CARBON-BEARING VOLATILES:

SURFACE ABUNDANCE ESTIMATES FROM EXOSPHERIC CONTENT CONSIDERATIONS.

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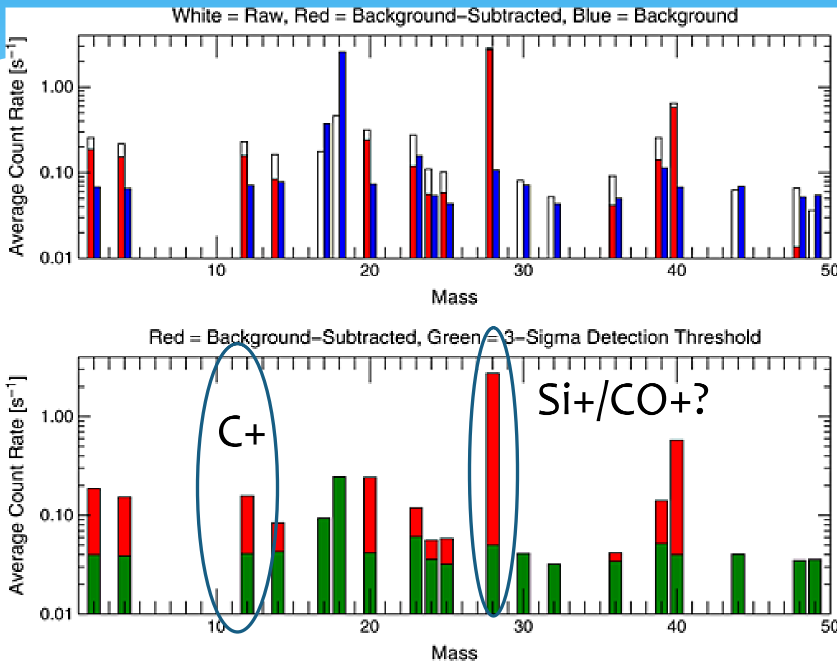
An exosphere of CO and CO_2?

Detections of lunar exospheric ions by the LADEE neutral mass spectrometer



Halekas et al. GRL 2015

If [CO+], then [CO]~10^4 cc

- Ion Measurements have long indicated predominance of mass 28 ions (Al+,Si+, or CO+?)

Motivating Questions:

- ❑ What are the expected levels of carbon-bearing volatiles in the exosphere of the Moon?
- ❑ And, based on flux balance, what would be the distribution of adsorbed species on the surface of the grains?

Expected carbon influx as the seed population for these exospheres

1) Solar wind:

- A long-term average of the carbon to proton abundance in the solar wind is ~2 – 3×10^{-4} [*von Steiger* et al., 2000].
- Assuming the average solar wind flux to be 2×10^{8} ions cm^{-2} s^{-1}, the carbon influx to the Moon is 4 – 6×10^{4} ions cm^{-2} s^{-1}

→ Methane gas, Trapped {carbides, CO, CO_2}

2) Micrometeoroids:

- The carbon fraction in CI chondrites is 8.5 wt% [Lodders and Fegley, 1998].
- Adopting a lower limit of the rate of micro-meteoritic flux onto the Moon of 5.12×10^{-17} gm cm^{-2} s^{-1} [*Cintala*, 1992] and an upper limit of 4.76×10^{-16} gm cm^{-2} s^{-1} (Furi et al., 2012) the carbon influx, F, is: $8.8\times10^{4} < F < 8.2\times10^{5}$ C atoms cm^{-2} s^{-1}

