Ending the Second Cosmological Li Problem

Ella Xi Wang

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Lithium

- Lithium is the heaviest element produced in Big Bang nucleosynthesis

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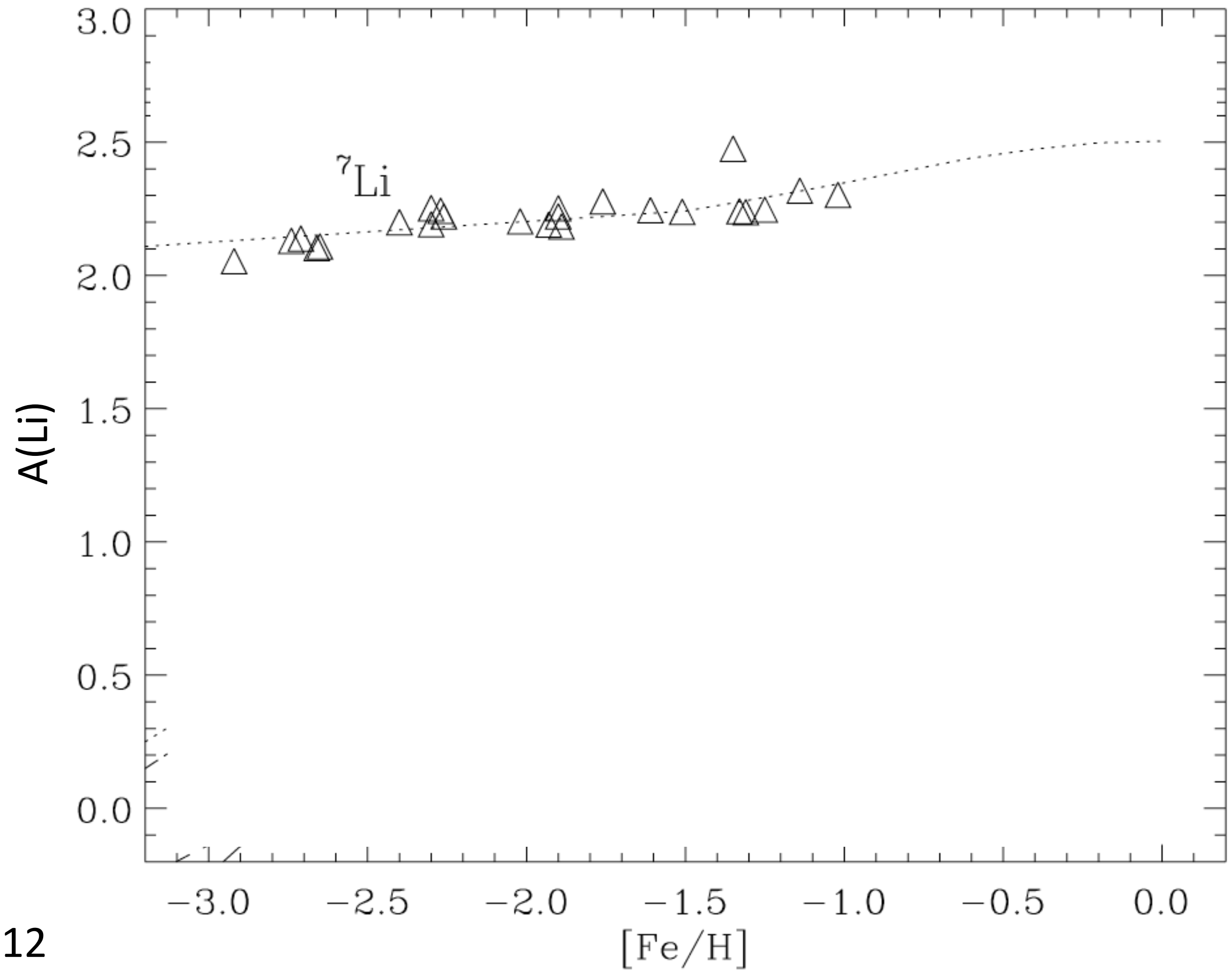
- The cosmological lithium problems

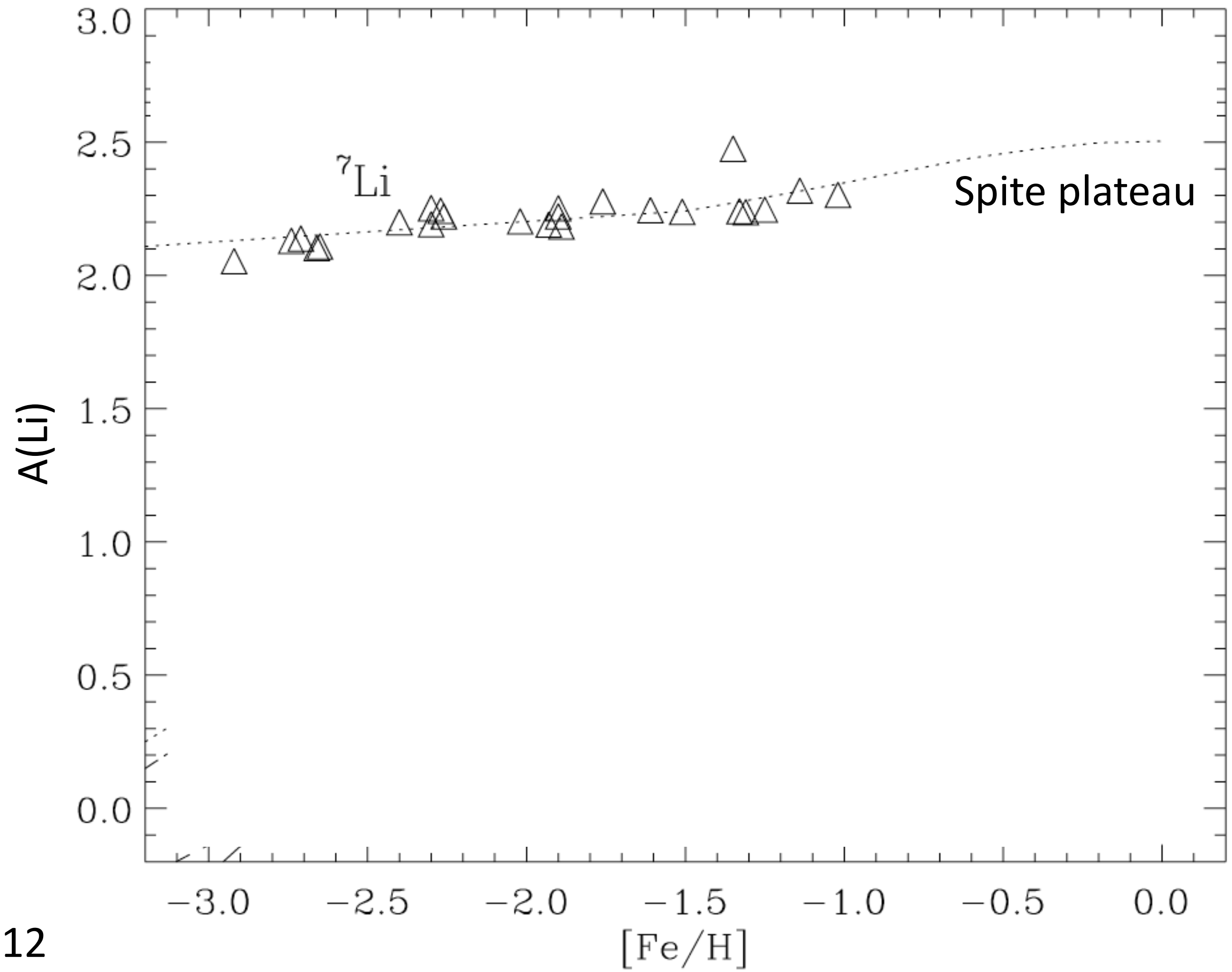
The cosmological lithium problems



Note: A(H) = 12

Asplund et al. 2006

The cosmological lithium problems



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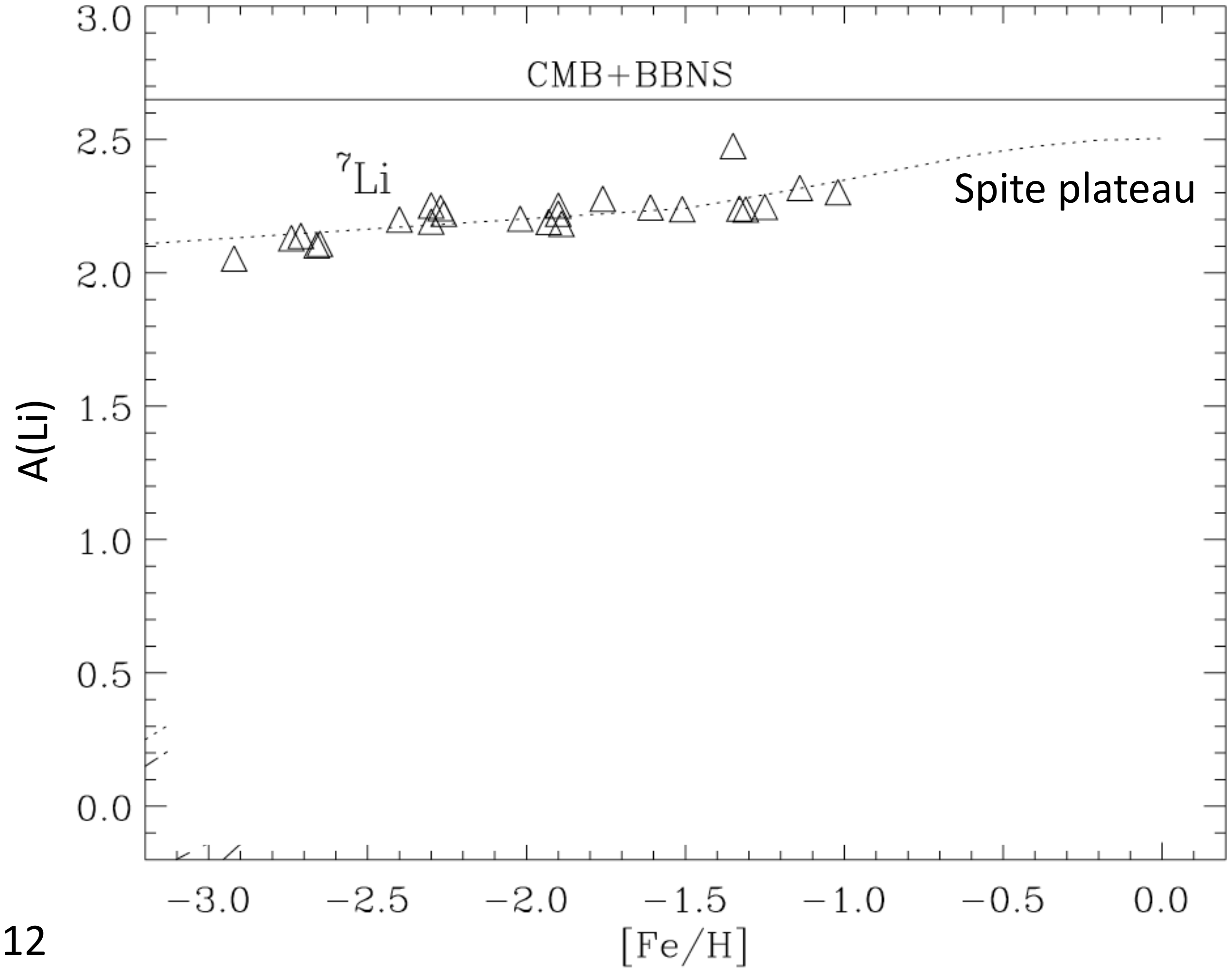

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The cosmological lithium problems

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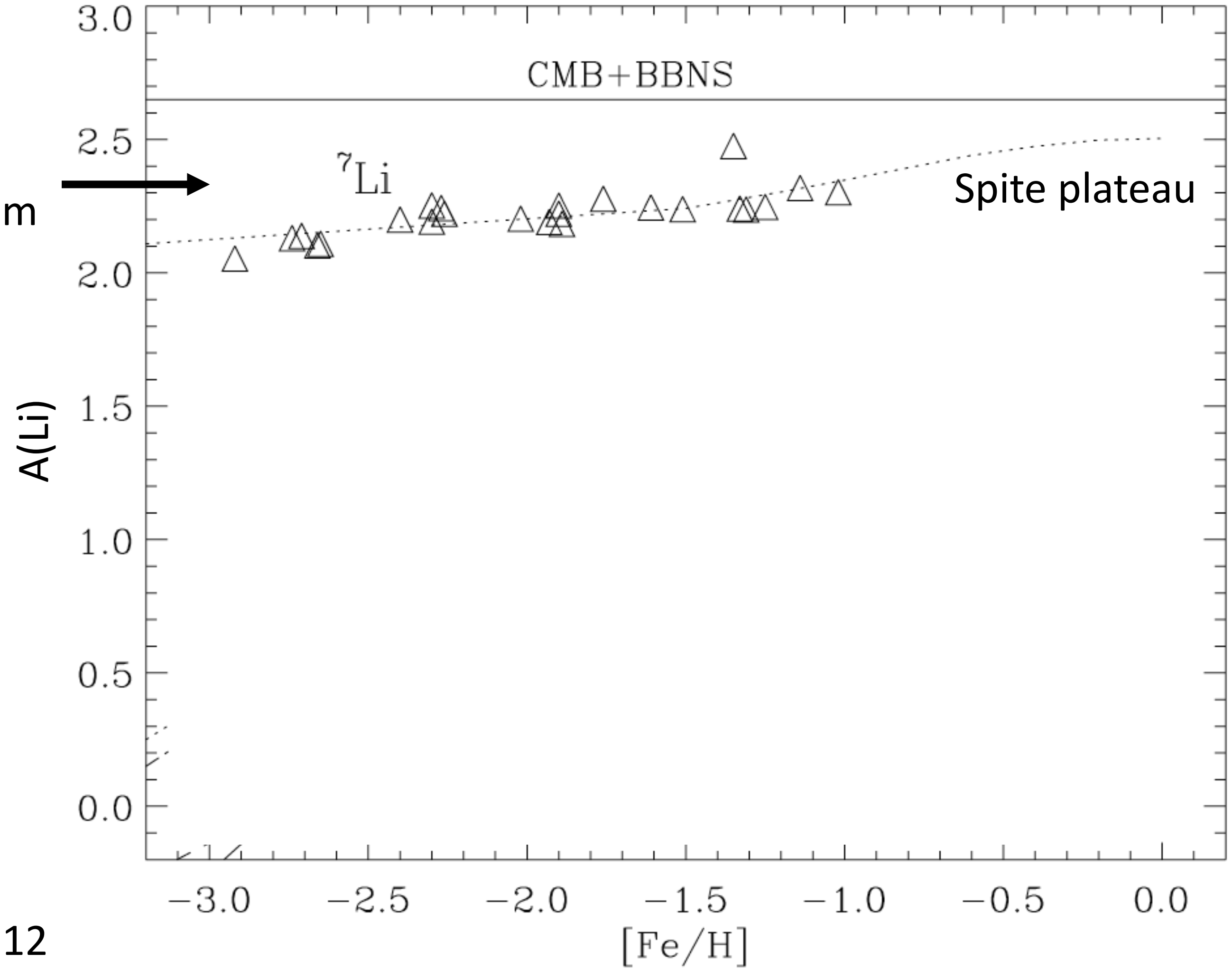

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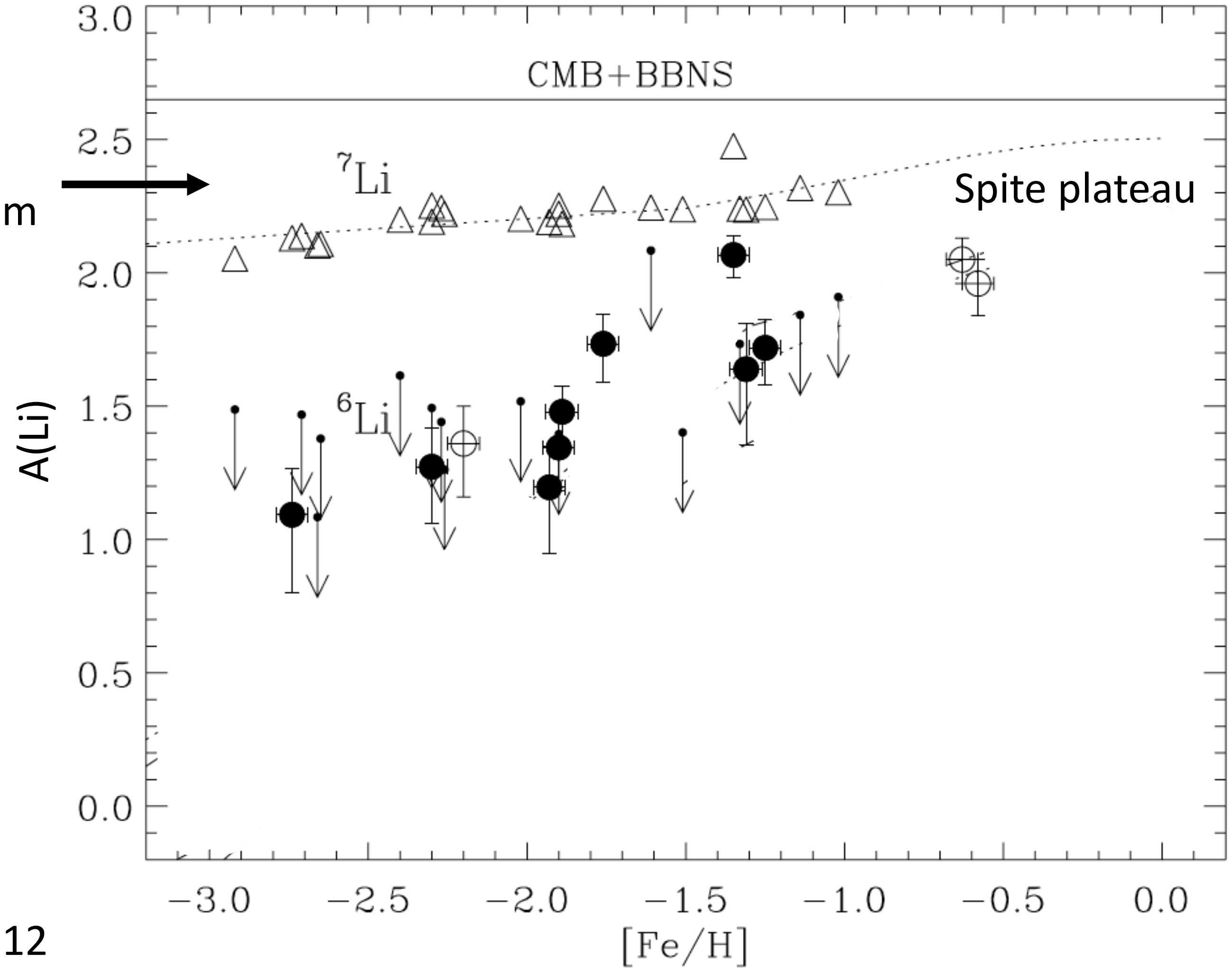

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The cosmological lithium problems

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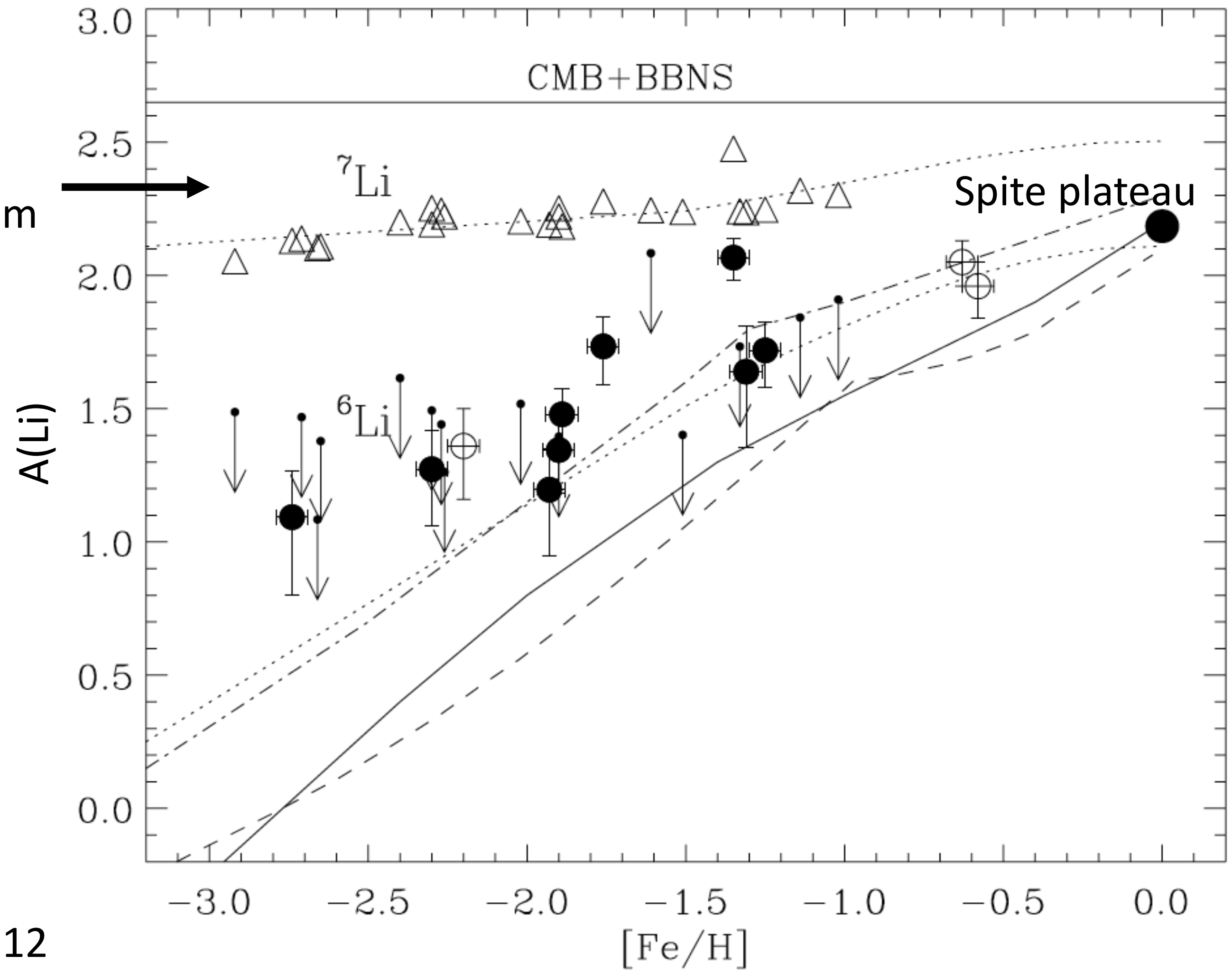

