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Atomic data for NLTE model atmospheres - The case of white dwarf stars

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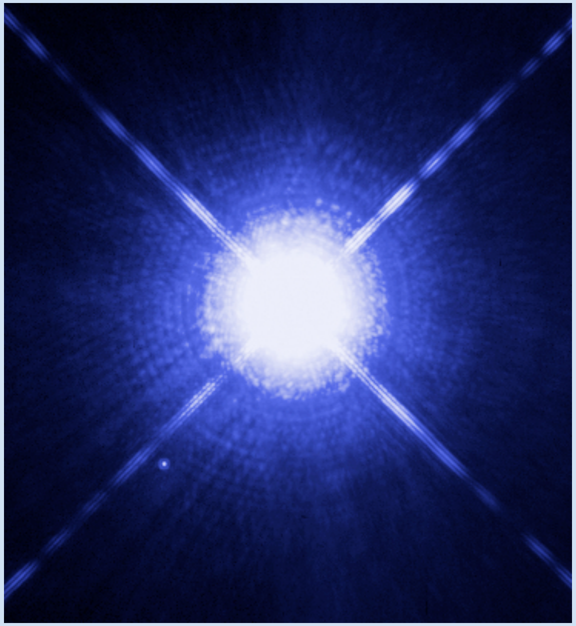
Introduction

- White dwarf stars?
- NLTE in stellar atmospheres
- Lyman/Balmer line problem
- Atomic data
- Model calculations
- Results
- Future Work



What is a white dwarf?

- Hot, dense star that has ceased nuclear fusion, T_{eff}~5,000-200,000+K
- Penultimate stage of it's life.
- Typical mass ~$0.5M_{\odot}$, radii ~$1R_E$.
- Very high surface brightness.
- Very large surface gravity, log *g*~7.5
- Densities > 10^{11}kg/m^3

What is a white dwarf?

- White dwarfs may be bright, but because of their compact size, they are very faint!
- Some white dwarfs have apparent magnitudes of +21!

What is a white dwarf?

- High UV flux, low density atmosphere, means radiative transitions dominate -> NLTE effects present.
- Such effects consist of non-Maxwellian velocity distributions, inequality of emission/absorption rates etc.
- T_{eff} and log *g* determined in NLTE differs from values determined in LTE.