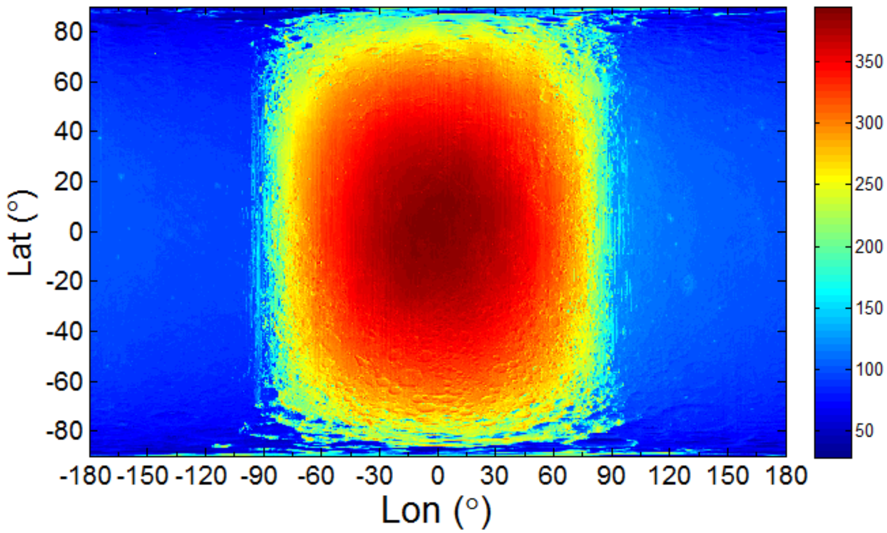
→ CO, CO2 gas

Mobility of carbon volatiles

Adsorbate	Adsorbent/Surface	Eact (eV)	Source
CO	TiO_2 (100)	0.42	Linsebigler et al 1995
CO	TiO_2	0.45-0.5	Raupp and Dumesic 1985
CO	ZnO (powder)	0.36	Wang et al. 2007
CO coadsorbed with CO_2	ZnO (powder)	0.64	Wang et al. 2007
CO	Fe (100)	0.62,0.88,1.08	Benziger and Madix, 1980
CO_2	MgO (100)	0.40	Meixner et al. 1992
CO_2	ZnO (powder)	0.46-0.67	Xia et al. 2008
CO_2	TiO_2	0.46	

- Major knowledge gap!
- Co-adsorbates influence the binding
- New TPD experiments on lunar simulants and samples initiated at GSFC (Jason McLain)

