Supergiant Studies out to Virgo & Fornax

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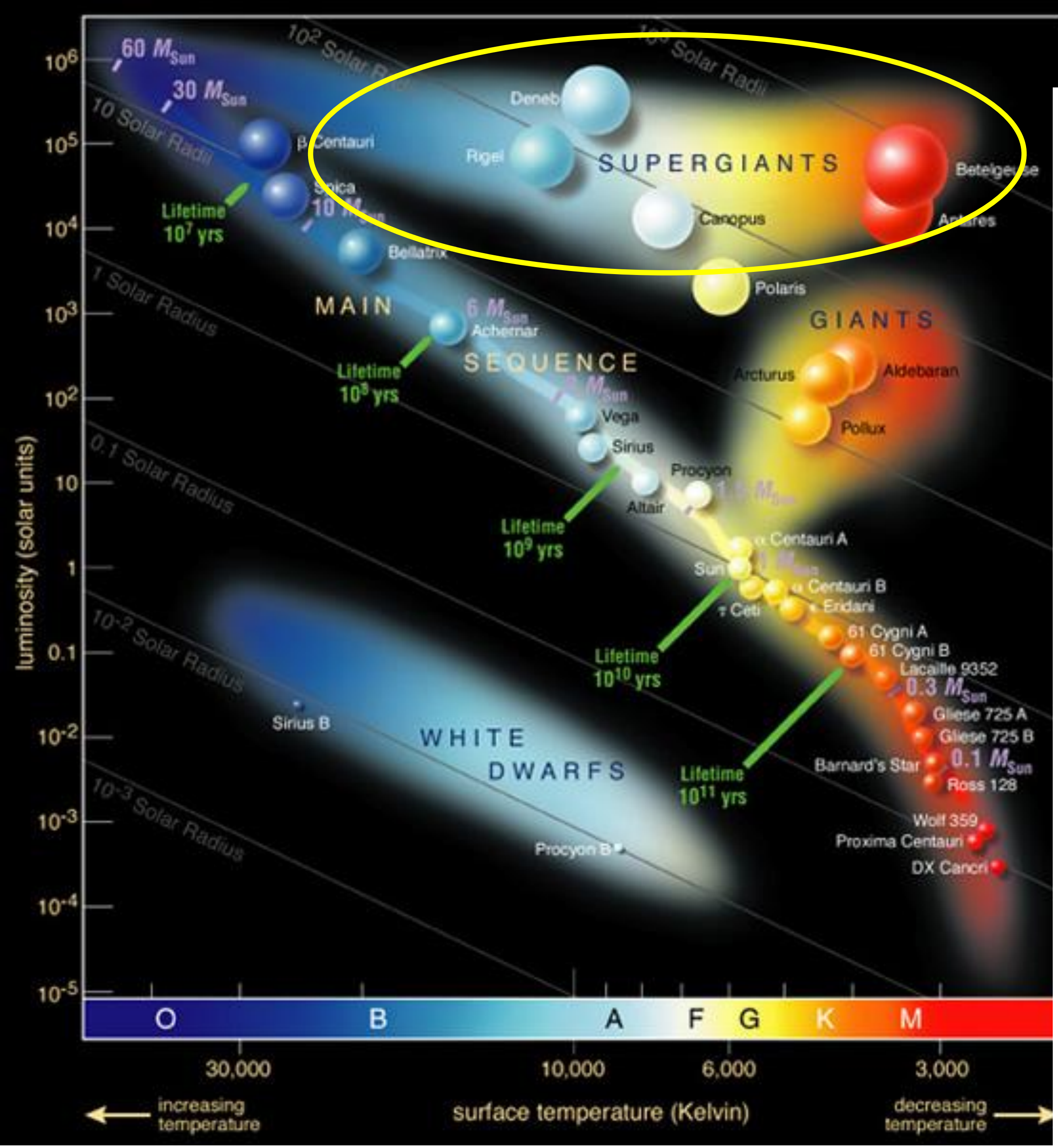
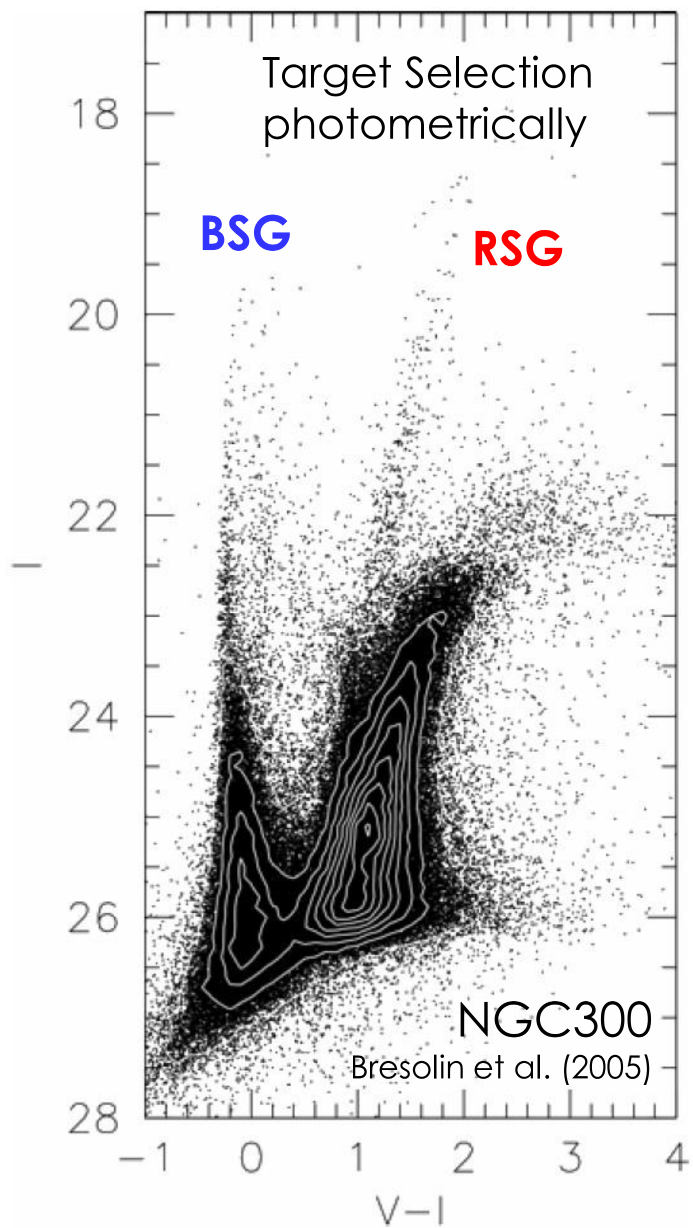
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Supergiants





Science Drivers: Extragalactic Case

- stellar atmosphere physics: NLTE, winds, ...
- stellar evolution: metallicity effects → He, CNO
- **galactochemical evolution:**
  abundance patterns/gradients
  → galaxies in Hubble sequence
  in field, groups & clusters
- cosmic distance scale: FGLR $L \sim \log g/T_{eff}^4$

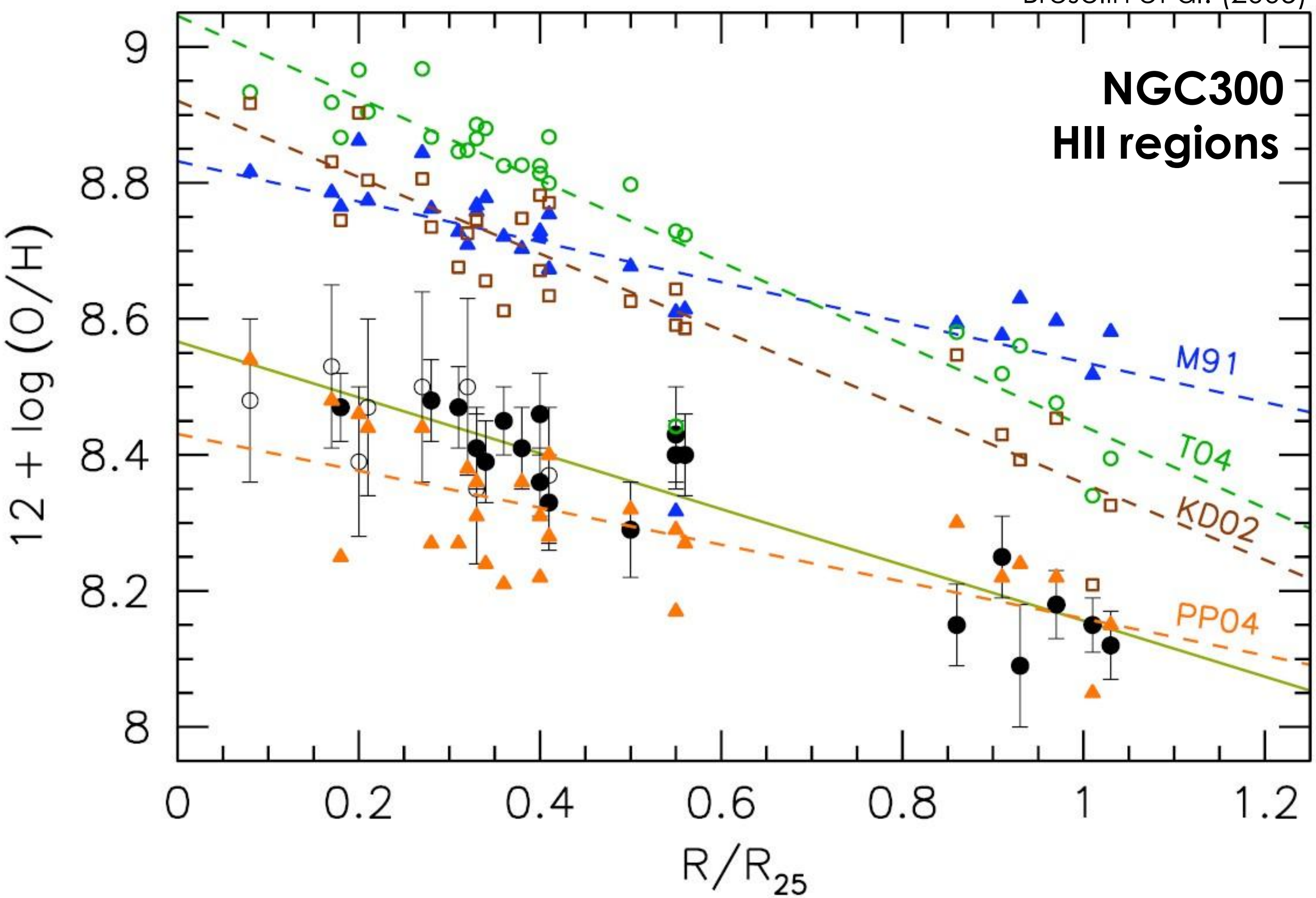
Flux-weighted Gravity-Luminosity Relationship

WLR $L \sim \dot{M}\, v_\infty\, R_*^{0.5}$

Wind momentum-Luminosity Relationship

Abundance Gradients in Spirals

Bresolin et al. (2005)

