GUVI changes to Level 1B product

Introduction

The GUVI products went through many changes internal to the GUVI team before the current release of the new Level 1B product. The radiances and pointing information are now more accurate, and there are new variables to allow easy access to information not previously contained in the L1B (counts, backgrounds, and geolocations at other altitudes). In order to reprocess the archive, we set up multiple processing streams on a cluster in order get through the 16 years of data in less than one year.

GIUSEPPE – can you comment on these numbers…

Table 1 - Version summary: Calibration, Software, Products

GUVI L1B Versions	Old Archive	New (2017) archive
Calibration	9 (GUVI1_TIMED_v009.ncdf)	13 (GUVI1_TIMED_v013.ncdf)
Software	3	5
Product	8	13

Calibration changes

Changes made to the calibration are listed in Table 2 below. The GUVI team went through three intermediate calibration versions (v010, v011, v012) internally before we were satisfied with the state of the improved v013 calibration.

Table 2 - Changes to the Calibration

Change	Description
121.6 nm lineshape	GUVI 1216 lineshape was measured on orbit and is now used for 1216 background subtraction
Pixel Solid Angle	The effective width of the optical slit was determined on orbit by observations of daylit earth. The slit width determination was used in conjunction with pixel lengths determined from laboratory data to update individual pixel responsivities. Changes in pixel solid angle produce a gradual change in responsivity along the slit from one pixel to the next, but not much change in slit averaged responsivity.
LBH long responsivity correction	A mismatch between the true definition of the LBHL wavelength boundaries on the satellite and that used in the ground software calculations caused the inferred LBHL responsivities to be too low for data obtained after November 2004 . This correction leads to smaller LBHL radiances for a given number of observed LBHL instrument counts in the revised products.
Limb step pointing correction	The scan mirror step positions were adjusted based on the positions of stars observed on the limb
Spacecraft roll position correction	Correction for PVAT file positions because of an error in the assumed TIMED star tracker alignment
Yaw pointing correction changed	Comparisons with stellar positions in limb observations showed that the yaw pointing correction needed to be changed by 0.3 degrees from its initial value, -0.8, to -1.1 degrees. The yaw direction is perpendicular to the scan direction.
Along track pixel angle optical vignetting distortions corrected	Offsets determined from limb profiles implemented and evaluated for correctness
Spectrograph flat-fielded	Spectrograph data had not been flat-fielded, so pixels along the slit had different radiances: previously, the slit average was reasonably accurate, but individual pixels could vary by 20%. Now corrected.
Consistent responsivities	Radiances now have been made consistent across all calibration periods (i.e., between spectrograph and imaging modes and between different spacecraft color tables).
Count bias	Bug in software fixed where background subtracted count-rates close to 0 were set equal to zero, causing a slight bias to radiance averages when combining pixels.
Long background subtraction	GUVI algorithm for long wavelength background subtraction was replaced with a more accurate SSUSI derived algorithm.
NetCDF4 format	NetCDF3 files replaced with NetCDF4 files with internal compression, so no longer a need to store the data in gzipped files.

Software

The software has gone through many changes as well. Some of these changes were to create a new near realtime product to assist the Air Force Weather Agency (AFWA) with monitoring of Space Weather. Major changes to the software are listed in the sections below.

Replacement of Level 1C with Sensor Data Record (SDR) format similar to DMSP/SSUSI SDR.

The Air Force Weather Agency (AFWA – now the 557th Weather Wing) was using data made from observations of GUVI's sibling instrument, the Special Sensor Ultraviolet Spectrographic Imager (SSUSI) on the Defense Meteorological Satellite Program (DMSP). AFWA uses the Sensor Data Record (SDR) product instead of the Level 1C previously used by GUVI. The SDR product development has now superseded the GUVI Level 1C. The SDR contains gridded, binned radiances and there is now a limb product. Gridded radiances are simple averages of L1B pixel radiances. An advantage to doing this is that eventually other SSUSI analysis software can be used on these data products.

Spectrographic Level 1B and Level 1C

On Dec. 7, 2007, the GUVI mirror scanning motor failed, putting the GUVI instrument in a fixed disk observation position. To get the most science out of the instrument, GUVI was put into spectrographic stare mode. A new Spectrographic Level 1B product was developed so that that data could be made available for detailed studies of spectral features in the data. In addition, a level 1C product that bins 5 color spectrographic data (synthesized from color tables applied to spectrographic data during ground processing) is available, making for radiances with very low levels of uncertainty.

Changes by software version

The changes by software version are listed below. We are now in version 5.0, with version 6.0 in development

Software Version 4.0

- Software was ported from Solaris to Linux.
- Changes made to enable realtime processing capability for Space Weather nowcasting.
- C++ overall control structure was removed and replaced with a more flexible perl script
- Repository moved to Subversion CM
- Many additions to imaging L1B:
    - night and auroral reference altitude geolocations,
    - subtracted backgrounds written to L1B files.
    - Count decompression errors written in L1A
- Experimental version of Spectrographic L1B product.

Software Version 5.0

- New Calibration file and file format.

- Software adapted from DMSP/SSUSI to make SDR product to replace L1C products

Software was written to make Spectrographic L1B products.

- Corrected count error
- Implemented optical vignetting corrections
- Implemented new long wavelength background subtraction procedure
- Implemented NetCDF4

Product Format changes to L1B

New variables have been added. We have not changed the naming of any variables in the v008 product version so that any analysis tools written with the old data can still be used. However we feel the new variables will enable more complete analyses to be done.

