Discussion Session: Simulation Challenges in Modeling the ISM

Discussion Leader:
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First, let's define the subject

- "Simulation challenges": the focus should be on numerical methods needed to model the physics of the ISM.
- "Modeling the ISM": the focus is on small scales, say < 1kpc.

Keep these points in mind…

What physics is needed to model the ISM?

- Dynamics
  - Magneto-hydrodynamics (MHD)
  - Self-gravity
  - Radiation transport (both diffuse and point sources)
  - Cosmic rays
- Microphysics
  - Heating and cooling
  - Chemistry
  - Dust grains (dynamics and growth/destruction)
- Diffusive processes
  - Non-ideal MHD effects (resistivity and ambipolar diffusion)
  - Thermal conduction
- Sub-grid models
  - Sink particles
  - Supernovae and stellar winds

Potential topics for discussion

1. What are the challenges for numerical methods to capture this physics *ab initio*?
2. What are the resolution requirements?
3. Diagnostics and testing: how do we know our simulations are correct?

"Fidelity to physics and numerical accuracy are often confused."

Volker Springel, ThinkShop2018

4. Coupling to smaller scales: can any of this physics be replaced with a "sub-grid model" used in ISM simulations themselves?
5. Coupling to larger scales: how to describe the results with a "sub-grid model" in cosmological simulations?

1. Challenges for Numerical Methods

Dynamics

- Magneto-hydrodynamics (MHD)
  - AMR versus moving mesh versus SPH.
  - Higher-order methods.
  - Keeping div(B)=0.
- Self-gravity
- Radiation transport (both diffuse and point sources)
  - FLD versus M1 versus VET versus (TE + reduced speed of light) versus MC.
  - Adaptive ray-tracing versus ??
- Cosmic rays
  - Do hydro simulations with isotropic diffusion capture the physics correctly?
  - Standard CR-energy eqn approach versus two moment formalism.
  - MHD plus kinetic particles to study streaming instability.

1. Challenges for Numerical Methods

Microphysics

- Heating and cooling
- Chemistry
  - What is the right reaction network?
  - Advection errors in moving mesh versus AMR.
  - Coupling to radiative transport.
- Dust grains (dynamics and growth/destruction)
  - Are dust formation/destruction processes understood well enough?

1. Challenges for Numerical Methods

Diffusive processes

- Non-ideal MHD effects (resistivity and ambipolar diffusion)
- Thermal conduction
  - Can diffusive scales be resolved?

Sub-grid models

- Sink particles
  - How to handle magnetic field?
- Supernovae and stellar winds
  - Can be modeled directly with sufficient resolution.

2. Resolution requirements

- ISM is a multi-phase medium, must at least resolve each phase, and mixing rate between phases.
- Is explicit dissipation required to resolve interfaces to achieve convergence?
- What quantities converge? Do all codes converge to the same solutions?

3. Diagnostics and testing

- ISM turbulence is chaotic and stochastic. Small changes can produce large differences, and solutions at different times can be different. How do we account for this?
- Please report and publish test results.

4. Are sub-grid models useful?

- Is there the necessary scale-separation to allow sub-grid models to be used?
- Which physics?

5. How to “coarse grain” the solutions to create sub-grid models for larger scales?