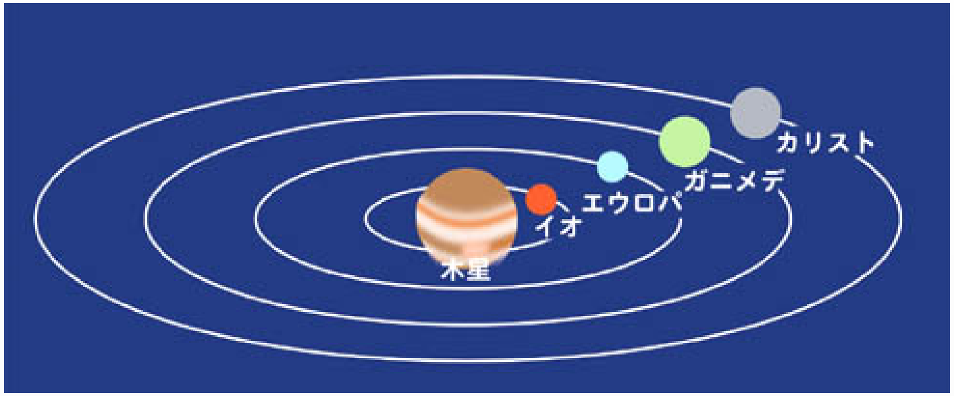
time variation of 130.4 nm atomic oxygen emission near Io observed by hisaki/EXCEED
ひさき衛星によるイオ周辺の130.4nm 酸素原子発光の時間変動解析

#古賀 亮一 [1]; 土屋 史紀 [1]; 鍵谷 将人 [1]; 坂野井 健 [1]; 吉川 一朗 [2]; 村上 豪 [3]; 山崎 敦 [3]; 木村 智樹 [4]; 吉岡 和夫 [5]; 米田 瑞生 [1]

[1] 東北大・理・惑星プラズマ大気研究センター; [2] 東大・新領域創成; [3] ISAS/JAXA; [4] RIKEN;[5]東大・地惑

Introduction



Io is one of the remarkable moons of Jupiter called Galilean moons
Average revolution cycle 421,700km($6R_J$)
Revolution period　1.76 days

Fig.1 Orbits of Galilean satellites
(Hiratsuka City Museum,
http://www.hirahaku.jp/hakubutsukan_archive/tenmon/)

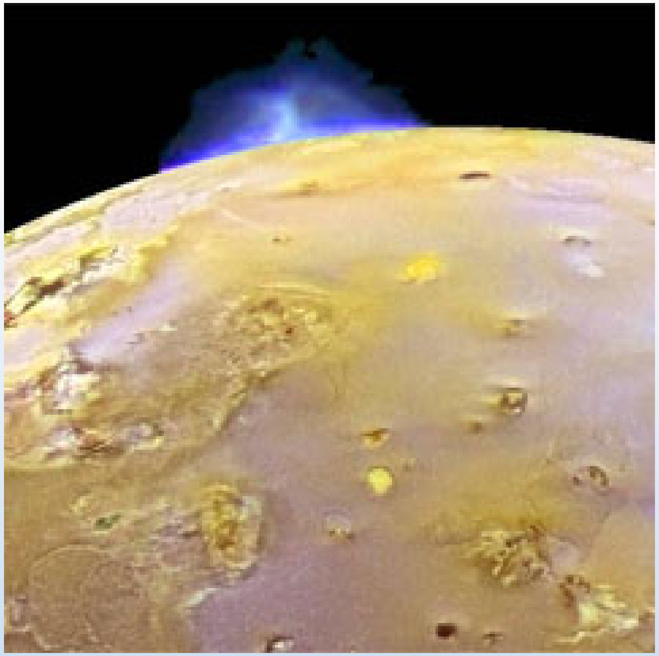


Fig.2 Galileo image of Io showing an erupting volcano on the limb (NASA/JPL)

Io is the most volcanically active body in the Solar system
Candidate of mechanism which makes atmosphere which is mainly composed of S, SO, SO_2

① Sublimation of SO_2
② Volcanism
③ (Ion sputtering from solid surface)

Which support Io's atmosphere, volcanism or sublimation？

Previous study; time variation of neutral sodium emission

- The D-line(589.6 and 589.0nm) brightness of sodium nebula faithfully reflects the column density (emission is only due to the resonant scattering of the solar light caused by sodium nebula)
- there is a clear correlation between the D-line brightness and Io's infrared brightness at 3.5μm which is due to thermal emission from Io's volcanoes (Mendillo et al., 2004)

- D-line brightness of the sodium nebula is a good index for Io's volcanism especially with plume.
- Next slide, Haleakala observatory of sodium nebula between December 2014 – April 2015 (Yoneda et al., 2015)

