Influence of Faint Light Sources on the Moon's Permanently Shadowed Regions

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Motivation and Objectives

- Light from a variety of sources is incident on the lunar surface within “permanently shadowed regions” (PSRs) near the poles that are never directly exposed to sunlight
- We survey predictions for these light sources that cover a broad range of wavelengths from the infra-red to the far-UV, where most of the incident energy appears
- Implications for:
  - Surface temperature of the lunar regolith
  - Stability of volatiles and surface chemistry
  - Suitability of the Moon as a platform for astronomical observatories

Sources of PSR Illumination

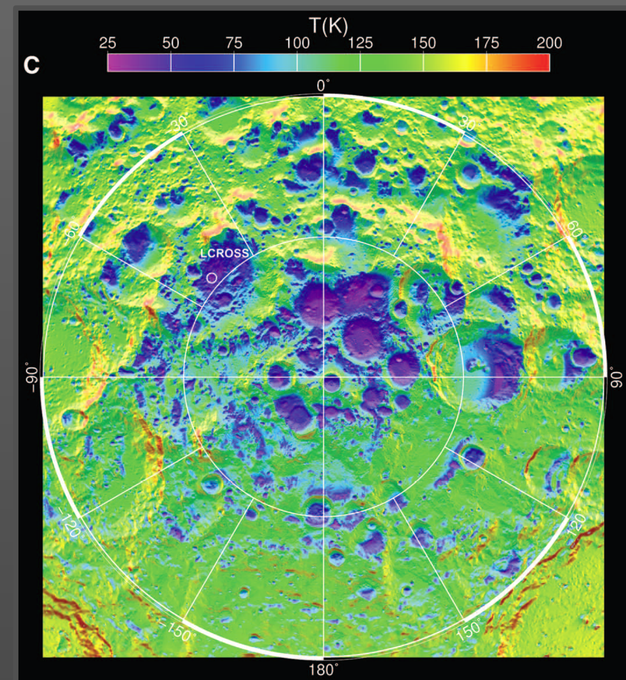
1. Sunlight scattered from directly illuminated surface
2. Earthshine (direct and scattered)
3. Diffuse broadband galactic background
4. Lyman-alpha from interplanetary hydrogen
5. Zodiacal light from inner solar system dust
6. Emission lines from exospheric species (Na and K)
7. Sunlight scattered by exospheric dust:
   - Tenuous dust clouds from possible natural transport
   - Denser dust clouds from either a local LCROSS-scale impact or kicked-up by exploration and/or in-situ resource utilization (ISRU) activities

Surface-scattered Sunlight into PSRs

Paige et al. (2010) had direct and scattered sunlight, as well as direct Earthshine, in their thermal model.

It did a remarkable job of matching the LRO Diviner observations – although there were some discrepancies.

Assumed an internal heat flow of **16 mW m^{-2}** based on Apollo data.

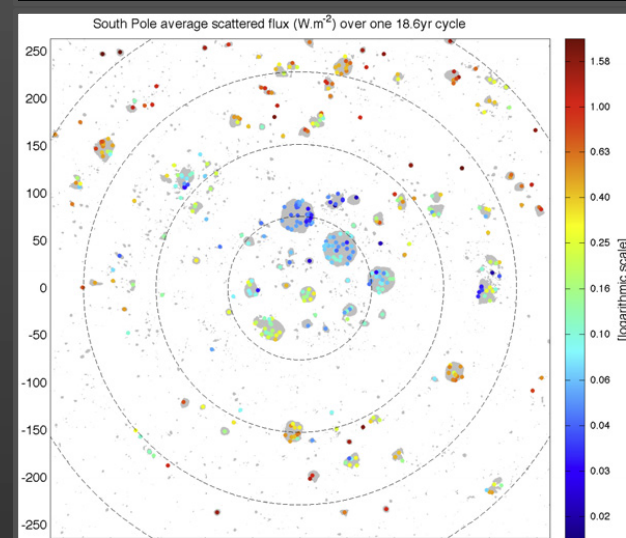


Mazarico et al. (2011) estimated scattered sunlight at selected points:

Flux ranged from **0 to ~7,000 mW m^{-2}**

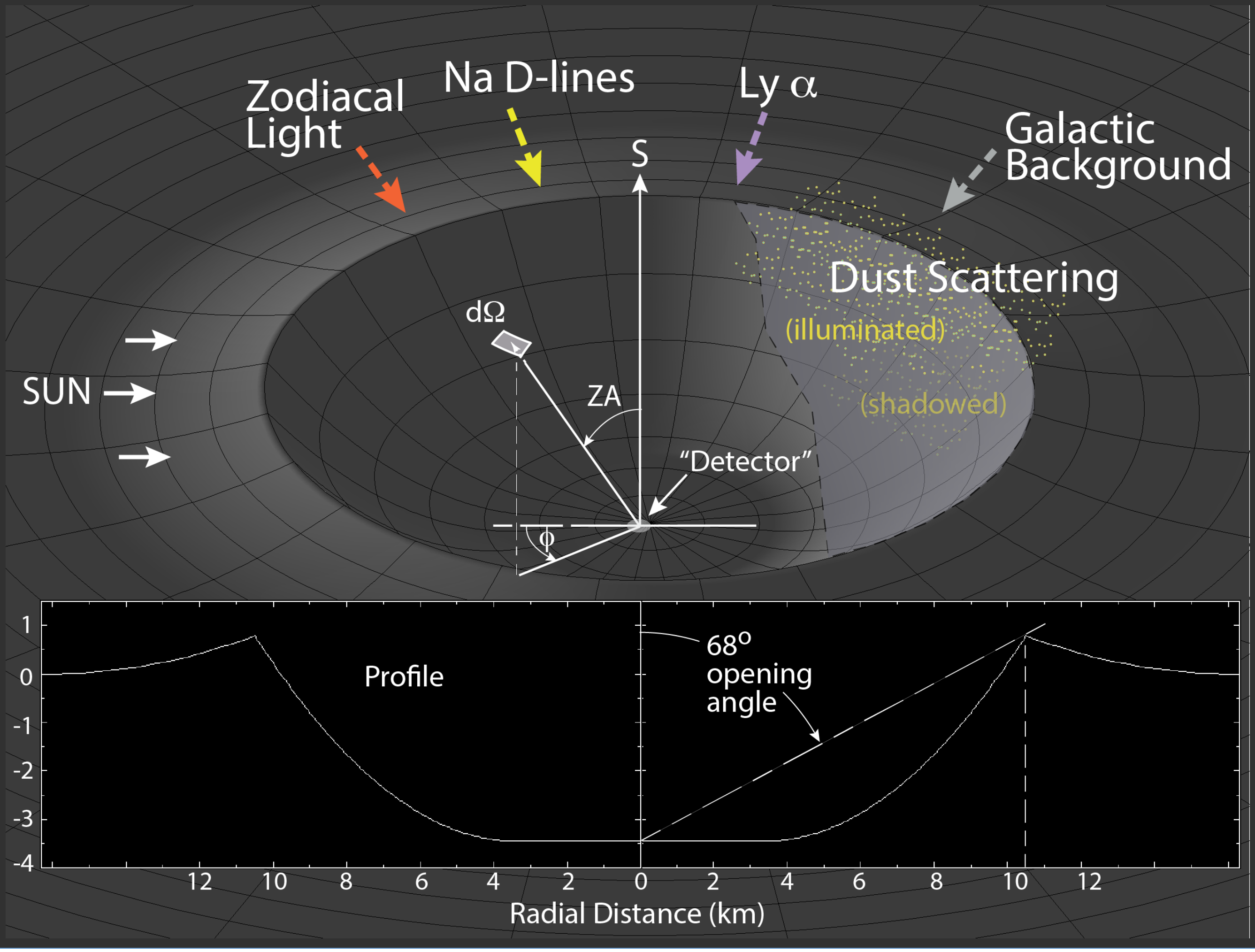
Annual averages **~10 to 1,500 mW m^{-2}**

Conceivable that some areas do not see any scattered sunlight.

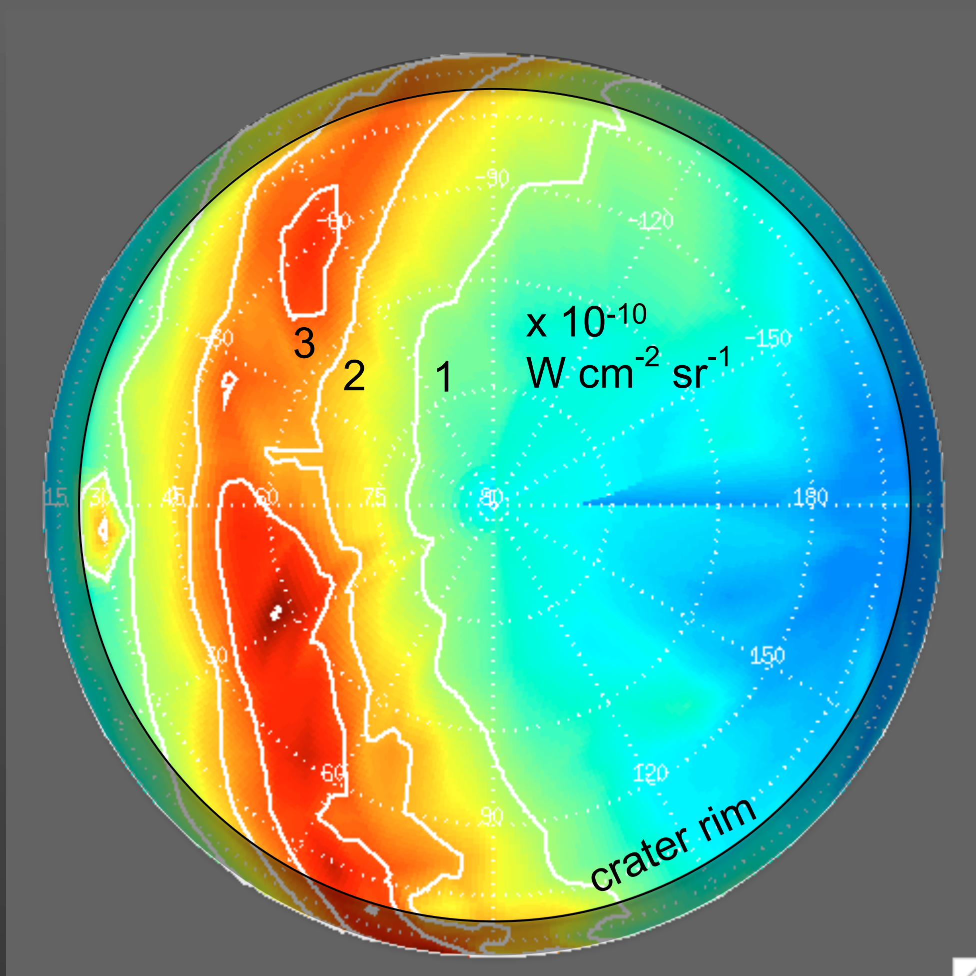


Polar Crater – Illumination Geometry

- Rotate each source to (Φ,ZA) coordinates: $\boldsymbol{I_{source}(\Phi,ZA)}$ [W cm^{-2} sr^{-1} nm^{-1}]
- UV-NIR wavelength integration to get broadband radiance $\boldsymbol{B(\Phi,ZA)}$ [W cm^{-2} sr^{-1}]
- Solid angle integration $\int B(\Phi,ZA)\cos(ZA)\,d\Omega$ gives irradiance [W cm^{-2}] at center



