

Lorentz Center Workshop on Numerical Recipes in Star Formation

July 21 – 25, 2025

Summary Report

We organized a Lorentz Center workshop on computational methods in star formation from July 21 to July 2025 in Leiden. The workshop was aimed at discussing ongoing research in star formation theory and simulations, and providing a platform for the community to come together to discuss recent advancements and challenges in numerical techniques. Some key elements of the workshop were designed be discussions and talks on numerical implementations of radiation hydrodynamics, magnetic fields and turbulence, chemistry, and cosmic rays in cloud-scale to galactic-scale simulations focused on star cluster formation and stellar feedback. We envisioned facilitating collaborative discussions on caveats and code comparisons, aiming to better understand the role of physics versus numerics in simulations.

Many numerical algorithms used by the star formation community are the same as that used by galaxy and cosmology communities, so the outcomes of this workshop will also enable further research in large scale cosmological simulations developed and used by the Dutch astronomical community. The end goals of our workshop will also act as starting point for stellar N-body dynamics, which is critical to understand the evolution of star clusters, evolution of binary stars, mergers, and gravitational wave sources. The Netherlands has a thriving astrochemistry community, which has been pushing for a workshop like ours to find novel ways to integrate chemistry in hydrodynamics simulations.

This was an invite-only workshop, with 53 confirmed participants that span across most groups in the world working on star formation theory. 27 of the 53 participants are early career researchers (8 PhDs, 19 postdocs) actively involved in developing simulations. We set up a daily goal for each of the five days, taking up the key physical processes in star formation one by one: Monday was devoted to general hydrodynamics, the topic for Tuesday was turbulence and magnetic fields, on Wednesday we covered chemistry and radiation, and Thursday was allotted to gravity and N-body dynamics.

A central theme throughout the week was the development of simulations that self-consistently couple gravity, turbulence, radiation, magnetic fields, and chemistry, while balancing the scientific trade-offs between including more physics and increasing numerical resolution. This led to a lively and thought-provoking debate around the fundamental question: “Is more resolution always better?” Participants discussed how increasing resolution may not always yield a corresponding scientific gain if the inclusion of key physical processes must be compromised due to computational constraints. Likewise, the apparent lack of influence of a given physical process at a particular resolution does not necessarily imply that the process is unimportant – it may simply reflect the limitations of the numerical setup. These discussions helped clarify the need for carefully designed simulations that prioritize physical realism and reproducibility over brute-force resolution.

All members presented a short talk on the caveats they face in their simulations, and self-organized themselves into working groups formed to further analyze these caveats via real time debugging and standardized testing. New GPU-accelerated frameworks were also showcased, and the importance of moving to GPUs in the era of exascale computing was a

topic that was repeatedly emphasized. Three of these groups have continued to work together since the workshop. The first group is working on creating a carefully-controlled numerical experiment to understand numerical differences in treatments and effects of magnetized protostellar outflows within different codes. The second group is looking into the diversity of sub-grid prescriptions used to form and evolve ionized bubbles around massive stars. The third group has come up with a way to standardize numerous chemistry formats floating around the community by introducing JAFF – Joint Astrochemistry File Format. JAFF is expected to be produced as a scientific output that will set a benchmark for the community, setting a legacy for this Lorentz Workshop. Overall, the workshop proved both timely and fruitful, fostering new collaborations and laying the groundwork for best practices in the field.

The Scientific Organizers were:

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