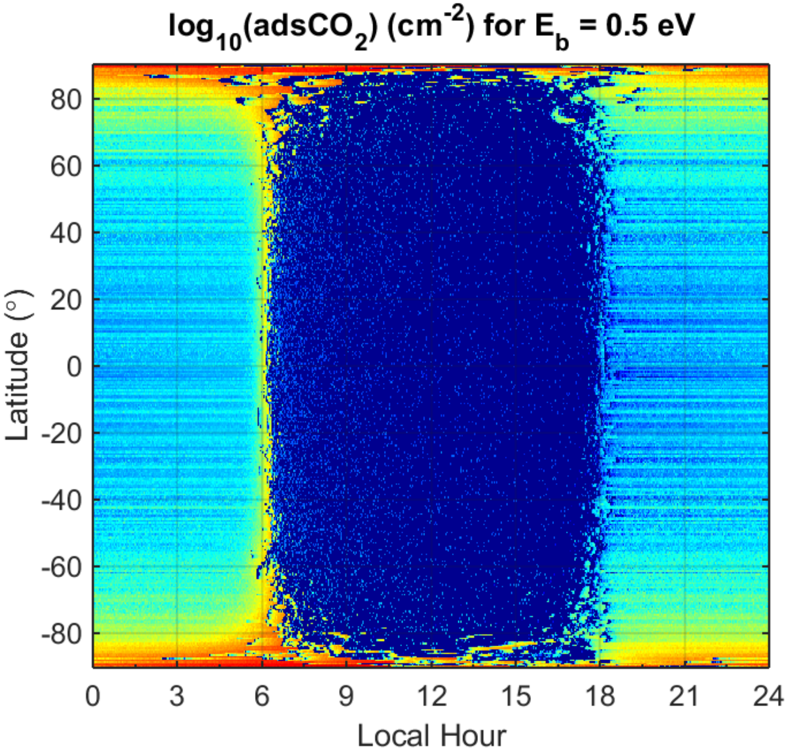
Migration calculations

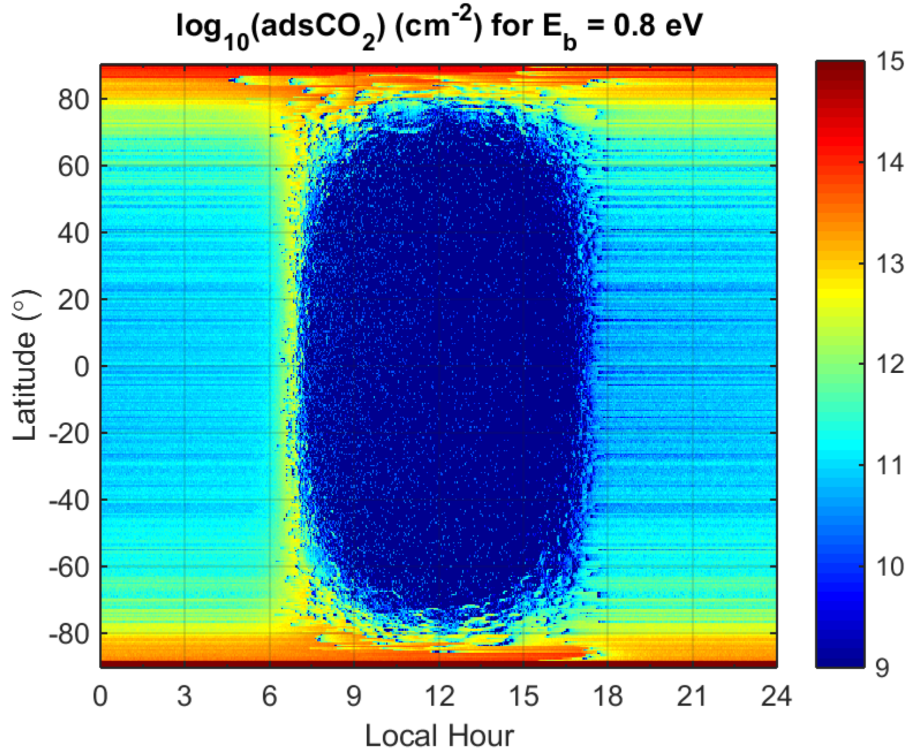


Adopted 23 gridded Diviner temperature maps, Resolution 0.5x0.5 deg

- Assume full vaporization of impactors (no contribution from trapped carbon in soil)
- Half CO, Half CO_2
- $\tau(CO_2)$ = 4.95E5 s, $\tau(CO)$=1.3E6 s (quiet Sun, charge exchange and electron impact dissociation/ionization losses not accounted yet)
- Tiv=2000 K here
- Recycled vapors assumed to stick
- Activation energy for desorption treated as free parameter, Eb=0.5 and Eb=0.8 eV (same for all soils)
- Pre_exponential=1.E13 /s

