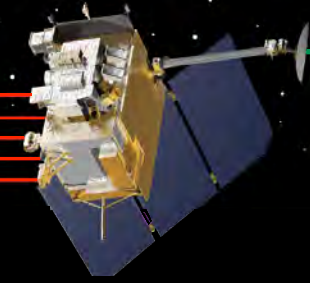
LEAG 2015
2015.10.21



Illumination Modeling at the Lunar Poles

and its Benefits to Exploration and Science Investigations

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and J.B. Nicholas
NASA GSFC

Support for Exploration

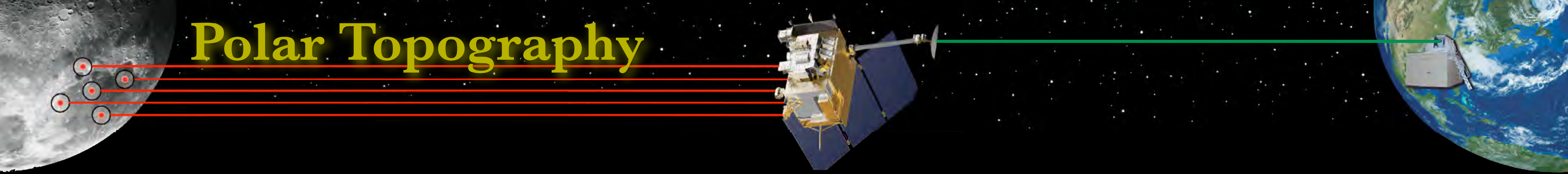
- There have been many studies of illumination conditions at the lunar poles !

- With actual spacecraft images:
  - Bussey et al., GRL, 1999
  - Bussey et al., Nature, 2005
  - Speyerer and Robinson, Icarus, 2013

- With topographic shape models derived from ground-based radar:
  - Margot et al., Science, 1999
  - Zuber and Garrick-Bethell, Science, 2005

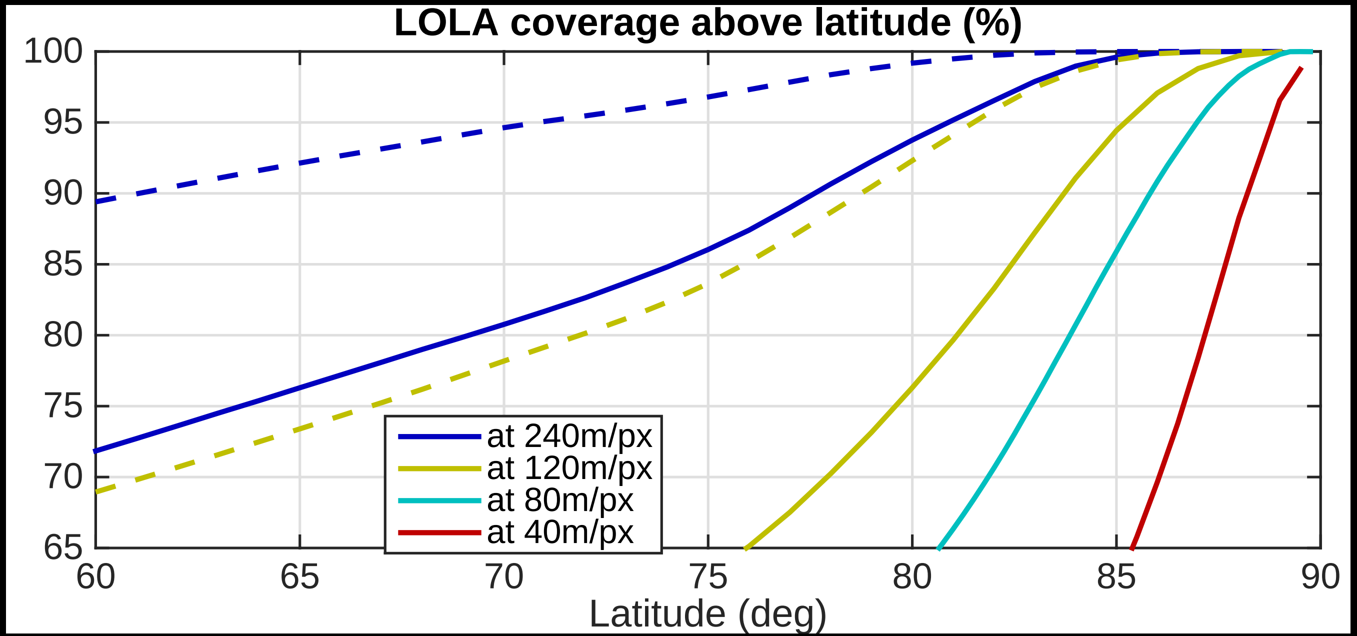
- And more recently with DEMS derived from orbital laser altimetry :
  - Noda et al., GRL, 2009
  - Bussey et al., Icarus, 2010
  - Mazarico et al., Icarus, 2011
  - De Rosa et al., PSS, 2012
  - McGovern et al., Icarus, 2013
  - Gläser et al., Icarus, 2015

Polar Topography

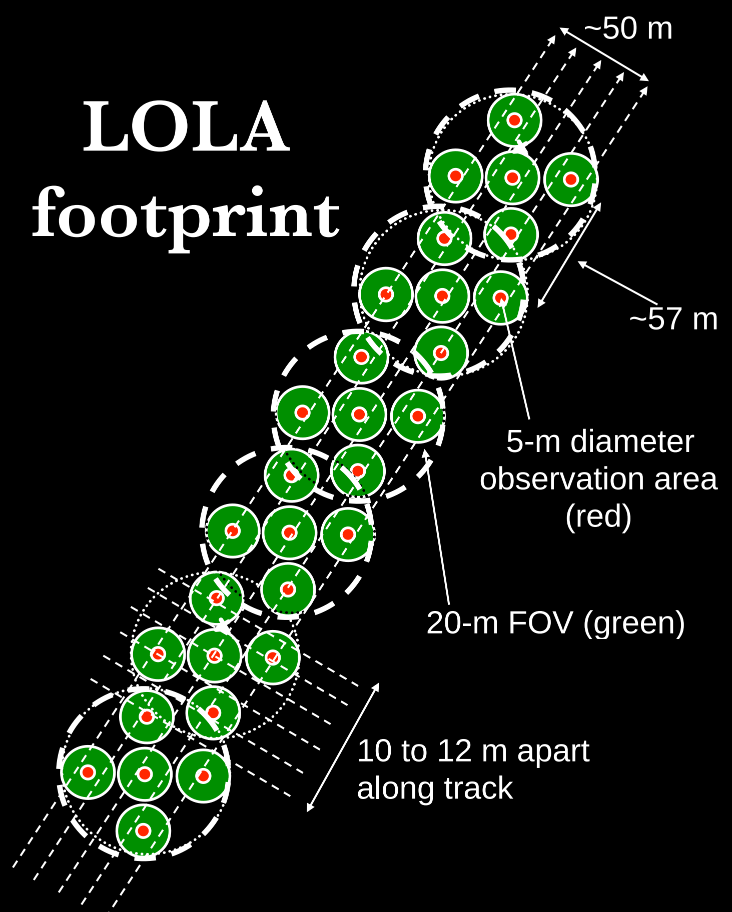


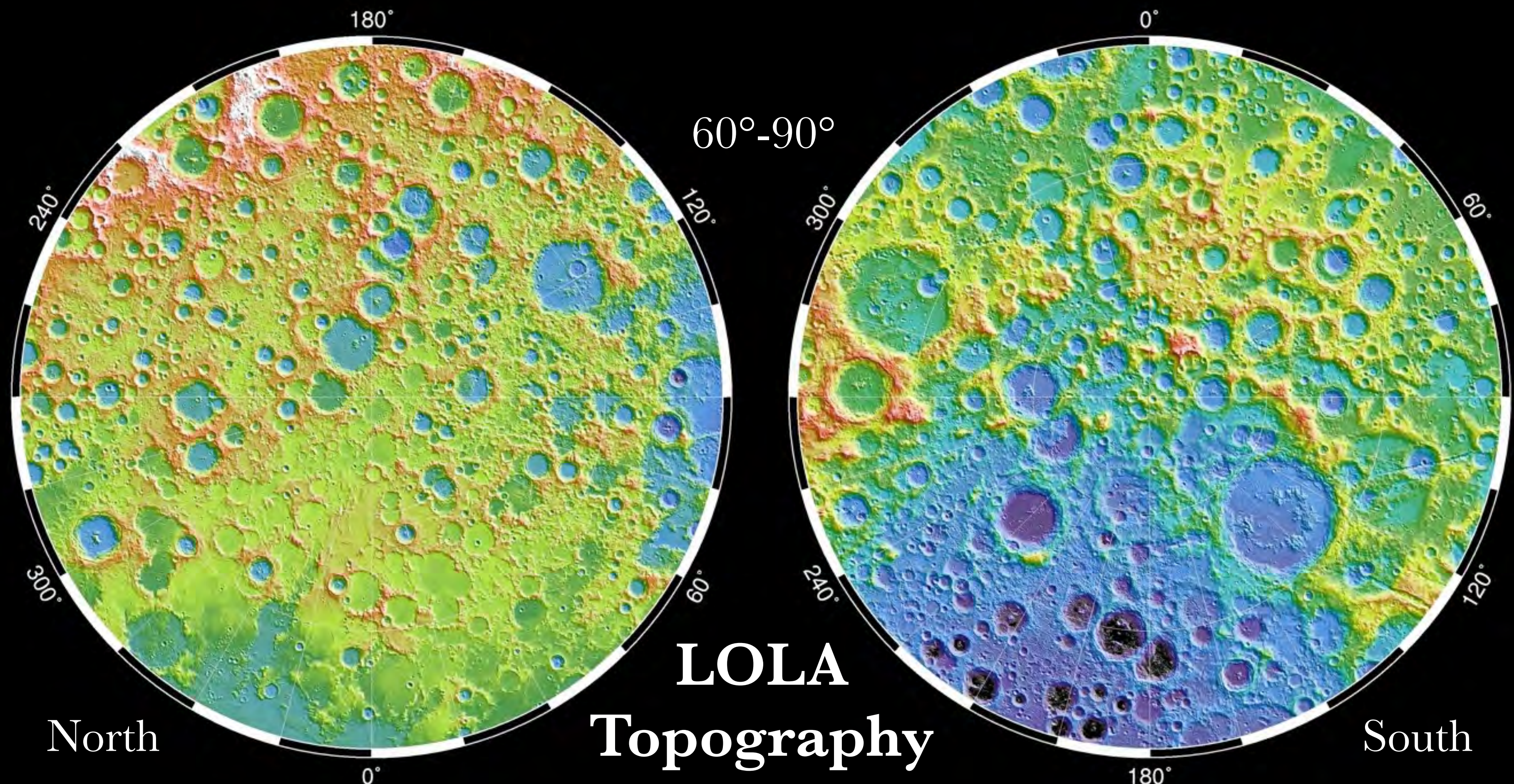
- With ~6.8 billion altimetric measurements over the Moon, LOLA provides excellent coverage, in particular of the lunar polar regions.

