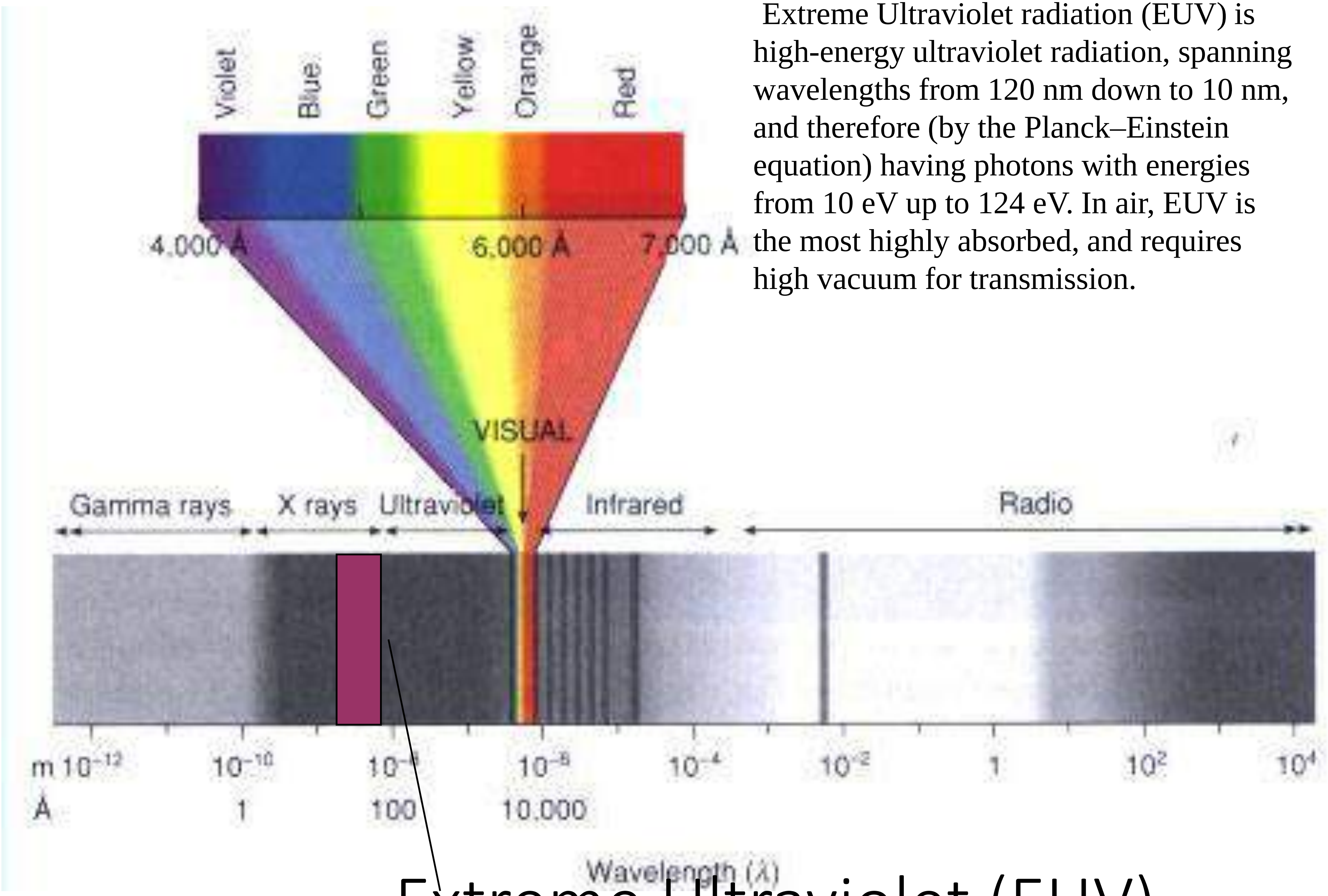
Overview of imaging the planetary exospheres in the EUV spectral range

Ichiro Yoshikawa
(yoshikawa@k.u-tokyo.ac.jp)
東京大学
THE UNIVERSITY OF TOKYO

April 30, 2015, 10:00-10:30



Extreme Ultraviolet radiation (EUV) is high-energy ultraviolet radiation, spanning wavelengths from 120 nm down to 10 nm, and therefore (by the Planck–Einstein equation) having photons with energies from 10 eV up to 124 eV. In air, EUV is the most highly absorbed, and requires high vacuum for transmission.

Extreme Ultraviolet (EUV)

現在の研究場所

- 東京大学(本郷)： 地球惑星科学の講義/実習、観測機の開発
  イプシロンロケットが打ち上げた惑星望遠鏡はここで開発しました。

極端紫外線較正実験施設

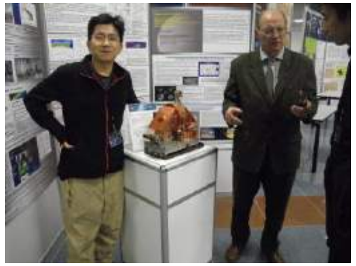
＠東京大学理学部1号館

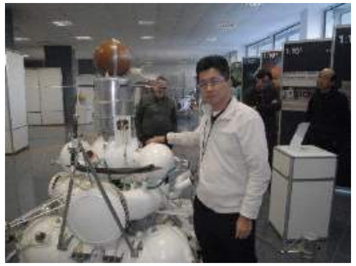
- 宇宙科学 境試験、人工衛星の運用
- 分子科学 端紫外光を用いた観測機の較正試験

- フランス トン大)と
  共同で惑星探査の共同開発研究

cnrs
dépasser les frontières

LATMOS

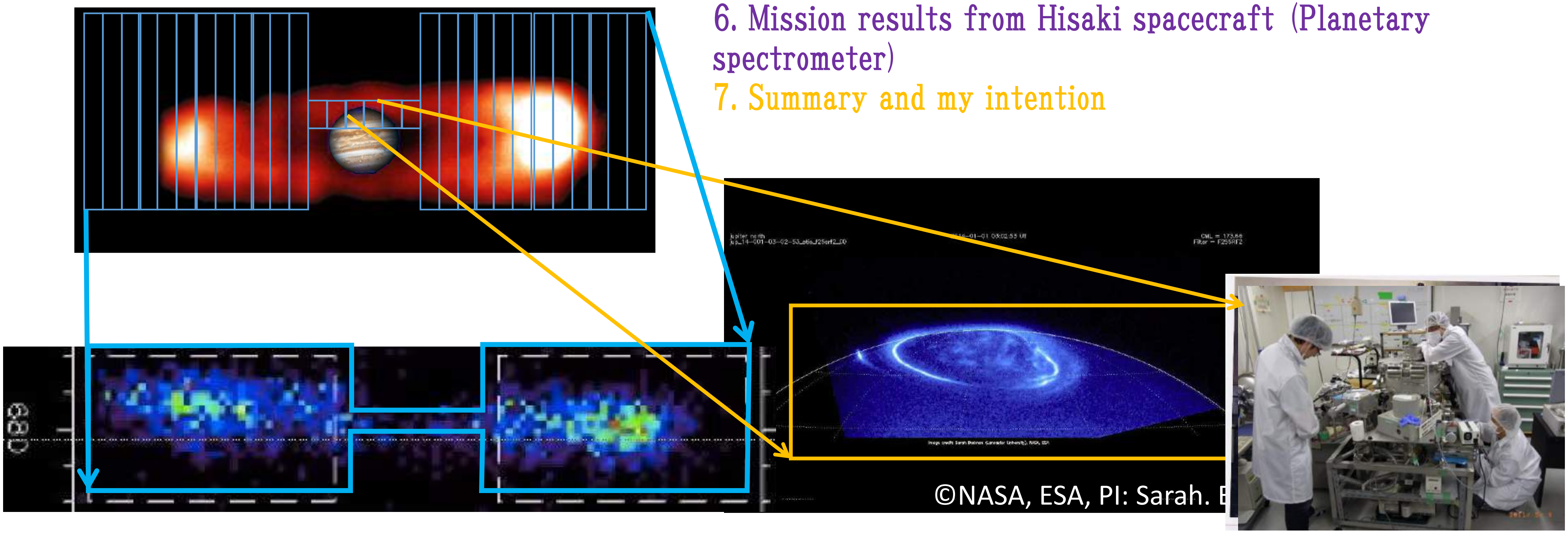




ИКИ
ИНСТИТУТ
КОСМИЧЕСКИХ
ИССЛЕДОВАНИЙ
РАН

Today's Contents:

1. Introduction of ISAS exospheric explorations
2. Proposition of EUV spectral range
3. Mission result from NOZOMI spacecraft (Mars Orbiter)
4. Mission results from Kaguya spacecraft (Lunar orbiter)
5. Technical breakthrough in EUV
6. Mission results from Hisaki spacecraft (Planetary spectrometer)
7. Summary and my intention

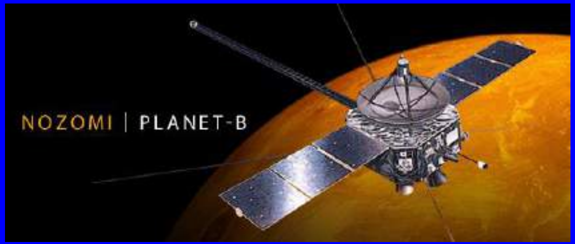


Recent ISAS science missions

Summary of planetary exospheric explorations conducted by ISAS (current and surely executed in the near future)

FY

| 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 2000 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 13 | 14 | 15 | 16 | 17 | 18 | 19

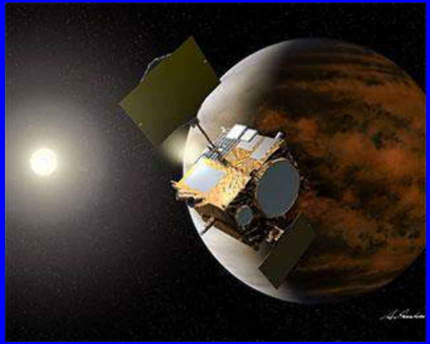


AKEBONO (survived 26 years) 15

GEOTAIL

NOZOMI 98 04

REIMEI



KAGUYA

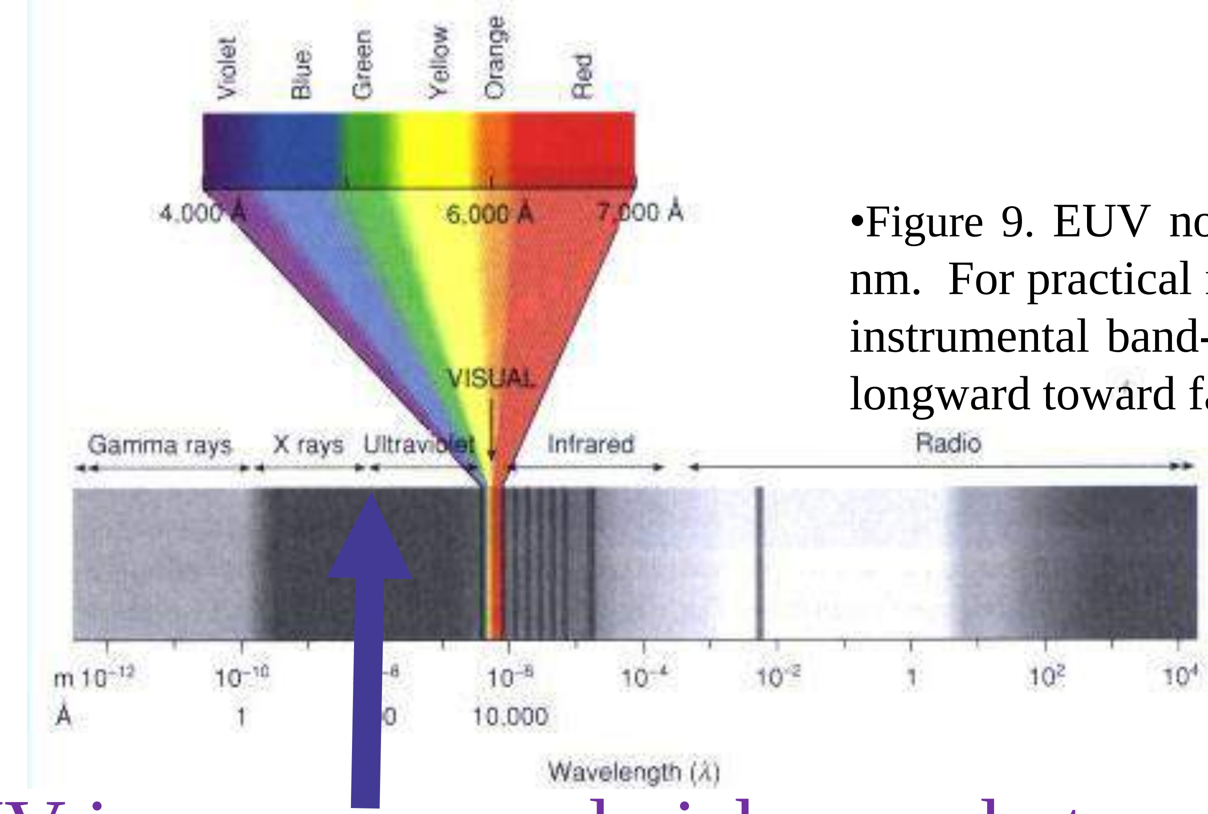
AKATSUKI

HISAKI

ERG

BEPI COLOMBO 17 24

2. Proposition of EUV spectral range

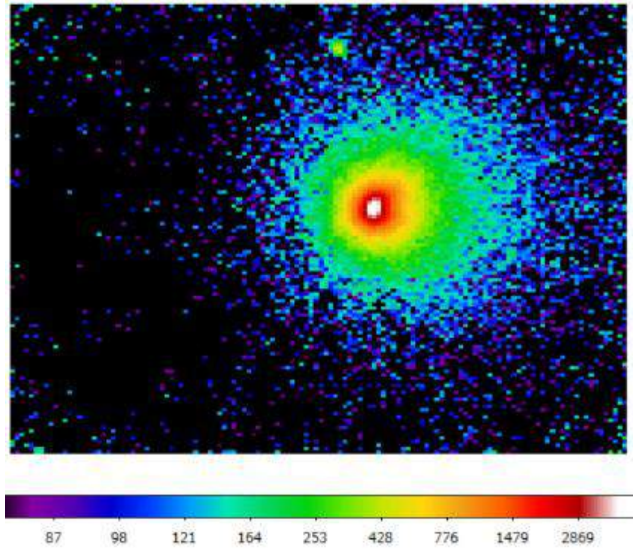


•Figure 9. EUV normally spans the wavelength from 10 to 100 nm. For practical reasons, the both edges are often ambiguous as instrumental band-pass extends shortward into the soft X-ray or longward toward far ultraviolet.

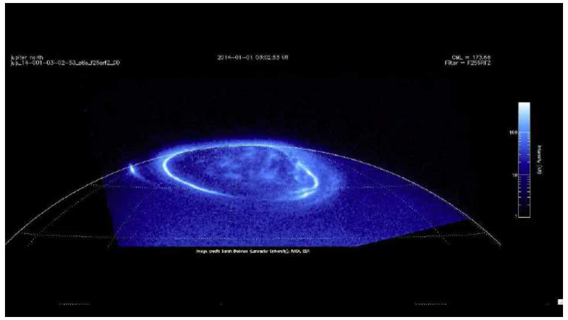
EUV is a narrow and niche gap between UV and X-ray.

EUV is *UUV*

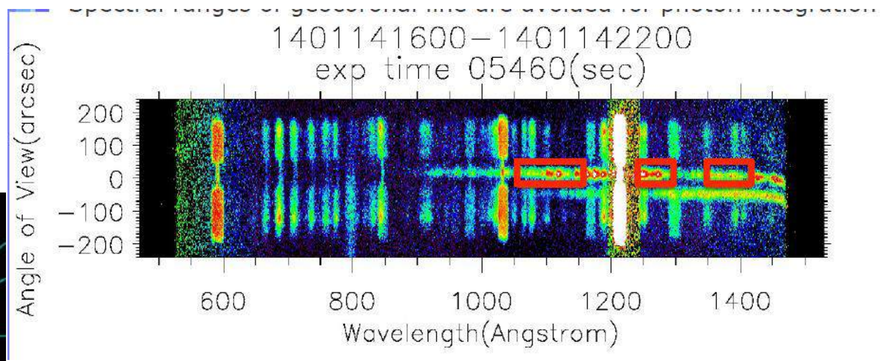
Planetary exospheres are bright at many EUV emissions!

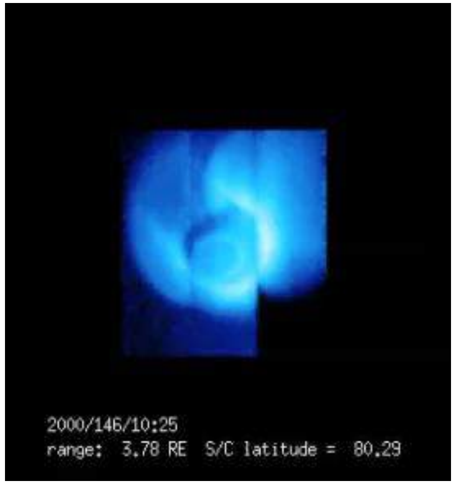


Geocorona: Hydrogen at Lyman-α (121.6nm), taken by *LAICA* on ultra-small satellite, PROCYON, last year.

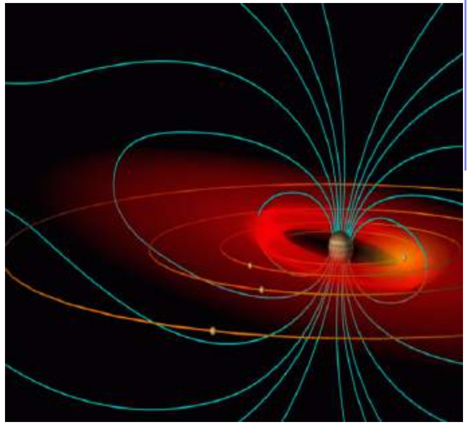


Jupiter aurora, taken by *Hubble Space telescope*



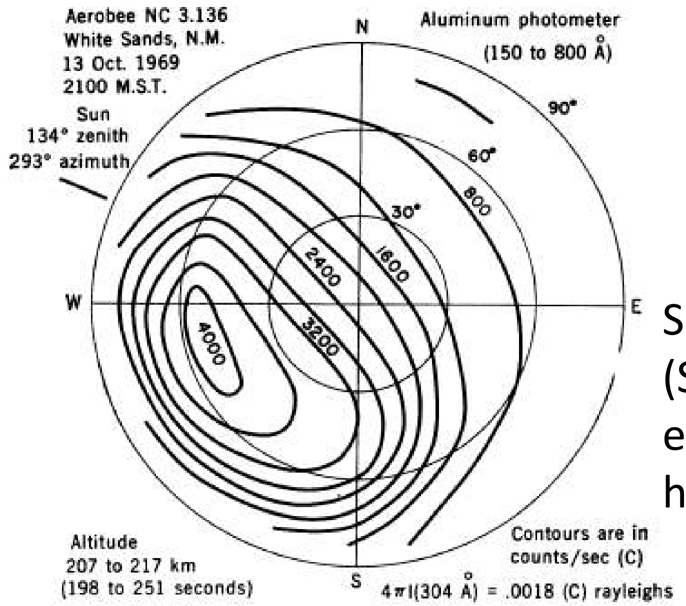


Plasmasphere at He ion (30.4nm), taken by *IMAGE satellite*(NASA).

