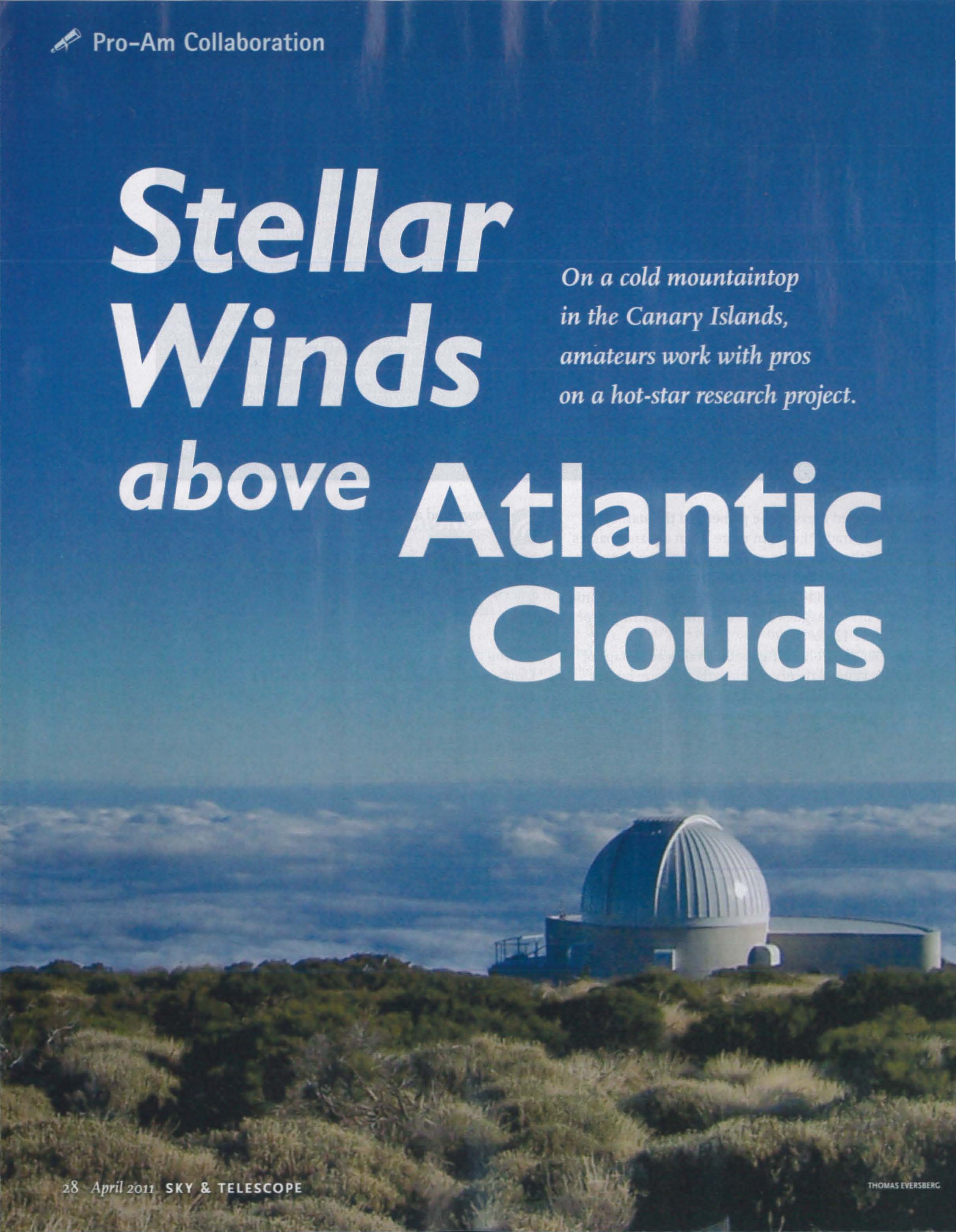
Stellar Winds above Atlantic Clouds

On a cold mountaintop in the Canary Islands, amateurs work with pros on a hot-star research project.



