Atmospheric modelling of massive stars in the IR domain

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Dear LOC, SOC and friends,

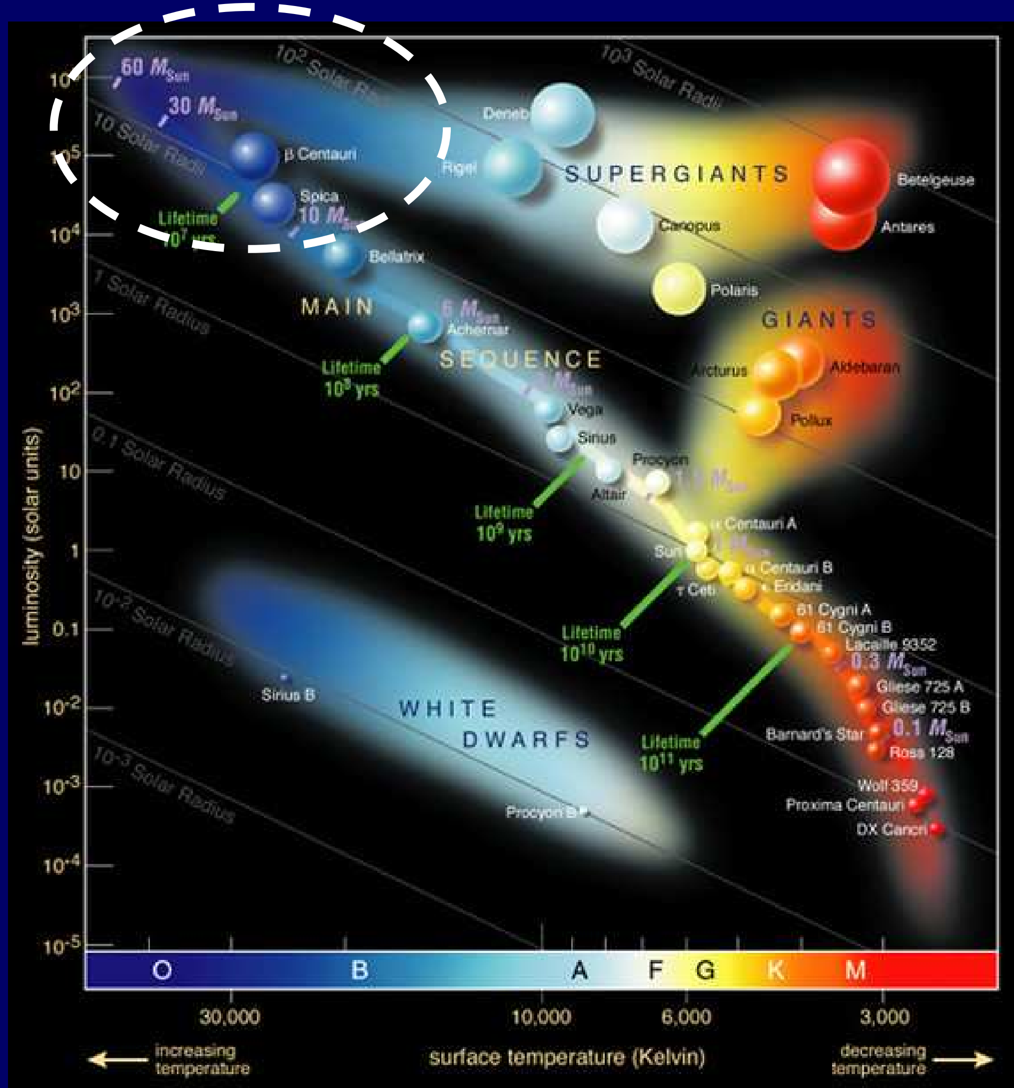
my apologies for my absence.

I wish you a very productive IAU GA and SpS5.

@ Norbert: thank you for presenting this review!

Fernanda Nieva

Massive blue stars



no WRs: Crowther, Hamann

no RSG: Bergemann

e.g. OB stars in star-formation regions

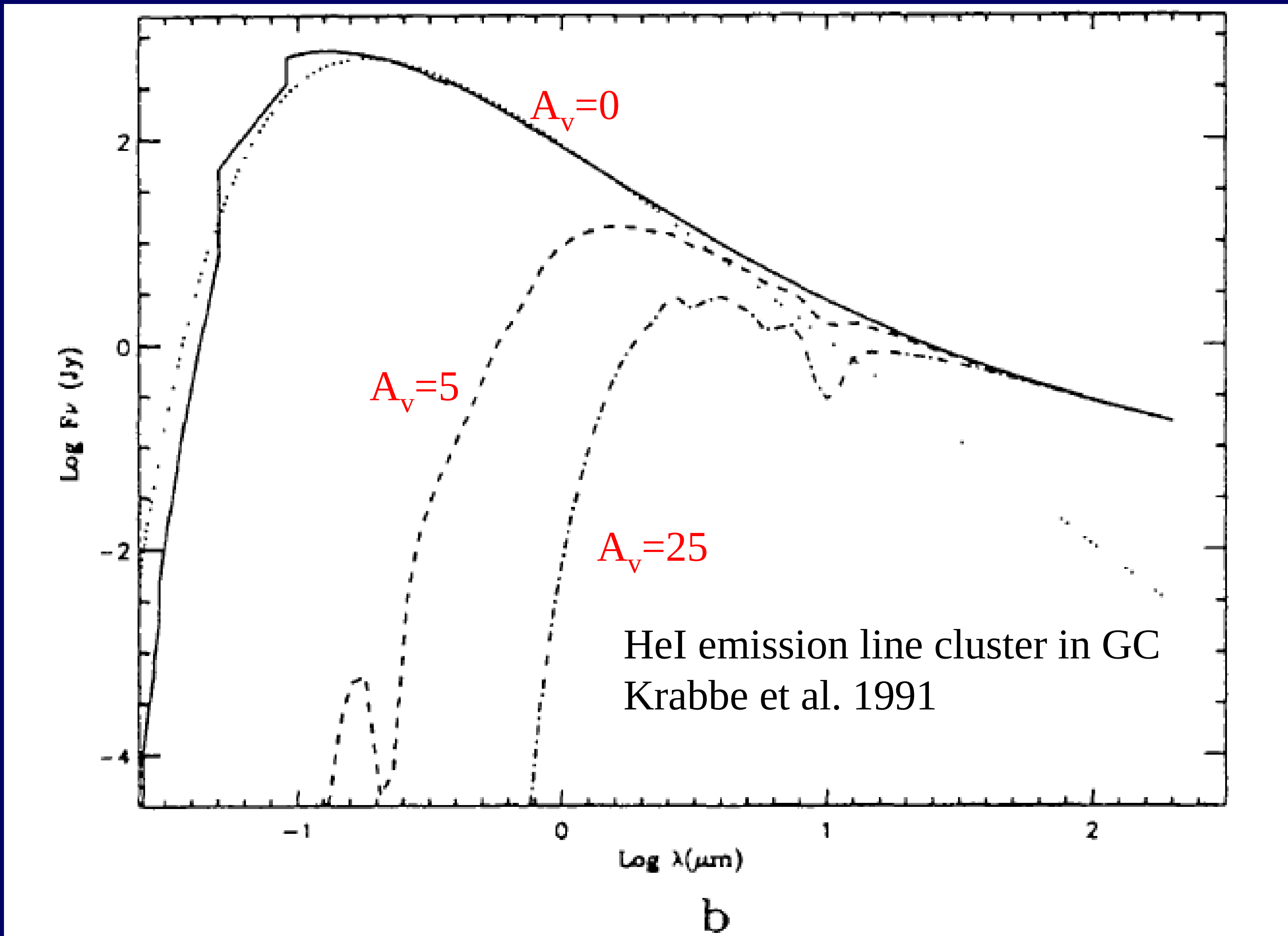
1- deposit energy & momentum to the ISM

2- can ionize gas clouds through UV radiation

3- less evolved dwarfs & giants:
→similar composition than parent clouds

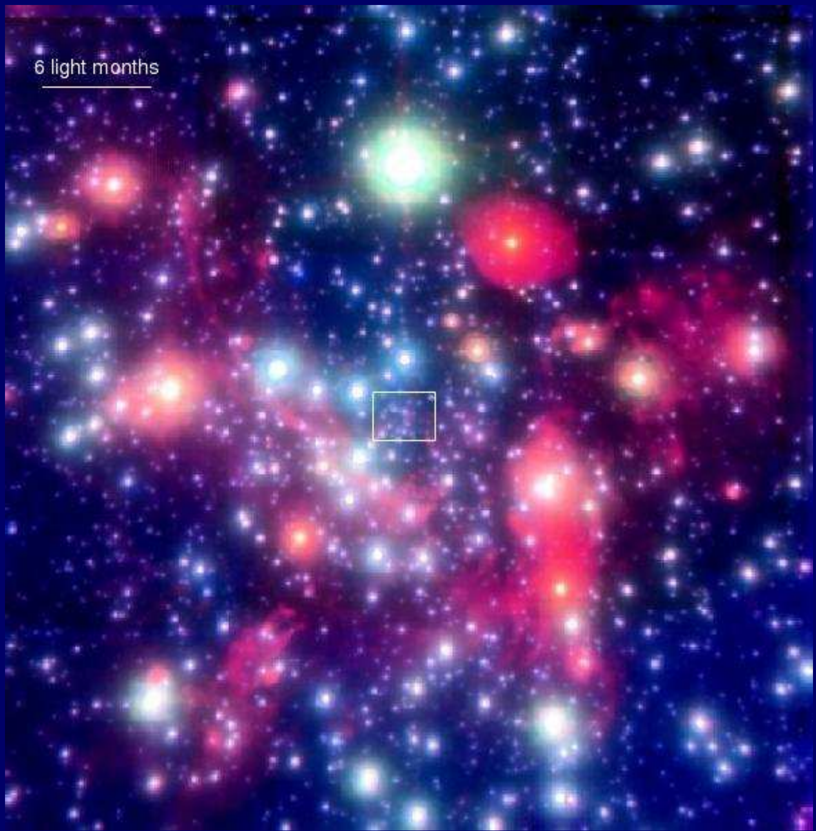
4- luminous: can be studied at large distance

Motivation for observations of hot stars in the NIR

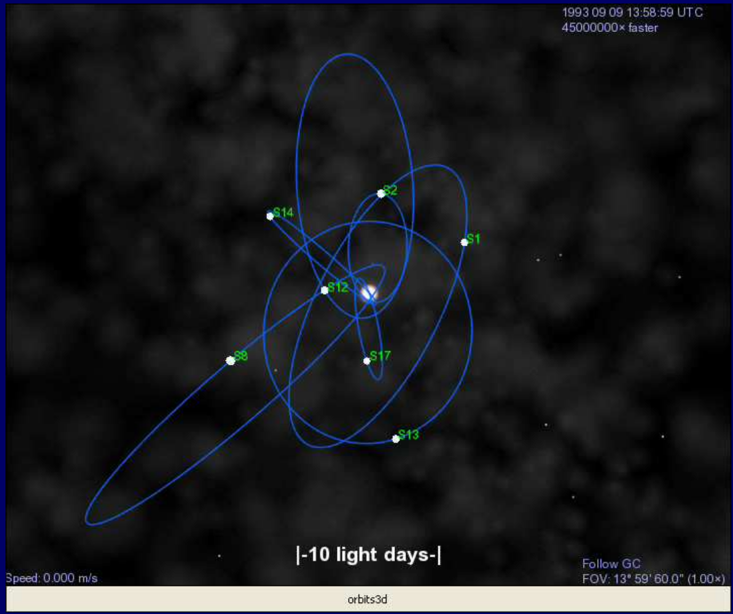


Najarro et al. 1997

e.g. OB stars in the Galactic Center



http://www.mpe.mpg.de/ir/GC/



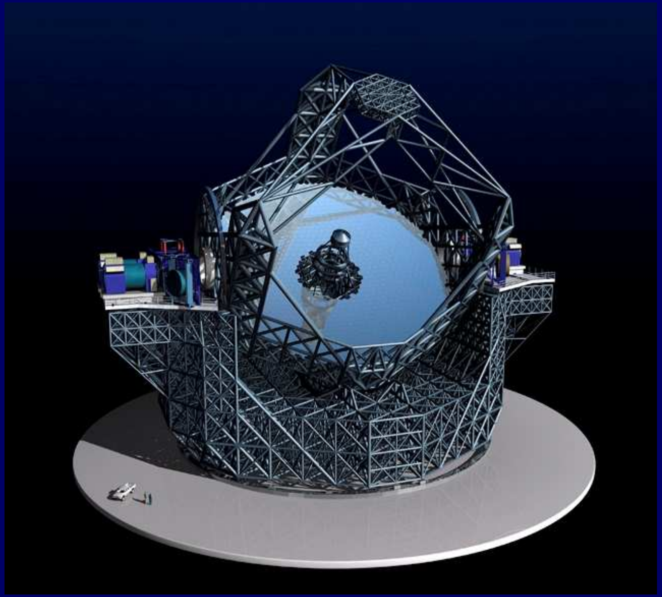
Why near-IR spectroscopy of OB stars?

