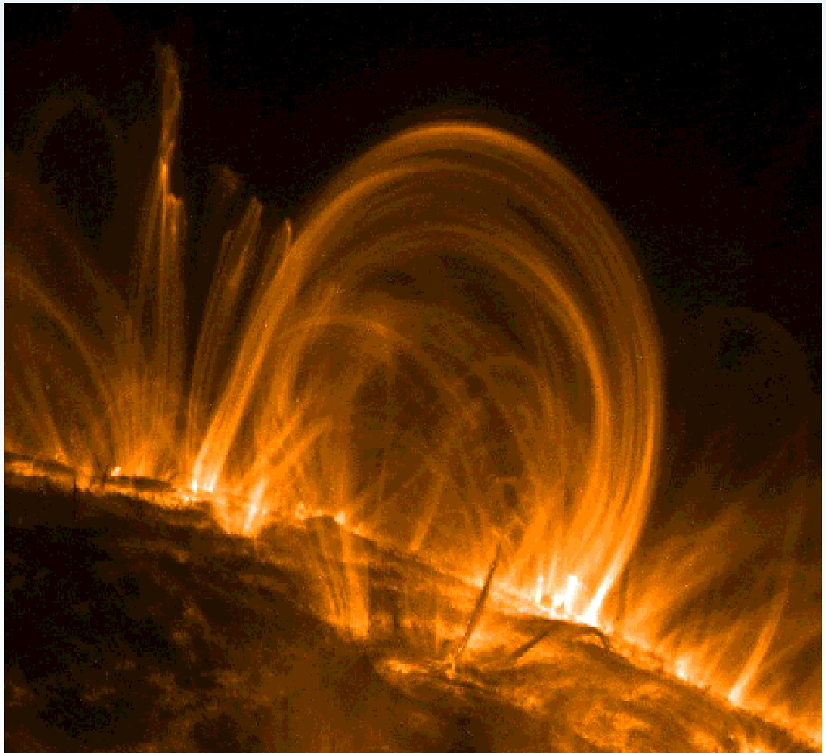
UCL DEPT. OF SPACE & CLIMATE PHYSICS
SOLAR & STELLAR PHYSICS GROUP

VOTADA
VO Tools and Atomic Data for Astrophysics

Giulio Del Zanna



EUV image of solar coronal loops (TRACE)

- The VOTADA project aims at providing accurate atomic data for ions and derived products/tools for astrophysical applications within the Astrogrid (PPARC-UK) and VO.
- Collaboration:
  - Silvia Dalla (Univ. Manchester - Astrogrid)
  - Kevin Benson (UCL/MSSL - Astrogrid)
  - Peter Young (RAL, UK)
  - Helen Mason (Univ. of Cambridge, UK)

Main user community: X-rays, EUV, UV

- Atomic data calculations – we need archives and standards for output results.

