CHIANTI
An atomic database for astrophysical plasmas

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Overview

A – Background

B – The CHIANTI database

C – Data benchmarking for CHIANTI

D – Future CHIANTI work

A - Background

CHIANTI was born within the solar spectroscopy community in the early 1990s

1 - Need of a large amount of atomic data

2 - New X-ray, EUV, UV instruments were launched

3 - Number of users was increasing

Background (II)

Before CHIANTI, each scientist had to look for the atomic data he/she needed in the literature

This process was inefficient

- Selection:
  - Not atomic physics experts
  - Disconnection between solar and atomic physics communities
- Implementation:
  - Very time consuming
  - Software duplication
- Results
  - Comparison between results from different authors was also dependent on the atomic data used

Background (III)

Only a few databases were known to solar physicists:

MEKAL	(Nederlands)
ADAS	(UK)
Arcetri Spectral Code	(Italy)
Raymond & Smith	(USA)

They all had some limitations:

- Line intensity calculation
- Data handling/user friendliness/software were in their infancy
- Limited interaction with new space missions

Requirements of a database

In order to be suitable for the analysis of modern high-resolution spectra, atomic databases need to

- be complete	**- no lines left behind**
- be accurate	**- plasma diagnostics must not be hindered by**
	- atomic physics uncertainties
	- approximation in line intensity calculation
- be user friendly	
- be transparent	**- the user can independently check the original data and their accuracy**
	- no black box
	- all data independently refereed in peer reviewed literature

Also, atomic data and predicted emissivities from databases *need to be benchmarked against observations*

B - The CHIANTI database

CHIANTI was developed in order to meet these needs, AND:

Be compact
Be freely available

CHIANTI is a complete spectral code:

Database

- Includes 280+ ions
- Atomic data: Energy levels, A values
- Electron/proton-ion collision data
- Continuum calculation data
- Ionization/recombination data

Software

- Plasma diagnostics
- Synthetic spectrum calculation
- Data handling software

The CHIANTI database (II)

CHIANTI includes the following processes:

- Electron and proton collision excitation
- Photoexcitation
- Innershell and dielectronic satellite lines
- Recombination into excited levels
- Ionization and recombination rates

CHIANTI collision data are scaled and stored

- Very compact database
- No loss of accuracy

CHIANTI spectral range:

- Primary range: 1-2000 A
- Useable range: Any spectral line beyond 2000 A emitted by ions in CHIANTI

The CHIANTI database (III)

CHIANTI data are:

- In ASCII format
- Selected from the refereed literature
- Critically assessed and evaluated
- With references to original literature

→ CHIANTI is completely transparent to the end user

- FREELY available on the web at

http://www.chiantidatabase.org

- Fully documented through user guides

CHIANTI also provides:

- a mailing list
- Email assistance to users at:

chianti_help@halcyon.nrl.navy.mil

CHIANTI diffusion

CHIANTI is the standard, reference database for solar physics

CHIANTI spread well beyond solar physics:

Solar system objects	(planets, asteroids, comets)
Interstellar medium	
Stellar physics	(solar-type, O-type, binary, symbiotic etc)
Stellar evolution	(protostellar disks and jets, T-Tauri stars, novae, planetary nebulae, white dwarfs, neutron stars, supernovae)
Extragalctic astronomy	(AGN, quasars, Seyfert galaxies, galaxy clusters, primordial metallicity)
Atomic physics	(data benchmark, new calculations, laboratory astrophysics)

Most common uses:

- Plasma diagnostics
- Radiative loss calculation
- Time-dependent effects
- Line identification

CHIANTI diffusion (II)

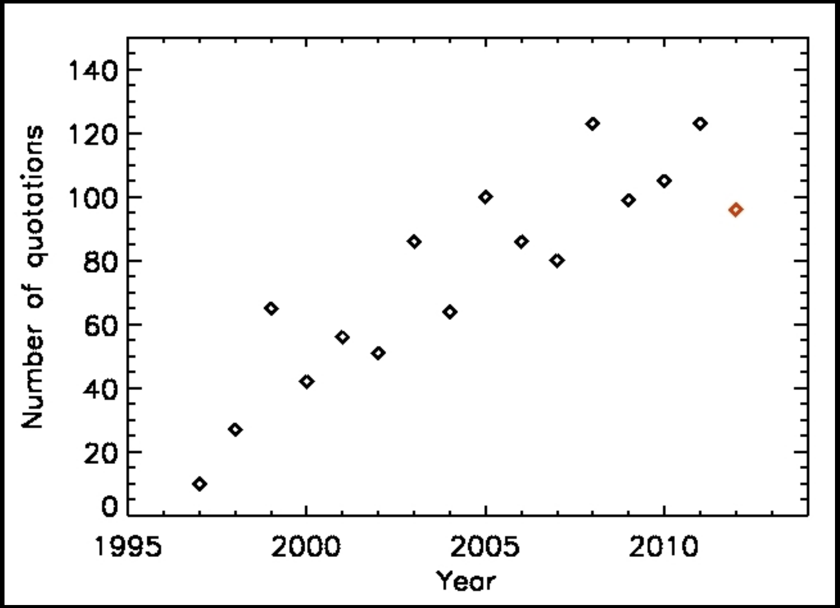
Space missions using CHIANTI data:

SOHO	SDO
Yohkoh	GOES
TRACE	RHESSI
SECCHI	RESIK
Hinode	SPHINX

Other databases and software packages use CHIANTI:

- APEC/APED
- XSTAR
- HAOS-DIPER
- PANDORA
- PintOfAle

CHIANTI QUOTATIONS



C - Data benchmarking for CHIANTI

CHIANTI was developed in order to provide a database that was:

- → Complete
- → Accurate

Completeness and accuracy:

These two characteristics are linked
To achieve them, we continuously

1 - Assess data before including them in CHIANTI
2 - Compare CHIANTI predictions with observations

Before including data in CHIANTI

All CHIANTI data are critically assessed and evaluated before being inserted into CHIANTI

The main data included in CHIANTI are:

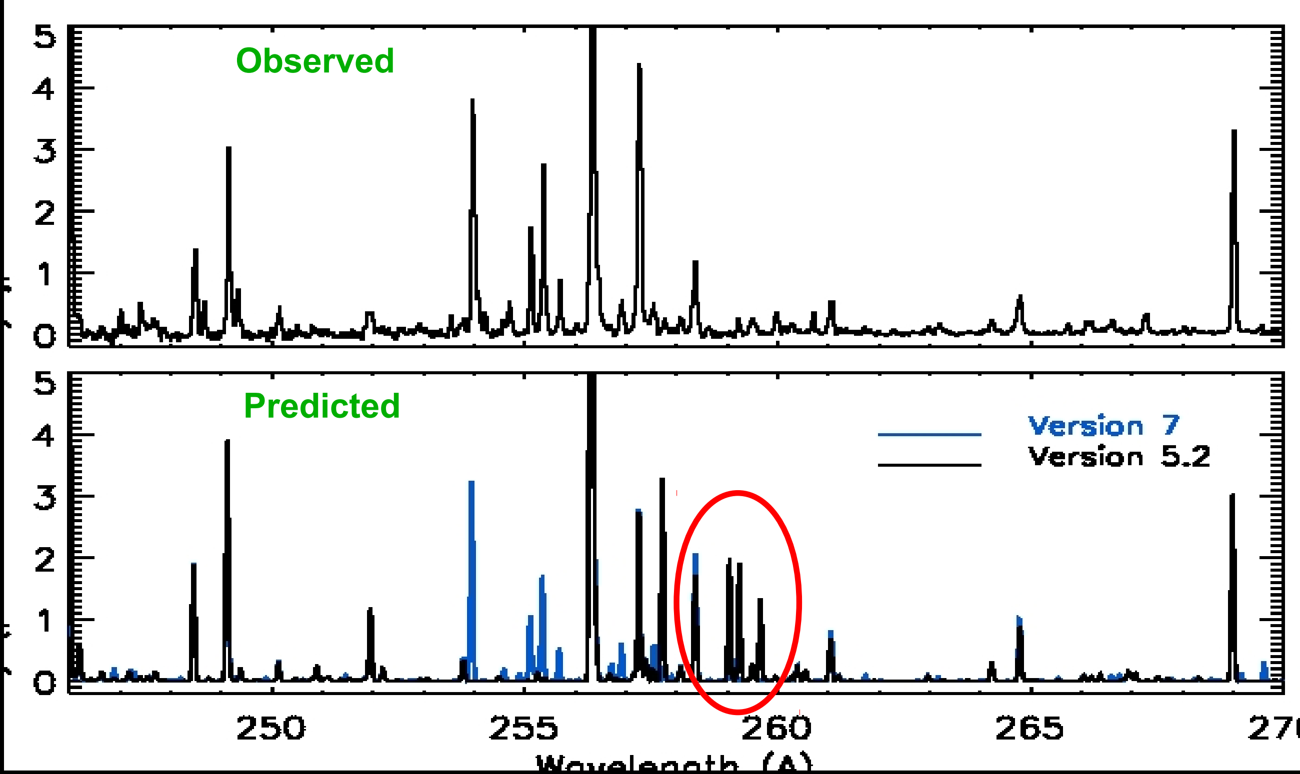
	Observed	Calculated
Energy levels	X	X
Radiative data	X	X
Electron-ion excitation		X
Proton-ion excitation		X
Ionization rate coefficients	X	X
Recombination rate coefficients		X

Before including data in CHIANTI (II)

Energy levels

- Review all laboratory, solar and stellar observations
- Measure level energies
- Associate them to levels in CHIANTI models