Level 1B Disk and Limb:

Added additional leap second to config file for leap seconds added on 1/1/2006 and 1/1/2009 – v008 data in 2006 and 2007 one second off

New Variables:
Count Information:

- Counts – photon counts
- CountDecompError – estimated error in compressing high count rate range

Backgrounds:

- Background1216 – background counts estimated due to 1216 scattering
- Background1304 – background counts estimated due to 1216 scattering
- BackgroundLong – background counts estimated due to long wavelength light
- BackgroundDark – background counts estimated due to detector noise

New Disk Variables
New Piercepoint Geolocations at 350 km (night) and 110 km (auroral)

- PiercePointLatitude_Night
- PiercePointLongitude_Night
- SolarZenithAngle_Night
- PiercePointLatitude_Auroral
- PiercePointLongitude_Auroral
- SolarZenithAngle_Auroral

Altitudes specified as global attributes in files

- Geolocation_Altitude_m = 150000 meters
- Geolocation_Altitude_Night_m = 350000 meters
- Geolocation_Altitude_Auroral_m = 110000 meters

Radiance Changes to GUVI Colors

The responsivities used in GUVI Calibration v013 and v009 can be compared to determine how the radiances differ in the two versions. Taking the ratio of slit-averaged responsivities from v009 and v013, we can determine the ratio of the radiances for each of the GUVI colors as shown in Table 3 and Table 4 below. The values in Table 4 include the effects of updates to the grating-scattered and stray light backgrounds in the revised calibration, and are more representative of the changes one would expect in comparisons of the old and new data products.

Table 3 - Change in radiance from responsivity changes alone

Color	Radiance ratio (v013/v009)
1216	+8%
1304	+6%
1356	-6%
LBHS	-5%
LBHL	-35%

Table 4 - Change in radiance including effects of background subtraction

Color	Radiance ratio (v013/v009)
1216	+8%
1304	+6%
1356	-5%
LBHS	-1%
LBHL	-19%

The percent change in radiance for individual pixels, including the effects of background subtraction as in Table 4, is shown for each of the five GUVI imaging colors in Table 5.

Table 5 - Percent Change in GUVI radiance versus color and pixel (v013/v009)

% Change in Radiance		Spatial Pixel Index													
Color	Slit Average	0	1	2	3	4	5	6	7	8	9	10	11	12	13
1216	8	-5	1	4	7	8	11	11	13	12	13	12	12	10	7
1304	6	1	4	3	5	5	5	6	7	6	7	7	8	9	8
1356	-5	-9	-10	-7	-8	-6	-4	-4	-5	-5	-2	-3	-1	-1	-1
LBH1	-1	-6	-5	-4	-3	-1	-2	-2	-1	-1	1	2	3	3	4
LBH2	-19	-24	-22	-24	-19	-17	-22	-25	-22	-21	-16	-13	-16	-15	-15

Radiances Changes For a Typical GUVI Orbit

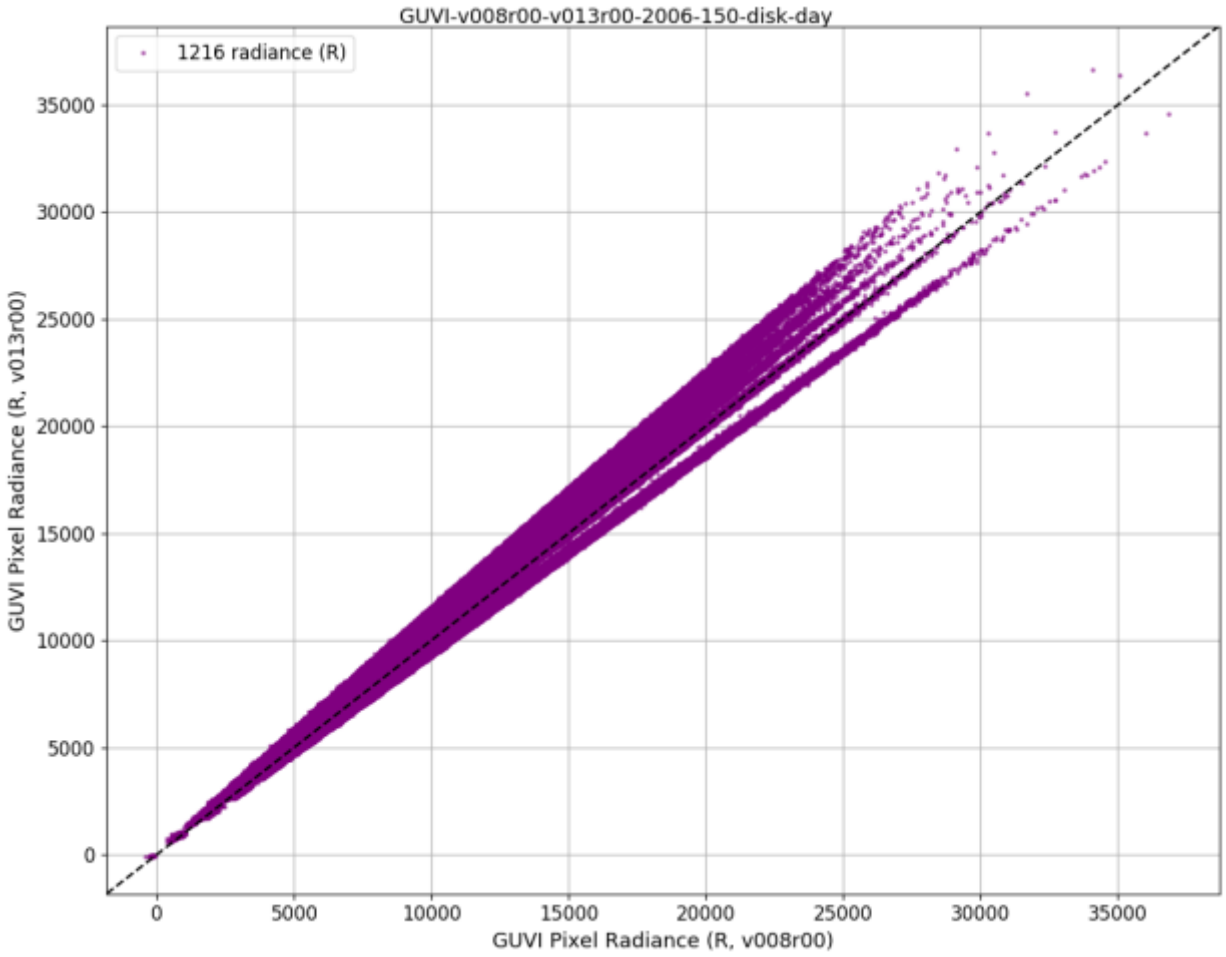
Radiances are plotted for a day's worth of data on May 30, 2006. The vertical axis in the plots corresponds to the new v013 radiances, while the horizontal axis corresponds to the old v009 radiances.

