Imperial College London

NEW ACCURATE ATOMIC DATA FOR ASTROPHYSICS APPLICATIONS BY HIGH RESOLUTION FOURIER TRANSFORM AND GRATING SPECTROSCOPY

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Studies of neutral, singly and doubly ionised iron group element spectra

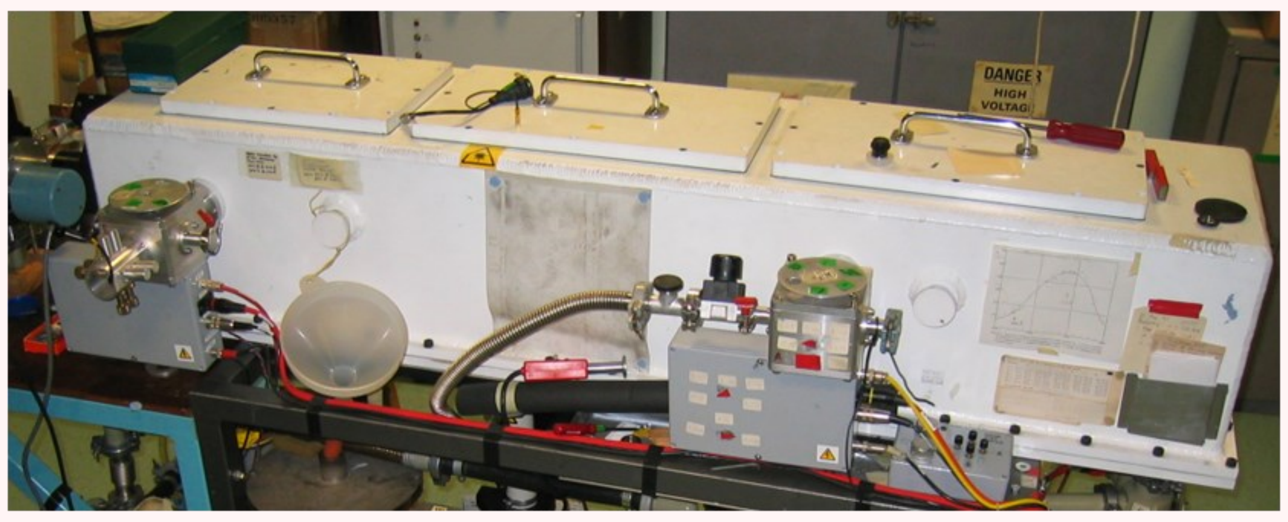
The Imperial College spectroscopy group is studying neutral, singly and doubly ionised iron group element spectra using high resolution Fourier Transform Spectroscopy (FTS) at Imperial College (IC), and, in collab-oration with NIST, Grating Spectroscopy.

Data needs for astrophysics applications:

Wavelengths and **atomic energy levels** accurate to 1 part in 10^7,

Oscillator strengths, ideally to 10% accuracy or better,

Data for line broadening effects such as **hyperfine structure.**



The Imperial College VUV FT Spectrometer

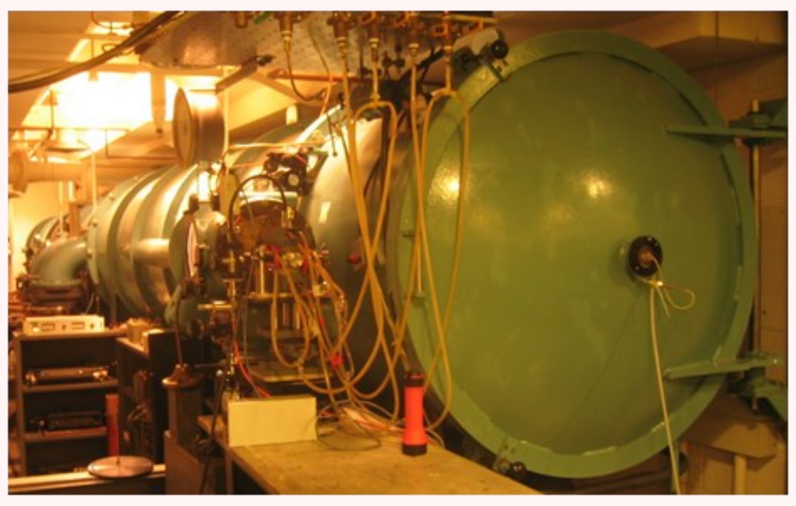
Spectral range: 140 — 800 nm.

