
LETG

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High Tension

It is well-known that the working environment of the CXC is just like that of the relaxed innovation fermenters *Google* and other trendy tech megacommerce (what, time for table tennis *again*—no wonder this article is late). The title above must then refer back to *Chandra Newsletter 19*, where I described the secular gain droop experienced since launch by the HRC-S, the primary readout detector for the LETGS. Charge liberated by the ping-ponging electron cascades initiated within the microchannel pores by photon and particle interaction with the top plate of the two-plate sandwich, and amplified by 1800 V or so of high-tension, ages the plates. This occurs primarily through chemical migration in the bottom plate where the charge mainly comes from, sapping some of the instrument's photoelectric efficiency at an average rate of about 0.6% per year. It is a known behavior of microchannel plates and can in principle be remedied by increasing the high tension to compensate. In the same *Newsletter 19*, HRC instrument scientist Ralph Kraft described the procedure we adopted to investigate the voltage change required to recover the gain—basically making stepwise adjustments of the voltage during real-time telemetry contact in the middle of an observation of the LETG standard candle HZ43, hoping the instrument did not get upset, all while playing table tennis.

The experiment worked: the gain was observed to increase in a linear, well-behaved fashion with increases in voltage in 20 V steps across top and bottom plates. Comparison of the mean detector pulse height amplitude for the HZ43 photon events dispersed over the outer plates of the detector for the different voltages with those observed earlier in the mission enabled us to determine the voltage settings needed to restore the initial on-orbit performance. The gain change with voltage seen in the real-time telemetry passes are illustrated in Figure 1, showing the analysis by Brad Wargelin made during occasional breaks between sets. Settings for the blue curve were chosen for the new operating voltage. These corresponded to potential differences of 1819.6 V across the bottom plate and 1791.0 V across the top.

One of the problems we hoped to remedy by

restoring the gain was the steady decline in the detector quantum efficiency that has accompanied the gain droop (see *Newsletter 19*). The QE could be re-calibrated using further observations of HZ43 obtained at the new adopted voltage settings, at least for wavelengths down to 50 Å or so. At shorter wavelengths, things get a bit more tricky, since we run out of point-like steady sources of cosmic X-rays and have to rely on ones that vary. Observations of the blazar Mkn 421 were therefore planned for last July, at both new and old voltages, relying on the source not to vary too much during the observations so that we could discern the voltage-related count rate differences. The source behaved for the first half of the observation, then bolted off toward higher fluxes nearer the end. The voltage changes were, however, cunningly interleaved with LETG+ACIS-S observations to provide a comparison, and we were still able to determine the higher energy QE change to a precision of about 1.5%.

Expert *Chandra* analyst Nick Durham reduced and blended all the data together into a thick, creamy sauce, and after the ping-pong balls settled we found that the raised voltage saw a jump in the QE by about 6% at the longest wavelengths and lowest energies, with the change declining in magnitude going toward higher energies by a percent or two. This trend is not unexpected: the gain droop caused a small fraction of the lowest pulse height photon events to be lost to the particle background noise and an event lower level threshold discriminator. Since the mean pulse height increases with increasing photon energy, the largest QE loss, and conversely the largest QE recovery, is then expected for the lower energy photon events.

The QE is actually a three-dimensional function—of the two spatial dimensions of the detector as well as photon energy—and we have only re-calibrated it essentially in one dimension. This calibration is then only valid if the QE changed by the same amount over the whole detector. Indications are that this is a pretty good assumption, but perhaps not quite good enough, with potential changes in the QE uniformity of the order of a few percent. Calibrating the QEU on the ground is relatively straightforward—the detector can be placed in front of a uniformly-illuminating X-ray source. In-flight, we have the worst case scenario: focusing of the uniformly-illuminating X-ray source to a single point by the most precise X-ray mirrors ever made. Getting around this stunning design defect will present considerable difficulties for us in the coming year. . . oh, already time for another game?

