Mercury's exospheric sodium

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Mercury

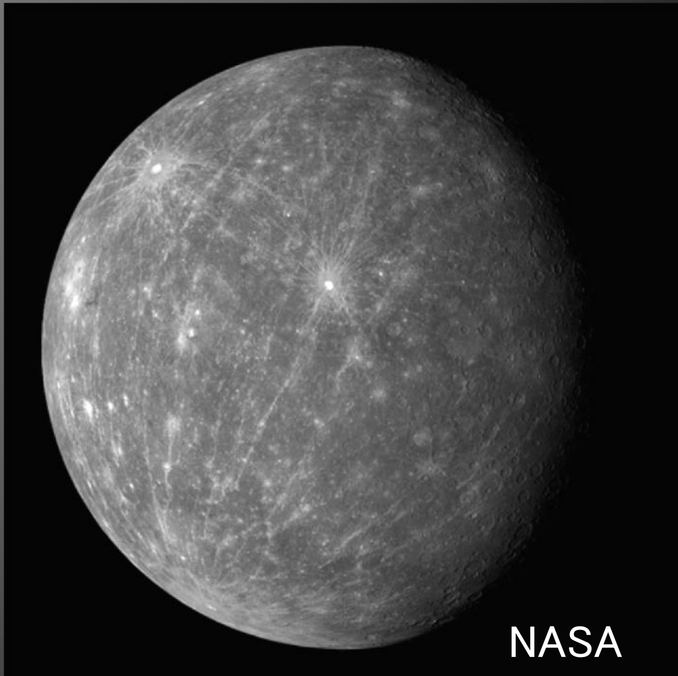
--土星までの惑星の中で唯一周回衛星による観測が行われていない惑星

--金星・火星にはない

弱い固有磁場を持つ

↑流体核の存在[Margot et al., 2007]

--大気は非常に薄く無衝突



NASA

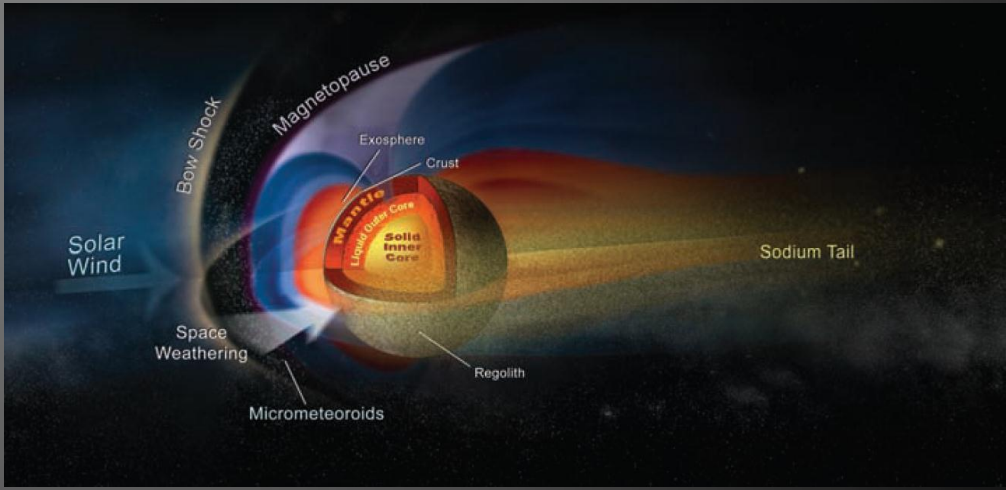
水星大気

- **水星固体表面と水星環境の相互作用**

--大気圏・電離圏がなく、太陽風・磁気圏粒子が地表に衝突

--太陽光・隕石ダストの衝突

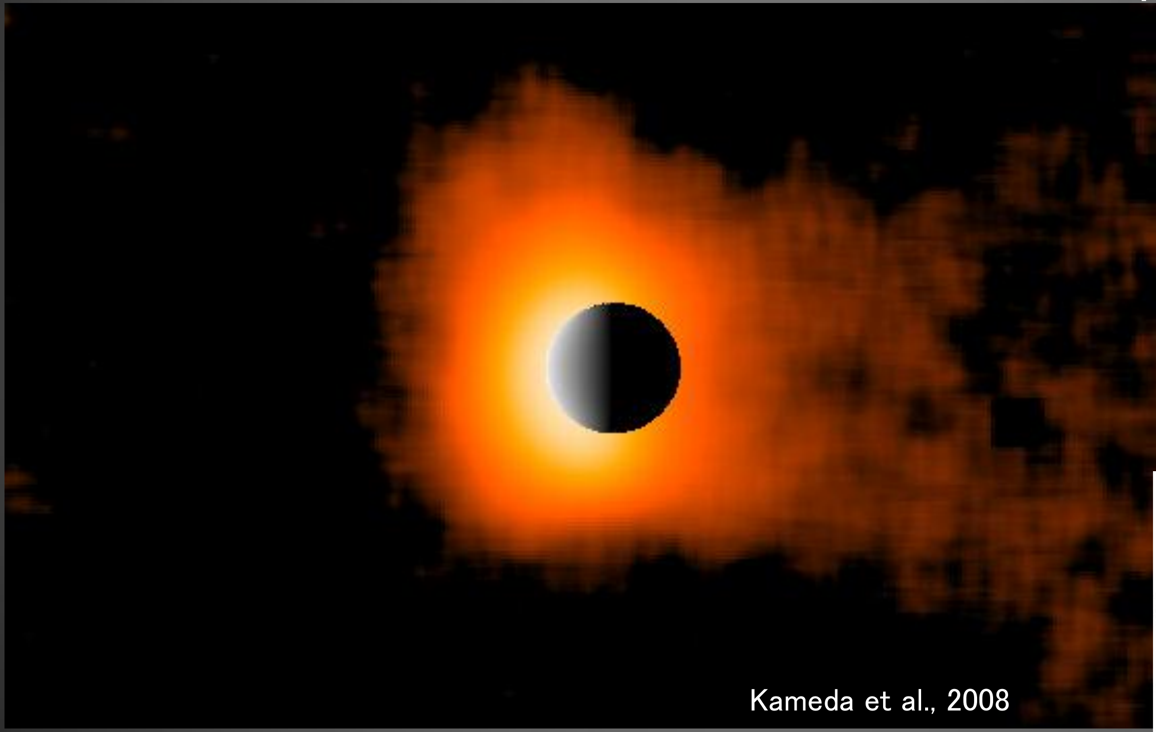
表面物質が大気中に放出され、無衝突のまま惑星間空間に散逸していく



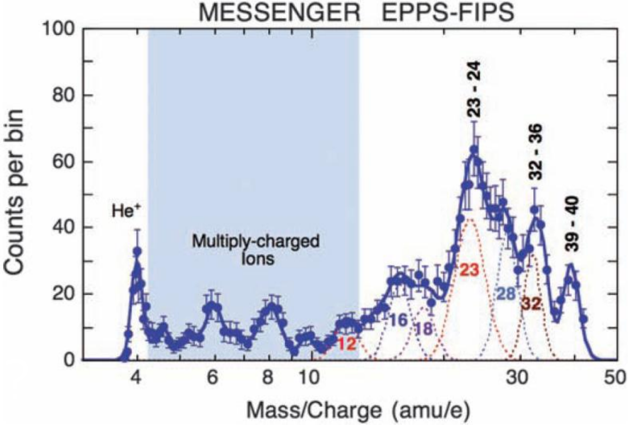
Solomon et al. 2008

Mercury's exosphere

Collisionless atmosphere P~10^{-12} atm
Released from the surface ・Impact to the surface (SP, SW, IPD)
・Loss to the Interplanetary Space



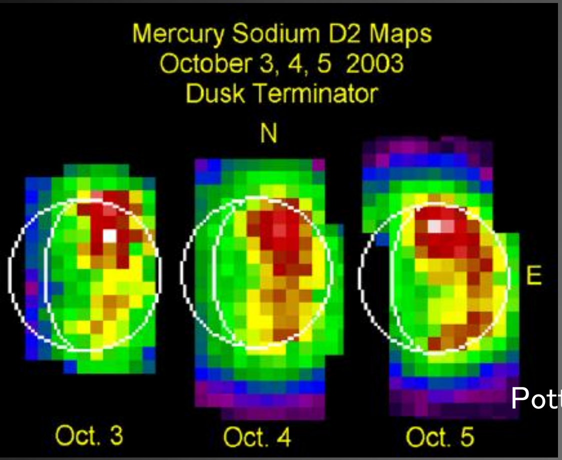
Kameda et al., 2008



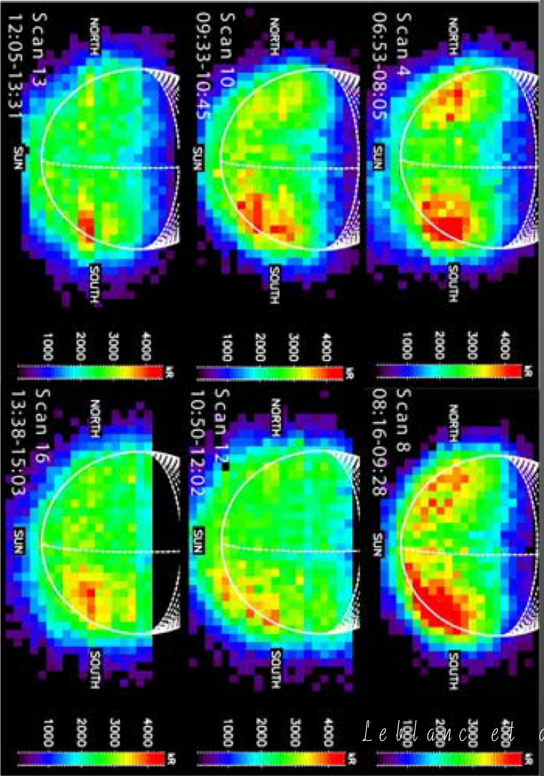
Zurbuchen et al., 2008

Remote Sensing: H,He,O,**Na**,K,Ca,Mg,Ca+,Al?,Fe
In Situ : H^+,He^+,**Na^+**(Mg^+),O_2^+,K^+(Ca^+,Ar^+), etc.

Source process of Mercury's exosphere?



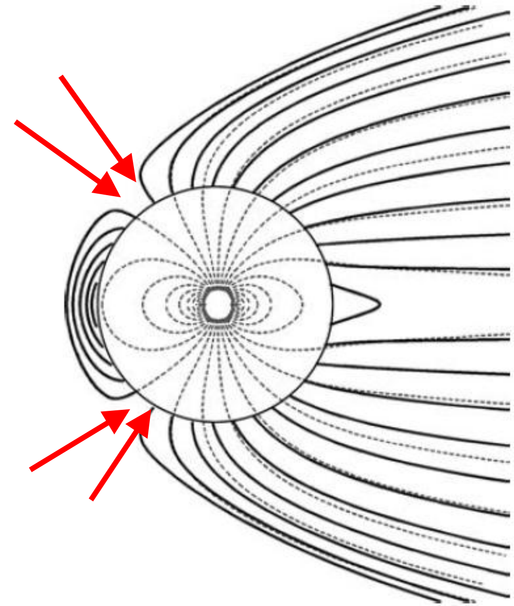
Potter et al., 2008



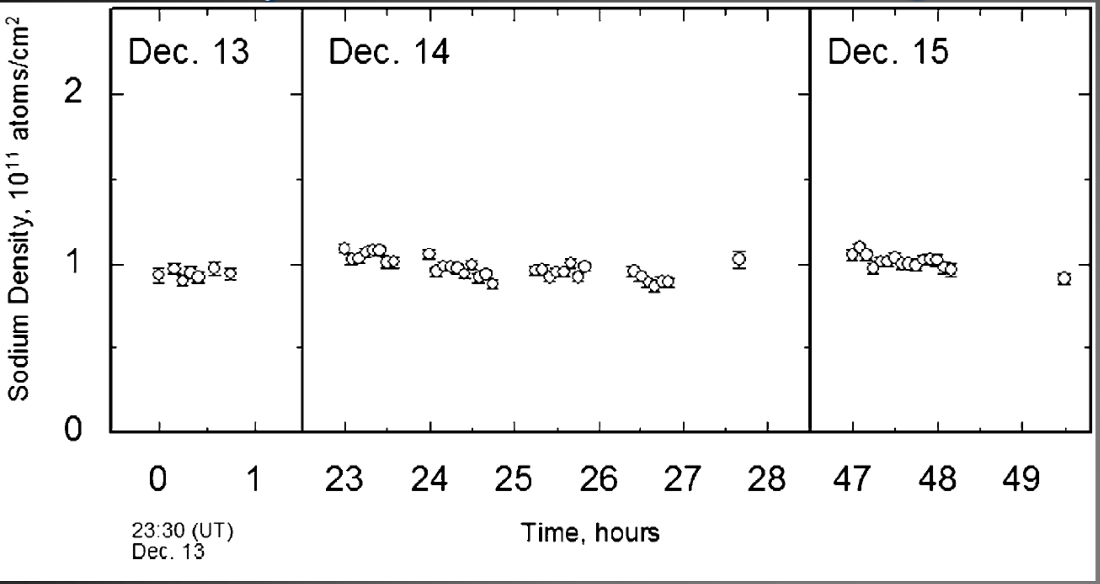
Leblanc et al., 2009

Concentration at High latitudes and Temporal variability

→ **Effect of Solar wind impact??**



Temporal variability of average density

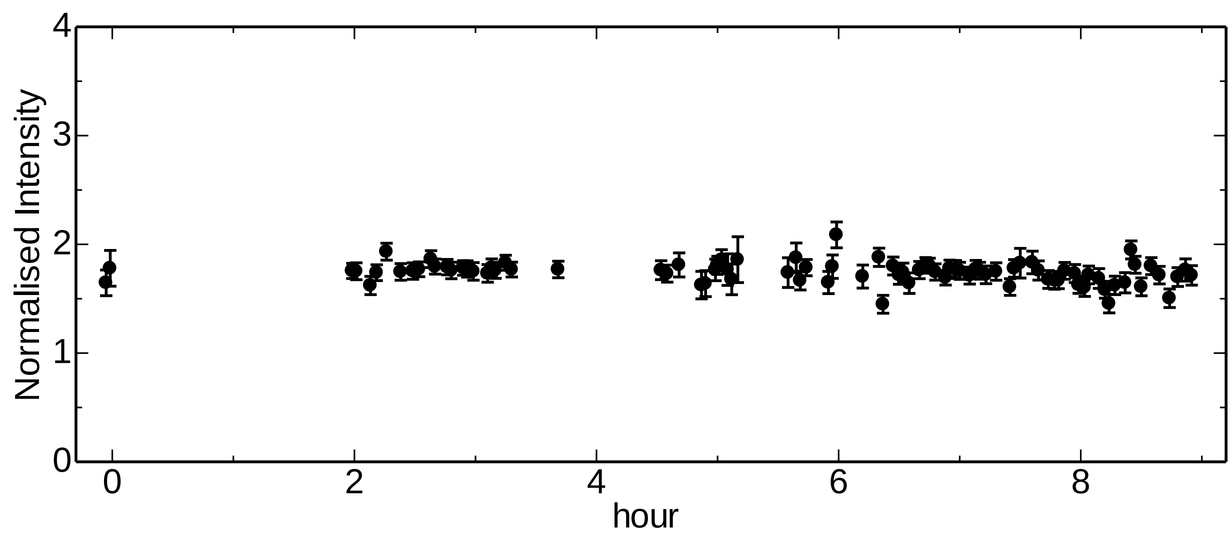


Kameda et al., 2007

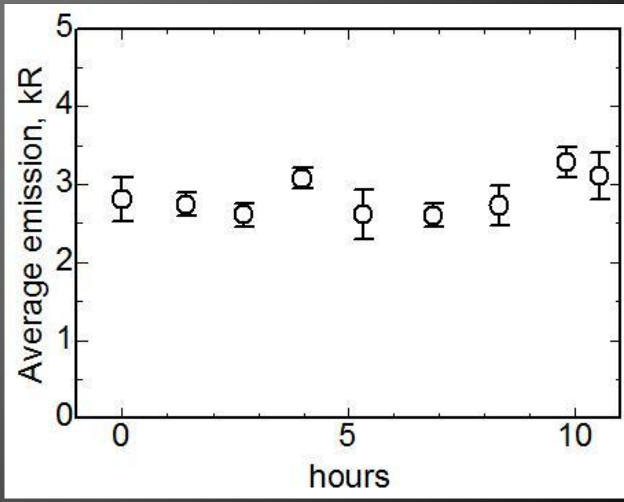
Dec 2005 & Aug 2008 (OAO in Japan)

Temporal variability of Average density <~10%

→SW variability should be higher.



