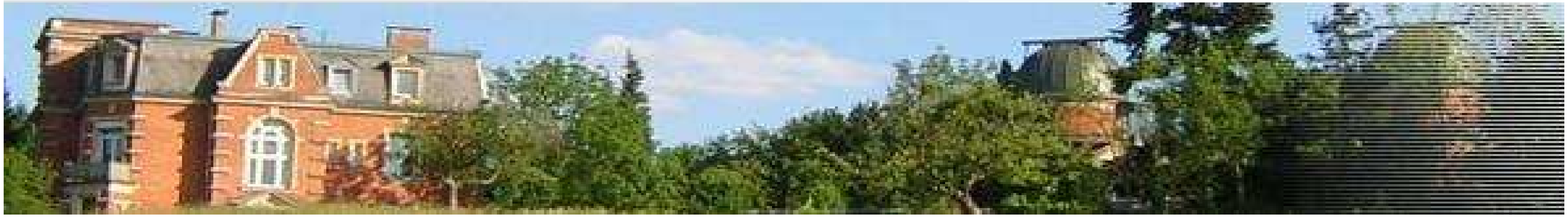

Near-IR Spectroscopy of A-type Supergiants with CRIRES

Norbert Przybilla

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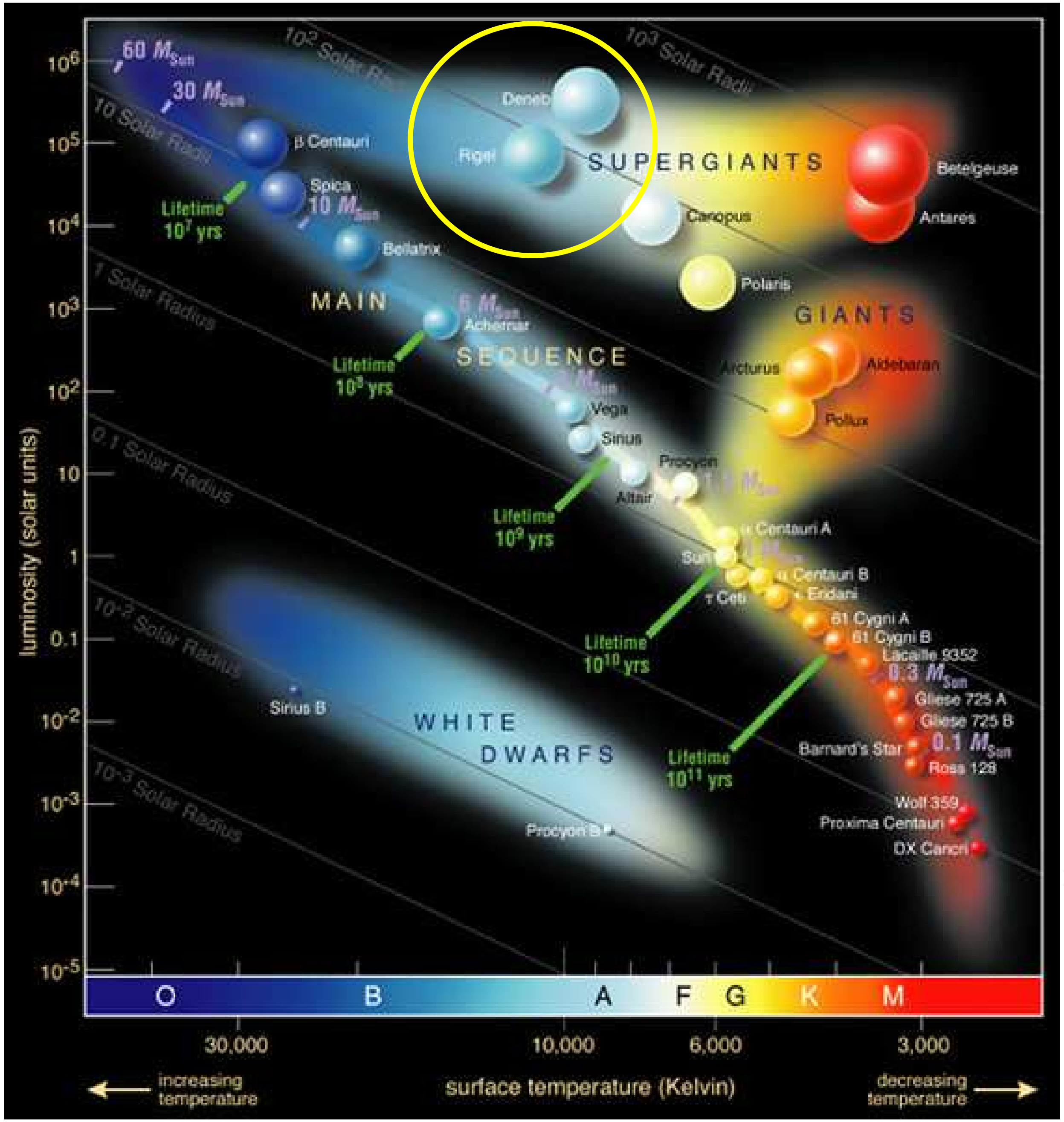
NATURWISSENSCHAFTLICHE FAKULTÄT

ecap ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Outline

- Intro: why near-IR spectroscopy of BA-SGs
- Diagnostic Challenges
- Benchmark Spectroscopy:
  Galactic BA-SGs with CRIRES

