Non-Linear Detector Response of LWS LW-Detectors

SAI/2001-042/Rp, 12/12/2001

Thomas G. Müller

ISO Data Centre, Astrophysics Division, Space Science Department of ESA,
Villafranca, P.O. Box 50727, E-28080 Madrid, Spain

Thomas.Mueller@esa.int

Abstract

LWS observations at flux levels below Uranus show systematic offsets in some detectors when comparing the calibrated source fluxes with models. All stressed Ge:Ga detectors (LW2, LW3, LW4 and LW5) are affected in a similar way, while LW1 shows offsets in the opposite direction. LWS L01 (grating scans) and L02 (fixed grating) fluxes of the detectors LW2 and LW3 (and most likely also LW4 and LW5) are systematically underestimated, up to 30 % for the faintest sources. This effect is similar to the behaviour of the ISOPHOT stressed Ge:Ga detectors, which was attributed to a non-linear behaviour of the detectors. (Note: This effect is different from the "strong source correction" or "debiasing effect" which also is sometimes called non-linearity effect, but related to the readout electronics which produced non-linear ramps for very bright sources.) The non-linear detector responses have been investigated and possible influences by other effects, like debiasing, transients and sky background influences, have been discussed. The results are based on a set of far-IR calibrators (planets and asteroids) which cover the complete flux range between the main calibrator Uranus and the detection limits. The results also allow to correct (stitch) jumps between individual detectors without loosing the photometric reliability of the flux values. For the SW detectors no problems have been seen and they are therefore left out from the following report.

1 INTRODUCTION

The far-IR LWS detectors (LW2, LW3, LW4, LW5) are stressed Ge:Ga detector units (Clegg et al. 1996), similar to the ISOPHOT far-IR detectors (Lemke et al. 1996). The analysis of ISOPHOT calibration observations showed that the stressed Ge:Ga detector responses are flux dependent, i.e. non-linear in the sense that the photocurrent and hence the resulting output signal is not proportional to the incident flux (Laureijs et al. 2001). In case of ISOPHOT the effect has been taken out by tuning the internal fine calibrator source (FCS) to the source signal by the AOT logic. In some cases this method was problematic: Measurements with a wide range of sky signals are sometimes calibrated by a single FCS flux level. The non-linearity effects influence therefore the flux calibration where the source signals are far away from the FCS signal (for example in multi-aperture photometry; multi-filter photometry covering a range of different fluxes; maps and scans for which the source-to-background contrasts are high).

In case of the LWS the changing detector responses for different times, orbit positions and detector histories have been calibrated out by taking into account the fixed illuminator flash sequence before and after each scientific measurement. But the detector response at different flux levels on the sky can only be seen in direct comparison with celestial standards. The LWS flux calibration is purely bases on Uranus. This calibration approach worked fine for a large fraction of the LWS observations which have a flux level comparable to that of Uranus. For sources much brighter or much fainter than Uranus the single source calibration approach can be problematic. And in case of the stressed Ge:Ga detectors one can expect from PHT experience that sources with 3 orders of magnitude higher or lower fluxes than Uranus can be off by as much as 50 %.

In the following a set of asteroid and star observations (Section 2), taken in fixed grating mode L02, was analysed in detail and different effects like debiasing, transients and sky background influences, have been discussed (Section 3). The results show detector non-linearity effects for LW1, LW2 and LW3 (Section 4), but also for LW4 and LW5 indications for similar effects can be seen in L01 and L02 observations. Based on asteroid thermophysical models together with reliable background estimates from COBE-DIRBE, one can derive the flux over-/underestimation for the LW detectors, depending on the incoming flux level (Section 5). Possible improvements and the extension to flux levels above Uranus are also discussed.

2 OBSERVATIONS

The following analysis includes good quality fixed grating (L02) observations of Uranus, Neptune and the asteroids Ceres, Pallas, Vesta and Hygiea. Additionally, two measurements of the bright star α Boo were analysed (Tables 1, 2 and 3 in the Appendix). Saturn measurements have so far not be included due to the difficulties to disentangle debiasing effects in the data reduction. Far-IR Saturn models are available from Sunil Sidher (RAL), but modeling the ring influences were excluded. Nevertheless, Saturn might be a good source to extend the results in the future to higher flux levels. The planetary satellite have also been left out because of possible straylight influences from the bright and close planets.

3 DATA ANALYSIS

The OLP 10.0 data were manually reduced, including deglitching, dark current subtraction and default calibration. Only the stabilized signals after the first 100 sec integration time were taken to avoid transient effects and ensure perfectly comparable conditions for all sources. The calibrated signals were averaged and background subtracted. The final results were then compared directly to model predictions of the corresponding sources, calculated for the given observing time.

In the following some of these aspects are elaborated in more detail.

