CHETEC INFRA

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008324 (ChETEC-INFRA).

Astronuclear Abundances

Final Report of the Work Package 5

2021-2025

17/09/2025

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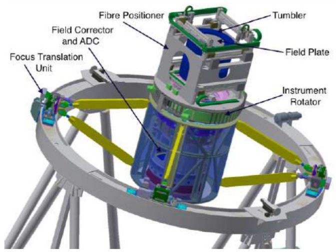
From starlight to abundances of chemical elements

ABUNDANCES OF CHEMICAL ELEMENTS IN STARS: CURRENT TRENDS AND ADVANCES

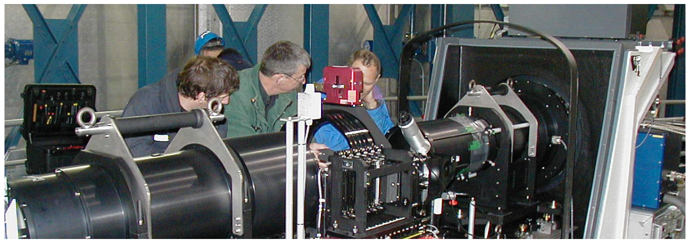
- Millions of stars studied with modern spectroscopic surveys

WHT (4.2m)

WEAVE
Fibers: 1004
Objects: ~850 per exposure
Range: 404–685 nm;
Resolution: 18000-30000



VLT UT2 (8m)



GIRAFFE
Objects: ~120 per exposure
(132 fibers with Medusa)
Range: 370–900 nm; ~20 nm per exp.
Resolution: 18000-30000

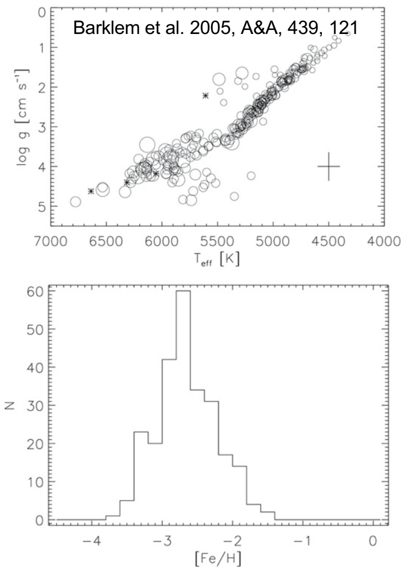
From starlight to abundances of chemical elements

ABUNDANCES OF CHEMICAL ELEMENTS IN STARS: CURRENT TRENDS AND ADVANCES

- Millions of stars studied with modern spectroscopic surveys

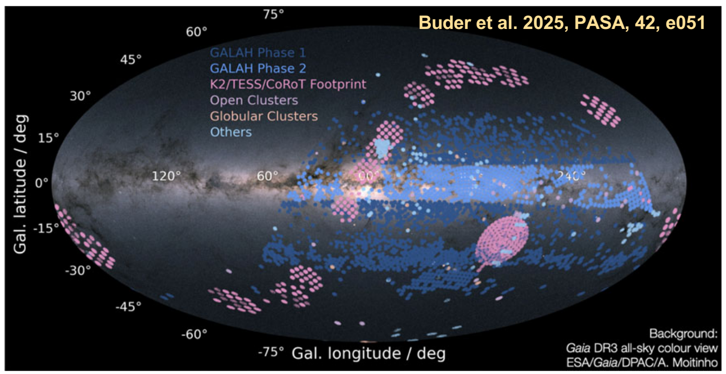
Initial HERES sample

Nb of stars = 252



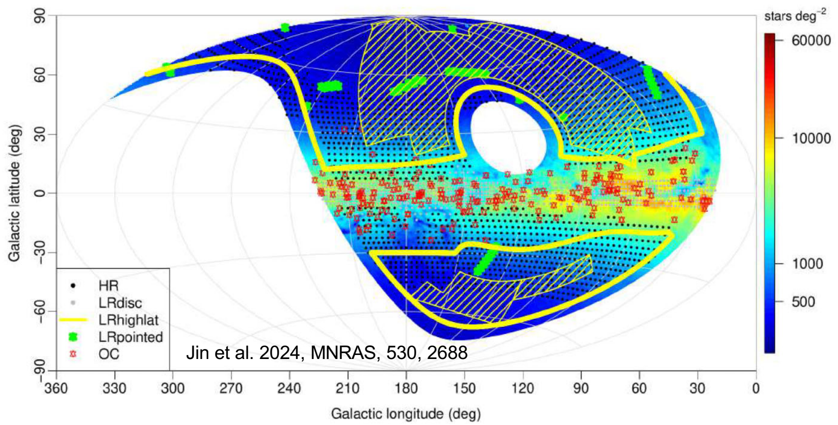
GALAH DR4

Nb of stars ~10^6



WEAVE GA surveys

Nb of stars ~ 5 x 10^6



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From starlight to abundances of chemical elements

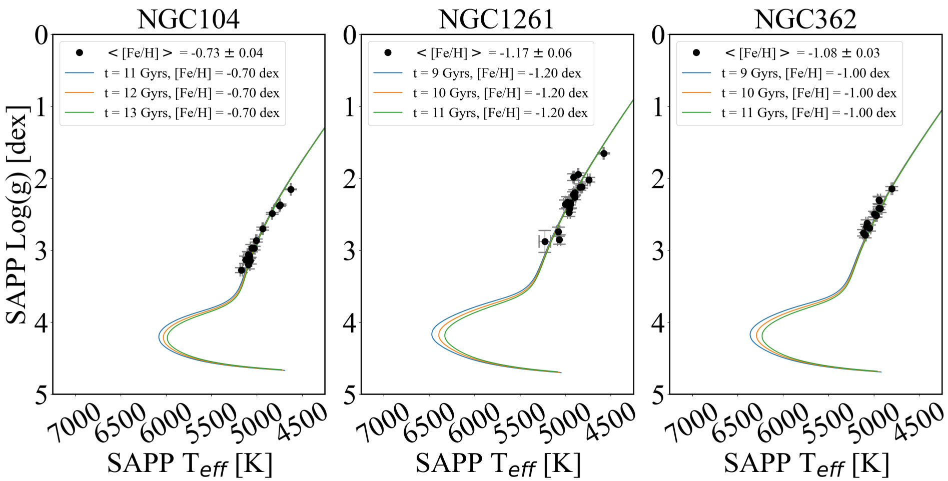
ABUNDANCES OF CHEMICAL ELEMENTS IN STARS: CURRENT TRENDS AND ADVANCES

- Millions of stars studied with modern spectroscopic surveys
- Impressive advances in automated state-of-the-art abundance analysis tools

