Issues of Modelling Tungsten in Hot Plasmas

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and the ASDEX Upgrade Team

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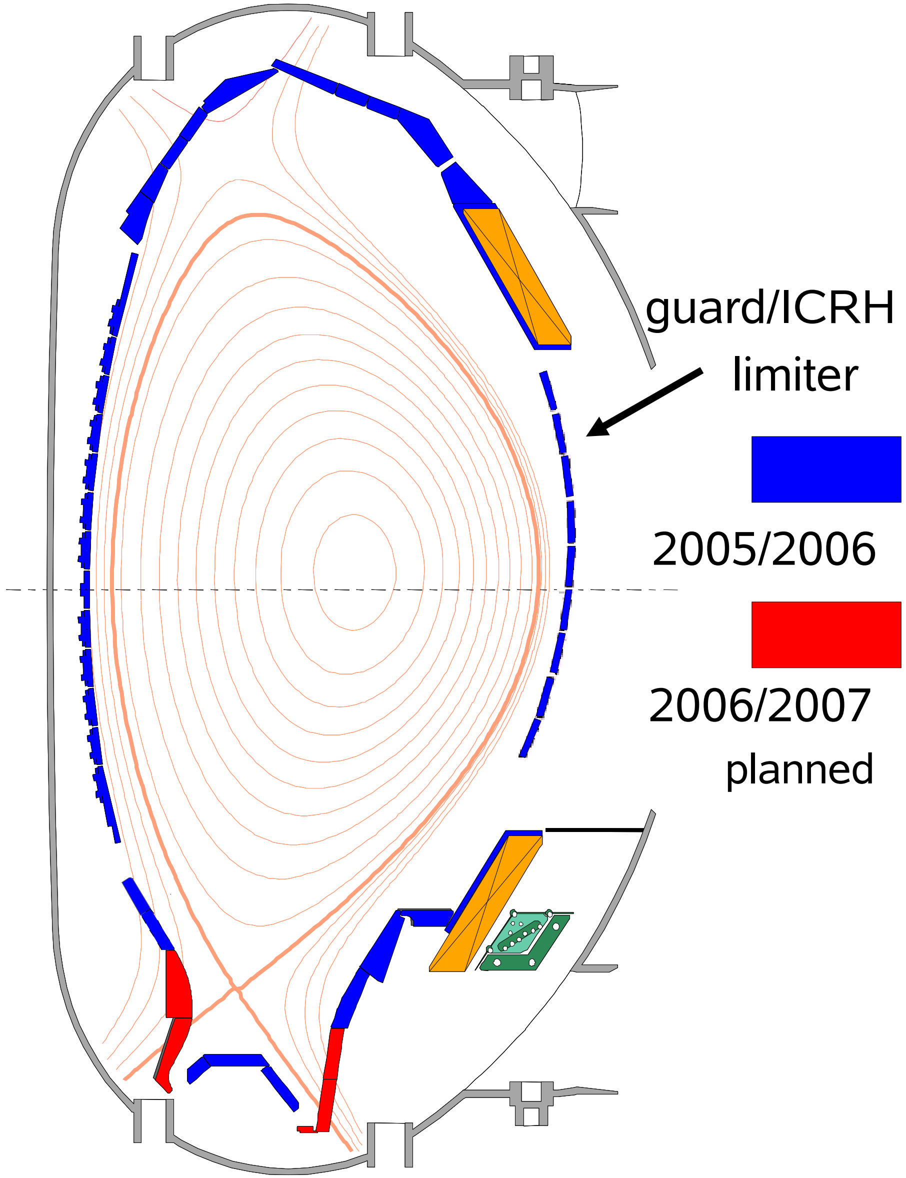
Overview

