Constraining the low-mass end of the IMF from integrated-light spectroscopy

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EWASS/Sp12, Turku, 12 July, 2013

Focus of this Talk

- Brief review of past and current work on estimates of the contribution by cool dwarfs to the integrated light of galaxies, constraining the low-mass end of the IMF

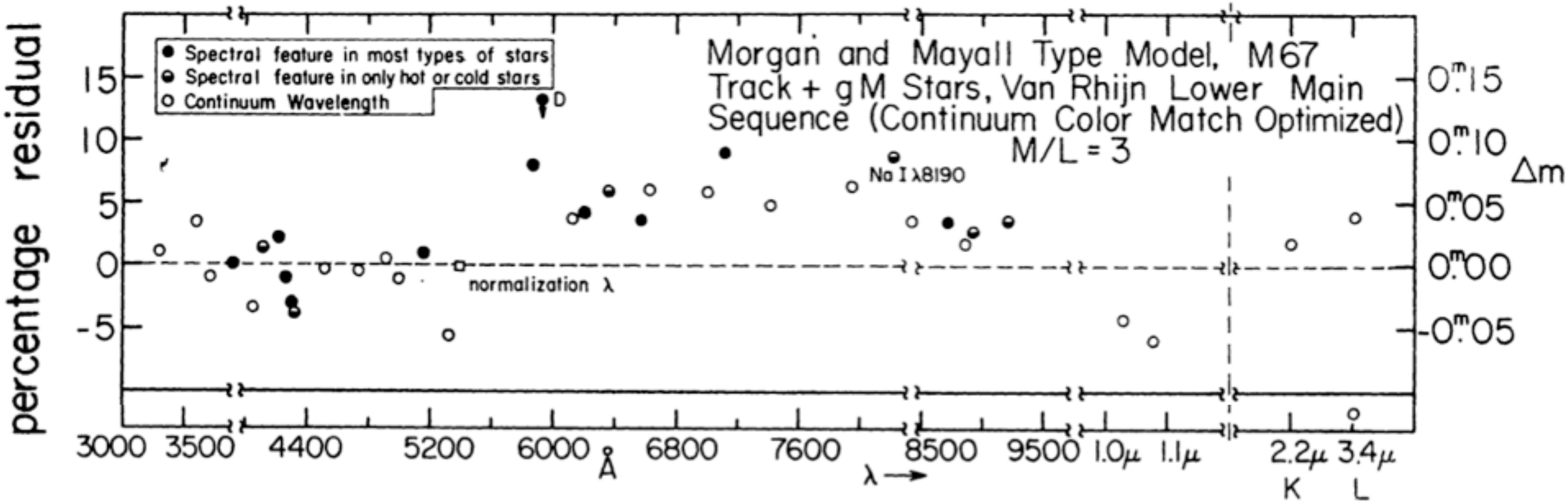
- Highlight some uncertainties and suggest directions towards improvement

Motivation

- Dynamical studies provide an accurate measure of M/L, but can't discern who contributes to M
- Integrated light studies address that problem and can constrain the shape of the IMF
- But that is a **difficult** problem

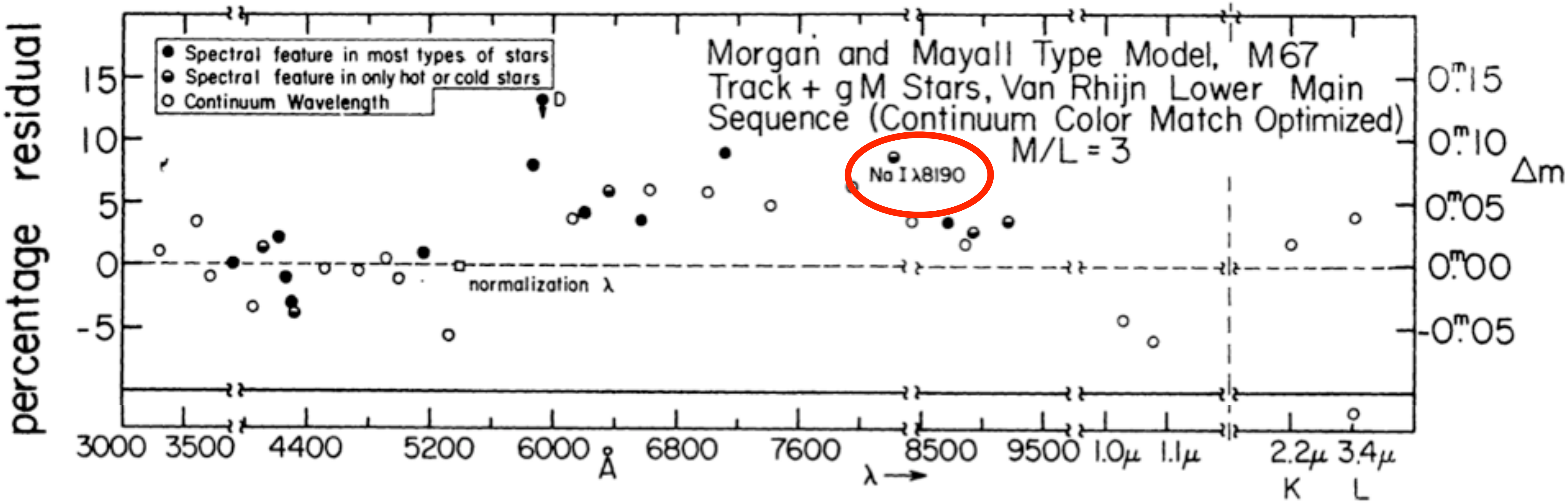
A Very Difficult Problem

The dwarf-rich nucleus of M31



- Spinrad & Taylor (1971)
- Photoeletric scanner observations at 16/32 Å steps
- Simple modeling based on observations of bright stars
- Required dwarf-rich models to match NaI at 8190 Å
- M/L ≈ 44

The dwarf-rich nucleus of M31



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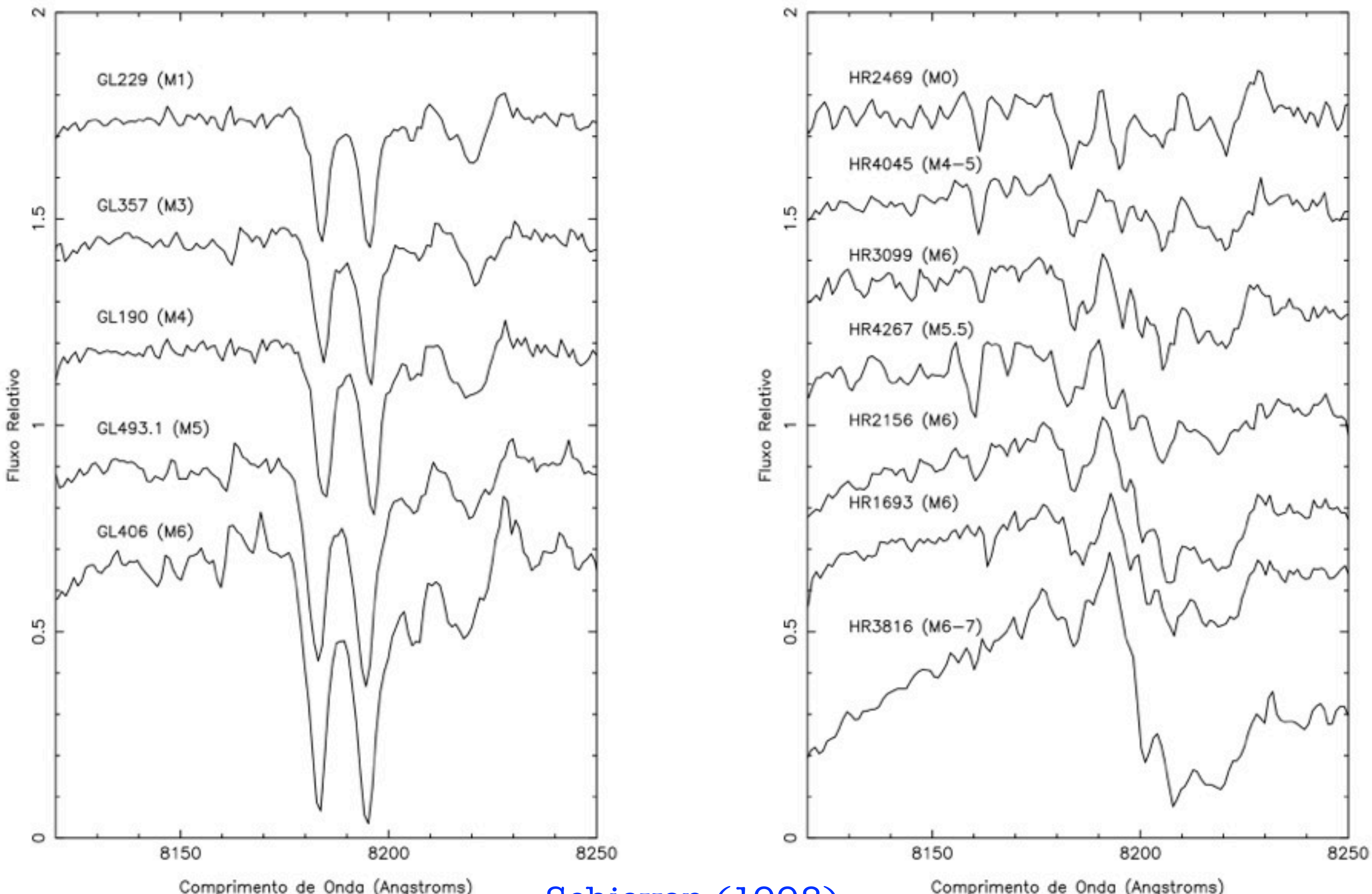
History

- Through 70s, 80s, and 90s, studies focused on a range of spectral indices: NaI 8190 Å, CaT (8498, 8542, 8667 Å), FeH 9900 Å, and CO 2.3 μm
- Largely inconclusive, due to model and data limitations
- Spinrad & Taylor (1971), Whitford (1977), Cohen (1978), Faber & French (1980), Arnaud & Gilmore (1986), Carter et al. (1986), Hardy & Couture (1988), Couture & Hardy (1993), Kroupa & Gilmore (1994), Schiavon et al. (2000), Cenarro et al. (2003)

Gravity Sensitive Lines: NaI 8190



Schiavon (1998)

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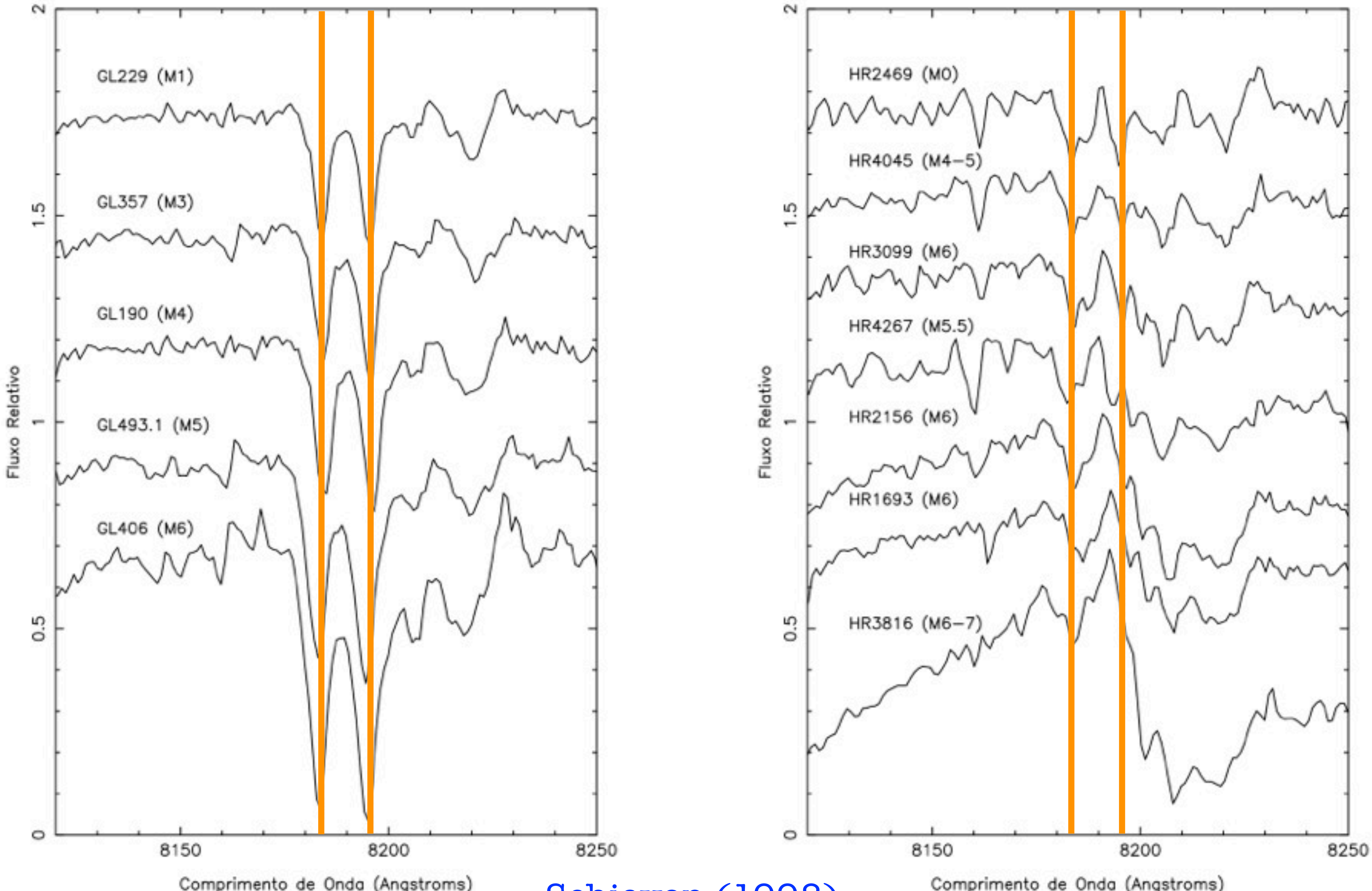

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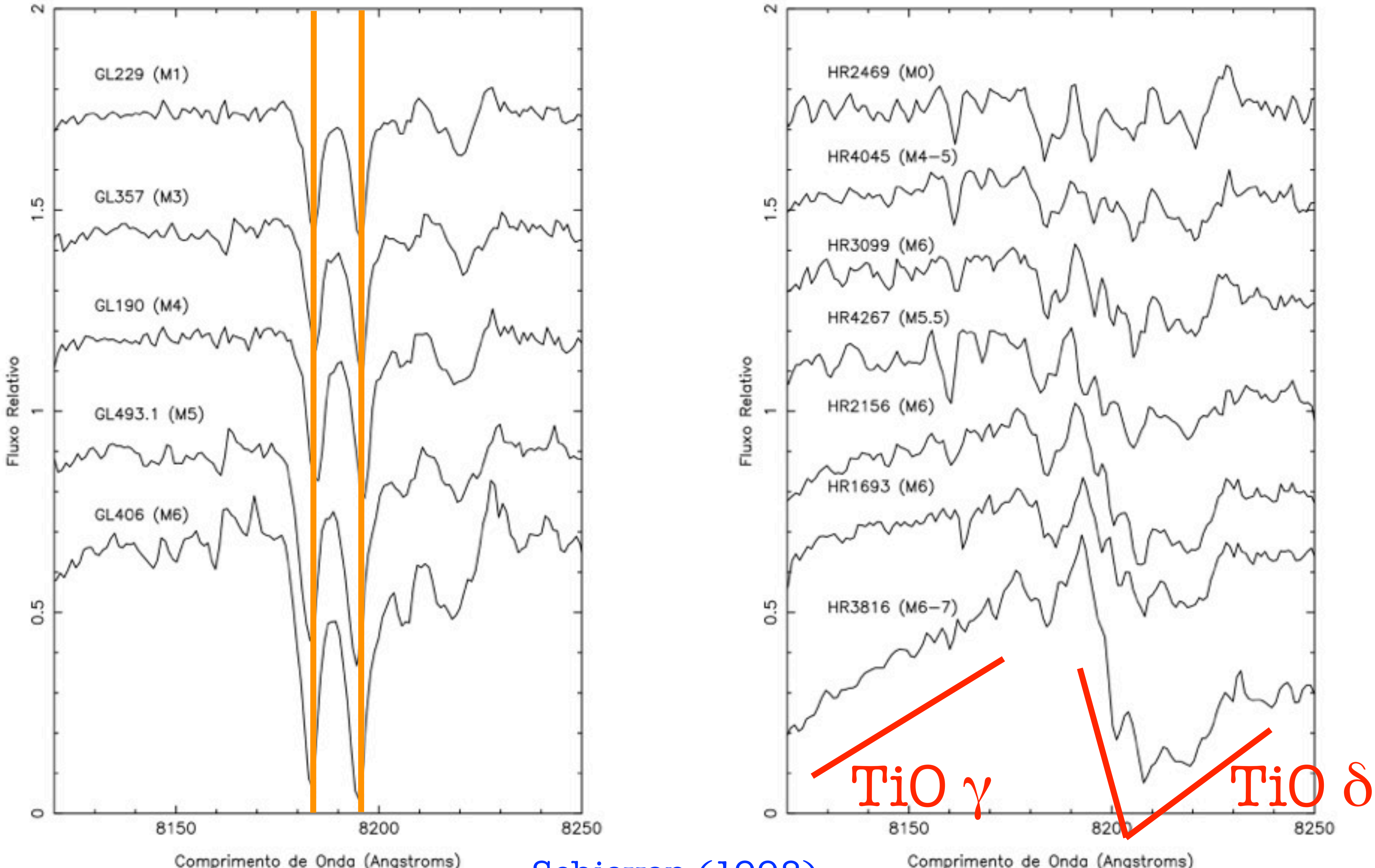
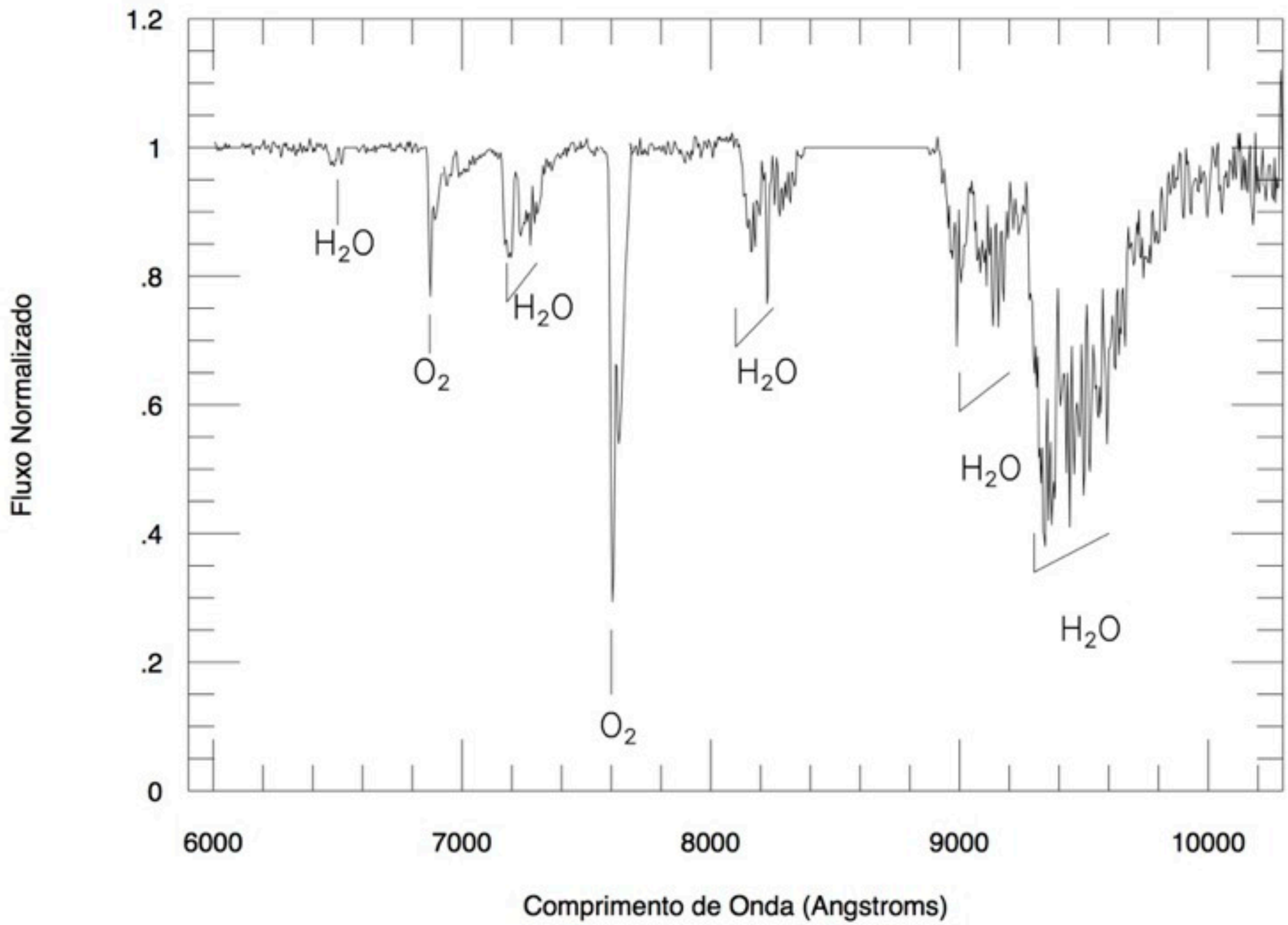