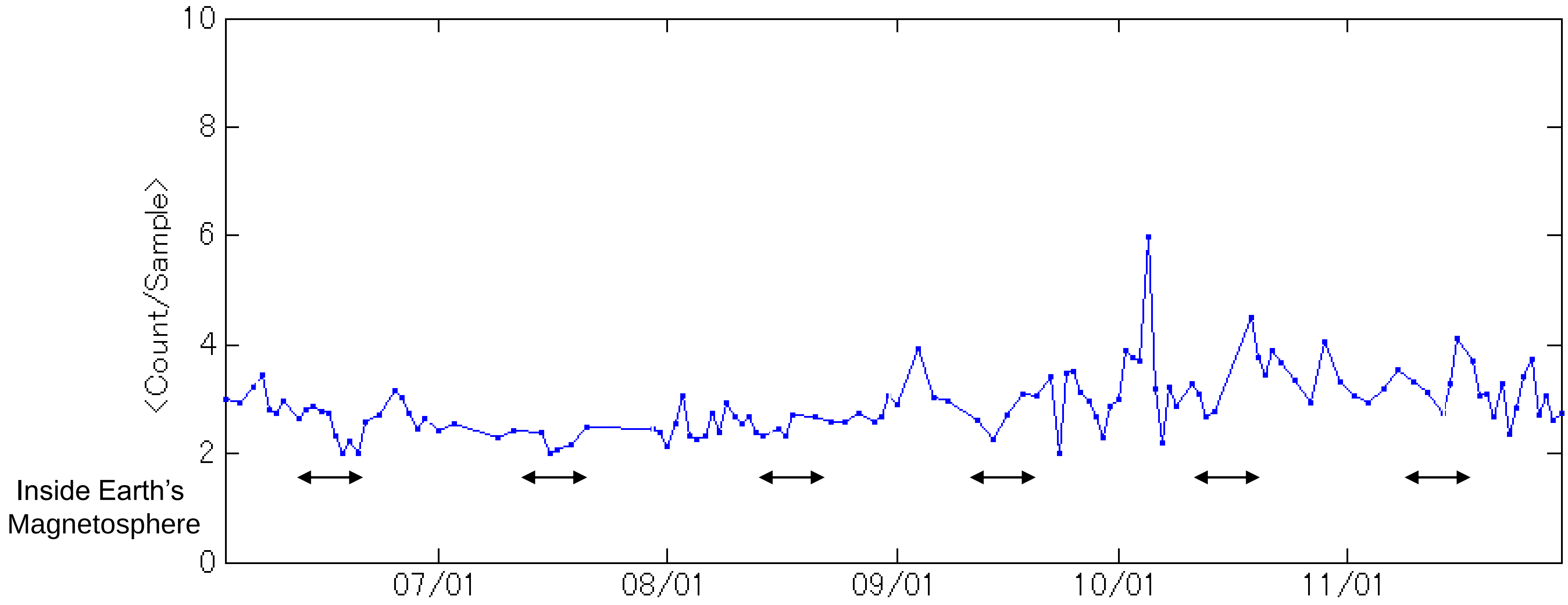
25 Aug 2008



1σ~9% [Leblanc et al. 2009]

For Reference
Lunar Na ion observed by PACE-IMA on Kaguya

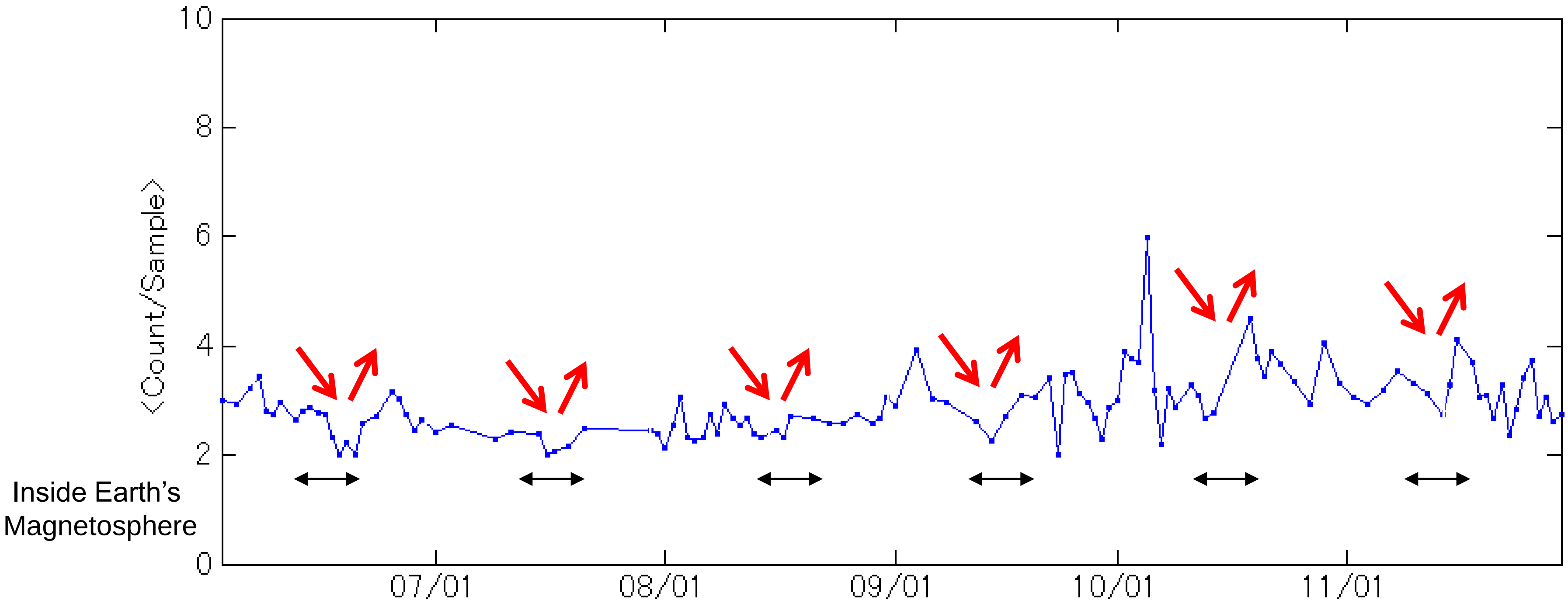
Count/Sample



Yokota et al.

For Reference
Lunar Na ion observed by PACE-IMA on Kaguya

Count/Sample

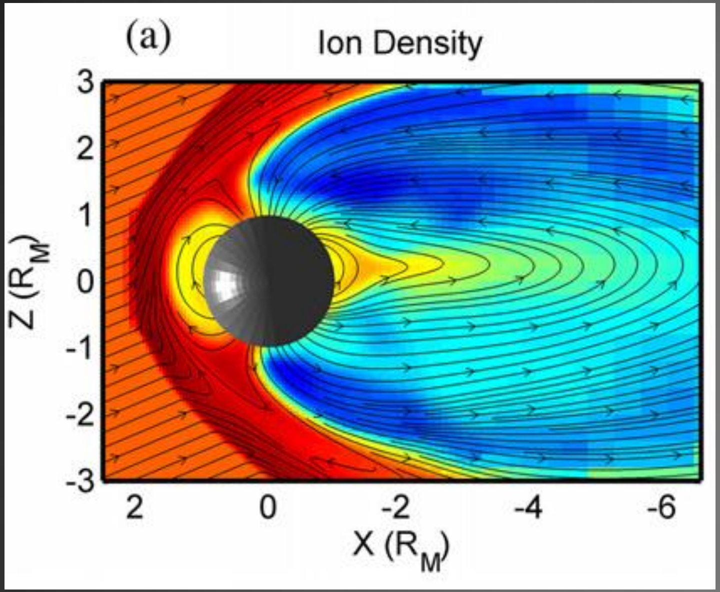


Yokota et al.

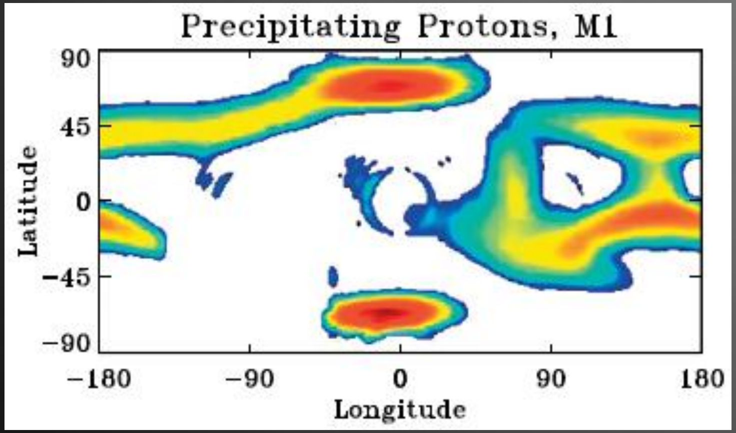
Solar Wind sputtering is not dominant source process, but "Gardening" is possibly effective.

↑SW particles sticks into the surface and diffuses material.

Solar Wind–Magnetosphere–Surface



Benna et al., 2010



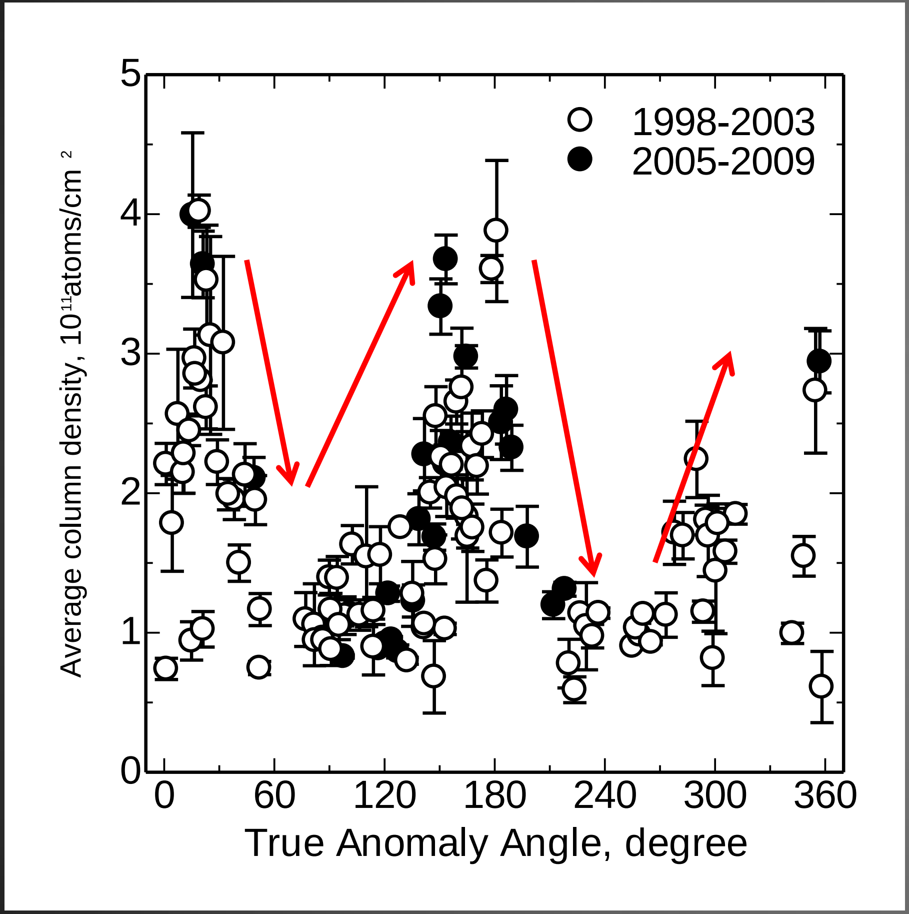
Burger et al., 2010

Simulation has already been done based on the data obtained in Messenger Flyby.

*Ion flux to the surface

*Sodium density on the dayside

Long-term variability



● Potter et al. (2007)

○ Kameda et al. in prep.
Okayama and Haleakala

$$d_{ave}=\Phi_{source}\,\tau_{lifetime}$$

$$\Phi_{PSD}\propto r^{-2}$$

$$\tau_{PI}\propto r^{2}$$

$$\rightarrow d_{ave}=const.$$

In 1 Mercury year, the average density changes by a factor of ~4.

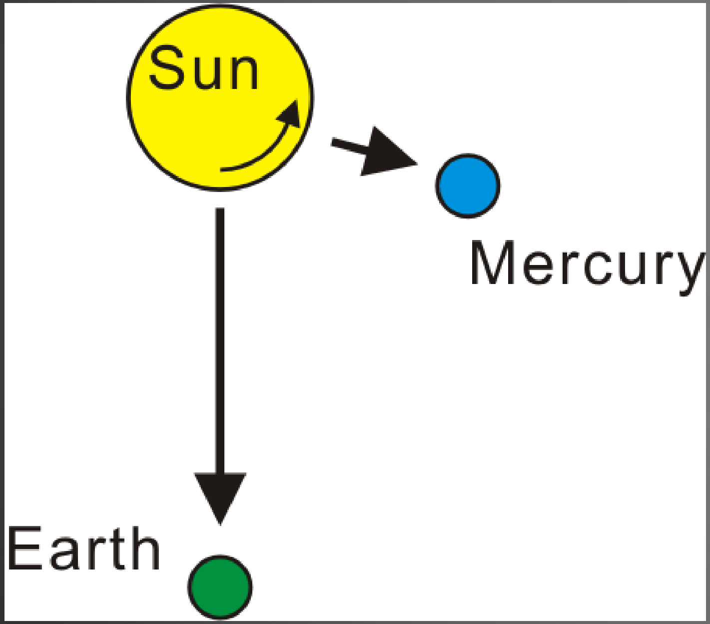
What makes sodium released from the surface?

Average Na density vs

1, F10.7 solar flux
2, Solar flux (0-200nm)
3, Solar wind proton flux
4, Distance from ecliptic plane
5, Distance from symmetry plane
of Interplanetary Dust distribution
6, Tidal force

1. f10.7 solar flux

- F10.7 solar flux →UV/EUV flux



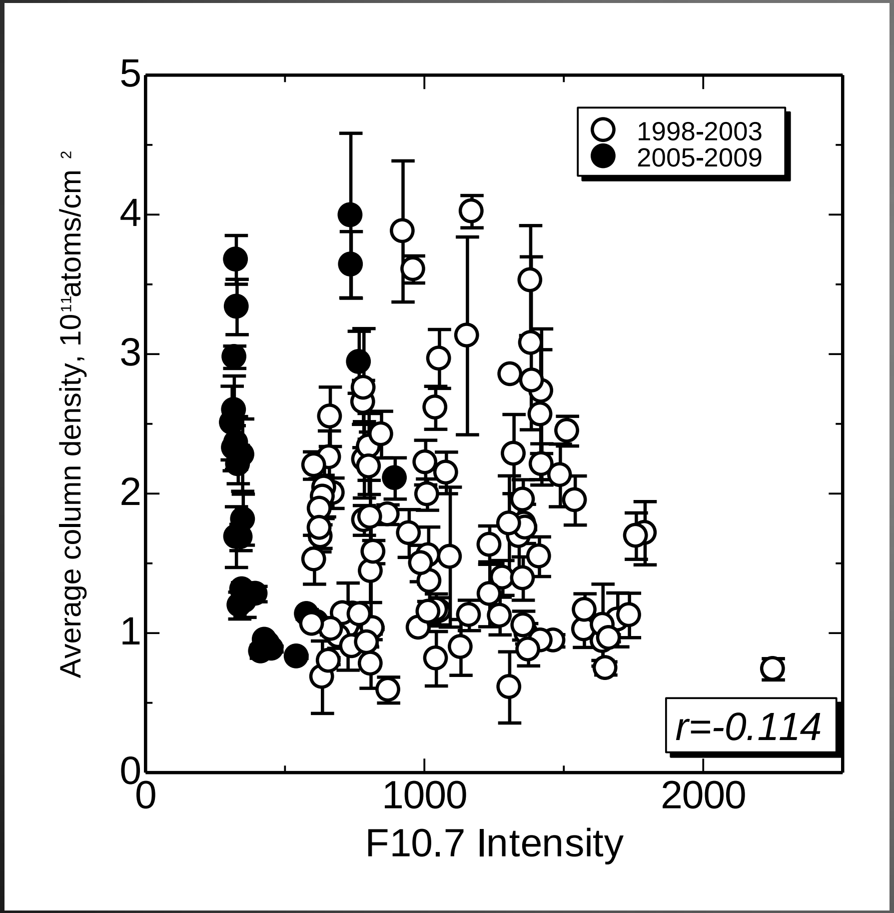
- F10.7 at Mercury is estimated considering the heliospheric distance

and

the rotation of the sun assuming F10.7 is dependent on longitude and independent on time.

1. f10.7 solar flux

- F10.7 solar flux →UV/EUV flux → PSD



No correlation

(the same as shown by Kameda et al. (2009)

using the data obtained in 1998–2003 and 2006)

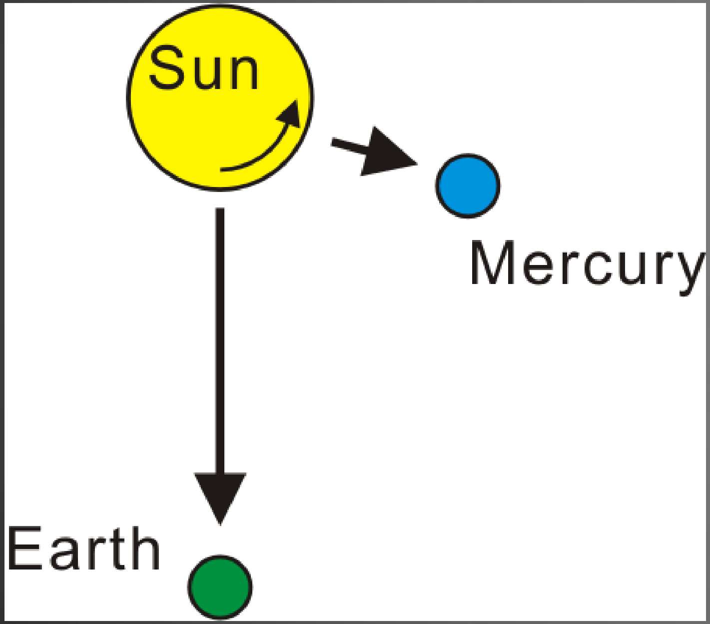
What makes sodium released from the surface?

Average Na density vs

1, F10.7 solar flux → No
2, Solar flux (0–200nm)
3, Solar wind proton flux
4, Distance from ecliptic plane
5, Distance from symmetry plane
    of Interplanetary Dust distribution
6, Tidal force

2. Solar flux (0-200 nm)

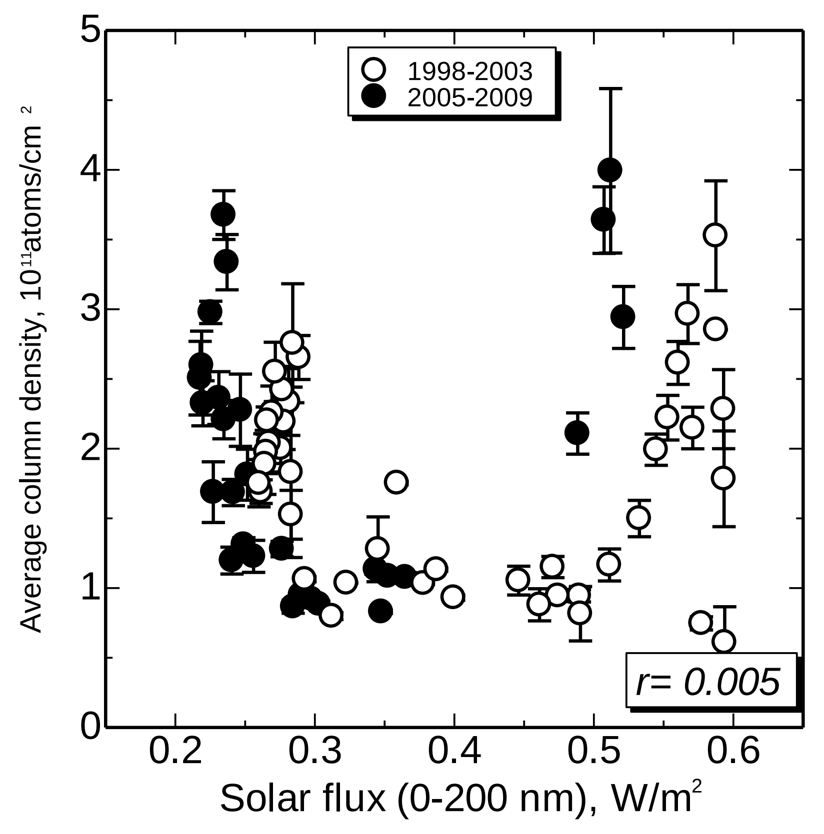
LASP



Solar EUV Experiment (SEE) on TIMED measured the solar flux at the wavelength of 0–200nm.

The flux at Mercury was estimated in the same way as F10.7.

2. Solar flux (0-200 nm)



No correlation

(SEE Observation was started in Feb 2002.)

PSD threshold wavelength is ~ 300 nm [Yakshinskiy and Madey, 2004].

