New Insights with WFC3 IR Observations

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Over the past several decades, astronomical observations at near-infrared wavelengths have become increasingly common. Access to this part of the electromagnetic spectrum provides multiple benefits, including the ability to observe dust-enshrouded sources, detect important spectral features in cooler objects, and measure rest-wavelength visible and ultraviolet light in distant (i.e., highly red-shifted) galaxies. Both technology and the nature of astronomical sources make the 1–2-micron-wavelength region suitable for such observations. Unfortunately for ground-based observations, the Earth's atmosphere in this range is plagued by strong and variable emission and absorption features, which interfere with observations of faint sources and molecular constituents that also occur in our atmosphere, such as water. For observations at wavelengths longer than ~2 microns, thermal emission from the Earth's atmosphere and from the telescope itself become the limiting factors. This situation has motivated multiple space missions with cold optics (e.g., *Infrared Astronomical Satellite*, *Infrared Space Observatory*, *Spitzer*, *Herschel*, *Wide-Field Infrared Survey Explorer*, and the upcoming *James Webb Space Telescope*).

Early in *Hubble*'s development, the value of including an infrared instrument was widely understood. The development of such an instrument for *Hubble* became an important driver of infrared-detector technology, with benefits accruing to other space missions as well as ground-based astronomy. The Near Infrared Camera and Multi-Object Spectrometer (NICMOS), which was installed in *Hubble* in 1997, defined a generation of ground-based detectors and validated *Hubble*'s potential for near infrared science. Today, Wide Field Camera 3 (WFC3), launched in 2009, includes an infrared channel for broad-band imaging and slitless spectroscopy limited primarily by the natural background in space. WFC3 incorporates the fruits of advancing detector technologies, offering 16 times the number of pixels of a NICMOS detector, greatly improved noise properties, and increased sensitivity.

Persistence

WFC3's infrared detectors have some known limitations, which we have strived to characterize and mitigate. Our initial expectation was that image persistence would be important, which has proven correct. In the *Institute Newsletter* (Vol. 29, Issue 1, **https://blogs.stsci.edu/newsletter/2012/07/30/persistence-and-after-images-in-wfc3ir-data/**), K. Long, S. Baggett, and K. Levay discussed image persistence and the strategies to cope with it. These strategies include careful planning of observation sequences (e.g., dithering multiple exposures), identifying the observations most likely to cause strong residual images and avoiding science observations for several hours after such observations, and developing a mechanism to track the exposure history of each pixel to predict persistence images. The implementation of spatial scanning (see *Institute Newsletter* Vol. 30, Issue 1, J. MacKenty, **https://blogs.stsci.edu/newsletter/2013/04/05/notes-from-the-wfc3-team/**) has opened the door for observations of targets brighter than ~10th magnitude. Spatial scanning creates very short *effective* exposure times as the source trails over a series of pixels. Combined with dispersion of the light using the slitless grisms, high signal-to-noise ratio observations of bright stars with transiting exoplanets are now possible. At the extreme, we have successfully measured Vega using these techniques and the grism in the –1st order.

Despite such advances, we have recently reached three interesting conclusions: (1) that the charge trapping causing persistence also has important consequences for the linearity and repeatability of short

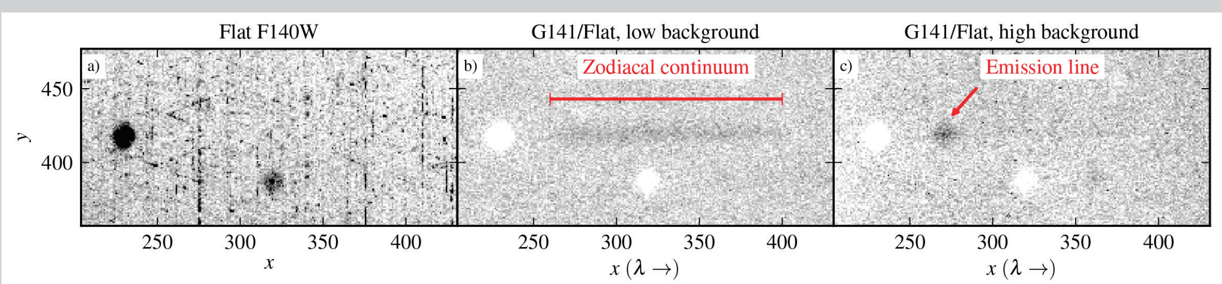

Figure 1: "Negative slit" spectra of the dust particles reveal the spectrum of a background source. (a) A flat field exposure using the F140W filter. (b) The smooth continuum of zodiacal light in observations taken when *Hubble* observes in the Earth's shadow. (c) Helium emission at 1.083 microns dominates spectra taken when *Hubble* observes the Earth's atmosphere illuminated by the Sun.

observations of bright targets, (2) that persistence from an intensive exposure of the detector may have effects that last many days, and (3) that subsequent exposure to moderate flux causes enhanced persistence. These phenomena represent a common theme: observers are pushing WFC3 to its limits and uncovering new factors to consider.

