LWS L03 HPDP

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1 Processing used

A detailed description of the calibration and data reduction carried out is given by Lerate et al. (2006) and Polehampton et al. (2007). A description of the operation of the instrument is given in the LWS Handbook by Gry et al. (2003). The following spells out the main steps and algorithms used in the data reduction.

1.1 Processing with FP_PROC

The data were taken from the standard OLP 8 pipeline reduction at the 'Standard Processed Data' stage (LSPD). This gives data still in engineering units (FP gap voltage and detector photocurrent). Data from all 10 LWS detectors were then reduced using the LIA routine FP_PROC. Improved calibration files and algorithms that were released in LIA version 10 (Lim et al. 2002) were used and this allowed both prime and non-prime data to be included (see the LWS Handbook, section 6.14 for a definition of non-prime data). The reduction included subtraction of dark currents and stray light (determined as described by Lerate et al. 2006 and Polehampton et al. 2007) and interactive shifting of the miniscans. Additional corrections that were applied in LIA 10 but not in previous versions of FP_PROC were: improved grating response funtions in FP mode; correction for FP side order contamination; improved detector responsivity drift correction; and extended FP throughput calibration (for a full description of the improvements implemented in FP_PROC for LIA 10 see Polehampton (2002) and the LWS Handbook sections 6.15 and 6.16). The dark current plus stray light values determined for the survey are given in Table 1 for each FP and compared to the standard nominal dark values.

For the Orion dataset, a velocity correction to the Heliocentric frame of reference was applied in FP_PROC. No velocity correction was applied to the Sgr B2 dataset at this stage.

1.2 ISAP

The data were then deglitched by hand using ISAP (Sturm et al. 1998). Further details of this step are given by Polehampton (2002) and Polehampton et al. (2007). Bad miniscans (e.g. noisy due to low transmission) were also deleted.

Table 1: Dark current and stray light values for FPS and FPL (Orion values from Lerate et al. 2006 and Sgr B2 values from Polehampton et al. 2007).

Detector	Orion FPS (10^{-16} A)	Orion FPL (10^{-16} A)	Sgr B2 FPS (10^{-16} A)	Sgr B2 FPL (10^{-16} A)
SW1	-	-	$^{(a)}$	-
SW2	6.10±0.20	-	$^{(a)}$	3.0$^{(b)}$
SW3	4.97±0.19	-	2.48±0.09	3.3±0.25$^{(b)}$
SW4	2.41±0.11	5.48±0.49	1.33±0.04	1.6±0.1
SW5	2.11±0.06	5.75±0.56	1.80±0.03	1.9±0.2
LW1	3.80±0.15	4.20±0.07	2.8±0.1	2.7±0.1$^{(c)}$
LW2	1.03±0.05	4.64±0.06	0.60±0.07	0.46±0.03
LW3	2.01±0.42	4.83±0.35	2.2±0.4	1.41±0.2
LW4	4.41±0.65	5.28±0.28	4.1±0.6	2.52±0.02
LW5	1.49±0.14	1.47±0.06	1.8±0.1	1.43±0.02

$^{(a)}$ Nominal value assumed

$^{(b)}$ Estimated from comparison of lines measured with both FPs

$^{(c)}$ Special modelling performed for LW1 - see Polehampton (2002).

