Discussion on Implementing a New GSICS Lunar Model

Tom Stone and Hugh Kieffer
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Motivation for Implementing a new GSICS lunar model

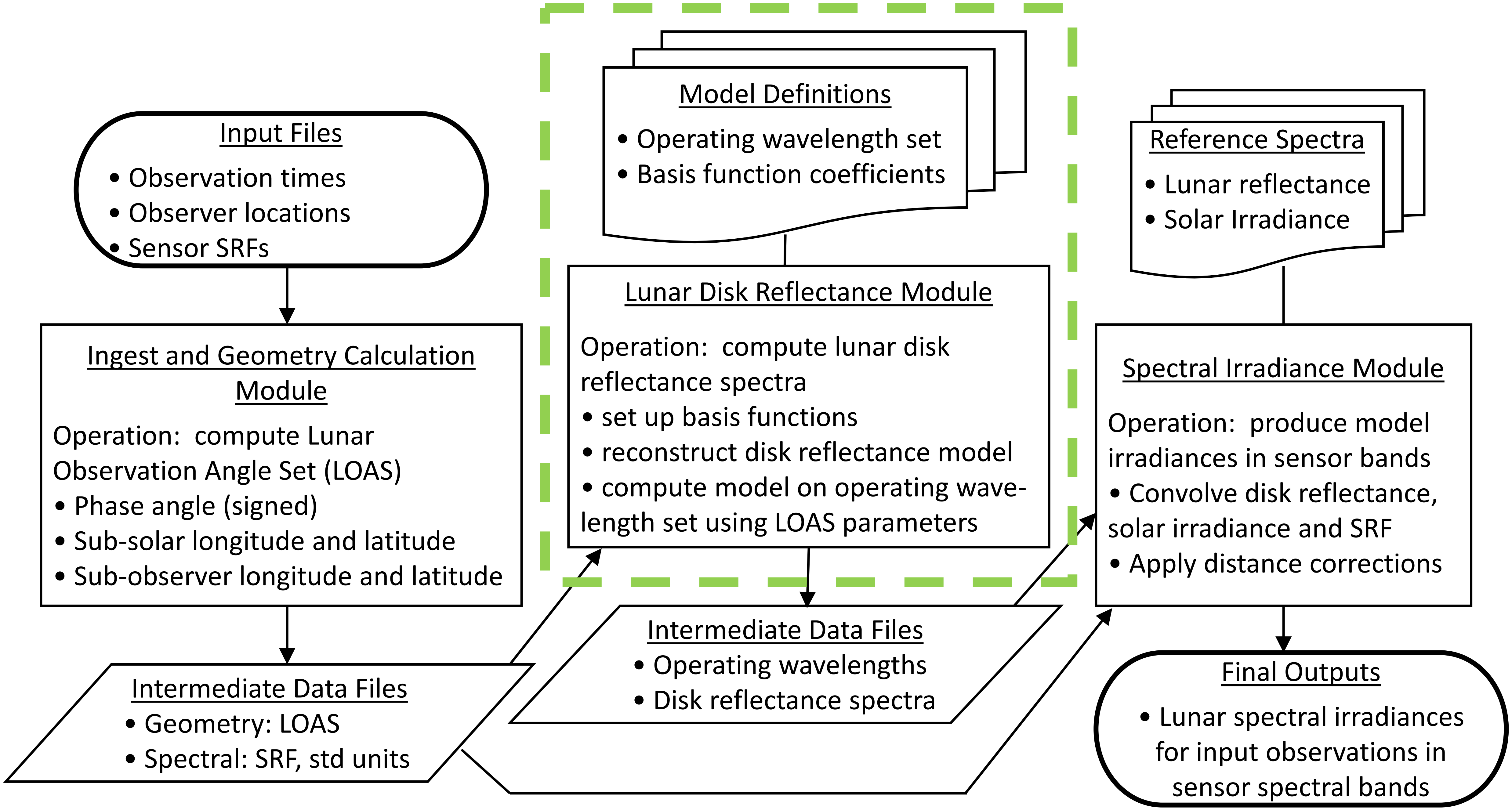
- The current GIRO (GSICS Implementation of ROLO) was written by EUMETSAT in 2014 following the first GSICS/CEOS-IVOS lunar calibration workshop
  - to allow GSICS users access to ROLO model results
  - first release 3Q 2014; many current users
- Since 2014, new measurements of the Moon show limitations in the ROLO/GIRO
  - most notable: 5-8% low bias in model-generated lunar irradiances
- Recently a new lunar irradiance model has been developed by H. Kieffer
  - SLIMED: Spacecraft-based Lunar Irradiance Model
  - to be described by Hugh in the next slides
  - initial lunar calibration results show improved relative and absolute accuracy

