# NON-LTE ABUNDANCE ANALYSIS OF THE MOST IRON-POOR STARS IN THE GALAXY


RANA EZZEDDINE

(JINA-CEE POSTDOCTORAL FELLOW)

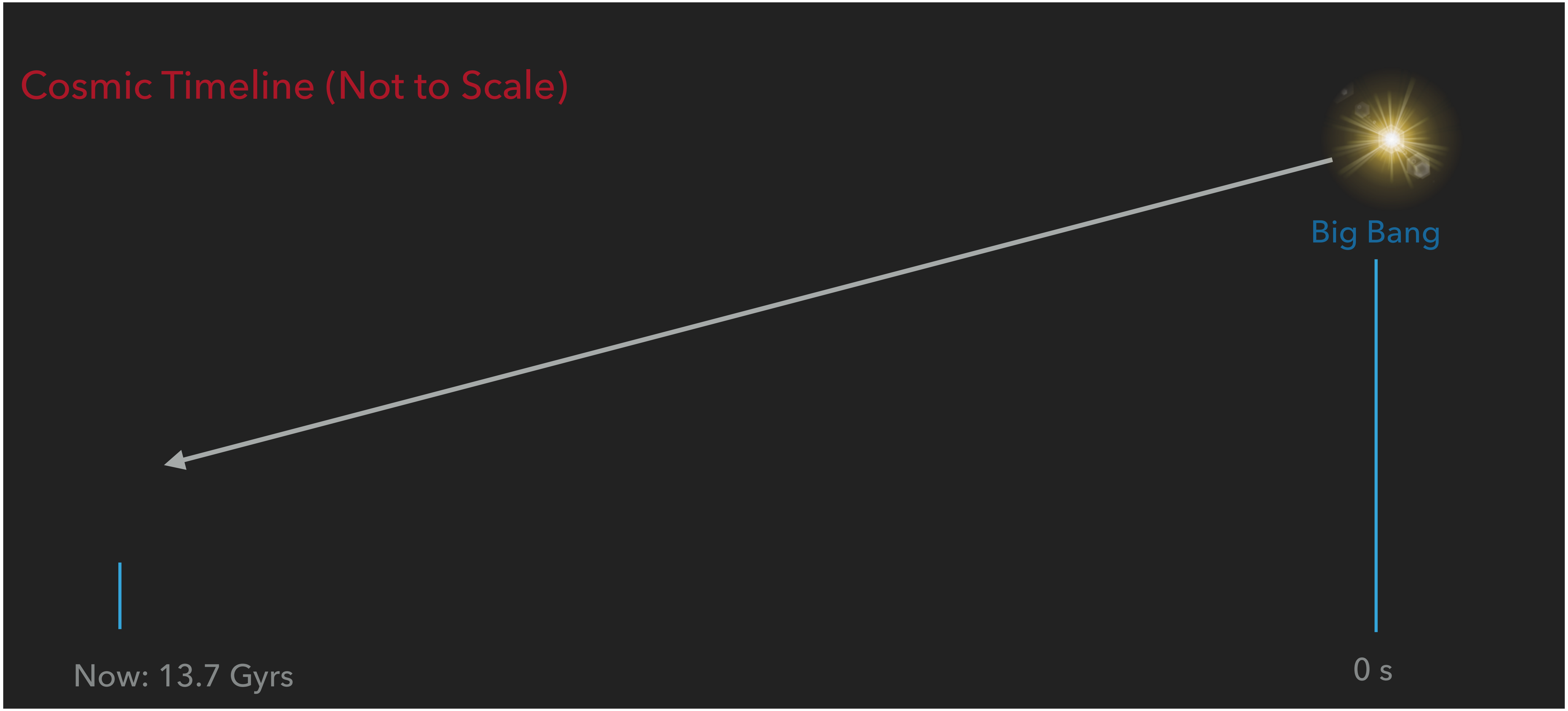
IN COLLABORATION WITH: ANNA FREBEL, BERTRAND PLEZ, TATYANA SITNOVA, LYUDMILLA MASHONKINA.

- What are the most Iron-poor stars in the Galaxy?

- Why are they important & What can we learn from them?

## WHAT ARE THE MOST IRON-POOR STARS?

- They are the rare stellar relics of the early universe.
- They have records of the "First" Population III stars recorded in their atmospheres



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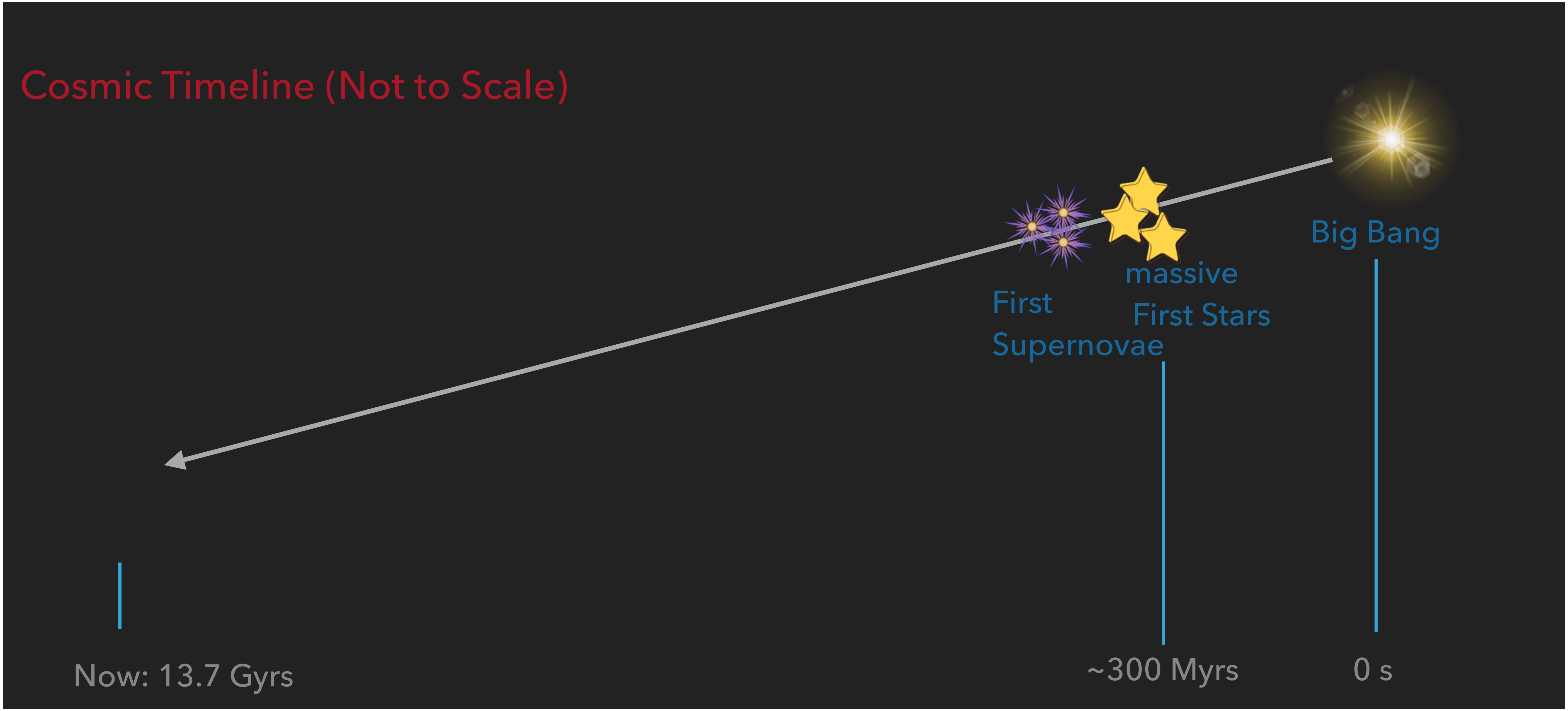

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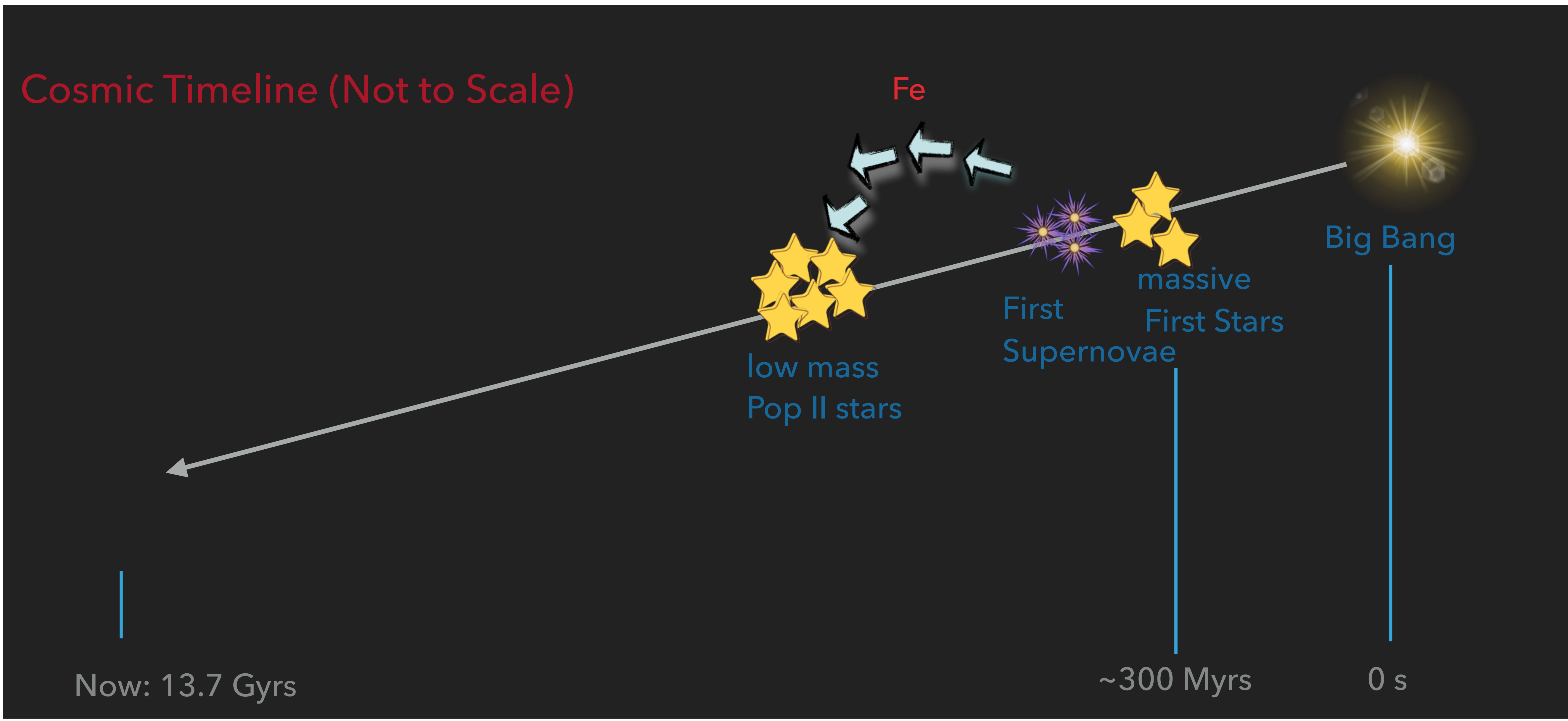

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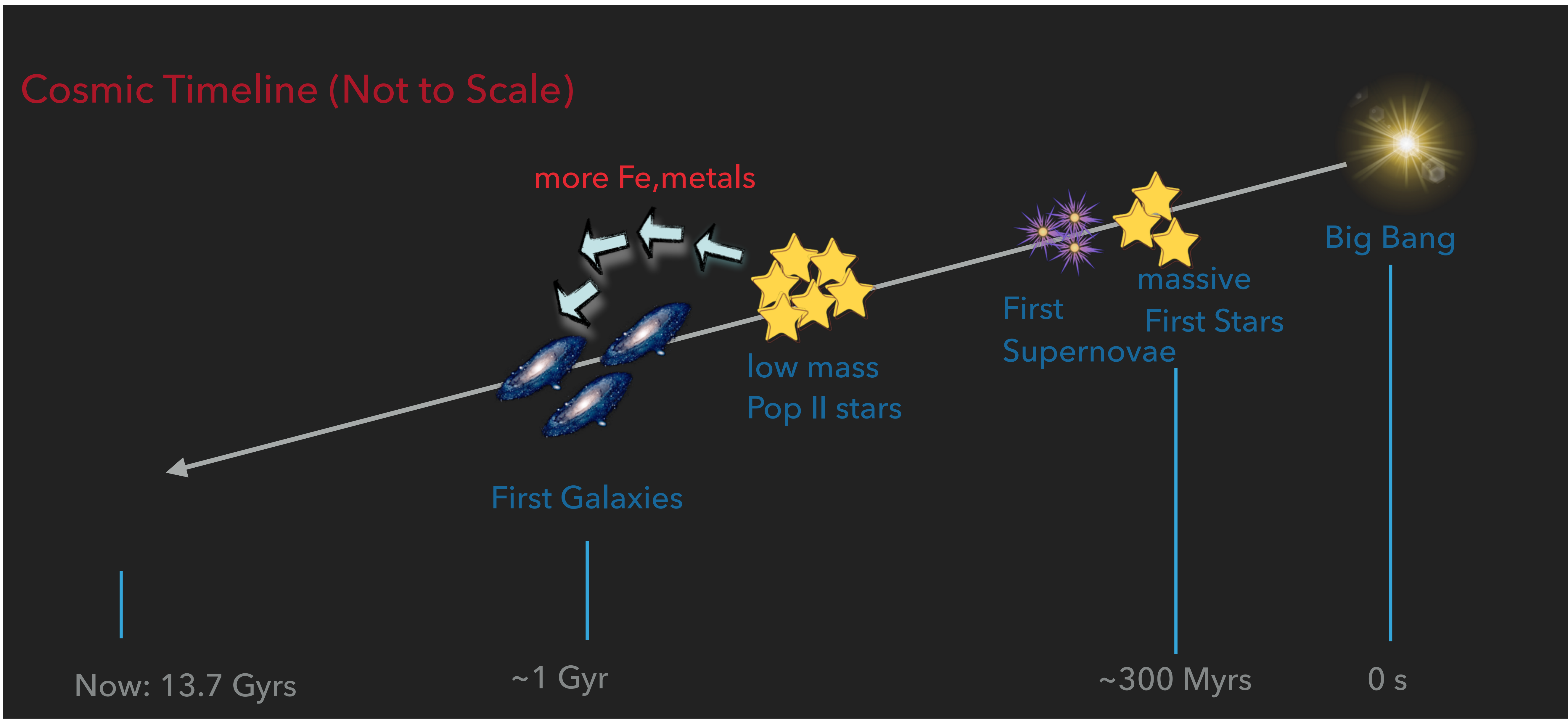