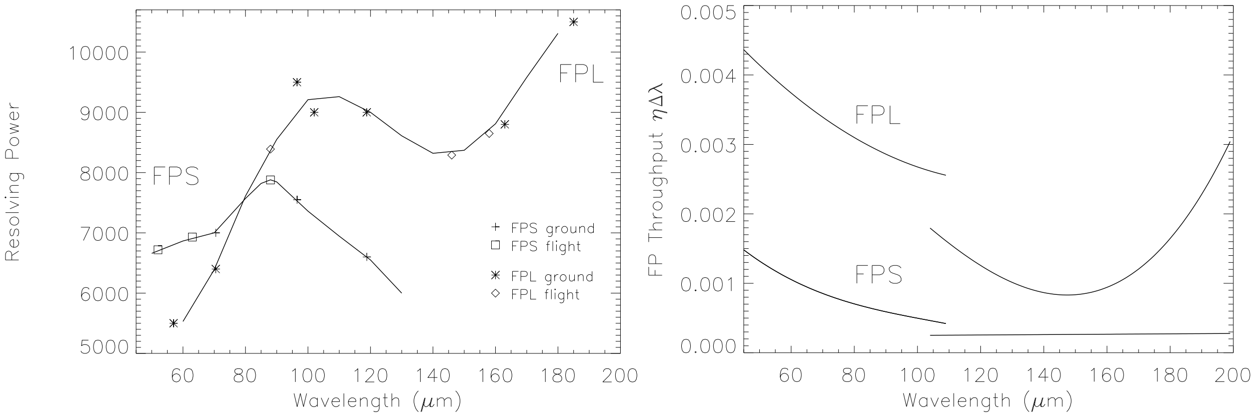

Figure 1: Left: Resolving power of FPS and FPL (defined as $\lambda/\Delta\lambda_{\rm FWHM}$) from ground-based and in-flight measurements. Right: Third order polynomial fit to the total measured FP throughput for FPS and FPL (defined as the product of FP transmission efficiency and resolution element equivalent width).

A correction was applied to each file to place all observations into the Kinematical Local Standard of Rest frame (LSR). For the Orion dataset, this consisted of a correction from Helicentric to LSR velocities. For the Sgr B2 dataset, no previous correction had been made and so the data were corrected directly to the LSR frame, taking account of the motion of the spacecraft (which was <1 km s^{-1}). The corrections are shown in Tables 6 and 7 and were applied using,

$$\lambda_{\rm corr} = \lambda - \left(\frac{\nu_{\rm corr}}{c}\right)\lambda \tag{1}$$

FIRST PRODUCT SAVED HERE: Unaveraged result of FP_PROC and ISAP processing, with all good data (prime + non-prime) included in one file per ISO TDT. Velocity correction to LSR frame applied.

1.3 Continuum division

The data for each detector in each observation were then fitted with a continuum level, which was divided into the data. The continuum level was determined in different ways for the two sources.

For the Orion dataset, the continuum level was calculated by applying a boxcar smooth function to each individual miniscan after masking out strong features. The smoothing factor was considered to be ten times the resolution element (≈0.1 μm). See Lerate et al. (2006) for details.

For the Sgr B2 dataset, the continuum level was defined by masking out all strong lines, re-binning (including data from every miniscan in the observation) the spectrum with bin size equal to 1/4 of the resolution of the LWS grating (the grating element width is 0.3 μm for the SW detectors and 0.6 μmm for the LW detectors). This re-binned continuum was interpolated back to the original FP resolution using a spline fit. See Polehampton et al. (2007) for details.

1.4 Binning each observation

The continuum level as defined above was divided into the data for each detector in each TDT, and the data binned to 1/4 of the resolution of the FP.

For the Orion dataset, the binning function in ISAP was used. However, for Sgr B2, the FP resolution was taken from Figure 1, and a variable bin size with wavelength to match the resolution changes was used.

The final product gives the standard deviation in the data points used to calculate the value in each bin (equal to zero if less than 3 points were averaged in the bin).