- Data coverage enables accurate illumination modeling



LOLA footprint



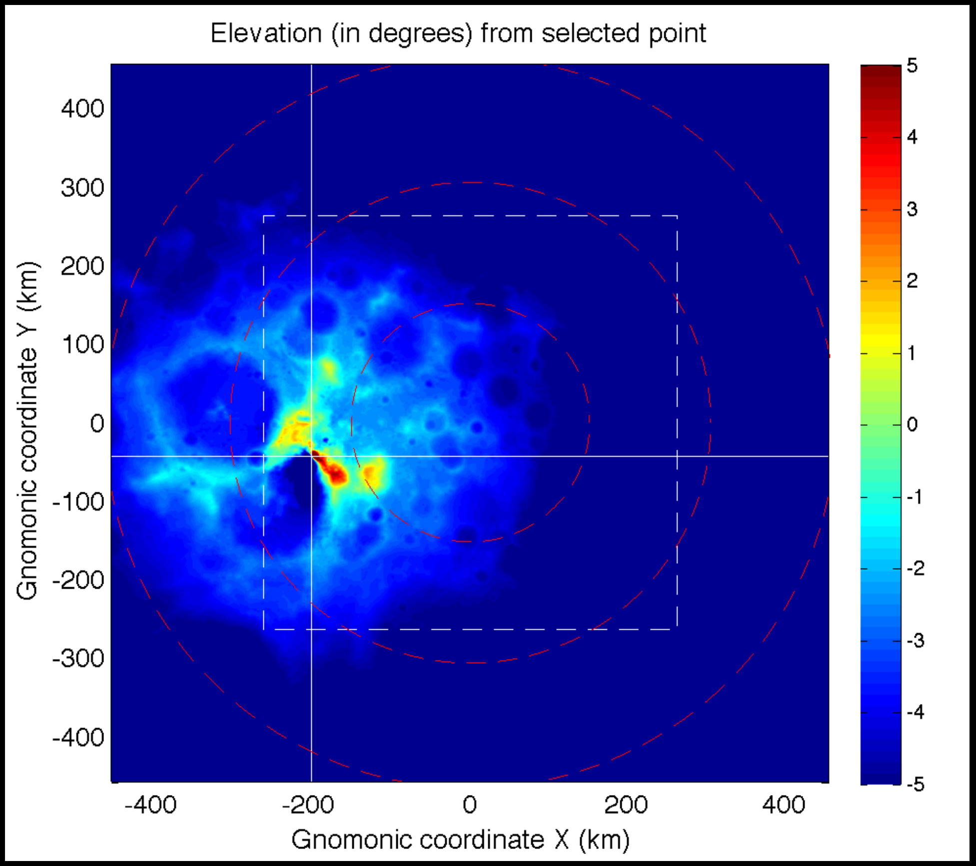


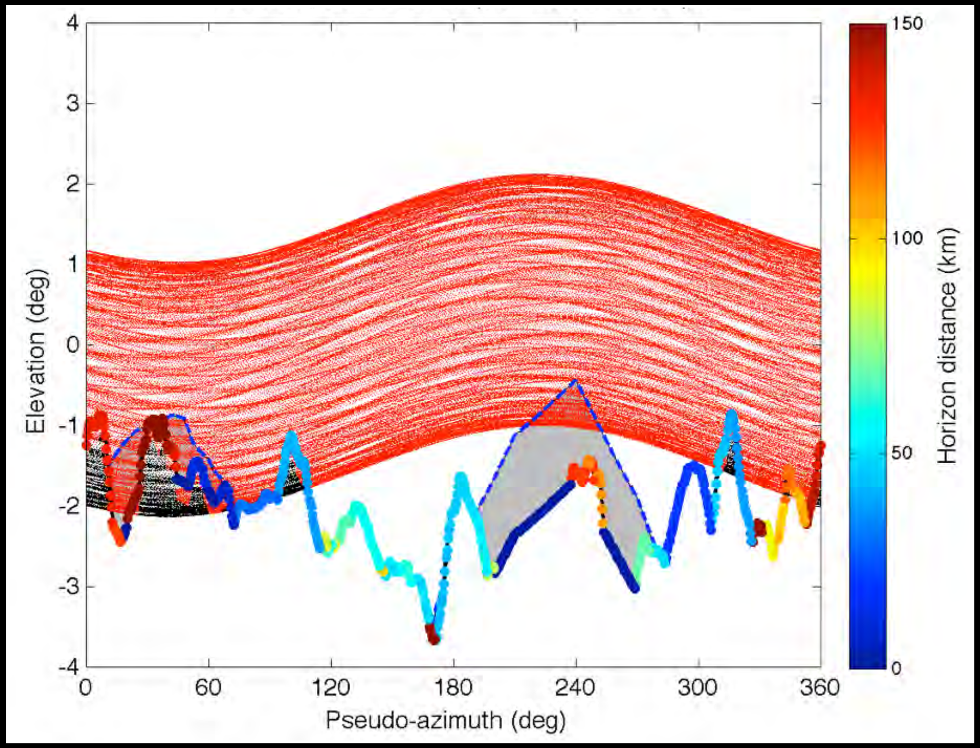
LOLA Topography

Illumination Modeling
Horizon Method

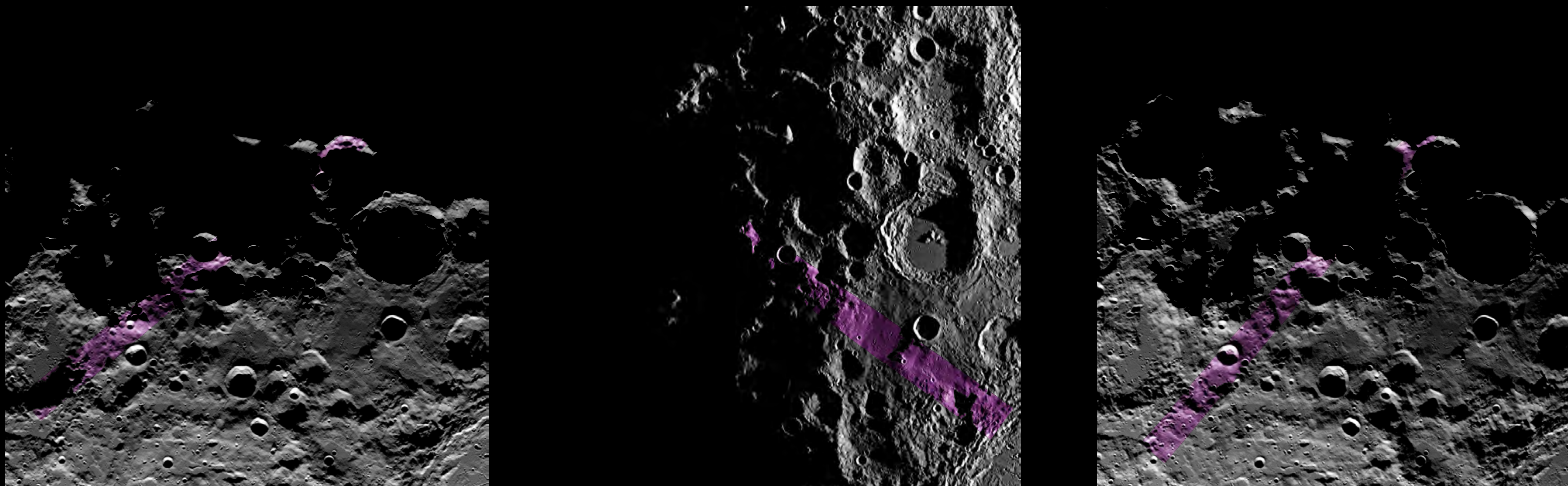
- Horizon method
  - calculate horizon elevation for each point in all directions
  - ‘elevation maps‘ enable quick calculation of regional illumination at any Sun position
  - high azimuthal resolution (0.5°)
  - simulations made at various resolutions (240mpp to 2mpp)

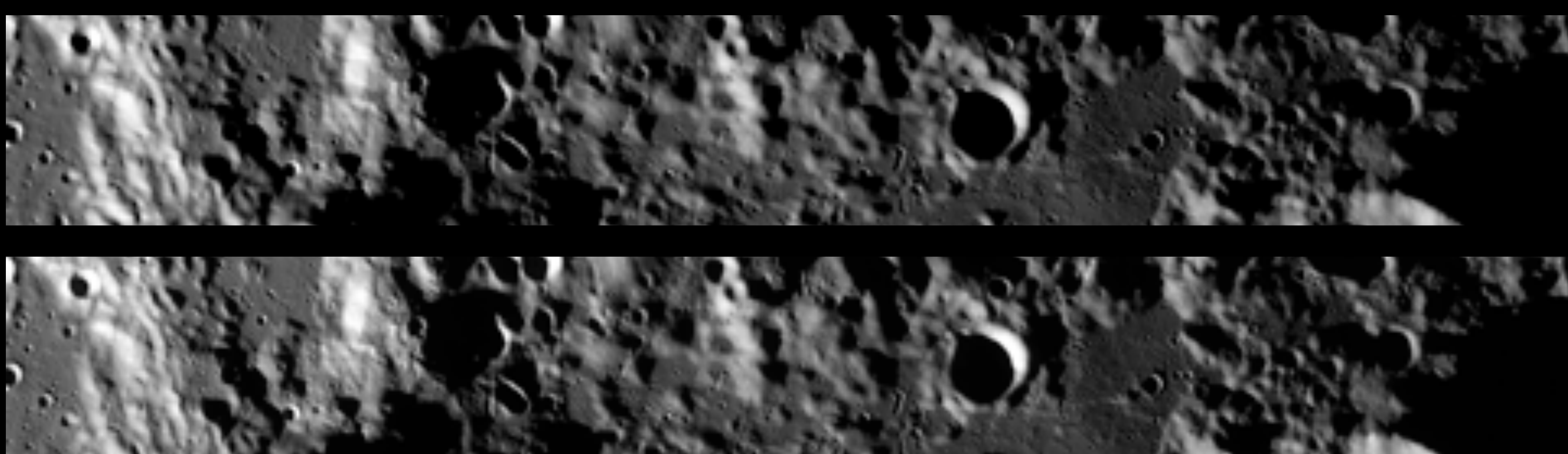
- extended illumination source
  - Sun angular radius calculated from distance
  - accurate Sun-horizon intersection algorithm
  - no limb darkening





Illumination Modeling
Validation with LROC WAC

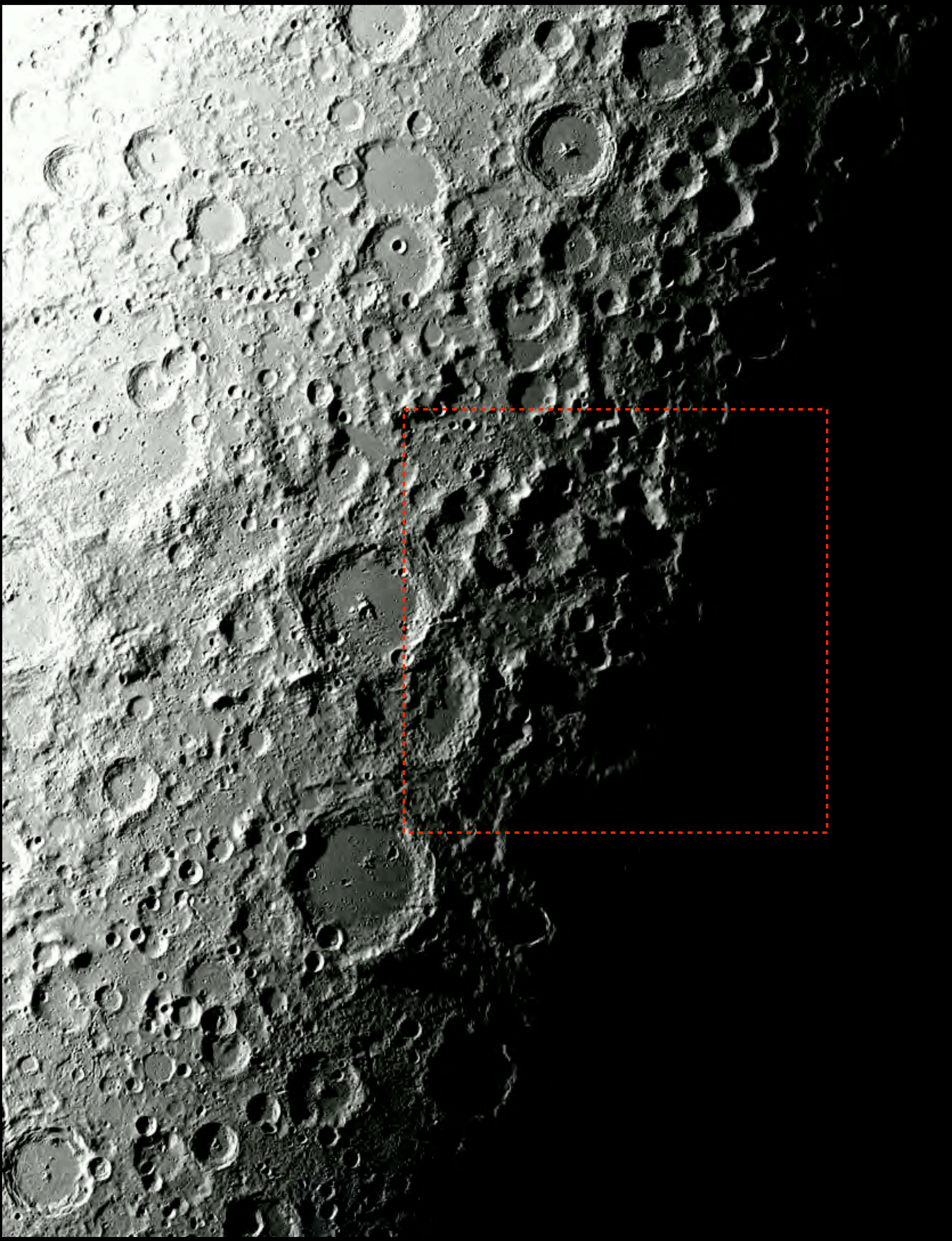




[Robinson and Speyerer]

Illumination Modeling
Sample output

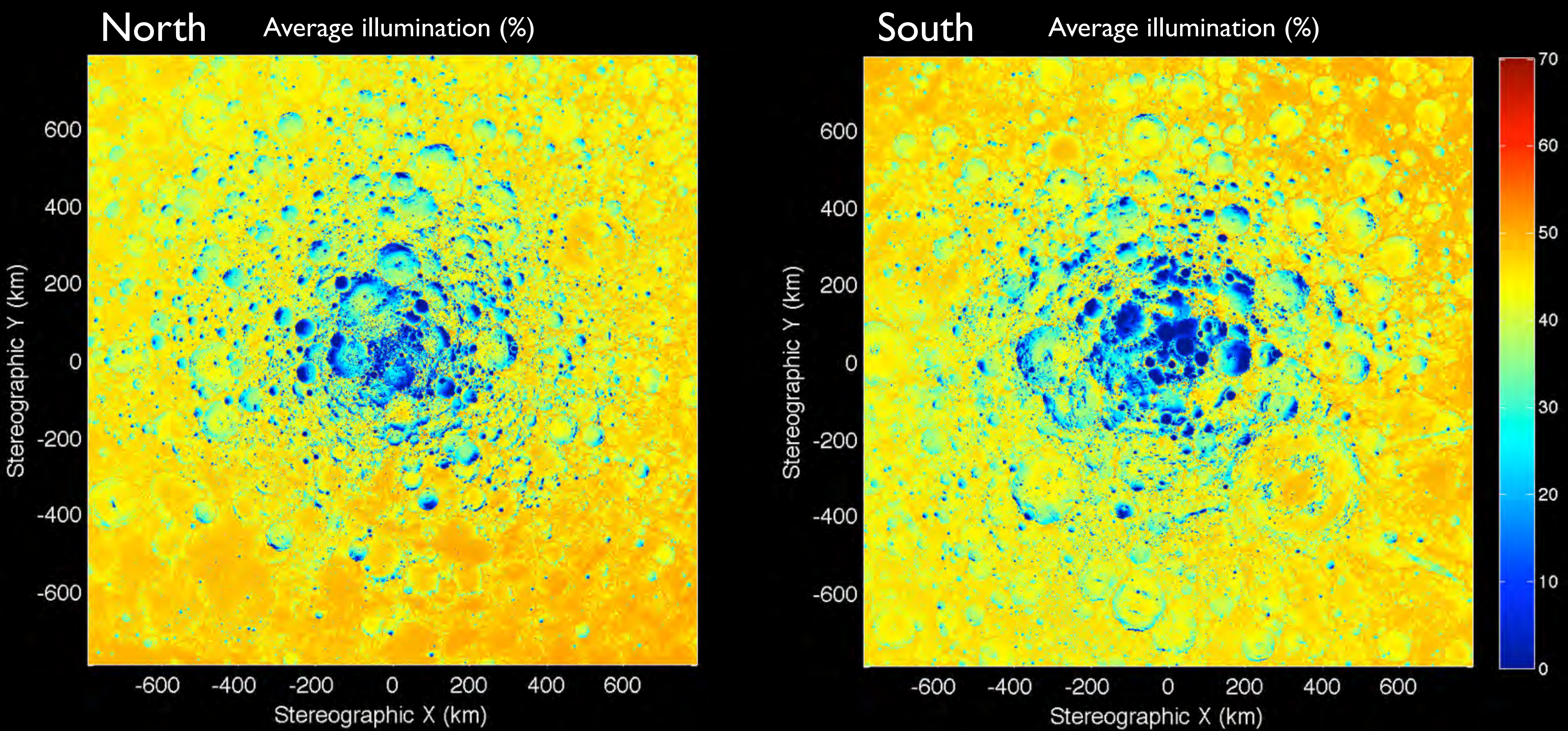
65°-90°



80°-90°

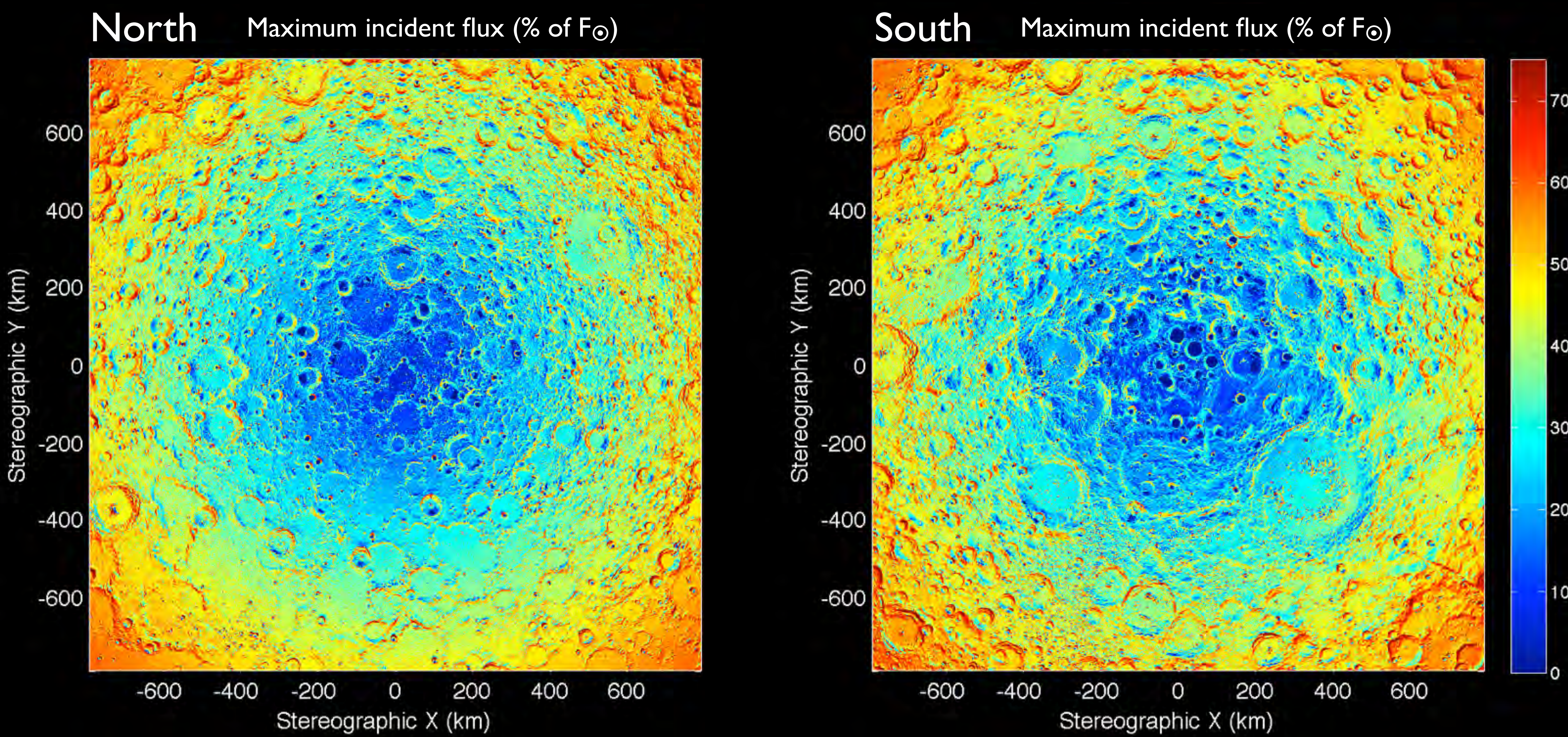
illumination over 28 days, 1h timestep
centered on LCROSS impact (Oct. 9, 2009 11:30)

