Time variation of 130.4nm atomic oxygen emission near Io observed by hisaki/EXCEED

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Io, one of the Jupiter moon, is the most volcanically active body in the solar system because of its large tidal force from Jupiter. Main components of Io's atmosphere are SO_2, and its dissociative sulfur and oxygen atoms. The rest components (a few percent) are neutral sodium and potassium. Origins of the atmosphere are thought to be gaseous plume driven by volcanic activity and sublimation of SO_2 frost, but it is not clear which is dominant. The object of this study is to understanding the atmospheric generation process through the time variation of 130.4nm atomic oxygen emission near Io.

The brightening event of the extended sodium nebula was reported by the ground imaging observation from December 2014 to May 2015 (Yoneda et al., 2015). To show the behavior of atomic oxygen during the period, we analyzed the time variation of atomic oxygen, one of the main components of volcanic gas, -near Io ($1R_J$) by using data observed by hisaki/EXCEED. We selected observed data when Io was in the dawn side (Io's phase angle of $45°\sim135°$) and in the dusk side ($225°\sim315°$), and accumulated photons which came from around Io within a range of $\pm60''$ on each day to acquire enough S/N. We carefully selected data when the local time of Hisaki was in the range of 20-4h to avoid the contamination from geocorona. As a result, it is found that the brightness of atomic oxygen emission was 11R at the beginning of January, but started to increase in the middle January and showed the maximum of -32R in the middle of February. It decreased by the end of May and returned the normal brightness (10R). The result shows behavior of 130.4nm atomic oxygen emission is similar to that of atomic sodium emission and atmospheric generation process of SO_2 and NaCl may be similar when Io is volcanic active.

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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

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About Io's volcanic activities

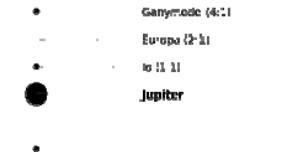


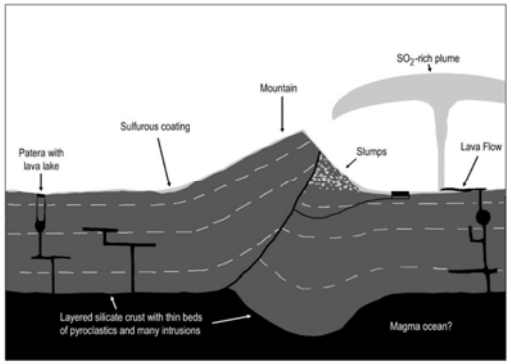
Fig.1 (upper) diagram of Laplace orbital resonance
(below) Image of Io showing an erupting volcano (NASA/JPL)

Io is the most volcanically active body in the Solar system
Candidate of mechanism which maintains atmosphere which is mainly composed of

① Sublimation of SO_2 frost
② Volcanism (SO_2 is major components, $NaCl$ is minor)
③ (Ion sputtering from solid surface)

How much does volcanism influence Io's atmosphere and neutral clouds?

Two types of Io's volcanic activities



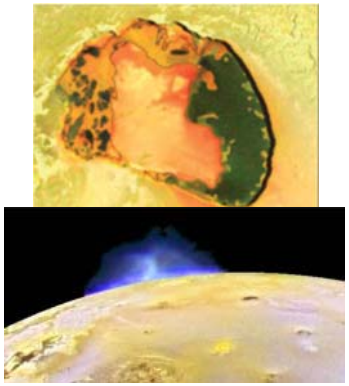


Fig.2 (left)Cartoon of Io's crust(McEwen et al., 2004) (right) image of Plume and lava lake (Rosaly et al., 2004)

1. Lava lake type – emit silicate lava flow from subsurface magma ocean. They also evaporate sulfurous coating surface
2. Plume type – emit SO_2 rich gas like geyser

Plume is the signature of volcanism that is more direct injection of volcanic gases into Io's atmosphere than lava lake

purpose

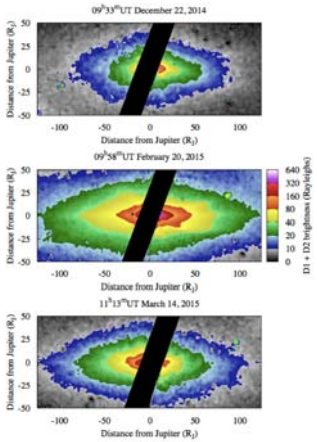


Fig.3 Three images of Jupiter's sodium nebula obtained in the observation period (Yoneda et al, 2015)

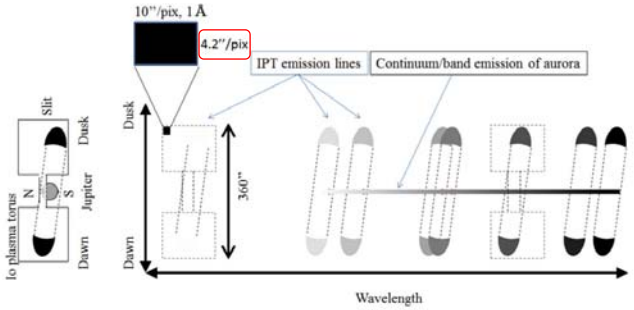
- An enhancement that had begun at the end of January 2015 and subsided at the end of March 2015
- But neutral sodium is a minor component

- Targets of this study are
  - ➢ To research time variation of 130.4nm atomic oxygen emission when Io is volcanic active.
  - ➢ To compare behavior of atomic oxygen emission with sodium nebula emission and discuss which atmosphere generation process is dominant, volcanism and sublimation.

