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

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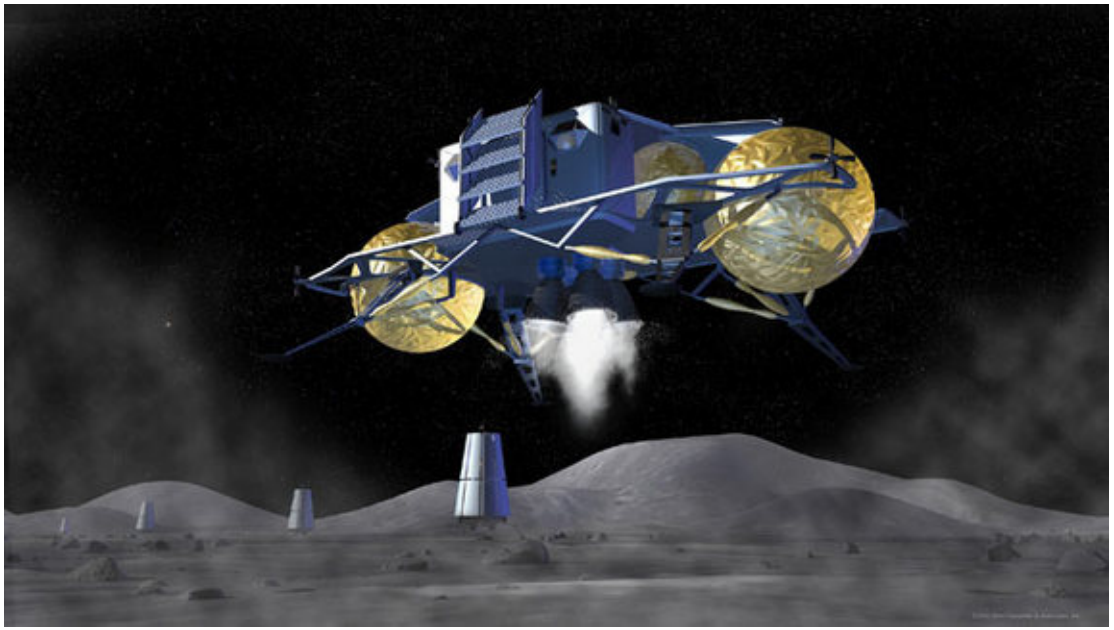
Introduction

- Exploration question: How does it affect the exosphere when a spacecraft lands on or launches from the Moon?



NASA

Introduction

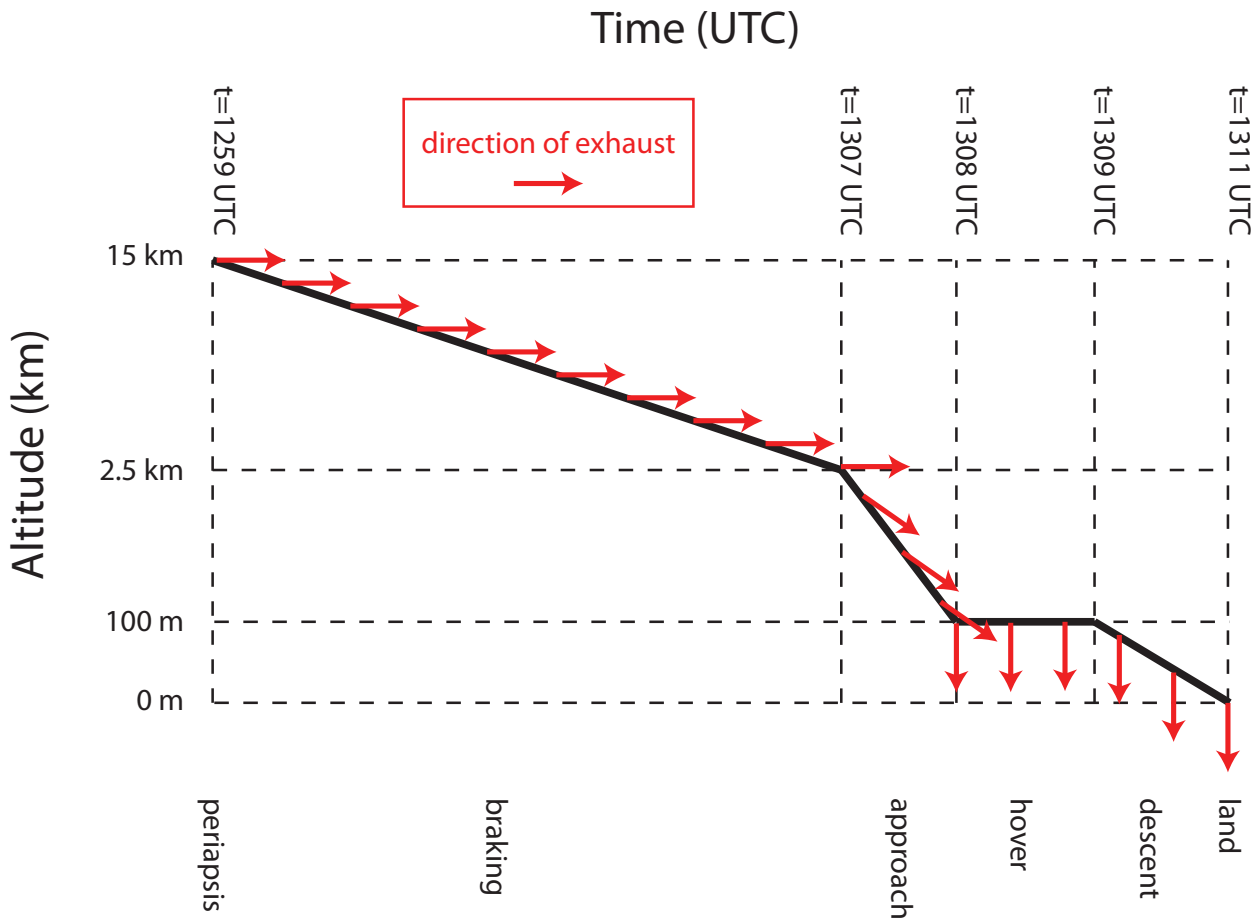
- Exploration question: How does it affect the exosphere when a spacecraft lands on or launches from the Moon?
- Opportunity Science:
  - Chang'e 3 landed on the Moon
    - When: 14 Dec. 2013 at 1311 UT
    - Where: Mare Imbrium, 44.1214°N, 19.5116°W (0818 LT)
    - How: 12.5 minutes of burning MMH and N_2O_4 starting at 15 km altitude
  - LADEE and LRO were there to measure perturbations to the exosphere

Model

- We model the initial impingement and subsequent propagation of exhaust gases from the descent of Chang'e 3.
  - Monte Carlo model
  - Ballistic equation of motion

- Results for water presented
  - Try to constrain adsorption and thermalization
    - Important parameters for migration of water to lunar cold traps.