Resolving power: 2 million at 200 nm.

Intensity calibration: using tungsten and deuterium standard lamps.

Light Sources: hollow cathode lamps,
Penning Discharge Lamp.

Beyond the spectral range of the IC FT Spectrometer we have supplemented our measurements with IR FT spectra recorded at NIST and Lund University, and VUV Grating spectra recorded at NIST (USA) (collaboration with G.Nave).



The NIST 10.7 m Normal Incidence Grating Spectrograph.

Spectra of doubly ionised iron group elements

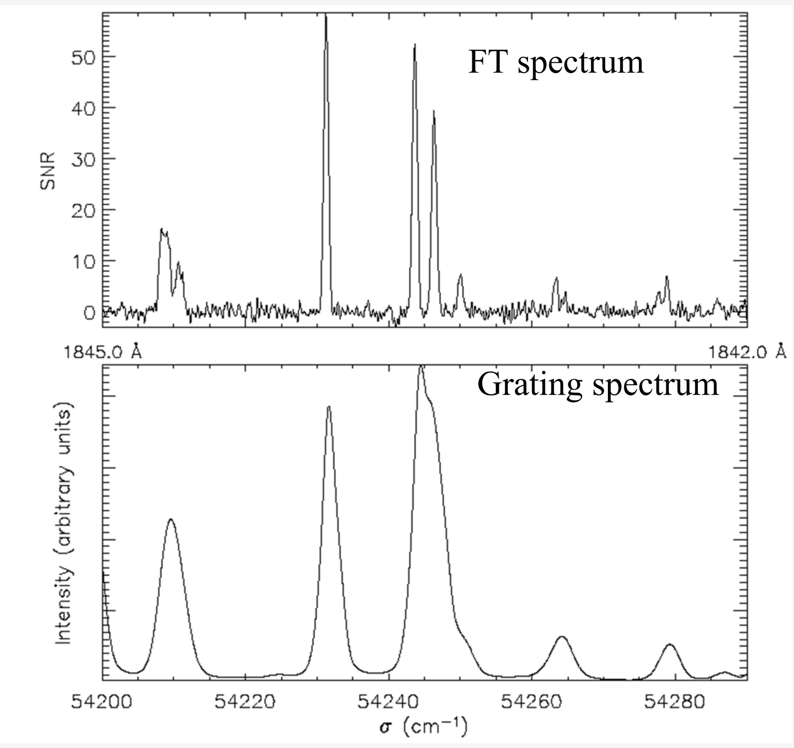
Accurate data for the singly and doubly ionised iron group elements are urgently required. Applications of the data include, for example, ASTRAL II, a hot star treasury programme (PI Ayres), on Hubble Space Telescope, STIS.

Cr III, Co III & Fe III spectra were measured in the IR-VUV at IC and NIST.

