The CHIANTI Atomic Database

An Overview of Data, Software and Applications

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Overview

1. Quick guide
2. History of project
3. Impact
4. Database contents
   a. Data for level balance
   b. Data for ion balance
5. Software
6. Data assessment
7. Applications

Quick guide

CHIANTI (data and software) is freely available over the web

Website: http://chiantidatabase.org

Contains data for **neutrals** and **ions**

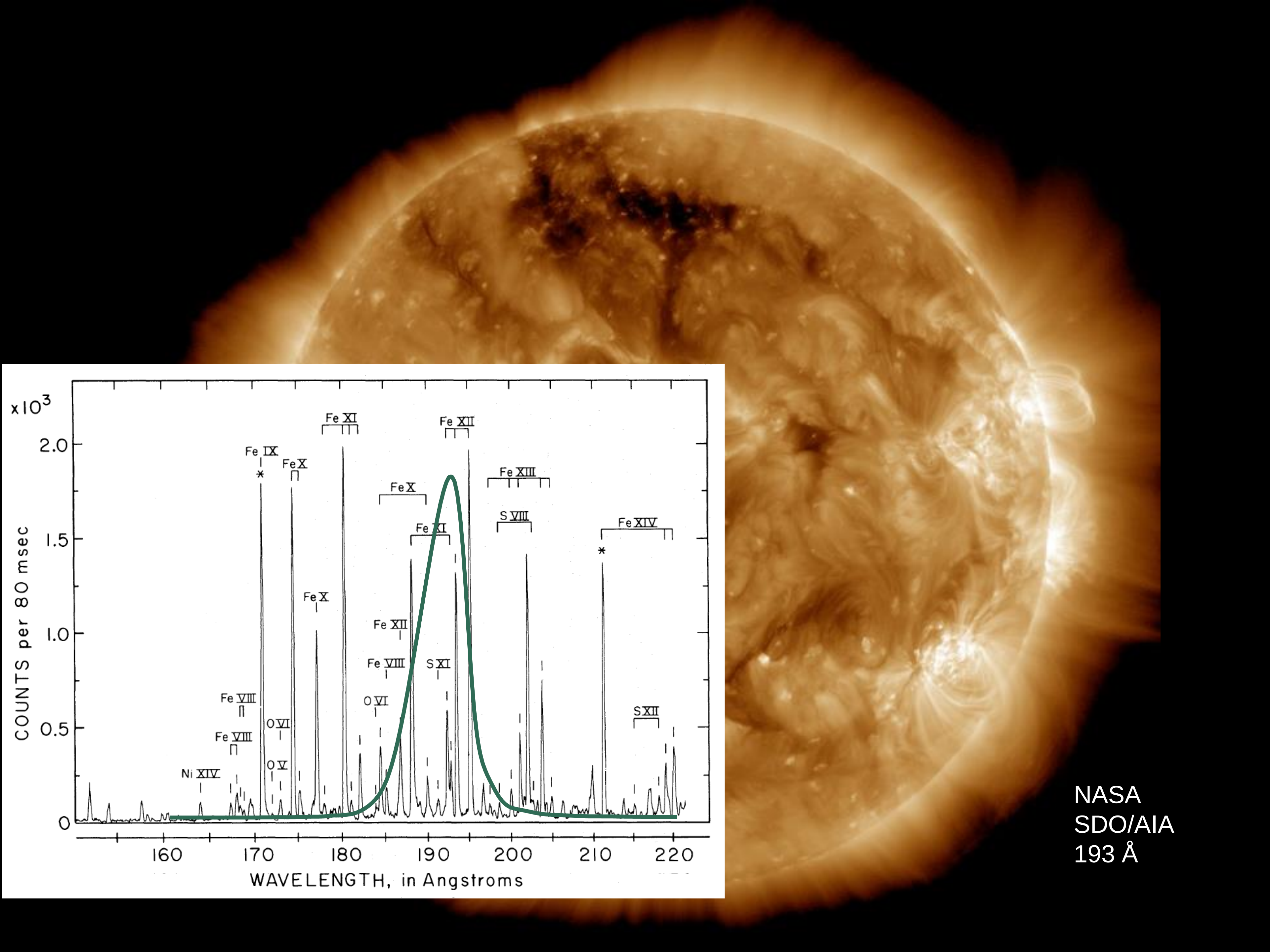
Current version: 8.0 (September 2015)

