# *BRIDGCE-IReNA 2024: Bridging Research in Disciplines of Galactic Chemical Evolution and Nuclear Astrophysics*

*8-10th July 2024*

*University of Surrey, Guildford*

The *BRIDGCE-IReNA 2024: Bridging Research in Disciplines of Galactic Chemical Evolution and Nuclear Astrophysics 2024* workshop brought together 42 participants from the UK and the USA to explore global research addressing key questions such as "Where are the elements created?" and "Which nuclear reactions shape stars?".

The BRIDGCE network, based in the UK, aims to bridge research across various disciplines, including galactic chemical evolution, nuclear and stellar astrophysics, hydrodynamics, stellar mergers and explosions, and observational astronomy. This 2024 workshop, sponsored by the Surrey University Institute of Advanced Studies, the Institute of Physics, the Royal Astronomical Society, IReNA and STFC, is key to both research and education of the UK nuclear astrophysics community, and this report outlines what we did and what was achieved.

The workshop was held in the Institute for Health building at the University of Surrey, Guildford, United Kingdom. Sessions were organised into three main themes which were mixed up across the three days of workshop to encourage cross-disciplinary synergies and discussion during the coffee breaks: **1 Nuclear and atomic physics, 2 Stars and stellar evolution and 3 Galaxies.**

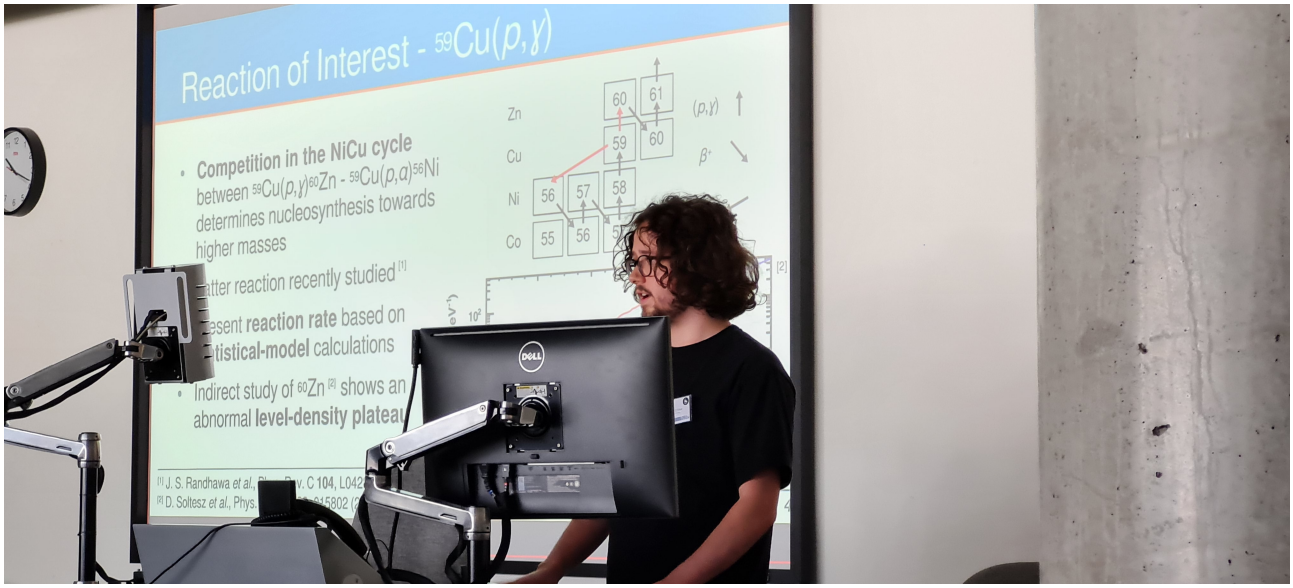
The highlights from each day are outlined in the sections below. The vital statistics of the meeting are then discussed, followed by a wholehearted thank you to our sponsors.