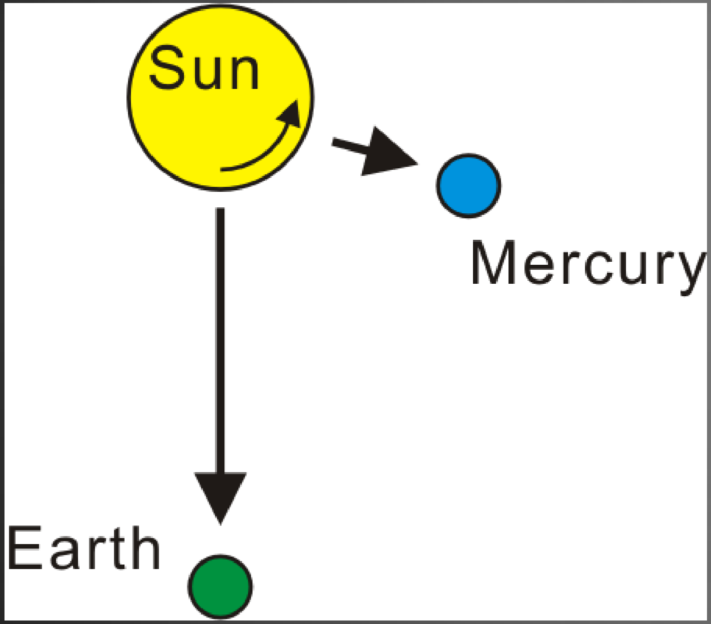
What makes sodium released from the surface?

Average Na density vs

1, F10.7 solar flux → No
2, Solar flux (0–200nm) → No
3, Solar wind proton flux
4, Distance from ecliptic plane
5, Distance from symmetry plane
of Interplanetary Dust distribution
6, Tidal force

2. Solar wind proton flux

LANL



Solar Wind Electron Proton Alpha monitor (SWEPAM) on ACE measured the solar wind proton flux at L1.

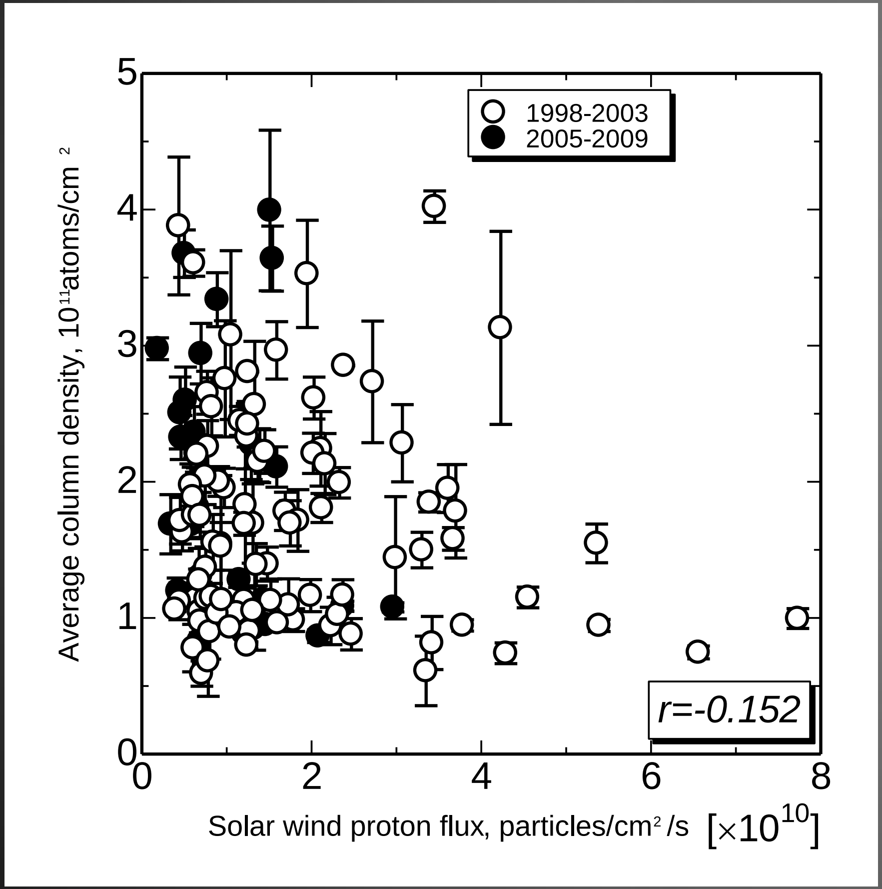
SW flux is estimated to be:

dependent on longitude

$\propto r^{-2}$

velocity is constant

2. Solar wind proton flux



No correlation

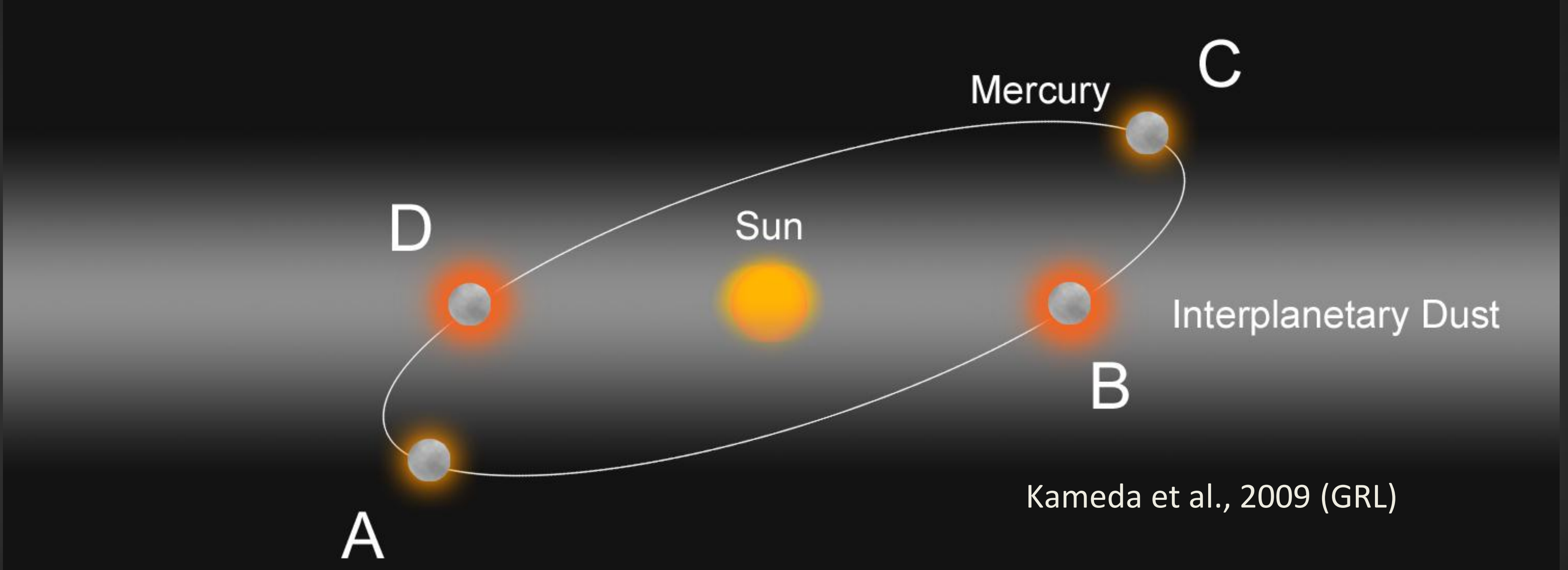
Sunspot number in 1998–2003 is more than 2005–2009

What makes sodium released from the surface?

Average Na density vs

1, F10.7 solar flux → No
2, Solar flux (0–200nm) → No
3, Solar wind proton flux → No
4, Distance from ecliptic plane
5, Distance from symmetry plane of Interplanetary Dust distribution
6, Tidal force

4. Distance from ecliptic plane



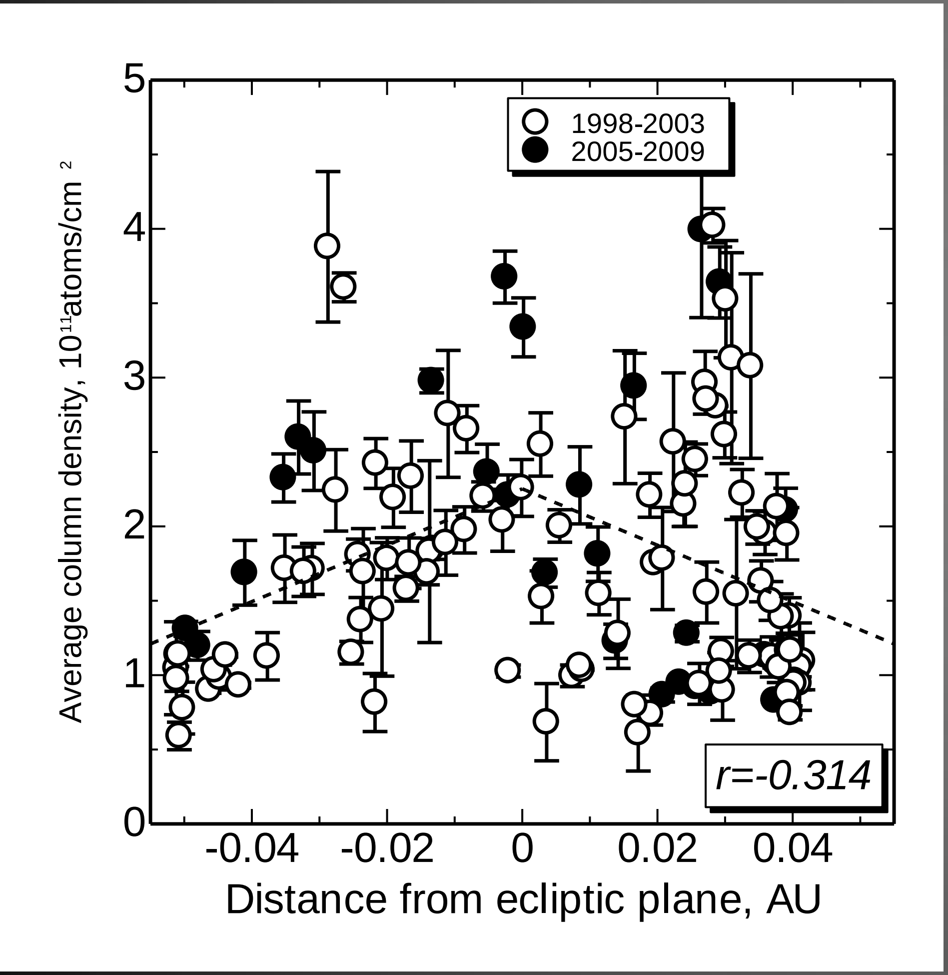
Kameda et al., 2009 (GRL)

Mercury's orbital plane is tilted (7deg) against the ecliptic plane and the interplanetary dust (IPD) is concentrated near the ecliptic plane.

→ Frequency of IPD impact is higher at B and D.

Potter et al., 2008

4. Distance from ecliptic plane



Weak inverse correlation

with absolute value of distance from ecliptic plane.

What makes sodium released from the surface?

Average Na density vs

1, F10.7 solar flux → No

2, Solar flux (0–200nm) → No

3, Solar wind proton flux → No

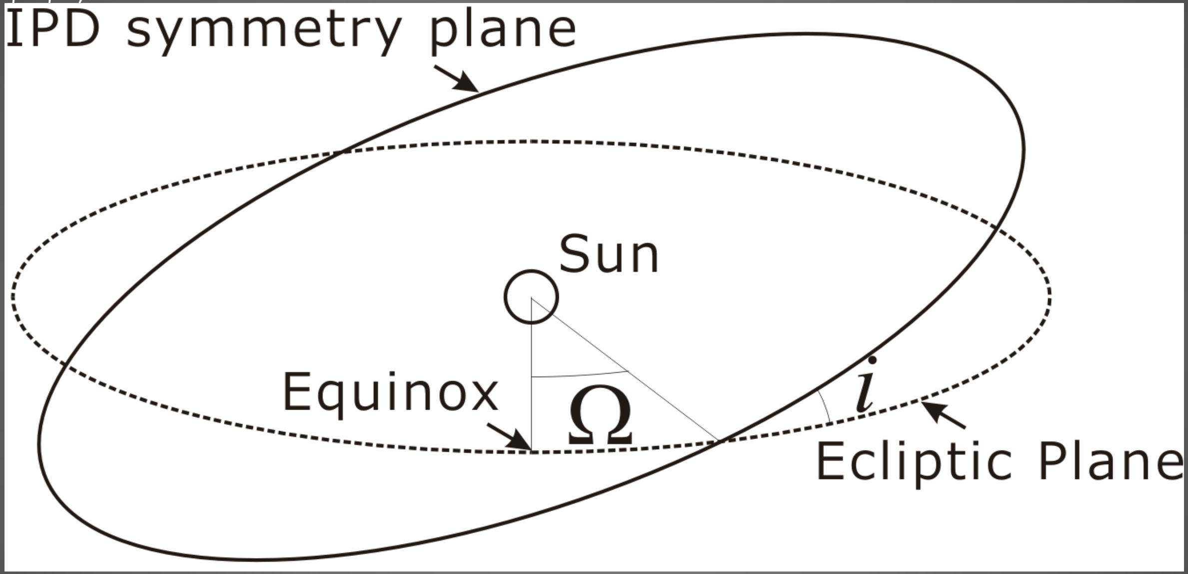
4, Distance from ecliptic plane → Weak

5, Distance from symmetry plane of Interplanetary Dust distribution

6, Tidal force

5. Distance from IPD symmetry plane

- Symmetry plane is tilted against the ecliptic

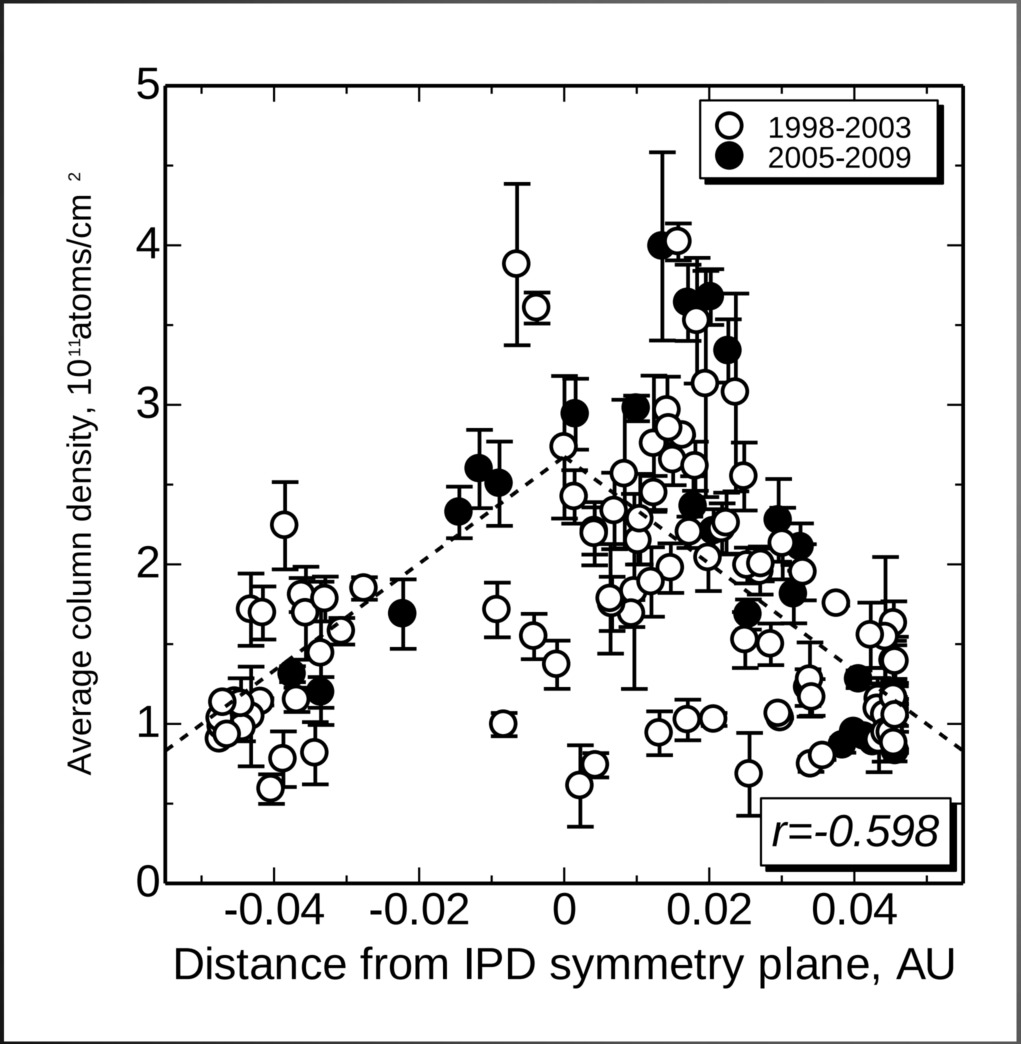


Ω : Ascending node, i : inclination

$\Omega = -31$ deg, $i = 2.9$ deg [Kameda et al., 2009]

*Mercury: $\Omega = 48$ deg, $i = 7$ deg

5. Distance from IPD symmetry plane



Correlated with the distance from IPD symmetry plane.

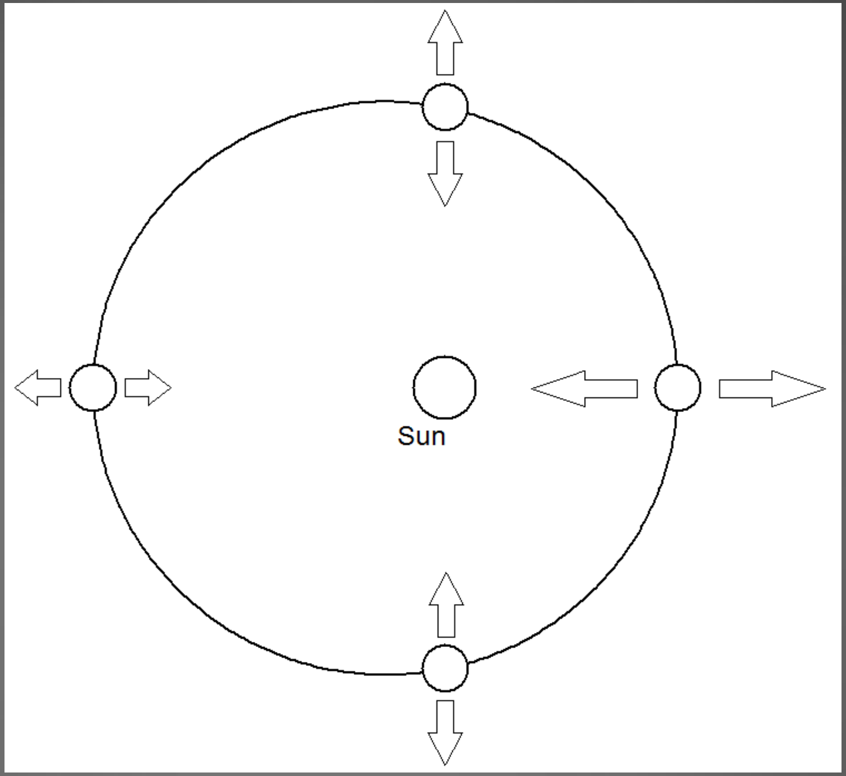
→ IPD impact is effective for the release of sodium atoms from the surface.