-Iron Project, UK Rmax, APAP (Atomic Processes in Astrophys.Plasmas) network

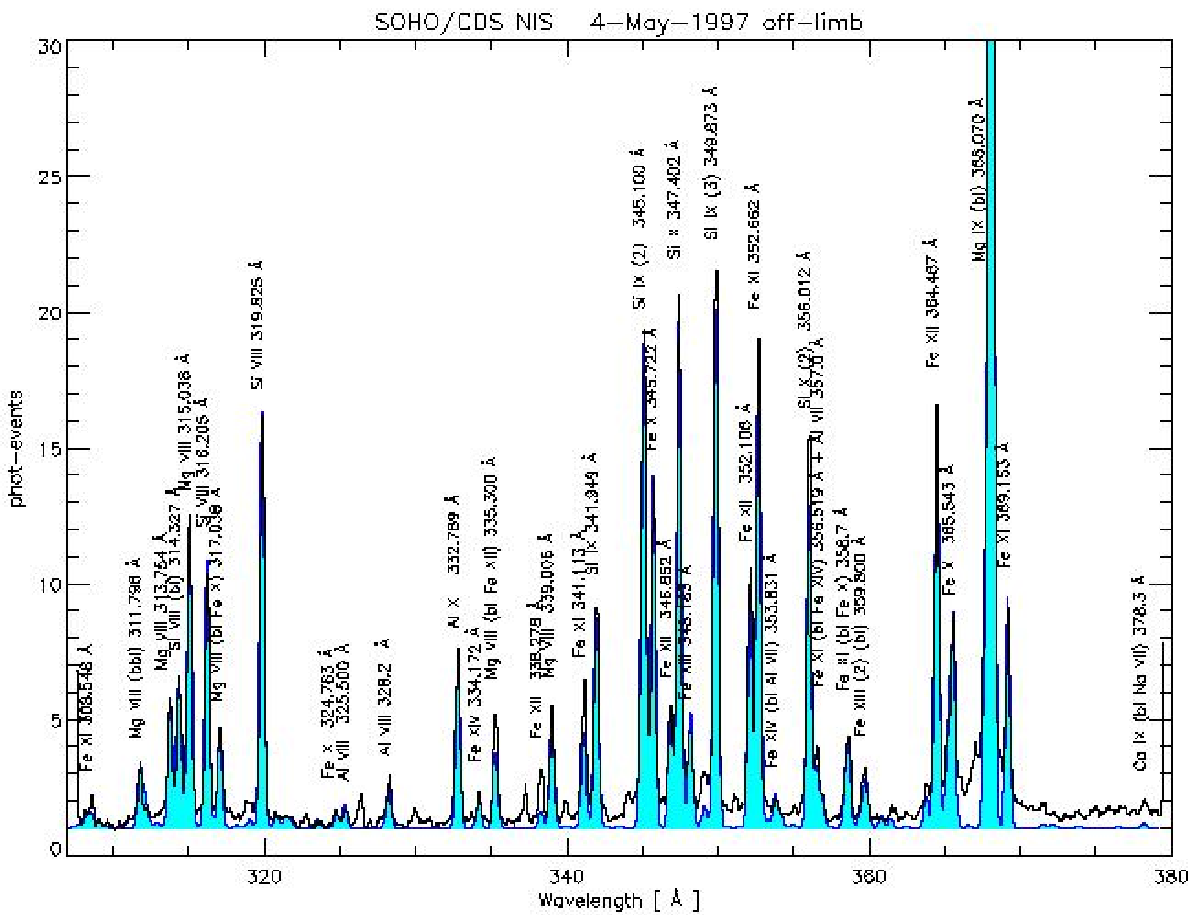
- Atomic databases – we need standards and ways to propagate references to original work.

-CHIANTI package, my contribution

- Tools: how we make tools to model observed spectra widely available?

Line emission

Black: observed solar spectrum (SOHO/CDS); blue: theoretical model spectrum



Del Zanna (1999)

- In optically-thin plasmas, line intensities are proportional to (e.g. Fe XII):

$$\varepsilon_{ij} = N_j A_{ji} = \frac{N_j}{N(\mathrm{Fe\,XII})} \frac{N(\mathrm{Fe\,XII})}{N(\mathrm{Fe})} \frac{N(\mathrm{Fe})}{N(\mathrm{H})} \frac{N(\mathrm{H})}{N_e} N_e A_{ji}$$

