Collisional-Radiative modeling of the Tungsten spectrum from the EBIT and EAST Tokamak

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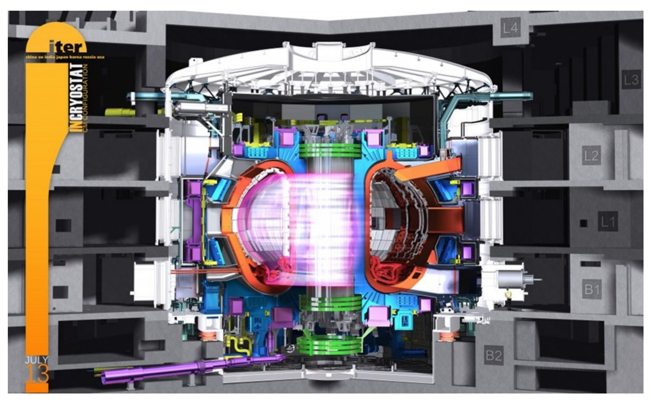
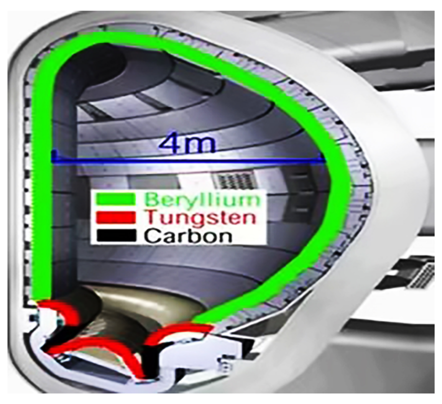
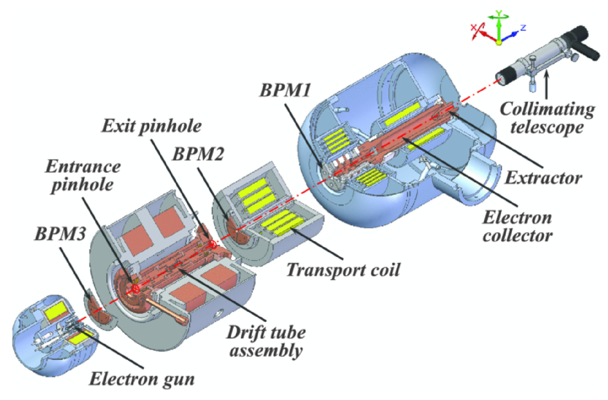
IAEA International Atomic Energy Agency

1. Motivation & Background

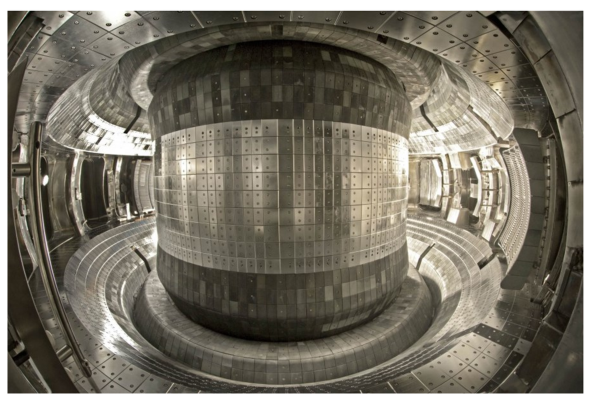




ITER(www.iter.org)



EBIT(Rev. Sci. Instrum 85, 093301)



EAST (www.ipp.cas.cn)

- **W (Z=74)** good candidate of the divertor:
  - High-energy threshold of Sputtering
  - Low sputtering yield
  - High re-deposition efficiency
  - Low tritium retention
- **W Impurities**:
  - Radiation loss from highly charged W ions
  - To be the diagnostics line

3.Result & Dissusion: EUV spectrum of W^{13+}-W^{15+} ions in the EBIT

Transition wavelength and rate of W^{13+} ions

Key	Lower	Upper	λ	λ^c_{exp}	$A(10^{11} s^{-1})$
	$[(4f^5_{5/2}4f^7_{7/2})_6 5p_{1/2}]_{13/2}$	$[(4f^5_{5/2}4f^7_{7/2})_6 5d_{3/2}]_{15/2}$	18.18		1.26
	$[(4f^6_{7/2})_6 5p_{3/2}]_{15/2}$	$[(4f^6_{7/2})_6 5d_{5/2}]_{17/2}$	21.03		1.52
	$[(4f^5_{5/2}4f^7_{7/2})_5 5p_{3/2}]_{13/2}$	$[(4f^5_{5/2}4f^7_{7/2})_5 5d_{5/2}]_{15/2}$	21.05		1.49
	$[(4f^4_{5/2})_4 5p_{3/2}]_{11/2}$	$[(4f^4_{7/2})_4 5d_{5/2}]_{13/2}$	21.07		1.41
	$[(4f^5_{5/2}4f^7_{7/2})_5 5p_{3/2}]_{15/2}$	$[(4f^5_{5/2}4f^7_{7/2})_6 5d_{5/2}]_{17/2}$	21.13		1.50
1	$[(4f^5_{5/2})_{5/2}5s^2]_{5/2}$	$[((4f^5_{5/2})_{5/2}5s_{1/2})_3 5p_{3/2}]_{5/2}$	24.09 23.87[a] 24.00[c]		0.62 0.63[a]
2	$[(4f^7_{7/2})_{7/2}5s^2]_{7/2}$	$[((4f^7_{7/2})_{7/2}5s_{1/2})_4 5p_{3/2}]_{7/2}$	24.17 23.95[a] 24.06[c]	24.32	0.55 0.54[a]
3	$[(4f^5_{5/2})_{5/2}5s^2]_{5/2}$	$[((4f^5_{5/2})_{5/2}5s_{1/2})_2 5p_{3/2}]_{7/2}$	24.61 24.41[a] 24.57[c]	24.77	0.53 0.51[a]
4	$[(4f^7_{7/2})_{7/2}5s^2]_{7/2}$	$[((4f^7_{7/2})_{7/2}5s_{1/2})_3 5p_{3/2}]_{9/2}$	24.69 24.53[a] 24.64[c]	24.83	0.55 0.61[a]
5	$[(4f^7_{7/2})_{7/2}5s^2]_{7/2}$	$[((4f^7_{7/2})_{7/2}5s_{1/2})_4 5p_{3/2}]_{5/2}$	24.76 24.71[a] 24.70[c]	24.91	0.57 0.54[a]
6	$[(4f^5_{5/2})_{5/2}5s^2]_{5/2}$	$[((4f^5_{5/2})_{5/2}5s_{1/2})_3 5p_{3/2}]_{3/2}$	24.93		0.58