3.1 Transients

Figure 1 shows typical examples of LWS transients of the LW detectors. One can see short- and long-term transients. The short term transients influence mainly the first 50 to 100 sec, the long term transients in LW4 and LW5 are not even stabilized after 1500 sec. The transient behaviour depends also on the actual flux level and probably also on the flux history of the detectors. No transient corrections have been applied in the following, but an attempt was made to minimize the transient effects for the final results by deselecting the first 100 sec integration time. This provided sufficient data even for the shortest measurements of 150 sec. For the LW4 and LW5 detectors only data between 100 and 150 sec have been taken to establish similar conditions and to minimize long term flux changes.

In Figure 1 only the first 300 sec have been plotted. The values which have been used for the following analysis have been calculated from integration periods starting at 100 sec (indicated by the triangles).

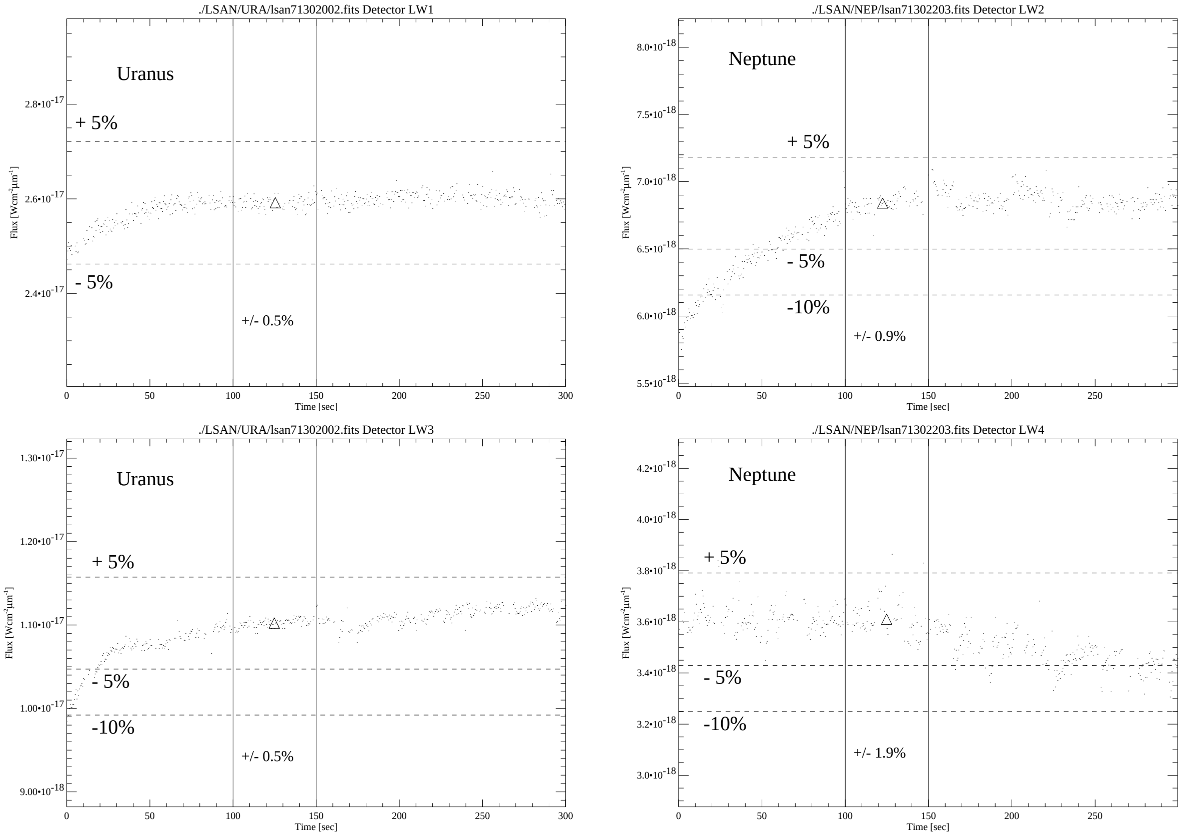
Based on the analysis of many observations at different flux levels the following additional results have been found per detector:

LW1: Signals at lower flux levels (asteroids and stars) show no transients at all.

LW2: Signals show a 10 to 15 % increase during the first 100 sec, even on the lowest flux levels.

LW3: The signals have a fast flux increase of up to 10 % during the first 50 sec and a long term transient (up- or downward) on much longer timescales.

LW4: The signals show no short term transients, but a very pronounced constant long-term transient of up to 10 % flux change every 100 sec for flux levels below Uranus.



