X-ray spectral model of Io plasma torus for hot plasma diagnostics

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自己紹介

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  - D論「木星準周期的低周波電波バースト現象の励起と伝搬」
  - 土星・木星探査機のプラズマ観測データ解析・数値実験等
  - SPRINT-A科学データ地上処理系・DB開発担当
  - 将来木星探査計画の科学検討参画

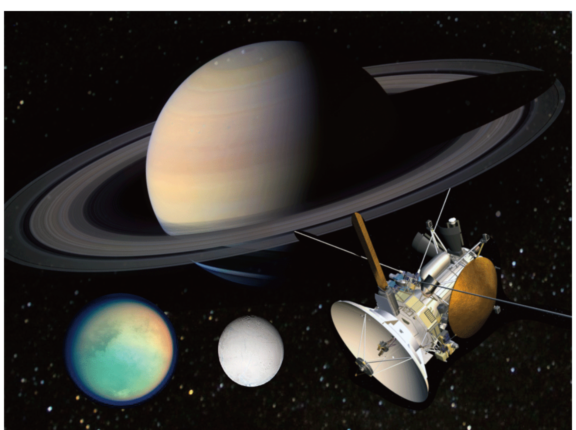
$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\epsilon_0}$$

大変申し訳ないのですが
木村の第一原理はこれし
かありません…

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial B}{\partial t}$$

$$\nabla \times \boldsymbol{B} = \mu_0 \left(\boldsymbol{j} + \epsilon_0 \frac{\partial \boldsymbol{E}}{\partial t} \right)$$



$$\frac{\partial f_s}{\partial t} + \mathbf{v} \cdot \nabla f_s + \frac{q_s}{m_s} (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \nabla_{\mathbf{v}} f_s = 0$$

Jupiter system and future campaign

Jupiter system

- Fast rotation: 9.92 hrs
- Internal mass source: plasmas from Io's volcano (Sulfur,Oxygen) form corotating "plasma torus"
- Huge magnetosphere:

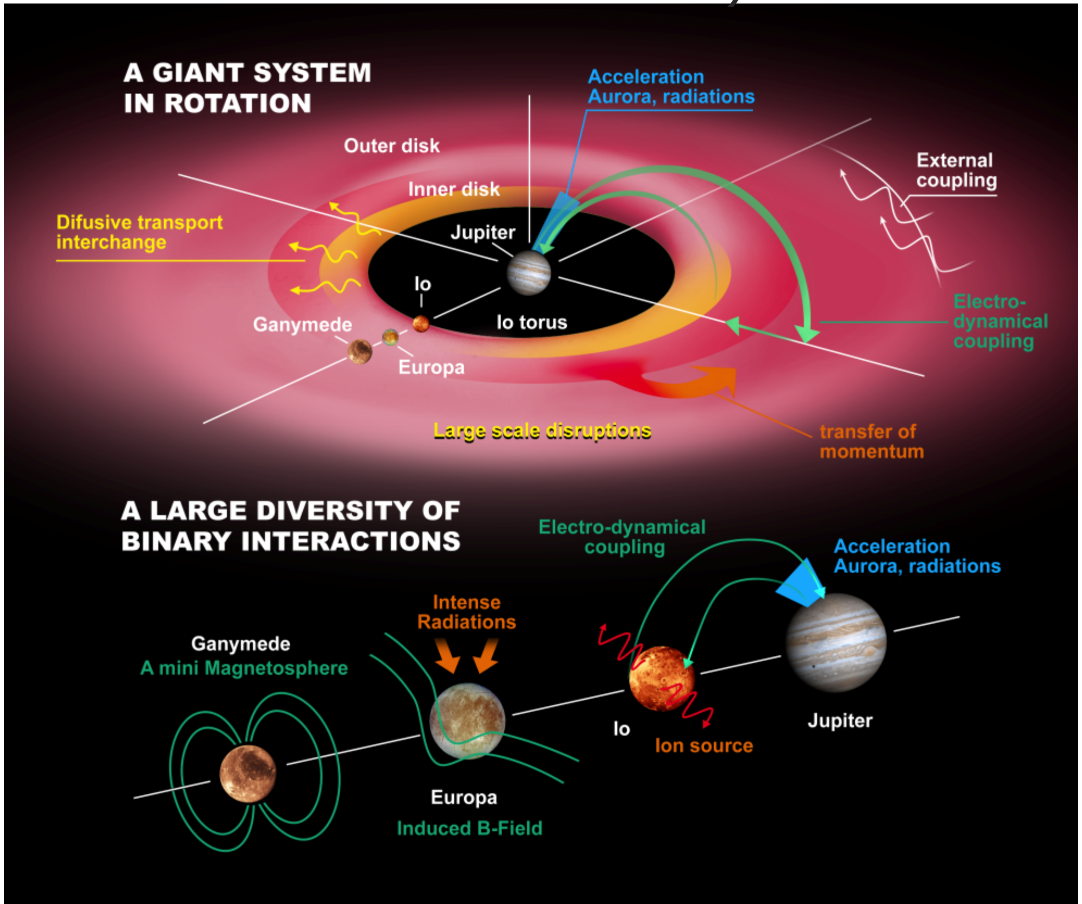
  sub-solar dist.~100Rj~7x10^6 km

  (cf. at Earth, sub-solar dist.~10Re~6x10^4km)

1 Jovian radius (1Rj)=71492km

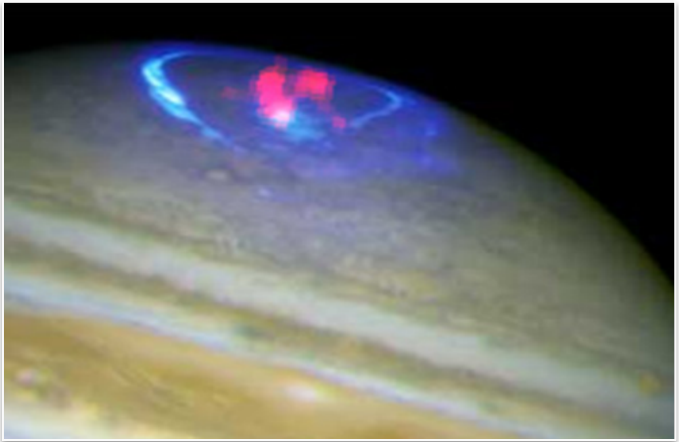
- Icy and volcanic satellites
  - Io
  - Europa

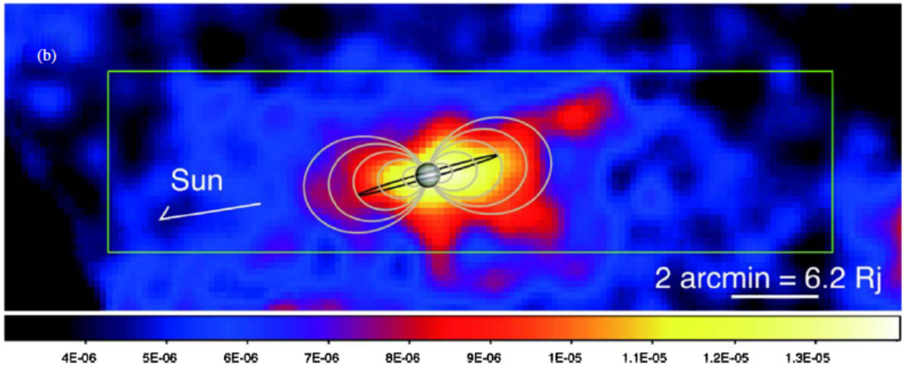
    (habitable zone?)
  - Ganymede

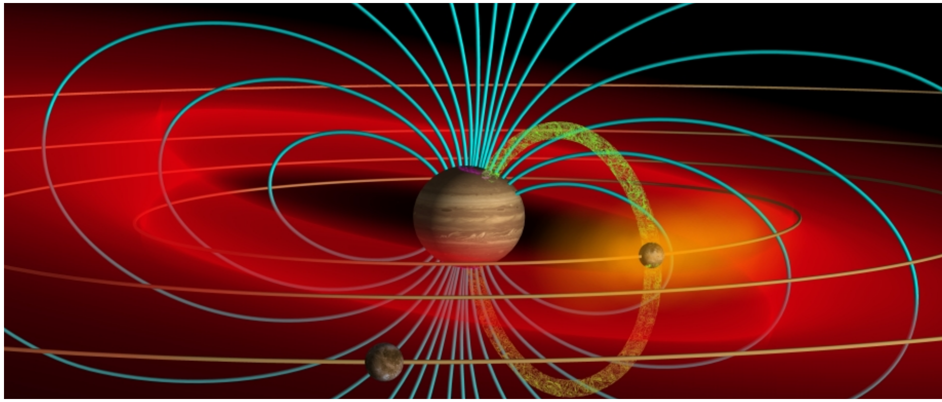


Giant particle accelerator with radiations

- aurora
  - 100kV-10s MV potential drop along polar magnetic fields
  - IR:H_3^+ band emission
  - UV:H_2 band emission
  - Xray: O(&S?) lines, bremss
  - radio: kHz-10sMHz by auroral electrons
- radiation belt
  - <50MeV electrons
  - synchrotron radiation
  - inverse-Compton scattering
- Io plasma torus
  - a few eV cold BG plasma
  - 100s eV hot minor plasma
  - UV&X-ray:
    O&S lines, bremss





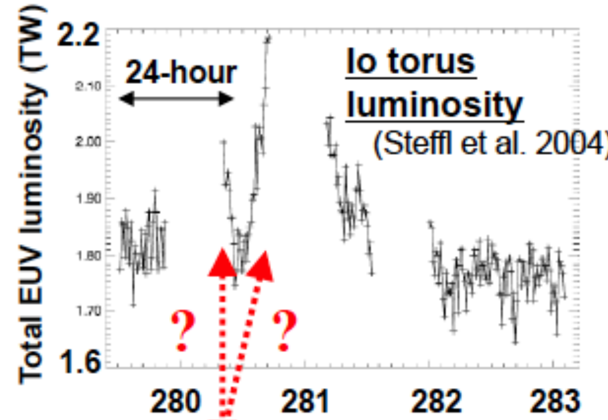


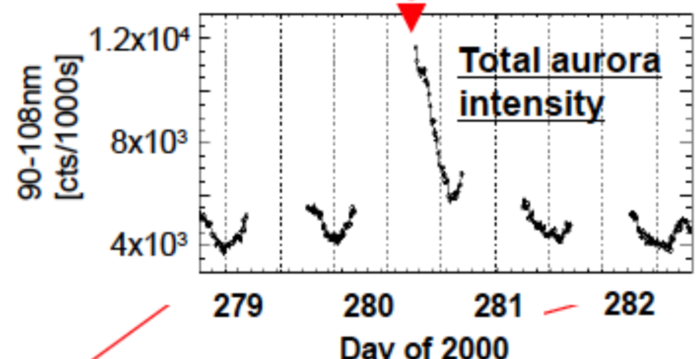
Global plasma heating & acceleration

Cassini/UVIS found torus brightening events that correlate with those of the Jovian aurora

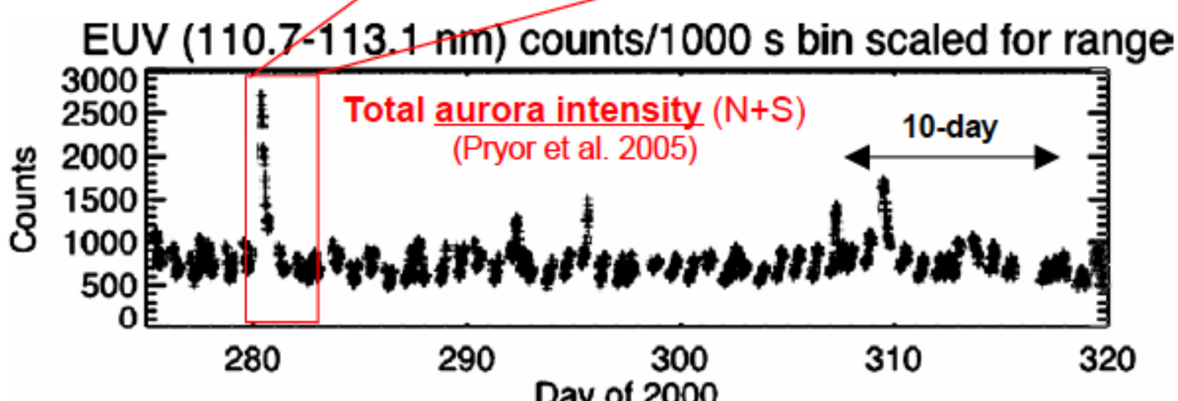
[Time scale of the brightening : 5-10 hours]

In the Cassini observations, however, due to the 10-h on/10-h off observation mode and the small number of events, it is difficult to make a definitive statement about the correlation between the torus and the aurora. (Stefll et al. 2004)



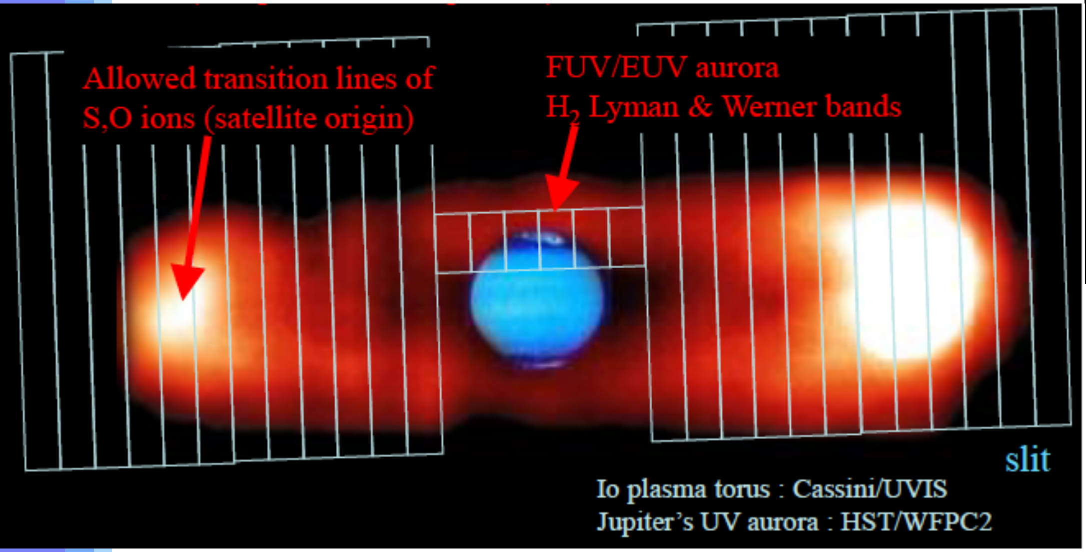


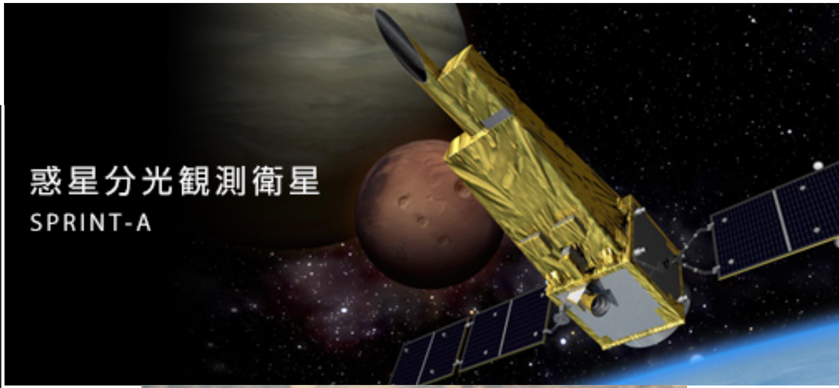
We expect that simultaneous observations of the aurora and the torus luminosities by EXCEED find the definitive relation between outer and inner magnetospheres of Jupiter.



