Code comparison: Problem 1

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Lawrence Livermore National Laboratory
EUV Litho, Inc.

Atomic kinetics of tin plasmas

Problem 1

This problem explores the atomic kinetics of tin under conditions relevant for EUV production.

Participants were asked to compute the charge state distribution, absorptivity, emissivity, **spectral purity**, internal energy density and radiative power losses for cases shown below:

ID	1	2	3	4	5	6	7
T_e	10	15	20	25	30	35	40
N_e	10^{19}						

Critical electron density for CO_2 laser light

ID	8	9	10	11	12	13	14	15	16
T_e	20	25	30	35	40	45	50	55	60
N_e	10^{20}								

ID	17	18	19	20	21	22	23	24	25
T_e	20	25	30	35	40	45	50	55	60
N_e	10^{21}								

Critical electron density for Nd:YAG laser light

Participants

We received **10** submissions for problem 1

Name	Institution	Code	non-LTE	LTE
Akira Sasaki	National Institute for Quantum and Radiological Sciences	**JATOM**		
Howard Scott	Lawrence Livermore National Laboratory	**Cretin**	**x 3**	
Ilya Vichev	Keldysh Institute for Applied Mathematics	**THERMOS**		
Igor Golovkin	Prism Computational Sciences	**PrismSPECT**		
John Sheil	Advanced Research Center for Nanolithography	**ATOMIC**		
Hilik Frank	Lawrence Livermore National Laboratory	**SEMILLAC**		

- Compare key quantities (average charge state, spectral purity, etc.) for each electron density group.
- Global comparison of internal energy density and radiative power losses.

ID	1	2	3	4	5	6	7
T_e	10	15	20	25	30	35	40
N_e	10^{19}						

ID	8	9	10	11	12	13	14	15	16
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ID	17	18	19	20	21	22	23	24	25
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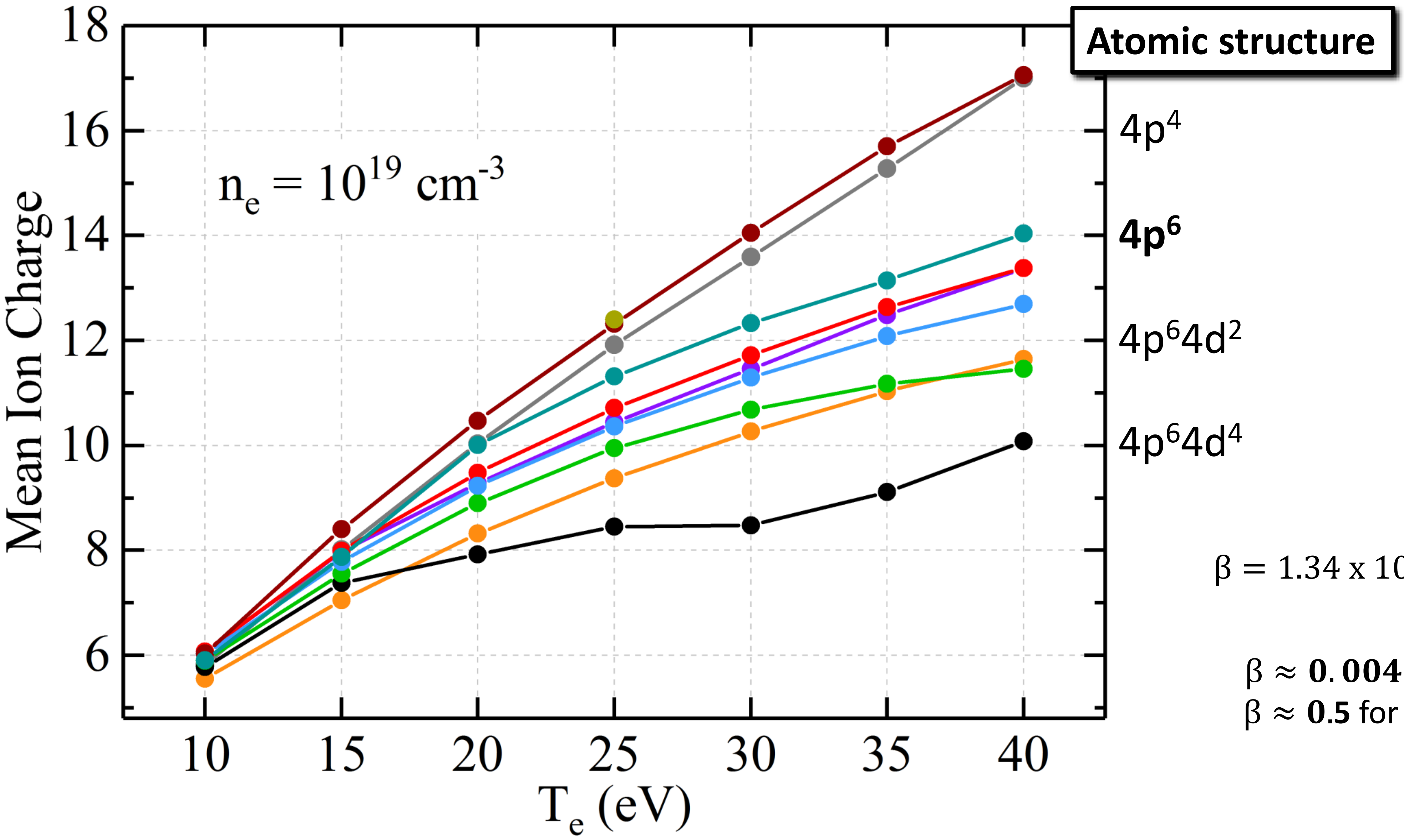
N_e	10^{21}								

$$n_e = 10^{19}\ cm^{-3}$$

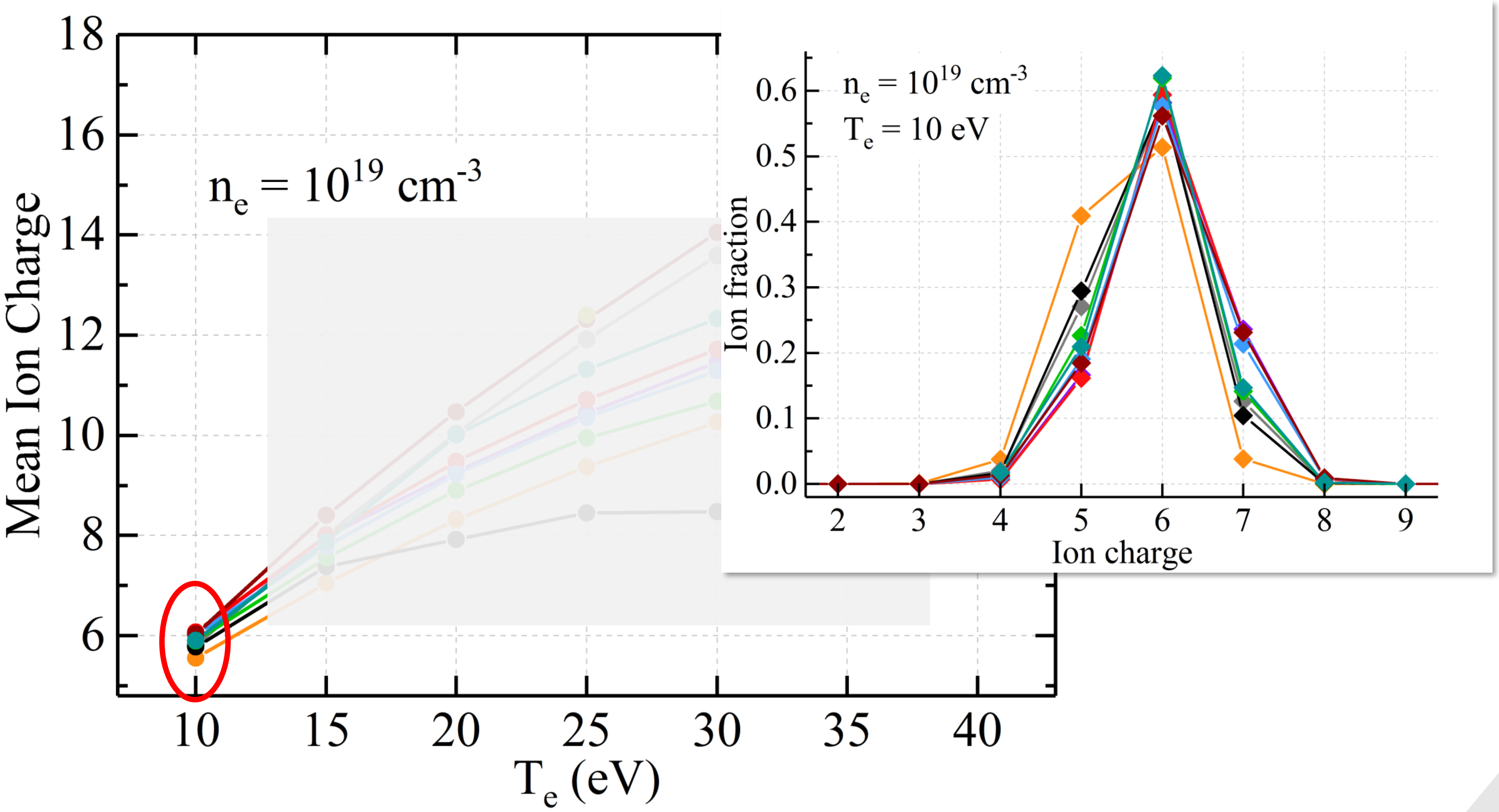
$n_e = 10^{19}$ cm^{-3}: Mean charge state



$\beta = 1.34 \times 10^{13} \frac{T_e^{7/2}}{n_e} \ll 1$ for LTE conditions

$\beta \approx \mathbf{0.004}$ for $T_e = 10$ eV
$\beta \approx \mathbf{0.5}$ for $T_e = 40$ eV

$n_e = 10^{19}$ cm^{-3}: Ion fraction



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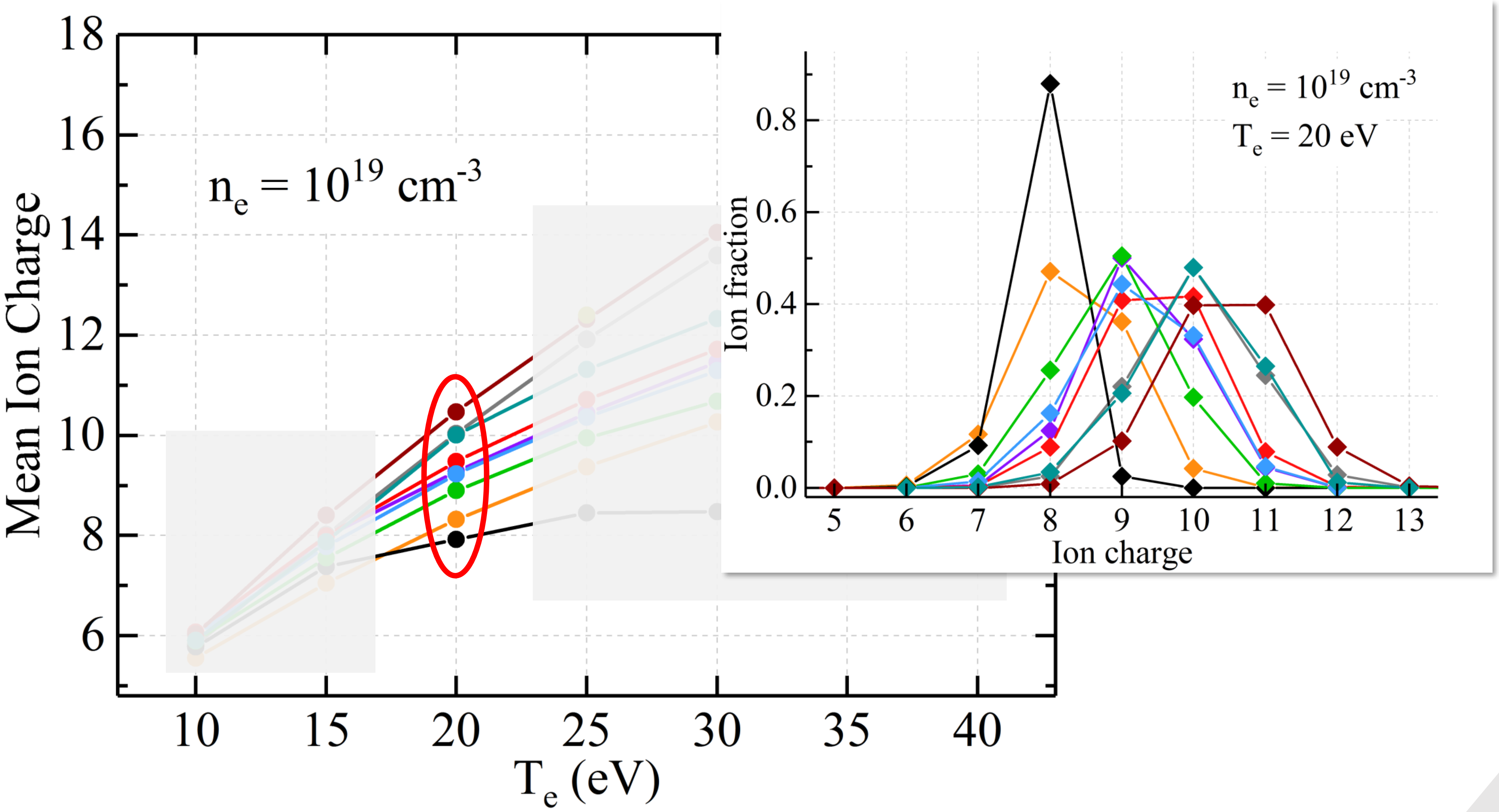

