Catalogue of LWS observations of asteroids*

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The catalogue of LWS (Long Wavelength Spectrometer) observations of asteroids contains 57 manually re-reduced datasets, including seven non-standard observations, which as such did not have final pipeline products available before. We outline the data reduction process and give an overview of the available data and the quality of the individual observations.

1 Overview

The ISO Data Archive contains 50 successful LWS [1, 2] standard observations of four different asteroids. Most of them were carried out using the LWS02 template, resulting in photometric measurements at ten wavelengths. Only four LWS01 grating scans were performed, covering the whole spectral range from 43 to 197 μm.

Additionally there exist 25 observations which were carried out in the non-standard LWS99 mode, most of them similar to LWS01 grating scans. For this catalogue, only LWS99 on-source grating scans were considered. The non-standard observations are characterised by experimental settings of the detector parameters (bias voltages and heater currents), an unusually high spectral sampling (13 samples per resolution element instead of four, as it was the standard setting later), and longer integration times per grating position (four ramps of 0.5s each instead of one). From the available observations we selected seven datasets for inclusion in this catalogue. These sets are grating scans with closed reference flashes, i.e. the dark current for this observations could be accurately determined despite the non-standard detector parameters. The spectral analysis of this data still remains difficult, since the relative spectral response function (RSRF) of the detectors used in the calibration process is based on observations performed in the standard LWS01 mode.

All standard observations are listed in Tbl. 1, while the non-standard observations are summarized in Tbl. 2.

2 Data Reduction

Data reduction was performed with the available standard reduction packages LIA (LWS Interactive Analysis) Version 10.2 and ISAP (ISO Spectral Analysis Package) Version 2.2. Additional own IDL-procedures were used for manual editing of the data on SPD (Standard Processed Data) level, and the generation of the final FITS and ASCII files.

In a first step, the pointing coordinates of each observation were checked against the ephemeris of the observed asteroid to detect any pointing problems. The maximum difference between asteroid position and telescope pointing was found to be 2.5 arcsec. The actual reduction process started at SPD level with

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a first visual inspection of the data in the time domain. Photometric LWS02 observations were manually de-glitched at this stage. The available pipeline data of grating scans was additionally inspected with ISAP to get a quick overview of the available scans and scan directions. A small IDL routine was used to check for the scan-numbering problem in the LWS01 data (see Section 3), and to apply any corrections if necessary.

Next, dark current determination and subtraction was perfomed using the interactive LIA routine `IA_DARK`, followed by the absolute responsivity correction with `IA_ABSCORR`. The LIA routine `SHORT_AAL` was used to create ISAP-compatible output spectra in the LWS Auto-Analysis format.

In the case of photometric LWS02 observations, the data was now averaged per detector to create the final FITS product.

In the case of grating scans a first round of manual de-glitching was performed, probably the most time consuming step in the reduction process. Now the data of each detector was normalized with the mean of this detector using ISAP's SHIFT-option with the gain-method. This was done separately for each scan direction and is equivalent to the (not performed) relative responsivity correction in LIA.

After some fine-zapping of remaining glitches, the data was averaged per detector with a bin width of typically 0.06μm, corresponding to an oversampling of four. In the case of bidirectional scans the data was now averaged over the scan directions (in the final spectra, the scan direction tag for this data is set to 2, while the original unaveraged up- and downscans are still available as scan directions 0 and 1). Especially at longer wavelengths some spectra clearly showed fringing, probably caused by background emission. The affected detectors were defringed within ISAP, for bidirectional data only the averaged spectrum was used for fringe detection and defringing to get the best possible signal-to-noise for the fringe fitting.

3 Quality flags

The LWS quality flags are a helpful tool to get a quick overview of potential problems remaining in the final data sets. In Tbl. 3 we specify the flags for each observation of the catalogue based on their criteria as described below. Additionally, all flags are contained in the FITS headers of the data products. A more comprehensive description of each flag can be found in [5], while general descriptions of the associated instrumental problems are contained in the LWS Handbook [3].

