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1st Korea-Japan Workshop
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Radiation processes of impurities in detached divertor plasmas of JT-60U

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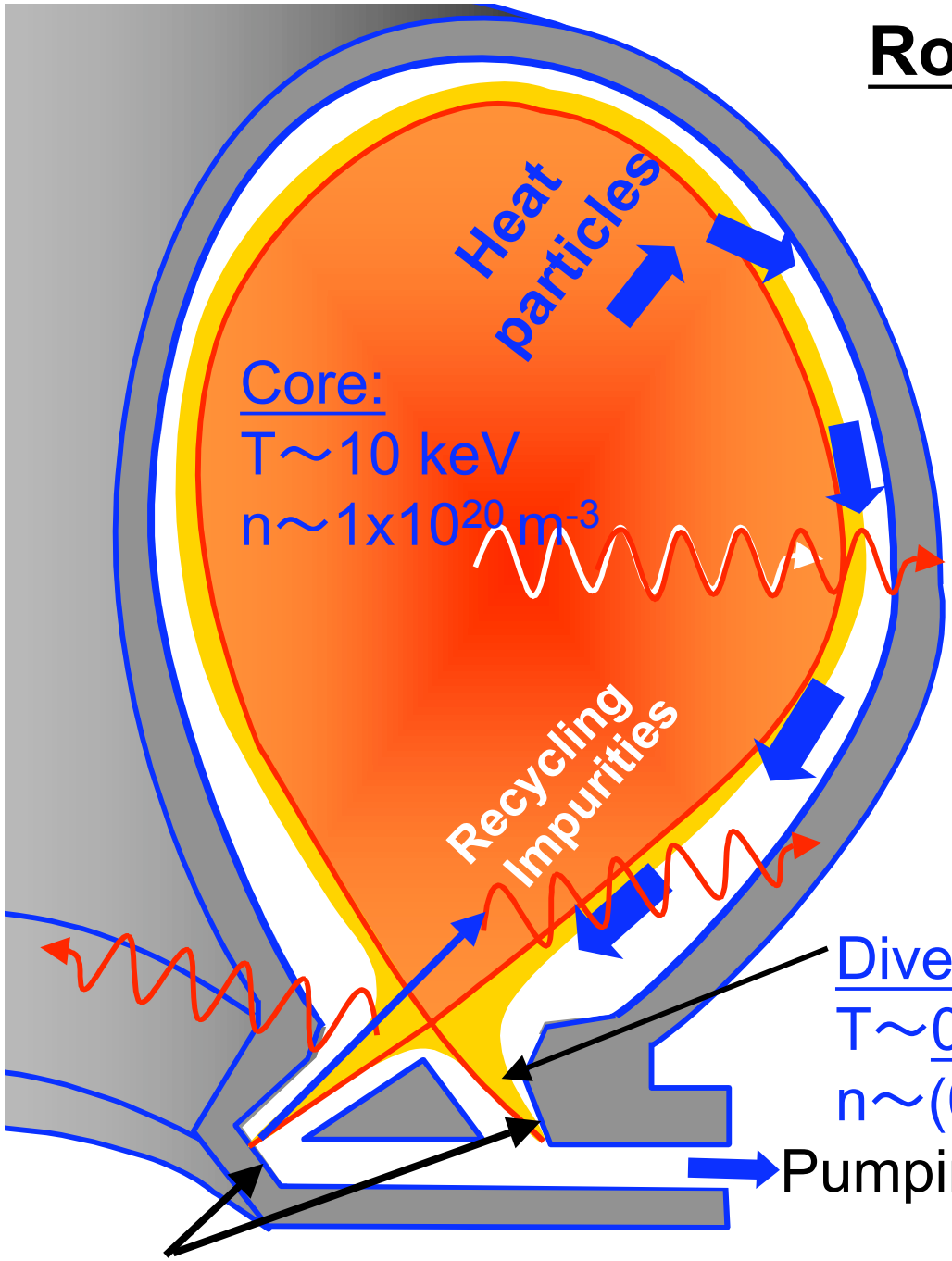


Roles of divertor

- Control of fuel particles
- Control of impurities
- **Mitigation of heat load onto target plates**

<= Detached plasma

Cooling process

Radiator? D, C^0, C^+ ,,,,,?

Process? Ionization(excitation)
Recombination,
CX?

Spatial distribution?

Divertor:
T～0.2*- 100eV
n～(0.1- 50*)x10^{19}m^{-3}

*Recombining plasma

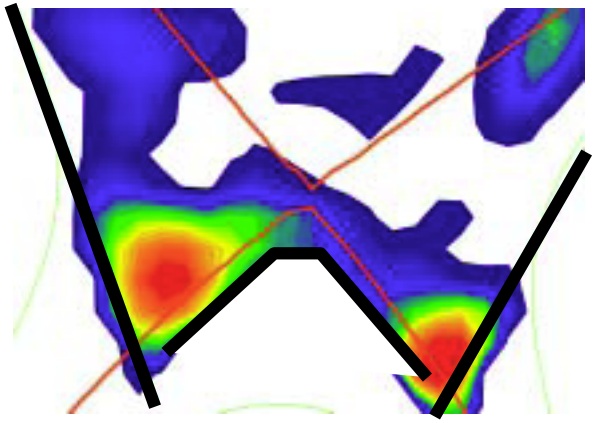
Divertor plates: Heat load => Erosion, impurities