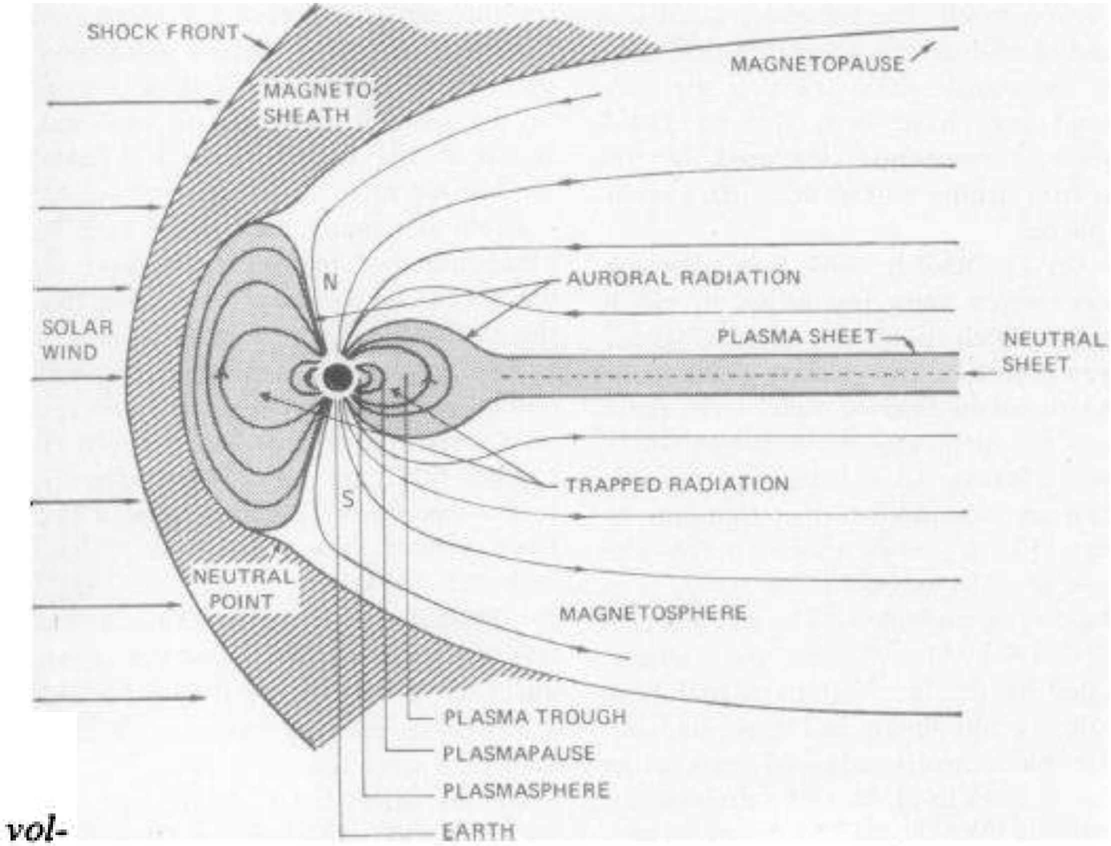


Jovian moon, Io, builds up bright torus in EUV spectral range, measured by *Hisaki* spacecraft

New geophysical perspective in the late 60s, proposed by Johnson



Sky Map at 30.4nm
(Solar resonantly scattering emission by singly ionized helium)



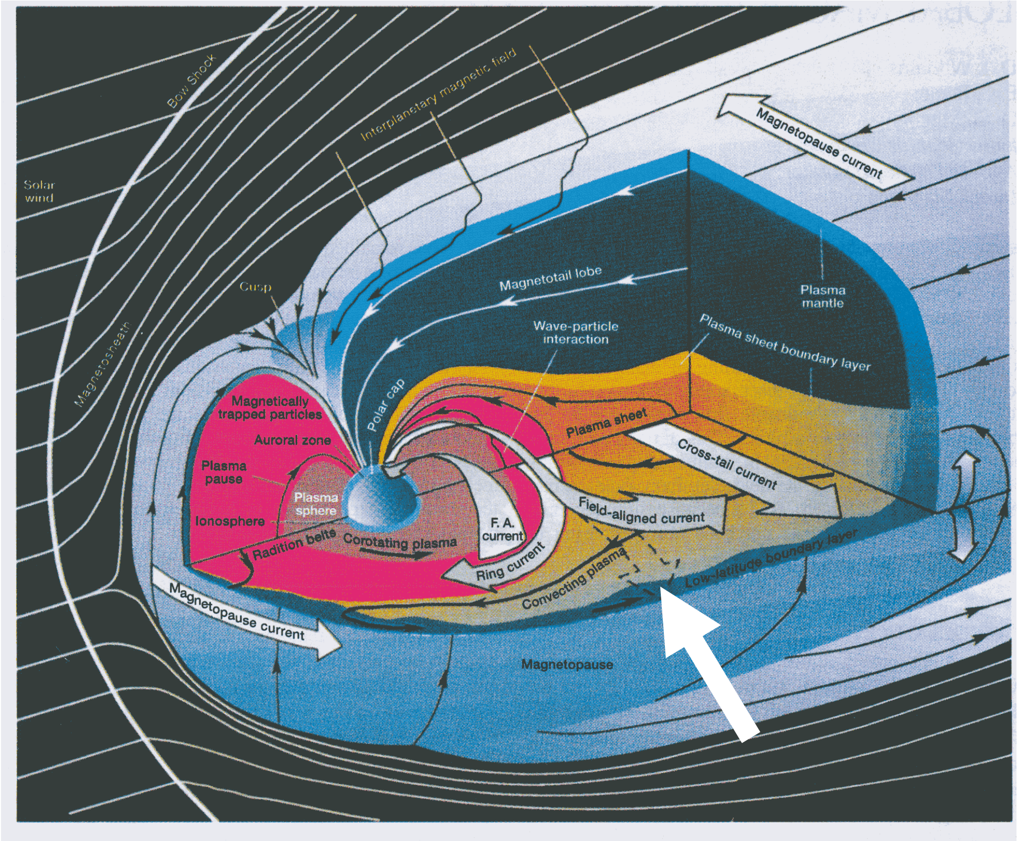
Johnson et al., *Science,* 1971

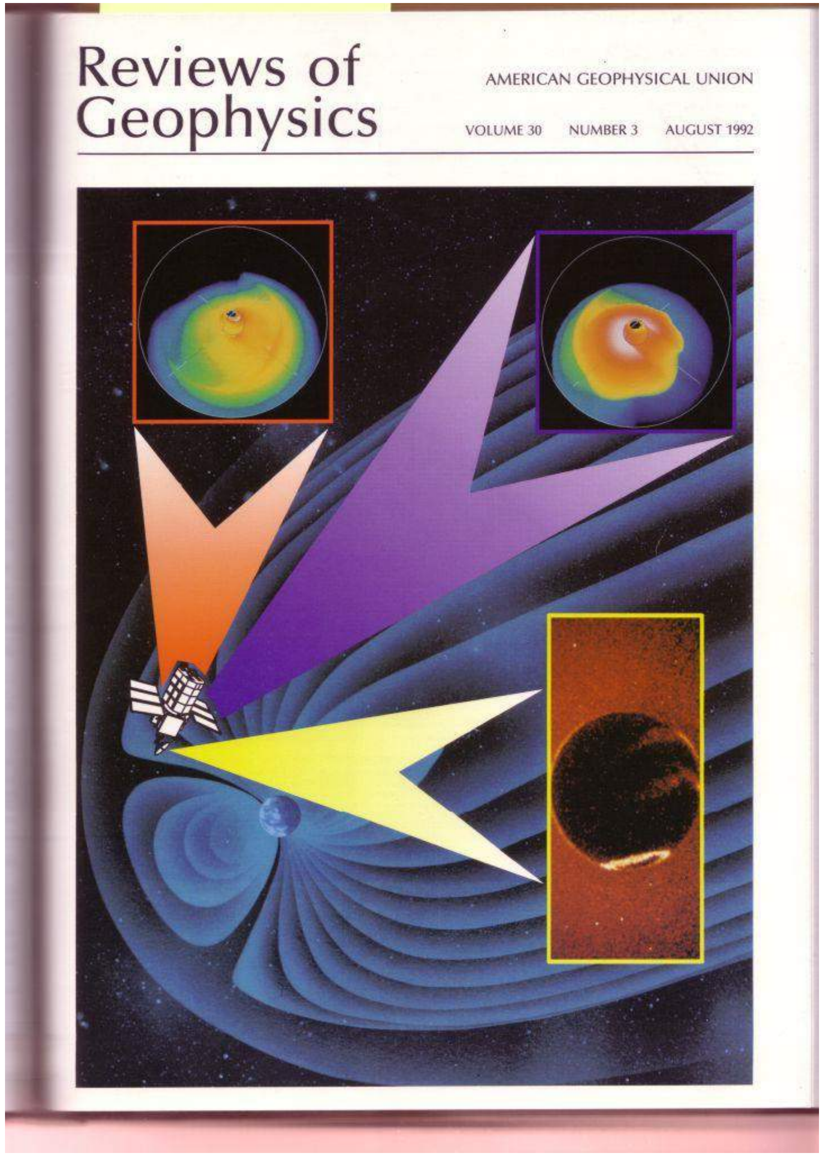
Magnetoglow: A New Geophysical Resource

Abstract. *Evidence has been found that the earth is immersed in a large volume of glowing helium ions. This ionic glow, at 304 angstroms, is similar to the geocoronal hydrogen glow in that it extends to very high altitudes, but it is unique in that it is largely confined to the closed field line portion of the magnetosphere. Because of its magnetic containment, this ionic radiation is called the "magnetoglow." Observations of the magnetoglow from inside and outside the magnetospheric cavity promise to provide a valuable means of studying the structural dynamics of the magnetosphere.*

His idea has directed us to global imaging of the exosphere in EUV!

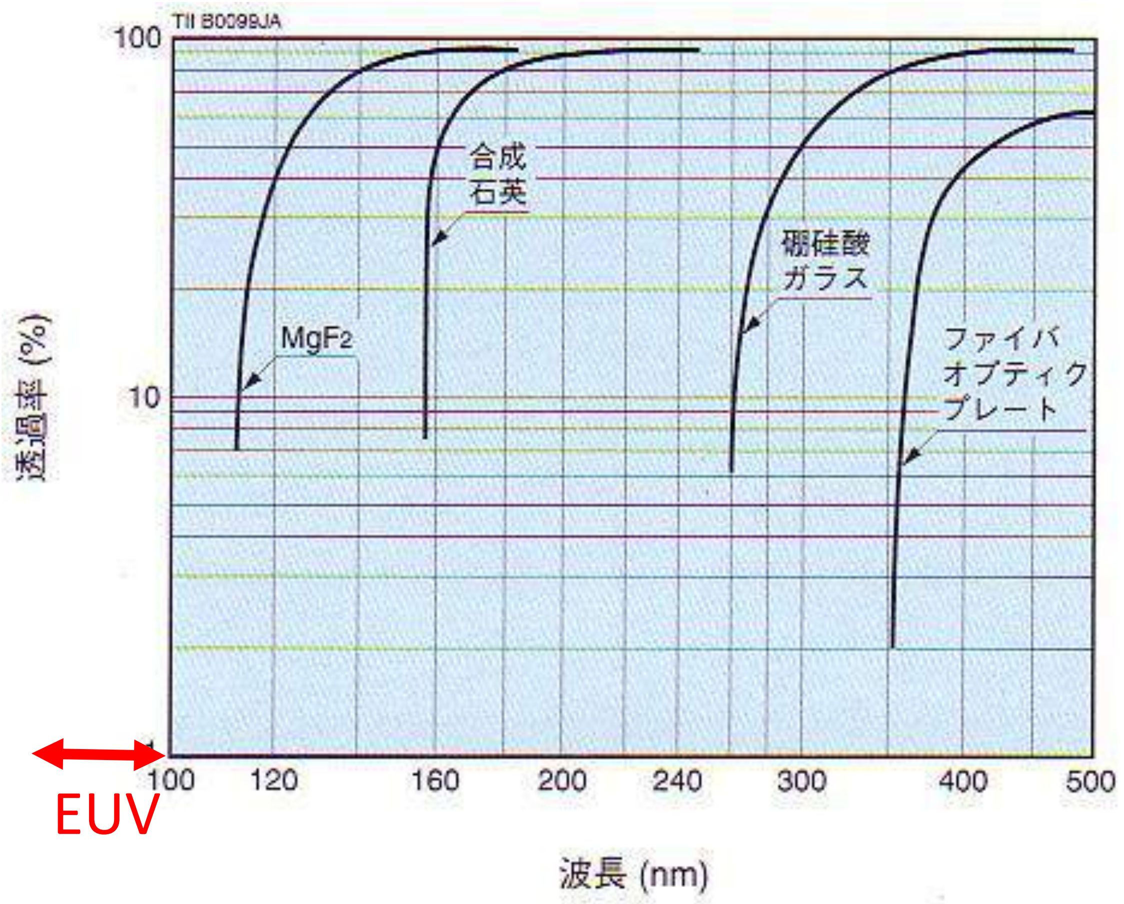
Global image of the Earth's magnetosphere
[Williams et al., 1992]



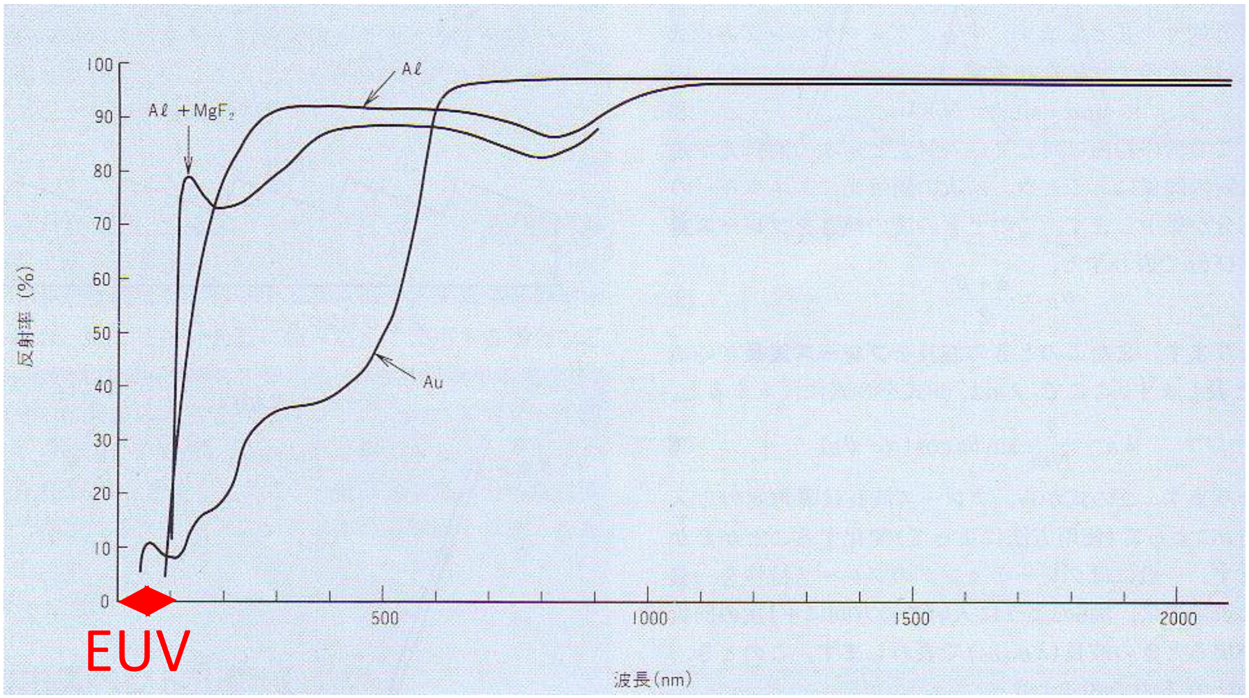


In the 90's, EUV imaging was intensively discussed to confirm this picture!

Gathering EUV photons is (was) difficult!



Transmittance of glass (Lenses)



Reflectivity of surface (Mirrors)

Any conventional optics has low efficiency in the EUV spectral region!

