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ChETEC-INFRA

Chemical Elements as Tracers for the Evolution of the Cosmos – Infrastructures for Nuclear Astrophysics

The Joint Research Activity 3 – Work Package 5 „Astronuclear abundances“

Arūnas Kučinskas, Vilnius University

Partners

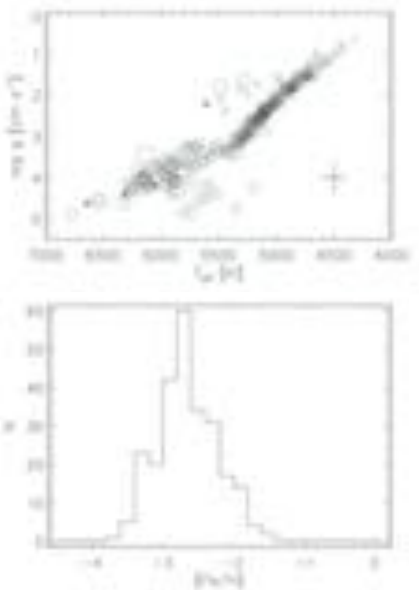
Associated partners

ChETEC-INFRA JRA3-WP5: rationale and goal

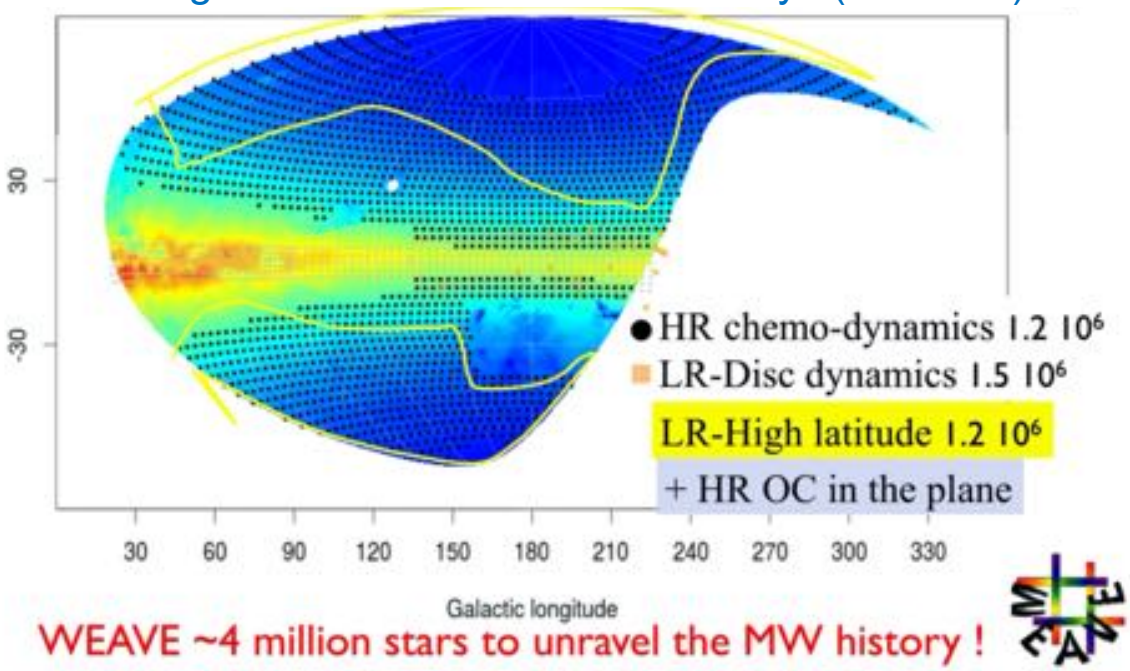
▷ RECENT ADVANCES IN STELLAR SPECTROSCOPY

- Massive spectroscopic surveys are becoming mainstream, huge increase in the data flow:
  - early surveys: 100-1000 stars (e.g. HERES, ...)
  - ongoing & planned surveys: 10^5–10^6 stars (APOGEE, WEAVE, 4MOST, ...)

Initial HERES sample (Barklem et al. 2005)



Coverage of the WEAVE HR/LR surveys (Hill 2017)



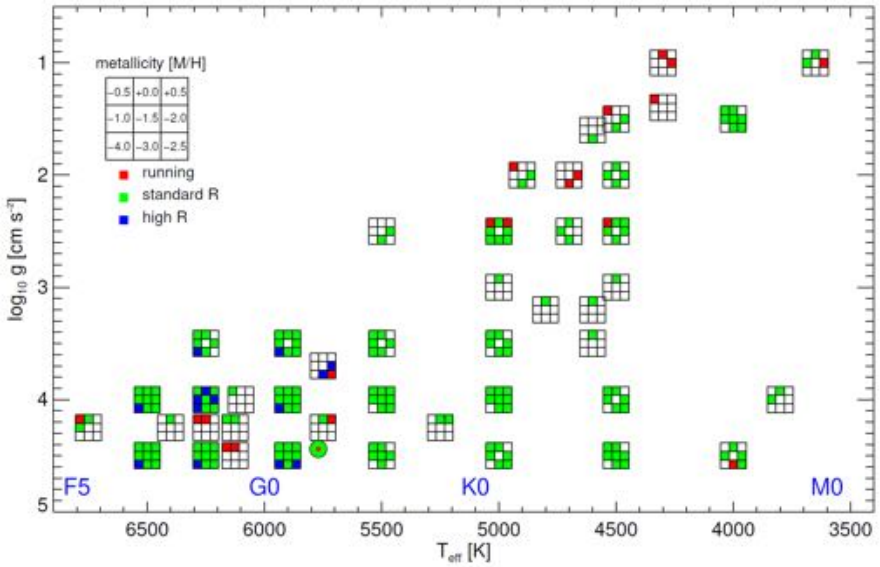
WEAVE ~4 million stars to unravel the MW history !