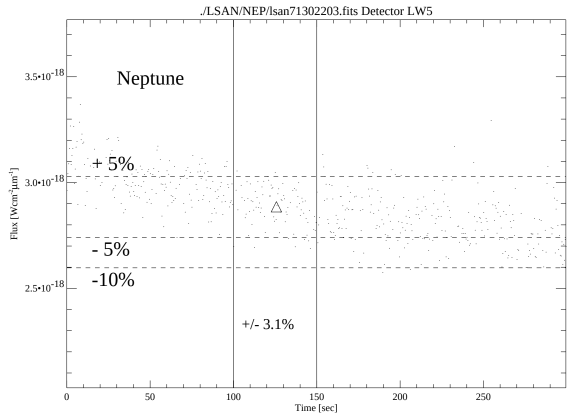


Figure 1: *Transient examples, taken from L02 fixed grating observations of Uranus and Neptune. Only the first 300 sec are shown. One can distinguish between short term transients (first 50 to 100 sec) and the long term transients, which are not even stabilized after 1500 sec (mainly LW4 and LW5). A reference flux value (triangle) was calculated for the integration time between 100 and 150 sec.*

LW5: LW5 is similar to LW4: No short term transients, but a constant flux decrease of 5 to 10 % per 100 sec on all flux levels, including Uranus.

It was also verified that solar system object tracking had no influence on the signal transients. For the SW detectors no investigations of the transient have been done, but for consistency reasons the first 100 sec have always been deselected in the following analysis.

3.2 Debiasing/Strong Source Correction

The high responsivity detectors LW1, LW2, LW3 and LW4 show debiasing effects. Infrared photons induce charged carriers in the detector which are accumulated on the feedback capacitor of the readout electronics during an integration. An electrical field is built up which reduces the actual bias. The stronger the illumination, the stronger the field and therefore the bias reduction. This effect causes the ramps to become non-linear with a downward curvature and the measured photocurrents are lower than expected for a given flux (Gry et al. 2001; Laureijs et al. 2001; Leeks 2000).

Mainly fluxes above 1000 Jy at 150 μm have to be corrected. For sources in the range between 500 and 1000 Jy (for example Uranus) the correction might be necessary and for sources below 500 Jy (all asteroids) the correction will not be necessary. The corrected subspectra are photometrically less reliable (they are therefore usually scaled accordingly, see for instance Gry et al. 2001: section on "The strong source correction"), but overlapping detectors agree much better on the shape of the spectrum.

The calibration sources Uranus and Neptune have been checked for debiasing effects (strange shaped, saggy sub-spectra, different shapes of the spectra of overlapping detectors), but no clear indications have been seen. Therefore, no correction has been applied.

3.3 Background contributions

The background contribution becomes important for all sources below the flux level of Uranus and in some cases also for bright sources on high backgrounds.

The background values have been taken from COBE-DIRBE (Hauser et al. 1998) weekly maps (25-100 μm) and yearly maps (140-240 μm), together with the LWS solid angles and the correction factors for extended sources (Gry et al. 2001). Maximal background contributions were 4 % for Ceres and up to 50 % for Hygiea with the largest influence at long wavelengths. The few dedicated LWS off-source measurements have not been analyzed.

3.4 Models

The asteroid models are based on Müller & Lagerros (1998) and on Müller et al. (1999). A validation of the asteroid spectra against independent far-IR observations (from SWS, LWS and PHT) was published by Müller & Lagerros (2001b). And a general description of the usage of asteroids as calibration sources is given in Müller & Lagerros (2001a).

The Uranus model was produced by Griffin & Orton (1993). The Neptune model is based on work done by Orton & Burgdorf (priv. comm.). The model of α Boo was taken from M. Cohen's list of extrapolated stellar spectra[1].

4 RESULTS

A comparison between the background subtracted LWS fluxes and the corresponding model predictions was used to test if the absolute calibration of LWS observations is correct at different flux levels. Figure 2 shows the results in terms of "observation over model ratios" for a sample of 13 Uranus, 13 Neptune, 15 Ceres, 14 Vesta, 4 Pallas, 2 Hygiea and 2 α Boo measurements. For the detectors SW1, SW2 SW3, SW4 and SW5 the ratios are in general close to 1.0, LW1 is in many cases larger than 1.0 and LW2, LW3 are on average smaller than 1.0. The uncertainties in LW4 and LW5 are too large to see systematic effects. A similar effect can also be seen in L01 grating scans (Figure 4).

To show the effects in a clearer way one can derive average observation-to-model ratios per source (mean and standard deviation) and plot them as a function of source brightness. Figure 3 shows the results for detectors LW1, LW2 and LW3. The SW2, SW3 and SW4 detectors were used as "baseline" and adjustments were made if the SW ratios were systematically below or above 1.0.

