Atomic data for astrophysics

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OUTLINE:

Some methods to measure chemical abundances in stellar coronae

Atomic data Calculations – e.g. **APAP Network (UK):**

Benchmark of atomic data

Atomic Databases: **CHIANTI and VAMDC**

Science & Technology Facilities Council

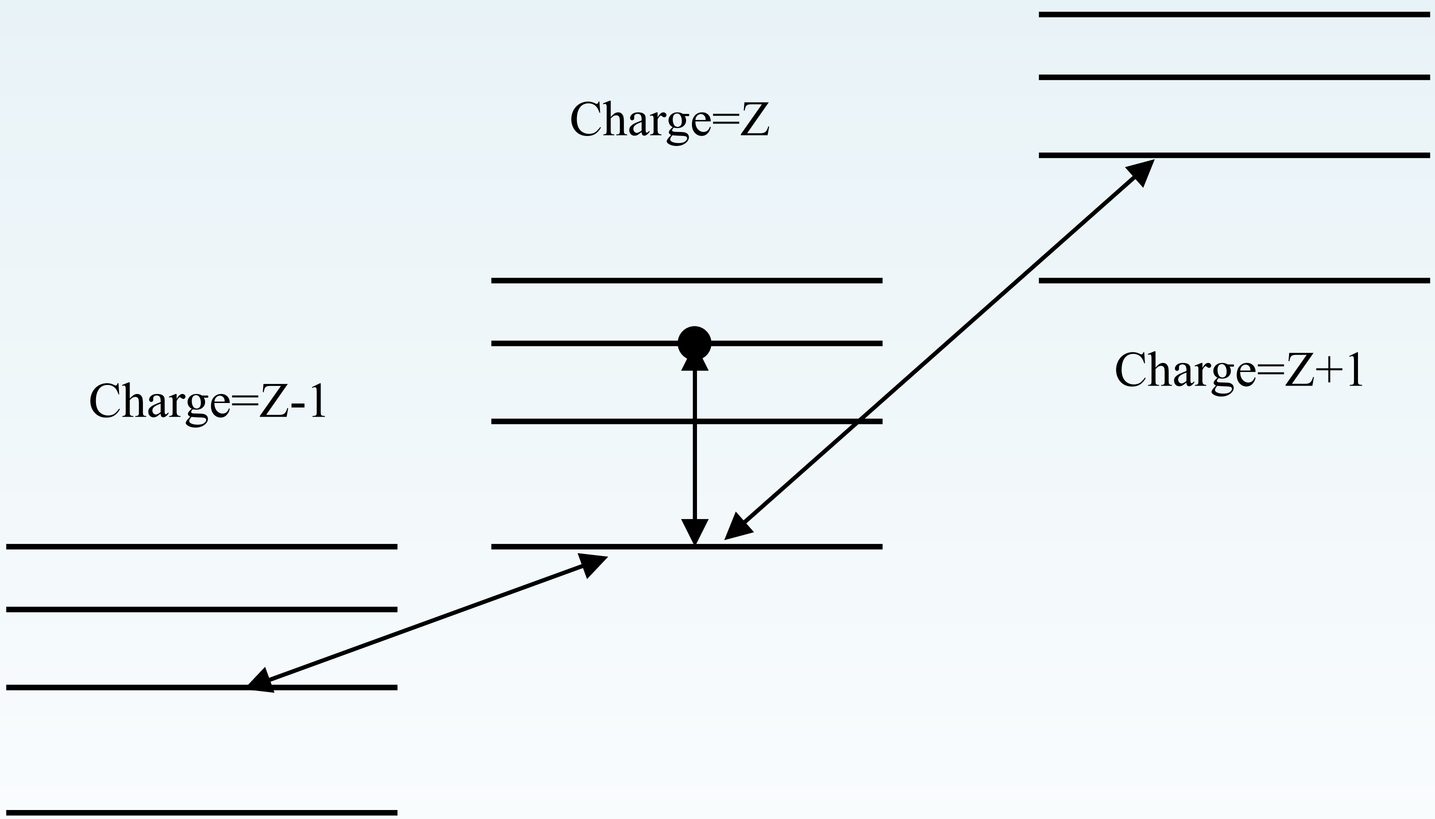
VAMDC Virtual Atomic and Molecular Data Centre

UNIVERSITY OF CAMBRIDGE

Ionization vs. excitation

Ionizations/recombinations occur on timescales of 1-100s

Dipole-allowed lines decay in 10^{-10} s. Forbidden ones in 10^{-4} s or longer



Treat separately excitation ionization

Intensities

- Separate excitation from ion/rec.

optically-thin plasmas line intensities are proportional to:

$$I \sim n_j\, A_{ji} = \frac{N_j(X^{+m})}{N(X^{+m})}\, A_{ji}\, \frac{N(X^{+m})}{N(X)}\, \frac{N(X)}{N(H)}\, \frac{N(H)}{N_e}\, N_e$$

A-value

Ion abundance (Te, Ne)

El. abundance

Level population (Ne,Te)

Atomic data

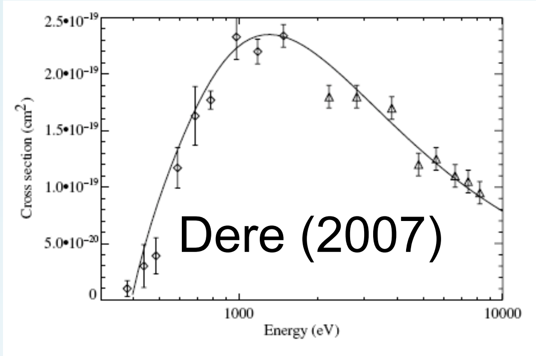
Measure:

Te, Ne, Abundances

Calculations of basic atomic data

1) **Direct-ionization by electron impact**:

Dere (2007) calculated ab-initio cross-sections of impact with ions and compared them with available experimental data for a large number of ions.



2) **Radiative recombination**: Badnell (2006).

3) **Dielectronic recombination**:
Badnell et al. (2003+ a number of papers).

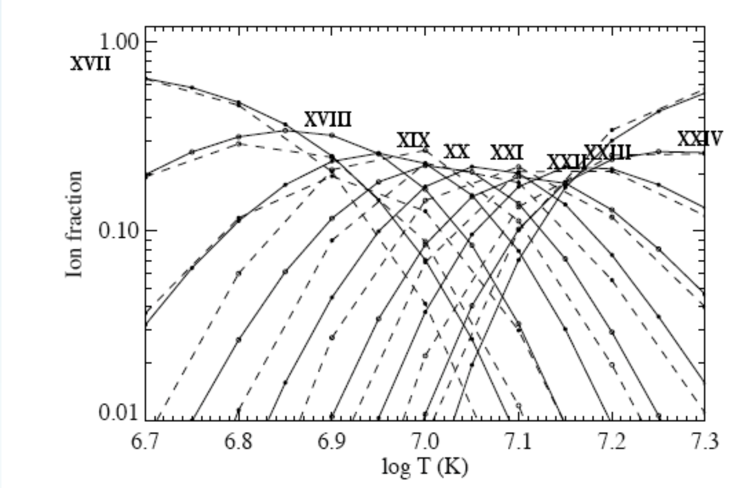


Fig. 3. Ionization equilibria for Fe XVII-XXIV. Full line - current calculations, dashed line = Mazzotta et al. (1998).

4) R-matrix **electron impact excitation**:

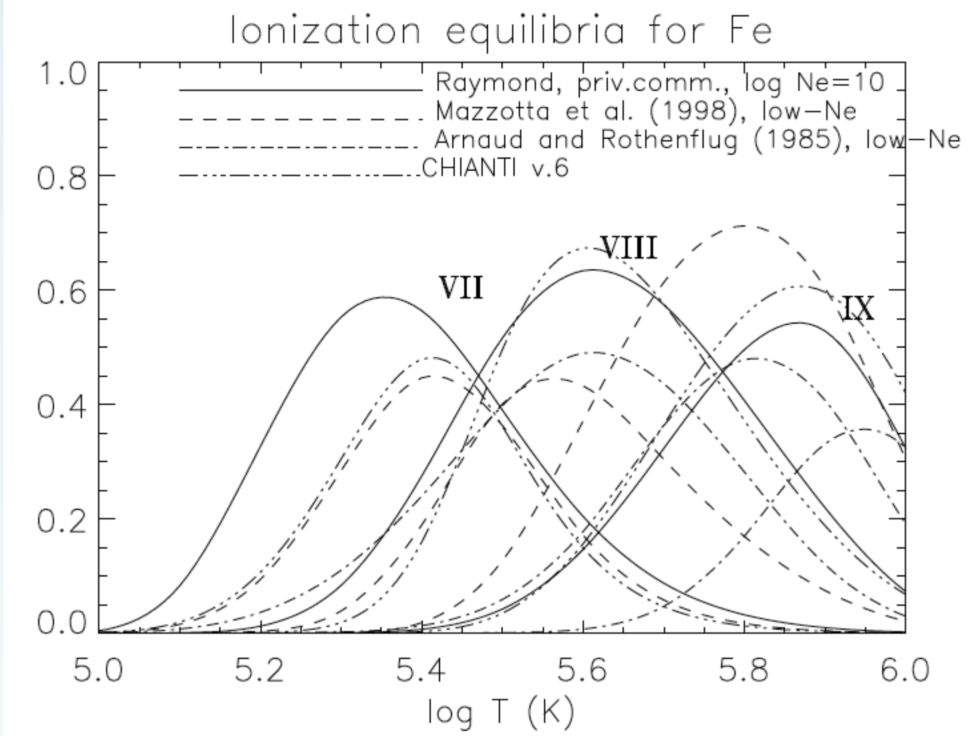
1) Iron Project
2) STFC-funded (UK)

APAP Network http://www.apap-network.org/

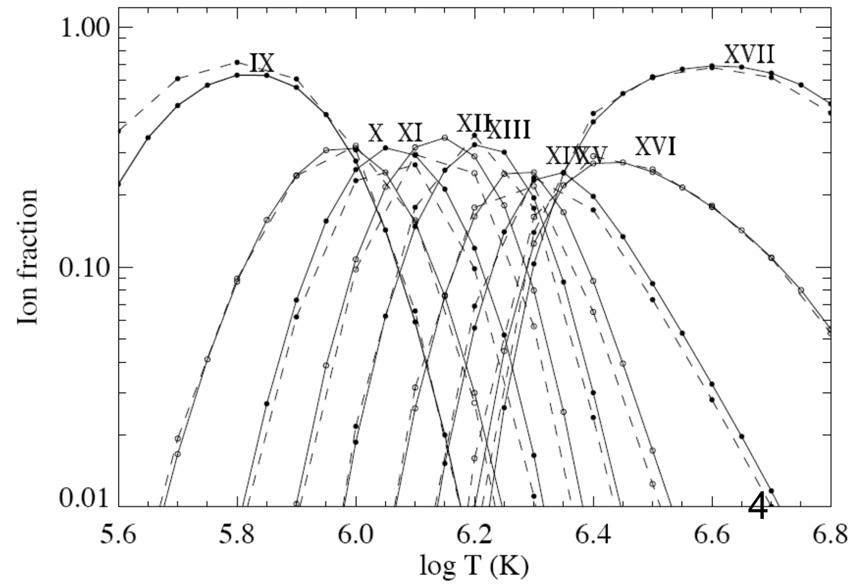
atomic structure and e- scattering data for all astrophysically-important ions, sequence by sequence.

