Charge Exchange Recombination Spectra for W^{64+}+H

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1st CRP on Data for Atomic Processes of Neutral Beams in Fusion Plasma
IAEA, Vienna, Austria

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Acknowledgements

- O. Marchuk

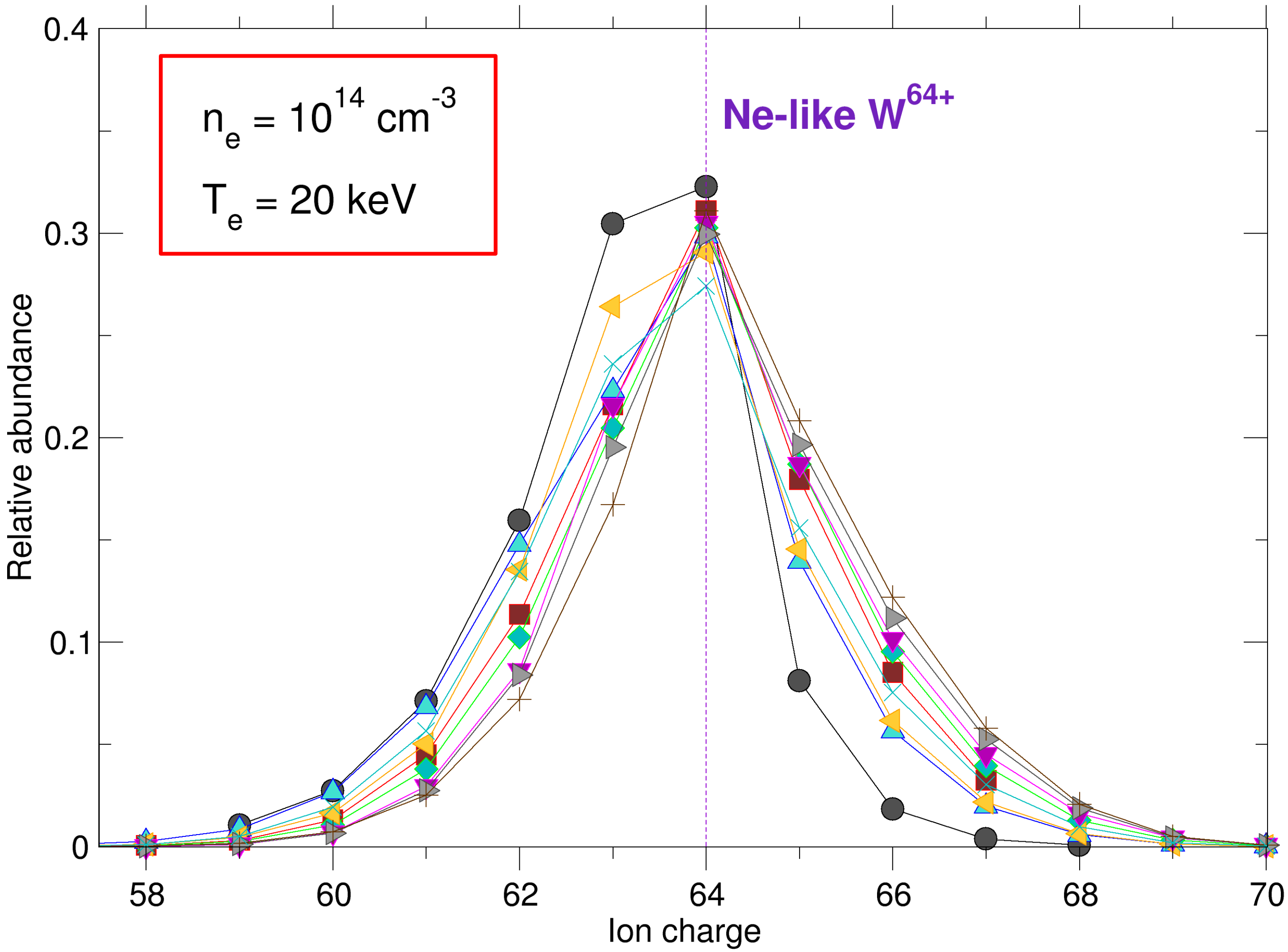
Plan

- Introduction
  - Ar CXR
- Method
- Atomic data: *n*- and *nl*-state-selective cross sections
- Model for W^{63+}
- Spectra
- Conclusions

What happens with W when a beam arrives?

- Charge exchange populates high-n states ***n ~ Z***$^{3/4}$
- Ionization balance changes
- New spectral features appear that can be used to locally diagnose the plasma…
- …however, there is no realistic data on CXRS of tungsten under ITER conditions

ITER: W ionization distribution



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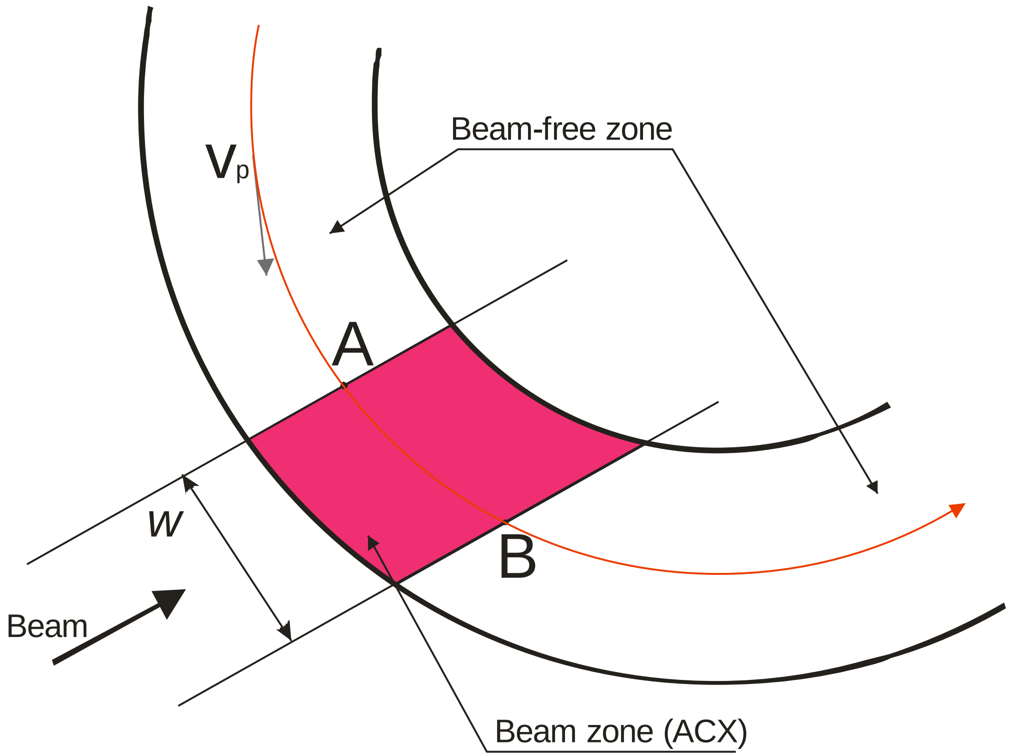
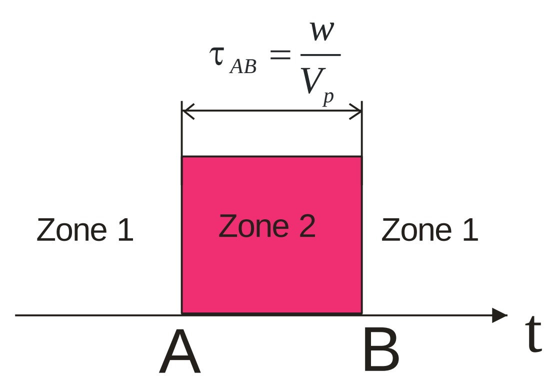
CX recombination in tokamaks: populations of excited states of Ar^{17+}

O. Marchuk et al, JPhysB 42, 165701 (2009)





Two-zone model

Goal: **analyze time-dependent kinetics of Ar impurities under CXRS conditions**

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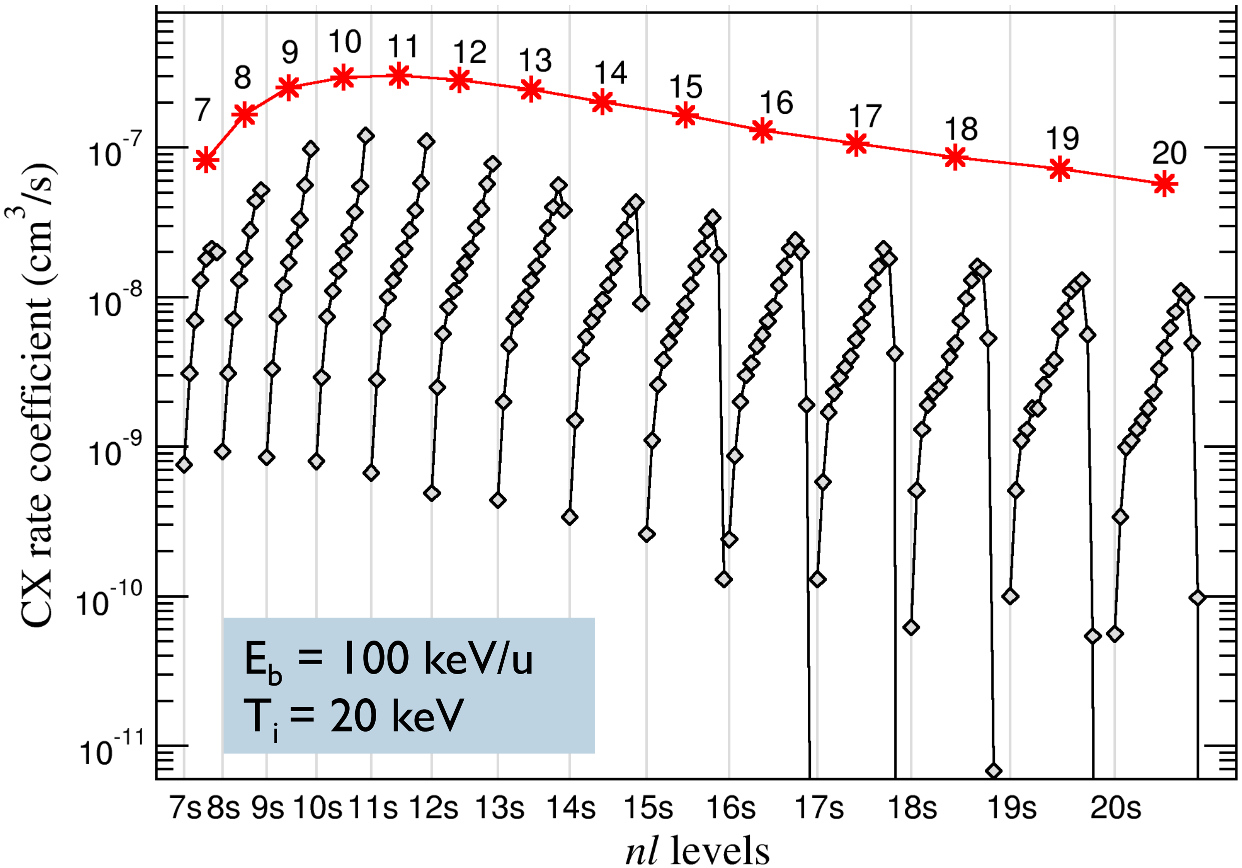
Model features

- H-like Ar:
  - n=14-15 at 428 nm
  - n=15-16 at 523 nm
- Li-like, He-like, H-like, and bare ions of Ar (total of **~250 levels**)
- Atomic data: CTMC CX rate coefficients (Hung, Krstic, and Schultz, ORNL)
- Main physical processes: electron- and proton-impact collisions, radiative processes, CX
- Time-dependent rate equations

CX rate coefficients

$Ar^{18+} + H \rightarrow Ar^{17+} + p$



Hung, Krstic and Schultz, CFADC-ORNL database

CX goes into high *n*'s:

$n \sim Z^{3/4} \approx \mathbf{9}$

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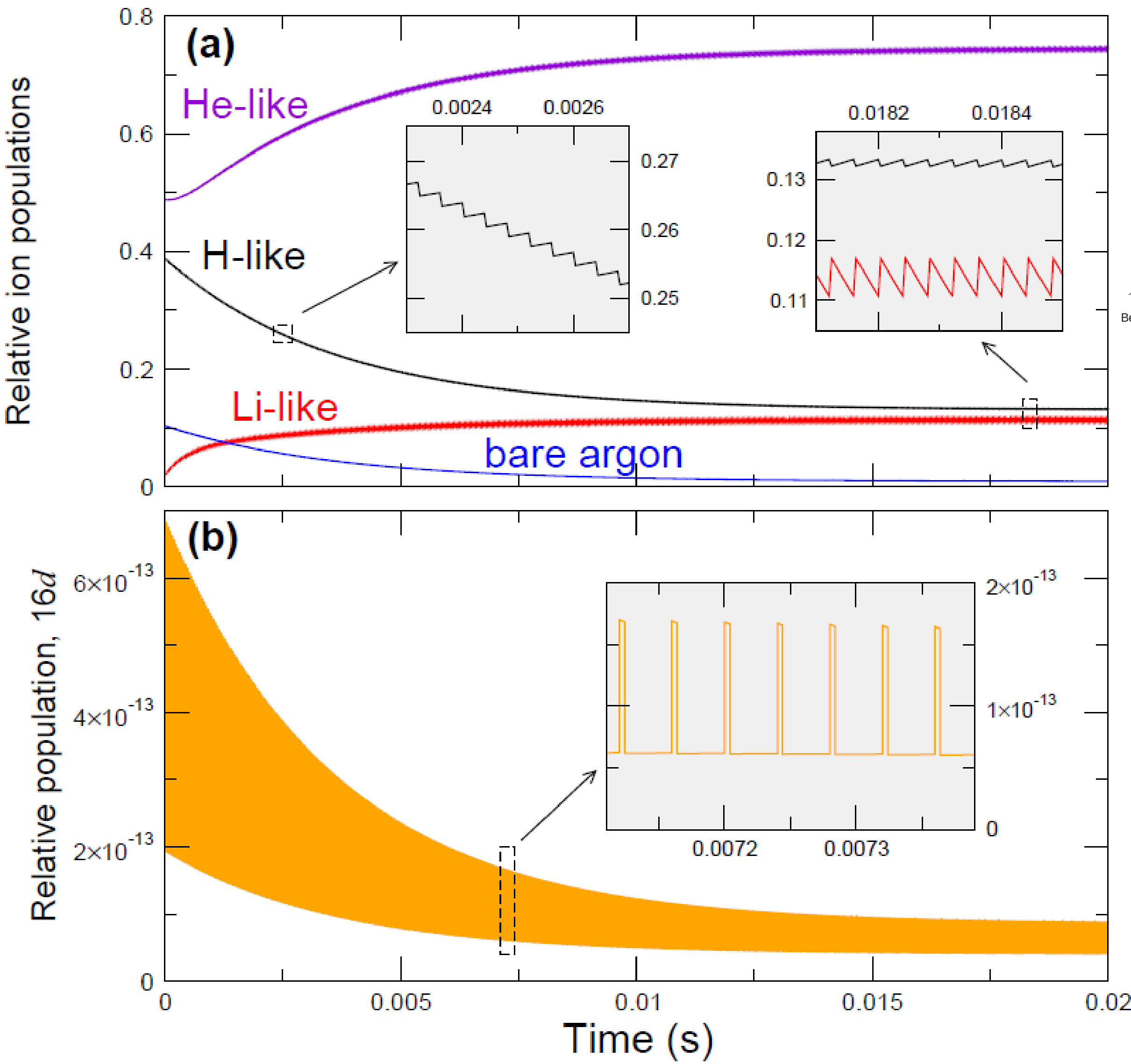
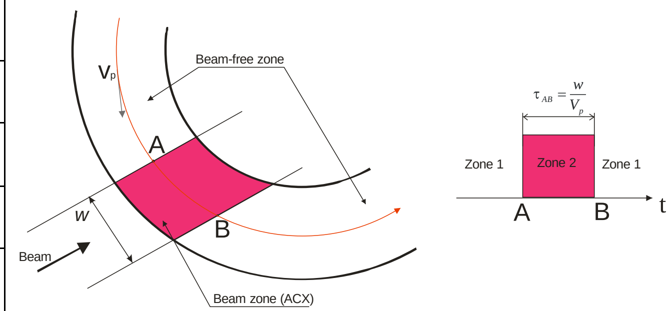
Full non-stationary model





Ionization balance changes

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W^{64+}+H: steady-state spectra

- Model should be much more extensive
  - **$64^{3/4} = 23$**!
- Thousands of levels: no time dependence (but this may change soon…)
- Spectroscopy of Na-like W^{63+}: only EUV (3s-3p D doublet) and x-rays (3-4 and 4-5)
- No CX data to compare against
  - **W^{60+}+H**: Illescas et al, Phys. Scr. **T156**, 014133(2013)

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Goals

- Produce atomic data for W^{64+}+H in a wide range energies
- Push the model to (reasonable) limits
- Analyze physical processes affecting level populations
- Calculate CX spectra in a wide spectral range

CTMC method: variants

- **pCTMC** (Abrines & Percival 1966, Olson & Salop 1977)
  - Original and most frequently employed
  - Microcanonical distribution reproduces QM electronic *momentum* (**p**) probability distribution
- **rCTMC** (Hardie & Olson 1983, Cohen 1985)
  - reproduces QM electronic *radial* (**r**) probability distribution
- Ar^{q+}+H: pCTMC agrees with AOCC (Schultz et al), rCTMC agrees with MOCC (Errea et al)
- We also tried AOCC and CDW but numerical issues turned out to be too difficult for such high-*n* states
- For ITER-related energies, pCTMC and rCTMC differ much less than for lower energies

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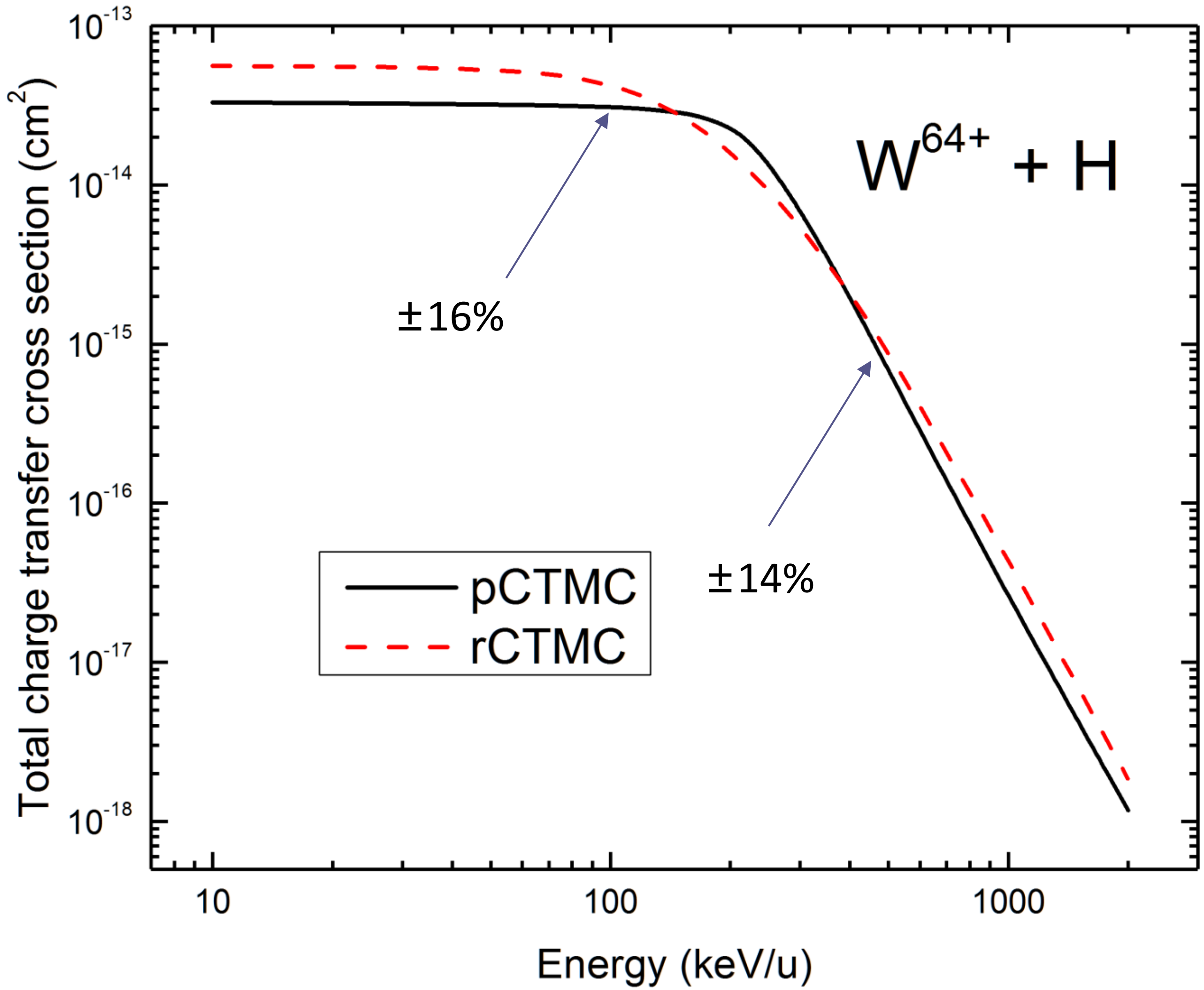
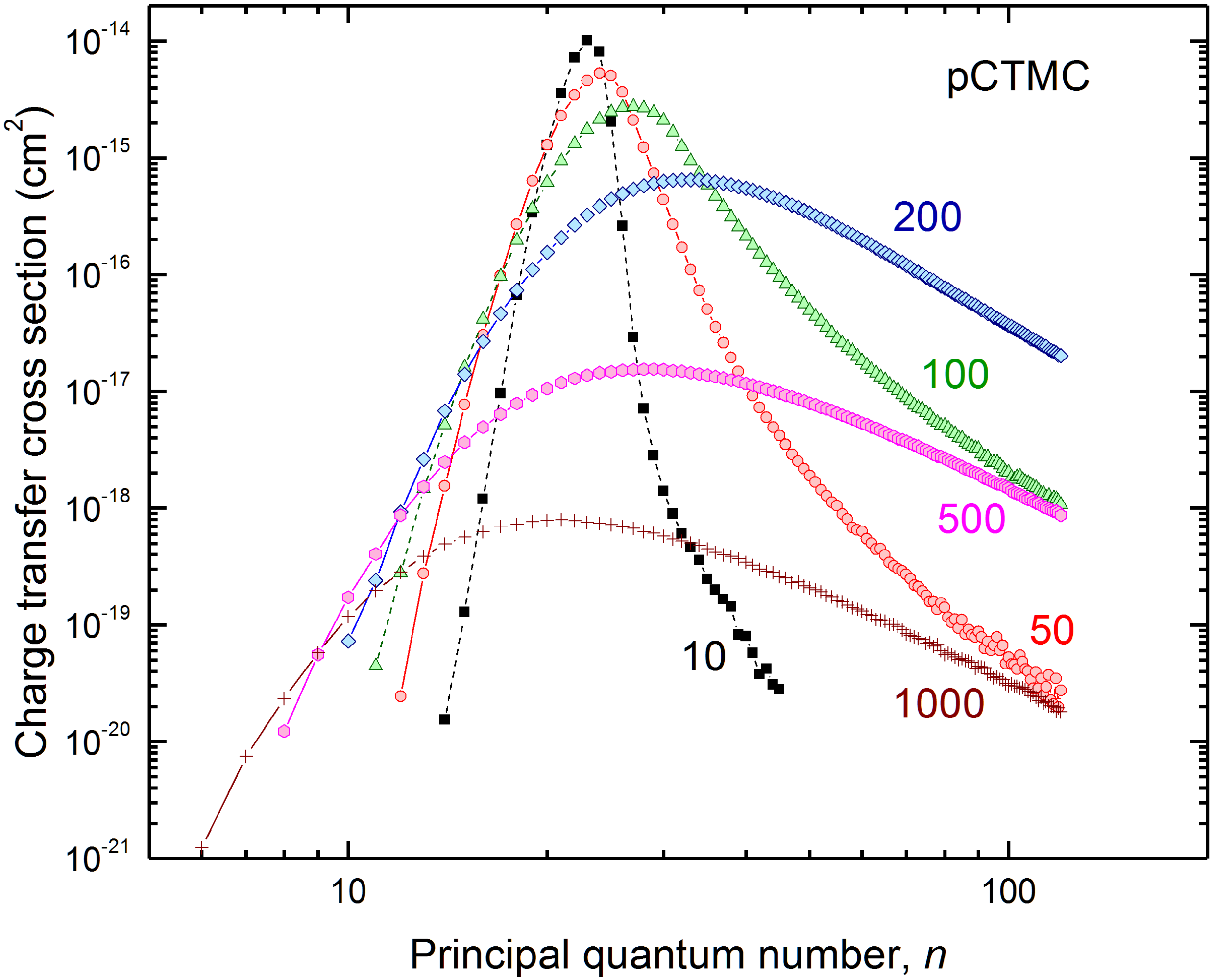
Total CTMC CX cross sections: 10-1000 keV/u