3.1 Unused flags

The following flags do not apply to any of the observations in this catalogue and are therefore neither included in Table 3 nor in the FITS headers:

- **Known extended source, Handbook Section 5.9:** All asteroids can safely be treated as point sources, their angular diameters were at all times well below one arcsecond.
- **Significant strong-source effects present, Handbook Section 5.7 and 6.10:** Detectors LW1-LW4 suffer from de-biasing effects at high flux levels. None of the asteroids had a flux of more than 300Jy in these detectors and no strong-source effects could be observed.
- **Near-infrared leak features, Handbook Section 6.7:** All asteroids have their intensity peak in the thermal infrared and are rather faint in the near-infrared. No leak features were observed in any of the observations.
- **57.16μm feature in SW2, Handbook Section 6.11:** This flag applies to Fabry-Perot spectra only.
- **Wheel position problem:** Only Fabry-Perot measurements were affected by this problem.
- **Saturation:** This did not occur for any of the observed asteroids.
- **Suspicious pointing / Pointing problem:** All observed asteroids were well centered with respect to the LWS beam profile [4]. The maximum offset was 2.5 arcsec and no pointing-related artifacts in the spectra could be observed.
- **Telemetry drop:** None of the observations contained in the catalogue suffered from telemetry problems. However, one of the standard observations in the archive (TDT 12606916) seems to be

affected by a number of telemetry drops. The archive files of this observation contain almost no valid data and was therefore not included in the catalogue.

- **Pipeline problem:** For the standard mode observations, all pipeline products were accessible through the archive. Non-standard observations are not yet available in other formats than Edited Raw Data (ERD), but this is not a problem of the pipeline.
- **Low sampling:** Normally, grating scans were sampled with at least four data points per spectral resolution element. This flag is not used, since all observations in this catalogue are well-sampled, and the non-standard observation are in fact oversampled with 13 points per resolution element.

3.2 Used flags

The following flags apply to at least one of the observations in the catalogue. The acronyms given in parentheses correspond to the column headings of Table 3.

- **Significant transient effects, Handbook Section 6.9 (TRNS):** The LWS detectors suffer from a variable response to changes in signal level. This leads to differences between up- and downscan in LWS01 observations and transients at the beginning of LWS02 observations. In the case of bidirectional grating scans this flag was set if there are significant differences between up- and downscan visible in at least one detector. For unidirectional scans there is unfortunately no possibility to detect transient effects. In some photometric LWS02 measurements there occured strong transients at the beginning of the observation, with durations of up to a few ten seconds. These observations are also flagged in our catalogue.
- **Strong mismatch between detectors, Handbook Section 6.3 and 6.5 (MISM):** The responsivity calibration is performed for each detector individually, and remaining systematic errors lead to differences between the flux in adajcent detectors, even after careful manual re-reduction. This flag is set if significant differences occur for at least two pairs of adjacent detectors, excluding detector SW1.
- **Presence of strong fringes, Handbook Section 6.2 (FRIN):** Observations of extended sources or an off-axis pointing lead to fringing especially at longer wavelengths. Though none of the reduced observations meet these two criteria, some of the asteroid spectra clearly show fringe patterns in detectors LW2-LW5. These fringes are probably related to extended background emission, and most of the fringed observations indeed show a background-related CII-emission-line at $158\mu m$. Affected observations were defringed in ISAP, in the case of bidirectional scans only the averaged spectrum was used for defringing to get the best possible signal-to-noise ratio. The flag is set for observations with two or more detectors showing fringe patterns, additionally the FITS headers of the observations contain a keyword with 10 boolean fringe flags, one for each detector.
- **Detector warm-up features, Handbook Section 6.8 (WARM):** Towards the end of the mission problems with the detector cooling system caused artificial features in the spectra of the stressed detectors, resembling broad emission features. In grating scans they can easily be identified, while for photometric observations it is not possible to detect the presence of such artifacts. However, warm-up effects may be responsible for increased flux values in detectors LW4 and LW5 in the case of the Vesta lightcurve series (Rev. 805). These observations show – like some grating scans with warm-up features – a highly increased dark current of the stressed detectors.
- **Abnormally high dark current, Handbook Section 6.4 (HIDC):** High dark currents should in principle not affect the observations presented in this catalogue, since dark current subtraction was performed manually. However, an increased measured dark current may be associated with other calibration issues like baseline drifts or changes of the detector temperature, leading to increased systematic errors or warm-up features in the resulting spectra. All non-standard observations show significant deviations of the dark current, caused by the experimental bias voltages and heater currents. A dark current measurement was considered as being abnormally high if the value was at least 3 standard deviations higher than the adopted fixed dark current as given in the Handbook Section 5.4. The flag is set if this was the case for at least one detector, excluding SW1. The FITS

header also contains a keyword with one flag per detector, not only indicating abnormally high, but also too low dark current values.

