Molecular and Metallic ions in the magnetosphere: ISSI team preliminary results

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Poor knowledge of magnetospheric ions for m/q>20

H^+, He^{++}, He^+, O^+ (N^+) : many works with may missions

(1) N_2^+, NO^+, O_2^+ : only few dedicated instruments

- cold ions < 50 eV (DE-1, Akebono, e-Pop) for M<40
- hot ion > 10 keV ions (DE-1, CRRES, POLAR, but no open data ...)
- energetic ions ≥100 keV (CRRES, POLAR, AMPTE, Geotail …).

(2) high-charge state ions (e.g., O^{6+}, Fe^{12+}): very few dedicated instrument

- energetic ions ≥100 keV (CRRES, POLAR, AMPTE, Geotail …).

(3) low-charge state metallic (non-volatile, e.g., Fe^+) ions: no dedicated instrument

- Moon missions as the source (Kaguya for 0.01-30 keV and LADEE for cold)

(however) non-dedicated instruments sometime detects molecular/metallic ions

- hot ions of 0.01-10 keV range (Arase, Cluster/CIS, POLAR, MMS)
- energetic ions ≥100 keV (Cluster/RAPID>400 keV, WIND).

By combining these patchy and incomplete data (database construction), we found several features that indicate sources of these heavy ions. **= ISSI objective**

"Very heavy" ion has its own importance

Si^+, Fe^+
O^{6+}, Fe^{12+}
N_2^+, NO^+, O_2^+

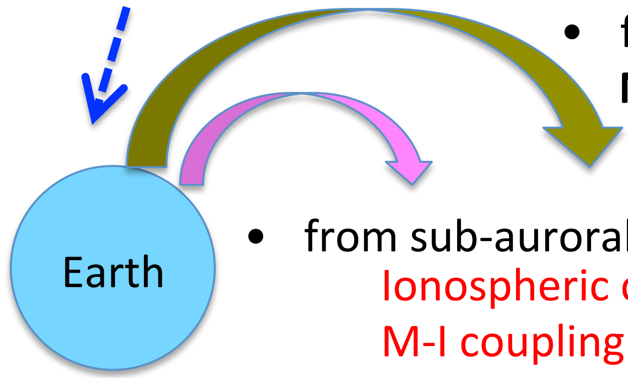
Solar wind – magnetosphere interaction

- directly from SW

O^{6+}, Fe^{12+}

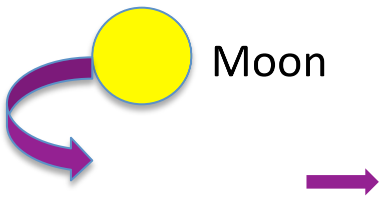
Atmospheric evolution
M-I coupling
Expansion of metal layer