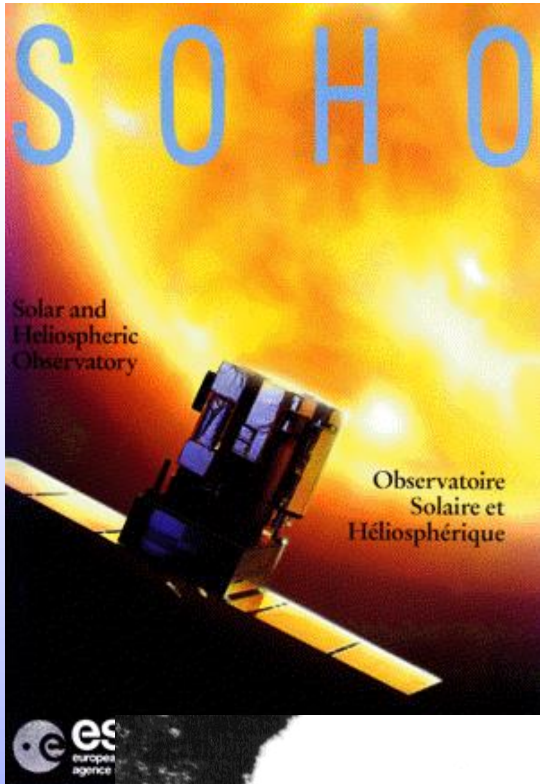
Original paper: Dere et al. (1997, A&A, 125, 149)

Current paper: Del Zanna et al. (2015, A&A, 582, 56)

Detailed user guide: http://chiantidatabase.org/cug.pdf

Keywords: astrophysics − the Sun − optically-thin − emission lines


NASA
SDO/AIA
193 Å
x10^3
COUNTS per 80 msec
2.0
1.5
1.0
0.5
0
Fe XI
Fe XII
Fe IX
Fe X
Fe X
Fe XIII
S VIII
Fe XI
Fe XIV
Fe X
Fe XII
Fe VIII
S XI
O VI
Fe VIII
O VI
Fe VIII
O V
Ni XIV
S XII
160
170
180
190
200
210
220
WAVELENGTH, in Angstroms



CHIANTI - an atomic database for emission lines

I. Wavelengths greater than 50 Å*

K.P. Dere[1], E. Landi[2], H.E. Mason[3], B.C. Monsignori Fossi[4], and P.R. Young[3]

[1] Naval Research Laboratory, Washington DC, U.S.A.
[2] Department of Astronomy and Space Science, Universit
[3] Department of Applied Mathematics and Theoretical P
[4] Arcetri Astrophysical Observatory, Florence, Italy

