Specification for a modular lunar spectral irradiance software system pre-LCW4 draft

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1 Overview

The ROLO lunar spectral irradiance model, in use for nearly two decades, was written in IDL, a proprietary language. To allow broad use, it was converted to C, an open language, and named GIRO (GSICS implementation of ROLO). However, at that time there was no other lunar model suitable for use in lunar calibration, and the architecture of GIRO has little consideration of incorporating other lunar models.

Now, other models are becoming available and some appear to be significant improvements to GIRO. There is a general desire within the lunar calibration community for a new lunar spectral irradiance model **system** which can incorporate various models of lunar reflectance with a minimum effort and which will be available to everyone. Also, this framework should anticipate expected developments, such as models treating polarization.

The concept of an architectural framework to accomplish this was suggested at the GSICS annual meeting 2023 Feb, and there have been several discussions within the VIS/NIR subgroup about the path forward. By vote 2023 July 11 the name "Lunar Spectral Irradiance Calibration System", LSICS. pronounced L6 (el-six). was chosen for this software system. An early need is a formal specification LSICS and of the files (or dataGroups (DG)) that interface between the several software modules that comprise it.

The DataGroup definitions are intended to support the development of new models, and well as application to specific observations.

This document is a draft of that specification.

This draft does not consider models that cover the thermal infrared or microwave spectral region.

1.1 Terminology

HK: Residual comments are shown in this font

All numerical values are TBD.

'L6' is shorthand for this software system.

"shall" means a requirement

"should" means a recommendation

"may" means the item is optional

"DataGroup" or DG is a term for sets of information that are commonly produced or needed together. They may be files.

The wavelength unit for VIS/NIR (solar reflectance) is nanometers. *SW: not needed*

'band' and 'channel', common in surface and atmosphere applications respectively, are equivalent.

"bands" refers only to bands with the majority of their spectral response between 300 nm and 2500 nm

Note: Wavelengths longer than about 2500 nm are subject to detectable (? better word) thermal emission.

Thermal emission from areas at the peak lunar surface temperatures (405 K) reach 10% of nominal solar reflectance (albedo 0.2) near 2330 nm. Whole-disk thermal radiation is near 92 C at small phase [Matthews,2008] which reaches 1% of reflected irradiance near 2250 nm and 10% near 2620 nm.

An "observation" is defined as near-simultaneous measurements by a group of bands. See §4.2

1.2 Lunar Spectral Irradiance Terminology

1) **Image** : The irradiance derived from an image, using the steradian per pixel and data number-to-radiance conversion for nominal science imaging.

2) **Observed** : Image irradiance corrected for all 'observer' effects. Any oversample factor has been applied.
This is what Teams submit to LSICS

3) **Reported** : Observed irradiance corrected to the GSICS consensus standard conditions, which would include adjustments for DistanceFactor and Solar Variation. Computed within LSICS

4) **Model** : Model-computed irradiance for GSICS consensus standard conditions. e.g., at standard distances and the reference Solar spectral irradiance. Computed within LSICS

5) **Predicted** : Model irradiance adjusted to the observations conditions. I.e., Model * (distance factor * solar variation)

The **calibration ratio** is 2/5 ≡ observed/predicted or 3/4 ≡ Reported/Model

1.3 Reference documents

1. High Level Description of the GIRO Application and Definition of the Input/Output Formats.
   EUMETSAT Document EUM/TSS/TEN/14/753739, 24 February 2015
   http://gsics.atmos.umd.edu/pub/Development/LunarWorkArea/GSICS_ROLO_HighLevDescript_IODefinition.pdf
2. Tom Stone and Hugh Kieffer: GSICS Annual Meeting: 2023 March 02:
   Discussion on Implementing a New GSICS Lunar Model
   http://gsics.atmos.umd.edu/pub/Development/Gsicsannualmeeting2023/7v_GSICS_2023_TStone_Lunar_model_discussion_Intro.pdf
3. Hugh H. Kieffer, Multiple-instrument-based spectral irradiance of the Moon
   Journal of Applied Remote Sensing (JARS). Vol. 16, Issue 3
   https://doi.org/10.1117/1.JRS.16.038502

2 Top level requirements

SW: Do not mix. We should not mix user requirements (what do we want the system to be able to do?) and system requirements (translation of the user requirements into a system to fulfill the needs).

Given a set of 1 to N observations of lunar irradiance by an instrument with 1 to M bands in the solar reflectance wavelength region, the L6 system will produce the **predicted** lunar spectral irradiance for those conditions.

Note: Some Lunar Modules may have limits on N or M or NM

TS: Dimension limits probably not necessary.

All files will be netCDF.

All routines will be coded in Python.

The L6 software system shall consist of several modules, to be applied in succession; the concept is described in Ref. 2.

The interfaces between modules shall consist of fully-defined sets of information here called "DataGroups". Each DataGroup is defined in a Table in the Appendix. A DataGroup may be a file or structure or group of arrays and scalars. The DataGroup input to the first L6 module and that output by the last L6 module shall be files. The total information may be grouped in ways different than organized here, but all that is listed as compulsory (2nd column in tables) shall be in the final set of DataGroups.