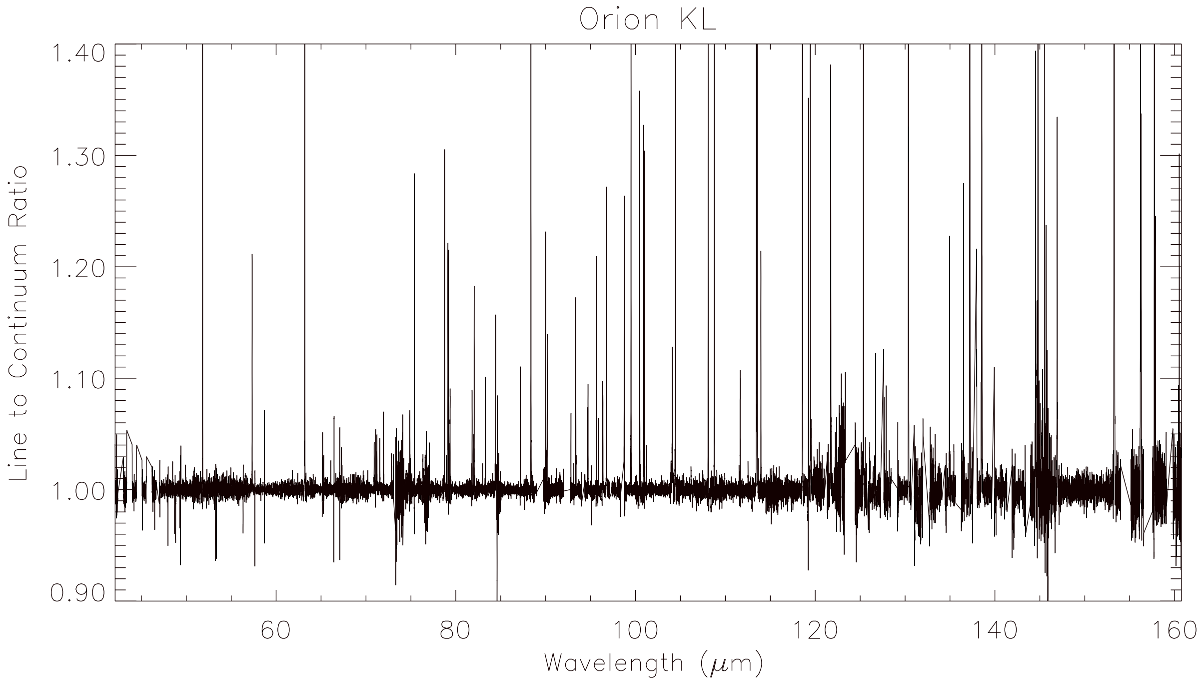

Figure 2: The full Orion BK/KL L03 FP spectrum after co-adding prime and non-prime data for all LWS detectors. Note the gaps in wavelength coverage.

SECOND PRODUCT SAVED HERE: Averaged, line to continuum ratio for each TDT.

1.5 Combining and binning the final spectrum

The final spectrum was obtained by taking the continuum fit, applying it to the unaveraged data and then combining all detector data from all observations. This combined all information from all detectors and TDTs. This final unaveraged dataset was binned at 1/4 of the FP resolution element (in the same way as the individual binning for each observation). This produced a single final spectrum across the entire LWS range.

The details of each TDT used in the survey are given in Tables 5 and 6, with the approximate coverage of the prime detector. The exact wavelength ranges covered by both prime and non-prime detectors are not shown. For non-prime detectors, the coverage is not continuous and there are gaps.

FINAL SPECTRUM PRODUCT: Single binned spectrum with all data combined into one file.

The final spectrum is shown in Figures 2 and 3.

2 Caveats - Orion

- No data from detector LW5 were included in the dataset due to the high noise on this detector.
- Only L03 data have been used - no L04 observations were included.