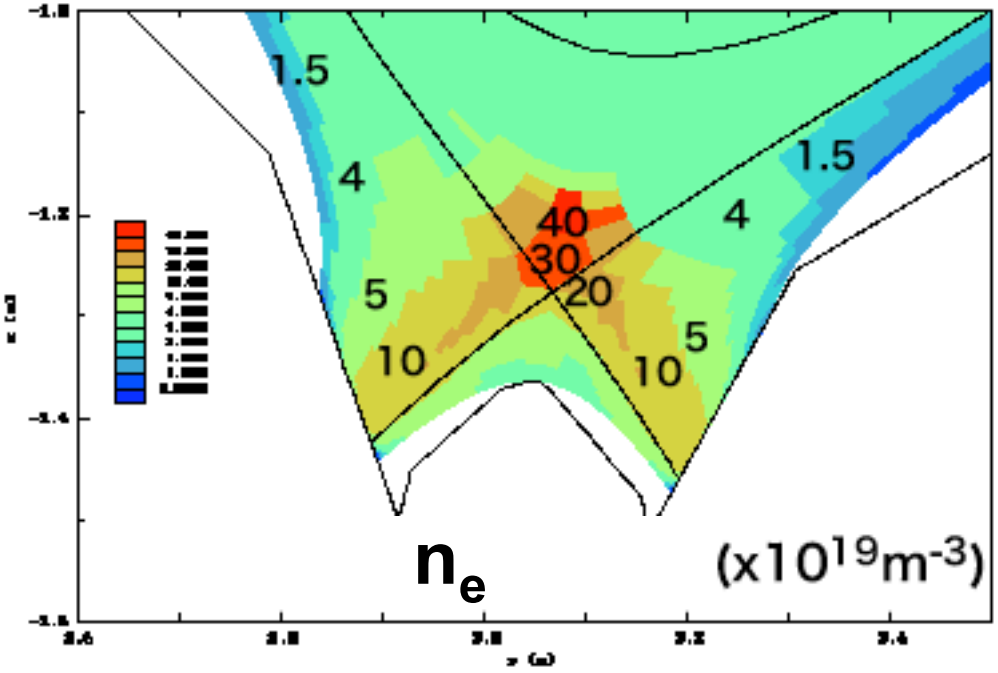
Previous results

- 2D radiation image

- 2D parameter distribution Calculated by SOLDOR

Attached



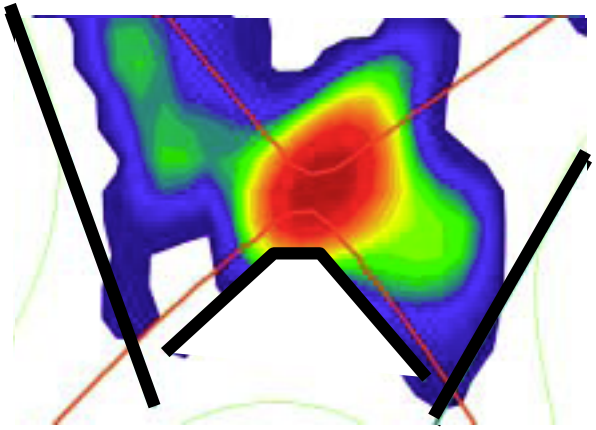


Highly-radiative, low-temperature and high-density plasma around the X-point

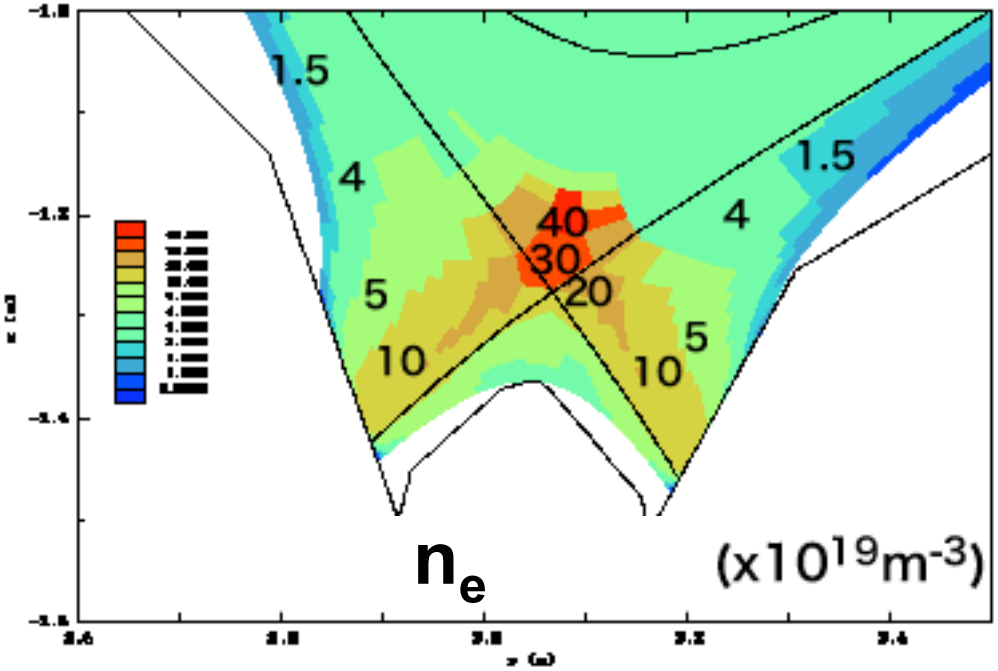
Previous results

- 2D radiation image

Detached plasma（MARFE）



- 2D parameter distribution Calculated by SOLDOR

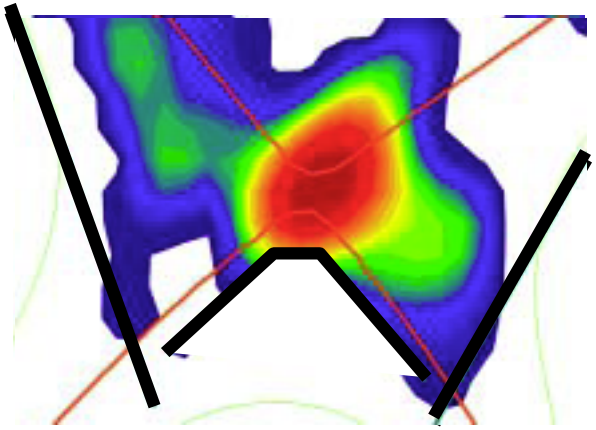


Highly-radiative, low-temperature and high-density plasma around the X-point

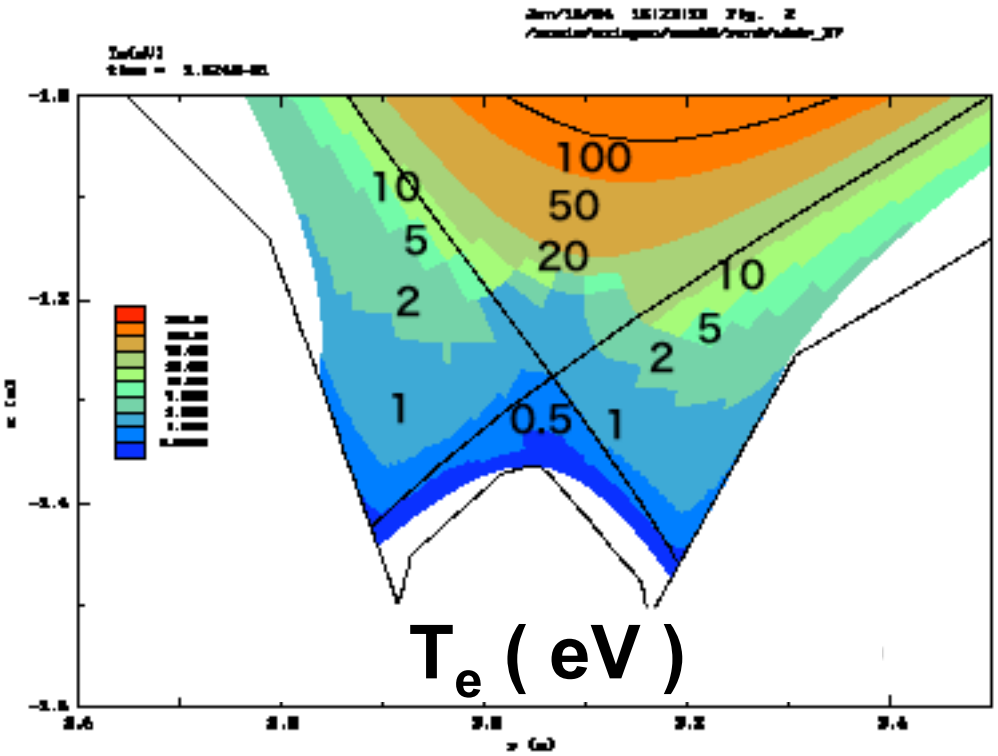
Previous results

- 2D radiation image

Detached plasma（MARFE）



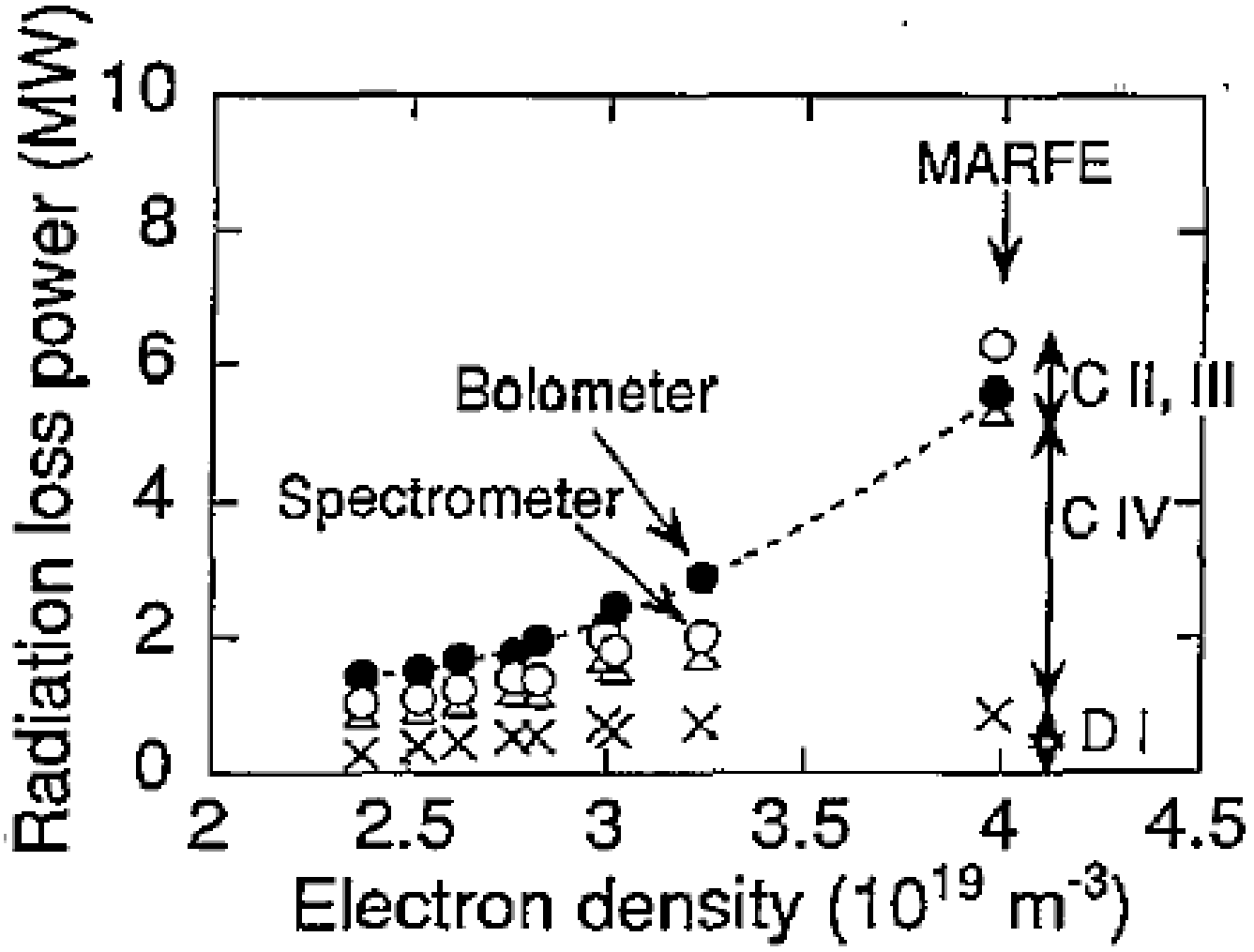
- 2D parameter distribution Calculated by SOLDOR



Highly-radiative, low-temperature and high-density plasma around the X-point

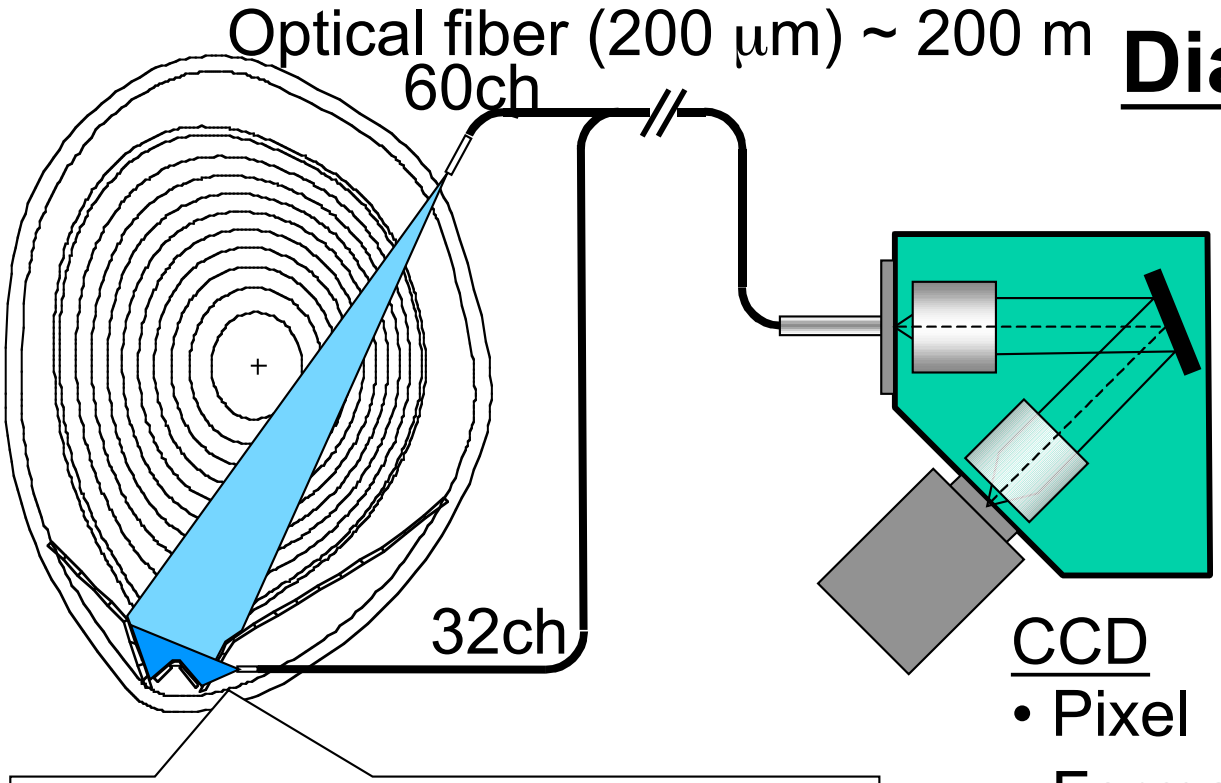
Previous results2

- Radiator



Assumption of T_e = 20 eV and C IV line radiation due to excitation from C^{3+} ground state is valid ?
, though detached plasma is very cold (T_e < 1 eV).

Diagnostics:visible

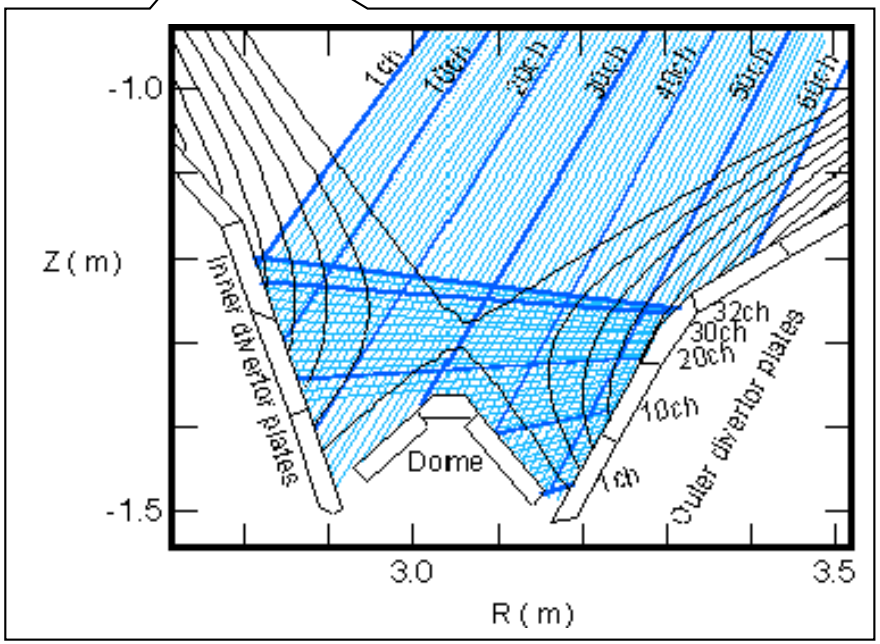


Spectrometer

- Grating :300 g/mm
- Focal length: 0.2 m
- F number : 2

CCD

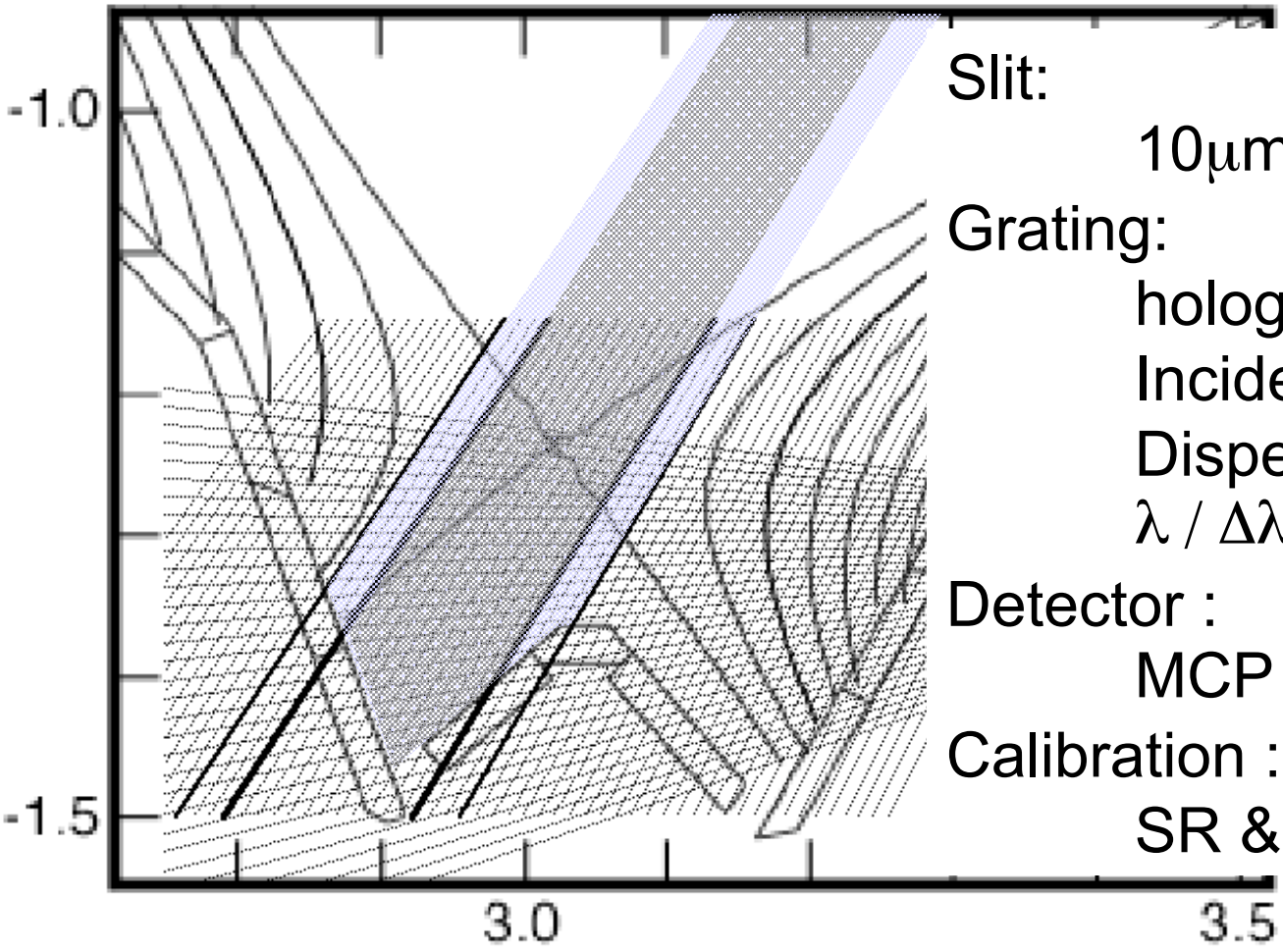
- Pixel : 20 x 20 μm
- Format : 1340 x1300 pixel



Specifications

- Instrumental width (FWHM):
  ~ 0.74 nm (2.3 pixels)
- Spectral Band:
  ~ 430 nm (350 - 780 nm)
- Spatial resolution:
  ~ 1 cm

Diagnostics: VUV



Slit:

10μm x 5mm

Grating:

holographic (300g / mm)

Incident angle 85°

Dispersion 2 nm / mm

$\lambda / \Delta\lambda \sim 150$

Detector :