Ion abundances

Latest ion abundances are, form some ions, very different from previous ones. Dere et al. (CHIANTI v6)



Del Zanna & Mason (2010)

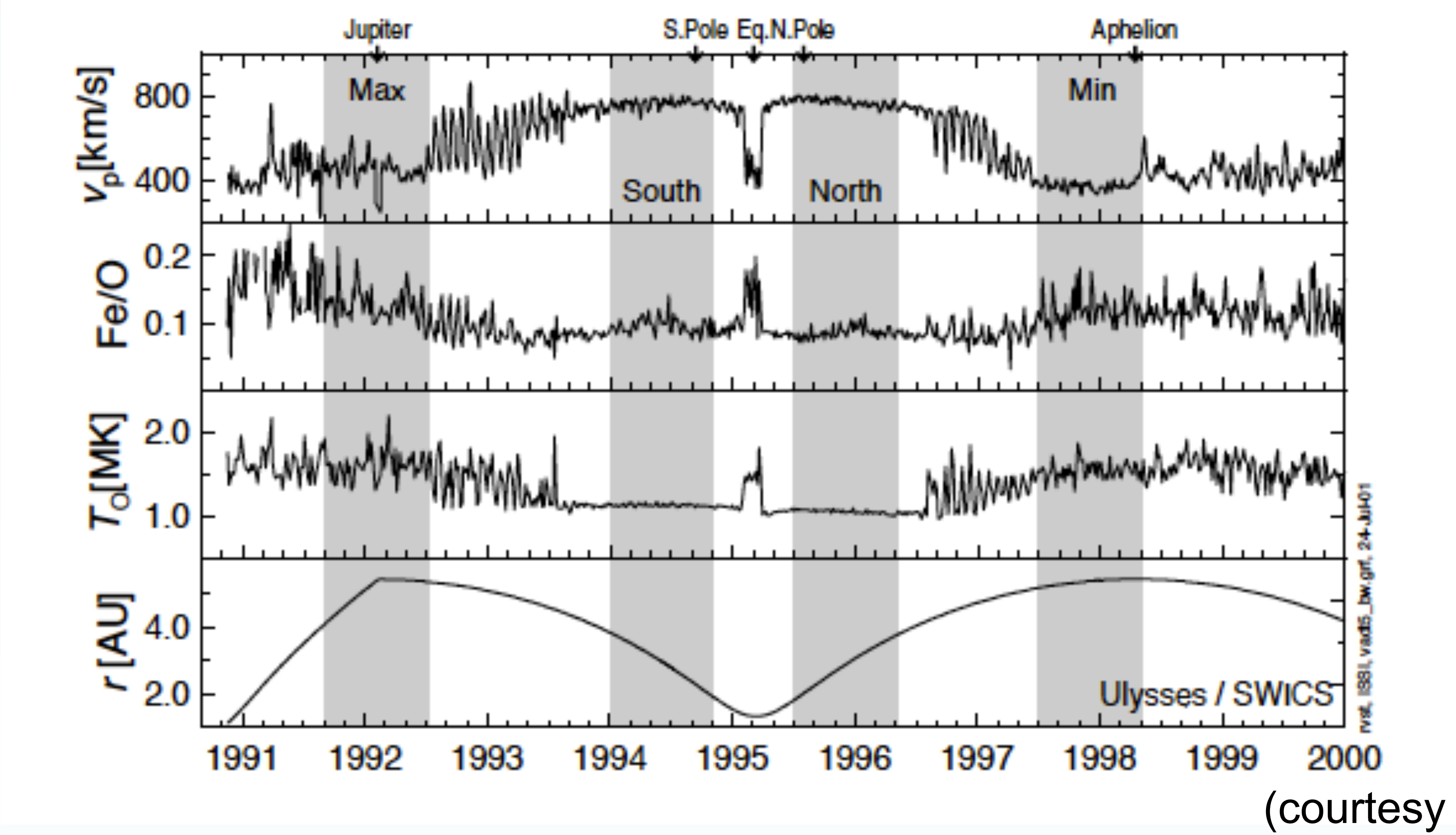


Time-dependent ionization can substantially affect spectral line intensities
(e.g. Raymond, Noci, etc.., see also Bradshaw,Del Zanna & Mason, 2003).

High densities affect ion abundances
(Burgess & Summers 1969)

In-situ measurements of the SW

Variation of low-FIP (e.g. Fe) vs. high-FIP (e.g. O) with solar wind.



(courtesy of R. von Steiger)

'Canonical' FIP bias was 4, now 2-3.
For some elements (Ar, Ne, He !) only 'coronal' values !

Intensities and EM/DEM

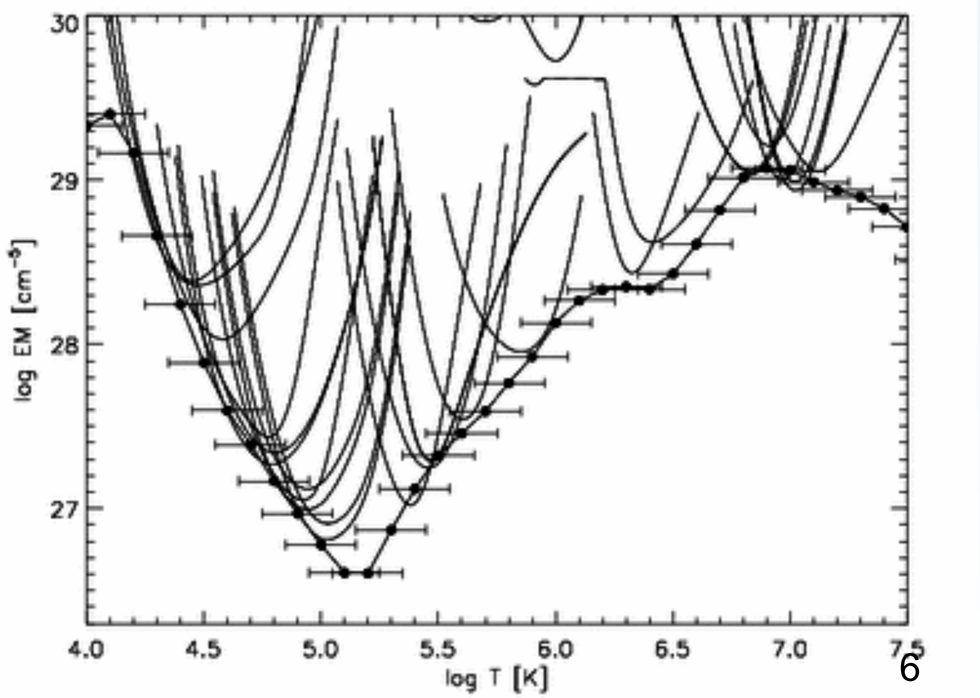
$$I(\lambda_{ij}) = \frac{h\nu_{ij}}{4\pi} \int N_j \, A_{ji} \, dh \; = \int Ab(X) C(T, \lambda_{ij}, N_e) N_e N_H dh \quad [\text{ergs cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}]$$

$$C(T, \lambda_{ij}, N_e) = \frac{h\nu_{ij}}{4\pi} \frac{A_{ji}}{N_e} \frac{N_j(X^{+m})}{N(X^{+m})} \frac{N(X^{+m})}{N(X)} \quad [\text{ergs cm}^{+3} \text{ s}^{-1}]$$

$$\text{DEM (T)} \equiv \; N_e N_H \frac{dh}{dT} \quad [\text{cm}^{-5}\text{K}^{-1}]$$
$$\text{EM} \equiv \int_h N_e N_H dh = \int_T DEM(T) \, dT \qquad [\text{cm}^{-5}]$$

EM Loci (see Del Zanna et al. 2002): plot

$$\frac{Iobs}{Ab(Y) \; Gji(Te)}$$



Some (significant) results based on approximations have provided incorrect FIP biases.

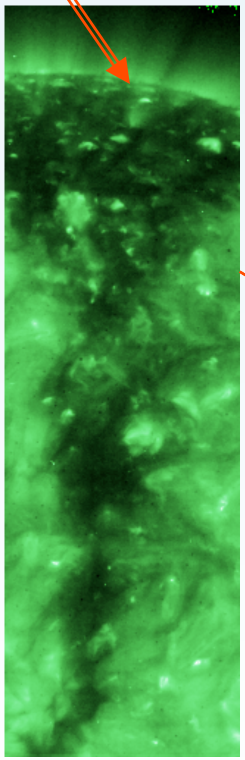
Chemical abundances of coronal hole plumes

The Widing and Feldman (1989) approximation: the abundances Ab(X) are obtained by imposing a continuous distribution of the values Ab (X) DEM_L

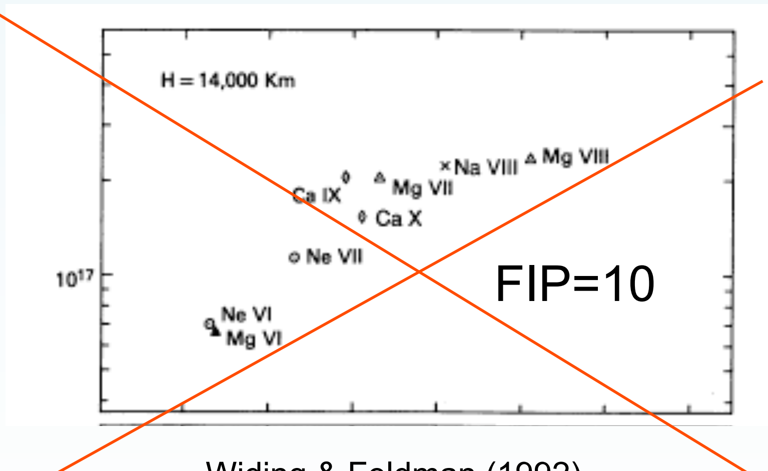
$$\frac{Iobs}{Ab(Y)\ Gji(Te)}$$

FIP effect overestimated by a factor of 10.

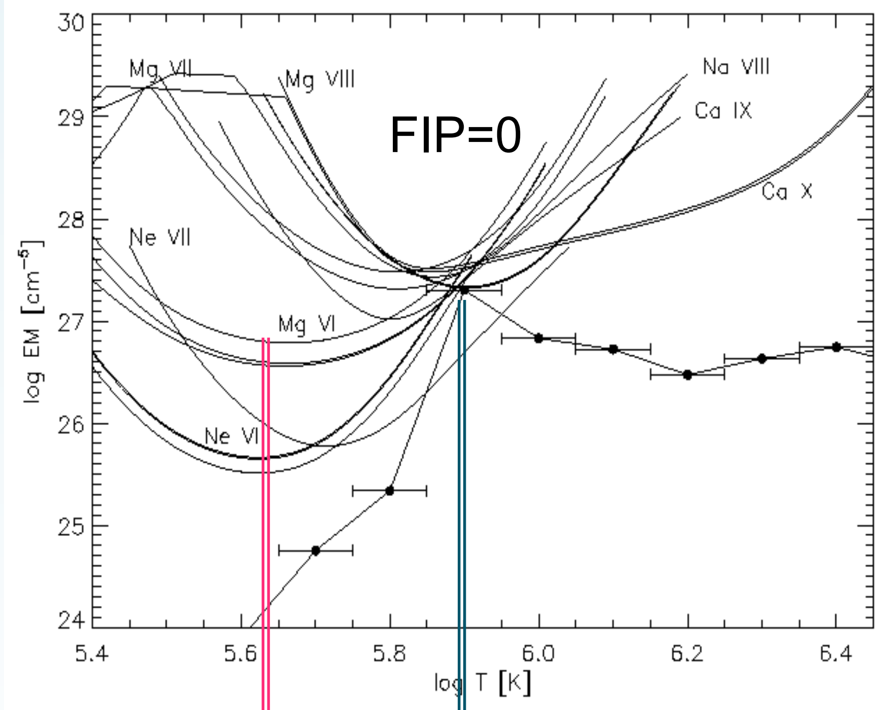
Plumes in coronal holes



$$\mathrm{DEM_L} \equiv \frac{I_{\mathrm{ob}}}{Ab(X) \int_T C(T)dT}$$



Widing & Feldman (1992)



Te of maximum emissivity in ionization equilibrium

Del Zanna et al. (2003)