Received July 24; accepted November 5, 1996

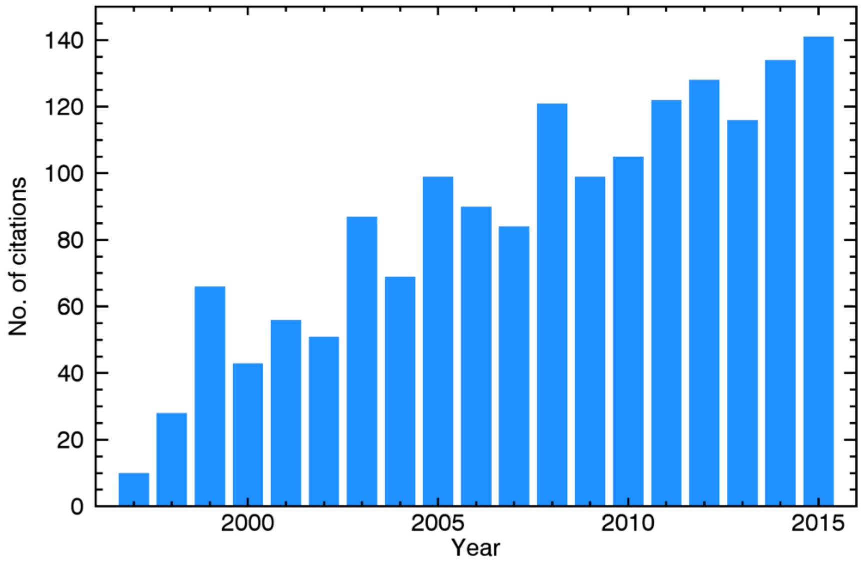
SOHO Workshop, 1993, Elba, Italy

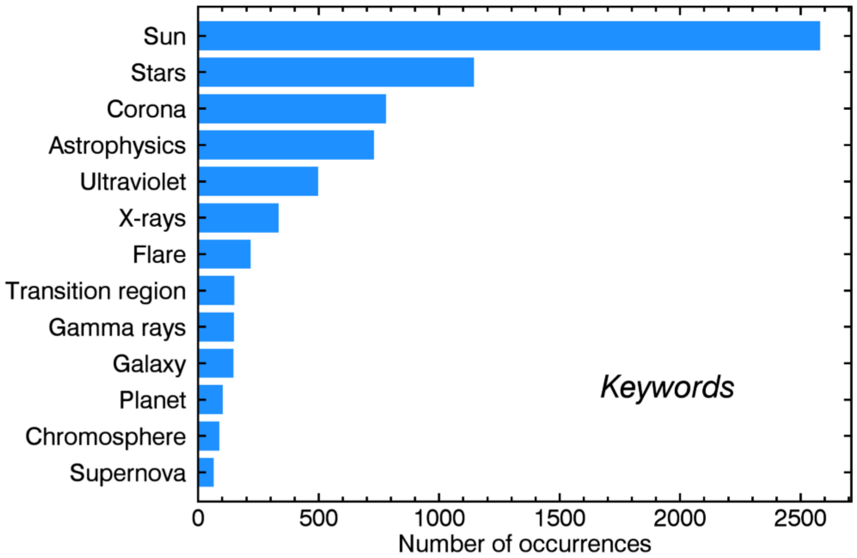
Who are the CHIANTI team?

(L-to-R) Giulio Del Zanna, Peter Young, Ken Dere, Massimo Landi (retired), Enrico Landi & Helen Mason

3. Impact

- Each version of CHIANTI is described in a paper
- These papers have received 2091 citations





CHIANTI 1: Dere et al. (1997, A&A)

CHIANTI 8: Del Zanna et al. (2015, A&A)

4. What is CHIANTI?

1. Sets of atomic data
   - for modeling the level balance equations
   - for modeling the ion balance equations
   - for modeling continuum emission
   - all data stored as plain ASCII files

For modeling CHIANTI separates level balance (within ion) from ion balance

Continuum emission not covered in this talk

2. A software package
   - both IDL and Python versions

4a. Level balance equations

- For low-density astrophysical plasmas, dominant processes are
  - electron excitation/de-excitation
  - spontaneous radiative decay

- Atomic quantities needed for modeling
  - observed energy levels
  - electron rate coefficients, C_{ij}
  - radiative decay rates, A_{ij}

A Maxwellian electron distribution is assumed

Database coverage

Ions in CHIANTI 8.0

- ≤ 10 levels
- < 100 levels
- ≥ 100 levels

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII	XXIX	XXX
H	25																													
He	49	25																												
C	42	204	20	331	49	25																								
N	47	58	204	20	268	49	25																							
O	7	35	46	204	166	268	49	25																						
Ne	-	138	86	22	49	204	46	243	49	36																				
Na	-	209	195	10	13	20	204	10	204	49	25																			
Mg	-	161	209	195	86	72	46	204	108	243	49	25																		
Al	-	20	161	209	195	10	15	20	204	10	243	49	25																	
Si	-	29	20	161	209	195	86	72	46	204	92	243	49	25																
P	-	-	-	-	161	209	3	10	15	20	204	10	204	45	25															
S	60	70	53	52	16	161	209	195	86	72	72	204	92	243	49	25														
Cl	-	5	5	5	-	-	-	-	-	10	15	20	204	10	204	49	25													
Ar	-	-	5	30	5	-	16	161	209	195	86	72	15	204	92	243	49	24												
K	-	-	-	-	5	5	-	-	161	209	3	10	15	20	204	10	204	49	25											
Ca	-	41	-	-	5	5	27	40	283	161	209	195	86	91	46	204	92	243	49	25										
Ti	-	-	-	-	-	-	-	-	-	-	16	161	209	3	10	72	20	15	10	20	-	-								
Cr	-	-	-	-	-	-	13	31	48	-	-	-	16	161	209	3	10	15	20	204	10	243	-	-						
Mn	-	-	-	-	-	-	-	13	31	48	-	-	-	-	161	209	3	10	15	20	204	10	204	-	-					
Fe	-	142	322	37	34	96	9	536	915	552	996	912	749	739	283	161	267	337	636	375	620	548	196	243	49	25				
Ni	-	17	-	-	-	-	-	-	-	-	599	31	48	143	483	40	159	161	209	195	58	15	20	204	92	243	49	25		
Zn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	161	209	-	10	72	20	-	10	243	49	-

Energy levels (ELVLC)

