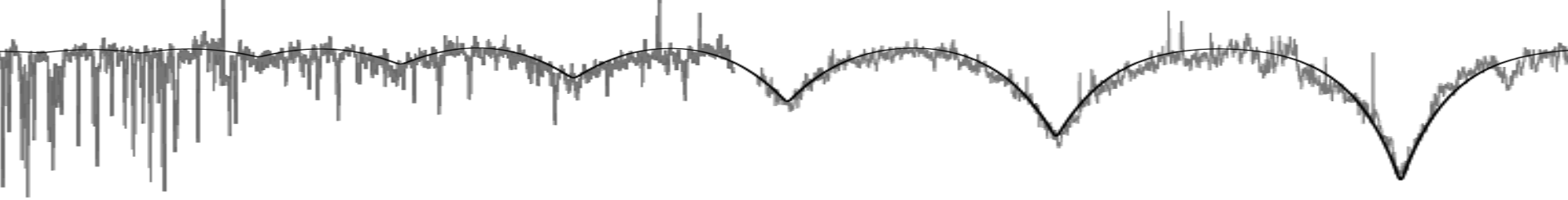


Quantitative Spectroscopy of Early-type Dwarfs and Giants

A Comprehensive Test of Common Hydrostatic LTE & non-LTE Model Atmosphere/Line-formation Codes

Norbert Przybilla

Dr. Remeis-Observatory Bamberg

M.F. Nieva & K. Butler

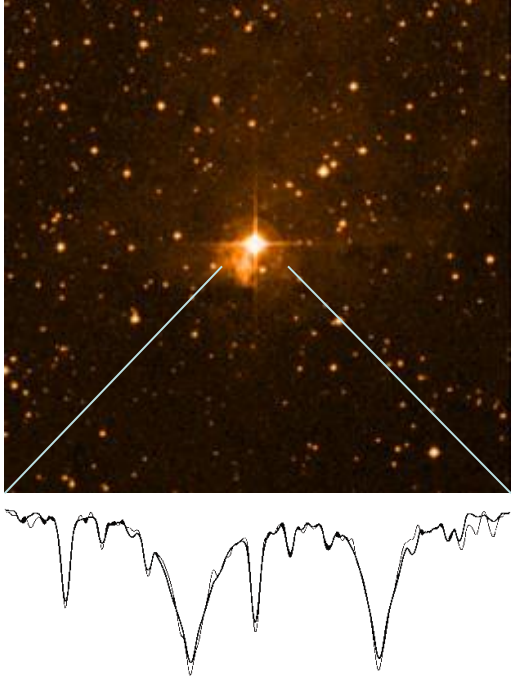
Friedrich-Alexander-Universität Erlangen-Nürnberg

ECAP ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Outline

- Intro
- Codes/Grids
- Goals
- Comparison: Atmospheric Structures, SEDs, Spectra
- Recommendations

Motivation

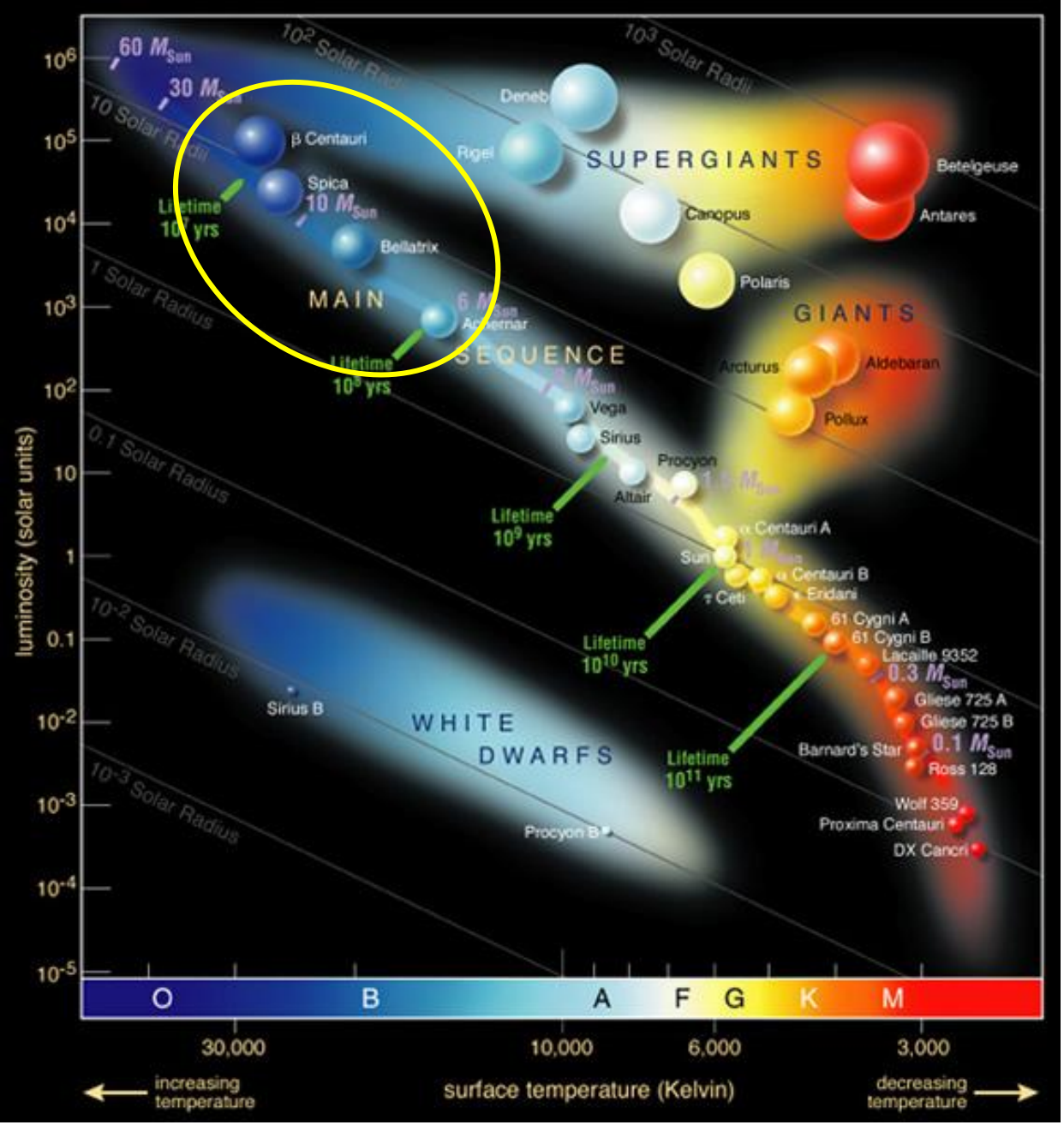


understanding stars from
interpretation of observation

→ photometry, spectroscopy

- fundamental stellar parameter: L, M, R
- atmospheric parameters: T_{eff}, log g, ξ, Y, Z, etc.
- elemental abundances

→ quantitative spectroscopy
via model atmospheres



Early-type Stars

- highly luminous
  - abundance indicators over large distances: Milky Way & beyond

Dwarfs & Giants (O9)-B3

$35000 > T_{eff} > 15000K$

- in contrast to cooler stars:
  - no convection
  - no atomic diffusion
- in contrast to hotter/more luminous stars:
  - negligible winds
  - compact atmospheres

Early-type Dwarfs & Giants

classical atmospheres:

- plane-parallel
- hydrostatic
- homogeneous
- stationary
- radiative equilibrium

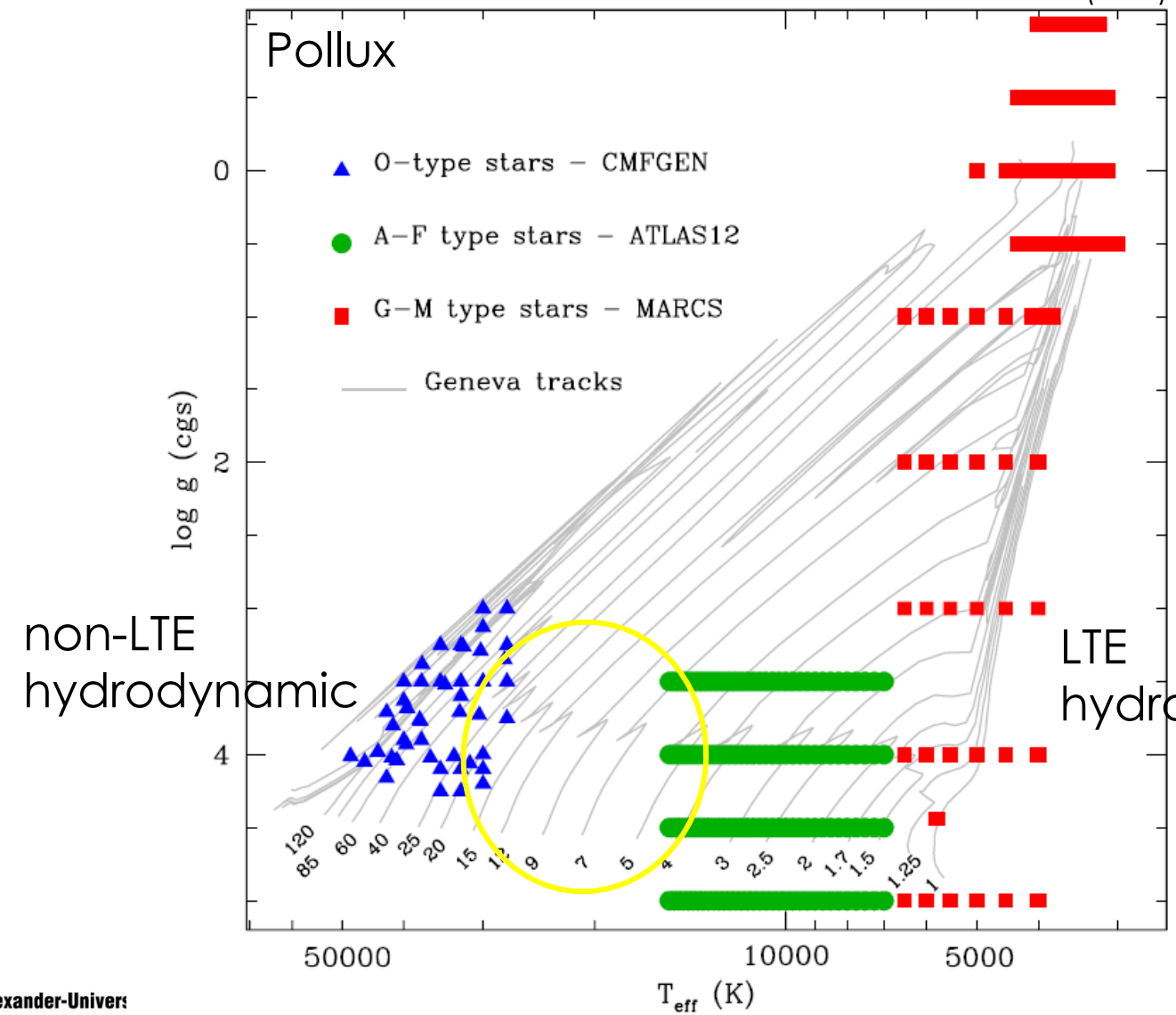
→ τ Sco: Unsöld (1942)

BUT: LTE or non-LTE ?

intense radiation field

Early-type Dwarfs & Giants

Palacios et al. (2010)



non-LTE
hydrodynamic

LTE
hydrostatic

Atmospheric Modelling: Codes

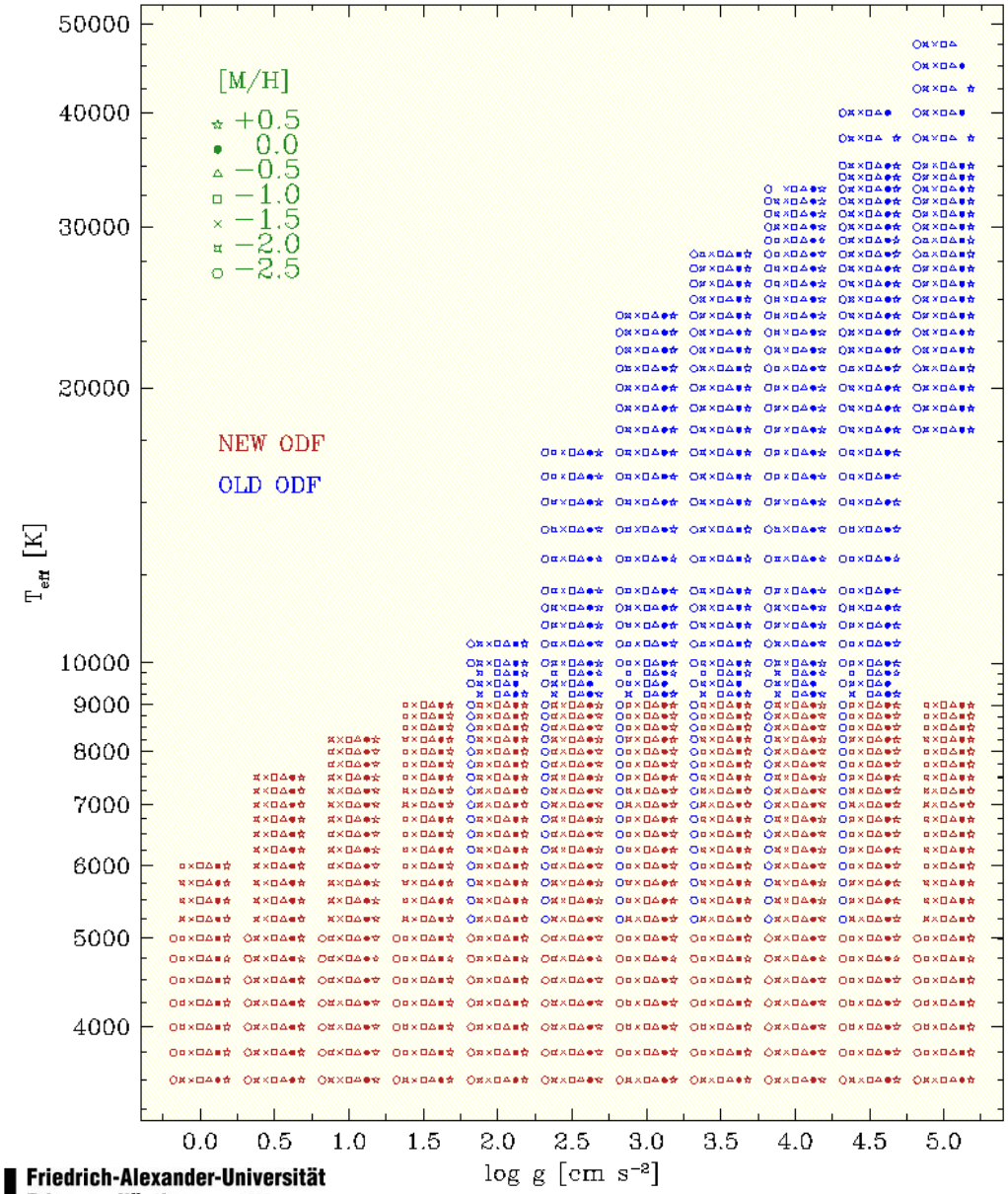
Classical LTE models:	ATLAS9/ATLAS12		ODF/OS
Spectrum Synthesis:	SYNTHE		
Classical non-LTE models:	TLUSTY	ALI/CL	OS
Spectrum Synthesis:	SYNSPEC		

