Non-LTE stellar parameters and abundances of metal-poor stars in the Galaxy

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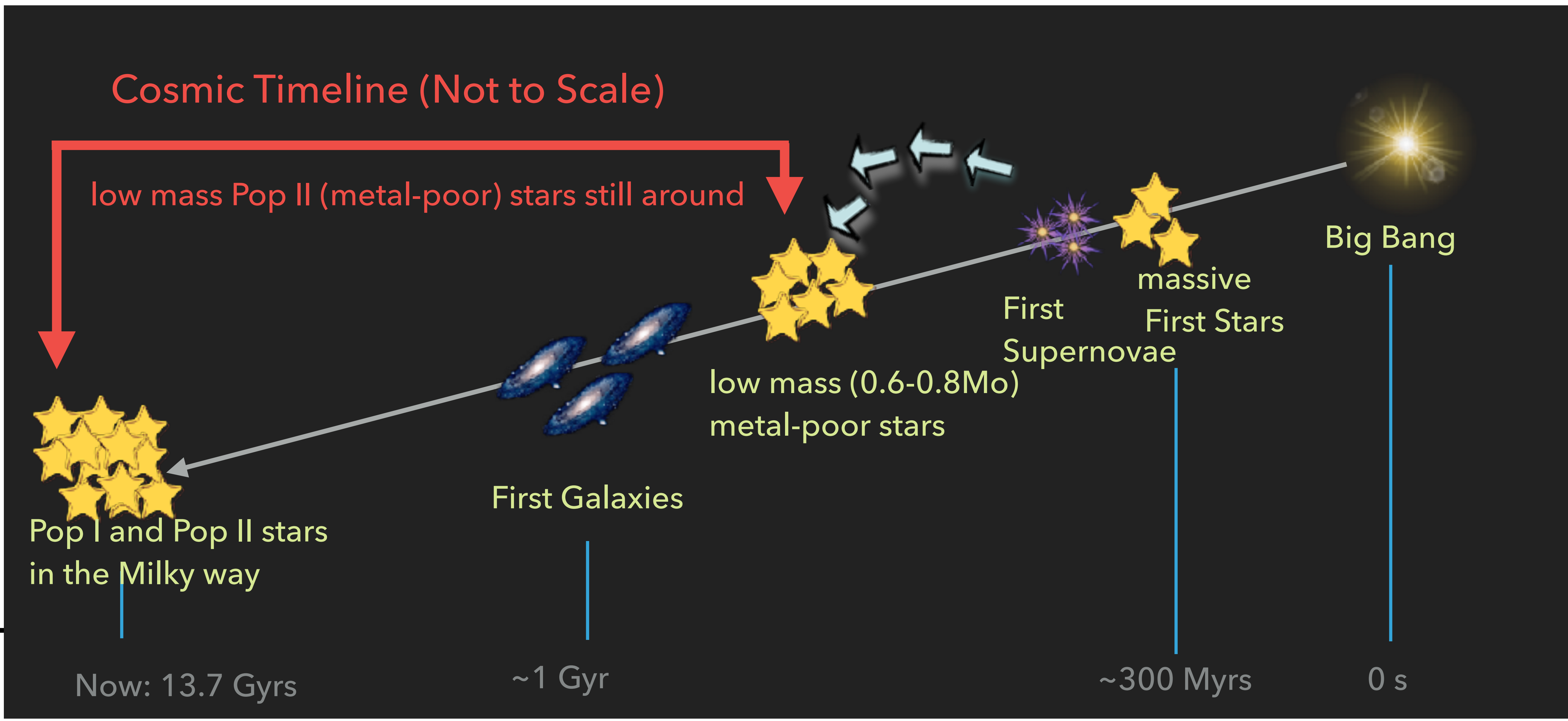
@AstroRana

JINA-CEE

Photo: Magellan Twin Telescopes
credit: Yuri Beletzky

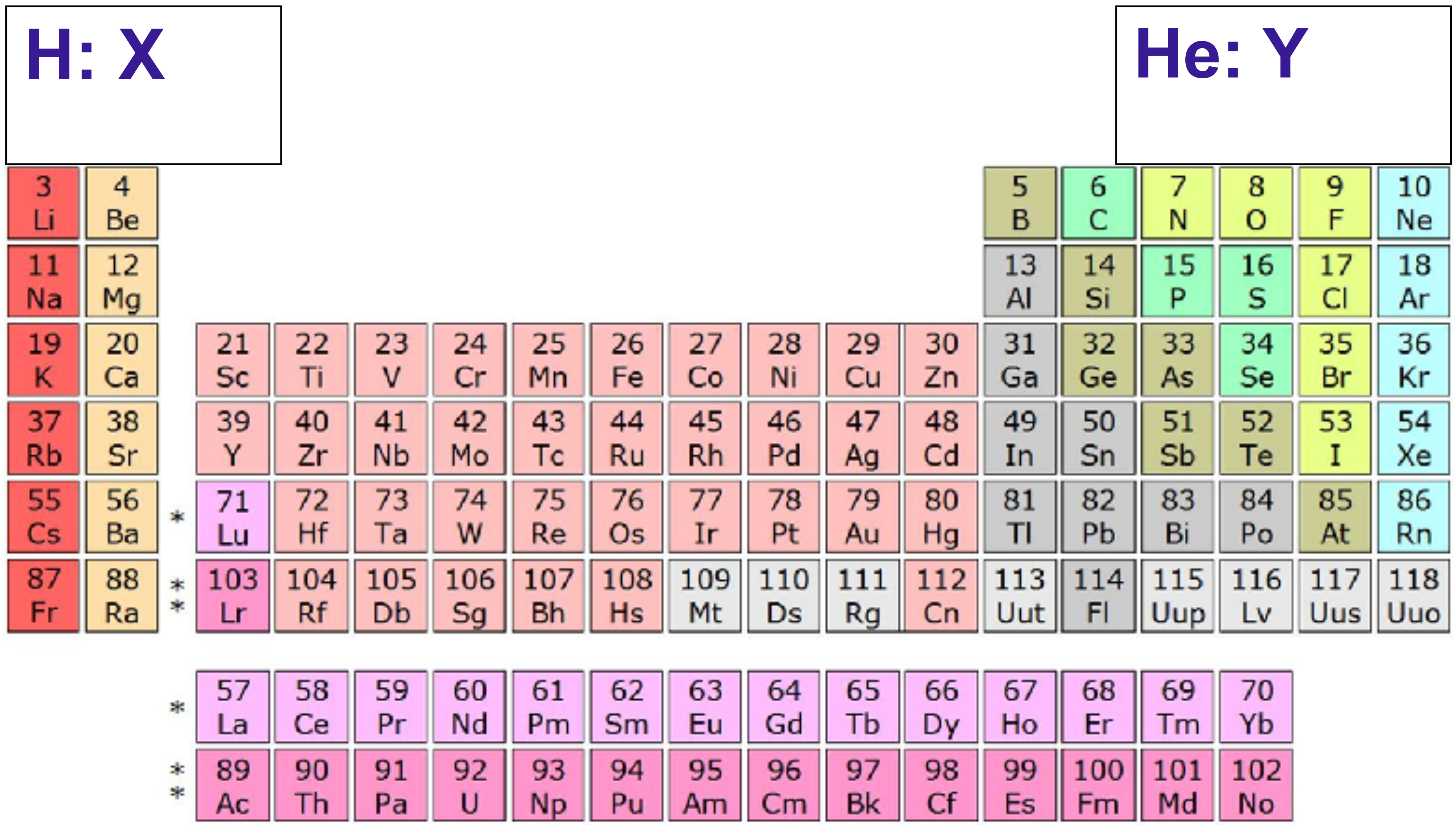
Refresher: What are Metal-poor stars?

