Seasonal variation of Mercury's exosphere deduced from MESSENGER data and simulation study

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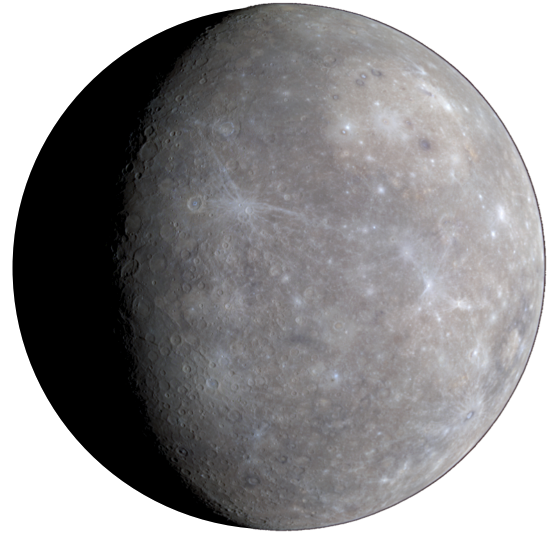
Mercury's atmosphere



- Collision-less atmosphere (~10^{-15}Pa)
  = Exosphere directly connects to the surface.
- H, He are supplied by solar wind,
  others are ejected from the surface.
- Drastically varies depending on TAA
  due to high eccentricity (0.21)

→ direct effect of
space environment on the bodies

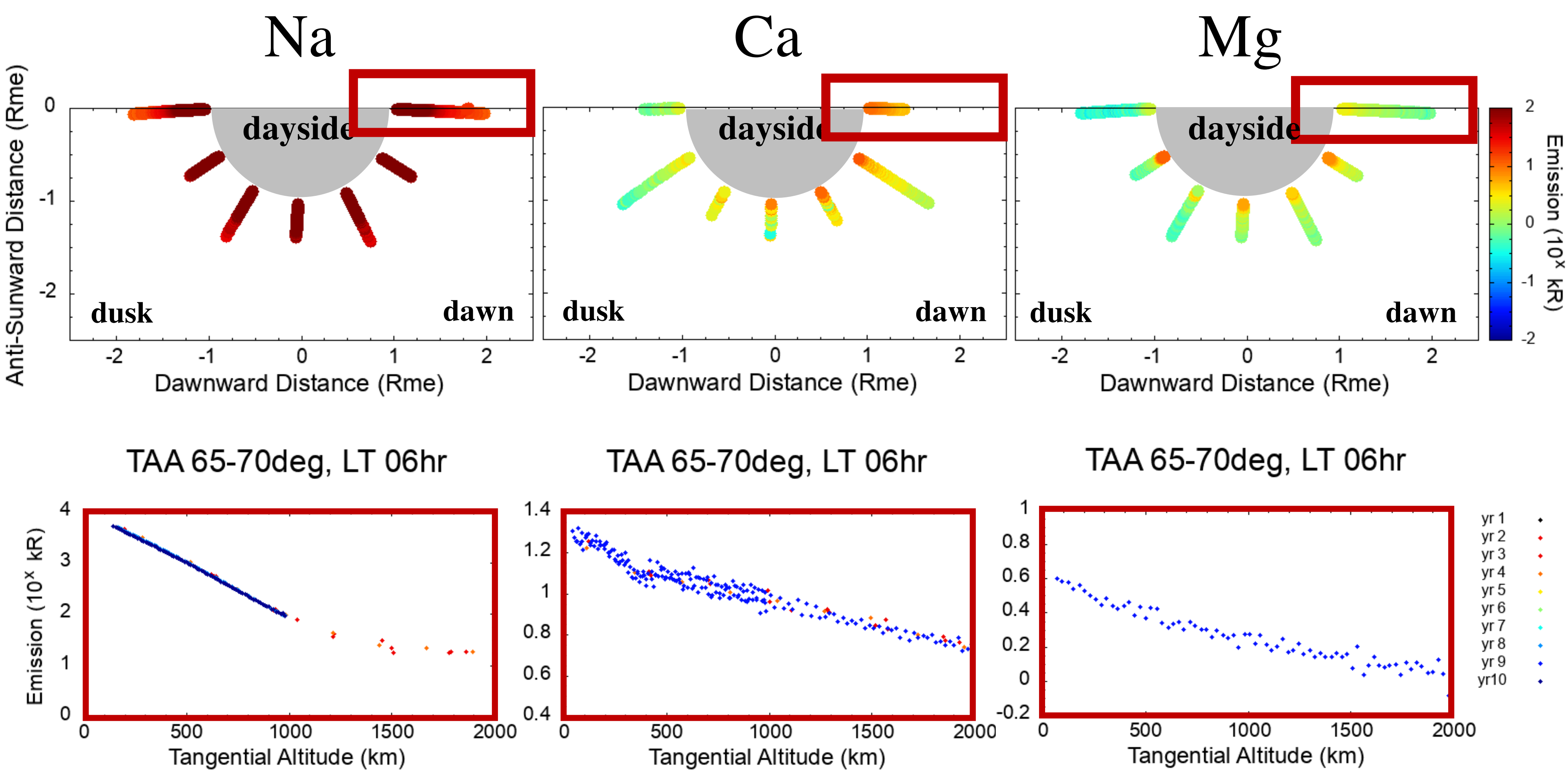
→ environment of general airless bodies

Major Species	Column Density ($\times 10^6$/cm^2)
Na	~200,000
Mg	~100,000
O	<40,000
H	~5,000
K	~1,000
Ca	<1,000
Al	~15

"Mercury Fact Sheet" by NASA.