3rd approach:
Non-LTE line-formation on prescribed classical LTE/non-LTE atmospheres

Stat. Eq. & Rad. Transfer:	DETAIL	ALI	ODF/OS
Spectrum Synthesis:	SURFACE		

Hybrid non-LTE: ATLAS+DETAIL+SURFACE → ADS

Model Atmospheres/Synthetic Spectra: Grids



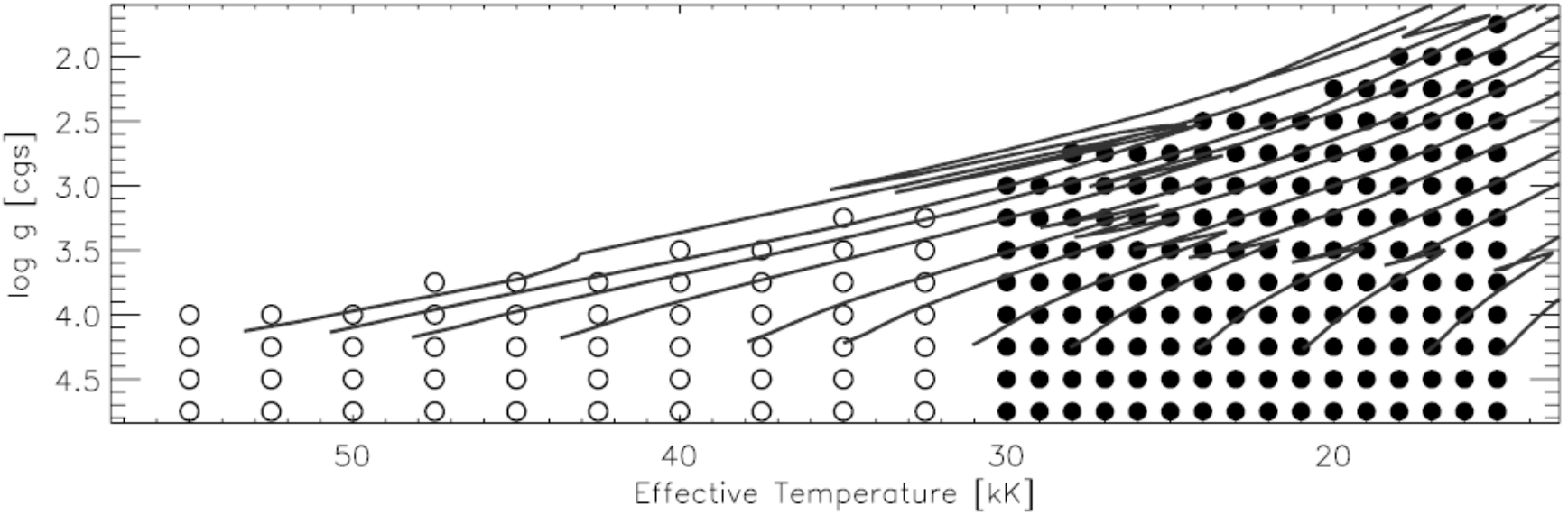
LTE Models:

Castelli:
ATLAS9 model atmospheres
+ fluxes

Munari et al. (2005):
Synthetic spectra (R_{max} = 20000)
using SYNTHE

Model Atmospheres/Synthetic Spectra: Grids

Lanz & Hubeny (2007)



OSTAR2002, BSTAR2006: Lanz & Hubeny (2003, 2007) using TLUSTY

ADS: so far no published grids – ongoing work

Goal

deriving maximum information from observation

at highest accuracy (no systematic errors) &

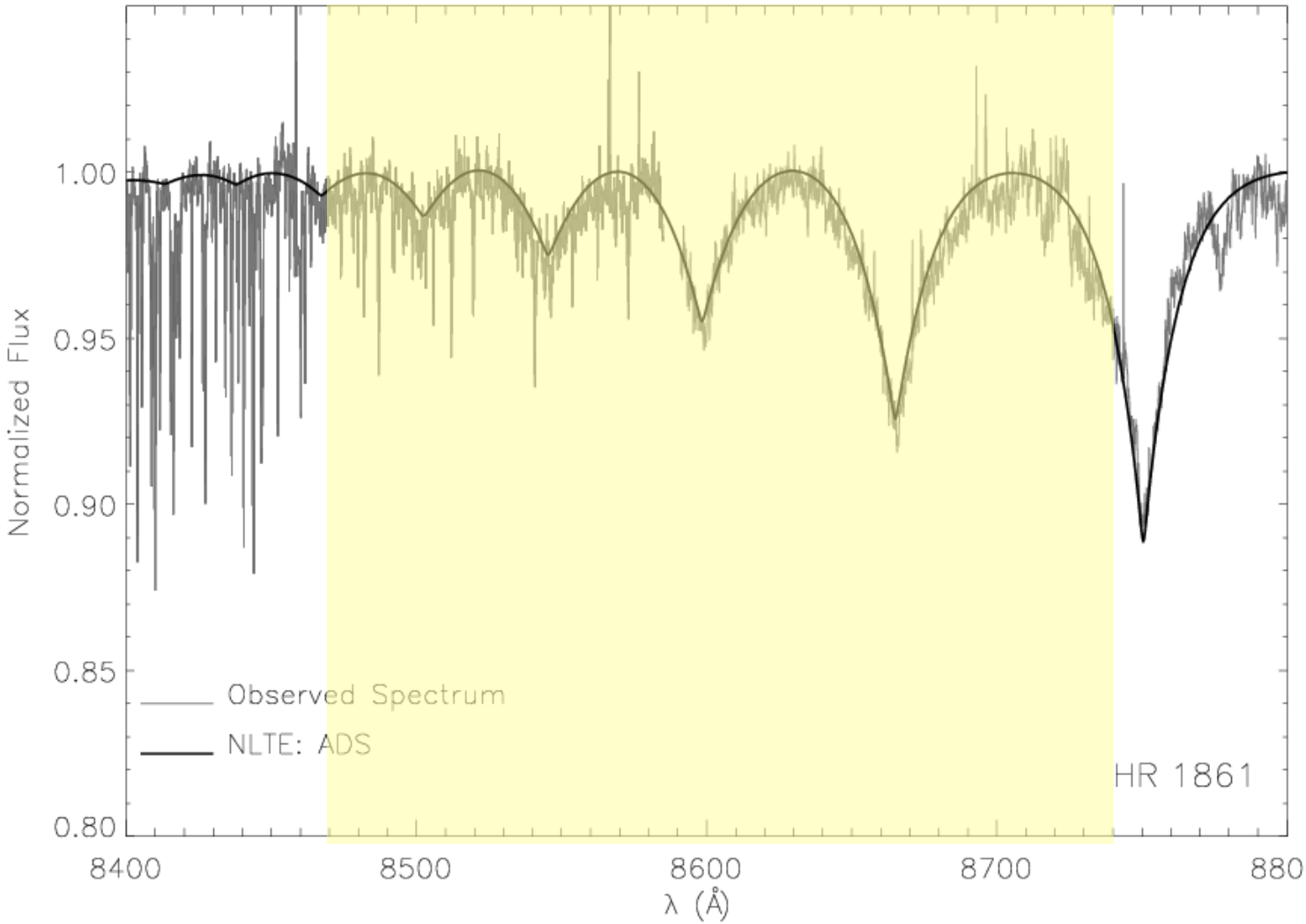
with highest precision (small statistical uncertainty)

meeting all observational constraints

→ model comparison without anchoring to observation of limited usefullness

Early-type Dwarfs & Giants: Gaia RVS

Nieva & Przybilla (2007)

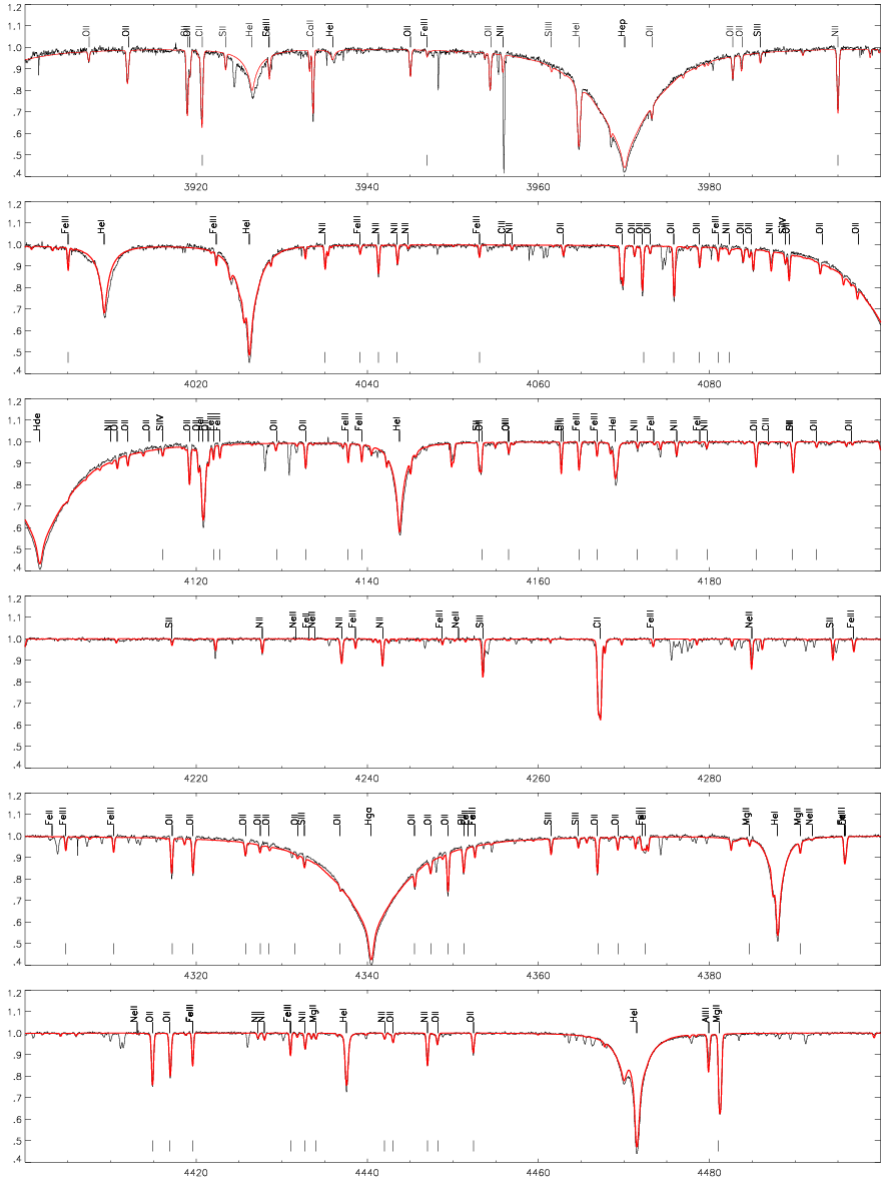


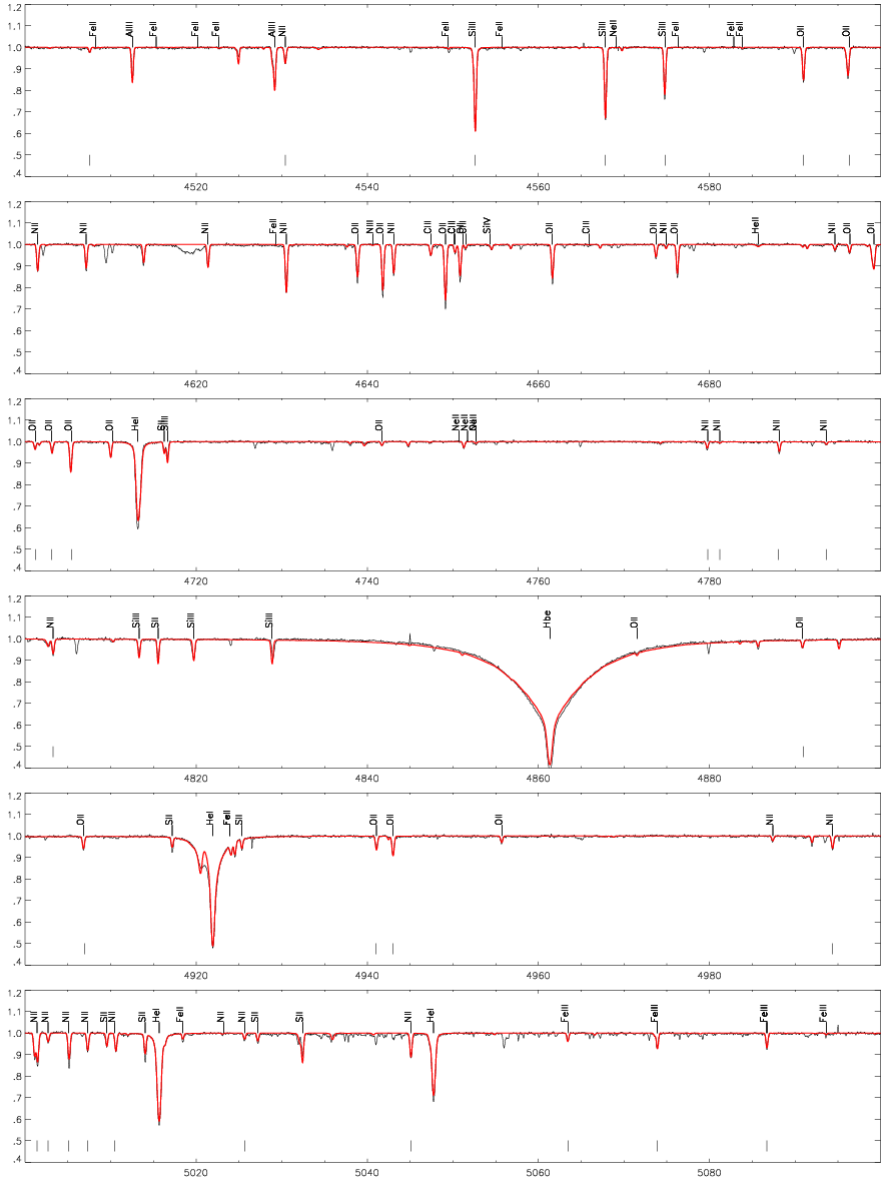
(B1 V)

