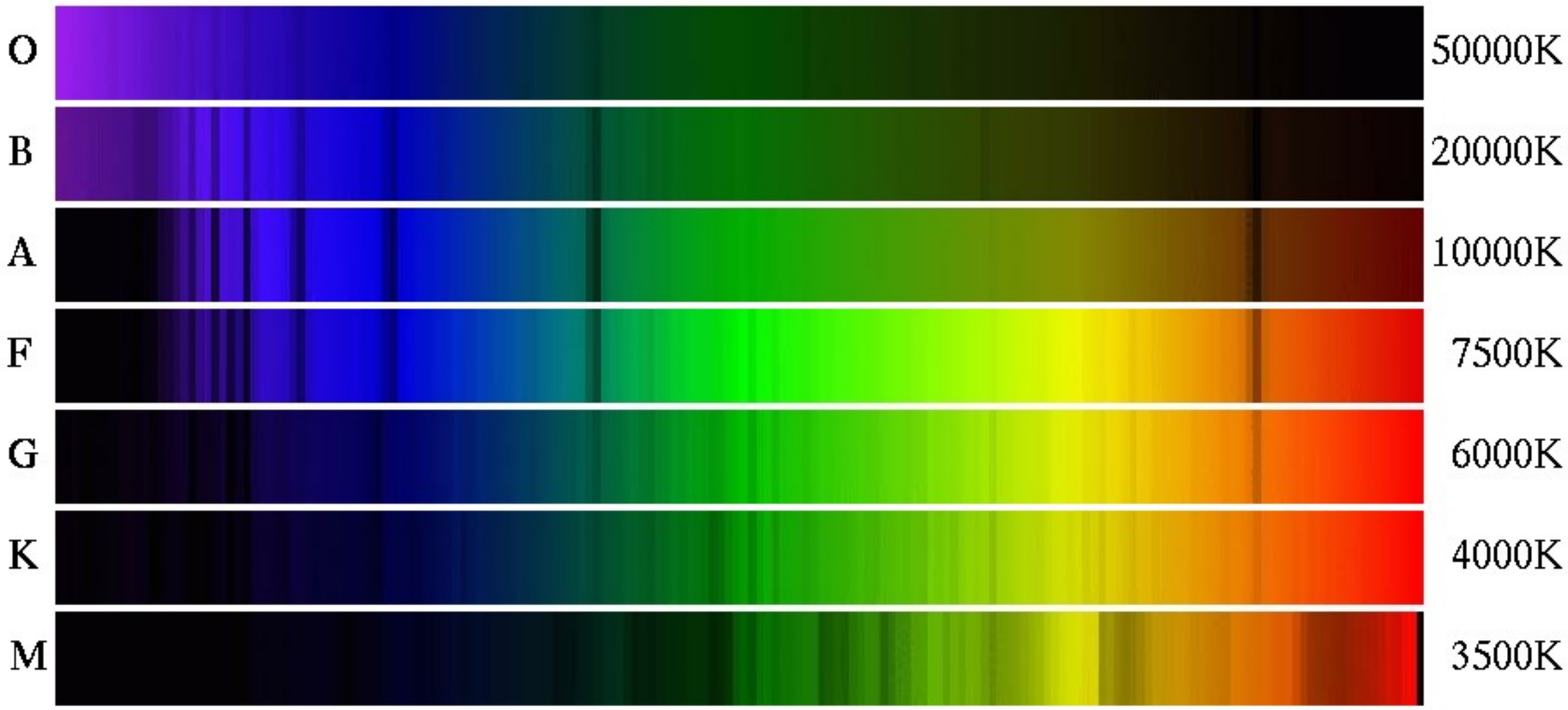
# 3D non-LTE abundances of metal-poor stars

**Anish Amarsi (MPIA)**

Kavli IPMU 3 Dec 2018

# Stellar spectroscopy

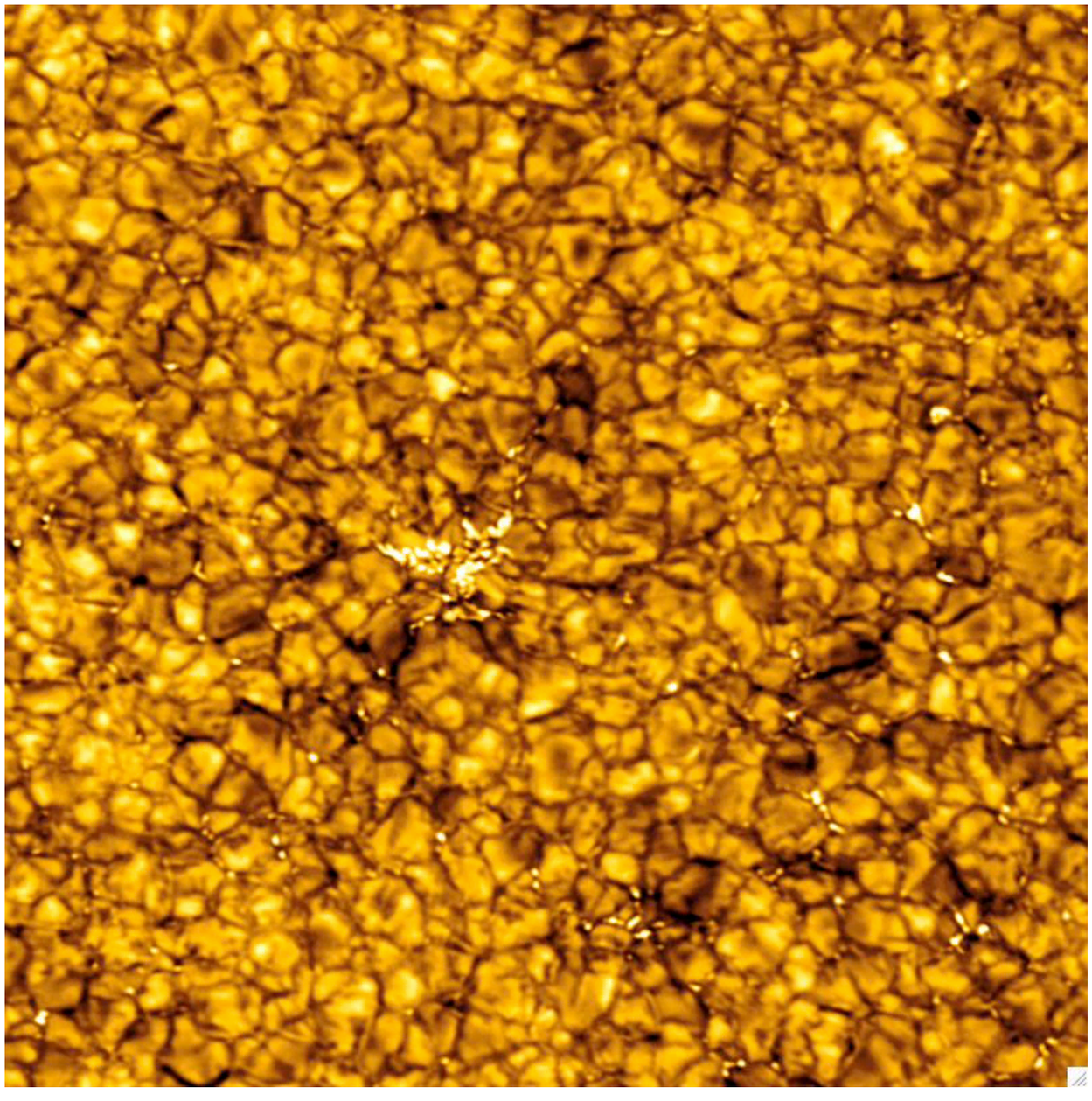



- Information in absorption & emission lines
- Infer stellar **parameters**; **abundances**

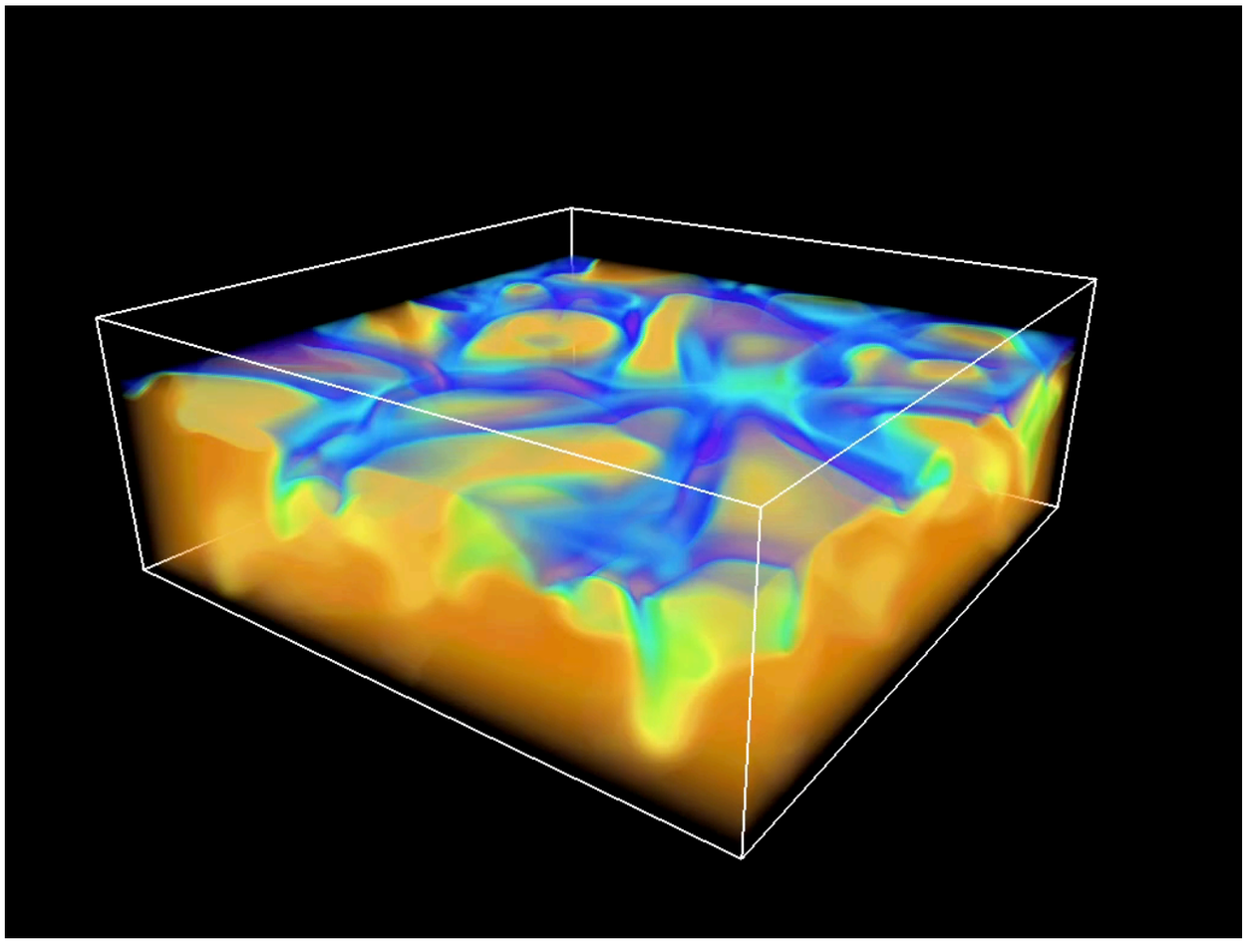
# Stellar spectroscopy


- Prone to **systematic modelling errors**
- 1D vs 3D; LTE vs non-LTE

# 1D vs 3D

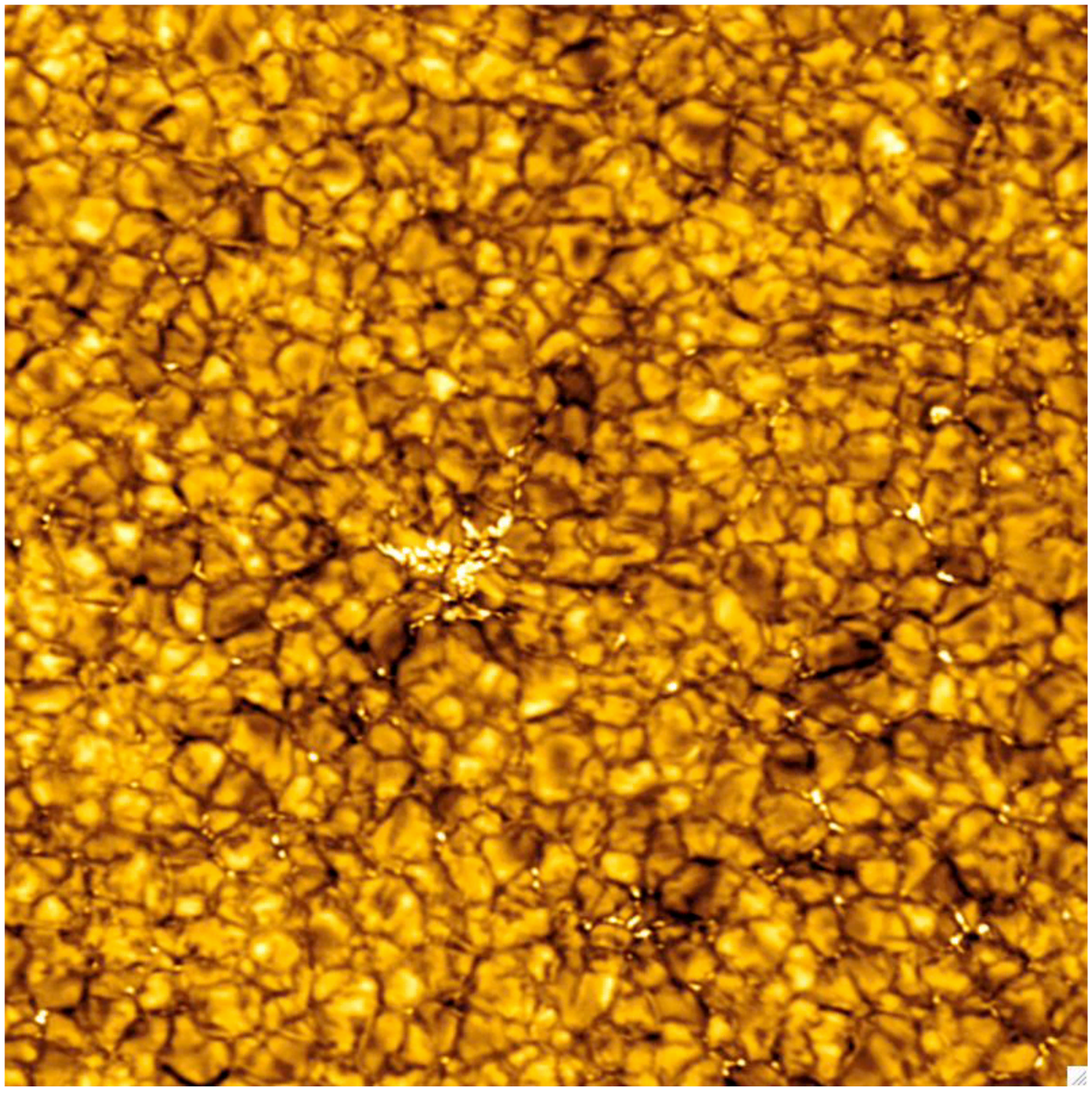


Observations (SST)



3D simulation (Collet+ 2018)

