LWS Grating Flux Calibration

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1. Aims

This note has several aims. It outlines the strategy used to derive the current (OLP 7) grating rsrf/flux calibration and describes the steps used. This is intended be both a reference for the current calibration and to also be a cookbook for those interested in using the routines mentioned to re-derive the calibration in the future. The derivation of the uncertainty in the RSRF will be addressed, however this note will not address is aspects of final accuracy from the pipeline using this calibration, as this is covered elsewhere e.g. in the LWS IDUM and the ISO Explanatory Supplement. Relevant to the area of LWS rsrf calibration but not addressed in this note are concerns about the accuracy of the Uranus model at short ($\leq$ 70 microns) wavelengths. It must be noted that this is an end of mission report, and can only reflect our current understanding. Work is ongoing in several areas notably in understanding the applicability of the Uranus model, detector transients and cross calibration with other instruments.

2. Introduction

The LWS RSRF and flux calibrations are both based on Uranus. The reason for this is that Uranus is the only 'flat' reasonably bright source with a well modelled spectrum in the LWS region. Although much calibration work in this wavelength region has been done using Mars, for LWS the Mars spectrum simply has too many lines to derive an RSRF. Also being an extremely bright source there are concerns about detector behaviour in this flux regime.

For the RSRF calibration the asteriods generally are too faint to achieve good enough S/N and non-solar system objects are either also too faint such as normal stars or do not have sufficiently accurate models. In principle a statistical approach using many different sources would be viable for the fine tuning of the flux calibration especially in the 60 and 100 micron region where IRAS data are available and with KAO data. However up to now only Uranus has been used which has a model accurate to 5wavelength range and has been observed 20 times with an L01 AOT throughout the ISO mission.

3. Derivation of RSRF

3.1 The Data

The data used to derive the RSRF comes from one 6 hour 34 full scan observation of Uranus done in revolution 317. This observation was done in a non-standard way and a COIF was used. The observation consisted of groups of 6 scans interleaved with dark current measurements. The last set of scans consisted of a group of 10 scans. This was immediately followed by a set of five illuminator sequences done with the 'new' scheme of flashing each illuminator once at the 180 level. Finally five illuminator sequences were done using the 'old' scheme of flashing the illuminators once at the 100 level then again at the 220 level. The data were processed in to the SPD equivallent for calibrationn observations CPD, and 12 LCPD files were produced, osn numbers 1,3,5,7,9 containing the dark current measurements, numbers 2,4,6,8,10 containing the grating scans. Number 11 contains 5 repeats of the new illuminator flash sequence and 12, 5 repeats of the old sequence.

The grating CPD files were read into IDL using the utility CONCAT (see appendix) which allowed the scans to be combined into one IDL structure. Another utility GR_SPLIT_NEW was then run to find the positions of individual grating scans in terms of the number of points in each scan.

3.2 Dark Current Subtraction

The dark current data were read in to IDL and inspected. It was clear that no significant change in the baseline dark current had occured over the entire observation, hence it was decided just to extract the dark current from a combination of the measurements using median clipping at 3 sigma and then a mean was taken. A (10,2) background array was created and the utility MEDSIG was used to determine a median and error for each detector.

3.3 Removing Bad Data and Drifts

The combined scans data were inspected for any anomalies and it was found that there were two anomalies,

1. SW4: The first 2 scans gave a much lower output than the rest and the second 2 scans a slightly higher output. It was decided not to use the first 4 scans.
2. SW5: The first 16 scans showed an obvious difference in responsivity to the last 18. A large glitch was found and it was decided that only the first 16 should be used.

The responsivity of the LWS detectors is known to linearly drift over the course of the approx. 8 hours between bias boost curings. The response drift is removed for all full grating scan observations by fitting a straight line to the areas under each scan and adjusting the the area at the central point in time. Once the good data had been isolated the the UTS was converted from a 1-D (n) array to a 2-D (10,n) array and the utility TRACESIG was used to correct for drifts.

For SW4 and SW5 subsets of data were created, and GR_SPLIT_NEW was run with different output variable names. TRACESIG was again run for each of these data, hence there were three arrays of output variables, one valid only for SW4, one valid only for SW5 and one valid for the rest.

3.4 Averaging

To average the data the utility AVG10 was called for each of the three sets of data. This routine produced a median average of all the scans for each point in the scan at a particular grating commanded position. The data were then clipped at 3 sigma and a mean was found. Once the averaging had been done for all the data sets, the SW4 and SW5 data was substituted back in to the main data array.