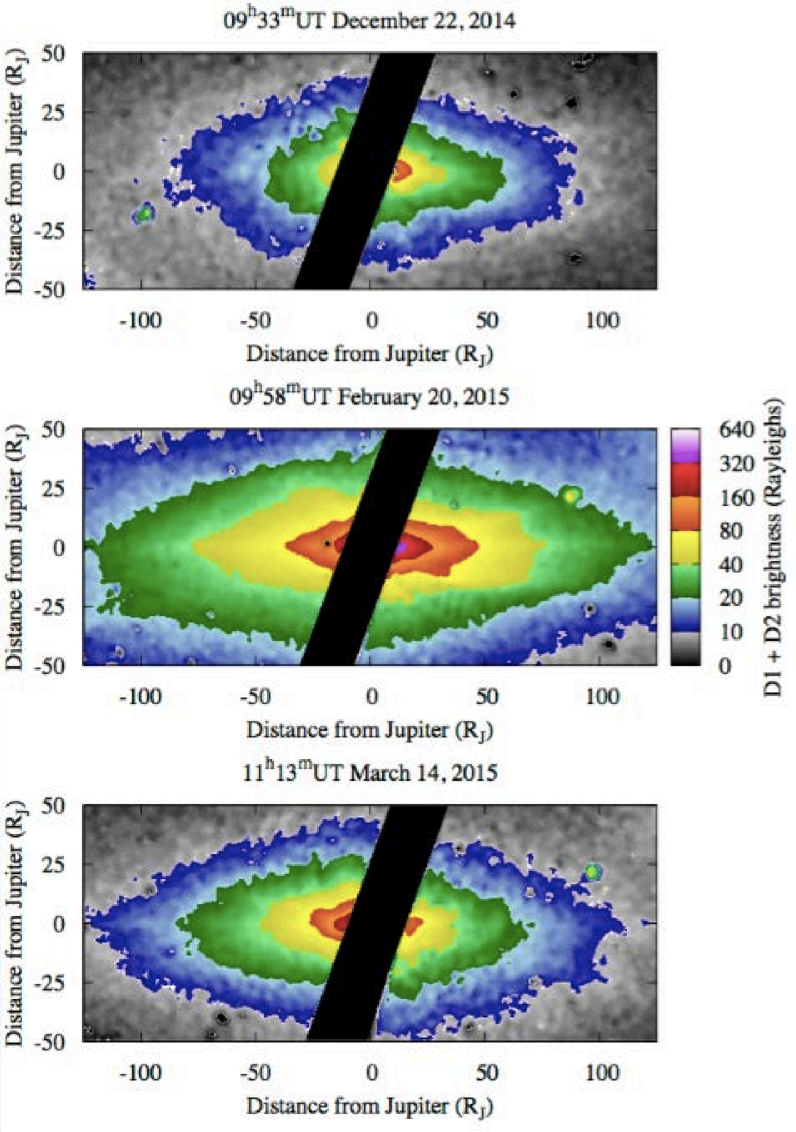


Fig.3 Three images of Jupiter's sodium nebula obtained in the observation period

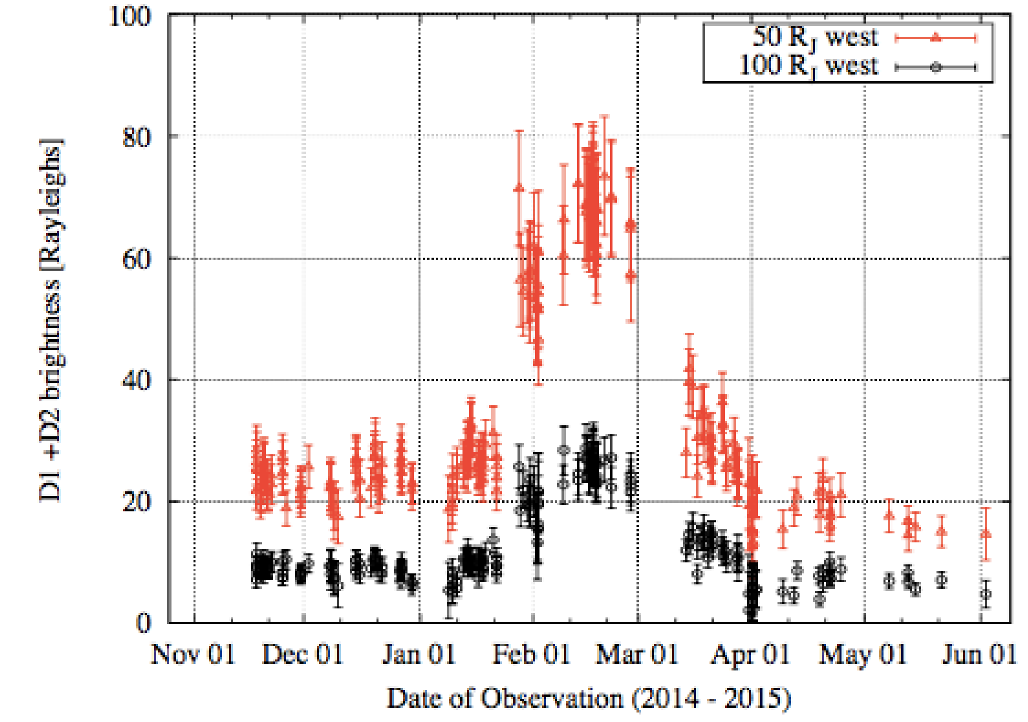


Fig.4 Variations in D-line brightness of sodium nebula at 50 and 100 RJ west from Jupiter.

An enhancement that had begun at the end of January 2015 and subsided at the end of March 2015

→Volcanic enhancement occur on Io

But neutral sodium is minor components

→how about neutral oxygen or sulfur?

purpose

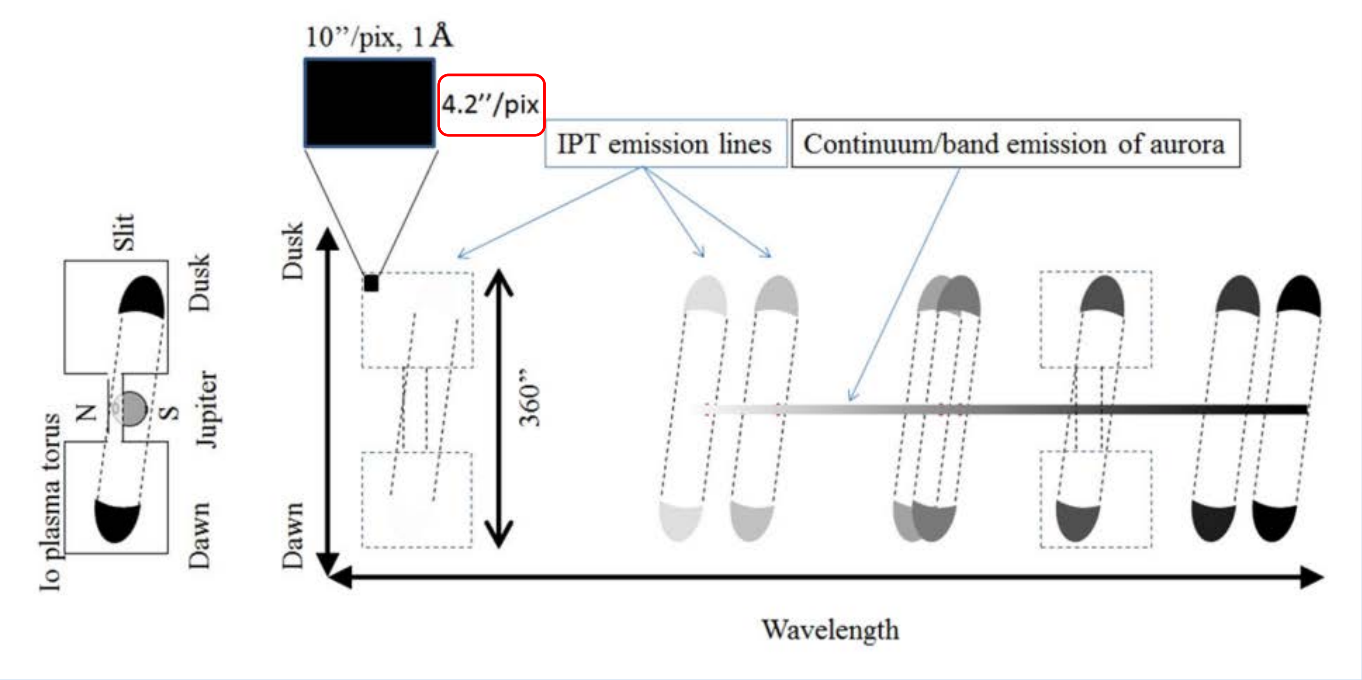
- <final goal>to know the variation of neutral oxygen column density between 2014/11/27~2015/5/5 and discuss how much volcanism supports Io's atmosphere

- <today's purpose>to know the variation of 130.4nm neutral oxygen emission between 2014/11/27~2015/5/5 and discuss the way that convert neutral oxygen emission brightness (Rayleigh) to column density.