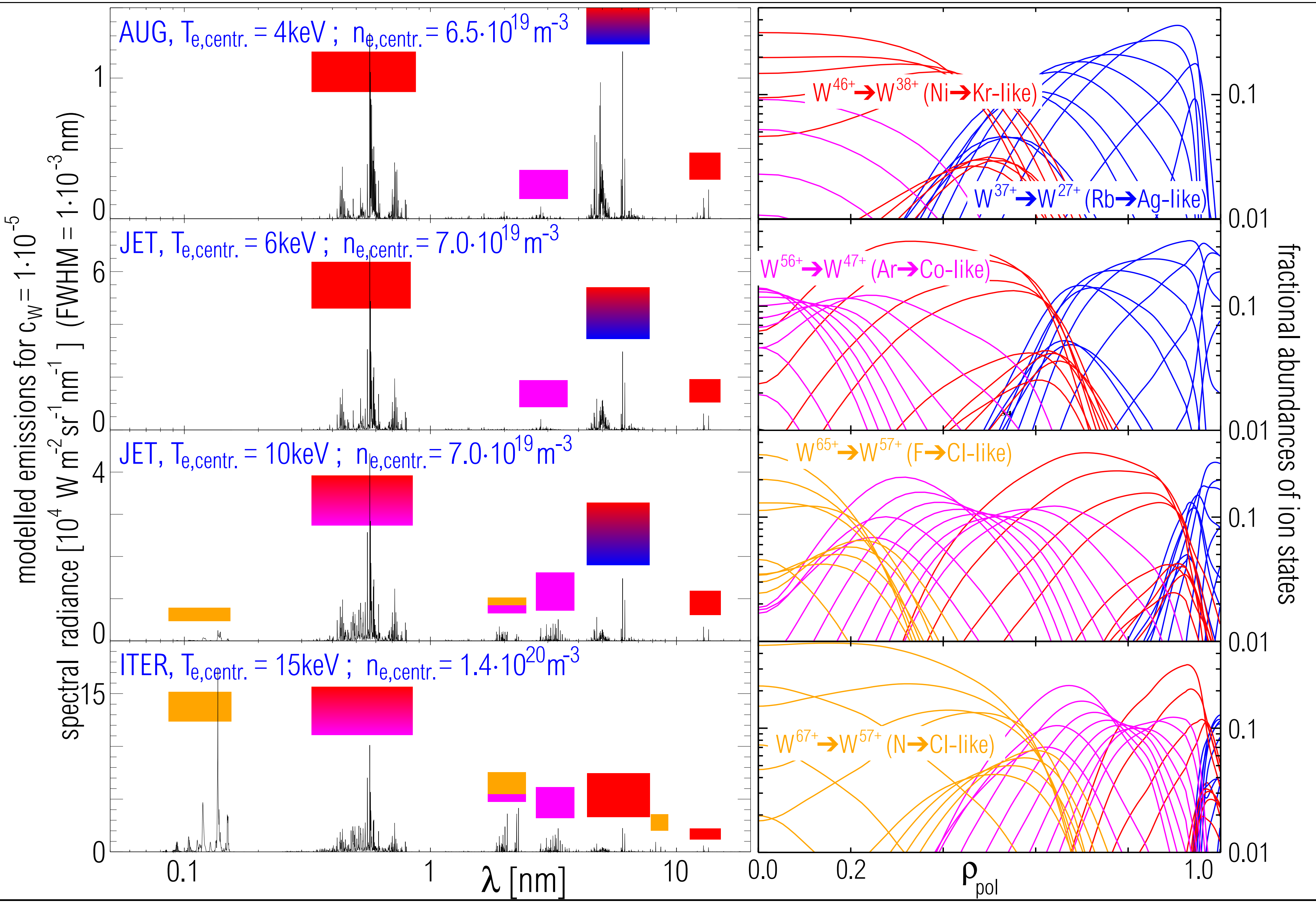
- Tungsten in AUG
- Modelling/Predictions for JET and ITER (focus on $T_e \geq 5$ keV)
- Ionization equilibrium of tungsten
- Special focus on single spectral line (0.793 nm) in SXR
- Low temperature emissions (<1keV and >50 eV)
- Cooling factor of tungsten