- Stored in ELVLC file
- Example: o_6.elvlc (O VI)

i	Configuration	Conf. index	2S+1	L	J	E_{obs} (cm^{-1})	E_{theor} (cm^{-1})
1	1s2.2s	1	2	S	0.5	0.000	0.000
2	1s2.2p	2	2	P	0.5	96375.000	97030.386
3	1s2.2p	2	2	P	1.5	96907.500	97793.028
4	1s2.3s	3	2	S	0.5	640039.800	639523.858
5	1s2.3p	4	2	P	0.5	666113.200	665756.955
6	1s2.3p	4	2	P	1.5	666269.800	665979.821
7	1s2.3d	5	2	D	1.5	674625.700	674023.368
8	1s2.3d	5	2	D	2.5	674676.800	674086.147

Radiative decay rates [WGFA]

- Stored in WGFA files
- Example: o_6.wgfa (O VI)

i	j	λ(Å)	gf	A
1	2	1037.6135	1.337e-01	4.198e+08
1	3	1031.9120	2.695e-01	4.298e+08
2	4	183.9370	5.768e-02	5.662e+09
3	4	184.1172	1.152e-01	1.128e+10
1	5	150.1250	1.744e-01	2.578e+10
4	5	3835.3300	2.240e-01	5.142e+07

Electron excitation (SCUPS)

- We store scaled versions of the effective collision strengths (upsilons)
- Scaling follows method of Burgess & Tully (1992, A&A)
- Example: o_6.scups (O VI)

i j

scaled temps

```
    1       2    8.853e-01    1.348e-01    6.091e-01     8     1    2.313e+00
 0.000e+00   1.429e-01   2.857e-01   4.286e-01   5.714e-01   7.143e-01   8.571e-01   1.000e+00
 1.689e+00   1.525e+00   1.386e+00   1.237e+00   1.070e+00   9.044e-01   7.653e-01   6.089e-01
    1       3    8.901e-01    2.711e-01    1.218e+00     8     1    2.185e+00
 0.000e+00   1.429e-01   2.857e-01   4.286e-01   5.714e-01   7.143e-01   8.571e-01   1.000e+00
 3.269e+00   3.071e+00   2.819e+00   2.545e+00   2.208e+00   1.849e+00   1.553e+00   1.218e+00
```

scaled ups

To retrieve upsilons: `IDL> ups=spl2ups('o_6',[i,j],temp)`

To retrieve rate coeff: `IDL> c=rate_coeff('o_6',temp,trans=[i,j])`

Sources of electron excitation data

- Most recent data are from the UK APAP network (http://apap-network.org)
- Systematic calculations along isoelectronic sequences
- Bespoke calculations for coronal iron ions (Fe VIII-XIV)

Nigel Badnell
Pete Storey
Helen Mason
Giulio Del Zanna
Alessandra Giunta
Luis Fernández Menchero

Additional level processes

1. Proton excitation/de-excitation
   – mainly for ground configuration
2. Level-resolved ionization/recombination
3. Dielectronic capture
4. Autoionization
   – rates stored in WGFA file
5. Two-photon decays (H and He-like only)
   – rates stored in WGFA file
6. Photoexcitation & stimulated emission
   – assume radiation field (e.g., black body)

Level-resolved ionization/recombination

- Dielectronic captures to auto-ionizing states
  - contained in separate dielectronic models (e.g., ‘o_6d’)
  - treated as electron excitations, so added to SCUPS file

- Ionization and recombination to bound states
  - treated as perturbing processes to level populations
  - added as *post-facto* corrections to populations for key ions
  - approximation works when population mostly in ground level
  - data stored in .RECLVL and .CILVL files

These processes important for
X-ray spectral modeling.

4b. Ionization balance

- For modeling the distribution of ion states in an electron-ionized plasma
- Need ion-to-ion total recombination and ionization rates
- In 2009 (CHIANTI 6) we started including these rates

Processes

- direct ionization
- excitation-autoionization

} Mainly from Dere (2007, A&A, 466, 771)