# 1D vs 3D



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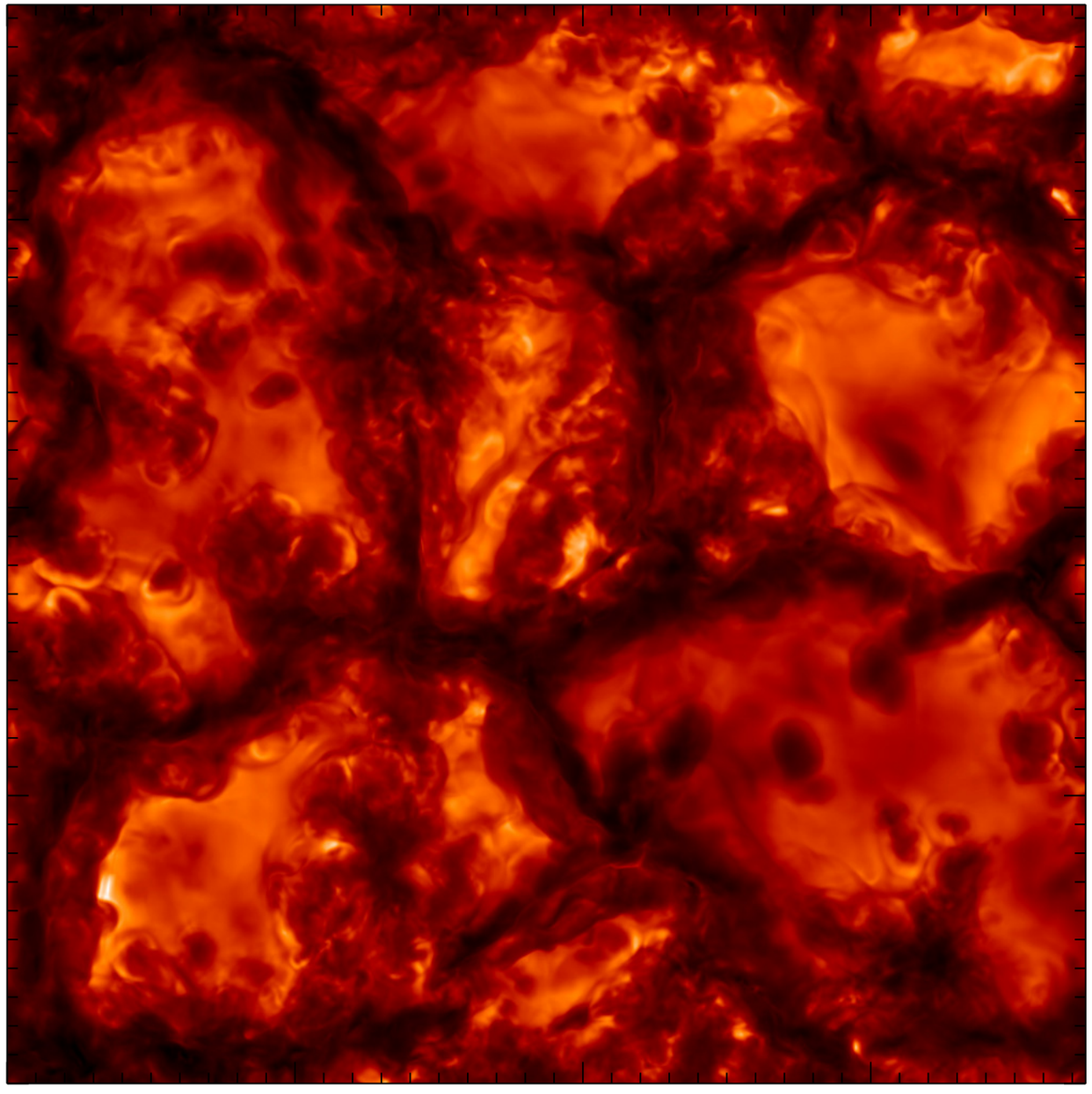

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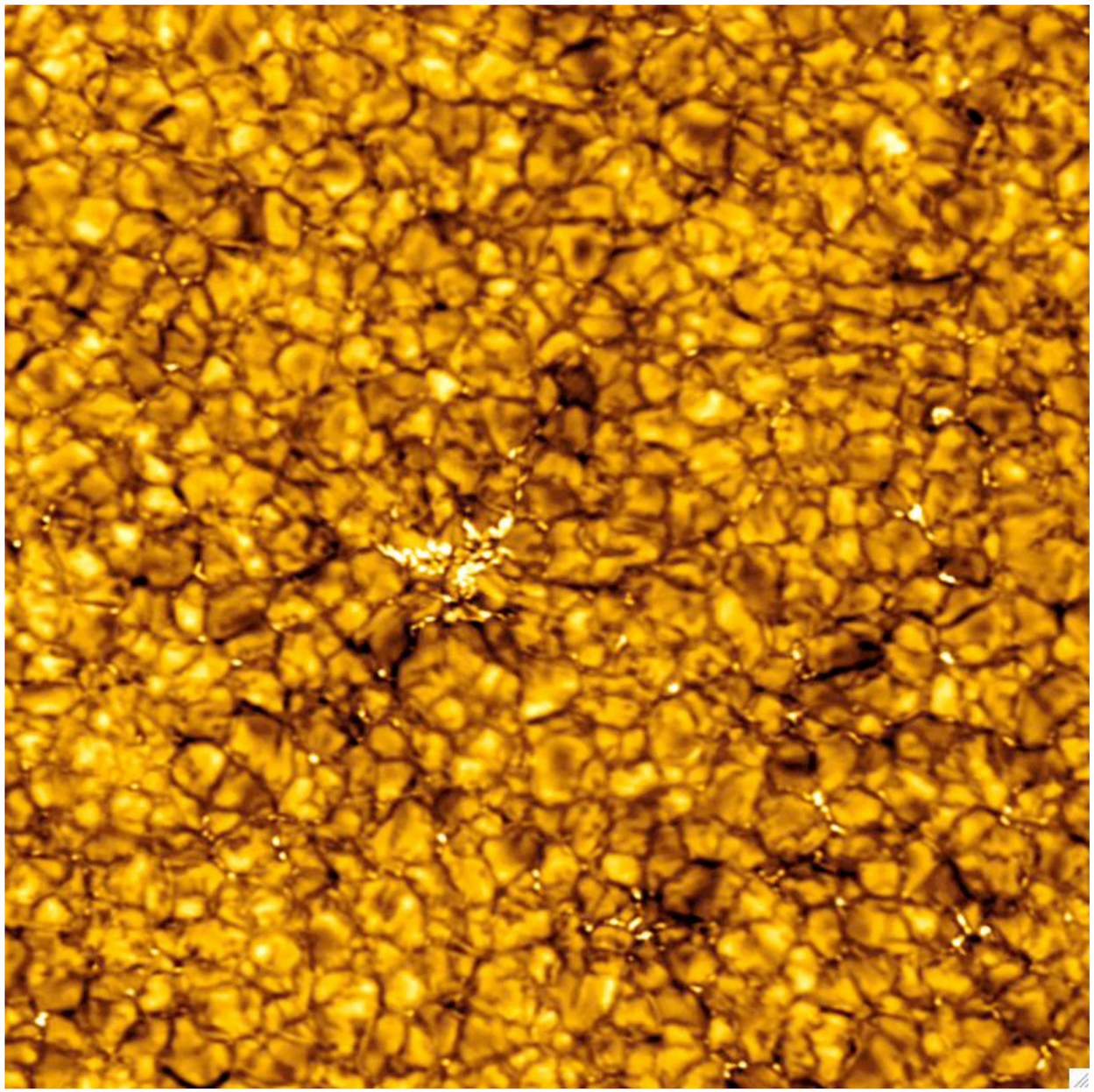
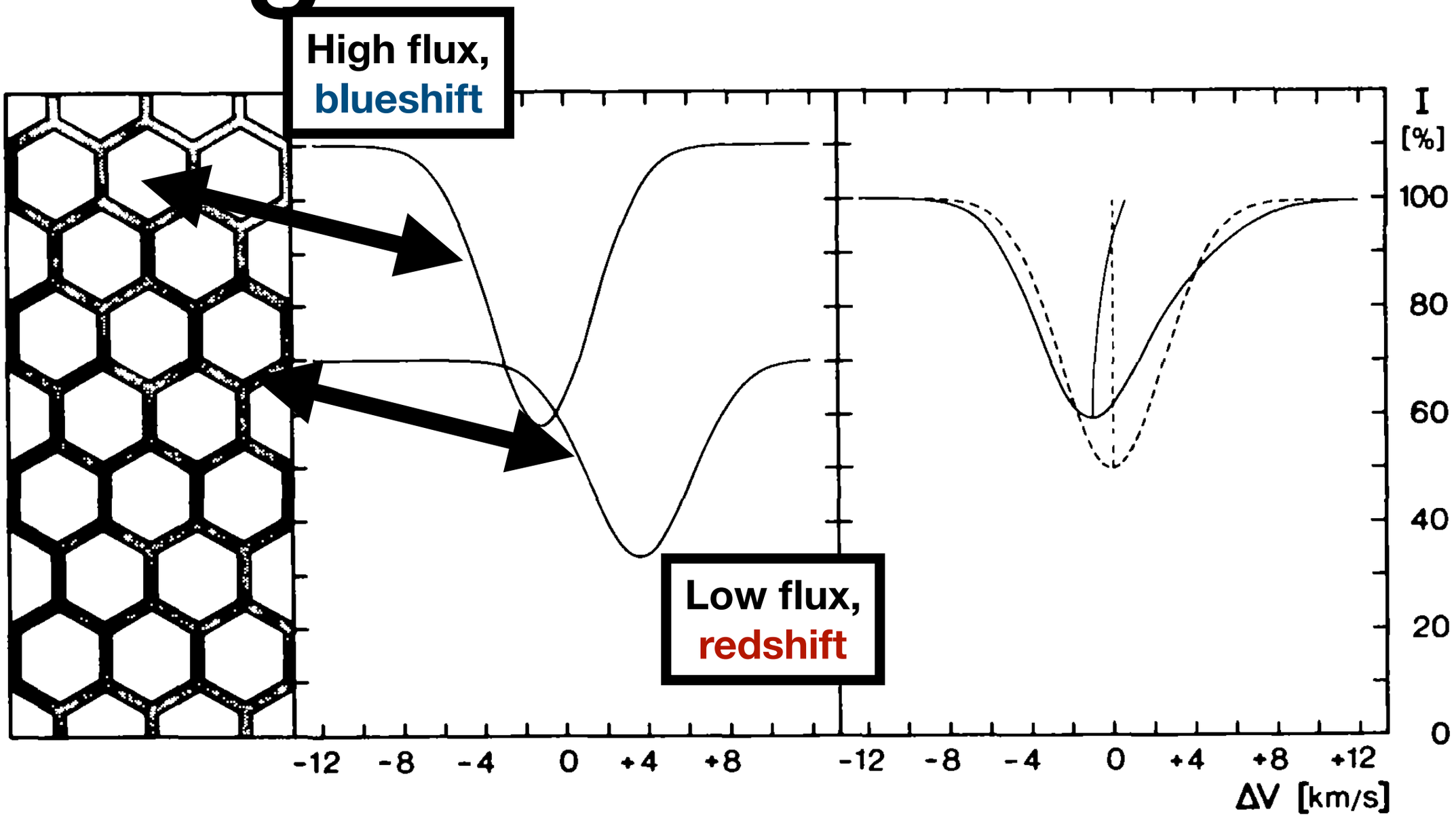


Observations (SST)