pCTMC: n-dependence for various collision energies



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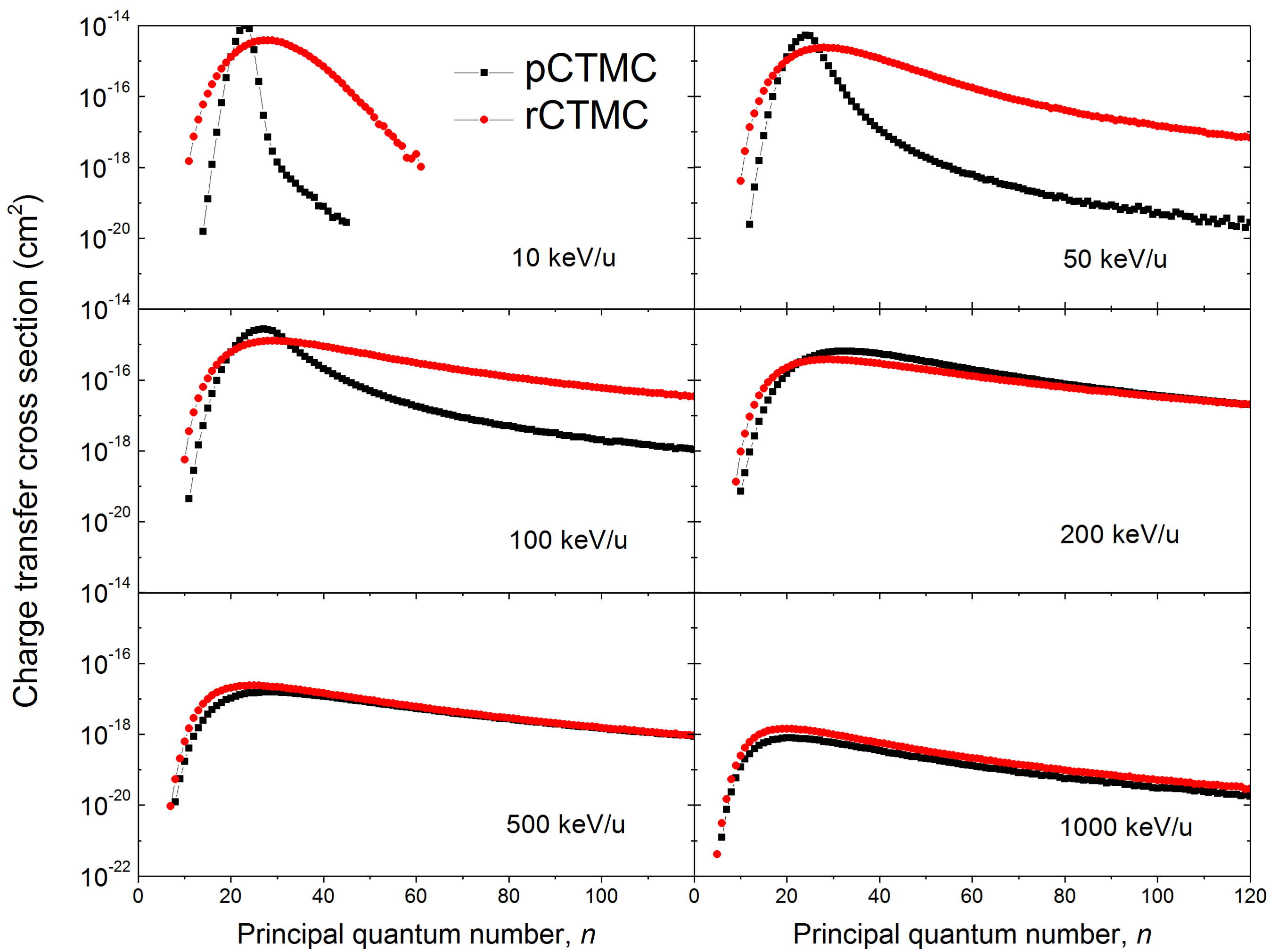
pCTMC vs. rCTMC



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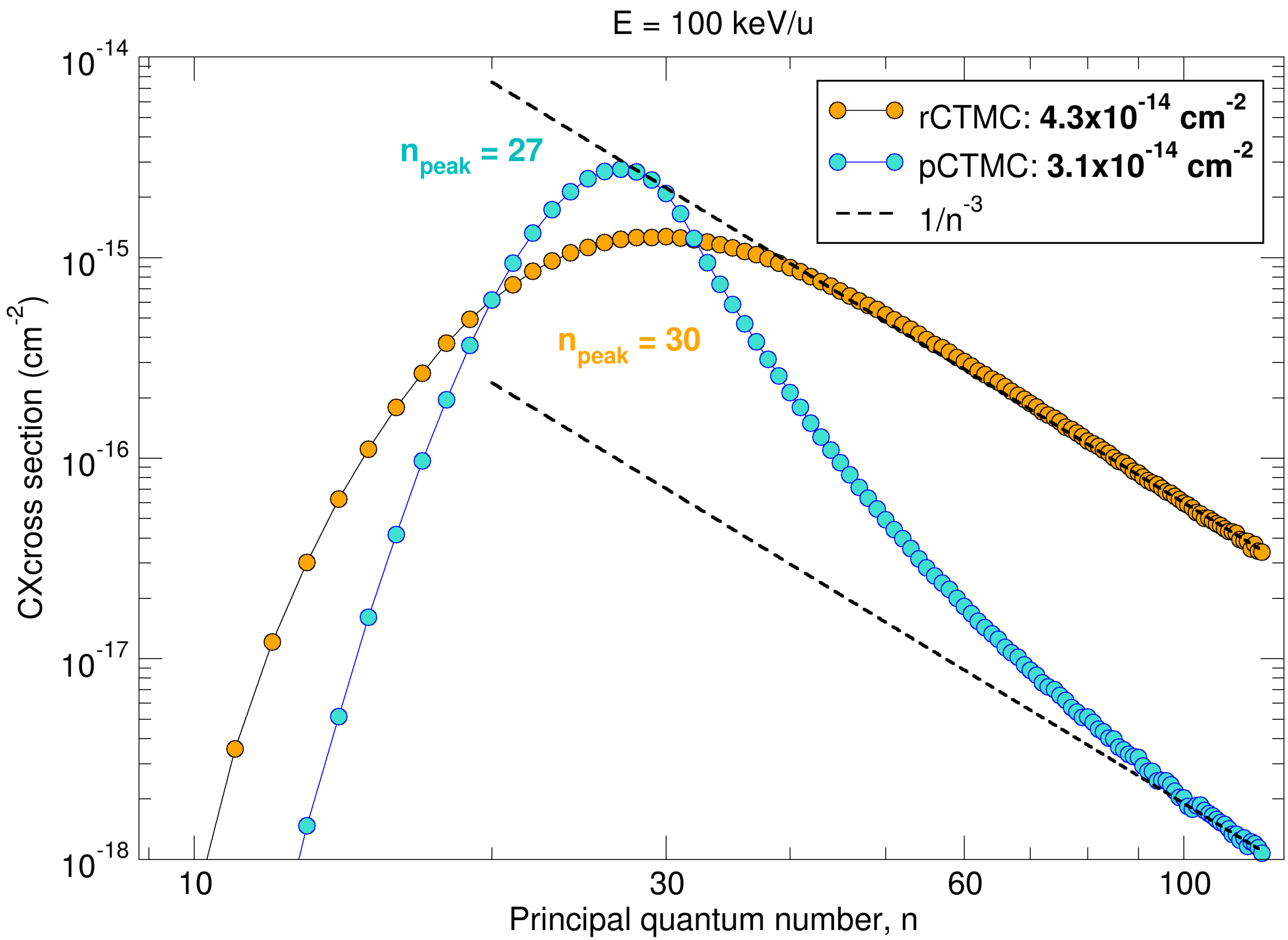
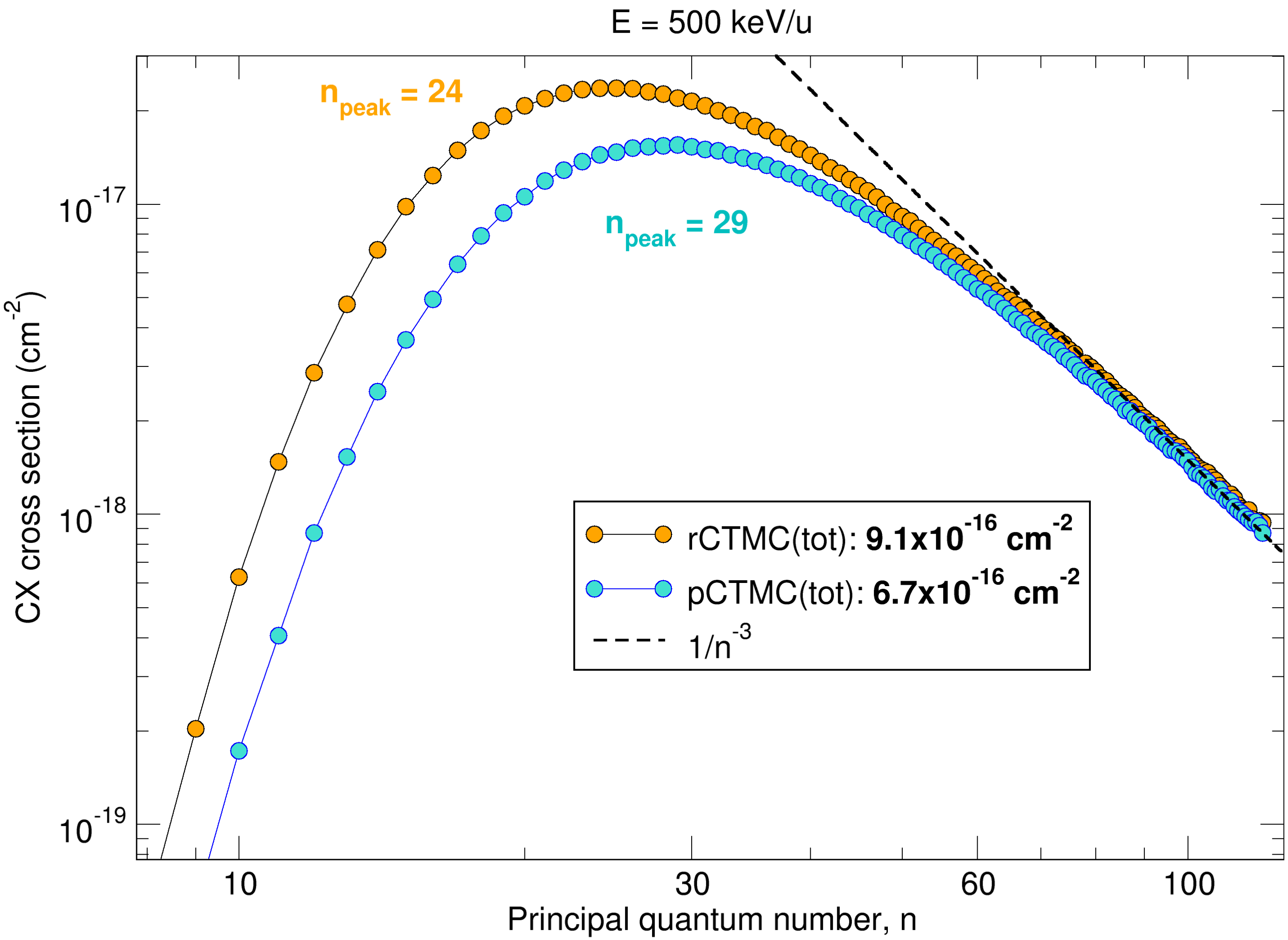
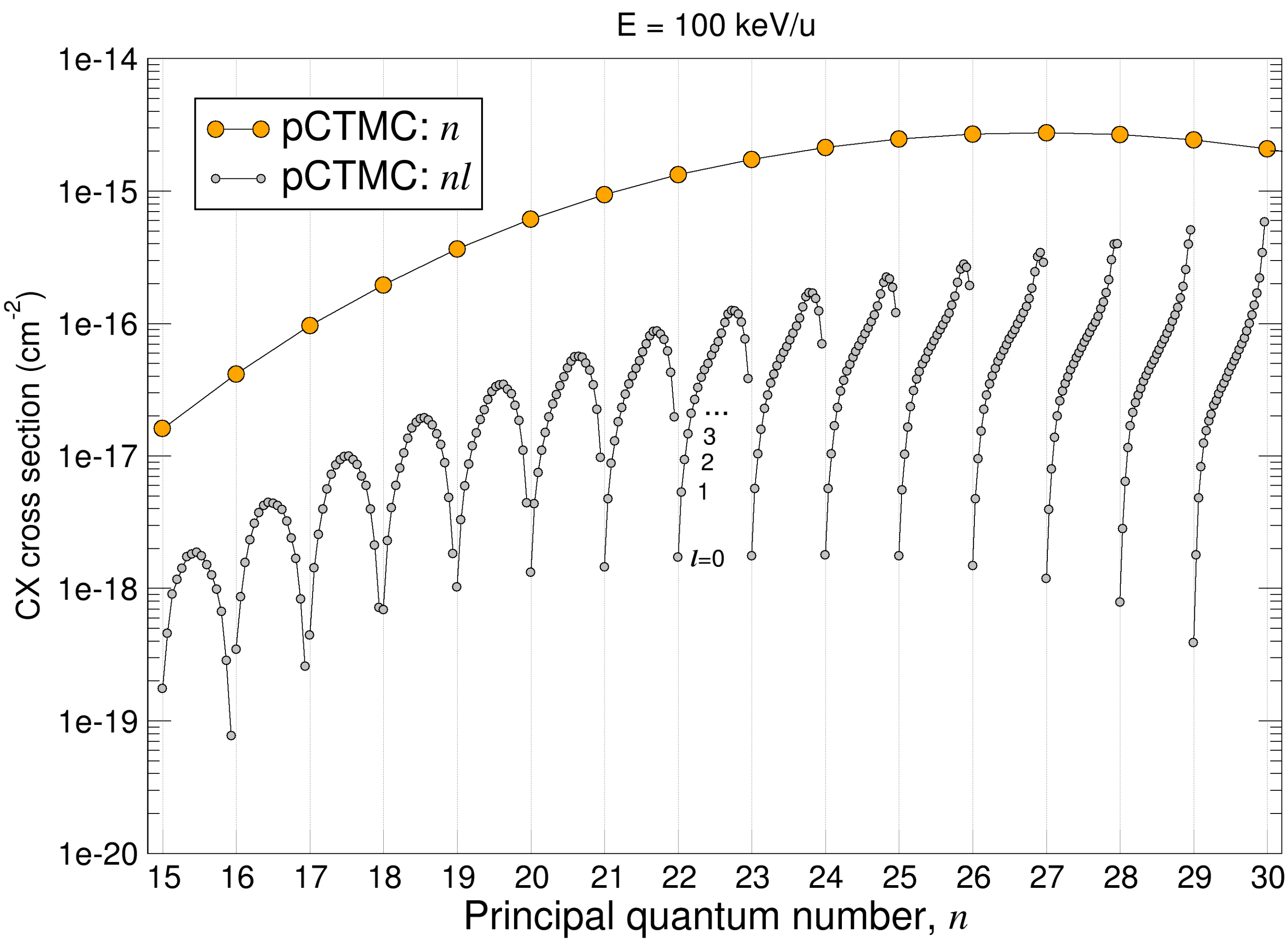
100 keV/u: rCTMC vs pCTMC