Actual Te

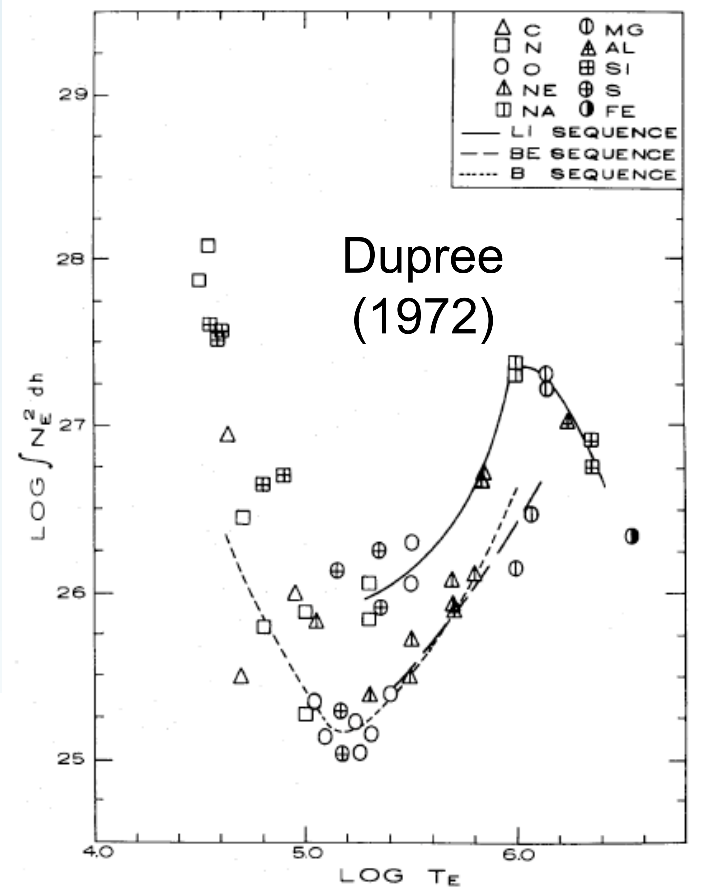
The problem of the 'anomalous' ions

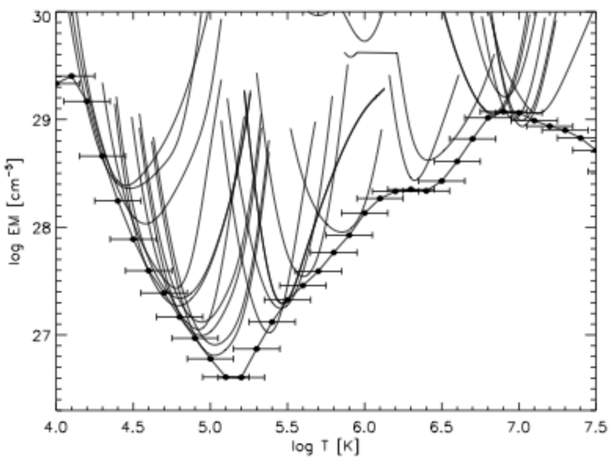
Anomalous EM for lines of the Li and Na isoelectronic sequences (from Burton et al. 1971).

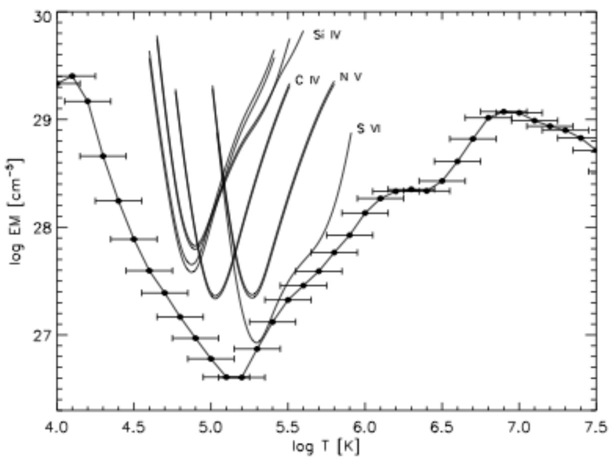
See Del Zanna (1999) and Del Zanna et al. (2001,2002)

Li-like N V and C IV are underestimated by factors of 3 and 10, while those of Ne VIII and Mg X are overestimated by factors of 5 and 10,respectively.

The problem was discovered to apply to stellar coronae by Del Zanna et al. (2002).

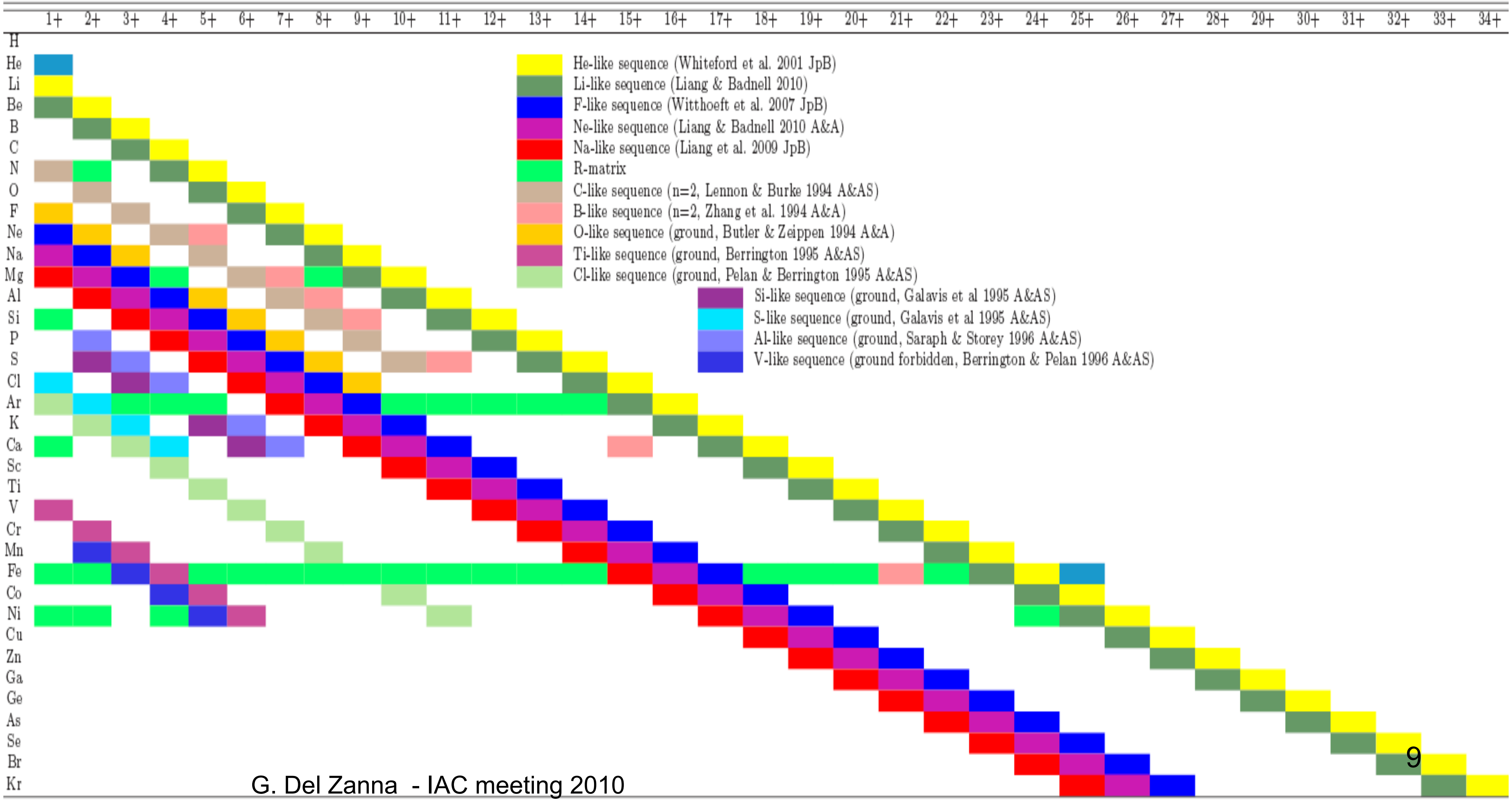






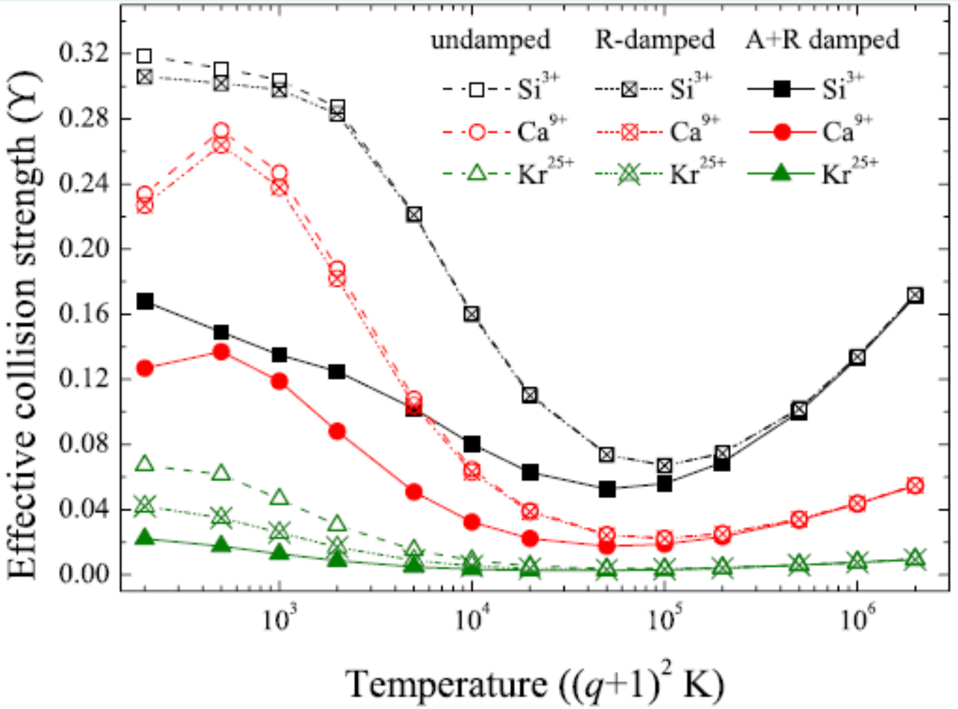
R-matrix data for astrophysically abundant elements

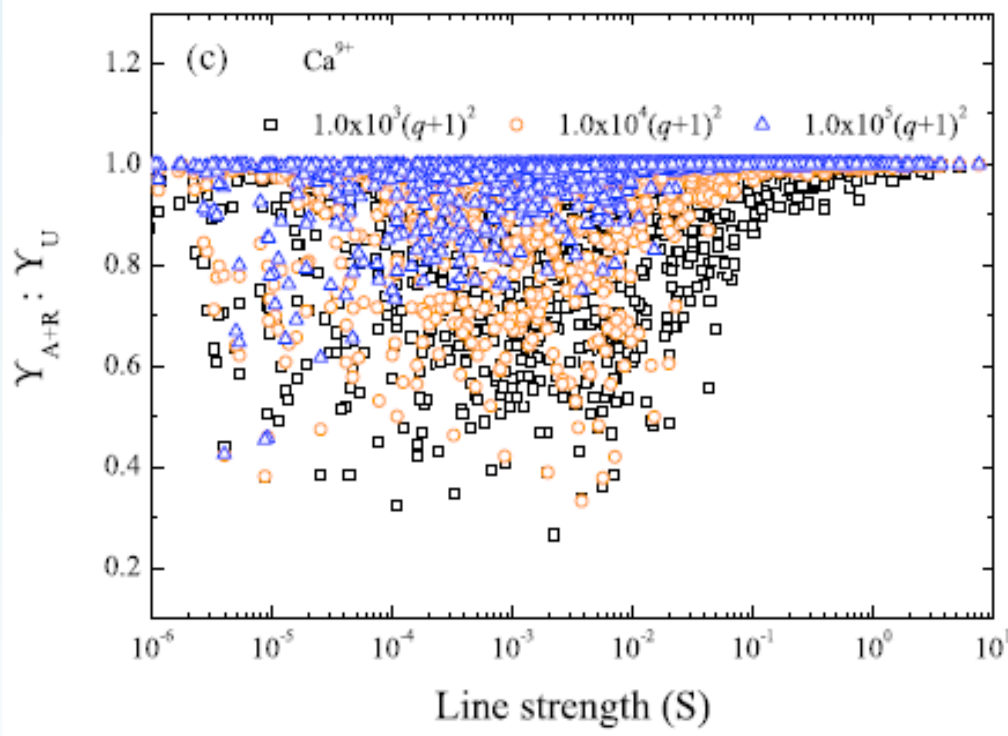
(APAP) : F-like: Witthoeft Whiteford Badnell (2007)
Na-like: Liang, Whiteford,Badnell (2009)
Ne-like: Liang et al. (2010, submitted)
Li-like: Liang & Badnell (2010)