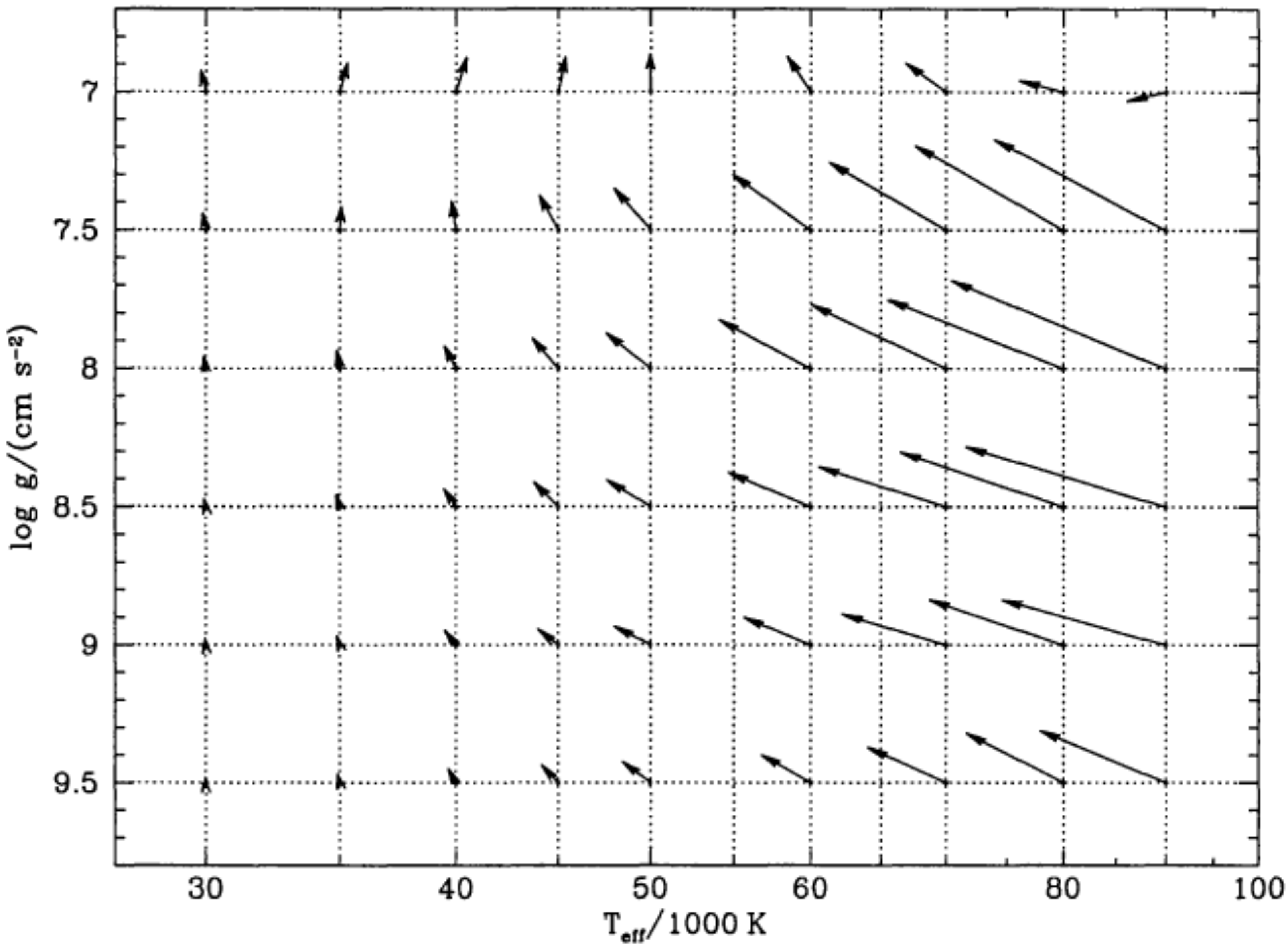
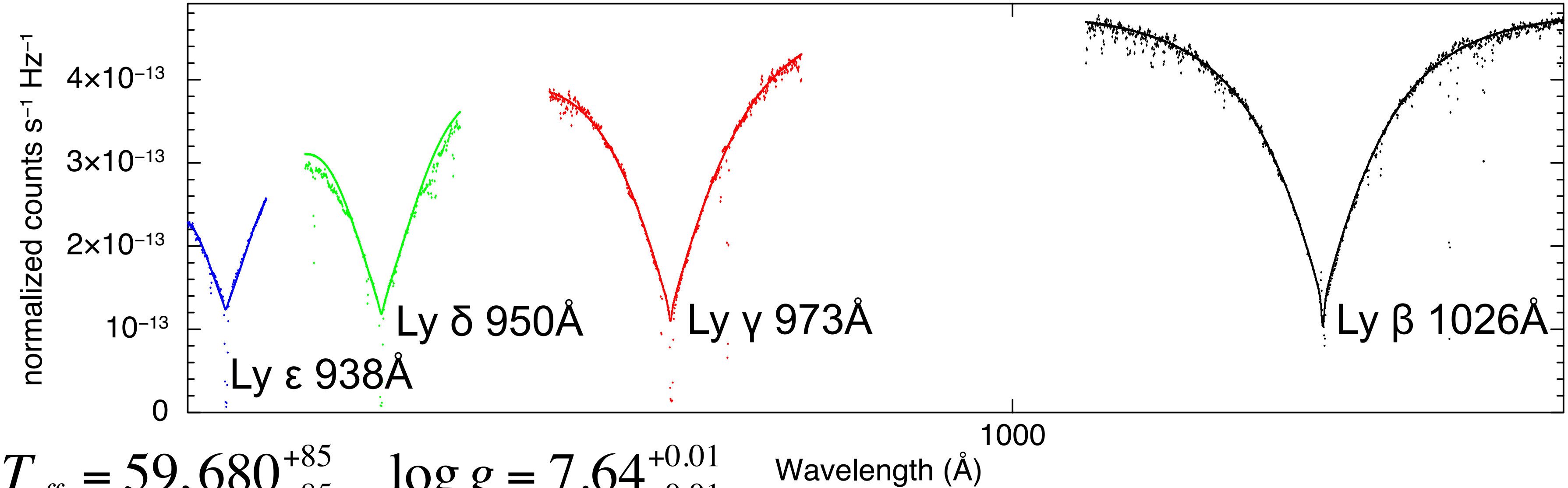
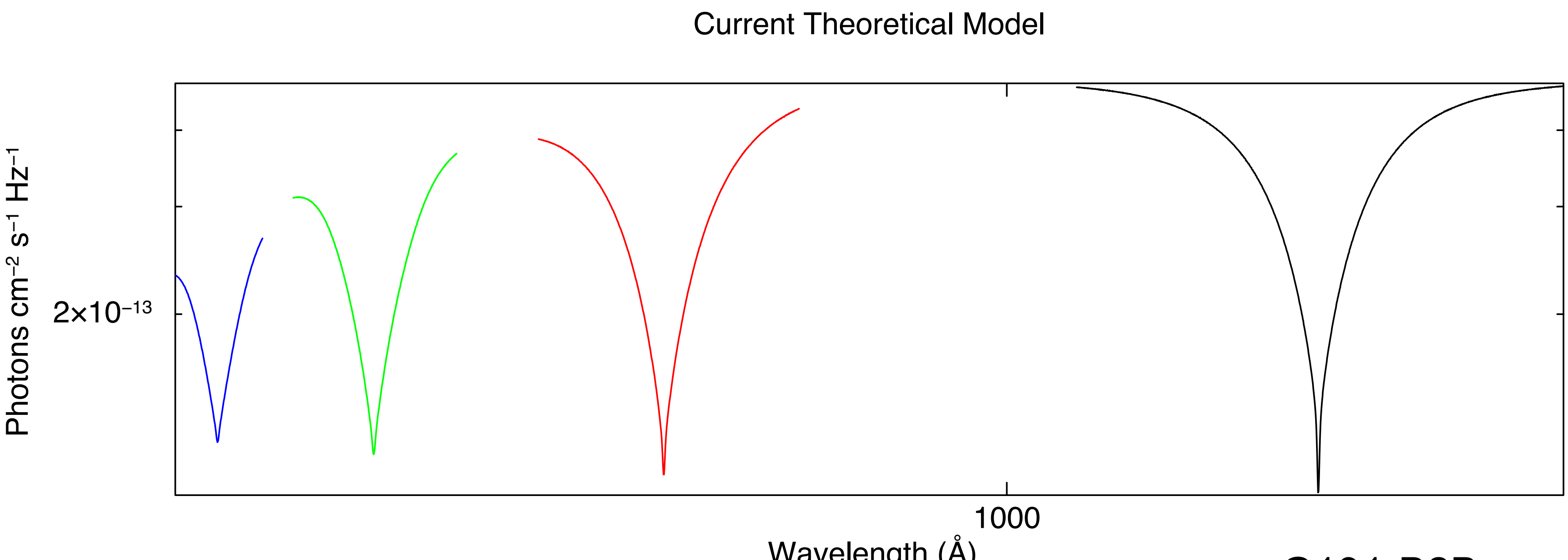


Figure 1. LTE offsets. The differences are magnified three times. The vectors give the correction, which must be applied to transform LTE results to the NLTE scale.