→ ground-based spectroscopy with wider wavelength coverage

Quantitative Spectroscopy (almost) without Systematics

Nieva & Przybilla (2011)





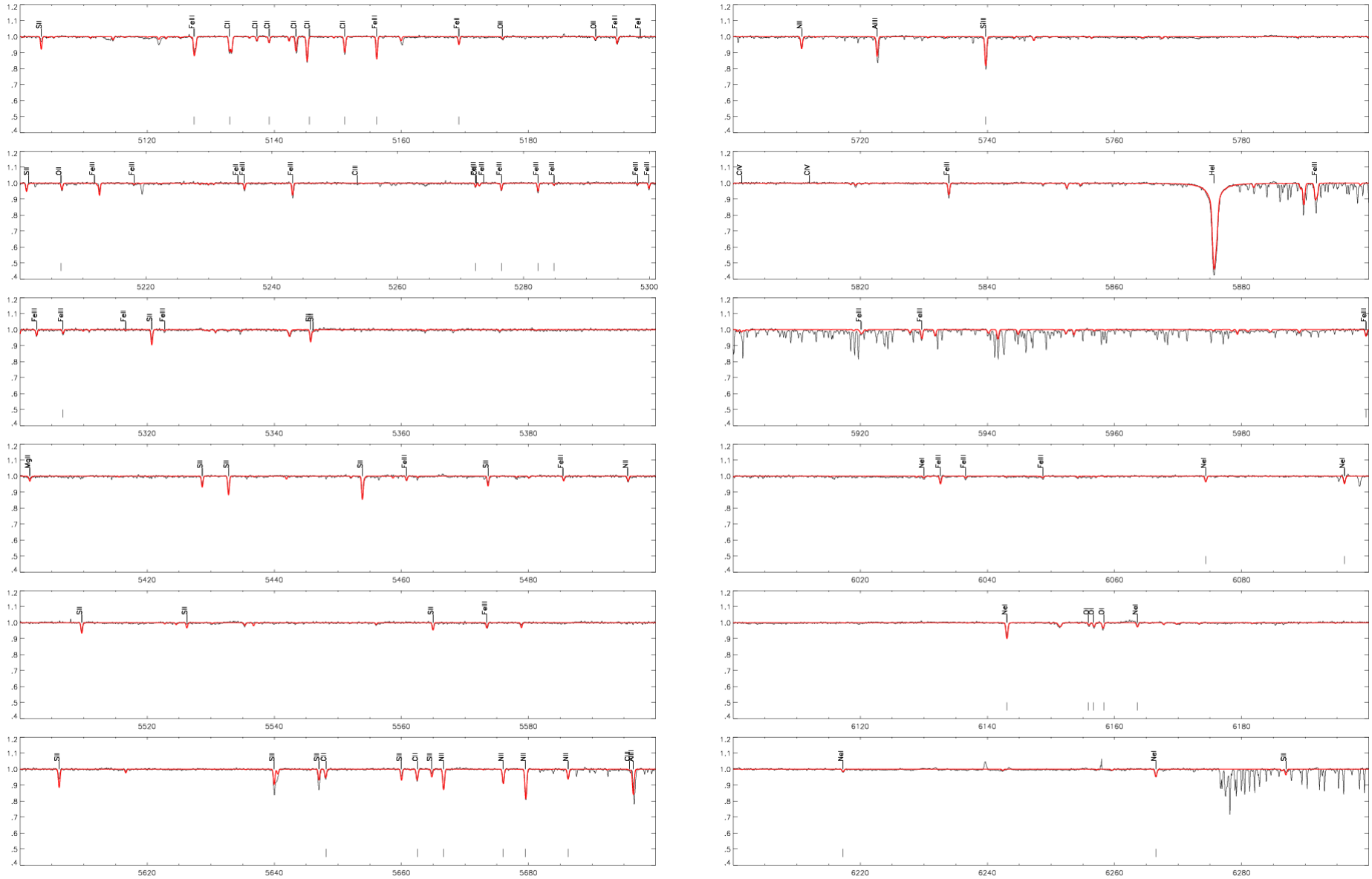
07 HD886

07 HD886

Spectrum: FOCES@2.2m Calar Alto Model: ADS

Quantitative Spectroscopy (almost) without Systematics

Nieva & Przybilla (2011)



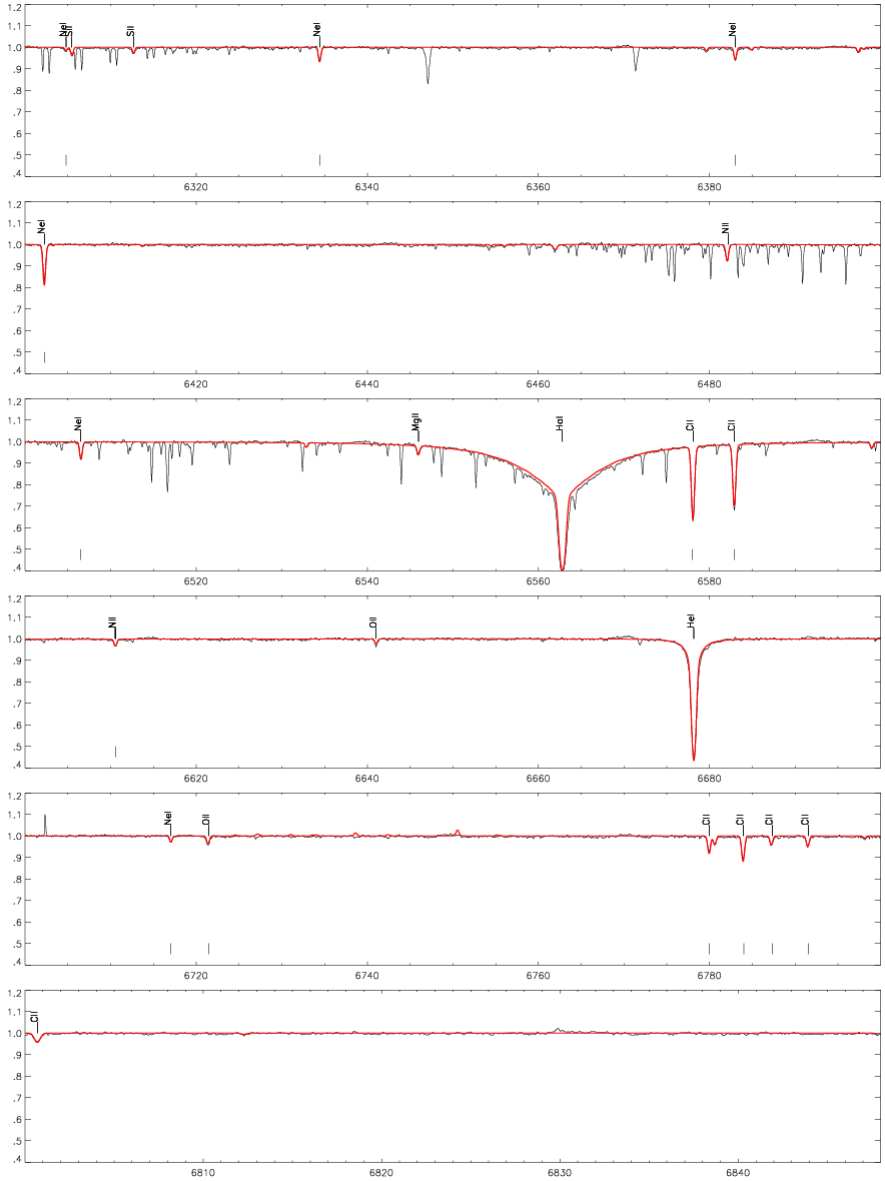
07 HD886

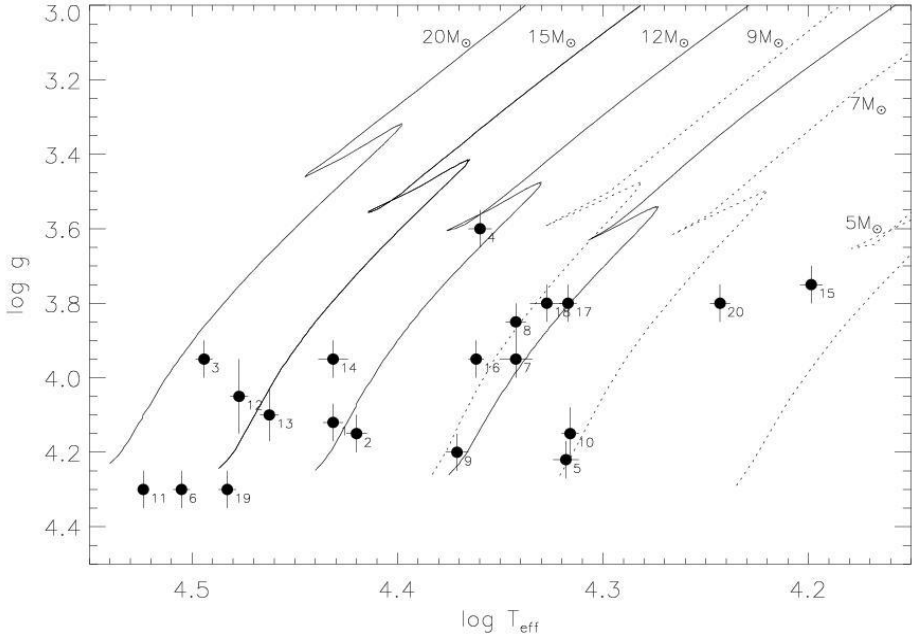
07 HD886

Spectrum: FOCES@2.2m Calar Alto Model: ADS

Quantitative Spectroscopy (almost) without Systematics

Nieva & Przybilla (2011)





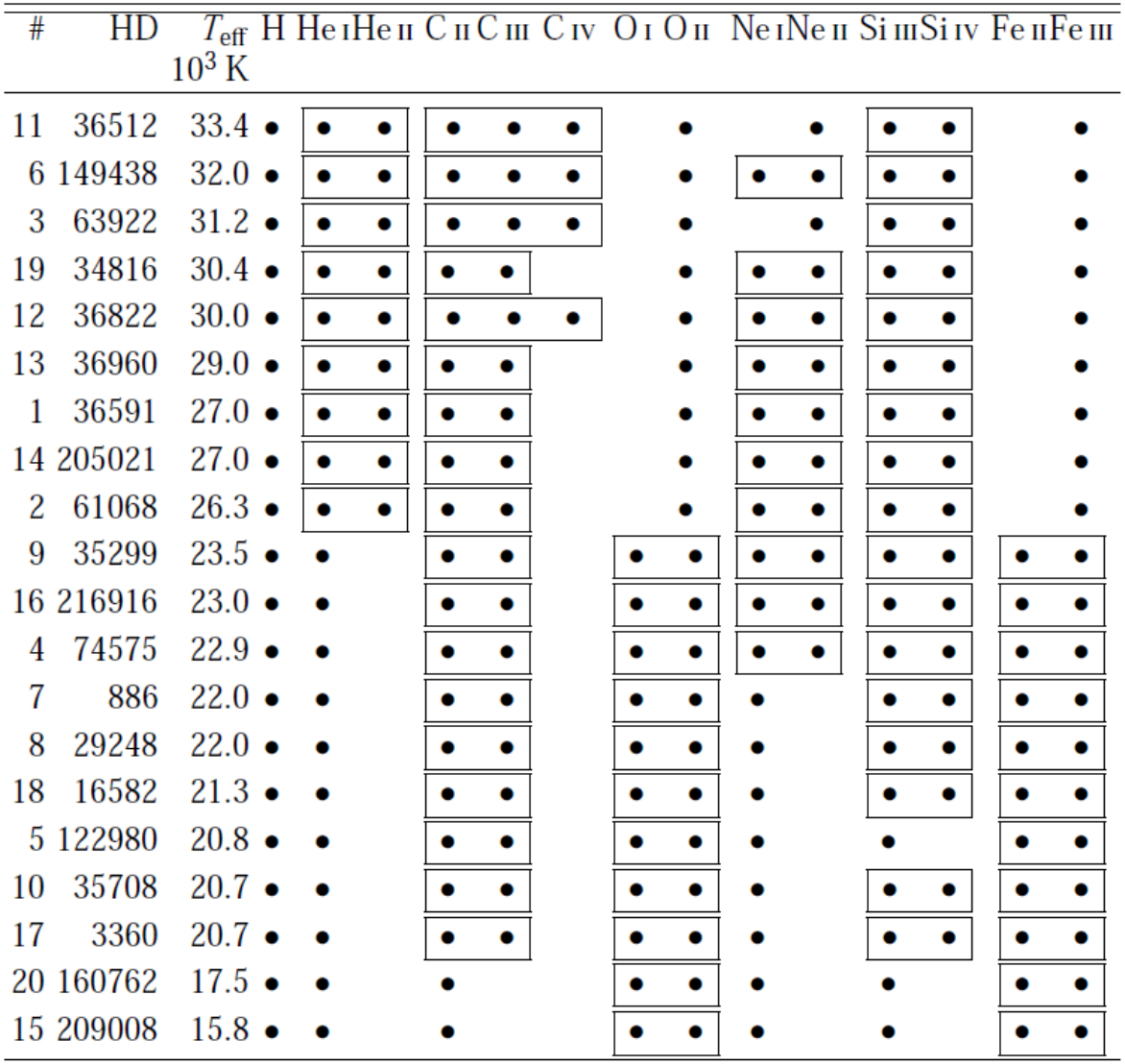
+ Nieva & Simon-Diaz (2011)

