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# Towards Scalable AMG-based Preconditioners for MHD and Multifluid Plasma Simulations

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**Center for Computing Research**

**Sandia National Labs**

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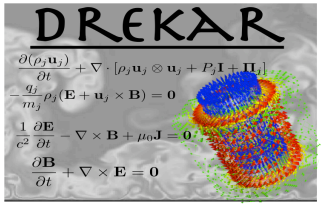
# Need for large-scale simulations

- Goal: high-fidelity solutions of transport phenomena for large-scale problems with complex physics and geometry
  - magnetohydrodynamic (MHD), multifluid electromagnetic plasma simulations
  - US DOE interest: pulsed fusion reactors (e.g. z-pinch), magnetically confined fusion (e.g. ITER tokamak)
- Requirements
  - Fast and robust solution methods for multiphysics problems
    - e.g. Newton-Krylov approaches
    - Block and fully-coupled preconditioners for multiphysics
    - Scalable solution methods: multilevel/multigrid
- Talk focus: our AMG-based preconditioned approach for large-scale FEM simulations
  - Drekar CFD/MHD application code (resistive MHD, recent capability: multifluid plasmas)
  - Trilinos solvers

# Drekar Implicit/IMEX FE Application

(J. Shadid, R. Pawlowski, E. Cyr, Smith, Phillips, Wildey, Sondak, Bettencourt, Miller, et al.)




- Navier-Stokes, LES, RANS, MHD; unstructured hex mesh
- Implicit (results for this talk) and IMEX
- Stabilized FEM: variational multiscale (VMS) (Hughes 1995)
  - many authors employ VMS for CFD
  - MHD/MHD turbulence with VMS
    - Shadid et al., Sondak+Oberai, Codina et al., Badia et al.
    - Most MHD turbulence simulations employ spectral methods
- Newton-Krylov solvers with AMG-based preconditioners
  - fully-coupled multigrid
  - physics-based block preconditioners
- Although this talk not focused on next generation architectures…
  - Drekar and Trilinos path forward for future architectures: Kokkos (C. Edwards, Trott, Sunderland, Ellingwood, Hammond; not part of this talk)
  - Matrix assembly
    - Panzer+Phalanx refactored to use Kokkos
    - Intrepid2 with Kokkos for discretization
  - Solve: many packages in the process of being refactored to Kokkos
    - refactor not yet complete---results for this talk for MPI-only
      - good scaling with $O(10^5)$ MPI processes is still critical

# Brief Trilinos overview (solver library portion)

- Classic Trilinos (Epetra-based) (Heroux et al.):
  - Limited by 32-bit integer global objects
  - Most packages employ flat MPI-only; future architectures?
- "Next-gen" or "second generation" Trilinos solver stack (Tpetra-based):
  - No 32-bit limitation on globals (employs C++ templated data types)
  - Path forward for future architectures: Kokkos (Edwards, Trott, Sunderland, Ellingwood, Hammond; not part of this talk)

| Functionality | Classic stack | Newer solver stack |
|---|---|---|
| Distributed linear algebra | Epetra | Tpetra (Hoemmen,Trott, etc.) |
| Iterative linear solve | Aztec | Belos (Thornquist,Hoemmen,etc.) |
| Incomplete factor | Aztec, Ifpack | Ifpack2 (Hoemmen,Hu,Siefert, etc.) |
| Algebraic multigrid | ML | MueLu (Hu,Prokopenko,Wiesner,Siefert,Tuminaro,etc.) |
| Partition & load balance | Zoltan | Zoltan2 (Devine,Boman,Rajamanickam,Wolf,etc.) |
| Direct solve interface | Amesos | Amesos2 (Rajamanickam,etc.) |

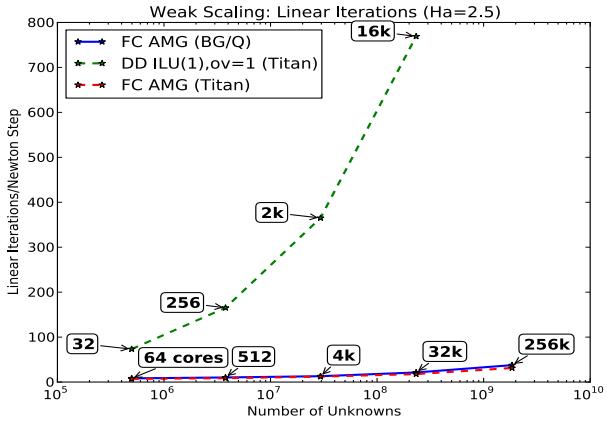
- PETSc is another well-known solvers library (ANL; Smith, Gropp, Knepley, Brown, McInnes, Balay, Zhang, et al.); 2015 SIAM/ACM CSE prize winner

# Trilinos MueLu Library: algebraic multigrid preconditioners

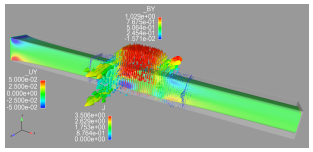
(J. Hu, A. Prokopenko, J. Gaidamour, T. Wiesner, C. Siefert, L. Berger-Vergiat, M. Mayr, R. Tuminaro)

- "Next-gen" ML (R. Tuminaro, J. Hu, C. Tong, M. Gee, M. Sala, C. Siefert)
- Smoothed aggregation (Vanek,Mandel,Brezina 1996)
  - Create graph where vertices are block nonzeros in matrix $A_k$
  - Edge between vertices i and j added if block $B_k(i,j)$ contains nonzeros
- Uncoupled aggregation; prolongation/restriction; nonsmoothed; $A_{k-1} = R_k A_k P_k$
- Repartition coarser level matrices (MueLu+Zoltan2) to reduce communication
- Coarsest level: serial direct solve (KLU; T. Davis) on 1 MPI process

Other approaches: LLNL Hypre (R. Falgout, U. Yang, T. Kolev, A. Baker, E. Chow, C. Tong, et al.), FEMPAR/MLBDDC (S. Badia, A. Martín, J. Principe, et al.), etc.