It is critical that the definition of the minimum contents all DataGroups be complete. The current tables are based upon the definitions for GIRO (Ref. 1), consideration of a new model system (Ref. 2 and Ref. 3) and anticipation of availability of polarization measurements. **The tables in the Appendix should be considered TBD pending discussion and approval by the GSICS community.**

Arrays within DataGroups shall support 1-to-many observations and 1-to-many bands (including spectrometers).

This L6 design includes the expectation that instrument team submissions will commonly include multiple observations in one file.

An additional goal is to design a system that can support the development of new models, which can involve processing many large sets of observations numerous times.

2.1 Standard Wavelengths

The L6 system may utilize a "Standard Wavelength Set" (SWS), a fixed set of wavelength points used for combining solar, Lunar and Instrument spectra. If used, the SWS shall be positive increasing monotonic and cover at least the 300 nm to 2400 nm range. A point spacing of about $\lambda/\Delta\lambda = 1000$ is recommended.

An SWS should be defined in a manner that different Lunar Modules (§6.3) may redefine the point set.

TS: specifying a standard wavelength set for L6 is not necessary - the disk reflectance module can specify the wavelength grid on which it operates, and the spectral irradiance module needs to have the capability to operate on the wavelength grid it imports from the interface file produced by the disk reflectance module.

TS: A standard wavelength set is not needed for the L6. The wavelength grid used by the Moon module can be imported from a design-specific external file that does not need to correspond to any L6 specification.

3 Global comments on prior version

Several: Follow GIRO terminology as much as possible. Backward compatibility. Minimizes instrument team re-coding effort.

SW: The Framework must follow GSICS conventions. Start with GIRO attributes and variables. Modify only where necessary.

SW: Do not mix requirements on the Framework with requirements related to science quality.
HK: A substantial reorganization of the document will be required to accomplish this.

SW: Add a graphic showing module linkage.

SW: Is the solar module needed (at this time)?

4 Input package

Data submission to the L6 system for calibration must contain the information described in this section. The data may be contained in separate files, as listed in Tables 3 and 4, or combined in other ways, TBD.

Units shall be specified for all numerical values. For only "srf", the units may be as chosen by the Team.

Because knowledge of instrument spectral response rarely changes after launch, that information is placed in a separate DG.

4.1 Spectral response

The system-level spectral response function (SRF, including detector responsivity and all optics) is required for each band. It shall be at the image level; e.g., averaged over individual detector elements. It should be provided by instrument teams for the configuration of normal science observations and, if different, the configuration of normal lunar observations.

If an instrument observes the Moon separately in multiple focal-plane arrays, these may be considered "sub-instruments" each with its own set of SRF's, or a single SRF set, averaged over arrays, may be used.

The SRF for one band consists of a set of wavelength and response pairs, in monotonic wavelength order.

- A representative value of wavelength uncertainty (fractional or in wavelength units) should be provided.
- Two representative values of response uncertainty, fractional uncertainty and precision, should be provided.

The spectral response will generally be treated as constant over an instrument mission.
If changes are known, full sets of SRF's should be supplied along with the time period to which each applies.

These data should be contained in a band wavelength and response file, Table 3.

SW: In some cases the SRF may be different for each observation. HK: How to handle this?

4.2 Time and view-point

The "Effective time" of a band observation is the instant by which 1/2 of total flux for the Lunar disk has been integrated.
For framing systems, this is the middle of the exposure time.
For scanning imaging systems, this is when the geometric center of the Moon is sampled.
"Effective time" shall be specified to a resolution and accuracy to support geometry calculations, i.e., to an accuracy of 0.01 degrees or better; see "near-simultaneous" below.
Effective time should be specified in ISO-8601 in UTC. Any other time system used must include a well-defined relation to UTC. Discontinuous time systems such as "UNIX" time (computer time) shall not be the only effective time provided.
A representative value for the uncertainty in 'effective time' for the instrument should be stated.

Observations are "near-simultaneous" if acquired in a time span during which the photometric angles change by no more than 0.01 degrees. This is about 10 seconds for LEO, 20 sec for GEO, and 150 sec for surface observatories.
If the range of effective times for all bands of an instrument exceeds this time span, bands should be grouped into subsets that satisfy this time span, and each subset treated as a separate observation.

"Sensing duration" is the time required to measure the radiance across the lunar geometric disk for one band, or to integrate the irradiance.
A representative value of 'Sensing duration' for the instrument, or for each band, should be stated.

The instrument location at the 'effective time' shall be given as Cartesian coordinates in km in the ICRF or J2000 Reference Frame centered on the Earth center-of-mass (as used in the JPL ephemeris) or some other ECI system different by less than 0.4 km (1 ppm of lunar distance).
A representative value of uncertainty in location for the instrument (offset distance) should be stated.
Alternate. If the instrument is in a fixed geographic location, that single location should be specified in WGS-80 (or later) coordinates; Degrees East, degrees North, elevation above the geoid in meters.

The above data should be contained in a 'time and view-point' DG, Table 4

4.3 Observed irradiance

The **observed** lunar spectral irradiance for each band for each observations shall be submitted in SI units. Note: micro-Watts m^{-2} nm^{-1} is convenient as values are on the order of 1.
Uncertainty of each measurement should be supplied. If done, the uncertainty shall be in the same units as irradiance.

These data should be contained in the team DG , Table 4

5 Naming and formats

In order for data to flow smoothly through the L6 modules, some consistency in file naming is required.

NOTE: All *file* naming conventions are TBD, pending review and consensus by the GSICS community. Those here are based on the practicality of working with many instruments. This section must be replaced by the final agreements.

