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

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Motivations and Objectives

Meteoroids impacting the Moon's surface play an important role in producing the lunar exosphere.

During meteoroid streams, fluxes can increase significantly compared with sporadic background.

Observed/anticipated effect of streams include:
- **Response of Na exosphere during Leonid storms**
- **Enhanced impact-ejection of exospheric dust**

Aim is to determine the influences of the meteoroid streams on the lunar environment during the LADEE mission, and understand the processes involved.

Distinguishing “Meteor” Terms

Meteoroid

- Particle in space originating from a comet or asteroid.
- Debris trails from these bodies initially form “streams” of particles on near-parallel trajectories with similar velocities.
- Streams eventually disperse to form “sporadic background”.
- At 1 AU, mostly originate from short-period comets.
- **These ones hit the Moon!**

Meteor

- A meteoroid that has entered the Earth’s atmosphere and burns up to form a meteor, or “shooting star”.
- If from a stream, then you get a “meteor shower”, or in extreme cases a “meteor storm”.

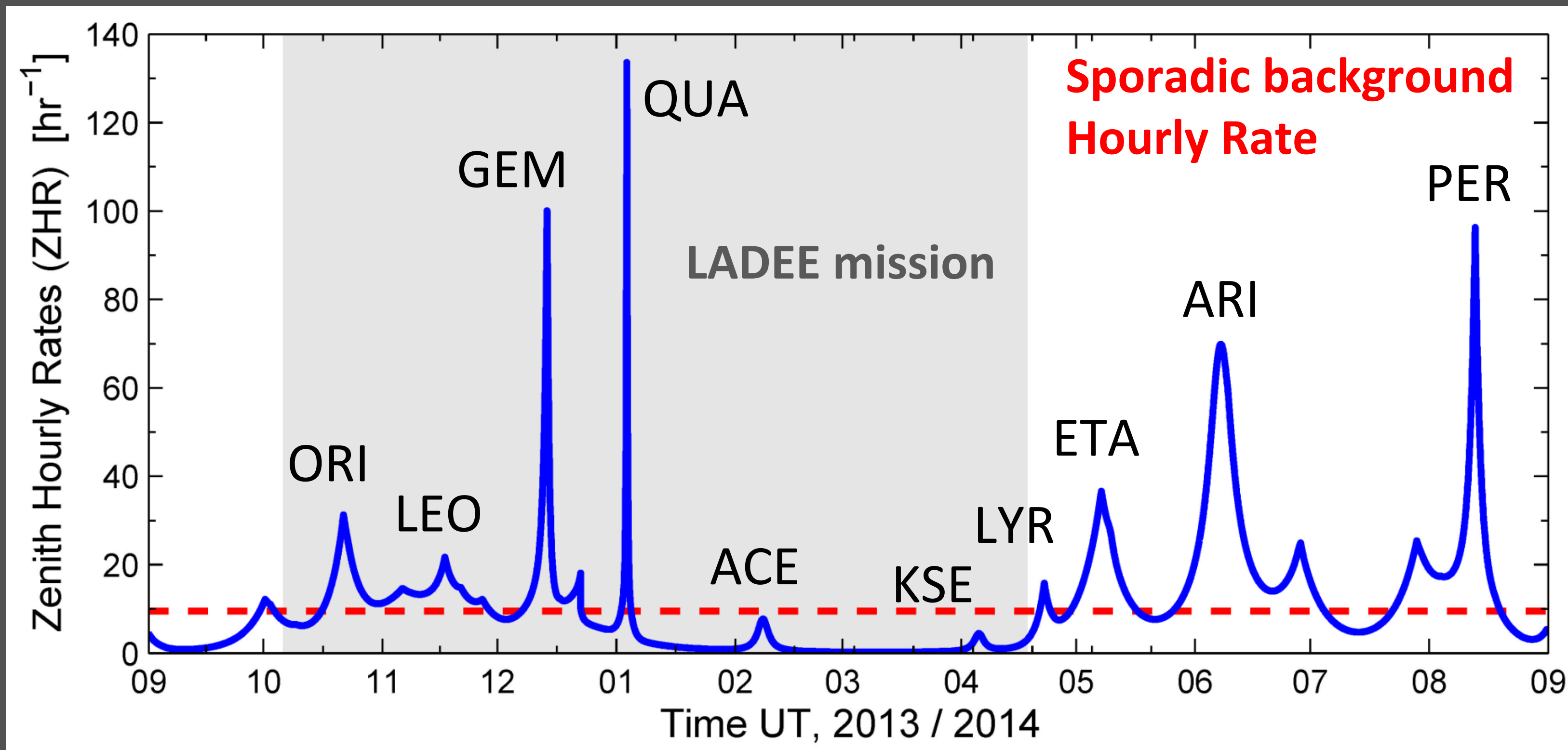
Meteorite

- If anything reaches the ground, it’s a meteorite.