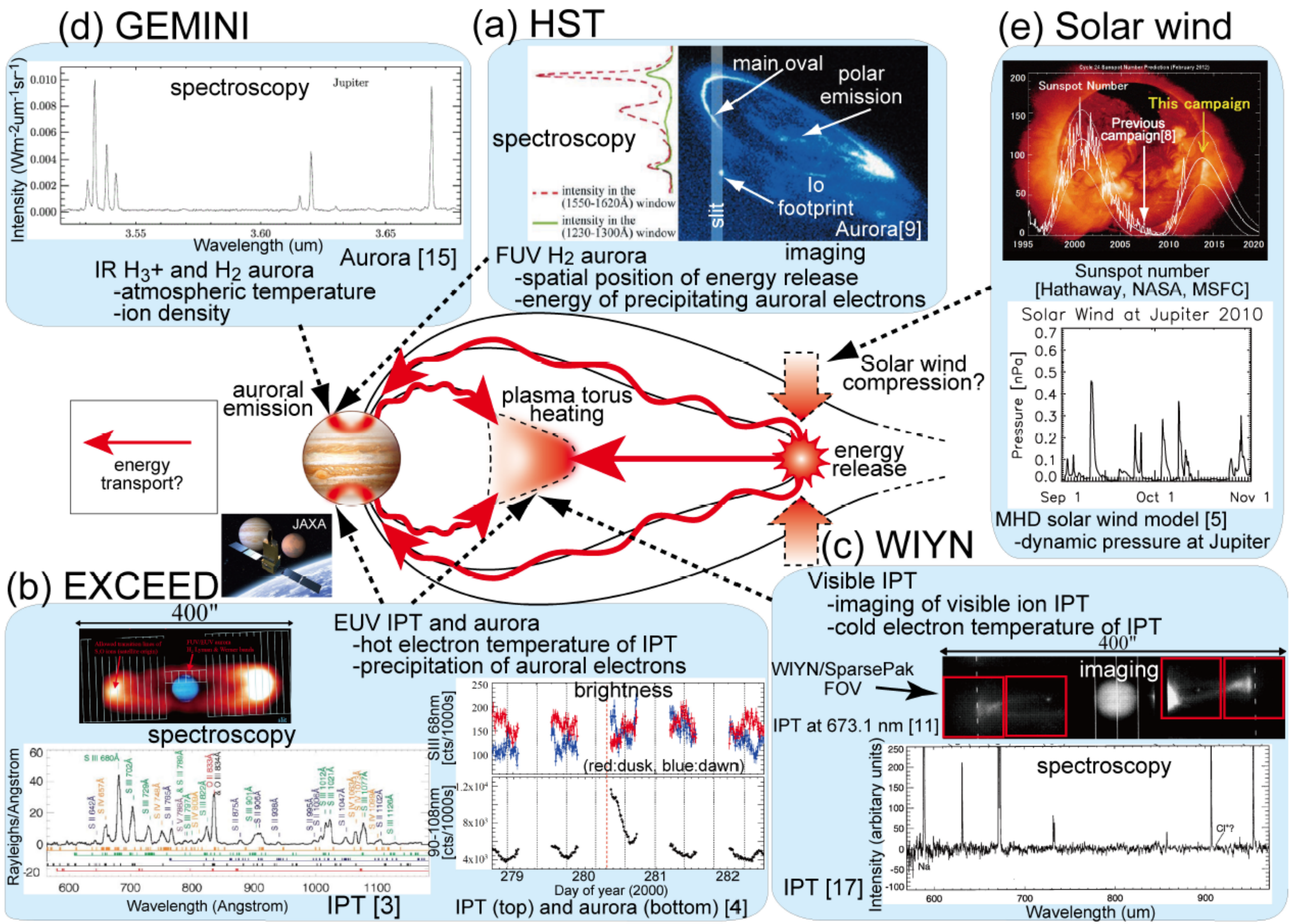
SPRINT-A satellite

- To be launched in late Aug, 2013
- JAXA's next generation solid launch vehicle 'Epsilon'
- EXCEED experiment : EUV spectroscopy of
  - Io plasma torus heating process
  - Venusian atmospheric escaping process
  - Martian atmospheric escaping process
- Plasma diagnostic (density, temperature, hot plasma fraction) from EUV spectra





HST-SPRINT-A Jupiter campaign



“X-EXCEED” Jupiter campaign

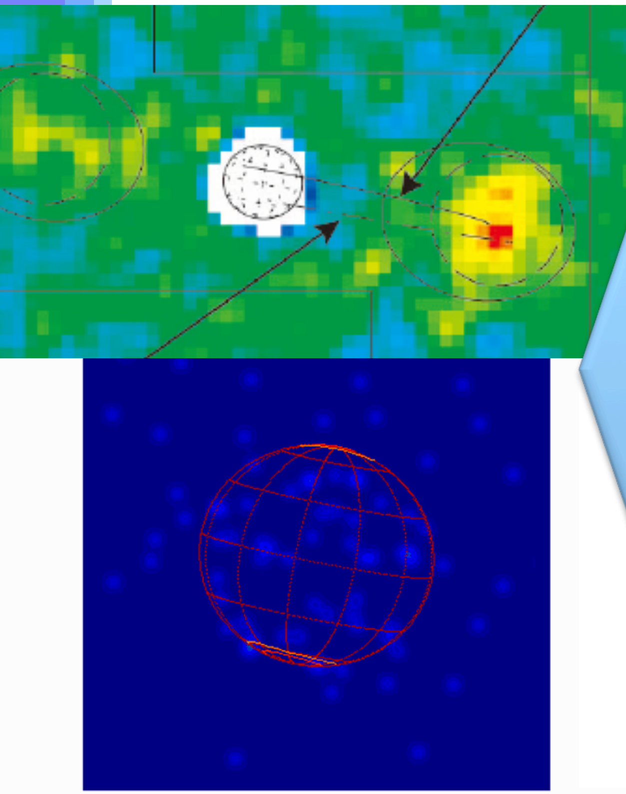


image
spect

SPRINT-A launch

SPRINT-A/HST campaign (approved)

SPRINT-A/CXO/XMM/Suzaku campaign (submitted)

primary operation

Continuous observation by SPRINT-A

late Aug | early Nov? | 1st Jan | 14th Jan | 7th Apr | 19th Apr

2013 | 2014

1. SPRINT-A	Io torus and jovian aurora EUV spectroscopy.
2. HST/STIS	Jupiter northern FUV auroral imaging and spectroscopy.
3. NOAO Gemini	Jupiter H3+ (4 micron) aurora.
4. IRTF	Jupiter H3+ (4 micron) ion winds in auroral region (spectroscopy).
5. Subaru	Jupiter H2 / H3+ (2-4 micron) auroral intensity: AO imaging and slit spectroscopy (7" slit).
6. HST/STIS	Jupiter southern FUV auroral imaging of Io and Ganymede footprints.
7. Chandra /XMM Newton	Jupiter X-ray aurora and IPT
8. NOAO Kitt Peak WIYN	Io torus visible wavelength spectroscopy.
9. Suzaku	Jovian inner magnetosphere diffuse X-ray.
10. Haleakala	Sodium nebula
11. U. Tokyo facility Chile	Sodium nebula
12. U. Padova	Io torus sulphur (and possibly sodium) lines using high resolution spectroscopy.
13. Apache Point	Io torus sulphur lines spectroscopy.
14 McMath-Pierce	Coronagraphic observations of torus in [SII] 6731A
15 Io Input/output facility	Coronagraphic observations of torus in [SII] 6731A, Mendillosphere
16. SOFIA	Jupiter.
17. HST/WFPC	Jupiter vortical and zonal winds at ~680 nm.
18. EVLA	Jupiter deep atmosphere.
19. Keck	Io volcanic activity in near-IR.
20. GEMINI	Io volcanic activity in near-IR.
21. McMath-Pierce	Io atmosphere at 630 nm.
22. ALMA	Spatial distribution of SO2 gas around Io.
23. U. California	Spatial distribution of SO2 gas around Io.
24. IRTF/SPEX	Io 1-5 micron spectroscopy monitoring campaign.
25. Atacama (U. Tokyo)	Io activity at 10 micron.

X-rays from Jupiter

Ezoe et al. (2012)

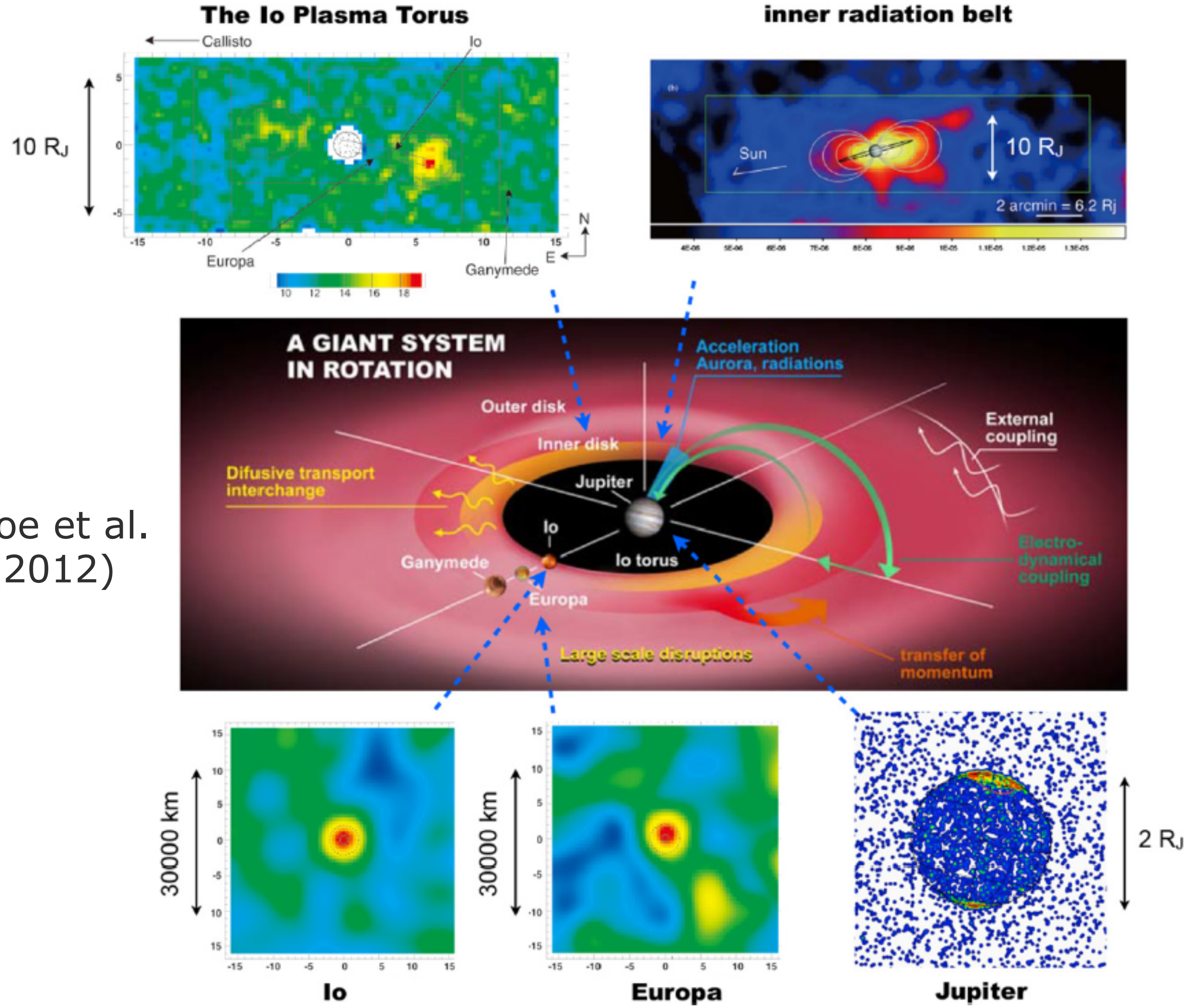
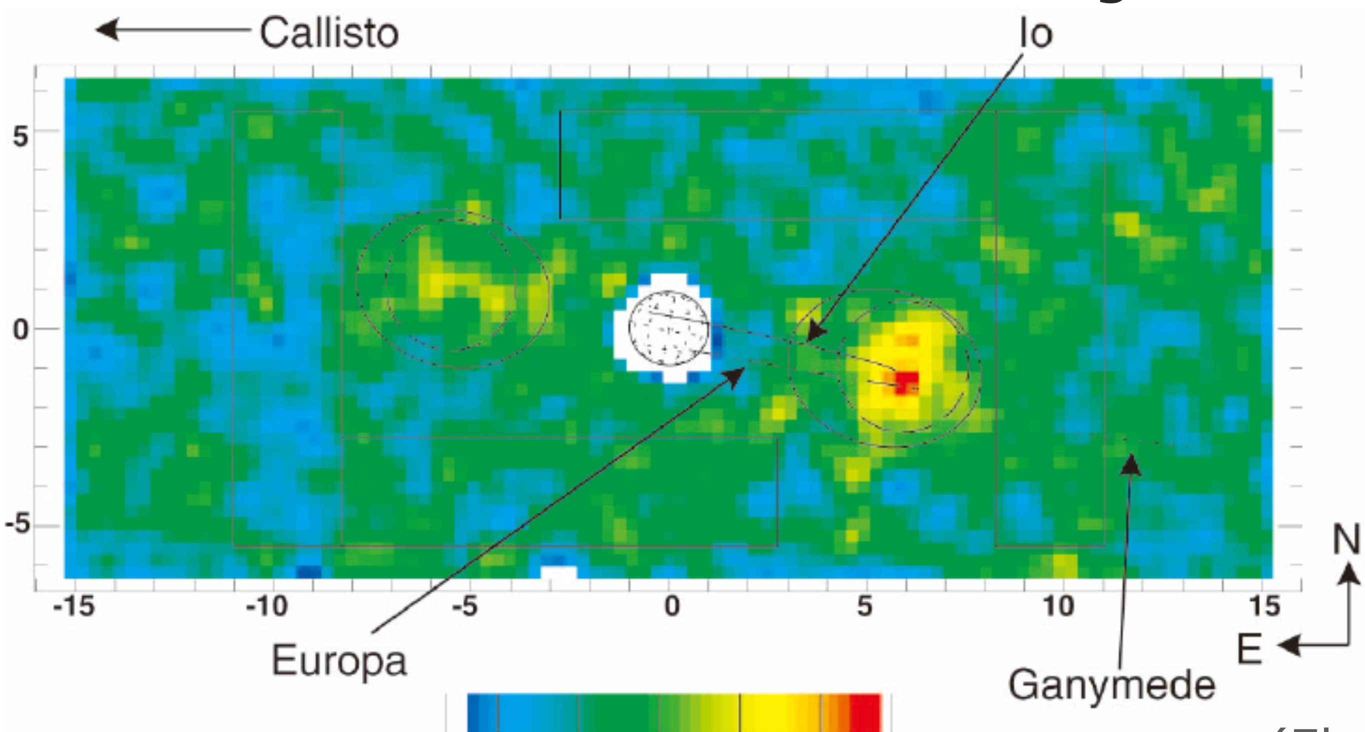


Fig. 1. The Jupiter system as a giant system in rotation (Blanc et al., 2009). Arrows indicate known X-ray sources in the Jupiter system: the Io plasma torus (Elsner et al., 2002), inner radiation belts (Ezoe et al., 2010), Jupiter (Gladstone et al., 2002), and the Galilean satellites (Elsner et al., 2002) (from left to right, top to bottom).