Galactic Background Radiance



Source:

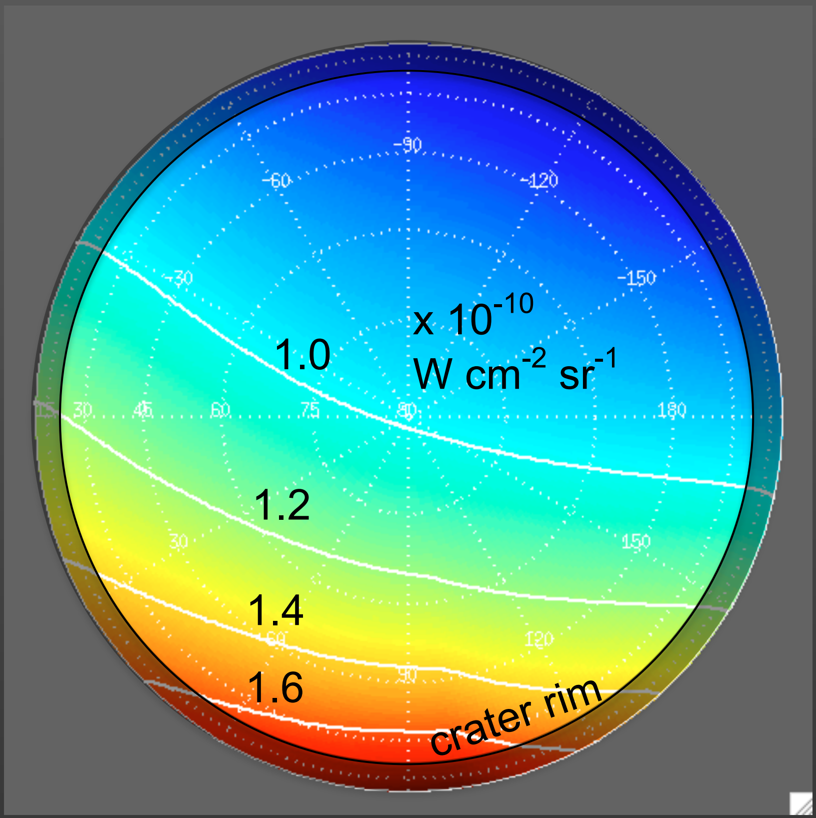
Two-color maps in S10 flux units, from Helios 1, 2, and Pioneer 10 (Leinert et al., 1998)

1 S10 = 1, 10th mag solar-type star per deg²

Interplanetary Sources

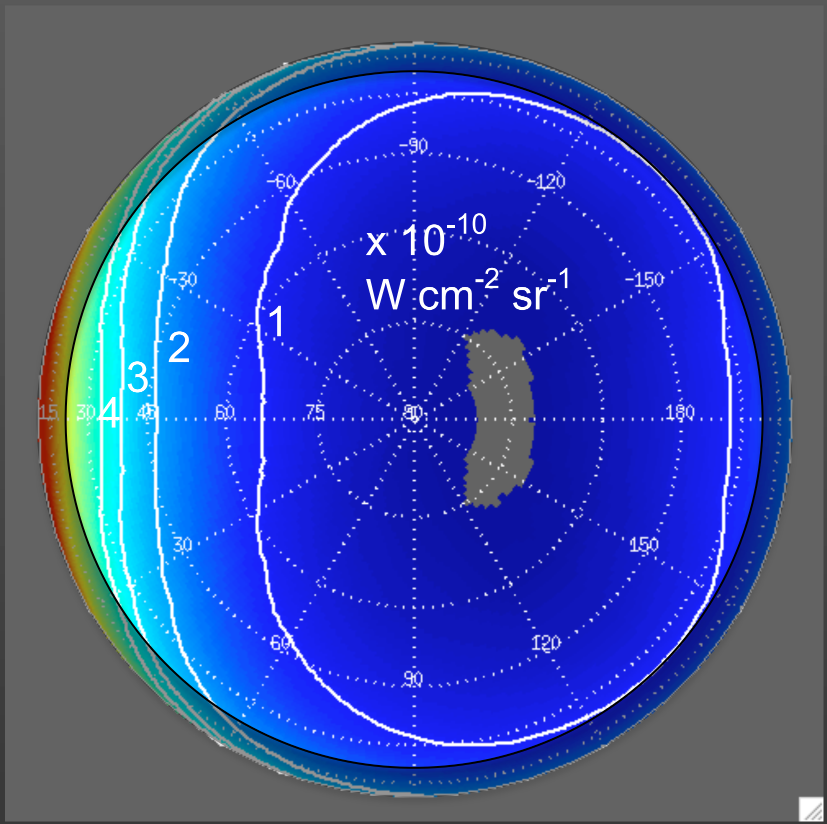
Lyman-alpha

Source: SOHO Solar wind anisotropies (SWAN) model at solar maximum [Courtesy: Wayne Pryor]