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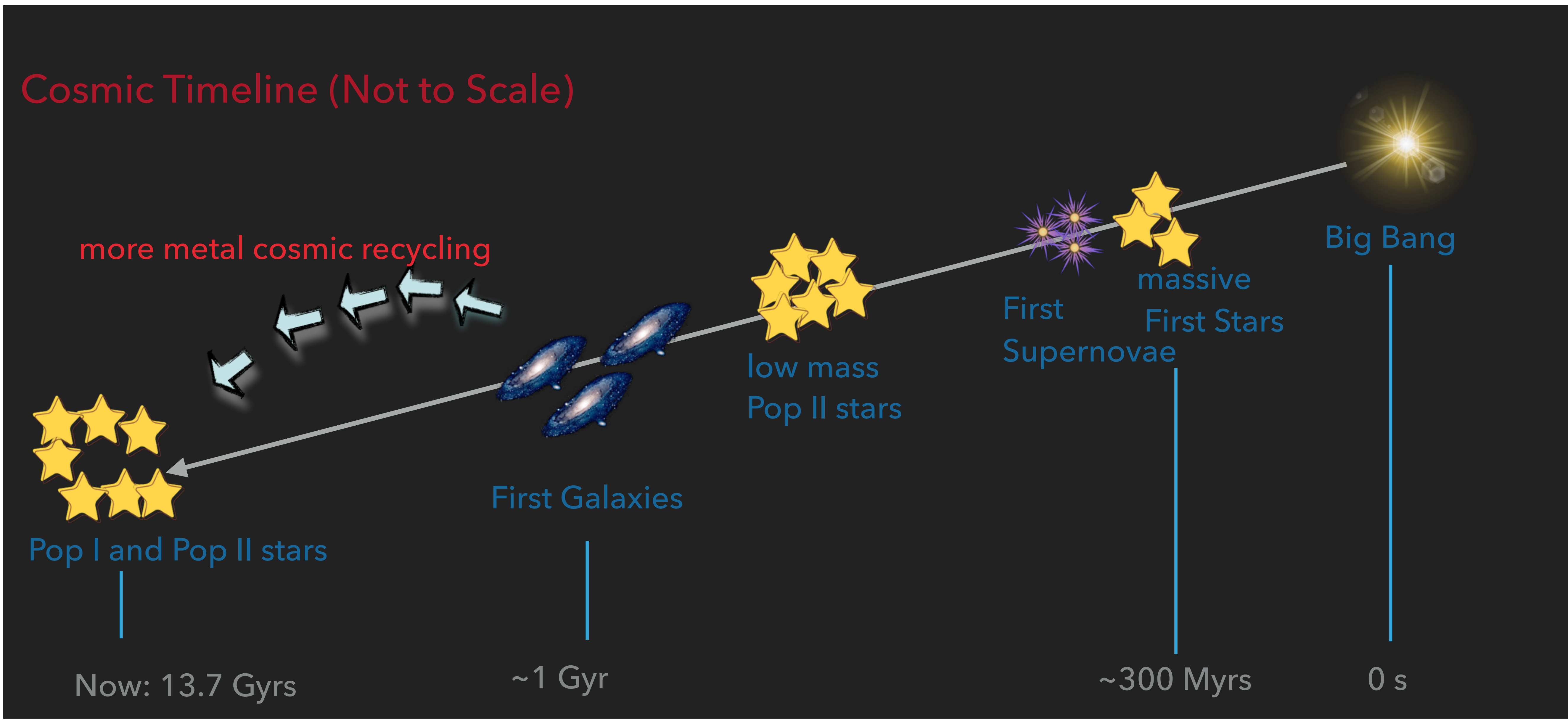

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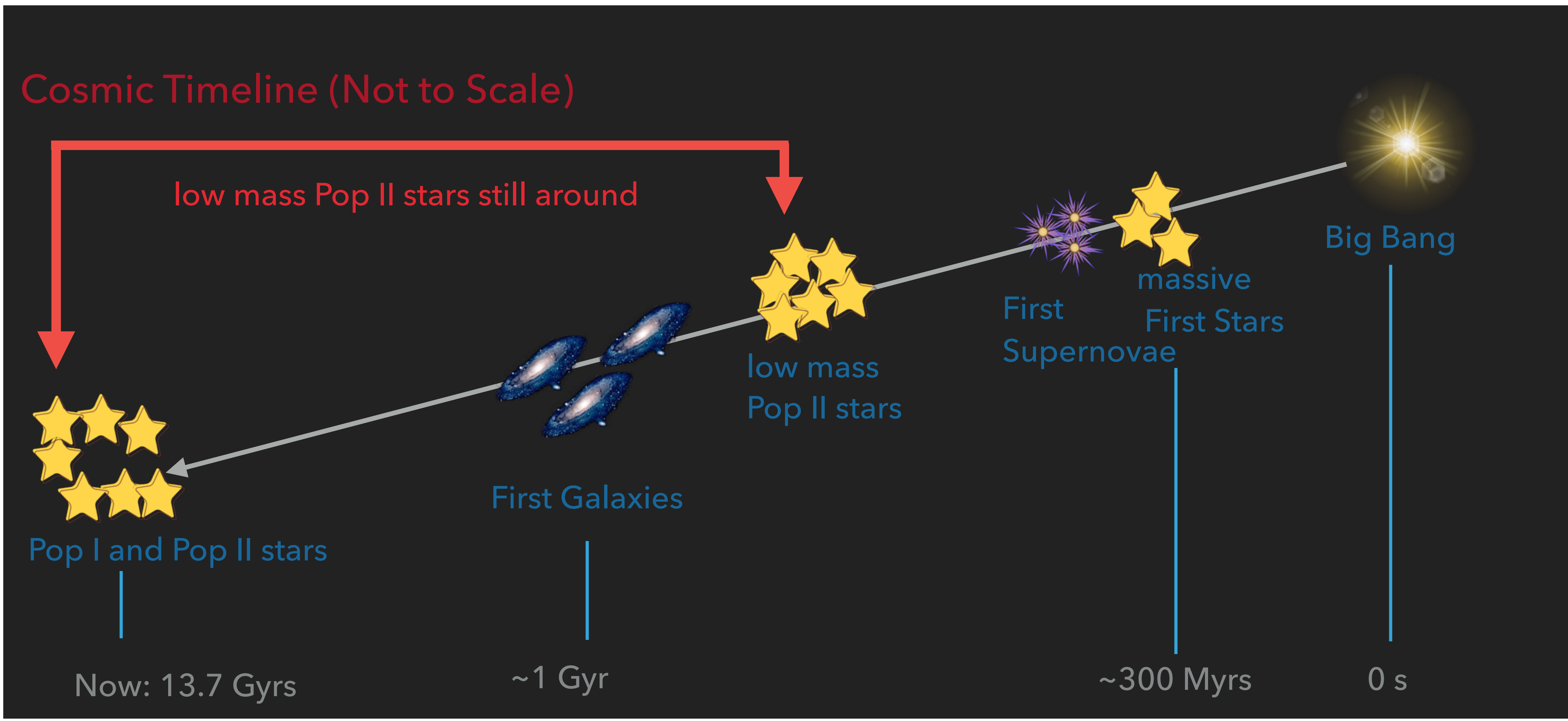
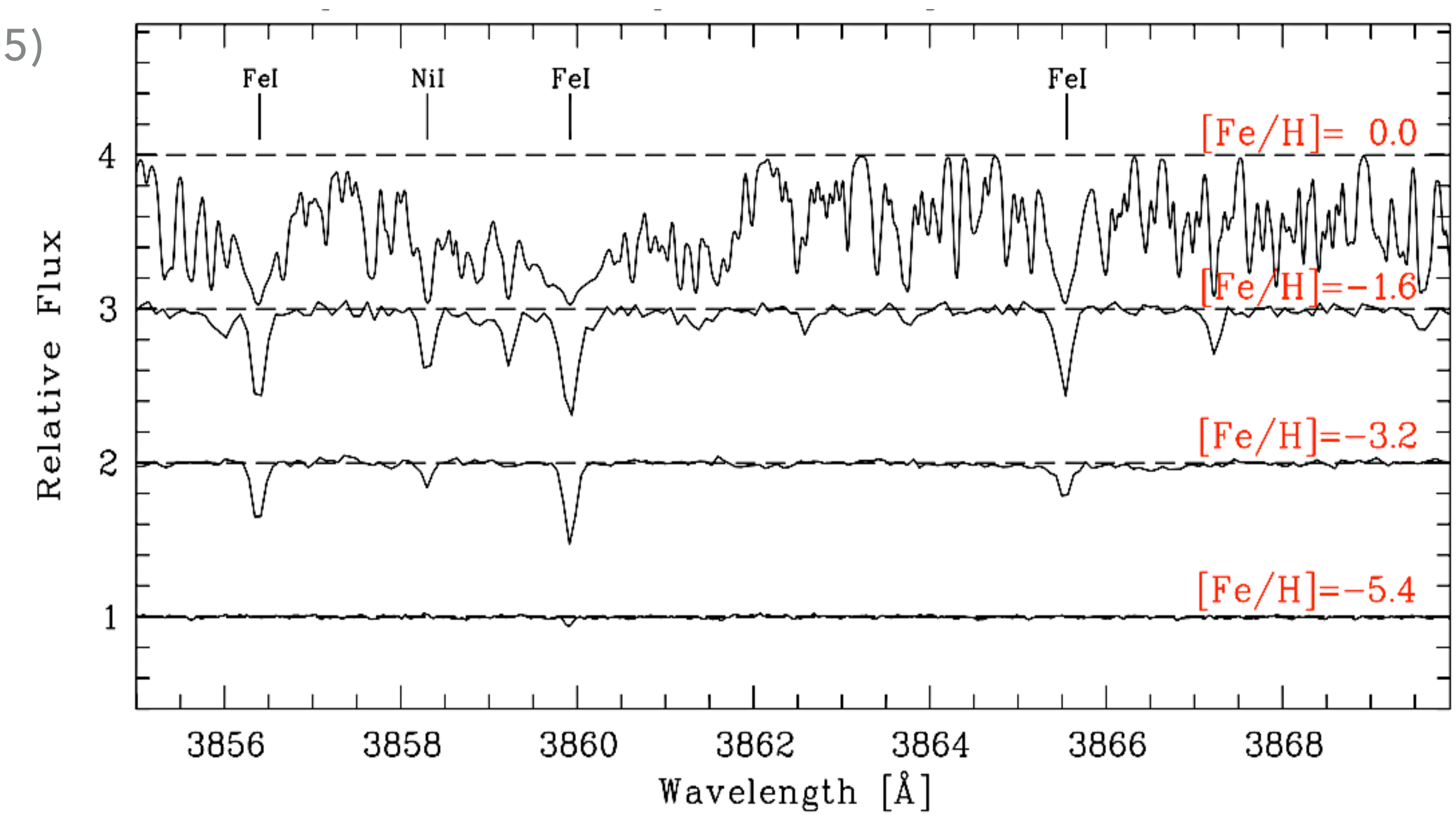


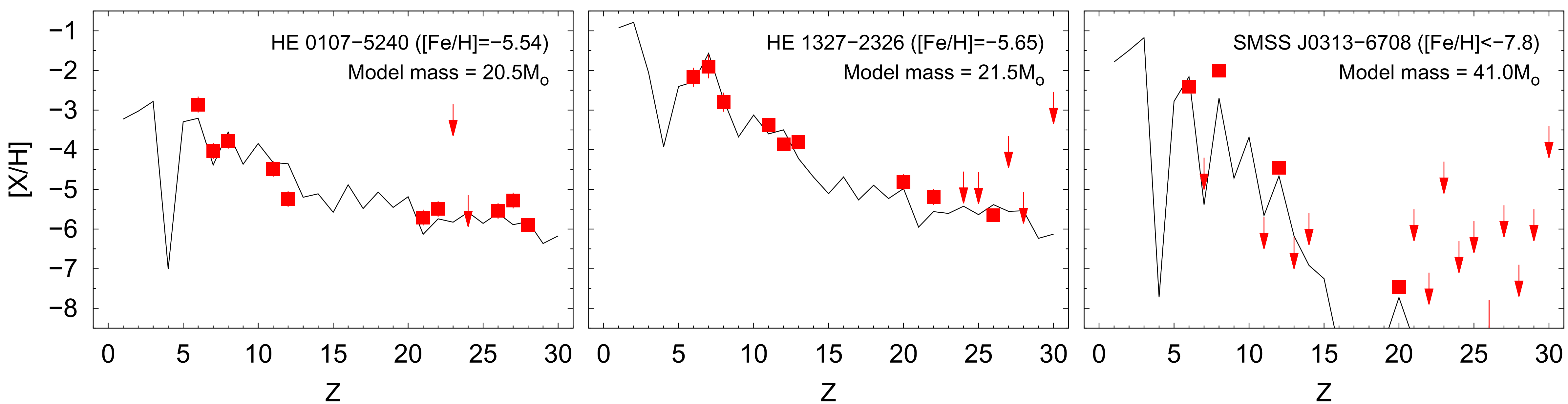
- Ultra Metal-Poor stars: -5.00<[Fe/H]<-4.00, number=~20
- Hyper Metal-Poor stars: [Fe/H] < -5.00, number=~5
  (SMSS J0313-6708 (Keller star)   [Fe/H] < -6.50)

Beers & Christlieb (2005)