Observations by MESSENGER

– difference in the atmospheric structure depending on the species



cf.) Cassidy et al., 2015, *Icarus*   cf.) Burger et al., 2014, *Icarus*   cf.) Merkel et al., 2017, *Icarus*

Purpose of this study

Understanding the response of airless bodies
to the space environments

This study aims to understand the cause of
the seasonal variability of Mercury’s neutral Na exosphere

- Na is so bright and easy to be observed that its behavior is understood best

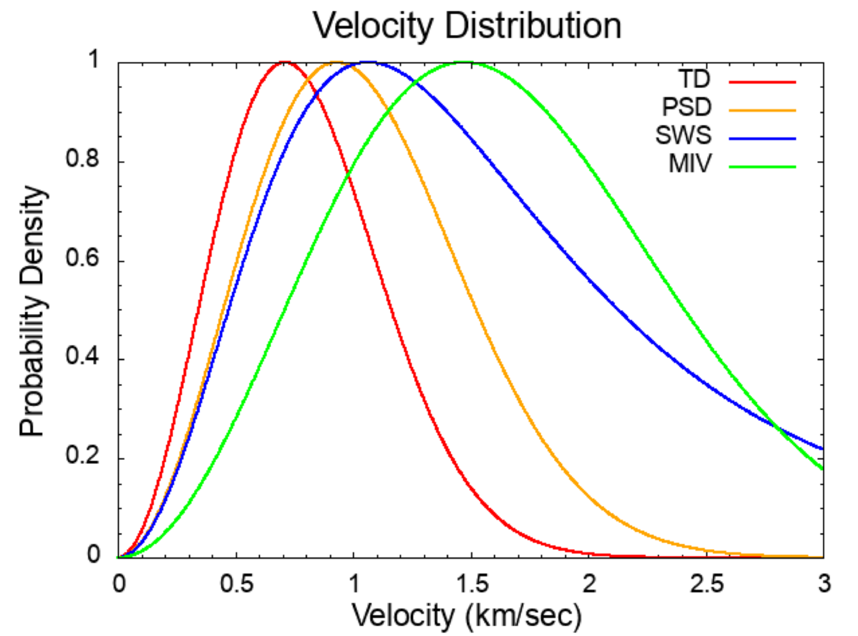
Desorption processes of Na from the surface

- Thermal Desorption **(TD)**

  Enhanced around perihelion
  & sub-solar point

- Photo Stimulated Desorption **(PSD)**

  Enhanced around perihelion
  & sub-solar point



- Solar Wind sputtering **(SWS)**

  Enhanced around perihelion & mid- or high-latitude region

- Micro-meteoroid Impact Vaporization **(MIV)**

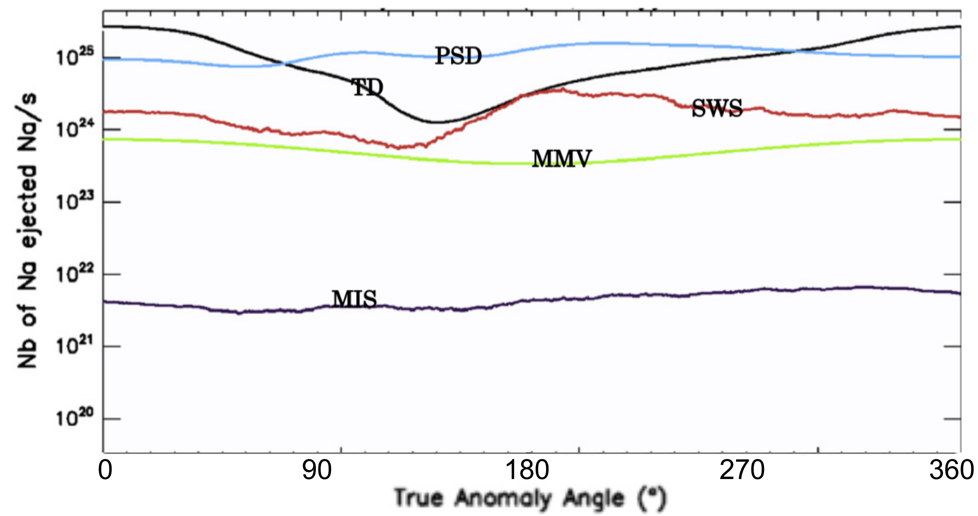
  Enhanced on leading hemisphere & around ecliptic plane

Previous research – theoretical model

- Estimation of seasonal variation of ejection rate
  by each process using numerical simulation

→ Ejection rate is not always minimum around aphelion

- Sputtering region is fixed
  at mid-latitude region
- Uniform MIV rate
- More precise assumption of
  Na supply to the surface is necessary



Leblanc & Johnson, 2010, *Icarus*

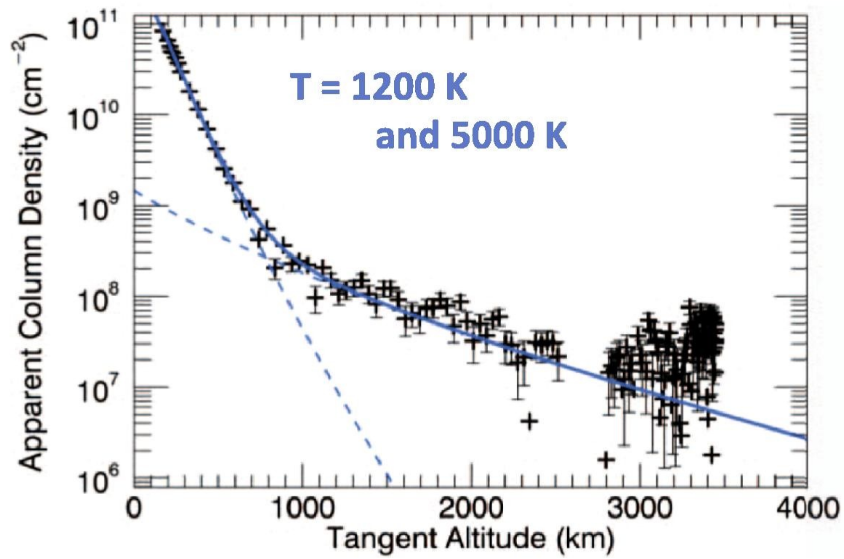
- Few studies have focused on fine spatial structure
  reflecting the observations by MESSENGER

Previous research – observations (vertical distribution)

- The initial velocity distribution was estimated using the vertical profile of the density observed by MASCS

→ Na ejected by PSD is dominant

- limited area where the major desorption process can be estimated
- still unknown major desorption process of high energy Na



Cassidy et al., 2015, *Icarus*

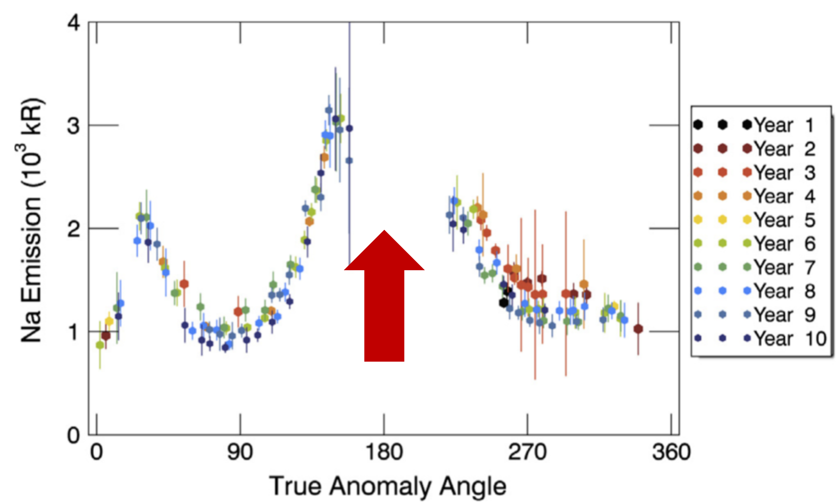
Previous research – observations (seasonal variation)

- Seasonal variation of Na emission at 300km above LT12 (MESSENGER / MASCS)

→ unexpected maximum around TAA180deg

Three hypothesis (Cassidy et al., 2015, *Icarus* & Cassidy et al., 2016, *GRL*.)