Polar Illumination
Illumination Results



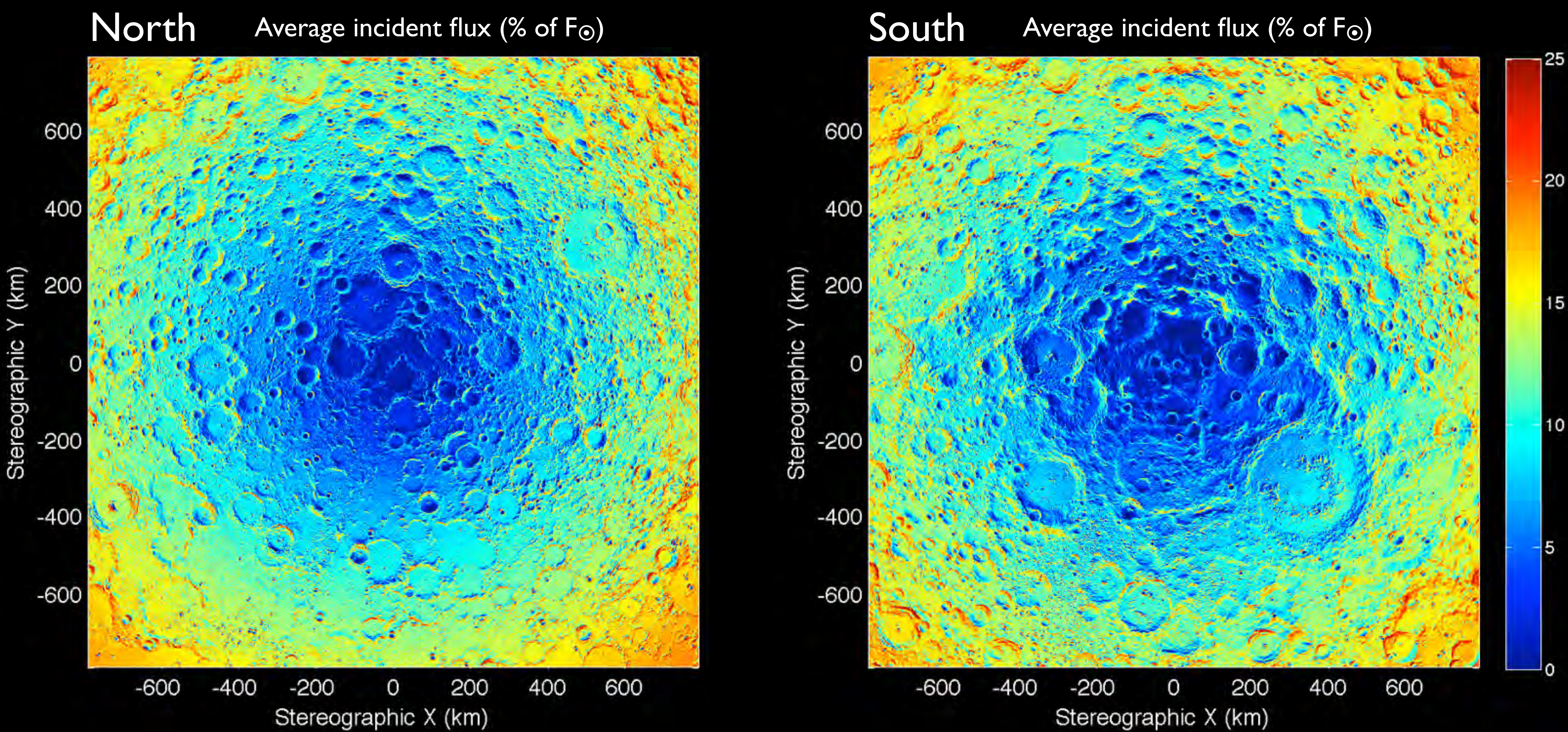
calculated over 18.6yr, 1h timestep
starting in 2020

Polar Illumination
Illumination Results



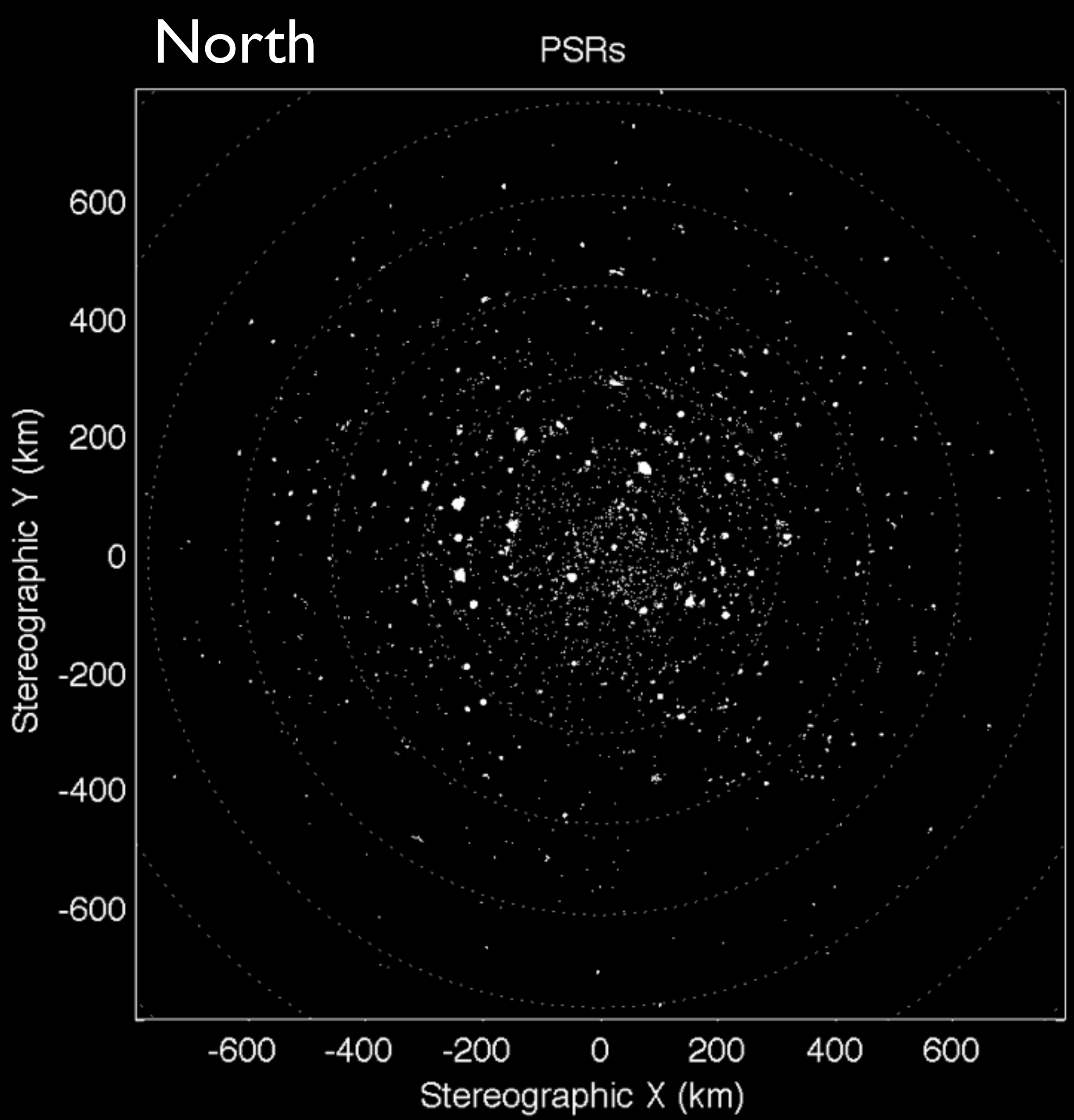
calculated over 18.6yr, 1h timestep
starting in 2020

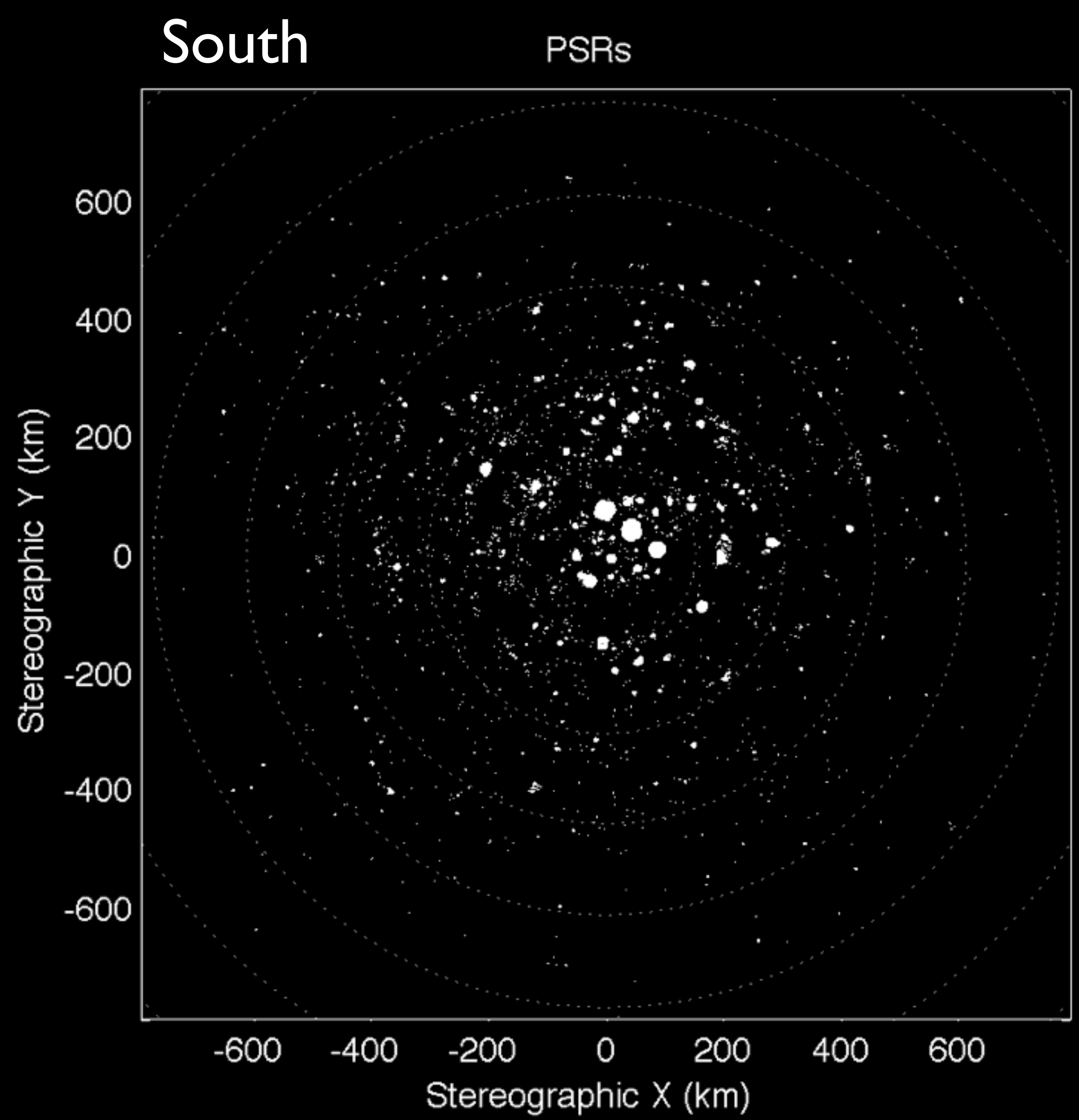
Polar Illumination
Illumination Results



calculated over 18.6yr, 1h timestep
starting in 2020

Polar Illumination
Areas in permanent shadow





calculated over 18.6yr, 1h timestep
starting in 2020

Polar Illumination
Area in permanent shadow

area (km^2) / region	Mazarico et al. (2011), 240m/px	Updated LOLA map, 240m/px	Updated LOLA map, 120m/px	Updated LOLA map, 60m/px	Updated LOLA map, 20m/px
>82.5° N	9670	10894	12335	13662	-
>85° N	5088	5609	6365	7025	-
>87.5° N	1811	1929	2137	2305	2830
>89° N	321	349	381	409	501
>82.5° S	12491	13217	14180	15374	-
>85° S	7106	7377	7774	8260	-
>87.5° S	3668	3735	3827	3928	4401
>89° S	428	441	463	488	572

Low -coverage or low-resolution topographic model can significantly underestimate total area in permanent shadow is

Illumination Modeling
Beyond illumination

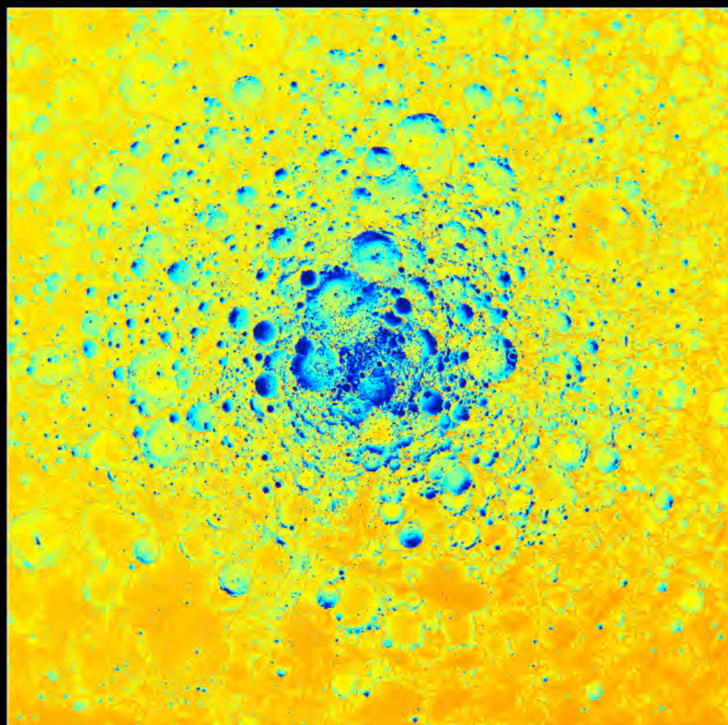
- Illumination modeling is a tool that can be used to benefit multiple types of work.

