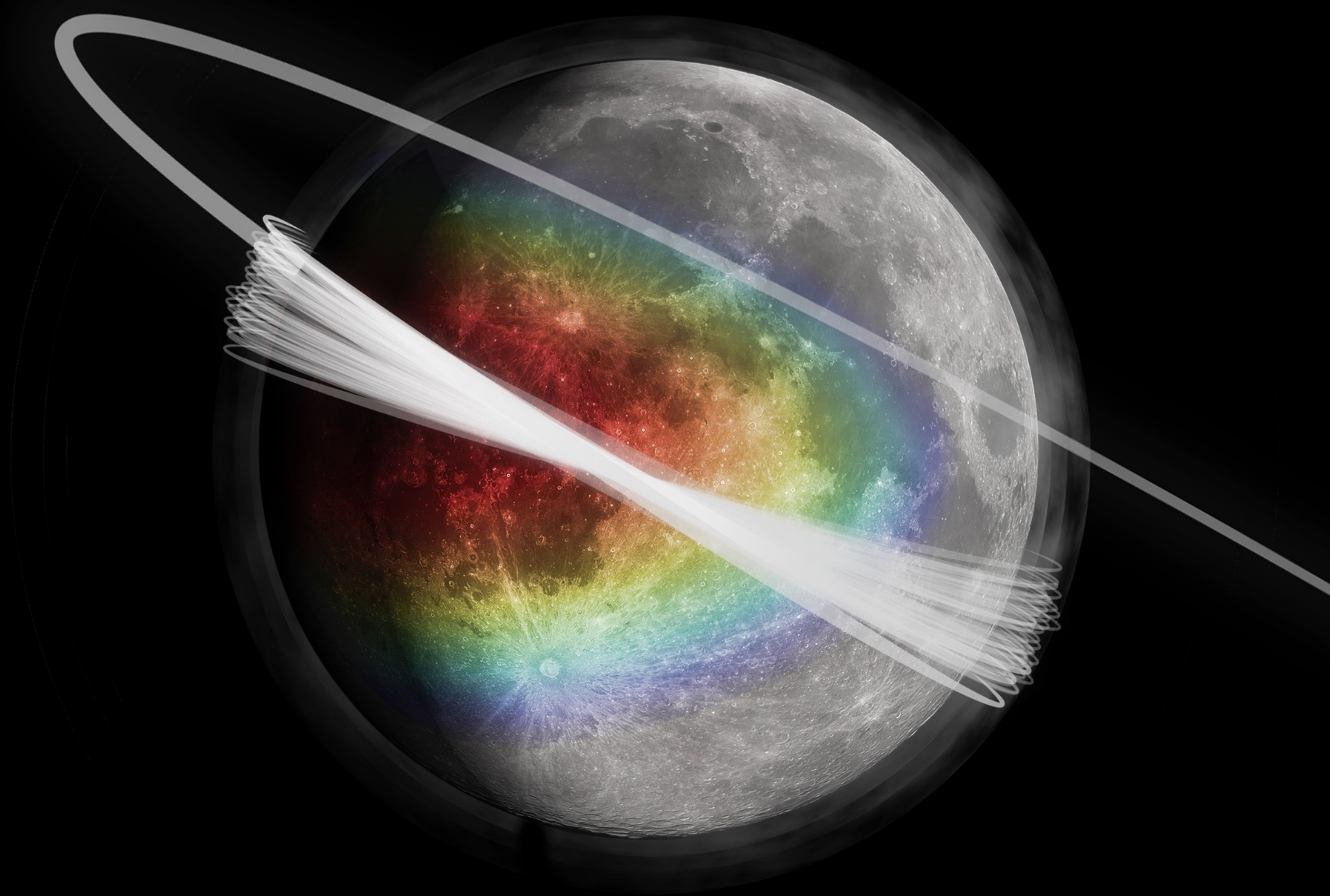
The Dust Environment of the Moon

J.R. Szalay
with contributions from
M. Horányi, M. Sarantos, D. Janches, P. Pokorny, S. Kempf,
E. Gruen, Z. Sternovsky, J. Schmidt, R. Srama