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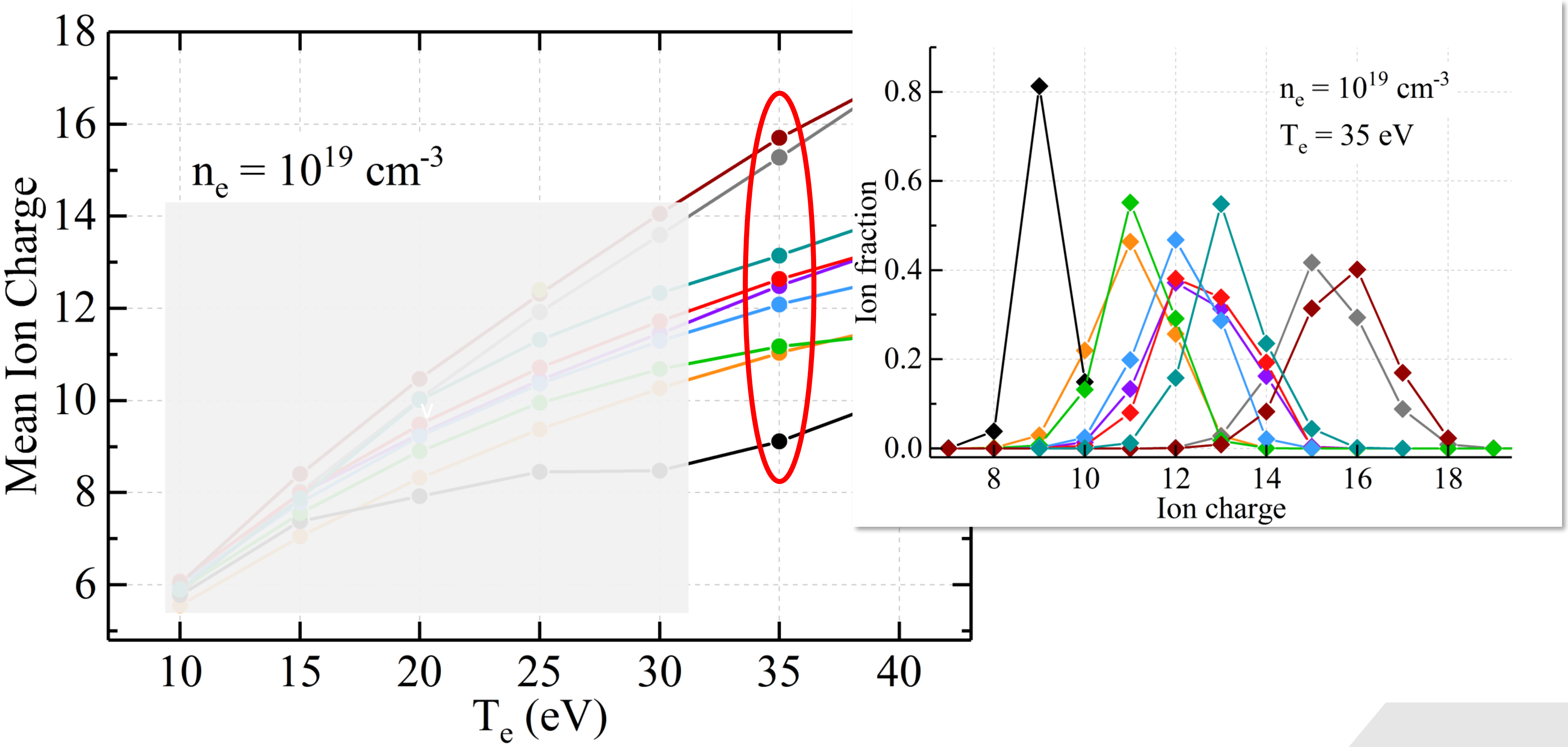
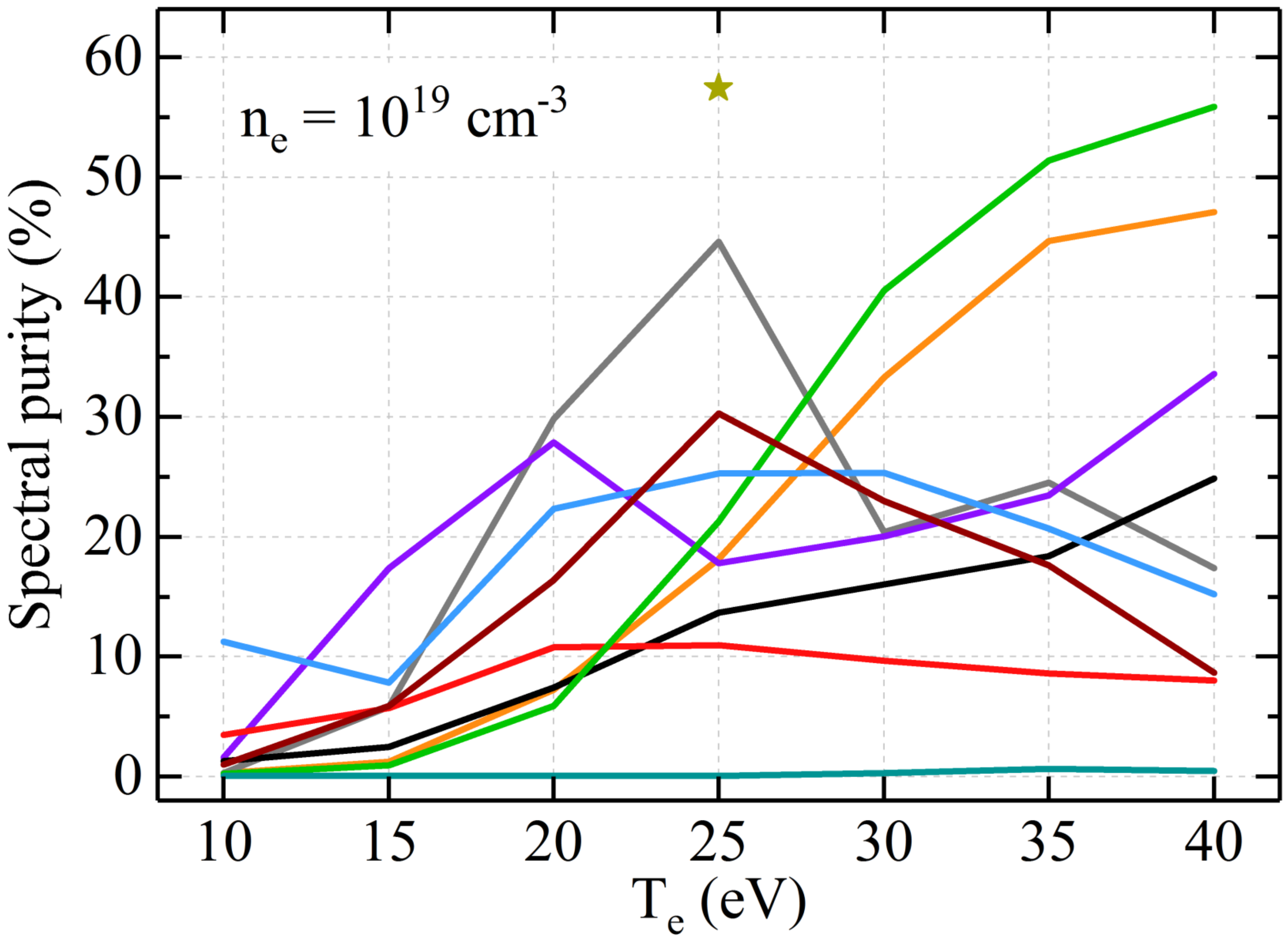
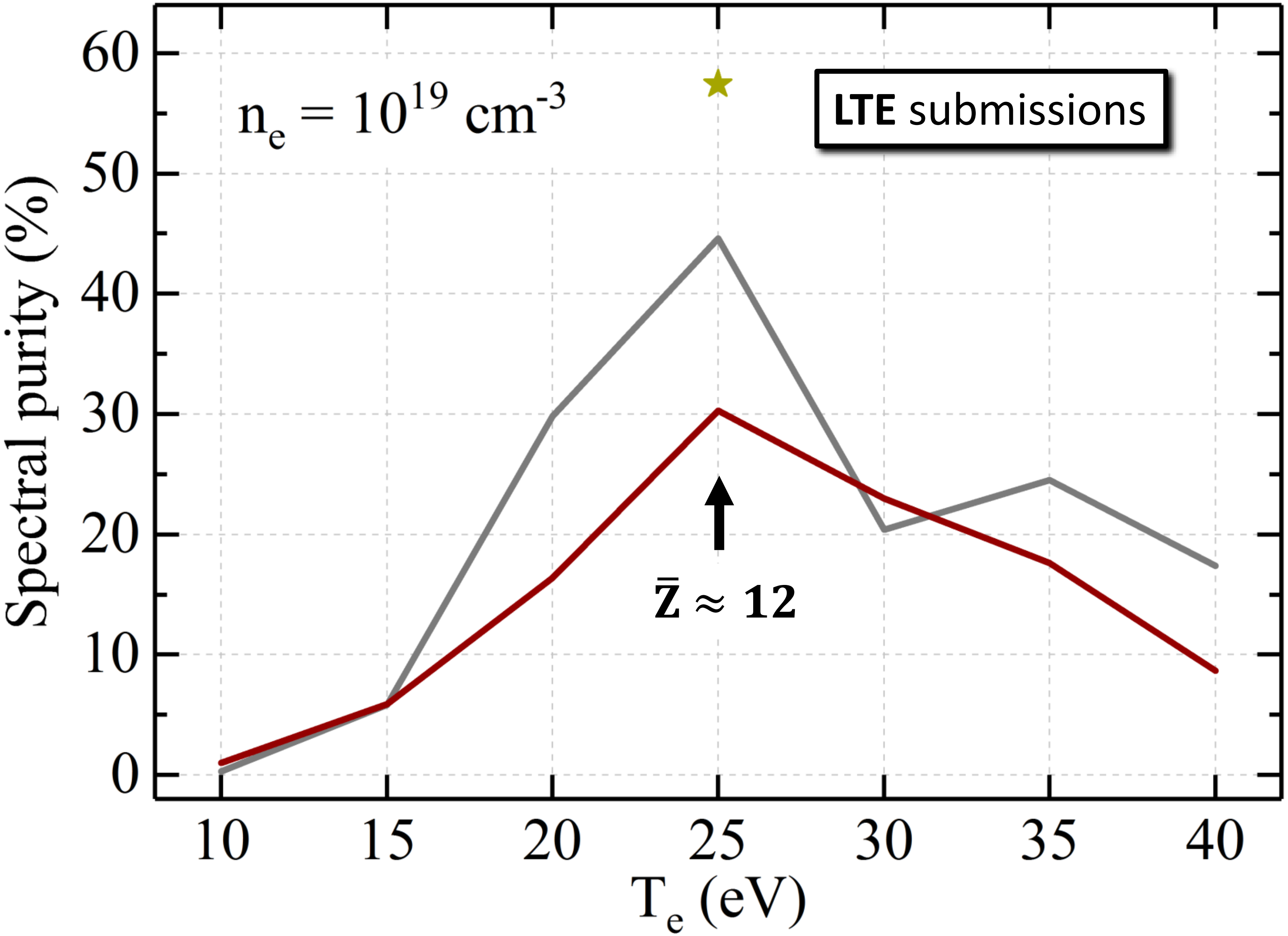


$n_e = 10^{19}$ cm^{-3}: Spectral purity



$$\text{Spectral purity} = \frac{\int_{13.365}^{13.635} \eta_\lambda d\lambda}{\int_5^{20} \eta_\lambda d\lambda}$$

$n_e = 10^{19}$ cm^{-3}: Spectral purity



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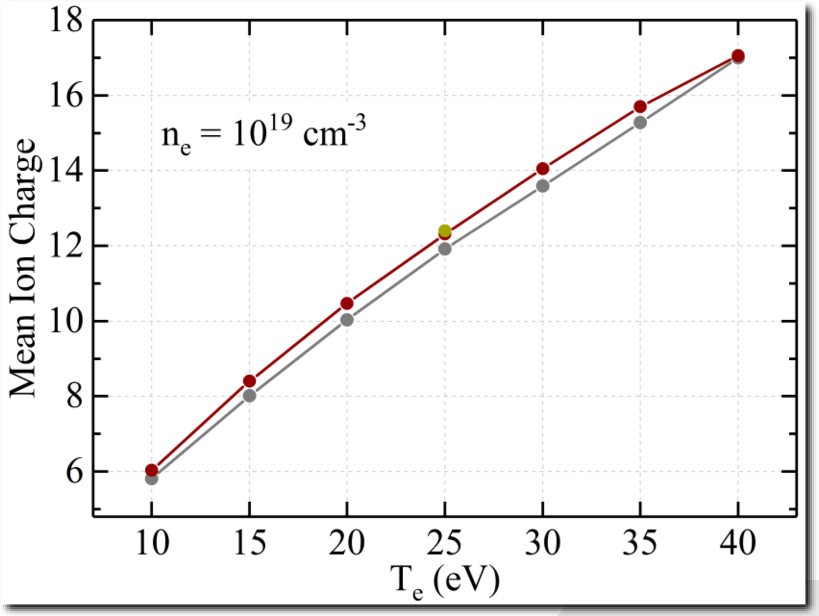
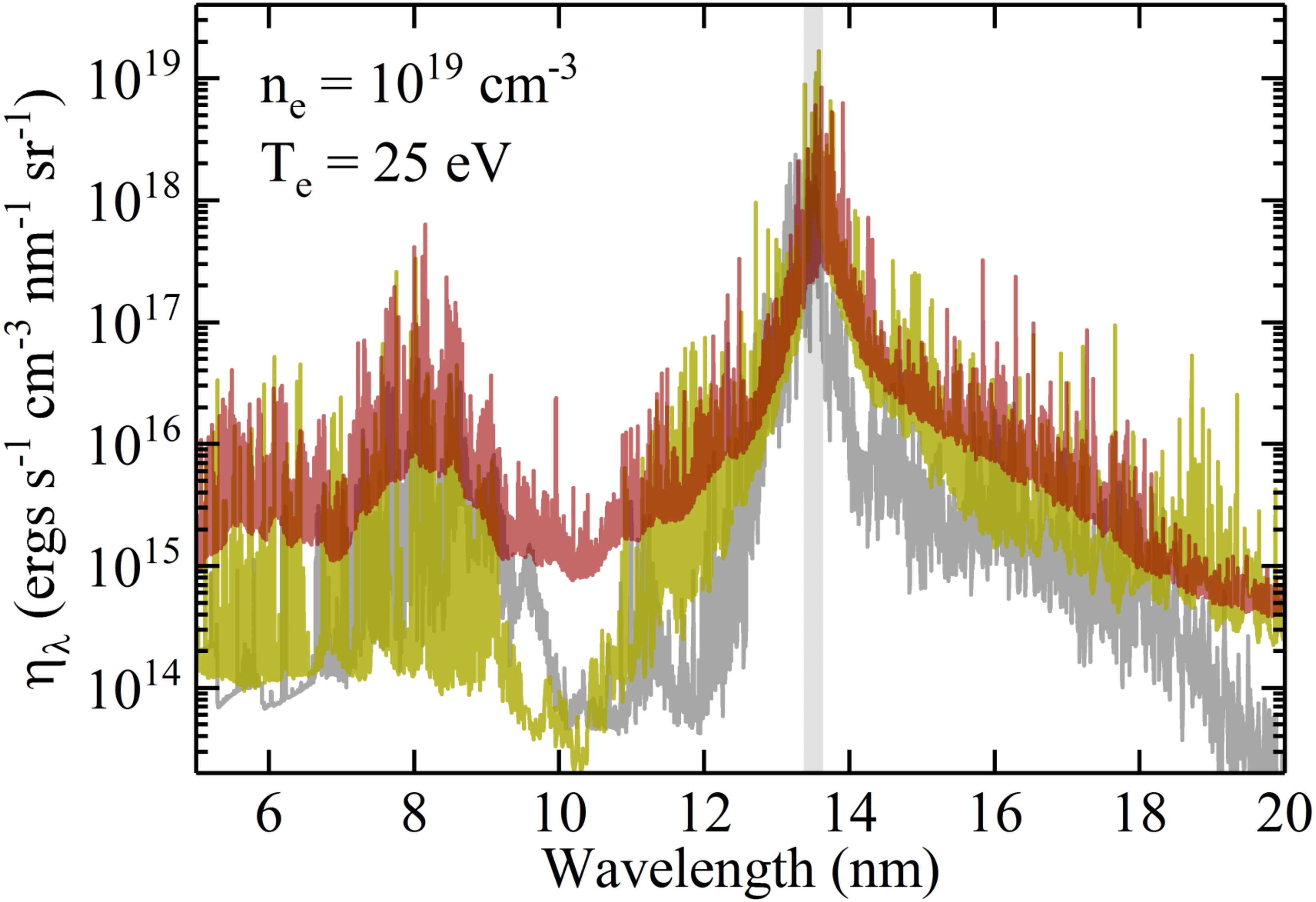
Peak in SP when $\bar{Z} \approx 12$