Na-like iso-electronic sequence (valence- and core-excitations)

Liang et al. (2009)



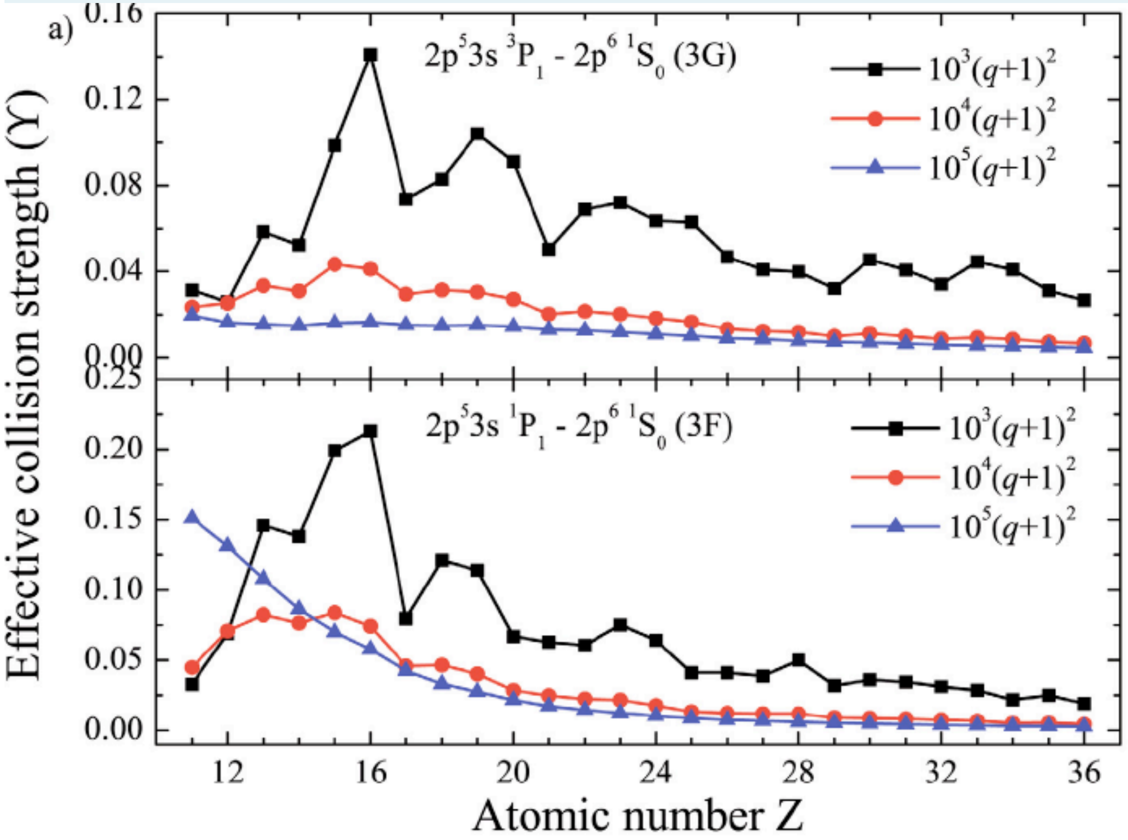


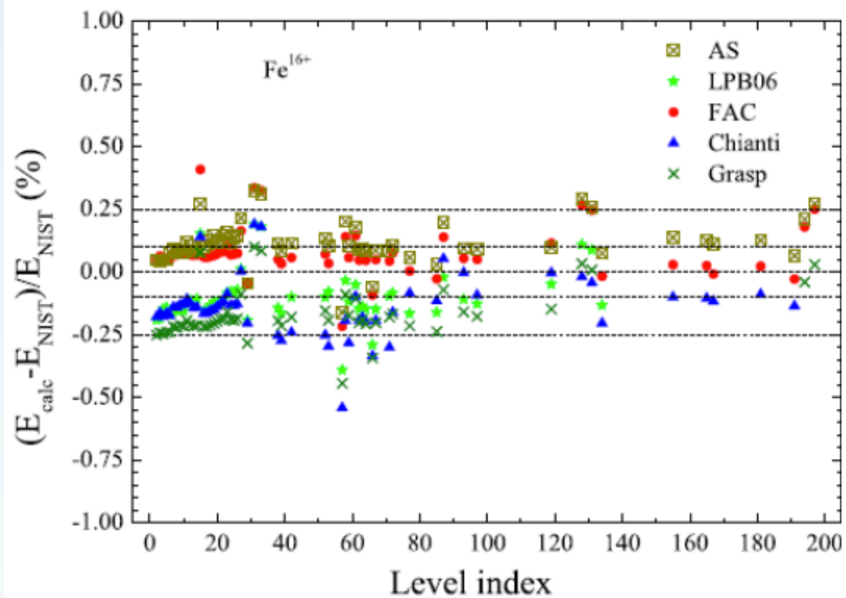
Radiation and Auger damping are included for the core-excitations, and found to be strong and widespread

Complicated structure appears as in cases of F-like and Ne-like sequence for considerable part of transitions

Ne-like iso-electronic sequence

Liang & Badnell (2010a)





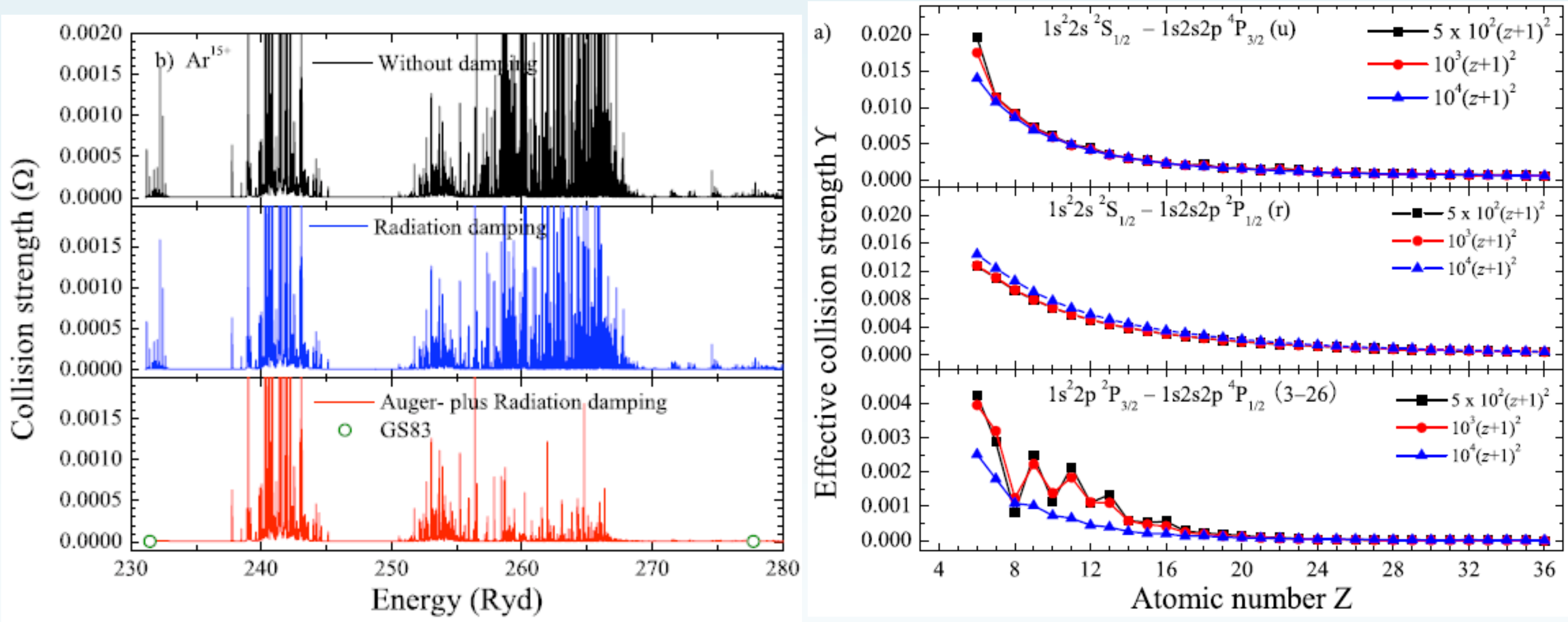
Large-scale calculation with 209 level CC expansions

Detail comparison made to check the accuracy of the sequence calculation

Complicate structure along the sequence appears

Li-like iso-electronic sequence includes core- and valence-excitations

Liang & Badnell (2010b)

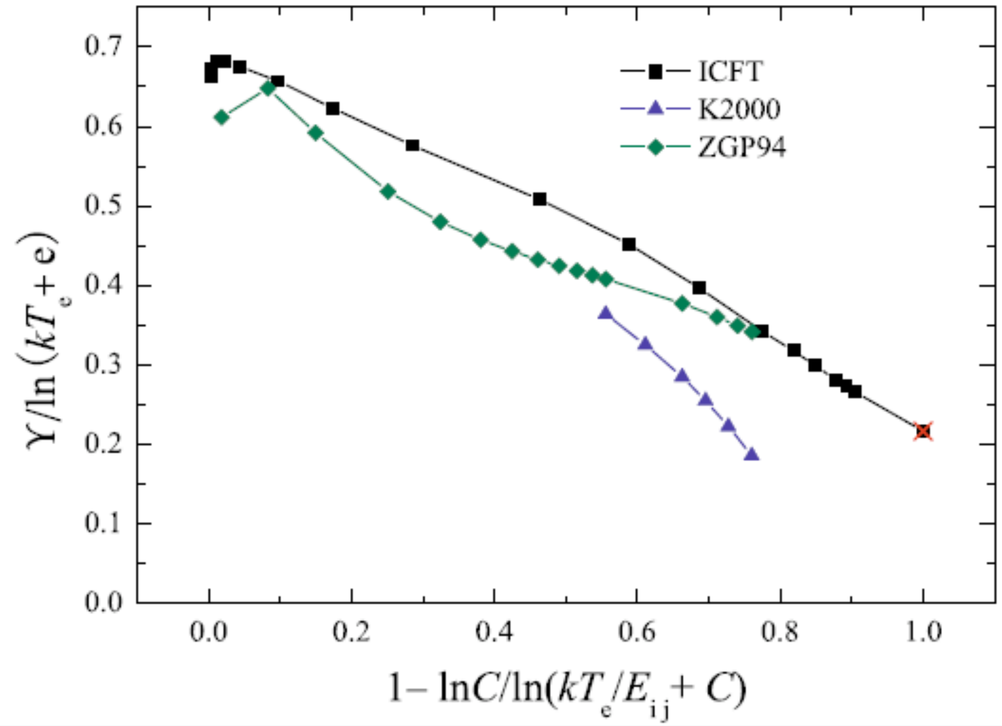


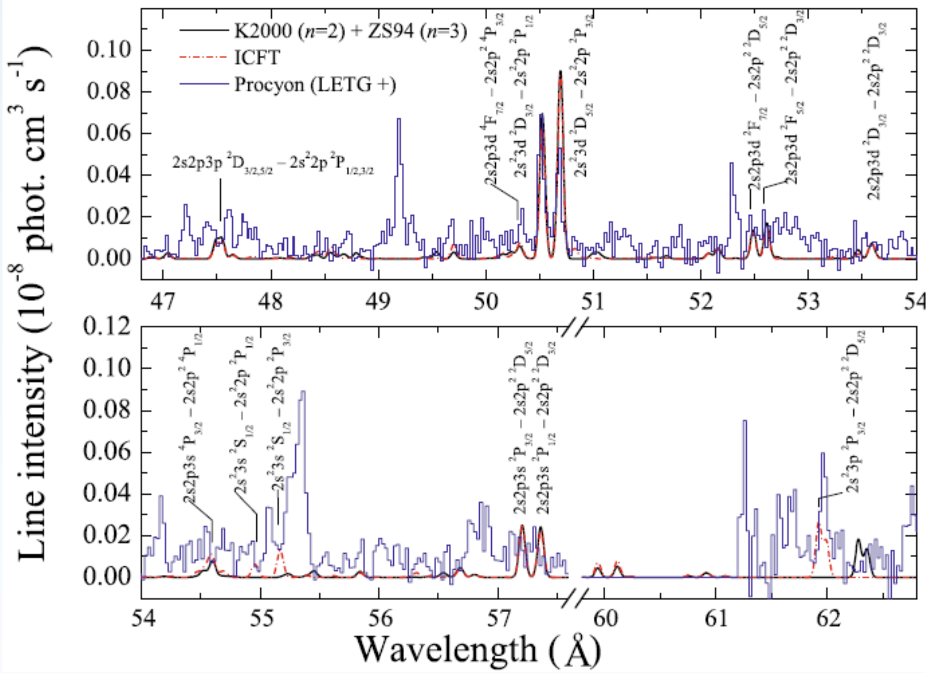
The inclusion of Auger and radiation damping significantly reduce the resonance enhancements

