# Effects of ISRU on the Lunar Environment

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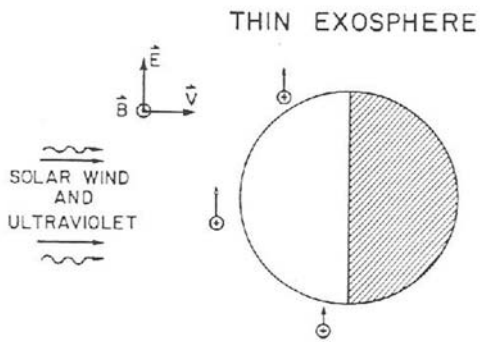
- ***Lunar environment and ISRU effects***
  ***- Atmosphere***
  ***- Dust***
- ***Special issues for a polar outpost***
- ***Outstanding problems***
- ***Requirements/Architecture fit***

# Lunar atmosphere

- The lunar atmosphere is a thin, surface-bounded exosphere
  - Nighttime densities are about $10^5/cm^3$
  - Total global mass is several metric tons
  - Gas releases disperse rapidly (expansion velocity of km/s)
  - Solar wind is the main source (~30 gm/sec), with smaller endogenous sources (e.g. Na, K, Ar)
  - Rapid loss by solar-wind ion pickup at the photoionization time ($10^6$ to $10^7$ s)
- Modification by Apollo was short-lived
  - 8,000 kg of rocket exhaust
  - cabin venting of 3 kg
  - astronaut suit life support at 1 kg/hr of $H_2O$
- Significant increase (by $10^3$?) may result in a long-lived atmosphere (requires about $10^4$ tons and 30 kg/s)



# Lunar atmosphere - ISRU effects

- Regolith contains volatiles of solar wind origin

  - Apollo: 100 ppm of $H_2$, He, $CO_2$, $CH_4$, $N_2$, (+$H_2O$?)

  - ~70% released by heating to 600 C; ~90% at 1400 C

  - recovering 1 ton of volatiles requires processing at least 10,000 tons of regolith
- Oxygen can be recovered by regolith chemical processing
- Some TBD fraction of volatiles or extracted oxygen will escape into the environment

  *Modest ISRU (few tons per year) could exceed the natural global atmospheric abundance (few tons, 30 gm/s), but might not have any persistent global effects*

# Lunar Dust Environment

- Dust might be a problem for operations, for human physiology, and possibly for astronomical observations
- Some dust sticks to surfaces mechanically
- Uncharged dust settles by gravity, so effects are local
- Dust may become electrically charged by sunlight/plasma effects or by tribocharging
  - electrostatically adheres to surfaces
  - horizontal transport and lofting by the surface electric field resulting from solar wind interaction, particularly at the sunlight terminator

# Lunar Dust Environment - ISRU Effects

- ISRU activities will generate dust as a TBD fraction of regolith that is excavated. Particles smaller than 5 microns comprise about 5% of the regolith. These are 500 times more abundant than volatiles.
- Release of fine dust could result in a substantial increase to the natural dust cloud thought to exist at the sunlight terminators, with degradation of optical astronomy
- An unknown is the dust fraction that might be charged and lofted.