Example: Fe VIII

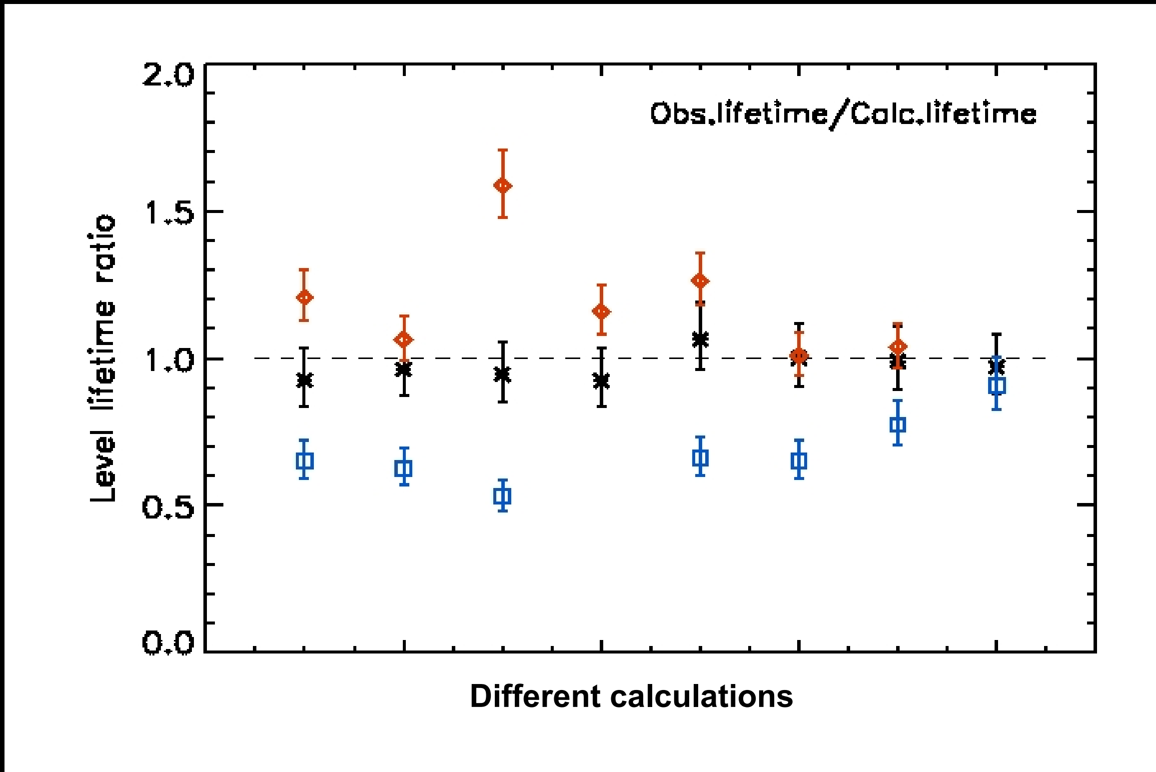


Before including data in CHIANTI (III)

Radiative rates

- Mostly from calculations
- Compare with few available measurements
  - Radiative rate
  - Level lifetime