Ablation of meteorites/debris



- from high-latitude **N_2^+, O_2^+, Si^+, Fe^+**

Solar wind – surface interaction
Micrometeorite – surface interaction



Moon

- from sub-auroral **N_2^+, O_2^+**

Ionospheric chemistry/physics
M-I coupling

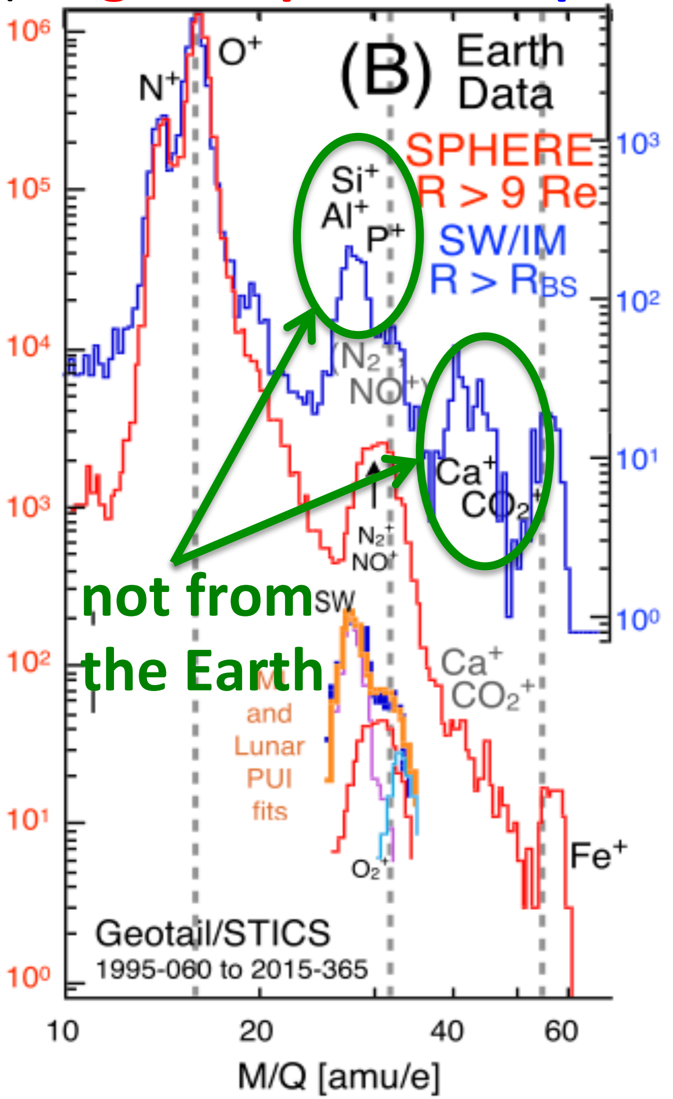
- exospheric: **Ne^+, Na^+, K^+, Ar^+**
- sputtered by SW and ionized: **Si^+, CO^+/N_2^+, Na^+, K^+, Ca^+, Fe^+**
- reflected SW **Fe^+**

⇒ **All are picked up to > 30 keV**

Problem is source of low-charge state:

- Moon vs. high-latitude?
- metal layer/space debris contribution?
- How much from low-latitude?

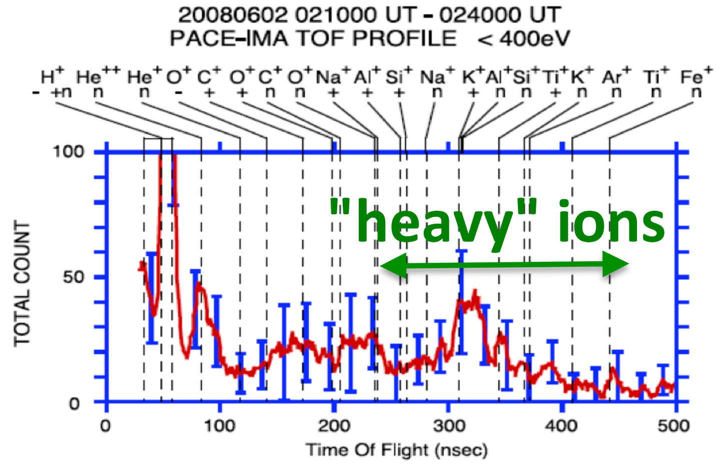
Low charge-state energetic ions (magnetosphere vs upstream)



Geotail/STIC statistics (Christon et al, 2020 fig 5)

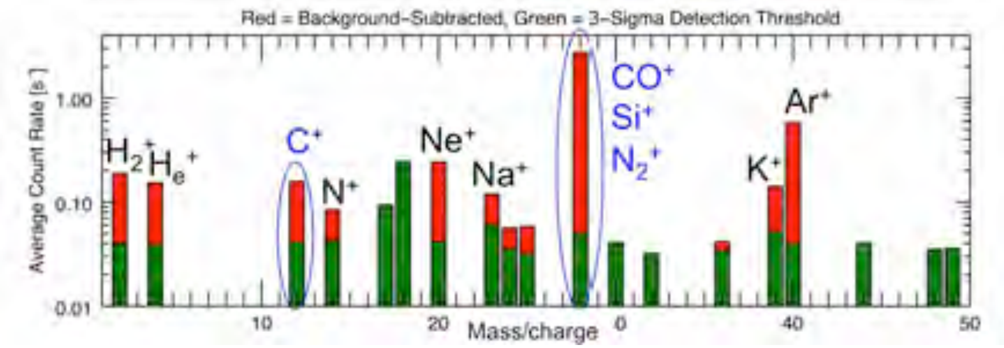
Moon source (pickup)?