~30 slowly rotating stars covering relevant part of HRD: ZAMS to TAMS

- empirical verification of modelling

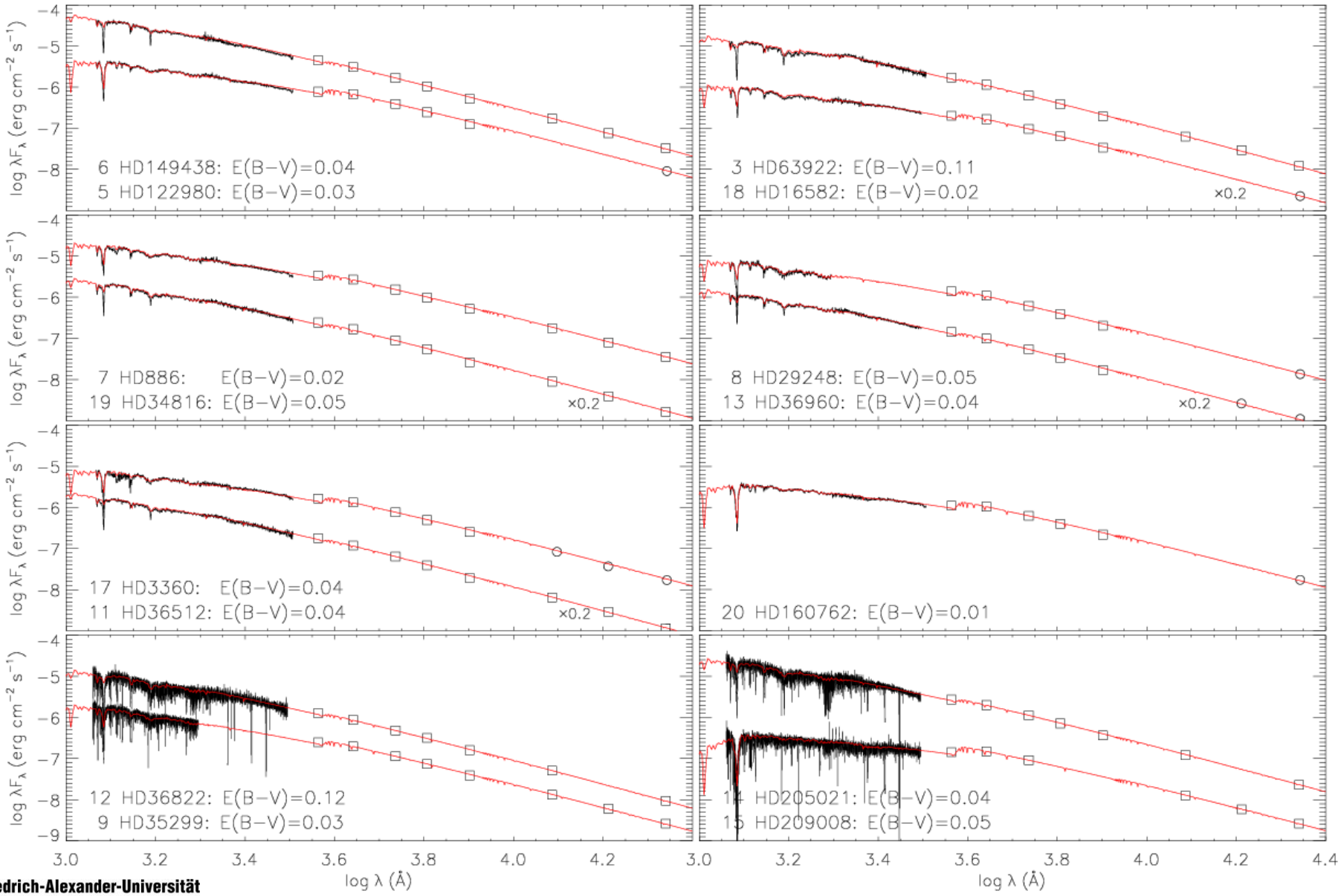
Simultaneous Establishment of Ionization Equilibria

Nieva & Przybilla (2011)



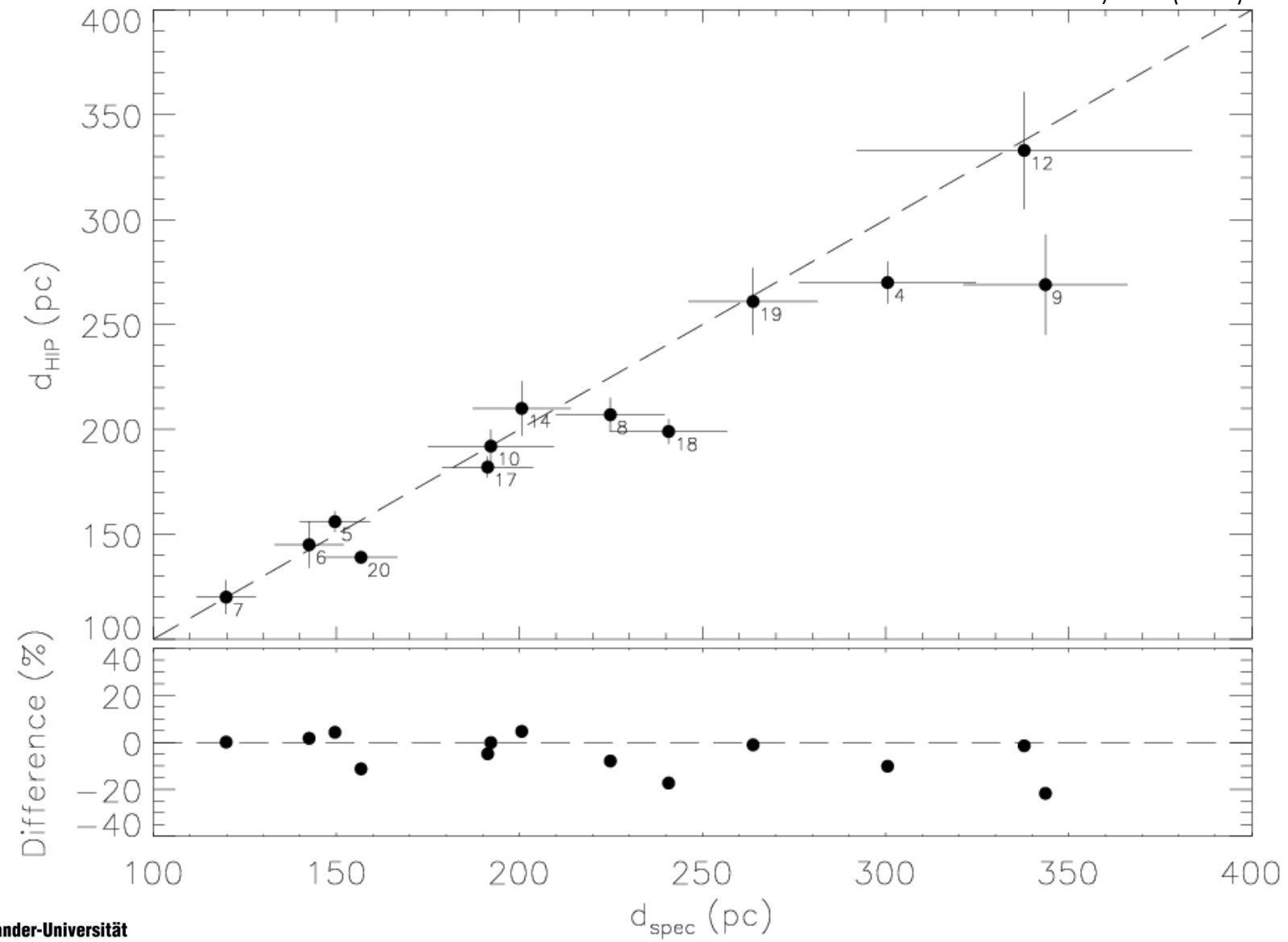
SEDs: IUE + UBVRIJHK Photometry

Nieva & Przybilla (2011)



Spectroscopic vs. Hipparcos Distances

Nieva & Przybilla (2011)



NLTE Diagnostics with ADS

using **robust analysis methodology** &
comprehensive model atoms

minimising systematics !

- ionization equilibria → T_{eff}
  elements: e.g. He I/II, C II/III/IV, O I/II, Ne I/II, Si III/IV, Fe II/III
  $\Delta T_{eff} / T_{eff}$ ~ 1…2% usually: 5…10%
- Stark broadened hydrogen lines → log g
  Δ log g ~ 0.05…0.10 (cgs) usually: 0.2
- microturbulence, helium abundance, metallicity

+ other constraints, where available: SED's, near-IR, …

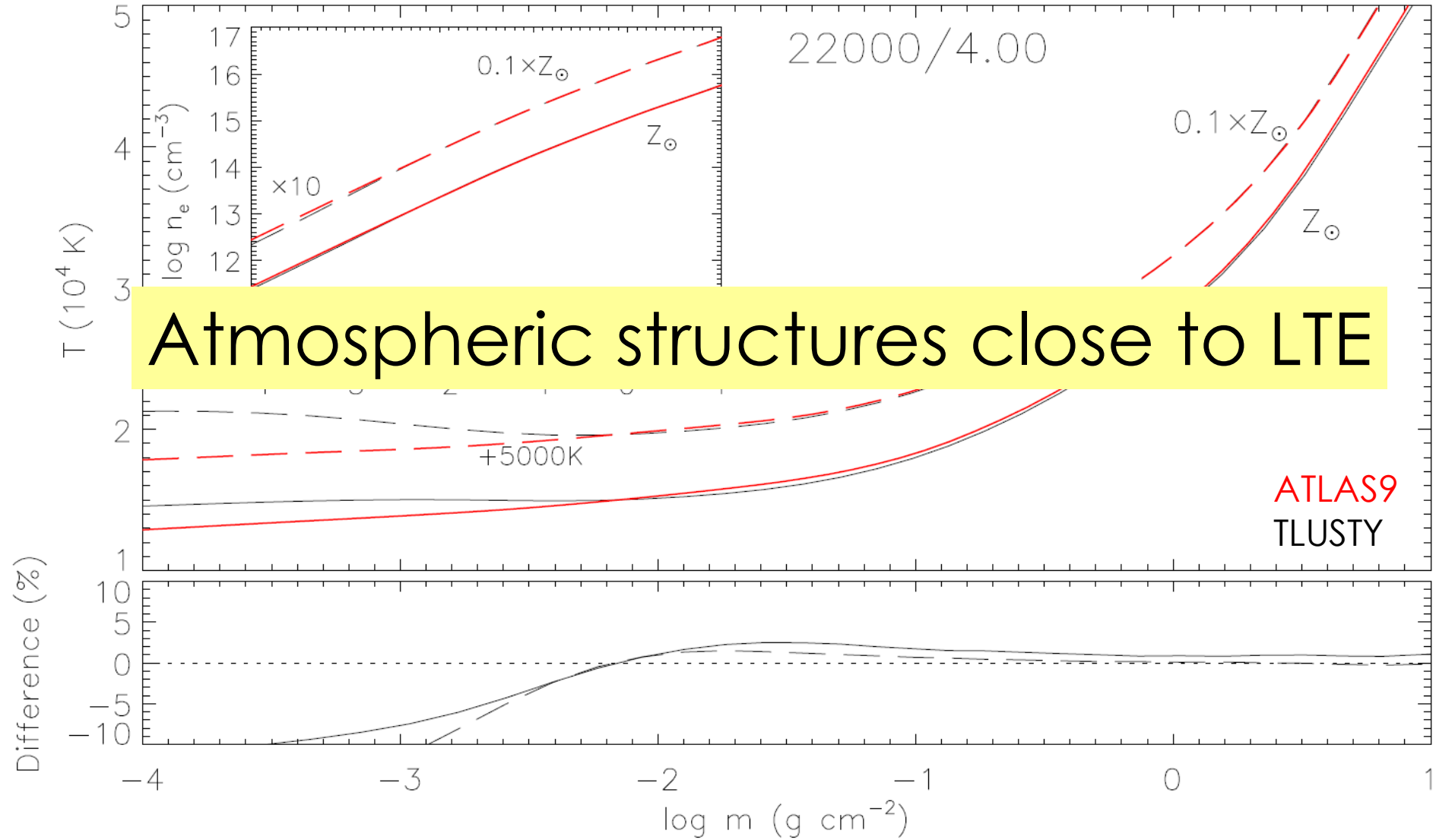
- abundances: **$\Delta\log\varepsilon$ ~ 0.05…0.10 dex** (1σ–stat.) usually: factor ~2
  $\Delta\log\varepsilon$ ~ 0.07…0.12 dex (1σ–sys.) usually: ???

