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WP6/NA1
"Comprehensive Nuclear Astrophysics"

ChETEC-INFRA General Assembly 2023

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WP6/NA1 “Comprehensive Nuclear Astrophysics”

Aims

- Link three types of nuclear astrophysics infrastructures to one model science case: the astrophysical s-process: AGB stars observed by means of ChETEC-INFRA telescopes are then modeled by ChETEC-INFRA HPC, and selected uncertain nuclear reactions be studied at ChETEC-INFRA nuclear labs

- Plan of action through textbook examples of cross-collaboration between astronomers, astrophysicists, nuclear physicists and cosmochemists

- State-of-the-art yields from all astrophysical sites that contribute to galactic nucleosynthesis will be merged into a brand-new, user-friendly galactic chemical evolution (GCE) platform

WP6/NA1 “Comprehensive Nuclear Astrophysics”

Structure

WP6 Coordination: Jordi José, UPC Barcelona

Task 6.1 Binary Star Database to support observations
(PIs: Camilla J. Hansen, UFrankfurt, & Richard Stancliffe, UHull; other participants: VU Vilnius)

Task 6.2 Cross-Collaboration Textbook Examples
(PI: Jordi José, UPC Barcelona; other participants: HUJI Jerusalem, ULB Brussels, HZDR Dresden, U Hull, MPIA Heidelberg, VU Vilnius)

Task 6.3 Galactic Chemical Evolution
(PI: Brad K. Gibson, UHull; other participants: CSFK Budapest, INAF)

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Task 6.1 – Report on main activities

Binary Star Database to support observations

SPECIFIC GOALS

-Training students in **all** astro-nuclear-disciplines: Observations, theory, experiments – the plan is to hire a student at MPIA, starting out with **observations**, and following train the student in **theory** (Hull), and **experiments** (Oslo / Frankfurt)
-**Observe AGB & CEMP-s stars**, derive RV + 1D, LTE abundances → apply corrections (in collaboration with WP5)
-**Run stellar evolution models & post processing** (AGB + s-process)
-**Experiments relevant for the s-process** (rates for Kr & Rb, cross sections for Bi & Pb)

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Task 6.1 – Report on main activities

Binary Star Database to support observations

MAIN ACTIVITIES PERFORMED AND ACHIEVEMENTS

To understand binary systems, their mass transfer, AGB stars – and the s-process that they host, we carried out binary monitoring through repeated radial velocity (RV) observations. The s-process nucleosynthesis is being explored via chemical abundance analyses of AGB and binary stars.

The current state of the RV part by number is:
(i) Total observing nights awarded: **46** at TNA telescopes: Moletai, Ondrejov, and Rozhen
(ii) Total number of stars observed: **202**
(iii) Total number of RVs measured: **271**
Approximate average RV_{rms}: ~ 4 km/s (best ≤ 0.8 km/s) at TNA telescopes which is comparable to literature RV_{rms} which typically cover a similar range ~ 0.05 – 3 km/s

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Task 6.1 – Report on main activities

Binary Star Database to support observations

MAIN ACTIVITIES PERFORMED AND ACHIEVEMENTS

The current state of the abundance part by number is:
(i) Total number of stars with estimated atmospheric parameters: **78**
(ii) Total number of stellar abundances/patterns computed: **4**
Target stars are observed at TNA facilities, with high- resolution echelle spectrographs at a moderate signal-to-noise (S/N) for RVs and high S/N for abundances.

Raw spectra are reduced using observatory pipelines and our own codes. Targets without RVs in literature are prioritized for follow up to build the RV database. Stellar parameters are estimated using the ATHOS and Xiru programs. These parameters are compared to the photometric and spectral results from Gaia DR3, and are in good agreement. Photospheric abundances are computed using the PyMOOGi program. Clean lines of the desired s-process elements are fitted using Gaussian profiles, and the abundances are computed. Abundances from blended lines are computed using spectral synthesis.

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Task 6.1 – Report on main activities

Binary Star Database to support observations

OUTCOMES

Outreach activities: We have participated in several local and virtual events (e.g., SNAQs)

Deliverables (Task 6.1, Month 12): **D6.1** was completed after 6 months, where we set up an online data base. We uploaded new abundances and RV results after 12 months as well.