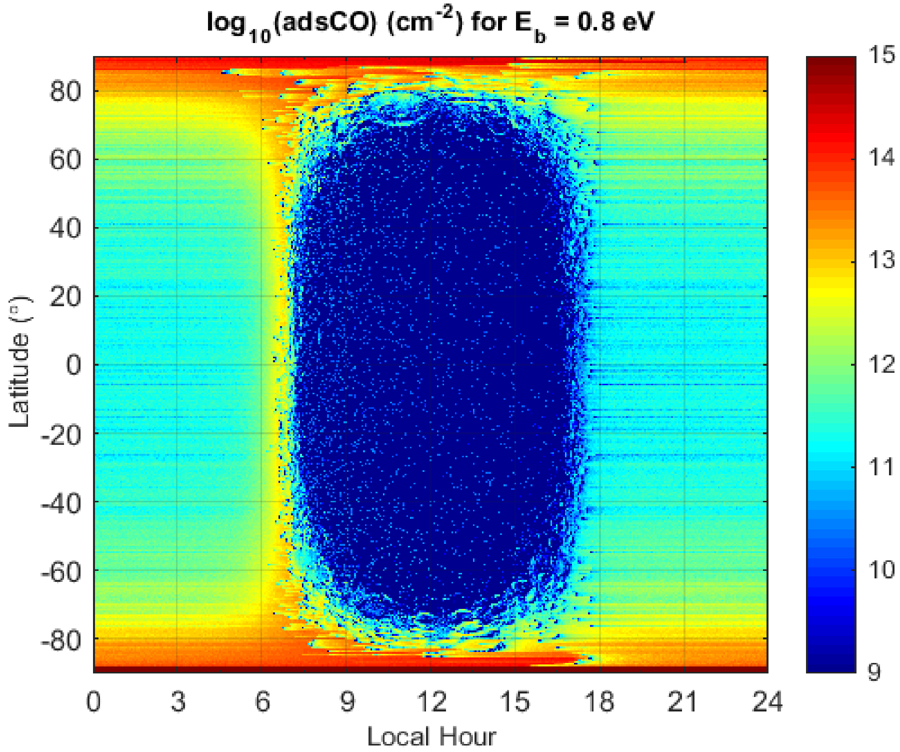
Simulated CO2 surface abundance

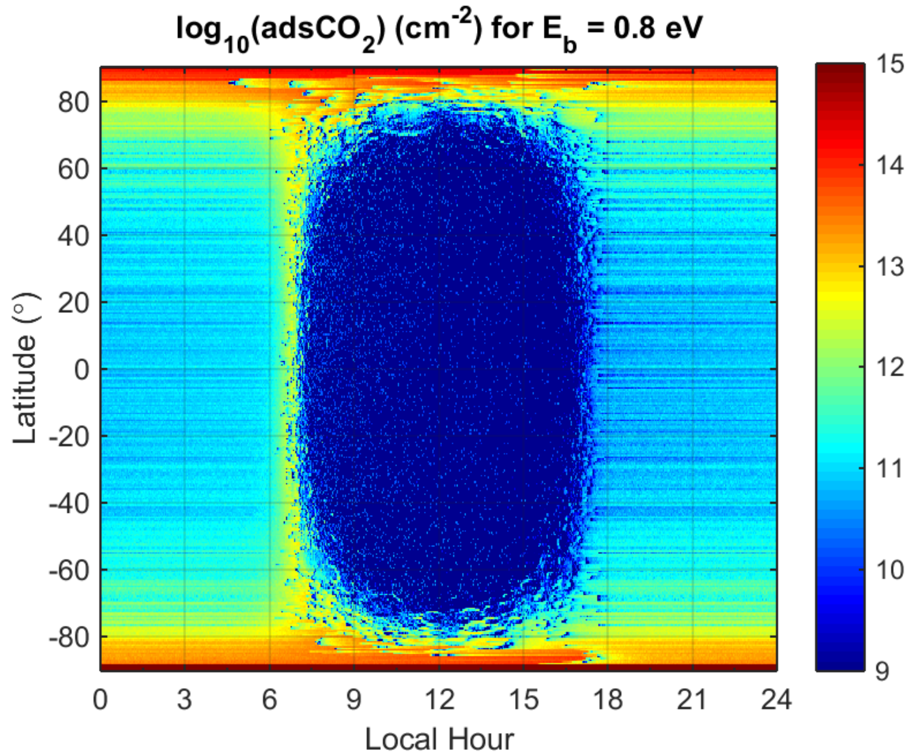




* Coverage approaches or exceeds monolayer under such assumptions (must account for coverage dependence of Eact)
* Patchier polar volatile distribution as Eact decreases