Occurrence of Meteoroid Streams

- In order to determine when streams occur we use the IAU List of Established Meteor Showers.
- Key parameters provided by the IAU Meteor Data Center www.astro.amu.edu.pl/~jopek/MDC2007
- Visual (eyeball, photo and video) and radar observations of meteors form the basis of this list.
- Streams form a “beam” of particles, so showers appear to emanate from a point on the sky called the “radiant”.
- The Earth and Moon will be completely immersed in the major annual meteoroid streams considered here.
- Meteoroids are mostly very small, << 1 gram

Established Annual Meteor Showers



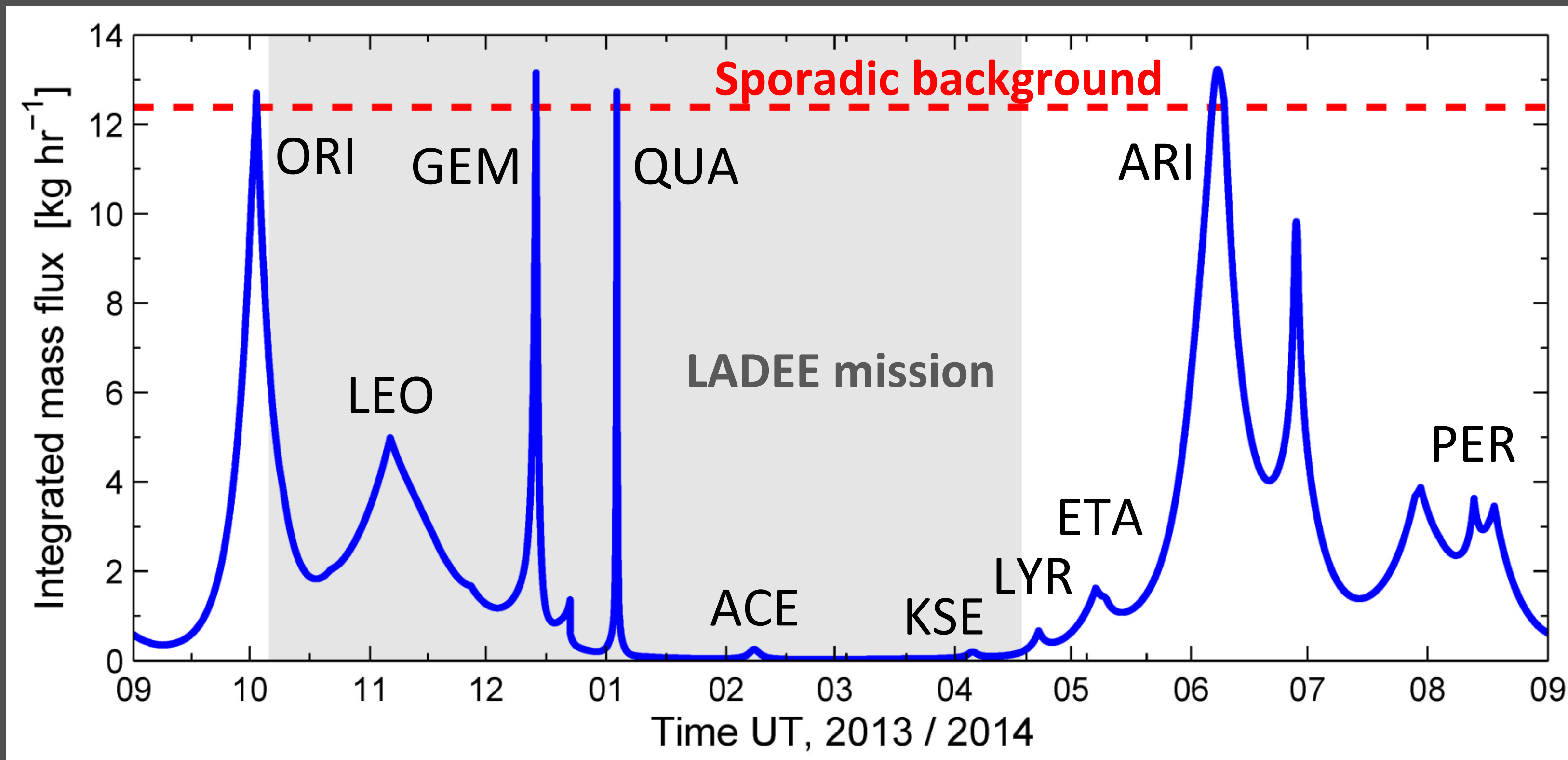
Combined Zenith Hourly Rates (ZHR) from all streams estimated using IAU list and method in *Jenniskens* (1994)

ZHR – meteor rate from a radiant seen by a standard observer under optimum viewing conditions.