Schiavon (1998)

Difficulties: Telluric Absorption



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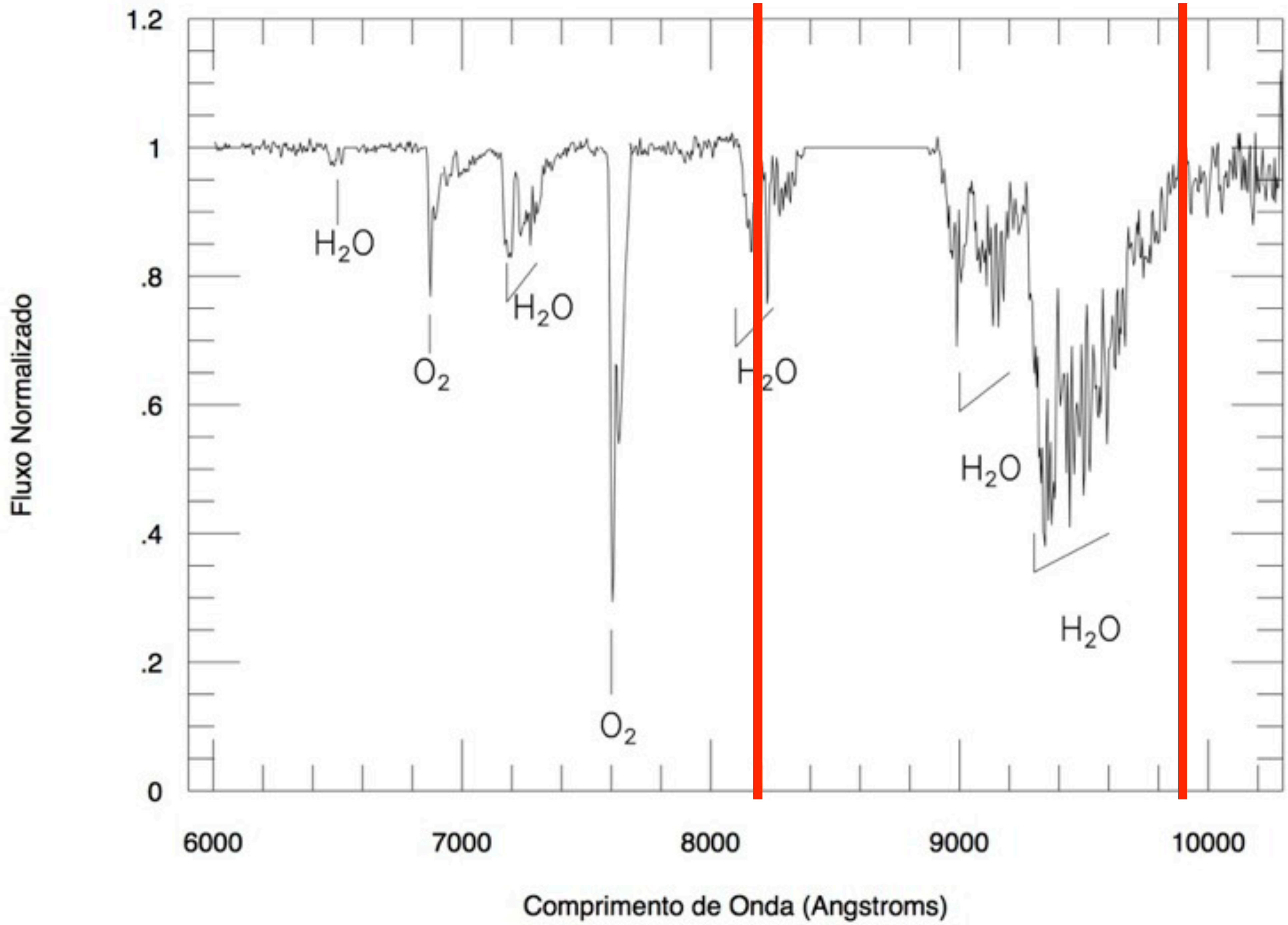
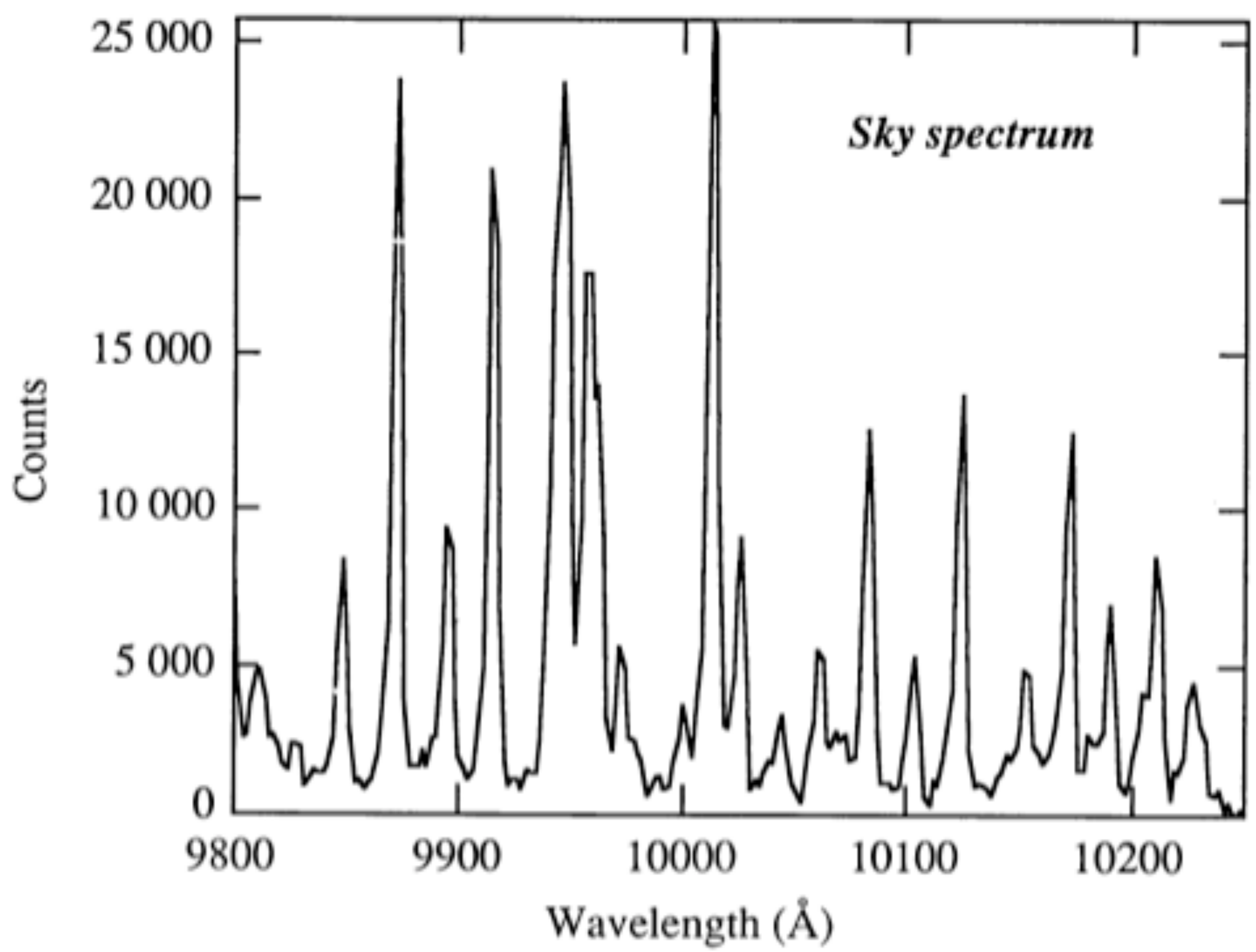
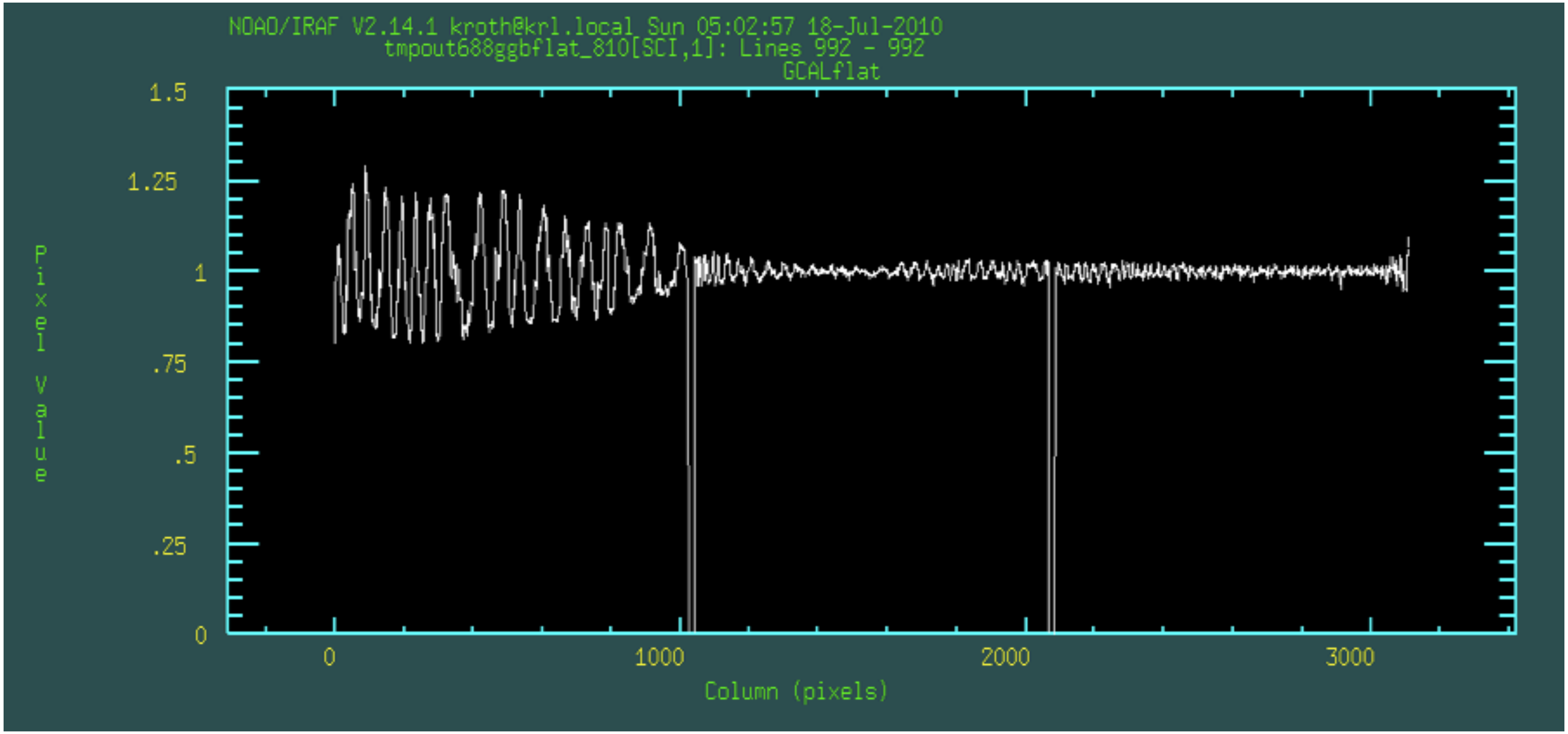