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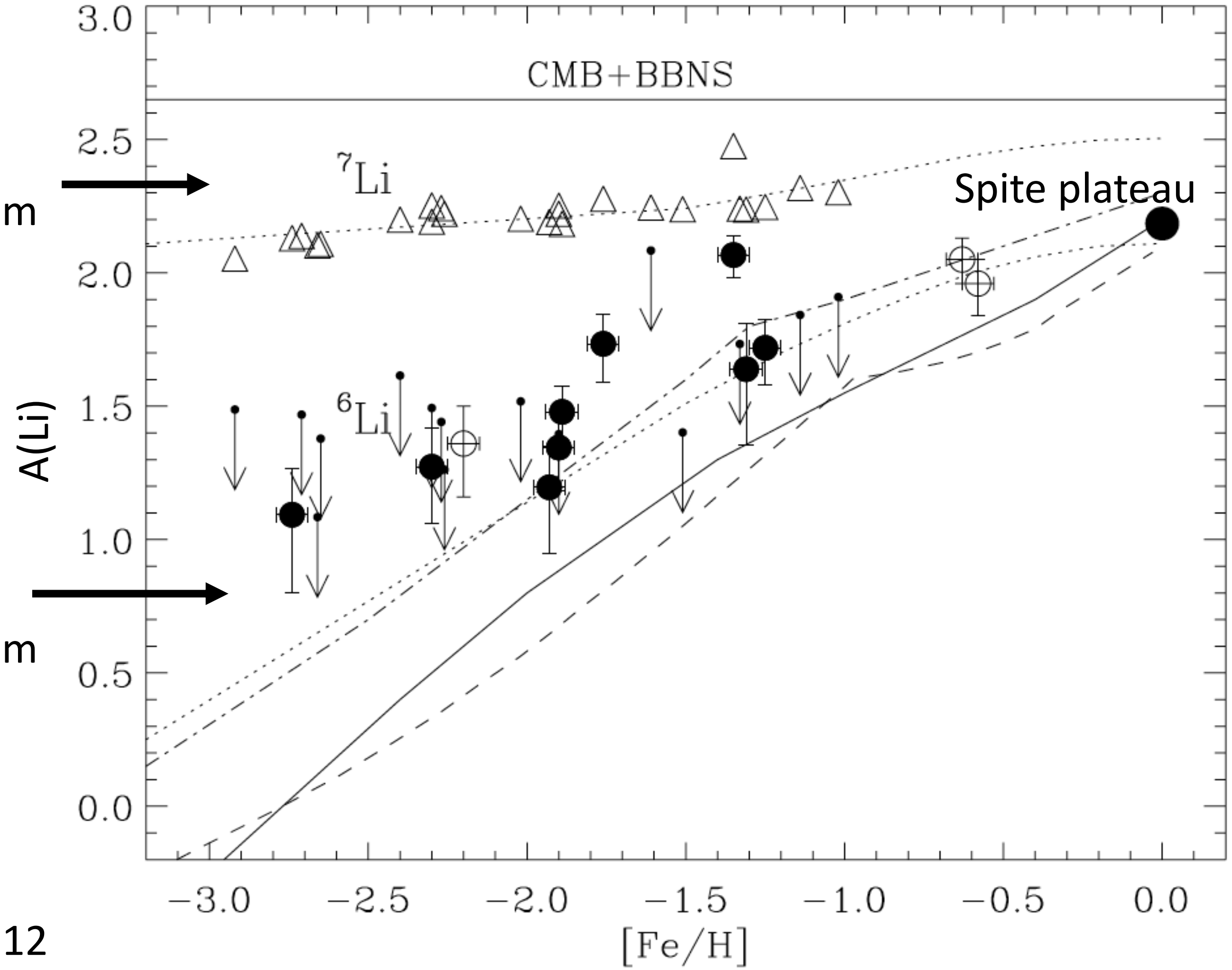
The cosmological lithium problems

Cosmological lithium problem

Second cosmological lithium problem



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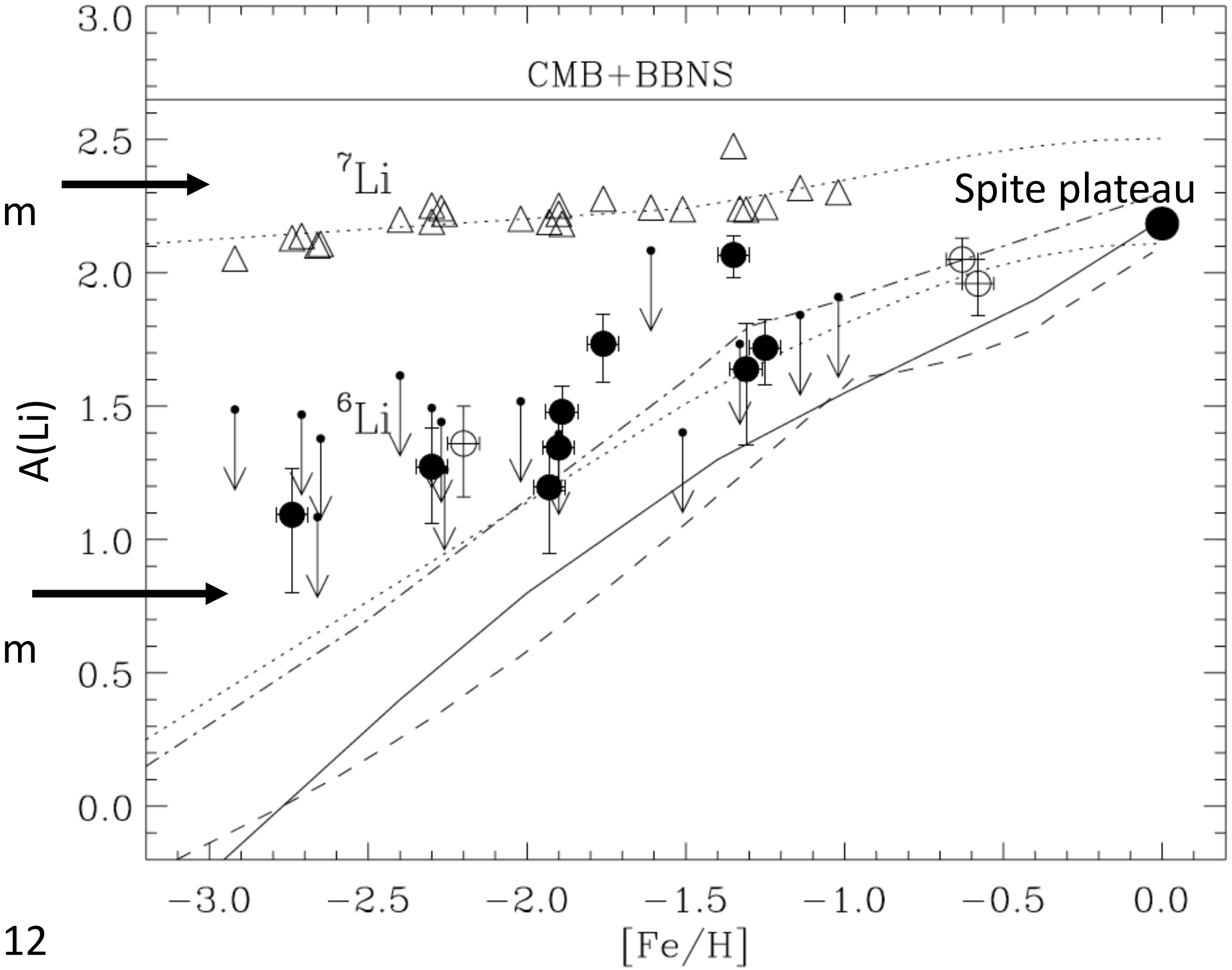

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Possible solutions

- Observational inaccuracies?

The cosmological lithium problems

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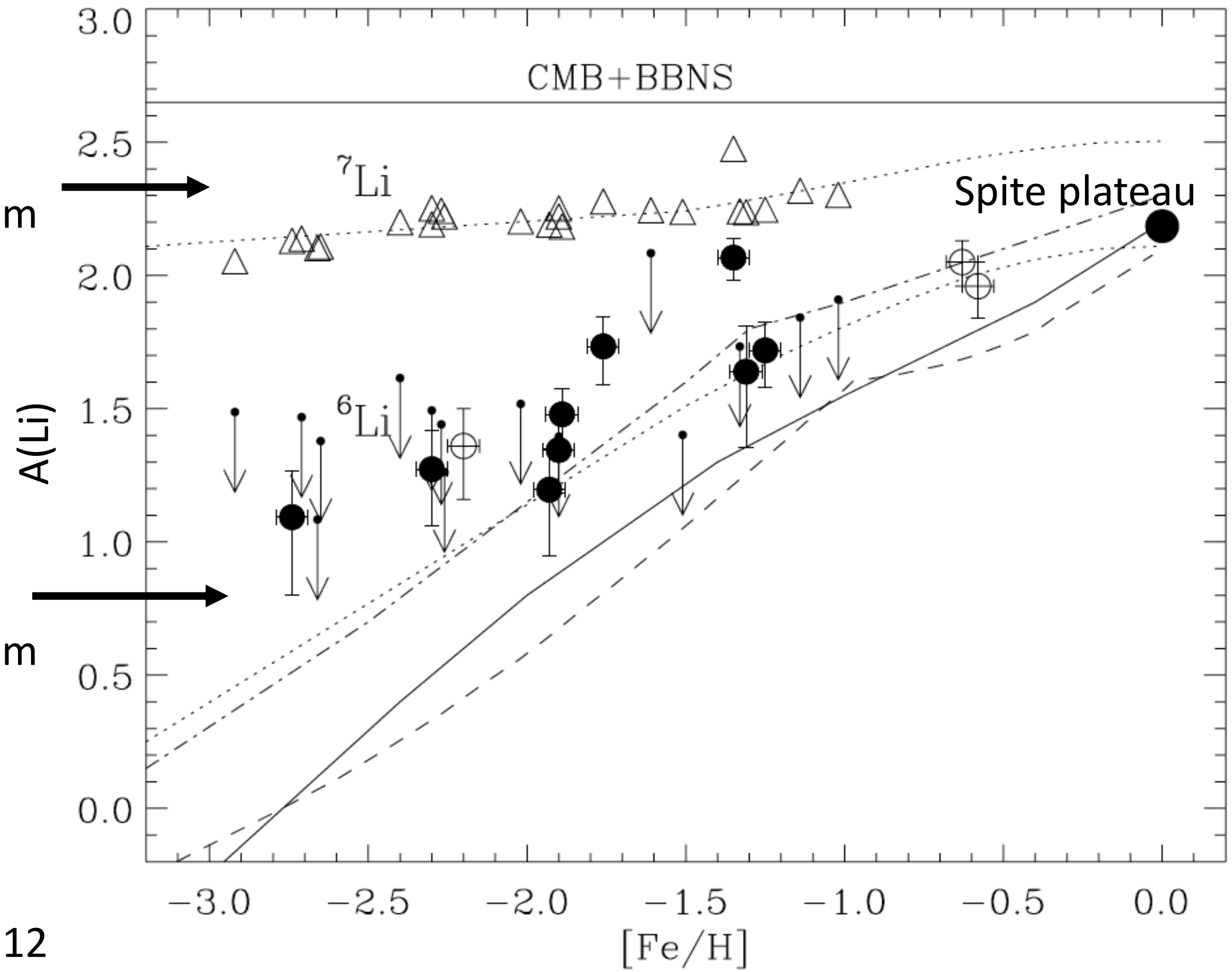

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The cosmological lithium problems

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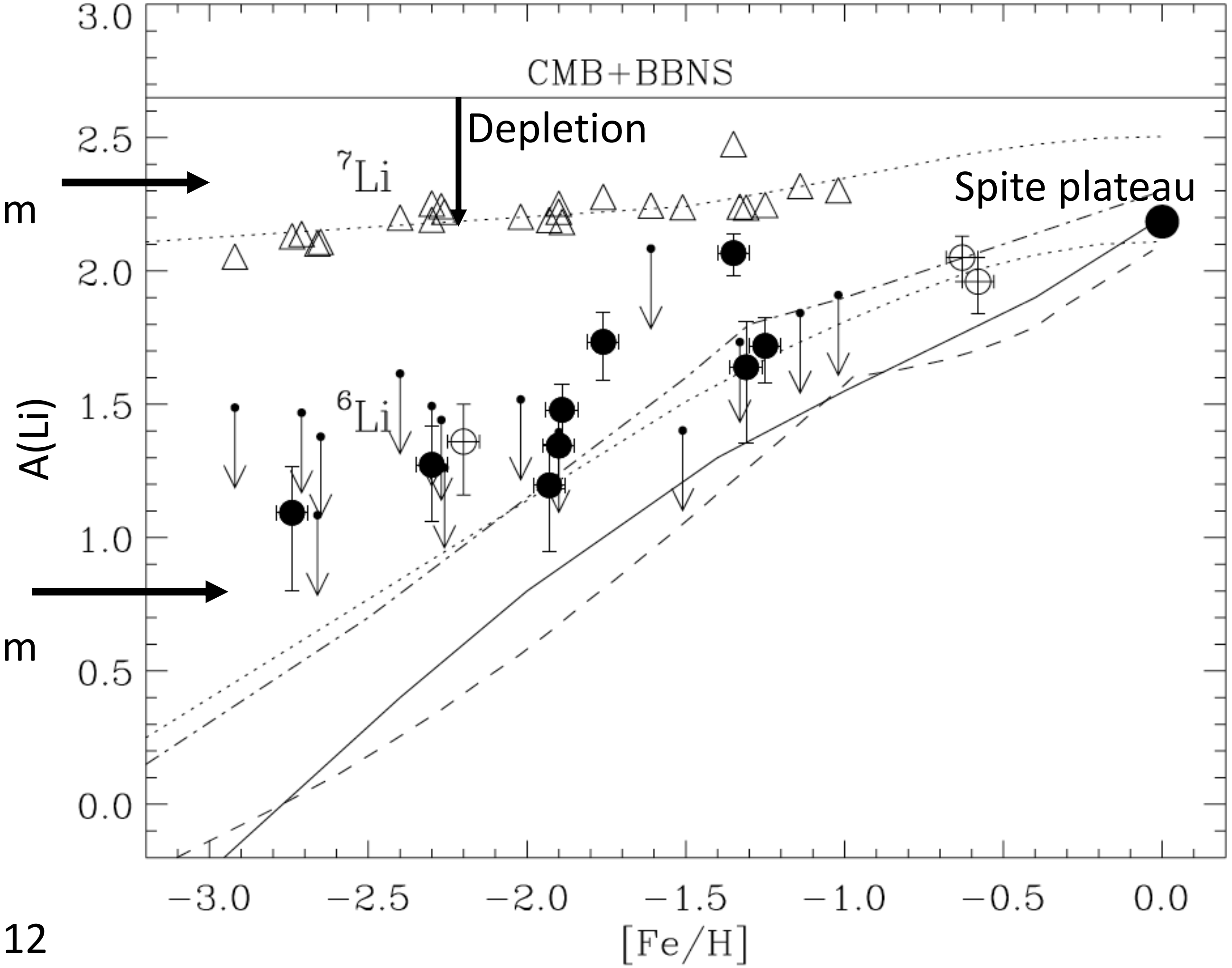

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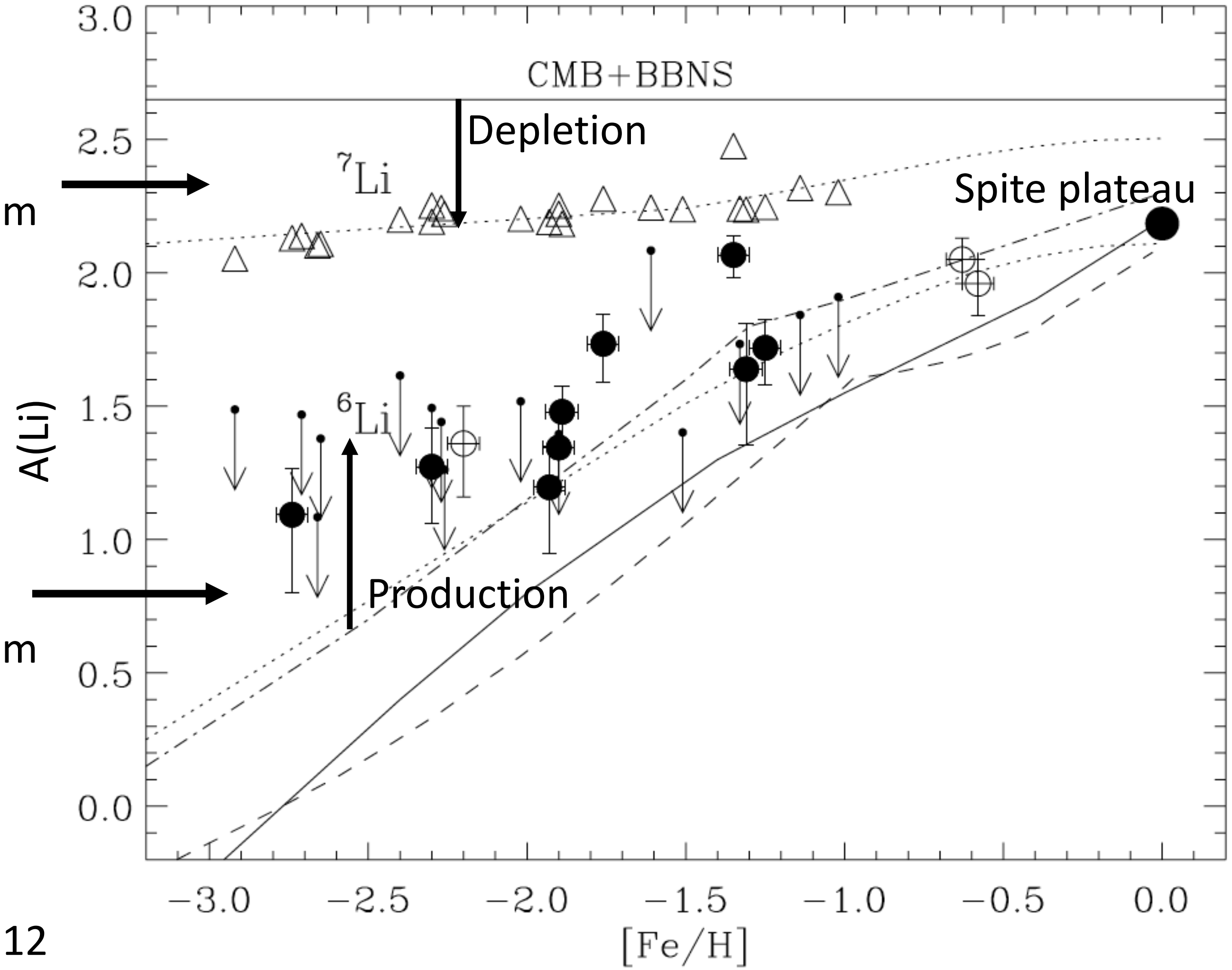

Cosmological lithium problem

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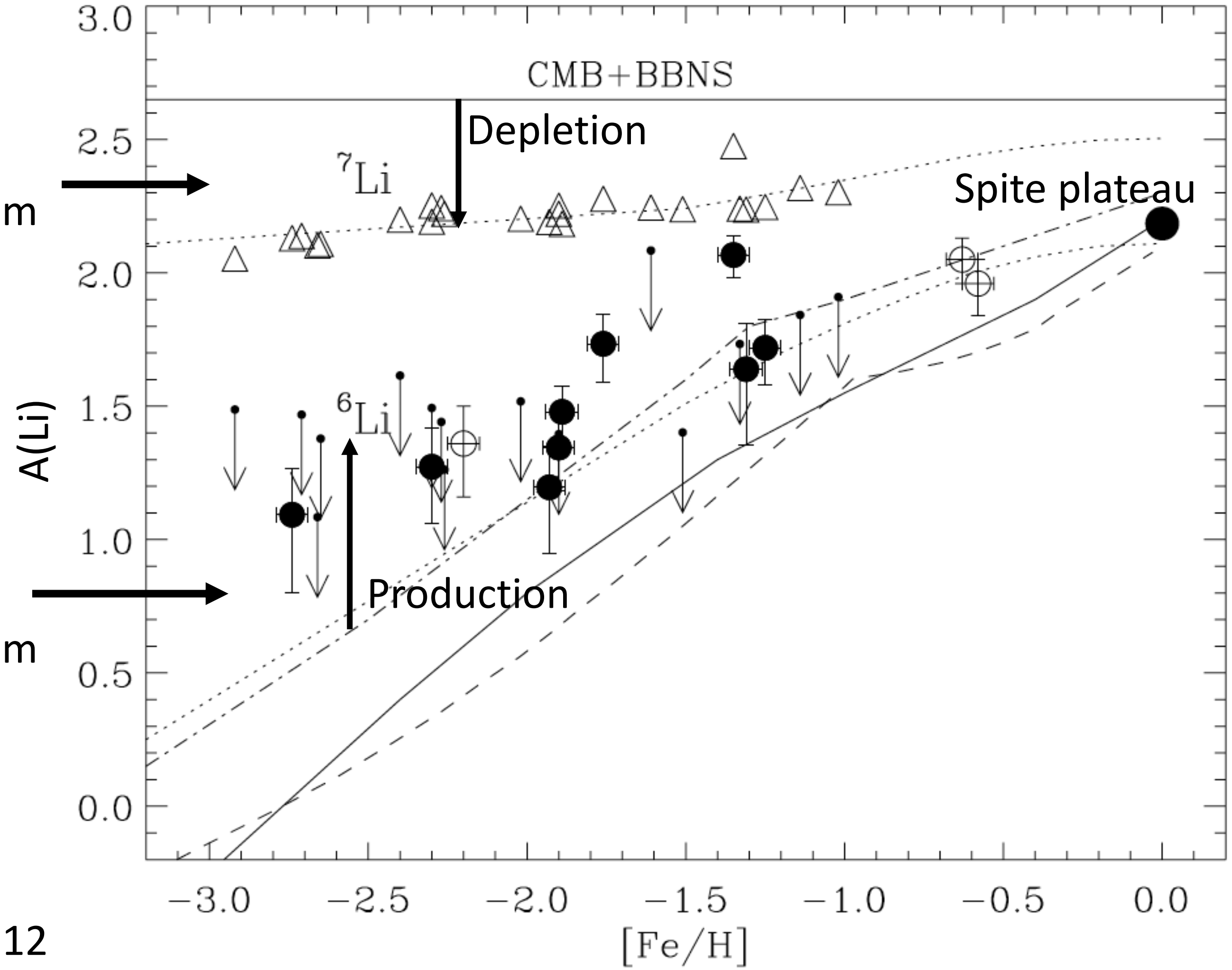

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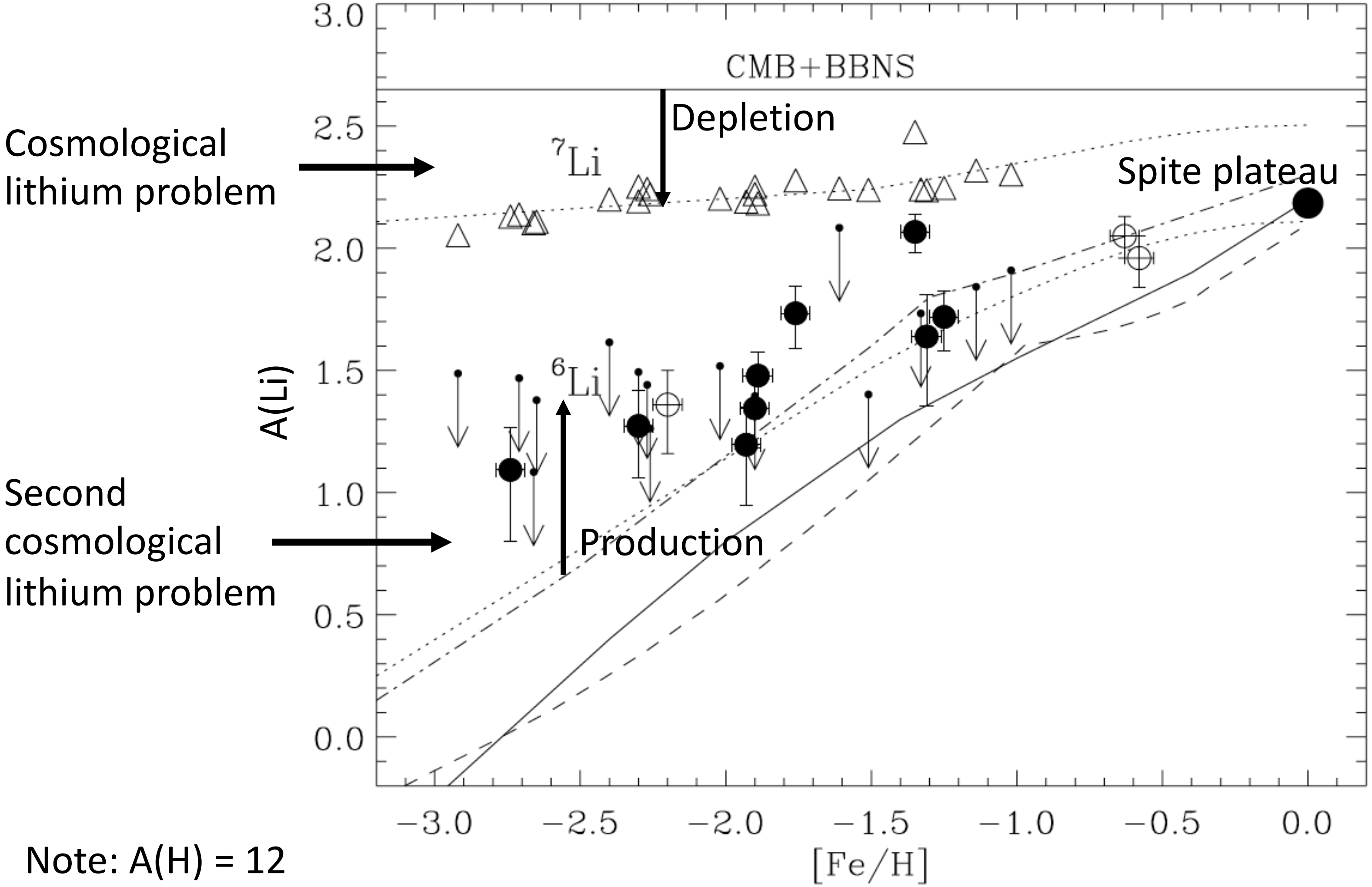
The cosmological lithium problems