Development of multi-layer coating mirrors

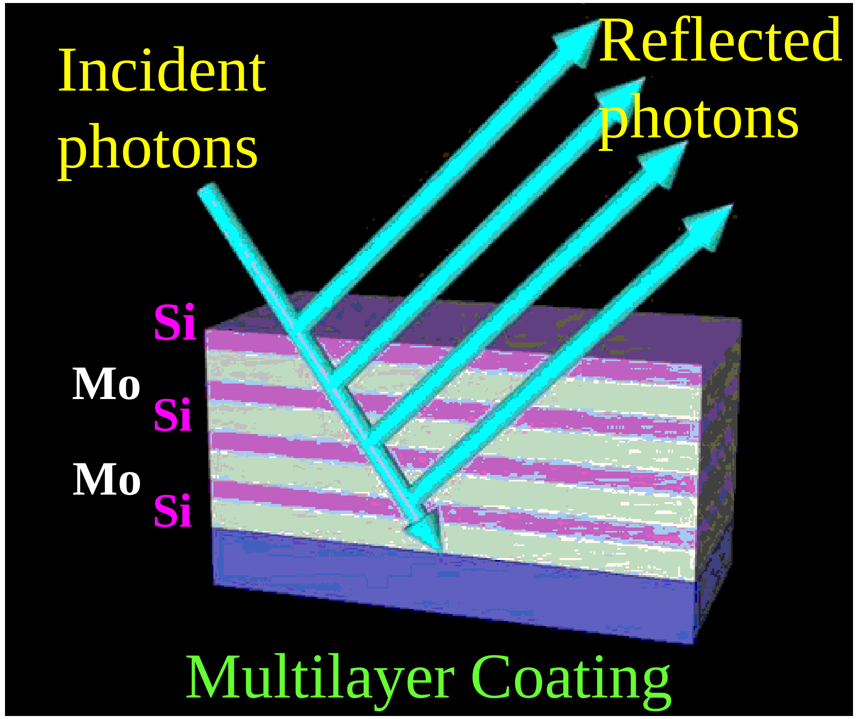
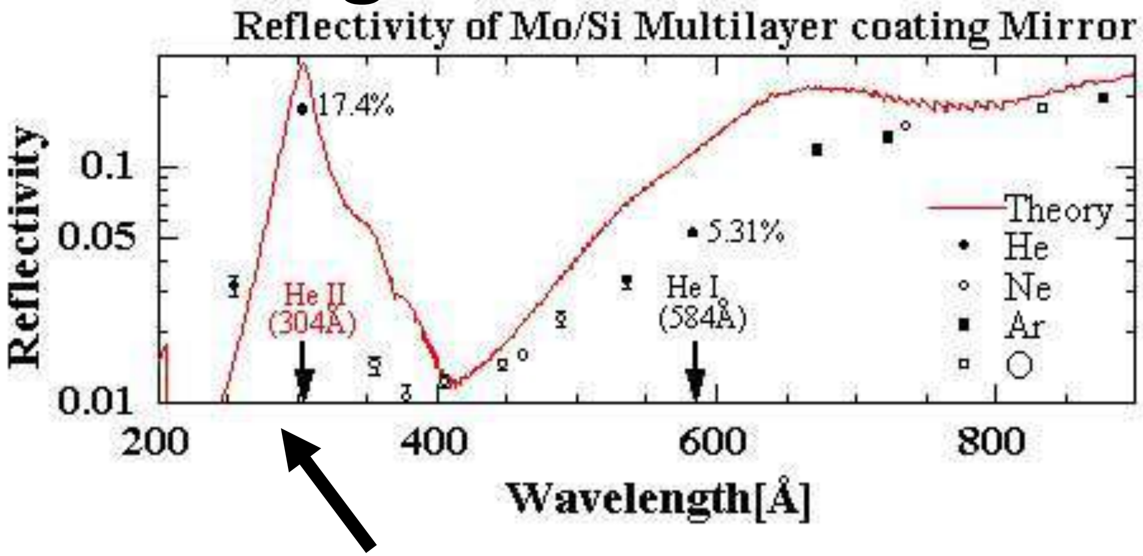
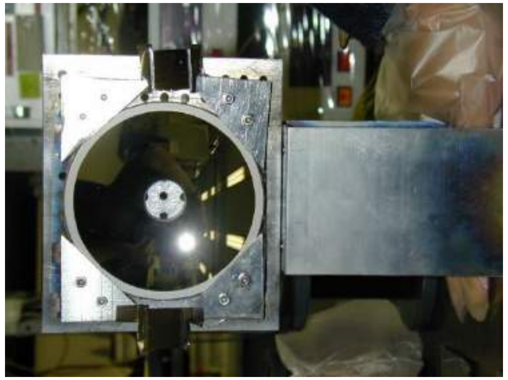


Figure2: In the late 90s, we started to develop a normal-incident and highly reflective coating in EUV for geophysical purpose. The multi-layer coating, which consists of twenty pairs of molybdenum and silicon layers, can enhance the reflectivity at the preferred wavelength.



We have achieved one-order magnitude higher reflectivity at the preferred wavelength than conventional.



Flight model of the mirror (D=6cm)

Multi-layer coating mirror realizes high efficiency at normal incidence.

Newly developed optics was demonstrated!.

Inside-out observation

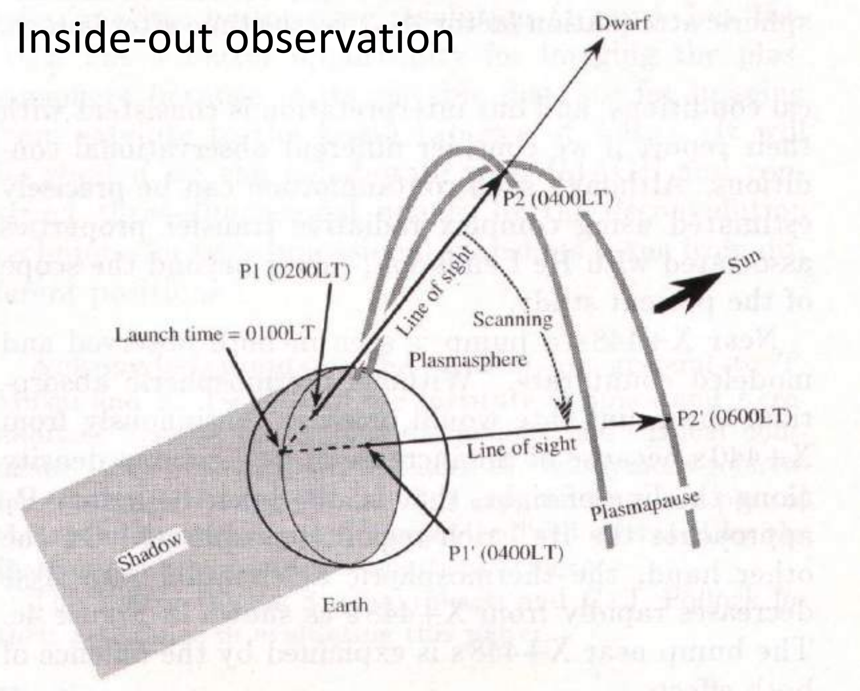
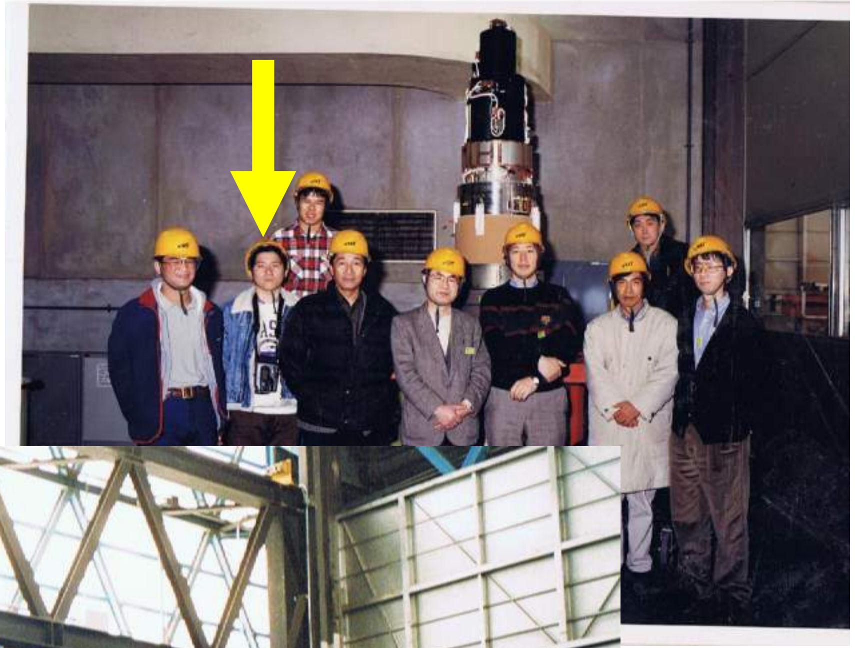


Figure 3. Diagram of observation viewing geometry in which $P1$ and $P2$ are the initial inner and outer boundaries of sunlit area within the plasmasphere while $P1'$ and $P2'$ are the final inner and outer boundaries at the dawnside of the sunlit area.



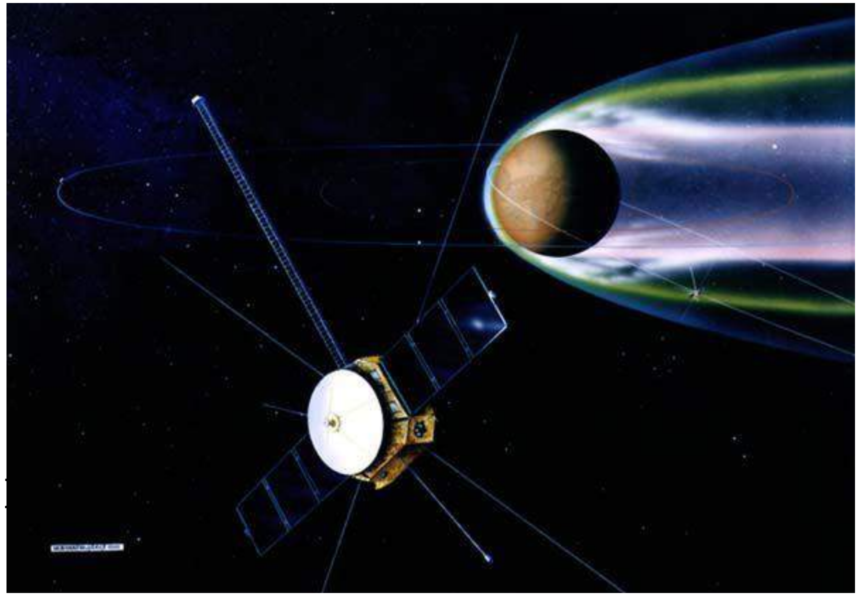
We succeeded in manufacturing of highly effective optics and employed it to the sounding rocket experiment. [*Yoshikawa et al.*, JGR, 1997]

This is a breakthrough which directs us to global imaging missions.

Overview of the NOZOMI mission
Japanese Mars orbiter

Where did Martian water go?

Atmospheric outflow from Mars



Spacecraft Mass

dry mass 255.86 kg

(science payload: 35 kg)

propellant 279.5 kg

Launch Vehicle: <u>M-V-3</u>

Mission Sequence (originally planned)

launch July 3, 1998

Mars Orbit Insertion October 1999

(This mission was failed during cruising phase to mars,

Orbit (originally planned)

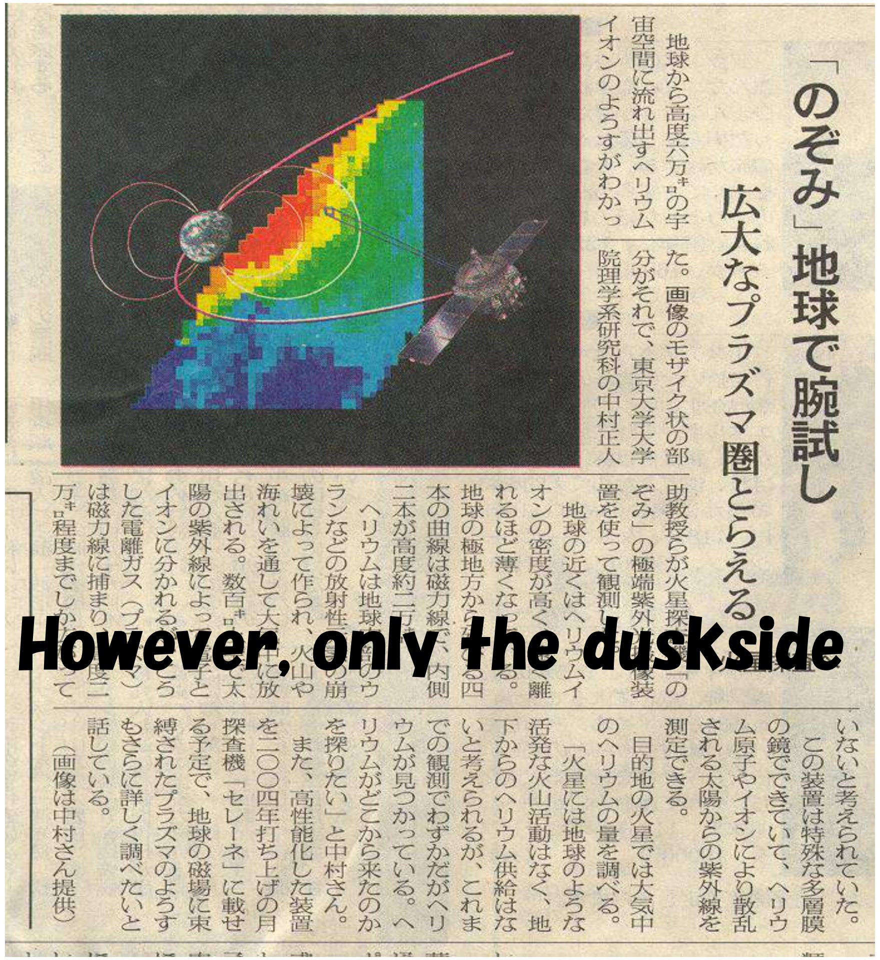
periapsis 150 km

apoapsis 15 Rm

Image the plasmasphere in EUV (15 years ago)

The most well-established newspaper in Japan (maybe)

[朝日新聞, January]



「のぞみ」地球で腕試し

広大なプラズマ圏とらえる

地球から高度六万キロの宇宙空間に流れ出すヘリウムイオンのようすがわかった。画像のモザイク状の部分がそれで、東京大学大学院理学系研究科の中村正人助教授らが火星探査機「のぞみ」の極端紫外[illegible]像装置を使って観測し[illegible]。

地球の近くはヘリウムイオンの密度が高く、離れるほど薄くな[illegible]る。地球の極地方から[illegible]る四本の曲線は磁力線で、内側二本が高度約二万[illegible]

ヘリウムは地球[illegible]のウランなどの放射性[illegible]の崩壊によって作られ、火山や海れいを通して大[illegible]中に放出される。数百キロで太陽の紫外線によって[illegible]子とイオンに分かれるところ[illegible]した電離ガス（プ[illegible]マ）は磁力線に捕まり[illegible]度二万キロ程度までしか[illegible]って

いないと考えられていた。

この装置は特殊な多層膜の鏡でできていて、ヘリウム原子やイオンにより散乱される太陽からの紫外線を測定できる。

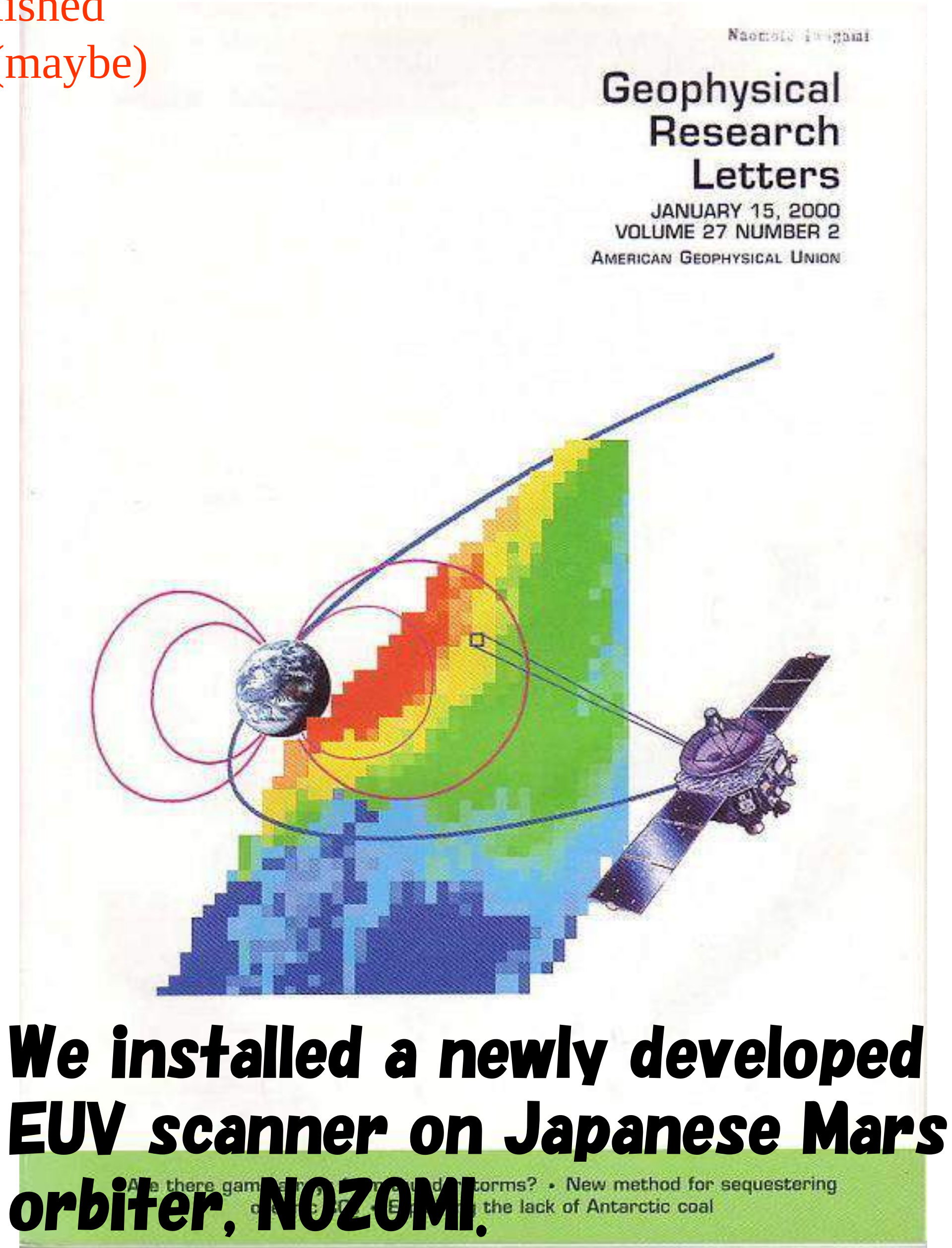
目的地の火星では大気中のヘリウムの量を調べる。

「火星には地球のような活発な火山活動はなく、地下からのヘリウム供給はないと考えられるが、これまでの観測でわずかだがヘリウムが見つかっている。ヘリウムがどこから来たのかを探りたい」と中村さん。

また、高性能化した装置を二〇〇四年打ち上げの月探査機「セレーネ」に載せる予定で、地球の磁場に束縛されたプラズマのようすもさらに詳しく調べたいと話している。

（画像は中村さん提供）

However, only the duskside



We installed a newly developed EUV scanner on Japanese Mars orbiter, NOZOMI.

