Benchmarking Visible Spectral Line Data, in particular one line in W^{27+} and a little on “holey states”

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Outline

Our Electron Beam Ion Traps, EBITs

W^{27+} one 4f electron outside a closed shell

W^{7+} and W^{13+} and … one missing 4f electron

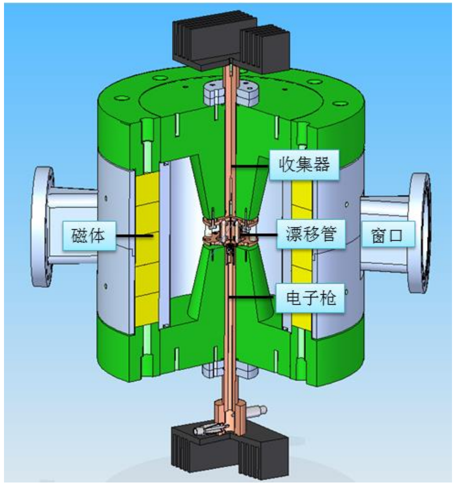
Holey states

Summary

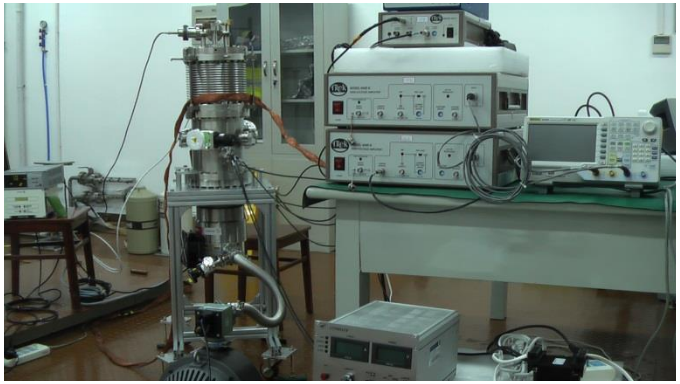
In Fudan we have three Electron Beam Ions Traps (EBITs)

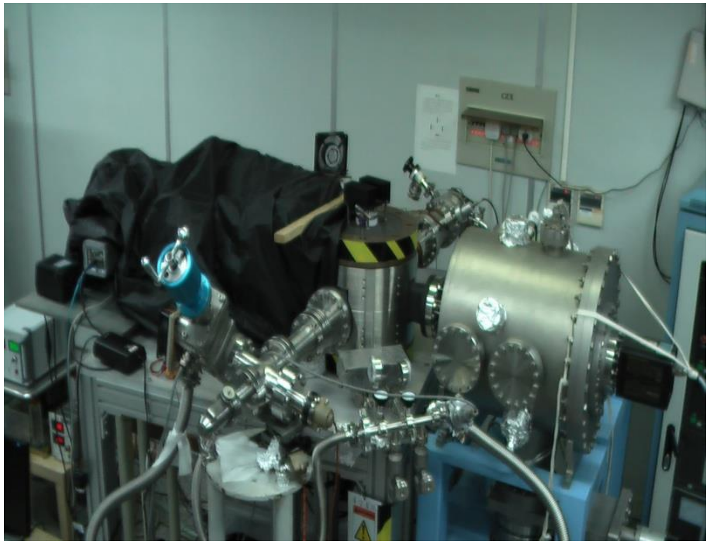
High energy EBIT

Permanent magnet EBIT



High temperature superconducting EBIT, much like CoEbit





Permanent magnet EBIT with two spectrometers

Visible spectroscopy of Tungsten

So much unknown, where to start ?

Start with something simple !

Utilize one of the unique properties of EBITs, we can, by tuning the electron beam energy, "know" the charge state of the emitting ion

Why is Tungsten such a problems for fusion ?

Think about florescent light tubes …

The plasma consists of 99.9% Argon and 0.1 % Mercury

YET, almost all the light emitted is from Mercury atoms !