Ion ab. Yi El. ab. Y

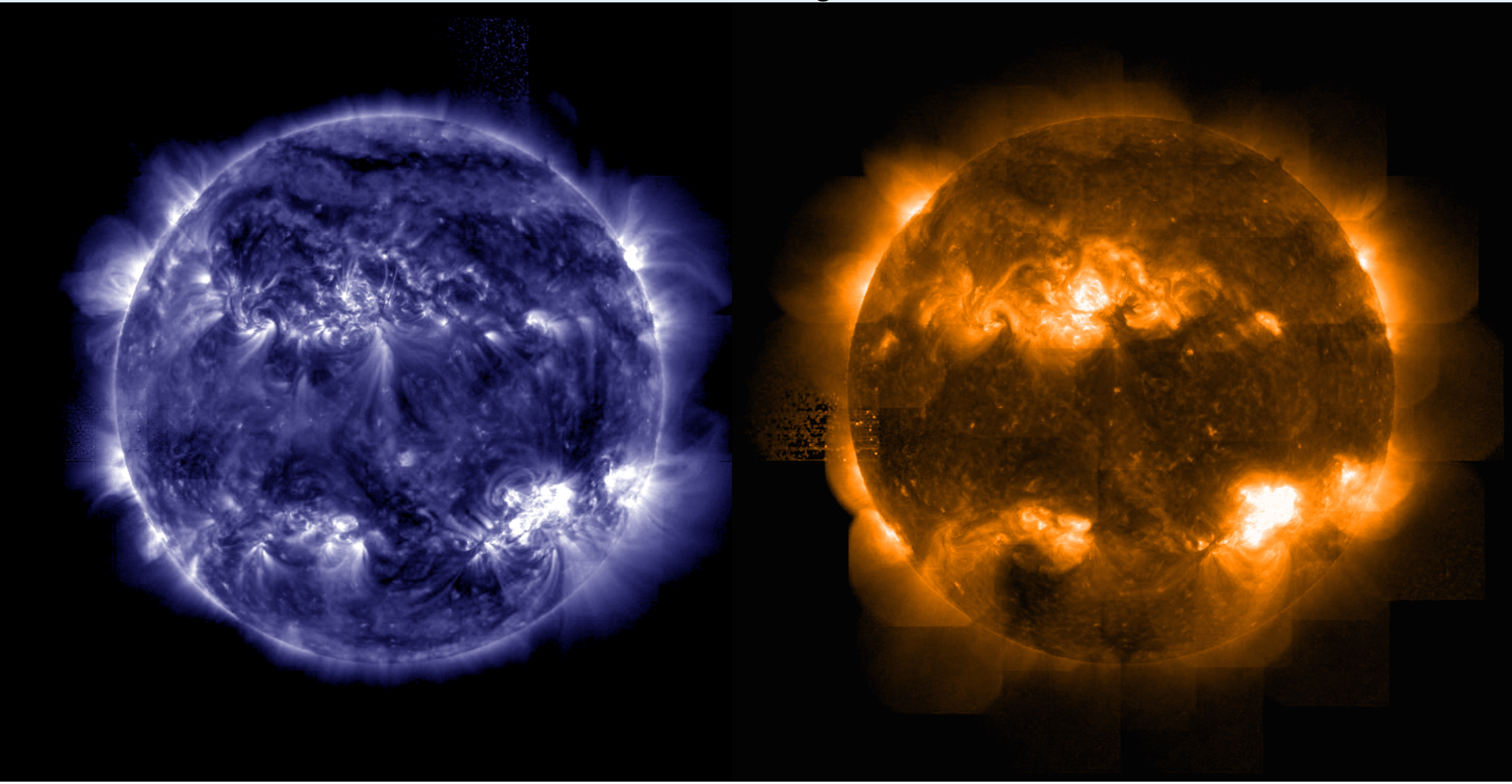
- Obtain densities, temperatures and elemental abundances from spectra (and broad-band data).
- Create synthetic spectra to be compared to observed ones (requires links to instrument properties)
- Create synthetic broad-band images
- Calculate instrument response functions
- Calculate radiative losses

$$E_R \sim N^2 \times \sum_Y Ab(Y) \times \sum_{i=1}^{Z+1} Y_i \varepsilon_i$$

Challenges ahead

Soon (2008) we will have 1Tb/day of high-resolution narrow-band EUV images. Also, large amounts of atomic data.

We need tools to handle large amounts of data.



TRACE EUV images of the solar corona

The CHIANTI package

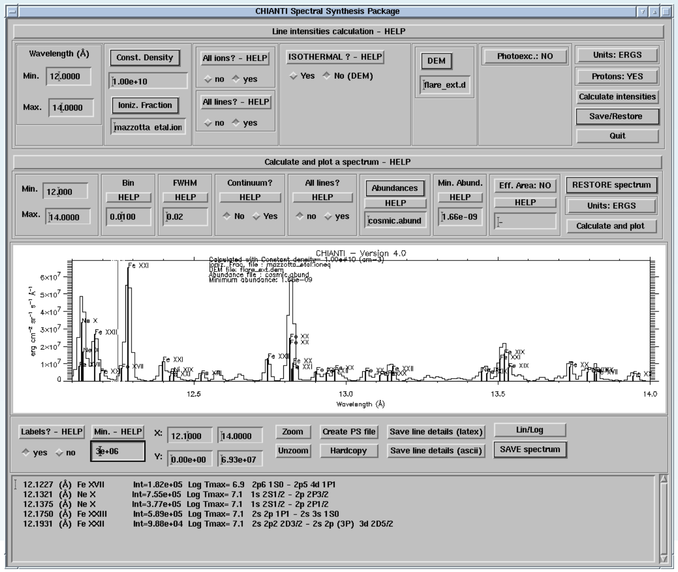
- Collaboration between UK, US and Italy.
- Freely available and user-friendly. First release in 1996, most up-to-date and described with published papers.
- Provides all atomic data (homogeneous) and IDL programs necessary for modelling spectra from collisionally-ionised plasmas. Mostly stellar coronae, but also used for a wide range of astrophysical objects (Chandra, XMM--Newton, FUSE, HST).
- Included in many other spectral codes such as: XSTAR, APED/ATOMDB XSPEC, ISIS, PINTofALE

