Antarctic Air Visits Paranal — Opening New Science Windows

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Extremely low humidity (precipitable water vapour [PWV] of ~ 0.1 mm) in the atmosphere above Paranal has been measured by a water vapour radiometer over a period of about 12 hours. PWV values < 0.2 mm are usually only found at very high altitude or in Antarctica. In fact a pocket of Antarctic air has been shown to be responsible for this phenomenon and it may occur a few times per year at Paranal. We highlight the science opportunities — created by new atmospheric windows — that arise in such conditions. The community is invited to provide feedback on how to make best use of low PWV with the VLT.

The dry episode over Paranal

The humidity in the atmosphere is measured in the form of precipitable water vapour — a measure of atmospheric water content. It is the amount (or depth) of water vapour in a column of the atmosphere if it were all to condense and fall as rain. The water vapour content of the atmosphere can be measured using the strong water line at 183 GHz. At the Paranal Observatory these measurements are made by the Low Humidity and Temperature Profiling radiometer (LHATPRO), manufactured by Radiometer Physics GmbH[1] and described by Kerber et al. (2012).

Given Paranal's sub-tropical location at 24.5 degrees latitude south it sounds far-fetched [pun intended] that Antarctic air would ever pass over Paranal, but this is exactly what happened on 5 July 2012. During that night LHATPRO recorded an episode of extremely low (~ 0.1 mm) PWV that lasted for more than 12 hours.

While a beautiful panorama of Paranal taken at sunset (Figure on p. 16) on 5 July 2012 doesn't show anything unusual to the human eye, atmospheric conditions were in fact anything but ordinary. Located in the Atacama Desert at 2635 metres above sea level, Paranal is a very dry place. Its median PWV is about 2.4 mm with some seasonal variations, but on this particular night it experienced a "dry episode" that was truly remarkable (Kerber et al., 2014). In Figure 1 the temporal evolution of the humidity is displayed as measured by the LHATPRO radiometer and the two spectrographs CRIRES and X-shooter at the Very Large Telescope (VLT). The spectroscopic observations were taken in support of routine science operations and the PWV was deduced from an analysis of their spectra using an atmospheric model (Querel et al., 2011). Such dry conditions are more commonly expected at sites at much higher altitude, such as the Atacama Large Millimeter/submillimeter Array (ALMA[2]) on the Chajnantor Plateau (5050 metres above sea level, median PWV 1.2 mm) or other particularly dry sites, such as locations in Antarctica (the median PWV at Dome C, 3233 metres above sea level, during winter is around 0.2 mm), which offer excellent atmospheric transparency for infrared and (sub-)millimetre astronomy.

Service mode and low PWV

This dry episode is the first such event at a major observatory that has been fully documented in terms of atmospheric and meteorological conditions. Other relevant ambient conditions (seeing, temperature, wind, etc.) were around, or below, their median values. Hence, the excellent atmospheric transparency at infrared wavelengths offered by the low humidity would have offered ideal conditions for infrared (IR) observations.

In this context it is worth noting that for service-mode observations with several IR instruments at the VLT (e.g., CRIRES and VISIR), PWV can be specified as a user-defined observing constraint. The PWV measurements from the PWV monitor are available in real-time in the control room of the VLT, allowing decisions on which observations to conduct in service mode to be taken with great flexibility. This schema allows potentially very demanding observations requiring a very low (< 0.5 mm) column of water vapour to be scheduled when very dry and stable conditions occur, such as the episode of extremely dry air described.

A careful analysis of meteorological conditions involving numerical models showed that on that date Antarctic air passed over Paranal, driven far to the north by an unusual combination of weather patterns; details are given in Kerber et al. (2014). Is this a freak or a once-in-ten-years event? In all likelihood it isn't: based on archival data produced by VLT spectrographs, similarly dry conditions (PWV < 0.2 mm) occur very rarely — one or two nights per year, while PWV less than 0.5 mm is encountered about 2 % of the time, and less than 1 mm is found 15 % of the time.

On account of the sparse nature of these observations the duration of events in the past remains unknown. Are such conditions also predictable in advance? Conditions for excursions of Antarctic air are certainly special, but weather forecasting with a focus on astronomical conditions is a field of active research (Sarazin et al., 2013) and the predictive power of atmospheric models is clearly improving.

What kind of science is enabled by low PWV?

As already mentioned, atmospheric transparency in the infrared is dramatically enhanced in such dry conditions beyond the standard windows (*J*-, *H*-, *K*-, *L*-, *M*-, *N*-, and *Q*-bands) in the 1–25 μm range that are routinely used for ground-based astronomy. We have identified a number of astrophysically important lines (Kerber et al., 2014) that benefit particularly from such conditions.