Converting to Mass Fluxes at the Moon

- Using method described in *Jenniskens* (1994) and *McDonnell et al.* (2001) we can convert to physical fluxes.
- Important parameters for this conversion are the "magnitude distribution index" χ and the stream velocity.
- Account for effects of gravitational focusing and slower impact velocities when estimating fluxes at the Moon.
- For comparison we show estimates for sporadic background fluxes, assuming entry velocity into Earth's atmosphere is 18 km s^{-1}.
- Fluxes integrated over target cross-section of the Moon and given as hourly rates to provide tangible values.

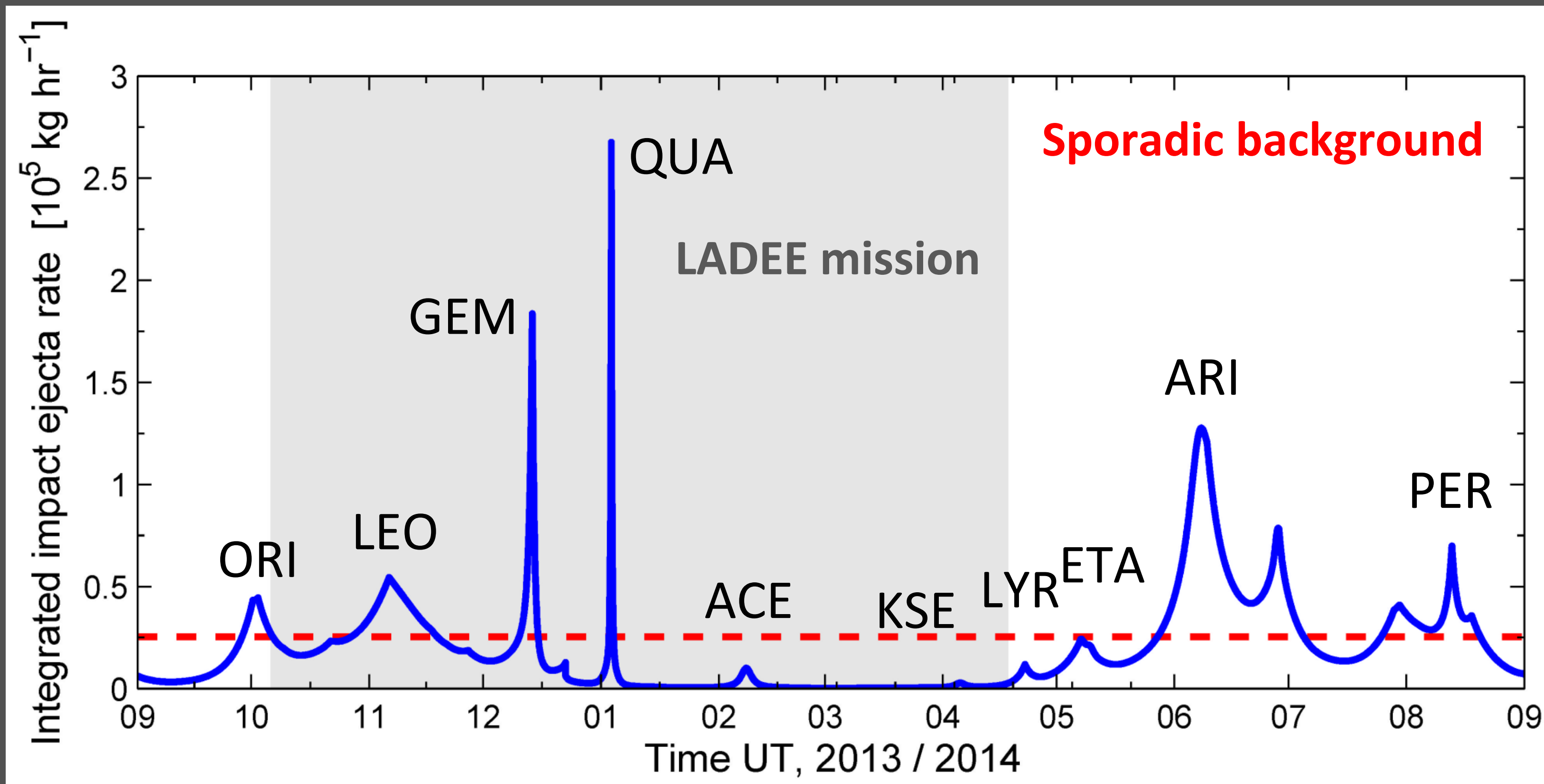
Stream Meteoroid Mass Flux at Moon



Ratio of stream to background mass flux is different than meteor rates due to effects of χ and impact velocities

Mass flux is most relevant to production of neutrals, ions and dust in the exosphere.