- supply of Na-undepleted surface from nightside to dayside by rotation
- expansion of exosphere of dayside due to weakening of solar radiation pressure
- accumulation of Na on "cold-pole longitude"

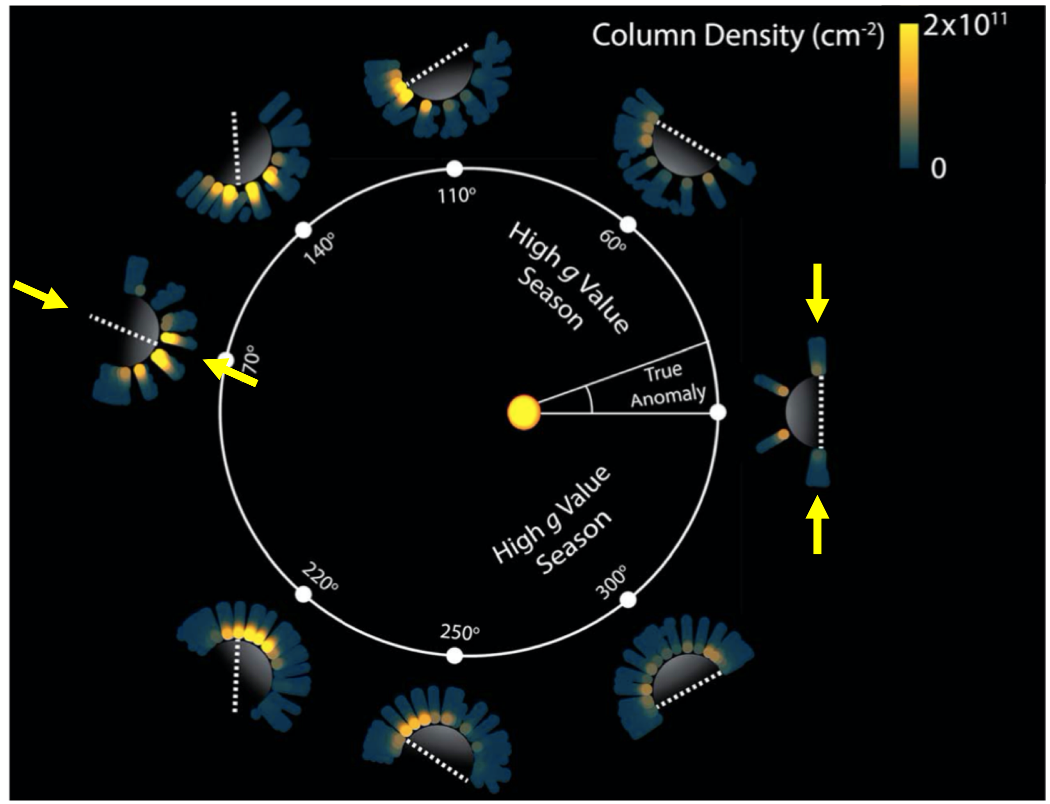


Cassidy et al., 2015, *Icarus*

Cold-pole longitude (Cassidy et al., 2016, *GRL*.)

- Na column density deduced from MESSENGER/MASCS data reaches a maximum around <u>a certain longitude</u> in all seasons
  "cold-pole longitude"

- Tendency to re-impact on cold-pole longitude around perihelion?
  - cold-pole longitude stays dawn/dusk region for long time
  - Na on this region is not desorbed owing to low temperature



Calculation model

Initial conditions

- all the Na is distributed uniformly on the surface

Equation of motion of atoms in the exosphere

$$\frac{\mathrm{d}^2\boldsymbol{r}_0}{\mathrm{d}t^2} = \frac{GM_{\mathrm{Sun}}}{r_0^3}\boldsymbol{r}_0 + \frac{GM_{\mathrm{Mercury}}}{r_1^3}\boldsymbol{r}_1 + \boldsymbol{b}$$

$\boldsymbol{r}_0$: position vector of atoms from the Sun

$\boldsymbol{r}_1$: position vector of atoms from Mercury

$\boldsymbol{b}$: solar radiation acceleration

Life time for photo-dissociation:

$\tau \sim 1.9\times10^5$ sec @1au

Ejection rate to the exosphere

Thermal Desorption (TD)

$$R_{\mathrm{TD}} = \left[1-\left\{1-\exp\left(-\frac{U}{\mathrm{k_B}T_s}\right)\right\}^{\nu\Delta t}\right]\sigma_{\mathrm{Na}}$$

Photo Stimulated Desorption (PSD)

$$R_{\mathrm{PSD}} = F_{\mathrm{ph}(>5eV)}\, Q_{\mathrm{PSD}} \cos Z\, \sigma_{\mathrm{Na}}$$

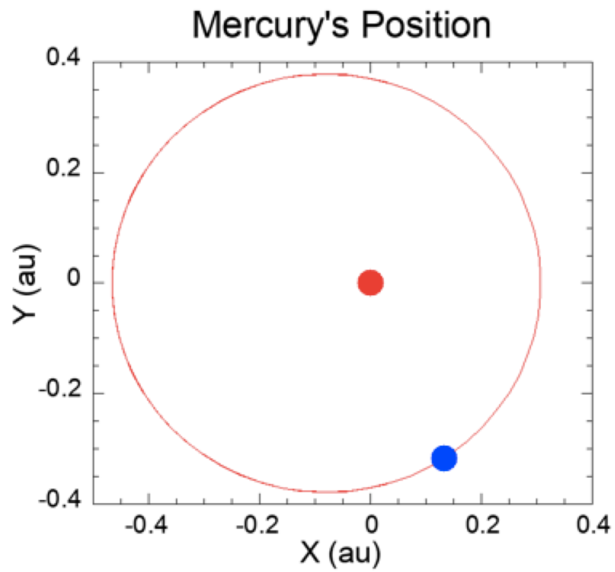
Solar Wind Sputtering (SWS)

