[P-29] Observation of the O_2^+ emissions in the Mars ionosphere with a visible spectrograph on Haleakala T60

T. Suzuki[1] (suzuki.t@pparc.gp.tohoku.ac.jp),

M. Kagitani[1], T. Sakanoi[1]

[1]Graduate School of Science, Tohoku University

2019/02/18

[Symposium on Planetary Science 2019
Poster Presentation]

Introduction : Martian ionosphere altitude profiles

- Observations of the ionosphere of Mars by the Neutral Gas and Ion Mass Spectrometer (conducted MAVEN) revealed the spatial structures in the density of ions [M.Benna et al., 2015]
- O_2^+ is the dominant ion in the ionosphere

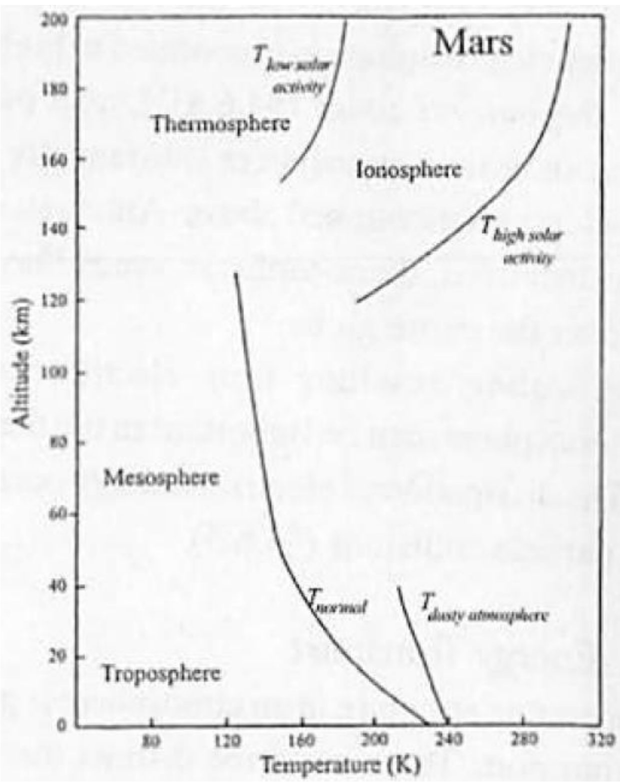


Fig.1 Thermal structure of Martian atmosphere [Barth et al., 1992]

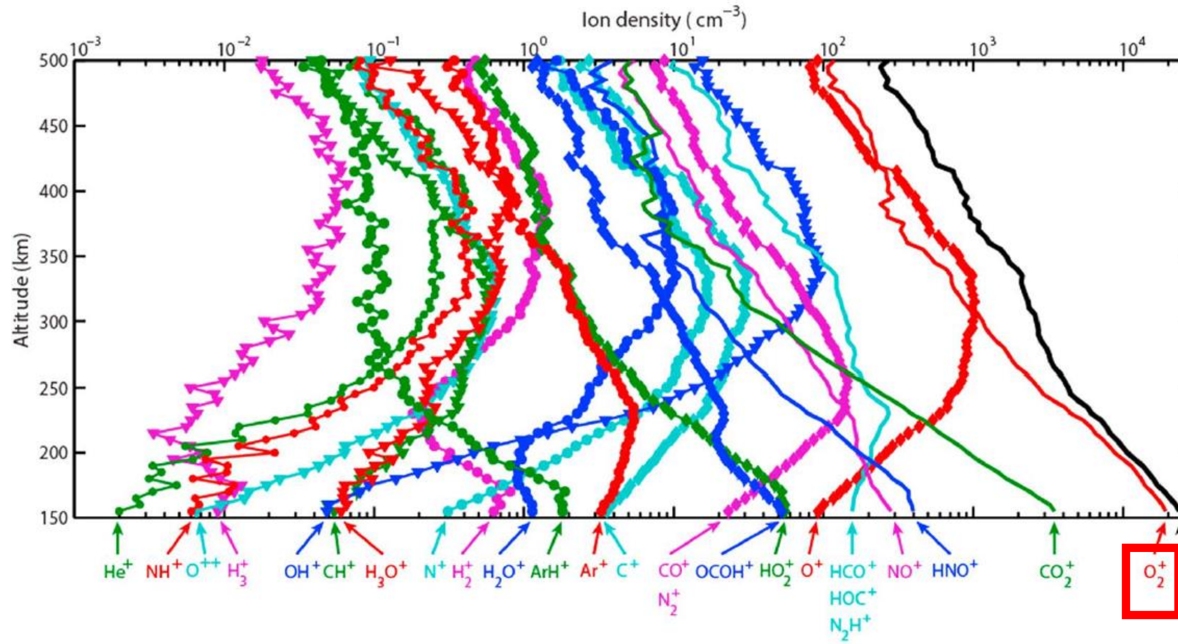


Fig.2 Altitude profiles of the averaged density of ionospheric ions measured by NGIMS at SZA=60° at altitudes between 150 and 500 km. The total ion density N_j is plotted in black. [M.Benna et al., 2015]

O_2^+ production and emission

Solar ultraviolet radiation photodissociate the major constituent of the atmosphere, CO_2, and produces *CO* and *O*

$$CO_2 \rightarrow O + CO$$

The predominance of O_2^+ is the result of the ion molecule reactions below

$$CO_2^+ + O \rightarrow O_2^+ + CO$$
$$O^+ + CO_2 \rightarrow O_2^+ + CO$$

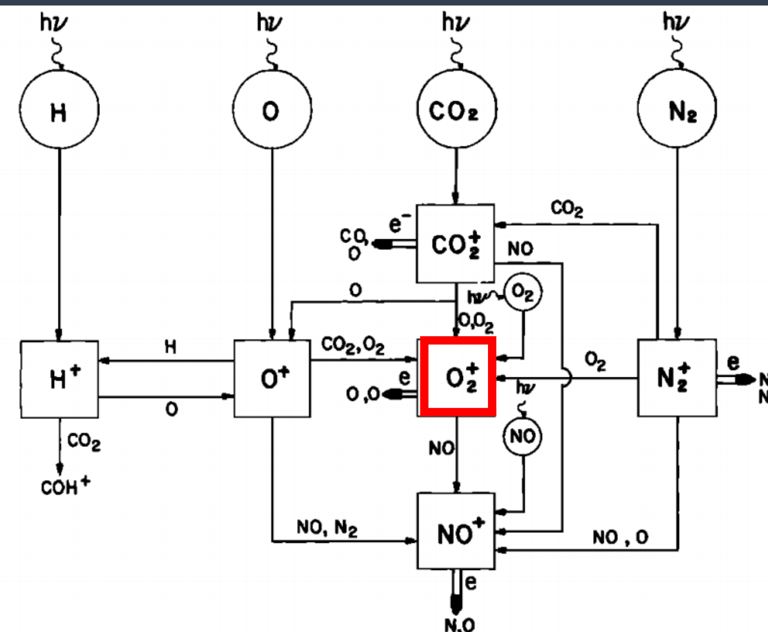


Fig.3 Ionospheric chemical reaction scheme [Chen et al., 1978]

Table1 Composition of the Martian Lower Atmosphere [Owen et al., 1977]

Gas	Proportion
Carbon dioxide (CO_2)	95.32%
Nitrogen (N_2)*	2.7%
Argon (Ar)*	1.6%
Oxygen (O_2)	0.13%
Carbon monoxide (CO)	0.07%
Water vapor (H_2O)	0.03%†
Neon (Ne)*	2.5 ppm
Krypton (Kr)*	0.3 ppm
Xenon (Xe)	0.08 ppm
Ozone (O_3)	0.03 ppm†

* Discovered by Viking experiments.
† Variable.

