New Atomic Data of Singly-ionised Nickel (Ni II)

Christian P. Clear[1], Juliet C. Pickering[1], Gillian Nave[2]

[1]Physics Department, Imperial College London, Prince Consort Road, London, SW7 2AZ, UK

[2]Quantum Measurement Division, National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899-8422, USA

Imperial College London

1. Introduction

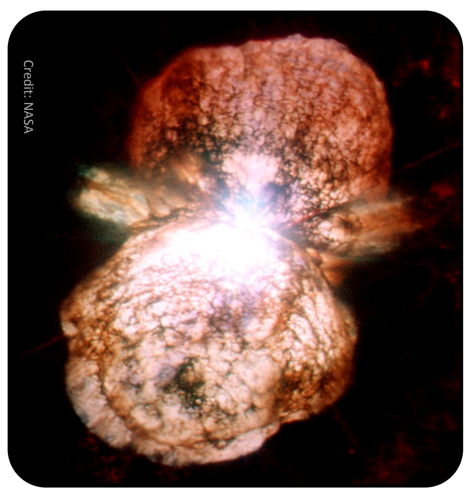
"Multimillion-dollar projects . . . are producing data that cannot be analysed because of a failure to support much cheaper lab work on the ground."

- *Nature* Editorial [1]

Advances in the resolution and spectral range of ground and space-based spectrographs have high-lighted the need for improved line wavelength and energy level values.

The last major work on the spectrum of Ni II was in 1970 [2]. Although comprehensive, these wavelength and energy levels accuracies (± 0.05 cm^{-1} [3]) are now insufficient for modern astrophysical applications.

An order of magnitude increase in the accuracy of Ni II atomic data is needed, and can be achieved with Fourier Transform Spectroscopy (FTS) [4].

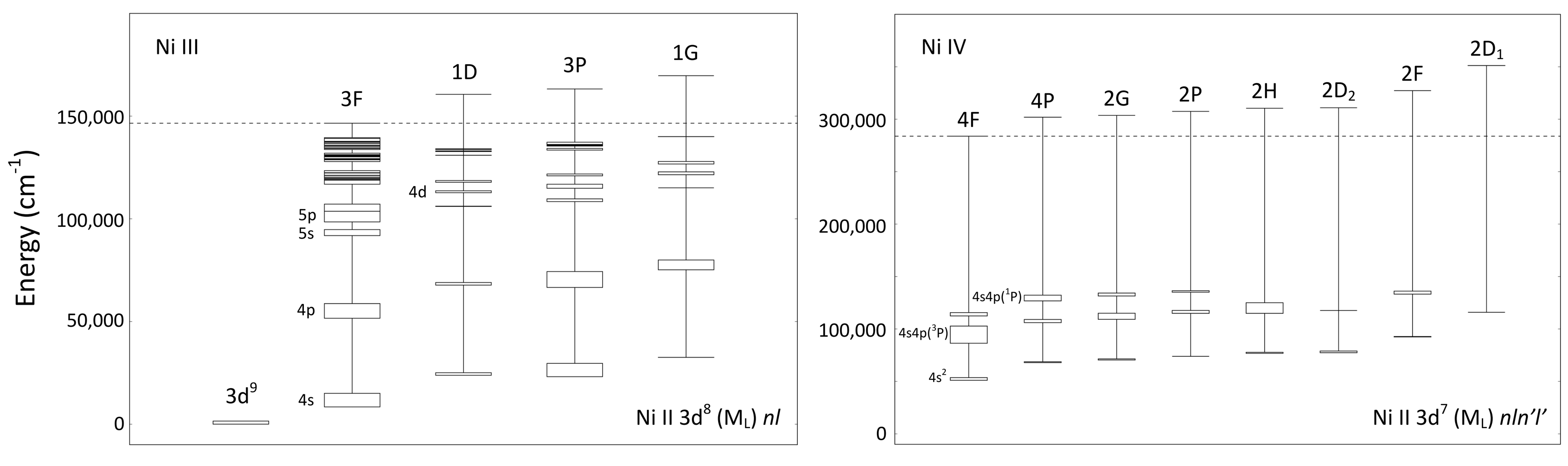


Ni II has been detected in Eta Carinae.

2. Singly Ionised Nickel

The complex atomic structure of iron group elements produces densely-populated spectra from the vacuum ultraviolet (VUV) to the infrared (IR). Combined with relatively high cosmic abundances, iron group element spectra account for the majority of opacity in stars.

Ni II has been observed in a wide variety of astrophysical spectra, including supernovae [5], evolved stars [6], γ-ray bursts [7], luminous blue variables [8] and many others.