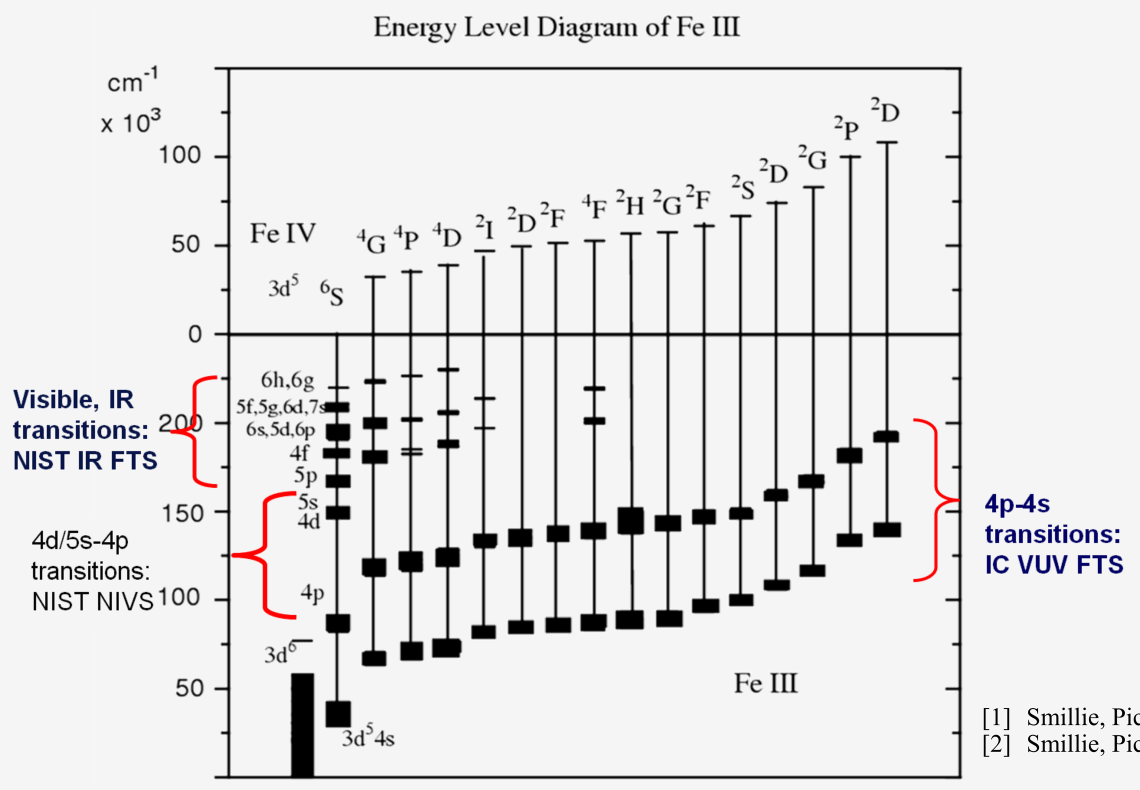
Results:

Cr III: standard wavelengths [1].

Co III: order of magnitude improve-ment in wavelengths and energy levels. 734 classified lines, uncertainty of strong lines ~ 0.004 cm^{-1}, and 287 of 288 levels have been revised [2].



Example section of the Co III spectrum



Fe III: term analysis is in progress:

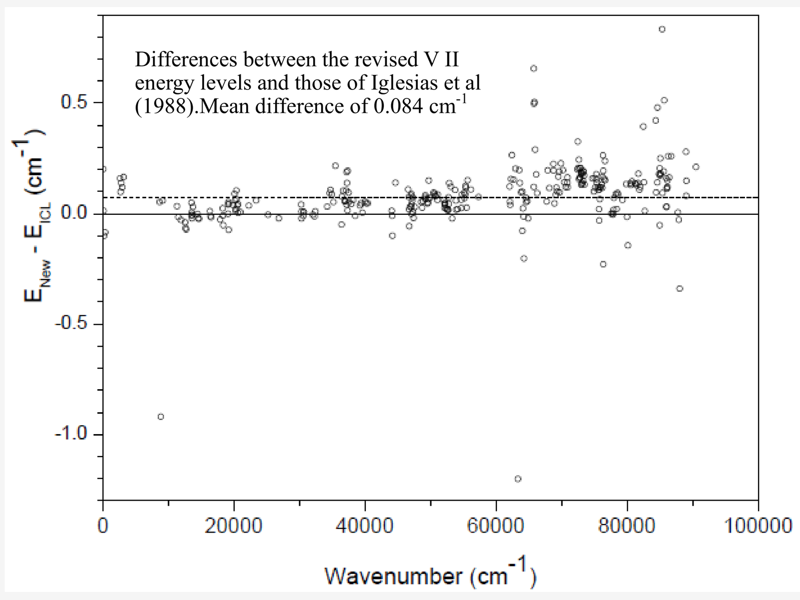
[1] Smillie, Pickering & Smith, 2008, MNRAS, 390, 733
[2] Smillie, Pickering, Nave & Smith, 2016, ApJS, 223,12

Neutral and Singly ionised 3d group element spectra

V II term analysis is now completed: 1242 classified lines in range 154-580 nm, with 409 energy levels, of which 5 are newly found levels [3].

Cr I term analysis is close to completion in collabo-ration with NIST, with new and revised energy levels.