1D simulation

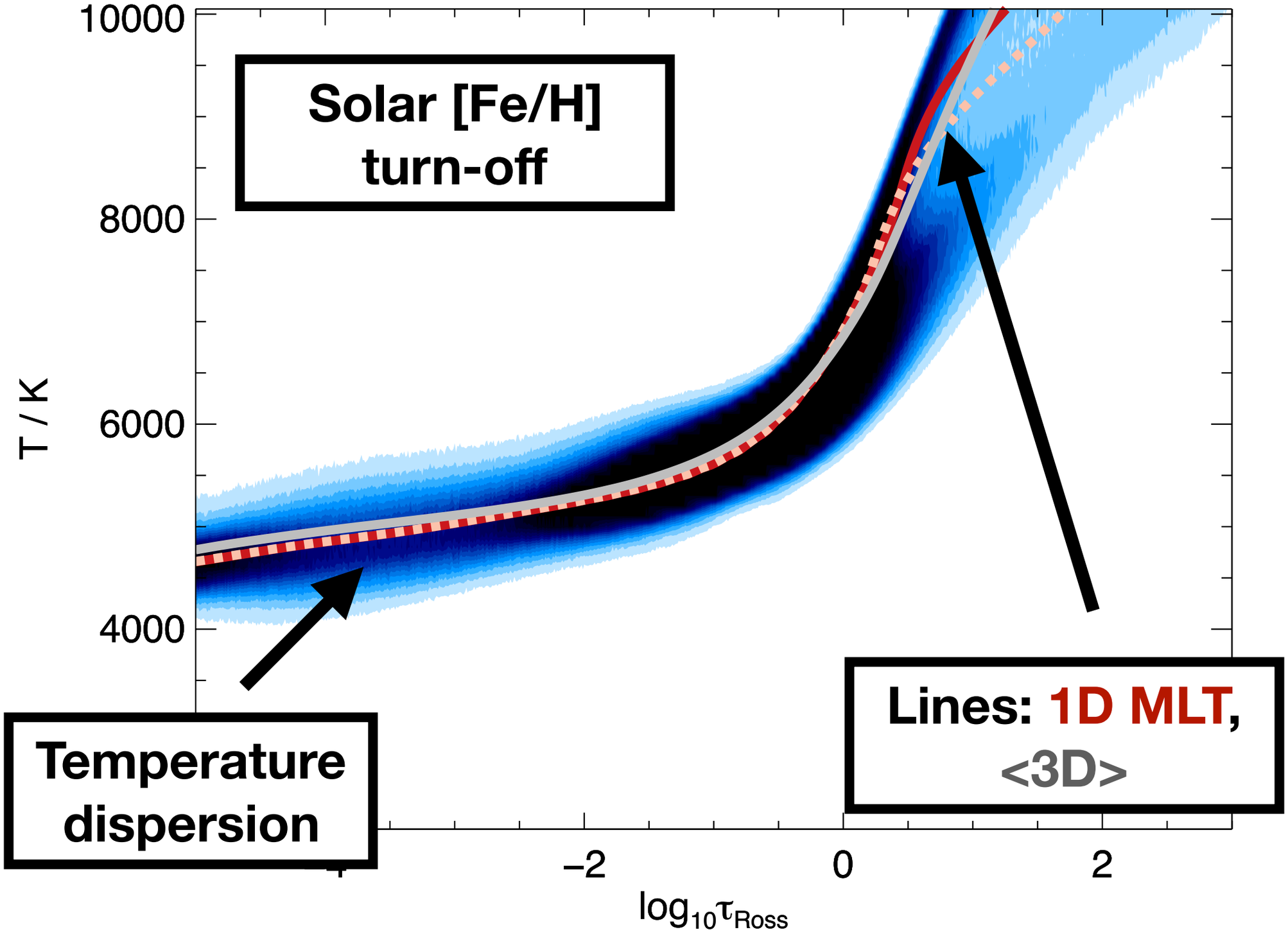
# 3D granulation effects



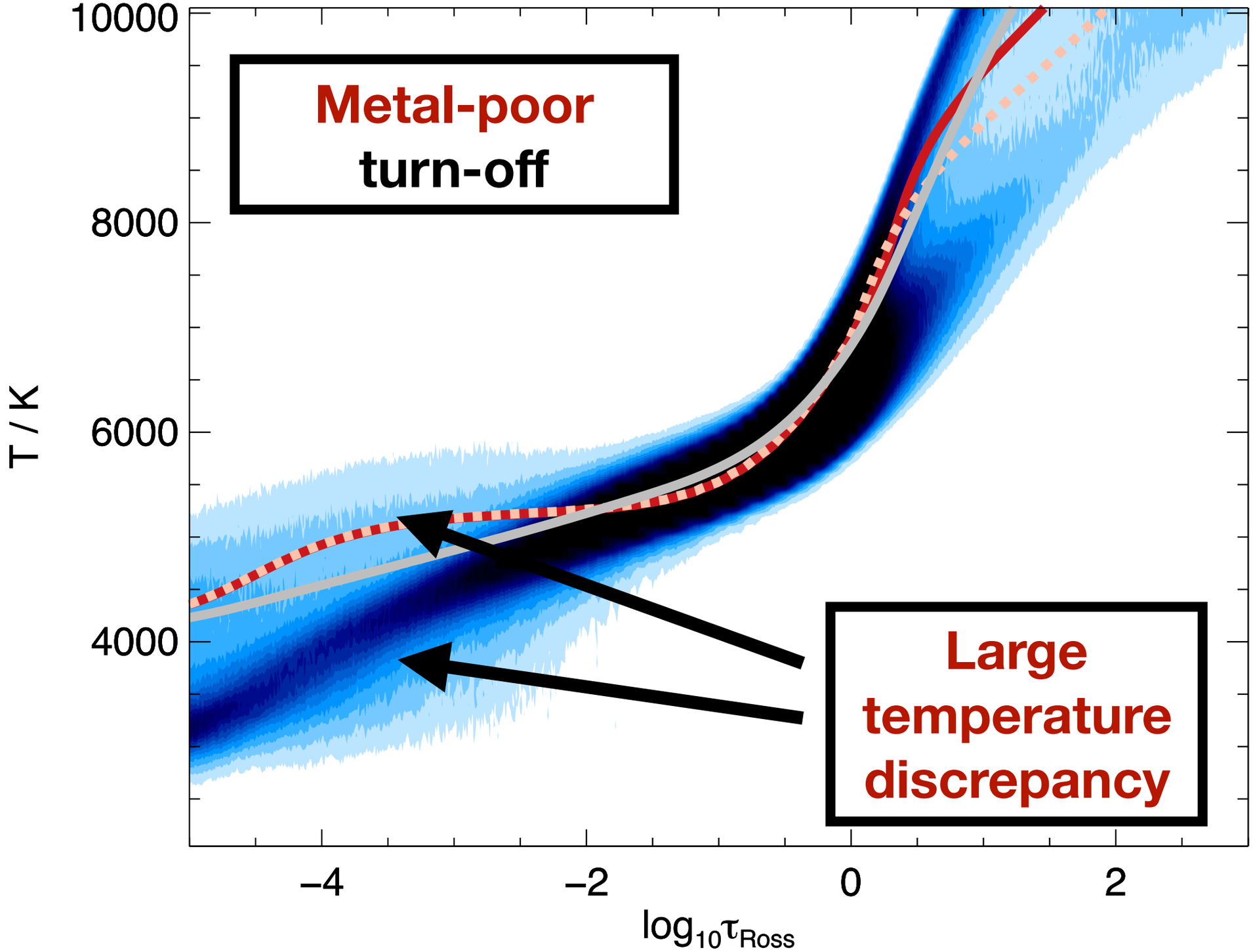

- Line blue shifts, skewing, broadening **Dravins+ 1981**

- **1D**: micro/macro turbulence **fudge parameters**

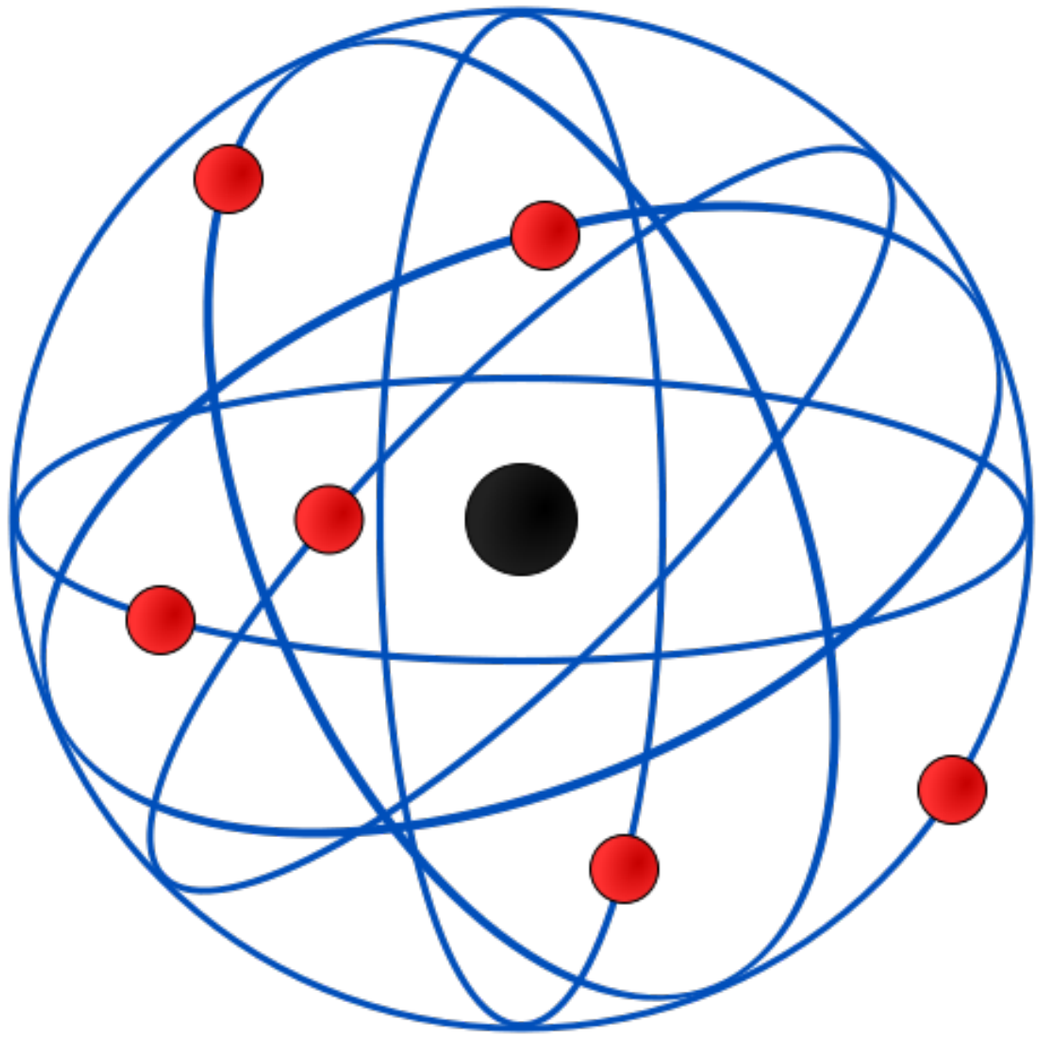
# Mean T: solar


Solar [Fe/H]
turn-off
Temperature
dispersion
Lines: 1D MLT,
<3D>
10000
8000
6000
4000
T / K
–2
0
2
log10τRoss

# Mean T: metal-poor



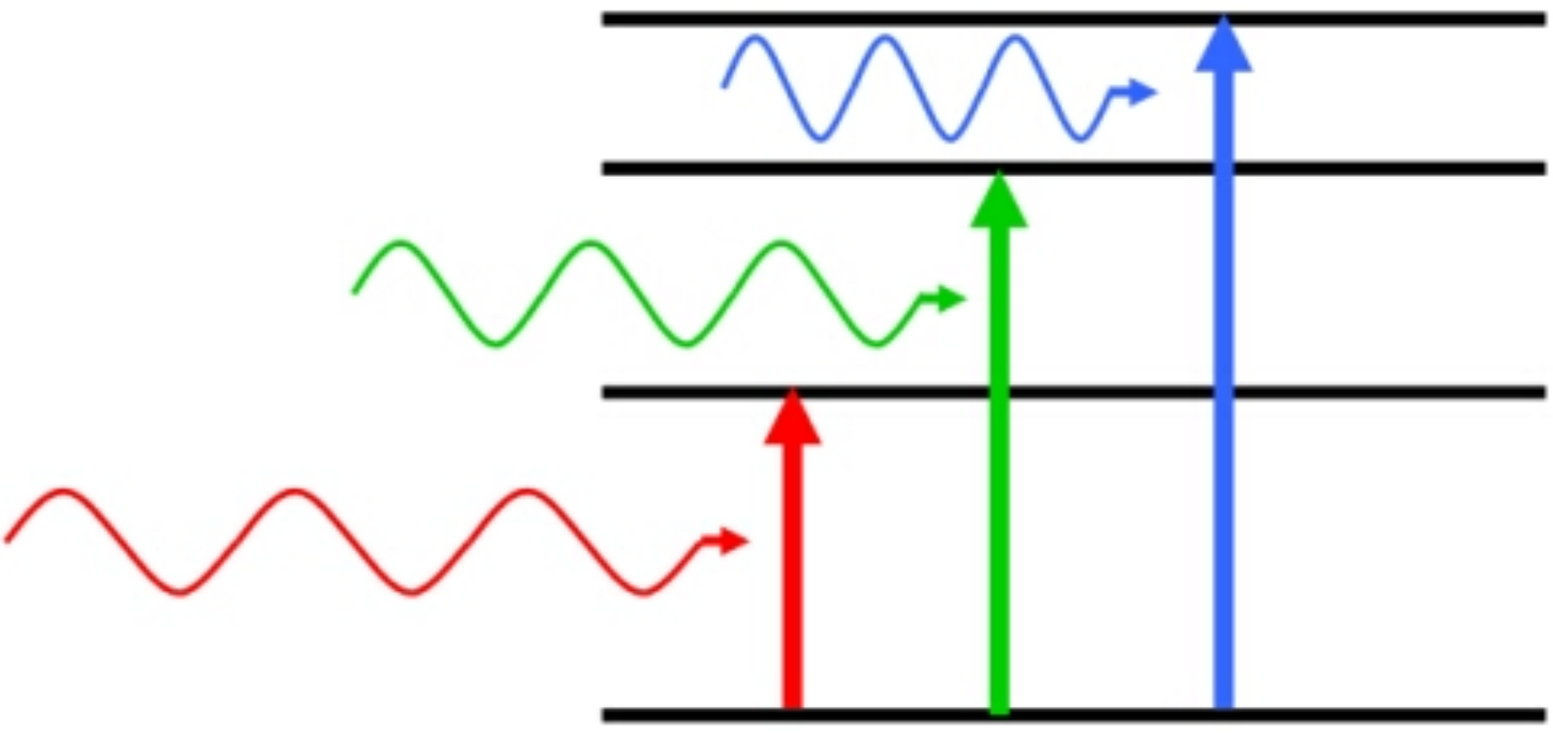
# LTE vs non-LTE



$e^{-\frac{E}{kT}}$ ?

- Need some model for energy partitioning
- Local thermodynamic equilibrium (LTE): **neglect radiation**

# LTE vs non-LTE

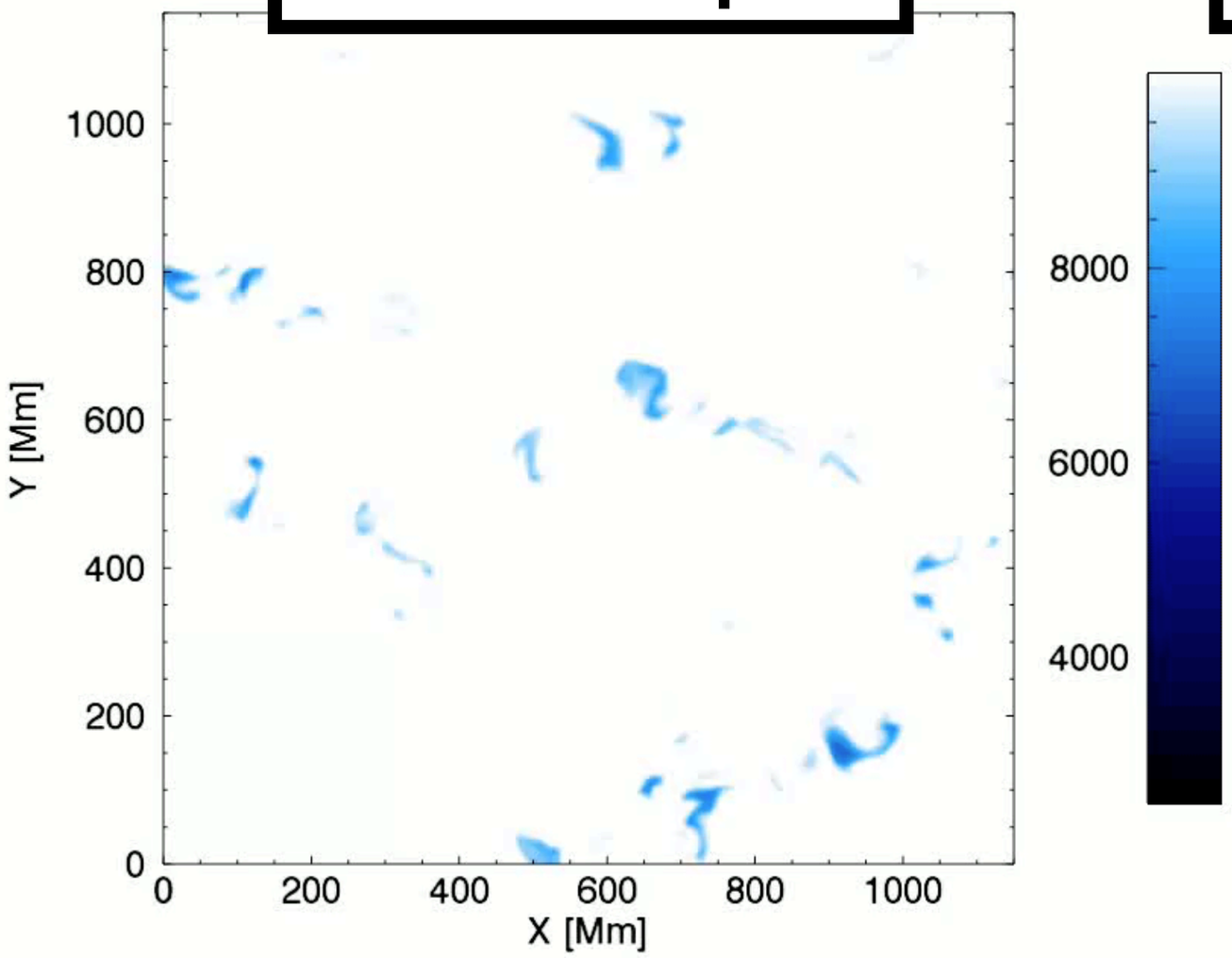


$$e^{-\frac{E}{kT}} \; ?$$

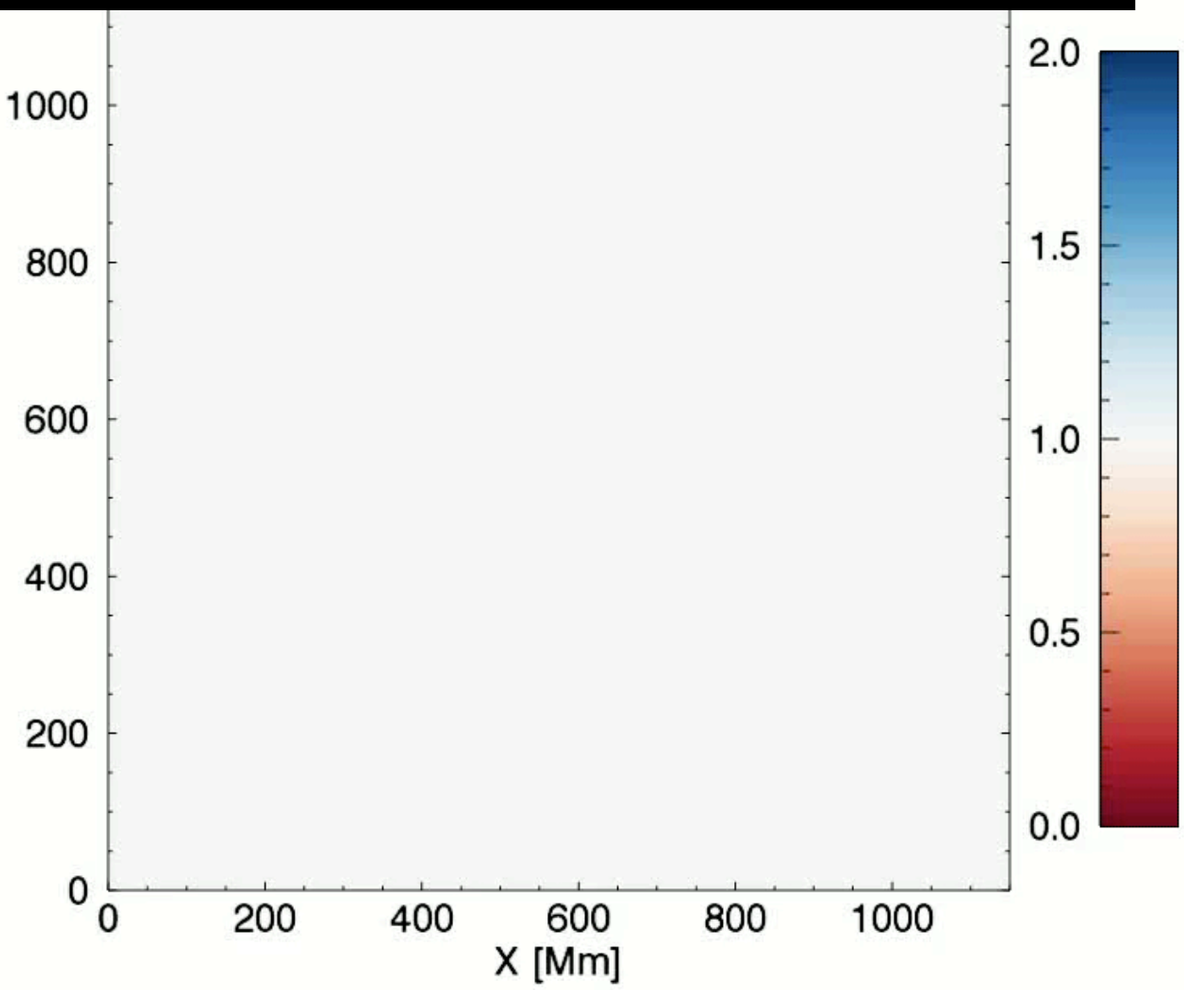
- Need some model for energy partitioning
- Local thermodynamic equilibrium (LTE): **neglect radiation**

