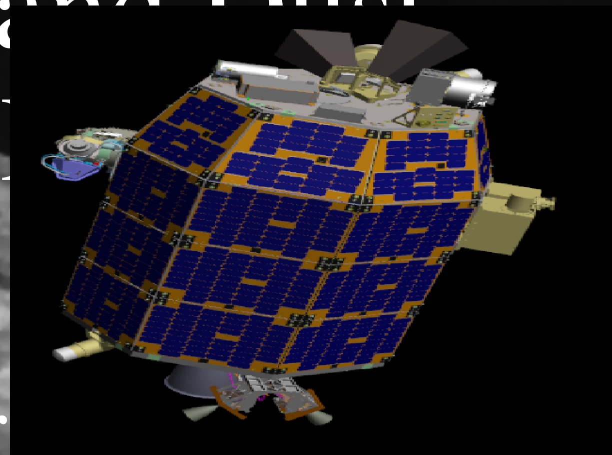
Barnstorming the Moon: Adventures of the Lunar Atmosphere and Dust Environment



Rick Elphic
LADEE Project Scientist
NASA Ames Research Center
On behalf of the LADEE Team

2014 Exploration Science Forum
21 July 2014

Lunar Exosphere/Dust Talks & Posters at ESF

The Latest From ARTEMIS: Halekas

Evidence for Diurnally Varying Hydration at the Moon's Equator from the Lunar Exploration Neutron Detector (LEND): Livengood

EXOSPHERES OVERVIEW: Variability of Helium, Neon, and Argon in the Lunar Exosphere as Observed by the LADEE NMS Instrument: Benna

Initial Results from the LADEE Ultraviolet-Visible Spectrometer: Colaprete

Propagation of Water in the Chang'e-3 Exhaust Plume from LADEE Observations: Hurley

LADEE/LDEX Observations of Pick-up Ion Variability in the Lunar Exosphere: Poppe

Lunar Volatile Transport in the Exosphere and from Impact Plumes: LRO/LAMP Observing Campaigns Coordinated with LADEE: Retherford

The Na and K Content of the Moon's Exosphere is Limited by the Impact Vaporization Rate: Sarantos

The Effects of Meteoroid Streams on the Lunar Environment: Observations from the LADEE Mission: Stubbs

Lunar Impact Ejecta Clouds Observed by LDEX: Horanyi

LADEE/LDEX Observations of Meteor Streams at the Moon: Szalay

Dust Around the Moon: Preliminary Results from the LADEE Ultraviolet Visible Spectrometer: Hermalyn

Lunar Exosphere/Dust Posters at ESF

Constraining refractory elements of the Moon's exosphere from LADEE measurements: Sarantos

ENAs Backscattering from Lunar Regolith: McLain

Martian planetary heavy ion sputtering of Phobos and Deimos: implications for the production of neutral tori: Poppe

LADEE UVS Observations of Solar Occultation: Exospheric Dust along lines-of-sight above the Dawn Terminator: Wooden

Ground-Based Lunar Meteoroid Impact Observations and the LADEE Mission: Day

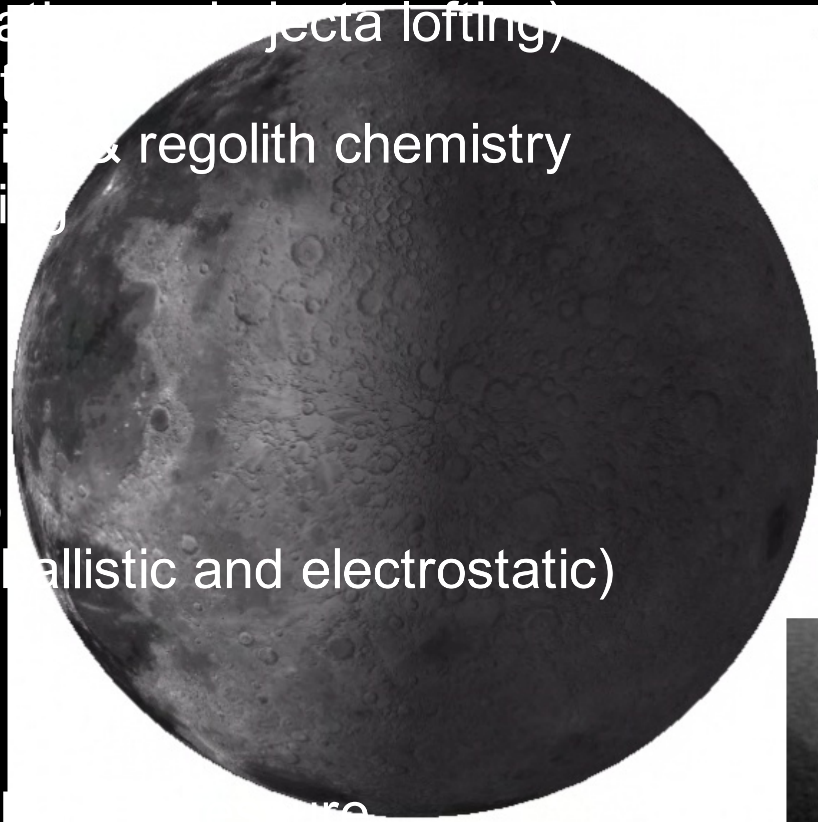
Properties of the Lunar Dust Exosphere as Seen by LDEX: Kempf

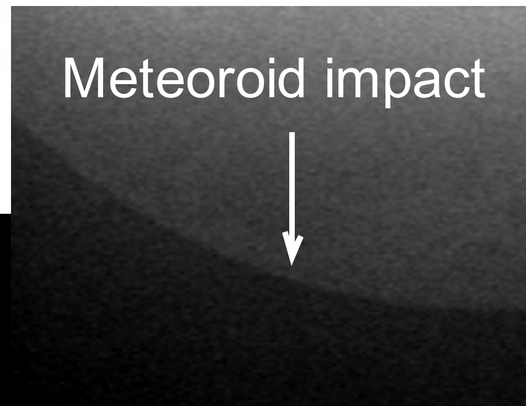
Many Processes at "Airless" Solar System Bodies

Sources:
- Photon-stimulated desorption
- Impact (vaporiza jecta lofting)
- Thermal desorpt
- Solar wind speci & regolith chemistry
- Interior outgassi
- Sputtering

Transport:
- Ballistic hops
- Photoion pickup
- Dust transport (allistic and electrostatic)

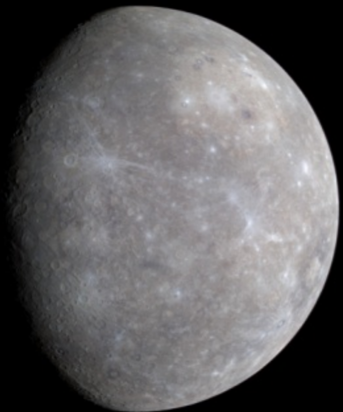
Losses:
- Photoionization
- Jeans escape/photon pressure
- Cold trapping (nightside and polar)