- radiative recombination
- dielectronic recombination

} Mainly from N.R. Badnell & collaborators

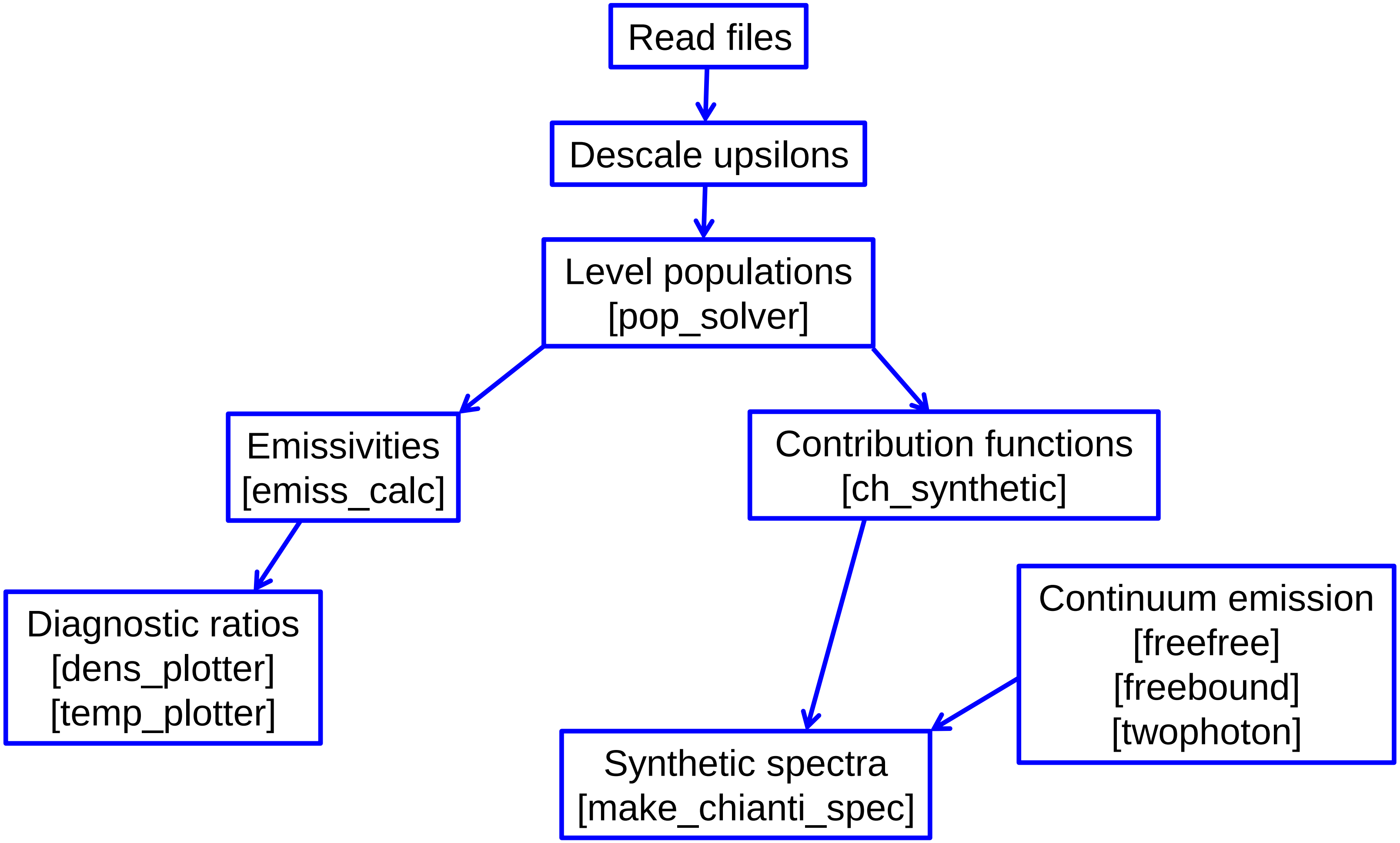
CHIANTI files

- DIPARAMS, EASPLUPS (ionization)
- RRPARAMS, DRPARAMS (recombination)

5. Software

- Software package written in the *Interactive Data Language (IDL)*
  - available as tar file from webpage
- Since 2010, a *Python* package (*ChiantiPy*) is available
  - http://chiantipy.sourceforge.net