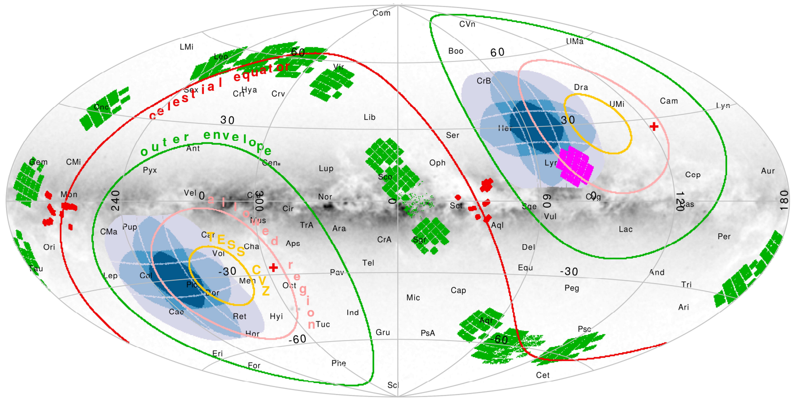
PLATO stellar parameter and abundance pipeline

Below: PLATO fields (in blue). **Left:** Surface gravities determined using the PLATO SAPP pipeline for several Galactic globular clusters (the SAPP was "calibrated" using the 1D MARC model atmospheres).

Gent et al. 2022, A&A, 658, A147



Rauer et al. 2025, Exp. Astron., 59, i26



From starlight to abundances of chemical elements

ABUNDANCES OF CHEMICAL ELEMENTS IN STARS: CURRENT TRENDS AND ADVANCES

- Millions of stars studied with modern spectroscopic surveys
- Impressive advances in automated state-of-the-art abundance analysis tools

HOWEVER

- “Classical” approaches *still* dominate automated abundance analysis:
  - 1D hydrostatic model atmospheres, local thermodynamic equilibrium (LTE) abundance analysis
  - 3D NLTE abundances analysis still rare, even in the contexts where this may make a difference
- Diverse landscape of abundance analysis tools:
  - Methods and tools differ, sizeable systematic differences in the results of different groups
  - Automated stellar abundance pipelines rarely open-source
  - AI forthcoming!

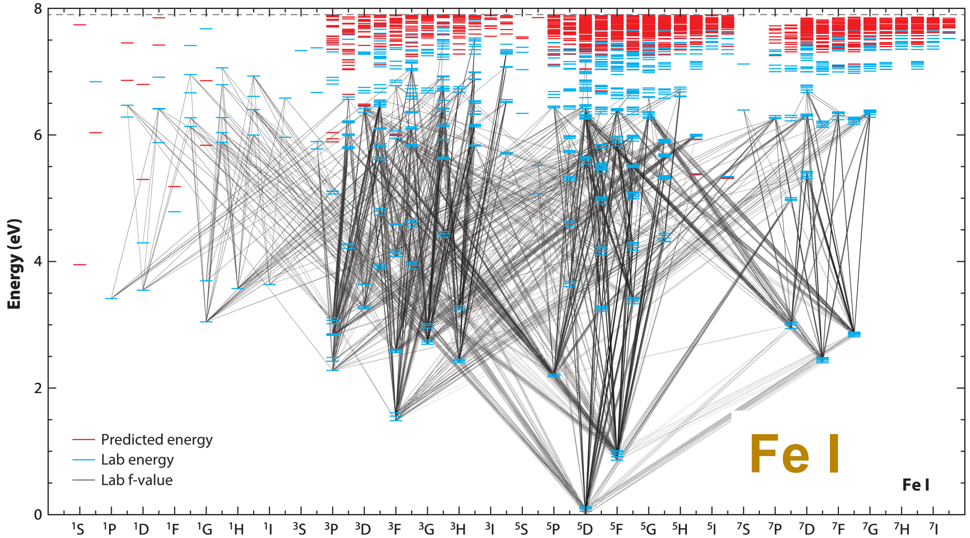
From starlight to abundances of chemical elements

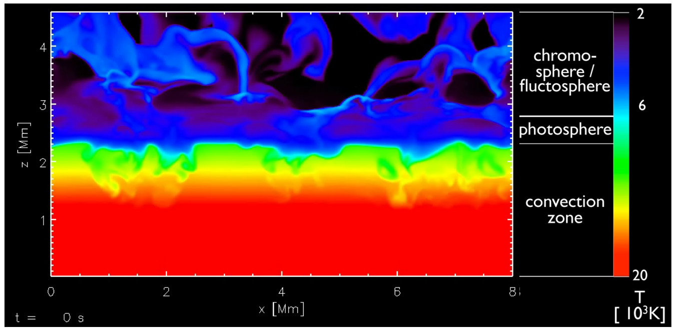
ABUNDANCES OF CHEMICAL ELEMENTS IN STARS: HOW TO IMPROVE?