Difficulties: Airglow

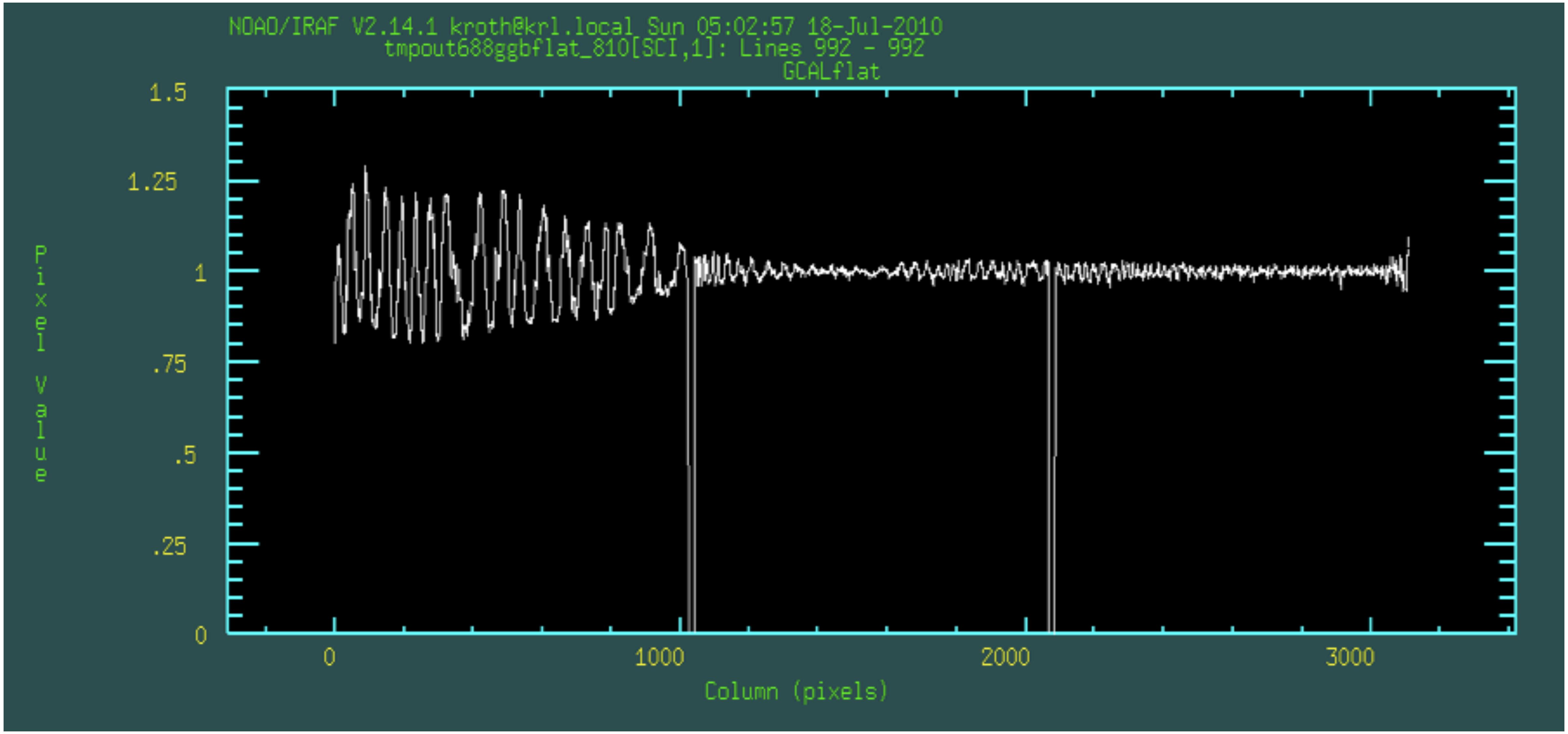


Difficulties: Fringing



1 μ ⟵ λ 0.6 μ

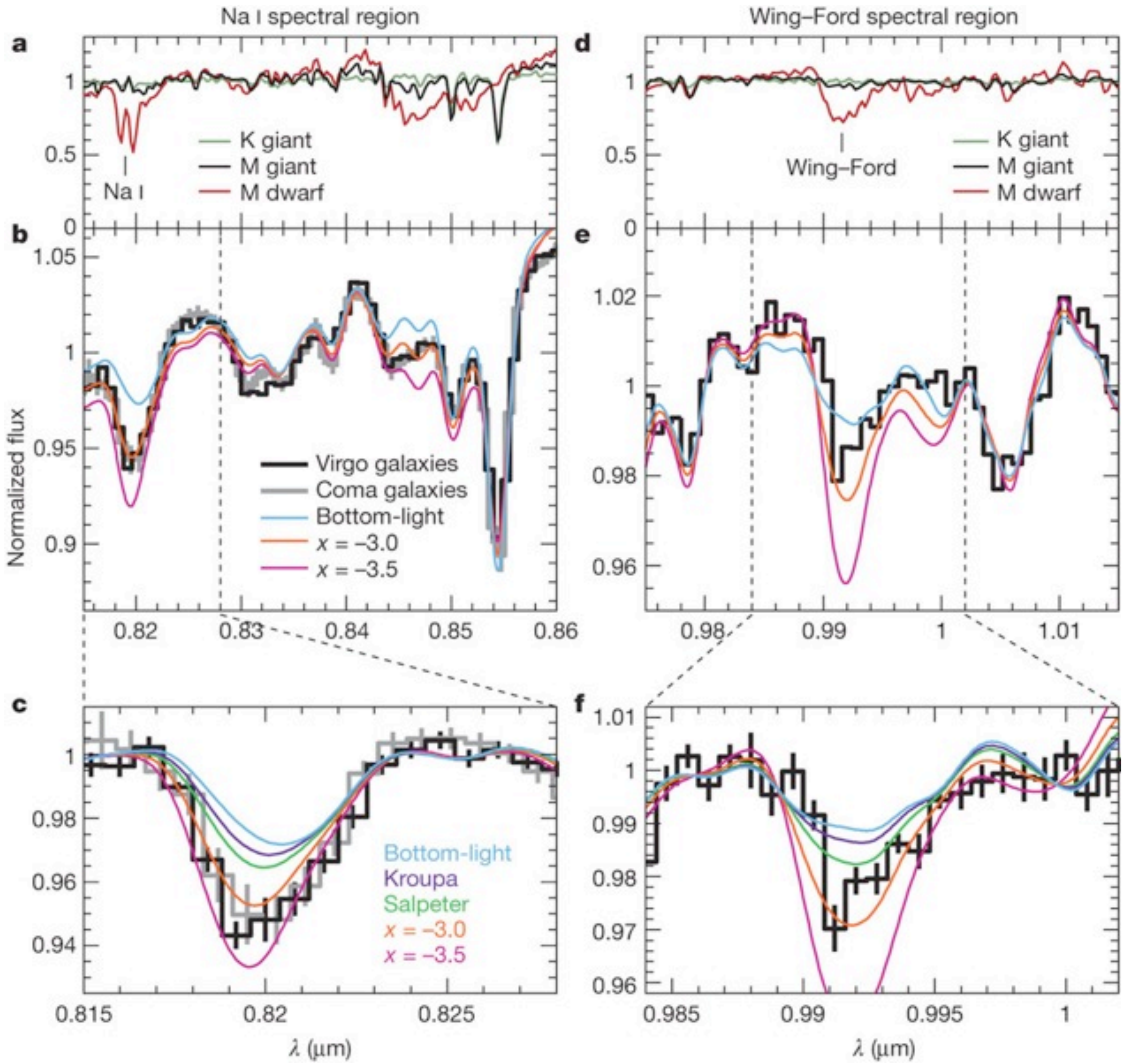
Difficulties: Fringing



1 μ ⟵ λ 0.6 μ

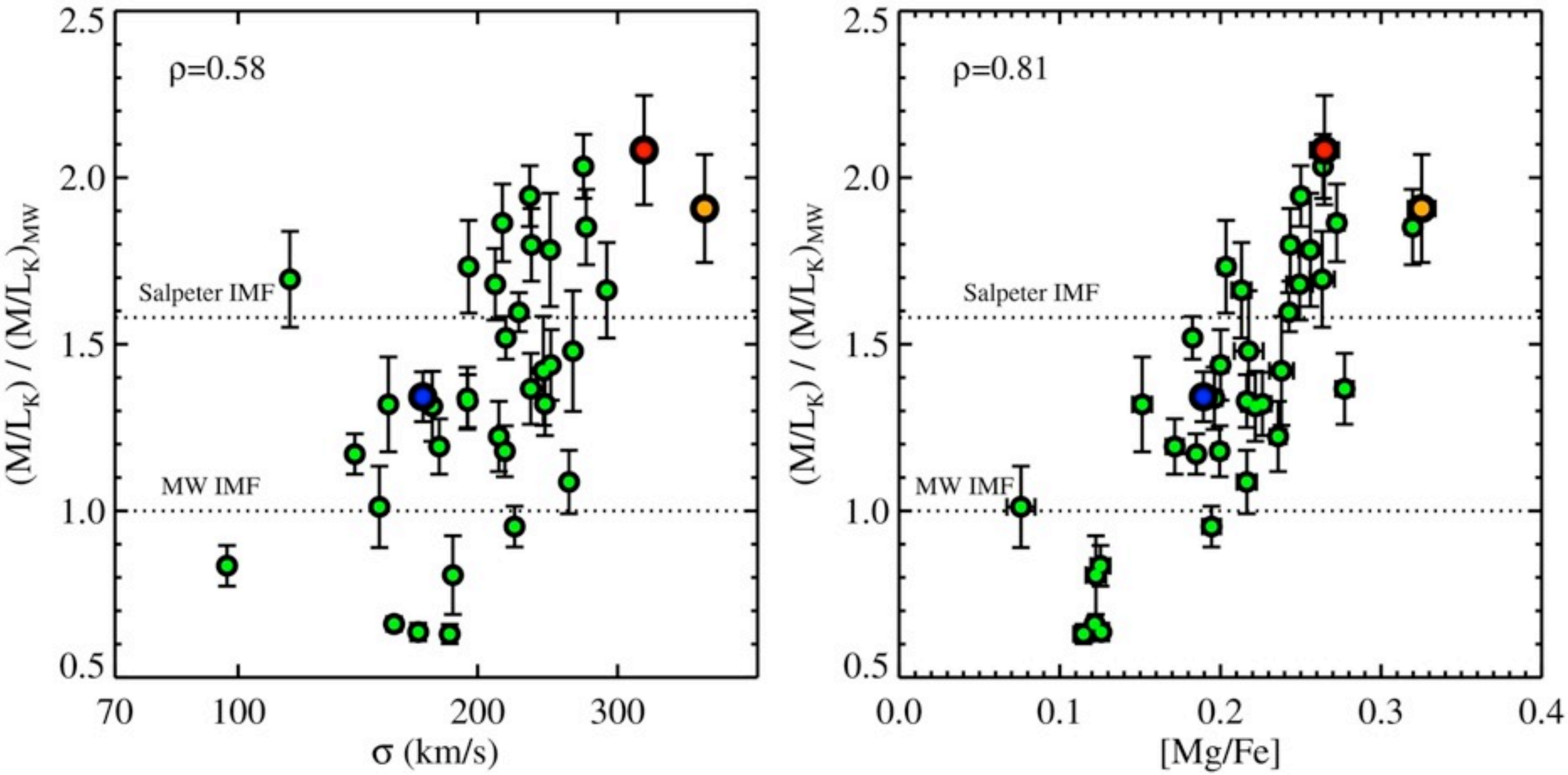
Largely overcome by deep depletion CCDs where fringing is reduced to ≈1%

Modern Times



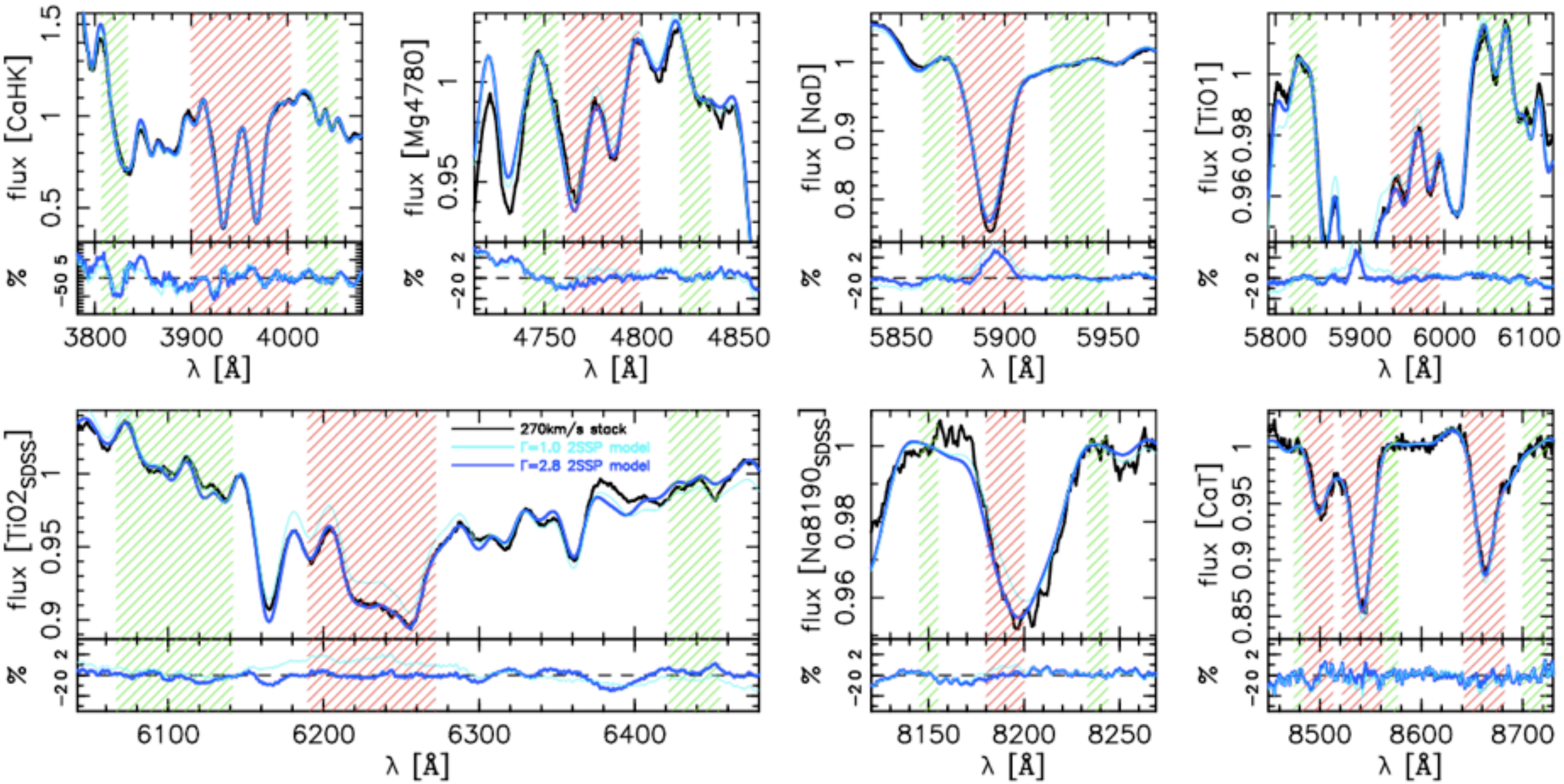
A substantial population of M dwarfs in ETGs

IMF as a function of global parameters



- Dwarf fraction correlates with σ and [Mg/Fe]
- Less scatter with [Mg/Fe] -> timescale for SF?

Confirmation from other groups/methods



La Barbera et al. (2013), Ferrera et al. (2012)

- Stacked spectra of +25,000 SDSS galaxies
- Analysis of several indices, alternative modeling approach
- IMF found to correlate more with σ than with [Mg/Fe]

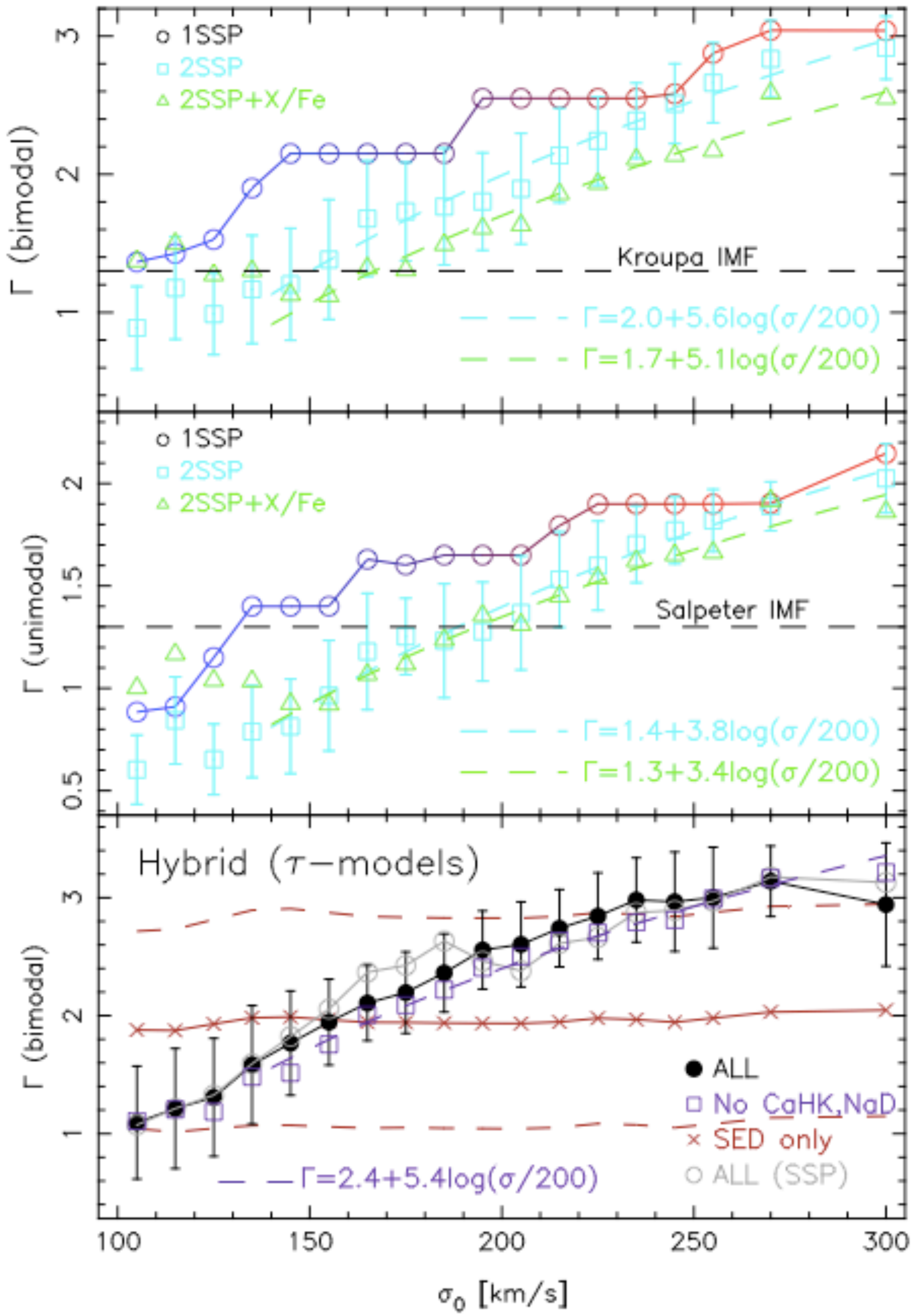
Confirmation from other groups/methods

La Barbera et al. (2013), Ferrera et al. (2012)

- Stacked spectra of +25,000 SDSS galaxies

- Analysis of several indices

- IMF found to correlate with σ



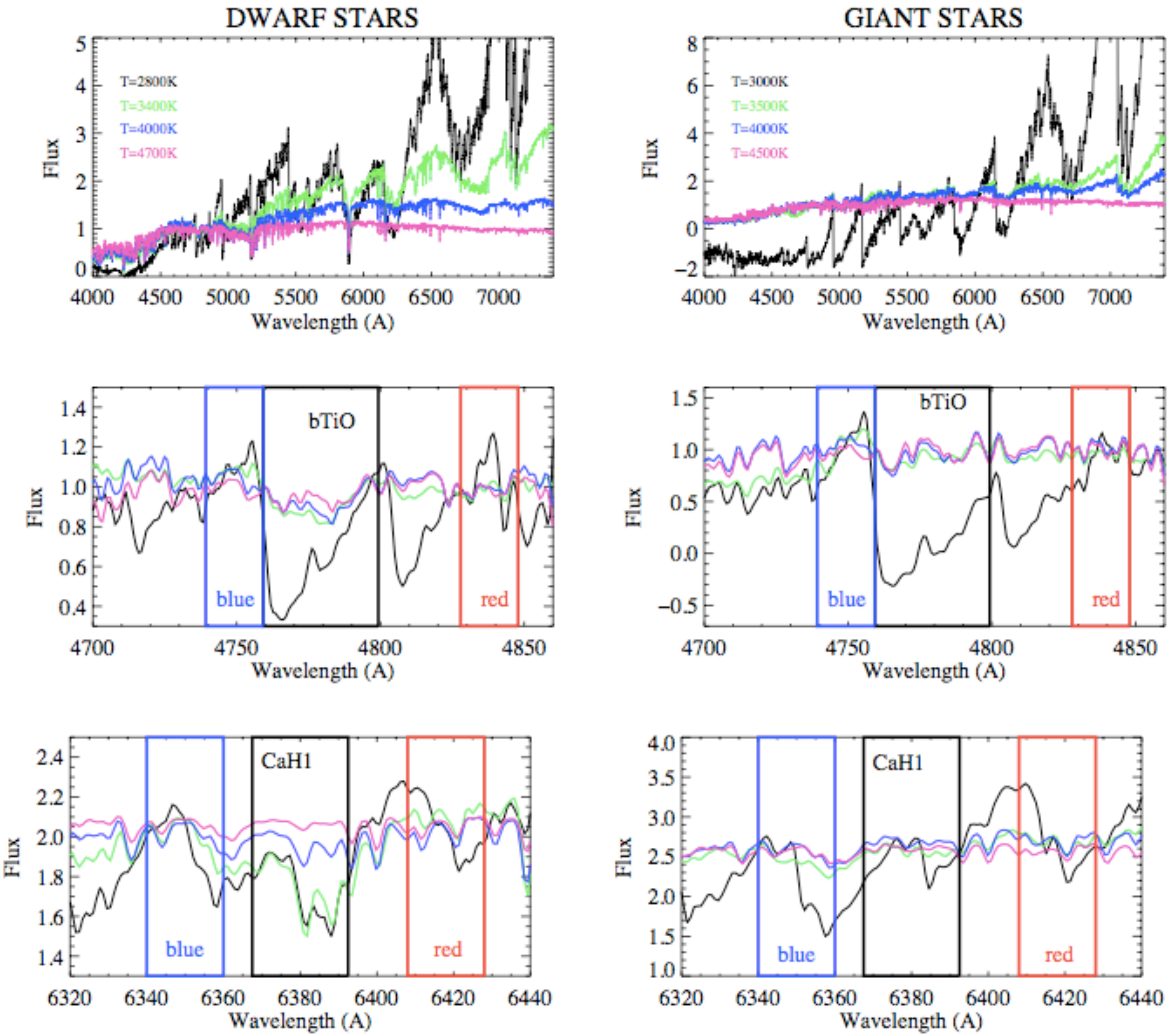
Confirmation from other groups/methods

Spiniello et al. (2013)