Example: Ca IX

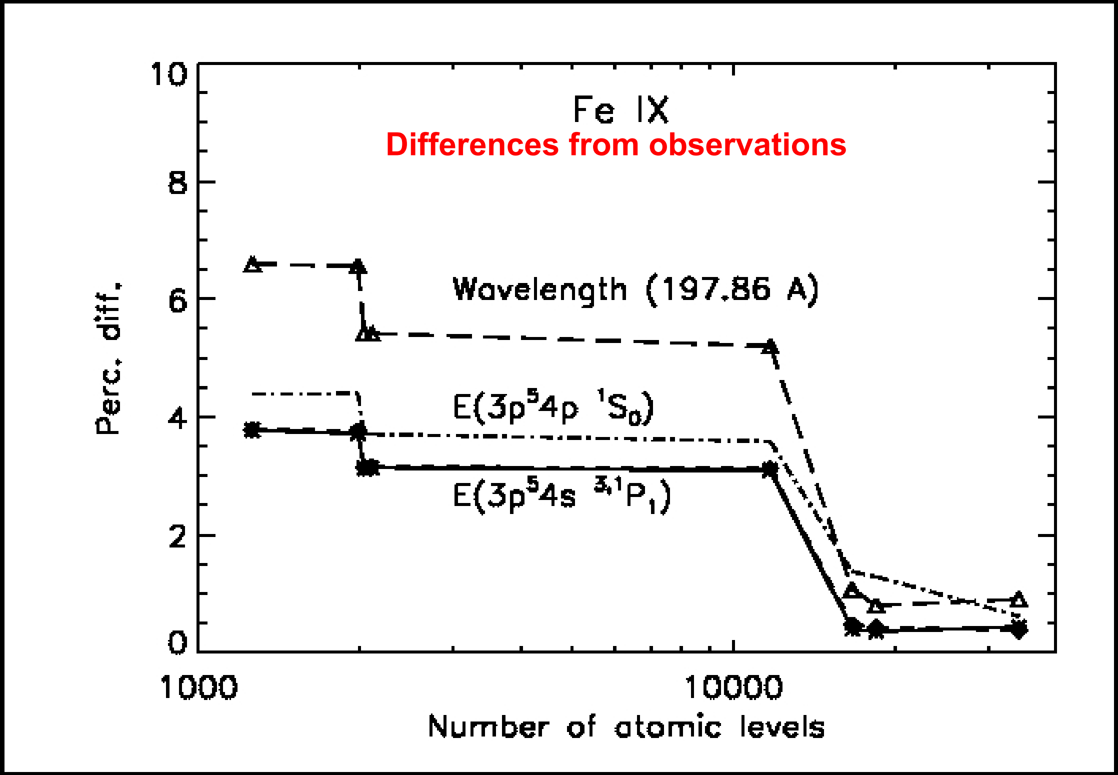


Before including data in CHIANTI (IV)

Radiative rates, energy levels, wavelengths

Compare among different calculations

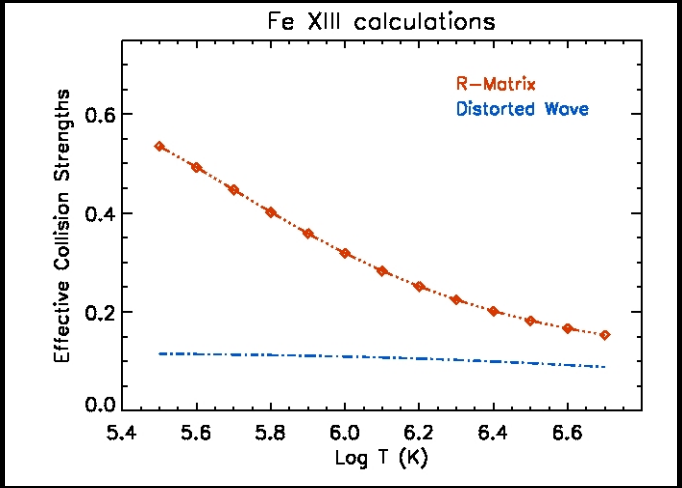
Atomic model completeness
Approximation used
"Stability" of results against model changes

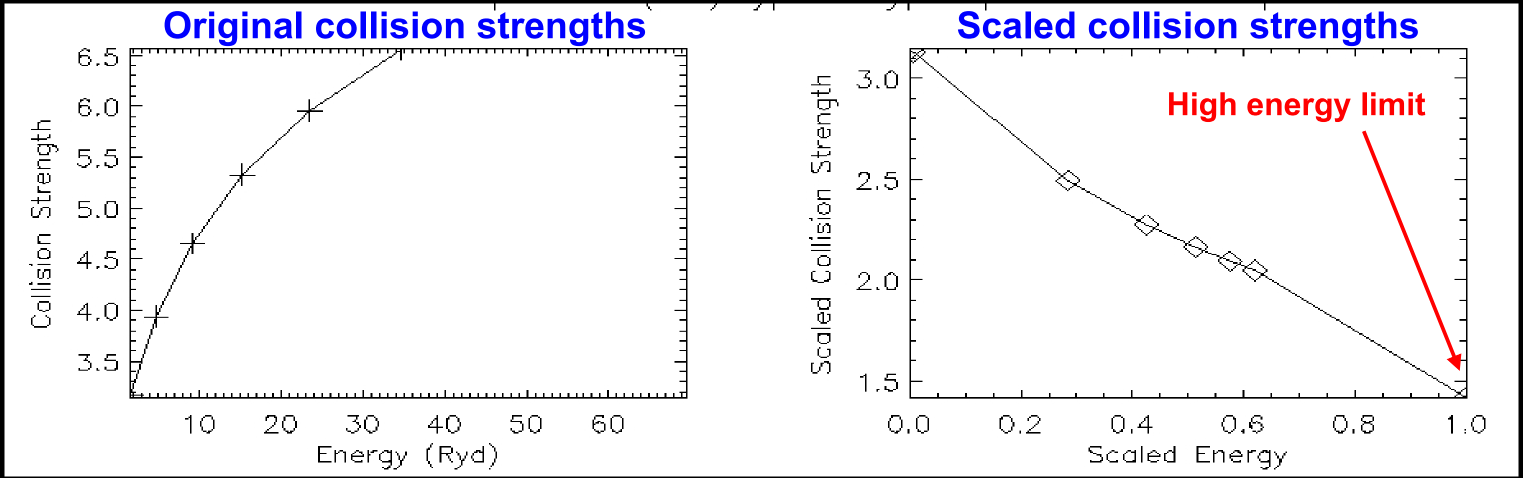


Before including data in CHIANTI (V)