$n_e = 10^{19}$ cm^{-3}: Emissivity



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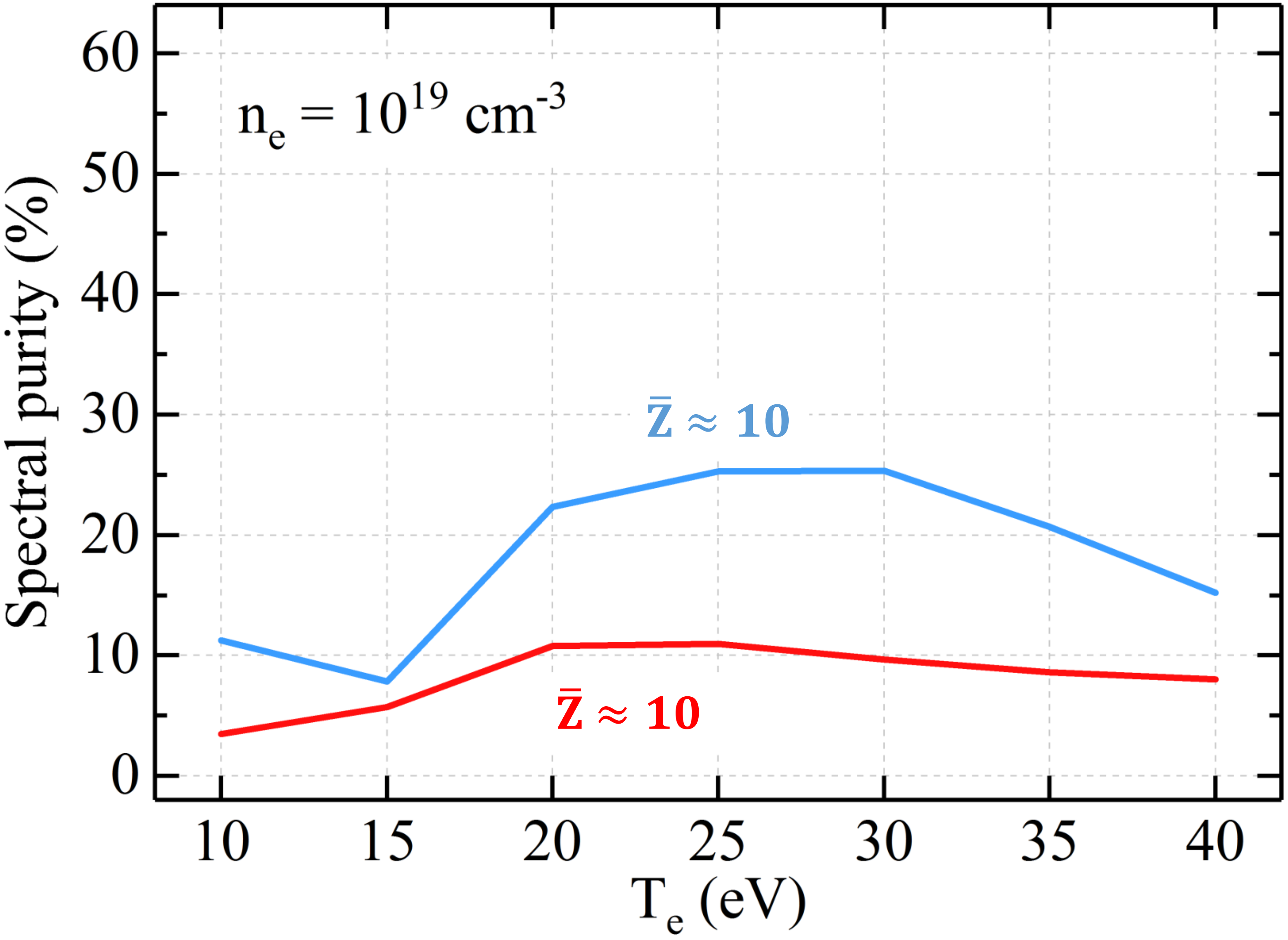

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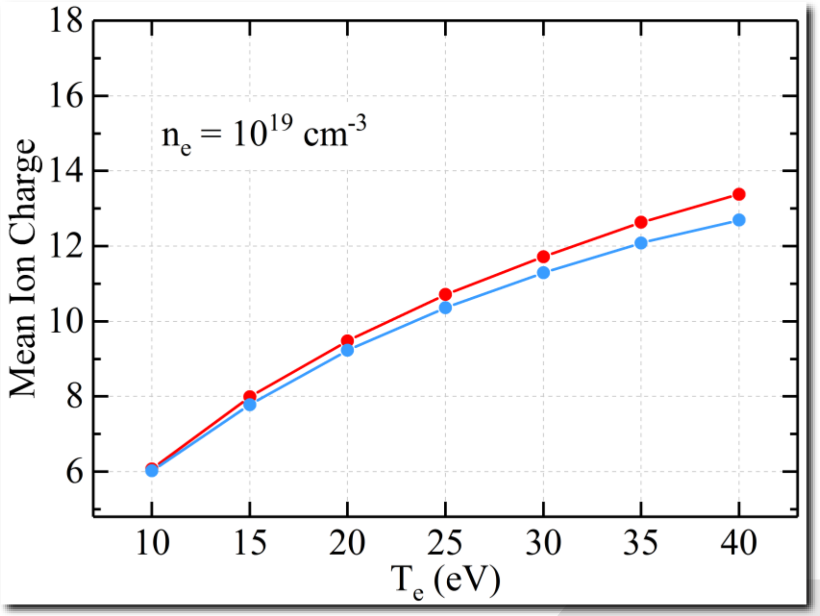

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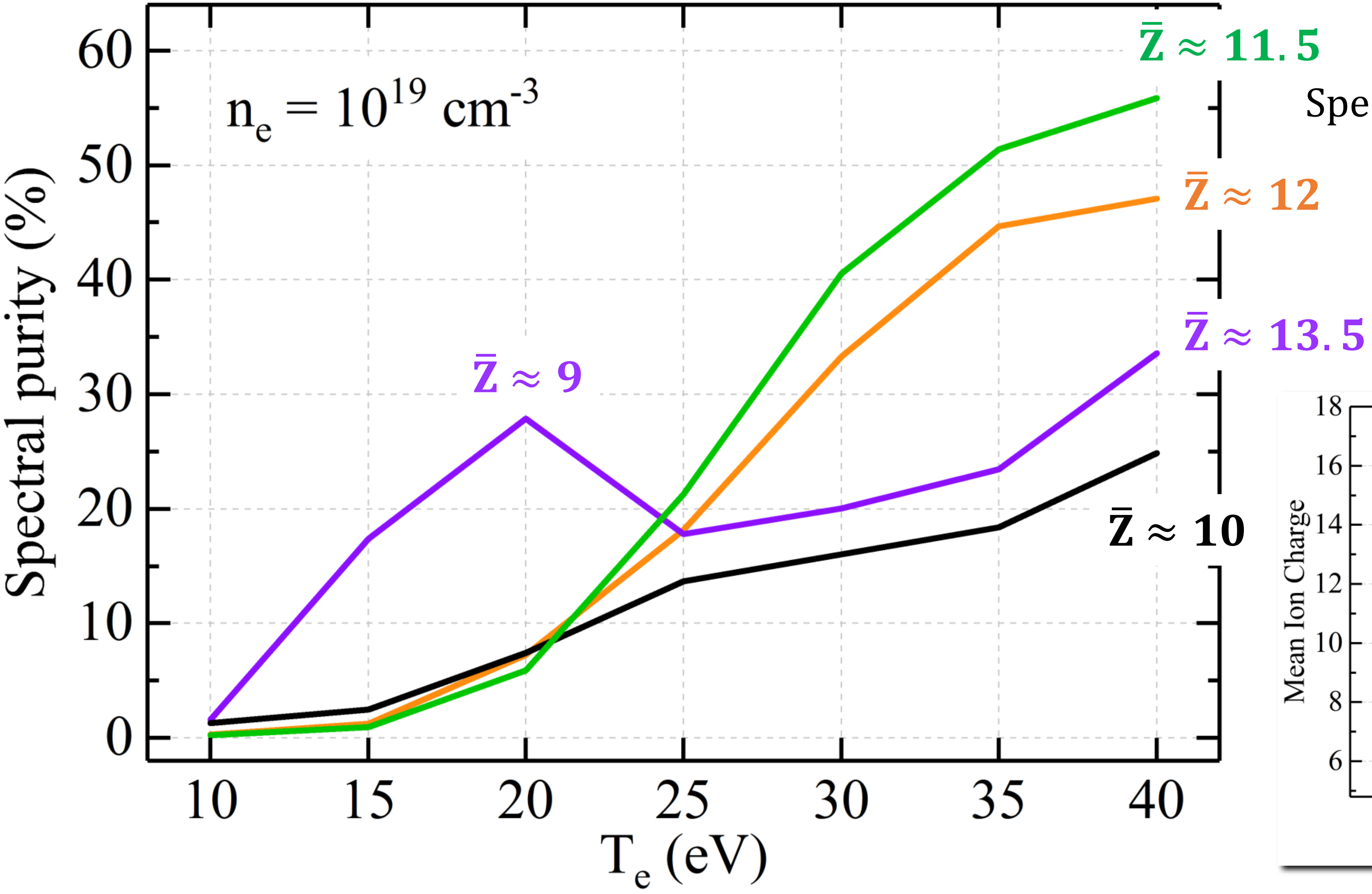

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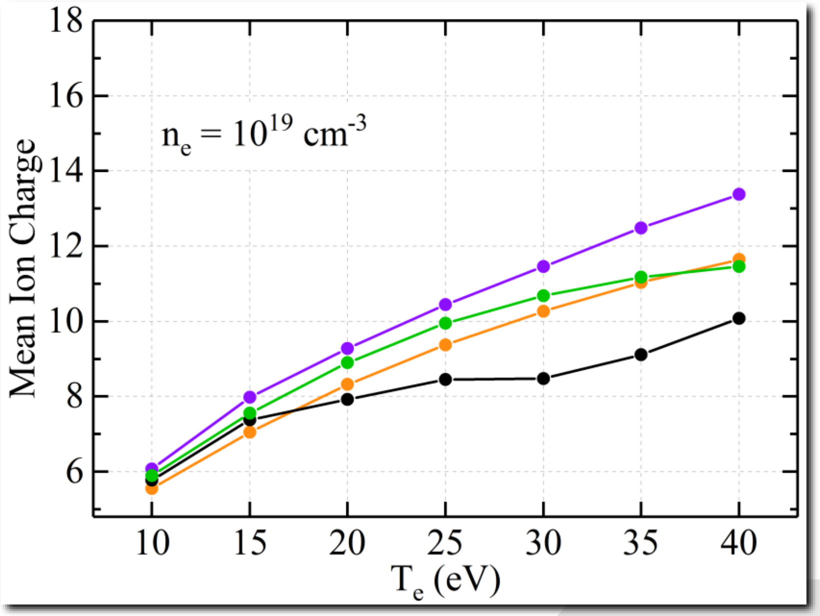