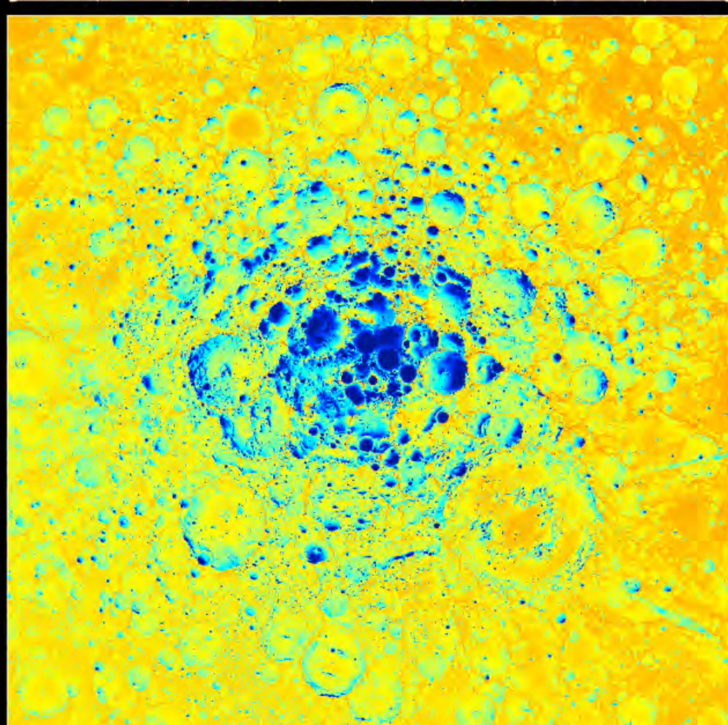
- Science data analysis
  - illumination products as new datasets to study concurrently (LEND, LAMP)
  - illumination state of FOV at time of measurement (LOLA, LEND)
  - measurement calibration by accounting for all illumination sources (LAMP)

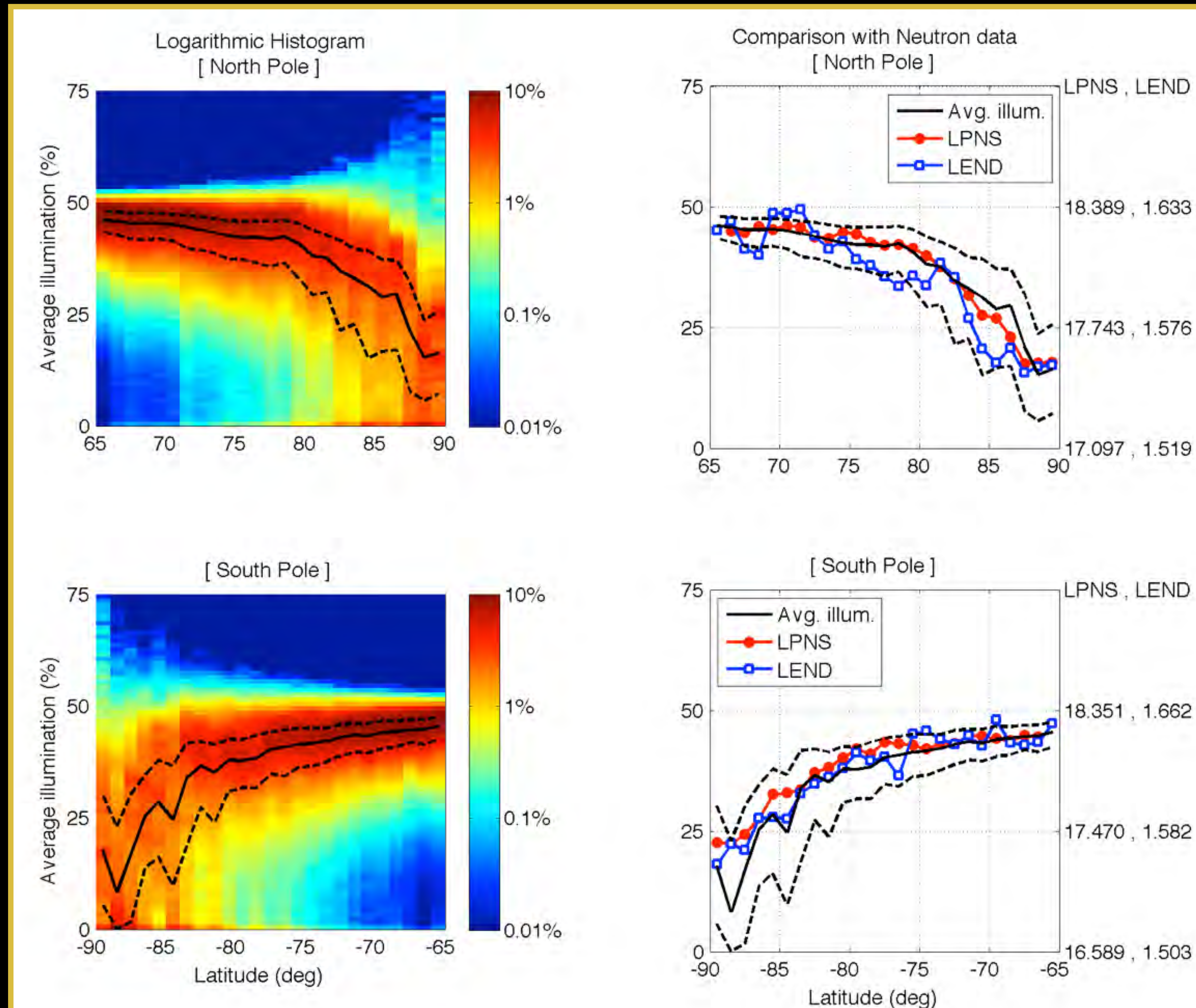
- Science data acquisition
  - optimal times and parameters for PSR imaging (LROC)
  - finding new opportunities for volatile observations

- Exploration
  - Earth visibility modeling
  - illumination prediction as input for best site selection

Support for Science
Correlation with neutron data

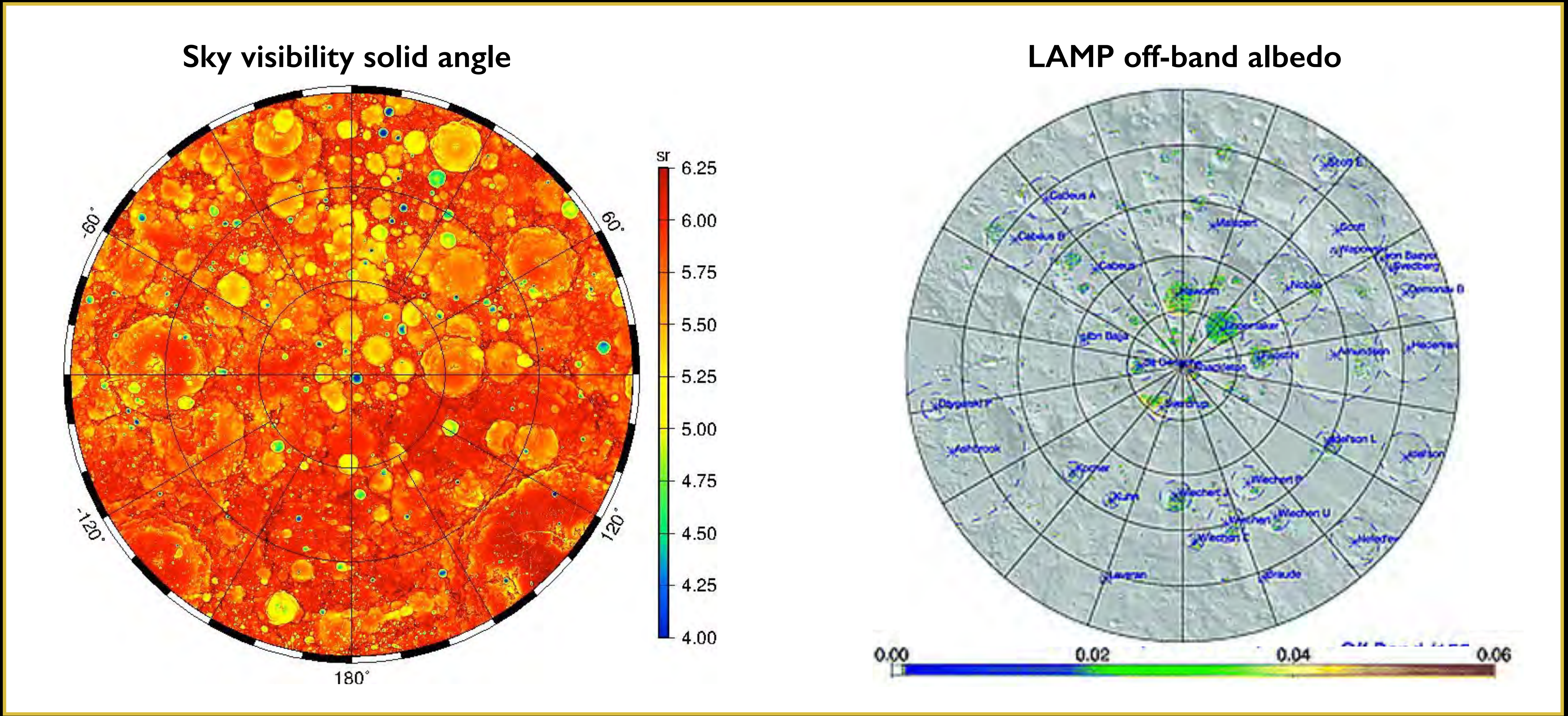






Support for Science
LAMP: surface UV albedo

- LAMP on LRO measures the starlight reflected from shaded areas
- to create albedo maps, which can detect surface frost for instance, one needs to account for the incident flux
- the amount of sky visible can help correct the IPM Ly-α flux map



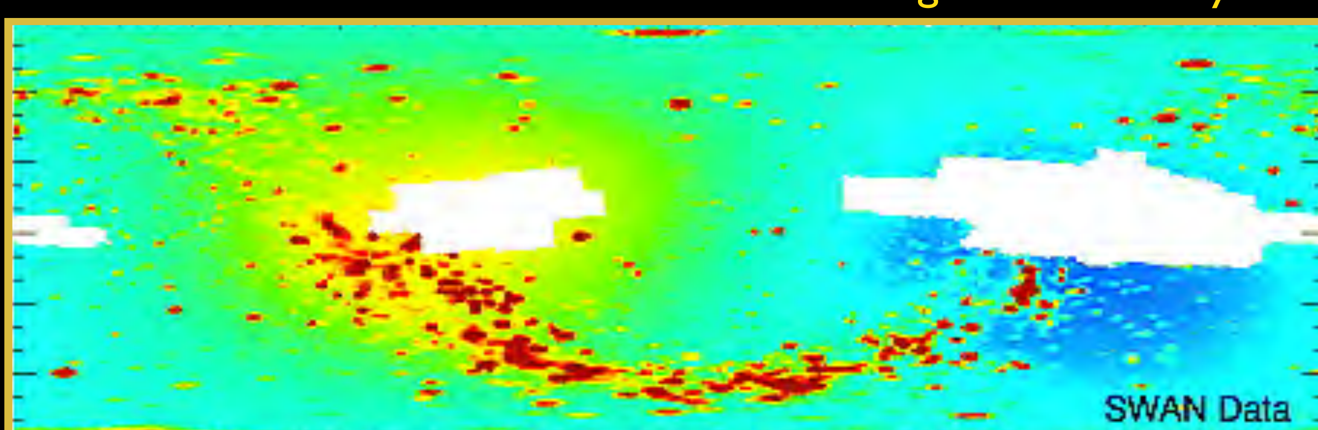
Gladstone et al., 2012

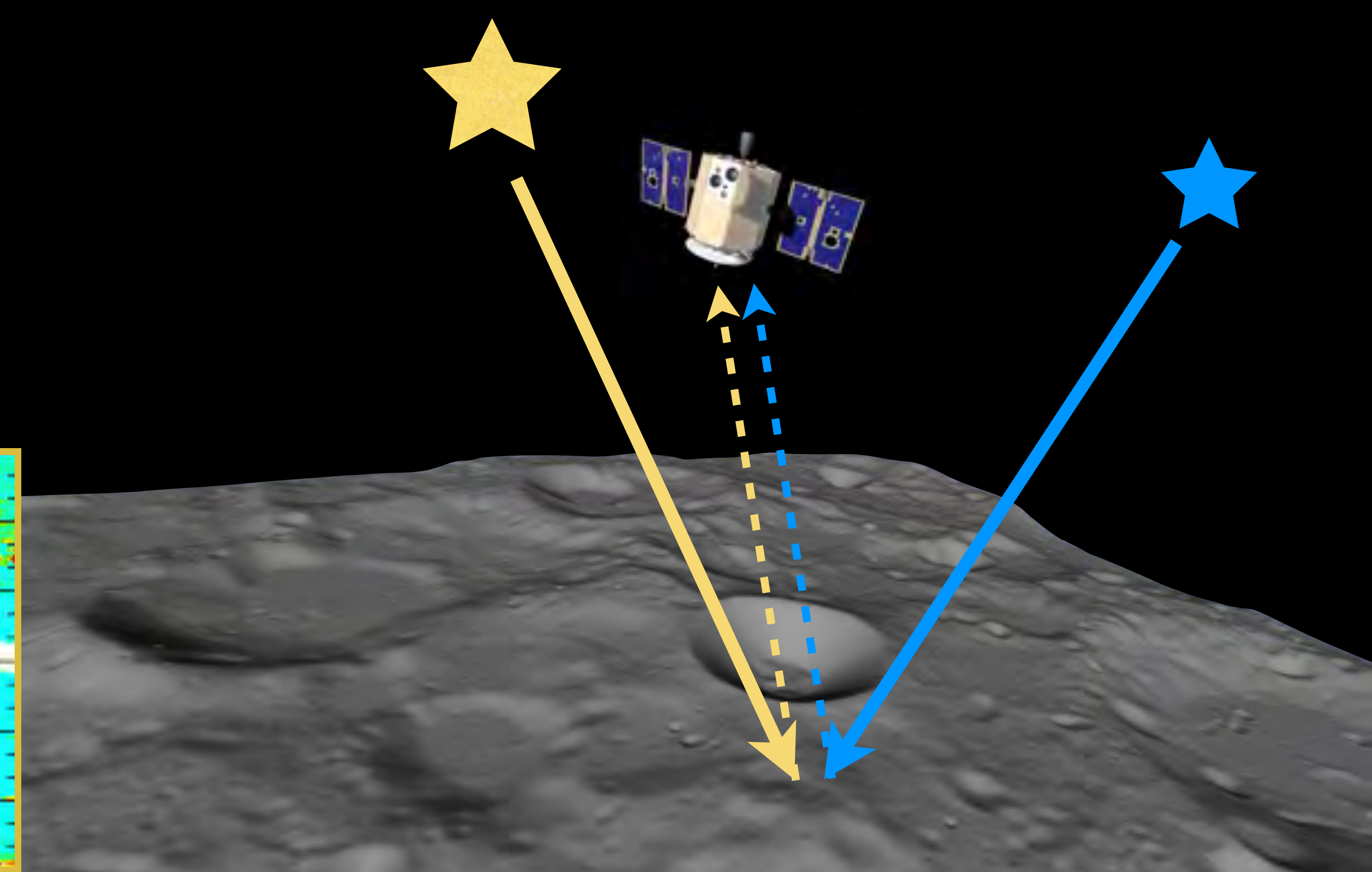
Science Data calibration
LAMP: improved correction