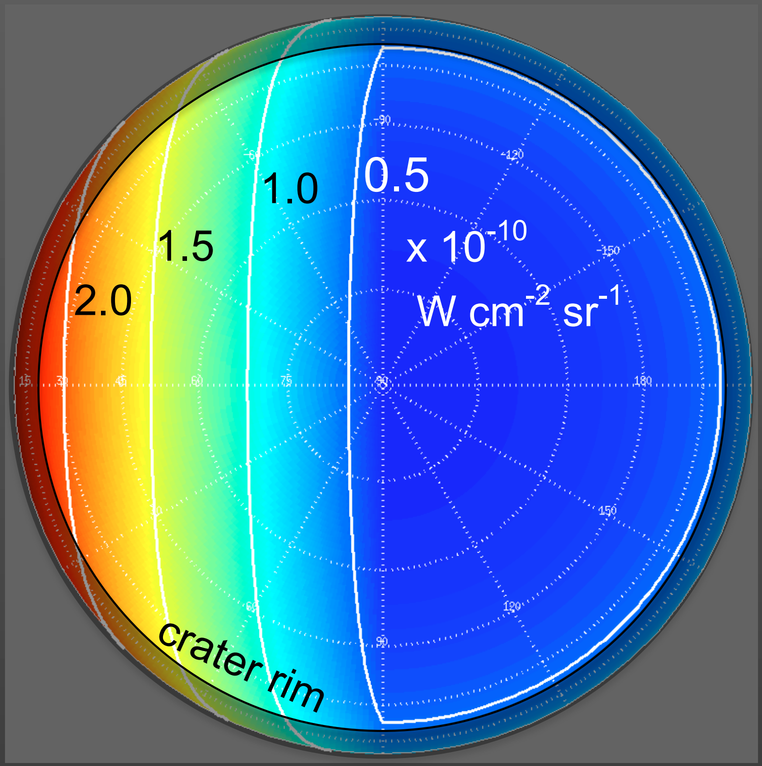
Zodiacal Light

Source: Helios 1 (Leinert et al., 1998), rocket photometry (Pitz et al. 1979)

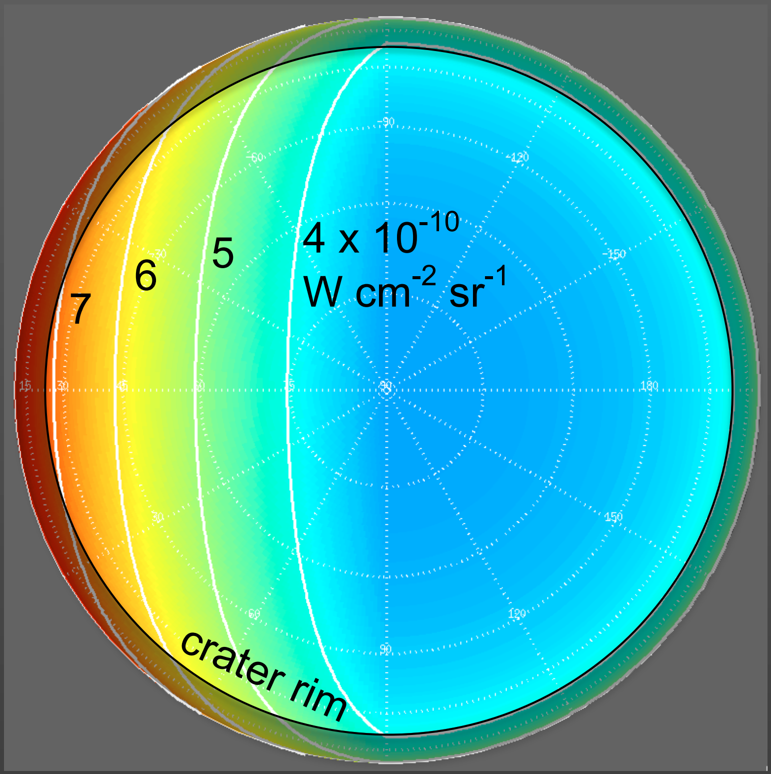


Radiance: Sodium and Potassium

Nominal Model (PSD dominates)



Enhanced Impact Vaporization



Sources: Potter & Morgan, Science, 1988;
Mendillo et al., GRL, 1991; Icarus, 1999

Exospheric Dust

Scattering code:

- Mie-scattering simulation code for lunar exospheric dust.
- Simple, 1D exponential dust distributions defined by surface concentration n_0 and scale height H
- Solar irradiance model from Solar Radiation and Climate Experiment/SORCE (U. Colorado, LASP)
- Dust optical constants from Shkuratov et al. (1999)
- Crater-wall shadowing