Tungsten in AUG

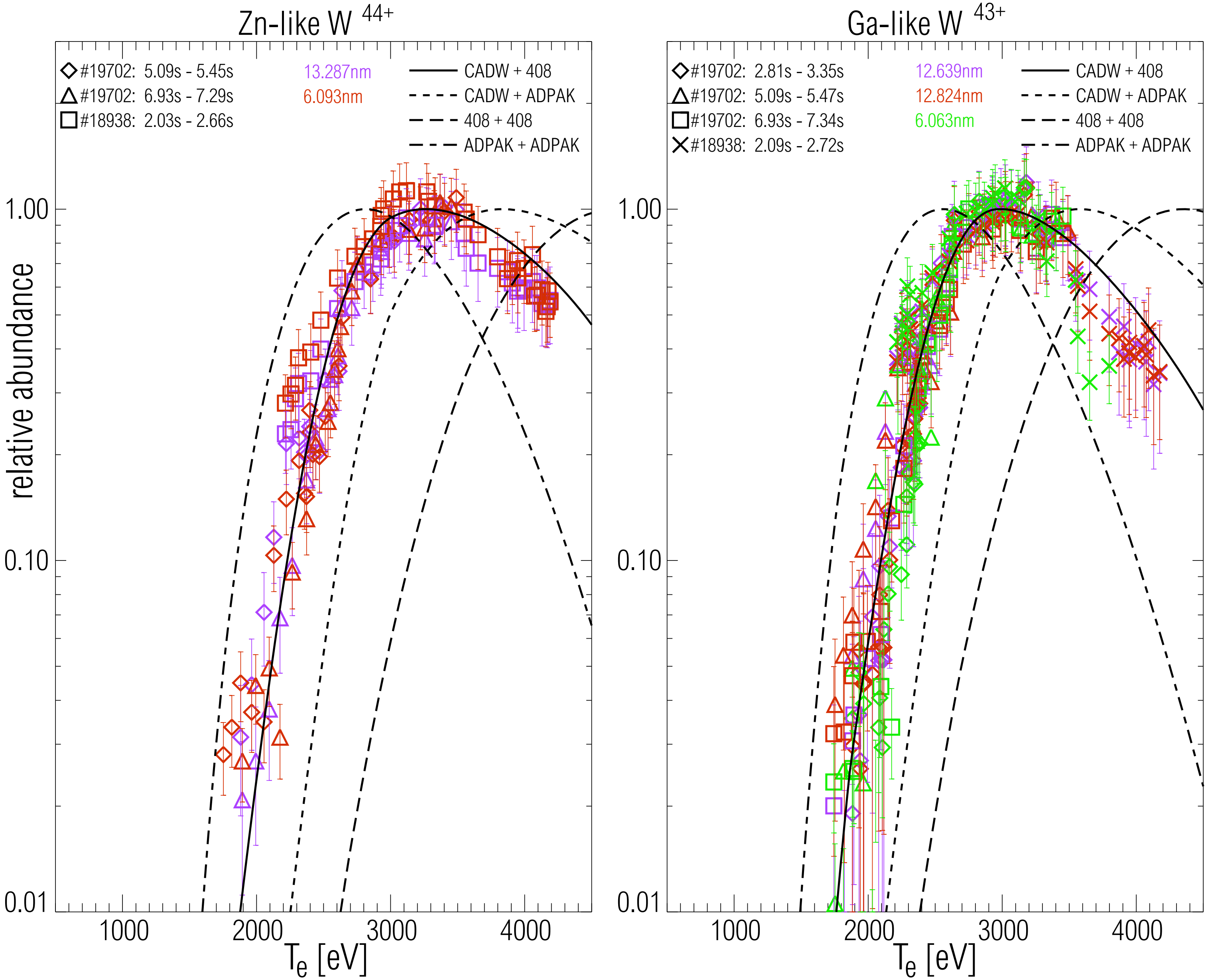
- 1995/1996 W-divertor experiment
- Increased tungsten coverage in main chamber since 1999
- 100% coverage in 2007 $\Rightarrow$ metal machine!



Predictions for JET and ITER



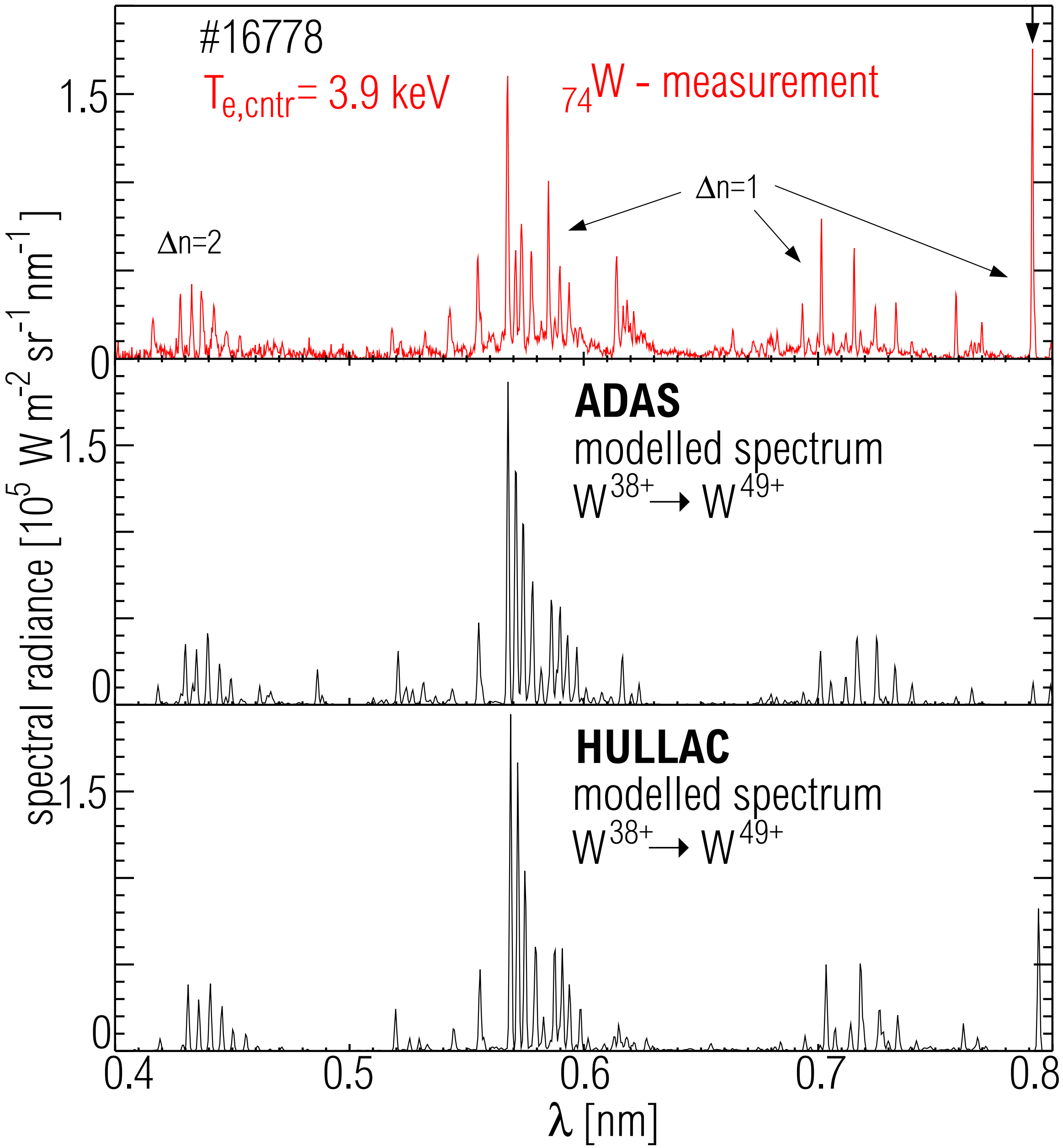
Fractional Abundances are Determined Experimentally for 1 – 4.5 keV