# LTE vs non-LTE

**Gas Temp.**




**Radiation Temp. / Gas Temp.**

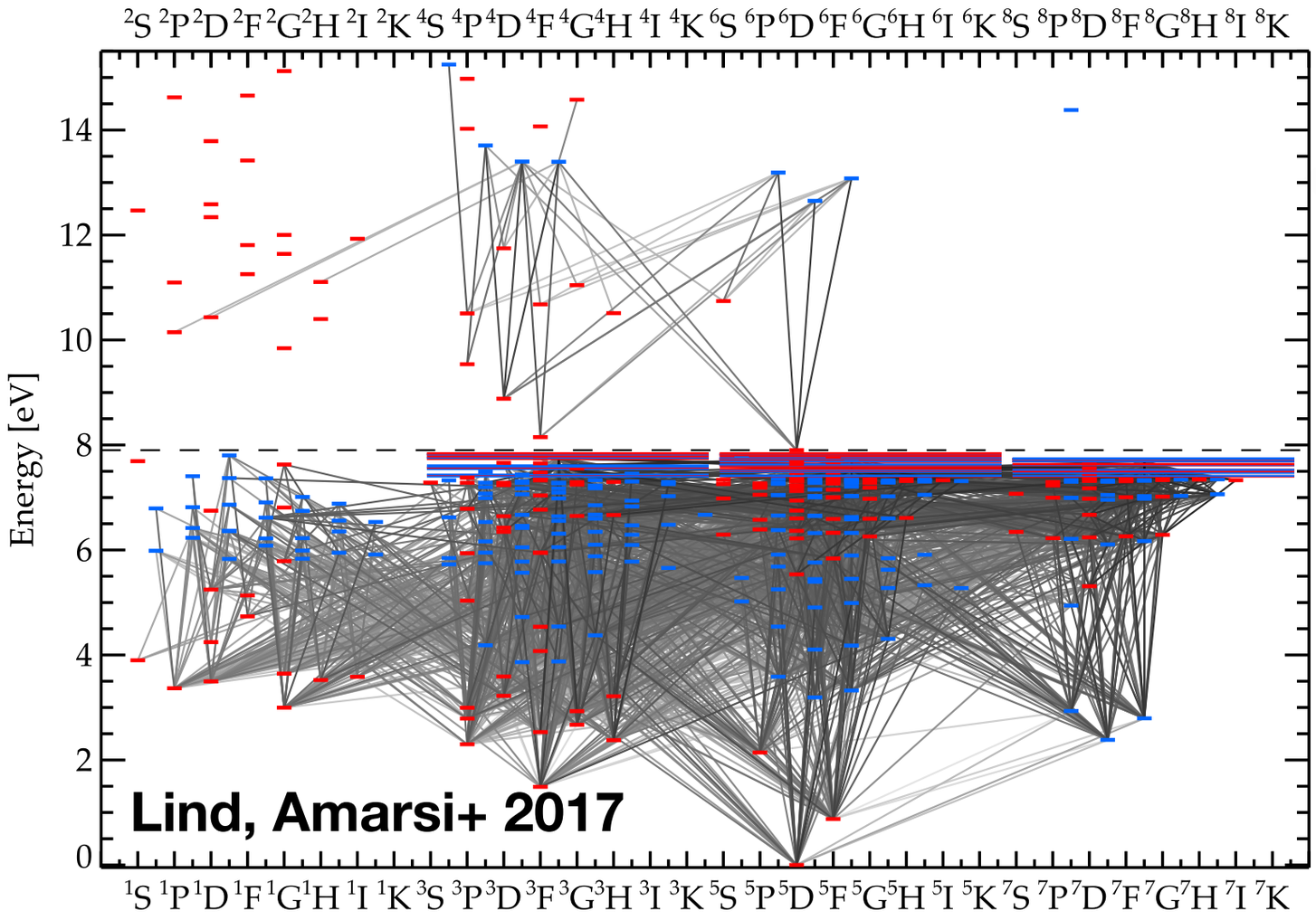


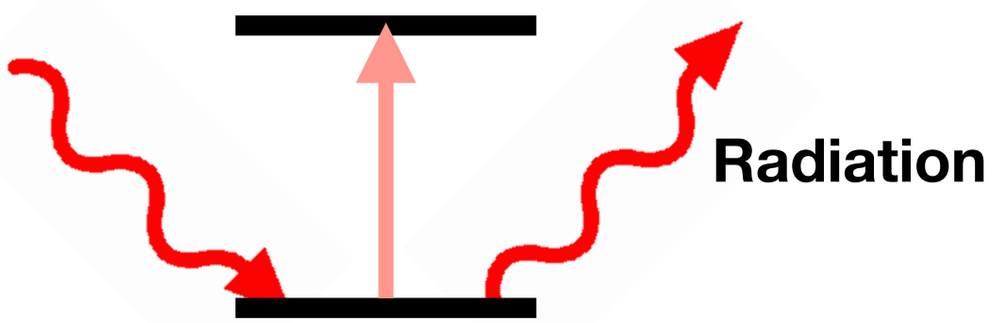

- Non-thermal radiation field

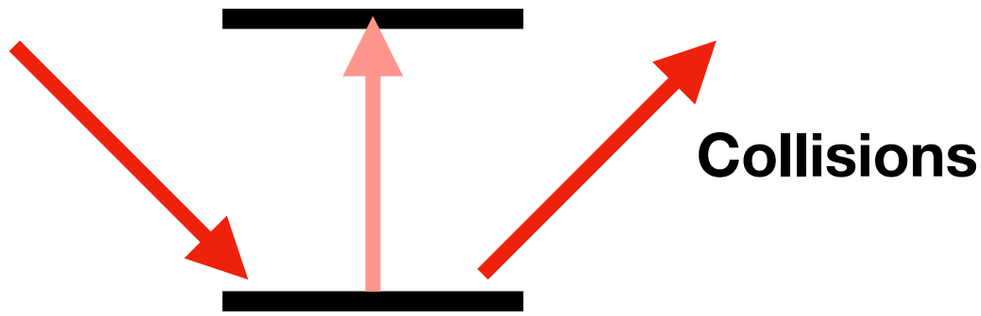
**movie credit: T. Nordlander**

- Variation with granulation features ==> **3D non-LTE**

# Non-LTE model atoms

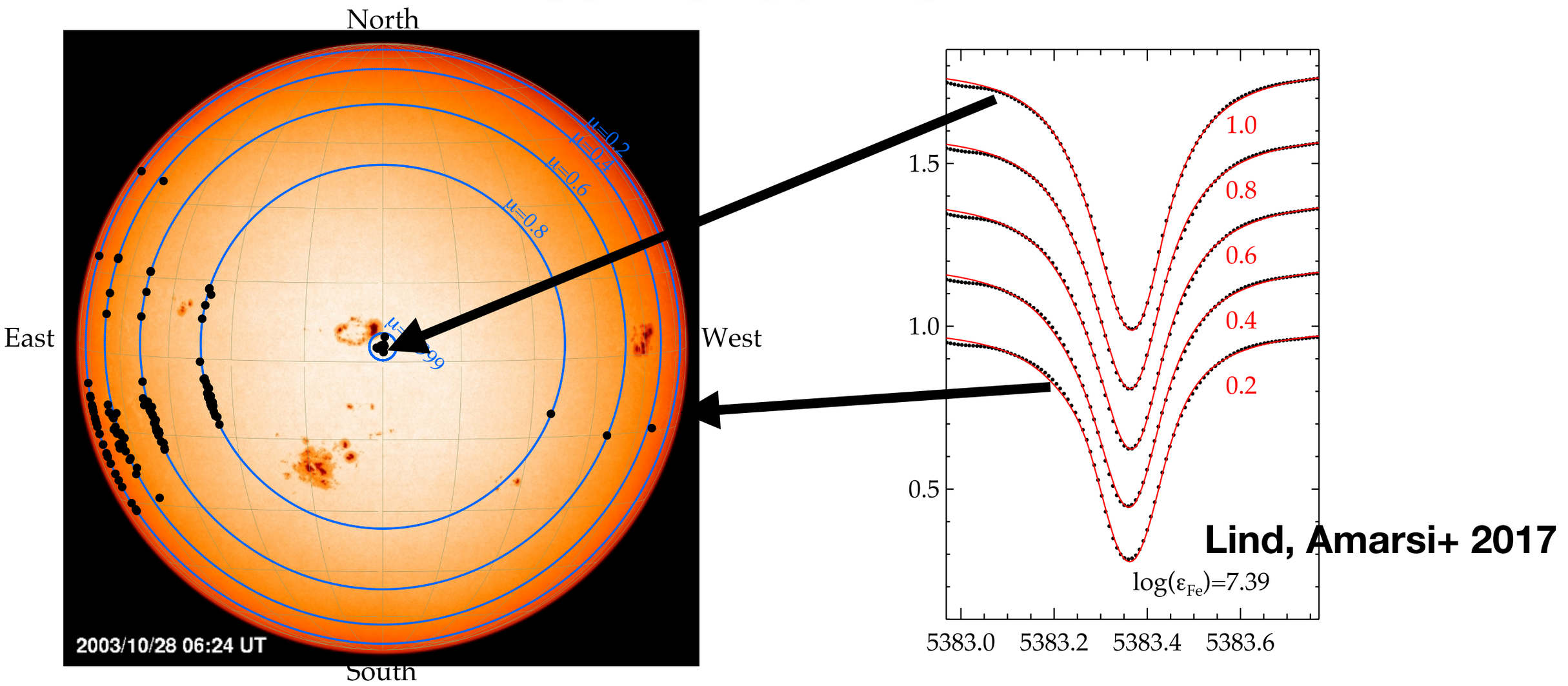



- Ongoing work on improving **atomic data** and building **realistic model atoms**

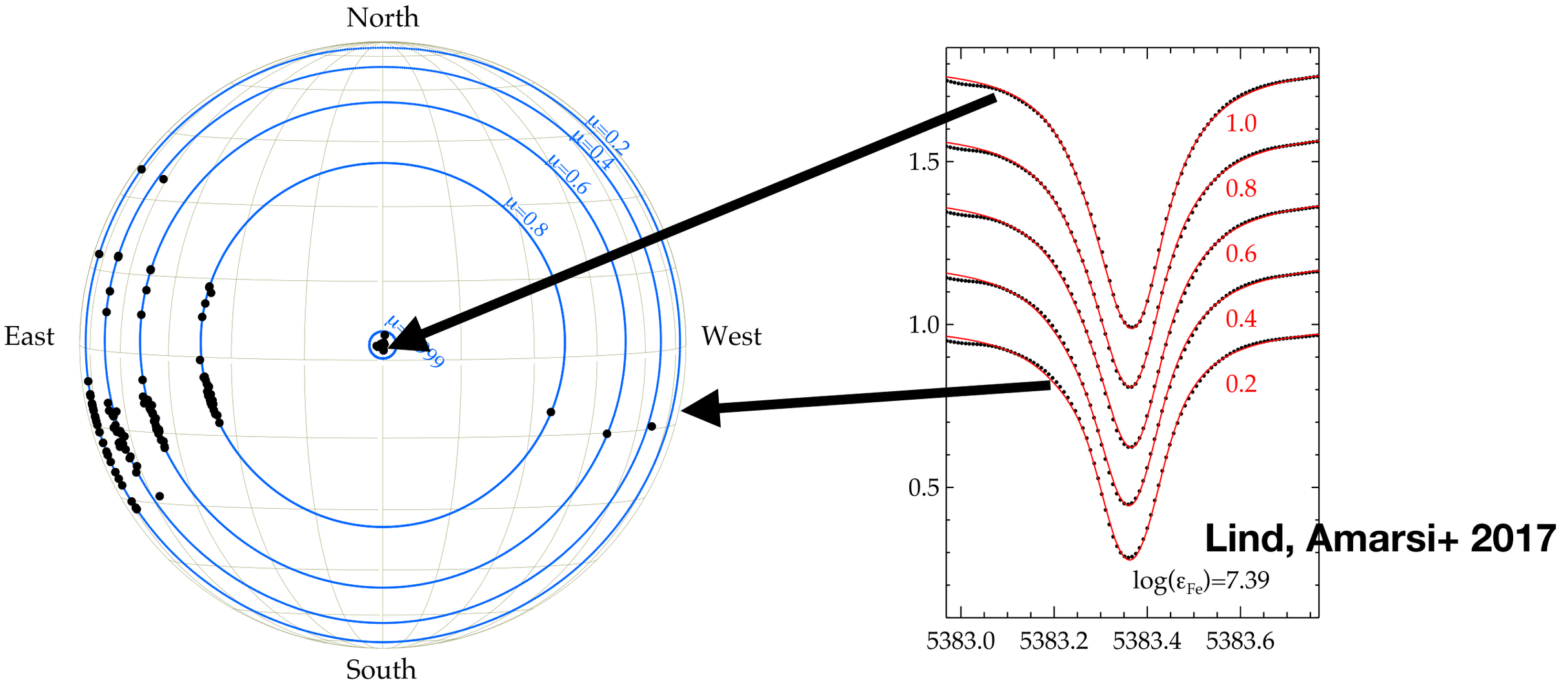
# Validation




- Test on Sun and on benchmark stars (CLV; excitation/ ionisation balance) — e.g. Pereira+2013, Amarsi+2016

- As good or better than **1D/LTE**, **w/o free parameters**

# Validation



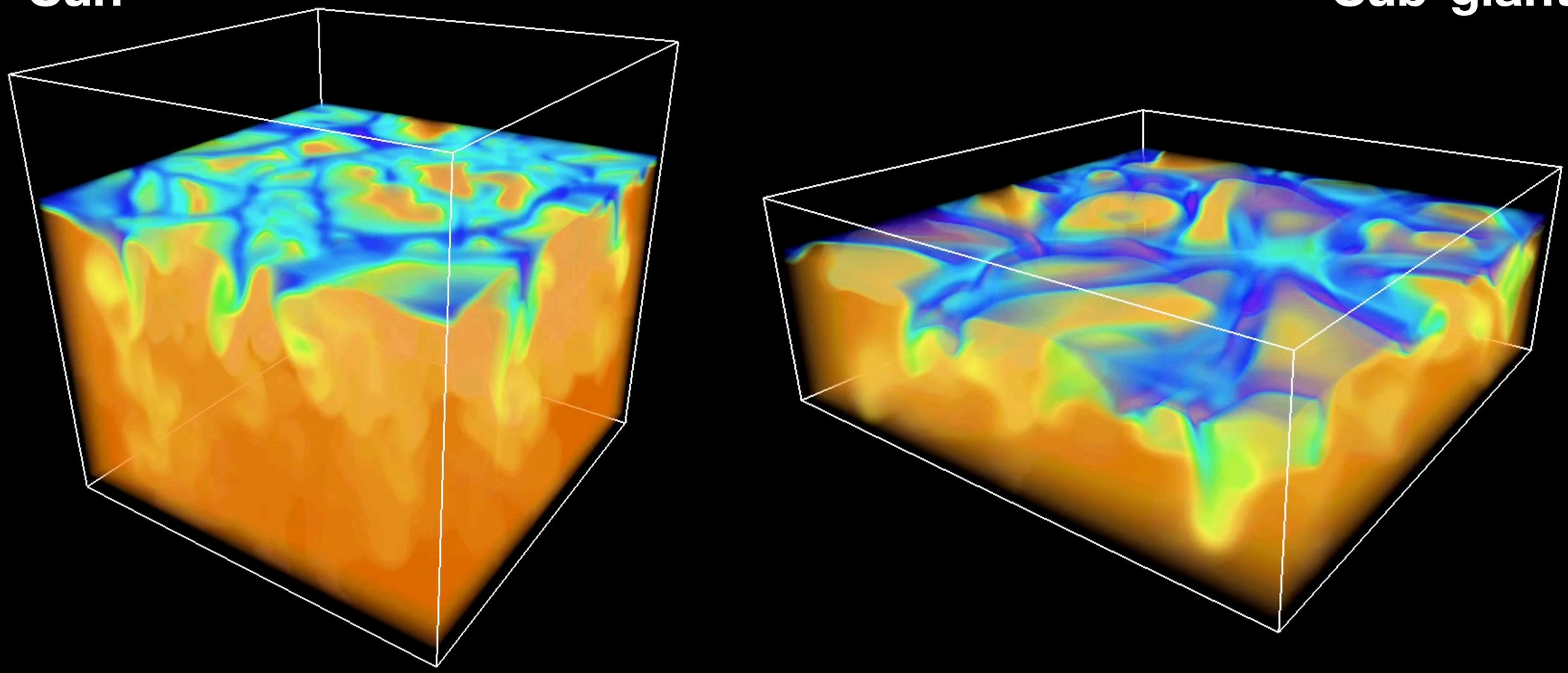

- Test on Sun and on benchmark stars (CLV; excitation/ ionisation balance) — e.g. Pereira+2013, Amarsi+2016