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Possible solutions

- Observational inaccuracies?
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- Exotic scenarios?
  - Modified nuclear reaction rates?
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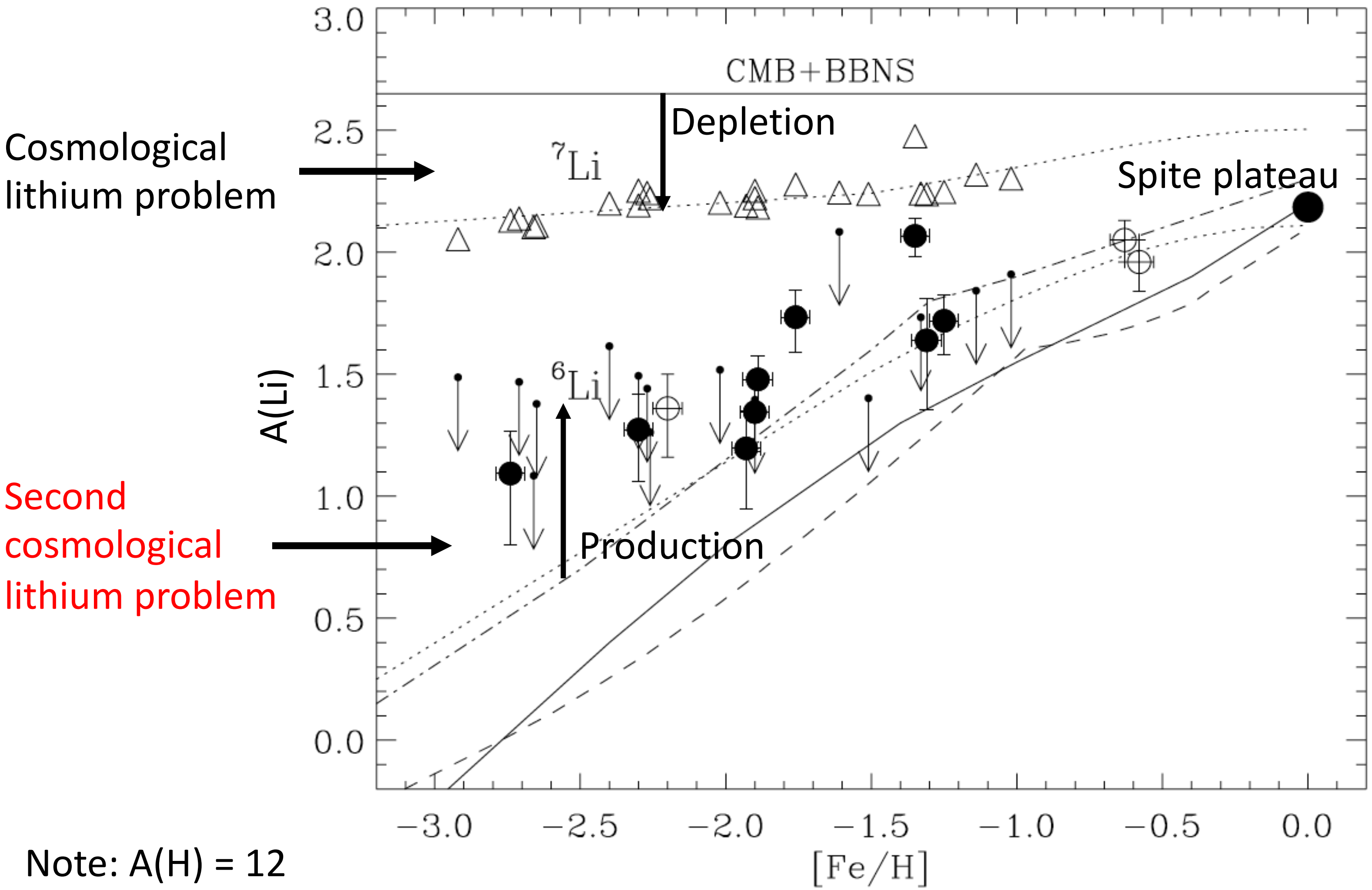
  - Dark matter?
  - Variations in fundamental constants?

The cosmological lithium problems



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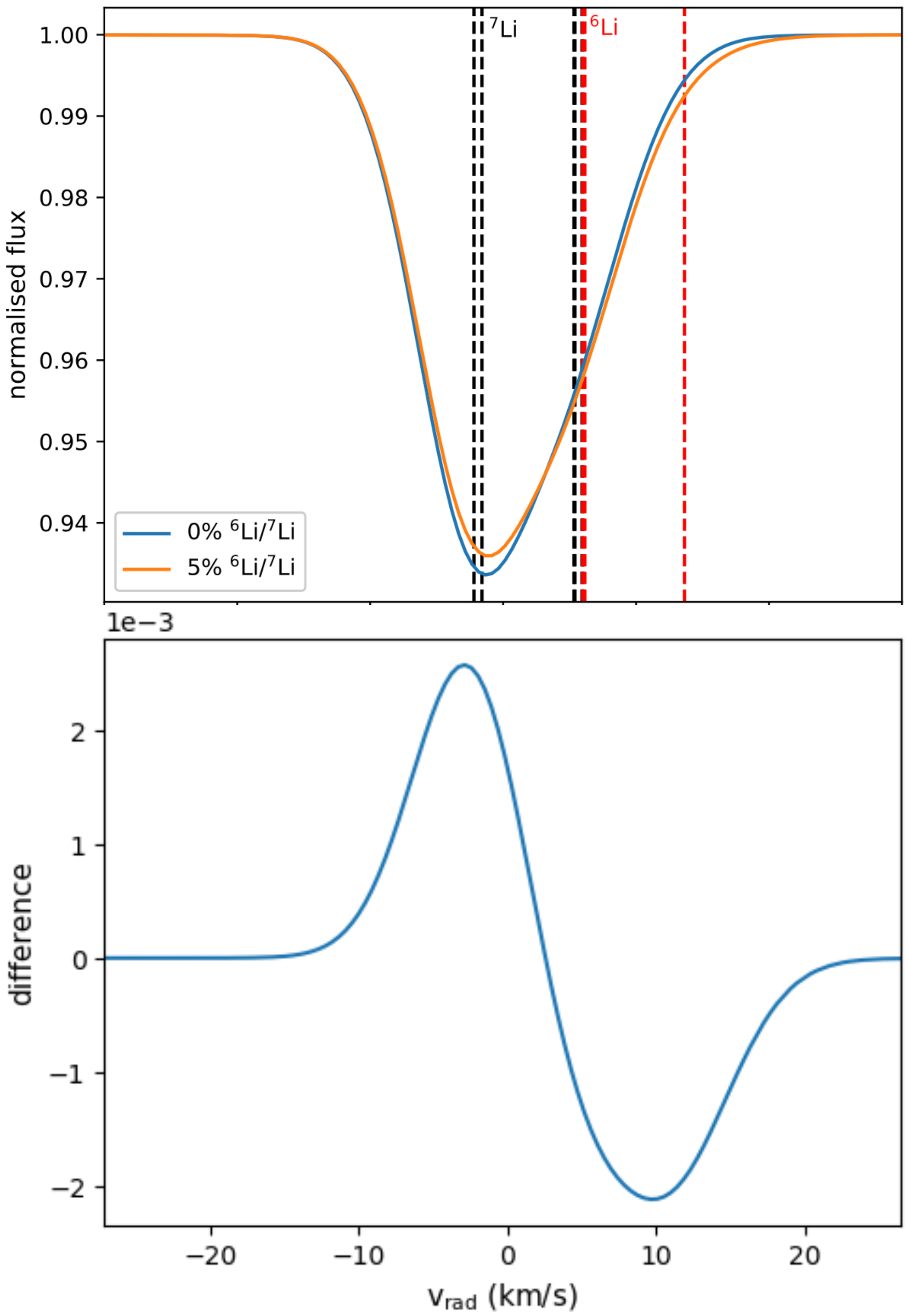
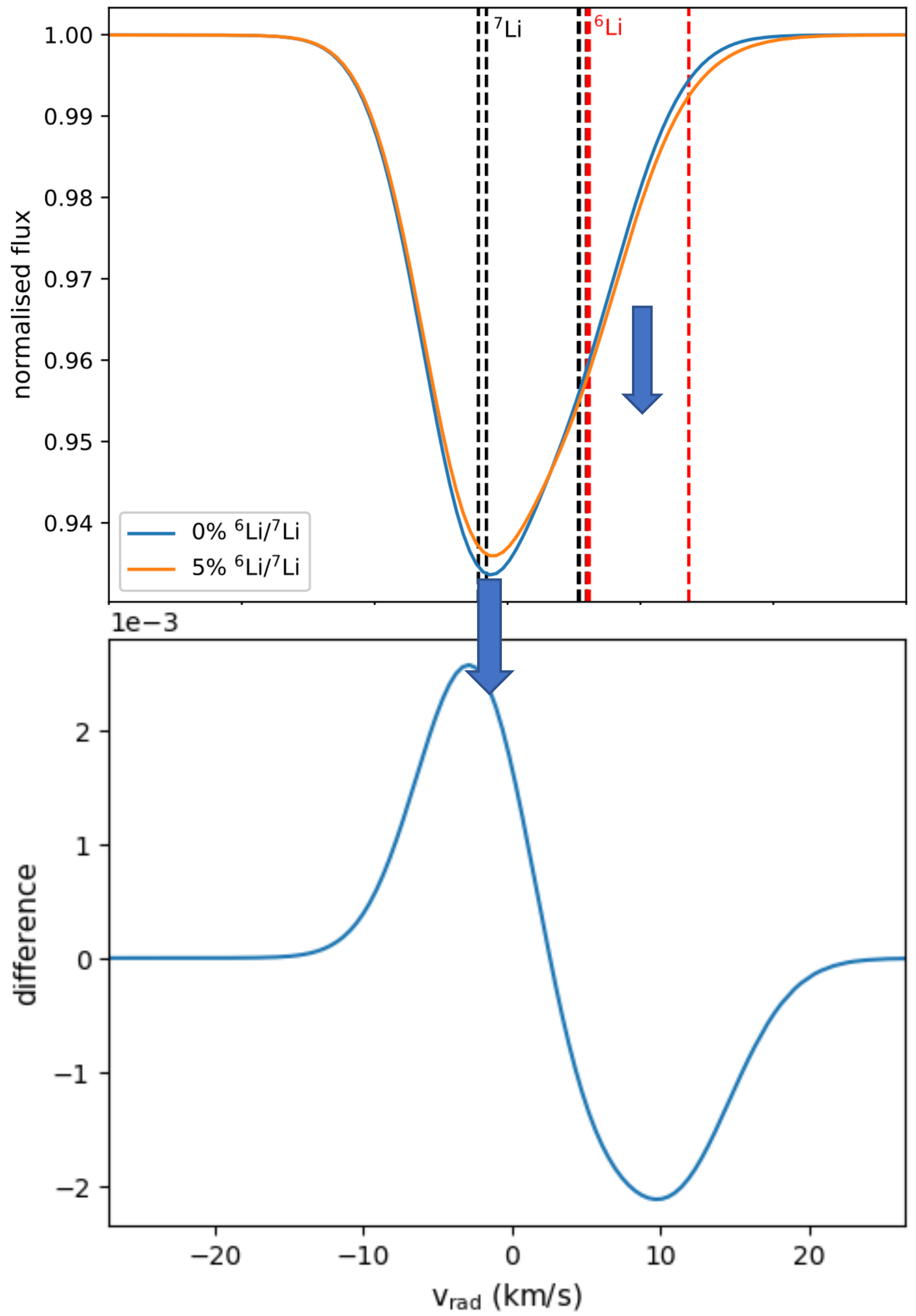
Li 670.8 nm line



Li 670.8 nm line

- Li abundance A(Li)



Li 670.8 nm line

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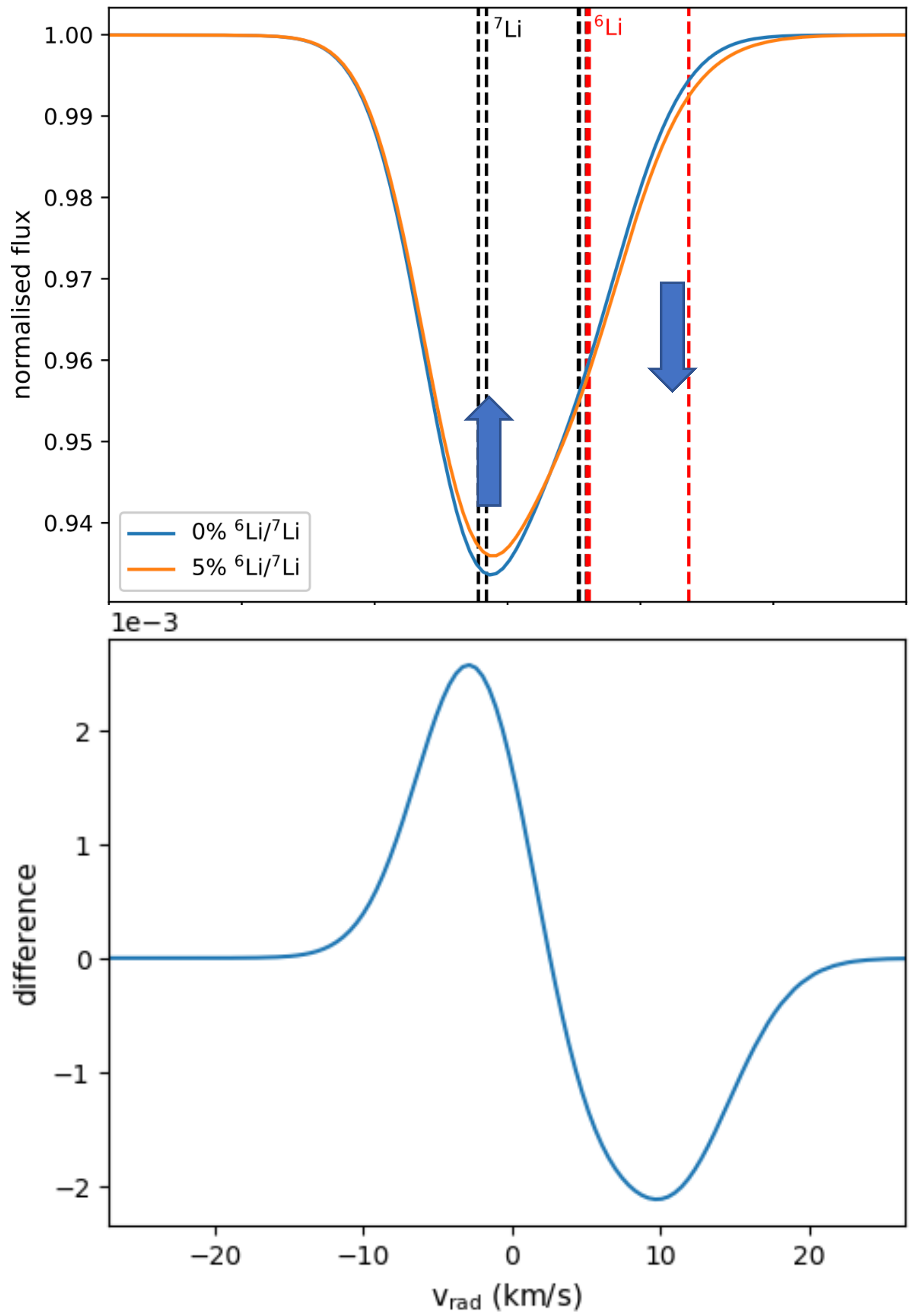
- Isotopic ratio $^6Li/^7Li$



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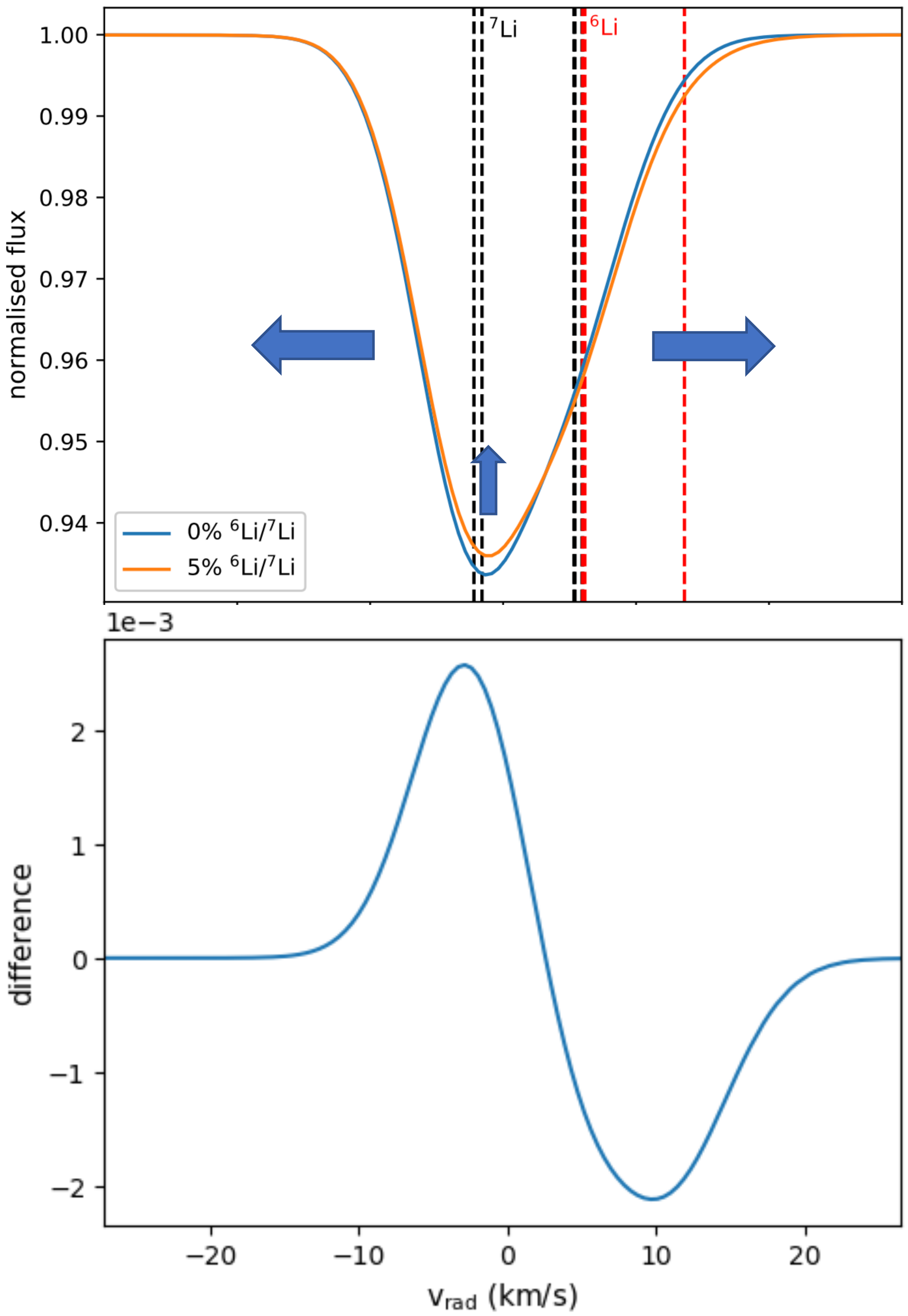