Galactic stellar astronomy

- Some Galactic regions observable both in optical & near-IR
- BUT: most regions observable in near-IR only
- Present and future generation of telescopes

Extragalactic stellar astronomy

- Future generation of ELTs



diffraction-limited observation with ELT
using AO → near-IR spectroscopy

Diagnostic challenges in NIR

- NIR line formation in O stars:
  transition region between photosphere and super-sonic wind
- complication in IR:
  amplification of non-LTE effects

  non-LTE line source function:

$$S_l = \frac{2h\nu^3/c^2}{b_i/b_j \exp(h\nu/kT) - 1}$$

$$|\Delta S_l| = \left| \frac{S_l}{b_i/b_j - \exp(-h\nu/kT)} \Delta(b_i/b_j) \right| \overset{h\nu \ll kT}{\approx} \left| \frac{S_l}{(b_i/b_j - 1) + h\nu/kT} \Delta(b_i/b_j) \right|$$

► **extreme sensitivity to very details of modeling**

Models

- non-LTE models

  hydrodynamic spherical line-blanketed non-LTE model atmospheres

  CMFGEN Hillier & Miller 1998

  FASTWIND Puls et al. 2005

  limited in complexity of model atoms

- hybrid non-LTE approach:

  hydrostatic plane-parallel line-blanketed LTE model atmospheres

  + non-LTE line formation

  ADS

  ATLAS9 Kurucz 1993

  + DETAIL/SURFACE Giddings 1981; Butler & Giddings 1985

  complex model atoms feasible

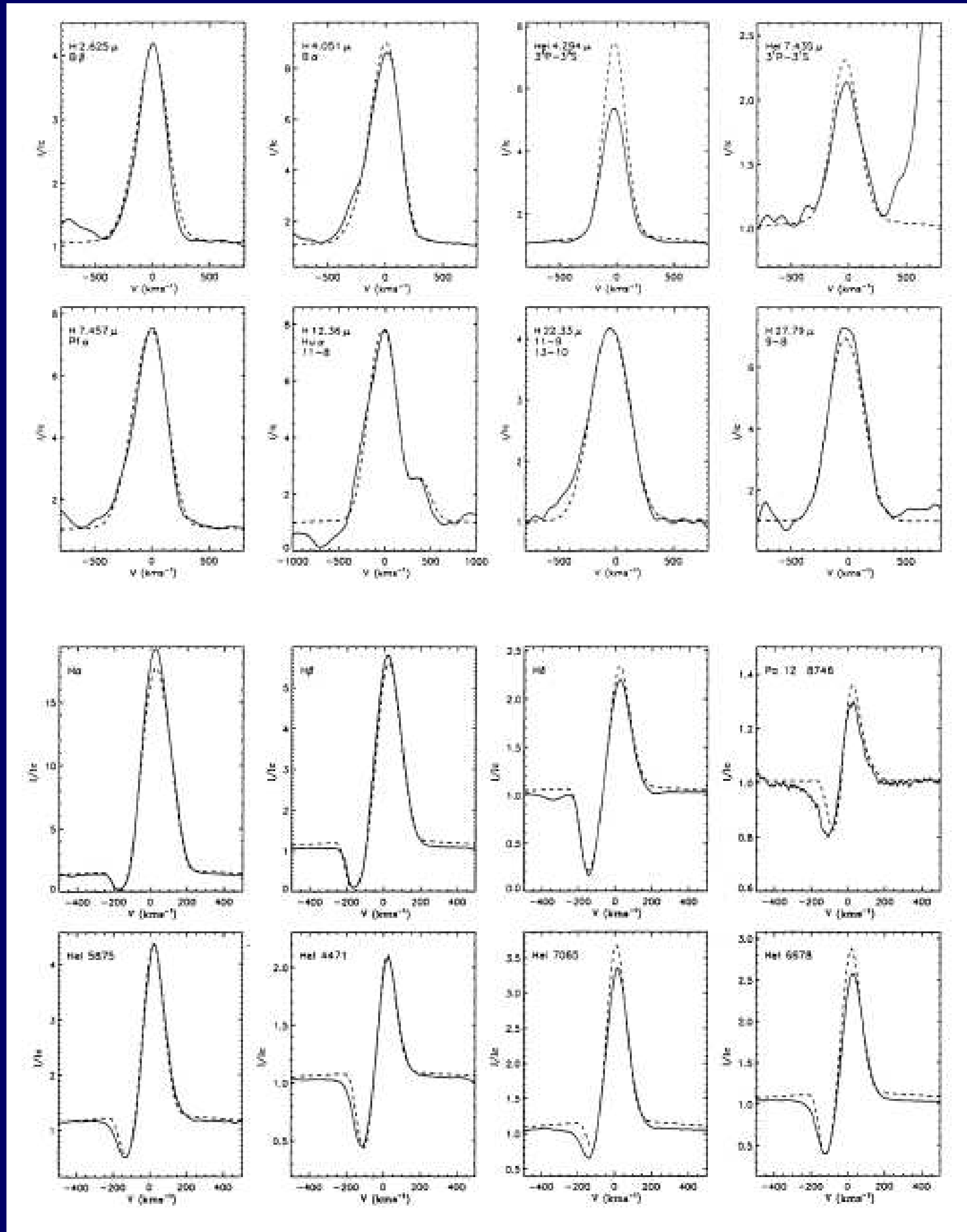
→ good for OB dwarfs & giants/weak winds Nieva & Przybilla 2007

driven by quality of observations

Important test: consistency of NIR and optical spectra

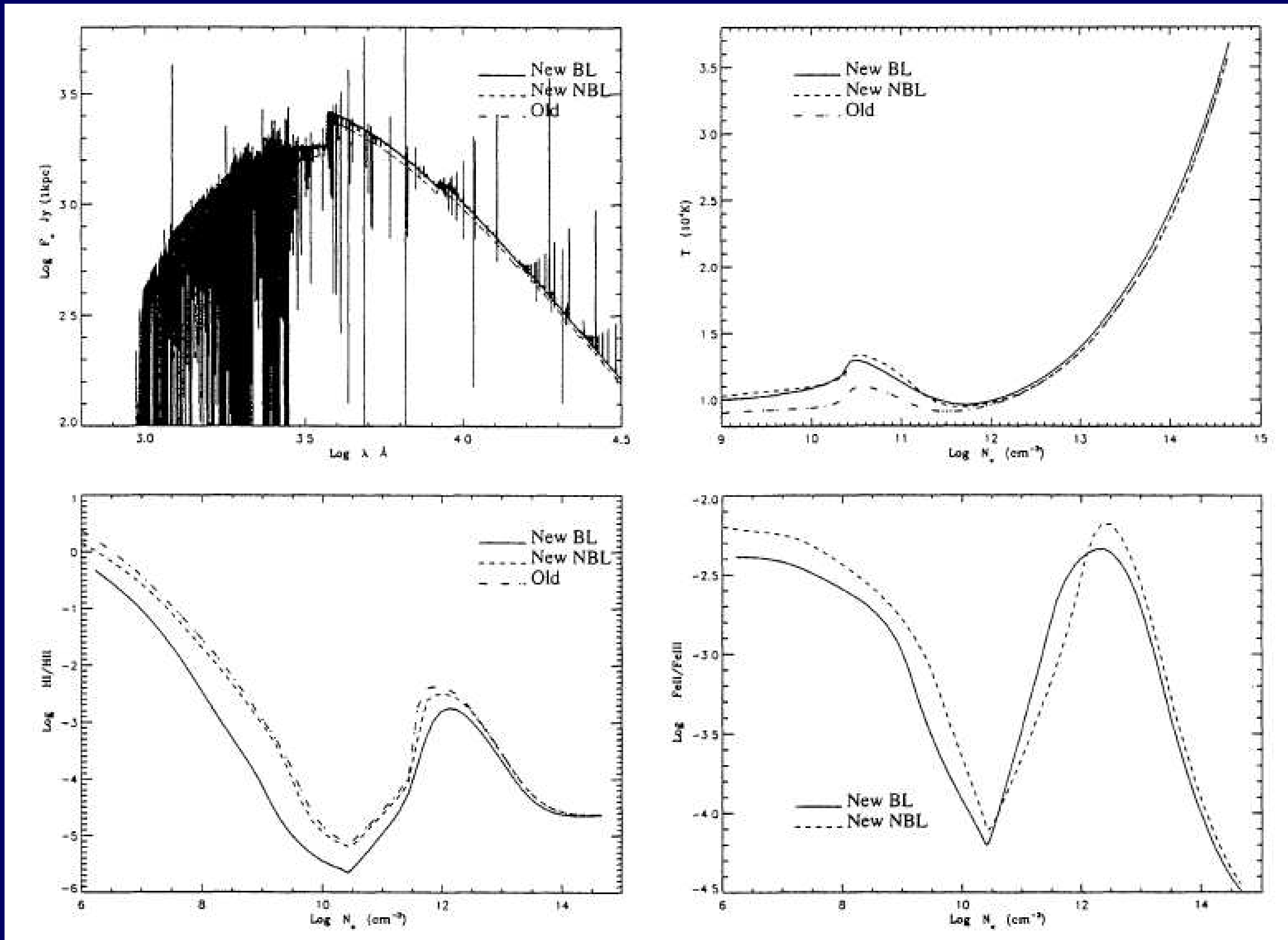
P Cygni:
early CMFGEN models: H+He+N
vs.
ISO-SWS & optical spectrum