ChETEC-INFRA JRA3-WP5: rationale and goal

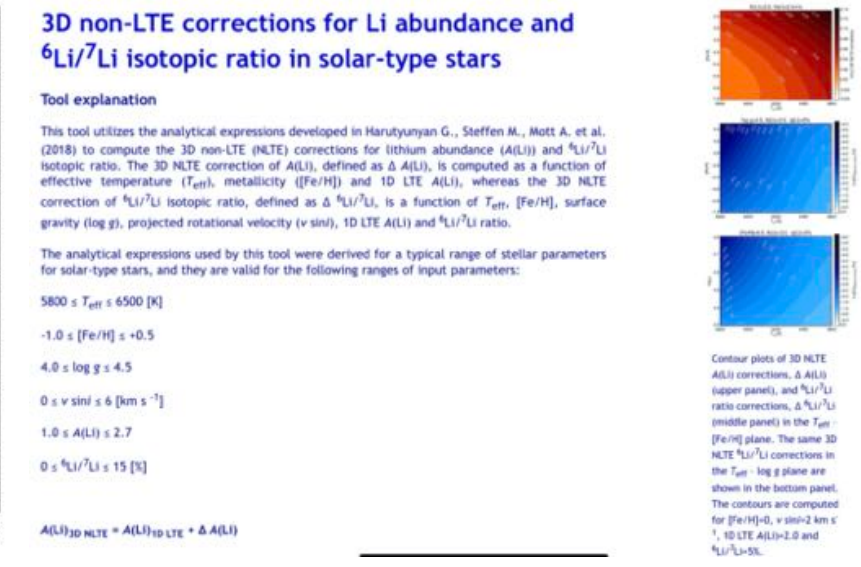
▷ RECENT ADVANCES IN STELLAR SPECTROSCOPY

- Massive spectroscopic surveys are becoming mainstream, huge increase in the data flow
- Impressive developments in 3D hydrodynamical modelling of stellar atmospheres and NLTE spectral synthesis

3D hydro model atmosphere grids (CO5BOLD: Ludwig et al. (2009) + updates)



3D NLTE abundance correction databases (3D NLTE Li: https://pages.aip.de/li67nlte3d/



ChETEC-INFRA JRA3-WP5: rationale and goal

▷ RECENT ADVANCES IN STELLAR SPECTROSCOPY

- Massive spectroscopic surveys are becoming mainstream, huge increase in the data flow
- Impressive developments in 3D hydrodynamical modelling of stellar atmospheres and NLTE spectral synthesis

▷ HOWEVER

- Methods and tools used to analyse stellar spectra very diverse
- Sizeable systematic differences in the results obtained by different groups and surveys
- Automated stellar abundance pipelines rarely open-source
- 3D NLTE stellar abundances still a rarity, even in the contexts where this may truly make a difference

ChETEC-INFRA JRA3-WP5: rationale and goal

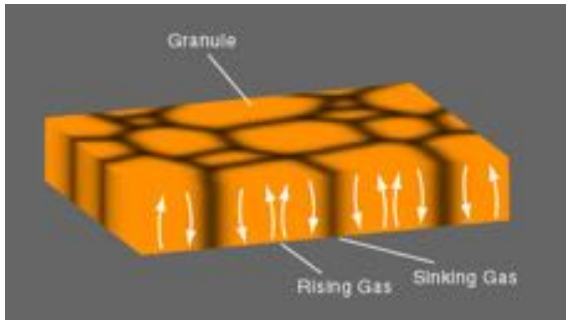
- GOAL

- To develop new advanced methodologies and tools for efficient, reliable and homogeneous analysis of spectroscopic data obtained for stellar abundance analysis at modern astrophysical facilities

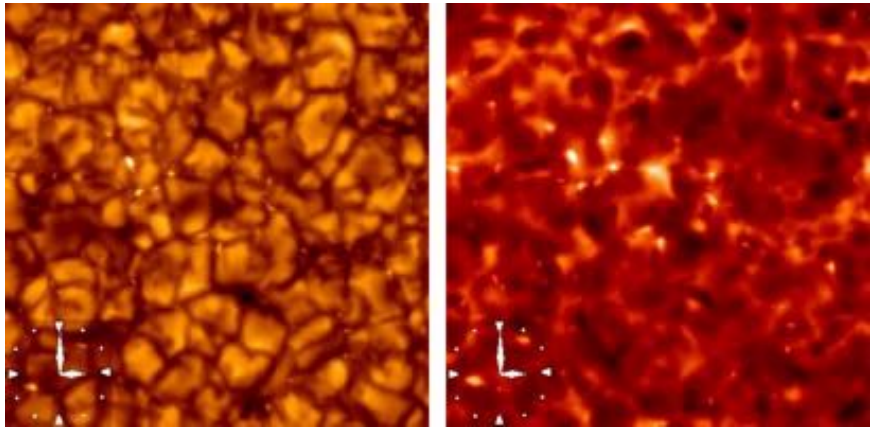
From starlight to abundances: beyond the classical approach