Publications: 1 (+3 in progress)

Talks in Conferences/Workshops/Schools: 2

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Task 6.2 – Report on main activities

Cross-Collaboration Textbook Examples

SPECIFIC GOALS

Provide the ChETEC-INFRA community with **textbook examples** of cross-collaboration between astronomers, astrophysicists, nuclear physicists, and cosmochemists.

(i) **Identification of suitable science cases** (i.e., nuclear reactions of astrophysical interest affected by large nuclear uncertainties) through **sensitivity studies**
(ii) **Feasibility studies** of the nuclear physics experiments planned to reduce their associated uncertainties
(iii) Preparation of a **proposal for the experiment**
(iv) **Measurement and data analysis**
(v) Evaluation of the **astrophysical/cosmochemical impact** for a specific stellar site

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Sensitivity studies → Identification of key reactions of astrophysical interest → Experiments

The Astrophysical Journal Supplement Series, 178:110–136, 2008 September

THE EFFECTS OF VARIATIONS IN NUCLEAR PROCESSES ON TYPE I X-RAY BURST NUCLEOSYNTHESIS

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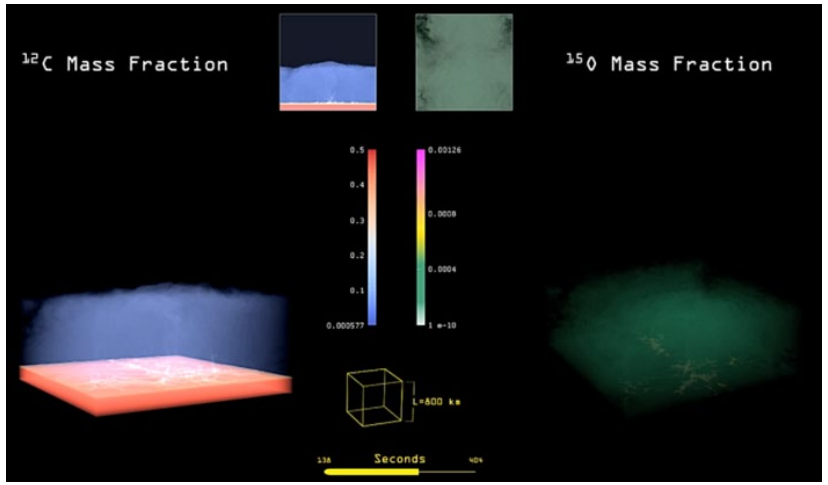
TABLE 20
Nuclear Processes Affecting the Total Energy Output by More than 5% and at Least One Isotope

Reaction	Models Affected
$^{15}O(\alpha, \gamma)^{19}Ne^{a}$	K04, K04-B1, K04-B6
$^{18}Ne(\alpha, p)^{21}Na^{a}$	K04-B1, K04-B6
$^{22}Mg(\alpha, p)^{25}Al$	F08
$^{23}Al(p, \gamma)^{24}Si$	K04-B1
$^{24}Mg(\alpha, p)^{27}Al^{a}$	K04-B2
$^{26g}Al(p, \gamma)^{27}Si^{a}$	F08
$^{28}Si(\alpha, p)^{31}P^{a}$	K04-B4
$^{30}S(\alpha, p)^{33}Cl$	K04-B4, K04-B5
$^{31}Cl(p, \gamma)^{32}Ar$	K04-B3
$^{32}S(\alpha, p)^{35}Cl$	K04-B2
$^{35}Cl(p, \gamma)^{36}Ar^{a}$	K04-B2
$^{56}Ni(\alpha, p)^{59}Cu$	S01
$^{59}Cu(p, \gamma)^{60}Zn$	S01
$^{65}As(p, \gamma)^{66}Se$	K04, K04-B2, K04-B3
$^{69}Br(p, \gamma)^{70}Kr$	S01
$^{71}Br(p, \gamma)^{72}Kr$	K04-B7
$^{103}Sn(\alpha, p)^{106}Sb$	S01