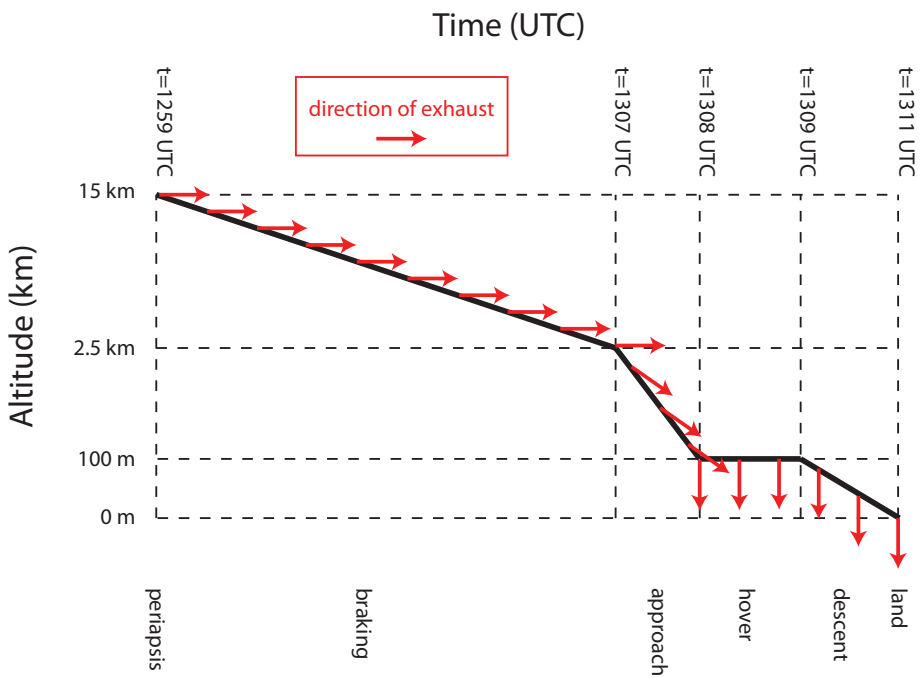
Chang'e 3 Descent



Mass, direction, timing, and trajectory estimates courtesy of MSFC/Dan Thomas & JSC/Ryan Whitley

Chang'e 3 Descent

Trinks and Hoffman, 1983



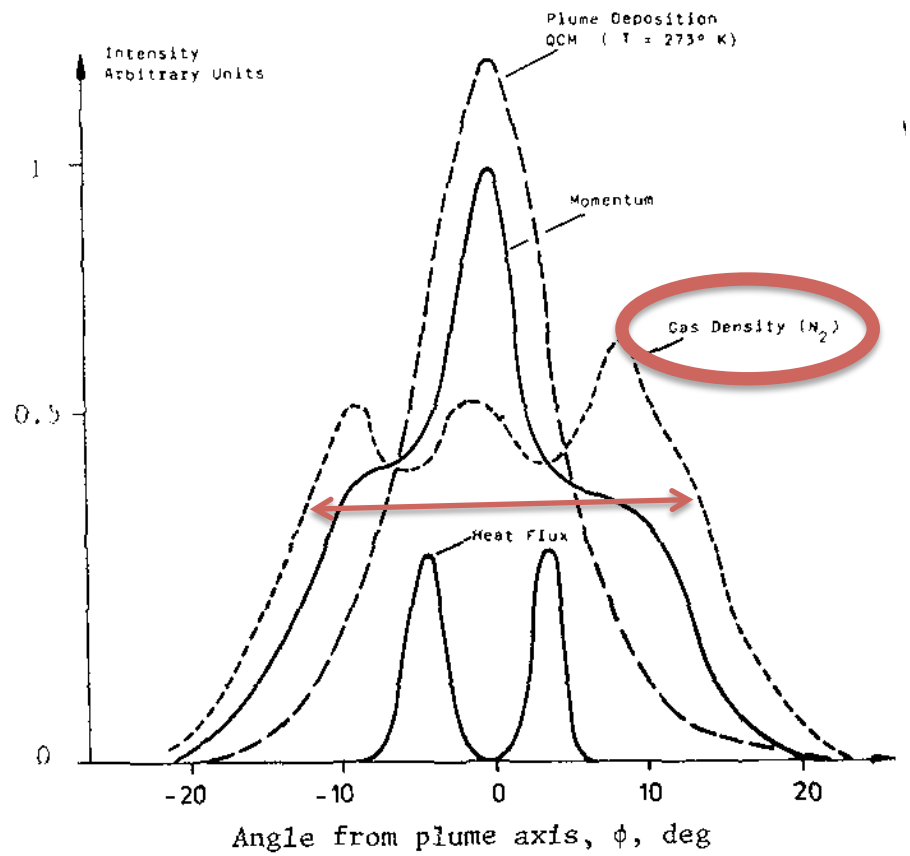


Fig. 22 Compilation of experimental results

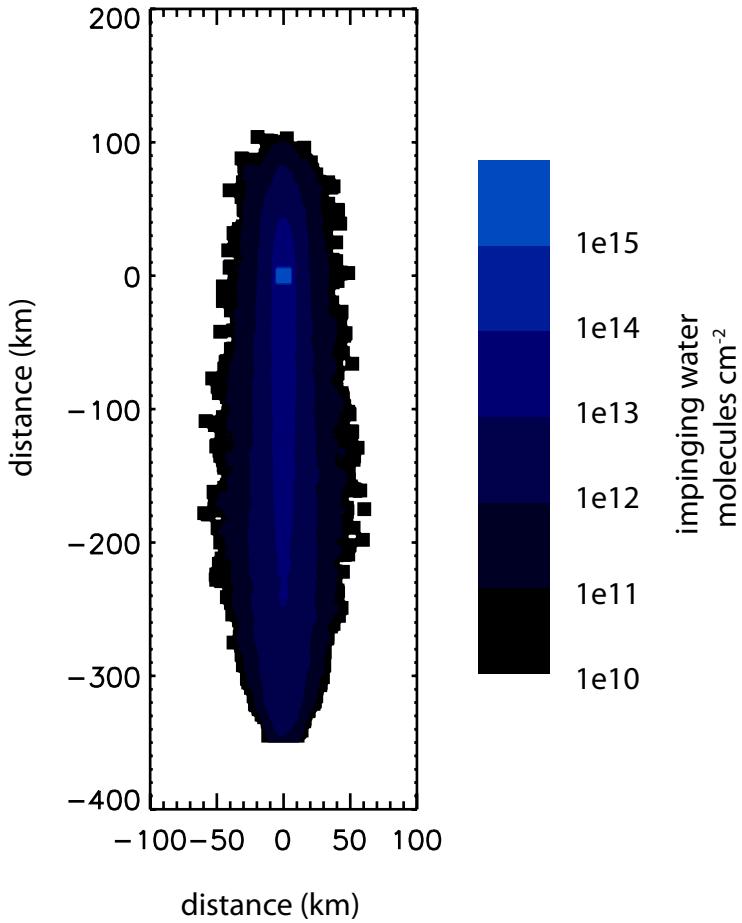
Exhaust Byproducts

$CH_3(NH)NH_2$ and N_2O_4

Molecule	Fraction[1]	Expected exhaust mass (kg)	Mass contacts surface (kg)	Molecular mass (Daltons)	T_{phot}[2] (s)
N_2	41.8%	625	171	28	1e6
H_2O	29.8%	446	122	18	6.7e4
CO	17.4%	260	71	28	1.3e6
CO_2	8.8%	132	36	44	5.0e5
H_2	1.5%	22	6	2	6.7e6
NO	0.3%	4.5	1	30	2.9e5
H	0.2%	3.0	< 1	1	1.4e7
OH	0.1%	1.5	< 1	17	1.3e5
O_2	0.1%	1.5	< 1	32	2.1e5