Sputtered ion (< 400 eV) from Moon



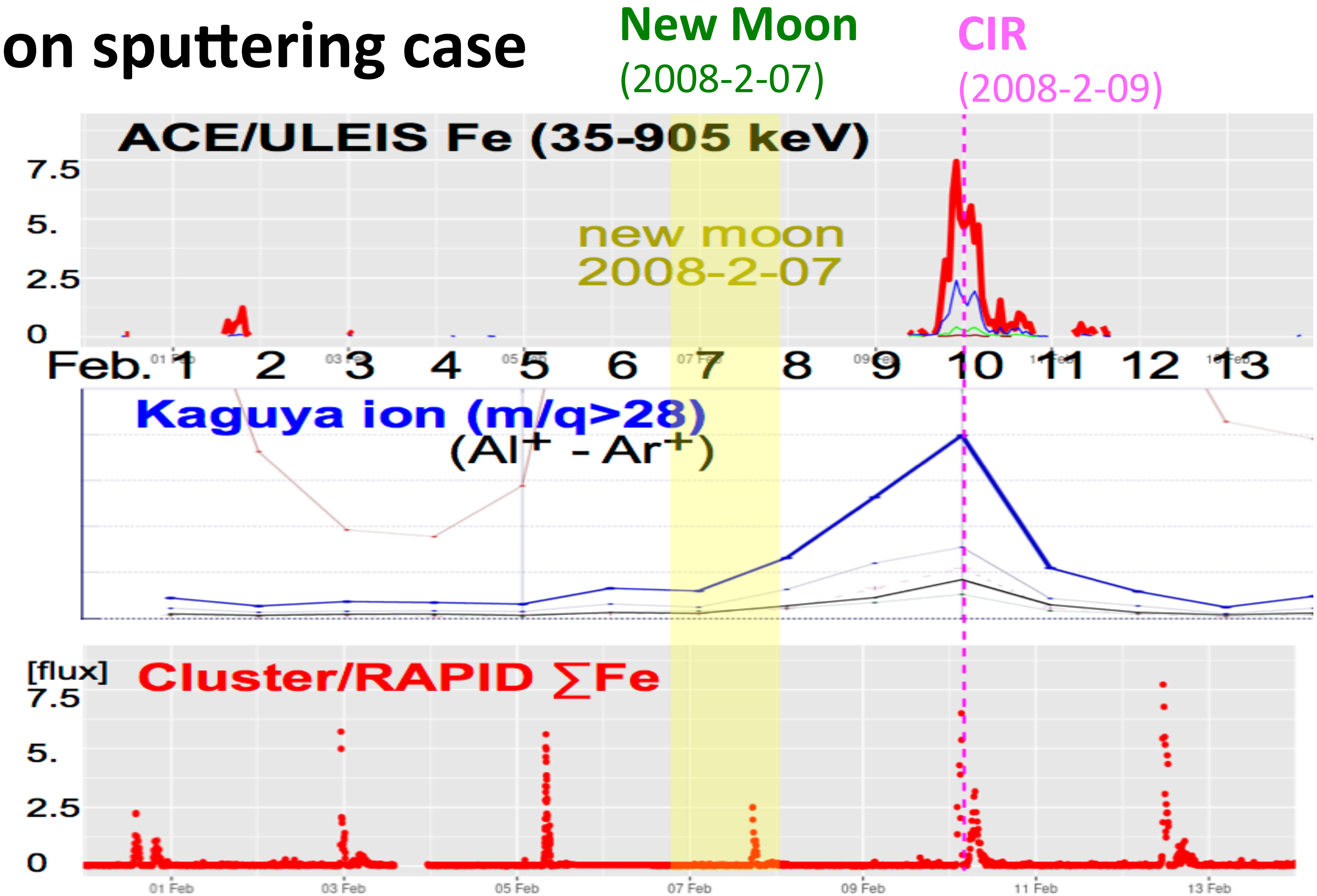
Kaguya data (Saito et al, 2010 fig32)