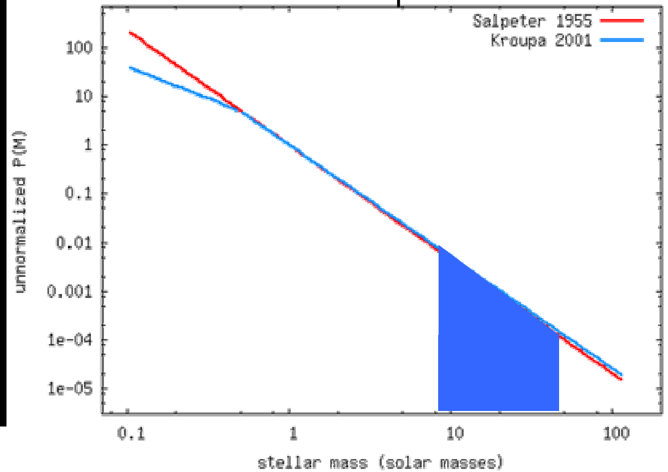
BA-Supergiants



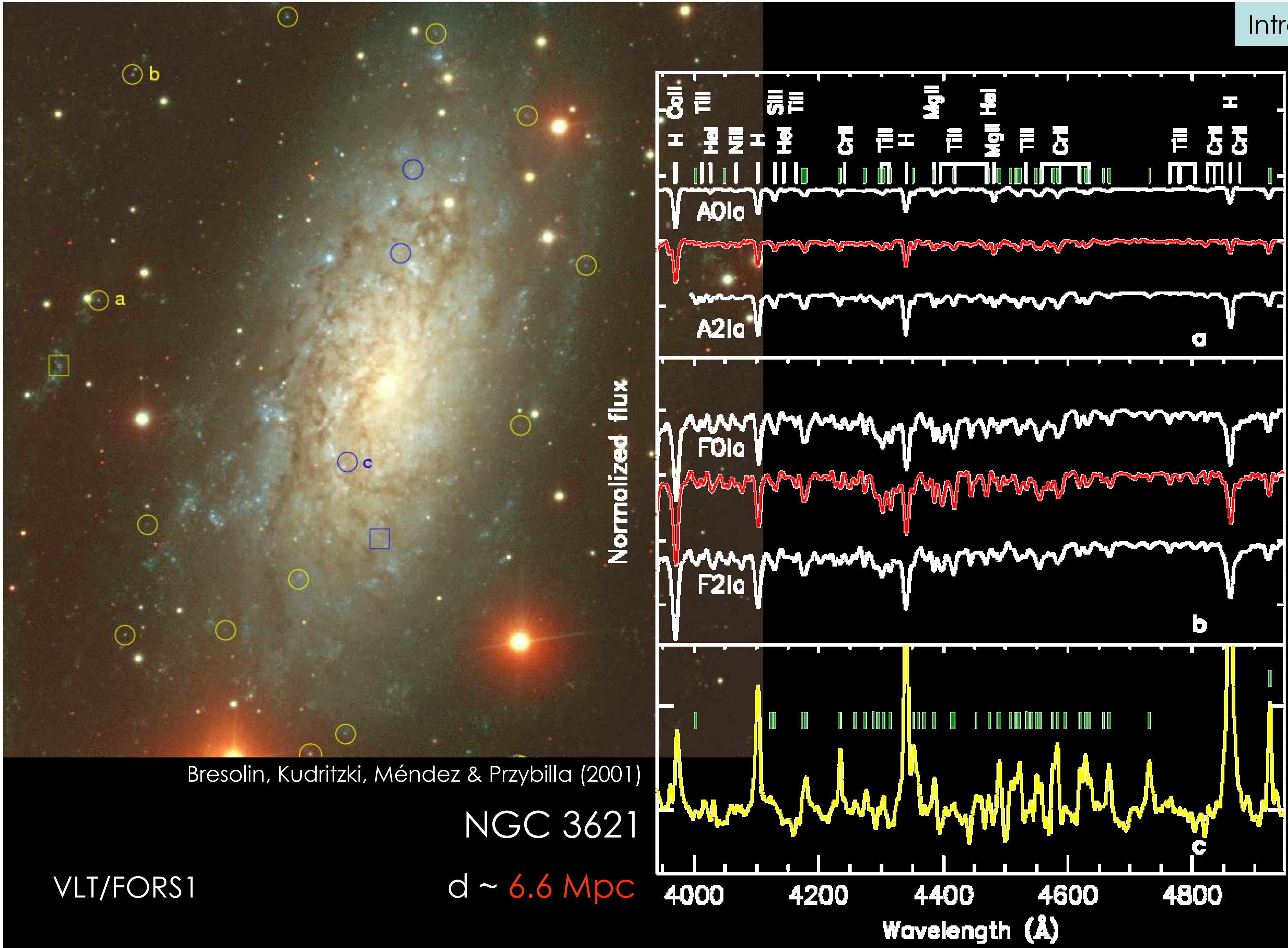
- evolved progeny of OB main-sequence stars
- T_{eff}: ~ 8000 ... 15000 K
- M: ~ 8 ... 40 $M_\odot$
- L: ~ 10^4 ...$10^{5.5}$ $L_\odot$
- R: ~ 50 ... 400 $R_\odot$

→ spectroscopy@high-res throughout Local Group

→ @med-res: out to 7-8Mpc



blue: photometric target selection

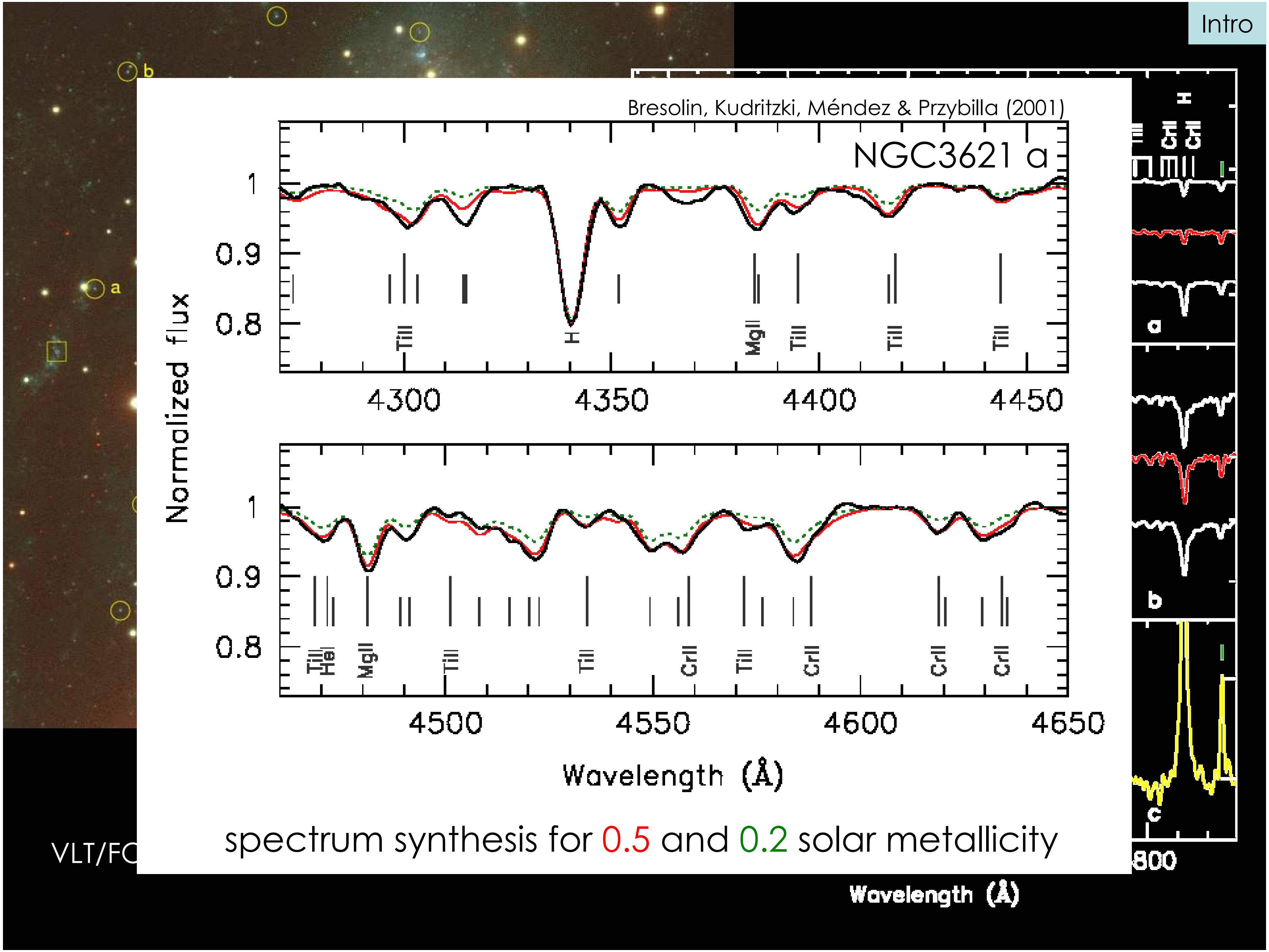


Bresolin, Kudritzki, Méndez & Przybilla (2001)