- **Low number of scans (LSCA):** The elimination of spurious features like glitch-related peaks in the spectra relies on the availability of multiple scans of the same wavelength region. This flag is set if fewer than four scans were present in the input data.
- **Slow scanning (SSCA):** Normally, one integration per wavelength setting was performed in each scan. In the case of the non-standard observations four integration ramps per wavelength and scan were obtained to minimize transient effects. Since the relative spectral response function was created using standard observations with normal scan speed, systematic errors and spurious spectral features may occur.
- **Large number of negative fluxes in one or more detectors (NFLU):** Even careful manual dark current subtraction cannot guarantee that small systematic errors due to baseline drifts result in negative flux values in the final spectra. Some of the background measurements with their very low fluxes suffer from this problem and had to be flagged.
- **Original pipeline data affected by scan-numbering problem (SNUM):** Bad scan numbering can in principle lead to problems with the relative responsivity correction. However, since the problem was detected and corrected before starting the actual reduction process, the final data is in no way affected. Nevertheless, this flag may serve as a warning for users trying to reduce these data sets on their own.
- **High glitch rate (GLIT):** Observations during increased space weather or at beginning and end of the science window may suffer from increased hit rates of charged particles in the detectors and readout electronics. The flag is set for observations with glitch rates at least twice as high as the normal values.

4 Data products

The final highly processed data products are provided as standard FITS files in ISAP-compatible AAR format and raw ASCII text files.

4.1 ASCII files

The ASCII files start with a short header, containing some basic information like the date of the observation, the object name and the template used for the observation (all non-standard observations read “L01” here, since they are equivalent to standard grating scans), followed by a line with the column headings as in this example:

```
#TELESCOP = 'ISO'                    //
#INSTRUME = 'LWS'                    //
#TDT      = '05500301'               // TDT identifier of observation
#OBJECT   = '210004 VESTA'           // Object name given by proposer
#OBSERVER = 'LWS_CAL '               // Observer name
#EOHAAOTN = 'L01     '               // Observation template
#EOHAUTCS = '96011081024'            // Start of observation yydddhhmmss
#EOHAUTCE = '96011093834'            // End of observation yydddhhmmss
#COMMENT  = 'This file is part of the HPDP catalogue of'
#COMMENT  = 'LWS observations of asteroids'

#DET WAVE      FLUX    STDEV1 STDEV2  SDIR}
```

The table columns contain the following data:

`DET`	Detector number 0-9, corresponding to SW1-LW5
`WAVE`	Wavelength in μm
`FLUX`	Flux in W/cm^2/μm
`STDEV1`	Standard deviation (in W/cm^2/μm) of the flux as calculated during the averaging and rebinning in ISAP. This standard deviation reflects the pure statistical noise of the data without systematic errors due to dark current or responsivity uncertainties. The values given in this column can be used to assess the reliability of any spectral features found in the data of a single detector. In case of photometric LWS02 observations the averaging of typically several hundred data points leads to very small values in this column. This standard deviation should really only be used when analyzing LWS01 grating scans.
`STDEV2`	Standard deviation (in W/cm^2/μm) including calibration related errors, i.e. noise in the dark current and absolute responsivity determination as well as uncertainties of the relative spectral response function. This standard deviation should be used in photometric applications. Please note that the given values do not reflect any uncertainties introduced by the Uranus flux models on which the photometric calibration of LWS was based. The absolute accuracy of the Uranus model is supposed to be better than ± 5%, empirical studies point to a value of ~3% [6, 7].
`SDIR`	Scan direction: 0 = forward, 1 = backward, 2 = averaged The unaveraged spectra may be used to check for spurious features in the averaged product resulting from transient effects and related up/down differences. Scan direction 2 is only present in bidirectional grating observations and always 0 in the case of LWS01 data.