- O_2^+ emission...resonance fluorescence

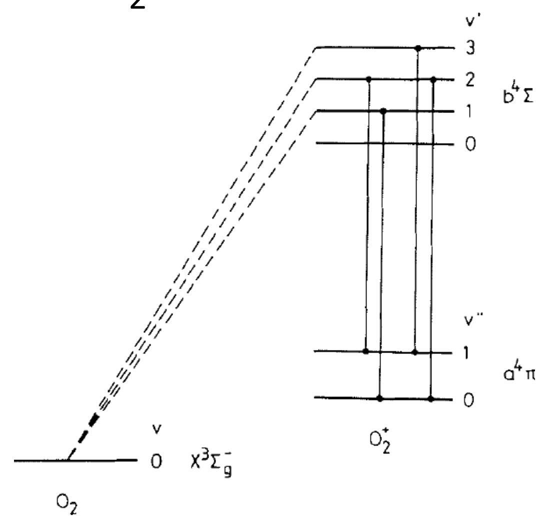


Fig.4 Vibrational levels of O_2 and O_2^+ showing excitation transitions (dashed lines) and emissions transitions (solid lines) for O_2^+ 1NG bands [K. Henriksen et al., 1987]

loss mechanism

- A number of mechanism are capable of giving atmospheric particles sufficient energy to escape from Mars
- Neutral escape through dissociative recombination of O_2^+ may be as important or possibly much more important for atmospheric loss [H. Nilsson et al., 2011; C. J. Schrijver et al., 2016]

$$O_2^+ + e^- \rightarrow O^* + O^*$$

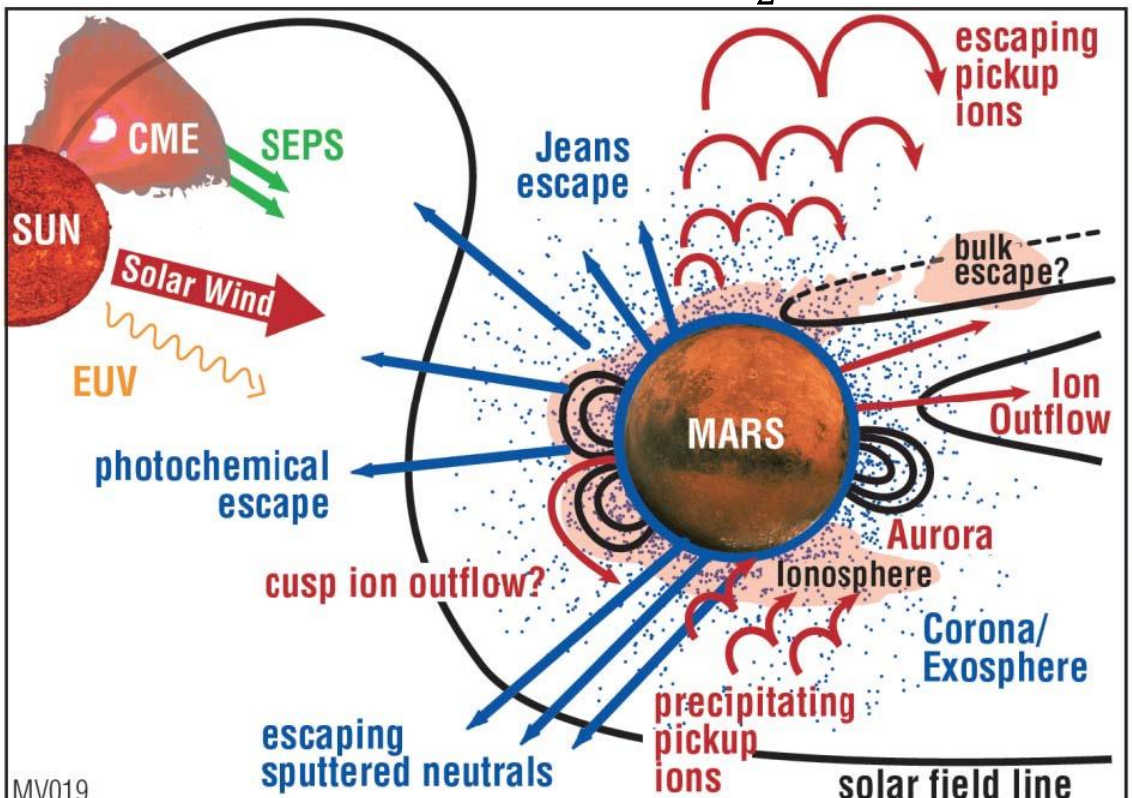


Fig.4 Schematic loss mechanism for Martian atmosphere
https://phys.org/news/2014-02-maven-satellite-mars-atmosphere.html

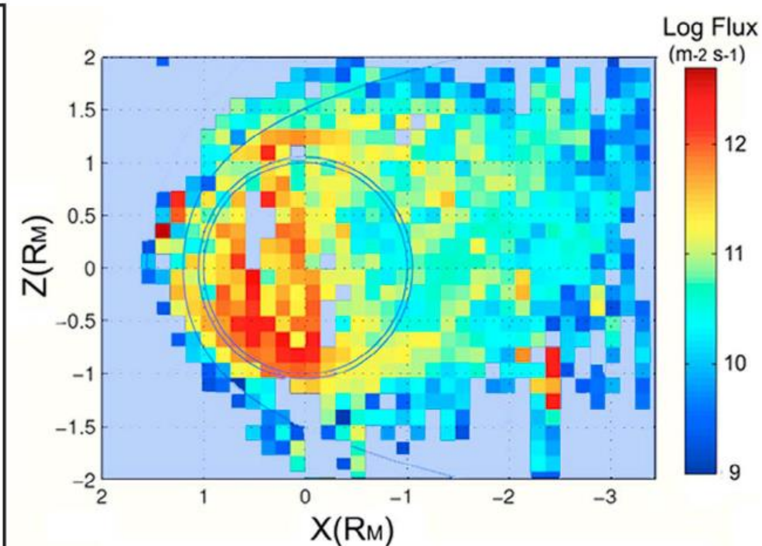


Fig.5 The XZ distribution of low energy (<200 eV) ionosphere O^+ fluxes near Mars [R. Lundin et al., 2011].

