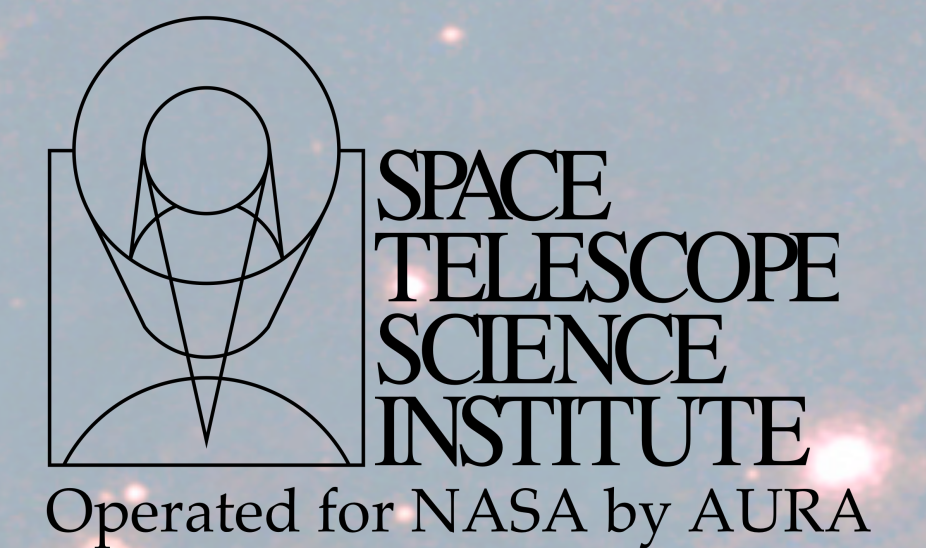


# WFC3 IR Detector: On-Orbit Performance

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## ABSTRACT

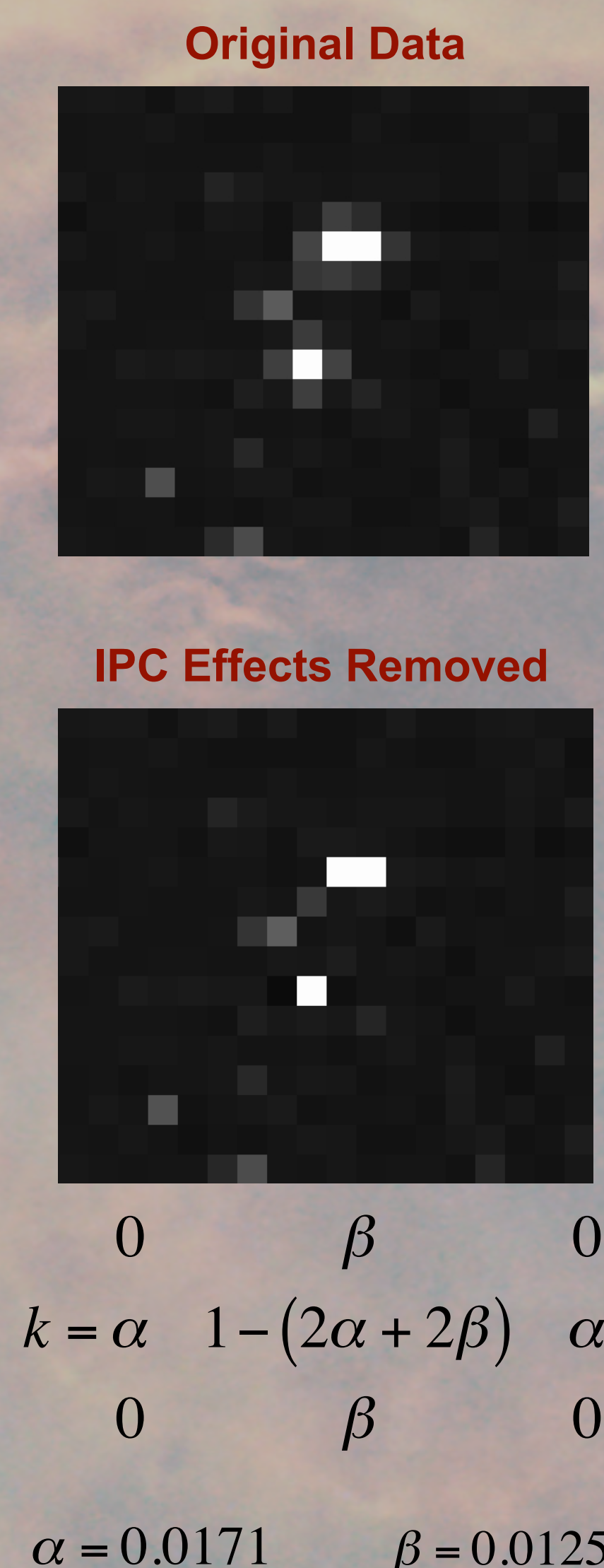
In the 20 months since Wide Field Camera 3 (WFC3) was installed in the Hubble Space Telescope (HST), the WFC3 team has collected and analyzed a large amount of calibration data. We describe the current status of several IR channel characterization and calibration efforts, including persistence, inter-pixel capacitance, high contrast imaging, count rate-based non-linearity (a.k.a the Bohlin effect), and snowballs. We also summarize the photometric performance of the IR channel, focusing on temporal stability.

## INTER-PIXEL CAPACITANCE (IPC)

Inter-pixel capacitance (IPC) is a form of crosstalk present in many array detectors due to capacitance coupling between adjacent pixels. This results in some of the signal from a given pixel spreading out into its nearest neighbors, producing correlated signals between those pixels. In the case of a single high-signal pixel, such as a pixel with high dark current or impacted by a cosmic ray, IPC will cause elevated signals in the four pixels surrounding the high-signal pixel, producing a cross-like source in the image. Examples are shown in the sources in the top image to the right. By effectively smoothing the source, IPC results in artificially low Poisson noise for extended sources. And, as seen in the top image, the effects of cosmic rays and certain types of bad pixels will expand to cover a larger area (i.e. 5 pixels rather than 1), potentially making photometry more difficult.