Surface-Boundary Exospheres

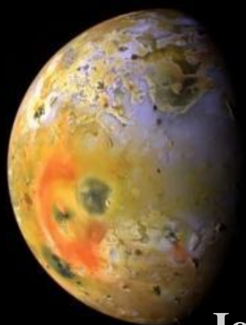
Moon



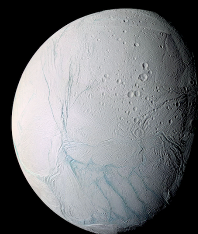
Mercury

Large Asteroids,
KBOs

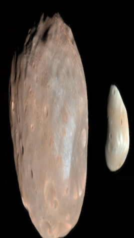
Europa &
other
moons



Io



Enceladus

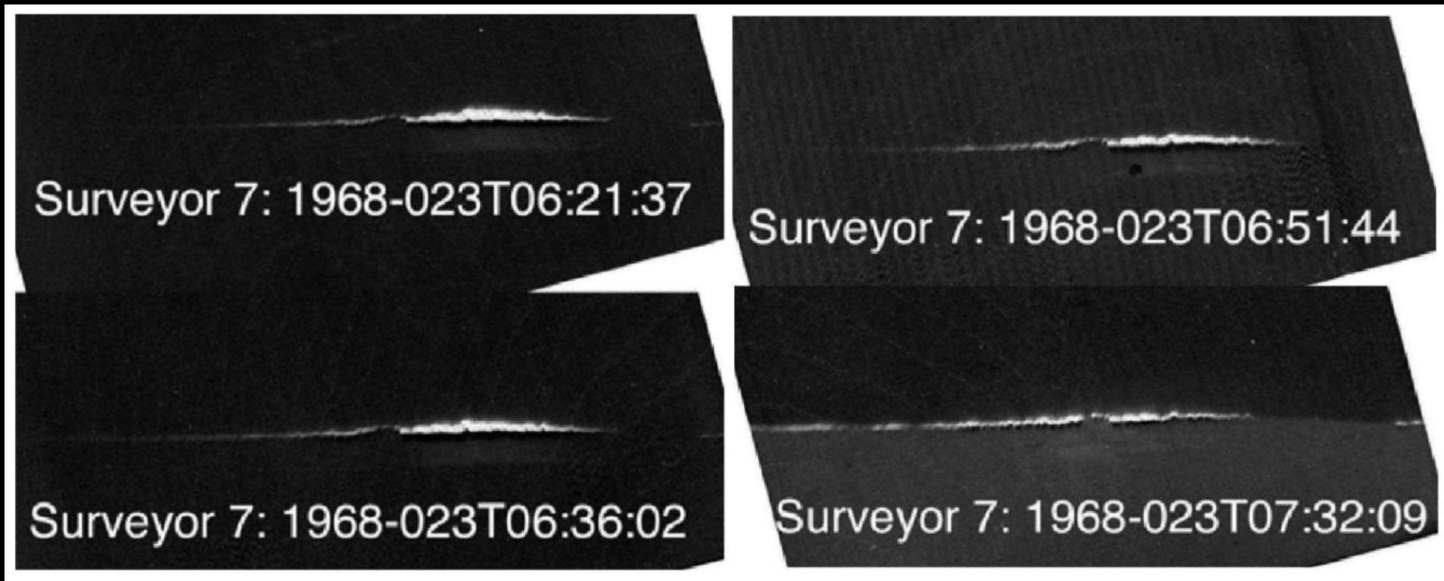


Phobos &
Deimos

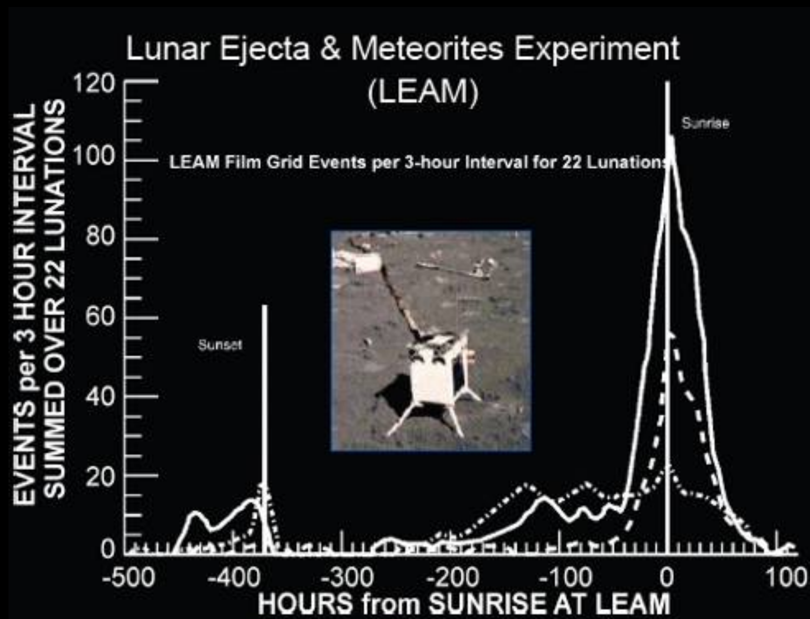
Surface-Boundary Exospheres (SBEs) may be the most common type of atmosphere in the solar system…

…and dust dynamics may occur at all these bodies as well.

A Dusty Lunar Sky?



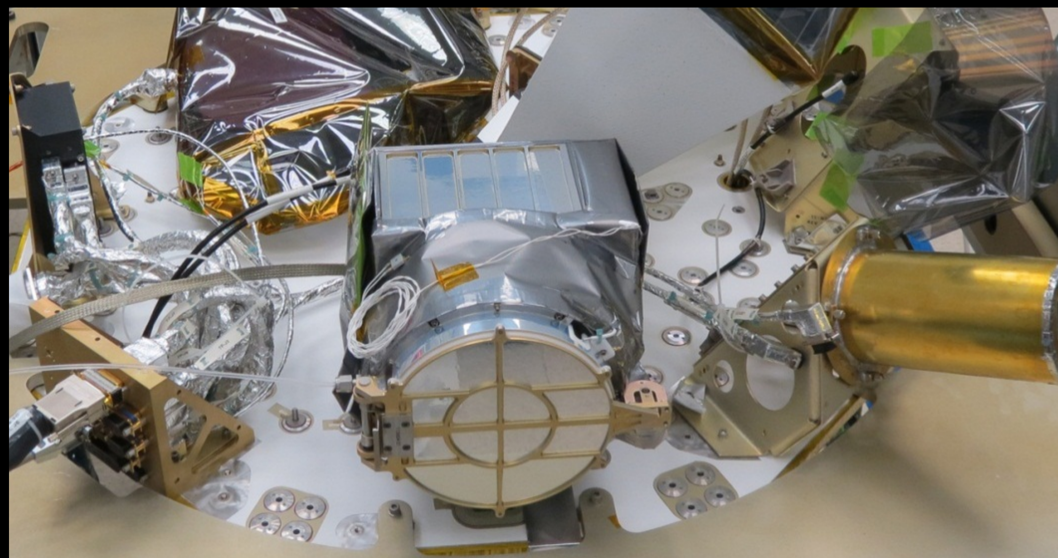
Apollo Astronaut sketch (G. Cernan)