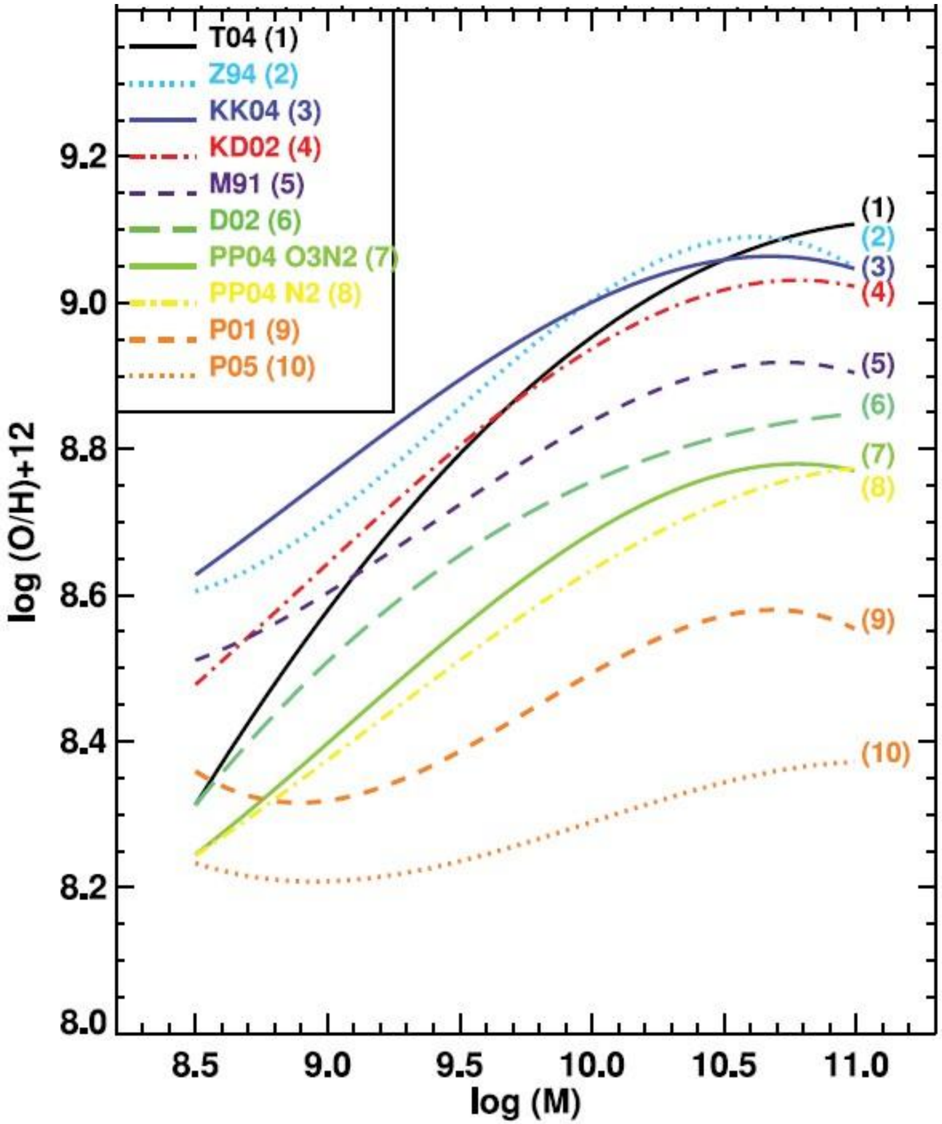


- direct T_e-determination vs. various strong-line methods, e.g. R_{23}
  - ➡ **different slopes, different absolute values**
  - ➡ **constraints on chemical evolution of individual galaxies?**

+ electrons may not follow Maxwell-Boltzman distribution
  κ-distribution ➡ hidden systematics?

Nicholls, Dopita & Southerland (2012)

Mass-Metallicity Relationship

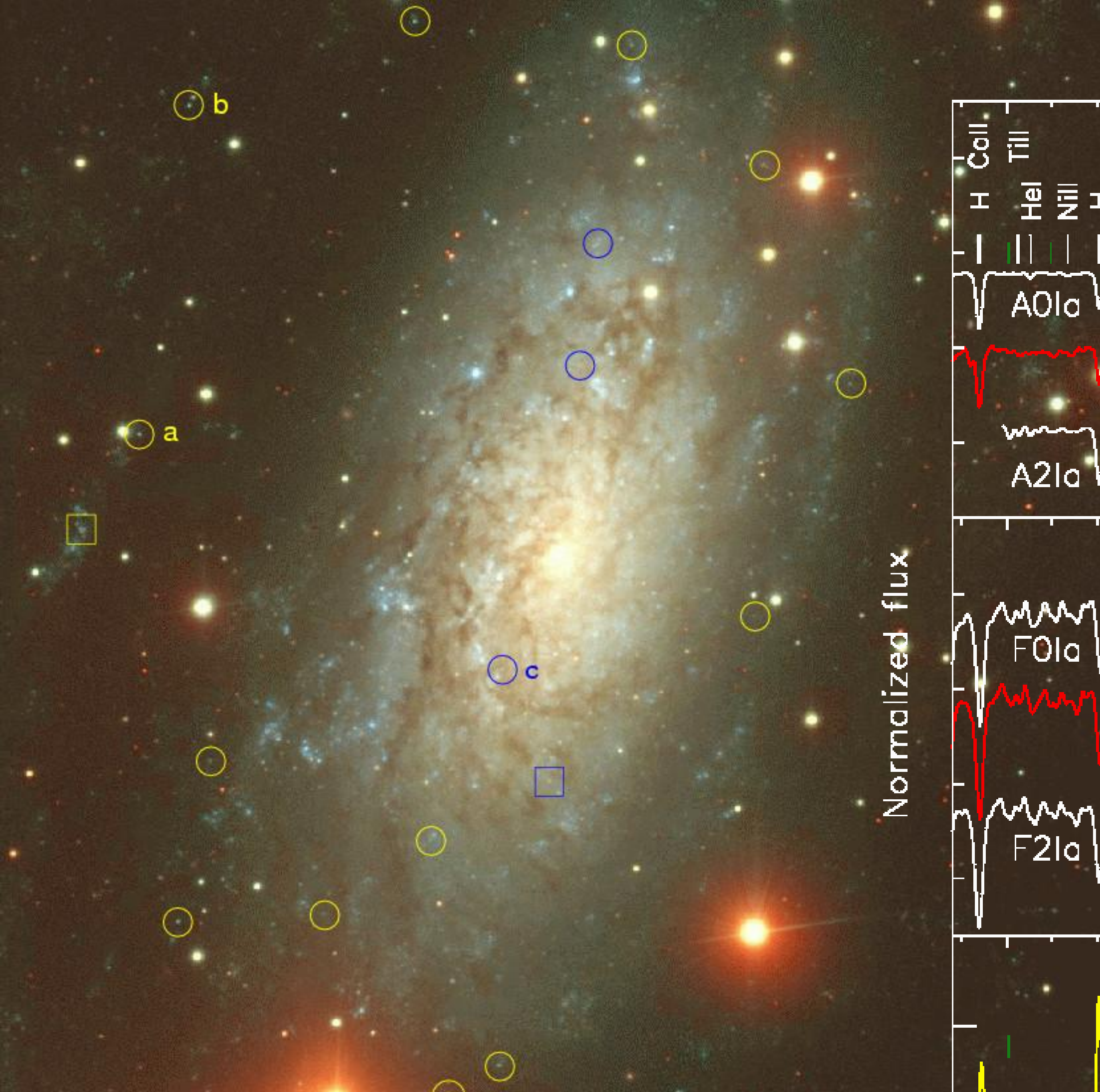


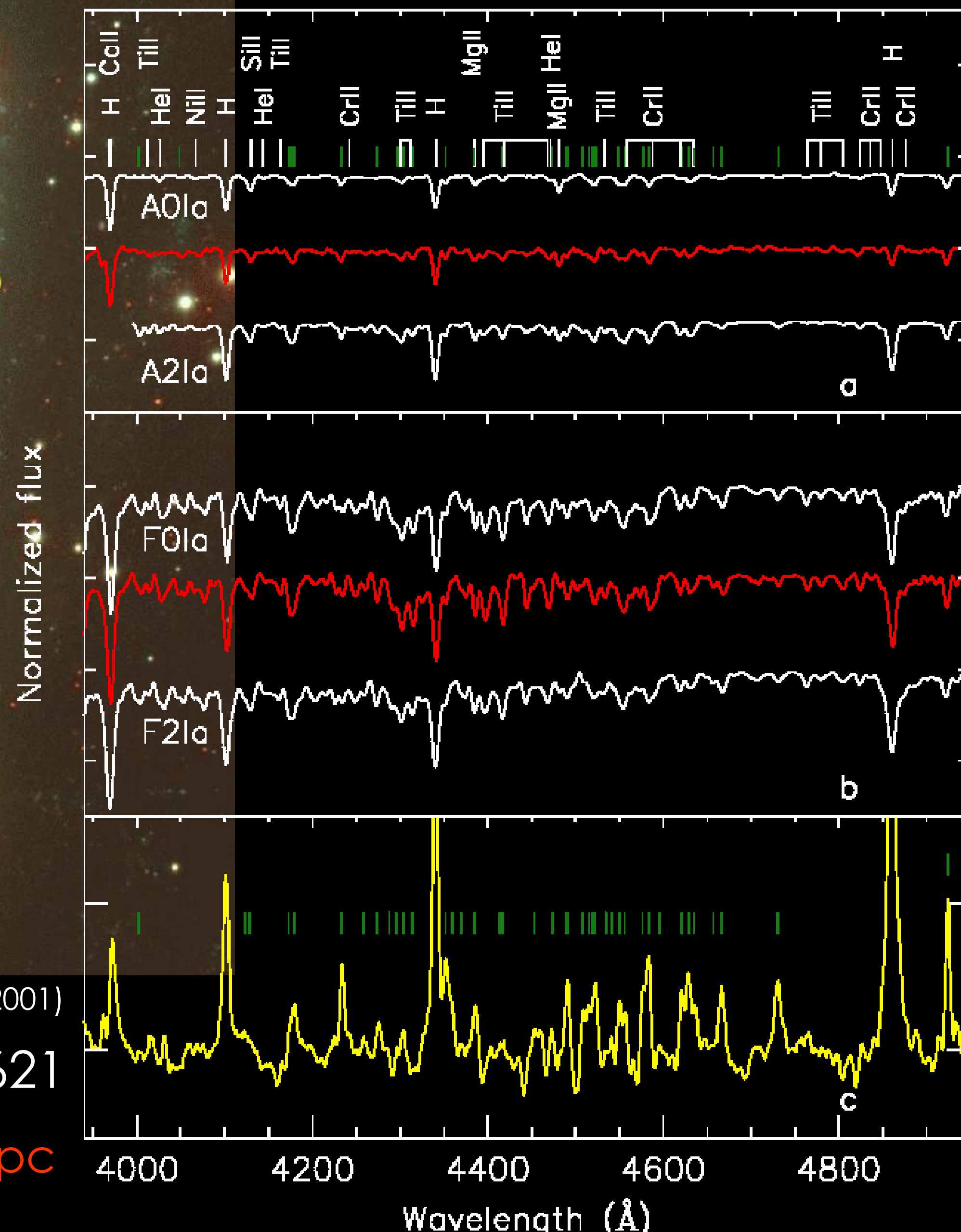
Kewley & Ellison (2008)

- metallicity determination for 25,000 SDSS galaxies
- 10 different strong-line calibrations
- 10 different results on M-Z relation