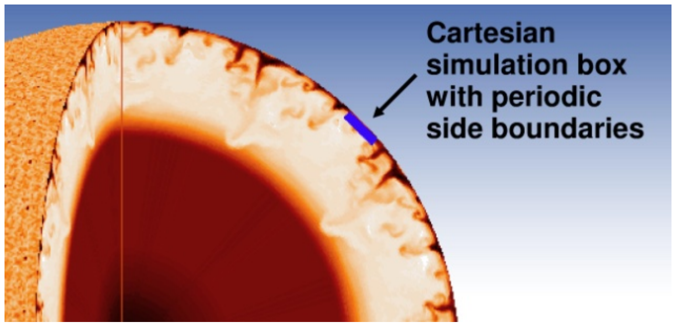
- 3D hydrodynamical model atmospheres instead of “classical” 1D hydrostatic
- Non-local thermodynamic equilibrium (NLTE) abundance analysis instead of ”classical” LTE

3D NLTE abundances instead of 1D LTE

Lind & Amarsi 2024, ARAA, 62, 475







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From starlight to abundances of chemical elements

ABUNDANCES OF CHEMICAL ELEMENTS IN STARS: HOW TO IMPROVE?

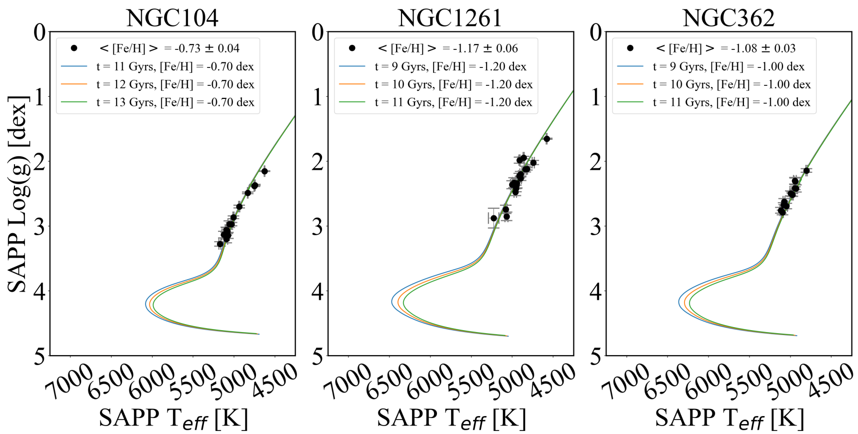
- 3D hydrodynamical model atmospheres instead of “classical” 1D hydrostatic
- Non-local thermodynamic equilibrium (NLTE) abundance analysis instead of ”classical” LTE

→ **3D NLTE abundances instead of 1D LTE**

- Automated open-source abundance pipelines

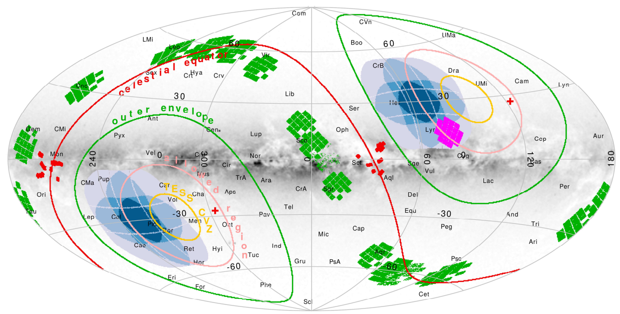
→ **Stellar parameters & 3D NLTE abundances for large numbers of stars**

Gent et al. 2022, A&A, 658, A147



PLATO stellar parameter and abundance pipeline

Rauer et al. 2025, Exp. Astron., 59, i26



Left: PLATO fields (in blue).
Far left: Surface gravities determined using the PLATO SAPP pipeline for several Galactic globular clusters (the SAPP was “calibrated” using the 1D MARC model atmospheres).

ChETEC-INFRA WP5: goals and deliverables

THE GOAL

Homogenize stellar abundance analyses by providing new abundance analysis methods and tools

THE DELIVERABLES

- Database of 3D NLTE Abundance Corrections
- Homogeneous Open-Source Stellar Pipeline

THE TEAM

27 participants from 19 institutions (13 countries)

Partners

Associated partners

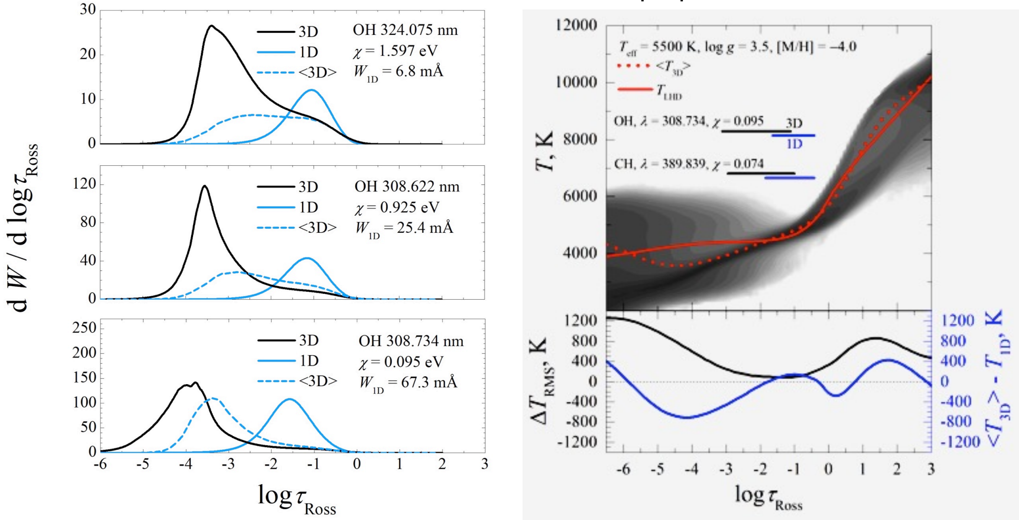
ChETEC-INFRA WP5: why 3D NLTE?