W^{27+}

W^{27+}, simple structure, $4d^{10}4f\ ^2F_{5/2,7/2}$ as the ground term.
i.e, a single 4f electron outside the closed $4d^{10}$ shell

Therefor there will be an M1 transition between these two levels

Relatively simple calculation to establish the wavelength region

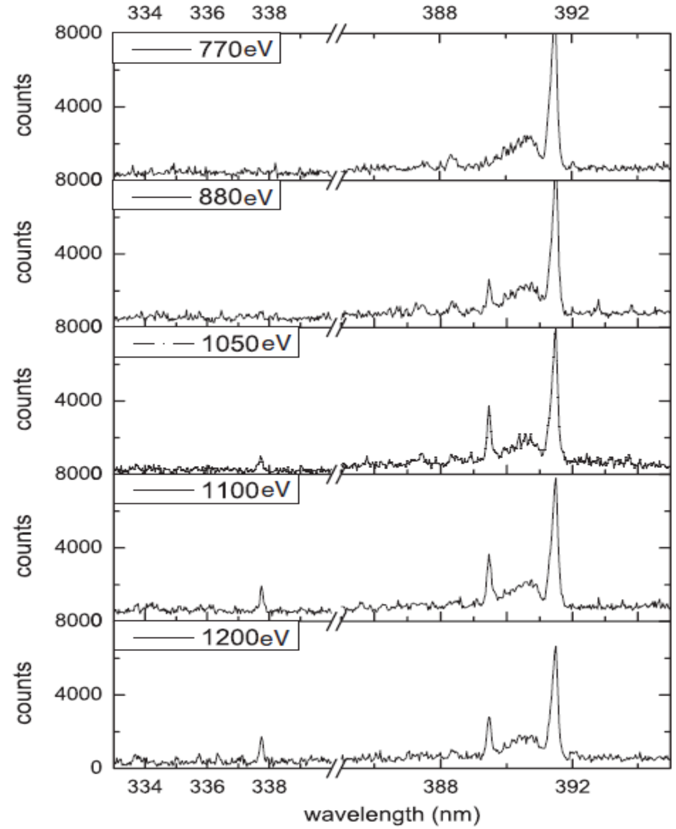
Strange range of wavelengths before our work:
Kramida, 3030 Å
ADAS 3469.4 Å

One problem with EBIT, and any light source is to establish the charge state of the emitting ions.

W^{27+}

After analysis we chose the line at 3376.43 +- 0. 26 Å as arising from the Ag-like ground state M1 transition

Ag-like Tungsten. W^{27+}



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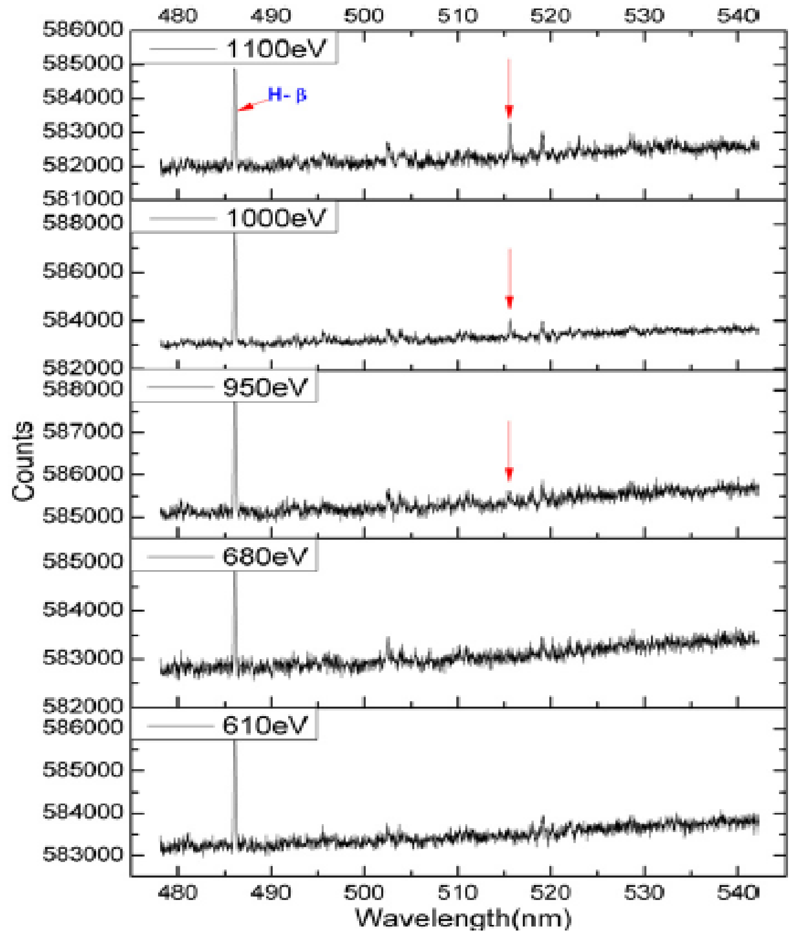
Isoelectronic Yb^{23+}