→ **systematic bias of order 0.5-0.8 dex in Z**

→ **independent indicator required**



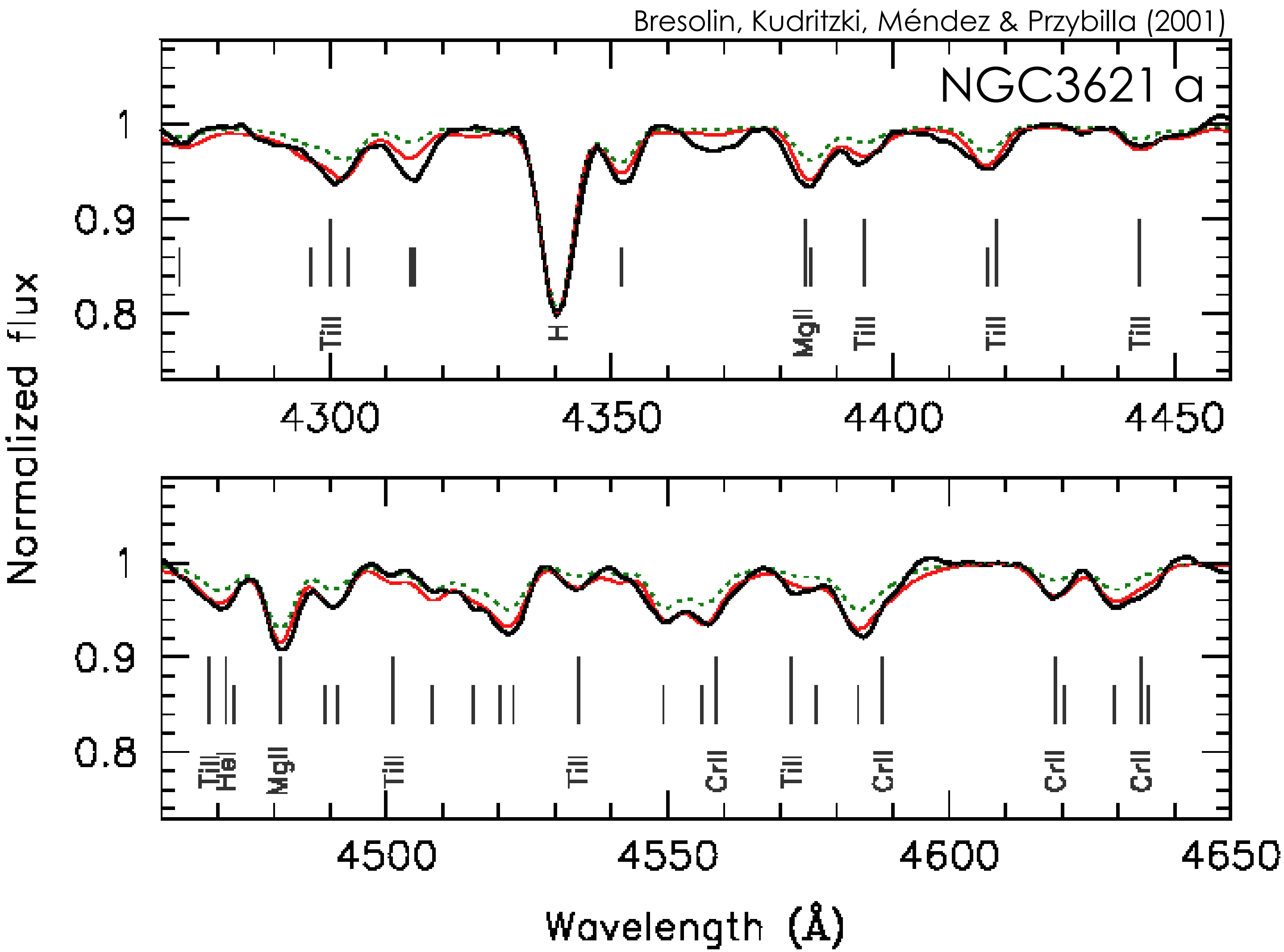


Bresolin, Kudritzki, Méndez & Przybilla (2001)

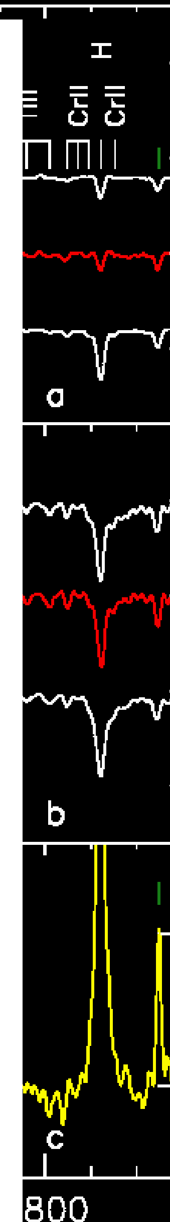
NGC 3621

VLT/FORS1

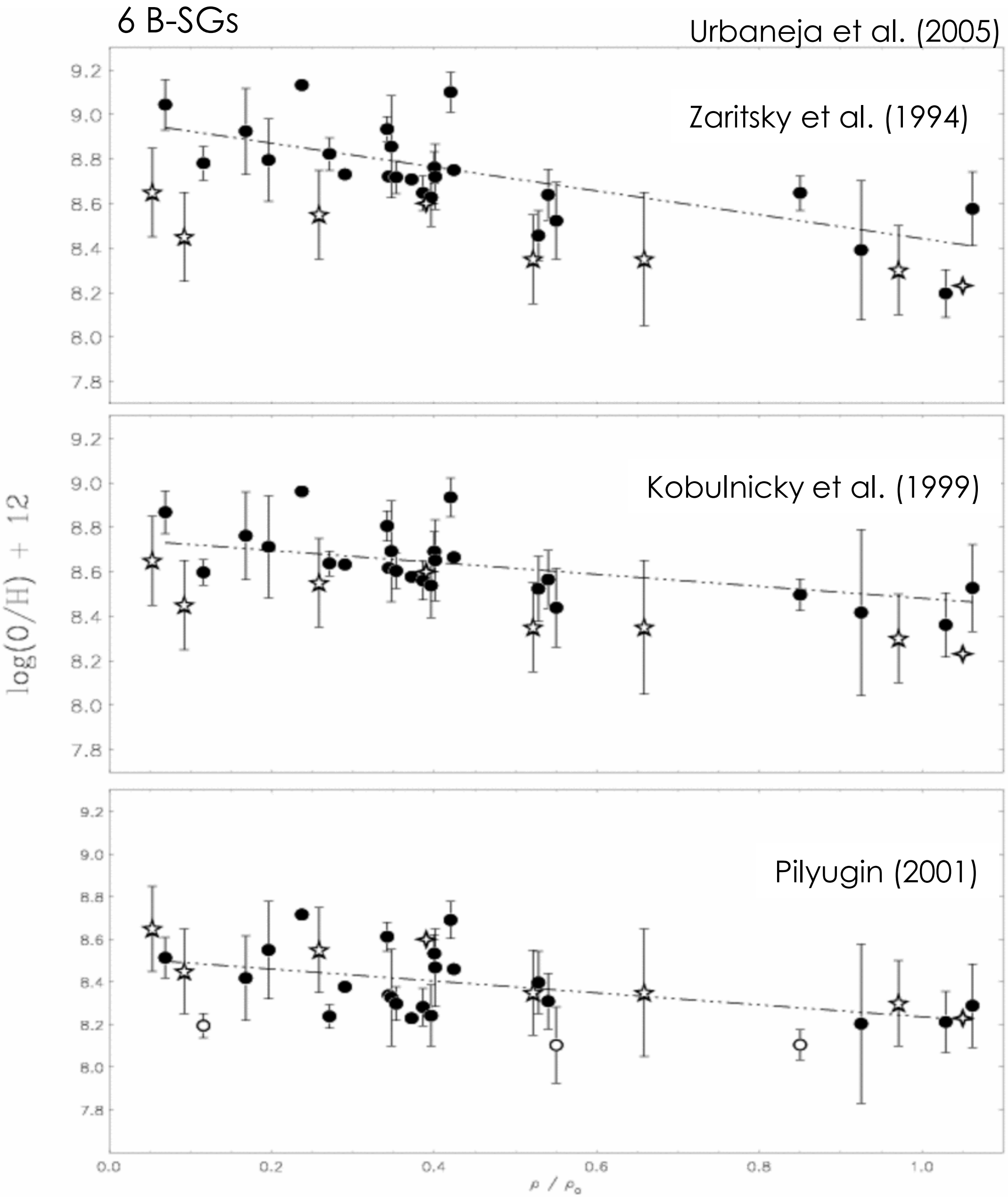
d ~ 6.6 Mpc



spectrum synthesis for 0.5 and 0.2 solar metallicity



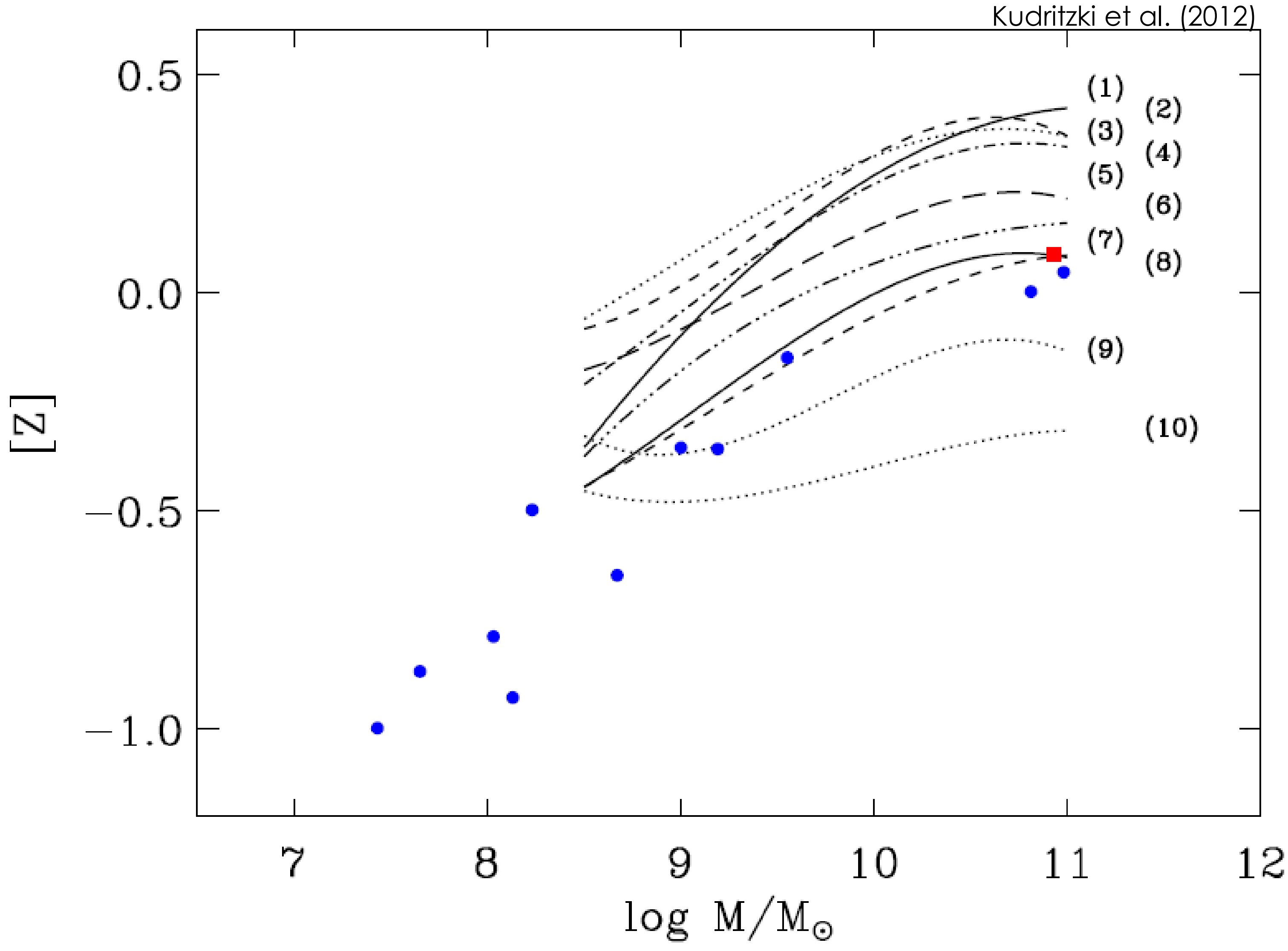
VLT/FC



NGC300: Abundance Gradient BSGs vs. HII regions

- different trends for HII-regions from 3 different R_{23}-calibrations
- **independent verification and extension via stellar analyses**
- **systematic bias in published gradients**

Mass-Metallicity Relationship from BSGs



metallicities in literature overestimated by factor ~ 2

From the Local Group to Virgo & Fornax

NGC6822 14'

Field of View
7' perfect

NGC300 27'

NGC253 26'

CenA
16'