Electron ion collision excitation rate coefficients

- Review all existing calculations
- Compare atomic model completeness
- Compare calculation method
    - R-Matrix, Distorted Wave, etc
    - relativistic, semi-relativistic, etc
- Check high energy behavior





After including data in CHIANTI

There are two main benchmarks:

- Completeness
- Accuracy

We have steadily compared CHIANTI spectra with

- High resolution solar and stellar spectra
- High resolution laboratory spectra

In each comparison, we

- Determine areas of strength
- Determine areas of weakness

→ Address weaknesses in a new CHIANTI version

After including data in CHIANTI (II)

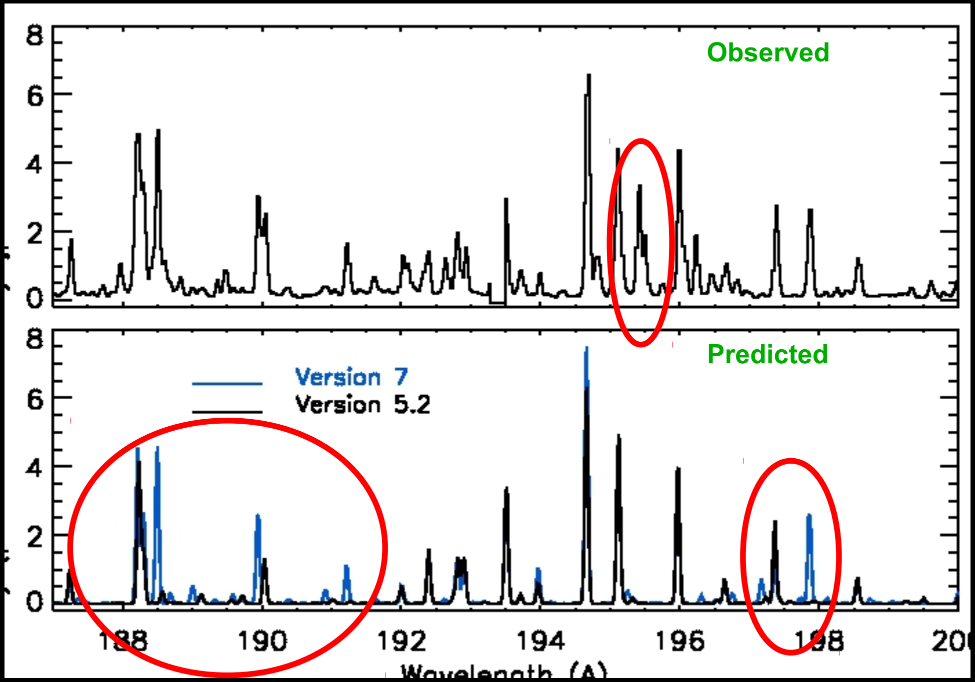
Comparison history

Version	Instrument	Wvl. Range	Outcome
V1	SERTS	170-450 A	V2 release (minor ions, improved data)
V3	CDS SUMER	308-630 A 500-1600 A	V4 release (proton excitation rates, improved data)
V4	SMM/FCS RESIK	7-20 A 3-8 A	V5 release (X-ray Fe data)
V5,V6	EIS	170-292 A	Fe VIII-XIV (new data development)
V7	Chandra	10-170 A	V7.1 release (Fe soft X-ray data)

After including data in CHIANTI (III)