(I) ADVANTAGES OF USING 3D HYDRODYNAMICAL MODEL ATMOSPHERES

- Allows to account for the influence of non-stationary phenomena in stellar atmospheres on:
  - Stellar atmospheric structure
  - Spectral line formation properties and line strengths

Metal-poor subgiant BD+44493

Kolomiecas et al., in prep.



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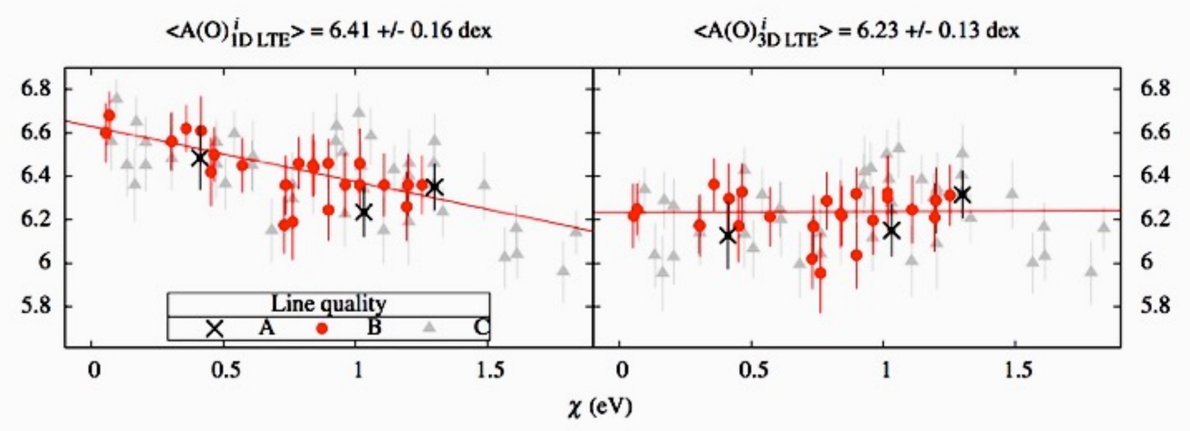
ChETEC-INFRA WP5: why 3D NLTE?

(I) ADVANTAGES OF USING 3D HYDRODYNAMICAL MODEL ATMOSPHERES

- Allows to account for the influence of non-stationary phenomena in stellar atmospheres on:
  - Stellar atmospheric structure
  - Spectral line formation properties and line strengths
  - Differences between the 3D and 1D abundances

Oxygen abundance from OH lines in the metal-poor giant HD+122563

Prakapavicius et al. 2017, A&A, 599, A128



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ChETEC-INFRA WP5: why 3D NLTE?

(II) ADVANTAGES OF USING NLTE SPECTRAL LINE SYNTHESIS

- Differences in the departure coefficients for individual atomic level populations lead to:
  - significant differences between the NLTE and LTE line profiles
  - differences in NLTE and LTE abundances
- 3D plays a role, too!

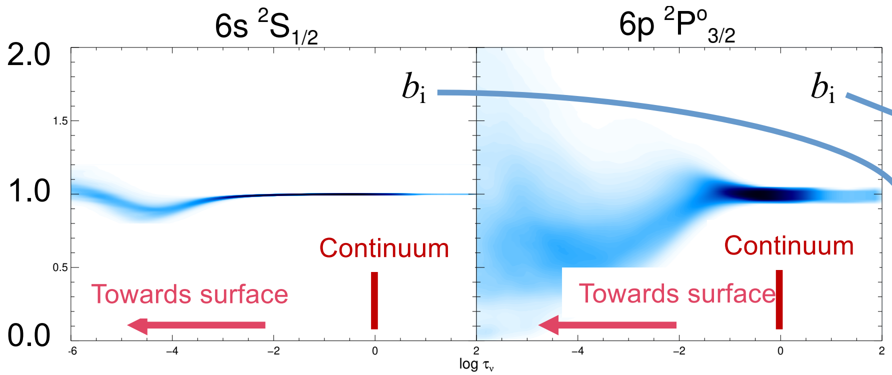
Atomic levels

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

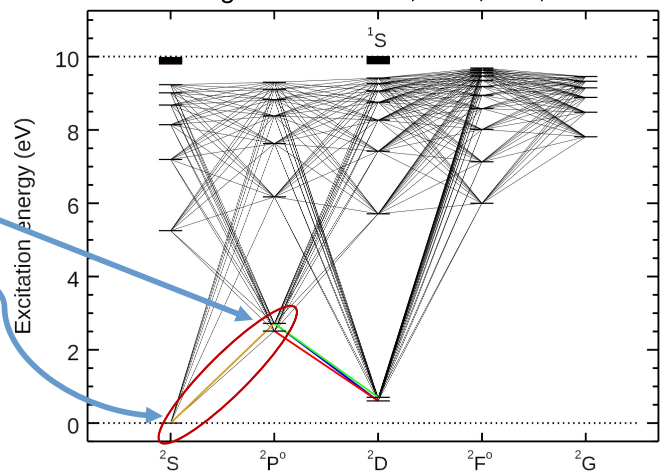
NLTE: departure coefficients $b_i = \frac{n_i^{NLTE}}{n_i^{LTE}}$

Ba II model atom

Gallagher, Steffen et al., in prep.