IDL software

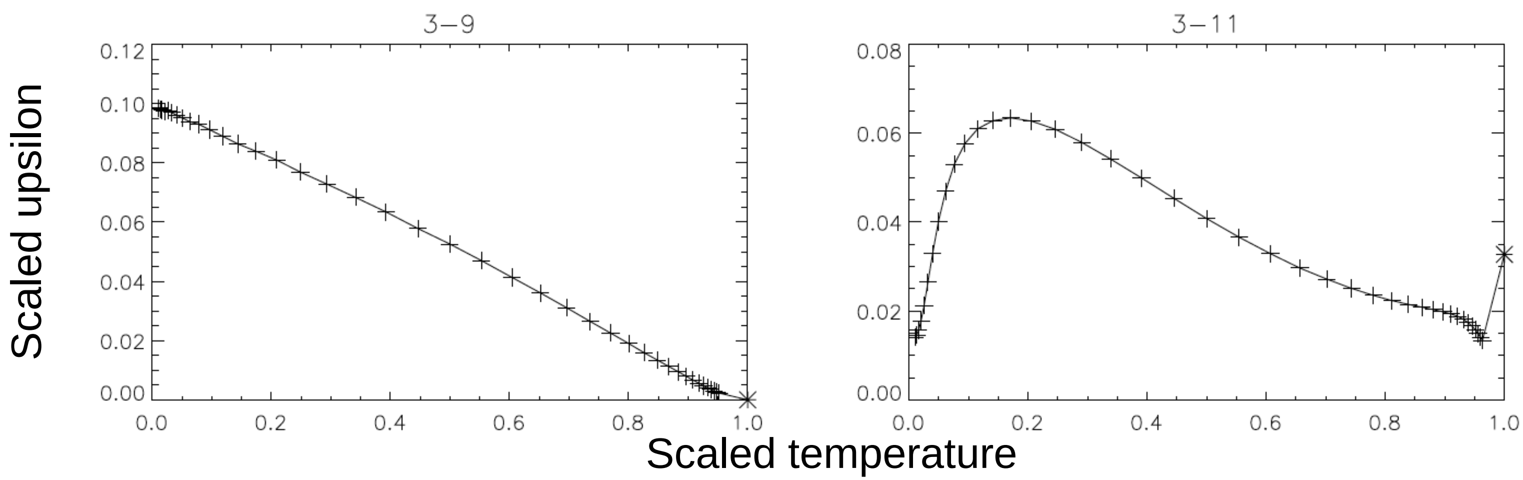


6. Data assessment

Assessment of the atomic data is a crucial part of CHIANTI

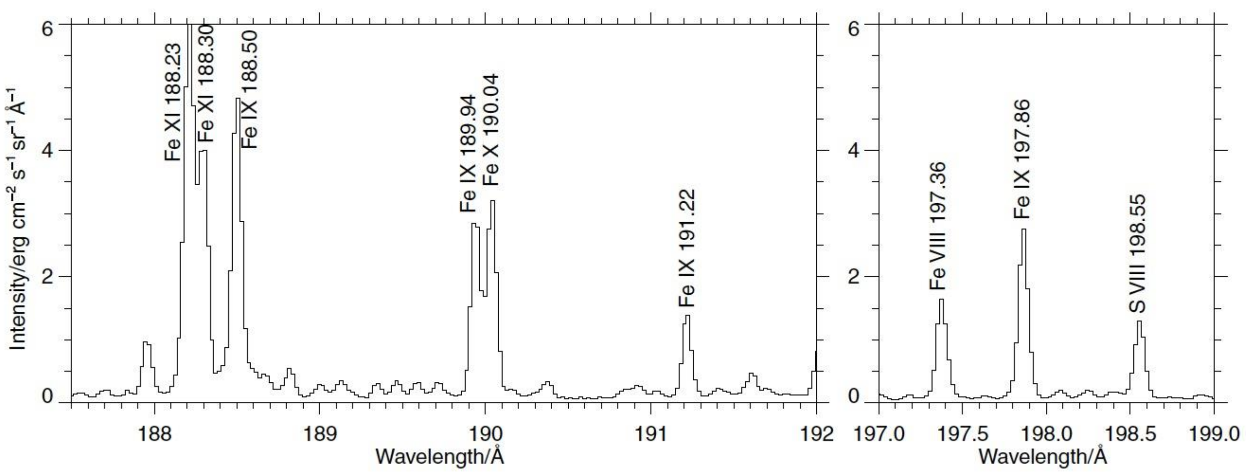
1. Each transition is assessed graphically
   – Burgess & Tully (1992) scaling used

2. Benchmark comparisons with solar and stellar spectra performed
   – intensities/fluxes predicted and compared with observations
   – gives confidence in data
   – identifies where new data are required