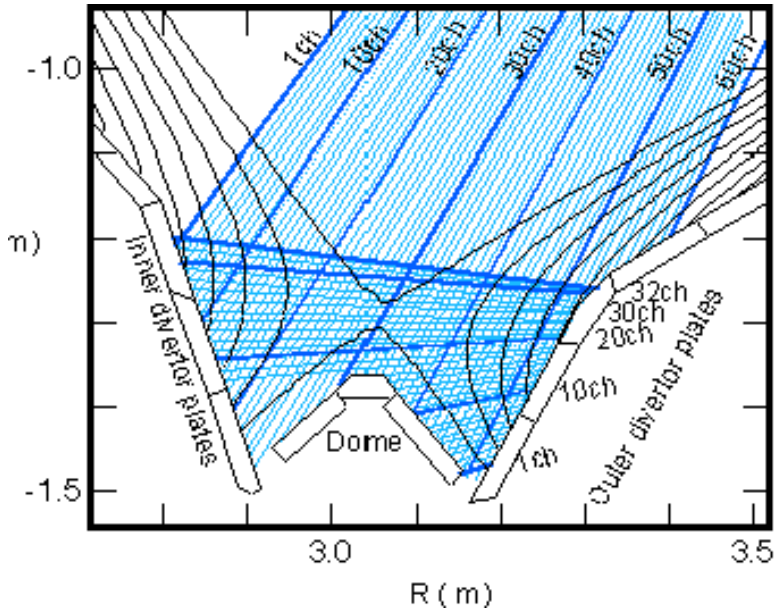
MCP 50 μm x 1024ch

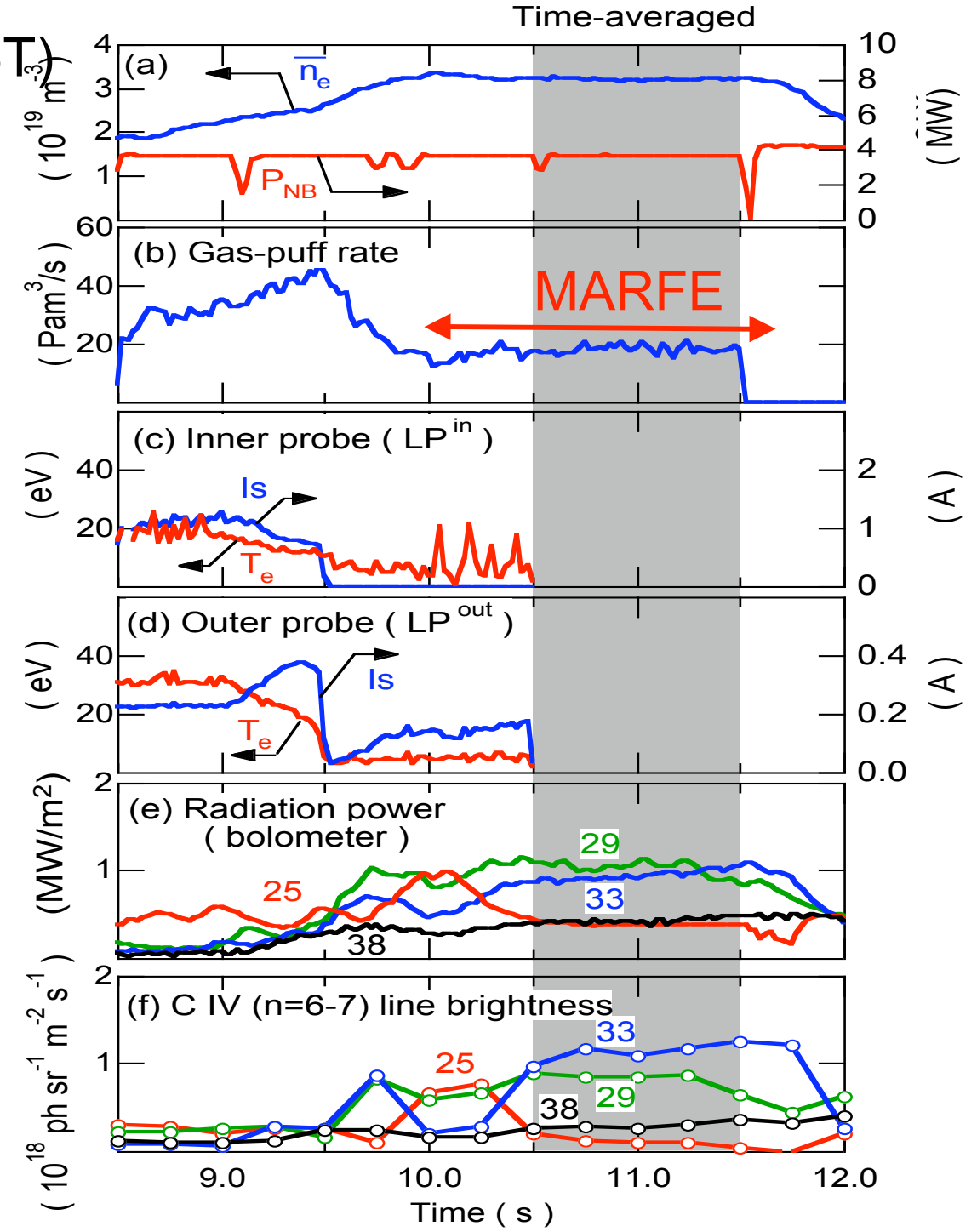
Calibration :

SR & Branching Ratio

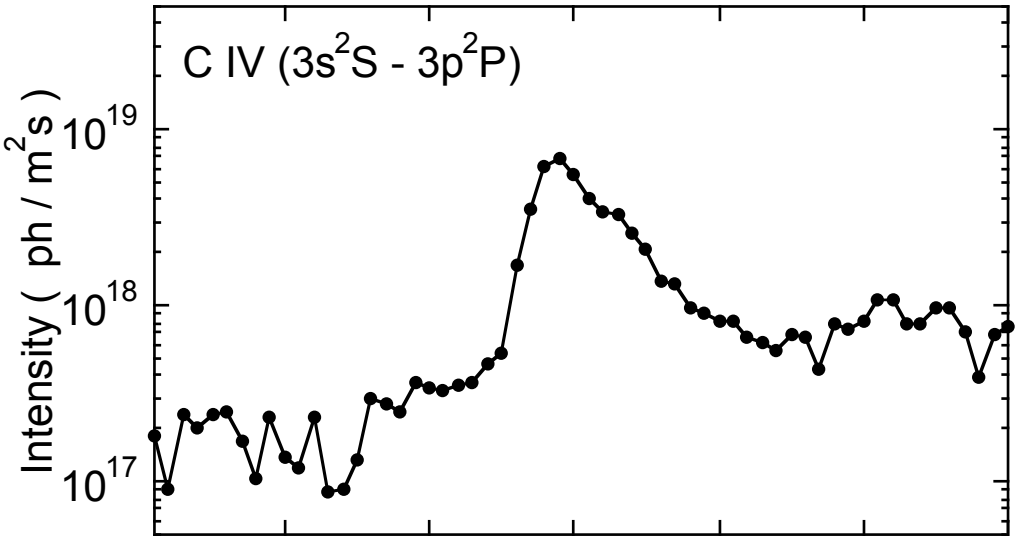
Waveforms(1.0MA/3.6T)