- Benchmark for atomic data
- Baseline ADAS (408+408) not good enough
- Good agreement for ion states Se-like W^{40+} to Ni-like W^{46+}
- Measurements above $T_e = 5\,\mathrm{keV}$ challenging

Modelled Spectrum in the SXR

- Spectral lines of Kr-like W^{38+} to about Mn-like W^{49+}
- Ni-like W^{46+} exhibits most intense spectral lines
- At ASDEX Upgrade the electric quadrupole line at 0.793 nm is monitored
- Why so large difference for 0.793 nm line?



from Ralchenko et al., PRA, 74, 042514 (2006)

- Upper state $(5/2, 1/2)_1$ is fueled also by $(3/2, 1/2)_1$ (not in Cowan code)
- Magnetic octopole (M3) is said to blend in EBIT spectrum
- In plasma, M3 is probably not important!?
- from Fournier et al.: population by ionization of Cu-like W^{45+}

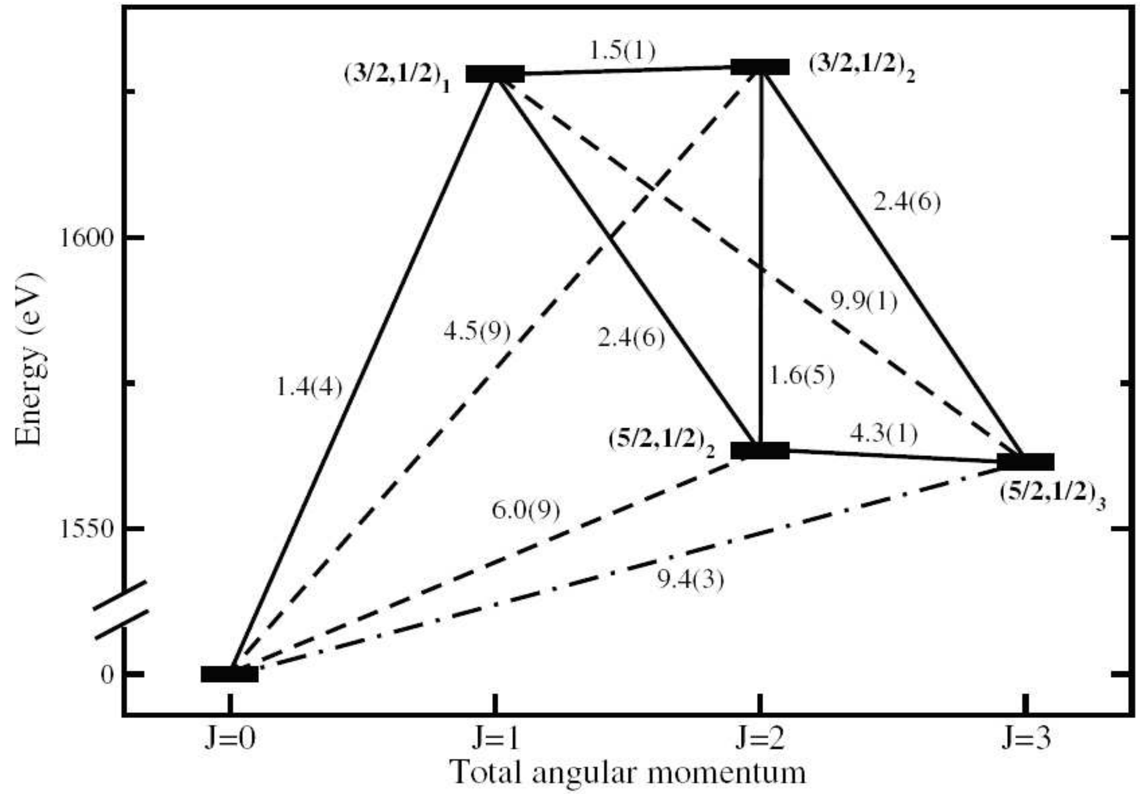
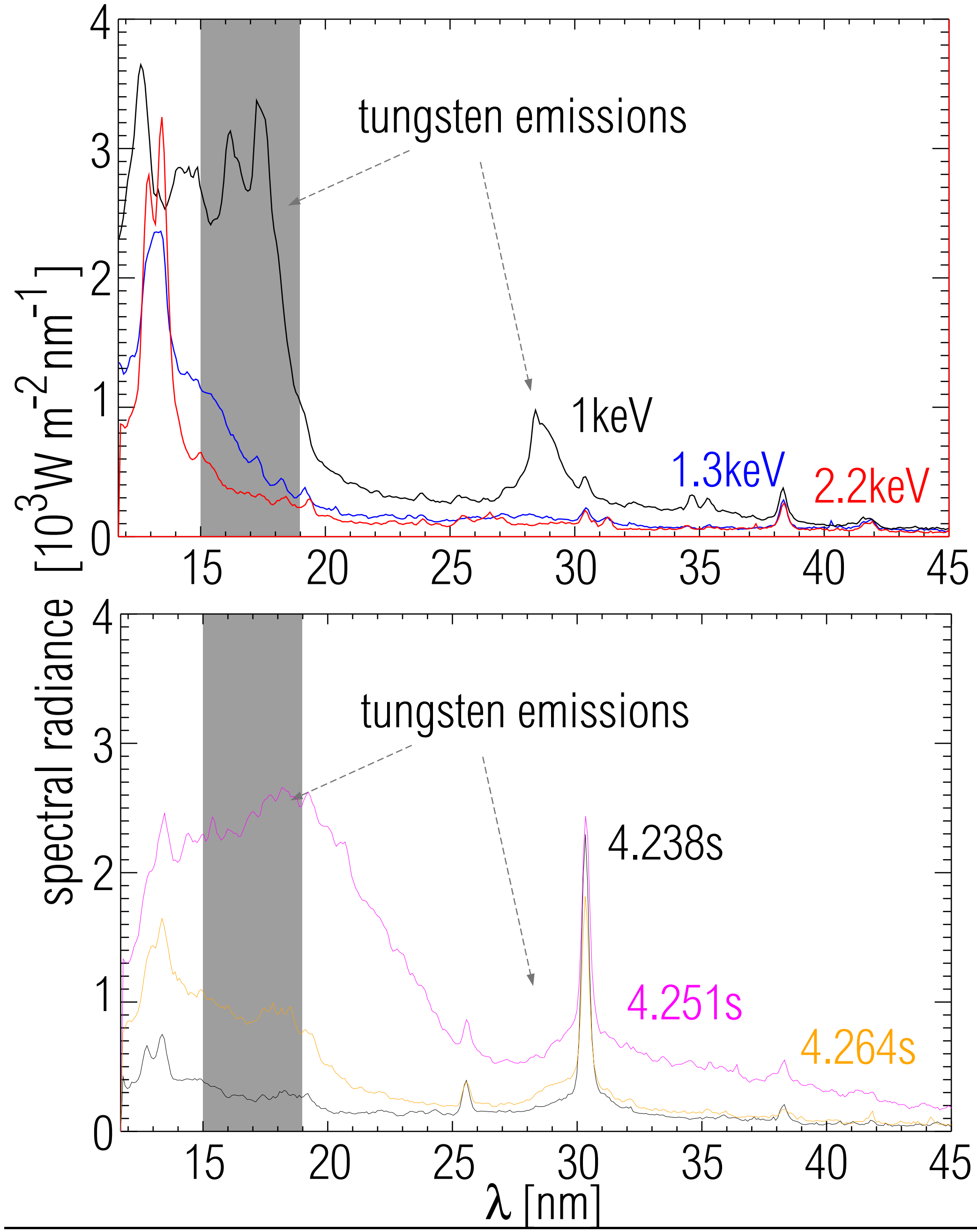


FIG. 2. Energy diagram for the $3d^{10}$ (ground state configuration) and $3d^94s$ (first excited configuration) levels in W^{46+}. Solid lines: $M1$ transitions; dashed lines: $E2$ transitions; and dot-dashed line: $M3$ transition. Transition probabilities (in s^{-1}) are given next to the corresponding lines. Notation $a(b)$ means $a \times 10^b$.

