**Bringing Stellar Evolution & Feedback Together**  
**25 – 29 April Lorentz Center@Oort**

**Scientific**

**Description and aims**
Massive stars play a crucial role in shaping their environment, accreting from dense protostellar disks and returning large amounts of energy as radiation and mass flows (“feedback”) that reach out to the intergalactic medium. Stellar evolution and feedback on larger scales are well-studied, but to date these communities rarely interact. In light of recent findings that show this connection is timely and crucial, this meeting will bring these communities together to interact, establish a set of common interfaces between the two problem domains, and propose where solutions across this interface will be found.

**Tangible outcome**
The workshop brought together researchers in the fields of stellar evolution and stellar feedback. The programme was a combination of short talks on key aspects of research in the two fields that intersect (e.g. the budget of stellar wind energy when considering single stars and binaries, or the environments that stars form in in different galaxies) and structured discussions (“breakouts”) centred around topics identified during the talks and informal coffee interactions. Moreover, the workshop, as well as the social programme on Wednesday (Koningsdag) gave people the opportunity to interact informally and build interdisciplinary collaborations, which we hope will bear fruit with future publications in top-ranked astronomy journals in the months to come.

The key concrete deliverable is a white paper written with the input of all attendees centred around notes from the breakouts. A first draft of the white paper was constructed on the last day of the workshop and will be collated by a sub-group in the weeks following the conference, with the intention of submitting it to the journal Astrophysics and Space Science, as well as the public pre-print service arXiv.

The workshop was also highly successful in bringing together researchers in different countries and at career stages. A significant number of early career researchers across the planet took part actively, with strong interaction between online and in-person participants. This, as well as the white paper, will have a positive impact on the careers of young researchers and provide opportunities for future interdisciplinary projects.

**Scientific breakthrough**
The scientific impact of the workshop is to identify how the fields of stellar evolution and feedback intersect. One key breakout theme was that of “Unknown Unknowns”, i.e. what interfaces between the two fields were we to date not even aware of, or what processes do we still not understand well enough to implement in a holistic model of how stars shape the wider universe? All of the breakouts, however, contributed to shaping our picture of what the state of the art is on the problem. Topics included how we can compare simulations and observations in astrophysics, uncertainties in the budget of UV radiation escaping to ionize galaxies and the inter-galactic medium, how the effect of stars combines in large populations, differences between stars today and stars in the cosmic past, how we can use galaxies in our local group to understand the diversity of feedback, how the elements that make up planets and life are generated in stars, the role of interacting binary stars, how the unseen internal structure of stars behaves, and how feedback from stars flows from small scales where the stars form to (inter-)galactic scales.

**“Aha” moments**
The purpose of the workshop was to generate “aha” moments in researchers who to that point had not interacted widely with researchers in the other field or taken part in similar collaborations. Some example “aha” moments came from the radical differences in feedback from stars when interacting in binaries (e.g. the “stripped envelope” phase), drastic changes in how feedback operates when different processes (e.g. mass loss from stars as winds vs radiation) interact, finding massive stars without any observable formation environment around them, the fact that some massive stars may not go supernova at the end of their lives (and establishing precisely when and where they do, especially since most massive stars are in binary systems). Overall, a striking and sobering finding was that our understanding of stars and galaxies is still evolving drastically, and as it does, so too will our ability to map the interaction between stars and the wider universe.
Organization

Format of the workshop

The workshop began with a set of flash introduction talks of < 1 minute to give people a taste of what everyone in the workshop worked on and to link names to faces. We also ran two review talks on each topic to give both groups a grounding in each others’ fields. The programme on the first 3 days of the workshop was subsequently devoted to a mix of “crash course” talks where early career researchers were invited to highlight an aspect of their work that raised interesting questions for the other field (e.g. what happens to radiation feedback when binary evolution is considered? How do stars form differently in galaxies in the early universe?) Day 4 (Friday) was devoted to final discussions and synthesis of what was learned into a white paper, which will be submitted for publication in the coming weeks. Poster talks were also arranged during a roundup session to allow poster submitters to promote their work. The workshop also featured a social day (Wednesday) due to the Center being closed for Koningsdag, which allowed participants to interact informally. A boat tour was organized, with impromptu activities such as a bike tour to the tulip fields arranged in the afternoon.

The workshop was fully hybrid, aside from informal coffee breaks and social activities. This was facilitated by use of 360-degree Owl cameras, which allowed high-quality sound and video input for online participants. Talks were all streamed to Zoom, with a main Zoom window displayed in the room to allow attendees to view slides either in person or online. 4 Owls were on hand, allowing 4 breakout discussions to be held. For smaller paper working groups on Friday, laptop cameras were sufficient. Some participants joined in-person for part of the time and online for the rest due to other commitments. Talks were recorded, and notes taken from each breakout, including some with diagrams. There was no pressure from the organisers for invitees to pick either in person or online attendance.

An online Slack board was used to coordinate events online and in person, including social activities. The white paper was constructed using the online collaborative writing tool Overleaf. A wonder.me space was opened to allow for informal online discussions outside of the structured talks and breakouts, but as far as we are aware this was not used.

Overall, the use of hybrid participation was highly successful and should become the norm for most events of this nature. It made the workshop more inclusive by allowing people with childcare commitments or geographic constraints to take part. It also led to a more early-career in-person component since some senior attendees stayed online due to teaching constraints. This allowed young researchers to express themselves more freely, take leadership of activities and make connections with their peers. The presence of an in-person component provided an “anchor” to the event, where attendees interacted informally as well as in formal sessions. Online participants often did not interact informally with attendees outside of sessions, although we believe that this was more due to their focusing on things outside of workshop sessions (e.g. work, family) rather than a lack of provision of opportunities for interaction. Online participants interacted strongly with organized events including the paper writing sessions on Friday.

Other comments

We ran a 1-day online-only event in 2021 due to the covid lockdown. This was a successful primer to the in-person event this year (2022). In the post-meeting report, we highlighted how online-only participants tend not interact extensively outside of organized sessions, while in-person attendees naturally start discussions. This was improved drastically with the presence of an in person “anchor” event, so that attendees could choose to interact at their own pace. We hope that future events can continue to iterate and improve on this formula.

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