→ **fine ruler**

→ **solid results**

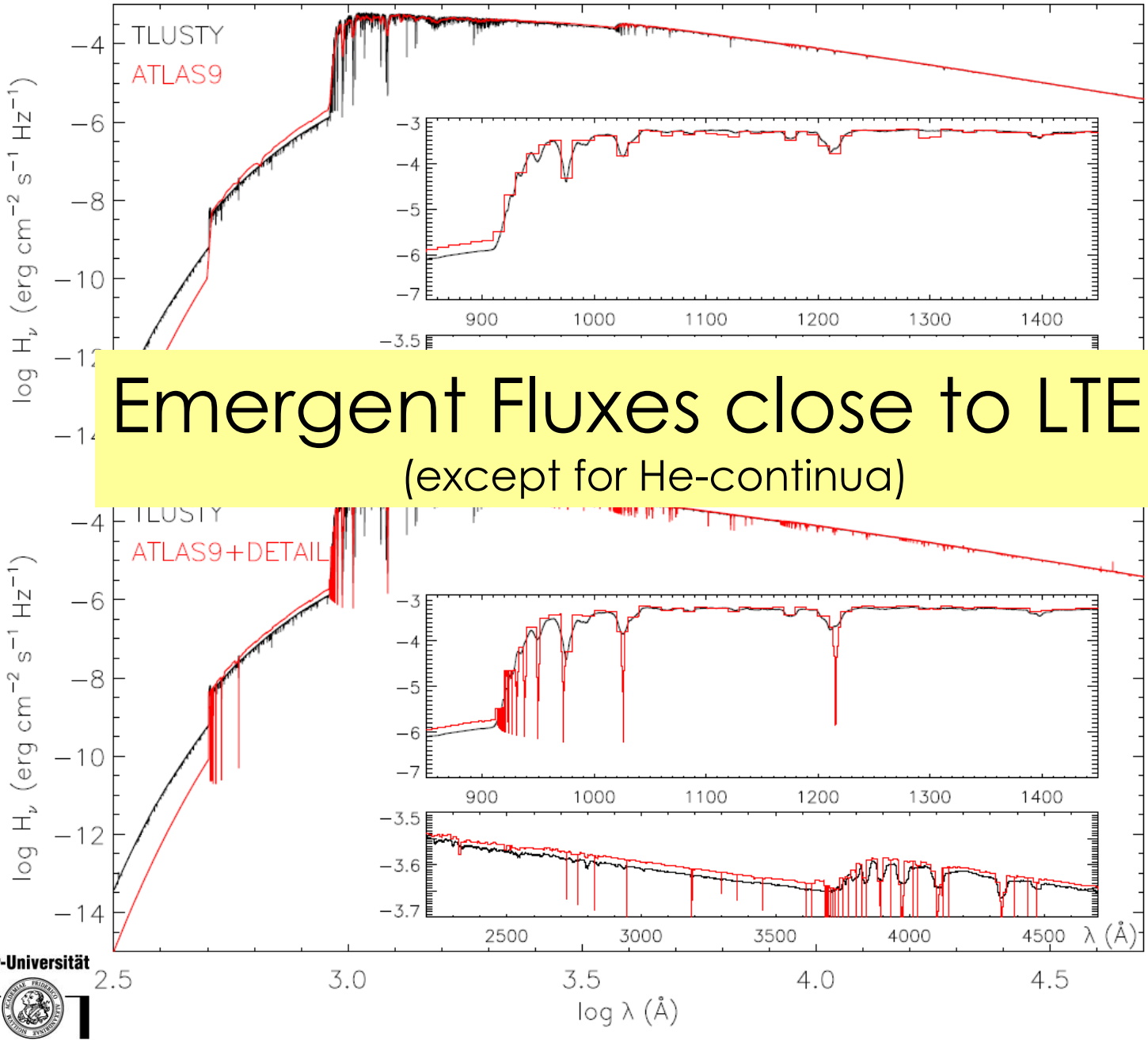
→ good basis for model comparisons

Atmospheric structures



Atmospheric structures close to LTE

SEDs

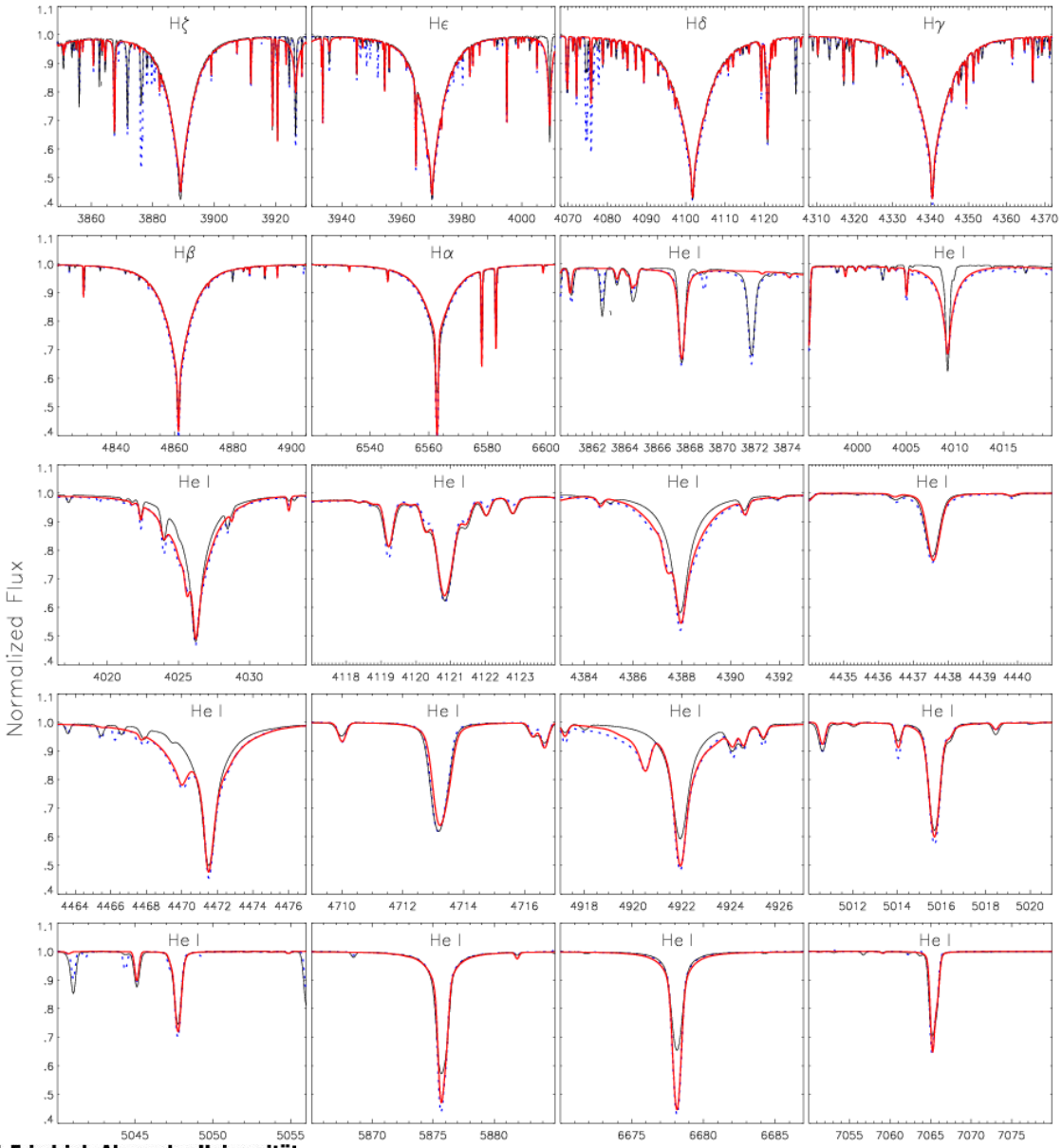


Emergent Fluxes close to LTE

(except for He-continua)

Line Profiles: H+He

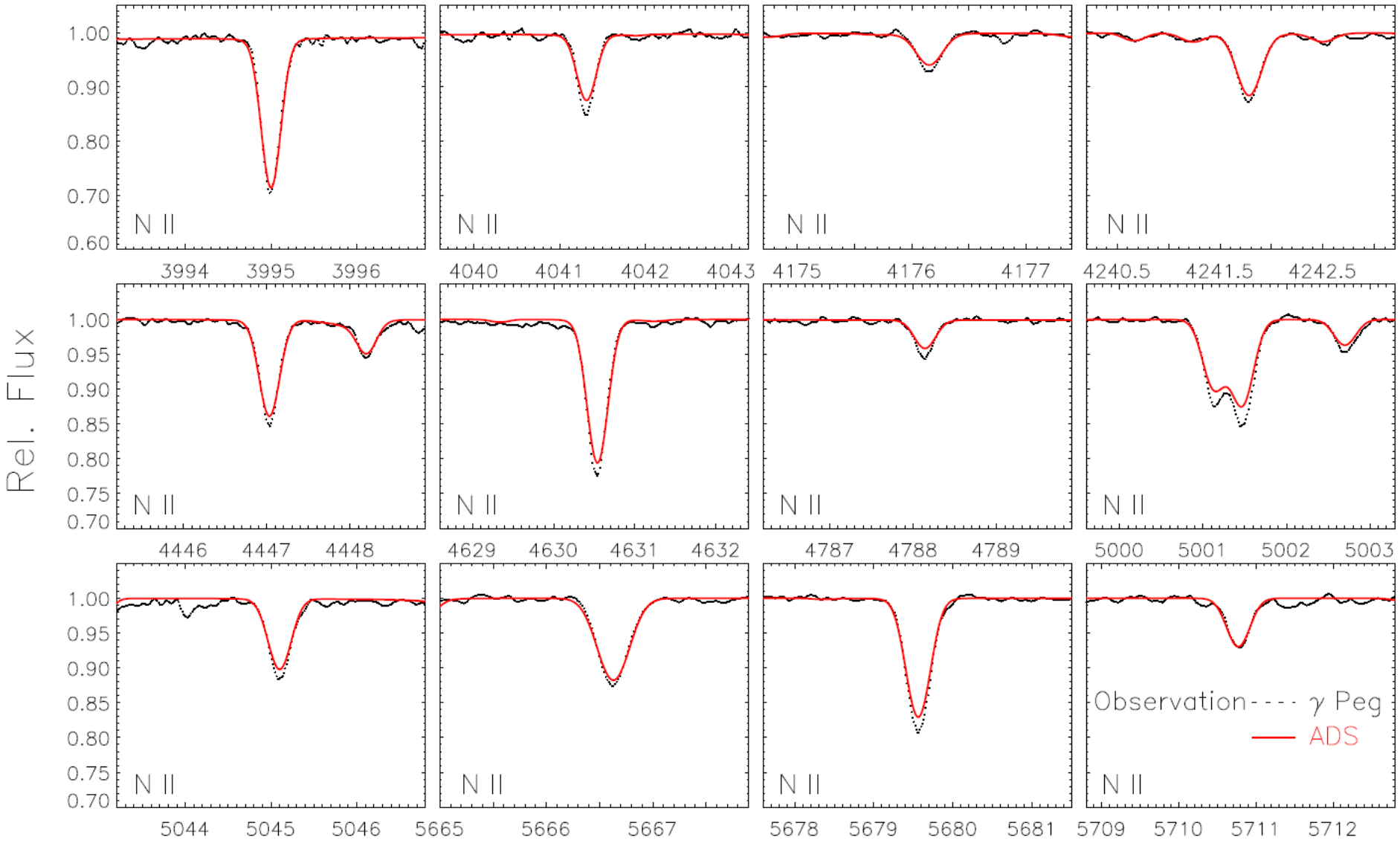
22000/4.00



depending on parameters:

- non-LTE effects on Balmer wings – or not
- non-LTE effects on He-lines - or not

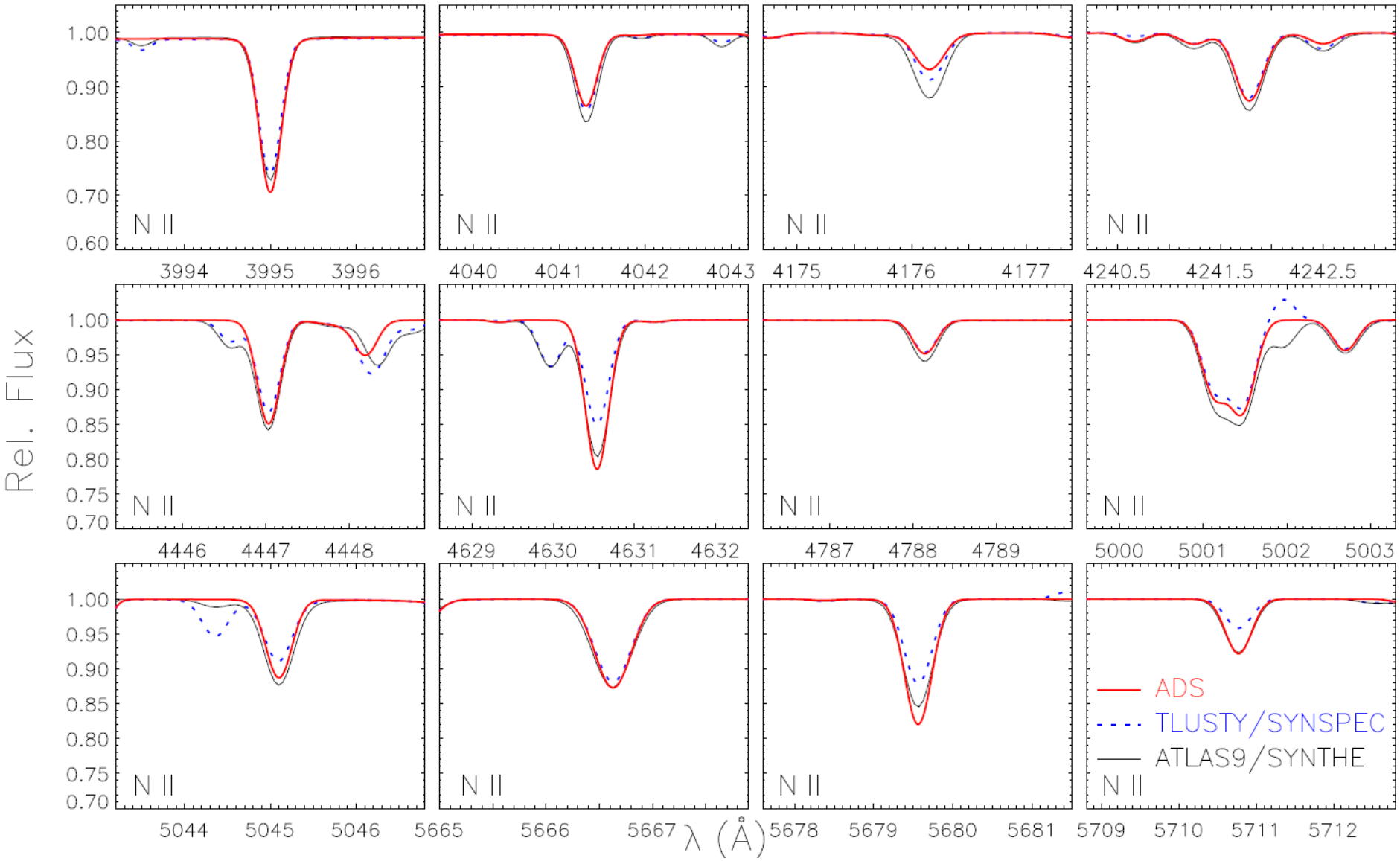
Line Profiles: Nitrogen



global spectrum synthesis – not best fits!