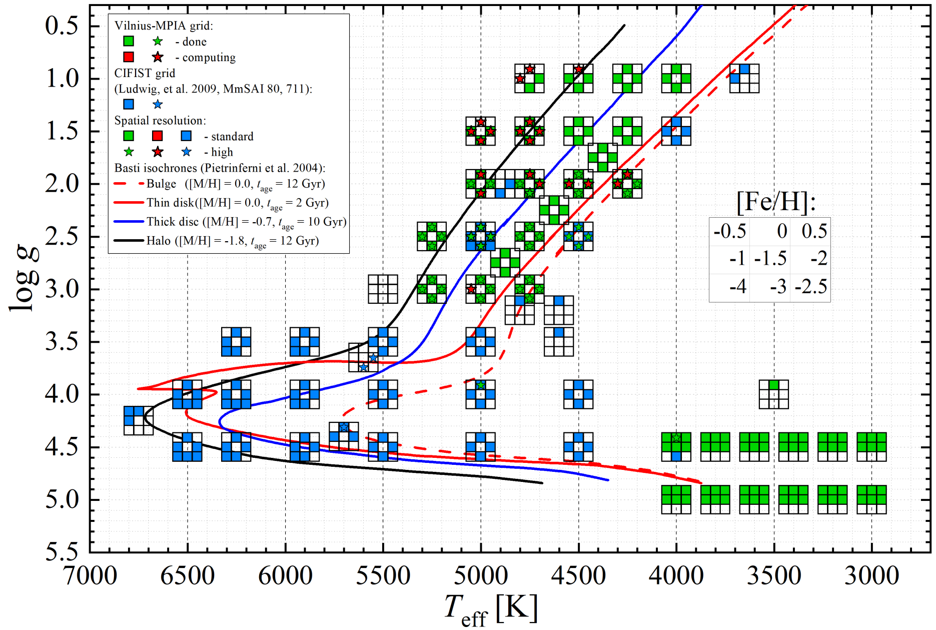
Gallagher et al. 2020, A&A, 634, A55



ChETEC-INFRA WP5: results

TASK 5.1: A GRID OF 3D HYDRODYNAMIC MODEL ATMOSPHERES

- New grid of 3D hydrodynamical model atmospheres
  - 75 low-res + 35 high-res 3D model atmospheres
  - 11 million CPU hours used

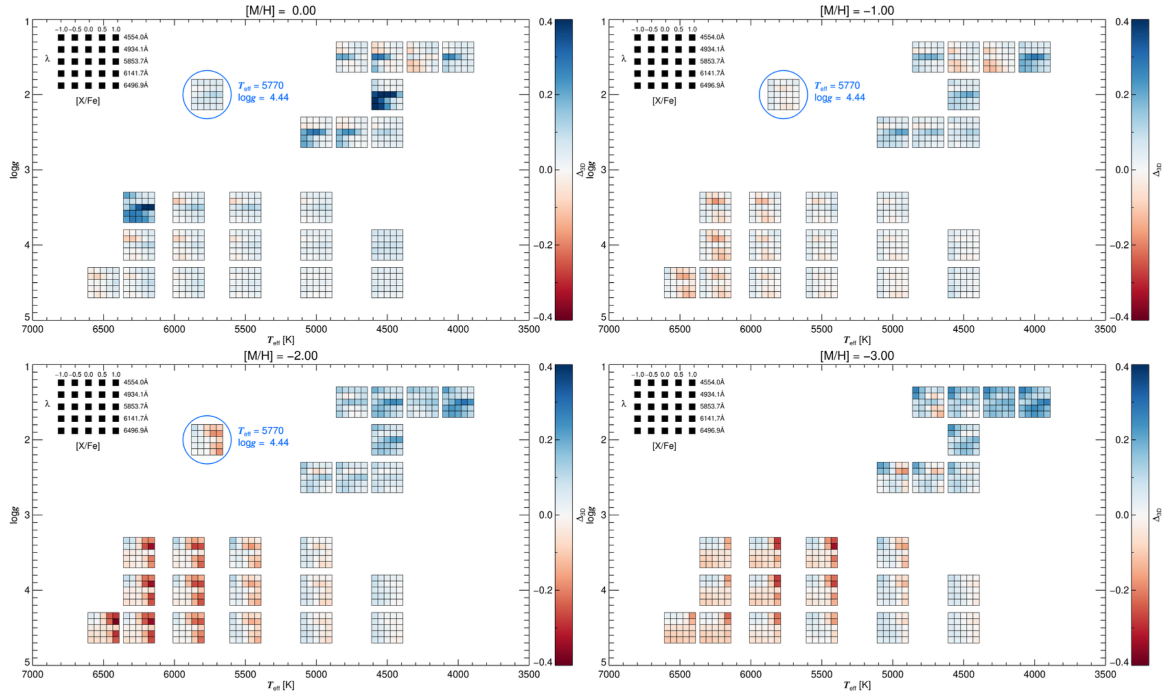


ChETEC-INFRA WP5: results

TASK 5.1: 3D NLTE ABUNDANCE CORRECTIONS DATABASE

- New tool for 1.5D NLTE abundance analysis:
  - NLTE15D code for the computation of 1.5D NLTE abundance corrections