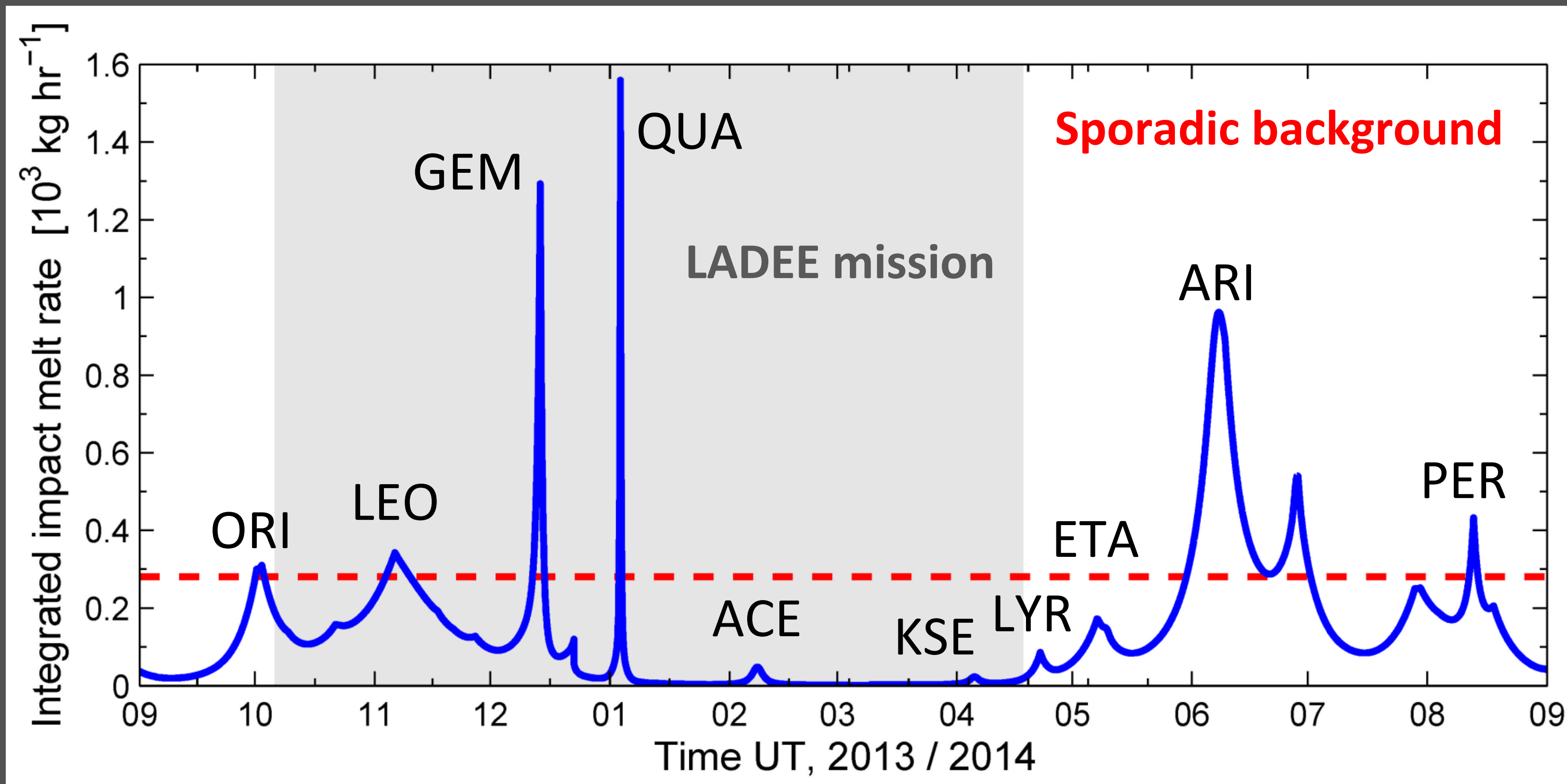
Ejecta Production Rate from Streams



Total ejecta mass rate (particles, melt and vapor) estimated using *Koschny and Grün* (2001) formula.