3 Caveats - Sgr B2

- Data below 70 μm observed using FPL was included in the final spectrum dataset, even though these wavelengths are outside of the nominal operating range of FPL. This means that the wavelength calibration drifts off with wavelength below 70 μm. This effect has not been corrected, but can be characterised by comparing FPL non-prime and FPS prime data. This shows that the offset is not more than $\sim$25 km s^{-1} (see Polehampton et al. 2007). Only the final spectrum dataset contains these non-prime FPL data and

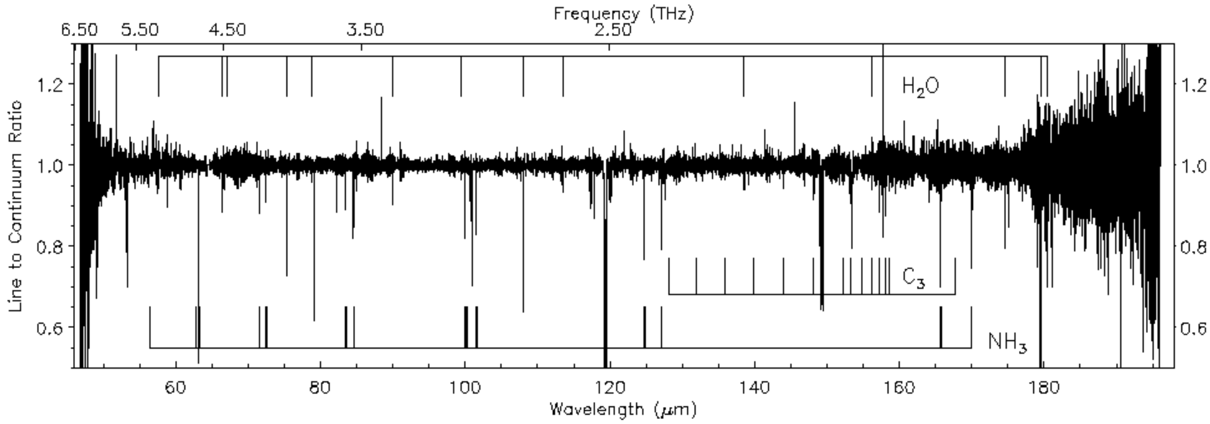

Figure 3: The full Sgr B2 L03 FP spectrum after co-adding prime and non-prime data using FPL for all LWS detectors (below 70 μm only non-prime data were used). The positions of detected features for several species are shown. The data were binned at 1/2 the instrumental resolution element.

the intermediate data products are not included in the HPDP dataset (ie there is no data for SW1, SW2 or SW3 for FPL in products 1 and 2).

- Prime data are included for FPS for products 1 and 2 only, but not included in the final spectrum. This is because the transmission by FPS was much lower than FPL and all of the data that could be recovered are very noisy.
- FPL non-prime data from LW5 is not included, due to the high noise level.

4 Data Products

The HPDP dataset consists of three different products, representing different stages of the data reduction process. The first two products contain data from a single TDT in each file, while the third contains the combined results from all TDTs for the object. In general, the product formats are identical for Orion and Sgr B2, but any differences are noted below. All the datasets will be available through the ISO Data Archive from early 2007.

4.1 Product 1

As described in Section 1, the first product contains un-averaged data from the LIA routine 'FP_PROC'. A separate product is produced for each TDT, containing the data from all good detectors. Typically, about 5 detectors per TDT had sufficiently good data to be included in the files. The science unit is flux, in W cm^{-2} μm^{-1}. The wavelengths are corrected to LSR velocity. The filenames have the following format:

`L03_TDT_FP.fits`
e.g. `L03_66002003_FP.fits`

The data are stored as standard FITS binary tables, in what is known as 'YAAR' LSAN format. This is used by the ISAP software, and uses shorter tag (column) names than OLP LSAN files. The structure is summarised in Table 2. The FITS primary header contains the keywords from the LSPD file used as input to FP_PROC, with comments updated to identify the HPDP.

4.2 Product 2

As described in Section 1, the second product contains averaged data, derived from the first product. A separate product is produced for each TDT. The science unit is line-to-continuum ratio. As with product 1, the wavelengths are corrected to LSR velocity. The filenames have the following format:

L03_TDT_LC.fits
e.g. L03_66002003_LC.fits

The FITS file format is very similar to product 1, but the exact usage of some tags is different. The structure is summarised in the Table 3.

