Scaling Information for
"Four Projects in Astrophysical Magnetohydrodynamics"

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In order to quantify the performance and scaling, and to select the number of nodes to use for our jobs, we perform strong scaling studies for each of our four projects. For each suite, a fiducial simulation is performed that targets the physics packages, root grid size, particle count, and approximates the unpredictable adaptive mesh refinement (AMR) structure of the production simulations. We perform a single time step on the root grid, which takes many time steps on the subgrids. That time step is then repeated several times with an increasing number of nodes. Table 1 summarizes each of the suites, the total cost, the physics package used, the AMR structure, the cost per update, and the number of nodes to be used.

Table 1: Summary of allocation request. The total node hours and disk usage are in the first two columns, broken down by project. The physics packages used in eash project and adaptive mesh refinement (AMR) structure determine the cost per zone-update, $\mathrm{SU_{zu}}$ for each simulation suite. The number of nodes, N_N, is in the last column.

Name	Node Hours	Disk	Physics	AMR	$\mathrm{SU_{zu}}$	N_N
Turbulence	9.2×10^4	5.6×10^3	Hydro + Driving	None	4.1×10^{-11}	32
Cores	5.8×10^3	2.0×10^4	MHD + Gravity + Particles	4 levels, all space	3.3×10^{-10}	32
CMB	2.5×10^4	1.7×10^4	MHD + Driving	None	7.3×10^{-11}	32
Galaxies	2.4×10^5	2.2×10^4	MHD + Gravity + Cooling	8 level nest	3.3×10^{-10}	9
Archive		7.0×10^4				
	3.6×10^5	1.3×10^5				

The results can be seen in Figure 1. Shown in the figure is $\mathrm{SU_{zu}}$, the number of service units for the update of one cell, assuming 64 cores per node. Each of our four suites uses a different set of physics modules, which changes the cost between suites. Additionally they have different adaptive mesh refinement (AMR) structure, which changes the overhead. We discuss each suite below.

The quantity $\mu = core - hours/zone - update$, given perfect scaling, is independent of the problem size and number of cores used. It depends only on the combination physics solvers. The cost per zone-update is $\mathrm{SU_{zu}} = \frac{\mu}{\mathrm{N_C/N_N}}$, and the total cost $SU = \mathrm{SU_{zu}N_ZN_U}$, where N_Z is the total number of zones, and N_U is the total number of updates. $\mathrm{SU_{zu}}$ also depends on the number of cores per node, N_C/N_N, and all runs we use 64 cores per node. Given perfect scaling, $\mathrm{SU_{zu}}$ is independent of processor count. However, our scaling is imperfect, and the optimal node number is selected from Figure 1.

The blue line shows a set of fiducial simulations that use only the relevant hydro solvers and gravity. The hydro (or MHD) solver and gravity solver are the most expensive part of the code, so we present their timing alone as a baseline. The simulations use either Piecewise Parabolic Method (**?**) for the pure hydro turbulence simulations, or the second order MHD scheme of (**?**) for the other three. The points in the blue line are, bottom to top, PPM, MHD, PPM+Gravity, MHD+Gravity.

The orange line shows the scaling for the fiducial *turbulence* simulations. These simulations will only use PPM and the turbulent driving module, so only slightly more expensive than the baseline. The fiducial simulation is, as the production simulations will be, 1024^3 root grid with no AMR. We run on 4, 8, 16, and 32 nodes, using 64 cores per node. The result is $\mathrm{SU_{zu}} = 2\times10^{-11}$ on 4 cores, and 4×10^{-11} for 32 nodes. Production runs will run on 32 nodes, as the small increase in cost will be offset by the much shorter run time.

The green curve shows the strong scaling for the fiducial *cores* simulation. This simulation has 512^3

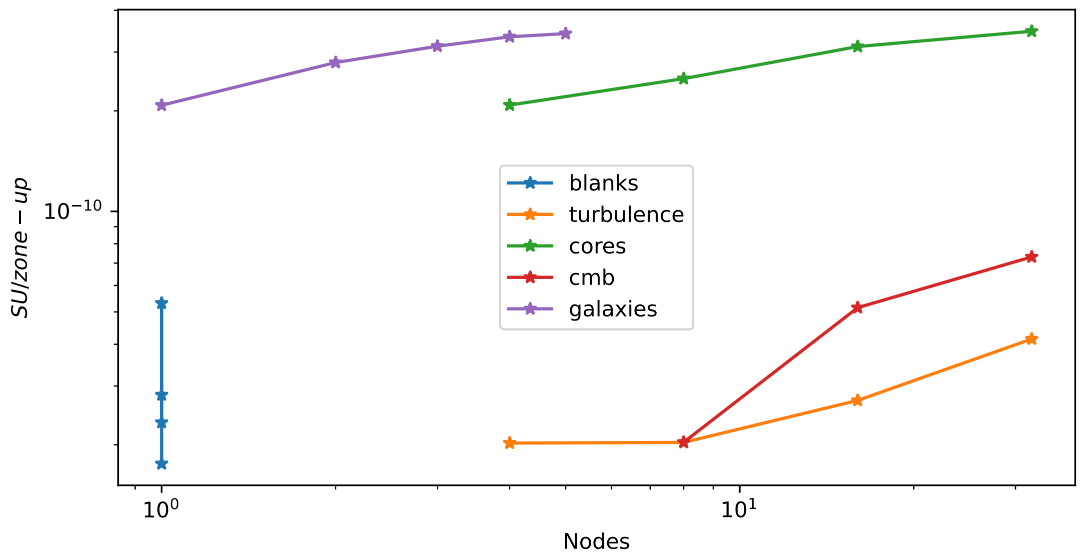

Figure 1: The cost per zone-update for each of our simulation suites. Each fiducial simulation is nearly identical to the target production simulations.

zones and 1024^3 tracer particles. On each of 4 levels, we refine a cubic region with volume based on the simulations in (**?**). This package uses the gravity solver and MHD solvers as well as the particle update machinery. For this simulation, the density and pressure are uniform, which simplifies the setup but does not affect the timing of the solver. We will run these simulations on 32 nodes as well, as the timing is favorable. Using 32 nodes will also give more peak memory, which is important as the memory load during the simulation is far from constant as the mesh structure rebuilds itself.

The red line shows the scaling for the *foregrounds* simulations. The fiducial simulation is also 1024^3 and driving like the *turbulence* suite, but uses the MHD solver so is slightly more expensive. Due to the increased memory of the extra magnetic fields, we run on 8, 16, and 32 nodes. We find $\mathrm{SU}_{\mathrm{zu}} = 2\times10^{-11} - 7\times10^{-11}$. Again, we will use 32 nodes due to the short run times.

The final suite is the *galaxies* suite, shown in purple. This suite employs the most additional physics packages (including star formation, cooling and heating, and chemistry). The AMR structure is a nest of refinements, each about 1/8 of its parent by volume (about half the length), that allows us to resolve both the disk and the circumgalactic medium. It also gives roughly constant memory per level. The fiducial simulations use 5 levels of refinement, rather than the target 9, but the amount of overhead relative to useful work doesn't change much going from 5 to 9 levels We use the same target root grid of 1.3 Mpc in physical size and 256 zones on a side. The AMR structure that Enzo produces is coincidentally 64 grid patches per level, so we run our scaling study from 1 to 5 nodes with 64 cores per node. This scaling is good, rising from 2×10^{-11} to 3×10^{-11}. The refinement structure will continue to 9 levels in the production runs, so we will use 9 nodes for the production simulations.

References

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