Atomic spectroscopy
(needs mostly for ions)

Giulio Del Zanna
DAMTP, CMS, University of Cambridge, UK

High-resolution spectroscopy and broad-band imaging requires

- completeness and accuracy in the atomic data (e-ion scattering and A-values)
- accurate wavelengths (Doppler measurements)
- line identifications
Atomic data

CAlculation:
UK APAP Network http://www.apap-network.org/
has become the main ion atomic data provider
for fusion and astrophysics
(Strathclyde, UCL, Cambridge)

BENCHMARK:
EUV line identifications and benchmark

Distribution:
CHIANTI (www.chiantidatabase.org) has now become
the reference atomic database for ions
(often better than NIST), included in most
atomic spectral codes for astrophysics
(hundreds of citations per year).

CHIANTI v.7 are available in VAMDC (Virtual Atomic and
Molecular Data Center: http://portal.vamdc.eu)
1) Many users (e.g. modellers) need, e.g. the emissivities to calculate the radiative lossess for plasma.
2) Ne or Te from line ratios
3) Simulated spectra

The CHIANTI programs are mostly in IDL, not directly accessible. GUls will be made available to access the data via VAMDC.
V.8 will be included into VAMDC.

- New format for energy and rates files.
- All excitations included (data usable for high-Ne plasmas)
- Data for a few isoel. seq.from UK APAP network.
New additions to CHIANTI v.8:
- S I – new (Tayal 2004)
- N I (Tayal 2006)
- C I – new neutral (Wang+2013)
- Fe III – new ion (Badnell 2014)
- S II (Tayal & Zatsarinny 2010)
- S III: Hudson et al. (2012)

A-values from various sources.

More data are needed

Orion Nebula
(Mesa Delgado et al, 2009).
SUMER QS spectrum 704-790 (Curdt et al 2001)

SUMER QS spectrum 972.5-1050 (Curdt et al 2001)

Solar Orbiter (2018- ) next ESA/NASA solar major mission
UV/EUV spectroscopy

G. Del Zanna - VAMDC meeting - Belfast 2015
Solar corona: EUV

Six broad-band EUV images every 12s

EUV spectra every 10s

Used to study the heating of the solar corona. Ne, Te, chemical abundances

G. Del Zanna - VAMDC meeting - Belfast 2015
Hinode EIS and iron unidentified lines

Del Zanna (2011): most brightest iron coronal lines finally identified with the help of laboratory plates after 8 years! More work still needed.

G. Del Zanna - VAMDC meeting - Belfast 2015
Mostly from iron!
A lot of cool/unidentified lines in AIA bands (Del Zanna+2011). more work needed.

G. Del Zanna - VAMDC meeting - Belfast 2015
He-like (Whiteford et al. 2001, up to n=5)
Li-like (Liang & Badnell 2011, 204 levels up to n=5 + inner-shell)
B-like (Liang+2012, 204 levels, up to n=4)
Na-like (Liang+2009, 161 levels, up to n=6 + inner-shell)
Ne-like (Liang+Badnell 2010, 207 levels, up to n=7)
Accurate data needed for Ne diagnostics

Hinode EIS spectra have pushed the needs for more accurate atomic data. A discrepancy in Ne from Fe XII has been noted.

Young et al. (2009)
New large-scale R-matrix calculations

- DW calculations for some n=4 levels significantly underestimate collision strengths. Soft X-rays
- Cascading from higher levels significantly increases the populations of lower levels. EUV

- Fe VIII (new ICFT+STJK – TEC): Del Zanna & Badnell 2014
- Fe IX: Del Zanna et al. (2014) up to n=5
- Ni XI up to n=4 (Del Zanna et al. 2014)
- Fe X: Del Zanna et al. (2012) up to n=4
- Fe XI: Del Zanna & Storey (2012) up to n=4, merged with Del Zanna et al. (2010)
- Fe XII: Del Zanna et al. (2012) up to n=4
- Fe XIII: Del Zanna & Storey (2012) up to n=4
- Ni XV, same target as Fe XIII (Del Zanna et al. 2012)

More calculations of this kind are needed.

G. Del Zanna - VAMDC meeting - Belfast 2015
• The new atomic data produce lower densities.
Quiet Sun EUV irradiance spectrum

Modelling (red) shows overall very good agreement within 10-20%
SIRIUS

Stellar & ISM Research via In-orbit Ultraviolet Spectroscopy
First high-resolution EUV spectroscopic astrophysical mission
(ESA-CAS proposal, led by M. Barstow – Leicester Univ.)

Slitless, normal incidence off-axis EUV spectrograph
R~5000, peak $A_{\text{eff}} > 10 \text{ cm}^2$, $\lambda \lambda \text{ 180-240 Å}$

G. Del Zanna - VAMDC meeting - Belfast 2015
Simulation using CHIANTI v.8.
The 210-250 Å region is largely unexplored.

G. Del Zanna - VAMDC meeting - Belfast 2015
CHIANTI v.7.1: DW data + identifications (Del Zanna 2012). V.8: R-matrix data

Recalibrated QS spectrum (Del Zanna 2012)

quiet Sun (Manson 1972)

Quiet Sun

R-matrix data

Del Zanna (2012)

CHIANTI v.7.1b

CHIANTI v.7

Soft X-rays - a lot more of missing data
How many years to sort out 1 A bin?

AIA 94 A images show ubiquitous presence of Fe XVIII (Warren et al. 2012) and provide for the first time detailed information of hot plasma in active regions.

Solar spectrum
Manson (1972)

Laboratory spectrum. One line still to be identified!

New DW calculations for Fe VIII, Fe IX (O’Dwyer+2012)
New Fe XIV identification (Del Zanna 2012)
First scattering Fe X calculations (Del Zanna+ 2012)

G. Del Zanna - VAMDC meeting - Belfast 2015
Conclusions

Would be useful to produce a `laboratory astrophysics’ approach where all the UK groups (laboratory and theoretical calculations) are coordinated to support the astrophysics community.

Significant laboratory and theoretical work is still needed to reach completeness and accurate wavelengths.

Significant international interest in providing uncertainties on atomic data.