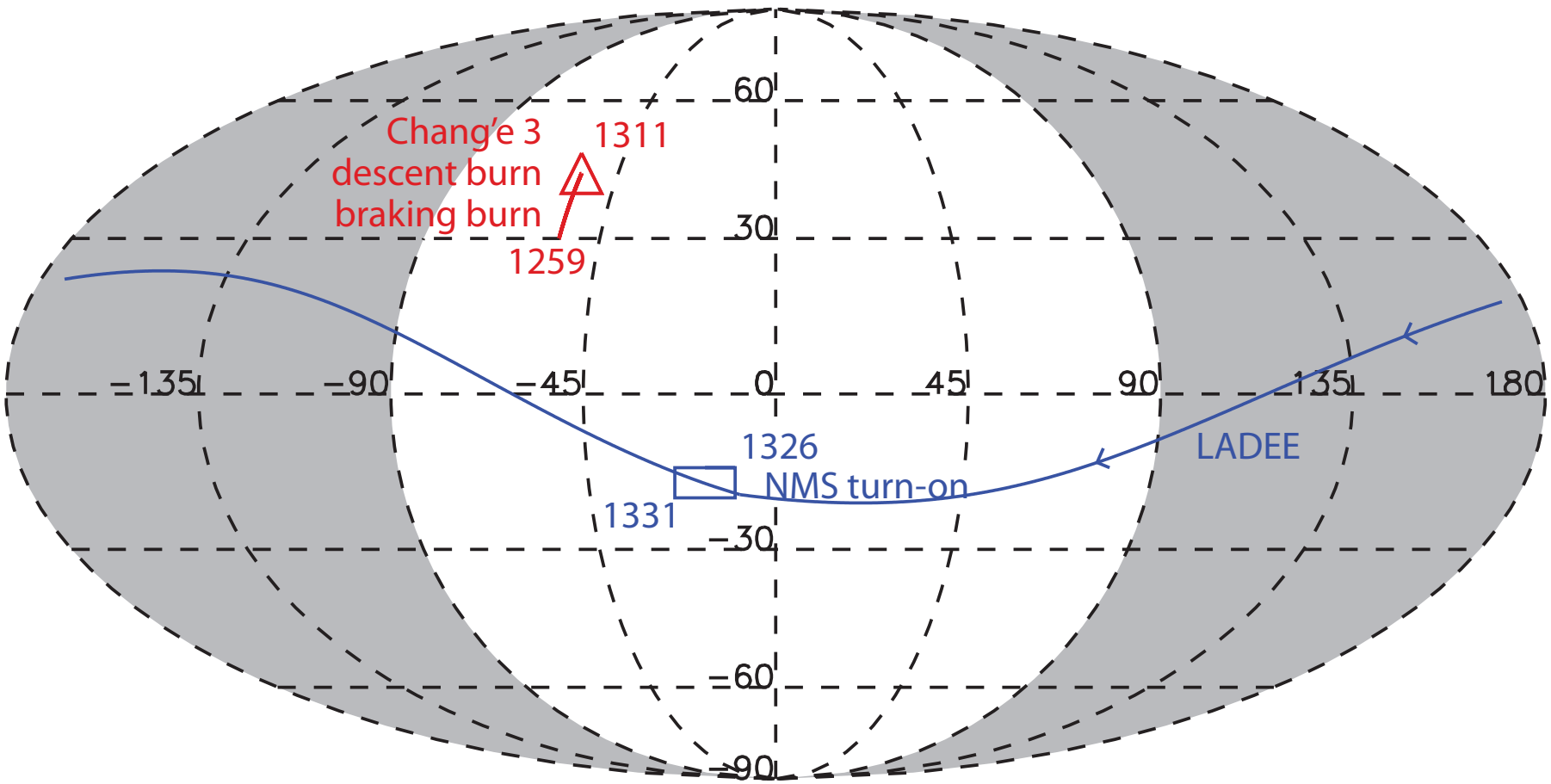
[1] Guernsey and McGregor, AIAA 86-1488, 1986
[2] Huebner et al. PSS 1992

Modeled Exhaust Impingement

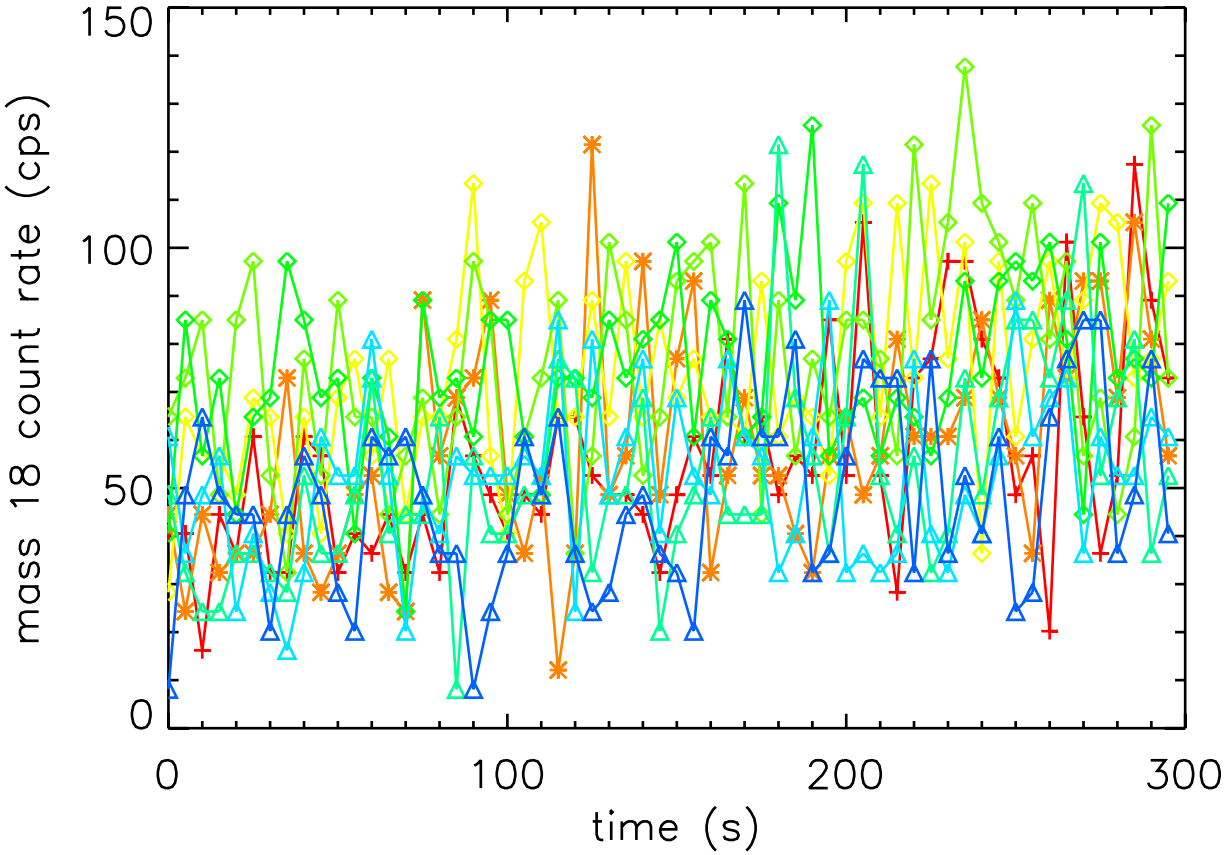


- Water initially contacts the ground along a swath about 450 km long along the entry track and about 100 km wide
  - 122 kg H_2O impinges on the surface
- Some fraction may adsorb for long periods, reducing the amount of water migrating
  - About 38% impinge on a region containing less than a monolayer.