3D NLTE abundance corrections for Ba II lines
© Andrew J. Gallagher, AIP



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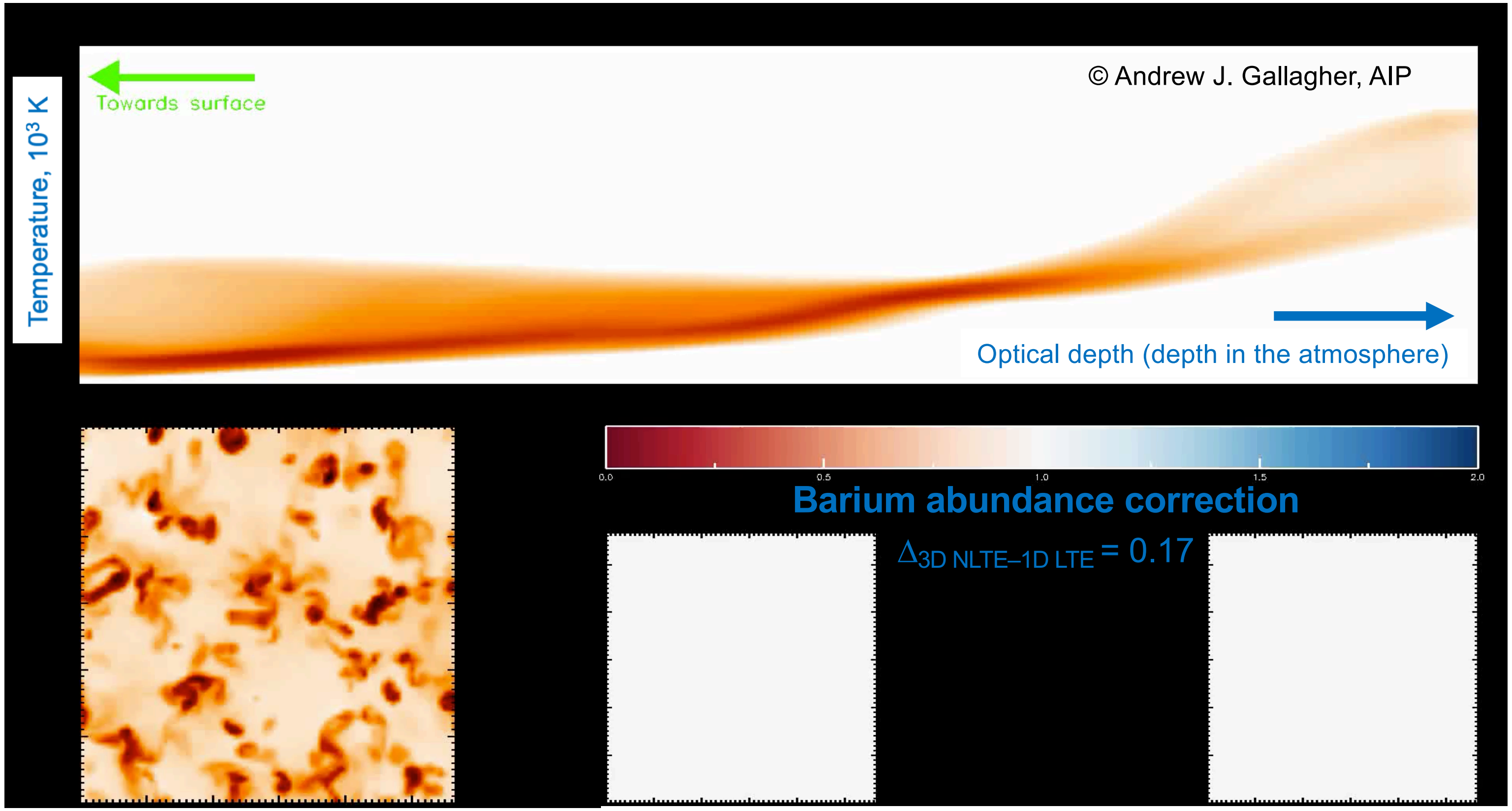
ChETEC-INFRA WP5: results

Ba II 4554.033 Å line formation in the atmosphere of red giant star



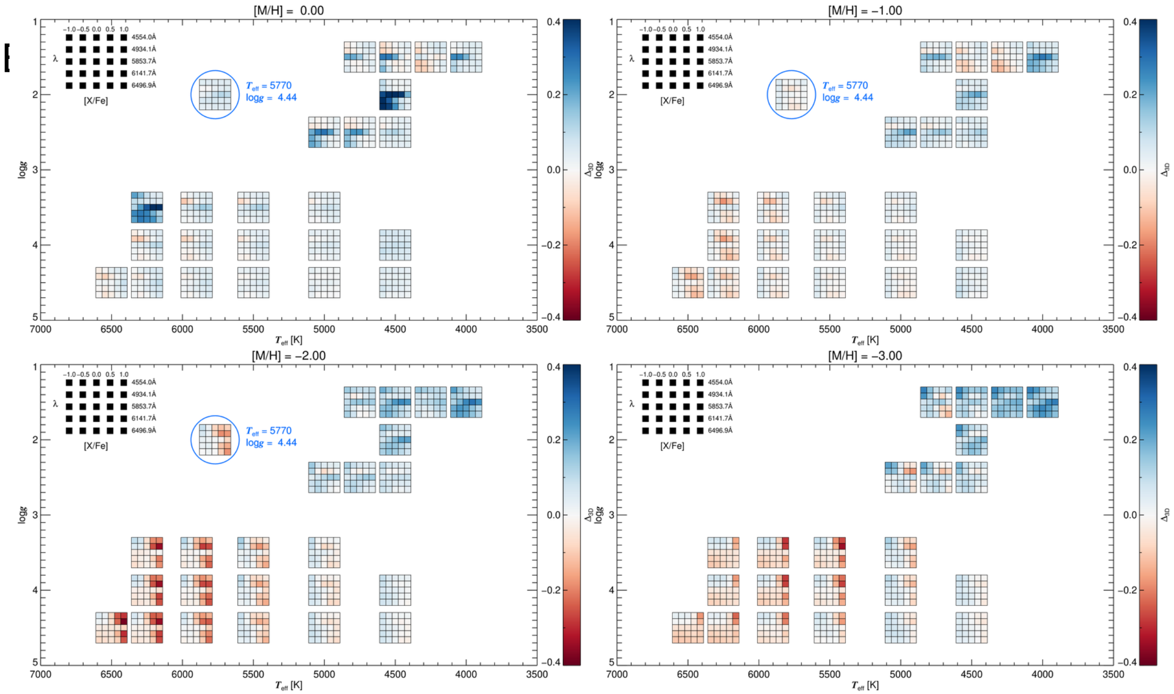
Temperature map | Departure, lower level | **Ba II 4554 line** | Departure, upper level

ChETEC-INFRA WP5: results

TASK 5.1: 3D NLTE ABUNDANCE CORRECTIONS DATABASE

- New tool for 1.5D NLTE abundance analysis:
  - NLTE15D code for the computation of 1.5D NLTE abundance corrections
- Grid of 1.5D NLTE abundance corrections for
  - 1.5D NLTE corrections for 92 3D models
- Grid of 1.5D NLTE abundance corrections for Sr
  - 1.5D NLTE corrections for 32 3D models
- Computations carried out on HPC clusters at Vilnius University (Lithuania), IAP (Germany), and Hull University (UK)
- Abundance correction database: https://www.chetec-infra.eu/3DNLTE/