Instrument; hisaki/EXCEED

- The Sprint-A (hisaki) satellite with EUV spectrometer(EXCEED) is orbiting around earth and make spectral image around planet
- Flight altitude 950～1150km
- Revolution period 106minites(13 orbit per day)
- Wavelength range 60～145nm
- Wavelength resolution 0.3～1.0nm
- Spatial resolution 17”

Fig.5 schematic spectral image with the dumbbell-shape slit (Yoshikawa et al., 2014)



Observation

- Period;2014/11/27~2015/5/5
- We overlapped the data whose center corresponds to the Io's location within a range of ±60" (see next slide)
- Phase angle　dawn side　45°　~135°

  dusk side　225°　~315°　(see below figure)
- Radiation noise >0.01[count/pix/min]→eliminate
- To avoid geocorna emission, we use only data whose Local time is between20~4 hour (see next slide)

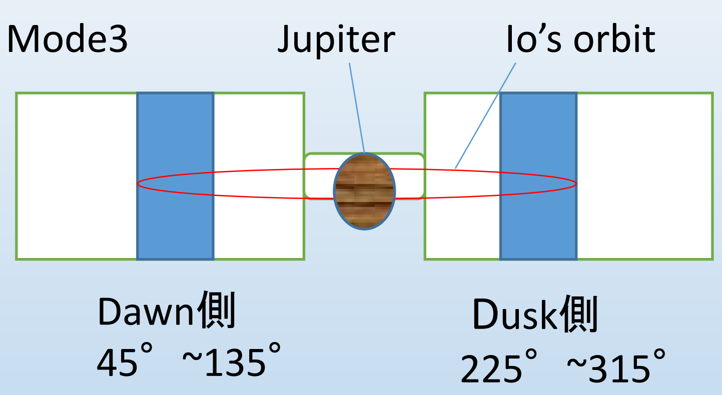


Fig.6 slit of mode3,which was used to observe UV emission in the Io torus

Observation; way of analysis

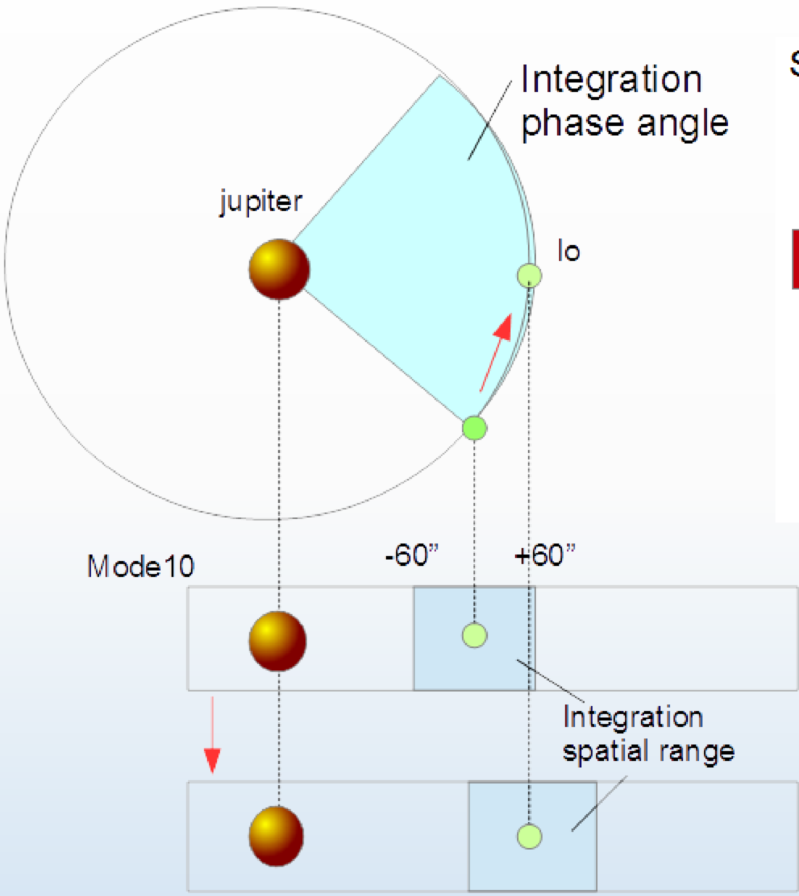


Fig.7 method of superposition of data(left; Io is on slit, right; Io is off slit)