Exospheric cold ion at Moon



LADEE data (Halekas et al, 2015 fig3)

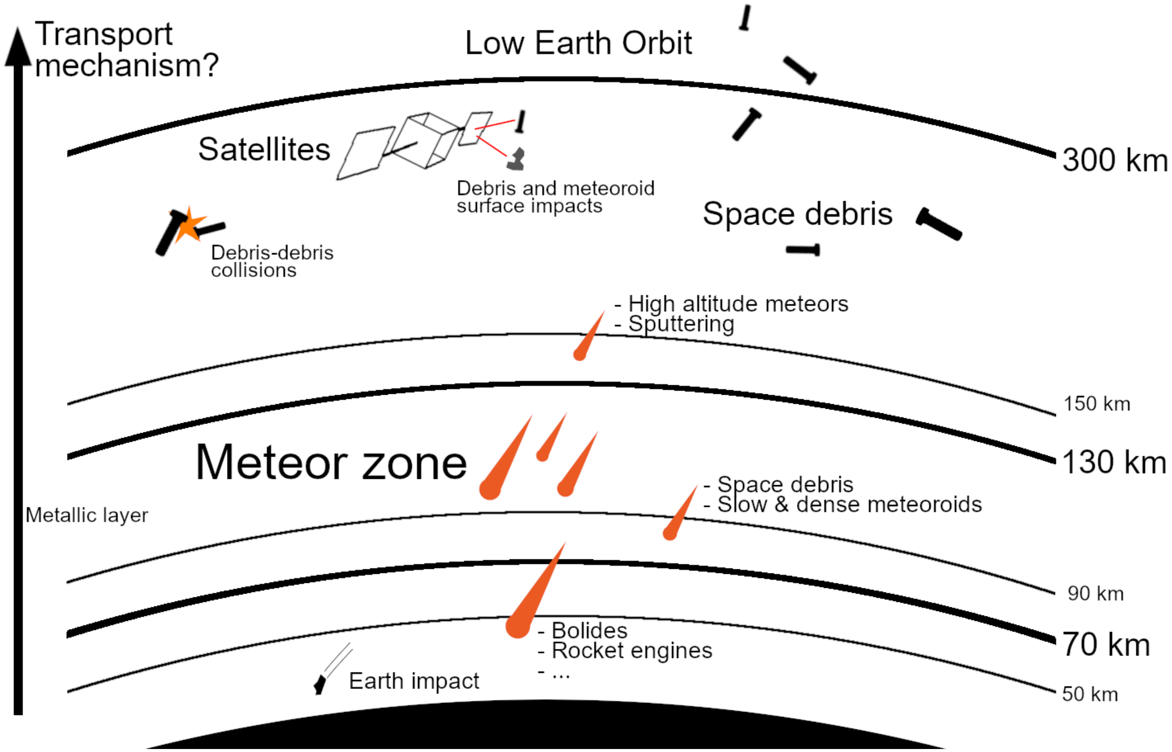
Moon sputtering case

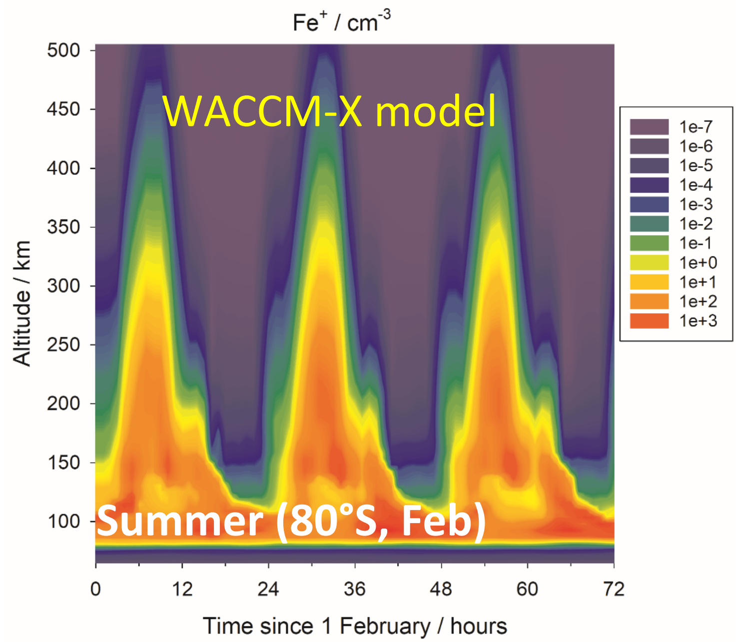


Geotail/STICS cnt/day (m/q>28)	3	7	0-1	4	-	0	4	3	7	0	2

Moon react to SW ⇒ magnetosphere? (unclear)

Relation to meteor and space debris (model)