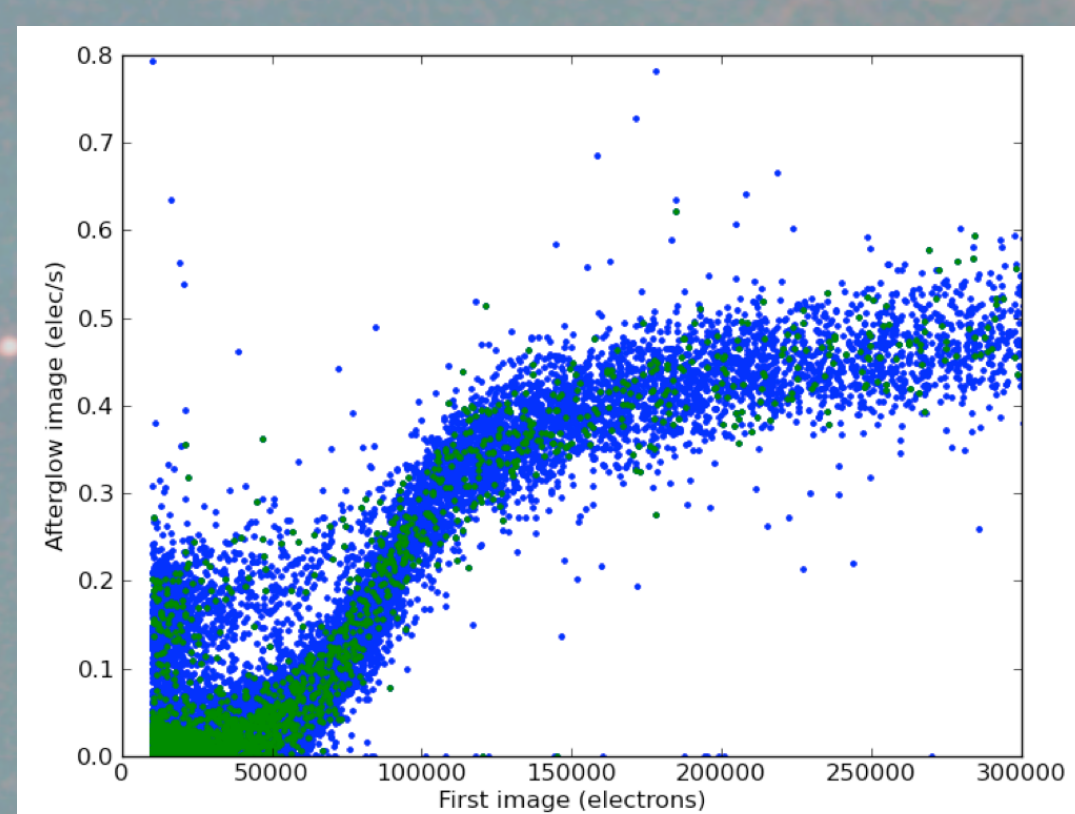
In WFC3 ISR 2008-26, McCullough suggests deconvolution as a method for removing IPC. In this case, the kernel is a 3x3 matrix given by  $k$  below. The flux in the central pixel is reduced by an amount  $(2\alpha+2\beta)$ , where the pixels to the left and right of the central pixel each steal a fraction  $\alpha$  of the flux, while the pixels above and below the central pixel acquire  $\beta$  of the total flux. We have found that deconvolving WFC3/IR data with the kernel  $k$ , and using the  $\alpha$  and  $\beta$  values below, we were able to largely remove IPC effects from the data. The image to the right shows the same data as in the top image after using deconvolution to remove the IPC effects. Note how the hot pixels have lost the surrounding halo of above background-level pixels.

By removing IPC effects, the impact of bad pixels and cosmic rays across the array is minimized, lessening the chance of a target of interest being affected by bad pixels. While total flux is preserved with IPC, spatially limiting the effects of bad pixels and cosmic rays can potentially lead to more accurate photometry and astrometry. Please see WFC3 ISR 2008-26 for more details.