Surficial CO vs CO2

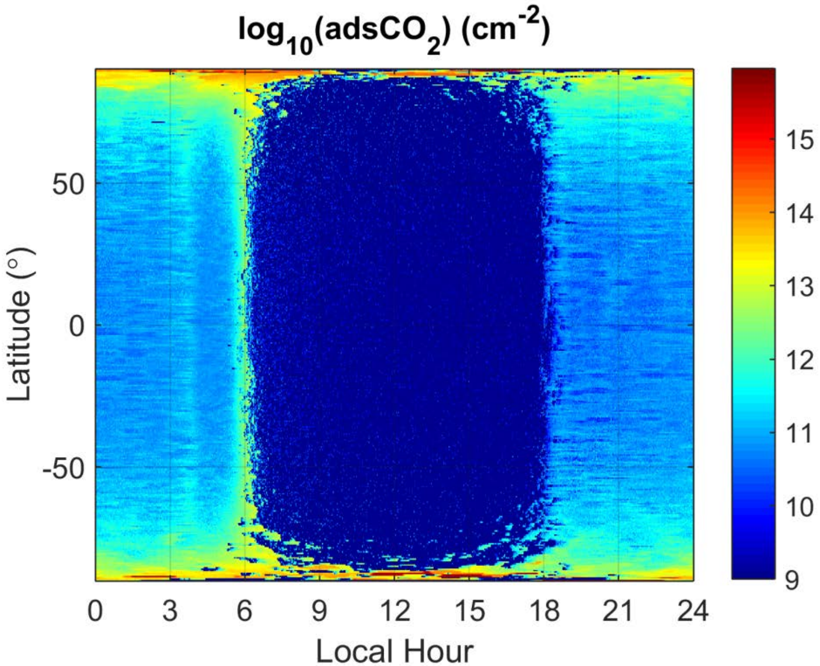




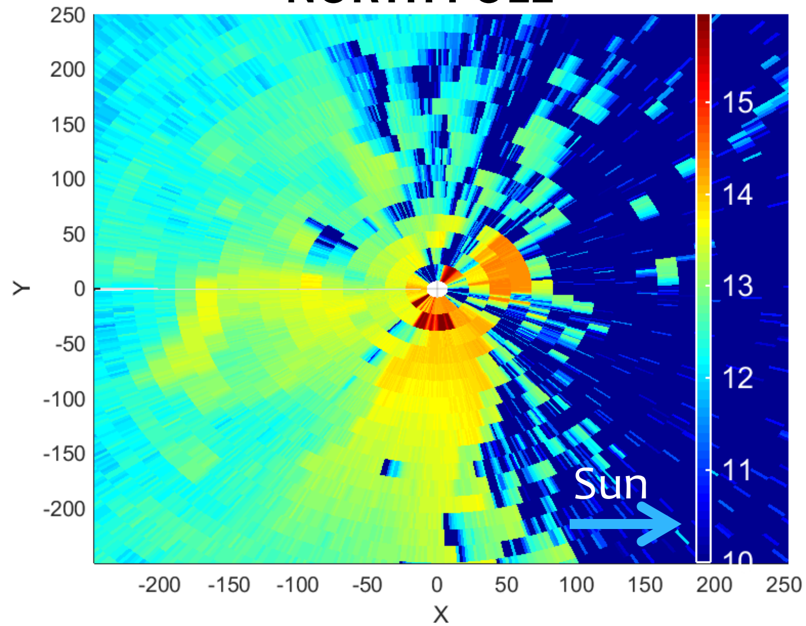
Assuming similar binding and source rates, we would expect significant amounts of CO to migrate to the poles as well (especially since its lifetime to dissociation is longer)