Example: EUV line identification

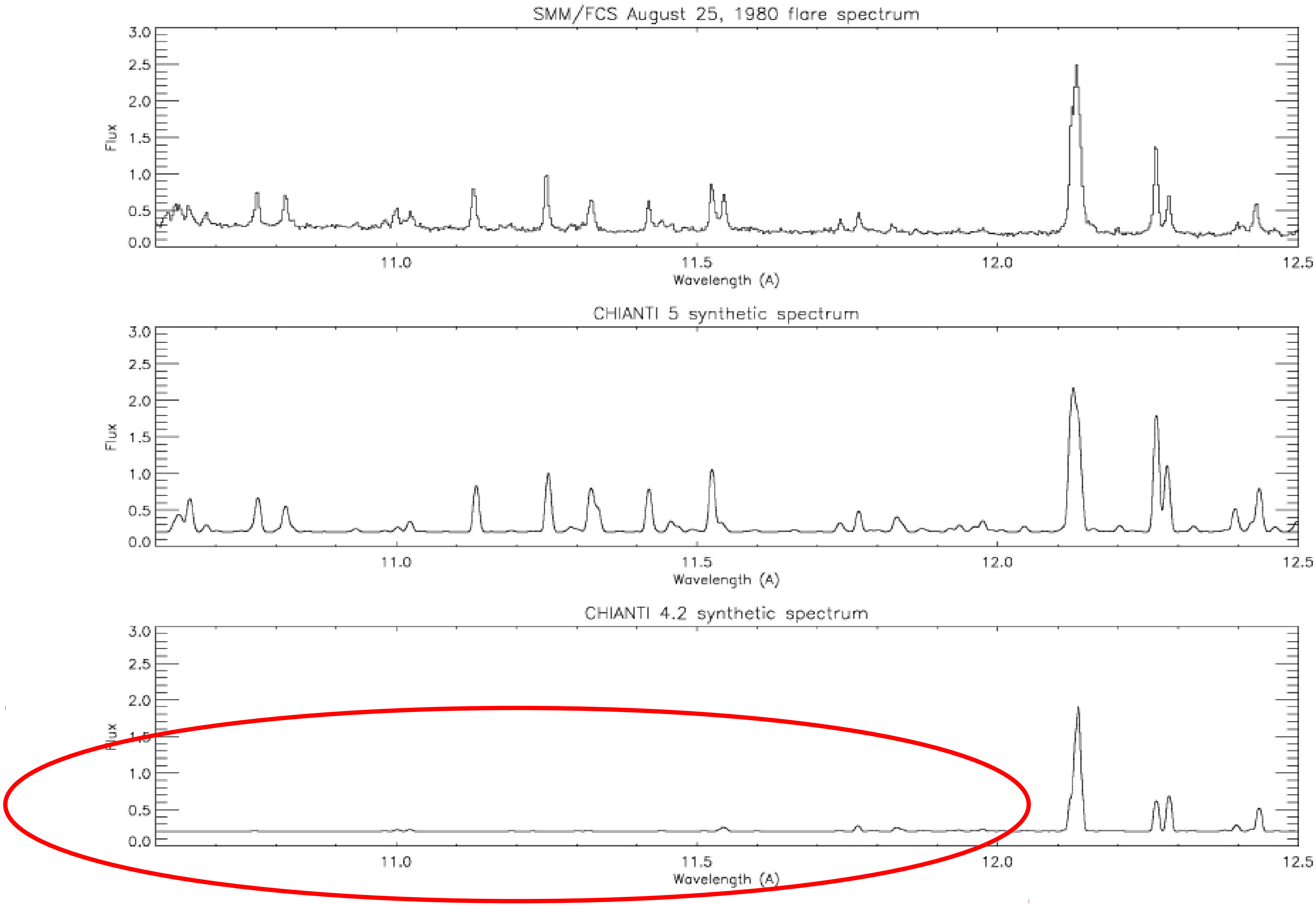
- Comparison of CHIANTI V6 with solar spectra of cool bright point:
  - Instrument: Hinode/EIS
  - Wavelength range: 170-292 A
  - Results:
    - New line identifications for Fe VIII and IX
    - Important for diagnostics of the solar corona



After including data in CHIANTI (IV)

Example: X-ray spectrum completeness

- Comparison of CHIANTI V.4 with solar flare spectrum
  - Instrument: SMM/FCS
  - Wavelength range: 7-20 A
  - Results:
    - Excellent agreement (within 30%) above 12 A
    - Incomplete data for Fe XVII-XXIII below 12 A
    - New calculations performed by CHIANTI team


SMM/FCS August 25, 1980 flare spectrum
CHIANTI 5 synthetic spectrum
CHIANTI 4.2 synthetic spectrum
Flux
Wavelength (A)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
11.0
11.5
12.0
12.5

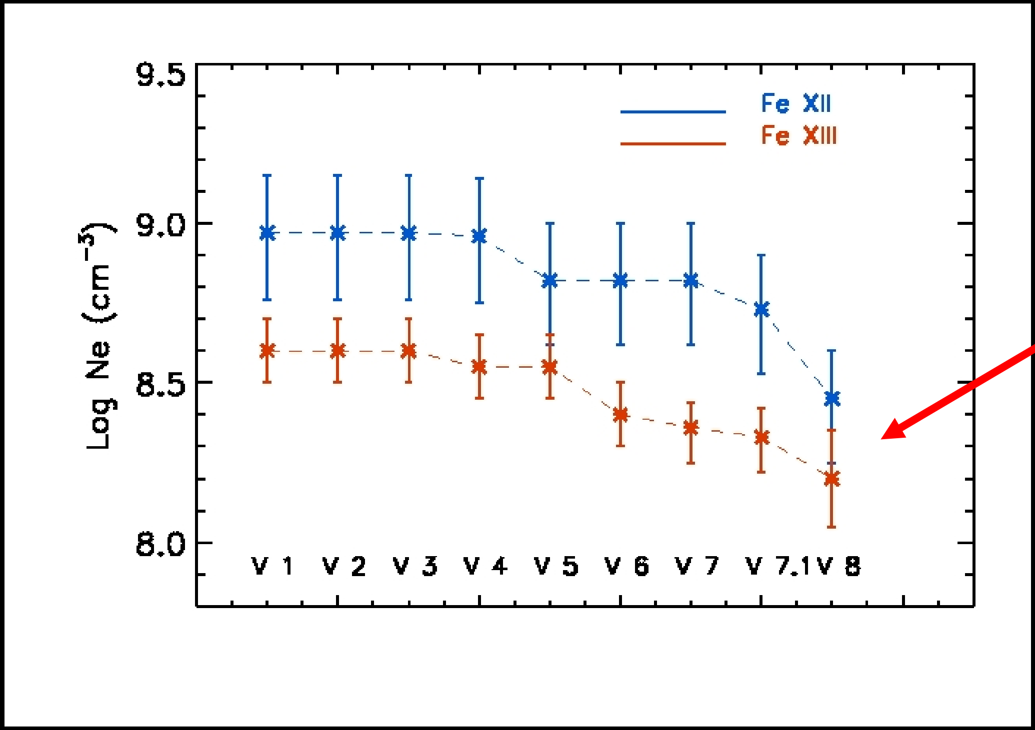
After including data in CHIANTI (V)

