Poster Presentation for EUVL Symposium: Source-81

Atomic Model and Equation of State for Hydrodynamic Simulation of Laser Plasma Sources

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Category: Theoretical work (Simulation)

Introduction:

Necessity of hydrodynamic simulation of EUV generation
Atomic codes for hydrodynamic simulation
Build up appropriate models with enough accuracy and less computation time

Model:

Simple atomic model in which principal quantum number and azimuthal quantum number
Average ion model
Plasmas are assumed to be optically thin-limit (Collisional Radiative Equilibrium)
Statistical model to estimate each charge state density in the spectrum calculation

Results & Conclusion:

We have developed a simple atomic model for radiation transport in hydrodynamic code
The simple atomic models are enough for reproducing rough EUV spectra
Results of the full hydrodynamic simulation

Relating Presentation: Source-85
Radiation Hydrodynamic Simulations of Laser-Produced Plasma for EUVL
Atsushi Sunahara et al (Institute for Laser Technology)
Takeshi Nishikawa (Okayama University)
Masakatsu Murakami et al (Osaka University)

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To make accurate hydrodynamic simulations

High-Z plasmas like Xe and/or Sn-plasma,

energy transport by radiation (X-ray and EUV)
play an important role to construct the plasma structure

Estimating accurate emissivity and opacity of

wide spectrum range,
wide plasma parameters (temperature and density)
with less computation time

is necessary

To estimate detailed number of conversion efficiency to EUV,
more accurate model might be required.

Why Average Ion Model

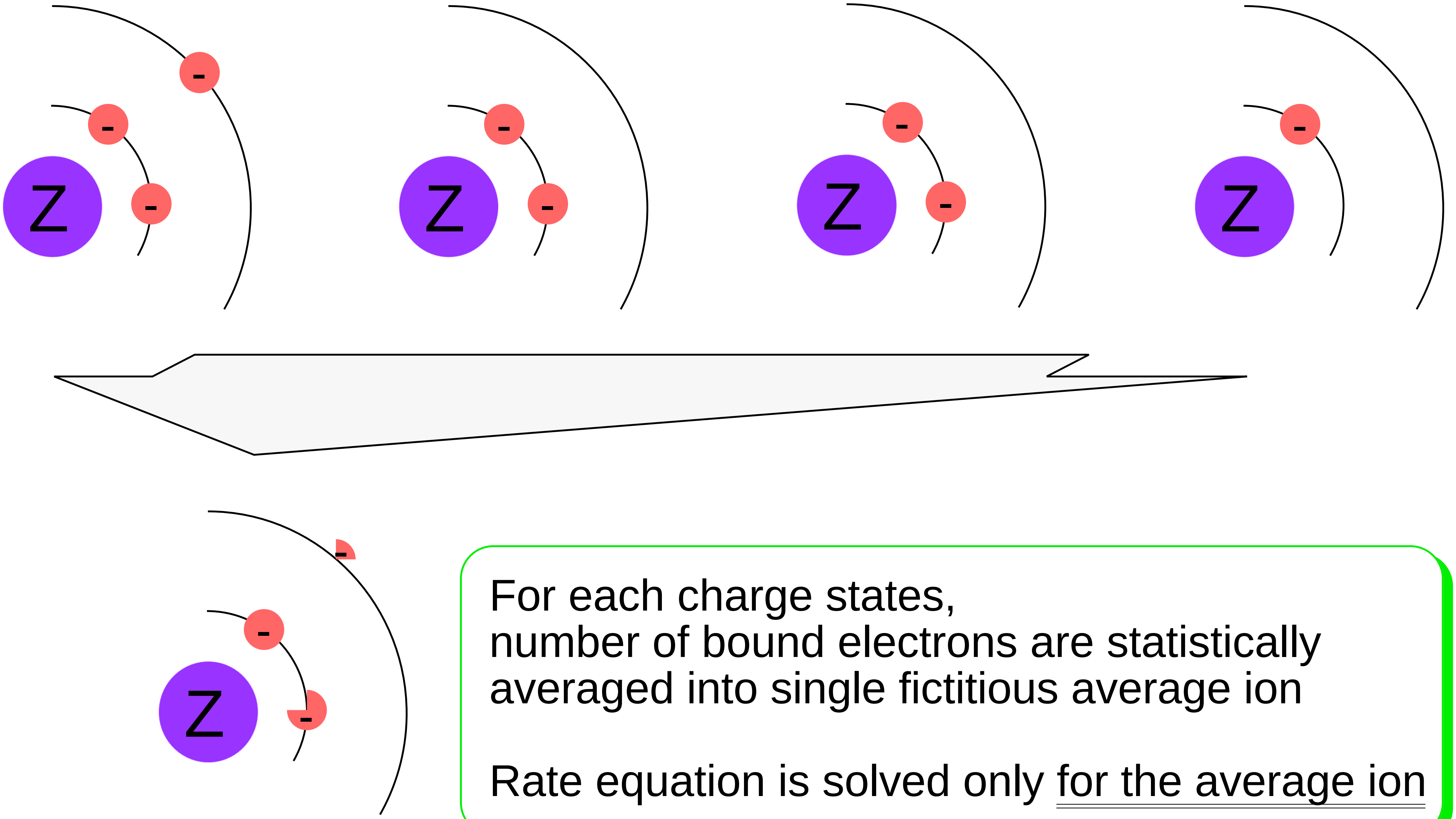
To solve full rate equation for Xe- or Sn-plasma is
still difficult and time consuming.
We need detailed cross sections for many processes.
Not only energy level and oscillator strength, but
Collisional ionization cross section
Collisional excitation cross section
are required!