- As good or better than **1D/LTE**, **w/o free parameters**

# Stagger code

**Sun**

**Sub-giant**

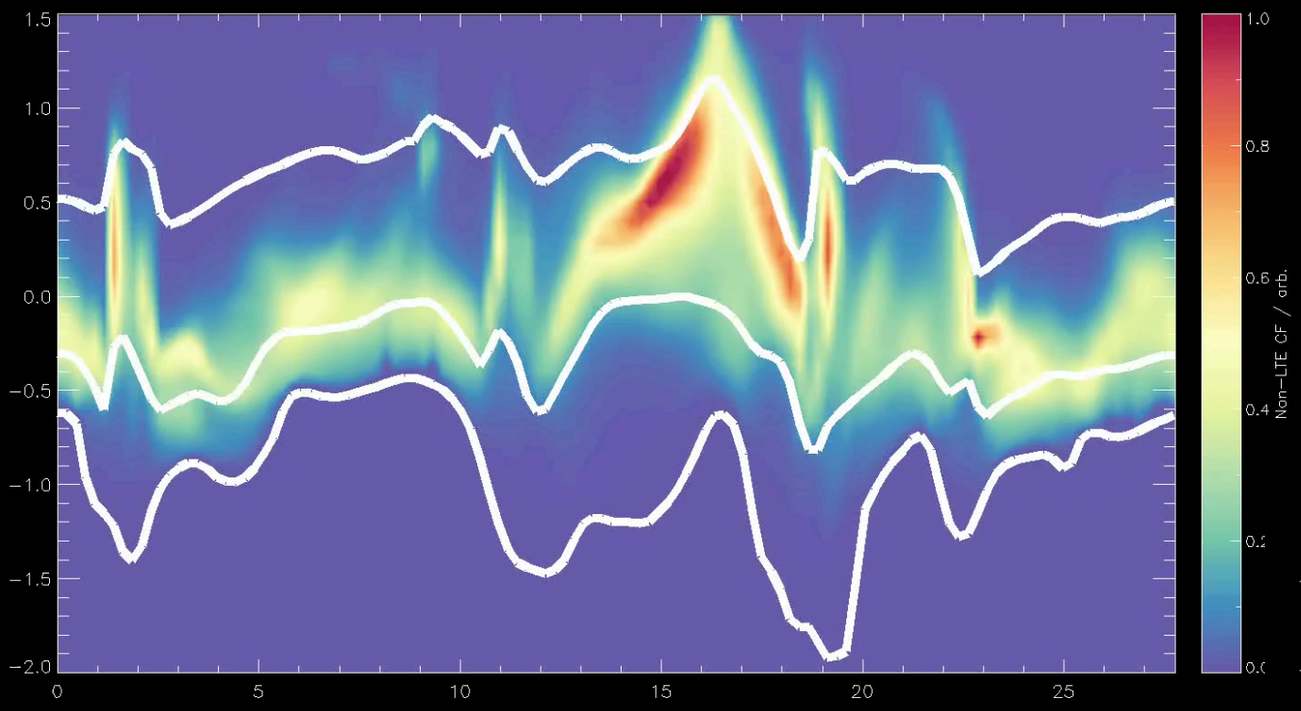


**movie credit: R. Collet**

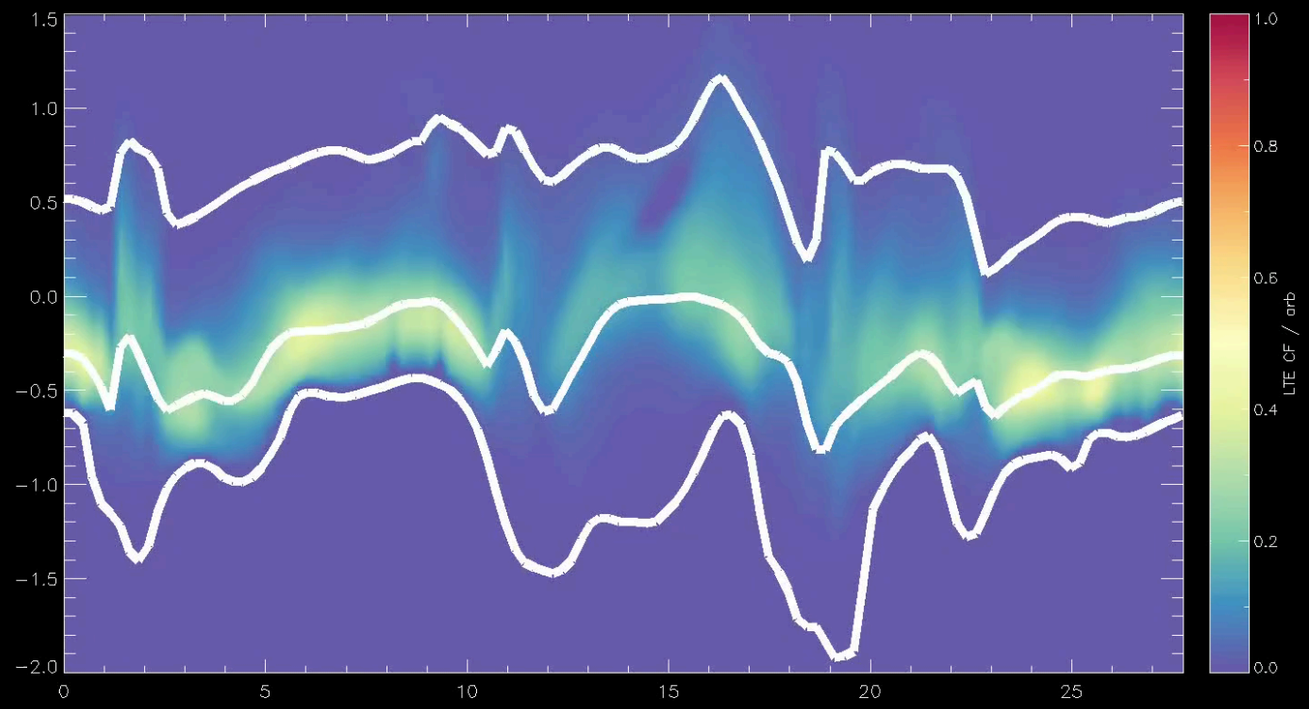
- 3D (magneto-)hydrodynamics
- 3D LTE radiative transfer with opacity binning

# Balder code

## Non-LTE contribution



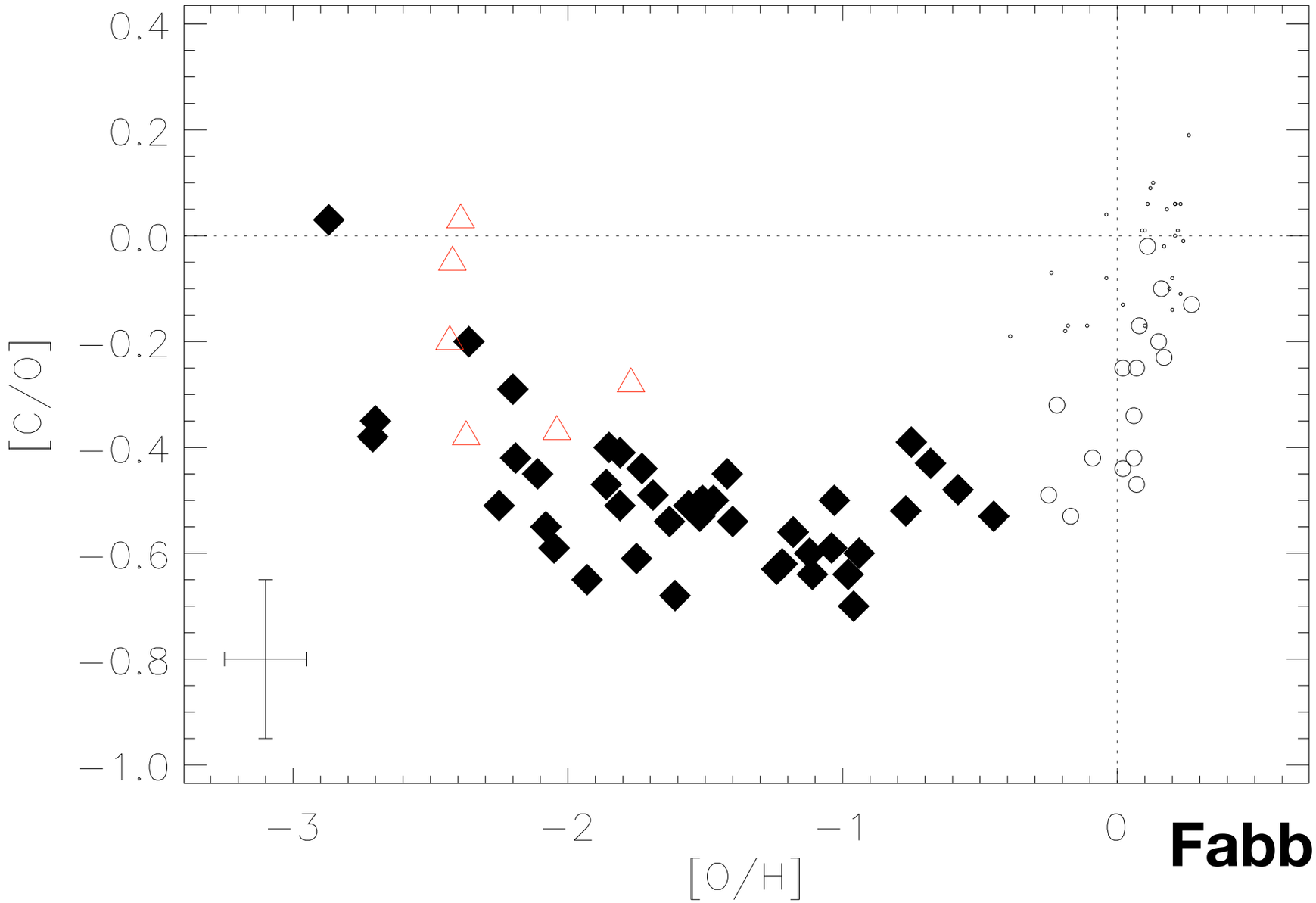

- 3D multi-level non-LTE radiative transfer
- ALI algorithm (R&H 1992)
- Updated background opacities
- Efficient MPI parallelisation




## LTE contribution

# Carbon, oxygen, and iron

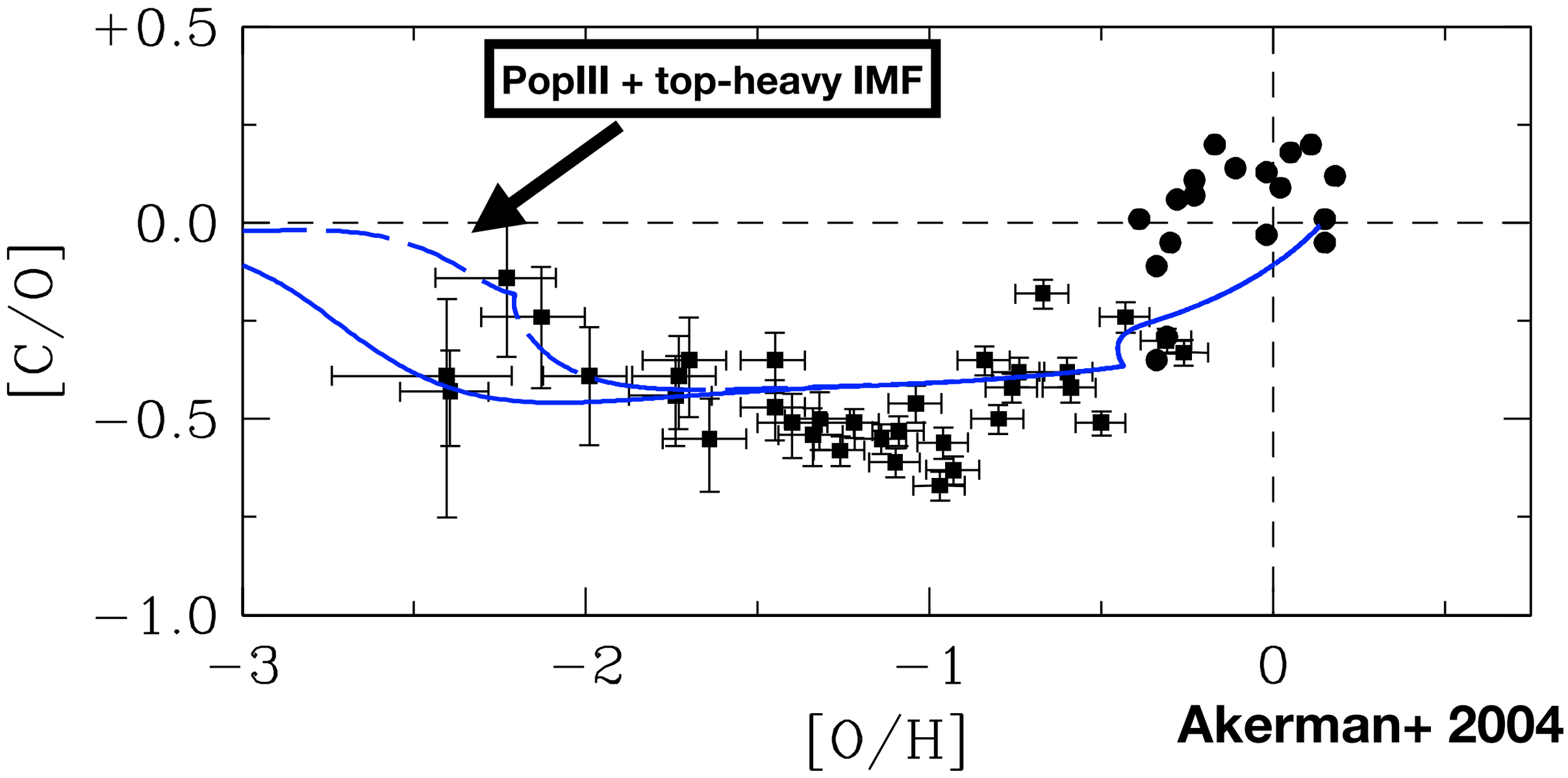
# [C/O] vs [O/H]