- Stacked spectra of 1,000s of SDSS galaxies

- Analysis of blue and red indices

- IMF found to correlate with σ



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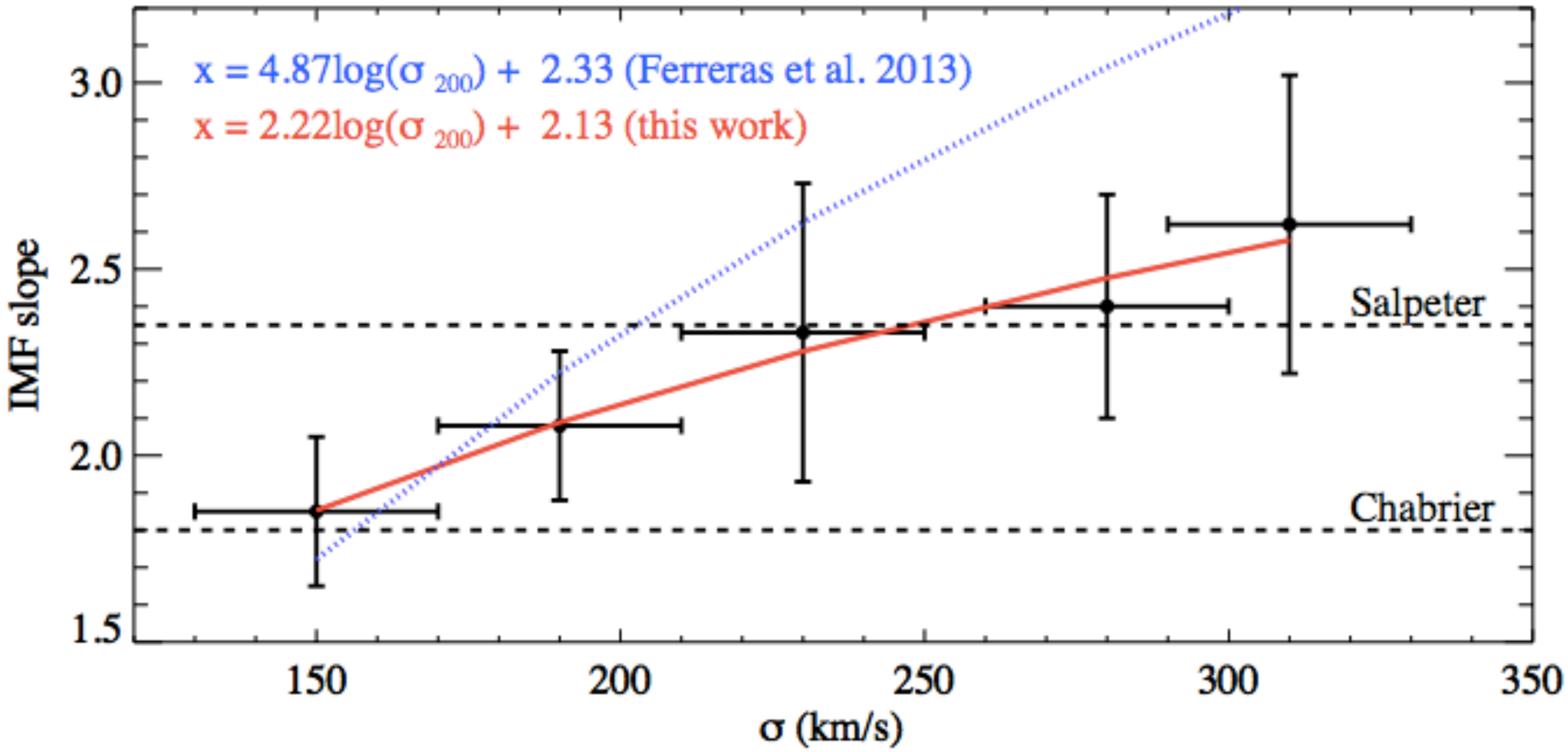
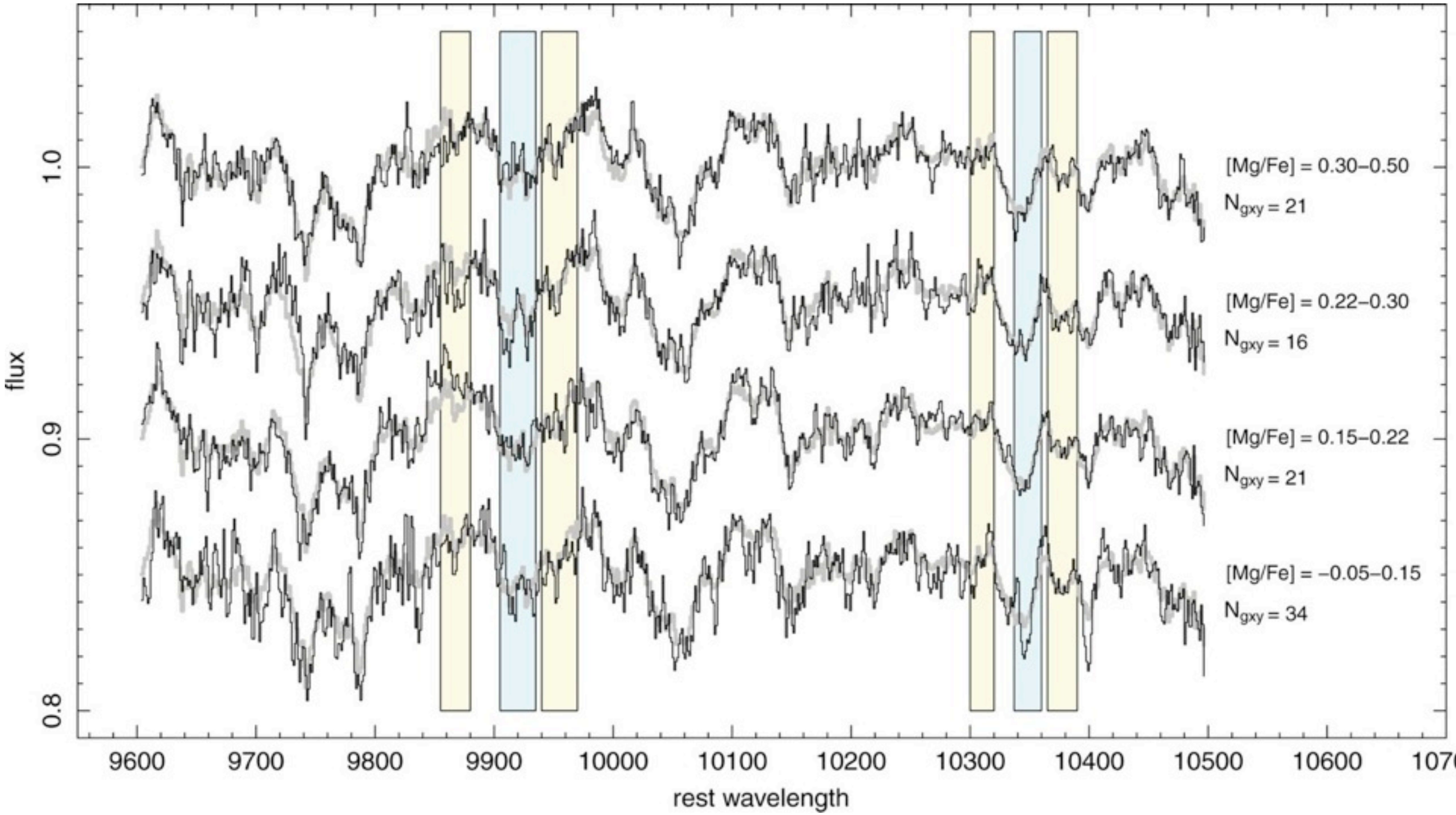


Spiniello et al. (2013)

- IMF also found to correlate with σ, but note disagreement in slope

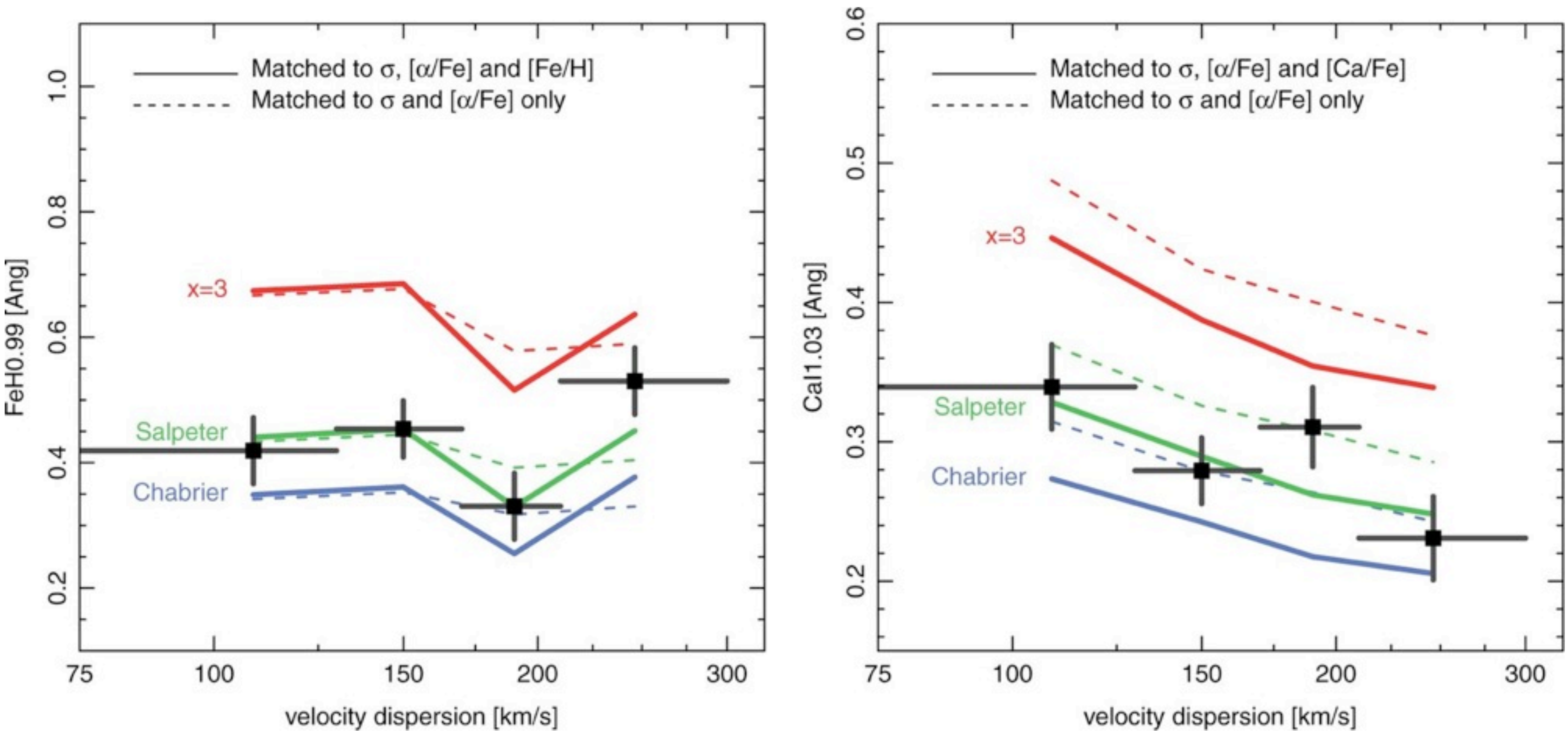
Dissonance: NIR spectra of Coma galaxies



Smith et al. (2012)

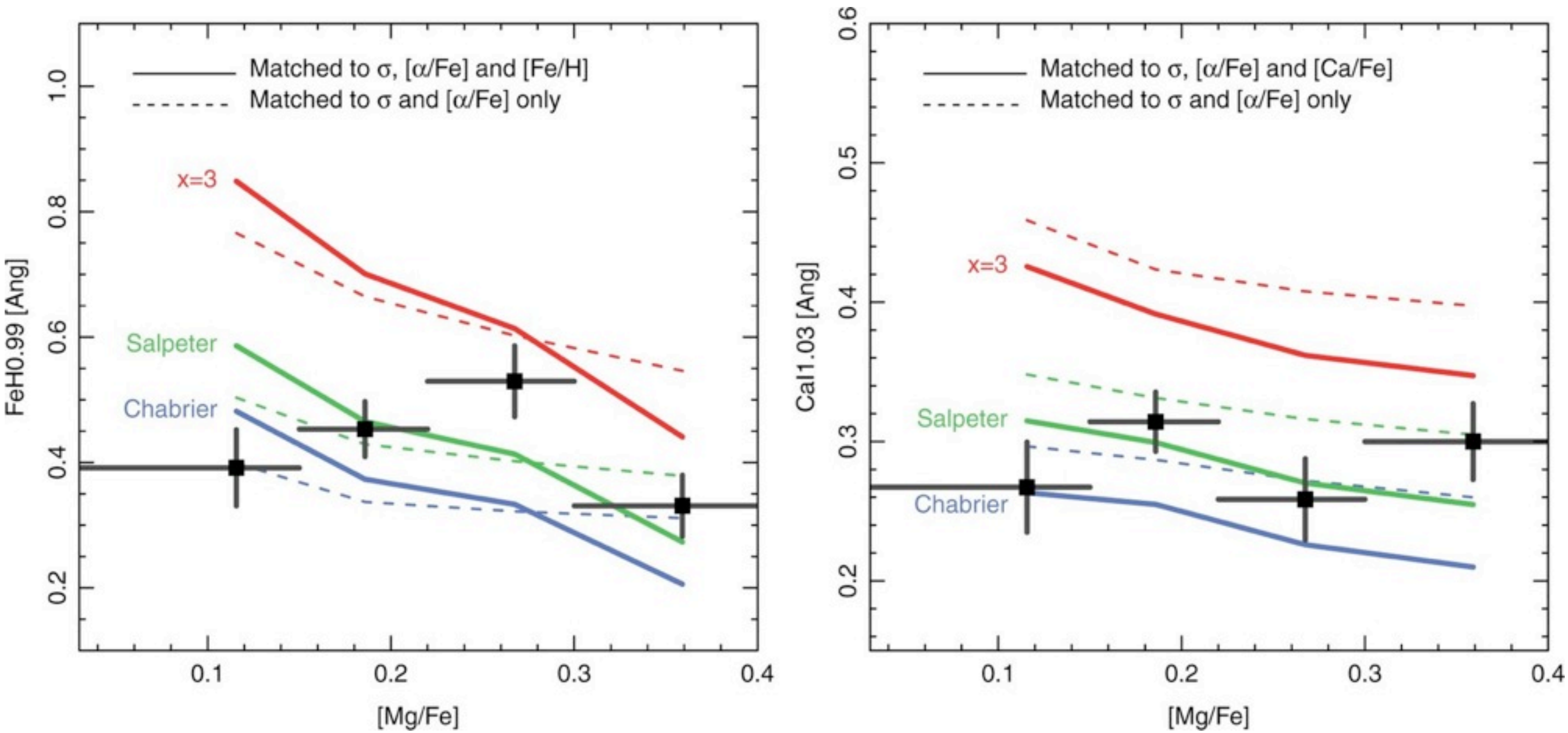
- Stacked J-band spectra from Subaru/FMOS
- Analysis based on WFB and the CaI 1.03 μm line