IMAGE/NASA mission (15 years ago, 2000)

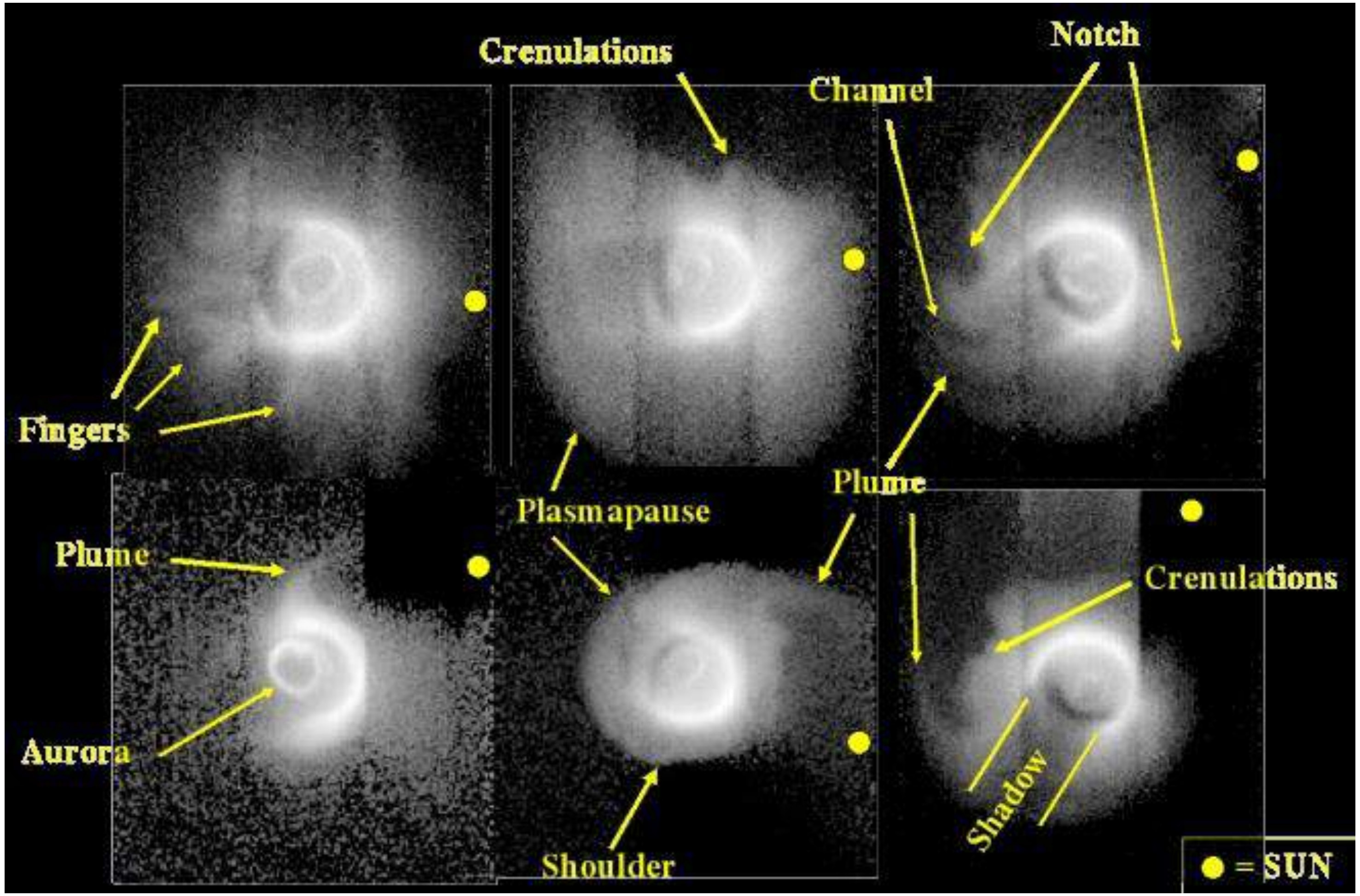
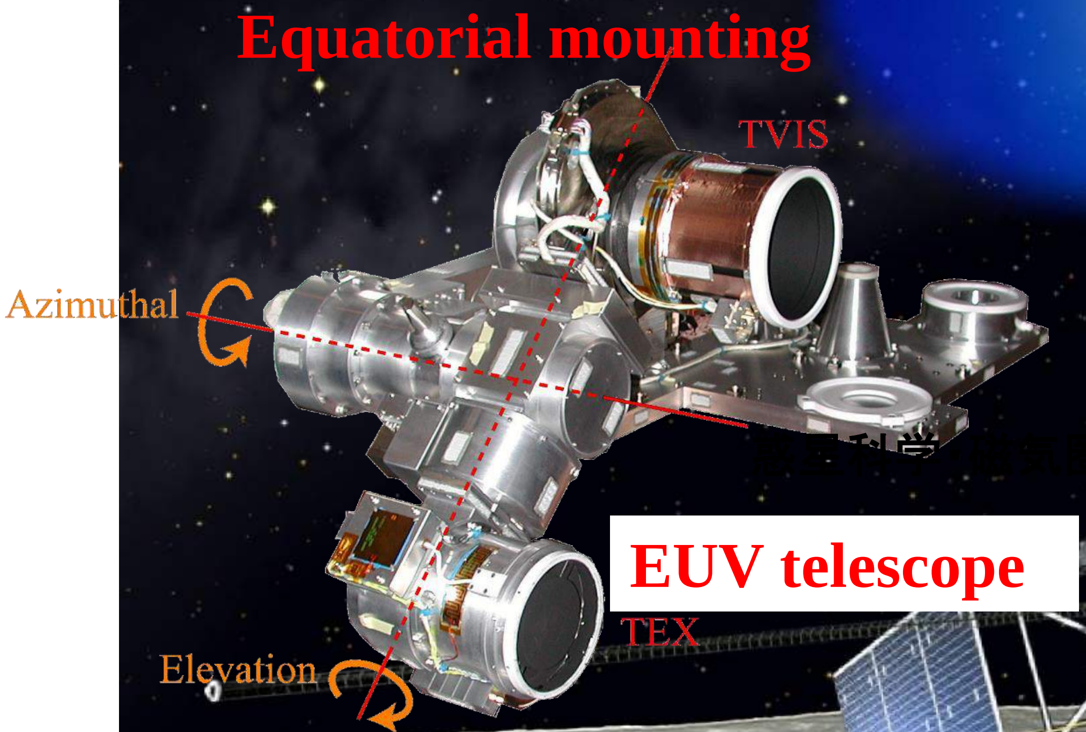


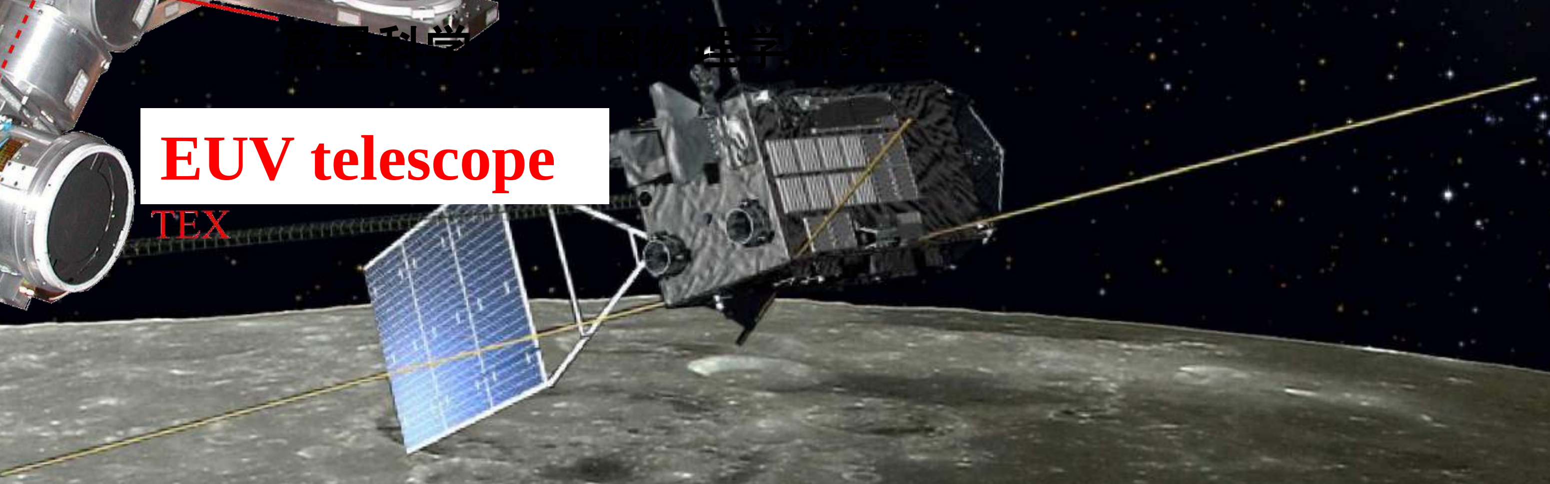
Figure : One year later, NASA carried out excellent mission to dedicate to plasmaspheric imaging in EUV. It took movie of the whole plasmasphere from the above. Unique features, such as finger, shoulder, and notch, were identified and named by IMAGE mission.

More recently,

EUV Imager on Kaguya spacecraft



Kaguya is the Japanese lunar orbiter, launched in 2007 after the IMAGE mission was ended. Kaguya investigated lunar surface, plasma environment, magnetic field, etc. Two telescopes were on the equatorial mounting



Our imager was unique instrument on Kaguya, which dedicated to geophysics.

Perspective from the Moon

Constantly slow rotation (2-hour lagged from the Earth's one).

Looking down from the north.

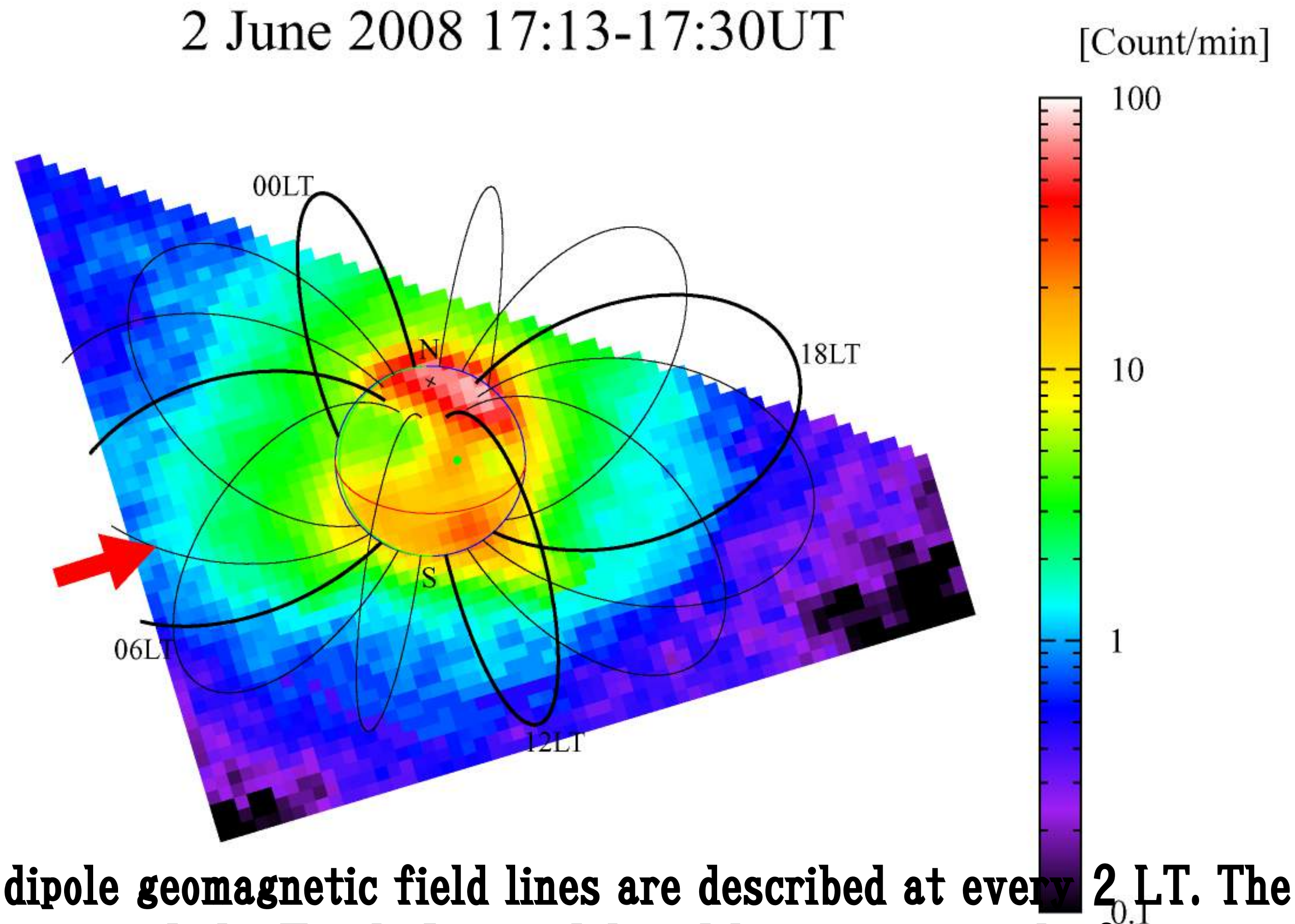
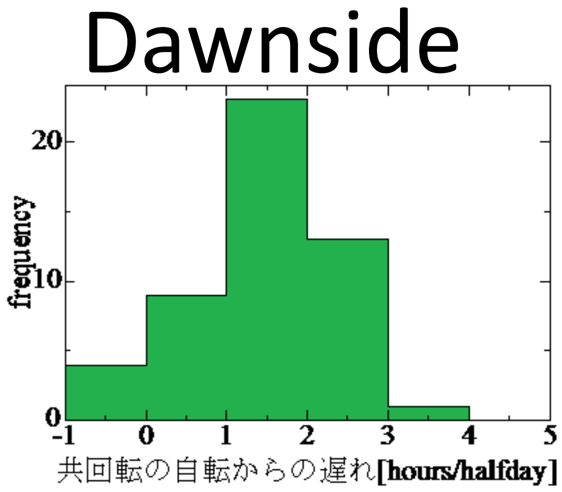


Fig. 5: The dipole geomagnetic field lines are described at every 2 LT. The plasma ridge rotates around the Earth. It was delayed by approximately 2 hours in comparison with the Earth's rotation.

G. Murakami, et. al., Earth, planet and Space, 2010

Delay behind the rotation of the Earth



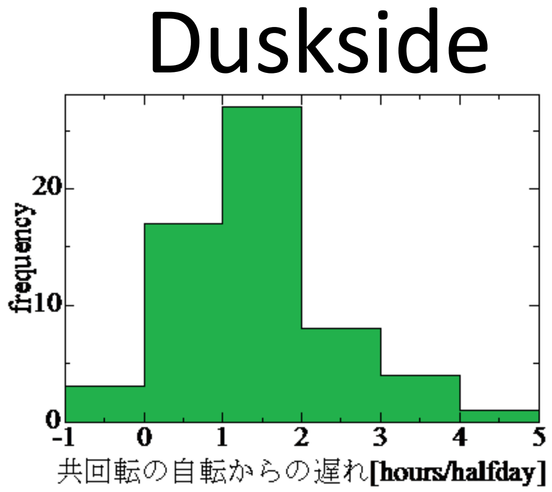
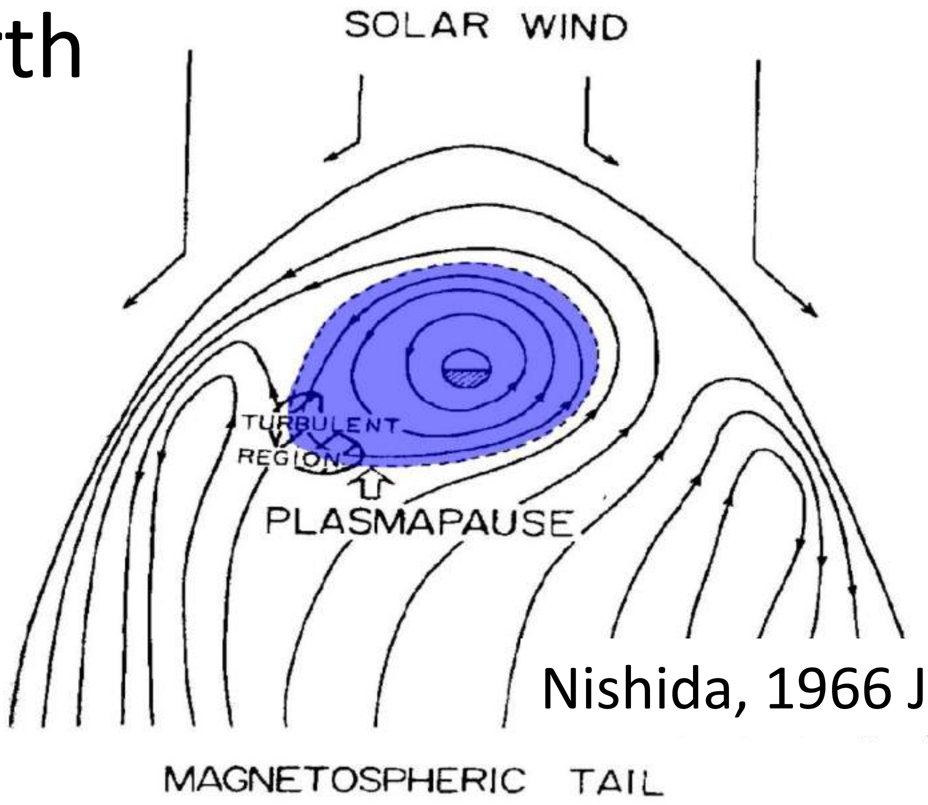


Figure 11: Delay of the plasmaspheric rotation behind the Earth's rotaion. The plasmasphere by approximately 1 hour slowly rotates around the Earth in both side.