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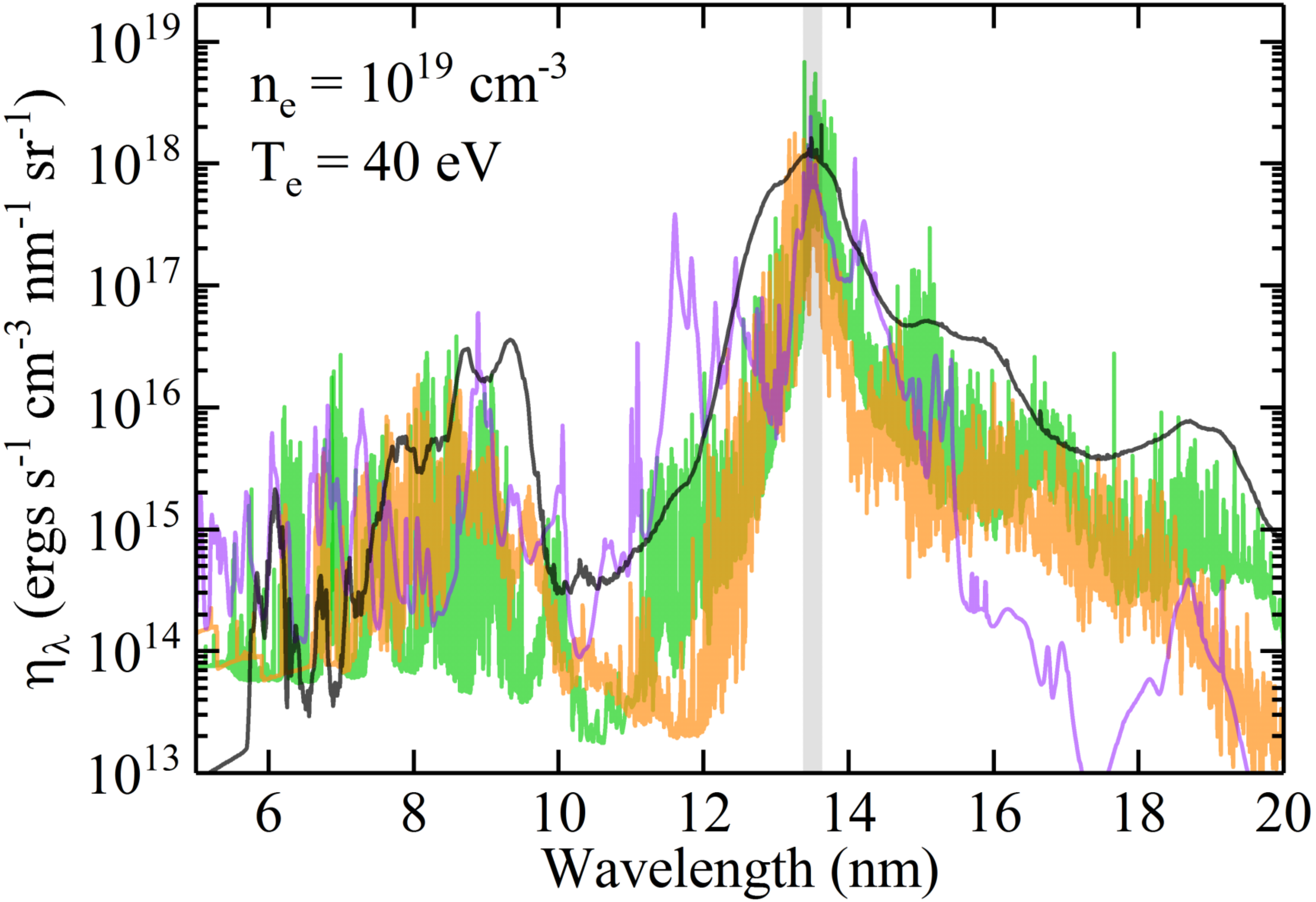
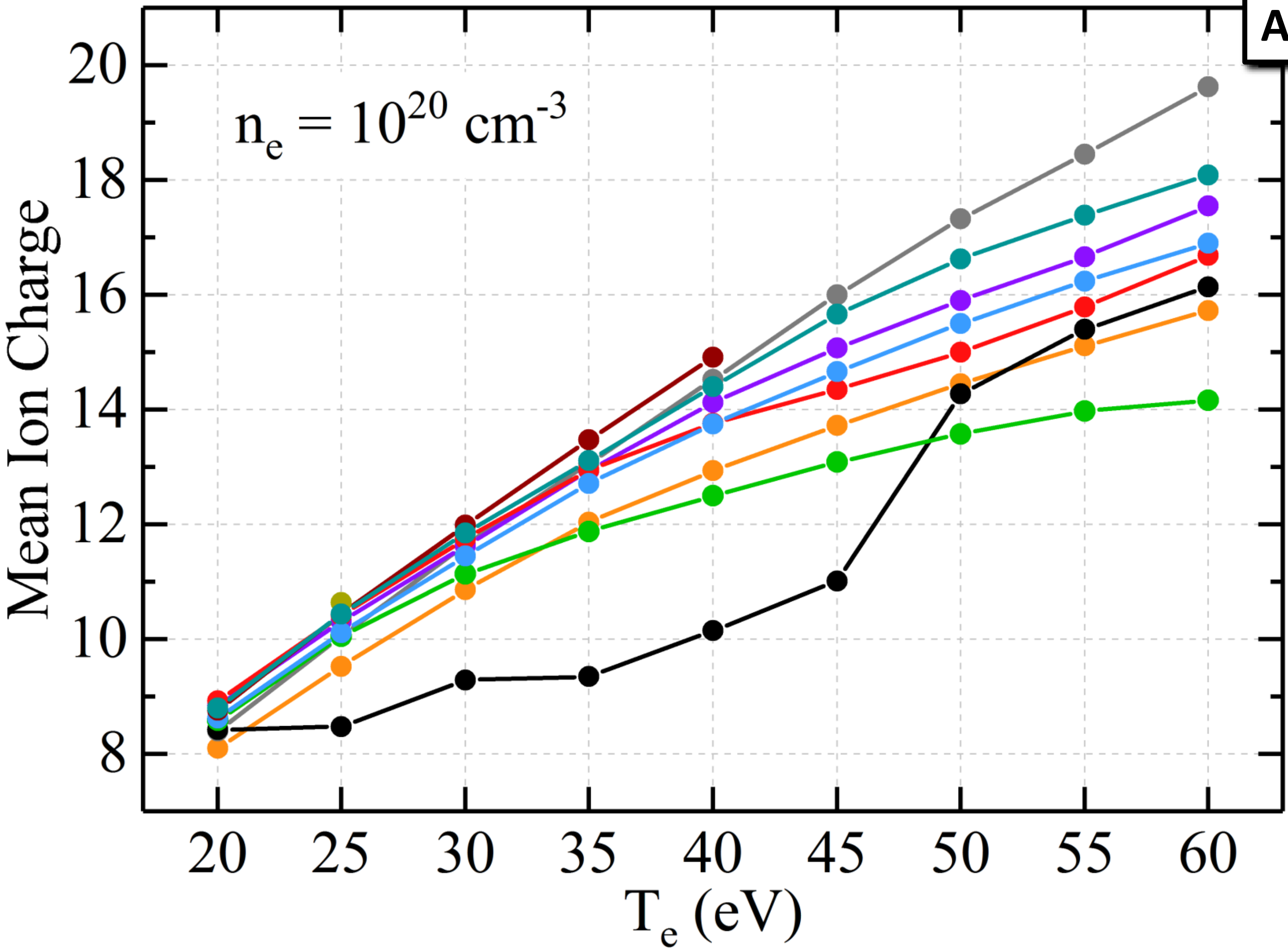


$$n_e = 10^{20}\ cm^{-3}$$

$n_e = 10^{20}$ cm^{-3}: Mean charge state



Atomic structure

4p^4

4p^6

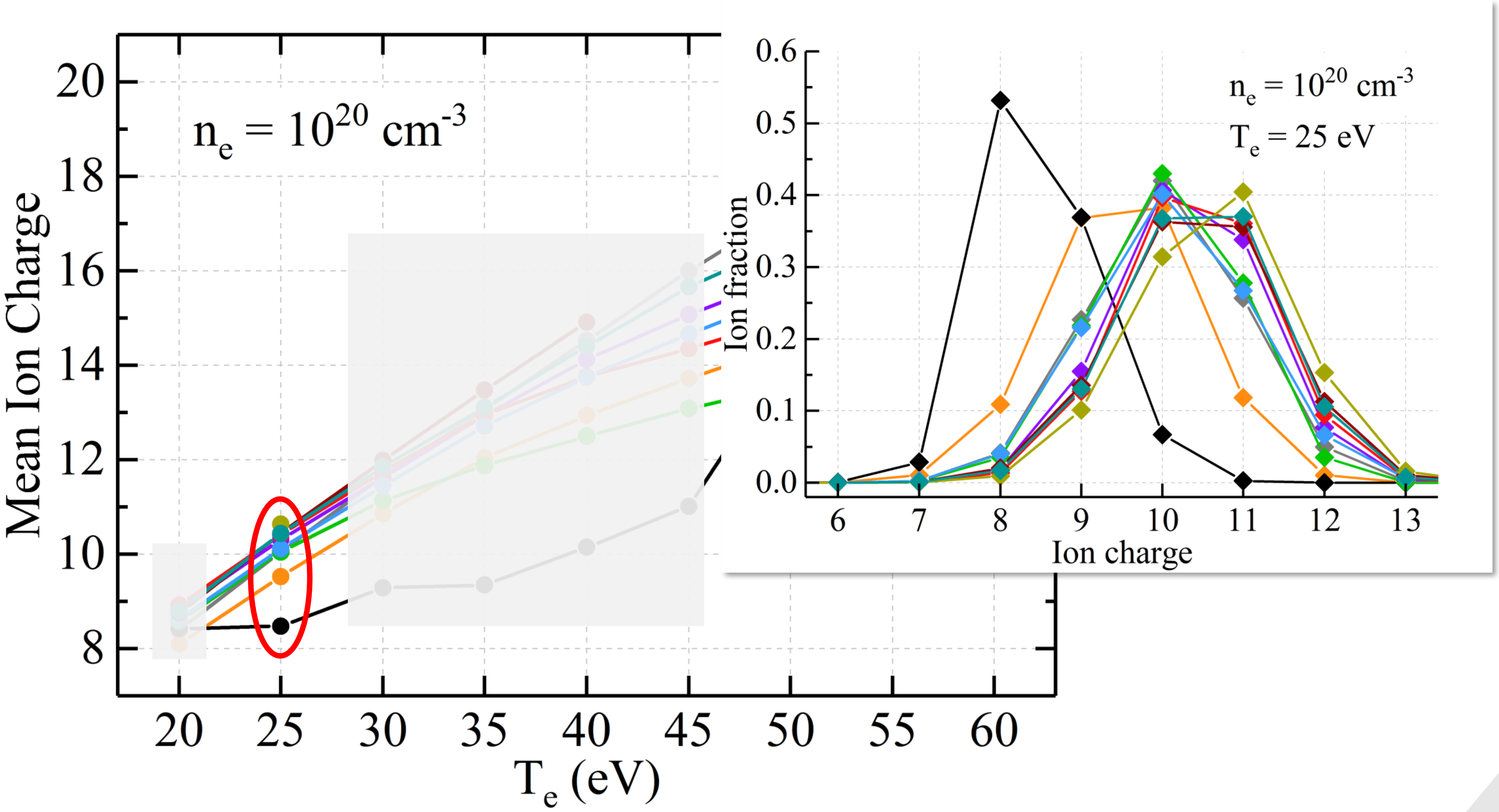
4p^{6}4d^2

4p^{6}4d^4

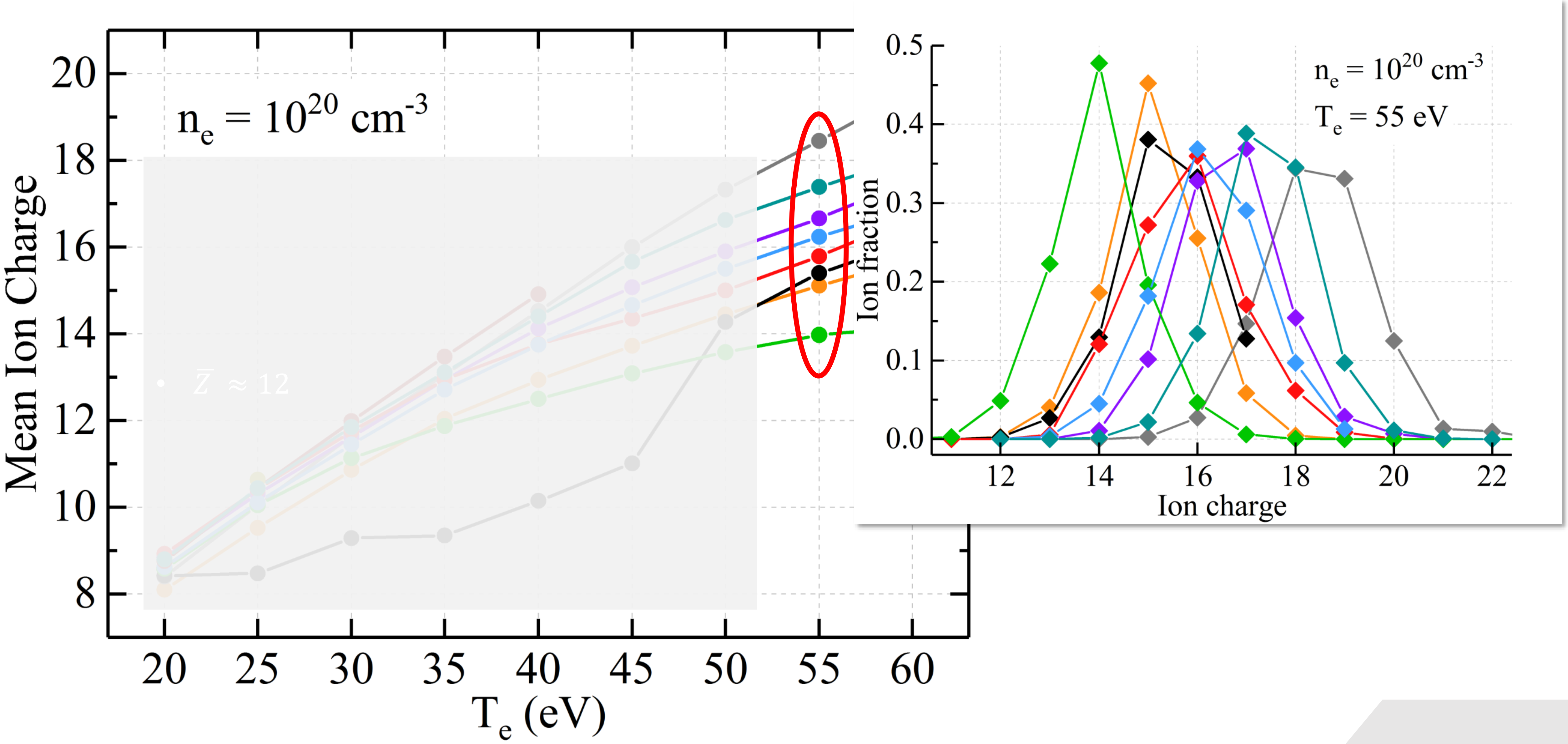
$$\beta = 1.34 \times 10^{13} \frac{{T_e}^{7/2}}{n_e} \ll 1$$ for LTE conditions

$\beta \approx \mathbf{0.005}$ for $T_e = 20$ eV
$\beta \approx \mathbf{0.22}$ for $T_e = 60$ eV