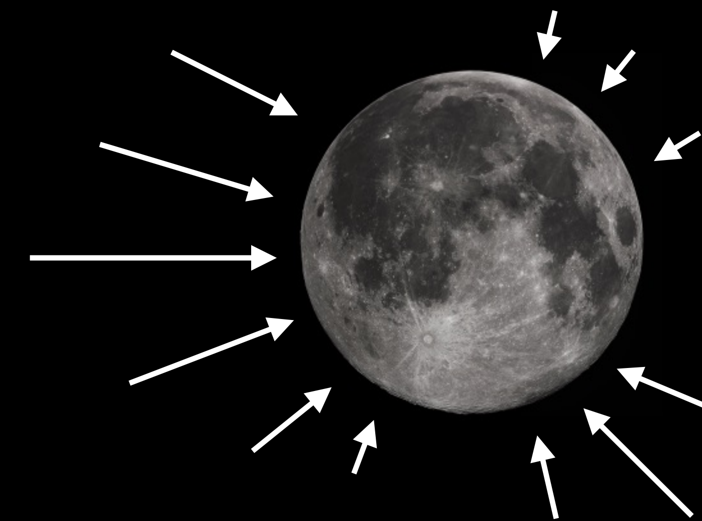


http://www.britannica.com/topic/Comet-Hale-Bopp

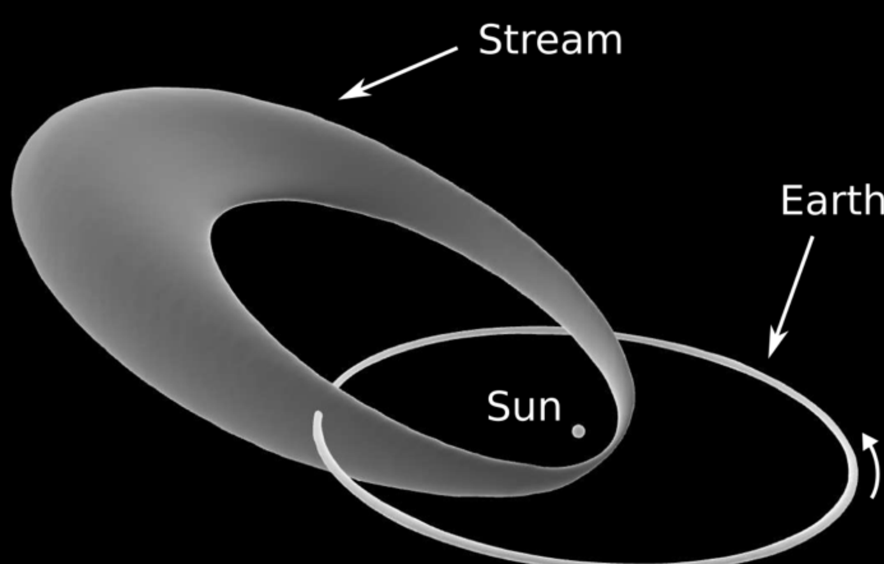

©Matthew Dieterich


NASA/ARC

Meteoroid Sources

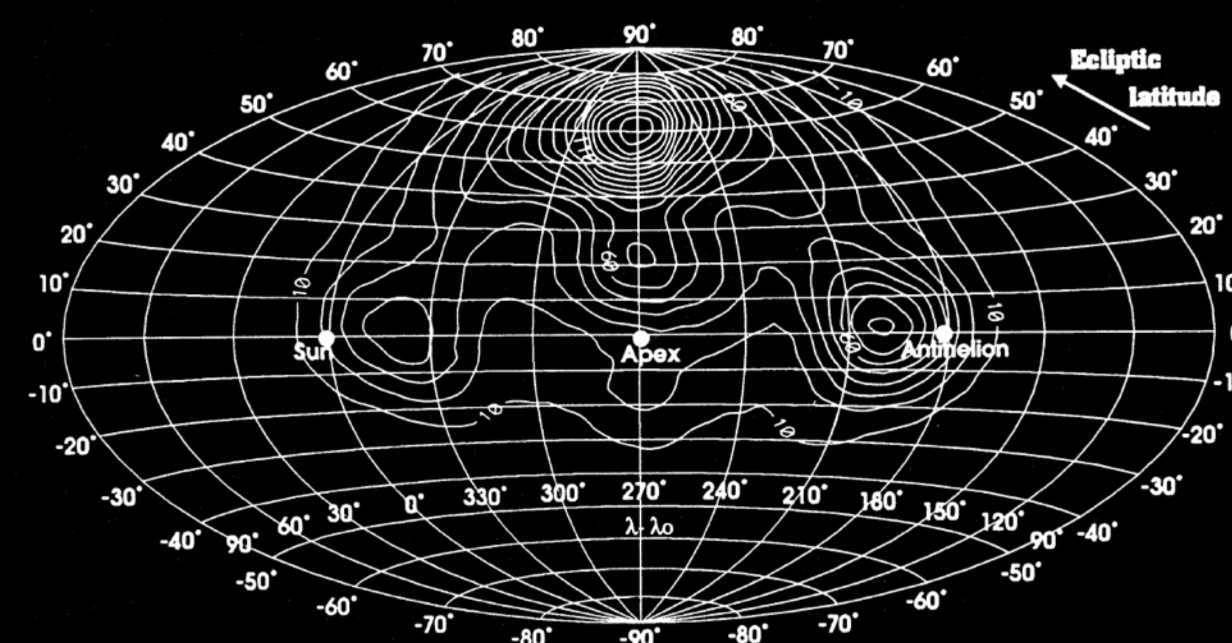


Meteor Showers



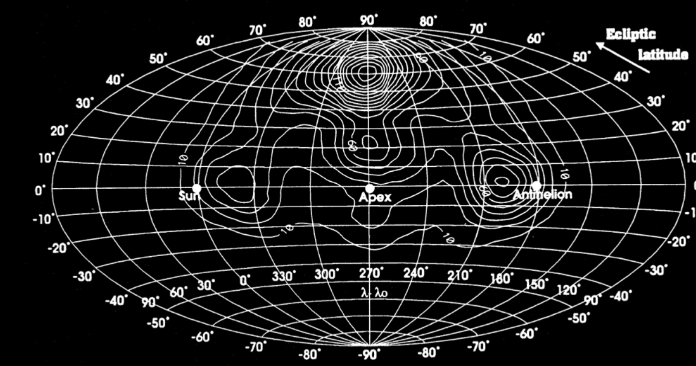
Barensten and Lefevre, 2006

Sporadic Meteoroids

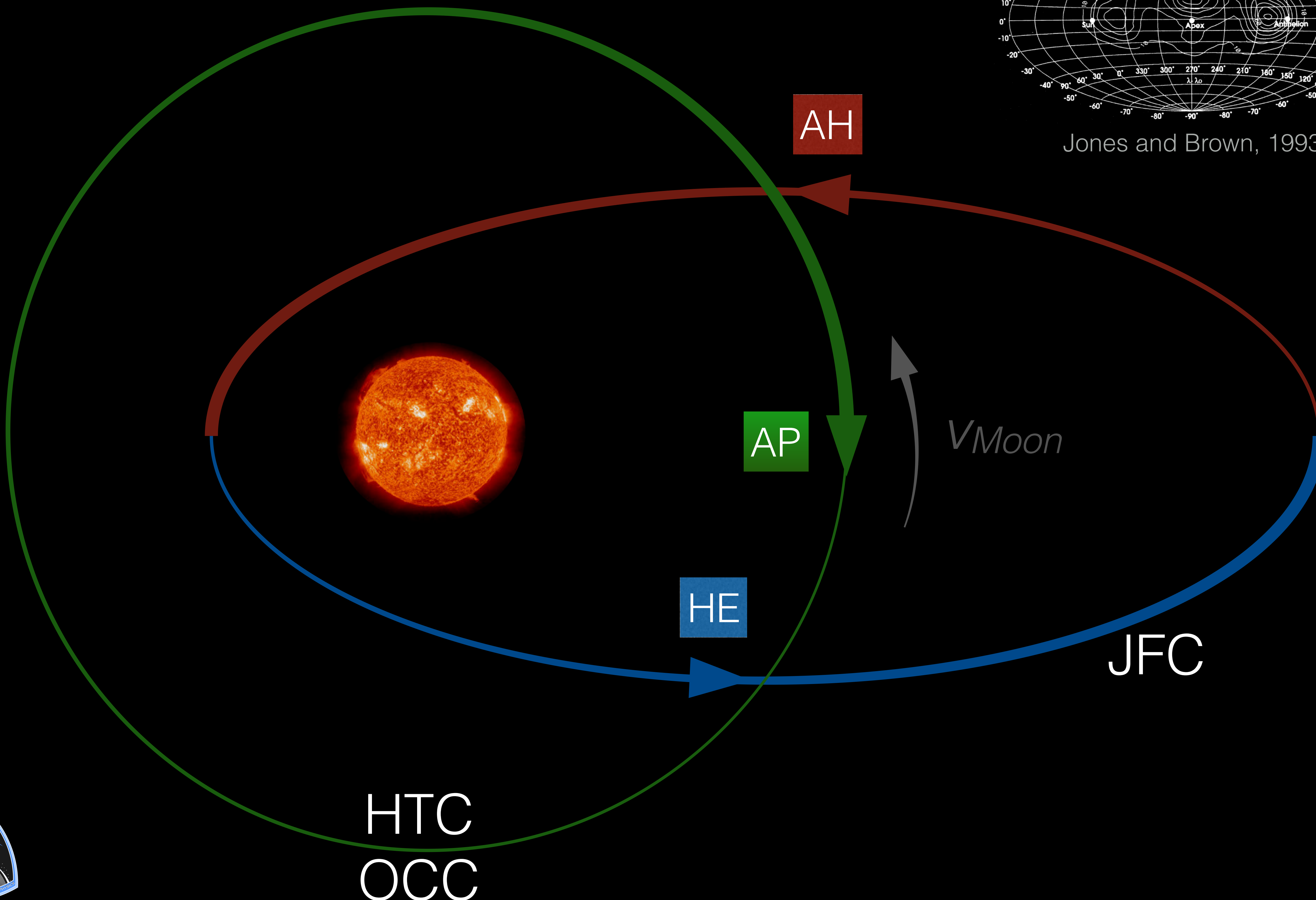


Jones and Brown, 1993

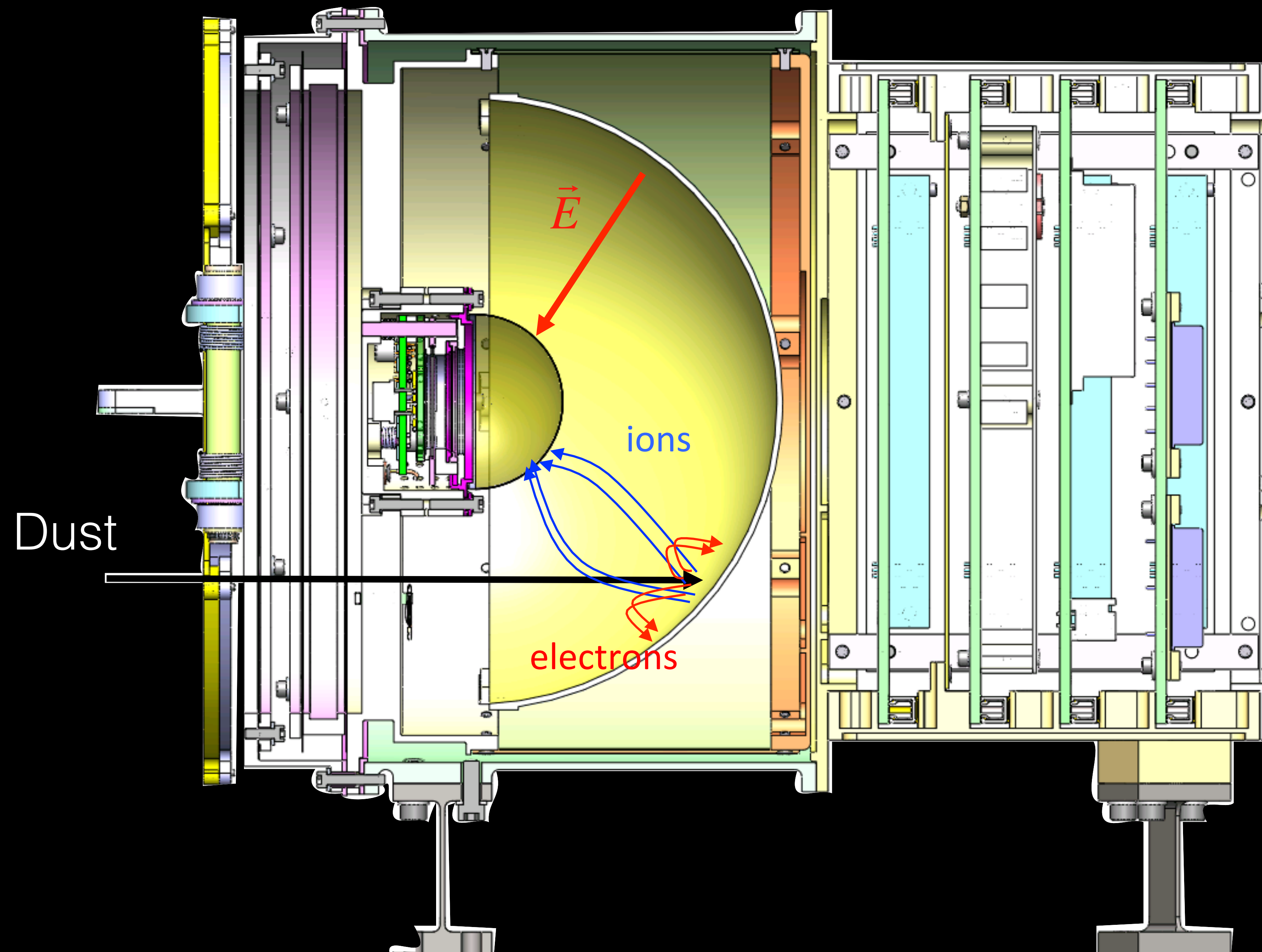
Sporadic Meteoroid Sources



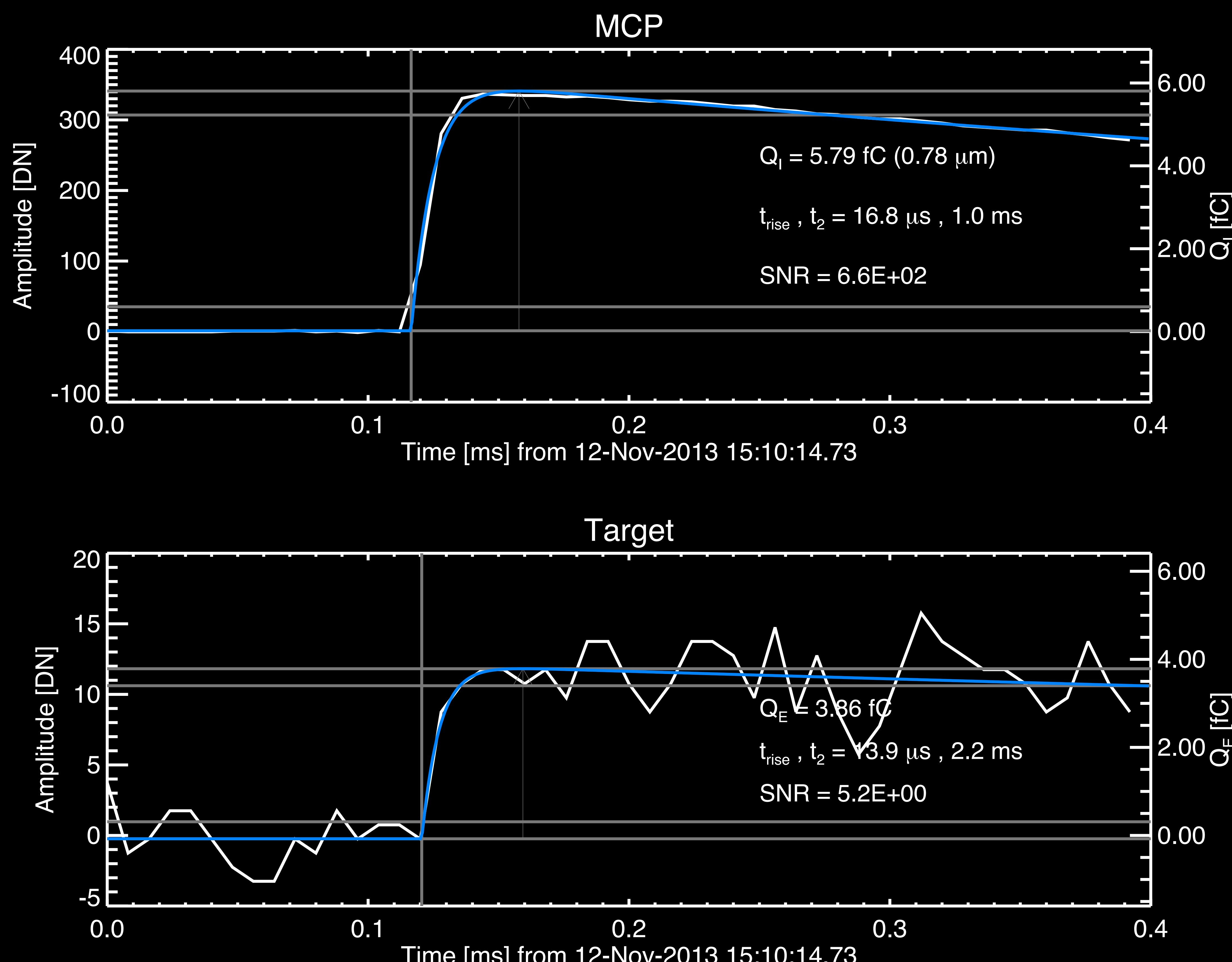
Jones and Brown, 1993



LDEX

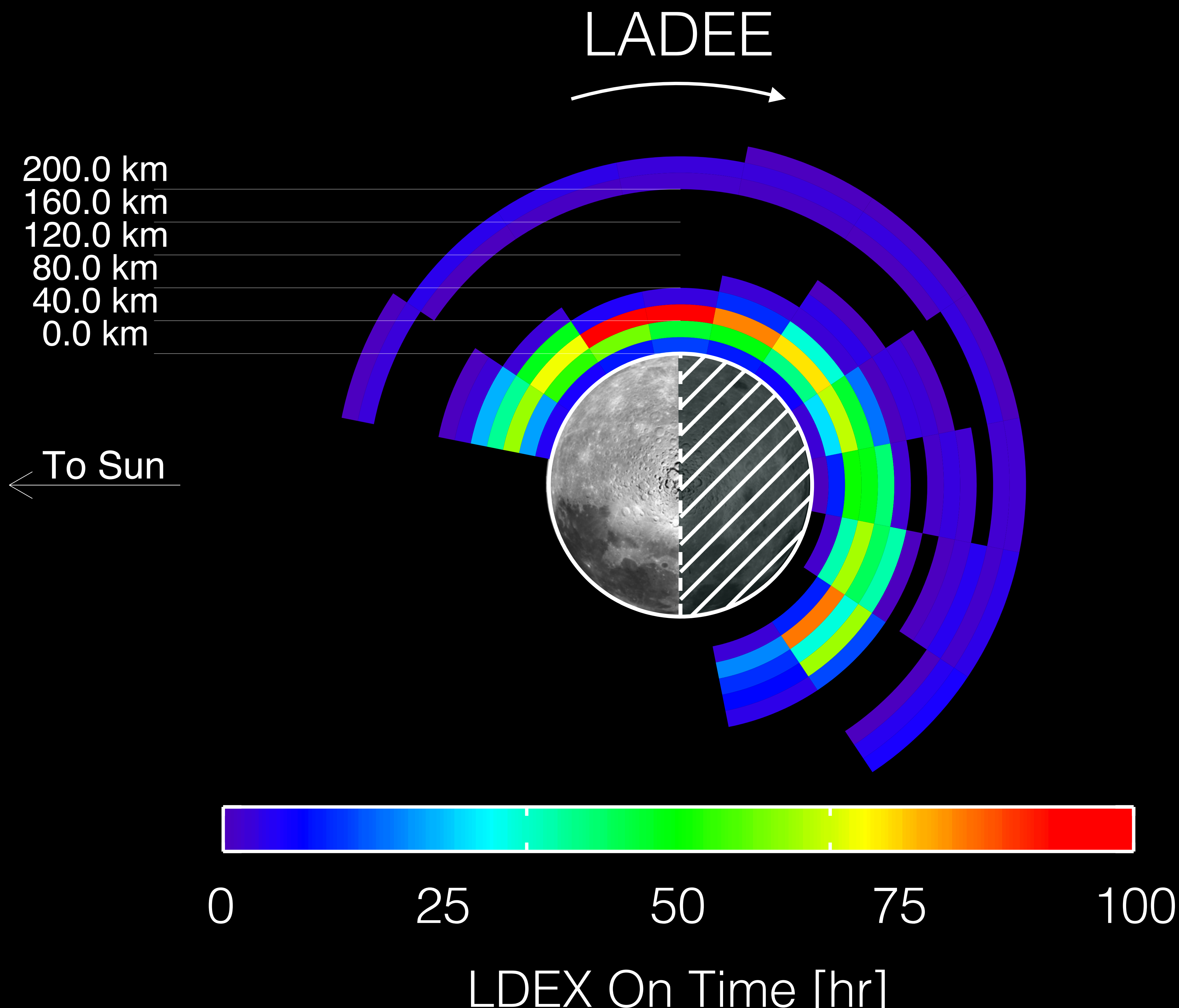


Waveforms



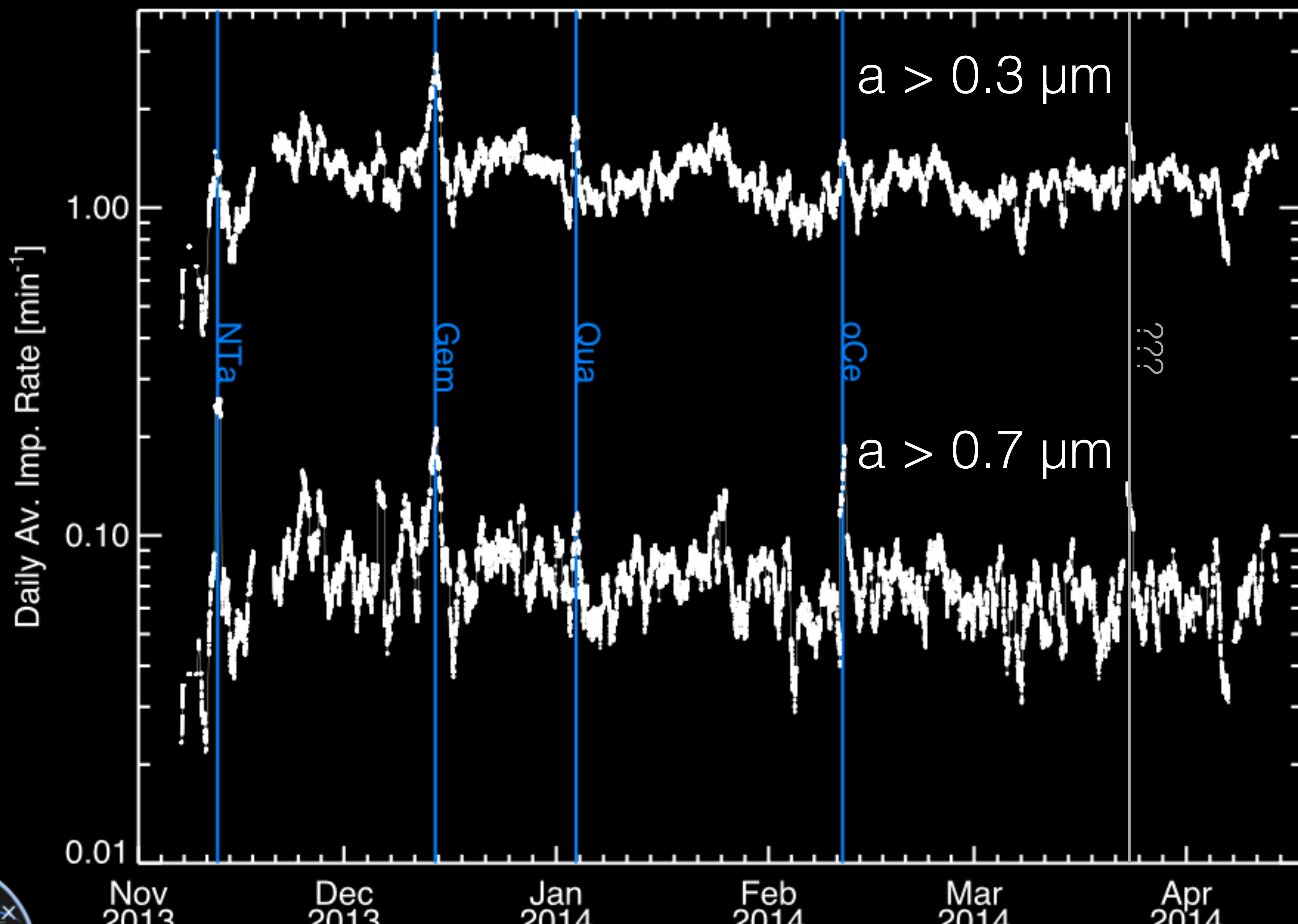
Horányi *et al.*, *SSR*, 2014

LADEE Mission

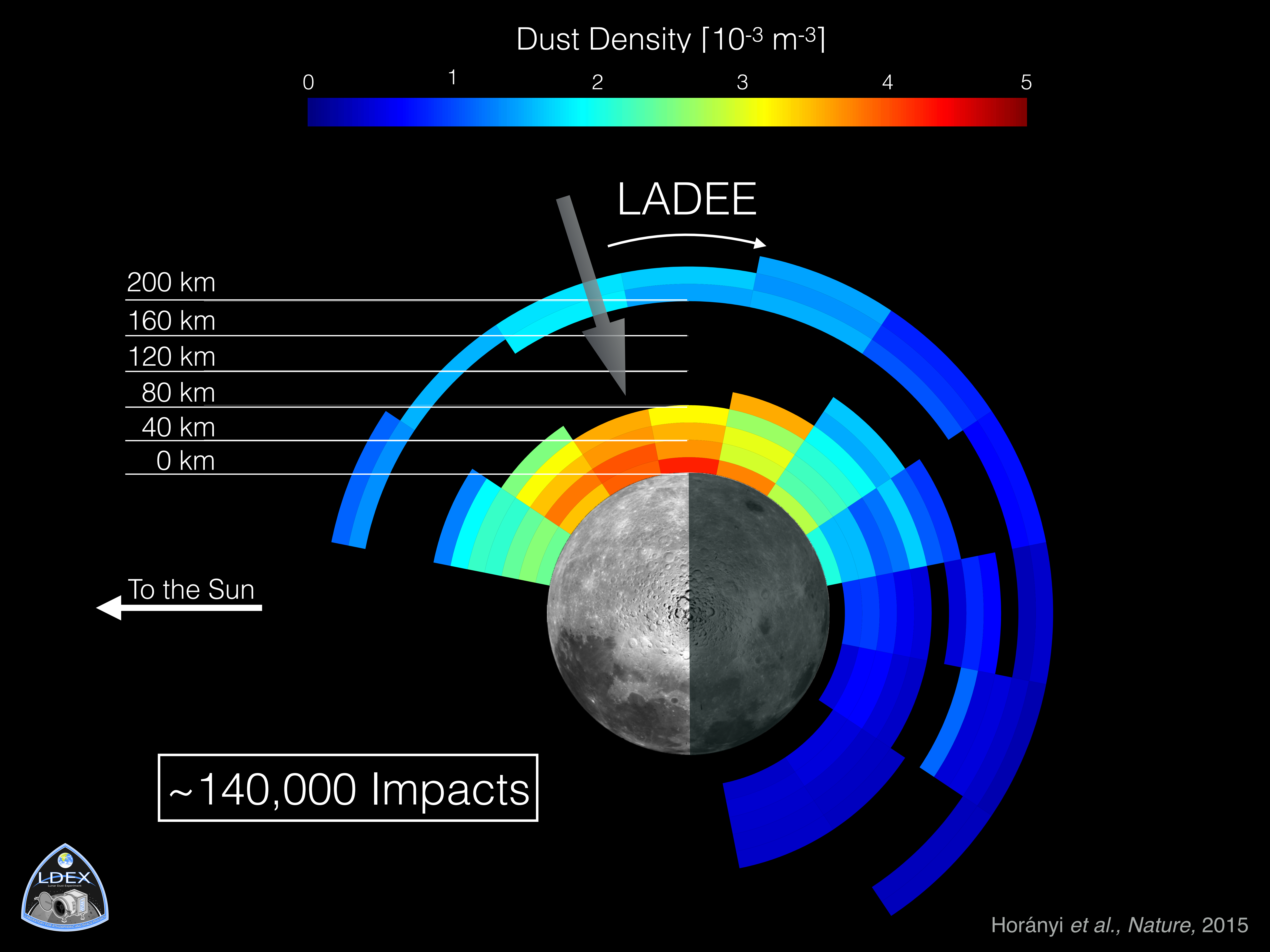


The Lunar Dust Exosphere

Impact Rate



Horányi *et al.*, *Nature*, 2015


Dust Density [10^-3 m^-3]
0
1
2
3
4
5
LADEE
200 km
160 km
120 km
80 km
40 km
0 km
To the Sun
~140,000 Impacts
LDEX
Horányi et al., Nature, 2015

HE

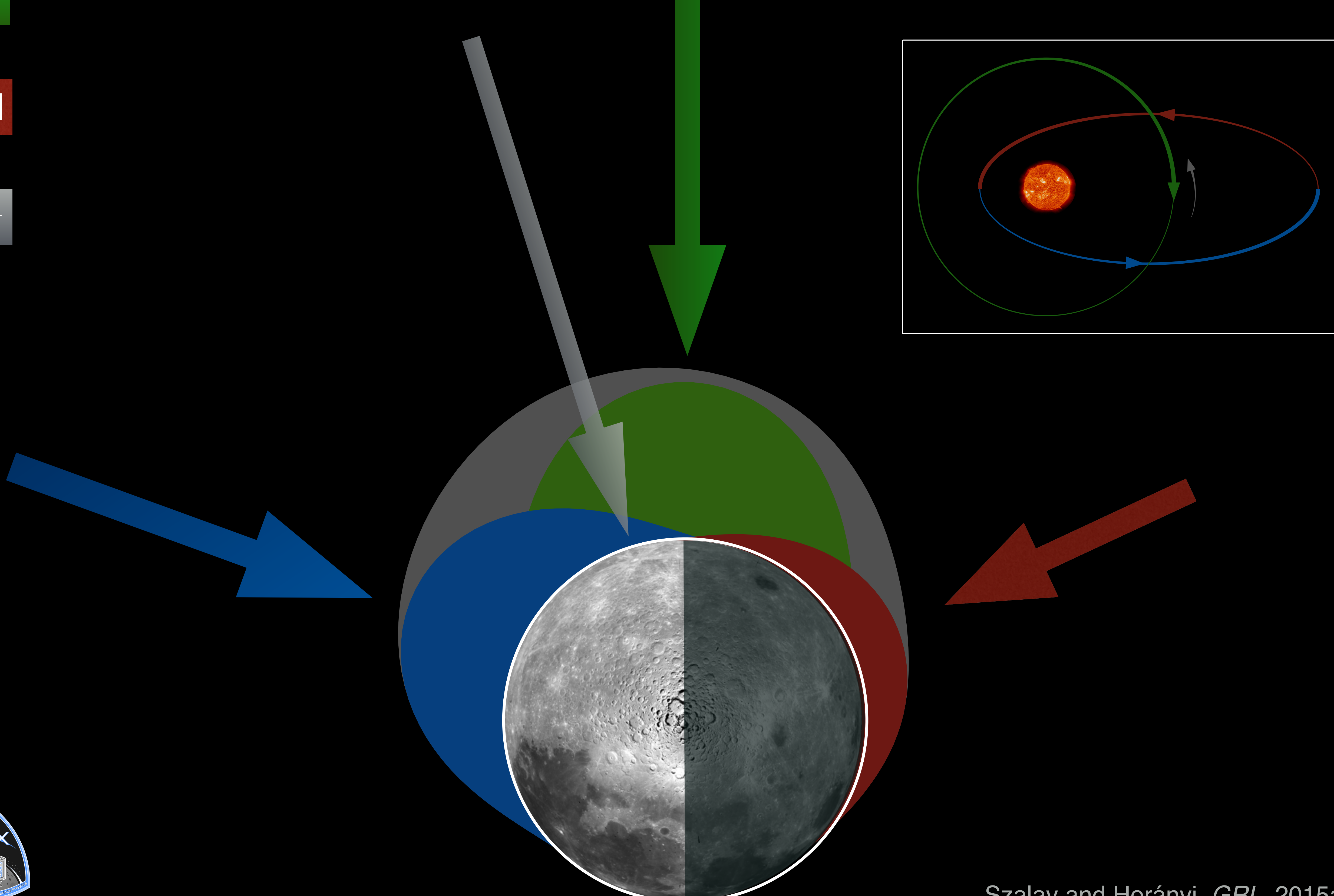
AP

AH

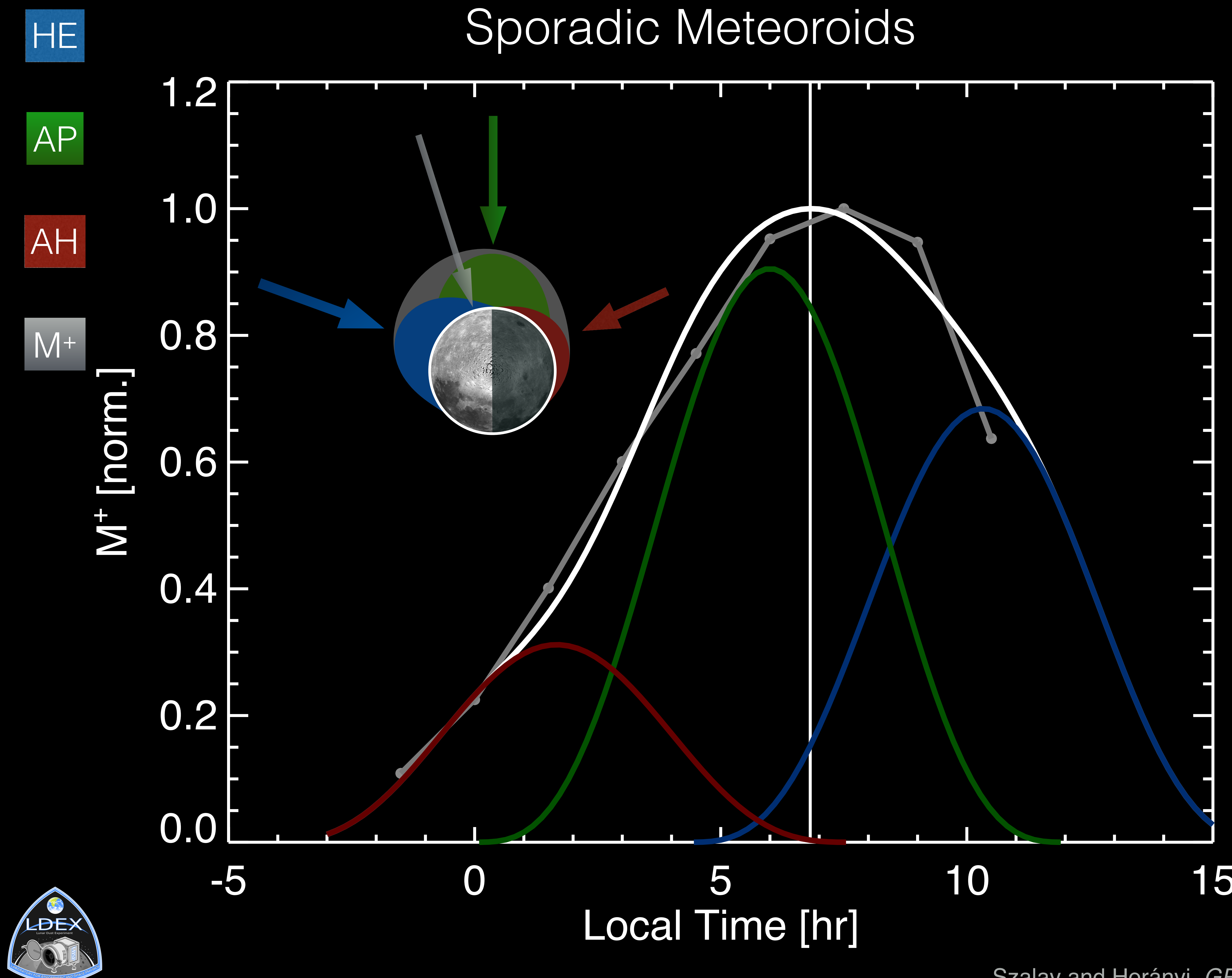
M+

$$M^+ = \sum_s F_s m_s^{\alpha+1} v_s^{\beta} \cos^3(\varphi - \varphi_s)$$

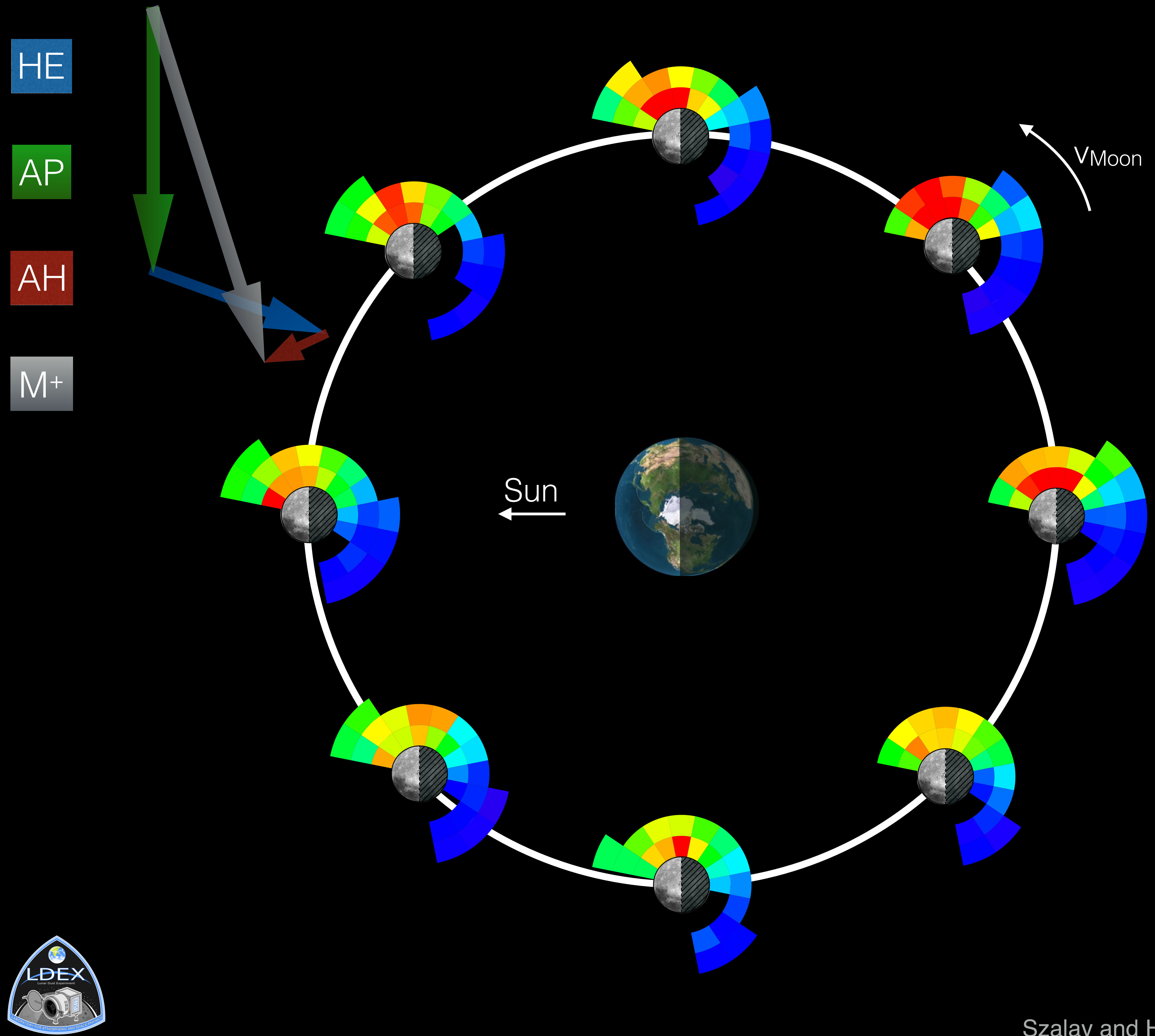
Gault (1973), Koschny and Grün (2001)