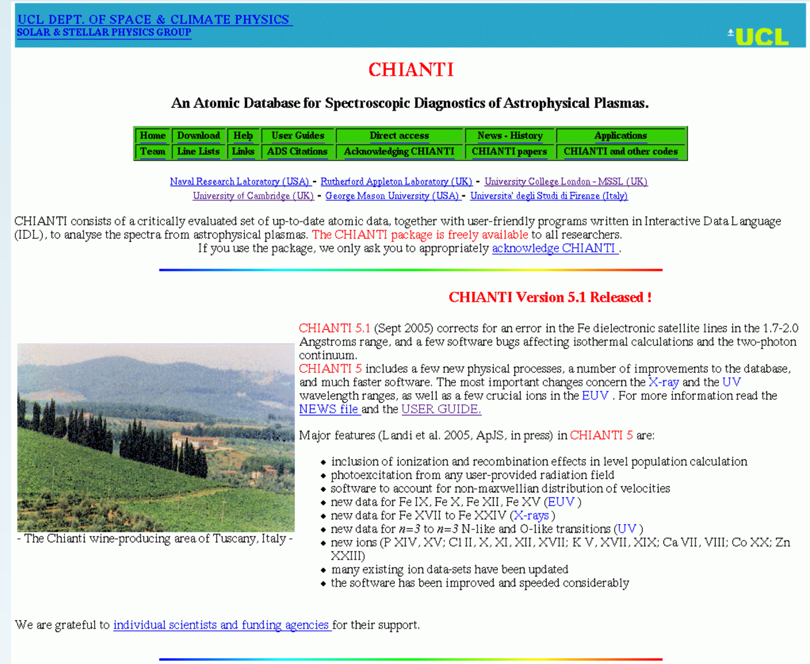
Over 800 citations

CHIANTI atomic package

Data, IDL programs, User Guides

www.chianti.rl.ac.uk





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CHIANTI

An Atomic Database for Spectroscopic Diagnostics of Astrophysical Plasmas.

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Team | Line Lists | Links | ADS Citations | Acknowledging CHIANTI | CHIANTI papers | CHIANTI and other codes

Naval Research Laboratory (USA) - Rutherford Appleton Laboratory (UK) - University College London - MSSL (UK)
University of Cambridge (UK) - George Mason University (USA) - Universita' degli Studi di Firenze (Italy)

CHIANTI consists of a critically evaluated set of up-to-date atomic data, together with user-friendly programs written in Interactive Data Language (IDL), to analyse the spectra from astrophysical plasmas. The CHIANTI package is freely available to all researchers. If you use the package, we only ask you to appropriately acknowledge CHIANTI .

CHIANTI Version 5.1 Released !

- The Chianti wine-producing area of Tuscany, Italy -

CHIANTI 5.1 (Sept 2005) corrects for an error in the Fe dielectronic satellite lines in the 1.7-2.0 Angstroms range, and a few software bugs affecting isothermal calculations and the two-photon continuum.
CHIANTI 5 includes a few new physical processes, a number of improvements to the database, and much faster software. The most important changes concern the X-ray and the UV wavelength ranges, as well as a few crucial ions in the EUV . For more information read the NEWS file and the USER GUIDE.

Major features (Landi et al. 2005, ApJS, in press) in CHIANTI 5 are:

- inclusion of ionization and recombination effects in level population calculation
- photoexcitation from any user-provided radiation field
- software to account for non-maxwellian distribution of velocities
- new data for Fe IX, Fe X, Fe XII, Fe XV (EUV)
- new data for Fe XVII to Fe XXIV (X-rays)
- new data for n=3 to n=3 N-like and O-like transitions (UV)
- new ions (P XIV, XV; Cl II, X, XI, XII, XVII; K V, XVII, XIX; Ca VII, VIII; Co XX; Zn XXIII)
- many existing ion data-sets have been updated
- the software has been improved and speeded considerably

We are grateful to individual scientists and funding agencies for their support.