Figure 3 clearly reveals trends going with the flux levels on the detectors. For source fluxes close to Uranus the calibration works fine, but for fainter sources the calibrated source fluxes are underestimated (ratios smaller than 1.0 for LW2 and LW3) or overestimated (ratios larger than 1.0 for LW1). For the faintest sources this effect is biggest. LW4 and LW5 signals have large uncertainties and this non-linearity effect can not be seen in such a clear way.

[1] http://www.iso.vilspa.esa.es/users/expl_lib/ISO/wwwcal/isoprep/cohen/composites/alp_Boo.dat

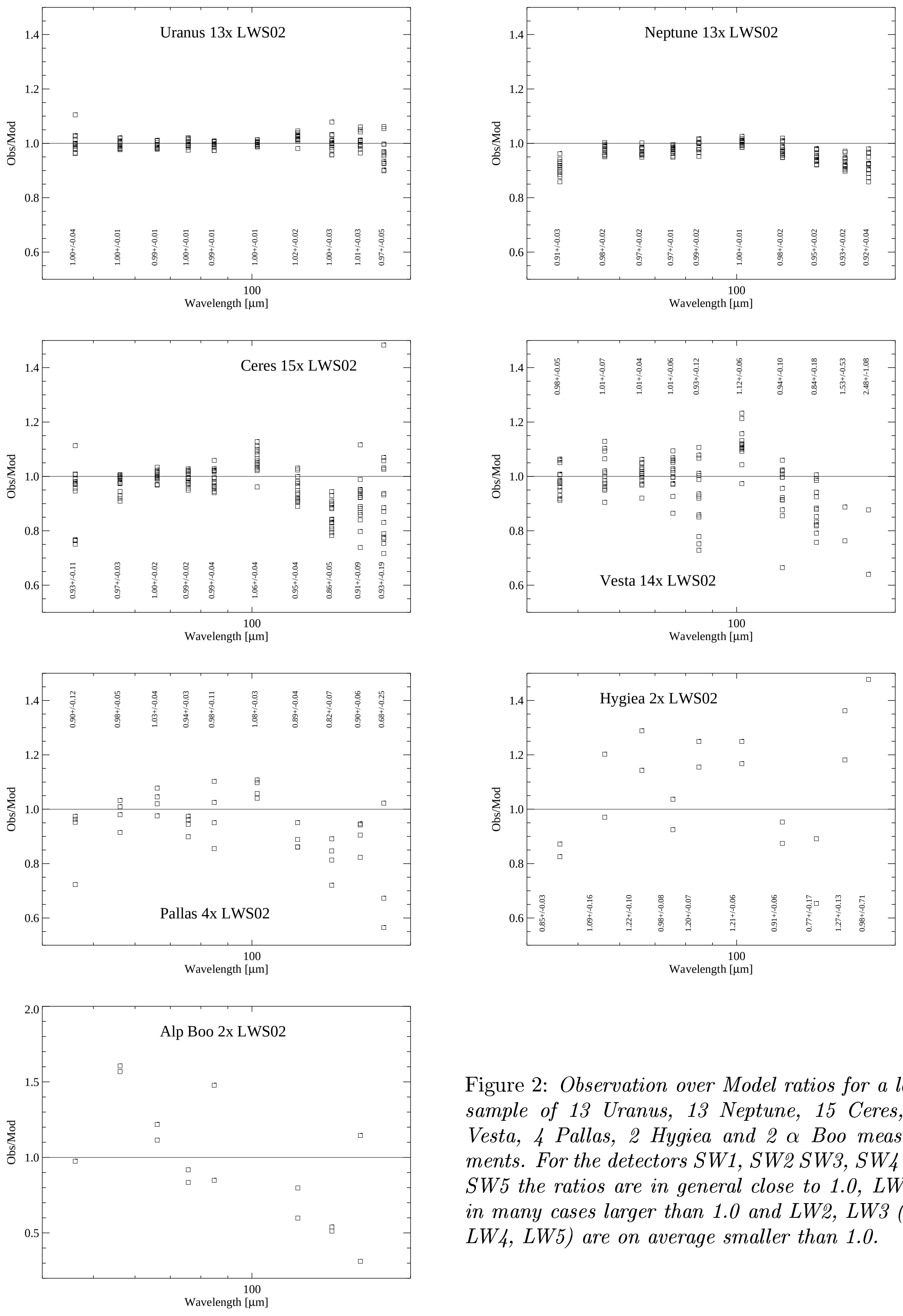


Figure 2: *Observation over Model ratios for a large sample of 13 Uranus, 13 Neptune, 15 Ceres, 14 Vesta, 4 Pallas, 2 Hygiea and 2 α Boo measurements. For the detectors SW1, SW2 SW3, SW4 and SW5 the ratios are in general close to 1.0, LW1 is in many cases larger than 1.0 and LW2, LW3 (and LW4, LW5) are on average smaller than 1.0.*