A case in point is the hydrogen Paschen-α (Pa-α) line at 1875 nm, which is unobservable (transmission less than 2 %) under median PWV conditions on Paranal. This

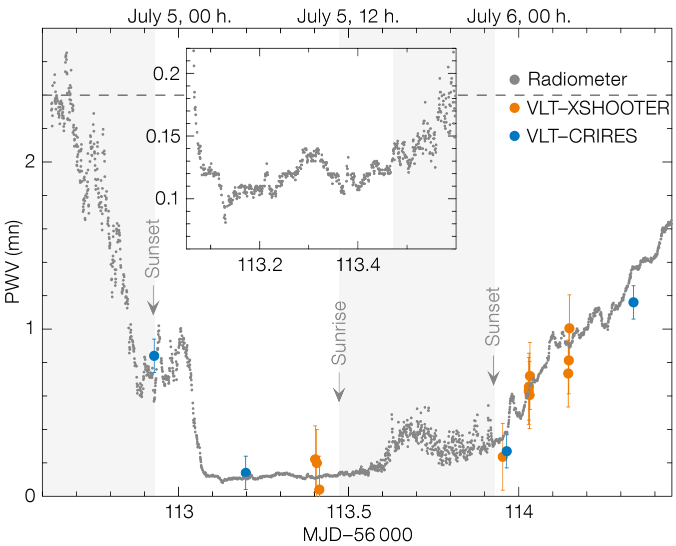

Figure 1. Time series of the PWV measured above Paranal from 5–6 July 2012. The data points in black are from the LHATPRO radiometer, while PWV measurements derived from VLT instruments are overplotted. The dashed line indicates the Paranal overall night-time median PWV (2.4 mm). Times of sunrise and sunset (see Figure on p. 16) are indicated; note the larger variability of PWV during daytime. Insert: Enlarged view of the dry episode showing the high level of stability during the 12-hour period as well as the extremely high precision of the radiometer data. The larger number of VLT measurements taken on 6 July (after MJD 56113.5) are in response to the very low PWV recorded the previous night. Figure from Kerber et al., 2014.

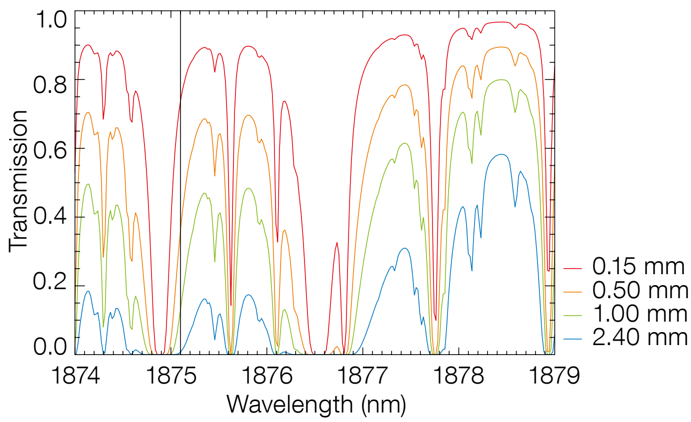

Figure 2. Transmission of the Earth's atmosphere in the region of the Pa-α line at 1875.1 nm. At PWV = 0.5 mm a transmission of 35 % is reached. Note that for extragalactic sources even higher transmission will be achievable due to redshift and PWV as high as 1 mm may offer usable conditions (modified from Kerber et al., 2014).

intrinsically strong line is prevalent in many astrophysical sources, is less affected by dust extinction than Hα, and, due to its wavelength, benefits significantly from adaptive optics. At low PWV atmospheric transmission improves rather dramatically (Figure 2), and reaches more than 75 % under the conditions encountered on 5 July 2012. This is why such observations are currently either done from space or at very high altitude. The University of Tokyo operates a camera (Motohara et al., 2008) equipped with Pa-α filters at its 1-metre telescope on Cerro Chajnantor (5640 metres) and recently the First Light Infrared Test Experiment CAMera (FLITECAM) on the Stratospheric Observatory for Infrared Astronomy (SOFIA) received similar filters (McLean et al., 2012).

This of course begs the question of how such new science could be enabled by making use of these extraordinary conditions on Paranal. The VLT, with its user-specified constraints on atmospheric conditions, is already prepared to accept very demanding scientific programmes in service mode that can only be performed during a small fraction of the time. Low-PWV science takes this one step further, but for spectroscopic observations. No additional investment in hardware is required to conduct low-PWV science using existing spectrographs (in fact, a first spectroscopic observation of Pa-α in a young stellar object has already been secured under very good but not excellent conditions and will be the subject of a future publication). This demonstrates that current VLT spectrographs can take advantage of such conditions and deliver new and exciting science.

In terms of imaging, the VLT offers telescopes with an 8-metre primary mirror and instruments with adaptive optics providing exceptional image quality. However, a small investment in hardware may be necessary to enable low-PWV science with existing and planned imagers. Narrowband filters for Pa-α — and an off-band wavelength — would have to be procured. One imager that would combine these qualities could be ERIS[3], currently under design by ESO and external partners from the Max-Planck Institute for Extraterrestrial Physics (with contributions from ETH Zürich) and INAF–Arcetri Astrophysical Observatory.

The authors would like to encourage the ESO community to send their feedback on low-PWV science with the VLT and their thoughts about Pa-α or other filters in the context of instrument development or upgrades[4].

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References

Kerber, F. et al. 2014, MNRAS, in press
Kerber, F. et al. 2012, The Messenger, 148, 9
McLean, I. S. et al. 2012, Proc. SPIE, 8446, 844619
Motohara, K. et al. 2008, Proc. SPIE, 7014, 70142T
Querel, R. R., Naylor, D. A. & Kerber, F. 2011, PASP, 123, 222
Sarazin, M., Kerber, F. & De Breuck, C. 2013, The Messenger, 152, 17

Links

[1] Radiometer Physics GmbH, Germany: http://www.radiometer-physics.de
[2] ALMA Observatory: http://www.almaobservatory.org
[3] ERIS: http://www.eso.org/sci/facilities/develop/instruments/eris.html
[4] Comments for low PWV science with ESO instrumentation to: lowpwv@eso.org