X-ray from Io plasma torus

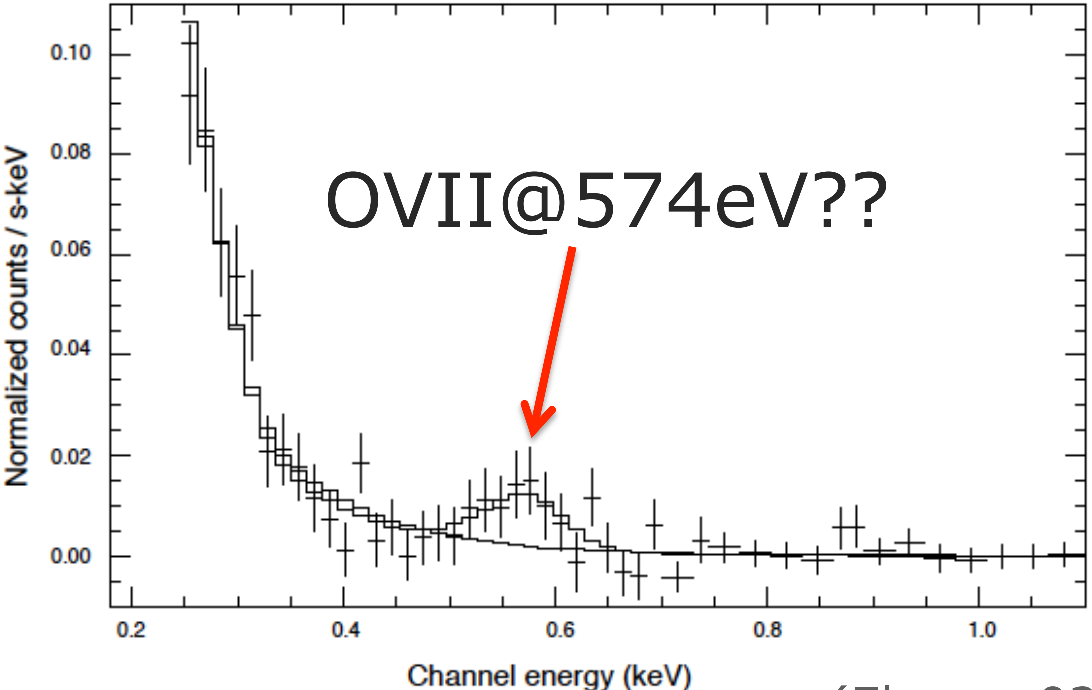
- Soft X-rays from IPT observed by CXO/ACIS (Elsner +02)
- electron: bremsstrahlung
- ion: unknown. OVII line via Charge Exchange??



(Elsner+02)

FIG. 2.—HRC-I image of the IPT (2000 December 18). The image has been smoothed by a two-dimensional Gaussian with $\sigma = 7''.38$ (56 HRC-I pixels). The axes are labeled in units of Jupiter's radius, R_J, and the scale bar is in units of smoothed counts per image pixel ($7''.38 \times 7''.38$). The paths traced by Io (*solid line*, semimajor axis 5.9 R_J), Europa (*dashed line*, semimajor axis 9.5 R_J), and Ganymede (*dotted line*, semimajor axis 15.1 R_J) are marked on the image. Callisto (semimajor axis 26.6 R_J) is off the image to the dawn side, although the satellite did fall within the full microchannel plate field of view. For this observation, Jupiter's equatorial radius corresponds to $23''.9$. The regions bounded by rectangles were used to determine background. The regions bounded by dashed circles or solid ellipses were defined as source regions.

IPT spectra



(Elsner+02)

cf. OVII lines can exist with T~40eV-6keV in collisional equilibrium plasma WITHOUT CX (ATOMDB, Smith+)

Thermal Bremsstrahlung Plus Gaussian Line[e]

T (eV)	56 (+6/−5)
$EM^{d}/10^{40}$	7 (+4/−2)
E_{line} (eV)	567 (+10/−12)
σ (eV)	0 (+28)
A (10^{-6} counts s^{-1} cm^{2})	4 (+1/−1)

electron Bremss

OVII@574eV??

Ultra relativistic electrons

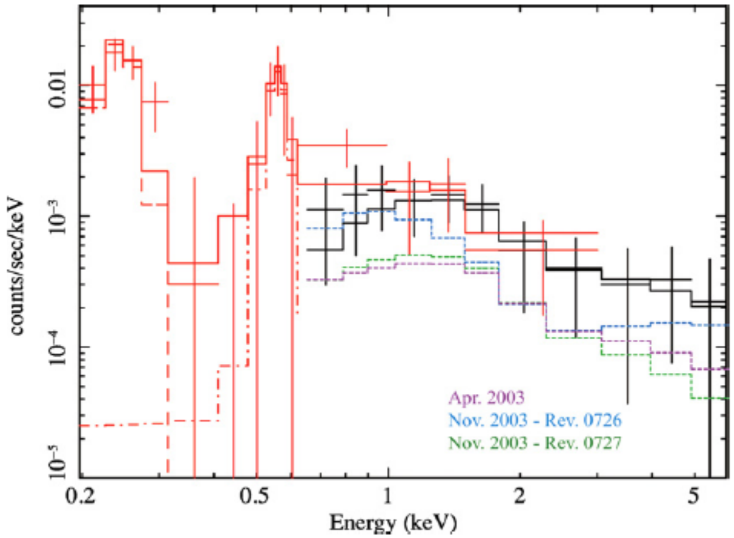
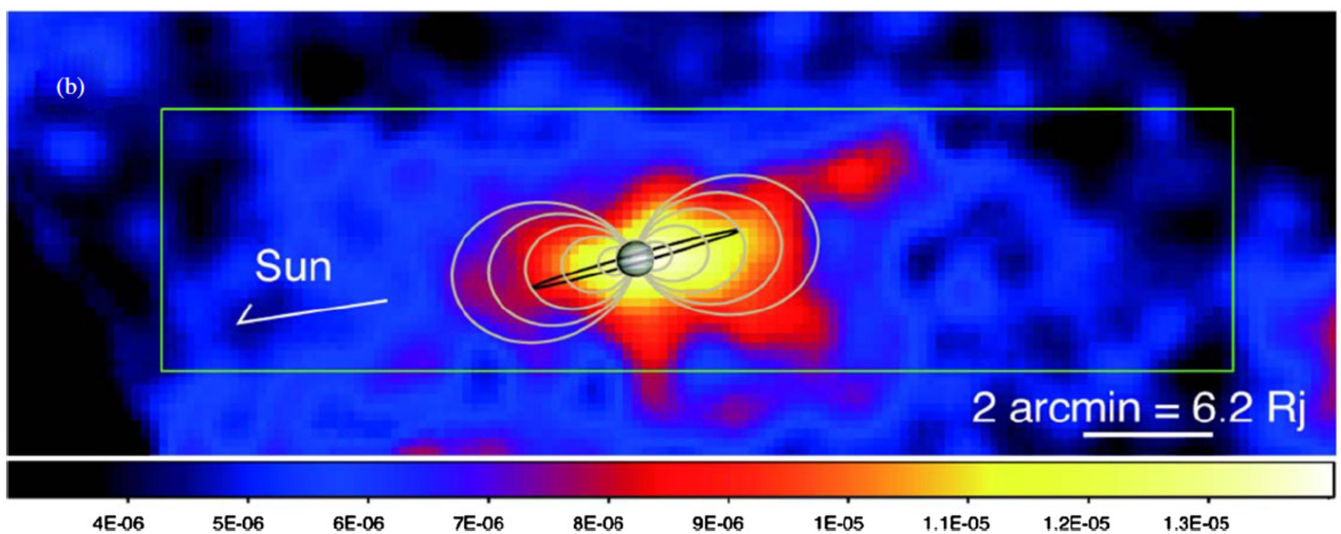


Figure 4. Background subtracted BI (red) and FI (black) spectrum of the extended emission region, compared with the best-fit power-law plus two Gaussian models (solid line). Two Gaussians are shown in dashed and dash-dotted lines. Purple, green, and blue dashed lines plotted for the FI spectrum are Jupiter's auroral continuum emission models in *XMM-Newton* observations (Branduardi-Raymont et al. 2007a).

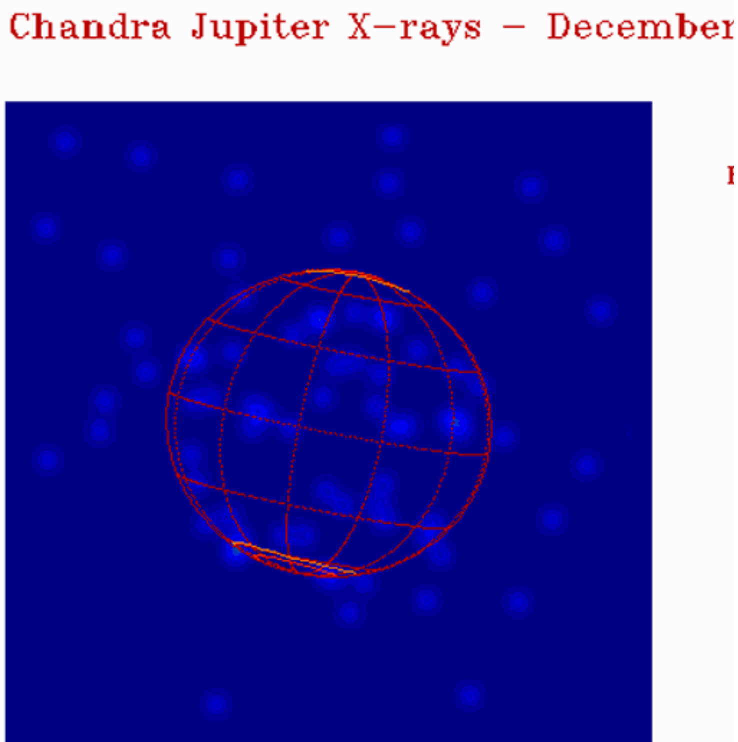
(A color version of this figure is available in the onlin

- Electrons with energies up to 50 MeV
- Inverse-Compton scattering from radiation belts (Ezoe et al., 2010)

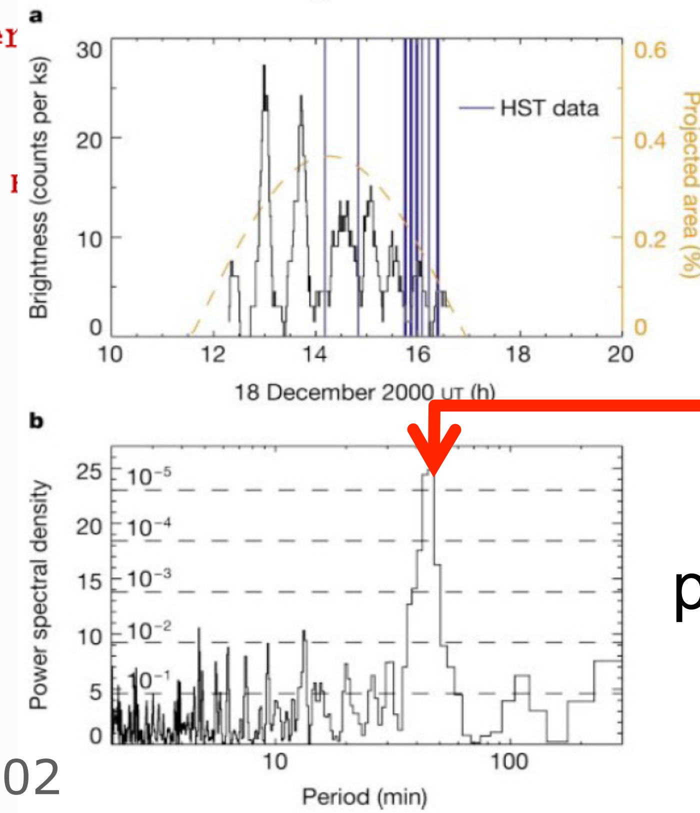


Polar QP X-ray aurora

- Northern X-ray "hot spot" pulsating with 45 min period (Gladstone+02)
- Charge exchange of higly-stripped heavy ions (C^{+n}, S^{+n}, O^{+n}) (e.g., Elsner et al., 2005)
- Potential drop of >8 MV is required (Cravens et al., 2003)
- Acceleration process: unknown. Cusp RX? Alfvenic accel.? (Bunce et a., 2004; Kimura et al., 2012)



Gladstone+02



light curve

(black solid)

~45 min

periodicity

Satellites

- Soft X-rays from satellite surface (Elsner et al. 2002)
- Oxygen K-shell fluorescent emission by bombardment energetic H, S, and O ion from IPT

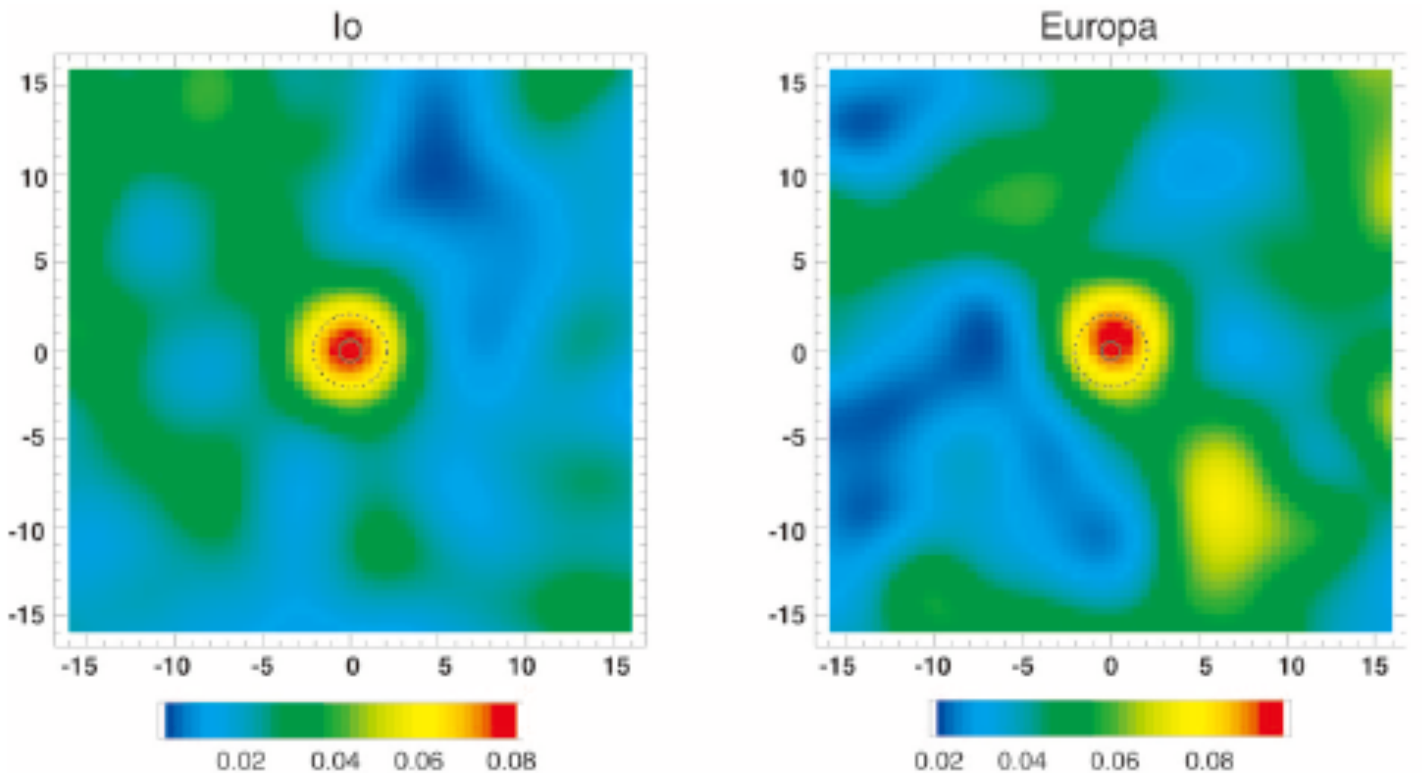


FIG. 1.—ACIS images of Io and Europa (250 eV < E < 2000 eV). The images have been smoothed by a two-dimensional Gaussian with $\sigma = 2\farcs46$ (5 ACIS pixels). The axes are labeled in arcsec ($1'' \simeq 2995$ km), and the scale bar is in units of smoothed counts per image pixel ($0\farcs492 \times 0\farcs492$). The solid circle shows the size of the satellite (the radii of Io and Europa are 1821 and 1560 km, respectively) and the dotted circle the size of the detect cell.