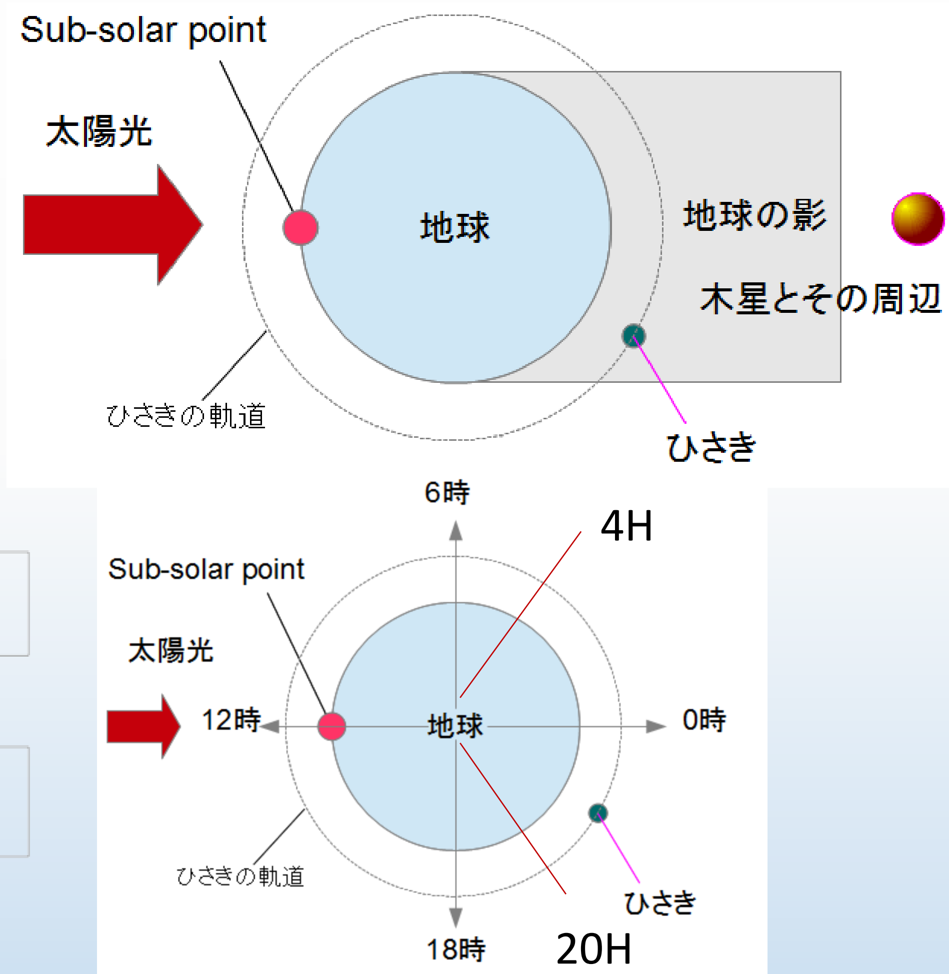
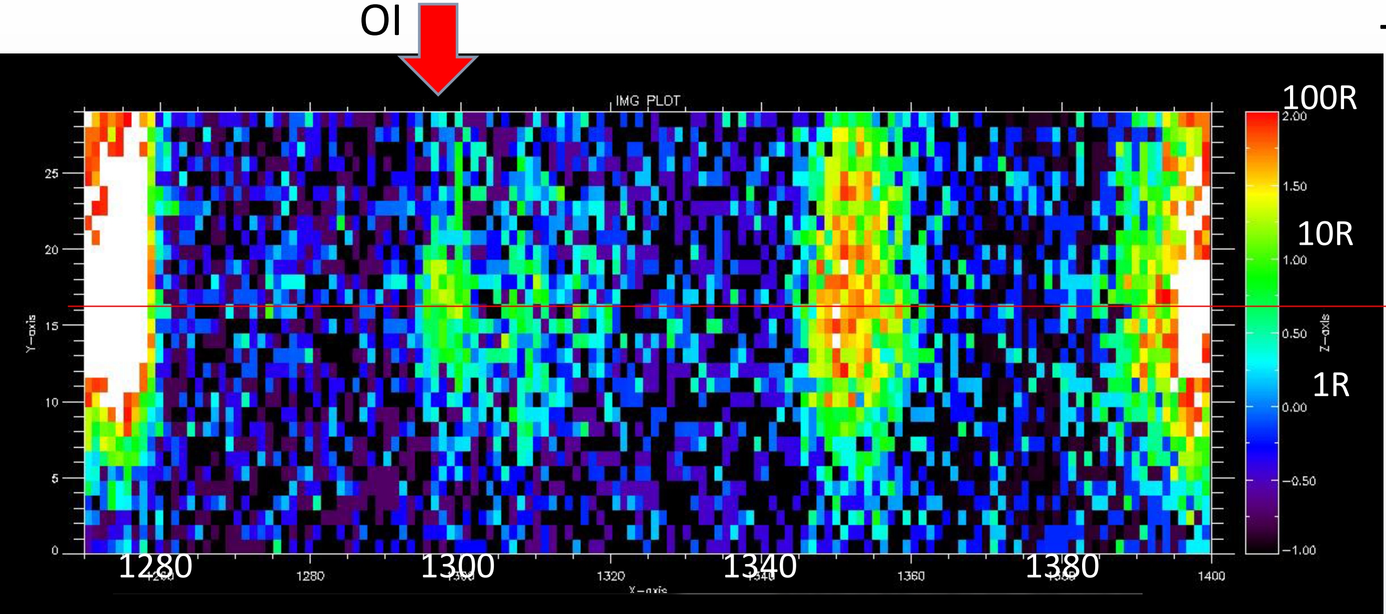


Fig.8 explanation of local time
The date used in this analysis is only between 20~4H

Observation; spectra around 130.4nm emission on Io



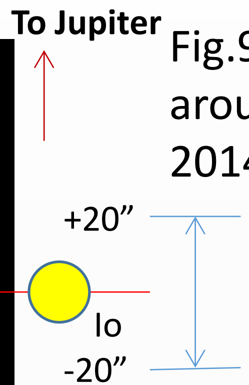


Fig.9 Brightness around Io between 2014/11/27~12/6

イオ中心±1
木星半径平
均の明るさ

Color bar
→brightness
R=Rayleigh/pixel

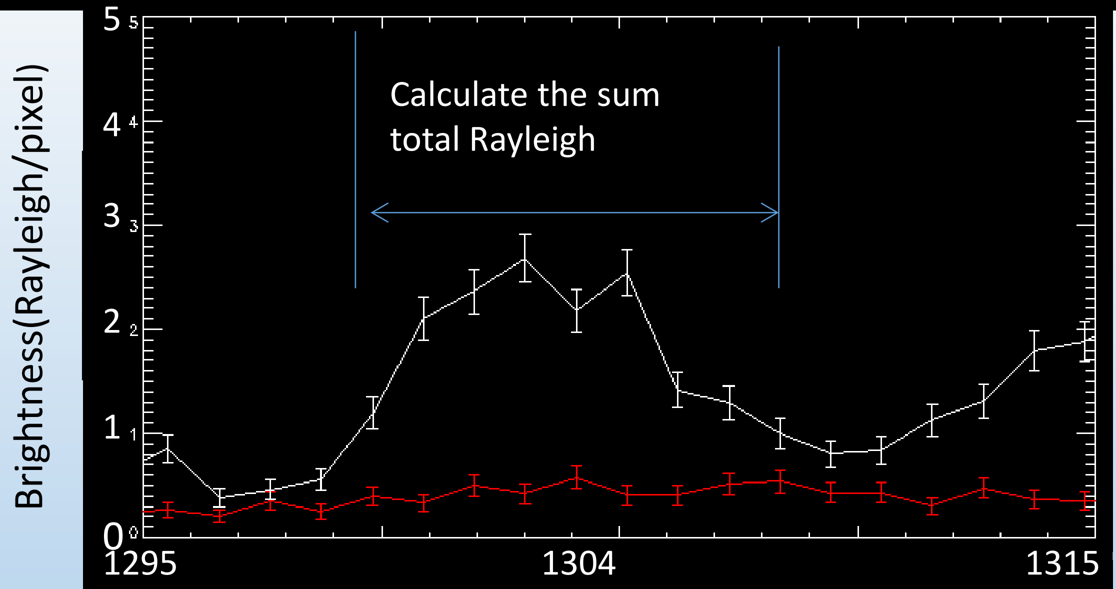


Fig.10 Average brightness around Io between 2014/11/7~12/6
(white line)Io is in the center of slit
(red line)sky-mode observation(geocorona)