What makes sodium released from the surface?

Average Na density vs

1, F10.7 solar flux → No
2, Solar flux (0–200nm) → No
3, Solar wind proton flux → No
4, Distance from ecliptic plane → Weak
5, Distance from symmetry plane
of Interplanetary Dust distribution
→ Correlated
6, Tidal force

6. Tidal force

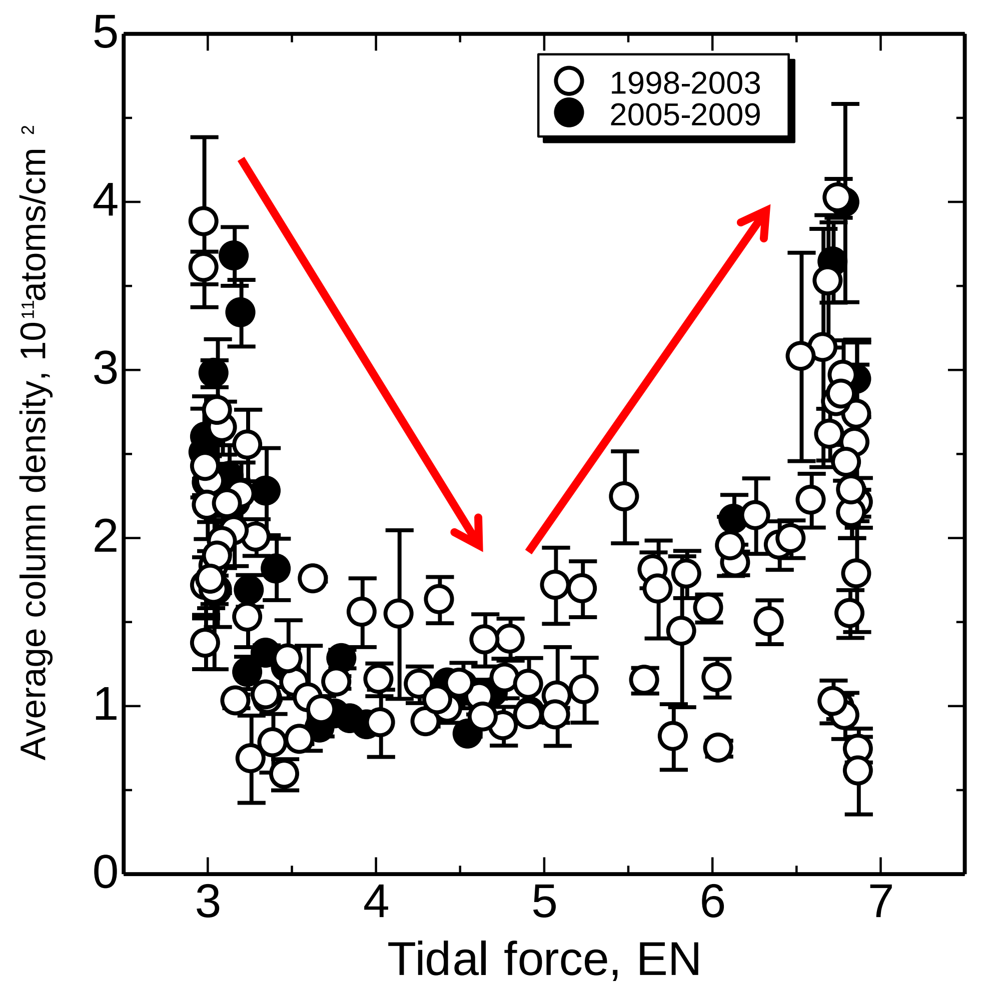


Mercury's orbital is eccentric (e ~0.2).

→ Tidal force at perihelion is twice stronger than that at aphelion.

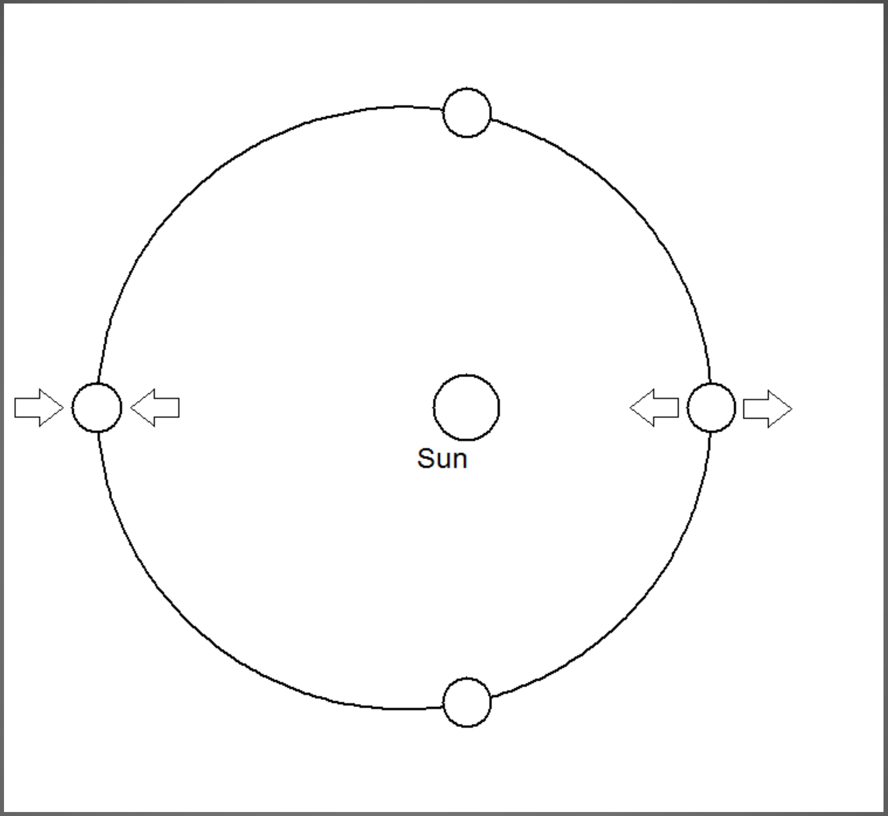
Potter et al., 2008

6. Tidal force



Atmosphere is dense near perihelion and aphelion (but not always).

6. Tidal force



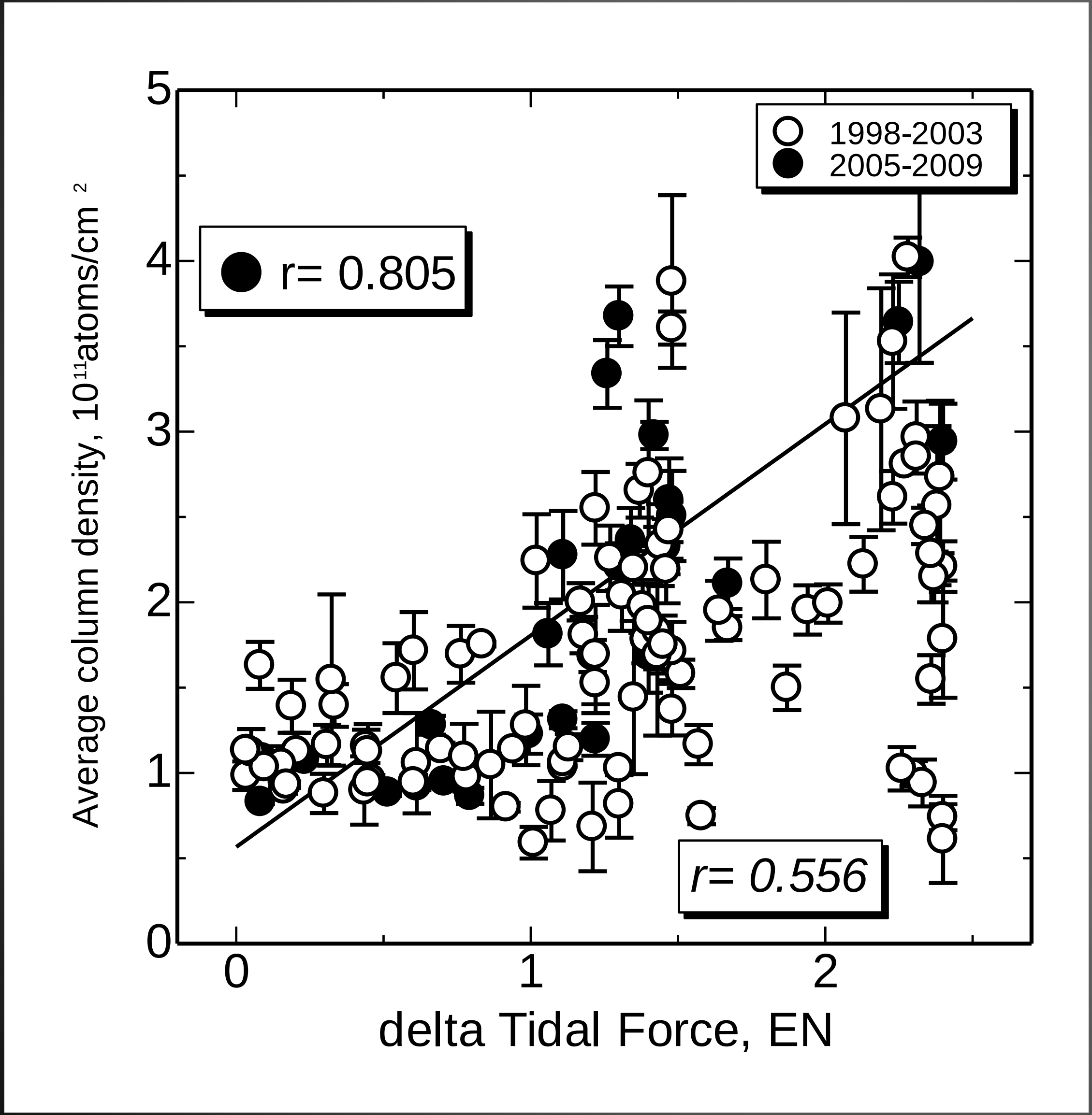
Potter et al., 2008

Tidal force is always outward.

→Relative tidal force is inward at aphelion and outward at perihelion.

→Distortion is greatest at perihelion and aphelion.

6. Tidal force



- **Tidal force is not a release process, however,,,**
- **Tidal force will possibly increase the source rate, e.g., refreshing the surface layer.**

Potter et al., 2008

What makes sodium released from the surface?

Average Na density vs

1, F10.7 solar flux → No
2, Solar flux (0–200nm) → No
3, Solar wind proton flux → No
4, Distance from ecliptic plane → Weak
5, Distance from symmetry plane of Interplanetary Dust distribution
6, Tidal force → Animation

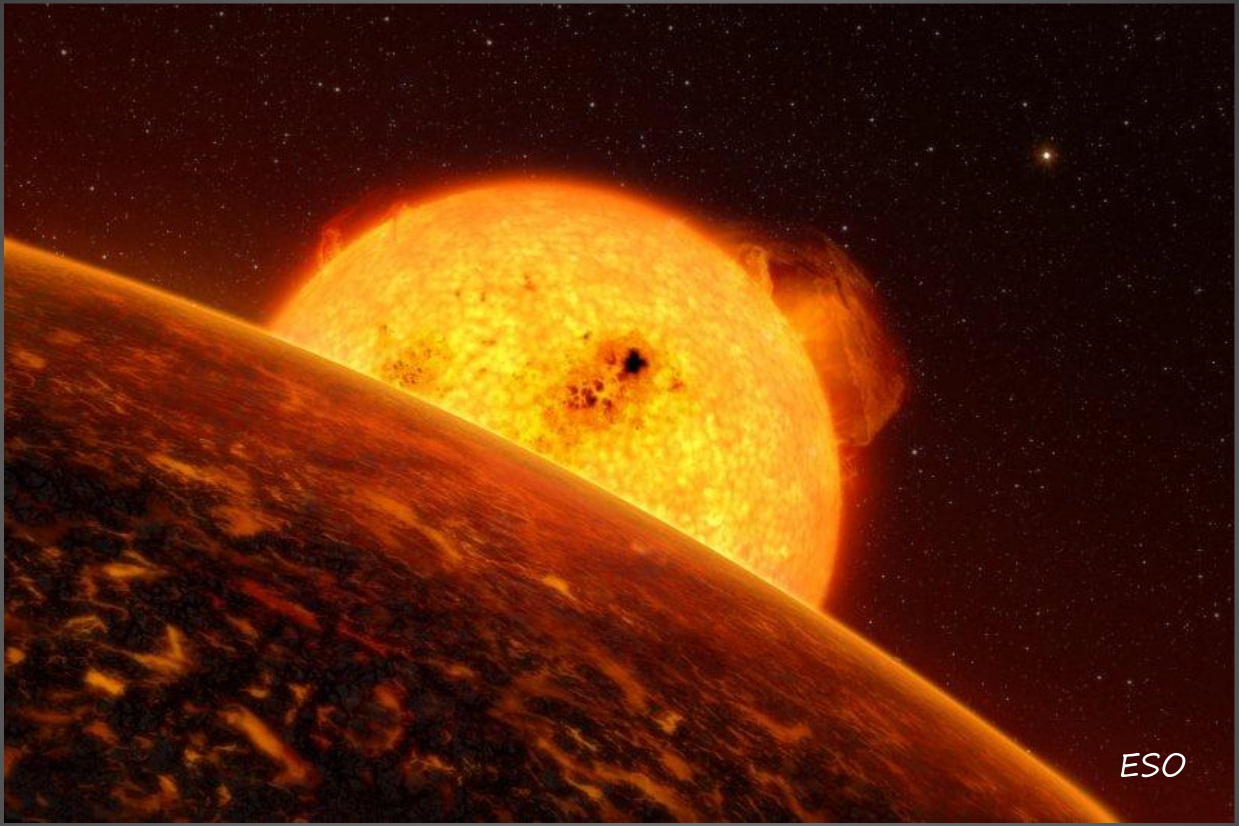
IPD impact? Tidal force?

The perihelion and aphelion is near the ecliptic plane.

→It is difficult to know which is more effective and explain sodium concentration at high latitudes.

→Mercury Dust Monitor on BepiMMO and Mercury lander in the future.

~~Super Earth~~ Super Mercury


ESO

CoRoT-7b: 0.017 AU ($5M_E$)
(CoRoT-7c: 0.046 AU ($9M_E$))

ここなら熱脱離(?)が支配的

What makes sodium released from the surface?

Average Na density vs

2, Solar flux (0–200nm) → No

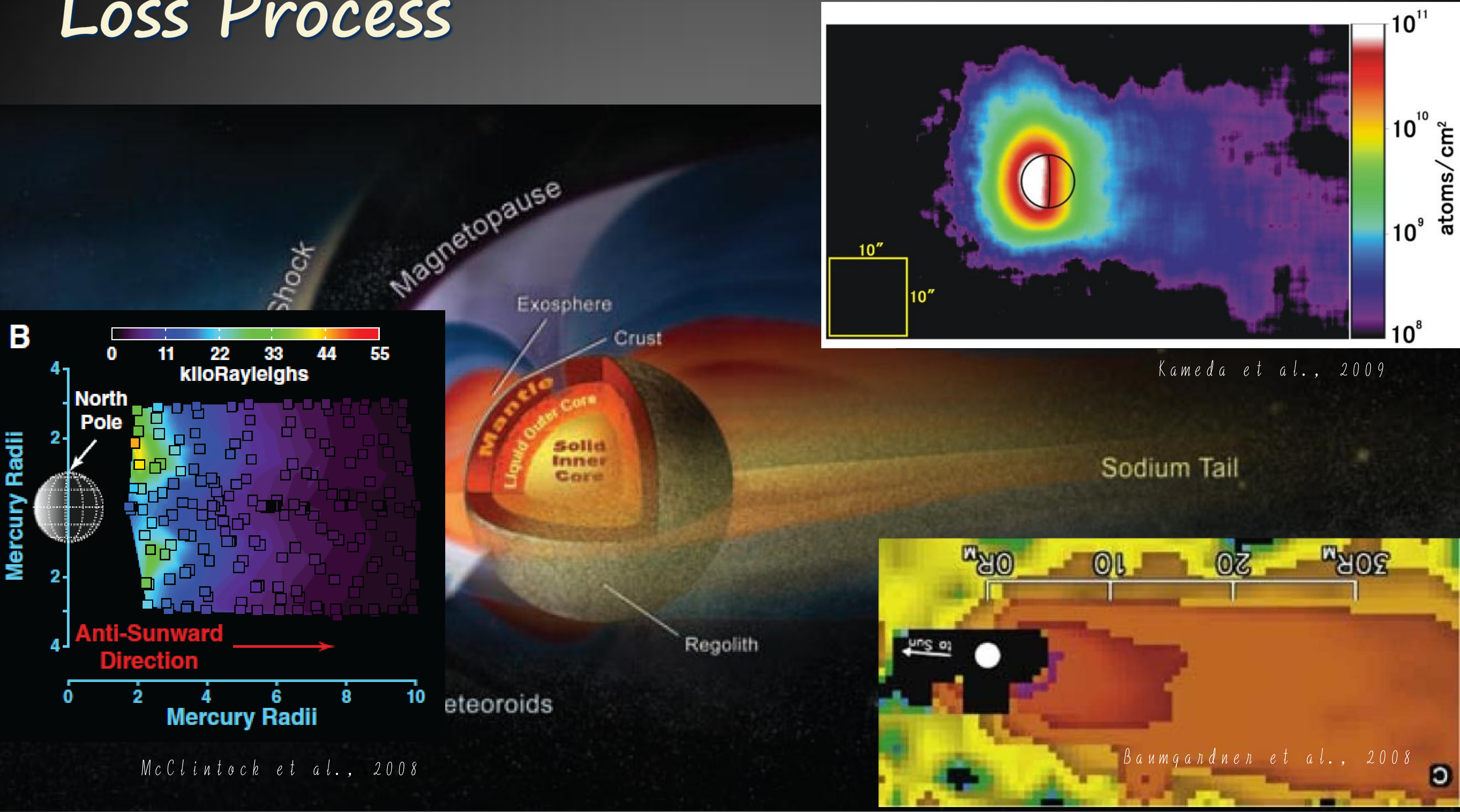
MASCS data for UV reflected on surface

3, Solar wind proton flux → No

Precipitation detected using FIPS

→ Long-term monitoring from March 18, 2010 will provide us something new.