NGC 3621

VLT/FORS1

d ~ 6.6 Mpc


Intro
Bresolin, Kudritzki, Méndez & Przybilla (2001)
NGC3621 a
Normalized flux
1
0.9
0.8
TiII
H
MgII
TiII
TiII
TiII
4300
4350
4400
4450
TiII
HeI
MgII
TiII
TiII
CrII
TiII
CrII
CrII
CrII
4500
4550
4600
4650
Wavelength (Å)
spectrum synthesis for 0.5 and 0.2 solar metallicity
VLT/FC
a
b
c
800
Wavelength (Å)

Science Drivers

- stellar atmosphere physics: NLTE, winds, ...
- stellar evolution: metallicity effects
- 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

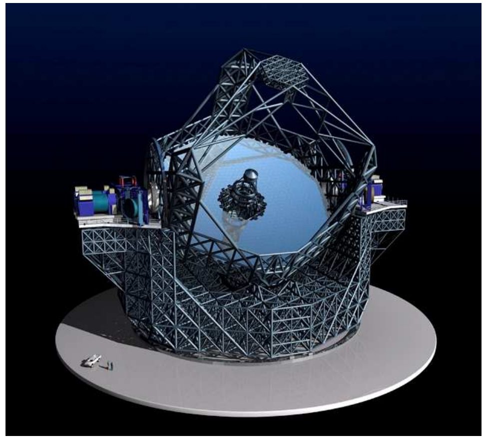
ESO PR Photo 08a/99 (27 February 1999)

Barred Galaxy NGC 1365
(VLT UT1 + FORS1)

Stellar Spectroscopy in Virgo & Fornax

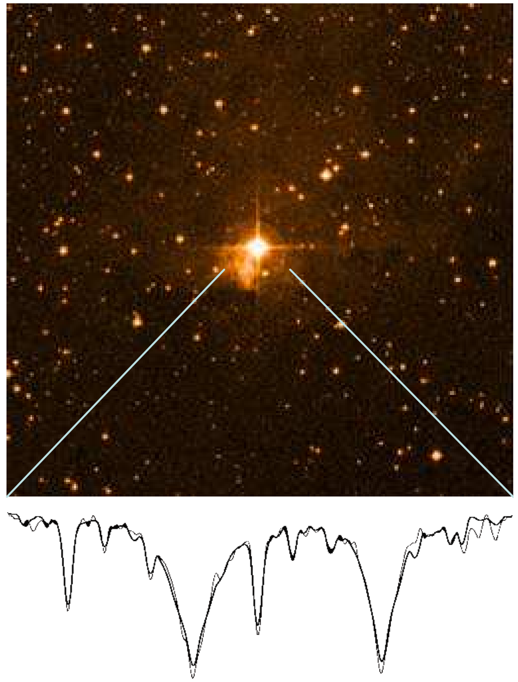
problem: spatial resolution
1"@20Mpc: ~100pc

→ diffraction-limited observation with ELT using AO



→ near-IR spectroscopy

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

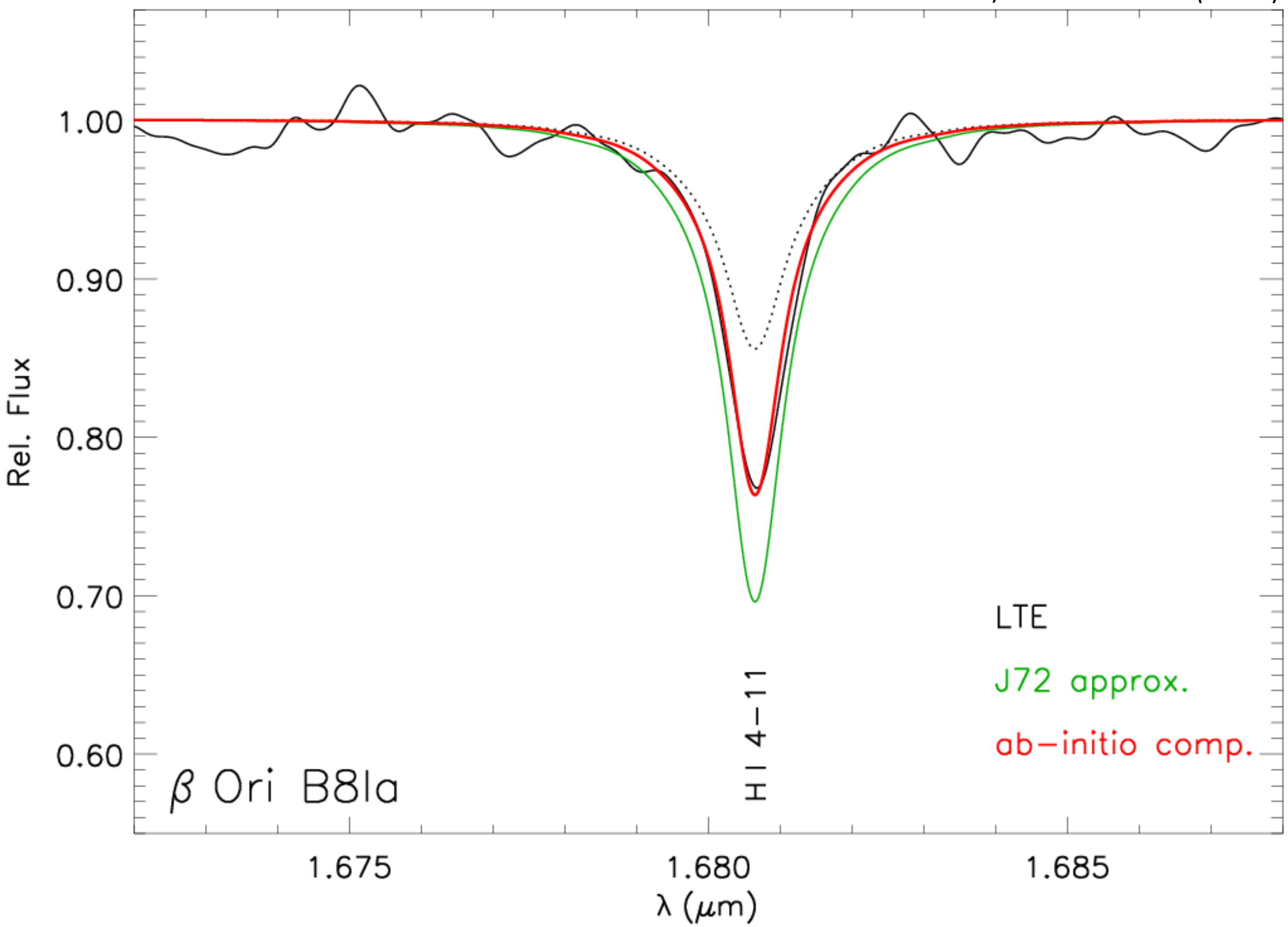
NLTE line source function:

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

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

NLTE: need for accurate atomic data

Przybilla & Butler (2004)