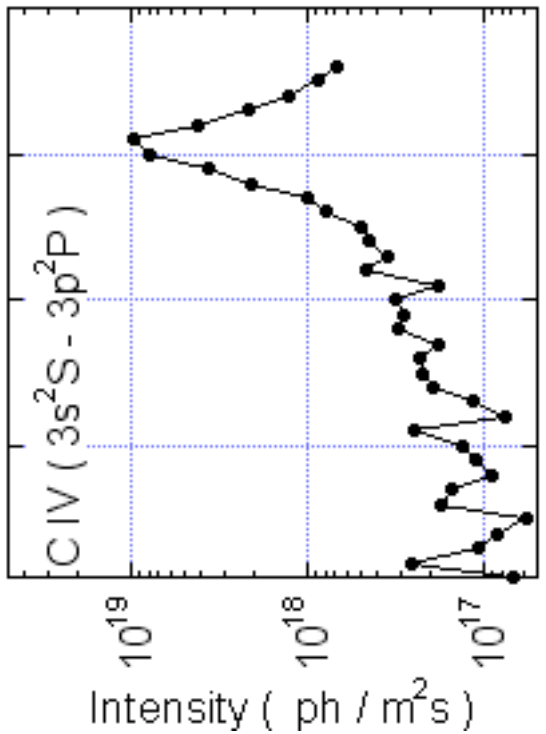
Analyzed
during MARFE phase

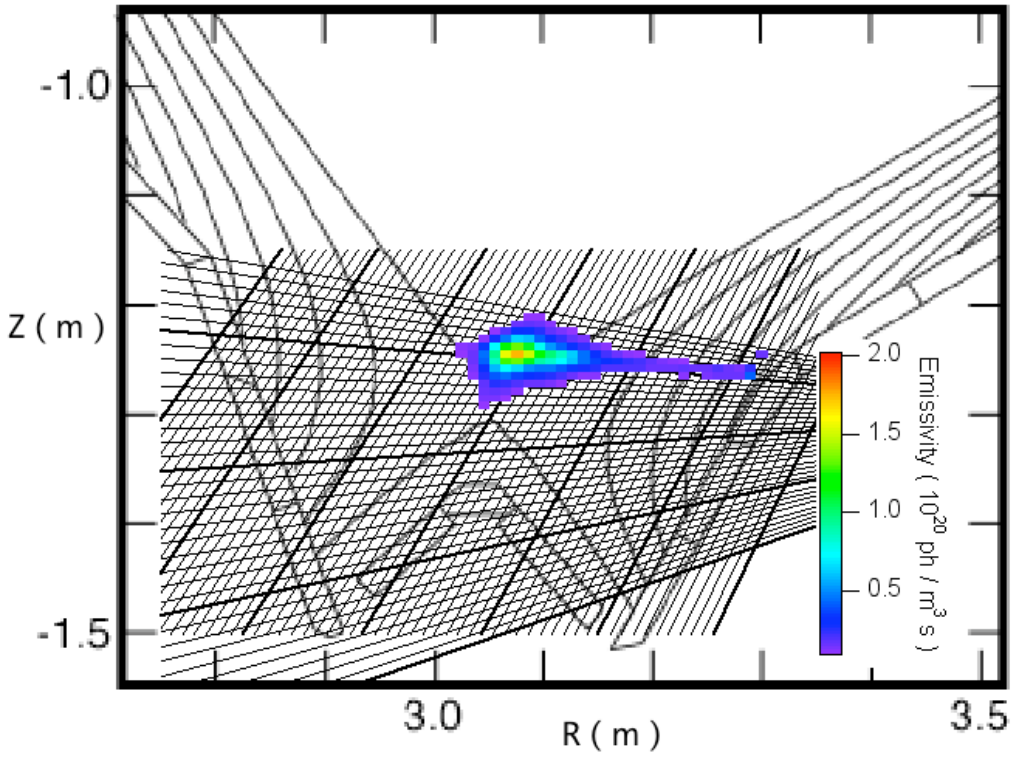




C IV emissivity reconstruction







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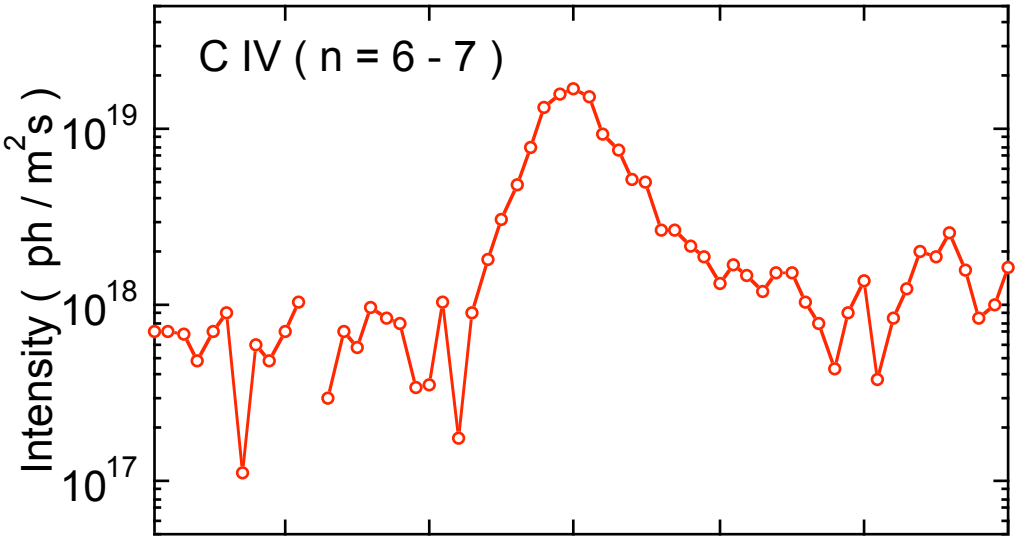
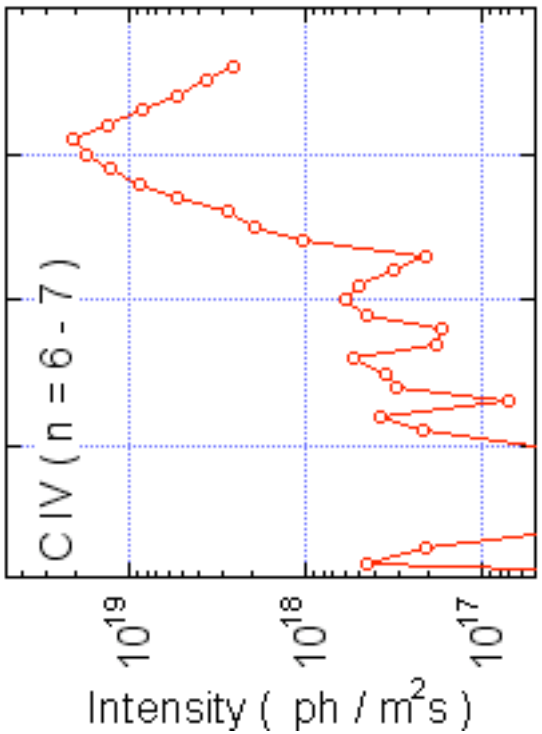
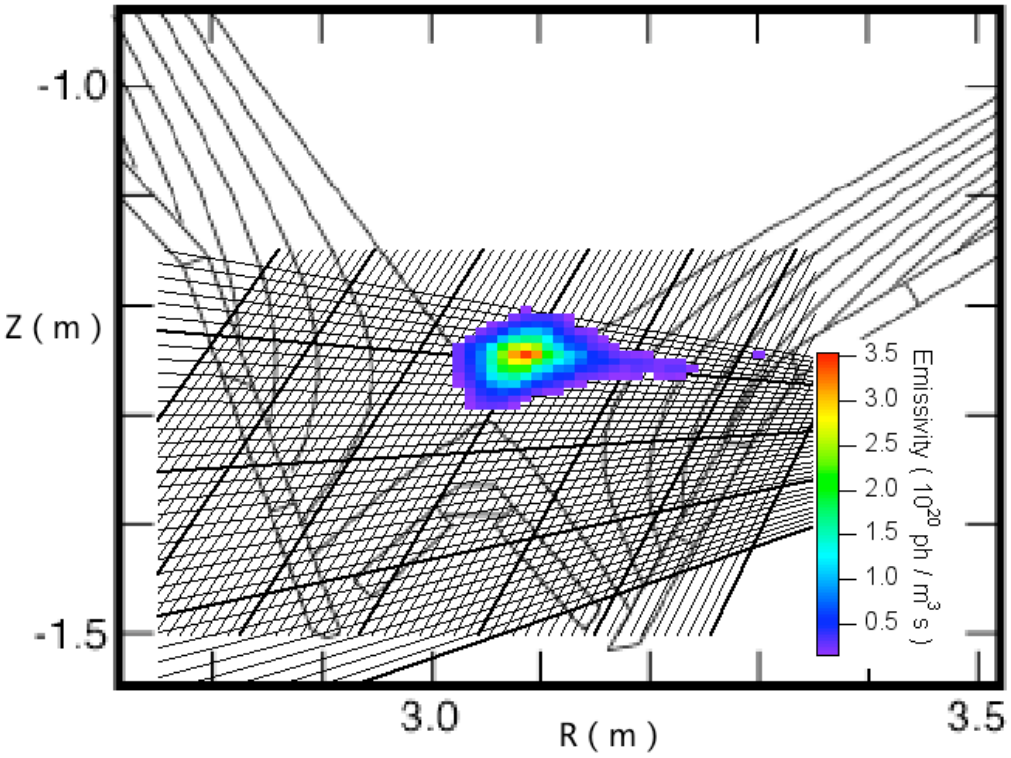
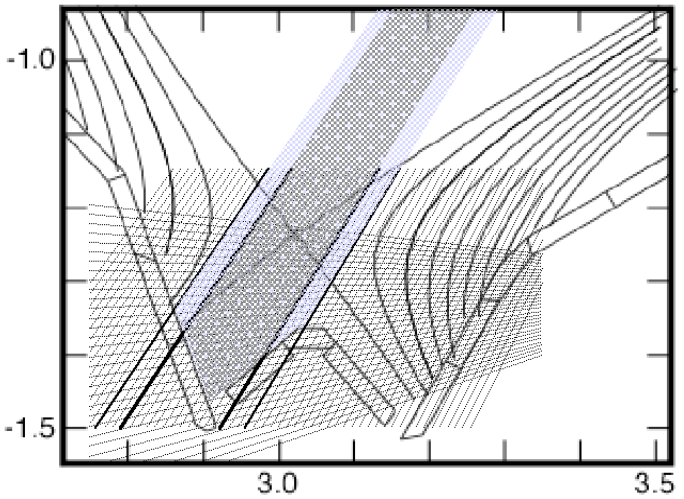
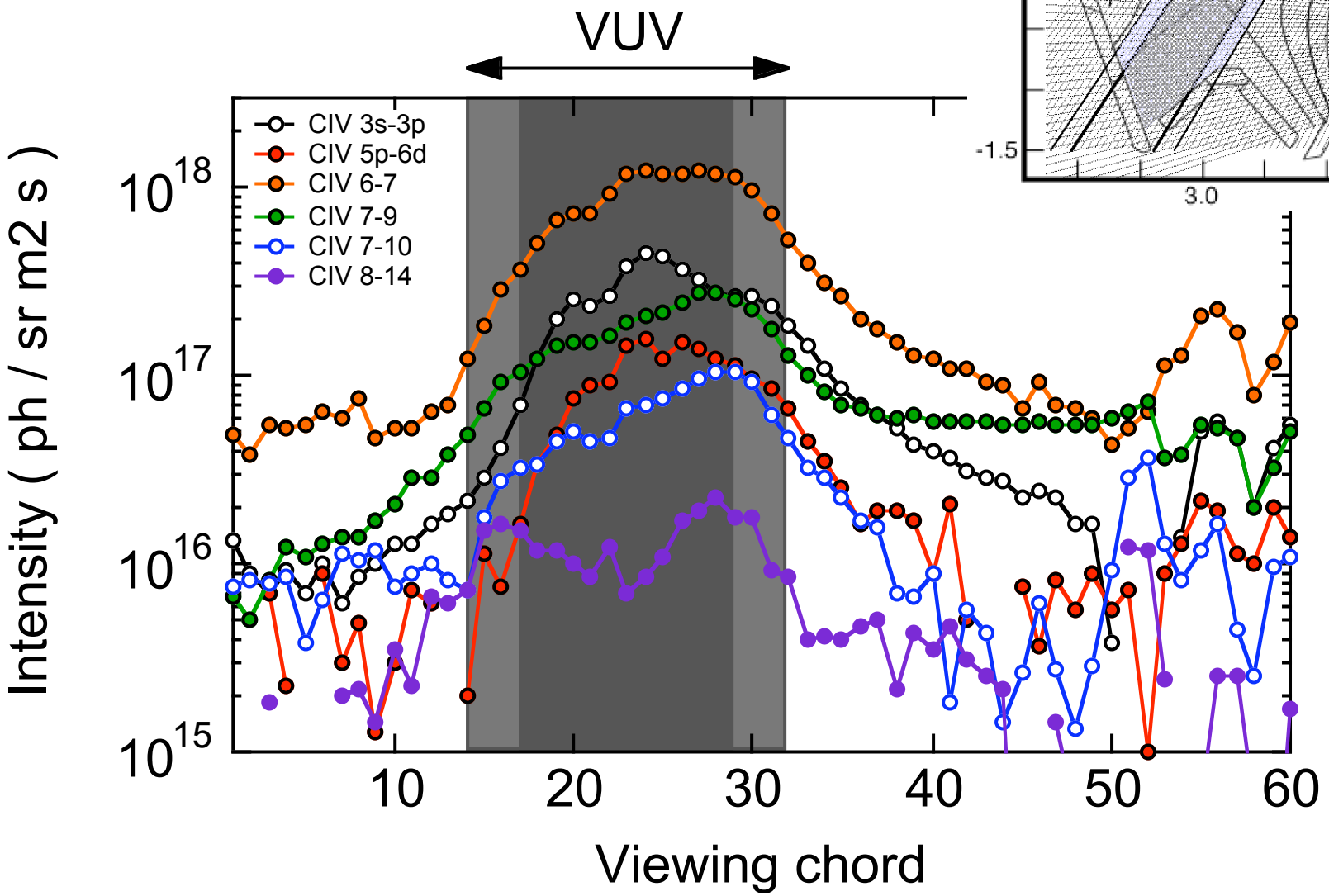




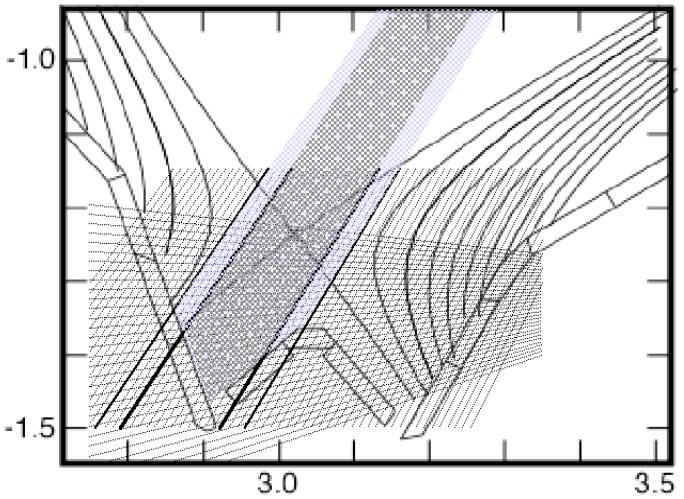


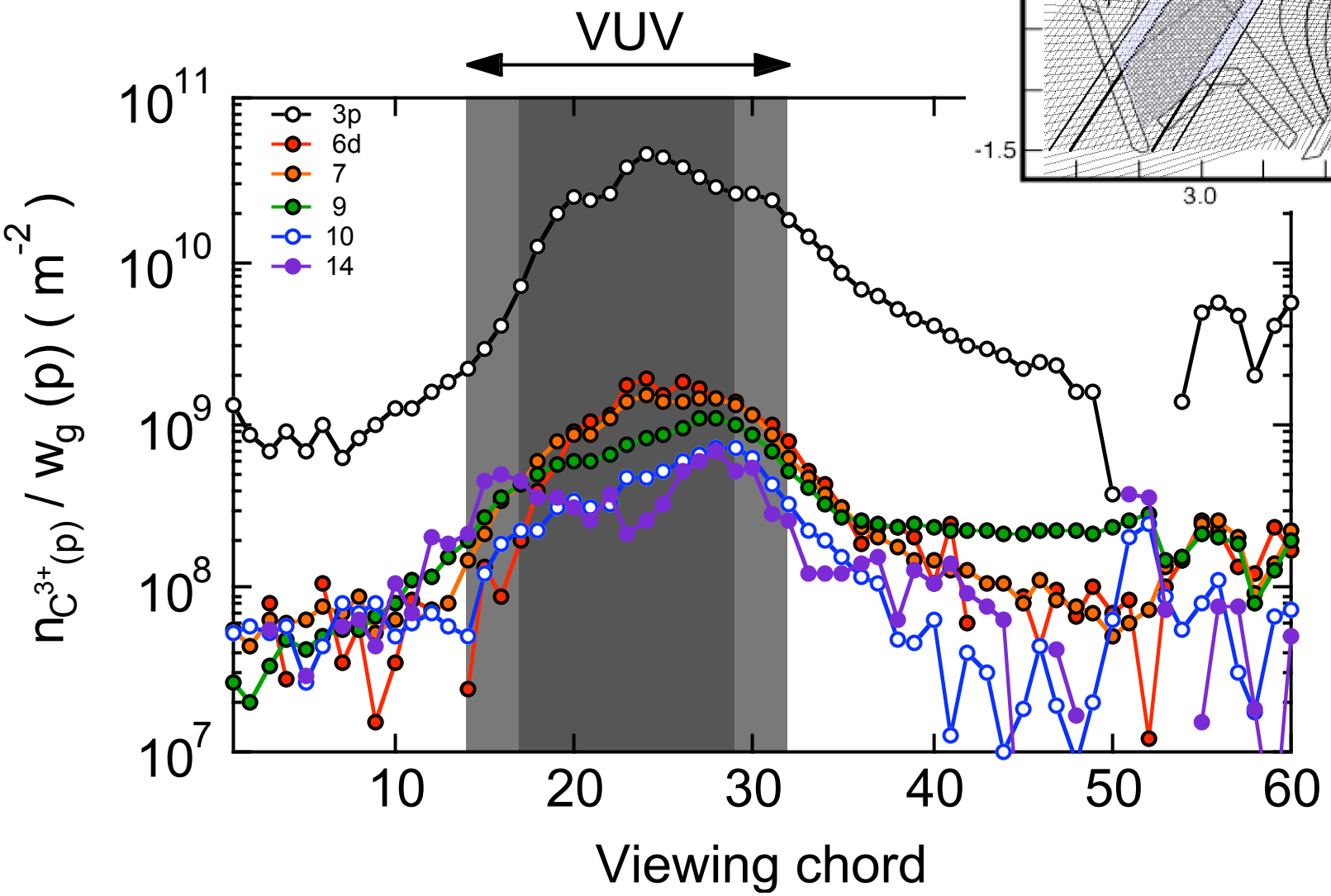
C IV intensity distribution from visible