SW: Standard input and output file names are codified by GSICS. If intermediate files are created, there might be more flexibility. However, if those files are going to be part of GSICS deliverables, they have to follow GSICS conventions. GSICS has adopted WMO conventions.

For DataGroups that cover the same set of observations, the order of observations and the order of bands shall be the same in all DataGroups.

Attribute and variable names shall conform to the specifications of Tables 3 to 9.

Every variable shall have associated with it:
long_name: describing the variable
fill_value: identifying values which are invalid or not specified
Every numerical variable shall have associated with it:
units: relating the values to SI units. Standard powers-of-1000 multipliers, such as milli, m or nano, n are allowed.

The first part of Input Package file names shall identify the instrument and should have a (brief) section that provides uniqueness for multiple submissions for an instrument. Here, this part of the name is called the "stem"

The last part of L6 file names before the extension (.nc), called the "file-type", shall be consistent for each file-type and should correspond in a recognizable way to the DataGroup name. It is suggested that an underscore precede the file-type.

The 'stem' for all output files shall correspond to the Input Package stem.

A fill value of -999 is adequate for most numeric or character variables. An exception is 'satpos', requiring a magnitude of at least 50,000 for GEO. However, lunar calibration has been done from Mars, so the magnitude should be at least 4.1e8 km.

6 Modules

All modules reading an Input package should initially check that the file contents and formats are proper for the L6 system.

Some data flow concepts are shown in Figures 1 and 3.
Note: The last two were constructed late in the specification process.