Martian crustal magnetic fields control ionosphere

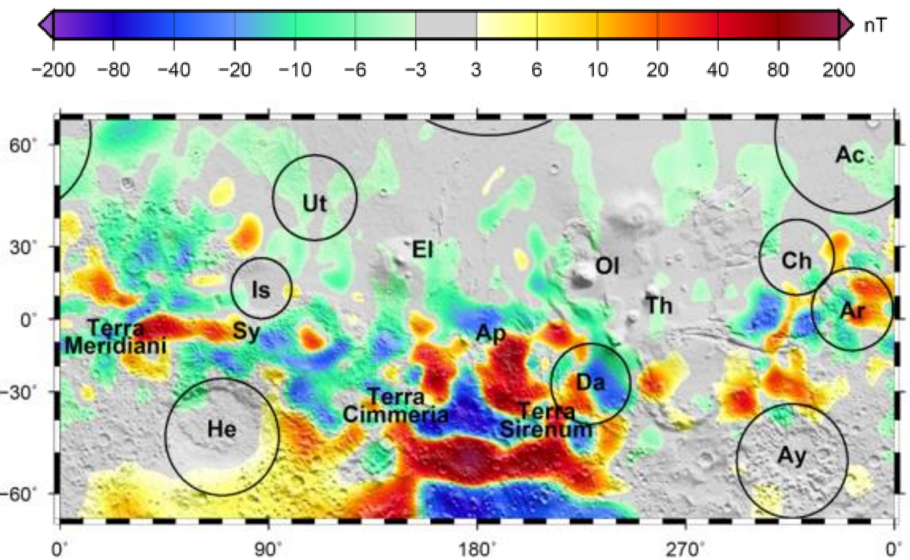


Fig.6 Predicted radial component of the Martian magnetic field at an altitude of 400 km [Benoit Langlais et al., 2009]

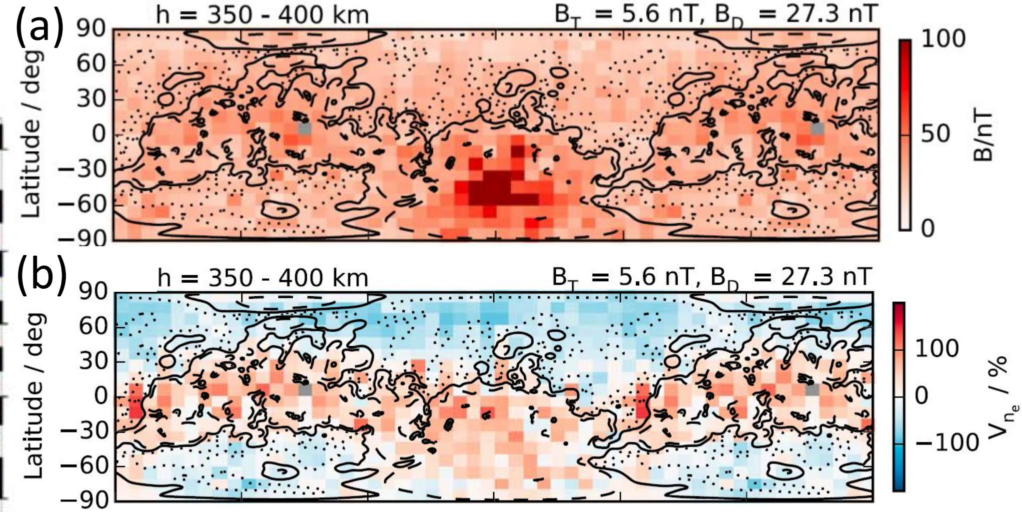
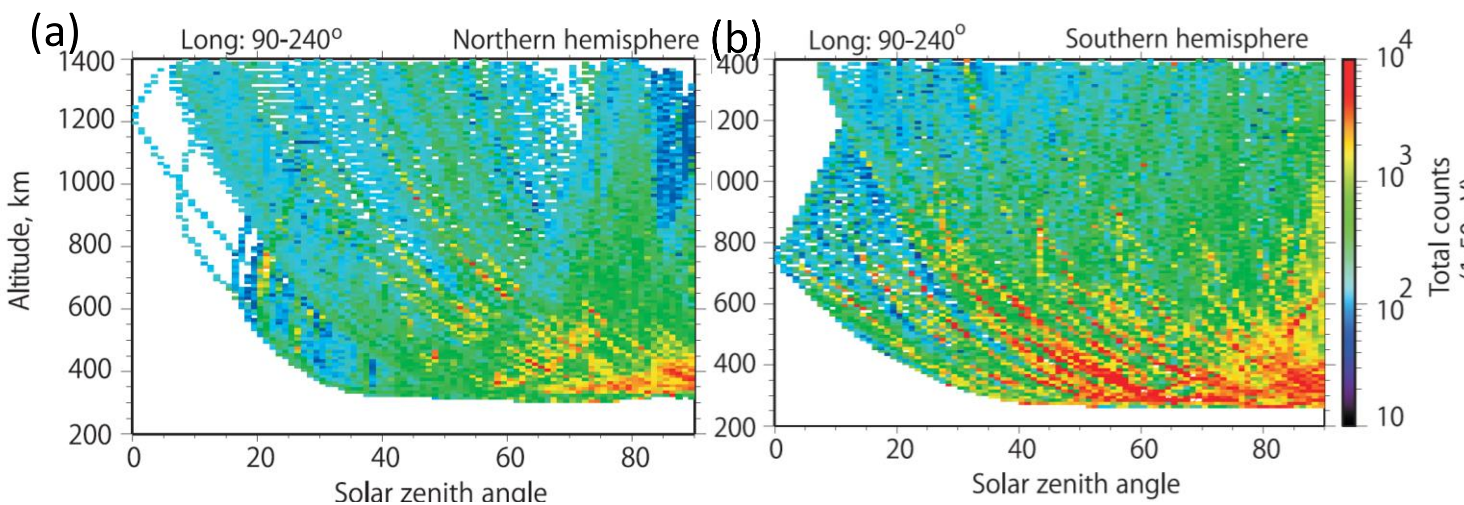


Fig.7 (a) Measured averages of |B|
(b) Relative differences (%) between local and averaged plasma densities [D. J. Andrews et al., 2015]



Northern hemisphere

Southern hemisphere

Fig.8 The fluxes of O^+ as a function of SZA and altitude in the (a) northern and (b) southern hemisphere [E. Dubinin et al., 2012]

Purpose of This Study

- to detect of O_2^+ emission in Martian ionosphere with Haleakala T60/Vispec (ground-based telescope and Spectrograph)
- to calculate ion density and temperature

*Martian probe measurements are limited in special coverage, so global models are needed to calculate global escape rates

Final Goal

- to observe the time and spatial variation of emission of Martian ionosphere
- to determine how the rate of escape of Martian atmosphere gas to space depends on solar activity and planetary parameters (e.g. temperature, crustal magnetic fields)
- to estimate the total mass of atmosphere loss to space over the history of Mars

Instruments : T60/Vispec, Dataset

- T60...main mirror is 60 cm telescope
- Vispec...Visual imager and Spectrograph with Coronagraphy

Fig.9 T60 Telescope facility

Table2. Specifications of Vispec

CCD	13 micro-m/pixel, 1024 × 1024
Spatial resolution	0.52”/pixel
wave length dispersion	20.7 pm/pixel
wave length resolution	10,000
sensitivity	2.17E-4 counts/R/s @561 nm