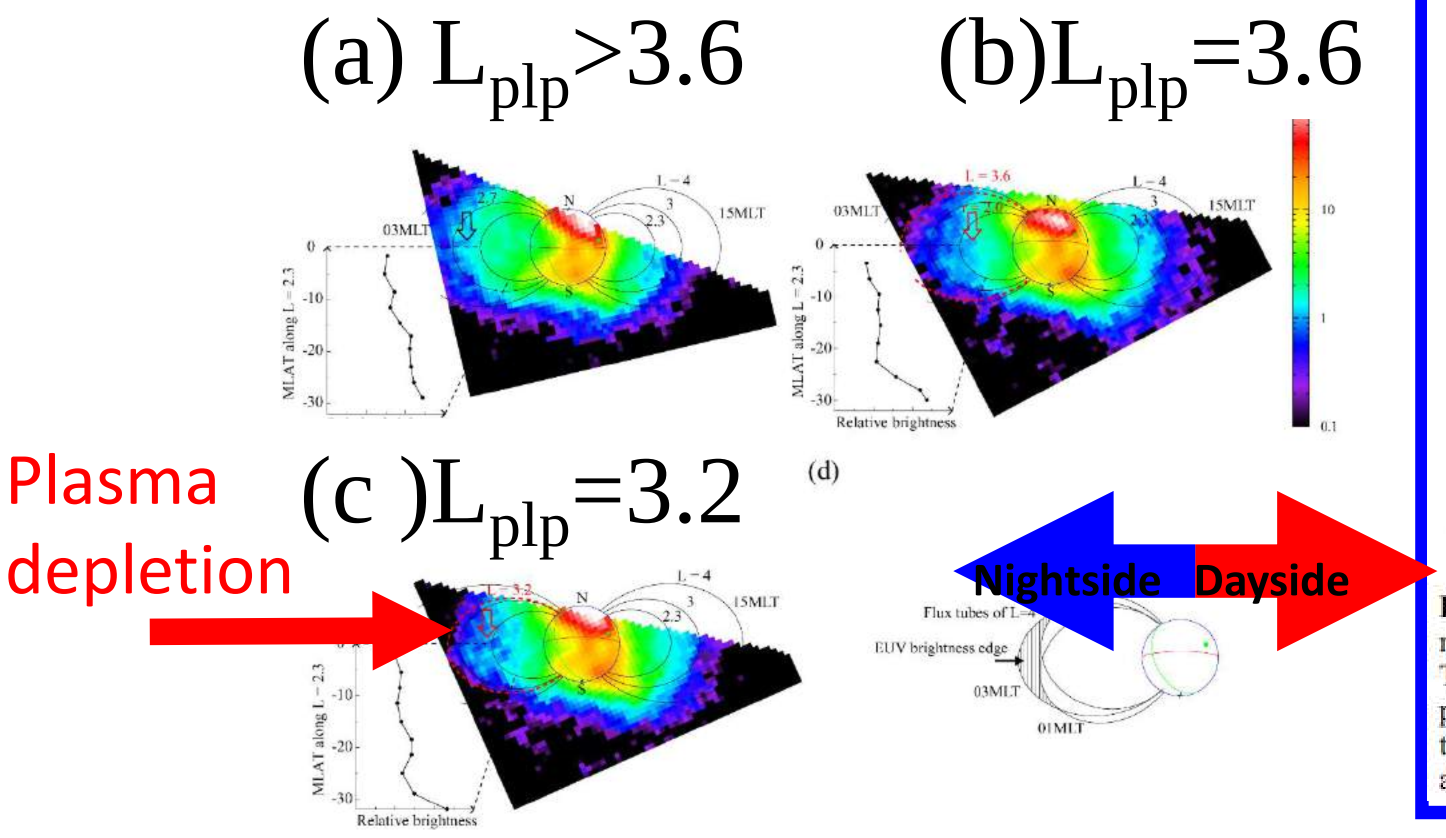
Nishida, 1966 JGR

Figure 1: According to the plasmaspheric formation theory proposed by Nishida (1966), the rotation in the duskside plasmasphere should be lagged in comparison with the Earth's rotation due to the dawn-to-dusk electric field induced by solar wind.

The plasmasphere rotates at constantly slow speed! This is new finding.

Plasmaspheric evolution from the side view

Donkey Ear



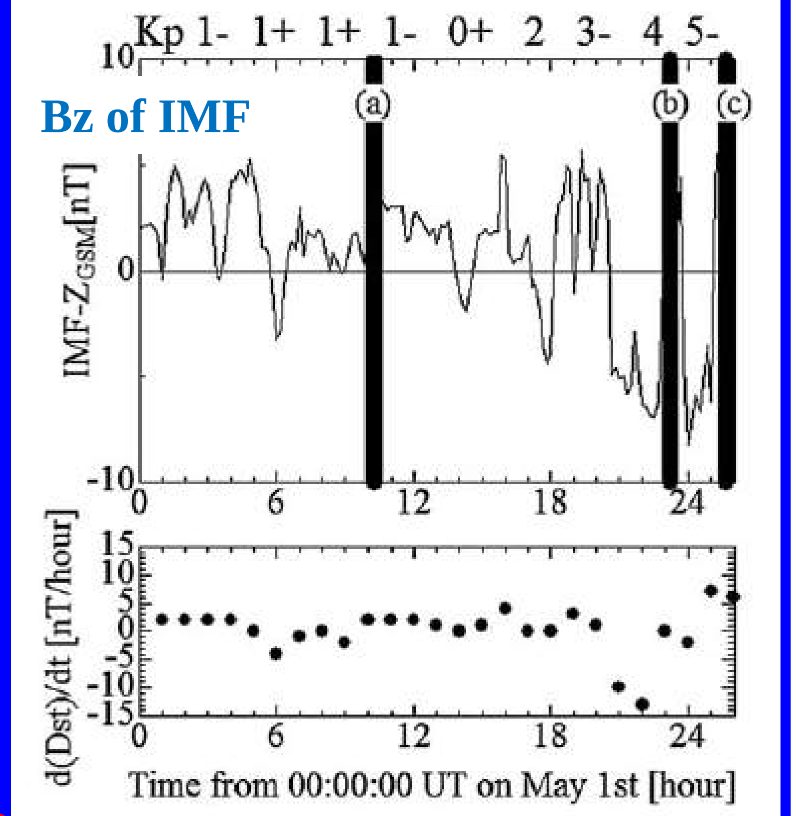
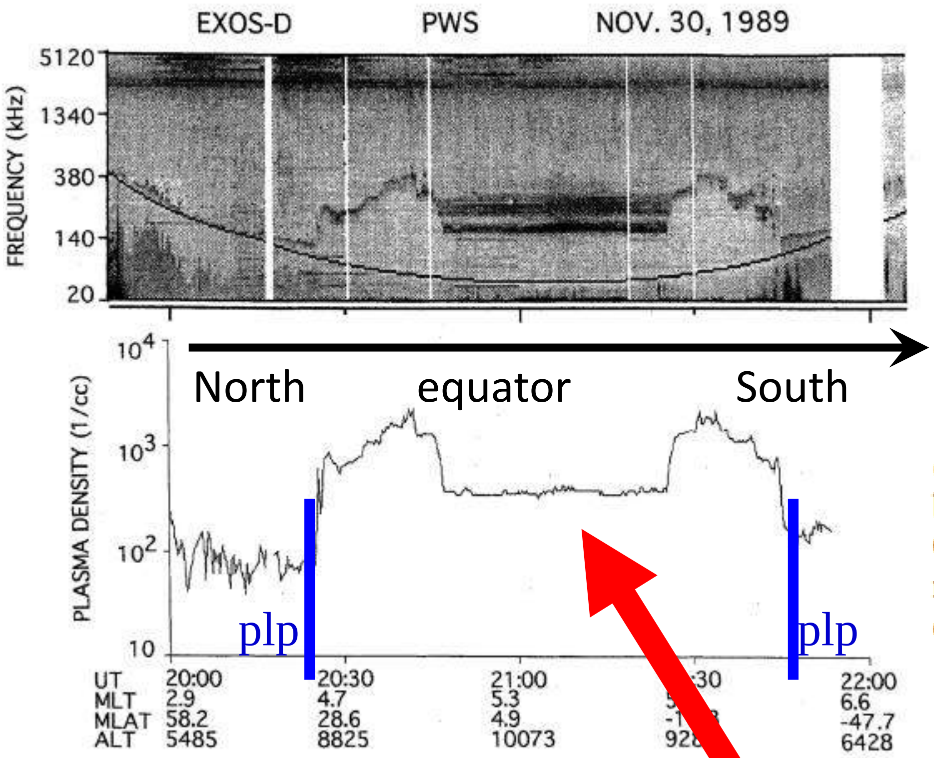


Figure 2. IMF z component obtained by the ACE measurement, Kp index, and the time derivative coefficient of Dst. The ACE data are presented with a 1 h time delay to compensate for the propagation from the measurement point to the Earth. The observation windows for Figures 1a, 1b, and 1c are indicated by vertical bars.

Figure2: During a northward tendency of IMF, the plasmasphere is stable. The southward turning of IMF initiates an inward motion of the nightside plasmasphere, the plasmasphere started to shrink to the lower L-values. This is the first time to witness the plasmaspheric evolution *"from side"*. There was plasma depletion near the equator.



Plasma depletion on the equator:
found by in-situ measurement in the past

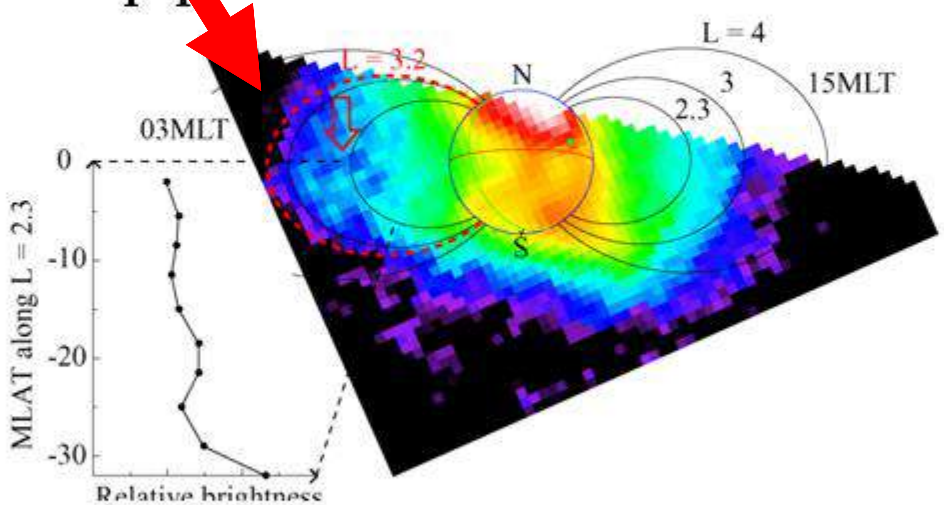
[20] An apparently related phenomenon was reported by *Oya* [1997]. Oya studied electron density profiles obtained by the polar orbiter (EXOS-D) with an apogee of 10,000 km. On some orbits during periods of recovery after disturbances, regions of depressed plasma densities were found near the equator at L = 2.5. When apogee was near the equator, the

Fig. 3. Example of the donkey ears phenomena revealed by the upper hybrid w... (EXOS-D) satellite (A) and obtained electron density (B). The obtained ele... which apogee is in the equator region around 10,000 km, in this case, show... of the quiet time plasmasphere in the same region. There are shock like conta... in the latitude around 47~48° both in the northern and southern hemispheres... along the approximately symmetrical satellite orbit with respect to the mag... density profile in this period is called "donkey ears phenomena" (after Oya...

He named

the off-equatorial peaks "donkey ear"......?

L_{plp}=3.2



Skip?

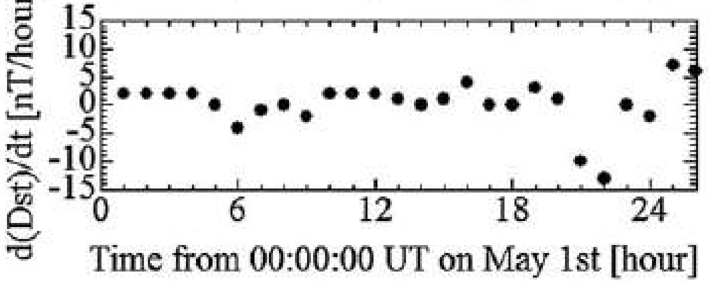


Figure 2. IMF z component obtained by the ACE measurement, Kp index, and the time derivative coefficient of Dst. The ACE data are presented with a 1 h time delay to compensate for the propagation from the measurement point to the Earth. The observation windows for Figures 1a, 1b, and 1c are indicated by vertical bars.

Table 2. Travelling time of drifting plasma.

Time varying rate of Dst	5nT/h	10nT/h	30nT/h
Normalized mean location of the ring current, R_{se}	5	4.5	4
Normalized position of the apogee of the Akebono satellite, R_l	2.5	2.5	2.5
Initial location of the start of the drift motion	4	3.5	3
Estimated transit time	7.37×10^4sec (20.5h)	3.13×10^4sec (8.7h)	6.875×10^3sec (1.9h)

"Donkey Ear" proposed by Oya (1997)

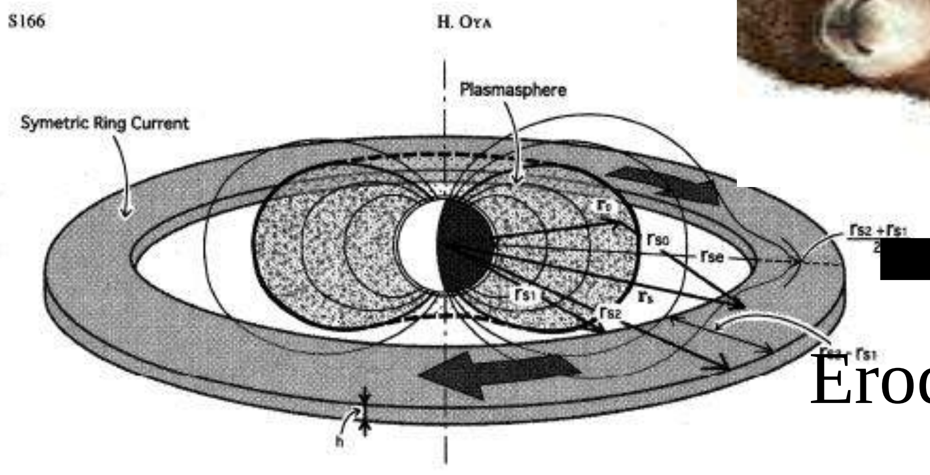
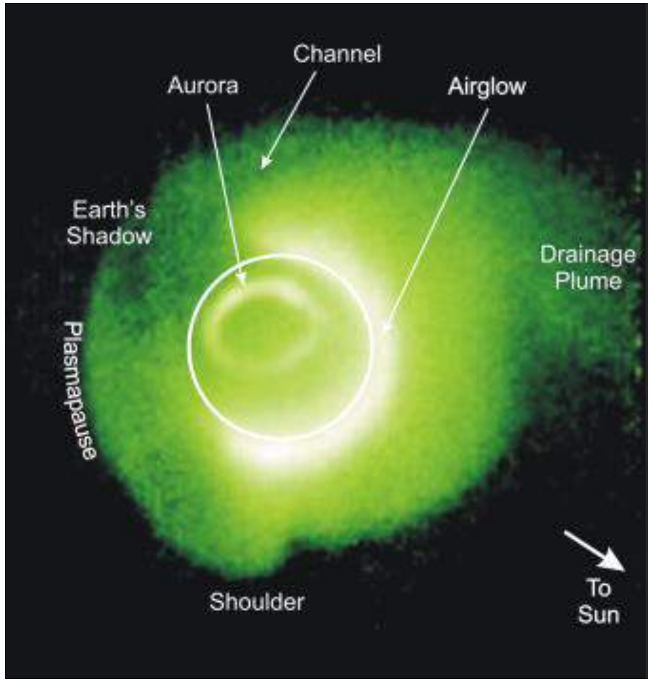


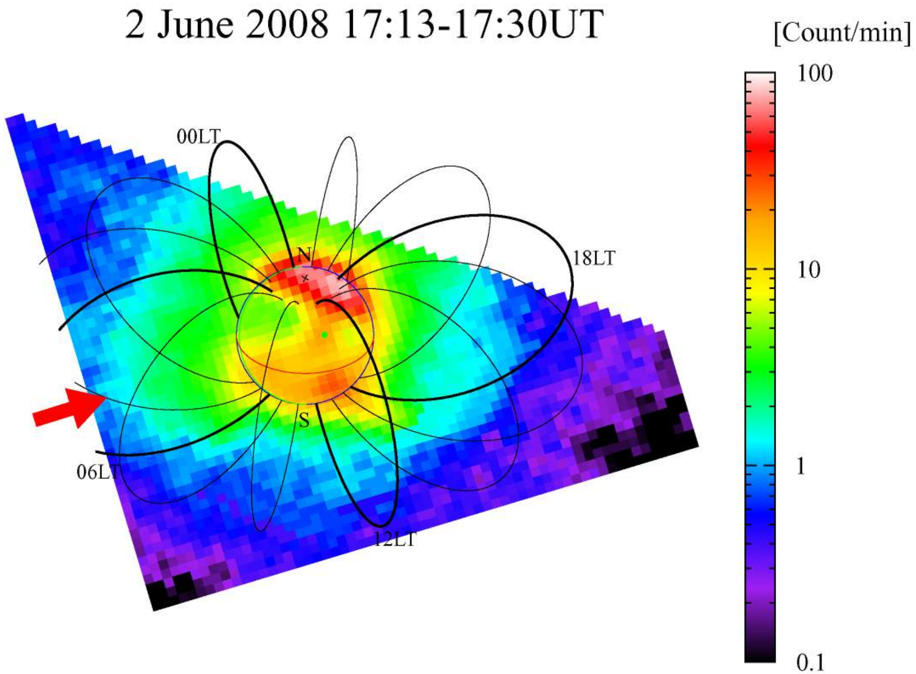
Fig. 6. Model of the symmetric ring current. Region of ring current pervades from r_{s1} to r_{s2} in radial direction with constant thickness of h. Magnetic field intensity at the position r_0 caused by the ring current can be expressed by using the Dst that also can be expressed by the integration effects of ring current whose element is located at the distance of r_{se} (see Eqs. (10)–(12)).

