

plasma spectroscopy

Motoshi Goto
National Institute for Fusion Science

introduction

LHD

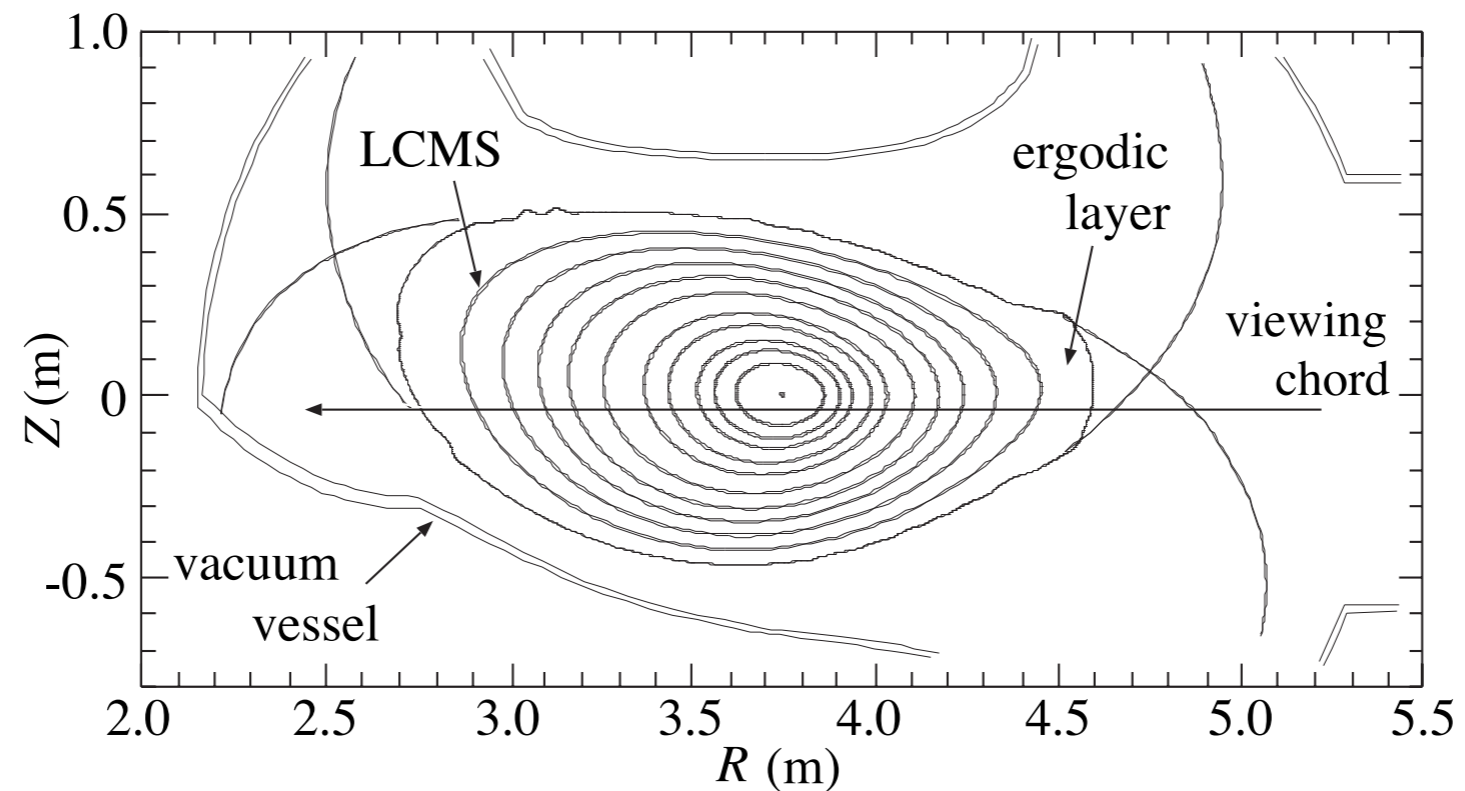
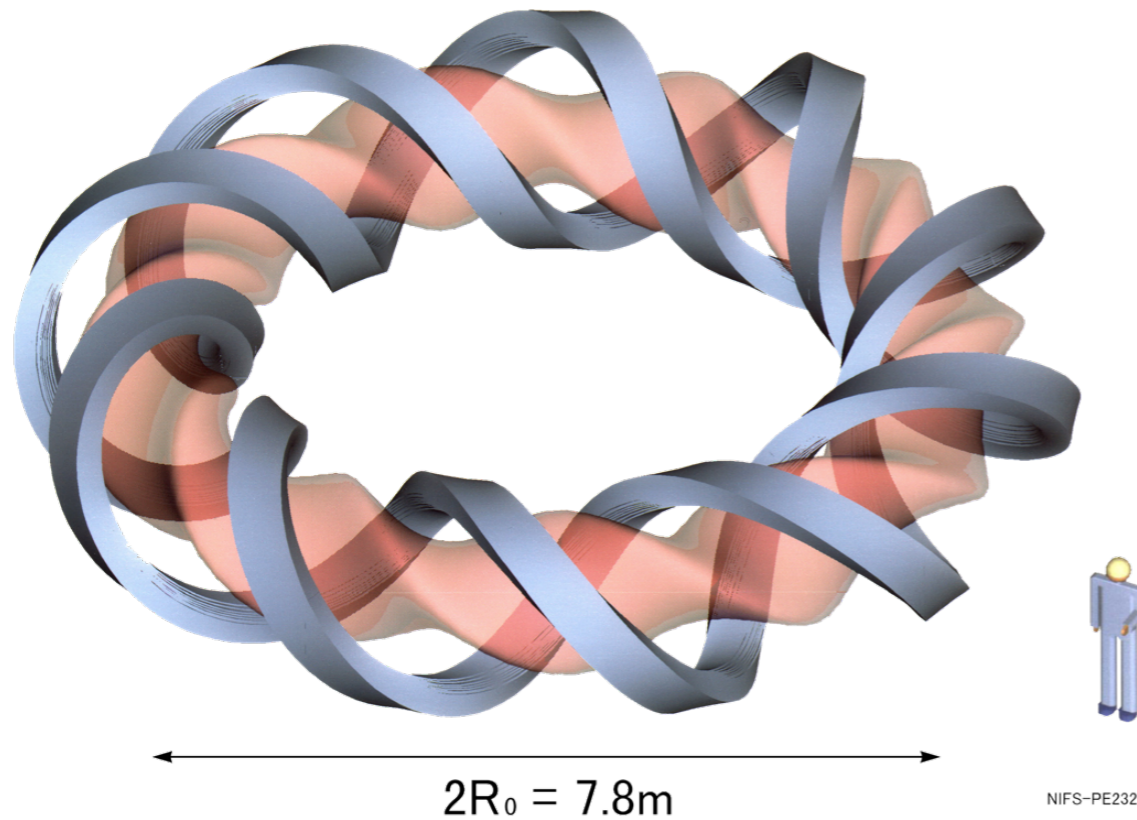
achievements

$$P = 15 \text{ MW}$$

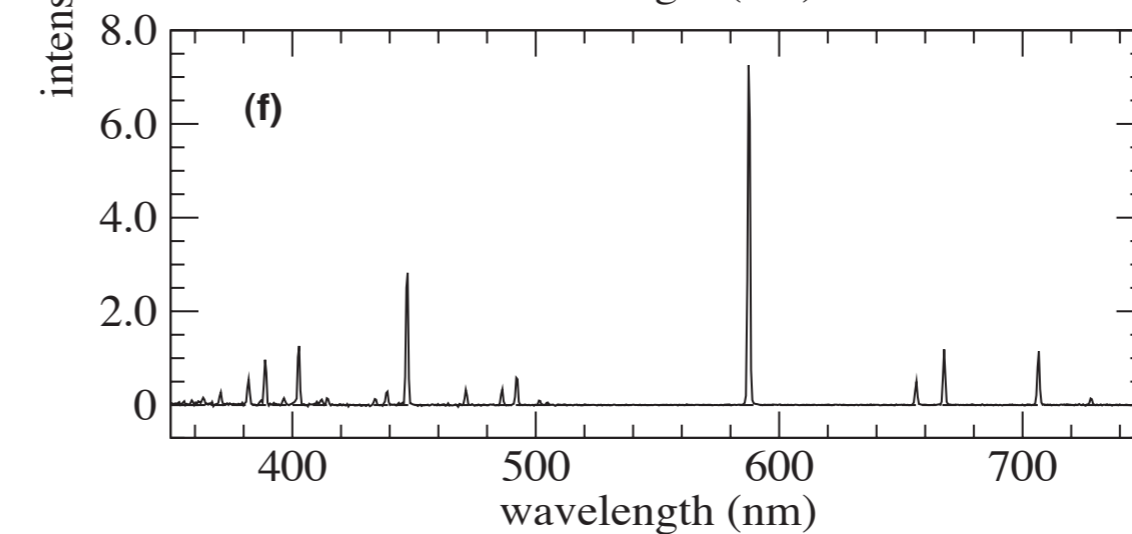
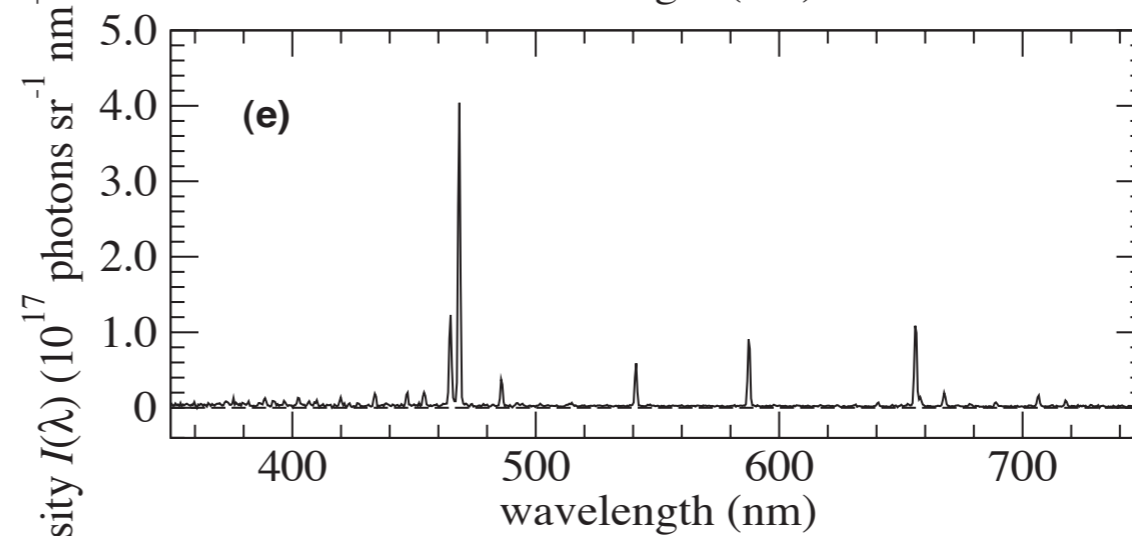
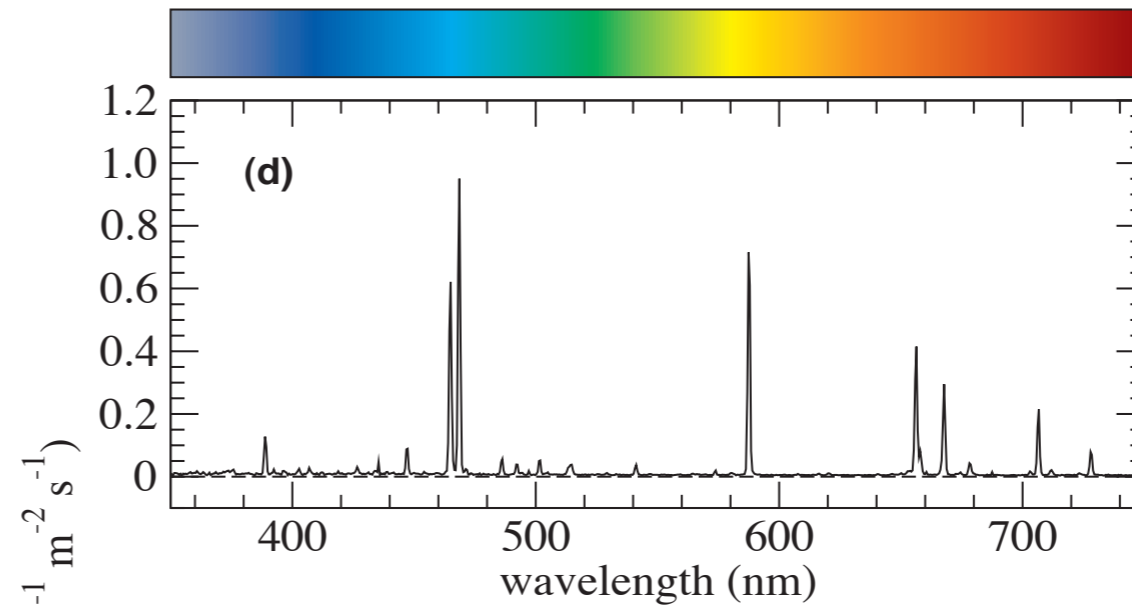
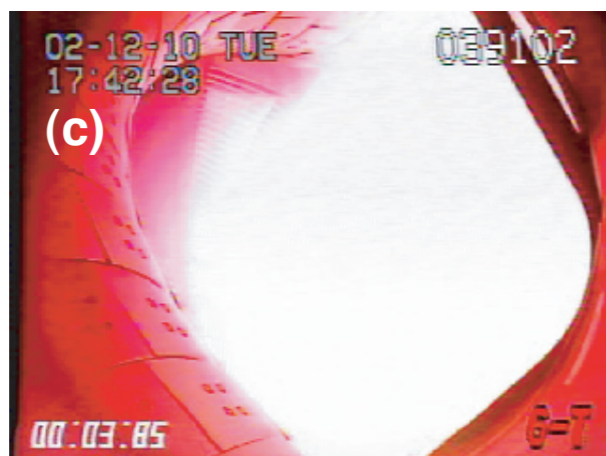
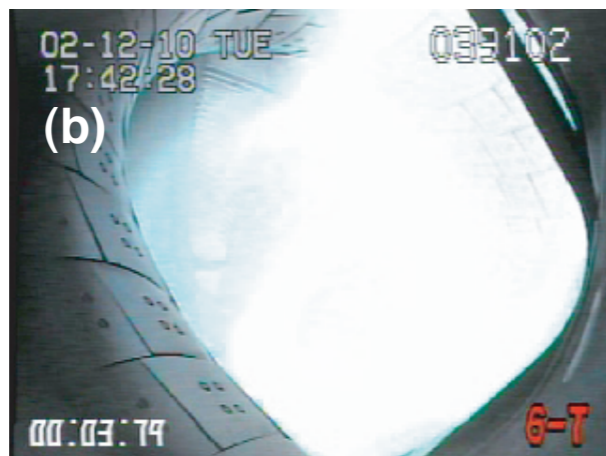
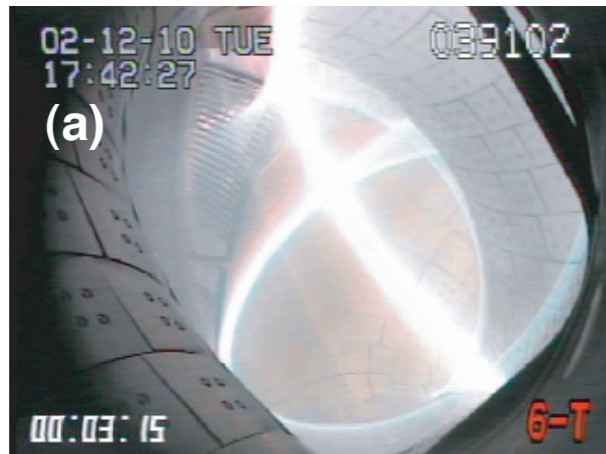
$$T_e = 10 \text{ keV}$$