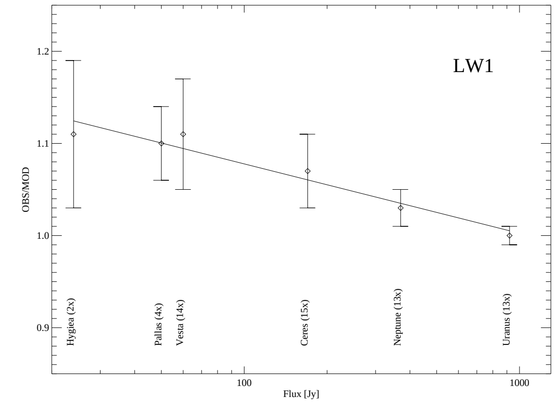
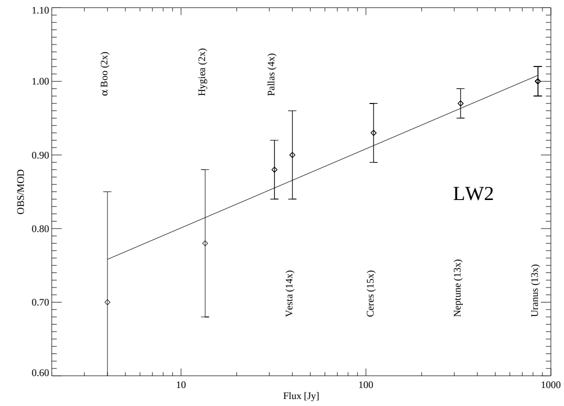
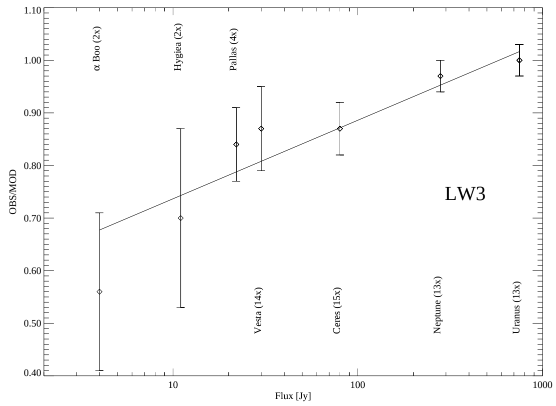


Figure 3: *Observation-to-model ratios per source and plotted as a function of source brightness for the detectors LW1, LW2 and LW3. The error bars are the standard deviations derived for the individual sources.*





5 DISCUSSION

The non-linearity effects in stressed Ge:Ga detectors LW2 and LW3 are similar to the effects in ISOPHOT (Laureijs et al. 2001). Fainter sources produce smaller photocurrents than expected. In case of PHT the non-linearity is calibrated out by tuning the FCS to the corresponding flux level. For the LWS Figure 3 can be used in the given flux range to derive an empirical corrections. For LW4 and LW5 the signals have large uncertainties and the flux range covered by the asteroids and planets is not sufficient to establish a similar relation. For LW1 the opposite effect can be seen: Fluxes are systematically too high for sources below Uranus. The reason for that is unknown, but it was speculated that the Uranus LW1 measurements might still be affected by debiasing which would then explain the findings.
It can be assumed that fluxes above Uranus are also affected by the non-linear detector response, but debiasing effects are overlaid and difficult to separate.

Summary of the results:

- Detector non-linearity behaviour can clearly be seen in LW2, LW3 and most likely also in LW4, LW5.
- LW1 signals show the opposite effect for sources fainter than Uranus.
- The flux overestimation for LW1 is up to 15 % for faint sources.
- The flux underestimation for LW2 and LW3 is up to 30 % for faint sources.
- The stressed PHT Ge:Ga-detectors show similar effects (up to 50 % flux loss for going 3 orders of magnitude down in flux).
- Background subtraction method (based on COBE-DIRBE) works fine (proof is given by the results from the SW detector fluxes which agree almost perfectly with model predictions on all flux levels and for different background contributions).
- Nice agreement between L01 and L02 measurements of the same sources.