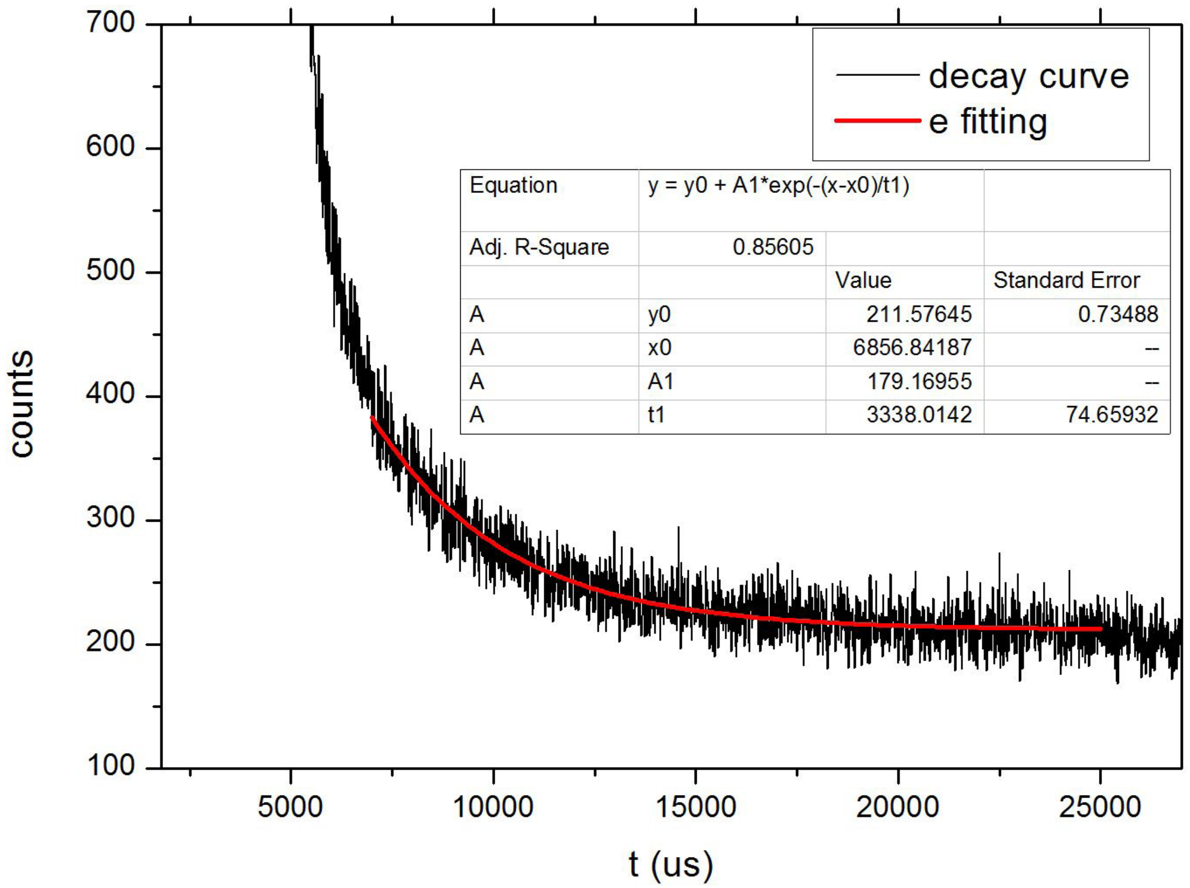
The W^{27+} work of course needed backing up, so an iso-electronic study using Yb^{23+}