Polar CO2 frosts

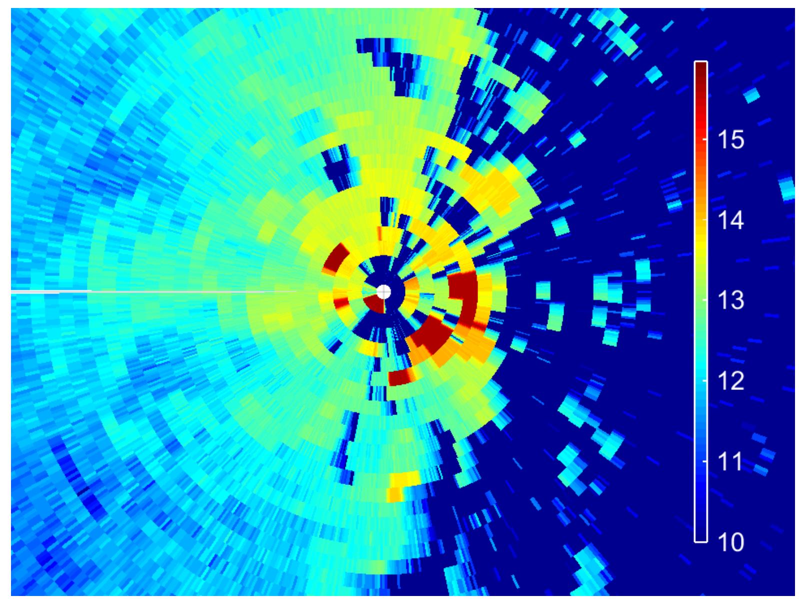
Eb=0.5 eV



NORTH POLE



SOUTH POLE



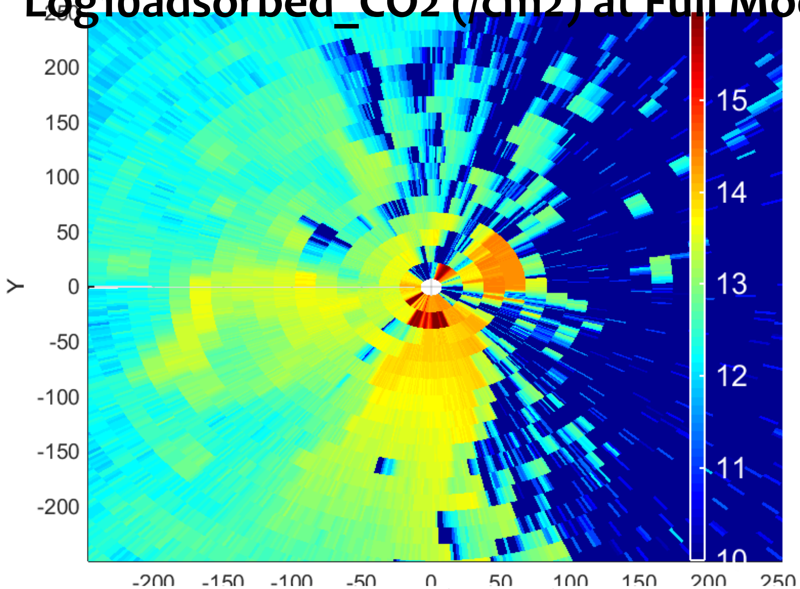
Time-dependent simulation run for 60 lunations