The FITS primary header contains the same keywords as product 1, with comments updated to identify the HPDP.

4.3 Product 3

As described in Section 1, the third product contains the combined averaged data from all the TDTs for each object. Due to the ISO data archive architecture, a separate identical product is provided for each TDT. The science unit is line-to-continuum ratio. As with products 1 and 2, the wavelengths are corrected to LSR velocity. The filenames have the following format:

L03_TDT_Final.fits
e.g. L03_66002003_Final.fits

The FITS file format is different to that for products 1 and 2, with a reduced number of tags. The structure is summarised in the Table 4.

Table 2: FITS file columns for product 1.

Tag Name	Type	Description
WAVE	FLT(32)	Wavelength (μm)
FLUX	FLT(32)	Flux (W cm^{-2} μm^{-1})
STDEV	FLT(32)	Standard deviation in Flux (W cm^{-2} μm^{-1})
DET	INT(32)	Detector number (0-9)
LINE	INT(32)	Line number (mini scan number in observation)
FLAG	INT(32)	Required by ISAP - set to zero.
SCNT	INT(32)	FP Scan count
SDIR	INT(32)	Scan direction = 0 = Forward (All L03 scans are Forward)
STAT	INT(32)	LSPD status flag - set to zero
RPID	INT(16)	Raster Point - set to zero

Table 3: FITS file columns for product 2.

Tag Name	Type	Description
WAVE	FLT(32)	Wavelength (μm)
FLUX	FLT(32)	Line to continuum ratio
STDEV	FLT(32)	Standard deviation in Line to continuum ratio
DET	INT(32)	Detector number (0-9)
LINE	INT(32)	Line number (Orion only - set to zero for Sgr B2)
FLAG	INT(32)	Required by ISAP - set to zero
SCNT	INT(32)	FP Scan count - set to zero
SDIR	INT(32)	Scan direction = 0 = Forward (All L03 scans are Forward)
STAT	INT(32)	LSPD status flag - set to zero
RPID	INT(16)	Raster Point - set to zero

Table 4: FITS file columns for product 3.

Tag Name	Type	Description
WAVE	FLT(32)	Wavelength (μm)
FLUX	FLT(32)	Line to continuum ratio
STDEV	FLT(32)	Standard deviation in Line to continuum ratio
FLAG	INT(32)	Required by ISAP - set to zero

4.4 Support

The staff at the UKIDC can provide support with the understanding and use of the LWS03 HPDP dataset. Please contact: `isouk@rl.ac.uk`.

5 Glossary

CCLRC - Council for the Central Laboratory of the Research Councils
FITS - Flexible Image Transport System
HPDP - Highly Processed Data Products
ISAP - ISO Spectral Analysis Package
ISO - Infrared Space Observatory
LIA - LWS Interactive Analysis
LSAN - LWS Science ANalysis, the main LWS science product
LSPD - LWS Standard Processed Data
LSR - Local Standard of Rest
LWS - Long Wavelength Spectrometer
OLP - Off-Line Processing, the pipeline used to produce ISO data products
RAL - Rutherford Appleton Laboratory, part of the CCLRC
TDT - Target Dedicated Time, the unique reference number for each ISO observation
UKIDC - UK ISO Data Centre, located at RAL

6 References

Gry, C., Swinyard, B., Harwood, A., et al. 2003, ISO Handbook Volume III (LWS), Version 2.1, ESA SAI-99-077/Dc
Lerate, M., Barlow, M. J., Swinyard, B. M., et al. 2006, MNRAS, 370, 597
Lim, T. L., Hutchinson, G., Sidher, S. D., et al. 2002, SPIE, 4847, 435
Polehampton, E. T. 2002, PhD thesis, Oxford University
Polehampton, E. T., Baluteau, J.-P., Swinyard, B. M., et al. 2007, MNRAS, accepted, astro-ph/0702725
Sturm, E., Bauer, O. H., Lutz, D., et al. 1998, in Astronomical Data Analysis Software and Systems VII, ASP Conference Series 145, 161

Table 5: Log of all reduced Orion BN/KL L03 observations. Observations are sorted by wavelength range covered by the prime detector. The length of the observation in seconds, the observation date and the observed coordinates are shown in the remaining columns.