To implement SLIMED as the GSICS lunar model, we need to rebuild the software system

from GIRO to ???

Rebuilding the GSICS lunar model software system

- A conceptual framework has been developed for this effort
  - document drafted by T. Stone:
    "Proposed Framework for Implementing a New GSICS Lunar Model"
  - distributed 23 February 2023
  - NOTE: *proposed*
  - **main topic of today's discussion**
- No particular programming language specified
  - a modern language (GIRO was written in C)
  - Python nominally targeted
- Modular programming approach
  - design to be adaptable to use different lunar model kernels
    - the model kernel is lunar disk-equivalent reflectance
    - including the unilluminated portion of the disk, where reflectance ≈ 0
  - interface using only standardized intermediate files
    - file type and format TBD



Input Files
• Observation times
• Observer locations
• Sensor SRFs
Ingest and Geometry Calculation Module
Operation: compute Lunar Observation Angle Set (LOAS)
• Phase angle (signed)
• Sub-solar longitude and latitude
• Sub-observer longitude and latitude
Intermediate Data Files
• Geometry: LOAS
• Spectral: SRF, std units
Model Definitions
• Operating wavelength set
• Basis function coefficients
Lunar Disk Reflectance Module
Operation: compute lunar disk reflectance spectra
• set up basis functions
• reconstruct disk reflectance model
• compute model on operating wave-length set using LOAS parameters
Intermediate Data Files
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• Disk reflectance spectra
Reference Spectra
• Lunar reflectance
• Solar Irradiance
Spectral Irradiance Module
Operation: produce model irradiances in sensor bands
• Convolve disk reflectance, solar irradiance and SRF
• Apply distance corrections
Final Outputs
• Lunar spectral irradiances for input observations in sensor spectral bands

Plan to make SLIMED Lunar Irradiance calibration widely accessible

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SLIMED: A follow-on to ROLO model, is published:
Multiple-instrument-based spectral irradiance of the Moon.
Jour. Applied Remote Sensing. Vol. 16, Issue 3
https://doi.org/10.1117/1.JRS.16.038502   Open Access

- Developed in IDL, requires a license. Need to convert to a public language.
- e.g., Python or some version of C. IDLrecoded so that all files are now NetCDF,
- Development required the use of effective wavelength. Application need not.
- Model is defined by combinations of photometric angles and wavelength.
  Any revised model using the same scheme can use the same code!
- SLIMED model can be implemented in the 'Framework' concept.
- There is an algorithm description document: Algo.pdf

Design principles & goals

- The instrument information needed to do lunar calibration has ***different permanence***.
- Spectral: **S** Band spectral response; commonly stable over the life of a mission.
- Geometry: **G** (time and location) Usually static soon after each observation.
- Irradiance: **E** May be computed multiple times as image processing procedures improve or DN⇒radiance coefficients change.
-
- Allow calibration to be run at any institution.
- Minimize the instrument team effort required.
- Accommodate observatories and aircraft, as well as spacecraft
- Keep file sizes small enough for email transfer between institutions.
- Optionally allow separation of information based on its permanence.
- -------------------- The Task: after agreement on file content ---------------------------
- Build **Ingest** as a GIRO-to-SLIM instrument data converter. Should work for all teams.
- Build the ~3 processing modules.