▷ PATHWAYS TO IMPROVE

- 3D hydrodynamical model atmospheres instead of 1D hydrostatic:
  - realistic representation of surface convection
  - tools for computing 3D hydro models available
  - 3D model atmosphere grids needed

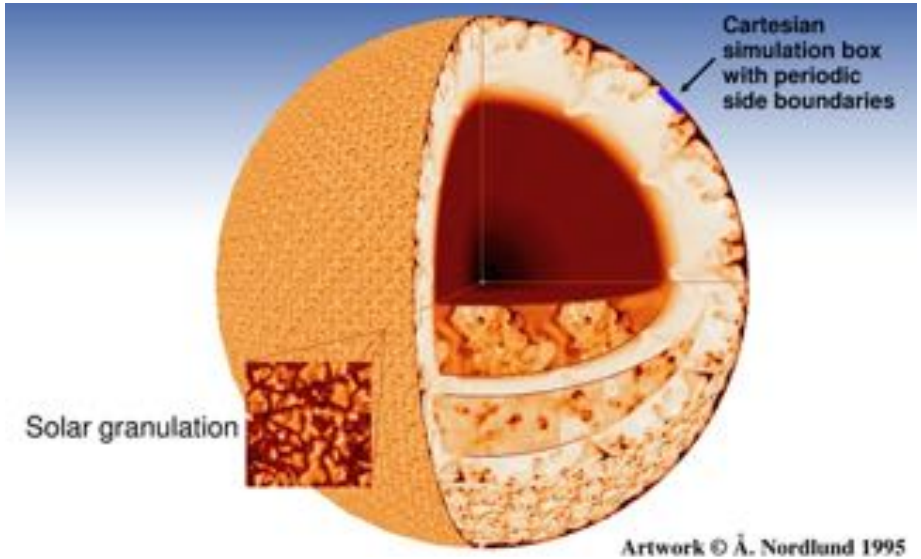


OBSERVATIONS



Quiet Sun: in the G-band (430 nm, left) and Ca II H band (397 nm, right; SOT/HINODE).

3D HYDRO MODEL ATMOSPHERES



From starlight to abundances: beyond the classical approach

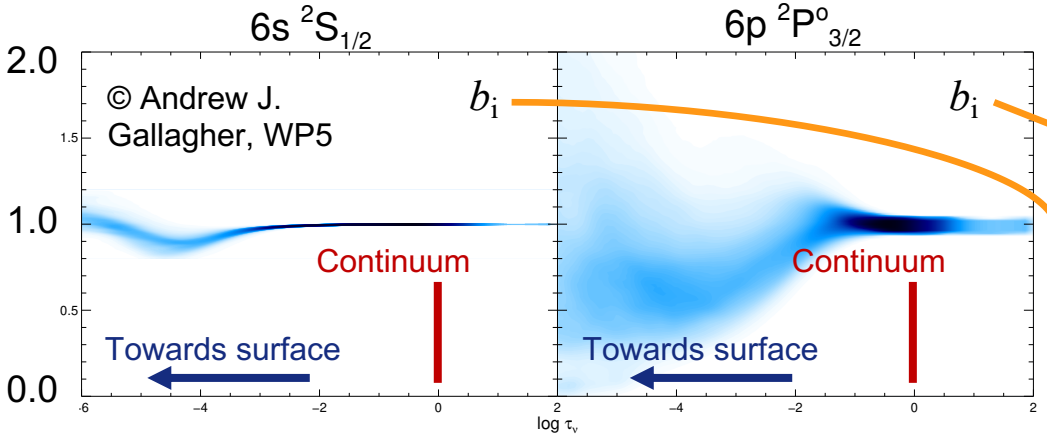
▷ PATHWAYS TO IMPROVE

- 3D hydrodynamical model atmospheres instead of 1D hydrostatic
- Non-local thermodynamic equilibrium (NLTE) spectral synthesis instead of LTE:
  - significant deviations from LTE in the line forming regions
  - 1D NLTE tools exist, some can be adapted for 3D analysis

Atomic levels

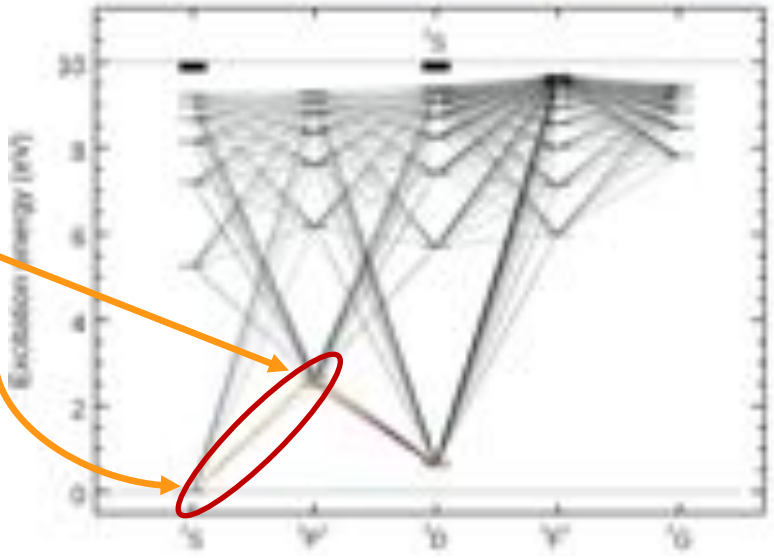
LTE: Boltzmann equation $\frac{n_i}{n_j} = \frac{g_i}{g_j} e^{-E_{ij}/kT}$