4.2 FITS files

The FITS files contain the full header information as available from the input data. The standard deviation is the same as `STDEV2` in the ASCII files. Information concerning flags was added to the primary header using boolean values with the following keywords:

`LWSFTRNS`	Significant transient effects present
`LWSFMISM`	Strong mismatch between detectors
`LWSFWARM`	Detector warm-up features visible
`LWSFHIDC`	Abnormally high dark current
`LWSFLSCA`	Low scan number
`LWSFSSCA`	Slow scanning
`LWSFNFLU`	Large number of negative flux values
`LWSFSNUM`	Scan numbering problem in original data
`LWSFGLIT`	High glitch rate
`LWSFFRIN`	Presence of strong fringes

Two additional keywords are used to specify which detectors were affected by fringes or dark current deviations:

`LWSFHDCD`	Dark current deviation, one flag per detector. H = abnormally high, L = abnormally low, N = normal dark current
`LWSFFRID`	Fringe flag, one per detector. Detectors with a 'T' in this keyword were defringed.

5 Acknowledgments

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The ISO Spectral Analysis Package (ISAP) is a joint development by the LWS and SWS Instrument Teams and Data Centers. Contributing institutes are CESR, IAS, IPAC, MPE, RAL and SRON.

References

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[5] "List of Flags affecting LWS observations":
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Table 1: Overview of reduced standard LWS asteroid observations.

	Object	TDT	Date	AOT	Remarks
(1)	Ceres	09300401	1996-02-18	LWS02	
		09304102	1996-02-18	LWS02	Background rev. 93
		10500402	1996-03-01	LWS02	
		11900214	1996-03-15	LWS02	
		11905611	1996-03-15	LWS02	Background rev. 119
		12600114	1996-03-22	LWS02	
		25800302	1996-07-31	LWS02	
		25805903	1996-08-01	LWS02	Background rev. 258
		26500301	1996-08-07	LWS02	
		26505602	1996-08-08	LWS02	Background rev. 265
		32100204	1996-10-02	LWS02	
		32103506	1996-10-03	LWS02	Background rev. 321
		53802209	1997-05-07	LWS02	
		57902409	1997-06-17	LWS02	
		59401908	1997-07-02	LWS02	
		72001901	1997-11-05	LWS02	
		74803304	1997-12-03	LWS02	
		74803403	1997-12-03	LWS01	Contaminated by warmup features
		75502902	1997-12-09	LWS01	Background rev. 748
		75503003	1997-12-10	LWS02	
		76200502	1997-12-16	LWS02	
		76903102	1997-12-24	LWS02	
		76903203	1997-12-24	LWS01	
(2)	Pallas	23000306	1996-07-03	LWS02	
		23002907	1996-07-04	LWS02	Background rev. 230
		25100202	1996-07-24	LWS02	
		25103603	1996-07-25	LWS02	Background rev. 251
		26500503	1996-08-07	LWS02	
		26505204	1996-08-08	LWS02	Background rev. 265
		27200203	1996-08-14	LWS02	
		27202004	1996-08-15	LWS02	Background rev. 272
(4)	Vesta	24402202	1996-07-17	LWS02	
		24404603	1996-07-18	LWS02	Background rev. 244
		80500101	1998-01-28	LWS02	
		80500104	1998-01-28	LWS02	
		80500107	1998-01-28	LWS02	
		80500110	1998-01-28	LWS02	
		80500113	1998-01-28	LWS02	
		80500116	1998-01-28	LWS02	
		80500119	1998-01-28	LWS02	
		80500122	1998-01-28	LWS02	
		80500125	1998-01-28	LWS02	
(4)	Vesta	80500128	1998-01-28	LWS02	
		80500131	1998-01-28	LWS02	
		80500134	1998-01-28	LWS02	
		80500137	1998-01-28	LWS02	

Table 1: (continued)

	Object	TDT	Date	AOT	Remarks
(10)	Hygiea	83201702	1998-02-24	LWS01	Contaminated by CII background emission.
		83201803	1998-02-24	LWS02	
		84801302	1998-03-12	LWS02	
		85303402	1998-03-17	LWS02	

Table 2: Overview of reduced LWS99 asteroid observations.