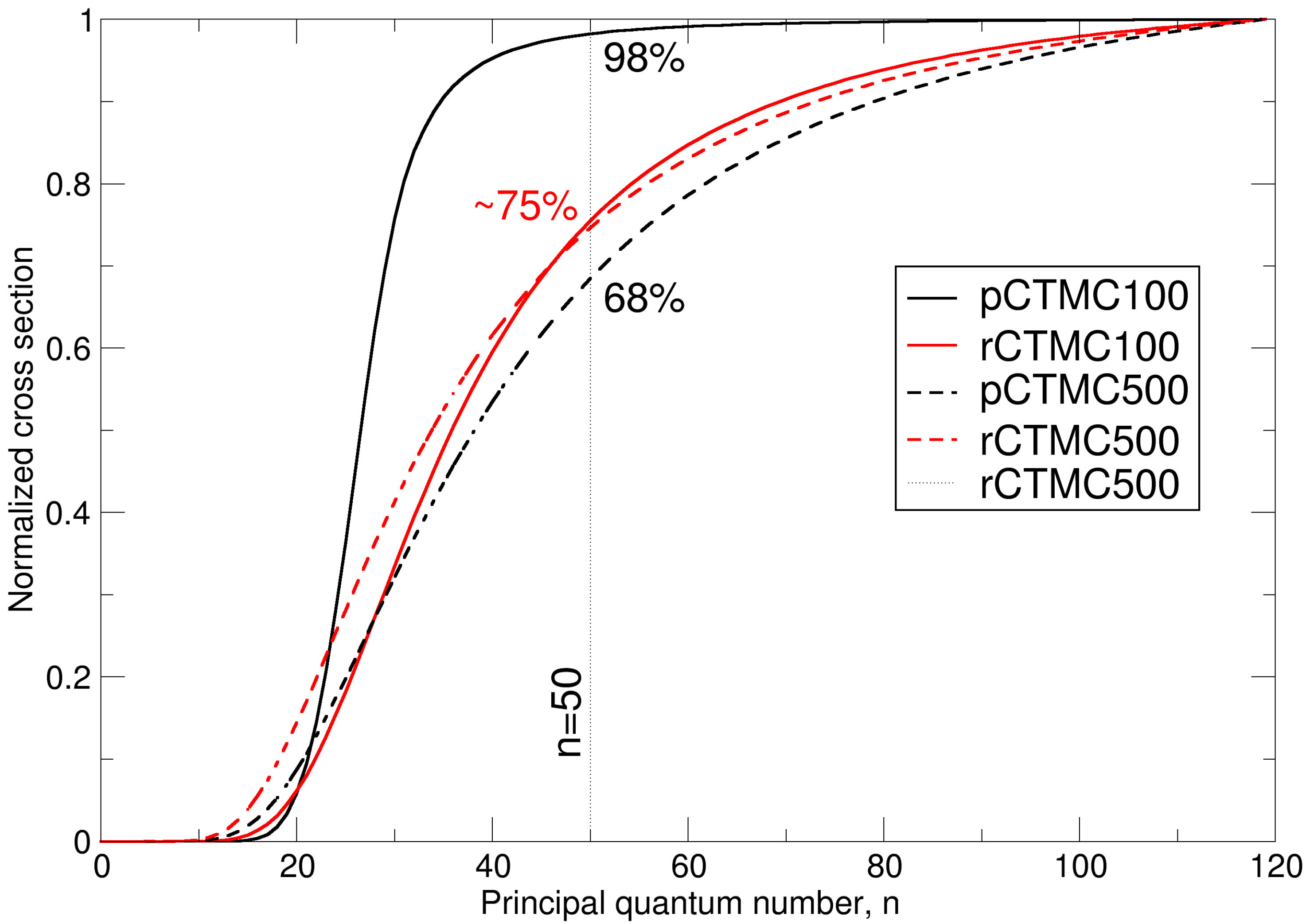
500 keV/u: rCTMC vs pCTMC



nl state-selective cross sections



Model size?



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Spectra modeling for W^{63+}

- Atomic data: **Flexible Atomic Code** (Gu)
- 2500 singly-excited levels $1s^2 2s^2 2p^6 nl$ (n<=50) and 3660 autoionizing states (relativistic configurations) $1s^2(2s2p)^7 nln'l'$ above ionization limit
- Electron- and proton-impact excitations, ionization, radiative recombination, dielectronic recombination, radiative decay
- CTMC cross sections
  - Rate = $n_o \cdot v \cdot \sigma$
  - $n_o \cdot v \sim 10^{18}$ cm^{-2}s^{-1}

- Collisional-radiative code **NOMAD** (Ralchenko & Maron)
  - General non-Maxwellian time-dependent code
  - Various effects included
  - EBITs, astrophysics, z-pinches, laser-produced plasmas,…
  - neutral beam physics: MSE, emission
- 20 keV
- 10^{14} cm^{-3}
- Steady-state plasma

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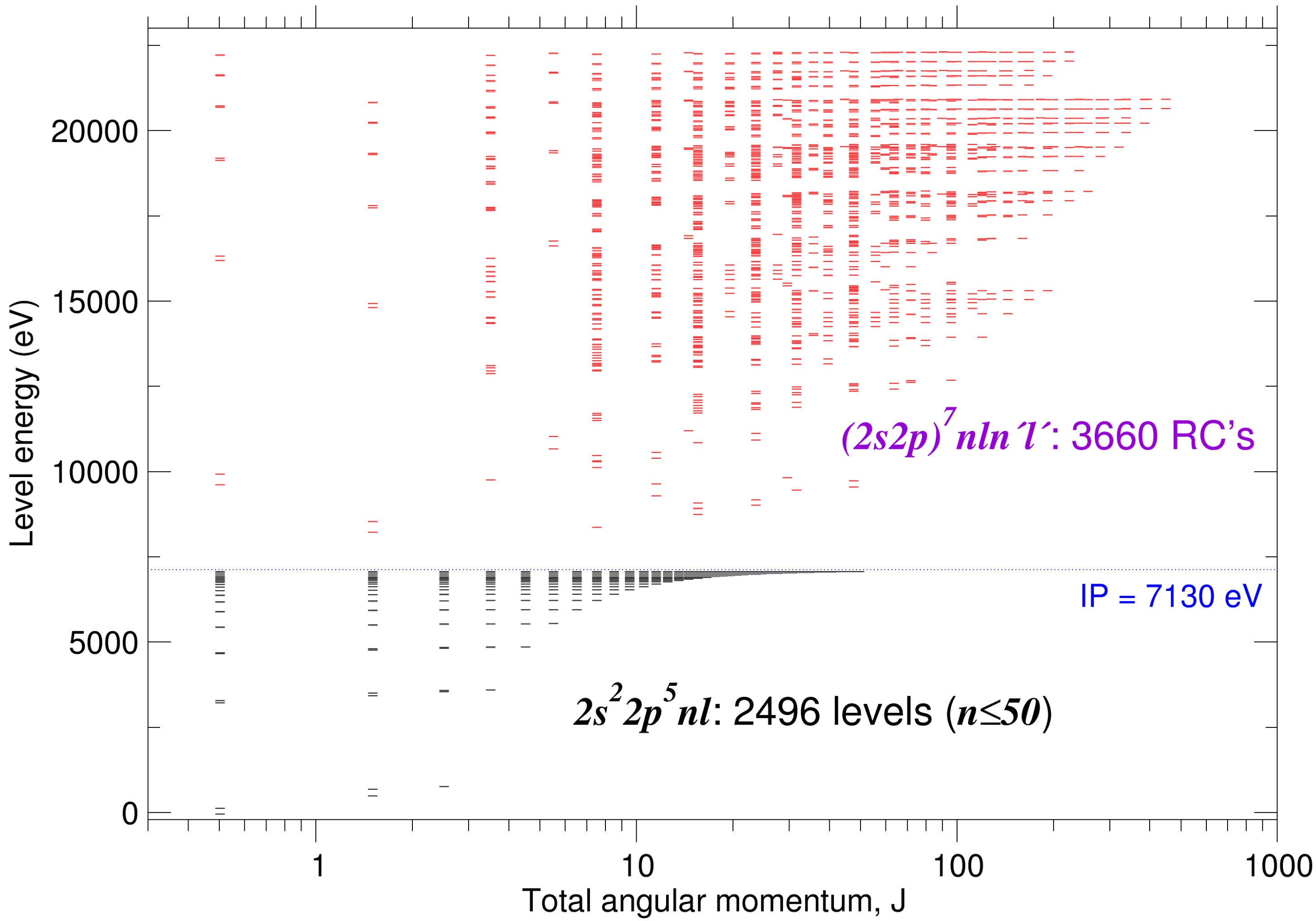
Level structure of W^{63+}