Dissonance: NIR spectra of Coma galaxies



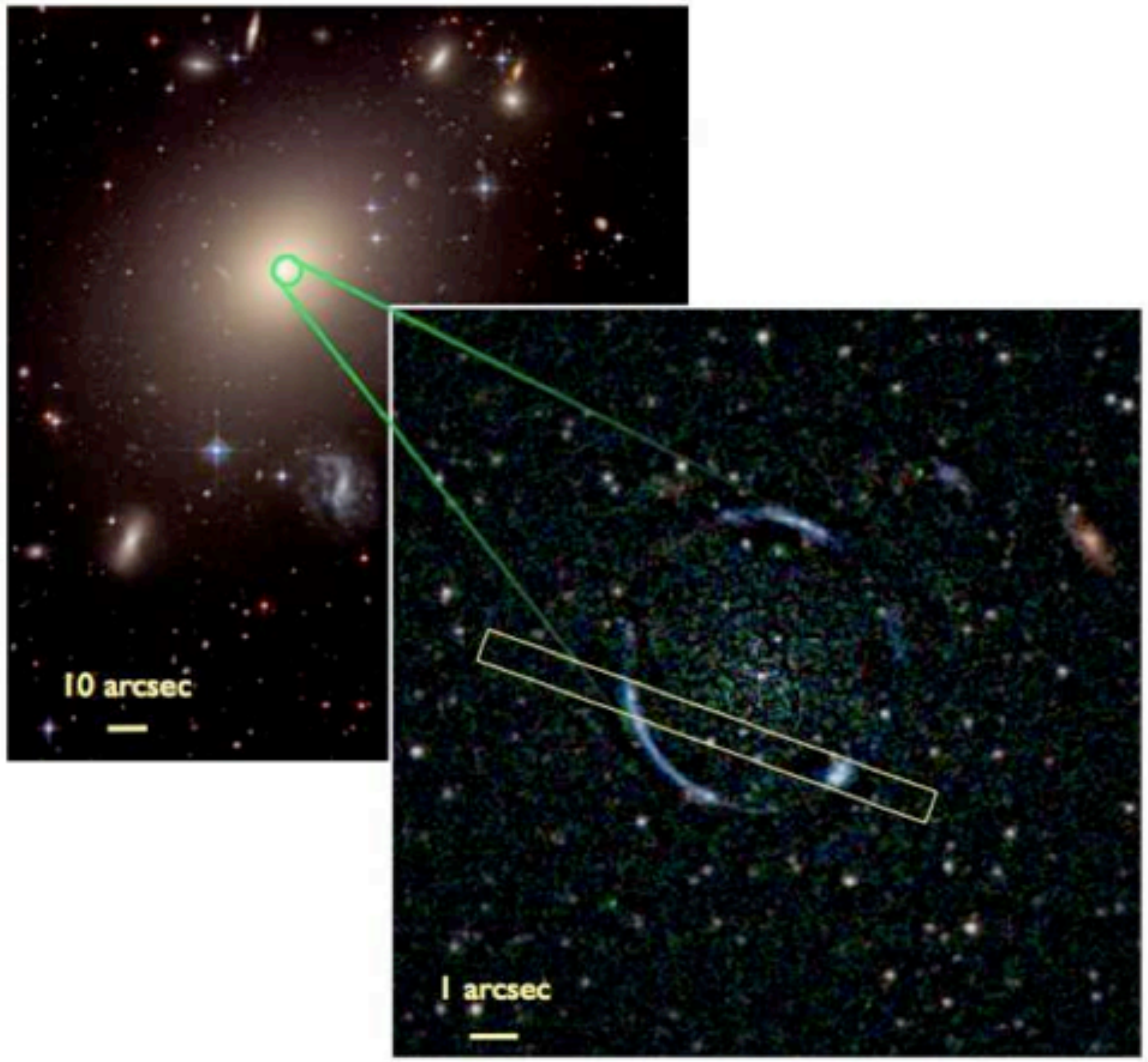
- No correlation found between IMF and σ
- Data consistent with Salpeter

Dissonance: NIR spectra of Coma galaxies



- A possible trend with [Mg/Fe], in qualitative agreement with Conroy & van Dokkum, although based on conspiracy

Dissonance: ESO 325-G004



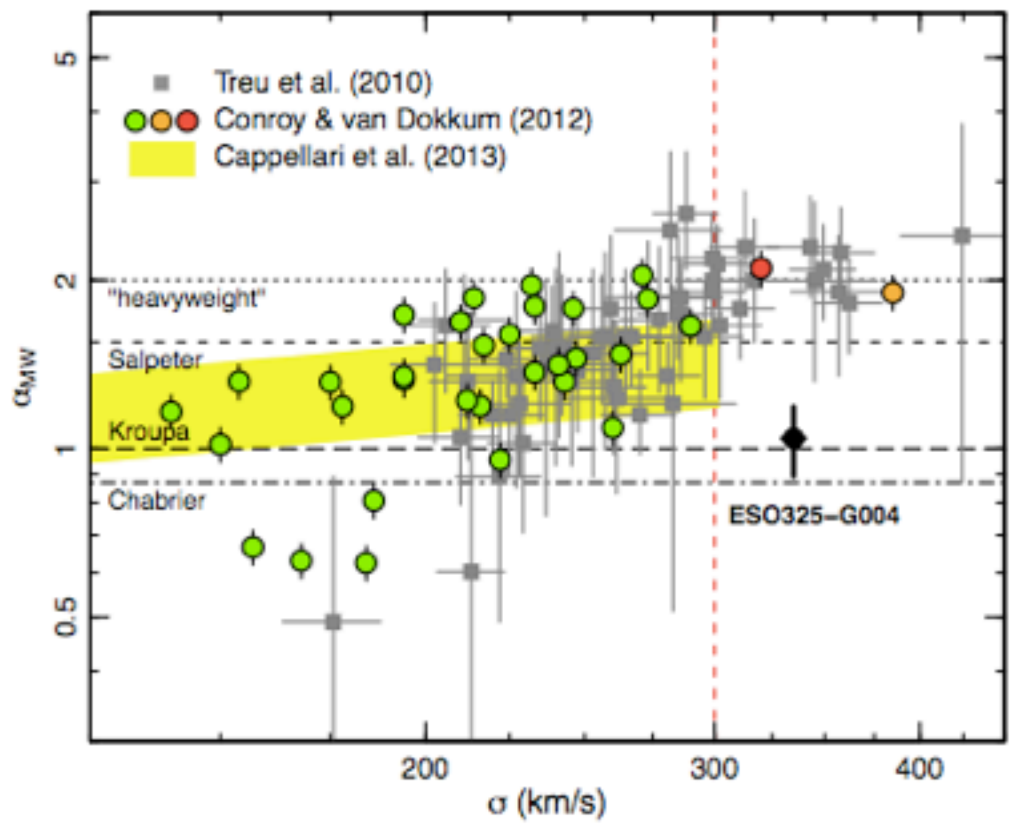
Smith & Lucey (2013)

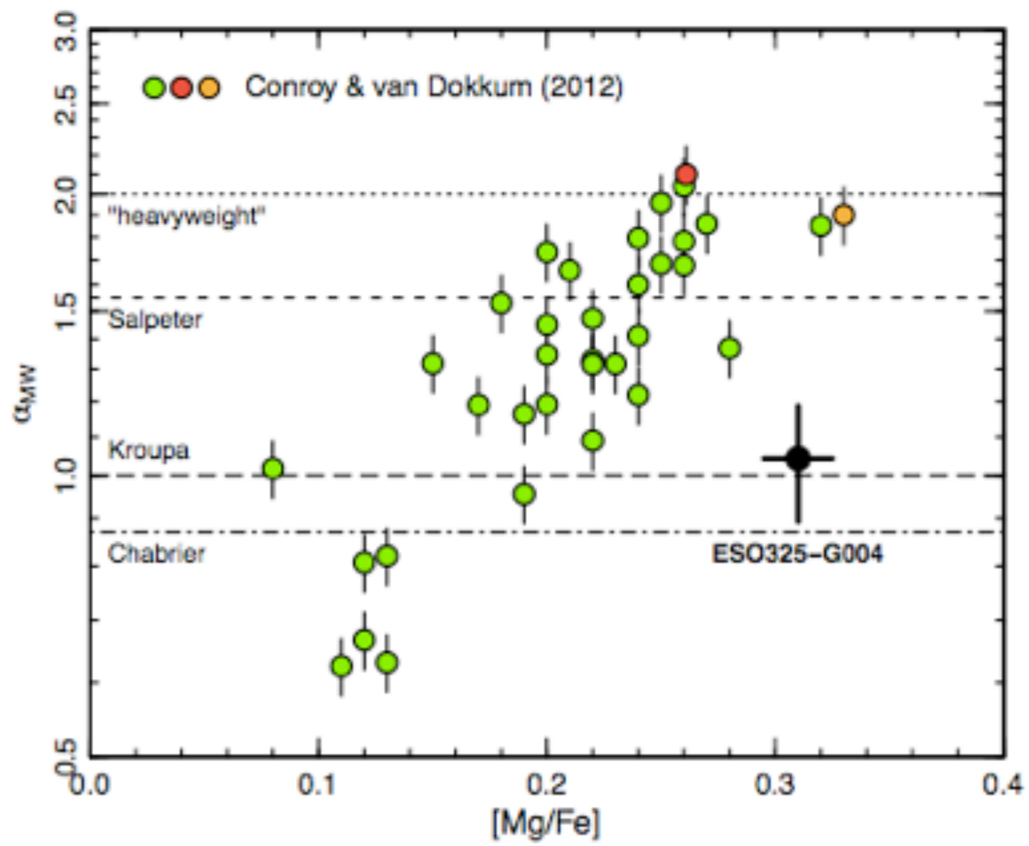
- Nearest known strong-lensing galaxy (z = 0.035)
- Arcs within $R_{eff}/4$ are essentially determined by stellar mass

Dissonance: ESO 325-G004

Smith & Lucey (2013)

- IMF more bottom heavy than Salpeter excluded at 99.8% confidence level
- In stark disagreement with trends with [Mg/Fe] and σ
- But one galaxy only
- Dependence on compactness may alleviate the tension (see Conroy et al. 2013 arXiv: 1306.2316)





Summary

- It is possible to constrain the low mass end of the IMF on the basis of integrated spectra of galaxies, thanks to improvements on data and models. Kudos to Vazdekis, Conroy, et al.

- These analyses indicate the presence of a trend between IMF and galaxy velocity dispersion, in general agreement with dynamical studies (Cappellari et al., Treu et al.)

- Not clear whether trend is due to a correlation with mass, metallicity, or [Mg/Fe] (SF timescale, IMF)

Summary

- The more indices, the wider the spectral region, the better. Kudos to Spiniello, La Barbera, Smith, Conroy, et al.
- The jury is still out, given remaining inconsistencies between teams and uncertainties in the method

Model Uncertainties

- Stellar evolution: can we predict numbers, Teff, and L of (giant) stars for various chemical compositions correctly?
- Stellar atmospheres: can we predict the spectrum of a cool star for given L, Teff, and chemical composition?

Difficulties: M Dwarfs are faint

Contribution to the integrated light in the far red from:

- RGB: 55%
- HB: 10%
- AGB: 10%
- KM dwarfs: 10%
- TO and SG: 5%

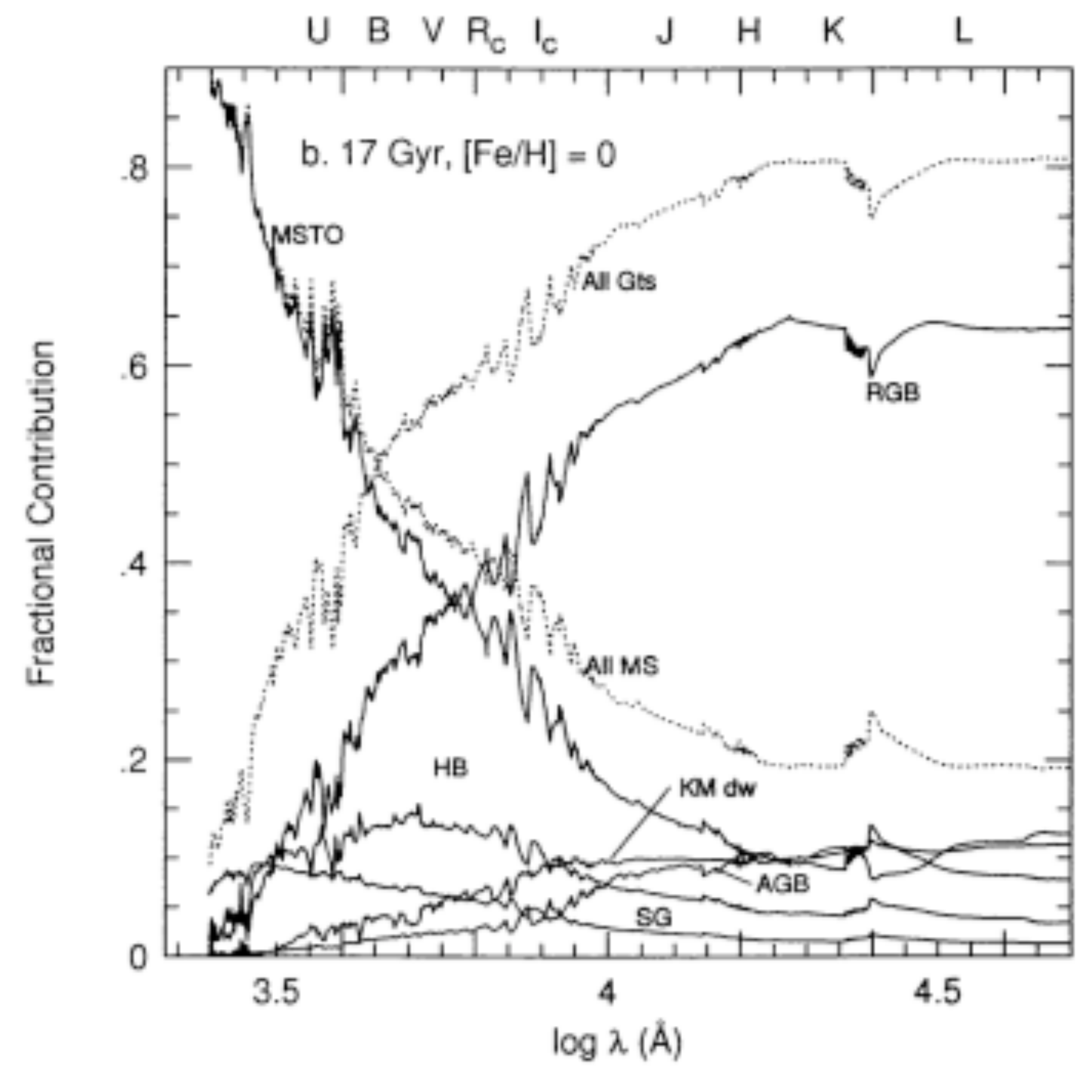


FIG. 41*b*

Worthey (1994)

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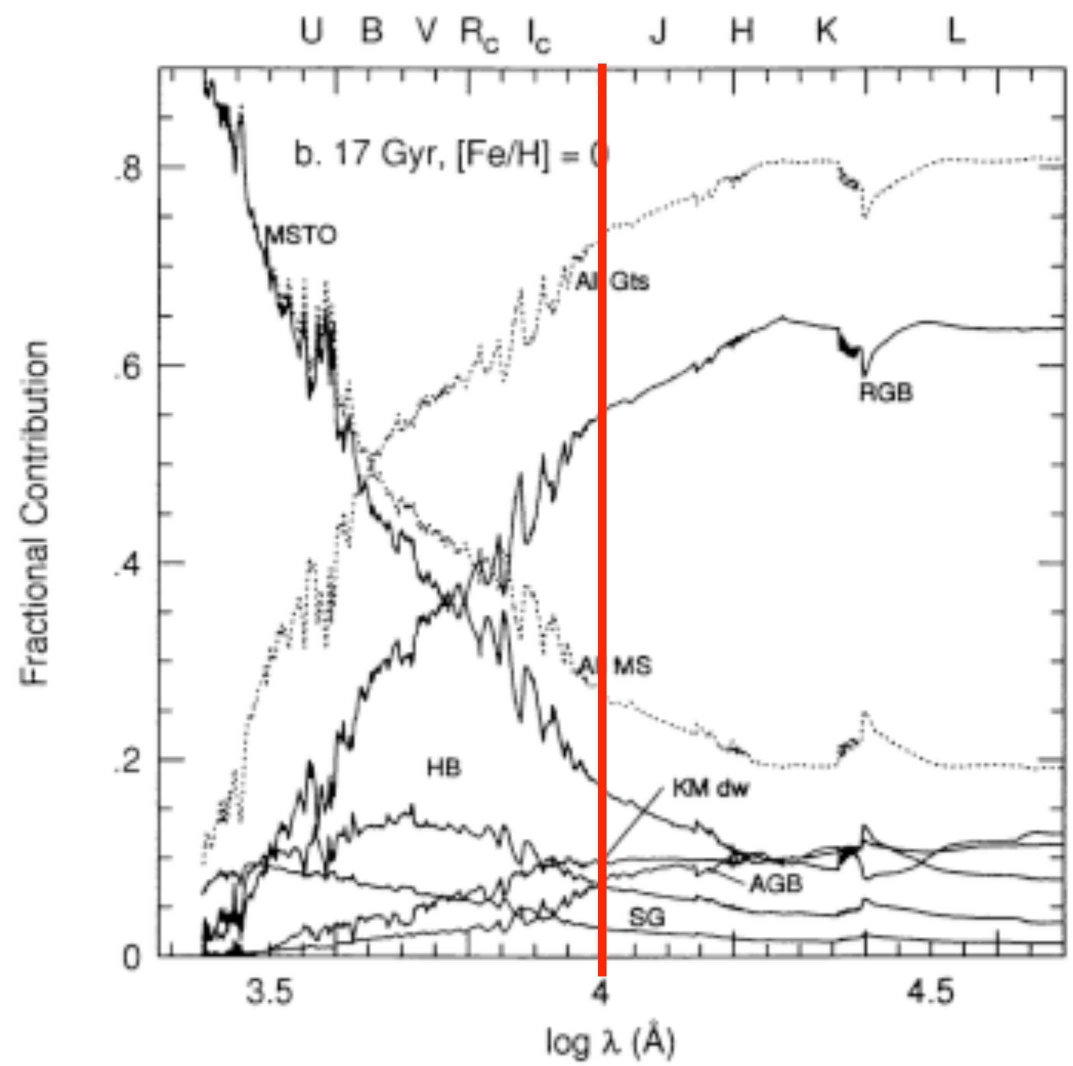