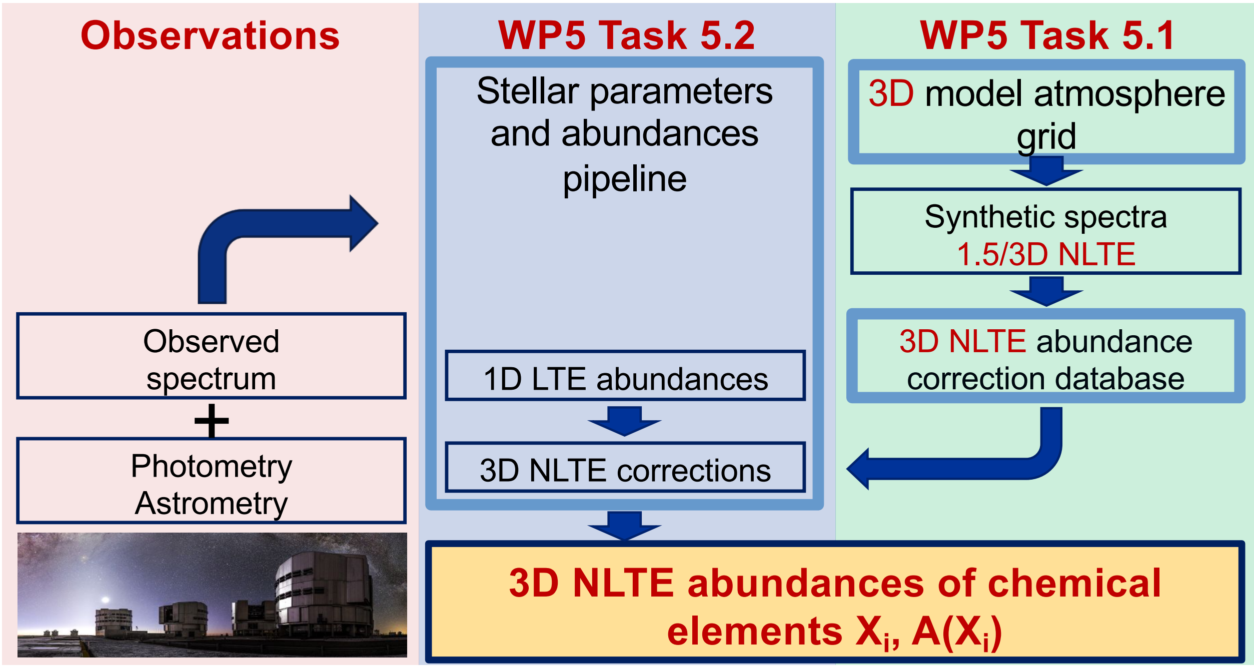
3D NLTE abundance corrections for Ba II lines
© Andrew J. Gallagher, AIP



ChETEC-INFRA WP5: results

TASK 5.2: ABUNDANCE DETERMINATION PIPELINE

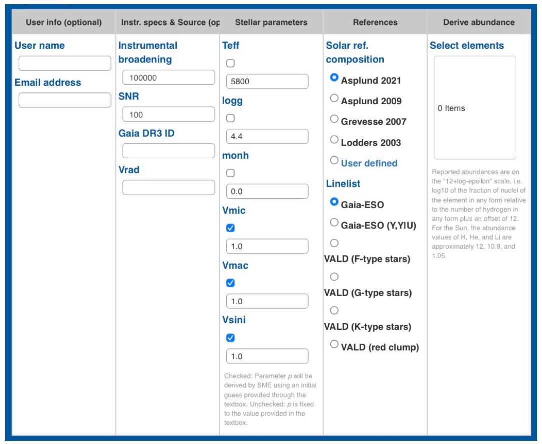
- Automated open-source abundance pipeline: stellar parameters, 3D/1D LTE/NLTE abundances



ChETEC-INFRA WP5: results

TASK 5.2: ABUNDANCE DETERMINATION PIPELINE

- New automated open-source tool webSME:
  - automated stellar parameter and 3D/1D LTE/NLTE abundance determination pipeline, and its online interface
  - 1.5D NLTE abundance corrections for Ba II lines (Sr I and II forthcoming)
  - already used for Bachelor/Master projects at Uppsala; paper on webSME forthcoming



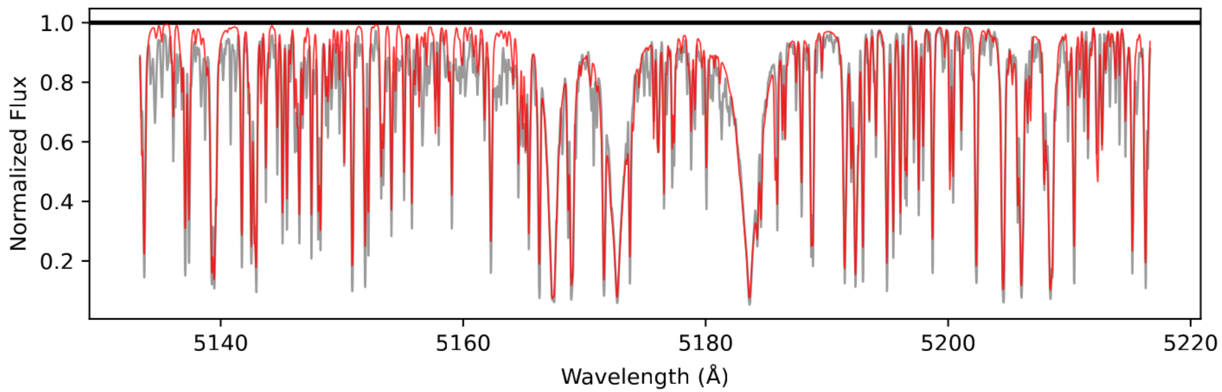


Fig. 3. Observed spectral range around the Mg I λ 5167-5183 magnesium triplet of β Gem (gray) and best-fit result from `webSME` (red).