- But going further, we can perhaps improve the corrections to the received flux calculations by:
  - avoiding the need to do a degree-2 fit of the IPM background
  - calculating the contribution of the UV-bright stars, which can reach 10+% of the total flux
  - taking into account the UV from Earthshine which is important in certain geometries

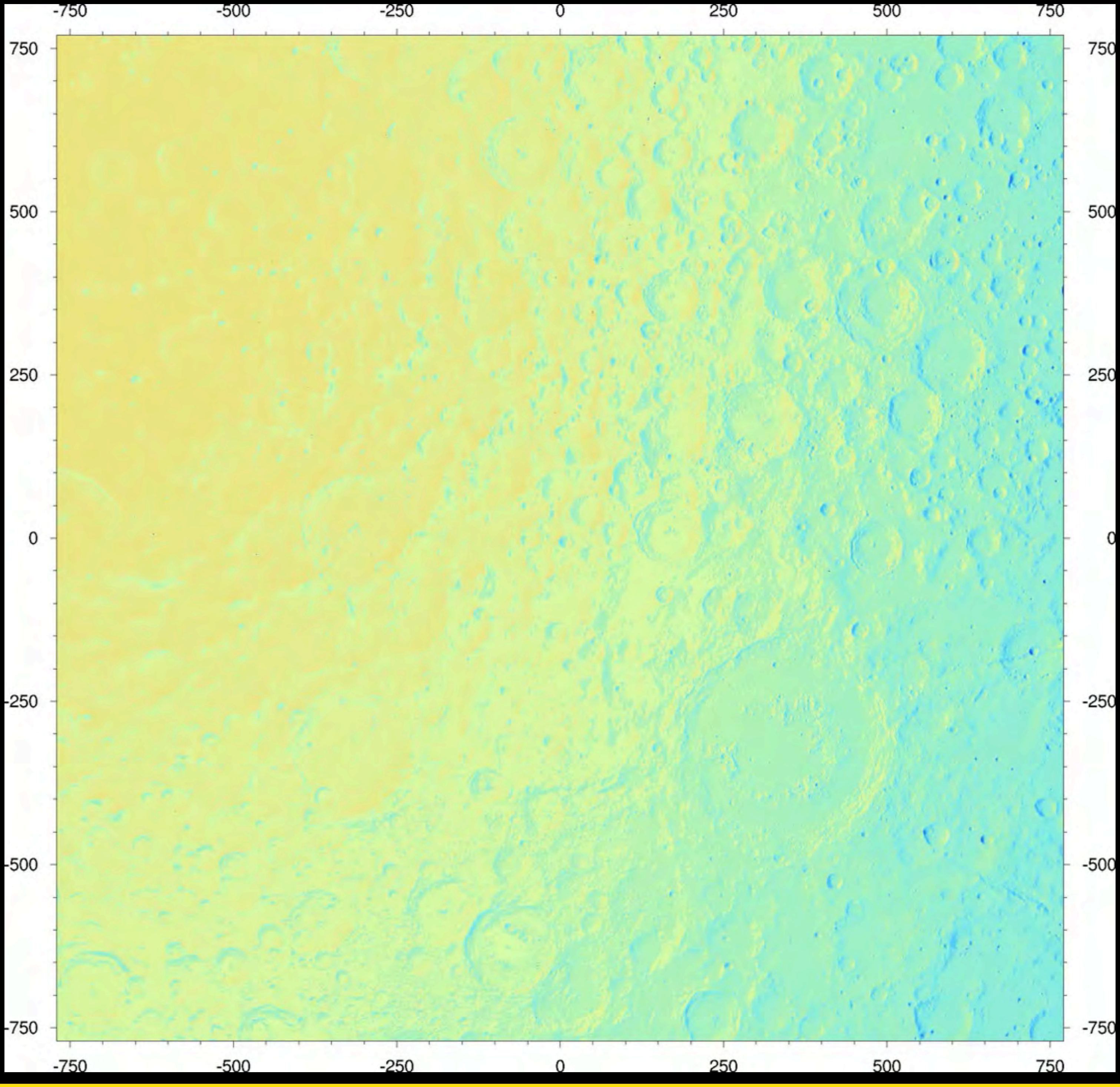
Earthshine in UV

High-resolution Ly-α



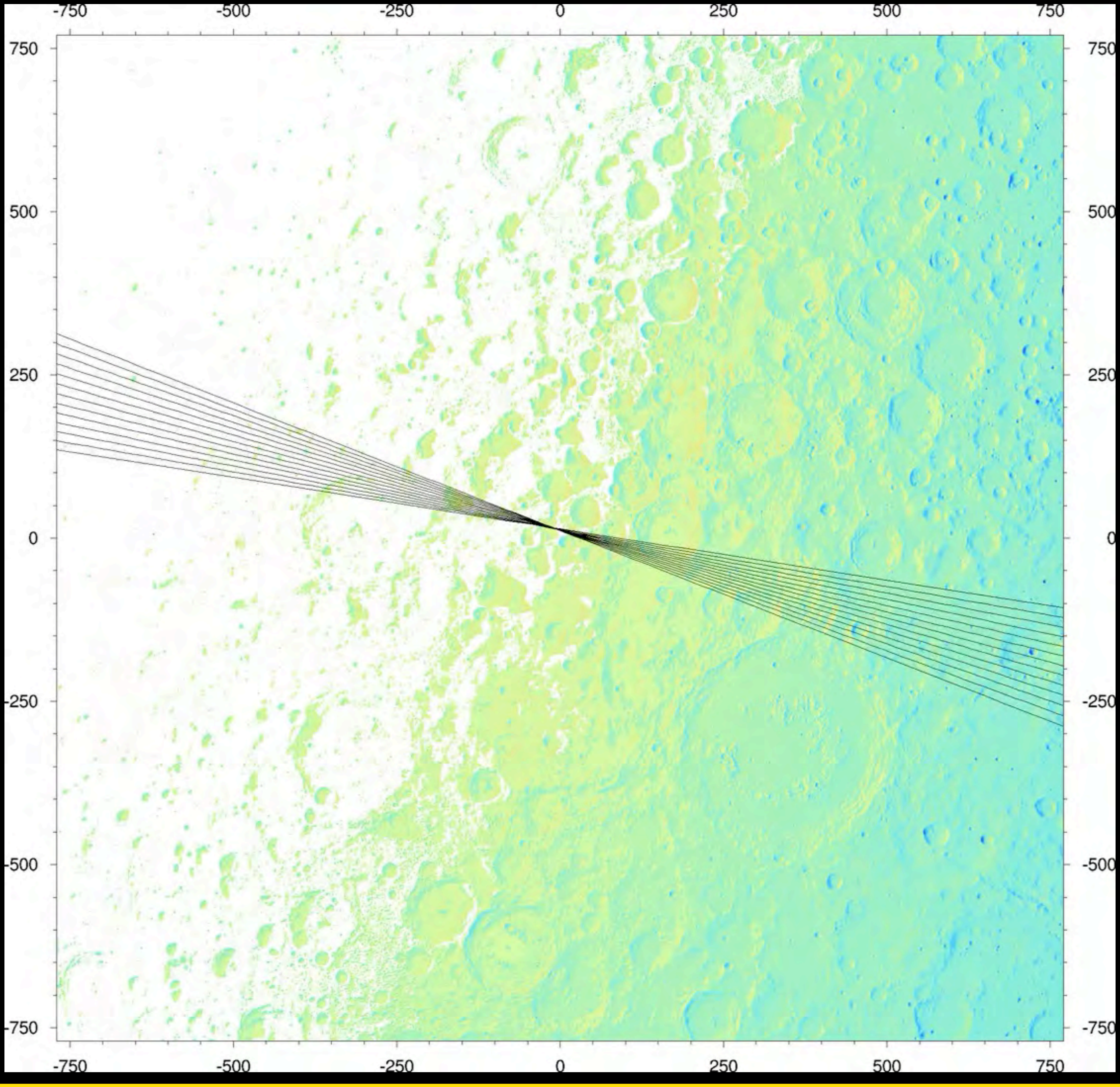


Science Data calibration
Example: UV flux on surface



- This movie shows the total incident flux from the 1,000 UV star sources.
- It appears to be dominated by a few bright stars.

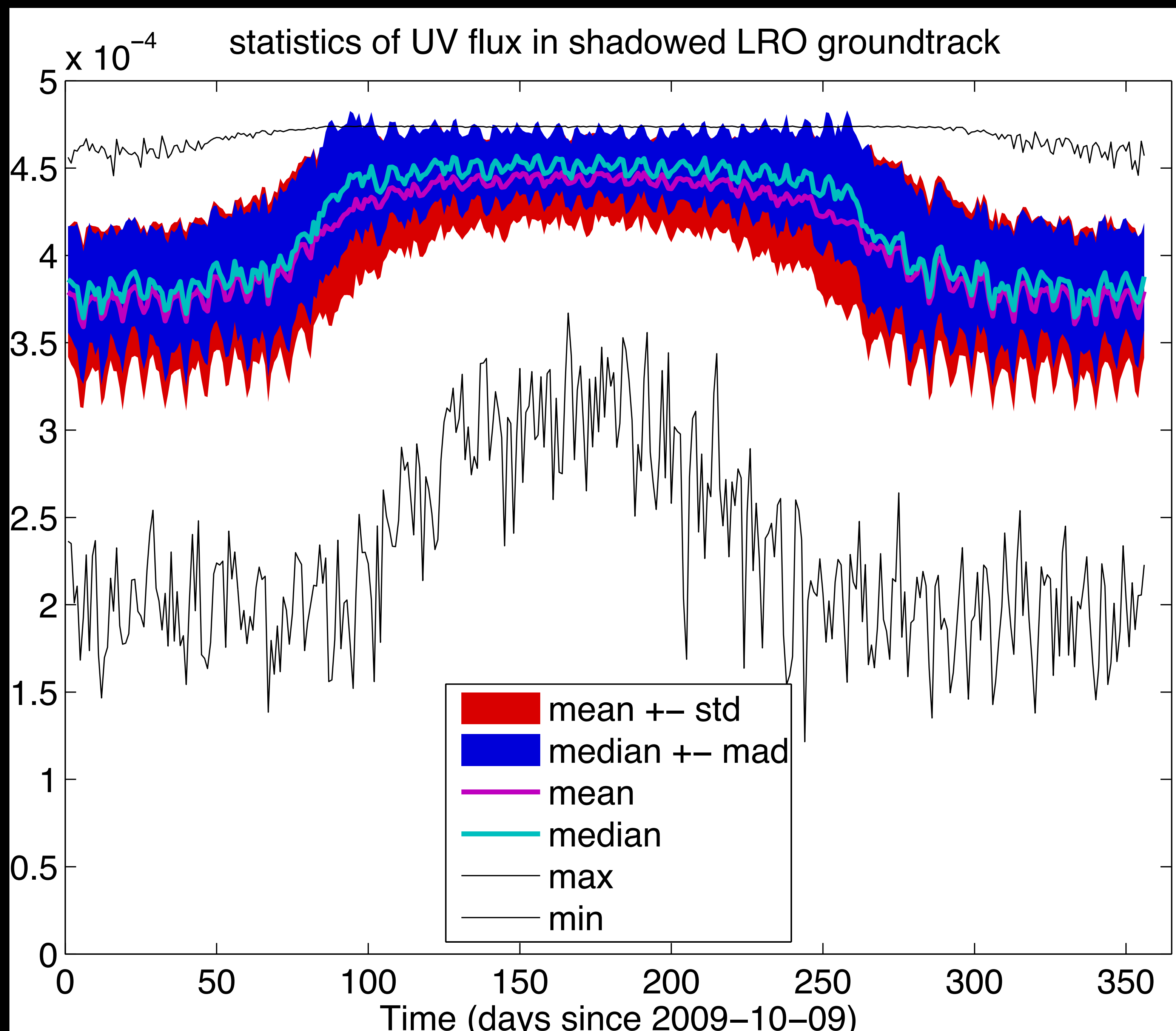
Science Data calibration
Example: what LRO samples



- The sunlit regions are now white, and the LRO orbits each day in black.
- A yearly signal appears due to the LRO orbit (beta angle)

Science Data calibration
Example: UV flux time series

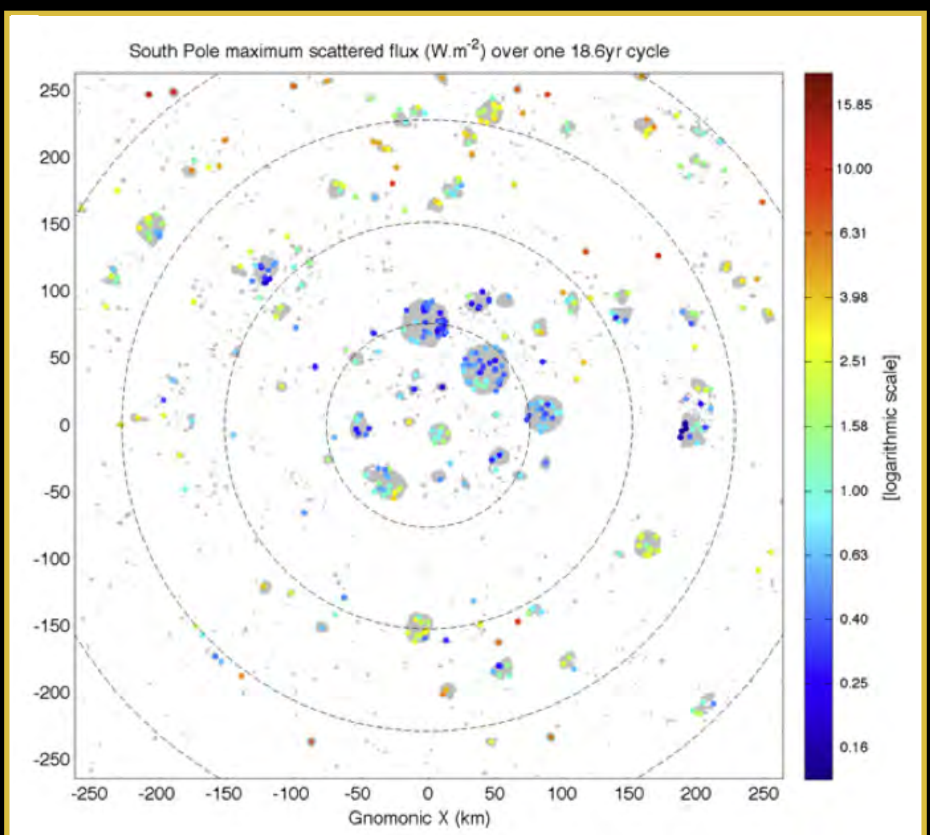
• An illumination model can predict the received UV flux at LRO at each LAMP measurement time, and help go further in the analysis.