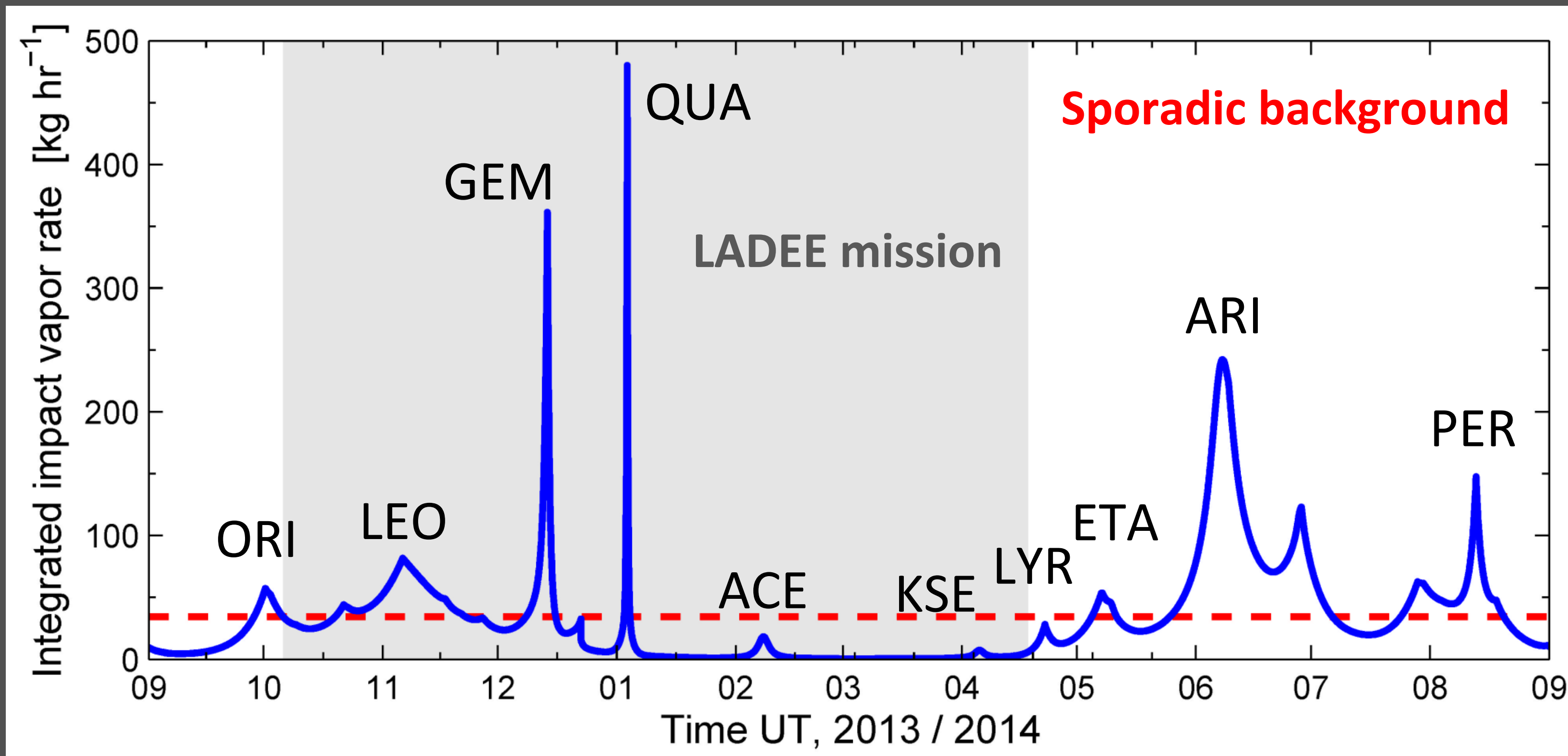
Very high ejecta yields ~10^4, stream meteoroids are more efficient than sporadics due to higher impact velocities.

Melt Production Rate from Streams



Melt ejecta mass rate estimated using *Cintala* (1992) formula. High ejecta yields ~10^2.