The following plots show radiances compared pixel by pixel for imaging data taken over multiple orbits on May 30, 2006. Since each pixel is calibrated separately, 14 lines appear on graph, one for each spatial pixel, the slope of which is the ratio of the new radiances to the old radiances for that particular pixel.

Due to the pixel solid angle correction, there is a spread in the ratio of new values to old values among the individual pixels of all five GUVI colors. This "fan effect" is most distinct in the color 1216 plot, and is mainly a consequence of the per-pixel responsivity ratio between the two calibration files.

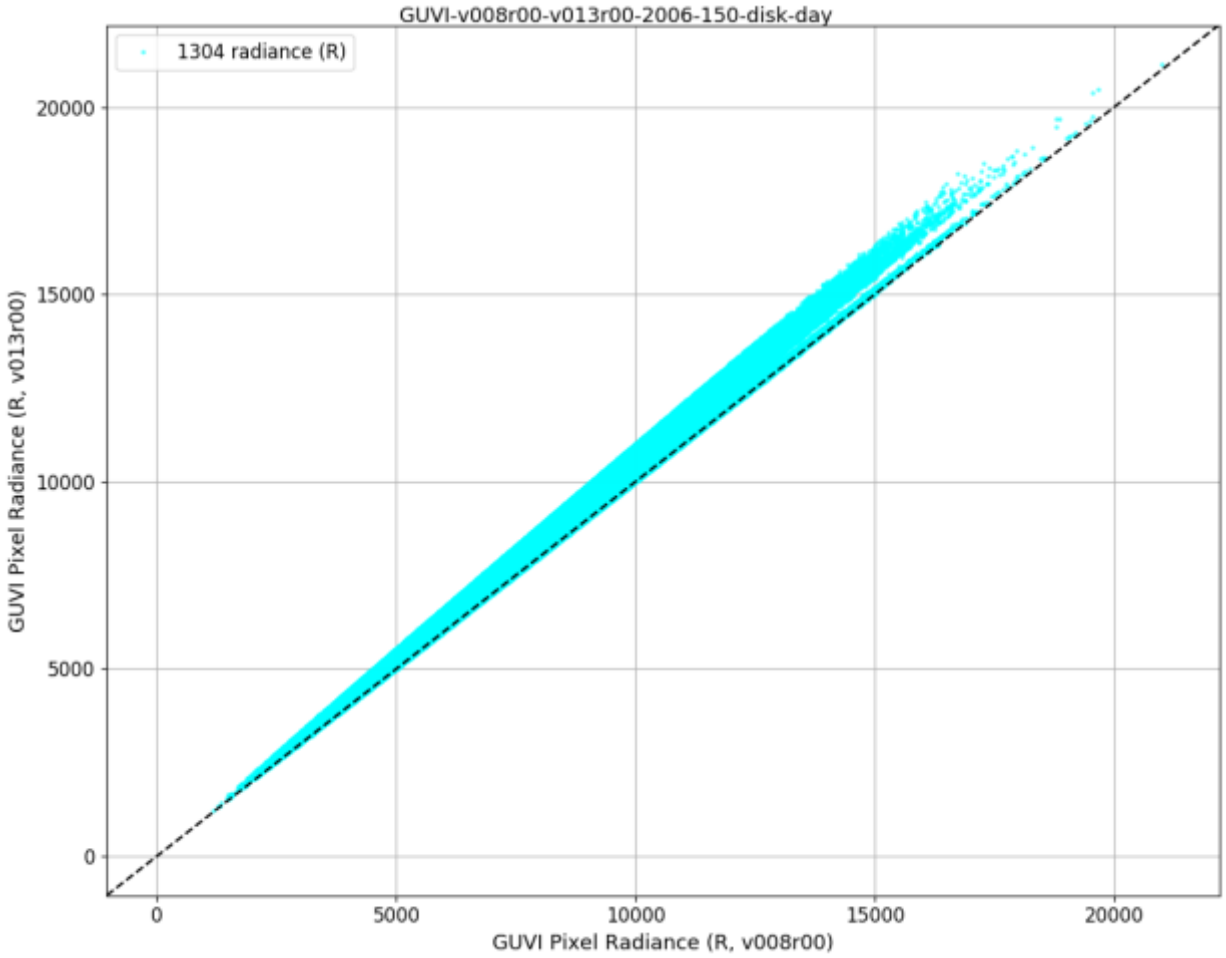
For colors longward of 1216, the revised 1216 line shape enters only in the sense that the fraction of scattered 1216 emission contained within the color table boundaries is computed from the extended wings of the 1216 line shape. For 1356 and the LBH bands the plots get a bit more complicated since the subtracted backgrounds create a lot of "fuzz" in these radiances. Any values that are less than zero are a consequence of that counting statistic "fuzz". The generally low count values for these colors produces a clumping of points around the corresponding discrete integer (raw) count values, evident as a step-like appearance in the 1356 and LBH plots. Changes made to the 1216, 1304, and long background masks also play an increasingly large role in the radiance distributions as we go from the 1356 color to the LBHS and LBHL colors, where instrument responsivity begins to drop off and the larger detector areas involved accumulate more of the scattered light from the bright 1216 and 1304 lines.