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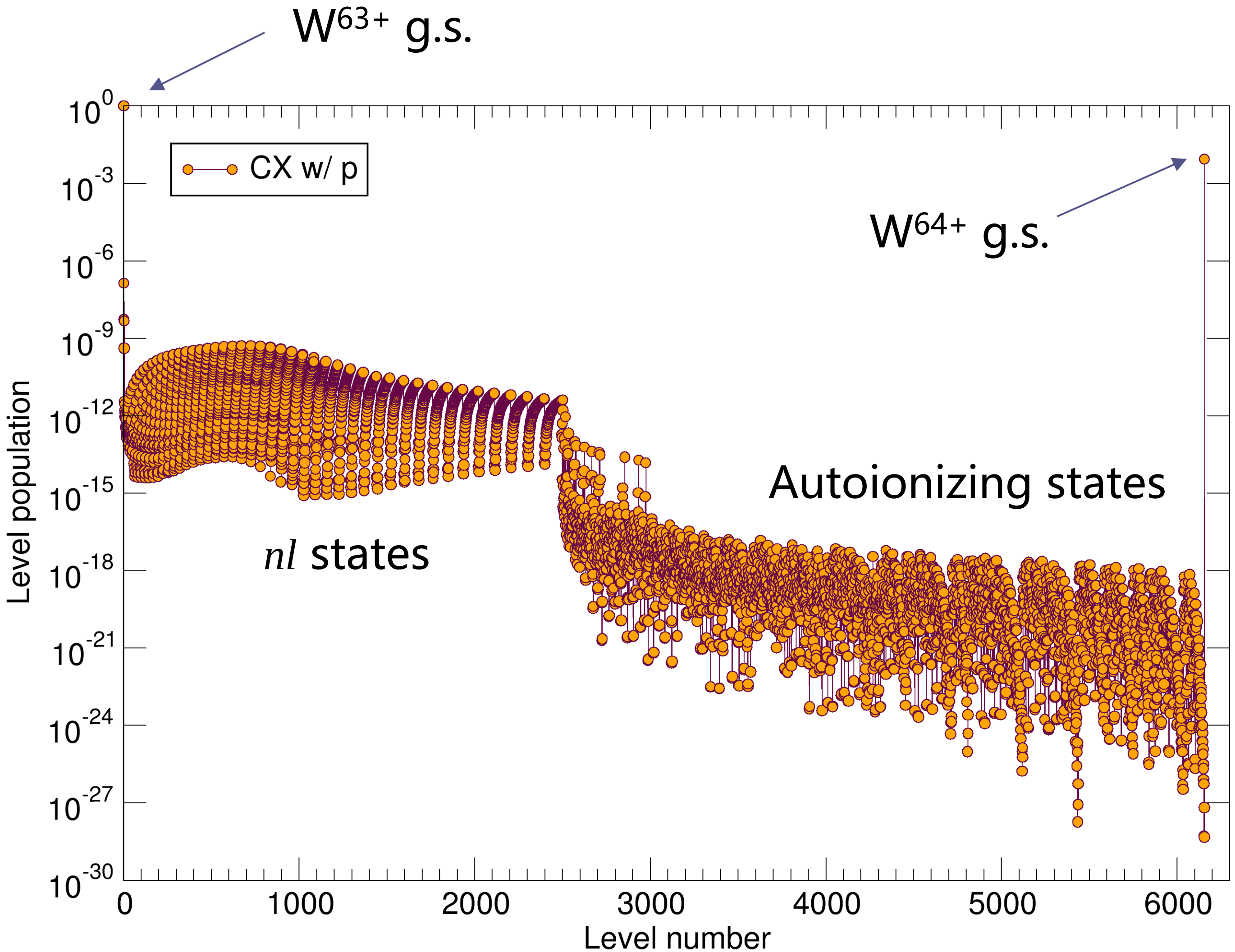
Level populations



$$\frac{N_{63}}{N_{64}} = \frac{RR + DR}{ION}$$

$$\frac{N_{63}}{N_{64}} = \frac{RR + DR + CX}{ION}$$

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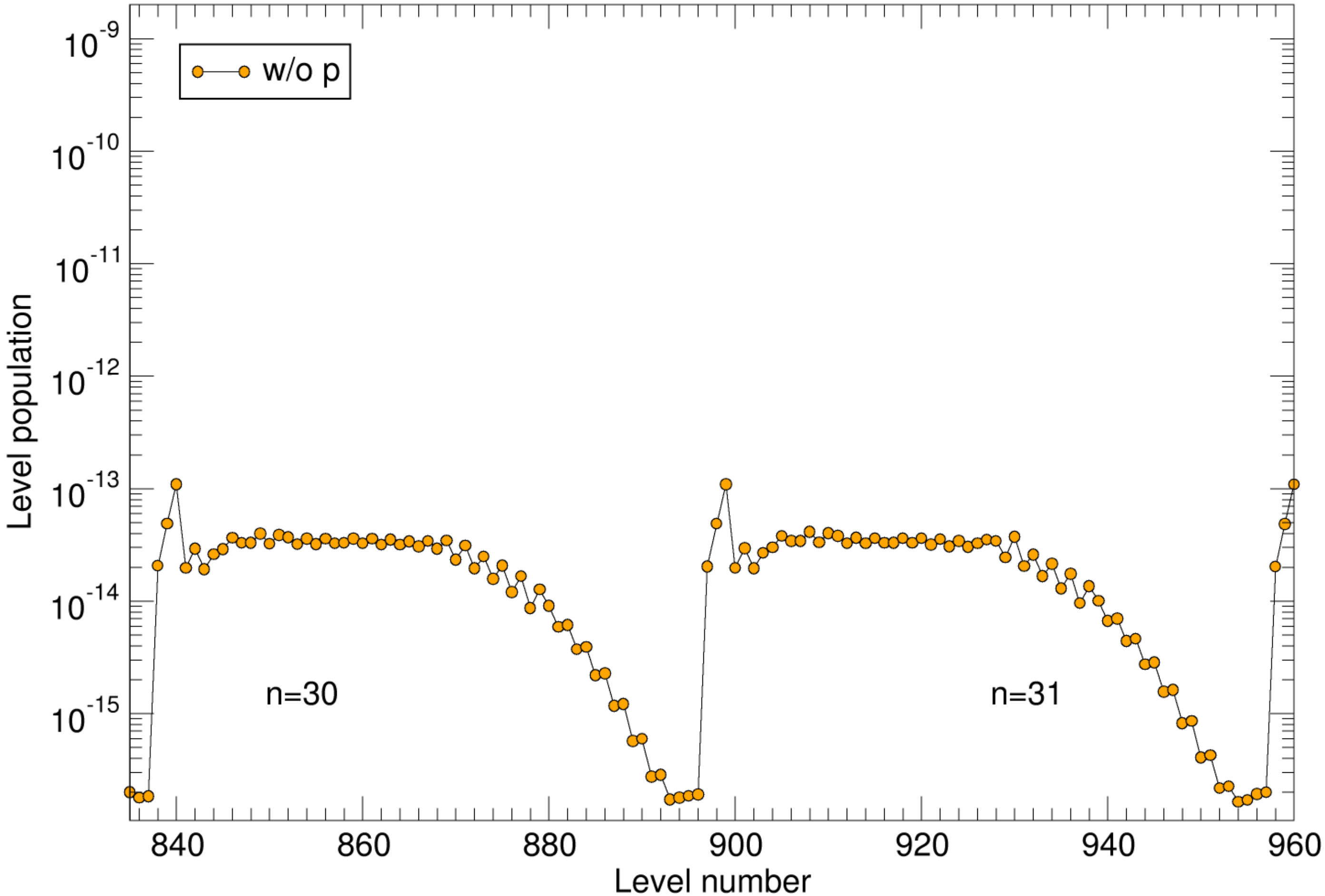
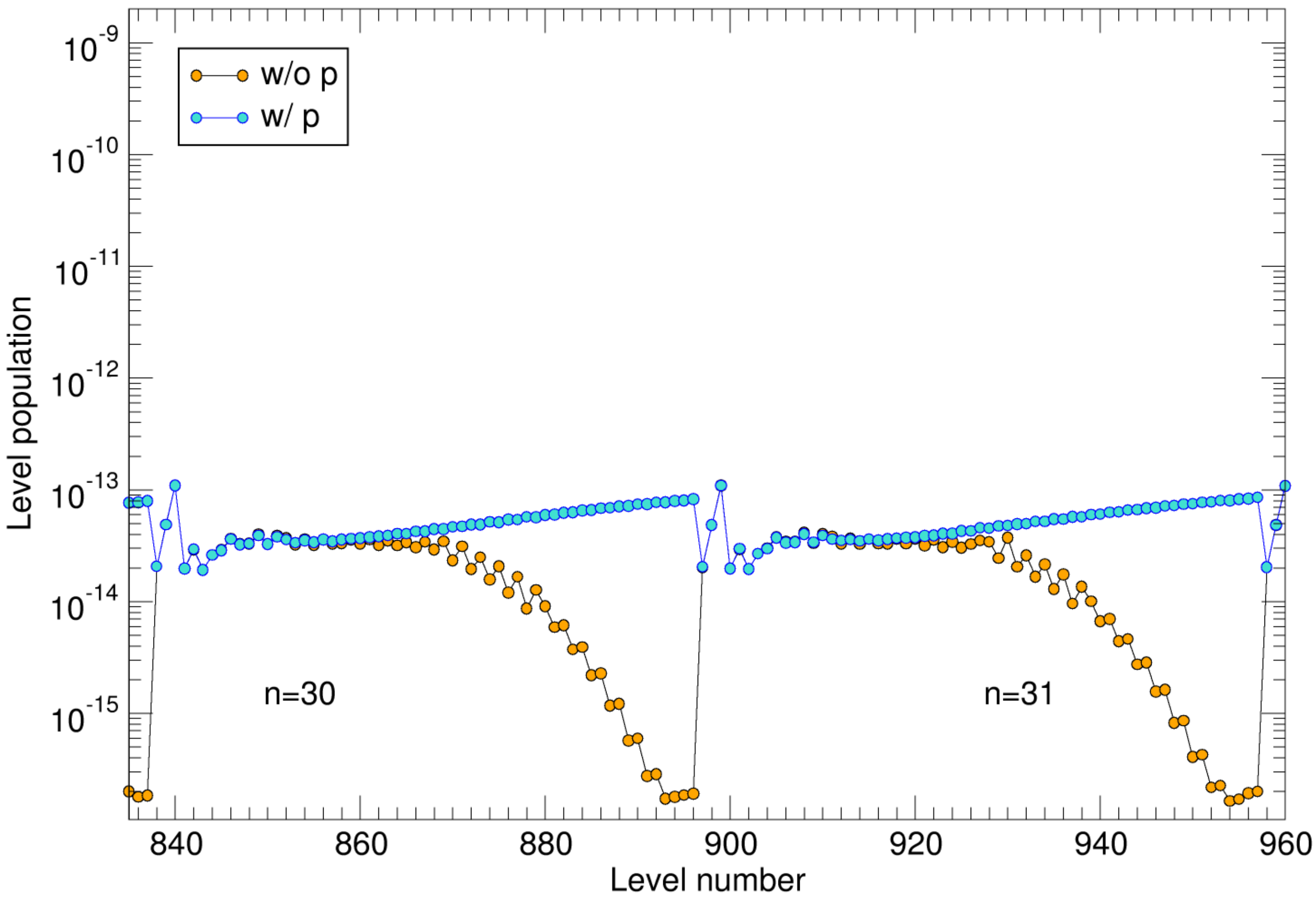
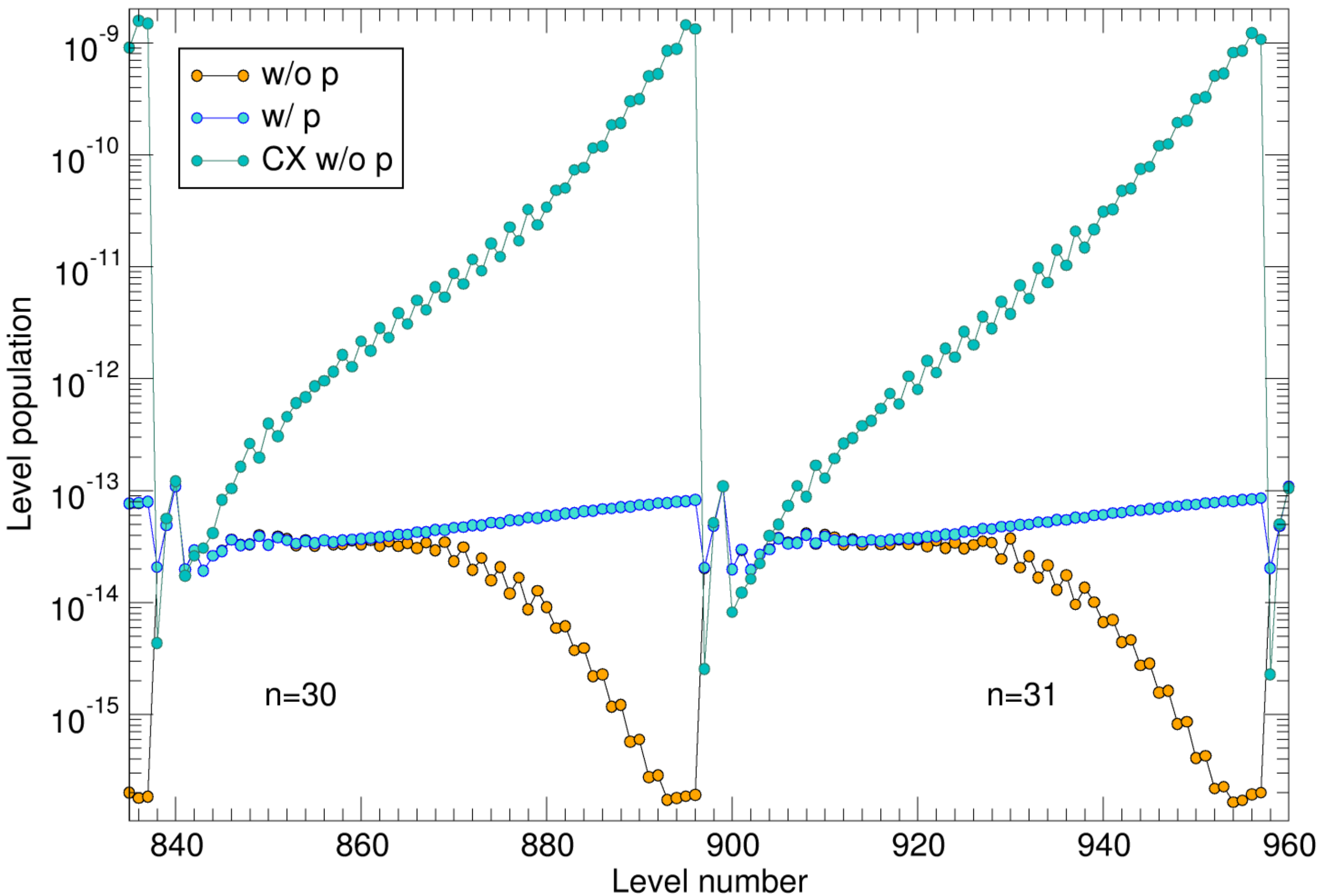
Electrons-only plasma



