USB extenders, FITS formats, and, and, and…; it was wonderful!

The German MONSters at one of the pre-mission workshops.

Berthold Stober and Thomas Hunger at the lathing machine.

Then I bought the flight tickets for the German gang. It was a strange experience to order some tickets and pass the "point of no return" without buying the tickets for our Portuguese friends and for Rémi in Canada. I did not have everything under control. But in fact, I learned very early that these unknown friends somewhere abroad are as crazy about astronomy as I am, and hence, 100% reliable. Some days later I received the information that all tickets had been reserved for the Portuguese people as well and I started accommodation reservations at the Observatory. One cannot begin to count the emails sent back and forth to Johan on Tenerife to get answers on different questions and open issues about the telescope. It may be that we could have managed all preparations without him but I doubt that it would have been completed as well and as safely as it actually went. The art of campaign management does not consist of organizing all the details in advance, but the willingness to leave experts off the chain and then see how problems simply disappear.

Then I left for Montreal together with Britta. Beside my holidays in Tony and Ann Moffat's house and their cottage in Ontario, I wanted to discuss the campaign with him and his PhD student Rémi. Soon after our arrival, Ann informed me about her ever-lasting indifference towards all things astronomical (she loves culture and books) and Tony informed me about his new enthusiasm for garbage recycling, his new sailboat and the world-wide ground-based WR140 activities, in Canada, the USA, Finland, France and India. Our necessary spectral resolution and the wavelength intervals to be observed were crucial issues and we all agreed with Tony that we should make the run as easy and, hence, as little risky as possible.



Tony Moffat & Rémi Fahed.

Tony explaining the beauty of the WR 140 periastron passage. I am thrilled!

Back in Germany we began to prepare our equipment box for shipping to Tenerife so that it would arrive early and Johan could check it for potential damage. Shipping our box was somewhat difficult because Tenerife is not a member of the European Custom Union. After some discussion with respective shipping companies, we sent the box four weeks before our run started.

Johan at the residence at Izaña Observatory being sure that the whole MONS campaign is completely nuts.

The run

The first observers, Berthold and Lothar, left Germany on November 30, 2008.

Johan Knapen and Berthold Stober installing the spectrograph together with technician John Morrison.

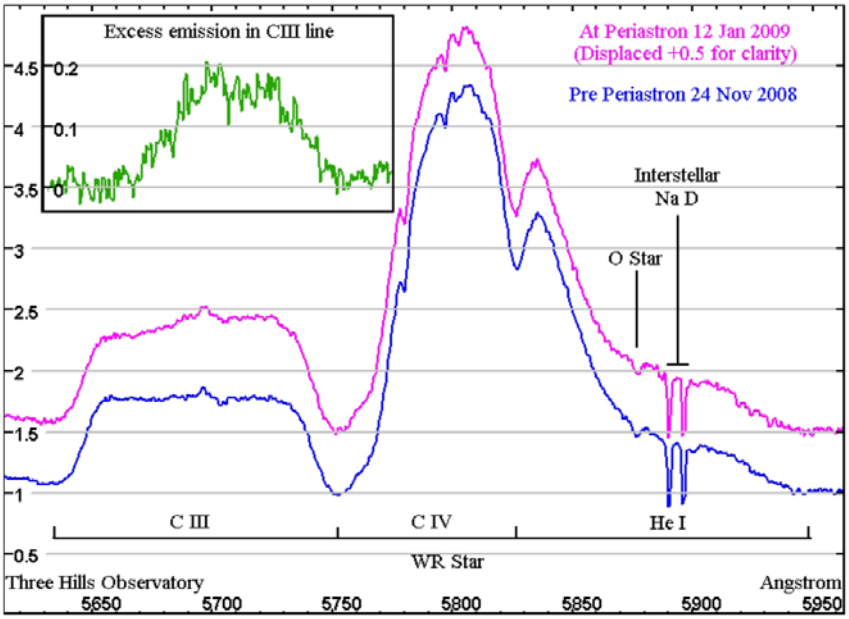
In the first two weeks they spent a lot of their time just setting up the campaign. As is typical at most telescopes, both small and large, they had some technical problems at first, e.g. with the CCD camera (the USB transceiver failed and we had to change the CCD) as well as with the optical system (the focus was difficult to adjust). But we eventually solved all problems with patience, commitment and with support from the colleagues in Europe and America. We had to define a routine on the mountain and then had to transfer it to the teams that followed. Often we increased our stress with technical alerts via email to everybody, but solved all problems with our combined technical expertise. Berthold and Lothar established the whole set-up in a very professional manner.