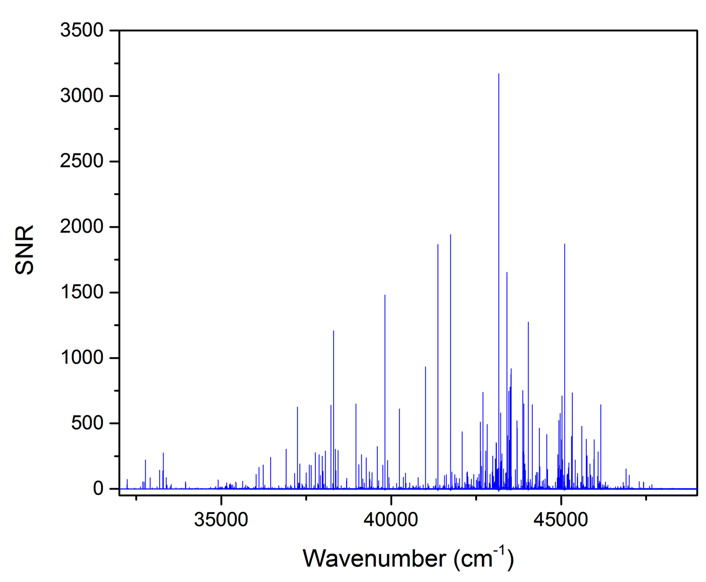


Energy level diagrams for singly and doubly excited Ni II. Energy level data from [2]. Dashed lines indicate ionisation energies.

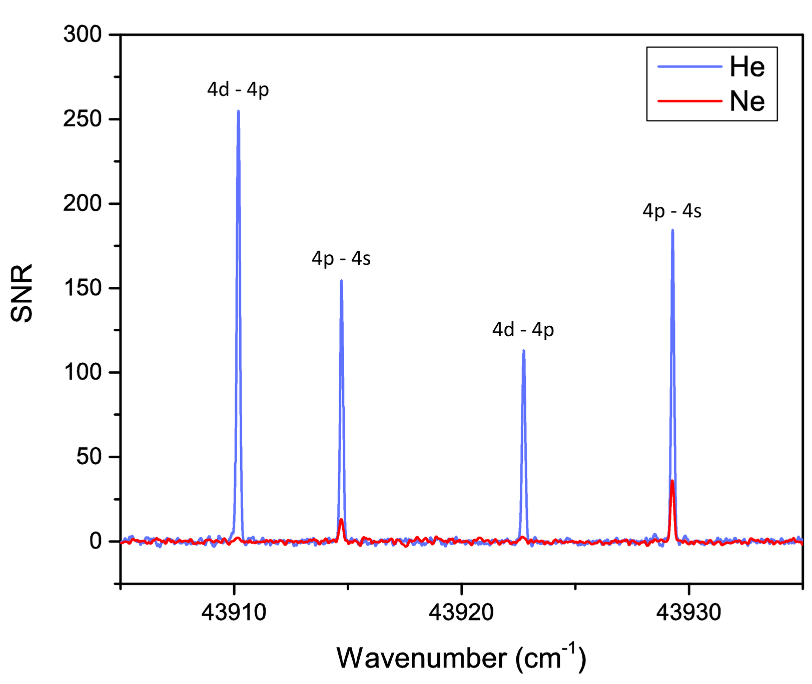
3. Imperial College FTS

The Imperial College FT spectrometer provides high spectral resolution (R ~ 2 million at 200 nm) and high wavenumber accuracy (at least 1 part in 10^7) across a broad spectral range, making it an ideal instrument for large-scale term analyses.

A nickel-helium water cooled hollow cathode lamp (HCL) is used as a stable source of neutral atoms and singly-ionised ions of nickel.



Spectrum of a Ni-He HCL (10 mbar, 800 mA).



Spectra of a Ni-He and Ni-Ne HCL at 800 mA with 10 mbar and 4 mbar pressure respectively.

The ionisation energy of helium preferentially excites high-lying levels of Ni II which are not populated with neon as a filler gas [9].