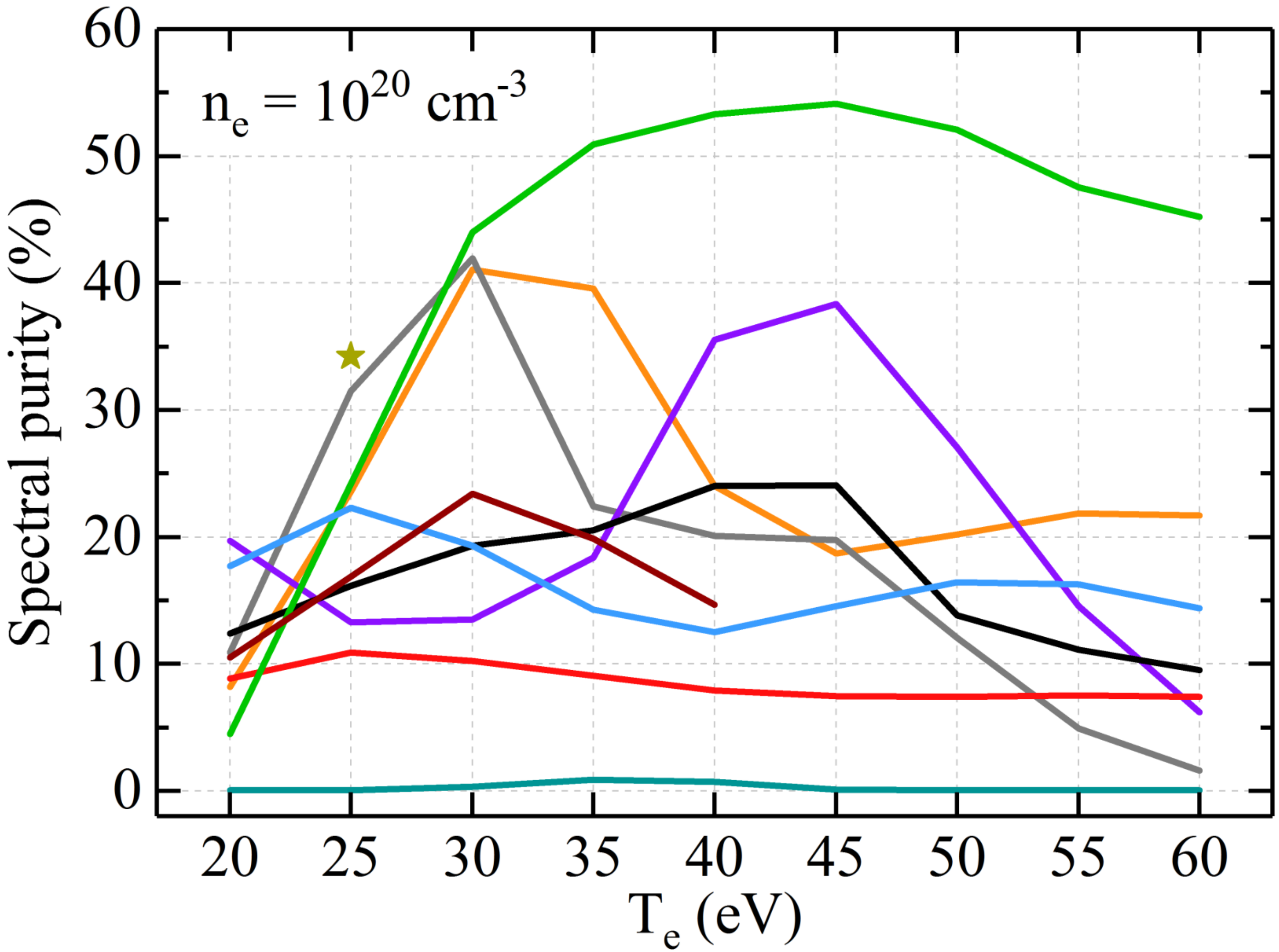
$n_e = 10^{20}$ cm^{-3}: Ion fraction



$n_e = 10^{20}$ cm^{-3}: Ion fraction



$n_e = 10^{20}$ cm^{-3}: Spectral purity



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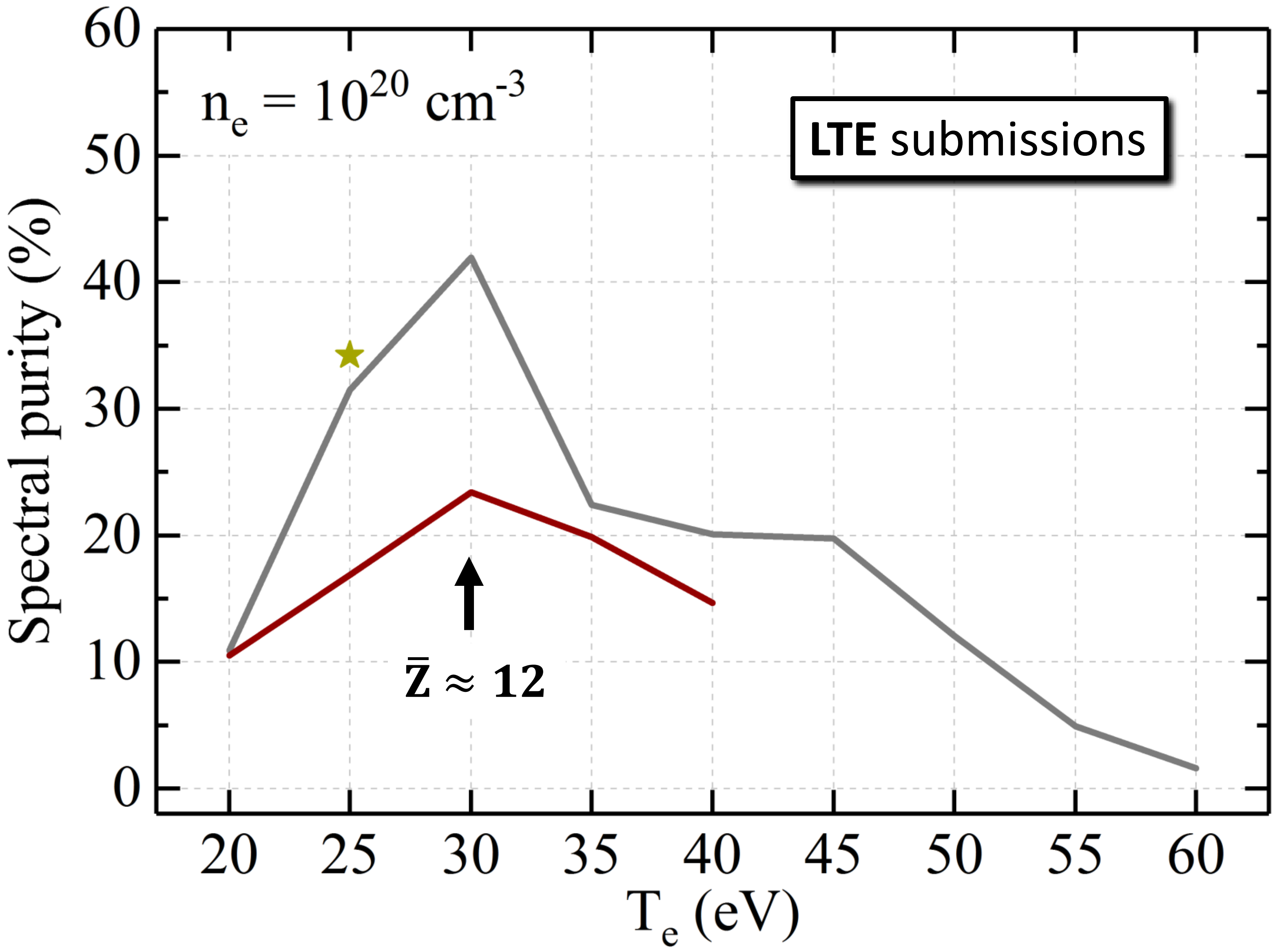

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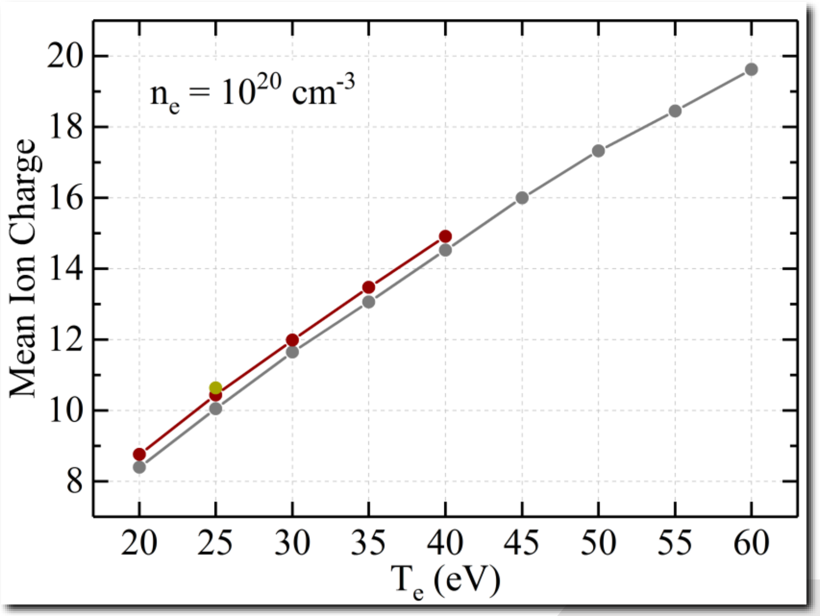
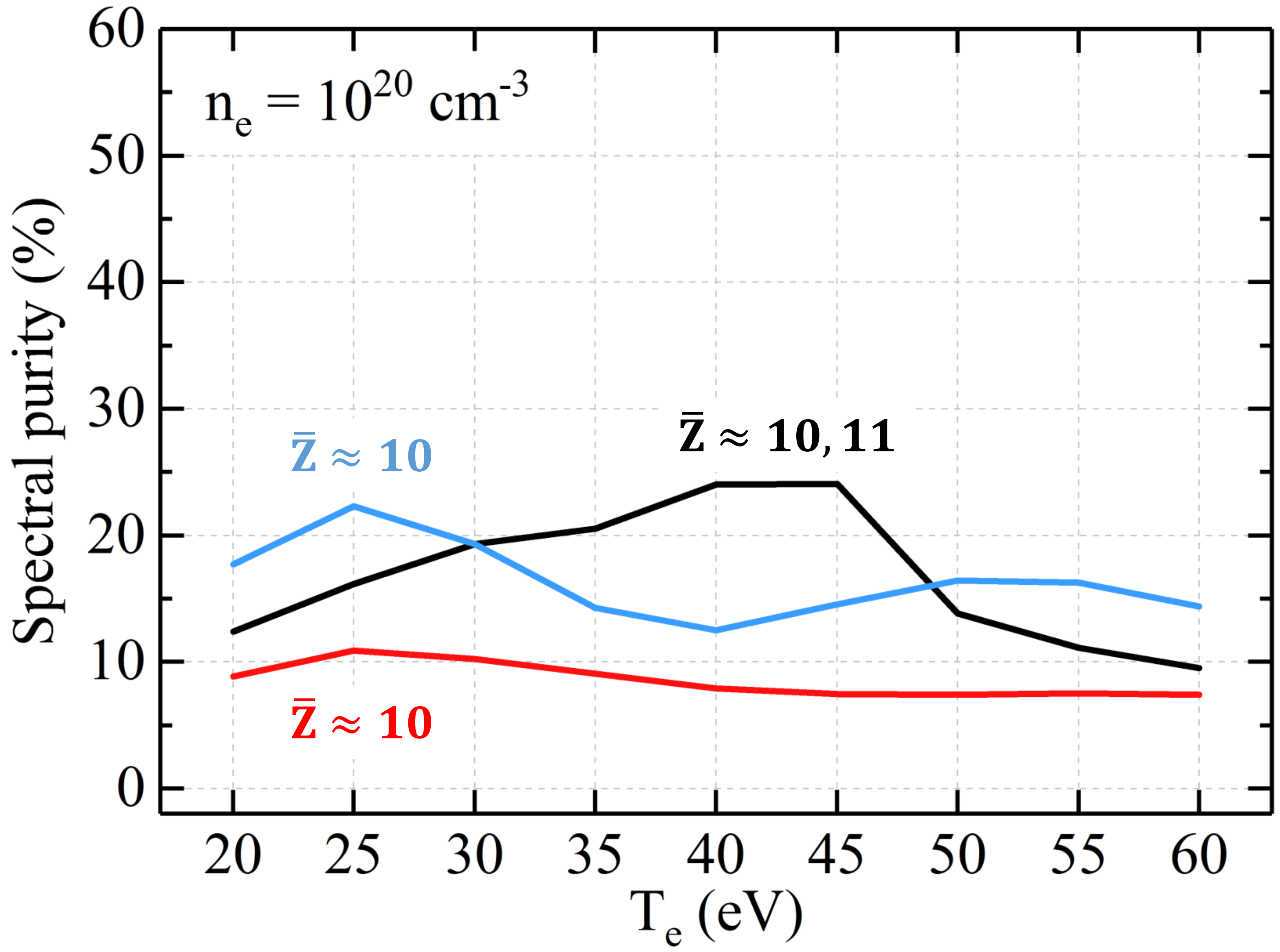


