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Accurate atomic data for Galactic Surveys

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Abstract. Fourier Transform spectroscopy is able to provide high accuracy atomic parameters needed by many ongoing galactic surveys. Our laboratory has carried out a study of the neutral iron spectrum over the last years to measure oscillator strengths much needed for the calculation of chemical abundances. The main aim of this contribution is to encourage further dialogue with astronomers regarding their current necessities of spectroscopic data, as this would help spectroscopists to prioritise present-day needs within the field.

Keywords. atomic data, techniques: spectroscopic, stars: abundances

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1. Introduction

The analysis of stellar spectra is vital in the determination of chemical abundances, the understanding of galaxy formation and evolution or the synthesis of the different elements. However, despite the large investment of time and money done to record spectra of astrophysical objects at unprecedented resolution, this work is being hindered by the lack of accurate atomic data, the Achilles' heel of stellar parameter determination (Bigot & Thévenin 2006). As stellar models are strongly dependent on parameters such as transition probabilities (Heiter *et al.* 2015) and their accuracy, this shortage of data or its poor quality leads to mistaken values of the chemical abundances and stellar ages.

The Fourier Transform Spectroscopy (FTS) Laboratory at Imperial College London has been conducting a very fruitful collaboration with the National Institute of Standards and Technology (NIST), the University of Wisconsin and the University of Lund over the last years to obtain accurate oscillator strengths (transition probabilities) for many spectral lines needed in surveys such as Gaia-ESO or APOGEE. The results can be found in Ruffoni *et al.* (2013), Ruffoni *et al.* (2014) and Den Hartog *et al.* (2014). The $\log(gf)$-values are obtained by combining branching fractions obtained in a Fourier Transform Spectrometer with upper energy level radiative lifetimes measured in a time-resolved laser-induced fluorescence experiment.

2. Atomic data needs

Due to the strong influence of atomic data on the algorithms used to model stellar atmospheres, a big effort is being made to compile critically reviewed line lists with reliable atomic data for different surveys (Heiter *et al.* 2015, Shetrone *et al.* 2015) that can be used as a standard input for the different models. This assures some homogeneity in the final results (Smiljanic *et al.* 2014) and allows the comparison of the different techniques (Hinkel *et al.* 2016). However, the existing experimental atomic data is very scarce. This obliges astronomers to chose values from a very limited selection which, on many occasions, contains atomic data with very high uncertainties.

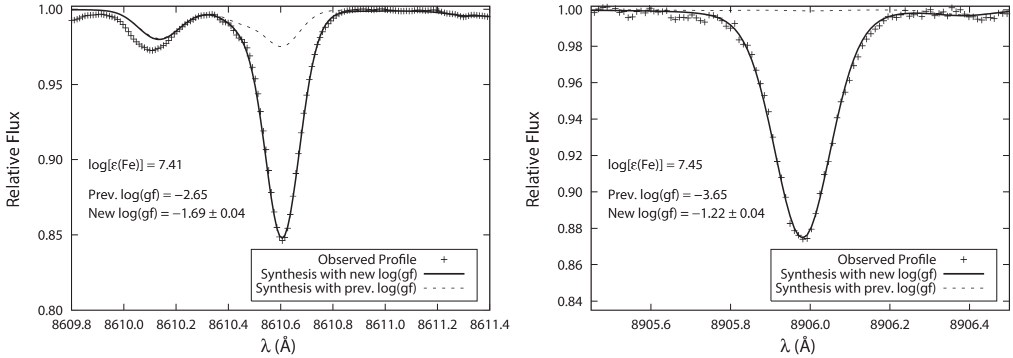

Figure 1. Sample line profiles used to measured Fe abundance.

The uncertainty of the oscillator strength used for the calculation of chemical abundances has a direct impact on the accuracy of the abundance obtained. Data needs have been previously discussed in some detail in Pickering *et al.* (2011), but the fast development of new surveys using high resolution spectra suggests that a new revision of the current atomic data necessities should be undertaken. Hence the appeal we would like to launch to all the Gaia community to start a fluid exchange of ideas to determine what data might be needed for future data releases.