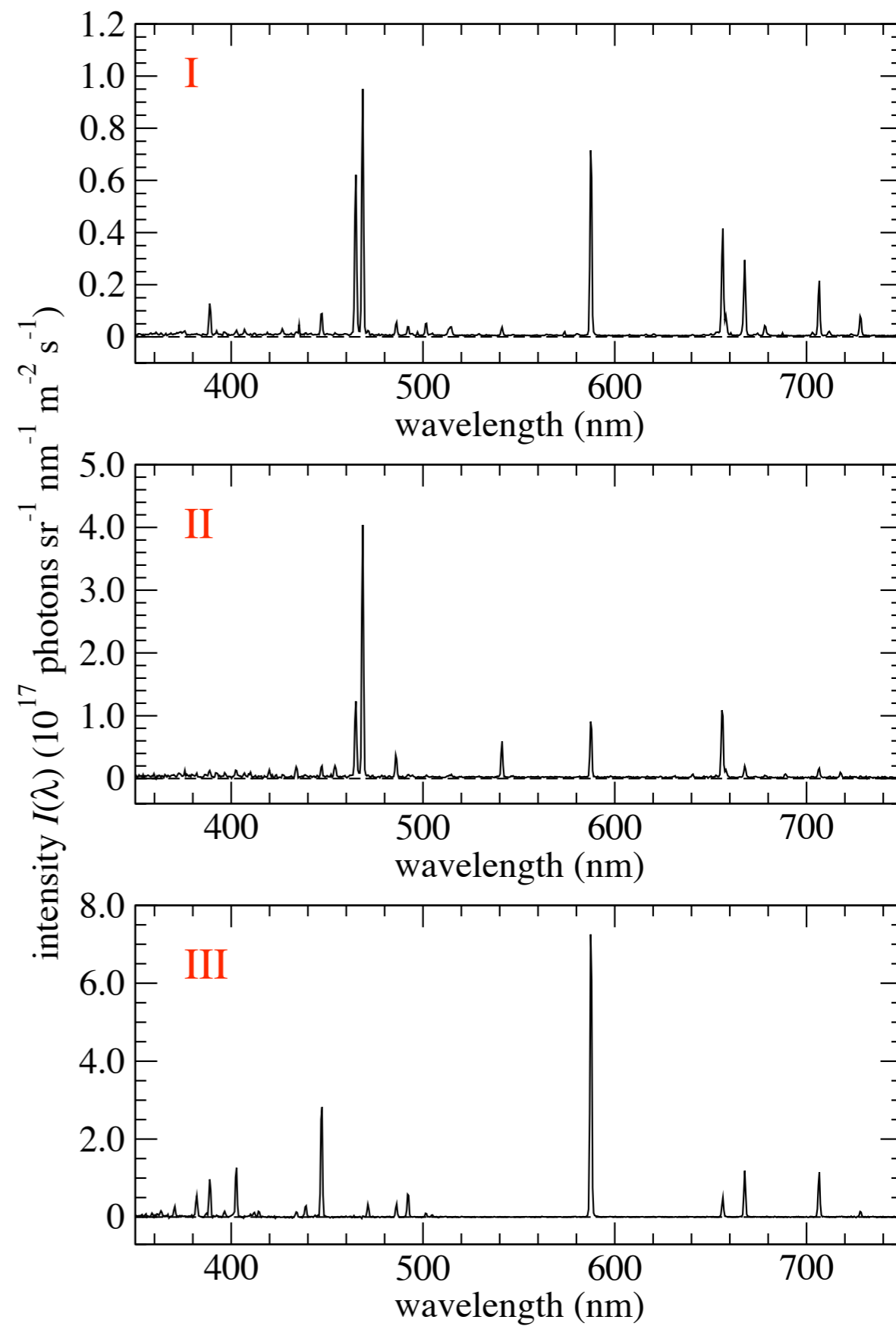
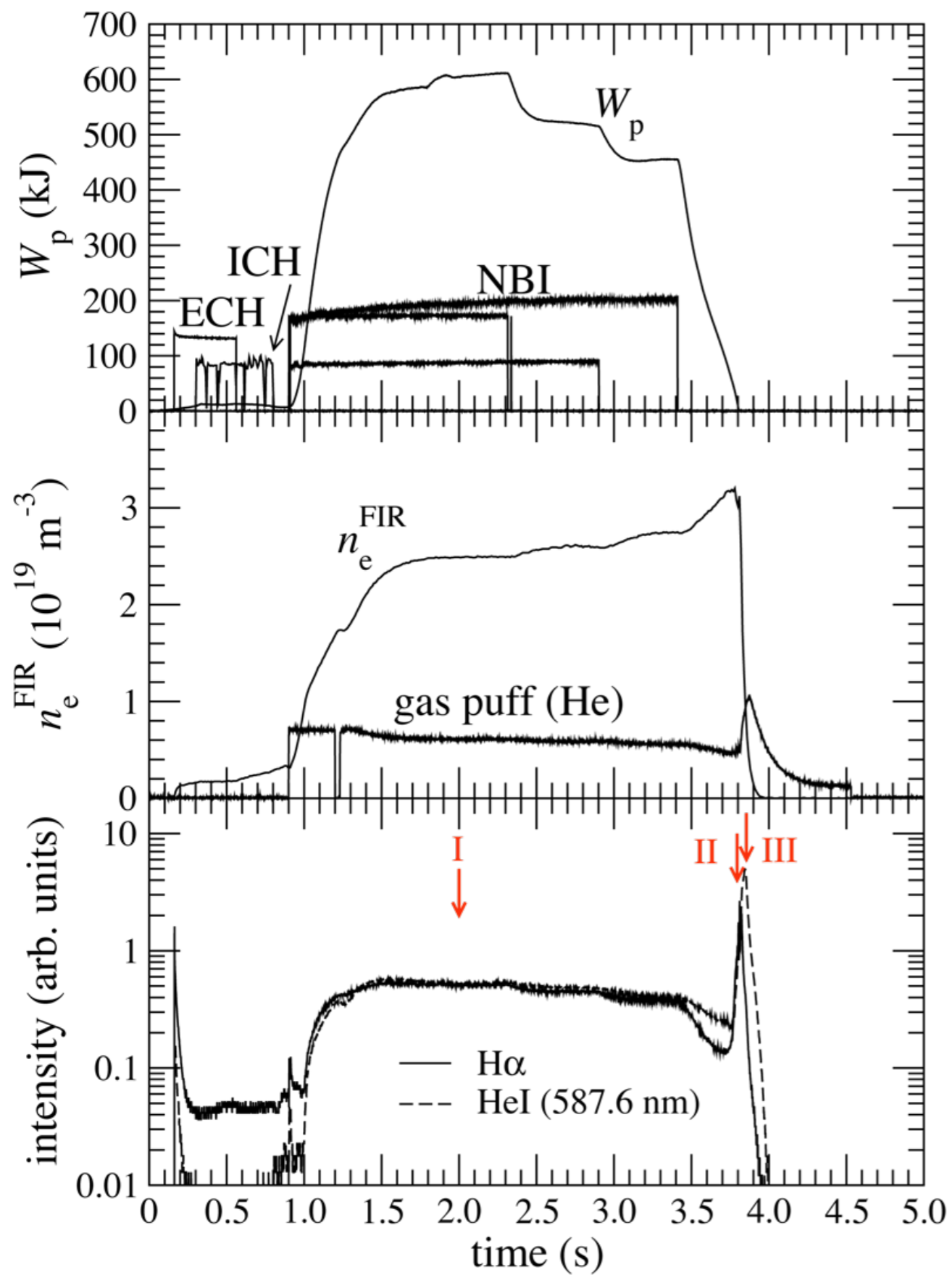
$$T_i = 13 \text{ keV}$$

$$n_e = 3 \times 10^{20} \text{ m}^{-3}$$



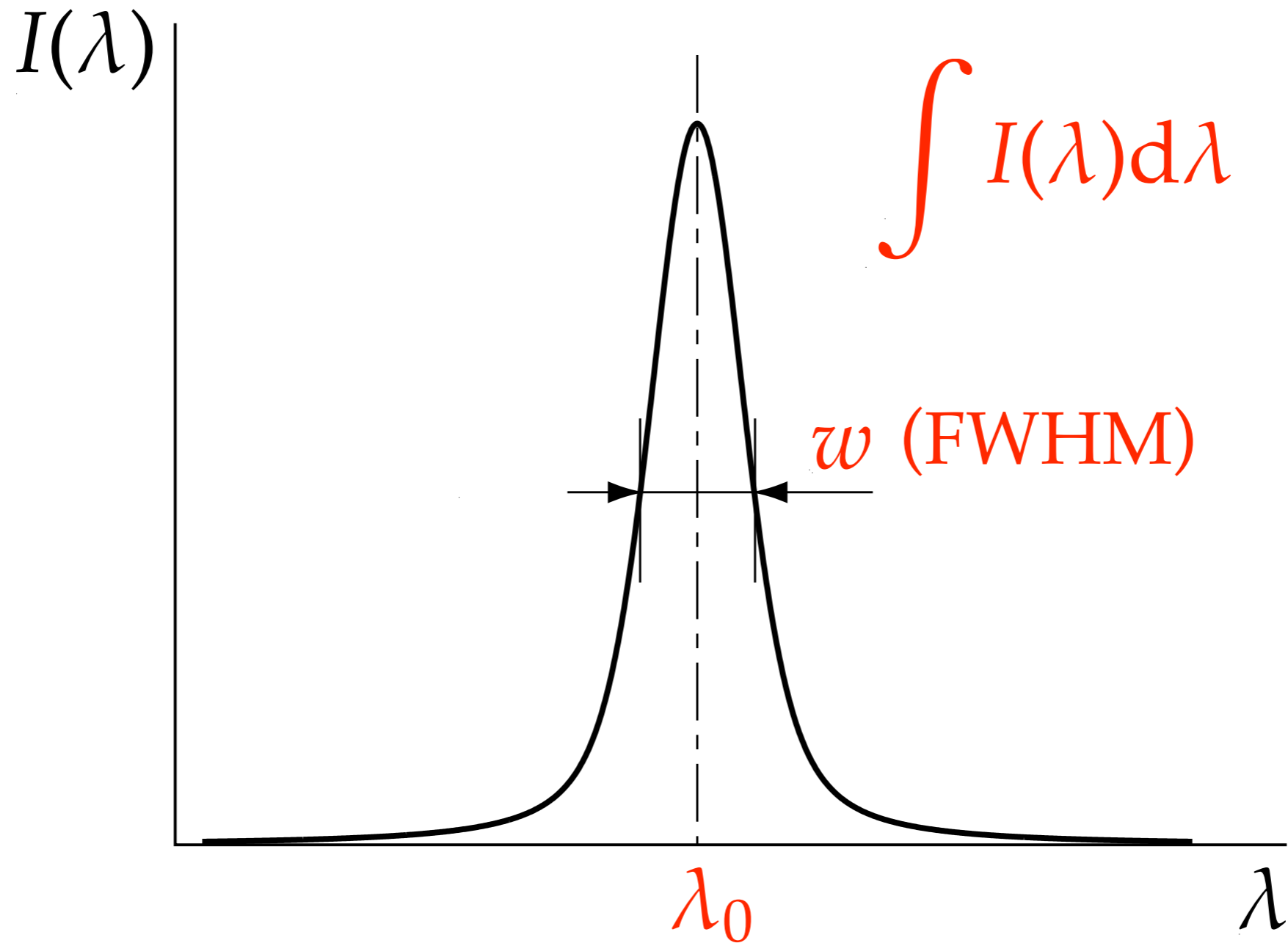
discharge with helium gas





line radiation

properties of emission line



what can be known?