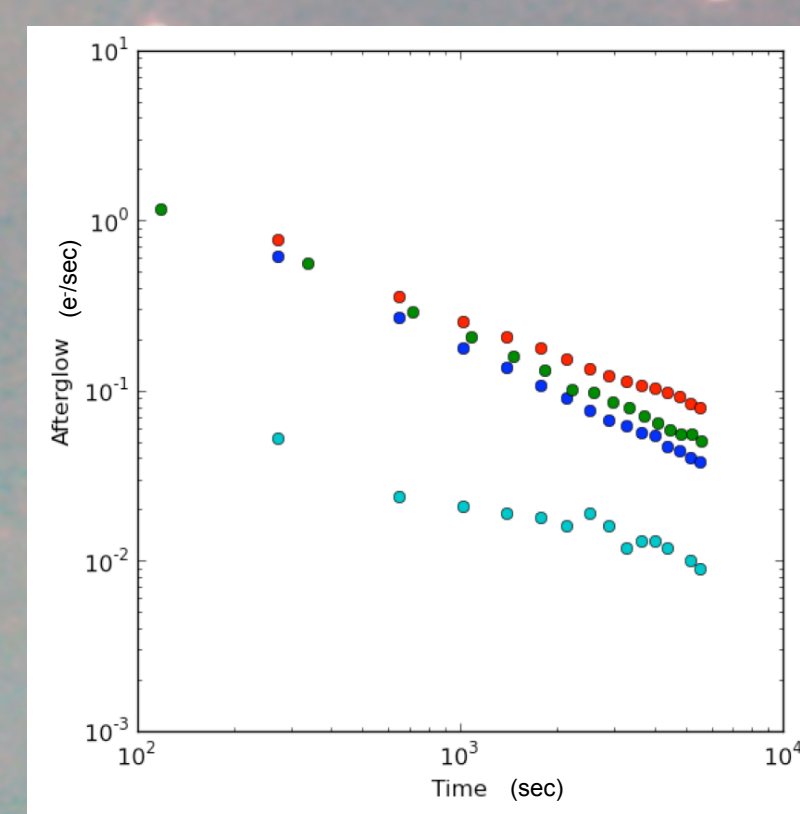
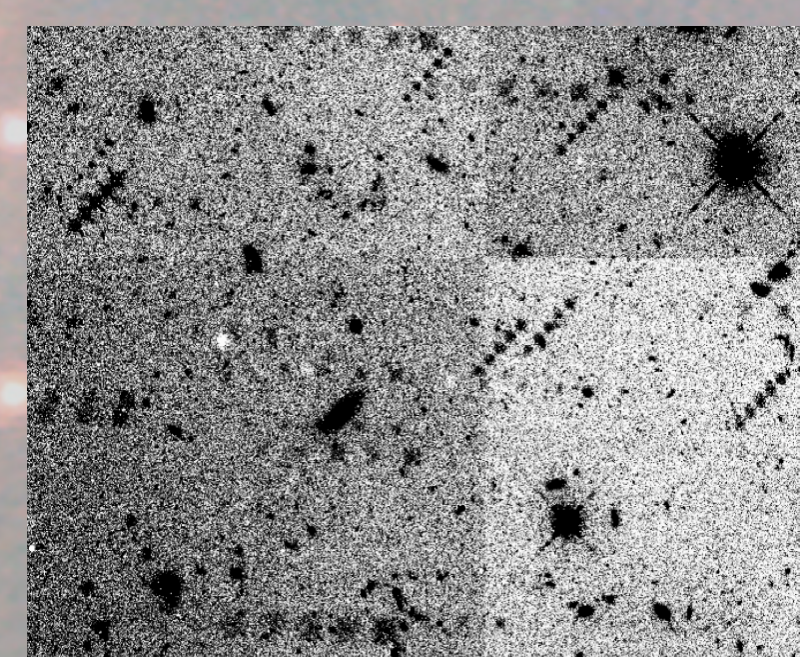


## PERSISTENCE

Persistence has been observed in the IR channel whenever a pixel is exposed to light that exceeds more than about half of the full well. Persistence is most easily detectable when bright targets are observed in previous visits (of others), but self-persistence also occurs when exposures containing bright targets are dithered on the detector within a visit. The image at right shows an example of persistence resulting from a previous observation composed of 4 dither positions in a diagonal line.



The plot to the left shows persistence signal rate as observed after a portion of the IR array was illuminated with a bright star. Note that the persistence is fairly small until the exposure level reaches about 2/3 of full well (50,000 e<sup>-</sup>). The plot at right shows the decay of persistence signal with time. Note that the nominal dark current rate is 0.04 e<sup>-</sup>/sec.



### Reducing Persistence Through Observation Planning

- Do not dither a bright object across the region of your image containing your most important science data.
- Dither where possible. MultiDrizzle can reduce the effects of persistence.
- If possible, keep exposure levels below saturation everywhere in the image.
- If persistence will be a problem in your observation, try to take your "thinnest" exposures first. Be careful of over-exposing broad band images simply to fill out an orbit.

### Searching for Persistence in Your Data

- Display the first image of a visit with histogram equalization scaling and look for obvious dither patterns (as with the top figure above).
- Run MultiDrizzle on your images and subtract the last individually drizzled, distortion corrected image (..single\_sci.fits) from the first image of this type.

Persistence properties and mitigation strategies are discussed in more detail in Section 7.9.4 of the Instrument Handbook, as well as on the WFC3 website's persistence page: [http://www.stsci.edu/hst/wfc3/ins\\_performance/persistence/](http://www.stsci.edu/hst/wfc3/ins_performance/persistence/)