	Object	TDT	Date	Type	Remarks
(1)	Ceres	07500601	1996-01-31	Scan	CII background emission
		07500701	1996-01-31	Scan	CII background emission
		07501301	1996-01-31	Scan	CII background emission, non-standard bias voltages
		07501401	1996-01-31	Scan	CII background emission, non-standard bias voltages
(4)	Vesta	05500201	1996-01-11	Scan	non-standard bias voltages
		05500301	1996-01-11	Scan	non-standard bias voltages
		05500401	1996-01-11	Scan	non-standard bias voltages

Table 3: Quality flags for all reduced LWS observations, given as boolean True or False. The acronyms used for the different flag types can be found in the headings of the flag explanations in section 3.

TDT	TRNS	MISM	WARM	HIDC	LSCA	SSCA	NFLU	SNUM	GLIT	FRIN
05500201	F	T	F	T	F	T	F	F	F	F
05500301	F	T	F	T	F	T	F	F	F	F
05500401	F	T	F	T	T	T	F	F	F	F
07500601	F	F	F	F	F	T	F	F	F	T
07500701	F	F	F	F	F	T	F	F	F	T
07501301	F	T	F	T	T	T	F	F	F	F
07501401	F	T	F	T	T	T	F	F	F	T
09300401	F	F	F	F	F	F	F	F	F	F
09304102	T	F	F	F	F	F	F	F	F	F
10500402	T	F	F	F	F	F	F	F	F	F
11900214	F	F	F	T	F	F	F	F	T	F
11905611	F	F	F	F	F	F	T	F	F	F
12600114	F	F	F	F	F	F	F	F	T	F
23000306	F	F	F	F	F	F	F	F	F	F
23002907	F	F	F	F	F	F	T	F	F	F
24402202	F	F	F	F	F	F	F	F	F	F
24404603	F	F	F	F	F	F	F	F	F	F
25100202	F	F	F	F	F	F	F	F	F	F
25103603	F	F	F	F	F	F	T	F	F	F
25800302	T	F	F	F	F	F	F	F	T	F
25805903	F	F	F	F	F	F	F	F	F	F
26500301	F	F	F	F	F	F	F	F	F	F

Table 3: (continued)

TDT	TRNS	MISM	WARM	HIDC	LSCA	SSCA	NFLU	SNUM	GLIT	FRIN
26500503	F	F	F	F	F	F	F	F	F	F
26505204	F	F	F	F	F	F	T	F	F	F
26505602	T	F	F	F	F	F	F	F	F	F
27200203	F	F	F	F	F	F	F	F	F	F
27202004	F	F	F	F	F	F	F	F	F	F
32100204	T	F	F	F	F	F	F	F	F	F
32103506	F	F	F	T	F	F	T	F	F	F
53802209	F	F	F	F	F	F	F	F	F	F
57902409	F	F	F	F	F	F	F	F	F	F
59401908	F	F	F	F	F	F	F	F	F	F
72001901	F	F	F	F	F	F	F	F	F	F
74803304	F	F	F	T	F	F	F	F	F	F
74803403	F	T	T	T	F	F	F	F	F	F
75502902	F	T	T	F	F	F	F	F	F	F
75503003	F	F	F	T	F	F	F	F	F	F
76200502	F	F	F	T	F	F	F	F	F	F
76903102	F	F	F	F	F	F	F	F	F	F
76903203	T	T	F	F	F	F	F	F	F	F
80500101	F	F	F	T	F	F	F	F	T	F
80500104	F	F	F	T	F	F	F	F	T	F
80500107	F	F	F	T	F	F	F	F	T	F
80500110	F	F	F	T	F	F	F	F	F	F
80500113	F	F	F	T	F	F	F	F	F	F
80500116	F	F	F	T	F	F	F	F	F	F
80500119	F	F	F	T	F	F	F	F	F	F
80500122	F	F	F	T	F	F	F	F	F	F
80500125	F	F	F	T	F	F	F	F	F	F
80500128	F	F	F	T	F	F	F	F	F	F
80500131	F	F	F	T	F	F	F	F	F	F
80500134	F	F	F	T	F	F	F	F	F	F
80500137	F	F	F	T	F	F	F	F	F	F
83201702	F	F	F	F	F	F	F	T	F	T
83201803	F	F	F	T	F	F	F	F	F	F
84801302	F	F	F	F	F	F	F	F	F	F
85303402	F	F	F	F	F	F	F	F	F	F