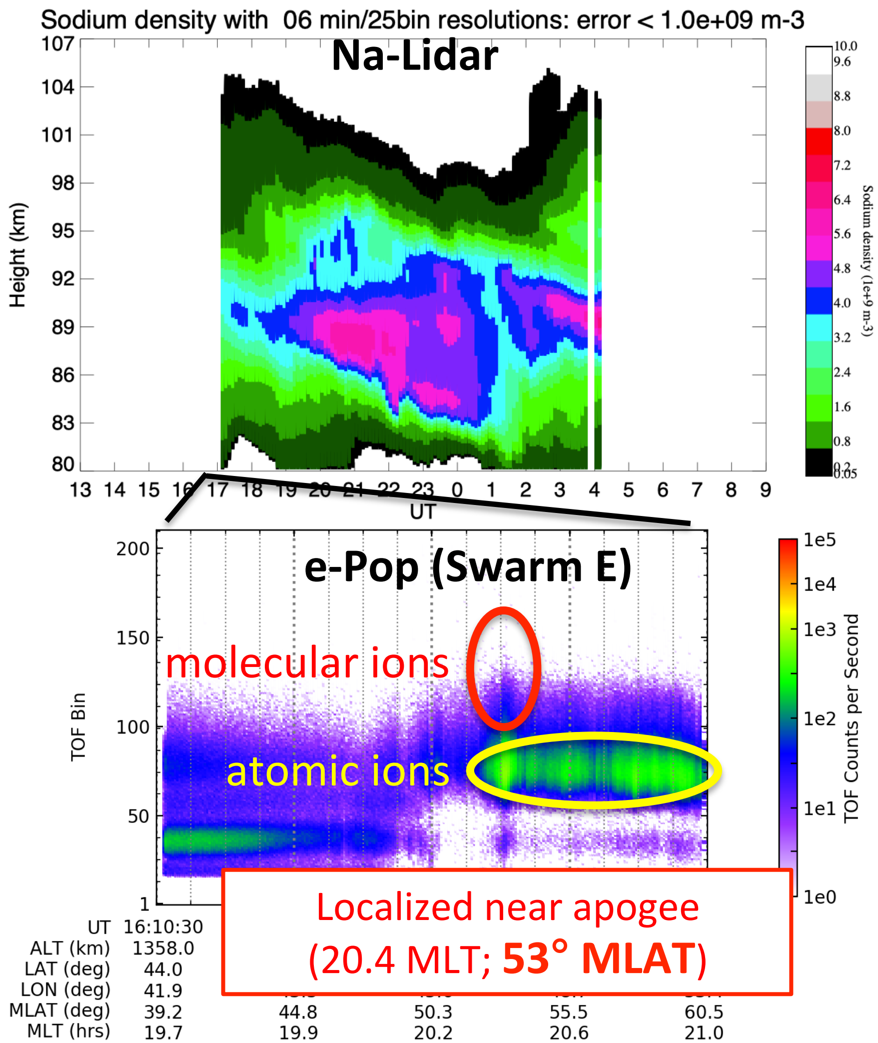


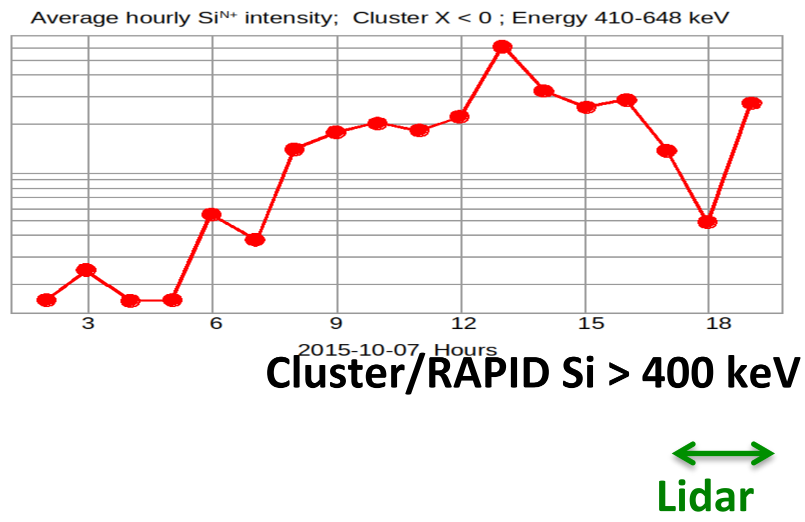
Modeled meteor-ablated Fe^+ (Wu et al., 2021)

- Estimate based on metallic layer observation
- Daily transport > 500 km (summer only)

  ⇒ may reach magnetosphere during major storm