Szalay and Horányi, *GRL*, 2015a



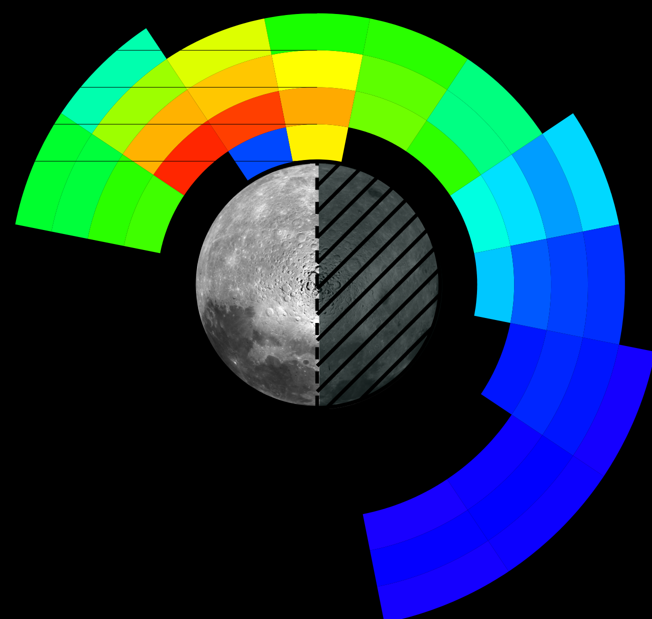
Szalay and Horányi, *GRL*, 2015a



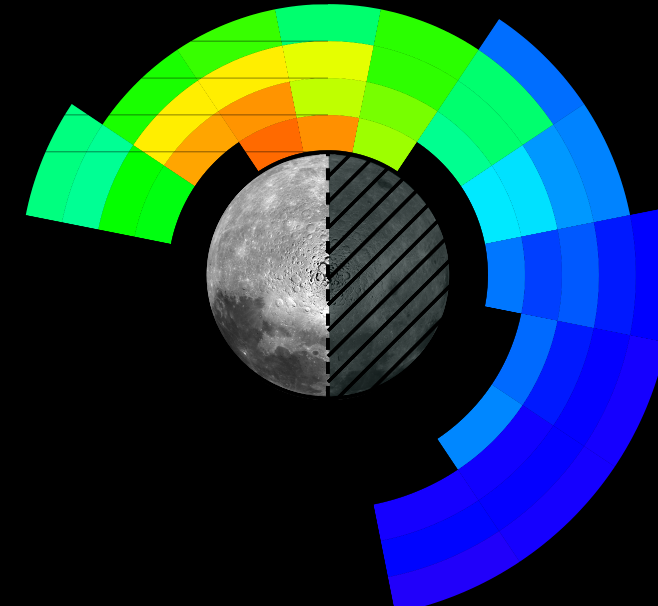
Szalay and Horányi, *GRL*, 2015a

Annual Variation

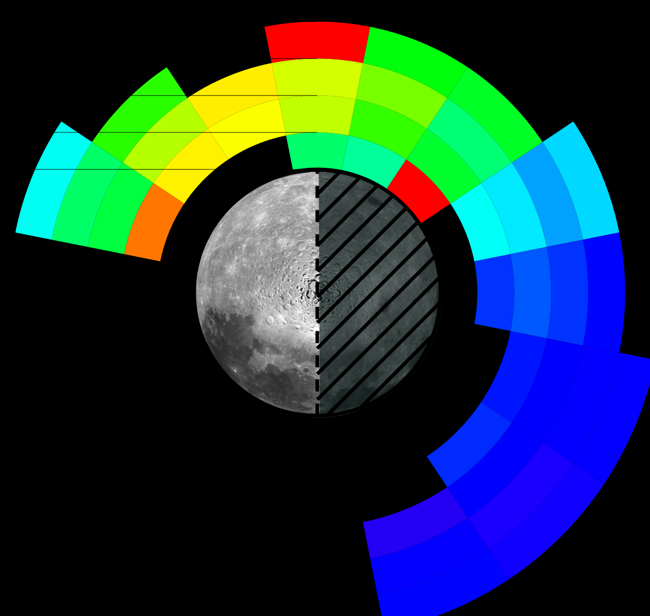
Jan. 2014



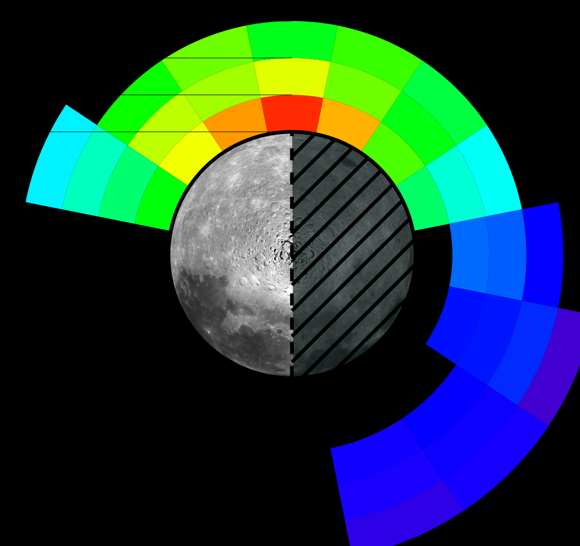
Feb. 2014



Mar. 2014

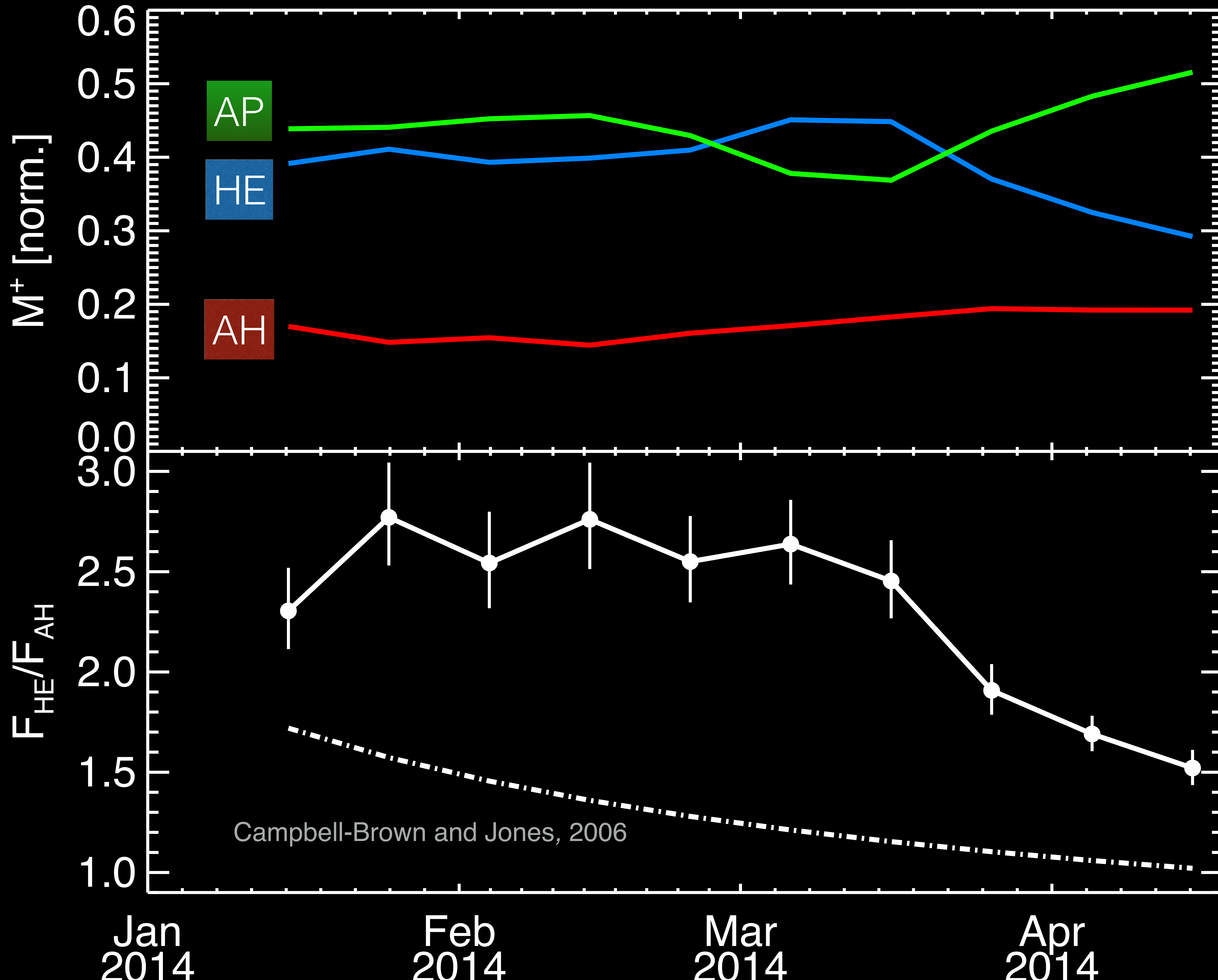


Apr. 2014



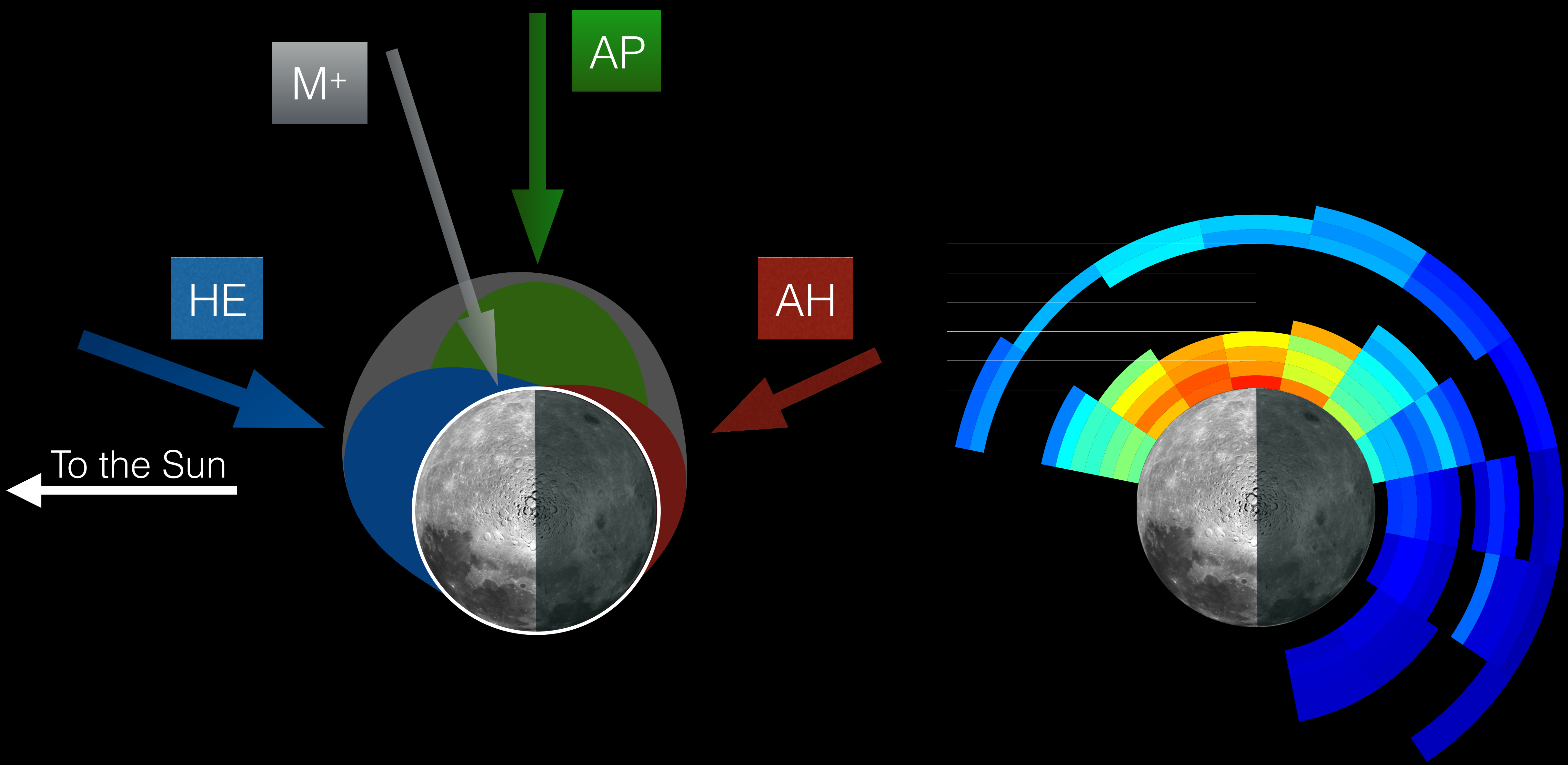
Szalay and Horányi, *GRL*, 2015a

Annual Variation of HE/AH sources from LDEX Data

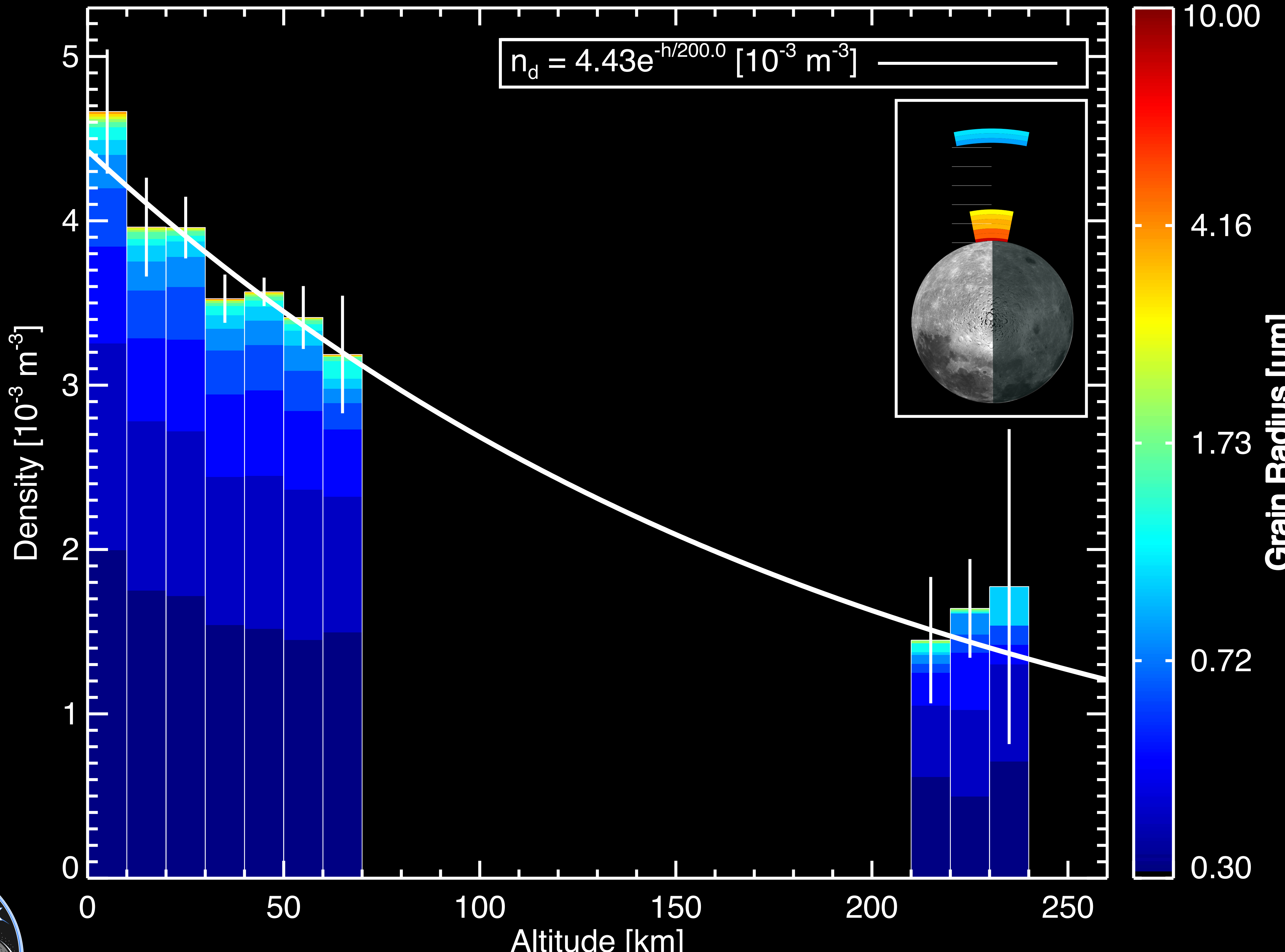


Szalay and Horányi, *GRL*, 2015a

Structure of the Lunar Dust Cloud

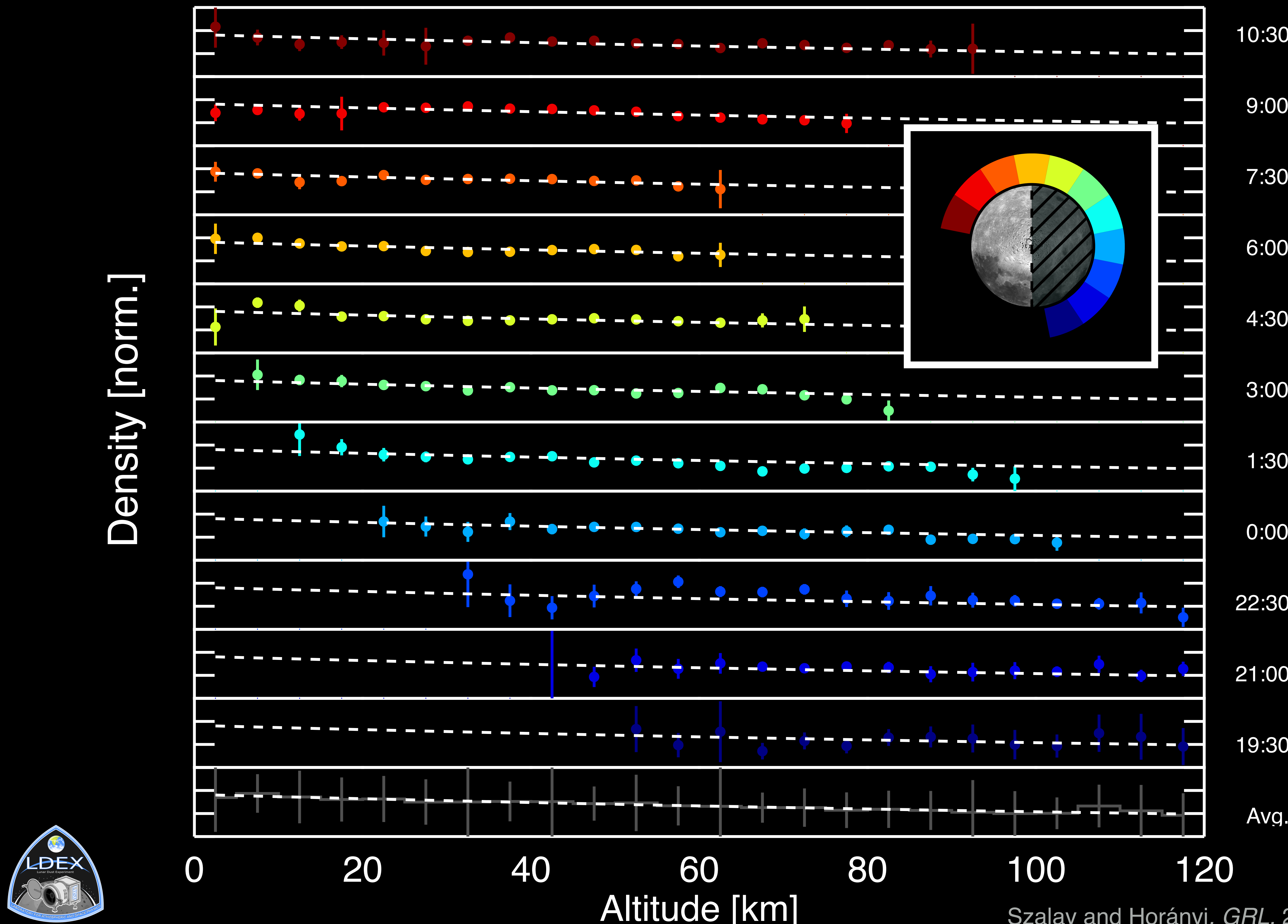


High Altitude Densities



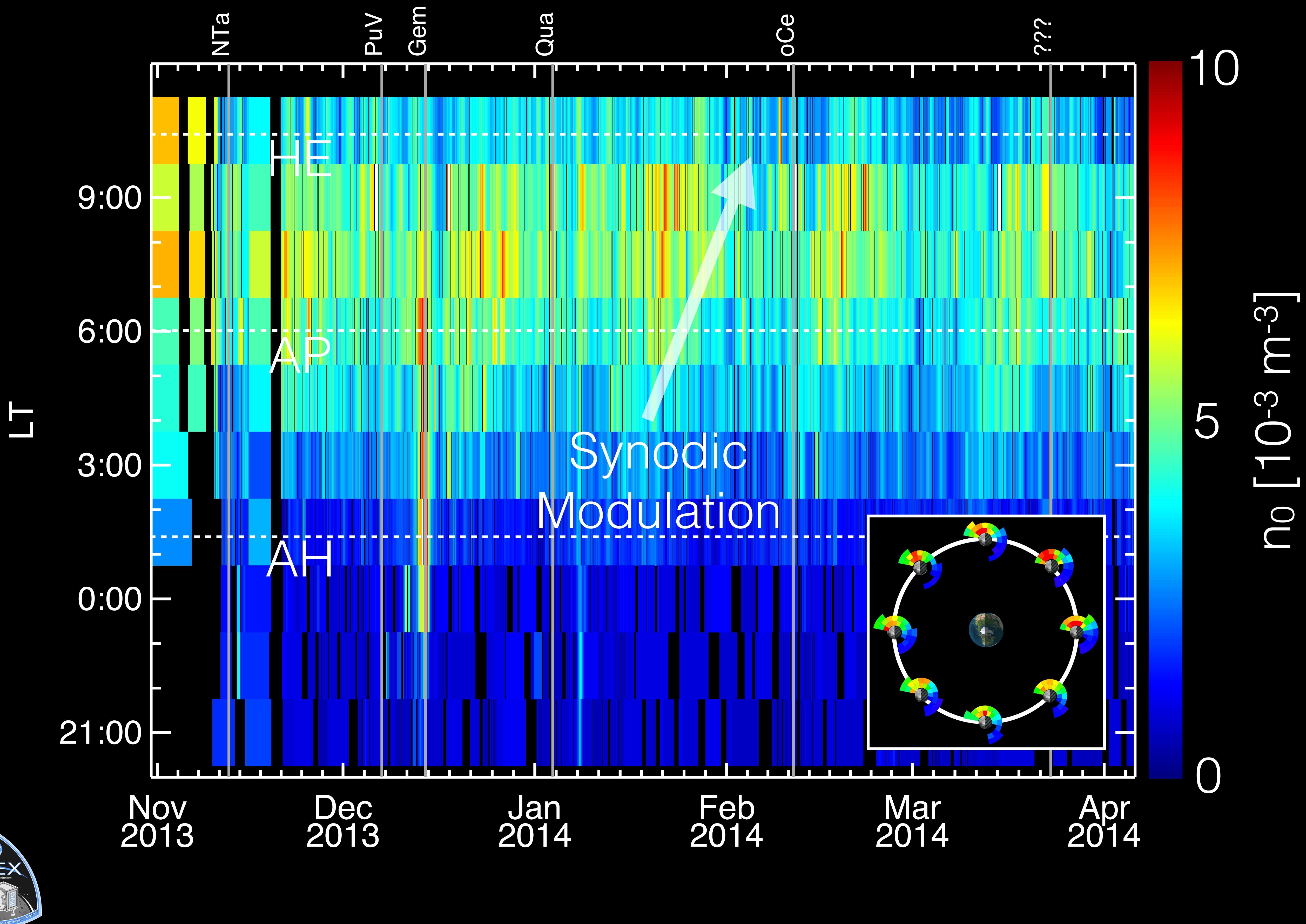
Szalay and Horányi, *GRL*, 2016a

$$n(h) = n_0 e^{-h/\lambda}$$

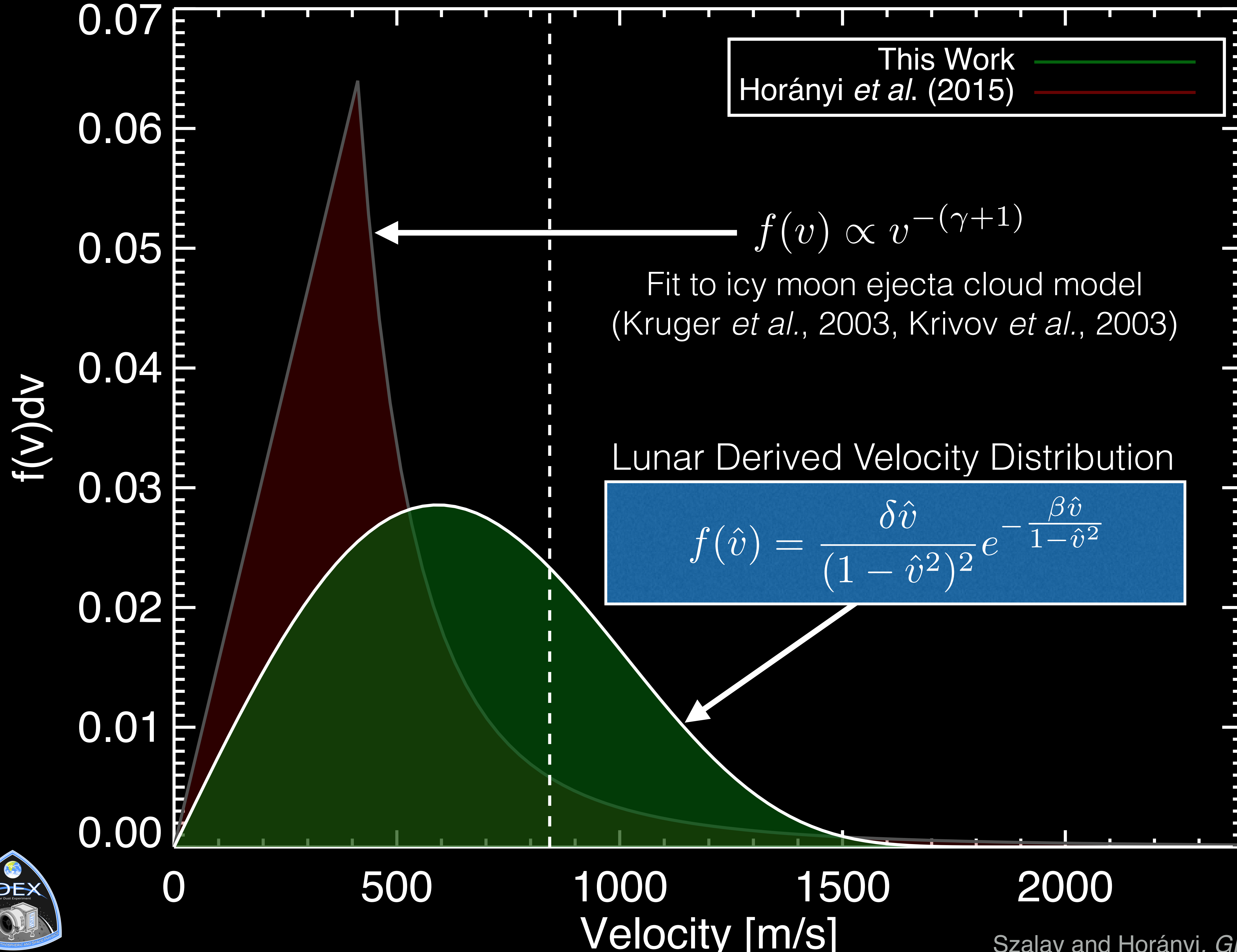


Szalay and Horányi, *GRL*, 2016a

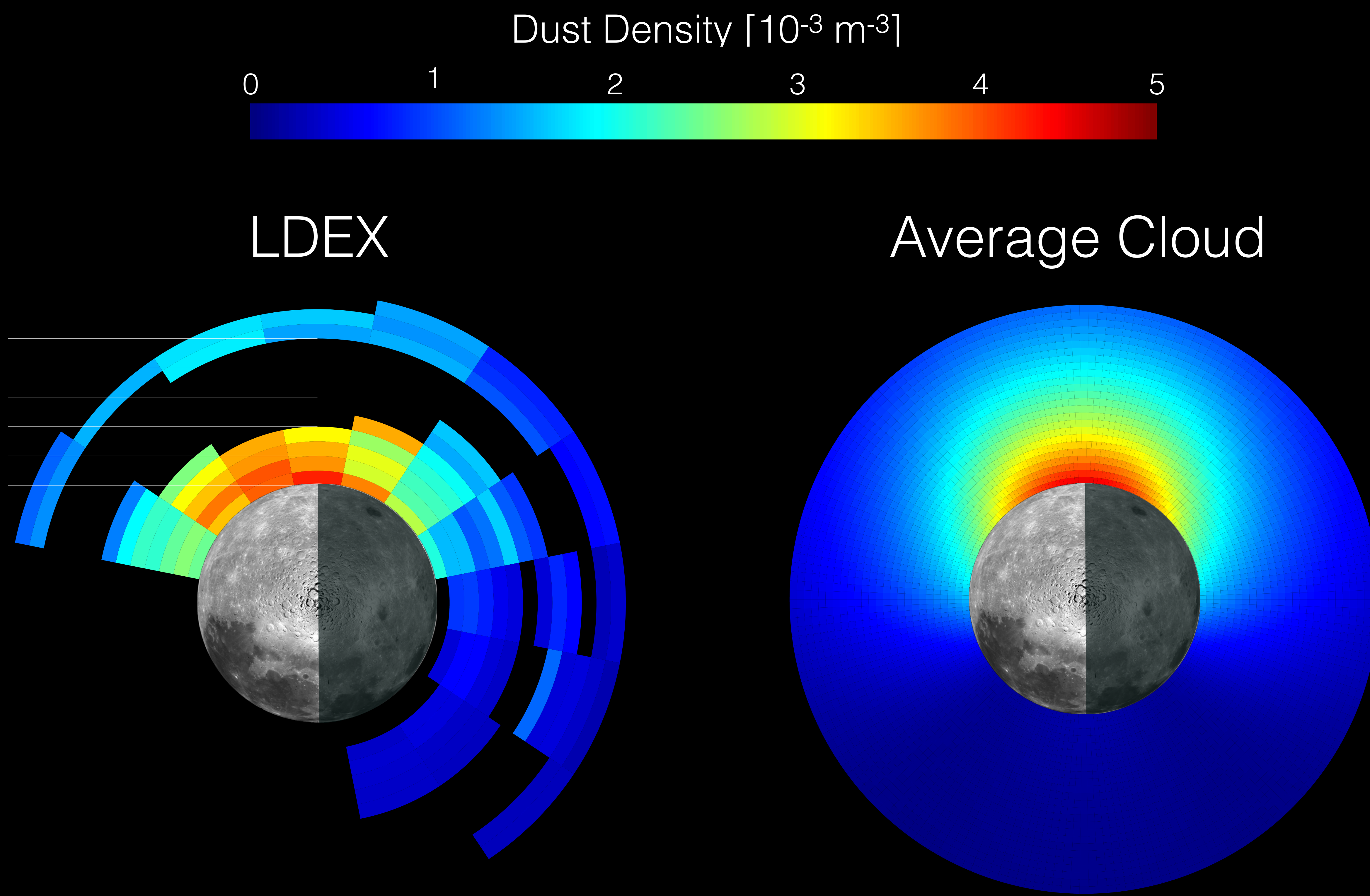
Local Time Asymmetry



Velocity Distribution Function



Szalay and Horányi, *GRL*, 2016a

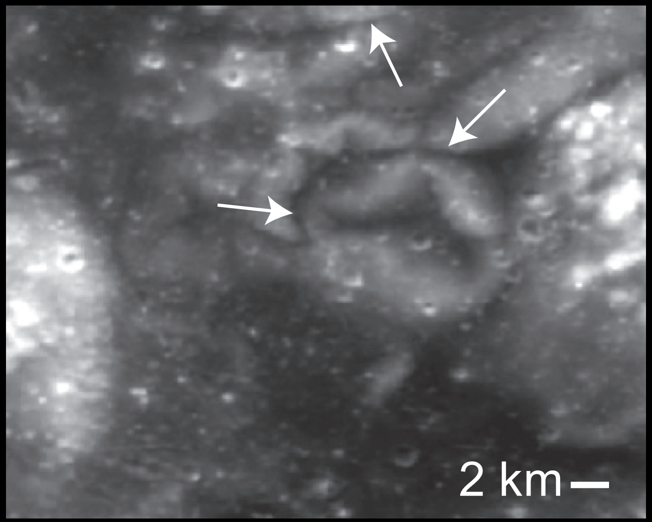


$$n(h,\varphi,a) = e^{-h/\lambda}\left(\frac{a}{a_{\mathrm{th}}}\right)^{-3\alpha} \underbrace{n_w \sum_s w_s \cos^3(\varphi-\varphi_s)\Theta(\varphi_s-\pi/2)}_{n_0(\varphi)}$$

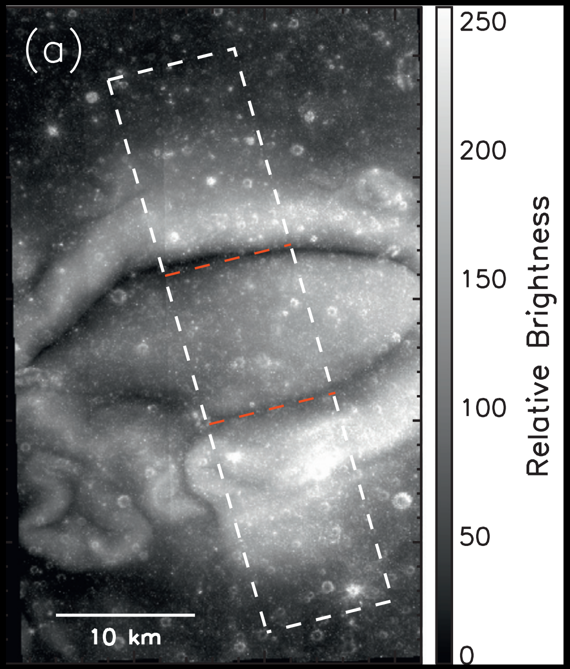
Szalay and Horányi, *GRL*, 2016a

Impact Gardening

Swirls

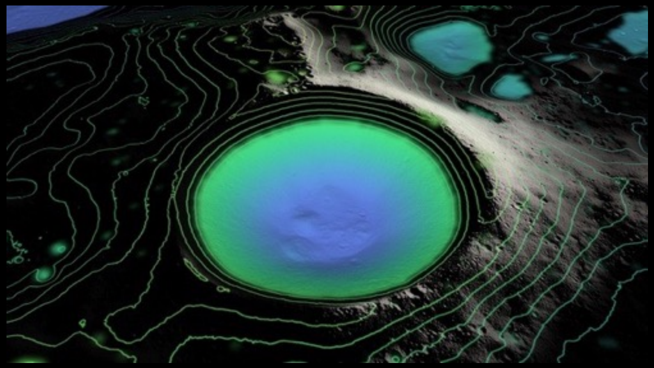


Garrick-Bethell *et al.*, (2011)

