Working with M^3 Data

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M^3 Data Tutorial at AGU

December 13, 2010

For Reference

- Slides and example data from today's workshop available at http://m3dataquest.jpl.nasa.gov
- See Green et al. (2010) and Boardman et al. (2010) for complete descriptions of topics discussed here

Topics to be discussed

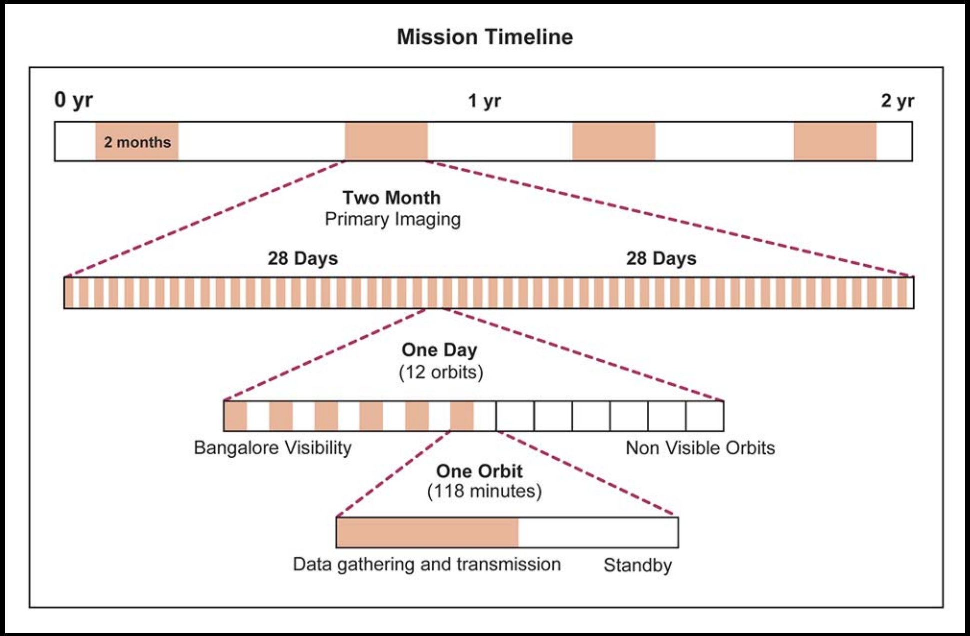
- M3 observation history
- Instrument design
- Data set description
- Calibration pipeline
- Walkthrough of calculating I/F with M3 L1B data in ENVI

slides online at http://m3dataquest.jpl.nasa.gov

M3 Mission History

Planned vs. Actual Flight

- Planned observation time was 4 two-month optical periods defined by equatorial solar zenith of 0-30°



- One month was to be contiguous low-resolution (Global Mode) overview; the remainder was to be used for the optimal high-resolution resolution data (Target Mode).

Planned vs. Actual Flight

- Thermal issues plagued the spacecraft as soon as it arrived at the Moon on November 8, 2008
- Lost the 1st of 2 star trackers before a single image was taken
- Extended commissioning phase was required, lasting into Jan 2009

Planned Vs. Actual Flight

- The ISRO Chandrayaan-1 Mission Operations team did a fantastic job redesigning the mission in real time throughout the mission lifetime
- Despite all the challenges, M3 was able to meet minimum mission requirements thanks to heroic efforts on the part of Ch-1 and M3 team members
- LOLA topography data was essential for orthorectification

Planned vs. Actual Flight

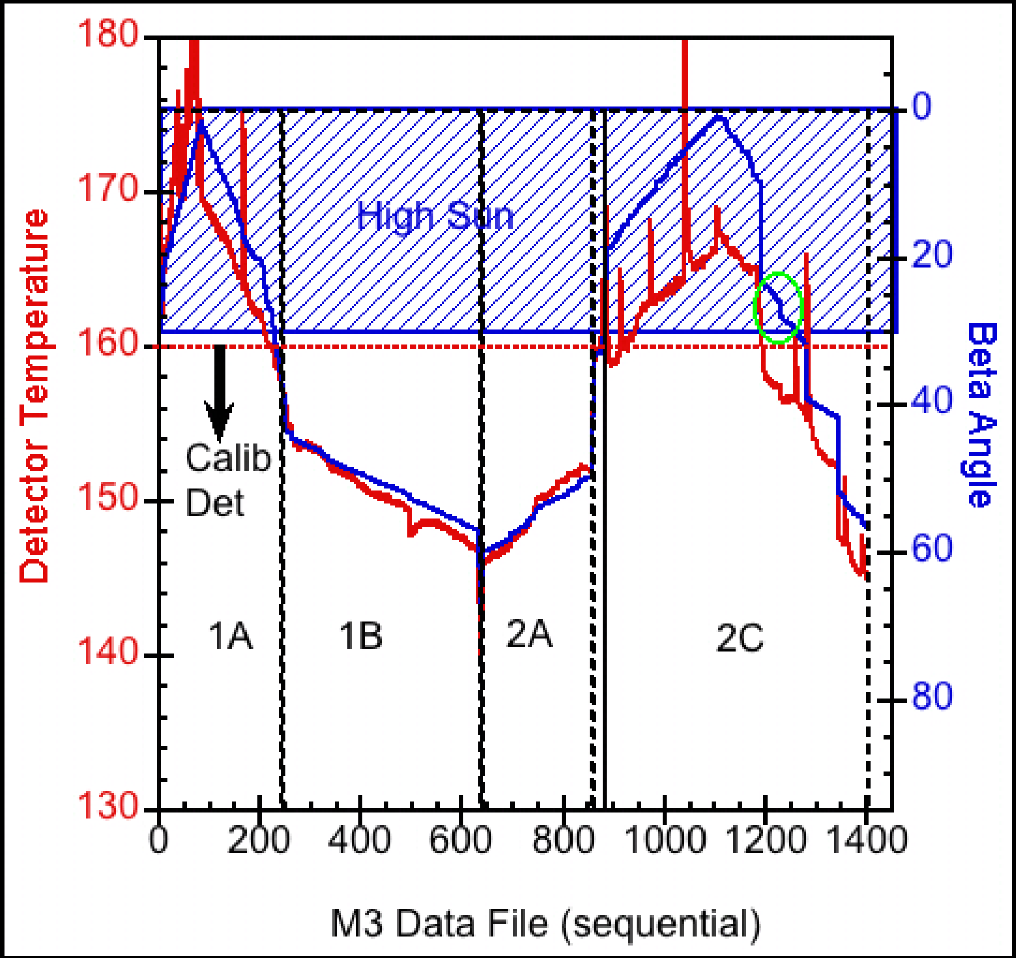
- Impact on data:
  - Instrument was operated at less favorable viewing conditions, resulting in lower reflected surface signal, increased effects of shadows and highly variable thermal environment
  - The spacecraft acquired data intermittently during two optical periods
    - Almost all M3 data were acquired in reduced resolution (Global) mode; very few optimal resolution (Target) mode data acquired
    - Most of 2nd optical period taken at higher orbit (200km vs 100km) and with no star tracker

M3 Optical Periods

- M3 observed data during two optical periods
- The team subdivided the optical periods based on data characteristics:

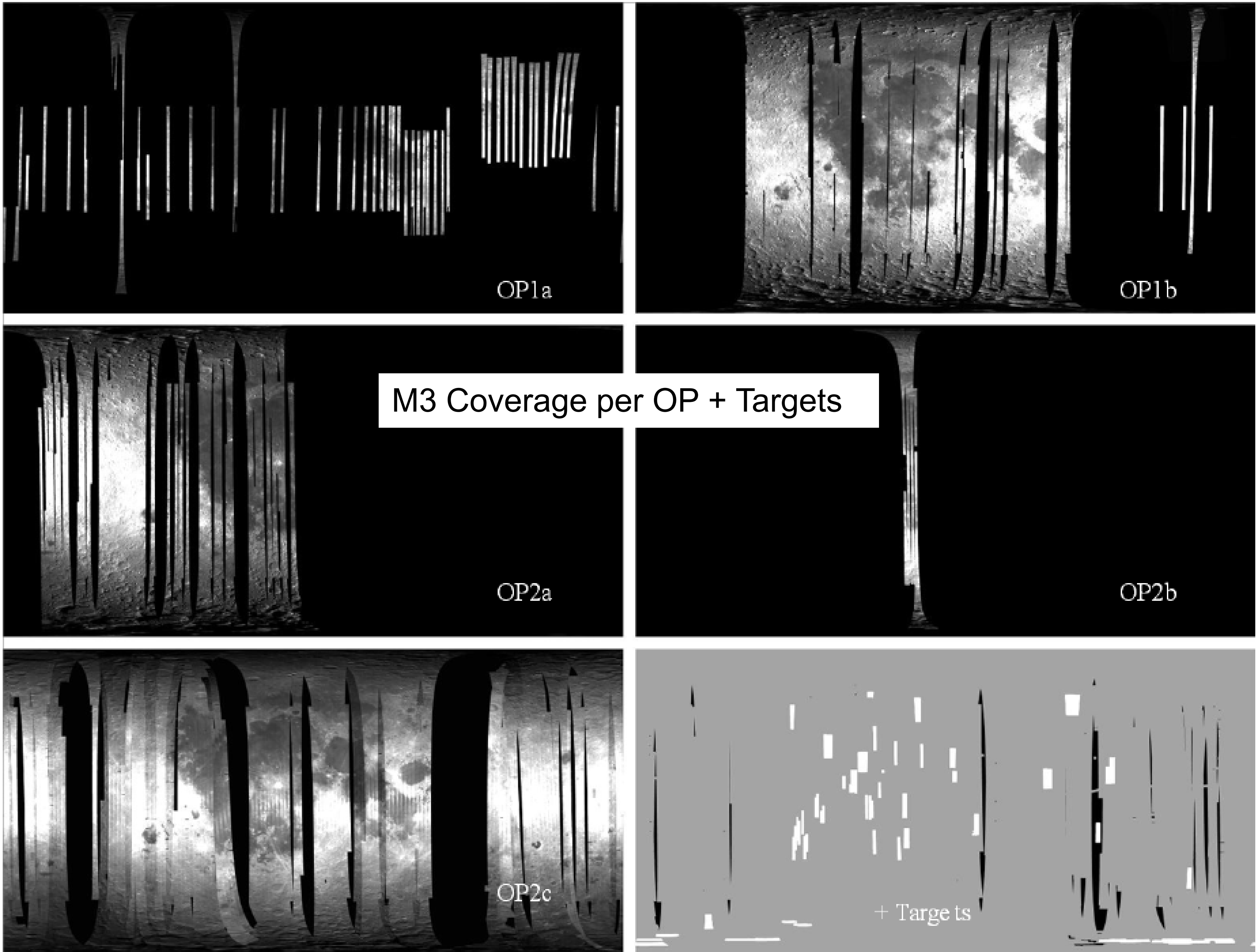
Period	Dates	Image Strips	Orbit	Star Sensors	Status
OP1A	Nov 18 - Jan 24	119	100 km	1 of 2	extended commissioning
OP1B	Jan 25 - Feb 14	247	100 km	1 of 2	operational, high solar zenith angles
OP2A	Apr 15 - Apr 27	197	100 km	1 of 2	operational, high solar zenith angles
OP2B	May 13 - May 16	20	200 km	0 of 2	S/C emergency, orbit raised
OP2C	May 20 - Aug 16	375	200 km	0 of 2	operational, variable conditions

M3 Environment During Data Acquisition



- Optimal low detector temperature acquistions occurred during highest beta angles (angle between orbit plane and sun direction) and lowest signal

M3 Coverage per OP + Targets

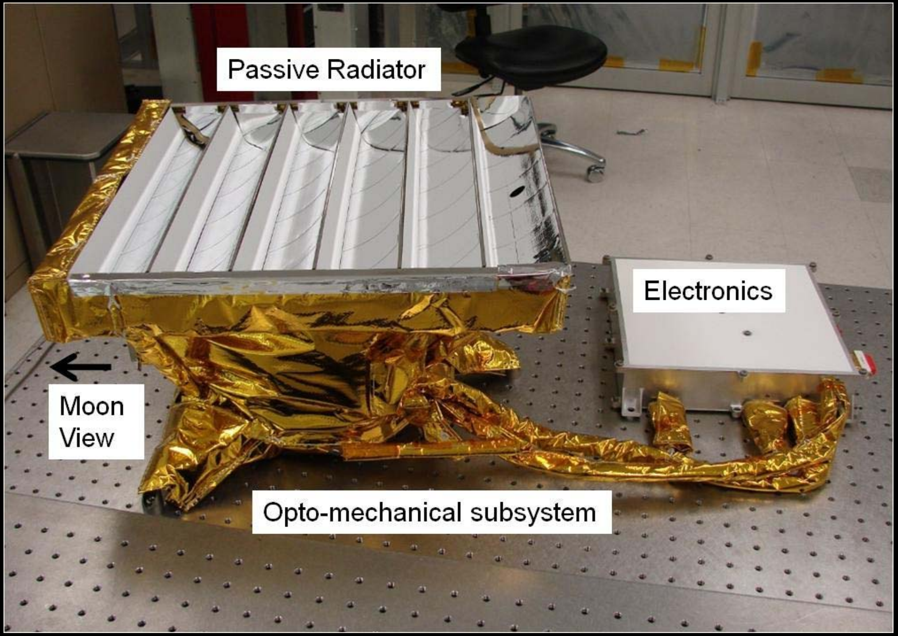


PDS Delivery Schedule

- Level 0 and Level 1B:
  - OP1: June 2010
  - OP2: December 31, 2010
- Level 2:
  - OP1 and OP2: June 2011 still in progress

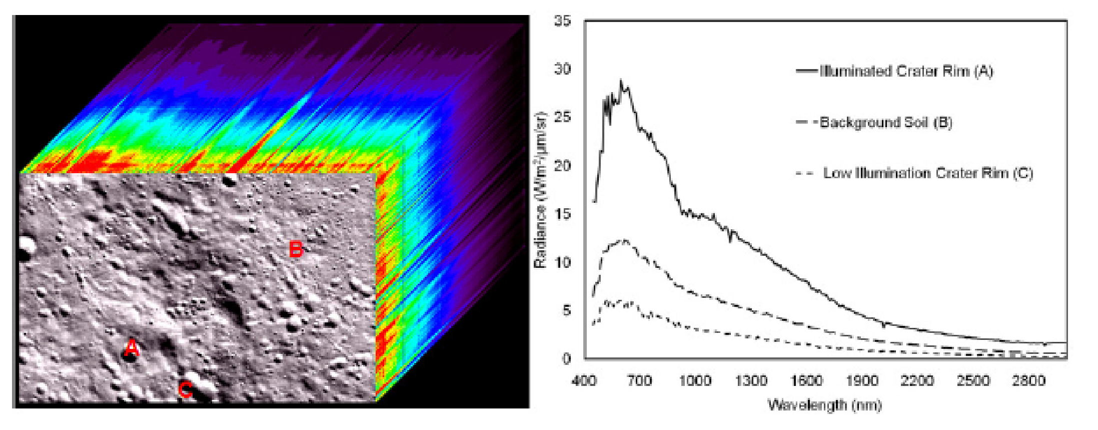
L0 = raw spacecraft data, L1B=radiance + backplanes, L2 = reflectance