- Stellar Archeology: uses stellar relics of the early universe.
- Most metal-poor stars preserve records of “First” Population III stars in their atmospheres



Refresher: What are Metal-poor stars?

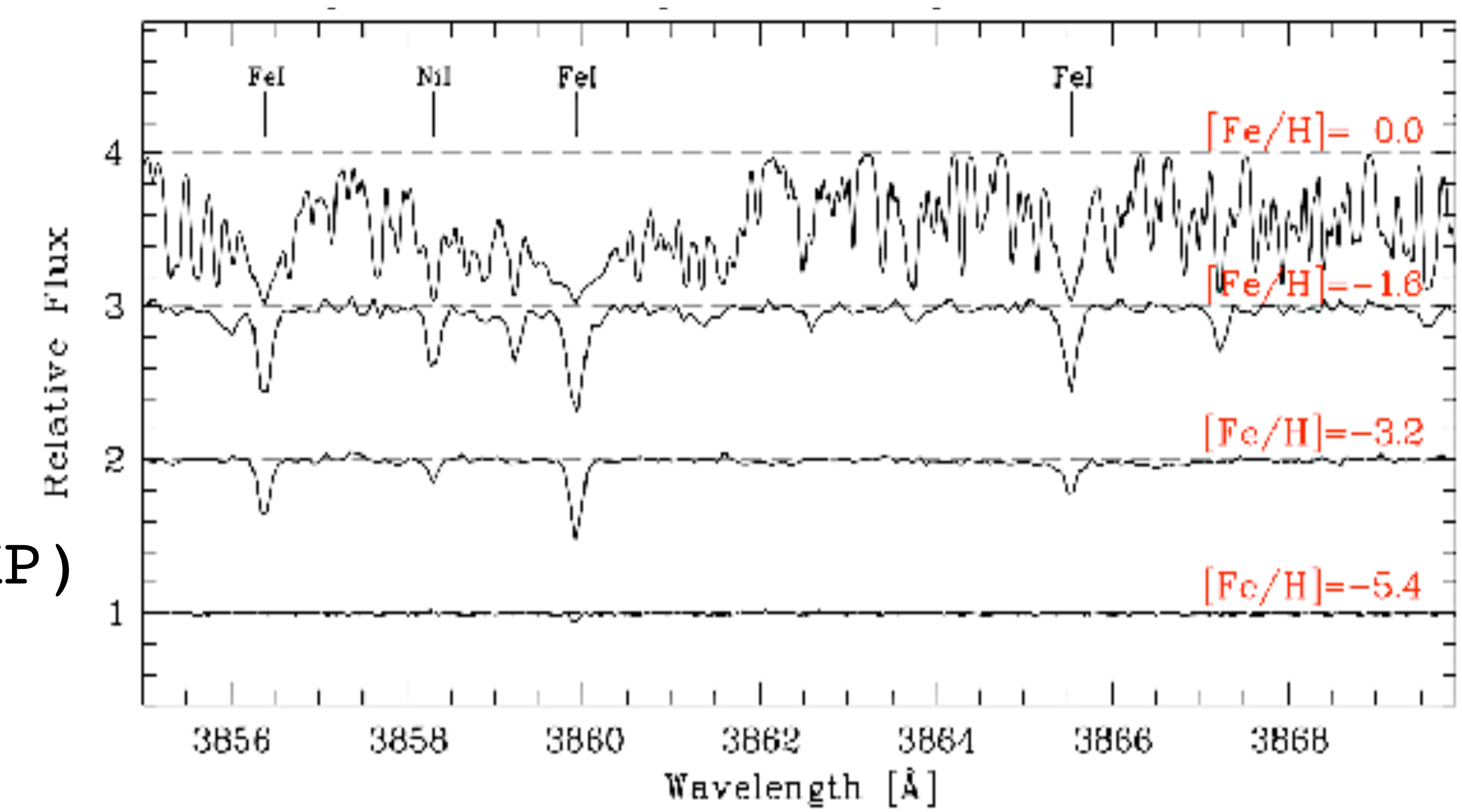
Astronomers'
Periodic Table



With time, more and more <u>of</u>
all elements were made!

Refresher: What are Metal-poor stars?

- Metal-poor
  [Fe/H] < -1
- Very metal-poor (VMP)
  -3 < [Fe/H] < -2
- Extremely metal-poor (EMP)
  -4 < [Fe/H] < -3
- Ultra metal-poor (UMP)
  -5 < [Fe/H] < -4
- Hyper metal-poor (HMP)[Fe/H] < -5
- Mega metal-poor (MMP) [Fe/H] < -7 (Keller star 2014)
- Ridiculously metal-poor [Fe/H] < -10



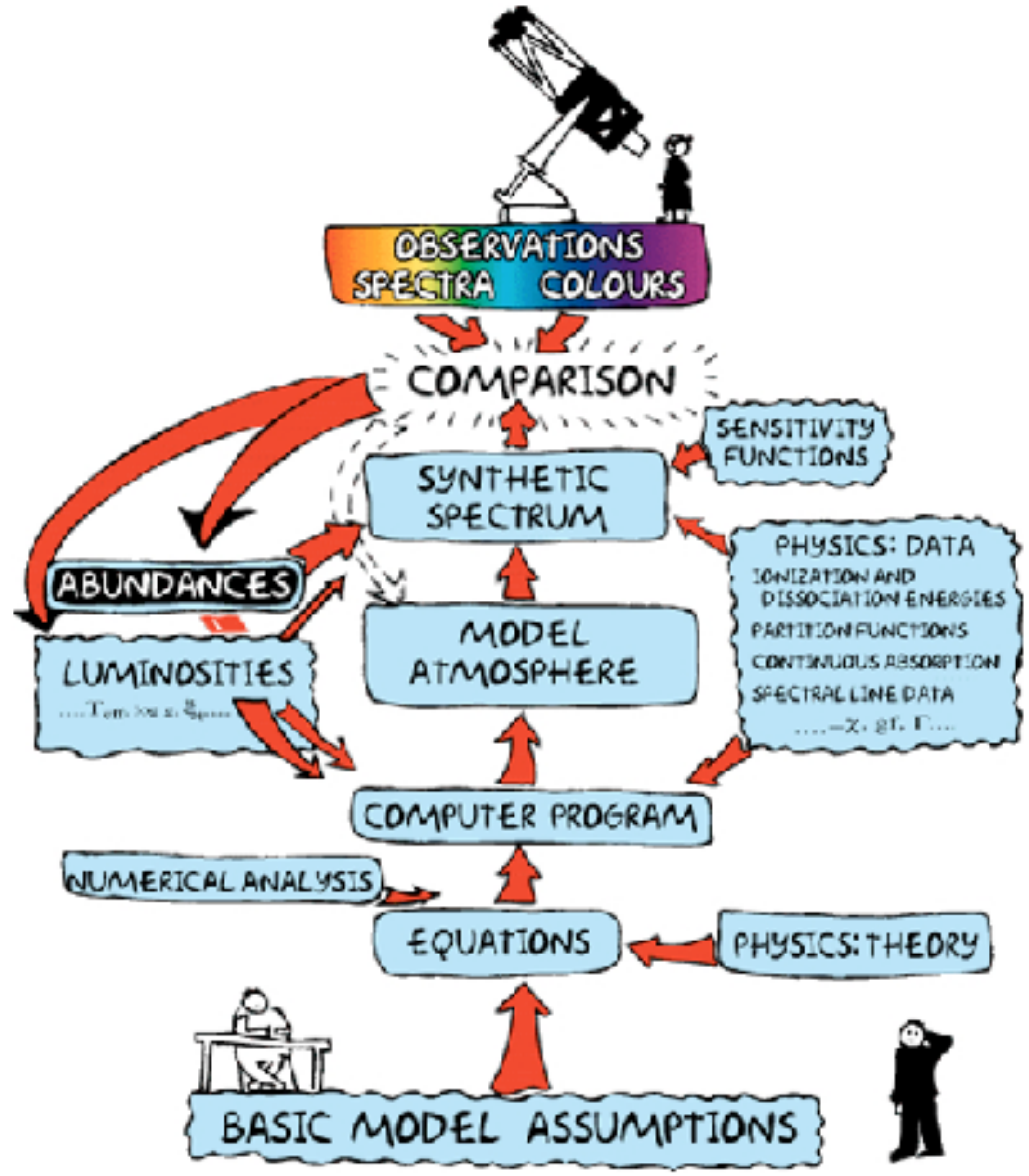
Beers & Christlieb (2005)