- Mass dependent (Mg^+ is lifted more)
- Space debris origin ⇒ too low altitude (but Al+ may reach…)

Relation to sodium layer and low-latitude source: 2015-10-07 CME event

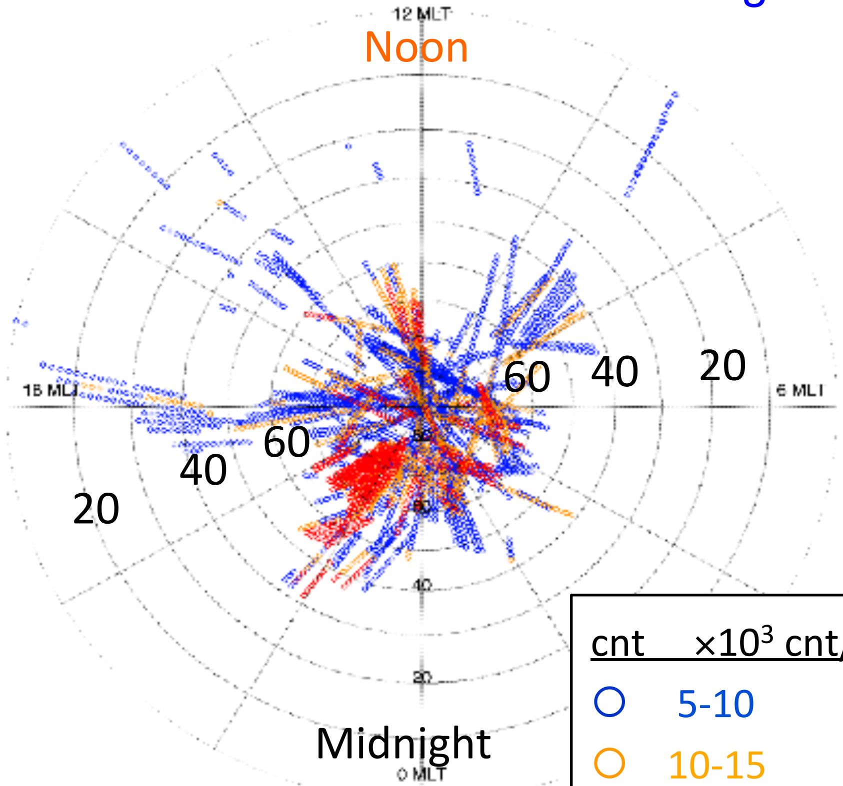




Could reach magnetosphere?