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



Observation

- Period;2013/12/19~2014/4/24, 2014/11/27~2015/5/5
- We overlapped the data whose center corresponds to the Io’s location within a range of ±20” (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 the data only when HISAKI’s local time is between20~4 hour (see next slide)

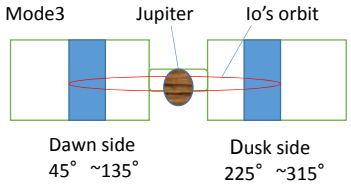


Fig.5 slit of mode3,which was used to observe UV emission in the Io torus

Observation; way of analysis

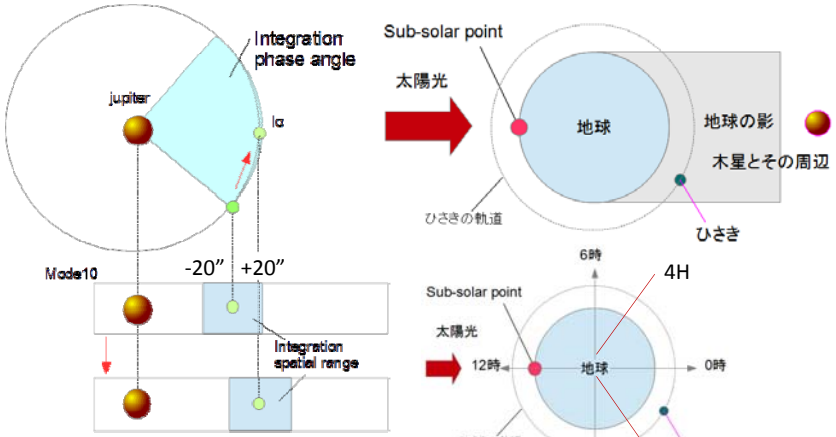


Fig.6 method of superposition of data(left; Io is on slit, right; Io is off slit)

Fig.7 explanation of local time
The date used in this analysis is only between 20~4H

Observation; spectra around 130.4nm emission on Io

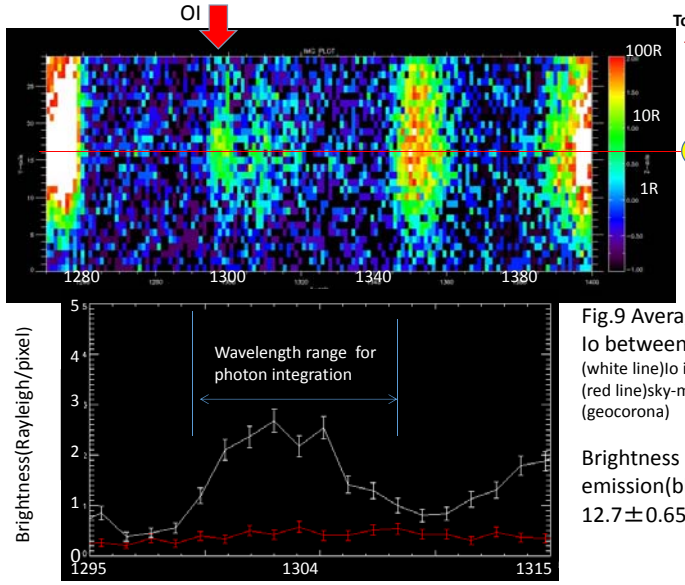


Fig.8 Brightness around Io between 2014/11/27~12/6

Brightness near Io ($-1R_J$)