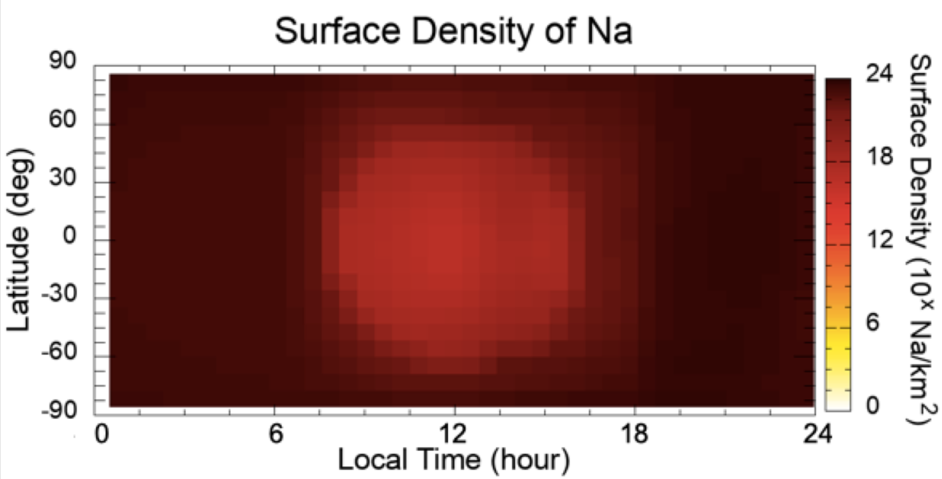
$$R_{\mathrm{SWS}} = F_{\mathrm{SW}}\, Y_{\mathrm{SWS}}\, f_{\mathrm{Na}}$$

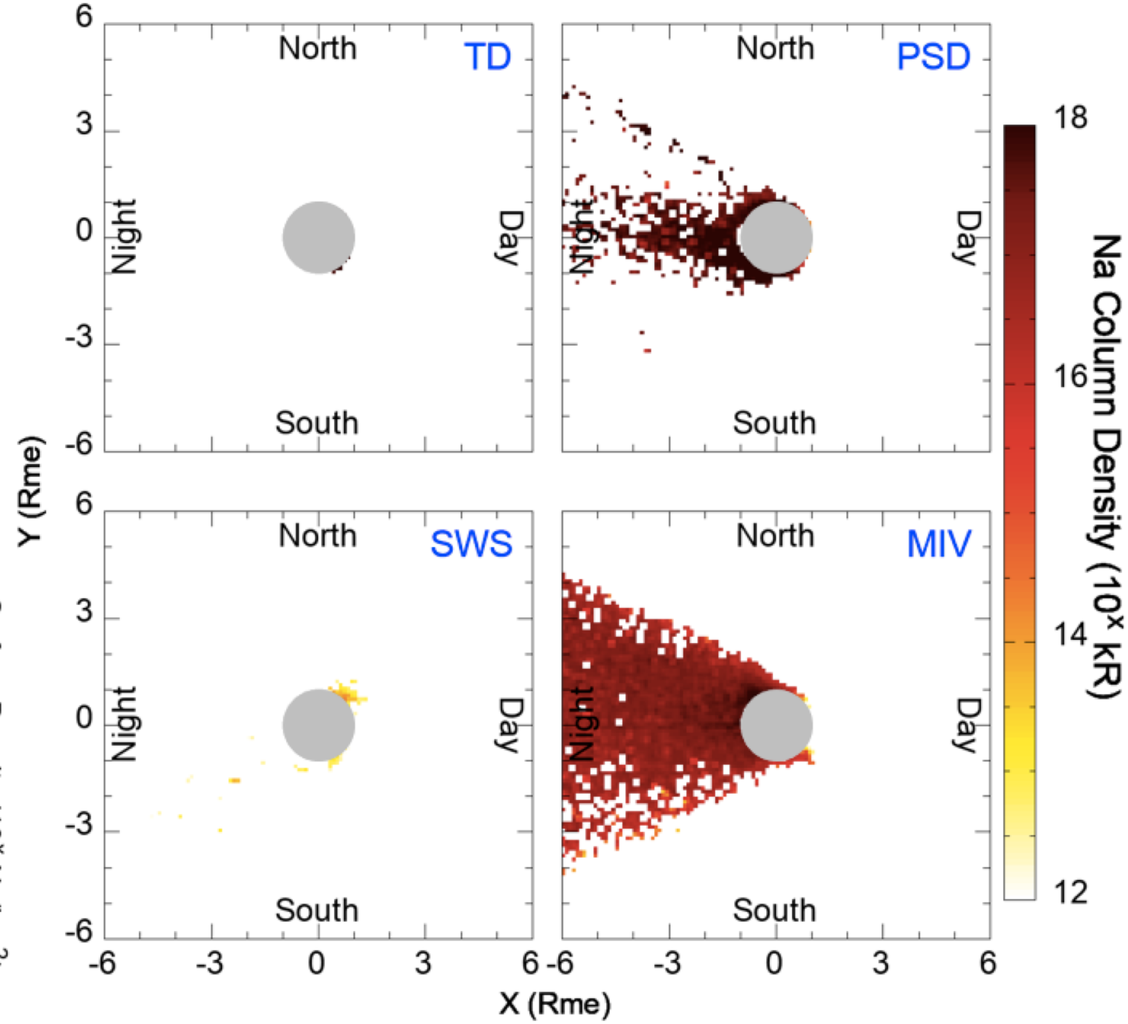
Micro-meteoroid impact vaporization (MIV)