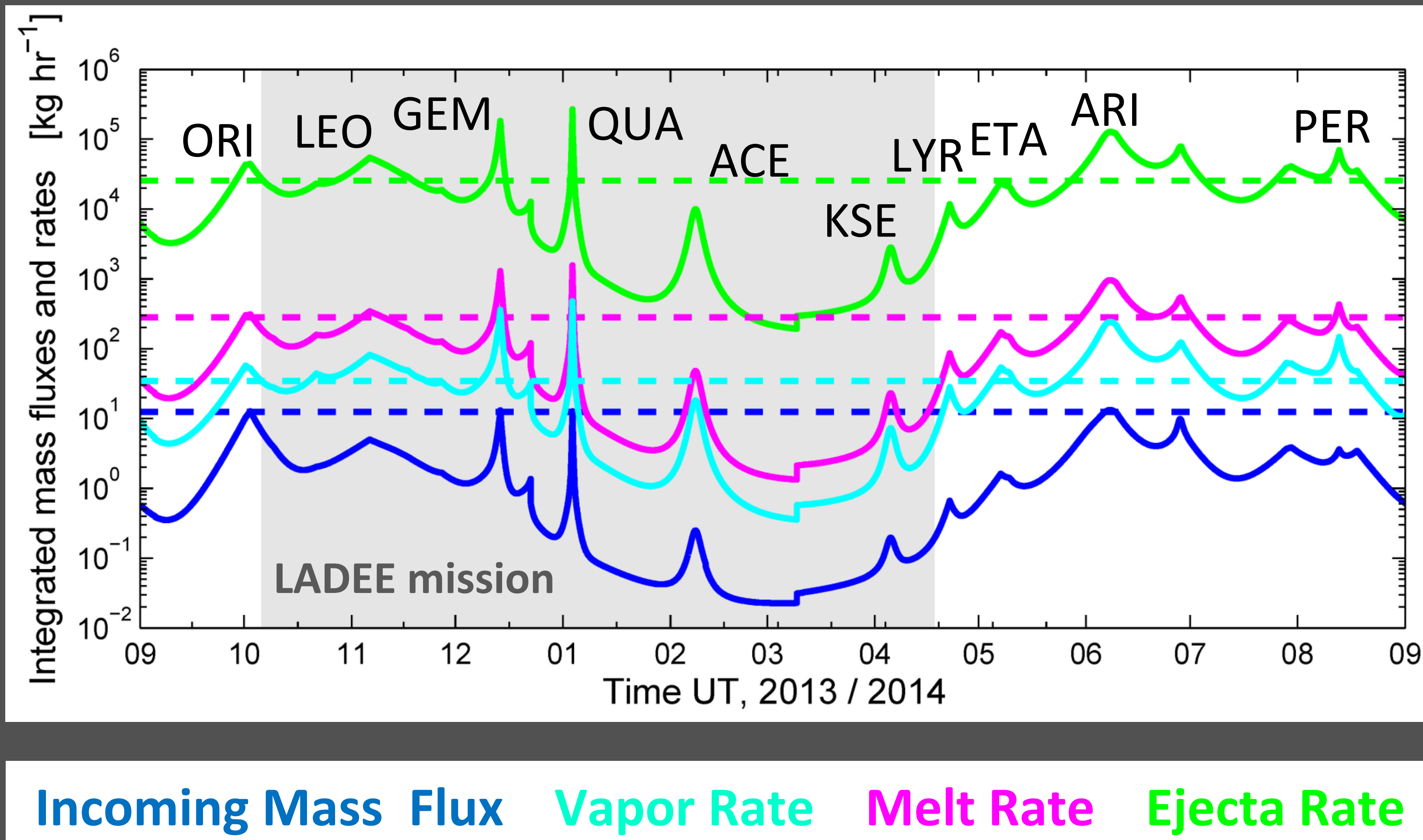
Vapor Production Rate from Streams



Vapor ejecta mass rate estimated using *Cintala* (1992) formula. Ejecta yields ≈10–100.

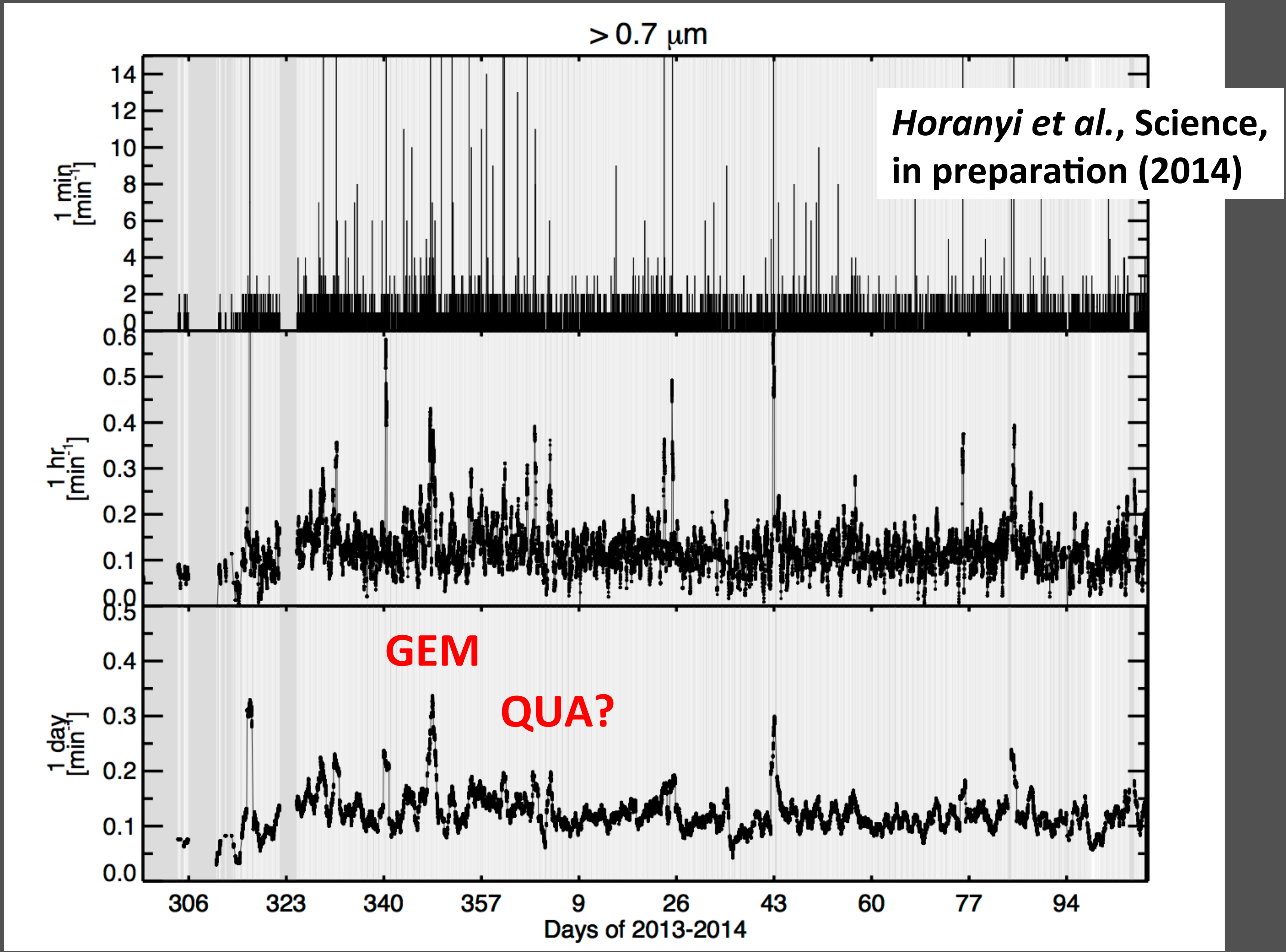
Most relevant to formation of exosphere (e.g., Na and K) – as discussed by Tony Colaprete et al. earlier …