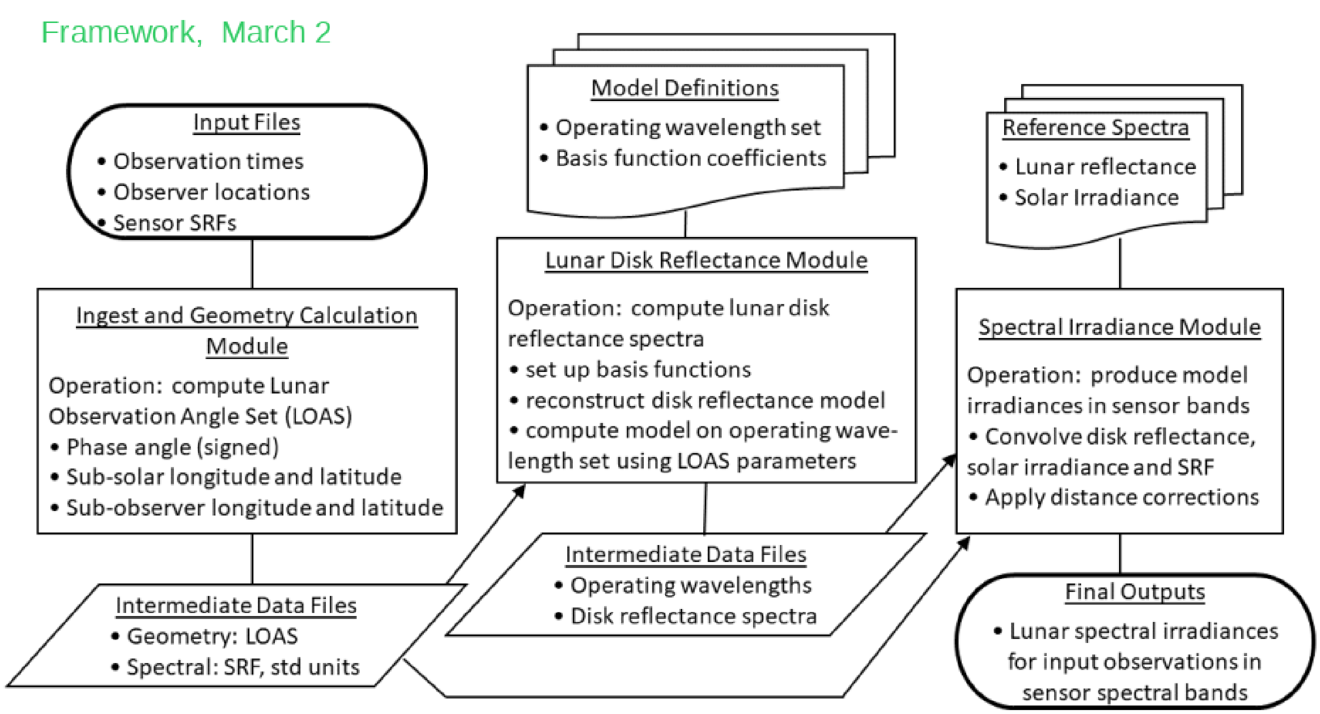

Figure 1: 2023 March Framework presentation flowchart

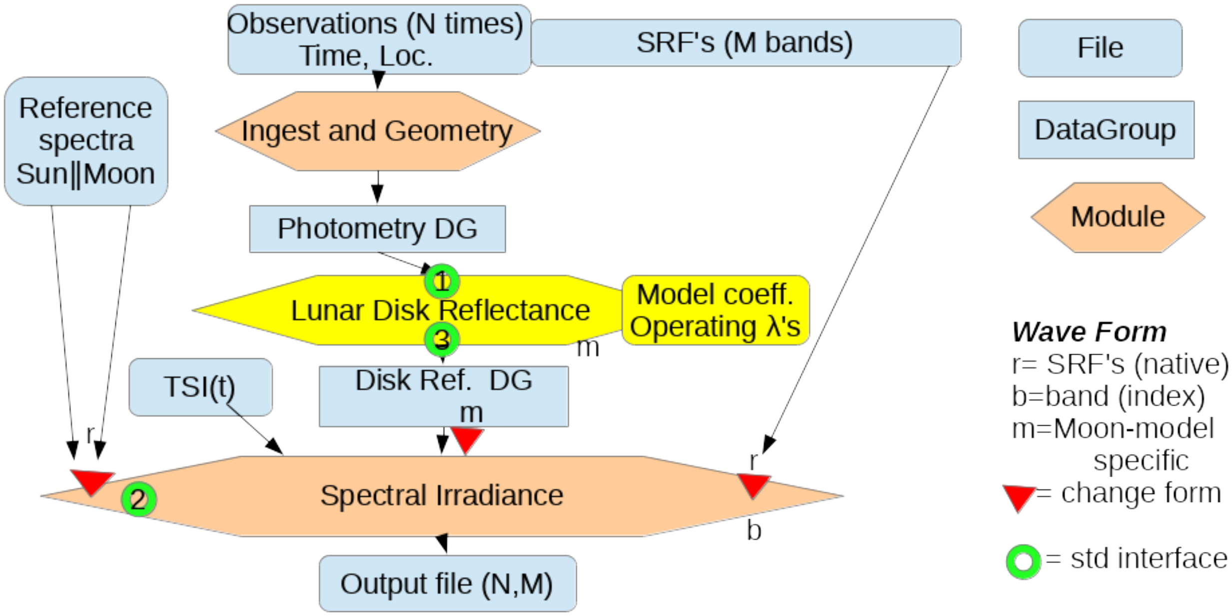

Figure 2: Flowchart derived from the 2023 March Framework presentation. The single letters above and below modules indicate the manner in which SRF's and spectra are represented upon input and output.

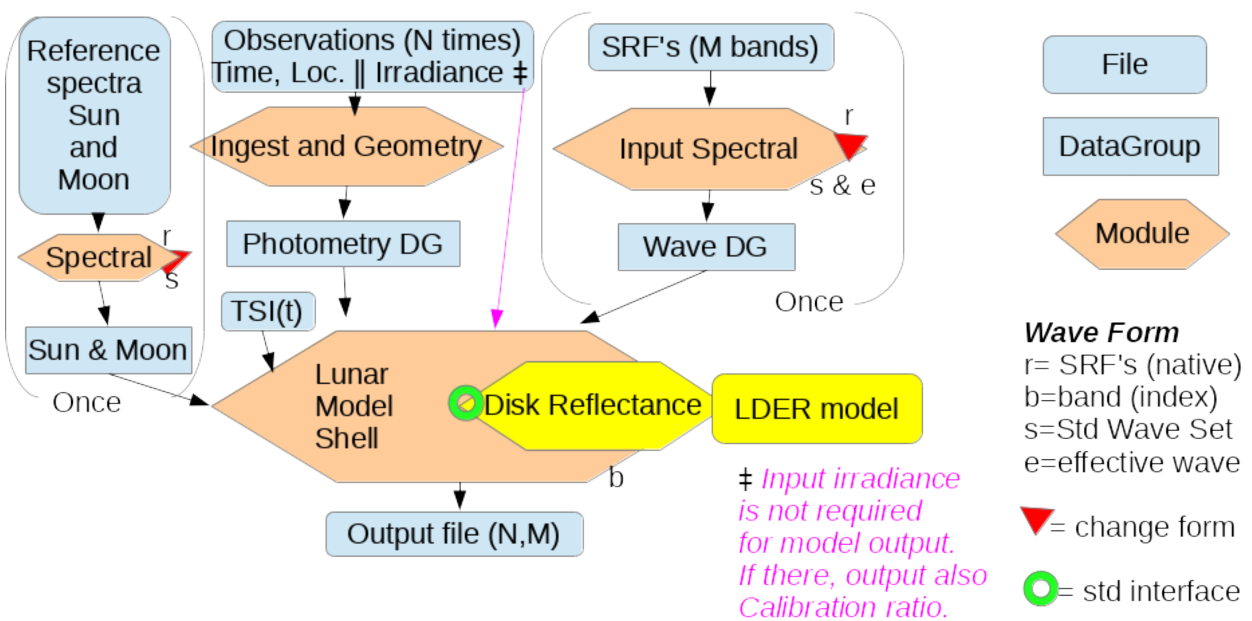

Figure 3: Flowchart based on a "shell" around the Disk Reflectance Module and using a Standard Wavelength Set. Groups within round brackets need be run only when source spectra change. The two Spectral modules can be the same code.

6.1 Input Spectral Module

2023Nov21 Note: There is debate over where spectral processing is done in the Framework. HK suggests that GSICS adopt some standard wavelength set and this module re-samples all spectra onto the set as a service to the Lunar Module, which could choose to ignore it!

TS: What I envision: Spectral re-sampling, if done, happens in the spectral irradiance module. The SRFs will be available to the disk reflectance module, and generating effective wavelengths (as SLIM requires) gets done in that module.