$$R_{\mathrm{MIV}} = F_{meteo}\overline{M_{\mathrm{vapor}}}\, f_{\mathrm{Na}}$$

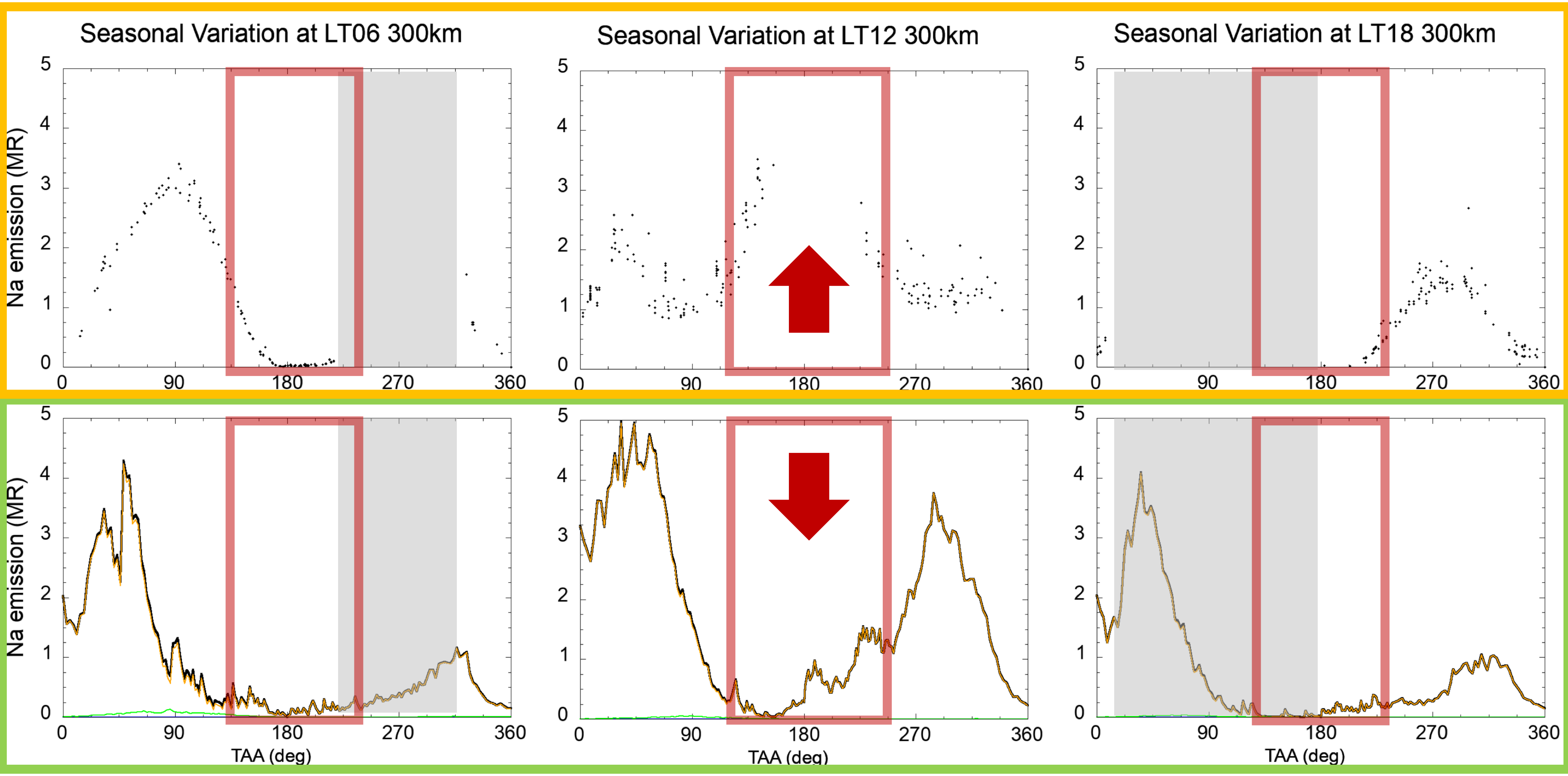
Results of calculation







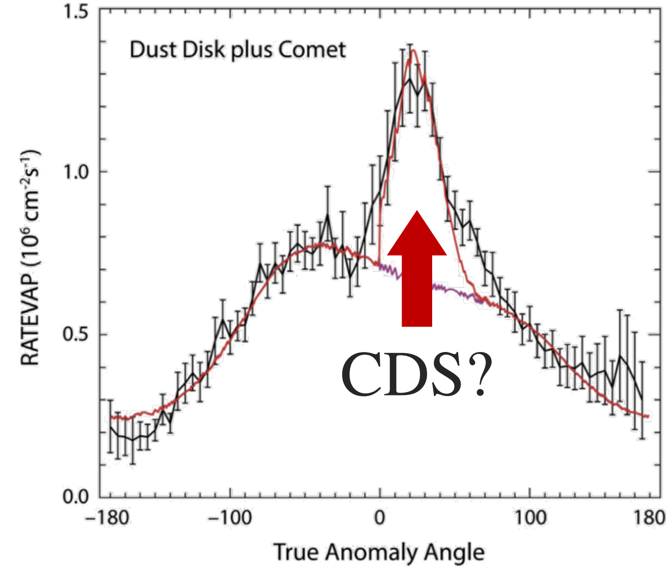
Comparison between observations and model



Ejection of Ca by CDS impact

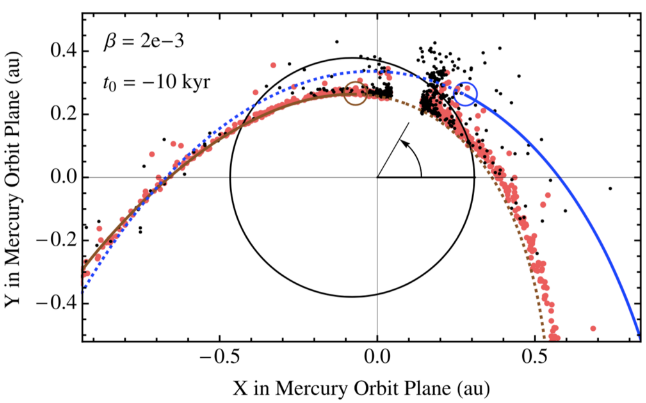
- Comet Dust Streams (CDS)
  = accumulation of comets' ejecta in orbit
- The peak of Ca ejection rate at
  TAA=25deg is likely to be due to CDS
- Short-term and local ejection is expected