H atom:

analytical solution

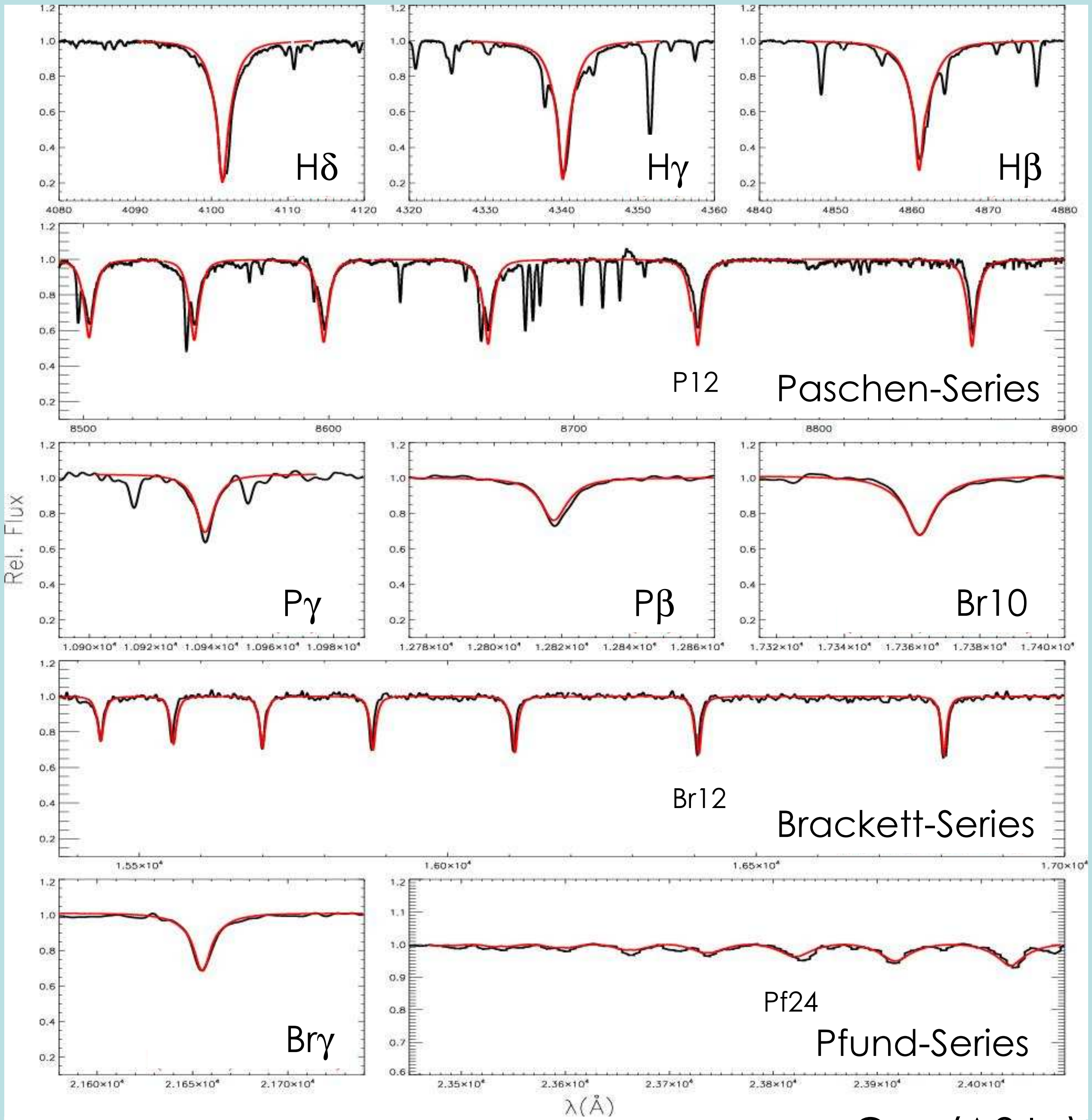
except

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



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

  $\Delta T_{eff} / T_{eff} \sim 1\%$

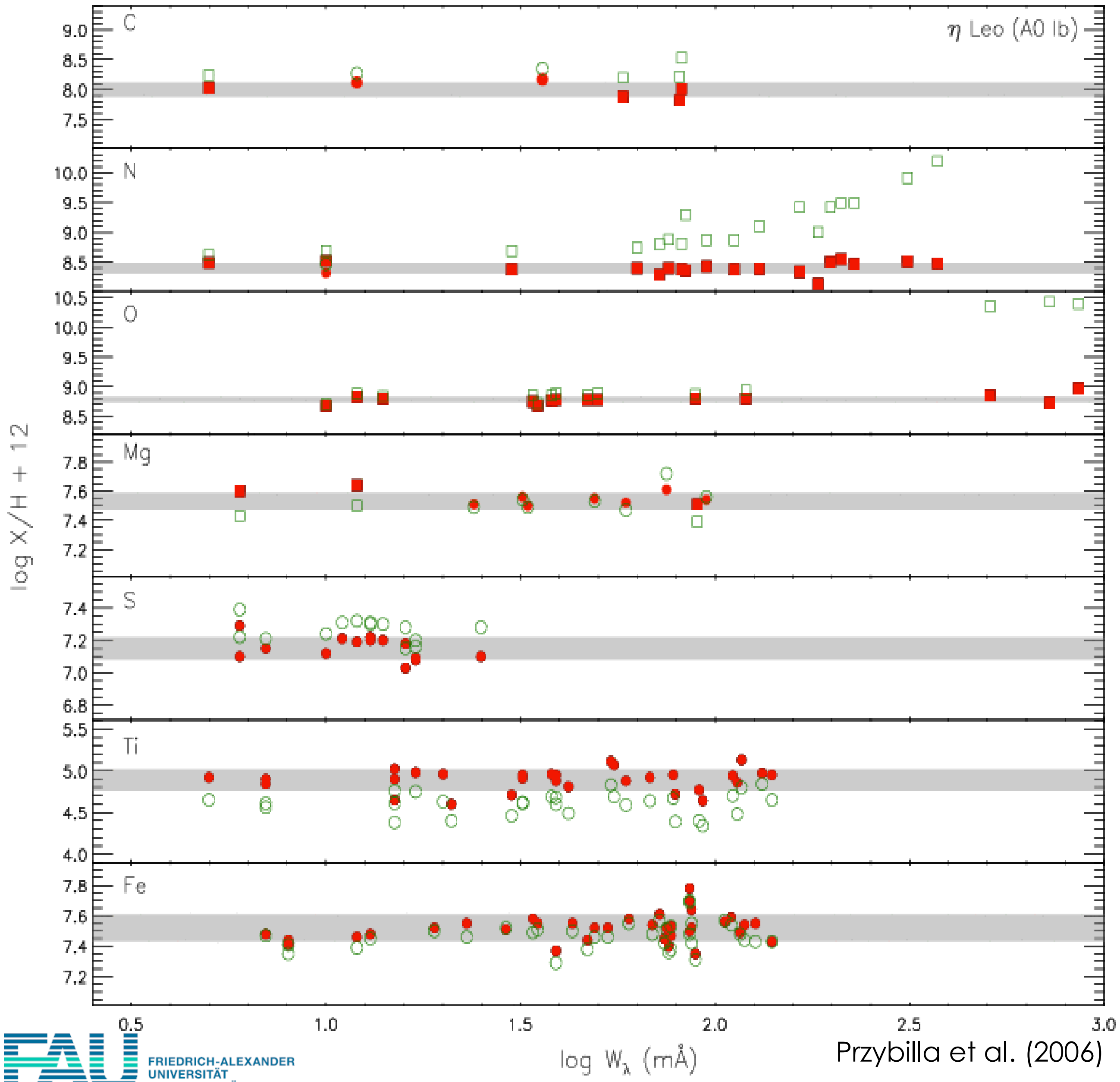
- Stark broadened hydrogen lines → log g

  $\Delta \log g \sim 0.05 \ldots 0.10$ (cgs)