Comparison of Mass Fluxes and Production Rates from Stream Meteoroids

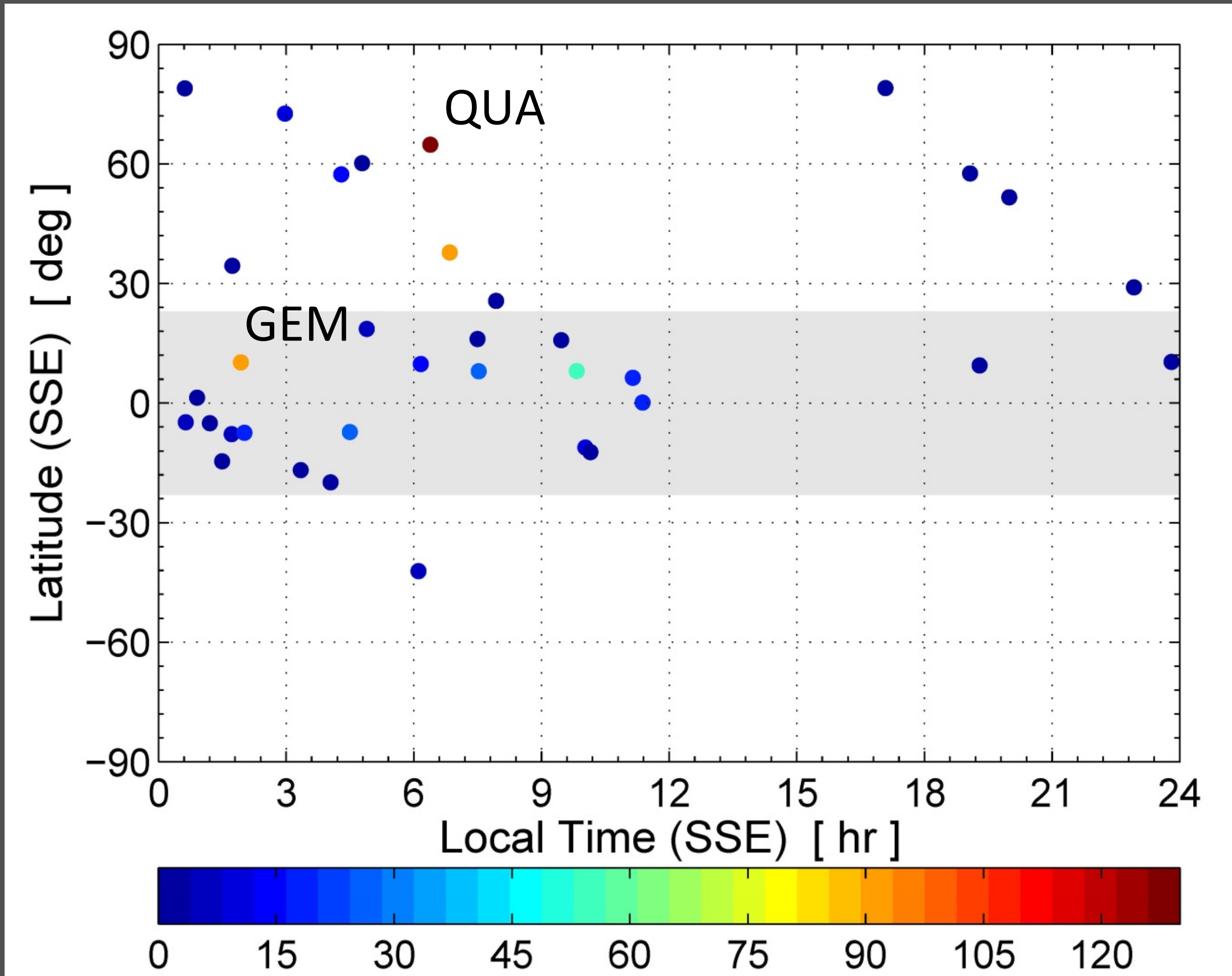


Majority of ejecta mass is in the form of particulates, which forms exospheric dust.