## 1 Nuclear and atomic physics

The study of some of the smallest particles in our Universe may seem out of place in a workshop about galactic chemical evolution, but it is at the scale of nuclei and atoms that the chemical elements are made. We held two sessions on these topics, on days two and three.

**Day two** began with an excellent invited talk when Rebecca Surman discussed R-matrix data, this time from the observational astrophysics point of view. Having this review open the subject was inspirational for those working in the field of heavy-element production in neutron-star mergers and supernovae. The programme then extended into the unknown with talks on p-process isotopes by Sophie Abrams, again relevant to neutron stars accreting material inside stellar common envelopes. Ben Wallis then spoke about electron captures in plasmas, a practical application of nuclear theory that is relevant in both stars and on the Earth. Another invited speaker David Jenkins, from the University of York, then spoke about the relation between nuclear reactions involving two carbon-12 nuclei to the Hoyle State predicted by Fred Hoyle 1954.

Cathy Ramsbottom, of The Queen's University of Belfast, opened **day three** with an invited talk on the subject of R-matrix data applied to astrophysics, another crucial step in interpreting astrophysical data from merging compact stars. It was great to hear such a clear overview of the theory behind R-matrix simulations and this benefited particularly the inexperienced researchers at the workshop. The exotic nickel-copper nuclear-reaction cycle was then addressed by Surrey student Conner O'Shea, showing that this makes zinc-60 in X-ray bursts which is potentially observable. The topic then shifted to the relatively large: atoms and their spectroscopy. Leo Mulholland discussed optically-thin spectral features from neutron-star merger events and how local thermodynamic equilibrium computations, which are used throughout astrophysics, may not be enough to understand the spectra we see from such events. Chris Cousins finished the day's fun with an explosive talk about supernovae and, in particular, the production of chromium-46 and its observational through spectroscopy to investigate resonant states.



## 2 Stars and stellar evolution

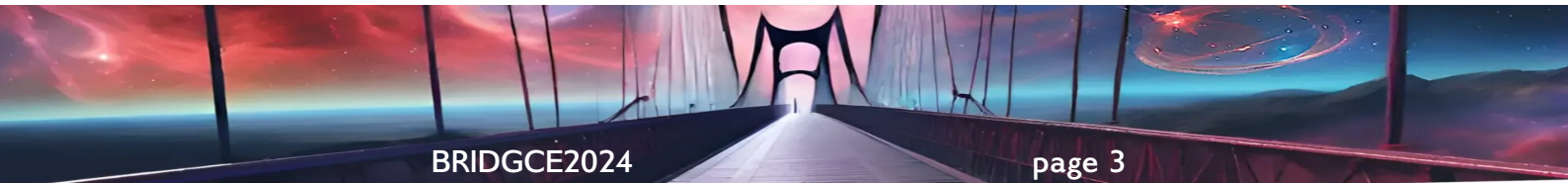
The scale between tiny nuclei and enormous galaxies is bridged by the stars. The hot, dense centres of stars are where protons fuse to make helium, then helium fuses to make carbon, and eventually heavy elements are made alongside the release of huge amounts of energy. On Earth, we benefit from this luminous energy to keep us warm and allow plants to grow. Exotic stars were a particular focus of this workshop.

**Day one's** stars session opened with the invited talk of Christine Collins, from Northwestern University, on the properties of matter in merging neutron stars. She explained the plethora of observations that now exist of these bright, luminous "kilonovae" and how heavy elements are made in the process. The need for accurate atomic data and expensive, state-of-the-art three-dimensional hydrodynamical calculations was highlighted. Merged stars were also a focus of the talk of Alex Hackett, from the Institute of Physics of the Czech Academy of Sciences. His study of Thorne-Zytkow objects, in which a neutron star merges with a less-evolved red giant star, provides a unique environment for the formation of heavy elements.