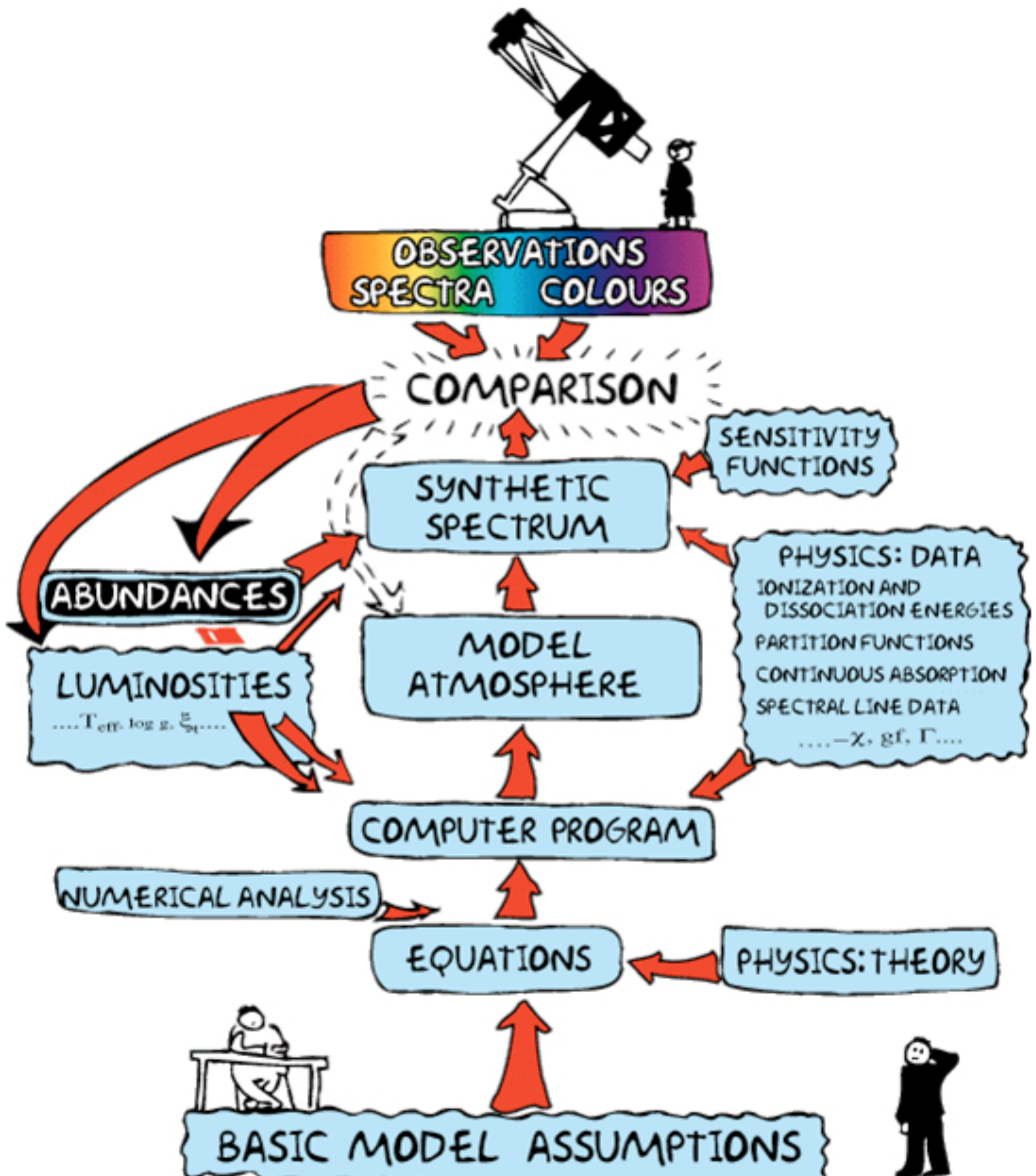
## WHY ARE THEY IMPORTANT?

- Comparing UMP & HMP stellar abundance patterns to Pop III Supernova nucleosynthesis yields to determine Pop III progenitor properties: Mass, SN explosion energy, Mixing fractions,..
- Depends on derived elemental abundances : need precise abundances




Placco et al. (2015)

# ABUNDANCES ARE NOT DIRECTLY MEASURED, BUT DERIVED!




B. Gustafsson, Astronomical Observatory, Uppsala (2009)

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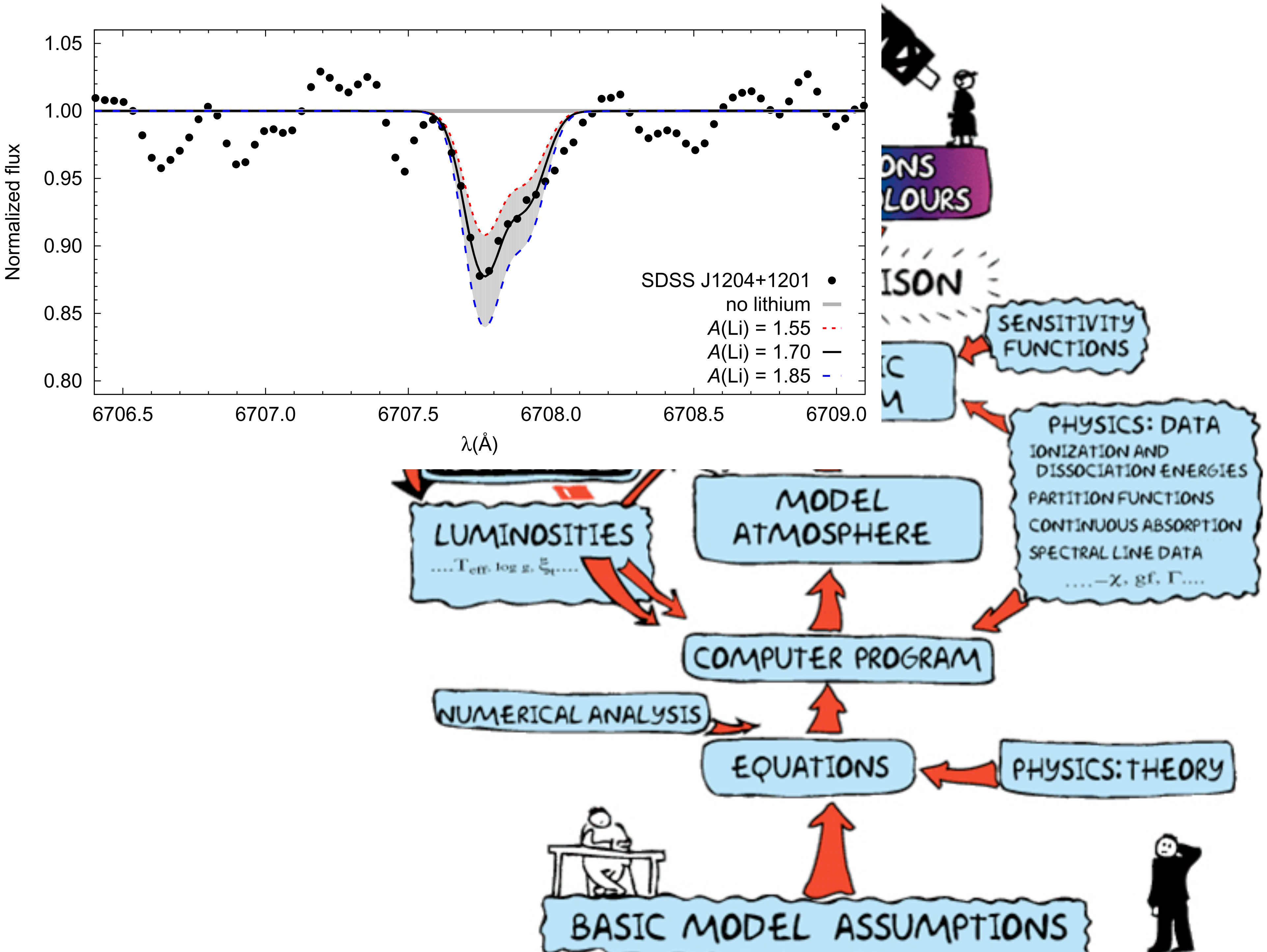
Spectral Synthesis

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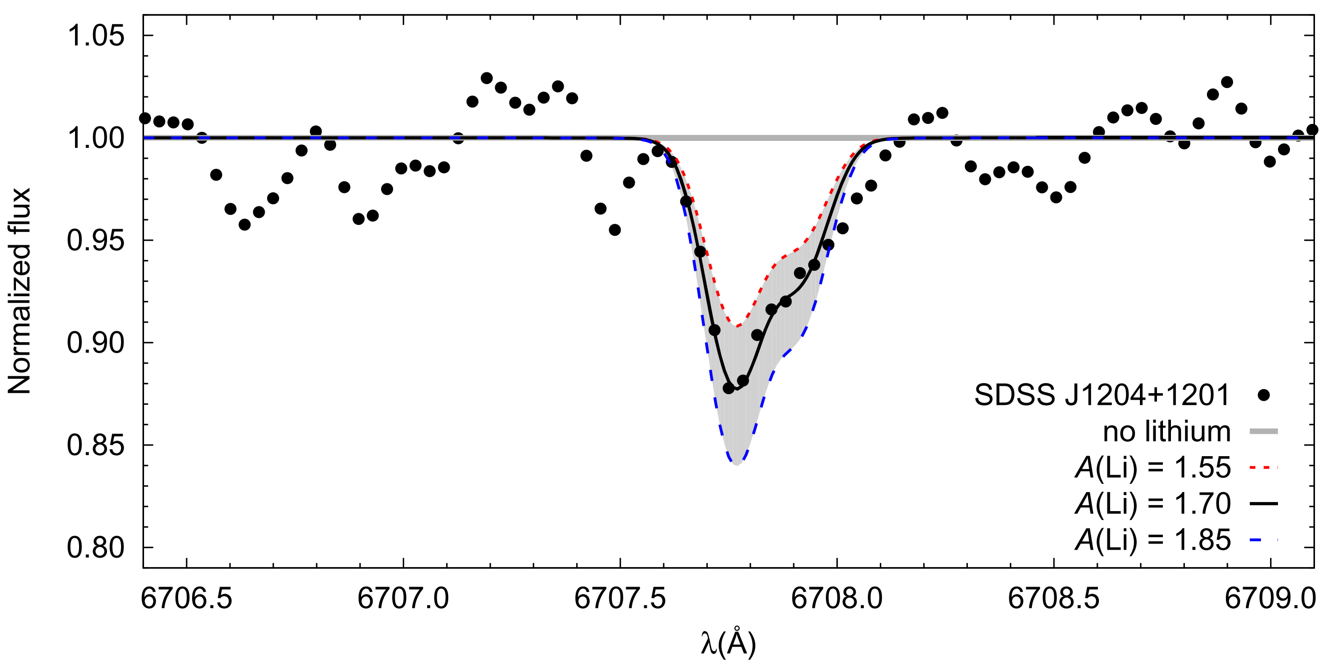
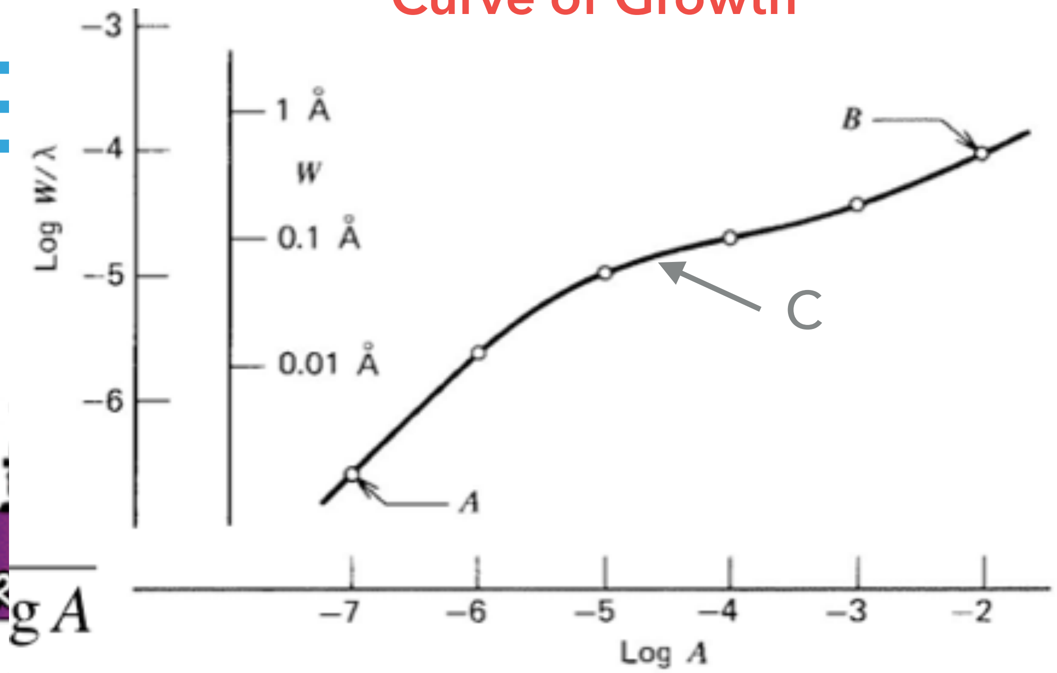
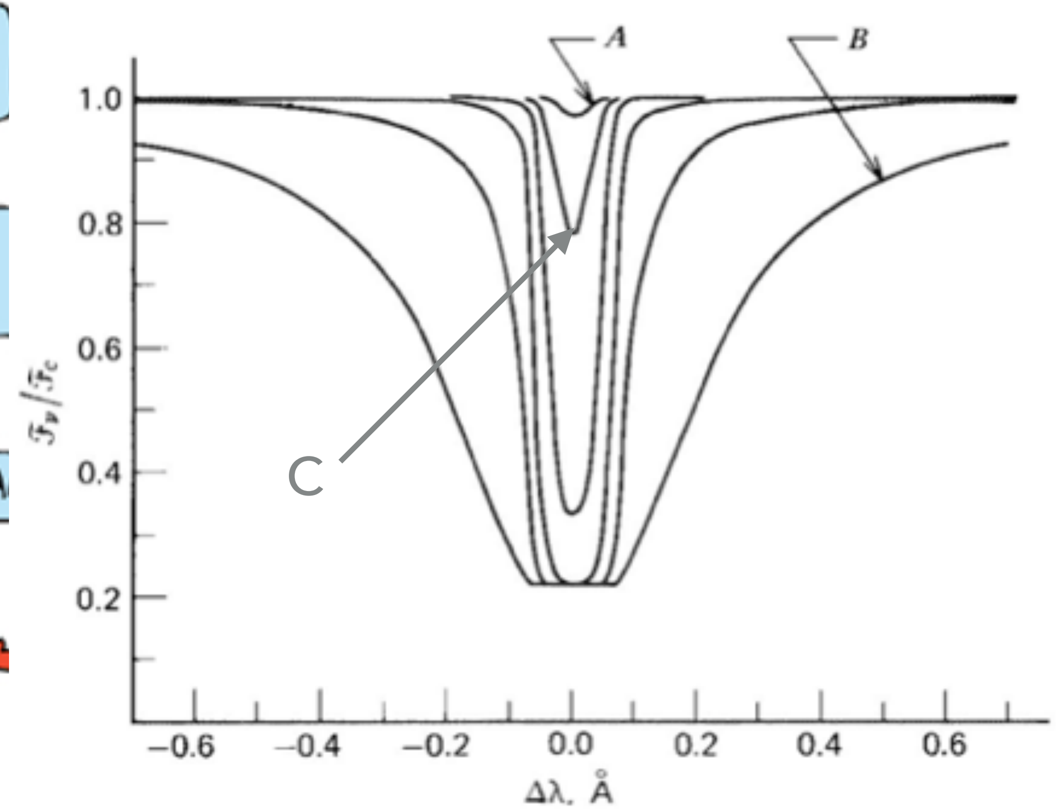
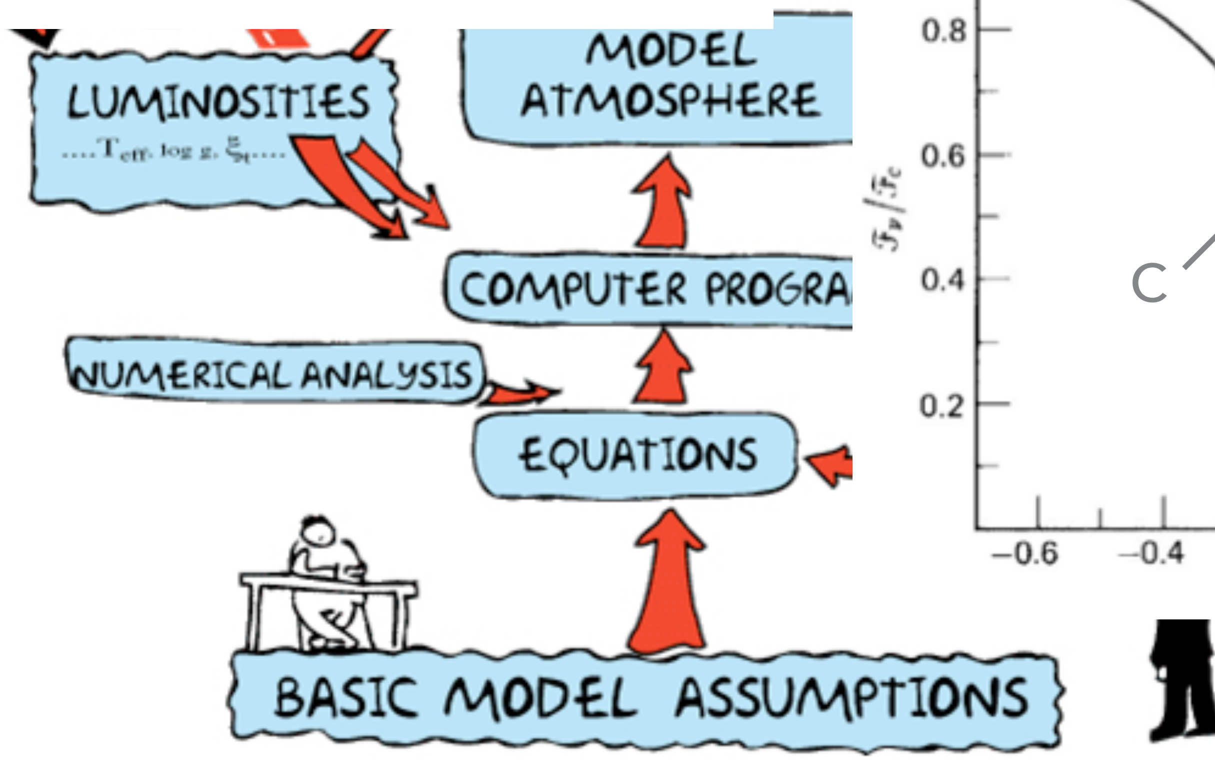