## COUNT RATE NON-LINEARITY

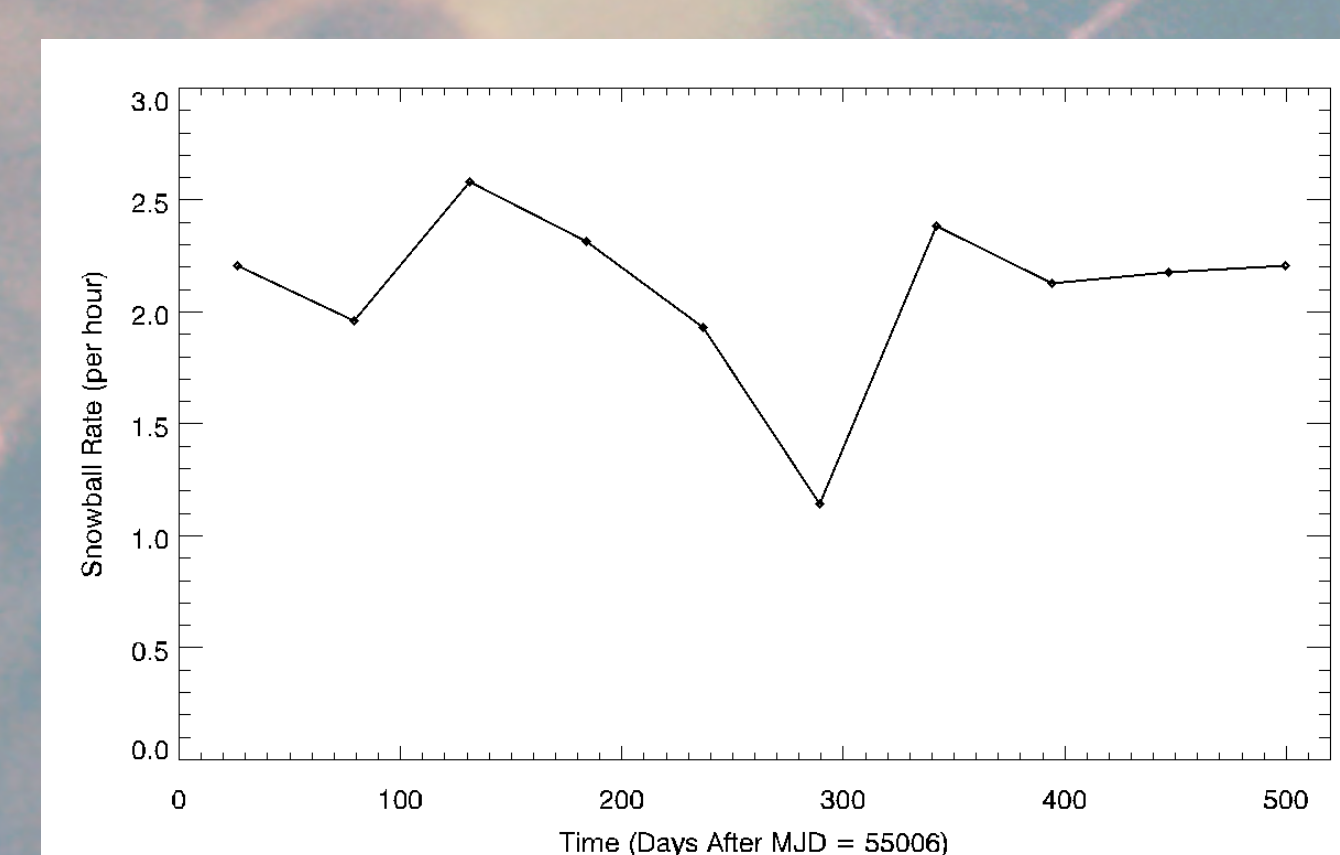
Past studies have found that the WFC3/IR detector suffers from a count rate-based non-linearity (a.k.a the Bohlin Effect), similar to that seen in NICMOS detectors. An initial measurement of this effect was made by comparing photometry of stellar clusters between WFC3/IR and ACS/WFC and NICMOS, where the count rate non-linearity effects are well characterized. This study revealed a non-linearity in the IR channel of  $0.010 \pm 0.003$  magnitudes per dex of count rate, in the sense that low count-rate sources to appear fainter than they should. Results are discussed in WFC3 ISR 2010-07. A second study, using reflected Earth limb light, is detailed in WFC3 ISR 2010-15, and produced identical results

This can have a non-negligible effect on photometry of faint sources. For example, if the photometry of a sky-dominated source (which is ~10 magnitudes, or 4 dex, fainter than the star used to calculate the IR zeropoint) is calibrated using the IR zeropoint, the count rate non-linearity will cause the source's brightness to be too faint by  $0.04 \pm 0.01$  magnitudes. **Currently, no correction for this effect is made in any of the standard WFC3 data reduction software.** Observers must manually correct their results.