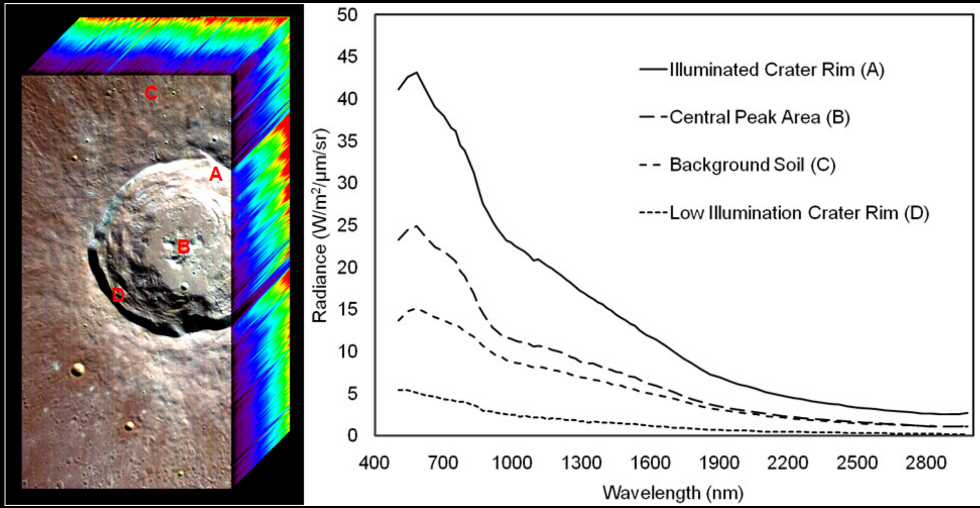
M3 Instrument



Operational Modes

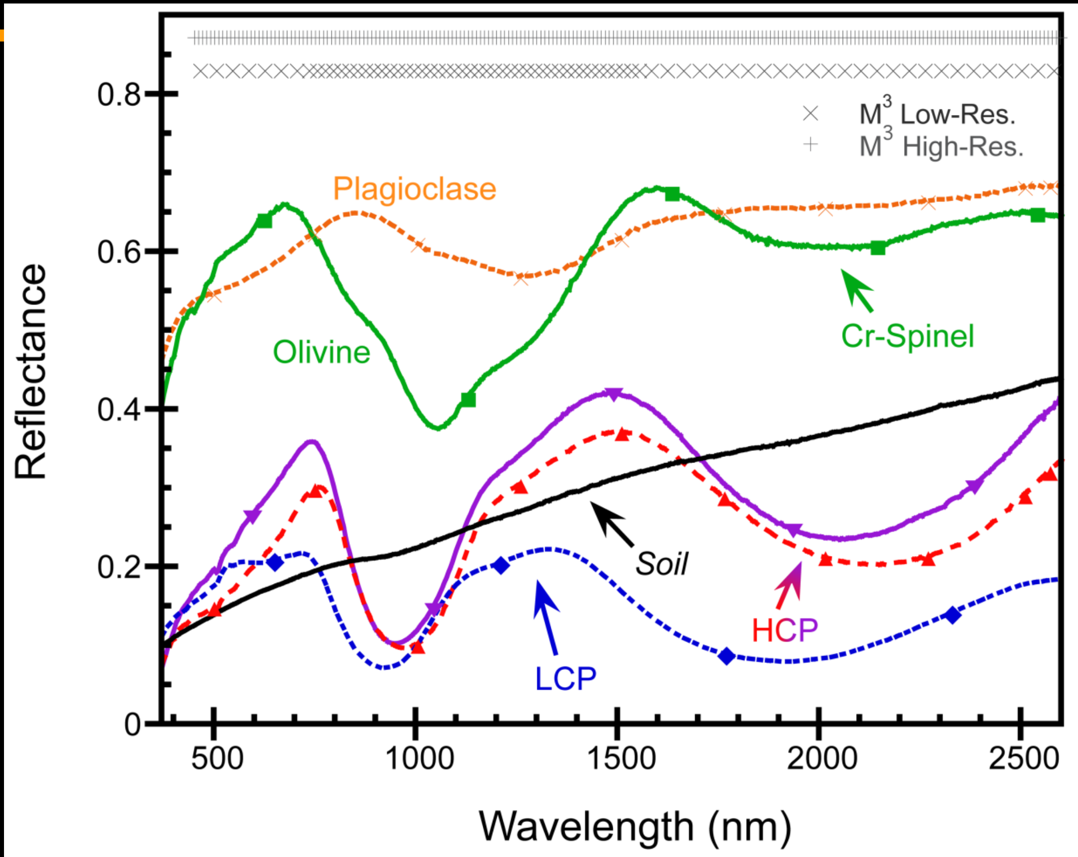
- Target (Optimal Resolution)
  - High spatial/spectral resolution mode
  - Only a few target observations were actually acquired
- Global
  - M3 Instrument acquires full resolution data then onboard software averages data to produce reduced resolution data
  - Lower resolution mode for mapping the entire Moon
  - Almost all M3 data were acquired in Global mode





Spatial and Spectral Resolution

- Spectral Coverage:
  - Target: 446-3000 nm
- Spectral Resolution:
  - Target: 10nm
  - Global: 20 or 40 nm
- Spatial Resolution:
  - Target: 70 m/pixel
  - Global: 140 m/pixel
  - from 200 km orbit spatial sampling remains 140 m/pixel, but cross-track is ~280m/pixel



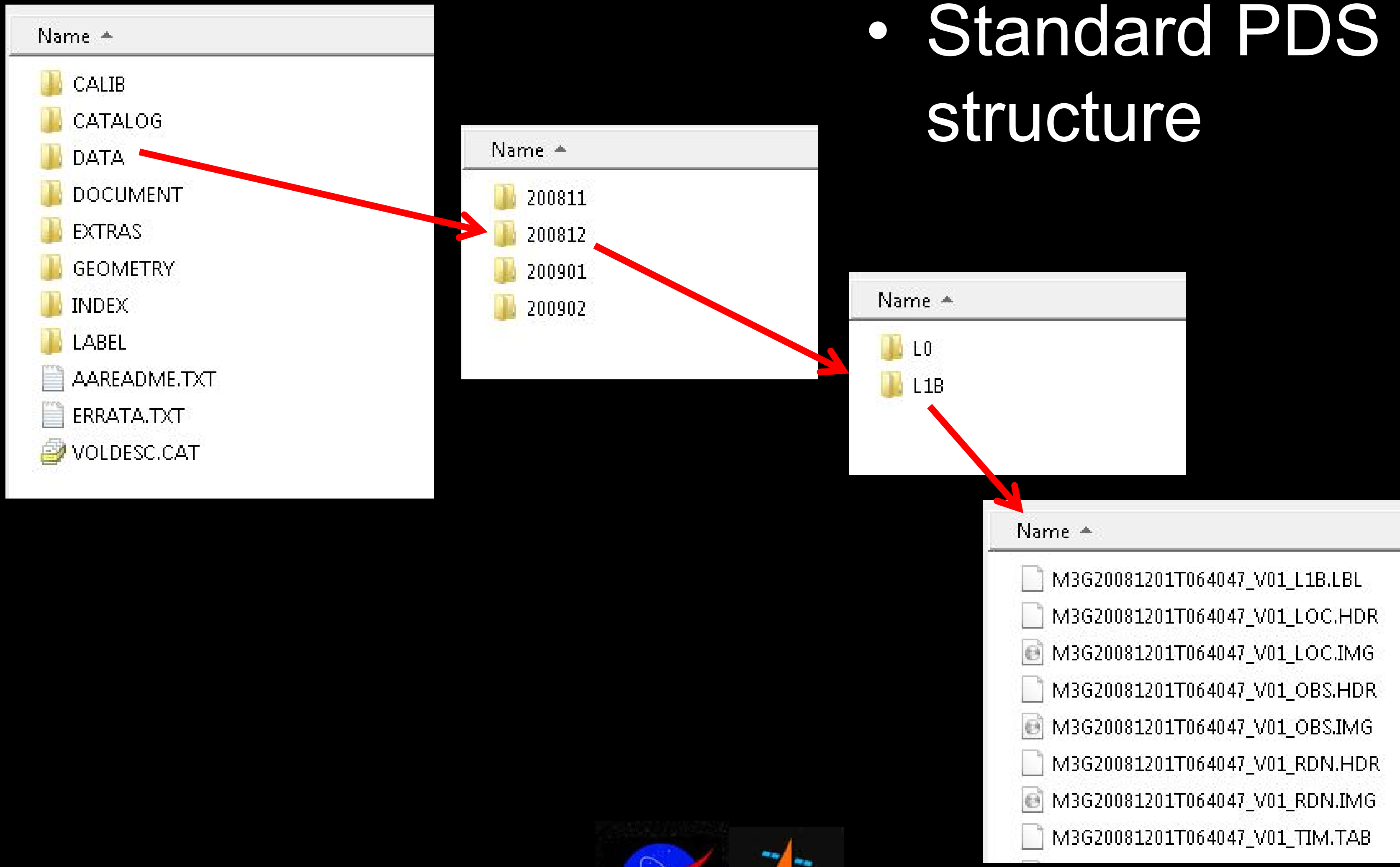
Instrument Design

- Pushbroom spectrometer
  - Each detector readout is 1 line of an image cube. The entire image is built as M3 moves along the ground track.
- High Spectral/Spatial Uniformity
  - Greater than 90% spectral crosstrack and spectral IFOV uniformity

M3 File Formats/PDS Structure

PDS Directory Structure

- Standard PDS structure



M3 File Naming Convention

$$\underbrace{\text{M3G20090204T113444}}_{\text{Basename}}\_\underbrace{\text{V01}}_{\text{Version}}\_\underbrace{\text{RDN}}_{\text{Data Type}}.\underbrace{\text{IMG}}_{\text{File Type}}$$

- Basename – covered next slide
- Version –always "V01" in June 2010 L1B PDS delivery
- Data type – tells you the type of information stored in the file
  - Possible values in L1B delivery:
    - L0 – raw spacecraft data
    - RDN – radiance
    - OBS – observational data (incidence, emission, phase angles, etc.)
    - LOC – location data (latitude, longitude, radius)
    - TIM – time of observation
    - L0, L1B – PDS label type
- File Type – tells you the file format
  - Possible Values in L1B delivery:
    - IMG – raw binary image data
    - HDR – ENVI header
    - LBL – PDS label
    - TAB – tabular data stored in ASCII format

M3 File Naming Convention (cont’d)

Example Basename: M3G20090204T113444

M3 G 2009 02 04 T 11 34 44

Always “M3”