## Curve of Growth



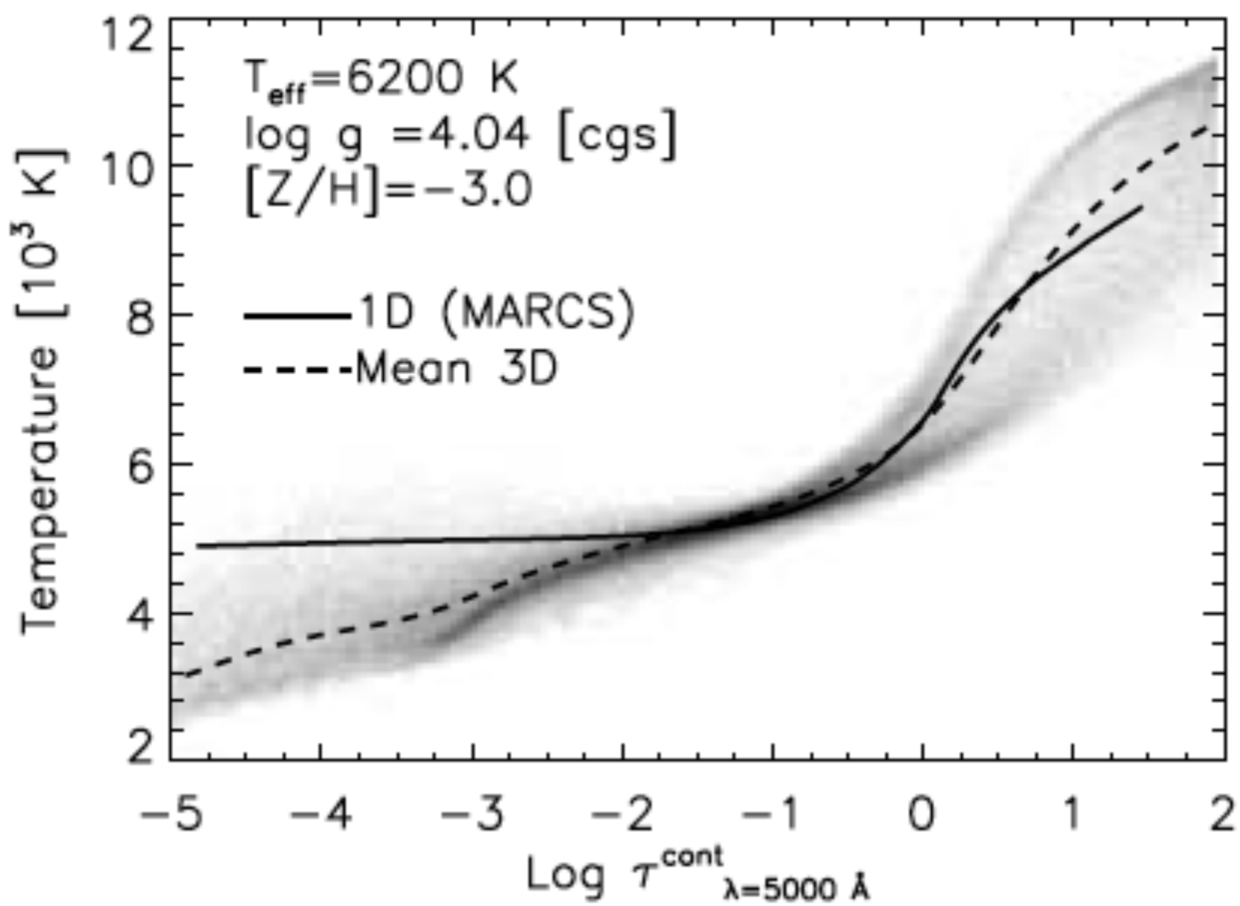
Abundances are not measured BUT determined

- 1D vs. 3D
- Plane-parallel vs. spherical geometry
- Homogeneity
- Stationarity
- Hydrostatic equilibrium
- Flux constancy (radiative equilibrium)

# ABUNDANCE MODELLING ASSUMPTIONS

Remo Collet

Abundan rmined

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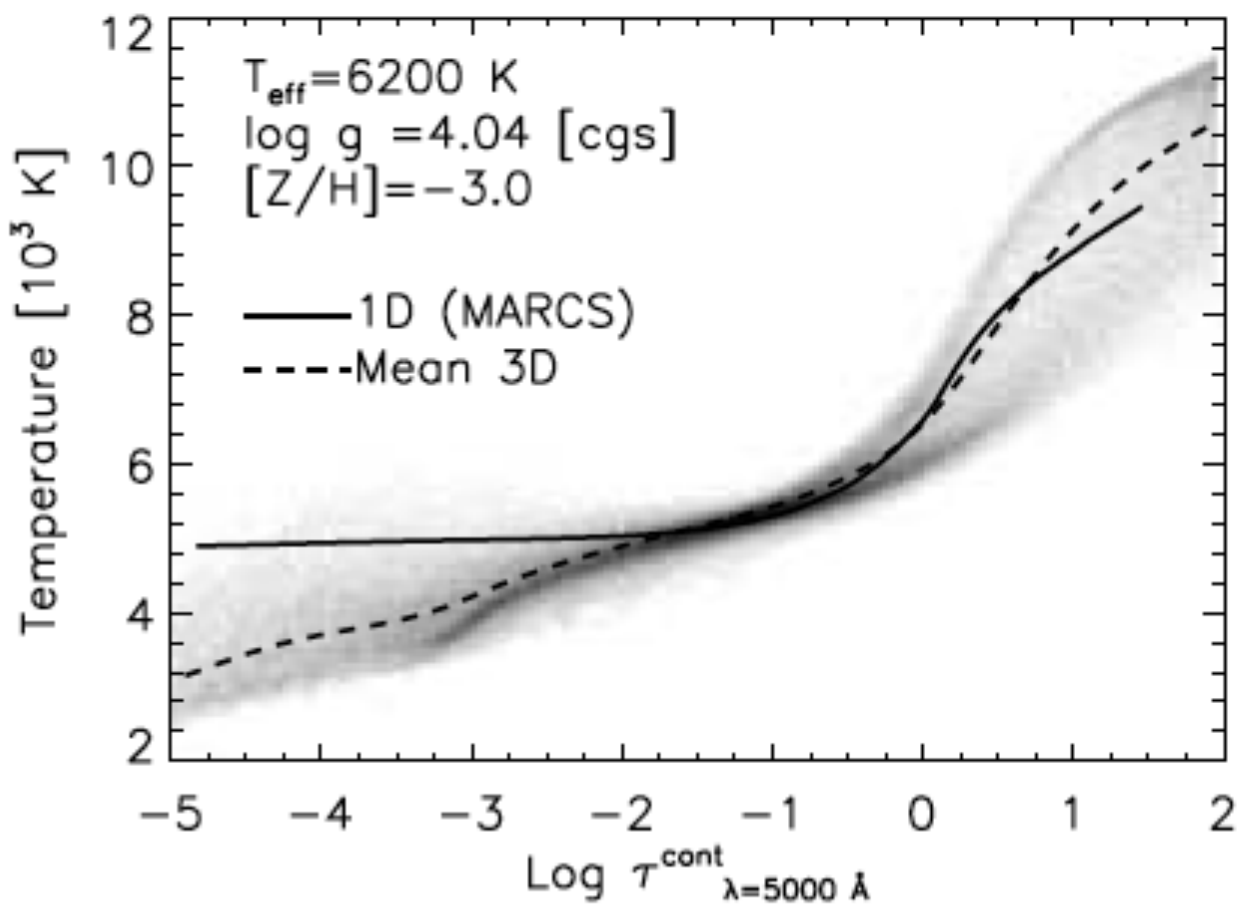


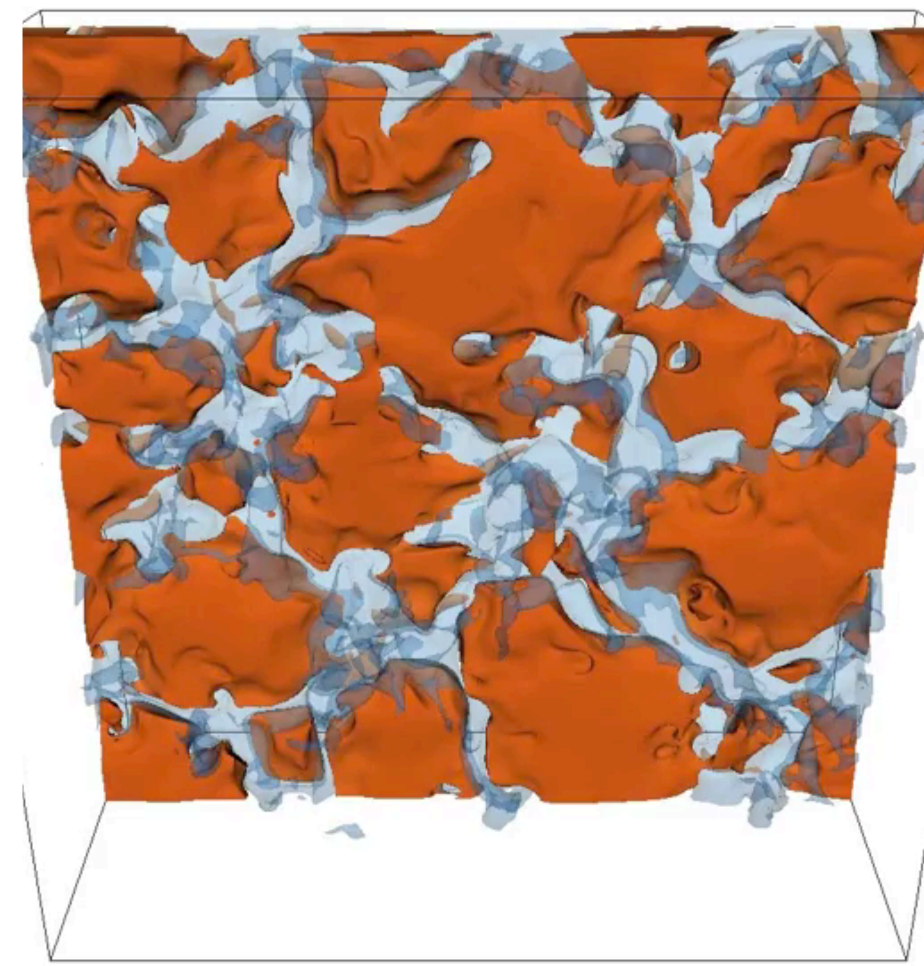

Mathias Steffen (priv comm.)