Electrons and protons



Electrons and CX



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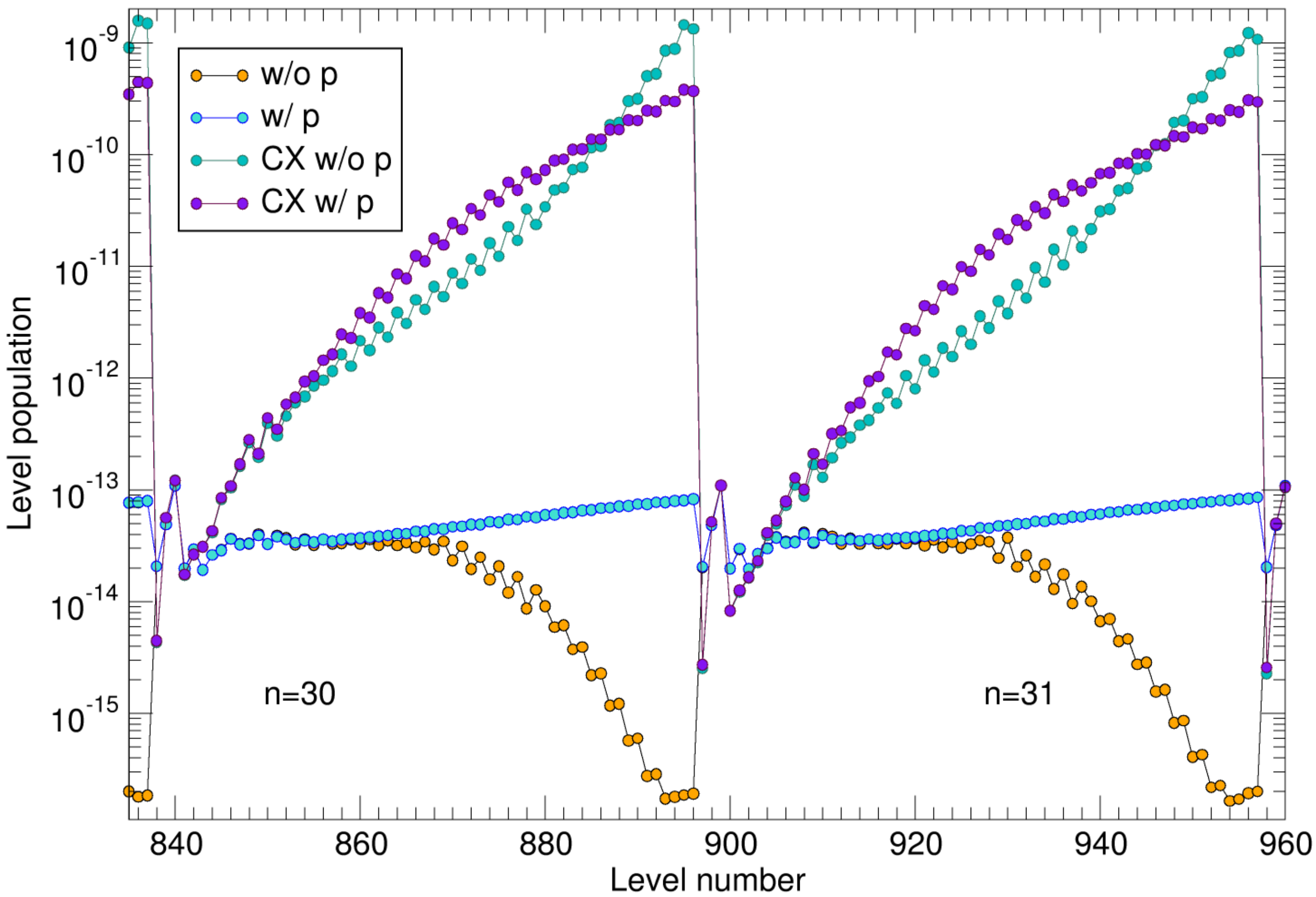
Electrons, protons, and CX