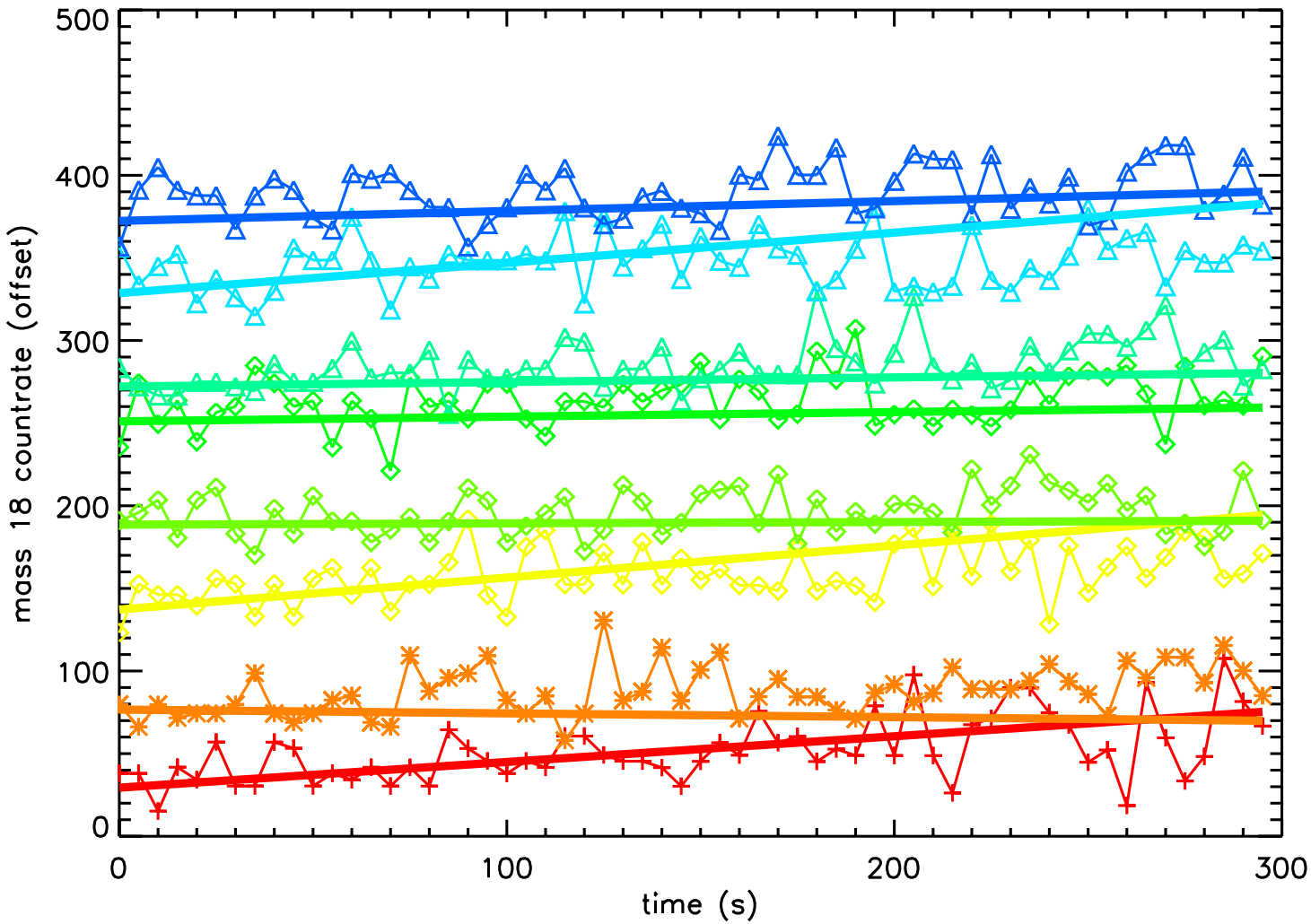
Change'3 and LADEE Positions



Mass 18—data

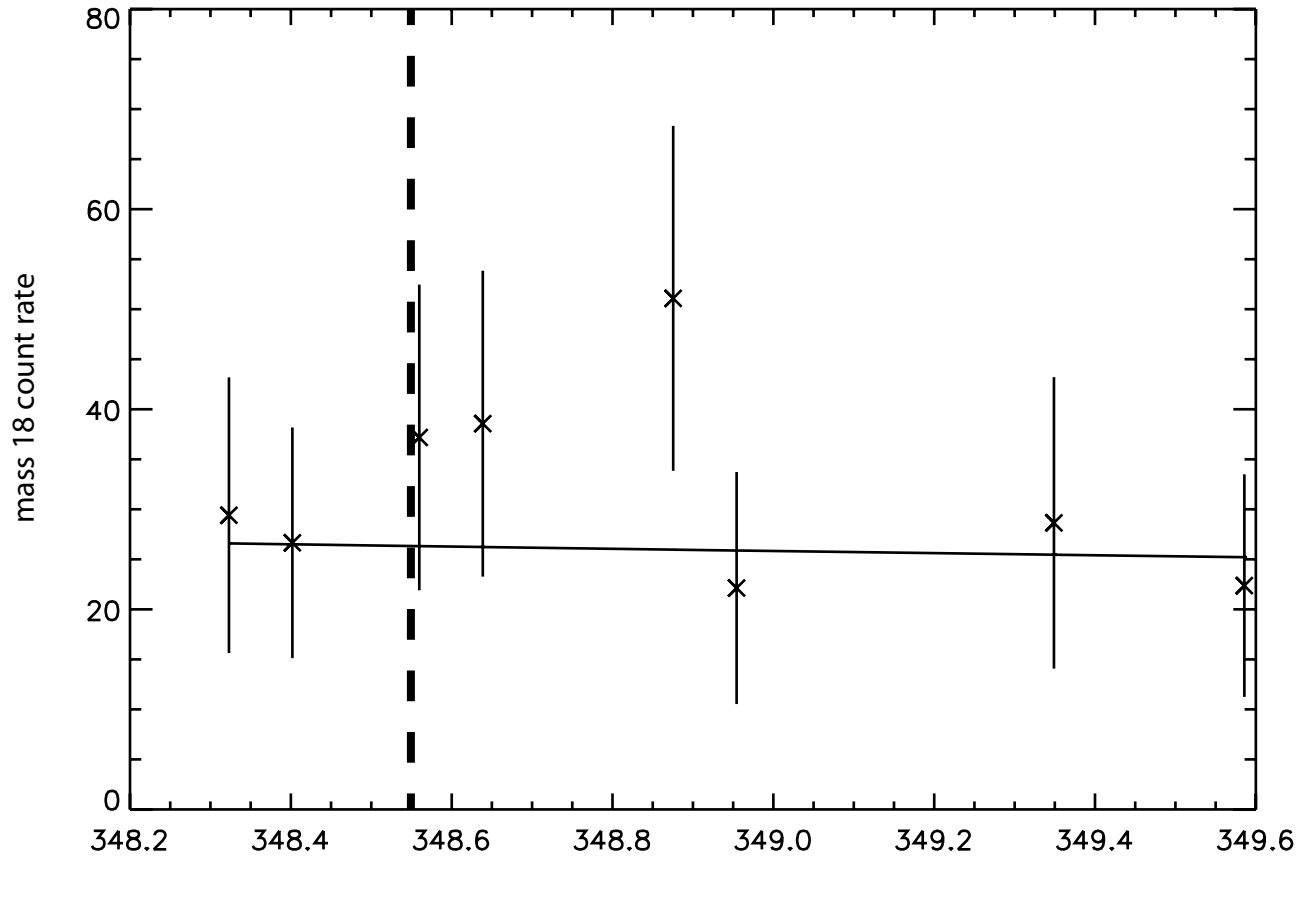


Mass 18, with linear fits