- Weak scaling: MHD generator
- Re = 500, $Re_m$ = 1, Ha = 2.5
- Cray XK7, IBM Blue Gene/Q



Additive Schwarz domain decomposition does not scale
Multigrid critical for performance and scaling

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# MueLu strong scaling: Poisson equation

(with J. Hu, J. Shadid, A. Prokopenko, E. Cyr, R. Pawlowski)

(Image courtesy LLNL)

- 3D Poisson (1 DOF/mesh node); Drekar
- Simple cube geometry, near uniform mesh
- Fixed problem size (2.4B DOFs); 1 MPI task/core BG/Q
- Optimal iteration count to 1.6 million cores (full-scale Sequoia BG/Q)

| MPI | CG iterations | Solve t (s) | MG setup (s) | DOFs/MPI |
|---|---|---|---|---|
| 131,072 | 6.3 | 1.17 | 7.67 | ~18,800 |
| 262,144 | 6.0 | 1.08 | 12.35 | ~9400 |
| 524,288 | 6.3 | 1 | 25.43 | ~4700 |
| 1,048,576 | 7.3 | 0.91 | 53.04 | ~2400 |
| 1,572,864 | 7.0 | 0.94 | 128.9 | ~1500 |

- MPI+X has potential to help (for Trilinos, X=Kokkos)
  - 100k MPI + 16 OpenMP would delay suboptimal scaling
  - 1.6M MPI processes ➡ MPI takes a lot of memory

# Resistive (incompressible) MHD model

(J. Shadid, R. Pawlowski, E. Cyr, L. Chacon)

Navier-Stokes + Magnetic Induction

$$\rho\frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\cdot\nabla\mathbf{u}) - \nabla\cdot(\mathbf{T} + \mathbf{T_M}) - \rho\mathbf{g} = 0$$

$$\mathbf{T} = -(P + \frac{2}{3}\mu(\nabla\cdot\mathbf{u}))\mathbf{I} + \mu[\nabla\mathbf{u} + \nabla\mathbf{u}^T]$$

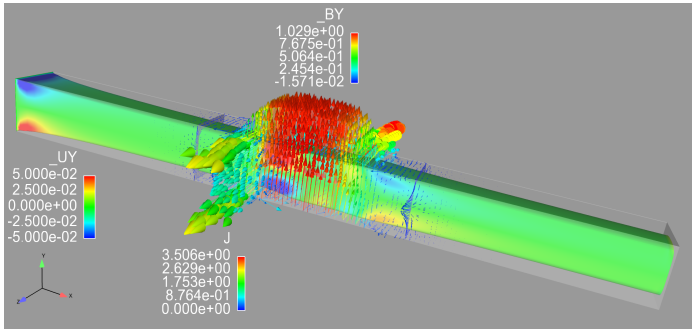
$$\mathbf{T_M} = \frac{1}{\mu_0}\mathbf{B}\otimes\mathbf{B} - \frac{1}{2\mu_0}\|\mathbf{B}\|^2\mathbf{I}$$

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\mathbf{u}) = 0$$

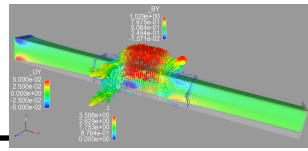
$$\rho C_p\left[\frac{\partial T}{\partial t} + \mathbf{u}\cdot\nabla T\right] + \nabla\cdot\mathbf{q} - \eta\|\mathbf{J}\|^2 = 0$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla\times(\mathbf{u}\times\mathbf{B}) + \nabla\times(\frac{\eta}{\mu_0}\nabla\times\mathbf{B}) = \mathbf{0}$$

Steady-state MHD generator
- Flow with external cross-stream B field
- 8 DOFs/mesh node



# Weak scaling: fully-coupled multigrid MHD



(with J. Shadid, J. Hu, A. Prokopenko, E. Cyr, R. Pawlowski)

| MPI | DOFs | GMRES iterations /Newton | Time/Newton step (s) | | |
|---|---|---|---|---|---|
| | | | Multigrid setup | | Solve |
| | | | Hier+smoo | Smoother | |
| 128 | 845,000 | 14.0 | 12.4 | 11.0 | 4.7 |
| 1024 | 6,473,096 | 20.0 | 14.7 | 13.0 | 6.6 |
| 8192 | 50,658,056 | 30.8 | 16.9 | 14.2 | 10.1 |
| 65,536 | 400,799,240 | 53.4 | 20.3 | 16.1 | 17.9 |
| 524,288 | 3,188,616,200 | 98.7 | 45.3 | 19.1 | 40.1 |

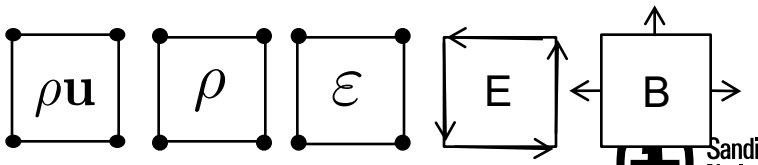
- BG/Q: 1 MPI/core
- Multigrid prec setup time/Newton step
- Smoother: ILU(0) overlap=1

- Drekar 3D MHD generator on BG/Q (simple geometry)
- Algorithmic scaling challenging for nonsymmetric matrices
  - 4096x increase in size: 6.0x iterations, 7.3x time
  - Petrov-Galerkin or energy minimization approaches promising
  - Need better aggregation, better smoothers, etc.
- Another challenge: sparse matrix-matrix multiply ($A_c$=R*A*P)
- Employ reuse of construction of hierarchy + smoothers (Prokopenko,Hu)
  - Application dependent (e.g. cannot reuse for adaptive mesh)
  - Critical for transient simulations ($10^4$ or $10^5$ time steps)

# Multi-fluid Plasma System Model

| | |
|---|---|
| Density | $\frac{\partial \rho_a}{\partial t} + \nabla \cdot (\rho_a \mathbf{u}_a) = \sum_{b \neq a} (n_a \rho_b \bar{\nu}_{ab}^{+} - n_b \rho_a \bar{\nu}_{ab}^{-})$ |
| Momentum | $\frac{\partial (\rho_a \mathbf{u}_a)}{\partial t} + \nabla \cdot (\rho_a \mathbf{u}_a \otimes \mathbf{u}_a + p_a I + \Pi_a) = q_a n_a (\mathbf{E} + \mathbf{u}_a \times \mathbf{B})$ $- \sum_{b \neq a} [\rho_a (\mathbf{u}_a - \mathbf{u}_b) n_b \bar{\nu}_{ab}^{M} + \rho_b \mathbf{u}_b n_a \bar{\nu}_{ab}^{+} - \rho_a \mathbf{u}_a n_b \bar{\nu}_{ab}^{-}]$ |
| Energy | $\frac{\partial \varepsilon_a}{\partial t} + \nabla \cdot ((\varepsilon_a + p_a)\mathbf{u}_a + \Pi_a \cdot \mathbf{u}_a + \mathbf{h}_a) = q_a n_a \mathbf{u}_a \cdot \mathbf{E} + Q_a^{src}$ $- \sum_{b \neq a} \left[ (T_a - T_b) k \bar{\nu}_{ab}^{E} - \rho_a \mathbf{u}_a \cdot (\mathbf{u}_a - \mathbf{u}_b) n_b \bar{\nu}_{ab}^{M} - n_a \bar{\nu}_{ab}^{+} \varepsilon_b + n_b \bar{\nu}_{ab}^{-} \varepsilon_a \right]$ |
| Charge and Current Density | $q = \sum_k q_k n_k \qquad \mathbf{J} = \sum_k q_k n_k \mathbf{u}_k$ |
| Maxwell's Equations | $\frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t} - \nabla \times \mathbf{B} + \mu_0 \mathbf{J} = \mathbf{0} \qquad \nabla \cdot \mathbf{E} = \frac{q}{\epsilon_0}$ $\frac{\partial \mathbf{B}}{\partial t} + \nabla \times \mathbf{E} = \mathbf{0} \qquad \nabla \cdot \mathbf{B} = 0$ |