Color bar →brightness R=Rayleigh/pixel

Fig.9 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; 2013~2014

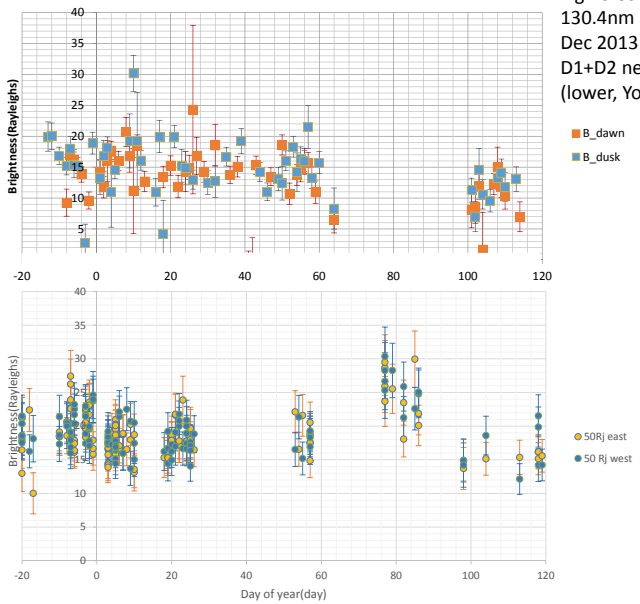


Fig.10 Compare to the variation of 130.4nm atomic oxygen emission from Dec 2013 to April 2014 (upper) and D1+D2 neutral sodium nebula emission (lower, Yoneda et al., 2015)

Result; 2014~2015

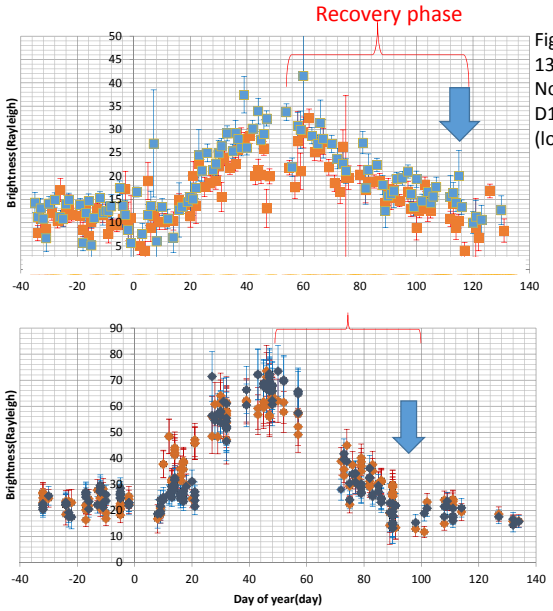


Fig.11 Compare to the variation of 130.4nm atomic oxygen emission from Nov 2014 to May 2015 (upper) and D1+D2 neutral sodium nebula emission (lower, Yoneda et al., 2015)

Fig. Correlation between neutral oxygen and sodium emission from Nov 2014~May 2015 (upper), and from Dec 2013~April 2014 (lower)

Table.1 Correlation coefficients between neutral oxygen and sodium emission in this observation

	Dawn side	Dusk side
2014~2015	0.529	0.862
2013~2014	-0.272	-0.165

Discussion; Generation process of Io's Atmosphere

- Correlation coefficients 2014~2015 is high, 2013~2014 is low (negative)

- $NaCl$ is only emitted to the Io's atmosphere by volcanic plume and lava lake
- High correlation coefficient between the sodium and oxygen emissions suggest the similarity in their generation processes.

- Volcanically active → gaseous plume is dominant process

Discussion; recovery phase of oxygen and sodium emission

- Boiling point; NaCl(1658K)$\gg SO_2$(263K) (under 1bar)
- Na is emitted only by eruption or near hot spot because of high boiling point.
  →enhancement stopped after volcanic event
- SO_2 is likely to be emitted not only in crater but in wide lava lake area.
  → enhancement continued for the moment after volcanic event

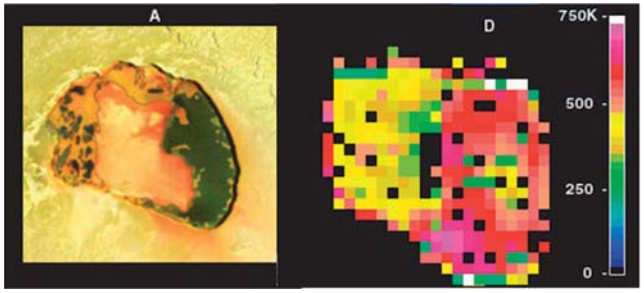


Fig.12 Lava lake on Io imaged by SSI (A) and NIMS (D) during Galileo fly-by (Rosaly et al., 2004)

Summary and future work

- We confirmed the time variation of 130.4nm atomic oxygen emission near Io when volcanism was active and found its behavior was similar to that of sodium emission
- To discuss the relation between the atmospheric generation process and volcanic activity, we need to derive atomic oxygen column density from emission brightness of atomic oxygen at 130.4nm.
- *130.4nm emission is excited by solar scattering and electron impact excitation*
- $Brightness = B_{solar} + B_{electron}$
  $= \frac{4\pi}{10^6}(\int n(z)\, g dz + \int n(z) n_e \alpha(T_e) dz)$

reference

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- Yoneda et al., 2015, Brightening event seen in observation of Jupiter's extended sodium nebula,Icarus,Vol261,pp31-33
- Skinner and Durrance, 1986, neutral oxygen and sulfur densities in the Io torus, the Astrophysical Journal, Vol310, page966-971