TDT Number	Prime Wavelength Range (μm)	Length (s)	Date (dd.mm.yy)	J2000 RA	J2000 Dec
66302402	47 – 52	5586	9.9.97	$5^h35^m14^s.17$	$-5°22'33''.5$
66302406	47 – 52	5586	9.9.97	$5^h35^m14^s.17$	$-5°22'33''.5$
66002003	52 – 57	4434	6.9.97	$5^h35^m14^s.17$	$-5°22'33''.4$
66002007	52 – 57	4434	6.9.97	$5^h35^m14^s.17$	$-5°22'33''.4$
70101704	57 – 63	5726	17.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
70101708	57 – 63	5726	17.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
70001205	63 – 70	5641	16.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
70001209	63 – 70	5642	16.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
69901510	70 – 73	2592	15.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
69901514	70 – 73	2591	15.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
69901312	77 – 81	4106	15.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
69901316	77 – 81	4106	15.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
69901413	81 – 85	3842	15.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
69901417	81 – 85	3842	15.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
70001105	85 – 89	2530	15.10.97	$5^h35^m14^s.16$	$-5°22'33''.7$
70001127	85 – 89	2530	16.10.97	$5^h35^m14^s.17$	$-5°22'33''.8$
87301008	99 – 104	2924	6.4.98	$5^h35^m14^s.15$	$-5°22'33''.4$
87301030	99 – 104	2924	6.4.98	$5^h35^m14^s.15$	$-5°22'33''.4$
87300909	104 – 109	2748	6.4.98	$5^h35^m14^s.15$	$-5°22'33''.4$
87300931	104 – 109	2748	6.4.98	$5^h35^m14^s.15$	$-5°22'33''.4$
82702210	109 – 115	3226	19.2.98	$5^h35^m14^s.15$	$-5°22'33''.5$
82702232	109 – 115	3226	20.2.98	$5^h35^m14^s.15$	$-5°22'33''.5$
84101911	115 – 121	3140	5.3.98	$5^h35^m14^s.15$	$-5°22'33''.4$
84101933	115 – 121	3140	5.3.98	$5^h35^m14^s.15$	$-5°22'33''.5$
82602316	147 – 154	3830	18.2.98	$5^h35^m14^s.15$	$-5°22'33''.5$
82602338	147 – 154	3830	18.2.98	$5^h35^m14^s.15$	$-5°22'33''.5$

Table 6: Log of all reduced Sgr B2 L03 observations. Only the wavelength range recorded on the prime detector is shown. In some observations the specified wavelength coverage was split between two prime detectors (this occurred at the edge of the detector nominal range). The length of the observation in seconds, the observation date, the number of repeated FP miniscans and the LSR velocity correction applied are shown in the remaining columns.