THOMAS EVERSBERG

AMATEUR ASTRONOMERS have always admired professionals for their awesome telescopes and equipment, their access to the world's best observing sites, and also for their detailed, methodical planning to do the most productive possible projects. Compared to what most of us do, professional astronomy is in a different league.

This is a story of how some of us went there and played on the same field.

Backyard amateurs have always contributed to astronomy research, but digital imaging and data collection have broadened their range enormously. One new field for amateurs is taking spectra of bright, massive stars to monitor variable emission lines and other stellar activity. Skilled amateurs today can build, or buy off-the-shelf, small, high-quality spectrographs that meet professional requirements for such projects.

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Professional spectrographs, meanwhile, are usually found on heavily oversubscribed telescopes that emphasize "fashionable" research and projects that can be accomplished with the fewest possible telescope hours granted by a time-allocation committee. It's hard to get large amounts of time for an extended observing campaign. So we created an unusual pro-am collaboration in order to bypass this problem.

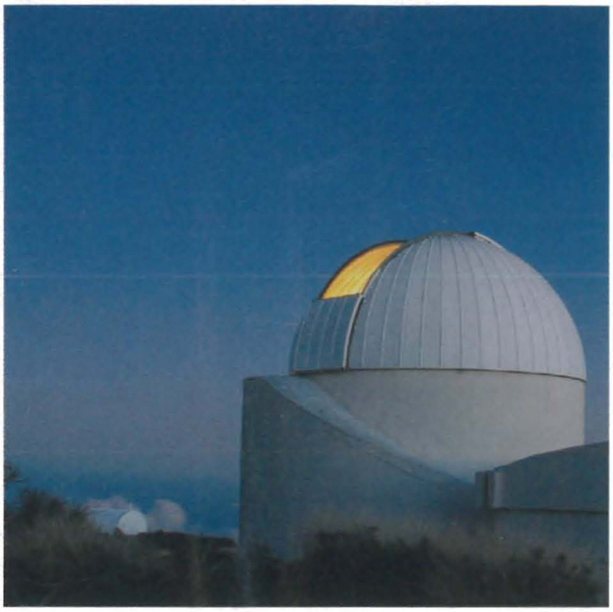
The Idea

In 2006 I had a discussion with my mentor and friend Anthony Moffat at the University of Montreal, who for many years has been a specialist in massive hot stars. Our topic was how to mount an observing campaign for the ultra-hot binary star WR 140 in Cygnus, the best known of the "colliding-wind" binaries. WR 140, at a distance of about 6,000 light-years, appears as a single, unassuming, magnitude-7.1 point of light in a telescope (or binoculars). But there's a lot going on here. The pair consists of a carbon-rich Wolf-Rayet star and a more massive, type-O5 star swinging around each other every 7.9 years. Their orbit is highly elliptical; at the far end of the ellipse the two stars are 30 astronomical units apart, but around periastron they rapidly dip to within about 2 a.u. of each other. At each such swing-by, the system creates a thick burst of carbon-rich dust, goes through a series of spectral changes at visible wavelengths, and displays a sequence of X-ray and radio changes as well. From observations of many kinds, astronomers have figured out that most of these phenomena arise where the two stars' powerful winds collide. In fact WR 140 has become the archetypal colliding-wind binary. But some of the geometry and physics has remained obscure.

HIDDEN IN PLAIN SIGHT In one of the summer Milky Way's most familiar rich fields for binoculars, the colliding-wind binary star WR 140 (also known as HD 193793 and V1687 Cygni) is almost lost among other 7th-magnitude specks.

JOSÉ RIBEIRO

WORKHORSE The Mons Telescope, a 1972-era 20-inch Cassegrain, poses above the project's second Portuguese team: Luis Carreira, Filipe Alves, José Ribeiro, and Alberto Fernando (left to right).



FILIPE DIAS

LOOKING UP Twilight falls on the Mons Telescope as preparations wrap up for its nightly rendezvous with a very interesting 7th-magnitude speck.

The two stars were next due to swing close by each other in January 2009. If we wanted to learn more, this was when the whole sequence of events ought to play itself out again.