**Fabbian+ 2009**

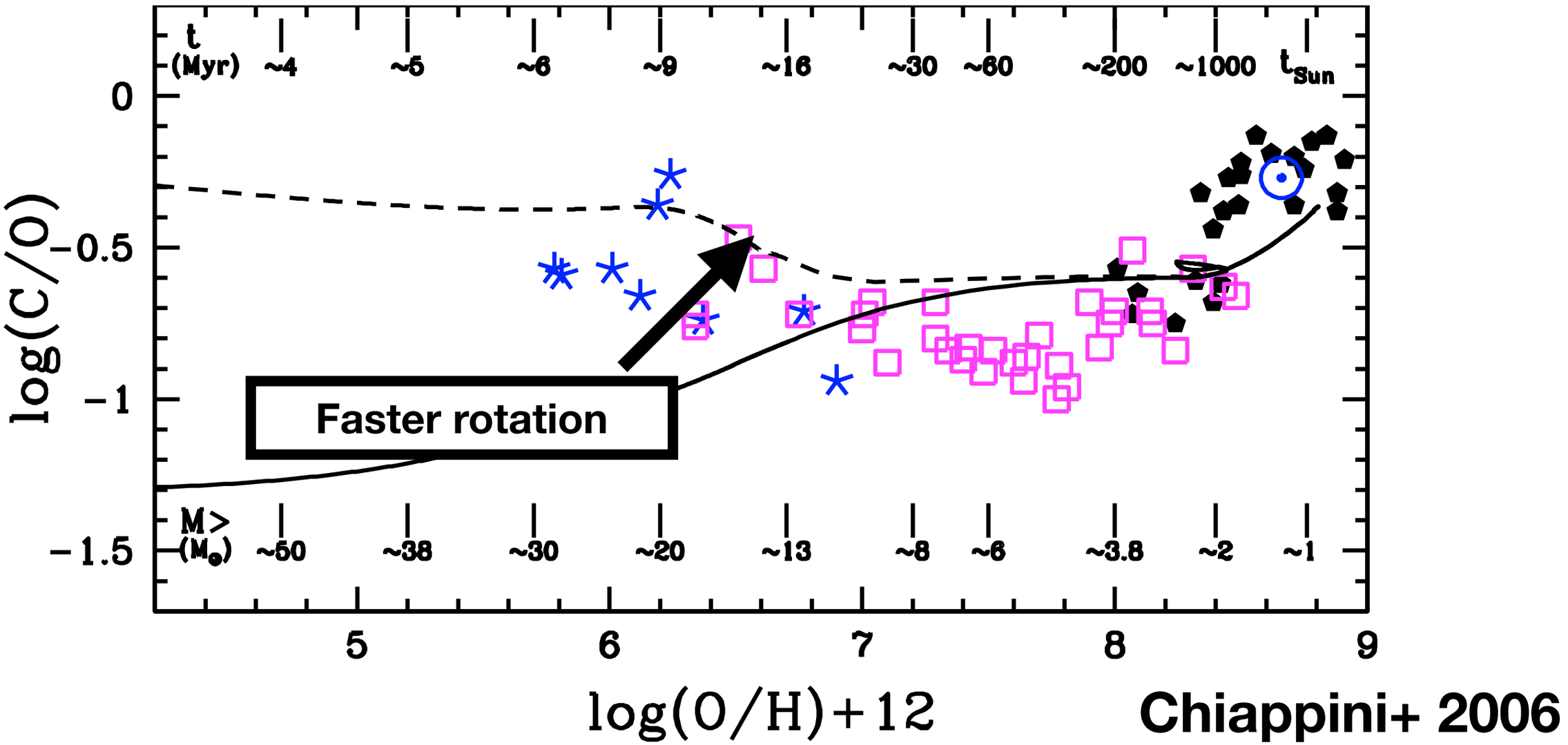
- Reported upturn at low [O/H]

# [C/O] vs [O/H]




- Upturn at low [O/H] ==> Pop. III signature?

# [C/O] vs [O/H]

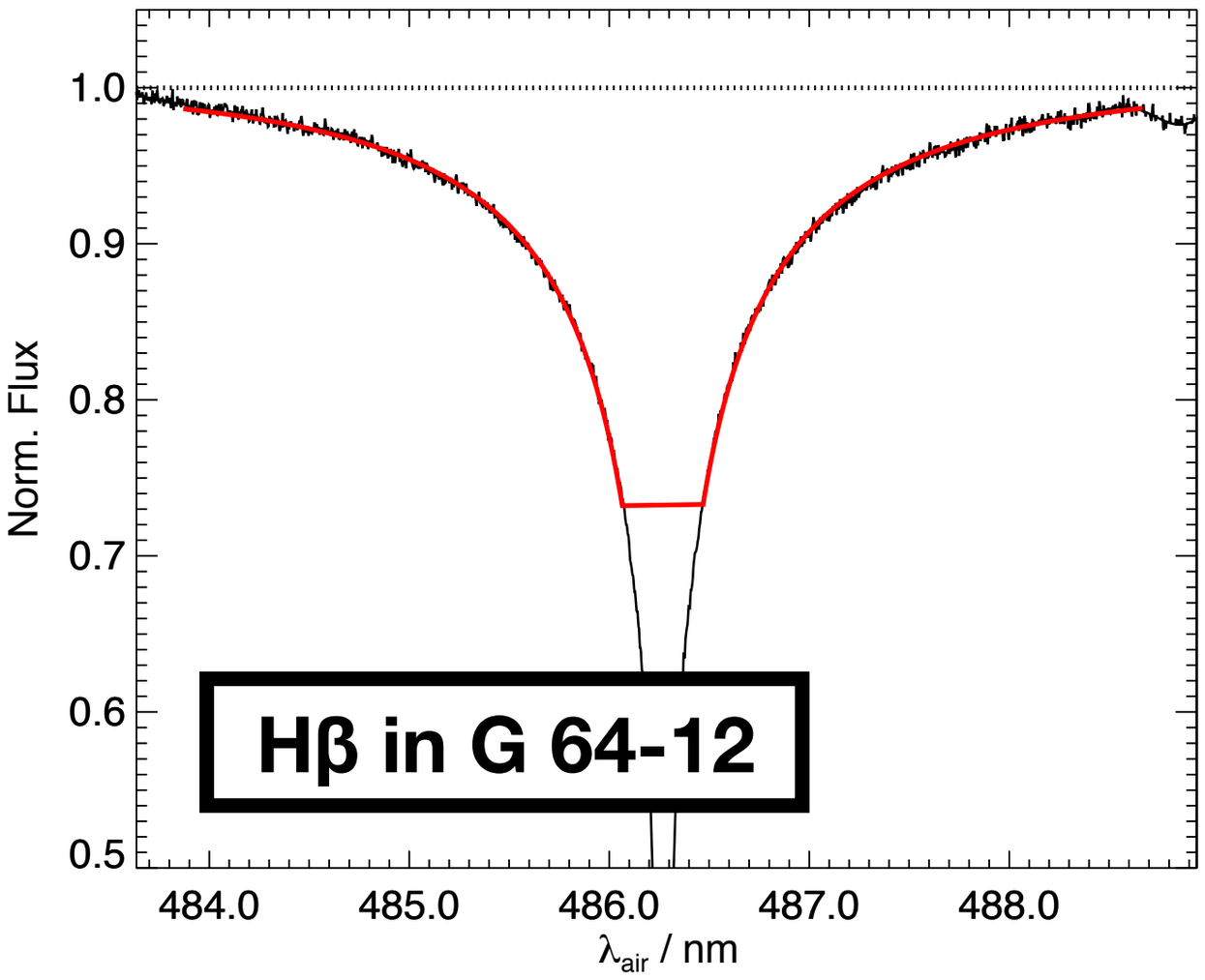


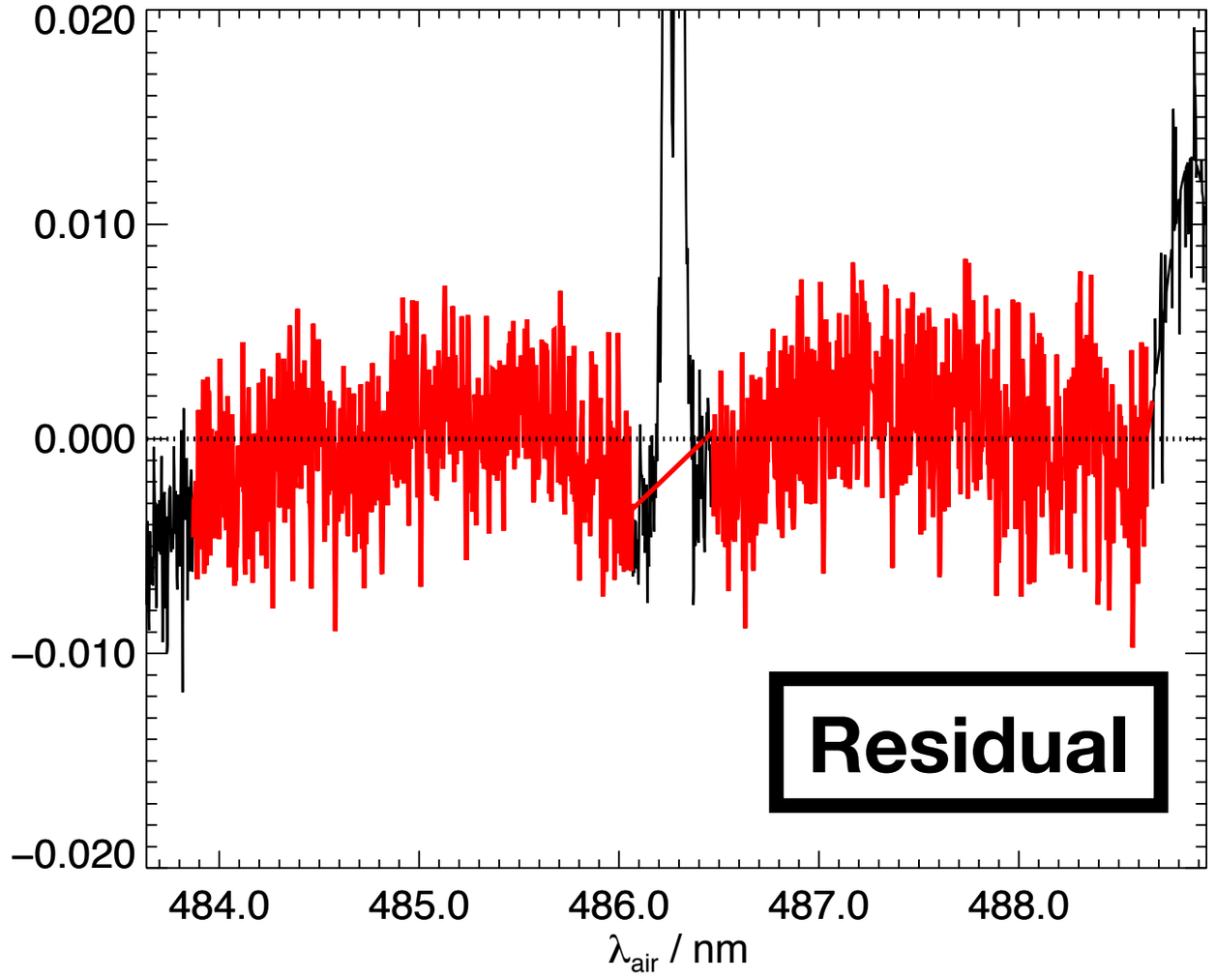

- Or, faster-rotating stars at lower [O/H]?

# Revisiting [C/O] vs [O/H]

- We carry out a “**full**” 3D non-LTE re-analysis
- Stellar parameters **and** abundances based on 3D non-LTE
- 40 metal-poor turn-off halo stars (Nissen+ 2007)
- Easy to replicate method to larger samples

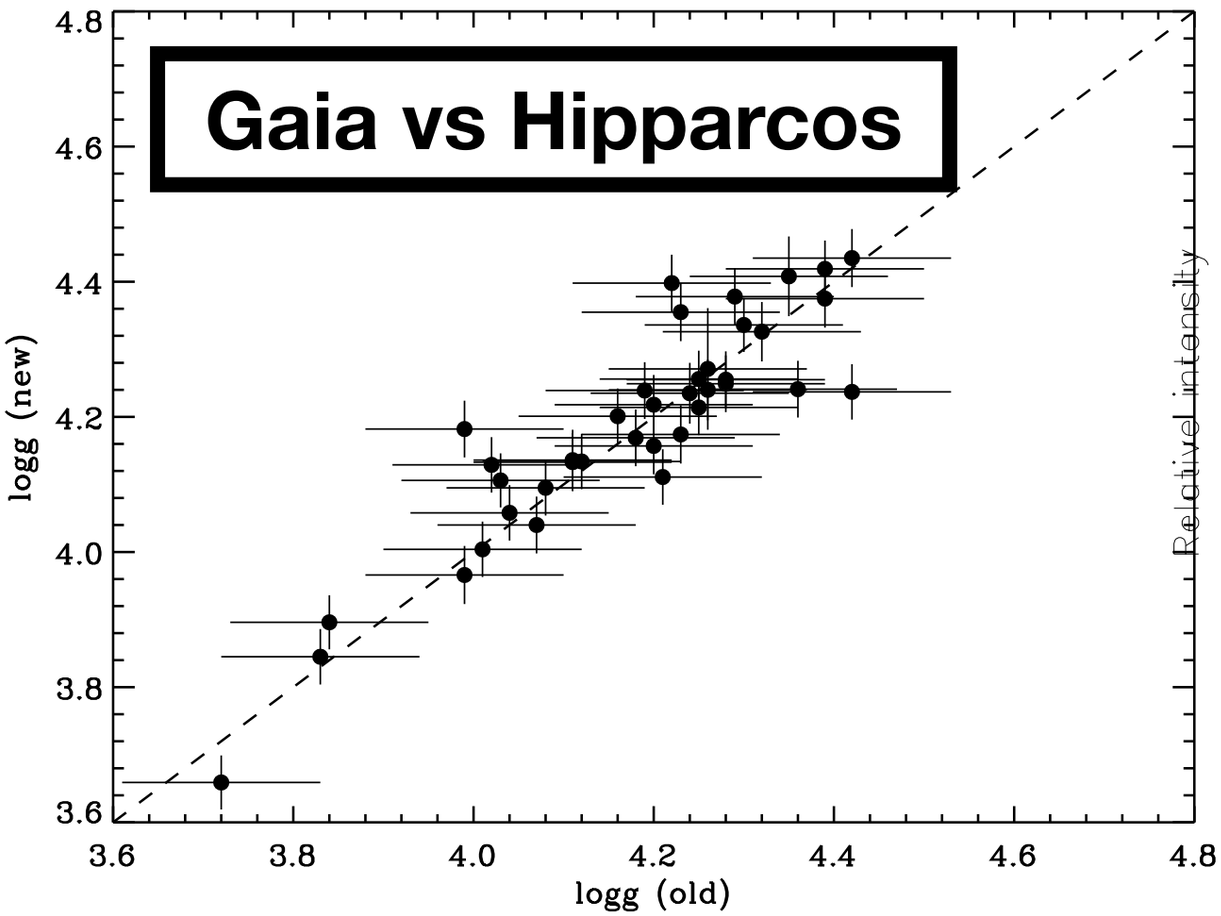
# A “full” 3D non-LTE analysis

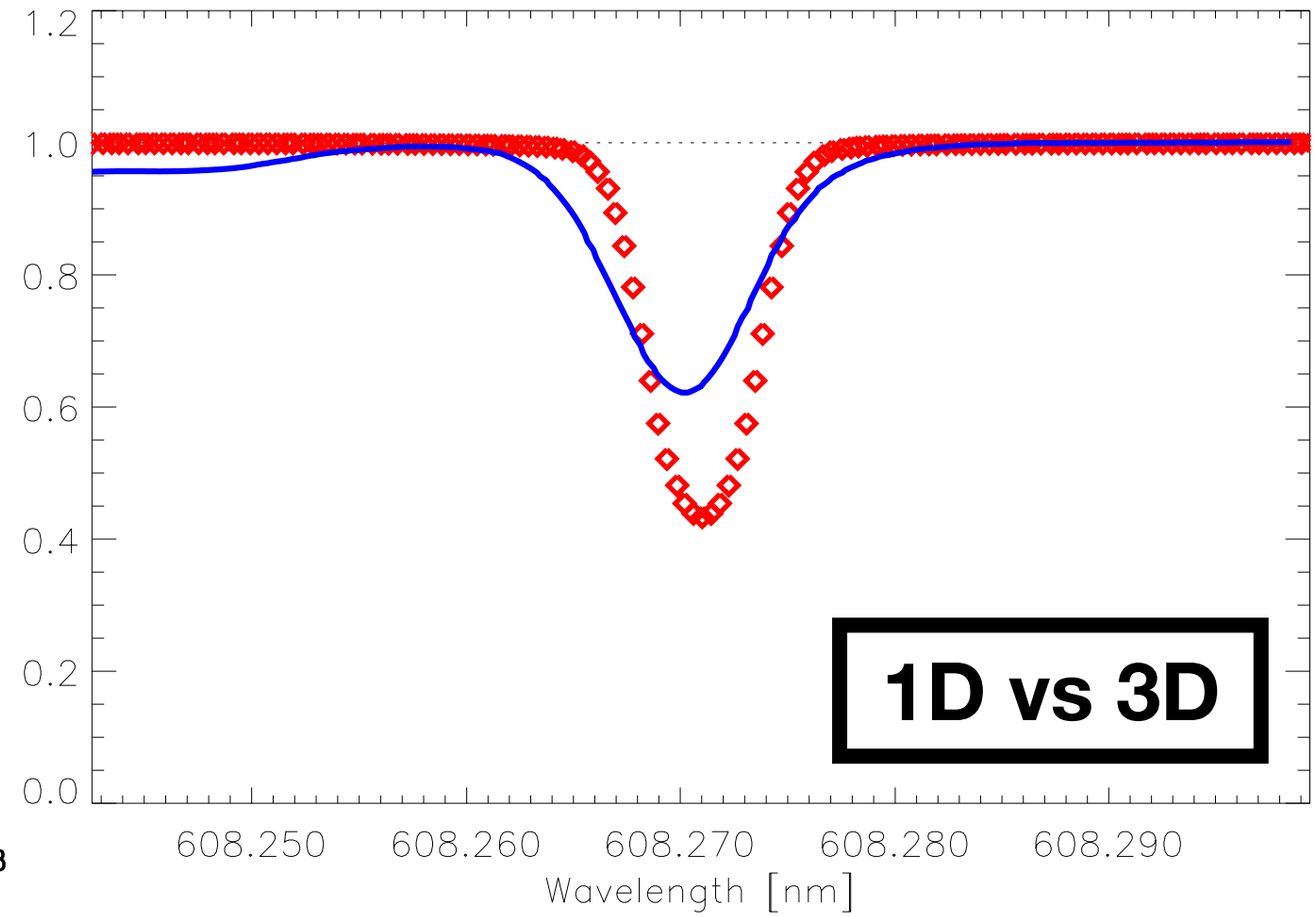



- Effective temperatures from **3D non-LTE Hβ** lines
- Grid available: Amarsi+ 2018