► quantitative NIR spectroscopy



Najarro et al. 1997

Importance of line blanketing and blocking

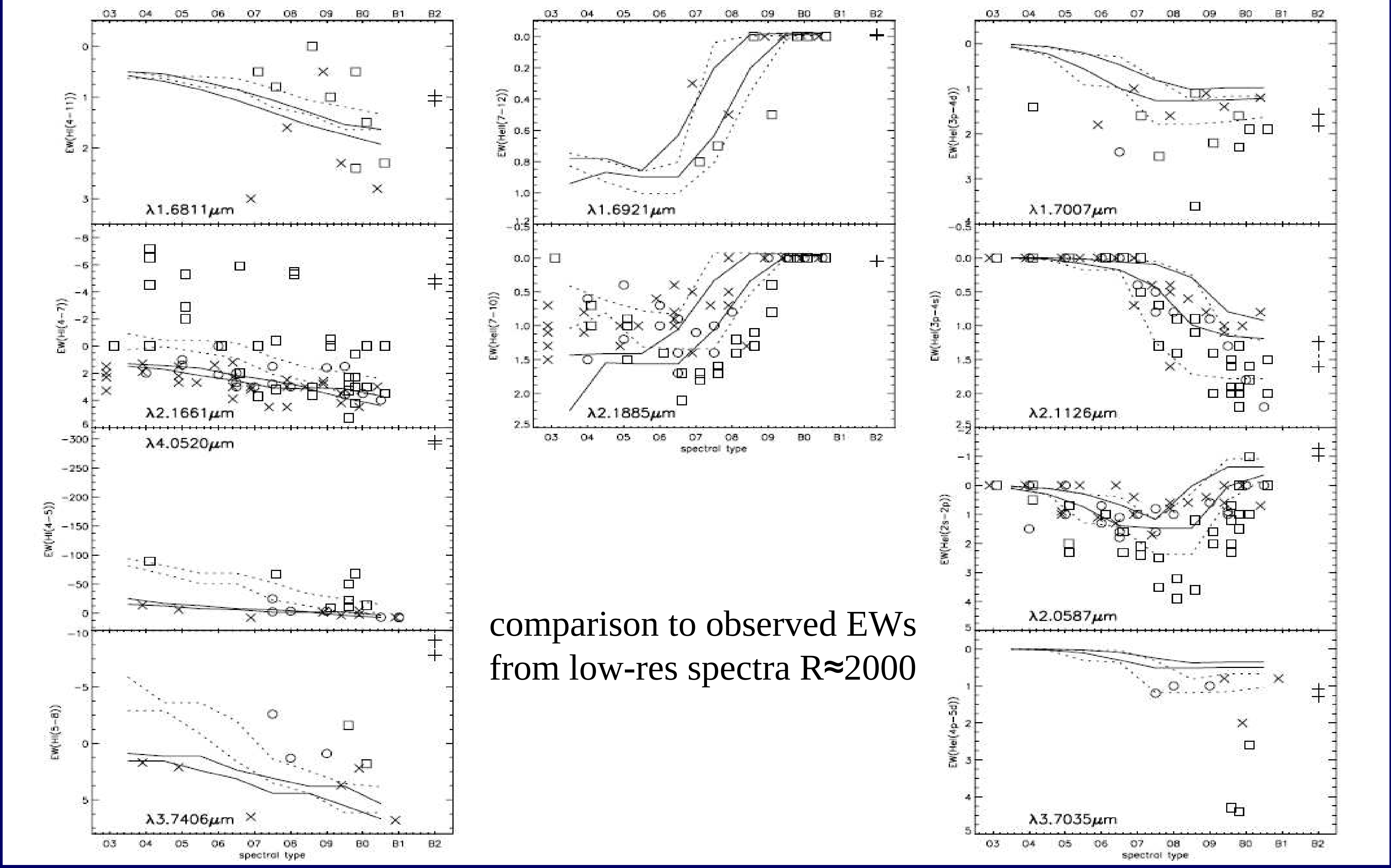


CMFGEN model for P Cygni star HDE316285 Najarro et al. 1999

► application: Pistol star in GC

Systematic NIR line trends for O stars

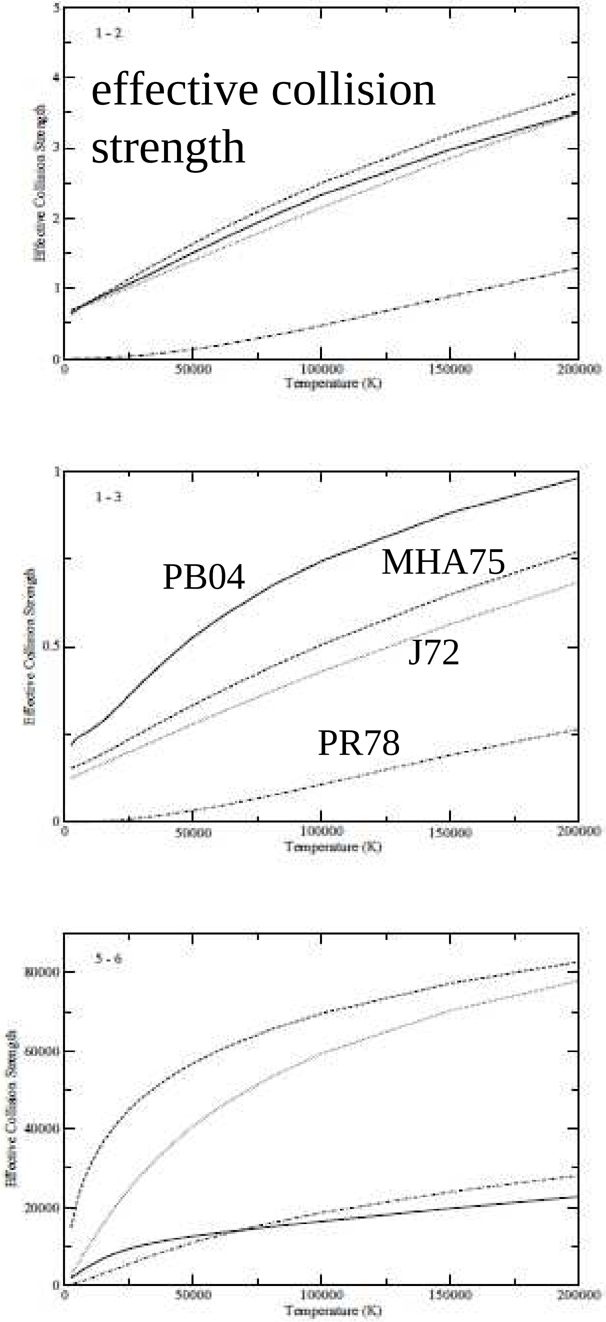
CMFGEN

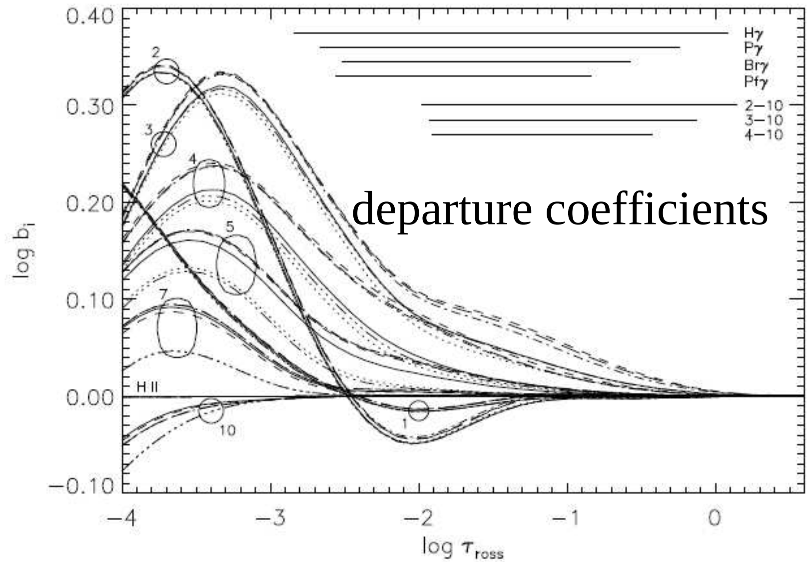


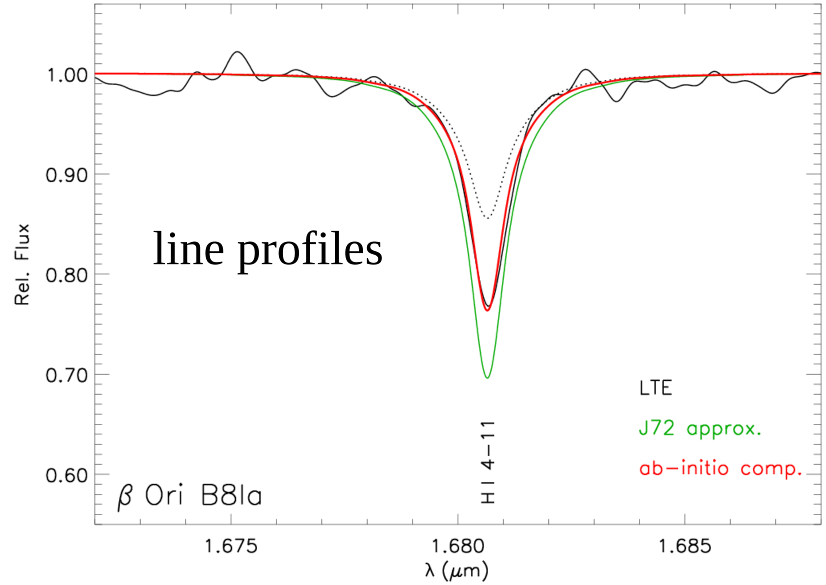
comparison to observed EWs
from low-res spectra R≈2000

Lenorzer et al. 2004

Importance of atomic data #1







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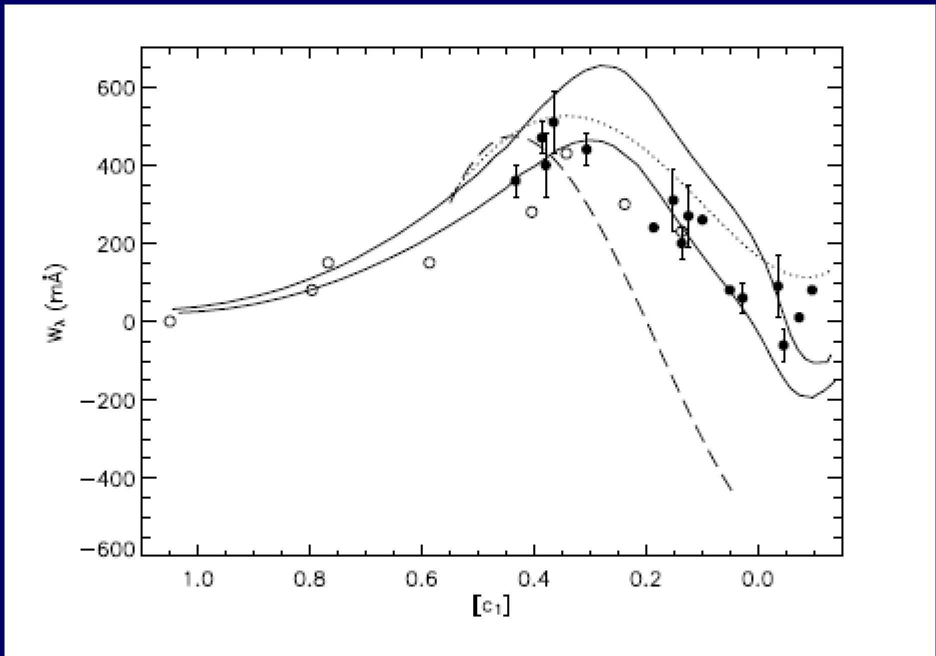
Przybilla & Butler 2004

Importance of atomic data #2/line blocking



line trends for HeI 1.083mm
in B-type dwarfs

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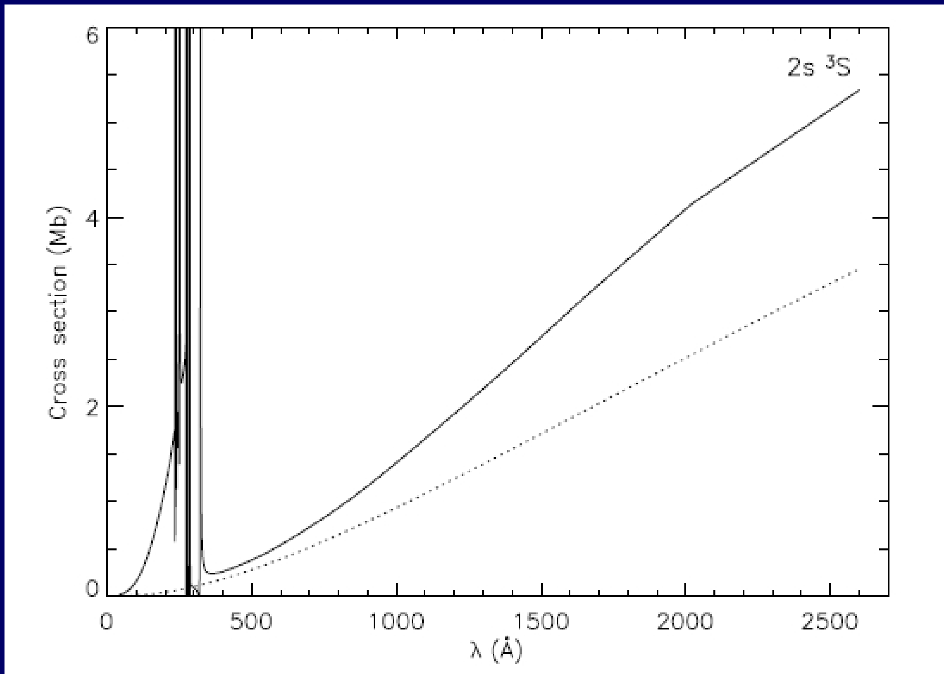
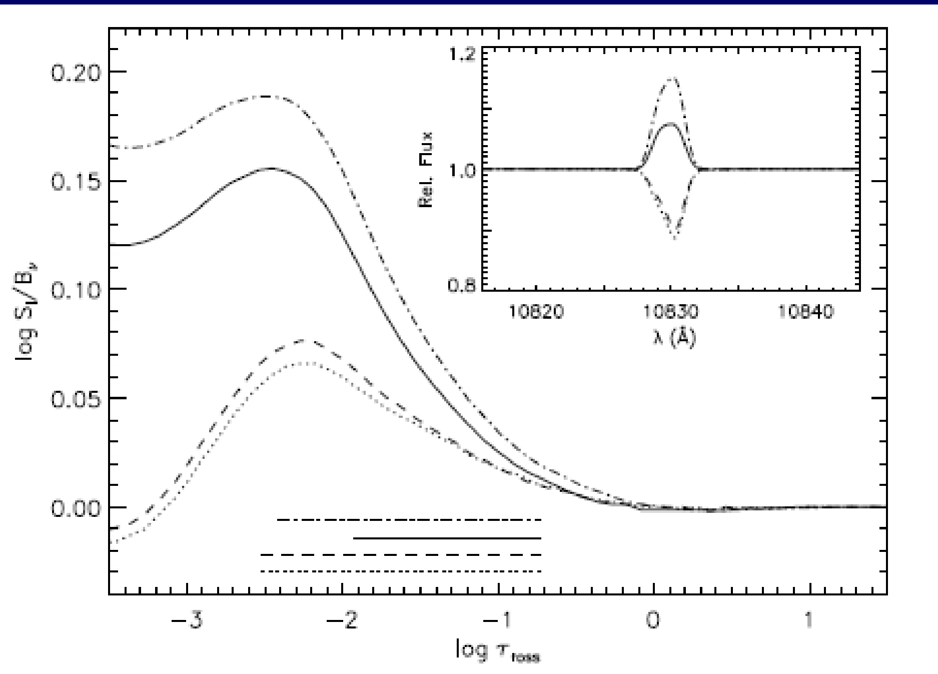
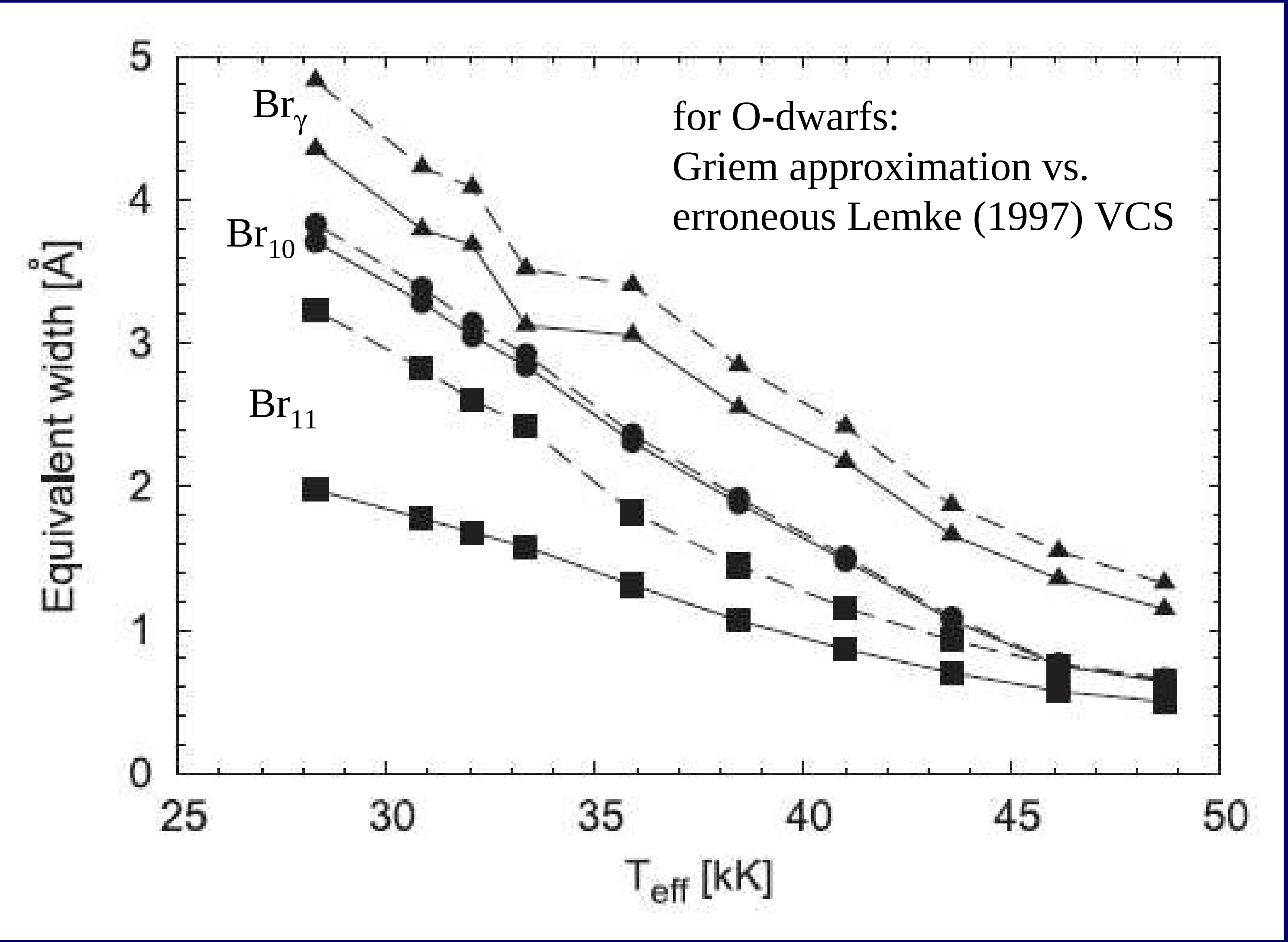
Przybilla 2005