How & Why SLIMED model works

- Derived using ”Data”: lunar irradiance measured by bands of 12 instruments, 90,000 points.

  Each input point (time,band) has its own geometry and effective wavelength.
- Lunar model fit is a multiplier of λ/1000 resolution reference “Moonlight”

  “Moonlight” = reference Solar spectral irradiance x Moon nominal albedo spectrum

  Avoids having to fit complex spectra. 'Wave” = *w* = ln wavelenght in μm is a Basis Function
- “MapLib” is a libration model based on mapping by lunar orbiters at VIS/NIR bands.

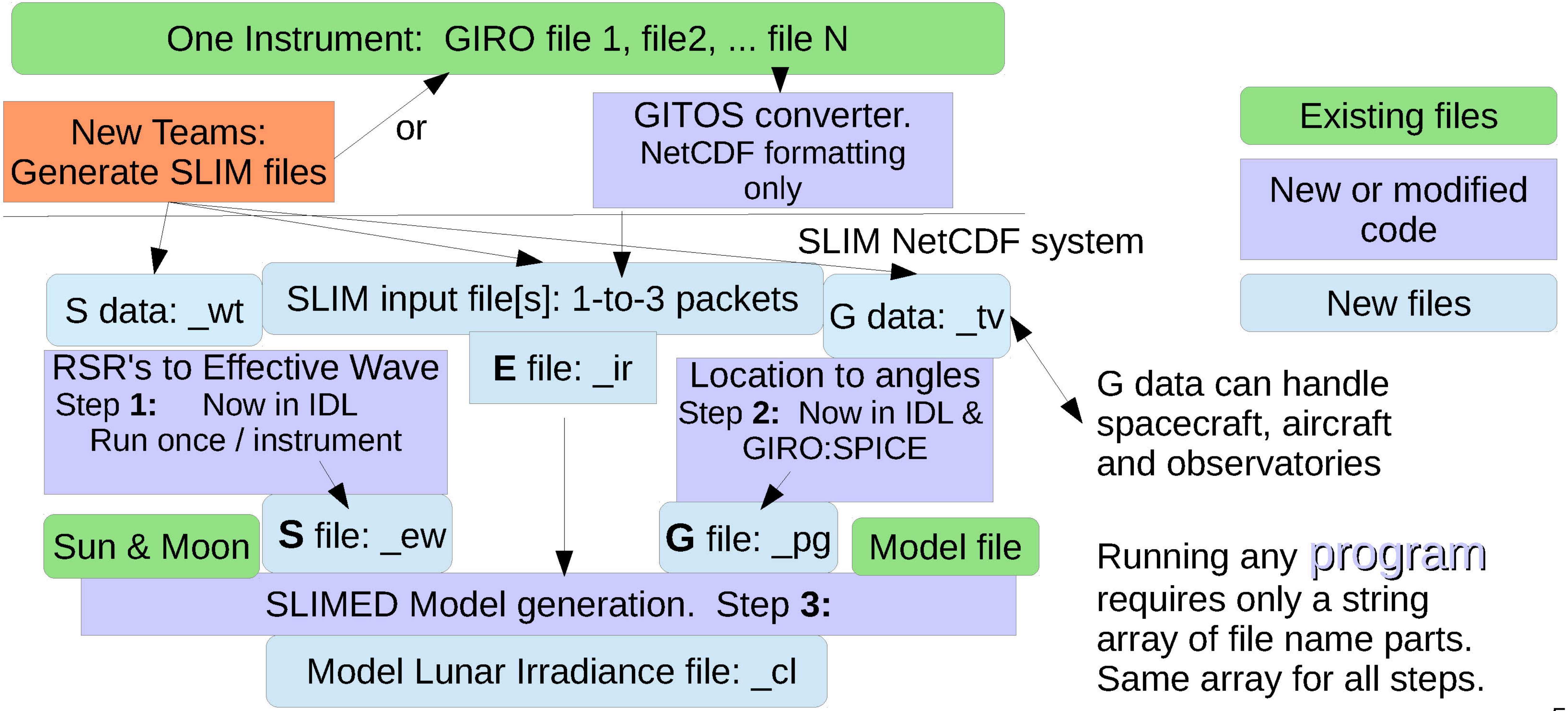
  This reduces the task of the “Fit” conceptually to: Data / (Moonlight x MapLib)
- A “gain factor” for each instrument band is derived during Fit. This is NOT in final model.
- Model is: Moonlight × [MapLib(24 terms) × Fit (34 terms)] .