Nodal discretization for fluids, compatible discretization for electromagnetics



# Fully discrete 2-fluid system

$$\begin{bmatrix}
\mathbf{D}_{\rho_i} & \mathbf{K}^{\rho_i}_{\rho_i u_i} & 0 & \mathbf{Q}^{\rho_i}_{\rho_e} & 0 & 0 & 0 & 0 \\
\mathbf{D}^{\rho_i u_i}_{\rho_i} & \mathbf{D}_{\rho_i u_i} & 0 & \mathbf{Q}^{\rho_i u_i}_{\rho_e} & \mathbf{Q}^{\rho_i u_i}_{\rho_e u_e} & 0 & \mathbf{Q}^{\rho_i u_i}_{E} & \mathbf{Q}^{\rho_i u_i}_{B} \\
\mathbf{D}^{\mathcal{E}_i}_{\rho_i} & \mathbf{D}^{\mathcal{E}_i}_{\rho_i u_i} & \mathbf{D}_{\mathcal{E}_i} & \mathbf{Q}^{\mathcal{E}_i}_{\rho_e} & \mathbf{Q}^{\mathcal{E}_i}_{\rho_e u_e} & \mathbf{Q}^{\mathcal{E}_i}_{\mathcal{E}_e} & \mathbf{Q}^{\mathcal{E}_i}_{E} & 0 \\
\mathbf{Q}^{\rho_e}_{\rho_i} & 0 & 0 & \mathbf{D}_{\rho_e} & \mathbf{K}^{\rho_e}_{\rho_e u_e} & 0 & 0 & 0 \\
\mathbf{Q}^{\rho_e u_e}_{\rho_i} & \mathbf{Q}^{\rho_e u_e}_{\rho_i u_i} & 0 & \mathbf{D}^{\rho_e u_e}_{\rho_e} & \mathbf{D}_{\rho_e u_e} & 0 & \mathbf{Q}^{\rho_e u_e}_{E} & \mathbf{Q}^{\rho_e u_e}_{B} \\
\mathbf{Q}^{\mathcal{E}_e}_{\rho_i} & \mathbf{Q}^{\mathcal{E}_e}_{\rho_i u_i} & \mathbf{Q}^{\mathcal{E}_e}_{\mathcal{E}_i} & \mathbf{D}^{\mathcal{E}_e}_{\rho_e} & \mathbf{D}^{\mathcal{E}_e}_{\rho_e u_e} & \mathbf{D}_{\mathcal{E}_e} & \mathbf{Q}^{\mathcal{E}_e}_{E} & 0 \\
0 & \mathbf{Q}^{E}_{\rho_i u_i} & 0 & 0 & \mathbf{Q}^{E}_{\rho_e u_e} & 0 & \mathbf{Q}_E & \mathbf{K}^{E}_{B} \\
0 & 0 & 0 & 0 & 0 & 0 & \mathbf{K}^{B}_{E} & \mathbf{Q}_B
\end{bmatrix}
\begin{bmatrix}
\rho_i \\ \rho_i \mathbf{u}_i \\ \mathcal{E}_i \\ \rho_e \\ \rho_e \mathbf{u}_e \\ \mathcal{E}_e \\ \mathbf{E} \\ \mathbf{B}
\end{bmatrix}$$

16 Coupled Nonlinear PDEs (continuity, momentum, energy for ions+electrons; Maxwell equations)

Group the hydrodynamic variables together (similar discretization)

$$\mathbf{F} = (\rho_i, \rho_i \mathbf{u}_i, \mathcal{E}_i, \rho_e, \rho_e \mathbf{u}_e, \mathcal{E}_e)$$

Resulting 3x3 block system

$$\begin{bmatrix}
\mathbf{D}_F & \mathbf{Q}^F_E & \mathbf{Q}^F_B \\
\mathbf{Q}^E_F & \mathbf{Q}_E & \mathbf{K}^E_B \\
0 & \mathbf{K}^B_E & \mathbf{Q}_B
\end{bmatrix}
\begin{bmatrix}
\mathbf{F} \\ \mathbf{E} \\ \mathbf{B}
\end{bmatrix}$$

Reordered 3x3

$$\begin{bmatrix}
\mathbf{Q}_B & \mathbf{K}^B_E & 0 \\
\mathbf{K}^E_B & \mathbf{Q}_E & \mathbf{Q}^E_F \\
\mathbf{Q}^F_B & \mathbf{Q}^F_E & \mathbf{D}_F
\end{bmatrix}
\begin{bmatrix}
\mathbf{B} \\ \mathbf{E} \\ \mathbf{F}
\end{bmatrix}$$

# Physics-based Approach Enables Optimal AMG Sub-block Solvers

Use upper triangular factor of block LU decomposition as preconditioner

$$P = \begin{bmatrix} \mathbf{Q}_B & \mathbf{K}_E^B & 0 \\ 0 & \hat{\mathcal{D}}_E & \mathbf{Q}_F^E \\ 0 & 0 & \hat{\mathbf{S}}_F \end{bmatrix}$$

2 Schur complements to solve

$$\hat{\mathbf{S}}_F = \mathbf{D}_F - \mathcal{K}_E^F \mathcal{D}_E^{-1} Q_F^E$$

Fluid sub-solve: Node-based coupled CFD type system.

SIMPLEC approximation for $S_F$

$$\hat{\mathcal{D}}_E = \mathbf{Q}_E - \mathbf{K}_B^E \bar{\mathbf{Q}}_B^{-1} \mathbf{K}_E^B$$

Maxwell subsystem: electric field Edge-based curl-curl type system.

$$\mathbf{B} = -\bar{\mathbf{Q}}_B^{-1} \mathbf{K}_E^B \, \mathbf{E}$$

Magnetic field: Face-based simple mass matrix Inversion.