Loss Process



McClintock et al., 2008

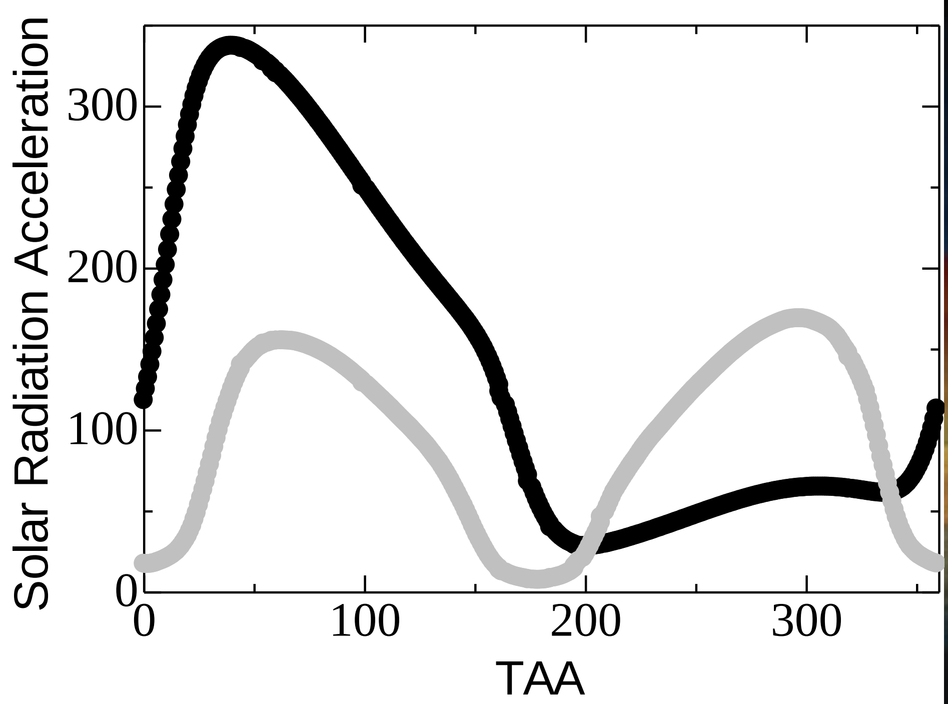
Kameda et al., 2009

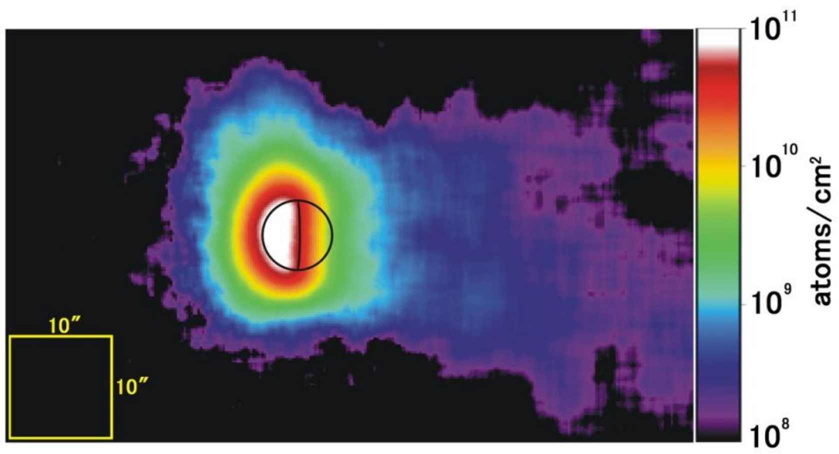
Baumgardner et al., 2008

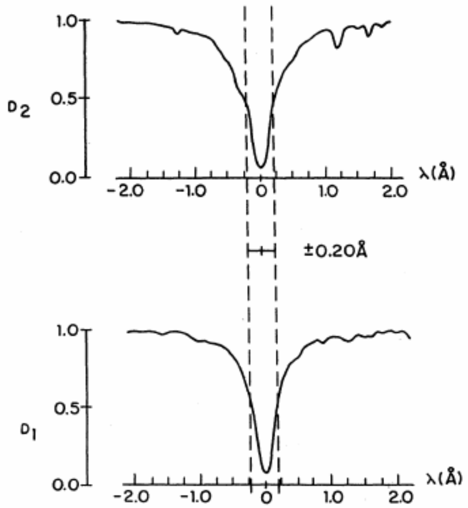
After released from the surface, sodium atoms move toward antisunward direction due to solar radiation pressure.

→ Photoionized in ~3 hours → Loss to the interplanetary space.

Loss process (Solar Radiation Pressure)







Solar radiation pressure depends on True Anomaly Angle.

Gray line shows the result of calculation by Smyth and Marcon

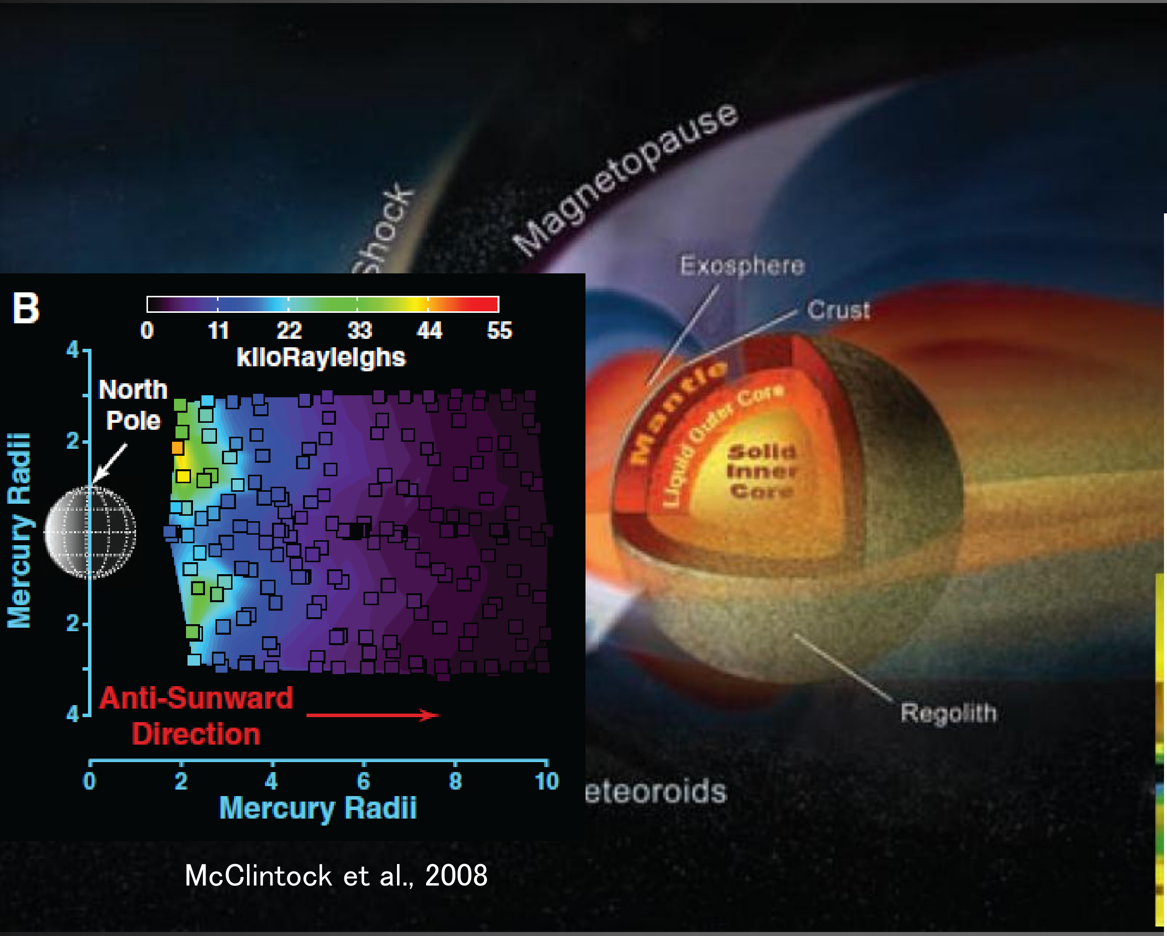
Black shows the result of ours.

Na tail will be longest at TAA of ~40.

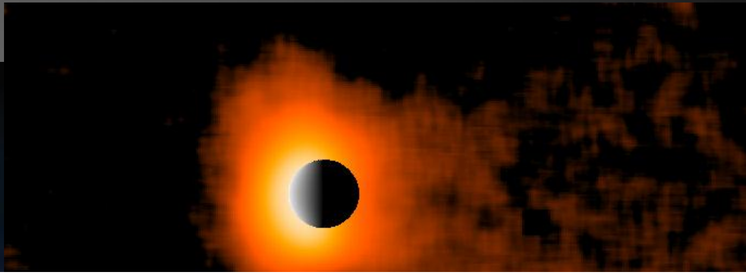
[Kameda et al., 2009 GRL]

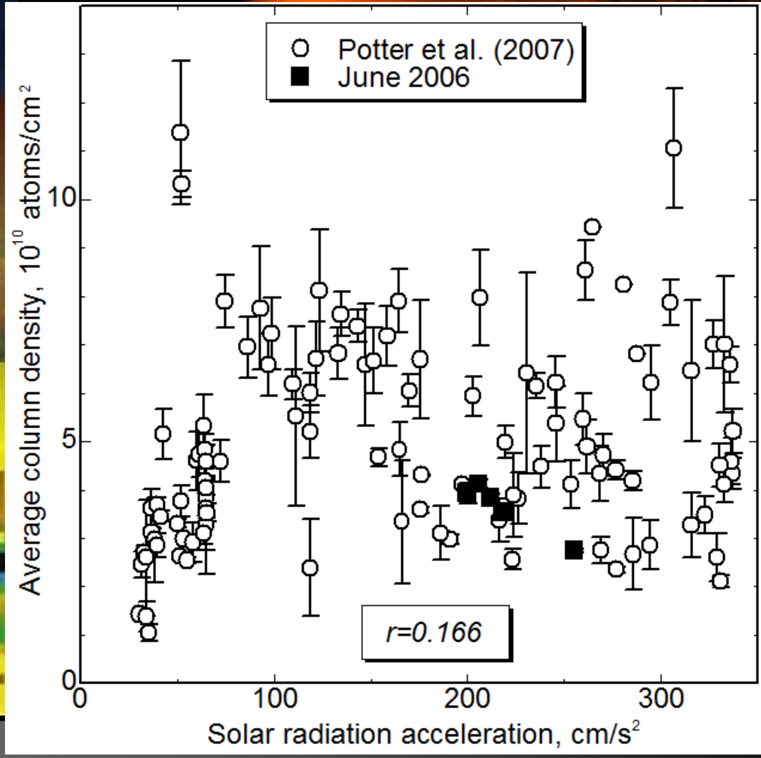
$$A_{ave} = \frac{\int_0^\infty A_v \exp(-t/\tau)\,dt}{\int_0^\infty \exp(-t/\tau)\,dt}, \frac{dv}{dt} = A_v, v_{t=0} = 0$$

Loss Process



McClintock et al., 2008

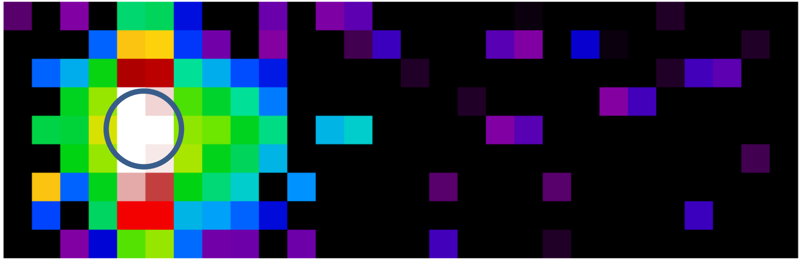




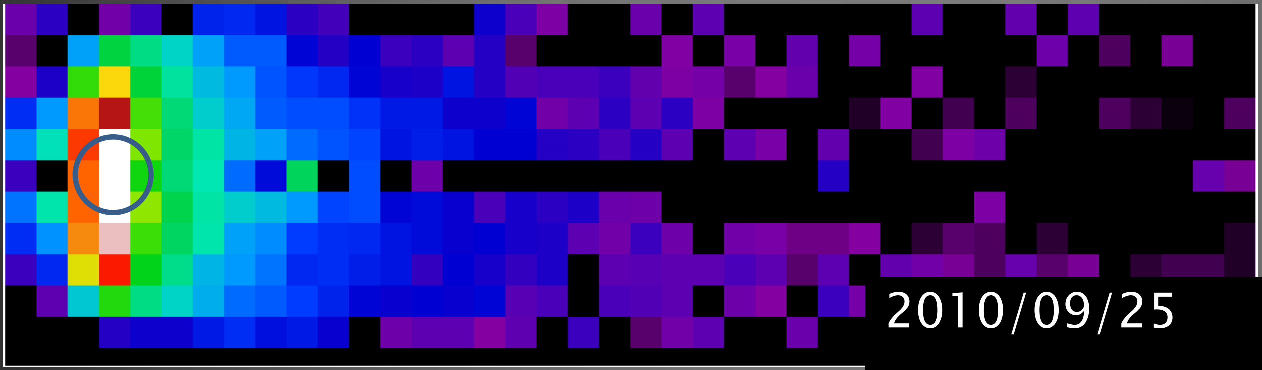
No correlation between Sodium density and solar radiation acceleration.

(Solar radiation acceleration depends on orbital position of Mercury)

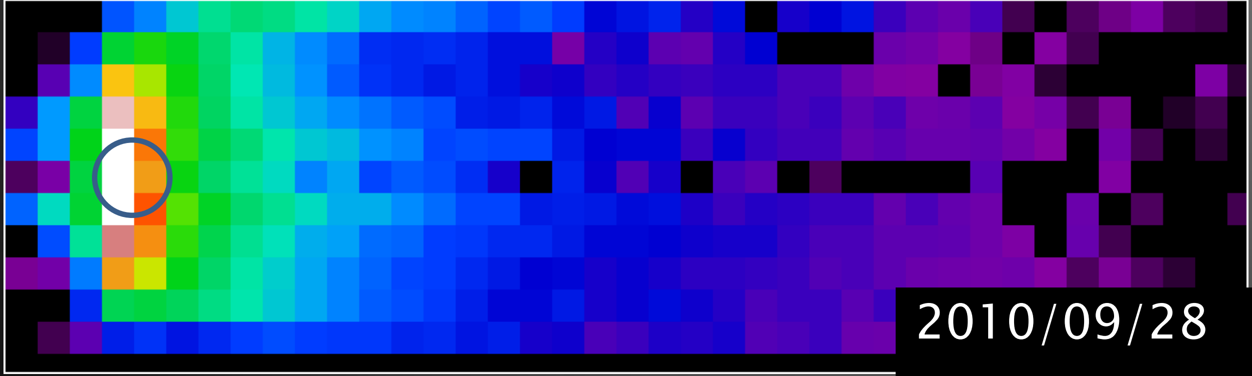
Observation at Haleakala Observatory



2010/09/19



2010/09/25



2010/09/28

Preliminary results

TAA=345, 23, 40

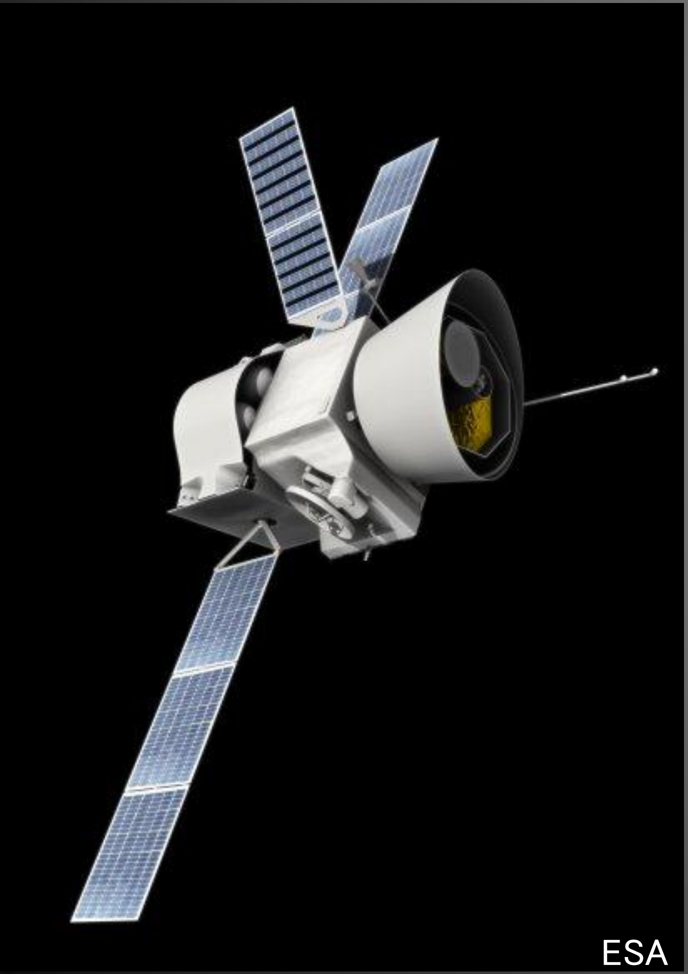
Distance of the tail varies with TAA.

Velocity resolution is~ 1km/s.

We plan to do

In 2011-2012.