Frebel (2018)

ABUNDANCES ARE ONLY AS GOOD AS THEIR MODELS

Abundances are not measured BUT determined using approximations:

- Plane-parallel vs. spherical
- Homogeneity
- Stationarity
- Hydrostatic equilibrium
- 1D vs. 3D atmospheres



- Local thermodynamic equilibrium (LTE)

B. Gustafsson, Astronomical Observatory, Uppsala (2009)

REFRESHER: SPECTRAL LINE FORMATION

LTE

- Matter assumed in equilibrium with the radiation field over a finite volume of gas.
- Properties of gas defined by one T at each depth.

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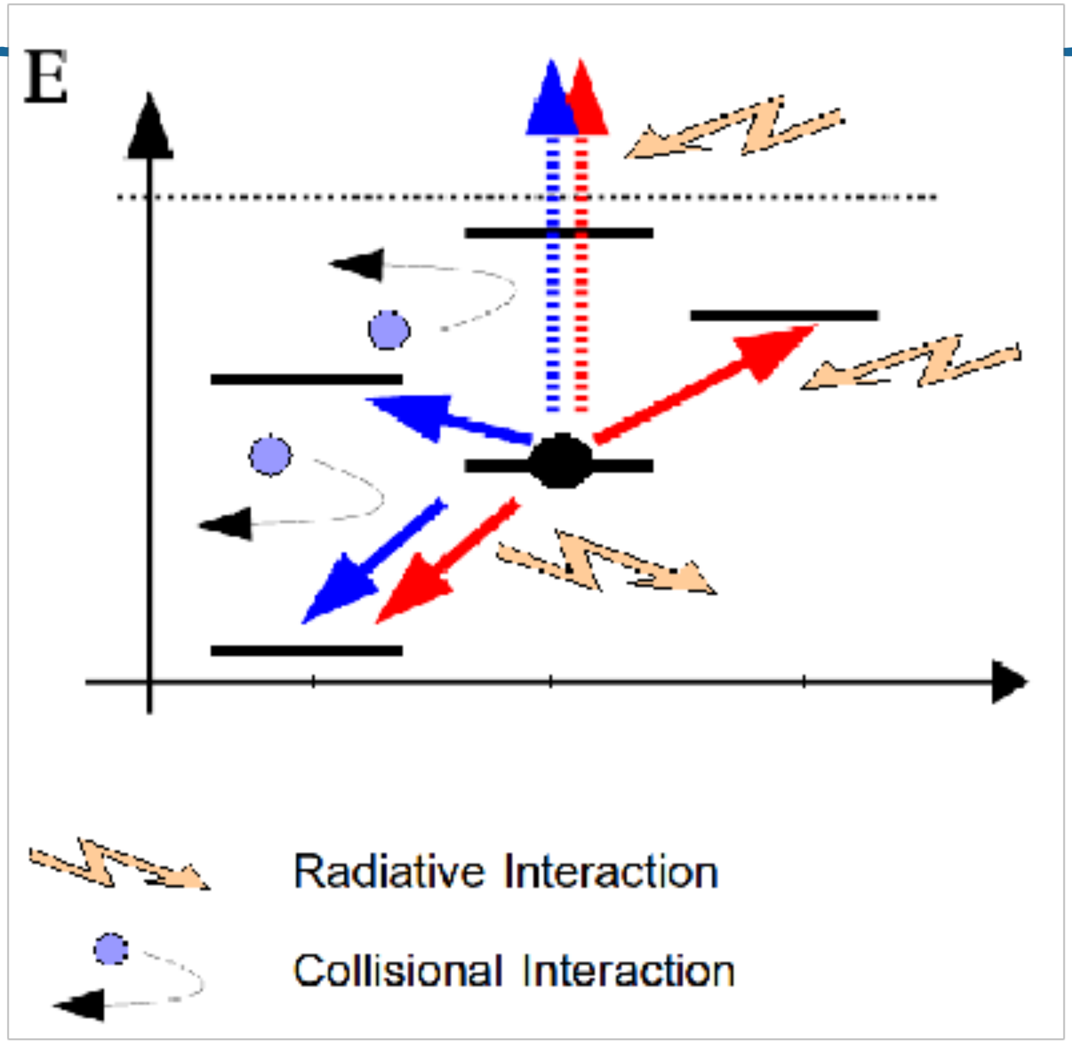
Non-LTE

Photons carry non-local information: Everything depends on everything,everywhere else!