Example: Density diagnostics with Fe XII and XIII

Fe XII and XIII lines:

- Amongst the brightest in the solar coronal spectrum
- Best density-sensitive intensity ratios
- Long-standing discrepancy

New calculations performed by the CHIANTI team

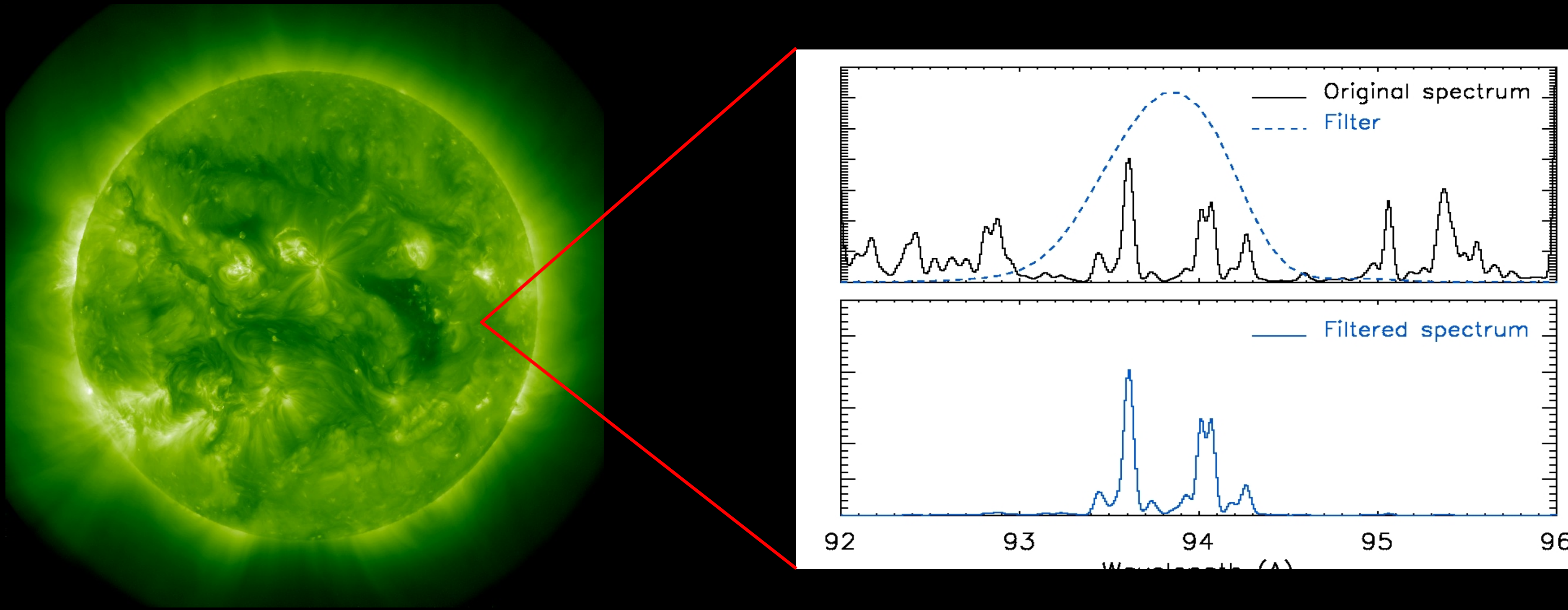


Agreement, at last!!

