Report on Ondřej Kincl's dissertation, "Extension of smoothed particle hydrodynamics based on Poisson brackets"

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As the supervisor of the thesis, I have been witnessing the development of this thesis as well as the underlying research. Ondřej Kincl came from an area of mathematical modeling of bladeless turbines Kincl et al. [2022] to a new topic – Smoothed Particle Hydrodynamics (SPH) which he explored with great enthusiasm and many new ideas.

In his first paper Kincl and Pavelka [2023b], he found out how to make globally reversible SPH simulations. Several ingredients were necessary, for instance a symplectic integrator and fixed-point arithmetic. To support the idea, he has developed a numerical code (written in the Julia language) that is publicly available Kincl and Pavelka [2023a]. All main ideas and practically all the code were developed by him.

In his second paper Kincl et al. [2023a], he found out how to solve numerically (using SPH) the system of Symmetric Hyperbolic Thermodynamically Compatible (SHTC) equations. The SHTC equations represent a system of hyperbolic partial differential equations that describe both fluids and solids at the same time. For instance, the Navier-Stokes-like behavior is achieved by letting the distortion field (an extra state variable related to the deformation tensor) relax to a quasi-equilibrium value. SPH equipped with this extra state variable can indeed model both fluids and solids within a single framework, which should be especially useful for problems where fluids and solids are in contact or transforming to each other. Although with three co-authors, the main idea how to extend SPH towards SHTC and the actual implementation and benchmarking was carried out by Ondřej Kincl.

In his third paper Kincl et al. [2023b], he found an SPH-numerical discretization of the two-component model of liquid helium-4. This numerical implementation made it possible to simulate the so called fountain effect, where a tiny heater leads to the formation of a jet (or fountain). Due to the complex free surface of the jet, the SPH-based discretization was especially convenient, in contrast with mesh-based methods. Although with two co-authors, the main idea and actual implementation of the code were done by Ondřej Kincl.

All three papers are remarkably elegant in their relation with differential geometry and Hamiltonian mechanics, and the findings are supported by comparison of numerical simulations with available benchmarks. The thesis then summarizes the findings in a clear and concise way. Ondřej Kincl has shown a great level of independence and ability to navigate his research behind the frontier of current knowledge in order to acquire new important and interesting results. Therefore, I wholeheartedly support his dissertation and recommend him for the Ph.D. degree at the Faculty of Mathematics and Physics, Charles University.

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