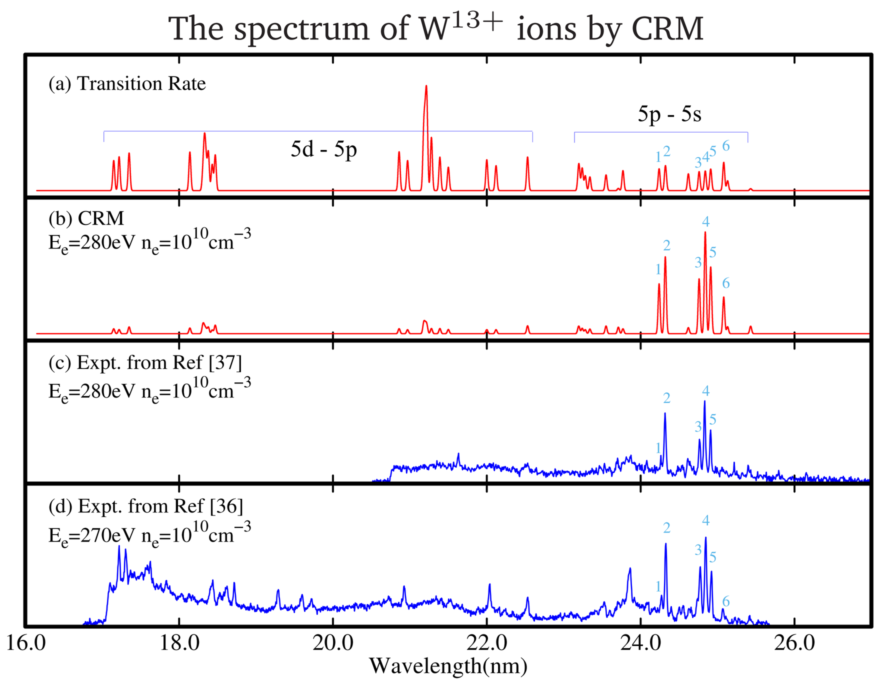
Transition wavelength and rate of W^{14+} ions

Key	Lower	Upper	λ	$A(10^{10} s^{-1})$	Int
1	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_6$	$[((4f^5_{5/2}4f^7_{7/2})_6 5s_{1/2})_{13/2}5p_{3/2}]_6$	22.83	8.29	2.78
2	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_5$	$[((4f^5_{5/2}4f^7_{7/2})_5 5s_{1/2})_{11/2}5p_{3/2}]_5$	23.19	3.32	1.20
3	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_5$	$[((4f^5_{5/2}4f^7_{7/2})_4 5s_{1/2})_{7/2}5p_{3/2}]_5$	23.28	4.01	1.47
4	$[(4f^6_{7/2})_6 5s^2]_6$	$[((4f^6_{7/2})_6 5s_{1/2})_{11/2}5p_{3/2}]_6$	23.32	6.12	3.62
	$[(4f^4_{5/2})_2 5s^2]_2$	$[((4f^4_{5/2})_2 5s_{1/2})_{3/2}5p_{3/2}]_3$	23.34	6.84	1.07
5	$[(4f^6_{7/2})_2 5s^2]_2$	$[((4f^6_{7/2})_2 5s_{1/2})_{3/2}5p_{3/2}]_3$	23.37	5.41	1.10
6	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_4$	$[((4f^6_{7/2})_6 5s_{1/2})_{11/5}p_{3/2}]_7$	23.40	7.35	1.60
	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_3$	$[((4f^5_{5/2}4f^7_{7/2})_3 5s_{1/2})_{5/2}5p_{3/2}]_4$	23.40	6.14	1.66
7	$[(4f^6_{7/2})_4 5s^2]_4$	$[((4f^6_{7/2})_4 5s_{1/2})_{7/2}5p_{3/2}]_5$	23.53	5.82	2.69
8	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_4$	$[((4f^5_{5/2}4f^7_{7/2})_4 5s_{1/2})_{7/2}5p_{3/2}]_5$	23.60	4.09	1.48
9	$[(4f^6_{7/2})_4 5s^2]_4$	$[((4f^6_{7/2})_4 5s_{1/2})_{9/2}5p_{3/2}]_3$	23.65	6.13	1.80
10	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_4$	$[((4f^5_{5/2}4f^7_{7/2})_5 5s_{1/2})_{11/2}5p_{3/2}]_5$	23.69	6.20	1.34
	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_3$	$[((4f^5_{5/2}4f^7_{7/2})_3 5s_{1/2})_{7/2}5p_{3/2}]_3$	23.69	4.34	1.62
	$[(4f^6_{7/2})_6 5s^2]_6$	$[((4f^6_{5/2})_6 5s_{1/2})_{13/2}5p_{3/2}]_5$	23.70	2.78	1.02
11	$[(4f^6_{7/2})_6 5s^2]_6$	$[((4f^6_{7/2})_4 5s_{1/2})_{9/2}5p_{3/2}]_4$	23.73	5.73	2.73
	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_5$	$[((4f^5_{5/2}4f^7_{7/2})_5 5s_{1/2})_{9/2}5p_{3/2}]_6$	23.74	6.84	1.95
12	$[(4f^4_{5/2})_4 5s^2]_4$	$[((4f^6_{5/2})_4 5s_{1/2})_{7/2}5p_{3/2}]_5$	23.81	7.68	5.72
13	$[(4f^6_{7/2})_6 5s^2]_6$	$[((4f^6_{5/2})_6 5s_{1/2})_{11/2}5p_{3/2}]_7$	23.88	5.83	3.18
	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_6$	$[((4f^5_{5/2}4f^7_{7/2})_6 5s^{1/2})_{13/2}5p_{3/2}]_5$	23.90	6.65	2.16
	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_6$	$[((4f^5_{5/2}4f^7_{7/2})_6 5s_{1/2})_{11/2}5p_{3/2}]_7$	23.92	4.69	1.09
14	$[(4f^5_{5/2}4f^7_{7/2})_{5/2}5s^2]_4$	$[((4f^5_{5/2}4f^7_{7/2})_4 5s_{1/2})_{9/2}5p_{3/2}]_3$	23.97	6.79	3.08