The importance of line broadening data

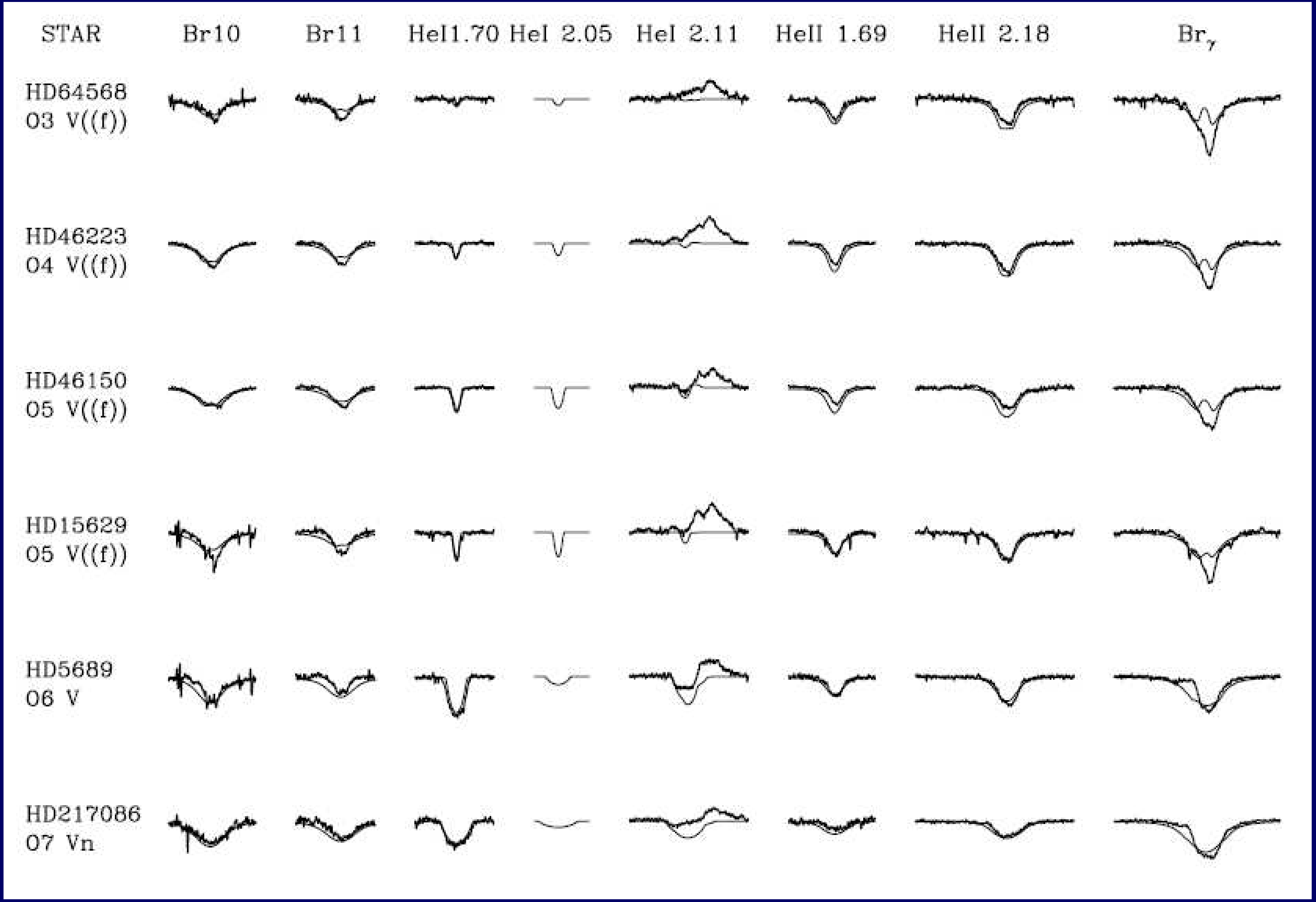


FASTWIND

Repolust et al. 2005

Quantitative NIR spectroscopy: dwarfs

FASTWIND

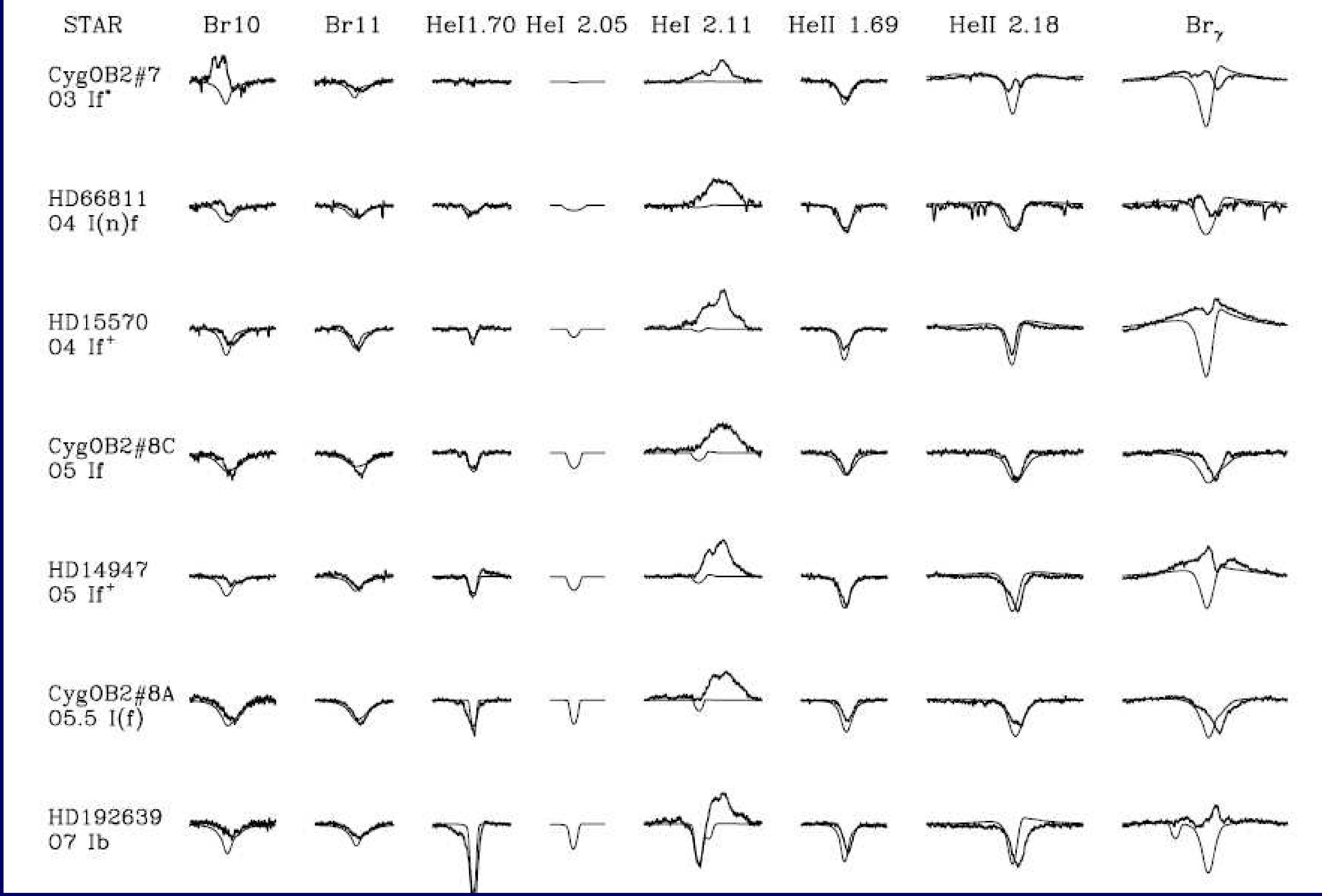


Observations: SUBARU-IRCS R≈12,000

Repolust et al. 2005

Quantitative NIR spectroscopy: supergiants

FASTWIND

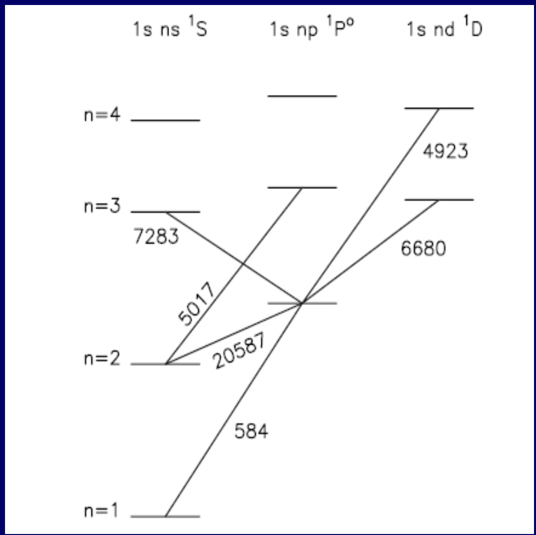


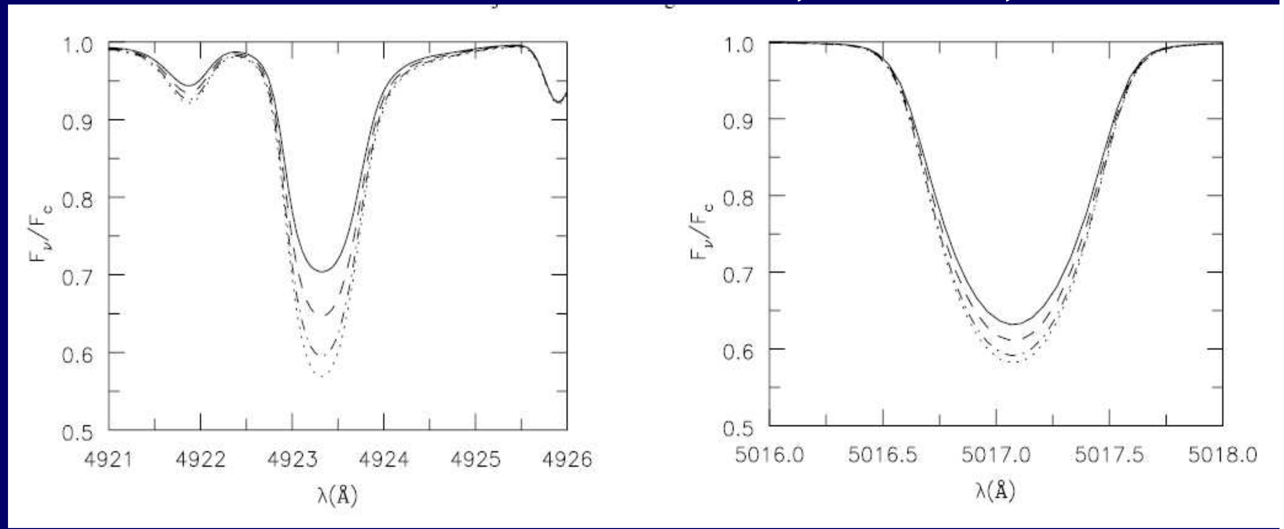
H/HeI/HeII H&K band lines become stronger if gravity decreases