Astrophysical impact of new reaction rates



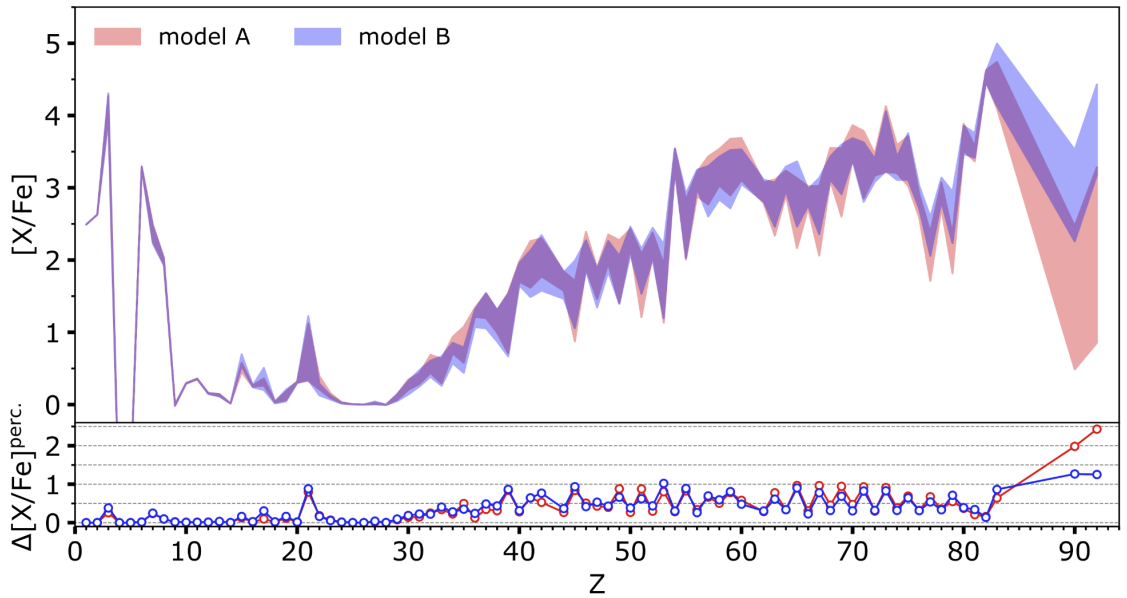
PHYSICAL REVIEW LETTERS 128, 182701 (2022)

Constraining the $^{30}P(p,\gamma)^{31}S$ Reaction Rate in ONe Novae via the Weak, Low-Energy, β-Delayed Proton Decay of ^{31}Cl

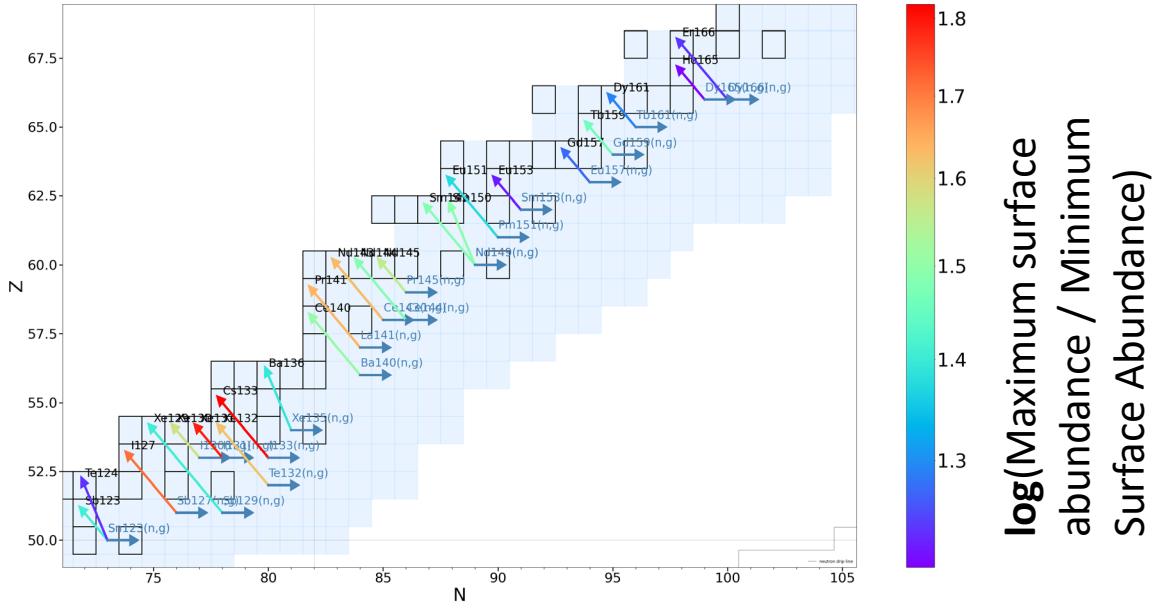
T. Budner,[1,2,*] M. Friedman,[1,3] C. Wrede,[1,2,†] B. A. Brown,[1,2] J. José,[4,5] D. Pérez-Loureiro,[1] L. J. Sun,[1,6] J. Surbrook,[1,2] Y. Ayyad,[1,7] D. W. Bardayan,[8] K. Chae,[9] A. A. Chen,[10] K. A. Chipps,[11,12] M. Cortesi,[1] B. Glassman,[1,2] M. R. Hall,[8] M. Janasik,[1,2] J. Liang,[10] P. O'Malley,[8] E. Pollacco,[13] A. Psaltis,[10] J. Stomps,[1,2] and T. Wheeler[1,2]