Matrix of the rate equation becomes so large
simply because Xe- or Sn-plasma has many sub-shell states.

So, we solve rate equation by the average ion model

Contribution from different charge state ions are treated
by statistical method

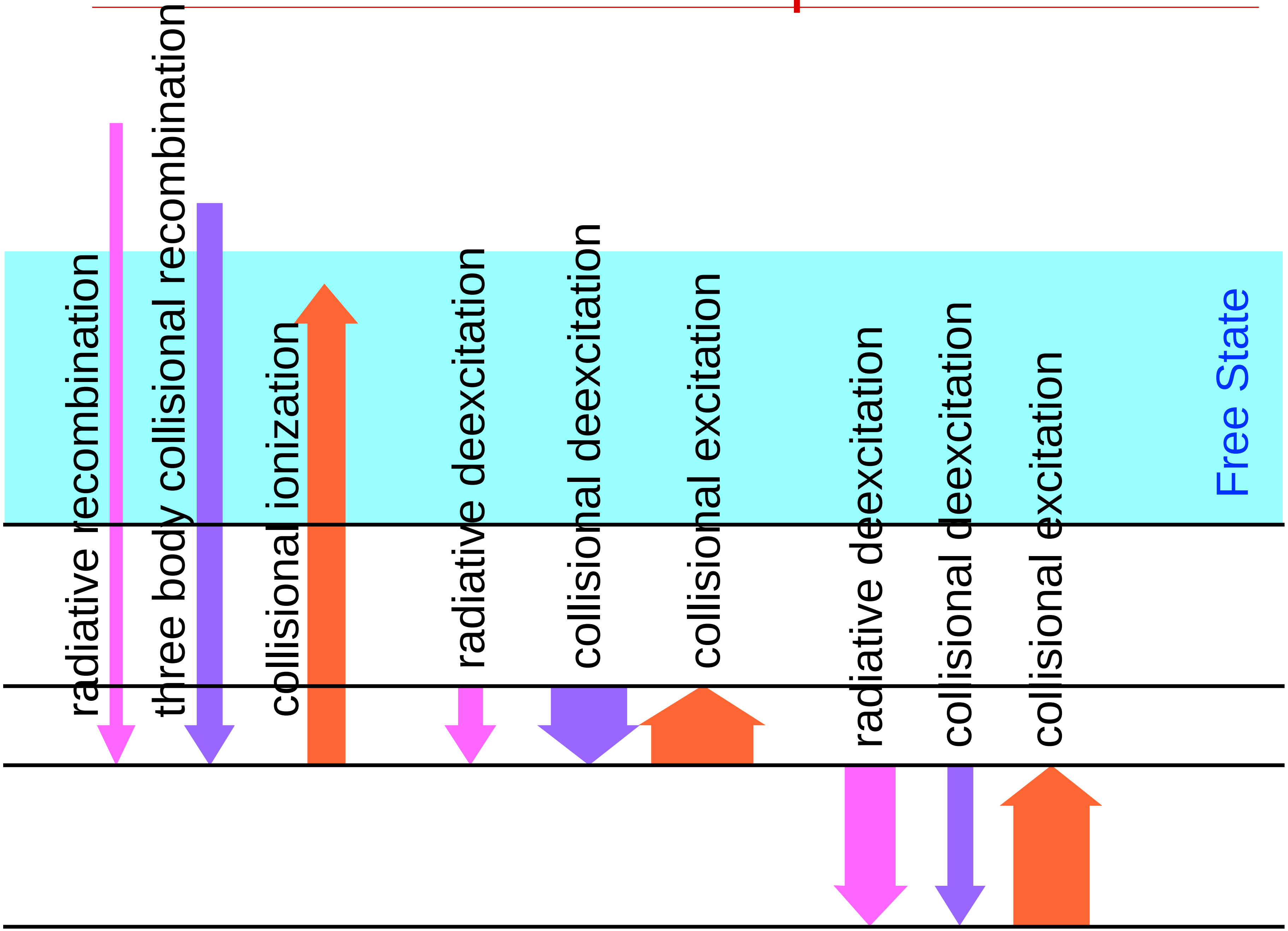
Average Ion Model



For each charge states,
number of bound electrons are statistically
averaged into single fictitious average ion

Rate equation is solved only for the average ion

Collisional Radiative Equilibrium Model



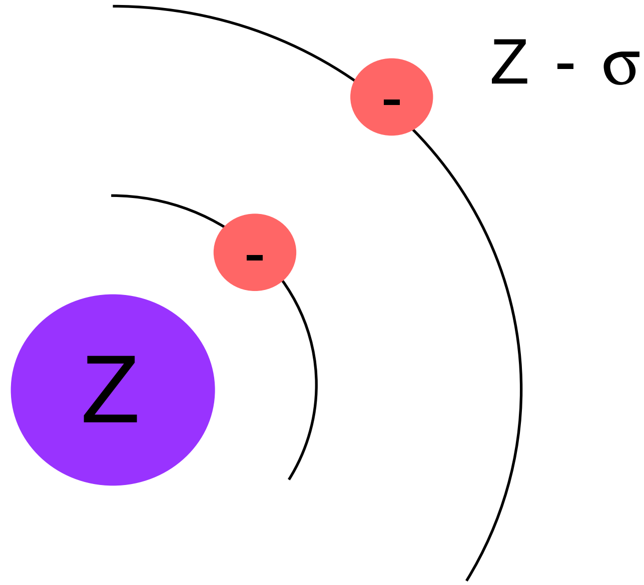
Screened Hydrogenic Model

$$_n = Z - \sum_{k \le n} P_k \sigma_{nk} \left(1 - \frac{1}{2}\delta_{nk}\right)$$

$$_n = -\frac{Q_n{}^2}{2n^2} + \sum_{k \ge n} P_k \frac{Q_k{}^2}{k^2} \sigma_{kn} \left(1 - \frac{1}{2}\delta_{nk}\right)$$

$$_{ion} = \sum_n -P_n \frac{Q_n{}^2}{2n^2}$$

$$\langle H \rangle = \sum_n P_n \left(\frac{Q_n{}^2}{2n^2} - \frac{ZQ_n}{n^2}\right) - \sum_n \sum_{k \le n} P_n P_k \frac{Q_n{}^2}{n^2} \sigma_{nk} \left(1 - \frac{1}{2}\delta_{nk}\right)$$



l-splitting effect

$$\Delta\langle H \rangle = -\sum_n \sum_{n'l'} P_n P_{n'l'} \frac{Q_{n'}{}^2}{n'^2} q_{nn'} g_{n'l'}$$