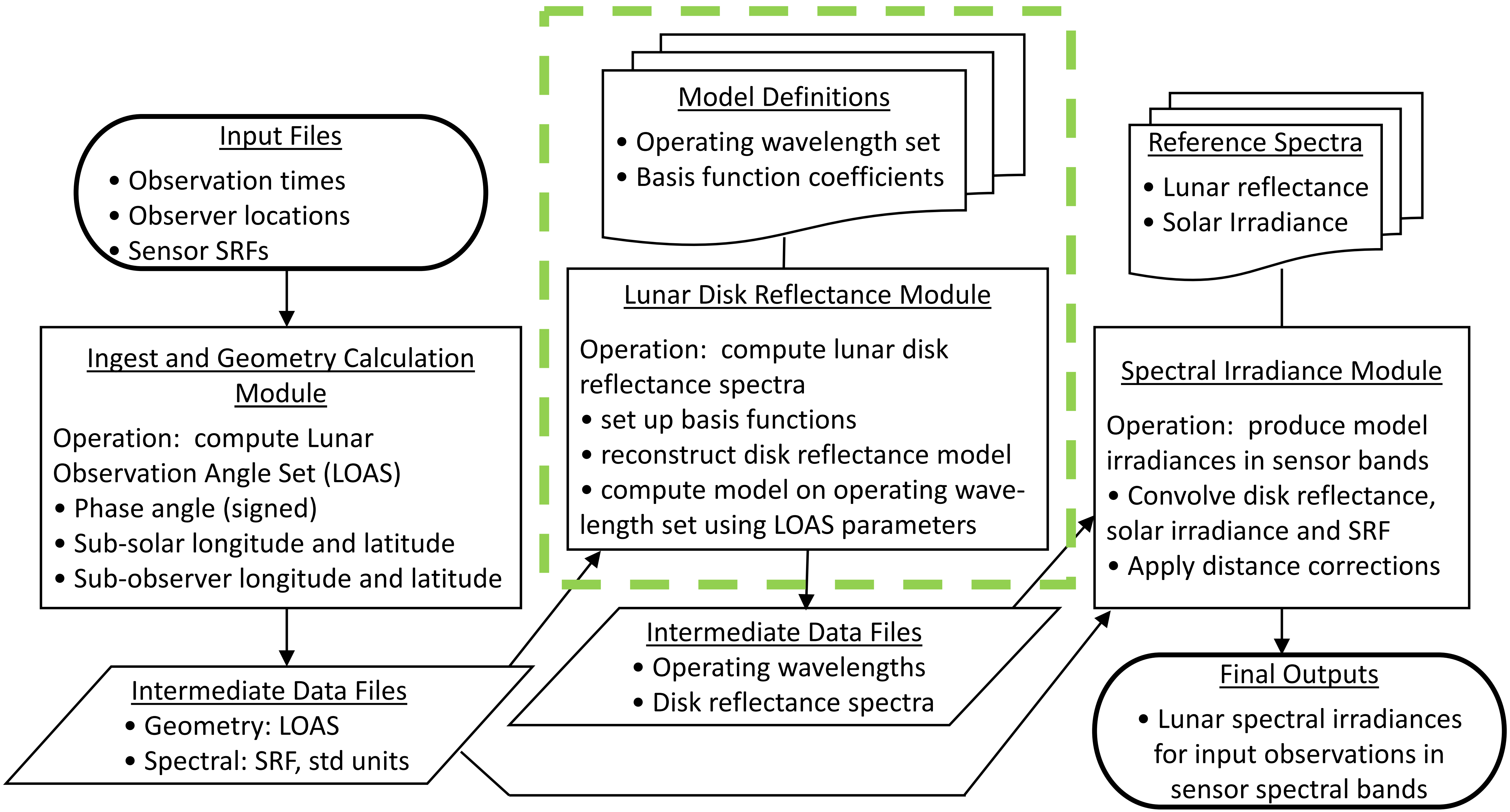
  Terms are products of photometric angles and 'wave”, to various powers.
- Model output can be at any set of wavelengths; normally an Instruments effective wavelengths.