After including data in CHIANTI (VI)

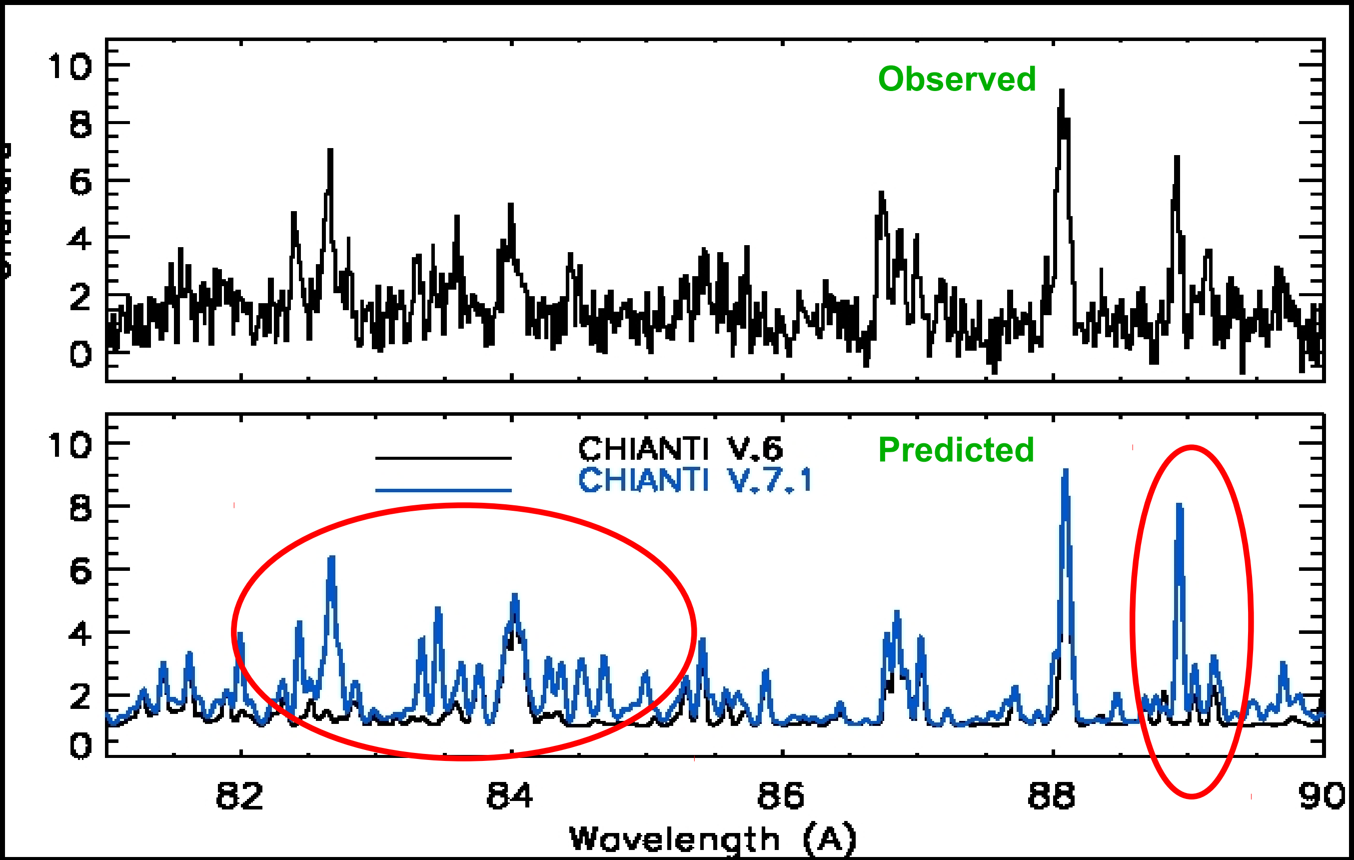
Example: 20-170 A wavelength range

- This range includes two channels of SDO/AIA
- These two channels are key to understand solar coronal heating
- Available CHIANTI V.6 were incomplete



After including data in CHIANTI (VII)

- Solution:
    - New CHIANTI calculations
    - Comparison with Chandra spectrum



Overall assessment

Overall CHIANTI assessment after 17 years:

- Overall excellent agreement
- A few areas where problems were present
    - Missing data
    - Incorrect or missing line identifications
    - Low quality data

Comparison with observations has led to

- A very complete and accurate database

- Close interaction with atomic physics community
    - New data calculations

The CHIANTI project has resulted in *great advances for the field of atomic astrophysics*

Future work

CHIANTI is still in need of a lot of work

Adding new data

- Improve the soft X-ray range
- Improve identification in the UV range
- Include data from lab measurements
- Extend to low ionization species

Change of CHIANTI format

- Improve accuracy of collision data stored in the data base
- Increase number of levels n CHIANTI ions to more than 1000

Backup slides

Background (IV)

Line intensity calculation:

They mostly relied on the "Coronal Model Approximation":

- Electron collision excitation from ground level only
- Radiative de-excitation

Some of them used Gaunt factors rather than original calculations of electron-ion collision strengths

- Database was smaller
- Computation time was faster

Comparison of data with observations was limited