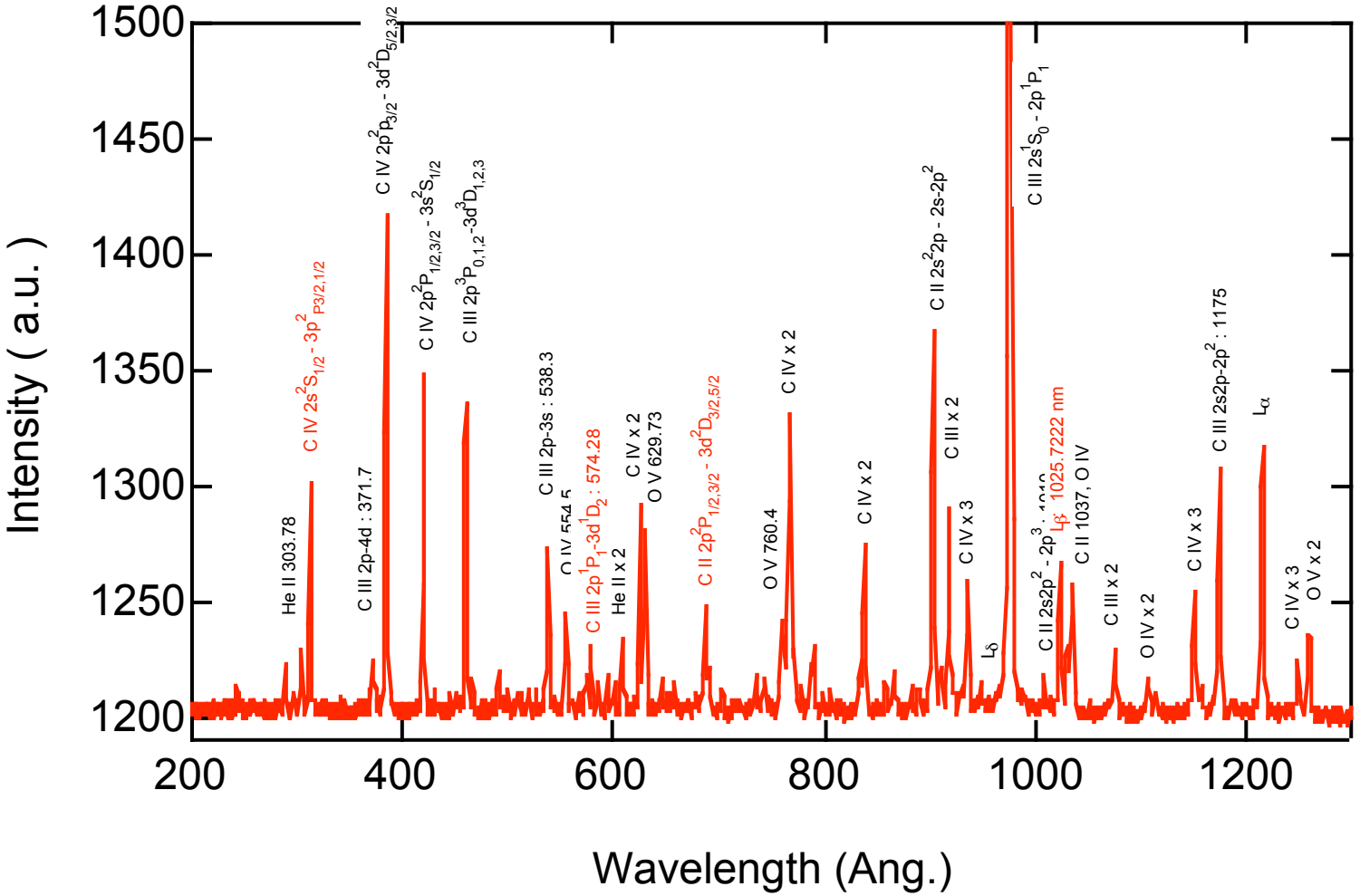


C IV Population distribution from visible

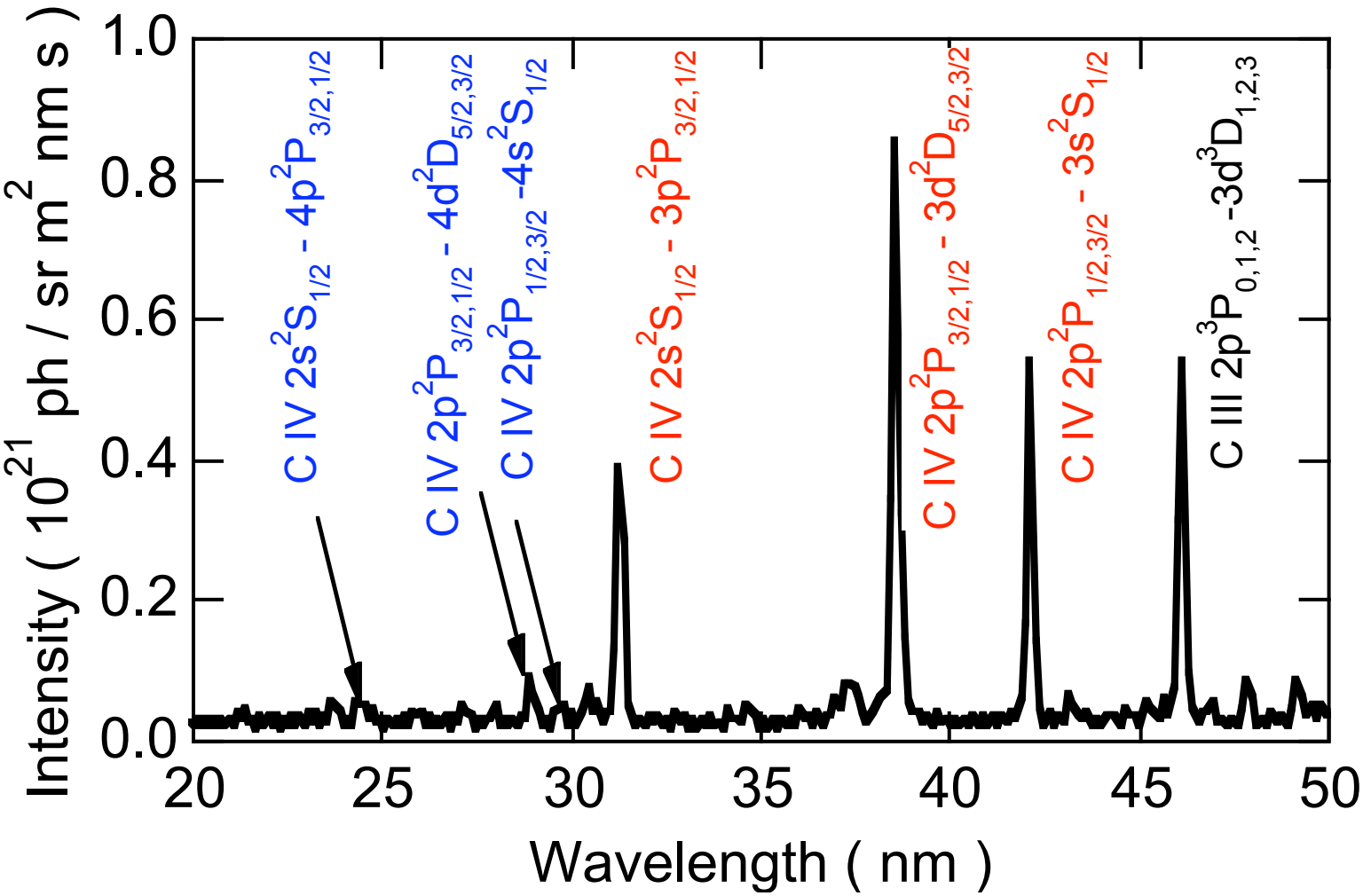




VUV spectrum

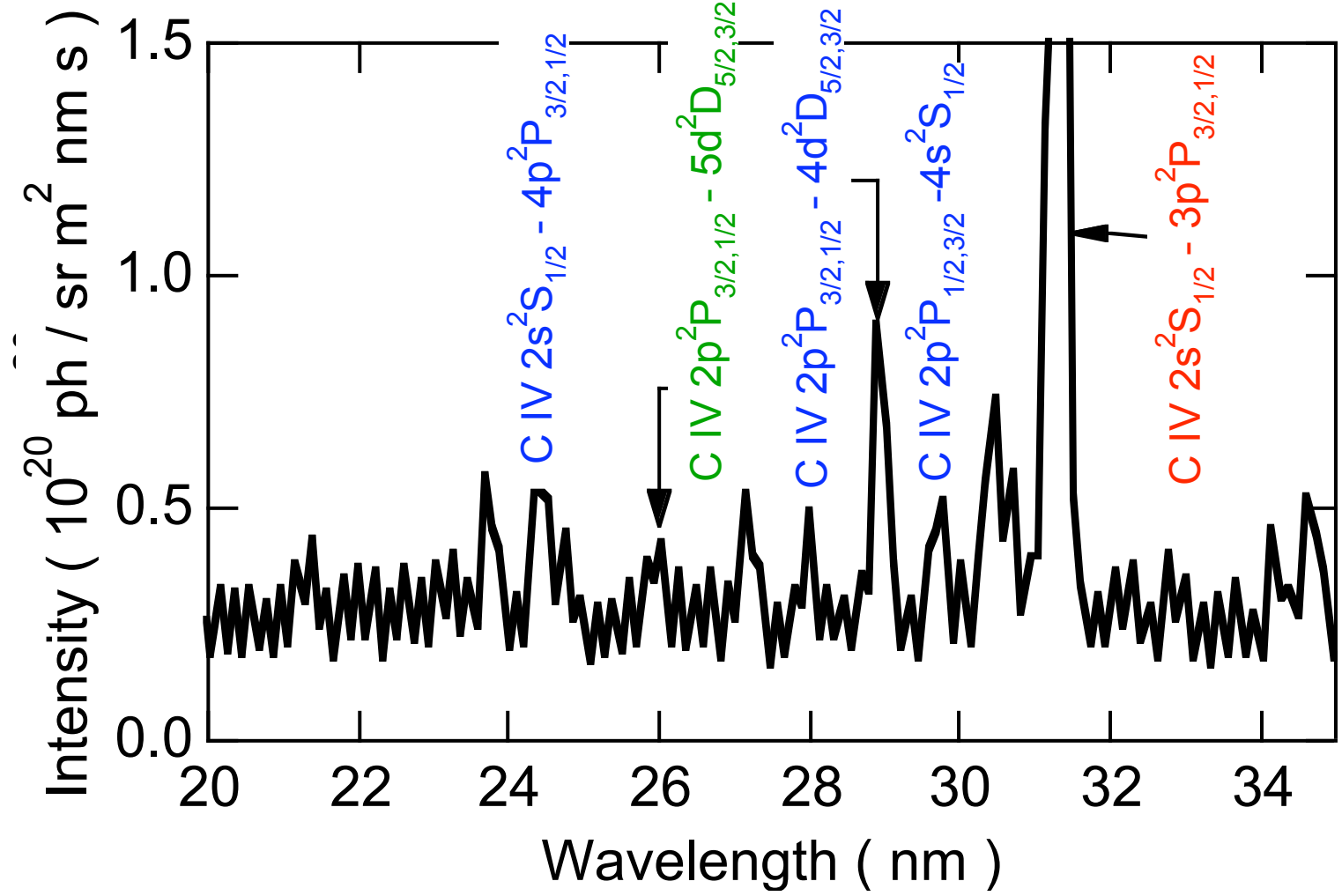


C IV spectrum (absolutely calibrated)



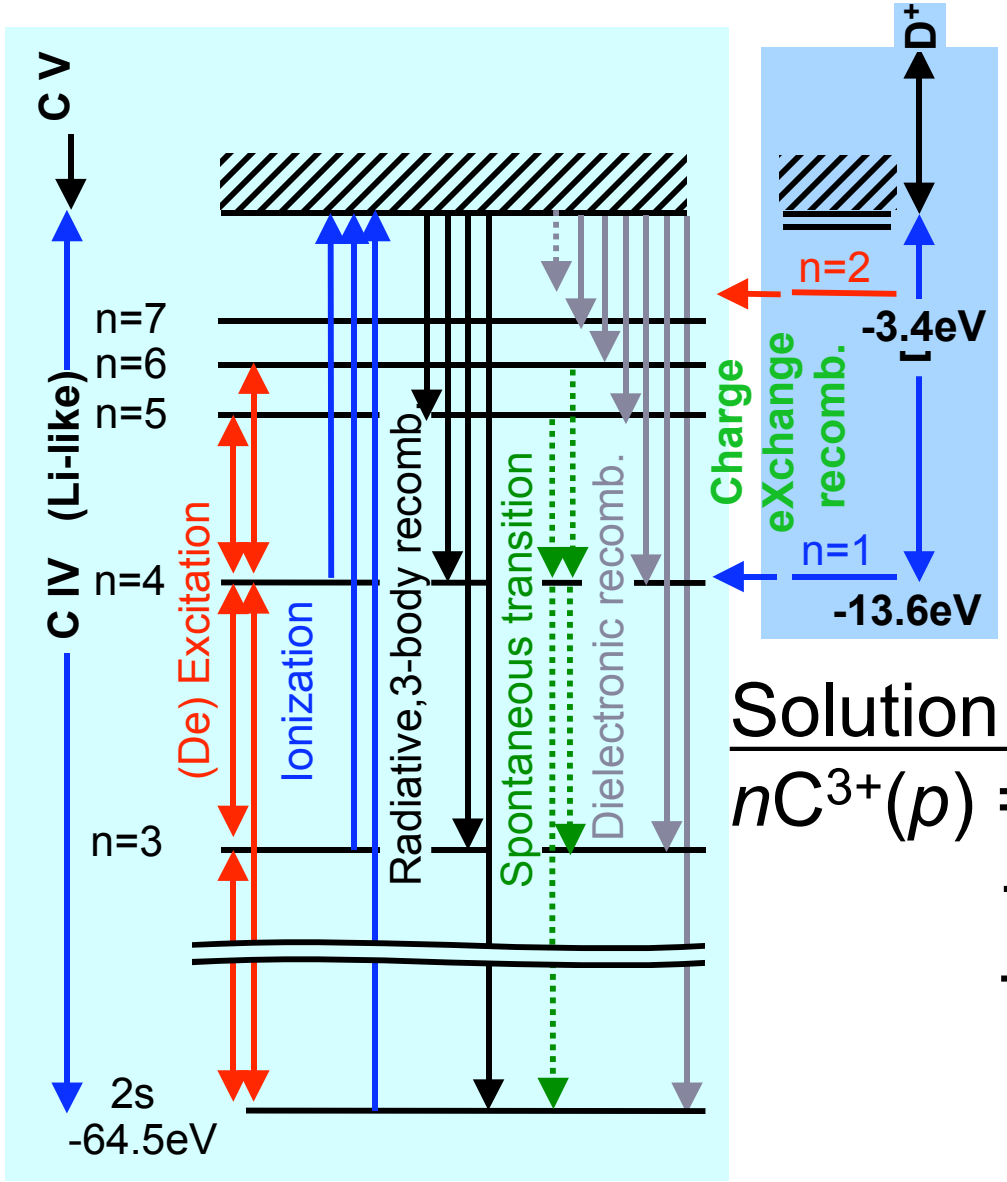
CIV (2 - 3, 4) lines are identified

C IV spectrum (absolutely calibrated)