$n_e = 10^{20}$ cm^{-3}: Spectral purity



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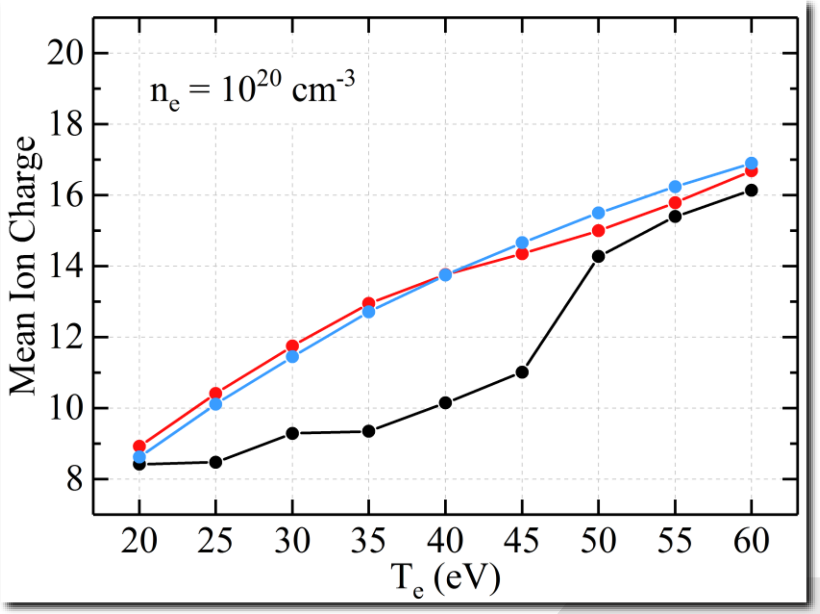
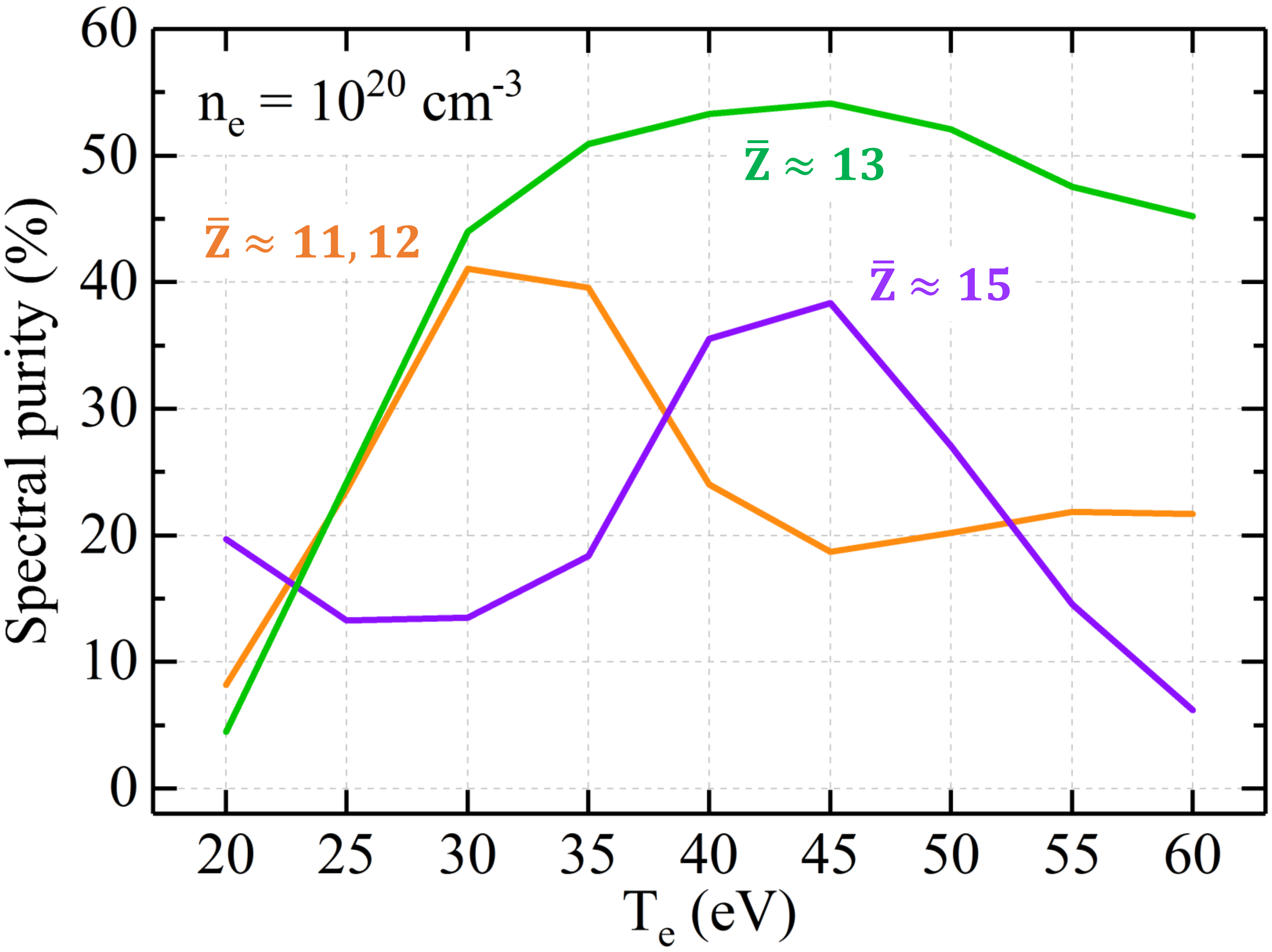


$n_e = 10^{20}$ cm^{-3}: Spectral purity



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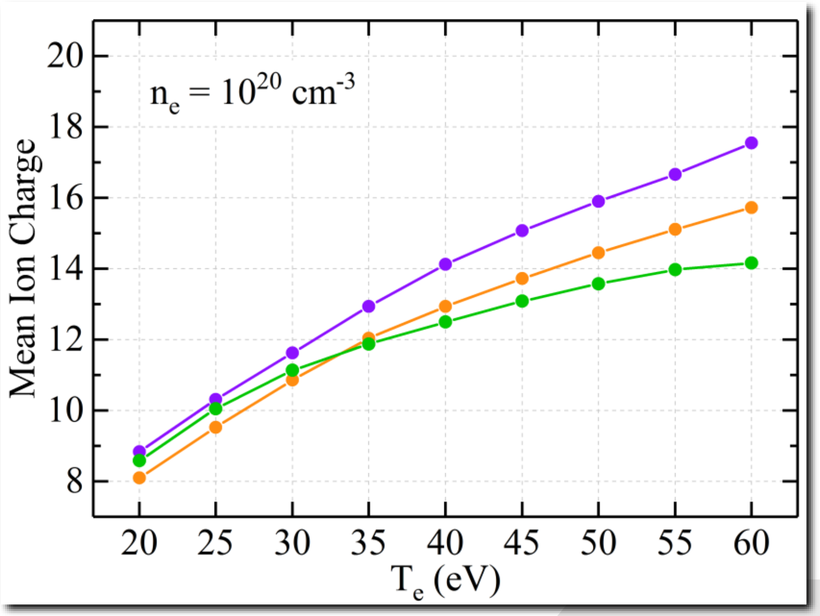
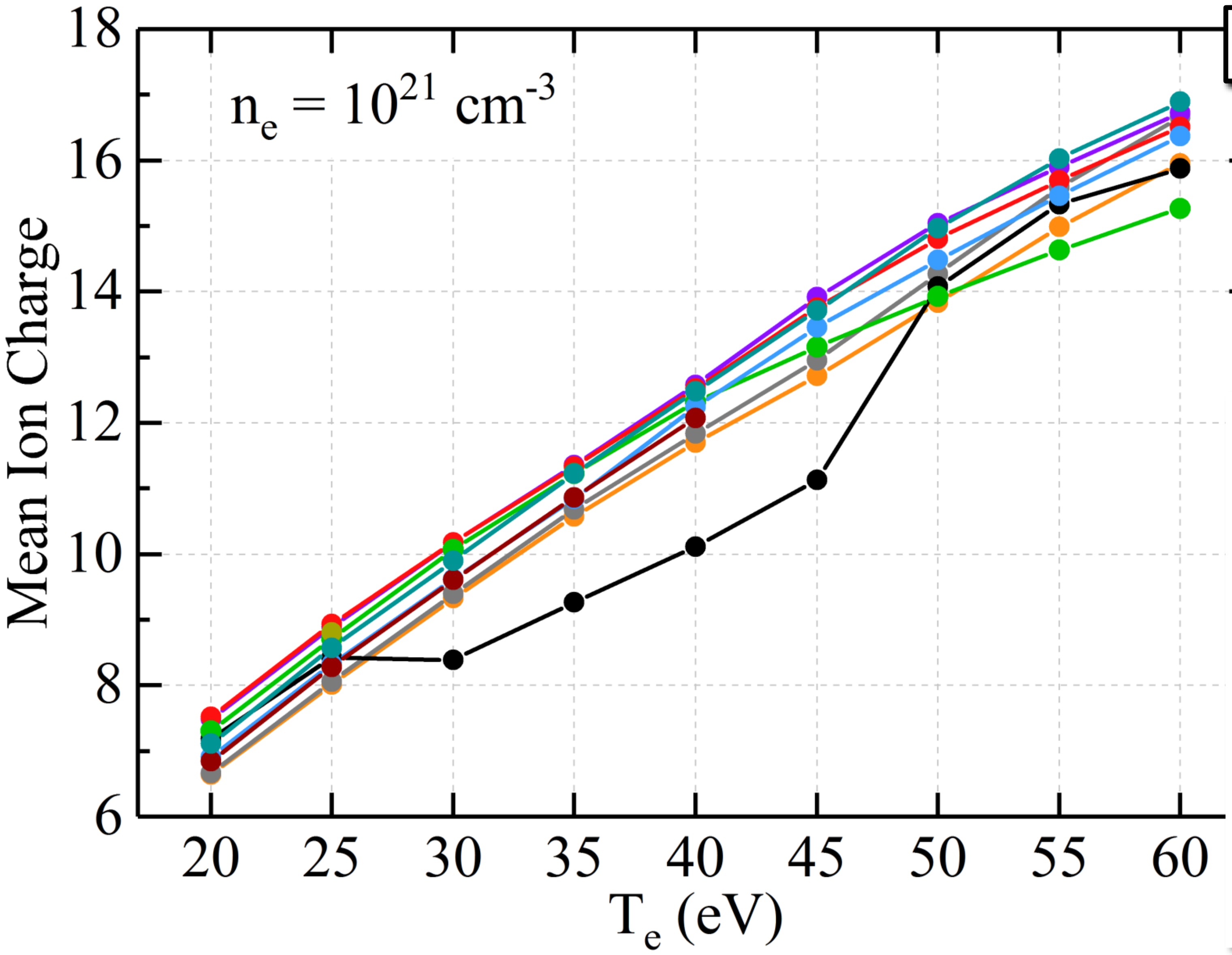


$$n_e = 10^{21}\ cm^{-3}$$

$n_e = 10^{21}$ cm^{-3}: Mean charge state



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$$\beta = 1.34\ x\ 10^{13} \frac{T_e^{7/2}}{n_e} \ll 1 \text{ for LTE conditions}$$

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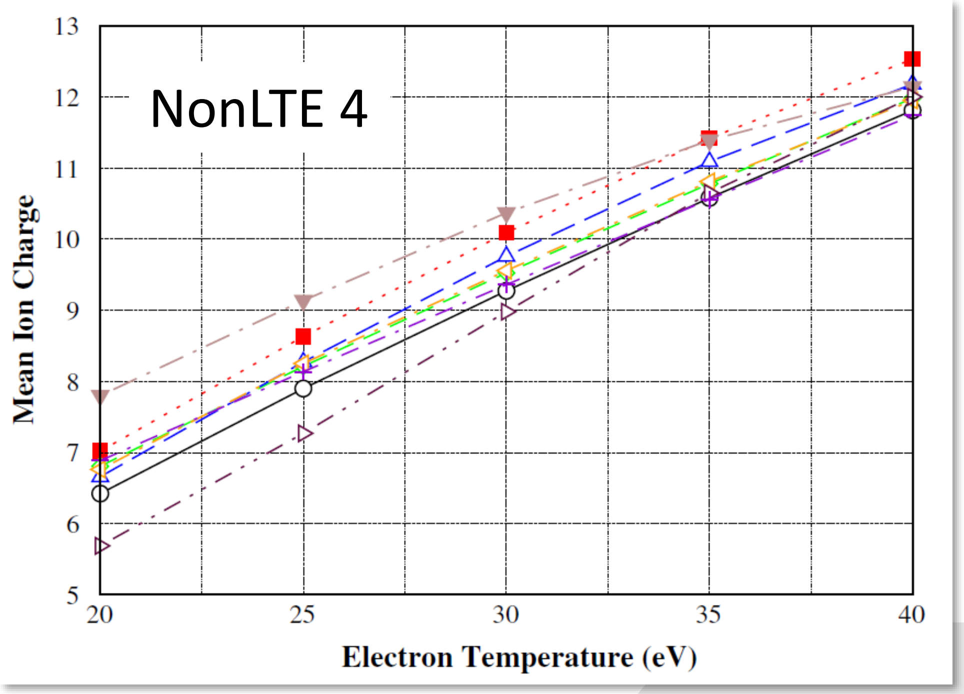
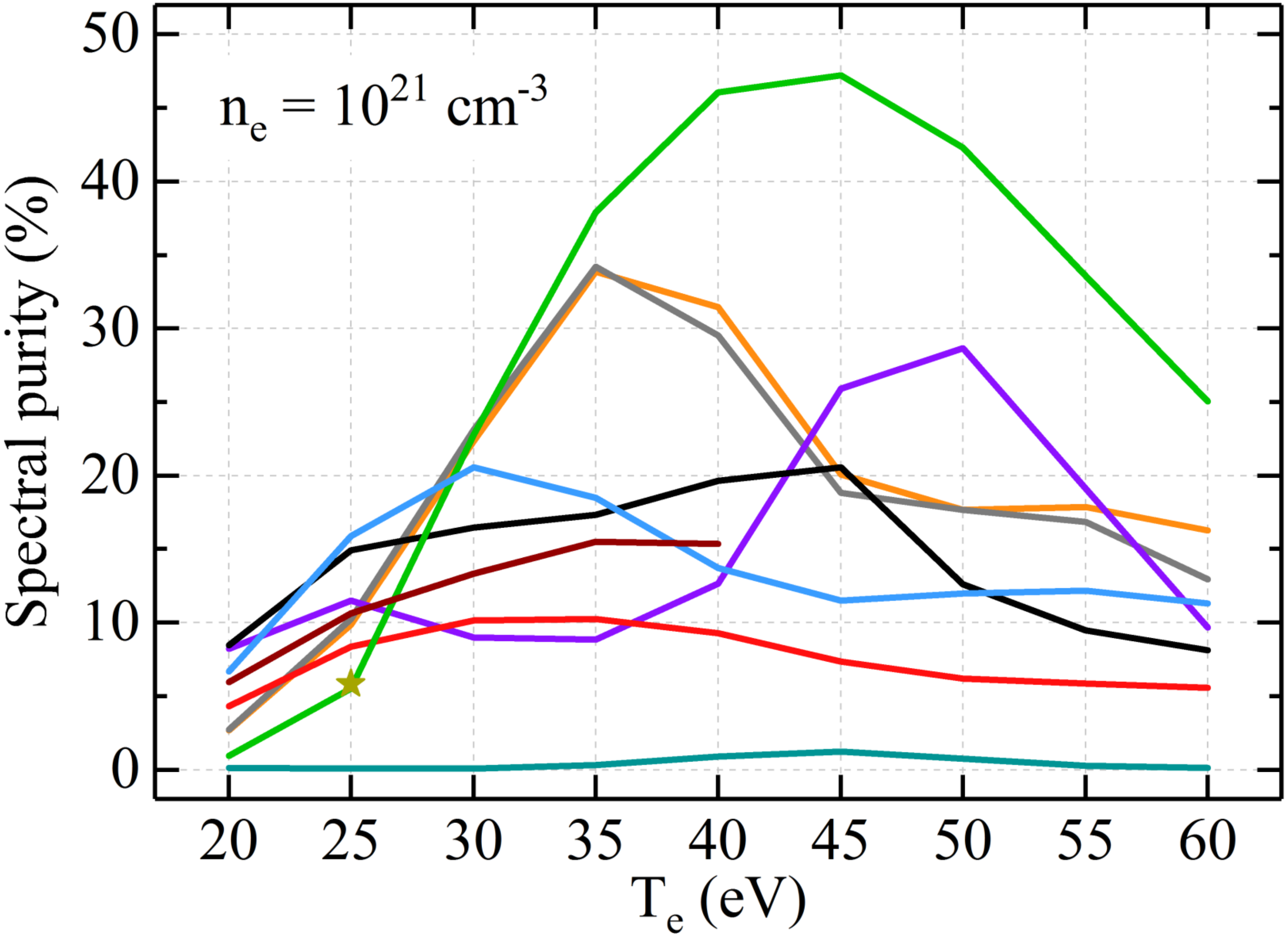