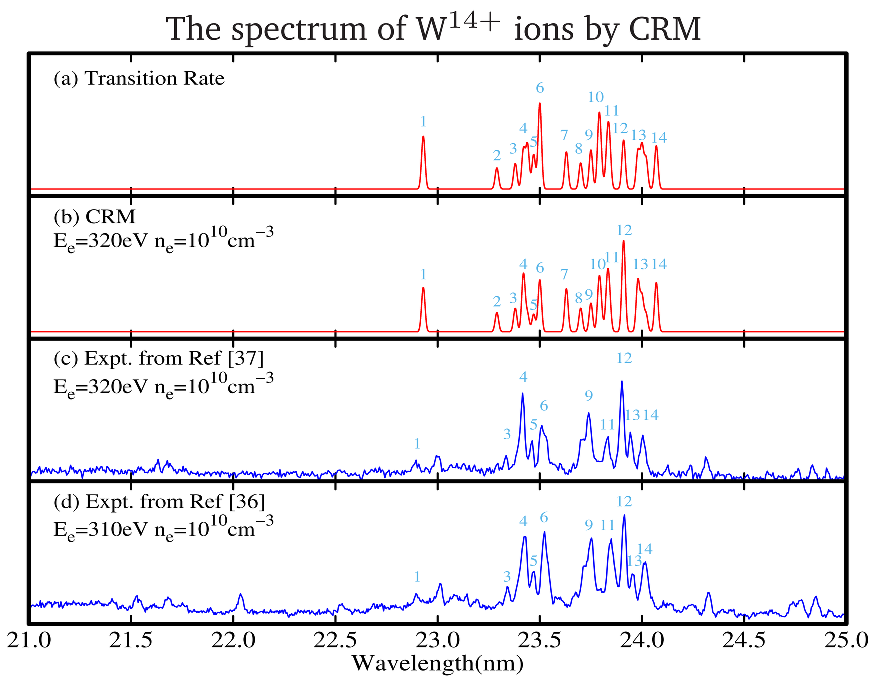
Transition wavelength and rate of W^{15+} ions

Key	Lower	Upper	λ	$A(10^{-10} s^{-1})$	Int
1	$[(4f^5_{7/2})_{15/2}5s^2]_{15/2}$	$[((4f^5_{7/2})_{15/2}5s_{1/2})_8 5p_{3/2}]_{15/2}$	22.48	5.89	2.36
2	$[(4f^5_{7/2})_{11/2}5s^2]_{11/2}$	$[((4f^5_{7/2})_{11/2}5s_{1/2})_6 5p_{3/2}]_{11/2}$	22.54	5.59	1.13
	$[(4f^5_{5/2}4f^6_{7/2})_{13/2}5s^2]_{13/2}$	$[((4f^5_{5/2}4f^6_{7/2})_{13/2}5s_{1/2})_7 5p_{3/2}]_{13/2}$	22.55	4.26	1.09
3	$[(4f^5_{7/2})_{15/2}5s^2]_{15/2}$	$[((4f^5_{7/2})_{15/2}5s_{1/2})_8 5p_{3/2}]_{13/2}$	22.66	6.20	2.21
4	$[(4f^5_{7/2})_{9/2}5s^2]_{9/2}$	$[((4f^5_{7/2})_{9/2}5s_{1/2})_4 5p_{3/2}]_{11/2}$	22.70	6.74	1.38
	$[((4f^4_{5/2})_4 4f^7_{7/2})_{7/2}5s^2]_{11/2}$	$[((4f^4_{5/2}4f^7_{7/2})_{11/2}5s_{1/2})_5 5p_{3/2}]_{13/2}$	22.70	6.83	1.14
	$[(4f^5_{7/2})_{11/2}5s^2]_{11/2}$	$[((4f^5_{7/2})_{11/2}5s_{1/2})_5 5p_{3/2}]_{13/2}$	22.70	5.13	1.25
5	$[(4f^5_{5/2}4f^6_{7/2})_{13/2}5s^2]_{13/2}$	$[((4f^5_{5/2}4f^6_{7/2})_{13/2}5s_{1/2})_6 5p_{3/2}]_{15/2}$	22.77	5.52	1.67
	$[(4f^5_{7/2})_{15/2}5s^2]_{15/2}$	$[((4f^5_{7/2})_{15/2}5s_{1/2})_7 5p_{3/2}]_{17/2}$	22.78	7.63	3.61
6	$[(4f^5_{5/2}4f6_{7/2})_6 5s^2]_{15/2}$	$[((4f^5_{5/2}4f^6_{7/2})_{15/2}5s_{1/2})_7 5p_{3/2}]_{17/2}$	22.92	6.99	1.03