H	I																											
He	I	II																										
C		II	III	IV	V	VI																						
N	I	II	III	IV	V	VI	VII																					
O		II	III	IV	V	VI	VII	VIII																				
Ne		II	III	IV	V	VI	VII	VIII	IX	X																		
Na			III	IV	V	VI	VII	VIII	IX	X	XI																	
Mg		II		IV	V	VI	VII	VIII	IX	X	XI	XII																
Al		II	III		V	VI	VII	VIII	IX	X	XI	XII	XIII															
Si		II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV														
P					V		VII	VIII	IX	X	XI	XII	XIII	XIV	XV													
S		II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI												
Cl		II								X	XI	XII		XIV		XVI	XVII											
Ar				IV			VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII										
K					V				IX		XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX									
Ca							VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX								
Ti											XI	XII		XIV	XV	XVI	XVII	XVIII	XIX	XX								
Cr													XIII	XIV		XVI	XVII	XVIII	XIX	XX	XXI	XXII						
Mn															XV		XVII	XVIII	XIX	XX	XXI	XXII	XXIII					
Fe		II				VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV	XXVI		
Co																	XVII		XIX	XX	XXI	XXII	XXIII	XXIV	XXV			
Ni												XII	XIII		XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII
Zn																				XX			XXIII	XXIV	XXV		XXVII	XXVIII

Link to references:

Acrobat Document

CHIANTI data

Currently, for each ion ascii files:

fe_12.elvlc	Energy levels (theoretical, observed), level descriptions
fe_12.wgfa	Transition probabilities, gf values, theoretical, observed wavelengths
fe_12.splups	spline fits to Maxwellian-averaged e-collision strengths

- CHIANTI emissivities are currently calculated for plasmas in ionization equilibrium, but non-equilibrium, non-Maxwellian plasmas will soon be included. Have photo-excitation but not photo-ionization.

- Building a database of radiative and dielectronic recombination rates, as well as collisional and photo-ionization rates / cross-sections
  →calculate time-dependent ionization

CHIANTI, Astrogrid and the VO

- CHIANTI data have been 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 will appear automatically in VOSpec, once registered. - in progress

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

- Database tables include: wavelength, A-value, gf-value, configuration, nLSJ, observed, theoretical energy of upper and lower levels. Line emissivities in a grid of temperatures and densities.

To do:
Add tables of chemical abundances and ion fractions.
Add continuum.
Write workflows/scripts. IDL ? Python ?

Spectral Lines table

Result of query to spectral lines table via AstroGrid DSA:

TOPCAT(1): Table Browser

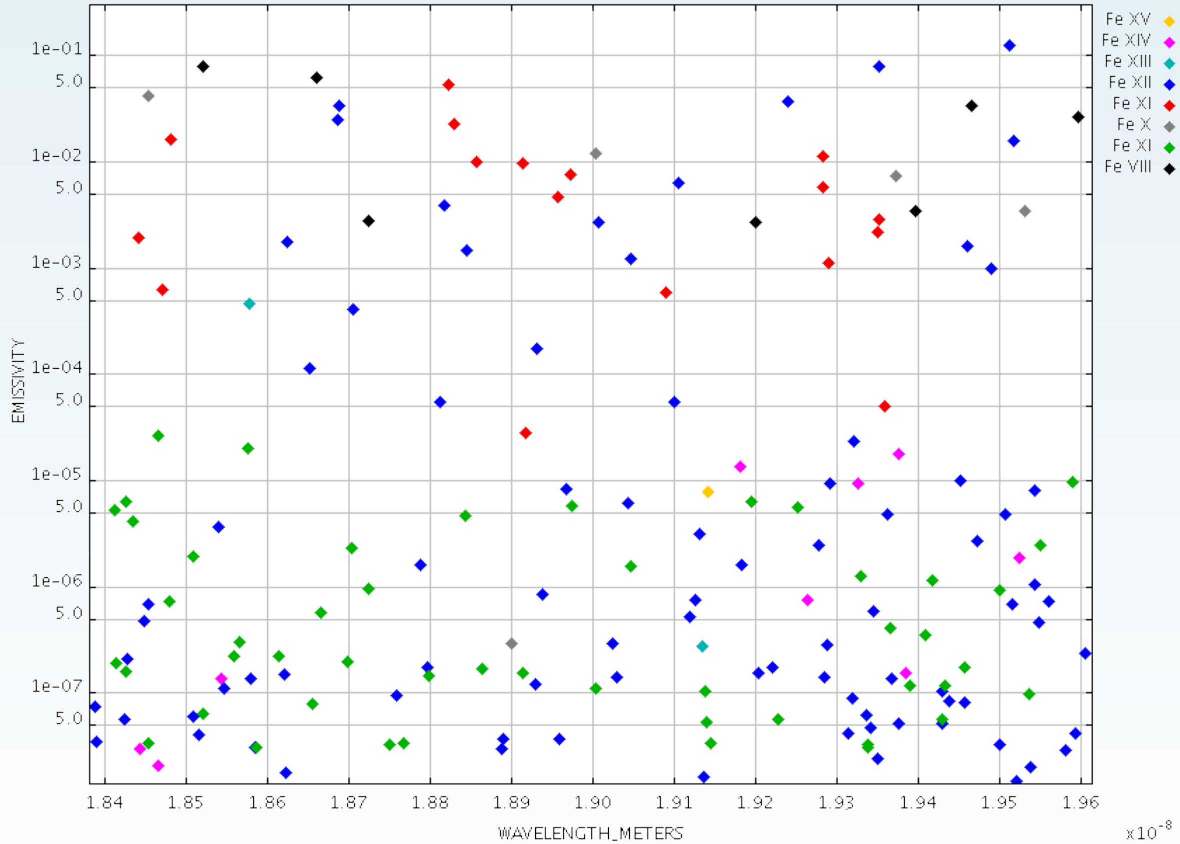
File Subsets Help

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

Emissivities table

- Table contains line emissivities calculated on a grid of temperatures and densities
- Results for Fe, for a query for log_density=5 and log_temperature=10 in wavelength range 180-200 Angstrom:



Benchmark (my own work)

- Transition probabilities - lifetimes (beam-foil spectroscopy)
- Line identifications and wavelengths using a wide range of laboratory and astrophysical spectra.
- Provide best estimates (empirically-adjusted) level energies and wavelengths.
- Uncertainties
- A lot of work is needed to revise/complete atomic data for the XUV. NIST data are incomplete.