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Next: Results for Maxwell subsystem; fluid sub-solve for multi-fluid is future work

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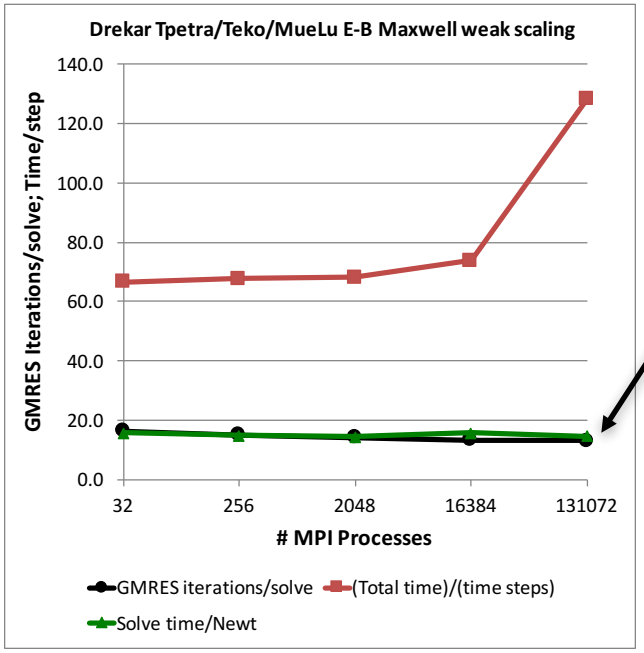
# Weak Scaling for Maxwell Subsystem


- 3D edge-based curl-curl E-B Maxwell subsystem: ML H(curl) AMG
- 3 sub-blocks (2 with rows = #edges); MueLu on sub-blocks
- cubic domain with cubic elements
- 10 time steps; total 20 linear solves (20 Teko/MueLu prec setup); Cray XC40




Teko 8.4B row matrices

- Good scaling on block solves (at least for solve; setup needs improvement)

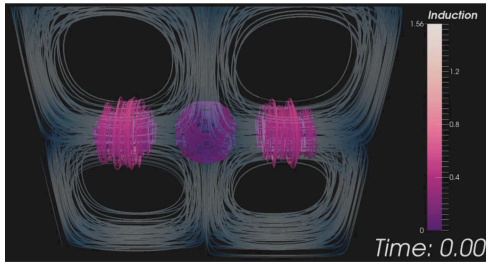
Work still in progress: multifluid results
Next we revisit single fluid full MHD systems

# Revisiting (single fluid) Full MHD Systems

- Our block preconditioner blocked by physics
  - Fully-coupled multigrid limited to co-located nodal discretizations
  - Fluid subsystem: nodal-based approach
- Consider solution approaches for (single fluid) full MHD system
  - More complex than the previous fluid subsystem
  - Our approach: MHD turbulence with VMS with fully-coupled Newton-Krylov (multigrid preconditioned)
- Effective smoothers critical for multigrid
  - Need to efficiently damp high frequency error
  - Relaxation not robust for our MHD problems; need ILU(0) overlap=1
- Krylov smoothers
  - Lots of previous work for SPD problems (Bank, Bornemann, Braess, Deuflhard, Douglas, Notay, Shaidurov, Vassilevski, etc.)
  - Some previous work for Helmholtz (Elman, Ernst, O'Leary, etc.)
  - Far less previous work for nonsymmetric (recently: Birken, Bull, Jameson, etc.)
  - Drekar GMRESR solve preconditioned by multigrid with GMRES smoother (possibly preconditioned with e.g. block Jacobi)
  - Setup much cheaper than ILU, but solve can be expensive

# Comparison of smoothers: transient Taylor-Green MHD vortex decay (VMS resistive MHD)

- Re=5100; cube domain, 20 time steps, CFL ~0.5
- linux cluster dual-socket SNB, IB fat-tree (TLCC2)




$128^3$ elem, 16.8M DOFs, 256 MPI

| smoother | | iters/dt | Prec setup(s) | Solve(s) | Prec+sol(s) | Mem(MB) |
|---|---|---|---|---|---|---|
| ILU(0)ov1 | | 14.2 | 257 | 94 | 351 | 1436 |
| GMRES | noprec | 15.4 | 23 | 258 | 281 | 917 |
| | ptGS | 13.6 | 26 | 409 | 435 | 917 |
| | bkJac | 13.1 | 36 | 250 | 285 | 927 |
| | bkGS | 12.0 | 33 | 559 | 592 | 930 |

$512^3$ elem, 1.07b DOFs, 16384 MPI

| smoother | | iters/dt | Prec setup(s) | Solve(s) | Prec+sol(s) | Mem(MB) |
|---|---|---|---|---|---|---|
| ILU(0)ov1 | ov1 | 37.3 | 407 | 280 | 687 | 1519 |
| GMRES | noprec | 31.0 | 92 | 610 | 702 | 1002 |
| | ptGS | 21.5 | 94 | 728 | 822 | 1002 |
| | bkJac | 21.9 | 60 | 458 | 518 | 1017 |

- GMRES can be faster than ILU; requires less memory
- DD-GMRES smoother reduces global communication, but at a penalty of higher iteration count and higher solve times at this scale; need to go to large scales to see potential benefit

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Note: have multiple Newton steps per time step