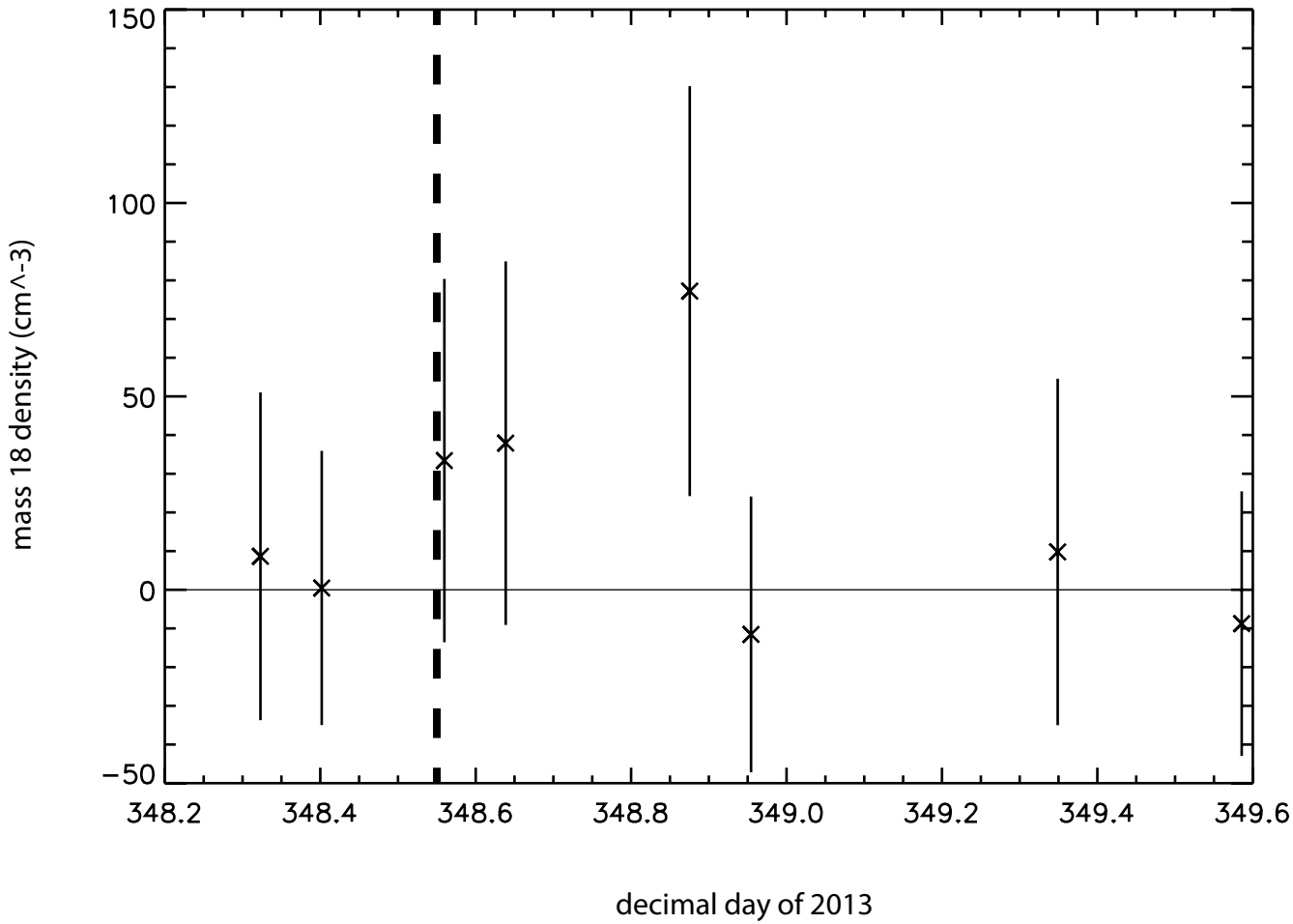


Temporal background

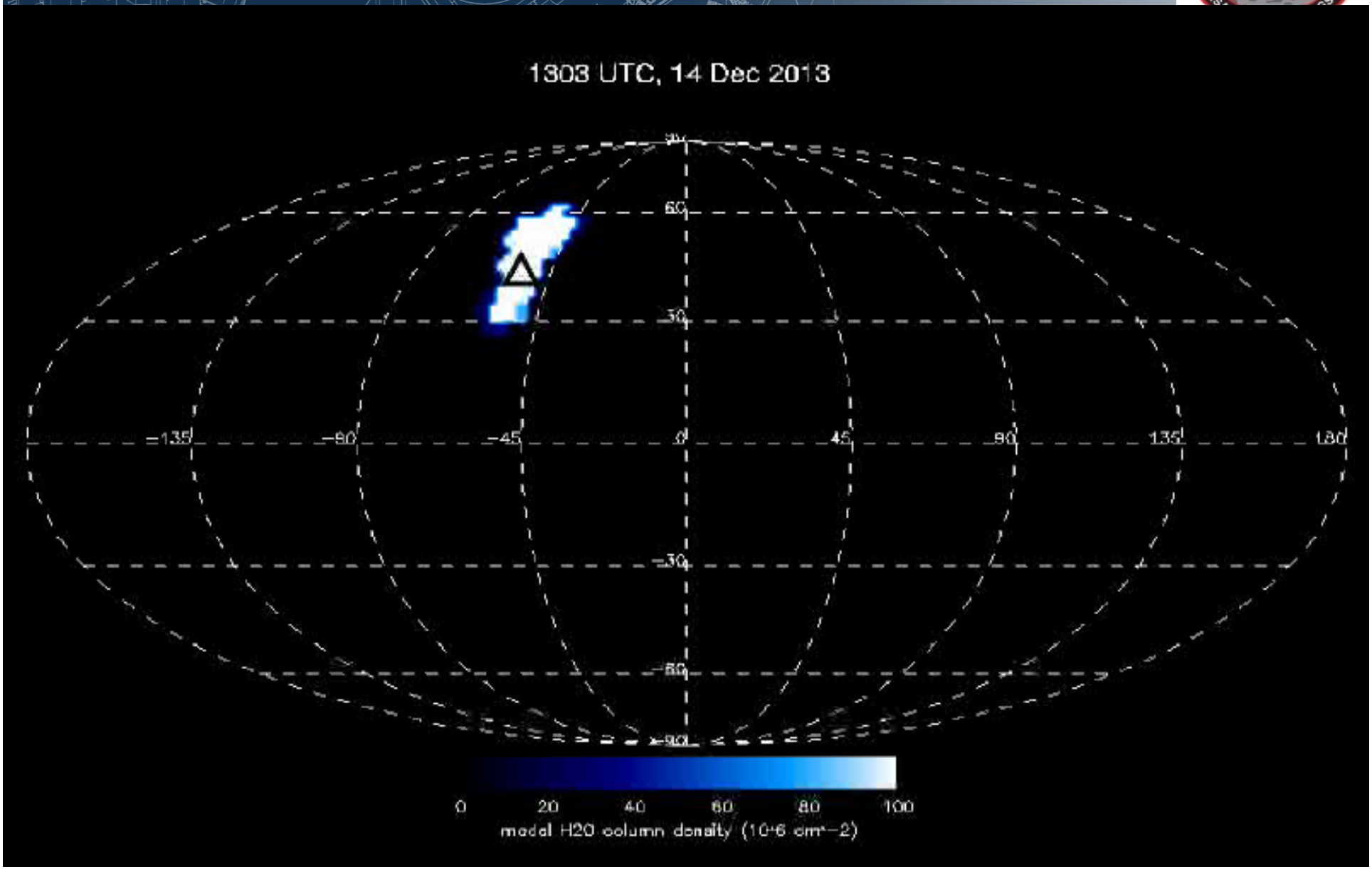
- Combination of Geminids and instrument background