3.5 Wavelength Conversion

The data points did had an associated grating position but not wavelength To get the data in terms of wavelength we read in the old LCGR file, and two arrays of dimension (10,4096) were extracted, one containing the wavelength values, and one the old respose values. The utility NCONV_GR was used to find the points in the LCGR file closest to the data points and this was used to establish a wavelength grid for the data. Both the data and the model of Uranus need to be on the same grid before division, this is achieved by re-gridding the poorly sampled Uranus model to the same scale as the data.

3.6 The Uranus Model

We had available a temperature model, (umodel.dat) based on a model generated by Griffin and Orton in 1993 but with 0.5K added to take proper account of Voyager data. The utility BBGEN was used to generate a flux model from this gridded onto the same grid as the data. This was then multiplied by 2.44×10^{-10} (the solid angle of Uranus at the time of rev 317) to convert from $W/cm^2/\mu m/sr$ to $W/cm^2/\mu m$.

3.7 Formatting for the Cal-G File

The spectral response file is in units of A cm^2 /W, therefore the spectral element size still needed to be removed. This was done by reading the LCGB cal G file into IDL and dividing the data by those values, to give the data in $A/\mu m$. The data were then divided by the generated Uranus model ($W/cm^2/\mu m$) to give RSRF profiles in units of A cm^2/W. There were some bad data points in the profiles and these were removed interactively with the ZAP2 utility. The profiles were then smoothed over 7 steps (1/2 resolution element) using the smooth library routine. they were then re-gridded to the LCGR wavelength scale using the utility C4096, and written to an LCGR file.

3.8 Error in the RSRF

The RSRF Cal-G file also gives an error per point on the RSRF. This error is the essentially the noise given by the averaging re-scaled in percentage terms to the RSRF. This was done taking the data set at the stage just after AVG10 had been applied, dividing the error on each point by the number of points (scans) used to calculate the error. Then the final filter value was multiplied by the error per point/the averaged data value to give the error per final filter point.

4. Illuminator Adjustment

4.1 Need For Illuminator Correction

The RSRF derived on Uranus and applied to any given observation of a source will only give an accurate flux calibration if the responsivity of the detectors at the time of the observation is the same as at the time of the Uranus observation in rev 317.

This ideal is not the case and infact the responsivity of the detectors is constantly changing giving an overall linear drift upwards between curings. The adopted method for removing this is to use the LWS illuminators as relative calibrators. Assuming the illuminator output is constant, the photocurrent given by the detectors to a standard flash sequence at the time of the Uranus observation can act as a reference. Any difference in photocurrent to this standard sequence at the time of a given observation can be ratioed with this sequence and the resultant constant is multiplied into the data to remove the drift. The photocurrent in response to the illuminators at the time of the observation is determined by averaging the responses to two illuminator sequences done at the beginning and end of the observation.

4.2 Deriving the Standard Flash

During the mission there were three different flash sequences used.

revs	no ramps	time	levels
0-237	8	1/2s	100 and 220
237-377	4	1s	100 and 220
442-875	24	1/2s	180

As the RSRF was effectively determined at the midpoint of the 6 hour observation i.e. the drift correction described above corrects to the midpoint, the standard illuminator sequence for this RSRF must be referenced to the same point in time.

Two of the three types of illuminator flash were taken at the end of the observation, relating to revs 0-237 (old style) and 442-875 (new style). The 5 illuminator flashes of each sequence were combined into a single sequence. To reference this to the midpoint of the scans the coefficients of fit determined for the scans were used to determine a set of adjustment factors. In the case of SW4 the reference was made to the midpoint of the actual scans used. For SW5 this method could not be used as the last scan of the observation was clearly still affected by the glitch. For this detector, the fit was used to reference to an illuminator flash at the end of the AOT before the observation. An assumption was made that for a the few seconds per level that occur during illumonator flashes the transient behaviour of the detector is the same for 1s ramps as for 1/2s ramps. Therefore to generate the third standard sequence the first four ramps of the old style sequence were used.