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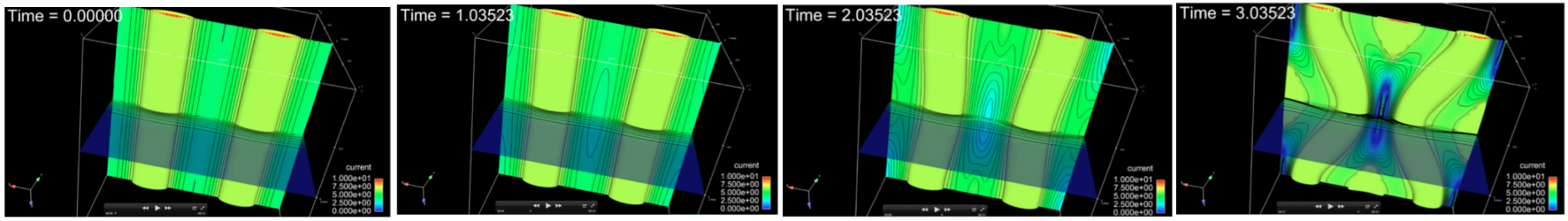
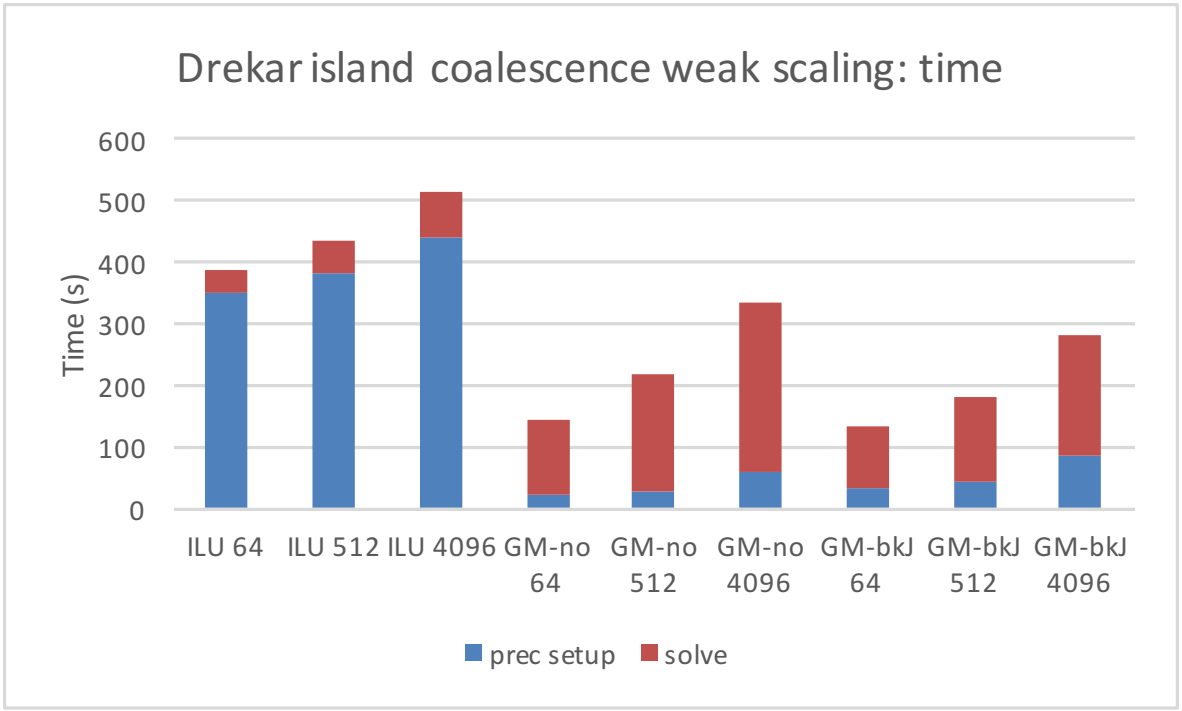
# Initial weak scaling: island coalescence comparison of smoothers

## Transient resistive MHD (8 DOF/mesh node)




- Transient: fixed time step of 0.1 (20 steps); Smoothers: ILU, GMRES (std relaxation did not work)
- $64^3$, $128^3$, $256^3$ elem: 2.1M, 16.9M, 135M DOF
- Dual-socket 2.6GHz SNB+IB fat-tree (TLCC2)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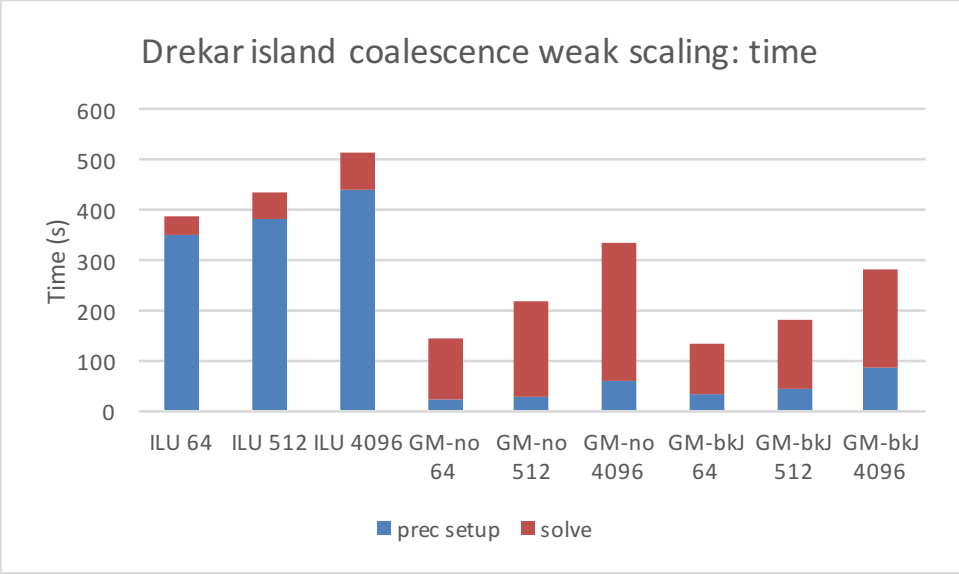
# Initial weak scaling: island coalescence comparison of smoothers

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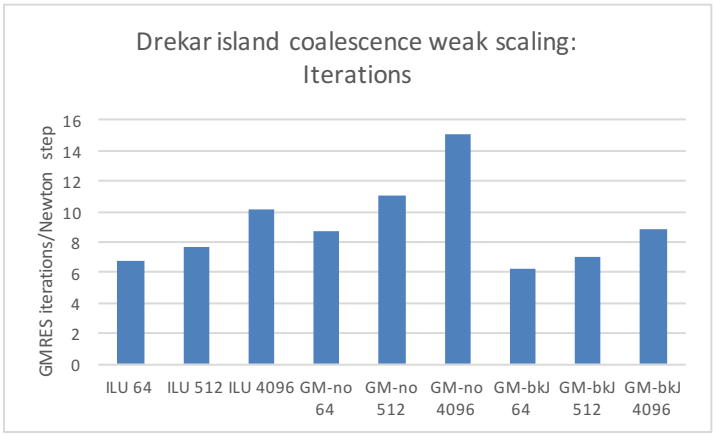