Sinks: dissociation/ionization,

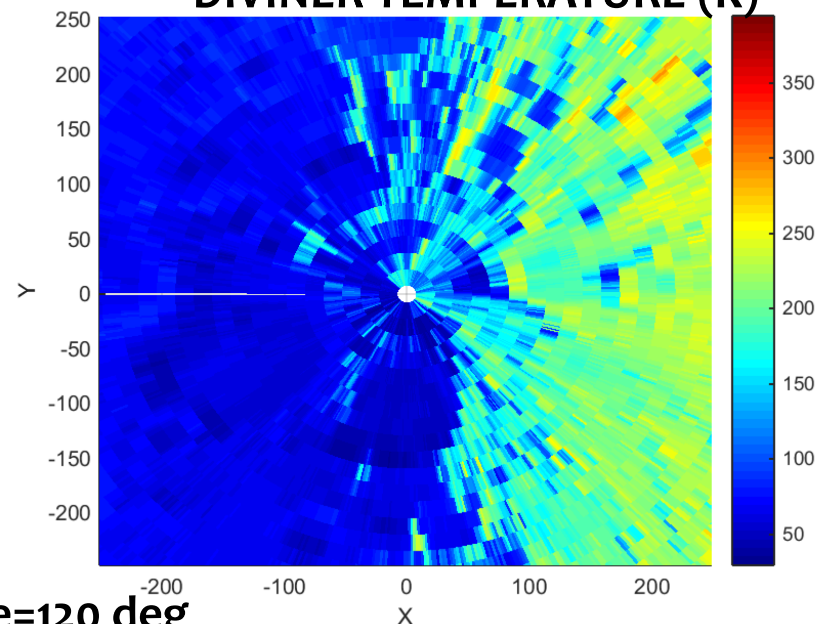
adsorbate sputtering

Diurnal variation of polar CO2 deposits

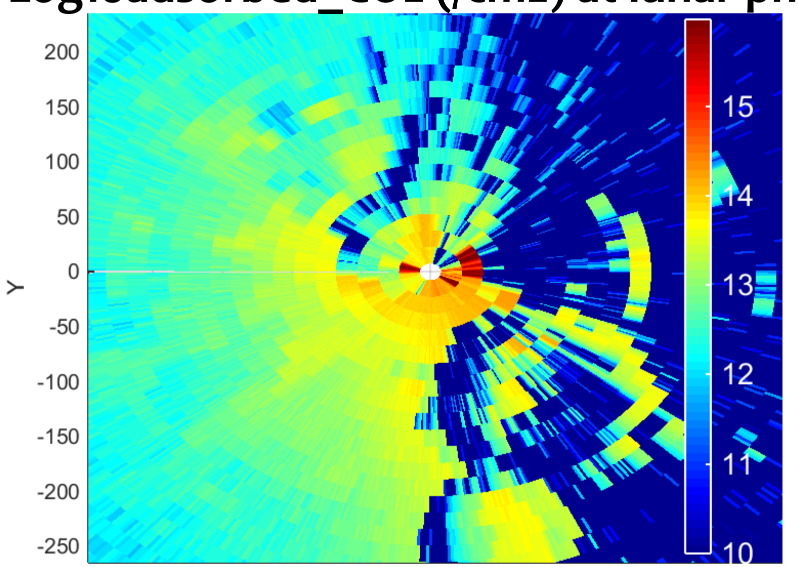
Log10adsorbed_CO2 (/cm2) at Full Moon



DIVINER TEMPERATURE (K)



Log10adsorbed_CO2 (/cm2) at lunar phase=120 deg



Limits to carbon-bearing exospheric species prior to LADEE

Detection methods:

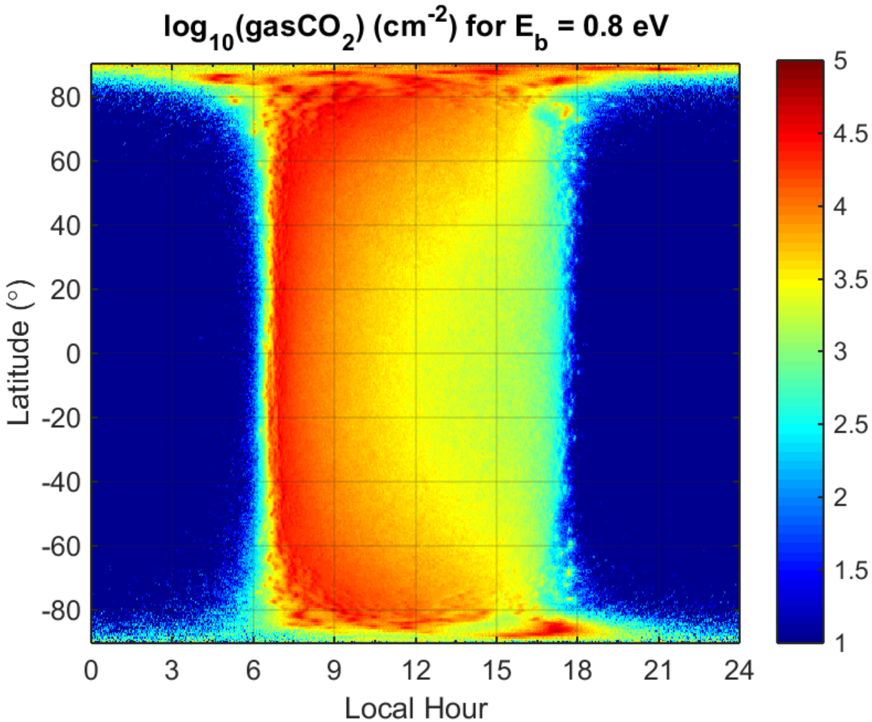
1) Lunar Atmosphere Composition Experiment (LACE) NMS, ~25 deg North: possible detections of [CO]predawn=1.E3 cc, [CO2]predawn=1.E3 cc, [CH4]predawn=1.E4 **cc**