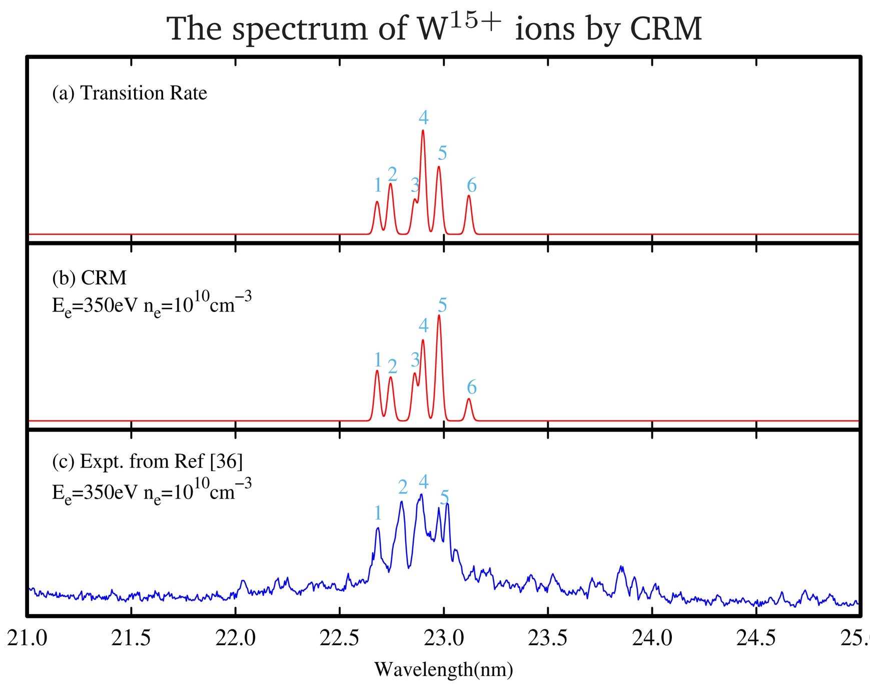
The spectrum of W^{13+} ions by CRM



The spectrum of W^{14+} ions by CRM



The spectrum of W^{15+} ions by CRM



Relevant publications: Xiaobin Ding et al. Collisional-radiative modeling of the 5p-5s spectrum of W XIV–W XVI ions,**Phys.Rev.A** 101 (4) (2020) 042509.