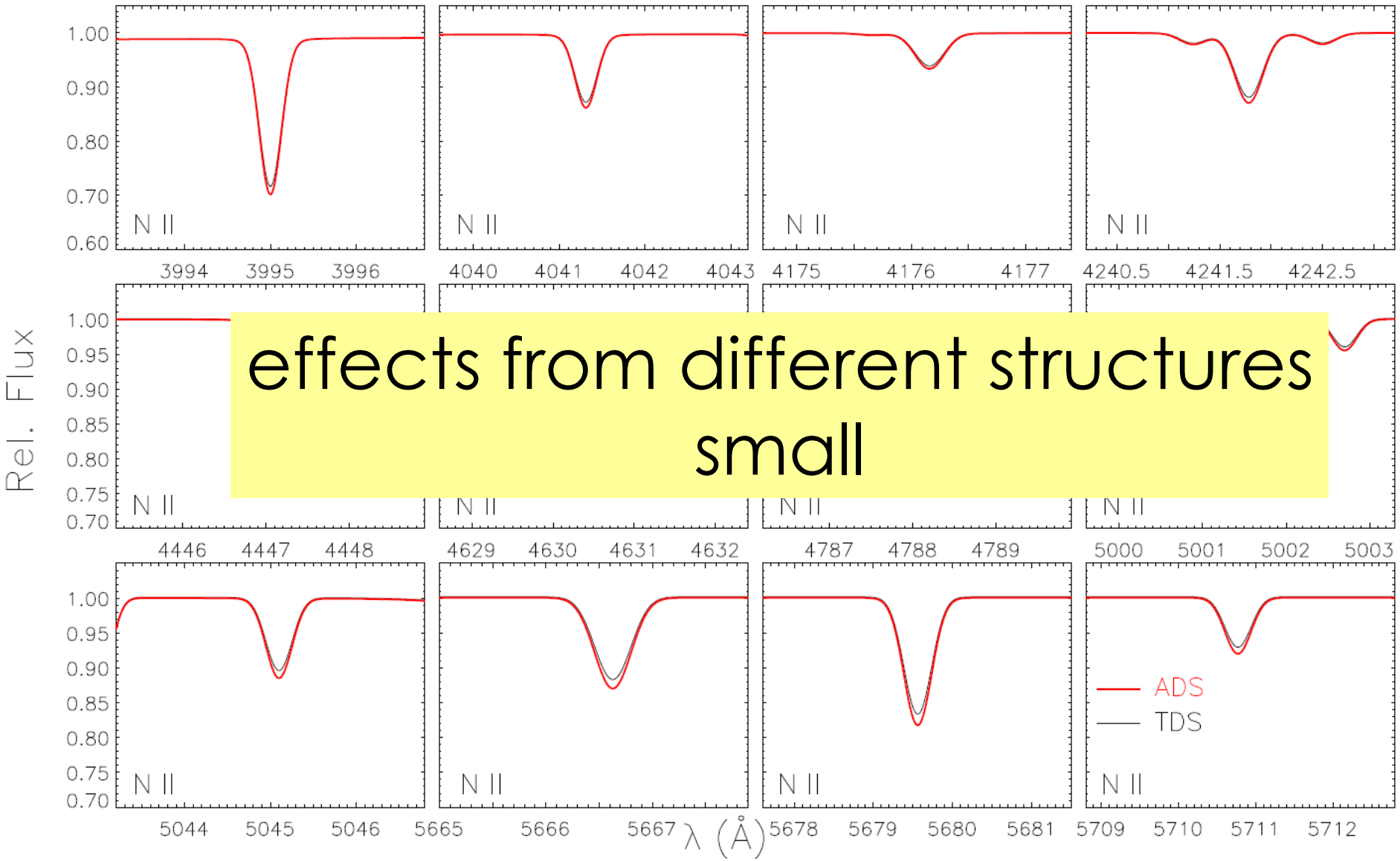
Line Profiles: Nitrogen

22000/4.00



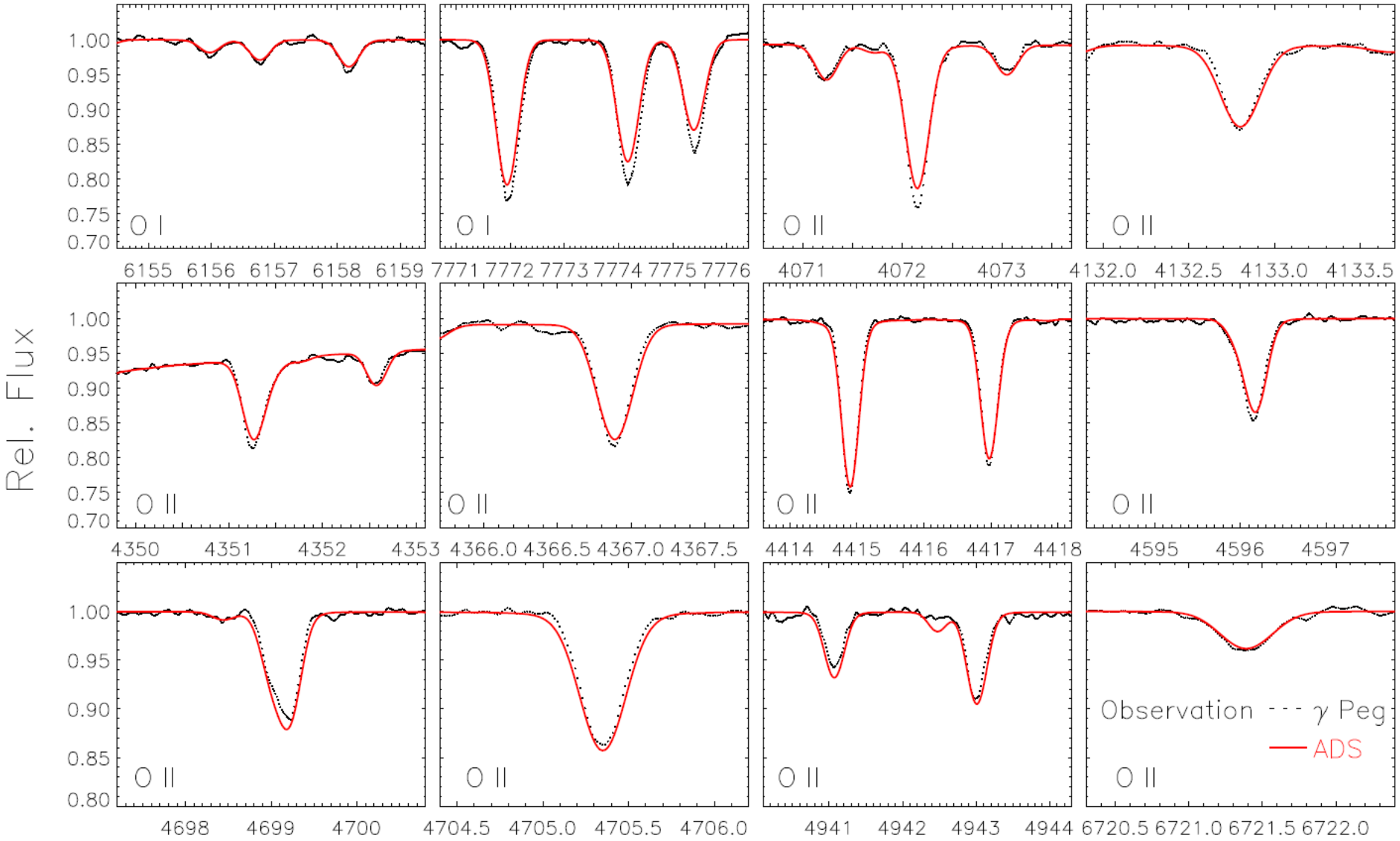
Profiles from LTE & NLTE structure

22000/4.00



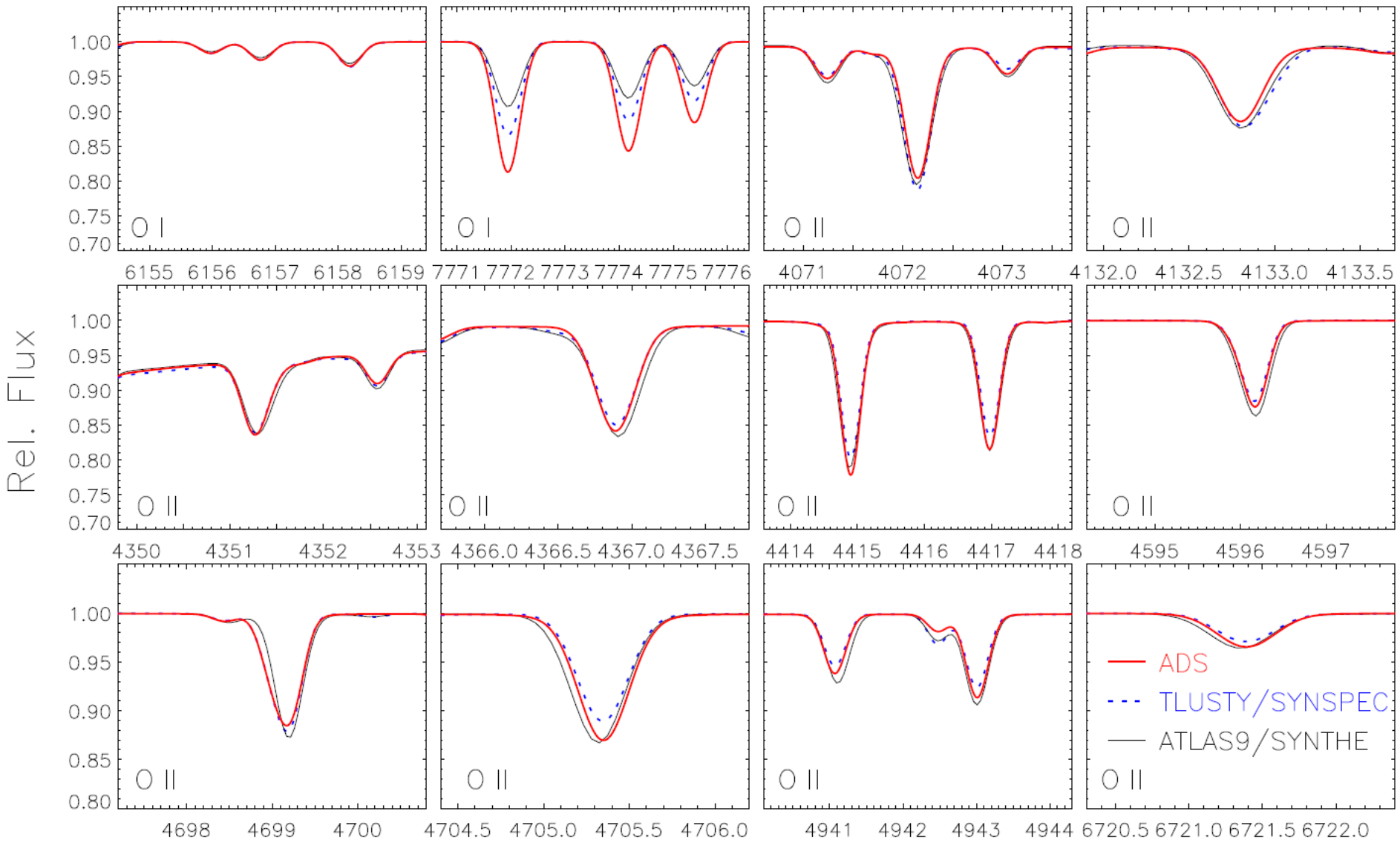
effects from different structures small

Line Profiles: Oxygen

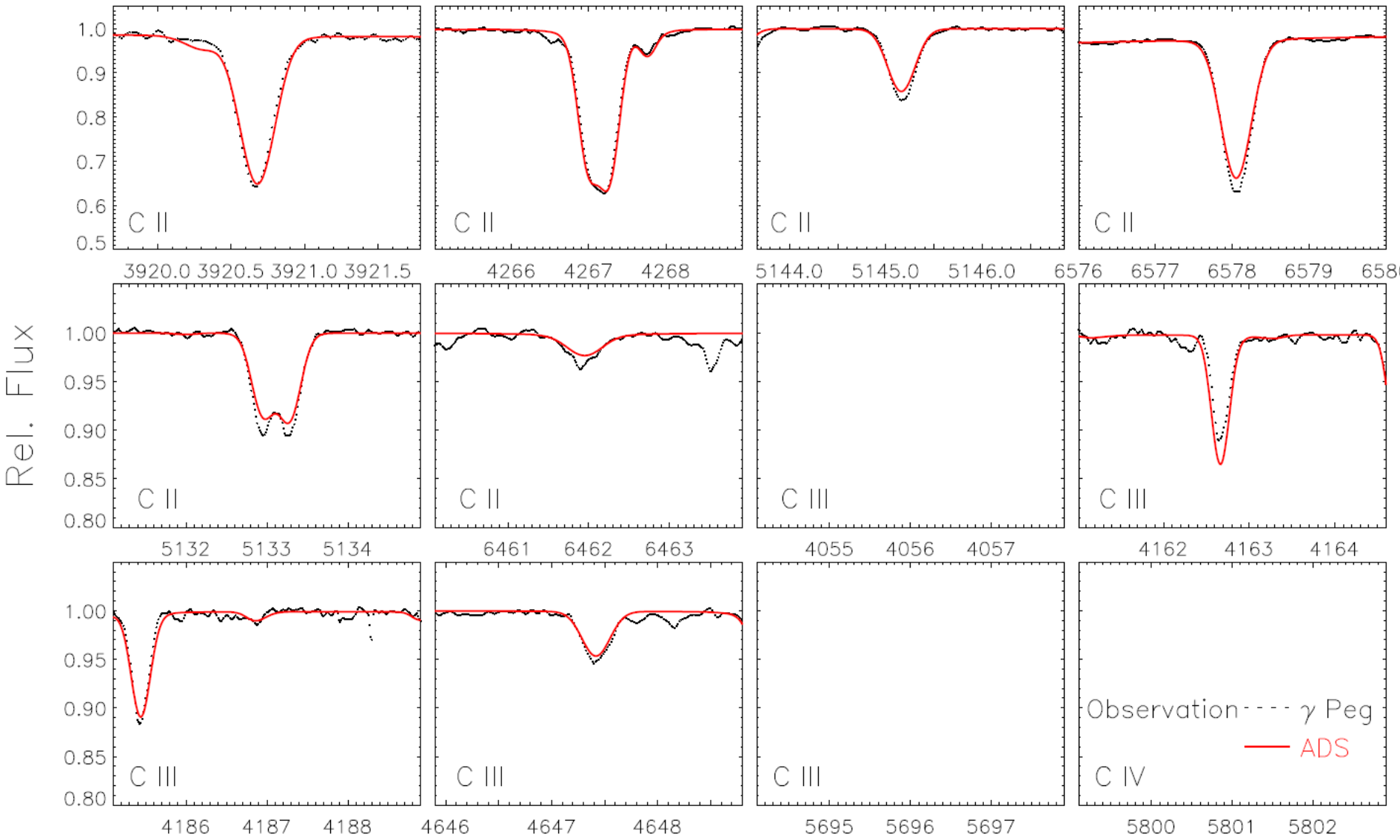