Notes:

1. It may be possible to define a lunar spectral irradiance system that uses only the band SRF's as submitted by the Teams, not requiring spectral re-sampling or the concept of 'effective wavelength'. In such a case, most of this section is not needed.

2. At a minimum, this module needs only to read the instrument SRF's. Because SRF's are commonly constant over the life of an instrument, processing of these data in preparation for the Spectral Irradiance Module (§6.5) is described here and need be done only once for an instrument. However, SRF processing could be in the Spectral Irradiance Module.

This module accesses the W DataGroup (Table 5) and re-samples the instrument SRF's for each band onto a "Standard Wavelength Set (SWS) " This process should be rigorous-weight-preserving, ensuring that the fraction of the SRF assigned to each individual SWS point domain, defined as the wavelength region between the adjacent midpoints between SWS points, is the same in the input and output.

The output is two arrays as specified in Table 5.
1) 'resampled wavelength', representing each band on the SWS points.
2) 'effective wavelength', computing for each band at least:
The effective wavelength for the Sun*Moon reference spectrum
The mean in-band spectral irradiance.

Note: The reference solar spectral irradiance and the reference lunar spectral reflectance both need to be re-sampled by the same algorithm onto the SWS points.

The effective wavelength for lunar light is defined by the reference solar spectral irradiance $S_0(\lambda)$, the reference lunar disk spectral reflectance $R_0(\lambda)$ (currently based on laboratory measurements of returned Apollo samples) and system-level spectral response function for band j, $T_j(\lambda)$

$$\lambda_{e_j} = \frac{\int_{\lambda_1}^{\lambda_2} \lambda \cdot S_0(\lambda) R_0(\lambda) T_j(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} S_0(\lambda) R_0(\lambda) T_j(\lambda) d\lambda} \tag{1}$$

Once all spectra are re-sampled as specified above, this integral is easily computed as

$$\lambda_{e_j} = \frac{\sum_{l=1}^{L} \lambda_l \cdot S_{0_l} R_{0_l} T_{jl} \Delta\lambda_l}{\sum_{l=1}^{L} S_{0_l} R_{0_l} T_{jl} \Delta\lambda_l}$$

where l are the points of the SWS.

Similarly, the mean in-band spectral irradiance is:

$$Ee_j = \frac{\sum_{l=1}^{L} S_{0_l} R_{0_l} \cdot T_{jl} \Delta\lambda_l}{\sum_{l=1}^{L} T_{jl} \Delta\lambda_l} \tag{2}$$

6.2 Geometry Module

This module accesses the DataGroup V values (Table 4) and the JPL planetary ephemeris for locations of the Sun, Earth and Moon. This module computes for each observation the values in Table 1 at a minimum. For observations from the Earth surface or atmosphere, it may be useful to also compute the zenith angle of the Moon.

For notational convenience the set of angles and distances produced for observation i at time t_i is called P_i.

These data should be output in the Geometry DataGroup, Table 6.

Table 1: Required photometric geometry. The first five angles constitute the Lunar Observation Angle Set (LOAS).

signed phase angle
sub-solar selenographic longitude
sub-solar selenographic latitude
sub-observer (-viewer) selenographic longitude
sub-observer selenographic latitude
Distance between the centers of the Sun and Moon
Distance between the center of the Moon and the viewer,
——- If the lunar model supports polarization ———
Lunar disk bright limb angle, †
Lunar north-pole position axis, †
† measured counterclockwise from celestial North

6.3 Lunar Module

This module produces lunar disk-equivalent reflectance (LDER) spectra for angles P_i at each observation time i in the P DataGroup.

TS: A standard wavelength set is not needed for the L6. The wavelength grid used by this module can be imported from a design-specific external file that does not need to correspond to any L6 specification.

The reference reflectance spectrum can be imported to this module from a design-specific external file that does not need to correspond to any L6 specification.

HK: The wavelength interface between each instrument band for any version of this module and the rest of the L6 system is most efficiently points on the SWS and, optionally, effective wavelengths.

Internal to this module, the representation of wavelength is not constrained. Here, it is called 'wave' and simply represented by 'w'. Several possibilities are listed in Table 2.

Table 2: Possible wavelength sets

Description	typical M
At the effective wavelength of each of the lunar model bands.	6=LIME to 32=ROLO
At the effective wavelengths of each instrument band	1 to 200
At the ensemble of SWS wavelengths used by the instrument.	~1500
At all of the SWS wavelengths.	Ref. 3 has 2114
At the ensemble of all instrument SRF points.	~ 5000, max. so far 16,513

This module will access the data of the P and W DataGroups.

This module should access a 'model definition' file of parameters that define the disk reflectance model; it may be unique for each model. Contents are not specified beyond the 'Standard set' in Table 3, plus a name for the lunar model. However, the model definition file should be structured so that modest revisions can be accommodated without changes to the module code.

The LDER spectra shall be output as 'disk reflectance' in DataGroup D for all spectral points needed by the Spectral Irradiance Module.

6.4 Solar Module

This module is optional; it handles variation of the solar spectral irradiance by computing a time and wavelength-dependent multiplier of the reference solar spectral irradiance. This is approximately a 0.1% effect. It may be replaced by the reference solar spectrum.

The Solar Module typically will access the following reference information:

Reference solar spectrum $S_0(\lambda)$, mean solar spectral irradiance [W m^{-2} nm^{-1}]. At a spectral resolution appropriate for the suite of instruments using lunar calibration (solar spectra are available at much higher resolution than needed here).