Below 1.2 keV - Poor Understanding



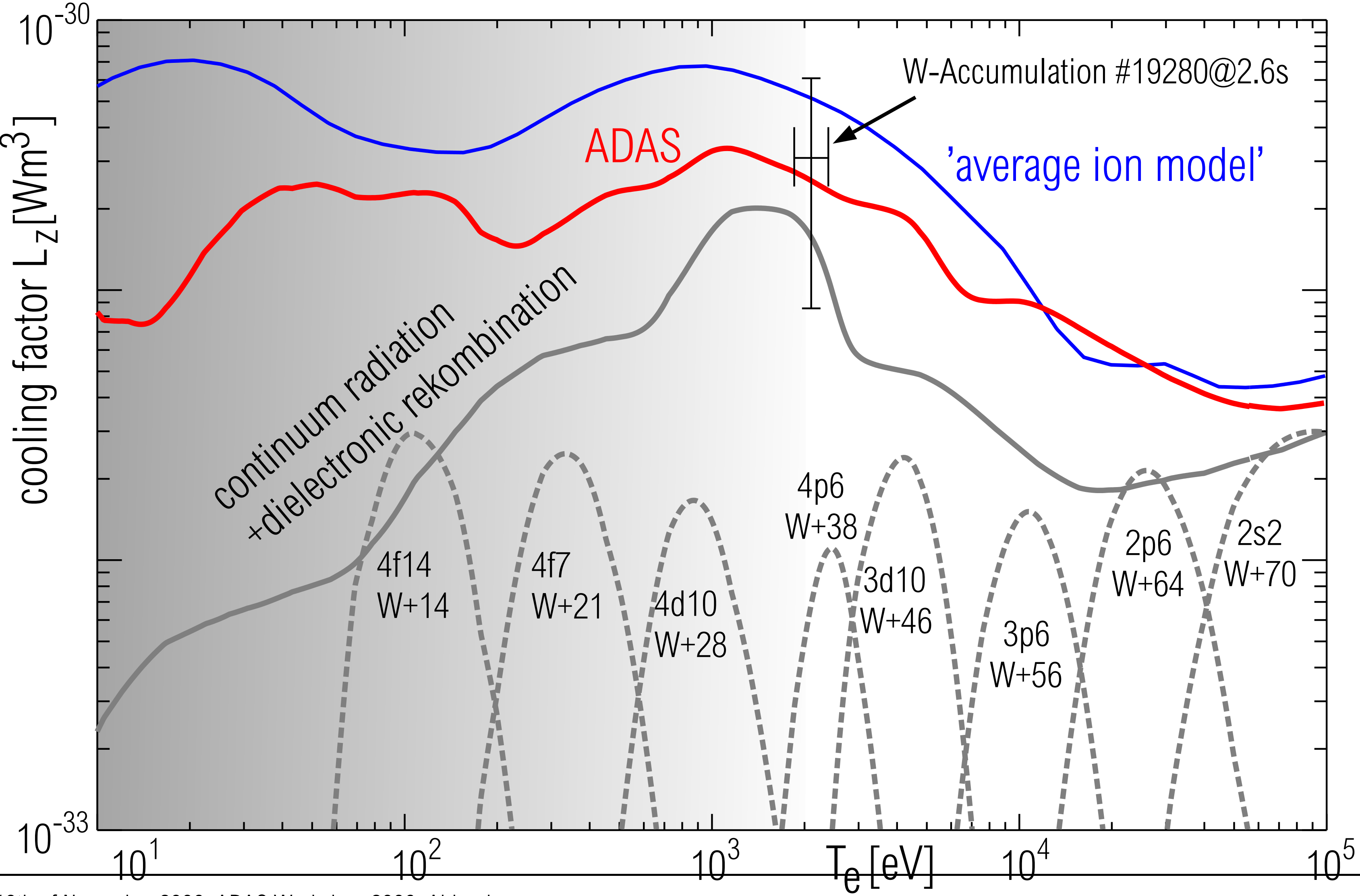
impurity accumulation at different temperatures

W-LBO at 4.25s

- Below 1.3 keV a spectral feature at 18 nm is observed in SPRD-spectrum
- Structure is emitted by ionization states below Ag-like W^{27+}
- In standard discharges the spectrum is clean

Plasma Cooling by Tungsten

- Connection to absolute concentration via cooling factor: $P_{rad}/V = L_Z \cdot n_e^2 c_W$
- Average Ion Model predicts slightly larger cooling factor than ADAS