Similar complicate structure appears as other iso-electronic sequence

Re-examination for several specific ions (Si^{9+})

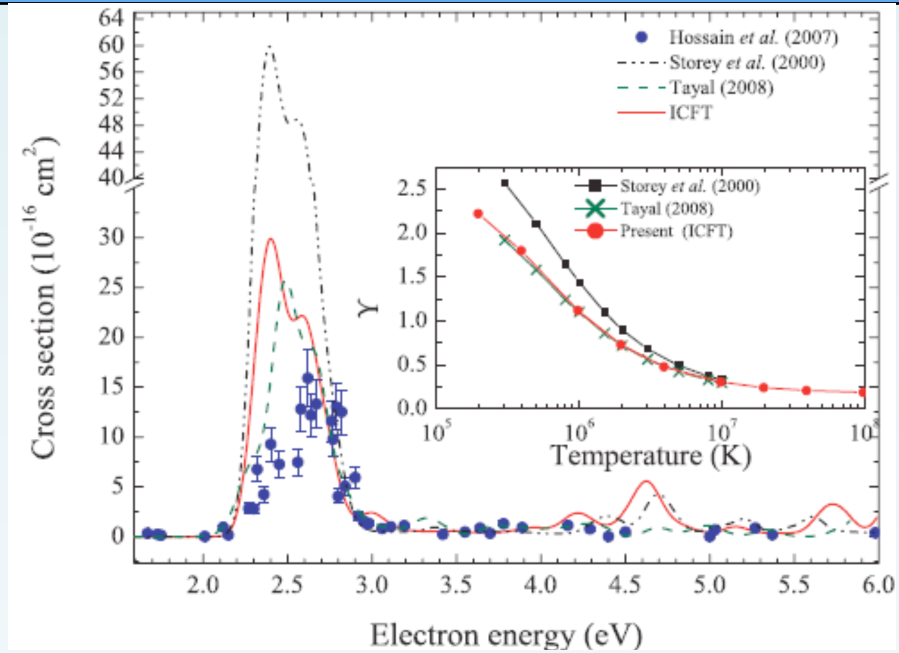
An improvement of the excitation data has been made with large-scale model.
Some new lines are identified with these resultant excitation data
(Liang et al. 2009)





Re-examination for several specific ions (Fe^{13+})

Liang et al. (2010)



	λ220.084/λ211.317	λ252.199/λ264.789	λ257.394/λ270.520	λ289.150/λ274.203	λ356.645/λ334.178	λ274.203/λ211.317	λ334.178/λ274.203	λ444.219/λ334.178	λ270.520/(λ264.789+λ274.203)
					Observations				
SERTS-89	0.25 ± 0.07	0.18 ± 0.06	0.38 ± 0.09	0.072 ± 0.024	0.028 ± 0.010	1.01 ± 0.18	0.62 ± 0.10	0.018 ± 0.005	0.24 ± 0.04
BFS08-QS		0.20	0.42	0.040		0.55			0.23
BFS08-AR1		0.18	0.53	0.048		0.46			0.24
BFS08-AR2		0.20	0.62	0.042		0.44			0.22
BFS08-Limb		0.21	0.50	0.054		1.76			0.27
BFS08-Limb + 20″		0.19	0.53	0.040		1.10			0.26
Present-QSoffLimb		0.21[a]	0.71	0.100[b]		0.40[b]			0.23[b]
Present-AR		0.20[a]	0.52	0.050[b]		0.46[b]			0.26[b]
Present-highn_e		0.21[a]	0.54	0.050[b]		0.46[b]			0.23[b]
MH73	0.28	0.26		0.060		0.60			0.26
					Laboratory (EBIT) measurements				
E_e = 325 eV	0.23 ± 0.07	0.12 ± 0.07[c]	0.57 ± 0.14[d]			0.49 ± 0.09			0.20 ± 0.03
E_e = 350 eV	0.17 ± 0.03	0.20 ± 0.03[c]	0.55 ± 0.06[d]			0.51 ± 0.08			0.20 ± 0.02
E_e = 375 eV	0.15 ± 0.02	0.22 ± 0.03[c]	0.61 ± 0.05[d]			0.50 ± 0.08			0.19 ± 0.03
E_e = 400 eV	0.17 ± 0.02	0.21 ± 0.03[c]	0.58 ± 0.04[d]			0.51 ± 0.08			0.20 ± 0.02
					Theory				
BRS95	0.22	0.23	0.71	0.095	0.038	0.37	0.63		0.35
YLT98	0.21	0.24	0.74	0.089	0.036	0.35 ± 0.03	0.69 ± 0.07	0.015 ± 0.002	
SMY00	0.22	0.24	0.66	0.061	0.029	$0.53^{+0.05}_{-0.03}$	$0.64^{+0.06}_{-0.04}$	$0.028^{+0.011}_{-0.009}$	$0.26^{+0.02}_{-0.01}$
T08	0.21	0.24	0.73	0.091	0.034				
Present	0.21	0.24	0.70	0.076	0.032	0.55	0.70	0.032	0.27

APAP/ADAS adf04 format

Target Energies

```
SI+ 9        14         10        3348008.(   )
    1 2S2 2P1            (2)1( 0.5)             0.0
    2 2S2 2P1            (2)1( 1.5)          7290.0
    3 2S1 2P2            (4)1( 0.5)        157687.0
    4 2S1 2P2            (4)1( 1.5)        160324.0
    5 2S1 2P2            (4)1( 2.5)        164438.0
    6 2S1 2P2            (2)2( 1.5)        294258.0
    7 2S1 2P2            (2)2( 2.5)        294455.0
    8 2S1 2P2            (2)0( 0.5)        375537.0
    9 2S1 2P2            (2)1( 0.5)        400444.0
   10 2S1 2P2            (2)1( 1.5)        404878.0
```

Te

High-E limit

```
  124 2P2 3D1            (2)2( 2.5)       2607801.0
  125 2P2 3D1            (2)2( 1.5)       2608628.0
   -1
10.00    3        2.00+04 5.00+04 1.00+05 2.00+05 5.00+05 1.00+06 2.00+06 5.00+06 1.00+07 2.00+07 5.00+07 1.00+08 2.00+08
    2    1 3.48+00 1.33+00 1.33+00 1.16+00 9.44-01 6.52-01 4.72-01 3.32-01 2.00-01 1.39-01 1.03-01 7.89-02 7.02-02 6.57-02 6.08-02
    3    1 3.07+05 3.23-02 3.79-02 3.86-02 3.47-02 2.86-02 2.53-02 2.11-02 1.42-02 9.78-03 6.73-03 4.54-03 3.77-03 3.40-03 1.03-04
    4    1 7.24+03 4.45-02 5.78-02 6.01-02 5.38-02 4.37-02 3.86-02 3.21-02 2.11-02 1.40-02 9.17-03 5.64-03 4.34-03 3.66-03 4.63-06
```

A-value

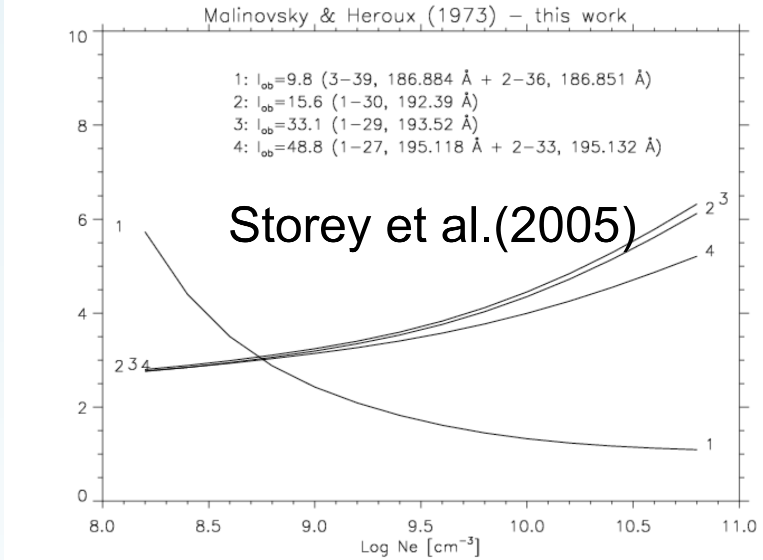
Rates

Benchmarking atomic data (Del Zanna 2004:)

In a series of papers, I have calculated and benchmarked atomic data for the XUV using a `novel' approach: atomic structure calculations and comparisons between

- observed and theoretical wavelengths (all brightest lines)
- observed and theoretical line intensities for a wide range of astrophysical and laboratory plasmas using the emissivity ratios:

$$F_{ji}(N_e, T_e) = C \ \frac{I_{ob} N_e}{N_j(N_e, T_e)\ A_{ji}}$$



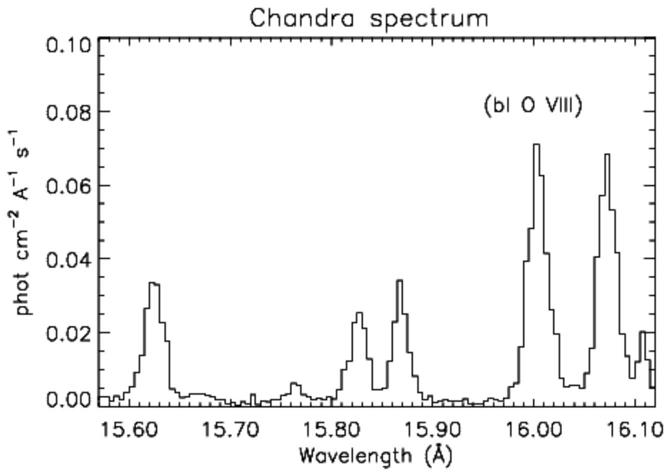
- observed (beam-foil spectroscopy) and theoretical lifetimes and branching ratios.

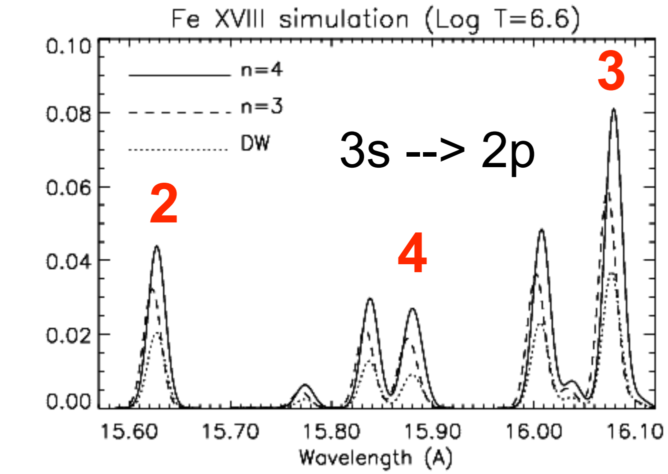
RESULT:

a large number of revised wavelengths (with uncertainties)
new identifications, new level energies (with uncertainties),
new diagnostic applications
For many ions NIST energies are not up-to-date. Not easy to trace original work.

