XGC: Gyrokinetic Particle Simulation of Edge Plasma

Presented by

Center for Plasma Edge Simulation Team

Physics and Applied Math
Computational Science

CPES team

Physics and applied math

New York University
Chang, Greengard, Ku, Park, Strauss, Weitzner, Zorin

Oak Ridge National Laboratory
Schultz, D'Azevedo, Maingi

Princeton Plasma Physics Laboratory
Hahm, Lee, Stotler, Wang, Zweben

Columbia University
Adams, Keyes

Lehigh University
Bateman, Kritz, Pankin

University of Colorado
Parker, Chen

University of California–Irvine
Lin, Nishimura

Massachusetts Institute of Technology
Sugiyama, Greenwald

Hinton Associates
Hinton

Computational science

California Institute of Technology
J. Cummings

Lawrence Berkeley National Laboratory
Shoshani

Oak Ridge National Laboratory
R. Barreto, S. Klasky, P. Worley

Princeton Plasma Physics Laboratory
S. Ethier, E. Feibush

Rutgers
M. Parashar, D. Silver

University of California–Davis
B. Ludäscher, N. Podhorszki

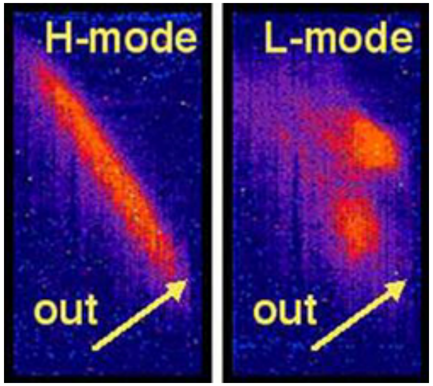
University Tennessee–Knoxville
M. Beck

University of Utah
S. Parker

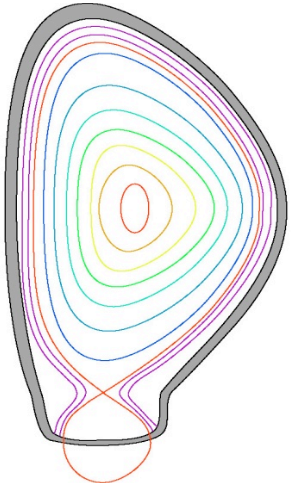
CPES Center for Plasma Edge Simulation

Physics in tokamak plasma edge

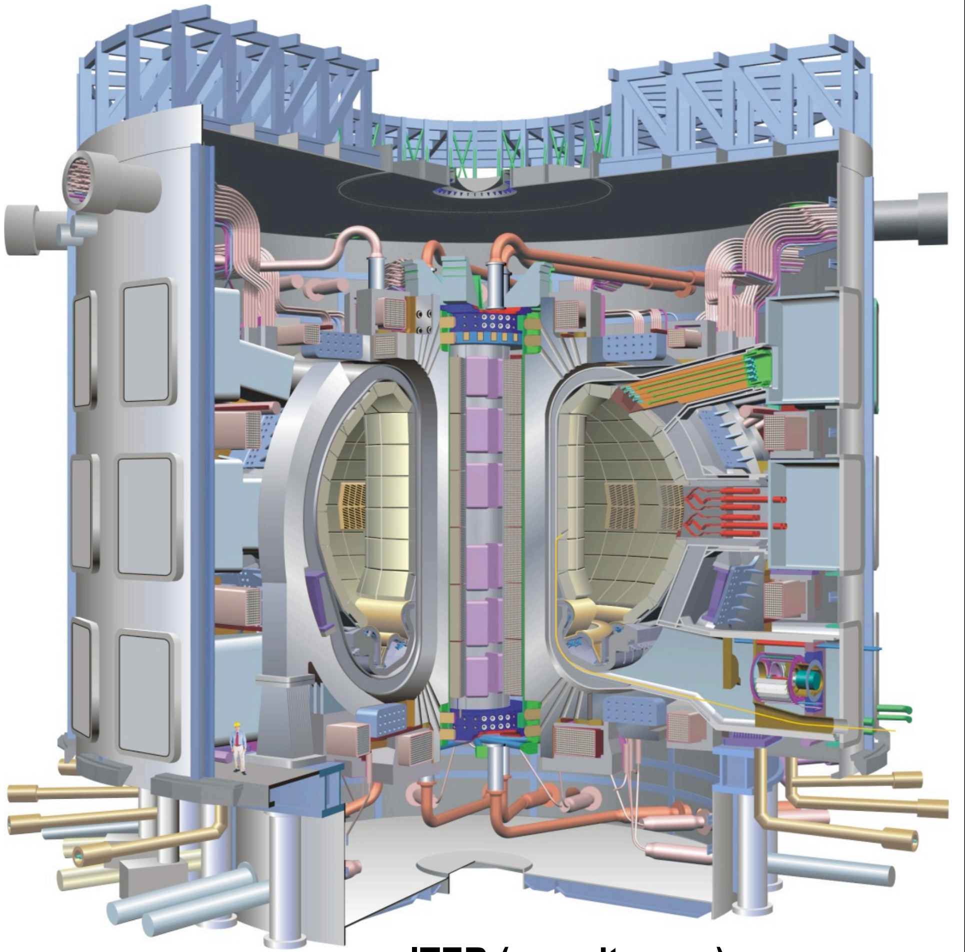
- Plasma turbulence (L-mode)
- Turbulence suppression (H-mode)
- Edge localized mode and its cycle
- Density and temperature pedestal
- Diverter magnetic field geometry
- Plasma rotation
- Neutral recycling