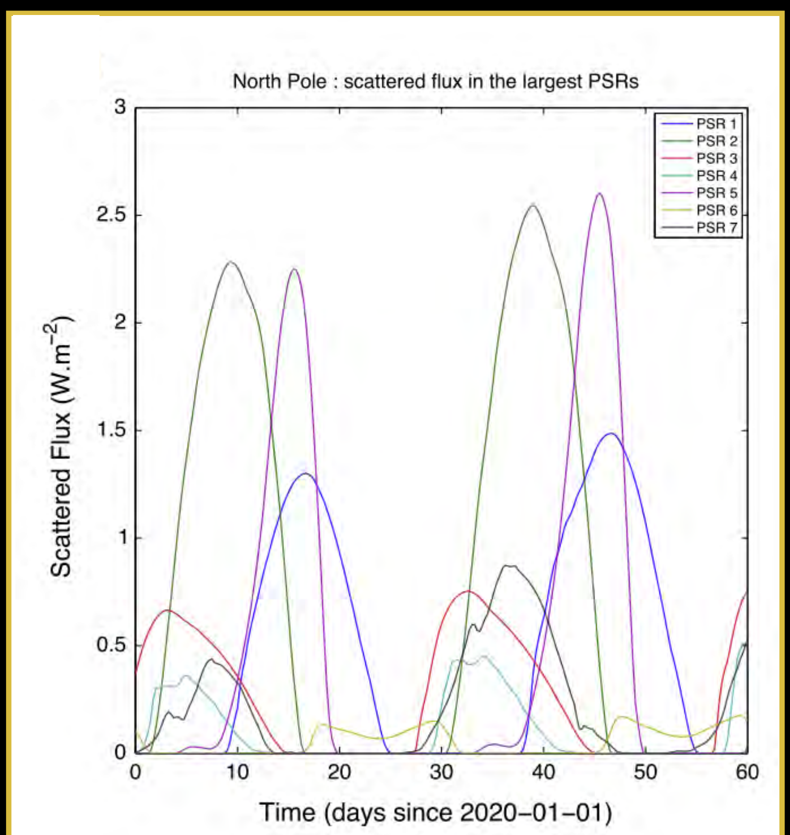
Science Data Acquisition
LROC NAC PSR campaign

- LROC is performing seasonal campaigns to image the largest PSRs with long-exposure imaging
  - LOLA illumination modeling of the scattered flux at certain locales can help provide quantitative metrics to optimize observation times during the campaign

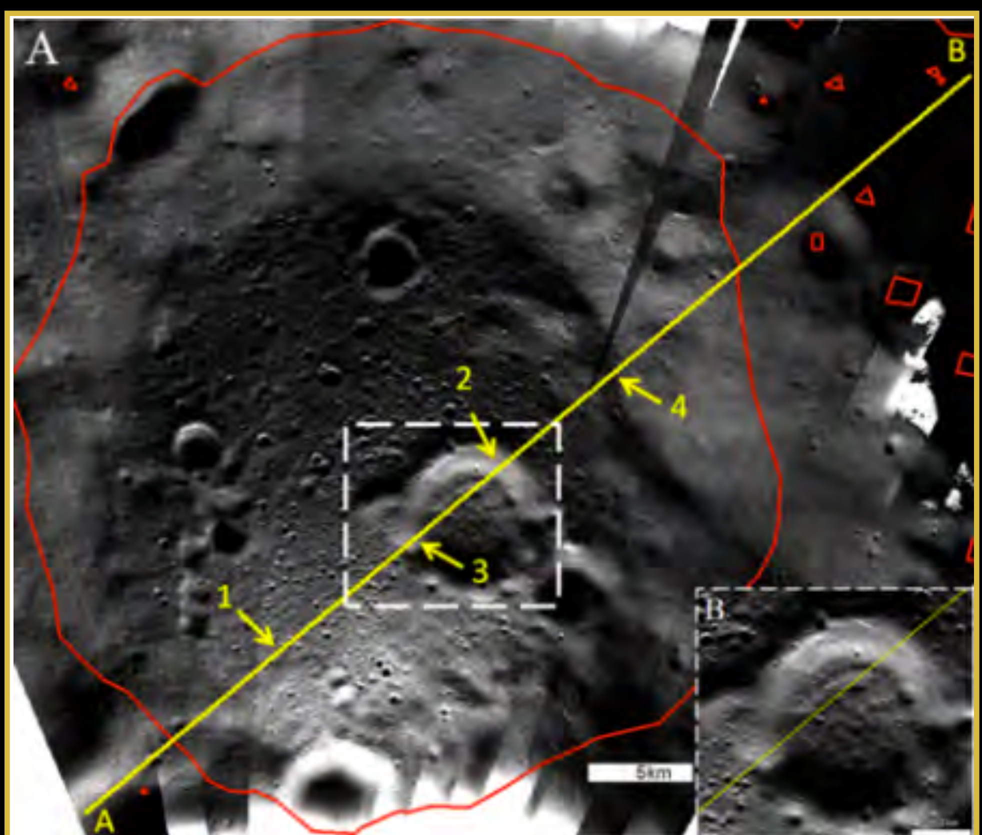
- Scattered flux simulations could also be helpful for future rover sorties into PSRs



Mazarico et al., 2011

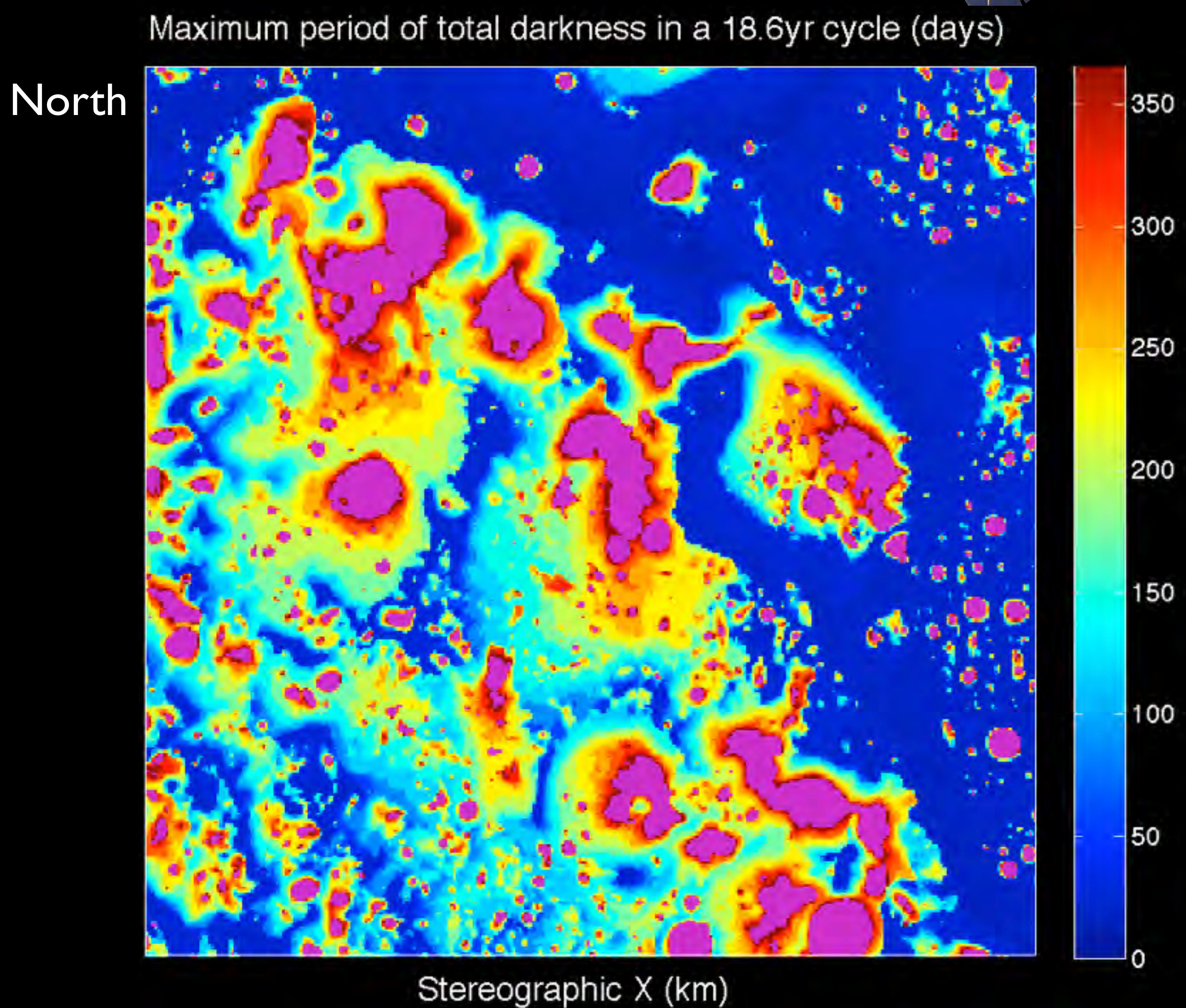


Mazarico et al., 2011



Koeber and Robinson, LPSC 2013

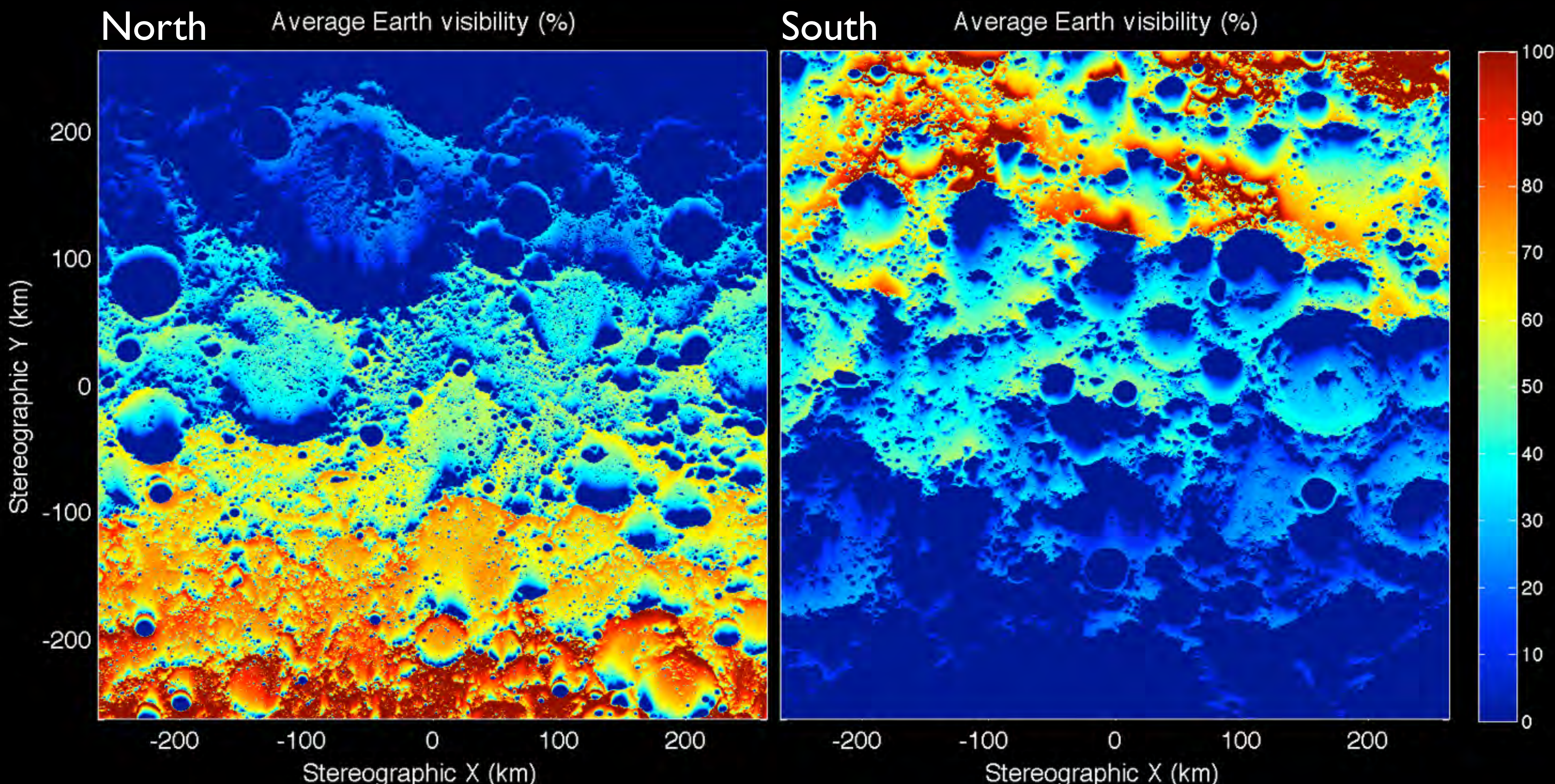
Science Data Acquisition
New opportunities



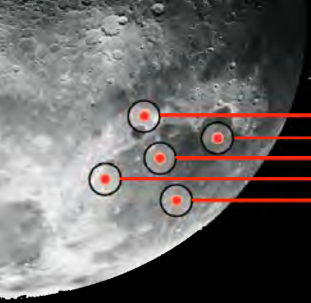
- large regions are shadowed for long periods and could be visited as environment transitions