X-ray spectral model of IPT

Purpose

- Background
  - Global energy release, transfer, and plasma heating processes may exist at Jupiter
  - Unknown X-rays emissions near OVII line and bremss from IPT [Elsner+02]
  - Charge exchange (CX), collisional electron excitation, ionization, recombination seem dominant in IPT [Delamere and Bagenal, 03]
- Purpose of this study
  - Development of 0D X-ray spectral model newly including CX process on the basis of astrophysical collisional plasma models
  - Diagnostic of IPT hot plasma temperature and density from X-ray spectra

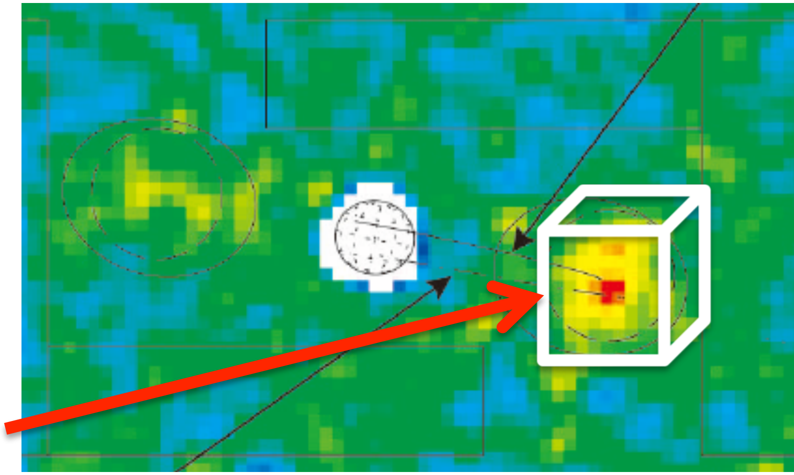
Relevant reactions

- Contributing to radiative process
  - Electron collision excitation (EXC):
    e.g., $O^{6+}+e \rightarrow O^{+6*}+e \rightarrow O^{+6}+e+h\nu$
- Contributing to chemical and radiative process
  - Charge transfer (electron capture) (TNS):
    e.g., $O^{7+}+X \rightarrow O^{6+*}+X^{+} \rightarrow O^{+6}+h\nu$
  - Electron recombination (REC):
    e.g., $O^{7+}+e \rightarrow O^{+6*} \rightarrow O^{+6}+h\nu$
  - Electron collision ionization (COL):
    e.g., $O^{5+}+e \rightarrow O^{+6*}+2e \rightarrow O^{+6}+2e+h\nu$
- Contributing to chemical process
  - Electron stripping (STR):
    e.g., $O^{5+}+X \rightarrow O^{+6}+X+e$、$O^{5+}+X^{+q} \rightarrow O^{6+}+X^{+q-1}$
- Red: charge exchange (CX) processes in this study
- Blue: collisional processes dealt in astrophysical plasma model (CHIANTI/APEC)

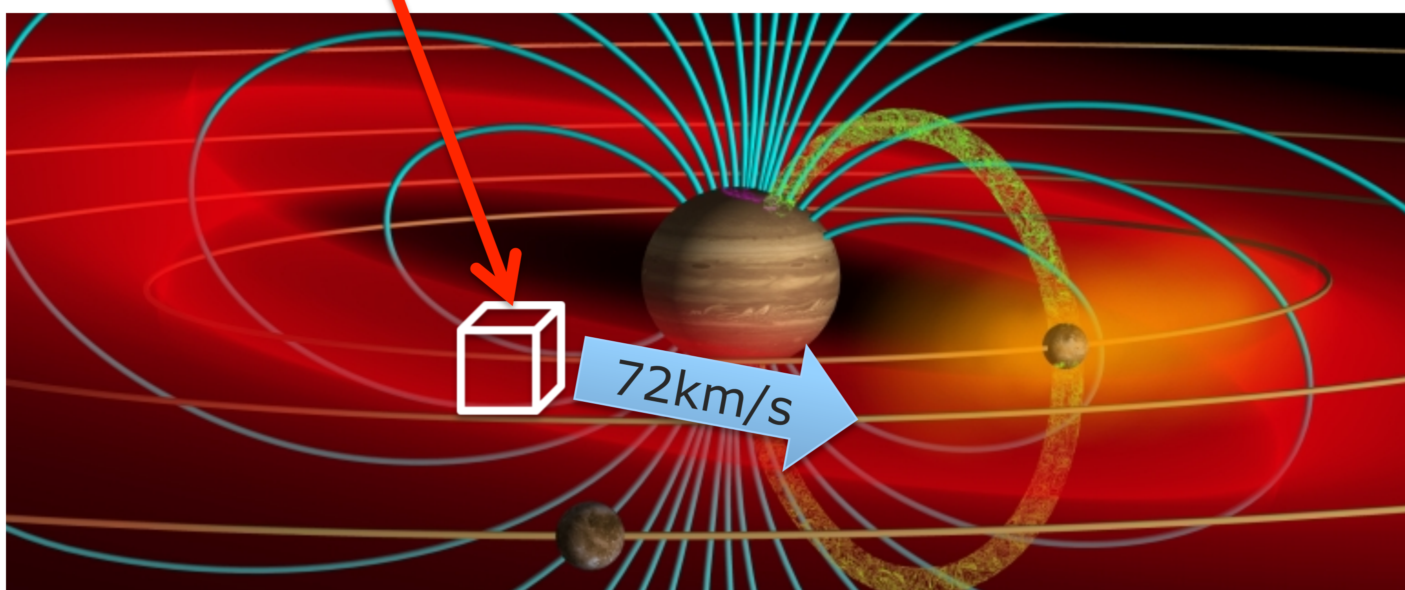
Chemical process

Simulation box

- zero dimensional
- corotating with IPT plasma at 6Rj
- Neutrals penetrate the box at relative velocities of corotating plasma wrt Keplerian velocity



corotating simulation box



Basic equations

$$\frac{dN_q}{dt} = Source_q - Loss_q = 0$$

COL REC STR (NEW) TNS (NEW)

$$Source_q = N_e N_{q-1} I_{q-1} + N_e N_{q+1} R_{q+1} + \sum_{t>q-1} N_t N_{q-1} S_{q-1,t} + \sum_{t<q+1} N_t N_{q+1} T_{q+1,t}$$

$$Loss_q = N_e N_q I_q + N_e N_q R_q + \sum_{t \neq q} N_t N_q S_{q,t} + \sum_{t \neq q} N_t N_q T_{q,t} + \frac{n_q}{\tau}$$

transport loss

$$N_p + \sum_{i=0}^{q} N_i = N_e$$

For q=0, neutral source rate is included:

neutral source

$$Source_q = N_0 + N_e N_{q-1} I_{q-1} + N_e N_{q+1} R_{q+1} + \sum_{t>q-1} N_t N_{q-1} S_{q-1,t} + \sum_{t<q+1} N_t N_{q+1} T_{q+1,t}$$

- N_q: density of ion with +q charge [/cc]
- N_p: proton density [/cc]
- N_e: electron density [/cc]
- N_t: fraction of CX target [/cc]
- I: electron collision ionization rate [cm^3/s]
- R: electron recombination rate [cm^3/s]
- S: electron stripping rate [cm^3/s]
- T: charge transfer rate [cm^3/s]
- tau: transfer loss rate [days]

These equations are solved as a steady problem by Newton method

Parameters

Free parameters	value, range	comments
ion fraction wrt total ion density $n_0, \cdots, n_q$	0.0-1.0	q=+8 for oxygen
electron density n_e	0.0-10^5 /cc	almost constant~4800/cc in the solutions
Fixed parameters	**value, range**	**comments**
Temperature	1eV-10keV	Ti=Te (equilibrium)
hydrogen/electron ratio	0.1	Delamere&Bagenal03
oxygen abundance wrt Hydrogen	9.0 (no sulfur)	O/S=1.7-5 Delamere&Bagenal03 Bagenal94
cross sections	See below	COL (I), REC (R), TNS (T), STR (S)
neutral source rate N_0	10x10^{-4} cm^3/s	Delamere&Bagenal03
transfer loss rate τ	50 days	Delamere&Bagenal03
Neutral velocity relative to corotating plasma v_{rel}	58 km/s ~ 280 eV for oxygen atom	Velocity btw corotation and Keplerian at 6 Rj

Cross sections and source rate

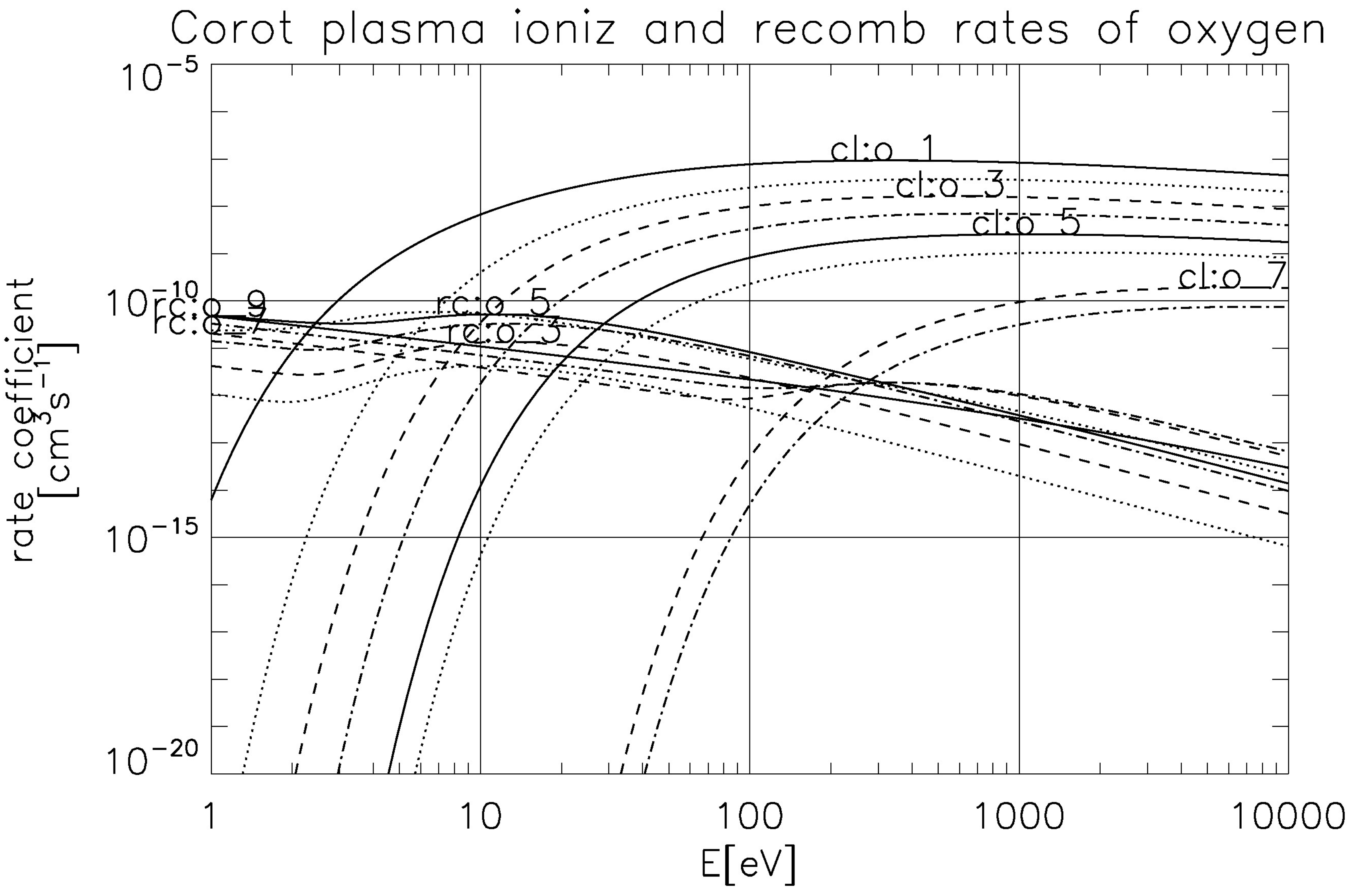
- Cross sections of COL (I) and REC (R) are from CHIANTI database
- Relative velocity btw neutrals and corotating plasma is incorporated in neutral’s rates
- Charge exchange cross sections are derived from Janev+83, 88
- CAVEAT: No complete CX cross section data at low collision energies (<1keV/amu). Especially for O-O reactions. Substituted to O-H reactions as an initial approach.
- No energy dependence of S and T on energy is assumed
- Source rates (alpha=I,R,S,T) are derived by

$$\alpha = \int_0^\infty \sigma(v) v f(v)\, dv$$

$$f(v) = 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} v^2 \exp\left(-\frac{mv^2}{2kT}\right)$$

- For n-i reactions at lower temp (<280eV), velocity = v_rel
- For n-i at >280eV, i-i, velocity = v_i
- For n-e, i-e, velocity = v_e

Source rates of COL and REC



CX cross sections

q′,q	σ (10^{-16} cm^2)	E (kev/u)	ref	q,q′	σ (10^{-16} cm^2)	E (kev/u)	ref	q,q′	σ (10^{-16} cm^2)	E (kev/u)	ref	q,q′	σ (10^{-16} cm^2)	E (kev/u)	ref
0,1	12.5	0.01	c,oh												
0,2	7.23	0.01	c,oh	1,2											
0,3	49.5	0.01	c,oh	1,3				2,3							
0,4	5.33	0.01	c,oh	1,4				2,4				3,4			
0,5	76.5	0.01	c,oh	1,5				2,5				3,5			
0,6	25.3	0.07	c,oh	1,6				2,6				3,6			
0,7	49.4	0.18	c,oh	1,7				2,7				3,7			
0,8	13.8	0.15	c,on	1,8	29	0.13	b,oo	2,8				3,8	8	0.13	b,oo

$$O^{+q} + O^{+q'} \rightarrow O^{*+q-1} + O^{+q'+1}$$

Reference
a:McGrath&Johnson89, b:Janev+83, c:Janev+88, d:Krasnopolsky+04
oo:Oxygen-Oxygen, on:Oxygen-Nitrogen, oh:Oxygen-Hydrogen