Edge turbulence in NSTX
(@ 100,000 frames/s)



Diverted
magnetic field



ITER (www.iter.org)

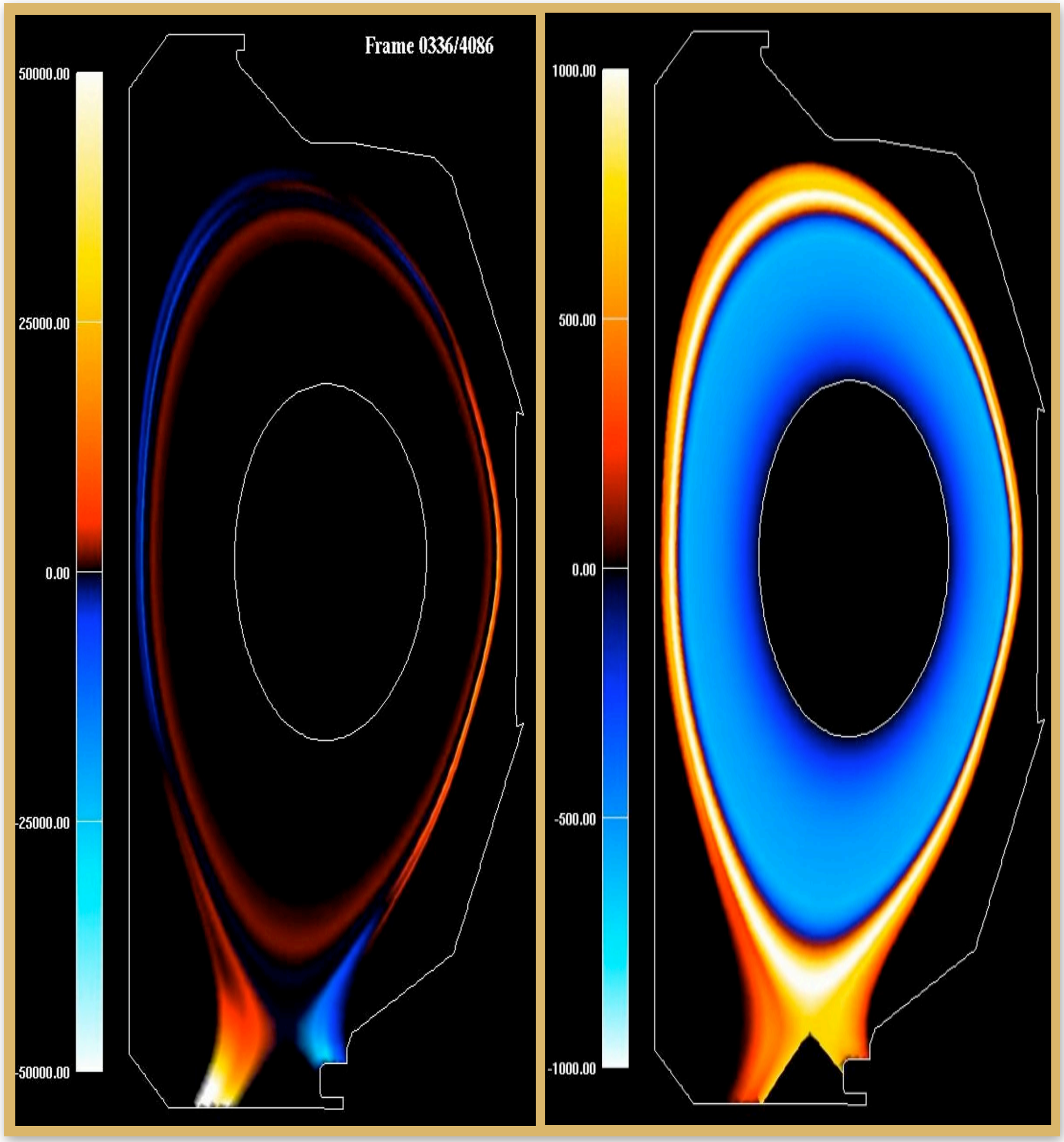
XGC development roadmap

Full-f PIC 1-D equilibrium code in 3-D magnetic field (**XGC0**)	1-D neoclassical pedestal buildup by neutral ionization, with D_{ANOM}
Full-f 3-D ion-electron electrostatic turbulence code (**XGC1**)	3-D neoclassical solution
	Electrostatic turbulence solution
	Study L-H transition
	Multiscale simulation of pedestal growth in H-mode
XGC-MHD coupling for pedestal-ELM cycle	
Full-f electromagnetic code (**XGC2**)	