4.3 Testing and Fine Tuning

The standard flash, RSRF calibration was tested by using the cal-G files generated in a test pipeline. All L01 observations of Uranus were used to see if this calibration returned the model. For the shape the RSRF proved satisfactory but there were some systematic shifts between detectors and the model. The average of for each detector was divided by the average of the model interploated to the data for each observation. An overall average was taken for the old style and new style illuminator flashes. For each observation the same angle as rev 317, 2.44E-10 sr was assumed. The ratioes obtained were:

Detector	Old Style	New Style
SW1	1.14	1.17
SW2	1.08	1.10
SW3	1.13	1.18
SW4	1.04	1.11
SW5	1.08	1.12
LW1	1.18	1.20
LW2	1.00	0.98
LW3	1.14	1.09
LW4	1.25	1.17
LW5	1.11	1.12

These were assumed to be systematic errors in the standard illuminator level, looking at individual ramp ratioes there was no evidence of systematic error in shape even in the artificial rev 237-377 sequence. These correction factors were applied to the LCIR file and a new beta version was produced. After obtaining the actual solid angles of Uranus a further minor adjustment was made.

Detector	Old Style	New Style
SW1	1.01	1.02
SW2	1.01	1.02
SW3	1.02	1.02
SW4	1.03	1.02
SW5	1.03	1.02
LW1	1.03	1.02
LW2	1.02	1.02
LW3	1.02	1.02
LW4	1.03	1.02
LW5	1.01	1.02

This was gave stitching to within 5% on almost all Uranus observations, with the exception being SW4 in later observations giving a higher than expected flux. The reason for this has not yet been dermined but may be an ageing effect. Tests on other point sources gave similar results so the calibration was adopted.

5. Appendix - Summary of Routines Used

1. Concat:

This utility reads the data from one or more LCPD files into four arrays, three (10,n) dimensional arrays, 10 detectors, n is the number of data points present and one array of n elements. Concat prompts for the number of files to concatenate and the filenames.

IDL > *concat*, *ux*, *uy*, *ue*, *itk*

Outputs:
ux, - Array of grating positions,
uy, - Photocurrents
ue, - Errors in photocurrents
itk, - ITK timekeys

2. Gr_Split_New

This utility was based on the Gr_Split utility written by Graeme Oldham but updated to cure some problems encountered when using Gr_Split. Before this can be run dx must be defined and can be done so by taking the first row of ux.

IDL> *Gr_Split_New*, *dx*, *scno*, *nscn*

Inputs:
dx - a one dimensional array, the x values.
Outputs:
scno - (10,n) array of the locations where the scan changes.
nscn - integer, the number of scans.

3. Tracesig

IDL> $tracesig, uts, uy, uyc, scnp, cofs, dtot, dtim$

Inputs:
uts is the time in seconds ie. utk/2^{14},
uy - photocurrents, given by concat,
scnp - given by gr_split_new,
Outputs:
uyc - new photocurrents,
cofs (10,2) ceofficients of linear
fit, dtot average in band, and dtim centre of scan.

4. Avg_10

IDL> $avg10, ux, uyc, ue, 3.0, ous, nux, nuy, nue, nne, /medmin$

Inputs:
ux - grating commanded position given by Concat.
uyc - photocurrents, given by Tracesig.
ue - photocurrent errors, given by Concat.
3.0 - median clipping size.
Outputs:
ous - structure containing data.
nux - (10,n) new x array.
nuy - (10,n) new photocurrent array.
nue - (10,n) new errors array
nne - (10) number of good points per detector.

5. Medsig
This is an imbedded function in New_LCSI (hence can only be used after doing .run New_LCSI).
IDL> $out = Medsig(in)$

6. Nconv_Gr

IDL> $nconv_gr, nux, nuy, oux, ouy, np = nne, wfgr = wfgr, filt = filt$

Inputs:
nux - x array
nuy - y array (photocurrents)
np - number of good points
wfgr- wavelength template, extracted from LCGR file
filt- response template
Outputs:
oux - x array
ouy - y array

7. Umod_inter

Reads in the model of Uranus and interploates onto an input grid, in this case given by oux.

IDL> $umod_inter,'umodel.dat', oux(0:9,0:1058), nne, modw, modt$

Inputs:
umodel - File containing model
nne - number of good points per detector
oux - interpolated x array
Outputs:
modw - wavelength array
modt - temperature array

8. Bbgen

Converts temperature model to flux model.

IDL> $bbgen, modw, uflx, temp = modt + 0.5$

Inputs:
modw - model wavelength array
temp - temperature model
Outputs:
uflx - model as a flux scale

9. Zap2

IDL> $zap2, x, y$

10. C4096

Interpolates wavelength and response arrays onto a scale defined by the current set of grating coefficients.

IDL> $c4096,'obl', modw, sfilt, wfilt, afilt, np = nne$

Inputs:
obl - name of grating coefficient file
modw - weavelength scale
sfilt - smoothed response profiles
np - number of good points per detector
Outputs:
wfilt - interpolated wavelength scale
afilt - interpolated responses