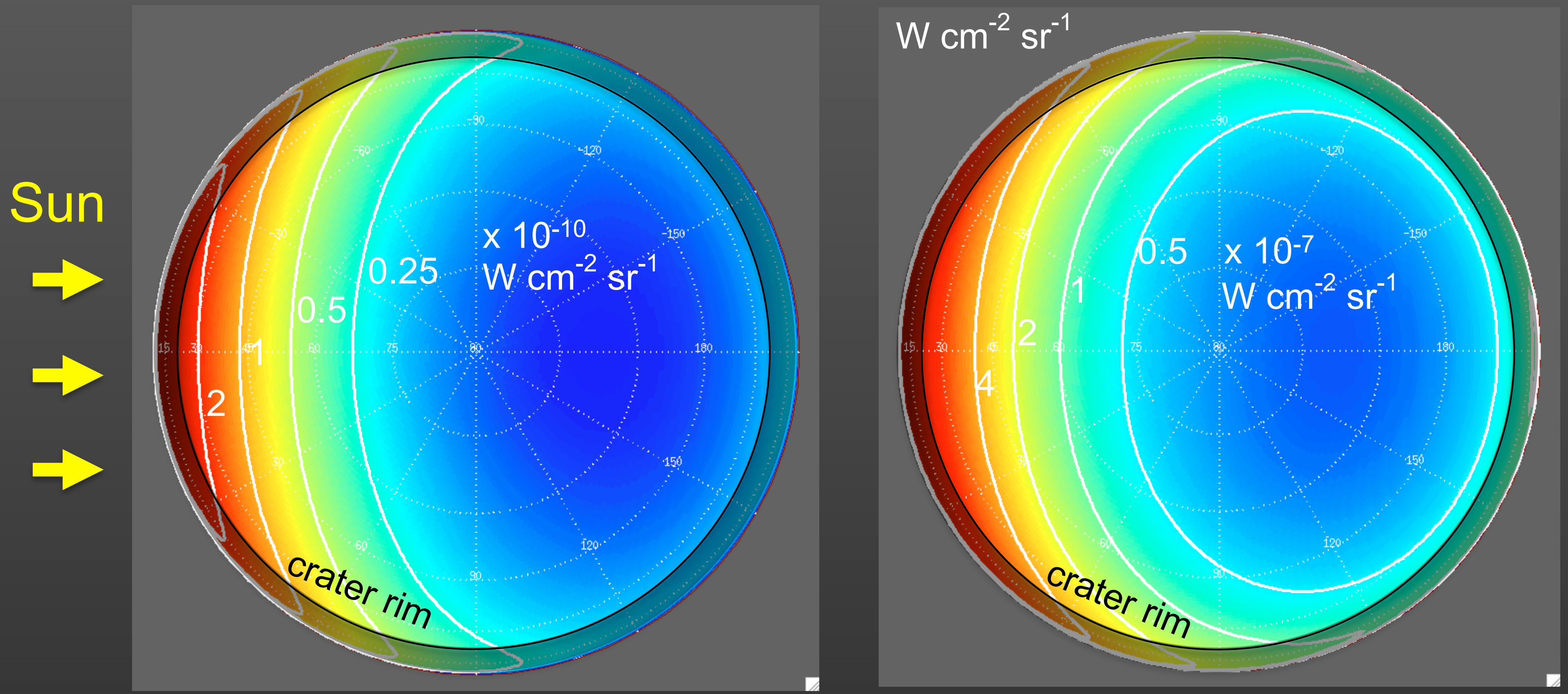
Exospheric Dust - Natural

LRO/LAMP, Clementine Upper-limit
(r_{grain}= 0.1 μm, n_0=10^{-5} cm^{-3}, H= 10 km)

(Feldman et al. 2014; Glenar et al. submitted)

Apollo 15 bright model
(r_{grain}= 0.1 μm, n_0=0.08 cm^{-3}, H= 5 km)

(McCoy 1976; Glenar et al. 2011)

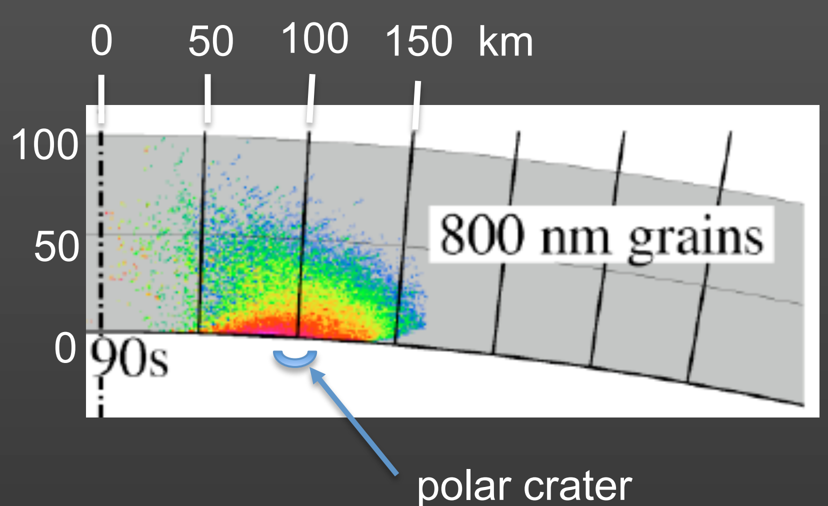


Exospheric Dust – Lunar Landing

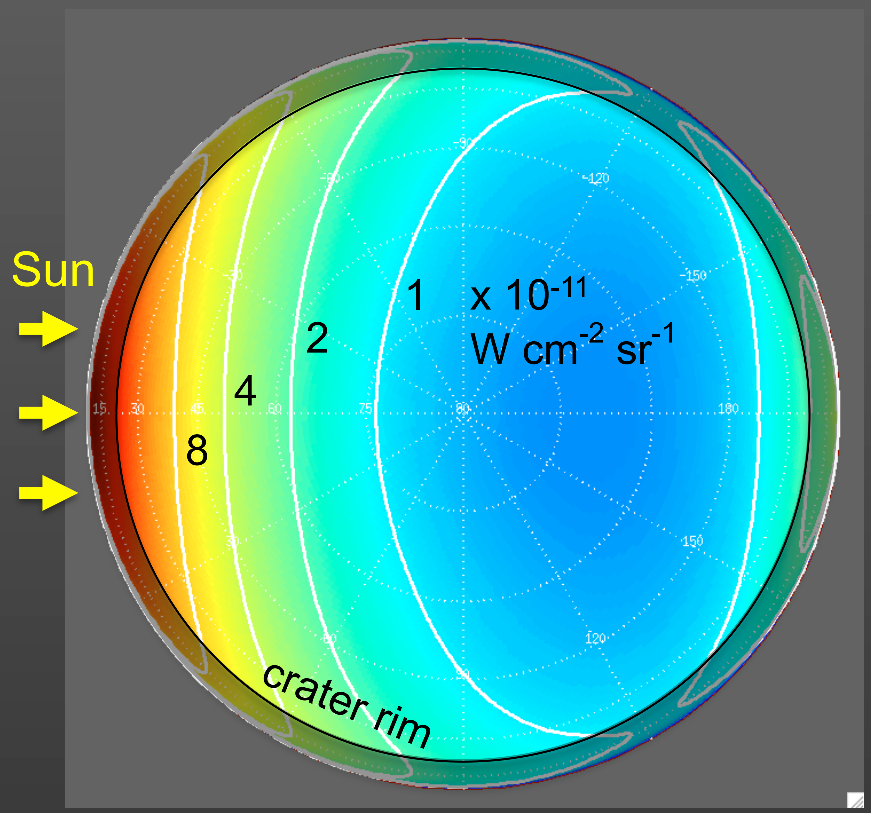
Plume Dust Concentration vs. Height & Radial Distance