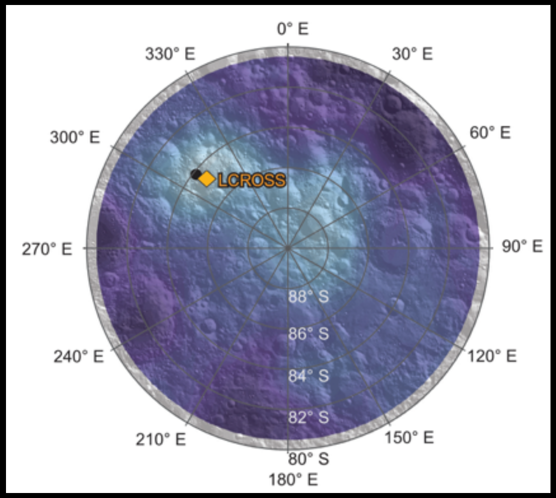


Poppe *et al.*, (2016)

Polar Regions



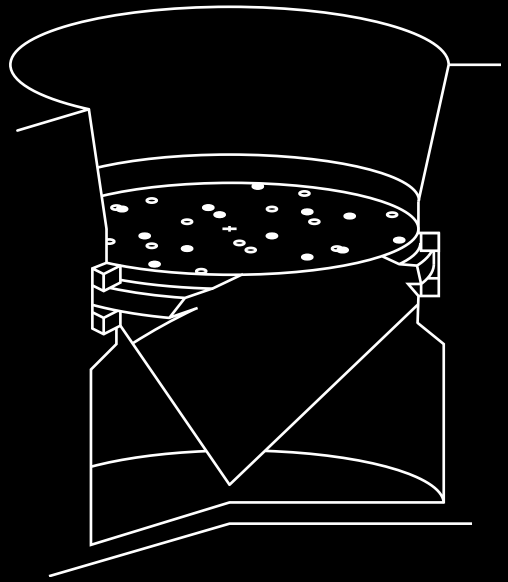
NASA GSFC



Siegler, Miller, Keane, *et al.*, (2016)

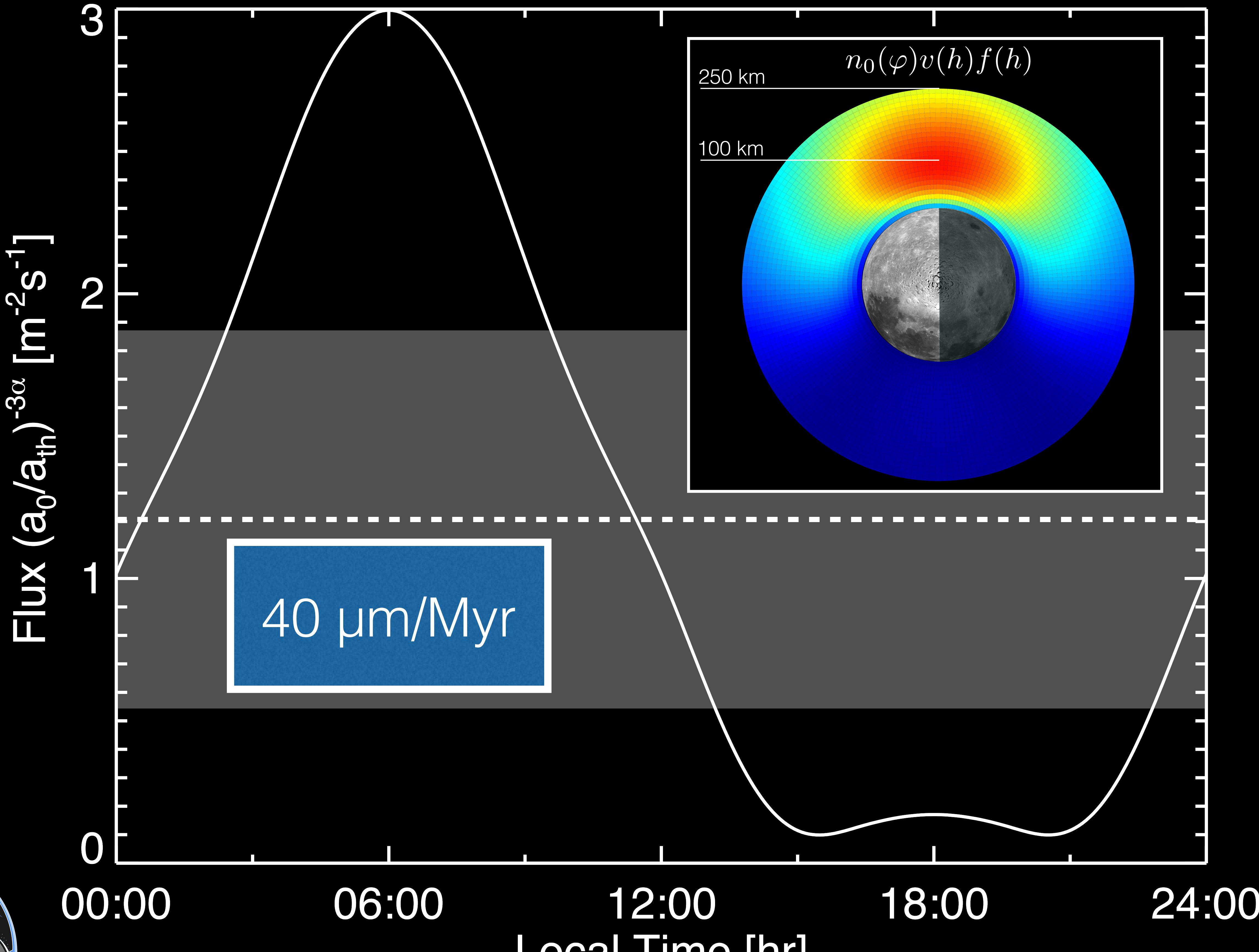
Instrumentation

NASA, AS14-67-9385



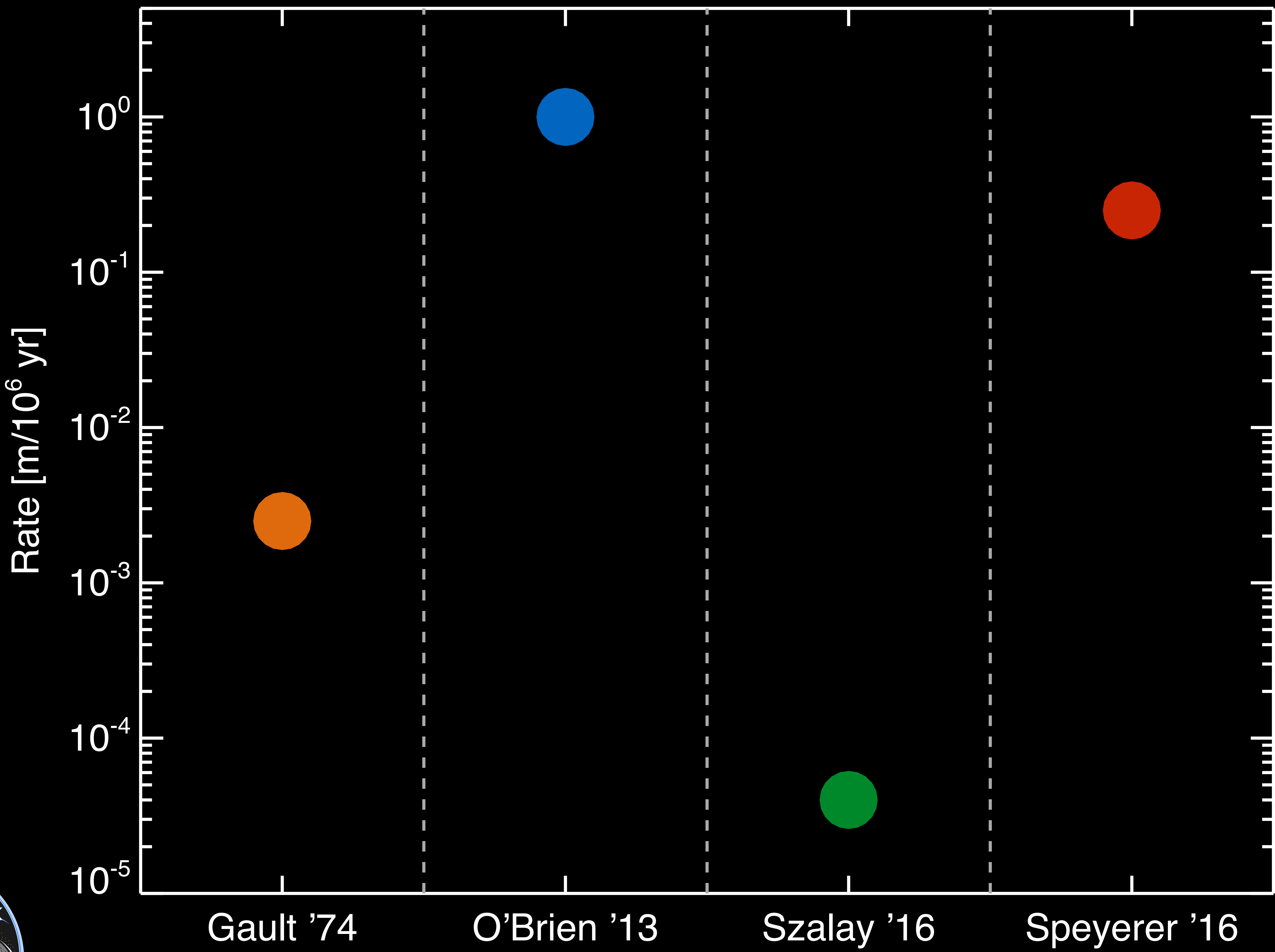
Murphy Jr *et al.*, (2014)

Impact Gardening



Szalay and Horányi, *GRL*, 2016a

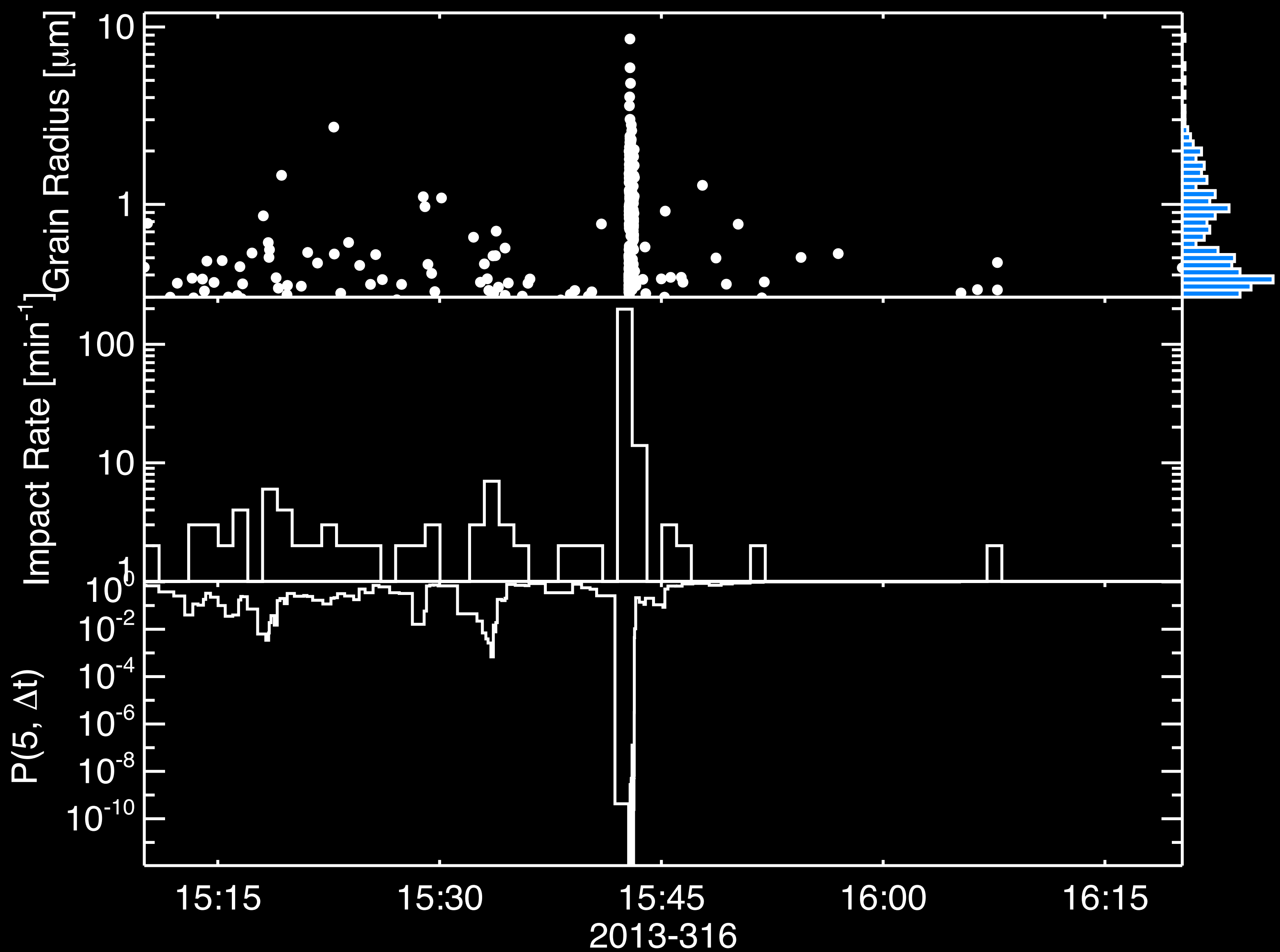
Lunar Impact Gardening Rates

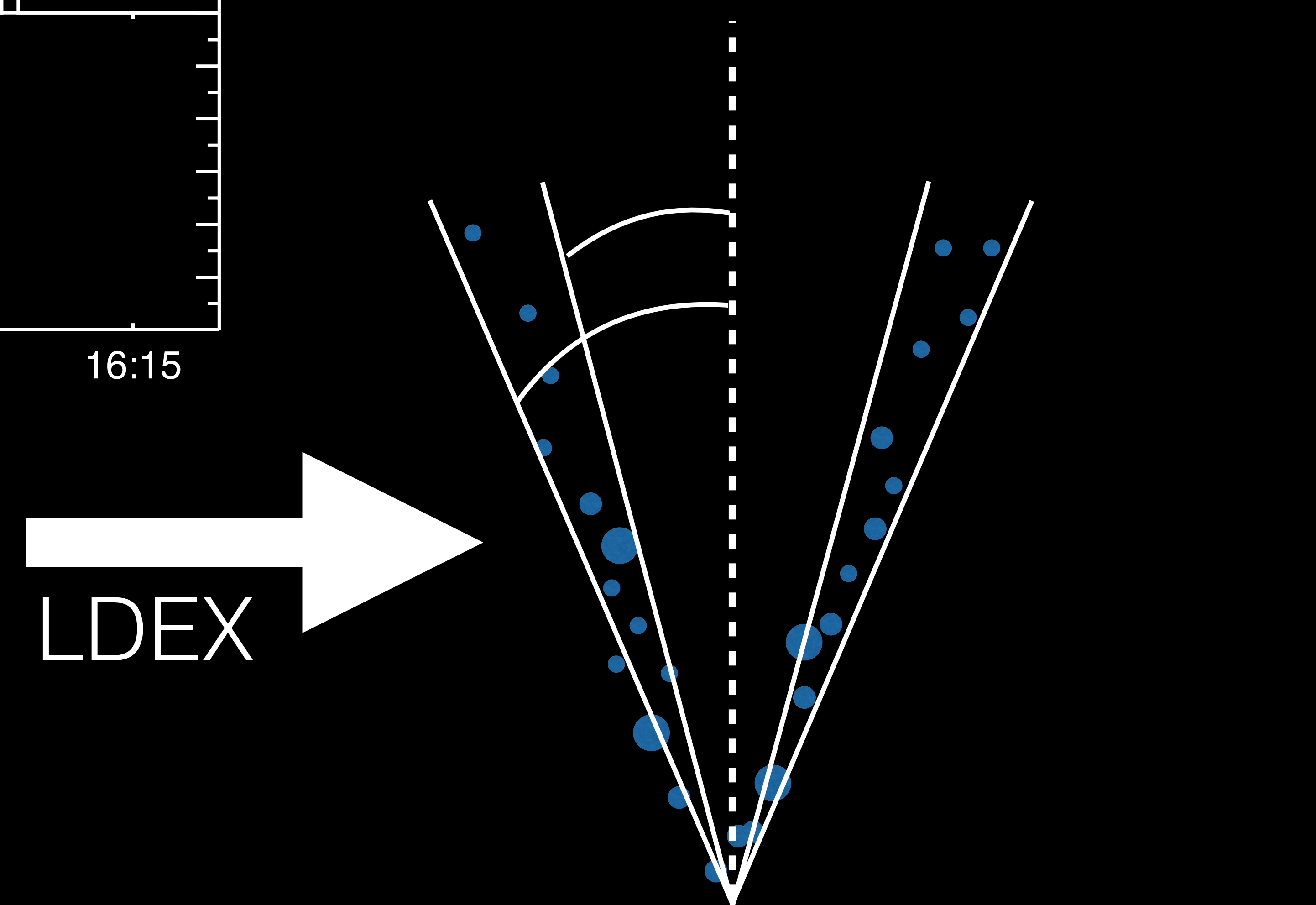


Meteor Showers at the Moon

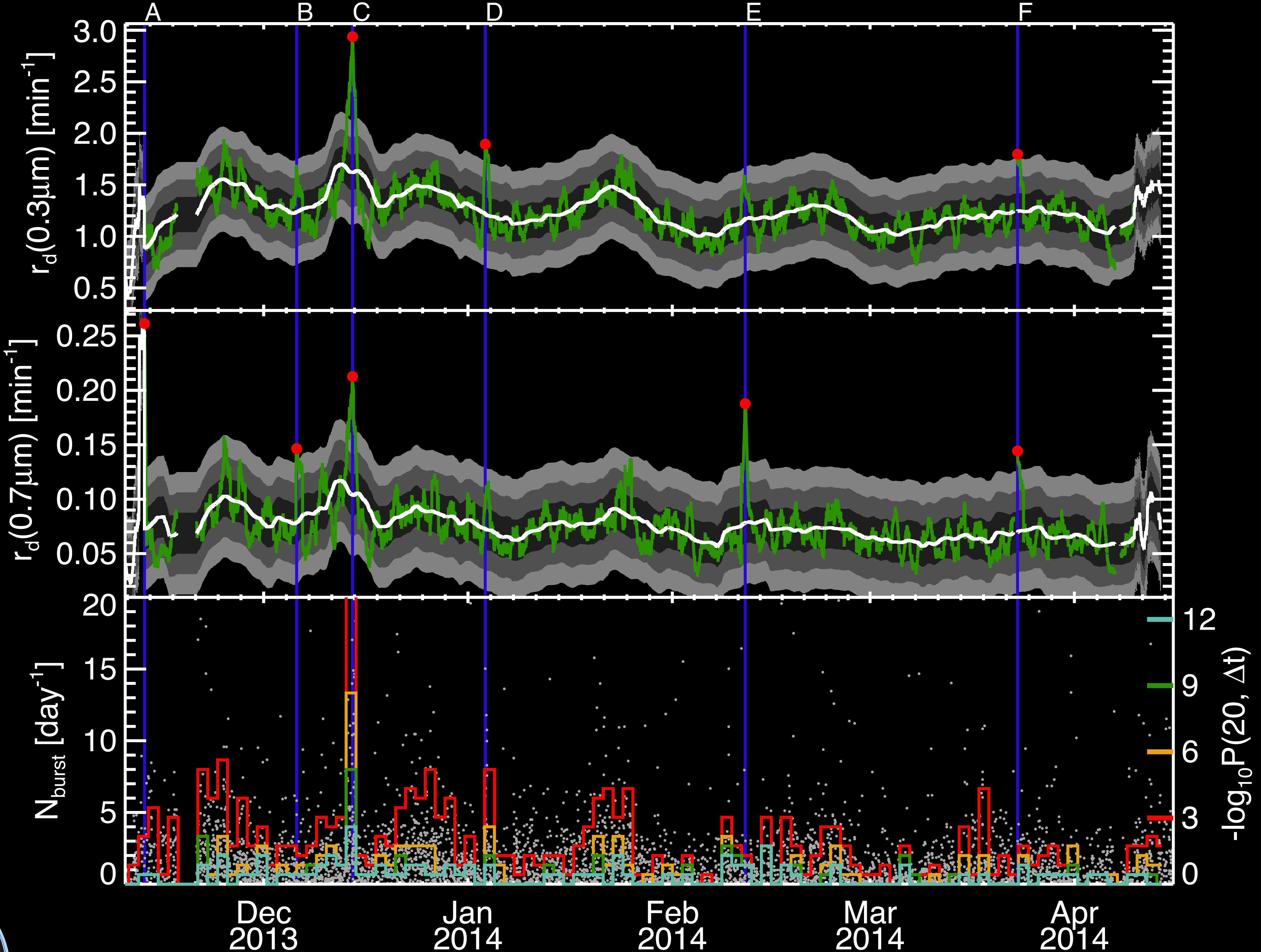
dispatch.com

Bursts


Grain Radius [μm]
Impact Rate [min^{-1}]
P(5, Δt)
10
1
100
10
1
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
15:15
15:30
15:45
16:00
16:15
2013-316


LDEX

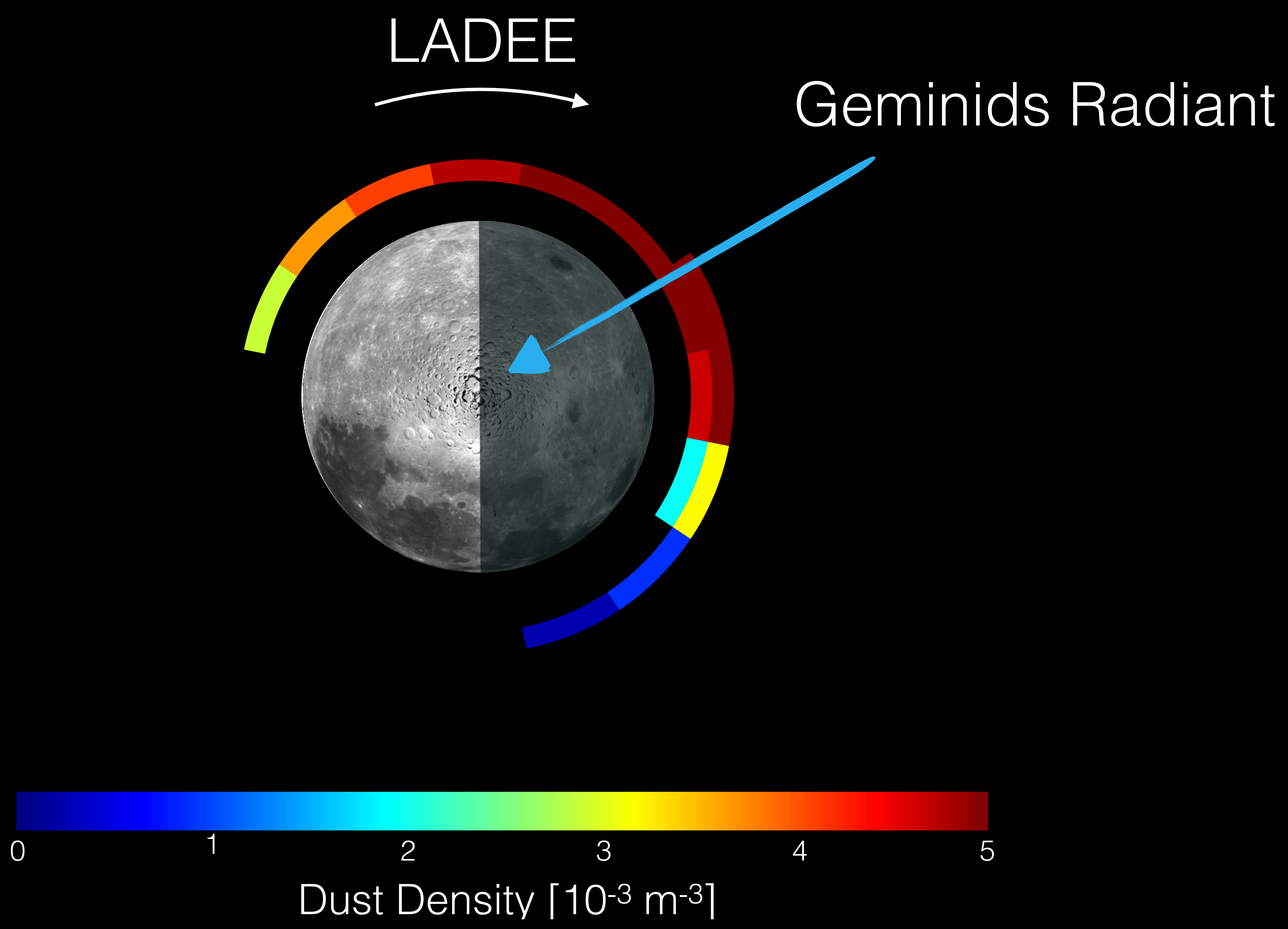
$$P(n,T) = 1 - e^{-\mu T} \sum_{\ell=0}^{n-1} \frac{\mu T}{\ell!}$$