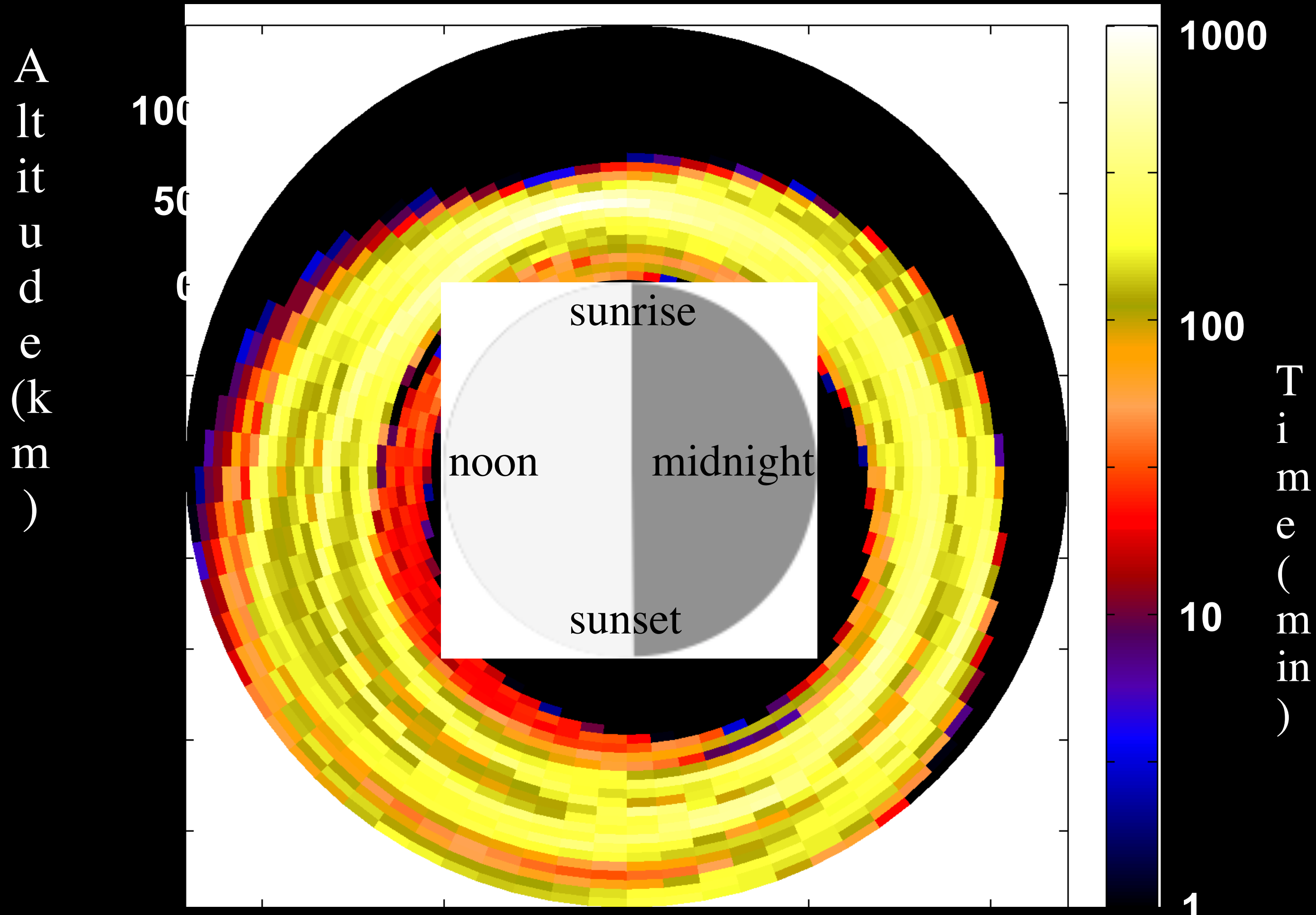
Berg et al., 1976

LADEE Science Payload

- Neutral Mass Spectrometer (NMS) measures in situ ambient lunar exospheric species (eg., Ar, He, Ne)
- Ultraviolet/Visible Spectrometer (UVS) measures emissions from exospheric species and scattered light from dust
- Lunar Dust Experiment (LDEX) measures in situ dust.