The *WR* star is a bare, carbon-rich stellar interior that has already blown off its hydrogen layers and is on its way to going supernova. As such it emits about 10 times as intense a wind as the hot *O* star, which still retains its hydrogen mantle. Because of this imbalance of power, the wind of the *WR* star wraps around and blows back the wind of the *O* star. The interface where the two winds collide forms a "shock cone" of dense, highly ionized, X-ray-hot material, vaguely comet shaped. We see the *O* star through the wall of the cone for most of the 7.9-year orbit.

Despite astronomers' successes in working out this picture, some important aspects of the system — such as the opening angle of the shock cone and even the tilt of the stars' orbit to our line of sight — remained poorly constrained.

As Tony Moffat and I discussed the possibilities, we knew that observing for just a few nights around the stars' periastron passage would not be enough. We needed an extended run of several months. This meant we would have to use relatively small telescopes with few demands on their time. And if amateurs were going to help fill this need, a big team would be essential: who wants to spend four months doing non-stop observing?

Another solution would be to use robotic telescopes instead of human observers. But then where's the hands-on fun?

After Tony and I met, I announced the idea on the forum of the Spectroscopy section of the German ama-

JOSÉ RIBEIRO

PRIME SITE On the island of Tenerife, 7,840 feet (2,390 meters) high in the steady air flowing across the Atlantic, Teide Observatory is home to 12 telescopes of up to 60 inches (1.52 meters) aperture. Much larger scopes grace the neighboring island of La Palma.

teur society *Vereinigung der Sternenfreunde* (spektroskopie.fg-vds.de) — and also, to recruit from other countries, on the forum of the Astronomical Ring for Access to Spectroscopy (ARAS: astrosurf.com/aras). I also designed a webpage for the project: www.stsci.de/wr140/index_e.htm. We let everyone know that WR 140's periastron passage should be observable with medium-resolution spectrographs on small telescopes.

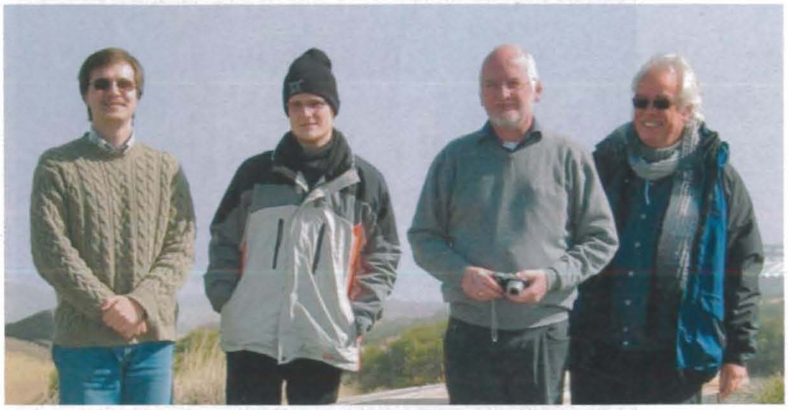
Sure enough, experienced amateurs in Germany, France, England, Portugal, and Spain took notice. It became clear that amateur spectroscopists could indeed help investigate this binary. Furthermore, we realized that a campaign would connect amateurs from different countries for exciting work in a field they love.

Within about two weeks almost 20 amateur spectroscopists announced their interest in joining a coordinated campaign. Professionals too were planning their own specialized campaigns, to be done in France, Finland, India, Canada, and the U.S., as well as in space by NASA's Rossi X-Ray Timing Explorer (RXTE) and Chandra X-ray Observatory. Continuous, long-term monitoring of the star, such as we intended, would be vital to tying everything together.

A few weeks later I flew to the island of Tenerife, in the Canary Islands off Morocco, to visit my longtime friend Johan Knapen, now a professor at the Instituto de Astrofíscia de Canarias (IAC), which runs the major observatories on Tenerife and La Palma. While approaching the island, I peered through the airplane window at the top of Teide Mountain high above the clouds and immediately recognized the telescopes of Teide Observatory in the Izaña district of the island. The site has first-class atmospheric conditions. I began to think. . . it obviously would be better for our group to have its own private telescope and run the WR 140 campaign here on the mountaintop rather from the cloudy mess of Europe. That's 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."