NLTE: departure coefficients $b_i = \frac{n_i^{NLTE}}{n_i^{LTE}}$



Ba II model atom

Gallagher et al. 2020, A&A, 634, A55



From starlight to abundances: beyond the classical approach

▷ PATHWAYS TO IMPROVE

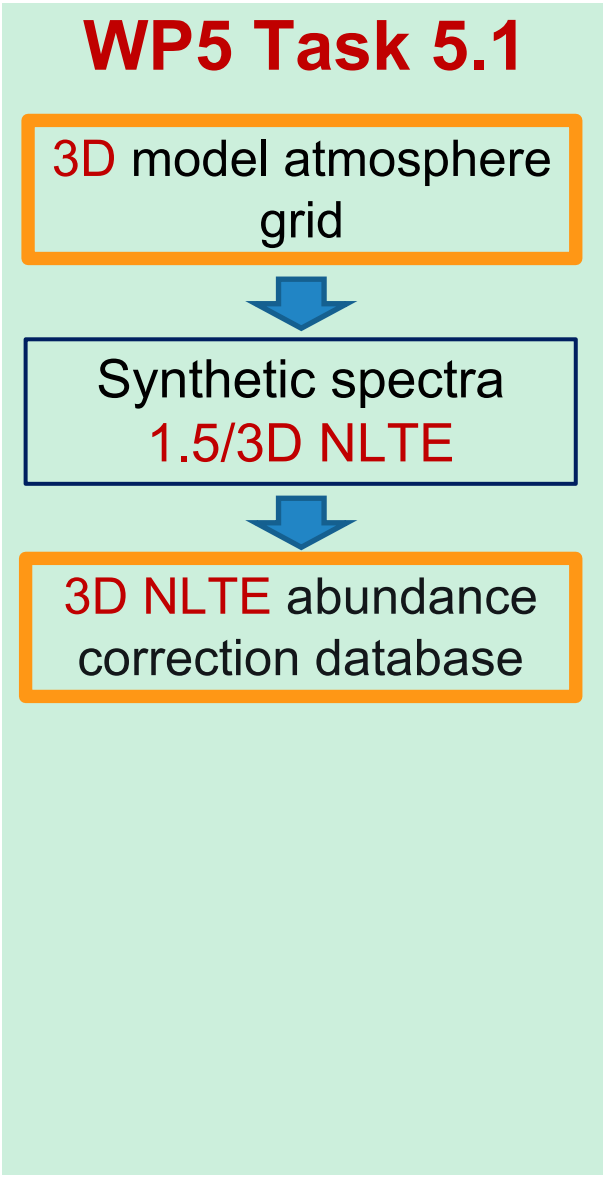
- 3D hydrodynamical model atmospheres instead of 1D hydrostatic
- Non-local thermodynamic equilibrium (NLTE) spectral synthesis instead of LTE
- 3D NLTE abundances instead of 1D LTE(NLTE):
  - 3D NLTE – 1D LTE abundance corrections can be computed for different types of stars and selected chemical elements