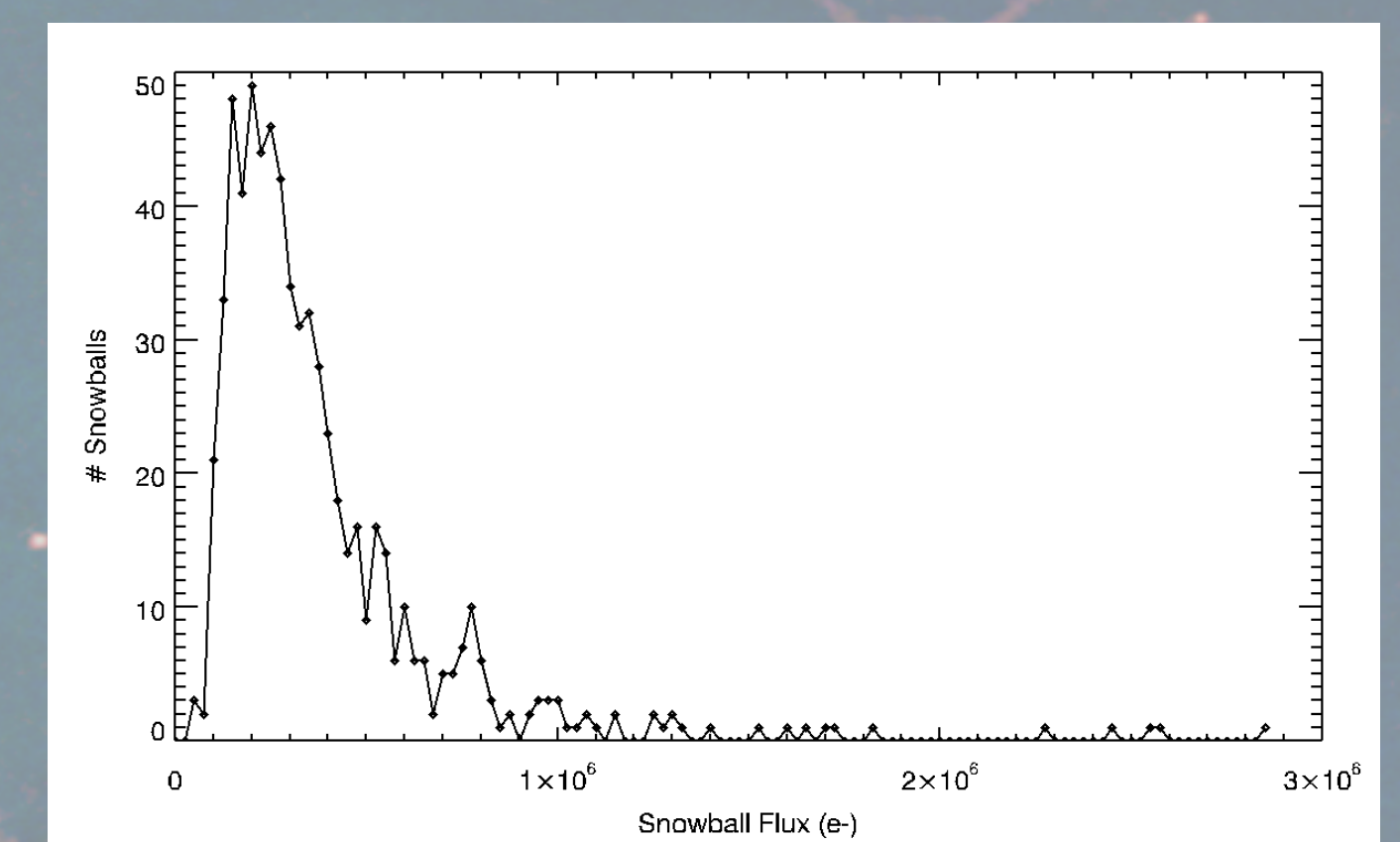
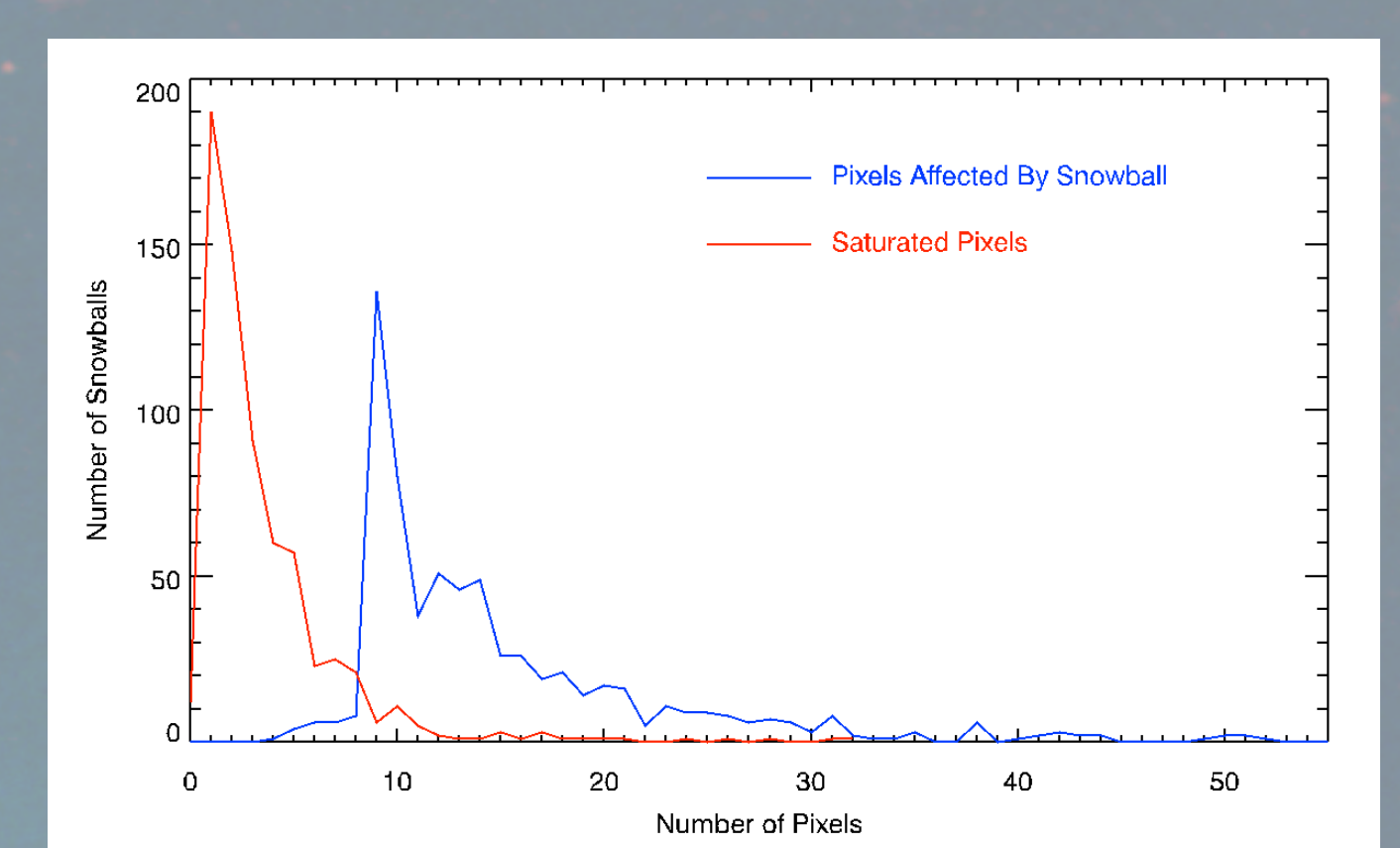
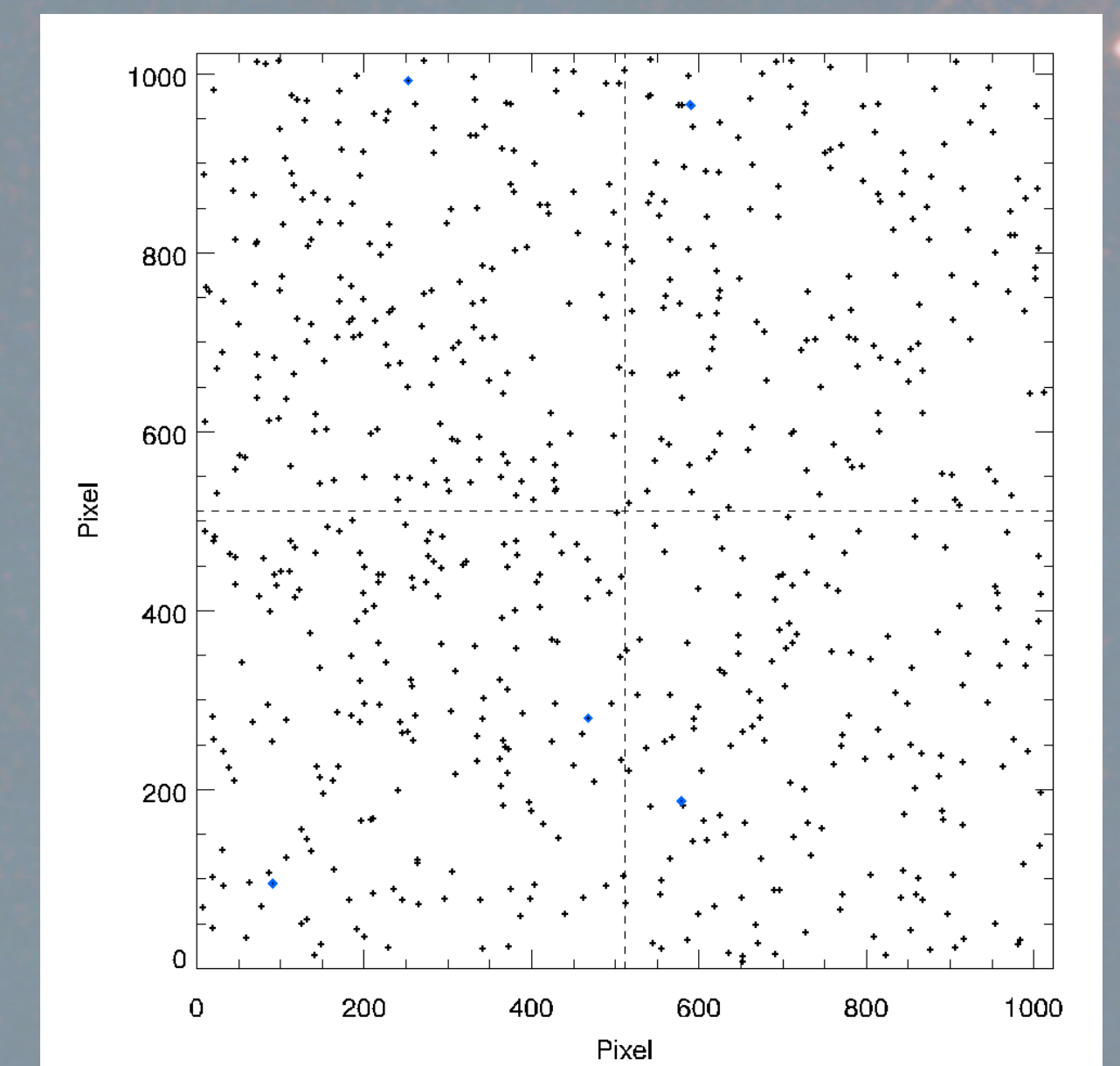
## SNOWBALLS