Production rate of Ca

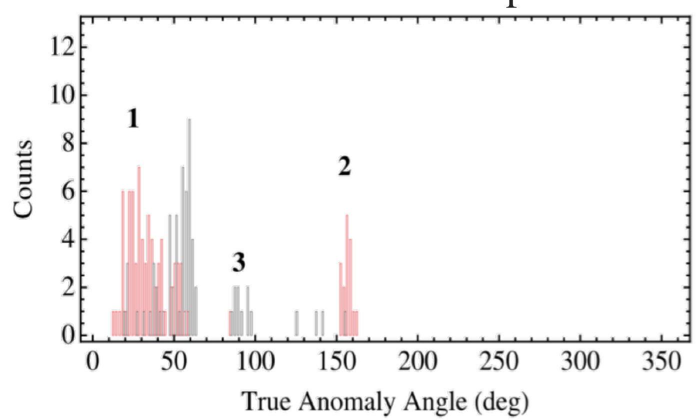


Killen and Hahn, 2015, *Icarus*

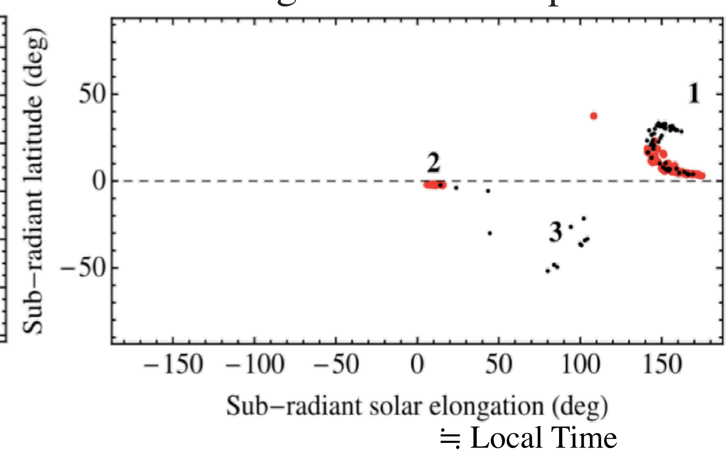
Orbit of CDS



Period of CDS impact



Region of CDS impact

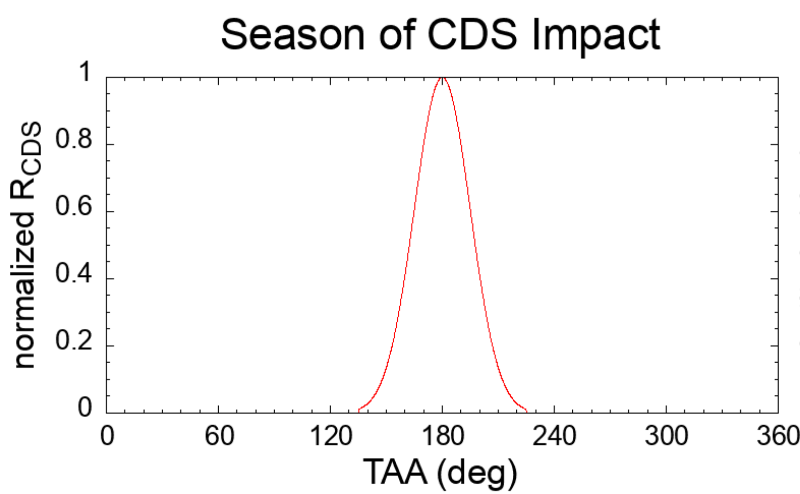


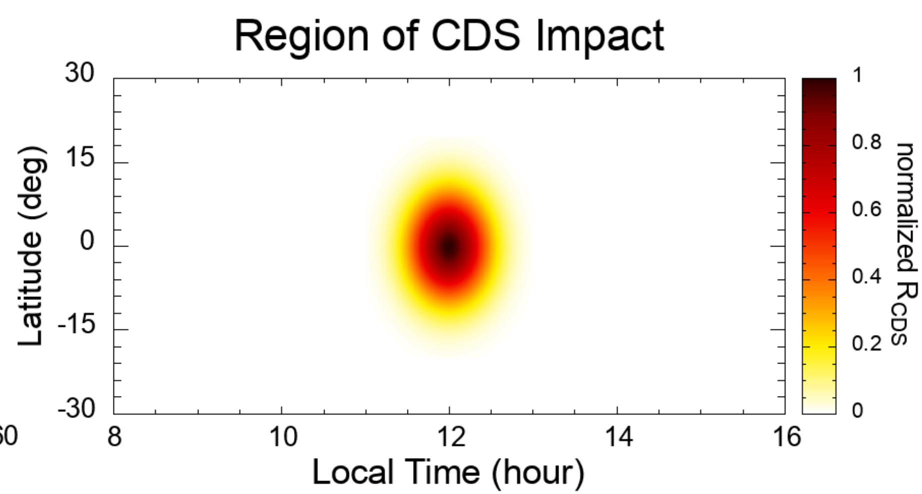
Christou et al., 2015, *GRL*.

Assumption of ejection rate by CDS (my model)

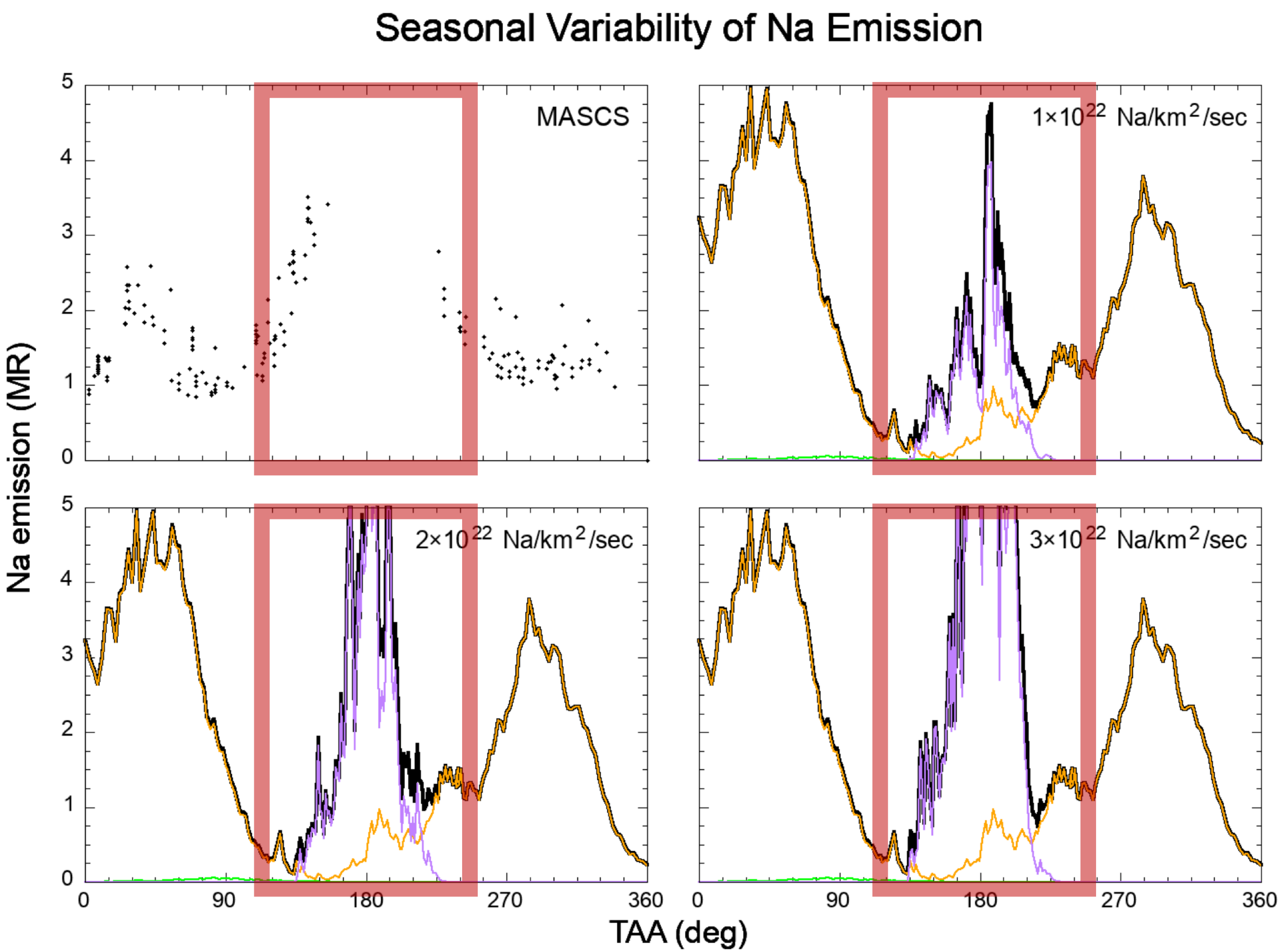
- Ejection rate is assumed by Gaussian distribution around aphelion and the sub-solar point