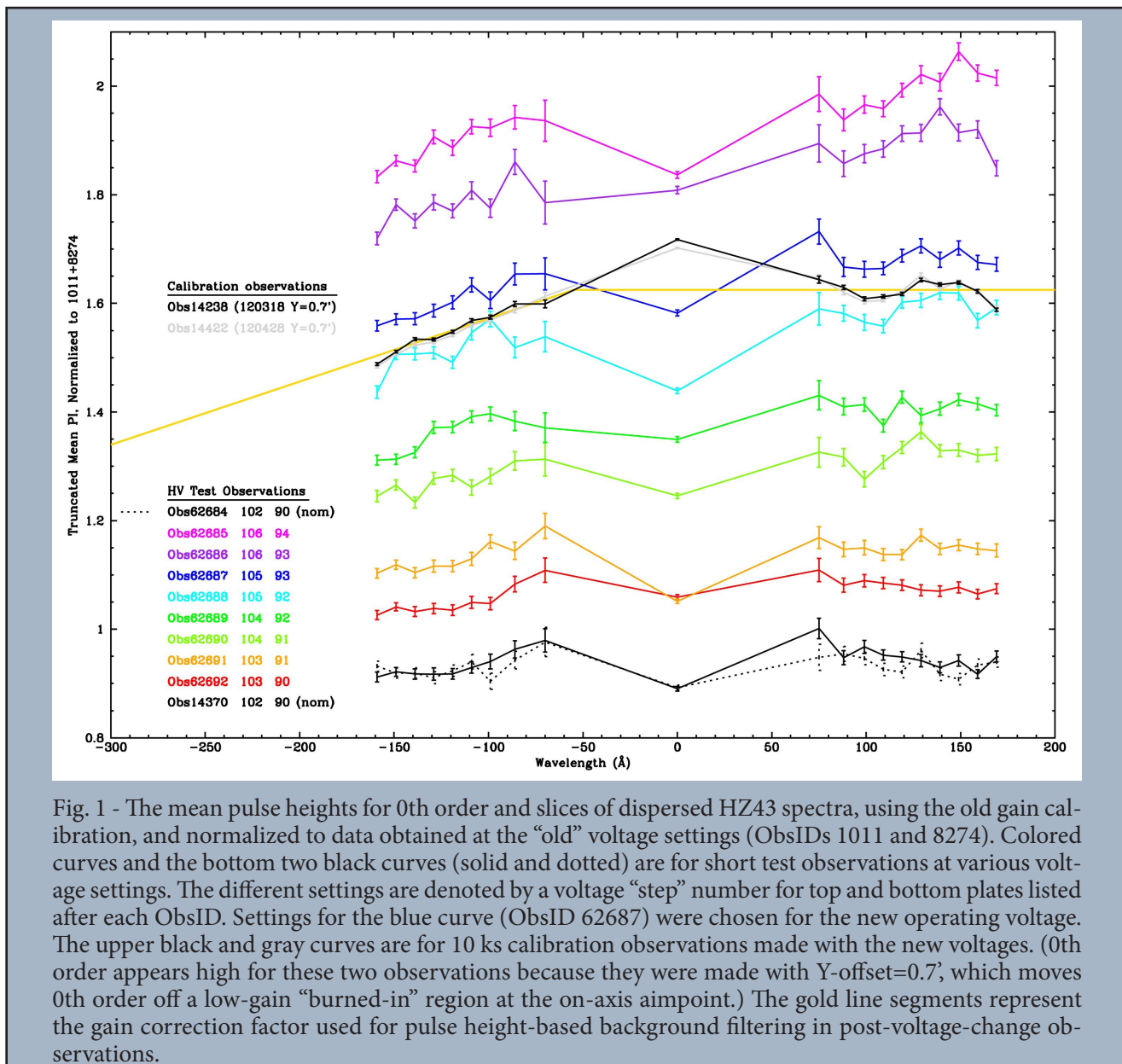
Broadening Horizons

If there is a celestial source designed by nature for application of a slitless, high-resolution X-ray spectrometer, it is the massive stellar wind. Spatially point-like, there are no overlapping dispersed images to disentangle, as is the case for significantly extended sources. The wind is thought shocked to X-ray temperatures, either by line-driven acceleration instabilities, or by the aid of magnetic channeling, and emits discrete spectral lines that can provide diagnostics of temperature, density and the strength of the local UV radiation field. On top of this, wind terminal velocities often exceed 1000 km s^{-1} —sufficiently large that they can be resolved by *Chandra's* gratings to truly utilize the dispersion, or velocity, dimension. Two recent papers

have exploited LETGS spectra to tackle outstanding problems in high-mass stellar winds.