Target density
O(100) in FoV
depends on galaxy

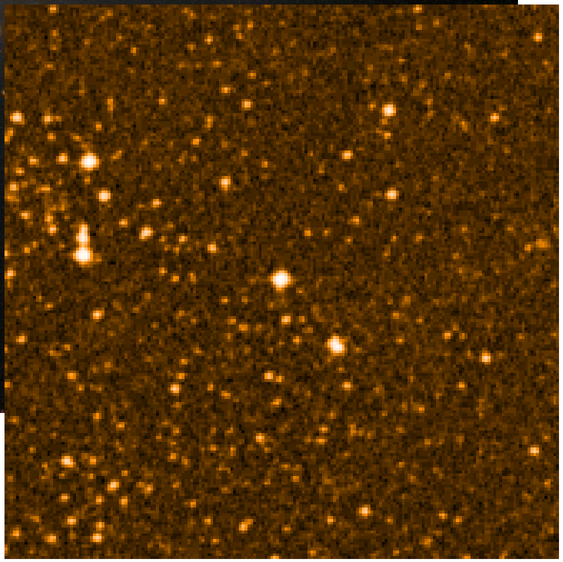
M100 (Virgo) 22'

NGC1365 (Fornax)
12'

Stellar Spectroscopy in Virgo & Fornax

problem: spatial resolution
1“@16.5Mpc: ~80pc

→ **diffraction-limited observation with ELT using AO (near-IR)**



5.5‘ x 5.5‘ in LMC
→ 1“ x 1“ @ Virgo

IFU
high-definition mode
spaxel-size 40mas

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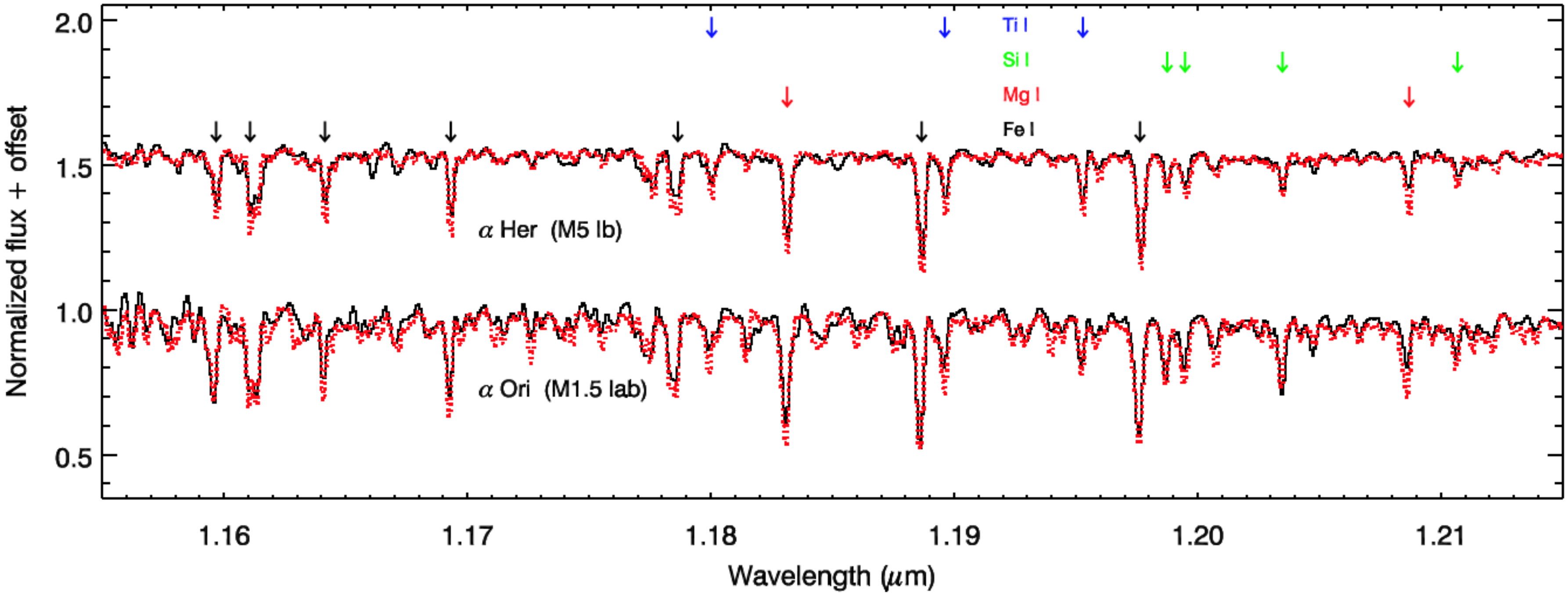
To resolve or not to resolve...

R ~ 5000 in BSG and RSG sufficient for quantitative work

Davies et al. (2010)



Wavelength coverage:

BSGs: J(H) He, CNO, α-elements, Fe

RSGs: JH CNO, α-elements, Fe

S/N constraints:

S/N > 50 100 ☺

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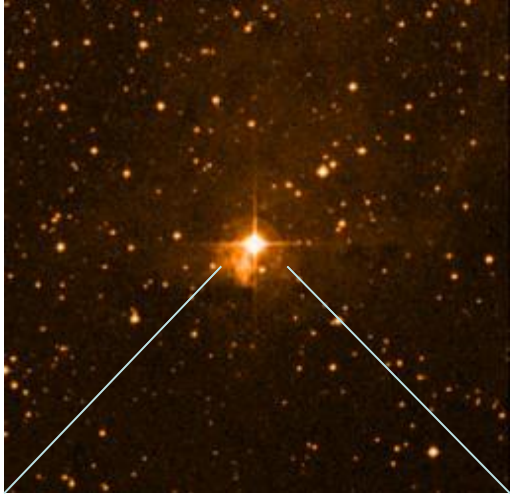
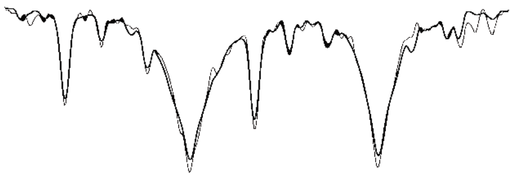
Diagnostic Problem





stellar analyses 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

complication in IR:
amplification of NLTE effects

NLTE line source function:

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

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

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

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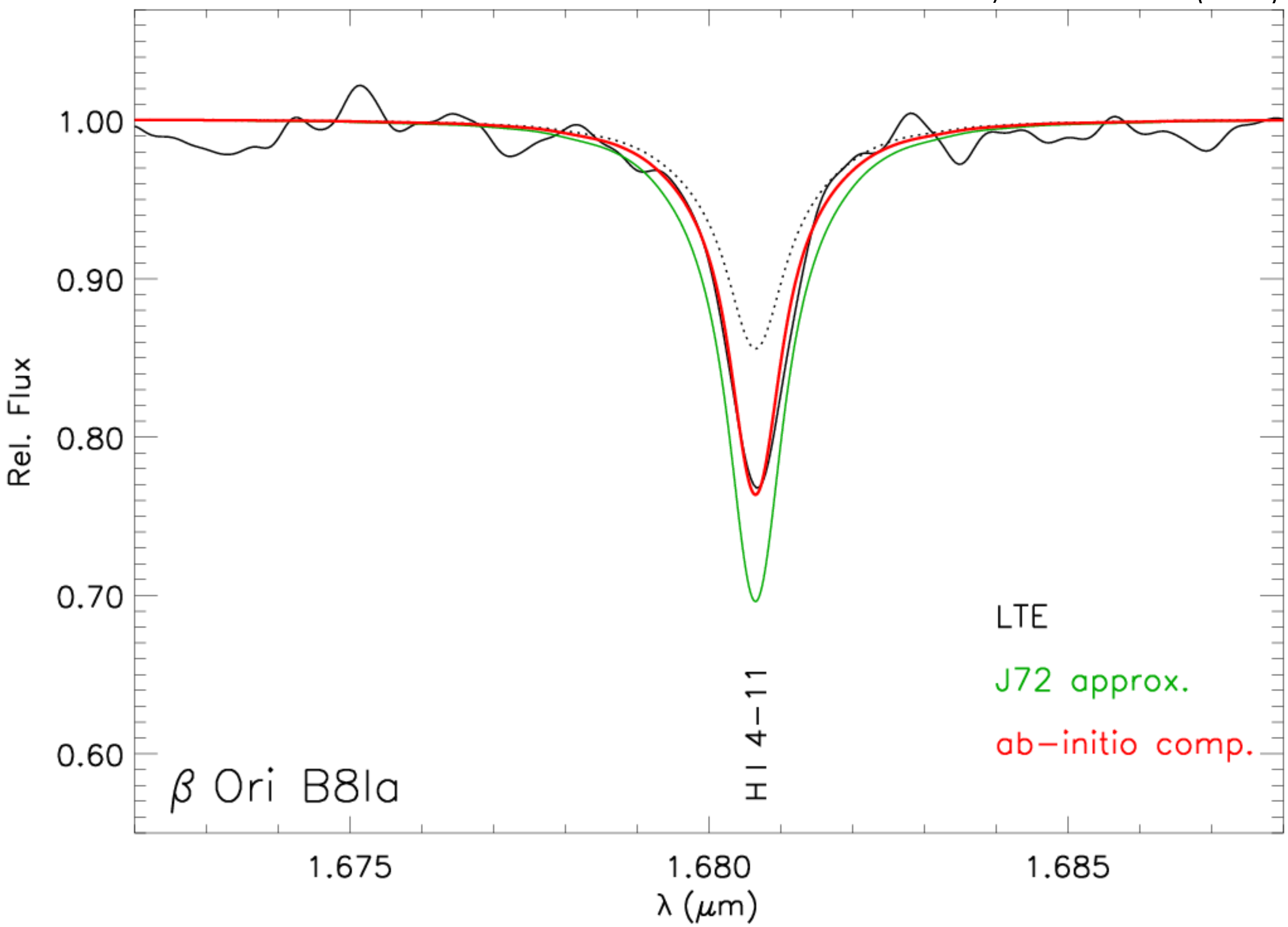
NLTE: need for accurate atomic data

Przybilla & Butler (2004)



H atom:

analytical solution

except

electron collisions: 3-body problem

ab-initio data

vs.