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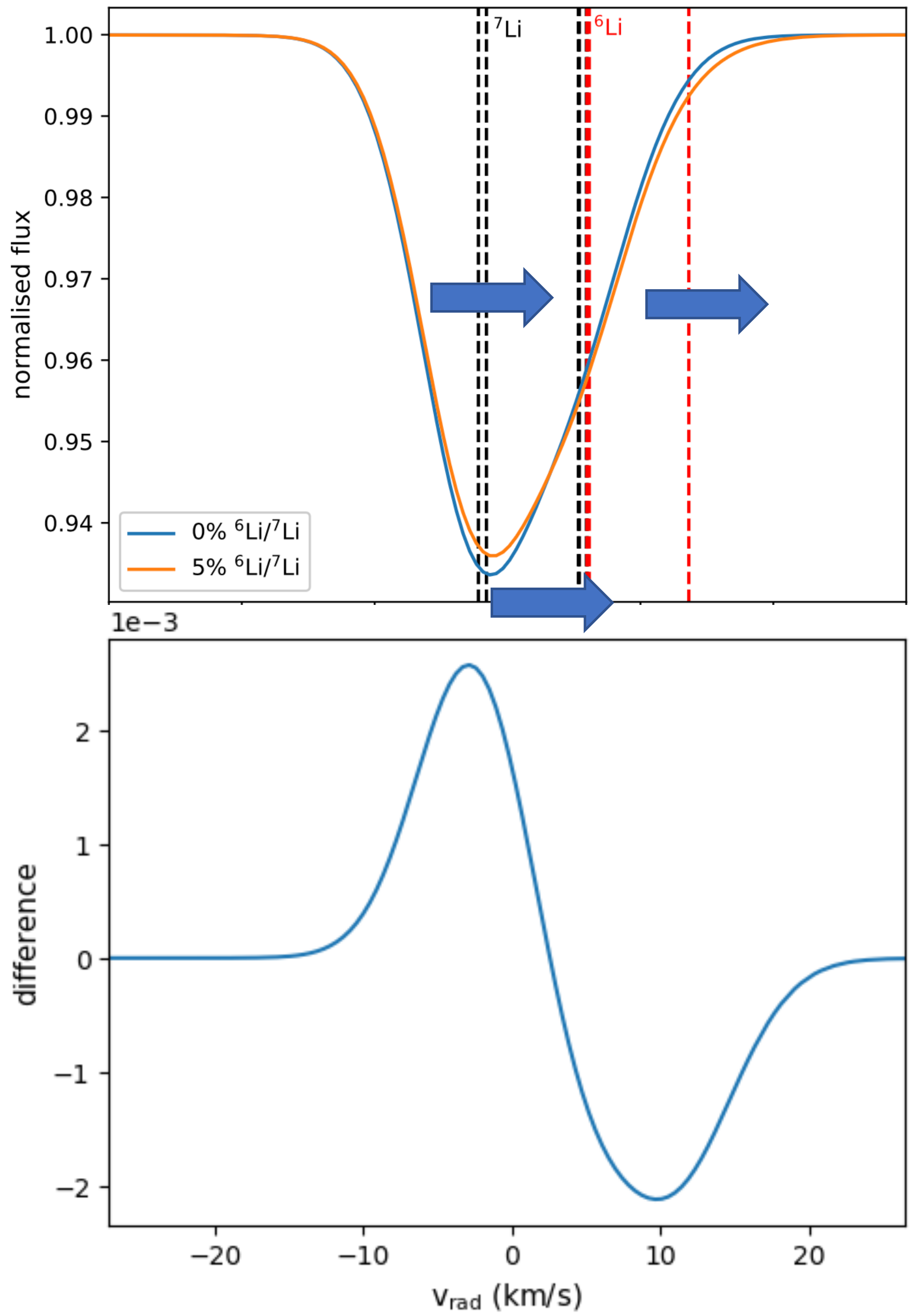
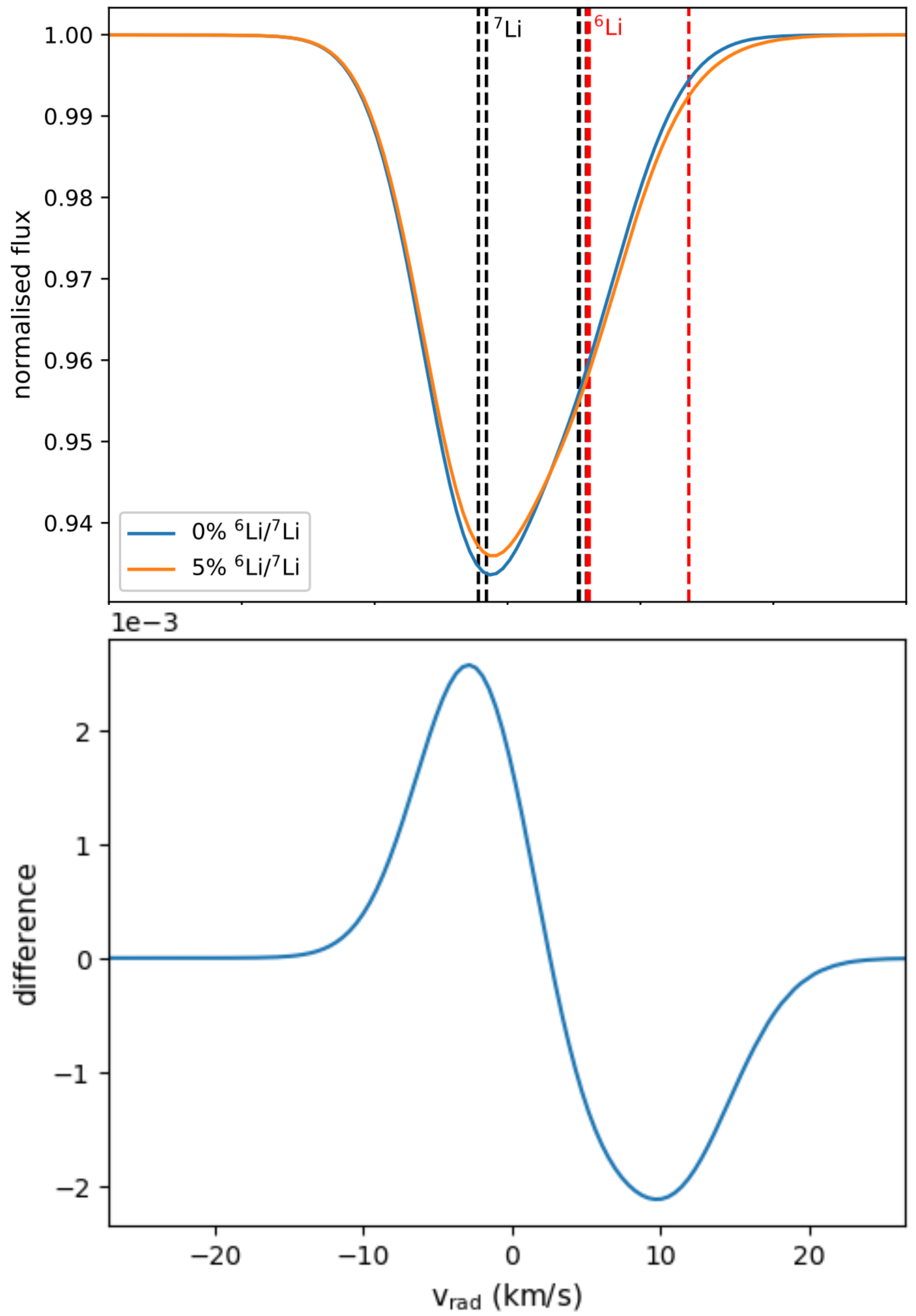


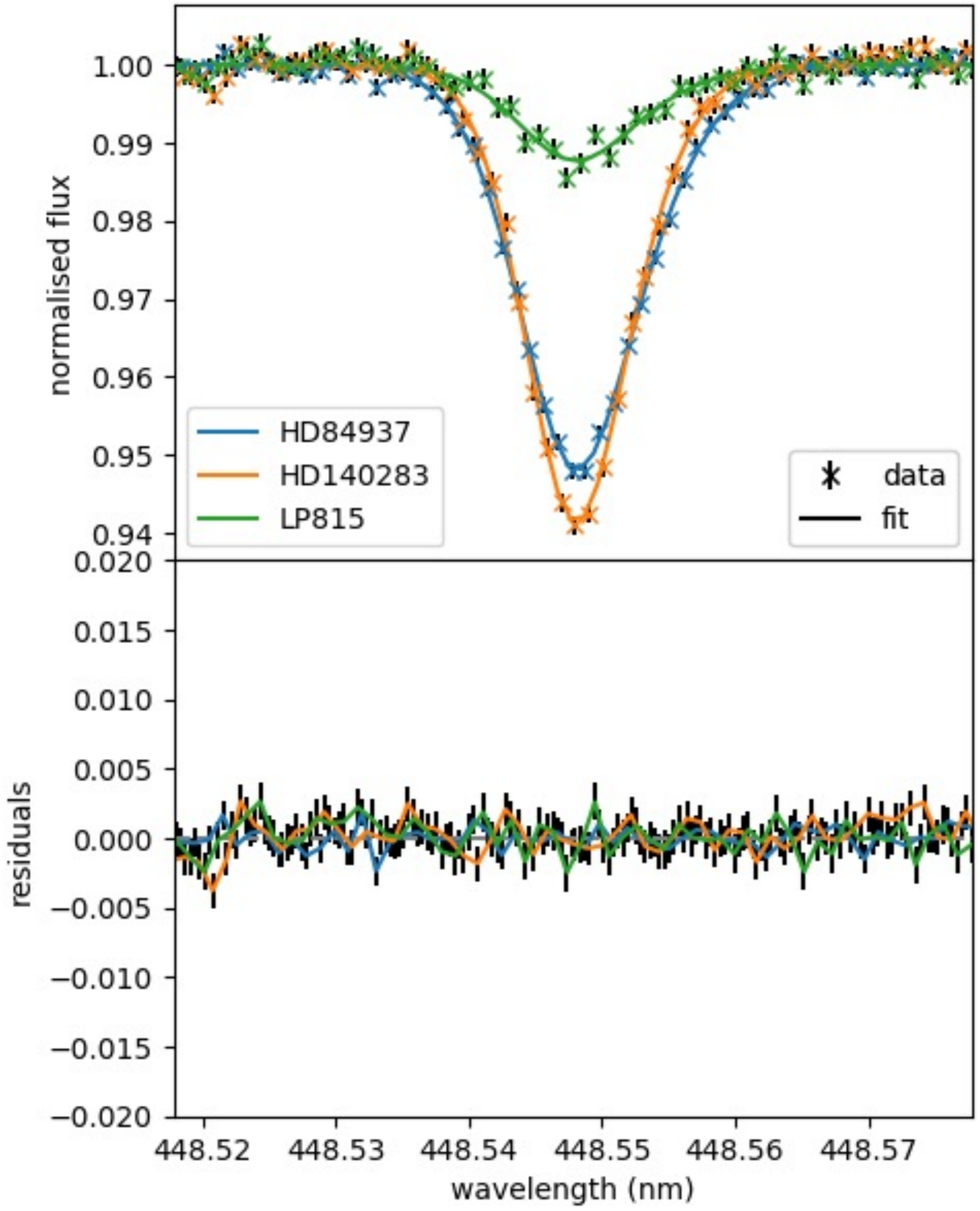
Li 670.8 nm line

- Li abundance A(Li)
- Isotopic ratio ^{6}Li/^{7}Li
- Rotational velocity vsin(i)
- Radial velocity v_{rad}
- <u>All partially degenerate!</u>



ESPRESSO spectra

- <30h on ESPRESSO@VLT



ESPRESSO spectra

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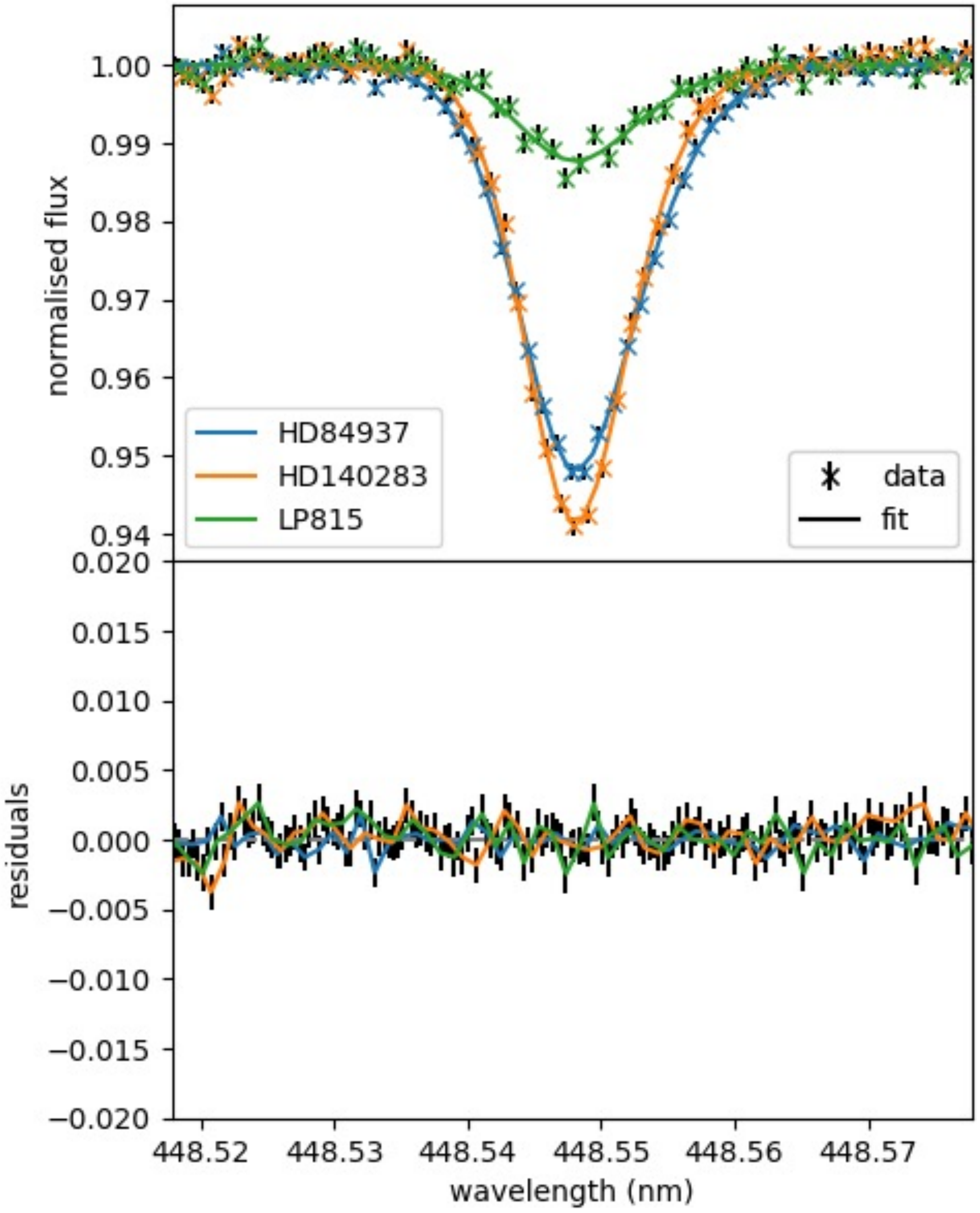

ESPRESSO spectra

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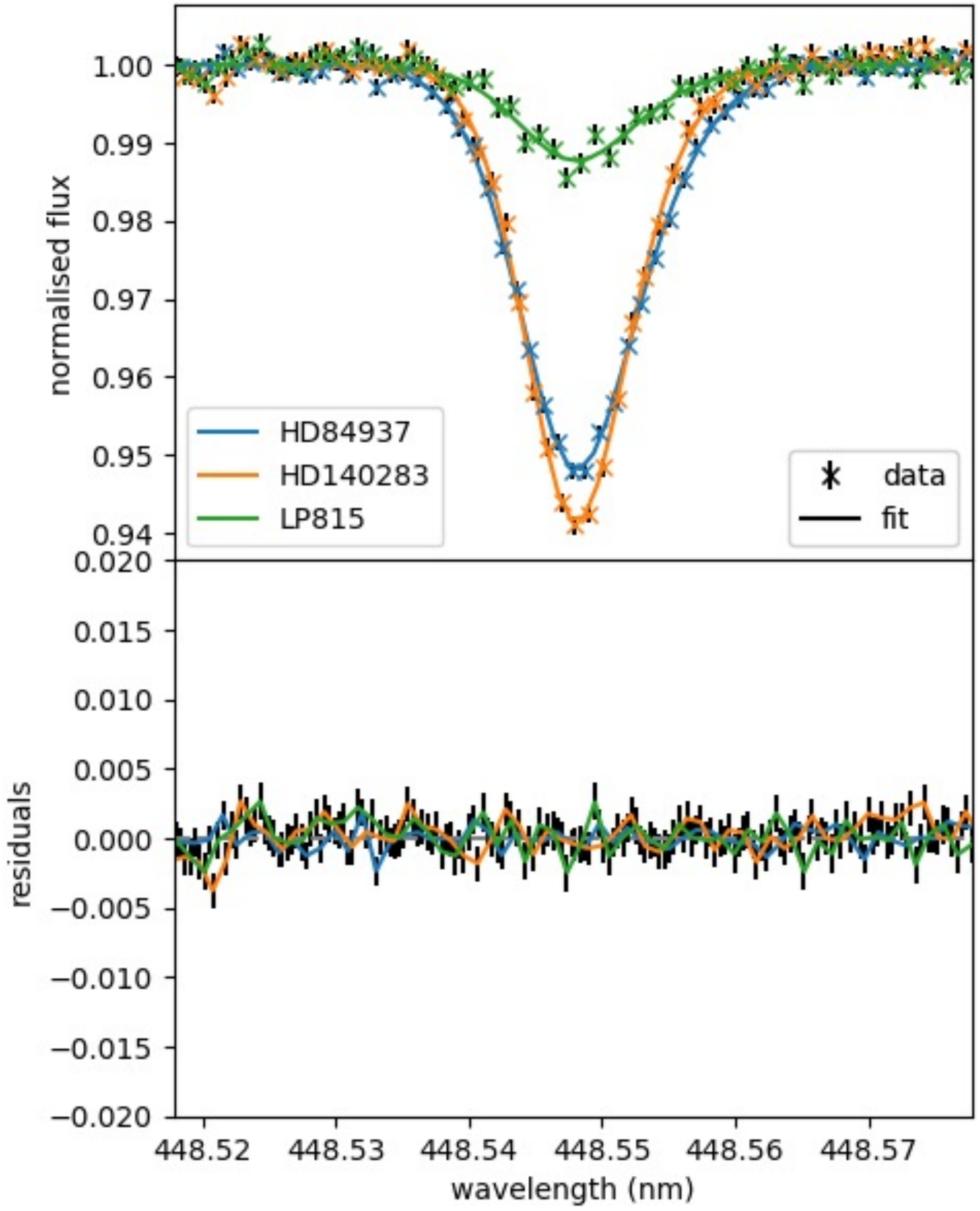
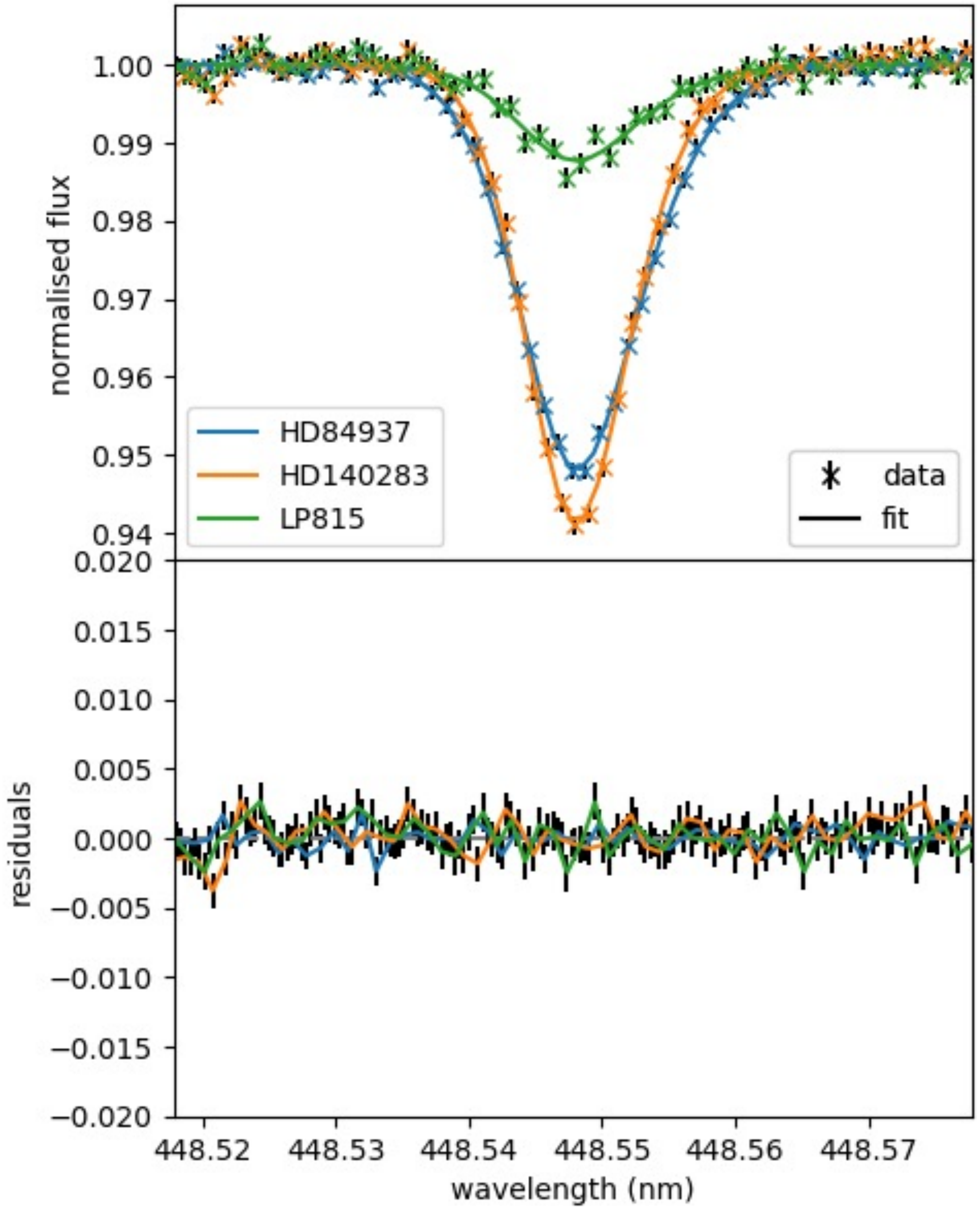
- S/N > 1000



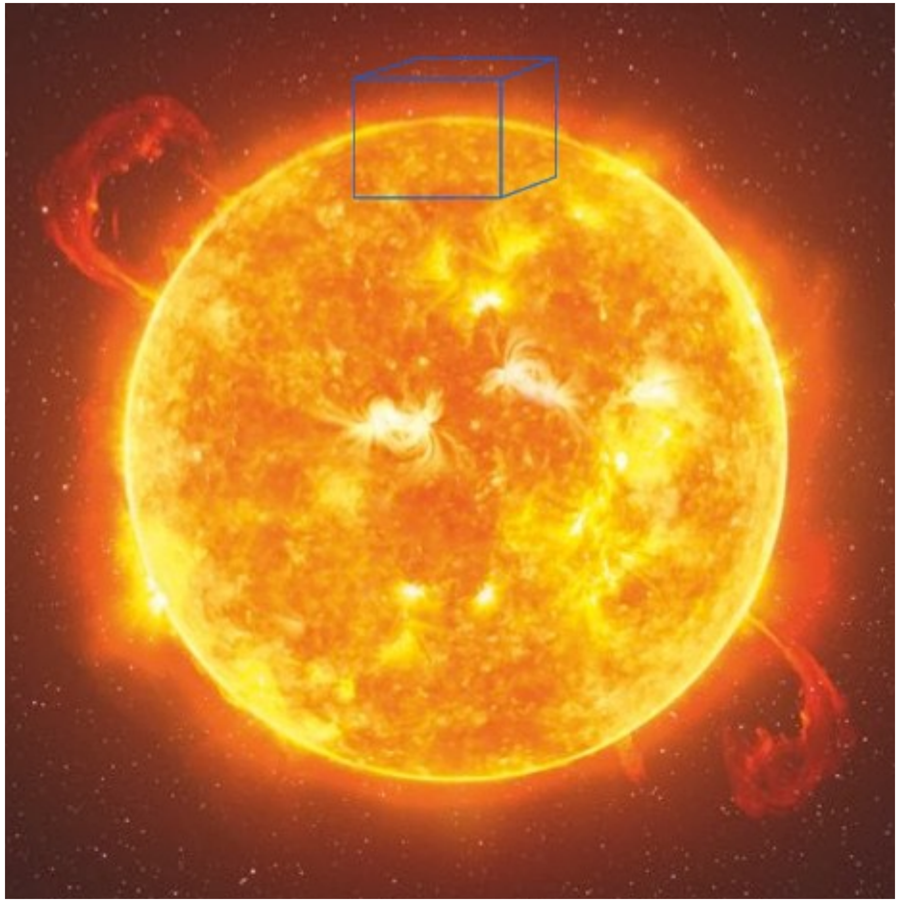
ESPRESSO spectra

- <30h on ESPRESSO@VLT
- R > 140 000
- S/N > 1000
- HD 84937: [Fe/H] = -2.07
  - Detections: Smith et al. 1993, 1998, Hobbs & Thorburn 1994, Cayrel et al. 1999, Asplund et al. 2006, Steffen et al. 2012
  - Non-detection: Lind et al. 2013
- HD 140283: [Fe/H] = -2.29
- LP 815-43: [Fe/H] = -2.70



Synthetic spectra: model atmospheres

- Model stellar atmosphere
  - “box-in-a-star”