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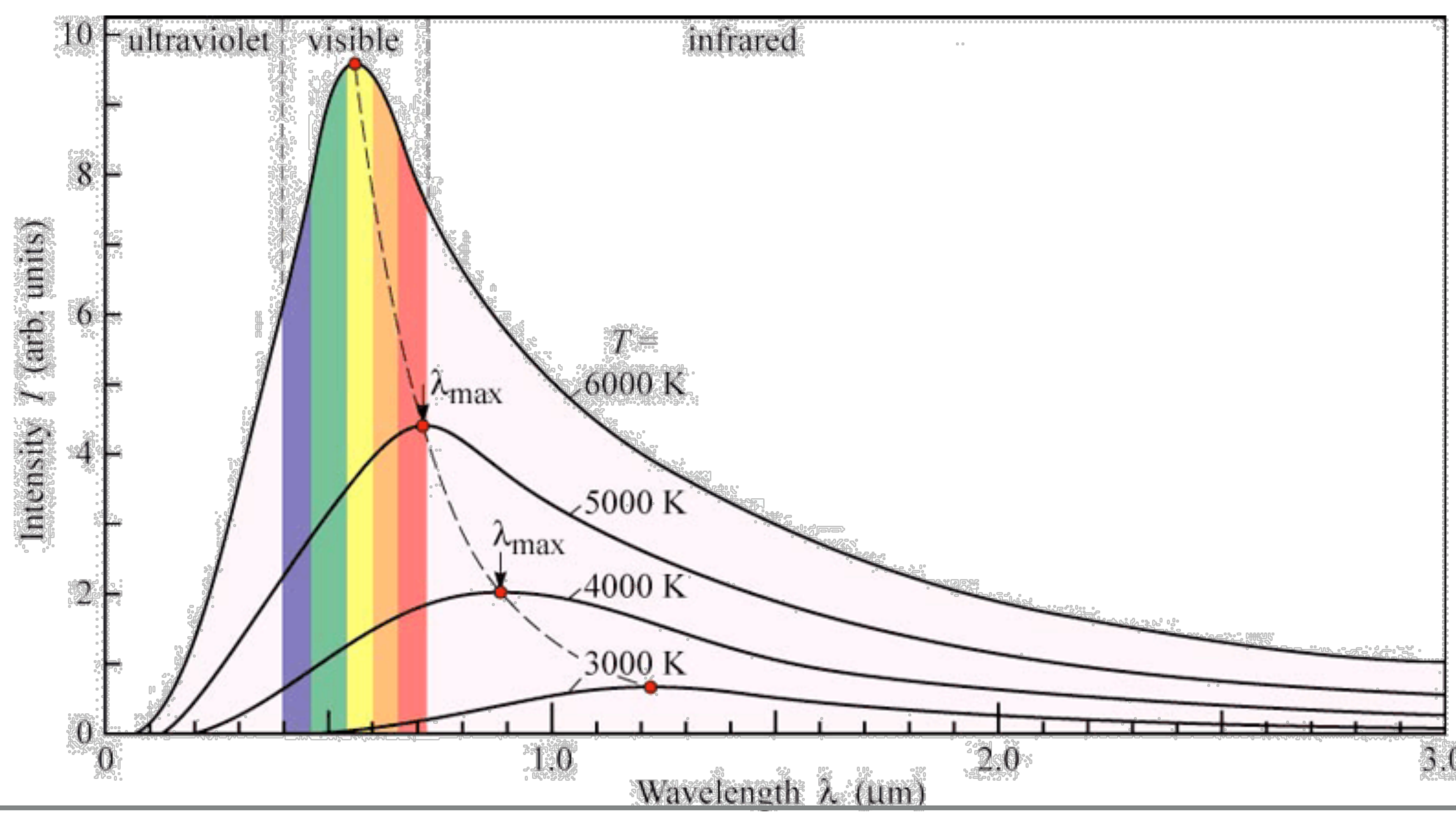
- 1D vs. 3D
- Plane-parallel vs. spherical geometry
- Homogeneity
- Stationarity
- Hydrostatic equilibrium
- Flux constancy (radiative equilibrium)

- Local thermodynamic equilibrium (LTE)

# LOCAL THERMODYNAMIC EQUILIBRIUM (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 (Saha-Boltzmann statistics)
- Source function S(ν ) = B(ν) ( Planck function, f(T) )
- Valid in cool Main Sequence stellar atmospheres where collisions dominate as to induce TE
- May or may not hold for a given spectral line



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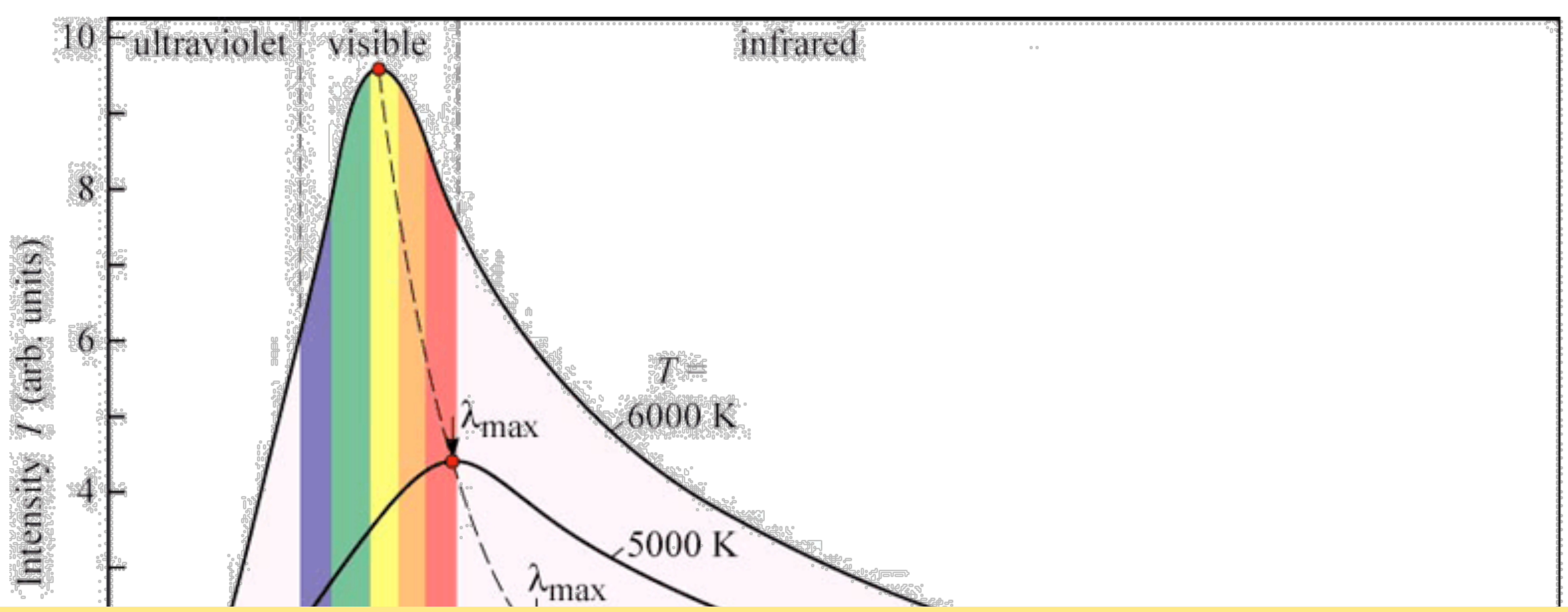
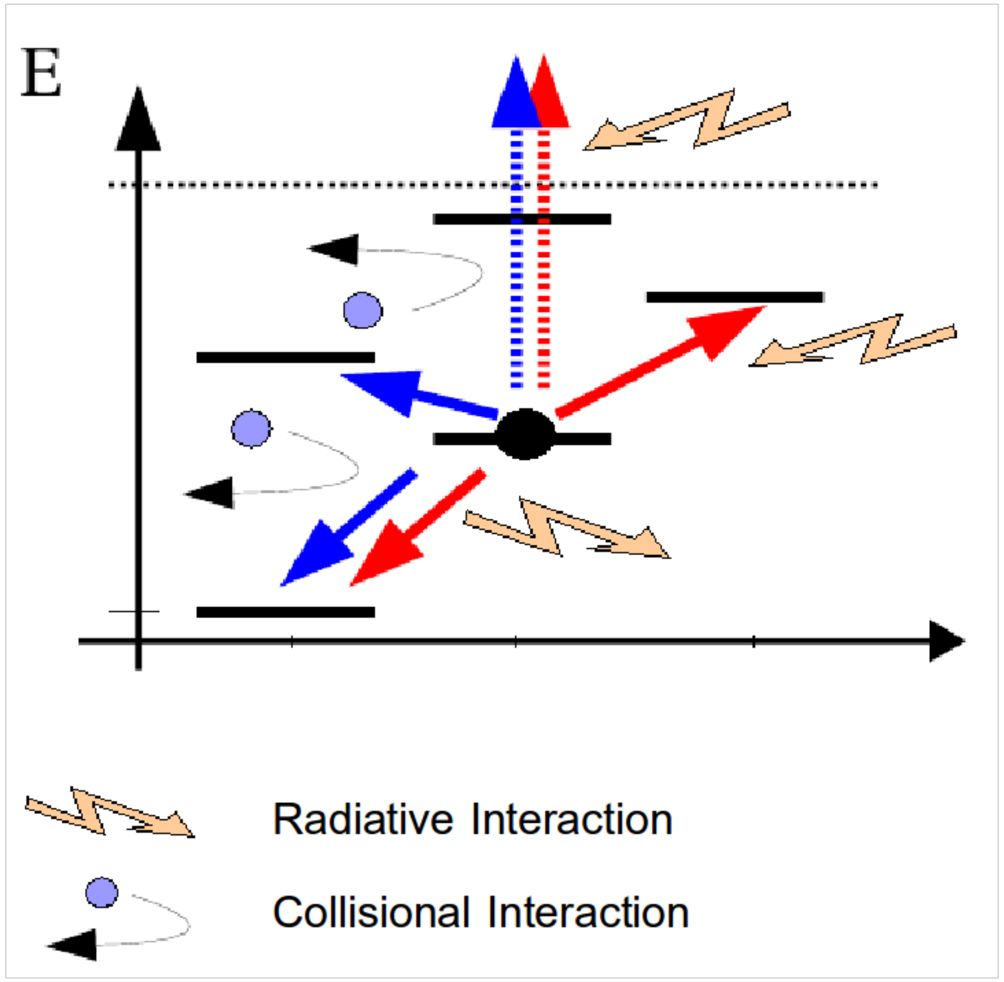



HOWEVER, (LUCKILY FOR US!!), IN REALITY, STARS ARE DYNAMICAL, NON-LOCAL SYSTEMS!

# NON-LOCAL THERMODYNAMIC EQUILIBRIUM EFFECTS

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



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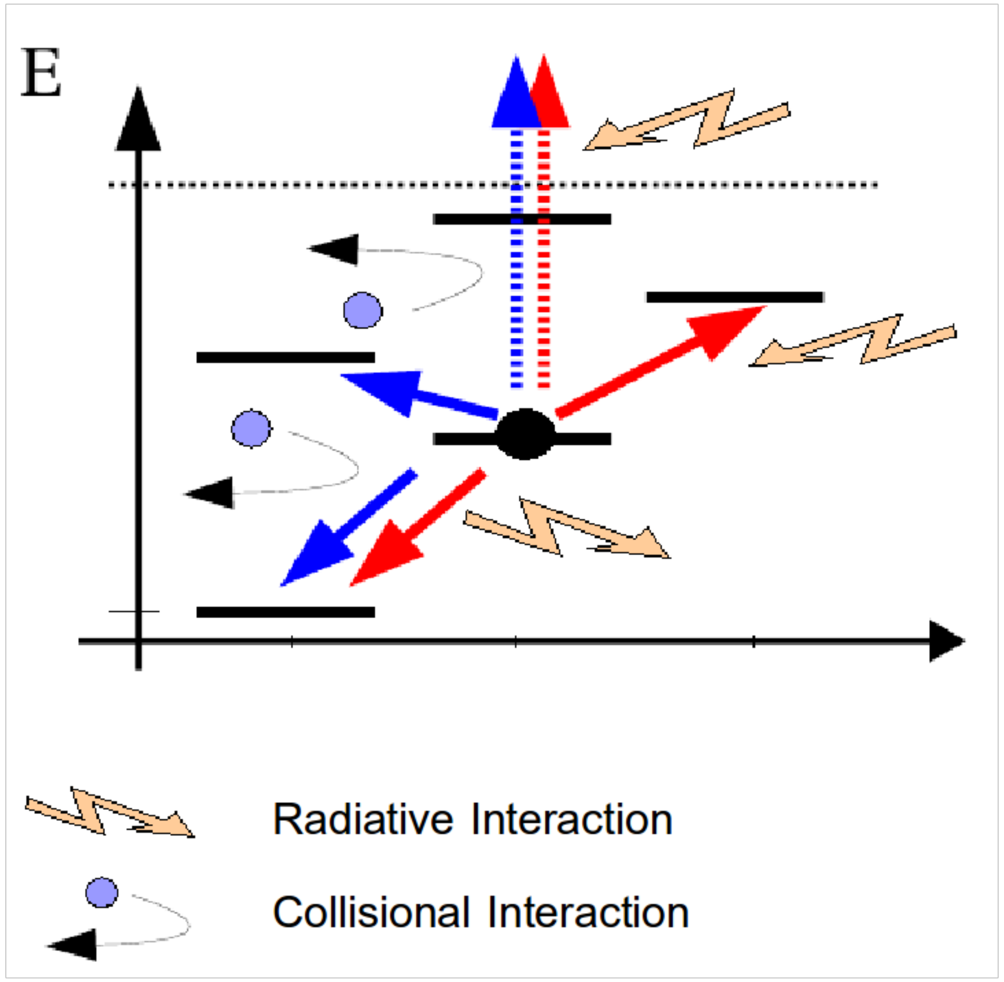


Statistical Equilibrium Equation has to be solved simultaneously with the radiative transfer equation:

$$n_i \sum_{j \neq i} (\mathbf{R}_{ij} + \mathbf{C}_{ij}) = \sum_{j \neq i} n_j (\mathbf{R}_{ji} + \mathbf{C}_{ji})$$