WP6/NA1 “Comprehensive Nuclear Astrophysics”

Sensitivity studies → Identification of key reactions of astrophysical interest → Experiments



Correlated models uncertainties and Non-correlated parameters uncertainties in early AGB stars



Identification of key (n,g) reactions for the i-process nucleosynthesis

S. Martinet’s Talk → Impact of the systematic and statistical nuclear uncertainties on the i-process nucleosynthesis

WP6/NA1 “Comprehensive Nuclear Astrophysics”

Task 6.2 – Report on main activities

Cross-Collaboration Textbook Examples

MAIN ACTIVITIES PERFORMED AND ACHIEVEMENTS

We have selected a small set of key reactions previously identified in existing sensitivity studies:

(1) ^{30}P(p,γ), relevant for classical novae

(2) ^{15}O(α,γ), relevant for type I X-ray bursts

(3) ^{26}Al(n,p) and ^{26}Al(n,α), relevant for core-collapse supernovae.

The impact of the new reaction rates has been evaluated with state-of-the-art stellar codes developed and maintained in WP6. PhD Students and young Postdocs have actively participated in all the different stages mentioned above, getting in turn training in computational astrophysics, observational astronomy, experimental nuclear physics, and cosmochemistry.

WP6/NA1 “Comprehensive Nuclear Astrophysics”

Task 6.2 – Report on main activities

Cross-Collaboration Textbook Examples

OUTCOMES

Outreach activities: multiple outreach activities have been conducted in the last 18 months by participants of Task 6.3, including “Seminar at SNAQs”, “Public Talk at INPC22, Cape Town”.

Deliverables (Task 6.2, Month 12): **D6.2**. We published on ChETEC-INFRA webpage a first version of the multidisciplinary guide to astronuclear science cases. It includes a discussion on the role of sensitivity studies in the identification of key reactions (and in the evaluation of the impact of their uncertainties), and a number of specific astrophysical scenarios in explosive nucleosynthesis for which such sensitivity studies have been conducted (e.g., novae and supernovae, X-ray bursts...).

Publications: 6 (+ 2 in progress)

Talks in Conferences/Workshops/Schools: 3

WP6/NA1 “Comprehensive Nuclear Astrophysics”

Task 6.3 – Report on main activities

Galactic Chemical Evolution

SPECIFIC GOALS

- Development of the **next generation of the OMEGA/OMEGA+ software pipeline**, linking GCE expertise at Hull, with those at CSFK and INAF. These subtasks include:

  *__Multi-zone extension__ to the existing single-zone versions of both codes
  *__Stellar population synthesis post-processing tool__
  *__Radial gas flows, churning, and 2D resonances__

- Maintenance of (i) **stellar yields databases**, and (ii) **stellar observational abundances databases**; integration with OMEGA/OMEGA+

WP6/NA1 “Comprehensive Nuclear Astrophysics”

Task 6.3 – Report on main activities

Galactic Chemical Evolution

MAIN ACTIVITIES PERFORMED AND ACHIEVEMENTS

The primary goal has been the development of the next generation of the OMEGA/OMEGA+ software pipeline, linking Galactic Chemical Evolution expertise at UHull, with those at CSFK and INAF. Among the achievements obtained so far:

- A framework for the multi-zone extension to the existing version of OMEGA/OMEGA+ has been designed and developments are ongoing.
- The multi-zone framework includes a prescription for radial gas flows.
- Working on a preliminary version of a stellar population synthesis and post-processing tool.
- PhD student attached to 6.3 has published a first-author paper using the OMEGA tools (Womack et al. 2023)

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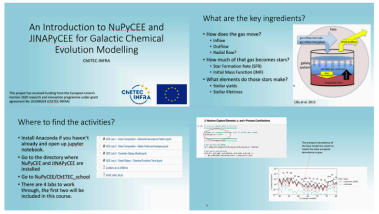
Galactic Chemical Evolution Modelling



A video course on GCE Modelling with NuPyCEE and JINAPyCEE that guides through the initial setup, and their application in two lab projects.

The course can be found on this page.

What did you like about this session?

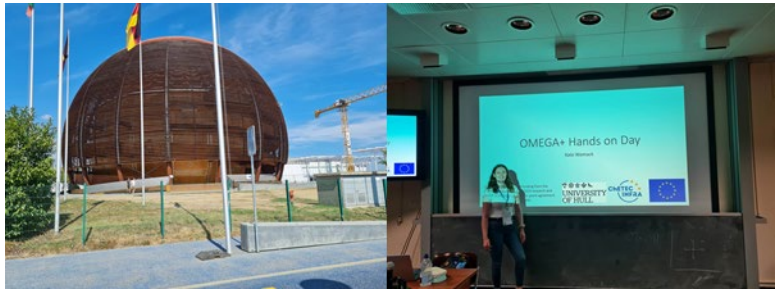
- The jupyter notebook format was helpful for the participants to visualise the concepts.
- Participants enjoyed the hands-on way of learning and liked how interactive the session felt.
- Participants enjoyed that the knowledge was gradually built up over the course of the session.
- Participants enjoyed the enthusiastic presenting style and the explainers of the main concepts of before starting each task.

Do you feel able to use OMEGA+ for basic chemical evolution modelling after this session?

Yes = 17

Somewhat = 9

No = 3



K. Womack’s Talk → Course on Galactic Chemical Evolution: Developments and Uptake

WP6/NA1 “Comprehensive Nuclear Astrophysics”

Task 6.3 – Report on main activities

Galactic Chemical Evolution

OUTCOMES

Outreach activities: 211 outreach events between May 2021 and Oct 2022 have been conducted by participants of Task 6.3, including “Pint of Science”, “Engineering UTC careers talk”, “Nova studios promotional film”, “Hull collegiate breakfast”, “Notre Dame”, “HERAS”, “Mexbrough and Swinton”, “York Astro”, “Guildford astro”, “Wakefield astro”, “Binding blocks x2” (GCSE and A-level versions), and “Wyke careers talk”

Deliverables (Task 6.3, Month 12): **D6.3**. We have launched an online and in-person OMEGA/Python training school (the latter was delivered as part of the NPA-X School).

Publications: 20

Talks in Conferences/Workshops/Schools: 5

WP6/NA1 “Comprehensive Nuclear Astrophysics”

Milestone:

- **M11** First documented example of cross-collaboration led by an early-stage researcher from outside the consortium involving identification of a key nuclear rate, supported by elemental or isotopic abundance determinations, in the framework of astrophysical simulations (Month 36).

Deliverables:

- D6.1 Provide AGB/binary database interface on project web site with open access to all new observations to outside users (Task 6.1, Month 6)
- D6.2 Publication on project web page of the first version of the multidisciplinary guide to astronuclear science cases (Task 6.2, Month 12)
- D6.3 First online training course active; expected 40 users-institutes per year (Task 6.3, Month 12)
- D6.4 Cross disciplinary training of a student/postdoc in all three disciplines – experiments (GUF, HZDR, and associate partner Oslo), theory (UHULL), Observations (MPG/VU) (Task 6.2; Month 24)
- D6.5 Report on uptake of web-based training courses (Task 6.3; Month 24)
- TBD D6.6 Scientific publication (review) on NA1 results (Task 6.3, Month 36)
- TBD D6.7 Report on uptake of web-based training courses (Task 6.3, Month 48)

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