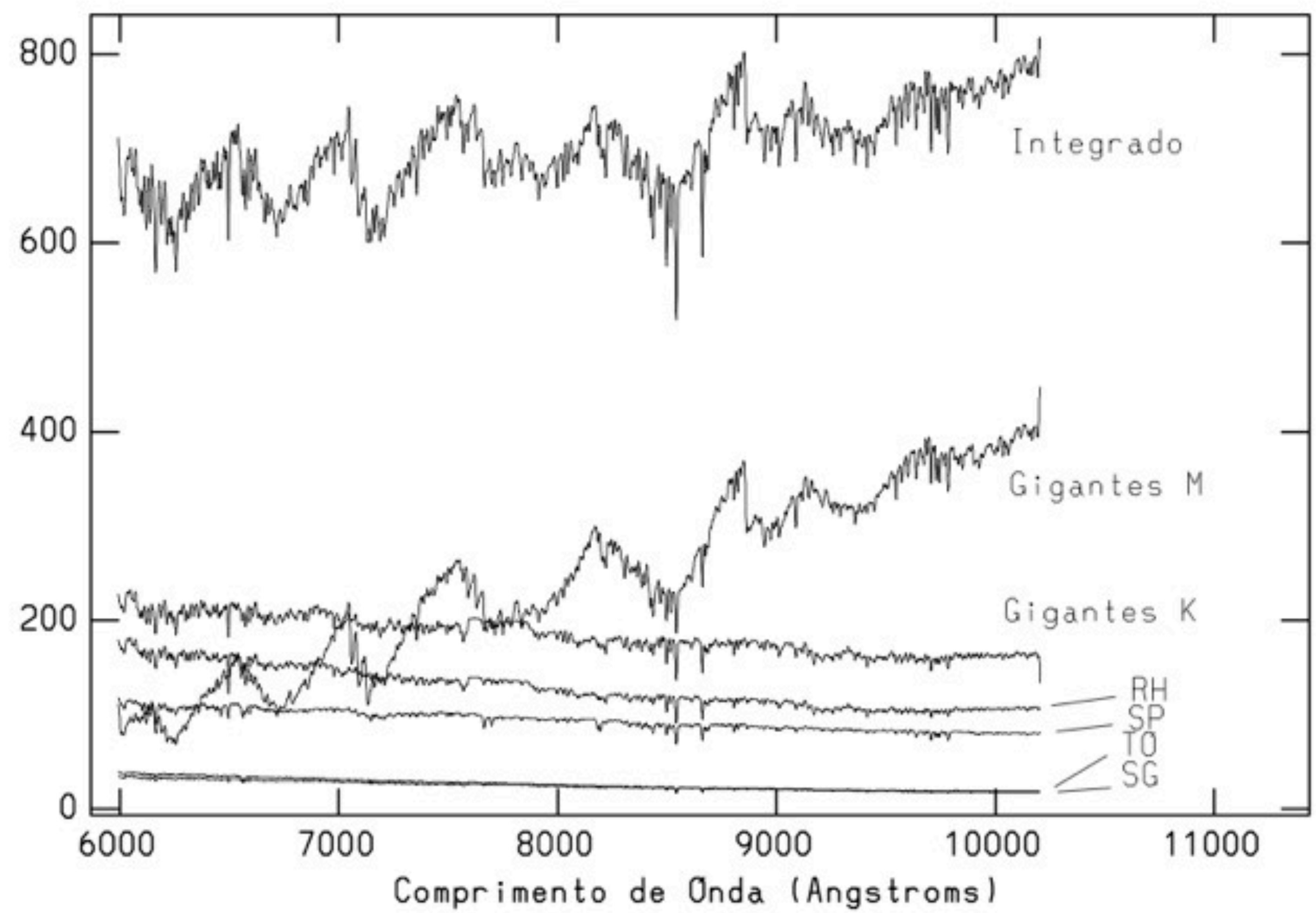
FIG. 41*b*

Worthey (1994)

Difficulties: M Giants are bright

Contribution to the integrated light in the far red from:

- M giants: 50%
- K giants: 25%
- HB (red): 15%
- KM dwarfs: 10%



Schiavon (1998)

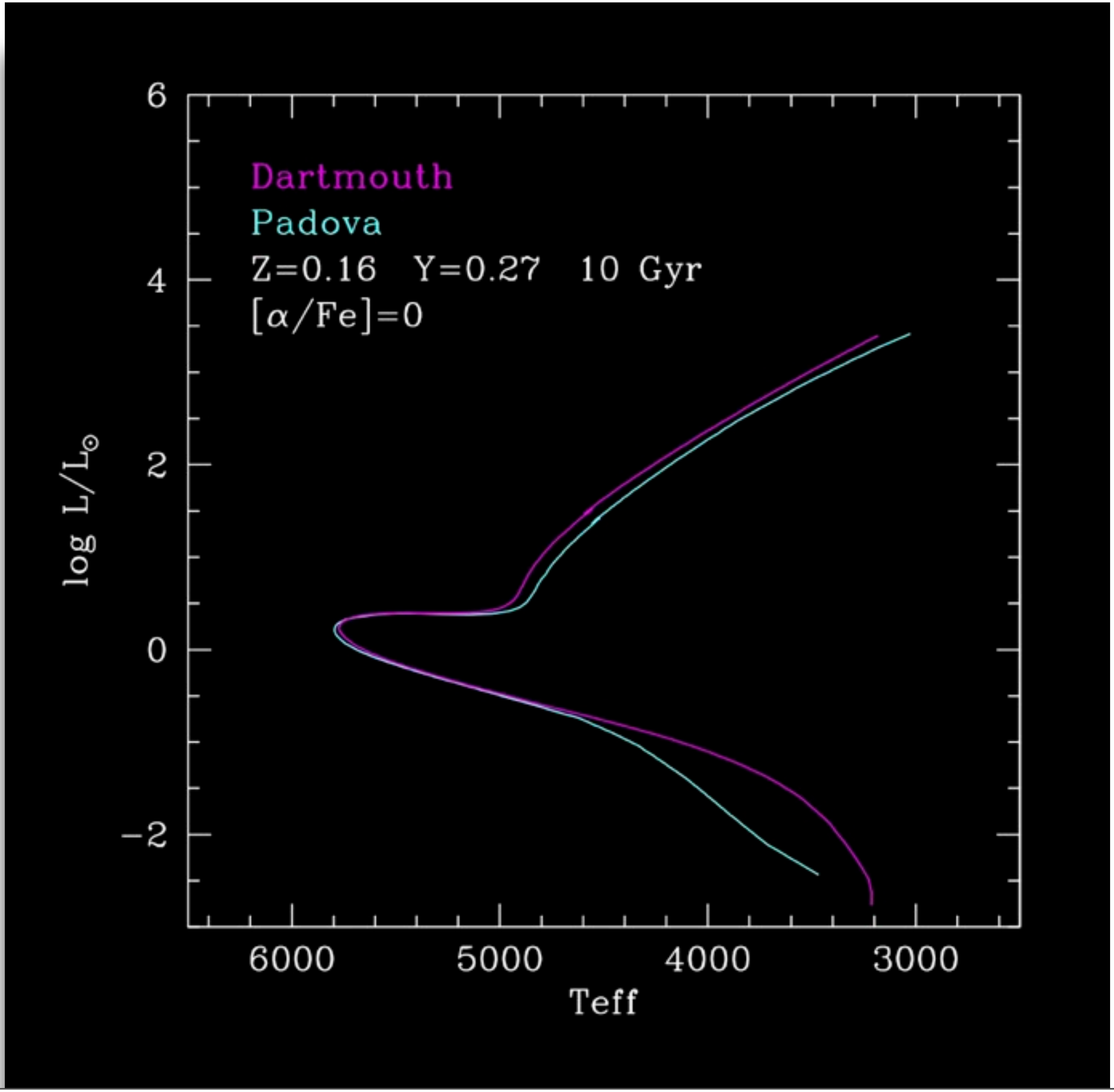
Based on CMD of NGC 6553

Stellar evolution uncertainties

Giants:
  Δ Teff ≈ 70-150 K

K Dwarfs:
  Δ Teff ≈ 500 K

Such uncertainties may have an impact on both absolute and relative IMF estimates



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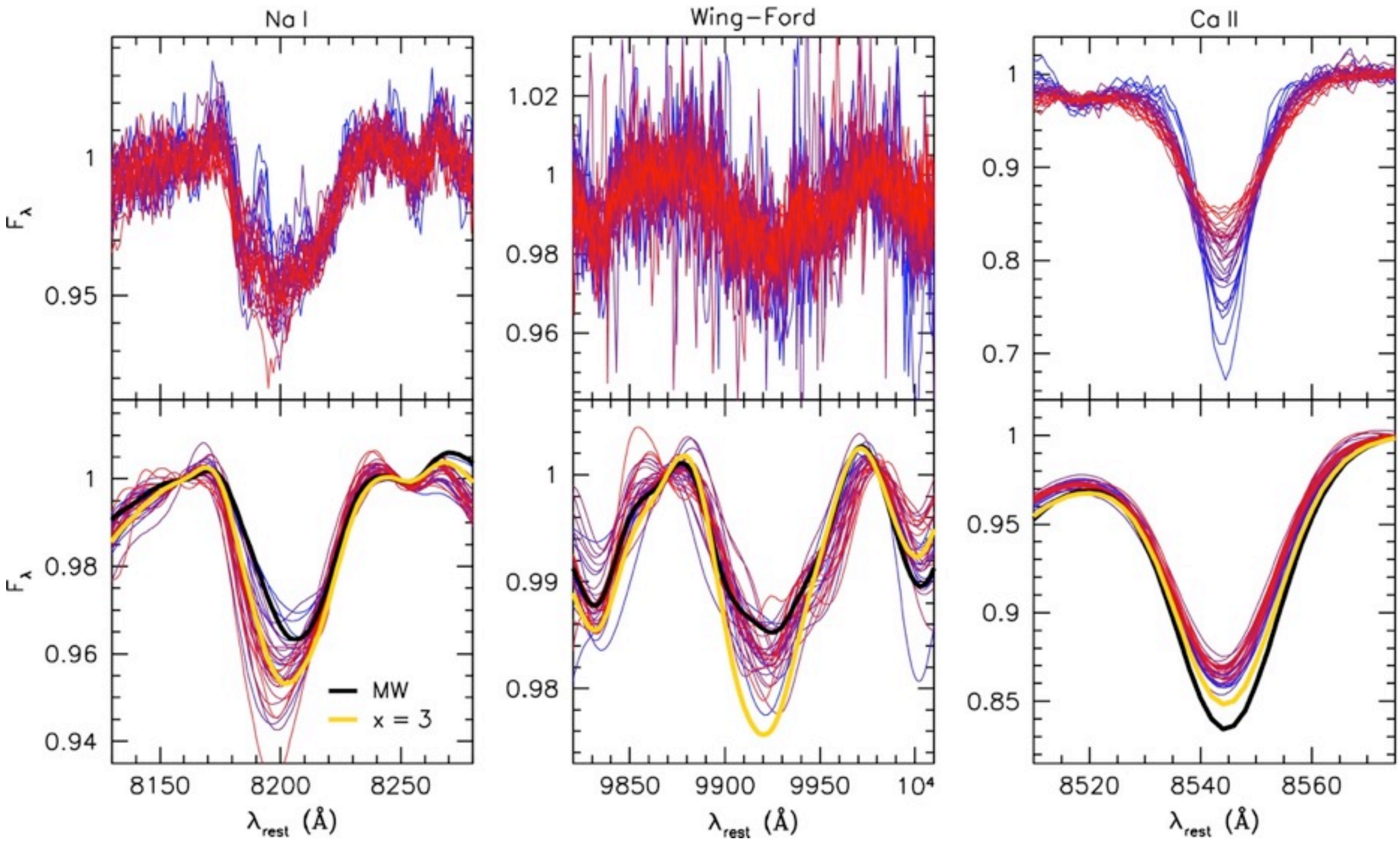


van Dokkum & Conroy (2012): 1-2% index flux variations

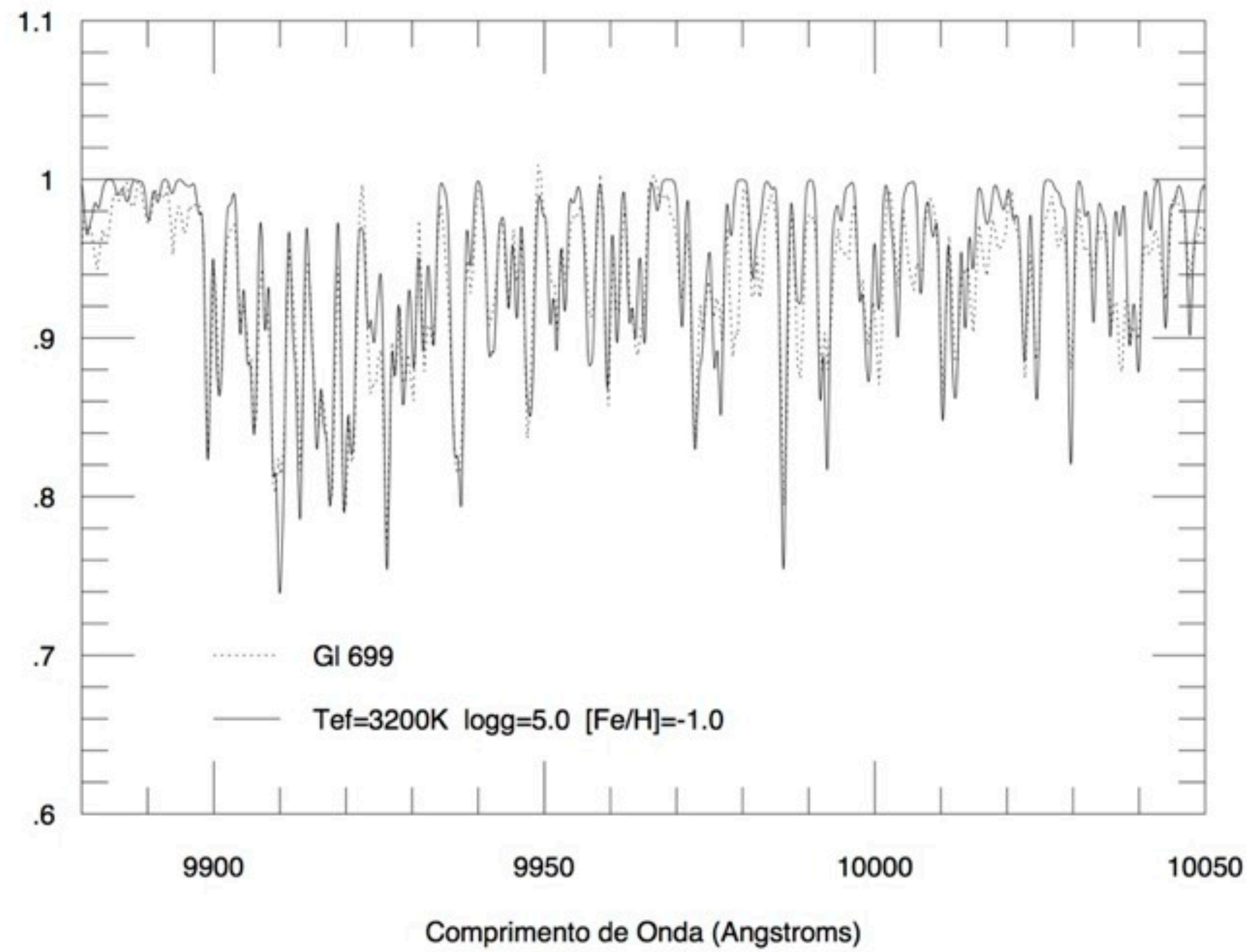
Spectral Uncertainties: Spectrum Synthesis

Spectrum synthesis based on 1998's state of the art

Uncertainties due to log gfs and model atmospheres

Still prevalent today (but BT-Settl looks promising)

Barnard's Star



Schiavon (1998)

Hybrid Approach

In view of these fundamental inaccuracies, one resorts to a hybrid approach, by which:

-- **Fiducial integrated model spectra** are based on **empirical libraries**

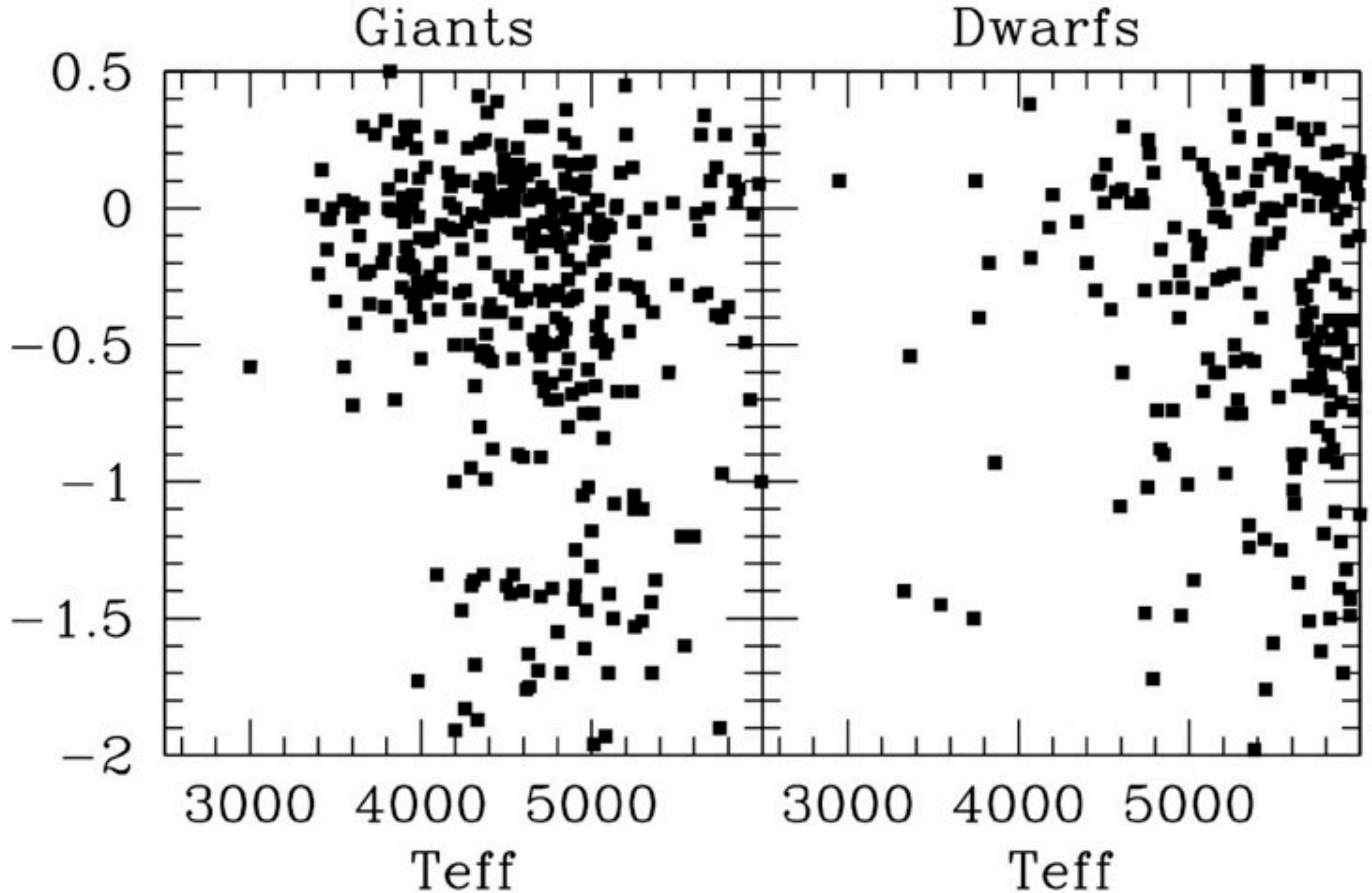
-- **Spectrum synthesis** is used **differentially** to correct spectra for **variable abundance ratios**