- microturbulence
- helium abundance
- metallicity

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

Elemental Abundances 1 (Visual)



Przybilla et al. (2006)

- 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

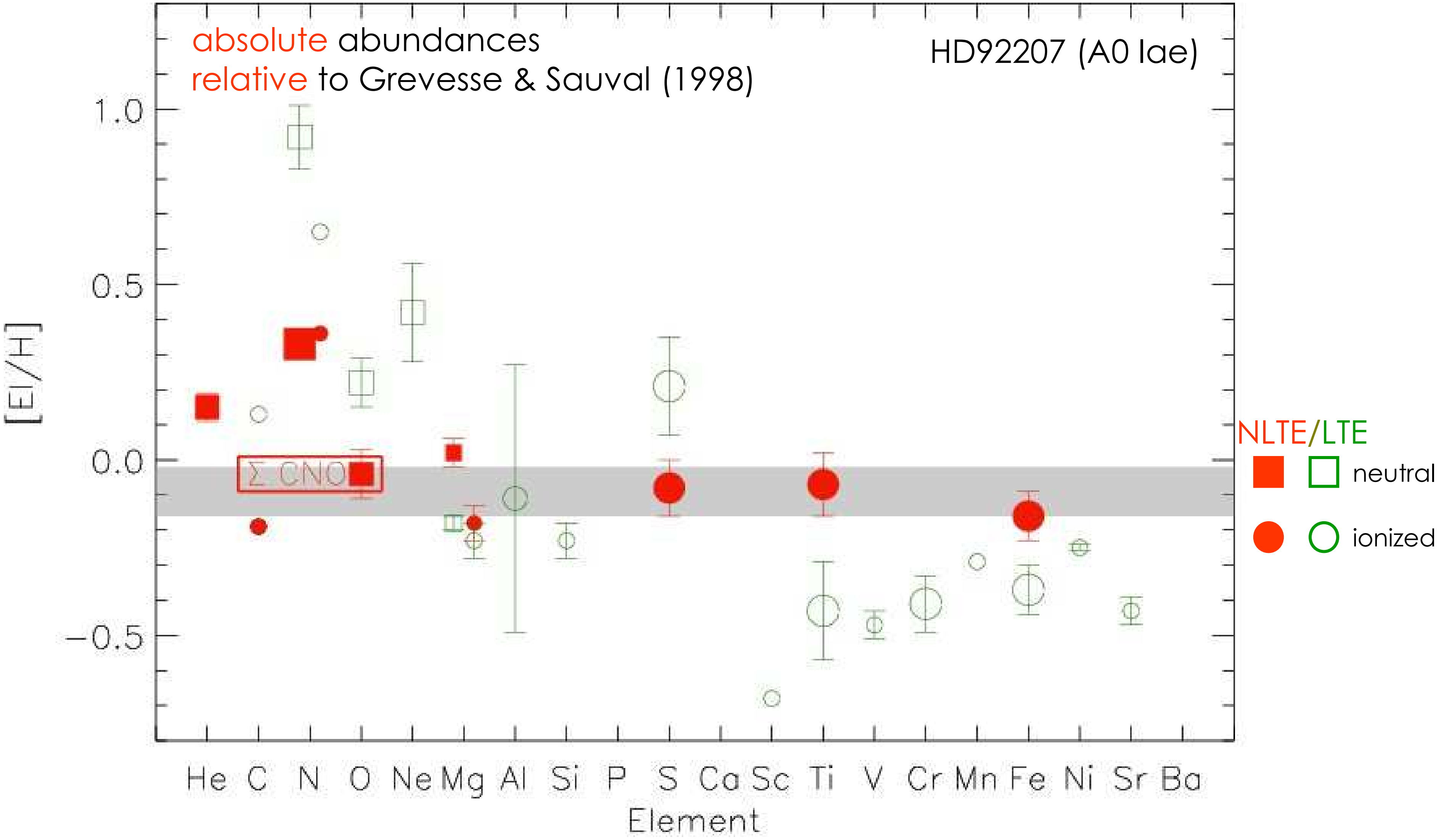
NLTE/LTE

neutral

ionized

Elemental Abundances 2 (Visual)

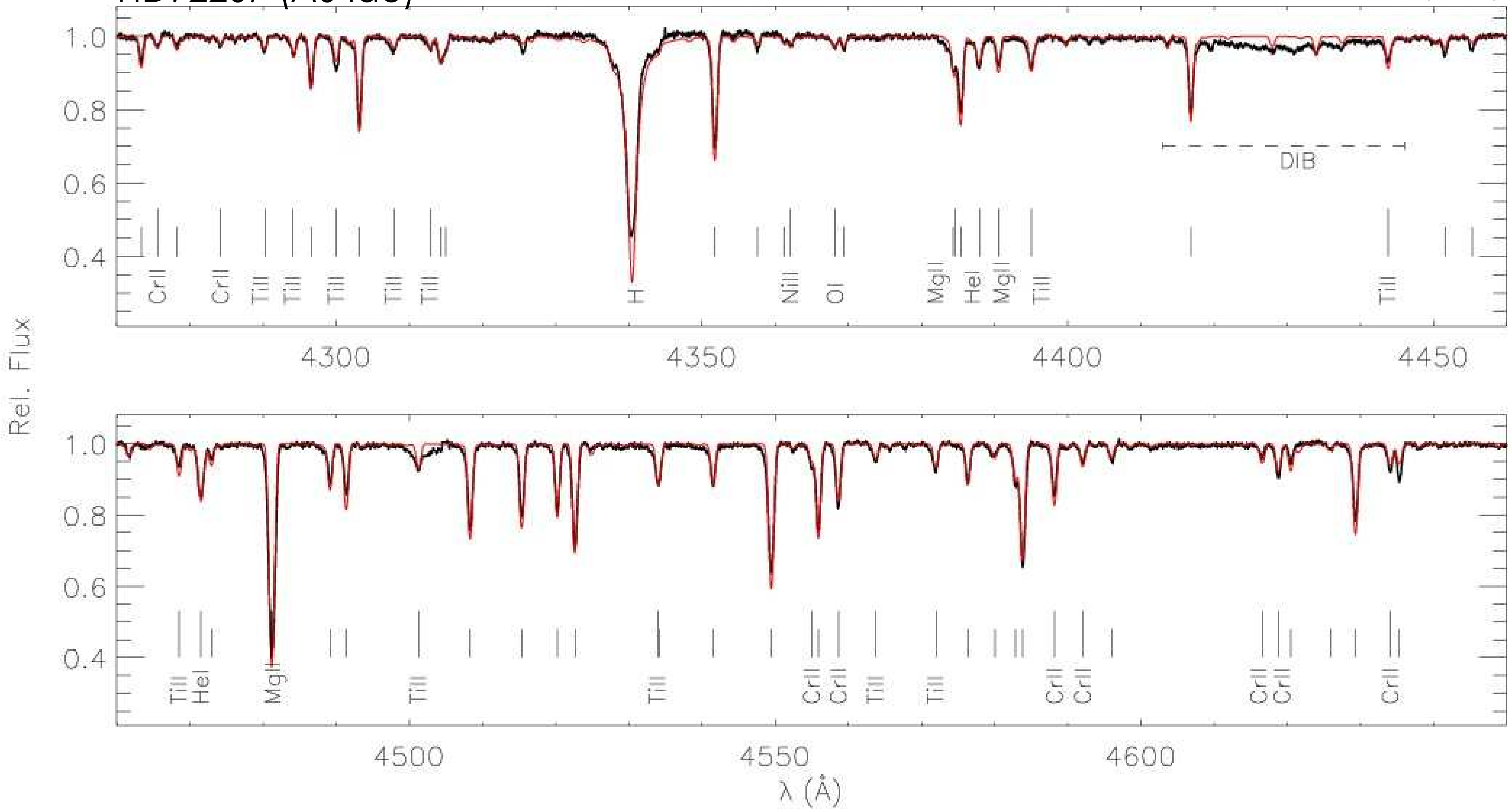
Przybilla et al. (2006)