Repolust et al. 2005

Details matter: HeI singlet–triplet inconsistencies

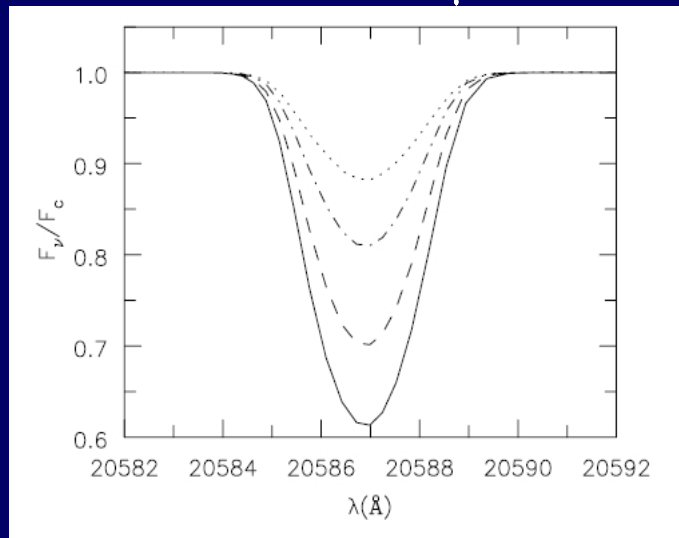
CMFGEN, TLUSTY, FASTWIND





Najarro et al. 2006

HeI 2.058μm

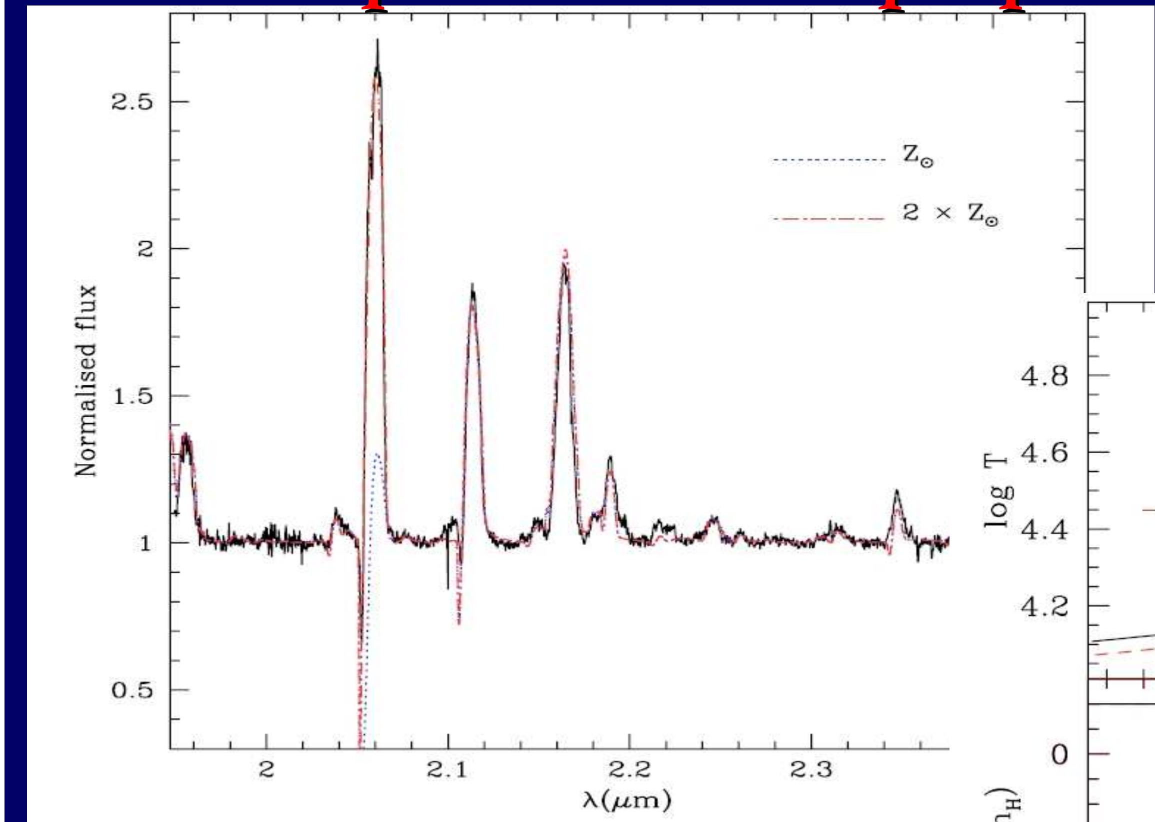


overlap of 584Å resonance line with two FeIV lines:

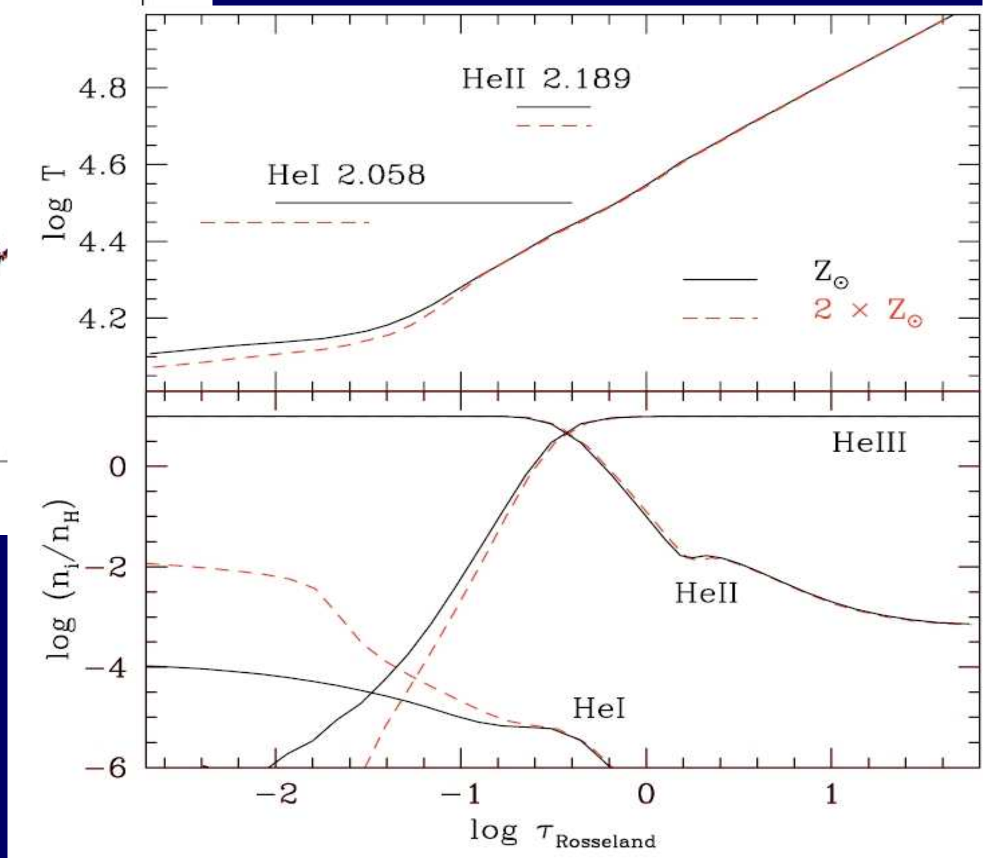
► sensitivity to treatment of

- line blenketing
- turbulence
- oscillator strengths

Central parsec cluster properties



CMFGEN



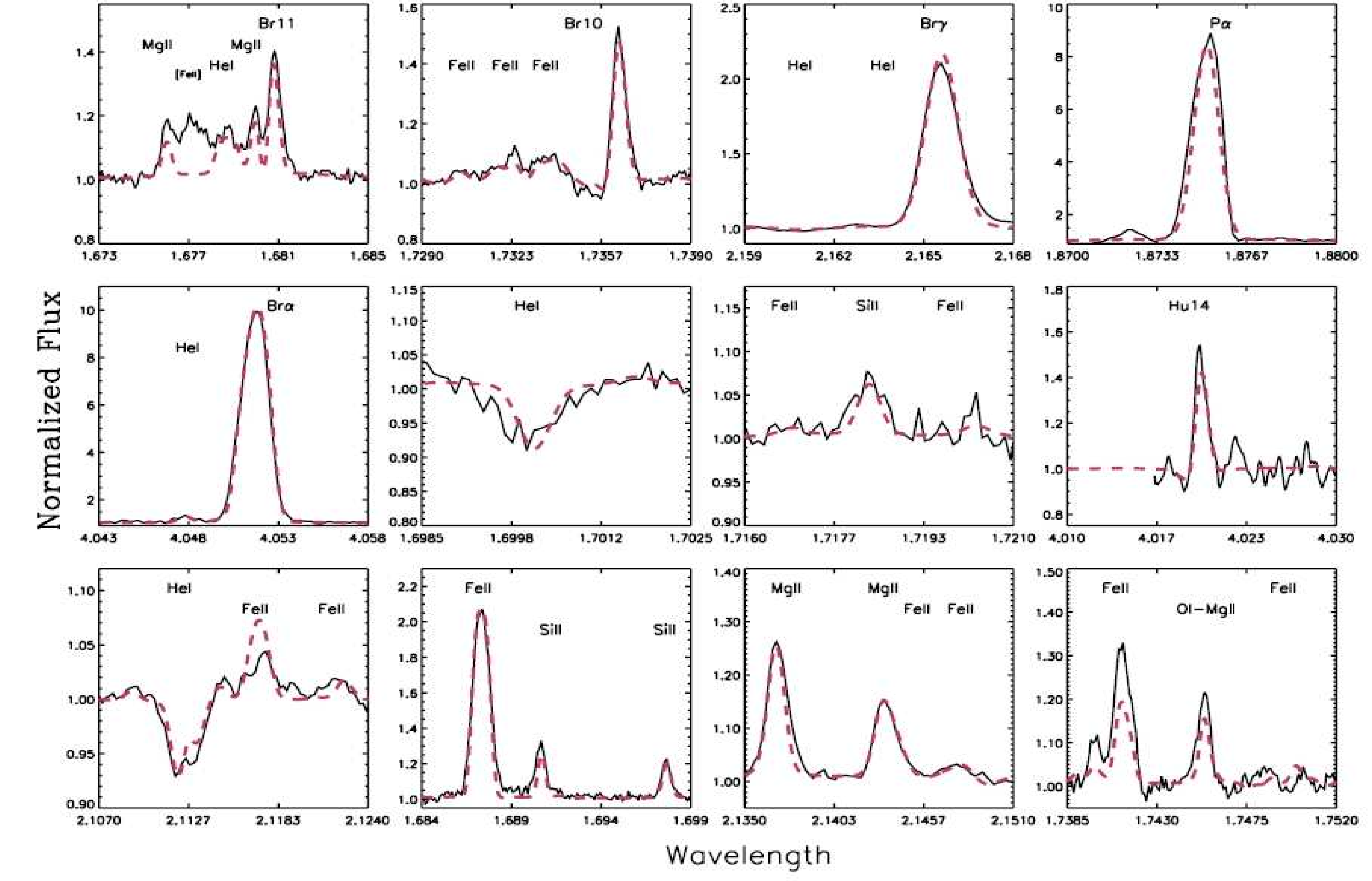
IRS9W (WN8): SINFONI@VLT R≈4000

- metallicity sensitivity of HeI 2.058μm

Martins et al. 2007

Metal abundances of hot stars from the NIR

CMFGEN

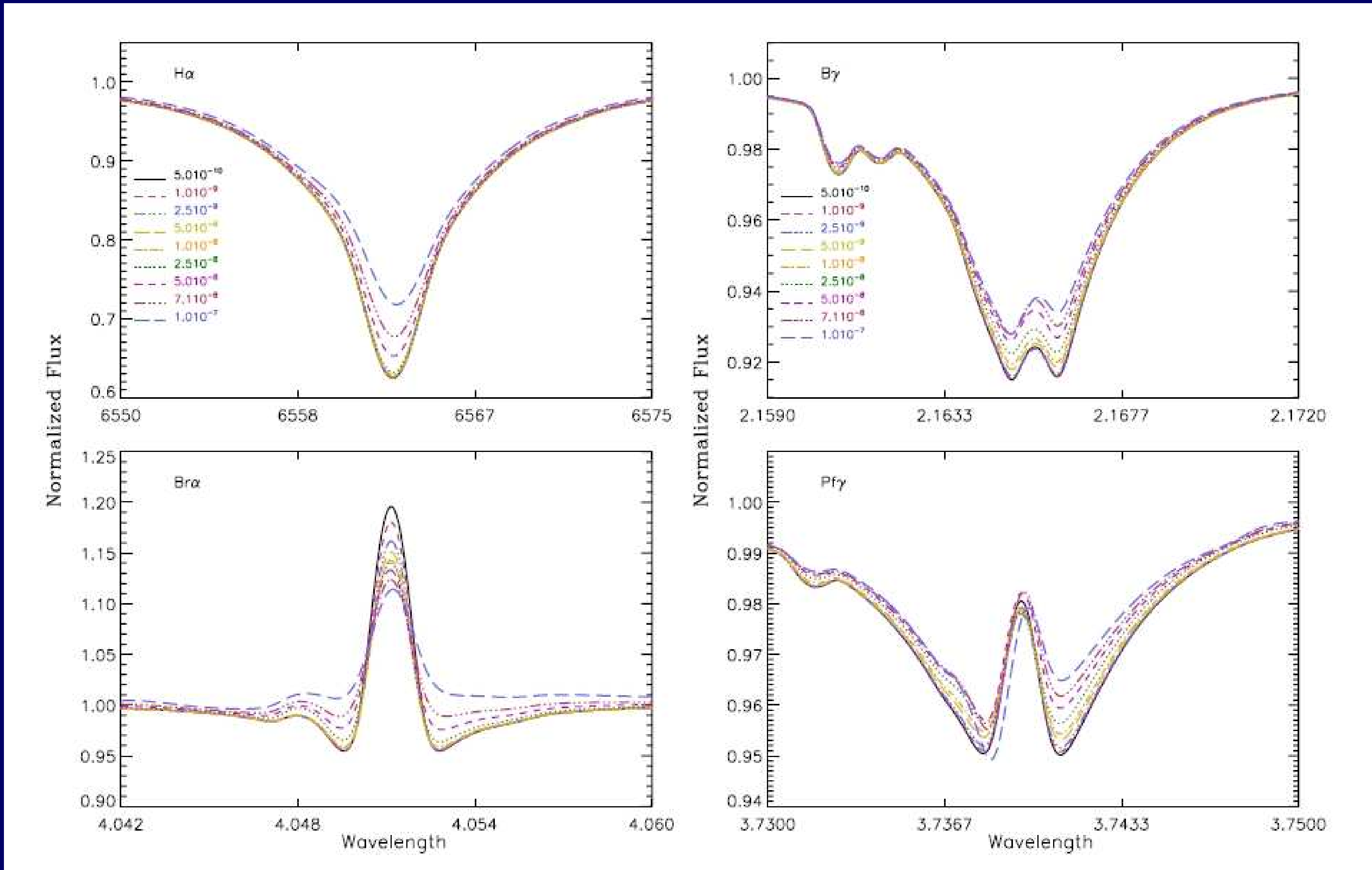


MgII, SiII, FeII abundances from Pistol Star in GC Quintuplet cluster

Najarro et al. 2009

NIR mass-loss diagnostics

CMFGEN



Brα & Pfγ spectroscopy: wind clumping & weak wind problem

Najarro et al. 2011

Pilot study with **CRIRES** for future ELT applications:

why 1st time high resolution?

- Telluric lines resolved (R~100 000)
- Spectral line identification (detailed line profiles)
- Detailed comparison observation / synthetic spectrum
- Model atoms calibrations (non-LTE physics)
- Benchmark study

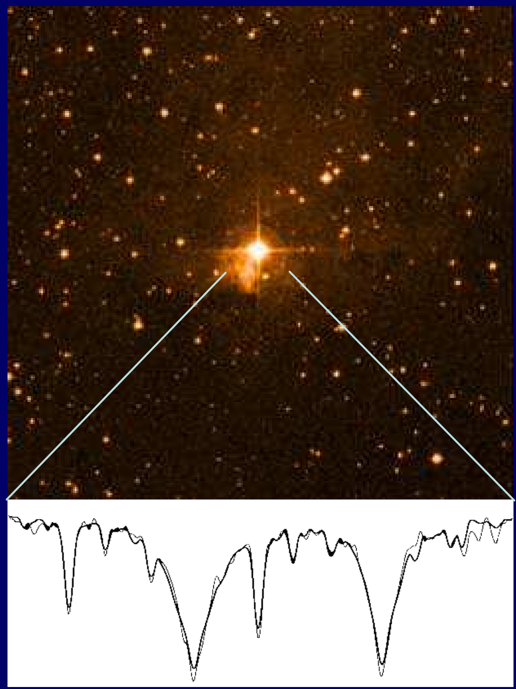
Previous work in the optical

- precise atmospheric parameters & metal abundances
- large reduction of systematic uncertainties

Nieva & Przybilla / Przybilla et al. series

stellar analyses from
quantitative spectroscopy:

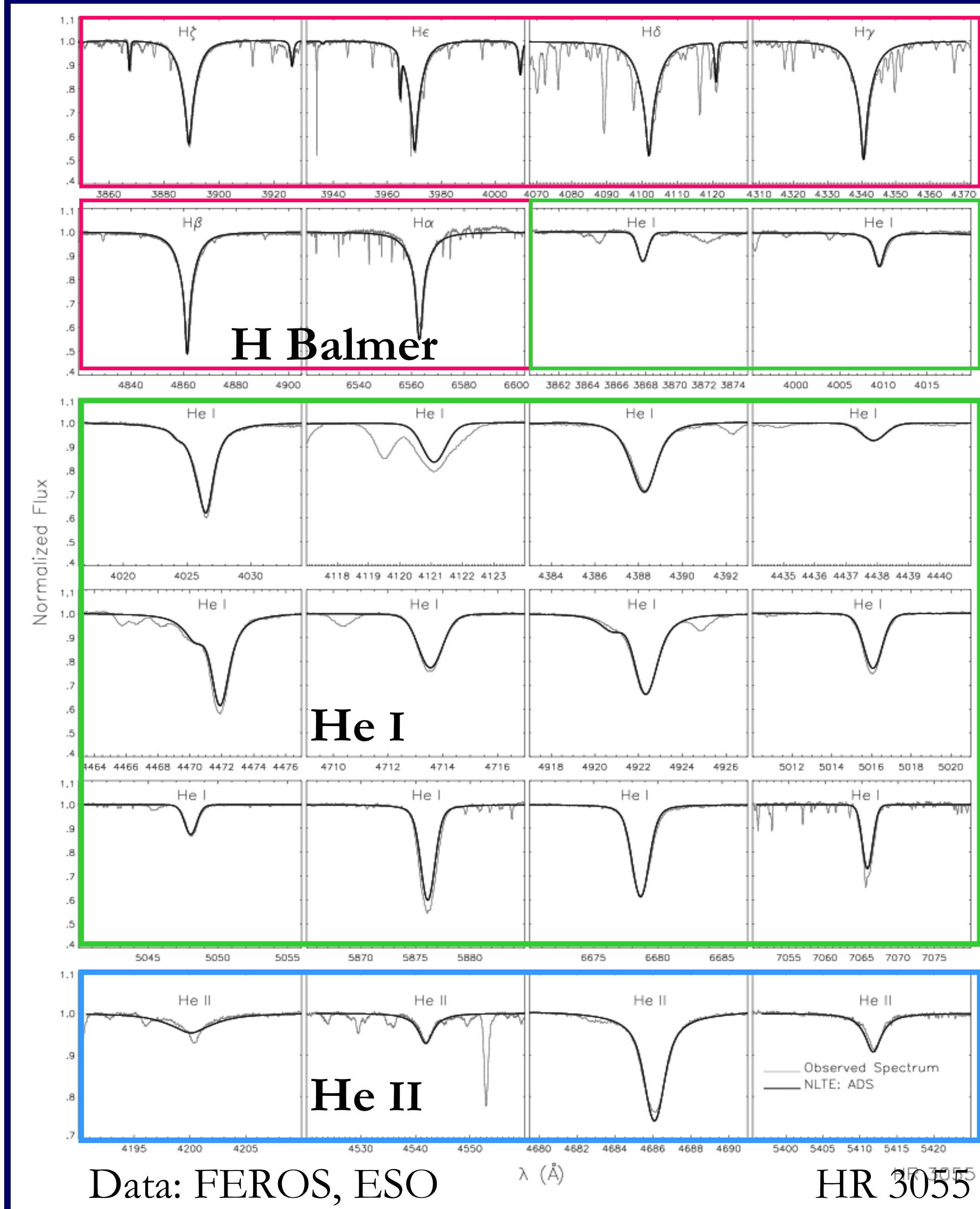
derivation of stellar parameters
& abundances from spectrum

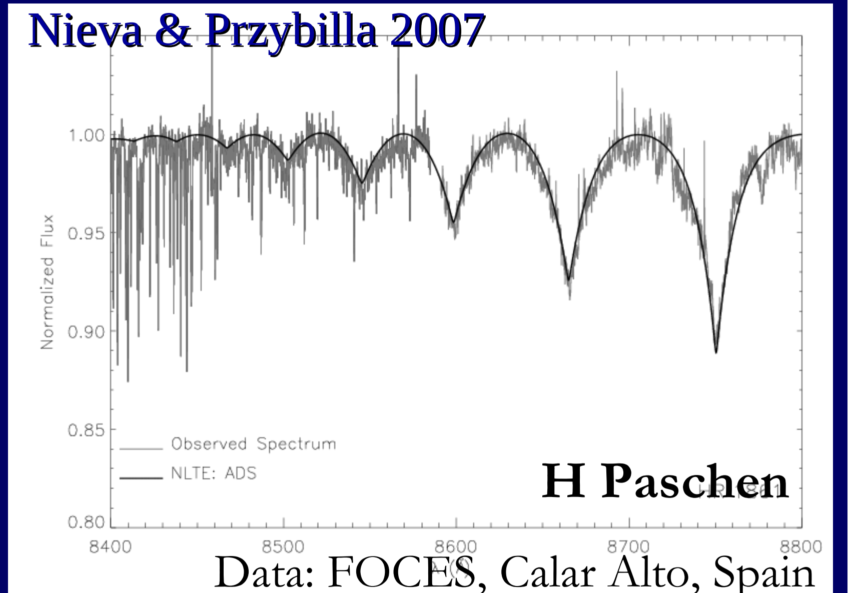


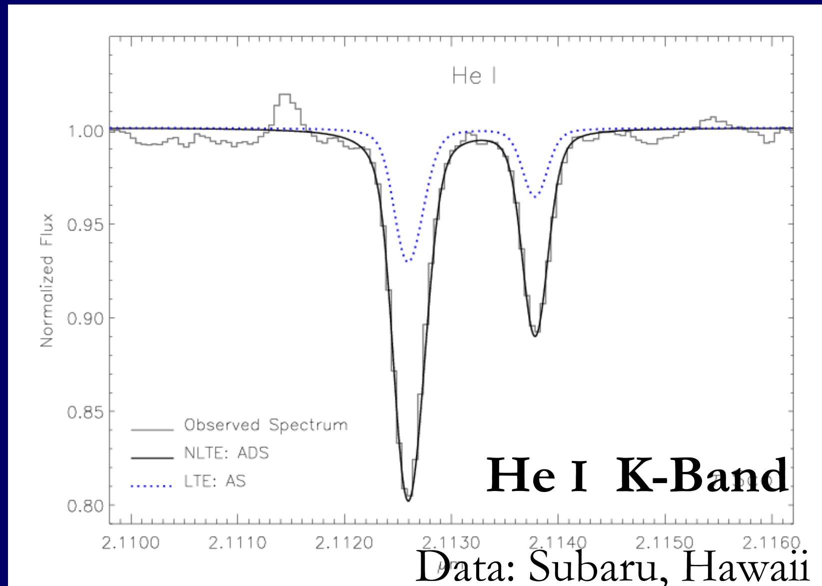
Simultaneous fits to most measurable H/He lines