(Morris et al.)

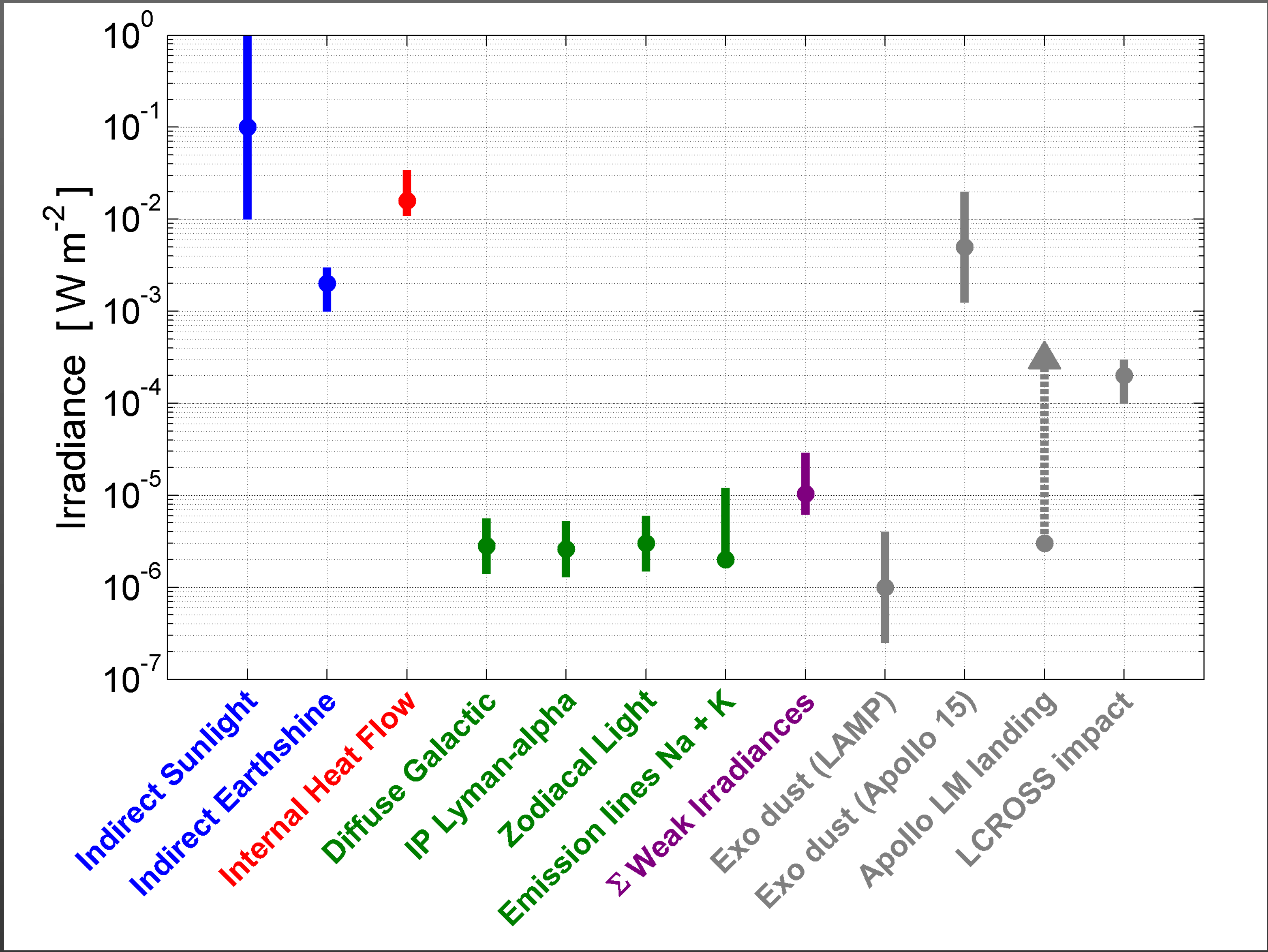
- Elapsed time = 90 sec
- Grain radius = 0.4 μm
- n_0= 1.3 x 10^{-7} cm^{-3}
- H= 13 km



