The Dust Between Us and the Big Bang

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We are requesting 2.4×10^5 SUs on Frontera and 1.8×10^5 Gb on the Ranch archival system in order to perform several studies of

1 Background

background stuff.

2 Methods

The code we will use is Enzo (Bryan et al. 2014; Collins et al. 2010), an open source code that has been used for a number of astrophysics applications (e.g. Abel et al. 2002; Correa Magnus et al. 2023). Enzo is an adaptive mesh refinement (AMR) code that can dynamically add resolution elements as the system requires it, using the strategy of Berger & Colella (1989) and Balsara (2001). We will use the constrained transport (CT) module (Collins et al. 2010; Gardiner & Stone 2005) that conserves the divergence of the field to machine precision. It uses FFT-based gravity for the root grid and multigrid relaxation for gravity on fine grids. The base MHD solver is a higher order Godunov method. We will use Grackle (Smith et al. 2017) to handle the chemistry and thermodynamics.

3 Simulations

Here we describe simulations.

4 Request Details

The cost for each simulation is found as

$$SU = t_{wall} N_N \tag{1}$$

$$t_{wall} = \frac{\sum_\ell N_Z N_U}{\zeta} \frac{1}{N_C}, \tag{2}$$

where SU is the total cost; t_{wall} is the run time; N_N is the number of nodes; N_Z is the number of zones per level ℓ; N_U is the number of updates per level; ζ is the performance measured in (zone-updates)/(processor-second); and N_C is the total number of cores. The cost, $zeta$, is determined in the scaling document. Total disk usage is found as

$$Disk = 4 N_Z N_F N_D \text{bytes}, \tag{3}$$

where each of N_Z zones contains N_F fields and we store N_D dumps for each run. The values of N_N, N_C, N_F, N_D and ζ can be found in Table **??**. The values of N_Z and N_U are outlined in Table **??**. We will outline the process for estimating N_Z and N_U.

The number of zones, N_Z, is computed from the problem geometry. All of these simulations will use fixed or static resolution, so N_Z is known. For the *turbulence* simulations, $N_Z = 2048^3$. For the galaxy simulations, N_Z will be computed level-by-level from the grid layout. We construct each level in grid patches of 32^3 zones each. Consistent patch size allows us to optimize the memory usage and performance of the simulation. The finest level is a thin pancake of $100 \times 100 \times 1$ grids. This covers the midplane with a resolution of 6.25 pc for the entire disk, to the dust scale height of $\pm$100pc and a side length of 20kpc. Resolution increases by a factor of 2 each level. The next two levels increase the aspect ratio of the refined region ($54 \times 54 \times 3$ and $30 \times 30 \times 11$ grids, respectively), and the remaining levels are $16 \times 16 \times 16$ grids. This grid structure gives an outer size of 8.2×10^5pc on a side with 6.25pc resolution over the whole disk at the midplane.

The number of updates is found from the total simulation time over the step size, $N_U = T/\Delta t$. T by the problem goals, and we estimate Δt from the solver behavior and prior results. As described above, the *turbulence* simulations will run for $T = 5t_{dyn} = 5/(2\mathcal{M})$ (in dimensionless code units), to statistically resolve the turbulence. The *galaxy* simulations will run for $T = 2$ Gyr, which represents roughly 8 orbits of the galaxy, hopefully enough time to grow the magnetic field. The timestep size, Δt, is found by a standard Courant condition,

$$\Delta t = \eta \frac{\Delta x}{(v + c_f)_{max}}, \tag{4}$$

where $(v + c_f)_{max}$ is the maximum signal velocity on each resolution level. Here, v is the velocity and c_f is the fast MHD speed. It is not possible to predict the exact value of this signal speed, so we calibrate to lower resolution simulations and use Equation 4 to rescale. For the *turbulence* simulations, we calibrate Δt to the fiducial simulations in Stalpes et al (2023). For the *galaxy* simulations, we calibrate to a low-resolution preliminary galaxy.

Table **??** shows a summary of the request. The first two rows show each of the *turbulence* simulations. The remaining rows outline the *galaxy* simulations, estimating N_Z and $N_U = T/\Delta t$ and the total cost, SU. Also shown in the table is the projected disk usage for the new simulations, as well as our archive already on Ranch of recently run hydrodynamical turbulence simulations and star formation simulations.

References

Abel, T., Bryan, G. L., & Norman, M. L. 2002, Science, 295, 93

Balsara, D. S. 2001, J. Comput. Phys, 174, 614

Berger, M. J. & Colella, P. 1989, J. Comput. Phys, 82, 64

Bryan, G. L., Norman, M. L., O'Shea, B. W., Abel, T., Wise, J. H., Turk, M. J., Reynolds, D. R., Collins, D. C., Wang, P., Skillman, S. W., Smith, B., Harkness, R. P., Bordner, J., Kim, J.-h., Kuhlen, M., Xu, H., Goldbaum, N., Hummels, C., Kritsuk, A. G., Tasker, E., Skory, S., Simpson, C. M., Hahn, O., Oishi, J. S., So, G. C., Zhao, F., Cen, R., Li, Y., & Enzo Collaboration. 2014, ApJS, 211, 19

Collins, D. C., Xu, H., Norman, M. L., Li, H., & Li, S. 2010, ApJS, 186, 308

Correa Magnus, L., Smith, B. D., Khochfar, S., O'Shea, B. W., Wise, J. H., Norman, M. L., & Turk, M. J. 2023, arXiv e-prints, arXiv:2307.03521

Gardiner, T. A. & Stone, J. M. 2005, J. Comput. Phys, 205, 509

Smith, B. D., Bryan, G. L., Glover, S. C. O., Goldbaum, N. J., Turk, M. J., Regan, J., Wise, J. H., Schive, H.-Y., Abel, T., Emerick, A., O'Shea, B. W., Anninos, P., Hummels, C. B., & Khochfar, S. 2017, MNRAS, 466, 2217