Visual

Near-IR







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Fits to C lines

Data: FEROS, ESO

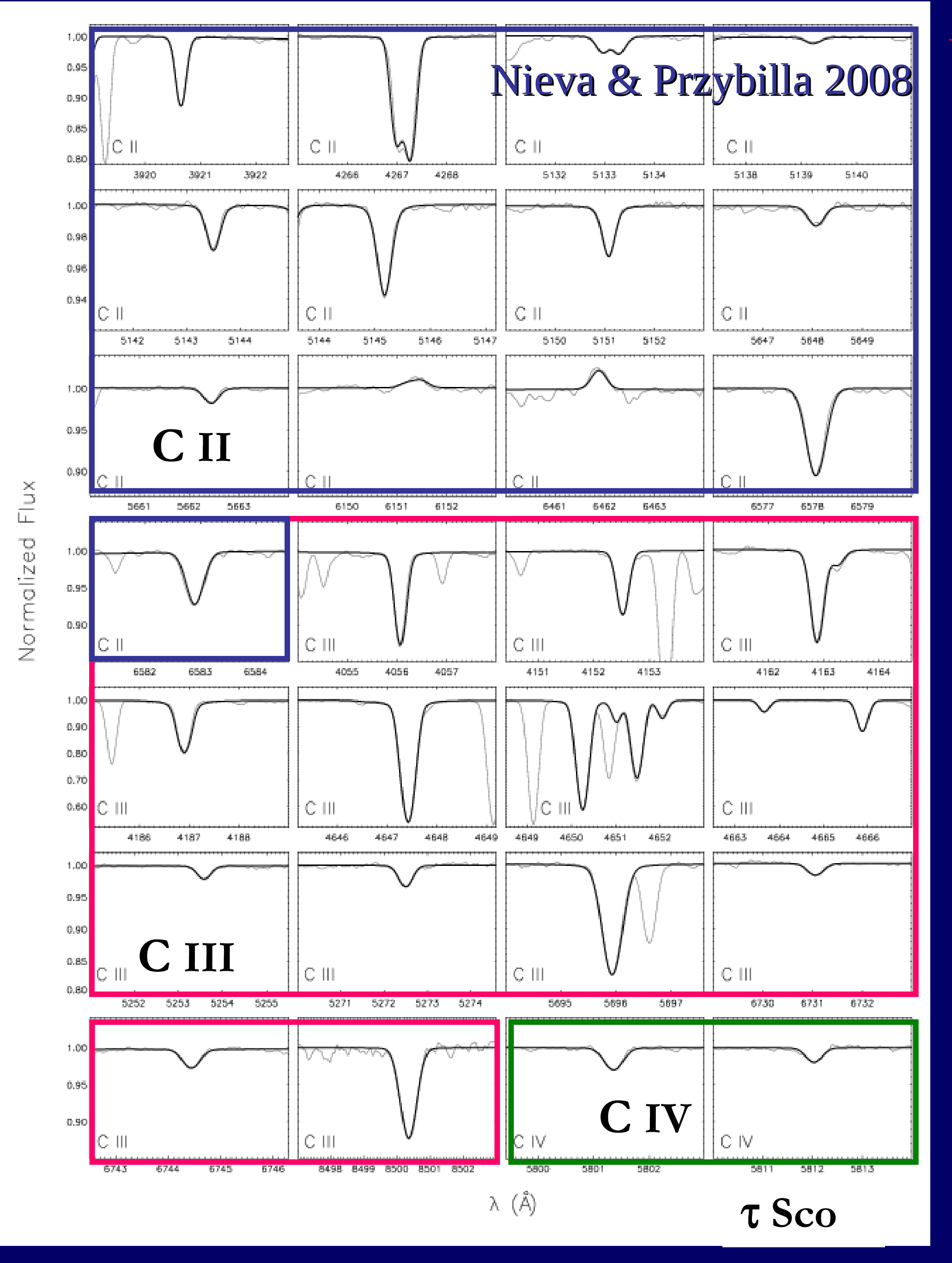
S/N up to 800

Precise quantitative analysis

All lines have very similar abundances

low 1σ–uncertainties

Similar analysis for other metals



Visual

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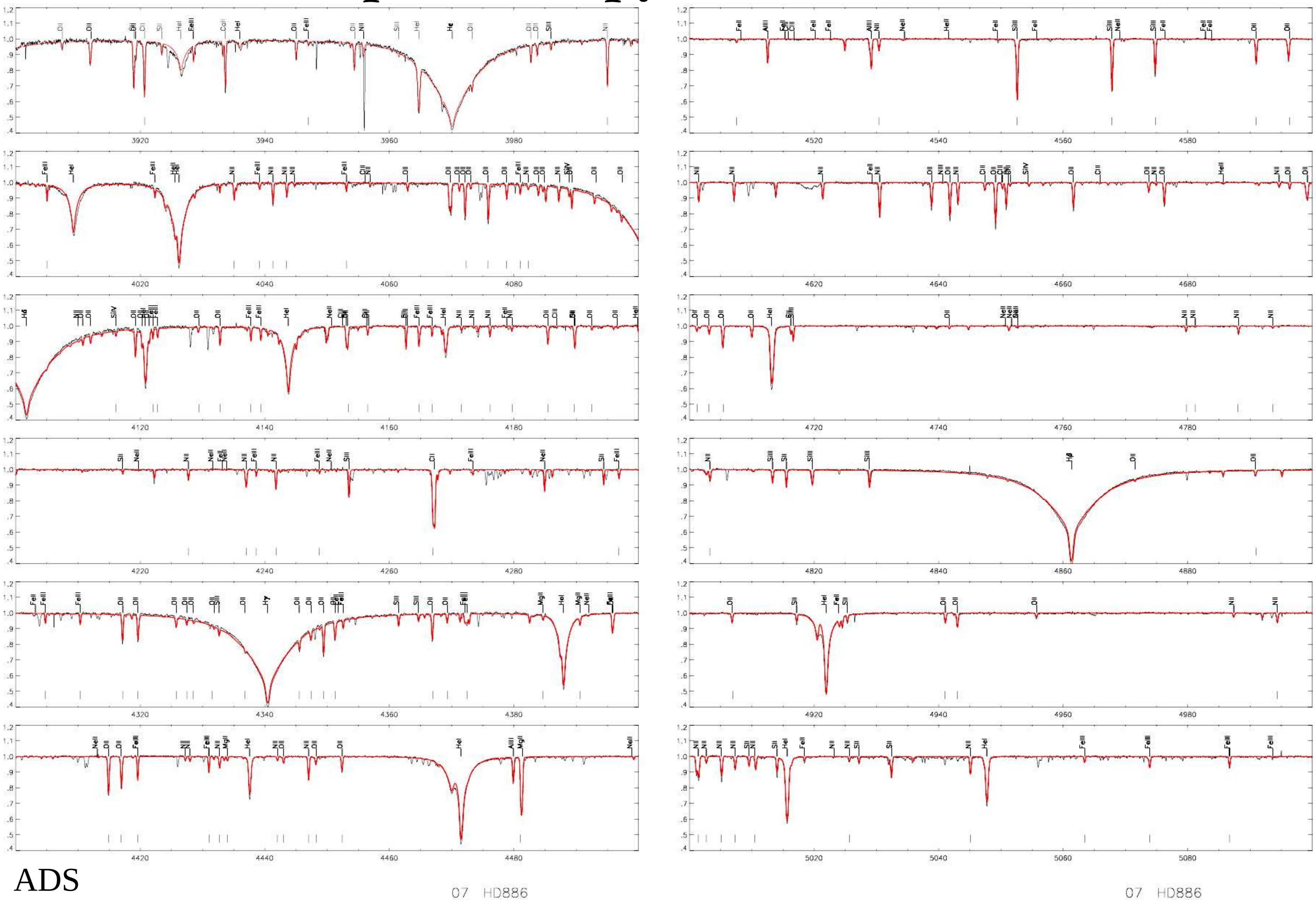
Quantitative Spectroscopy in Visual

Nieva & Przybilla (2012)



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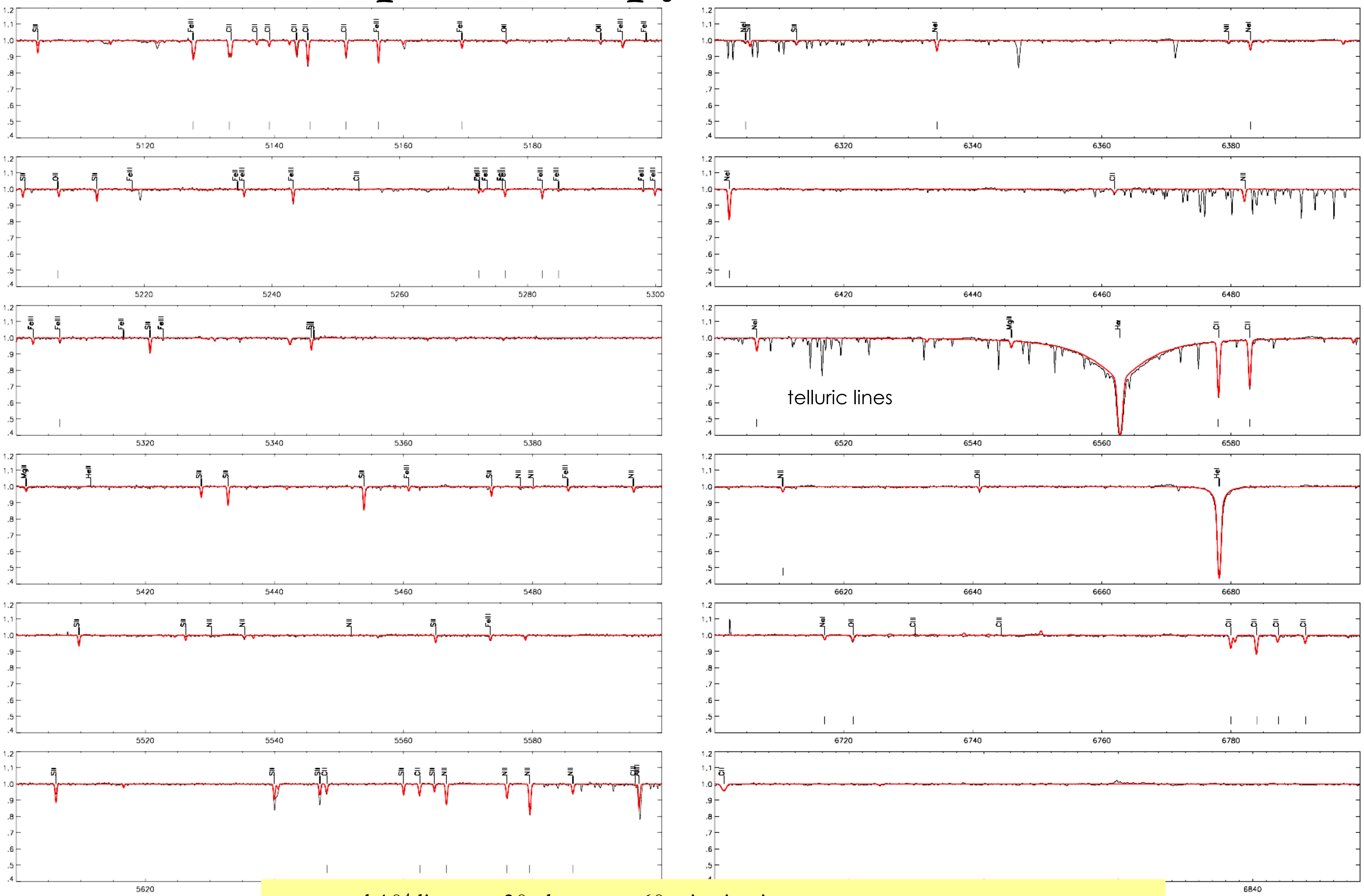
Quantitative Spectroscopy in Visual

Nieva & Przybilla (2012)



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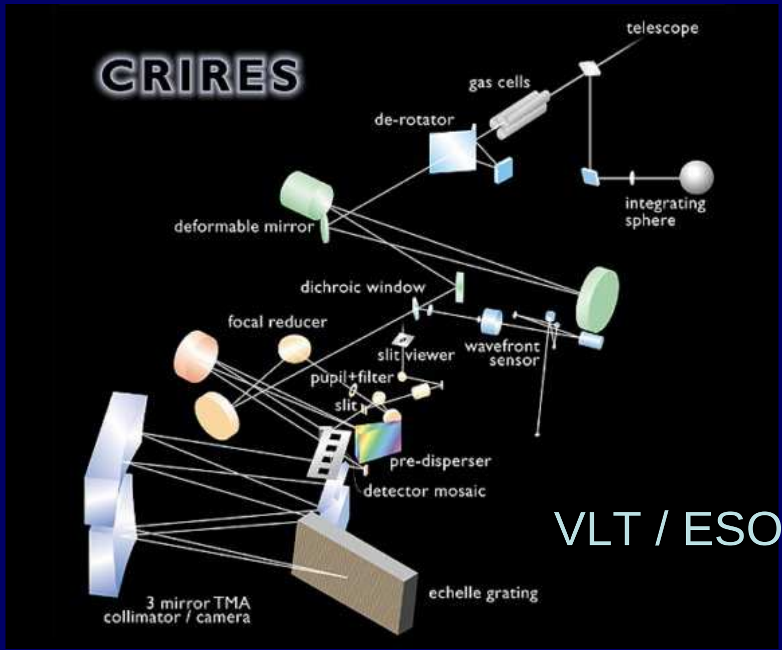
- several 10^4 lines: ~30 elements, 60+ ionization stages
- complete spectrum synthesis in visual (& near-IR) ~70-90% in NLTE