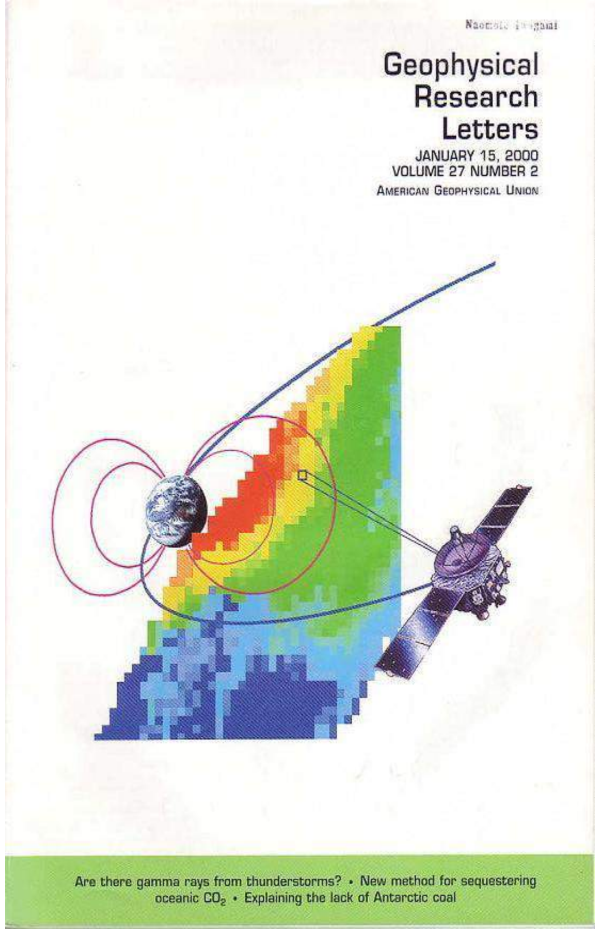
Fig. 5: Plasmaspheric material is eroded outward during a phase of decreasing Dst. A time variation of ring-current (Dst by -5 nT / h) might initiate the erosion. Unfortunately, AKEBONO spacecraft missed the event in 2008 due to the orbital and operational limitations. We are searching for other measurement to prove the existence of *"donkey ear"* during this period.

Technical issues

Why is Japanese image quality lower than NASA’s ?







We have two points to overcome in EUV optics.

1. Signal-to-Noise ratio should be increased (in multi-layer coating).

2. Optical aberration should be reduced

The first point is SNR in Multi-layer coating

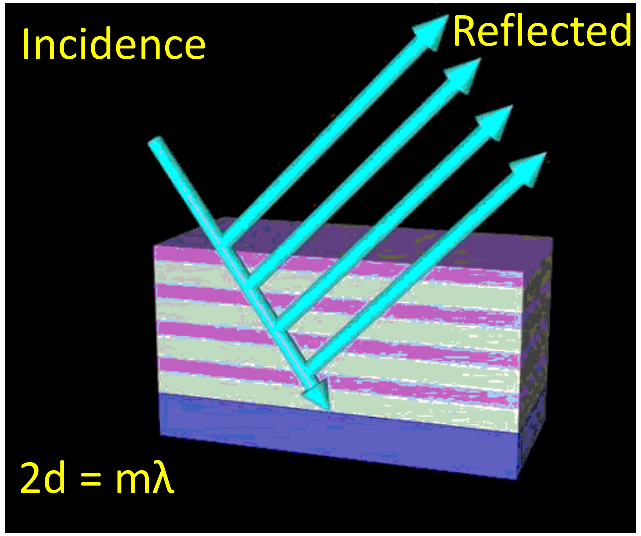


Figure 1: A pair of Uranium and Aluminum can reduce the contamination from He I (58.4nm)

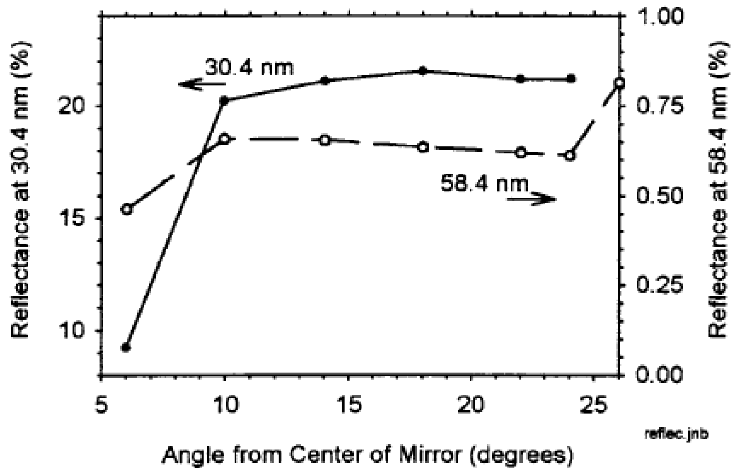


Figure 11. Reflectivity of a typical flight mirror as a function of angle measured from the center of the mirror.

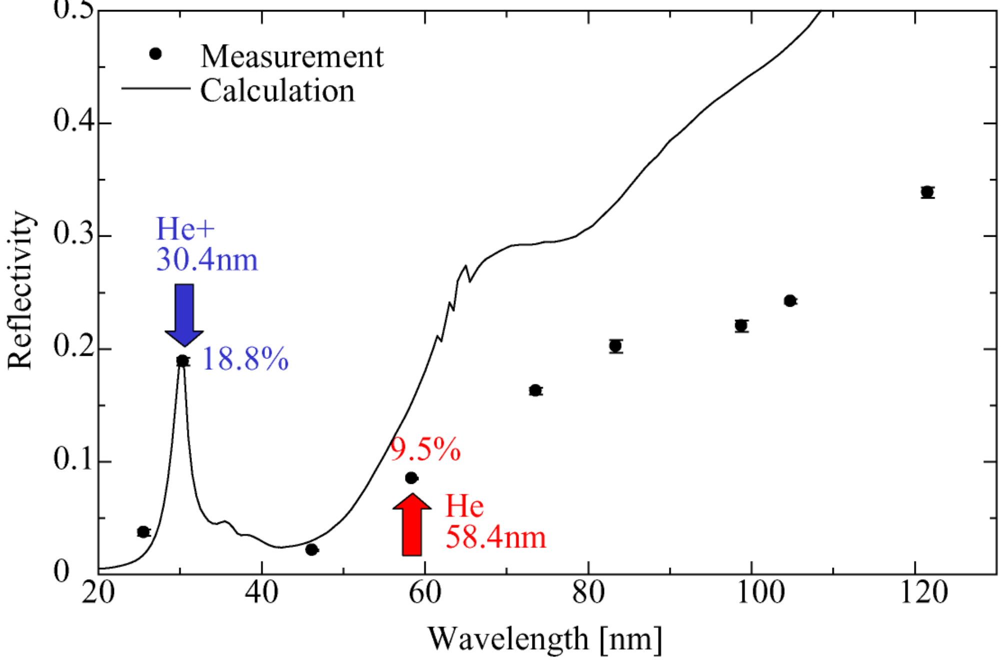


Figure 2: At the surface of the material, there is residual reflectivity at neutral helium emission at 58.4nm (He I).

Domestic rule was a hurdle for us.

Newly developed multi-layer coating

- to catch up with NASA

- to reduce the contamination from He I(58.4nm)

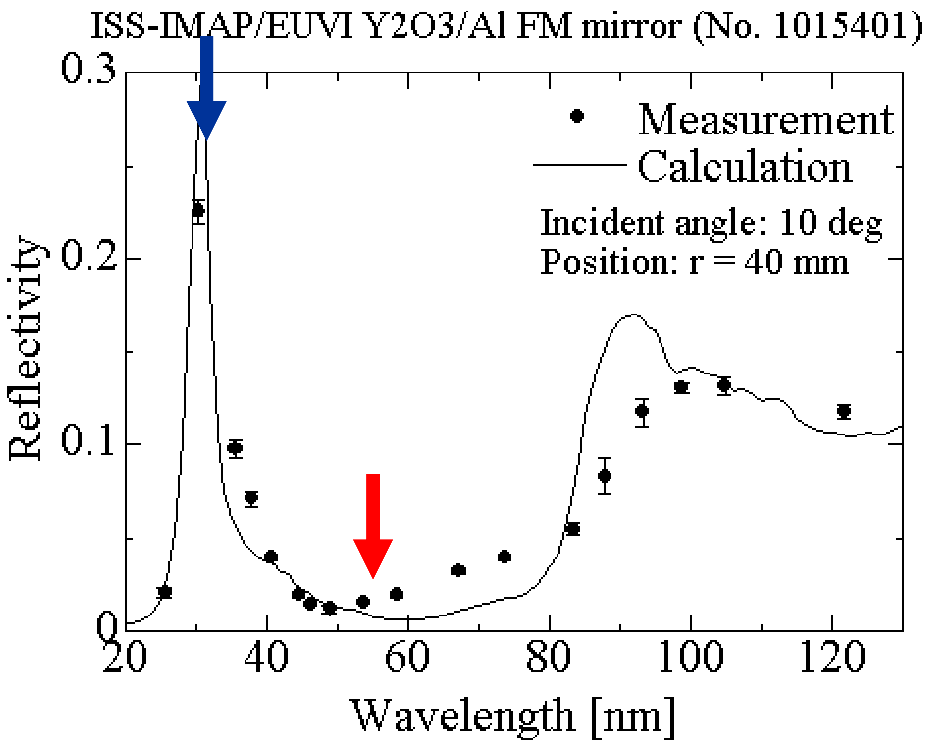


Fig 6. Instead uranium, we employ Y2O3. I can reduce the contamination and realize the similar level of NASA’s

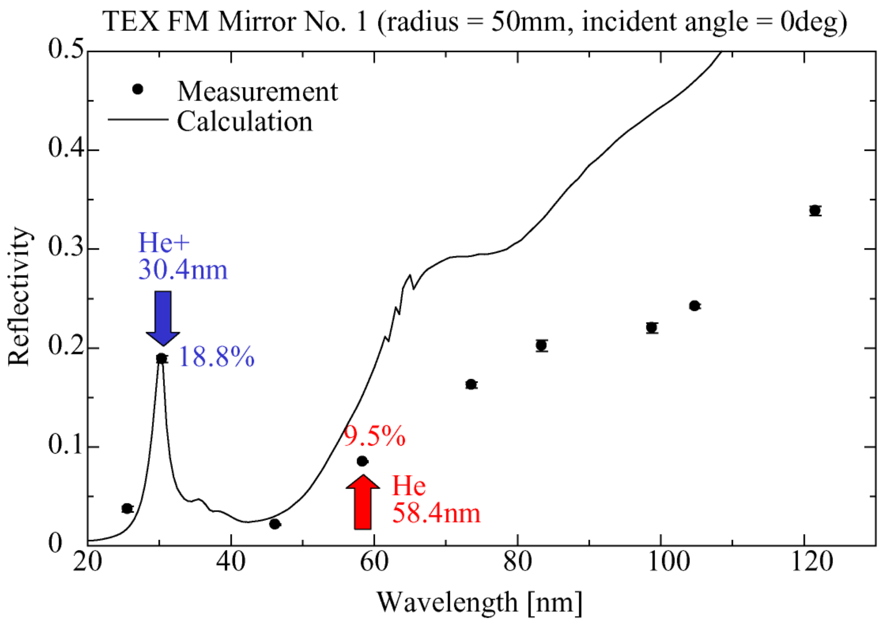


Fig 5. conventional mirror, consisting of Mo and Si. The reflectivity at 58.4 nm is relatively high.

We have found an alternative.

The second point is detector surface.

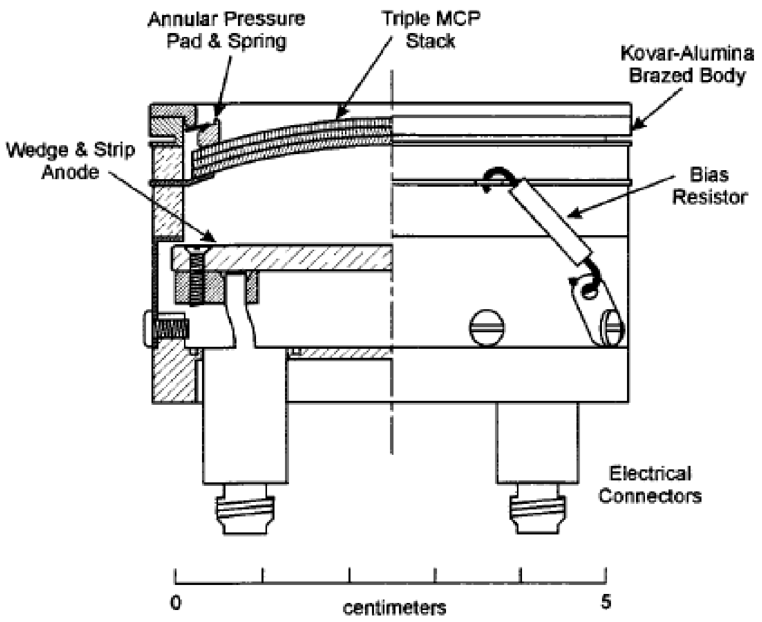


Figure 15. EUV detector design cutaway showing the individual elements of the detector.

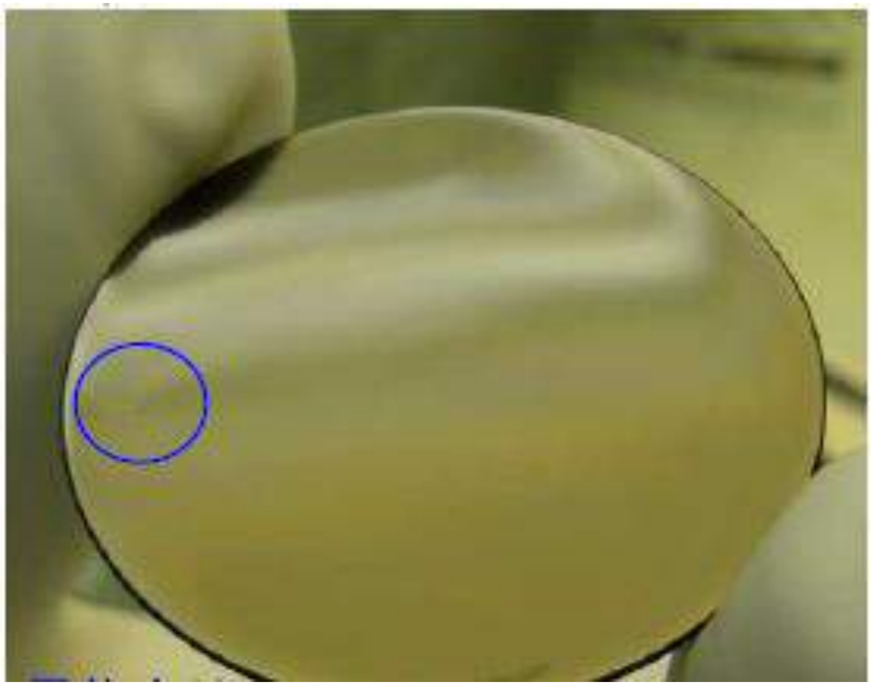


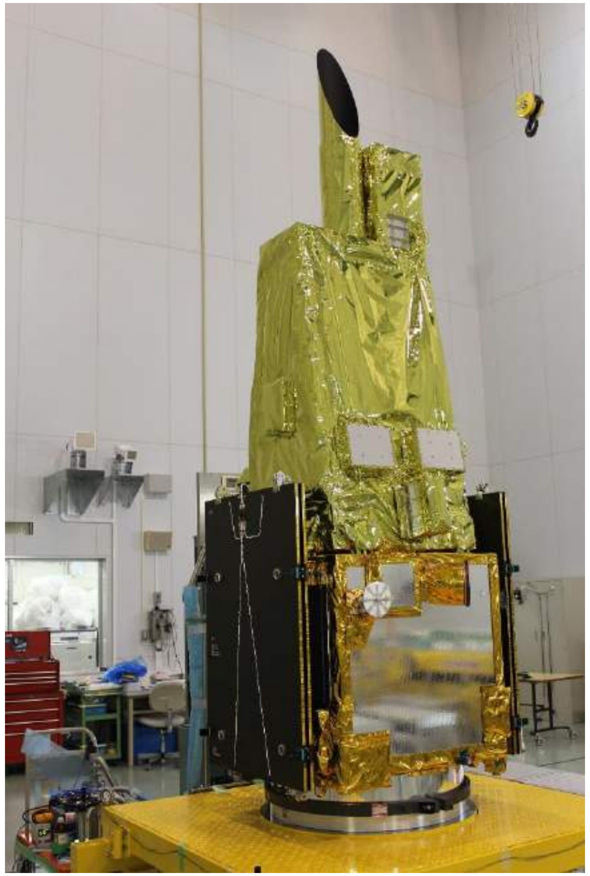
Figure 11: We have succeeded in manufacture of curved MCP with the help of MAMAMATSU photonics in Japan.

Image quality has increased!