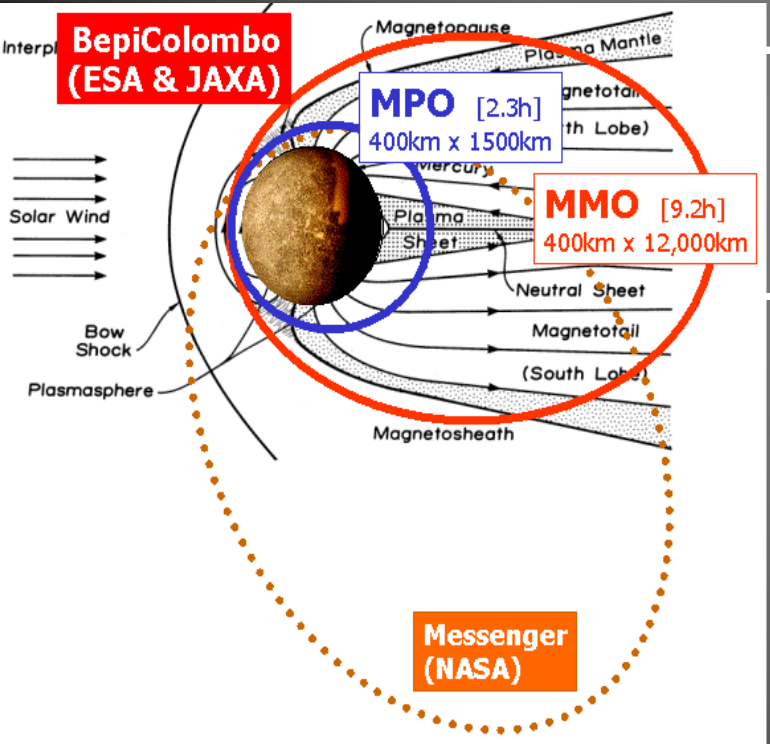
BepiColombo/MMO/MSASI


ESA

- **日欧共同水星探査計画**

--2014年打ち上げ
 2020年軌道投入

BepiColombo/MMO/MSASI

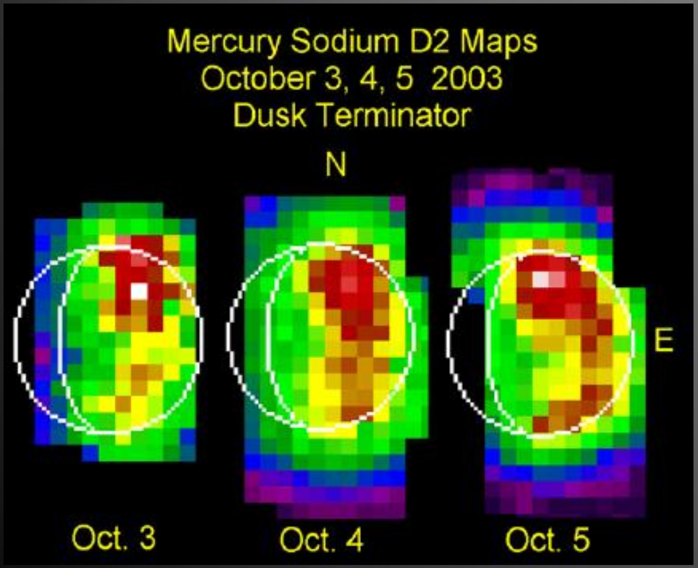


- **日欧共同水星探査計画**

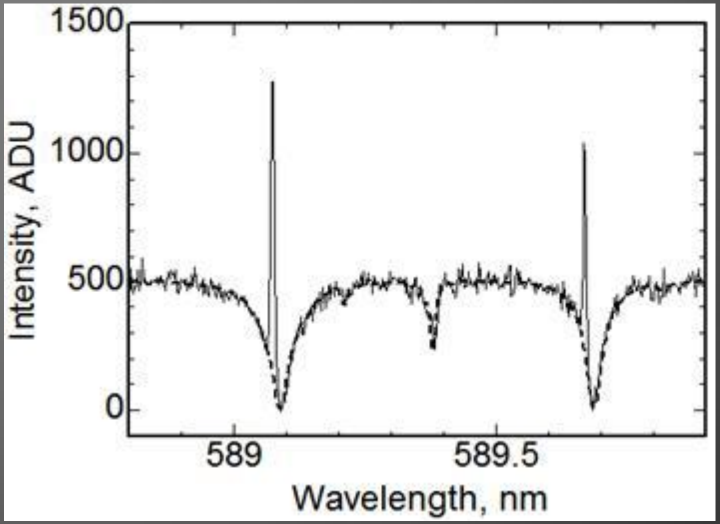
--2014年打ち上げ
 2020年軌道投入
--惑星表面探査（ESA)
磁気圏探査（JAXA)
輸送（ESA)

MSASI onboard BepiColombo MMO

- MSASI is "Mercury Sodium Atmosphere Spectral Imager."
- Spectral resolution of ~85,000 (7pm) enables us to observe distribution of Na exosphere on the **dayside.**

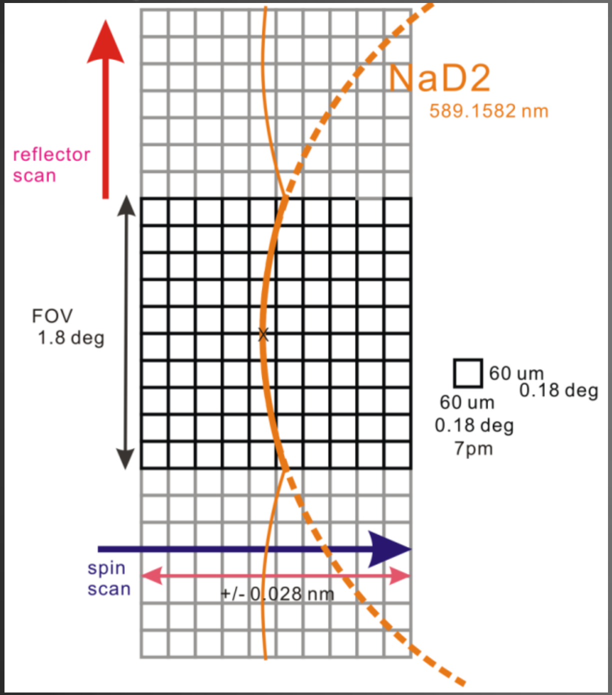


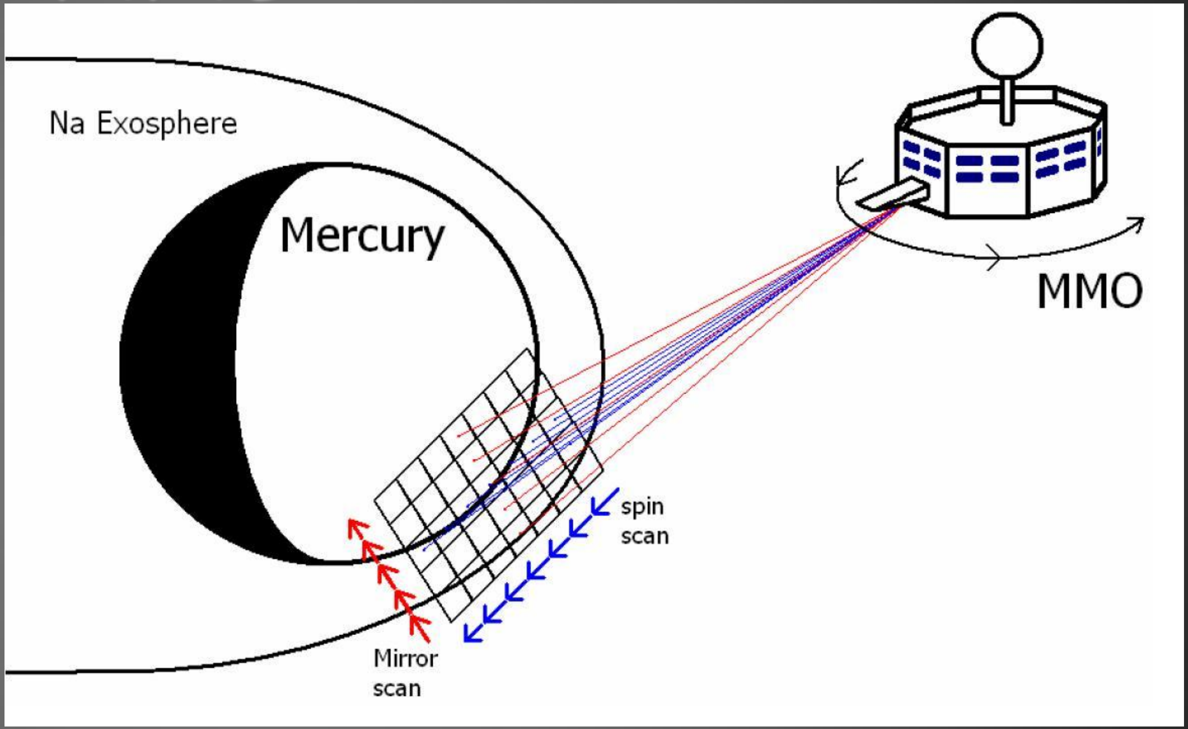
Potter et al., 2008



Line width of NaD is 5pm

Mercury Sodium Atmosphere Spectral Imager (MSASI) onboard BepiColombo MMO



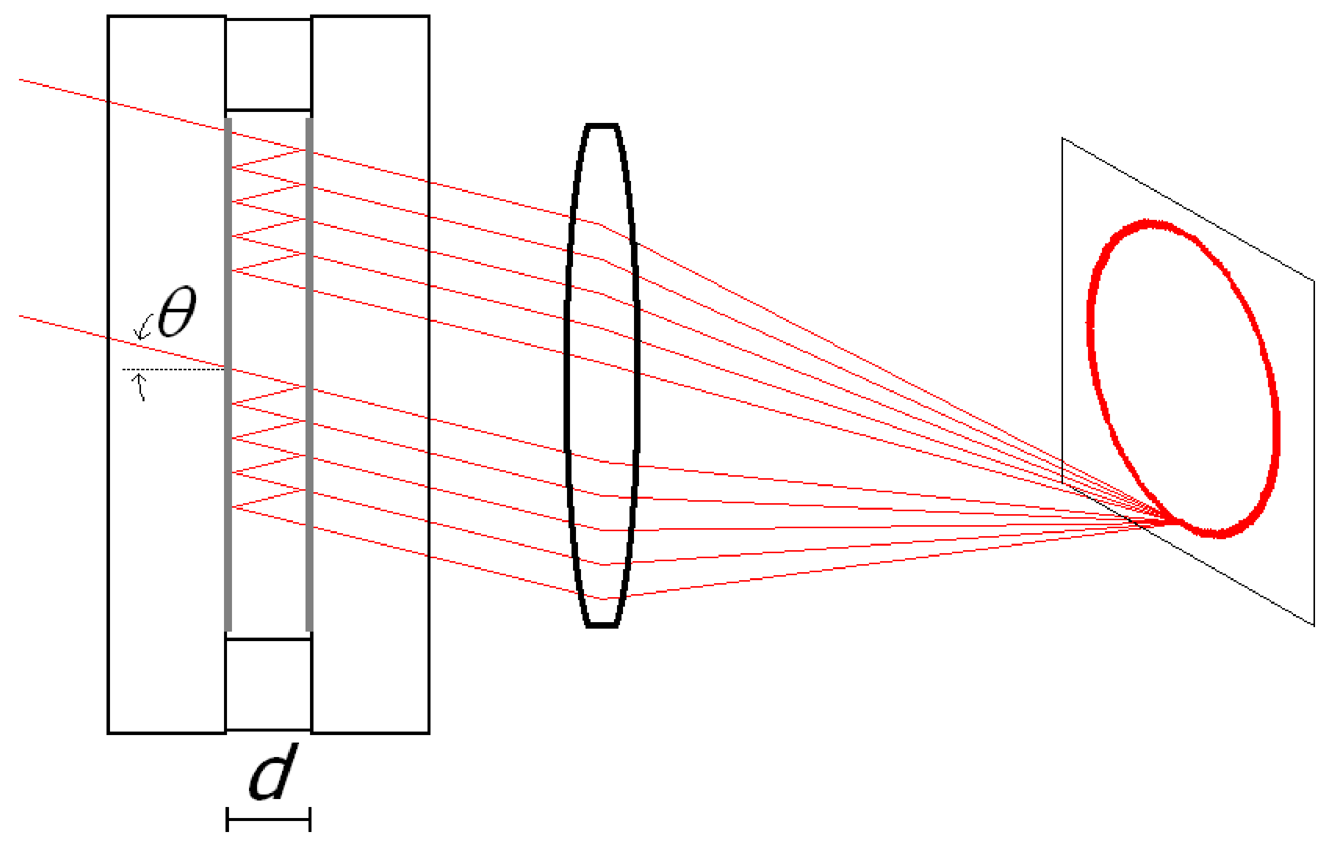


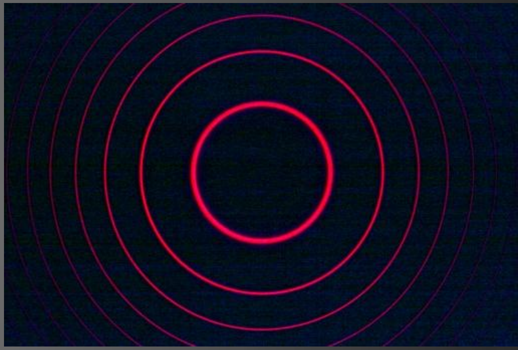
MMO is a spin-stabilized spacecraft. MSASI scans Mercury with moving mirror and S/C spin.

One pix corresponds to 2 msec. → The CMOS image sensor can take 500 images per sec.

The platescale is 1.3 km/pix at periapsis and 40 km/pix at apoapsis.

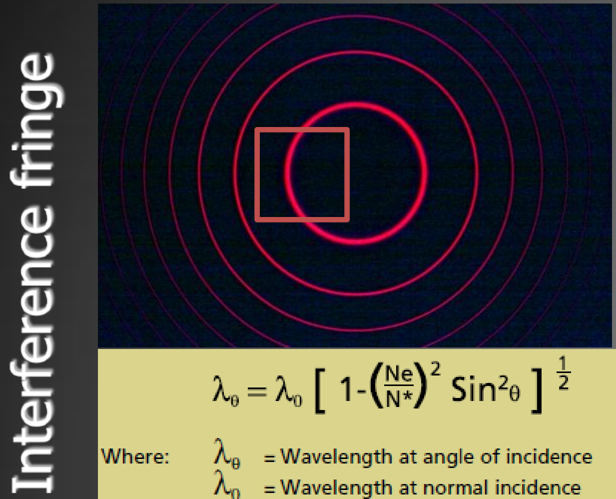
Fabry-Perot Interferometer





$m\lambda = 2nd\cos\theta$ → Transmission

Wavelength map on the detector

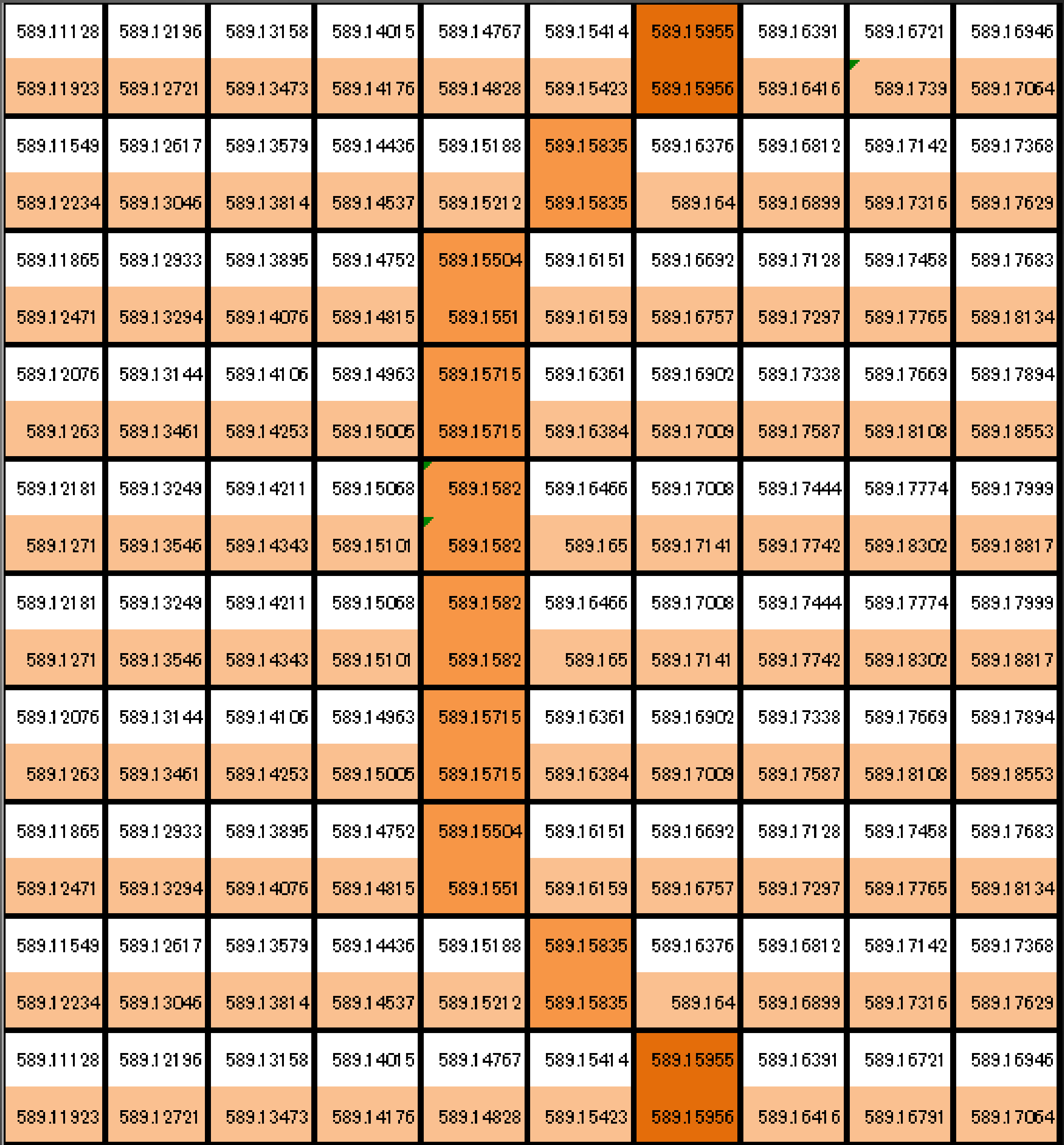


$$\lambda_\theta = \lambda_0 \left[1-\left(\frac{Ne}{N^*}\right)^2 \sin^2\theta \right]^{\frac{1}{2}}$$

Where: λ_θ = Wavelength at angle of incidence
λ_0 = Wavelength at normal incidence
Ne = Refractive index of external medium
N* = Effective refractive index of the filter
θ = Angle of incidence

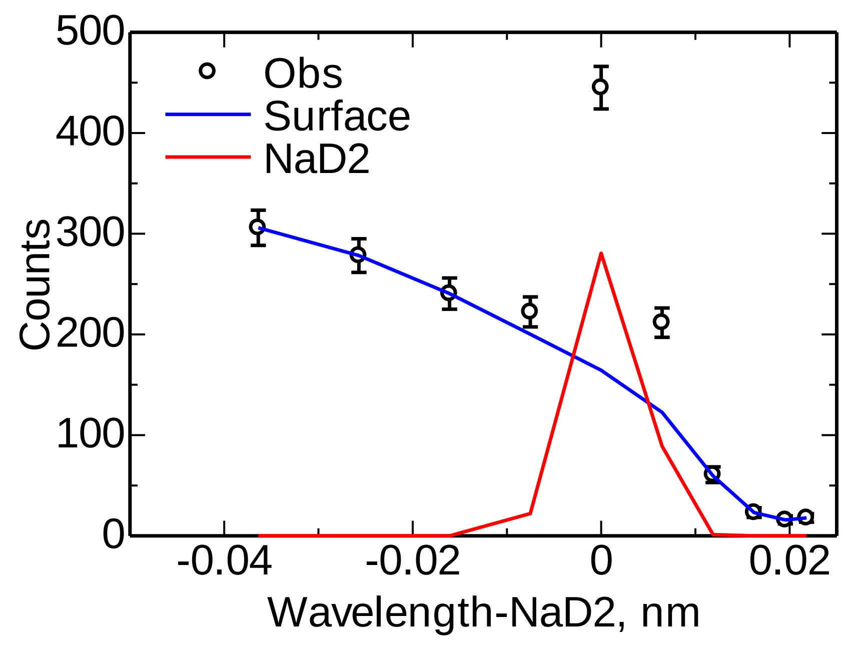
Transmit wavelength
∝ Cos θ (Etalon)
∝ Eq. above (Filter)