Ag-like Ytterbium, Yb^{23+}



J. Phys. B: At. Mol. Opt. Phys. 47 (2014) 185004

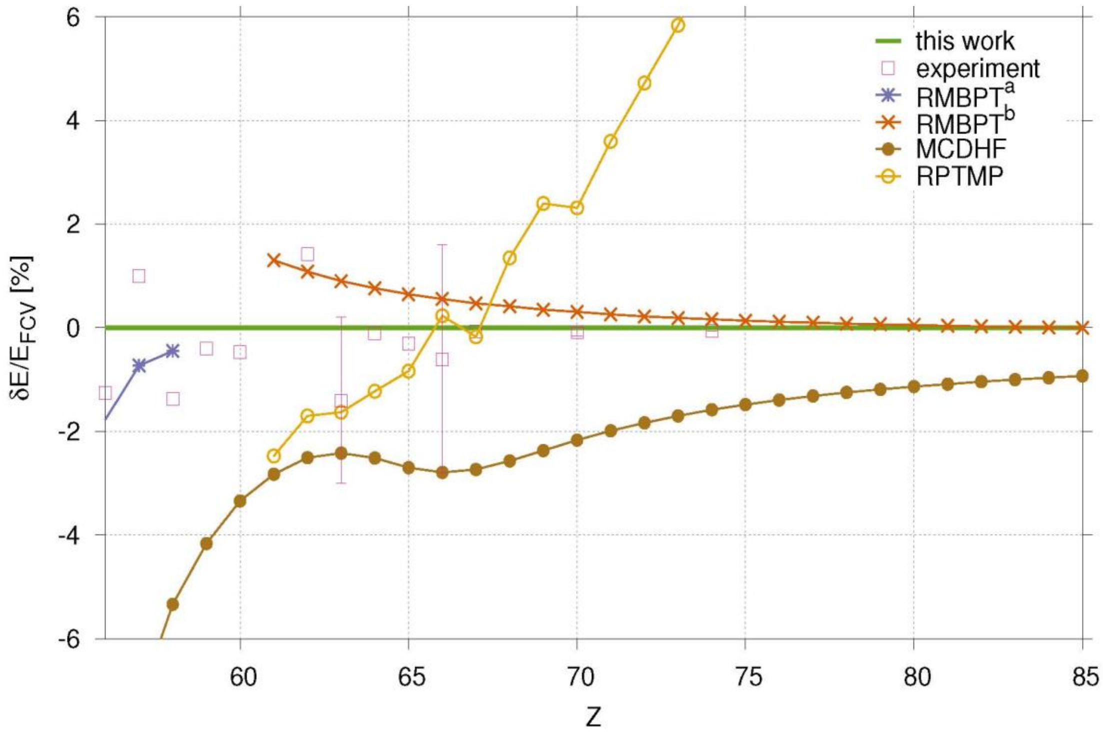
Life time estimation for the $^4F_{7/2}$ level in W^{27+}



Done using the magnetic trapping mode of EBITs

Ground state fine structure M1 transition in Ag-like ions

Large scale calculation including correlation down to the n = 2 shell. Biggest contribution came from the n = 3 shell