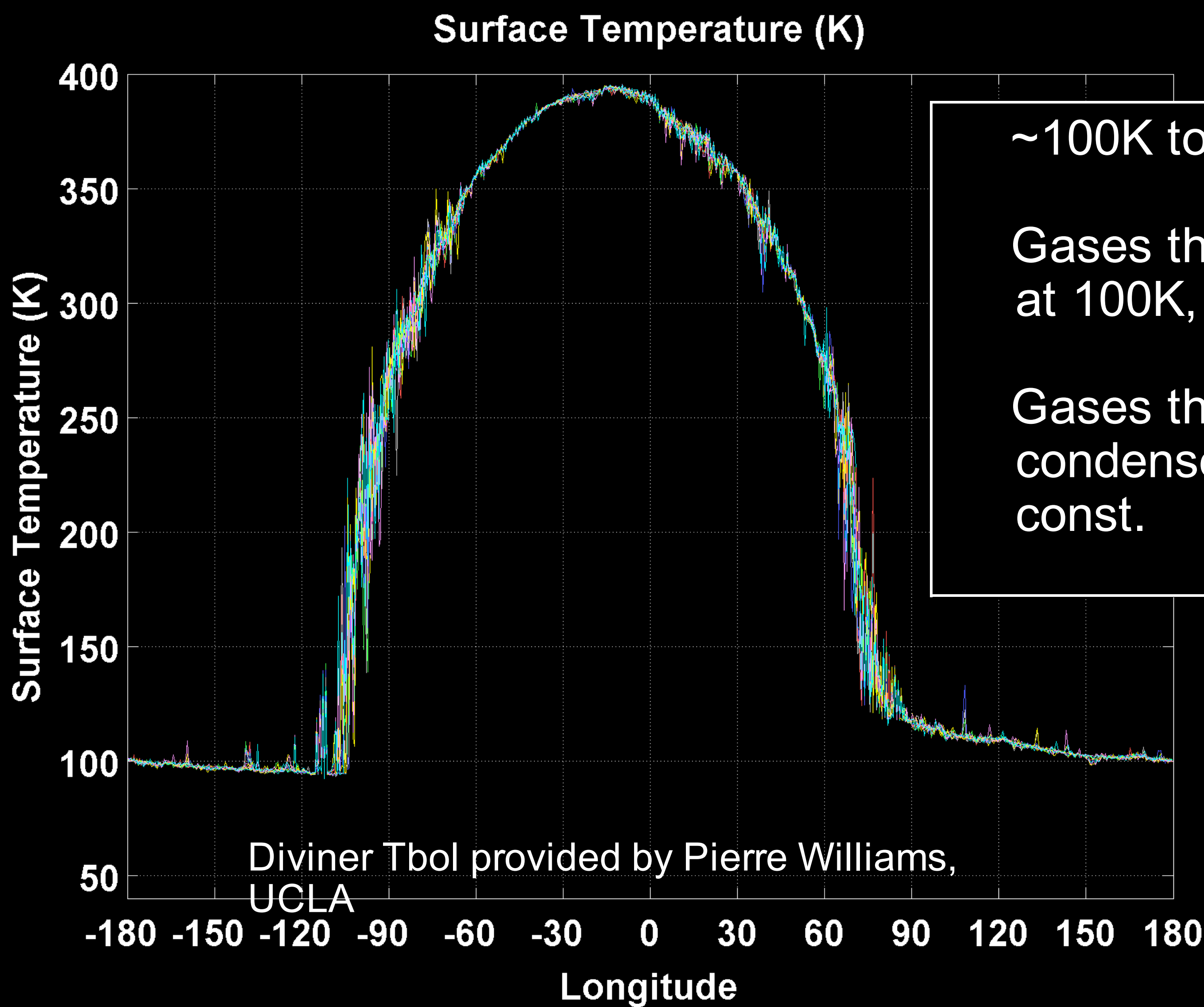


LADEE Science Orbit Coverage



5 km x 5 deg bins

Lunar Surface Temperatures



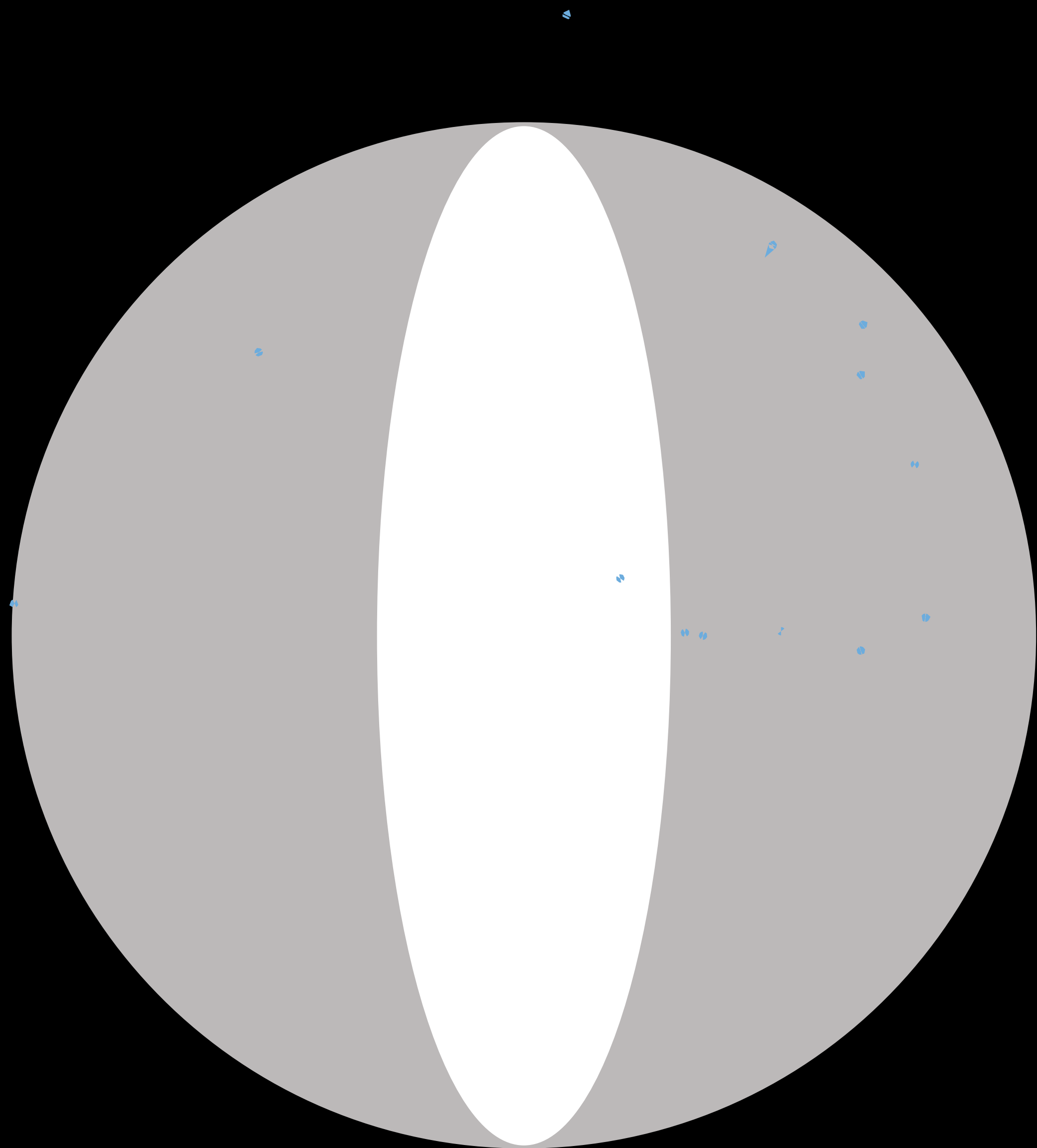
~100K to 390K at equator

Gases that can condense at 100K, will.

Gases that do not condense follow nT5/2 = const.