- NLTE: consistency & reduced uncertainties

Spectrum Synthesis in Visual

HD92207 (A0 Iae) Przybilla et al. (2006)

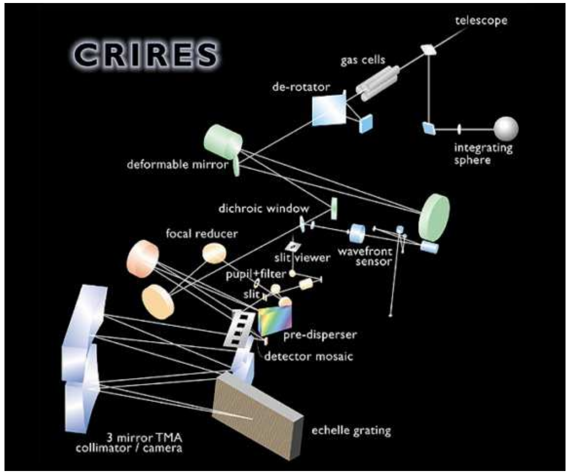


- several 10^4 lines: ~30 elements, 60+ ionization stages
- complete spectrum synthesis in visual (& near-IR) ~70-80% in NLTE

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

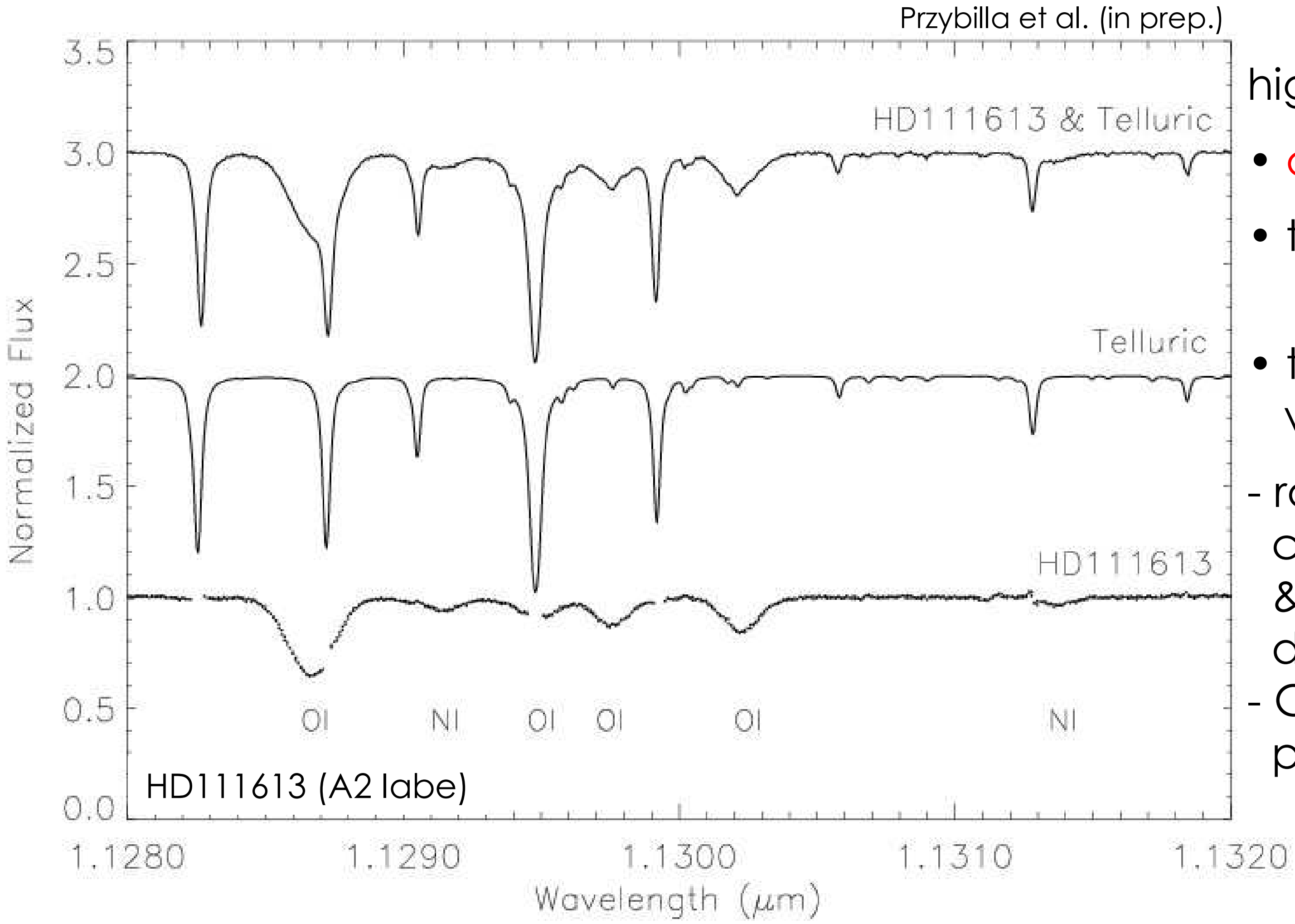


Pilot program: 3 A-SGs   HD87737 (A0 Ib)
                                          HD111613 (A2 Iabe)
                                          HD92207 (A0 Iae)

- (partial) coverage of J, H, K, L band

CRIRES-POP: Lebzelter et al. 2012, A&A, 539, A109
coverage of HRD for stars with K≤4.5mag with CRIRES spectra
~ 400h with VLT   Optical spectra: VLT/UVES

Telluric Line Correction



high-resolution:

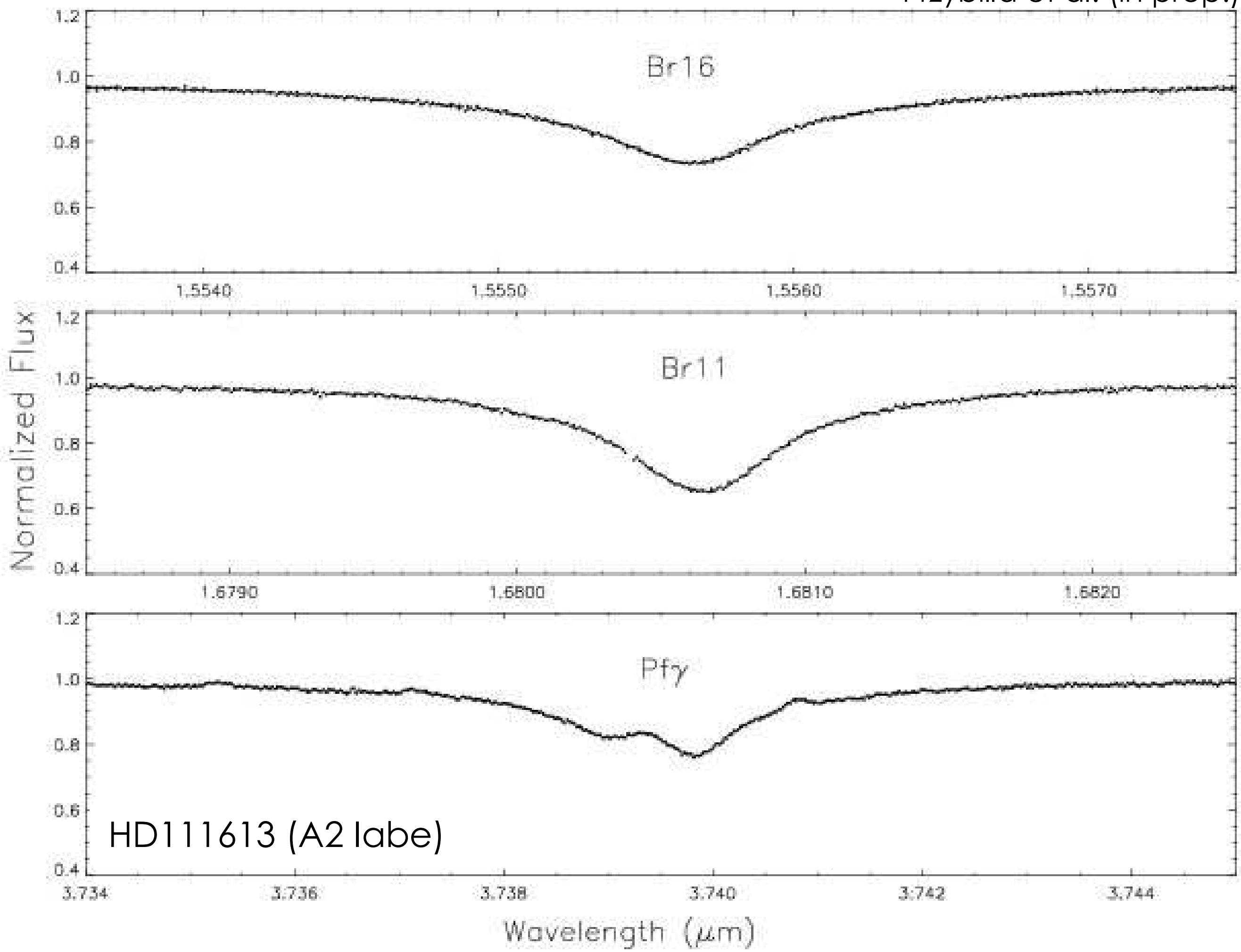
- detailed line profiles
- telluric lines resolved

- telluriv line removal via modelling:

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

Near-IR Hydrogen Lines

Przybilla et al. (in prep.)



high-resolution:

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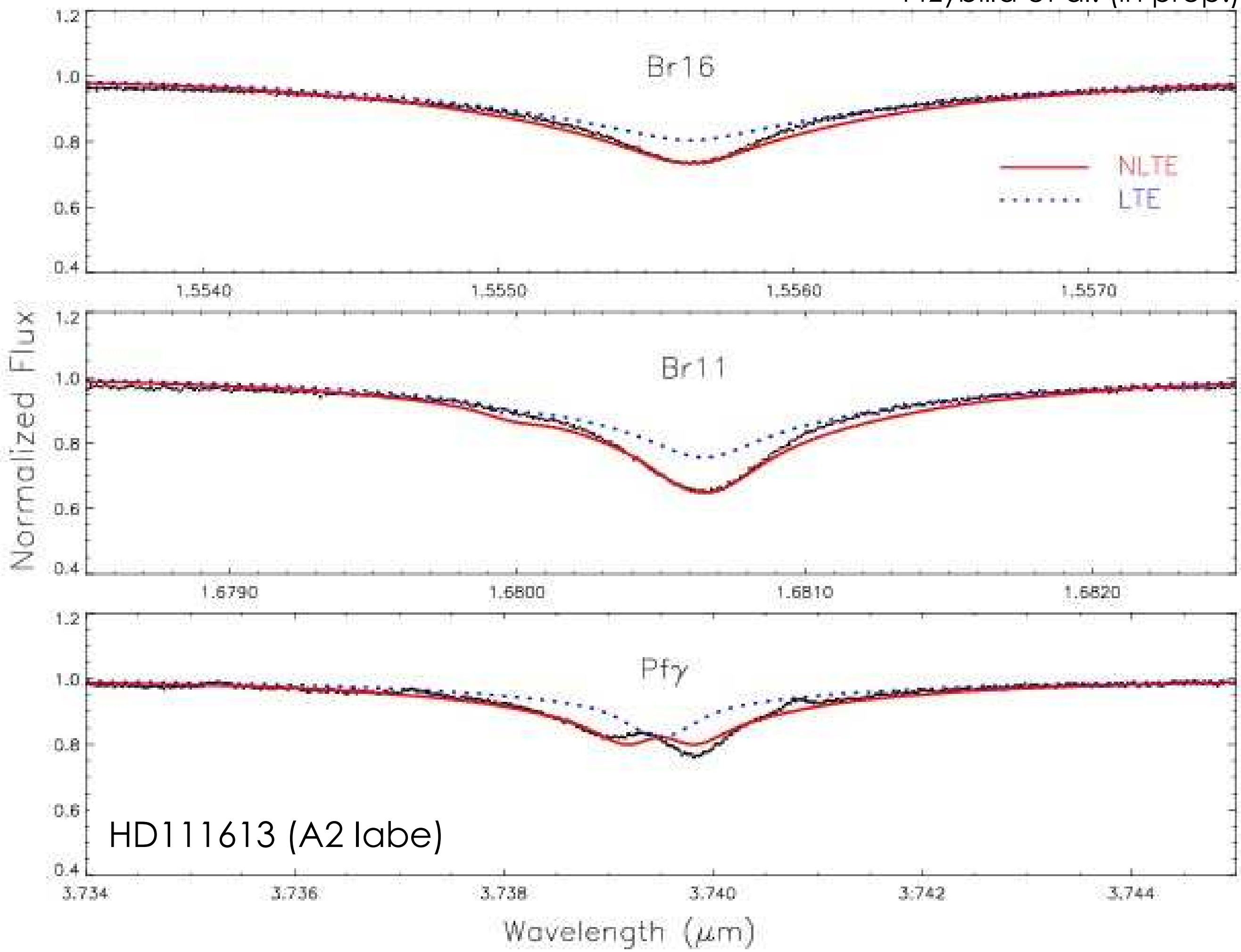
- telluric lines resolved

Near-IR Hydrogen Lines

Przybilla et al. (in prep.)



high-resolution:

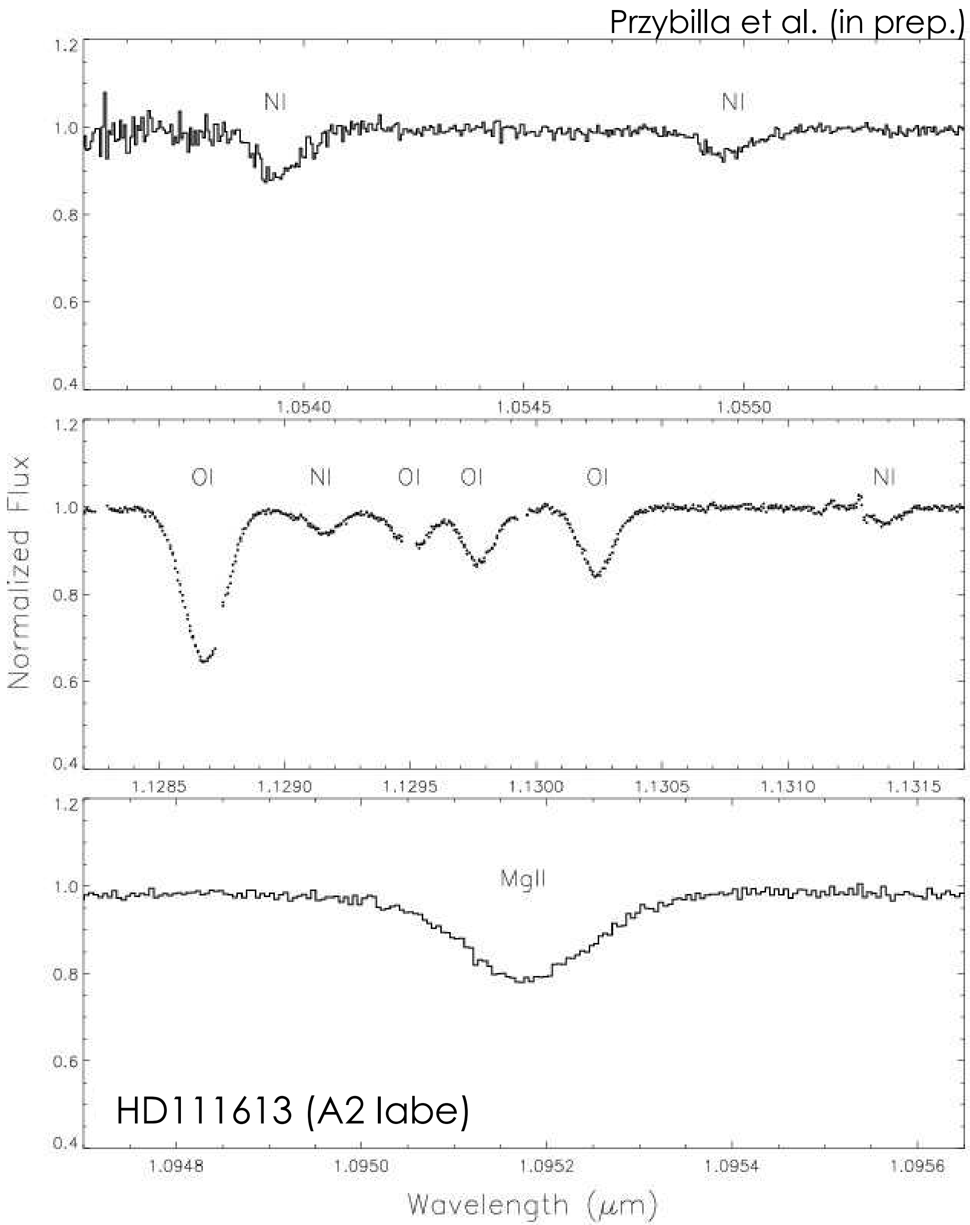
- detailed line profiles
- telluric lines resolved

analysis:

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

+ Brα: stellar wind

→ distances via FGLR & WLR



Near-IR Metal Lines

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

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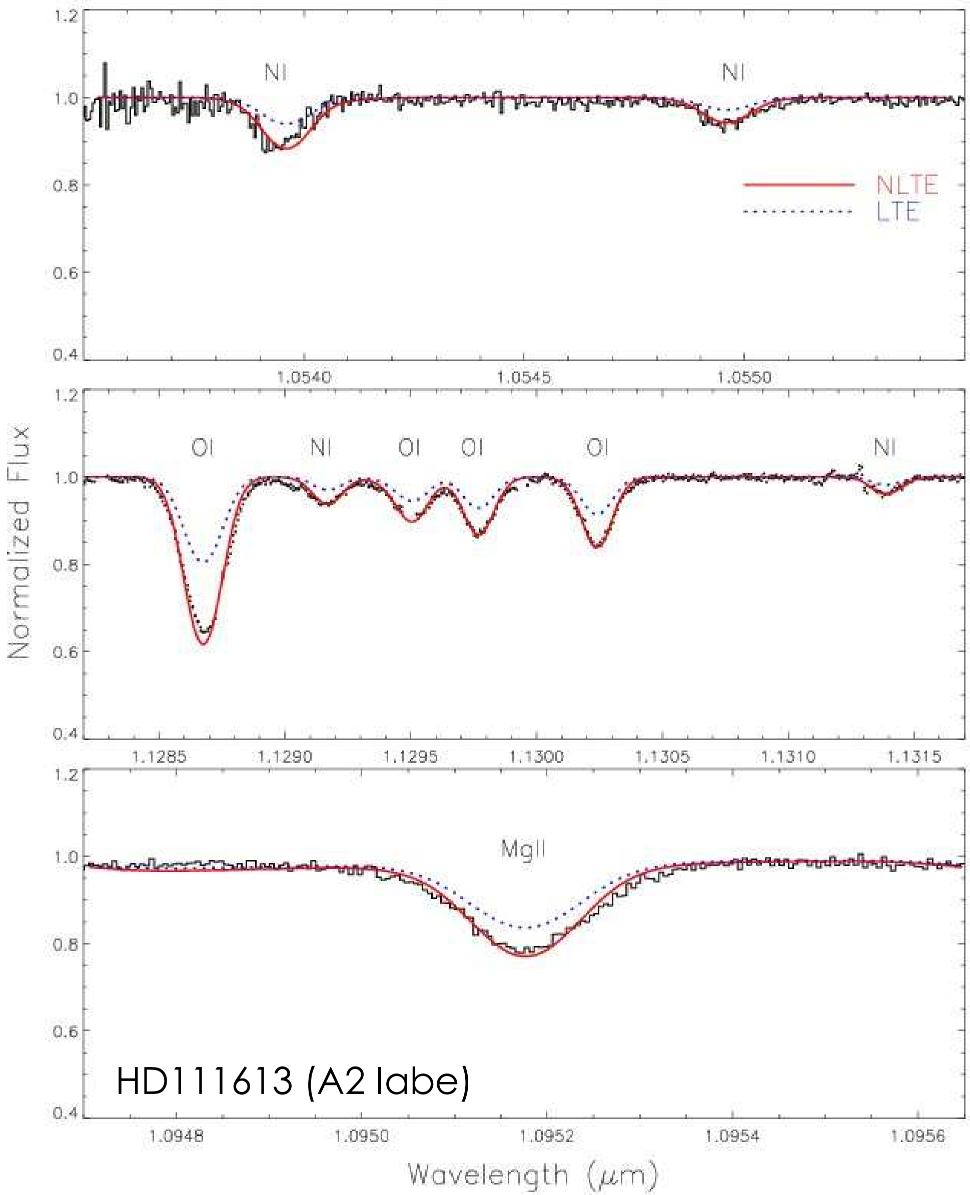

Near-IR Metal Lines

- 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

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Summary

- BA-SGs powerfull tools for studying
  - stellar evolution
  - galactochemical evolution
  - cosmic distance scale

- extragalactic stellar science with ELTs
  - ➡ near-IR spectroscopy using AO

- pilot study of Galactic BA-SGs with CRIRES@VLT
  - ➡ high-resolution near-IR spectra
  - ➡ testing & improving analysis methodology because of of challenging diagnostics