$$R_{\mathrm{CDS}} = R_{\mathrm{CDS}}^{(0)} \exp\left\{-\frac{(\mathrm{TAA}-180\mathrm{deg})^2}{2\sigma_{\mathrm{TAA}}^2}\right\} \exp\left[-\frac{1}{2}\left\{\frac{(\mathrm{LT}-12\mathrm{hr})^2}{\sigma_{\mathrm{LT}}^2}+\frac{\mathrm{lat}^2}{\sigma_{\mathrm{lat}}^2}\right\}\right]$$





Estimation of ejection rate by CDS

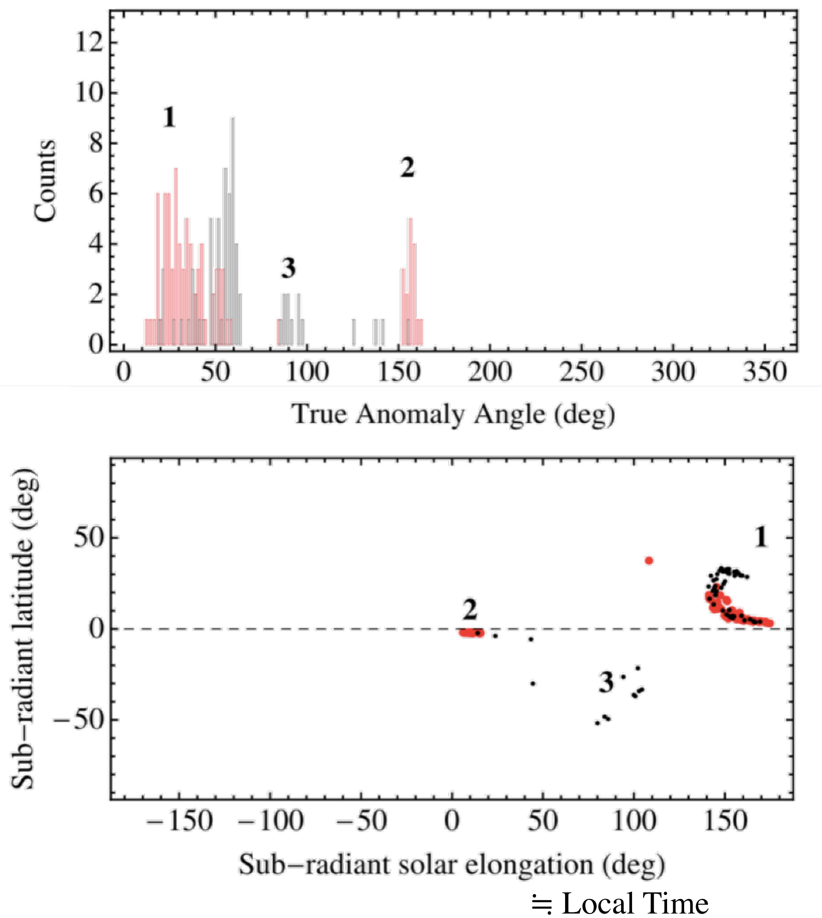


Maximum around aphelion can be reproduced assuming $R_{\mathrm{CDS}}^{(0)} \sim 10^{22}\,\mathrm{Na/km^2/sec}$