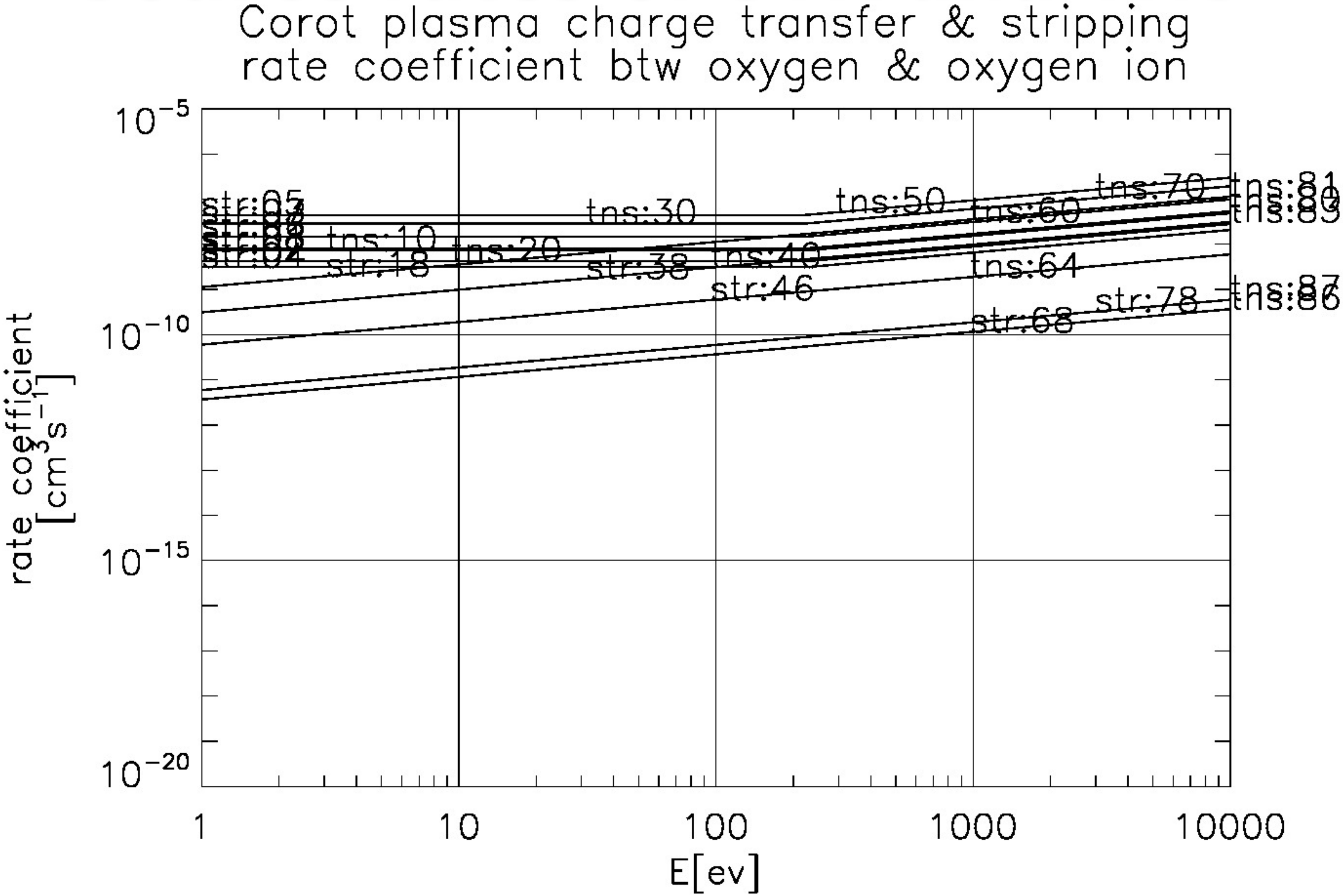
CX cross sections

q′,q	σ (10^{-16} cm^2)	E (kev/u)	ref	q,q′	σ (10^{-16} cm^2)	E (kev/u)	ref	q,q′	σ (10^{-16} cm^2)	E (kev/u)	ref	q,q′	σ (10^{-16} cm^2)	E (kev/u)	ref
4,5															
4,6	1.54	0.04	b,oo	5,6											
4,7				5,7				6,7							
4,8				5,8				6,8	0.09	0.24	b,oo	7,8	0.15	0.15	b,oo

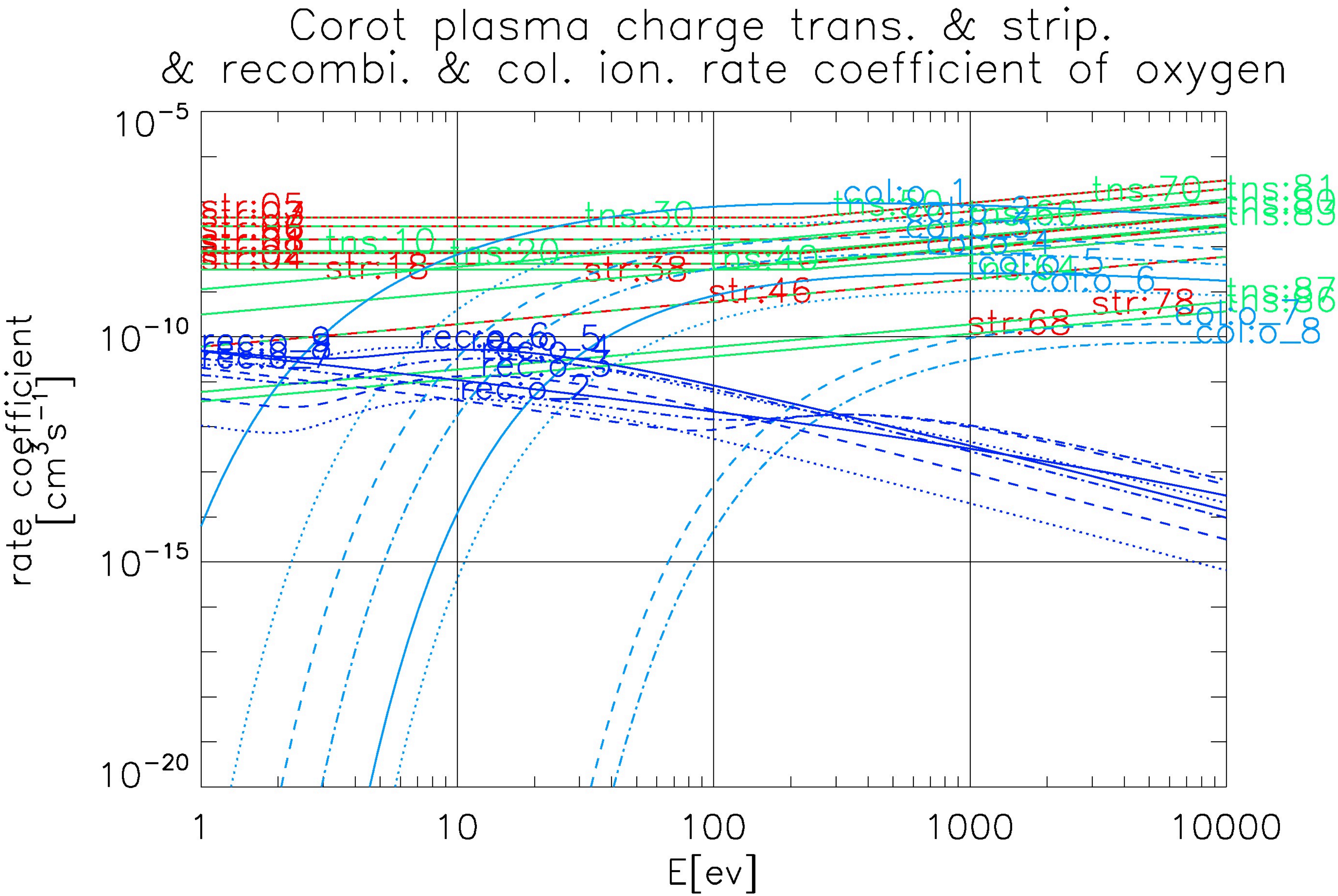
$$O^{+q} + O^{+q'} \rightarrow O^{*+q-1} + O^{+q'+1}$$

Reference
a:McGrath&Johnson89, b:Janev+83, c:Janev+88, d:Krasnopolsky+04
oo:Oxygen-Oxygen, on:Oxygen-Nitrogen, oh:Oxygen-Hydrogen