CIV (2 - 5) lines are too weak

Collisional-Radiative model for C IV

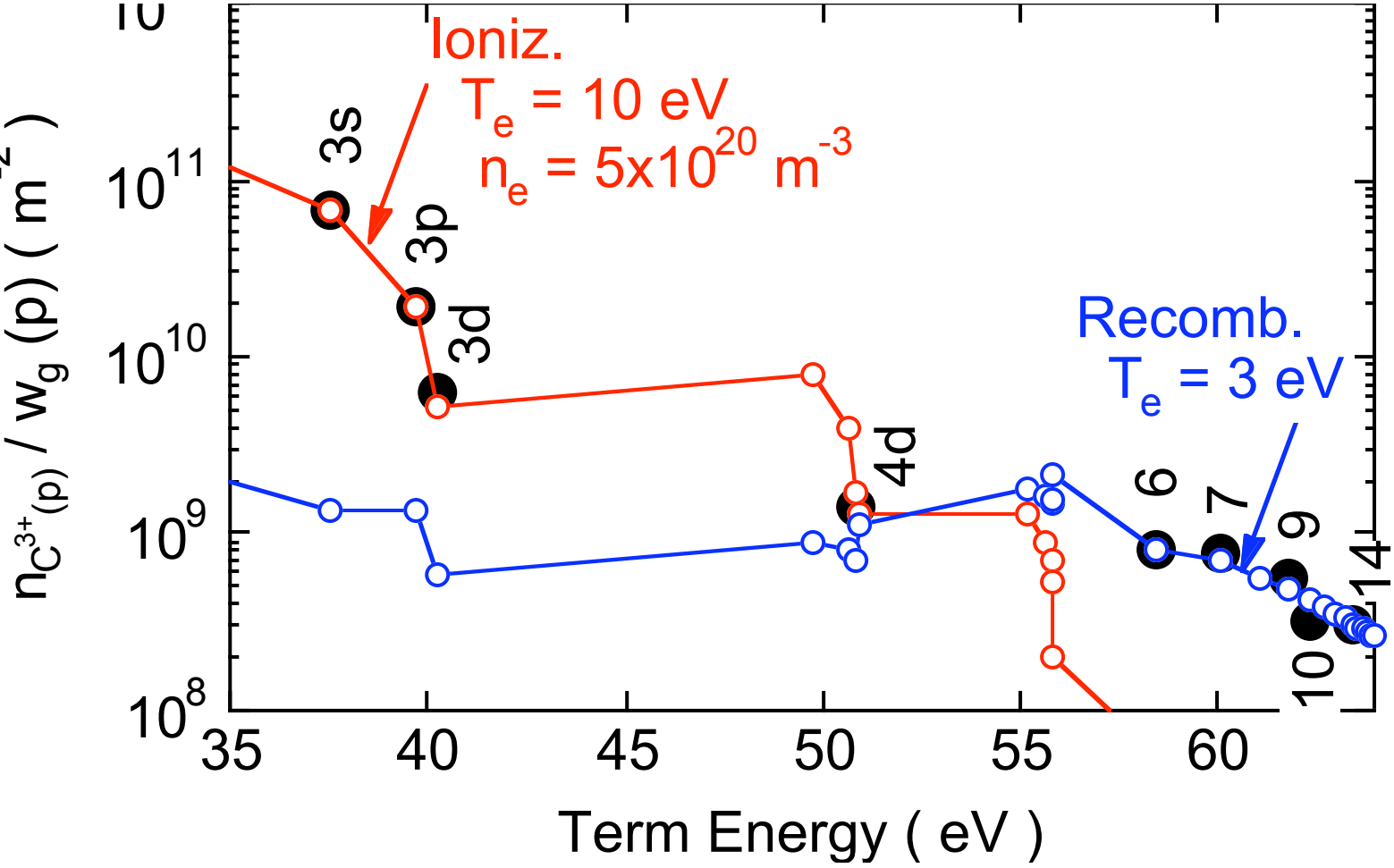


Solution of Rate Equation

$$nC^{3+}(p) = R_0 n_e n_{CV} \text{ (Recombining)} + R_0' n_D n_{CV} \text{ (CX-Recomb.)} + R_1 n_e n_{CIV} \text{ (Ionizing)}$$

C^{3+} Boltzmann plot

(comparison of measured and calculated (CR-model) population)

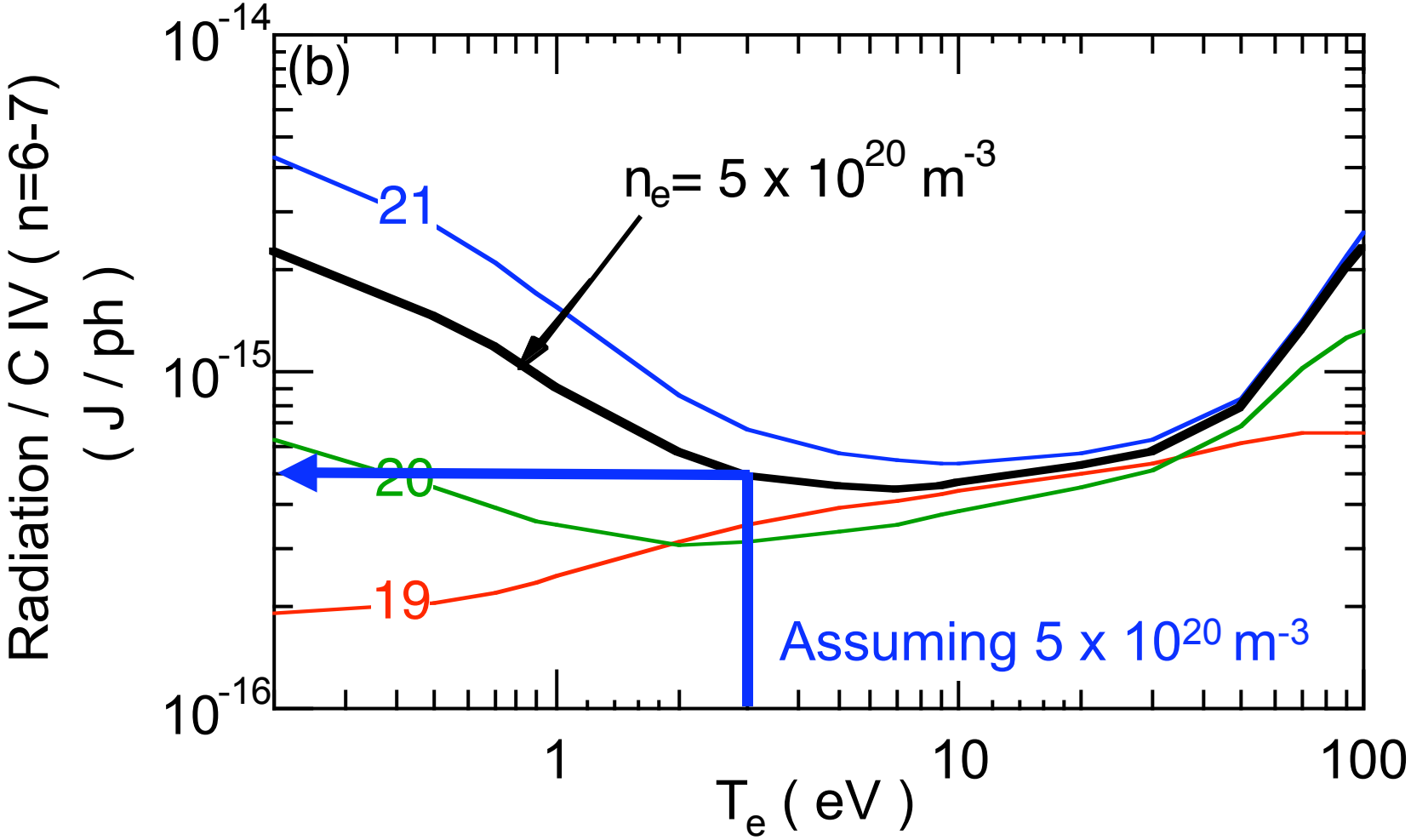


High n levels : recombining component

Low n levels : ionizing component

Different T_e ???

Radiation power (recombining C^{4+})



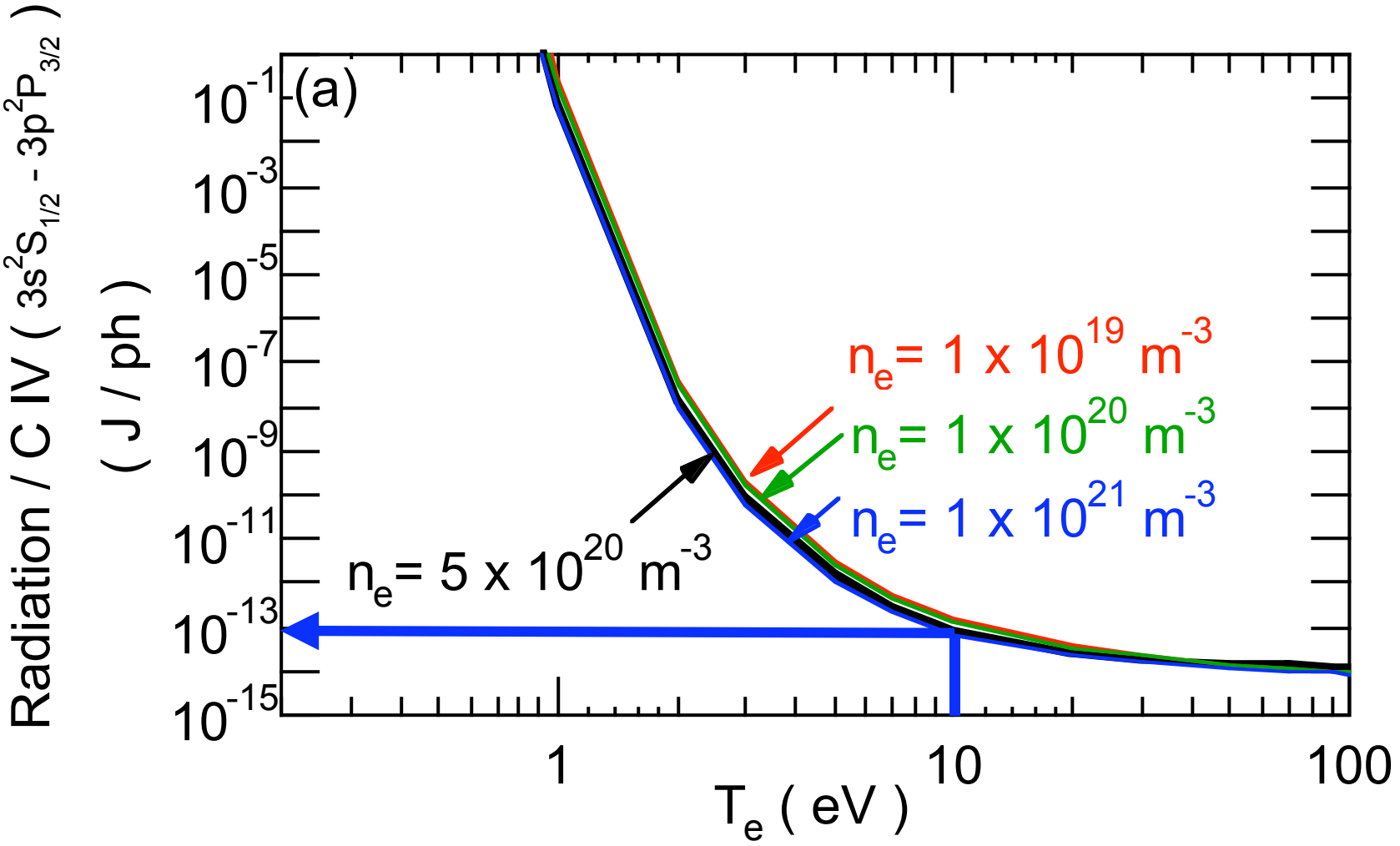
Rad / C IV (n=6-7) = 5 x 10^{-16} J/ph

C IV (n=6-7) = 1 x 10^{19} ph/m^2s

⇒ **Rad. = 5 kW / m^2**

~ 0.5% of total radiation (1 MW/m^2)

Radiation power (ionizing C^{3+})



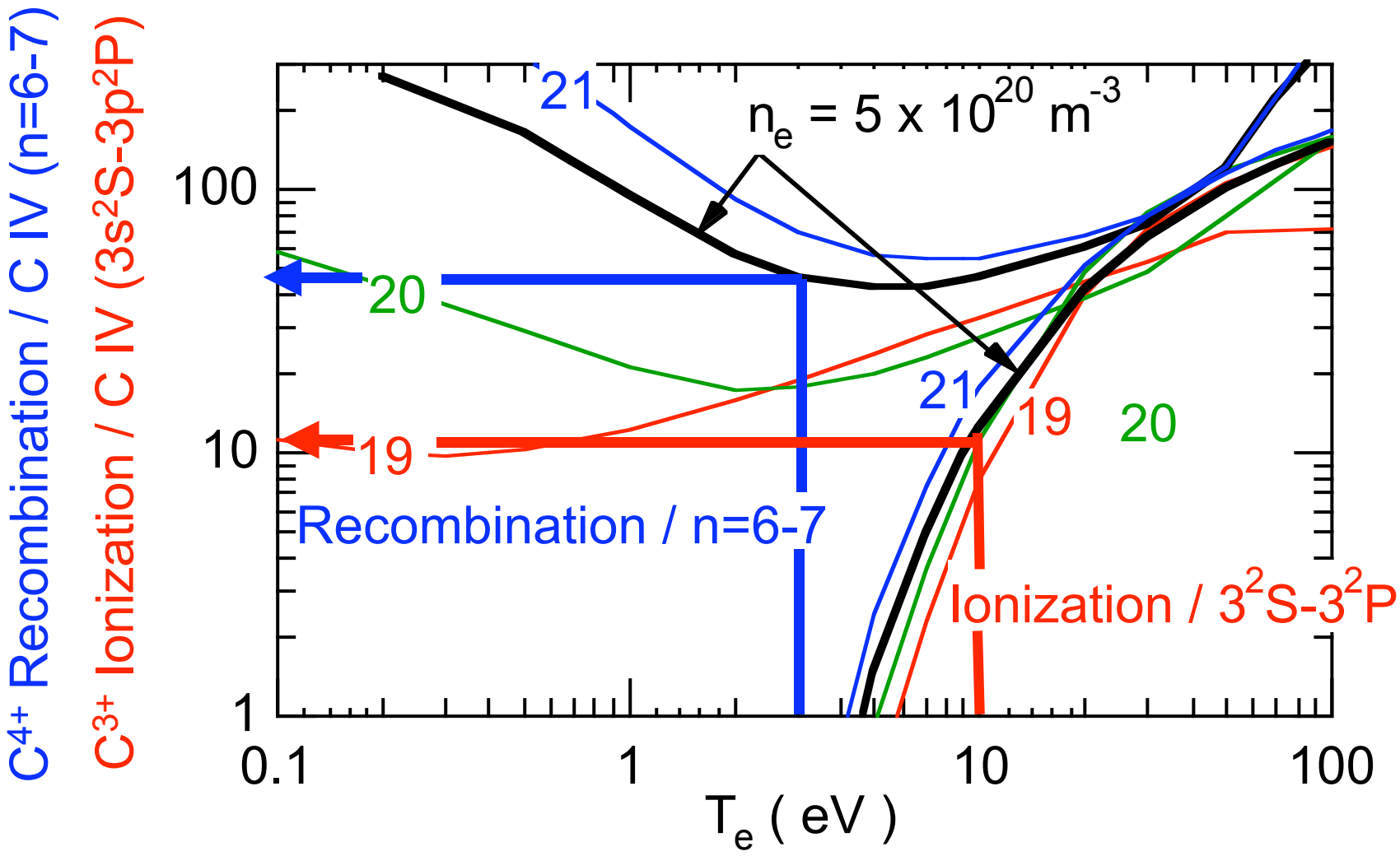
Rad / C IV (3s-3p) = 1 x 10^{-13} J/ph

C IV (3s-3p) = 4 x 10^{18} ph/m^2s

$\Rightarrow$ **Rad. = 0.4 MW / m^2**

~ 40 % of total radiation (1 MW/m^2)