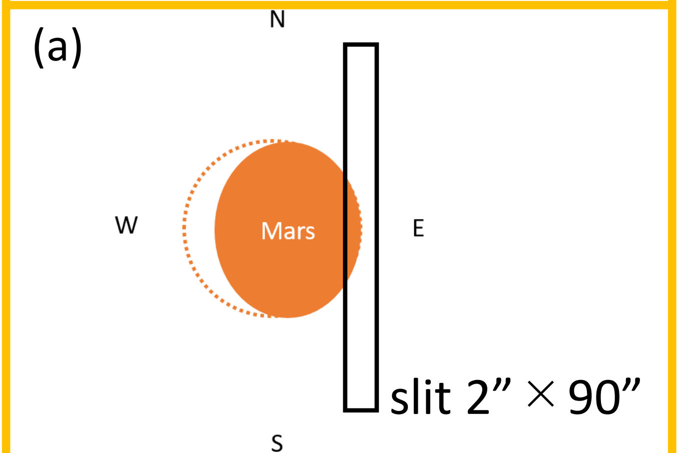
Table3. overview of observation

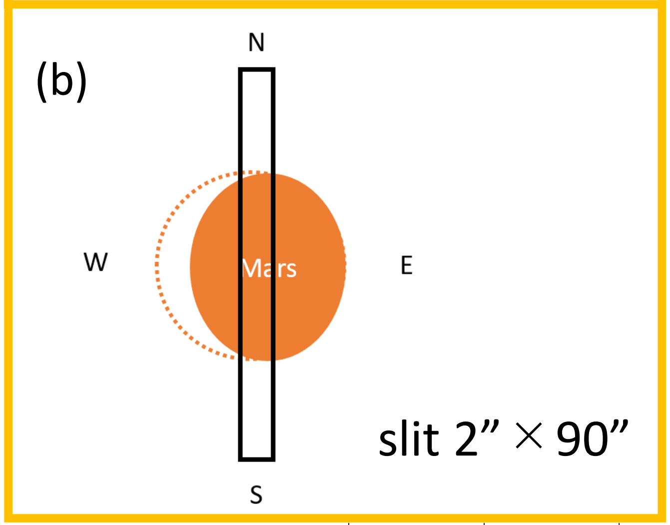
observation period	2018/9/10-2018/9/19 (JST)
observation wave length	549-570 nm
Apparent diameter of Mars	~18”
slit	2” × 90”
exposure time (per frame)	120 s (limb), 60 s (disk)
total valid frame	limb : 225 frame disk : 152 frame

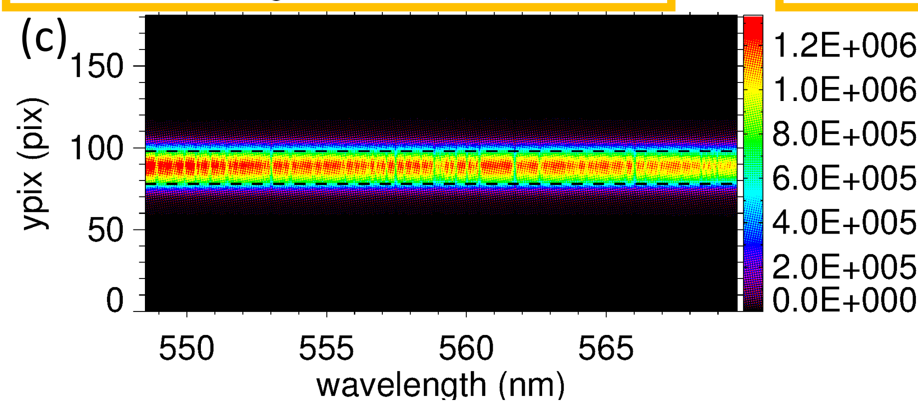
Fig.10 T60 Telescope

Data analysis : How to observe O_2^+ emission

limb observation (Fig.12 (b))		disk observation (Fig.12 (b))		O_2^+ emission (Fig.12 (c))
ionosphere O_2^+ 1NG bands + Martian disk sunlight reflection	−	Martian disk sunlight reflection	=	O_2^+ 1NG bands emission







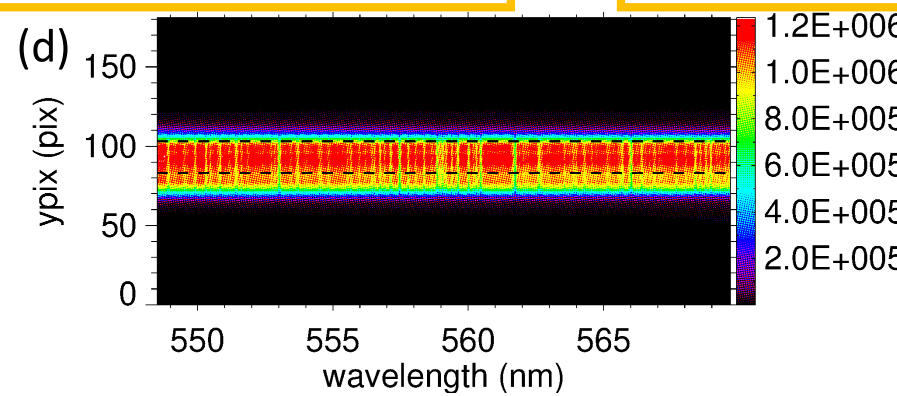


Fig.11 (a, b): Schematic view of the observing slit geometry (a) observation of Martian disk (b) observation of Martian limb. (c, d): The spectrum image of (c) limb, and (d) disk.