LOTHAR SCHANNE

MOMENT OF TRUTH Johan Knapen (left), Berthold Stober (right), and John Morrison attach the team's custom-built spectrograph and guiding-eyepiece assembly to the telescope.



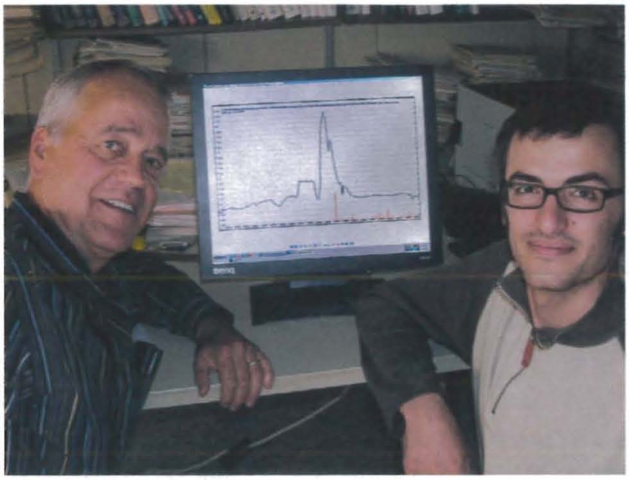
FILIPE DIAS

CHANGING OF THE GUARD The observing team of Filipe Dias and Thomas Bergmann arrive on the mountain to take over from Lothar Schanne and Berthold Stober (left to right).

The next weekend we visited the mountaintop and, off to the side of the many larger domes, the Mons Telescope: a 50-cm (20-inch) f/15 Cassegrain built in 1972 by Belgium's University of Mons. What we found was no match for some advanced amateur observatories. The telescope had electronic guiding but no go-to pointing. It had no spectrograph. Other things needed work. But it would serve.

Johan became as excited as me and promised local support. We did a quick cost calculation for a campaign of 3.5 months, with eight teams of two to four observers at the telescope for two weeks each, and came up with 700 Euros (roughly $1,000) per person including travel and accommodation at the observatory. We knew that many qualified amateurs would jump at the chance.

Tony became our main scientific partner. His Ph.D. student Rémi Fahed came on as well. Back in Europe I spoke to Gregor Rauw and Thierry Morel at the Université de Liège in Belgium about including additional target stars. They chose some hot *Oe* and *B* stars where we could investigate periodic phenomena in their winds. I announced the idea again in the spectroscopy discussion forums. Fifteen amateur astronomers, from a high-school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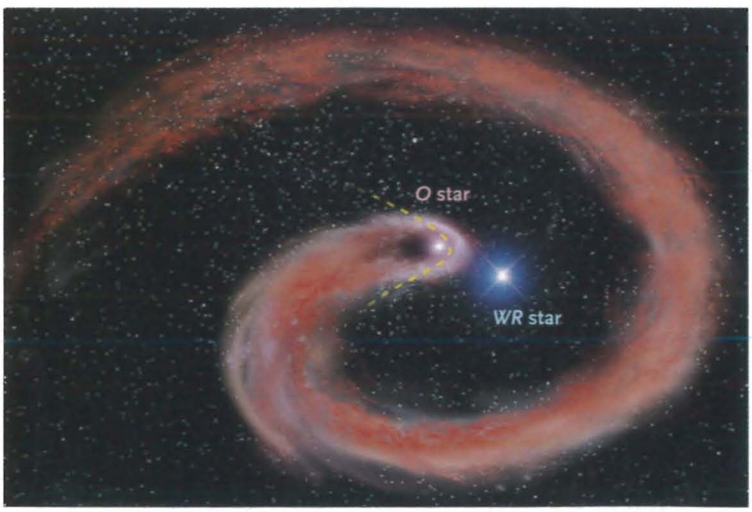
THE HUNTERS AND THEIR QUARRY Hot-star expert Anthony Moffat (left) and graduate student Rémy Fahed display part of a spectrum of WR 140. The flat-topped bump just left of center is the critical CIII emission line.

student to a physician, asked to join the campaign and work on the mountain.