$n_e = 10^{21}$ cm^{-3}: Spectral purity



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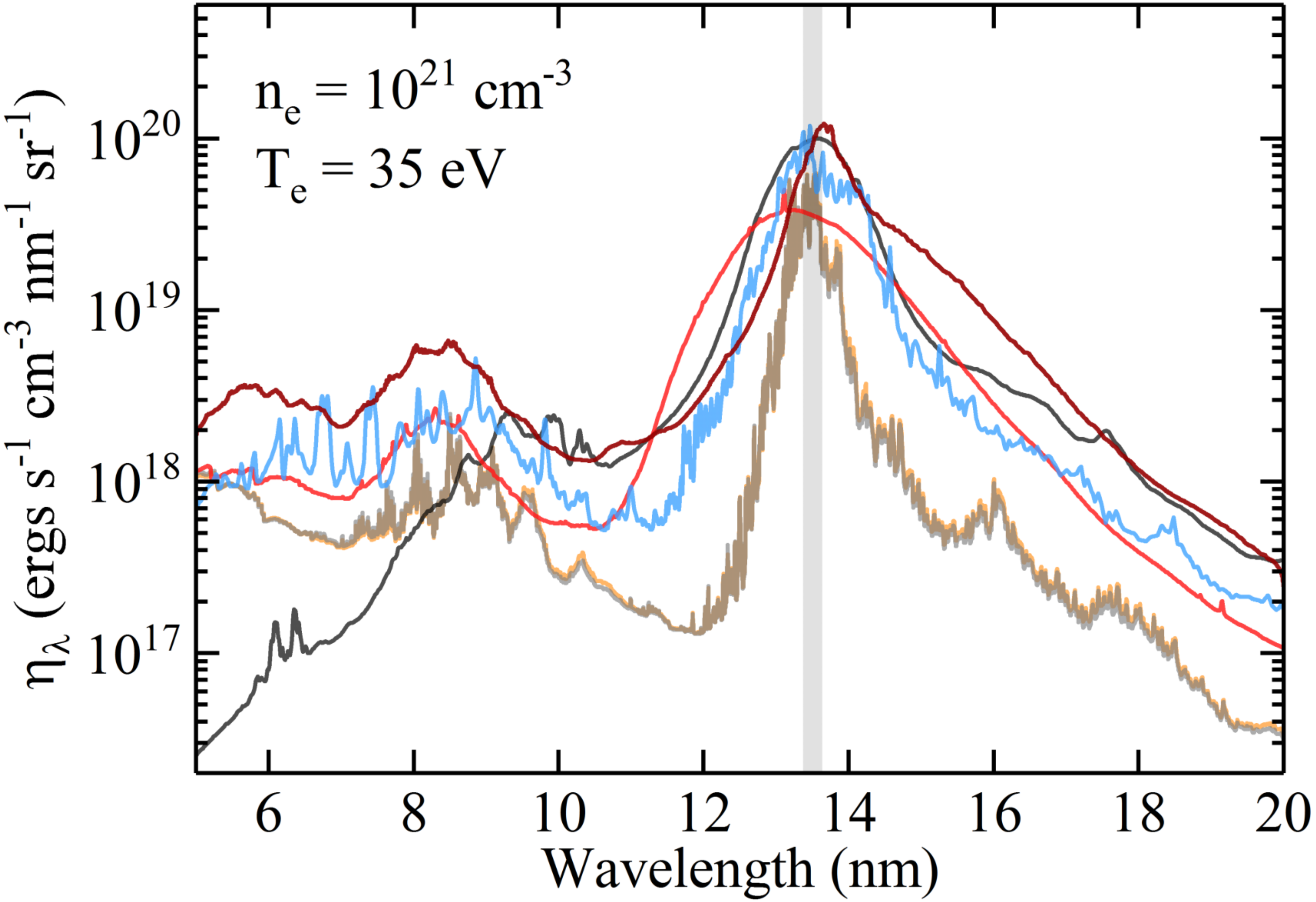
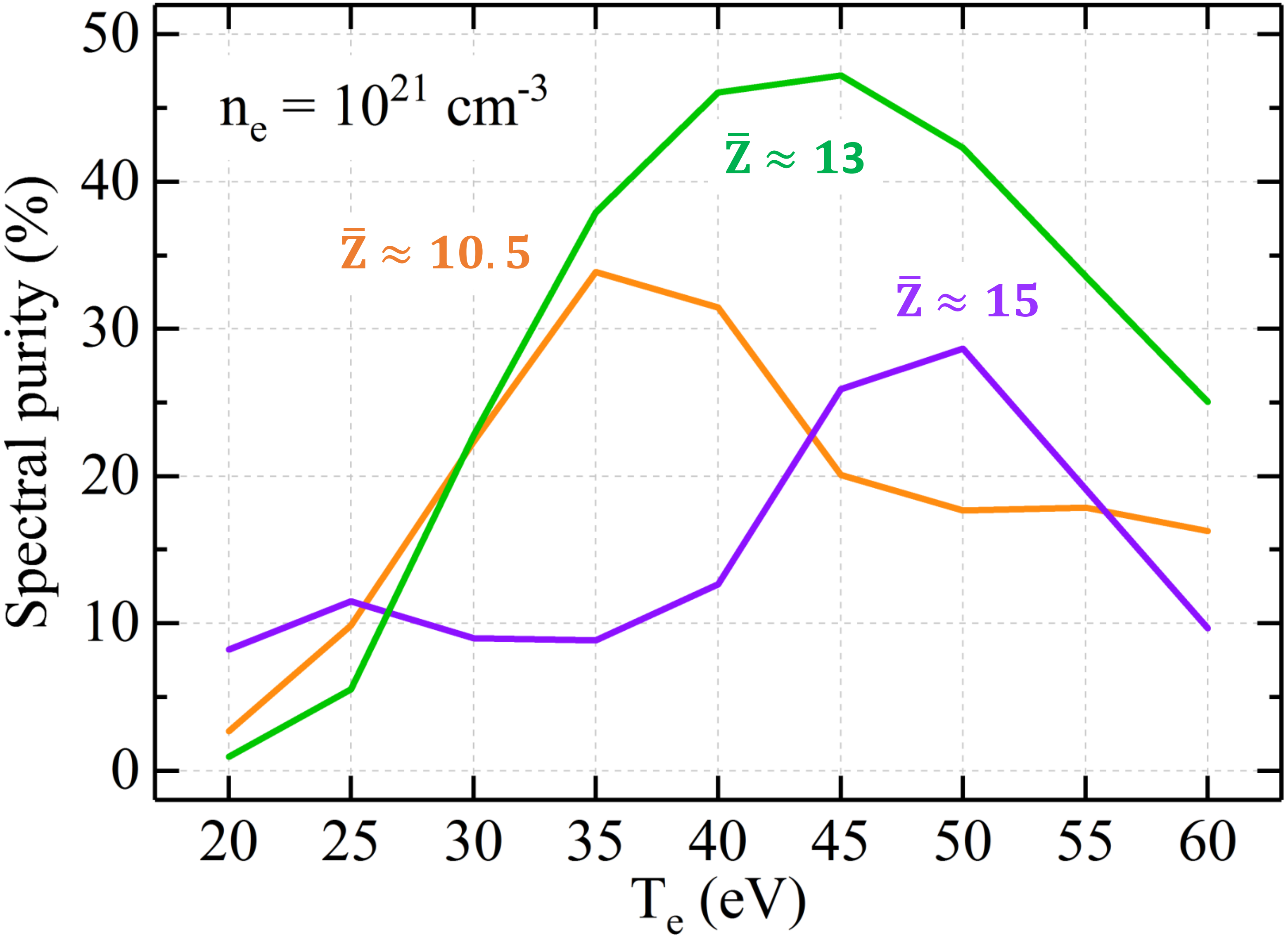


$n_e = 10^{21}$ cm^{-3}: Spectral purity



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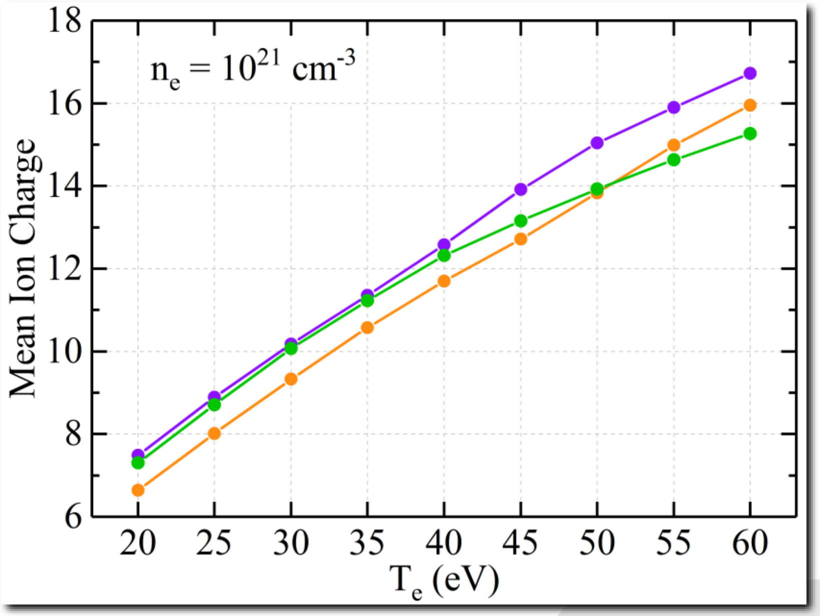
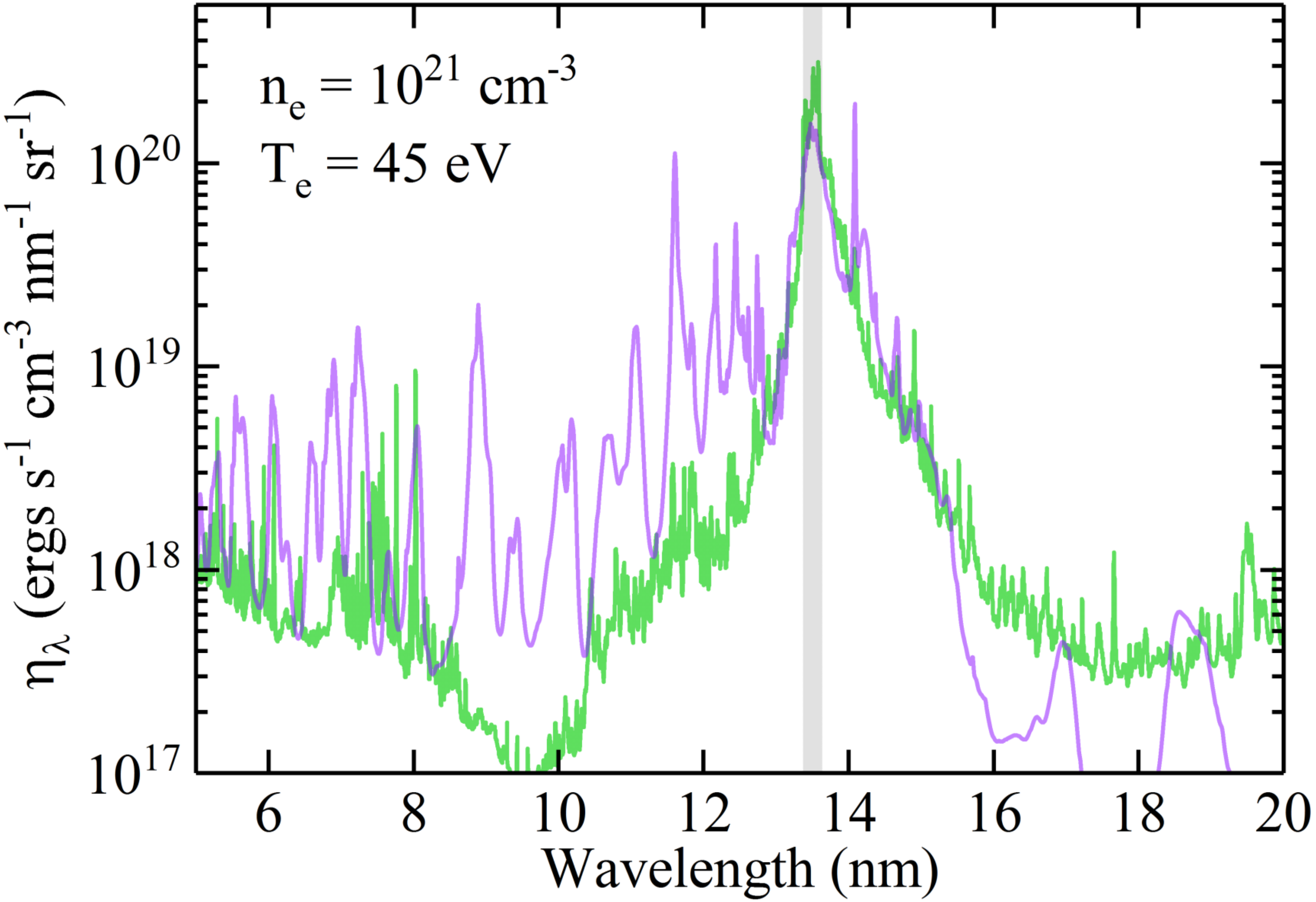
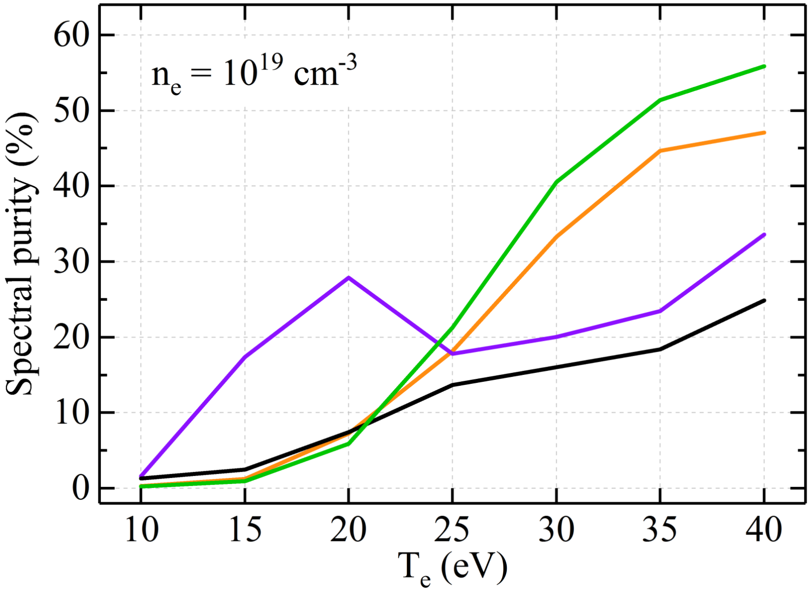