Brightness of 130.4nm emission(blue line)
12.7±0.65Rayleigh

Result; time variation of volcanic event

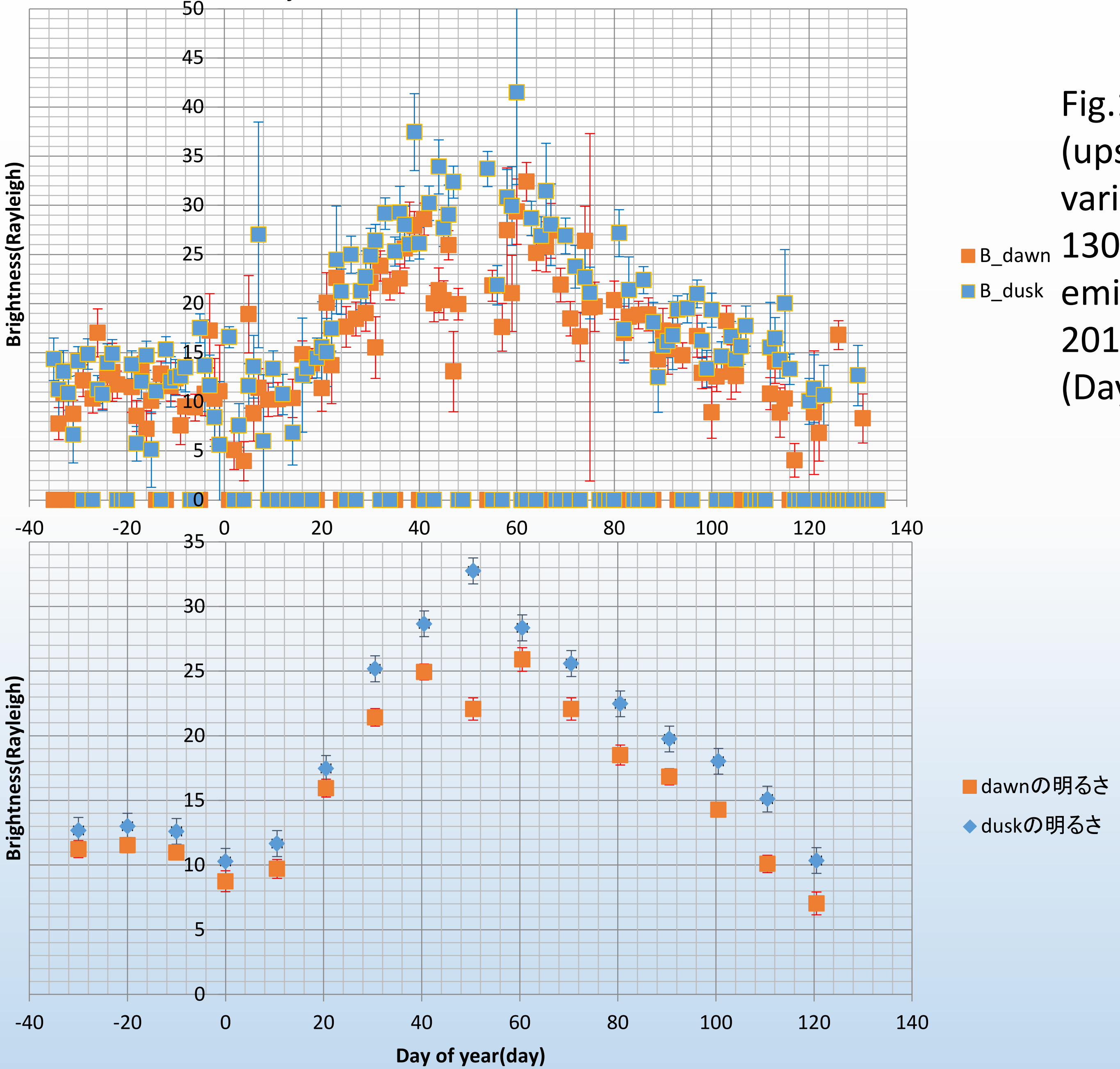


Fig.11 daily variation (upside) and 10days variation (downside) of 130.4nm neutral oxygen emission between 2014/11/24~2015/5/12 (Day1 = 2015/1/1)

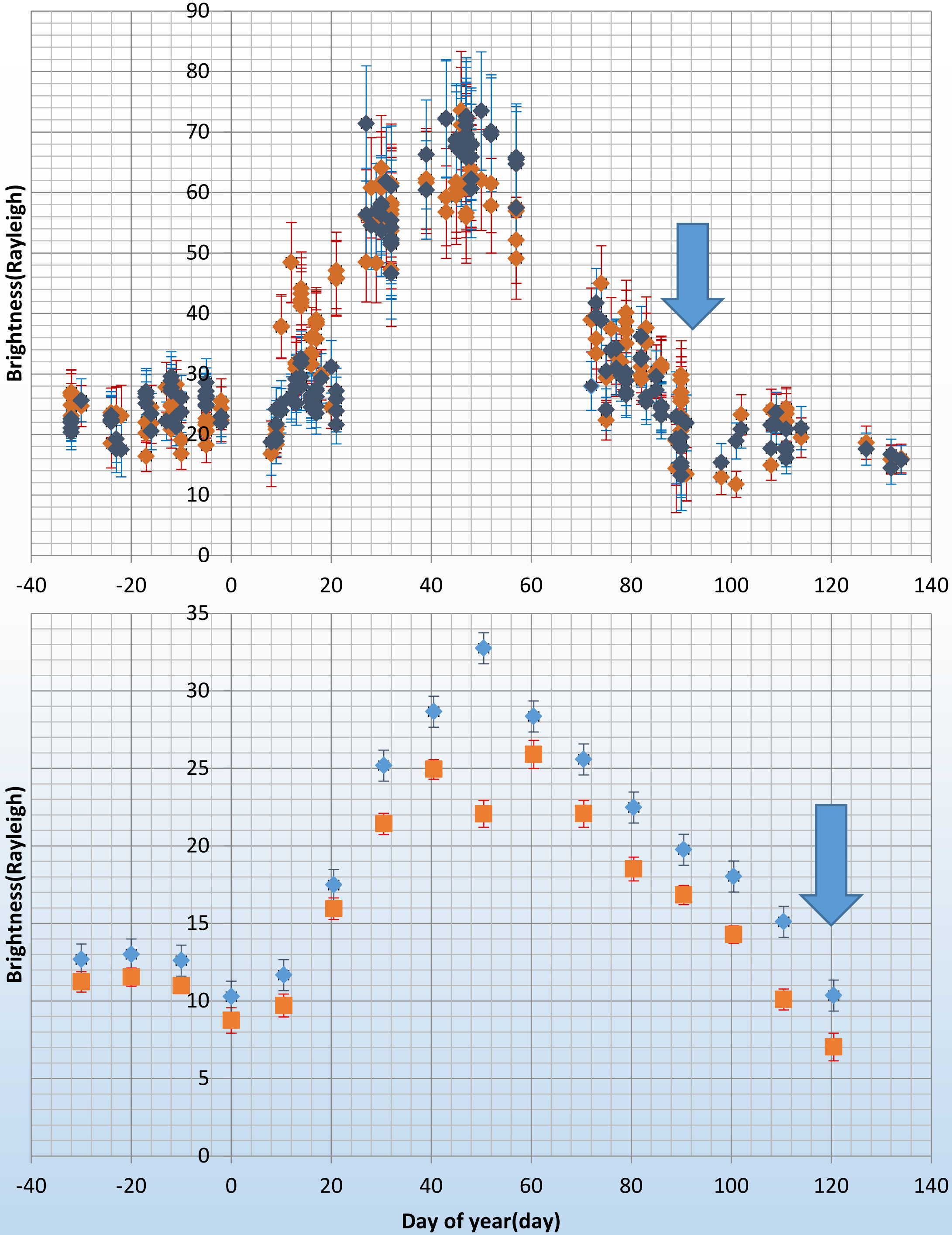


Fig.12 Compare to the variation of D1+D2 neutral sodium nebula emission (upper figure) and 130.4nm atomic oxygen emission (lower figure, Yoneda et al., 2015)