i	Configuration (% purity)	Term	E_{best}	E_{best}-E_{NIST}
1	$3s^2 3p^3$(93%)	$^4S^o_{3/2}$	0.0±0	0
2	$3s^2 3p^3$(84%) +5(10%)	$^2D^o_{3/2}$	41555.6±1	-10.4
3	$3s^2 3p^3$(96%)	$^2D^o_{5/2}$	46088.0±1	13
4	$3s^2 3p^3$(95%)	$^2P^o_{1/2}$	74107.0±1	-2
5	$3s^2 3p^3$(82%) +2(11%)	$^2P^o_{3/2}$	80515.0±1	0
6	$3s\,3p^4$(87%)	$^4P^e_{5/2}$	274373.0±5	0
7	$3s\,3p^4$(87%)	$^4P^e_{3/2}$	284005.0±5	0
8	$3s\,3p^4$(86%)	$^4P^e_{1/2}$	288307.0±5	0
9	$3s\,3p^4$(75%) +33(c3 19%)	$^2D^e_{3/2}$	339725.0±30	-295
10	$3s\,3p^4$(76%) +34(c3 19%)	$^2D^e_{5/2}$	341716.0±10	13
11	$3s\,3p^4$(45%) +26(c3 44%)	$^2P^e_{3/2}$	389719.0±20	13
12	$3s\,3p^4$(32%) +28(c3 28%) +13(28%)	$^2P^e_{1/2}$	394360.0±20	240
13	$3s\,3p^4$(52%) +12(14%) +28(c3 17%)	$^2S^e_{1/2}$	410401.0±20	-
14	$3s^2 3p^2$ (^{3}P) 3d(92%)	$^4F^e_{3/2}$	426920.0±100	-
15	$3s^2 3p^2$ (^{3}P) 3d(90%)	$^4F^e_{5/2}$	430758.0±100	-
16	$3s^2 3p^2$ (^{3}P) 3d(91%)	$^4F^e_{7/2}$	436088.0±100	-
17	$3s^2 3p^2$ (^{1}D) 3d(44%) +36(30%) +22(20%)	$^2F^e_{5/2}$	443318.0±500	-
18	$3s^2 3p^2$ (^{3}P) 3d(94%)	$^4F^e_{9/2}$	443121.0±30	-
19	$3s^2 3p^2$ (^{1}D) 3d(46%) +39(17%) +23(30%)	$^4D^e_{7/2}$	447070.0±50	-
20	$3s^2 3p^2$ (^{3}P) 3d(95%)	$^4D^e_{1/2}$	446977.0±500	-
21	$3s^2 3p^2$ (^{3}P) 3d(92%)	$^4D^e_{3/2}$	448071.0±500	-
22	$3s^2 3p^2$ (^{3}P) 3d(68%) +17(12%)	$^4D^e_{5/2}$	451651.0±100	-
23	$3s^2 3p^2$ (^{3}P) 3d(28%) +39(19%) +19(45%)	$^2F^e_{7/2}$	461474.0±100	-
24	$3s^2 3p^2$ (^{1}D) 3d(94%)	$^2G^e_{7/2}$	494518.0±200	-
25	$3s^2 3p^2$ (^{1}D) 3d(94%)	$^2G^e_{9/2}$	497256.0±300	-
26	$3s^2 3p^2$ (^{3}P) 3d(25%) +11(c2 43%) +37(23%)	$^2P^e_{3/2}$	501800.0±30	0
27	$3s^2 3p^2$ (^{3}P) 3d(83%)	$^4P^e_{5/2}$	512508.0±5	-2
28	$3s^2 3p^2$ (^{3}P) 3d(21%) +12(c2 38%) +35(28%)	$^2P^e_{1/2}$	513850.0±10	-
29	$3s^2 3p^2$ (^{3}P) 3d(80%)	$^4P^e_{3/2}$	516772.0±5	-
30	$3s^2 3p^2$ (^{3}P) 3d(80%)	$^4P^e_{1/2}$	519767.0±5	-3
31	$3s^2 3p^2$ (^{1}S) 3d(42%) +41(35%)	$^2D^e_{3/2}$	526127.0±10	7
32	$3s^2 3p^2$ (^{1}S) 3d(27%) +40(36%) +34(20%)	$^2D^e_{5/2}$	536939.0±10	-1101
33	$3s^2 3p^2$ (^{1}D) 3d(57%) +9(c2 14%) +31(21%)	$^2D^e_{3/2}$	553906.0±5	-124
34	$3s^2 3p^2$ (^{1}D) 3d(37%) +32(48%)	$^2D^e_{5/2}$	554632.0±5	22
35	$3s^2 3p^2$ (^{1}D) 3d(52%) +28(19%) +38(17%)	$^2P^e_{1/2}$	569794.0±50	854
36	$3s^2 3p^2$ (^{3}P) 3d(47%) +17(34%)	$^2F^e_{5/2}$	576733.0±10	-7
37	$3s^2 3p^2$ (^{1}D) 3d(62%) +26(25%)	$^2P^e_{3/2}$	577680.0±20	-60
38	$3s^2 3p^2$ (^{1}D) 3d(60%) +35(10%) +13(c2 11%)	$^2S^e_{1/2}$	576153.0±20	-3477
39	$3s^2 3p^2$ (^{3}P) 3d(59%) +23(36%)	$^2F^e_{7/2}$	581171.0±20	-9
40	$3s^2 3p^2$ (^{3}P) 3d(50%) +32(15%) +34(12%)	$^2D^e_{5/2}$	603940.0±20	10
41	$3s^2 3p^2$ (^{3}P) 3d(58%) +31(27%)	$^2D^e_{3/2}$	605540.0±50	60

Del Zanna & Mason (2005)

Questions

- What atomic data do users need ?
- How can we make atomic data available through the VO, have them used 'properly' and referenced ?

My wish list:

- Provide multiple datasets of atomic data.
- Atomic data:
    - excitation rates and cross-sections (APAP Network)
    - ionization and recombination rates and cross-sections
    - level energies and wavelengths
    - transition probabilities
- Provide both theoretical and measured values; uncertainties.
- Have standard protocols to access atomic data.
- Provide general tools to measure physical parameters from observed spectra.