Total solar irradiance (TSI) over time $H(t)$, [W m^{-2}], Time resolution of 5 days or smaller.

Wavelength sensitivity to TSI variation $f(\lambda)$, factor for solar spectral relative variation to TSI.

This module produces the solar spectral irradiance for each observation time at the same wavelength set of Table 2 as used for LDER.

These data should be output in the DataGroup D, Table 7.

Below is an example implementation based on Ref. 3.

As the TSI varies, the variation of spectral irradiance increases toward shorter wavelengths, represented here by a quadratic fit in log/log space over 290:2412 nm to the ratio f of solar spectral irradiance variation (high-pass filtered) to TSI variation; see Ref. 3 §2.3 .

$$f(\lambda) = \exp(-0.338752 - 0.785894 \ln \lambda + 0.202152 \ln^2 \lambda) \tag{3}$$

where λ is in micrometers.

The other required inputs are:
- Time of each observation (in days from 2000 Jan 01 00:00
- Effective wavelength of each band

Solar variation can be computed as

$$S_\odot(t,\lambda) = S_0(\lambda) \left[1 + \underbrace{f(\lambda) \left(\frac{H(t)}{H_0} - 1 \right)}_{\mathcal{H}} \right] \Longrightarrow S_{\odot ij} \tag{4}$$

where $S_\odot(t,\lambda)$ is the solar spectral irradiance and $H(t)$ the total solar irradiance; with subscript 0 being the long-term average. $\mathcal{H}(t,\lambda)$ is the solar variation model. It is applied to the time-independent model irradiances.

6.5 Spectral Irradiance Module

This module produces the **predicted** lunar spectral irradiances corresponding to the input observation times and locations, for the instrument spectral bands.

$$E_\oslash(\lambda,t) = \overbrace{S_\odot(\lambda,t)}^{\text{Solar Module}} \; \frac{\Omega}{\pi} \; \overbrace{\mathcal{R}(\lambda,t)}^{\text{Lunar Module}} \qquad \text{OR} \qquad S_{\odot ij} \frac{\Omega}{\pi} \mathcal{R}_{ij} \Longrightarrow \mathcal{E}_{ij} \tag{5}$$

Here $S_\odot(\lambda,t)$ is the solar spectral irradiance at 1 Astronomical Unit (au); this may be treated as constant or variable. Ω is the solid angle of the Moon, illuminated or not, at standard distance: 6.41780e-5 steradian.

Depending upon which choice was made in Table 2, some interpolation of $\mathcal{R}_{ij}$ may be required.

The lunar spectral irradiance predicted for an observation is $\mathcal{F}_{ij} = \mathcal{E}_{ij}/D_i$ where $D = d^2U^2$ is the 'distance factor' and d is the distance from the Moon (center) to the viewer ratioed to a standard distance of 384,400 km, near the mean Earth:Moon separation; and U is the Sun:Moon distance in au (1.4959787e8 km).

The calibration ratio is simply the **observed** spectral irradiance divided by the **predicted**: $\mathcal{C}_{ij} = E_{obs_{ij}}/\mathcal{F}_{ij}$

A DataGroups or Files

This section was written with using parts of Ref. 1 as a guide. The "NetCDF Climate and Forecast (CF) Metadata Conventions" document,

`https://cfconventions.org/Data/cf-conventions/cf-conventions-1.10/cf-conventions.html#_naming_conventions`

was not consulted.

DataGroups that are transferred internally within LSICS do not need to include the standard Global Attributes listed in Table 3

A.1 Abbreviations in the file tables

C column: Category:
- **c**: compulsory.
- **a**: Additional: optional. May be included
- **w**: which. Only if needed to distinguish between similar entities

TYPE column: Word type: Arrays are followed by an indication of dimensionality.
- S: string
- I: integer, generic. I1 is byte, I2 is 16-bit, I4 is 32-bit
- R: real, generic. R1 is 32-bit (single precision), R2 is 64-bit (double precision)

M is the number of bands, **N** is the number of dates.

Leading brackets in the description column contain the name used in GIRO, if different than here.

'dup4conv' means: duplicate of an earlier file, for convenience.

B File and DataGroup definition tables

Table 3: Instrument team, band spectral file contents.

NAME	C	TYPE	——- Global Attributes ———— Spectral data; DataGroup B
summary	c	S	Summary of file, identifying major contents.
institution	c	S	Name of organization generating this file.
insti_url	a	S	url of the institution.
license	a	S	Any legal limits or disclaimers.
platform	c	S	Name of spacecraft or observatory.
instrument	c	S	Name of instrument. Should not repeat 'platform'.
serial	w	S	Serial number within virtually identical instruments. May be null. See note
acronym	c	S	Short word for platform+instrument. Registered with GSICS to ensure unique.
launch	a	S	Launch date as yyyy-mm-dd
data_source	c	S	Source of the data, and any version number or date. Comments allowed.
history	c	S	Formatted processing history: [separator], date, software and version, email, source ... See note
id	c	S	File names(s) that institution would normally associate with these data. Commonly ridgedly formatted and long.
reference	a	S	List of materials describing the instrument, observations or processing.
oversamp_stat	c	S	Status of over-sample factor. Valid values are: 'none, 'team', 'calib'. See note
- - -	-	-	- - - End of standard ID set - - - - See note.
——	–	—-	———— Variables —————
band_id	c	S(M)	[channel_name] Name normally associated with the band, each unique. No more than 6 alphanumeric characters.
nom_wav	c	I2(M)	[effective_wavelength] Nominal wavelength in nm, each unique.
ifov	a	R1(M)	Spatial resolution at nadir. (M,2) if not close to square.
srf	c	R1(x,2)	[srf] System-level Spectral Response Function, bands concatenated. [*,0] is Wavelength or wave-number, [*,1] is the System-level spectral response. See note
nin_band	c	I2(M)	Number of points in each band in 'srf'.
polar_sens	c	R1(M,2)	If polarized. [*,0] is the fractional polarization sensitivity. [*,1] is the angle of maximum sensitivity, degrees; right-hand around +Z="nadir" from +X="spacecraft forward velocity".