approximations

until recently: medium resolution spectroscopy

- IR-lines equiv. to Balmer lines as gravity indicators stellar parameters/FGLR

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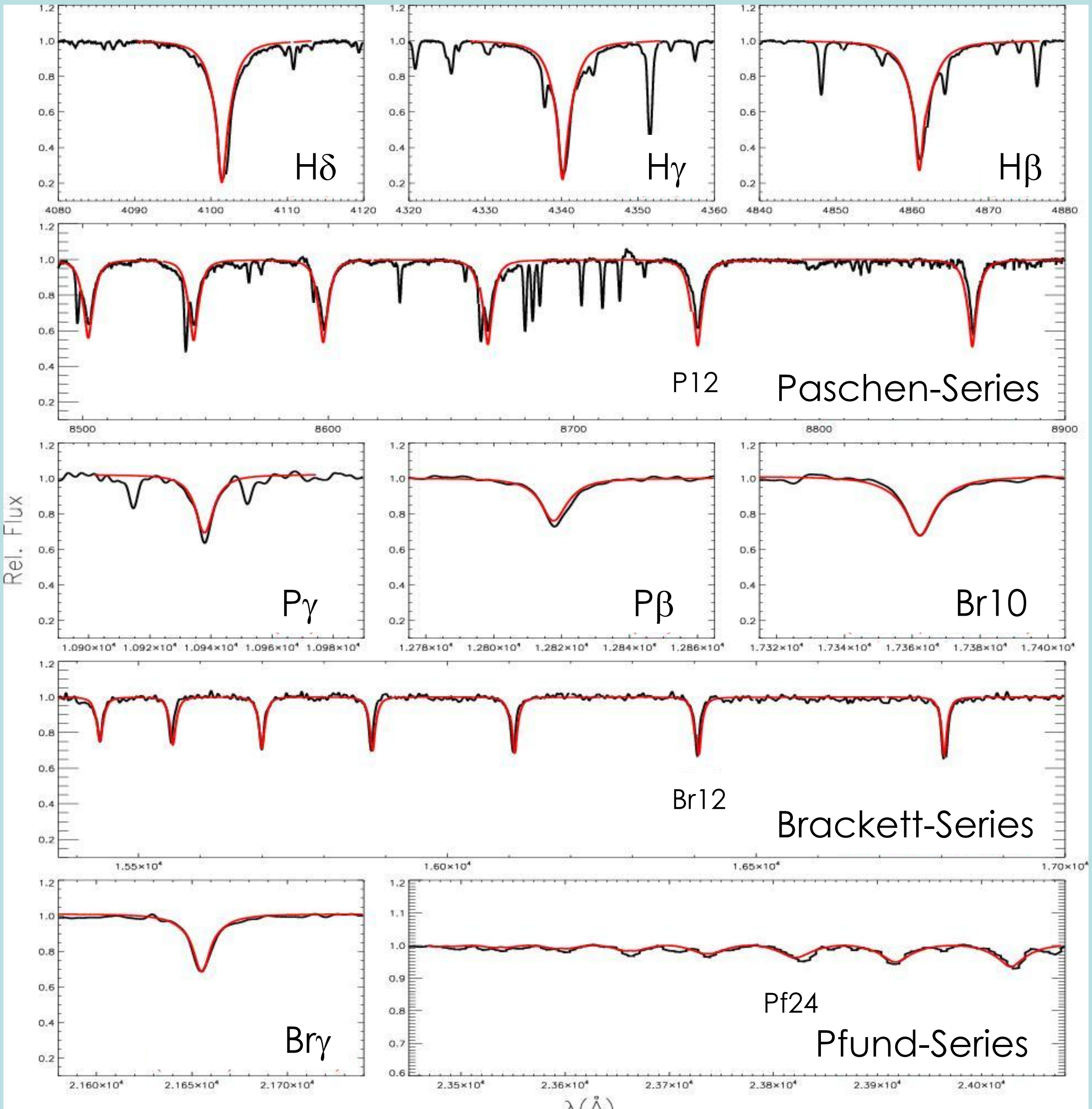


Schiller & Przybilla (2008)

α Cyg (A2 Ia)

H atom:

analytical solution

except

electron collisions:
3-body problem

ab-initio data
vs.
approximations

until recently:
medium resolution spectroscopy

NLTE Diagnostics in Visual: Stellar Parameters

- ionization equilibria → T_{eff}

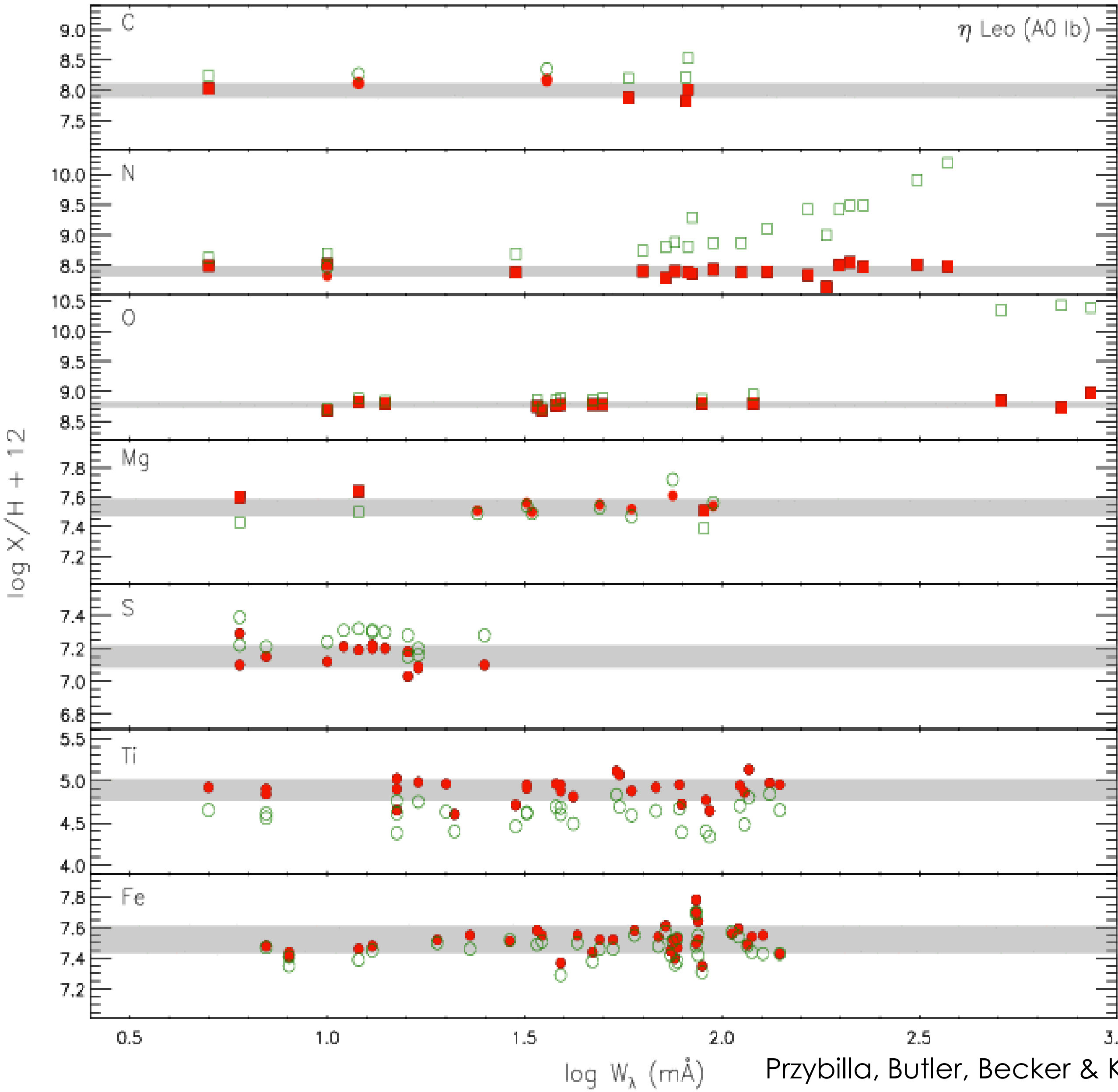
  elements: e.g. C, N, O, Mg, Si, S, Fe

  $\Delta T_{eff} / T_{eff} \sim 1\%$
- Stark broadened hydrogen lines → log g

  $\Delta \log g \sim 0.05 \ldots 0.10$ (cgs)
- microturbulence
- helium abundance
- metallicity

+ other constraints, where available: SED's, ...

Elemental Abundances 1 (Visual)



- NLTE:
  absolute abundances
  reduced uncertainties
  Δ log ε:
  ~ 0.05 - 0.10 dex (1σ-stat.)
  ~ 0.07 - 0.12 dex (1σ-syst.)

  reduced systematics

- typical uncertainties in literature:
  factor ~2-3 (1σ-stat.)
  + unknown syst. errors

NLTE/LTE

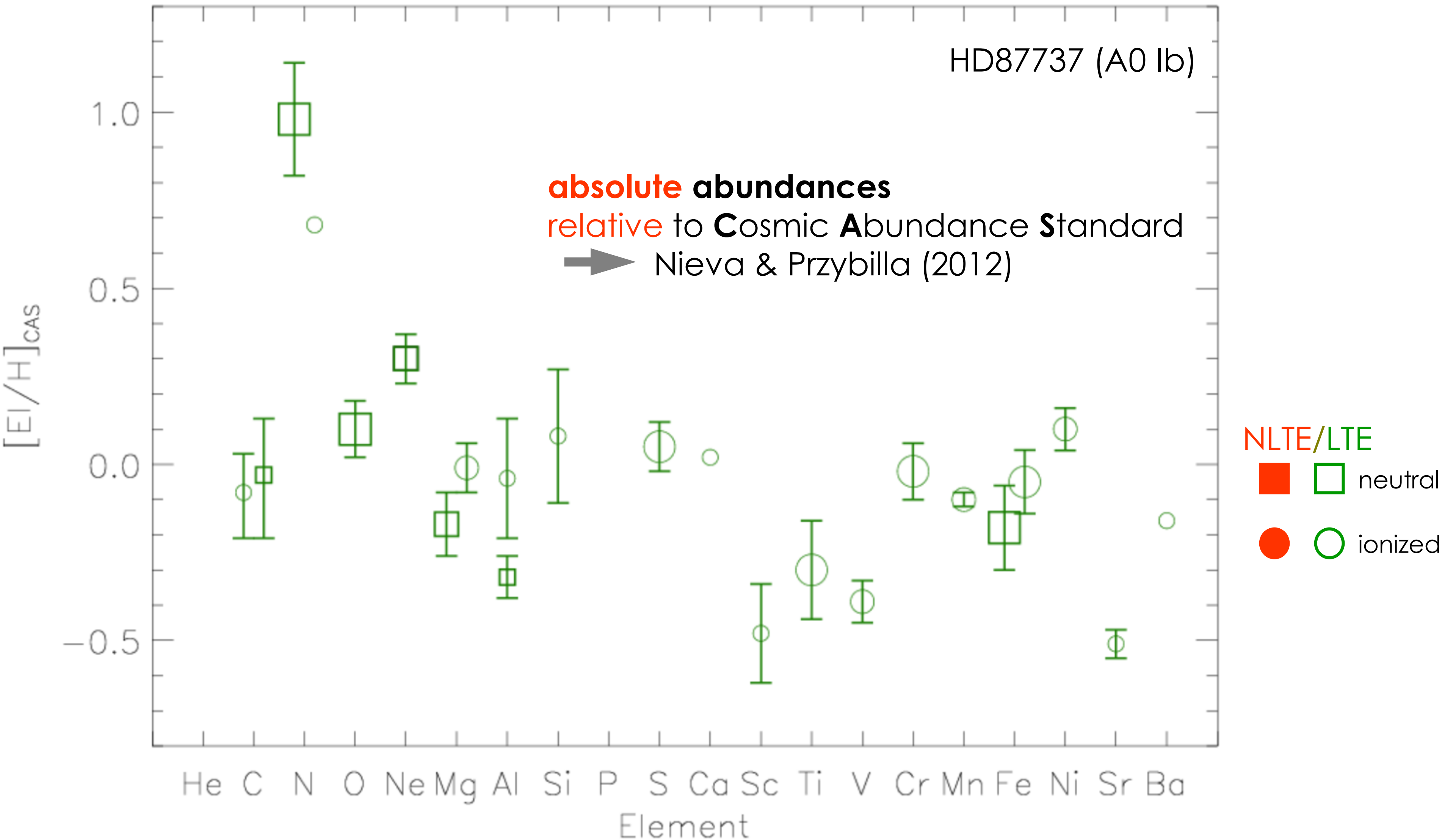
neutral

ionized

Przybilla, Butler, Becker & Kudritzki (2006)