4. Result & Dissusion: EUV spectrum of W^{43+}-W^{45+} ions in the EAST

E1 & M1 transition wavelength and rate of W^{43+}ions

Key	Lower	Upper	λ(Å)	$\lambda_{EXPT.}$(Å)	λ_{other}(Å)	$A(s^{-1})$	$A_{other}(s^{-1})$	Int.	Type
	$4s^24p\ ^2P_{1/2}$	$4s4p^2\ ^2P_{3/2}$	40.46		40.44[i] 40.27[j]	6.80(9)	6.38(9)[i] 5.48(9)[j]	1.03(-3)	E1
	$4s^24p\ ^2P_{1/2}$	$4s4p^2\ ^2S_{1/2}$	40.98		40.92[i] 40.81[j]	5.43(9)	5.91(9)[i] 6.28(9)[j]	6.76(-4)	E1
1	$4s^24p\ ^2P_{1/2}$	$4s^24d\ ^2D_{3/2}$	47.56	47.90[g] 47.69[i] 47.91[j]	47.63[h] 47.71[j]	1.25(12)		50.96	E1
2	$4s^24p\ ^2P_{3/2}$	$4s4p^2\ ^2P_{3/2}$	59.46		59.50[i] 59.01[j]	1.06(12)	1.05((12)[i] 1.12(12)[j]	0.16	E1
3	$4s^24p\ ^2P_{1/2}$	$4s4p^2\ ^2P_{1/2}$	60.57	60.61[g] 60.61[i] 60.63[j]	59.87[h] 60.58[i] 60.20[j]	7.06(11)	6.79(11)[i] 7.47(11)[j]	28.96	E1
	$4s^24p\ ^2P_{3/2}$	$4s4p^2\ ^2S_{1/2}$	60.59		60.56[i] 60.27[j]	4.99(11)	4.91(11)[i] 5.25(11)[j]	6.21(-2)	E1
4	$4s^24p\ ^2P_{1/2}$	$4s4p^2\ ^2D_{3/2}$	61.36	61.33[g] 61.29[i] 61.35[j]	60.82[h] 61.32[i] 61.11[j]	3.61(11)	3.63(11)[i] 3.62(11)[j]	31.32	E1
5	$4s^24p\ ^2P_{3/2}$	$4s4p^2\ ^4P_{5/2}$	64.03		63.97[h] 64.03[i] 63.95[j]	5.58(11)	5.44(11)[i] 5.48 (11)[j]	0.20	E1
	$4s^24p\ ^2P_{1/2}$	$4s4p^2\ ^4P_{3/2}$	68.40		68.36[h] 68.24[i] 68.21[j]	2.78(9)	2.77(9)[i] 2.87(9)[j]	1.09	E1
6	$4s^24p\ ^2P_{3/2}$	$4s^24d\ ^2D_{5/2}$	70.28		70.66[h] 70.61[j]	6.72(10)	9.23(10)[j]	0.55	E1
7	$4s^24p\ ^2P_{3/2}$	$4s4p^2\ ^2P_{1/2}$	116.10		116.50[i] 114.93[j]	2.67(10)	2.64(10)[i] 2.82(10)[j]	1.10	E1
8	$4s^24p\ ^2P_{3/2}$	$4s4p^2\ ^2D_{3/2}$	119.06		117.56[h] 119.04[i] 118.28[j]	1.91(10)	1.91(10)[i] 2.01(10)[j]	1.66	E1
m	$4s^24p\ ^2P_{1/2}$	$4s^24p\ ^2P_{3/2}$	126.60	126.29[h] 126.39[j]	126.01[h] 126.23[i] 126.43[j]	4.31(6)	4.36(6)[i] 4.33(6)[j]	13.33	M1
9	$4s^24p\ ^2P_{1/2}$	$4s4p^2\ ^4P_{1/2}$	128.14	128.17[h] 128.24[j]	127.06[h] 128.17[i] 127.30[j]	2.96(10)	2.96(10)[i] 2.90(10)[j]	16.08	E1
10	$4s^24p\ ^2P_{3/2}$	$4s4p^2\ ^2D_{5/2}$	134.85	134.81[e] 135.34[j]	134.55[h] 134.20[j]	1.38(10)	1.38(10)[i] 1.41 (10)[j]	2.46	E1

h by RELAC 0.12%
i by MCDF 0.09% , 2.01%
j by MCDF 0.50%, 6.83%

E1 & M1 transition wavelength and rate of W^{44+}ions

Key	Lower	Upper	λ(Å)	$\lambda_{EXPT.}$(Å)	λ_{other}(Å)	$A(s^{-1})$	$A_{other}(s^{-1})$	Pop.	Int.	Type
1	$4s4p\ ^3P_1$	$4s4d\ ^1D_2$	44.49	44.52[g]	44.38[h] 44.49[i]	5.43（10）	5.53(10)[i]	2.57(-11)	1.37	E1
2	$4s^14p\ ^3P_0$	$4s4d\ ^3D_1$	47.86		47.81[i]	6.02（11）	6.04(11)[i]	8.60(-13)	0.40	E1
3	$4s4p\ ^3P_1$	$4s4d\ ^3D_2$	48.54	48.61[d]	48.41[h]	1.01（12）	1.02(12)[i]	2.22(-12)	2.73	E1
4	$4s4p\ ^3P_1$	$4s4d\ ^3D_1$	49.21		49.19[i]	3.18（11）	3.19(11)[i]	8.60(-13)	0.20	E1
5	$4s^2\ ^1S_0$	$4s4p\ ^1P_1$	60.90	60.93[d] 60.87[f] 60.93[g]	60.73[g] 60.66[h]	6.59（11）	6.85(11)[i]	2.23(-10)	1.94(2)	E1
6	$4s4p\ ^3P_2$	$4s4d\ ^1D_2$	66.66	66.93[d]	66.46[h] 66.66[i]	2.00（11）	1.99(11)[i]	2.57(-11)	5.04	E1
7	$4s4p\ ^3P_2$	$4s4d\ ^3D_3$	68.77		68.76[i]	3.77（11）	3.78(11)[i]	1.94(-11)	0.17	E1
8	$4s4p\ ^1P_1$	$4s4d\ ^1D_2$	73.66		73.43[h] 73.86[i]	1.04（11）	1.06(11)[i]	2.57(-11)	2.63	E1
	$4s4p\ ^3P_2$	$4s4d\ ^3D_2$	76.17		76.15[i]	1.92（10）	1.94(10)[i]	2.22(-12)	0.05	E1
	$4s4p\ ^3P_2$	$4s4d\ ^3D_1$	77.83		77.82[i]	7.08（9）	7.12(9)[i]	8.60(-13)	0.01	E1
	$4s4p\ ^1P_1$	$4s4d\ ^3D_2$	85.45		85.69[i]	2.94（8）	2.87(8)[i]	2.22(-12)	7.91(-4)	E1
9	$4s^2\ ^1S_0$	$4s4p\ ^3P_1$	132.97	132.88[e] 132.75[f] 132.87[g]	132.07[h] 132.60[i]	1.73（10）	1.78(10)[i]	3.35(-9)	57.88	E1
m	$4s4p\ ^3P_1$	$4s4p\ ^3P_2$	133.80	134.80[e]	133.60[h] 133.45[e]	4.19(6)		1.28(-6)	5.35	M1