Table 4: Instrument team Lunar Observations: Viewer Time, location and observed irradiance DataGroup V

NAME	C	TYPE	——- Global Attributes ———— Viewer Geometry & Irradiance: DataGroup V
ditto	"	"	The standard set listed in Table 3. 'oversamp_stat' is controlling.
date_type	c	S	Normally 'UTC'. May be double precision of an approved numeric time system.
launch	c	S	Launch date, UTC.
sat_pos_ref	c	S	Reference coordinate system for Viewer location (satellite_position). E.g., 'J2000' or 'ITRF'
——	–	—-	———— Variables —————
date	c	S or R2(N)	Observation time of center of the Moons disk, UTC ISO-8601 or double. See note.
sat_pos	c	R1(N,3)	Viewer location (satellite_position). XYZ of Earth-Centered Inertial position. Required unless 'tele_loc' supplied.
tele_loc	c	R1(3)	Telescope location as Longitude E, latitude, elevation. Only if observatory.
orientation	c	R1(N,3)	[Only if polarized] Orientation of the instrument relative to the J2000 Reference Frame; 3 angles or a quaternion.
band_id	c	S(M)	[channel_name] Duplicate of that in W file for insurance.
irr_obs	c	R1(N,M)	Measured lunar spectral irradiance. Units: micro-Watt m^{-2} nm^{-1}. See note
obs_unc	c	R1(N,M)	One-sigma uncertainty of the measurement, same units. Independent of 'obs_qual'.
obs_qual	a	R1(N)	Relative uncertainty of the irradiance determination of each observation. Median value of 1.
conditions	a	R1(N,C)	Optional. Any number of columns of condition at each observation time.
oversamp_fa	a	R1[N]	Optional. Oversample-factor. Use depends upon 'oversamp_stat'.
modes	w	S[k]	Optional, Names of different modes.
nummod	w	I1[k]	If 'modes' present. Number of observations in each mode, aligned with 'modes'.

Table 5: Output wavelengths. DataGroup W

NAME	C	TYPE	——- Global Attributes ————- L6 wavelength: DataGroup W
ditto	"	"	The standard set listed in Table 3.
——	–	—-	———— Variables —————
wavelength_set	c	R1(few)	Parameters that define the Standard Wavelength Set.
band_id	c	S(M)	Name normally associated with the band. dup4conv
srf_grid	c	R1(x)	Spectral Response Function, bands concatenated, on the SWS points.
srf_index	c	I2(M,2)	Indices for 'srf_grid for each band. 0] is SWS first point, 1] is the number of points.
eff_wave	c	R1(M,x)	Effective wavelength array [band,item]. Each item described. Two are essential: effective wavelength for the reference lunar spectral irradiance and the mean in-band irradiance.

Table 6: Photometric geometry contents. DataGroup P

NAME	C	TYPE	——- Global Attributes ————- Photometric Geometry: DataGroup P
ditto	"	"	The standard set listed in Table 3
——	–	—-	———— Variables —————
etsec	c	R2(N)	Observation time of center of the Moon's disk, ephemeris time in seconds. See note.
pgeom	c	R1(N,11)	Photometric geometry: distances and celestial angles. P_i of Table 1
twist	c	R1(N)	[If polarized] Twist of the instrument X-axis relative to the Sun-from-Moon vector (degenerate at zero phase), measured anticlockwise around the disk from the north point of the hour circle through the center of the Moon, degrees.

Table 7: Moon and Sun Reference data. DataGroup D

NAME	C	TYPE	——- Global Attributes ————- Disk-equivalent-reflectance: DataGroup D
ditto	"	"	The standard set listed in Table 3
sun_name	c	S	Name (and date) of the reference solar spectrum
TSI_name	c	S	Name (and date) of the total solar irradiance model used.
spec_sens_name	c	S	Name (and date) of the relation used for solar spectral sensitivity.
moon_name	c	S	Name (and date) of the reference lunar spectrum
——	–	—-	————Variables —————
ref_sun	c	R1(x,2)	The Solar spectral irradiance (at 1 au.) at spectral resolution at least as fine as needed to support all uses in lunar calibration. [*,0] is the irradiance and [*,1] is the wavelength
TSI	c	R2(x,2)	TSI as a function of time. 0] is the data as days from 2000 Jan 01 00:00 UTC
spec_sens	c	R(few)	Power series coefficients for spectral sensitivity
moon_spec	a	R1(x,2)	Reference reflectance spectrum of the Moon.