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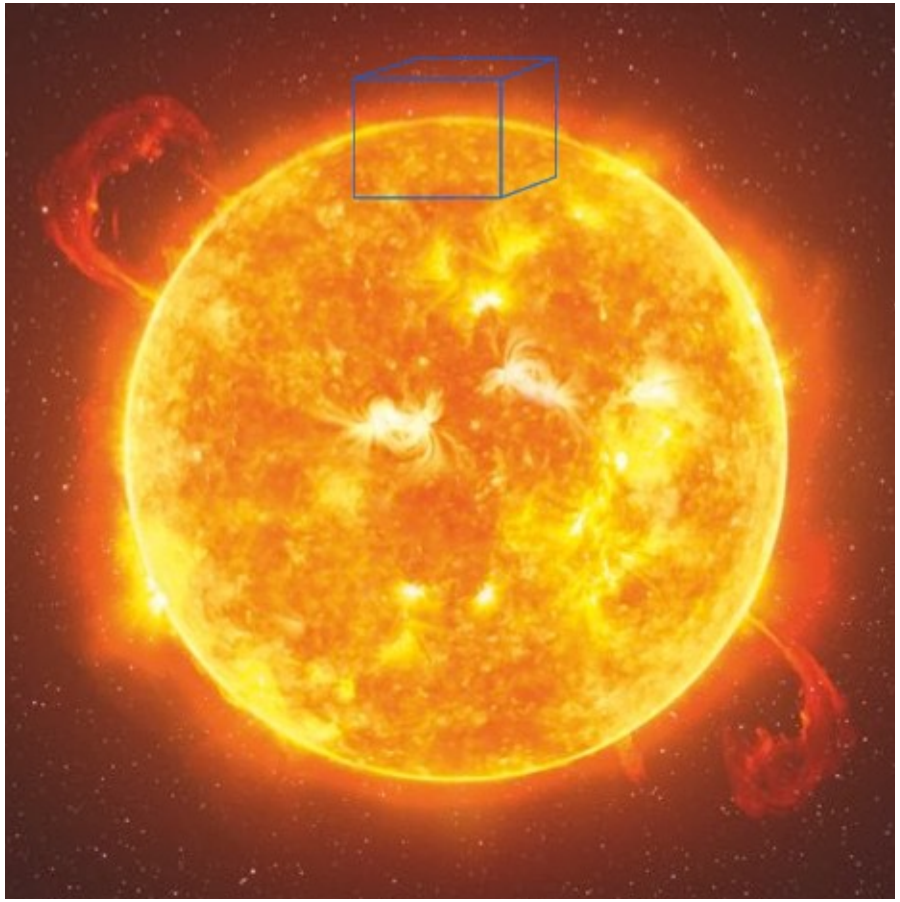
1D



Synthetic spectra: model atmospheres

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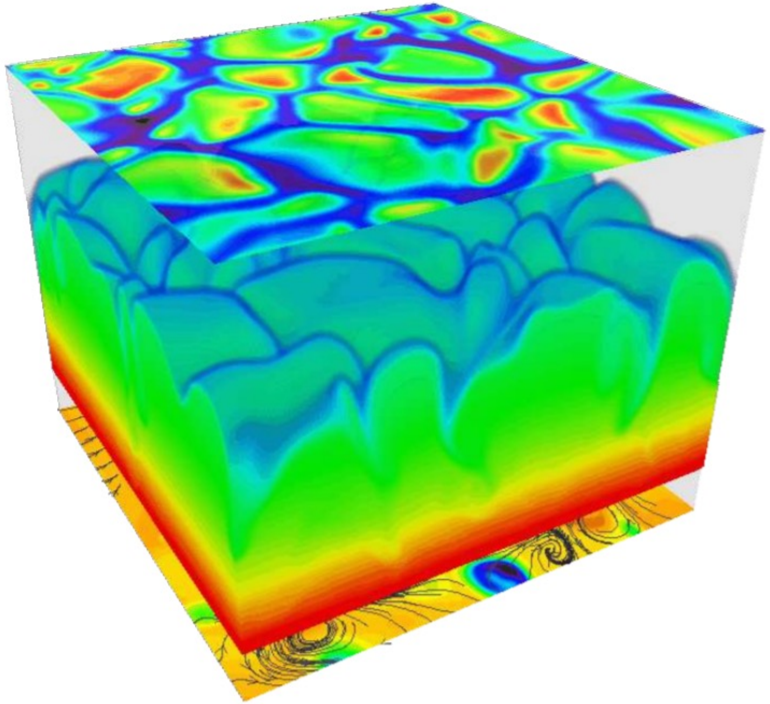
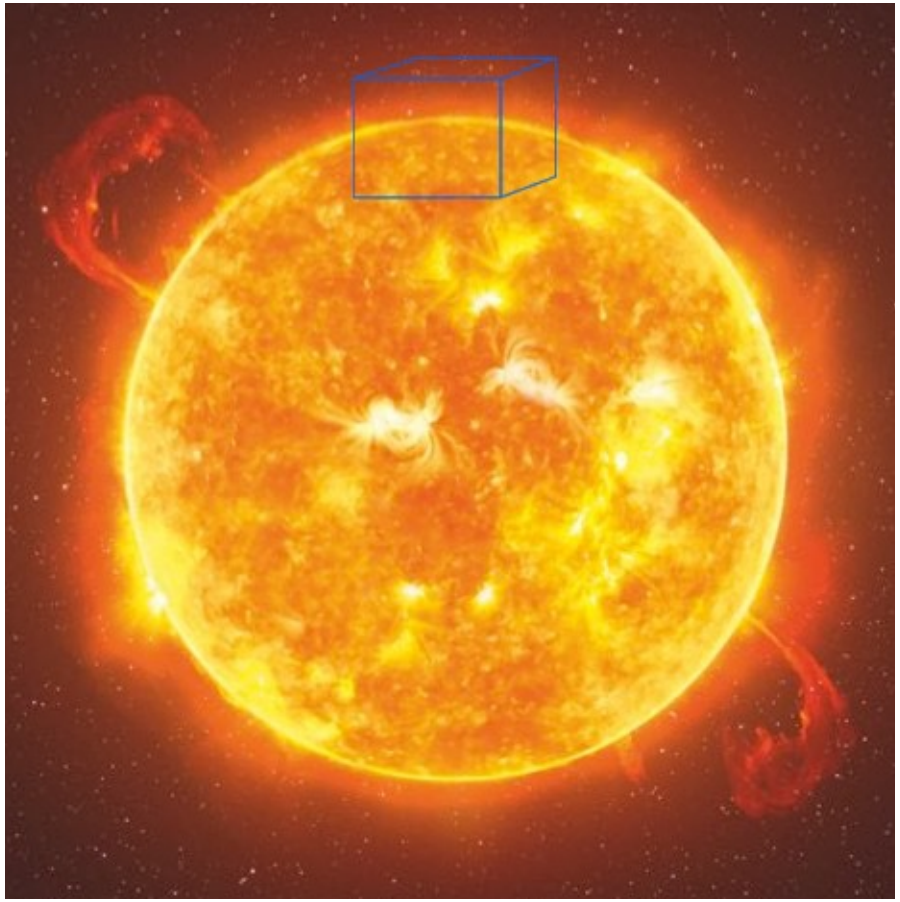
1D

3D

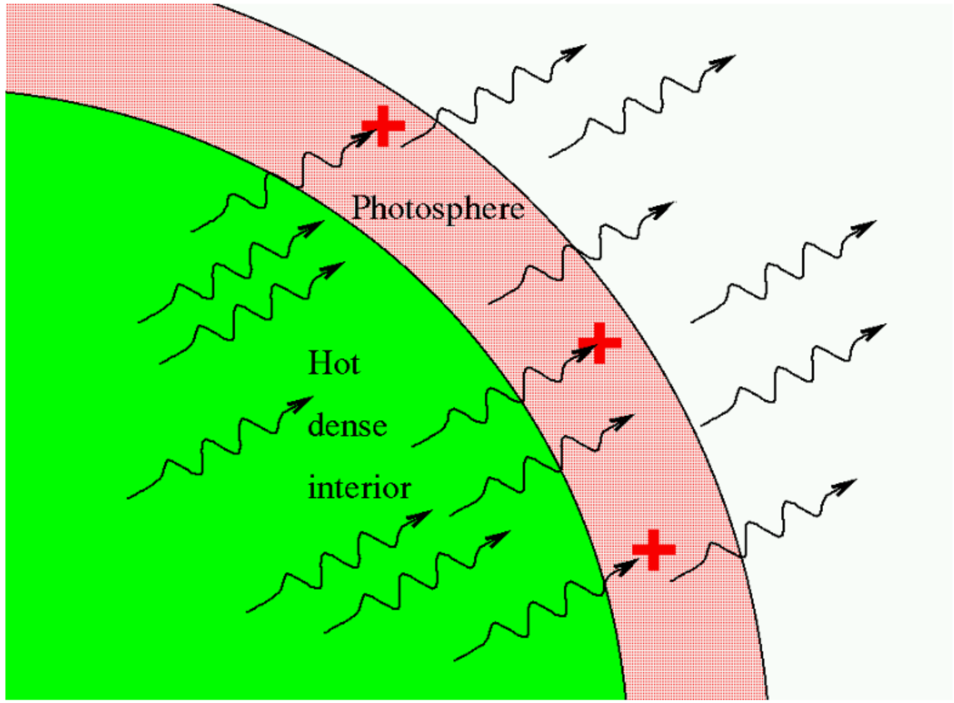




Synthetic spectra: radiative transfer

LTE

- Assume local thermodynamic equilibrium
- Held in deeper layers of the atmosphere



Synthetic spectra: radiative transfer

LTE

- Assume local thermodynamic equilibrium
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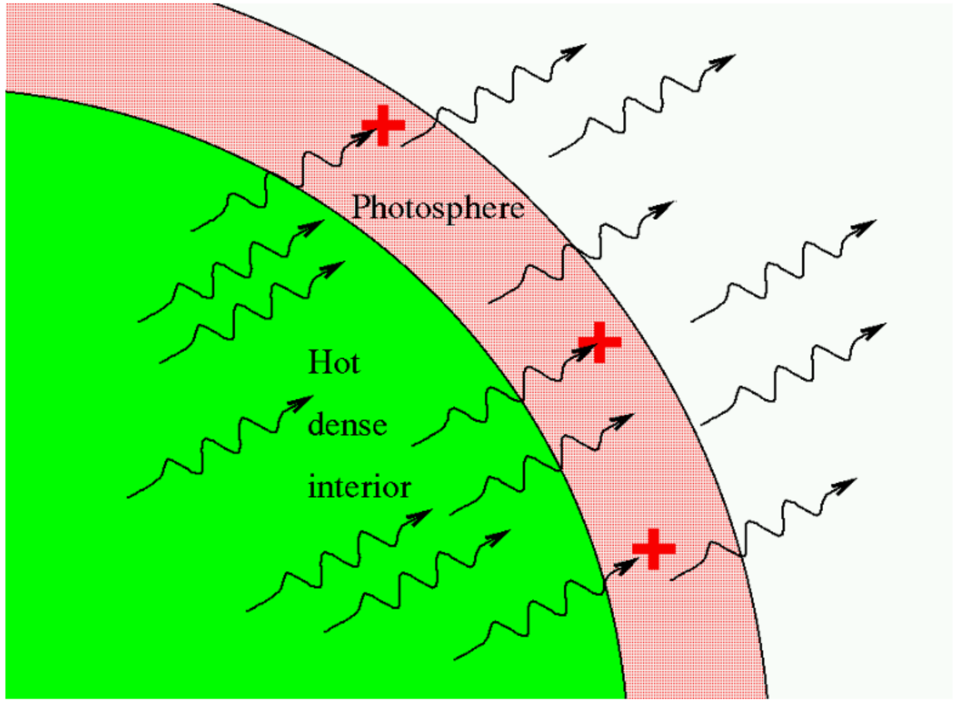
NLTE

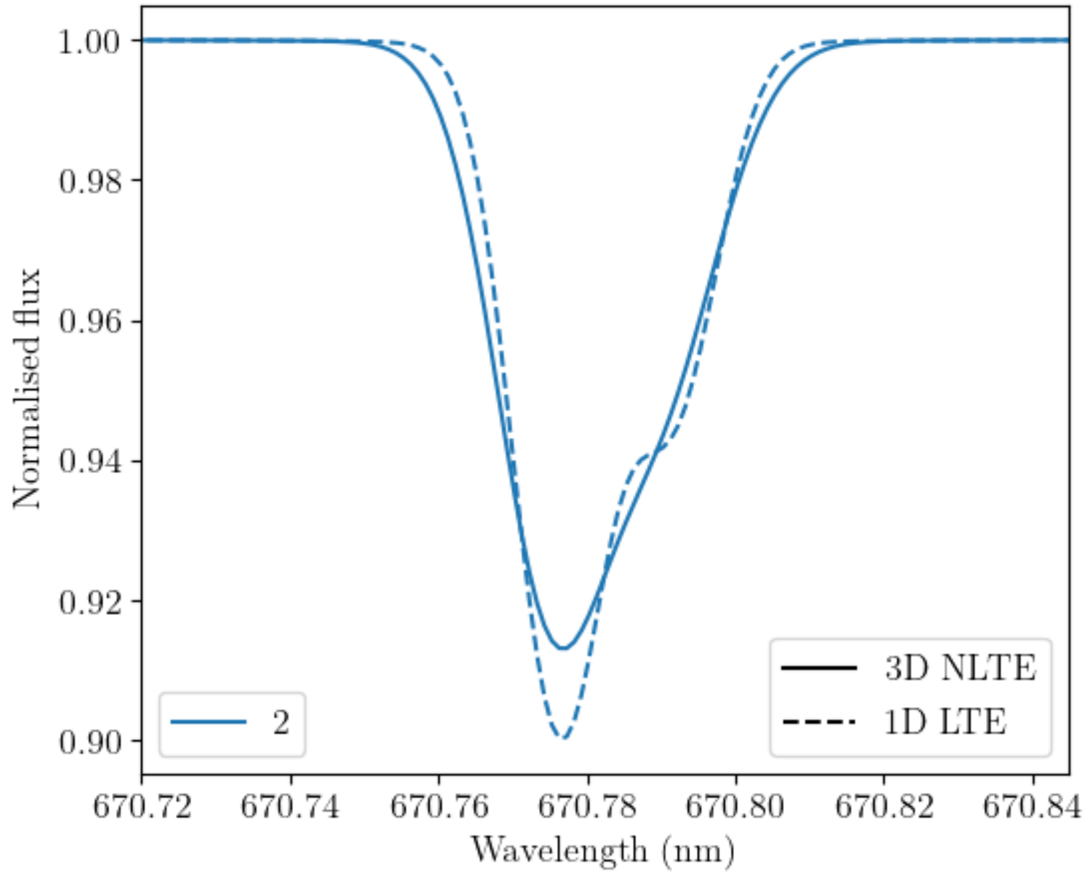
- Relax assumption of LTE
- Held in surface layers of the atmosphere



State of the art synthetic spectra

In the past…

- 1D hydrostatic model atmospheres
- LTE radiative transfer



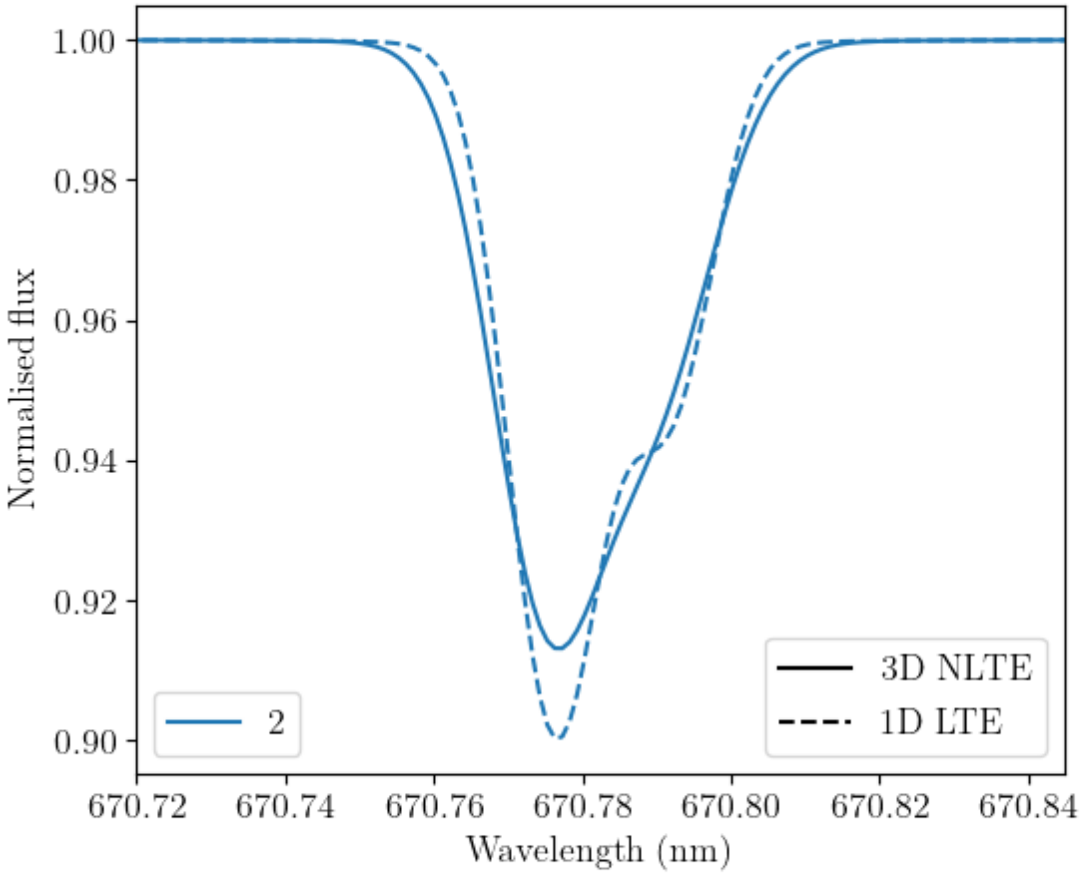
State of the art synthetic spectra

In the past…

- 1D hydrostatic model atmospheres
- LTE radiative transfer

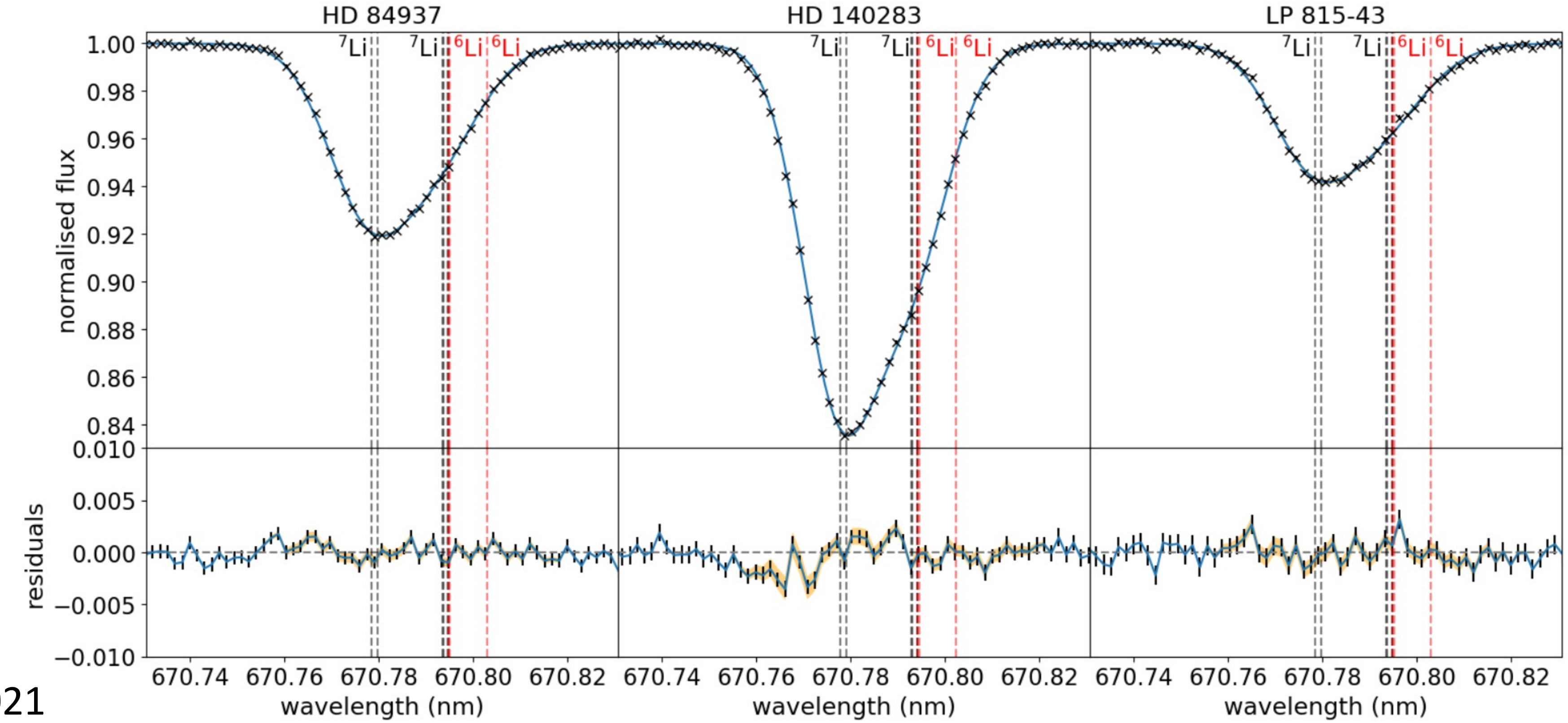
Today…

- 3D hydrodynamic model atmospheres
- NLTE radiative transfer



Li fit

- We use 3D NLTE synthetic spectra and 3 different fitting methods
- Fit: Li abundance, $^{6}Li/^{7}Li$, vsini, v_{rad}