From starlight to abundances: beyond the classical approach

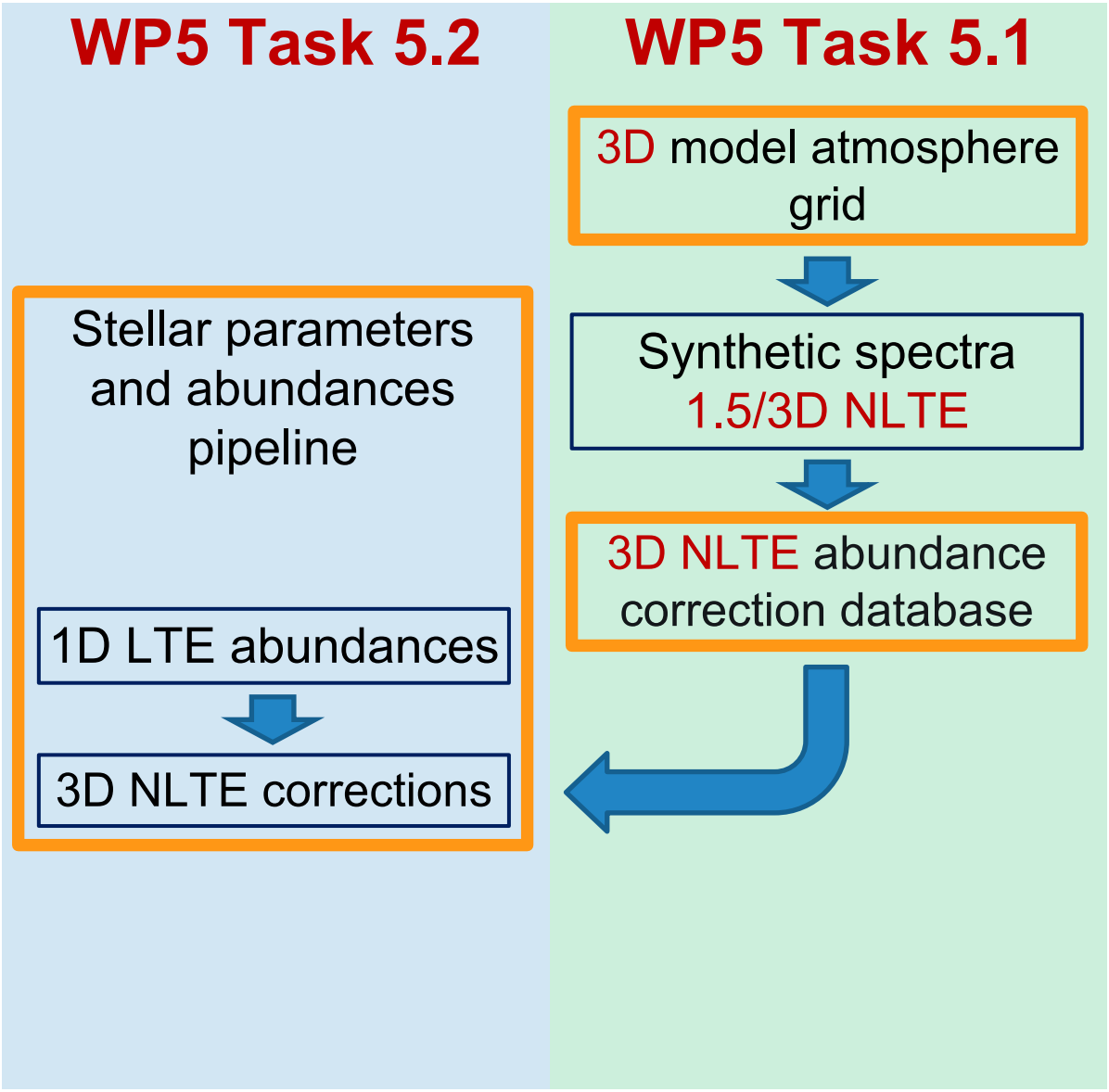
▷ PATHWAYS TO IMPROVE

- 3D hydrodynamical model atmospheres instead of 1D hydrostatic
- Non-local thermodynamic equilibrium (NLTE) spectral synthesis instead of LTE
- 3D NLTE abundances instead of 1D LTE(NLTE)
- Automated approaches to obtain stellar parameters and 3D NLTE abundances, for larger numbers of stars, instead of manual analysis

From starlight to abundances: the ChETEC-INFRA approach



From starlight to abundances: the ChETEC-INFRA approach



From starlight to abundances: the ChETEC-INFRA approach

Observations

Observed spectrum

+

Photometry
Astrometry

WP5 Task 5.2

Stellar parameters and abundances pipeline

1D LTE abundances

3D NLTE corrections

WP5 Task 5.1

3D model atmosphere grid

Synthetic spectra 1.5/3D NLTE

3D NLTE abundance correction database

From starlight to abundances: the ChETEC-INFRA approach

Observations

Observed spectrum

+

Photometry
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WP5 Task 5.2

Stellar parameters and abundances pipeline

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3D NLTE corrections

WP5 Task 5.1

3D model atmosphere grid

Synthetic spectra 1.5/3D NLTE

3D NLTE abundance correction database

3D NLTE abundances of chemical elements X_i, $A(X_i)$

JRA3-WP5 Task 5.1 “Database of 3D NLTE abundance corrections”

CURRENT SITUATION

- Joint WP5-WP6 Workshop (July 6, 2021):
  - needs of the community for the 3D NLTE corrections discussed
  - 1.5D NLTE corrections as starting step towards full 3D NLTE

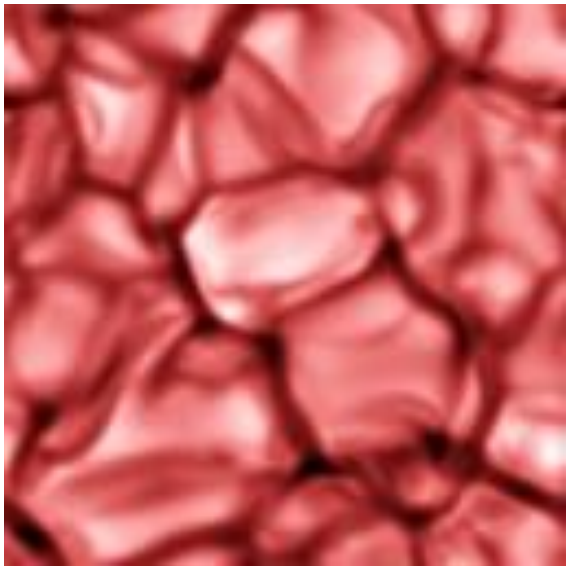
JRA3-WP5 Task 5.1 “Database of 3D NLTE abundance corrections”