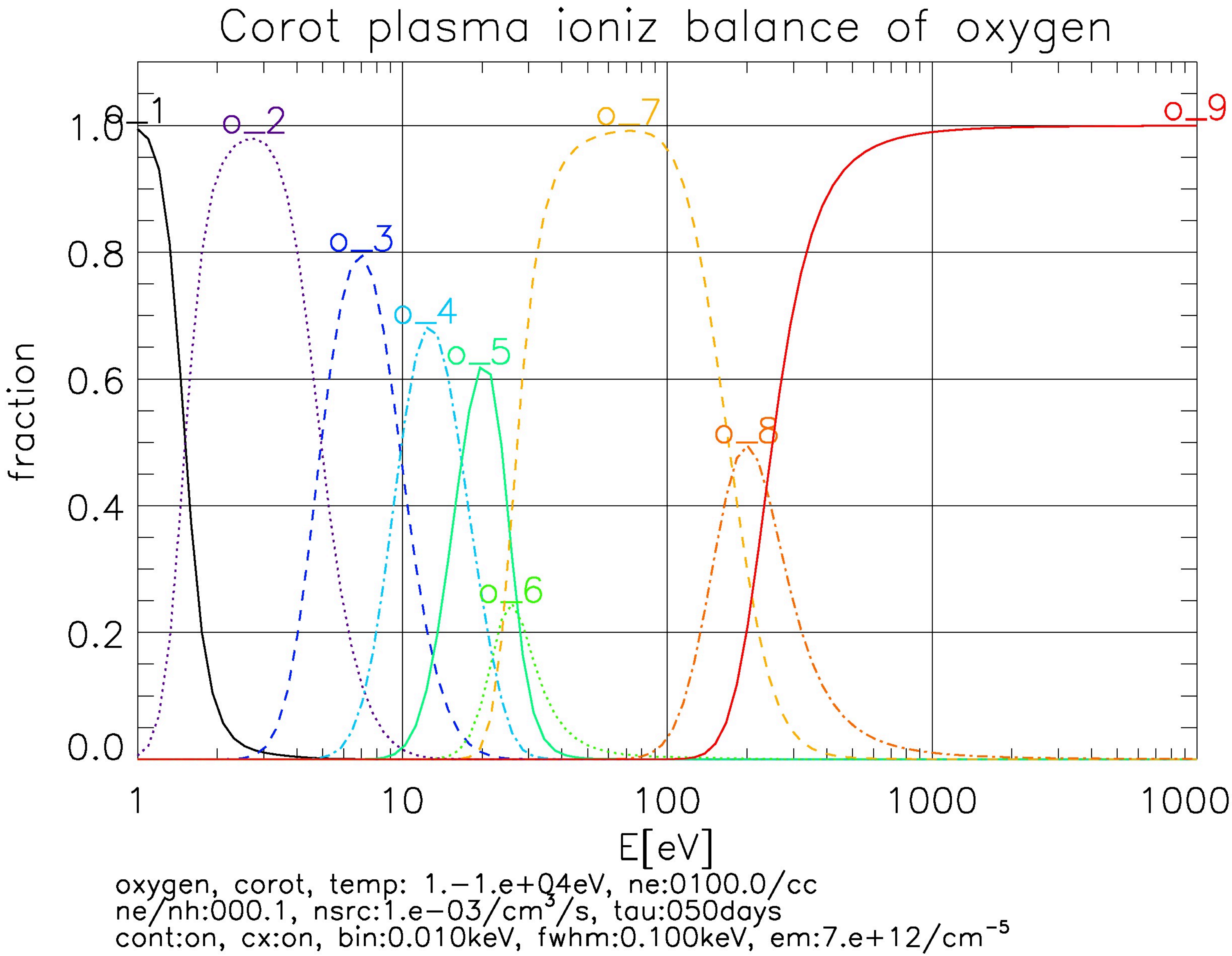
Source rates of STR and TNS



All source rates

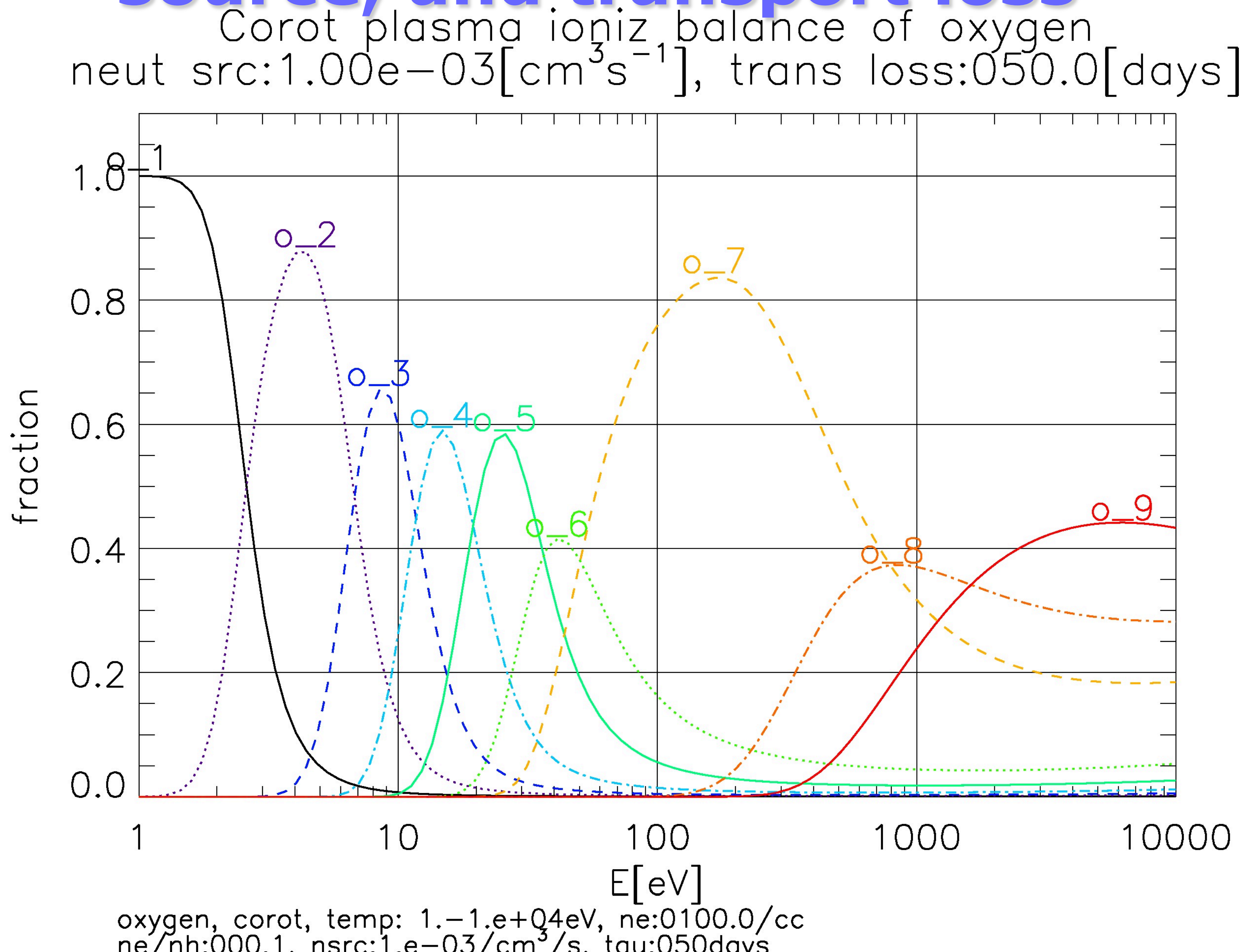


Ion balance: COL and REC

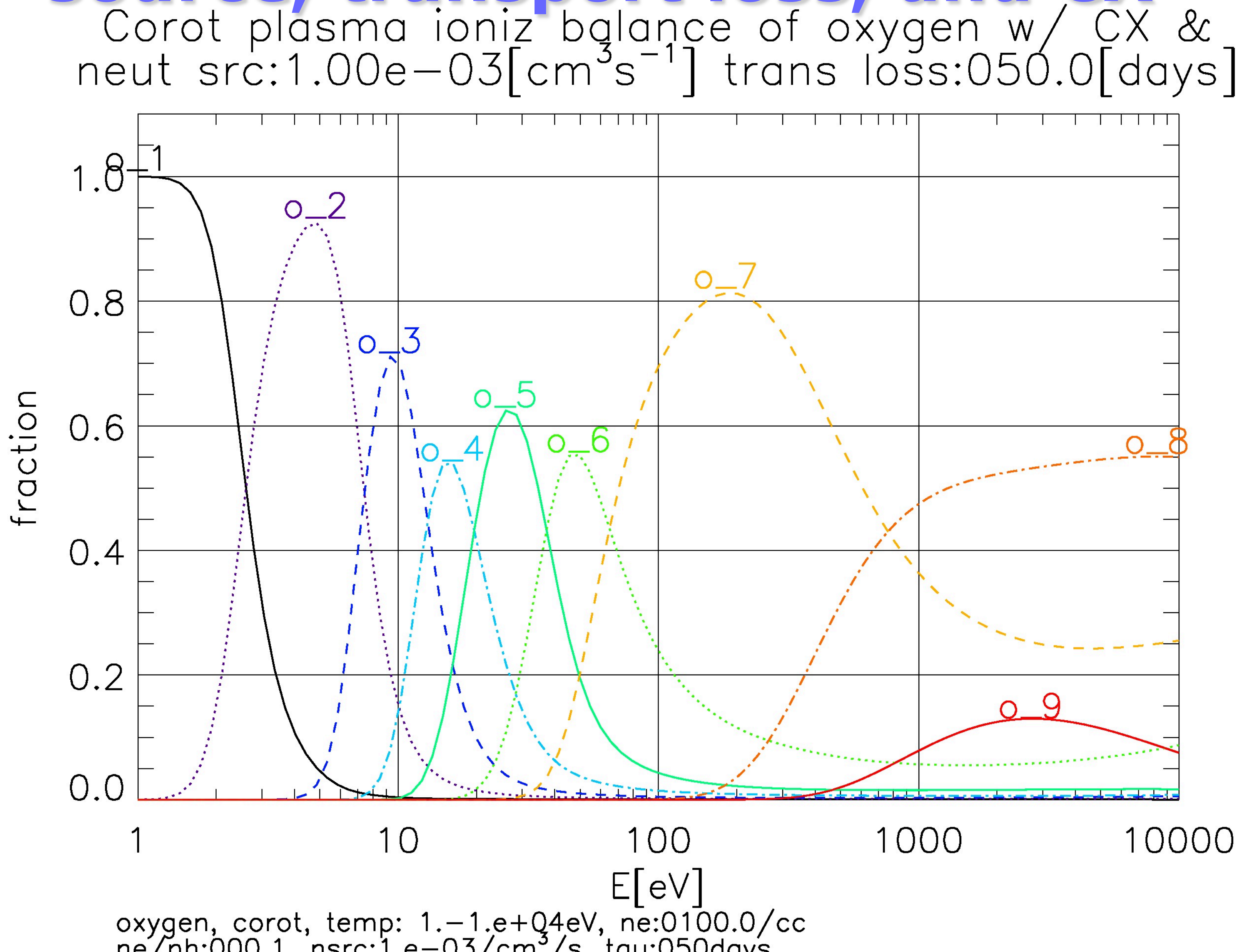


- Similar to astrophysical plasma models (e.g., CHIANTI, APEC)

Ion balance: COL, REC, neutral source, and transport loss



Ion balance: COL, REC, neutral source, transport loss, and CX



Radiative process

Theoretical line intensity

Population equation at i-th energy level

$$\sum_{\mathrm{j}} n_{\mathrm{j}} \alpha_{\mathrm{ji}} = 0$$

Electron collision excitation&de-excitation rate and radiative decay

$$\alpha_{ij} = N_e C_{ij}^e + A_{ij}$$

$A_{ij} = 0$ for $i < j$

Spectral intensity

$$I(\lambda_{ij}) = \frac{h\nu_{ij}}{4\pi} \int N_j \, A_{ji} \, dh \quad [\mathrm{ergs\ cm^{-2}\ s^{-1}\ sr^{-1}}]$$

$$I(\lambda_{ij}) = C(T_o, \lambda_{ij}, N_e) Ab(X) EM_h$$

Abundance of atomic species X wrt Hydrogen

$$Ab(X) = N(X) / N_H$$

$$C(T, \lambda_{ij}, N_e) = \frac{h\nu_{ij}}{4\pi} \frac{A_{ji}}{N_e} \frac{N_j(X^{+m})}{N(X^{+m})} \frac{N(X^{+m})}{N(X)} \quad [\mathrm{ergs\ cm^{+3}\ s^{-1}}],$$

Emission measure

$$EM_h = \int N_e N_H dh \quad [\mathrm{cm^{-5}}]$$

CHIANTI user guide (ver.7, Zanna+11)

Correction for COL, REC, & CX

$$N_g N_e C_{g\to i} = N_i A_{i\to g} \implies \left(\frac{N_i}{N_g}\right)_{\text{no ion/rec/cx}} = \frac{N_e C_{g\to i}}{A_{i\to g}}$$

Electron collision excitation — Radiative decay — i-th level to ground level

correction

$$N_e N_g C_{g\to i} + N_e N_{q-1} I_{q-1} + N_e N_{q+1} R_{q+1} + \sum_{t<q+1} N_t N_{q+1} T_{q+1,t} = N_i A_{i\to g}$$

New CX (TNS) term

$$\frac{N_e C_{g\to i}}{A_{i\to g}}\left(1 + \frac{n_{q-1}}{n_q C_{g\to i}} I_{q-1} + \frac{n_{q+1}}{n_q C_{g\to i}} R_{q+1} + \sum_{t<q+1} \frac{N_t}{N_e}\frac{n_{q+1}}{n_q C_{g\to i}} T_{q+1,t}\right) = \frac{N_i}{N_g}$$

ion fraction

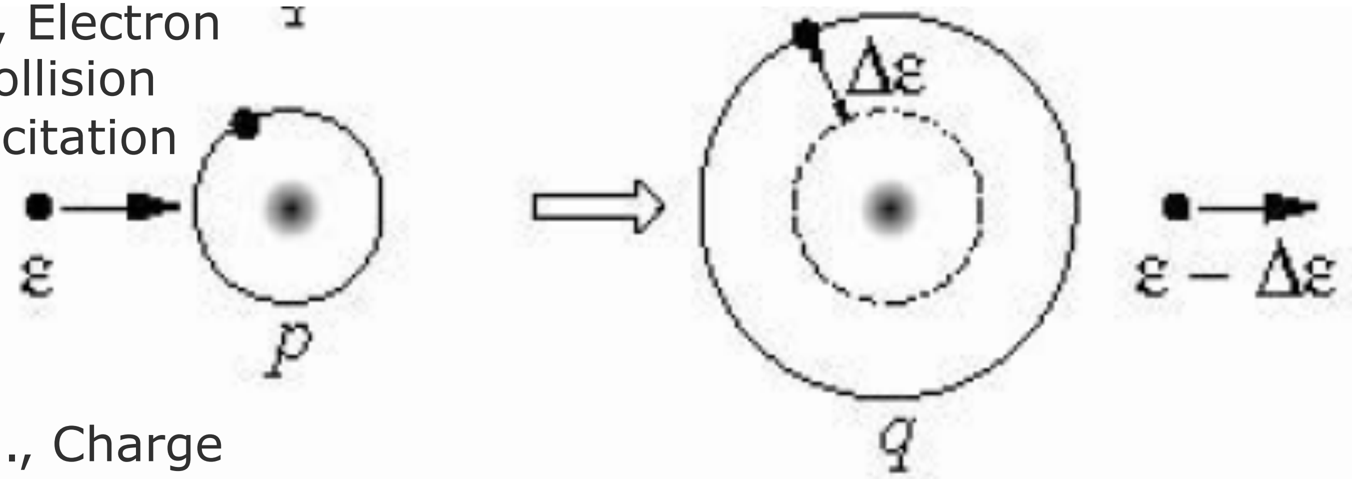
$$n_q = \frac{N_g}{N(X)} \approx \frac{N_q}{N(X)} = \frac{N(X^{q+})}{N(X)}$$

$$\left(\frac{N_i}{N_g}\right)_{ion/rec/cx} = \left(\frac{N_i}{N_g}\right)_{no\ ion/rec/cx} \times N$$

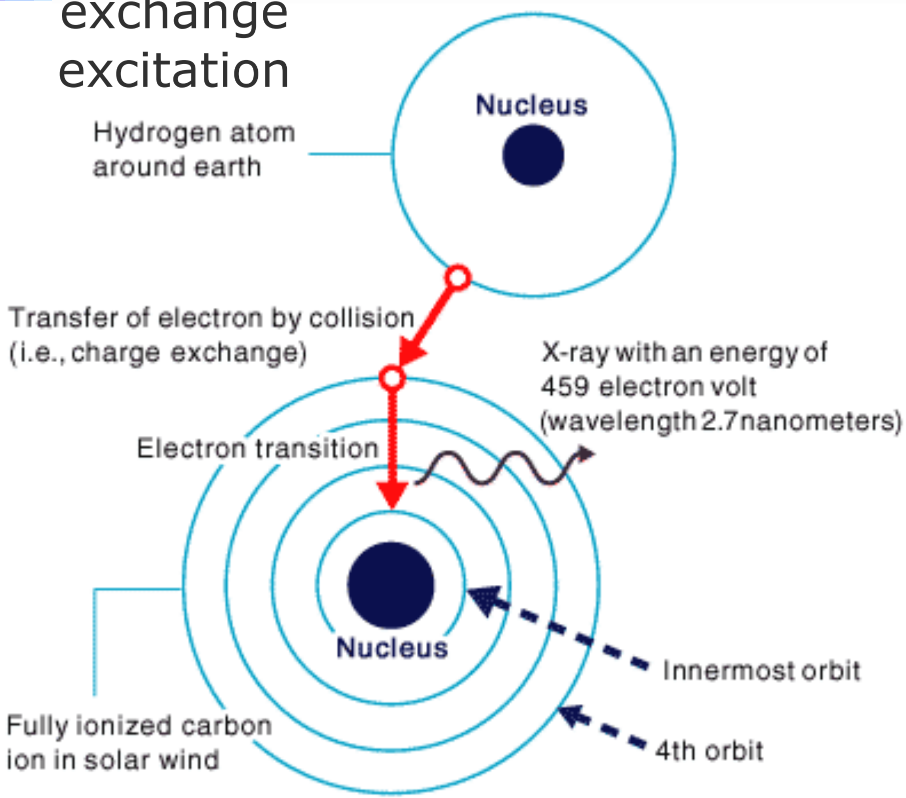
$$N = 1 + \frac{n_{q-1} I_{q-1} + n_{q+1} R_{q+1} + \sum_{t<q+1} N_t / N_e\, n_{q+1} T_{q+1,t}}{n_q C_{g\to i}}$$

Excitation process followed by radiation

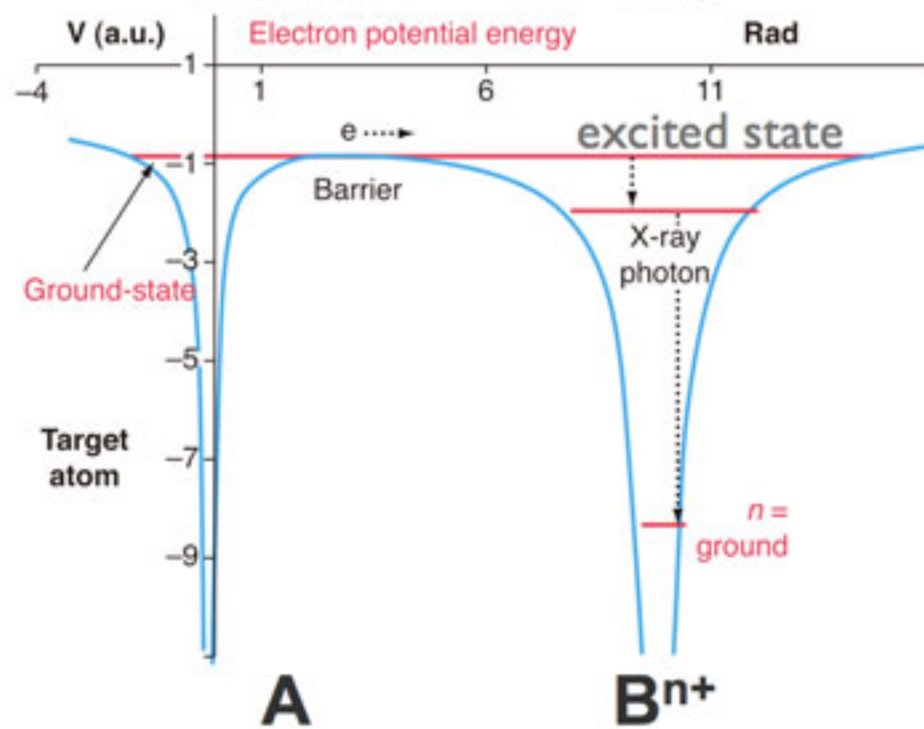
e.g., Electron collision excitation



e.g., Charge exchange excitation



$$A + B^{n+} \rightarrow A^{+} + B^{(n-1)+}$$



Many transitions...