C^{3+} and C^{4+} balance

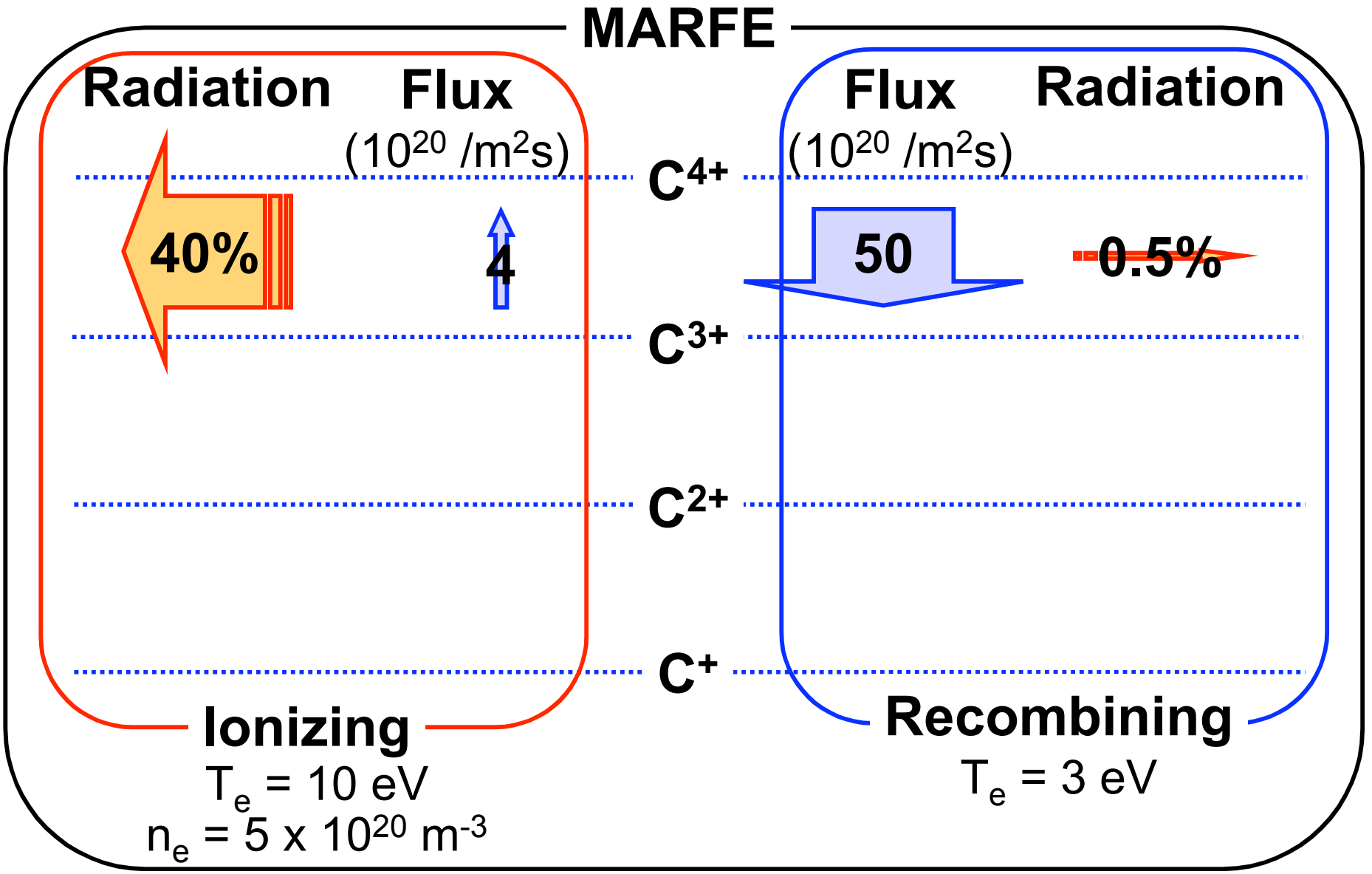


Recombination flux of C^{4+} = 50 x 1 x 10^{19} = 5 x 10^{20} /m^2s

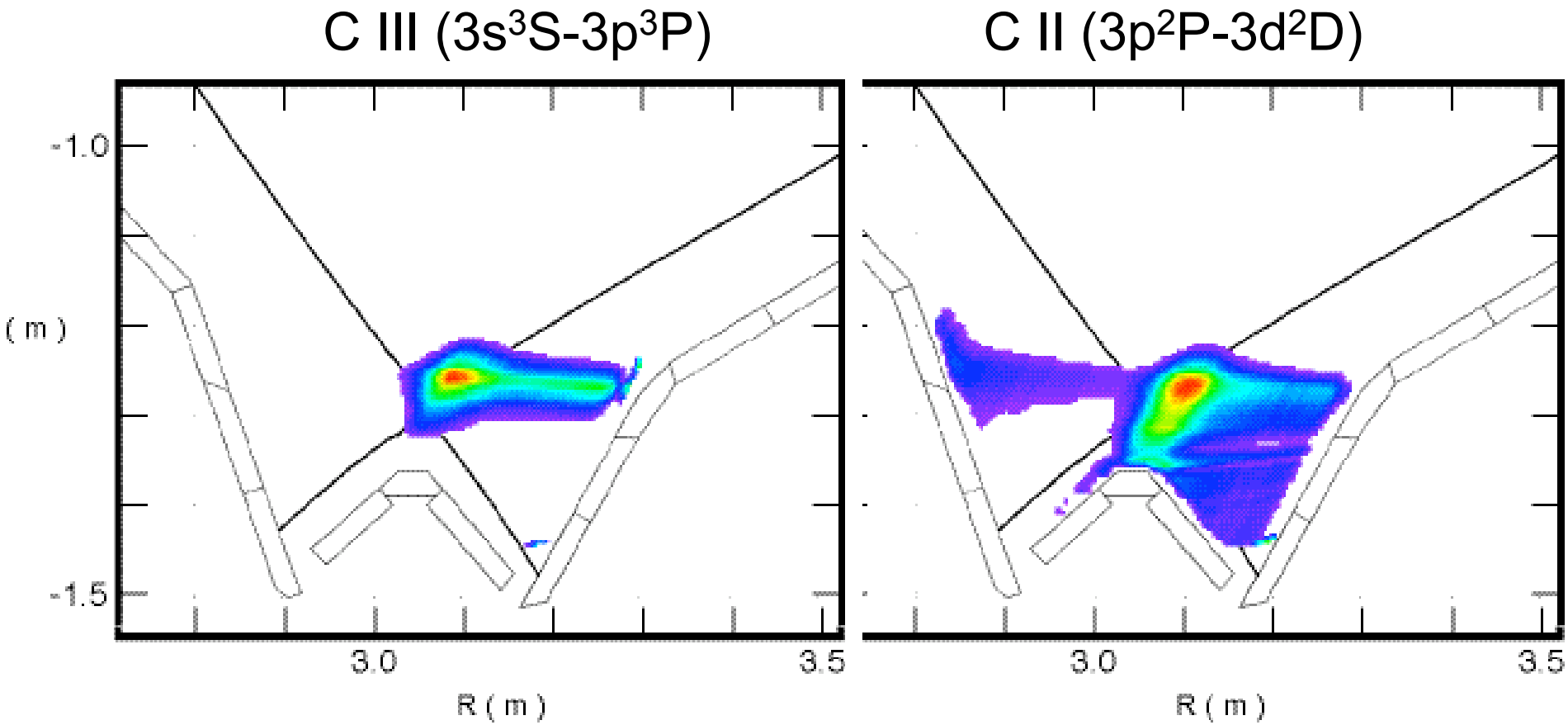
Ionization flux of C^{3+} = 10 x 4 x 10^{18} = 4 x 10^{19} /m^2s

⇒ **C^{3+} and C^{4+} balance : Recombination dominant**

Summary for C IV

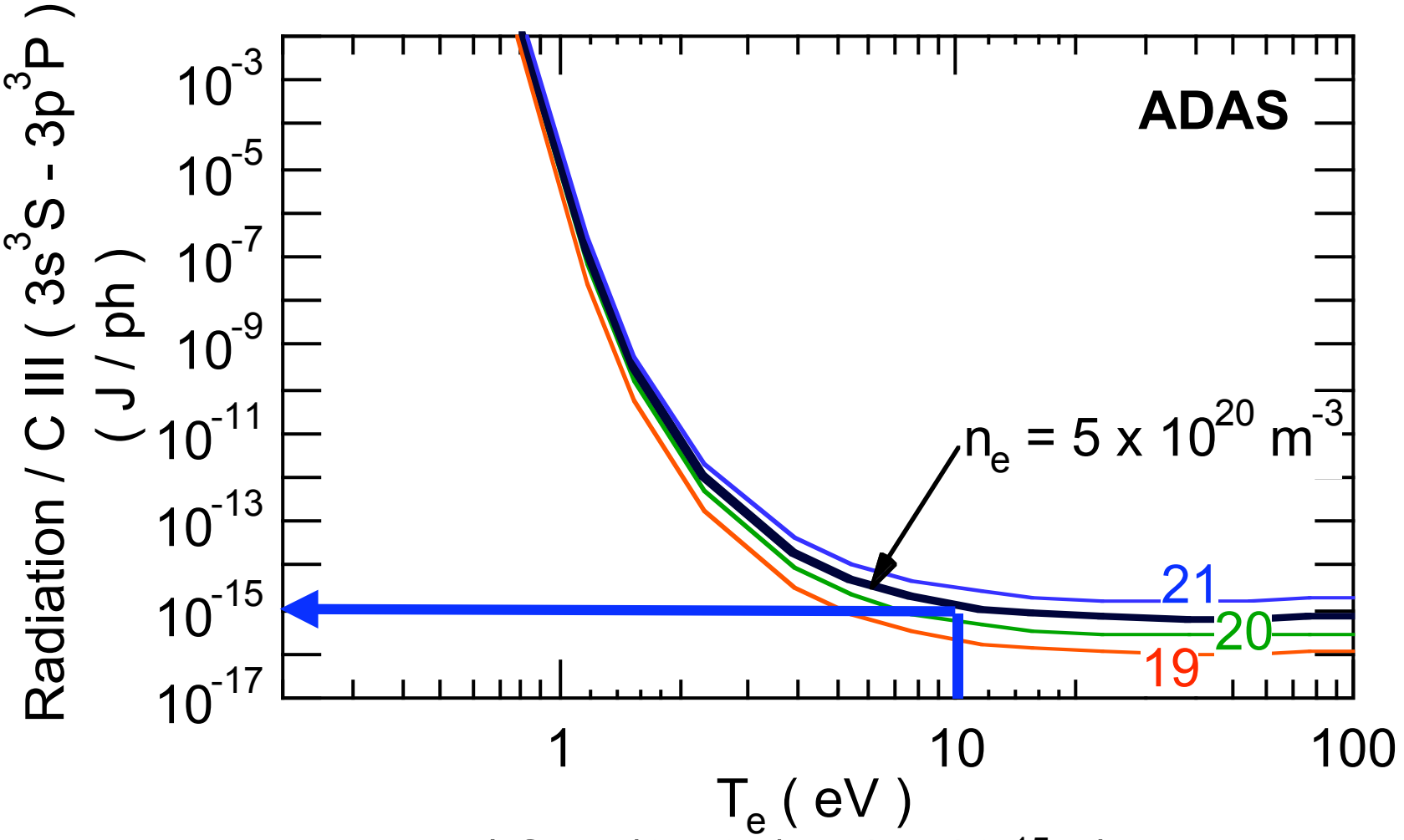


C II and C III emissivity reconstruction



- With decreasing ion charge,
  the peaks move towards the outer board.
- In the present work, assumed are:
  - T_e = 10 eV and n_e = 5 x 10^{20} m^{-3} (from C IV peak)
  - ionizing component for these lines

Radiation power (ionizing C^{2+})



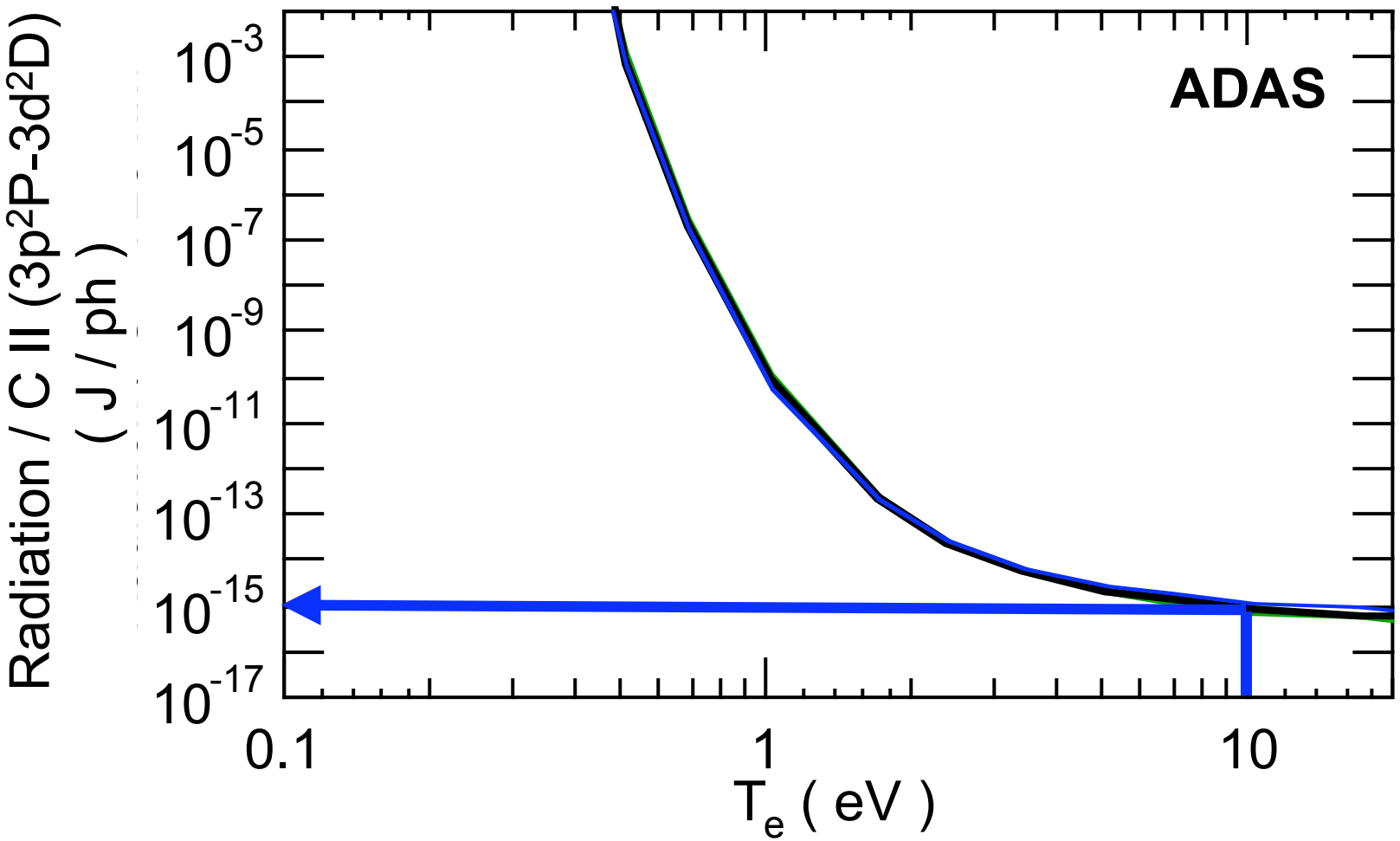
Rad / C III (3s-3p) = 1 x 10^{-15} J/ph

C III (3s-3p) = 4 x 10^{20} ph/m^2s

⇒ **Rad. = 0.4 MW / m^2**

~ 40 % of total radiation (1 MW/m^2)