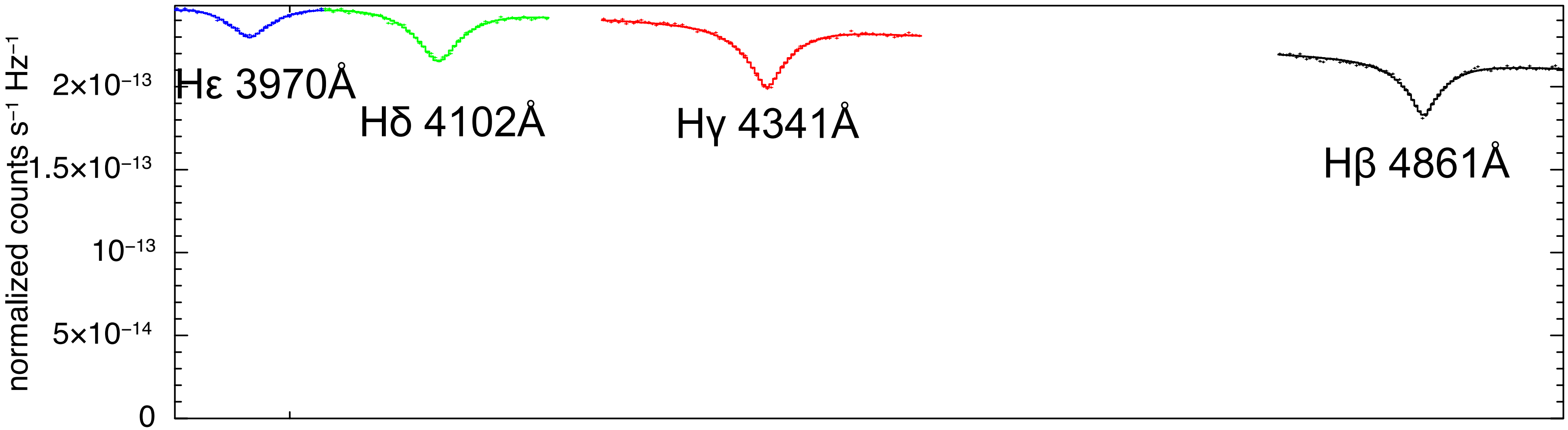
Napiwotzski et al. 1999



$$T_{eff} = 59{,}680^{+85}_{-85} \qquad \log g = 7.64^{+0.01}_{-0.01}$$



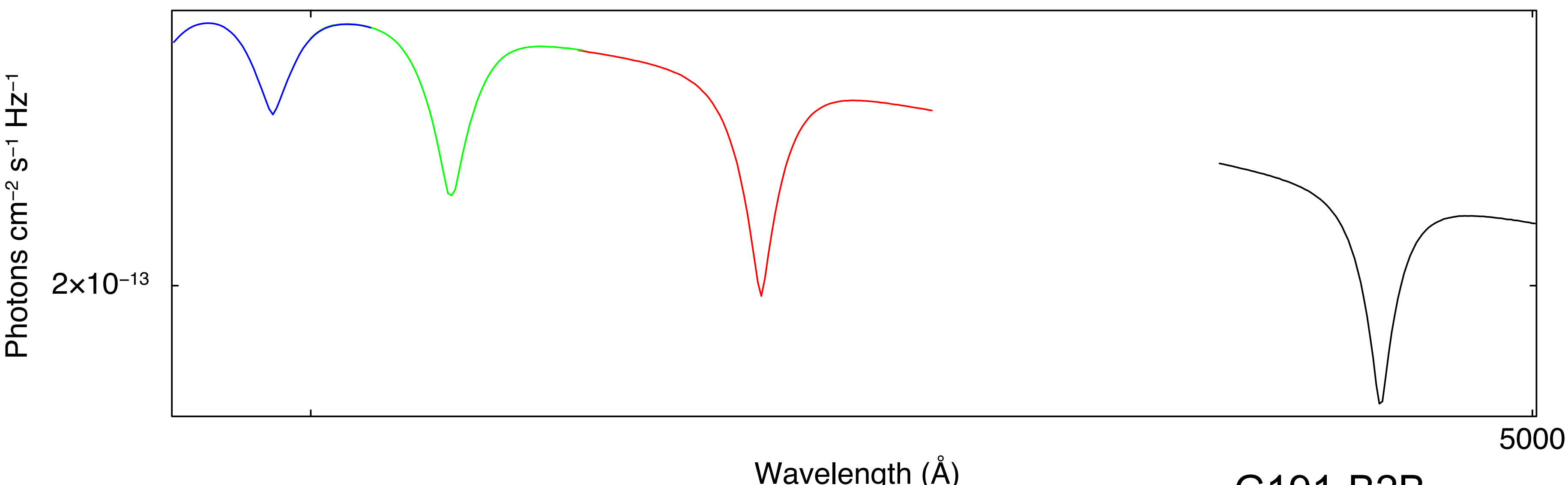
G191-B2B



$T_{eff} = 59{,}517^{+338}_{-336}$ $\log g = 7.59^{+0.02}_{-0.02}$

Wavelength (Å)

Current Theoretical Model



G191-B2B

The Lyman/Balmer Line Problem

- Identified by Barstow et al. (2003a).
- In hot DA white dwarfs (T>50,000K), T_{eff} measured with Lyman lines does not match T_{eff} measured with Balmer Lines.
- Discrepancies >10,000K have been observed.