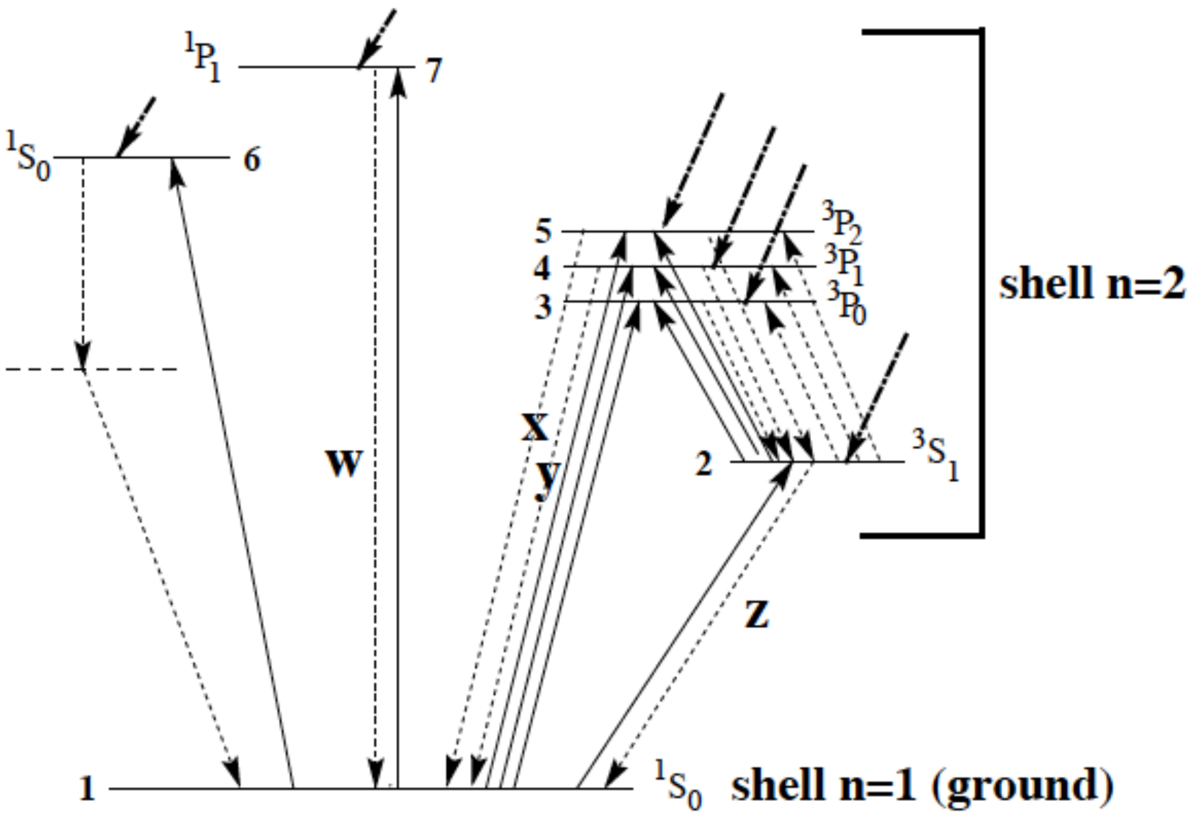


Fig. 1. Simplified Gotrian diagram for He-like ions. w, x, y and z correspond respectively to the resonance, intercombination and forbidden lines. *Full curves*: collisional excitation transitions, *broken curves*: radiative transitions and *thick dot-dashed curves*: recombination (radiative and dielectronic). *Note*: the broken arrow ($^1S_0$ to the ground level) correspond to the 2-photon continuum

Porquet and Dubau (2000)

CX excitation levels

line	config	Xray yields %	reference	regist in CHIANTI?
OVI	?	?	?	?
OVI	?	?	?	?
OVI	?	?	?	?
OVI	?	?	?	?
OVI	?	?	?	?
OVI	?	?	?	?
OVII	1s2s 3S1	59	Greenwood+01, O7+-He, 2.72kev/u	○
OVII	1s2p 3P1	16	Greenwood+01, O7+-He, 2.72kev/u	○
OVII	1s2p 1P1	11	Greenwood+01, O7+-He, 2.72kev/u	○
OVII	1s3p 1P1	8	Greenwood+01, O7+-He, 2.72kev/u	○
OVII	1s4p 1P1	6	Greenwood+01, O7+-He, 2.72kev/u	○
OVII	1s5p 1P1	0	Greenwood+01, O7+-He, 2.72kev/u	○
OVIII	2p	65	Greenwood+01, O8+-He, 3.11kev/u	○
OVIII	3p	13	Greenwood+01, O8+-He, 3.11kev/u	○
OVIII	4p	21	Greenwood+01, O8+-He, 3.11kev/u	○
OVIII	5p	1	Greenwood+01, O8+-He, 3.11kev/u	○
OVIII	6p	0	Greenwood+01, O8+-He, 3.11kev/u	○

CX excitation levels in x-ray

	line	config	Xray yields %	reference	regist in CHIANTI?
OV	2s.3?	?	?	?	?
OV	2s.4?	?	?	?	?
OV	2s.5?	?	?	?	?
OV	2p.3?	?	?	?	?
OV	2p.4?	?	?	?	?
OV	2p.5?	?	?	?	?

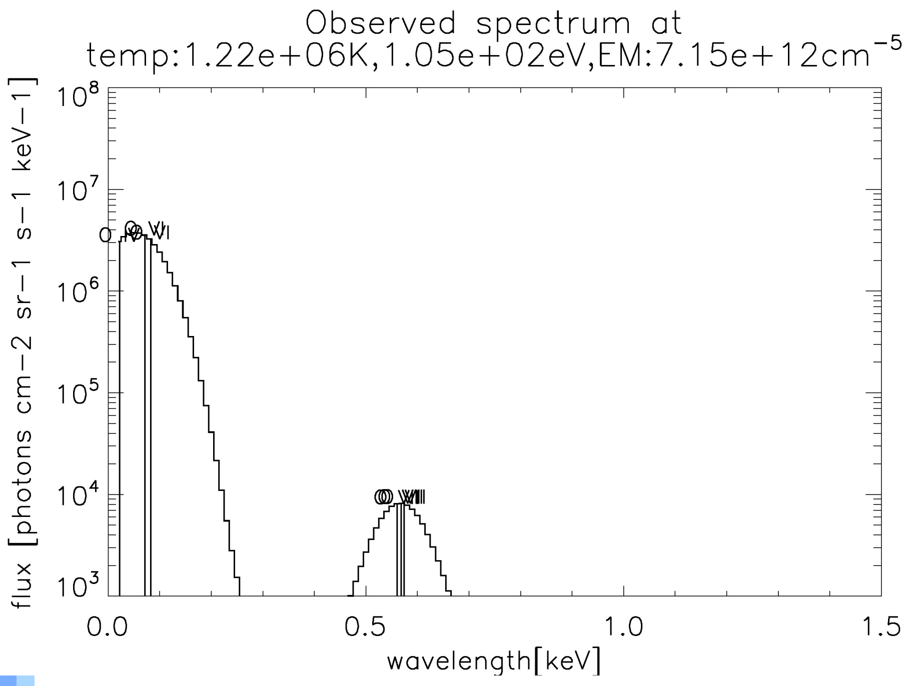
Synthetic spectra with CX

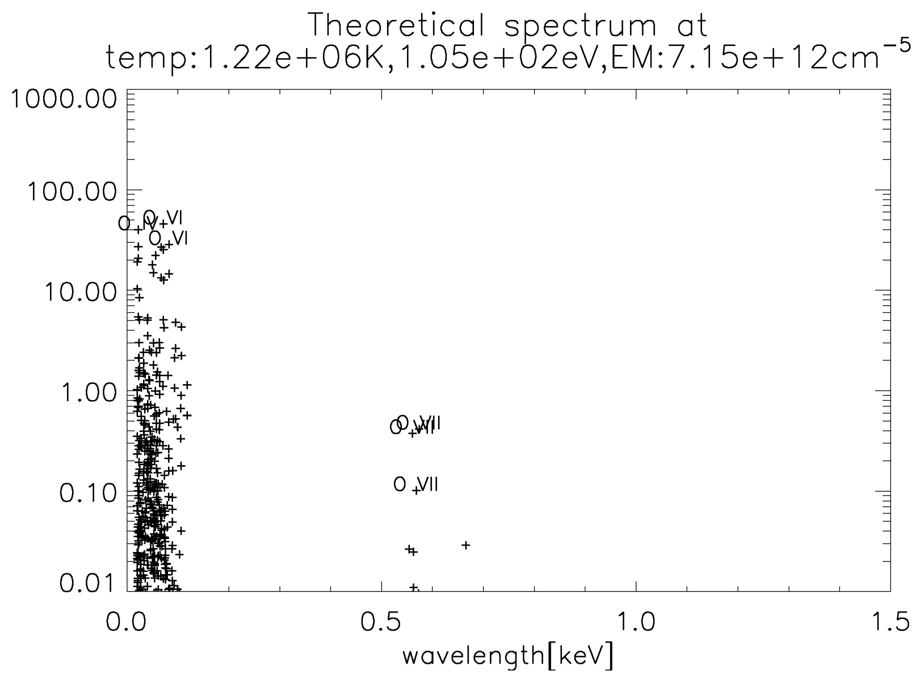
- T=105eV, ne=100/cc, ion balance: all

Simulated spectrum　　Theoretical spectrum

bin size=0.01keV

FWHM=0.1keV





Synthetic spectra with CX

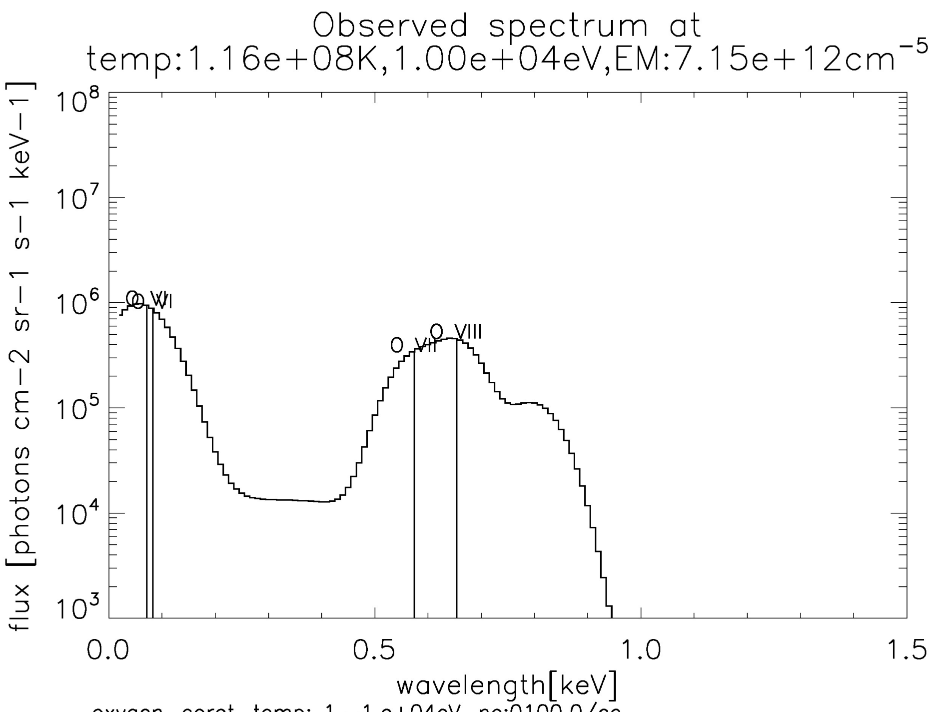
- T=10keV, ne=100/cc, ion balance: all

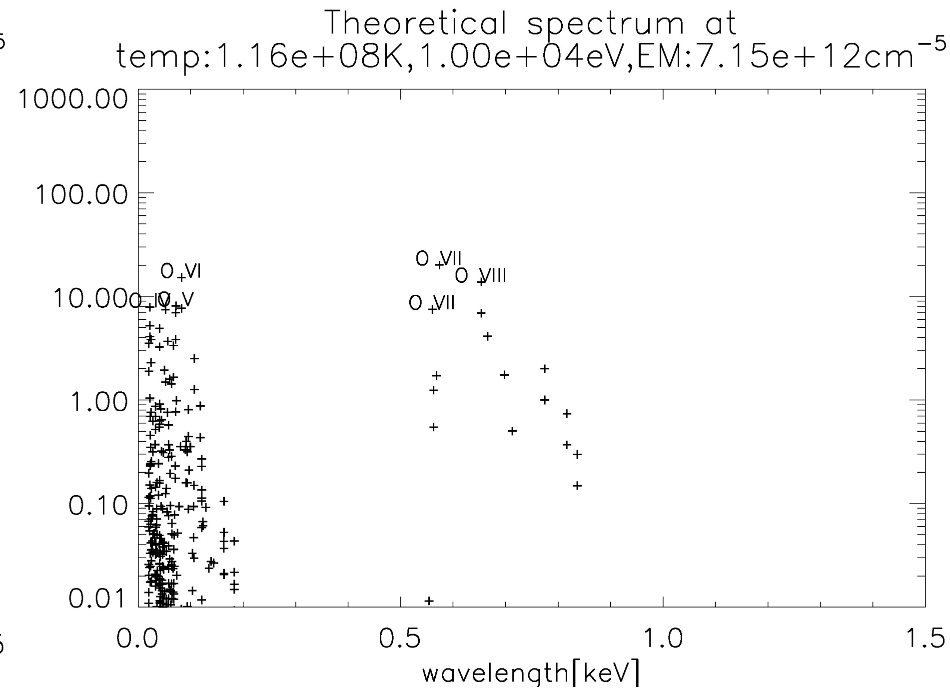
Simulated spectrum

bin size=0.01keV

FWHM=0.1keV

Theoretical spectrum





Synthetic spectra with CX

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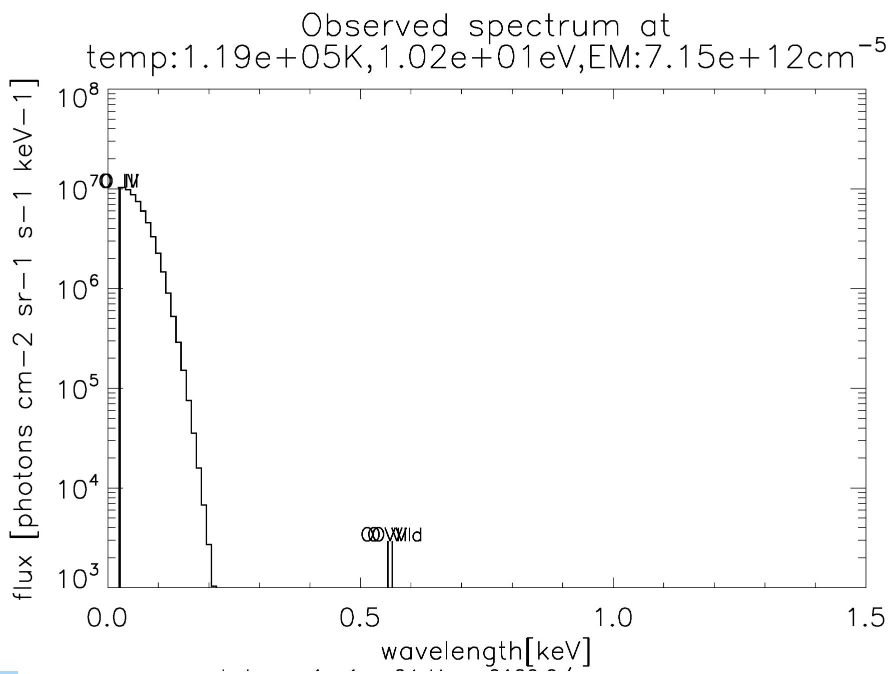
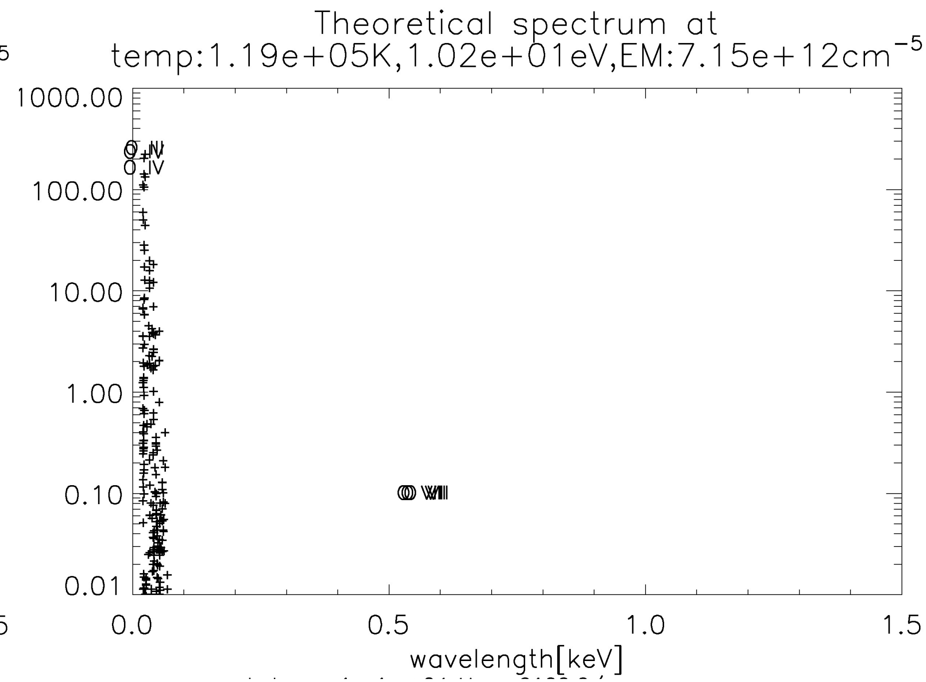