"Snowballs" are transient, high signal, extended sources which have been observed in WFC3/IR data since ground testing. Similar to a cosmic ray, all flux associated with a snowball appears on the detector instantaneously. The central ~1-10 pixels of a snowball are saturated and surrounded by more high signal pixels. The figure at the bottom of the panel shows a 7x7 grid of snowballs which have been extracted from IR data.

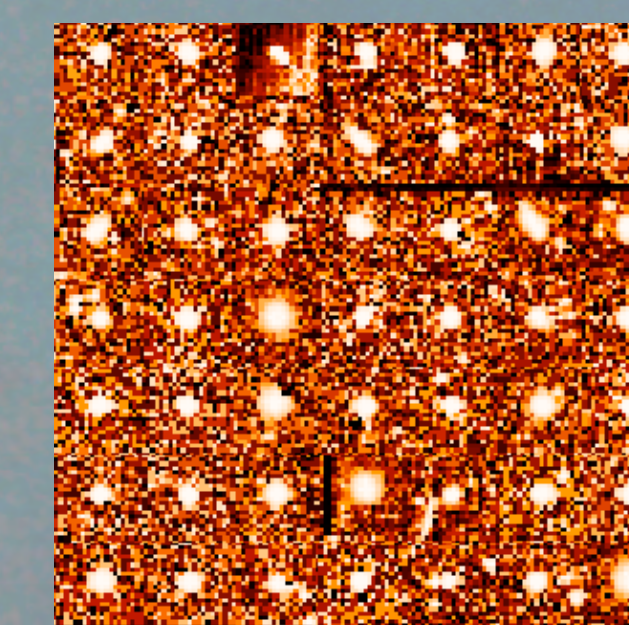
We have recently completed a survey of all WFC3/IR on-orbit calibration data in an attempt to identify snowballs (ISR in prep). This dataset represents 1.16 million seconds of exposure time, within which we identified 669 snowballs, for an overall rate of 2.08 snowballs per hour. The figure to the right shows a map of the location on the detector of all snowballs. Blue points indicate locations where snowballs have hit twice (5 locations).



The plot to the left shows the snowball appearance rate during Cycles 17 and 18. The plots to the right show histograms of the snowball areas and the number of saturated pixels. The plot below and to the right shows a histogram of the amount of flux contained within the snowballs.