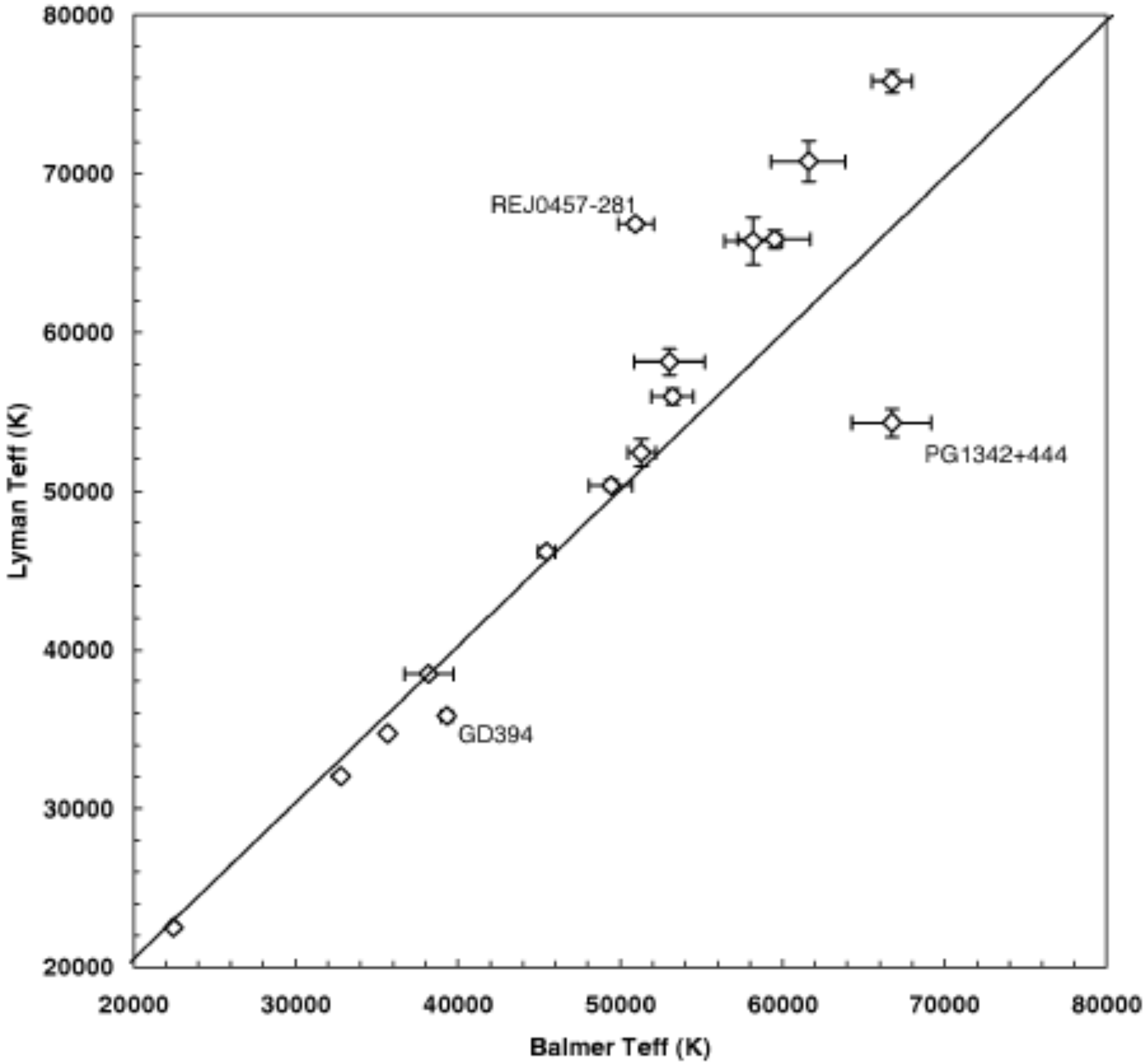


Figure 9. Scatter plot of the simple mean values of $T_{\rm eff}$ measured using the ground-based Balmer and *FUSE* Lyman lines. The error bars are calculated from the variance of the values in multiple observations or are the statistical 1σ error for single observations. The solid line corresponds to equal Balmer and Lyman line temperatures.

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Suggested contributions

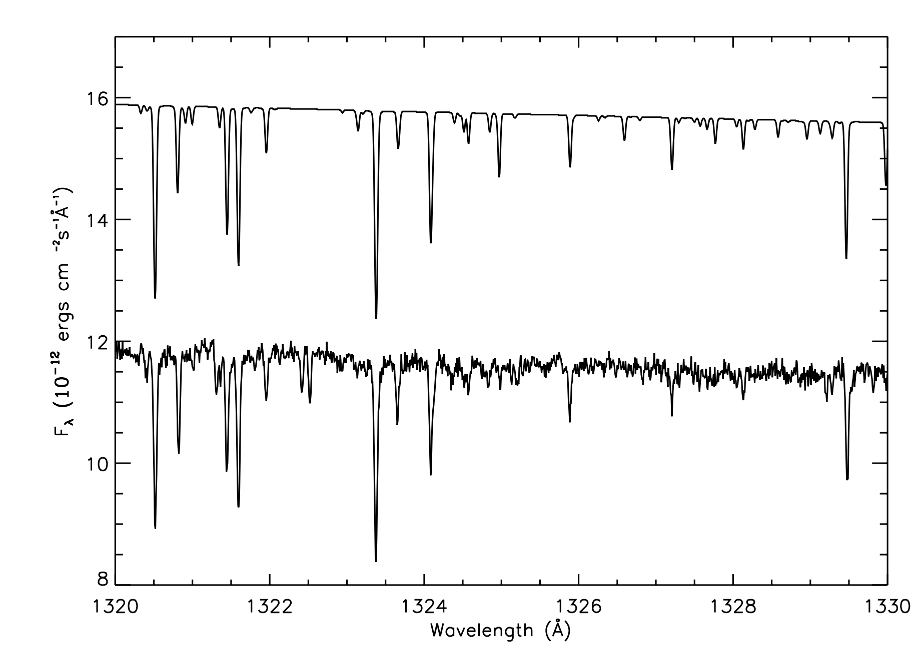
- Stark Broadening tables.
- Atmospheric composition.
- Line Blanketing/Heavy metal opacity - Atomic data used in model atmosphere calculations.
- Interstellar reddening.
- Investigate the first three today.

Hydrogen Stark Broadening Tables

- Two major tables, Lemke (1997), and Tremblay (2009) adapted for TLUSTY by Gianninas (2011).
- Lemke uses VCS theory of Vidal et al. (1973) up to n=22.
- Tremblay includes non-ideal effects, also based on the VCS theory.