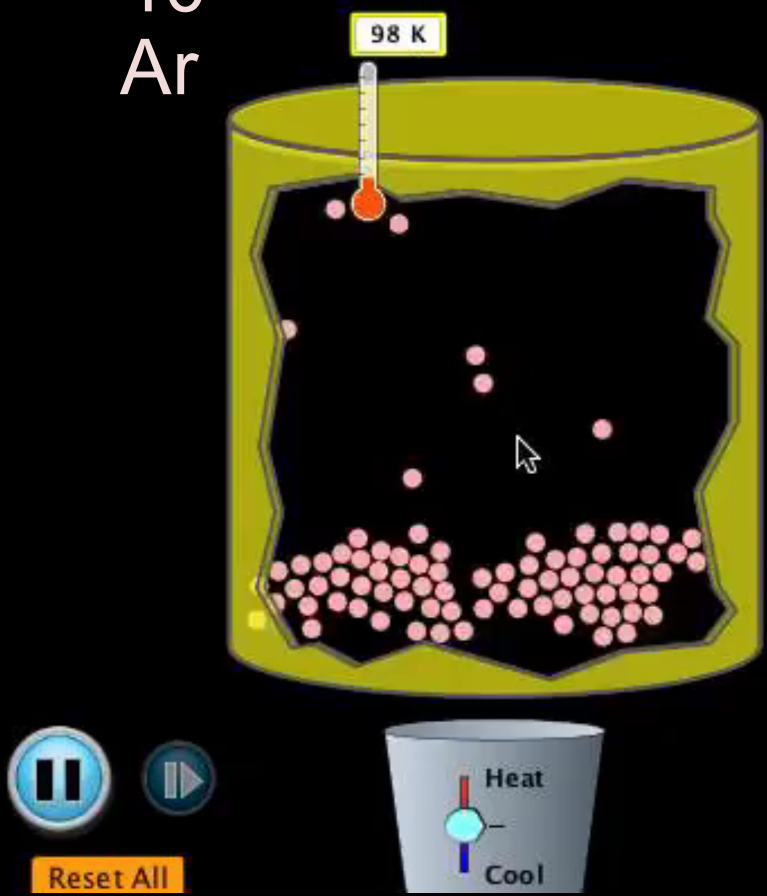
Path of Atoms in the Lunar Exosphere

Benna et al.,
LPSC, 2014

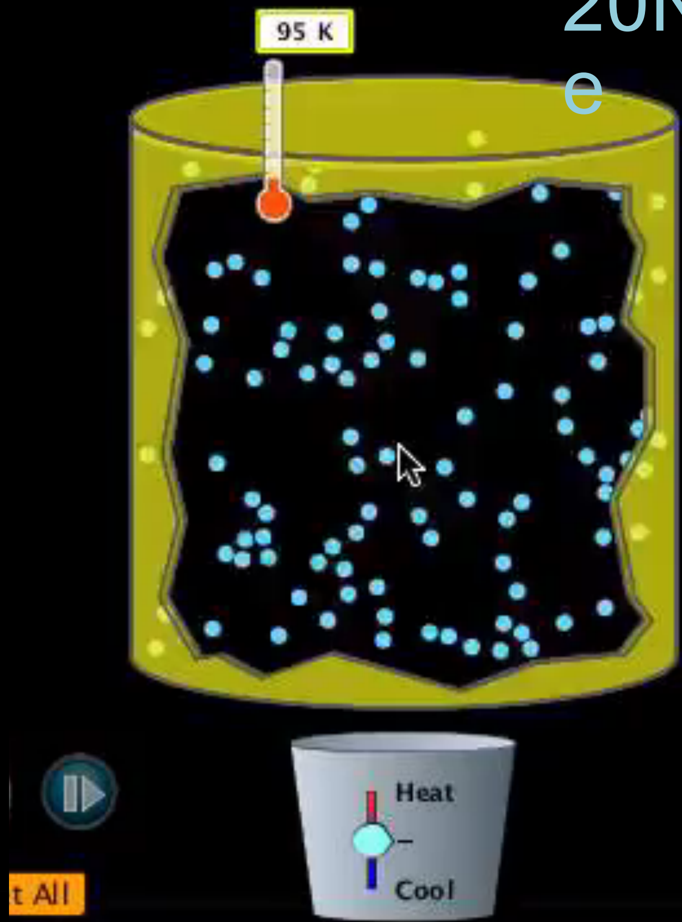


Condensable and Non-condensable Gases

40
Ar

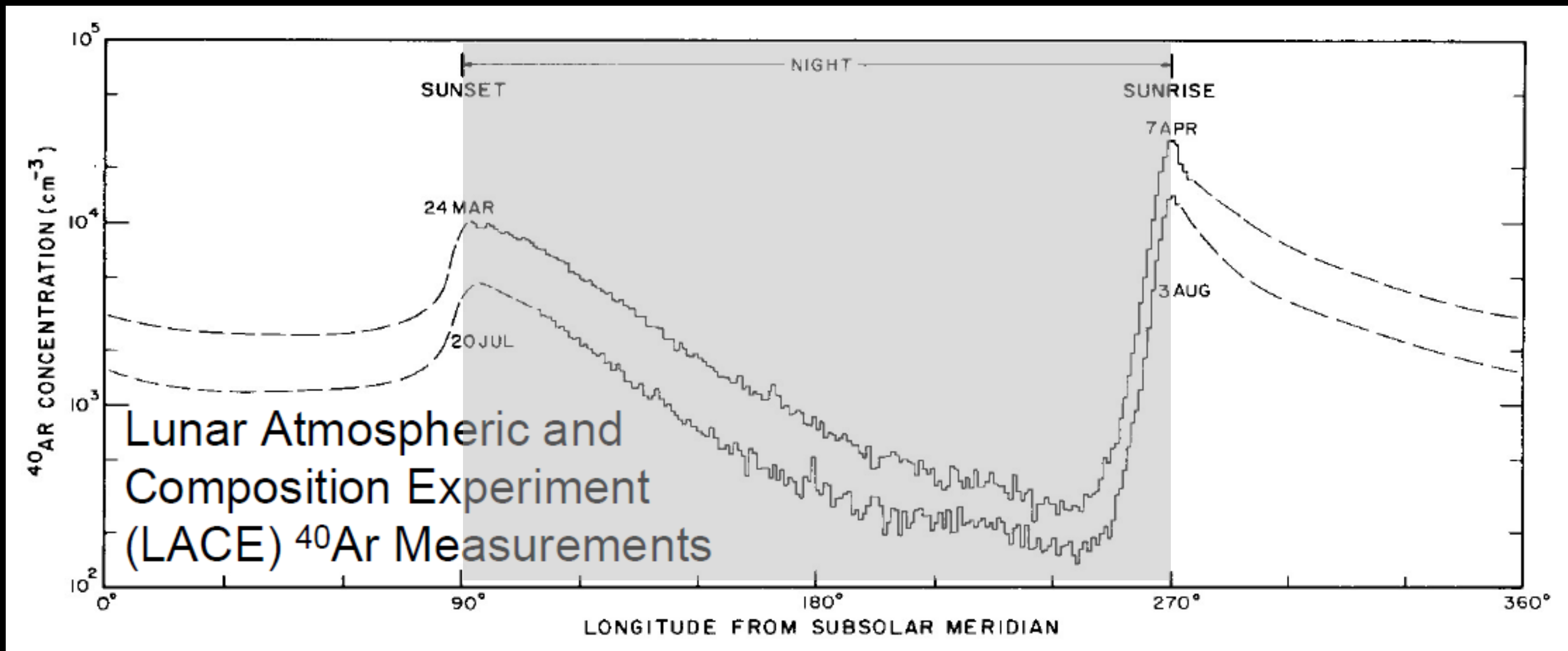


20N
e



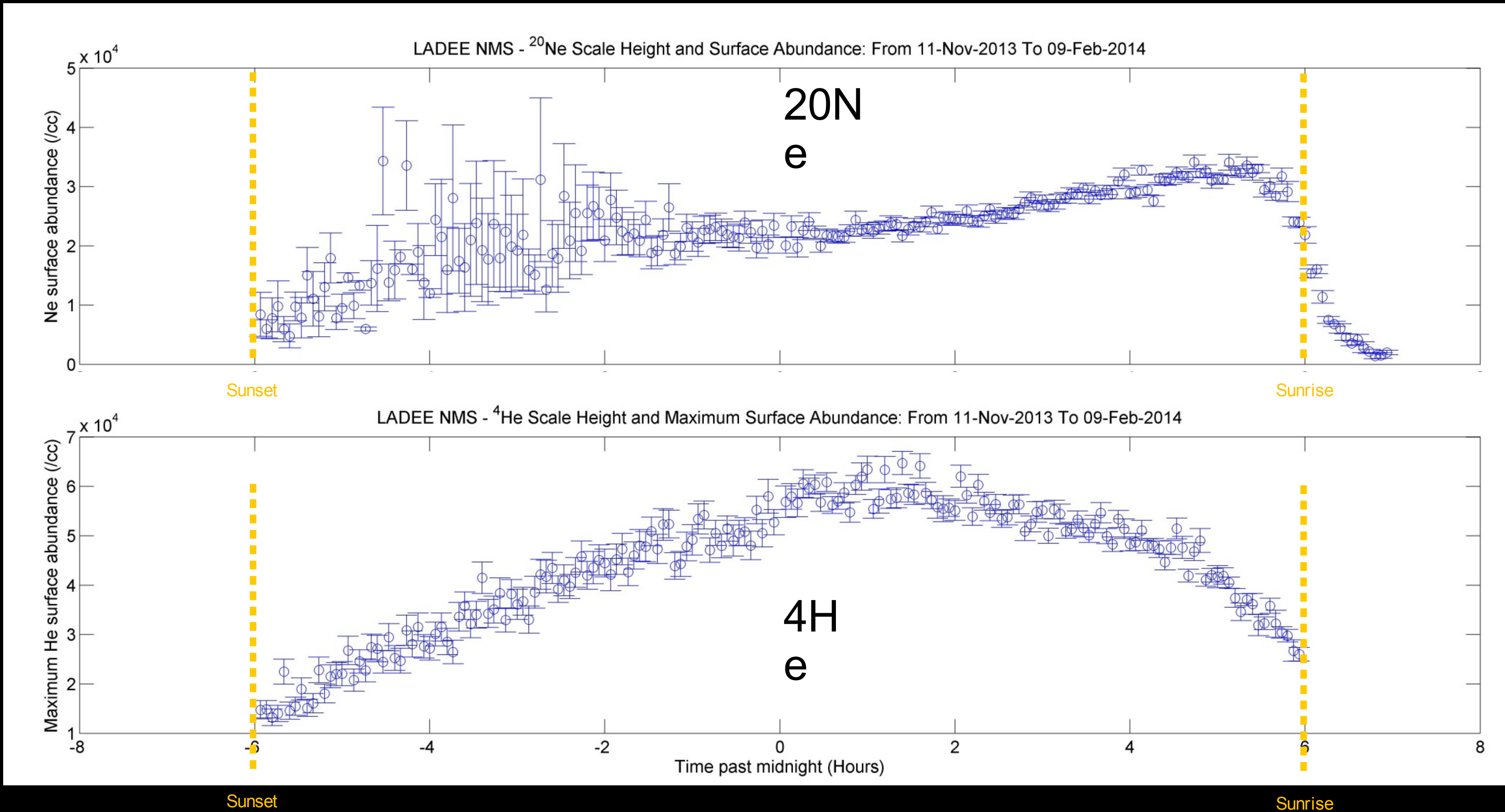
LACE Measurements of Lunar Argon

The Lunar Atmospheric and Composition Experiment on Apollo 17 made positive detection of Argon only at night.



Hodges and Hoffman, 1975

Mapping of Neon and Helium Surface Abundance (Benna, et al., LPSC, 2014)



As nightside Tsurf decreases, *n* increases due to *nT5/2 = const*.

He, with longer ballistic hop length, presages dawn earlier.

NMS Species Identification

EXOSPHERE

Species	Upper limit, #/cm^3 per L2 DOORS	UVS Estimated limit or detection (cm^-3)	NMS Estimated limit or detection (cm^-3)	Comments
CH4	10,000		<1000	Upper limit reduced
O	1000	261		Prelim. UVS estimate
OH	1.0E+06	11	detection!	Sporadic
H2O	100	103 (as H2O+)	detection! <100	Sporadic
CO	15,000	in work	Detects ions	NMS sees mass 28 as ions
S (or oxide)	150		<100	Upper limit reduced
Si	48	<50		Prelim. UVS estimate
Al	55	<178	detection!	Prelim. UVS upper limit
Mg	6000	2.5		Prelim. UVS estimate
Ca	1	<37	Detects ions	UVS 12/cm^3 for Ca+, NMS sees mass 40 ions
Ti	1	1.3		Prelim. UVS estimate
Fe	380	0.3		Prelim. UVS estimate

Characterizing the Lunar Atmosphere: LADEE UVS Sodium Observations

The Ultraviolet/Visible Spectrometer (UVS) has made unprecedented systematic maps of sodium in the lunar atmosphere.