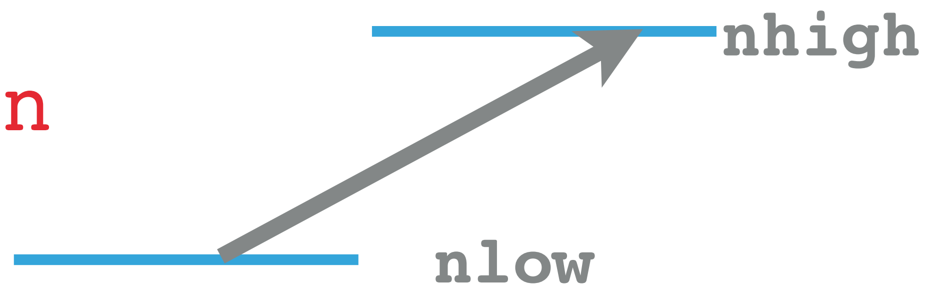


LTE VS NLTE

Fe I

LTE

1 line : 1 transition



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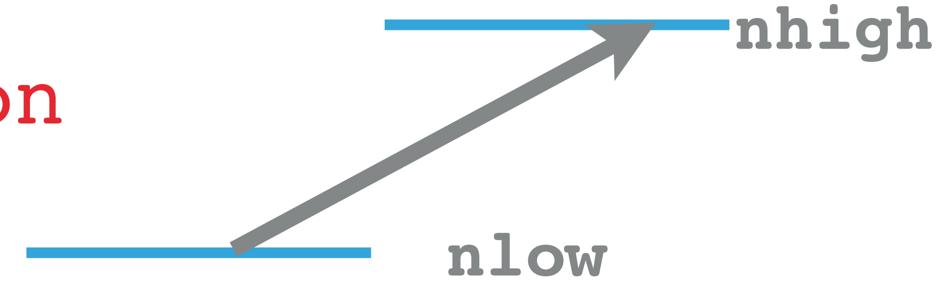
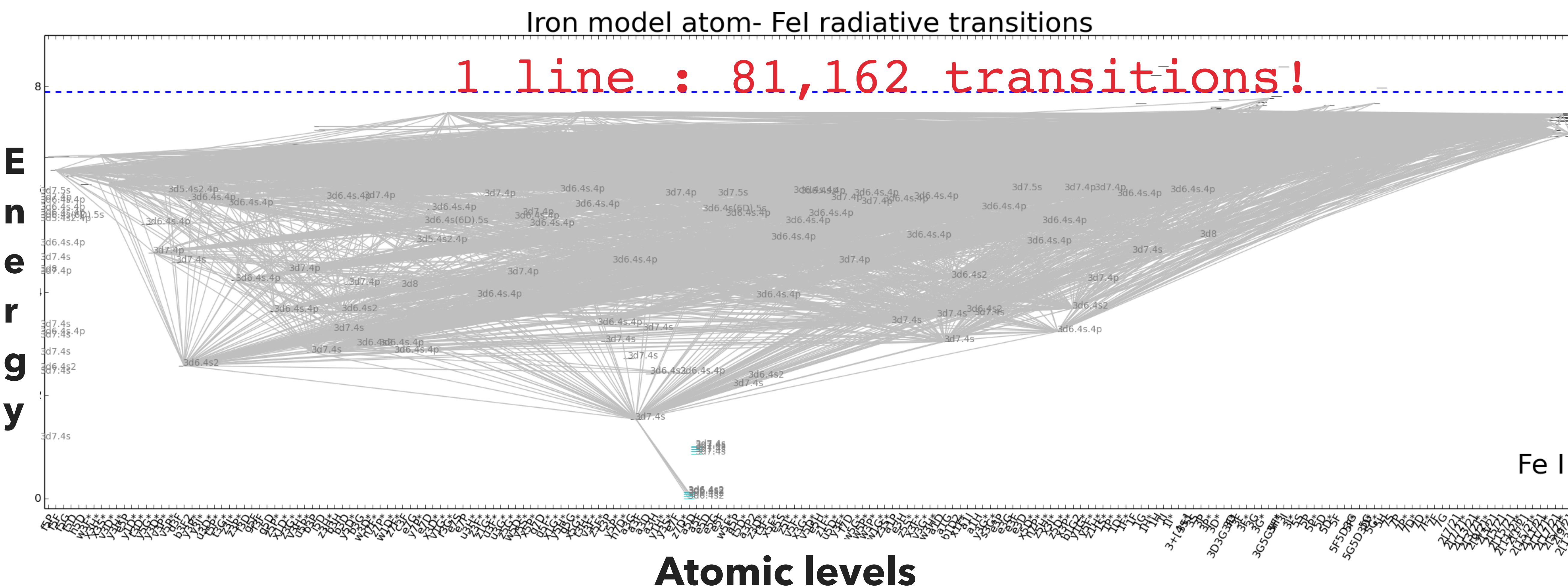


NLTE



Rana Ezzeddine, PhD, 2015

FORMATO2.0 (Merle et al. in prep)

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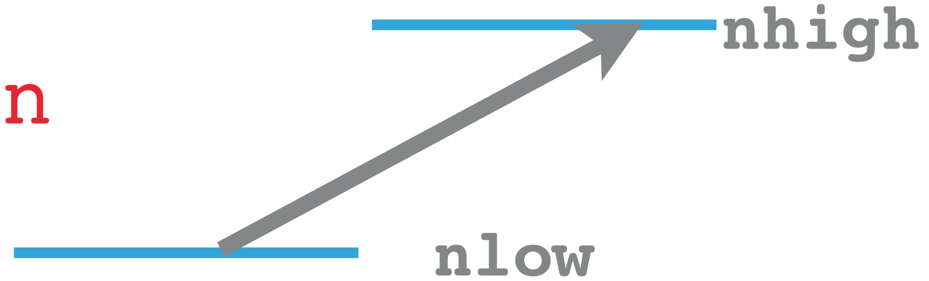

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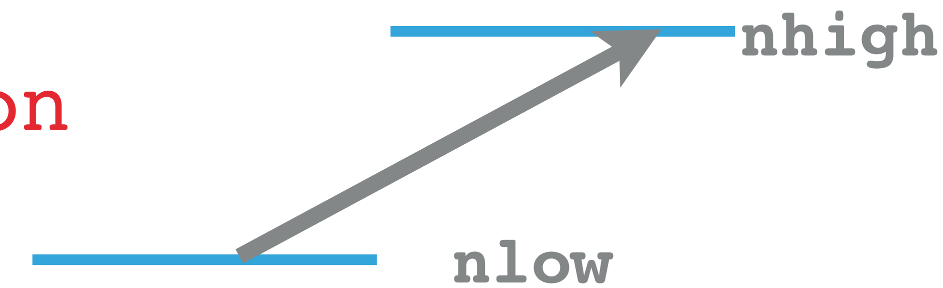

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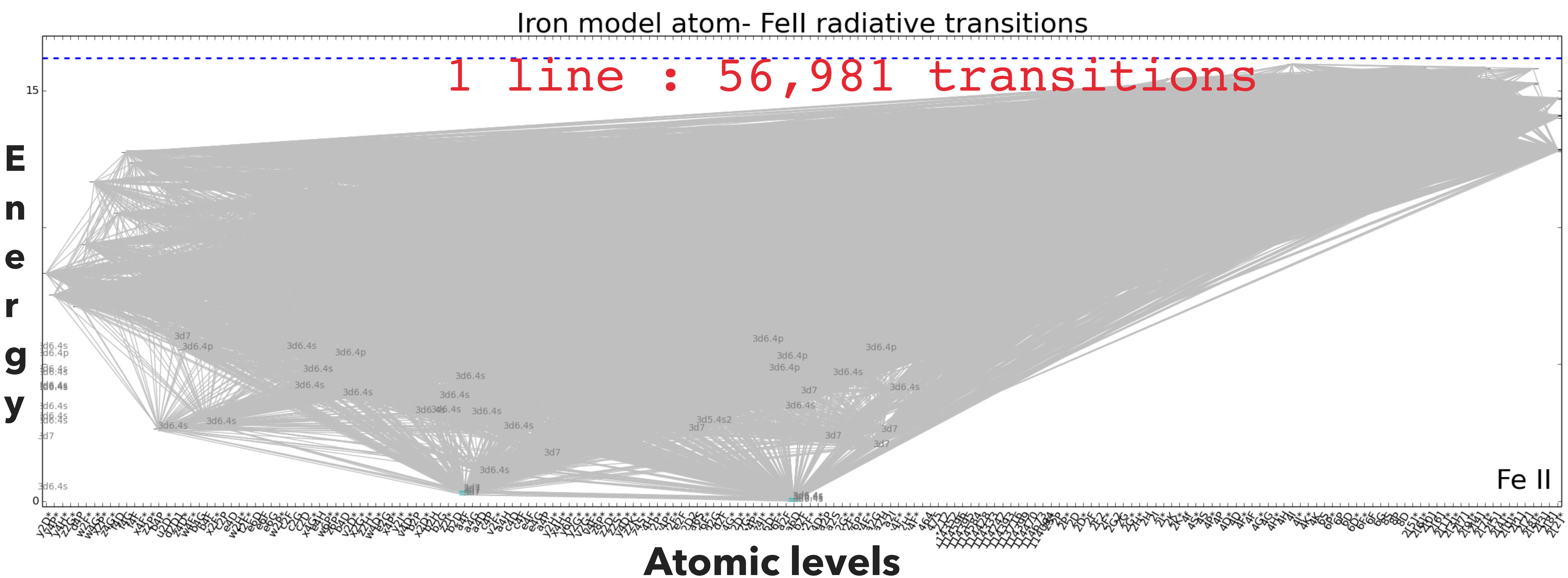