One problem was that during the months around WR 140's periastron, Cygnus would be near the horizon and setting soon after sunset or, later, rising soon before dawn. So we planned to observe our other *Oe* and *B* stars during the rest of the night. Our proposed run would start on December 1, 2008, and end March 23, 2009. In addition, other amateurs and professionals agreed to participate by making their own observations elsewhere. Everyone's data would be reduced and published together, and all participants would be coauthors for the three peer-reviewed papers that we hoped would result.



S&T: LEAH TISCIONE

DUST TAIL Each time the two stars come closest and the shock cone grows most intense, some process creates billows of carbon-rich dust on or near the cone's head. The hot dust later spirals away as the stars orbit, creating a complex infrared signature for the whole system.

With Johan's help we worked up a formal proposal and submitted it to the IAC's time-allocation panel — which assigned us 16 weeks, all to ourselves, on the 20-inch telescope at Izaña.

Getting Ready

We decided to use all our own equipment on the Mons Telescope, since it lacked most of the things we would need and we learned quickly that the local technical staff gave low priority to support. But we loved the challenge!

German amateurs Berthold Stober and Lothar Schanne, experienced in mechanics and instrument design, handled many aspects of getting everything set up. They fixed up and adapted a spectrograph donated by German amateur Wolfgang Arnold, and a CCD loaned by the German manufacturer Gerhard Fischer. They built a flip-mirror arrangement for guiding and implemented a Shapley lens as a focal reducer. It became clear that they would have the most difficult part of the project: making the entire system work.

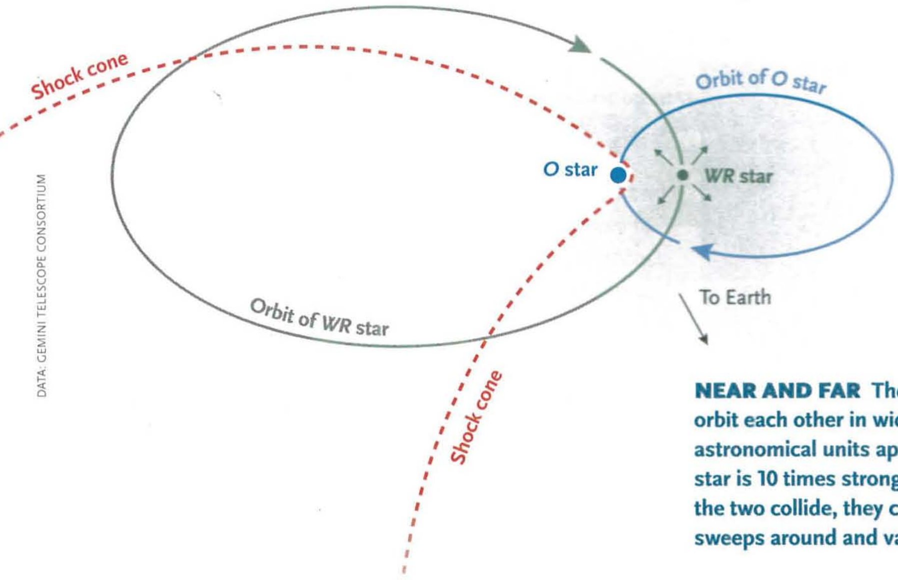
To start the ball rolling well in advance, we organized two workshops for participants, believing that the best ideas come in person, over coffee. We discussed finding charts, refraction, guiding problems, telluric lines, bias-, flatfield- and dark-correction images, shock fronts, excitation levels, ftp servers, USB extenders, FITS formats, and, and... it was wonderful!

I again visited Montreal, where Tony informed me about the other ground-based WR 140 activities worldwide. We resolved the crucial issues of the best spectral resolution and wavebands to observe in. Back in Germany, we shipped off our equipment four weeks before our allotted time began.