Wang et al. 2021

Li fit

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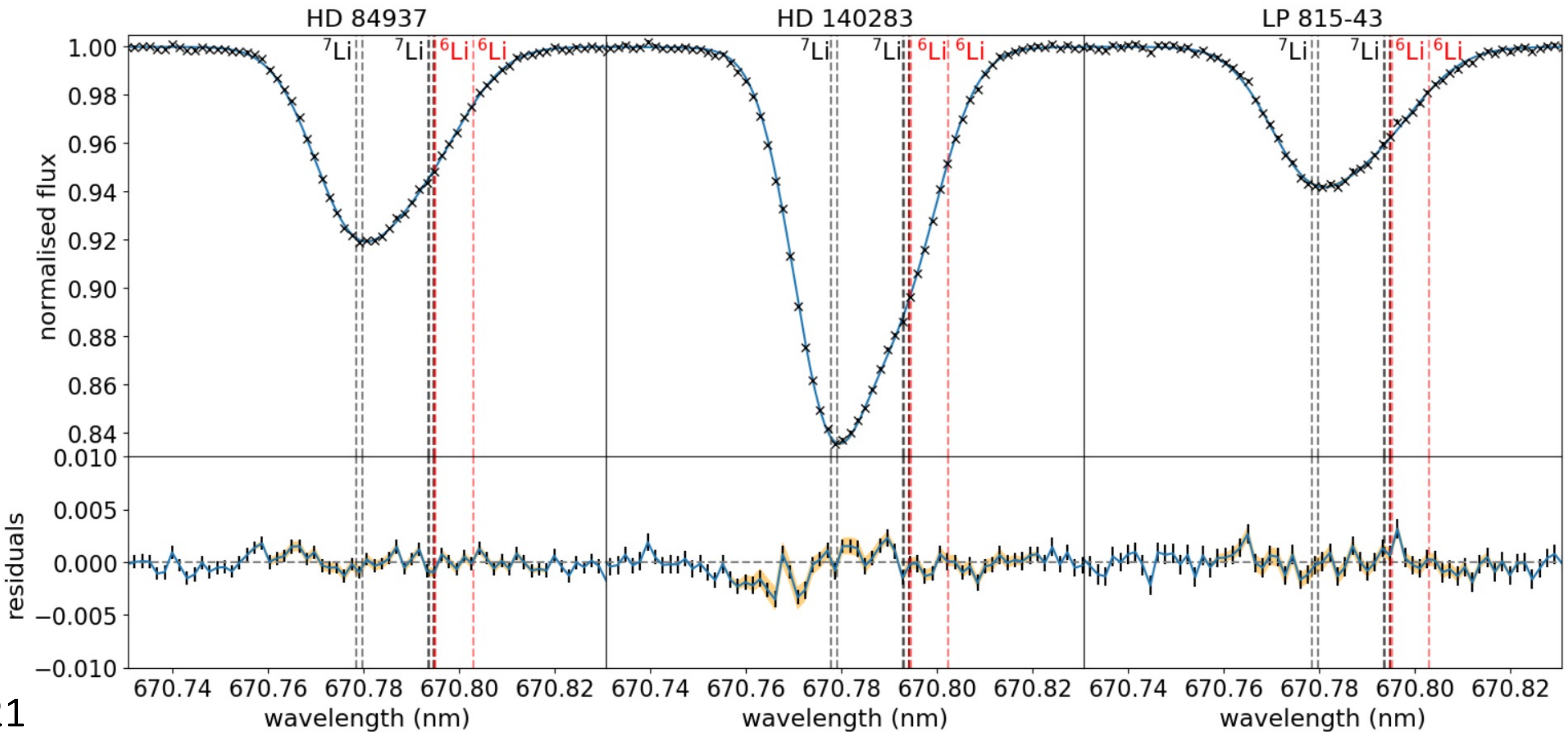
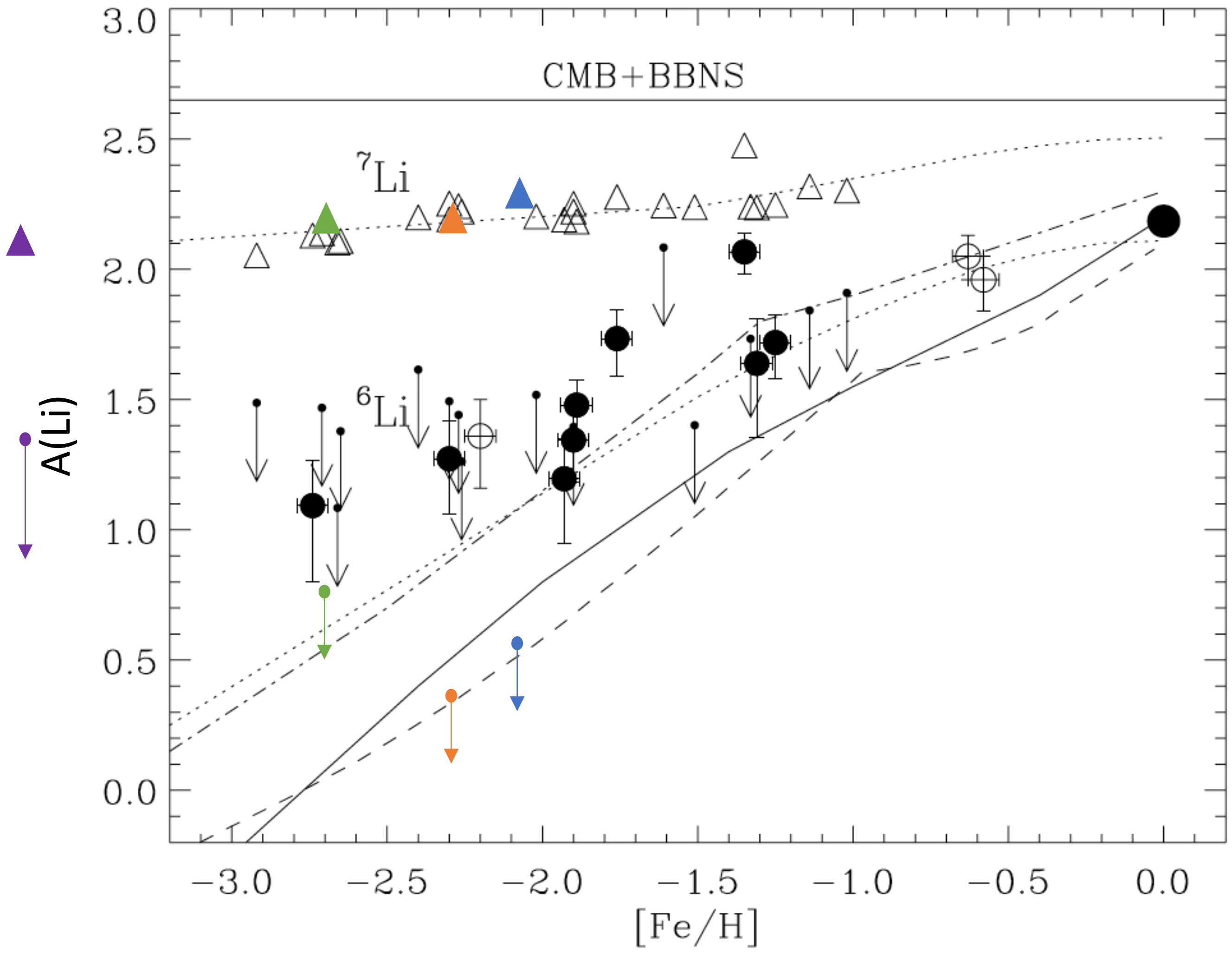
- 99% MCMC errors



Wang et al. 2021

Results



Asplund et al. 2006

HD 84937
HD 140283
LP 815-43
CS 22876–032A (González Hernández et al. 2019)

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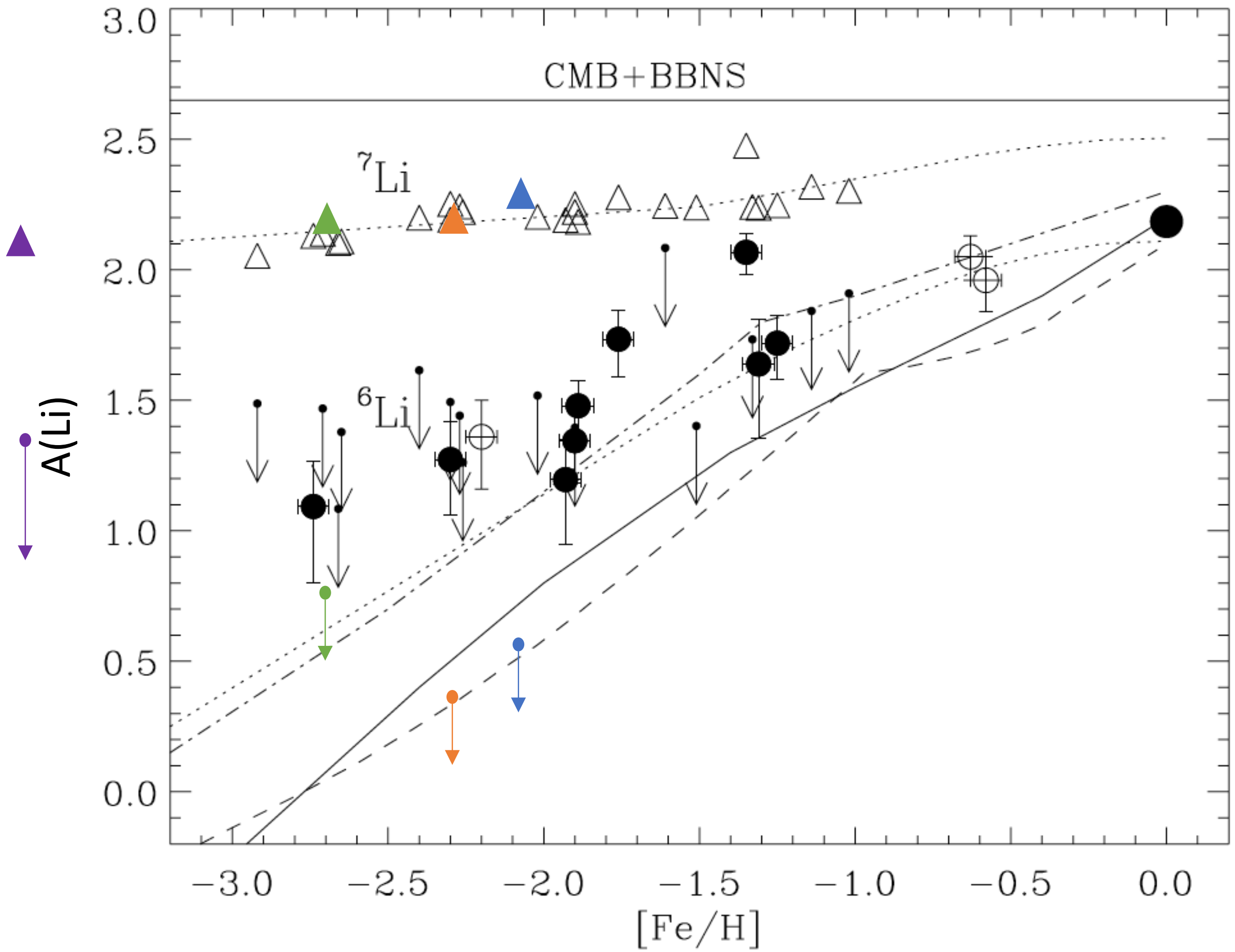

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- We do not detect ^{6}Li in any of our stars

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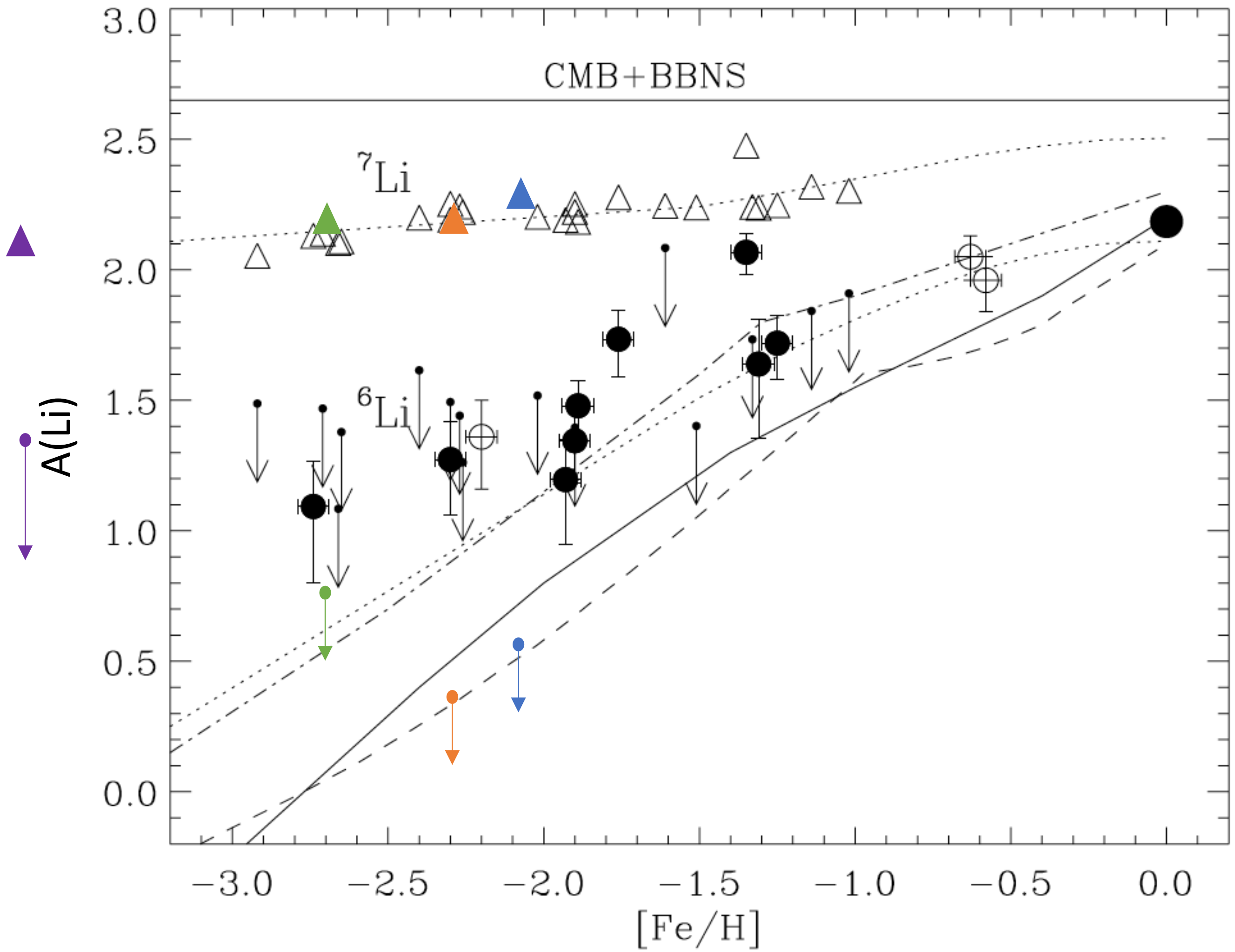

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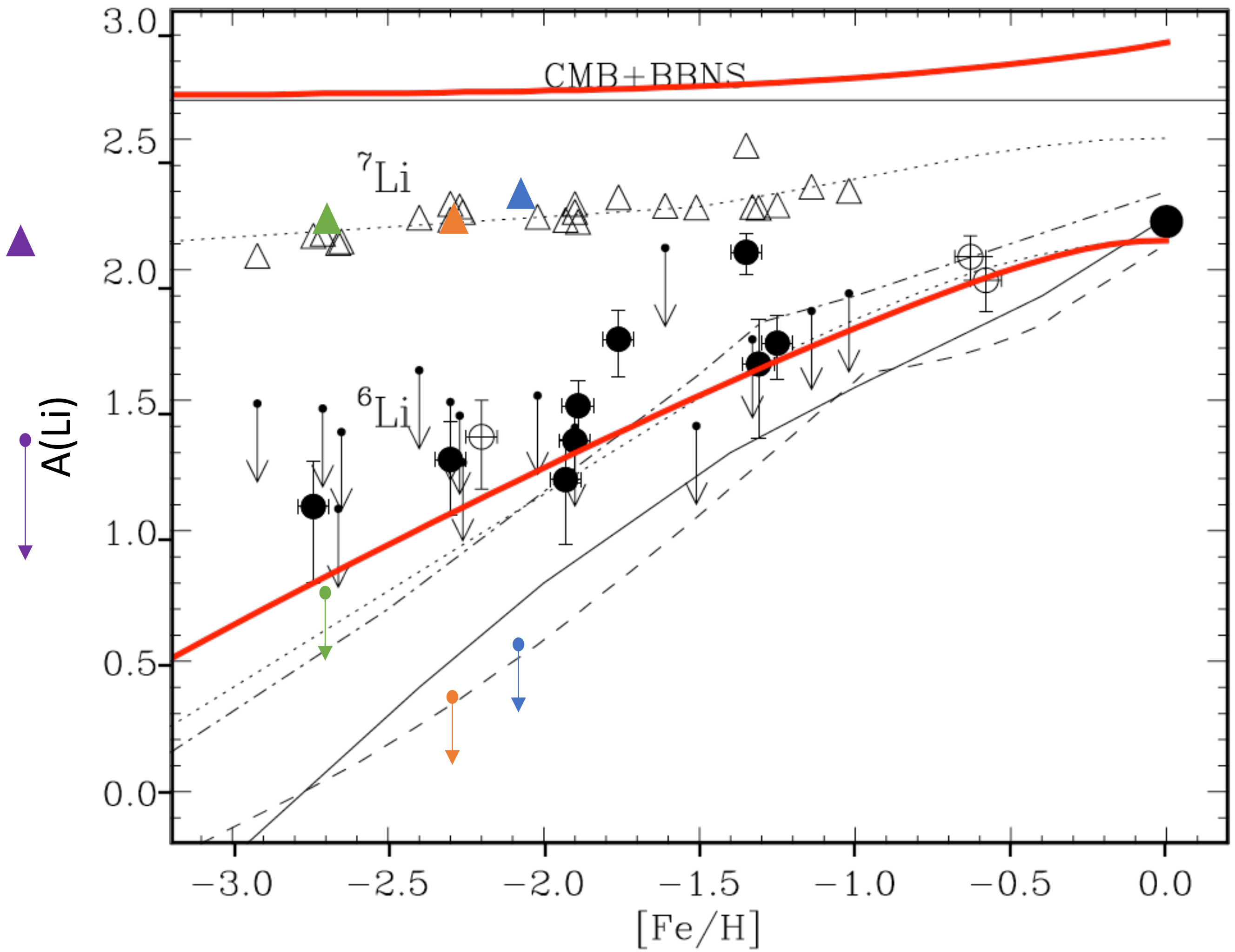

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GCR modelling (Fields & Olive 2022)

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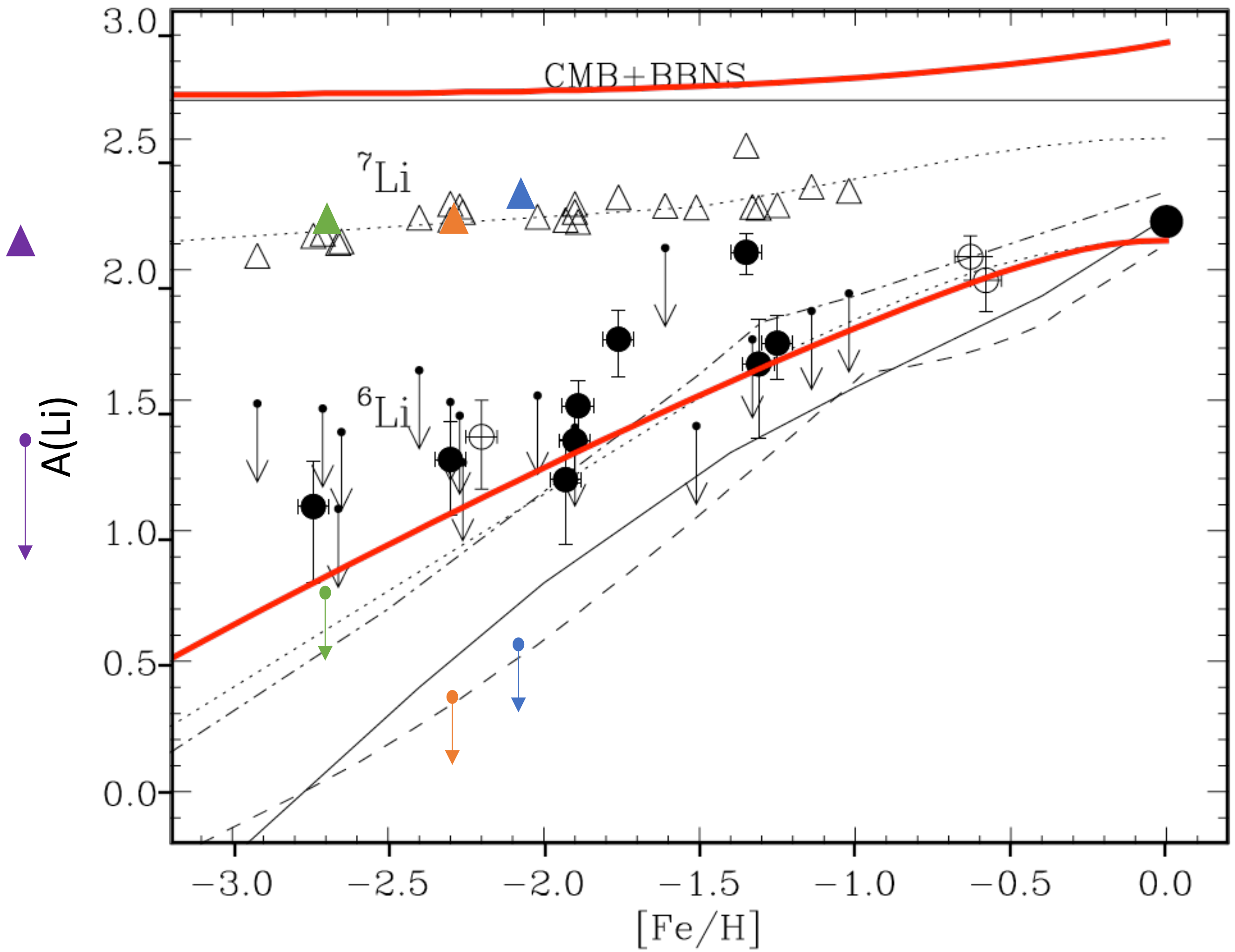

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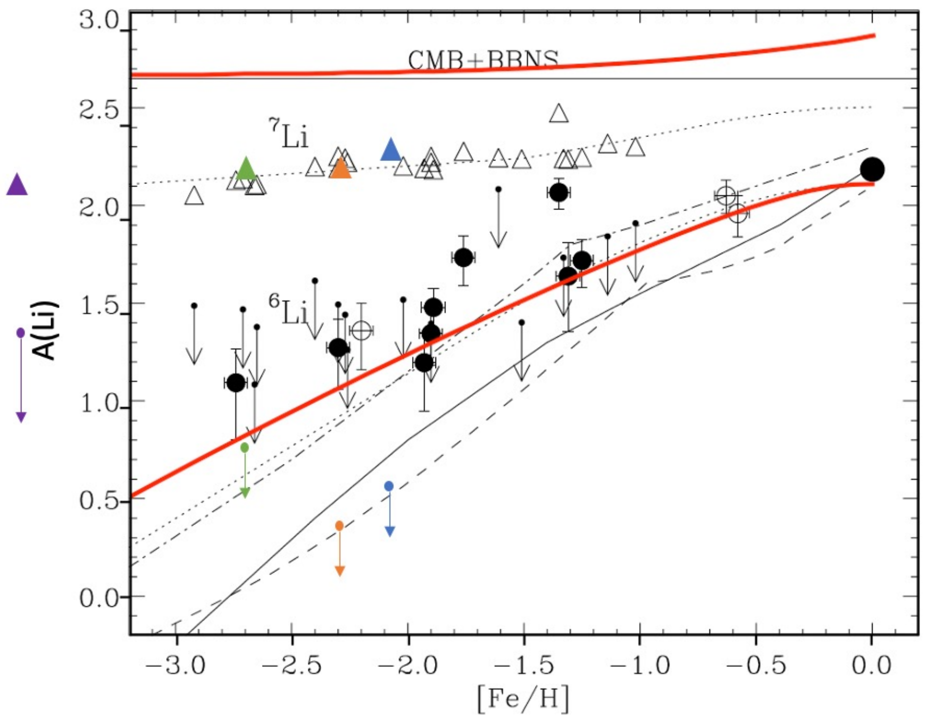
GCR modelling (Fields & Olive 2022)

- Both ^{7}Li and ^{6}Li are now consistent with depletion

arxiv: 2110.03822

Summary

- We revisit the longstanding second cosmological lithium problem (^6Li)



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Summary

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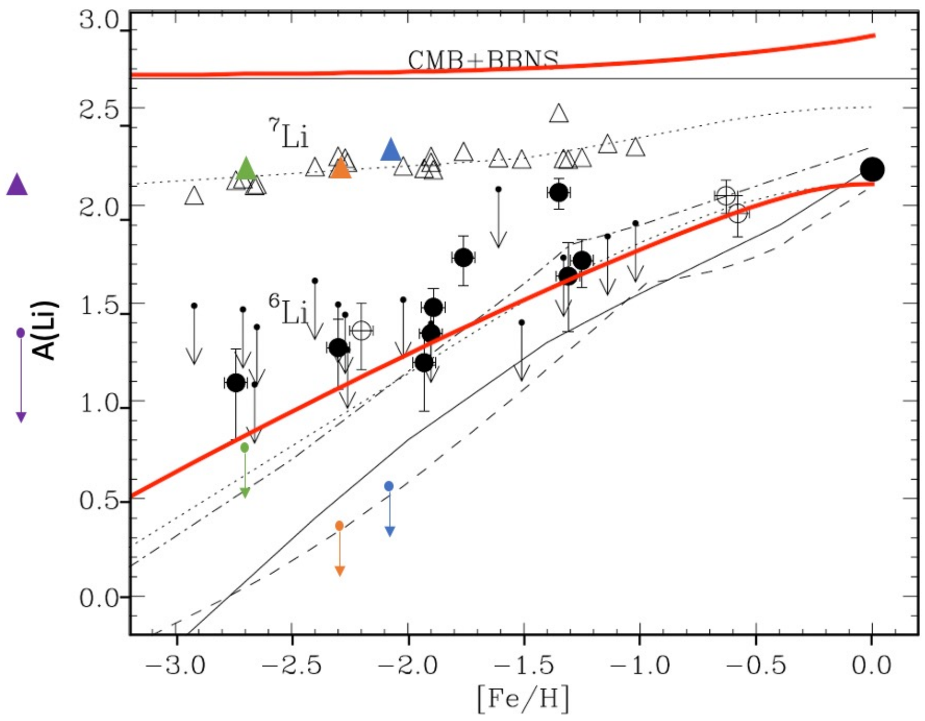
- We find that there is no longer any convincing evidence of ^{6}Li in very metal-poor stars
  - There is no second cosmological lithium problem