Current structure

- All files are NetCDF, with a lot of identification. **Processing modules used are:**
- **Ingest:** put instrument data into standard format
- **Spectral:** Band RSR's ⇒ resample onto fixed wavelength grid
- Compute effective λ and average in-band spectral irradiance for nominal Moonlight
- **Geometry**: Time and Viewer location ⇒ Lunar Observation Angle Set (LOAS)
- p,h,z,x,y, & DistFac. Must access ephemeris: Direct calls or SPICE/Horizons
- **Calibration**: LOAS, also: g=abs(p), q=1/g, w=wave(any of 3 forms)
- Evaluate lunar orbiter mapping Libration model, 'MapLib', then evaluate the Fit
- Convert terms, e.g. 'g2xw', to basis functions. Multiply by coefficients, then sum.
- Generate model irradiance. Adjust instrument observation for Std distance and oversample
- Ratio of adjusted observation to model is the calibration factor.

Flow: SLIMED in NetCDF





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Discussion

- The need for an improved lunar model
  - to have better comparisons to sensor measurements
- Usability of the GSICS lunar calibration system
  - re-use GIRO input files
- Distribution of the effort
  - different modules built by different agencies?

NOTE: the framework document is intended to be dynamic, i.e. to be modified with input from the community.

Backup Slides

Outlines taken from the framework document

Ingest and Geometry Calculation Module

Operations:

- Read input files for observations and sensor spectral response
  - could be existing GIRO input files
- Generate the Lunar Observation Angle Set (LOAS) used by the model kernel:

Lunar Observation Angle Set (LOAS)
• signed phase angle • sub-solar selenographic longitude • sub-solar selenographic latitude • sub-observer selenographic longitude • sub-observer selenographic latitude

Output:

- intermediate interface files for use by downstream modules
  - observation data file
  - sensor spectral response file
  - file type(s) and format(s) not specified
- standard units and reference frames, TBD
- no other processing, e.g. interpolation

Disk Reflectance Module

Sole function: generate lunar disk reflectance spectra for observations

- On a self-defined operating wavelength set

Operations:

- Establish operating wavelength set
- Input model definition parameters from external data files
- Set up basis functions
- Reconstruct the complete disk reflectance model
- Compute the model for input LOAS for each observation

Output:

- interface file(s) for use by the Spectral Irradiance module
  - operating wavelength set
  - disk reflectance spectra for observations

Spectral Irradiance Module

Function: convert model disk reflectance to spectral irradiance in sensor bands:

$$E_{\mathrm{Moon}} = \frac{\Omega_{\mathrm{Moon}}}{\pi} \; R_{\mathrm{disk}} \; E_{\mathrm{Sun}}$$

Operation:

- Convolution of disk reflectance spectrum, solar spectrum and sensor SRF
  - discrete numerical operation requires all three on the same wavelength set:

$$E_{\mathrm{Moon,band}} = \frac{\Omega_{\mathrm{Moon}}}{\pi} \; \frac{\sum_j R_{j,\mathrm{disk}} \; E_{j,\mathrm{Sun}} \; S_{j,\mathrm{band}}}{\sum_j S_{j,\mathrm{band}}}$$

- Apply distance corrections to actual observation location
  - Sun-Moon and Moon-observer distances

Output:

- Spectral irradiance for each sensor band for each input observation