Atmospheric compositions

- Pure Hydrogen.
- G191-B2B composition.



Preval et al. 2013	
Metal	Abundance X/H
He	1.00×10^{-5}
C	1.72×10^{-7}
N	2.16×10^{-7}
O	4.12×10^{-7}
Al	1.60×10^{-7}
Si	3.68×10^{-7}
P	1.64×10^{-8}
S	1.71×10^{-7}
Fe	1.83×10^{-6}
Ni	1.01×10^{-6}

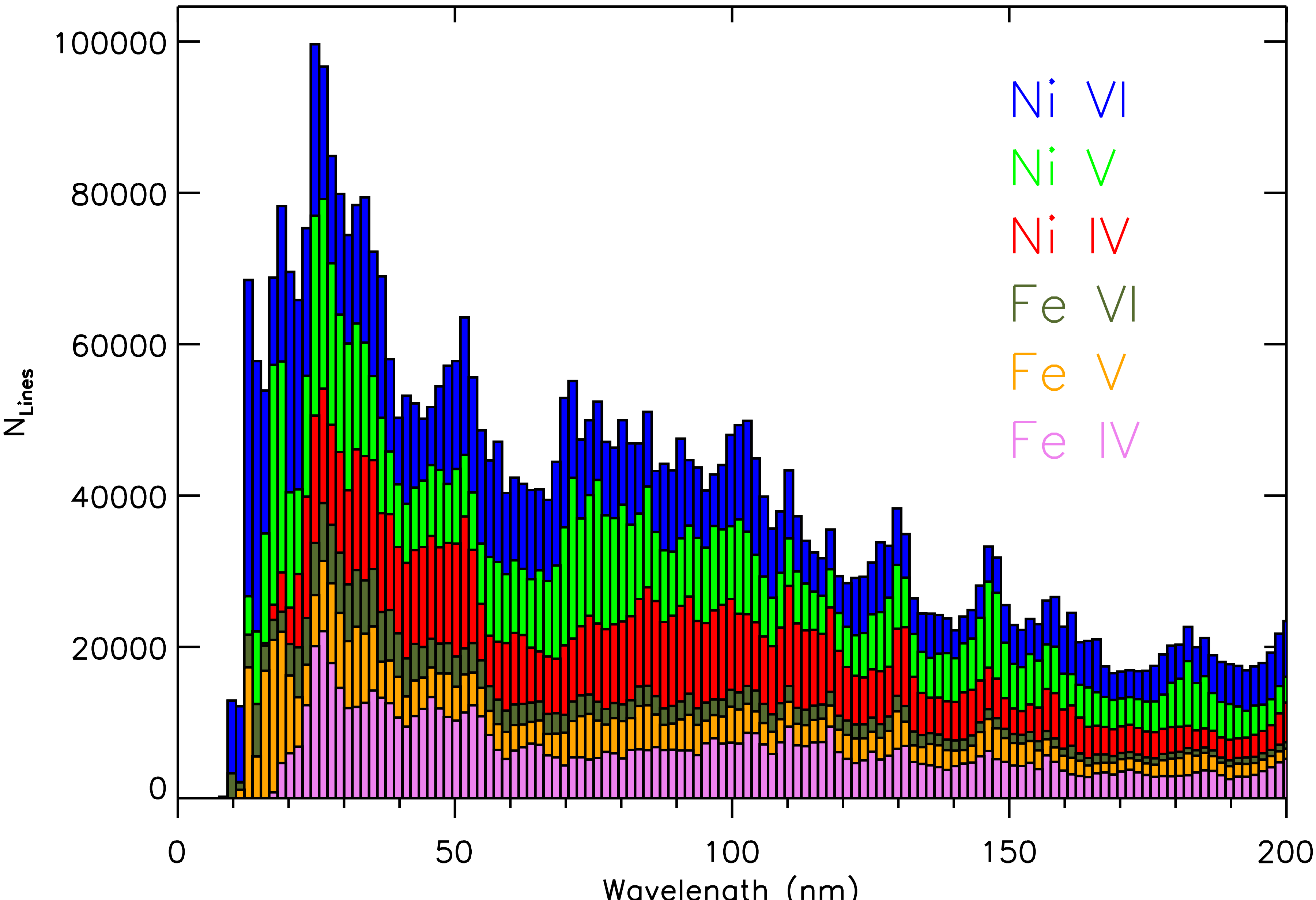
Kurucz data used in TLUSTY – 1991

Opacity Project PI: Fe IV, Fe V, Fe VI

Hydrogenic PI: Ni IV, Ni V, Ni VI

Ion	Energy Levels	Transitions
Fe IV	13,705	1,776,984
Fe V	11,986	1,008,385
Fe VI	4,750	475,750
Ni IV	13,172	1,918,070
Ni V	13,184	1,971,819
Ni VI	13,705	2,259,798
Total	70,502	9,410,806