The first observers, Berthold and Lothar, spent much of the first two weeks just setting up. As is typical at telescopes small and large, they had problems, such as with the CCD camera and the optical system. We also had to define a standard routine on the mountain and be able to transfer it to the teams that followed. But we eventually solved everything with patience, commitment, and support from the colleagues in Europe and North America. Berthold and Lothar established the whole setup in a very professional manner.

The second team, high-school student Thomas Bergmann and engineer Filipe Dias, ran the project over Christmas. The third team had bad luck — they were clouded out for a week and had an ice storm. Even so, we acquired data right through periastron in January, as spectra were taken by others on clear nights in Germany and England when clouds covered Teide — an unexpected switch!

We reduced all our spectra within just a few days, so that we were always informed about the ongoing status of WR 140. In the shock cone around the *O* star, carbon atoms are heated to the point of losing two electrons



NEAR AND FAR The two brilliant, massive stars of WR 140 orbit each other in wide loops, dipping from about 30 to 2 astronomical units apart. The stellar wind from the type-*WR* star is 10 times stronger than the wind from the *O* star. Where the two collide, they create an X-ray-bright shock cone that sweeps around and varies in intensity as the stars orbit.

— becoming CIII ions, which shine with a yellow emission at a wavelength of 569.6 nanometers. We saw extra, blueshifted CIII emission appear just before the stars' periastron passage, modifying the overall broad emission line around this wavelength. This new emission quickly moved to the redshifted side of the line just after periastron, then disappeared.

All the teams performed in perfect routine. As a member of the final team, I benefited from the extraordinary achievements of those before us. Our planning paid off; the harmony between software, telescope, and spectrograph was perfect, and we finished without untoward problems. After closing up on the last night, we had only to dismantle our equipment and ship it back to Germany.

Results

In May we held a wrap-up meeting in Portugal to discuss our first results and possible future campaigns. Among our conclusions:

- We published an updated value for the binary's orbital period, 2,896.5 ± 0.7 days, and we found the orbit to have a higher eccentricity than was previously known: 0.896 ± 0.002. This is important because all other parameters deduced for the system depend on knowing the orbit accurately.
- Our new value for the orbital inclination, 52° ± 8°, gives the following values for the two stars' masses: 16 ± 3 solar masses for the *WR* star, and 41 ± 6 for the *O* star.
- We fitted both the changing radial velocity and the changing width of the excess CIII emission to a simple geometric model that includes the opening angle of the shock cone, the velocity of the shocked material moving along the cone's surface, the binary's orbital inclination, and an angular shift due to Coriolis forces.
- Meanwhile, satellite X-ray observations showed that the system's X-ray flux dropped when we saw the excess CIII emission appear. This could be a sign of material cooling, but the effect has to be investigated in more detail. We're still reducing and analyzing our data in Canada and Belgium for a further, final publication.

But we did more than analyze stars. We showed that amateur spectroscopists have the engineering and technical skills, scientific knowledge, and collaboration abilities to carry out very fruitful pro-am spectroscopy at a professional observatory even across continents. As far as I know, ours was the first pro-am collaboration on this scale. As a result of this project, we expect that amateurs will be seen with new respect in future applications to other observatories.

And we have more plans brewing. Another outcome of this project has been the formation of the ConVento Group, a platform to establish future professional-amateur campaigns in photometry and spectroscopy (see www.stsci.de/convento). We've started something that we hope will have no end. ✦

Thomas Eversberg was educated as a professional astronomer, co-founded the Schnörringen Telescope Science Institute in Germany (www.stsci.de), and in his day job now works for the German Space Agency in Bonn.

Acknowledgements: I want to thank all the project participants for their skills, enthusiasm, and trust in this unique campaign. They made it work. They include Filipe Alves, Wolfgang Arnold, Thomas Bergmann, Luis Carreira, Rémi Fahed, Alberto Fernando, Gerhard Fischer, José Sánchez 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 und Berthold Stober, Nelson Viegas, Klaus Vollmann and Udo Zlender.

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