1216 disk radiance changes



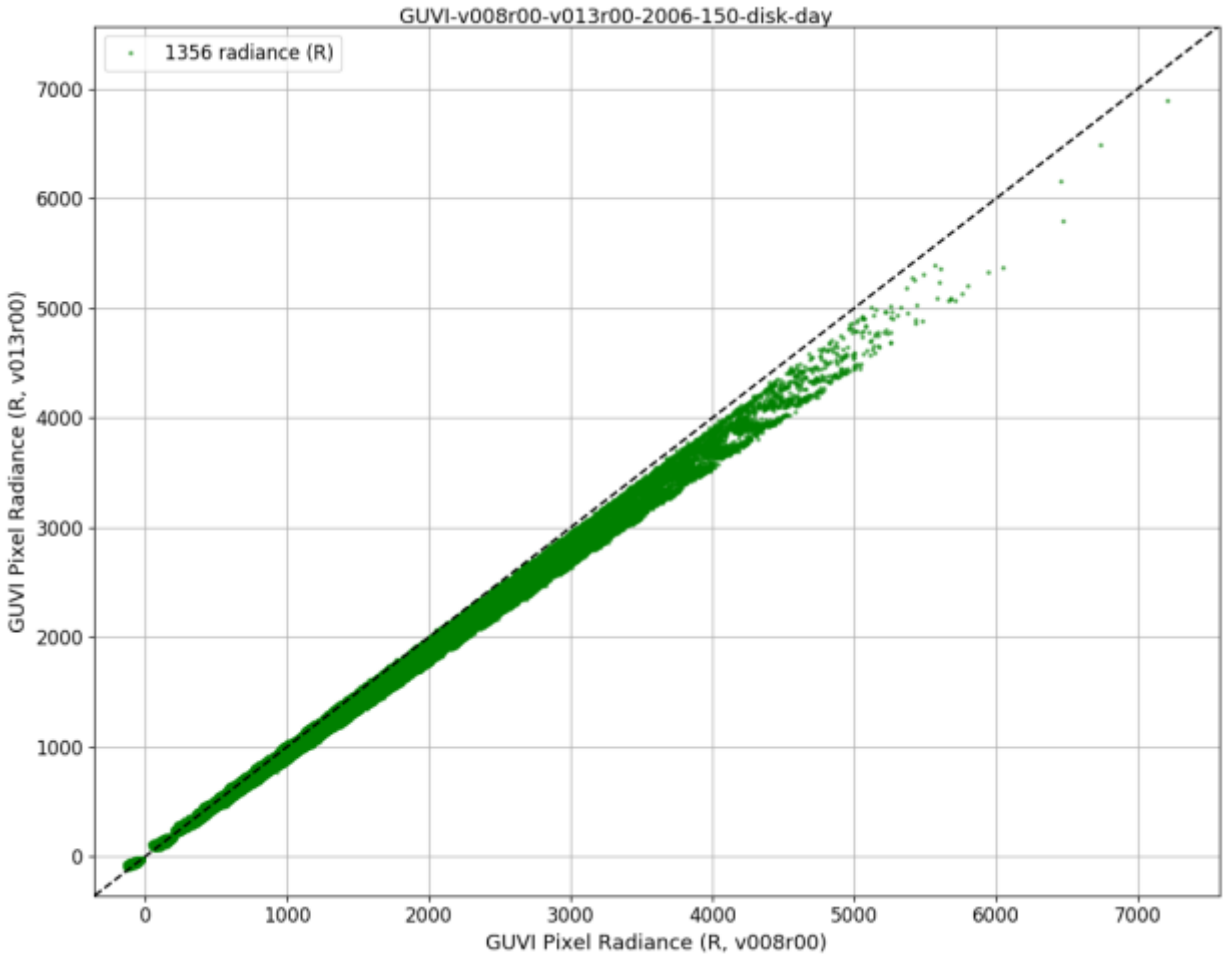
The old (v009) calibrated GUVI data is displayed on the horizontal axis while the new (v013) data is on the vertical axis. The pixel solid angle corrections, combined with the updated responsivities and 121.6 nm lineshape leads to radiance changes varying between -5% and +13% in the data. At higher radiances we can see that the different spatial pixels follow different tracks. The dashed black line is unit slope, y=x . The average 1216 radiance increased by 8% from v009 to v013, and thus the majority of the points in the scatter plot lie above the y=x line.