CURRENT SITUATION

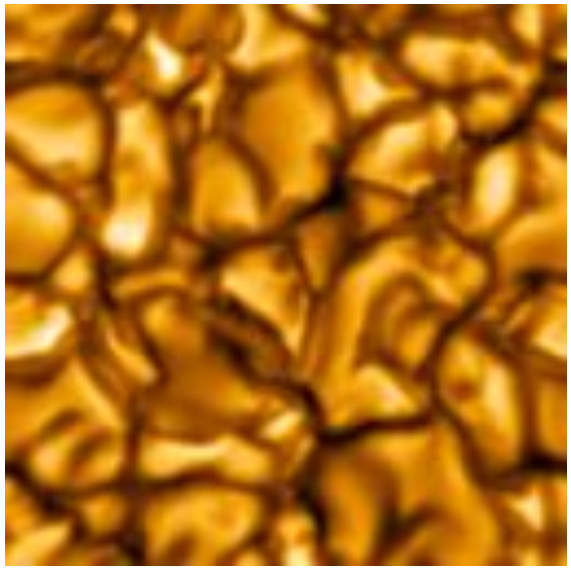
- Joint WP5-WP6 Workshop (July 6, 2021)
- Development of 1.5D NLTE spectral line synthesis tools:
  - First tests of Ba II NLTE line formation in the red giant ($T_{\rm eff}$=5000 K, log g = 2.5, [M/H]=0) and the Sun

Emergent light intensity of the 3D hydro models

Red giant



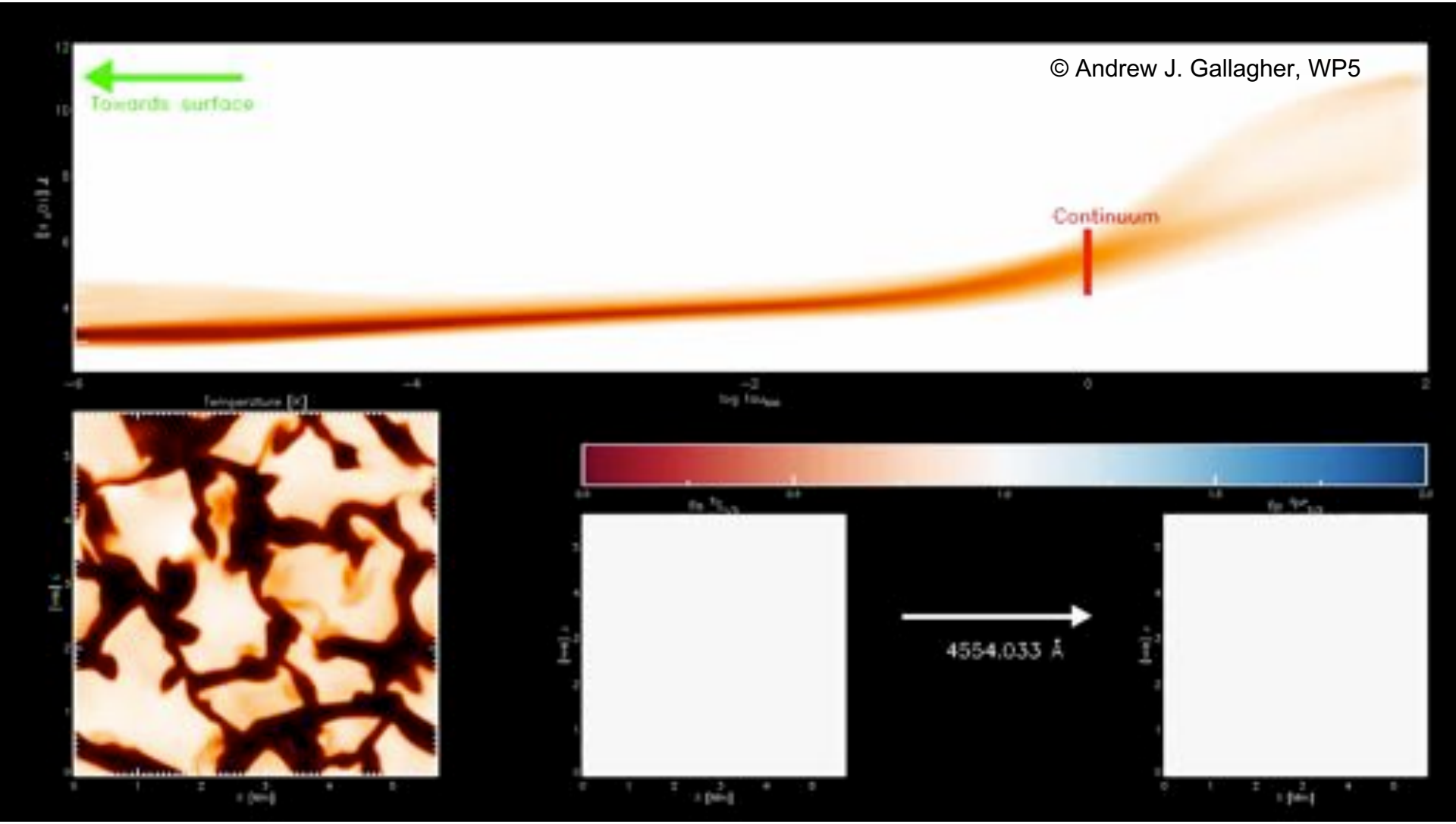
The Sun



© Jonas Klevas, WP5

JRA3-WP5 Task 5.1 “Database of 3D NLTE abundance corrections”