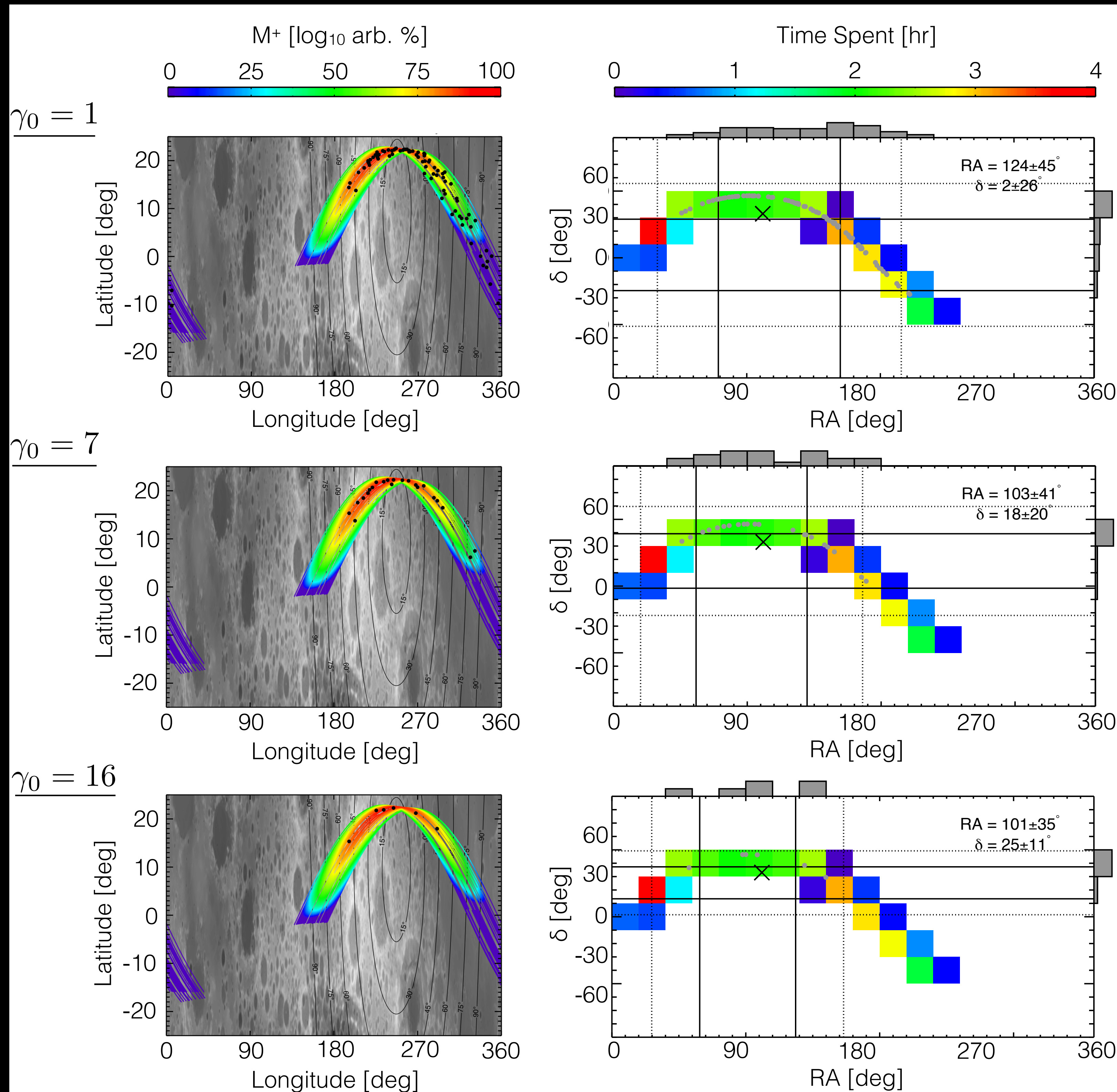
LDEX

Szalay and Horányi, *Icarus*, 2016b

Geminids



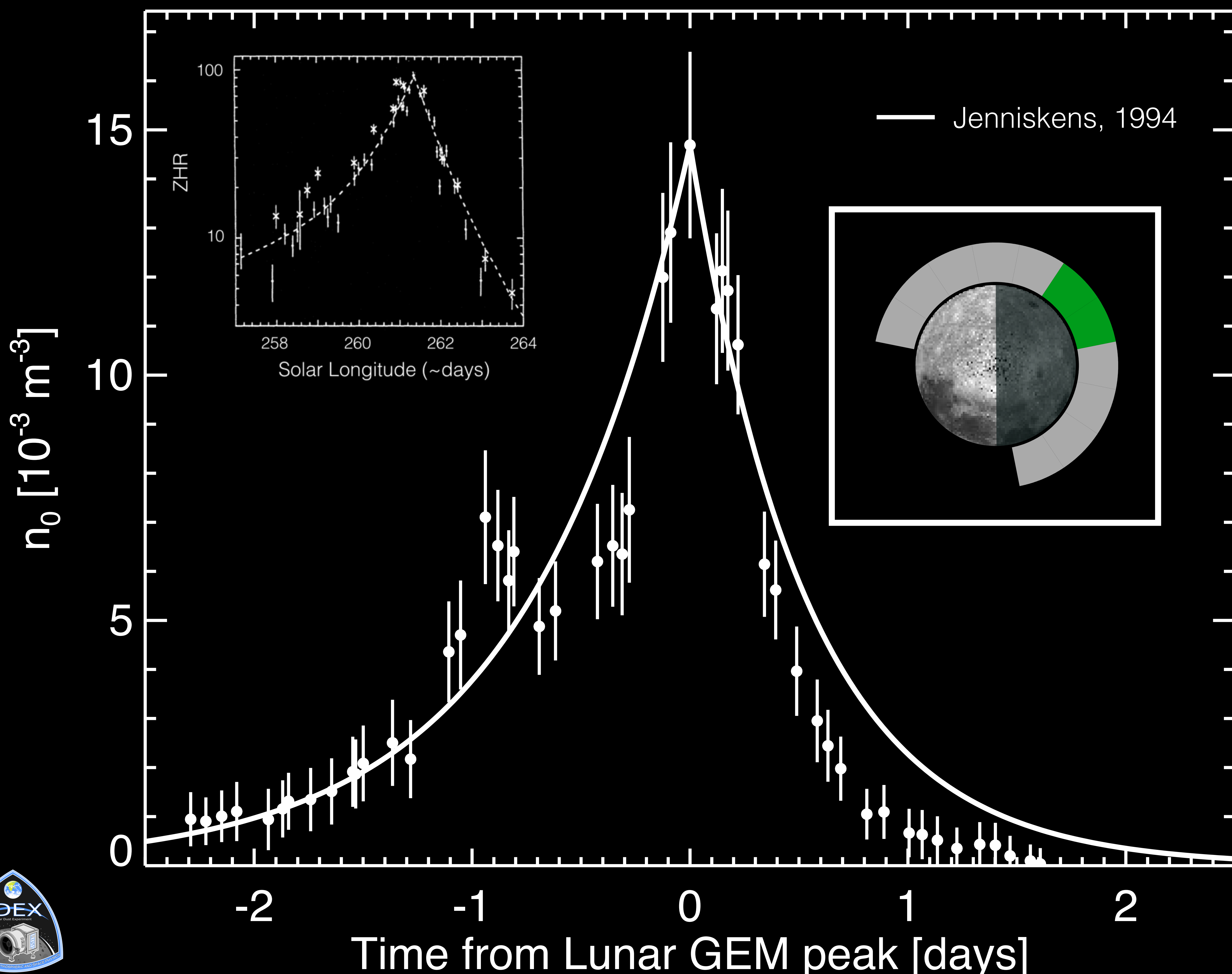
Geminids



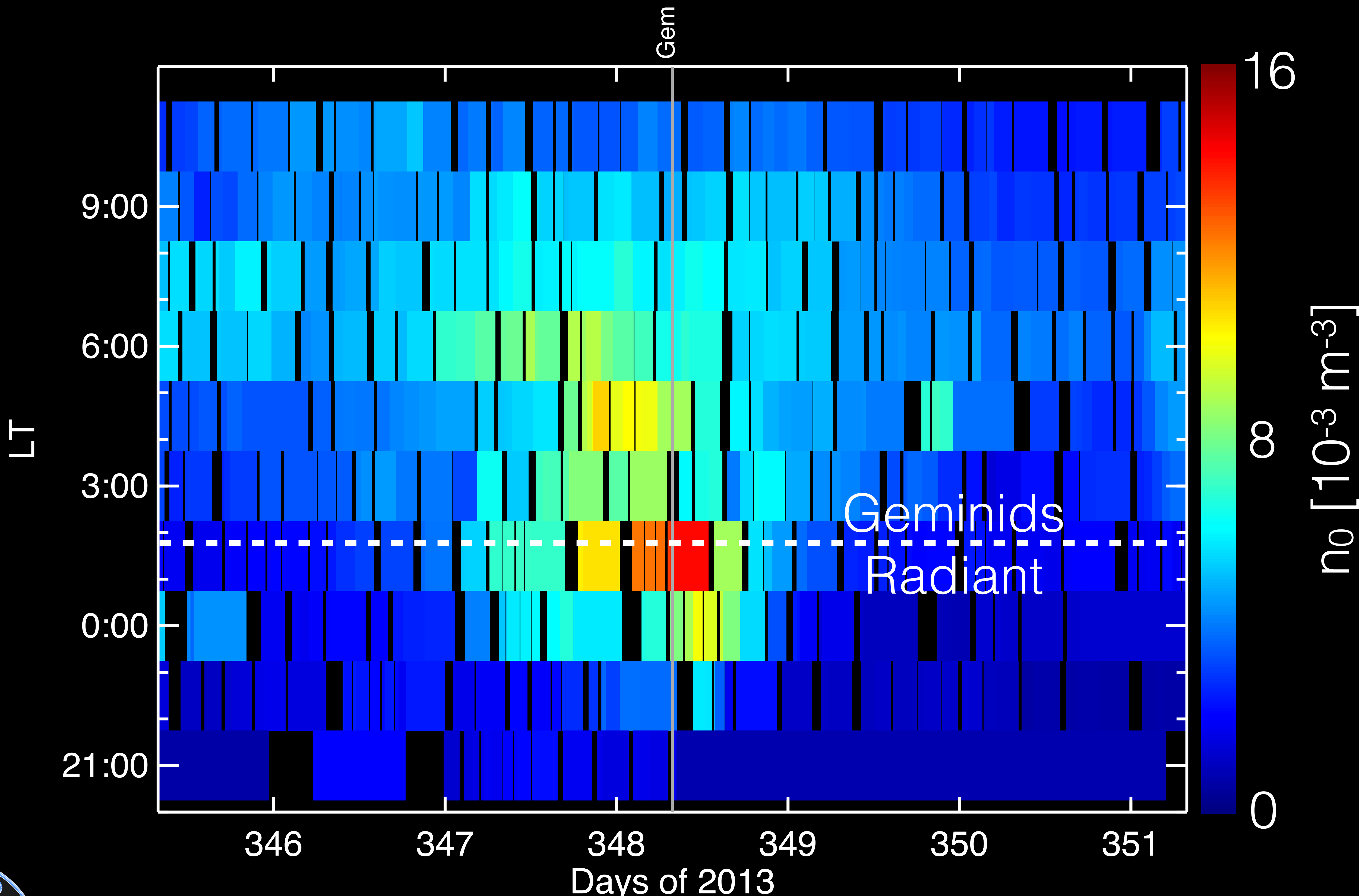
Future missions to airless bodies can characterize their local meteoroid environments with dust analyzers.