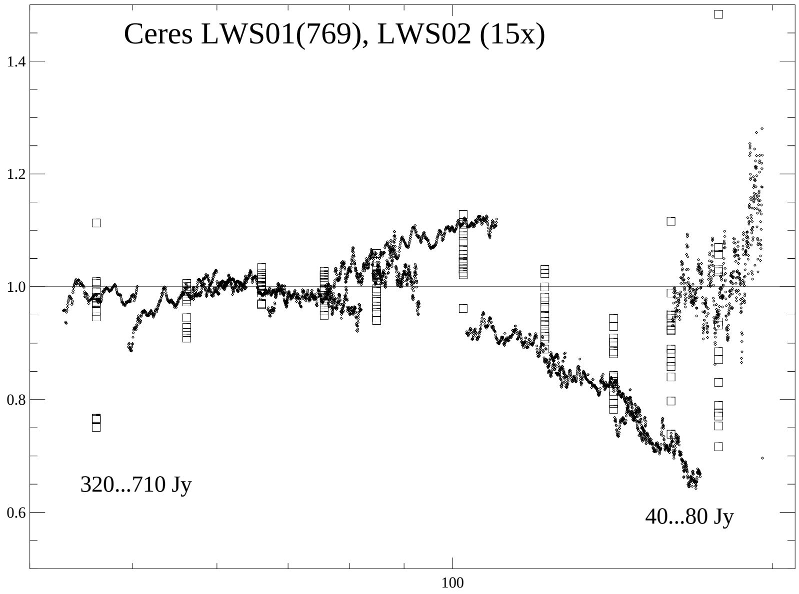


Figure 4: *Observation over model ratios for a large sample of 15 Ceres L02 observations together with a full grating scan (L01). Both modes show the same "jumps" between the individual detectors and the offsets for LW1, LW2, LW3 and LW4 (LW5 is too noisy).*

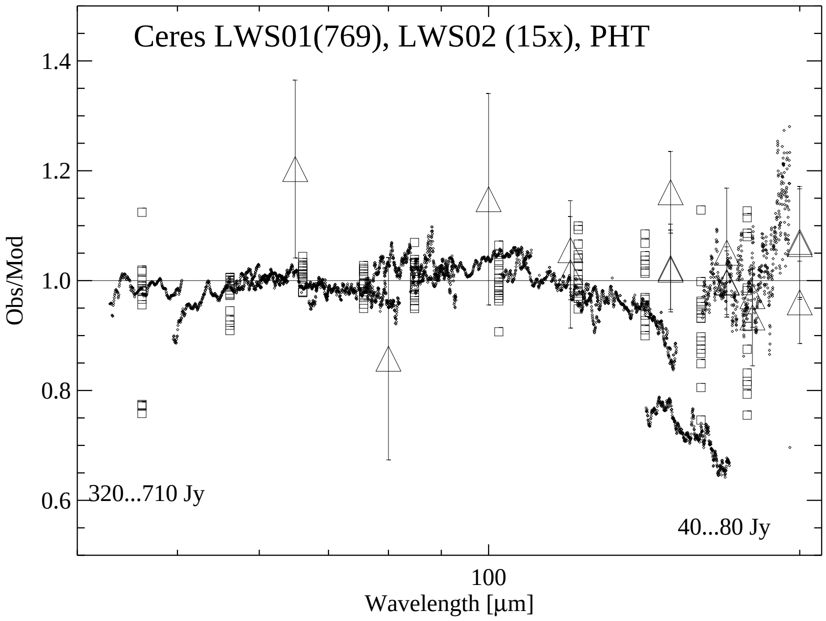


Figure 5: *Corrected observation over model ratios for a large sample of 15 Ceres L02 observations together with a full grating scan (L01) and a set of PHT observations. The comparison with the model is now much better for LW1, LW2 and LW4. No correction was applied to LW4 and LW5.*

- Agreement between LWS and PHT (P3, C100/200), after empirical non-linearity correction (see Figure 5).
- Photometric accuracy of L01 & L02 on asteroid flux level: 5-10 % for SW2, SW3, SW4, SW5, LW1, LW2, LW3; SW1: Large offsets in SW1 are meanwhile corrected by OLP Version 10.1 (different illuminator sequence for observations before revolution 237), the accuracy can now be given with 10-15 %; LW4 and LW5: Large uncertainties in the dark currents and non-linearity effects; the flux range provided by asteroids and planets is not sufficient to establish corrections.
- Transients clearly influence the signals, but the non-linearity trends in Figure 3 are **not** related to transient effects.

This work should be extended to higher flux levels, but special care is necessary due to the debiasing effects. One possibility would be to include grating scans of well-known bright sources. The necessary shifting of detectors (after bias corrections) might be a sign of non-linear detector behaviour. The stitching values are expected to be flux dependent and to be different for different detectors. For LW4 and LW5 suitable bright sources have to be found to establish similar relations as given in Figure 3 for LW2 and LW3. Mars and Saturn would probably be good candidates to consolidate and to extend the LWS non-linearity relations for the stressed Ge:Ga detectors.

In Figure 5 the non-linearity corrections have been applied (estimated from Figure 3) for the LW1, LW2 and LW3 detectors of the L01 and L02 observations. The comparison with the Ceres model is now much better. It can also be seen that a correction for LW4 would be necessary. For LW5 the flux level is probably too close to Uranus to be affected by non-linearities. Additionally to the LWS data some ISOPHOT measurements (Müller & Lagerros 2001b) are shown to independently prove the reliability of the Ceres model.