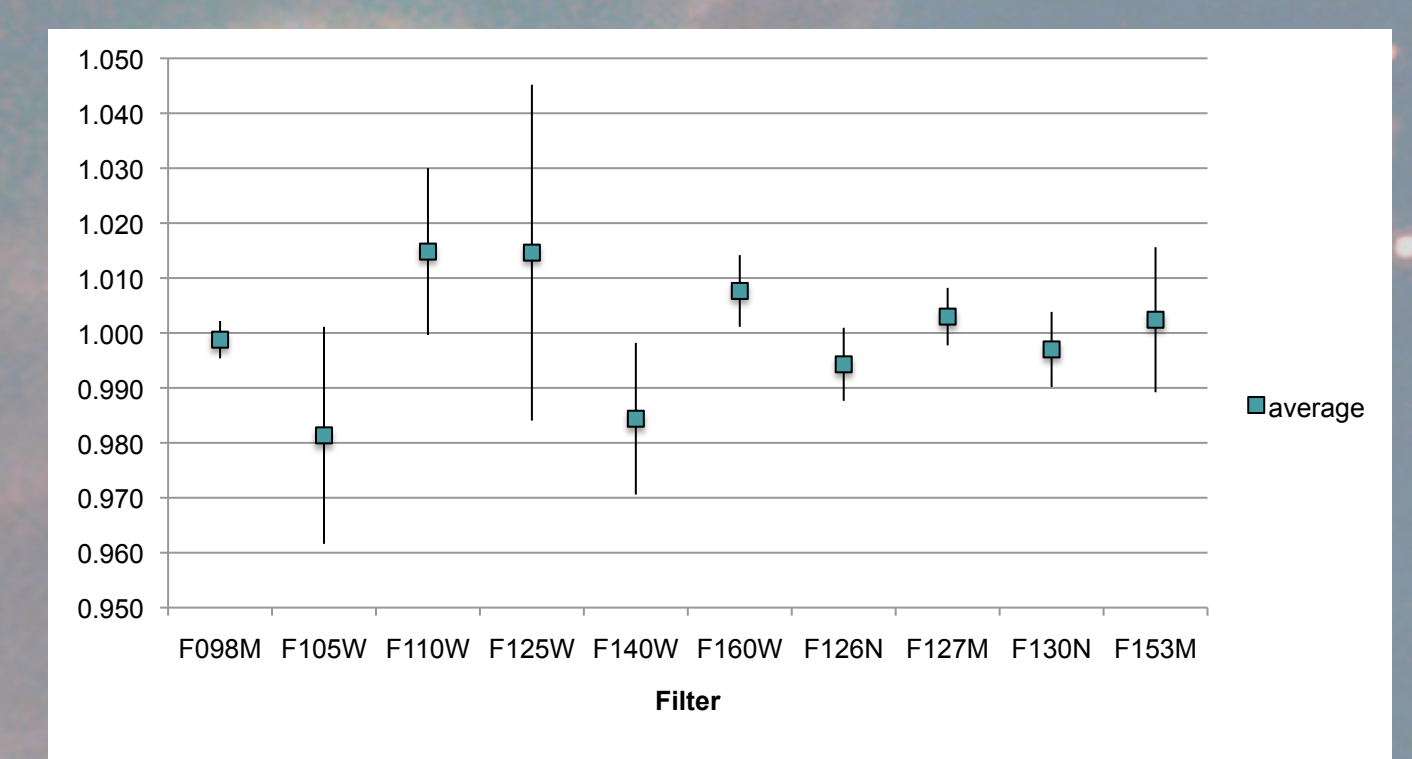
The cause behind snowballs is still unknown. See WFC3 ISRs 2009-43 and 2009-44 for more detailed information. Since snowballs behave similarly to cosmic rays, the cosmic ray rejection step within the calwf3 pipeline should remove them from science data.



## PHOTOMETRY

During Cycle 17, observations of GD71, GD153, G191B2B and P330E, in all 15 IR filters were taken to measure the photometric characteristics of the IR channel. The accompanying figure shows the repeatability of the photometry in drizzled images, over ~ 12 months during Cycle 17 for GD71 in several filters. Signal to Noise in each individual exposure is at least 100 in the narrow band filters, and ranges up to 1000 in the wide filters. This data is for an 0.4 arcsec aperture.

During Cycle 18, we are increasing the number of standard stars to 12 – including more spectral types and fainter stars to better understand systematic uncertainties.

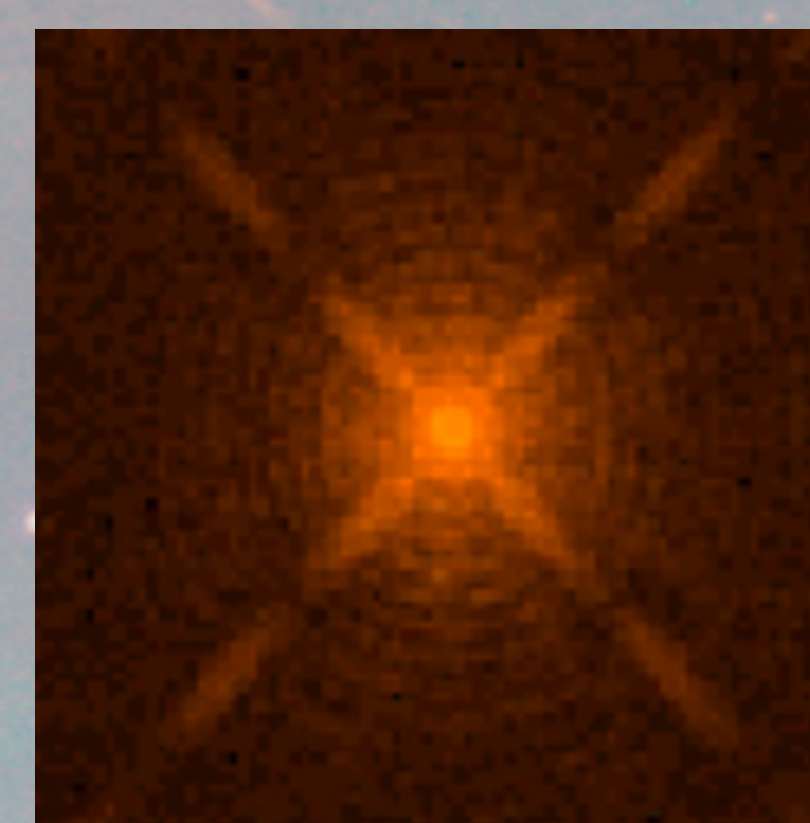


The error bars are +/- one standard deviation, which is between 1-2%, with the exception of F125W, whose photometry is affected by bad pixels in a couple of images.