- Enhancement of 130.4nm oxygen emission is roughly consistent with sodium emission
- Recovery phase of 130.4nm oxygen emission was longer than that of sodium emission(blue arrow)

Discussion; recovery phase of oxygen and sodium emission

- Boiling point; Na(1156K) $\gg SO_2$(263K)
- Na is emitted only by eruption because of high boiling point.
  →enhancement stopped after volcanic event
- SO_2 is likely to be emitted not only in crater but in lava lake.
  → enhancement continued after volcanic event

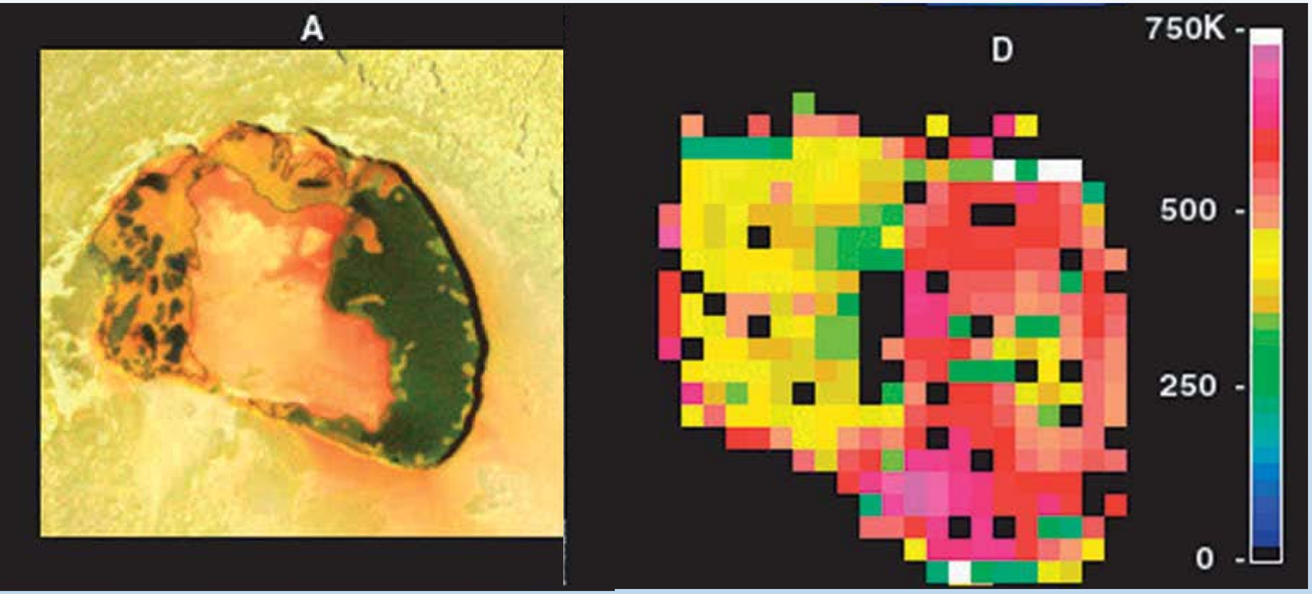


Fig.13 Lava lake on Io imaged by SSI (A) and NIMS (D) during Galileo fly-by (Rosaly et al., 2004)

Discussion; mechanism of 130.4nm emission

- Two process are considerable of 130.4nm atomic oxygen emission around Io

Column density; N(O), Brightness $B_{130.4nm} = B_1 + B_2$ (Rayleigh)

1. Solar scattering ; absorb 130.4nm sunlight selectively

$$B_1 = \frac{4\pi I}{10^6} = \frac{4\pi}{10^6}\int n(z) g dz = \frac{4\pi}{10^6} N(O) g$$

g; g-factor, related to solar irradiance
$n(z)$; oxygen number density
N_e; electron density

2. Electron impact ; $O + e^- \rightarrow O^* + e^-$

$$B_2 \propto \int n(z) n_e \alpha(n_e, T_e) dz$$

(Skinner and Durrance., 1986)

Excitation rate per atom ($cm^3 s^{-1}$)

n_e ;electron density
T_e ;electron temperature
α ;rate coefficient for electron impact excitations of atomic oxygen

- In the torus, collision deexcitation is unimportant, so α is a function only of T_e (Brown et al.,)
- To calculate atomic oxygen column density, we should know which is dominant process around Io.

Discussion; dawn-dusk asymmetries

- We found that brightness of 130.4nm atomic oxygen emission on dusk side is always larger than on dawn side in this observation
- Some previous observation showed brightness of neutral emission caused mainly by electron impact on dawn side were larger than on dawn side

species	Emission line(A)	Dusk/Dawn brightness ratio	Reference	
O	1356	~1.4	Ballester.,1989	Electron impact
	6300	~1.5	Scherb and Smyth.,1993	
S	1479 1814 1900,1914	~1.7 ~1.5 ~1.3	Ballester.,1989	
Na	5889,5895	~0.8 0.994(mean)	Bergstralh et al.,1975 Yoneda et al.,2015	Solar scattering
O	1304	1.17(mean)	This study	

Table.1 Observed Dawn-Dusk brightness asymmertries of neutral components in the Jupiter system

Discussion; Doppler sift of solar radiation

- Wavelength of 130.4nm sunlight around Io is represented as

$$\lambda = \frac{1+\frac{v}{c}sin\theta}{\sqrt{1-\frac{v^2}{c^2}}} \times \lambda_0$$

$\lambda_0 = 1304(\text{Å})$
v; revolution speed of Io
c; light speed
θ; phase angle of Io around Jupiter

- $c = 3.0 \times 10^5 (km/s), v = 17.3(km/s)$
- Doppler shift on dawn side ($\theta = 45\sim135°$)

→$\Delta\lambda = \lambda - \lambda_0 = 0.0532\sim0.0752(\text{Å})$

- Doppler shift on dusk side ($\theta = 225\sim315°$)