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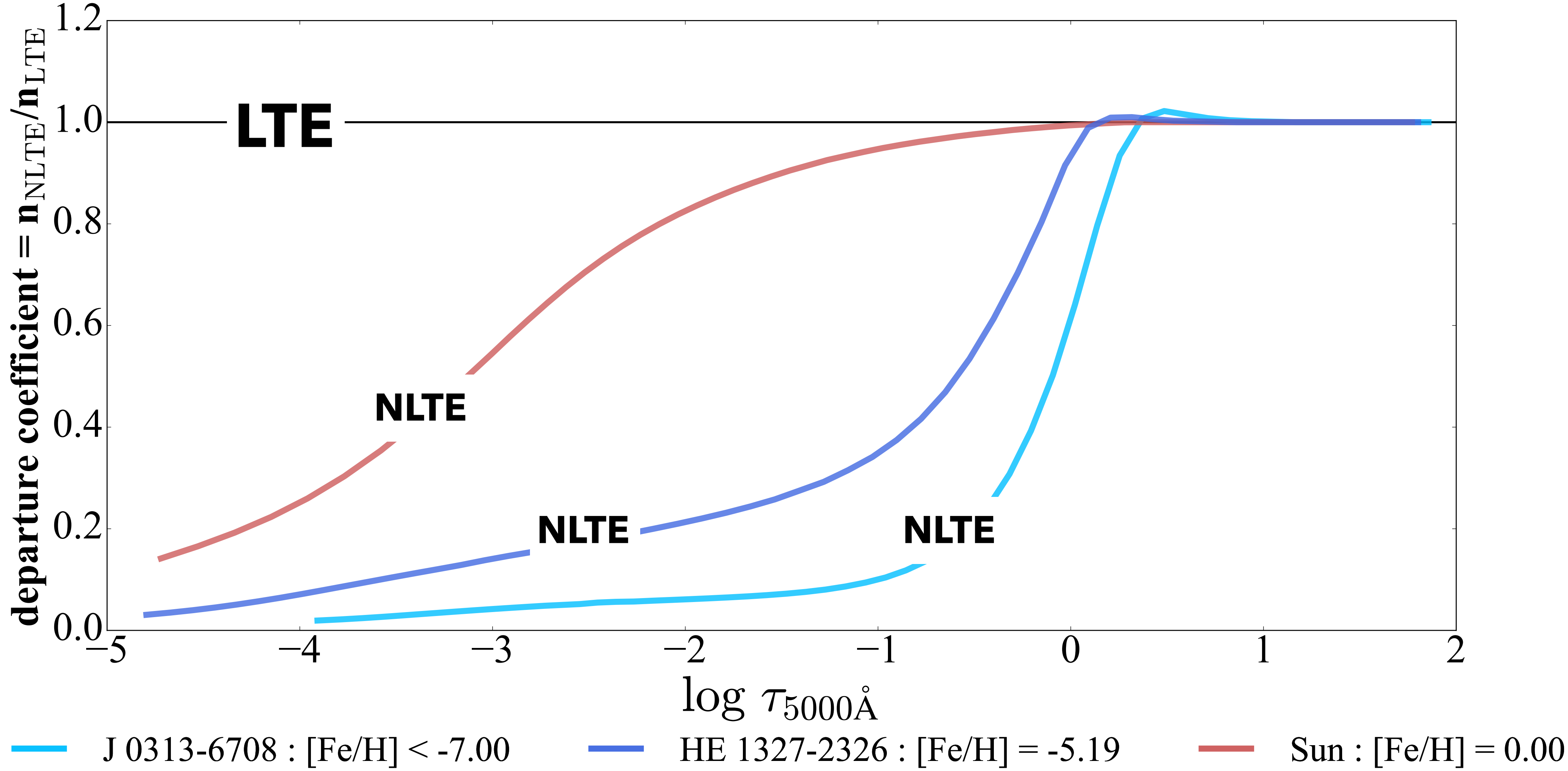
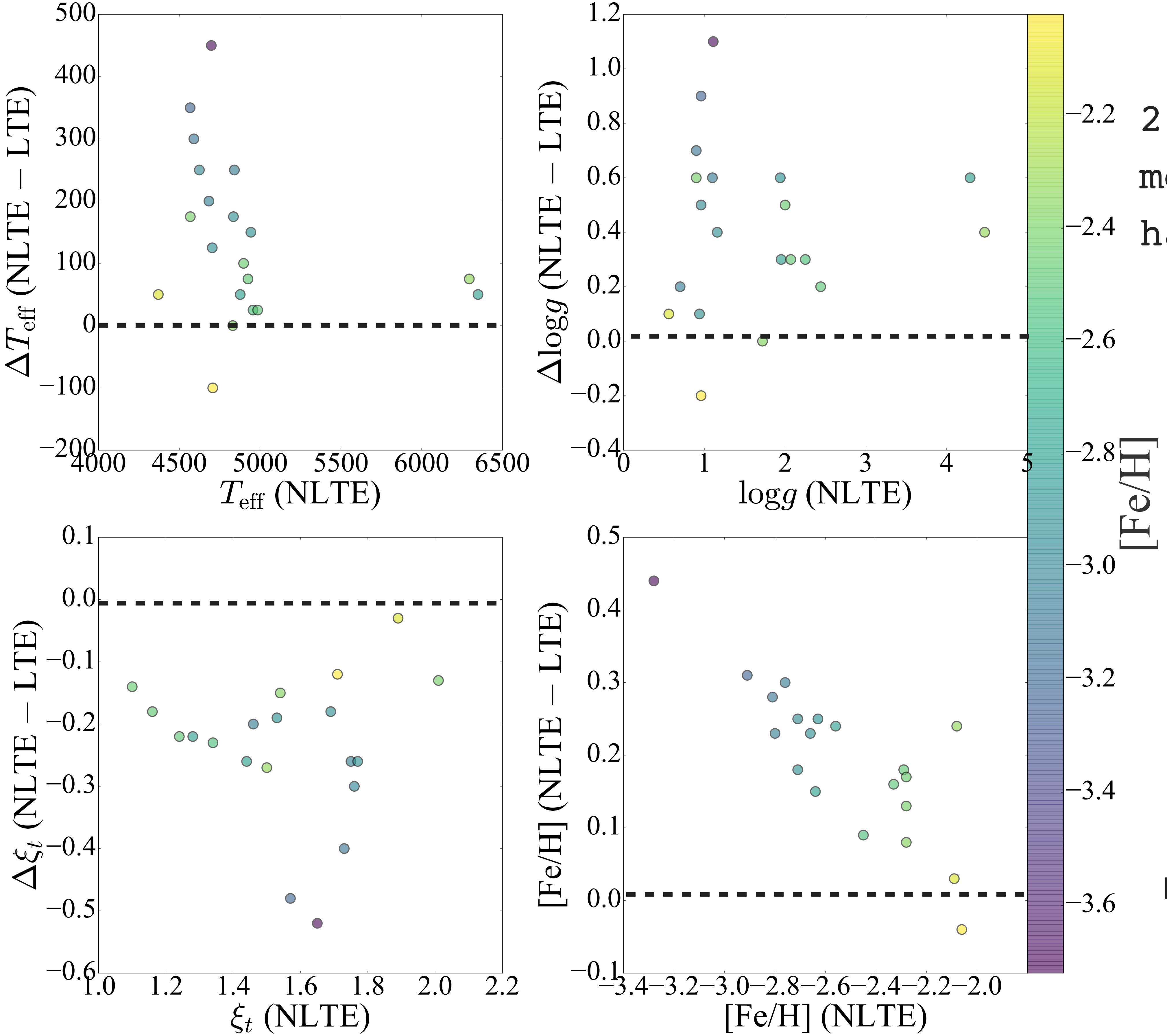
NON-LOCAL THERMODYNAMIC EQUILIBRIUM EFFECTS

$$\text{departure coefficient} = \frac{\text{level population density (NLTE)}}{\text{level population density (LTE)}}$$