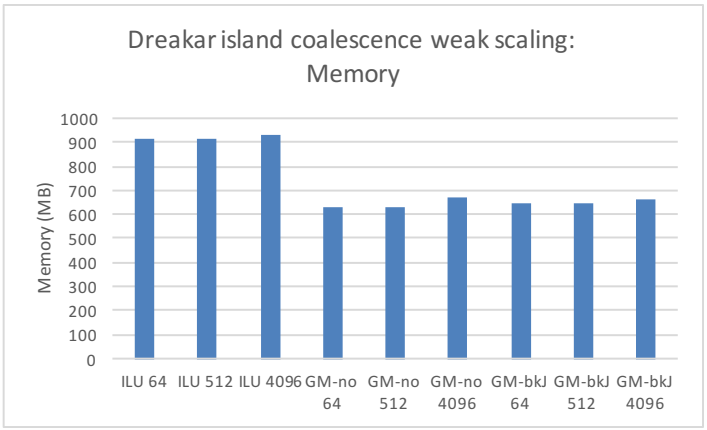


GMRES smoother is faster than standard ILU smoother, requires less memory

# Concluding remarks and future work

- Presented scaling studies for full MHD systems and Maxwell systems
  - Future work: multifluid systems
- Performed a comparison of multigrid smoothers for our MHD problems
  - initial empirical study for two test cases
  - initial evaluation of GMRES as alternative smoother to current standard (ILU)
    - Shows promise: can solve an initial class of relevant problems (appears competitive; expensive, but so is ILU)
    - Memory usage benefits (ILU requires ~40% more)
  - Go to larger scale; more test cases
  - Drawback: more communication?
  - Need to go back and try to analyze method more carefully
- Kokkos for manycore and accelerators (“X” for MPI+X)
- Many challenges for multigrid-preconditioned linear solve
  - algorithmic scaling for nonsymmetric problems
  - multigrid preconditioner setup (sparse mat-mat)

# Thanks For Your Attention!

Paul Lin (ptlin@sandia.gov)
John Shadid, Edward Phillips, Jonathan Hu,
Roger Pawlowski, Eric Cyr

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- Mark Hoemmen, Eric Phipps
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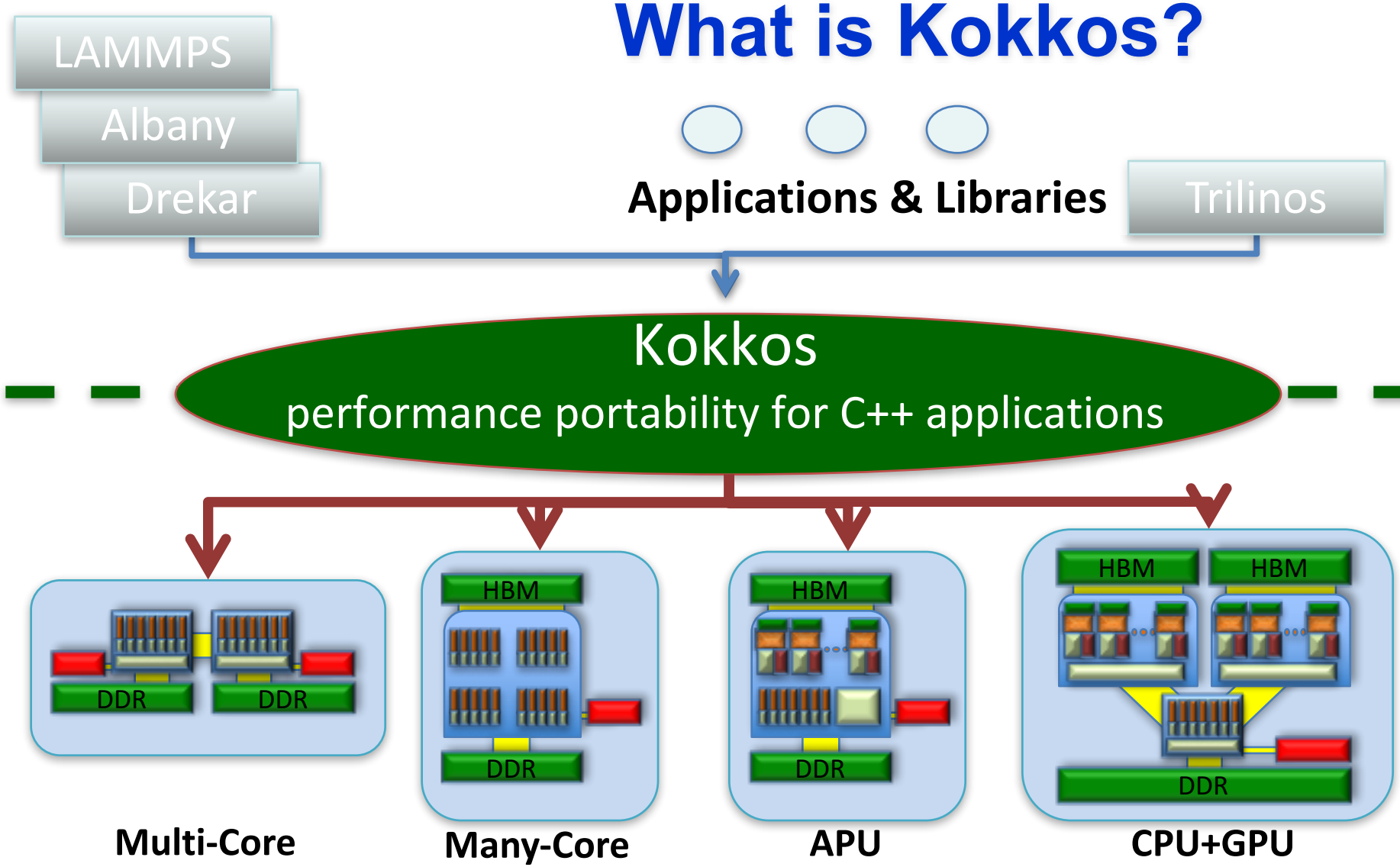
# Extra slides

# What is Kokkos?




**Cornerstone for performance portability across next generation HPC architectures at multiple DOE laboratories, and other organizations.**

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

Slide stolen from M. Bettencourt, who probably stole it from the Kokkos team

Sandia National Laboratories

# Abstractions
# Patterns, Policies, and Spaces

- **Parallel Pattern of user's computations**
  - parallel_for, parallel_reduce, parallel_scan, task-graph, ... *(extensible)*
- **Execution Policy tells *how* user computation will execute**
  - Static scheduling, dynamic scheduling, thread-teams, ... *(extensible)*
- **Execution Space tells *where* computations will execute**
  - Which cores, numa region, GPU, ... *(extensible)*
- **Memory Space tells *where* user data resides**
  - Host memory, GPU memory, high bandwidth memory, ... *(extensible)*
- **Layout (policy) tells *how* user array data is laid out**
  - Row-major, column-major, array-of-struct, struct-of-array … *(extensible)*
- **Differentiating: Layout and Memory Space**
  - Versus other programming models (OpenMP, OpenACC, …)
  - Critical for performance portability …