Data analysis : How to observe O_2^+ emission

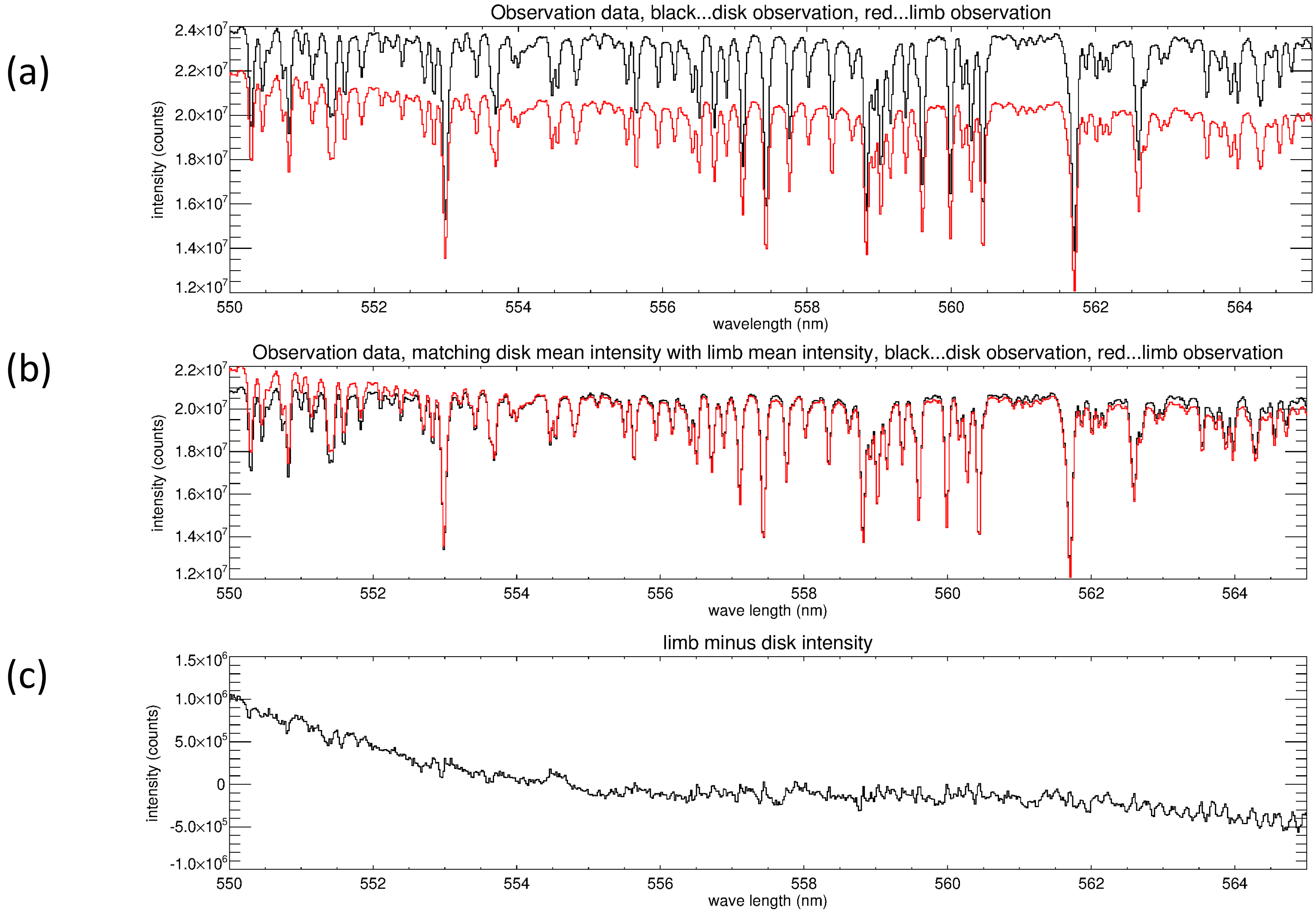


Fig.12 (a): Observation spectrum. Black curve is disk observation and red curve is limb observation. (b): Observation spectrum. Disk mean intensity matches limb mean intensity. (c): Limb spectrum subtracted disk spectrum (=O_2^+ 1 NG bands emission).

Observation O_2^+ 1NG bands emission spectrum

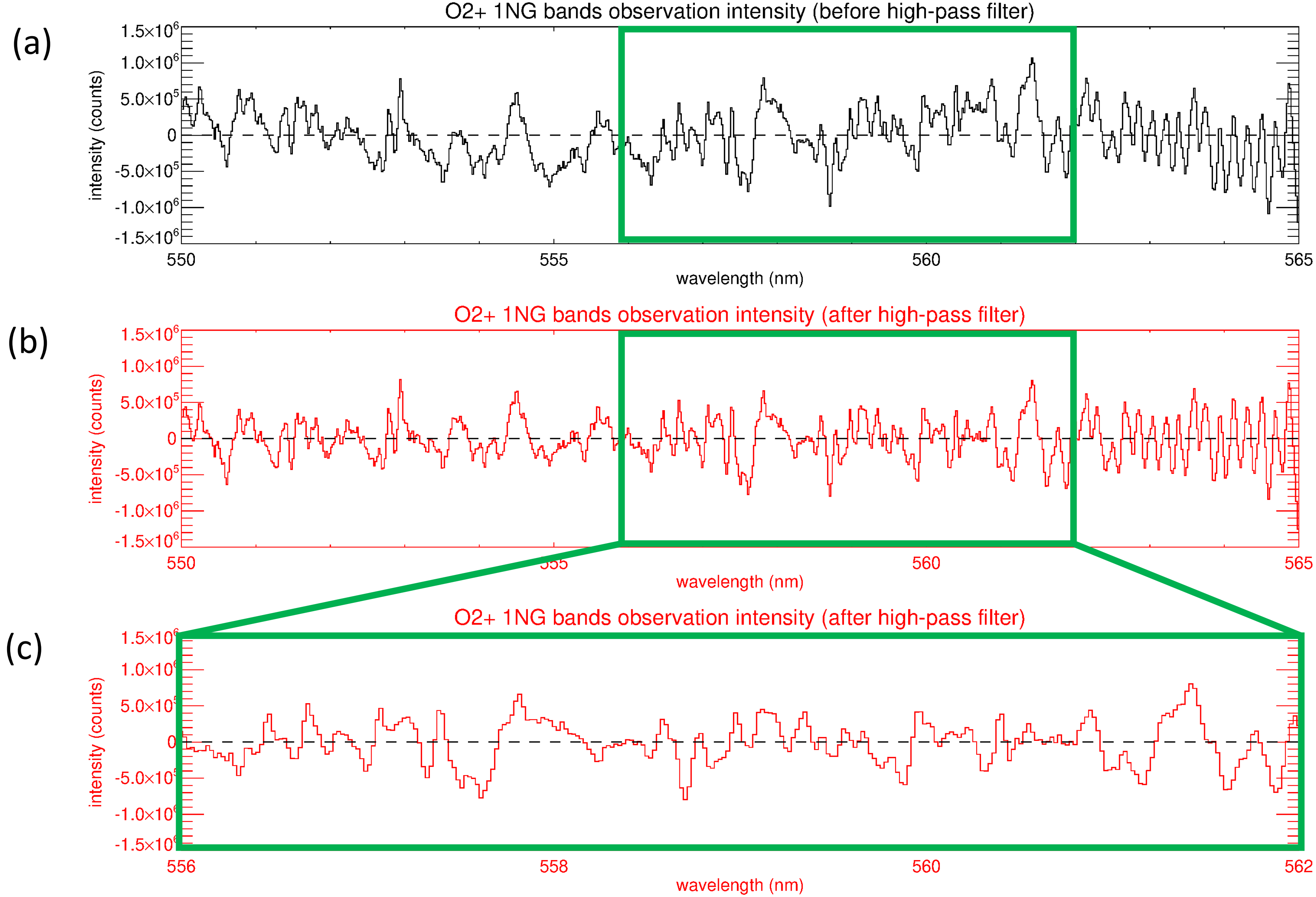


Fig.13 Observation O_2^+ 1NG bands emission spectrum. All frame are integrated. (a) spectrum before high-pass filter, and (b), (c) after high-pass filter.