1304 disk radiance changes



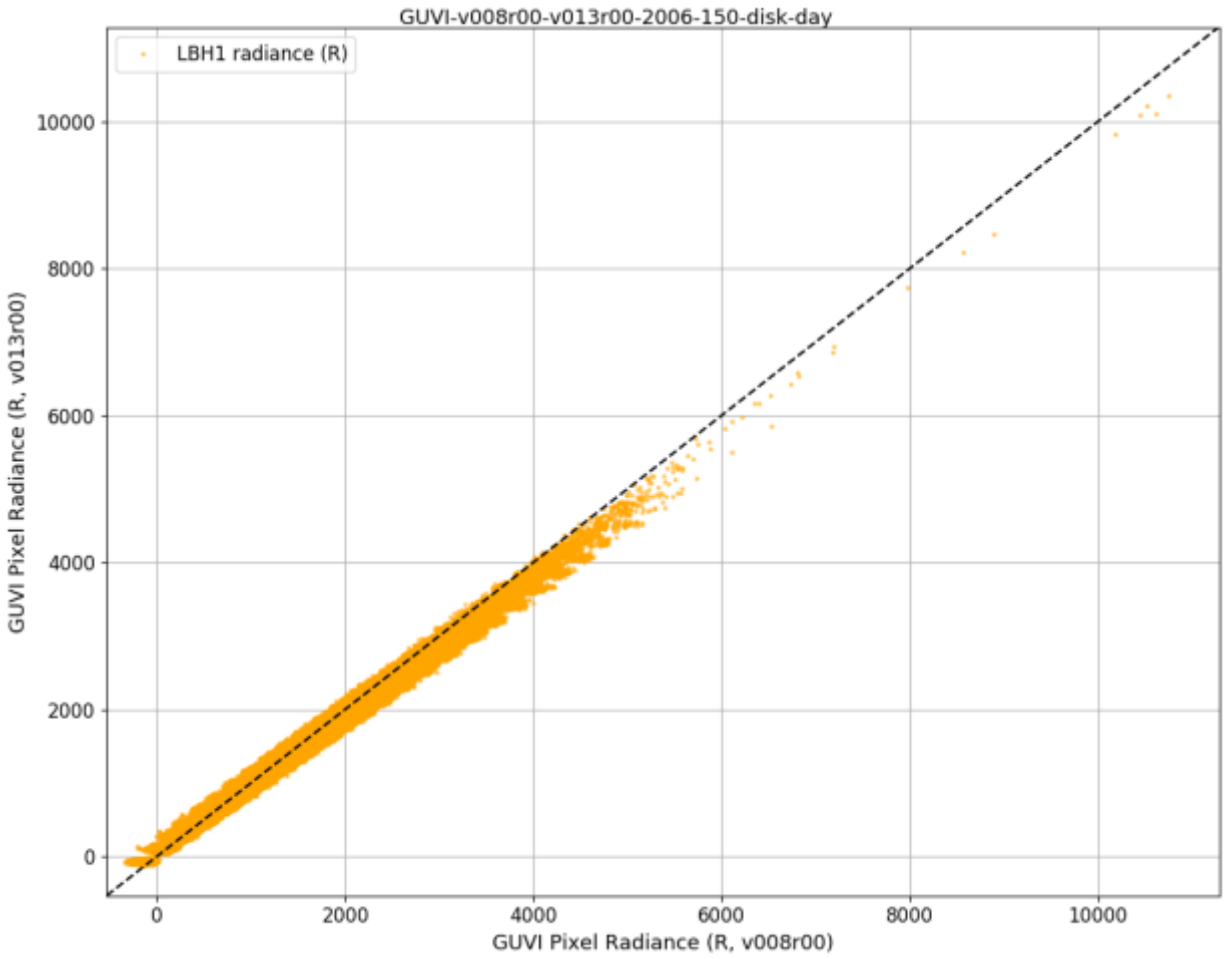
The old (v009) calibrated GUVI data is displayed on the horizontal axis while the new (v013) data is on the vertical axis. The average 1304 radiance increased by 6% from v009 to v013, and thus the majority of the points in the scatter plot lie above the y=x line.