observable		obtainable
shift		ion velocity
broadening	Doppler	T_i
	Stark	n_e
splitting	Zeeman	magnetic field
	Stark	electric field
intensity ratios intensity distribution		T_e, n_e ionizing or recombining
intensity		n_i

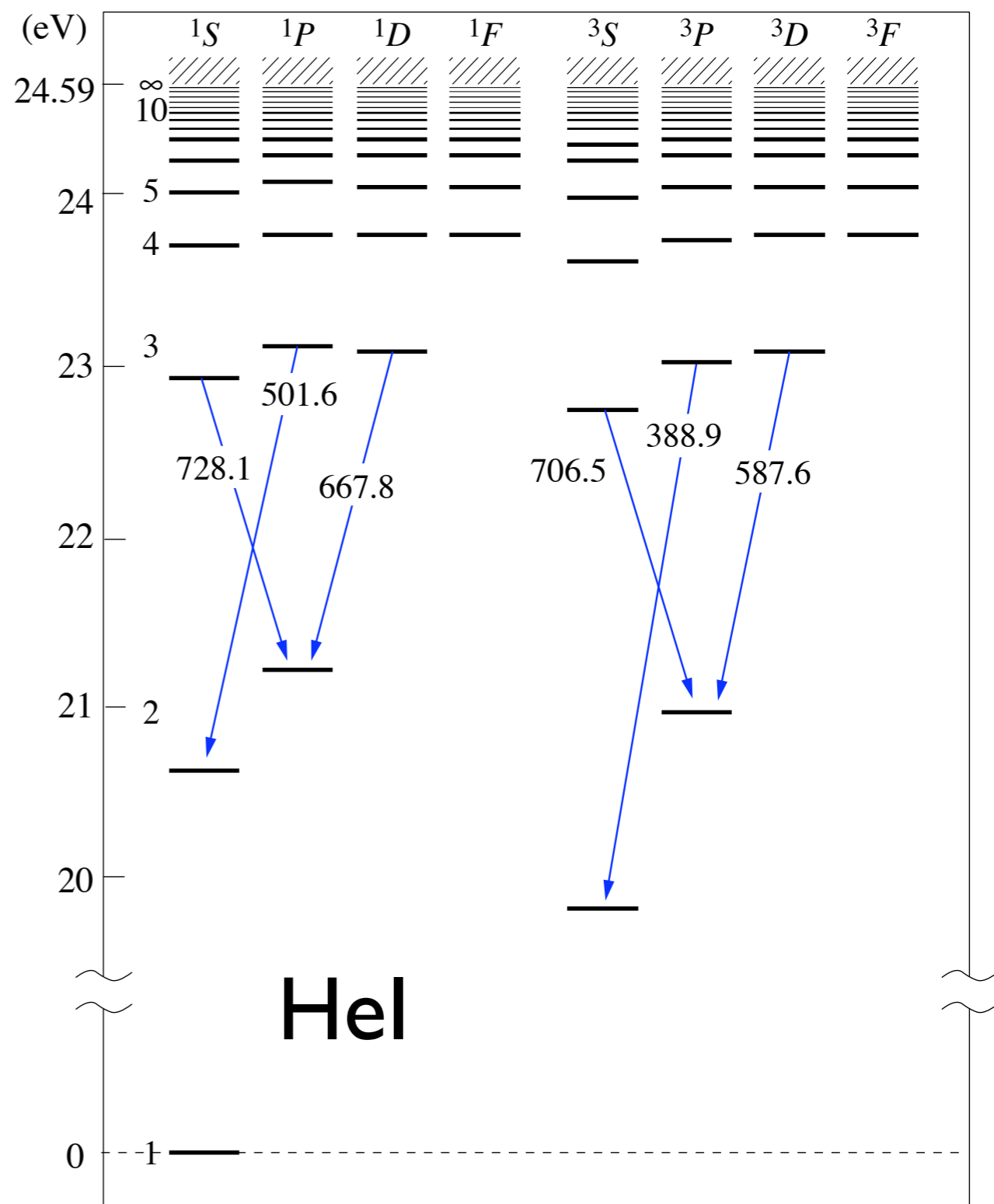
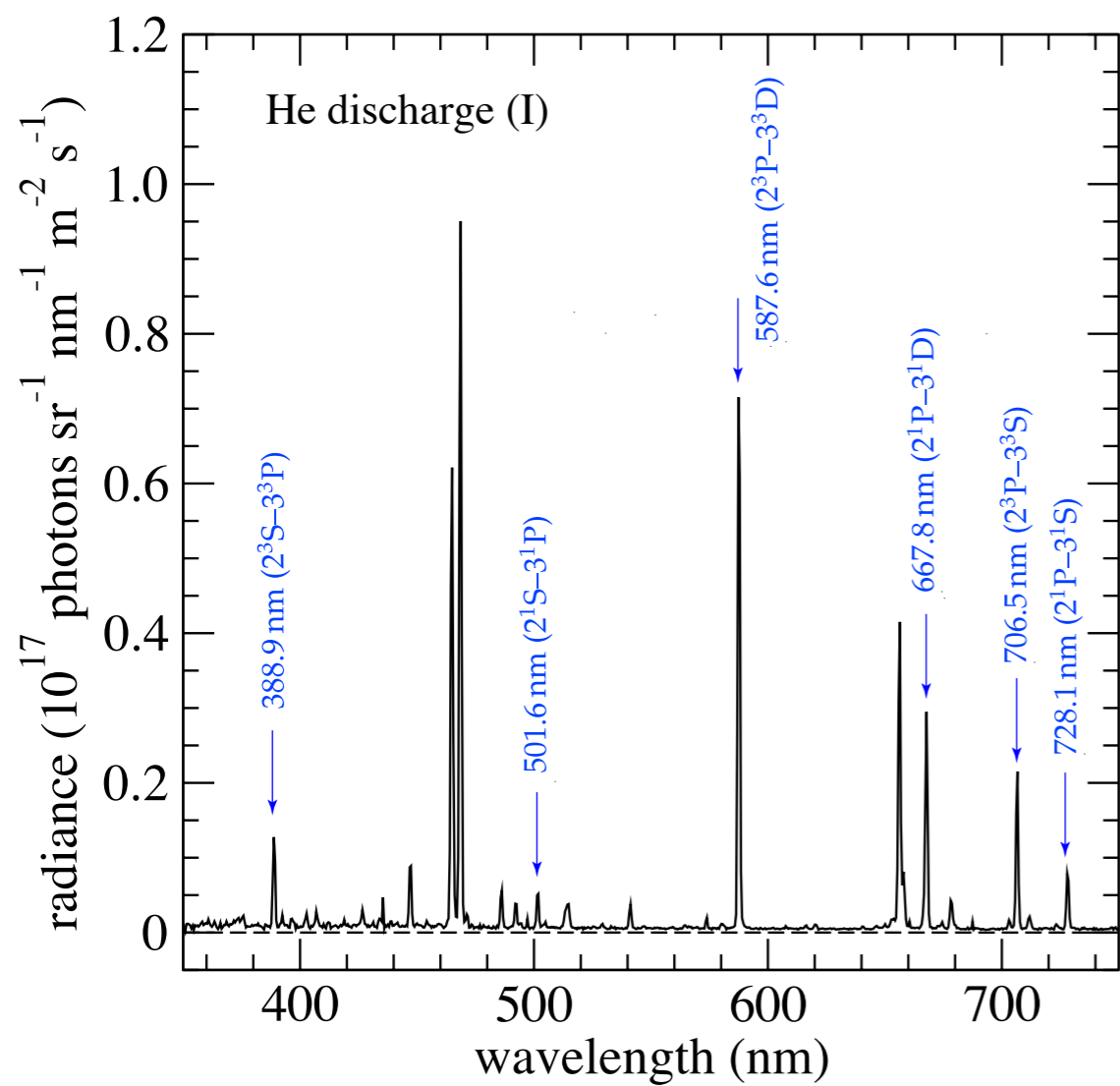
}

high resolution
measurement

}

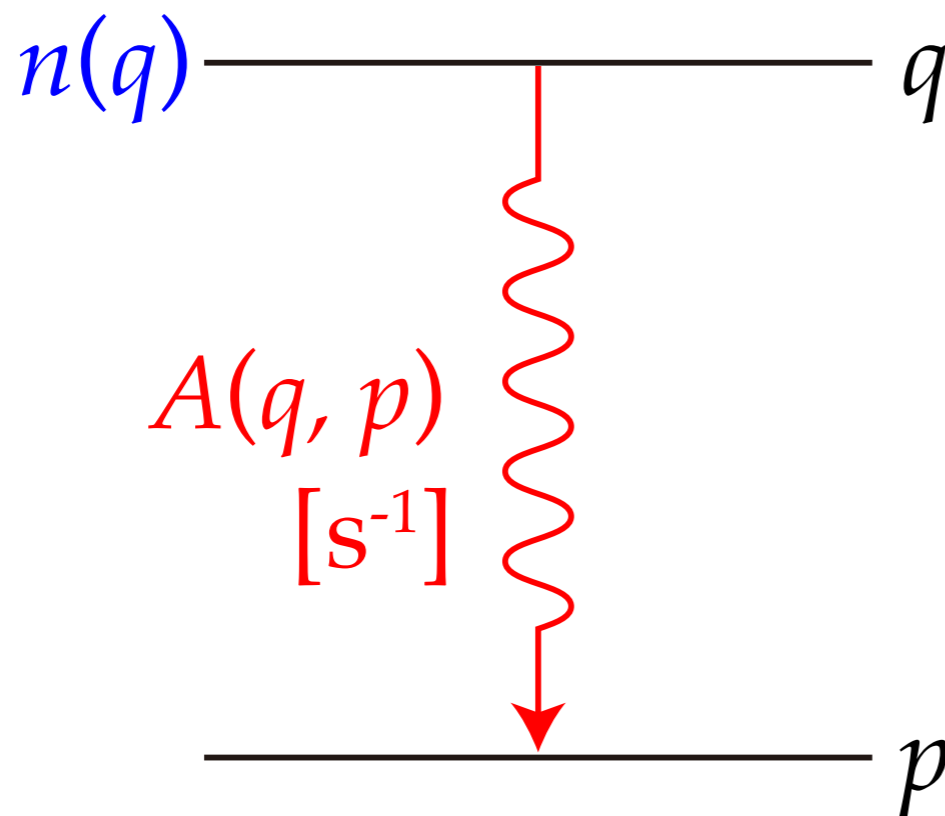
low resolution
measurement

line radiation and energy levels



line intensity

- intensity is the product of **population density** and **spontaneous transition probability** or **Einstein's A coefficient**