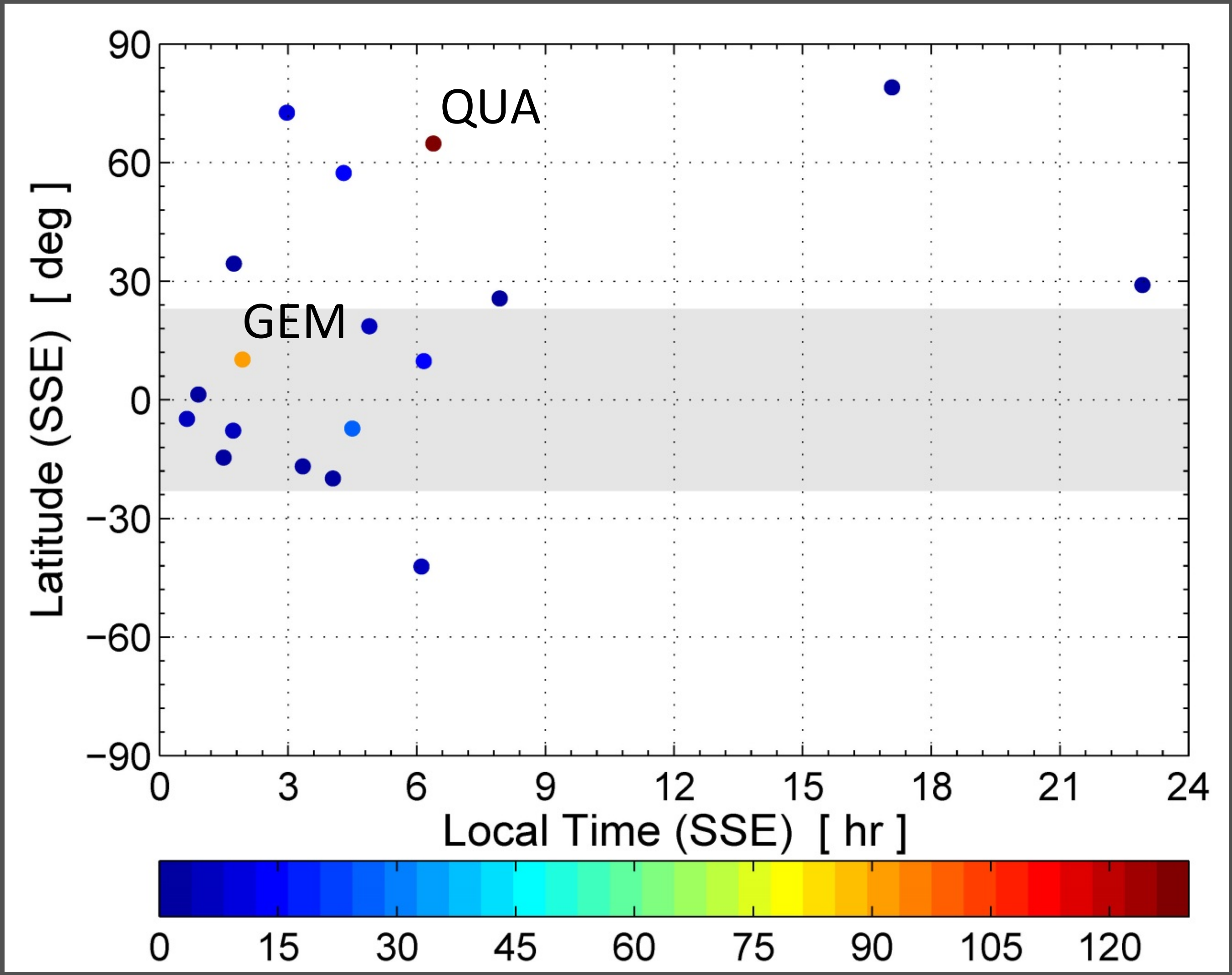
LDEX In Situ Observations of Ejecta Cloud



All Established Annual Meteoroid Stream Radiants at the Moon



Established Annual Meteoroid Stream Radiants at the Moon during LADEE



Summary and Conclusions

Based on estimates, we expect annual streams to have an observable effect on the exosphere.

The annual Geminids (GEM) and Quadrantids (QUA) are predicted to produce the highest ejecta mass production rates supplying the lunar exosphere – fortunate for LADEE!

Enhanced activity observed by LADEE (e.g., LDEX) more apparent during Geminids than Quadrantids

- Possible role of radiant location
- GEM near equator, QUA nearer the pole
- Localized processes around radiant?

Geminid parent body – “rocky comet” B-type chondritic asteroid (contains volatiles)