Zodiacal light

An original requirement on WFC3 stated that broad-band imaging and slitless spectroscopy must be limited by the zodiacal light. This requirement led to a design decision to limit the long-wavelength cutoff of the instrument to 1.7 microns, which avoided a dominant contribution from the thermal emission of the telescope. (This decision also had the consequence of permitting a straightforward and reliable approach to cooling the infrared detector.) Most WFC3 infrared observations encounter backgrounds of ~0.5 to 1.0 electrons per pixel per second. As a result, exposures longer than a few hundred seconds are background limited. Known exceptions include observing relatively close to the Sun, where the zodiacal light becomes much brighter, and in the rare circumstance that an observation skims along the bright limb of the Earth for a sustained interval.

Helium emission

Analysis of thousands of WFC3 infrared observations reveals a major exception to this background model. We sometimes encounter an excess background—by as much as five times—in two filters (F105W and F110W) and in both grisms (G102 and G141). Usually this excess is only present for part of an exposure. (WFC3 infrared exposures are obtained using multiple non-destructive readouts, so variations in the background during the exposure can be measured.) For the grisms, the two-dimensional structure of the observed background can vary, as well as the intensity within an exposure. These effects can become the limiting factor in analyzing such data.

We now understand that the source of this excess background is emission in the helium 1.0830 micron line from the terrestrial atmosphere. This emission is also observed from the ground during twilight—strong where the atmosphere is illuminated by the Sun, and vanishing inside the Earth's shadow.

Only these four grisms and filters in WFC3 transmit the helium wavelength.

We have taken advantage of the presence of small particles on the mirror in the infrared channel that selects between the ultraviolet–visible and infrared channels. Its surface is nearly in focus on the infrared detector, and the particles appear as features in images. When the grisms are employed, however, each point within the field of view is dispersed as a spectrum. In this circumstance, particles act as "negative slits," producing a spectrum of the background (see Fig. 1). For the "normal" level of background, the negative spectrum is featureless, but when the helium emission is present, a strong emission feature is seen in the G102 and G141 grisms. Lesson: we can go to space, but cannot fully escape the terrestrial impacts on near-infrared observations in low-Earth orbit!

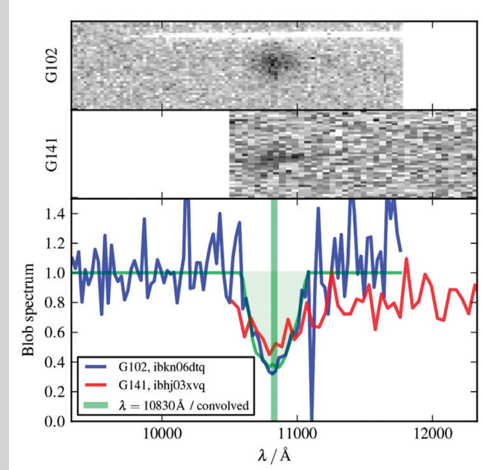

Figure 2: The emission-line component in the "negative slit" spectra occurs at the same wavelength—1.083 microns—in both the G102 and G141 grisms.

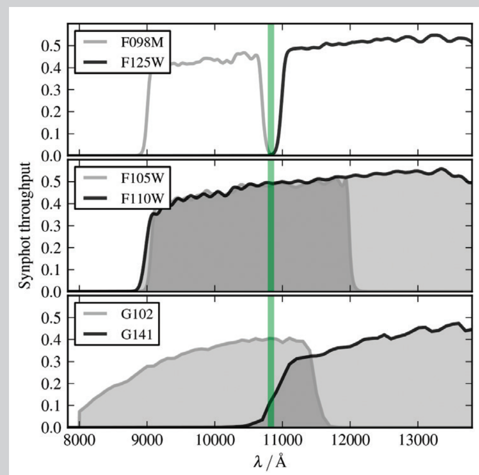

Figure 3: The F105W and F110W filters and both infrared grisms are sensitive to the He line at 1.083 microns. The F098M and F125W filters are not.

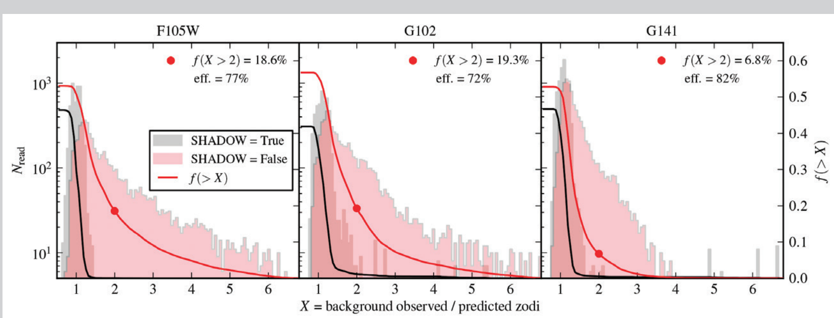

Figure 4: Distribution of background excess (over the nominal predicted zodiacal light) in individual WFC3/IR read-outs. The excess is caused by 1.0830-micron emission from helium in the illuminated Earth atmosphere. Nearly 20% of the WFC3/IR read-outs in the F105W filter and G102 grism show background levels more than twice the zodiacal "floor."