Szalay and Horányi, *Icarus*, 2016b

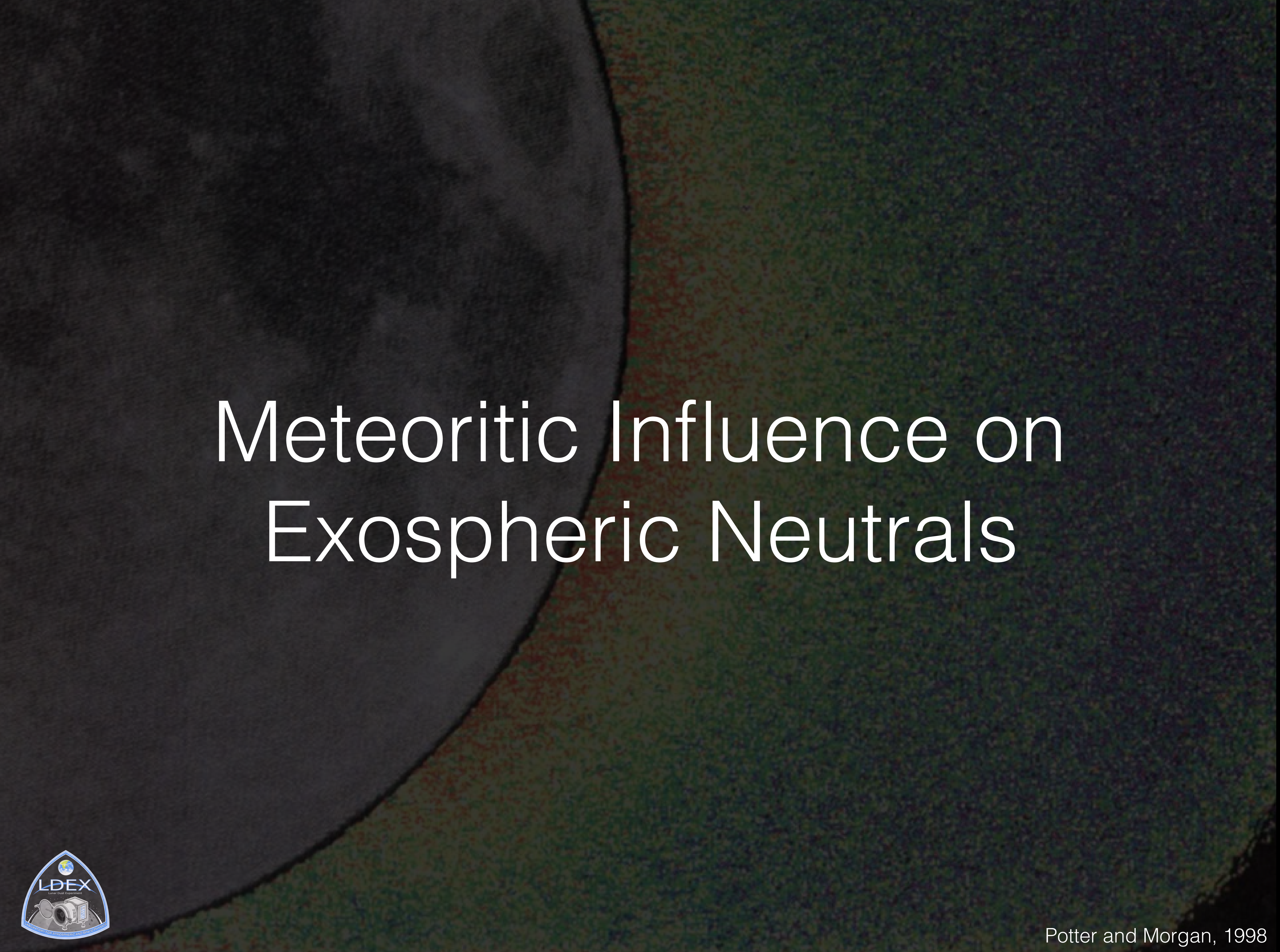
Probing the Structure of the Geminids



Geminids Local Time Dependence

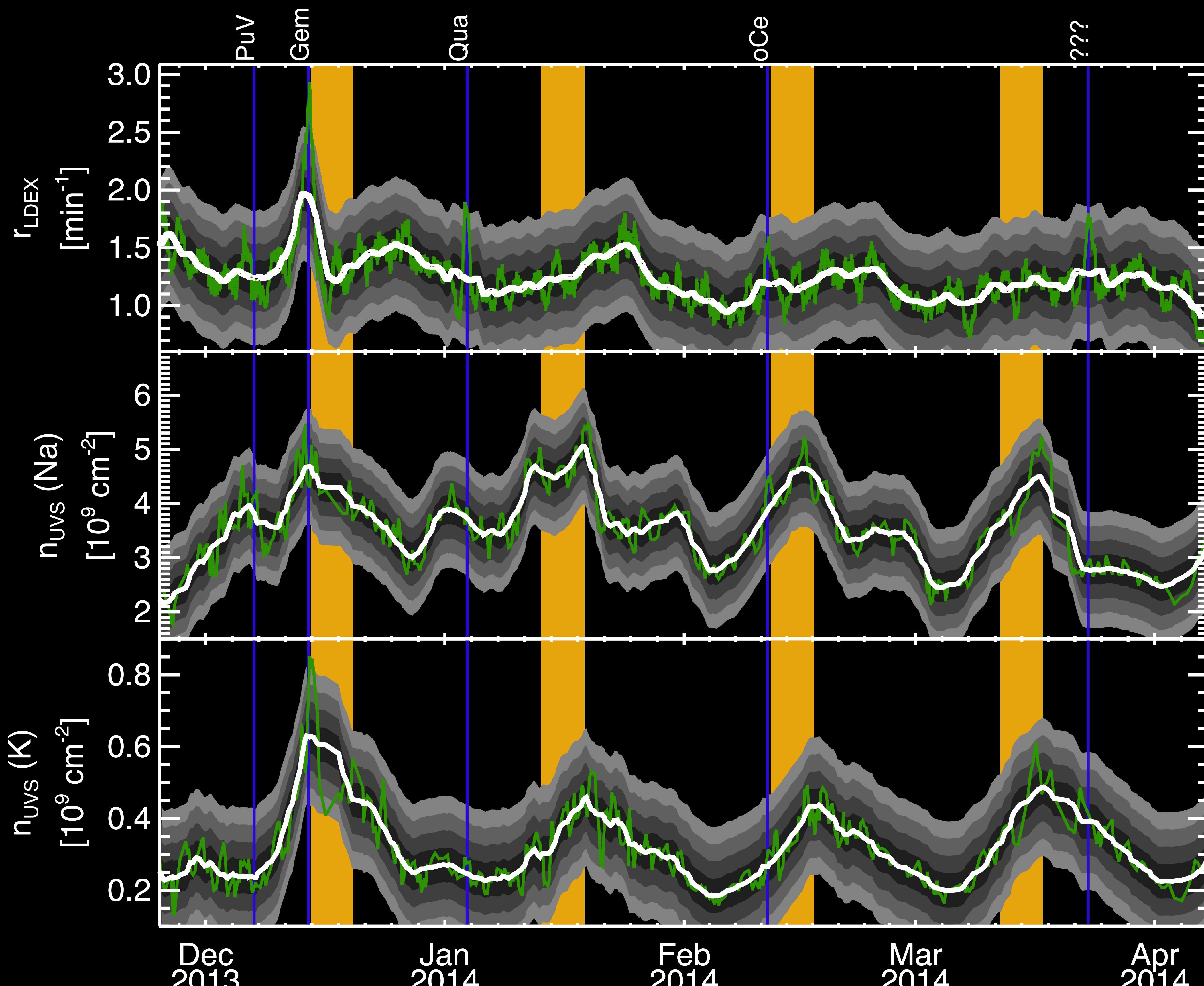


Meteoritic Influence on Exospheric Neutrals



Potter and Morgan, 1998

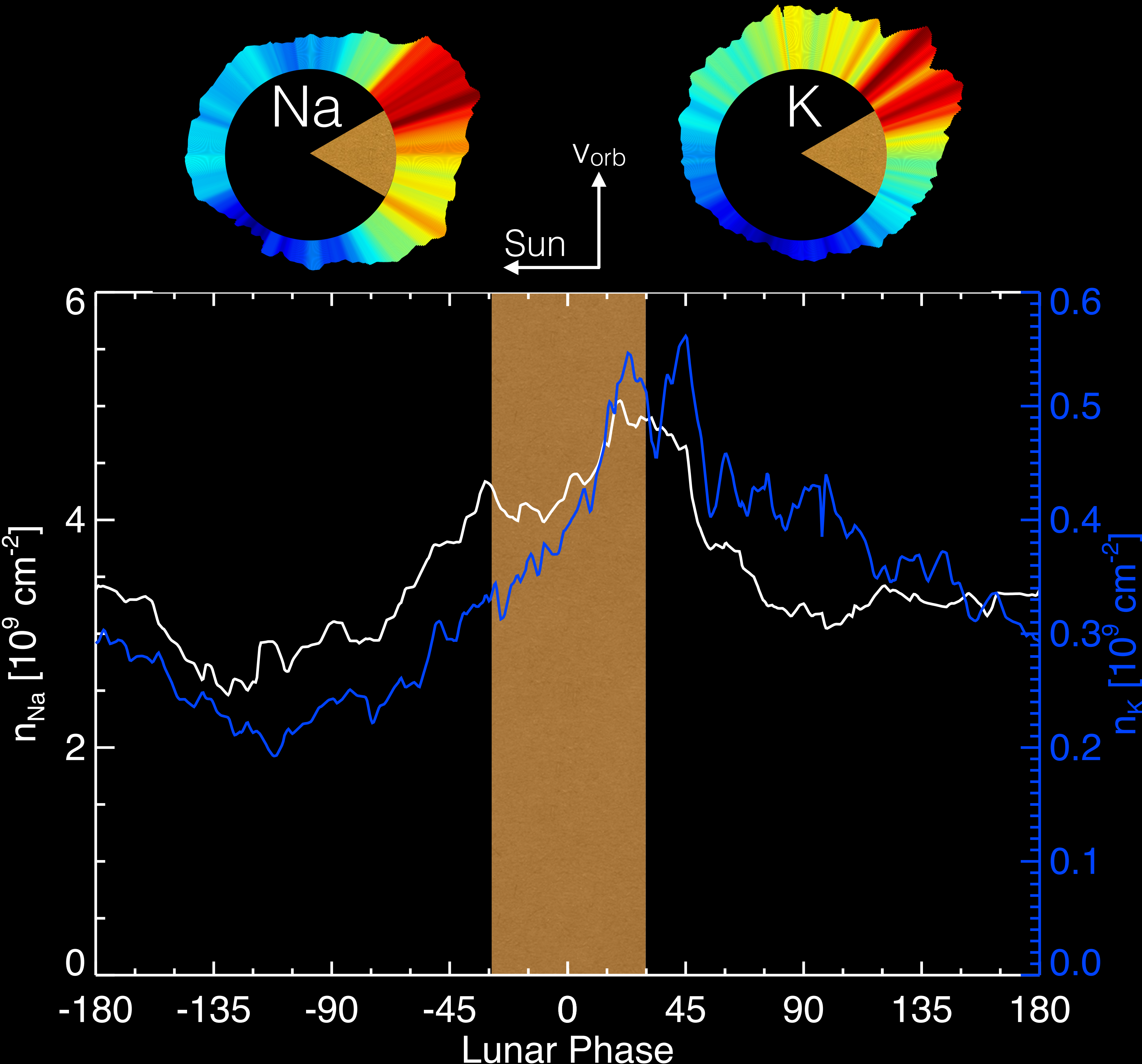
LDEX & UVS Data



LDEX

Szalay *et al.*, *GRL*, 2016c

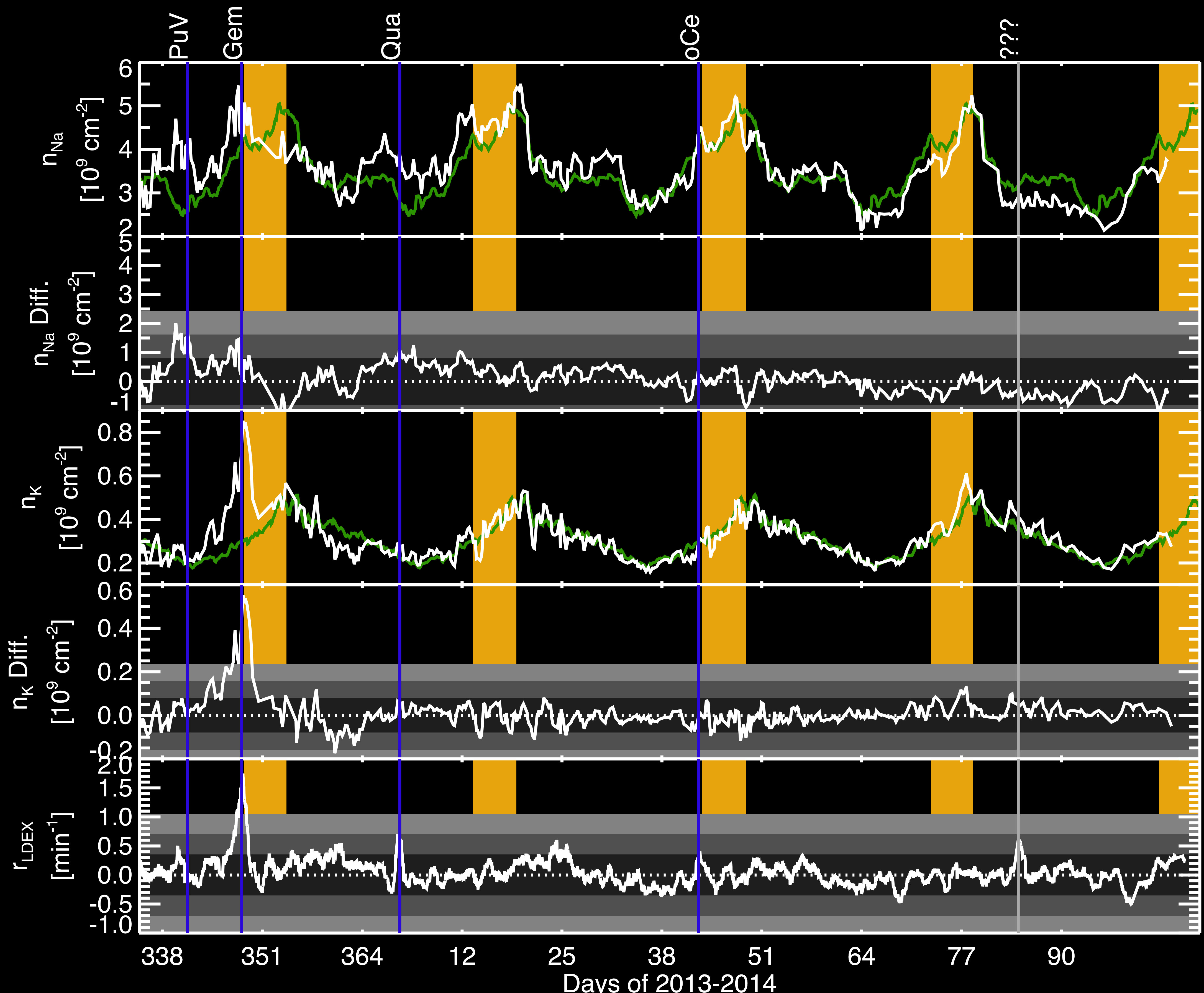
Synodic Dependence



Colaprete *et al.*, *Science*, 2016

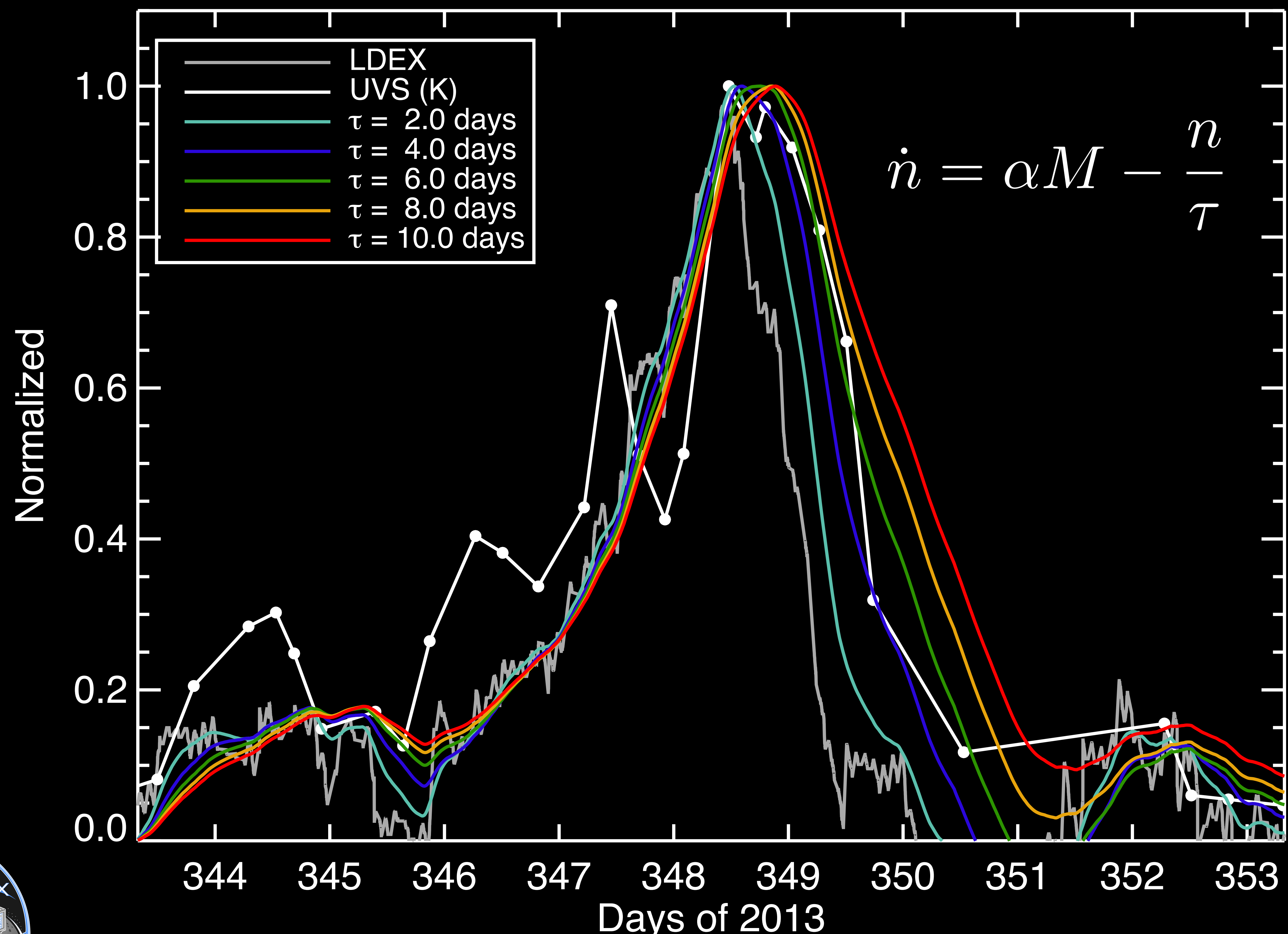
Szalay *et al.*, *GRL*, 2016c

Removing Synodic Trends



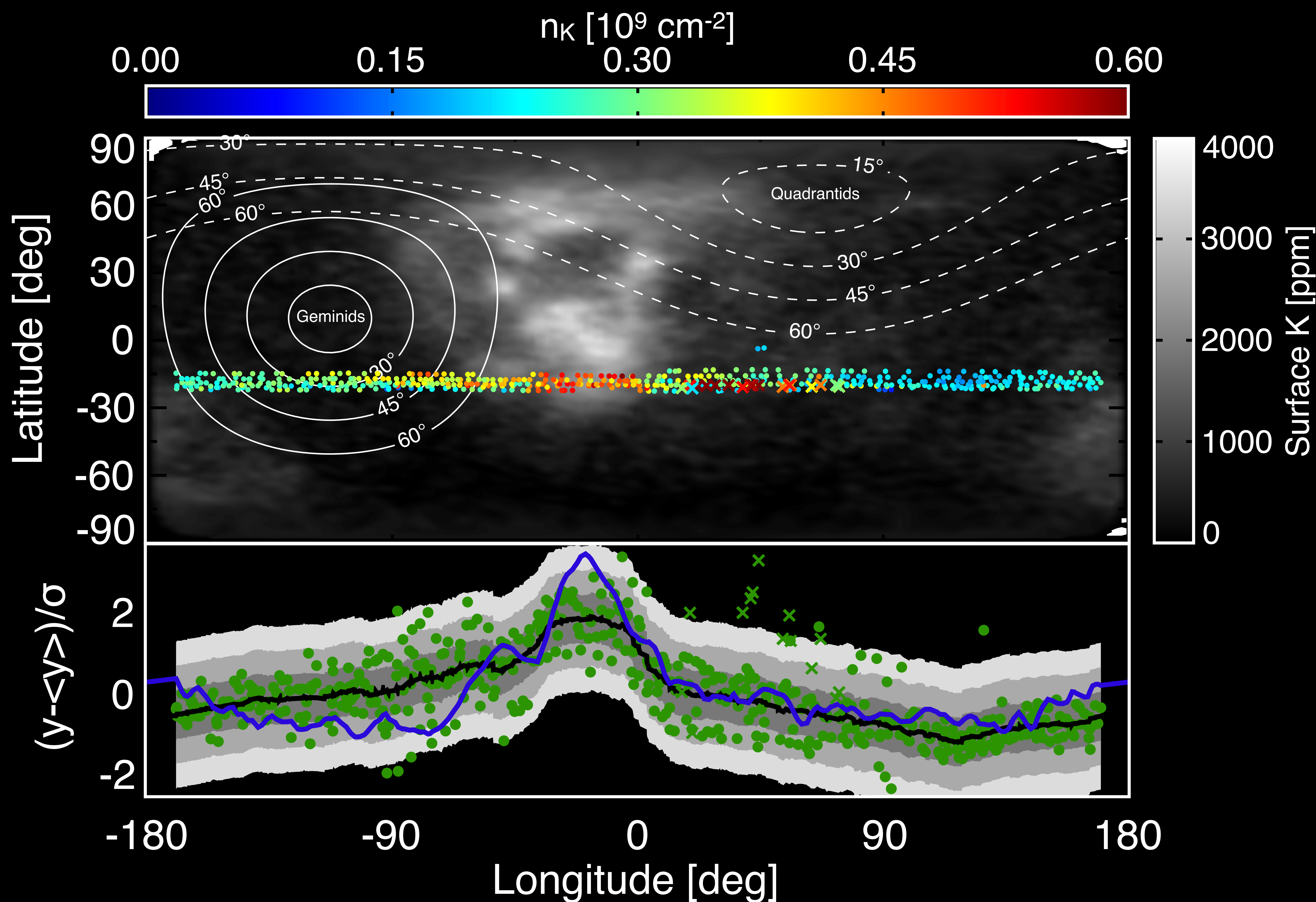
Szalay *et al.*, *GRL*, 2016c

Neutral Generation due to Meteoroid Bombardment



Szalay *et al.*, *GRL*, 2016c

Surface Potassium



Colaprete *et al.*, *Science*, 2016; Szalay *et al.*, *GRL*, 2016c

Ejecta Clouds at Near Earth Asteroids

NEA Dust Distribution

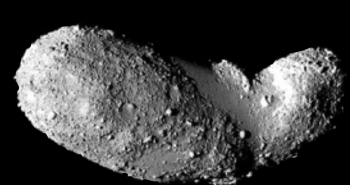
Lunar Derived Velocity Distribution

$$f(\hat{v}) = \frac{\delta \hat{v}}{(1-\hat{v}^2)^2} e^{-\frac{\beta \hat{v}}{1-\hat{v}^2}}$$

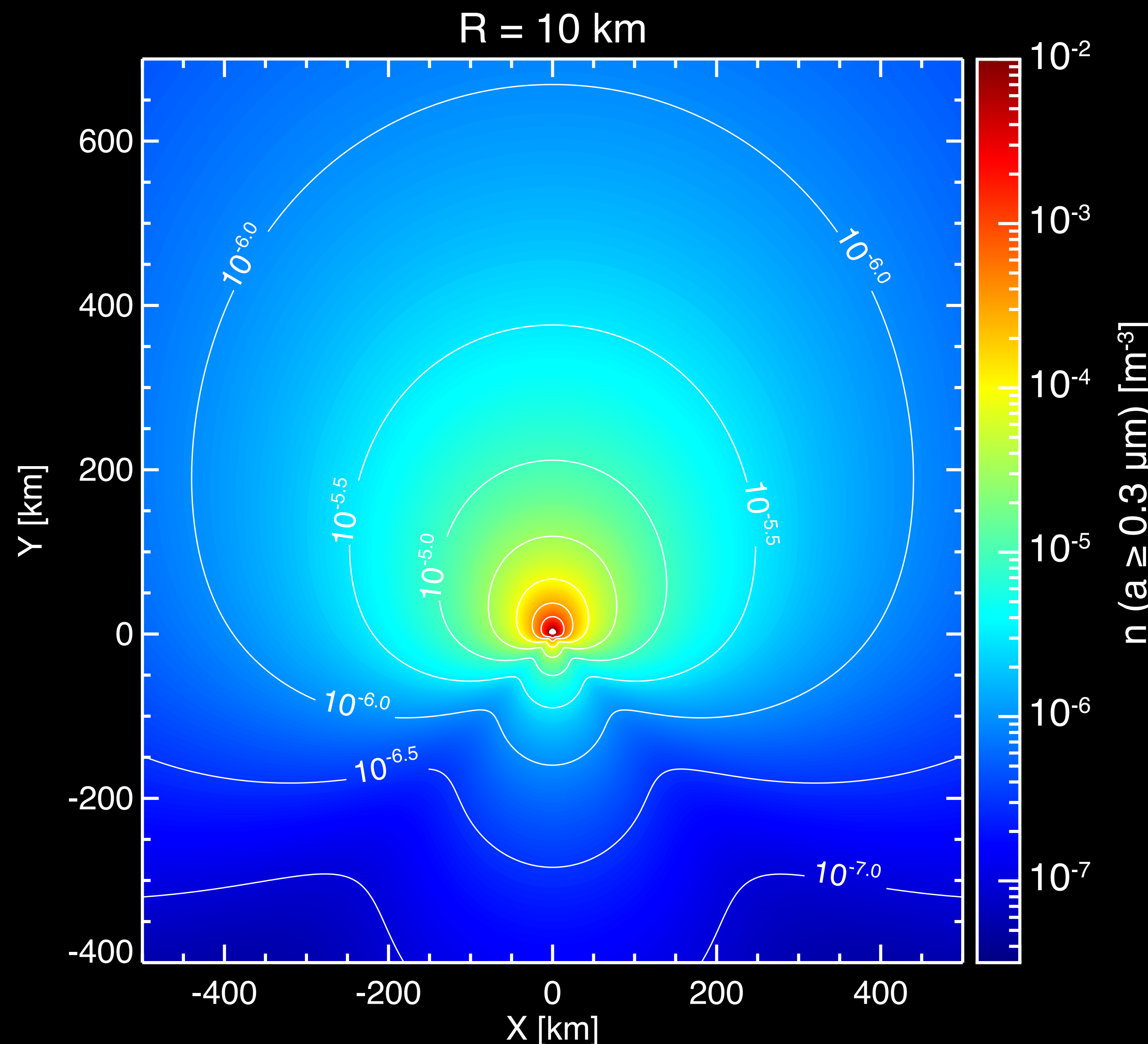
Asteroid Density Distribution

$$n(r,\varphi,a) = n_w \left(\frac{R}{r}\right)^2 a_\mu^{-2.7} w(\varphi)$$

$$e^{-(r-R)/\lambda}$$

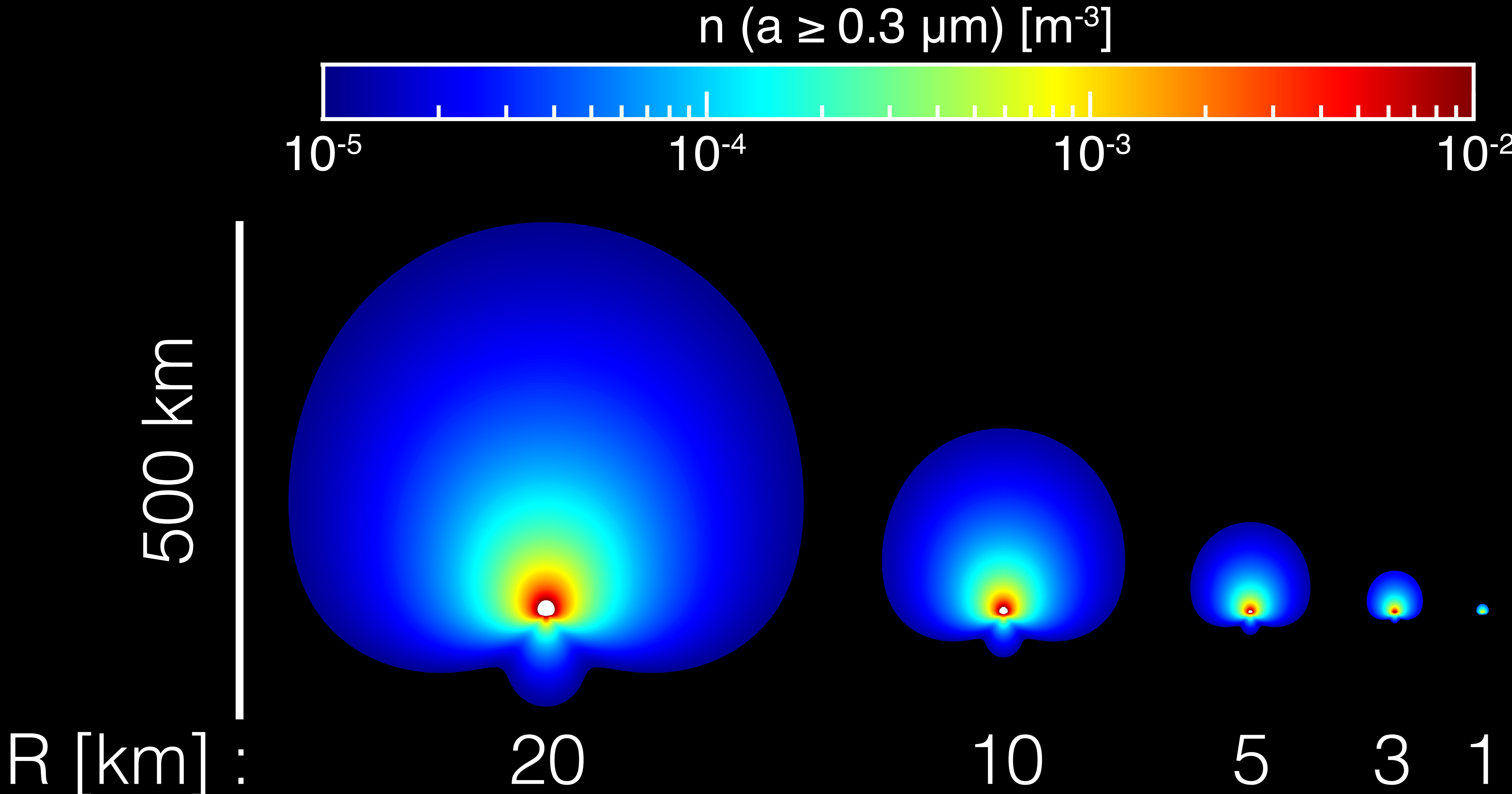


$$\frac{1}{r^2}$$



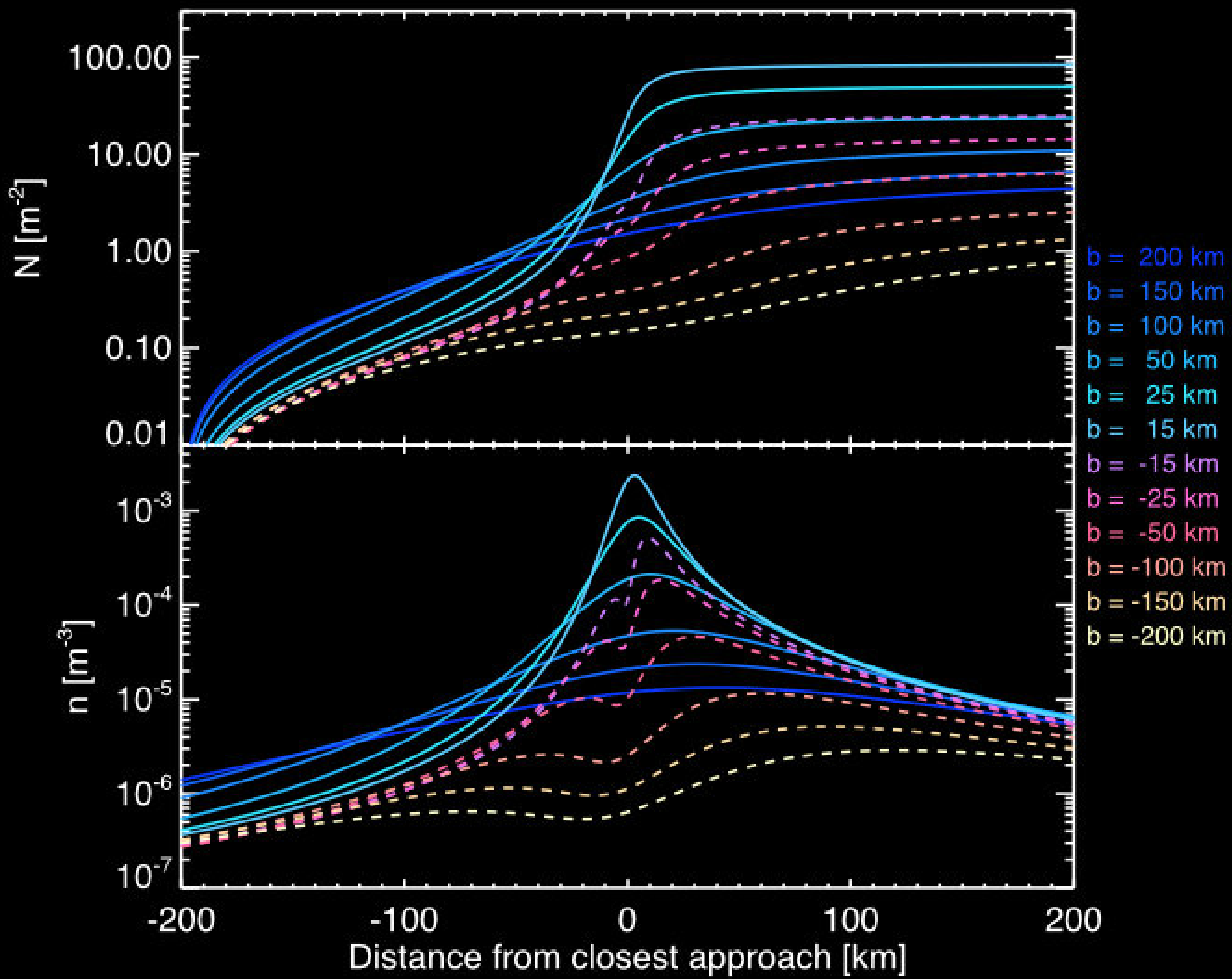
Szalay and Horányi, *ApJ Lett.*, 2016d

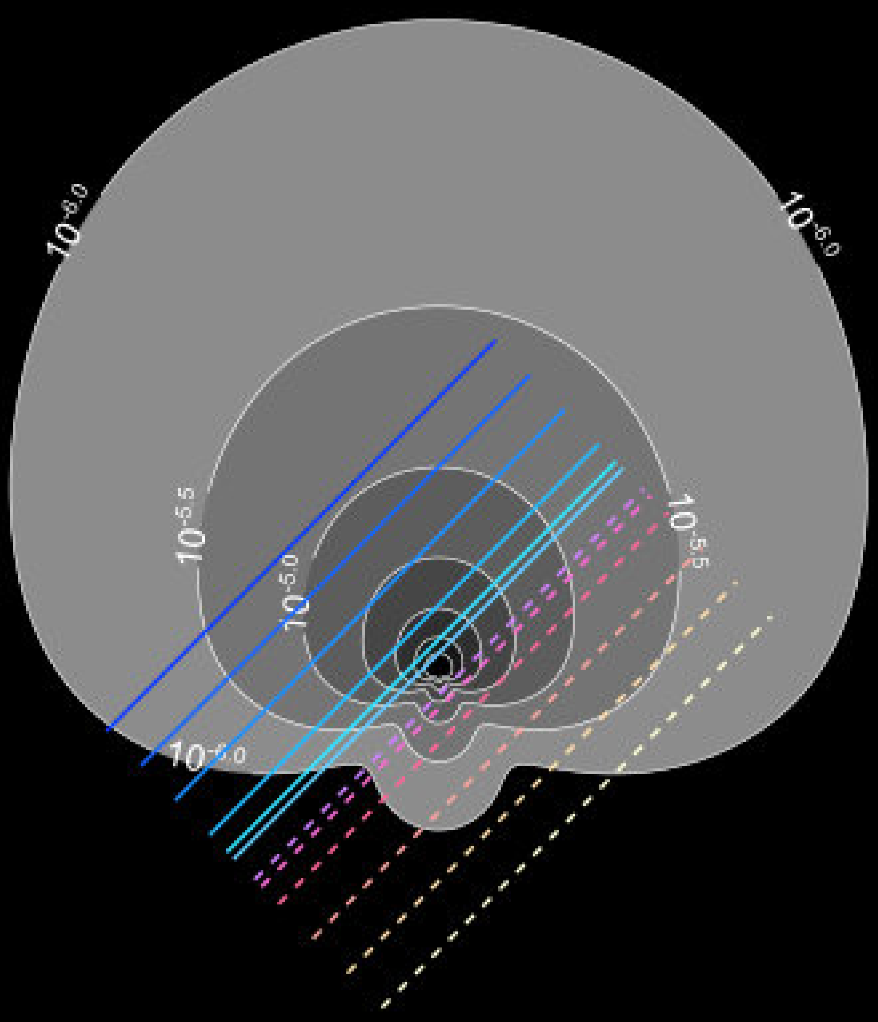
Asteroidal Dust Cloud Size



Szalay and Horányi, *ApJ Lett.*, 2016d

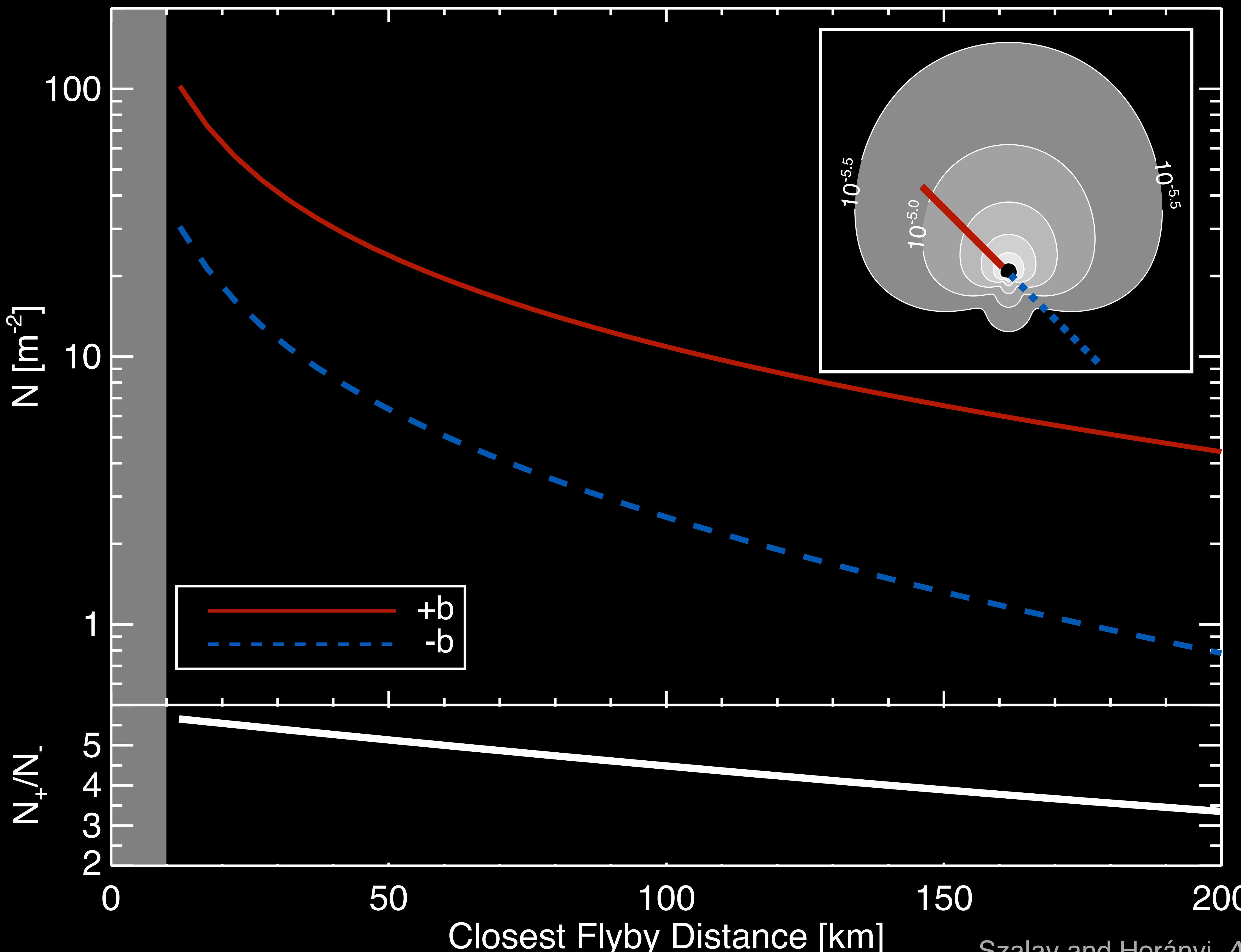
Asteroidal Flyby Geometry





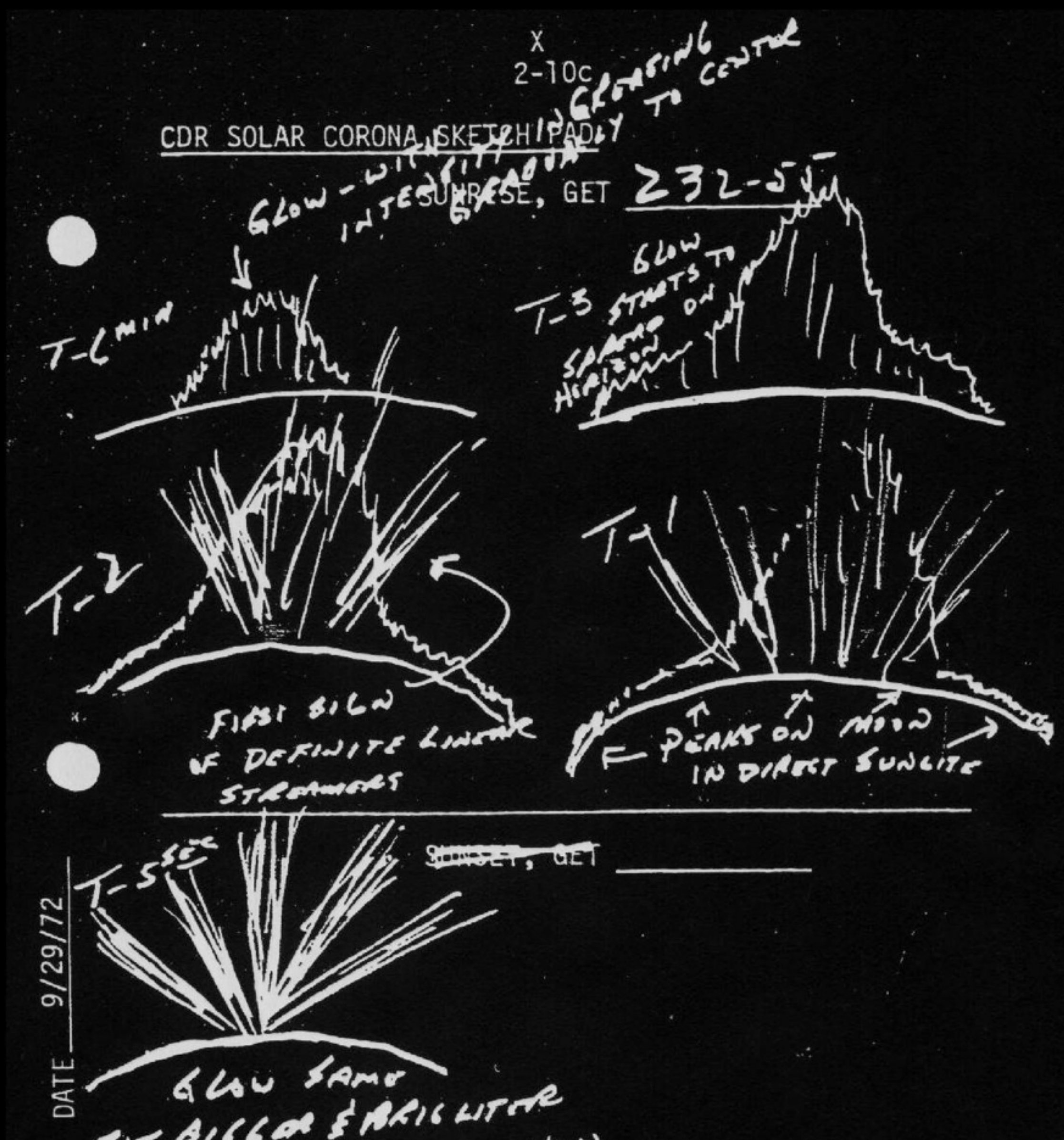
Szalay and Horányi, *ApJ Lett.*, 2016d

Future asteroid missions with dust analyzers would best characterize the ejecta by transiting the apex hemisphere.