One is the “weak-wind” problem, first identified from UV and optical spectra and described as “urgent” in the review of Puls et al (2008). The problem arises in the later-type O and early B dwarfs. Ultraviolet line profiles clearly show classical P Cygni wind signatures, but modeled mass-loss rates can be an order of magnitude lower than theoretical expectations. This is important because mass loss from hot stars can be sufficient to influence the evolution of the star itself and tends to dominate the injection of mass and energy into the ambient interstellar medium, playing a key role in cosmic feedback.

The ultraviolet, of course, does not tell the whole



story. Since shock-heating to X-ray temperatures is expected, and in analogy with other searches for missing baryons, the natural place to look for any hidden mass is in the X-ray spectral region. Huenemoerder et al. (2012) observed the prototypical weak-wind O star μ Columbae using the LETG and ACIS-S, together with Suzaku. Line profiles like that of O VIII illustrated in Figure 2 betray the hot, high-velocity wind, with a terminal velocity of 1600 km s^{-1} . Even the small blue-shift in the line profile expected because of some obscuration of the redshifted hemisphere by the central star might be discernible, though is not formally detected. The X-ray emission measure indicated that the outflow is almost an order of magnitude greater than that derived from UV lines and is consistent with the canonical wind–luminosity relationship for O stars. The wind is hidden from UV scrutiny because it is too hot and ionized. Huenemoerder et al. (2012) conclude that the “weak-wind” problem is largely, and perhaps completely, resolved by accounting for the hot wind seen in X-rays but not in the UV.

The very nature of the shocked-wind paradigm for single O-stars was questioned by Pollock (2007) based on *XMM-Newton* observations of the O9.7 Ib supergiant component of the ζ Orionis system. The X-ray

spectrum lacked evidence of substantial variation with wavelength of either plasma emission measure or velocity width that was expected in the instability-driven shock model. Pollock also noted that the spectrum appeared largely optically thin, and suggested that X-rays are not from the dense, central regions of the wind where it is strongly accelerated, but from farther out in the terminal velocity region. The shocks would then be collisionless and might explain another problem with the canonical model: that otherwise fairly similar O stars exhibit a scatter of an order of magnitude in X-ray luminosity. Magnetic fields in the region where the shocks occurred could then be the “missing variable” accounting for the scatter. Other essentially single O stars could provide further tests of the hypothesis.

Raassen and Pollock (2013) use the LETG+HRC-S to observe the O9.5 supergiant δ Orionis. Particular attention was paid to the He-like ions to establish the distance of the X-ray emitting ions from the stellar surface based on the UV excitation of the intercombination lines. The spectrum appeared thermal, and consistent with collisional equilibrium. The X-ray emitting plasma was found to be located $2\text{--}80 R_*$ from the stellar surface based on lines of Mg XI to C V, with the cooler ions located farther out in the wind, similar