Support for Exploration
Earth visibility

- same modeling can be used to assess Earth visibility for mission design

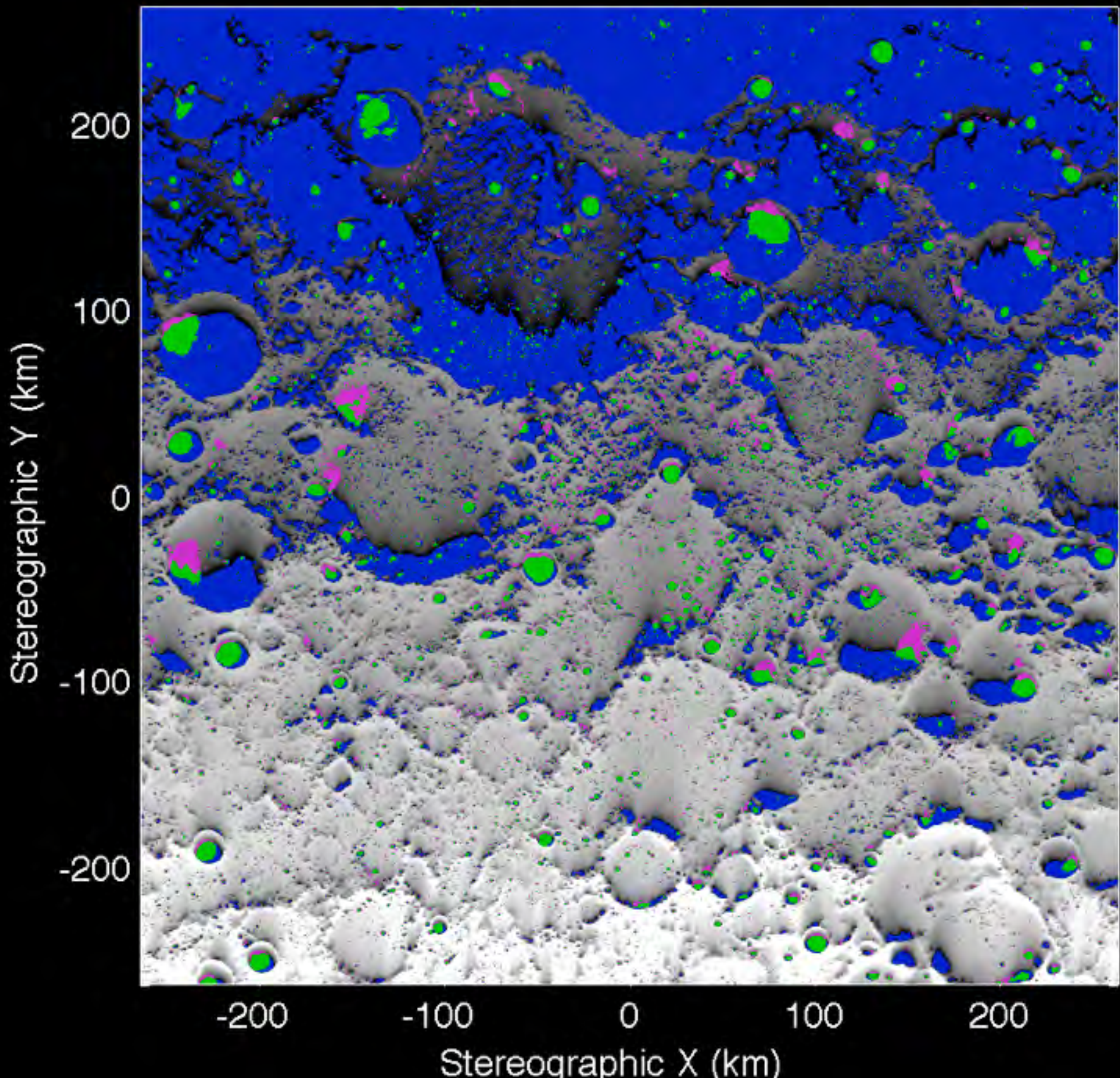


- few/no high-illumination or PSR area with better-than-average Earth visibility

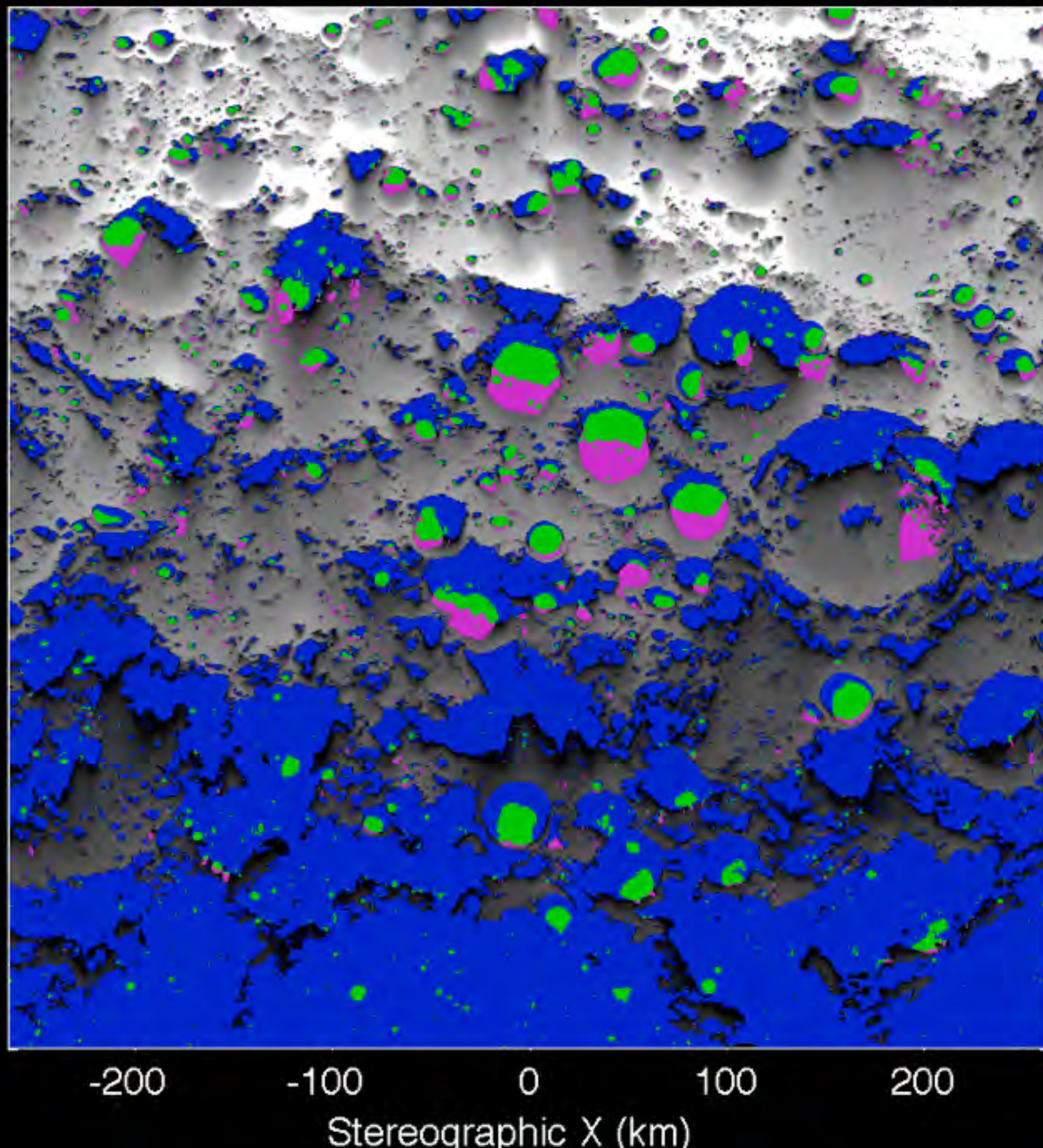


Support for Exploration
Earth visibility

North

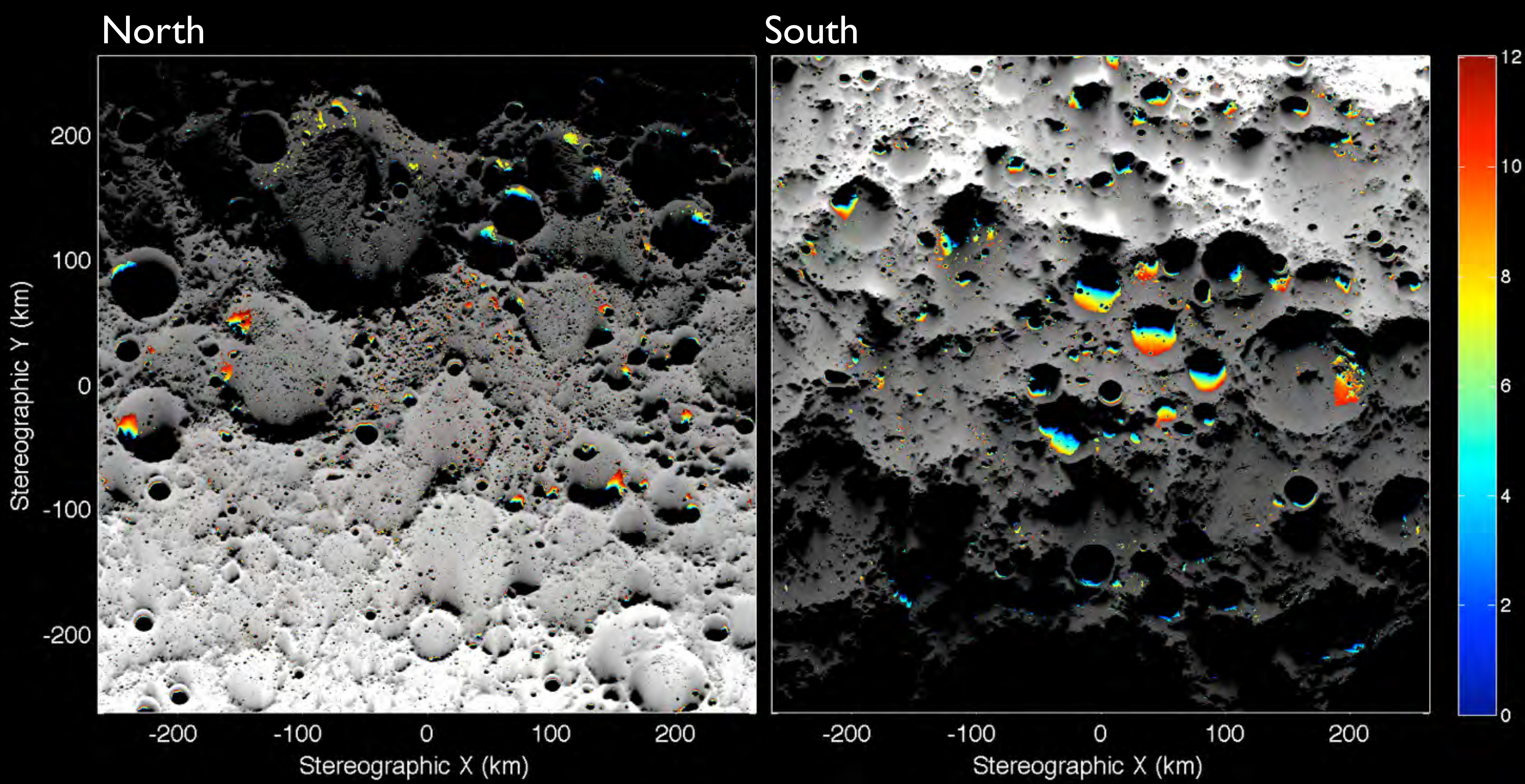


South



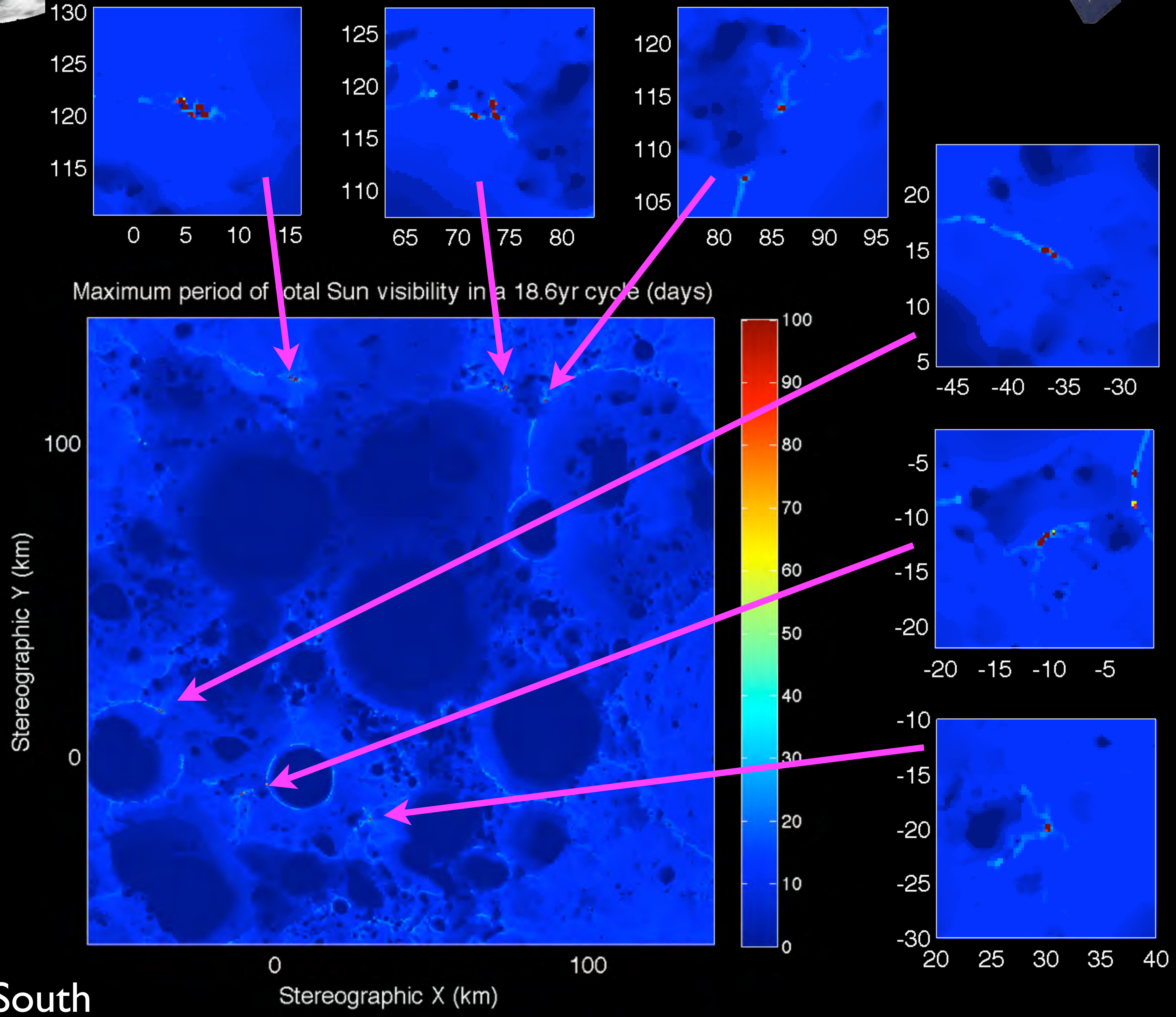
■ 0% Earth visibility ■ 0% Sun visibility ■ = ■ + ■

Support for Exploration
Earth visibility



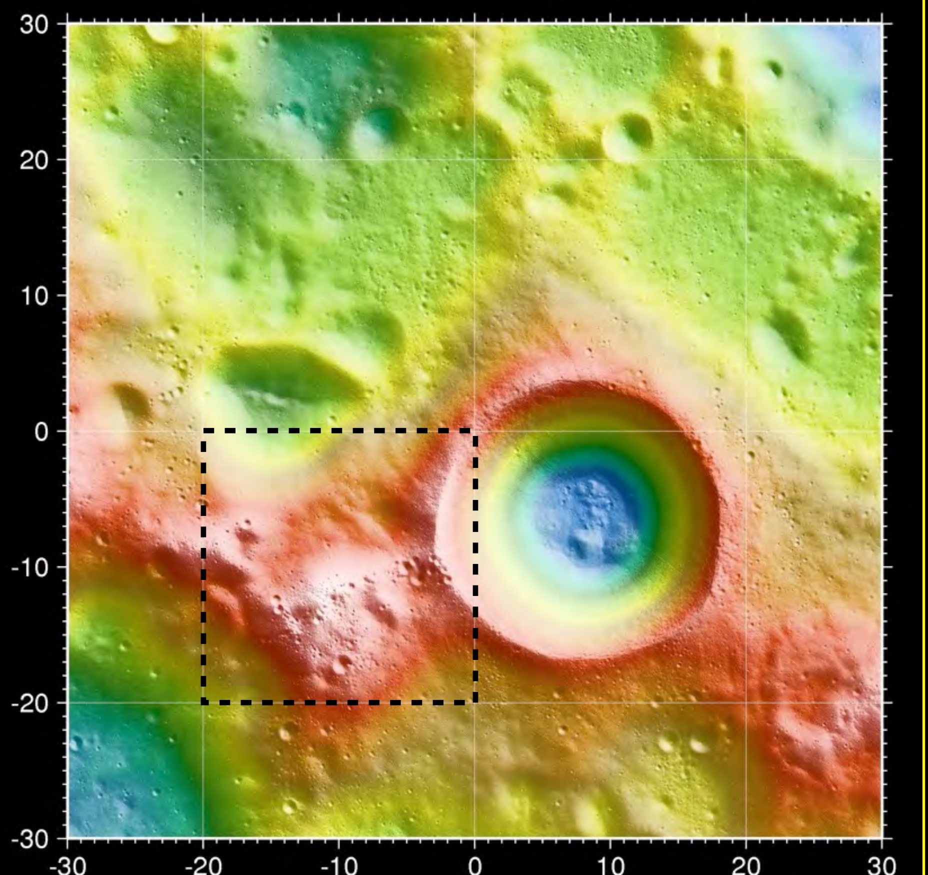
• longest period of Earth visibility (even partial) in PSRs maxima: 13.25d (North) and 11.75d (South)