TDT Number	Prime Wavelength Range (μm)	FP Used	Prime Detector	Length (s)	Date (dd.mm.yy)	Repeated Scans	Velocity Correction Applied (km s^{-1})
50400431	47.0 – 49.5	FPS	SW1	4646	3.4.97	3	−39.3
50400330	49.5 – 52.0	FPS	SW1/SW2	5934	3.3.97	3	−39.6
50400929	52.0 – 54.5	FPS	SW2	4309	3.4.97	3	−37.8
50401028	54.5 – 57.0	FPS	SW2	4200	3.4.97	3	−37.7
50900327	57.0 – 60.0	FPS	SW2/SW3	6492	8.4.97	3	−37.7
50400526	60.0 – 63.0	FPS	SW3	4540	3.4.97	3	−38.6
50400725	63.0 – 66.0	FPS	SW3	4490	3.4.97	3	−38.2
50400224	66.0 – 70.3	FPS	SW3	6184	3.4.97	3	−39.7
50400823	70.3 – 73.0	FPL	SW4	4446	3.4.97	3	−38.0
50400122	73.0 – 77.0	FPL	SW4	6364	3.4.97	3	−39.1
50900521	77.0 – 81.0	FPL	SW4/SW5	8828	8.4.97	3	−39.0
50900620	81.0 – 85.0	FPL	SW5/LW1	3448	8.4.97	3	−38.1
50800819	85.0 – 89.0	FPL	LW1	4366	7.4.97	3	−37.6
50800218	89.0 – 94.0	FPL	LW1	5232	7.4.97	3	−39.0
50800317	94.0 – 99.0	FPL	LW1	5134	7.4.97	3	−38.6
50800416	99.0 – 104.0	FPL	LW1	5040	7.4.97	3	−38.3
50800515	104.0 – 109.0	FPL	LW2	4708	7.4.97	3	−38.0
50600814	109.0 – 115.0	FPL	LW2	5492	5.4.97	3	−37.9
50601013	115.0 – 121.0	FPL	LW2	5424	5.4.97	3	−37.4
50601112	121.0 – 127.0	FPL	LW2	5244	5.4.97	3	−37.2
50700511	127.0 – 133.0	FPL	LW2/LW3	6054	6.4.97	3	−37.7
50700610	133.0 – 140.0	FPL	LW3	5812	6.4.97	3	−37.4
47600809	140.0 – 147.0	FPL	LW3	5806	6.3.97	3	−38.9
50700208	147.0 – 154.0	FPL	LW3/LW4	6418	6.4.97	3	−38.8
50700707	154.0 – 161.0	FPL	LW4	5566	6.4.97	3	−37.2
50600506	161.0 – 168.0	FPL	LW4	5536	5.4.97	3	−38.6
83800606	167.0 – 170.0	FPL	LW4	3342	2.3.98	4	−38.5
83600605	170.0 – 174.0	FPL	LW4	4246	28.2.98	4	−38.1
50600405	168.0 – 175.0	FPL	LW4	5553	5.4.97	3	−38.9
83600704	174.0 – 178.0	FPL	LW4	4096	28.2.98	4	−38.1
84900803	178.0 – 182.0	FPL	LW5	5917	13.3.98	6	−39.4
50700404	175.0 – 182.0	FPL	LW4/LW5	6146	6.4.97	3	−38.1
84500102	182.0 – 189.0	FPL	LW5	10158	9.3.98	6	−39.7
50600603	182.0 – 190.0	FPL	LW5	5494	5.4.97	3	−38.3
84700301	189.0 – 194.0	FPL	LW5	7060	11.3.98	6	−39.4
50600902	189.0 – 196.0	FPL	LW5	5468	5.4.97	3	−37.7

Table 7: Velocity correction factors to Heliocentric and Local Standard of Rest (LSR) frames applied to Orion KL data.

TDT	Heleocentric correction (km s^{-1})	LSR correction (km s^{-1})
66302402	−25.61	10.38
66302406	−25.48	10.24
66002003	−25.49	10.26
66002007	−25.39	10.15
70101704	−22.18	6.94
70101708	−22.01	6.77
70001205	−22.65	7.41
70001209	−22.46	7.22
69901510	−22.34	7.11
69901514	−22.28	7.05
69901312	−22.85	7.61
69901316	−22.69	7.45
69901413	−22.53	7.30
69901417	−22.42	7.18
70001105	−22.95	7.71
70001127	−22.87	7.64
87301008	24.46	−39.69
87301030	24.49	−39.72
87300909	24.36	−39.60
87300931	24.43	−39.67
82702210	24.84	−40.08
82702232	24.86	−40.10
84101911	26.47	−41.70
84101933	26.49	−41.73
82602316	24.56	−39.80
82602338	24.67	−39.90