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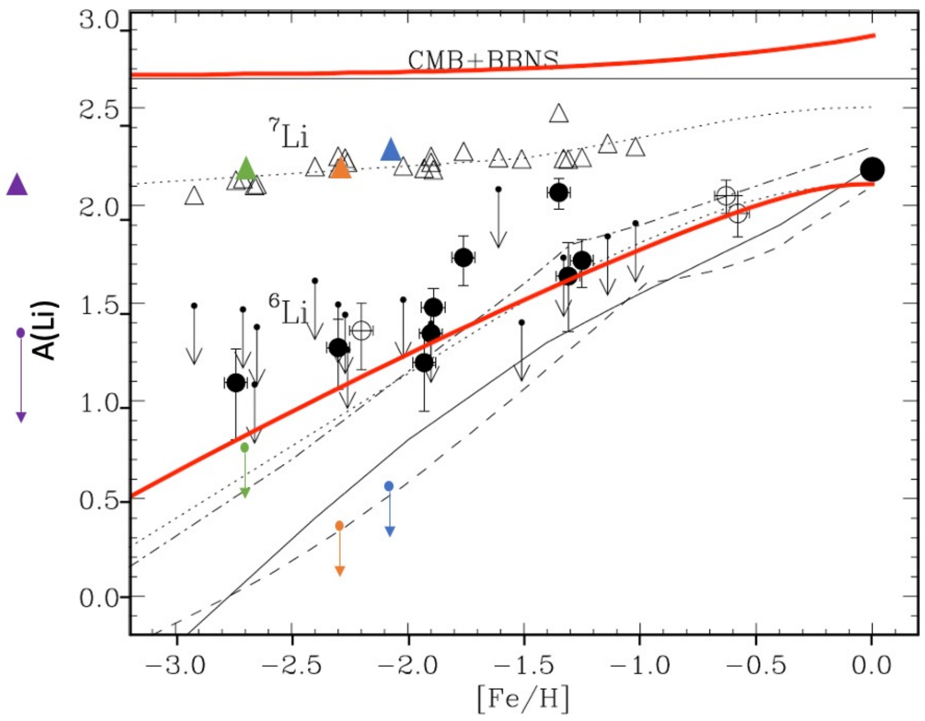
Summary

- We revisit the longstanding second cosmological lithium problem (^{6}Li)
- We find that there is no longer any convincing evidence of ^{6}Li in very metal-poor stars
  - There is no second cosmological lithium problem
- With new GCR modelling, there is strong evidence for depletion of both ^{6}Li and ^{7}Li through stellar physics (Fields & Olive 2022)
  - The likely solution to the cosmological lithium problem is stellar physics (Korn 2024)



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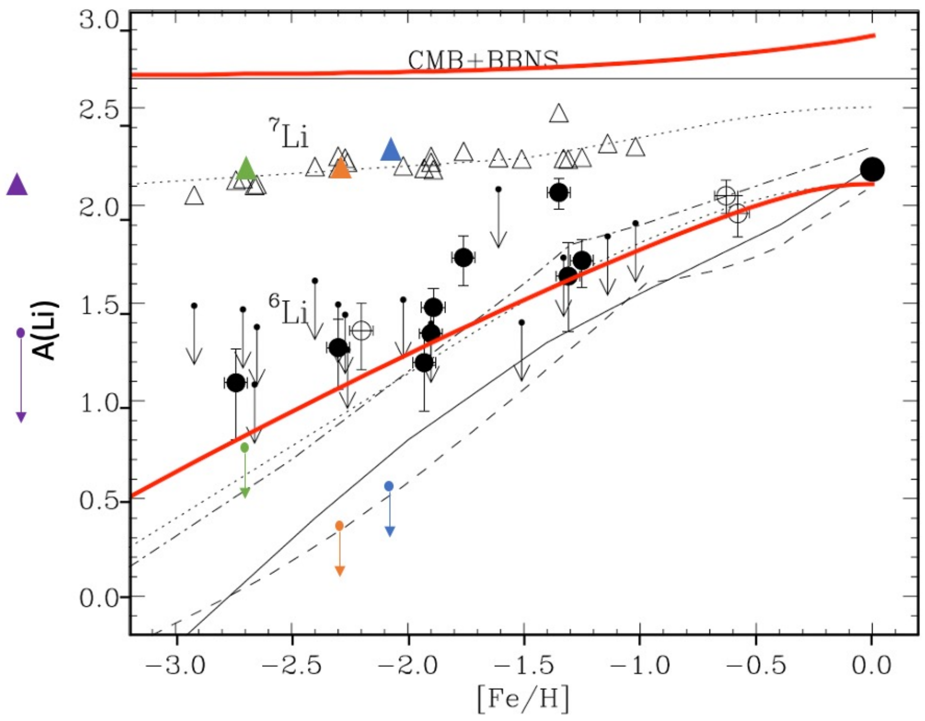

*If current ISM measurements hold then they would once again rule out stellar physics

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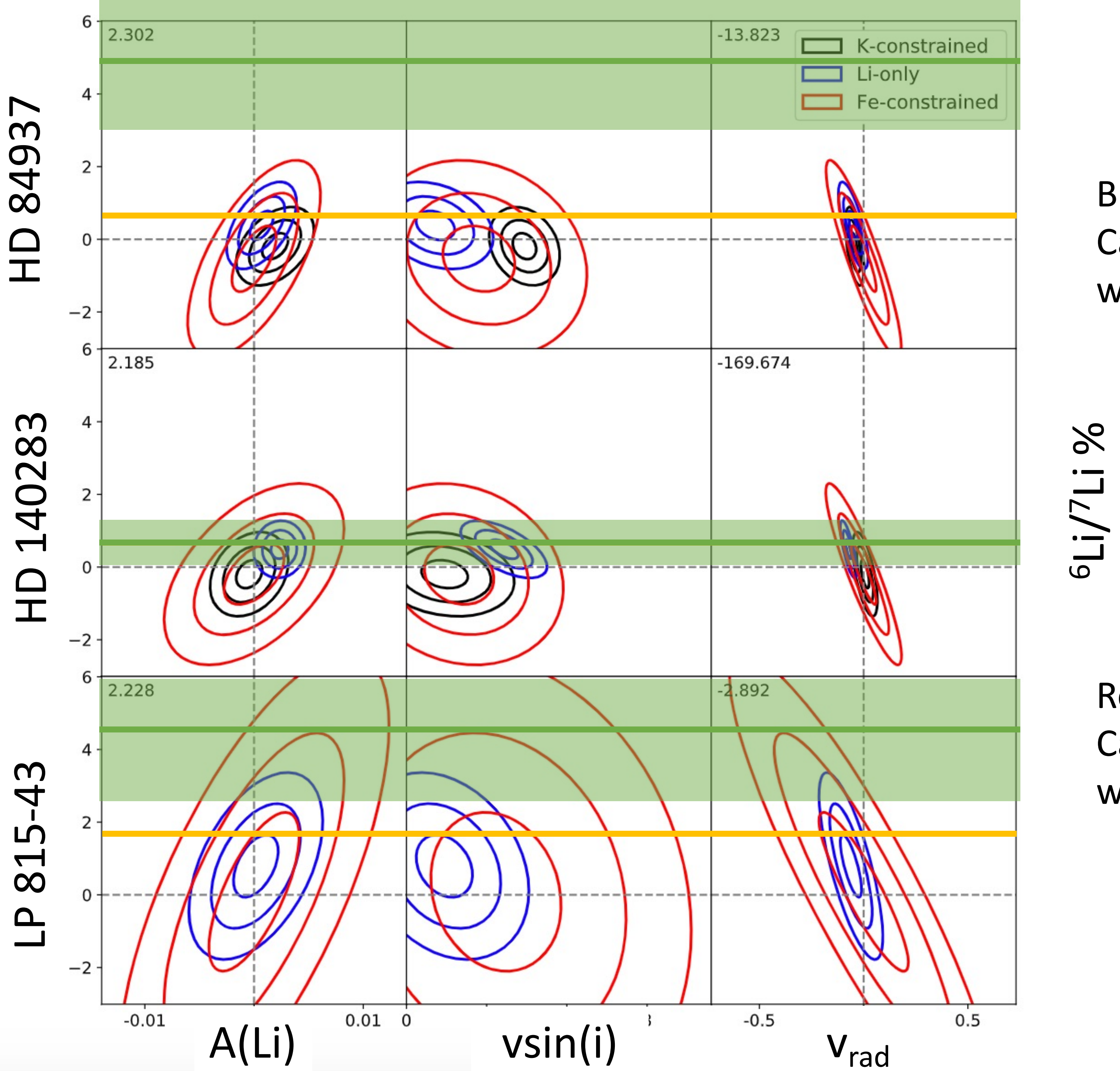
Results

2σ upper limits

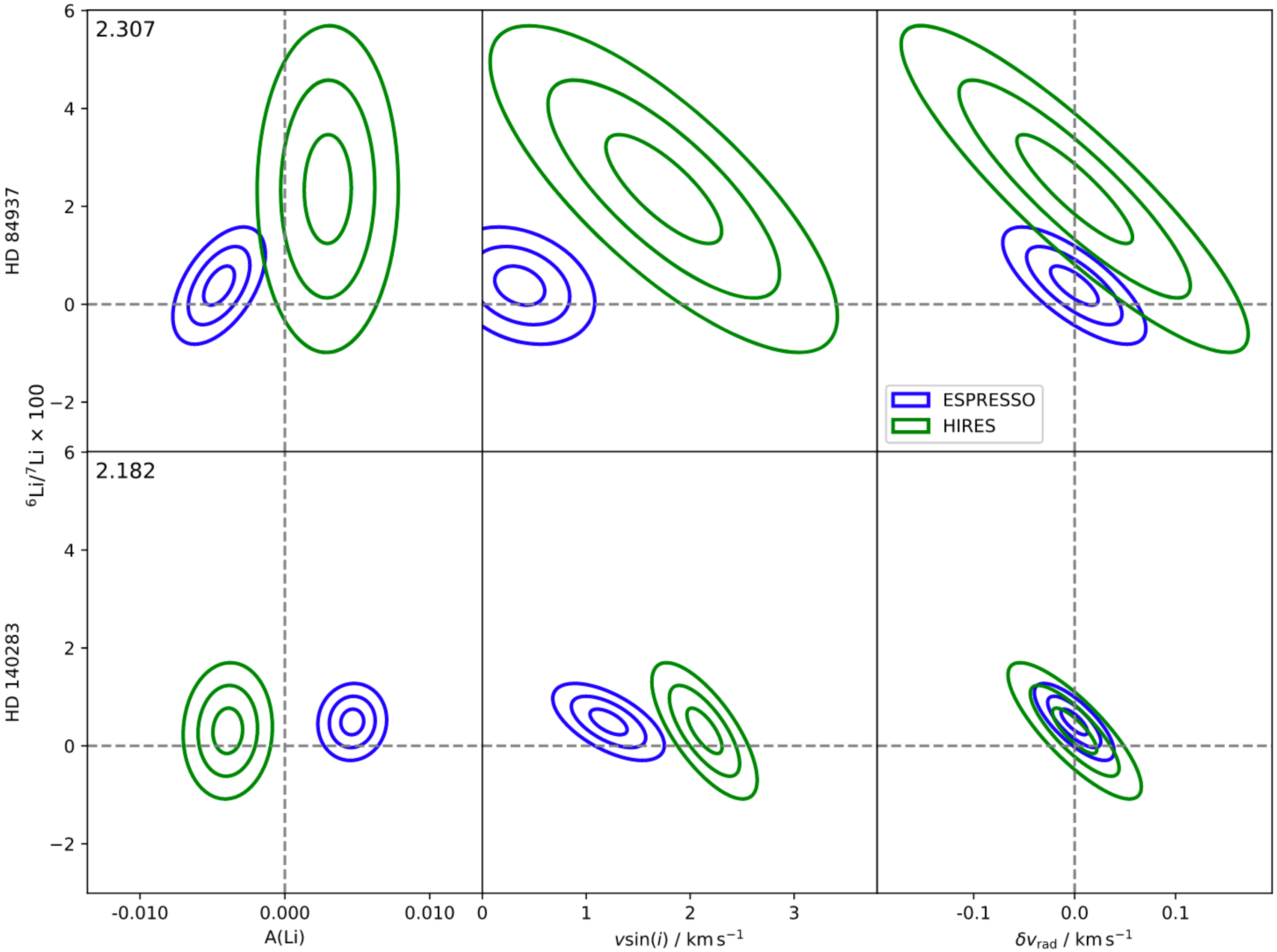
Previous measurements



Black: K-constrained
Calibrate vsin(i) and v_{rad} with K

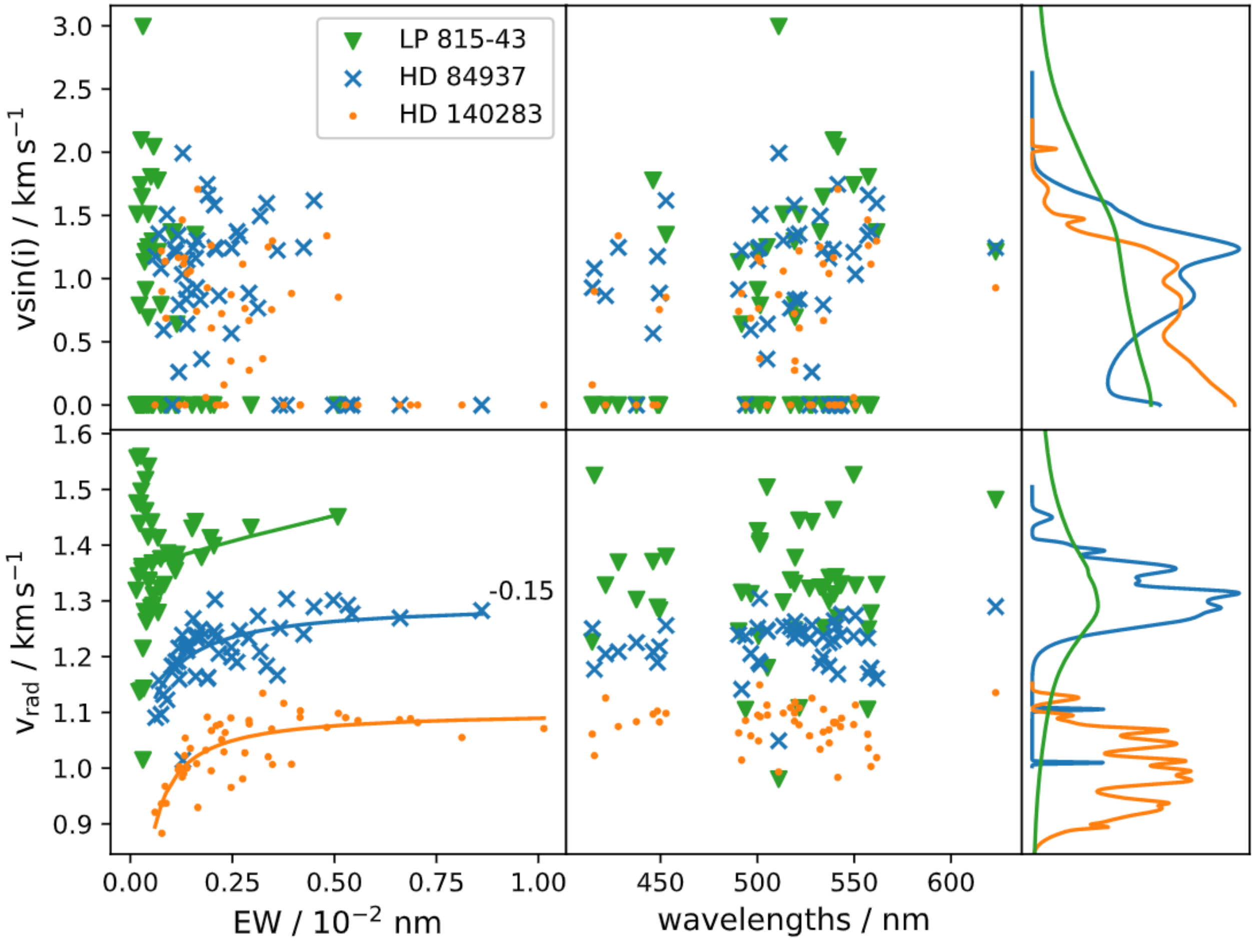
Red: Fe-constrained
Calibrate vsin(i) and v_{rad} with Fe