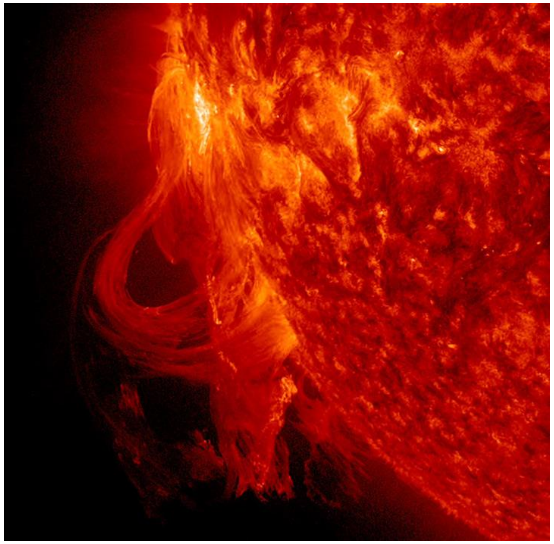
Data assessment example

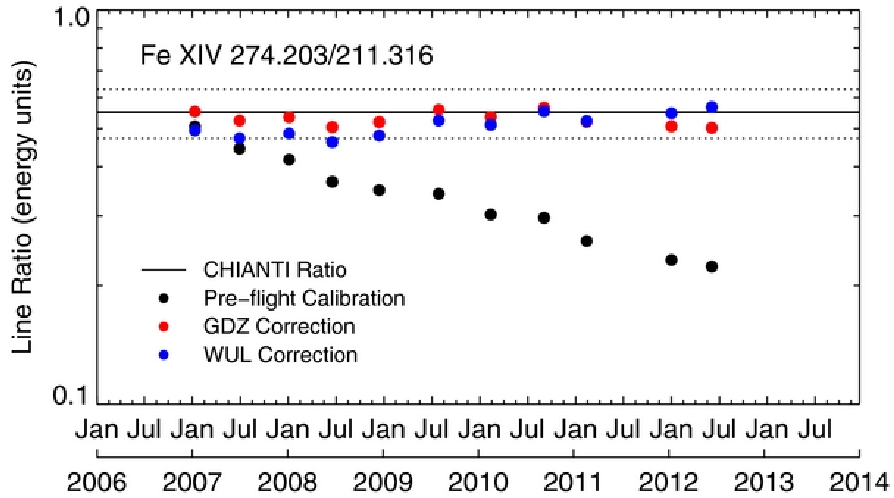
1. PY identifies four new Fe IX lines from Hinode/EIS spectra (Young, 2009, ApJL)
2. PY updates CHIANTI Fe IX model
3. CHIANTI 6 is released in 2009, with new data
4. Data is used by community (e.g., Brooks et al. 2009, ApJ)
5. IDs validated by lab measurements (Beiersdorfer & Lepson 2012, ApJS)
6. New Fe IX atomic data (Del Zanna et al. 2014, A&A) improves model
7. New data added to CHIANTI 8 (Del Zanna et al. 2015, A&A)



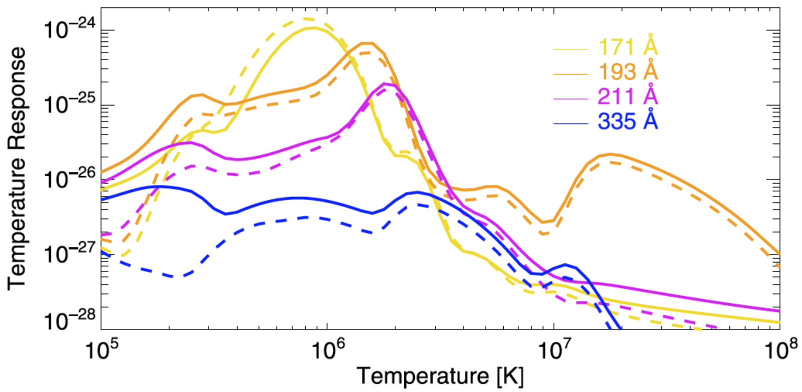
7. Applications: NASA instrumentation

- CHIANTI used for
  - deriving response functions
  - performing calibration





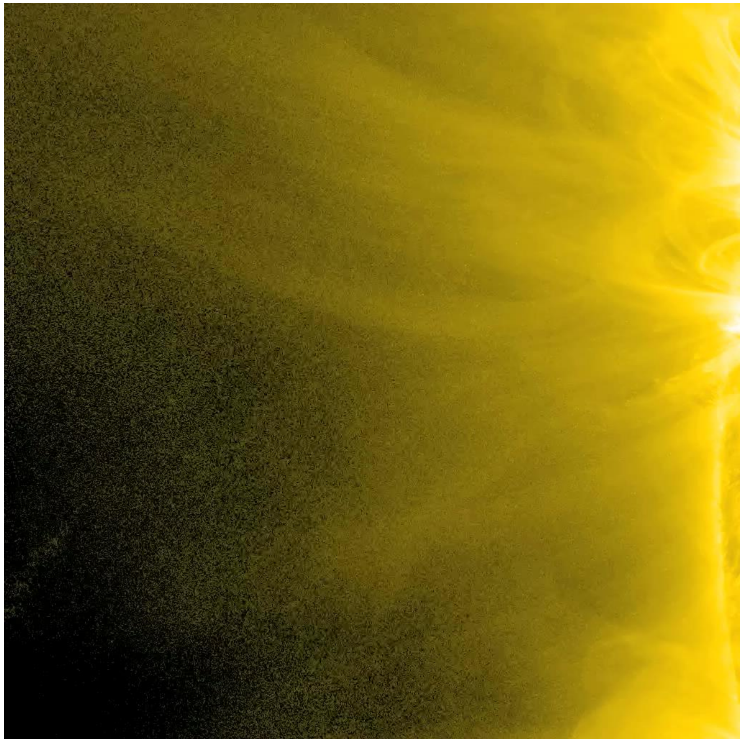
Hinode/EIS calibration (Warren et al. 2014)