Yes, some of them may reach the magnetosphere

N_2^+-NO^+-O_2^+ at 300-1500 km (Swarm-E) = observed at wide latitude range



cnt ×10³ cnt/s

○ 5-10

○ 10-15

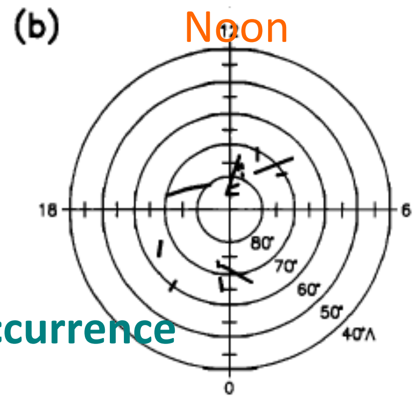
○ >15

Courtesy: V. Foss, 2019

low-cnt events = extend to low latitudes

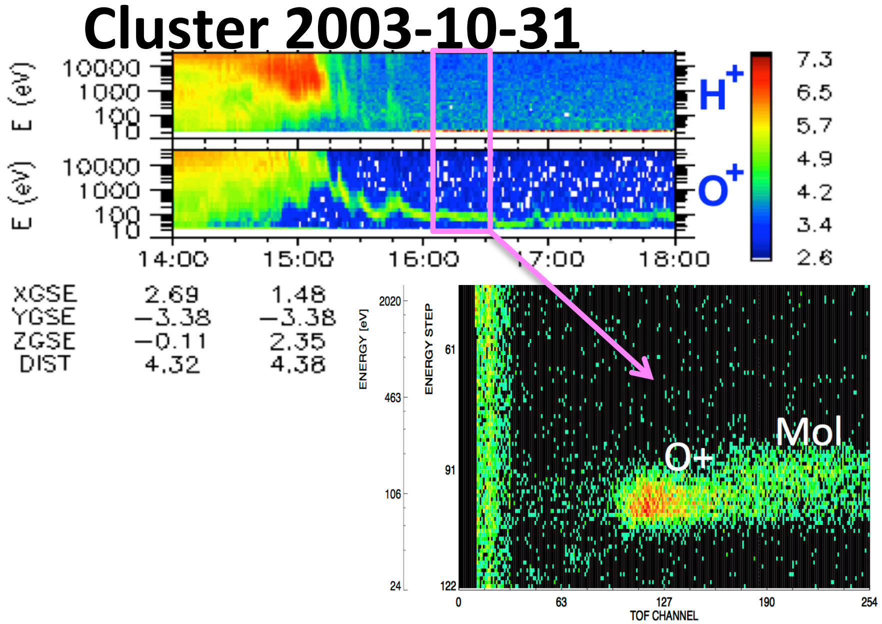
high-cnt events = only high latitudes

N_2^+-NO^+-O_2^+ at 6000-10000 km (Akebono) = only high latitude



Molecular ion occurrence

Generally only from high latitude, e.g.,



Recommendation

Data only suggests "possibility" of interpretations, but not conclusive.
$\Rightarrow$ What we need in future?

(1) Dedicated Instrument in future missions/observations
- magnetospheric mission including Moon gateway flight
- ionospheric mission to cover 150-1000 km with heavy ion capability
- simultaneous ground based observation of metal layer and outflow

(2) Modeling? (but input data are not good quality yet)

(3) more .... we are discussing