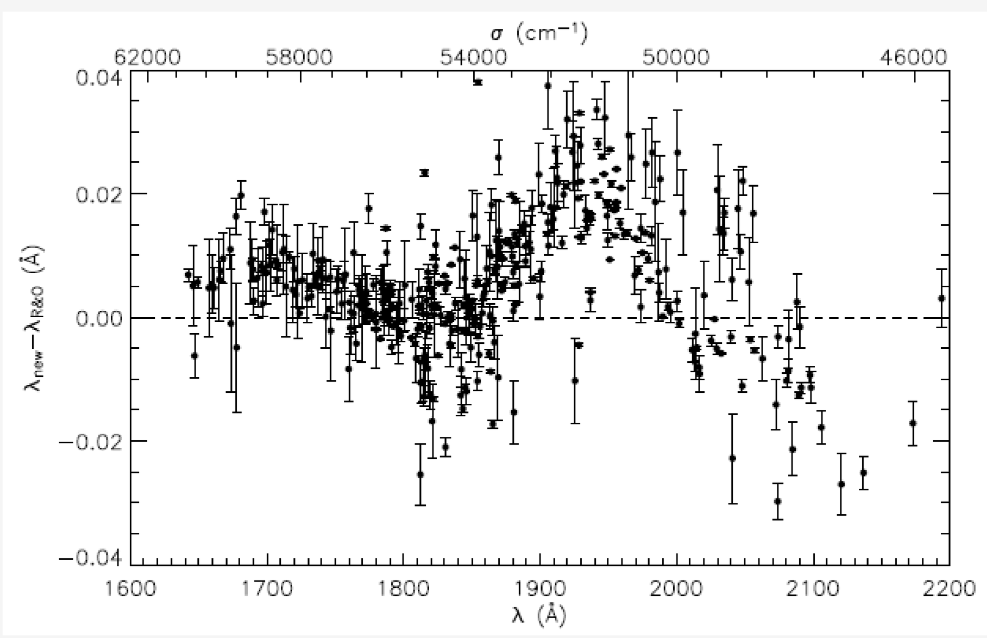
V I f-values: relative line intensities measured at Imperial College have been combined with new level lifetimes measured at the Lund Laser Centre to yield new f-values in the visible-IR (304—2000 nm) for stellar abundance analyses [4].



Mn I & II and **Ni II term analyses** are ongoing, in collaboration with NIST. Imperial College FTS spectra and NIST Grating Spectra are combined. (See other posters at this meeting.)

Forbidden Lines: accurate wavelengths for forbidden lines of Co II and V II published [5].

[3] Thorne, Pickering & Semeniuk, 2013, ApJS, 207, 13
[4] Holmes, Pickering, Ruffoni , Blackwell-Whitehead, Nilsson, Engström, Hartman, Lundberg, & Belmonte, 2016, ApJS in press
[5] Ruffoni & Pickering, 2013, ApJS, 207, 20



An example of wavelength accuracy improve-ment [2] is seen here with a comparison between our FTS measured Co III wavelengths and those of Raassen & Ortin (1984) (R&O) from grating spectra. Error bars are the combined uncertainties.

Although the wavelength uncertainty quoted in R&O is 10 mÅ, the wavelength differences exceed this significantly in many cases and exhibit a striking trend. Such a trend cannot be present in the FTS spectrum because the FTS wavenumber calibration is a wavenumber dependent shift.

We are open to requests for atomic data.

More information is available online:

http://www.sp.ph.ic.ac.uk/~julietp/FTS/research.htm

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Log *gf* s for Galactic surveys

We have been measuring a range of Fe I and Fe II oscillator strengths for the SDSS III/APOGEE and Gaia-ESO Galactic evolution surveys [6-9].

[6] Heiter, U et al, Atomic and molecular data for optical stellar spectroscopy, 2015, Physica Scripta, 90(5) 054010
[7] Den Hartog et al, Fe I oscillator strengths for transitions from high-lying even-parity levels, 2014, ApJS 215(2) 23
[8] Ruffoni et al, Fe I oscillator strengths for the Gaia-ESO survey, 2014, MNRAS 441(4), 3127
[9] Ruffoni et al, Infrared laboratory oscillator strengths of Fe I in the H-band, 2013, ApJ 779(1) 17