→Tilt angle
0.51 deg (Etalon)
1.39 deg (Filter)



589.11128	589.12196	589.13158	589.14015	589.14767	589.15414	589.15955	589.16391	589.16721	589.16946
589.11923	589.12721	589.13473	589.14176	589.14828	589.15423	589.15956	589.16416	589.1739	589.17064
589.11549	589.12617	589.13579	589.14436	589.15188	589.15835	589.16376	589.16812	589.17142	589.17368
589.12234	589.13046	589.13814	589.14537	589.15212	589.15835	589.164	589.16899	589.17316	589.17629
589.11865	589.12933	589.13895	589.14752	589.15504	589.16151	589.16692	589.17128	589.17458	589.17683
589.12471	589.13294	589.14076	589.14815	589.1551	589.16159	589.16757	589.17297	589.17765	589.18134
589.12076	589.13144	589.14106	589.14963	589.15715	589.16361	589.16902	589.17338	589.17669	589.17894
589.1263	589.13461	589.14253	589.15005	589.15715	589.16384	589.17009	589.17587	589.18108	589.18553
589.12181	589.13249	589.14211	589.15068	589.1582	589.16466	589.17008	589.17444	589.17774	589.17999
589.1271	589.13546	589.14343	589.15101	589.1582	589.165	589.17141	589.17742	589.18302	589.18817
589.12181	589.13249	589.14211	589.15068	589.1582	589.16466	589.17008	589.17444	589.17774	589.17999
589.1271	589.13546	589.14343	589.15101	589.1582	589.165	589.17141	589.17742	589.18302	589.18817
589.12076	589.13144	589.14106	589.14963	589.15715	589.16361	589.16902	589.17338	589.17669	589.17894
589.1263	589.13461	589.14253	589.15005	589.15715	589.16384	589.17009	589.17587	589.18108	589.18553
589.11865	589.12933	589.13895	589.14752	589.15504	589.16151	589.16692	589.17128	589.17458	589.17683
589.12471	589.13294	589.14076	589.14815	589.1551	589.16159	589.16757	589.17297	589.17765	589.18134
589.11549	589.12617	589.13579	589.14436	589.15188	589.15835	589.16376	589.16812	589.17142	589.17368
589.12234	589.13046	589.13814	589.14537	589.15212	589.15835	589.164	589.16899	589.17316	589.17629
589.11128	589.12196	589.13158	589.14015	589.14767	589.15414	589.15955	589.16391	589.16721	589.16946
589.11923	589.12721	589.13473	589.14176	589.14828	589.15423	589.15956	589.16416	589.16791	589.17064

Wavelength map on the detector



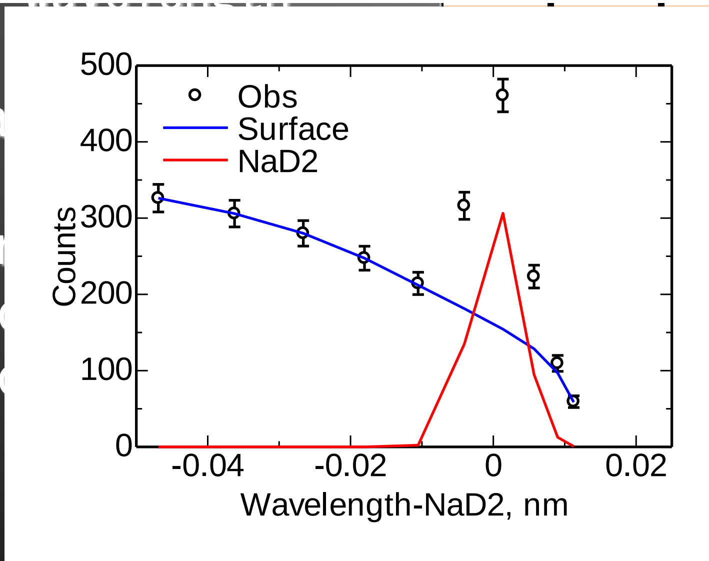
∝ Cos θ

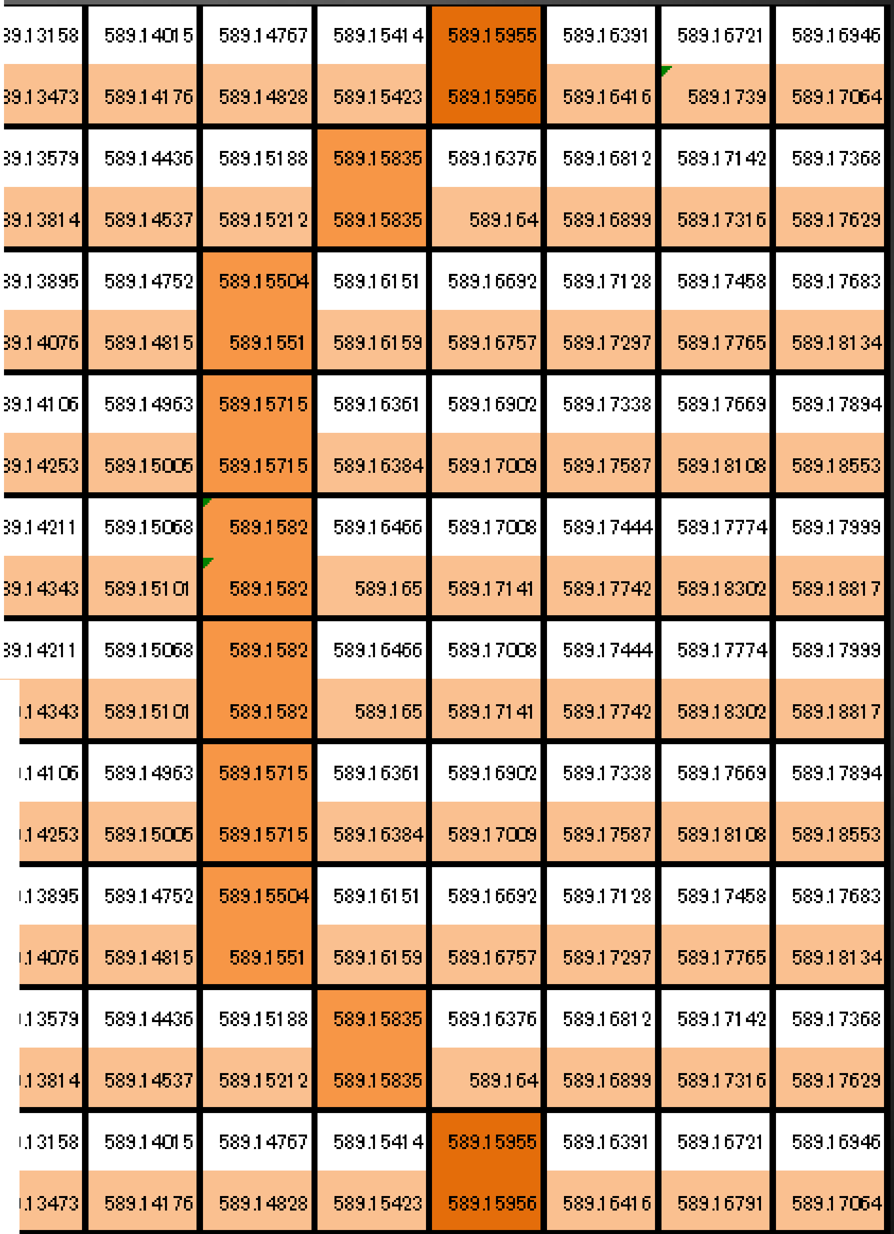
∝ Eq. a

→Tilt a

0.51 (

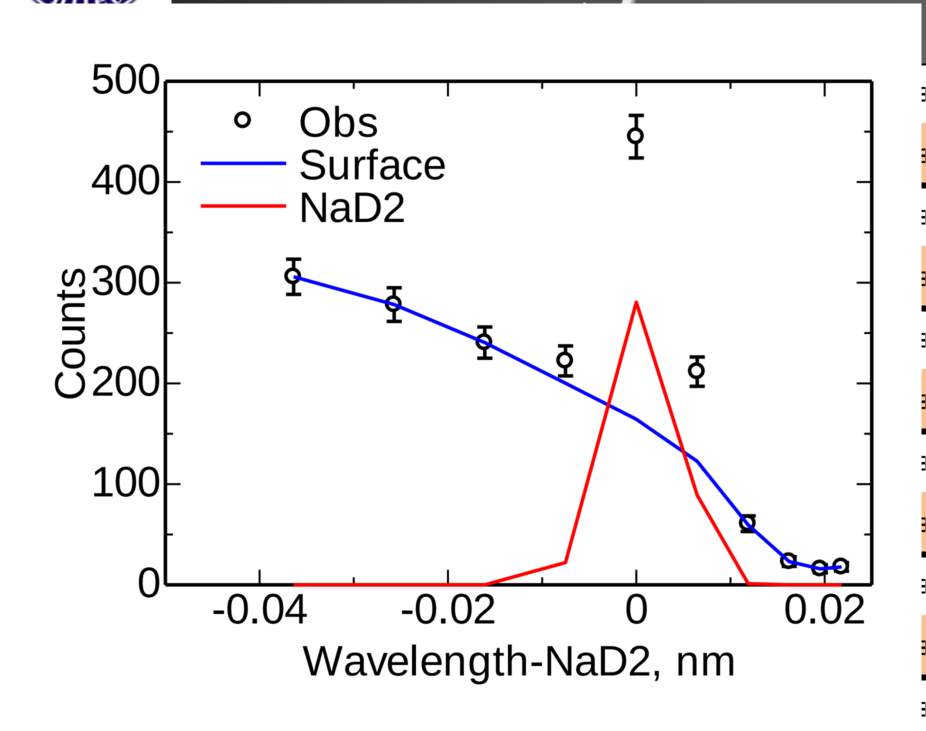
1.39 (





39.13158	589.14015	589.14767	589.15414	589.15955	589.16391	589.16721	589.16946
39.13473	589.14176	589.14828	589.15423	589.15956	589.16416	589.1739	589.17064
39.13579	589.14436	589.15188	589.15835	589.16376	589.16812	589.17142	589.17368
39.13814	589.14537	589.15212	589.15835	589.164	589.16899	589.17316	589.17629
39.13895	589.14752	589.15504	589.16151	589.16692	589.17128	589.17458	589.17683
39.14076	589.14815	589.1551	589.16159	589.16757	589.17297	589.17765	589.18134
39.14106	589.14963	589.15715	589.16361	589.16902	589.17338	589.17669	589.17894
39.14253	589.15005	589.15715	589.16384	589.17009	589.17587	589.18108	589.18553
39.14211	589.15068	589.1582	589.16466	589.17008	589.17444	589.17774	589.17999
39.14343	589.15101	589.1582	589.165	589.17141	589.17742	589.18302	589.18817
39.14211	589.15068	589.1582	589.16466	589.17008	589.17444	589.17774	589.17999
.14343	589.15101	589.1582	589.165	589.17141	589.17742	589.18302	589.18817
.14106	589.14963	589.15715	589.16361	589.16902	589.17338	589.17669	589.17894
.14253	589.15005	589.15715	589.16384	589.17009	589.17587	589.18108	589.18553
.13895	589.14752	589.15504	589.16151	589.16692	589.17128	589.17458	589.17683
.14076	589.14815	589.1551	589.16159	589.16757	589.17297	589.17765	589.18134
.13579	589.14436	589.15188	589.15835	589.16376	589.16812	589.17142	589.17368
.13814	589.14537	589.15212	589.15835	589.164	589.16899	589.17316	589.17629
.13158	589.14015	589.14767	589.15414	589.15955	589.16391	589.16721	589.16946
.13473	589.14176	589.14828	589.15423	589.15956	589.16416	589.16791	589.17064

Wavelength map on the detector



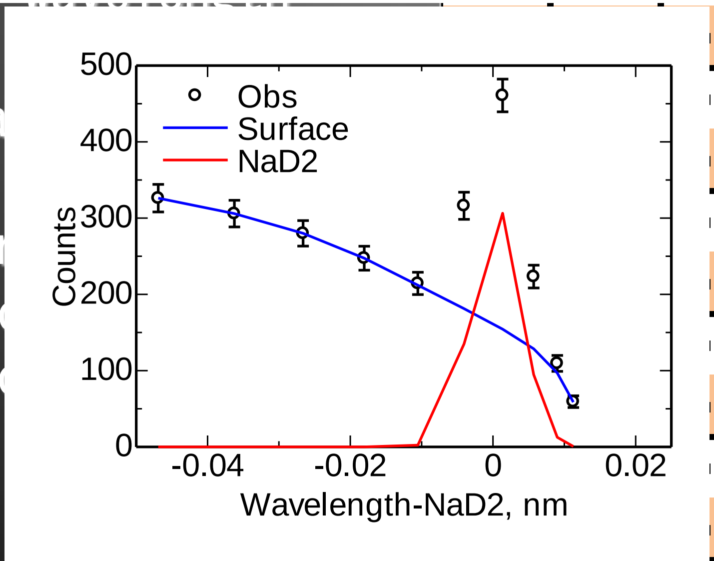
∝ Cos θ

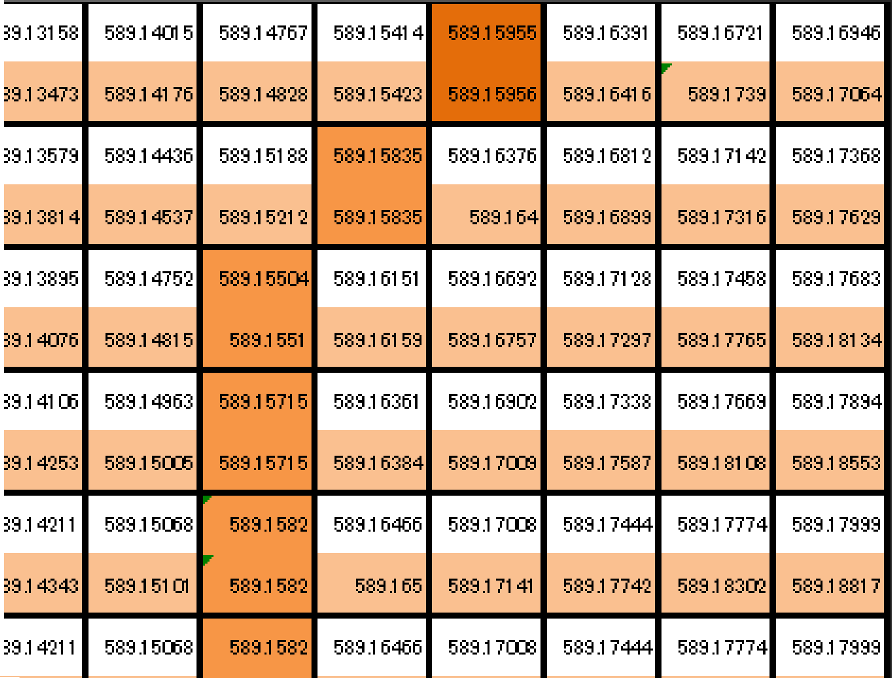
∝ Eq. a

→Tilt ar

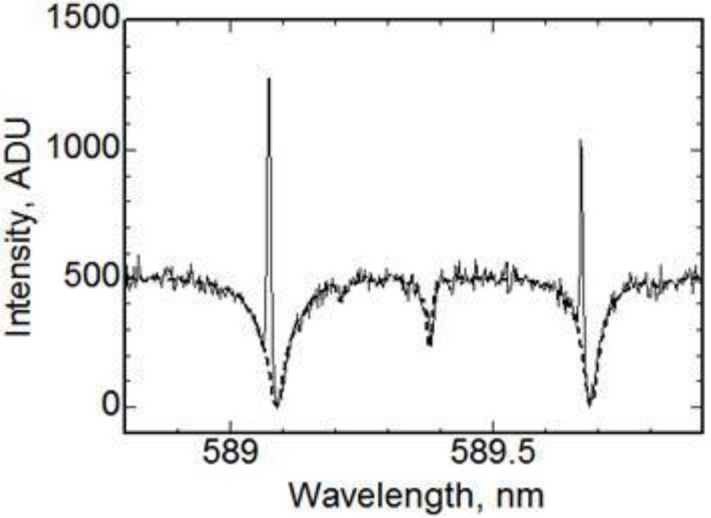
0.51

1.39

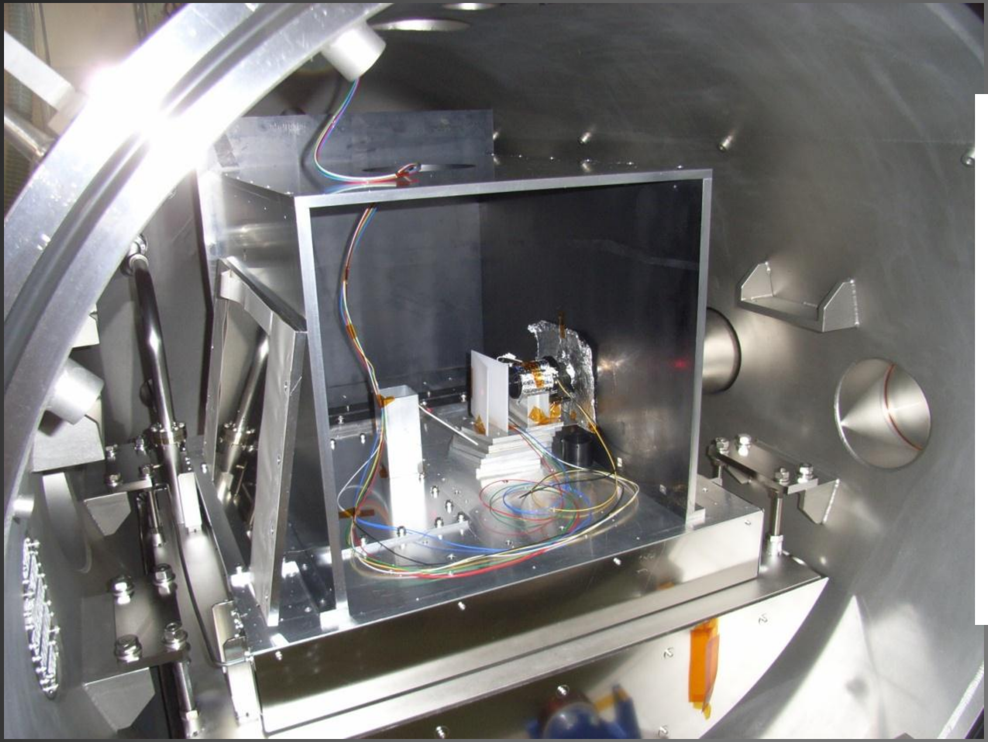


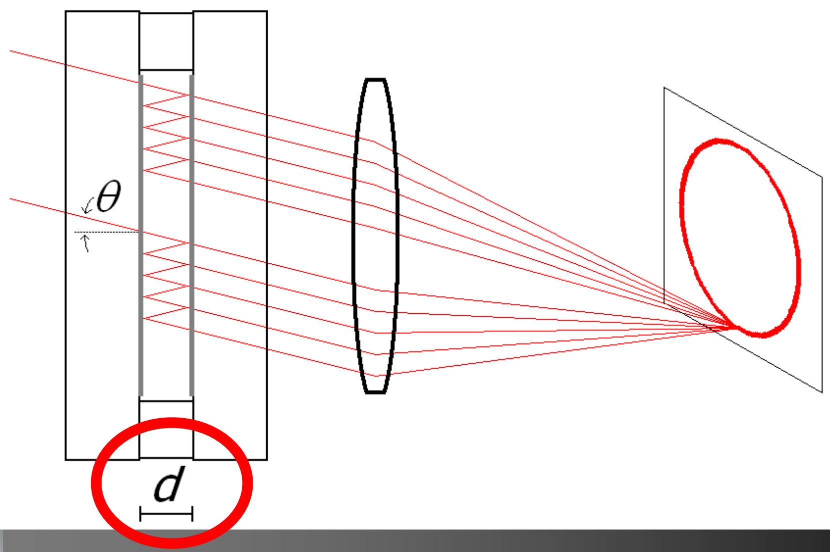


39.13158	589.14015	589.14767	589.15414	589.15955	589.16391	589.16721	589.16946
39.13473	589.14176	589.14828	589.15423	589.15956	589.16416	589.1739	589.17064
39.13579	589.14436	589.15188	589.15835	589.16376	589.16812	589.17142	589.17368
39.13814	589.14537	589.15212	589.15835	589.164	589.16899	589.17316	589.17629
39.13895	589.14752	589.15504	589.16151	589.16692	589.17128	589.17458	589.17683
39.14076	589.14815	589.1551	589.16159	589.16757	589.17297	589.17765	589.18134
39.14106	589.14963	589.15715	589.16361	589.16902	589.17338	589.17669	589.17894
39.14253	589.15005	589.15715	589.16384	589.17009	589.17587	589.18108	589.18553
39.14211	589.15068	589.1582	589.16466	589.17008	589.17444	589.17774	589.17999
39.14343	589.15101	589.1582	589.165	589.17141	589.17742	589.18302	589.18817
39.14211	589.15068	589.1582	589.16466	589.17008	589.17444	589.17774	589.17999
.14343	589.15101	589.1582	589.165	589.17141	589.17742	589.18302	589.18817
.14106	5						.17894
.14253	5						.18553
.13895	5						.17683
.14076	5						.18134
.13579	5						.17368
.13814	5						.17629
.13158	5						.16946
.13473	5						.17064