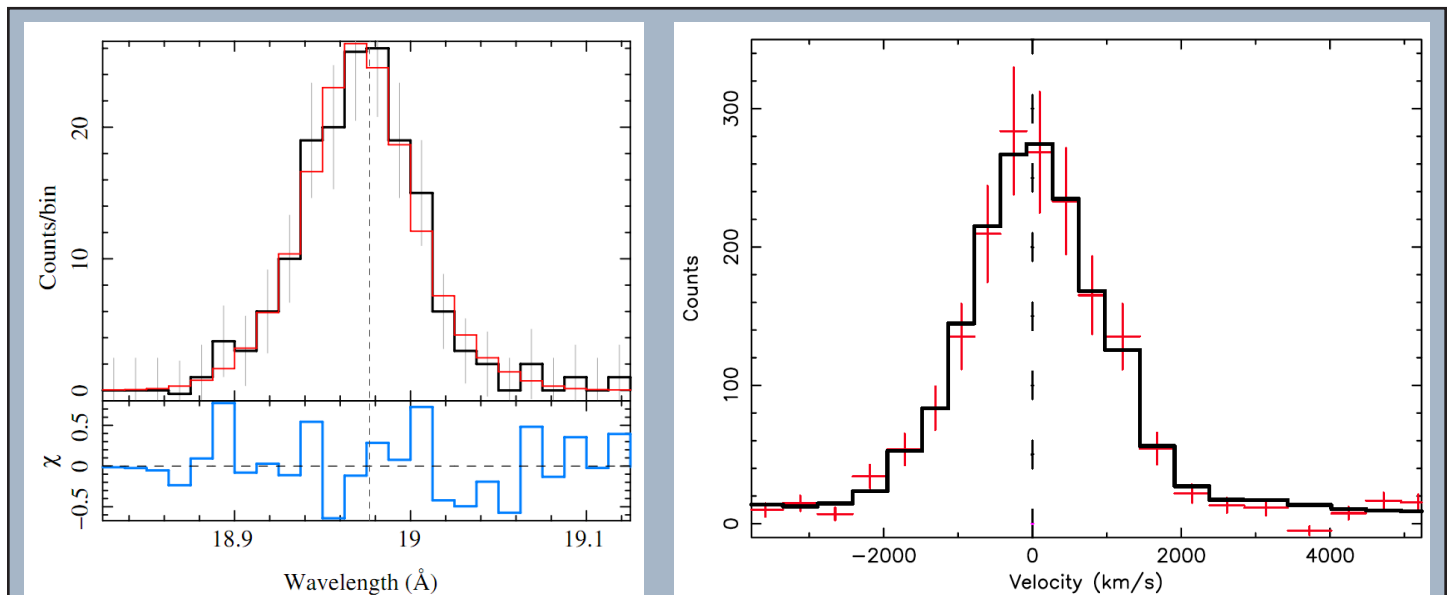


Fig. 2 - Velocity-broadened profiles of the H-like O VIII $\lambda 18.97$ Ly α line providing key diagnostics for O star winds. Left: The O VIII profile (black) seen in the LETG+ACIS-S spectrum of the O 9.5V “weak-wind” star μ Col. A wind model with terminal velocity $v_\infty = 1600 \text{ km s}^{-1}$ is shown in red, together with residuals in lower panel. The wind model indicates that nearly all the wind mass is at X-ray temperatures, eluding detection in the UV and alleviating the weak wind problem. From Huenemoerder et al. (2012). Right: The profile of the O VIII line in the LETG+HRC-S spectrum of the O9.5 supergiant δ Ori that tests the collisionless shock scenario of Pollock (2007). Observations are illustrated in red, together with a fitted Gaussian model in black (note that the instrumental line spread function is also significant here). The rest wavelength is also shown. The HWHM of $\sim 840 \text{ km s}^{-1}$ is possibly too small for a uniform, spherically-symmetric shocked-wind, and might betray the presence of self-obscuring clumps. From Raassen and Pollock (2013).

to the case of ζ Ori. Lines from the hot ions Mg XI, Ne IX, and O VIII, were formed close-in, however—from 2 to 10 R_* . The latter data then tend to support the canonical model, with shocks formed near the acceleration region of the deeper, more dense wind, rather than much farther out. This raises the possibility that both shock regimes are present.

Even such a mixed shock scenario is not quite that simple of course. Raassen and Pollock suggest that line profiles with HWHM ~ 840 km s⁻¹ are narrower than would be expected based on a wind terminal velocity of 2000 km s⁻¹. The observed O VIII line profile is shown in Figure 2. One possible explanation is that shocked clumps in the wind are self-shielding, with X-ray emission then preferentially observed orthogonally to the wind velocity vector, toward the limb where the line-of-sight velocity is small.

More observations, or at least a couple of games of table tennis, are clearly needed.

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References

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