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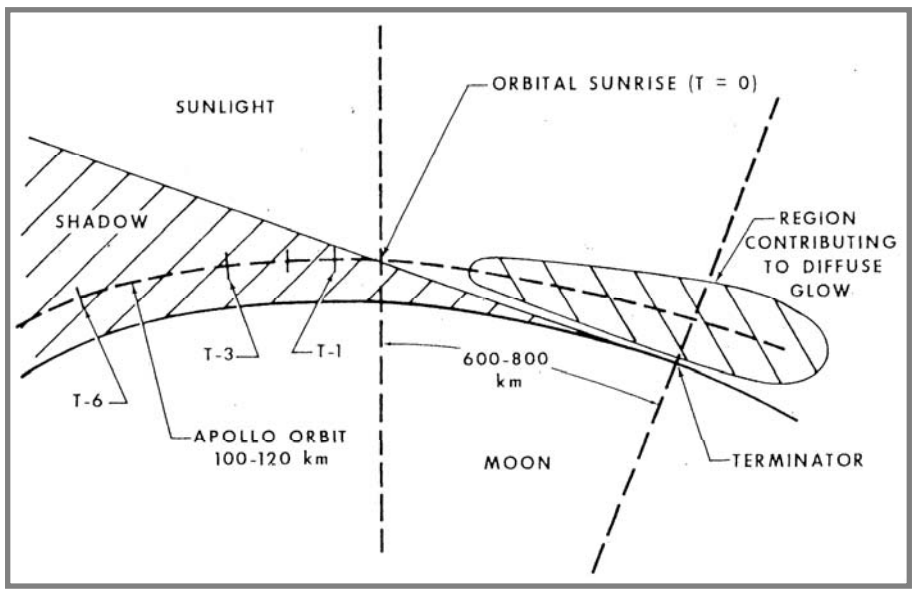



Terminator dust cloud observed from Apollo (McCoy, 1976)

Column mass density of ~4 grams per $km^2$

Particle size: ~0.5-5 microns

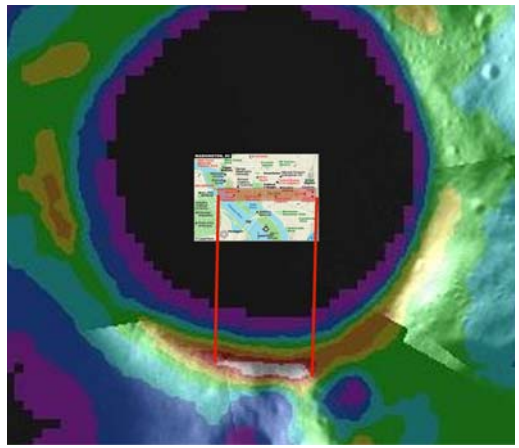
May be brighter than the terrestrial night sky

# Special issues for a polar outpost

- **Atmospheric gases**

  - Dispersal of gas releases will be complicated by delayed release from nearby intermittently-shadowed regions and by the proximity to the nightside

  - The gas release rate will greatly exceed the natural solar wind flux to the PSRs (0.7 kg/yr/km$^2$). Consequences are TBD.



- **Dust**

  - The pole is always near the terminator, so charged fine dust from ISRU might result in a high-altitude dust cloud. This could interfere with optical astronomy.

  - Dust might flow one-way into PSR without exit, with consequences TBD

# Some Outstanding Problems/Questions

- What are the composition and variability of the natural lunar atmosphere?
- What are its sources, losses, and resiliency?
- How do gas releases disperse across the lunar surface?
- How are volatiles transported to polar cold traps and what is their durability?
- Are there dust clouds at the sunlight terminators?
- What is the sky brightness at the poles?
- What is the electrodynamics of dusty plasmas at the lunar surface?
- What processes control the transport of charged dust?
- Does regolith excavation result in volatile emissions, dust release, and tribolelectric charging?

# Requirements to fulfill science objectives

- Measure the natural environment early with modern sensors so as to

  - identify natural components

  - understand processes that affect their variability
- Use observations, theory, and modeling to predict the consequences of ISRU
- Test methods to mitigate potentially adverse environmental effects
- Monitor the environment after the outpost is established

# Requirements to Fulfill Objectives

## Architecture Fit

- Measure the natural environment early with modern sensors so as to
  - identify natural components
  - understand processes that affect their variability

Prolonged measurements with robotic landers/orbiters prior to human return

- Use observations, theory, and modeling to predict the consequences of ISRU

Verify understanding with distributed measurements of dispersal and transport

- Test methods to mitigate potentially adverse environmental effects

Can be done at outpost

- Monitor the environment after the outpost is established

Use sensors at outpost and elsewhere