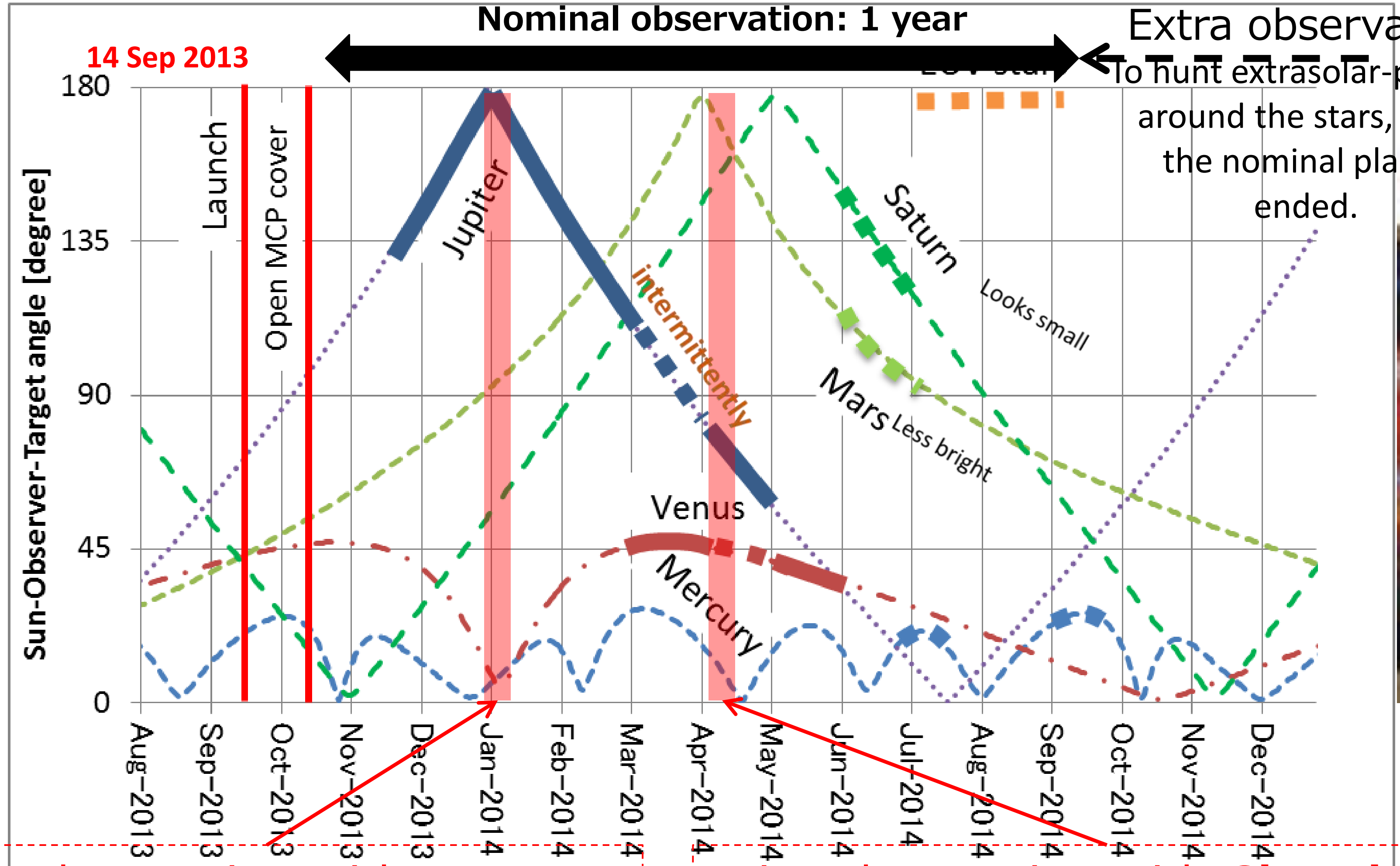
EXCEED on Hisaki spacecraft

EXCEED（boarded on Hisaki satellite）is an **existing** Earth-orbiting spectrometer working in the **EUV** spectral range, still observing planets

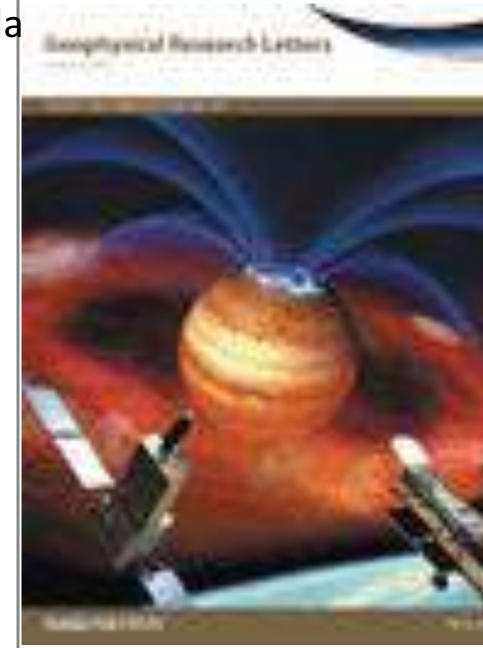
Figure 1: Sprint-A (Hisaki) with EXCEED was successfully launched by epsilon rocket from Uchinoura in 2013



Observation history of EXCEED



Extra observation
To hunt extrasolar-planets around the stars, after the nominal pla ended.



GRL cover image, this month

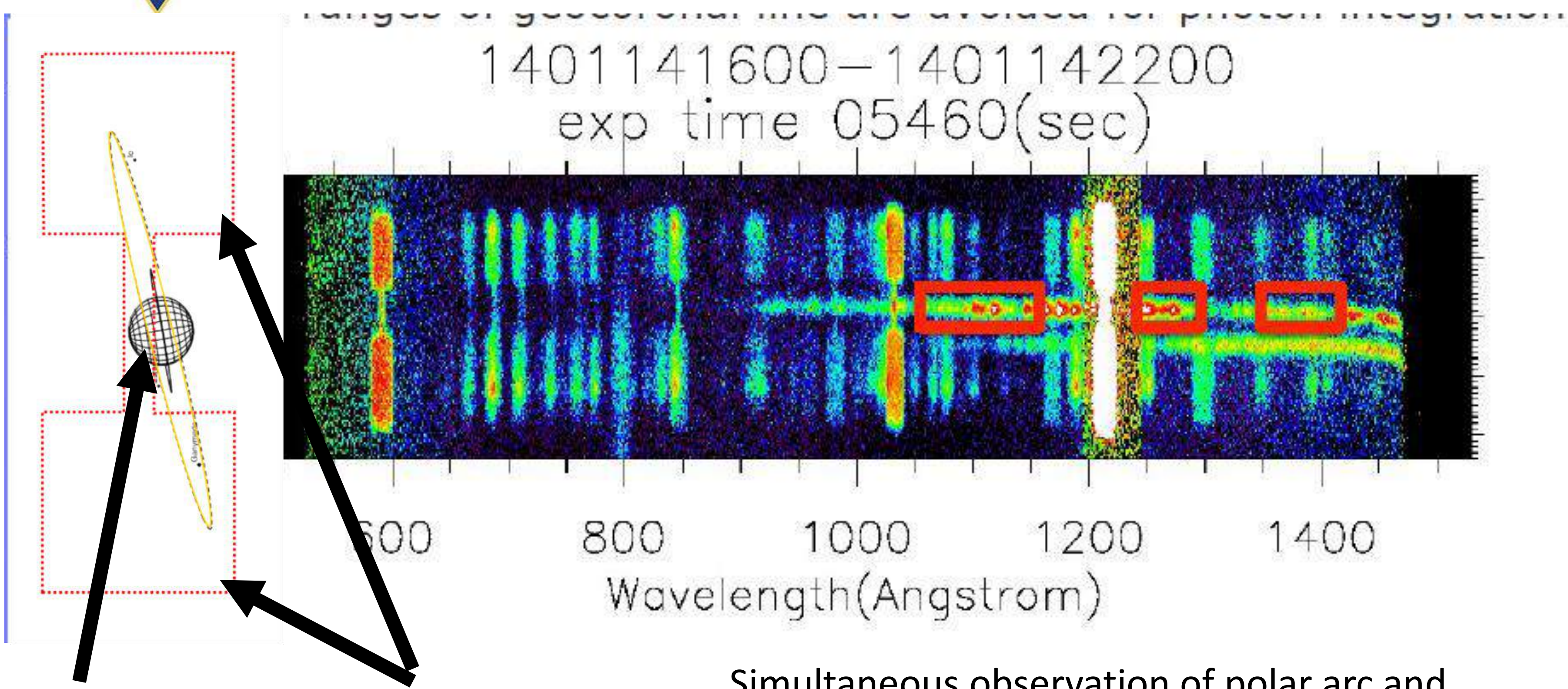
Joint observation with **HST**(UV)

Joint observation with **Chandra**, **Suzaku** (X-ray)

Jupiter

Average, Nominal, Usual feature of Jupiter seen by EXCEED

dumbbell

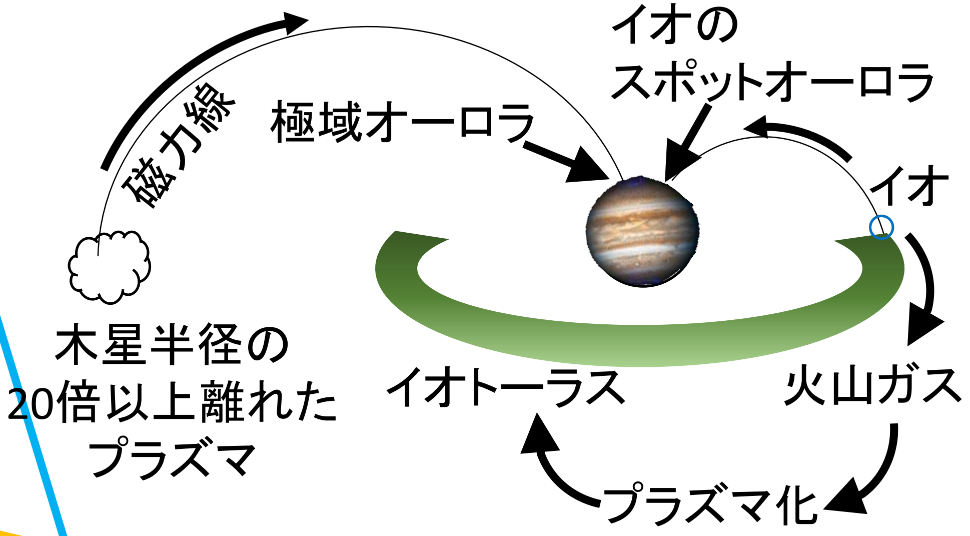


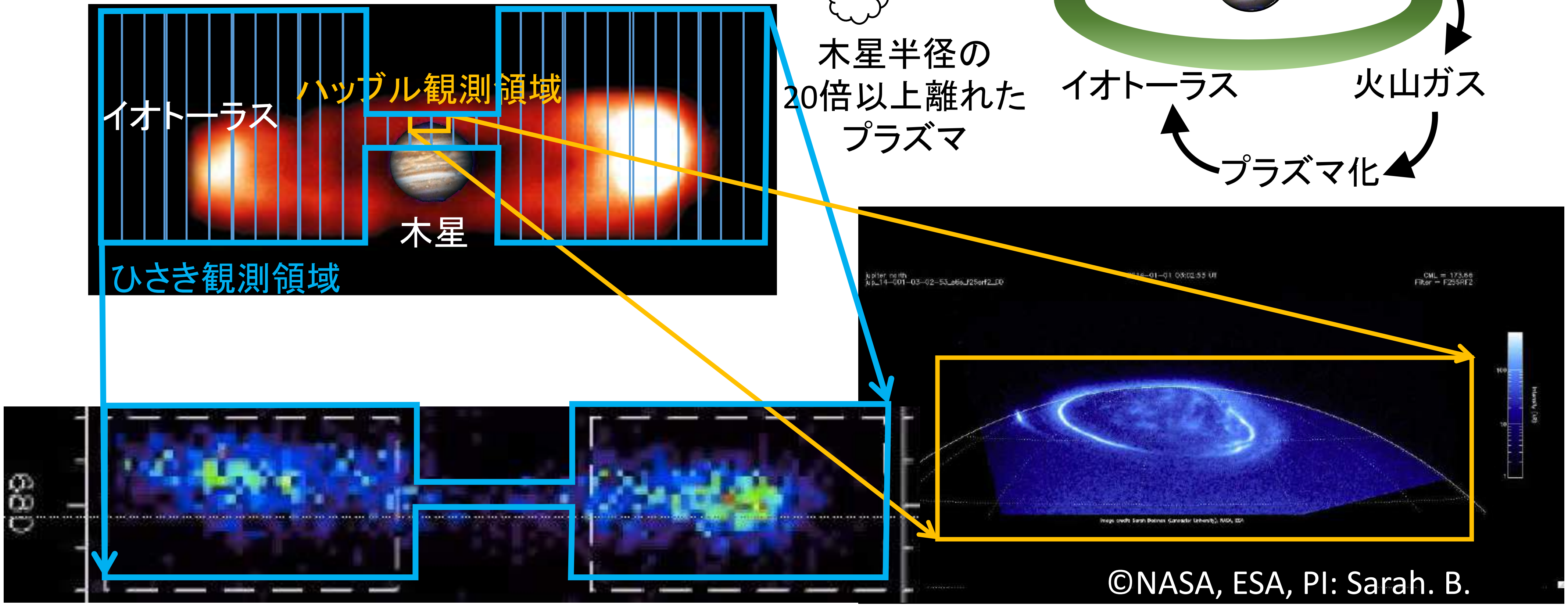
Northern pole IPT

<u>Simultaneous observation of polar arc and IPT are feasible.</u>

EXCEED-HST Jovian observation campaign

EXCEED has observed Io Plasma torus, while HST witnessed Jovian aurora.

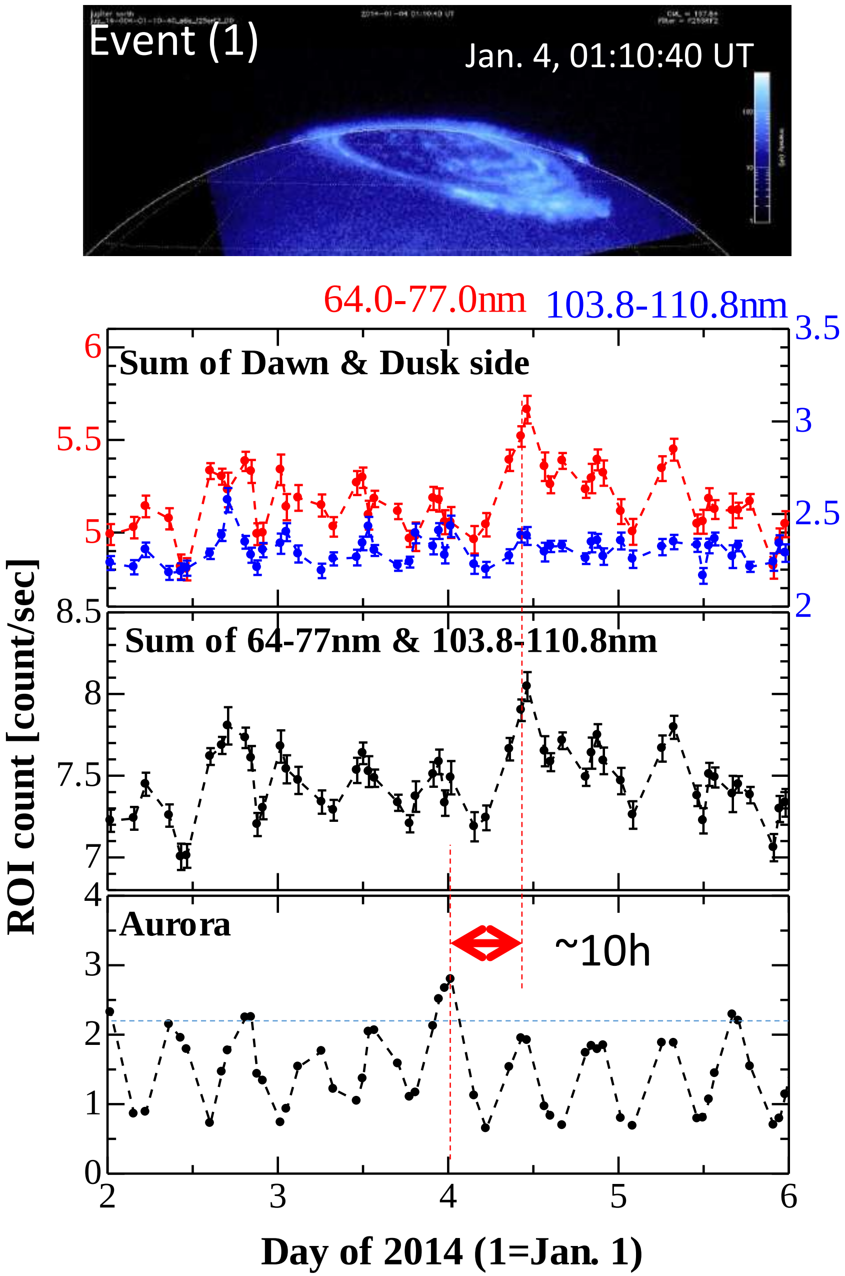


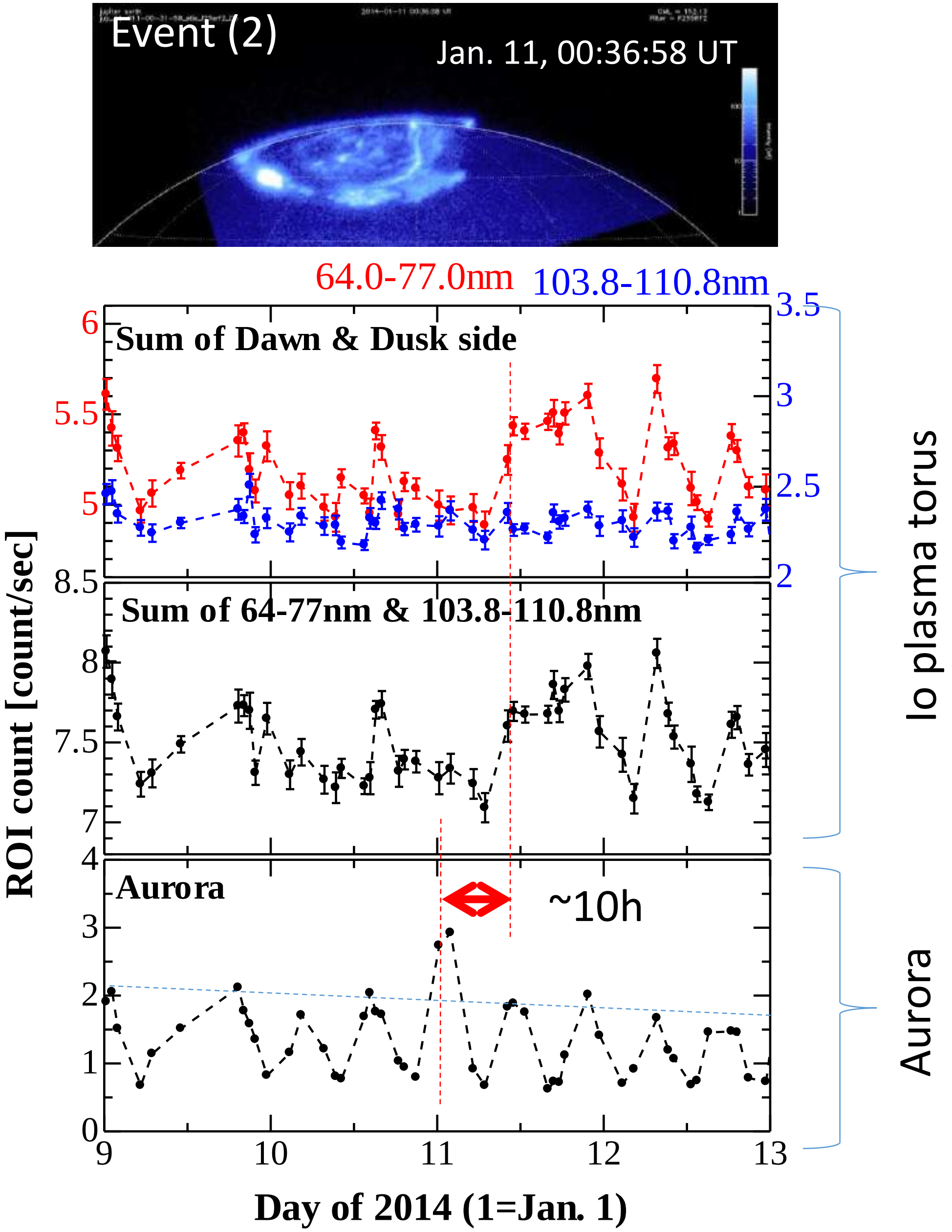


EXCEED (12/20～1/15観測分) (1/1～1/16観測分)

Figure 3. EXCEED has measured the variation of IPT in EUV, while HST has observed aurora with

Continuous observation of EXCEED with HST.