Line Profiles: Oxygen

22000/4.00

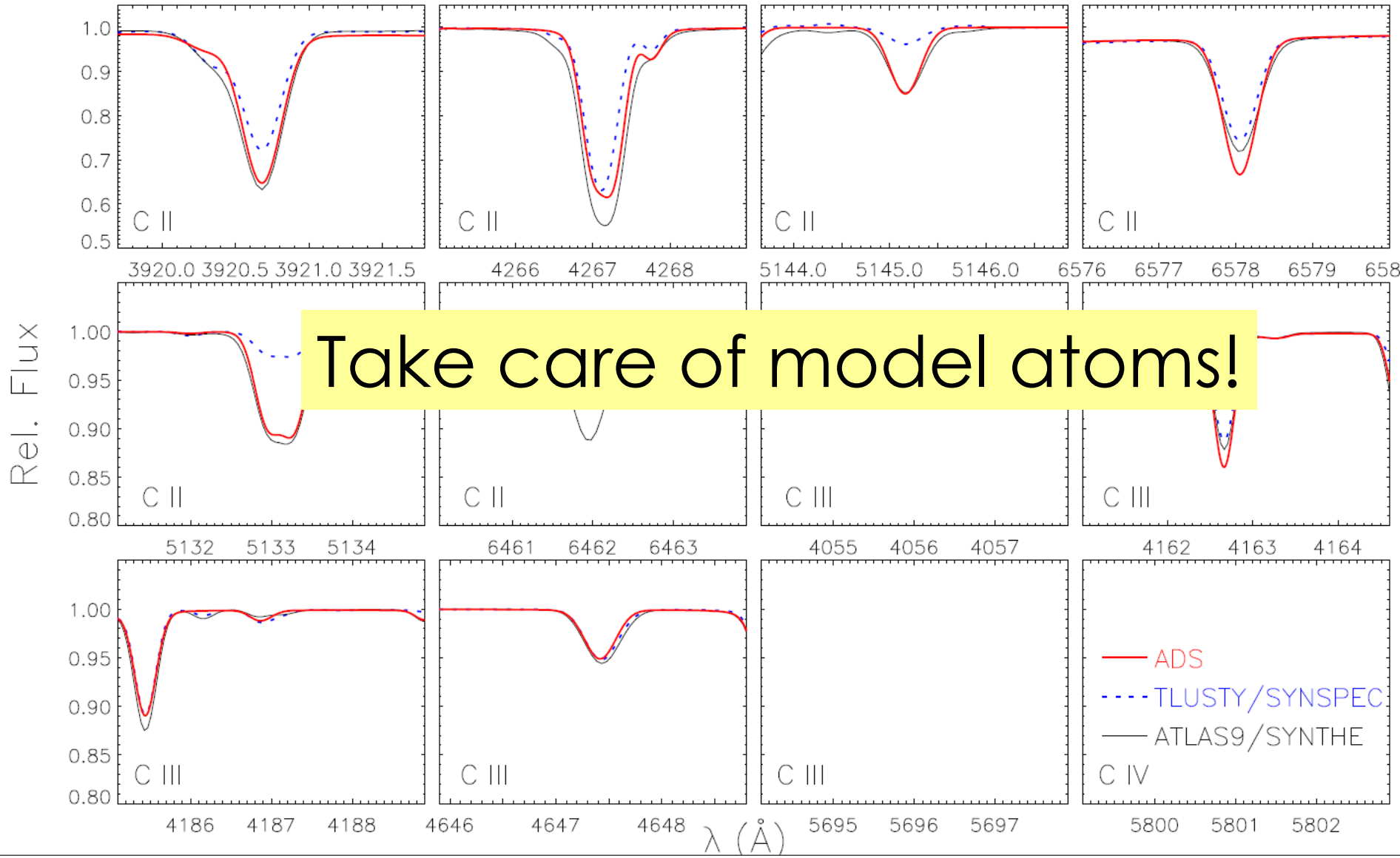


Line Profiles: Carbon



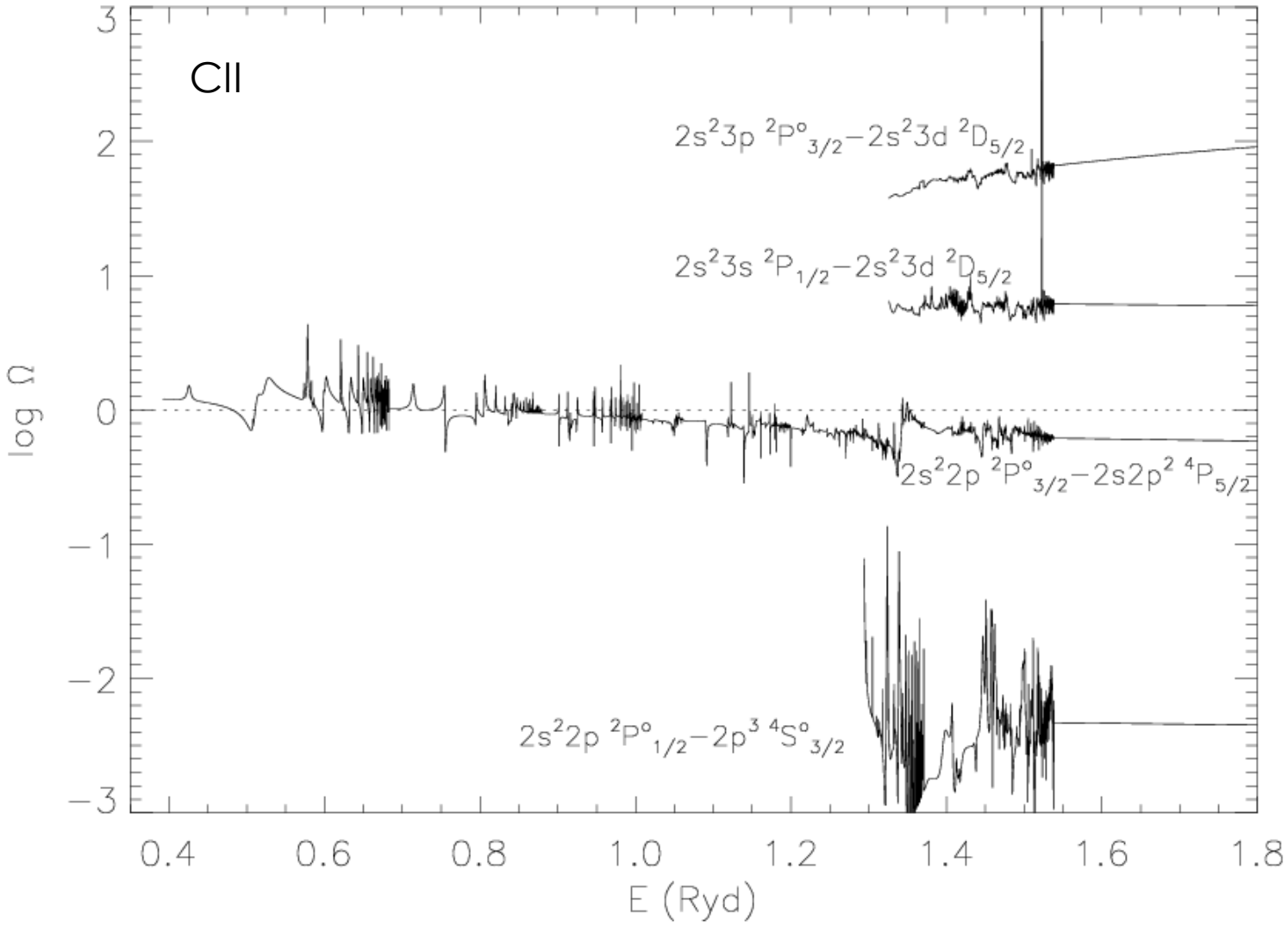
Line Profiles: Carbon

22000/4.00



Take care of model atoms!

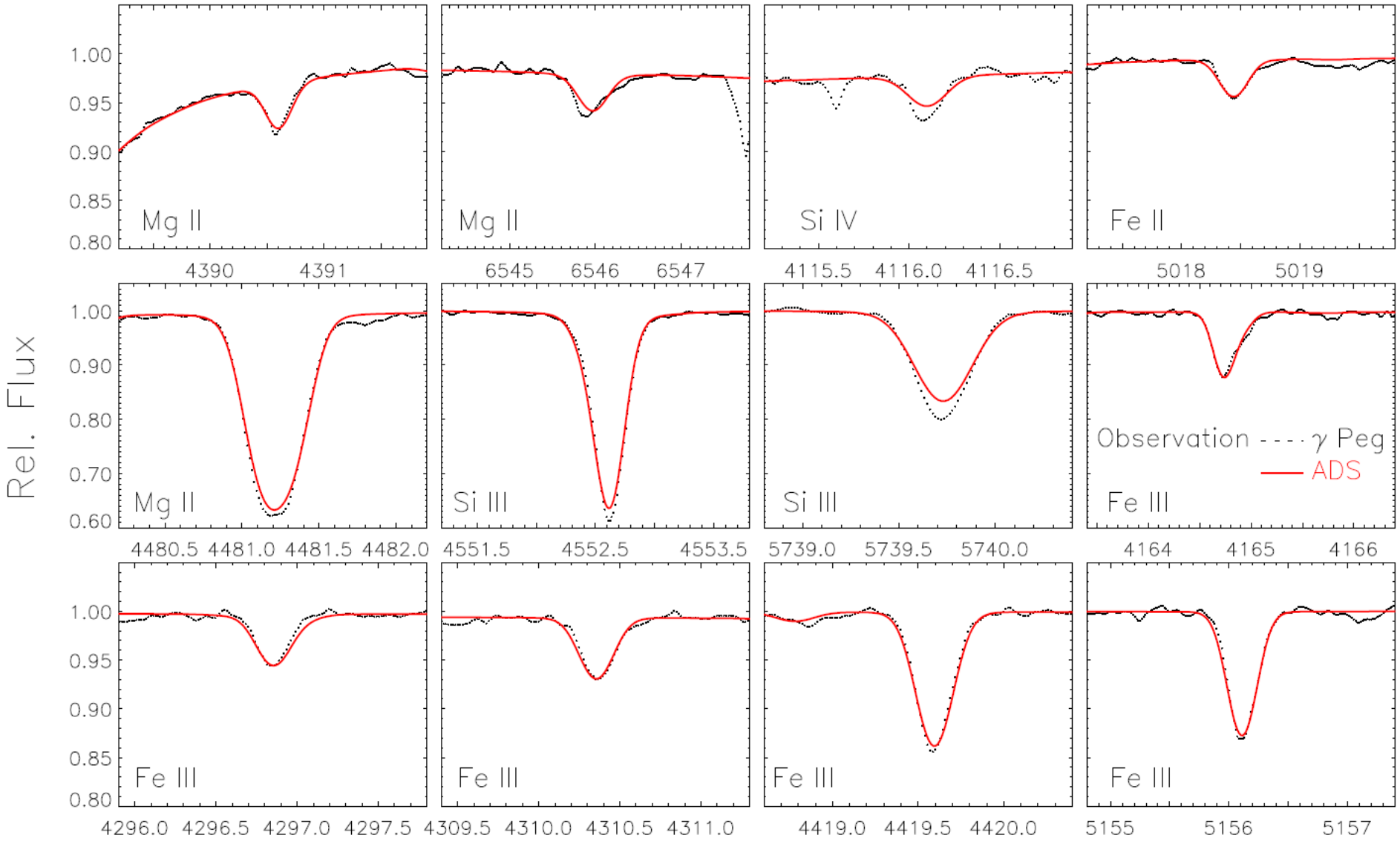
Example: collisional excitation via e-impact