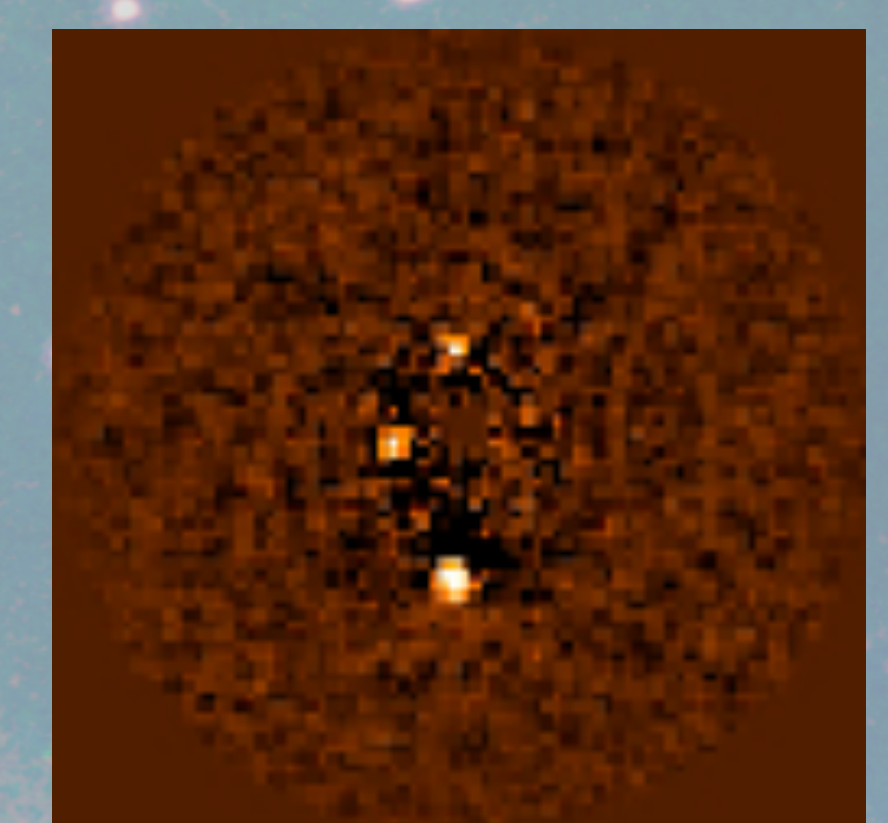
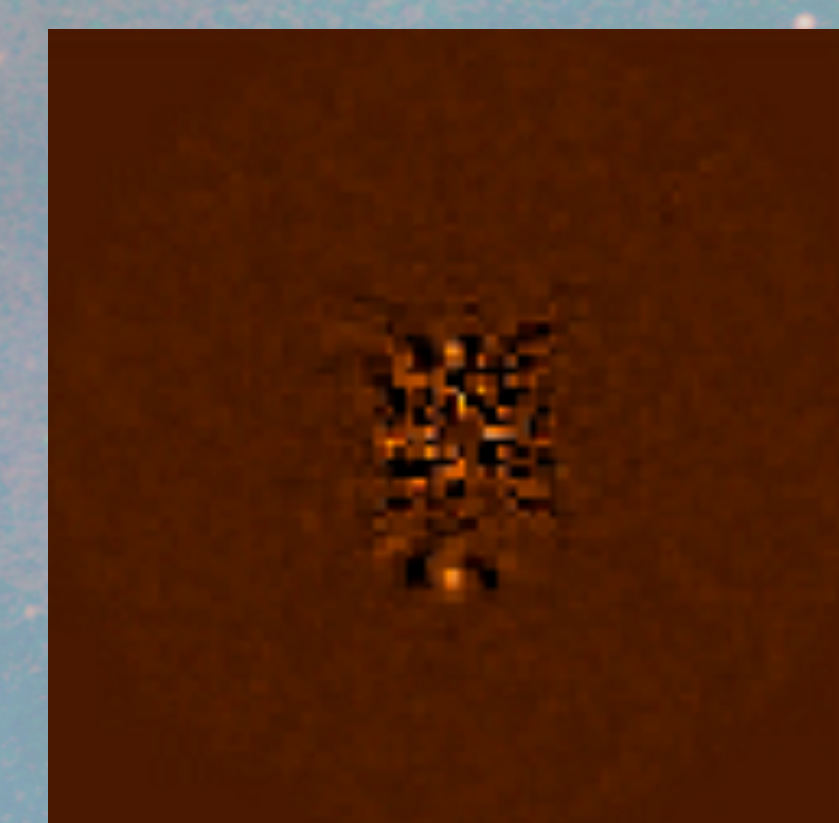
## HIGH CONTRAST IMAGING

Proposal 12354 was designed to measure the capability of the WFC3 camera to perform high contrast imaging. In the IR we observed the bright standard star HD165459 (V=6.86 mag) in the F128N filter for 3 orbits, with 3 orients per orbit.

The exposures were carefully designed with two goals in mind. First we wanted to have the maximum possible orients in 3 orbits, to perform angular differential imaging (ADI) (Marois et al. 2005). And second, we wanted to saturate the inner half arcsec to get sufficient flux in the wings of the PSF. In our observations we managed to saturate the inner 0.3" using 10s exposures with a total of 9 orients. Note that the IR channel pixel scale is 0.13"/pixel.



To measure the detection limit of the camera we injected four fake planets in the images (at 0.5", 0.8", 1.1", and 1.7" from the star) with a delta magnitude of 10 with respect to the star (as measured by the ETC).



The left image shows the star, the center image shows the result of carrying out ADI using the LOCI algorithm (Lafrenier et al. 2006) using only one orient of data as reference, and the right image shows the resultant ADI subtraction with all 9 orients. With every additional orient we were able to detect the injected planets with a higher SNR. Using all 9 orients we were able to recover three of the four artificial planets, with the innermost planet (0.8" from the star) undetected. The results clearly indicate that the WFC3/IR detector can be used for high contrast imaging (Rajan and Gilliland (in prep)).