F. Perrot, Phys.Scripta 39, 1989.

Ionization Potential

Xenon (Xe)

N	More	Perrot	Present	Carlson
29	-622	-772.07	-868.55	-857
30	-589	-744.19	-831.14	-819
31	-557	-677.19	-752.57	-737
32	-526	-648.9	-715.29	-701
33	-495	-621	-678.65	-651
34	-465	-593.52	-642.68	-618
35	-436	-566.48	-607.38	-583
36	-407	-539.87	-572.77	-549
37	-379	-429.77	-450.99	-452
38	-352	-402.69	-416.67	-421
39	-325	-376.09	-383.11	-390
40	-299	-350.02	-350.35	-358
41	-274	-324.48	-318.4	-325
42	-249	-299.48	287.27	-294
43	-225	-275.03	-256.96	-263
44	-201	-251.15	-227.49	-233
45	-178	-227.82	-198.86	-202
46	-156	-205.06	-171.06	-171
47	-45	-76.21	-92.14	-105.9
48	-37.8	-68.64	-78.62	-92.1
49	-31.1	-55.86	-59.95	-71.8
50	-24.8	-49.12	-48.55	-59.7
51	-18.9	-42.73	-38.05	-46.7
52	-13.5	-36.71	-28.48	-32.1
53	-8.48	-31.06	-19.83	-21.21
54	-3.93	-25.78	-12.1	-12.13

Tin (Sn)

N	More	Perrot	Present	Carlson
29	-451	-580.93	-664.93	-665.1
30	-424	-556.77	-632.23	-632
31	-397	-498.9	-563.77	-556.3
32	-370	-474.61	-531.48	-525
33	-344	-450.72	-499.83	-486.7
34	-319	-427.25	-468.85	-456.4
35	-295	-404.21	-438.55	-426.1
36	-271	-381.61	-408.93	-395.9
37	-248	-288	-304.62	-299.5
38	-225	-265.48	-275.85	-274.4
39	-203	-243.45	-247.85	-249.4
40	-182	-221.94	-220.64	-224.3
41	-161	-200.97	-194.24	-198.2
42	-141	-180.54	-168.66	-173.3
43	-122	-160.66	-143.91	-148.4
44	-103	-141.34	-119.99	-123.5
45	-85.1	-122.58	-96.91	-98.67
46	-67.7	-104.38	-74.67	-72.28
47	-14.1	-35.89	-39.65	-40.74
48	-10.1	-31.15	-30.67	-30.5
49	-6.53	-23.41	-11.85	-14.63
50	-3.42	-19.6	-7.23	-7.34

Statistical Method for Predicting Charge State Distribution

Population of the average ion model gives
probability of the electron occupation in the level *k*
For example,

$$P_{1s}=2, P_{2s}=2, P_{2p}=6, P_{3s}=2, P_{3p}=6, P_{3d}=10, P_{4s}=2, P_{4p}=5, P_{4d}=8, P_{4f}=0, \ldots =$$

$$x_{1s}{}^{2} x_{2s}{}^{2} x_{2p}{}^{6} x_{3s}{}^{2} x_{3p}{}^{6} x_{3d}{}^{10}$$

$$x_{4s}{}^{2} \frac{6!}{(6-5)!\,5!} x_{4p}{}^{5} \left(1-x_{4p}\right)^{6-5} \frac{10!}{(10-8)!\,8!} x_{4d}{}^{8} \left(1-x_{4d}\right)^{10-8} \left(1-x_{4f}\right)^{14}$$

•••

Here, $x_k = P_k / D_k$
D_k: Statistical weight of state *k*
P_k: Population of state *k* given by average ion model

Emissivity of Xe Plasmas

Temperature = 20 (eV)
Density = 0.01 (g/cm3)