Deviations from LTE increase toward lower metallicities

NLTE EFFECTS : STELLAR PARAMETERS



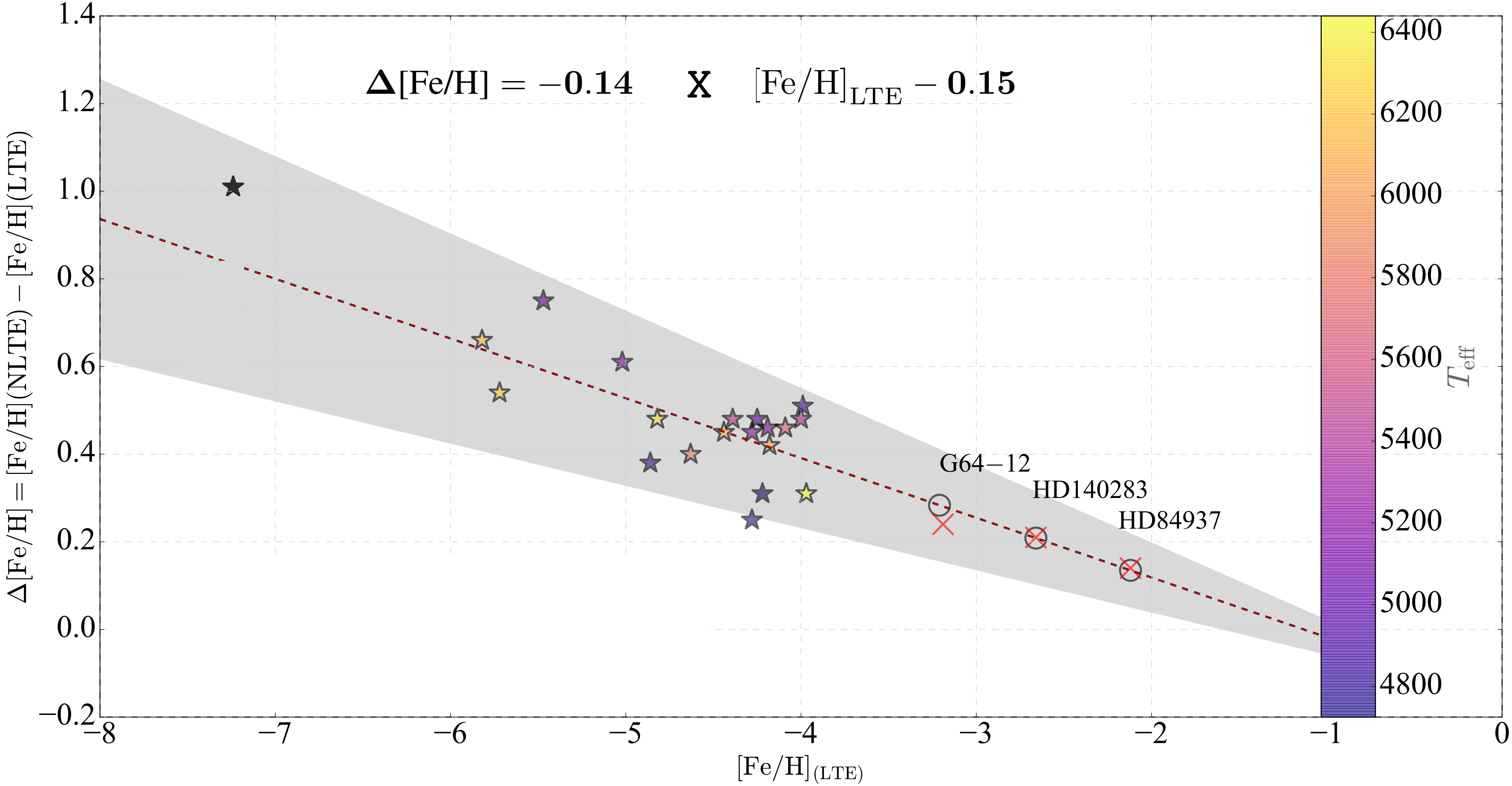
20 Standard metal-poor halo stars

Ezzeddine et al. (in prep)

NLTE EFFECTS : IRON

Departure from LTE can be severe toward the most metal-poor stars!

Ezzeddine et al. (2017)