Data storage ~ 500MB



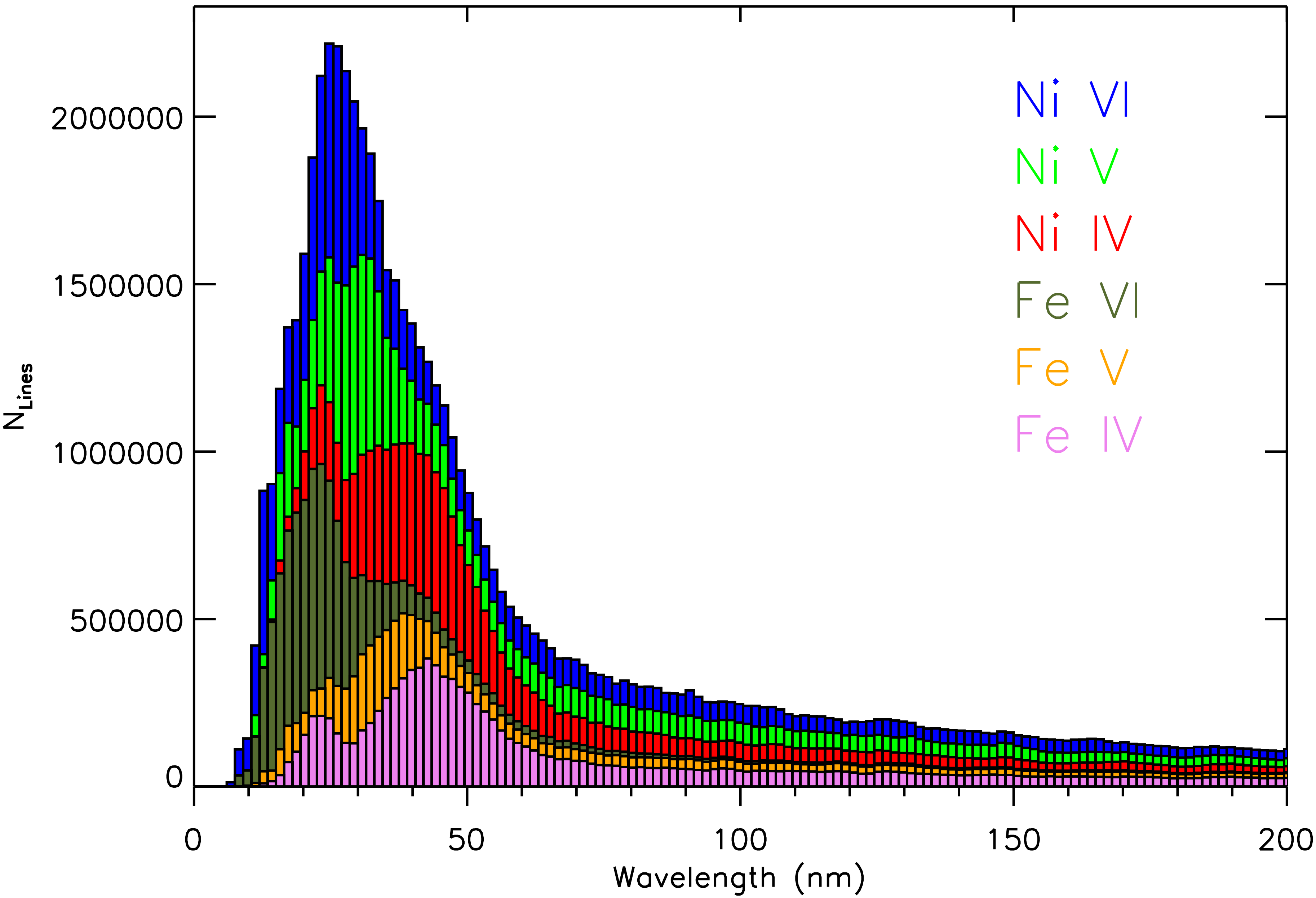
Ni VI
Ni V
Ni IV
Fe VI
Fe V
Fe IV
N_{Lines}
100000
80000
60000
40000
20000
0
0
50
100
150
200
Wavelength (nm)

Kurucz data – 2011

Ion	Energy Levels	Transitions
Fe IV	27,978	25,312,781
Fe V	14,086	11,674,853
Fe VI	22,257	13,731,648
Ni IV	37,860	32,416,571
Ni V	37,446	34,066,259
Ni VI	29,366	42,412,822
Total	168,993	159,614,934

Autostructure
PI

Data storage ~ 20GB



Ni VI
Ni V
Ni IV
Fe VI
Fe V
Fe IV
N_{Lines}
2000000
1500000
1000000
500000
0
0
50
100
150
200
Wavelength (nm)

Atomic data calculations

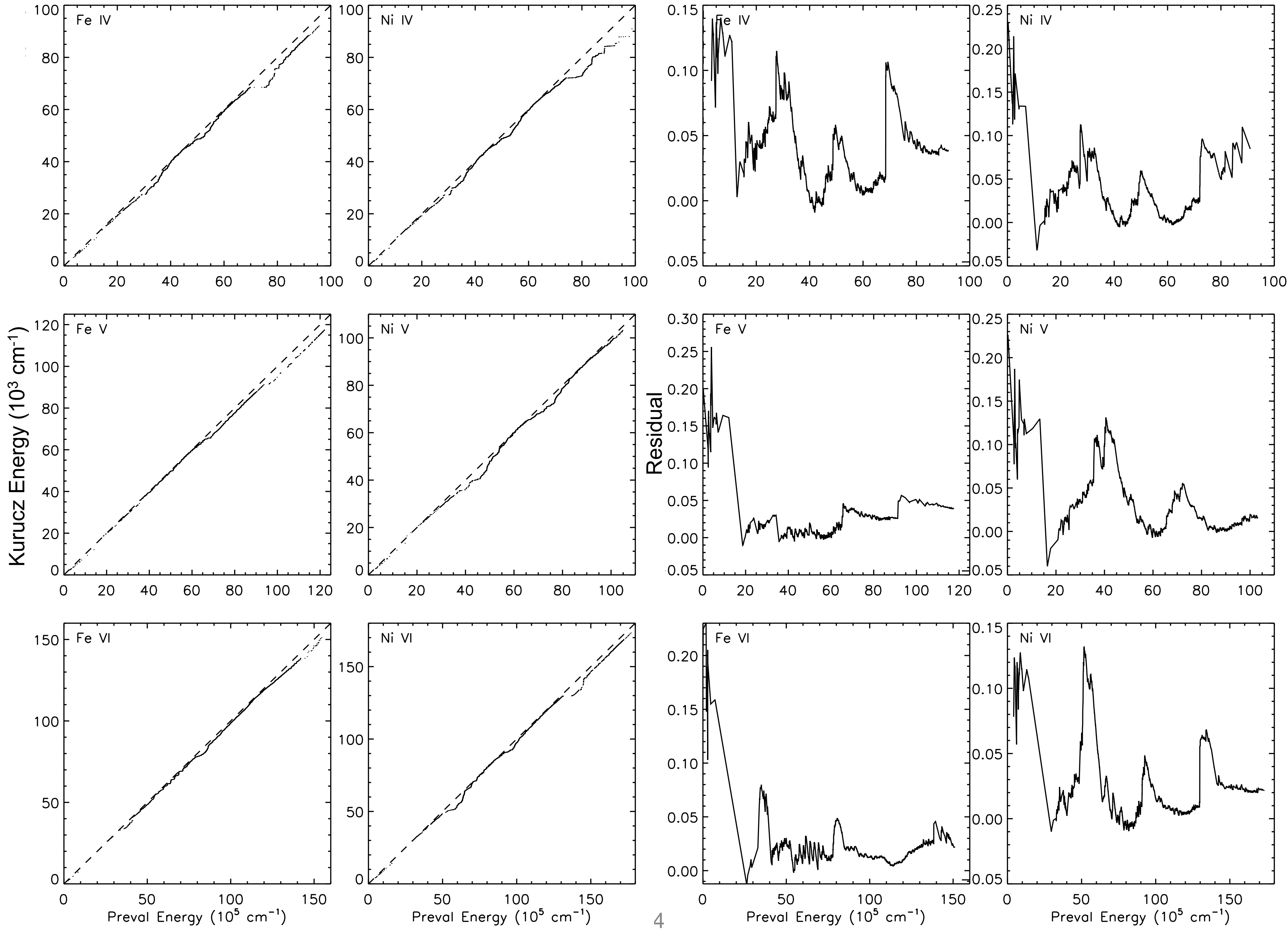
- Kurucz 2011 data extensive, but is not accompanied by photoionisation data.
- Calculate this data ourselves with AUTOSTRUCTURE.
- Use same configurations as Kurucz, assuming IC. Include 16 scaling parameters in TFDA potential to match Kurucz data.