$$I_{qp} = n(q)A(q, p)$$
$$[m^{-3}s^{-1}]$$

$$I'_{qp} = I_{qp}h\nu$$
$$[Wm^{-3}]$$

sensitivity calibration

irradiance

$$\eta = \frac{\varepsilon a}{L^2}$$

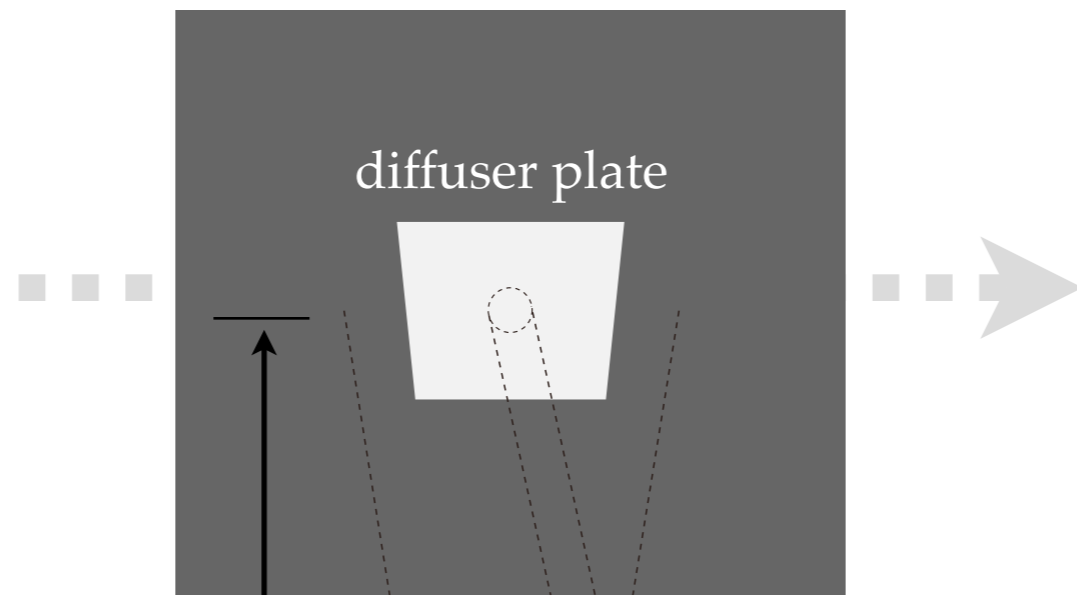
$$[\text{W nm}^{-1} \text{m}^{-2}]$$

radiance

$$\varepsilon' = \frac{\eta}{2\pi} = \frac{\varepsilon a}{2\pi L^2}$$

$$[\text{W sr}^{-1} \text{nm}^{-1} \text{m}^{-2}]$$

ε $[\text{W sr}^{-1} \text{nm}^{-1} \text{m}^{-2}]$
radiance



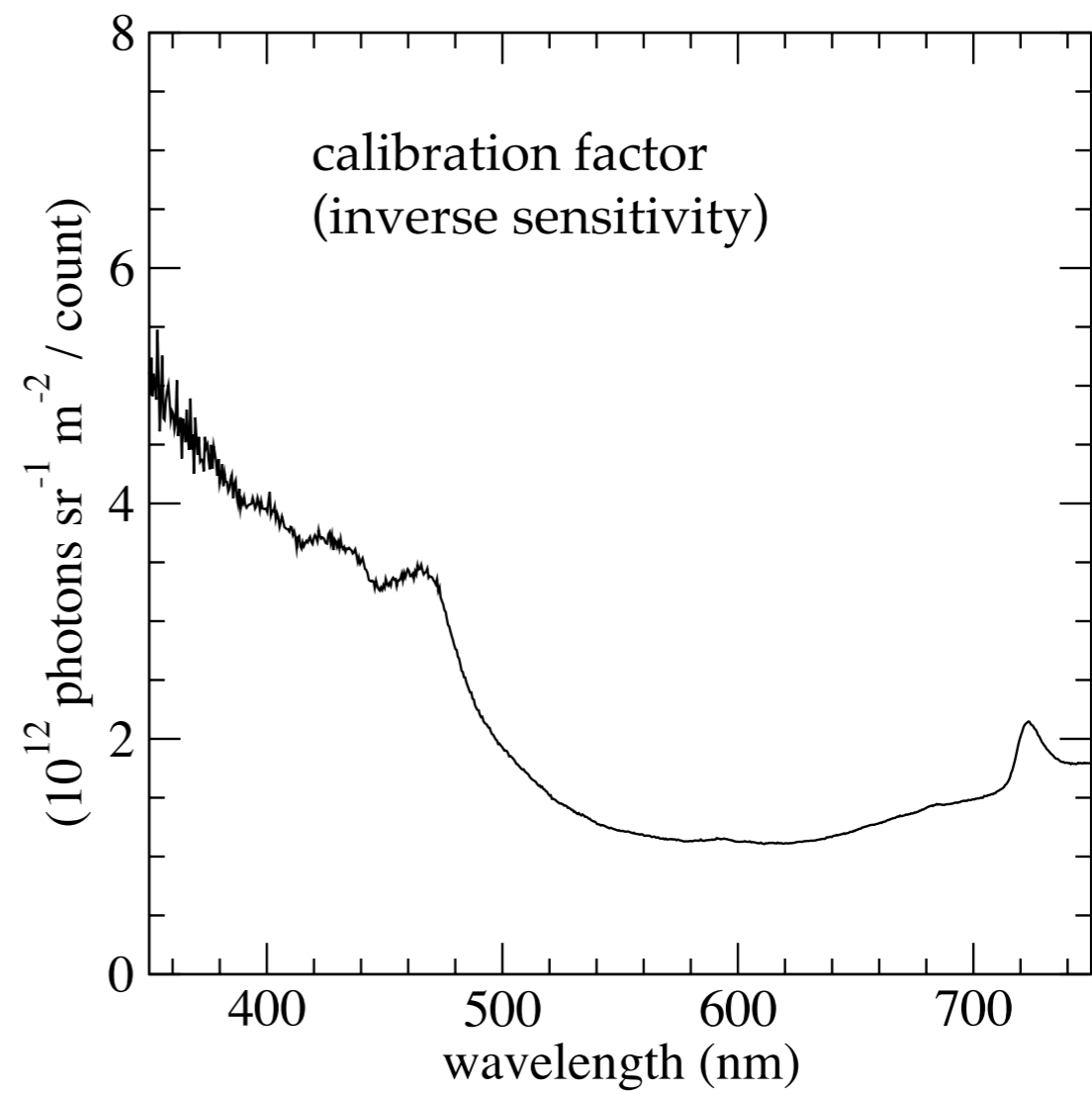
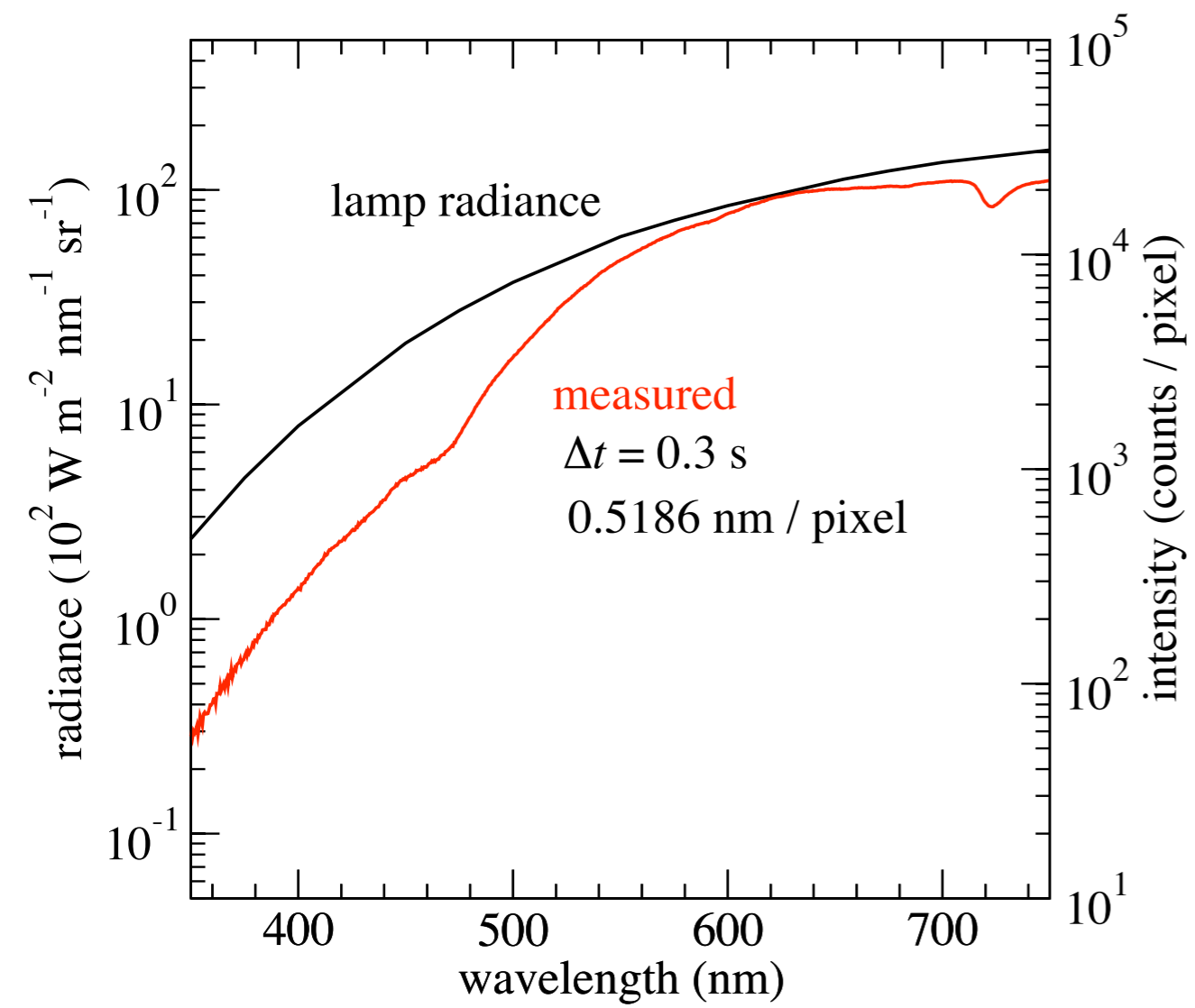
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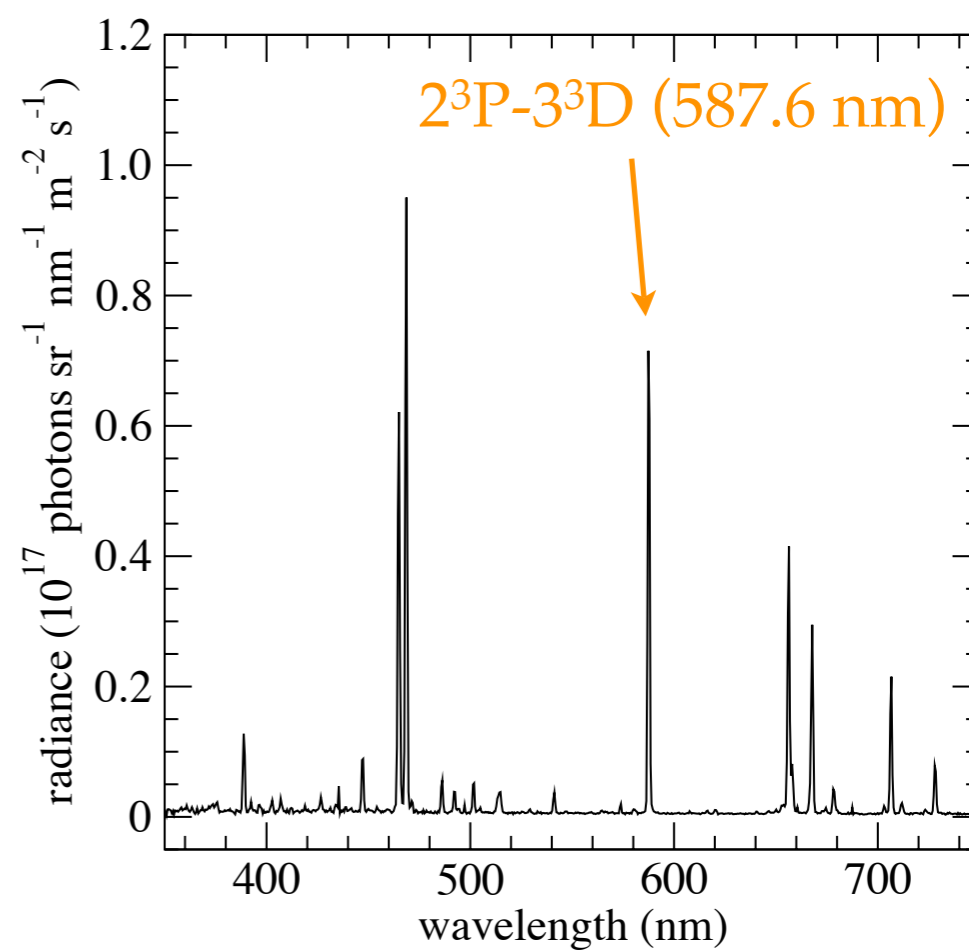
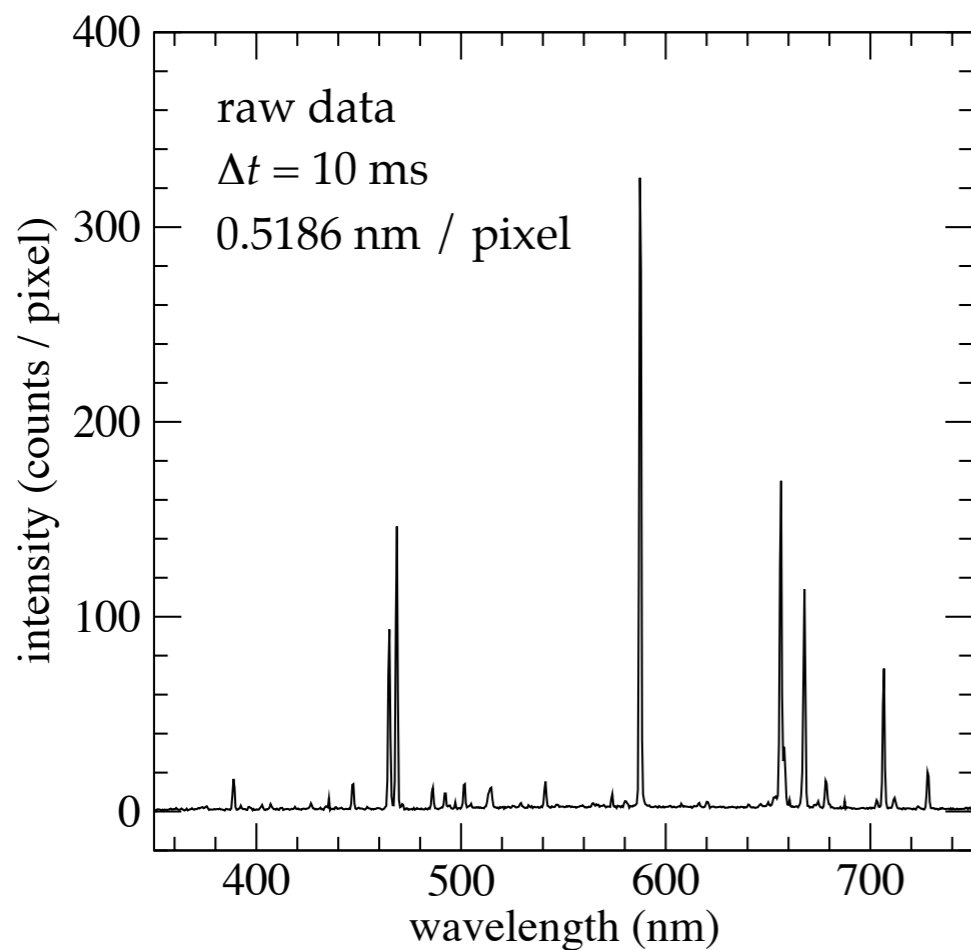
collimator