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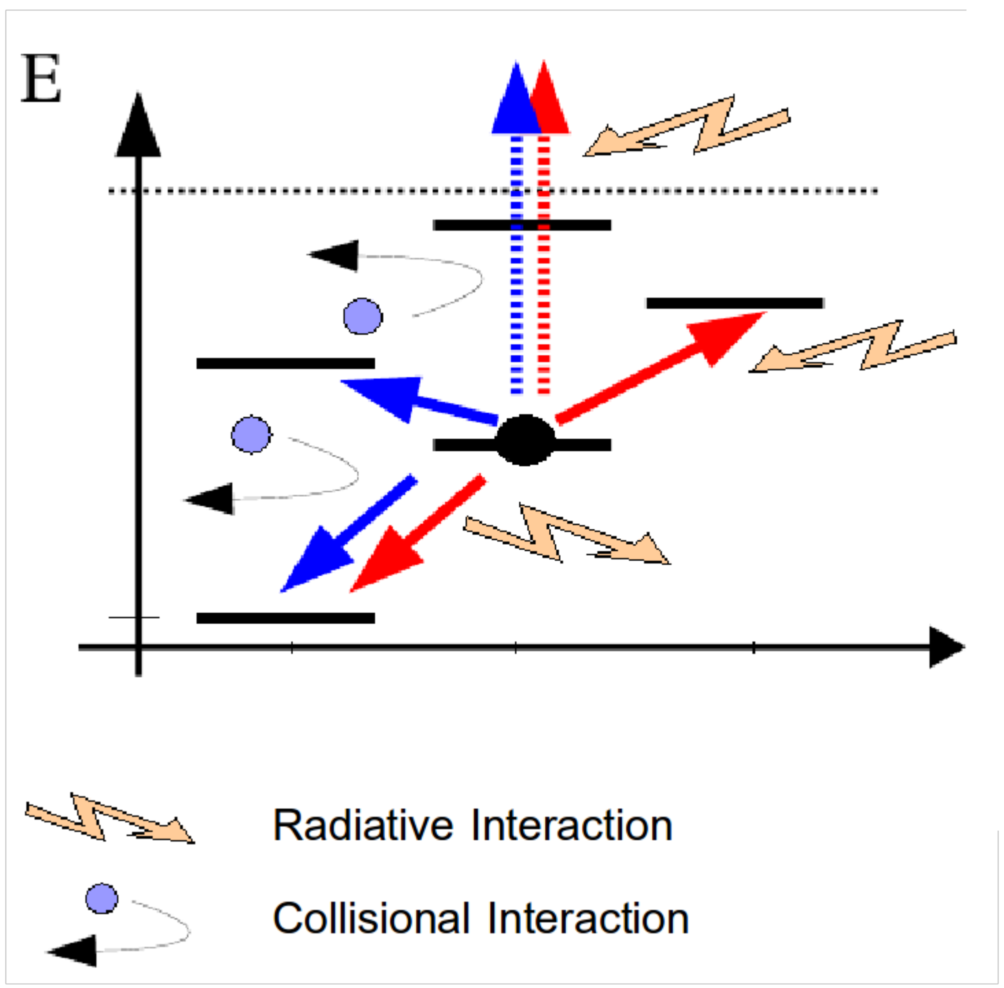
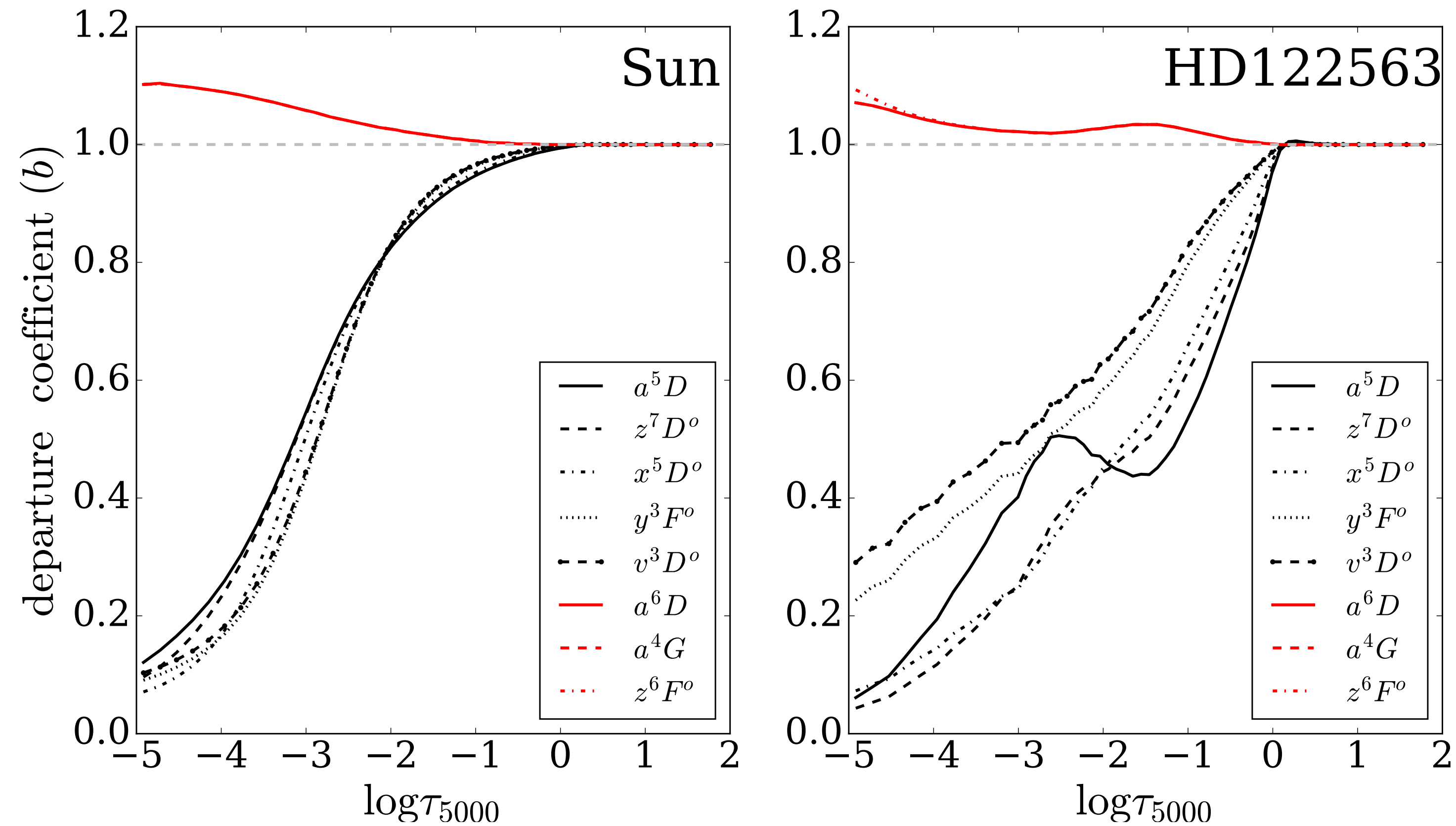



departure coefficient (b)= level population density (NLTE)/level population density (LTE)




*Ezzeddine et al 2017a*

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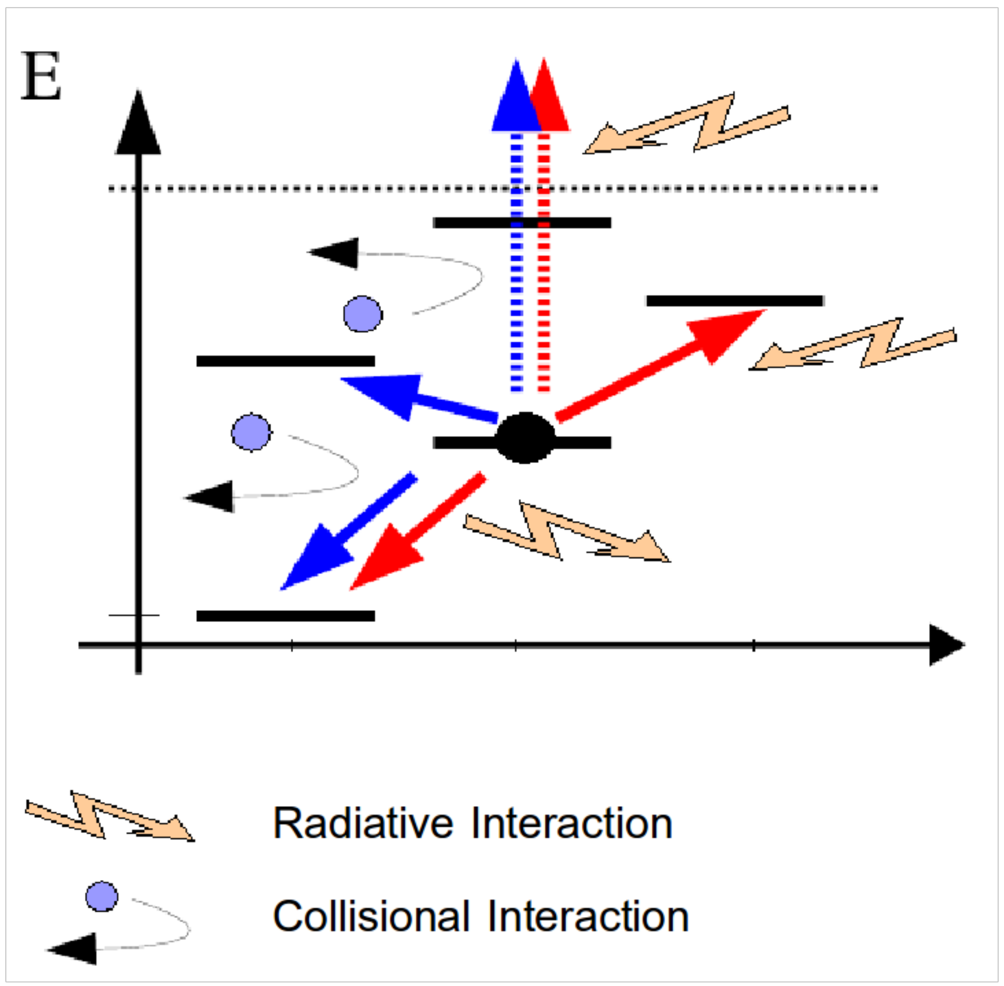
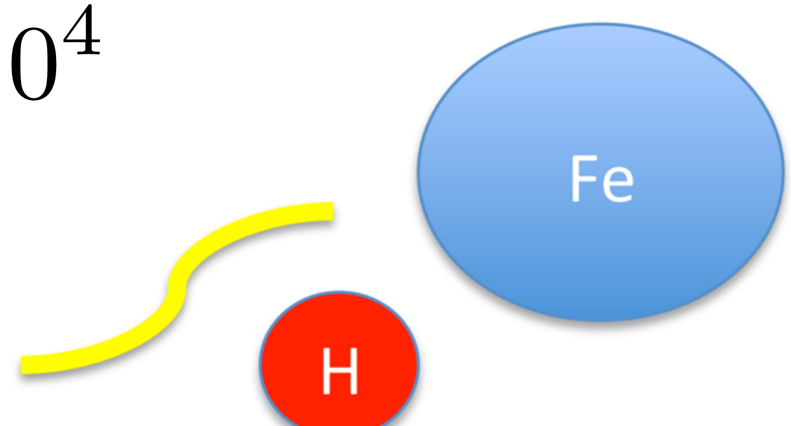
Bulk of atomic data required in NLTE calculations



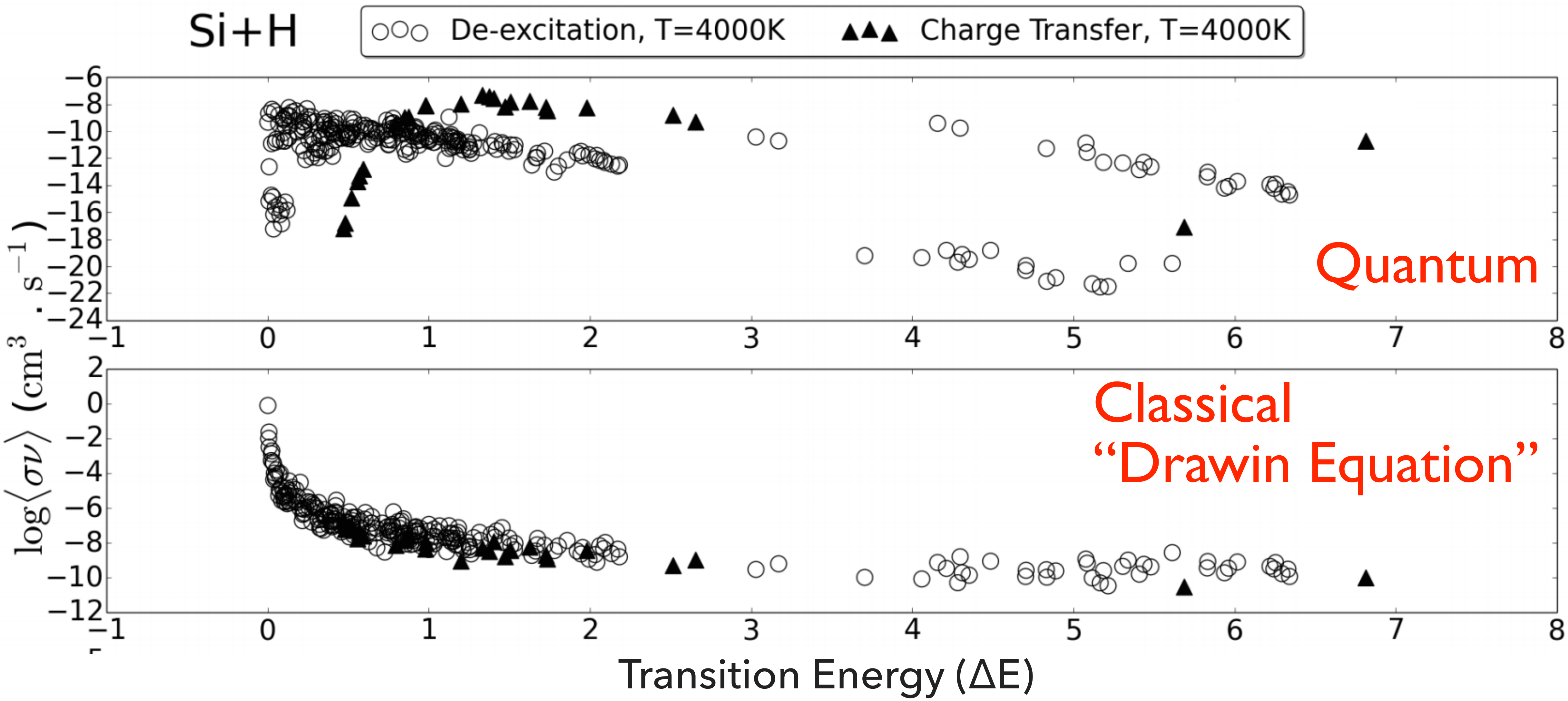

## Status Quo?

Large uncertainties still associated with collisional rates due to lack of experimental cross-section data, esp. collisions with Hydrogen in cool stars which plays an important role esp. in metal-poor stars.