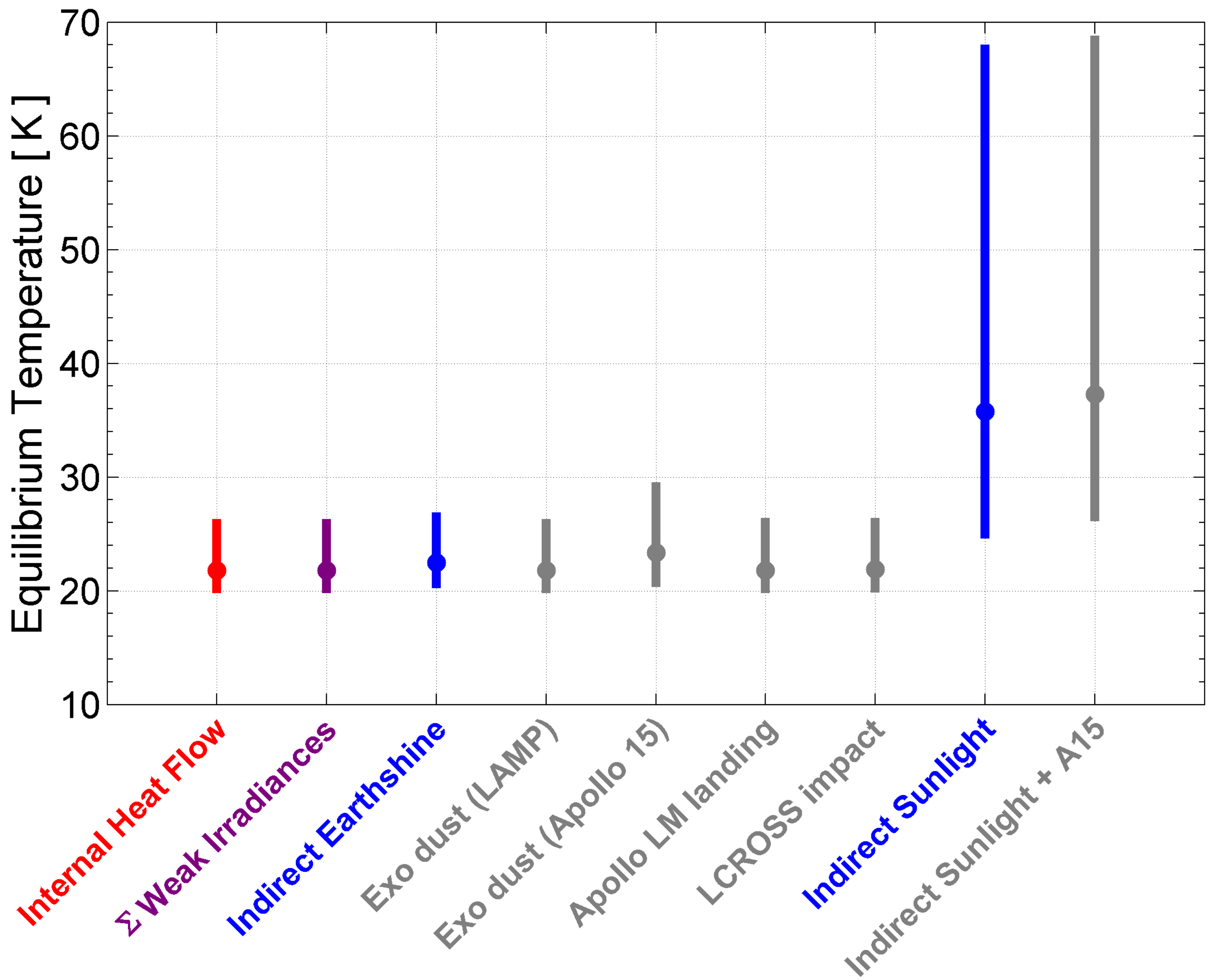
Polar Sky Brightness



Irradiance Comparison



Thermal Equilibrium Comparison

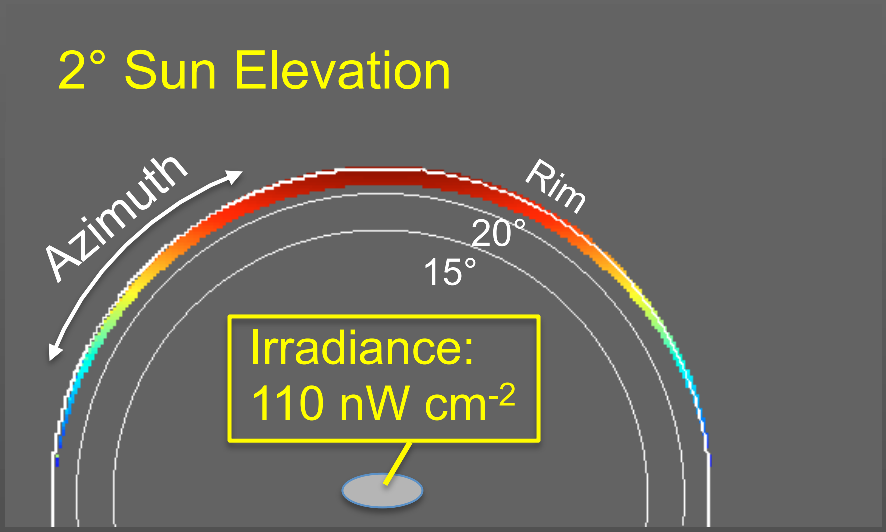


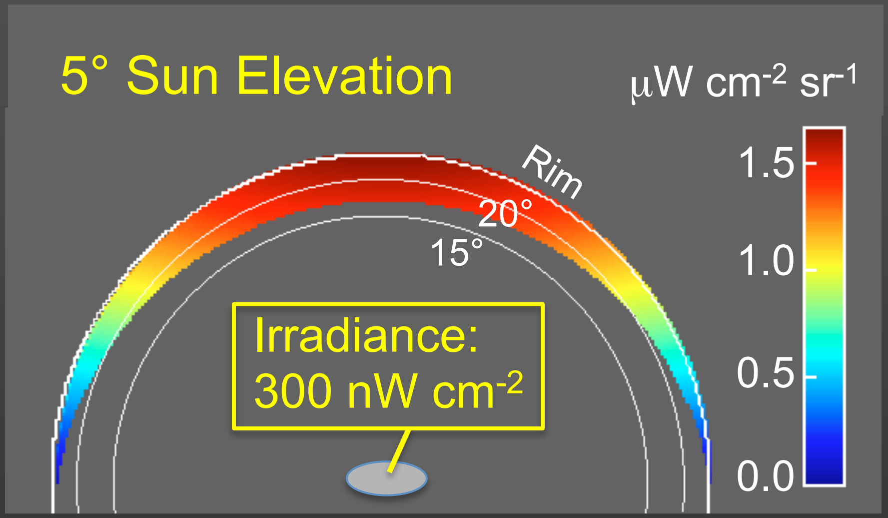
Summary and Conclusions

- As anticipated, weak irradiance sources (~10^{-5} W m^{-2}) have a negligible effect on thermal balance in PSRs:
  - Interplanetary Lyman-alpha; Diffuse galactic background
  - Zodiacal light; Lunar Sodium (D-lines) and Potassium
  - Exospheric dust based on LAMP and Clementine upper limits
- In absence of surface-scattered sunlight, an Apollo 15-like dust population would warm the coldest PSRs by ≈2–3 K
- The influence of the exospheric dust irradiance decreases with temperature due to the T^4 dependence
- Apollo LM landing estimate is a lower limit, but indicates that nearby exploration activity will not thermally disturb PSRs