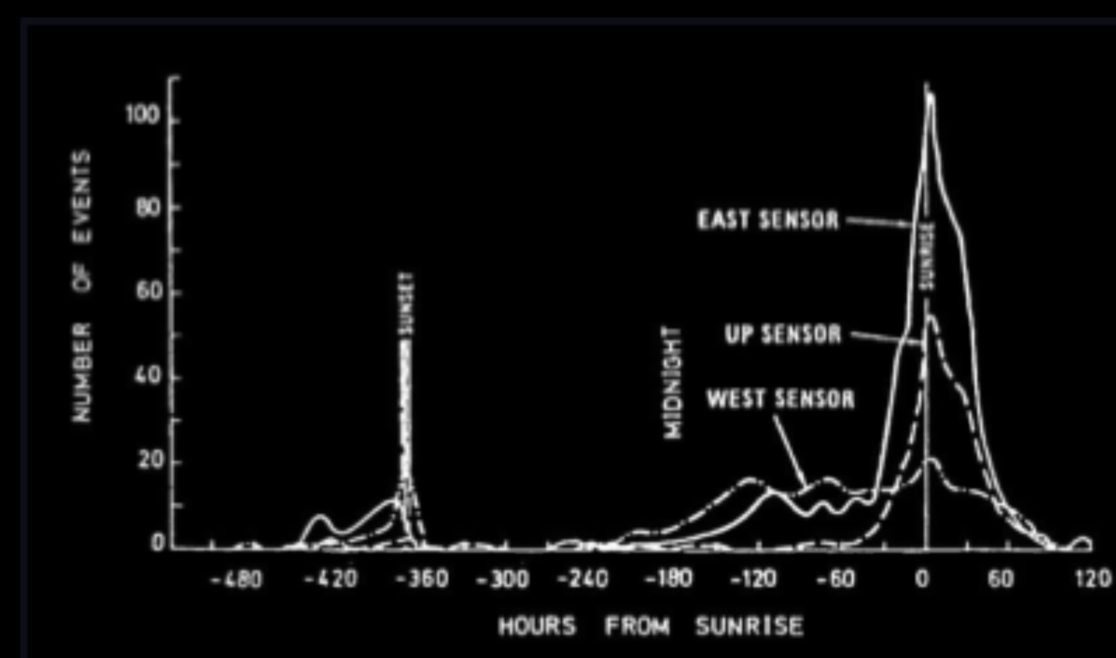
Szalay and Horányi, *ApJ Lett.*, 2016d

The Search for Electrostatically Lofted Dust

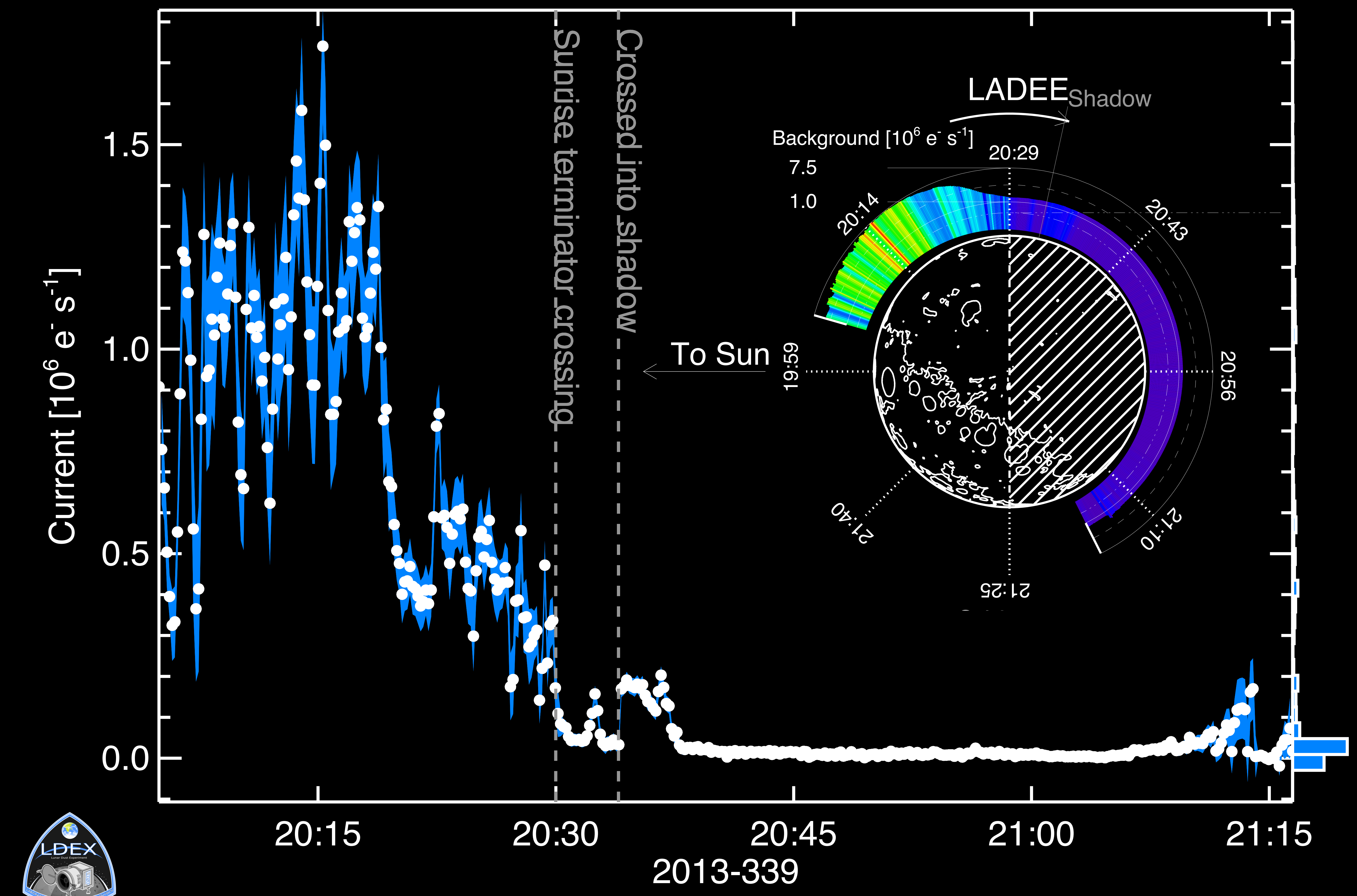


Sketch by G. Cernan

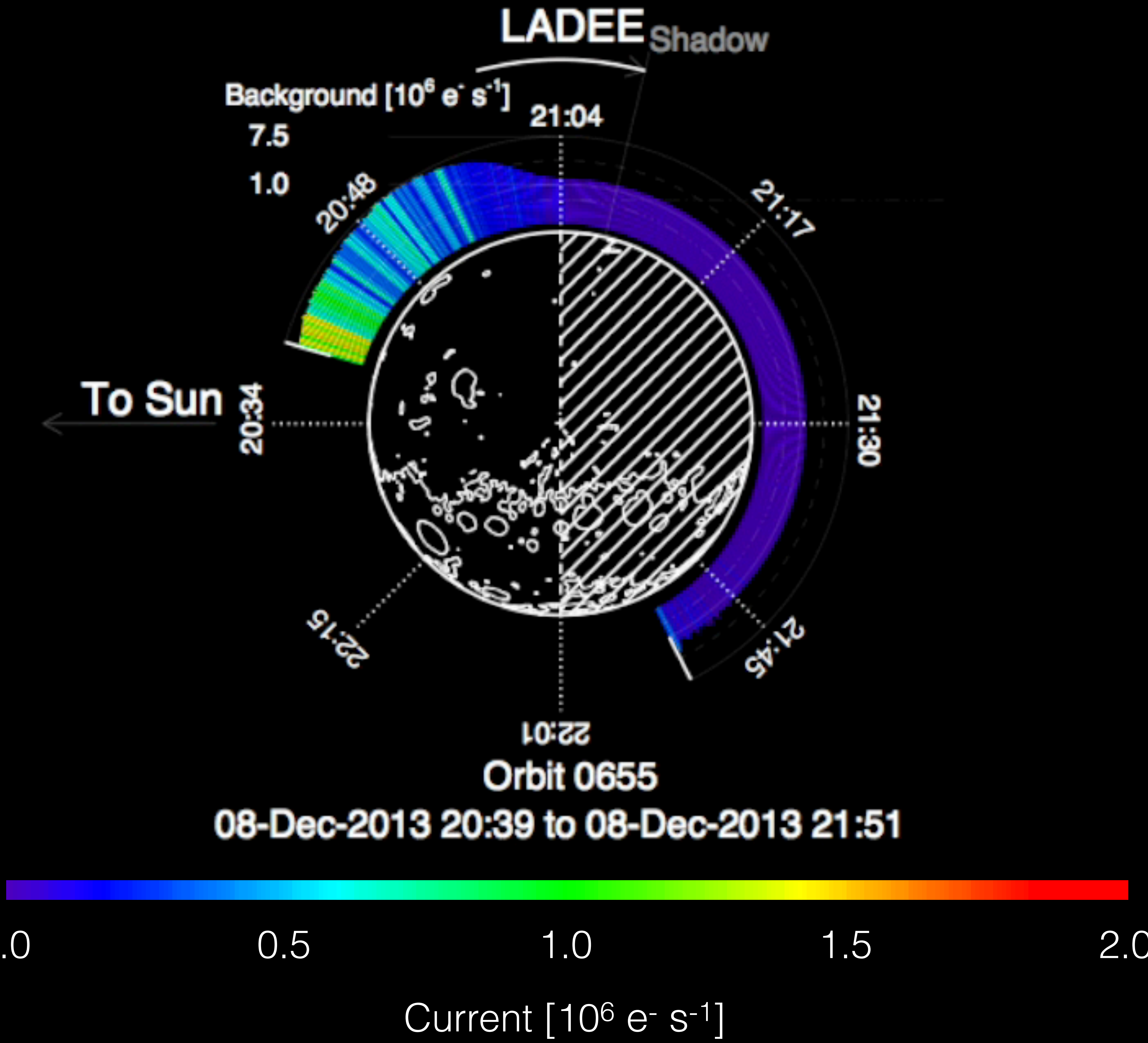
Colwell *et al.*, 2007



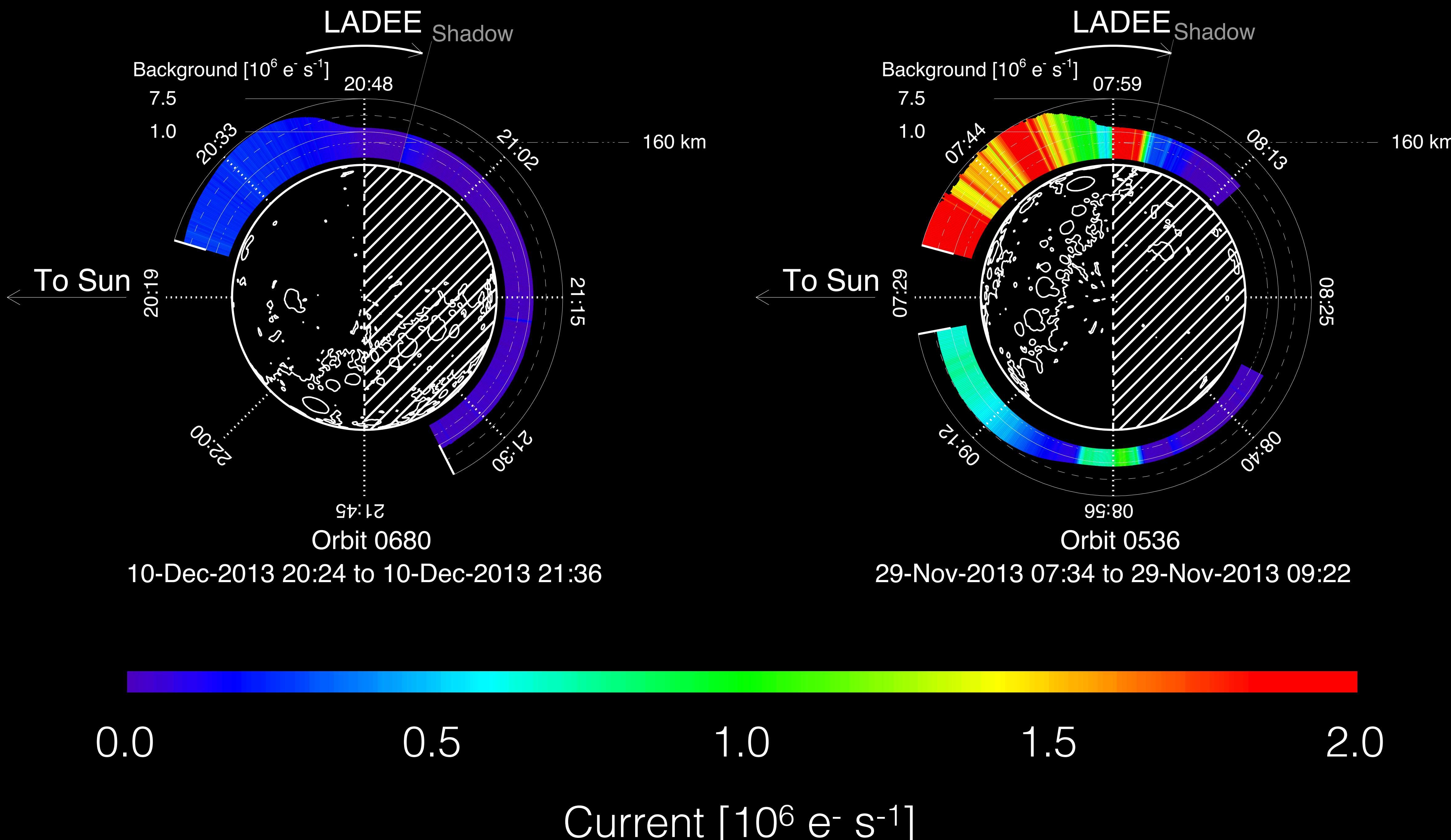
Berg *et al.*, 1976



Current [10^6 e⁻ s⁻¹]
0.0
0.5
1.0
1.5
20:15
20:30
20:45
21:00
21:15
2013-339
Sunrise terminator crossing
Crossed into shadow
To Sun
LADEE
Shadow
Background [10^6 e⁻ s⁻¹]
7.5
1.0
20:29
20:14
20:43
19:59
20:56
21:40
21:10
21:25
LDEX
Lunar Dust Experiment

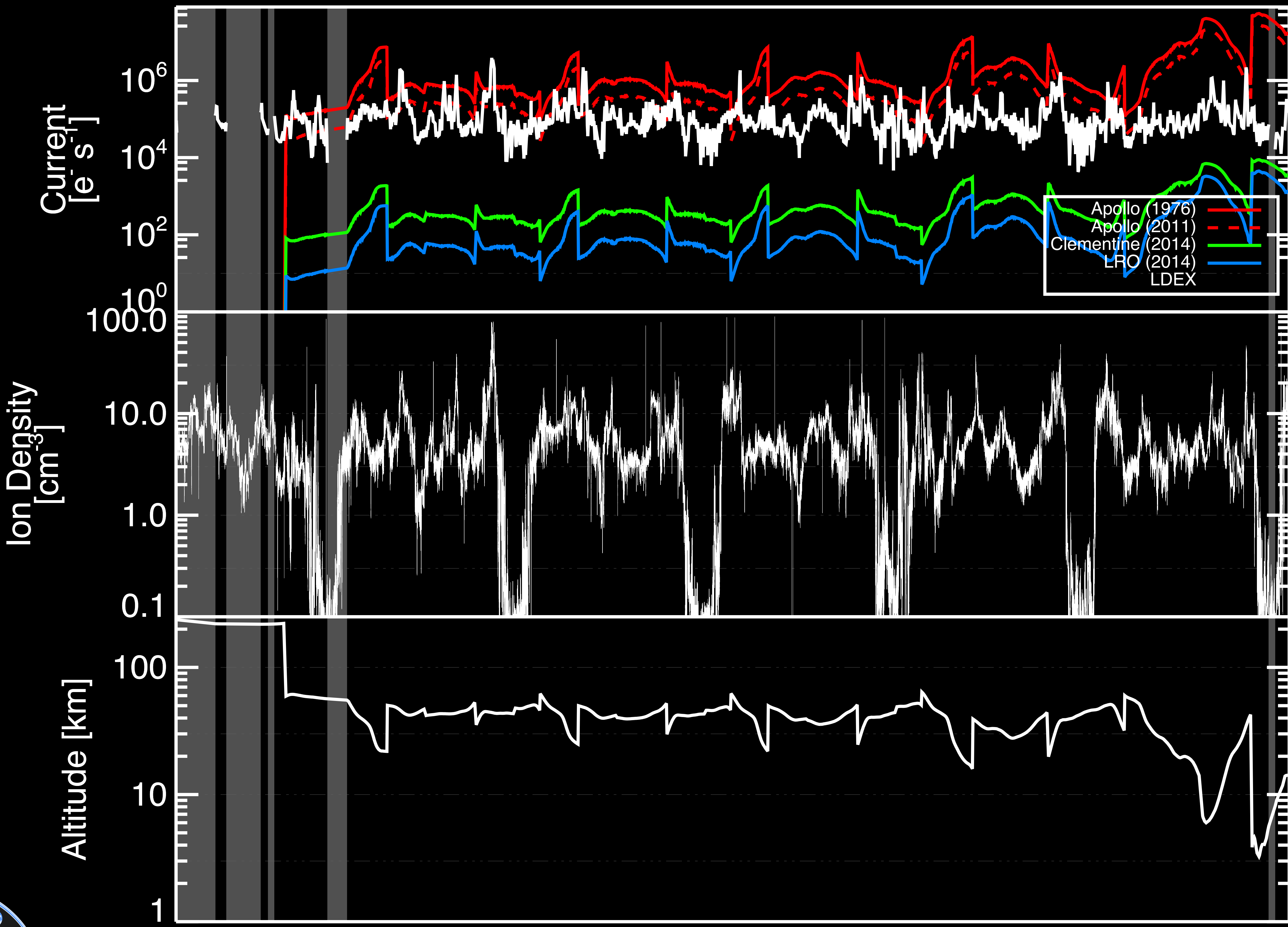

LADEE
Shadow
Background [10^6 e^- s^-1]
7.5
1.0
21:04
20:48
21:17
To Sun
20:34
21:30
22:15
21:45
22:01
Orbit 0655
08-Dec-2013 20:39 to 08-Dec-2013 21:51
0.0
0.5
1.0
1.5
2.0
Current [10^6 e^- s^-1]

Example Orbits



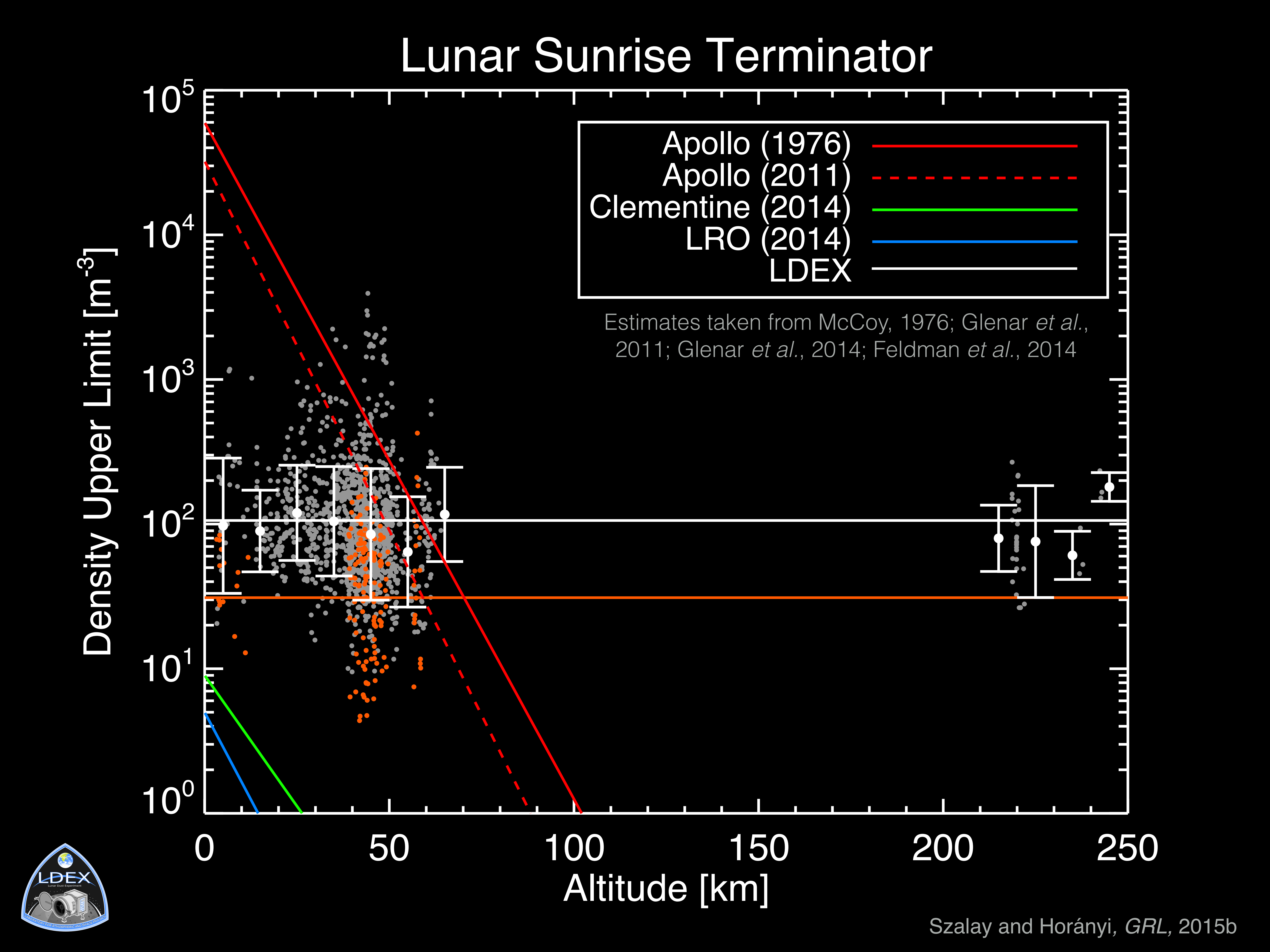
Szalay and Horányi, *GRL*, 2015b

Terminator Crossing (-2.5 to +2.5 min)



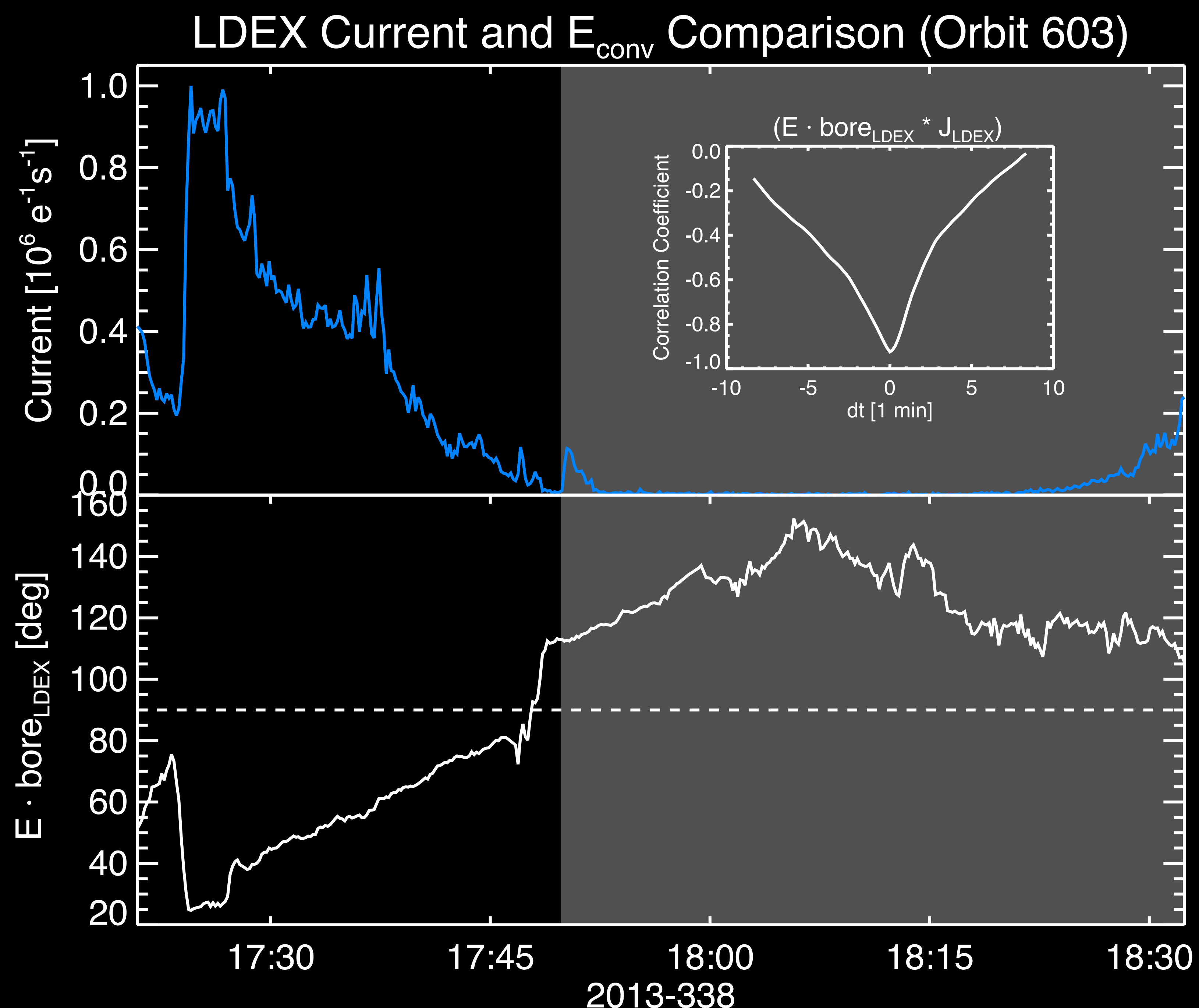
Estimates taken from McCoy, 1976; Glenar *et al.*, 2011; Glenar *et al.*, 2014; Feldman *et al.*, 2014