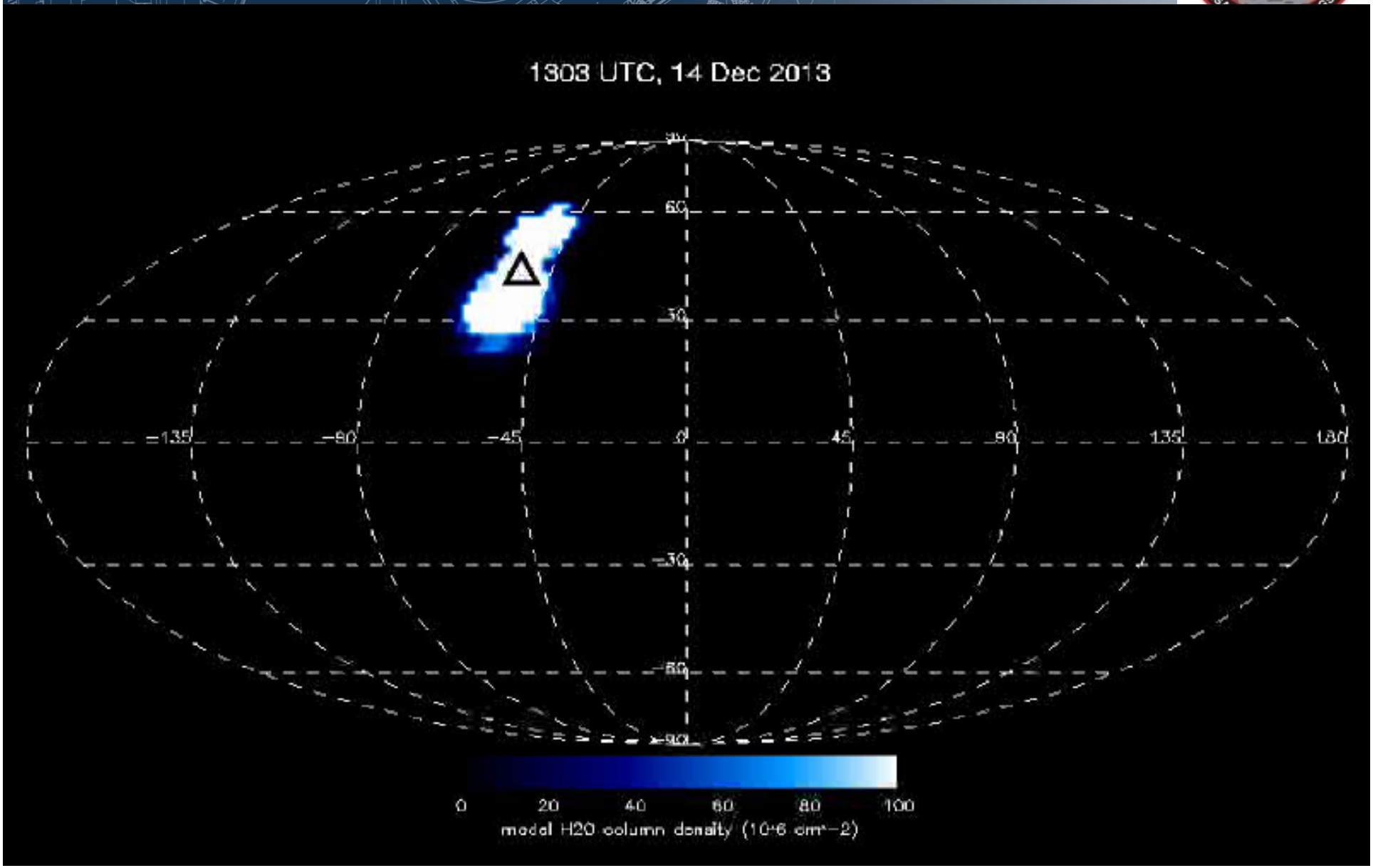
Water density



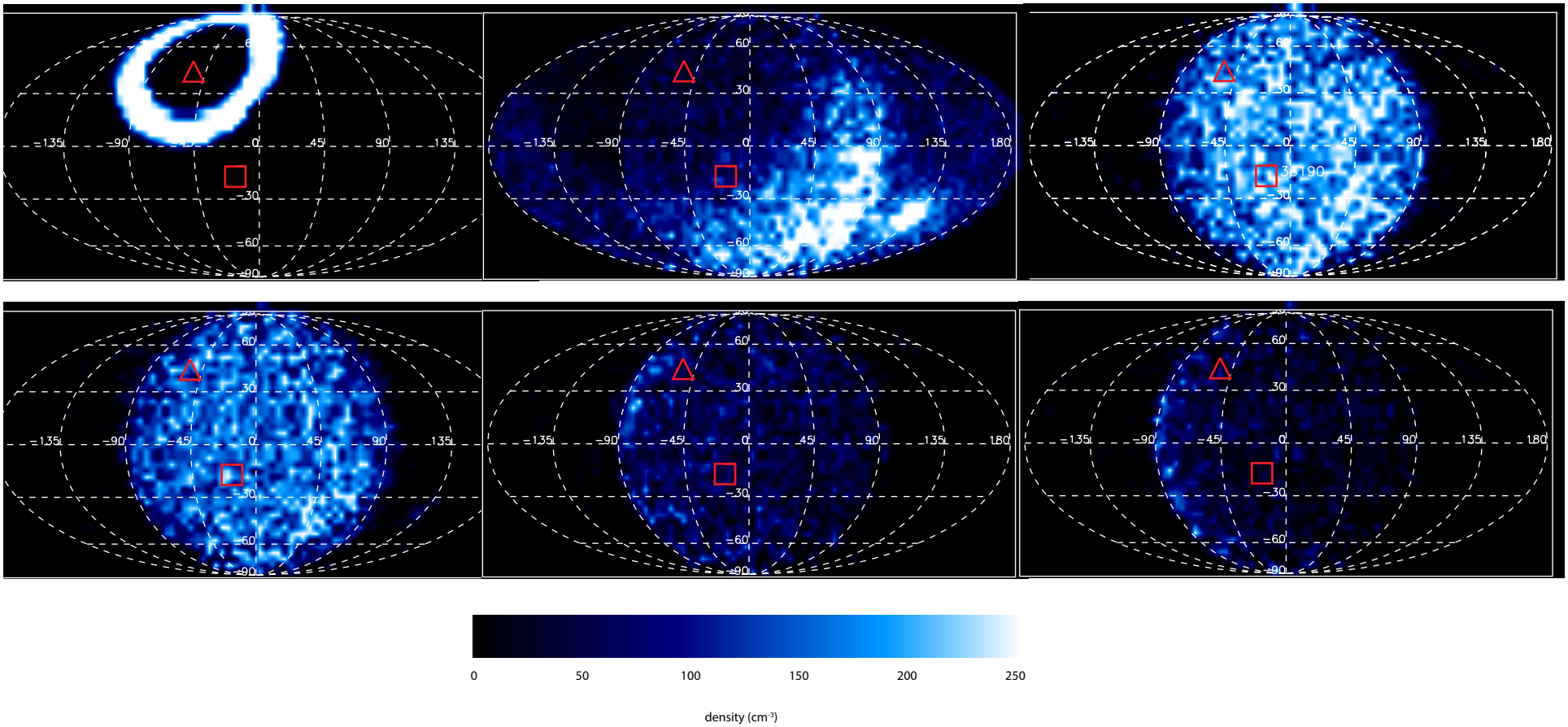
100% Thermalization



70% Thermalization

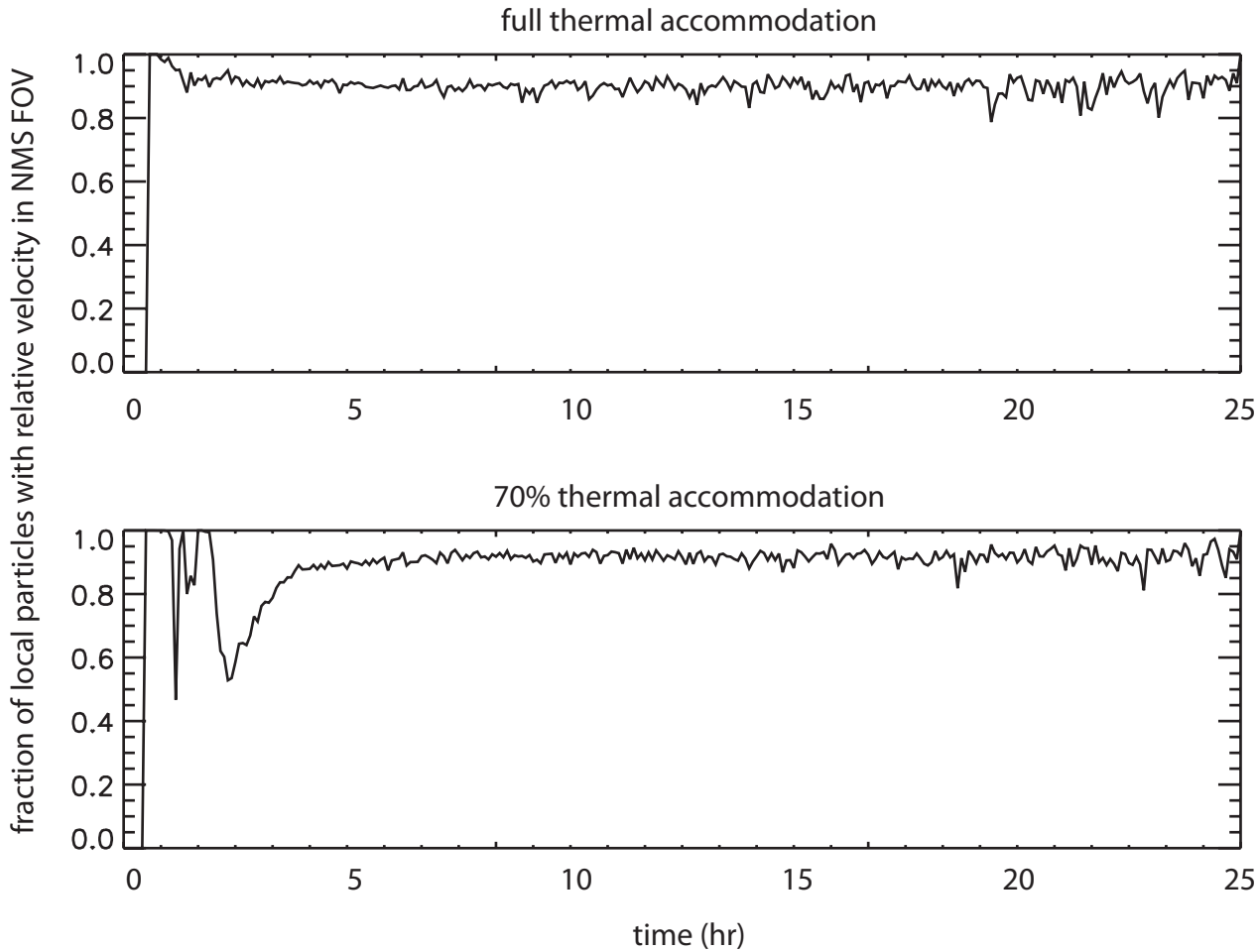


Model snapshots at LADEE observation times

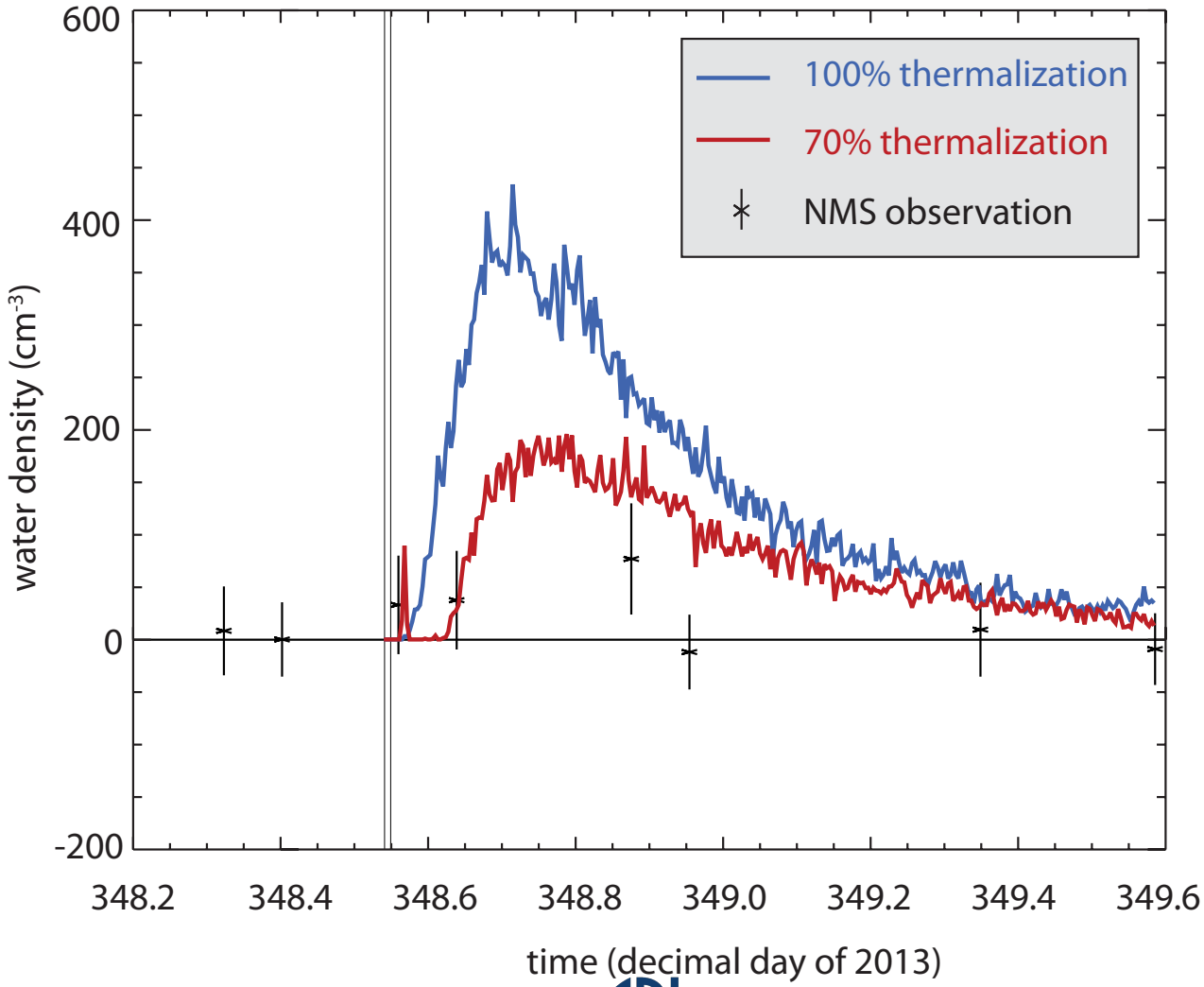


Correct for Particle Velocity

- The different runs have particles moving at different velocities
  - Only certain relative velocities can be detected by NMS
  - Ram enhancement is a function of relative velocity.



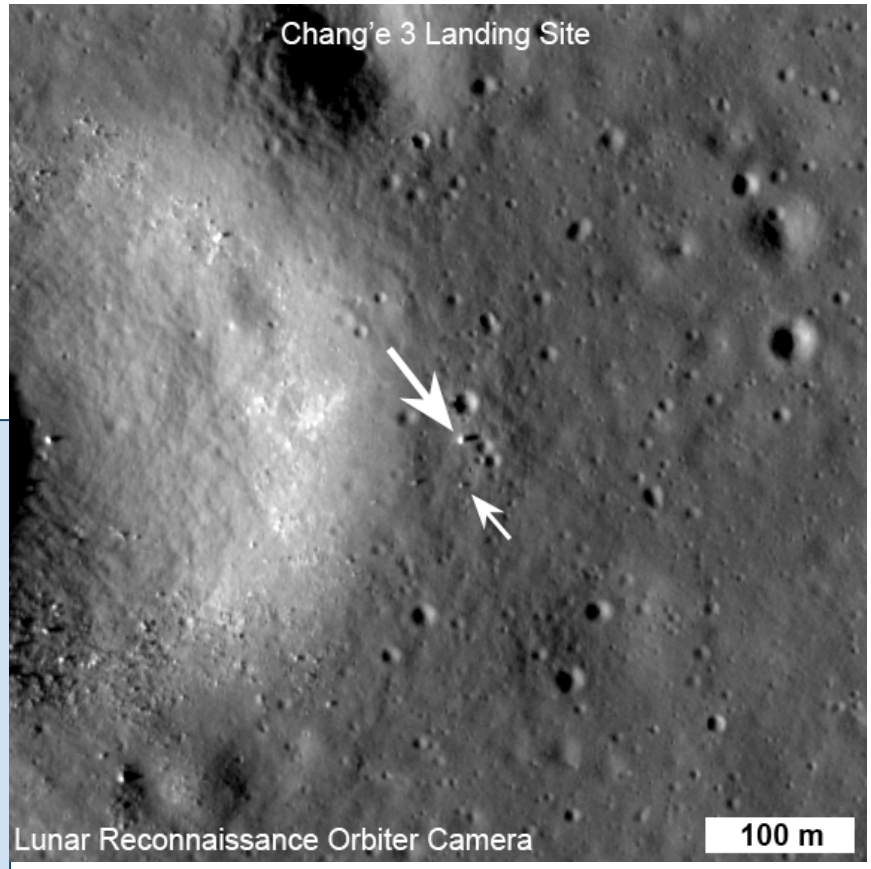