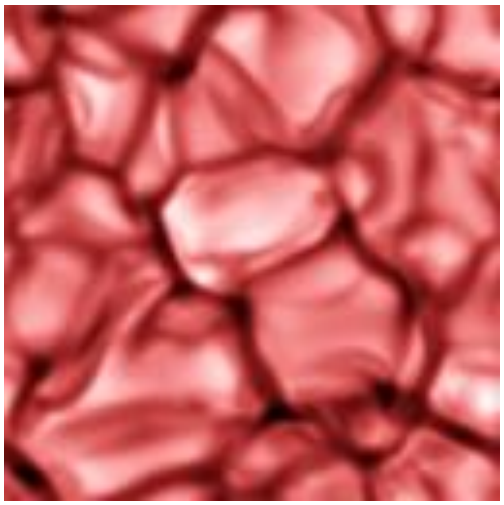
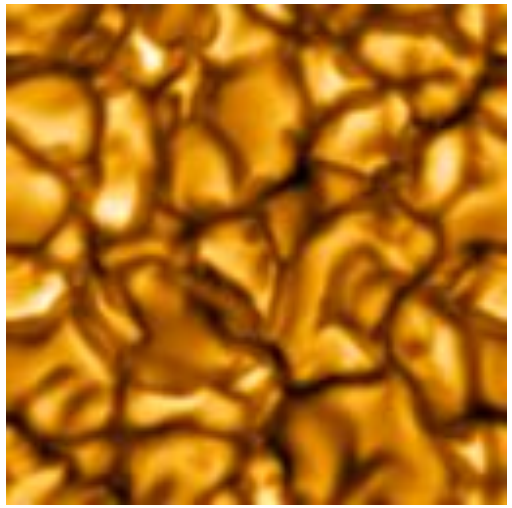
Be II 4554.033 A line formation in the atmosphere of red giant star



JRA3-WP5 Task 5.1 “Database of 3D NLTE abundance corrections”

CURRENT SITUATION

- Joint WP5-WP6 Workshop (July 6, 2021)
- Development of 1.5D NLTE spectral line synthesis tools
- ChETEC-INFRA TNA application for CPU time on the U Hull VIPER cluster (Feb 2022):
  - successful – 100000 CPU hours granted!
  - test computation of 1.5D NLTE corrections for Ba II in a small 3D model grid (autumn 2022)


JRA3-WP5 Task 5.1 “Database of 3D NLTE abundance corrections”

CURRENT SITUATION

- Joint WP5-WP6 Workshop (July 6, 2021)
- Development of 1.5D NLTE spectral line synthesis tools
- ChETEC-INFRA TNA application for CPU time on the U Hull VIPER cluster (Feb 2022)
- Hiring of new personnel:
  - 2 year PDRA position at AIP: Andrew J. Gallagher (from Oct 2021)

JRA3-WP5 Task 5.1 “Database of 3D NLTE abundance corrections”

FUTURE STEPS

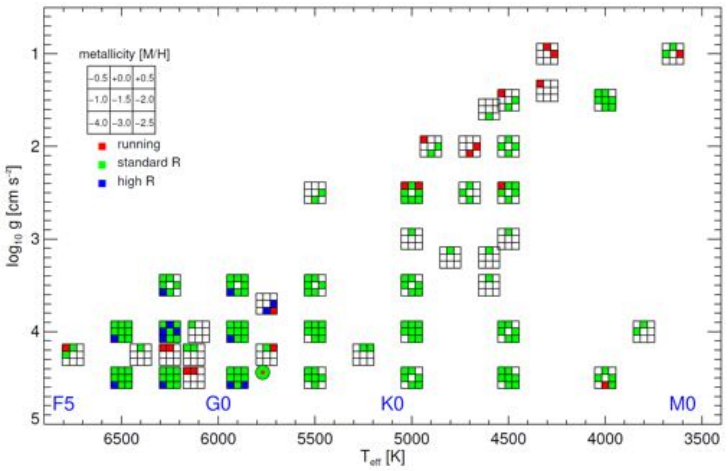
- Development and final testing of the 1.5D NLTE tools for Ba II spectral line synthesis
- Implementation of new model atoms into 1.5D NLTE tools (Pb? Sr?)

JRA3-WP5 Task 5.1 “Database of 3D NLTE abundance corrections”

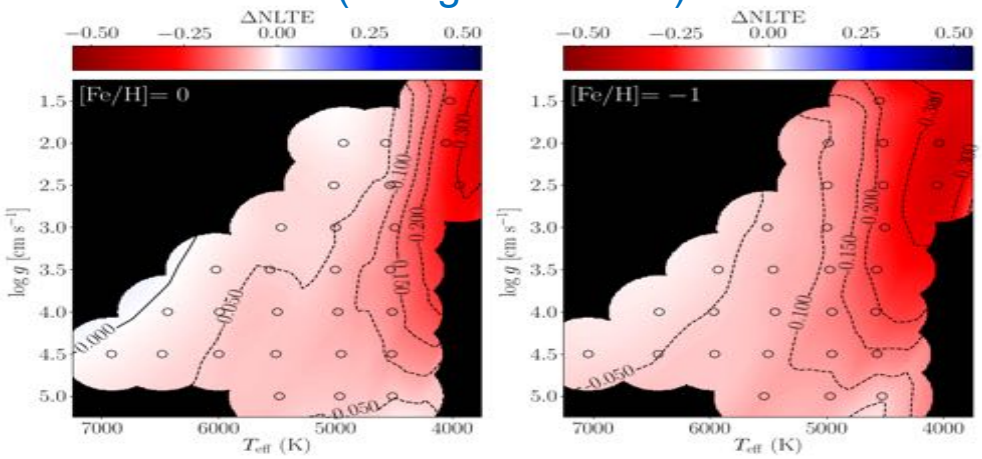
FUTURE STEPS

- Development and final testing of the 1.5D NLTE tools for Ba II spectral line synthesis
- Implementation of new model atoms into 1.5D NLTE tools (Pb? Sr?)
- Extended 3D hydro model grid for red giants
- 1.5D NLTE abundance corrections for Ba II (3D red giant grid)