Elemental Abundances

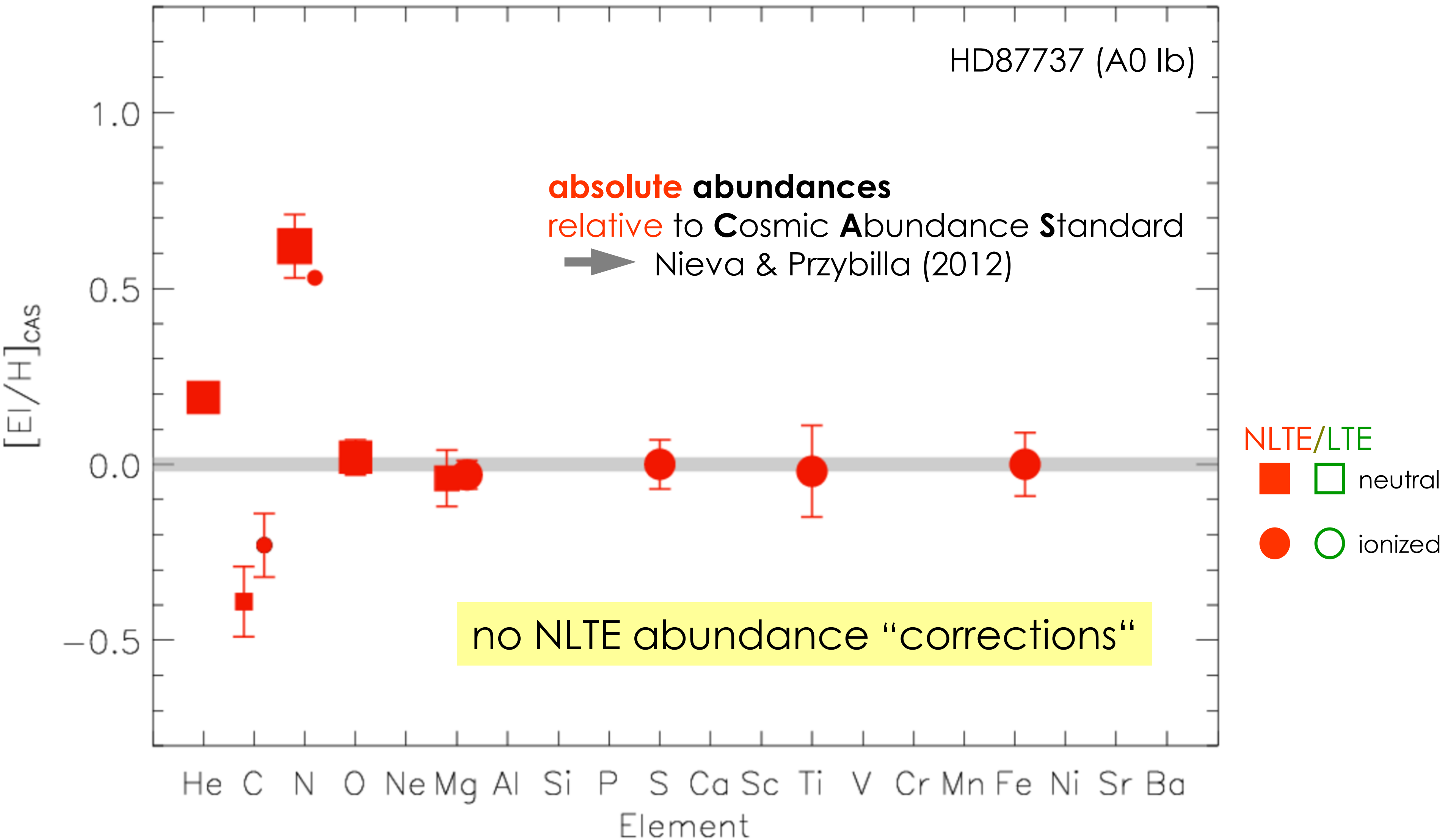
Przybilla et al. (2006)



- LTE: abundance pattern? - large uncertainties

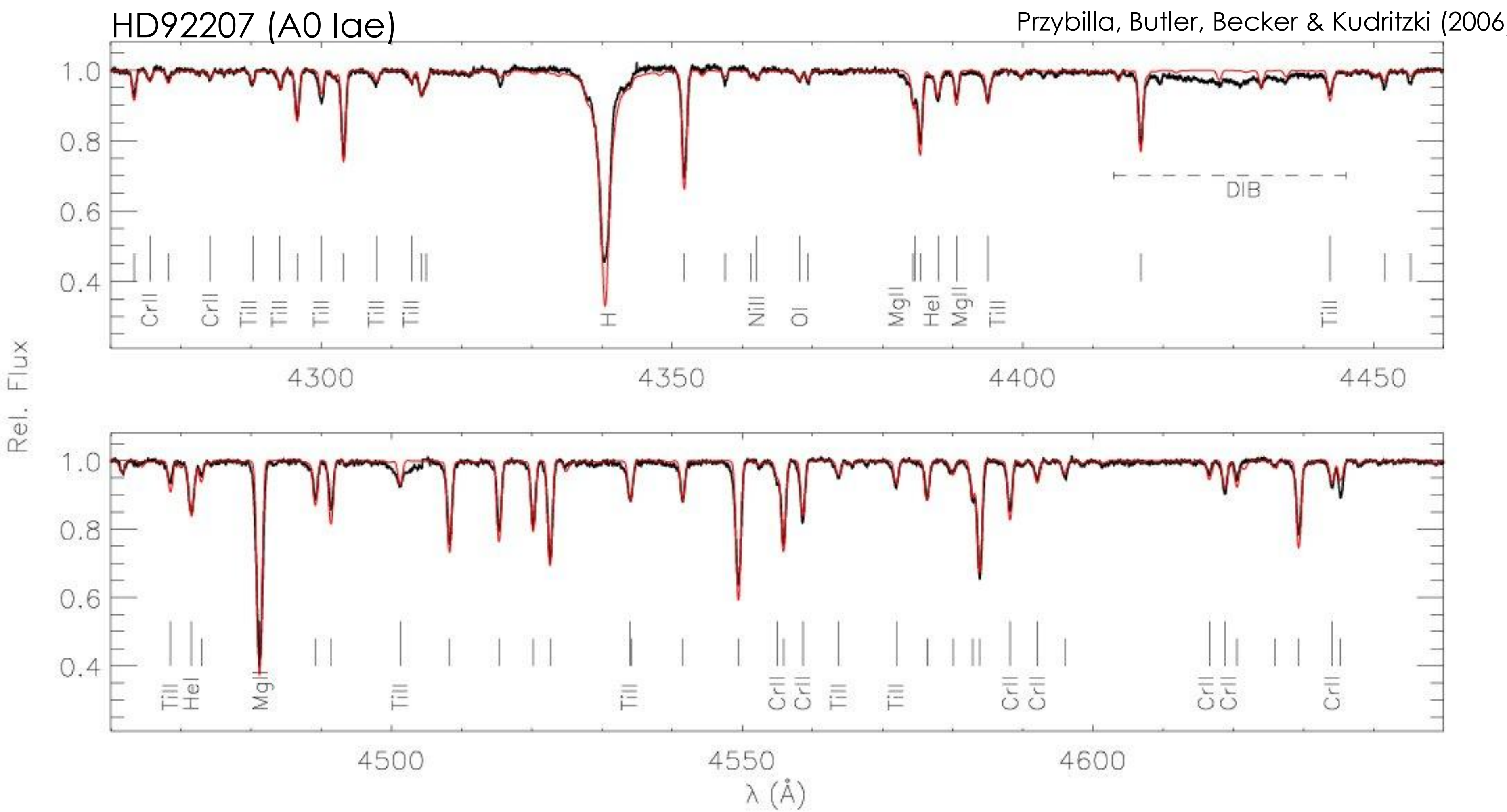
Elemental Abundances

Przybilla et al. (2006)



- NLTE: consistency & reduced uncertainties

Spectrum Synthesis in Visual



- several 10^4 lines: ~30 elements, 60+ ionization stages
- complete spectrum synthesis in visual (& near-IR) ~70-80% in NLTE

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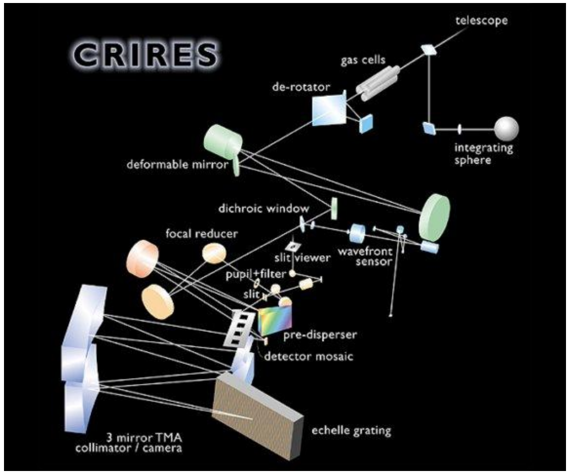
Benchmark spectroscopy: Galactic A-SGs with CRIRES

CRyogenic high-resolution **I**nfrared
Echelle **S**pectrograph CRIRES@VLT-UT1

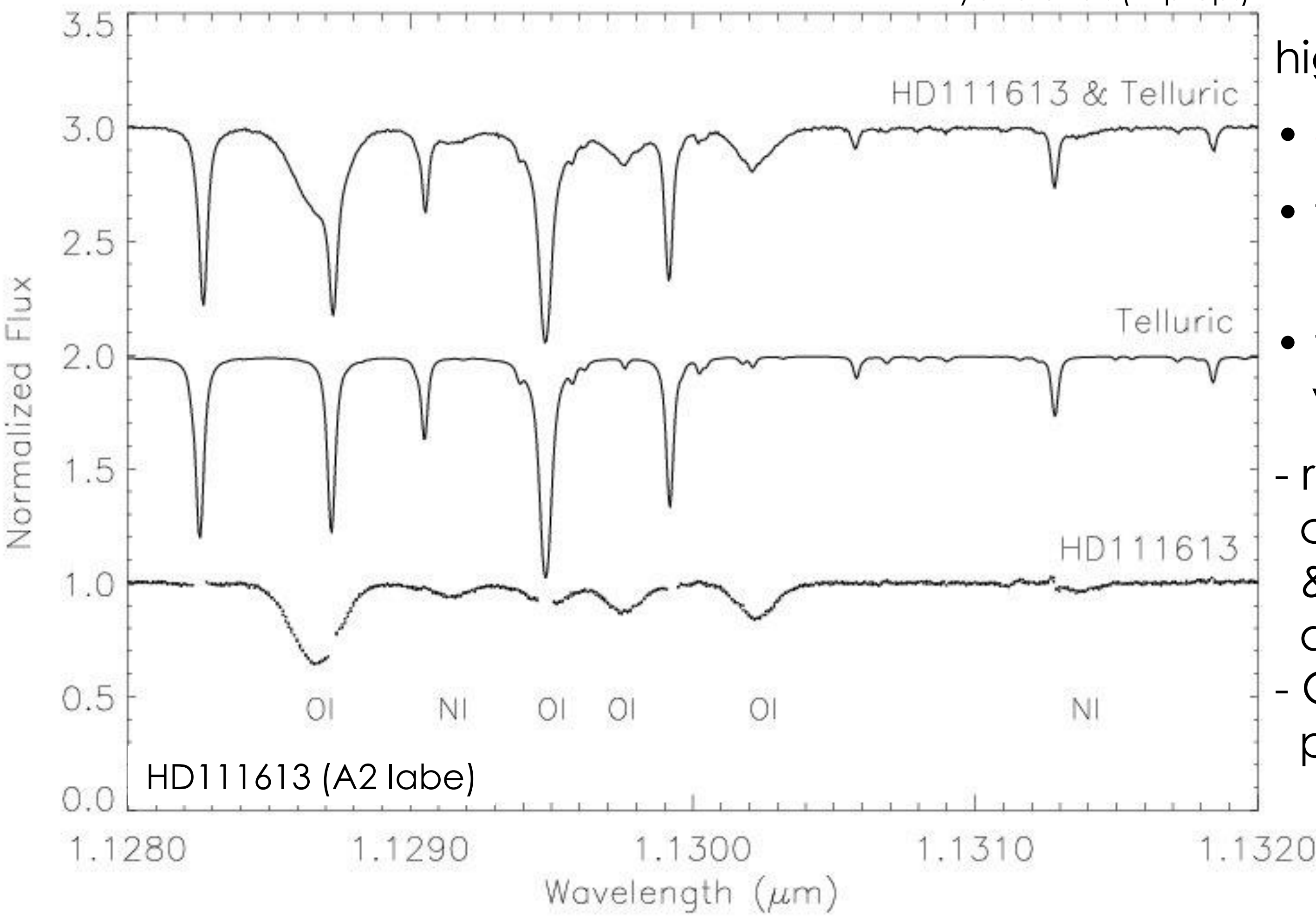
- high resolving power R = $\lambda/\Delta\lambda \leq 100{,}000$
- wavelength coverage 0.95 to 5.3 μm
- **~ 200 settings for full spectral coverage**
- detector: 4 x 4096 x 512 Aladdin III InSn