Ω=1
Van Regemorter Formula

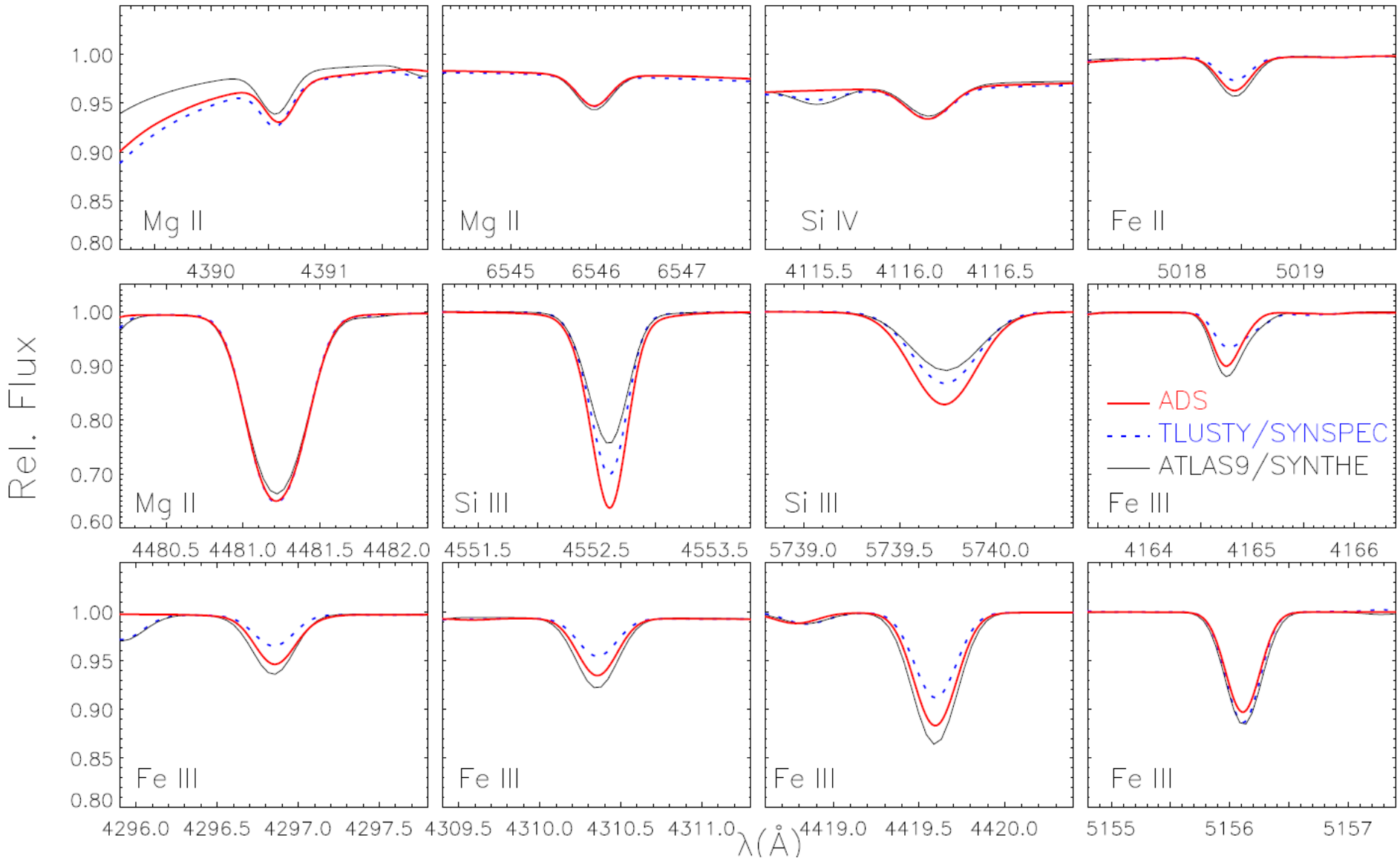
→ **detailed atomic data matter**

Line Profiles: Mg, Si, Fe

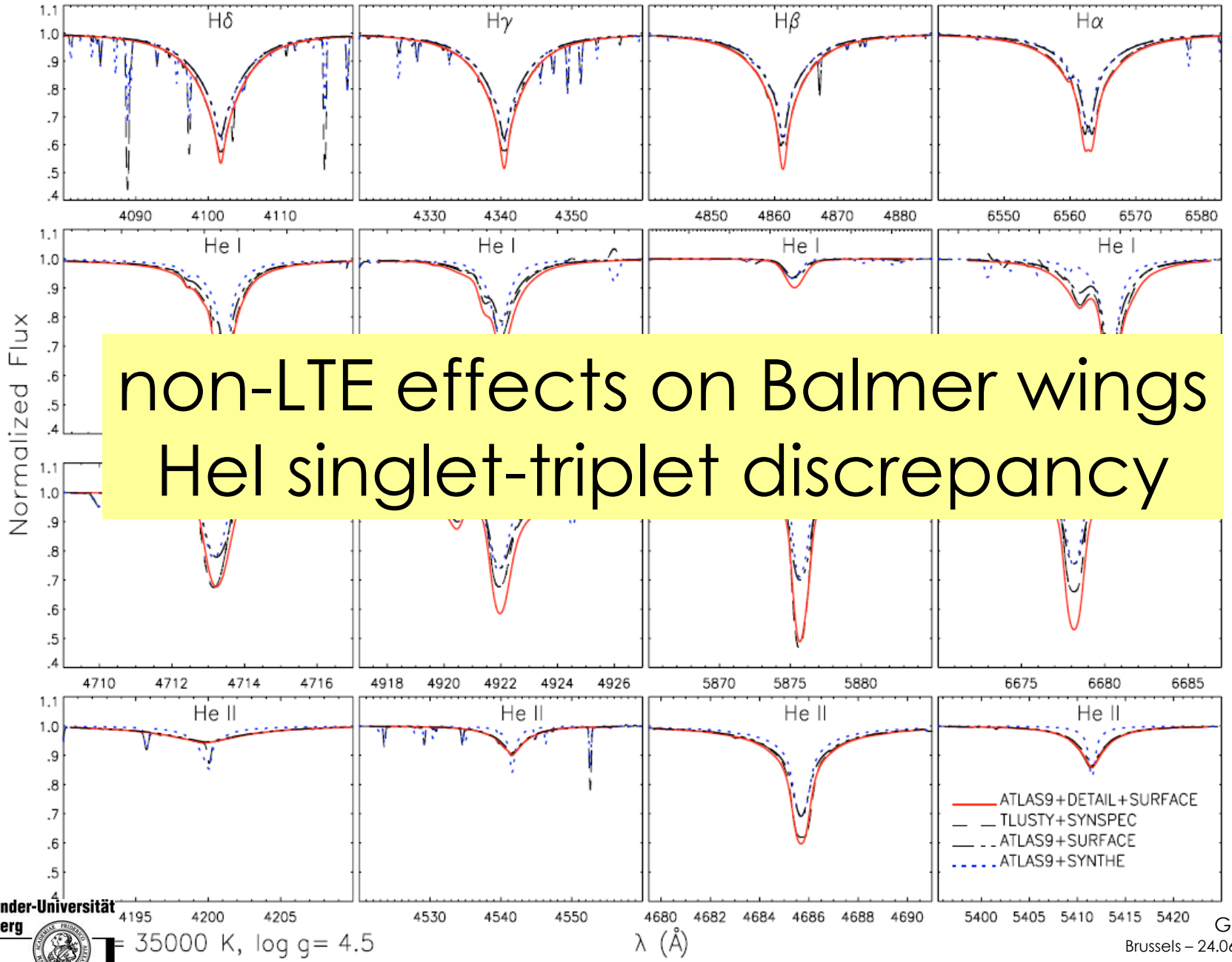


Line Profiles: Mg, Si, Fe

22000/4.00



Late O-star: H+He



non-LTE effects on Balmer wings
HeI singlet-triplet discrepancy

= 35000 K, log g= 4.5

highly complex behaviour
with parameter variations...

non-LTE ‘correction‘-approach not feasible

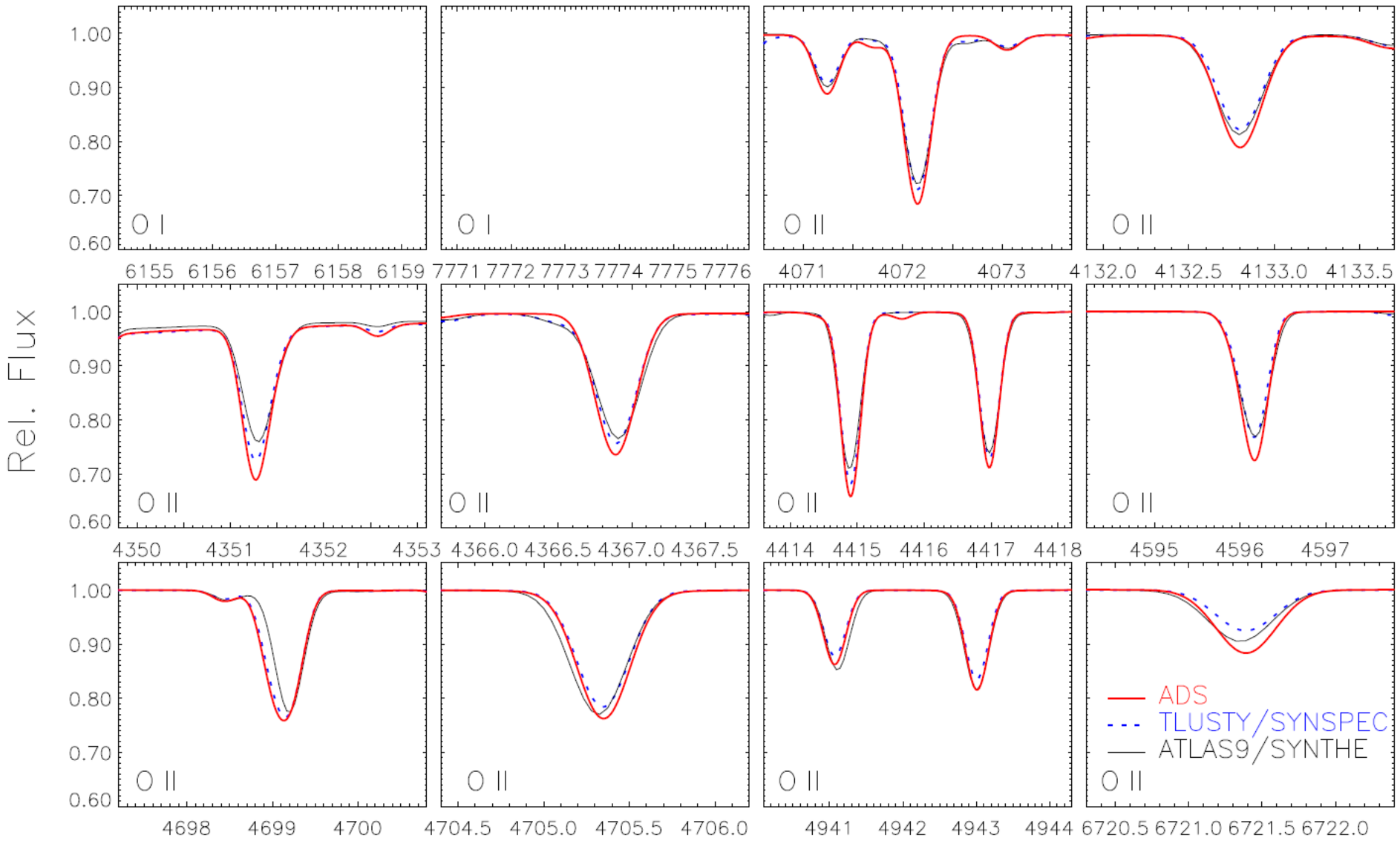
Summary

15000K ≤ Teff ≤ 35000K:

- atmospheric structures: very close to LTE $\Delta T/T(\text{NLTE-LTE}) \leq 1\%$
- SEDs: NLTE modelling required (Ly-)/He-continua
- line spectra: - LTE assumption highly limited – works sometimes for some lines
  - NLTE limited because of model atom implementations
- available LTE & NLTE grids **NOT** suited to reproduce observed spectra over extended wavelength regions, but useful for selected lines
- **alternative**: hybrid NLTE-modelling with tailored model atoms
- limitations: breakdown of hydrostatic approximation for hotter stars & some supergiants

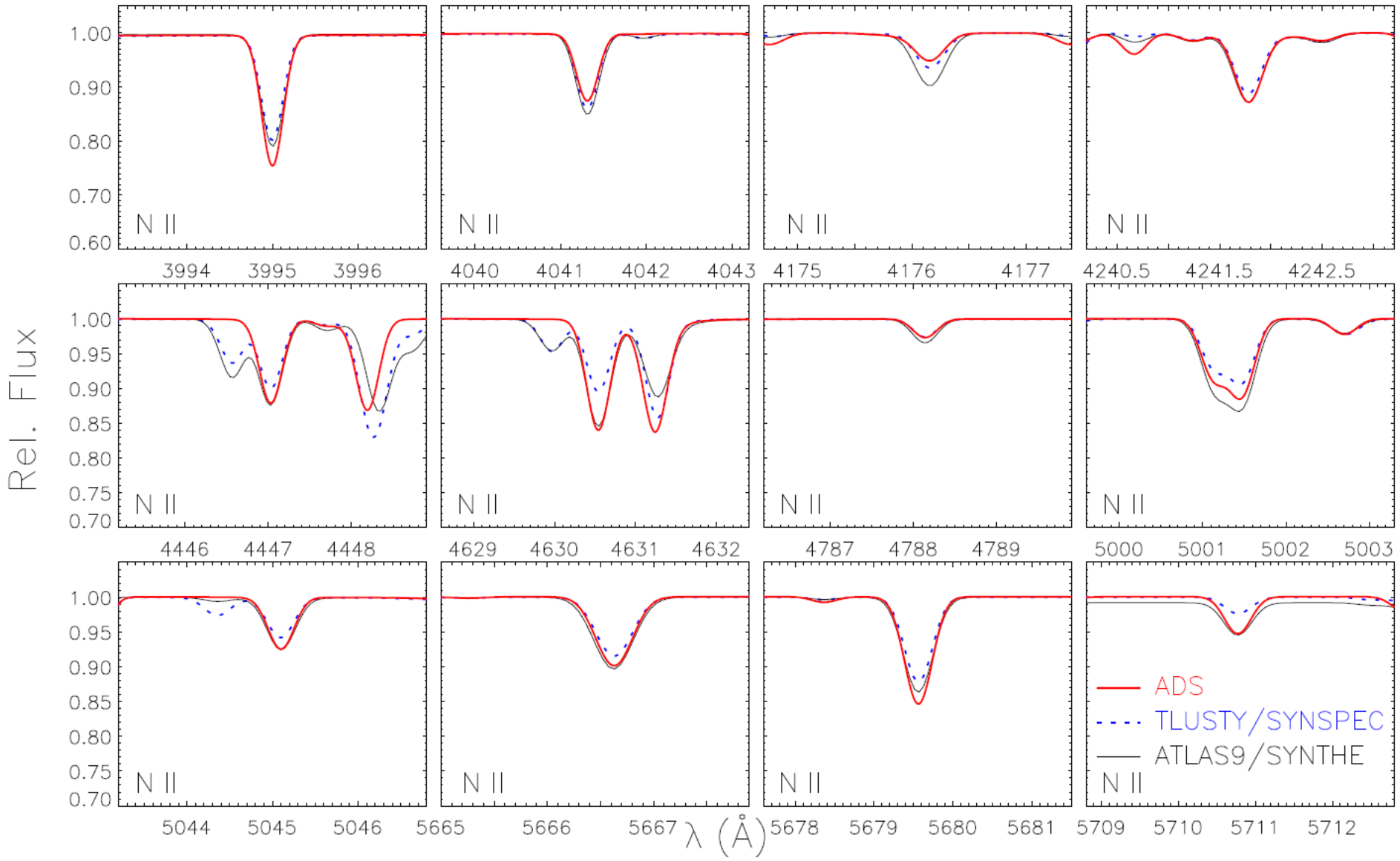
Line Profiles: Oxygen

30000/4.00



Line Profiles: Nitrogen

30000/4.00



Line Profiles: Carbon

30000/4.00