Table 8: Model output file: Model irradiance. DataGroup M

NAME	C	TYPE	——- Global Attributes ————- Model and Calibration: DataGroup M
ditto	"	"	The standard set listed in Table 3
lunar_model	c	S	Name of the lunar model [and its version].
——	–	—-	———— Variables —————
band_id	c	S(M)	Name normally associated with the band. dup4conv
eff_wave	c	R1(M,x)	Effective wavelength array [band,item]. dup4conv
utcd	c	R1(N)	Observation time, center of the Moon's disk, as days from 2000 Jan 01 00:00 UTC
irr_mod	c	R1(N,M)	Model spectral irradiance; micro-Watt m^{-2} nm^{-1}. If polarized, this is the maximum.
pol_irr	c	R1(N,M,2)	[If polarized] 0] is the orientation of the maximum irradiance, measured anticlockwise from the Sun-from-Moon vector (degenerate at zero phase), degrees. 1] is the fractional polarization.
sun_spec_irr	a	R1(N,M)	Solar spectral irradiance for each observation and each band.
LDER	a	R1(N,M)	Lunar Disk Equivalent Reflectance for each observation and each band.
calib_ratio	a	R1(N,M)	Calibration ratio. Absent if no instrument irradiance data supplied.
modes	w	S[k]	Optional, Names of different modes. See note. dup4conv
nin_mode	w	I1[k]	Number of observations in each mode, aligned with 'modes'. dup4conv

Table 9: Lunar image file contents: DataGroup I

NAME	C	TYPE	——- Global Attributes ————- Disk-equivalent-reflectance: DataGroup I
ditto	"	"	The standard set listed in Table 3
TBD	a	TBD	Any attributes in Ref. 1 associated with imagettes
——	–	—-	————Variables —————
TBD	a	TBD	Any variables in Ref. 1 associated with imagettes

C File Table Notes

The following attributes shall agree between DataGroups: 'platform', 'instrument', 'acronym' and 'serial'.

date Lunar observations are commonly initially labeled in UTC, preferably in ISO 8601 format and this time is used in input files. The GIRO standard for date has been seconds after 1970 Jan 1 00:00, Terrestrial Time, here labeled T7S. For photometric geometry, time is stored as Ephemeris Time in seconds. Time used for display and trends is commonly days from 2000 Jan 01 00:00 and is included in the output file.

Note: 'UNIX time' is discontinuous, it shall not be used.

history Human-readable history of processing, with at least the first 4 below set of 4+ items in order appended for each process. The item identifiers within brackets below should be included.

1) Entry separator, " [=> ". Omitted before the first entry.
2) Date of running the process as yyyymonddThh:mm
3) [pro∼] Process name + '(grave) + version date as yyyymondd
4) [mail∼] Institutional email address of the person who is responsible for this processing. May include additional contact information
5) [src∼] Name of [last] primary input file or other source of data.
6) [url∼] Optional: URL of a document describing this process.
7) [note∼] Optional: Notes: any additional description or comments.

Example: (one continuous string)

```
sliminb‘2023nov06@7 after @11 called 2023nov15u07:33 pro~slim2tr‘2023nov01
mail~HHKieffer@gmail.com src~/work2/slim/src/VIIRS/VIIRS_2023-08-24.Sgeom and
.Sirad [=> 2023nov15u07:36 pro~slim2pg‘2023nov02 mail~HHKieffer@gmail.com
src~/work2/slimnet/S/VIIRS_tr.nc [=> 2023nov19u18:14 pro~slim2uu‘2023nov14
mail~HHKieffer@gmail.com Tag wild points in calibration ratio
```

This growing attribute replaces 6 GIRO individual fields: 'date_created', 'date_modified', 'creator_name', 'creator_email, 'creator_url, and 'history', which could loose the record of prior processing.

'history' should be restarted whenever the Team inputs change.

irr_obs For lunar spectral irradiance, the system should use micro-Watt m^{-2} nm^{-1}, as do ROLO and SLIM; values are on the order of 1.
Values expressed in GIRO units of W m^{-2} μm^{-1} are smaller by a factor of 1000.

modes To accommodate different operational modes. E.g., different gains, space-port versus nadir port, GEO scan mode, ...

oversamp_fa, oversamp_stat Determination of any oversample-factor ('oversamp_fa', OSF) is done by the instrument team. It is commonly the same for all bands, but may be 2-D:[N,M]. 'oversamp_stat' (OSS) records the OSF status: 'none' if there is none. If OSF is applied before reporting 'irr_obs', then OSS should be 'team'; else it should be 'calib' and the OSF will be applied in the calibration stage. The value 'Yang' may occur for historic observations accompanied by the along-scan apparent size of the Moon; these are converted to oversampling factor in the geometry module.

polar_sens, pol_irr These are placeholders for polarization measurements; more terms may be required.

sat_pos If tele_loc absent, shall have N points of Cartesian Earth-Centered Inertial position as specified in §4.2. If tele_loc supplied, these Cartesian positions are optional.

serial Instrument serial number. If not null, shall be inserted in file names for identification.

srf Concatenation of wavelength and system-level Spectral Response Function within each band. Bands shall be in the same order as in 'band_id' and 'nom_wav'.

tele_loc Ground-fixed instrument location in WGS-84: degrees E (longitude) and N (latitude), and altitude in meters. Required if 'sat_pos' not supplied. If 'sat_pos' is also present, user can choose which to use.