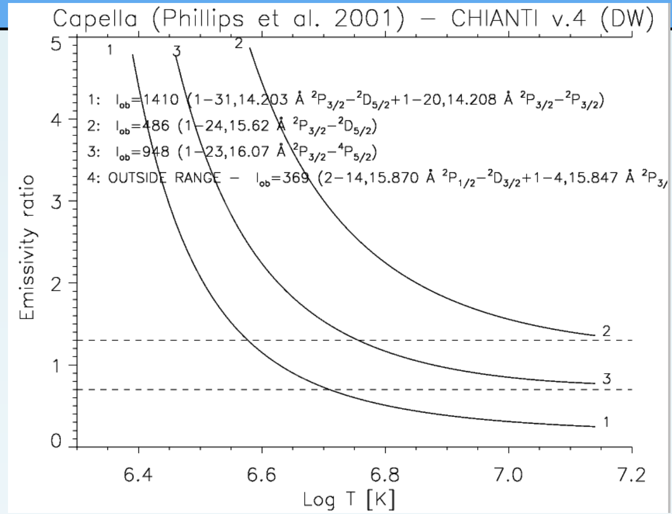
A-values of strongest lines normally accurate to better than 10%
Excitation data normally accurate to better than 20%

R-matrix ! Fe XVIII

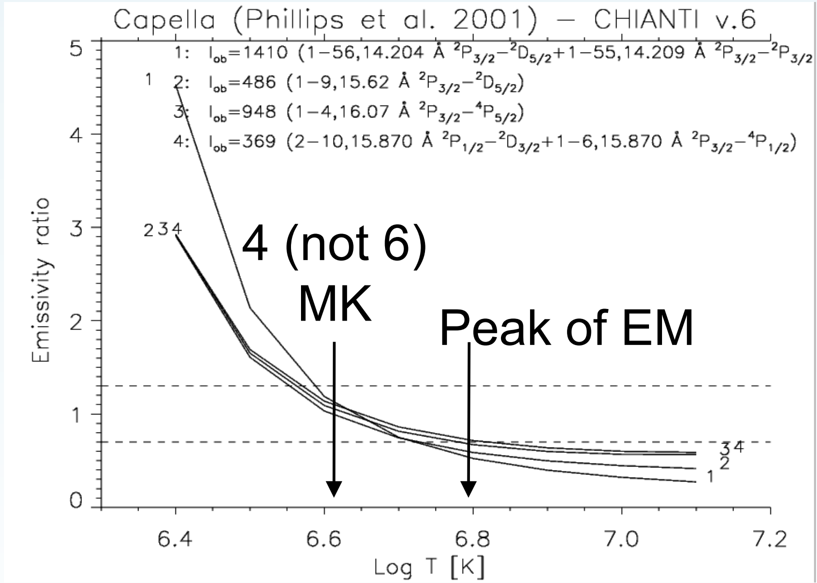




DW:



R-matrix:



The large discrepancies for the strong 3s--> 2p transitions have been resolved with the first R-matrix e- scattering calculation by Witthoeft, Badnell, Del Zanna et al. (2006).

New diagnostics to measure electron temperatures and densities (Del Zanna 2006).

i	Conf.	Lev.	E_{exp}	E_{NIST}	E_{bench}	E_{bench} (TEC)	E_{MR-MP}
1	$3s^2\,3p^4$	$^3P^e_2$	0	0	0	0	0
2	$3s^2\,3p^4$	$^3P^e_1$	12667	12667 (0)	12371 (297)	12397 (271)	12667 (0)
3	$3s^2\,3p^4$	$^3P^e_0$	14306	14312 (-6)	14283 (23)	14155 (151)	14312 (-6)
4	$3s^2\,3p^4$	$^1D^e_2$	37743	37743 (-1)	38324 (-581)	37748 (-5)	37743 (-1)
5	$3s^2\,3p^4$	$^1S^e_0$	80831	80814 (16)	83640 (-2809)	80842 (-11)	80814 (16)
6	$3s\,3p^5$	$^3P^o_2$	283551	283558 (-7)	283764 (-213)	283658 (-107)	283739 (-188)
7	$3s\,3p^5$	$^3P^o_1$	293158	293158 (0)	293229 (-71)	293089 (69)	293315 (-157)
8	$3s\,3p^5$	$^3P^o_0$	299163	299163 (0)	299059 (104)	298953 (210)	299308 (-145)
9	$3s\,3p^5$	$^1P^o_1$	361846	361842 (4)	365012 (-3166)	361678 (168)	361675 (171)
10	$3s^2\,3p^3\,3d$	$^5D^o_0$	387544	-	389671 (-2127)	387427 (117)	387622 (-78)
11	$3s^2\,3p^3\,3d$	$^5D^o_1$	387726	-	389870 (-2144)	387628 (98)	387811 (-85)
12	$3s^2\,3p^3\,3d$	$^5D^o_2$	387940	-	390118 (-2178)	387866 (74)	388020 (-80)
13	$3s^2\,3p^3\,3d$	$^5D^o_3$	388268	-	390506 (-2238)	388236 (32)	388335 (-67)
14	$3s^2\,3p^3\,3d$	$^5D^o_4$	389227	-	391510 (-2283)	389244 (-17)	389274 (-47)
15	$3s^2\,3p^3\,3d$	$^3D^o_2$	412856	-	416494 (-3638)	413082 (-226)	412968 (-112)
16	$3s^2\,3p^3\,3d$	$^3D^o_3$	415426	-	418774 (-3348)	415618 (-192)	415477 (-51)
17	$3s^2\,3p^3\,3d$	$^3D^o_1$	417049	-	420300 (-3251)	417205 (-156)	417139 (-90)
18	$3s^2\,3p^3\,3d$	$^3F^o_2$	422844	-	426701 (-3857)	422557 (287)	422920 (-76)
19	$3s^2\,3p^3\,3d$	$^1S^o_0$	-	-	428625	425466	425465
20	$3s^2\,3p^3\,3d$	$^3F^o_3$	426022	-	429980 (-3958)	425712 (310)	426149 (-127)
21	$3s^2\,3p^3\,3d$	$^3F^o_4$	430522	-	434444 (-3922)	430102 (420)	430589 (-67)
22	$3s^2\,3p^3\,3d$	$^3G^o_3$	-	-	453512	448623	448615
23	$3s^2\,3p^3\,3d$	$^3G^o_4$	450211	-	455092 (-4881)	450218 (-7)	450228 (-17)
24	$3s^2\,3p^3\,3d$	$^3G^o_5$	452416	-	457218 (-4802)	452414 (2)	452413 (3)
25	$3s^2\,3p^3\,3d$	$^1G^o_4$	459218	-	464621 (-5403)	459220 (-2)	459231 (-13)
26	$3s^2\,3p^3\,3d$	$^1D^o_2$	-	-	472489	466545	466458
27	$3s^2\,3p^3\,3d$	$^3D^o_1$	-	-	488110	481678	481722
28	$3s^2\,3p^3\,3d$	$^3P^o_0$	-	-	488573	482071	482618
29	$3s^2\,3p^3\,3d$	$^3P^o_1$	484830	-	491259 (-6429)	484676 (154)	484990 (-160)
30	$3s^2\,3p^3\,3d$	$^3F^o_3$	485039	-	491500 (-6461)	485125 (-86)	485081 (-42)
31	$3s^2\,3p^3\,3d$	$^3F^o_2$	-	-	492645	486234	486227
32	$3s^2\,3p^3\,3d$	$^3F^o_4$	486413	-	492671 (-6258)	486445 (-32)	486412 (1)
33	$3s^2\,3p^3\,3d$	$^3D^o_2$	489378	-	495788 (-6410)	489376 (2)	489528 (-150)
34	$3s^2\,3p^3\,3d$	$^3P^o_2$	494013	496090 (-2077)	500566 (-6553)	494055 (-42)	494053 (-40)
35	$3s^2\,3p^3\,3d$	$^3D^o_3$	497235	-	503664 (-6429)	497216 (19)	497452 (-217)
36	$3s^2\,3p^3\,3d$	$^1F^o_3$	525260	-	532842 (-7582)	525278 (-18)	525332 (-72)
37	$3s^2\,3p^3\,3d$	$^3P^{o\dagger}_1$	531070	526480 (4590)	540265 (-9195)	530770 (300)	531839 (-769)
38	$3s^2\,3p^3\,3d$	$^3P^o_2$	531304	531290 (14)	541300 (-9996)	531551 (-247)	531502 (-198)
39	$3s^2\,3p^3\,3d$	$^3S^{o\dagger}_1$	533445	533450 (-5)	543921 (-10476)	533838 (-393)	533343 (102)
40	$3s^2\,3p^3\,3d$	$^3P^o_0$	541777	541720 (57)	551873 (-10096)	542143 (-366)	541892 (-115)
41	$3s^2\,3p^3\,3d$	$^3P^{o\dagger}_1$	541424	541390 (34)	551800 (-10376)	541729 (-305)	541178 (246)
42	$3s^2\,3p^3\,3d$	$^3D^o_3$	554321	554300 (21)	564972 (-10651)	554308 (13)	554305 (16)
43	$3s^2\,3p^3\,3d$	$^3D^o_2$	561615	561610 (5)	572350 (-10735)	561671 (-56)	561556 (59)
44	$3s^2\,3p^3\,3d$	$^3D^o_1$	566396	566380 (16)	577055 (-10659)	566321 (75)	566299 (97)
45	$3s^2\,3p^3\,3d$	$^1D^o_2$	578890	578860 (30)	589847 (-10957)	578887 (3)	578539 (351)
46	$3s^2\,3p^3\,3d$	$^1F^o_3$	594047	594030 (17)	605953 (-11906)	594047 (0)	594518 (-471)
47	$3s^2\,3p^3\,3d$	$^1P^o_1$	623101	623080 (21)	636559 (-13458)	623094 (7)	623252 (-151)
48	$3p^6$	$^1S^e_0$	-	-	625608	614643	-

Fe XI – 6 years !

Atomic Data from the IRON Project

LXVIII. Electron impact excitation of Fe XI★

G. Del Zanna[1], P.J. Storey[2], and H.E. Mason[1]

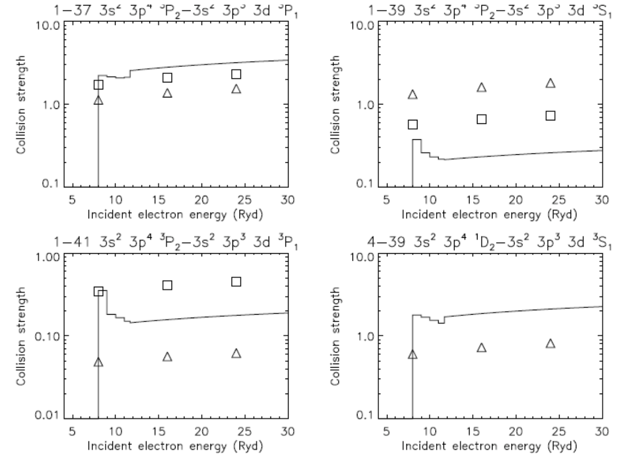


Fig. 7. Collision strengths for transitions involving the three $J = 1$ levels, averaged over 1 Ryd. Boxes indicate the GT99 values, while triangles the AK03 ones.

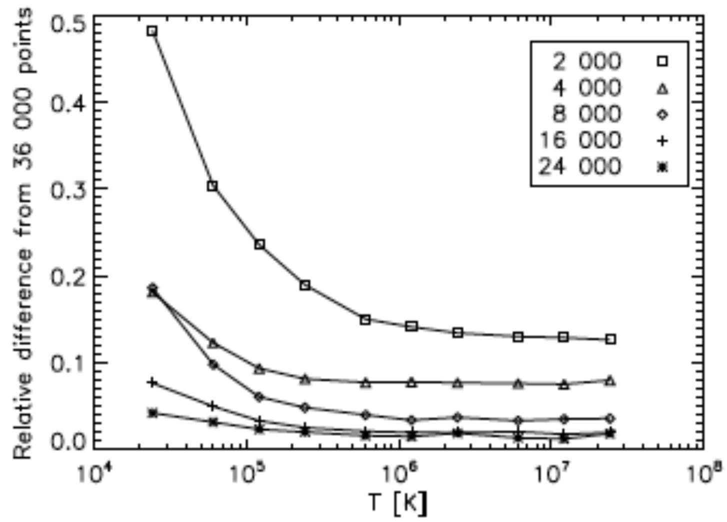
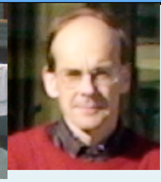


Table 3. Summary of line identifications for Fe XI.