Impact of comet dust streams less than 10^8kg can explain the maximum

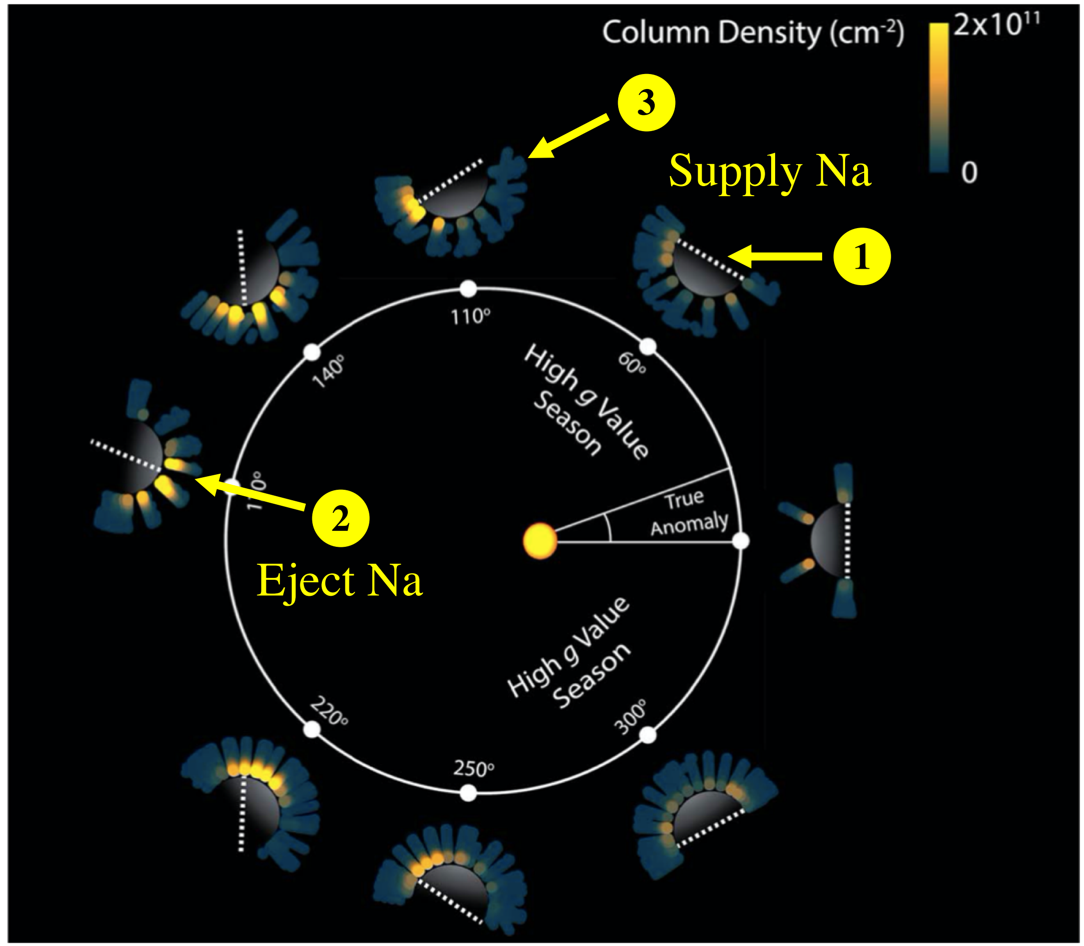
Possible scenario

CDS impact model
(made for Ca)



Christou et al., 2015, *GRL*.

Na column density observed by MASCS



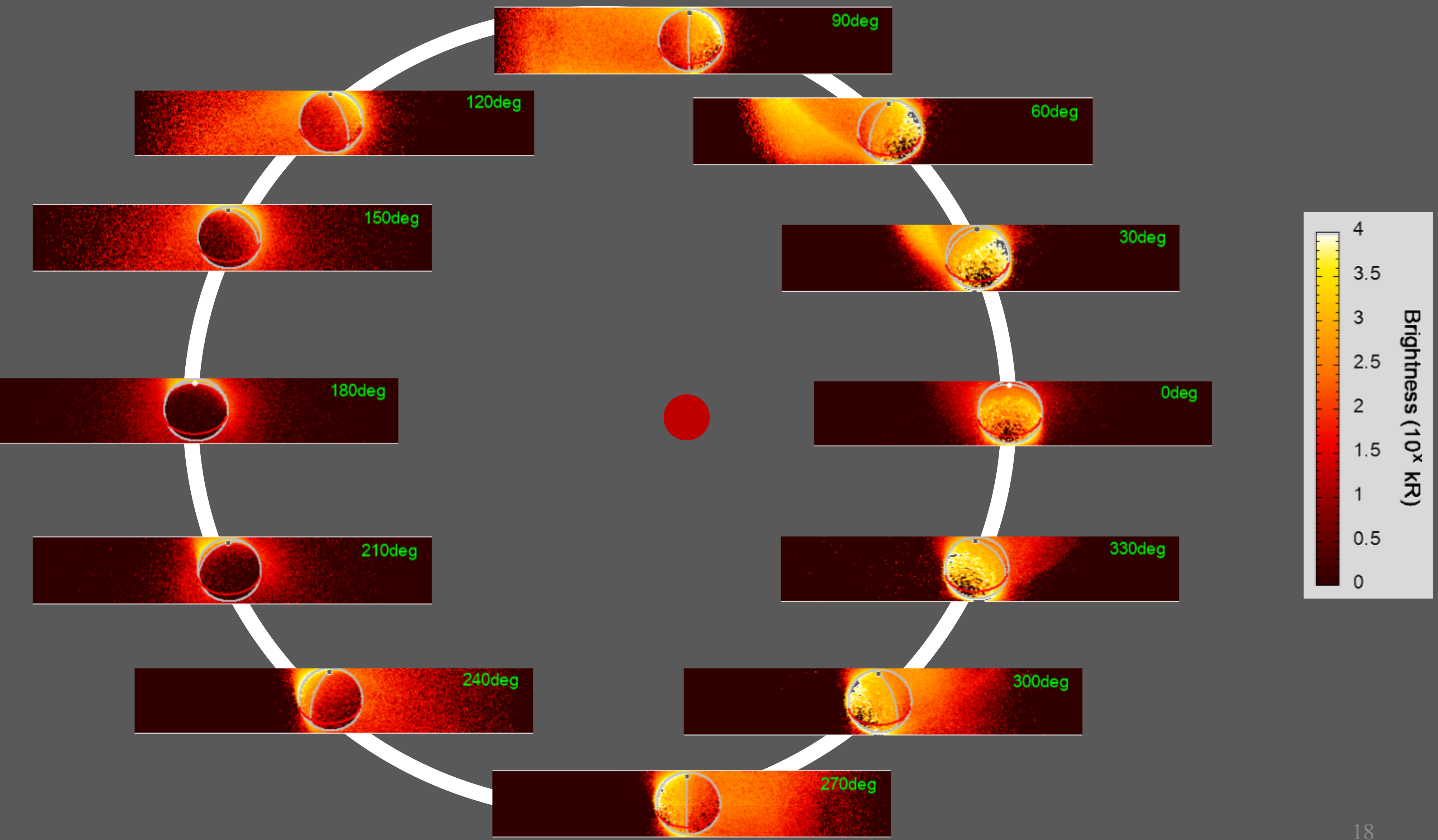
Cassidy et al., 2016, *GRL*.

Summary & Future work

- Na radiation above LT12 surprisingly turned out to have a maximum around aphelion by MESSENGER/MASCS
  - supply of Na-undepleted surface by rotation
  - expansion of exosphere & cold-pole
  - local and short-term ejection by comet dust streams?

- Considering the supply of Na by CDS
- Comparing model with data at all LTs (not only LT06, LT12 and LT18)

Prediction of observations by MIO/MSASI



Murakami et al., *in prep*.