Atomic data calculations

- Basis states covered ground states, plus all excitations of s, p, d, and f shells up to at least n=12.
- PI target states consider outer shell only (no inner shell electron liberation).
- Calculate total PI cross sections neglecting resonances. (Direct PI only)

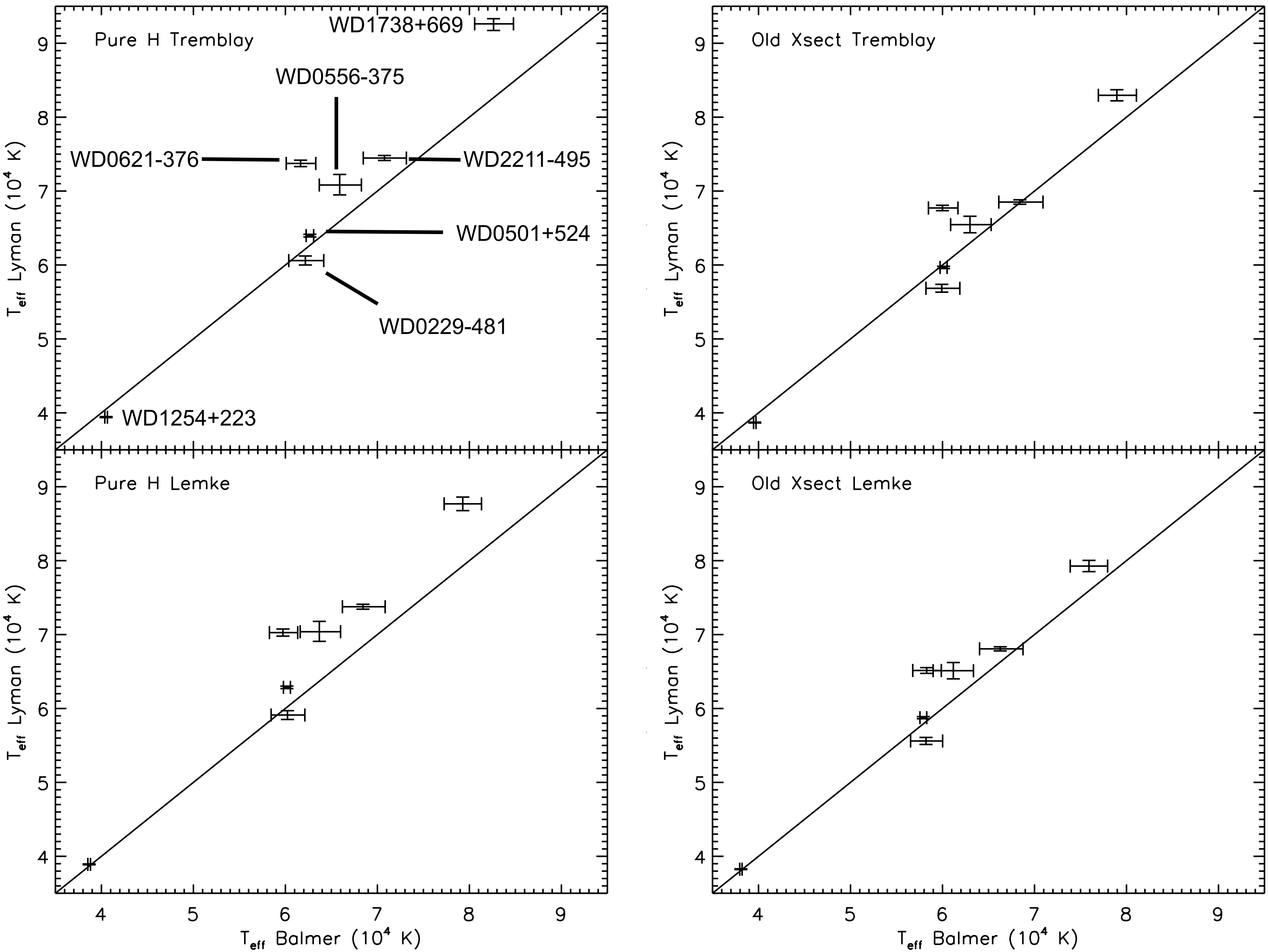
Atomic data calculations

Ion	Configurations	PI Configurations
Fe IV	115	4
Fe V	122	5
Fe VI	146	5
Ni IV	85	5
Ni V	87	5
Ni VI	121	5
Total	676	29


Fe IV
Ni IV
Fe V
Ni V
Fe VI
Ni VI
Kurucz Energy (10^3 cm^{-1})
Residual
Preval Energy (10^5 cm^{-1})

Model grid parameters

- Metallicity: 0 (Pure H), 1.0 relative to G191-B2B.
- T_{eff} 35,000-100,000K
- Log g 6.5 – 9.5 dex
- Stark Broadening: Lemke and Tremblay
- Cross sections: Opacity Project/ Hydrogenic, and Autostructure.