Model O_2^+ 1NG bands emission spectrum

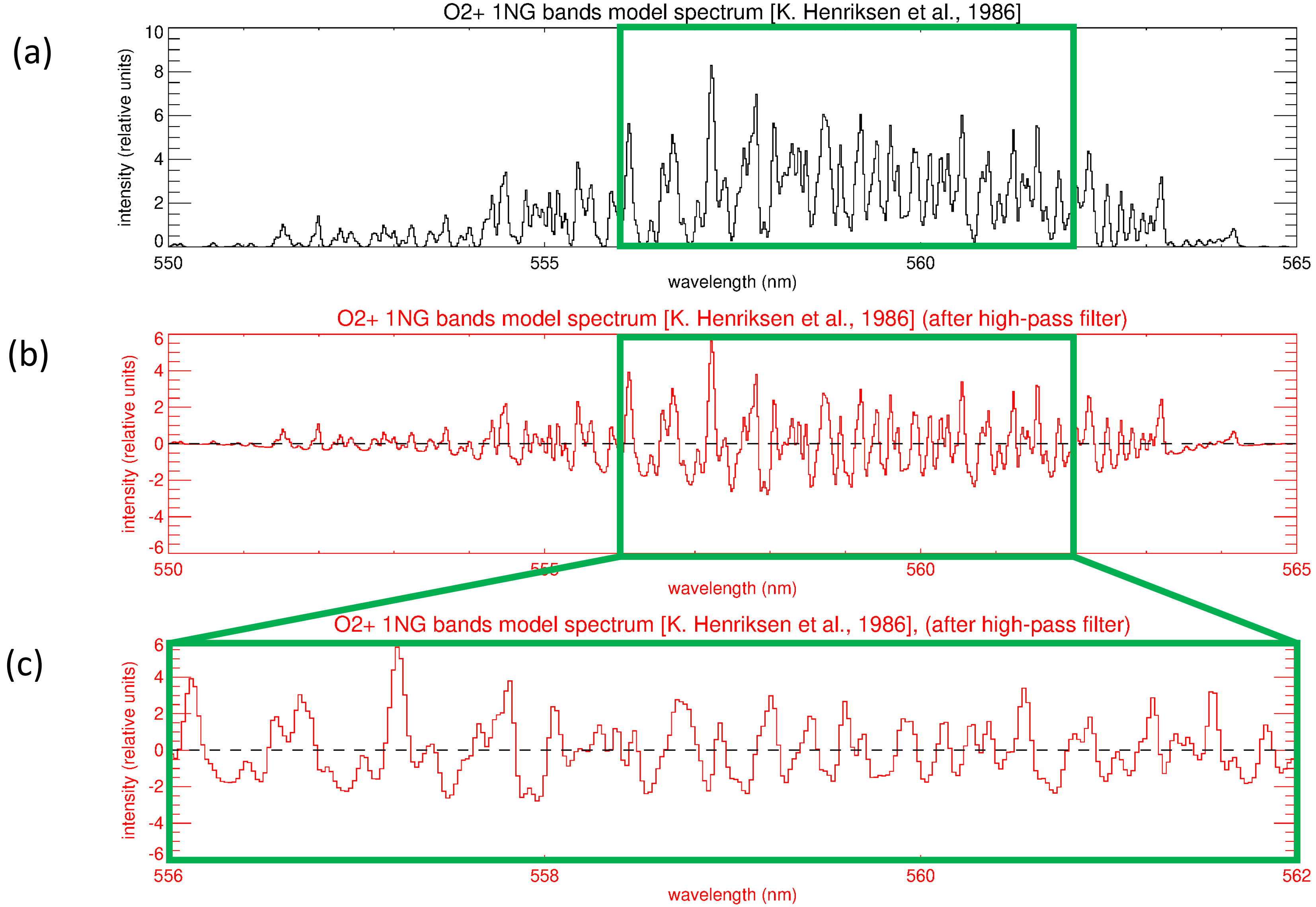
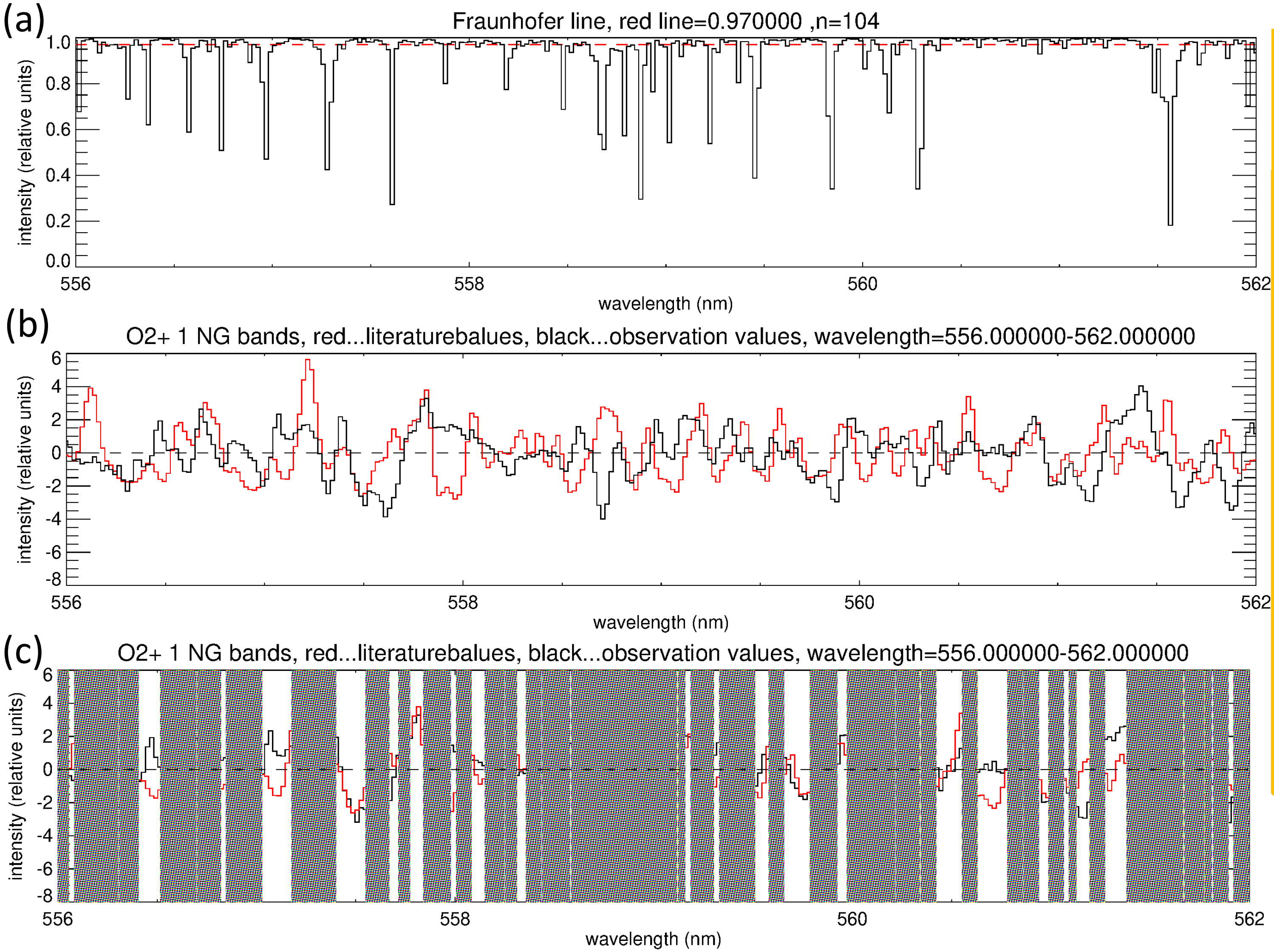


Fig.14 Model O_2^+ 1NG bands emission spectrum [K. Henriksen et al., 1987]. (a) before high-pass filter, and (b), (c) after high-pass filter.