Del Zanna (2010)

i-*j*	λ_{exp} (Å)	λ_{obs} (Å)	ID	Diff. ID
6-103	168.929	? 168.929(10) Be76	N	
1-43	178.058	178.056(4) Be76	G66	
4-46	179.758	179.758(10) Be76	G66	
1-42	180.401	180.401(2) Be76 (bl)	G66	
2-44	180.594	180.595(4) Be76	F71	
3-44	181.130	181.131(10) Be76	G66	
2-43	182.167	182.167(2) Be76	G66	
4-45	184.793	184.793(10) Be76 (bl u)	FG66	
1-38	188.216	188.216(2) Be76	B77	F71 (188.299)
1-37	188.299	188.299(2) Be76	J93	B77(189.94)
2-41	189.123	189.123(4) Be76 (bl u)	B77	J93 (192.619)
3-41	189.711	189.723(5) N (bl)	B77	
1-36	190.382	190.382(5) N (bl u)	N	Be76 (S XI)
2-39	192.021	192.021(5) N (bl)	B77	
3-39	192.627	192.624(5) N (bl u)	B77	
2-38	192.813	192.811(5) N (bl O V, u)	F71	
3-37	193.512	- (bl Fe XII 193.509(2))		
4-41	198.538	198.555(10) Be76 (bl S VIII)	B77	Be76, J93
1-35	201.112	201.112(5) N (bl Fe XIII)	N	
4-39	201.734	201.734(10) Be76 (bl Fe XII)	B77	
1-34	202.424	202.424(10) Be76 (bl u)	N	B77 (201.575)
4-38	202.609	- (bl S VIII 202.608(10))		
4-37	202.705	202.710(10) Be76 (bl)		
1-30	206.169	206.169(10) Be76 (bl u)	N	
1-29	206.258	206.258(5) N	N	
2-34	207.751	207.749(5) N (bl u)	N	
2-33	209.771	209.771(5) N (bl u)		
1-20	234.730	234.73(2) D78	N	D78 (Fe XV)
1-18	236.494	236.494(10) Be76	N	
1-17	239.780	? 239.78(2) D78	N	
1-16	240.717	240.713(4) Be76 (bl Fe XIII)	N	
1-15	242.215	242.215(10) (bl) Be76	N	
4-21	254.596	254.600(5) N	N	
1-14	256.919	256.925(5) N (bl Fe XII)	N	
4-20	257.547	257.547(10) Be76 (sbl)	N	
1-13	257.554	257.547(10) Be76 (sbl)	J93	T98 (257.26 T)
1-12	257.772	257.772(4) Be76	J93	T98 (257.55 T)
1-11	257.914	257.914(5) N	N	T98 (257.78 T)
4-16	264.772	bl Fe XIV 264.787	N	
4-15	266.586	? 266.613(5) N (bl)	N	
21-79	266.759	266.755(5) N (bl u)	N	

Good things come to those who wait…

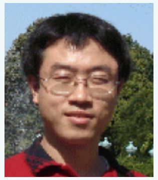




- Fe VII: Witthoeft et al. (2008) S
  Del Zanna (2010) ID
- Fe VIII: Griffin et al. (2000) S
  Del Zanna (2010) ID

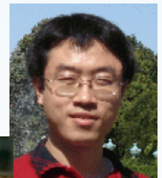

- Fe IX: Storey et al. (2002) S
- Fe X: Del Zanna, Berrington, Mason (2004) S, ID

- Fe XI: Del Zanna, Storey, Mason & Del Zanna 2010 S, ID

- Fe XII: Storey et al. 2005 (S); Del Zanna & Mason (2005) S, ID
- Fe XIII: Storey & Zeippen (2010) S

- Fe XIV: Storey et al. (2000); Liang et al. (2010) S
- Fe XV Berrington et al. (2005)



- Fe XVII: Loch et al. (2006), Liang et al. (2010).
  ID: Del Zanna & Ishikawa (2009).



- Fe XVIII: Witthoeft et al.(2006). Del Zanna (2006).
- Fe XX: Witthoeft, Del Zanna, Badnell (2007)
- Fe XXIII Chidichimo et al. (2005) S; Del Zanna et al. (2005) ID
- Fe XXIV Whiteford et al. (2002) S; Del Zanna (2006) ID

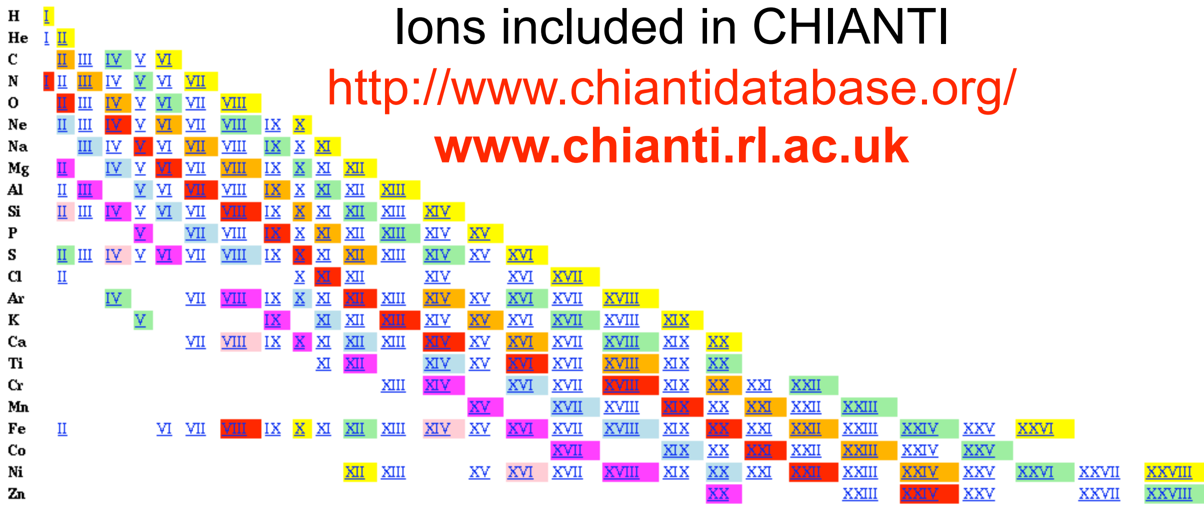
CHIANTI atomic package

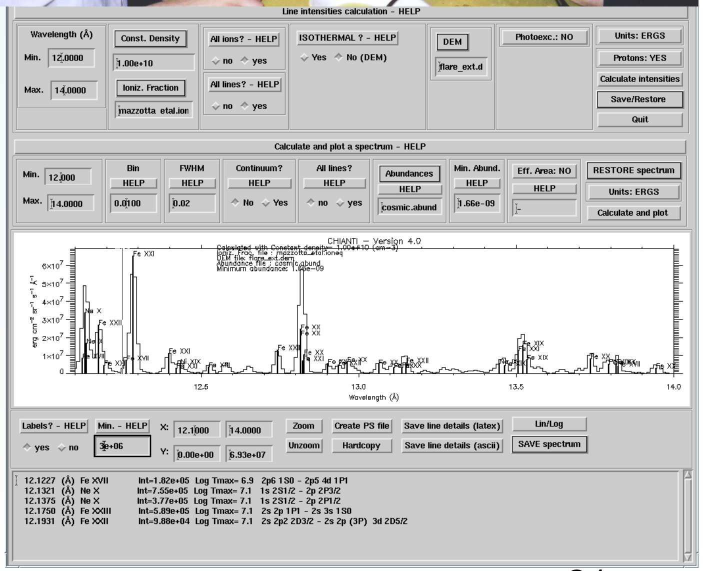
CHIANTI Provides all atomic data and IDL programs necessary for modelling spectra from collisionally-ionised plasmas for the XUV. Over 1000 citations.
User base: solar physics, astrophysics, X-ray, EUV, UV

Ions included in CHIANTI

http://www.chiantidatabase.org/

www.chianti.rl.ac.uk





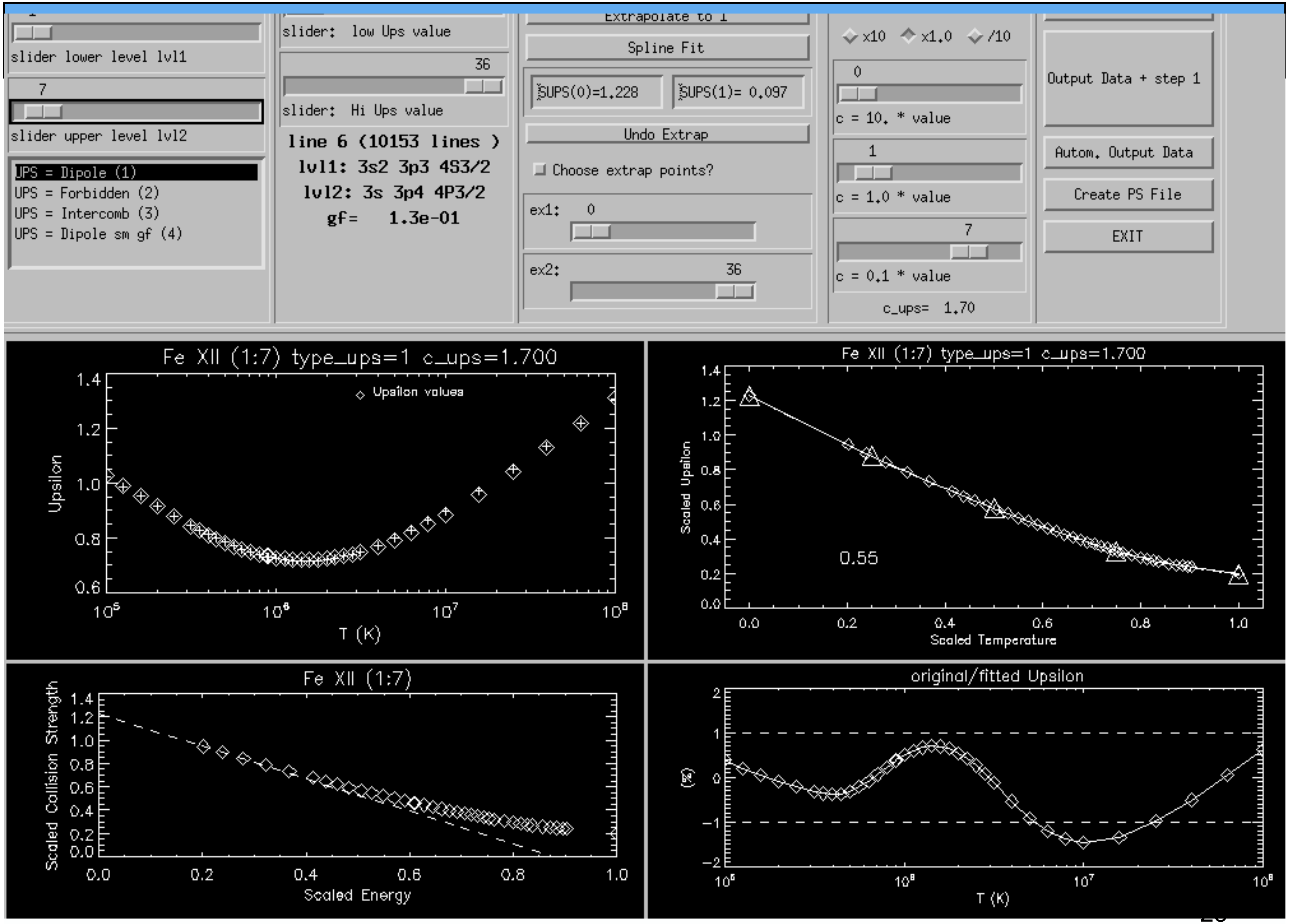
V.6 released (Dere et al.2009) contains **new atomic data and new ionization and recombination rates**

Basic atomic data from e.g. CHIANTI are included in many other spectral codes. Photoionization (XSTAR, CLOUDY, MOCASSIN) and others (ATOMDB, XSPEC, ISIS, PINTofALE).