Year Month Day Hour

Seconds

Always “T” Minutes

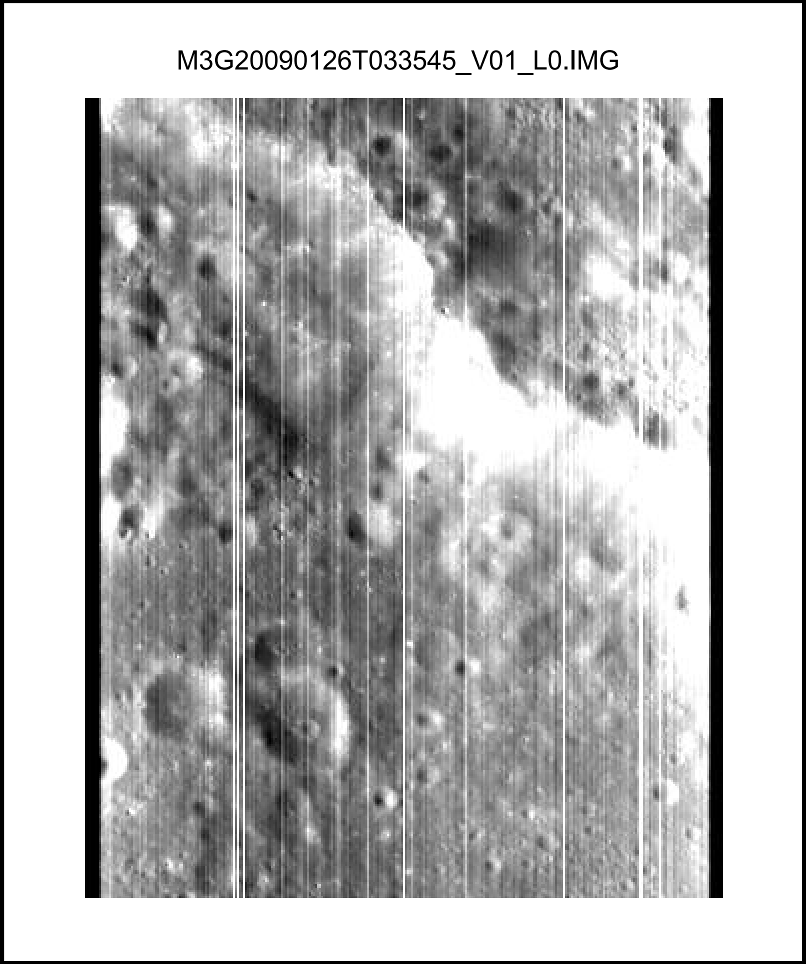
Observation mode: G=Global, T=Target

Note: Sorting by filename is only equivalent to sorting by observation time if you do not have global and target data mixed together. If you do have a mix of the two, remove the first three characters then sort by filename to also sort by observation time.

M3 image data format

- The following applies to all M3 image data:
- Files are raw binary data (no offset)
- Interleave is BIL (line-interleaved)
- Global data have 304 samples (columns) for all image types (except L0, which has 320)
- Target data have 608 samples (L0 has 640)
- Number of lines (rows) is variable (determined by length of observation)
- Data type is 32-bit floating point (LOC files are 64-bit double precision floating point)
- “Backplanes” = OBS, LOC, and TIM files

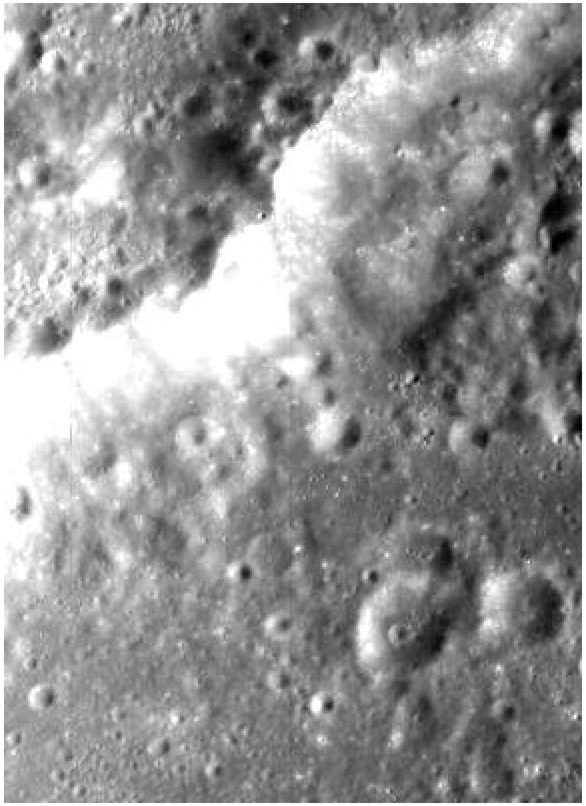
M3 Data types: L0



- L0 is raw spacecraft data, units are DN
- 320 samples which are reduced to 304 when converted to radiance (in Global mode, Target mode is 640/608)
  - The 16 columns that are removed are for monitoring dark signal level and scattered light
- Each frame has a 1280-byte header
- To directly compare L0 to radiance:
  - No sample or line flip starting Nov 16 2008
  - Sample only flip starting Dec 18 2008
  - Line only flip starting Mar 14 2009
  - Sample and line flip starting Jun 18 2009

M3 Data Types: L1B RDN

M3G20090126T033545_V01_RDN.IMG



- Radiance data, units W/(m^2 Sr μm)
- Steps used to create radiance described in calibration slides
- PDS label or ENVI header can be used to open
- ENVI header contains:
  - Calibration steps
  - Target wavelengths
  - Target FWHM
  - Dark Signal Image
  - Anomalous Detector Map
  - Flat Field Image
  - Detector Temperature
  - Beta Angle
  - Sample/Line flip code

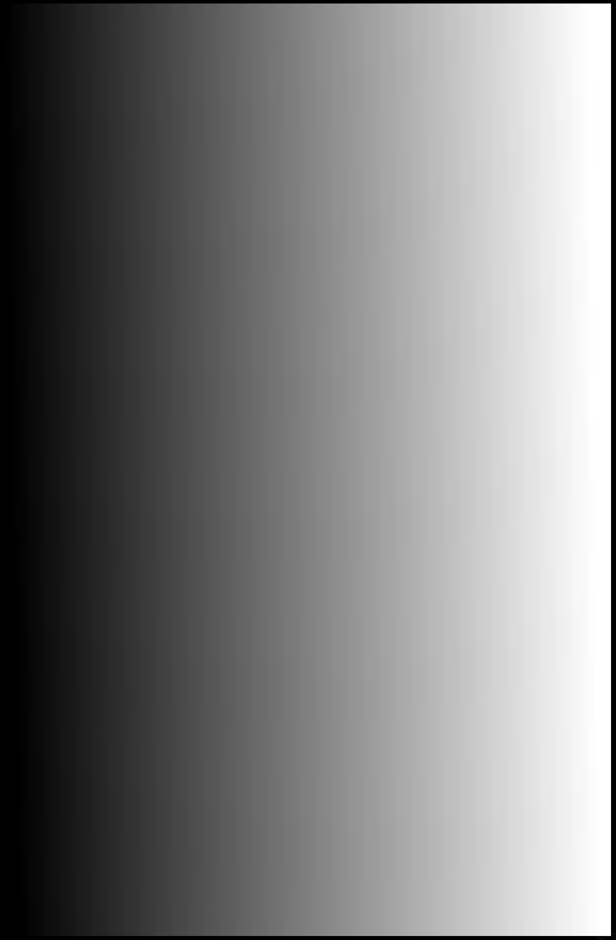
M3 Data Types: OBS

- List of bands in OBS file:
  - To-Sun Azimuth (deg)
  - To-Sun Zenith (deg)
  - To-M3 Azimuth (deg)
  - To-M3 Zenith (deg)
  - Phase (deg)
  - To-Sun Path Length (au-0.981919816030)
  - To-M3 Path Length (m)
  - Facet Slope (deg)
  - Facet Aspect (deg)
  - Facet Cos(i) (unitless)
- Values in the To-Sun Path Length band are the difference from the scene mean path length.

Scene-mean to-Sun path length (Different for each scene)

M3 Data Types: OBS

Phase band



Facet cos(i) band

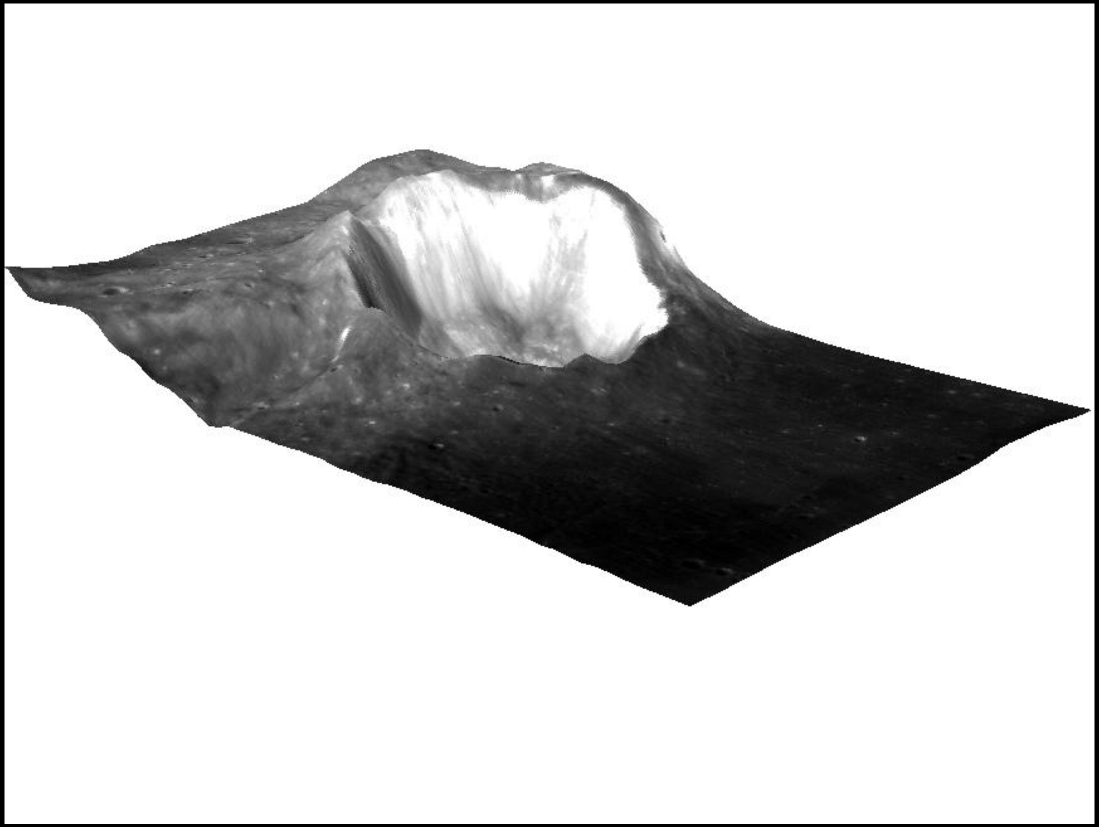
M3 Data Types: LOC

- List of channels in LOC file:
  - Longitude (Degrees East 0-360)
  - Latitude
  - Radius
- Subtract lunar radius of 1737.4 km to get difference in elevation from reference sphere
- Based on LOLA topography (Boardman, 2010)
- Reference frame is Moon Mean Earth Polar Axes (MOON_ME) frame