$$\frac{n_{\mathrm{H}}}{n_{e-}} \sim 10^4$$

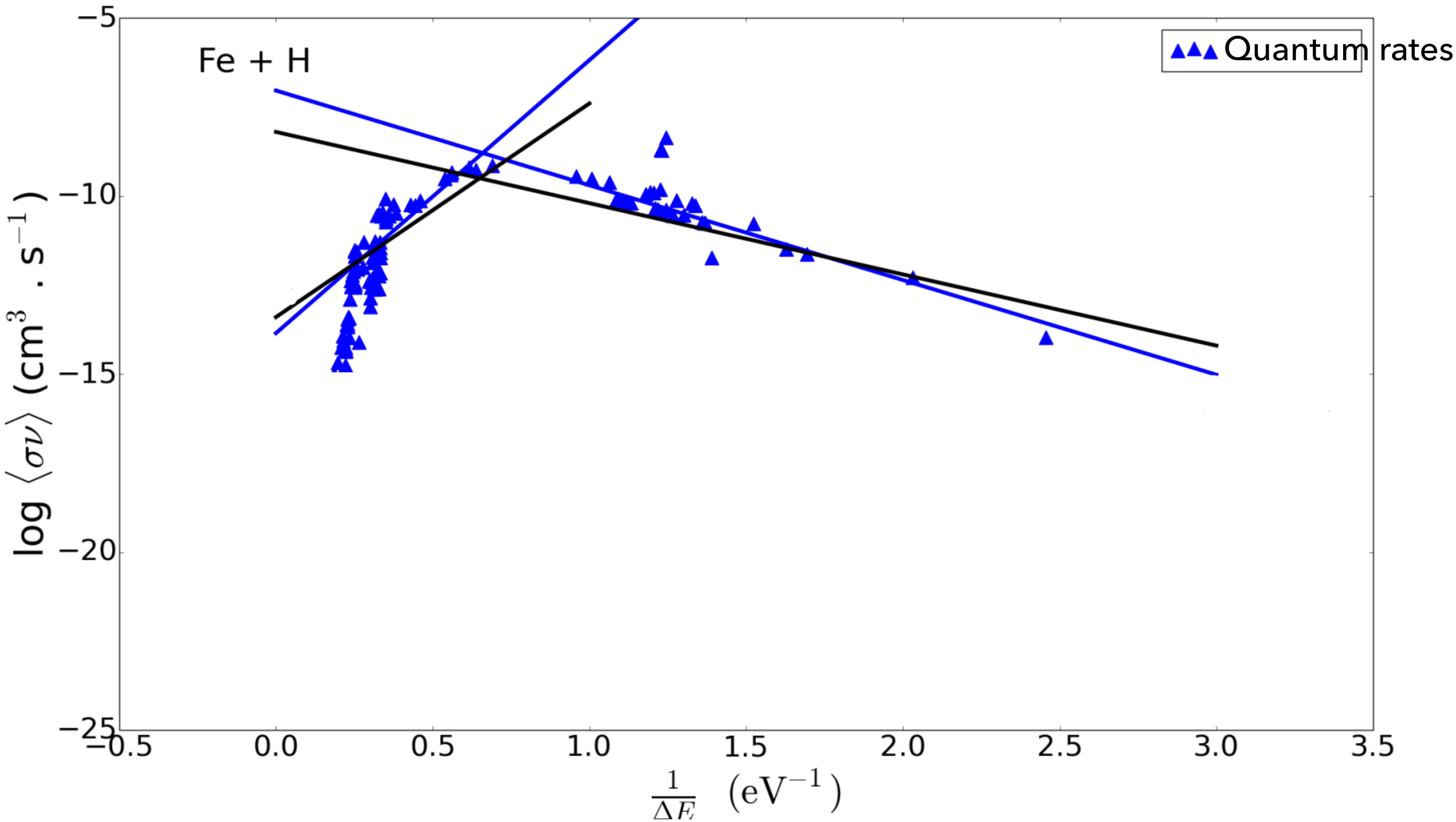


# ROLE OF HYDROGEN COLLISIONS




Classical approximation overestimates collisions by ~ 8 orders of magnitude

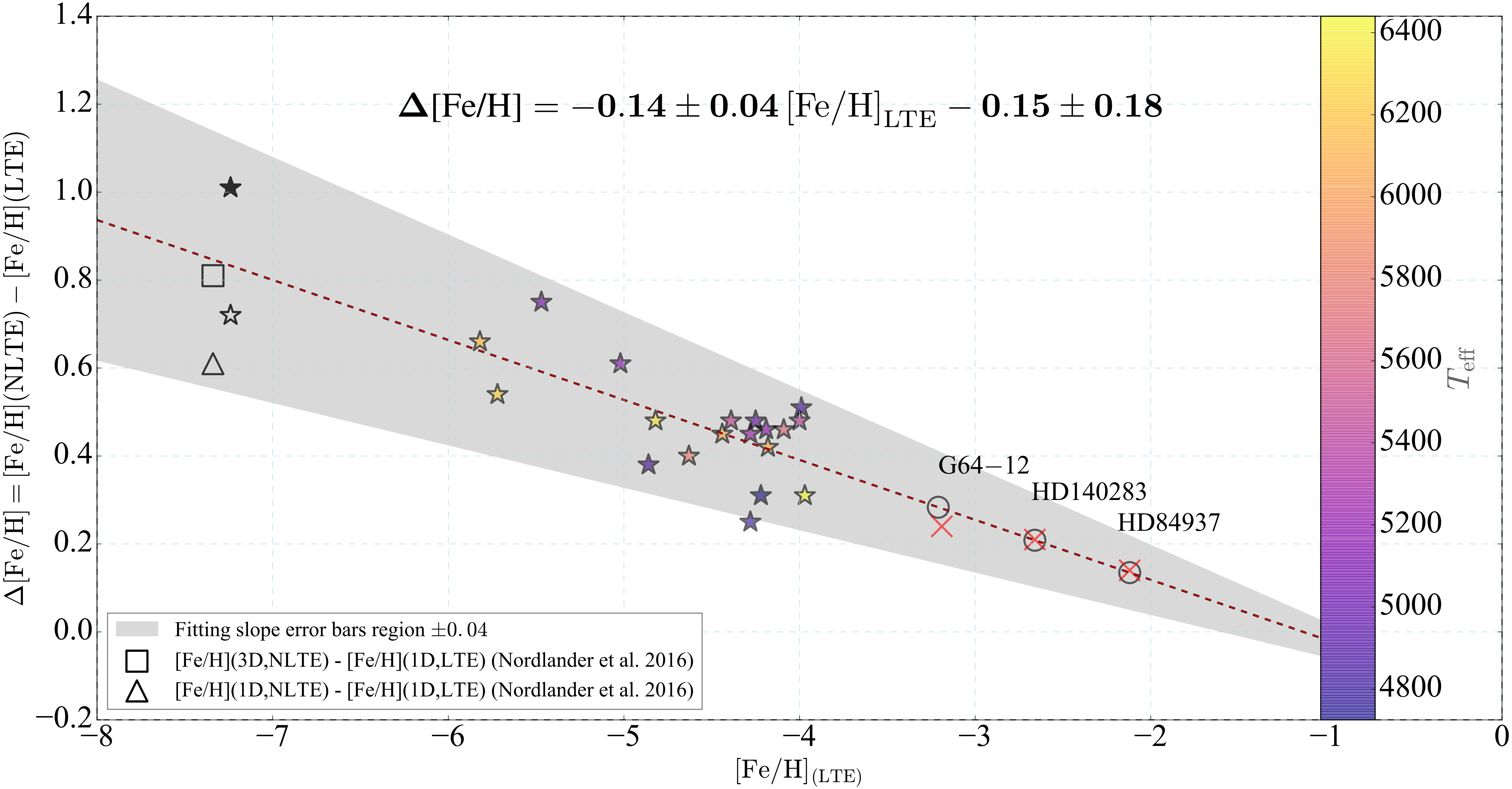
# Quantum Fitting Method




Ezzeddine et al. (2017a)

Departure from LTE can be severe in UMP stars!

*Ezzeddine et al. 2017b*



## NLTE EFFECTS

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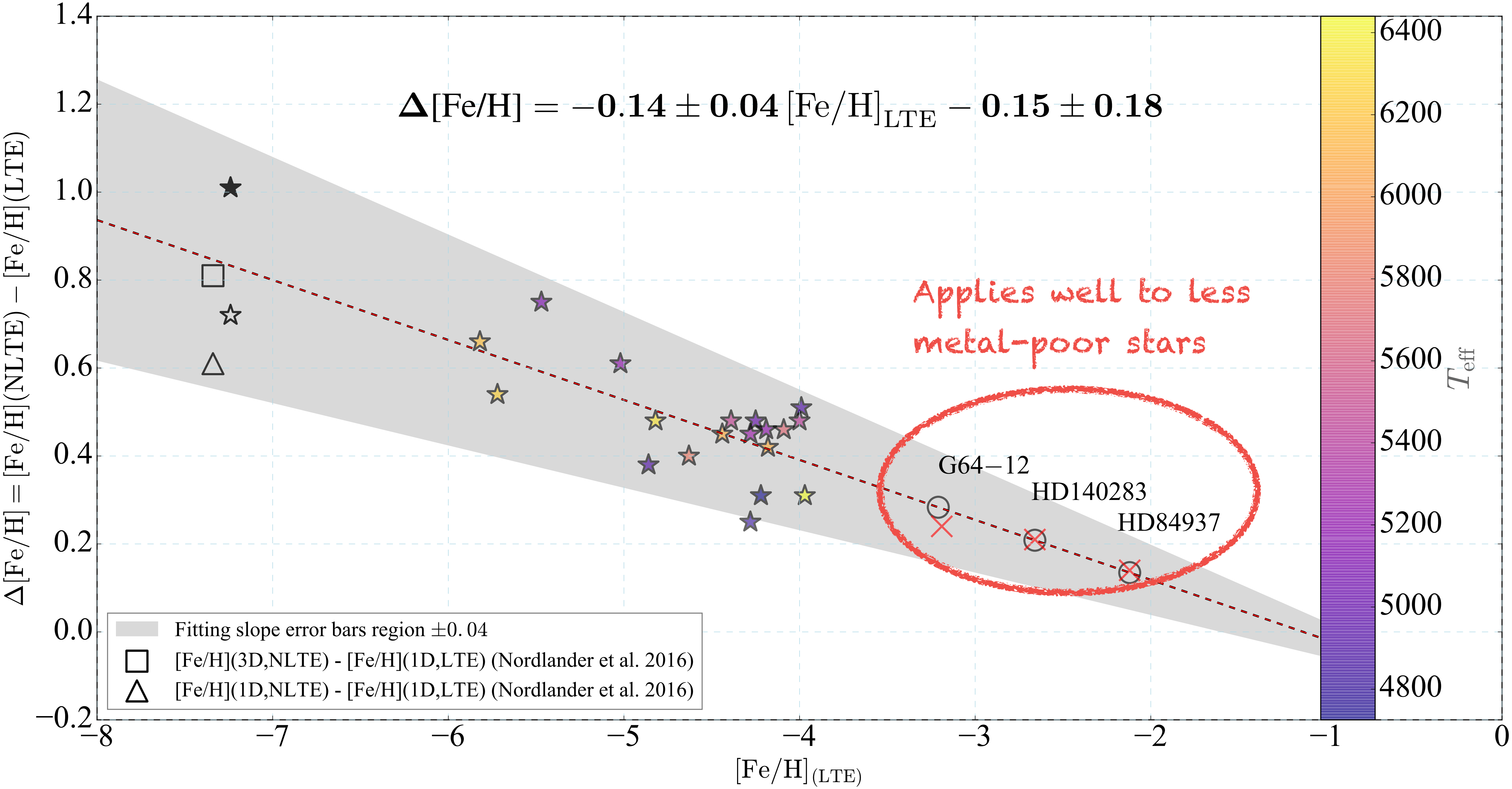
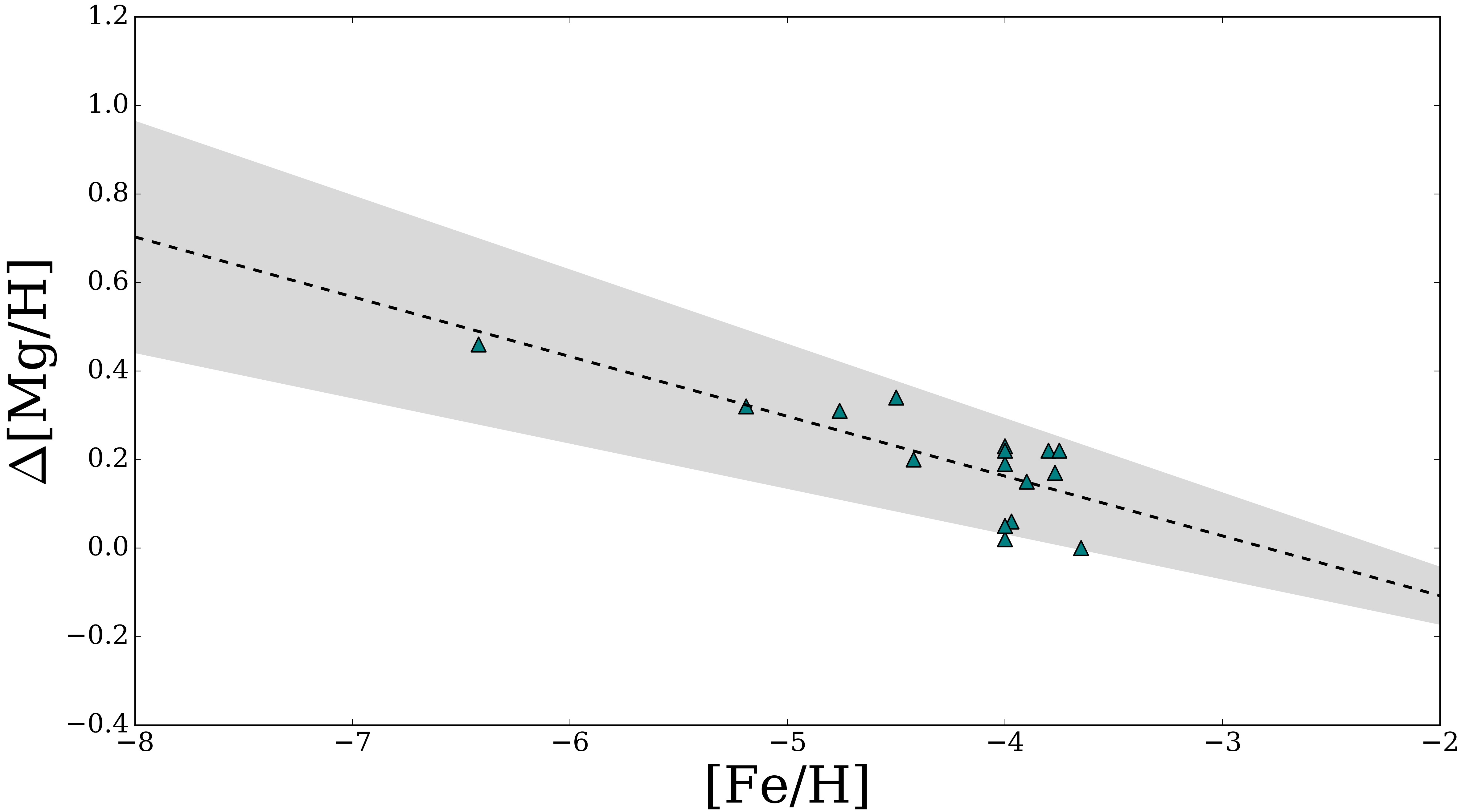