optical fiber

standard lamp

area of filament a





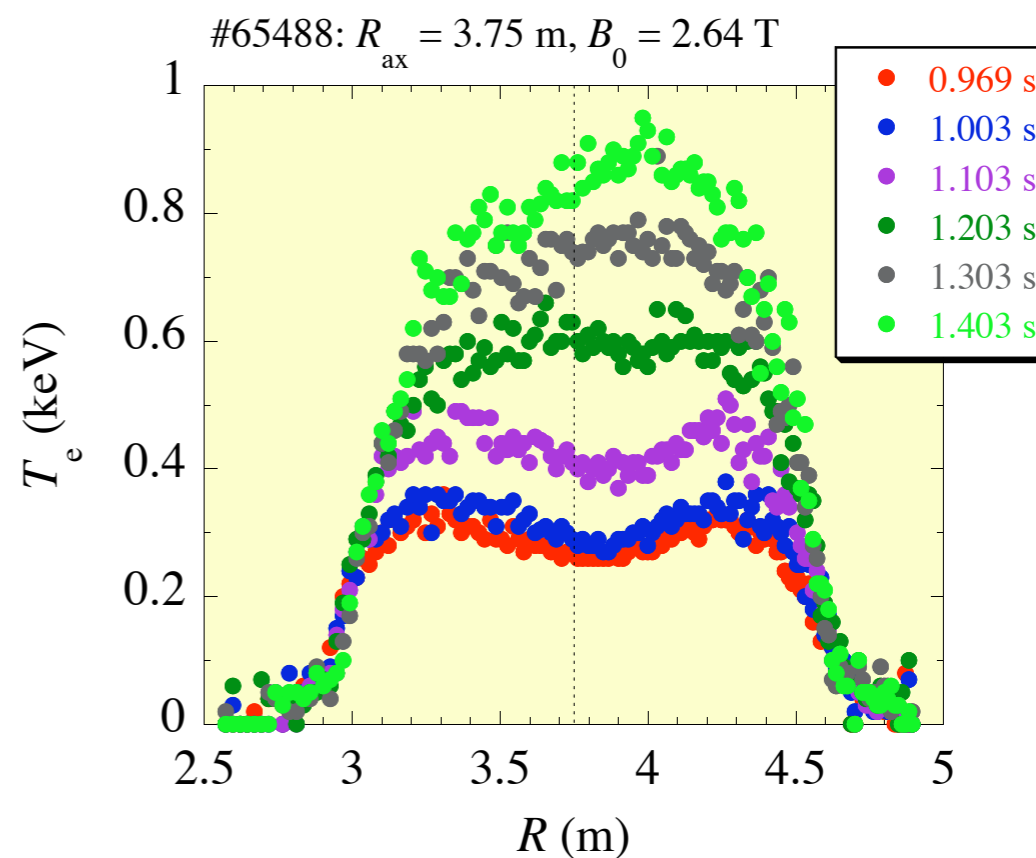
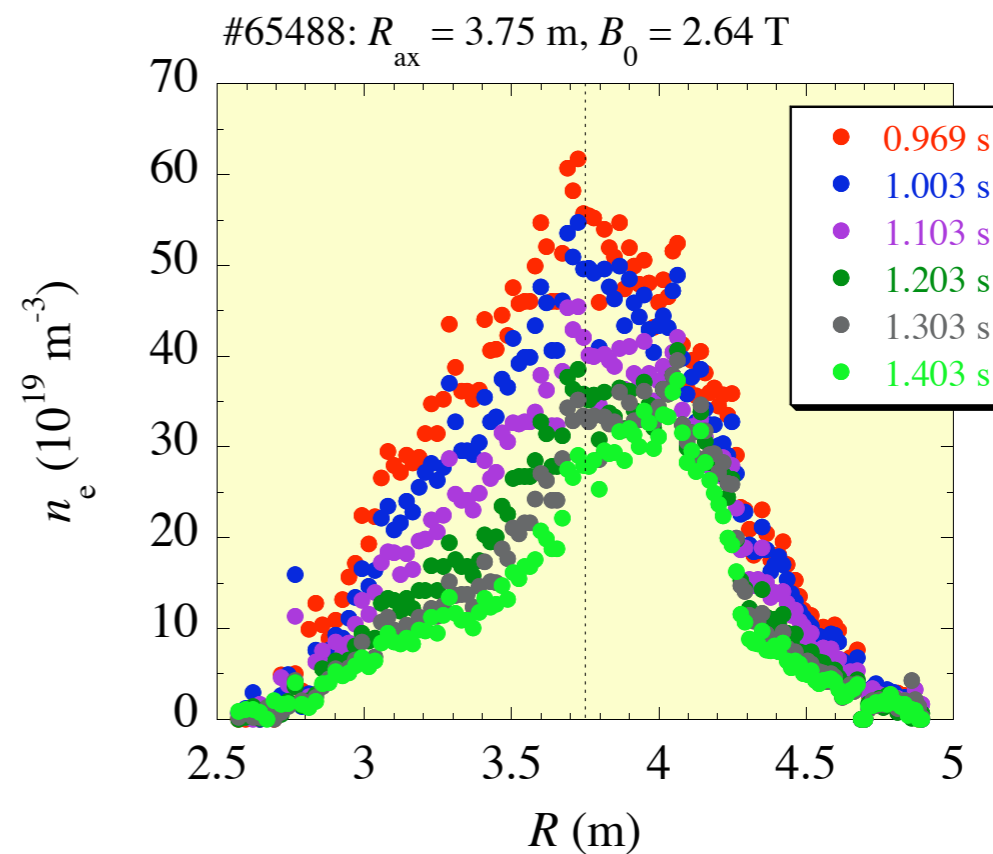
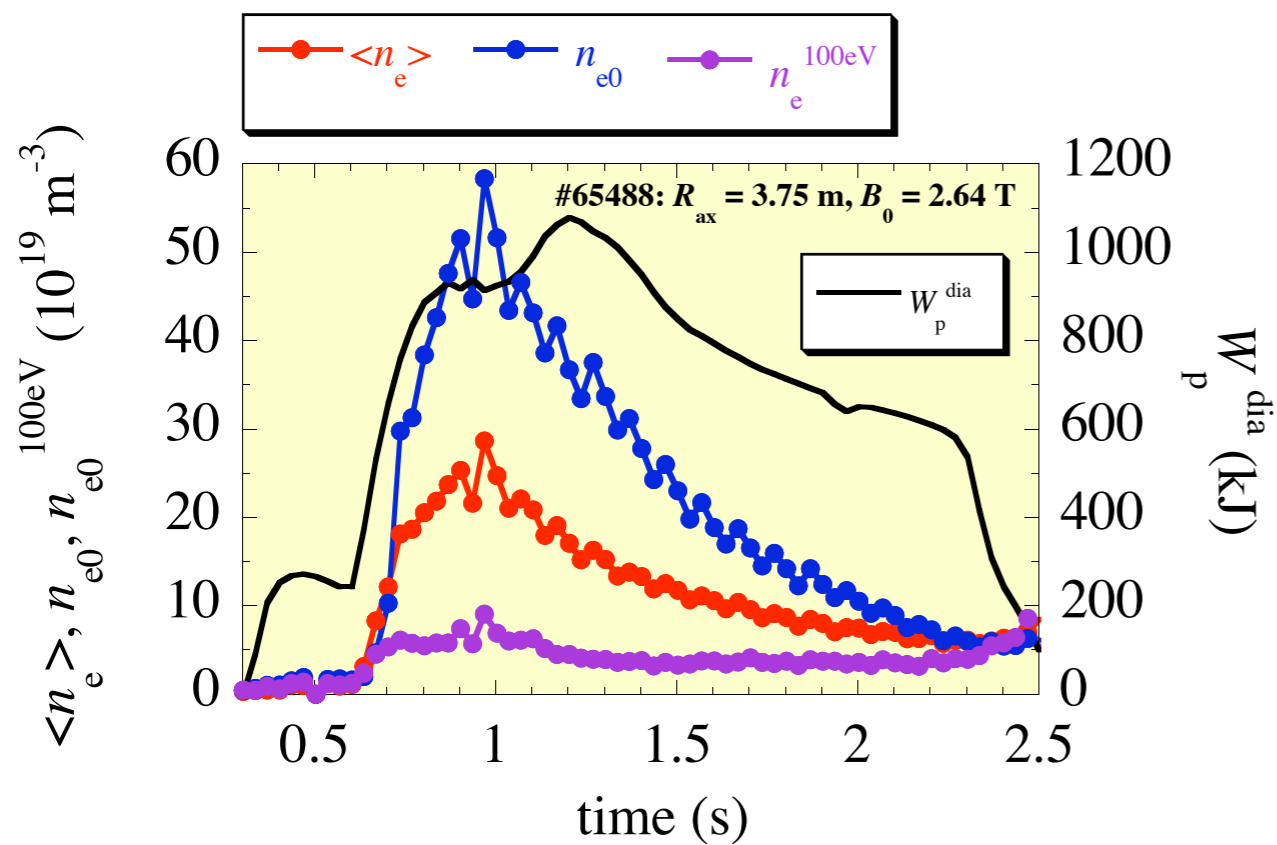
$$\int I(587.6) d\lambda = 1.1 \times 10^{19} \quad [\text{photons m}^{-3} \text{ s}^{-1}]$$