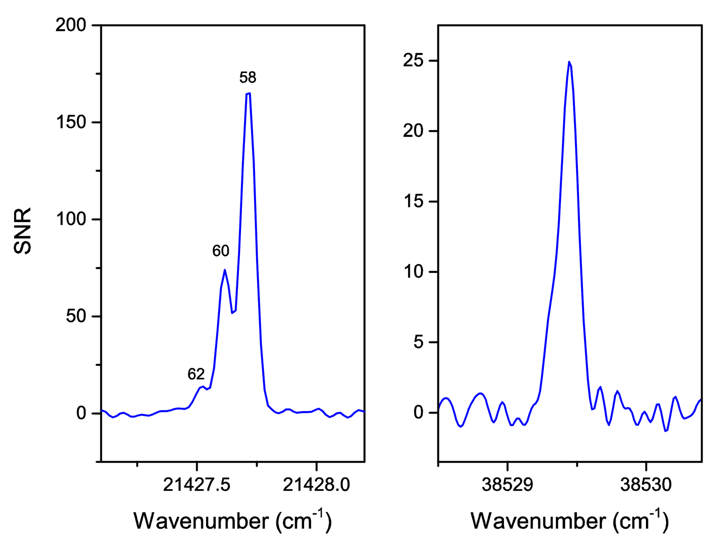
Most Ni II lines exhibit a ~5-10 times enhancement of intensity in helium compared to neon. For certain groups of transitions (such as $3d^8$(3F)5s - 4p) this can be as high as 50 times.

Numerous nickel lines display isotopic structure. A large proportion of the isotopic shift is due to the specific mass effect [10], meaning transitions between $3d^8nl$ and $3d^74snl$ exhibit appreciable shifts.

For lines in the IR and visible (which have smaller Doppler widths) the isotopic structure is resolved. This is not the case for wider lines in the VUV.

Isotope M	58	60	61	62	64
Abundance	68.3	26.1	1.1	3.6	0.9

Abundances of stable nickel isotopes [11].



Isotopic structure in $3d^74s^2$ - $3d^8$(3F)4p Ni II.

4. NIST Grating Spectra

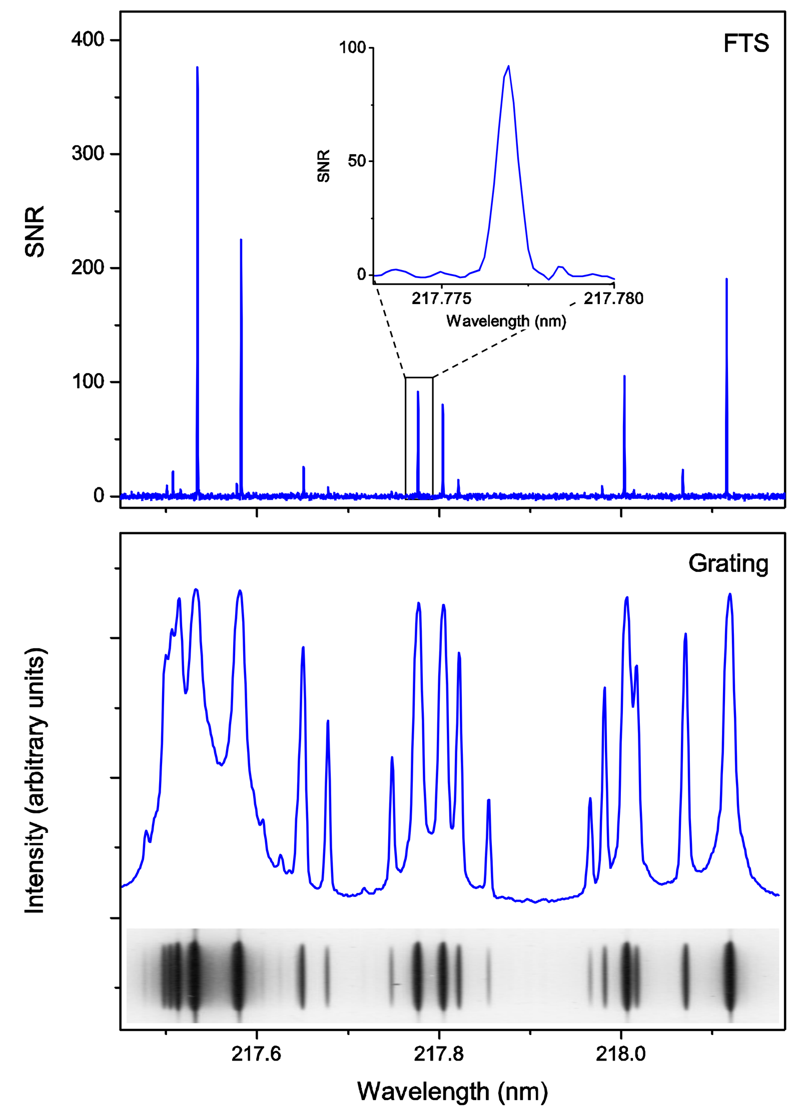
"The accuracy of measurement throughout the whole spectrum is not as great as I had hoped, but the effort of re-measurement is too great for me to undertake."

– A. G. Shenstone, discussing the Ni II spectrum in his 1970 publication [2].