ACKNOWLEDGMENTS

I would like to thank the LWS team for their support and for extensive and fruitful discussions about the LWS results. Especially Cecile Gry and Sarah Leeks helped and encouraged this work.

REFERENCES

CLEGG P.E., ADE P. A. R., ARMAND C. ET AL. (1996) The ISO Long-Wavelength Spectrometer. *A&A* **315**, L38-L42.

GRY C., SWINYARD B., HARWOOD A. ET AL. (2001) LWS - The Long Wavelength Spectrometer. SAI-99-077/Dc, Version 1.2.

HAUSER M. G., KELSALL T., LEISAWITZ D., WEILAND J. (Eds.) (1998), COBE Diffuse Infrared Background Experiment (DIRBE) Explanatory Supplement, Version 2.3, COBE Ref. Pub. No. 98-A.

LAUREIJS R. J., KLAAS U., RICHARDS P. J., SCHULZ B., ÁBRAHÁM P. (2001) PHT - The Imaging Photo-Polarimeter. SAI-99-069/Dc, Version 1.2.

LEEKS S. J. (2000) The Long Wavelength Spectrometer: Reduction and Interpretation of data on W28A2, a High-Mass Star-Forming Region. PhD Thesis, Queen Mary & Westfield College, University of London.

LEMKE D., KLAAS U., ABOLINS J. ET AL. (1996) ISOPHOT - capabilities and performance. *A&A* **315**, L64-L70.

MÜLLER T. G. AND LAGERROS J. S. V. (1998) Asteroids as far-infrared photometric standards for ISOPHOT. *A&A* **338**, 340-352.

MÜLLER T. G., LAGERROS J. S. V., BURGDORF M., LIM T., MORRIS P. W., SALAMA A., SCHULZ B., VANDENBUSSCHE B. (1999) Fundamental thermal emission parameters of main-belt asteroids derived from ISO. In *The Universe as Seen by ISO* (Eds. Cox, Kessler). ESA-SP 427, 141-144.

MÜLLER T. G. AND LAGERROS J. S. V. (2001a) Asteroids as Calibration Standards in the Thermal Infrared – Applications and Results from ISO. In *The Calibration Legacy of the ISO Mission*, ESA SP-481, in press.

MÜLLER T. G. AND LAGERROS J. S. V. (2001b) Asteroids as Calibrations Standards in the Thermal Infrared for Space Observatories. *A&A* accepted

APPENDIX: LIST OF OBSERVATIONS

Table 1: *Summary of L02 observations of calibration sources: Planets.*

Name	TDT	OBSID	PROPID	Date	Time	T_{int} [sec]
Uranus	31701203	LWS_CAL	LWS_P317	29-Sep-1996	05:55:45	532
Uranus	32103602	LWS_CAL	CAL_R321	03-Oct-1996	03:09:28	534
Uranus	32803702	LWS_CAL	CAL_R328	10-Oct-1996	02:18:53	534
Uranus	33503902	LWS_CAL	CAL_R335	17-Oct-1996	02:21:03	534
Uranus	34401202	LWS_CAL	CAL_R342	25-Oct-1996	22:45:47	534
Uranus	34901302	LWS_CAL	CAL_R349	30-Oct-1996	17:27:39	534
Uranus	35601302	LWS_CAL	LWS_R356	06-Nov-1996	22:19:07	532
Uranus	53802510	LWS_CAL	CAL_R538	07-May-1997	12:56:39	582
Uranus	54403402	LWS_CAL	CAL_R544	13-May-1997	13:21:44	584
Uranus	55205406	LWS_CAL	CAL_R552	21-May-1997	11:14:59	584
Uranus	70601803	LWS_CAL	CAL_R706	22-Oct-1997	02:29:55	772
Uranus	71302002	LWS_CAL	CAL_R713	29-Oct-1997	04:09:01	1998
Uranus	72701301	LWS_CAL	CAL_R727	12-Nov-1997	01:01:53	1998
Neptune	32103903	LWS_CAL	CAL_R321	03-Oct-1996	04:38:58	534
Neptune	34401506	LWS_CAL	CAL_R342	26-Oct-1996	00:49:53	534
Neptune	49602301	LWS_CAL	CAL_R496	26-Mar-1997	13:32:26	584
Neptune	51003001	LWS_CAL	CAL_R510	09-Apr-1997	14:02:37	584
Neptune	51703301	LWS_CAL	CAL_R517	16-Apr-1997	13:11:21	582
Neptune	52402701	LWS_CAL	CAL_R524	23-Apr-1997	12:01:47	584
Neptune	53802701	LWS_CAL	CAL_R538	07-May-1997	13:31:07	584
Neptune	54403204	LWS_CAL	CAL_R544	13-May-1997	12:47:14	584
Neptune	68500403	LWS_CAL	CAL_R685	30-Sep-1997	19:49:33	770
Neptune	69200503	LWS_CAL	CAL_R692	07-Oct-1997	21:53:55	770
Neptune	69801006	LWS_CAL	CAL_R699	13-Oct-1997	21:28:02	772
Neptune	71302203	LWS_CAL	CAL_R713	29-Oct-1997	05:07:27	1996
Neptune	72002306	LWS_CAL	CAL_R720	05-Nov-1997	03:12:15	772