Spectra

• objects: OB main sequence & giant stars
solar neighbourhood
apparently slow rotators

→ well studied in the visual



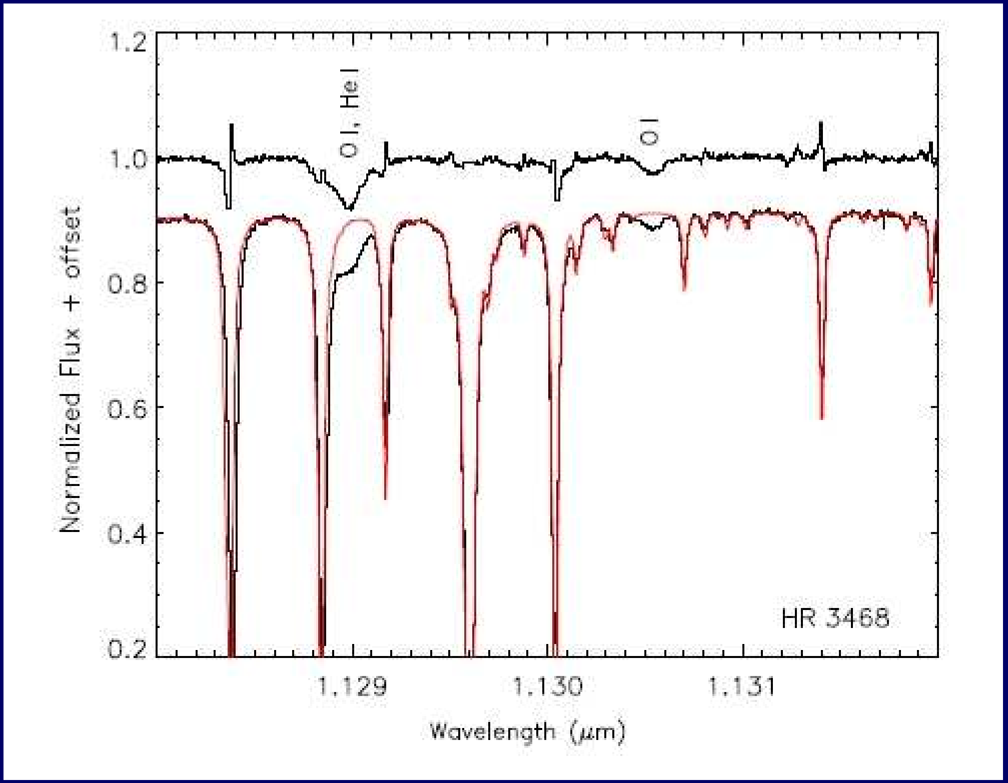
Käufl et al. (2004)

• data: high-S/N CRIRES spectra
broad wavelengh range: **~ .99 – 4.3 μm**

• data reduction: 1st approach: pipeline
now: customized reduction

Difficulties from observations: regions with strong telluric lines

(Example for old data reduction)



Telluric lines modeling: 1st approach

(Now: improved!)

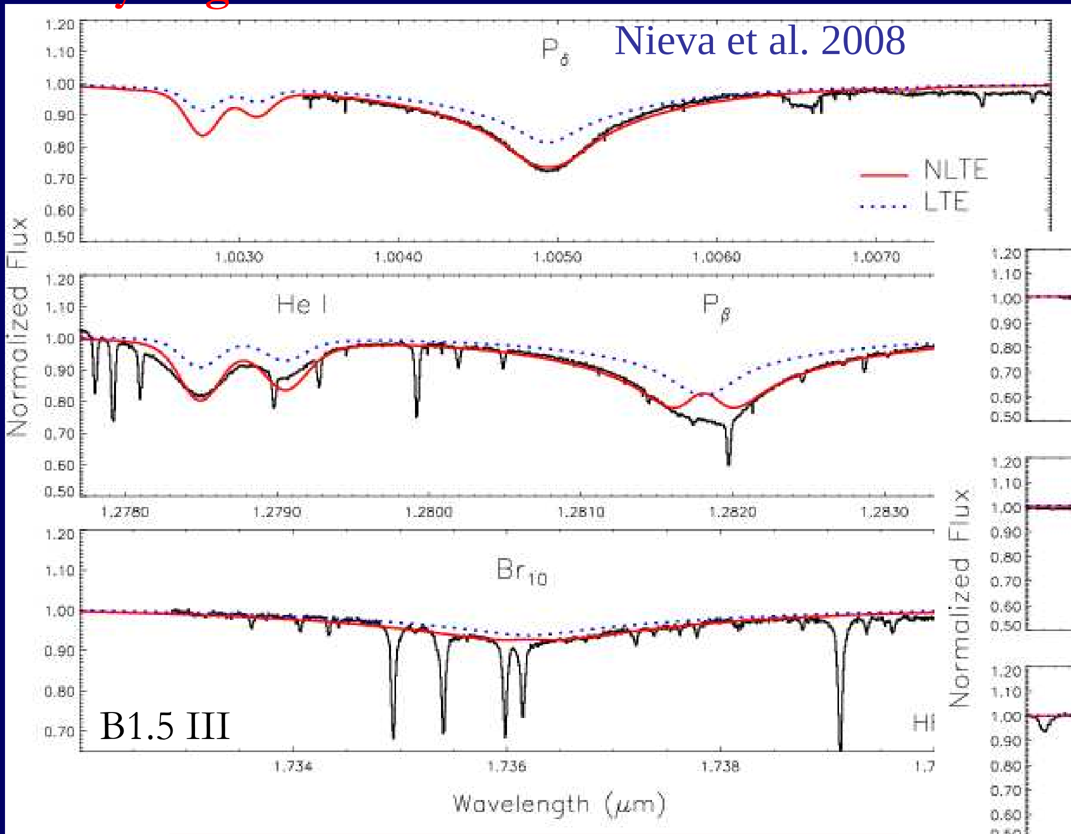
Nieva et al. (in prep.)

Modeling CRIRES stellar spectra

preliminary analysis:

- consistency with visual
- strong NLTE effects

Hydrogen



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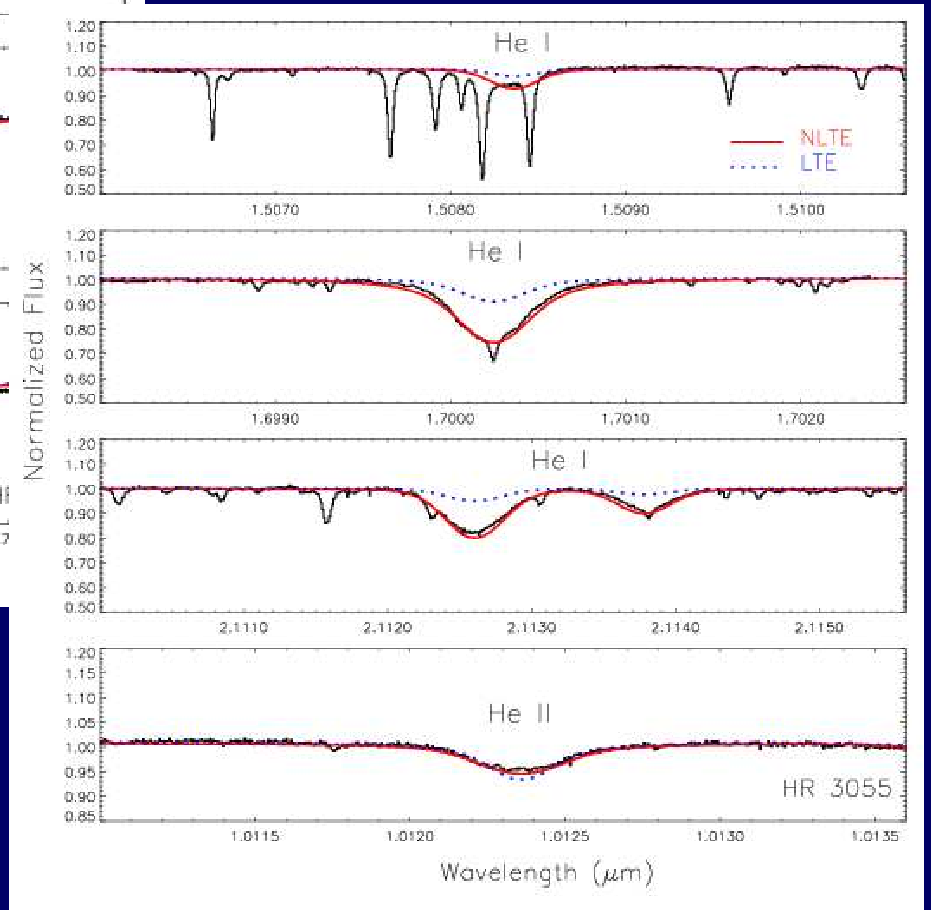
Helium

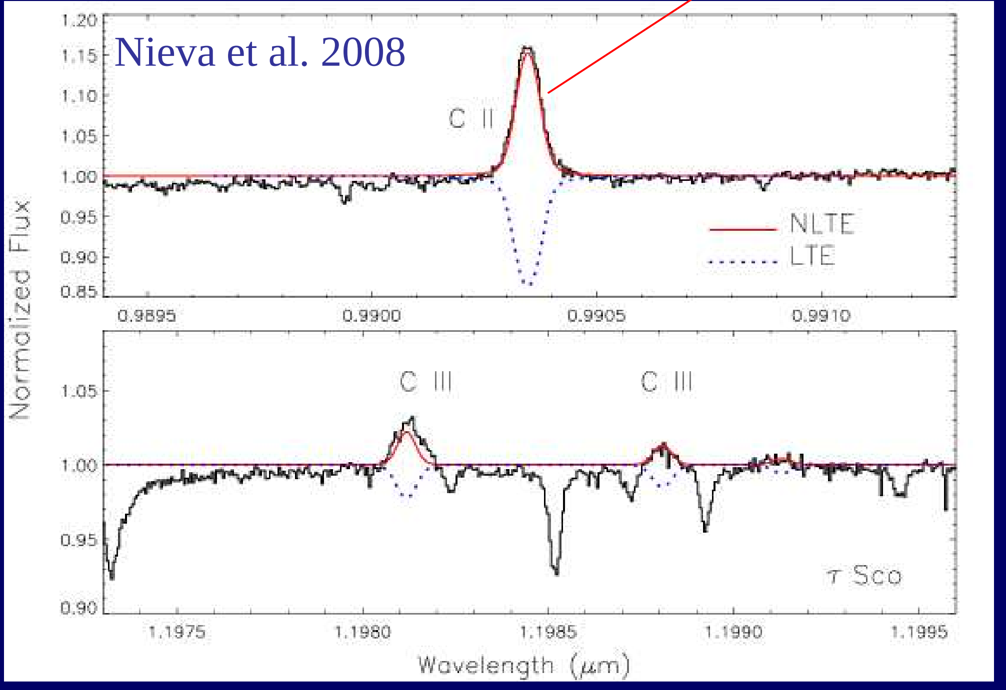


H lines → T_{eff} & log g
He lines → T_{eff} & ε(He)
He I/II ioniz. equil. → T_{eff} & log g

Modeling CRIRES stellar spectra

ADS

our models



H lines → T_{eff} & log g
He lines → T_{eff} & ε(He)
He I/II ioniz. equil.→ T_{eff} & log g
C II/III ioniz. equil.→ T_{eff} & log g

Quantitative agreement with visual

Also: α-elements

Model: so far NLTE populations from visual !

not best fits !

OB stars as science spectra

Achievements (so far)

Some lines are still unidentified !

- unprecedented metal line identification in massive stars @ high resolution
- reliable modeling of most identified lines (H, He & metals)
- hotter stars: simultaneous He I/II & C II/III ionization balance

In agreement with analysis in the optical

→ Important for chemical abundance studies in regions observable in near-IR only

Conclusion

- despite enormous sensitivities (non-LTE amplification)

astonishing quality of model fits

- still many challenges ► multiwavelength approach

The Future: Near-IR @ ELTs
application of models & analysis techniques

- near-IR spectroscopic studies of massive stars
- chemical composition @ high precision

  (star formation regions/stellar & galactochemical evolution/GC)

- in the Milky Way & other galaxies (Local Group and beyond)
- telluric standards for other science spectra
- lower resolution R~ 10 000-20 000 (limited also by stellar vsini)