Correlation between observation and model spectrum



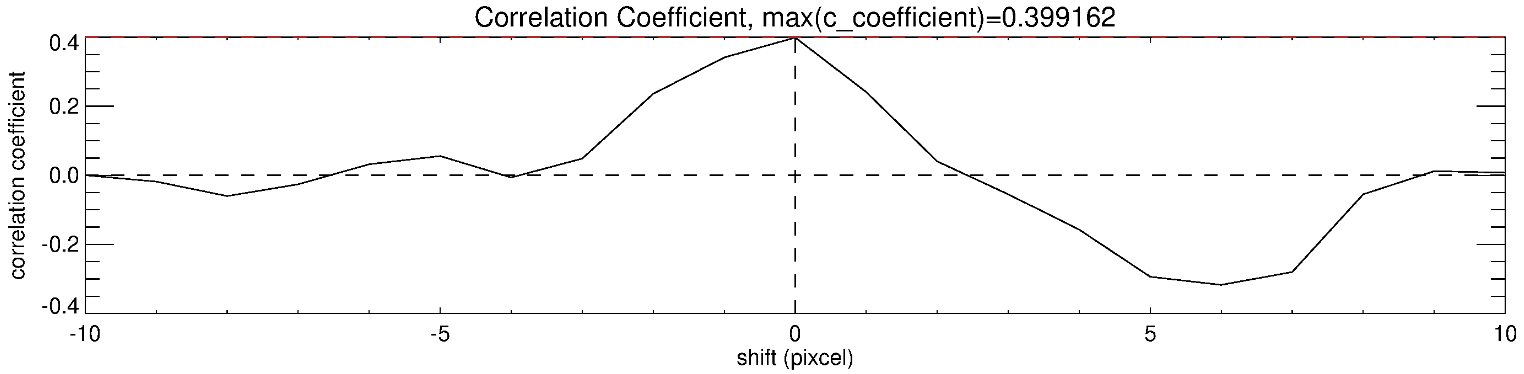
criteria of data selection

1. Little Fraunhofer line absorption
2. Little Fraunhofer line gradient
3. High O_2^+ emission model spectrum

Fig.15 (a): Fraunhofer lines. red dashed line is intensity ≧0.97. (b) ,(c): O_2^+ 1NG bands. black curve is observation value and red curve is model value. (c) only meeting the data selection criteria wavelength. No meeting the criteria wavelength is masked by gray line.

Correlation between observation and model spectrum

(a)



(b)

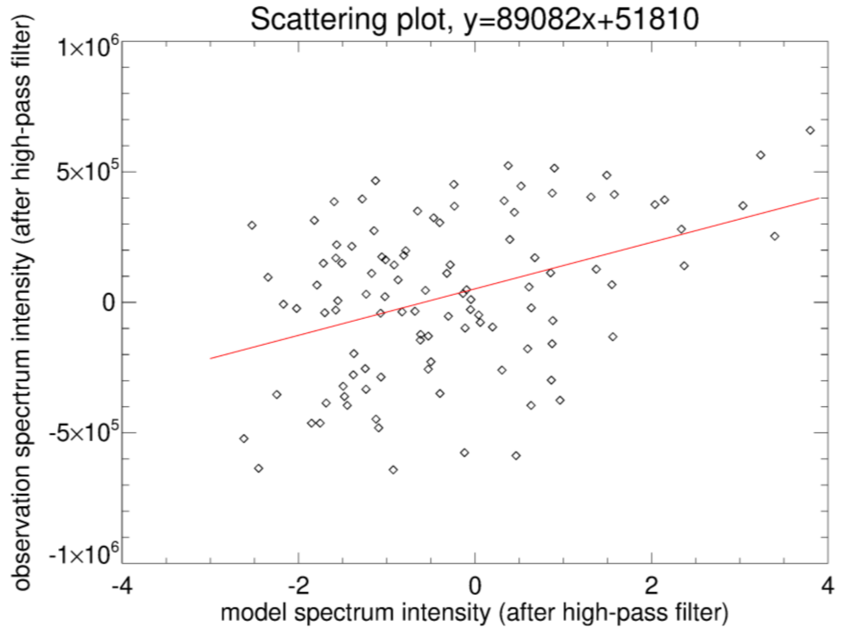
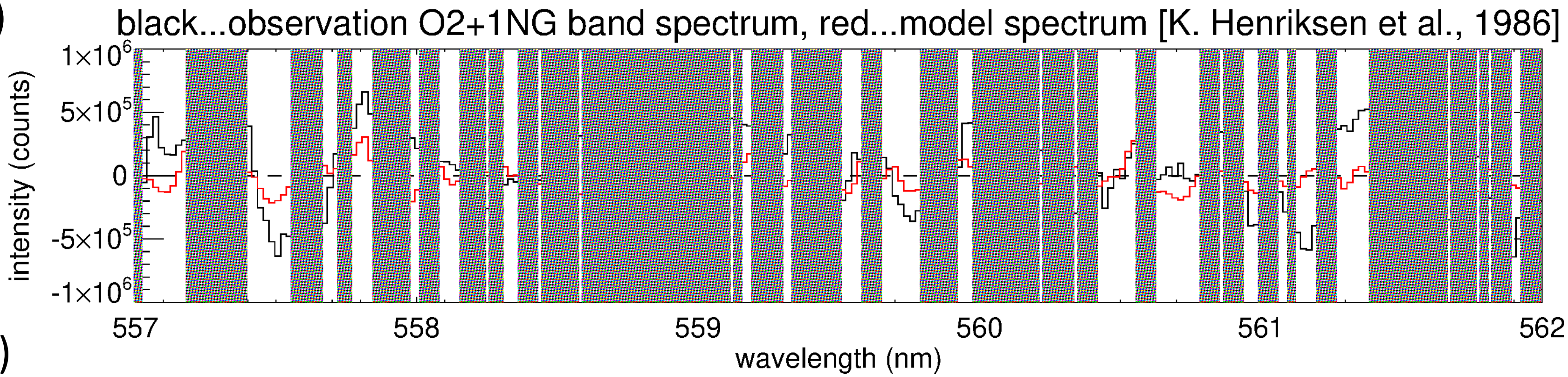


Fig.16 (a): Correlation Coefficient between observation spectrum and model spectrum (Correlogram). Correlation Coefficient is 0.40 at no lag. (b): Scattering plot between observation spectrum and model spectrum. red line is regression line.

Estimated O_2^+ 1NG bands intensity *and density*

(a)



(b)

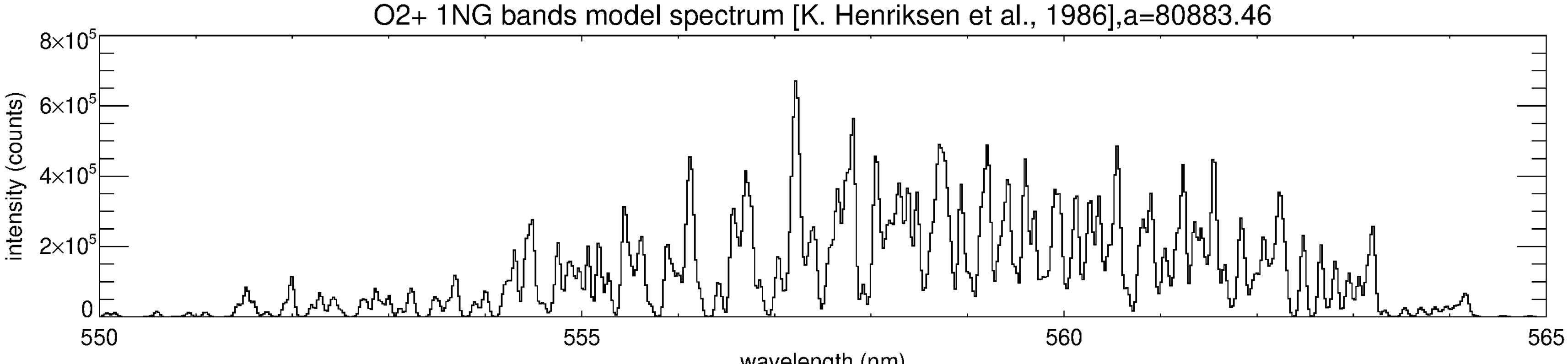
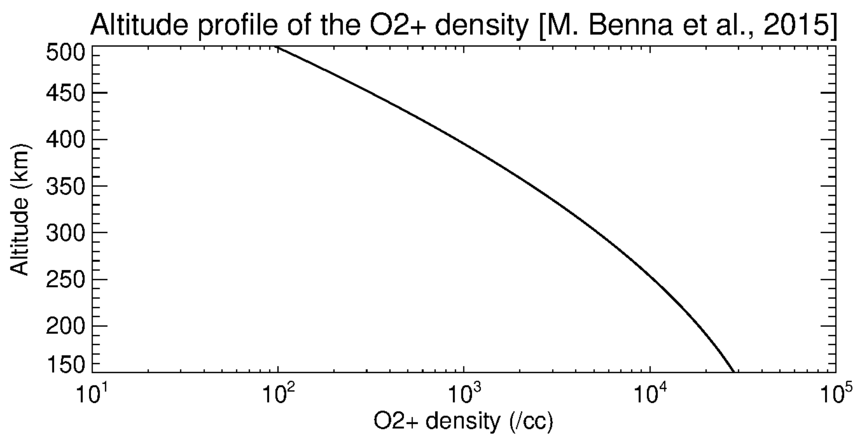