1356 disk radiance changes



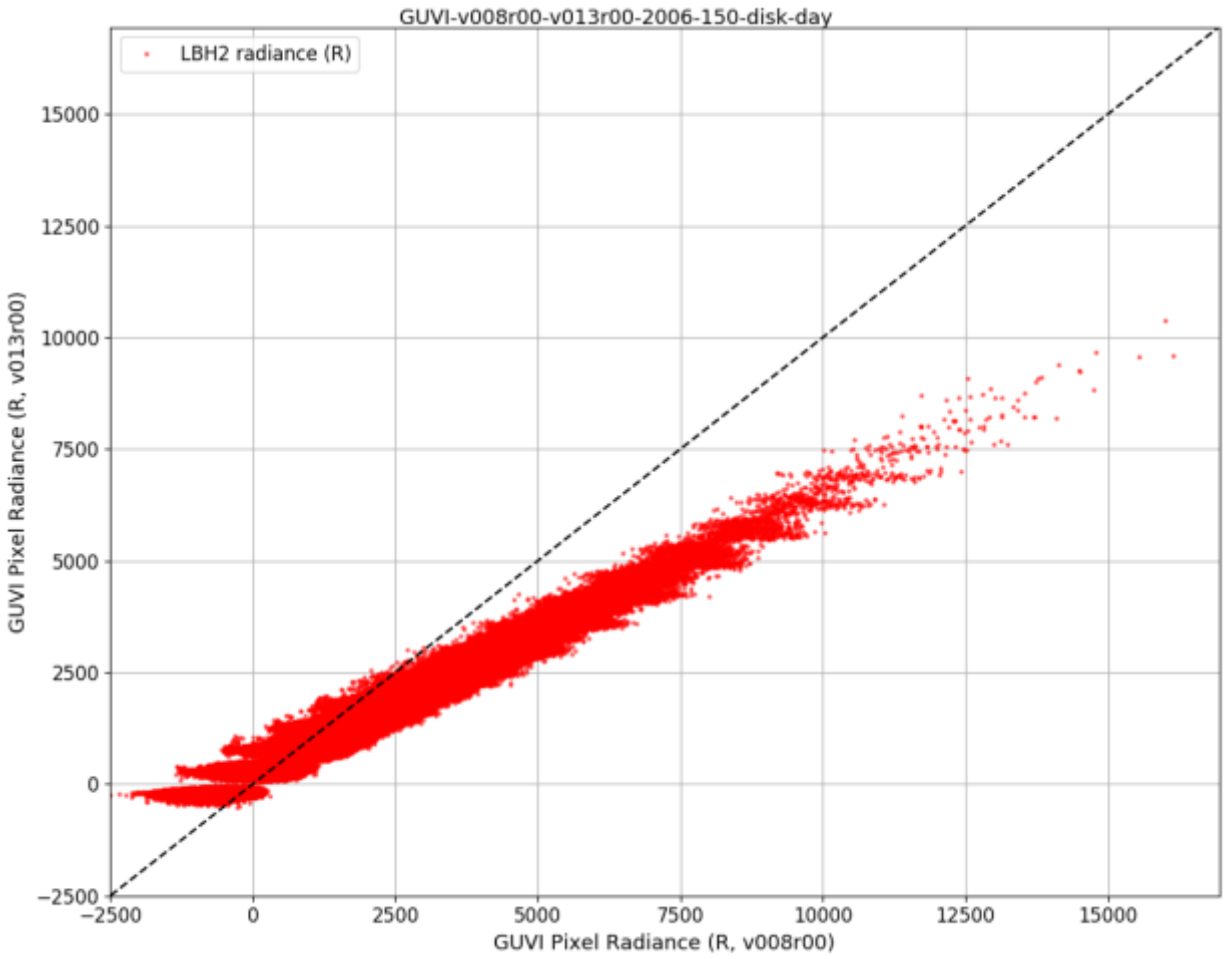
The old (v009) calibrated GUVI data is displayed on the horizontal axis while the new (v013) data is on the vertical axis. The average 1356 radiance decreased by 5% from v009 to v013, and thus the majority of the points in the scatter plot lie below the y=x line.

LBH short disk radiance changes



The old (v009) calibrated GUVI data is displayed on the horizontal axis while the new (v013) data is on the vertical axis. The average LBHS radiance decreased by 1% from v009 to v013; while the majority of the points in the scatter plot lie close to the y=x line, the combined effects of the slight responsivity increase and the changed backgrounds makes the new radiances slightly lower at the high radiance end. The converse is true at the low radiance end of the scale.