Conroy & van Dokkum (2012)
La Barbera et al. (2013)

Spectral Uncertainties: Empirical libraries

MILES

Spectra for 985 stars, with homogeneous stellar parameters



Cenarro et al. (2007)

Spectral Uncertainties: Empirical libraries

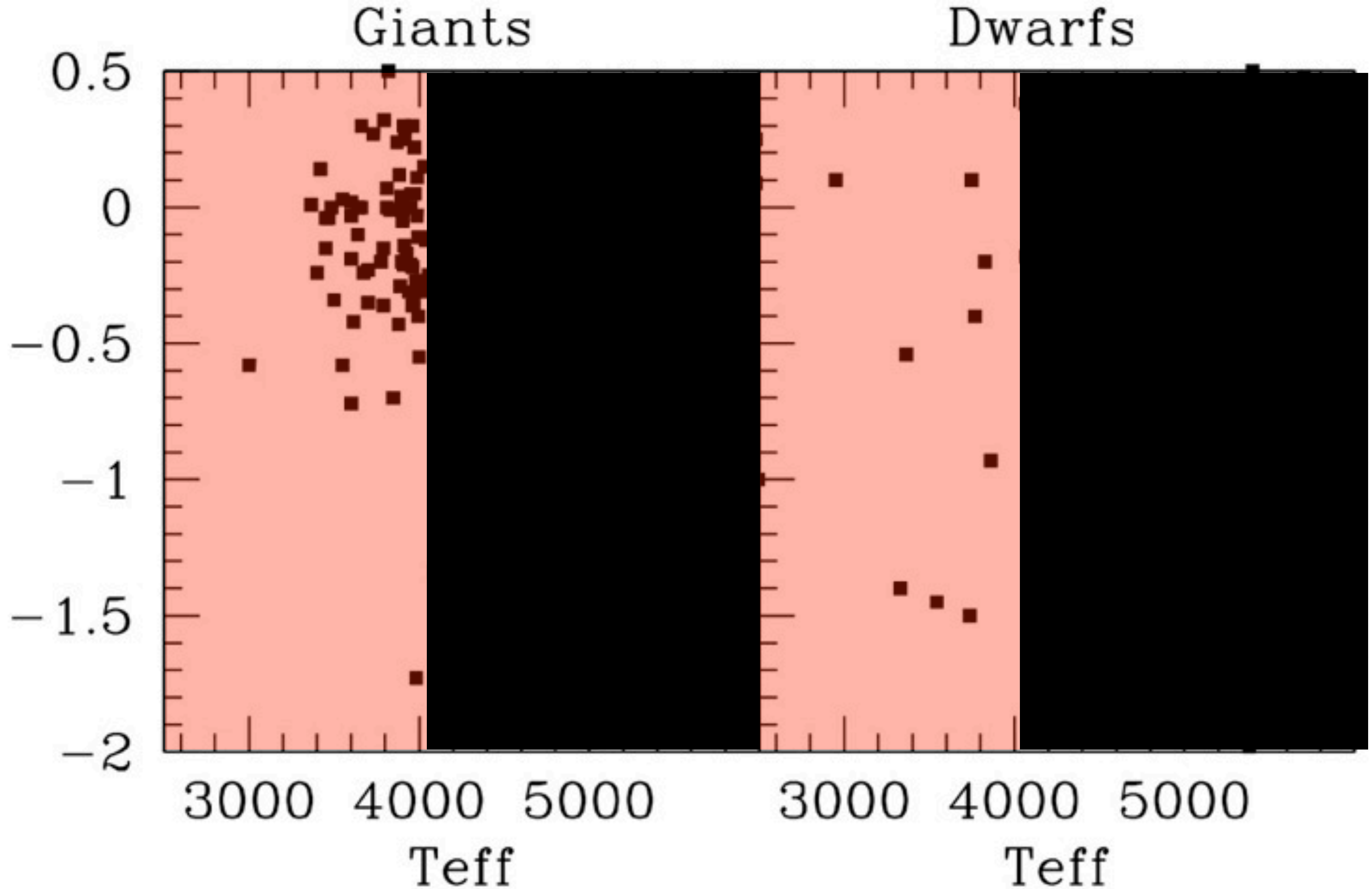
- 63 M giants
- 9 M dwarfs

With known (but uncertain) metallicity

Little or no information on abundance patterns

Conroy models based on 91 IRTF stars only

MILES library: 985 stars



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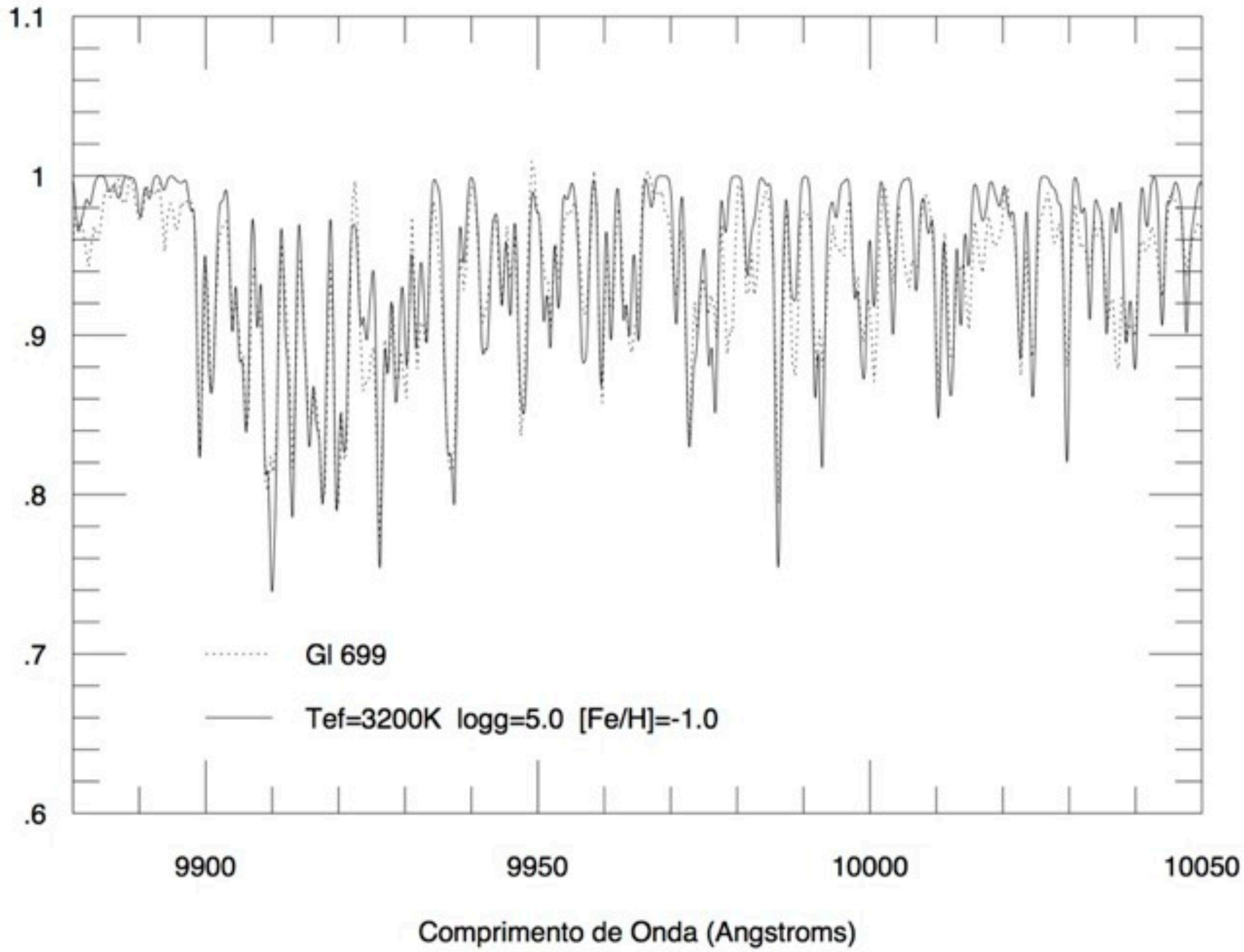
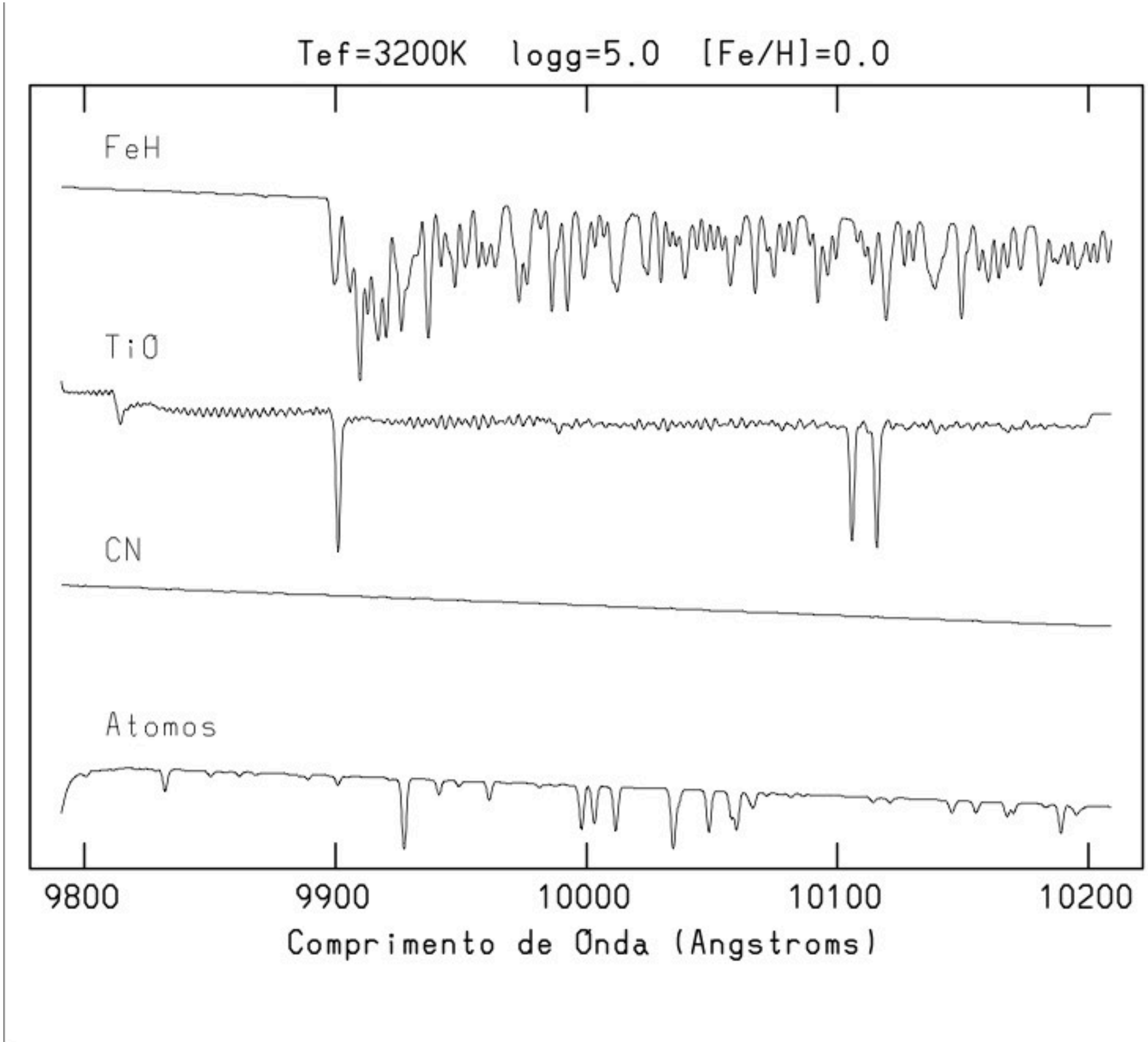
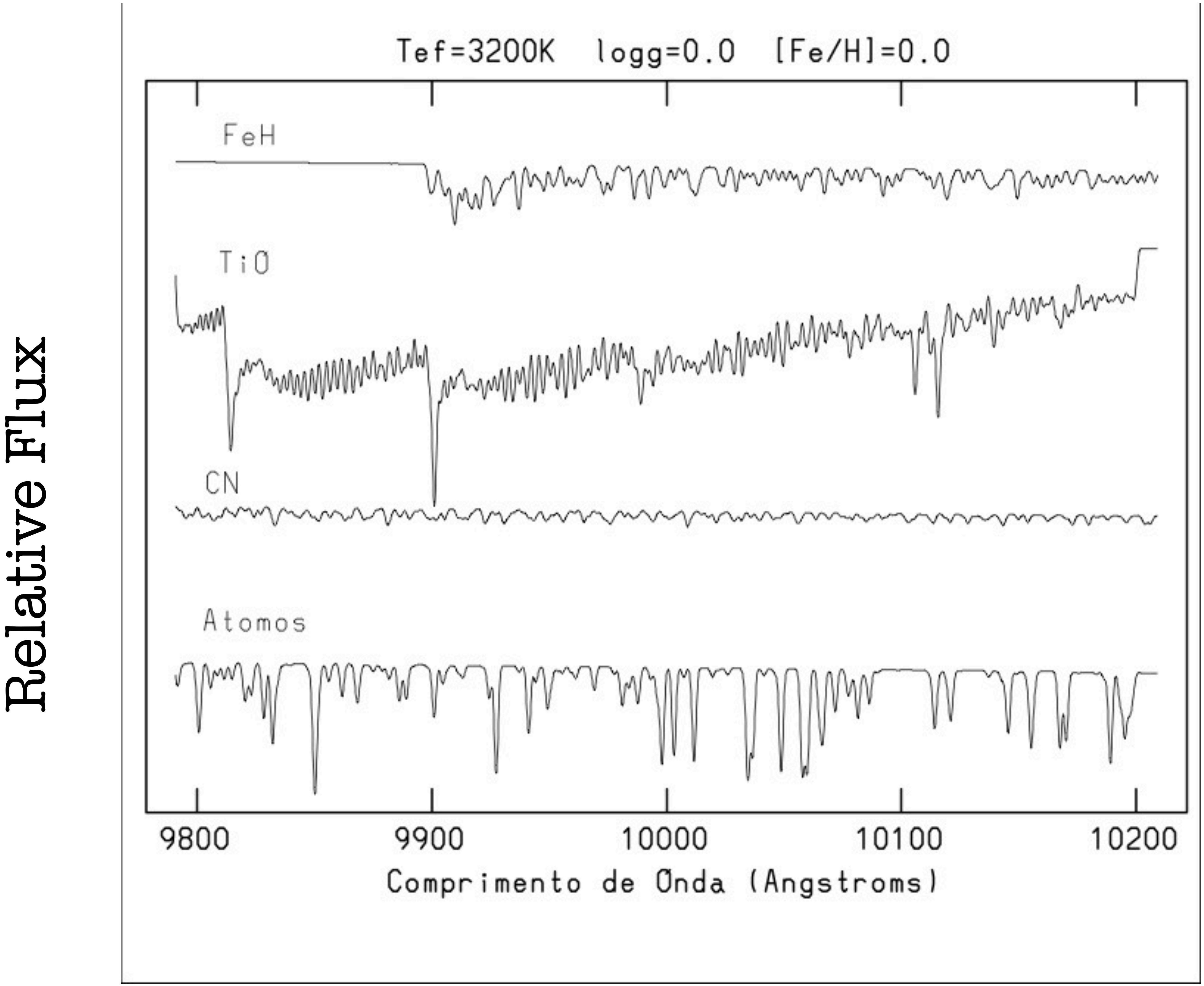
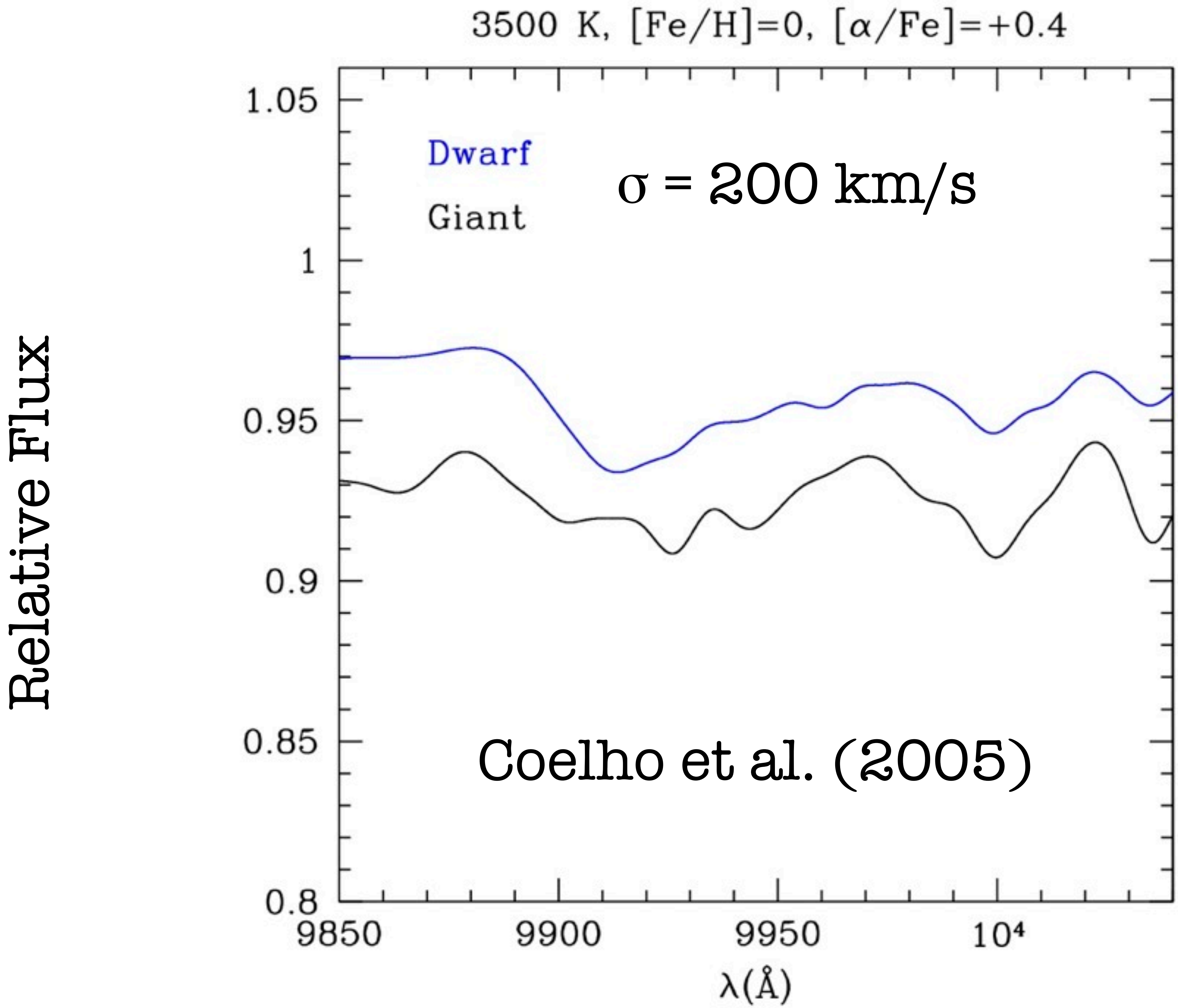