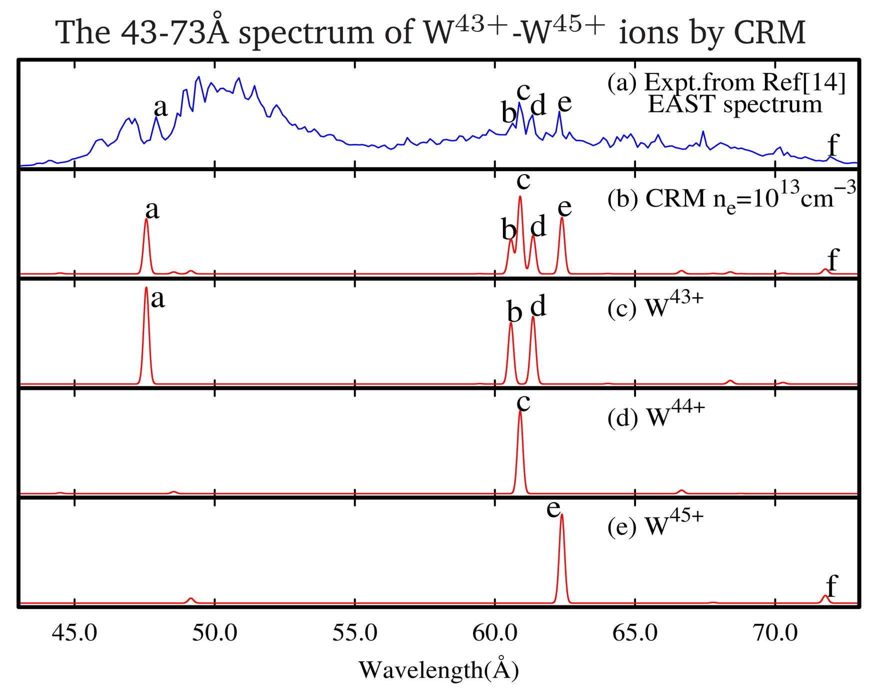
h by RELAC 0.37%
i by MCDF 0.13%, 1.3%

E1 transition wavelength and rate of W^{45+}ions

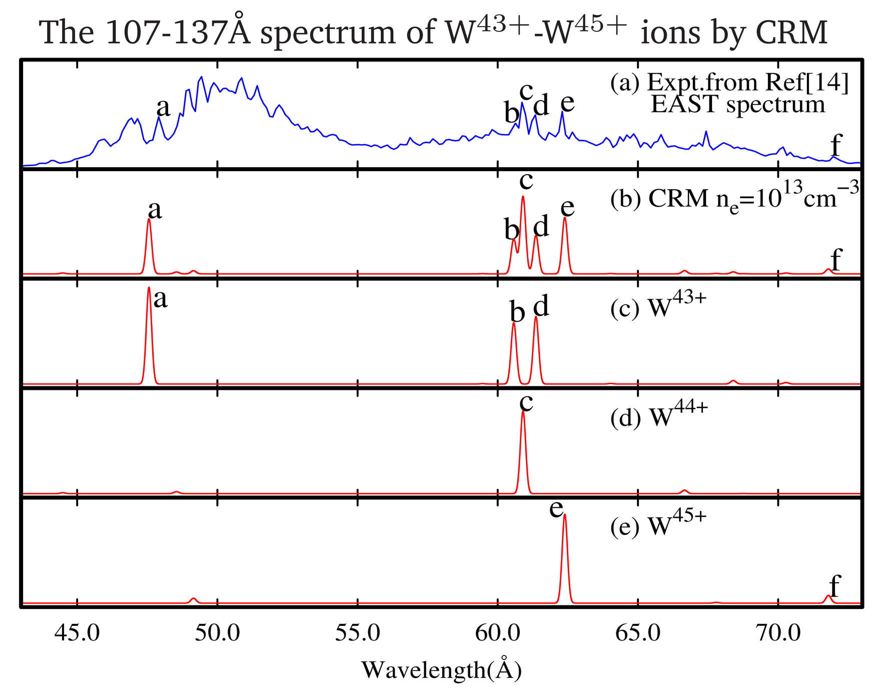
Key	Lower	Upper	λ(Å)	$\lambda_{EXPT.}$(Å)	λ_{other}(Å)	$A(s^{-1})$	$A_{other}(s^{-1})$	Pop.	Int.	Type
1	$4p\ ^2P_{1/2}$	$4d\ ^2D_{3/2}$	49.15	49.20[d]	49.16[h] 49.17[i]	8.11(11)	7.95(11)[i]	3.19(-12)	2.91	E1
2	$4s\ ^1S_{1/2}$	$4p\ ^2P_{3/2}$	62.39	62.33[d] 62.32[f] 62.32[g]	62.17[g] 62.44[i] 62.18[h]	4.19(11)	4.10(11)[i]	1.92(-10)	90.30	E1
3	$4d\ ^2D_{3/2}$	$4f\ ^2F_{5/2}$	67.79	68.15[d]	68.01[h] 67.98[i]	2.92(11)	2.78(11)[i]	1.03(-12)	0.34	E1
4	$4p\ ^2P_{3/2}$	$4d\ ^2D_{5/2}$	71.79	71.94[d]	71.89[h] 71.86[i]	3.29(11)	3.22(11)[i]	1.24(-11)	4.59	E1
5	$4d\ ^2D_{5/2}$	$4f\ ^2F_{7/2}$	74.34		74.59[h] 74.56[i]	2.39(11)	2.28(11)[i]	1.79(-12)	0.48	E1
	$4d\ ^2D_{5/2}$	$4f\ ^2F_{5/2}$	76.84		77.06[i]	1.43(10)	1.36(10)[i]	1.03(-12)	0.02	E1
	$4p\ ^2P_{3/2}$	$4d\ ^2D_{3/2}$	82.01		82.09[i]	3.60(10)	3.53(10)[i]	3.19(-12)	0.13	E1
6	$4s\ ^1S_{1/2}$	$4p\ ^2P_{1/2}$	126.99	127.12[e] 127.01[f] 127.20[g]	126.09[g] 127.22[i] 126.27[h]	4.75(10)	4.64(10)[i]	1.06(-9)	56.88	E1