Table 2: *Summary of L02 observations of calibration sources: Asteroids.*

Name	TDT	OBSID	PROPID	Date	Time	T_{int} [sec]
Ceres	09300401	LWS_CAL	LWS_R97	18-Feb-1996	04:26:56	524
Ceres	10500402	LWS_CAL	LWS_R105	01-Mar-1996	05:15:05	874
Ceres	11900214	LWS_CAL	ROUN_CAL	15-Mar-1996	02:38:35	524
Ceres	12600114	LWS_CAL	LWS_R126	22-Mar-1996	01:59:33	522
Ceres	25800302	LWS_CAL	CAL_R258	31-Jul-1996	18:22:16	982
Ceres	26500301	LWS_CAL	CAL_R265	07-Aug-1996	18:04:45	684
Ceres	32100204	LWS_CAL	CAL_R321	02-Oct-1996	14:27:09	532
Ceres	53802209	LWS_CAL	CAL_R538	07-May-1997	11:11:17	584
Ceres	57902409	LWS_CAL	CAL_R579	17-Jun-1997	08:51:47	558
Ceres	59401908	LWS_CAL	CAL_R594	02-Jul-1997	05:37:13	584
Ceres	72001901	LWS_CAL	CAL_R720	05-Nov-1997	01:05:25	558
Ceres	74803304	LWS_CAL	CAL_R741	03-Dec-1997	02:58:32	772
Ceres	75503003	LWS_CAL	CAL_R755	10-Dec-1997	01:31:34	772
Ceres	76200502	LWS_CAL	CAL_R762	16-Dec-1997	13:22:49	772
Ceres	76903102	LWS_CAL	CAL_R769	24-Dec-1997	01:02:24	772
Pallas	23000306	LWS_CAL	CAL_R230	03-Jul-1996	20:15:54	974
Pallas	25100202	LWS_CAL	CAL_R251	24-Jul-1996	18:41:00	984
Pallas	26500503	LWS_CAL	CAL_R265	07-Aug-1996	18:37:35	684
Pallas	27200203	LWS_CAL	CAL_R272	14-Aug-1996	17:13:59	684
Vesta	24402202	LWS_CAL	CAL_R244	17-Jul-1996	22:12:08	984
Vesta	80500101	BESCHULZ	VESTALC1	28-Jan-1998	10:28:26	958
Vesta	80500104	BESCHULZ	VESTALC1	28-Jan-1998	10:54:50	960
Vesta	80500107	BESCHULZ	VESTALC1	28-Jan-1998	11:21:16	958
Vesta	80500110	BESCHULZ	VESTALC1	28-Jan-1998	11:47:40	960
Vesta	80500113	BESCHULZ	VESTALC1	28-Jan-1998	12:14:06	958
Vesta	80500116	BESCHULZ	VESTALC1	28-Jan-1998	12:40:31	958
Vesta	80500119	BESCHULZ	VESTALC1	28-Jan-1998	13:06:55	960
Vesta	80500122	BESCHULZ	VESTALC1	28-Jan-1998	13:33:21	958
Vesta	80500125	BESCHULZ	VESTALC1	28-Jan-1998	13:59:45	960
Vesta	80500128	BESCHULZ	VESTALC1	28-Jan-1998	14:26:11	958
Vesta	80500131	BESCHULZ	VESTALC1	28-Jan-1998	14:52:35	960
Vesta	80500134	BESCHULZ	VESTALC1	28-Jan-1998	15:19:01	958
Vesta	80500137	BESCHULZ	VESTALC1	28-Jan-1998	15:45:25	960
Hygiea	83201803	LWS_CAL	CAL_R832	24-Feb-1998	22:37:21	808
Hygiea	85303402	LWS_CAL	CAL_R853	17-Mar-1998	21:59:54	1184

Table 3: *Summary of L02 observations of calibration sources: Bright stars.*

Name	TDT	OBSID	PROPID	Date	Time	T_{int} [sec]
α Boo	21701012	LWS_CAL	CAL_R217	21-Jun-1996	00:36:36	972
α Boo	27202201	LWS_CAL	CAL_R272	15-Aug-1996	03:06:06	1060