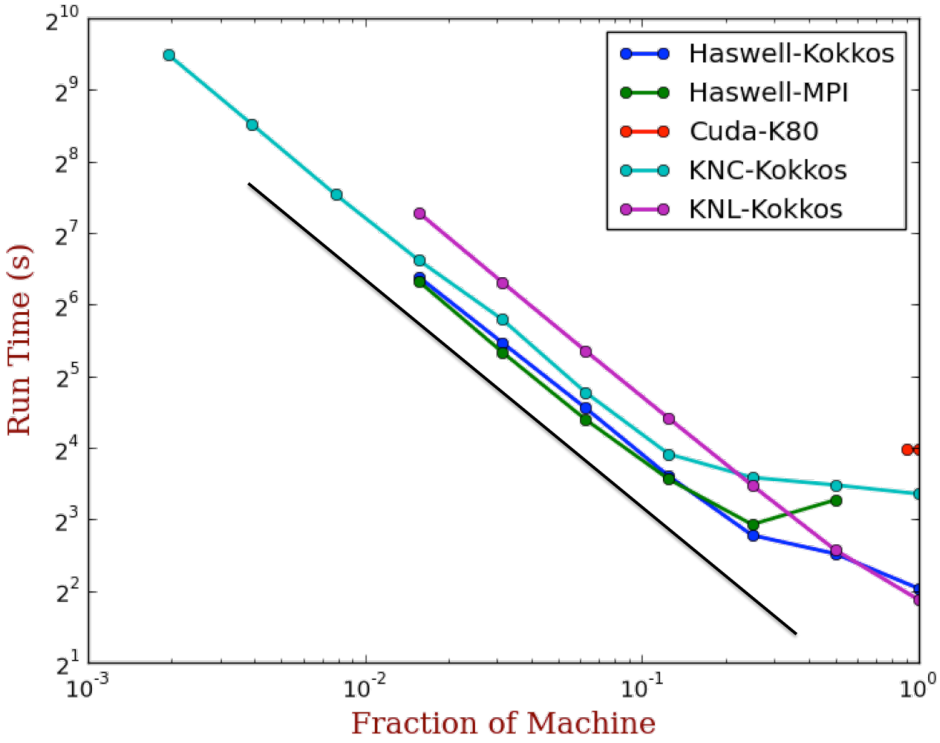
# “Next generation” platforms (NGP)

- Many-core processors and accelerators
- Many large platforms around the world with many-core processors and accelerators
- We use US DOE platforms
  - NERSC8 Cori Cray XC40: ~9700 Intel Xeon Phi Knights Landing (KNL)
  - LANL/SNL Trinity ATS-1 Cray XC40
    - Phase 1 ~9400 dual-socket HSW compute nodes
    - Phase 2 ~9000 Intel Xeon Phi Knights Landing (KNL)
  - LLNL ATS-2 Sierra: IBM POWER+NVIDIA GPUs
  - ORNL Summit: IBM POWER+NVIDIA GPUs
  - ANL Aurora: Intel Xeon Phi
- DOE has many huge legacy codes
  - especially NNSA Tri-labs (LANL, LLNL, SNL)

# First step towards NGP: matrix assembly

(M. Bettencourt, R. Pawlowski, E. Cyr)

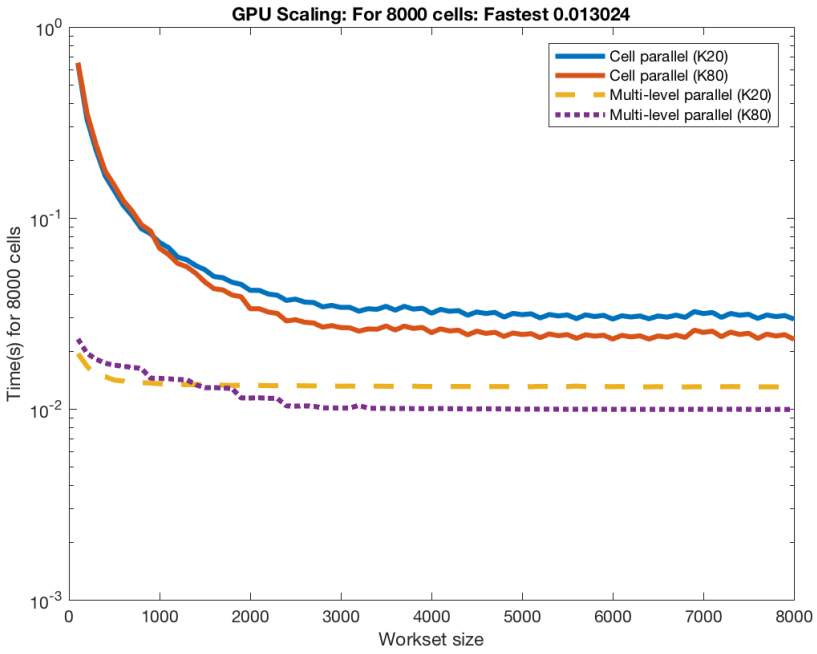
- Drekar FE assembly with Kokkos
- Electron full-Maxwell plasma system simulation
- Mixed-basis assembly using nodal (fluid), edge (electric field), face (magnetic field)
- FE integration and gather/scatter kernels (local-dense to global-sparse data structures)
- Dual-socket 16-core HSW
- Single GPU (K80)
- Single KNC (224 threads)
- Single KNL (256 threads)