Fig. (a): Fitting O_2^+ 1NG bands model spectrum to observation spectrum (after high-pass filter). black and red curve and gray line are same as Fig. 15(c). Model spectrum intensity is calculated by using least-square method. (b): Anticipated O_2^+ 1NG bands spectrum. Model spectrum intensity is calculated by using least-square method.

- O_2^+ 1NG bands intensity is 8.53 +/- 2.11 $\times 10^7$ (counts)
  => O_2^+ 1NG bands intensity is 691 +/- 171 kR
- In assuming all emission was made by resonance fluorescence, column density is 4.43 +/- 1.10 $\times 10^{13}$ (/cm^2)

Discussion : O_2^+ column density by simulation

(a)



(b)

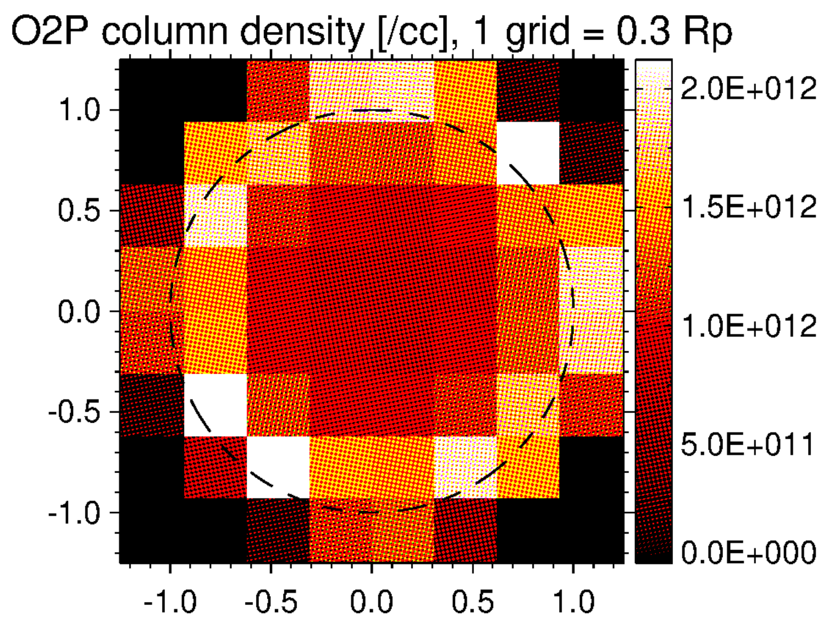


Fig.17 (a): Simulation altitude profile of the O_2^+ density (referenced of Fig.2 [M. Benna et al., 2015]),
(b): O_2^+ column density (/cm²), 1 grid=0.3 R_M (=~1020 km). Column density is ~2.0 ×10^{12} (/cm²)

Observation Column density is 4.43 +/- 1.10 × 10^{13} (/cm²)
Simulation Column density is ~2.0 × 10^{12} (/cm²)
=>
- ✓ Inaccuracy of subtraction of disk spectrum? (due to distortion of data?)
- ✓ Excitation on chemical reaction?
- ✓ Global high altitude O_2^+ profile?

Summary

- We have made the spectroscopic observation to detect Martian ionosphere O_2^+ 1NG bands since 2018/09/10 until 2019/09/19 (JST) with Haleakala T60/Vispec
- We supposed O_2^+ 1NG bands was detected because correlation coefficient between observation spectrum and model spectrum [K. Henriksen et al., 1987] was 0.40 at no lag.
- Observation O_2^+ 1NG bands intensity was estimated 691 +/- 171 kR, so column density of O_2^+ was calculated $4.43 \pm 1.10 \times 10^{13}$ (/cm^2).
- Column density of O_2^+ was ~2.0×10^{12} (/cm^2) by simulation.
- We don't conclude whether or not this column density is correct because of inaccuracy of subtraction of disk spectrum and not knowing global high-altitude O_2^+ profile.

References

- Hugh H. Kieffer, 1992, “MARS”, The University of Arizona Press
- M.Benna et al., 2015, “First measurements of composition and dynamics of the Martian ionosphere by MAVEN's Neutral Gas and Ion Mass Spectrometer”, GRL, vol. 42, Issue 21, pp.8958-8965, doi:10.1002/2015GL066146
- Tobias Owen et al., 1977, “The composition of the atmosphere at the surface of Mars”, AGU, vol.82, Issue 28, pp.4635-4639, doi:10.1029/JS082i028p04635
- K. Henriksen et al., 1987, “Analysis of auroral 0; first negative bands”, Canadian Journal of Physics, 65(9), pp.1119-1132, doi:10.1139/p87-183
- R. Lundin et al., 2009, “Atmospheric origin of cold ion escape from Mars”, GRL, Vol. 36, Issue 17, L17202, doi:10.1029/2009GL039341
- H. Nilsson et al., 2011, “Heavy ion escape from Mars, influence from solar wind conditions and crustal magnetic fields”, Icarus, Vol. 215, Issue 2, pp. 475-484, doi:10.1016/j.icarus.2011.08.003
- https://phys.org/news/2014-02-maven-satellite-mars-atmosphere.html
- R. Lundin et al., 2011, “On the relation between plasma escape and the Martian crustal magnetic field”, GRL, Vol. 38, Issue 2, doi:10.1029/2010GL046019
- Benoit Langlais et al., 2009, “Crustal Magnetic Fields of Terrestrial Planets”, Space Science Reviews, Vol. 152, Issue 1-4, pp. 223-249, doi:10.1007/s11214-009-9557-y

References

- D.J. Andrews et al., 2015, “Control of the topside Martian ionosphere by crustal magnetic fields”, JGR, Vol. 120, Issue 4, pp. 3042-3058, doi:10.1002/2014JA020703
- E. Dubinin et al., 2012, “Upper ionosphere of Mars is not axially symmetrical”, Earth Planets Space, 64, pp.113-120, doi:10.5047/eps.2011.05.022
- Carolus J. Schrijver et al., 2016, “HERIOPHYSICS”, Cambridge University Press