To improve the accuracy of existing Ni II wavelengths below the FTS lower wave-length limit (~140 nm), grating spectra were recorded with the NIST NIVS 10.7 m normal incidence spectrometer:

- Range: 72.7 - 260 nm
- Recorded on photographic plates.
- Calibration: Pt standard lines, strong FTS lines, FTS Ritz wavelengths.

The source used was a water-cooled Ni-He HCL operated at 2000 mA and 5.3 mbar heli-um pressure.

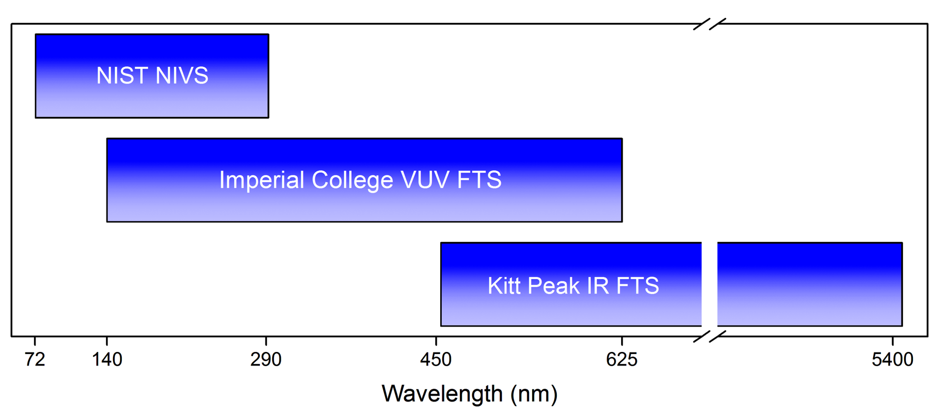


Top: FTS spectrum of Ni-He hollow cathode lamp (0.8 A, 10 mbar). Bottom: Intensity plot of scanned NIST photographic plate. Bottom inset: NIST photographic plate.

5. Analysis

New FTS spectra from Imperial College, existing FTS spectra from the Kitt Peak National Observatory and grating spectra from NIST will be used in the term analysis of Ni II.

The Ni II linelist will be created following the line fitting of the spectra.



Wavelength ranges of the spectra to be used in this work.

The FTS linelist will be wavelength-calibrated using Ni I lines (Litzén et al. [12]). These lines used argon II standard reference lines measured by Norlén [13] for calibration and so must be shifted onto the scale of the FTS argon II reference lines measured by Whaling [14].

Intensity calibration uses deuterium and tungsten standard lamps and will enable the calculation of Ni II log(gf)s from branching fractions. A recent paper by Cassidy et al. [15] will allow compari-son with theoretical values.

6. Conclusion

- Term analysis of the spectrum of Ni II is underway.
- FTS spectra will give an order of magnitude increase in energy level accuracy.
- New grating spectra will increase the accuracy of previously reported wavelengths.

References

[1] Editorial. *Nature.* **503/7477**, 437 (2013)
[2] Shenstone A. G., J. *Res. Nat. Bur. Stand.*, **74A**, 801 (1970)
[3] Corliss C. & Sugar J., *J. Phys. Chem. Ref. Data*, **14**, 587 (1985)
[4] Pickering J. C., *Vib. Spec.*, **29**, 27 (2002)
[5] Li R. et al., *Astrophys. J.*, **419**, 824 (1993)
[6] Richardson N. D., *Astron. J.*, **142**, 201 (2011)
[7] Vreeswijk P. M., *Astron. & Astrophys.*, **468**, 83 (2007)
[8] Davidson K. et al., *Astron. J.*, **121**, 1569 (2001)
[9] Johansson S. & Litzen U., *J. Phys. B.*, **13**, L253 (1980)
[10] Rosberg M. et al., *Mon. Not. R. Astron. Soc.*, **262**, L1 (1993)
[11] Clayton D., *Handbook of Isotopes in the Cosmos* , Cam. Uni. Press., (2003)
[12] Litzén U. et al., *Phys. Scrip.*, **47**, 628 (1993)
[13] Norlén G., *Phys. Scrip.*, **8**, 249 (1973)
[14] Nave G.. & Sansonetti C. J., *J. Opt. Soc. Am. B.*, **21:2**, 442 (2004)
[15] Cassidy C. M. et al., *Astron. & Astrophys.*, **587**, A107:1 (2015)

Acknowledgements

This work is supported by STFC(UK) and NASA.

Find out more!

E-mail: cpc14@ic.ac.uk

Website: www.imperial.ac.uk/people/c.clear14

Group website: www.sp.ph.ic.ac.uk/~julietp/FTS/

Author's website

This poster (pdf)