h by RELAC 0.24%
i by MCDF 0.16%, 3.20%

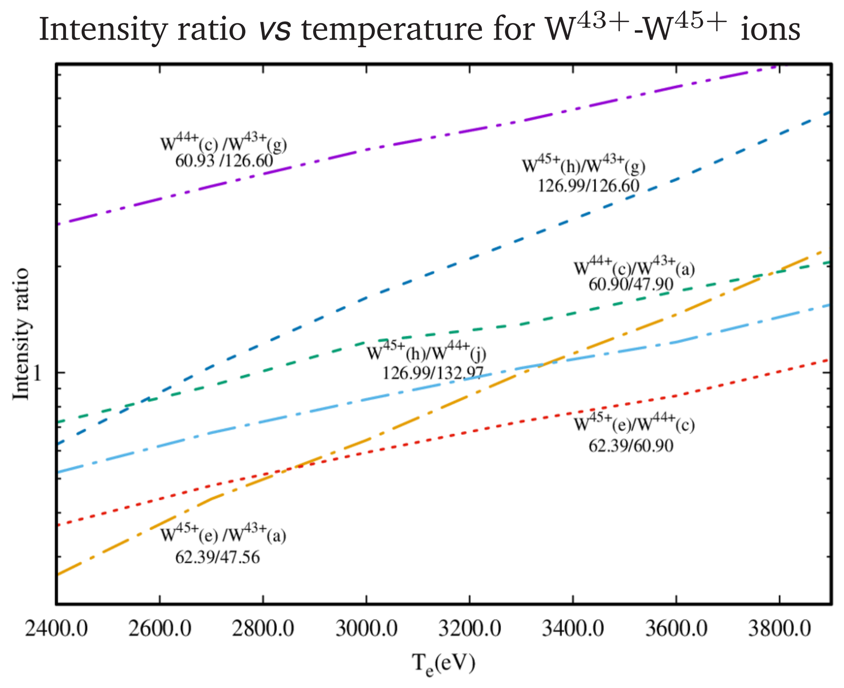
The 43-73Å spectrum of W^{43+}-W^{45+} ions by CRM



The 107-137Å spectrum of W^{43+}-W^{45+} ions by CRM



Intensity ratio *vs* temperature for W^{43+}-W^{45+} ions



Relevant publications: Xiaobin Ding et al. Collisional-radiative modeling for the EUV spectrum from W^{43+}-W^{45+} ions. **Phys.Lett.A** 420 (2021) 127758.

5.Result & Dissusion: The M1 transitions and visible spectra of W^{13+} ion

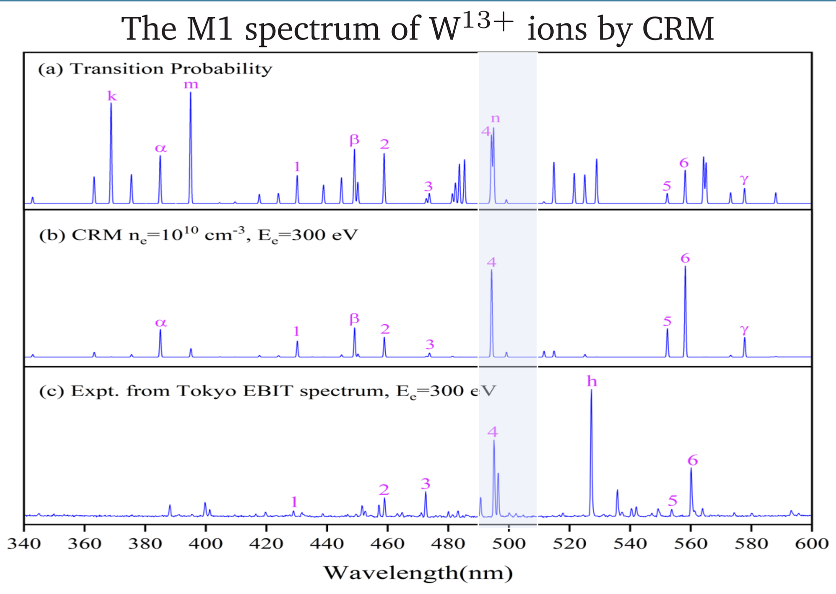
M1 transition wavelength and rate of W^{13+}ions