M3 Data Types: LOC

Band 3 “Radius”

750nm albedo draped over Radius band



M3 Data Types: TIM

One ASCII text record per frame:

Column 1: Frame Number

Column 2: UTC Time

Column 3: Year

Column 4: Decimal Day of Year

M3G20081118T222604_V01_TIM.TAB (Z:\m3team\DATA\RRAD\DATA\20081118_20090214\200811\L1B\)

File Edit Insert Format Settings Tools Window Help

1	2008-11-18T22:26:03.491014	2008	322.934762614844
2	2008-11-18T22:26:03.592772	2008	322.934763792605
3	2008-11-18T22:26:03.694531	2008	322.934764970366
4	2008-11-18T22:26:03.796289	2008	322.934766148128
5	2008-11-18T22:26:03.898048	2008	322.934767325889
6	2008-11-18T22:26:03.999806	2008	322.934768503650
7	2008-11-18T22:26:04.101565	2008	322.934769681411
8	2008-11-18T22:26:04.203324	2008	322.934770859173
9	2008-11-18T22:26:04.305082	2008	322.934772036933
10	2008-11-18T22:26:04.406841	2008	322.934773214695
11	2008-11-18T22:26:04.508599	2008	322.934774392456
12	2008-11-18T22:26:04.610358	2008	322.934775570217
13	2008-11-18T22:26:04.712116	2008	322.934776747979
14	2008-11-18T22:26:04.813875	2008	322.934777925740
15	2008-11-18T22:26:04.915634	2008	322.934779103501
16	2008-11-18T22:26:05.017392	2008	322.934780281262
17	2008-11-18T22:26:05.119151	2008	322.934781459024
18	2008-11-18T22:26:05.220909	2008	322.934782636785
19	2008-11-18T22:26:05.322668	2008	322.934783814546
20	2008-11-18T22:26:05.424426	2008	322.934784992307
21	2008-11-18T22:26:05.526185	2008	322.934786170069
22	2008-11-18T22:26:05.627944	2008	322.934787347830
23	2008-11-18T22:26:05.729702	2008	322.934788525591
24	2008-11-18T22:26:05.831461	2008	322.934789703352
25	2008-11-18T22:26:05.933219	2008	322.934790881114
26	2008-11-18T22:26:06.034978	2008	322.934792058875
27	2008-11-18T22:26:06.136736	2008	322.934793236636

- In OP2 the S/C is ascending and the time listing is reversed

Good Stuff in the PDS Directories

- CALIB
  - Record of detector temperatures, band pass functions, spectral calib. file (wavelength center positions), radiometric calibration coefficients
- DOCUMENT
  - Data Product SIS document that describes all files released to PDS down to the byte level, Archive Volume SIS describes PDS directory structure
- EXTRAS
  - Flat fields, anomalous detector element maps, quicklooks

Calibration

Current steps in radiance calibration (Version R)

- Raw image;
- Dark signal subtraction;
- Anomalous detector element interpolation;
- Interpolate filter edges c13, c50;
- Interpolate detector panel edges s81, s161, s241;
- Electronic panel ghost correction;
- Dark pedestal shift correction;
- Scattered light correction;
- Laboratory flat field;
- Image based flat field w/ photometry preserved;
- Apply radiometric calibration coefficients;
- Units (W/m^2/um/sr)

See Green et al (2010) for detailed description

Basic calibration equation

$$L_{l,s,\lambda} = RCC_{\lambda}(C_{s,\lambda}(DN_{l,s,\lambda} - \overline{DS_{s,\lambda}}))$$

- L = calibrated radiance
- RCC = Radiometric calibration coefficients
- C = term encompassing all correction factors (flat fields,etc.)
- DN = raw digital number
- DS = dark signal

Initial Steps of (ongoing) Level 2 Preparation

Converting Radiance to Reflectance

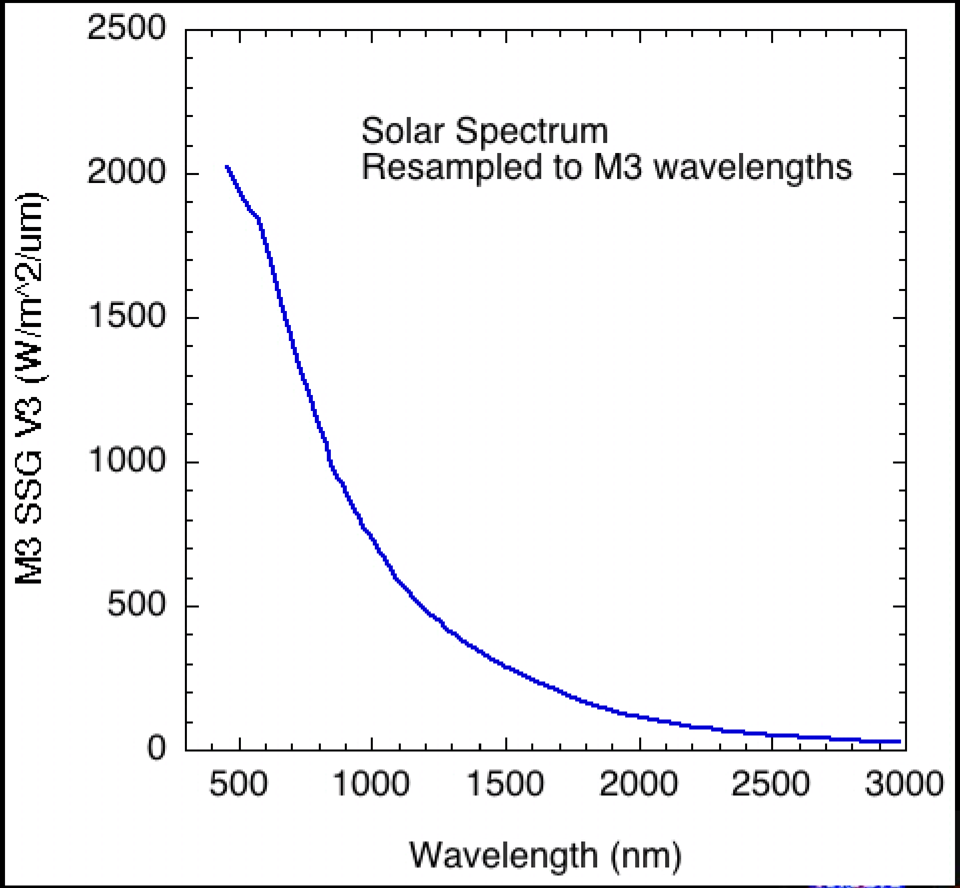
- Official M3 L2 Product is still under development
- Until that is available, team use an intermediate product called *I/F*

$$\frac{I}{F} = \frac{L\pi d^2}{F}$$

- Where:
  - L = measured radiance in $W/m^2/Sr/\mu m$
  - F = solar flux (solar spectrum) in $W/m^2/\mu m$
  - d = Moon-Sun distance in AU

Download M3 Solar Spectrum

http://m3.jpl.nasa.gov/docs/solar_spec_global85.txt



- MODTRAN-based
  (See Green et al, 2010)
- Global resolution version can be downloaded in ASCII format from the above link

Download M3 Solar Spectrum

http://m3.jpl.nasa...spec_global85.