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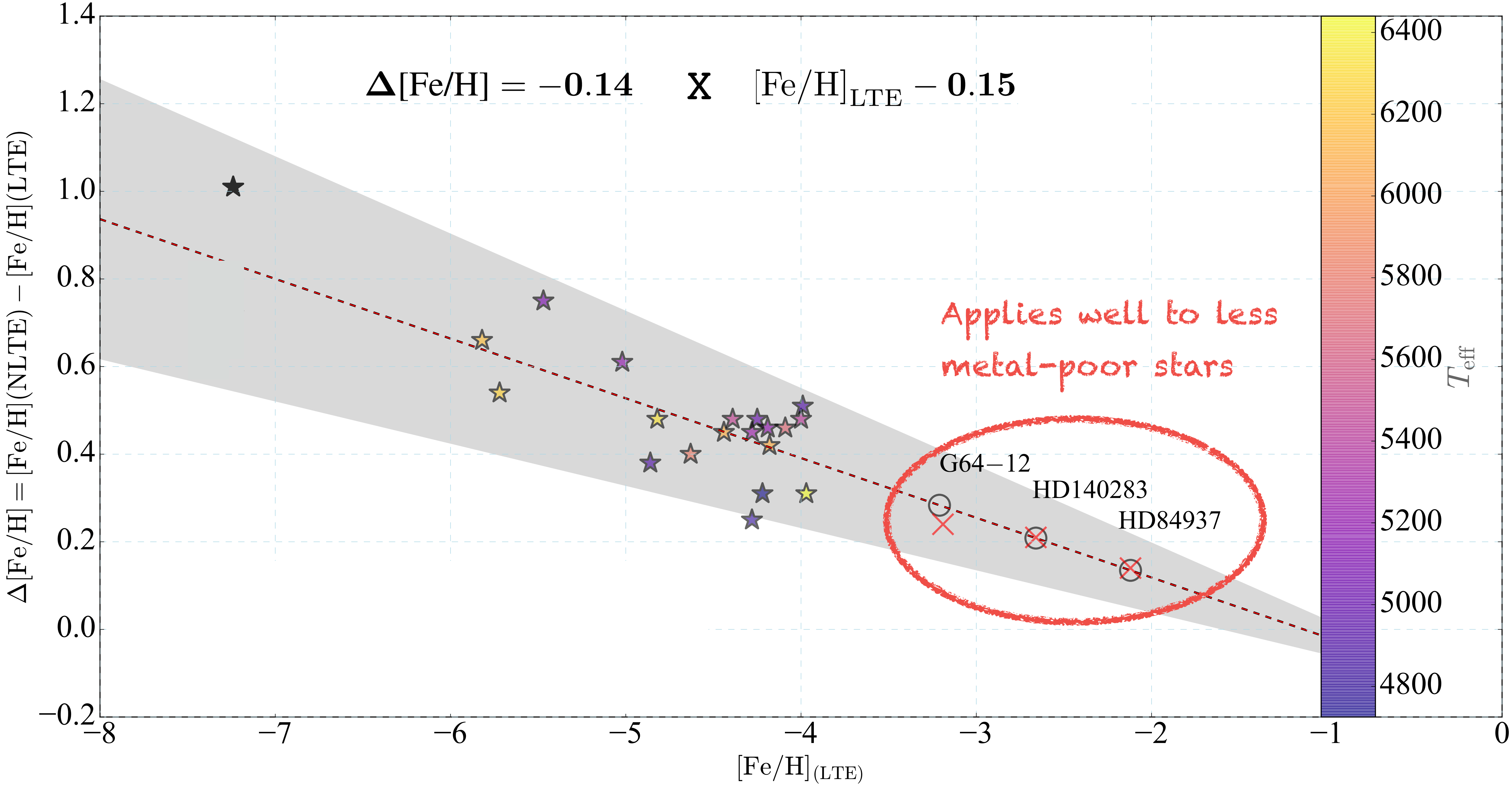
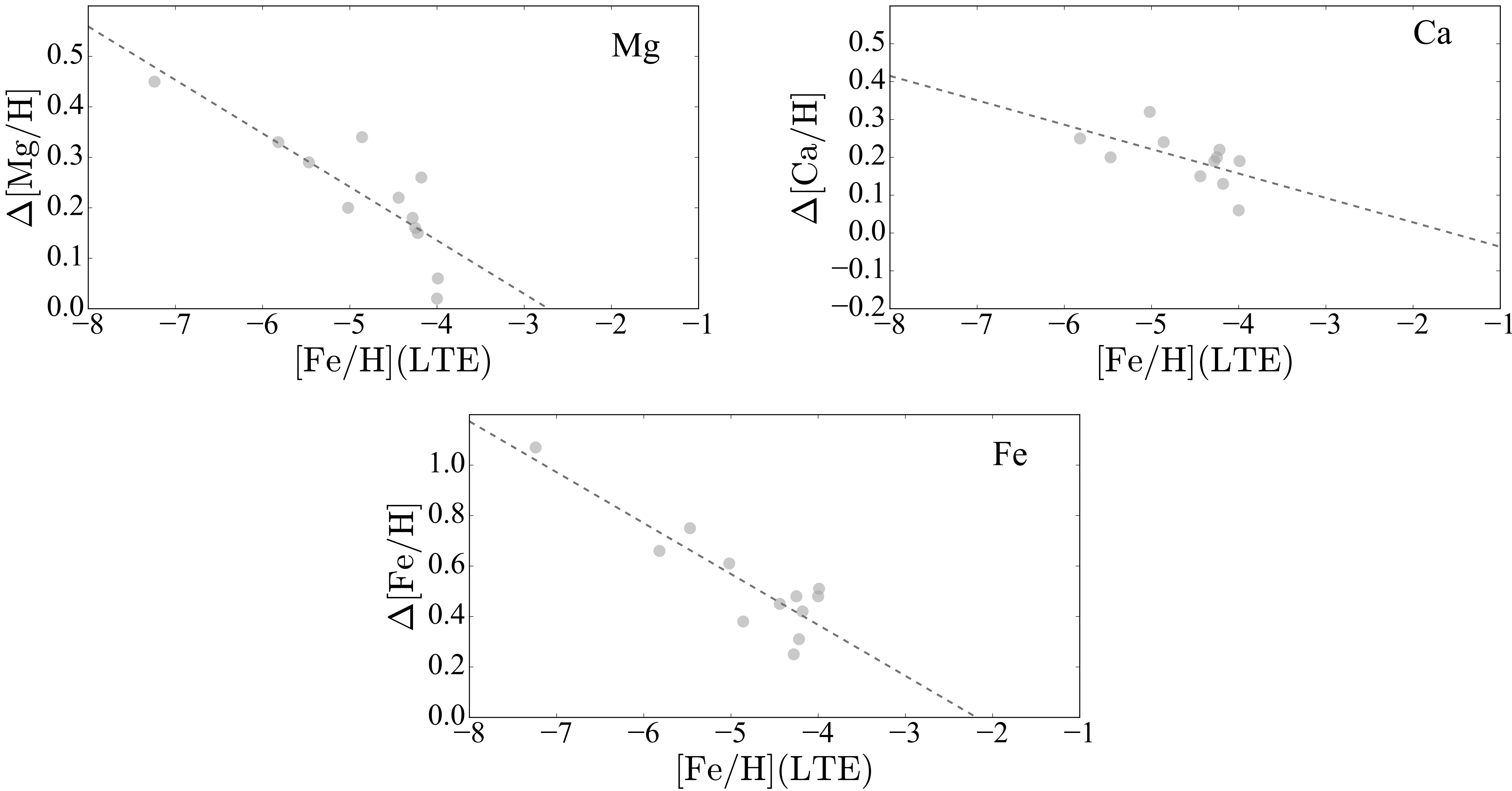


NLTE EFFECTS : MG & CA

Sitnova, Ezzeddine et al. (submitted)