Schiavon (1998)

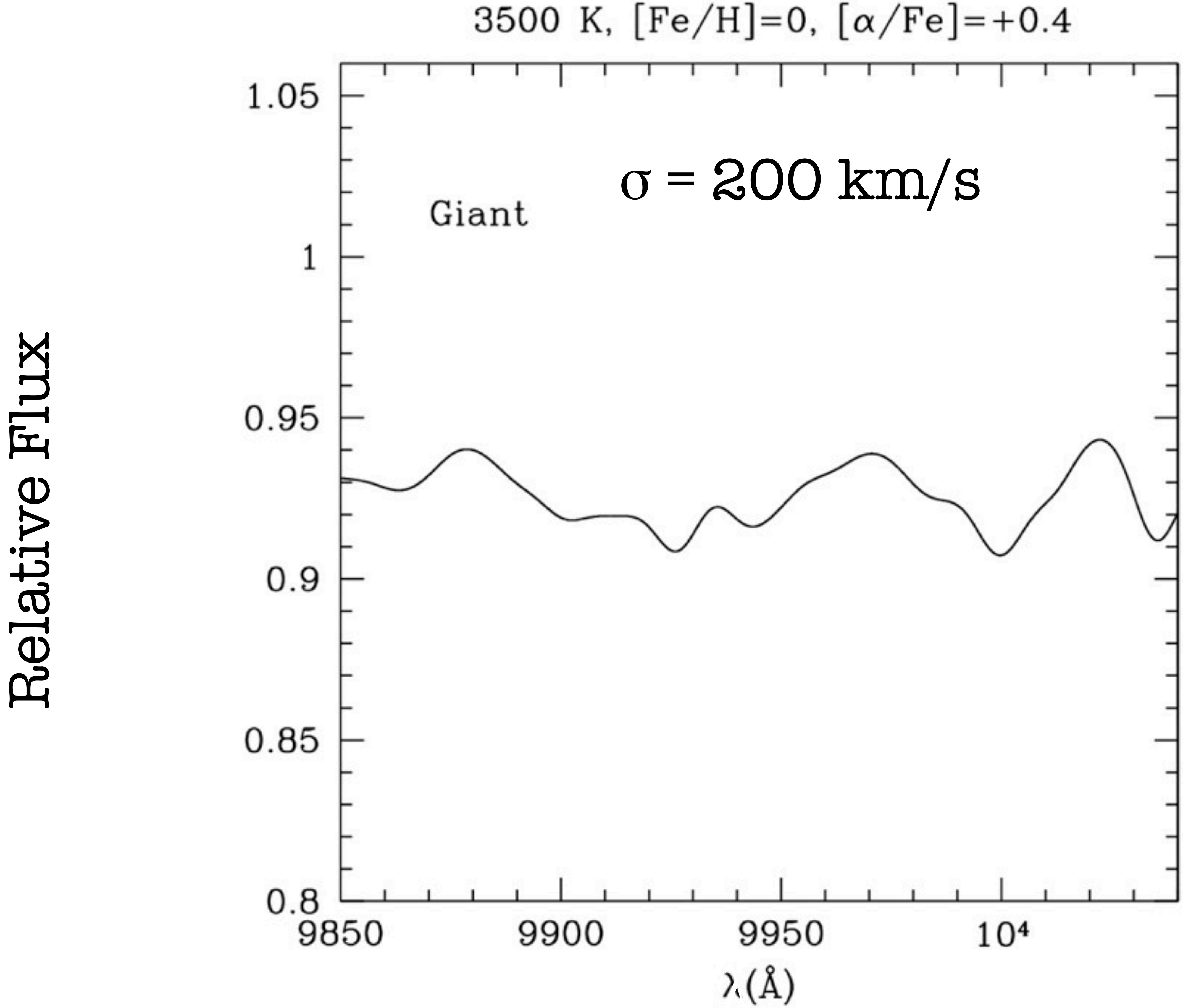
Relative Flux




Relative Flux
Tef=3200K logg=0.0 [Fe/H]=0.0
FeH
TiO
CN
Atomos
9800
9900
10000
10100
10200
Comprimento de Onda (Angstroms)



3500 K, [Fe/H]=0, [α/Fe]=+0.4
Relative Flux
Dwarf
Giant
σ = 200 km/s
Coelho et al. (2005)
1.05
1
0.95
0.9
0.85
0.8
9850
9900
9950
10⁴
λ(Å)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σ = 200 km/s
Giant
Relative Flux
1.05
1
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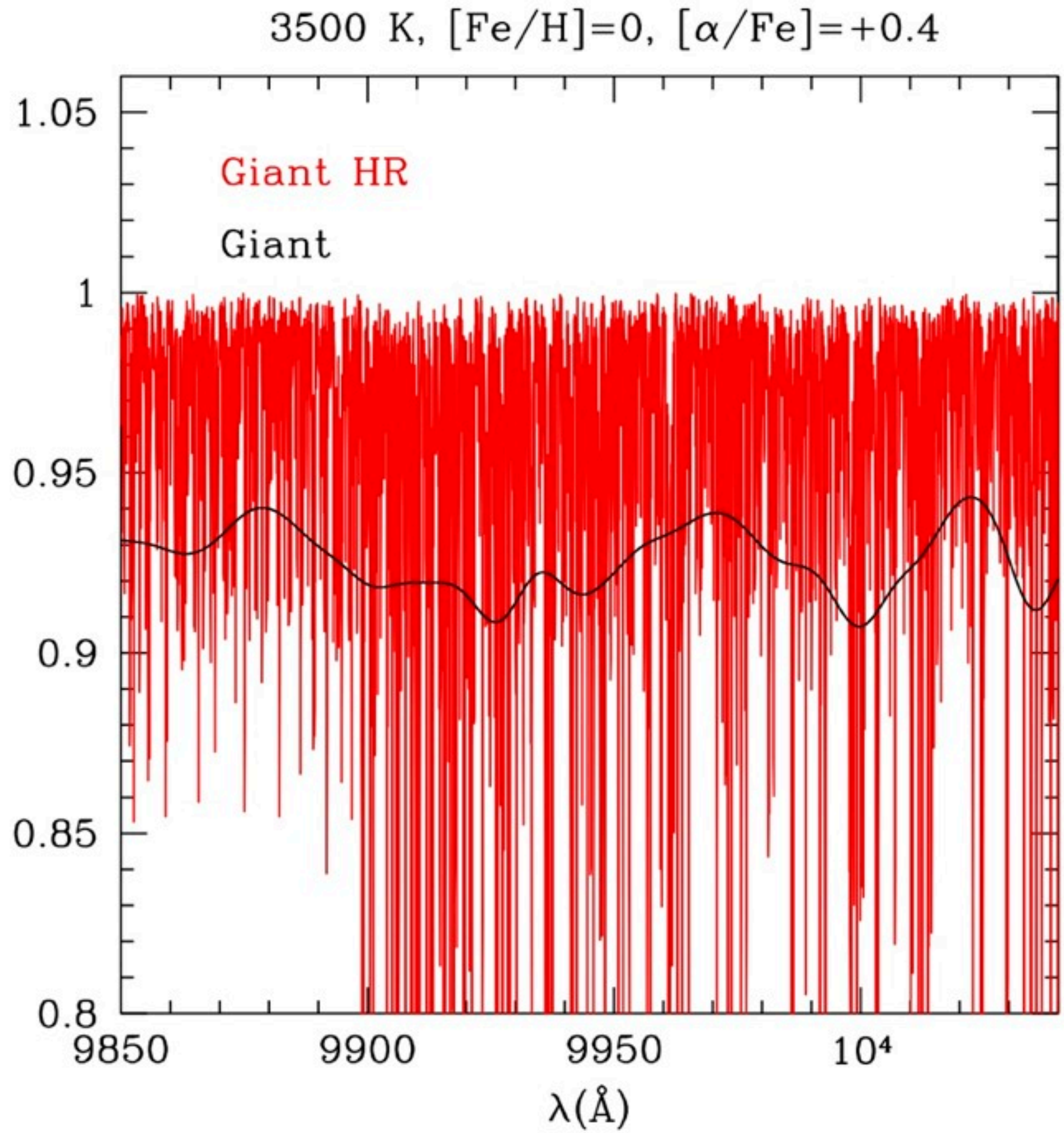
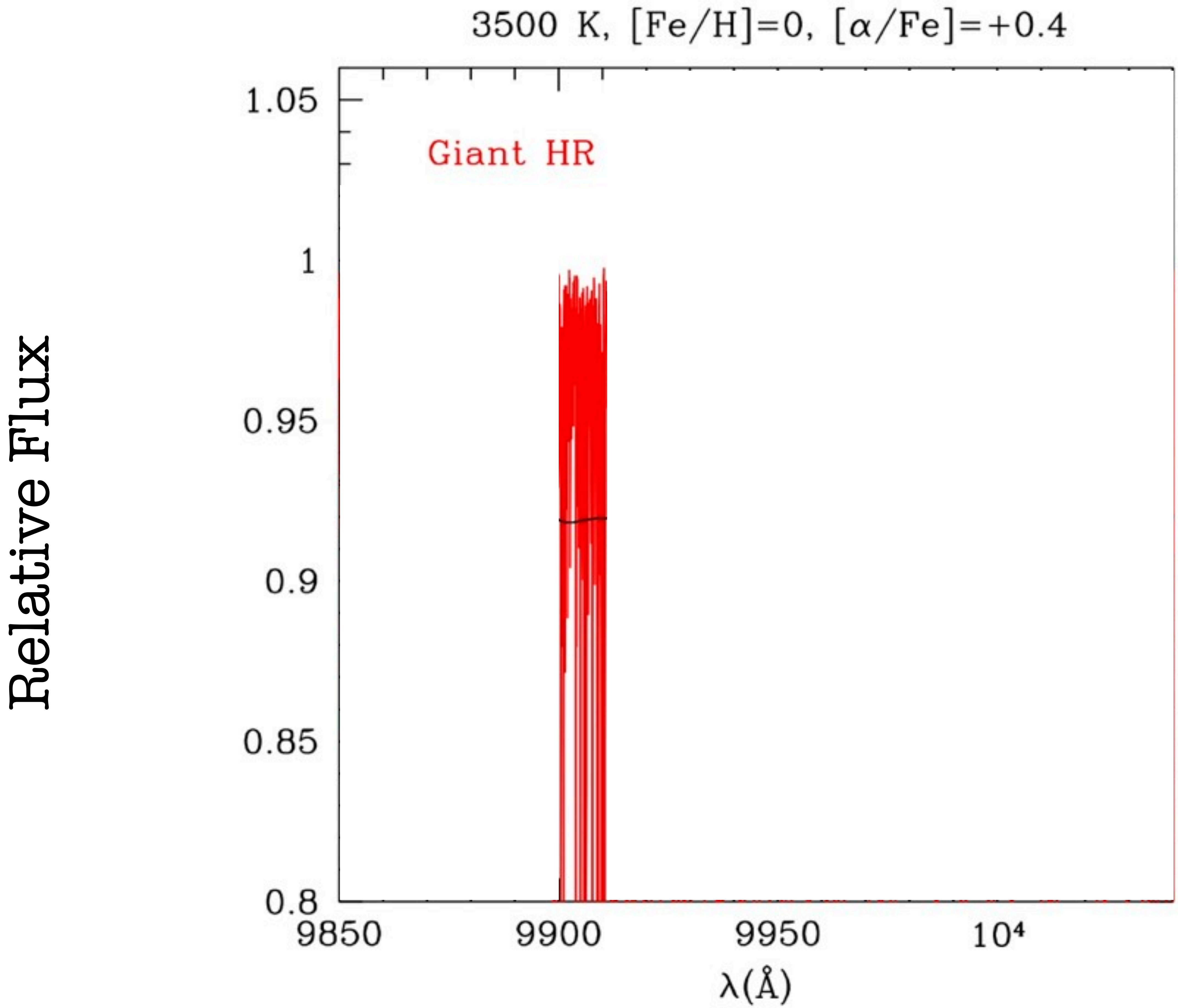
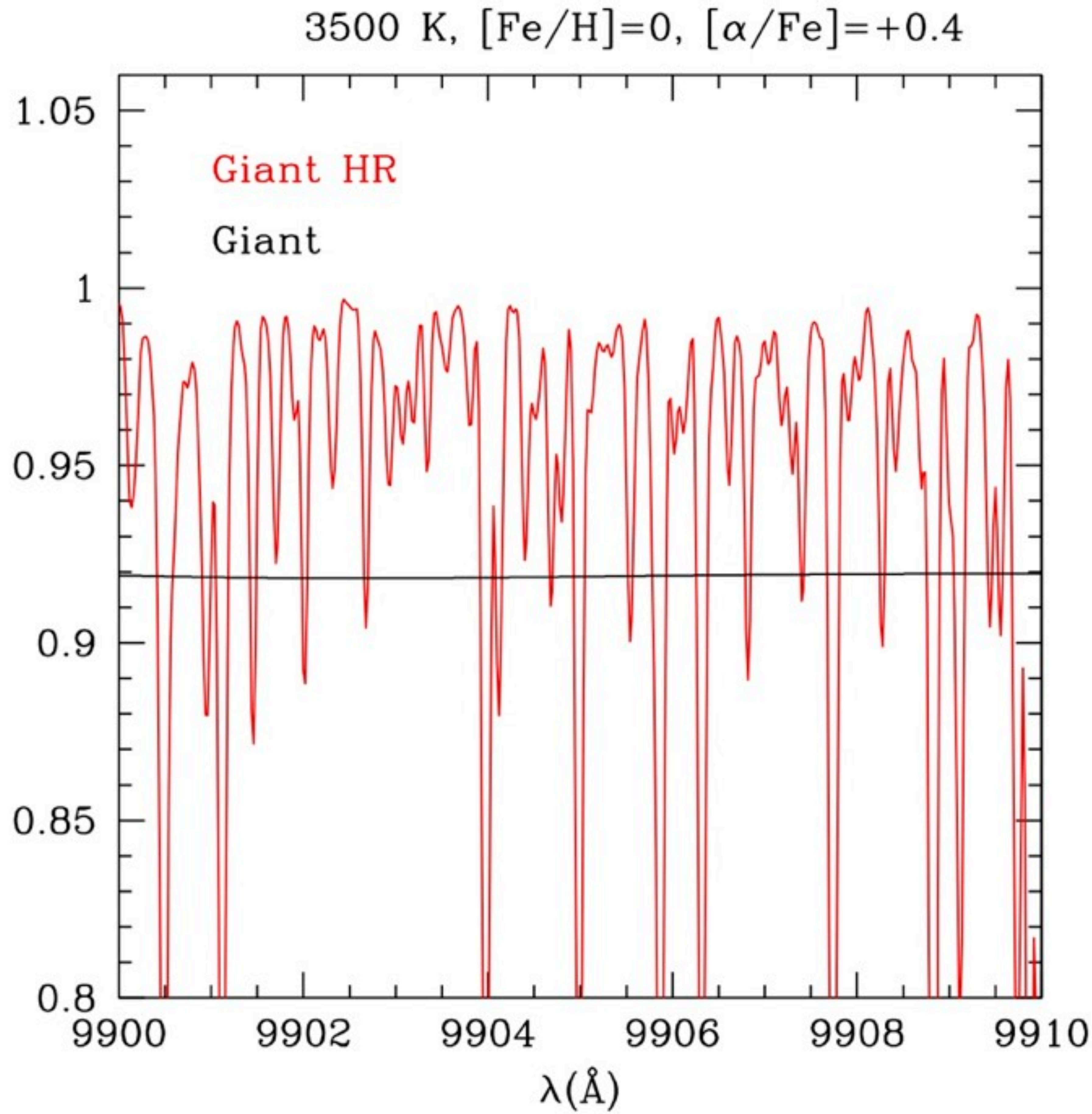
0.85
0.8
9850
9900
9950
10⁴
λ(Å)

Relative Flux




3500 K, [Fe/H]=0, [α/Fe]=+0.4
Giant HR
Relative Flux
1.05
1
0.95
0.9
0.85
0.8
9850
9900
9950
10⁴
λ(Å)

Relative Flux



Summary

- Need to address fundamental uncertainties from stellar evolution theory
- Need to improve theoretical stellar spectra: better model atmospheres, more accurate line opacities
- Both efforts will have a broader impact on our ability to understand stars and galaxies
- Within our reach in the near future