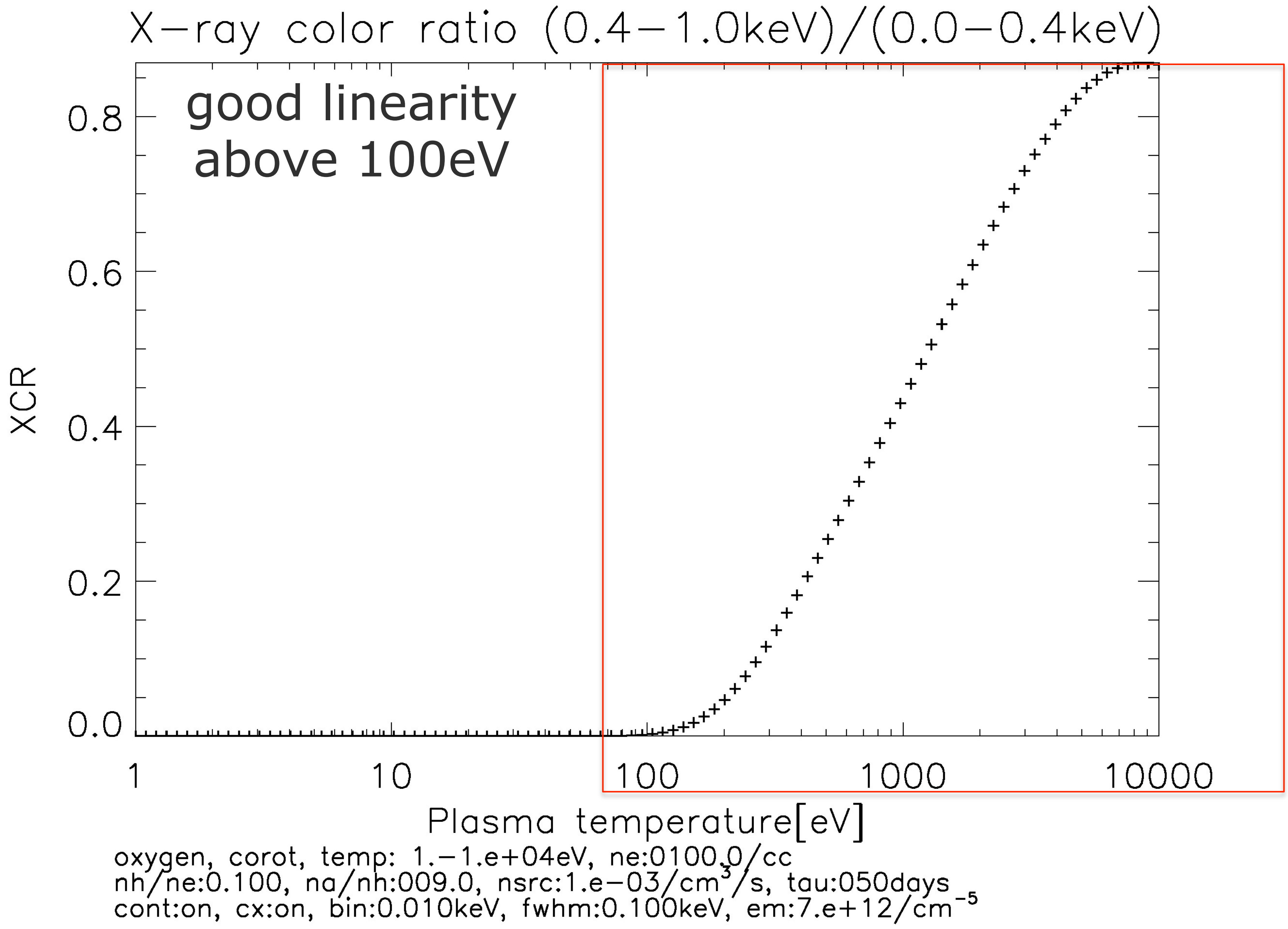
Theoretical spectrum

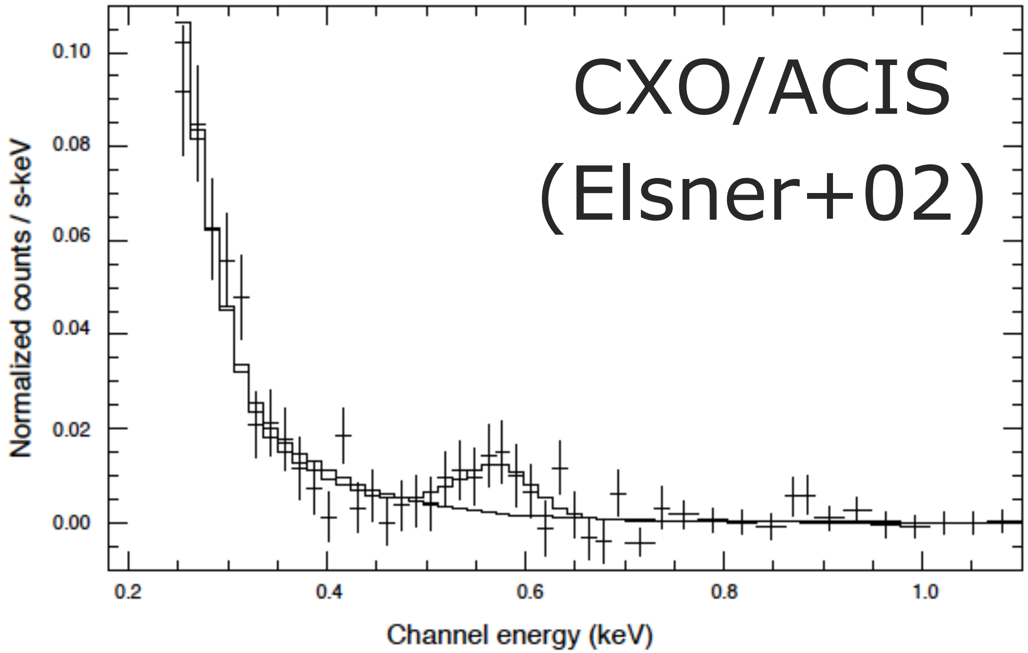


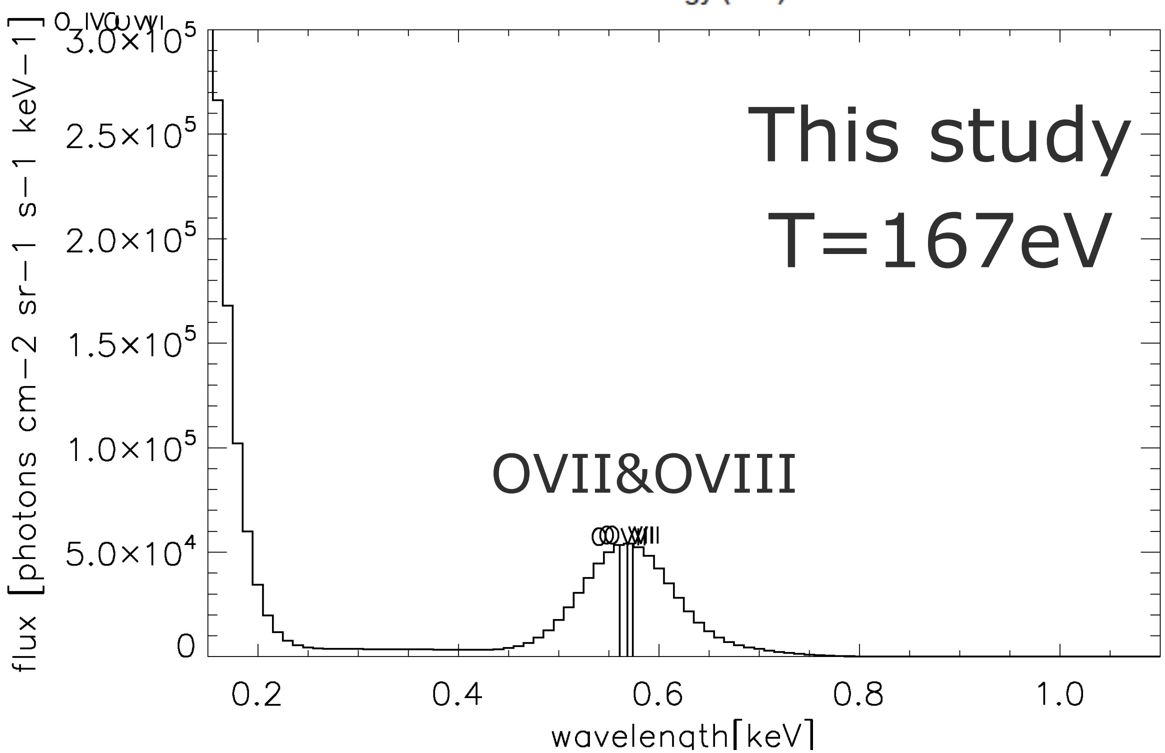
X-ray Color ratio

- A simple index for plasma temperature diagnostic by spectra
- Line ratio sensitive to temperature
- Emission measure of each line is canceled with each other
- XCR=I(0.4-1.0keV)/I(0.0-0.4keV)
- Emission measure and corresponding density will be diagnosed by comparison with observed intensity

X-ray color ratio with CX




CXO/ACIS
(Elsner+02)
Normalized counts / s-keV
0.10
0.08
0.06
0.04
0.02
0.00
0.2
0.4
0.6
0.8
1.0
Channel energy (keV)


This study
T=167eV
OVII&OVIII
flux [photons cm−2 sr−1 s−1 keV−1]
3.0×10^5
2.5×10^5
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
0.2
0.4
0.6
0.8
1.0
wavelength[keV]

Future work

- Complete necessary cross sections and transition probabilities
- Comparison of absolute intensity with observations (Elsner+02) with instrumental response

=>density diagnostic

- Fitting to the observed X-ray spectra over a finite wavelength range
  - more precise temperature and density diagnostics
- Incorporation of sulfur lines (minor but important)
- Effect of solar wind charge exchange at magnetosheath (minor?)

X-ray spectra

Direct diagnostic of IPT hot plasma (100eV-10keV)

- Hot plasma temperature
- Hot plasma density

constraint hot plasma

EUV spectra

Direct diagnostic of IPT cold (5eV-10s eV) plasma (Yoshioka+11, Steffl+04)

- Cold plasma Temperature
- Cold plasma density
- Hot plasma density OR temperature (>100 eV) are input parameters

Plasma diagnostic over a wide energy range (5eV-10keV)

EUV spectra of IPT (Yoshioka+11)

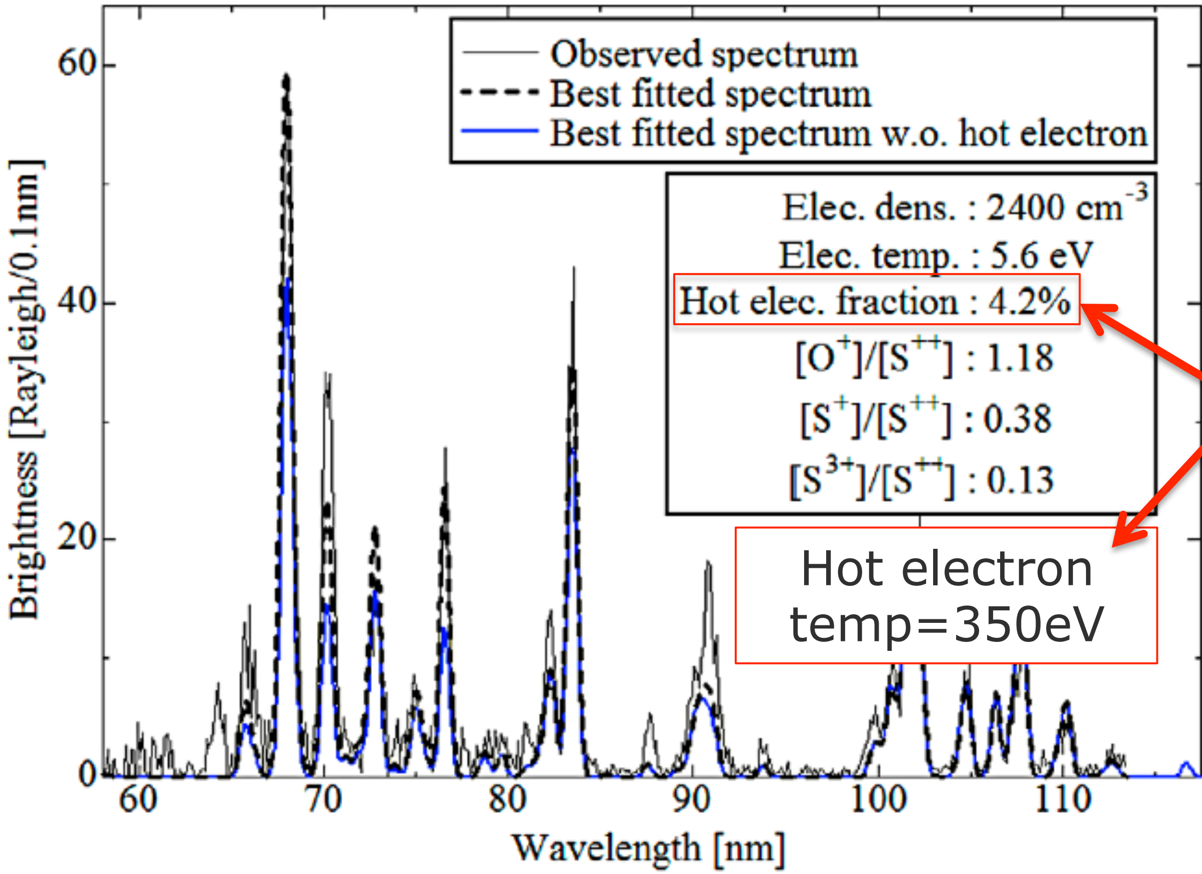


Figure 5. A fit of the model to an observed spectrum of the Io torus dusk ansa 5.9 R_J. The best fit parameters are indicated at the top right corner. The best fit model spectrum without hot electron component is also plotted for comparison.

Constraint these hot & minor component by X-ray spectra