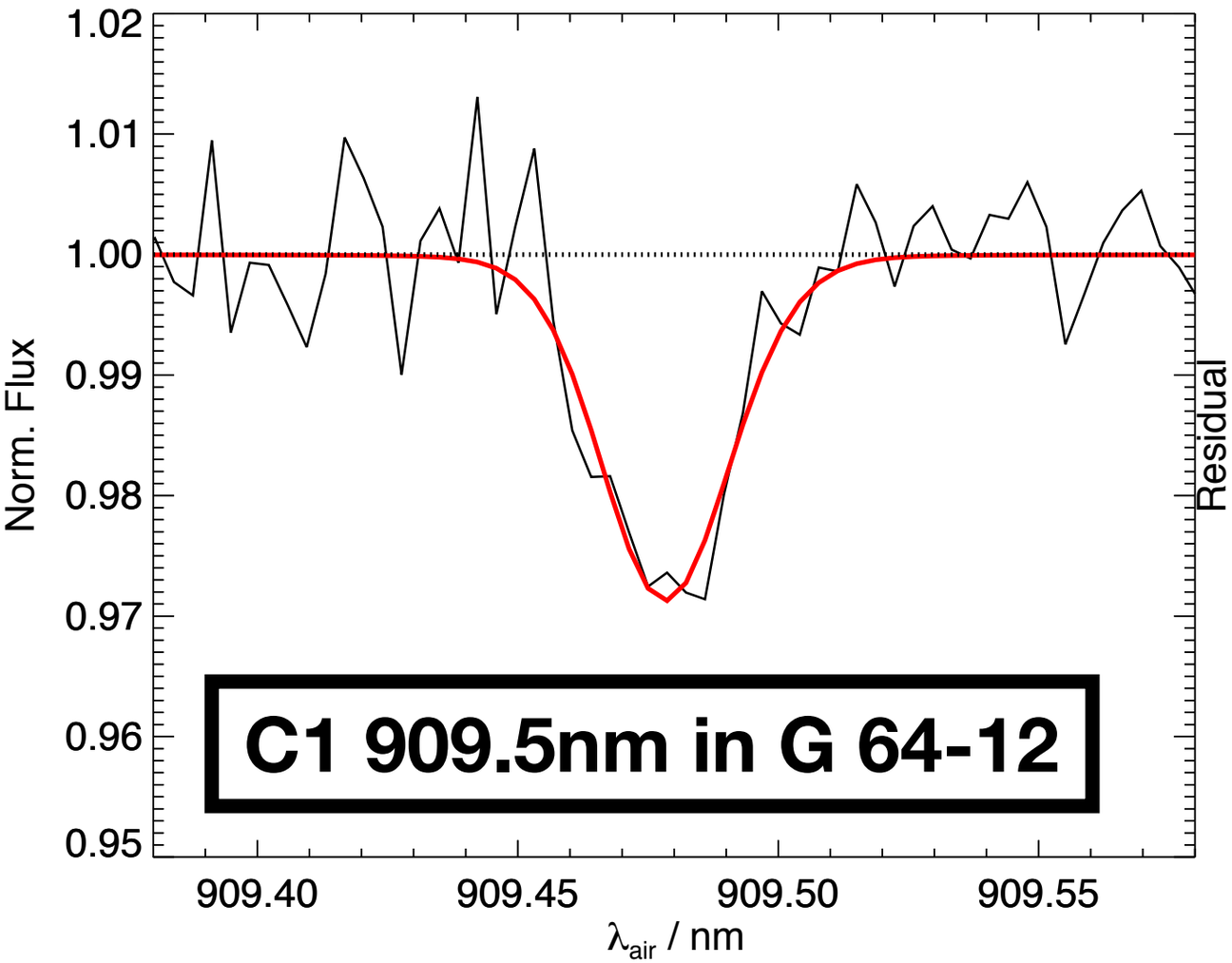
# A “full” 3D non-LTE analysis

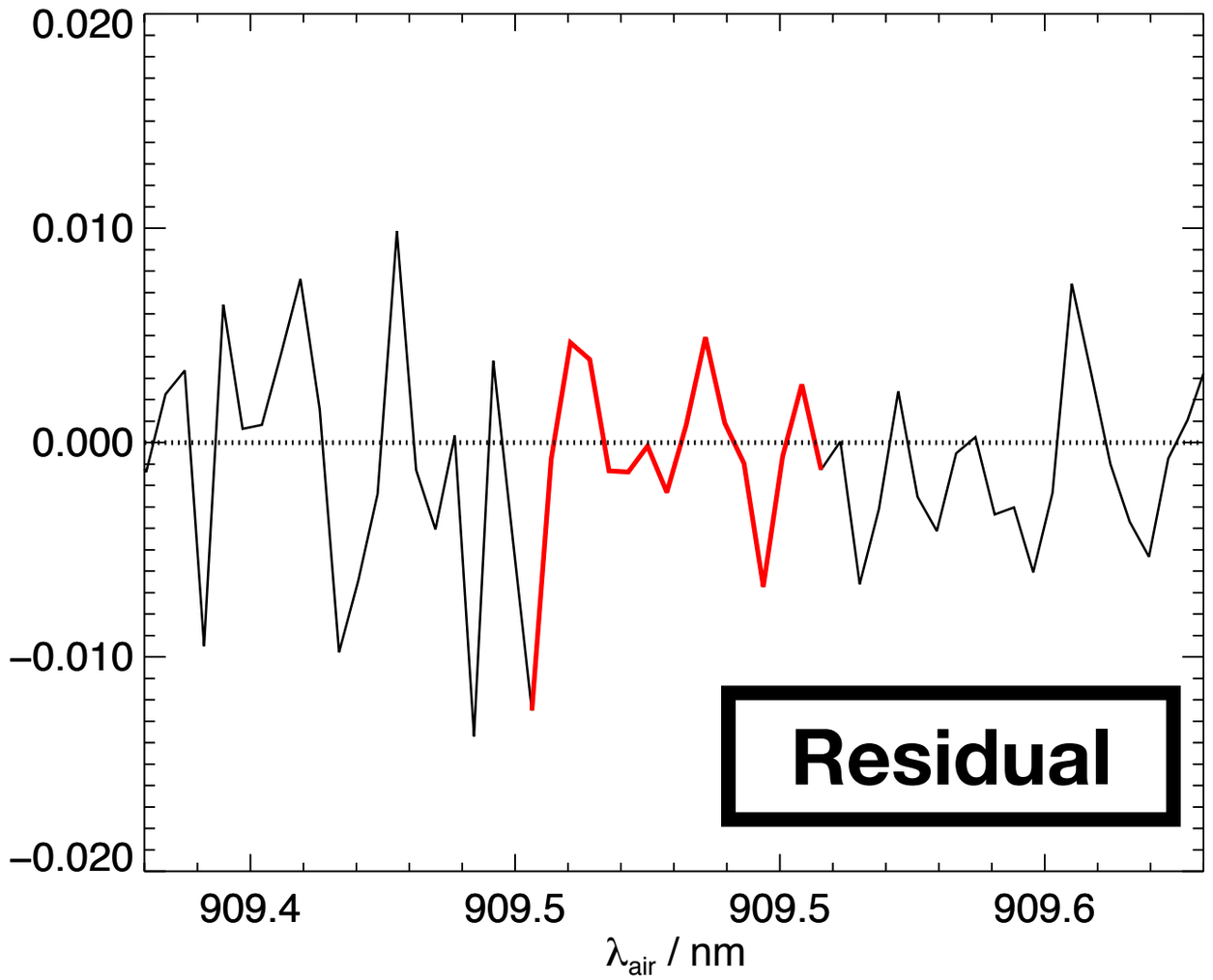



- Surface gravities from Gaia DR2
- [Fe/H] from 3D LTE Fe2 lines (small non-LTE effects for Fe2)

# A “full” 3D non-LTE analysis

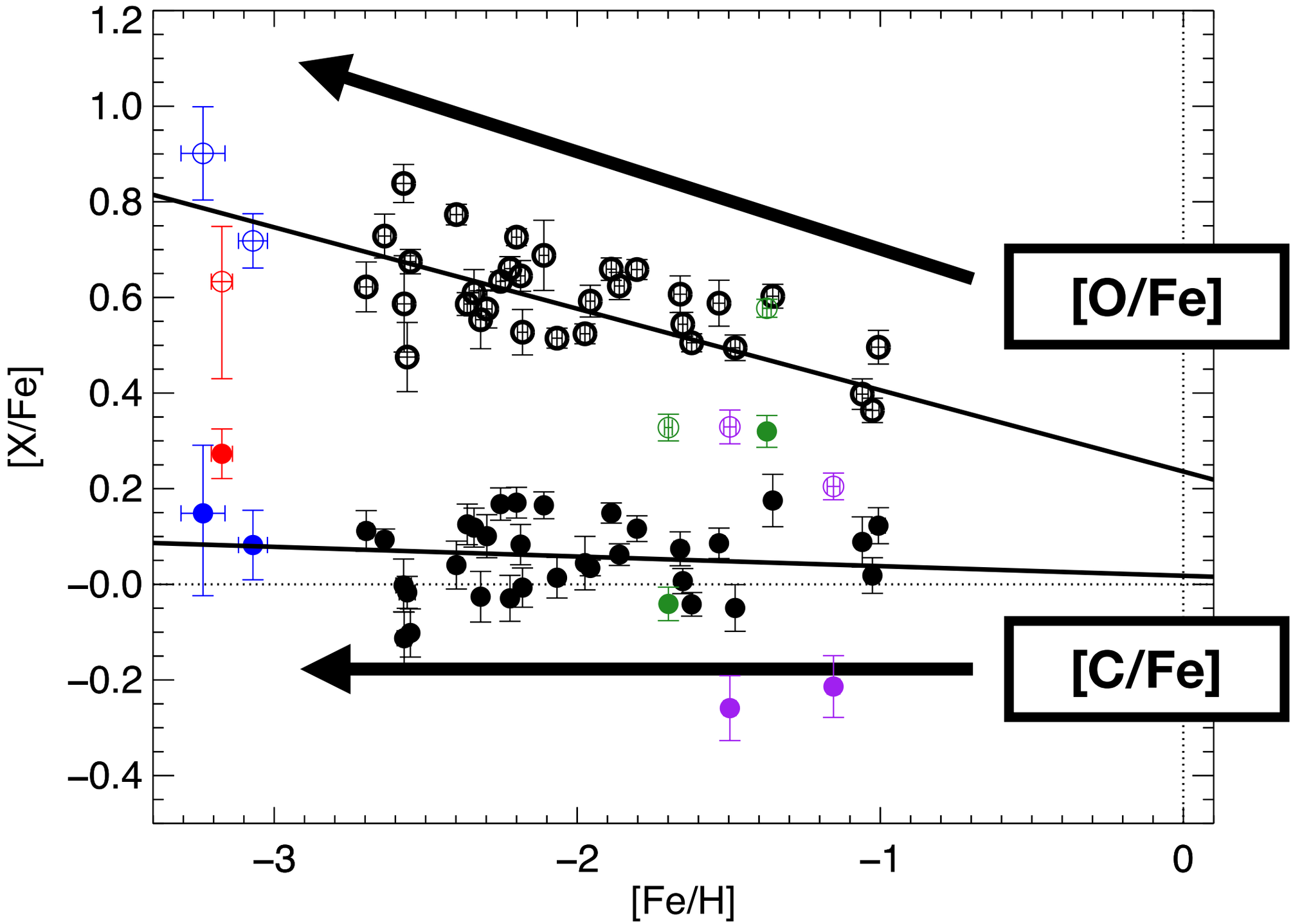


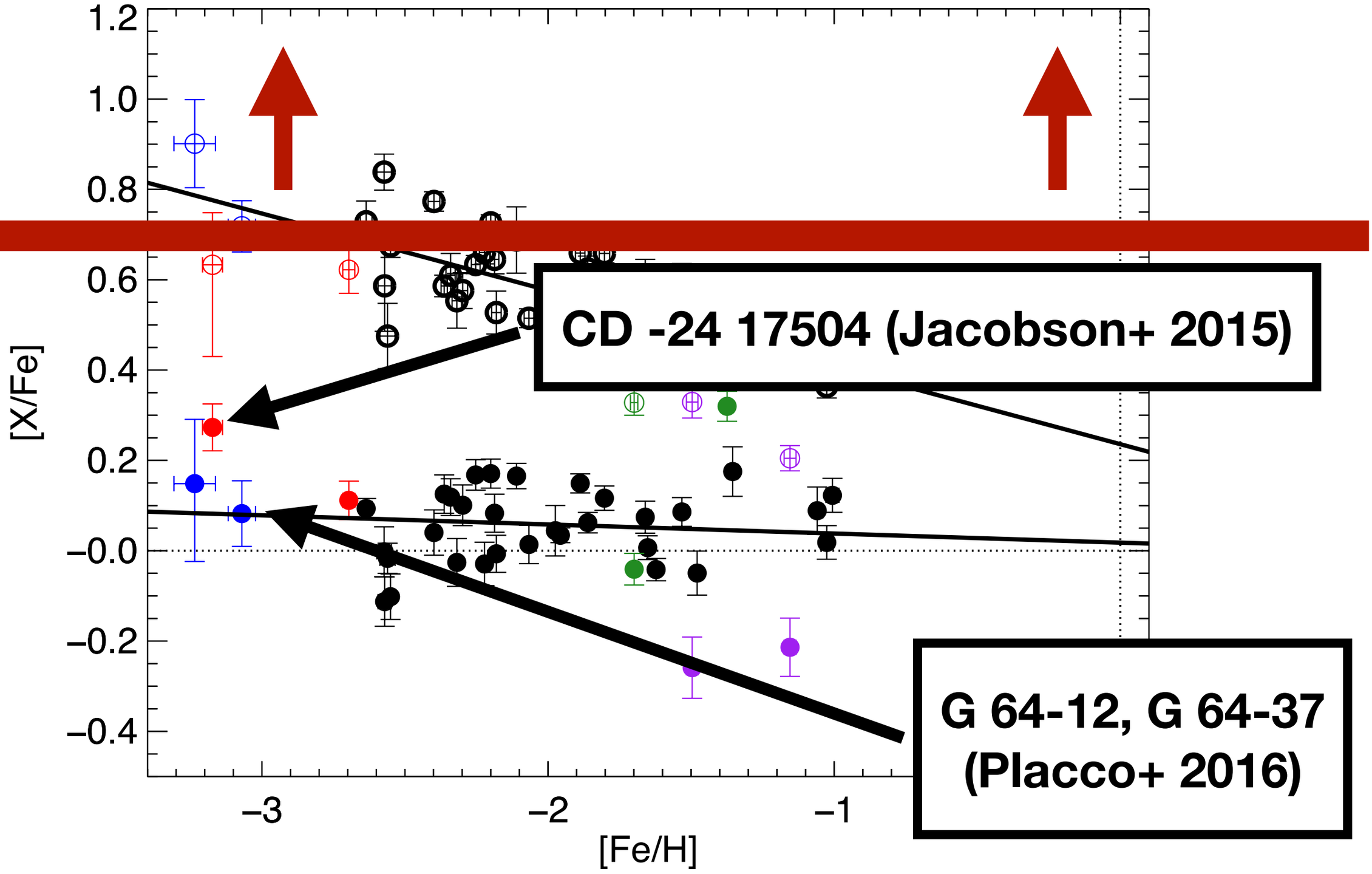

- Carbon and oxygen from 3D non-LTE IR lines
- Similar dependence to stellar parameters