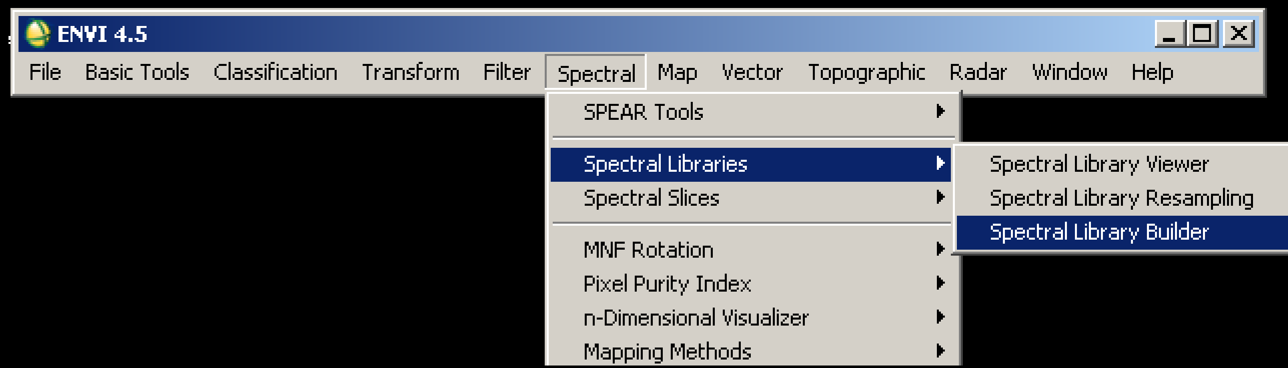
```
ENVI ASCII Plot File [Mon Nov 22 17:44:36 2010]
Column 1: Wavelength(nm)
Column 2: M3 SSG V3 (W/m^2/um)~~1
   460.989990  2022.662109
   500.920013  1934.504639
   540.840027  1875.621826
   580.765015  1833.137451
   620.689941  1689.644409
   660.609985  1550.267334
   700.537537  1428.238281
   730.479980  1324.721680
   750.440002  1271.074707
   770.400024  1216.917114
   790.364990  1162.946045
   810.330017  1107.837036
   830.290039  1053.718018
   850.250000   985.262878
   870.209961   946.577942
   890.174988   920.729126
   910.140015   879.042053
```

- File is tab-delimited ASCII text
- 3 lines of header information to be skipped when importing

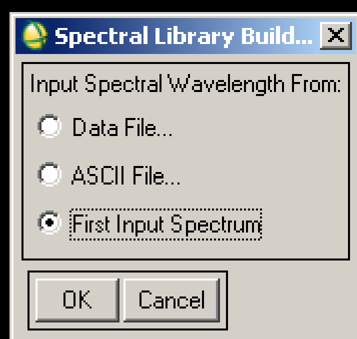
Example conversion of radiance to I/F in ENVI

Step 1: Import M3 Spectral Library

- Step 1:



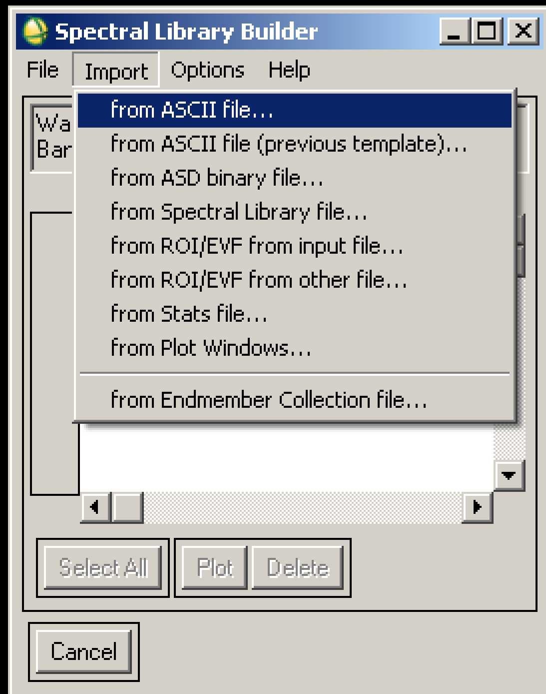
- Step 2:



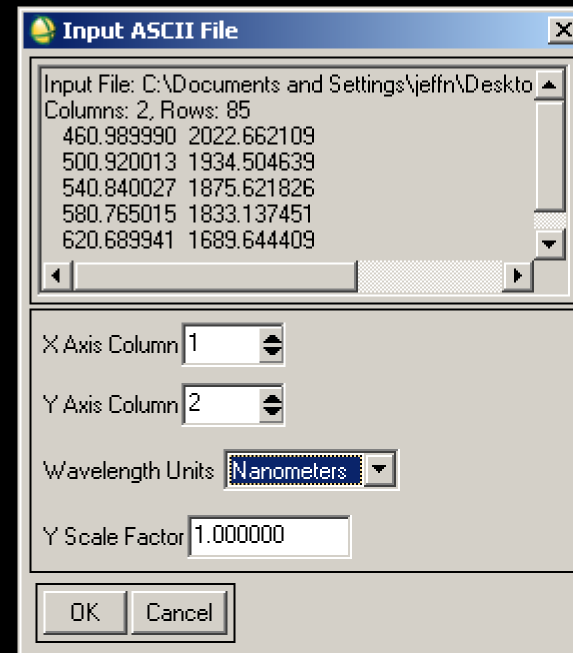
(Can also choose “ASCII File….” here but that has more steps)

Step 1: Import M3 Spectral Library

Step 3:

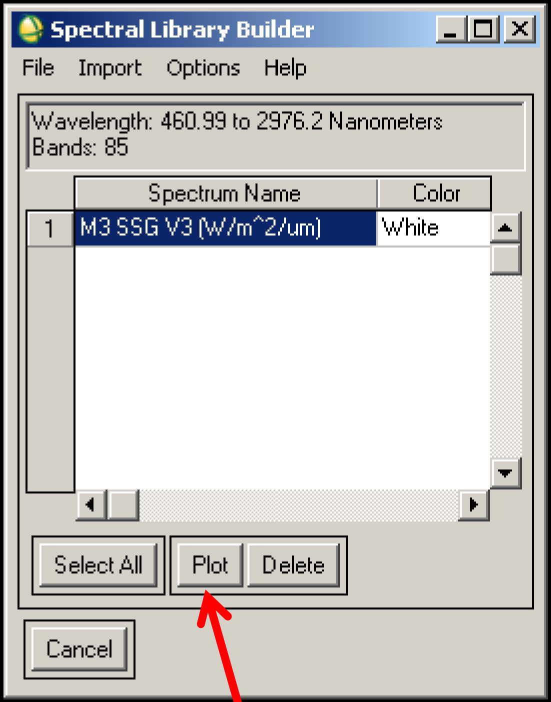


Step 4:



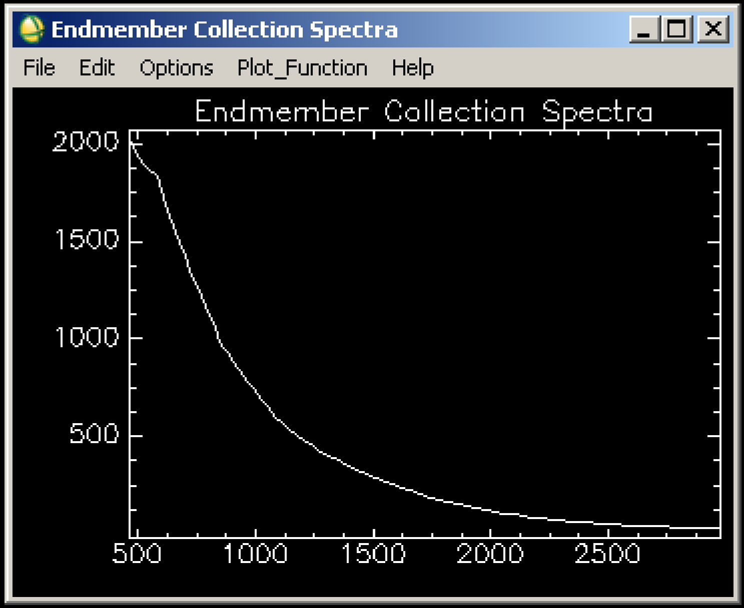
Step 1: Import M3 Spectral Library

Step 3:



Click Plot

Done!