→$-0.0752\sim-0.0532(\text{Å})$

Discussion; Doppler sift of solar radiation

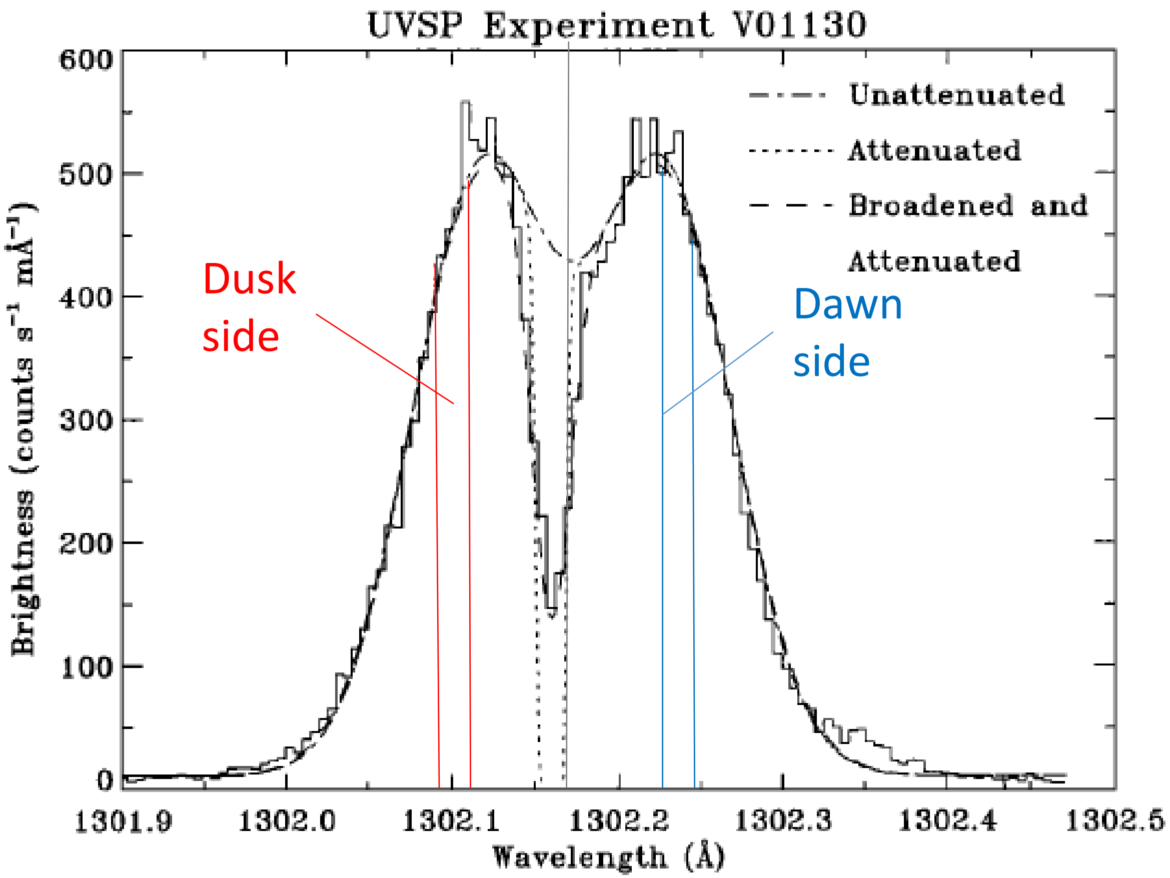


Fig.14 solar spectrum on earth measured by SMM (Glandstone, 1992). The dot-dashed line shows the nonlinear least squares fit to the data outside the terrestrial absorption feature.

It is not so much different between solar brightness on dawn side and on dusk side

Dawn-dusk asymmetries may not be caused by solar scattering

Summary and future work

- An enhance event of 130.4nm oxygen emission around Io occurred like neutral sodium nebula between 2014/11/27~2015/5/5
- dawn-dusk asymmetry of atomic oxygen emission at 130.4 nm was also found

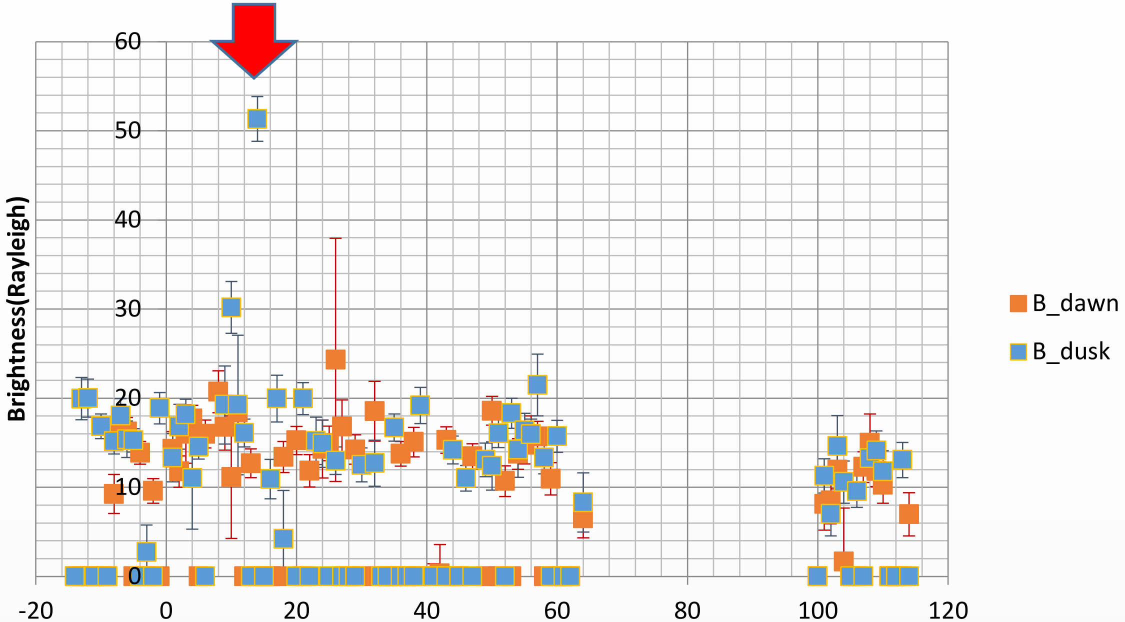
→130.4nm emission on Io may be caused mainly by electron impact

- We will estimate and compare between brightness caused by electron impact and by solar scattering

Reference

- Yoshikawa et al., 2014, Extreme Ultraviolet Radiation Measurement for Planetary Atmospheres/Magnetospheres from the Earth-Orbiting Spacecraft (Extreme Ultraviolet Spectroscope for Exospheric Dynamics: EXCEED) ,Vol184, Issue 1-4, pp 237-258
- Yoneda et al., 2015, Brightening event seen in observation of Jupiter's extended sodium nebula,Icarus,Vol261,pp31-33
- Scherb and Smyth, 1993, Variability of O I 6300-Å emission near Io, Journal of geophysical research, Vol98, pp729-736
- G.R.Glandstone, 1992, Solar O I 1304-Å triplet line profiles, Journal of geophysical research, Vol97, pp519-525