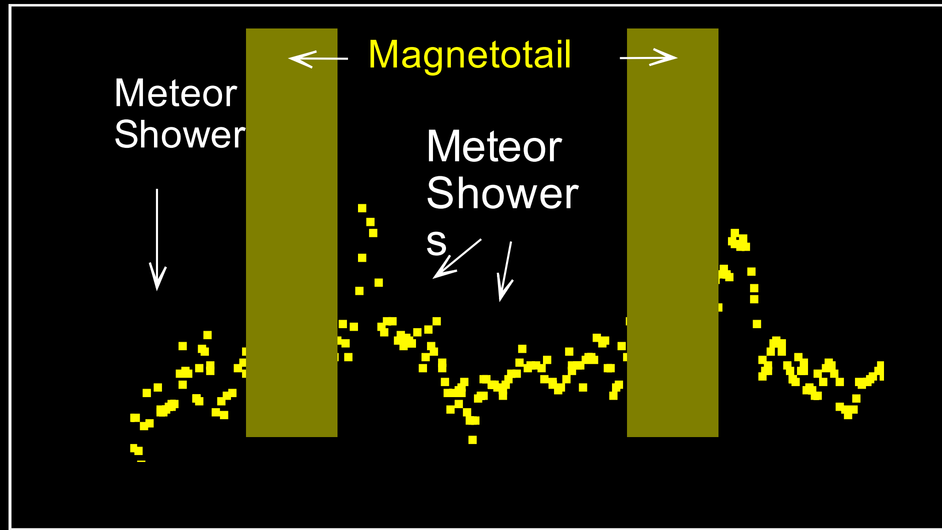
UVS finds sodium abundance:

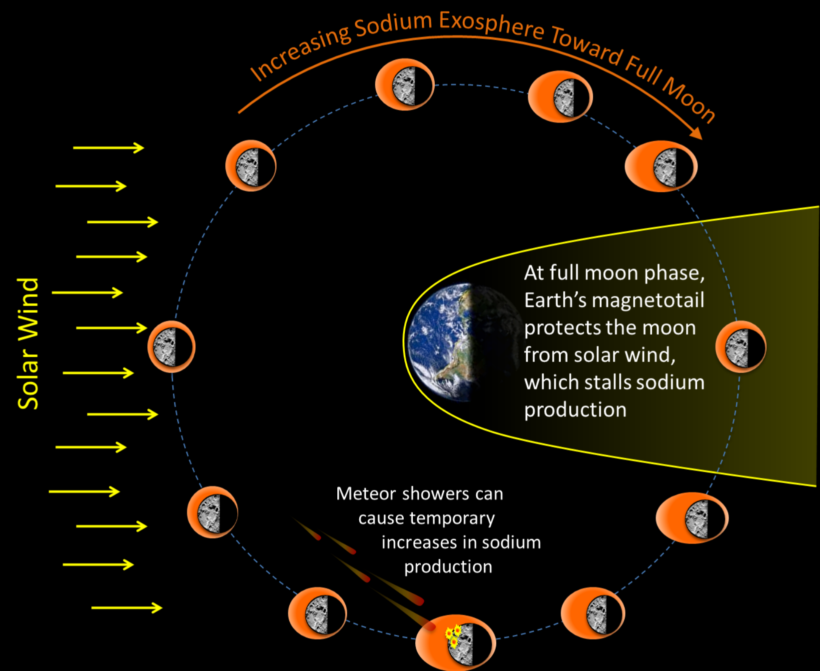
- Varies with lunar phase, increasing as the Moon approaches Full.
- Increases with meteoroid showers,
- Decreases when Moon is shielded from the solar wind by the Earth's magnetotail.

Suggests combination of sodium sources, including solar wind sputtering, and meteoroid impact vaporization.

UVS detected multiple other species!

These variations, combined with other LADEE observations, will constrain the processes at work at the moon, and other airless bodies in the solar system

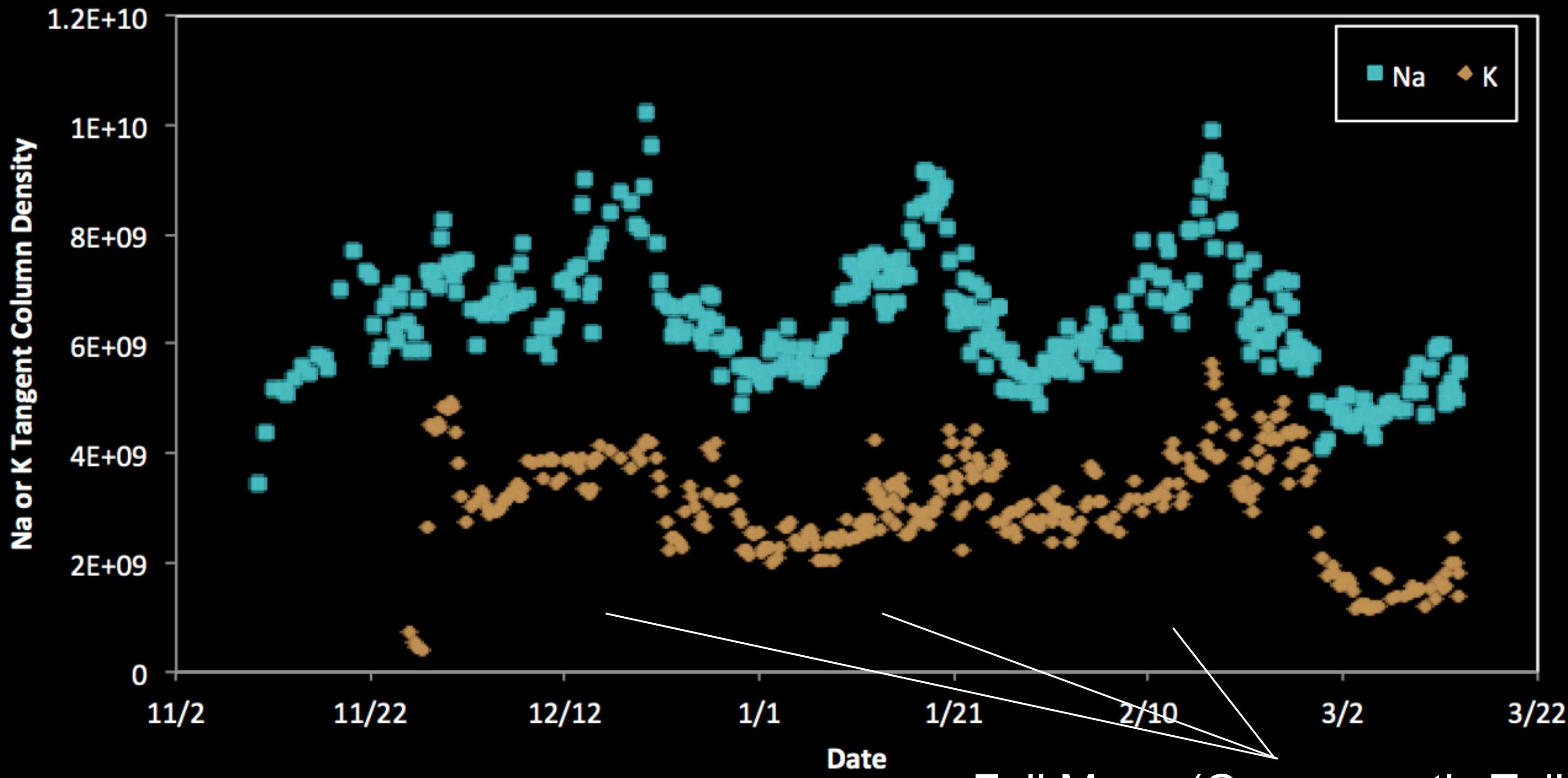




Characterizing the Lunar Atmosphere: LADEE UVS Sodium & Potassium Observations

Sodium & Potassium

Meteoroid Showers



Full Moon (Geomagnetic Tail)