# Results

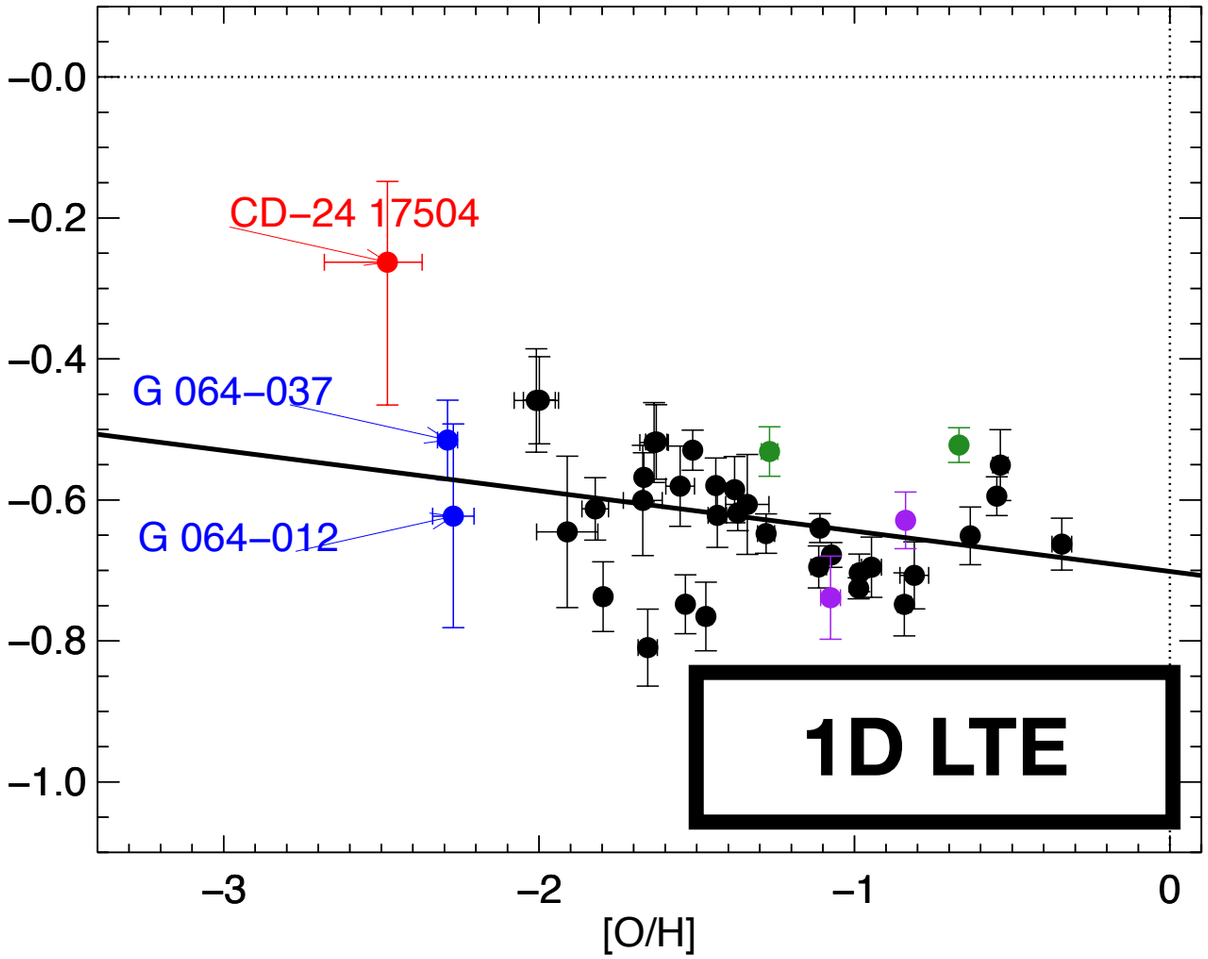
# [C/Fe] and [O/Fe]

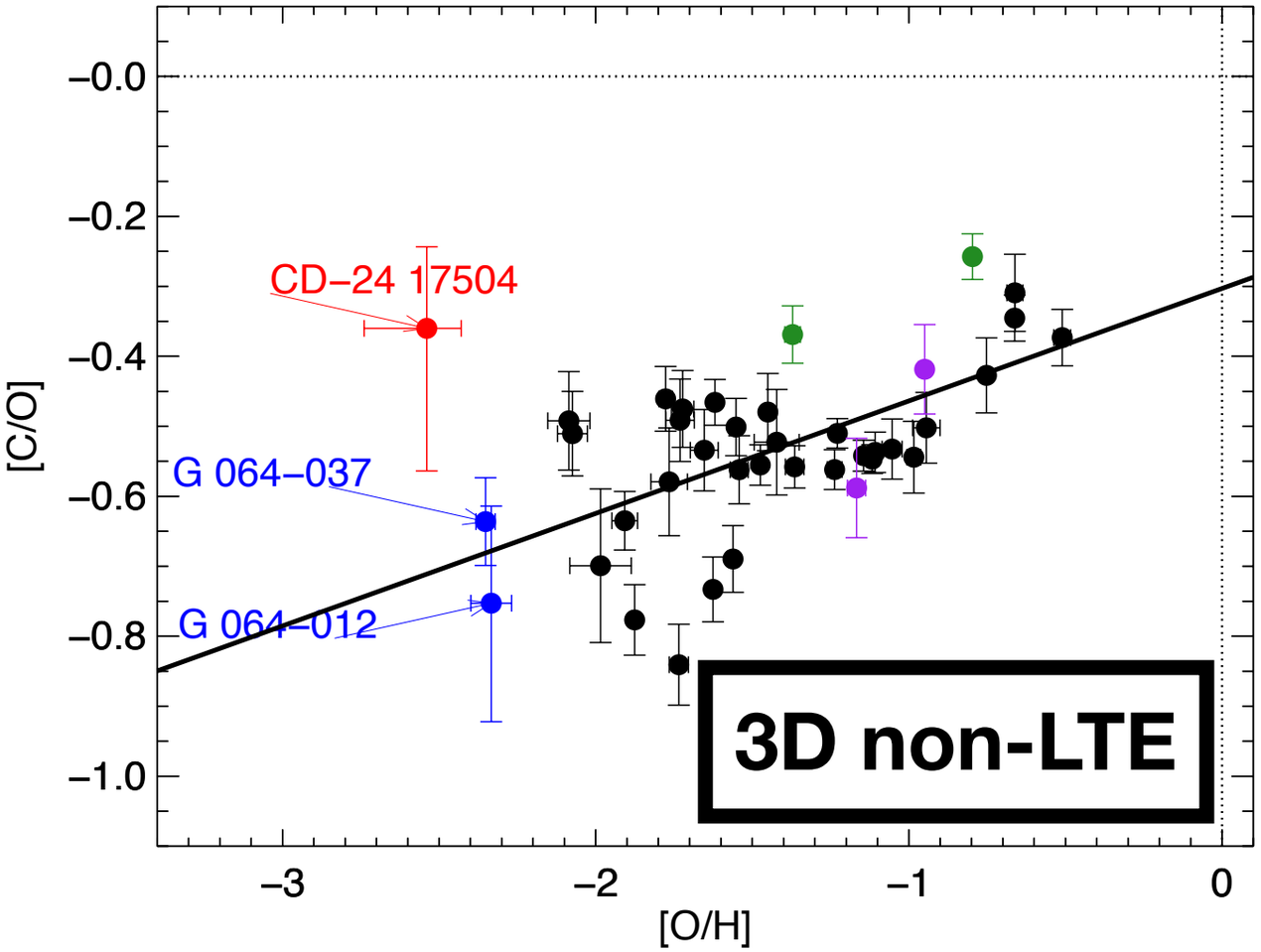


# CEMP stars


1.2
1.0
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
[X/Fe]
−3
−2
−1
[Fe/H]
CD -24 17504 (Jacobson+ 2015)
G 64-12, G 64-37
(Placco+ 2016)

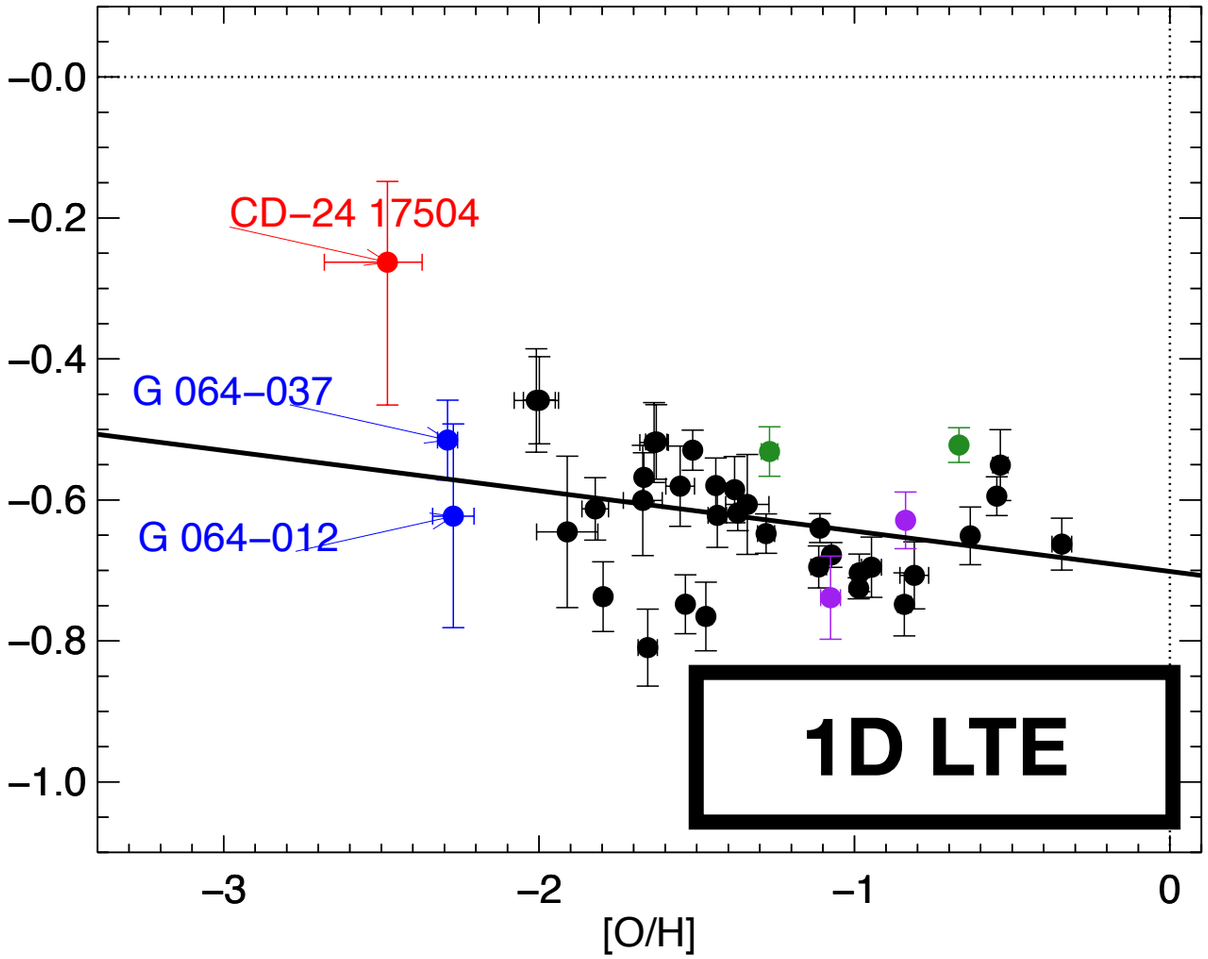
# [C/O] vs [O/H]

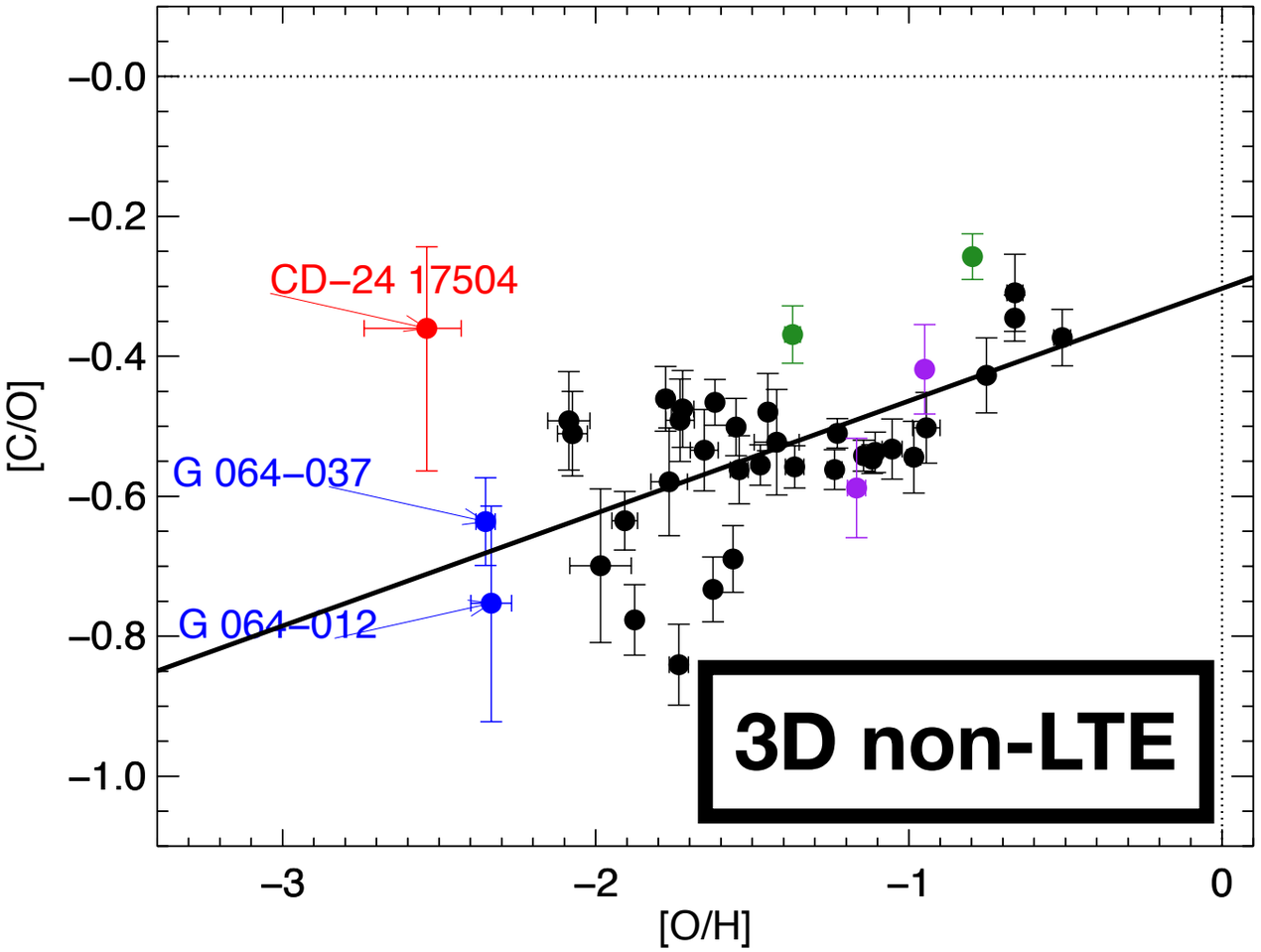



- 3D non-LTE: **no evidence of an upturn** in this sample
- 3D non-LTE trend **qualitatively different** to that in 1D LTE

# [C/O] vs [O/H]

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