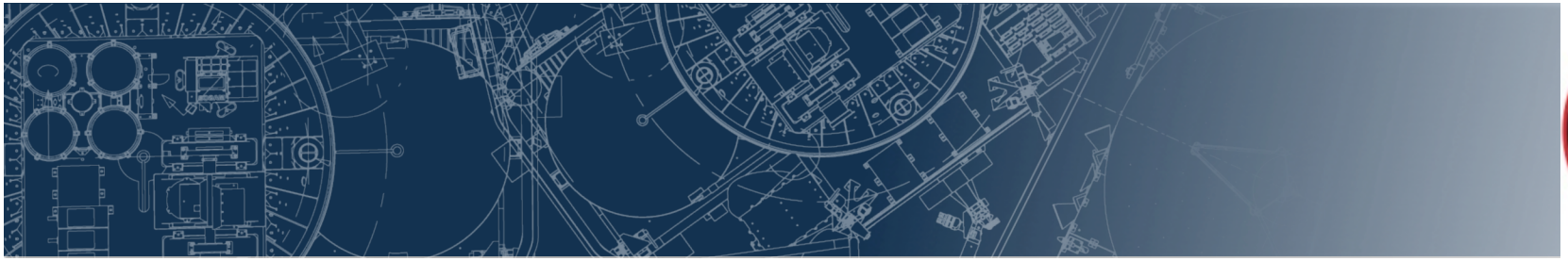
Compare to the model runs



Conclusion

- A total of ~446 kg of water is released into near-moon environment by the Chang'e 3 descent burn
  - ~122 kg of water in exhaust encounters the lunar surface
  - The initial impingement exceeds a monolayer/slab of water within ~2 km of the landing site or within 0.4 km for monolayer on grain surface
- Amount of thermalization has a strong influence on the subsequent propagation and loss of exhaust gases
  - LADEE would have detected water for 80-100% thermalization cases
  - Model/data comparison indicates ~<70% thermalization for water exhaust on contact with lunar regolith
  - Model/data comparison is also consistent with fractional long-term adsorption of water to regolith

Conclusion

- Exploration question: How do spacecraft landings on the Moon affect the lunar environment (especially the exosphere?)

Spacecraft landings on the lunar surface present a minor, short-lived perturbation to the lunar exosphere