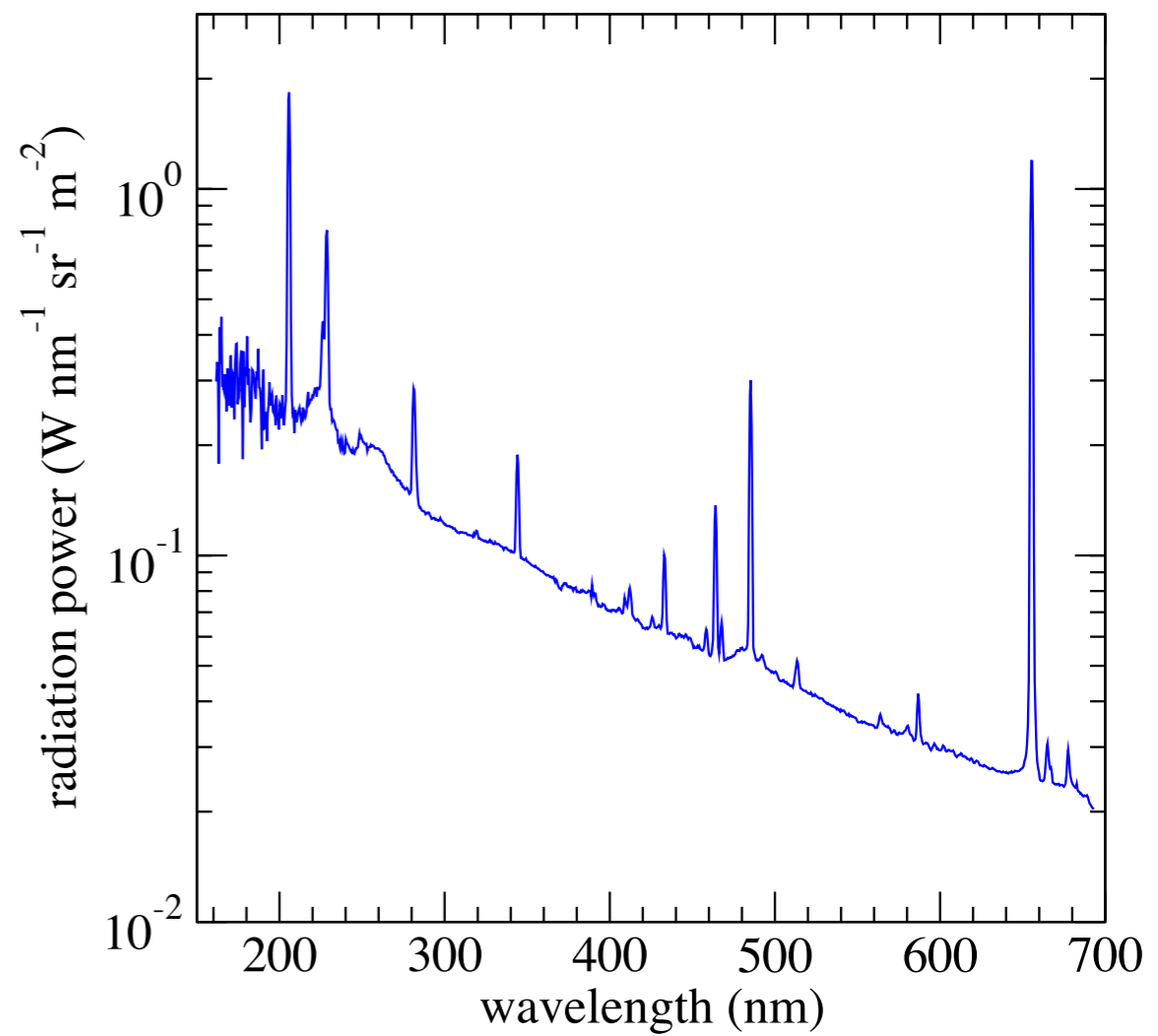
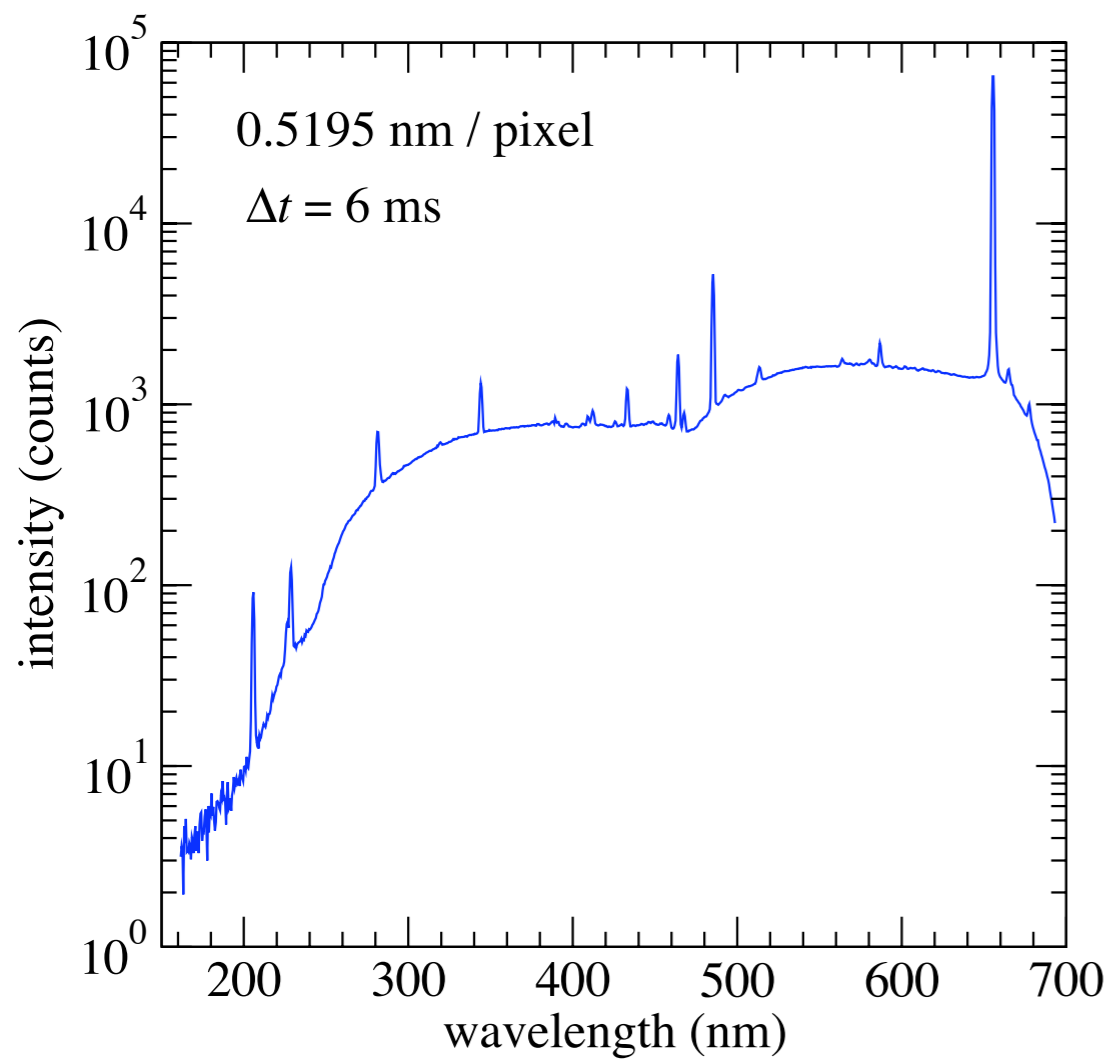
$$A(587.6) = 7.06 \times 10^7 \quad [\text{s}^{-1}]$$

$$n(3^3\text{D}) = 1.6 \times 10^{11} \quad [\text{m}^{-3}]$$

continuum radiation

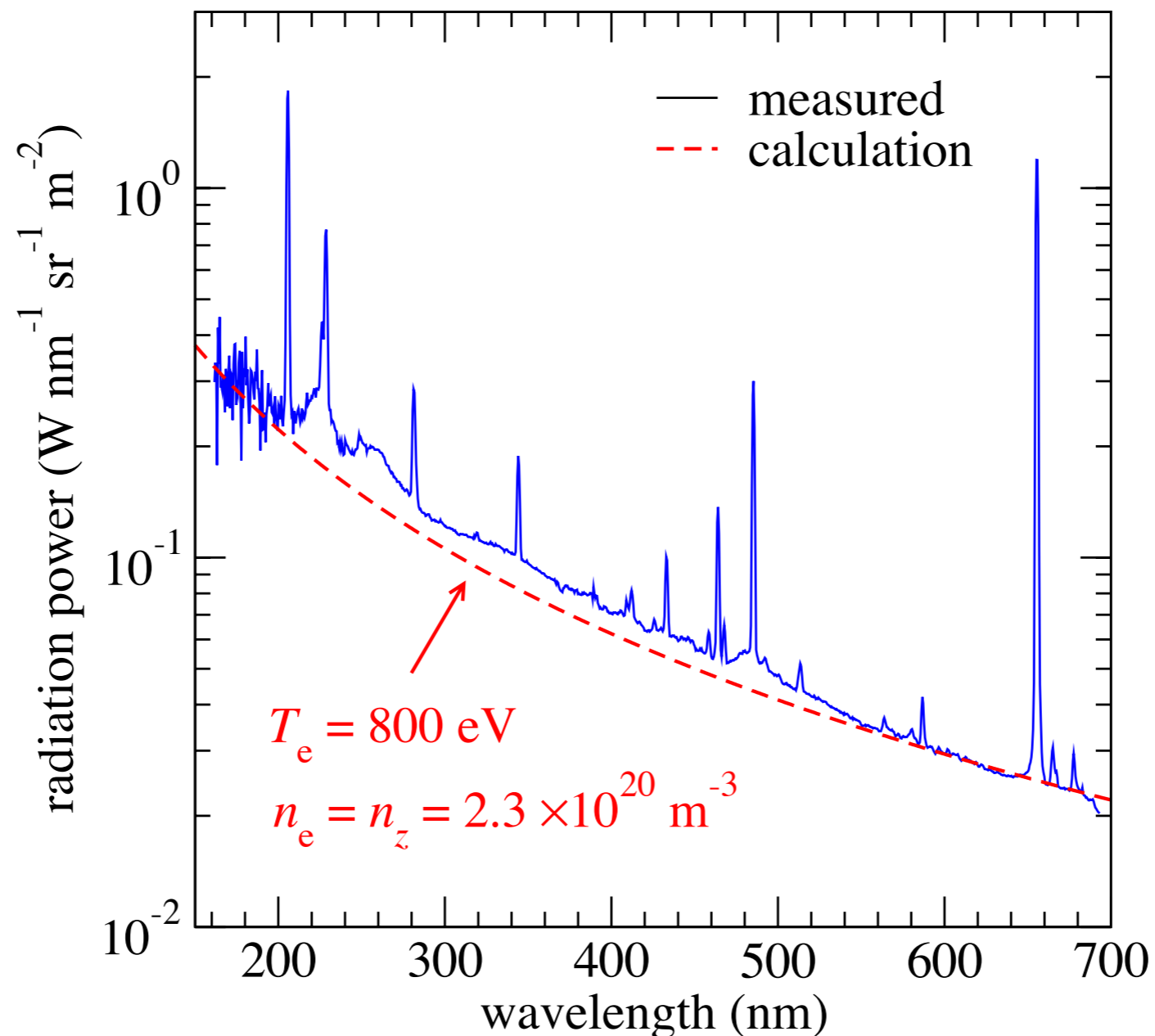
super dense core discharge





Bremsstrahlung

$$P^B(\lambda)d\lambda = \frac{2^6}{3\sqrt{3}} \sqrt{2\pi\alpha h} \left(\frac{a_0 R}{mc}\right)^2 \sqrt{\frac{m}{kT_e}} \exp\left(-\frac{hc/\lambda}{kT_e}\right) \langle g_{ff} \rangle Z^2 n_z n_e \frac{c}{\lambda^2} d\lambda$$