Radiation power (ionizing C^+)



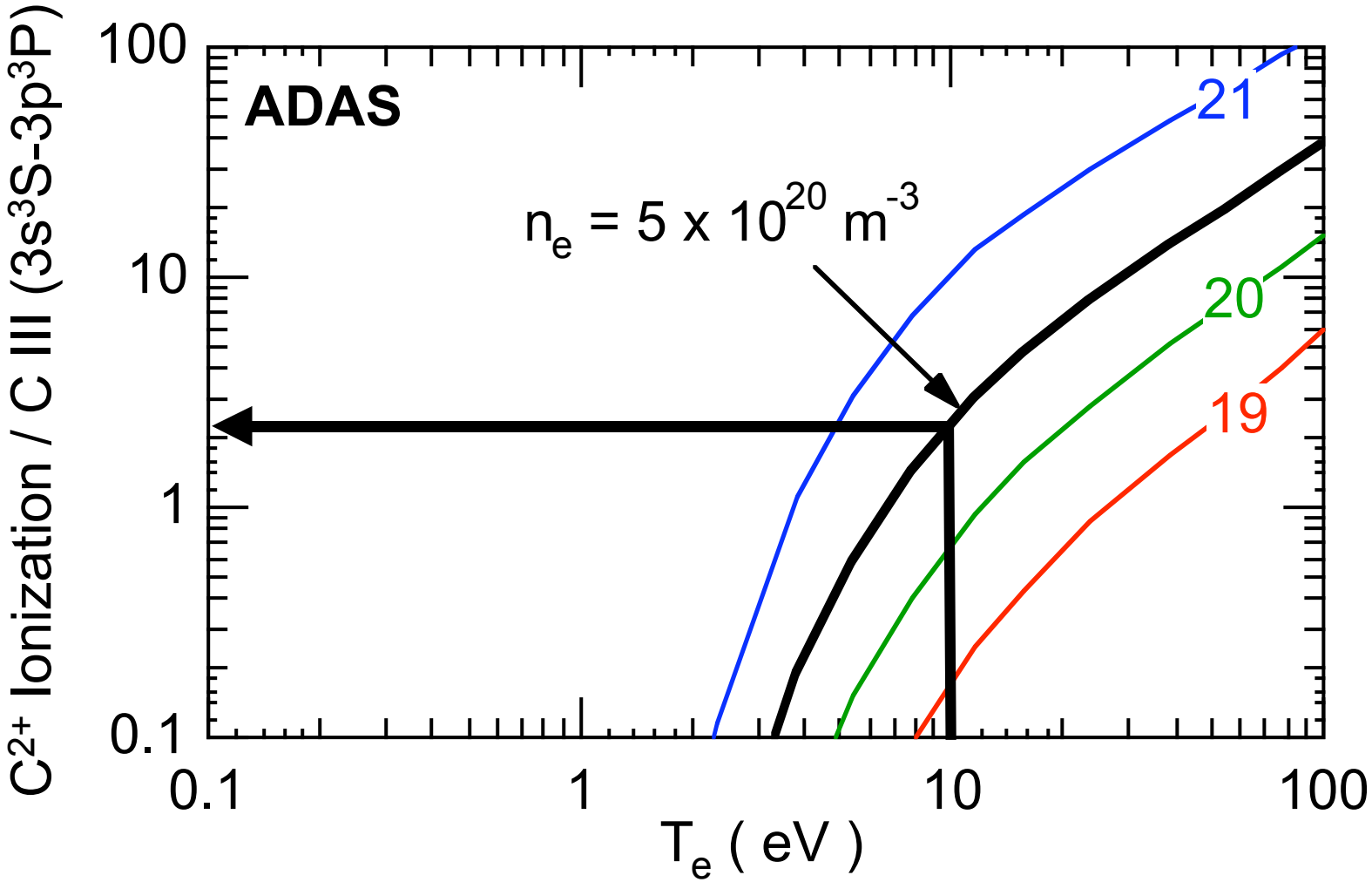
Rad / C II ($3p^2P$-$3d^2D$) = 1 x 10^{-15} J/ph

C II ($3p^2P$-$3d^2D$) = 6 x 10^{17} ph/m^2s

$\Rightarrow$ **Rad. = 0.6 kMW / m^2**

<< total radiation (1 MW/m^2)

Source of C^{3+}

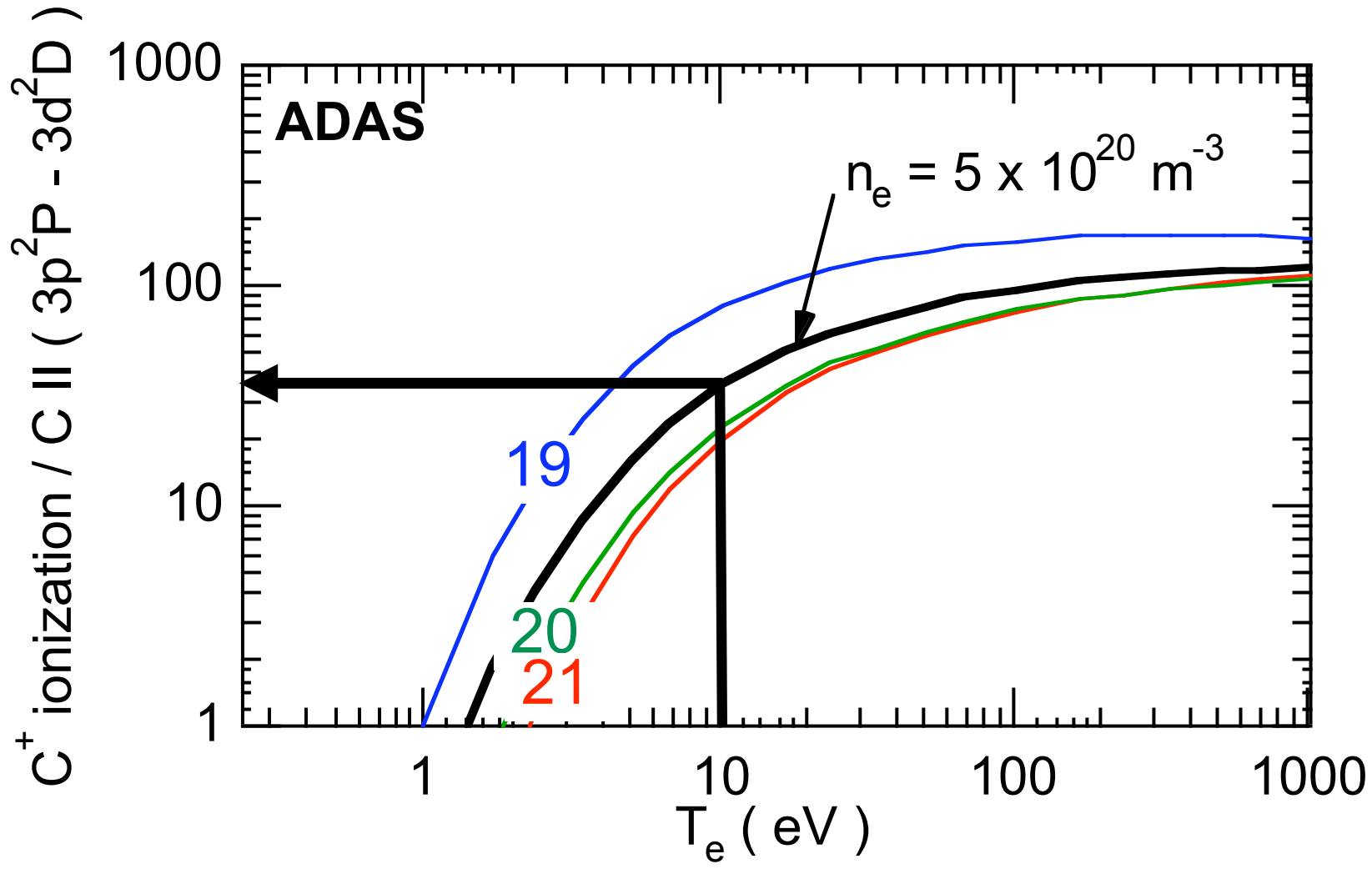


Ionization flux of C^{2+} = 2 x 4 x 10^{20} = 8 x 10^{20} /m^2s

⇒ **source of C^{3+} : comparable contribution of Ionization of C^{2+} and Recombination of C^{4+}**

(5 x 10^{20} /m^2s)

Source of C^{2+}

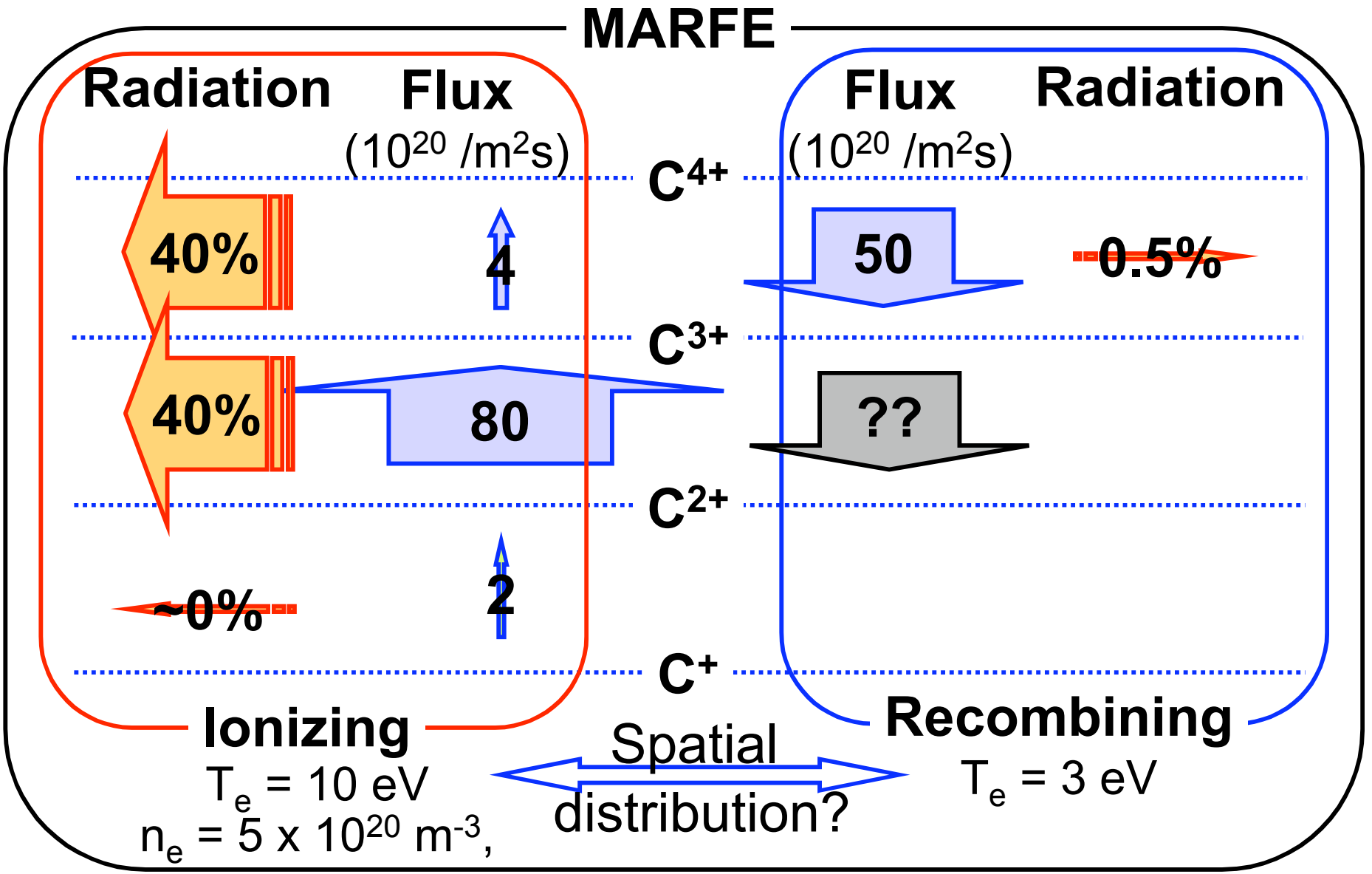


Ionization flux of C^{2+} = 35 x 6 x 10^{17} = 2 x 10^{19} /m^2s

⇒ **source of C^{3+} : Ionization of C^+ << Ionization of C^{2+}**

(8 x 10^{20} /m^2s)

Summary


MARFE
Radiation
Flux
(10^20 /m^2s)
Flux
Radiation
(10^20 /m^2s)
C4+
C3+
C2+
C+
40%
4
50
0.5%
40%
80
??
~0%
2
Ionizing
Te = 10 eV
ne = 5 x 10^20 m^-3,
Spatial
distribution?
Recombining
Te = 3 eV

Thank you !!