Pilot program: 3 A-SGs HD87737 (A0 Ib)
HD111613 (A2 Iabe)
HD92207 (A0 Iae)
- (partial) coverage of J, H, K, L band



Telluric Line Correction

Przybilla et al. (in prep.)



high-resolution:

- detailed line profiles
- telluric lines resolved

- telluriv line removal via modelling:

- radiative transfer code FASCODE & HITRAN molecular database
- GDAS atmospheric profiles

adaptation expertise of Innsbruck ESO In-Kind Project

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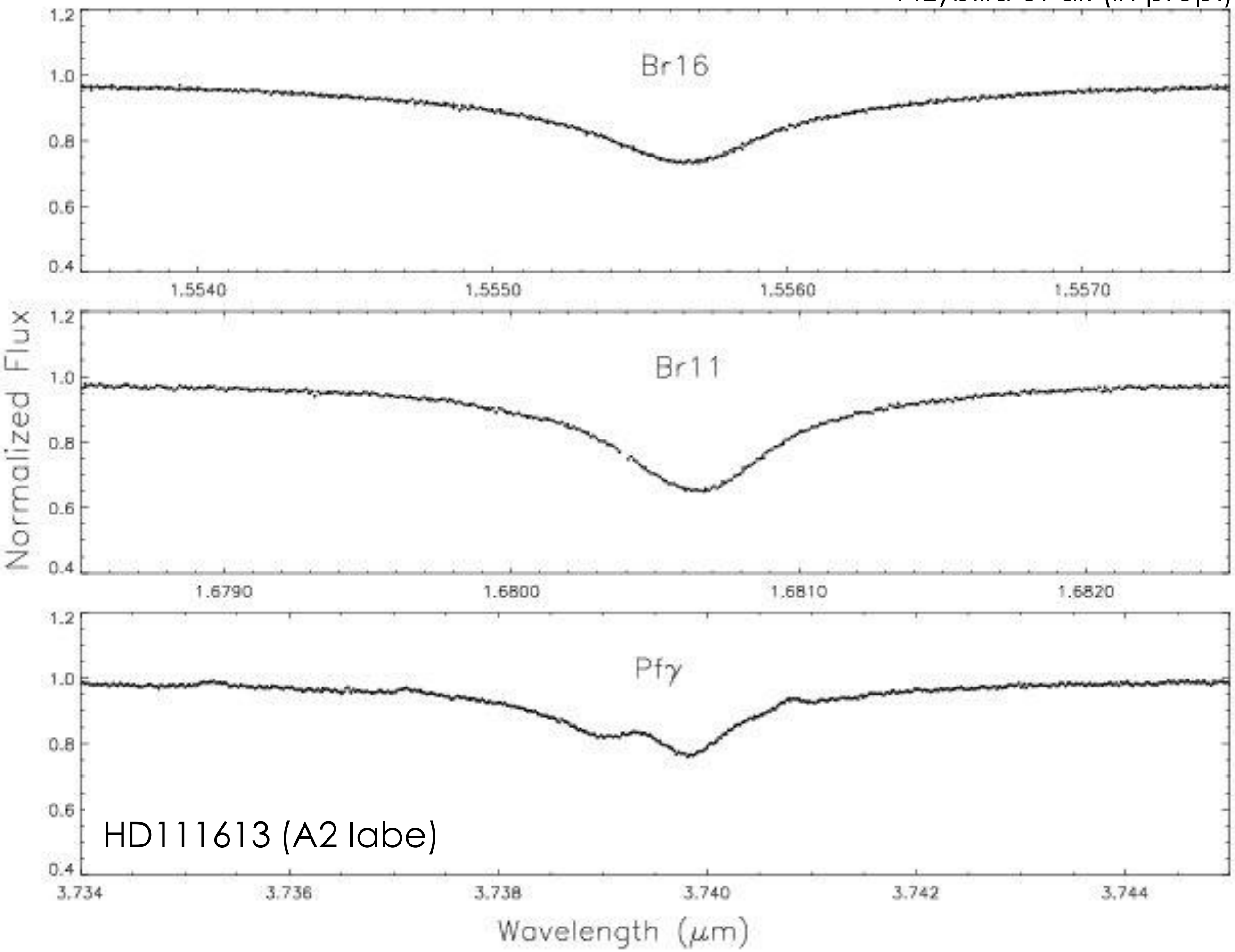
Near-IR Hydrogen Lines

Przybilla et al. (in prep.)

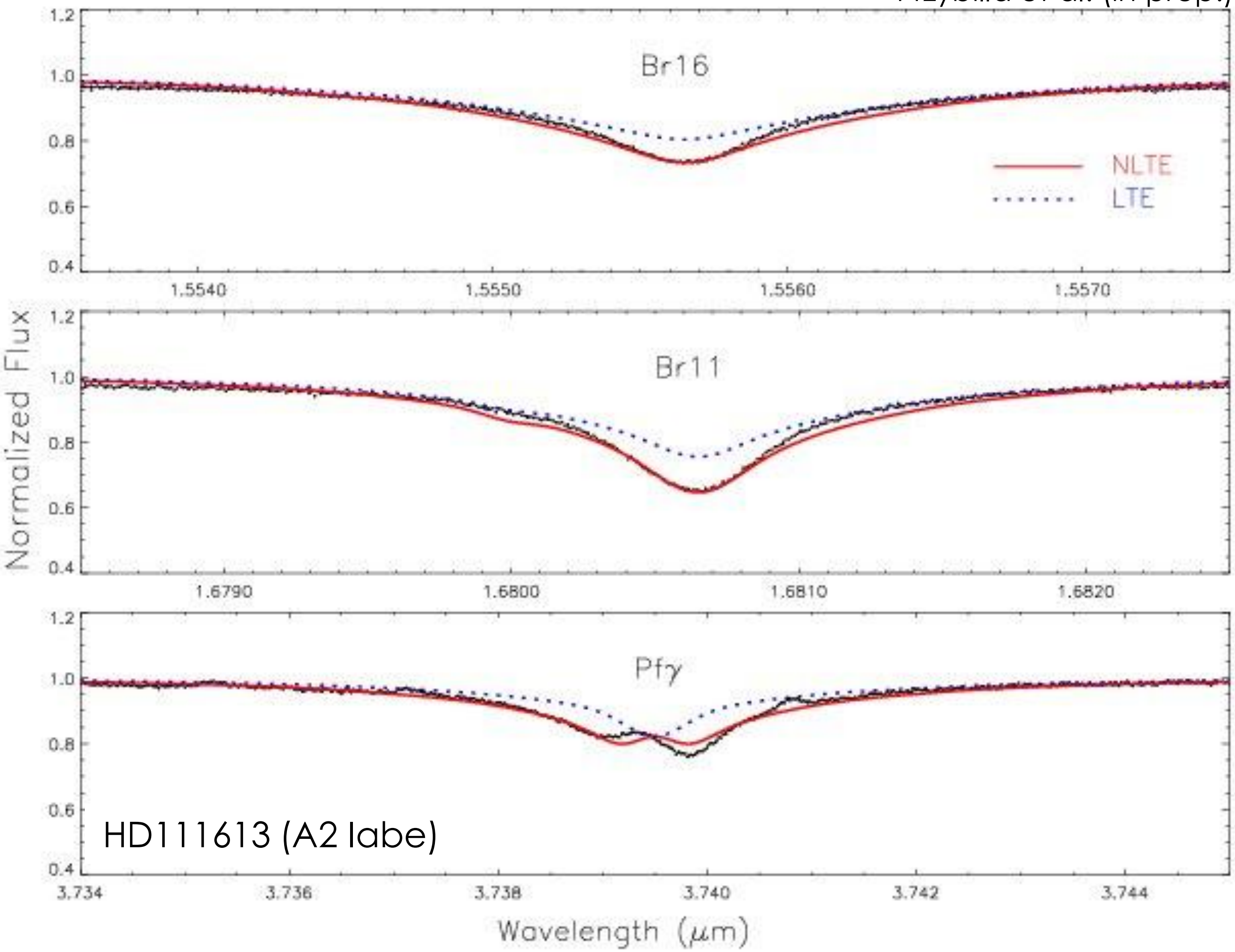


high-resolution:

- detailed line profiles
- telluric lines resolved

Near-IR Hydrogen Lines

Przybilla et al. (in prep.)



high-resolution:

- detailed line profiles
- telluric lines resolved

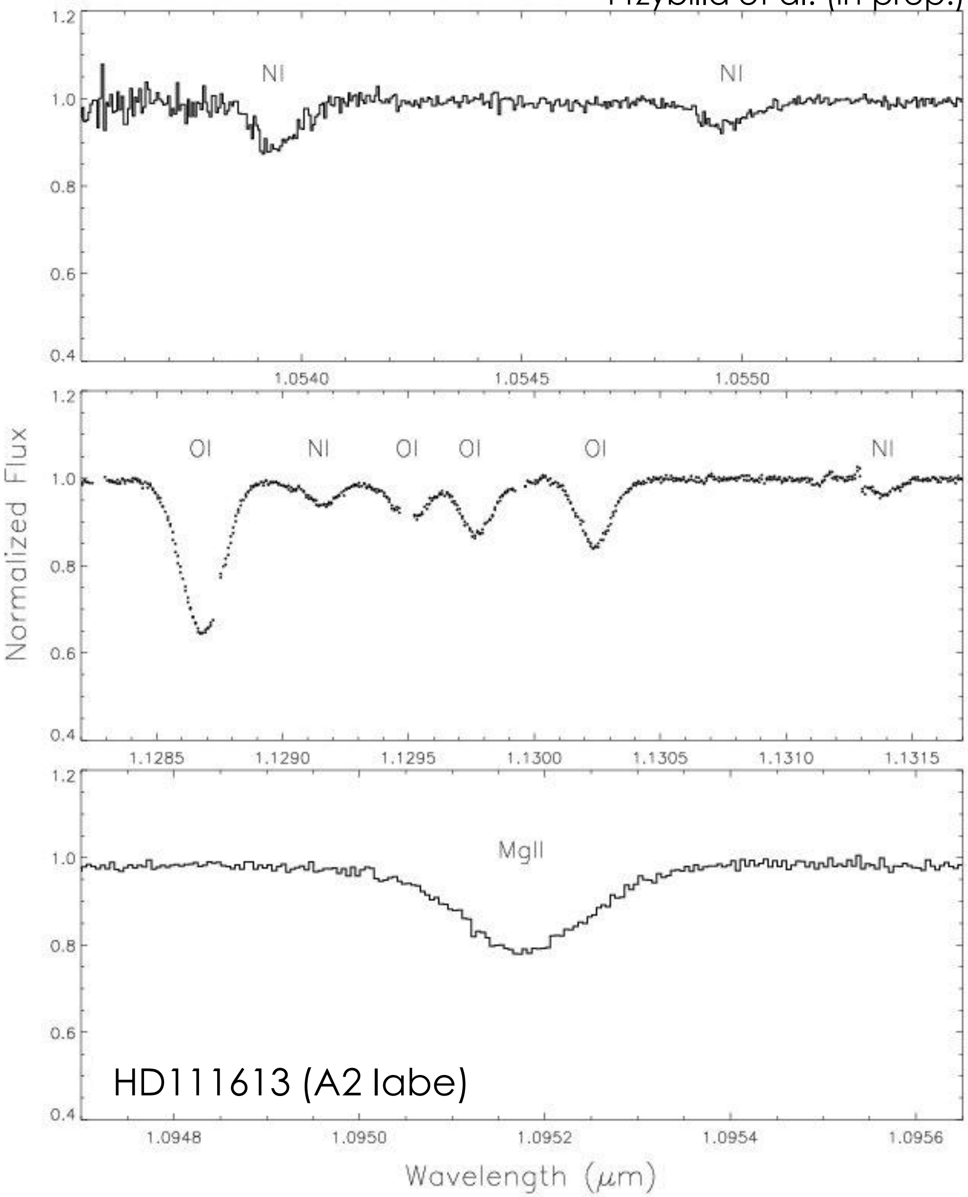
analysis:

- extension of previous modelling
- consistency with visual
- strong NLTE effects

+ Brα: stellar wind

➔ distances via FGLR & WLR

Przybilla et al. (in prep.)