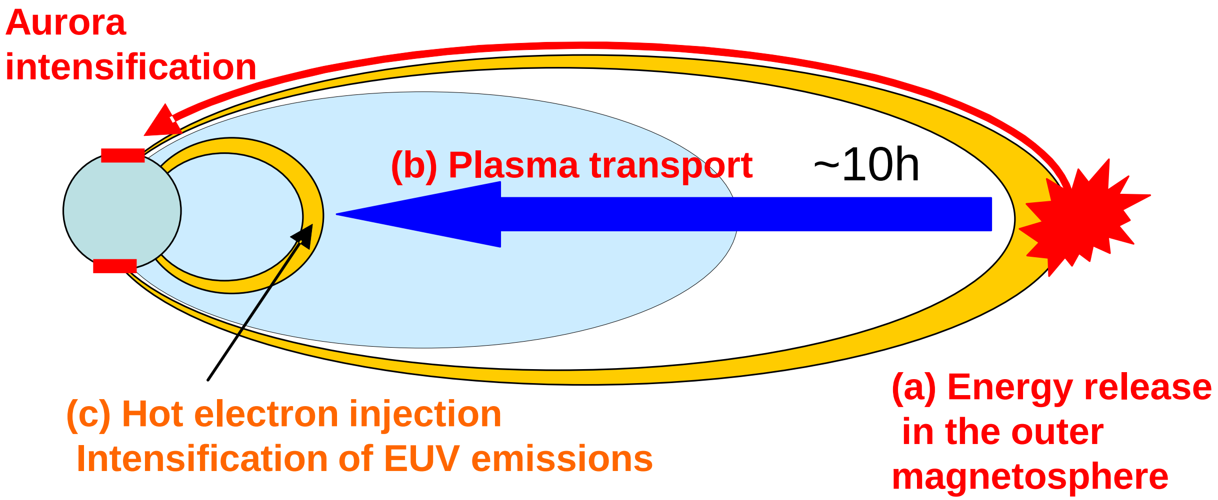


We_have shown that brightening of aurora is earlier than that of IPT by 10 hours!

Plasma/energy transport in the radial direction

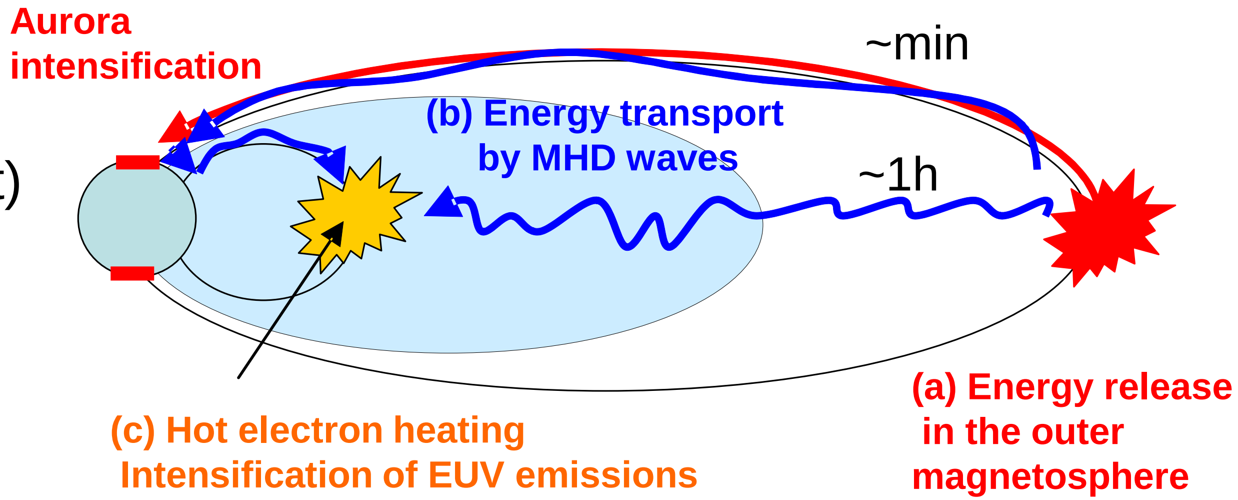
Hot electron injection by inward plasma transport

Inward plasma transport
(interchange ?)
Time scale :
<u>~10 hours</u>
(a few hours/RJ
near the torus)

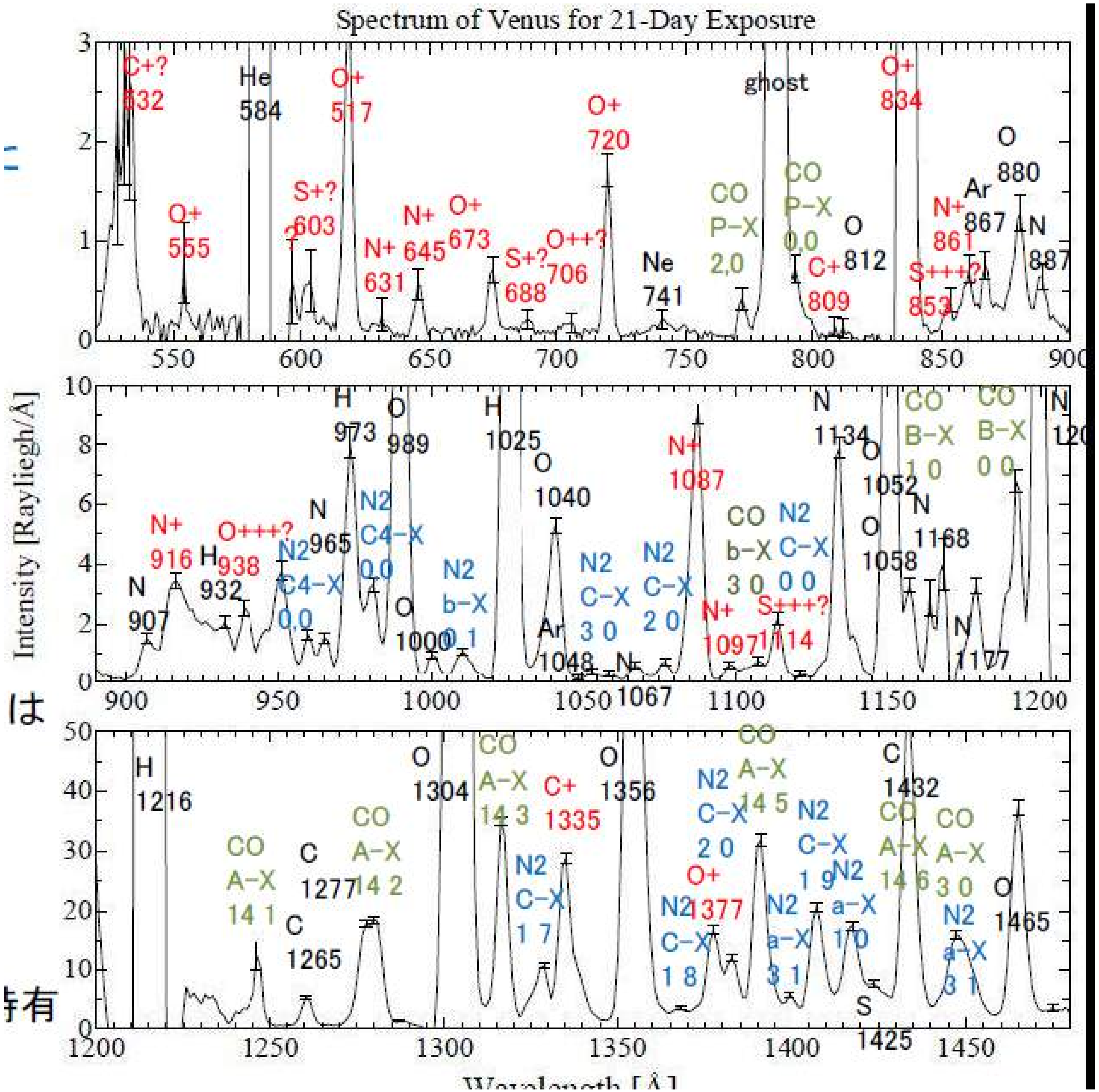


Energy transport by MHD waves (via equator or polar regions)

MHD wave
(via equator or high-lat)
Time scale :
<u>~1 hour or less</u>



Venus



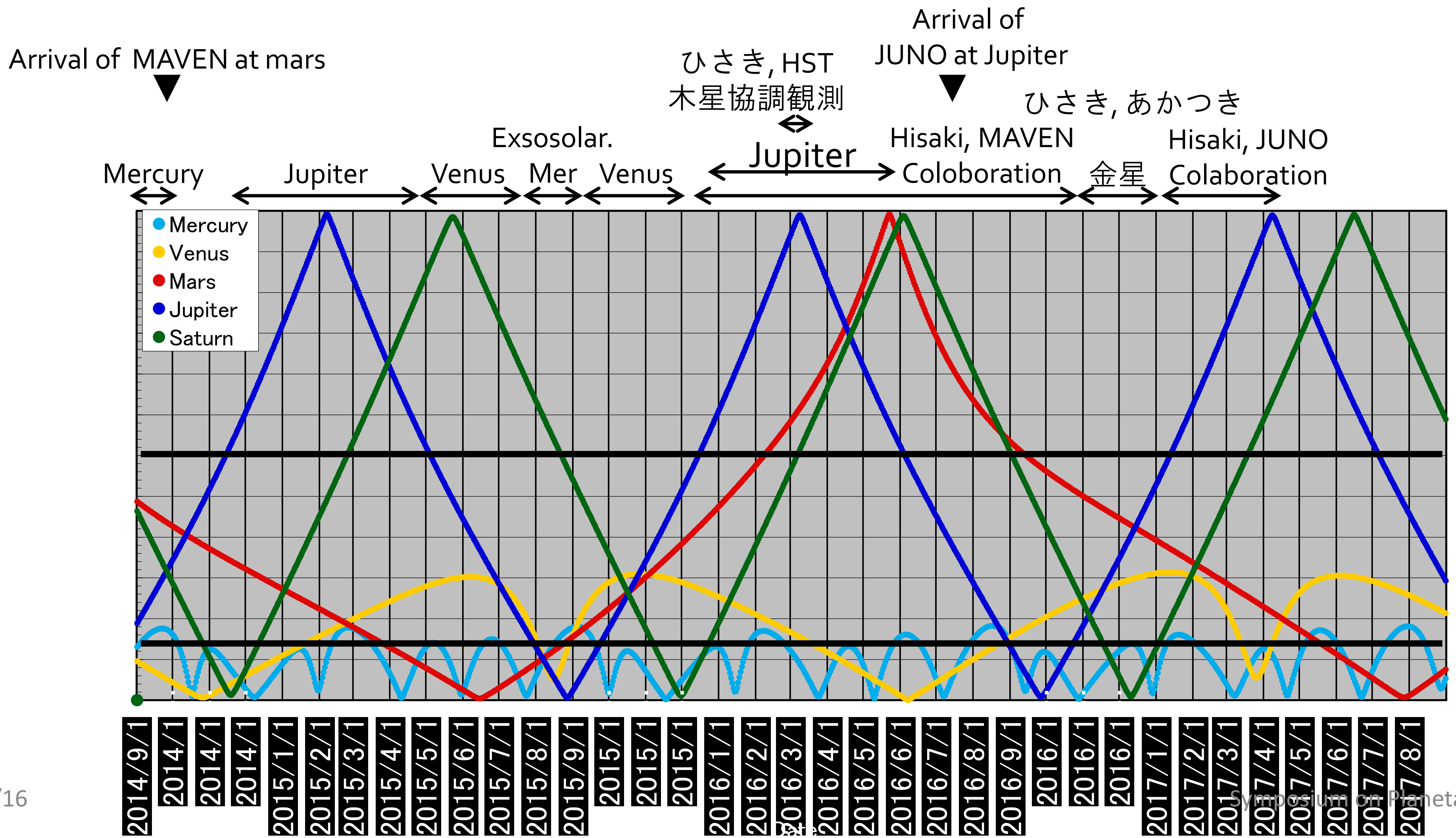
Venus spectrum

Figure 12: EUV spectrum of Venus. Exposure period is one-month. This is the longest exposure and highest S/N among the past Venus observations in EUV spectrum range. Most surprisingly, multi-charged ion such as sulfer and oxygen are identified. This is signature for charge-exchange process between solar wind and Venus exosphere.

Schedule to August 2017

Best season

Jupiter：2015/2/7, 2016/3/8, 2017/4/8 (衝)
Venus：2015/6/7, 10/26 , 2017/1/13 (最大離角)
Mars：2016/5/22 (衝)



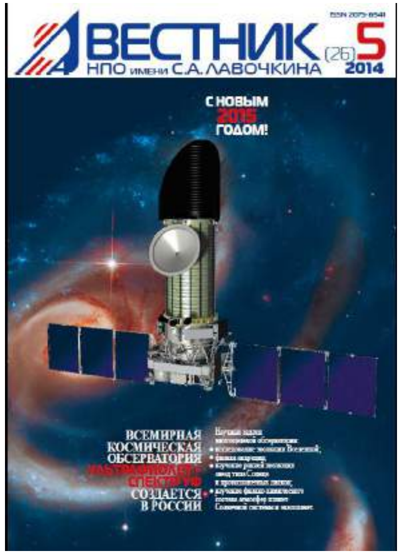
Summary and my intension

Our EUV imaging technique (as well as NSAS's) has reached full development in space plasma physics.

EXCEED continues the observation of the planetary exospheres until (to say the least) March 2016 (Official decision by ISAS/JAXA).

We hope the EXCEED mission extends (at least) several months in order to colaborate with JONO. (JUNO will arrive at Jupiter summer 2016.)

We hope EXCEED database becomes path-breaking for the future mission studies (e.g., ESA's Jupiter mission, JUICE).



Future explorations for the exospheres

Russia (IKI) is building up the Post –HST space telescope. One of the science targets is exospheres of extrasolar planets.

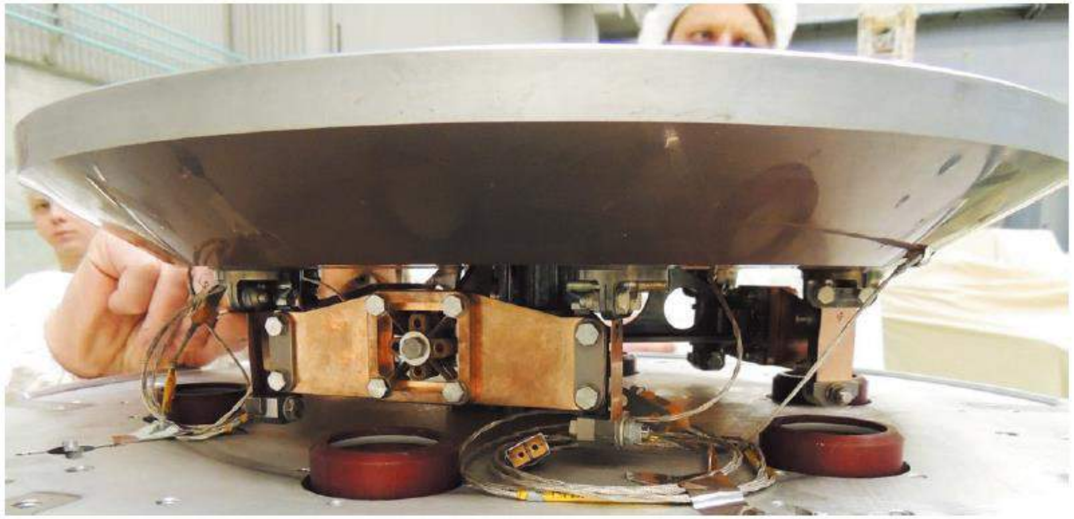
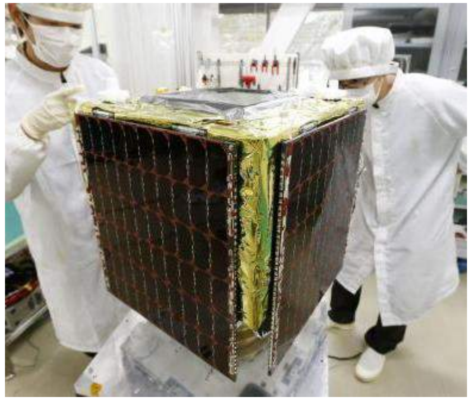
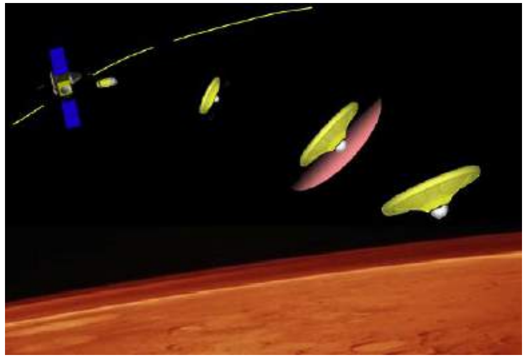


рисунок 7. Оправа вторичного зеркала





Micro-satellite built by University of Tokyo. This is challenging mission under the ISAS support.

42

来週の予定：
太陽系探査を目指した，観測装置WS　held by CPS (Kobe Univ.)

13:00-13:30 中間赤外線高分散分光器GIGMICSの開発と惑星科学への応用 (平原靖大(名古屋大学))

13:30-13:50 ERG衛星搭載 波動粒子相互作用解析装置 (加藤雄人(東北大学))

13:50-14:10 惑星探査用高コントラストオプティクスの基礎開発 (山崎 敦(宇宙科学研究所))

14:10-14:30 近赤外分光計の現在と将来 (岩田隆浩(宇宙科学研究所))