Thermal Vacuum Test





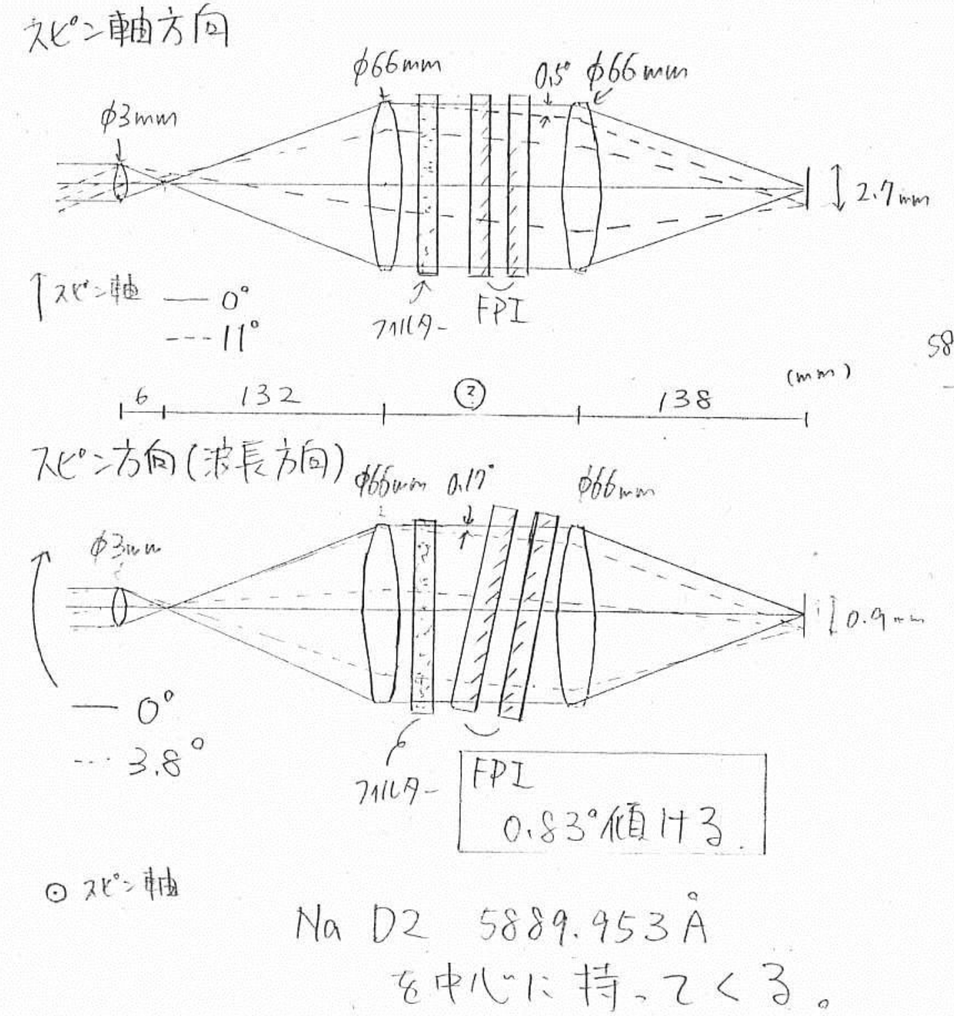
-20 degC ~ +60 degC

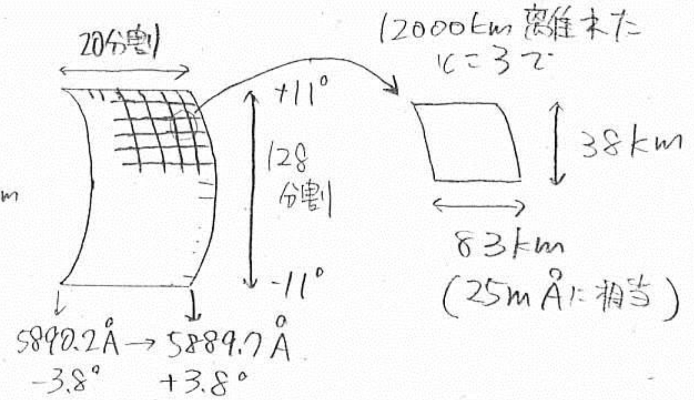
d=1.49 mm (Zerodur)

→ δd<+/- ~15 nm TEC~ 10^{-7}

→ **δCWL < 6 pm (Center Wavelength)**

光学設計 (2003年1月の太陽系シンポジウム)





左：光学系の設計図

　左上：横から見た図

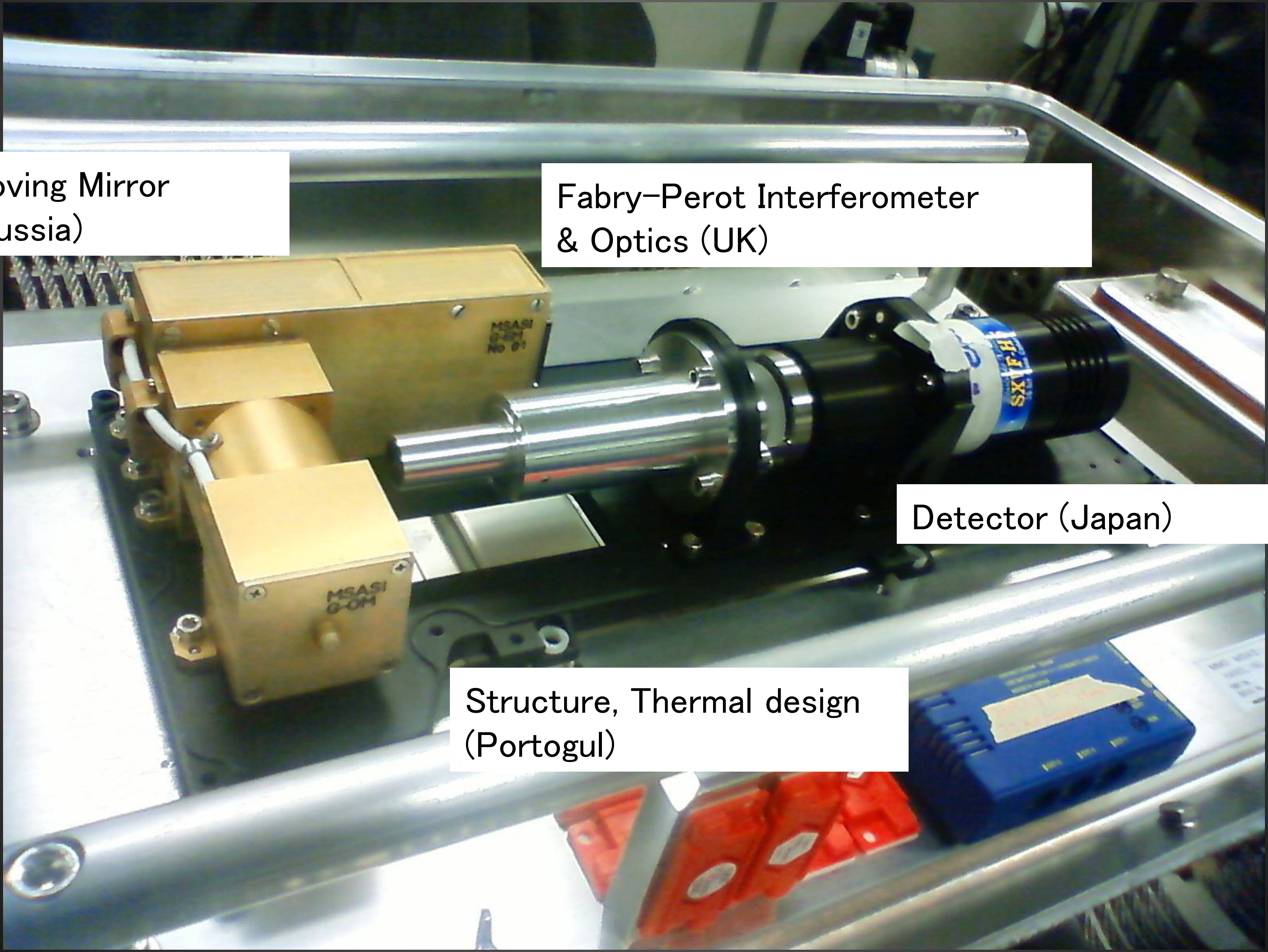
　左下：上から見た図

上：像面

要求される性能に従って
区画化した図

開口部φ3mmに入射する光量は、
上図の１区画毎に、
８．３×１０^4
[photons/100msec/25mÅ]

Laboratory Test Model



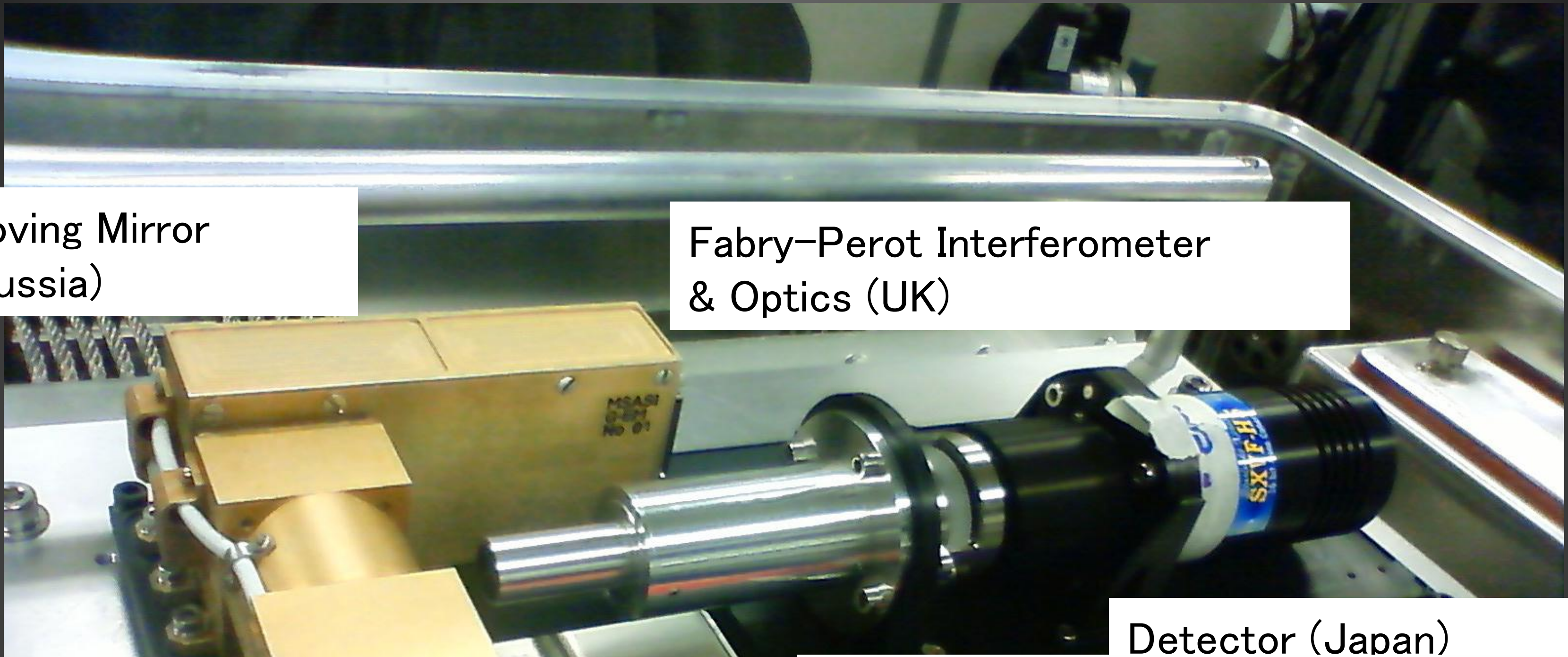
Moving Mirror
(Russia)

Fabry-Perot Interferometer
& Optics (UK)

Detector (Japan)

Structure, Thermal design
(Portogul)

Laboratory Test Model



Moving Mirror
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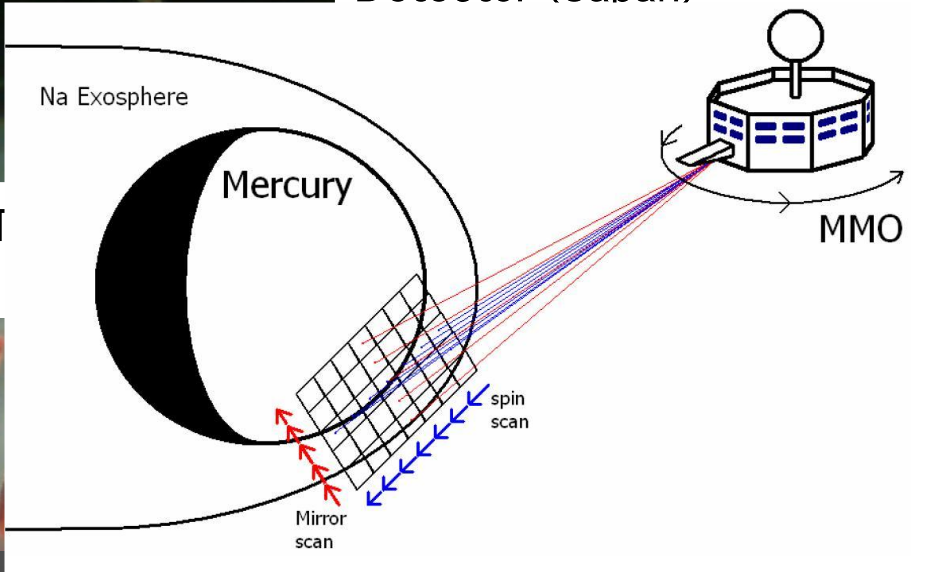
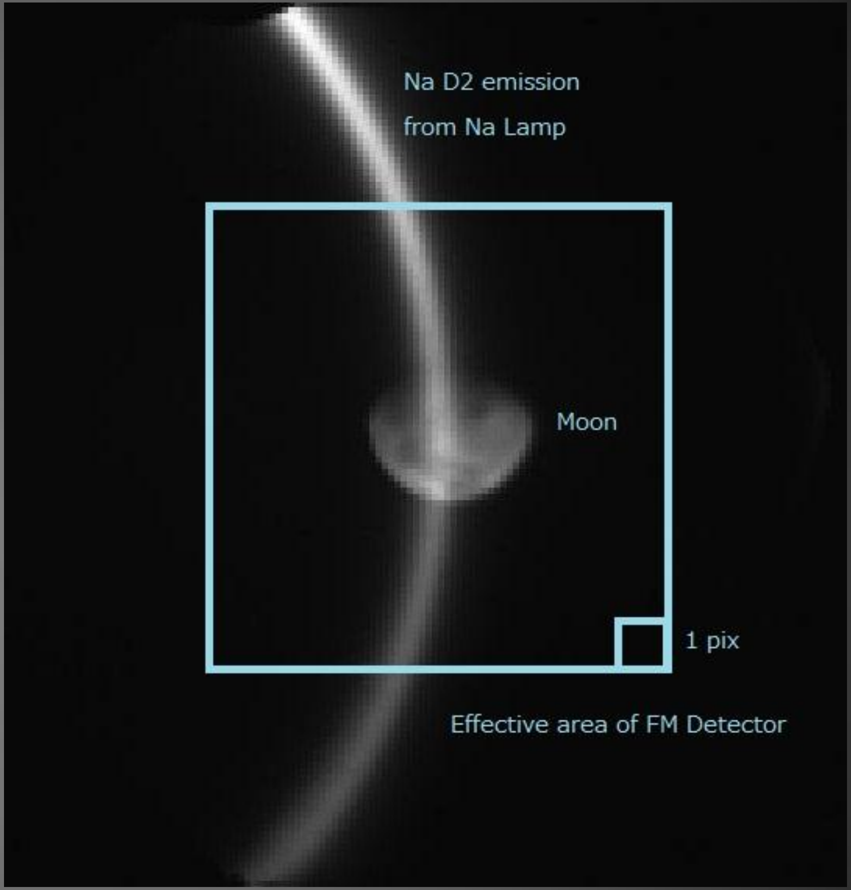
Detector (Japan)

Structure, T
(Portogul)



MSASI Observation

LTM on equatorial mounting
(The detector is not LTM.)



Moon and NaD2 line
(We turned on Na lamp was on for a short time during exposure for moon.)

MMO-MSASI


BepiColombo / MMO
武
蔵
Mercury Sodium Atmosphere Spectral Imager

End