CHIANTI data (ascii)

fe_12.elvlc	Energy levels (theoretical, observed), LSJ for Fe XII (Fe^{11+})
fe_12.wgfa	Transition probabilities, gf values, theoretical, observed wavelengths
fe_12.splups	spline fits to Maxwellian-averaged e^- collision strengths in Burgess & Tully (1992) scaled domain. Each transition is assessed. Data from IP, APAP-Network, literature.
fe_12.psplus	Same but for protons.
.diparams .drparams .rrparams	DI, DR, RR total rates

Version 7 (2010) – same format
Version 8 – new format


slider lower level lvl1
7
slider upper level lvl2
UPS = Dipole (1)
UPS = Forbidden (2)
UPS = Intercomb (3)
UPS = Dipole sm gf (4)
slider: low Ups value
36
slider: Hi Ups value
line 6 (10153 lines)
lvl1: 3s2 3p3 4S3/2
lvl2: 3s 3p4 4P3/2
gf= 1.3e-01
Spline Fit
SUPS(0)=1.228
SUPS(1)= 0.097
Undo Extrap
Choose extrap points?
ex1: 0
ex2: 36
x10 x1.0 /10
0
c = 10. * value
1
c = 1.0 * value
7
c = 0.1 * value
c_ups= 1.70
Output Data + step 1
Autom. Output Data
Create PS File
EXIT
Fe XII (1:7) type_ups=1 c_ups=1.700
Upsilon values
Upsilon
T (K)
Fe XII (1:7) type_ups=1 c_ups=1.700
Scaled Upsilon
Scaled Temperature
0.55
Fe XII (1:7)
Scaled Collision Strength
Scaled Energy
original/fitted Upsilon
(%)
T (K)

Normally we include only e excitation rates from ground state and to/from metastable levels. Valid until electron densities of 10^{14} cm $^{-3}$ or so for many ions.

CHIANTI emissivities are currently calculated for plasmas in ionization equilibrium.

There are ways to estimate emissivities for non-Maxwellian electrons

CHIANTI data and programs are distributed via

+ a tar file (www)
+ SolarSoft (IDL packages for Solar Physics).
+ (testing phase) Python interface (www)

ChiantiPy

The Python interface to the CHIANTI atomic database for astrophysical spectroscopy

Collisions with photons

Photoexcitation and stimulated emission Not important in the very low corona. However, at densities of about 10^7 starts to become important. It is also very important for the infrared forbidden lines and any low-density plasma not far from a strong source of photons (as a planetary nebula).

The generalised photon rate coefficient for a Maxwellian distribution is:

$$\mathcal{A}_{ij} = \begin{cases} W(R) A_{ji} \frac{\omega_j}{\omega_i} \frac{1}{\exp(\Delta E/kT_*)-1} & i < j \\ A_{ji} \left[1 + W(R) \frac{1}{\exp(\Delta E/kT_*)-1}\right] & i > j \end{cases}$$

Where W is the radiation dilution factor which accounts for the weakening of the radiation field at distance. Within CHIANTI, an uniform spherical source of black-body radiation is assumed by default. However, user-defined radiation fields can be specified.

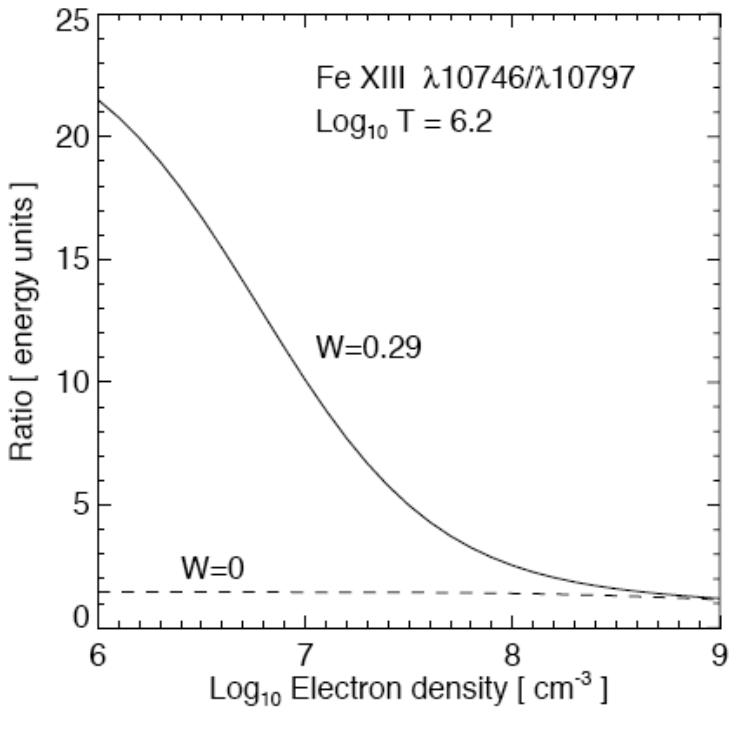


FIG. 3.—Fe XIII λ10746/λ10797 ratio plotted as a function of density for two different dilution factors. $W = 0$ corresponds to no radiation field, while $W = 0.29$ corresponds to 0.1 source radii above the source surface ($r_* = 1.1$).

CHIANTI v.3

CHIANTI & Astrogrid (VO) - 2006

- CHIANTI data were imported into a MySQL database.

  Tables: SpectralLines and LineEmissivities. Link to the VO:

1. using ESAC DAL Toolkit to install a SLAP server (DMMapper can translate from CHIANTI data model to Line data model)
   Data appear automatically in VOSpec, once registered. -

2. by means of **AstroGrid:** **www2.astrogrid.org** DSA software: user can build ADQL queries on the CHIANTI tables via Workbench.

Spectral Lines table

Result of query to spectral lines table via AstroGrid DSA:

TOPCAT(1): Table Browser

File Subsets Help

Table Browser for 1: votable

	LINE_NU...	CHEMIC...	IONISAT...	TITLE	FINAL_L...	INITIAL_...	TRANSI...	WAVELENGTH_METE...	THEORETICAL...	WEIGHTED_O...	EINSTEIN_A	FINAL_
1	183728	26	14	Fe XV 180.0108 A	154	267	2	1.80011E-8	1.80011E-8	0.5414	1.59200E10	3d 4
2	17160	26	22	Fe XXIII 180.0180 A	15	36	1	1.80018E-8	1.81598E-8	0.	727.3	2s 3
3	201205	26	8	Fe IX 180.0318 A	11	106	2	1.80032E-8	1.80032E-8	1.935	5.68600E10	3s2
4	191364	26	11	Fe XII 180.0329 A	10	105	2	1.80033E-8	1.80033E-8	0.000879	2.79900E7	3s 3
5	197329	26	9	Fe X 180.0382 A	35	84	2	1.80038E-8	1.80038E-8	0.289	8.60800E9	3s 3
6	16620	26	22	Fe XXIII 180.0400 A	4	7	1	1.80040E-8	1.80481E-8	0.06407	4.39500E9	2s 2
7	168282	26	17	Fe XVIII 180.0506 A	196	238	2	1.80051E-8	1.80051E-8	0.001184	6.09200E7	2s2
8	48765	26	21	Fe XXII 180.0554 A	154	212	2	1.80055E-8	1.80055E-8	0.04897	5.03800E9	2s 2
9	186344	28	14	Ni XV 180.0558 A	3	23	1	1.80056E-8	1.75817E-8	0.2433	1.66900E10	3s2
10	1147	15	14	P XV 180.0569 A	14	19	1	1.80057E-8	1.80008E-8	0.1671	8.58900E9	4d
11	183746	26	14	Fe XV 180.0604 A	155	268	2	1.80060E-8	1.80060E-8	3.244	7.41500E10	3d 4
12	183857	26	14	Fe XV 180.0623 A	161	281	2	1.80062E-8	1.80062E-8	0.008523	3.50700E8	3p 5
13	116151	26	19	Fe XX 180.0665 A	355	473	2	1.80067E-8	1.80067E-8	0.007767	7.98900E8	2s2
14	118329	26	19	Fe XX 180.0710 A	627	703	2	1.80071E-8	1.80071E-8	0.03371	1.15600E9	2s 2
15	183696	26	14	Fe XV 180.0710 A	152	253	2	1.80071E-8	1.80071E-8	0.1018	1.90400E9	3d 4
16	187740	26	11	Fe XII 180.0783 A	5	47	2	1.80078E-8	1.80078E-8	0.	9248.	3s2
17	194770	26	11	Fe XII 180.0926 A	22	140	2	1.80093E-8	1.80093E-8	0.5435	1.75700E10	3s2
18	200097	26	9	Fe X 180.0928 A	86	168	2	1.80093E-8	1.80093E-8	0.00157	1.59000E8	3s2
19	200139	26	9	Fe X 180.0928 A	86	169	2	1.80093E-8	1.80093E-8	0.001221	6.18200E7	3s2
20	195445	28	12	Ni XIII 180.0948 A	2	34	2	1.80095E-8	1.80095E-8	0.03633	1.49400E9	3s2
21	27975	10	5	Ne VI 180.0997 A	12	40	1	1.80100E-8	1.80043E-8	3.67800E-6	3.78000E5	2p3
22	183745	26	14	Fe XV 180.1148 A	155	267	2	1.80115E-8	1.80115E-8	0.02654	7.79600E8	3d 4
23	169495	18	8	Ar IX 180.1250 A	15	55	1	1.80125E-8	1.75766E-8	0.02555	1.75000E9	2s2
24	117906	26	19	Fe XX 180.1342 A	554	654	2	1.80134E-8	1.80134E-8	0.00568	1.94600E8	2s2
25	117916	26	19	Fe XX 180.1339 A	556	657	2	1.80134E-8	1.80134E-8	0.0435	2.23500E9	2s 2
26	56793	16	10	S XI 180.1361 A	45	49	2	1.80136E-8	1.80136E-8	0.	42.	2s2
27	180762	26	14	Fe XV 180.1361 A	42	107	2	1.80136E-8	1.80136E-8	0.00119	2.44600E8	3s 4
28	201196	26	8	Fe IX 180.1386 A	11	105	2	1.80139E-8	1.80139E-8	0.08465	3.47800E9	3s2
29	118115	26	19	Fe XX 180.1445 A	586	674	2	1.80144E-8	1.80144E-8	0.4235	7.25400E9	2s 2
30	118114	26	19	Fe XX 180.1480 A	586	673	2	1.80148E-8	1.80148E-8	0.01876	4.81900E8	2s 2
31	75807	26	20	Fe XXI 180.1489 A	415	539	2	1.80149E-8	1.80149E-8	0.01088	4.47100E8	2s 2
32	181504	26	14	Fe XV 180.1486 A	64	170	2	1.80149E-8	1.80149E-8	0.004342	1.78500E8	3p 4
33	86746	20	13	Ca XIV 180.1600 A	11	15	1	1.80160E-8	1.76078E-8	0.000137	1.41200E7	2s 2

CHIANTI atomic data for VAMDC

- WP4 SA1 Giulio Del Zanna & Helen Mason (DAMTP, Univ. of Cambridge)

- Collaboration with IoA (Nic Walton, Guy Rixon)
- MSSL, UCL (Len Culhane, Kevin Benson, Peter Kuen)

- BASIC DATA: first table: wavelength, A-value, gf-value, configuration, LSJ, observed, theoretical energy of upper and lower levels.
  To do: add other basic atomic data (rates).
  Maintain identity of each database.
  Problem of multiple calculations. CHIANTI policy is to select one.
  Problem of upgrades (main once every 1-2 years)
  Essential to provide **appropriate references to original calculation in the literature ! Not simple to transfer info.**

- DERIVED DATA (modelling): second table: line emissivities in a grid of temperatures and densities.
- To do: write simple scripts to call CHIANTI routines via the MSSL server (IDL and CHIANTI installed). Alternatively, write Python programs.

END

Thank you !