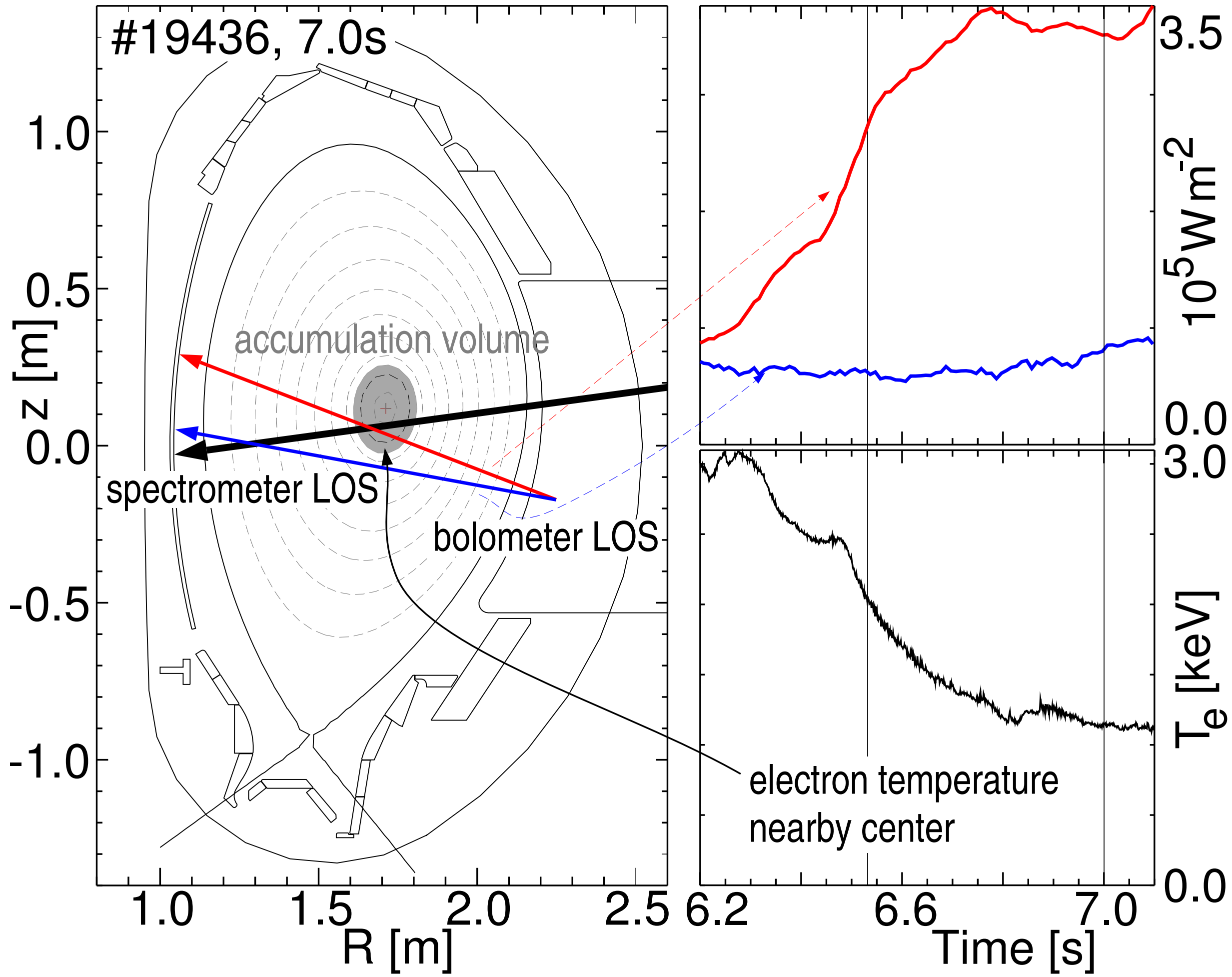


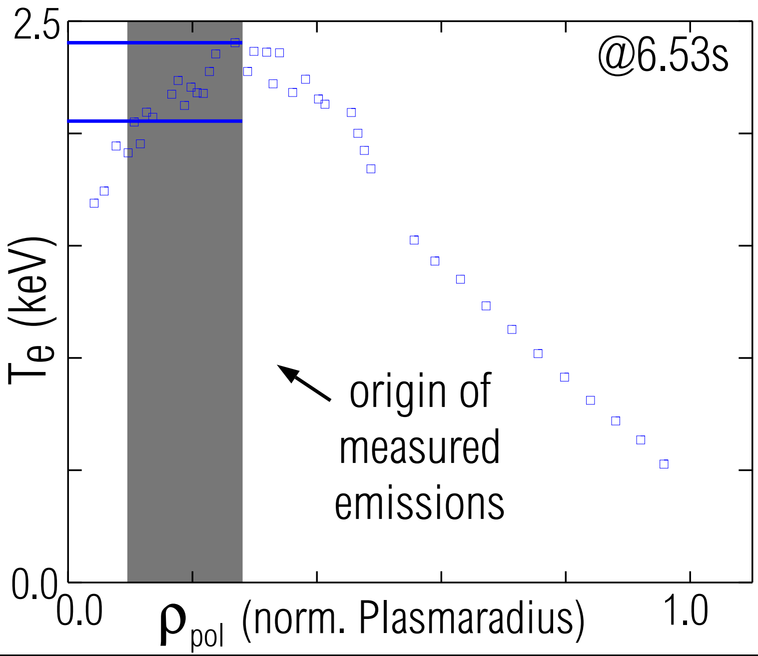
Future Work

- More detailed measurements of tungsten emissions below 1.2keV
  $\Rightarrow$ AUG, EBITs
- Measurements of tungsten lines above 5 keV
  $\Rightarrow$ JET, ILW at JET, AUG, EBITs
- Improved atomic data for special ion states (R-matrix)
  $\Rightarrow$ work-in, C. Ballance, D. Griffin
- Baseline-quality cooling factor below 2 keV
  $\Rightarrow$ work-in