Colaprete, et al., *LPSC*, 2014

UVS Species Identification

EXOSPHERE

Species	Upper limit, #/cm^3 per L2 DOORS	UVS Estimated limit or detection (cm^-3)	NMS Estimated limit or detection (cm^-3)	Comments
CH4	10,000		<1000	Upper limit reduced
O	1000	261		Prelim. UVS estimate
OH	1.0E+06	11	detection!	Sporadic
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CO	15,000	in work	Detects ions	NMS sees mass 28 as ions
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Ca	1	<37	Detects ions	UVS 12/cm^3 for Ca+, NMS sees mass 40 ions
Ti	1	1.3		Prelim. UVS estimate
Fe	380	0.3		Prelim. UVS estimate

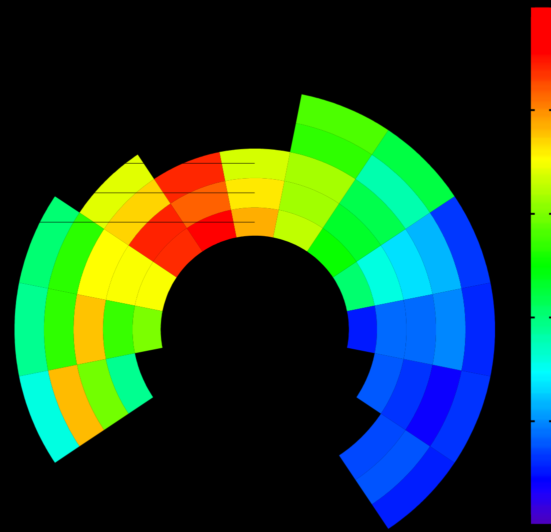
Characterizing the Lunar Dust Environment:

LDEX Discovers Lunar Dust Exosphere!

LDEX has recorded many tens of thousands of impacts from dust particles since arriving at the Moon in October, 2013.

A tenuous dust cloud engulfs the Moon, created by continual micrometeoroid bombardment of the surface; ejecta forms cloud.

Intermittently, LDEX also observes intense bursts of particles, likely from nearby impacts just minutes before LADEE passes by.



Dust density is greatest in post-sunrise sector, and higher at lower altitudes

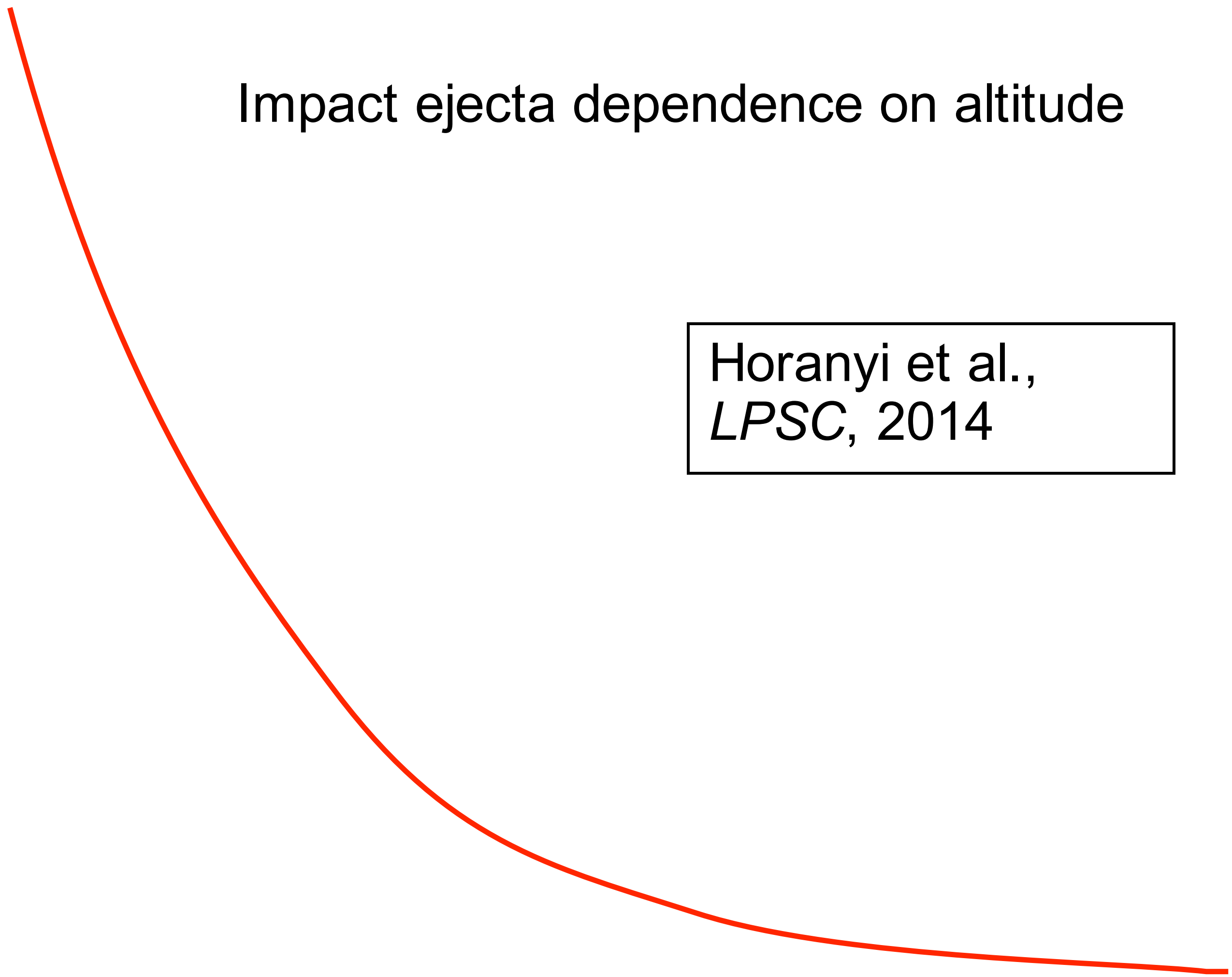
LDEX has not observed evidence for electrostatically levitated dust at the densities required to be visible to the human eye.

Characterizing the Lunar Dust Environment:

Horanyi et al.,
LPSC, 2014

Density of
grains with radii
> 0.7 µm

Dust Density vs. Altitude



Impact ejecta dependence on altitude

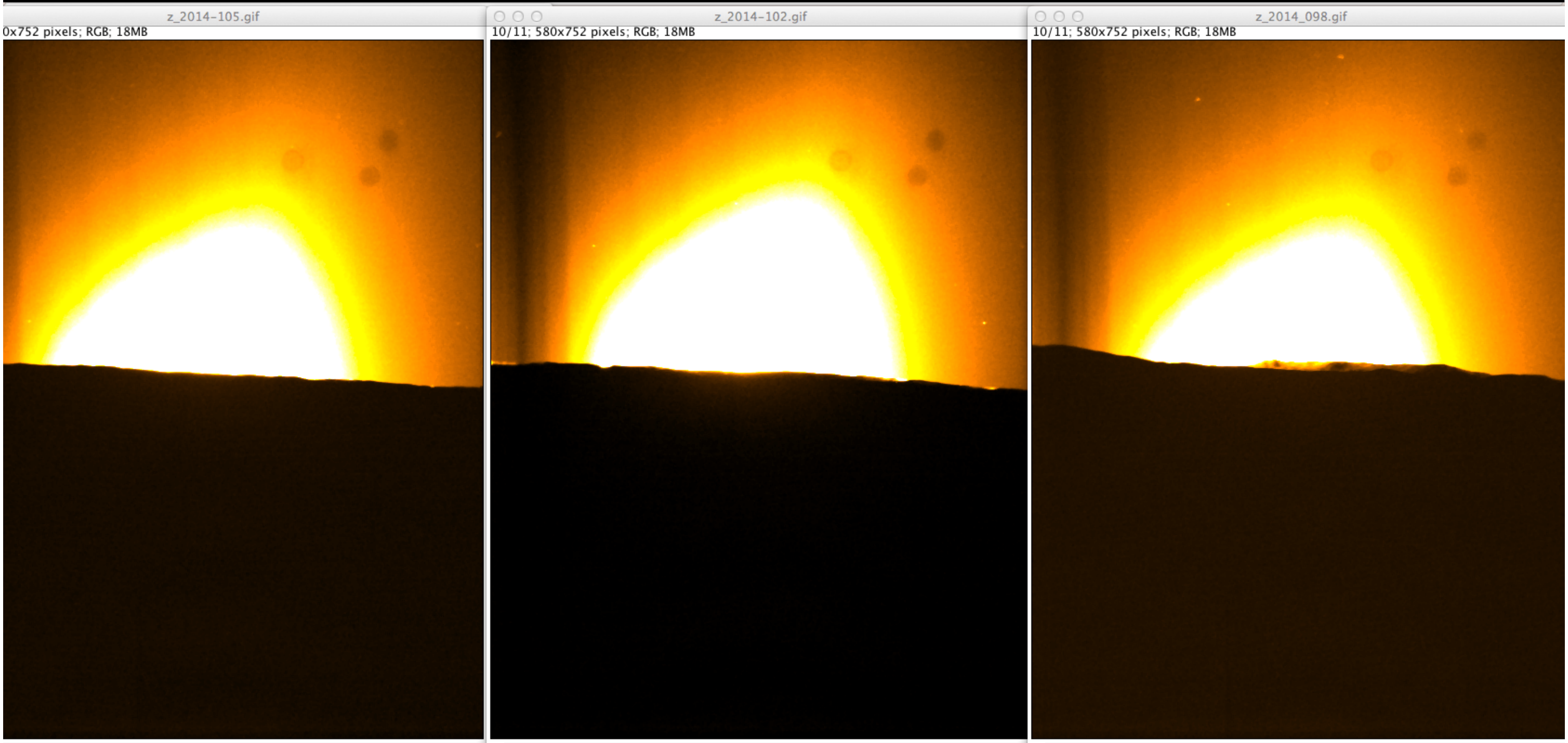
Horanyi et al., *LPSC*, 2014

Dust Densities

DUST

Population	**Density upper limit, #/cm^3 (per SDT report)**	UVS Density Estimate	LDEX Density Estimate	**Comments**
>= 1 micron	1.00e-04	<1.0e-04	2e-10	Consistent with meteoroid impact flux
100 nm - 1 micron	1.00e-04	<1.0e-04	<< 1.0e-04	factor of 10 below McCoy et al model

LADEE Orbital Sunrise
Star Tracker Images



No horizon glow – just coronal and zodiacal light

Just before orbital sunrise, some illuminated terrain

Summary

NMS have made observations of Argon, Neon and Helium in the exosphere and their diurnal variations.

NMS pursuing possible H2, O, OH, H2O, CO, Mg, Al, CO2, Ti… detections.

UVS has measured the spatial and temporal variations of the Sodium and Potassium exospheres for more than 4 lunations.

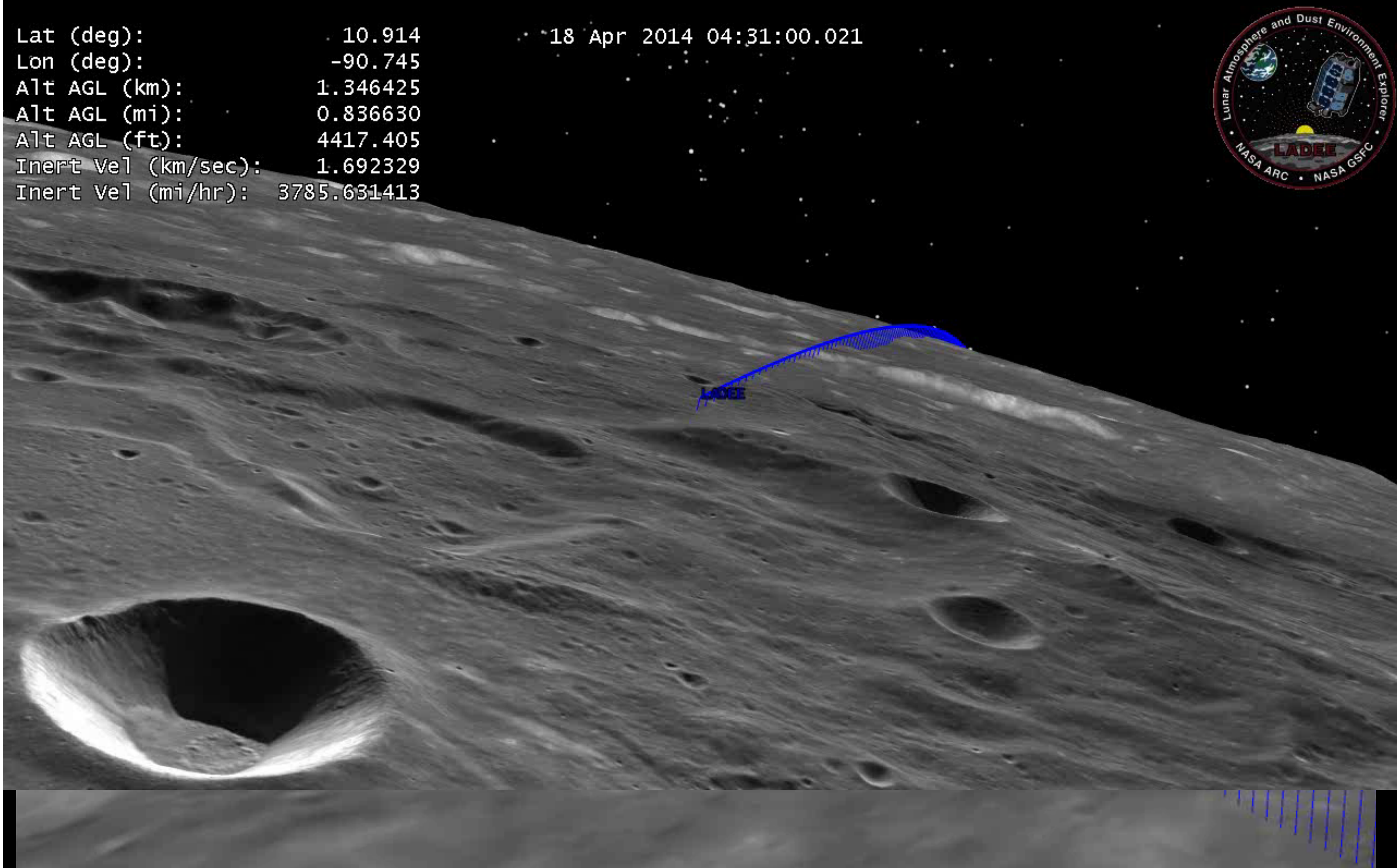
UVS pursuing possible O, OH, Mg, Si, Ti… detections.

LDEX has revealed the presence of a dust ejecta cloud engulfing the Moon, sustained by the continual bombardment by interplanetary dust particles.

Few x 10-4 m-3, grain size > 0.7 mm.

No evidence of electrostatically levitated dust.

LADEE's final orbit



LADEE Orbital Sunrise
Star Tracker Images