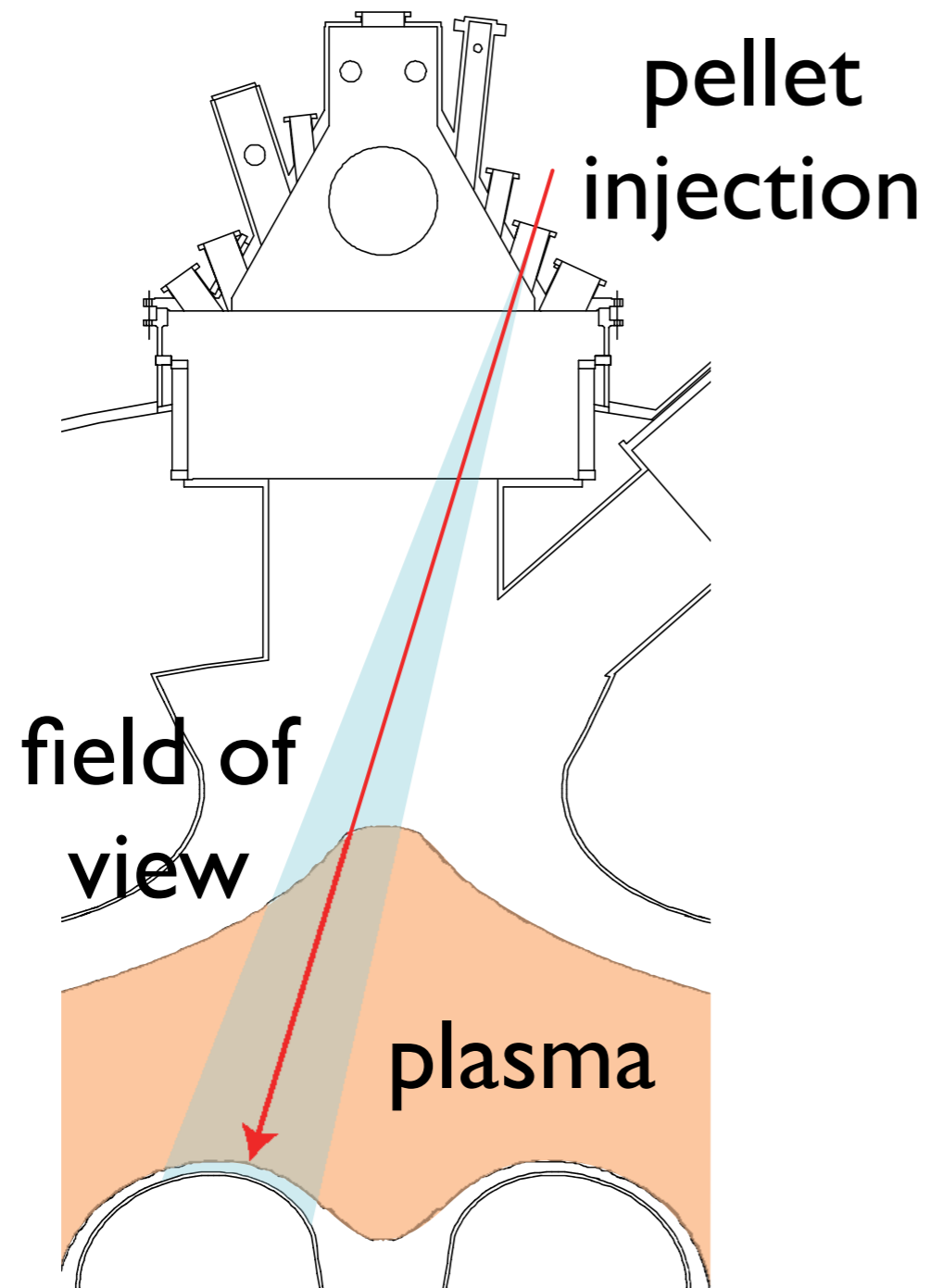


$$Z = 1$$

$$n_z = n_e$$

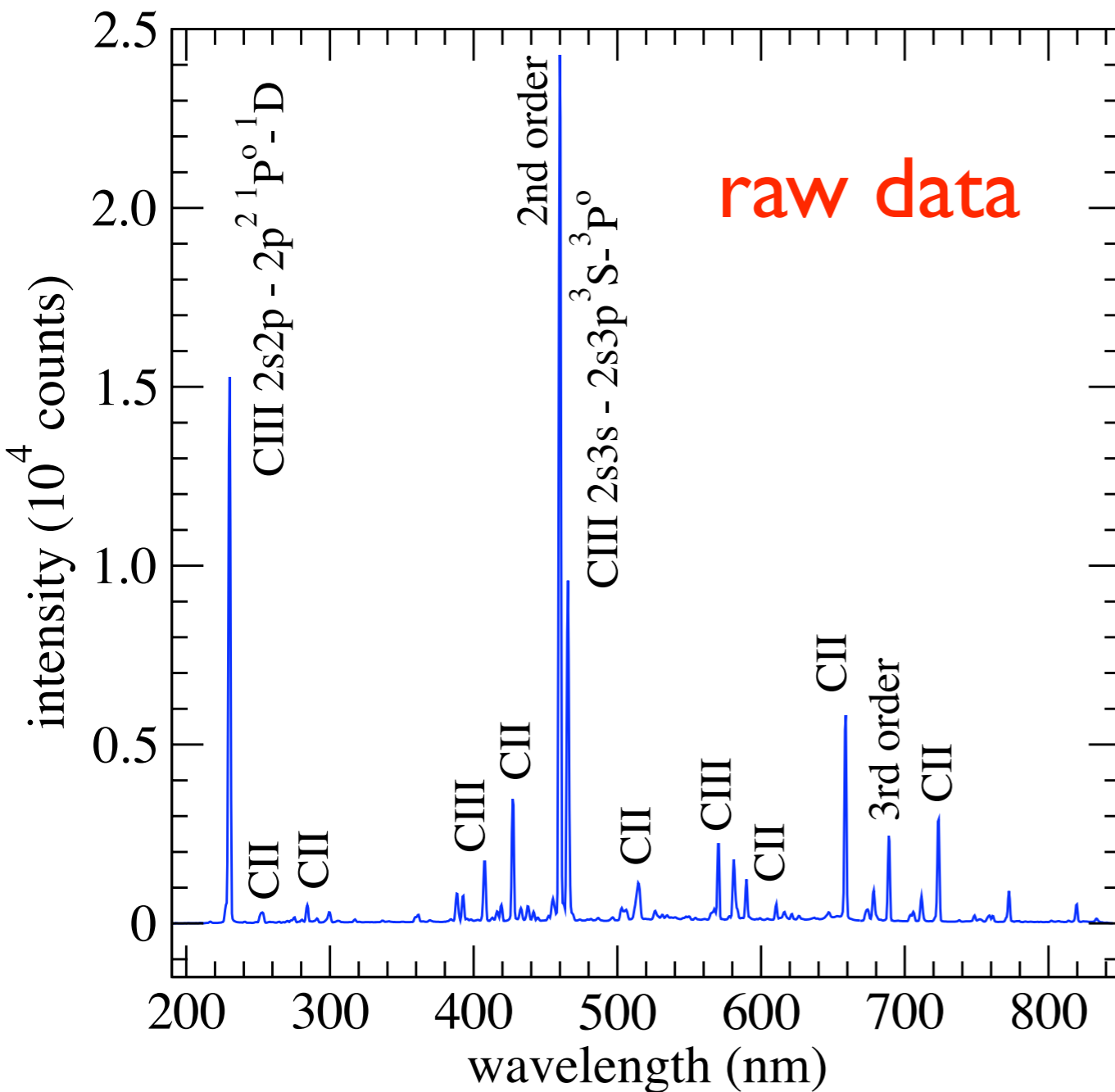
$$L = 1 \text{ m}$$

another high density
plasma — pellet cloud



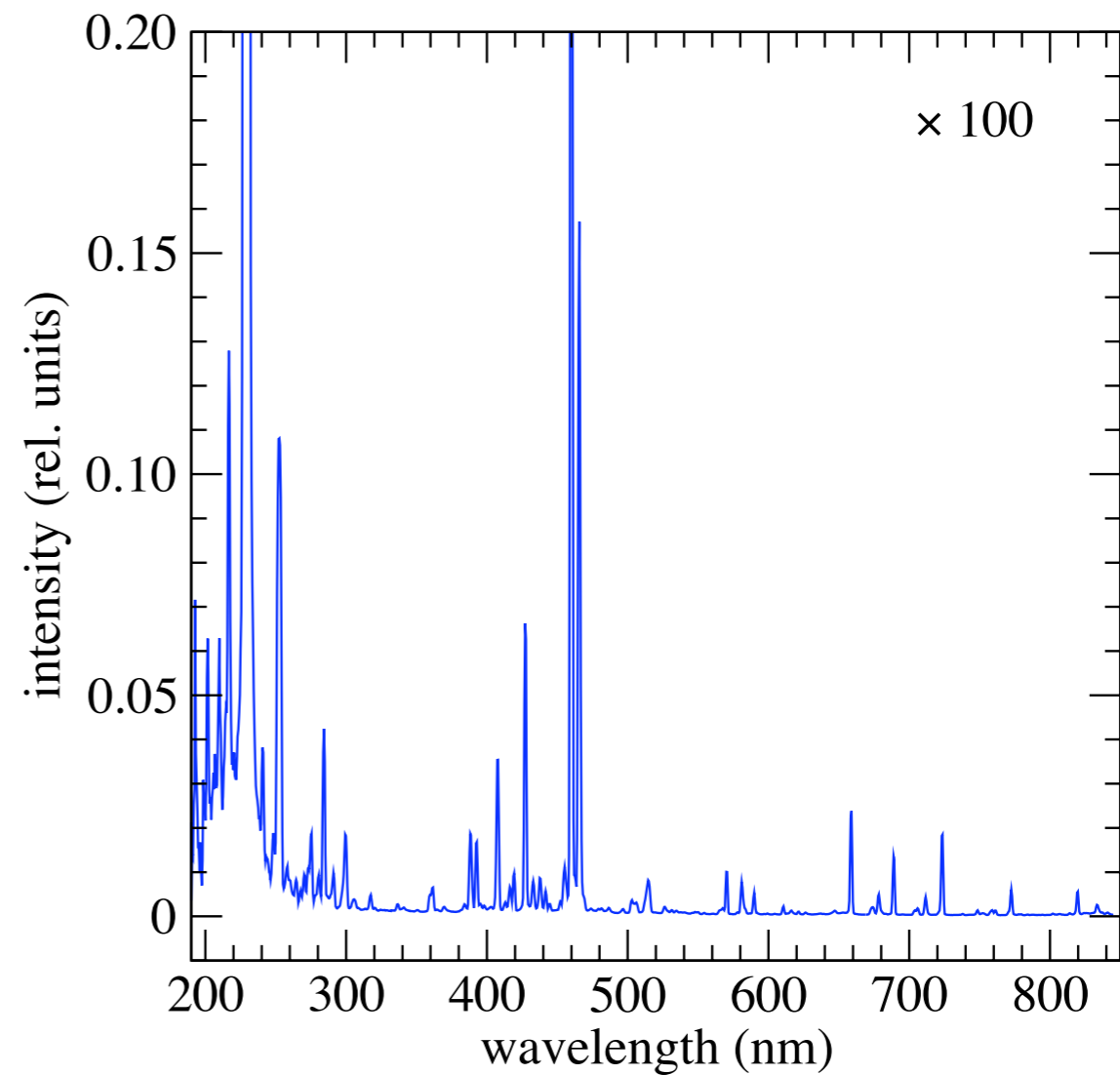
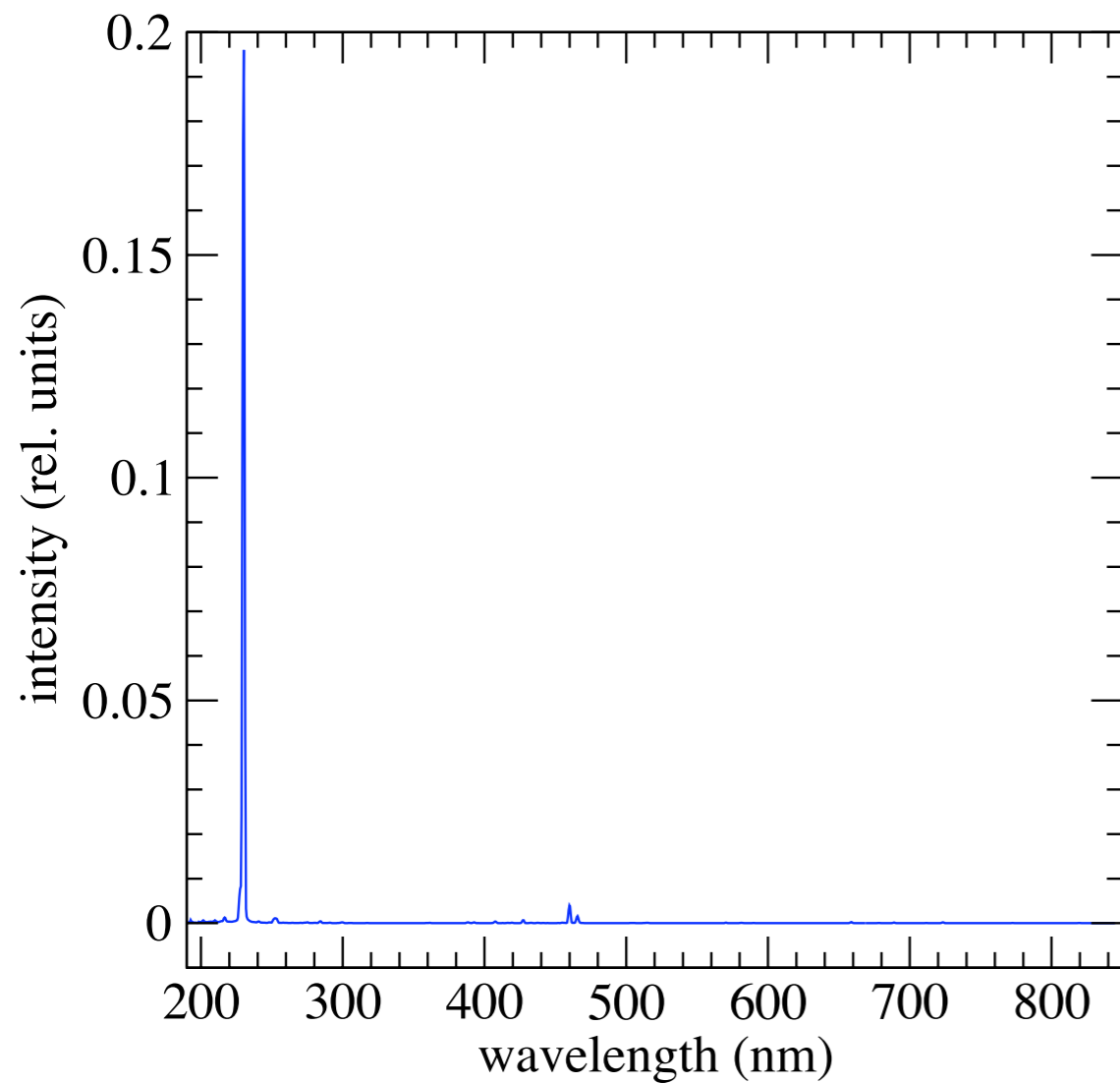
- carbon pellet is injected and the accompanying strong radiation from the cloud is measured
- pellet size is ~ 1 mm and the speed is ~ 200 m/s
- radiation continues several milliseconds and spectra are measured with $100 \mu\text{s}$ of sampling time

pure carbon spectrum



- a strong emission line is observed at around 230 nm
- sensitivity calibration is difficult for the wavelength range shorter than 350 nm