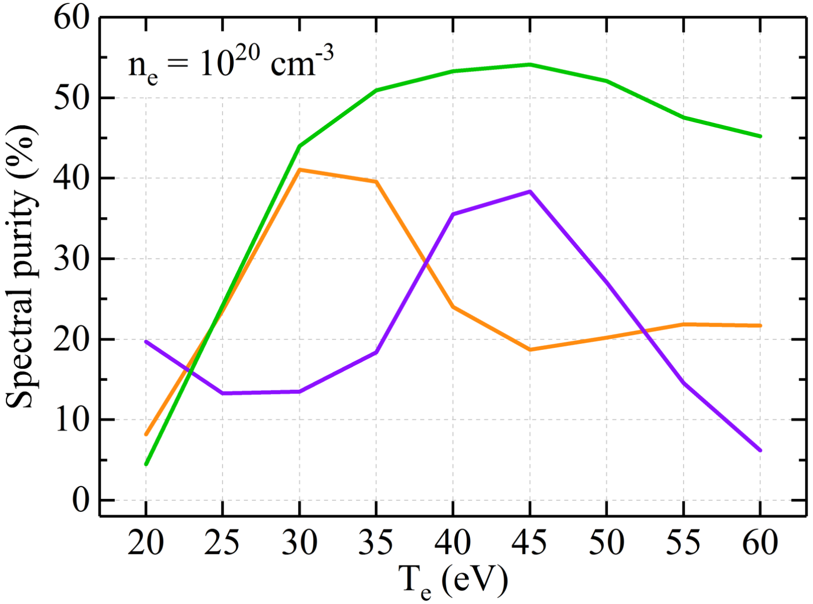
$n_e = 10^{21}$ cm^{-3}: Emissivity

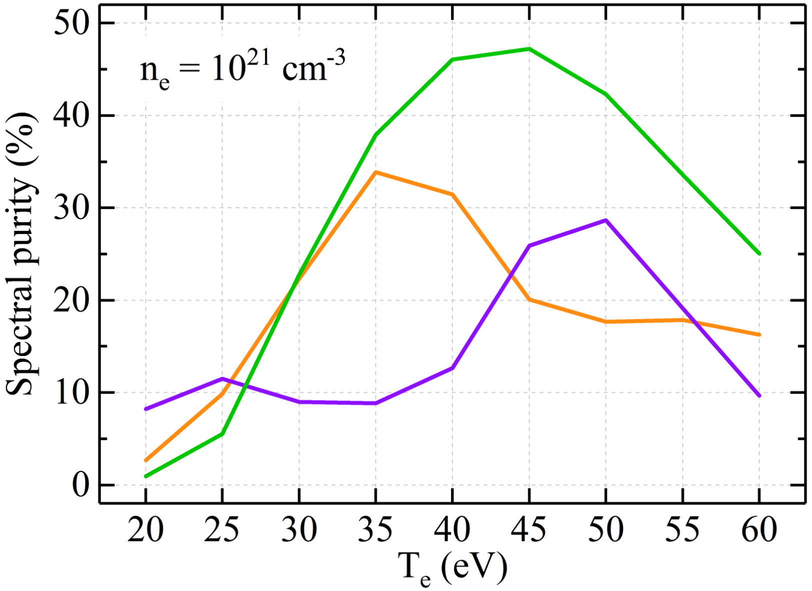


Spectral purity: $n_e = 10^{19}$, 10^{20} & 10^{21} cm^{-3}



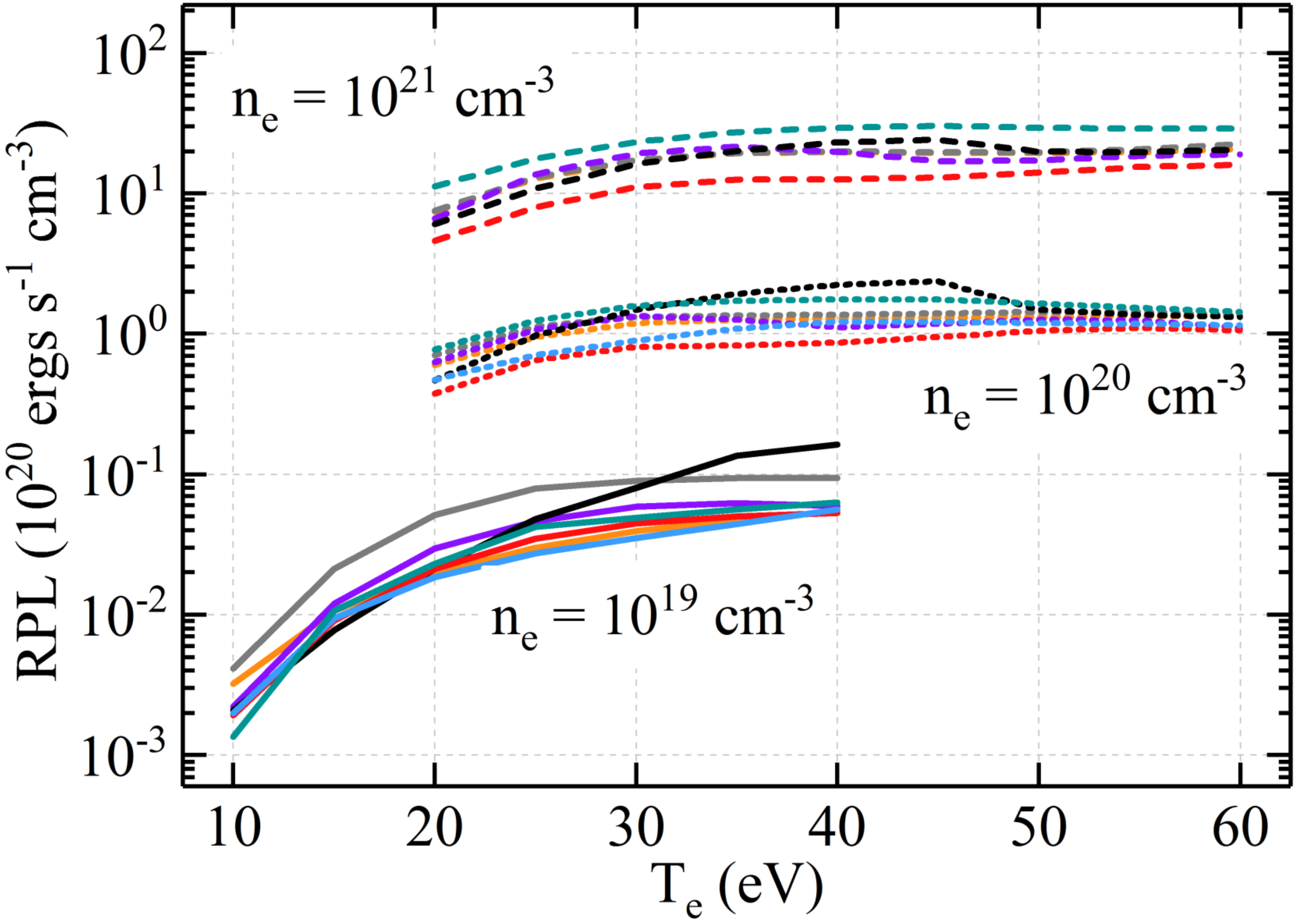
- Need **higher temperatures** at **higher densities** to achieve optimum charge state balance.





- Spectral purity decreases as you move to higher densities and higher temperatures

Radiative power losses: 10^{19}, 10^{20} & 10^{21} cm^{-3}



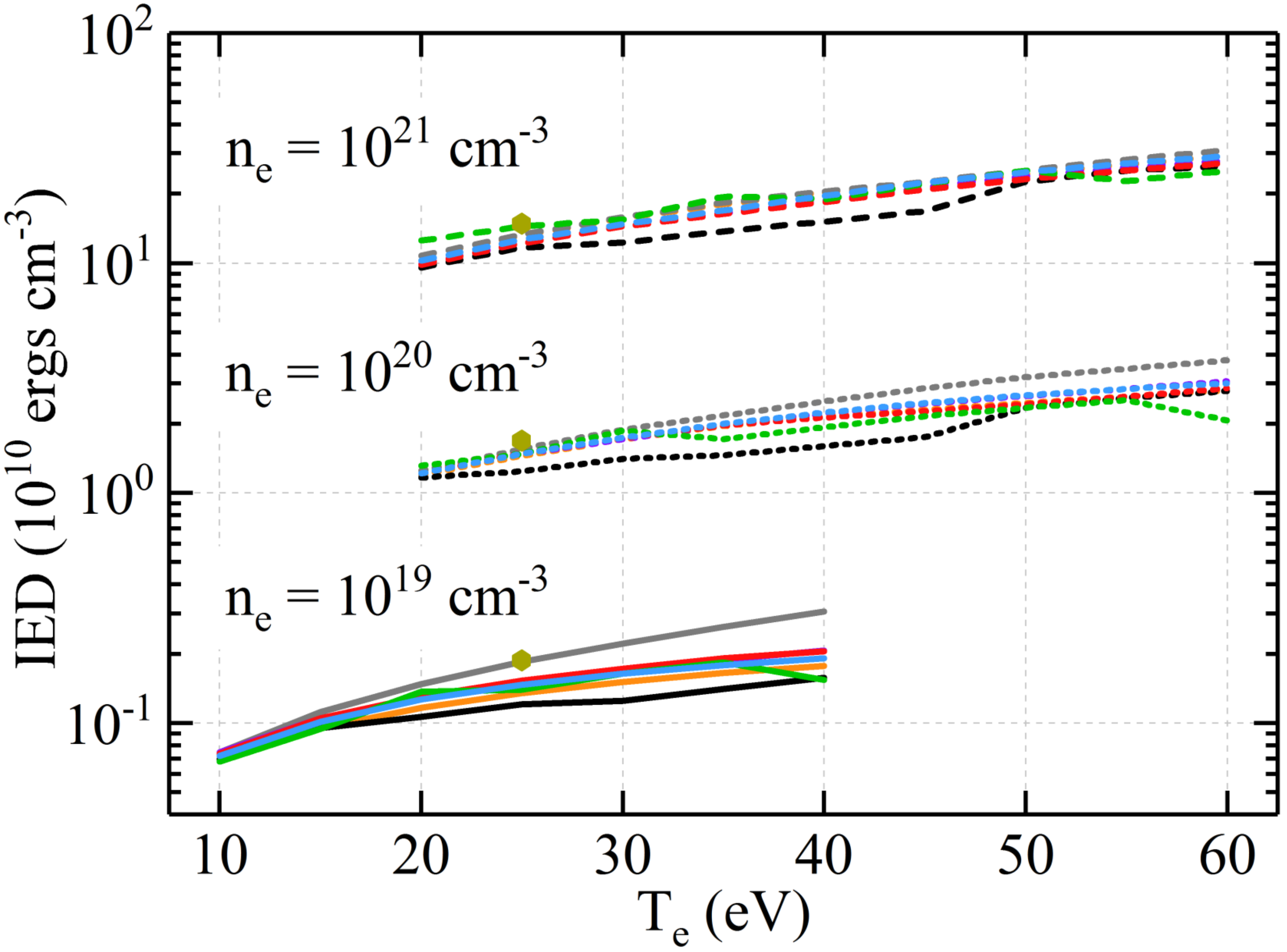
Radiative **P**ower **L**osses (**RPL**)

Total contribution from:

- **bound-bound**
- **bound-free** (recombin.) and
- **free-free transitions** (bremsstr.)

Good agreement between codes for all three electron density sets.

Internal energy density: 10^{19}, 10^{20} & 10^{21} cm^{-3}



Energy level

Population density

$$\mathrm{IED} = \sum_{i,Z} E_{i,Z} n_{i,Z}$$

levels, charge states

Good agreement between codes for all three electron density sets.

Conclusion

- Best agreement between mean charge values at low T_e.
- LTE submissions predict highest spectral purity for $\bar{\mathbf{Z}} \approx \mathbf{12}$. Greater spread in $\bar{\mathbf{Z}}$ for the non-LTE submissions.
- Spectral purity decreases with an increase in density (and temperature).
- Good agreement between codes for the radiative power losses and internal energy densities.