Support for Exploration
High-illumination Areas



High-resolution modeling

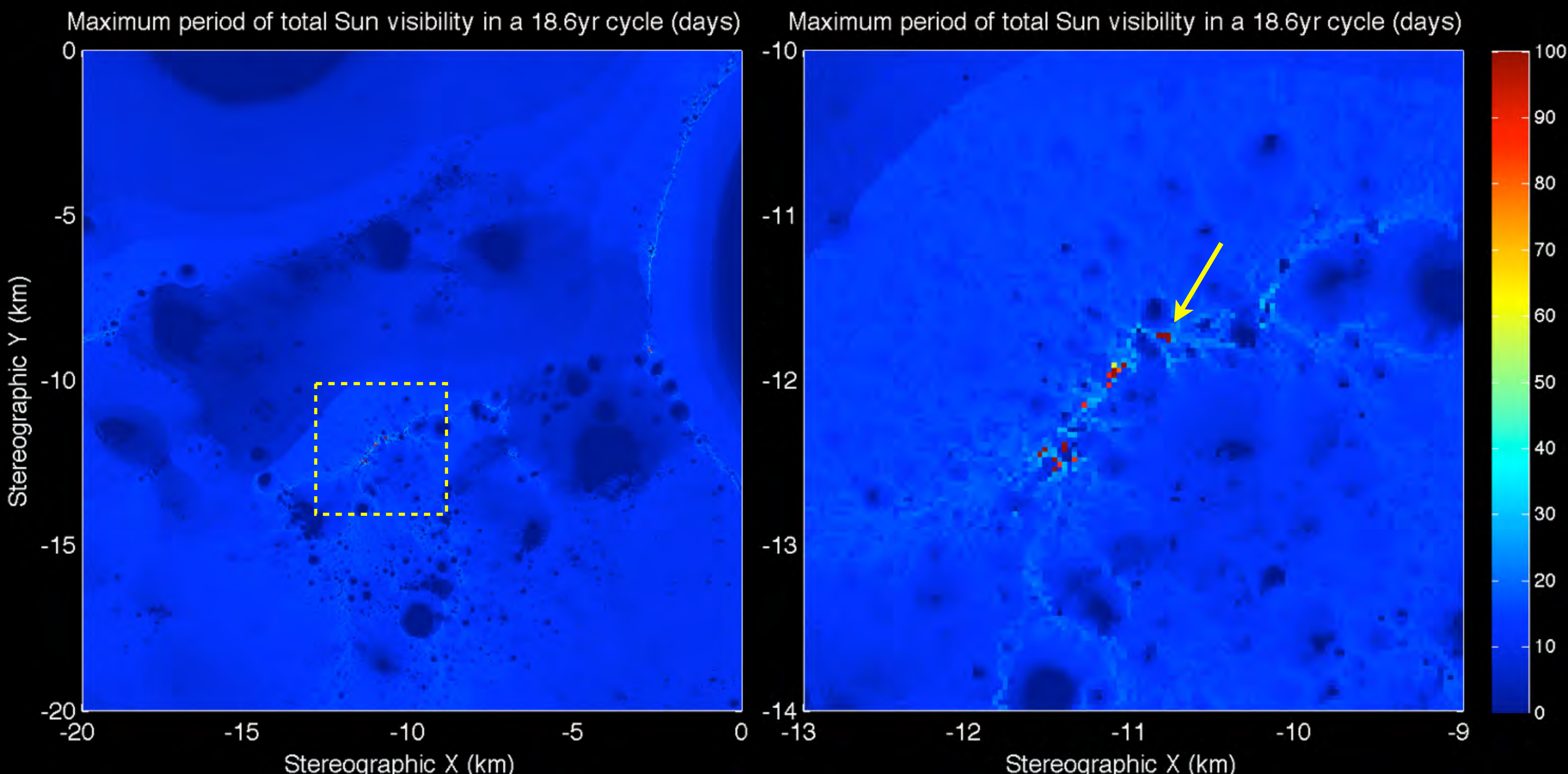
Focused high-res model:
- underlying DEM is 10mpp
- simulation output is 30mpp



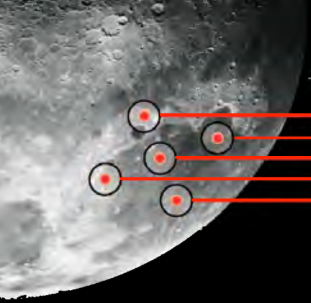
South

Support for Exploration
High-resolution modeling

- at higher resolution, high-illumination areas are significantly reduced

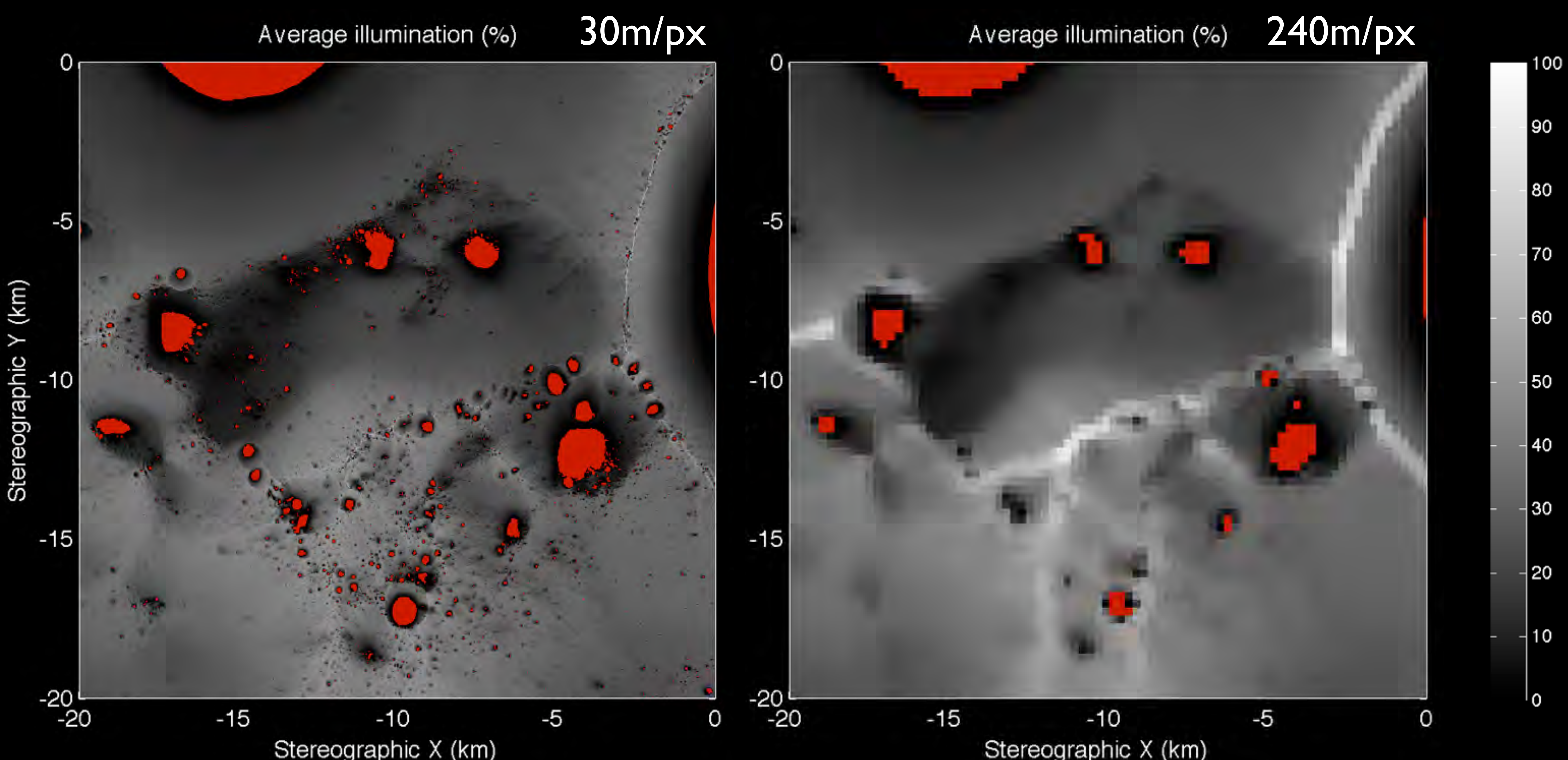


South



Support for Exploration
High-resolution modeling

- At the poles, high-resolution modeling shows much more area as PSR



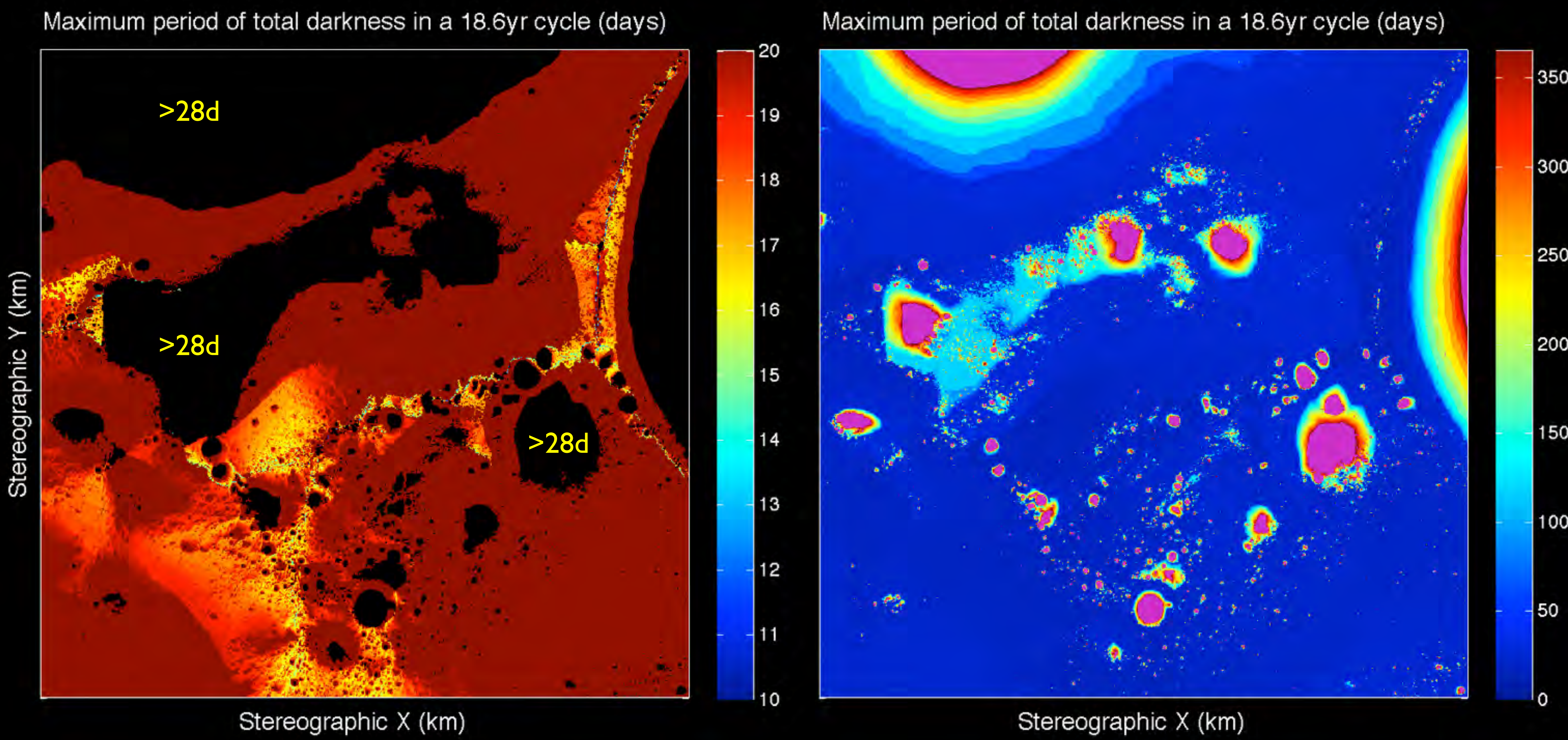
South

PSR ~ 14.53km^2

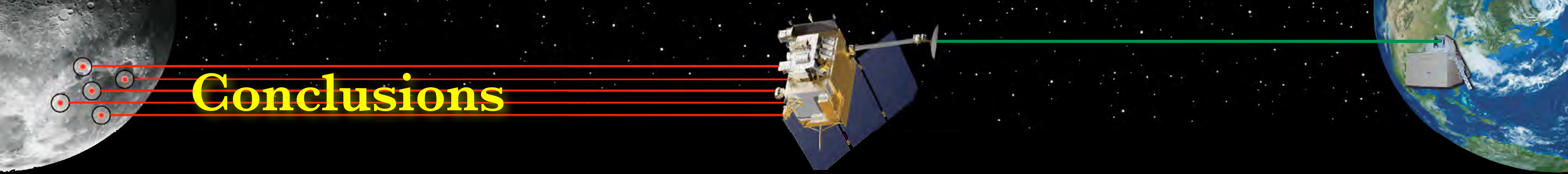
PSR ~ 9.56km^2

Support for Exploration
High-resolution modeling

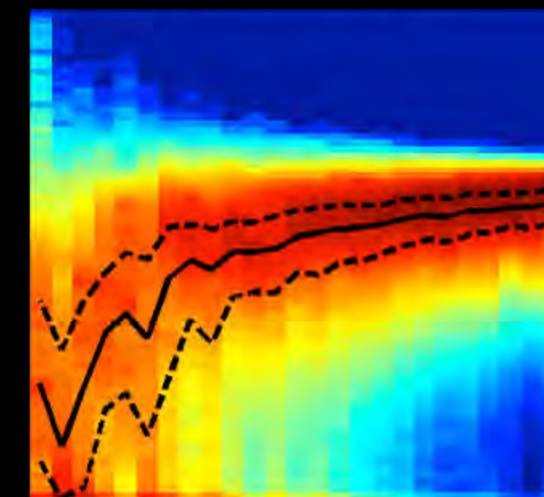
- Low-illumination areas near high-illumination sites



South



Conclusions



- LOLA provides excellent coverage of the lunar polar regions, allowing illumination studies over large areas and at high resolutions relevant to science and exploration.

- Illumination modeling allows a number of fruitful studies to:
  - inform science data collection
  - maximize science data return and analysis
  - plan and conduct surface mission operations