# NLTE EFFECTS

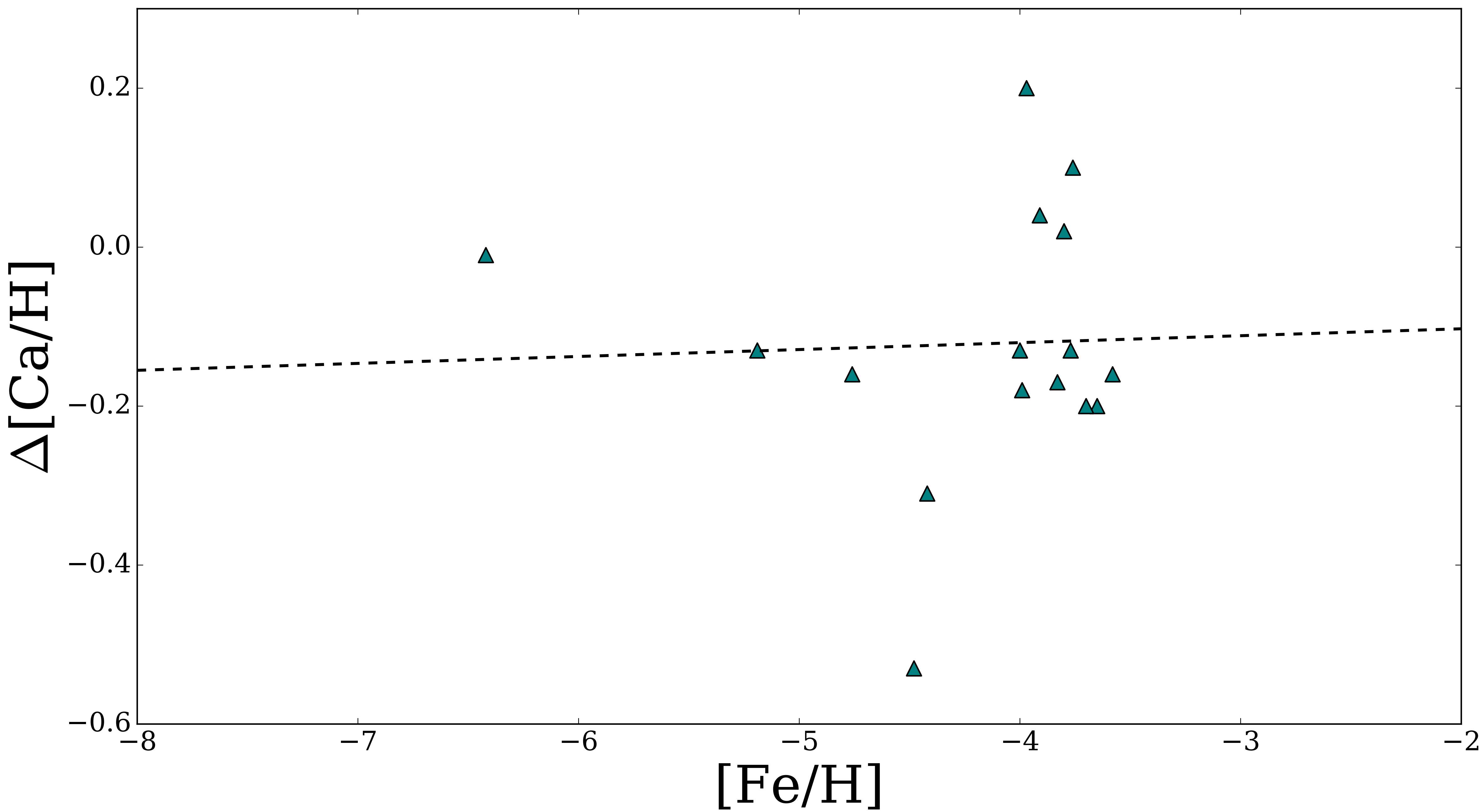
Similarly for Mg

*Ezzeddine et al. 2017c (in prep.)*



… and Ca (with larger scatter)

*Ezzeddine et al. 2017c (in prep.)*



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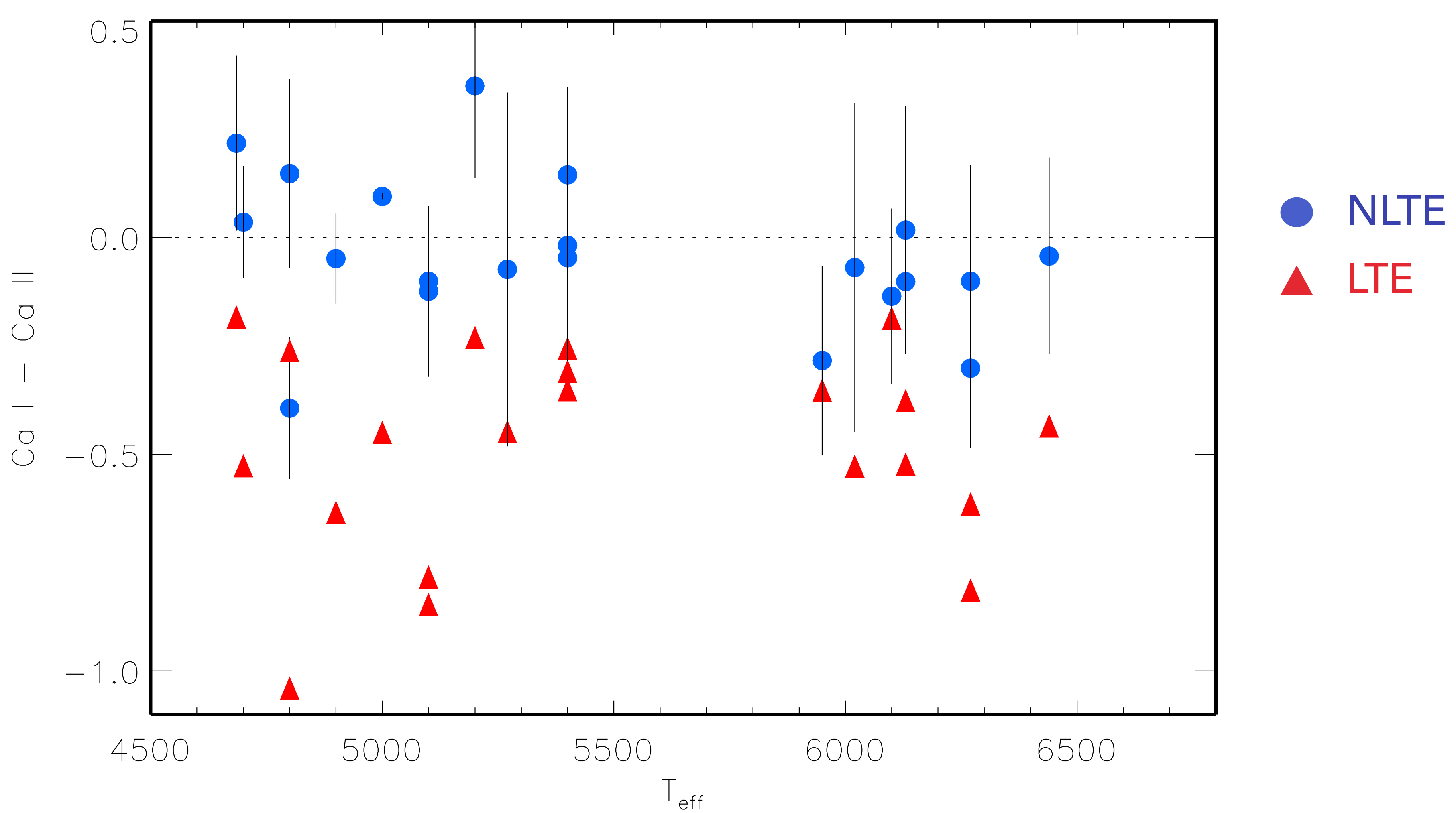
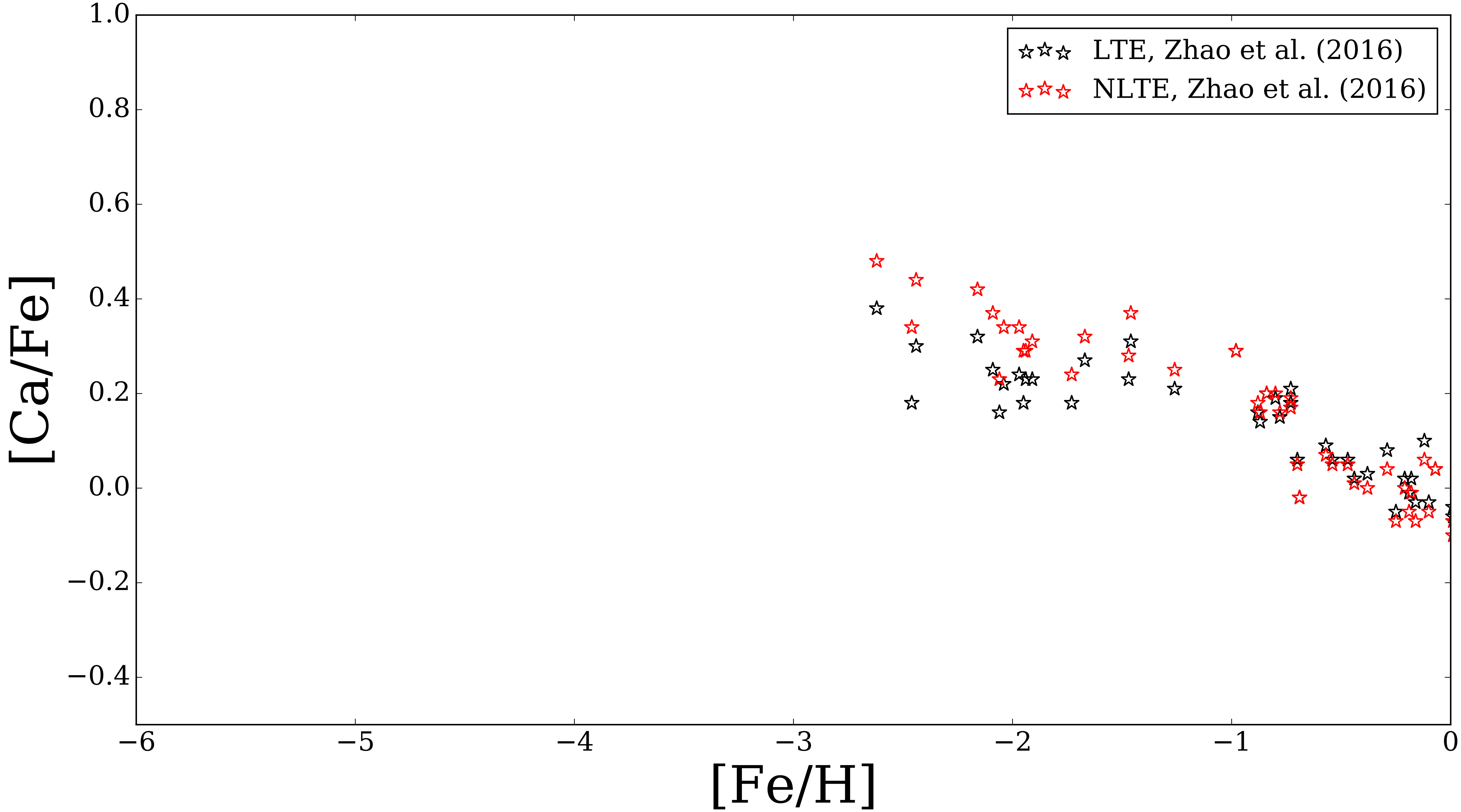



**Better agreement between Ca I and Ca II in NLTE vs. LTE**

*Ezzeddine et al. 2017c (in prep)*



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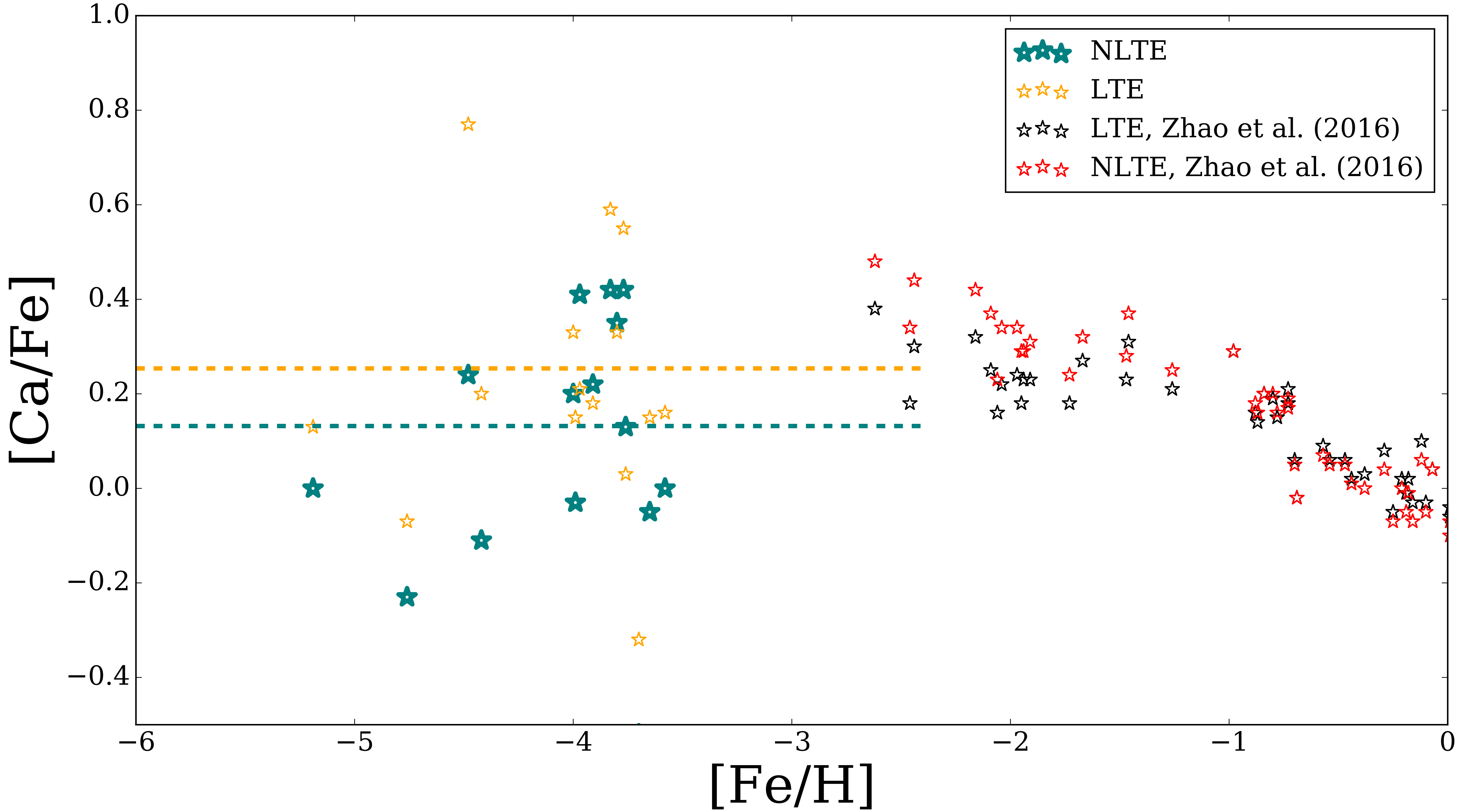

- What are the most Iron-poor stars in the Galaxy?
  - They are relics of Pop III stars, with imprints of their chemical compositions in their atmospheres
- Why are they important & What can we learn from them?
  - They can be used to directly understand and constrain the IMF and properties of Pop III stars and first SN.
  - They give us the opportunity to investigate the chemical evolution and enrichment in the early universe.
  - Accurate modeling of atmospheres in UMP stars (NLTE) is very important