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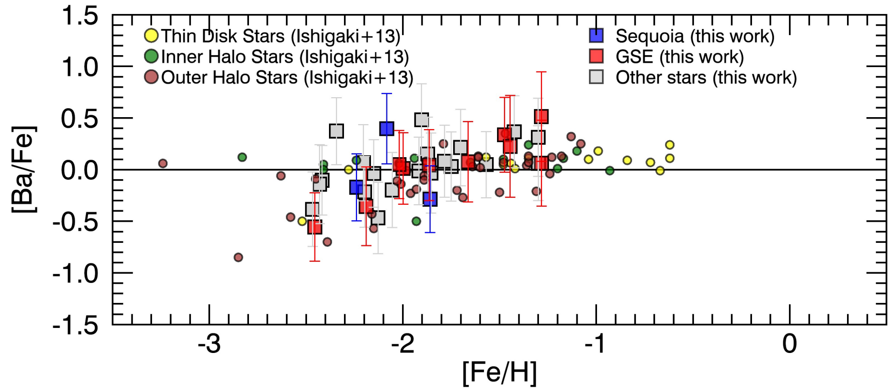
ChETEC-INFRA WP5: results

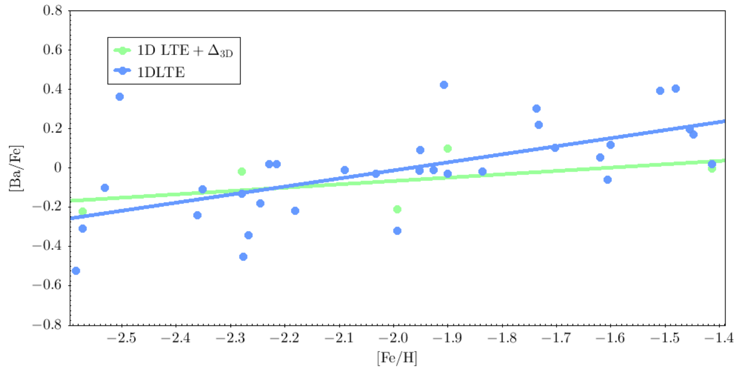
A SUCCESS STORY: PROJECT MINCE

- “Measuring at Intermediate Metallicity Neutron Capture Elements” (MINCE; talk by Gabriele Cescutti!)
- Abundances in the Galactic halo stars at [Fe/H] = -1 … -2.
- ChETEC-INFRA: small-to-medium size telescopes, high-res spectra
- A significant amount of data via ChETEC-INFRA TNA
- MINCE Papers I – III published
- Public MINCE database: http://archives.ia2.inaf.it/mince/
- **Future**: final sample of 200-300 stars, **WP5 abundance pipeline to obtain 1.5D NLTE abundances of s-process elements**

Star	Teff	log g	[Fe/H]	Ba corr
Sun	5770	4.44	0.00	-
HD 115575	4393	1.50	-1.99	0.2
BD +48 2167	4468	1.50	-2.29	0.2
BD +11 2896	4254	1.50	-1.41	0.067
BD -00 4538	4482	1.50	-1.90	0.216
BD +03 4904	4497	1.50	-2.58	0.177

MINCE II
Francois et al. (2024)





ChETEC-INFRA WP5: results

DELIVERABLES

- Database of 3D NLTE Abundance Corrections:
  - ***D5.1***, month 24 “Publish on the ChETEC-INFRA web page a first version of 3D NLTE abundance corrections grid for a limited number of chemical elements”
  - ***D5.3***, month 42 “Scientific publication on a new grid of 3D hydrodynamical model atmospheres covering the range of stellar atmospheric parameters from dwarf to giant stars”
  - ***D5.5***, month 48 “Publish on ChETEC-INFRA web page an open-access web-based database of 3D NLTE abundance corrections for a number of key s-process chemical elements computed using the new 3D hydro grid”
- Homogeneous Open-Source Stellar Pipeline:
  - ***D5.2***, month 30 “Publish open-source pipeline on project web page”
  - ***D5.4***, month 42 “Publish on project web page open-access web-based database of corrections of surface abundances for the effects of stellar evolution”

ALL DONE

ChETEC-INFRA WP5: results

SCHOOLS, OUTREACH

- First ChETEC-INFRA Observational School in Ondrejov, July 2023:
  - ~20 students
  - 3 nights of remote observations with NOT, lots of data obtained for the analysis
  - successful usage of webSME pipeline by students to analyze the data obtained
  - students (and lecturers!) excited!
- Second ChETEC-INFRA Observational School: Prague, July 2025:
  - ~20 students
  - 4 x 0.5 nights of remote observations with NOT, lots of data obtained for the analysis
  - successful usage of webSME pipeline by students to analyze the data obtained
  - students (and lecturers!) excited!
- Masterclass by Hannes Nitsche et al. on cosmological lithium problem, utilizes the webSME pipeline

ChETEC-INFRA WP5: results

HIRING OF PERSONNEL

- 2-year PDRA at the Astrophysical Institute Potsdam (Andrew J. Gallagher)
- 2-year PDRA (1-year funding from ChETEC-INFRA) at Uppsala Observatory (Johannes Puschnig)
- 2-year PDRA at the Trieste Astronomical Observatory (Chi Thanh Nguyen)
- 1-year PDRA at Vilnius University (Jonas Klevas / Edgaras Kolomiecas)

ChETEC-INFRA WP5: conclusions

SUMMARY AND CONCLUSIONS

- Goals of ChETEC-INFRA WP5 achieved, deliverables completed
- New collaboration networks and teams have been built
- Obtained scientific results shared not only with the community, but with the broader society, too
- Two schools for young scientists organized, both highly ranked by the students

ChETEC-INFRA – A KEY VEHICLE FOR ACHIEVING ALL THIS

THANK YOU!

Partners

Associated partners