Near-IR Metal Lines

- metal lines in near-IR:
  C, N, O, Mg, Si, Fe + He

→ stellar evolution

→ **galactochemical evolution**

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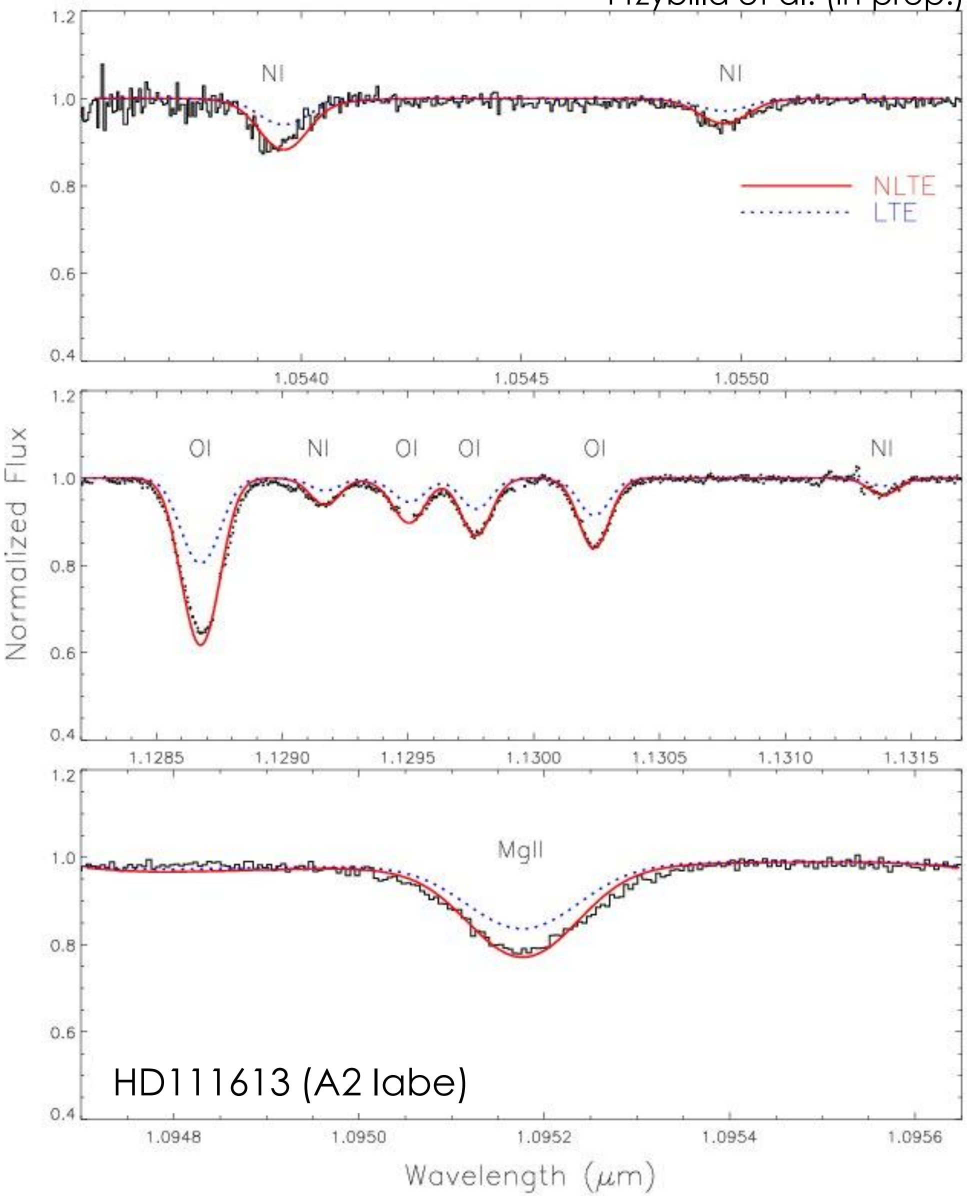
Przybilla et al. (in prep.)



Near-IR Metal Lines

- metal lines in near-IR:
  C, N, O, Mg, Si, Fe + He

  → stellar evolution

  → **galactochemical evolution**

- analysis:
  - extension of previous modelling
  - strong NLTE effects
  - good agreement with visual but adjustment of some model atoms necessary (NLTE amplification)
    → improved atomic data

CRIRES-POP

Lebzelter et al. 2012, A&A, 539, A109

- coverage of HRD for ~ 25 stars with K≤4.5mag with CRIRES spectra
  ~ 400h with VLT
- **supergiants: A8, F3, G8, K3, M1**
- high resolving power R = $\lambda/\Delta\lambda \leq$ 100,000
- almost full wavelength coverage 0.95 to 5.3 mm
- optical spectra: UVES-POP

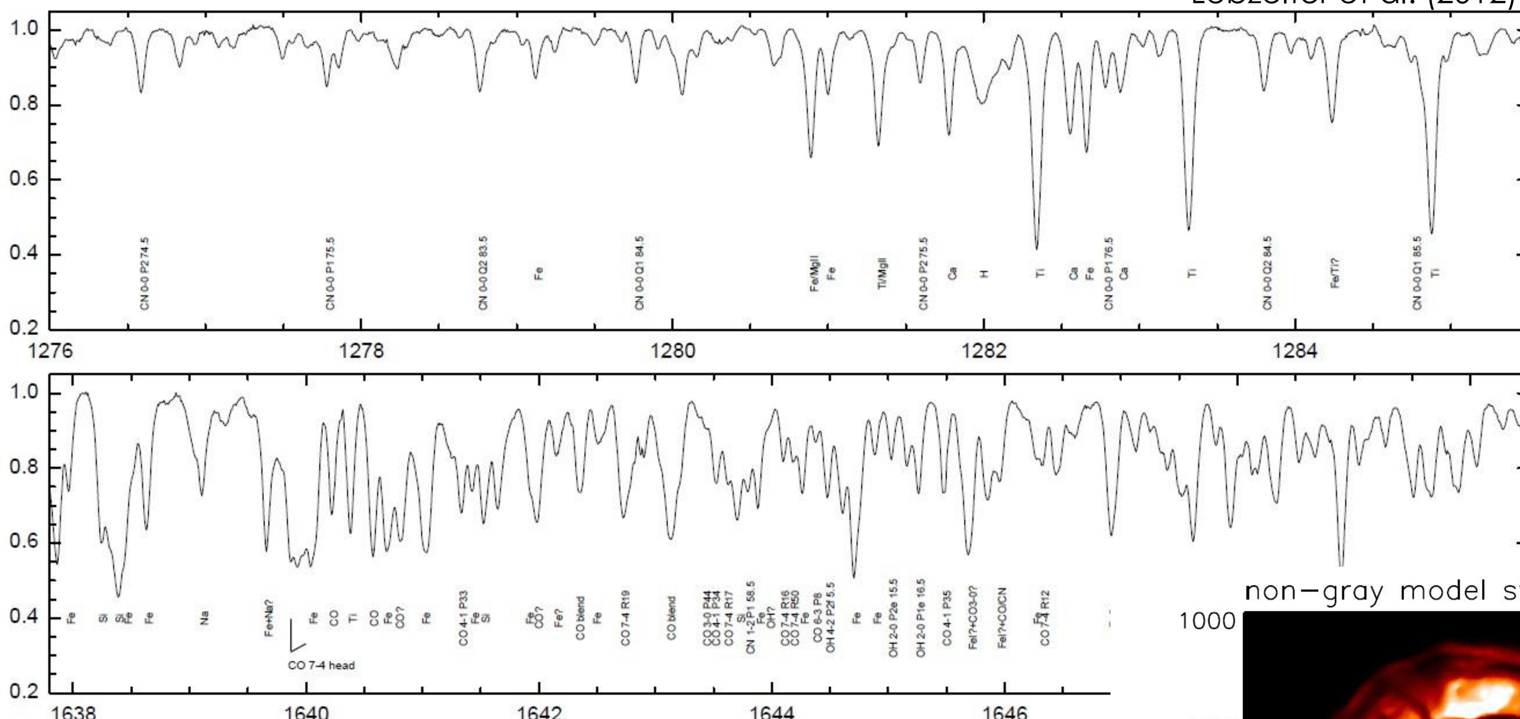
CRIRES-POP

HD225212 (K3 I)

Lebzelter et al. (2012)

J

H



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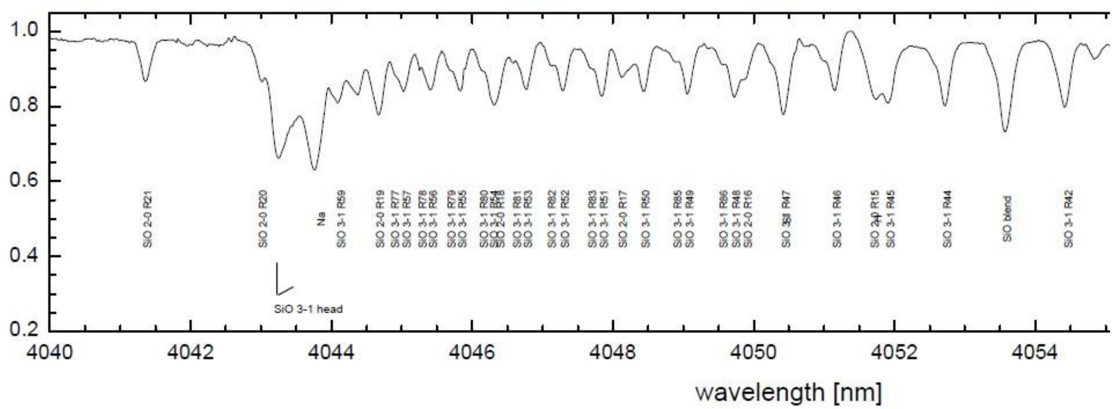

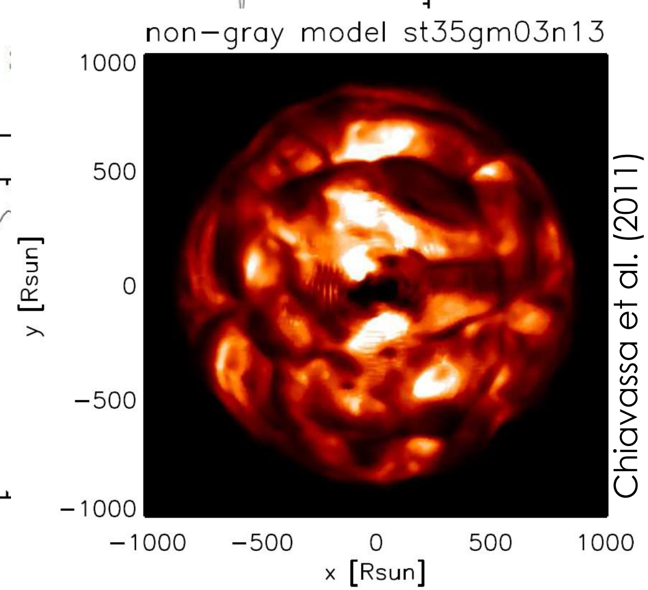

RSGs: theoretical challenges NLTE+3D

Summary

- BSG/RSGs powerfull tools for studying
  - stellar evolution
  - galactochemical evolution
  - cosmic distance scale

- extragalactic stellar science with E-ELT
  → near-IR MOS using **MOSAIC**

- pilot study of Galactic SGs with CRIRES@VLT + CRIRES-POP
  → high-resolution near-IR spectra
  → **challenging telluric correction**
  → testing & improving analysis methodology because of of **challenging diagnostics**