Appendix, time variation of normal event



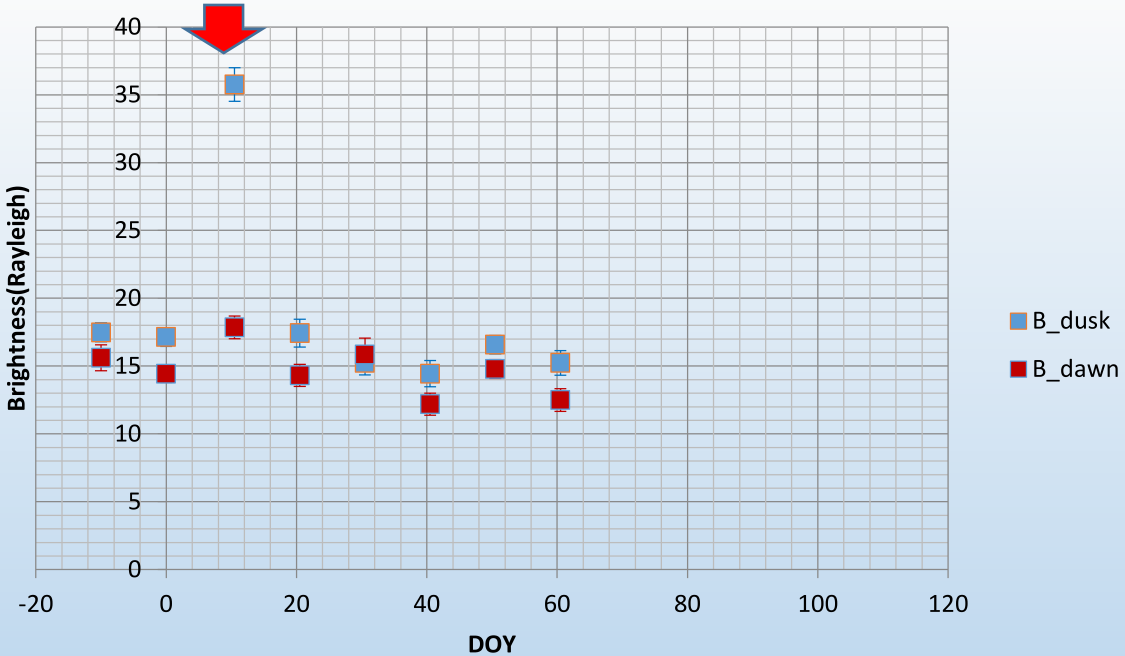
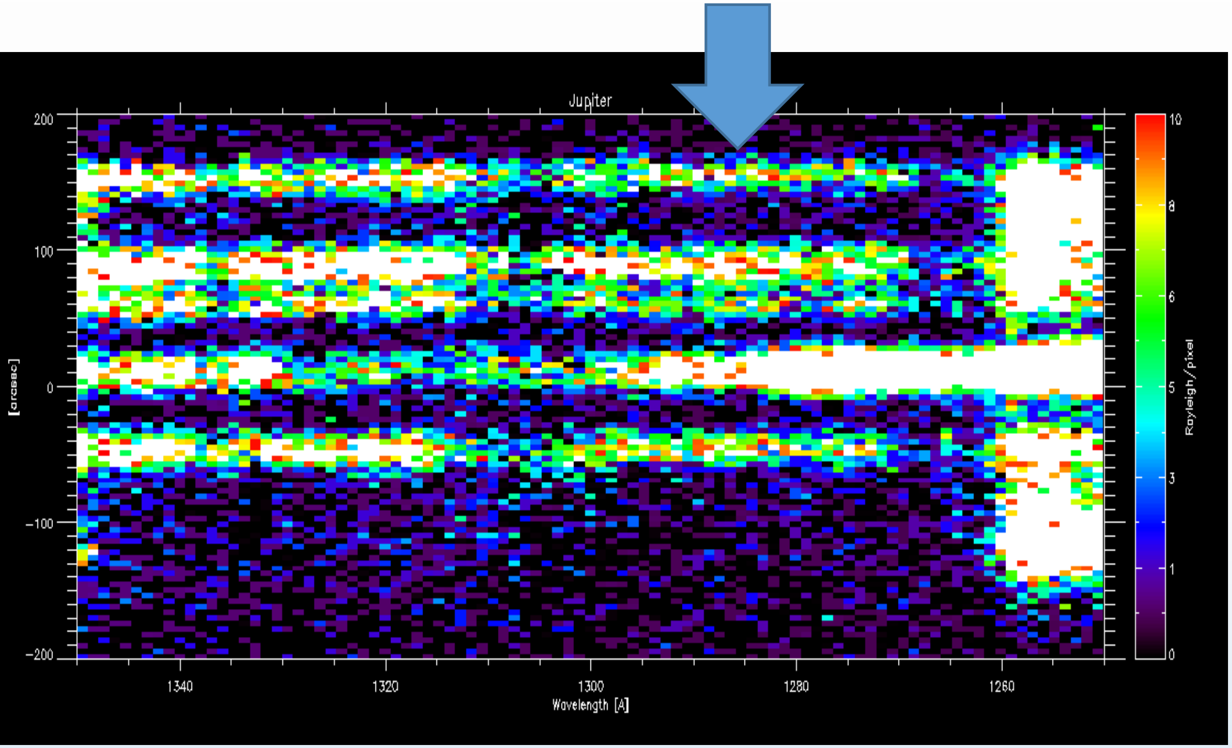


Fig.15 daily variation (upside) and 10days variation (downside) of 130.4nm neutral oxygen emission between 2013/12/18~2014/4/24 (Day1 = 2015/1/1)

Appendix



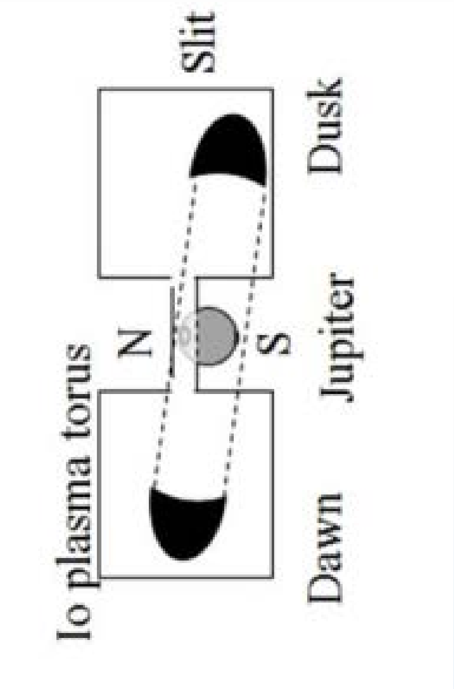


Fig.16 spectra around Jupiter and Io torus in 2014/1/10.
Stripe-like emission was caused by EUV star radiation, it made 130.4nm brightness abnormal value on dusk side in 2014/1/10 (page15, red arrow)