Key	Upper	Lower	λ(nm)	A	I_{Theo}	λ_{Expt}(nm)
k	$[(4f^4_{5/2})_4 5p_{3/2}]_{11/2}$	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_5 5p_{3/2}]_{13/2}$	368.83	266.20		
α	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_3 5p_{1/2}]_{7/2}$	$[(4f^6_{7/2})_4 5p_{1/2}]_{7/2}$	385.03	127.20		
m	$[(4f^4_{5/2})_2 5p_{1/2}]_{3/2}$	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_2 5p_{1/2}]_{3/2}$	395.02	196.90		
1	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_3 5p_{1/2}]_{7/2}$	$[(4f^6_{7/2})_4 5p_{1/2}]_{9/2}$	430.19	74.31	0.18	429.03[a]
β	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_3 5p_{1/2}]_{5/2}$	$[(4f^6_{7/2})_4 5p_{1/2}]_{7/2}$	449.09	144.10		
2	$[(4f^4_{5/2})_4 5p_{1/2}]_{9/2}$	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_5 5p_{1/2}]_{11/2}$	458.90	132.90	0.22	459.08[b]
3	$[(4f^4_{5/2})_4 5p_{1/2}]_{9/2}$	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_5 5p_{1/2}]_{9/2}$	473.82	27.03	0.04	472.68[b]
4	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_5 5p_{1/2}]_{9/2}$	$[(4f^6_{7/2})_6 5p_{1/2}]_{11/2}$	494.26	180.40	0.96	495.16[a]
n	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_5 5p_{3/2}]_{13/2}$	$[(4f^6_{7/2})_6 5p_{3/2}]_{15/2}$	495.00	199.80		
5	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_3 5p_{1/2}]_{5/2}$	$[(4f^6_{7/2})_4 5p_{1/2}]_{7/2}$	552.27	27.05	0.31	553.81[a]
6	$(4f^5_{5/2})_{5/2}$	$(4f^7_{7/2})_{7/2}$	558.21	88.38	1.00	560.25[a]
γ	$[((4f^5_{5/2})_{5/2}4f^7_{7/2})_4 5p_{1/2}]_{9/2}$	$[(4f^6_{7/2})_4 5p_{1/2}]_{9/2}$	577.79	40.39		

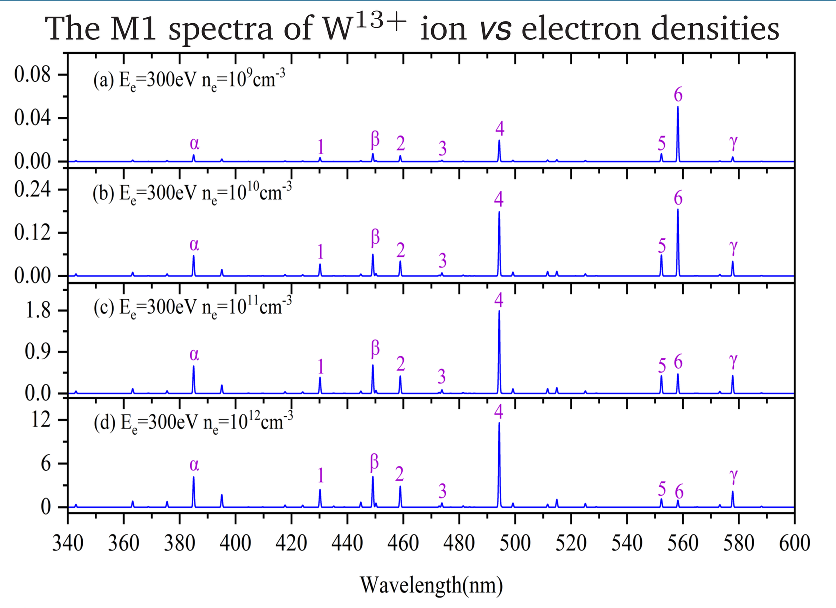
≤ 0.36%

[b] A. Komatsu et al. *Plasma.Fusion. Res* 2012 7 1201158.

The M1 spectrum of W^{13+} ions by CRM



The M1 spectra of W^{13+} ion *vs* electron densities



Relevant publications: Xiaobin Ding et al. The M1 transitions and visible spectra of W^{13+}ions. **Phys.Lett.A** 454 (2022) 128500.

2. Method

- Multi-configuration Dirac-Fock Hamiltonian.

$$\hat{H}_{DC}=\sum_{i=1}^{N}\hat{H}_i+\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{1}{r_{ij}}$$

- Radiative Transition Rates.

$$A_{fi}=\left|\langle\psi_f\left\|O_M^L\right\|\psi_i\rangle\right|^2$$

- *Collisional-Radiative Modeling.*

$$\frac{dn(p)}{dt}=\sum_{q>p}F(q,p)n_e n(q)+\sum_{p<q}[C(q,p)n_e+A(q,p)]\,n(q)-\left[\sum_{q>p}C(p,q)n_e+\sum_{q<p}F(p,q)n_e+\sum_{p>q}A(p,q)\right]\times n(p)$$

6. Conuslion

1. The 5p-5s transition spectra of W^{13+}–W^{15+} ions have been calculated by the RCI and CRM. The present theoretical results are in good agreement with the experimental results

2. The transition data and spectra of W^{43+}-W^{45+} ions have been calculated by the RCI method and CRM in different plasma conditions. The present theoretical results are in good agreement with the experimental results and previous theoretical values. All the observed transitions of W^{43+}-W^{45+} ions are assigned according to the present calculation.

3. A reasonable CRM has been constructed to simulate and explain the M1 visible spectrum of W^{13+} ion observed in EBIT. The present calculations are in reasonable agreement with the available theoretical and experimental data. For the first time, the corresponding transitions of the 5 measured lines are identified.

7. References

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8. Acknowledgement

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