calibrated spectrum

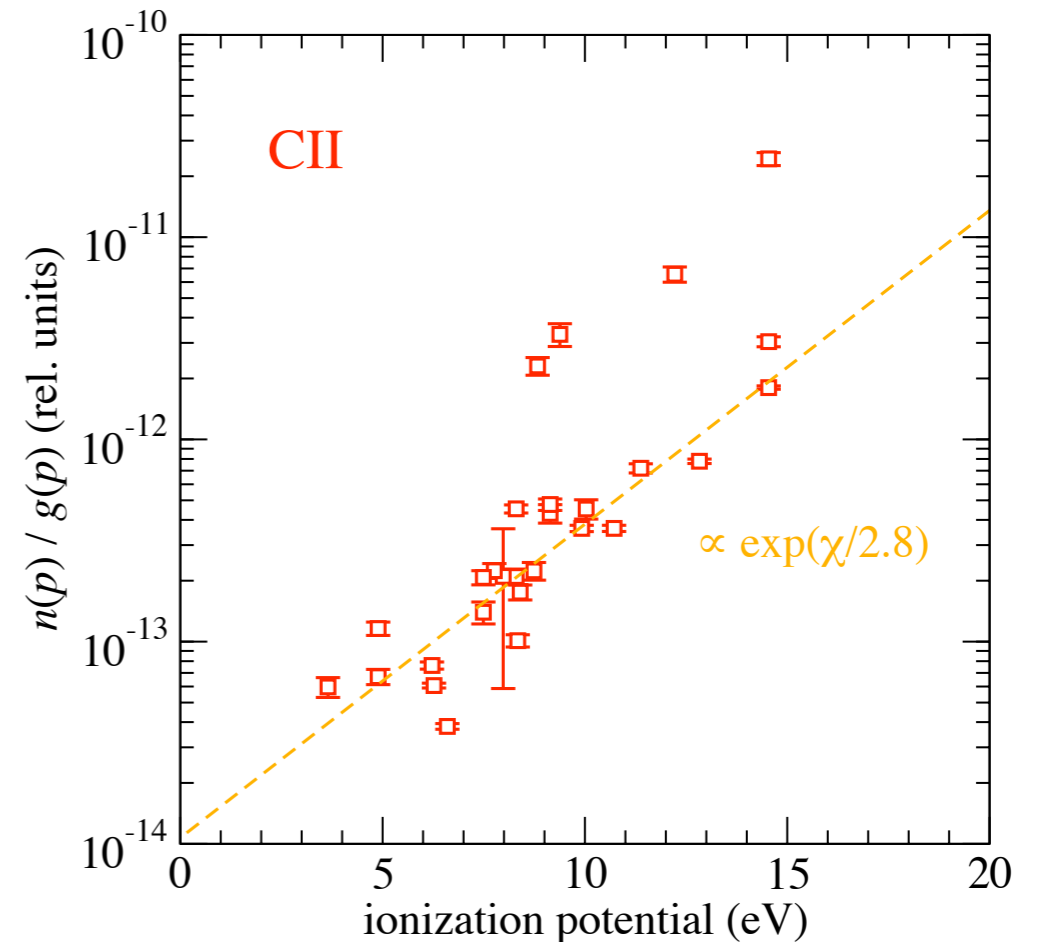
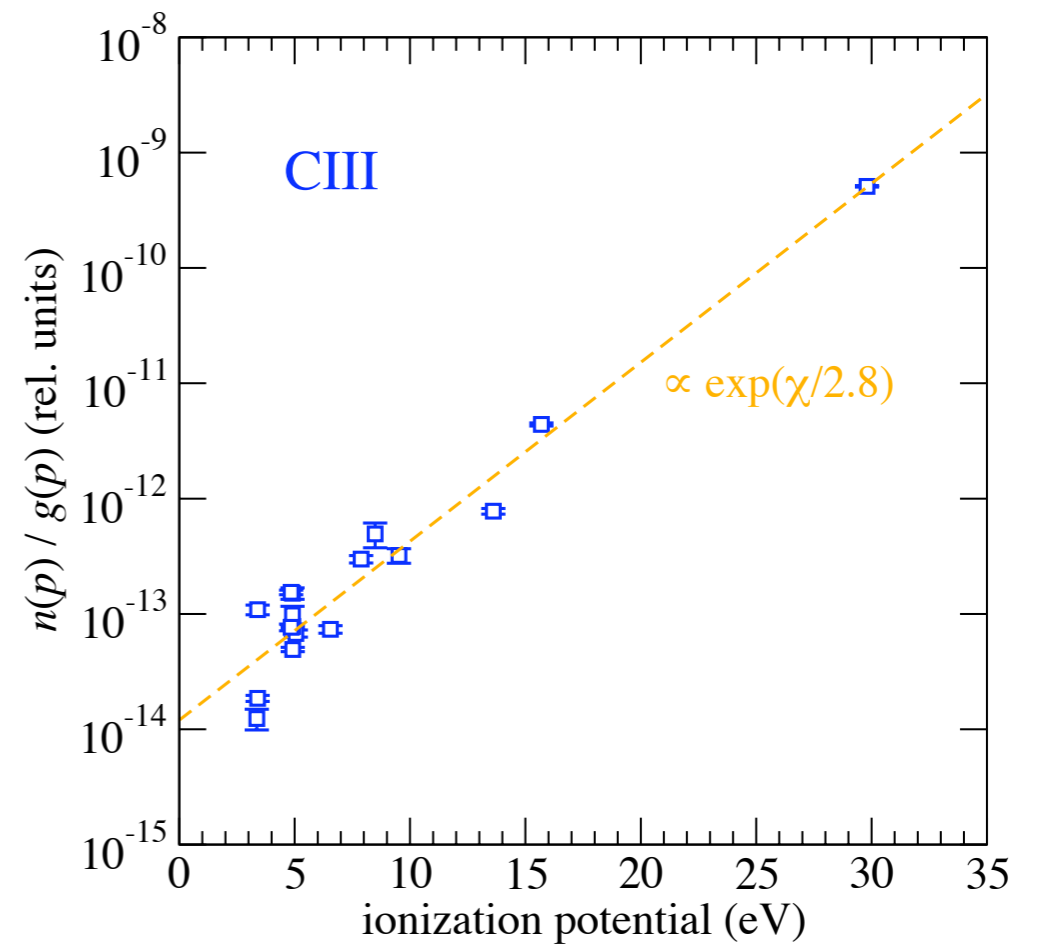


population distribution for CIII and CII ions

if LTE is established,
population is expressed
with **Saha-Boltzmann**
equation

$$\frac{n_{z-1}(p)}{g_{z-1}(p)} = \frac{1}{2g_z(1)} \left(\frac{2\pi m k T_e}{h^2} \right)^{-3/2} \exp\left(\frac{\chi_{z-1}(p)}{k T_e} \right) n_z(1) n_e$$

$T_e = 2.8$ eV is inferred

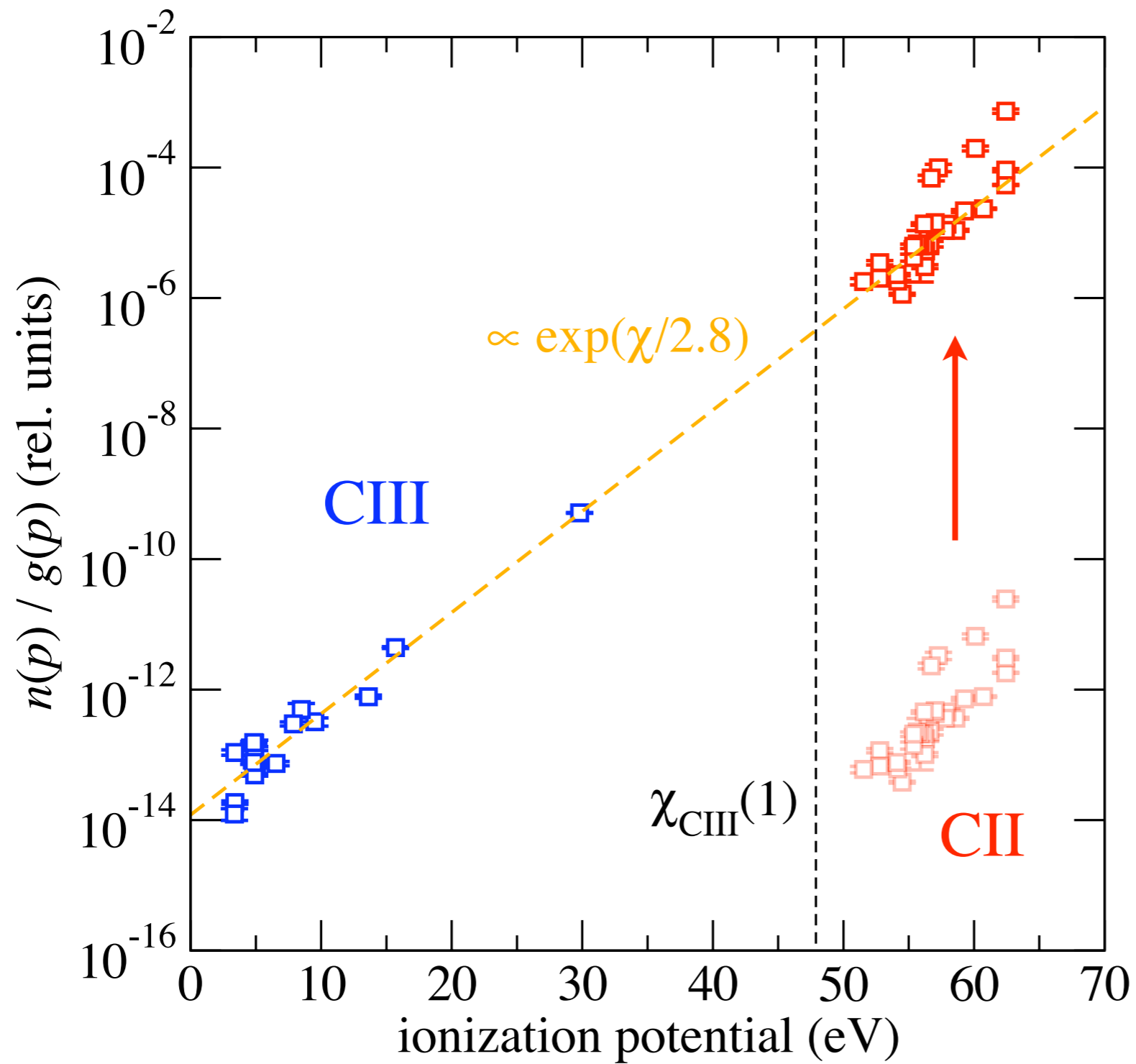


under complete LTE condition
populations of CIII and CII are respectively
determined as

$$\frac{n_{2+}}{g_{2+}(p)} = \frac{1}{2g_{3+}} \left(\frac{h^2}{2\pi mkT_e} \right)^{3/2} \exp \left[\frac{\chi_{2+}(p)}{kT_e} \right] n_e n_{3+}(1)$$

$$\frac{n_{1+}}{g_{1+}(p)} \left[\frac{2}{n_e} \left(\frac{h^2}{2\pi mkT_e} \right)^{-3/2} \right] = \frac{1}{2g_{3+}} \left(\frac{h^2}{2\pi mkT_e} \right)^{3/2} \exp \left[\frac{\chi_{1+}(p) + \chi_{2+}(1)}{kT_e} \right] n_e n_{3+}(1)$$

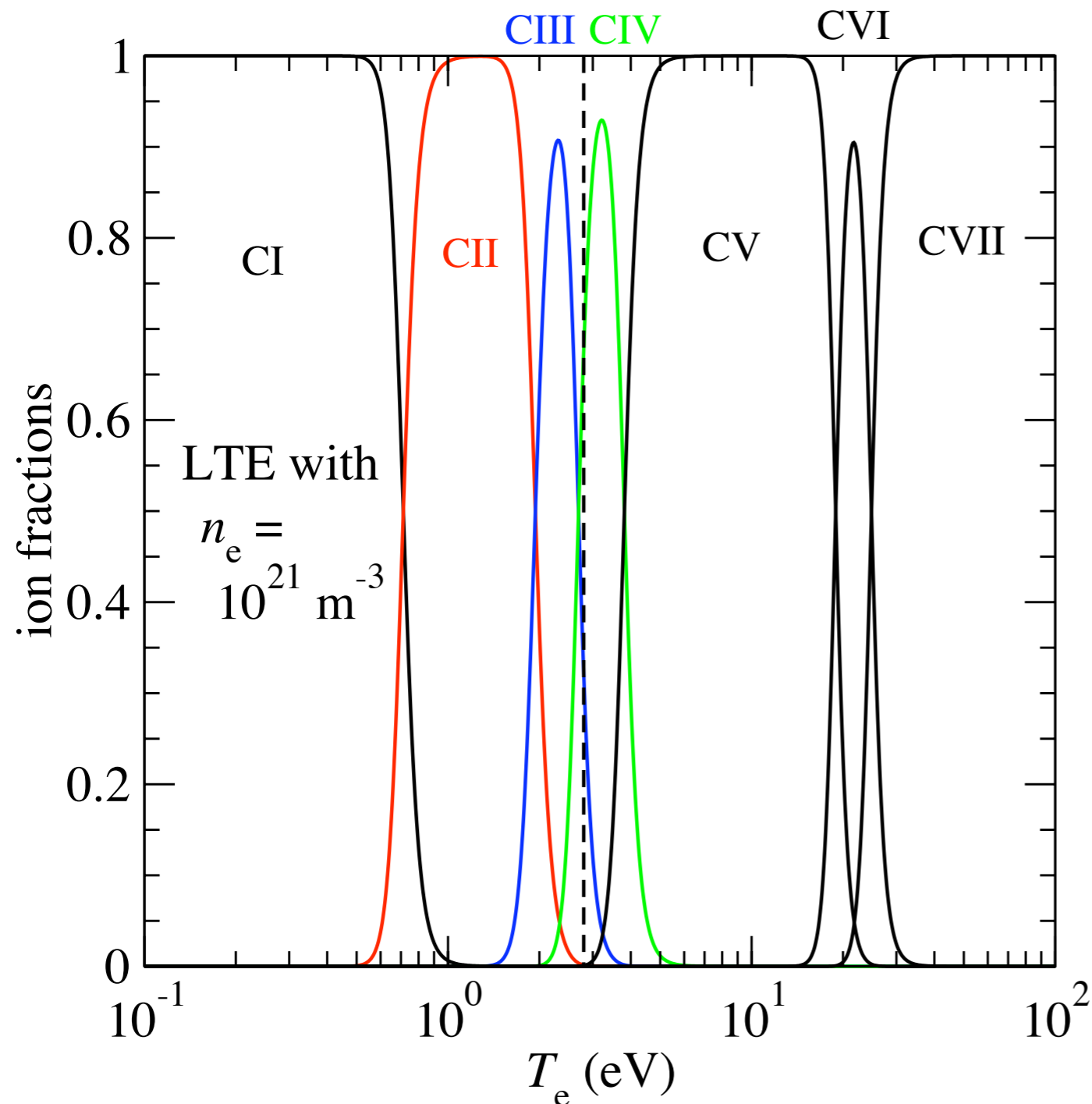
the points on the Boltzmann-plot should appear
on the same line



$$\times \frac{2}{n_e} \left(\frac{h^2}{2\pi m k T_e} \right)^{-3/2}$$

$$n_e = 9.4 \times 10^{20} \text{ m}^{-3}$$

ion abundances



- it is understandable that C II and C III lines are dominantly observed