The explosive theme continued with Umberto Battino's, from Keele University, presentation on the production of the radioactive aluminium-26 isotope in massive stars. This led to much discussion, especially because of the local interest in the Surrey nuclear and astrophysics groups regarding the production of this mysterious isotope. Interacting stars were then discussed by Yan Gao, from the University of Birmingham, who discussed triple stars and how they exchange angular momentum through their tides. The explosions of stars as supernovae was then returned to by Mikako Matsuura, from the University of Cardiff, linking massive explosions back to the small scale where dust is formed. Given that the recently-launched James Webb Space Telescope (JWST) sees this dust back to near the beginning of time, the science in this field is more active and exciting now that it has been for decades.

**Day three** focused on the final fates of stars, particularly after they explode as supernovae. Ryan Alexander, of the University of Hull, looked at satellite galaxies, near our Milky Way, which have been polluted by type-Ia supernova (SNIa) explosions. The data from these galaxies is breaking new ground in both its quality and quantity, and the hope is that these can be used to pin down the origin of the mysterious SNeIa which still elude even the best modelling efforts. Caitlin Chambers, from the University of Keele, then discussed the fate of massive stars, in particular the impact rotation has on their lives and final explosive deaths, and the link to low-metallicity very-massive stars, up to 500 times the mass of the Sun, in the early Universe.

The last few minutes of the lives of such stars were then explored by Vishnu Varma, also from Keele, in three-dimensional simulations of nuclear burning of silicon in massive stars. This topic is key because it links expensive but precise 3D hydrodynamics simulations to the more traditional, and computationally far cheaper, 1D simulations more commonly used by the community. The final structure of the star relies on us getting the mixing simulated here absolutely right, and this work is a wonderful step forward in this regard. This day, and workshop, finished with a talk by Kelsey Lund, from North Carolina State University and Los Alamos Laboratory, on magnetic fields and how they impact nucleosynthesis in merging neutron stars. Most stellar astrophysicists mostly ignore magnetic fields, but in these compact, general-relativistic merging stars, the magnetic fields are extreme and cannot be neglected. Kelsey linked the magnetohydrodynamics of such systems with the nuclear physics far from the valley of stability. Truly, this is amazing work with many applications mentioned by the audience.



## 3 *Chemical evolution of Galaxies*

Galaxies are where the impact of nuclear reactions in stars is felt, measured and changes with time. In the past, astronomers have focused on our Milky Way galaxy because the quality and quantity of observations is greatest there. However, with the advent of modern telescopes like JWST, we can now see galaxies right back to the dawn of time in a range of electromagnetic wavelengths from radio, through infra-red and visible light, to ultraviolet, X-ray and gamma-rays. The opening talk on **day one** of the BRIDGCE workshop was the superb James-Webb spaced-telescope (JWST)-themed review by invited speaker Emma Curtis-Lake. She discusssed the first results from JWST and how these challenge our fundamental understanding of galactic evolution and measurements of the chemistry, particularly helium and nitrogen, in very young galaxies.

How the chemistry of galaxies changes as they age was the highlight of the opening talk of **day two**'s afternoon session by Rob Yates, of the university of Hertfordshire, who spoke about cosmic metals and dust, also the vital building blocks of planets. Following this, Louise Welsh from the observatory in Trieste, looked at damped Lyman-alpha systems which are identified by absorption in the hydrogen lines of their spectra. These are thought to be young galaxies, and the focus was on finding galaxies as close to the pristine Big Bang metal-free composition as possible and measuring their chemistry, such as $^{12}C/^{13}C$ ratio and oxygen abundance, hence was truly fundamental astrophysics. Continuing the first stars theme, Dyna Ibrahim, of Hertfordshire, talked about chemical enrichment in the first stages of the cosmos when the stars were very massive, many hundreds of times the mass of our Sun. The signature of nitrogen was found to dominate in these young systems, as found in the JWST observations that opened the galaxies themed sessions.