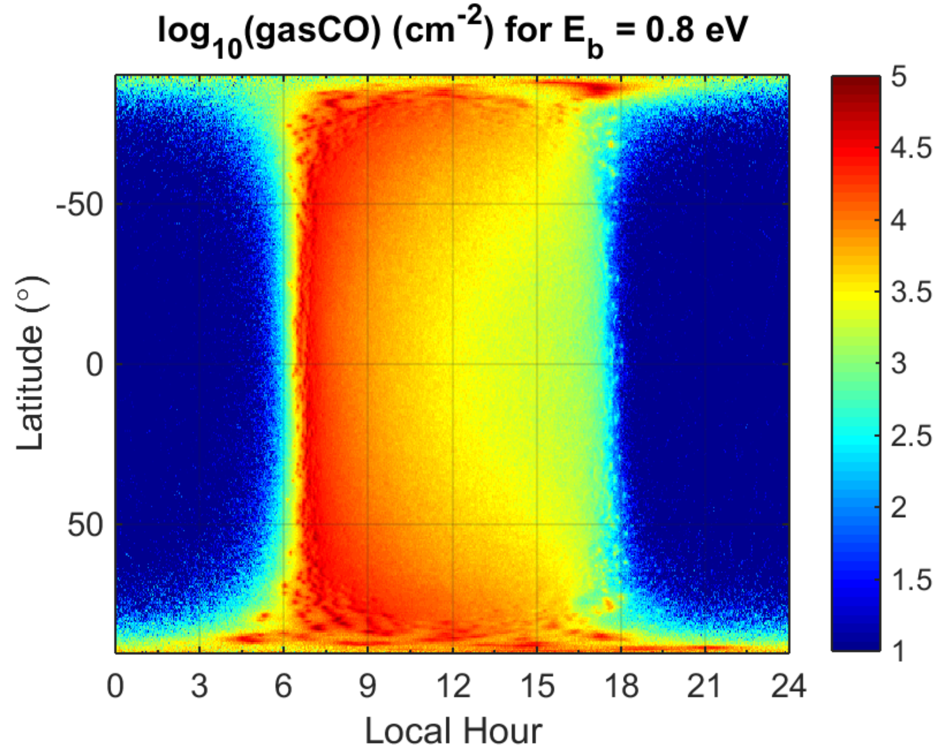
“*In all three cases, the signal increase began several hours before sunrise, and Continued to rise until the instrument became background saturated around sunrise*”

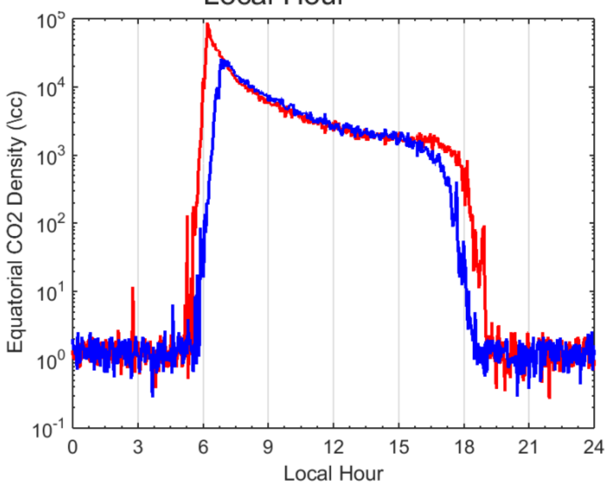
1) Apollo UVS: [CO_g]<14,000 cc (Feldman and Morrison, 1991)

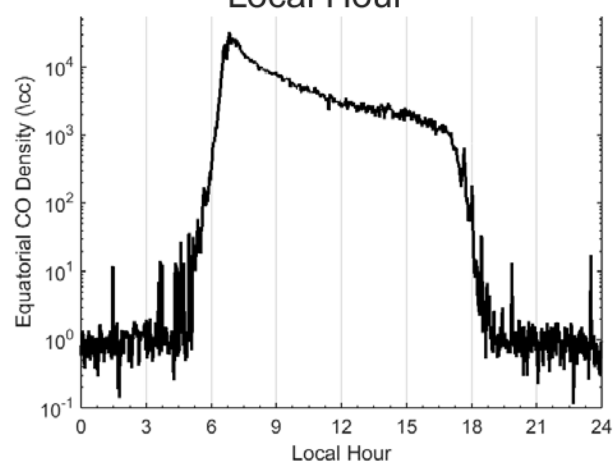
2) LRO LAMP: [CO_g] <700 cc ,polar nightside (Cook et al. 2013)

Estimated Exospheric densities









Conclusions

* Significant CO and CO_2 exospheric densities can be expected by the vaporization of micrometeoroids
* Estimates seemingly do not exceed known limits
* Can map global transport and deposition into poles at unprecedented 0.5x0.5 deg resolution
* Resulting polar deposits for CO and CO_2 would really be "frosts" (1-10 ML)