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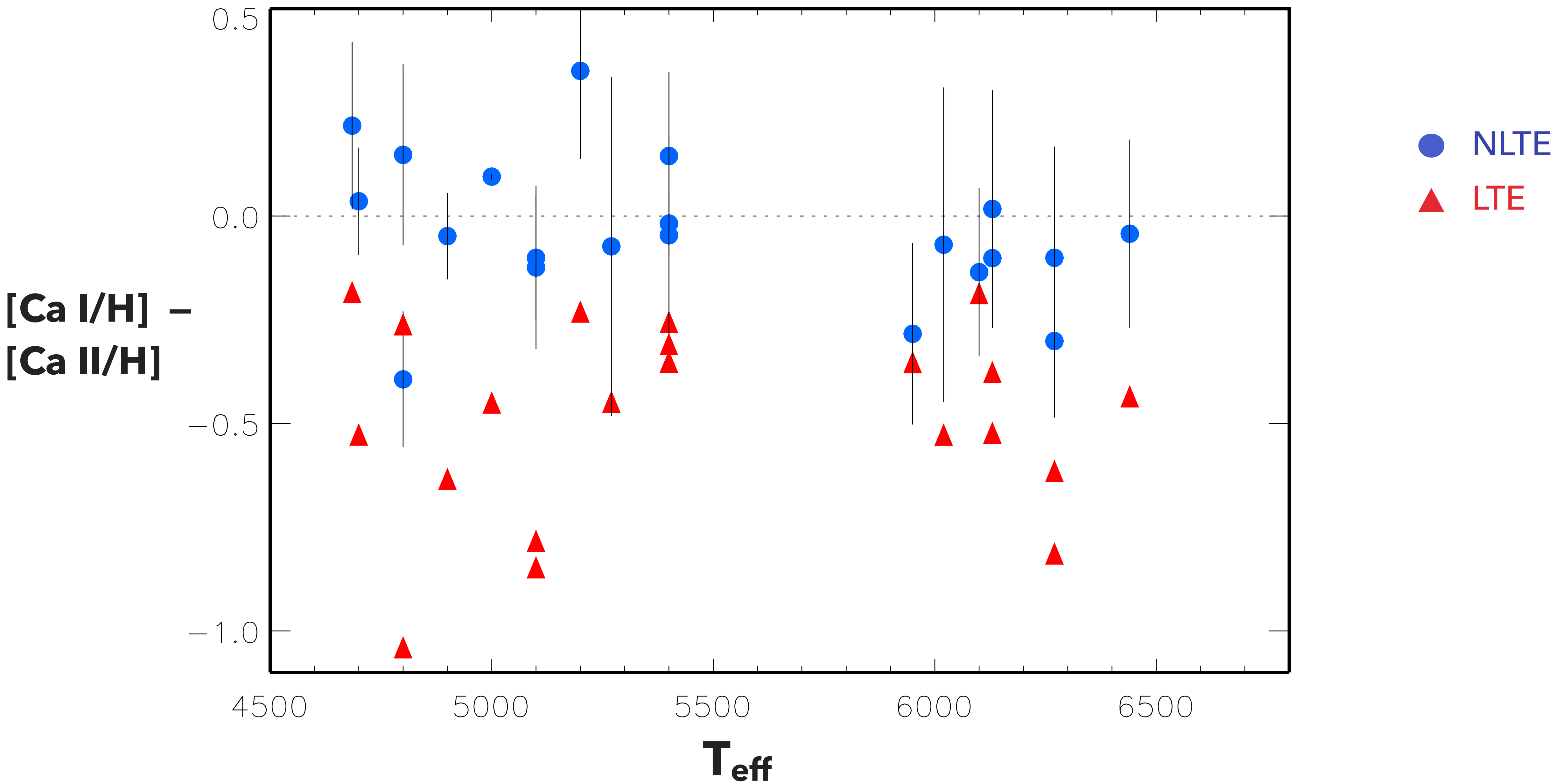
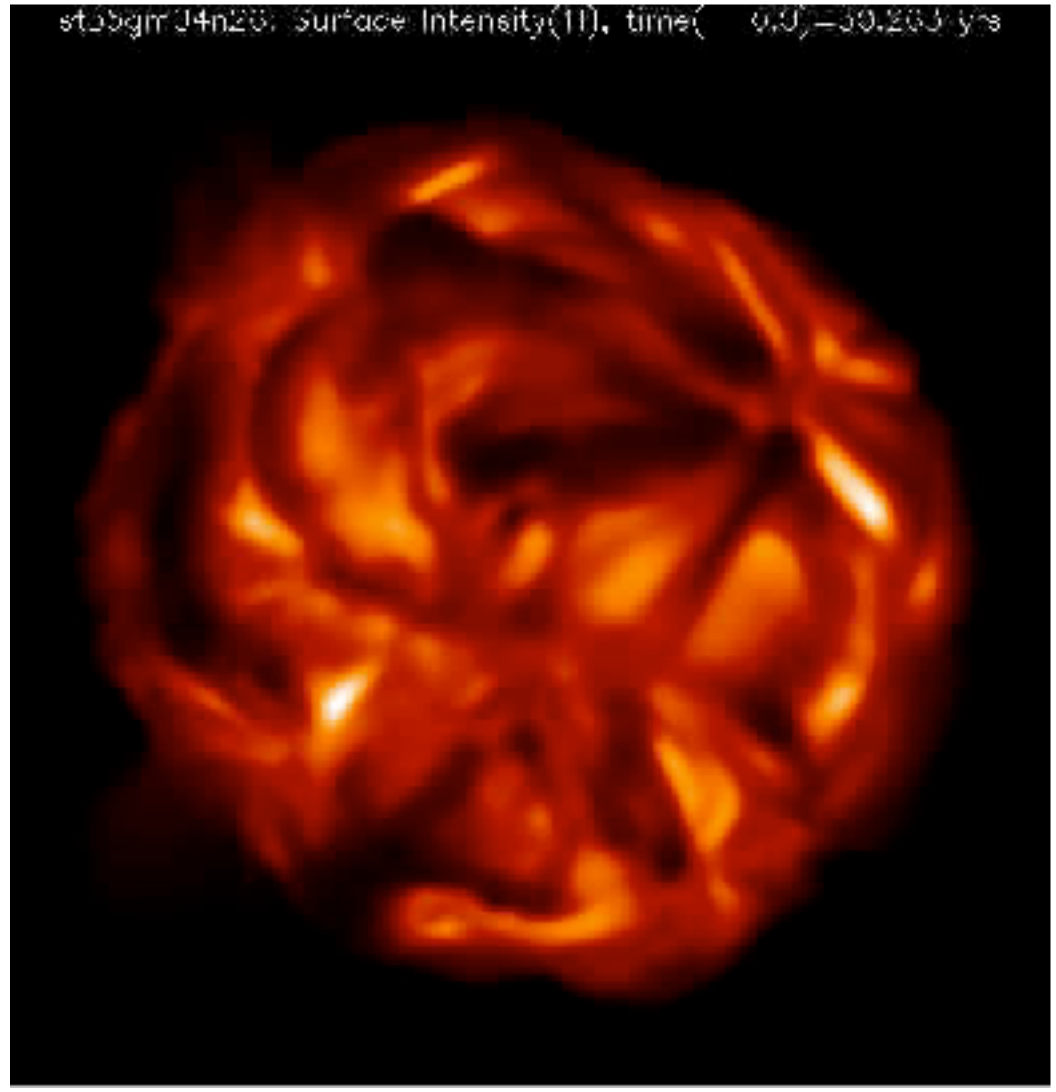


Agreement between Ca I and Ca II in NLTE vs. LTE in UMP stars! This highlights that NLTE works for extreme cases as well as less metal-poor stars!

TAKE AWAY POINTS

- Stellar abundances are only as good as our models
- Departures from LTE abundances in metal-poor stars can be severe
- Accurate modeling of atmospheres in iron-poor stars (NLTE) is important. Ignoring NLTE effects can:
  - overestimate T_{eff} ~ 50- 600 K
  - underestimate log g ~ 0.2 - 1 dex
  - underestimate [Fe/H] ~ 0.2 – 1.0 dex
  - underestimate [Mg/H] up to 0.5 dex
  - underestimates [Ca/H] from Ca II lines up to 0.5 dex
- NLTE effects important to include in abundance determinations of large samples, i.e, large spectroscopic surveys. **Possible with our new dense NLTE metal-poor abundance grid! If interested, talk to me on coffee break :)**

STELLAR ATMOSPHERES ASSUMPTIONS : IS 1D OKAY VS 3D?



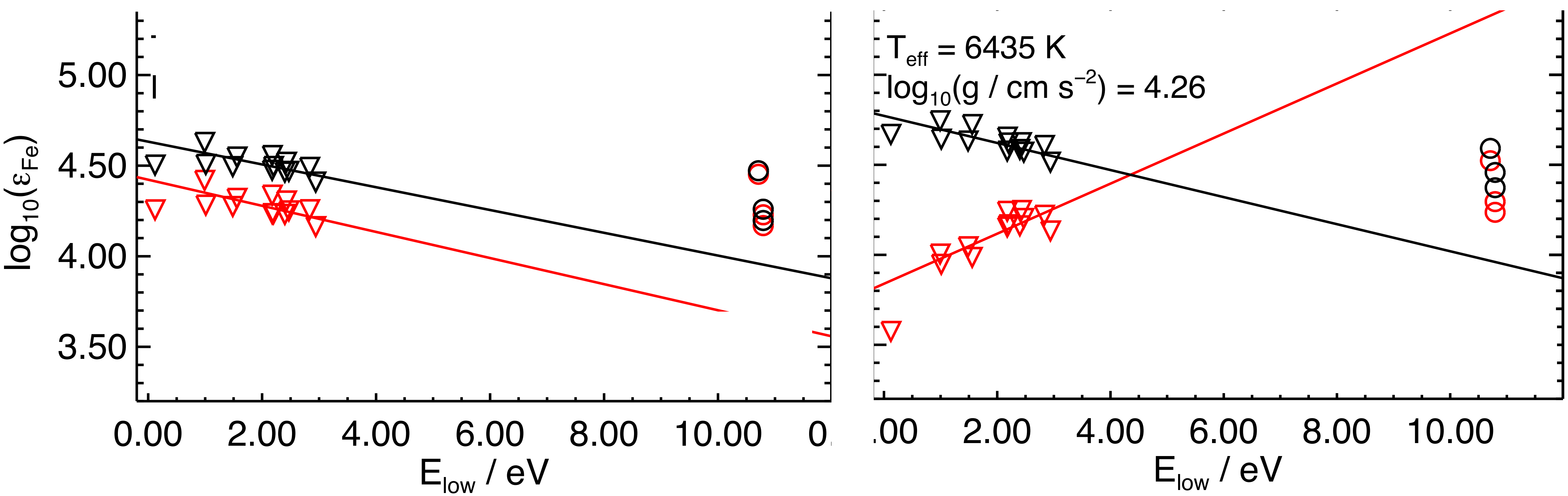
Matthias Steffen
3D COBOLD simulations

3D important for CNO elements : large 3D effects

STELLAR ATMOSPHERES ASSUMPTIONS : IS 1D OKAY VS 3D?

Amarsi et al. (2016)

1D **3D**



NLTE **LTE**

1D, NLTE better than 3D, LTE!