SDO/AIA response functions (Boerner et al. 2014)

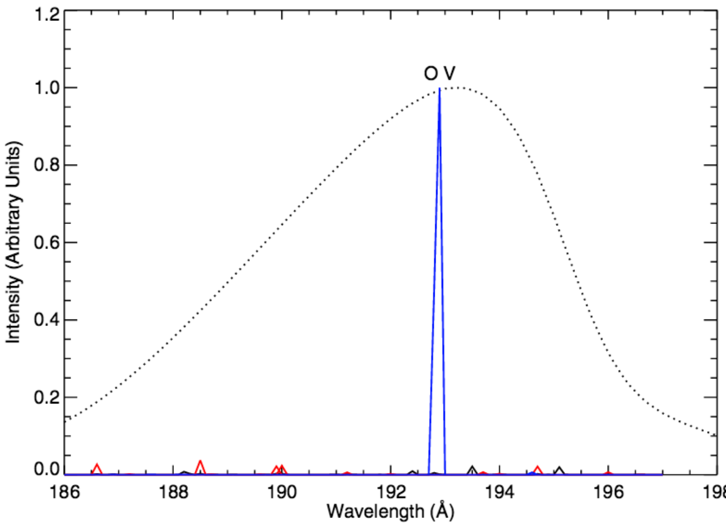
Applications: comet emission

- Comet Lovejoy passed through the Sun's corona



NASA SDO/AIA 171Å

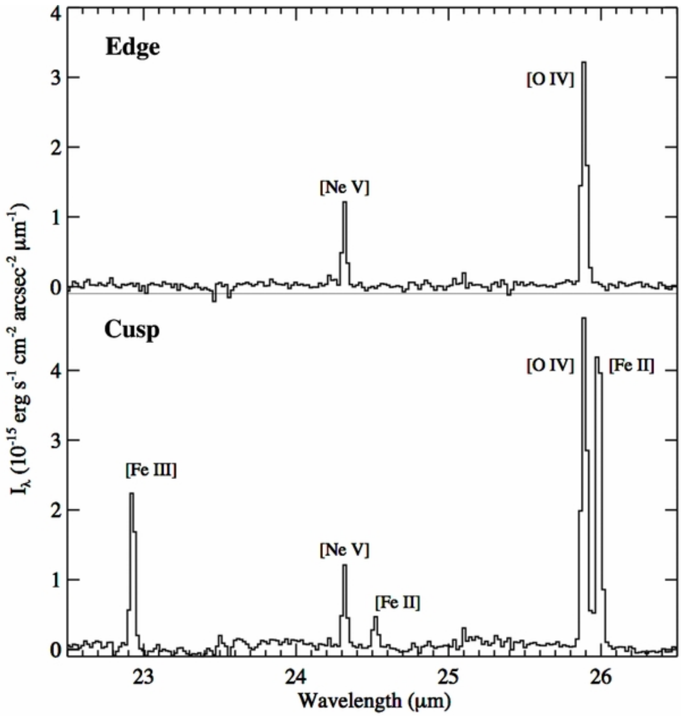
Bryans & Pesnell (2012, ApJ)
- used CHIANTI to demonstrate that AIA comet emission mostly from oxygen



Applications: Cygnus Loop

NASA GALEX

- Supernova remnant
- Sankrit et al. (2014, ApJ) presented *Spitzer* observations
- CHIANTI used to model spectrum



Summary

- CHIANTI is a freely available atomic data and software package
- Widely used in astrophysics
  - analysis of spectra
  - predicting radiative emissions from theoretical models
  - instrument calibration
- Benchmarking and assessment critical to success of project

http://chiantidatabase.org

Coming soon: special issue of J. Phys. B on astrophysical spectroscopy

CHIANTI paper -> http://files.pyoung.org/papers/chianti.pdf