Wang et al. 2021

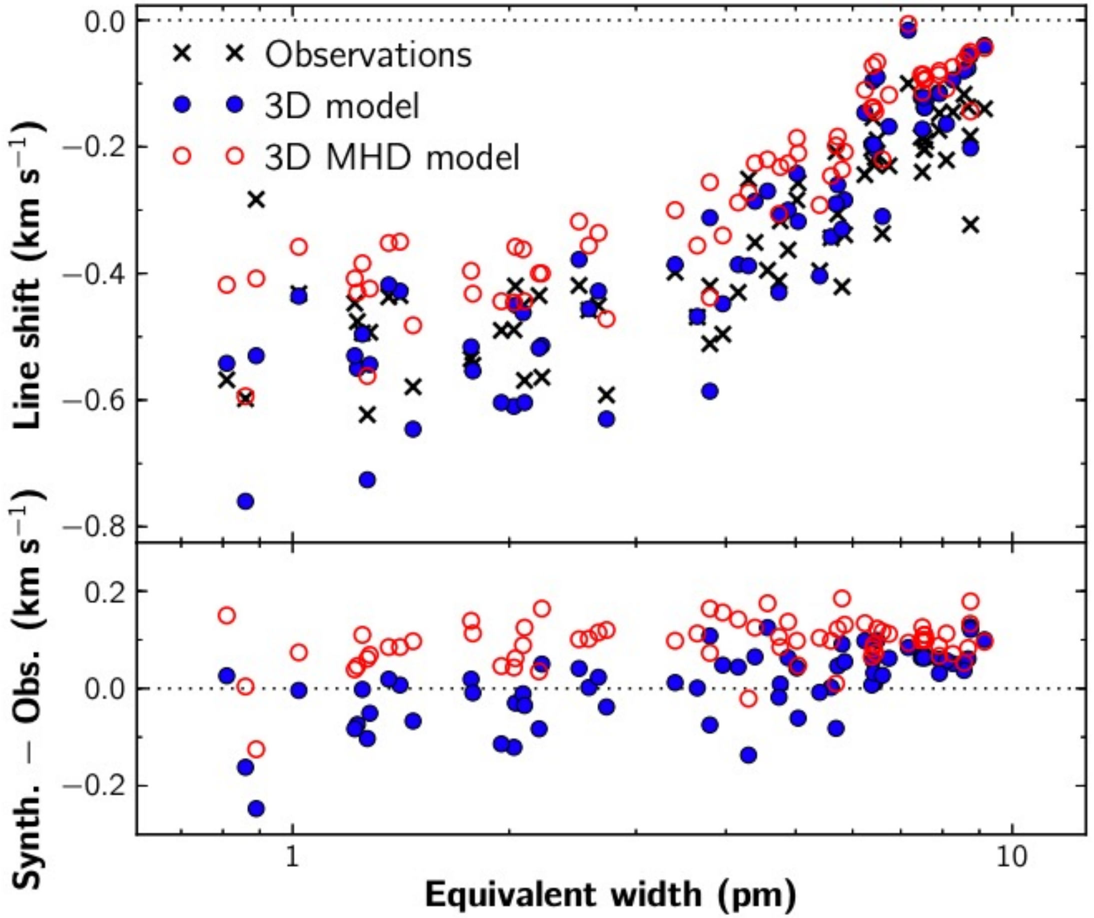


Wang et al. 2021

Fe fits

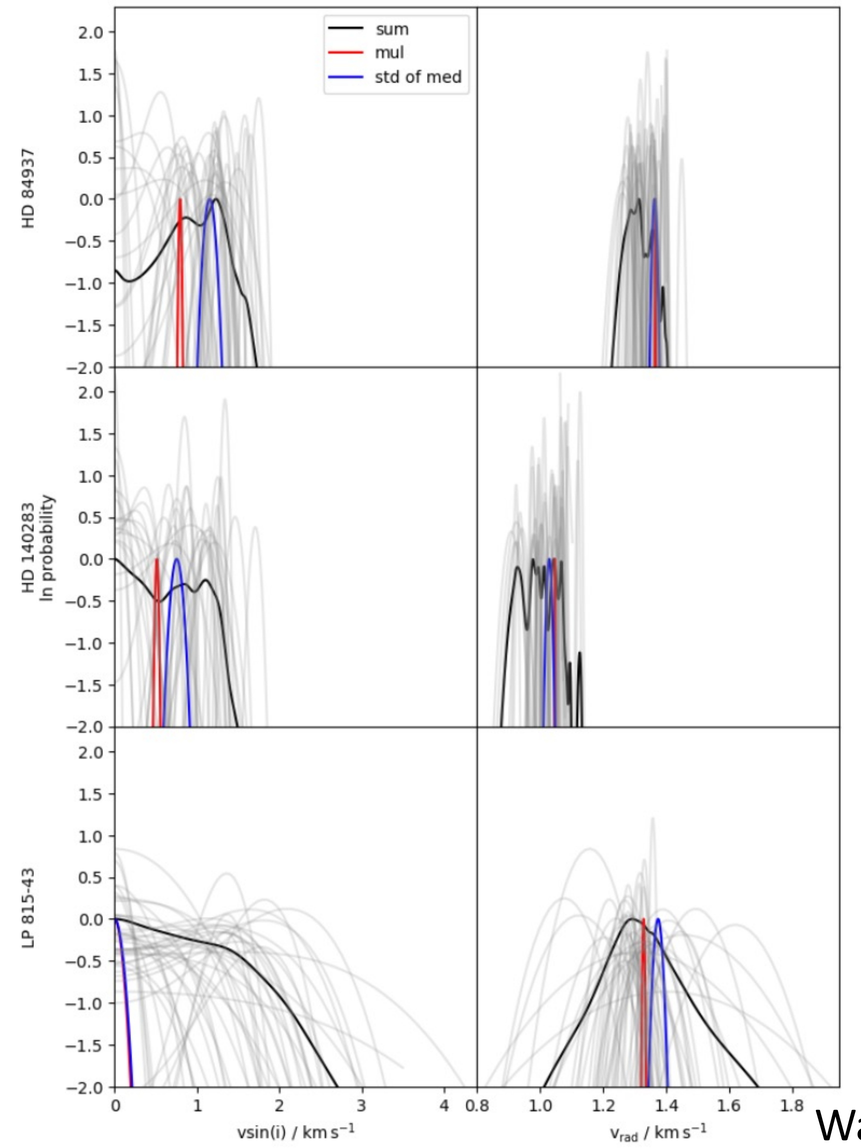


Wang et al. 2021



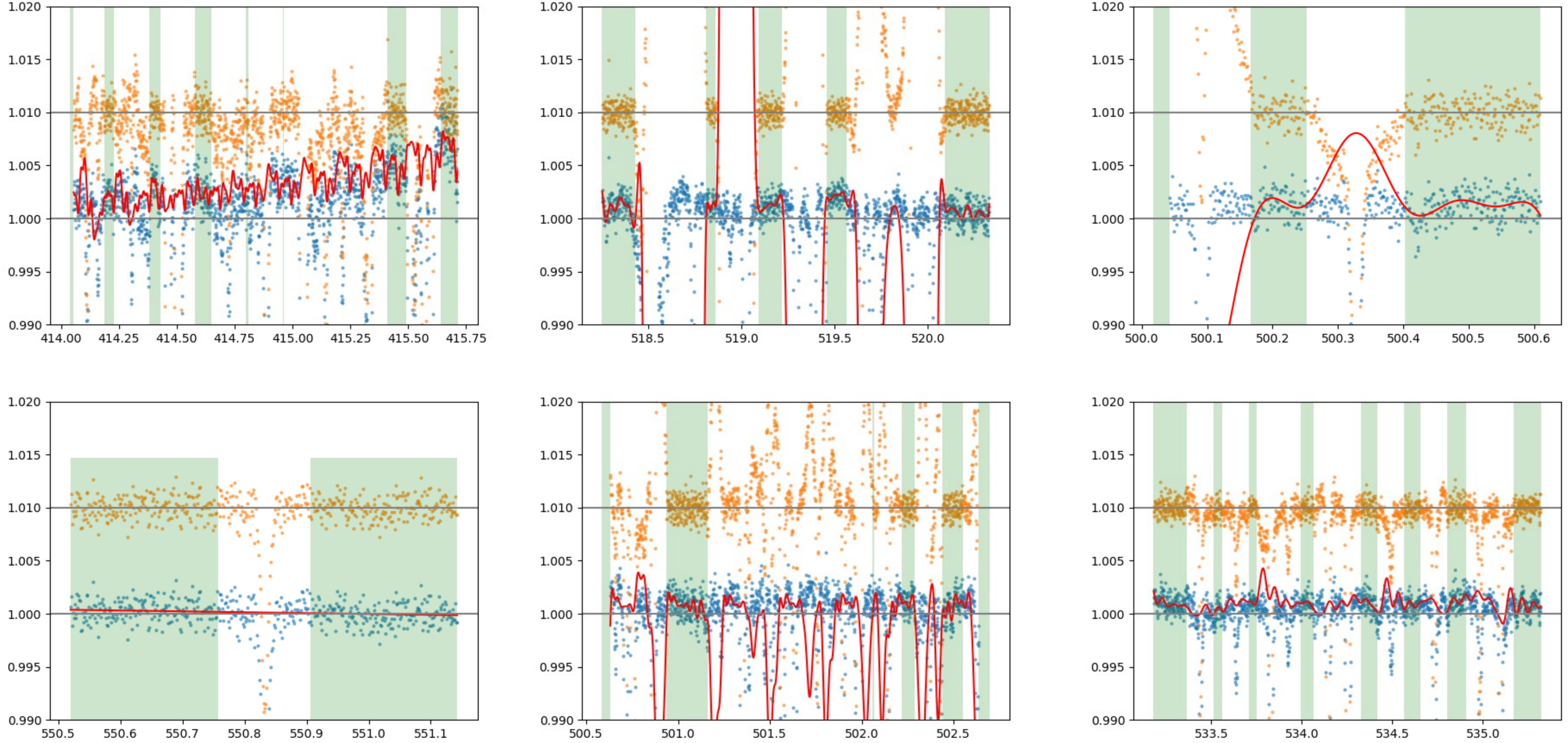
Pereira et al. 2013

Fe probability distributions

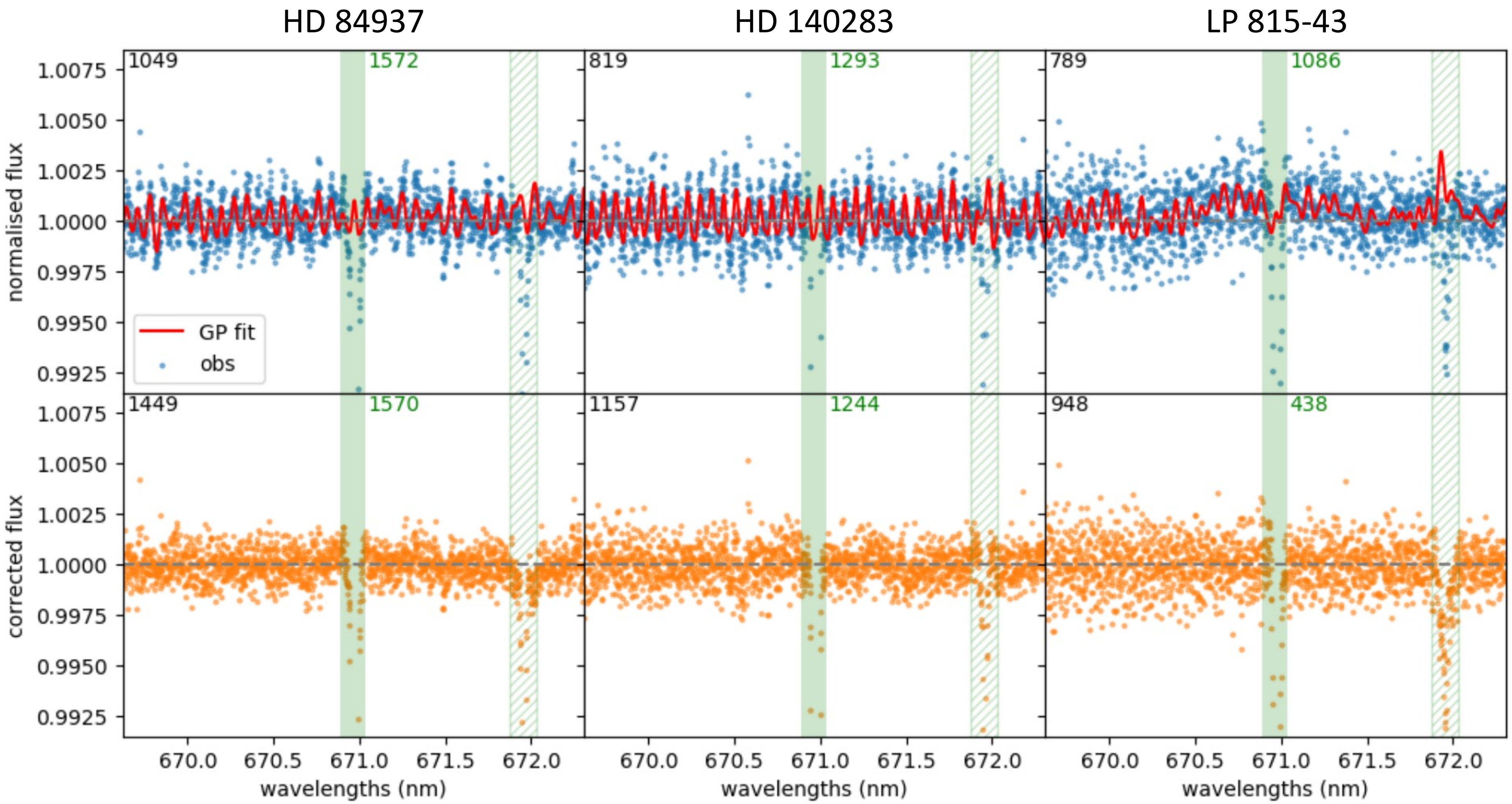


Wang et al. 2021

Gaussian Process fitting doesn't always work



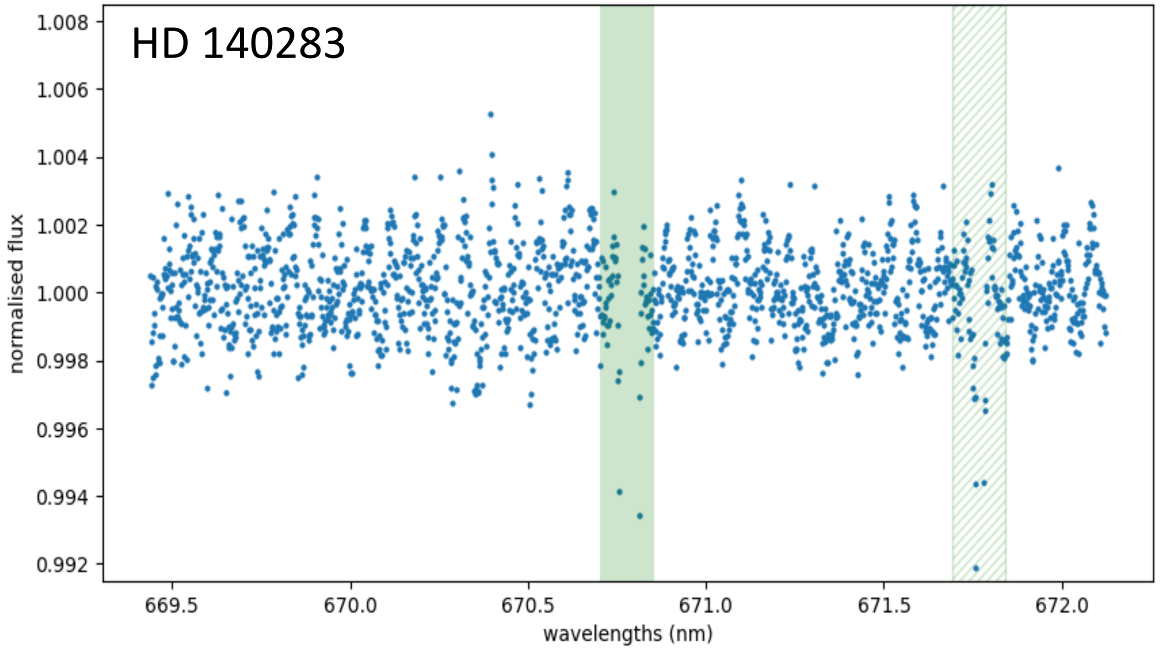
ESPRESSO residual interference pattern

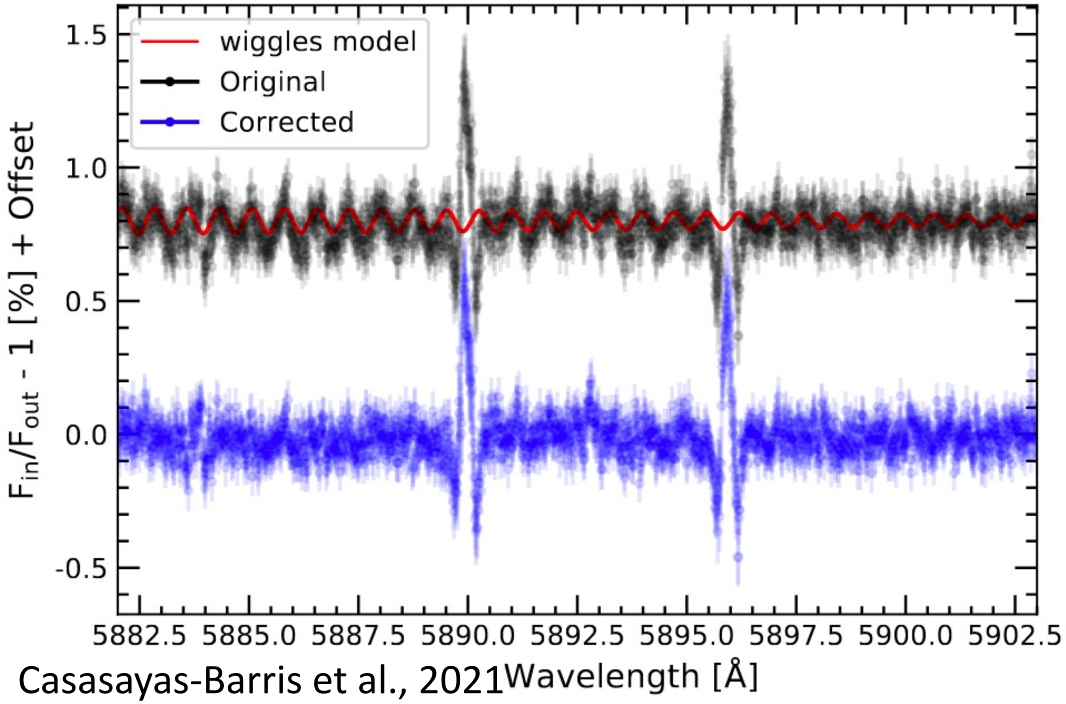


Wang et al. 2021

Wiggles in the continuum

- Periodic
- Not pixel dependent
- Changes a bit over time (maybe related to angle of telescope)

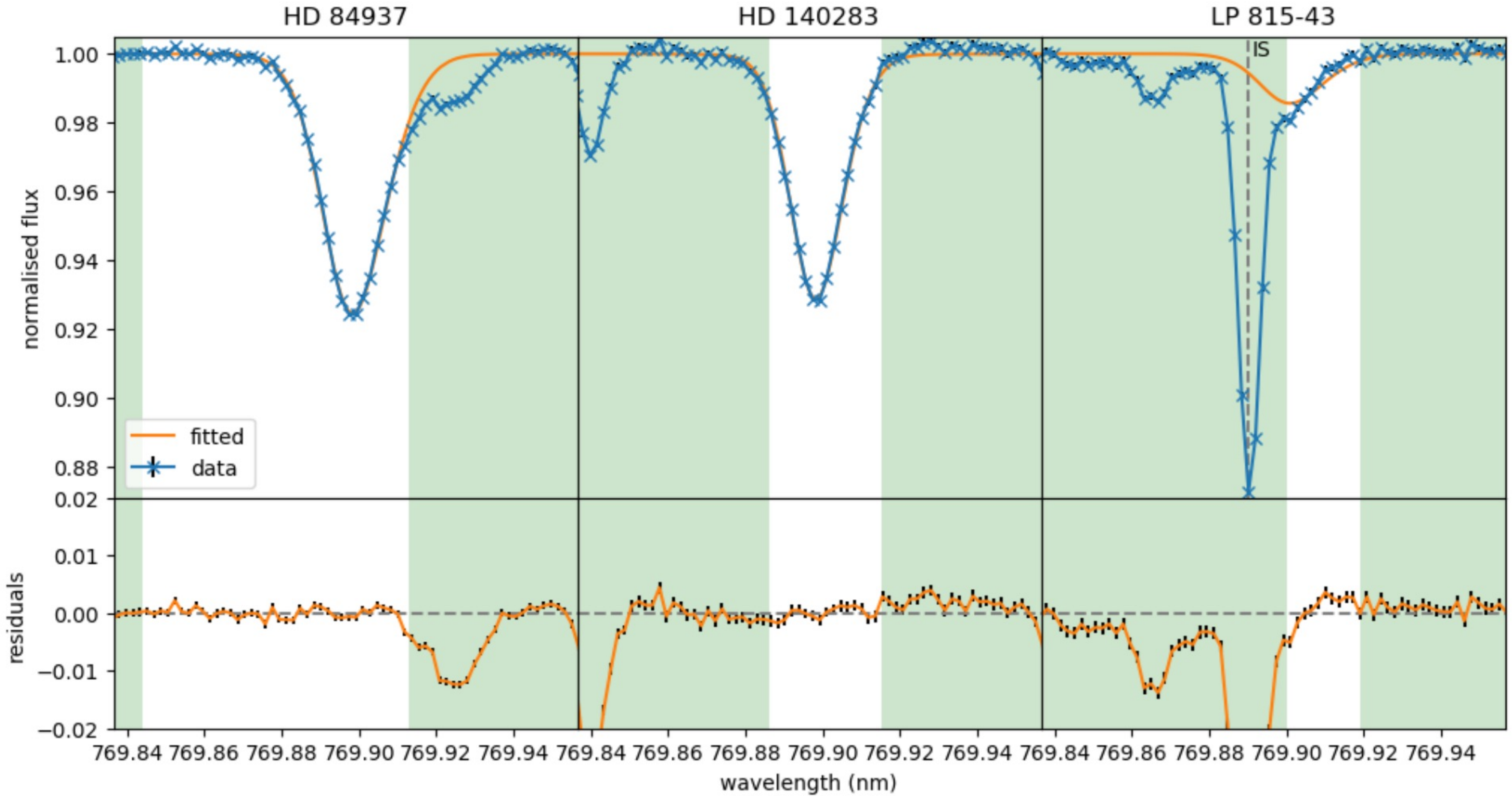




Casasayas-Barris et al., 2021

K fit

- vsini, v_{rad} from K calibration line

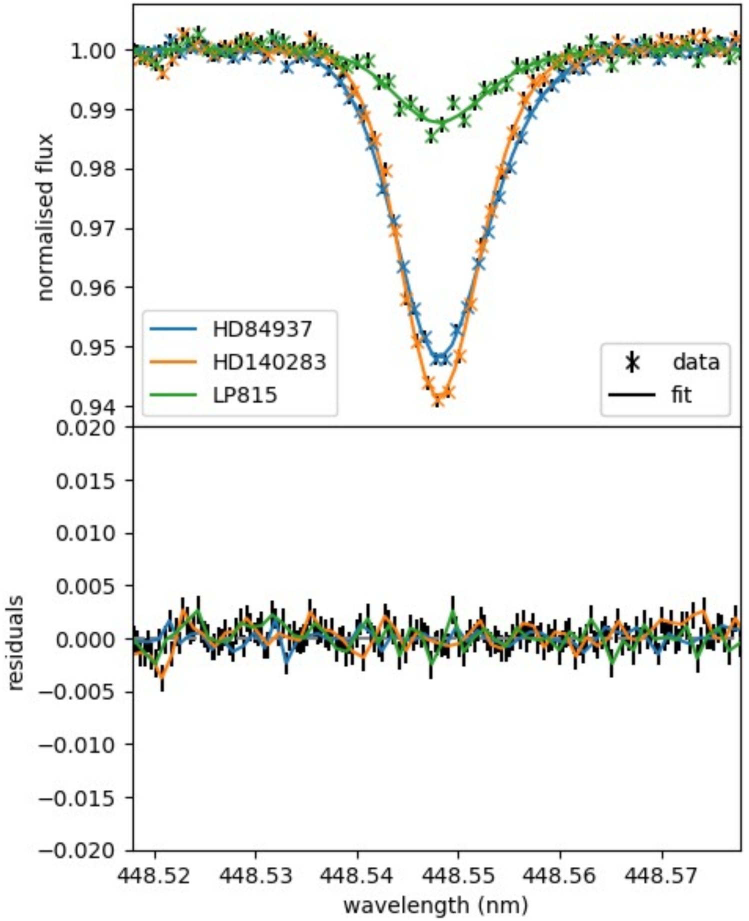


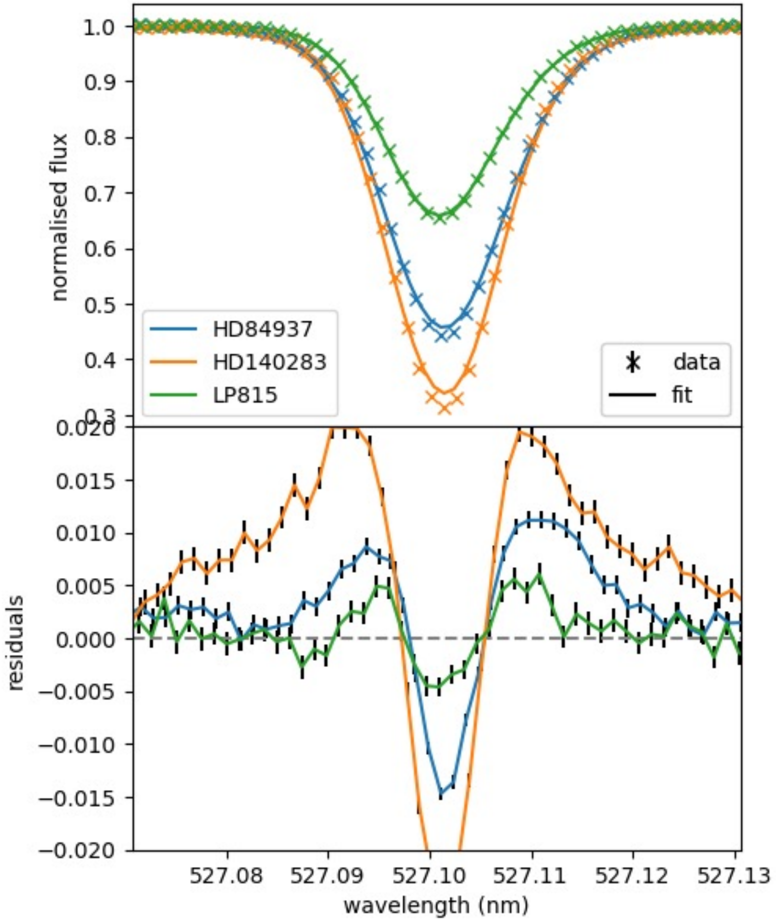
Wang et al. 2021

Fe fit

- vsini, v_{rad} from Fe calibration lines

Lower χ^2 fit





Higher χ^2 fit

Different flavours of spectral synthesis

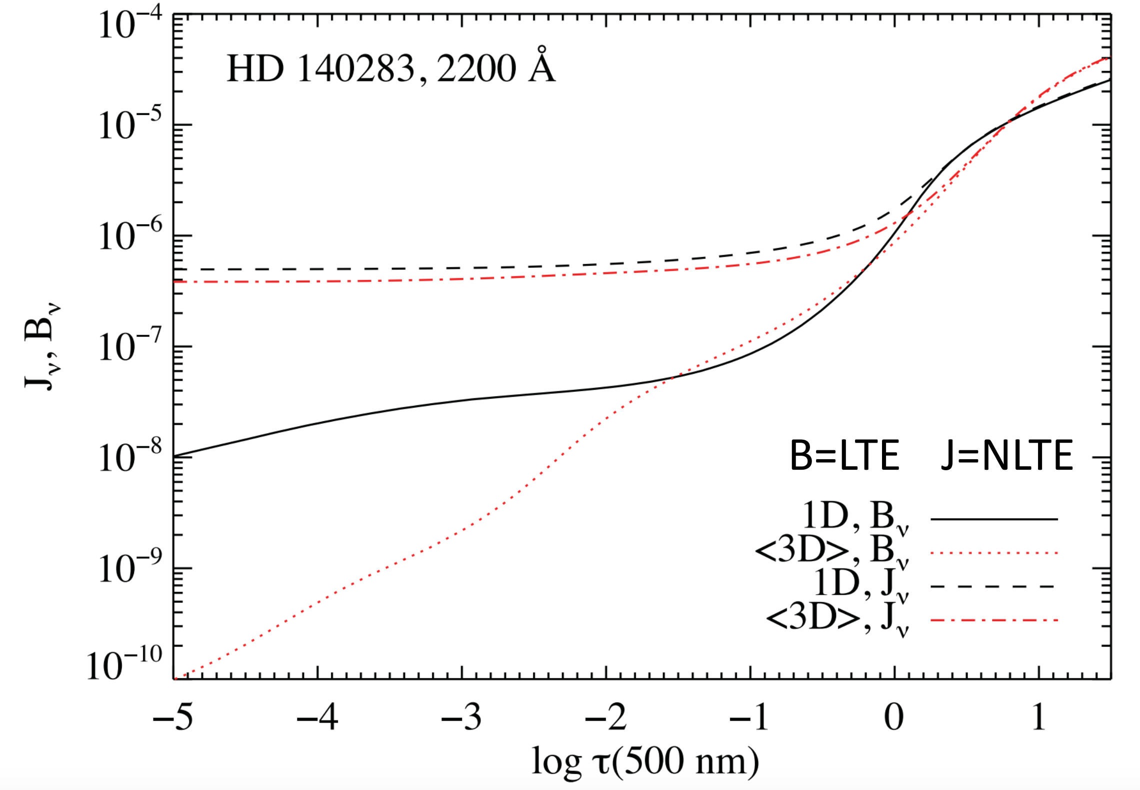
LTE

- Assumes local thermodynamic equilibrium
- Populations are given by Boltzmann distribution
- Rate equations are given by Saha distribution

NLTE

- Does not assume local thermodynamic equilibrium
- Populations depend on intensities at all wavelengths and locations
- Rate equations depend on radiation field

Synthetic spectra: radiative transfer



Radiation field compared to the local Planck function for HD 140283