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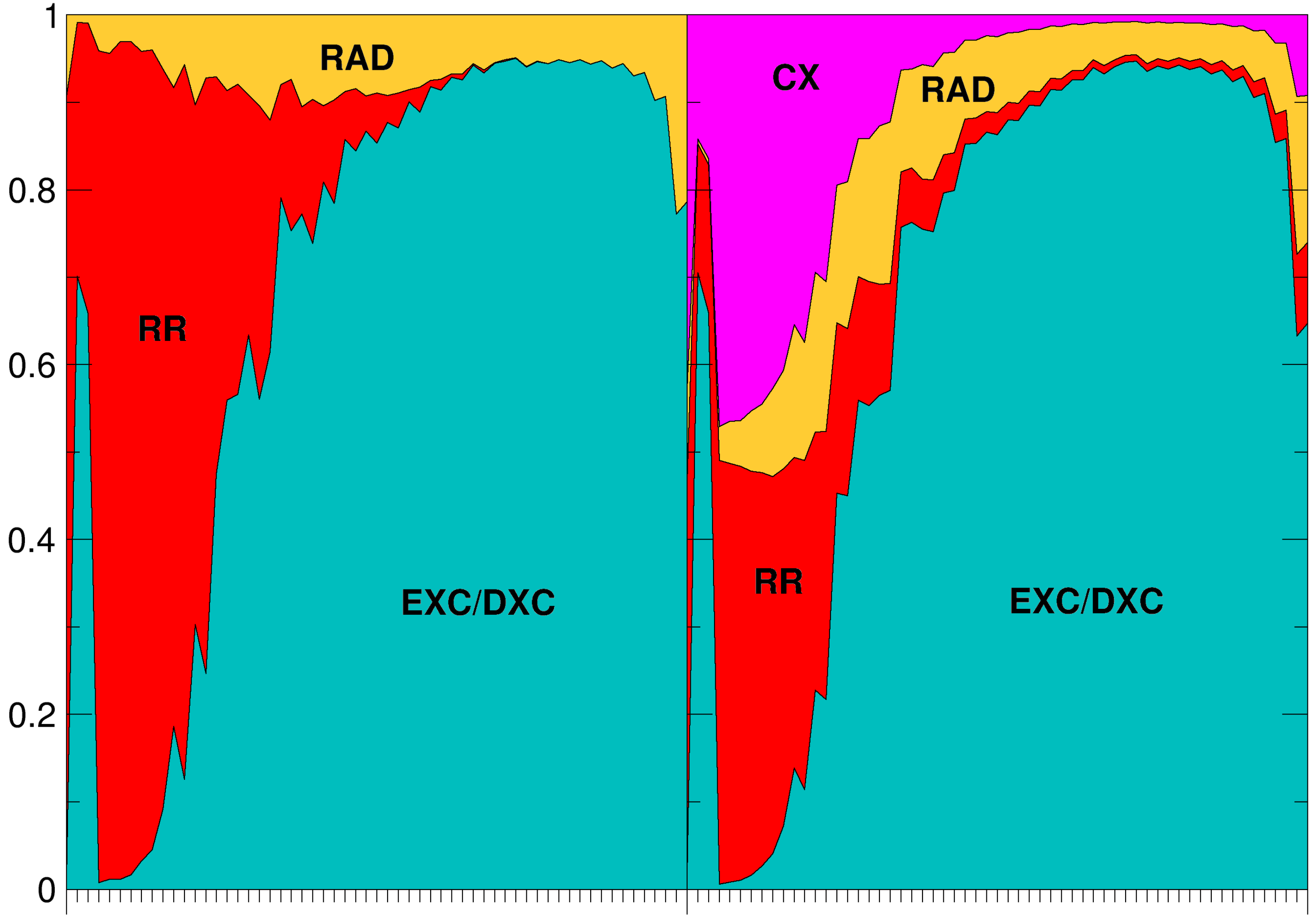
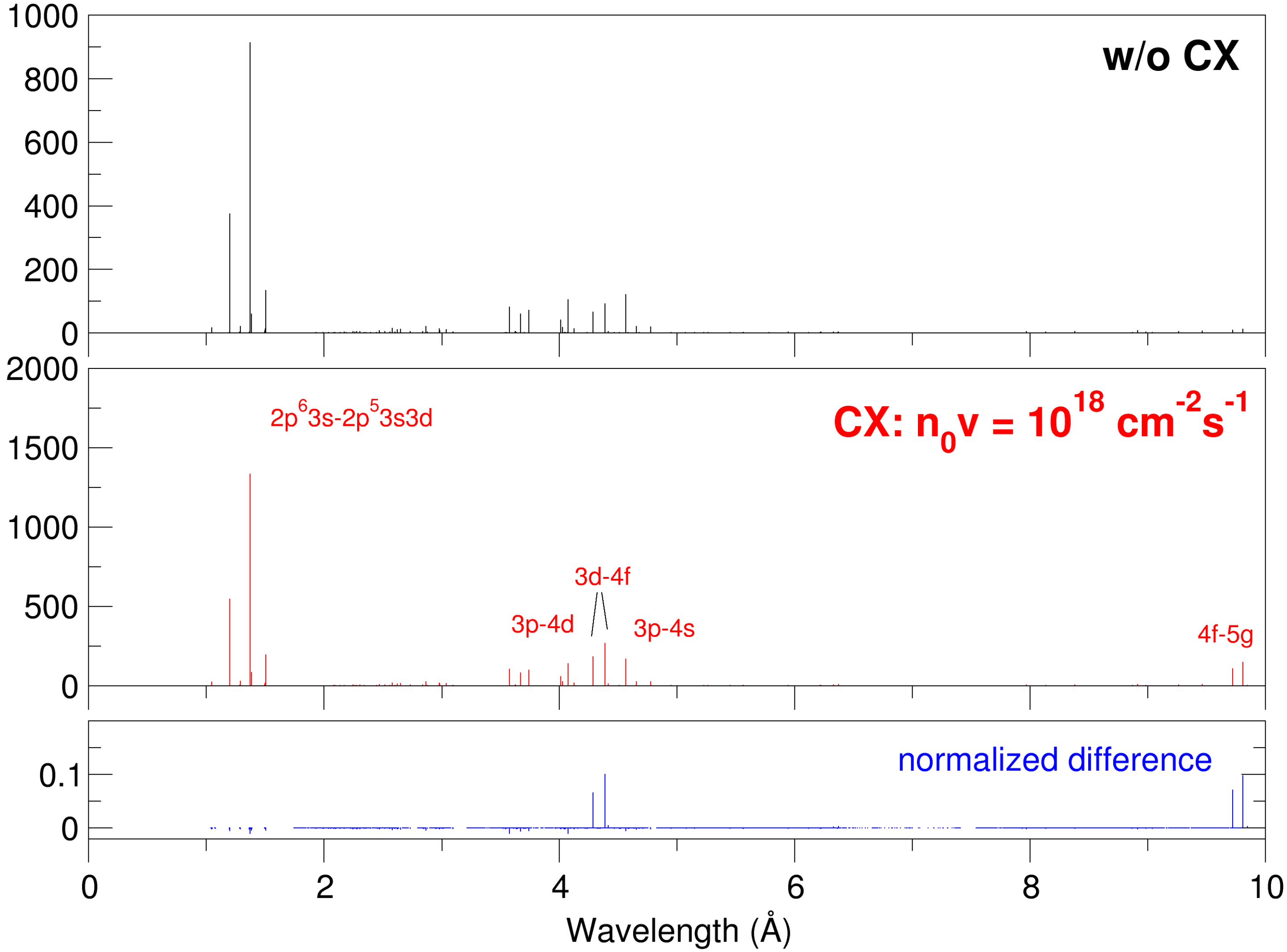
Population influx: rCTMC 100, n=31



pCTMC 100 keV/u: 1-10 Å



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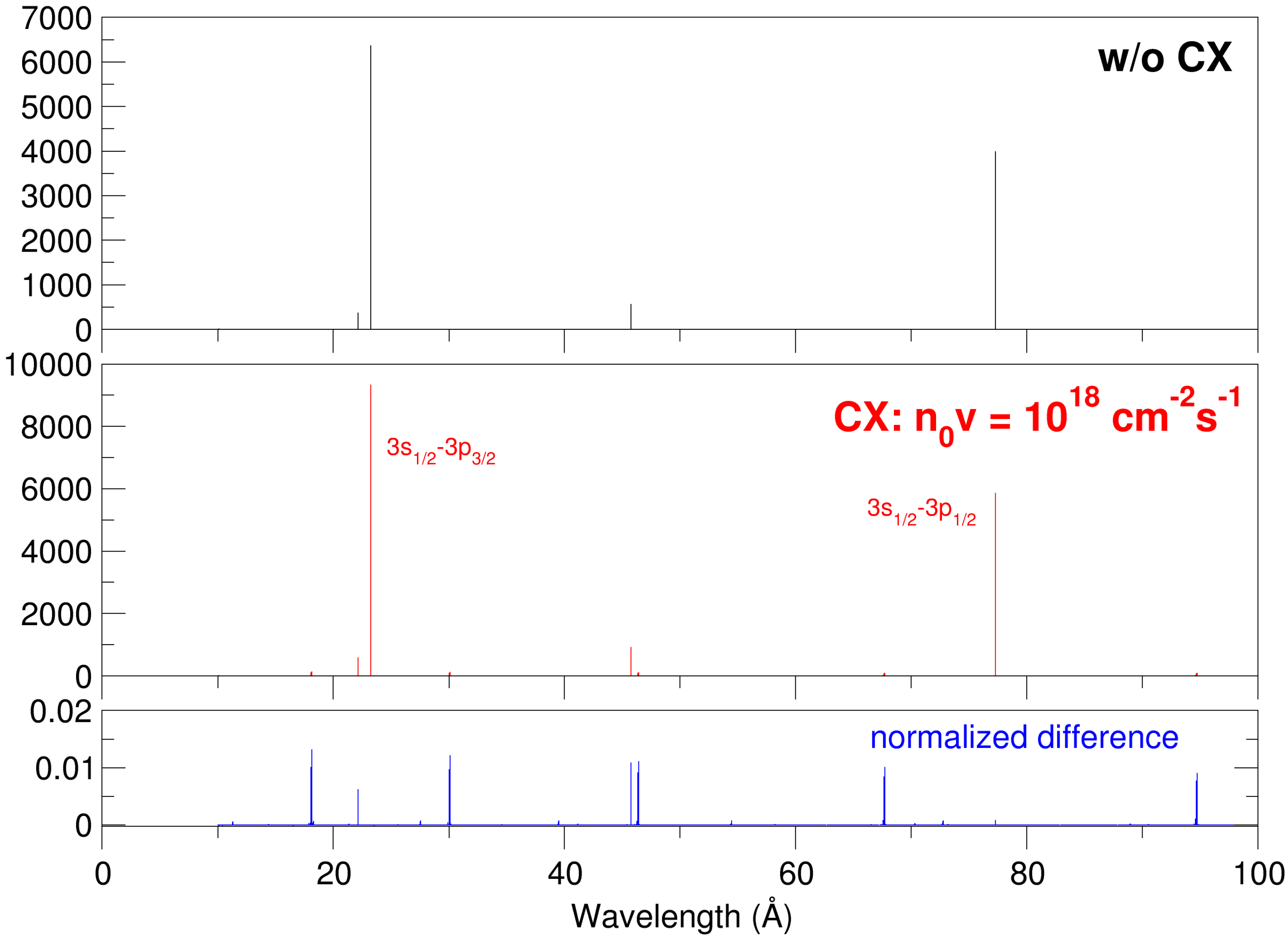
pCTMC 100 keV/u: 10 - 100 Å



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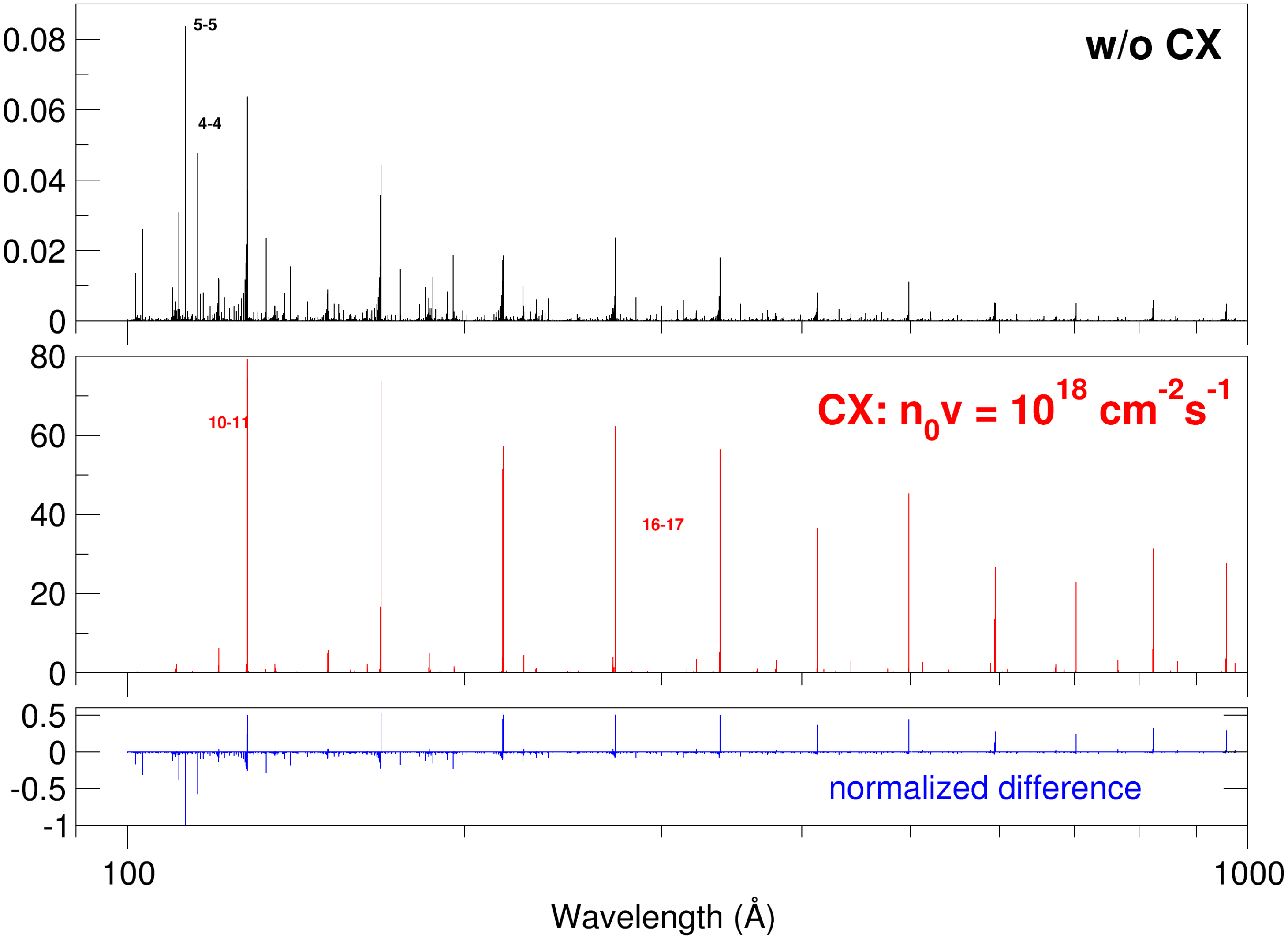
pCTMC 100 keV/u: 100 - 1000 Å