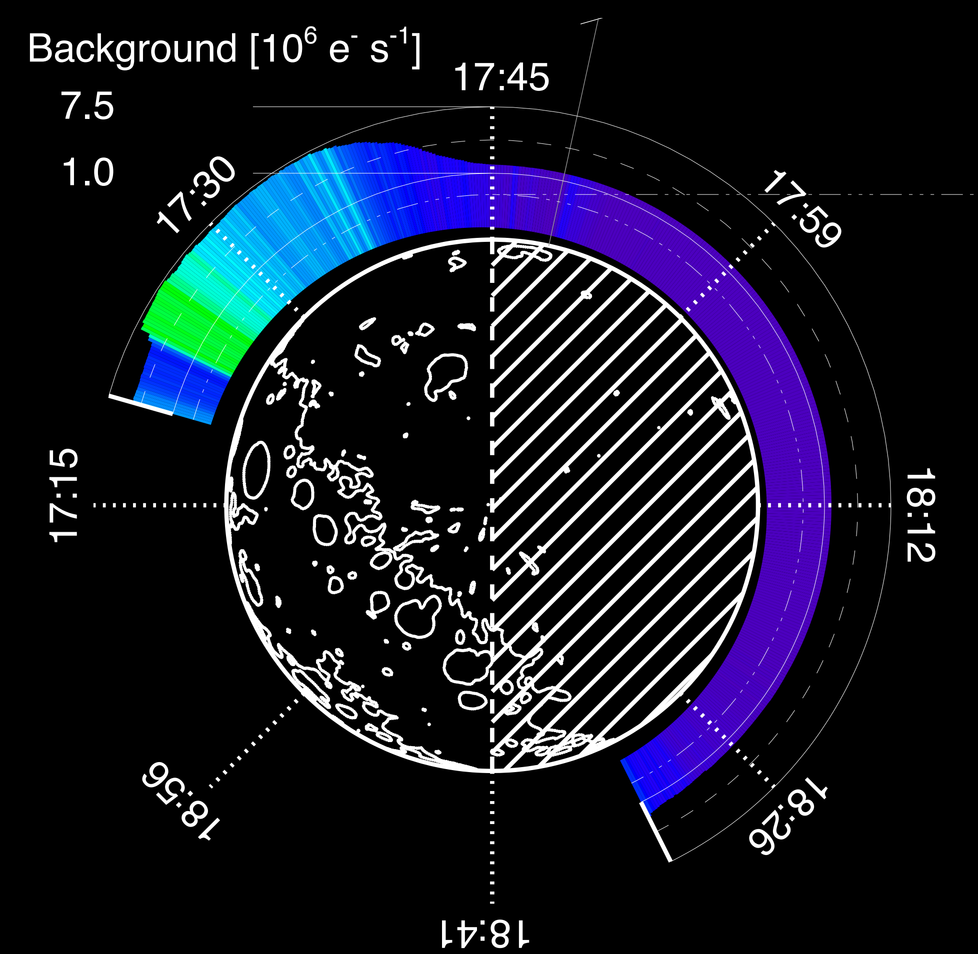
Szalay and Horányi, *GRL*, 2015b



Lunar Sunrise Terminator
Apollo (1976)
Apollo (2011)
Clementine (2014)
LRO (2014)
LDEX
Estimates taken from McCoy, 1976; Glenar et al., 2011; Glenar et al., 2014; Feldman et al., 2014
Density Upper Limit [m-3]
10^5
10^4
10^3
10^2
10^1
10^0
0
50
100
150
200
250
Altitude [km]
LDEX
Szalay and Horányi, GRL, 2015b

Dayside Current





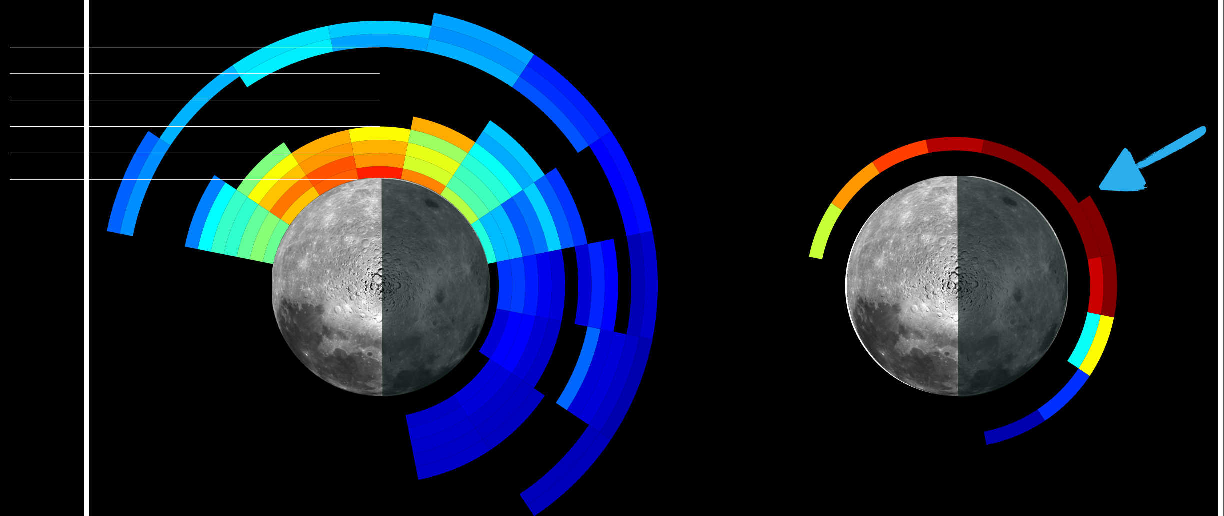
LDEX measurements constrain pickup ion scale height and abundance ratios.

Poppe *et al.*, *GRL*, 2016

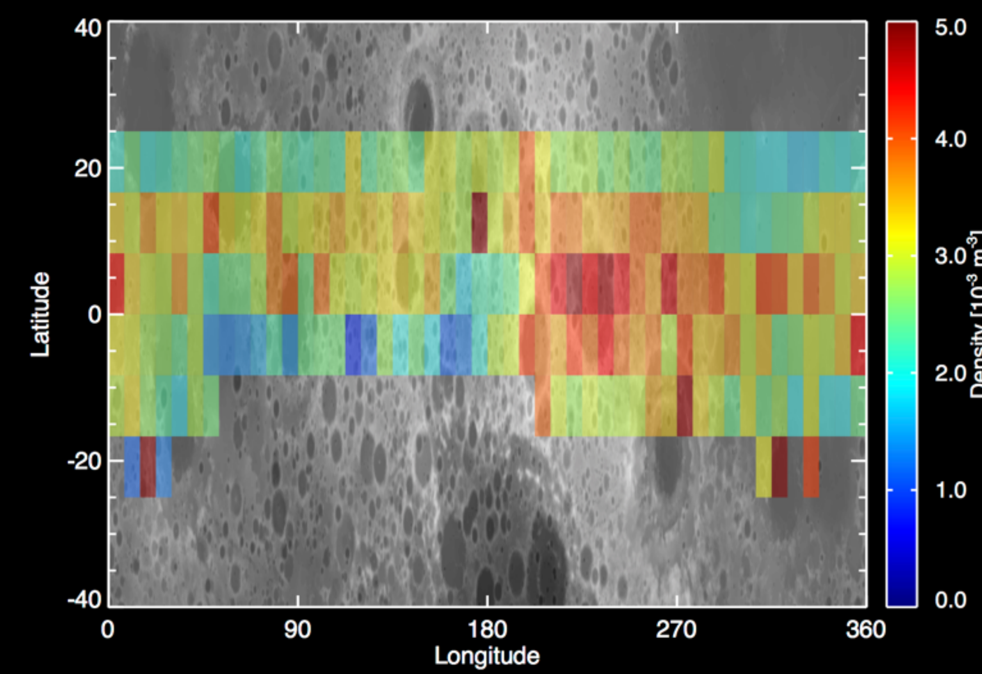
Outlook

Impact Yield Studies

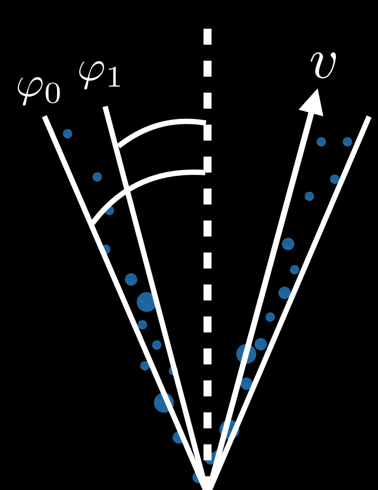
Geminids as a probe

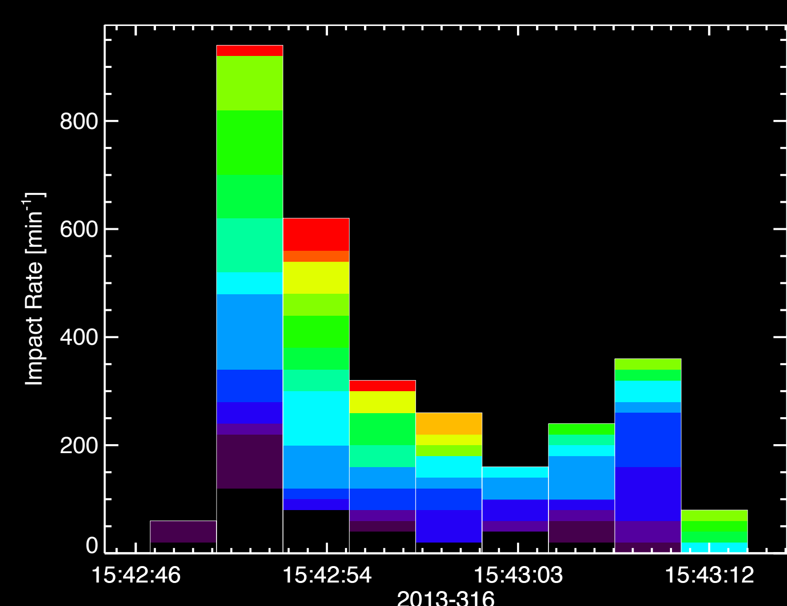


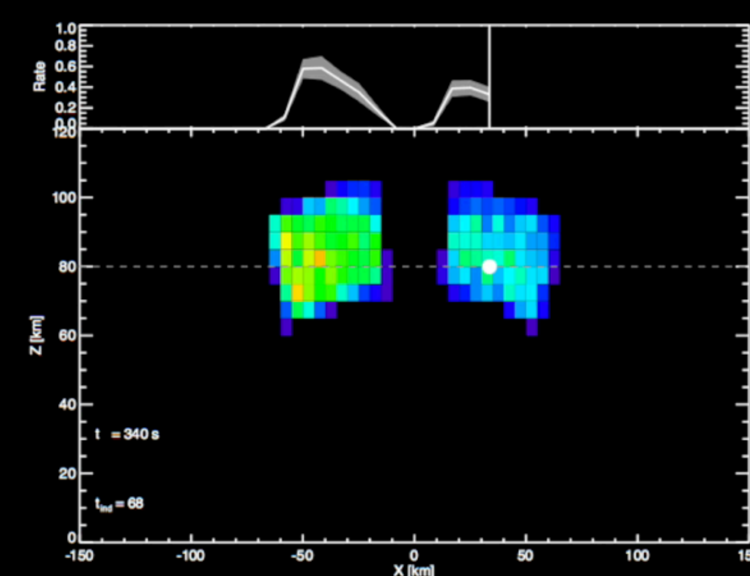
Surface Dependence



Modeling Ejecta Plumes

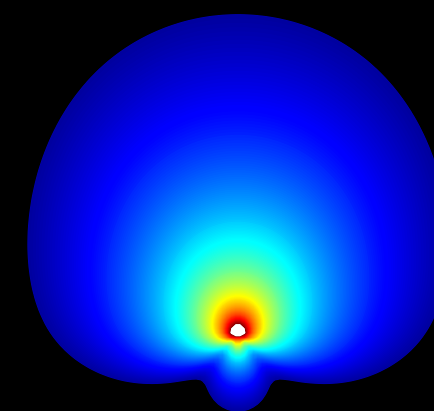




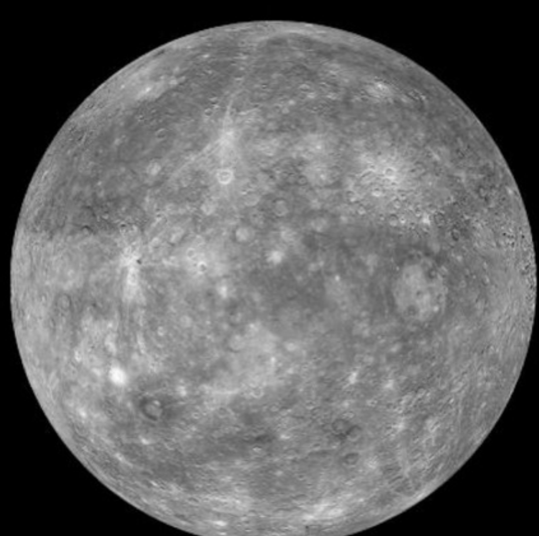


Ejecta Rates from Regolith Bodies in the Solar System

Lunar response as a function of flux, velocity, angle, surface material

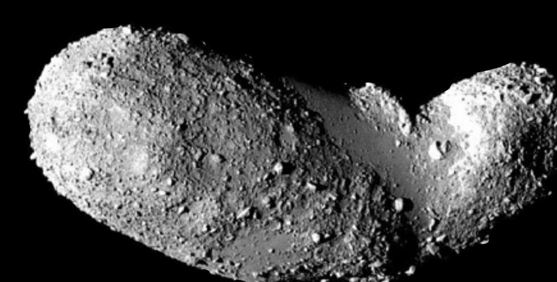


Impactor Flux Model



Mercury

Moons

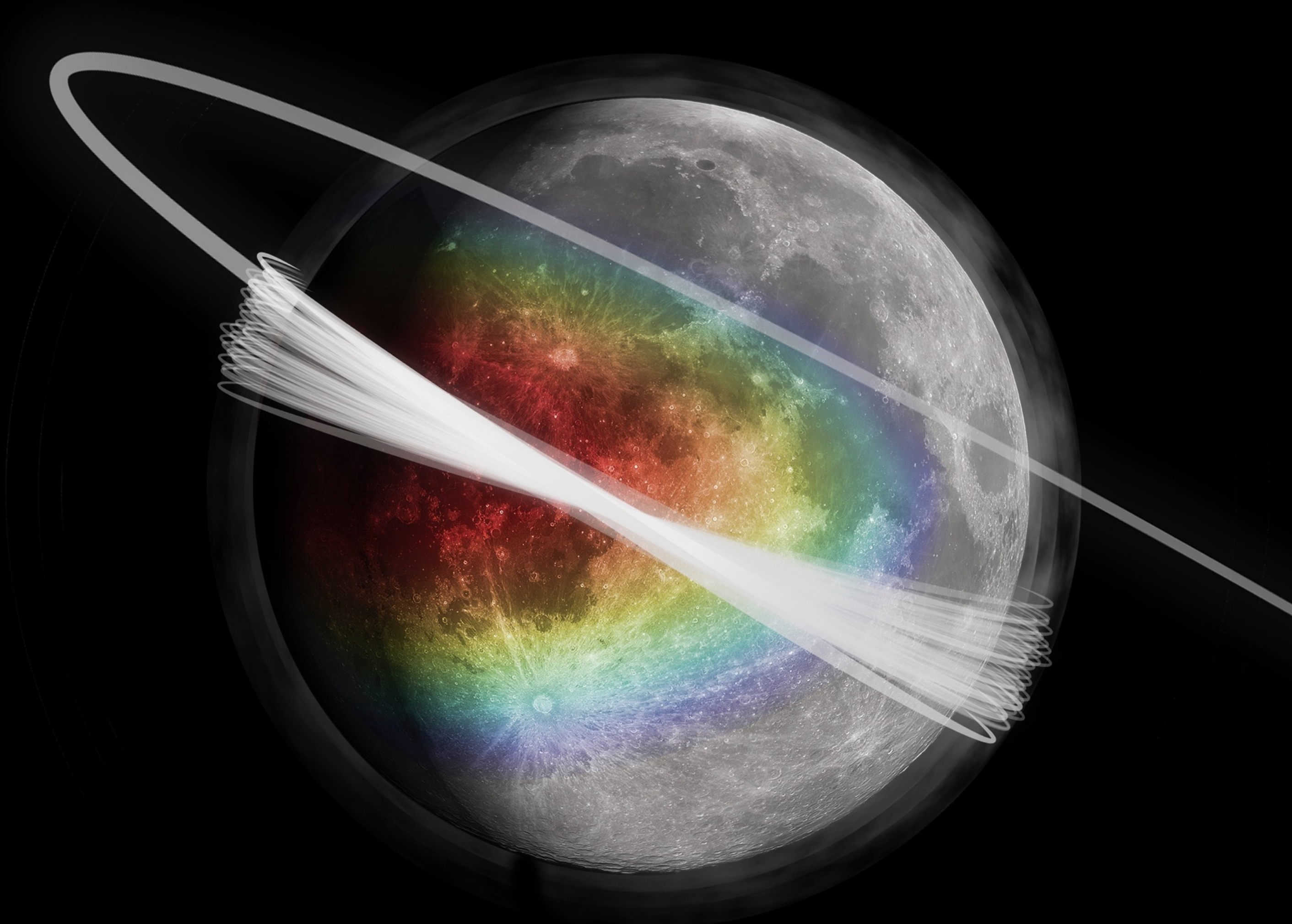


Asteroids

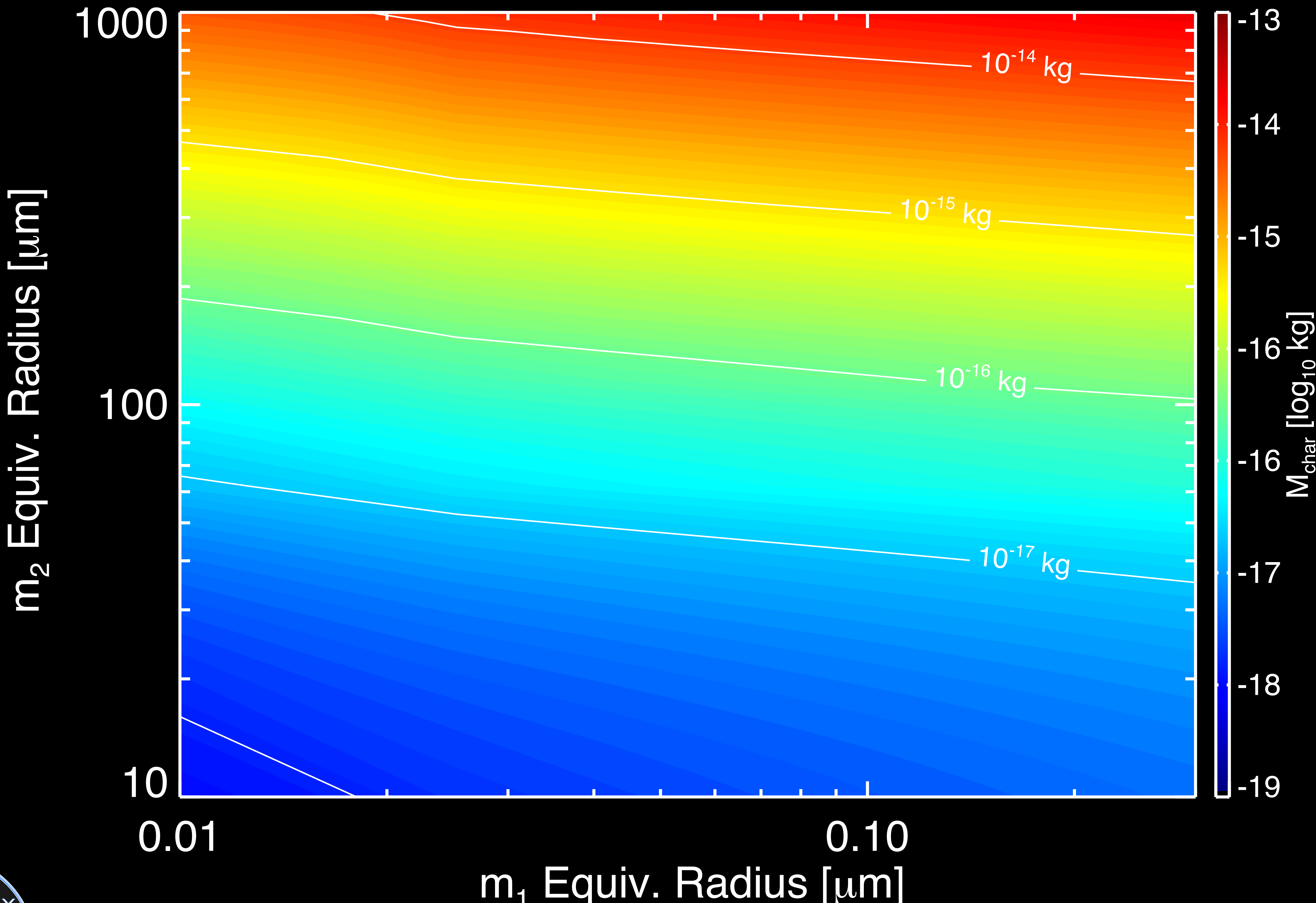
Airless KBOs

Conclusions

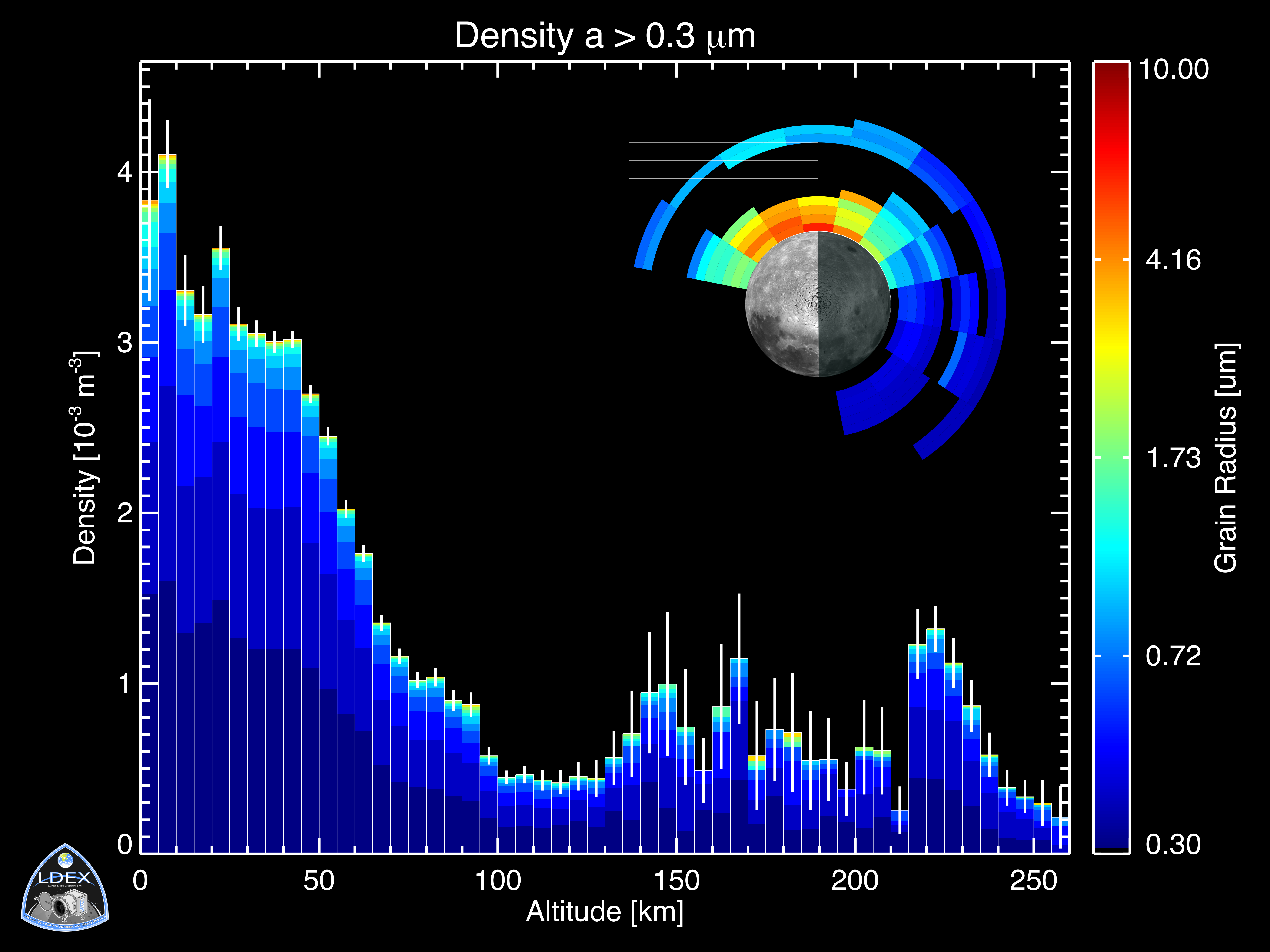
- Lunar dust cloud is sensitive to changes in impactor flux.
- A fit for the entire equatorial lunar dust density distribution is derived.
- No evidence for electrostatically lofted dust from h = 3-250 km.
- Similar processes take place on all airless bodies in the solar system.



LDEX
Lunar Dust Experiment



1000
100
10
0.01
0.10
m$_2$ Equiv. Radius [μm]
m$_1$ Equiv. Radius [μm]
10^{-14} kg
10^{-15} kg
10^{-16} kg
10^{-17} kg
-13
-14
-15
-16
-16
-17
-18
-19
M_{char} [$\log_{10}$ kg]


Density a > 0.3 μm
Density [10^-3 m^-3]
Altitude [km]
0
1
2
3
4
0
50
100
150
200
250
Grain Radius [um]
10.00
4.16
1.73
0.72
0.30
LDEX
Lunar Dust Experiment

Meteor Showers