Pure H Tremblay
WD1738+669
WD0556-375
WD0621-376
WD2211-495
WD0501+524
WD0229-481
WD1254+223
Old Xsect Tremblay
Pure H Lemke
Old Xsect Lemke
T_eff Lyman (10^4 K)
T_eff Balmer (10^4 K)

Results

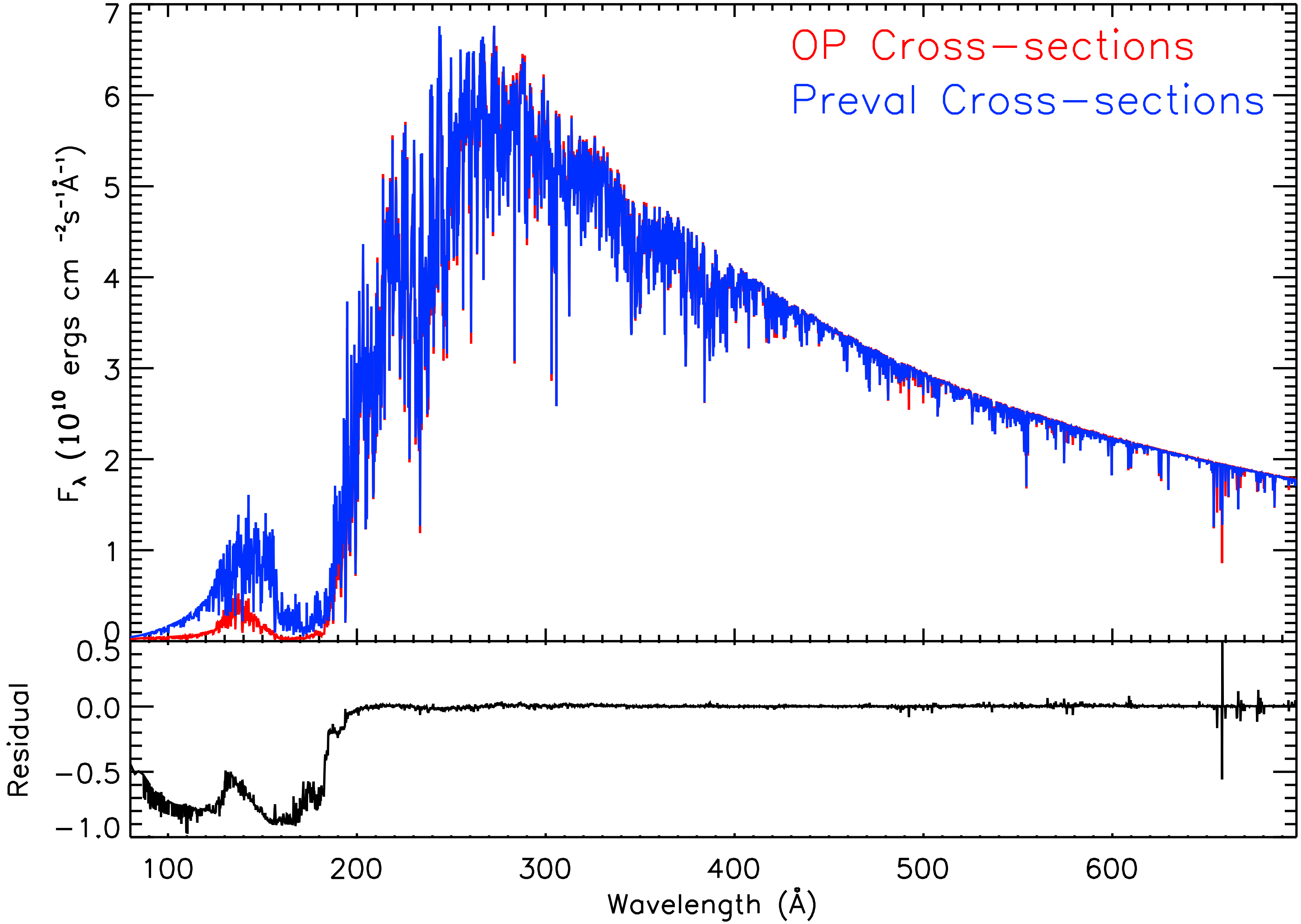
- Tremblay tables improve agreement between Lyman/Balmer T_{eff}.
- Dominant factor improving agreement is detailed abundances.
- Use of new cross sections vs old cross sections inconsequential.

Future work

- Include more stars in Lyman/Balmer line sample, including Pure H stars.
- Extend model grids to account for variable metallicities. Currently calculated Z=0.001, 0.01, 0.1, 0.2, and 1.0. Next is 0.5, 2.0, 5.0, 10.0, and 100.0.

Conclusion

- Lyman/Balmer line problem may be solved with detailed abundance analysis, coupled with more detailed stark broadening calculations.
- The cross sections used/number of included transitions in the model atmosphere appears inconsequential.


OP Cross-sections
Preval Cross-sections
F_λ (10^{10} ergs cm^{-2}s^{-1}Å^{-1})
Residual
Wavelength (Å)
0
1
2
3
4
5
6
7
0.5
0.0
−0.5
−1.0
100
200
300
400
500
600