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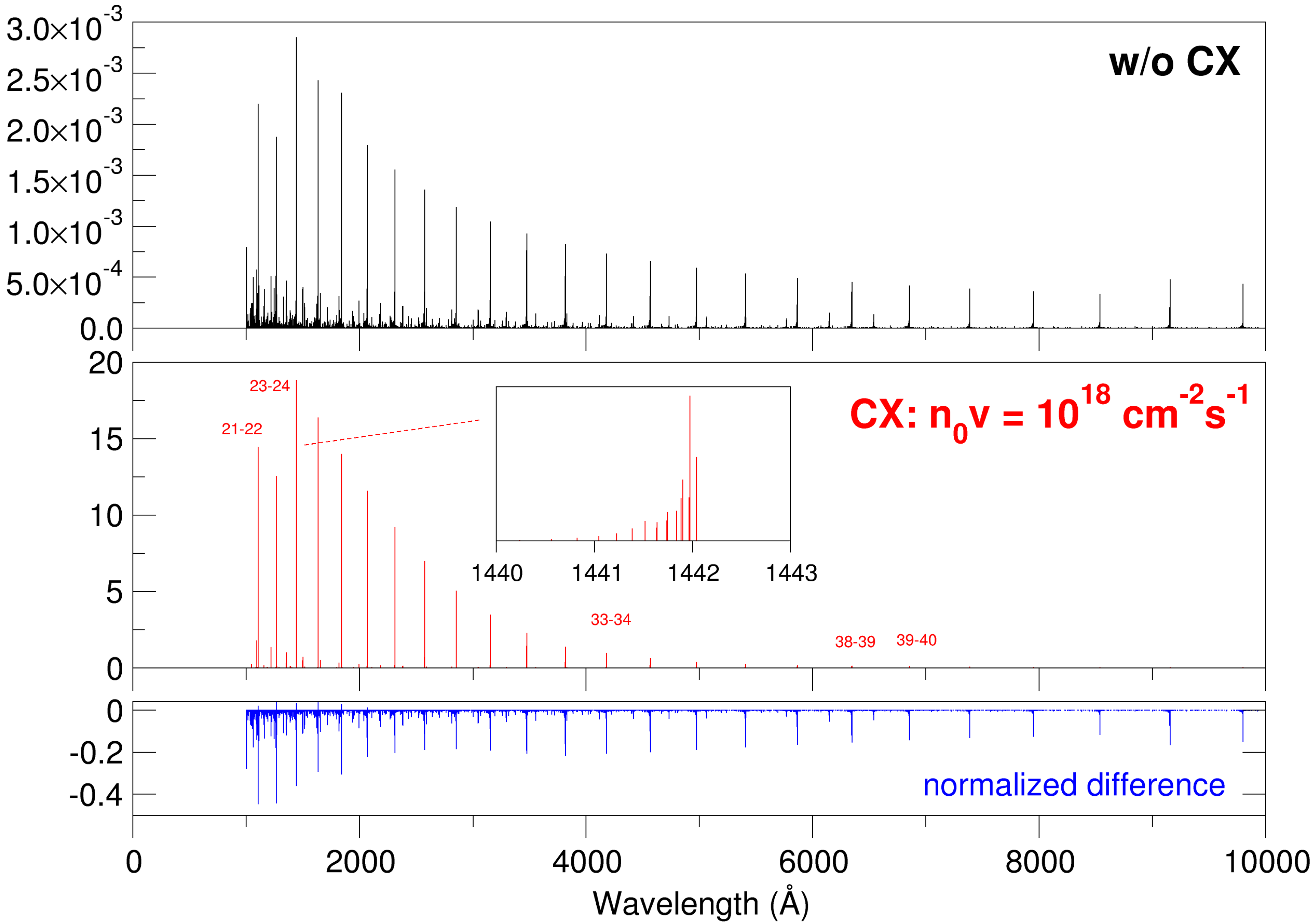
pCTMC 100 keV/u: 1000 - 10000 Å



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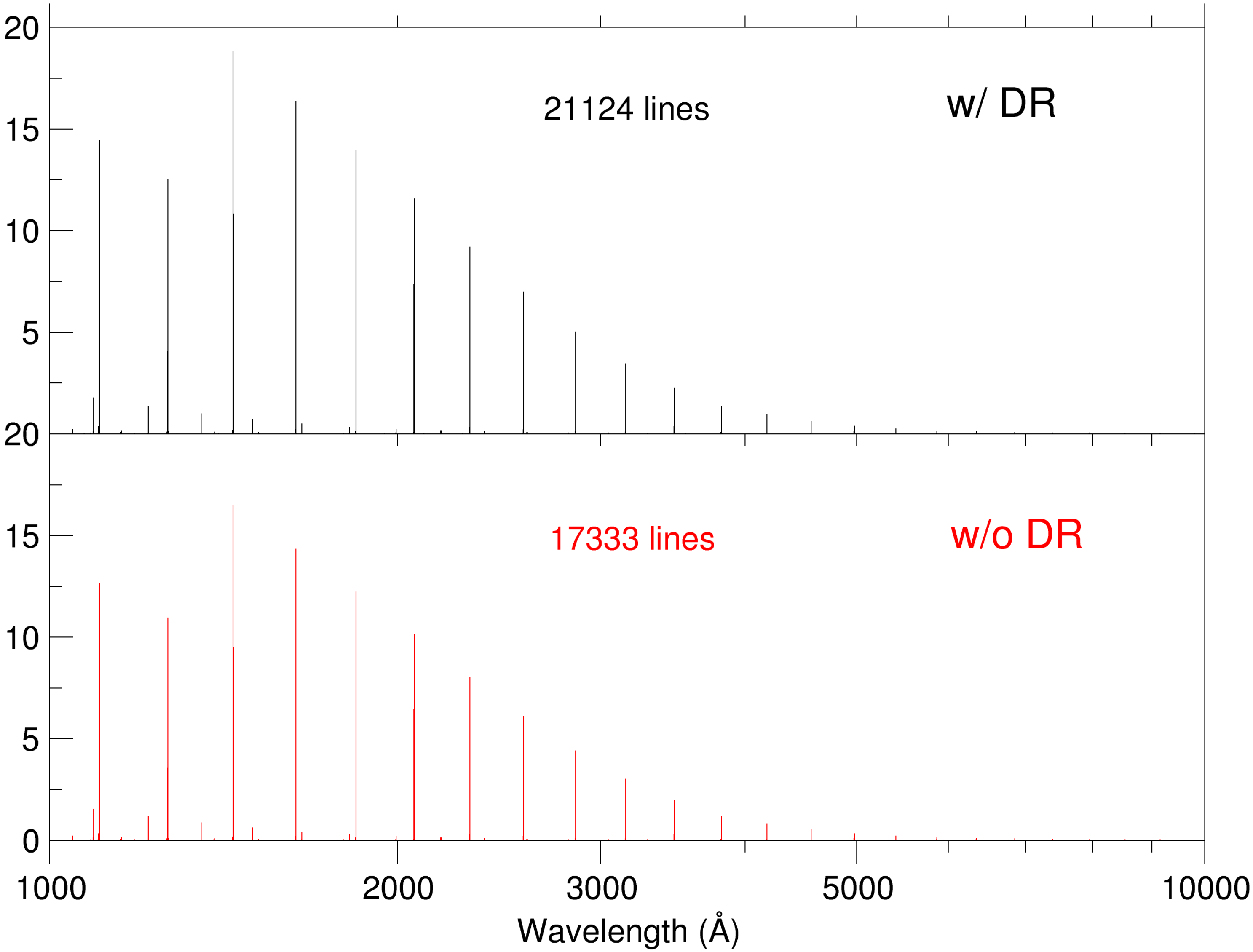
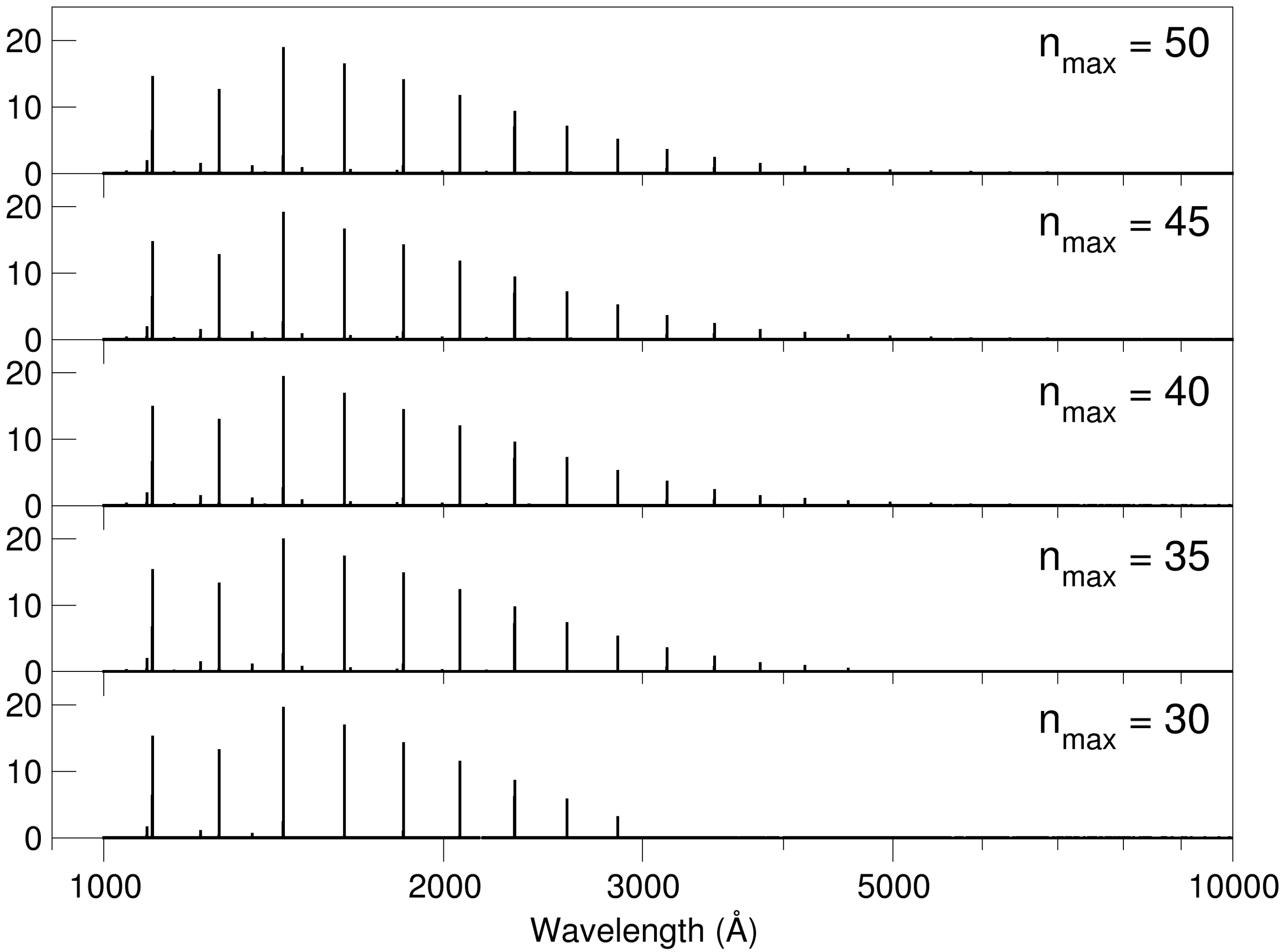
With DR vs. without DR



Visible spectra vs. n_{max}



100 keV/u
pCTMC

10^{18}

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Conclusions

- pCTMC and rCTMC charge exchange cross sections were calculated for W^{64+}+H a wide range of collision energies from 10 keV/u to 1000 keV/u
- A large-scale collisional-radiative model was developed for W63+ including main electron- and proton-induced collisions in typical conditions of ITER core plasma (20 keV, 10^{14} cm^{-3})
- CXR spectra were calculated across a wide spectral range from 1 Å and 10000 Å
- These spectra can be used for analysis and diagnostics of ITER plasma
- More calculations and modeling for different plasma/beam conditions are on the way