CO5BOLD model grid
(Ludwig et al. 2009)



NLTE abundance correction grid for Li I
(Wang et al. 2021)



JRA3-WP5 “Homogeneous open-source stellar pipeline”

CURRENT SITUATION

- Completely new collaboration built specifically for ChETEC-INFRA

JRA3-WP5 “Homogeneous open-source stellar pipeline”

CURRENT SITUATION

- Completely new collaboration built specifically for ChETEC-INFRA
- WP5 T5.2 Workshop in Trieste (May 5, 2022):
  - Discussion of the current status
  - Decisions about the future steps and actions

JRA3-WP5 “Homogeneous open-source stellar pipeline”

CURRENT SITUATION

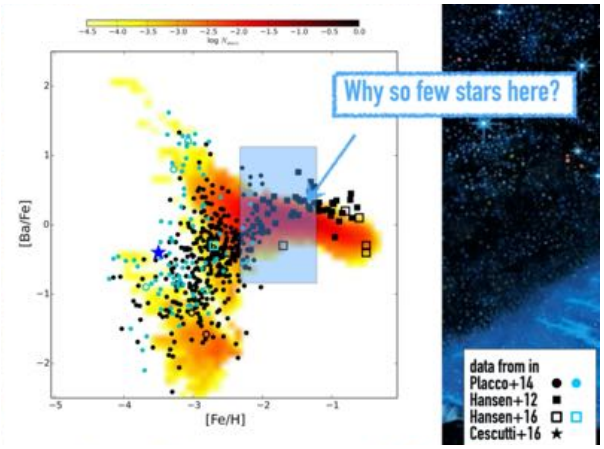
- Completely new collaboration built specifically for ChETEC-INFRA
- WP5 T5.2 Workshop in Trieste (May 5, 2022)
- Hiring of new personnel:
  - 2 year PDRA position at UU: selection of candidates now ongoing

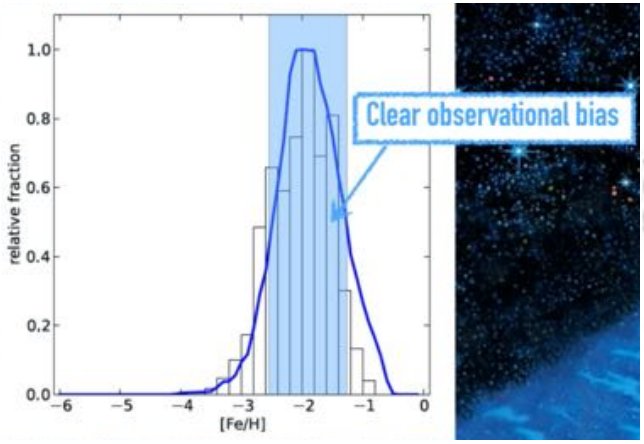
JRA3-WP5 “Homogeneous open-source stellar pipeline”

CURRENT SITUATION

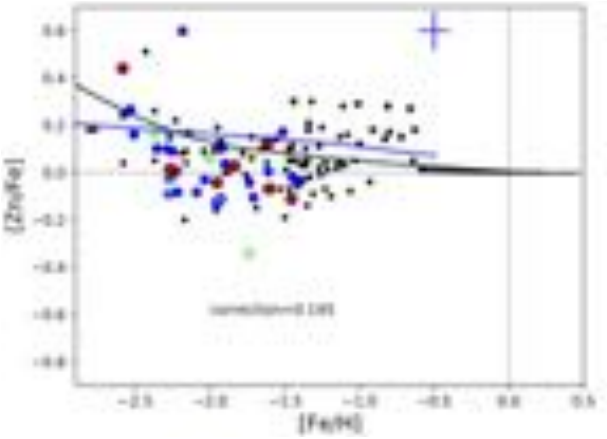
- Completely new collaboration built specifically for ChETEC-INFRA
- WP5 T5.2 Workshop in Trieste (May 5, 2022)
- Hiring of new personnel
- Several observational projects initiated
  - WP6.1 – see talk of Alex Dimoff tomorrow
  - MINCE – 2 successful TNA proposals, 3 nights of observations
  - potential application of WP5 products for 3D NLTE abundance analysis

© Cescutti (2020)





Cescutti et al. (in prep)



JRA3-WP5 “Homogeneous open-source stellar pipeline”

FUTURE STEPS

- Hiring of PDRA at Trieste: autumn 2022
- First version of the stellar pipeline and first tests:
  - late 2022 – early 2023

EXCITING TIMES AHEAD!

ChETEC-INFRA WP5 is open to new collaborations!

Please get in touch if interested!

▷ **ChETEC-INFRA JRA3-WP5**

Partners

Associated partners

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andreas.korn@uu.se