Break-down of Line-Of-Sight Integral

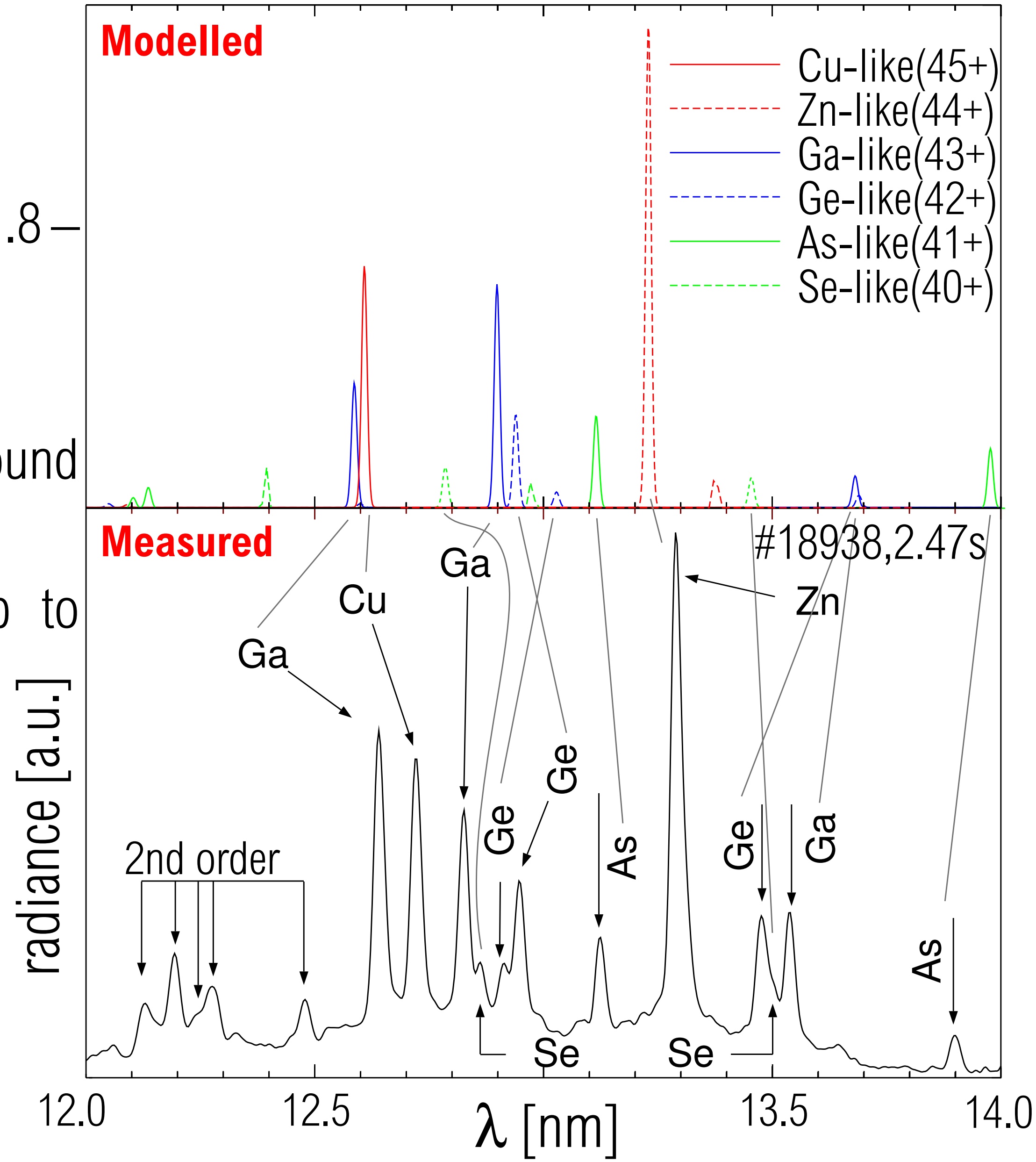
- Special discharges with 'impurity accumulation'
- Spectrum dominated from emissions at narrow T_e range
- Dominant ion states depend on T_e in accumulation zone





- Time traces of spectral lines contain relative abundance vs. T_e

- Around 13 nm: Lines emitted at 1.8 – 4.5 keV
- Identification available (AUG)
- Redundancy with spectral lines around 5 nm
- Visible in SPRED spectrometer up to 14 nm
- Line blending at 13.29 nm: Be-like Fe^{22+} and Zn-like W^{44+} $\longrightarrow$ safety feedback of LHCD



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