3. Progress in new atomic data

The acute need for new accurately measured atomic parameters within the field of astronomy can be tackled by using high-resolution Fourier Transform spectroscopy. Transition probabilities, for example, can be obtained experimentally by combining branching fractions, BF, measured from high resolution emission spectra with upper level lifetimes obtained from time-resolved laser-induced fluorescence:

$$A_{ul} = \frac{BF_{ul}}{\tau_u} \tag{3.1}$$

with u and l representing the upper and lower energy level, respectively, and τ the radiative lifetime. Oscillator strengths can be obtained from transition probabilities by using the expression:

$$\log(g_l f) = \log\Big[A_{ul} g_u \lambda^2 \times 1.499 \times 10^{-14}\Big] \tag{3.2}$$

where g_l and g_u are the statistical weights of the lower and upper energy level and λ is the wavelength of the spectral line expressed in nm. Fourier transform spectroscopy has evolved dramatically over the past thirty years and nowadays, it is able to provide values of transition probabilities with uncertainties as low as 5% (0.02 dex in $\log(gf)$) for strong transitions.

The iron spectrum is of vital importance to obtain stellar metallicity. We have provided urgently needed Fe I oscillator strengths for two different surveys: APOGEE, where several tens of new Fe I $\log(gf)$s were measured in the H-band (1.5 - 1.7 μm) (Ruffoni *et al.* 2013) and the Gaia-ESO (GES) Survey (Ruffoni *et al.* 2014, Den Hartog *et al.* 2014). Studies of the Fe I spectrum within the GES spectral range revealed over 500 lines that were strong and unblended in stellar spectra. Around 50 of them had no previously published data and were urgently needed by GES. Fig 1, taken from Ruffoni *et al.* (2014), illustrates two sample line profiles used to measure the Solar Fe abundance

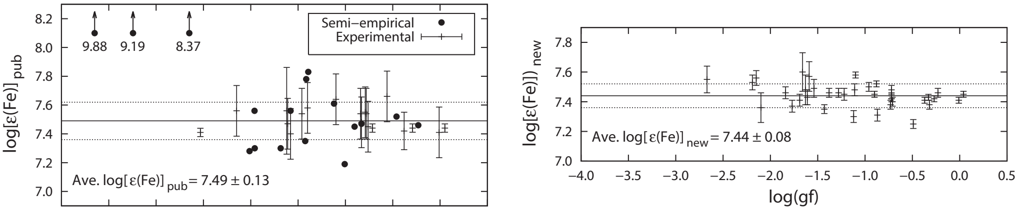

Figure 2. Determination of line-by-line solar Fe abundances using unblended solar lines.

($\log[\varepsilon(Fe)]$). The value of the Fe abundance provided in the plot was obtained by fitting the spectral lines with our new oscillator strengths. The dotted line shows the profiles that would have been obtained for these abundances with the best previously published $\log(gf)$-values.

To assess the impact of our new results on stellar spectral syntheses, we determined line-by-line solar Fe abundances for those that are unblended in the Sun and have good broadening parameters and continuum placement. It can see from Fig 2 (Ruffoni *et al.* 2014) how our new laboratory measured $\log(gf)$s have smaller uncertainties and the mean abundance calculated with them agrees well with recent values taken from the literature.

Collaboration with astronomers has been very fruitful, especially regarding the preparation of target line lists needed by different surveys. Our group has also published transition probabilities of neutral vanadium (Holmes *et al.* 2016) and is currently working on other elements such as manganese, nickel or scandium. Other data available from laboratory spectra are line wavelengths, used in cosmology to study the variation of fundamental constants, atomic energy levels needed to improve the theoretical modelling of lines and hyperfine splitting parameters to improve the synthesis of stellar spectra.

4. Conclusions

We would like to launch an appeal to collaborate with all those astronomers and research groups working on Gaia or any of the ongoing galactic surveys and who need accurate atomic data. Working closely with astronomers to know their data necessities, we will be able to provide very accurate atomic parameters that are much needed within the field.

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