LBH long disk radiance changes

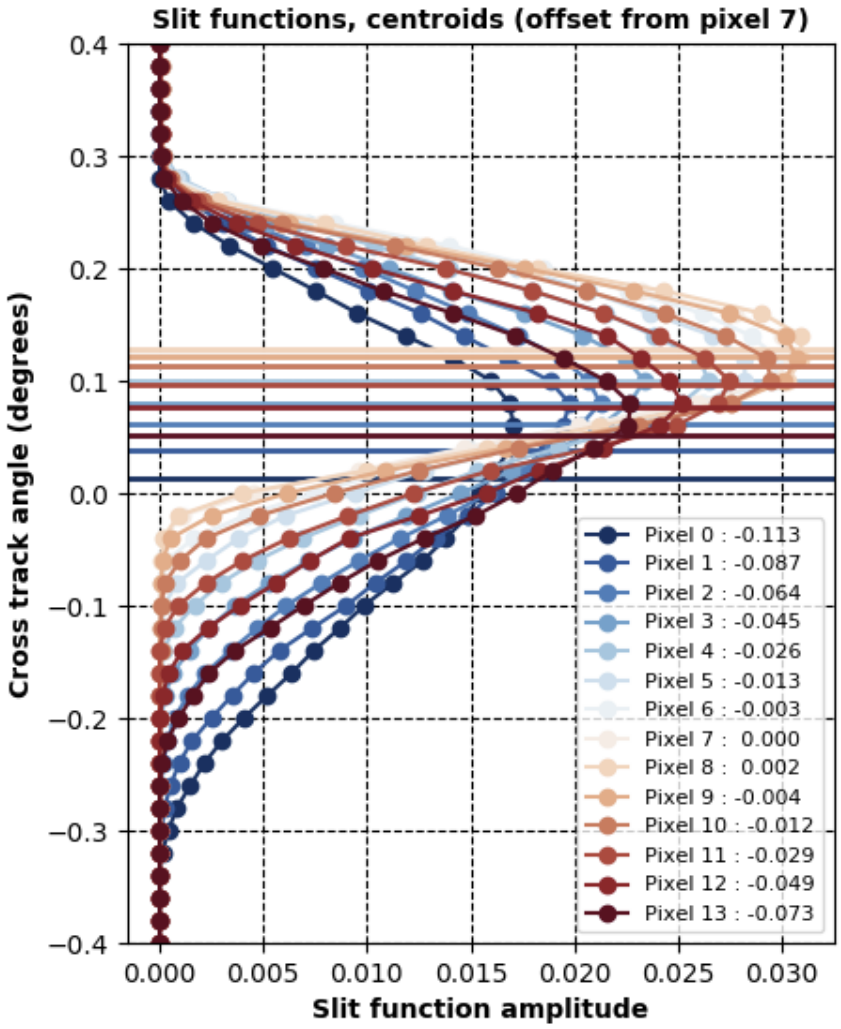


The old (v009) calibrated GUVI data is displayed on the horizontal axis while the new (v013) data is on the vertical axis. The average LBHL radiance decreased by 19% from v009 to v013; the majority of the points in the scatter plot lie below the y=x line, but the combined effects of the rather large responsivity increase (owing to the correction of the spectral region assigned to the instrument color tables for these emissions) and a net reduction in the subtracted backgrounds makes the new radiances substantially lower at the high radiance end (responsivity change dominates), while at the low radiance end of the scale the new values are slightly larger (smaller background subtraction dominates).

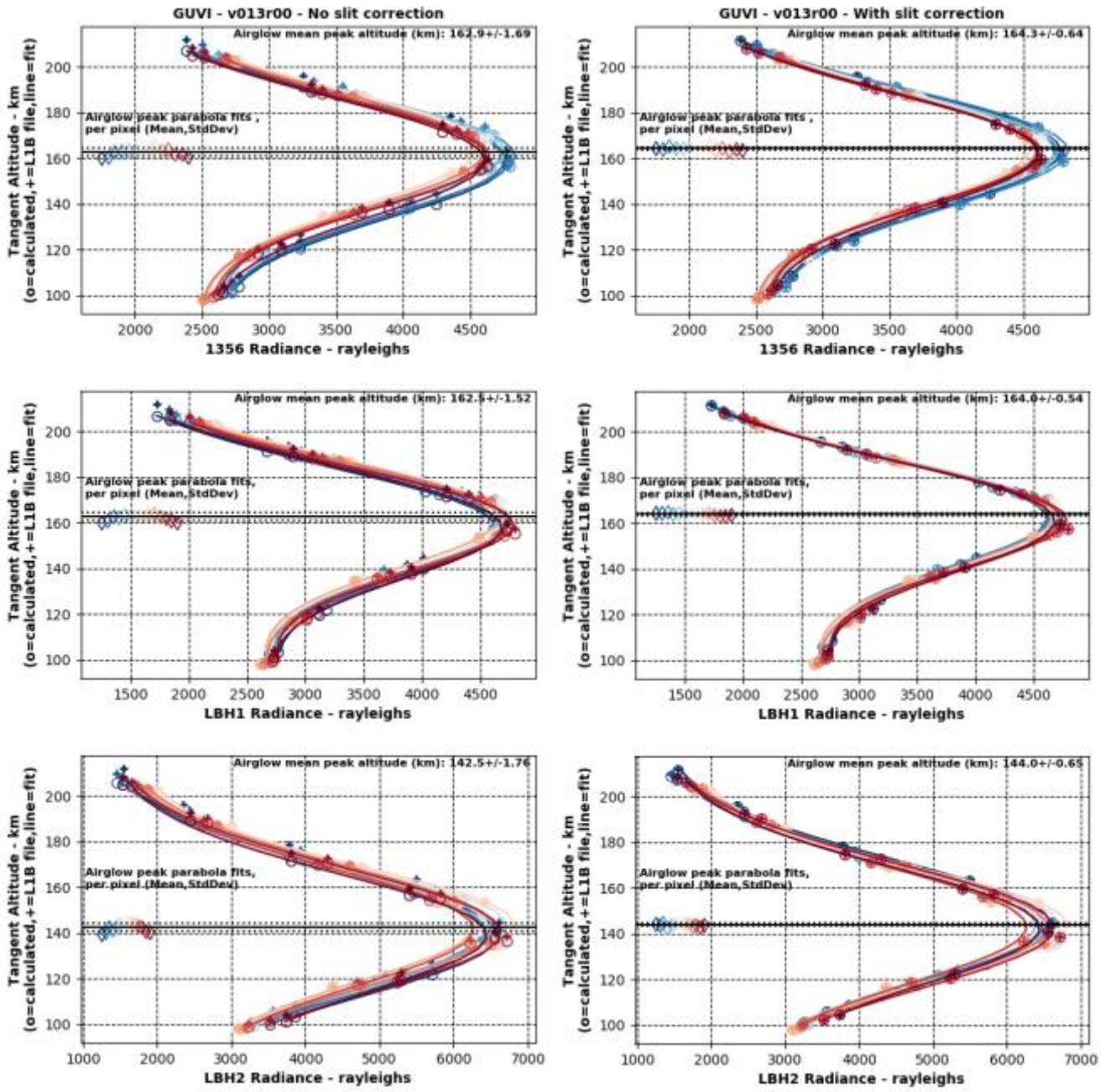
Pointing Changes to GUVI Pixel angles

Limb angle step positions

Derived step angles from stellar observations from GUVI were made and incorporated into the calibration table. These corrections were typically of the order of hundredths of a degree, but are different for each limb elevation angle.



In addition, a correction was made for the curvature of the slit function (see figure above), which shifts the centroid of the observed airglow by varying angular amounts from one end of the slit to the other. The addition of this correction moves the heights of the airglow peaks to a uniform value for each spatial pixel (see figure below).