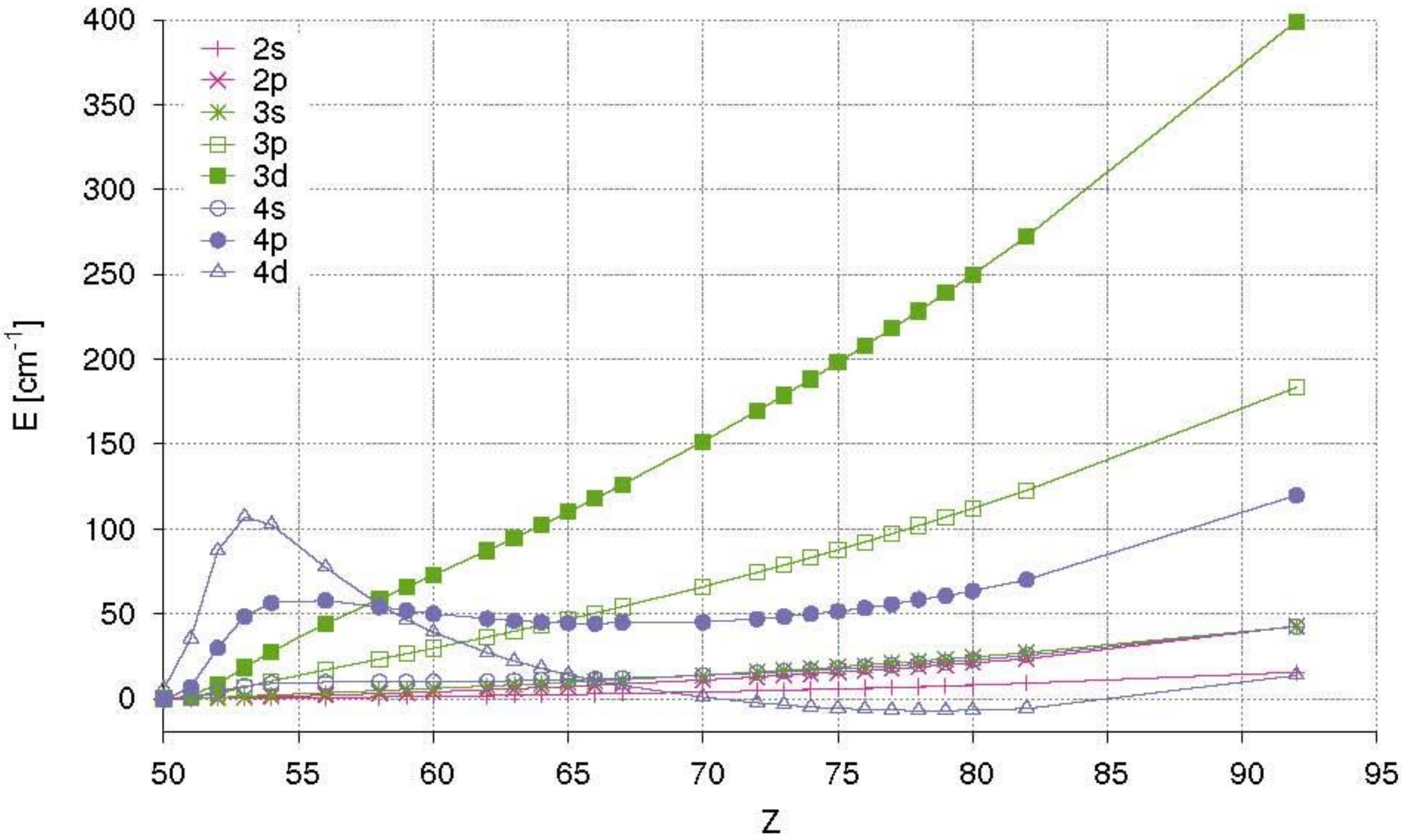


The quantity δE (defined below) along the Ag-like sequence. The green line is by definition zero, note our experimental data sit on the green line and most other experiments are very close. The other calculations show interesting trends

$$\delta E / E_{\mathrm{FCV}}^{\mathrm{tot}} = (E_{\mathrm{method}} - E_{\mathrm{FCV}}^{\mathrm{tot}}) / E_{\mathrm{FCV}}^{\mathrm{tot}}$$

PHYSICAL REVIEW A 89, 062511 (2014)

Contributions to the level energy



Contributions from core-valence correlation with different core subshells (relative to Dirac-Fock energies) to the 4f ^{2}F fine structure energy separation of Ag-like ions with nuclear charges $50 \leq Z \leq 92$. Note the dominating behaviour of core-valence correlation with 3d rather than 4d in the mid-and high-Z regime.

We have begun a study of single 4f hole states

$4f^{13}5s^2\ ^2F$ W^{13+}

$4f^{13}5s^25p^6\ ^2F$ W^{7+}

$4f^{13}$ is not the ground term for tungsten, this becomes the ground term around Hg, but we can look at the way the calculations converge

One final thing, holey states

Examples are:

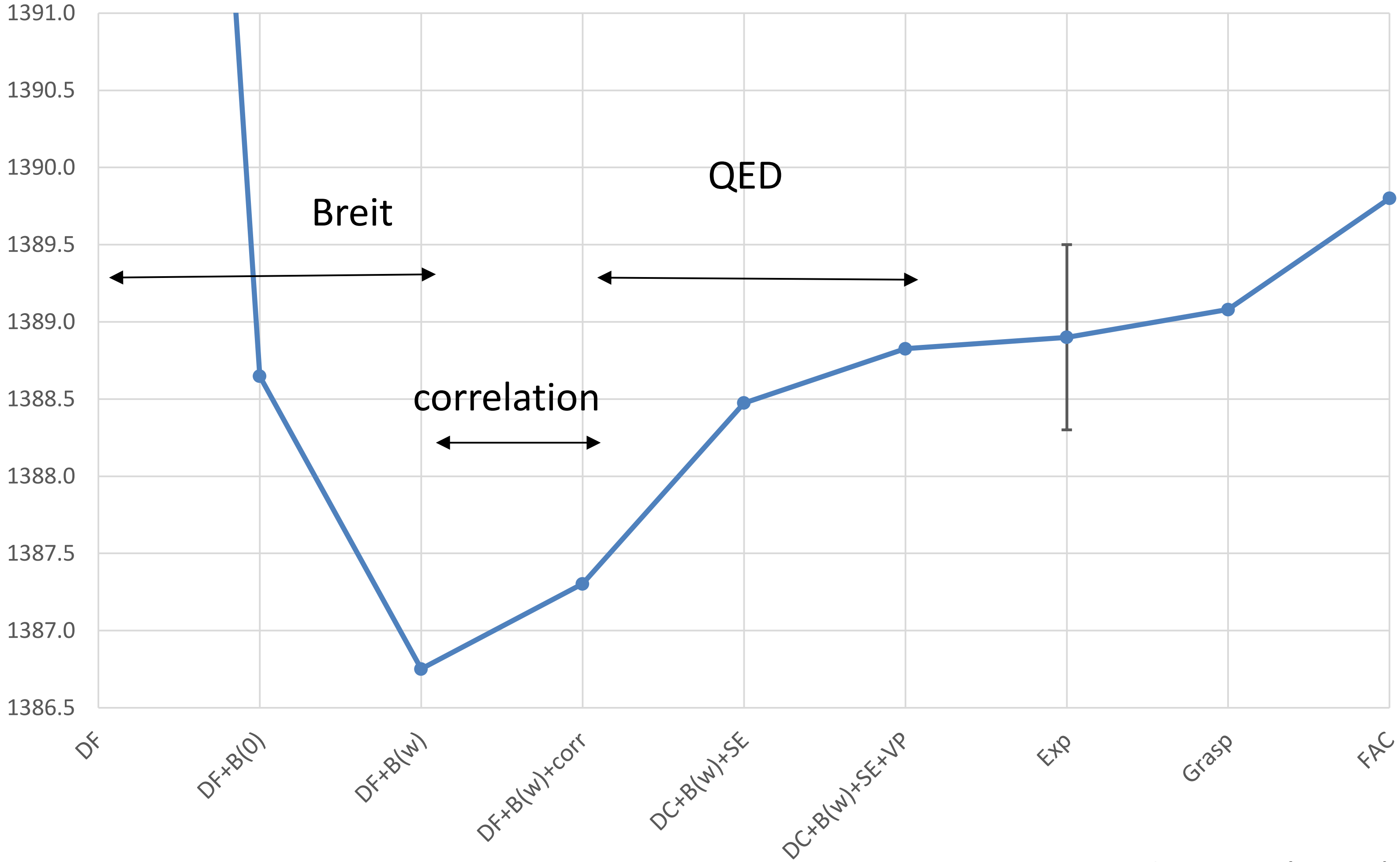
$2p^5$ $3d^9$ $4f^{13}$

Why are these interesting

The influence of electron correlation on the ^2P, ^2D and ^2F fine structure is very small for these terms

So, through comparison of precise spectroscopic measurements with calculation "with and without QED and Breit contributions" we can test how these are included in, for example, GRASP for multi-electron high Z systems

λ of $2p^5\ ^2P_{1/2}$ - $^2P_{3/2}$ in F-like W^{65+}



Brage et al. HCI-conference (2016)

Summary

Three EBITs in Fudan

Very good agreement between experiment and theory for the ground state M1 transition in W^{27+} (0.06 %)

Increasing difficulties in calculating singe 4f hole configurations with more closed outer shells

A possible way to test how the QED and Briet interaction is included in codes such as GRASP

Thank you very much
for your attention

Seasonal Greetings and a
Happy Winter Solstice