Our *youngster* Thomas Bergmann agreed to spend his time at MONS during Christmas, together with Filipe Dias from Lisbon. We all realized Thomas' skills as a spectrograph designer for his own private observatory and Filipe as a professional in computer engineering (in fact, he vastly improved the pointing software for MONS).

Filipe also made an extended run and remained on the mountain together with his partners Eva Santos and Nelson Viegas. However, they were clouded out for a complete week as an ice storm passed over Teide observatory. Filipe made a hilarious movie about the "*Icy observatory*" which can be found on YouTube. We all had a lot of fun looking at it.

Filipe Diaz and Thomas Bergmann take over from Lothar Schanne and Berthold Stober (left to right).

Even during periastron passage in January, Rémi Fahed successfully acquired data and additional spectra were made in Germany and England when clouds dominated over Teide. (Now, that's a switch!) It was unique to obtain these extra spectra, being quickly reduced within a few days. Hence, we were always well informed about the running status of WR140 and it was impressive to see the development of the shock cone in time.



Spectral variability of WR 140 within seven weeks (Courtesy of Robin Leadbeater).

The second Portuguese team at the MONS telescope. Luis Carreira, Filipe Alves, José Ribeiro and Alberto Fernando (left to right).

All teams performed in perfect routine. Thomas Hunger from Germany and Nando Romeo from Holland, as well as the pure Portuguese gang of Alberto Fernando, Filipe Alves, José Ribeiro and Luis Carreira, completed their missions . As a member of the final team together with Norbert Reinecke, we benefited from the extraordinary achievements of those before us. The harmonic game between software, telescope and spectrograph, implemented during three months was perfect (recall that we had no GoTo mechanism) and we finished the run without special problems. And after finishing the last night we only had to dismantle our equipment for transportation to Germany.

Résumé

All our data will presently be reduced and analyzed in Canada and Belgium for further publication. Thomas Bergmann wrote an extended report for his school about his experience; I squeeze out my brain by writing this text and everybody in the campaign will write down his and her experience, feelings and impressions for a joint book, to show our grandchildren what we have done, when our skins were less wrinkled. In addition, we are now planning a final campaign wrap-up meeting in Portugal to meet each other in person just for the fun of it.

Overall, one should be aware of two additional important results. First, we showed that collaboration between amateur and professional astronomers can be very fruitful. Amateurs do have the necessary technical skills and basic scientific knowledge. Second, we can expect that we and other amateur astronomers will now be positively acknowledged, especially with respect to future applications at various observatories. As far as I know, our pro-amateur campaign is the first of its kind on this scale and we can hope that the work of experienced amateur groups will be more and more appreciated and supported by the professional science community.

Acknowledgements:

I thank all project participants for their various skills, their enthusiasm and trust in this unique campaign. They made it work and include : Filipe Alves, Wolfgang Arnold, Thomas Bergmann, Luis Carreira, Rémi Fahed, Alberto Fernando, Gerhard Fischer, José Gallego,

Filipe Dias, Thomas Hunger, Robin Leadbeater, Tony Moffat, Thierry Morel, Gregor Rauw, Norbert Reinecke, José Ribeiro, Nando Romeo, Eva Santos, Lothar Schanne, Otmar Stahl, Barbara and Berthold Stober, Nelson Viegas, Klaus Vollmann and Udo Zlender.

I want to thank Prof. Francisco Sanchez, Director of the Instituto Astrofisico de Canarias (IAC) and Miquel Serra for assistance and the generous allotment of telescope time at MONS.

My special thanks, however, go to Johan Knapen, my friend and colleague at the IAC. Only with his lasting and friendly local support were we able to laugh about Rudi Völler and Frank Rijkaard.

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