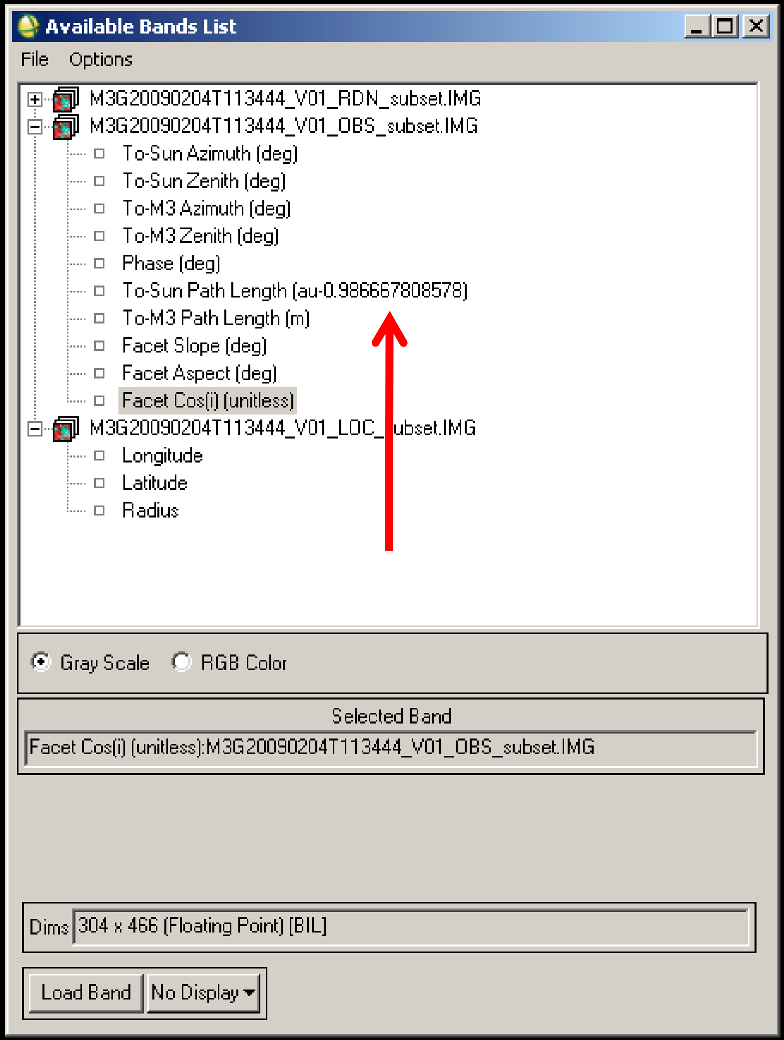


(Can save file as spectral library from File menu)

Step 2: Open Files

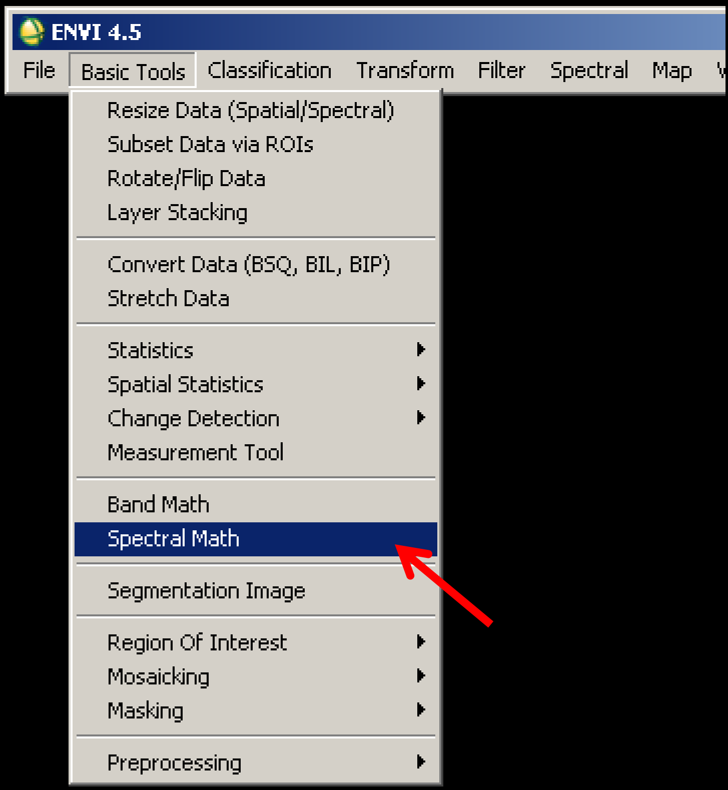
- Open radiance (RDN) file in ENVI:
  - File > Open Image File
- Open observations (OBS) file also
  - This step can be skipped if you want to use 1.0 AU for the Moon-Sun distance (~2% error)
- Open <u>and plot</u> the M3 solar spectrum if you have not already

Step 3: Get the Moon-Sun Distance



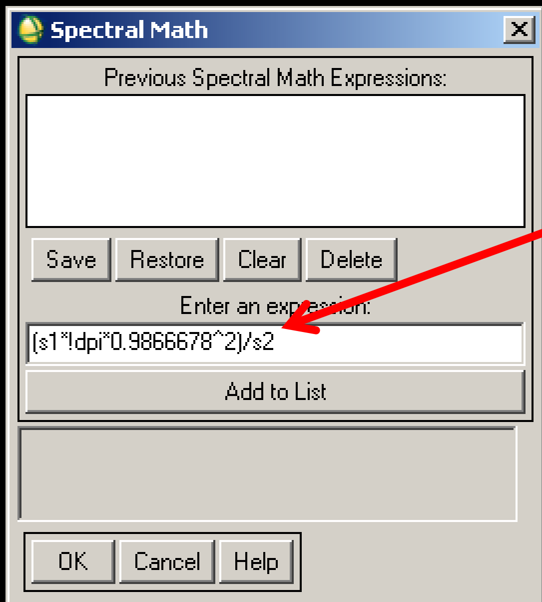
- Get mean distance from list of band names of the OBS file
- Could use per-pixel values in the To-Sun Path Length Band (band math)

Step 4: Call Spectral Math



- Select Spectral Math under Basic Tools menu (also under Spectral menu)

Step 5: Enter the expression



- Expression is:

(s1*!dpi*0.9866678^2)/s2

Radiance

Double precision π

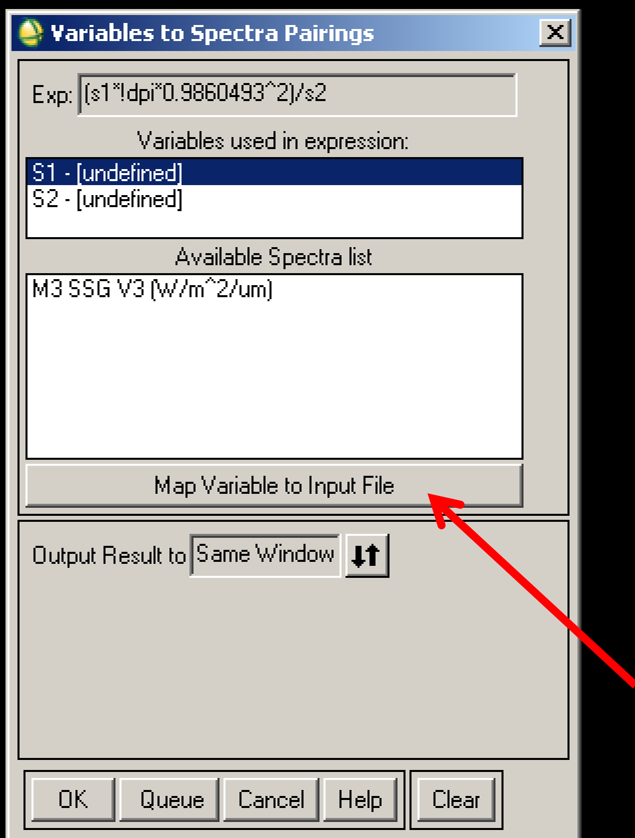
Moon-Sun distance squared

Solar Spectrum

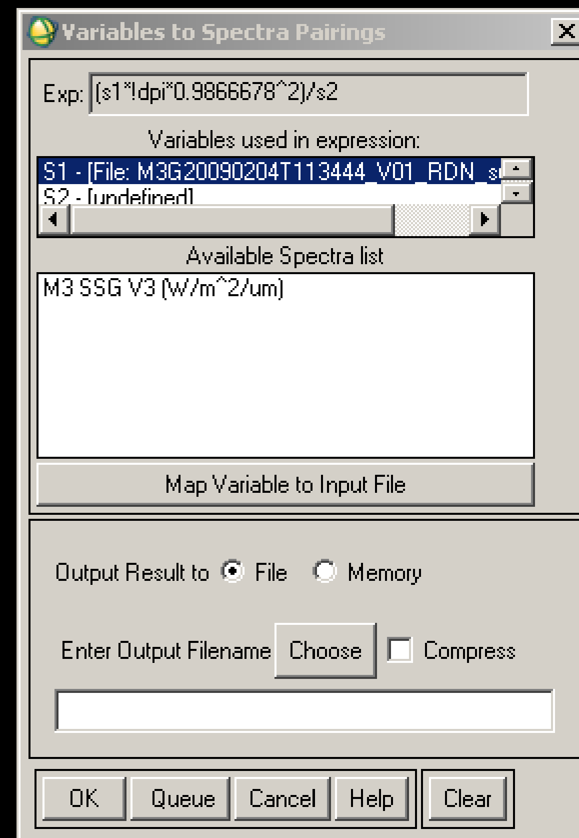
$$\frac{I}{F}=\frac{L\pi d^{2}}{F}$$

Step 6: Define s1

Click “Map Variable to Input File” and select your radiance (RDN) file



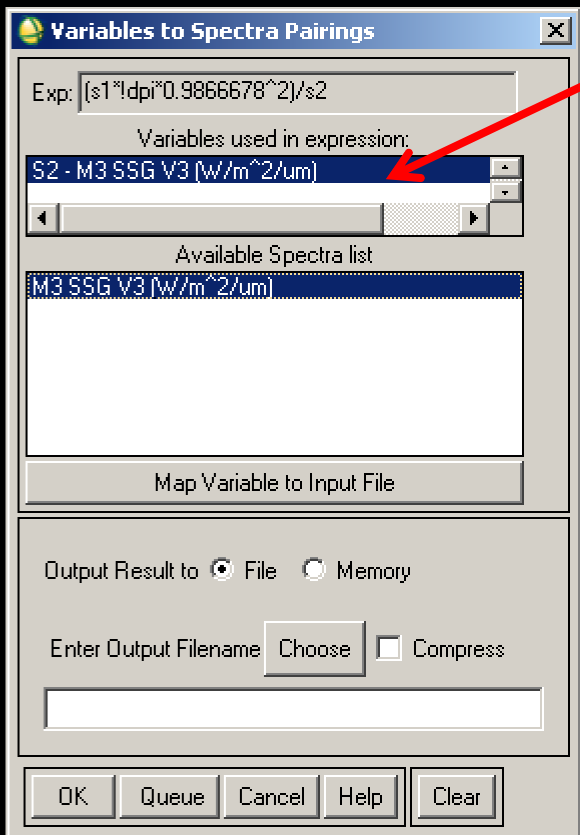
Should end up with this:

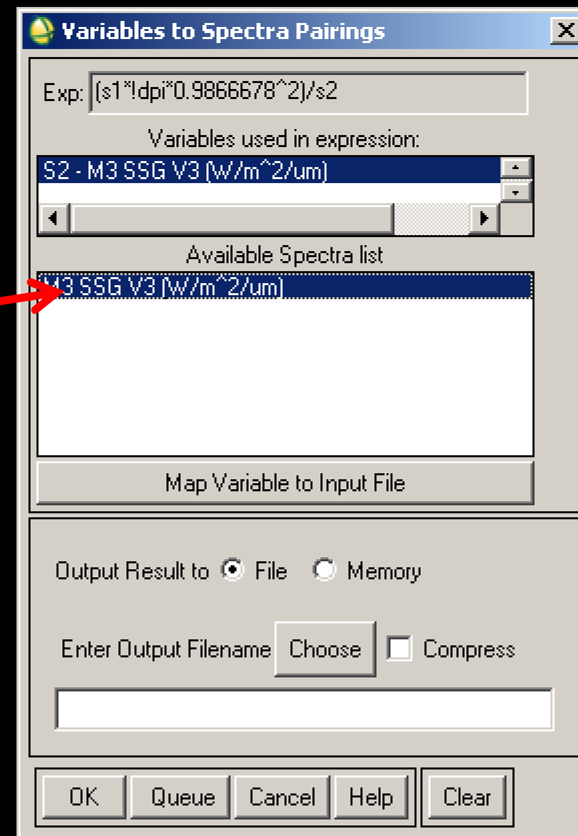


Step 7: Define s2

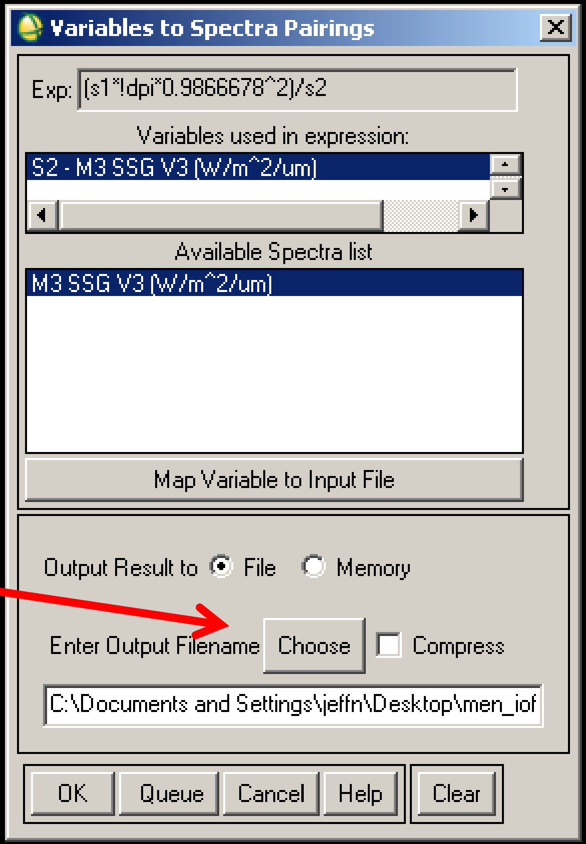
First Click

Second Click

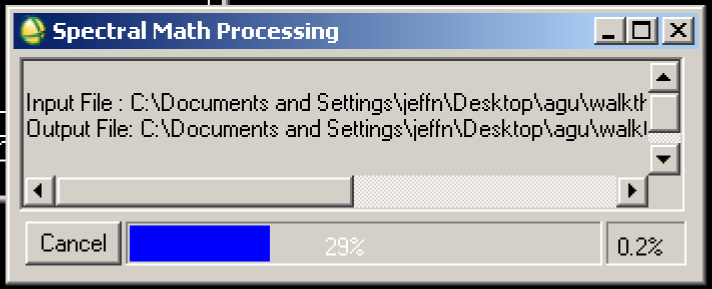




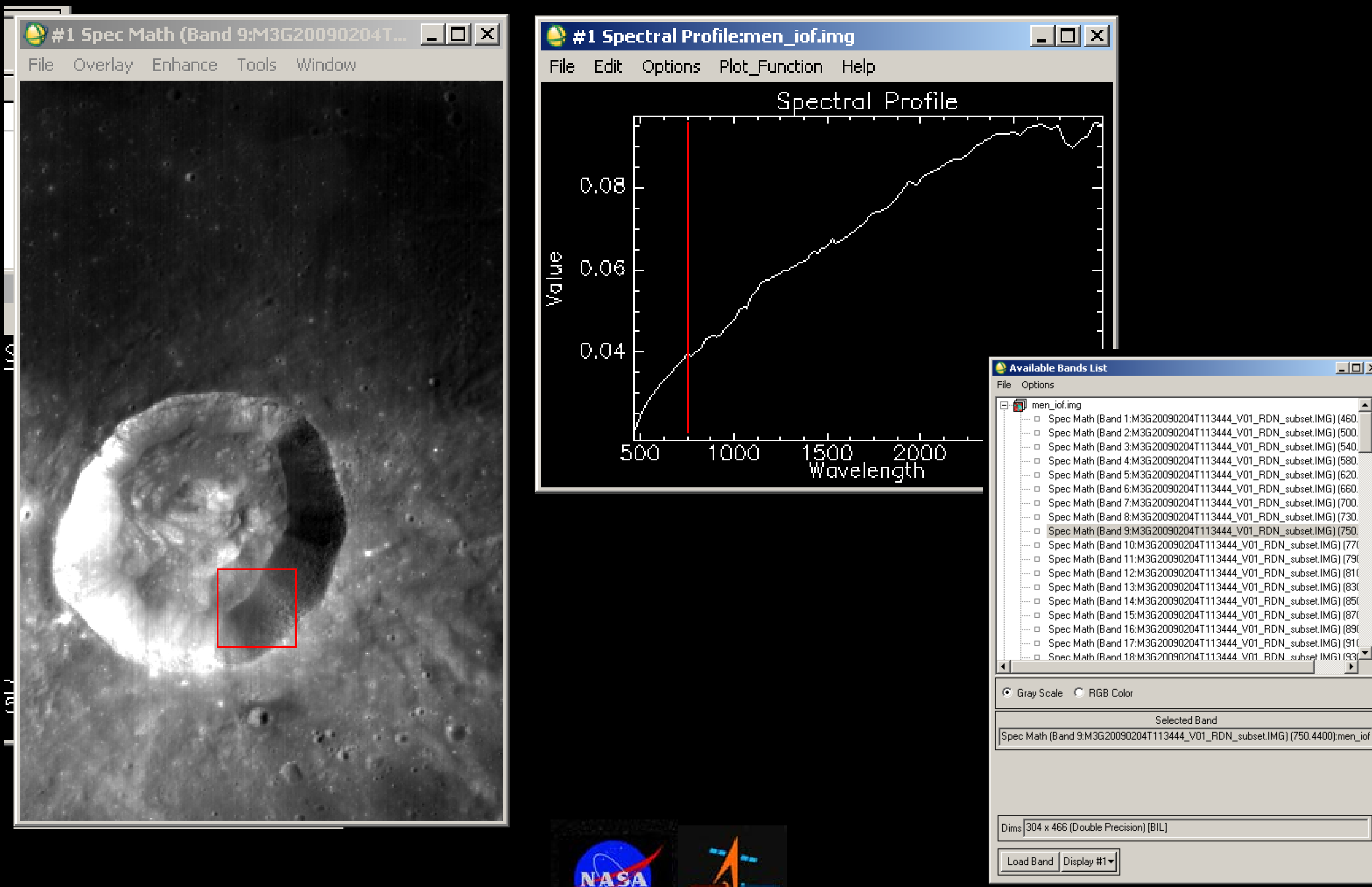
Step 8: Choose Output File



- Then click “OK” and ENVI goes to work…



Last Step: Enjoy!



Check your work!

- Example radiance, observations, and I/F file posted to M3 website so that you can make sure you get the same answer we do:
- http://m3dataquest.jpl.nasa.gov

Presentation slides available there also