- **Unlikely to significantly effect the thermal stability of water ice that is either on the surface (≈101 K) or buried (≈145 K)**

Backup

Indirect Earthshine





Crater Wall Reflectance Viewed at Crater Center

Model assumptions:

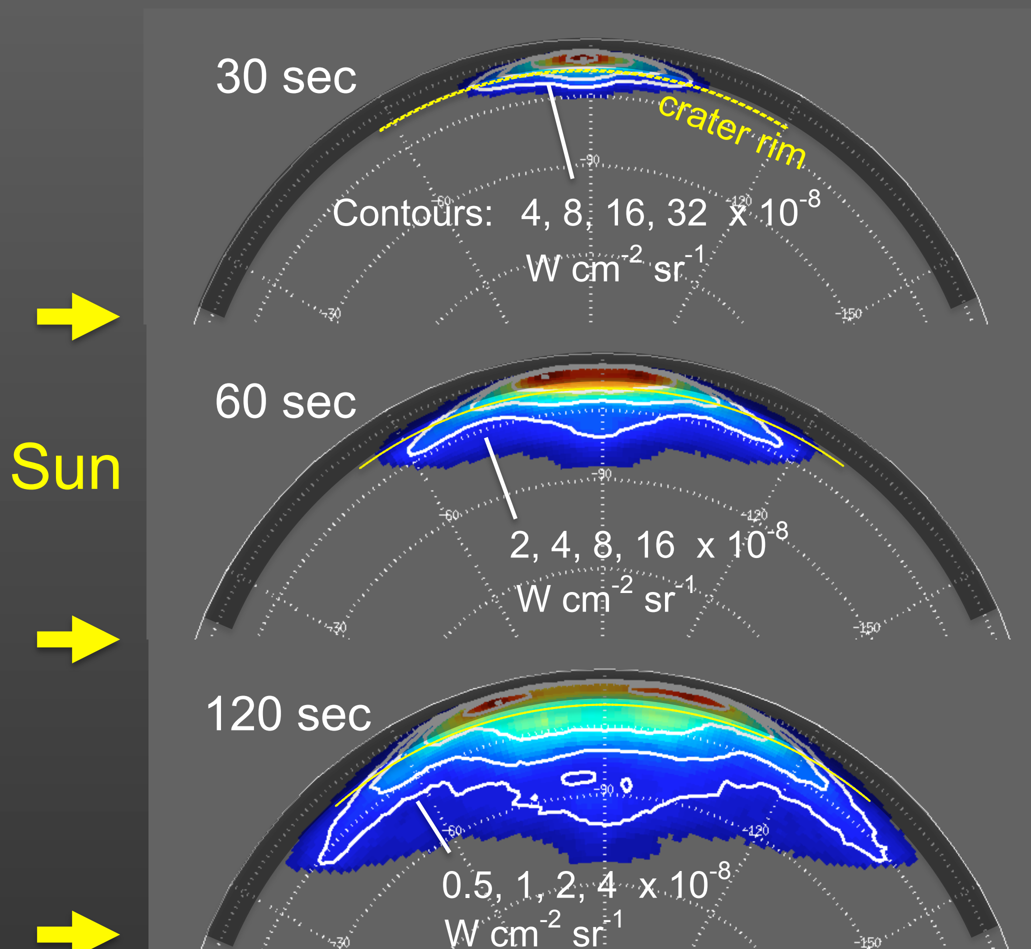
- Earth considered a Lambert point source (for now), with (A_L=0.4).
- Wavelength integration from near-UV (350 nm) to near-IR (2400 nm)
- Crater wall reflectance: Hapke BRDF (Hapke, 1993). w(λ) adjusted to match reflectance of mixed Apollo soils (Gougen, 2012).

High surface brightness, but small solid angle; hence moderate irradiance at "detector".

Exospheric Dust

Case III: "LCROSS scale" Impact Simulation

Elapsed time from impact:



- Impact beyond crater rim (x= 20 km)
- Brightness maps of sunlight scattering (λ=550 nm) from ground-based imaging (Stryker et al. 2013).
- Broadband computations using lunar spectral reflectance (Apollo "mix", USGS, www.moon-cal.org)