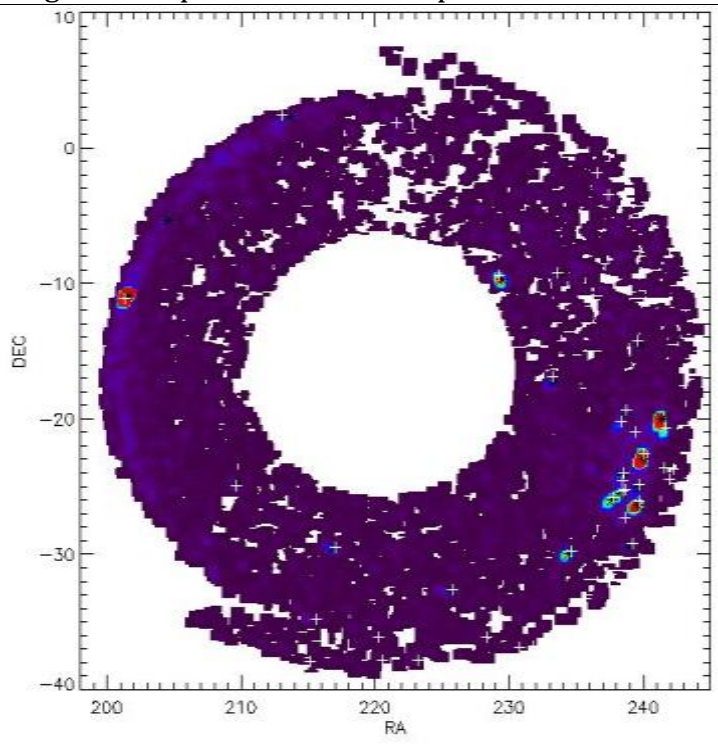
In the figure above, the dayglow radiance limb profiles vs. geolocated tangent altitude for each GUVI limb pixel are plotted for 135.6 nm (top row), LBHS (middle row) and LBHL (bottom row). The left column shows the uncorrected values and the right column shows the values with the corrected look angles. To highlight the corrections, the peak altitudes (from a parabolic fit) are plotted as circles for each pixel on the left edge of the graph. As you can see the uncorrected "frown" pattern gets corrected to a straight-line uniform altitude.

Roll Correction

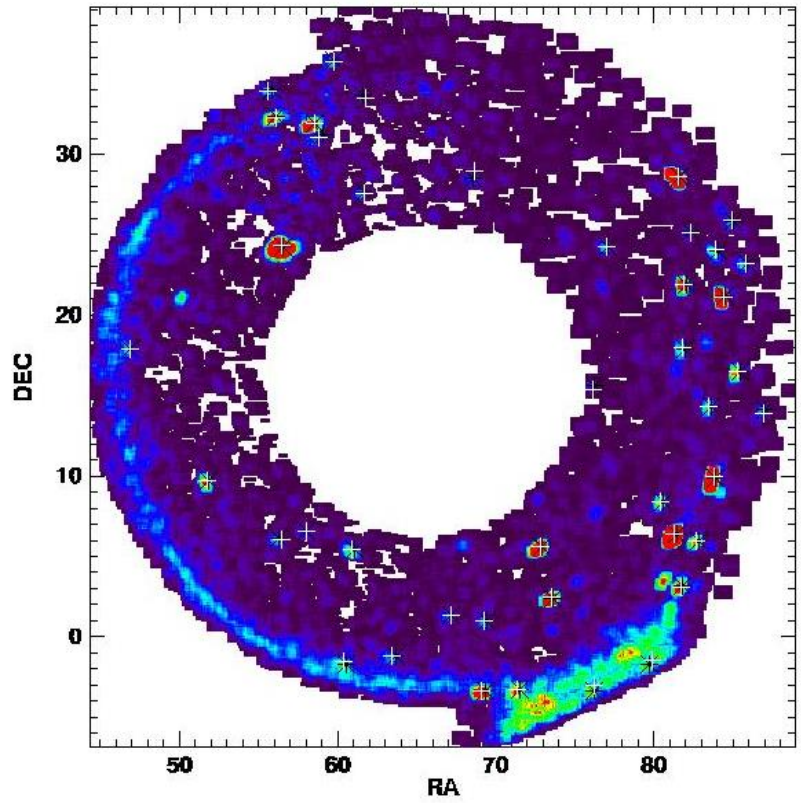
The PVAT files were off by 0.109 degrees in the roll correction owing to an error in the assumed alignment of the star trackers. This angle is now subtracted from all mirror elevation steps.

Yaw Correction

By comparing observed stellar positions with catalogued positions, we found that changing our assumed yaw angle from -0.796 to a yaw angle of -1.15 degrees in yaw aligned the observed and catalogued star positions. Some representative shots are shown below.



Old GUVI Yaw angle. GUVI 3 month limb LBHS night radiances, referred to as the donut of science. Here we have plotted the Right ascension and declination of the GUVI pixels instead of the more usual geolocations coordinates. The positions of bright UV stars are marked with white crosses (+). Here we see a slight misalignment in stellar positions



New GUVI Yaw Angle. Another plot of GUVI LBHS night radiance pixels plotted in right ascension and declination. This time we have used the updated GUVI yaw angle of -1.15 degrees.
Here we see a good alignment between the stellar positions and the GUVI radiance spots/

Spectrographic L1B

The current archival spectrographic L1B is product version 10 and created with Calibration version number 11. The new product will be version 13 created with Calibration version number 13.

GUVI Spectrographic L1B Versions	**Old Archival**	**New (2017) archival**
Calibration	11	13
Software	4	5
Product	10	13

Version 13 spectrograph radiances have been verified to be consistent with version 13 imaging mode radiances.