# First step towards NGP: matrix assembly for GPU

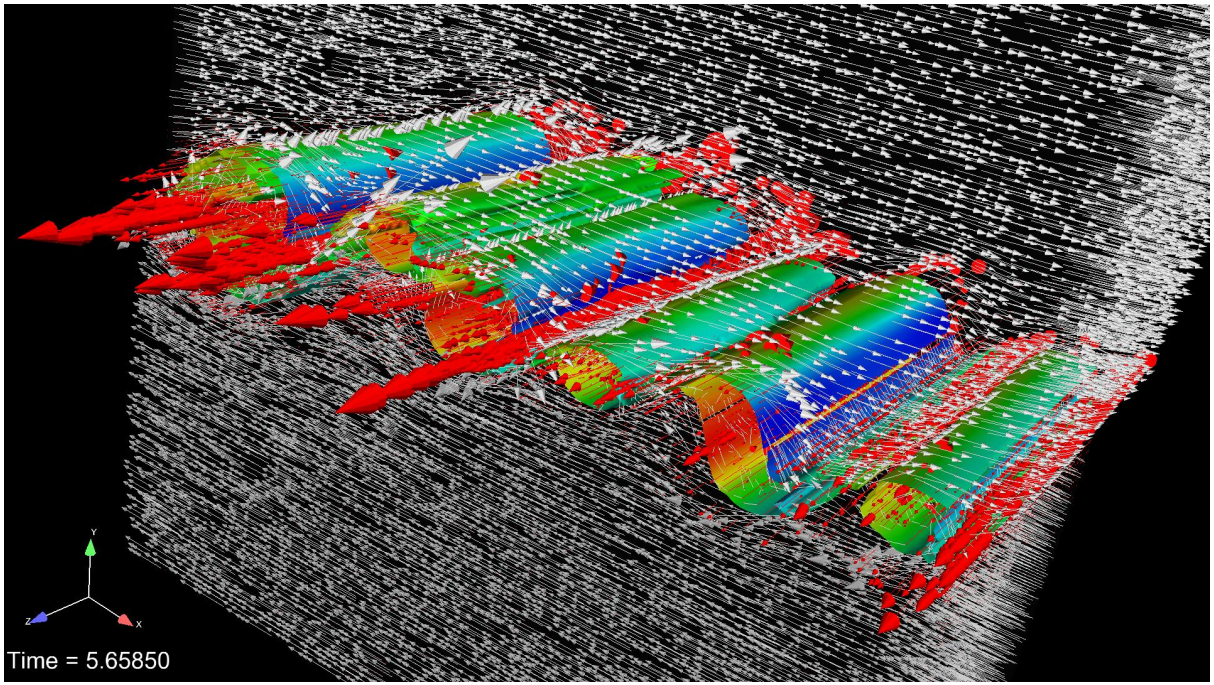
(C. Trott, M. Bettencourt, R. Pawlowski, E. Cyr, E. Phipps)

- Original GPU results below expectations due to lack of parallelism in assembly kernels
- To expose more parallelism, need to extend physics kernels to hierarchical parallelism
- Impact of hierarchical parallelism of a core CFD computational kernel extracted to a standalone test (work with Christian Trott)
- Future work: hierarchical parallelism in Drekar matrix assembly



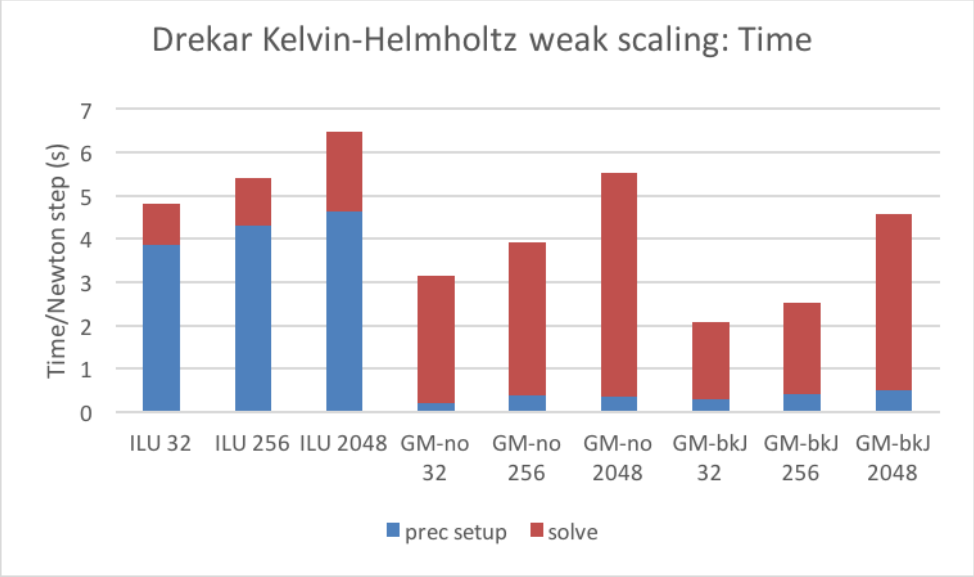
# Hydromagnetic Kelvin-Helmholtz: comparison of smoothers weak scaling study

Transient resistive MHD (8 DOF/mesh node)




- Transient: all run to t=3.0 (CFL ~0.8)
- 532K DOF ($\Delta$t=3/480), 4.23M DOF ($\Delta$t=3/960), 33.7M DOF ($\Delta$t=3/1920)
- Smoothers: ILU, GMRES (noprec and blkJac)
- Dual-socket 2.6GHz SNB+IB fat-tree (TLCC2)

# Hydromagnetic Kelvin-Helmholtz: comparison of smoothers weak scaling study




- Transient: all run to t=3.0 (CFL ~0.8)
- Smoothers: ILU, GMRES
- 532K, 4.23M, 33.7M DOF
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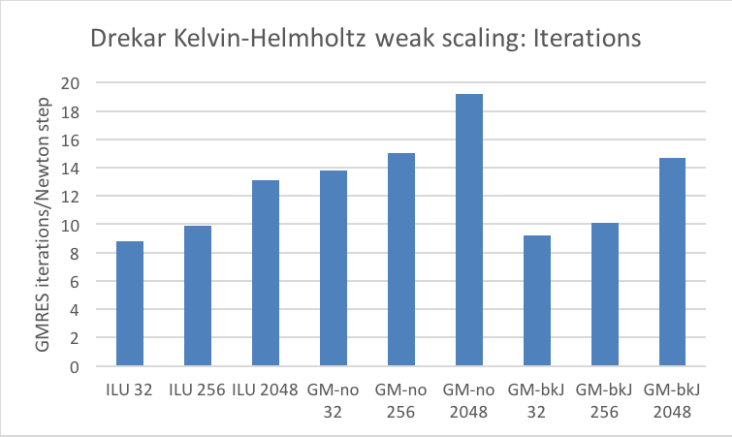


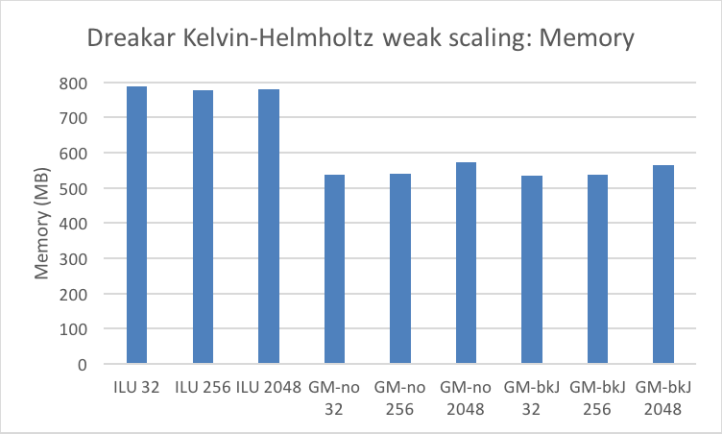


GMRES smoother is faster than standard ILU smoother, requires less memory