## *Outreach*

Finally, because it does not fit directly into the science programme but is of vital importance to our work, Andy Brittain of the Lady Eleanor Holles School, Hampton, gave us an enthralling introduction to using stellar astrophysics in school outreach programme. BRIDGCE has been particular strong in this regard, especially through the *Stars for Schools* programme organised by Robert Izzard, and many new ideas and volunteers to help came forward after this talk. We now have plans to internationalise the project, including foreign languages, and expand to more schools in more countries. It was great to see new enthusiasm for outreach in schools which continues an excellent BRIDGCE tradition.

## *People and progress*

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| **Attendees** | **42** |
| **Female** | **48%** |
| **Early-career** | **71%** |

A total of 42 attendees joined the workshop, with 37 participating in person, fostering a vibrant and engaging three-day event on the University of Surrey campus in July 2024. Two-thirds of the attendees delivered presentations, including distinguished speakers from the IReNA network in the USA. Highlights included talks on neutron-star merger ejecta and the role of nuclear astrophysics, galactic and cosmic dust production, the merging stellar halos of the ancient Milky Way, hydrodynamics and nuclear burning in dying stars, and the dynamics of triple star tidal interactions.

Of the attendees, 48% were female which is well within 50% allowing for Poisson-counting uncertainty. A large fraction, 71%, were early-career researchers, i.e. PhD students or non-permanent-staff postdoctoral researchers. These numbers demonstrate BRIDGCE's ongoing commitment to gender equality and the nurturing of the next generation of scientists interested in galactic chemical evolution and all related disciplines. The schedule allowed ample time for questions and discussions, both during formal sessions and informally during breaks and evening social gatherings in Guildford town centre. New projects and funding applications have already emerged from the workshop, and the feedback from participants was overwhelmingly positive. A few comments received are listed below.

- The BRIDGCE 2024 meeting was a great science workshop. It was fantastic to bring together such a variety of speakers, I particularly enjoyed the atomic physics talks!
- I thought that the BRIDGCE2024 workshop in Guildford was great! It provided an excellent opportunity to hear about the impressive range of UK work on nuclear astrophysics, which was particularly beneficial, I think, for the PhD students in our group - really good for them to help appreciate the variations connections between our fields, and to make connections with other early career researchers with complementary expertise. Many thanks for organising, and hosting!
- The BRIDGCE collaboration is one of the few opportunities for the UK astrophysics and nuclear physics communities to connect, and exchange ideas about how to advance the fields of stellar evolution and galaxy formation. Over the years, I benefited tremendously from attending these meetings, and this year was no exception. A great thank you for this year's sponsors and organizers of the meeting!
- Thank you for organising BRIDGCE2024 meeting. As an observing astronomer, it is great to meet a lot of theoreticians, and also atomic physicists. Especially, I was excited to see the model for gravitational waves improving.

## *Organising committee and administrative support*

- Dr Robert Izzard, University of Surrey (chairman)
- Dr Payel Das, University of Surrey
- Dr Andreea Font, Liverpool John Moores University
- Professor Raphael Hirschi, Keele University
- Professor Chiaki Kobayashi, University of Hertfordshire
- Professor Alison Laird, University of York
- Professor Gavin Lotay, University of Surrey
- Dr Stuart Sim, Queen's University Belfast
- Dr Matthew Williams, University of Surrey
- Astha Astha (University of Surrey)
- Louise Jones (Institute of Advanced Studies, University of Surrey)

## *Acknowledgements*

This workshop was made possible thanks to the generous financial support from the Institute of Advanced Studies at the University of Surrey, the Institute of Physics, the Royal Astronomical Society, the Science and Technology Facilities Council, and IReNA. Early-career researchers, in particular, benefited from the excellent facilities, accommodation, travel support, and sustenance provided by the University of Surrey completed with fine coffee from The Hideout. Special thanks go to Louise Jones, Mirela Dumic and especially Astha Astha for their outstanding administrative support. Beyond its scientific success, the workshop was a thoroughly enjoyable experience for all participants and it set a very high standard for future BRIDGCE events, as the following photograph of BRIDGCE chair Prof. Chiaki Kobayashi shows, taken at the workshop dinner at the March Hare in Guildford.