Black: Achieved • Blue: In progress • Red: To be developed

XGC1 code

- Particle-in-cell code
- 5-dimensional (3-D real space + 2-D velocity space)
- Conserving plasma collisions
- Full-f ions, electrons, and neutrals
- Gyrokinetic Poisson equation for neoclassical and turbulent electric field
- PETSc library for Poisson solver
- MPI for parallelization
- Realistic magnetic geometry containing X-point
- Particle source from neutral recycling

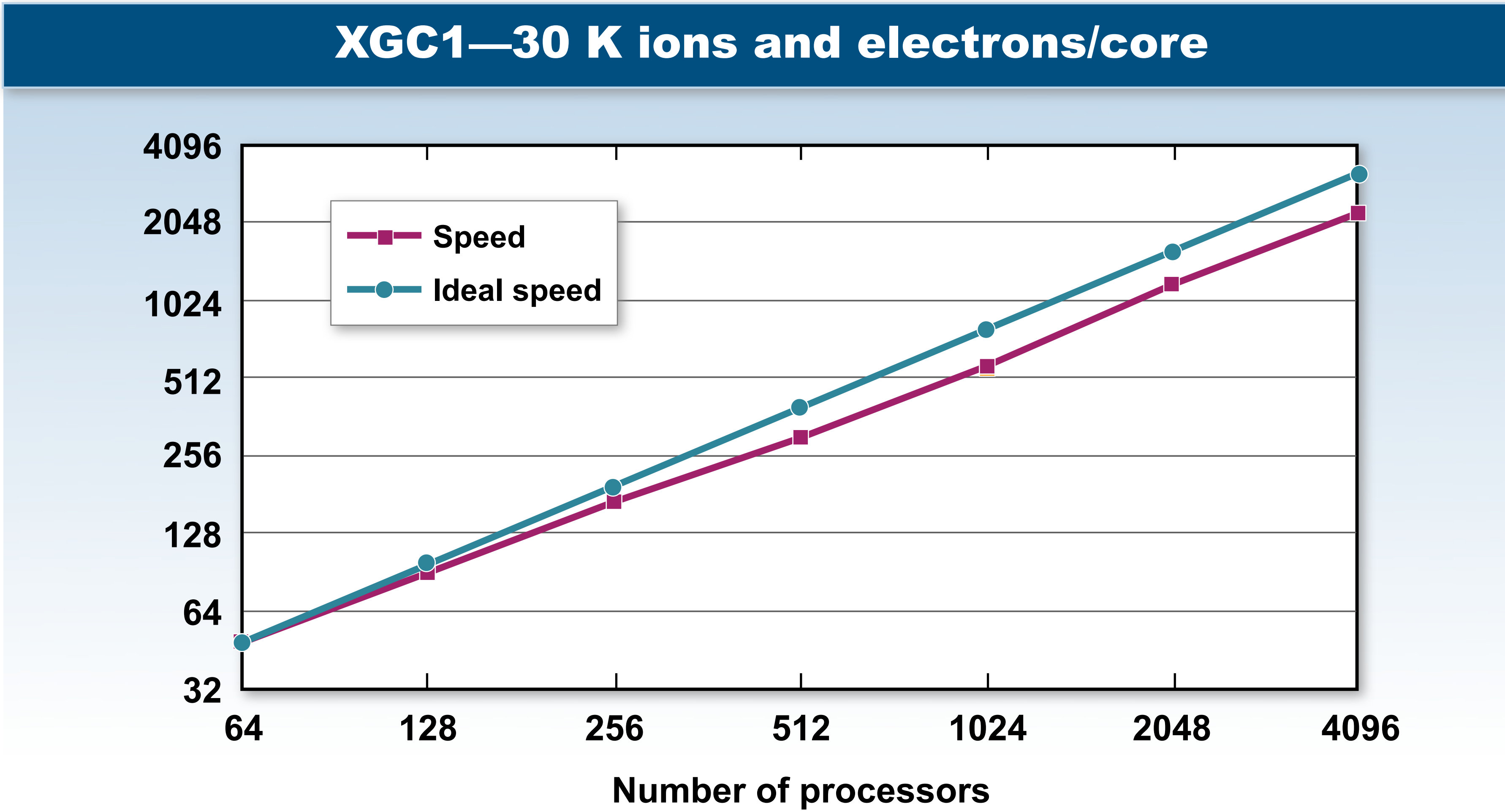


Peak performance of XGC1 on Jaguar

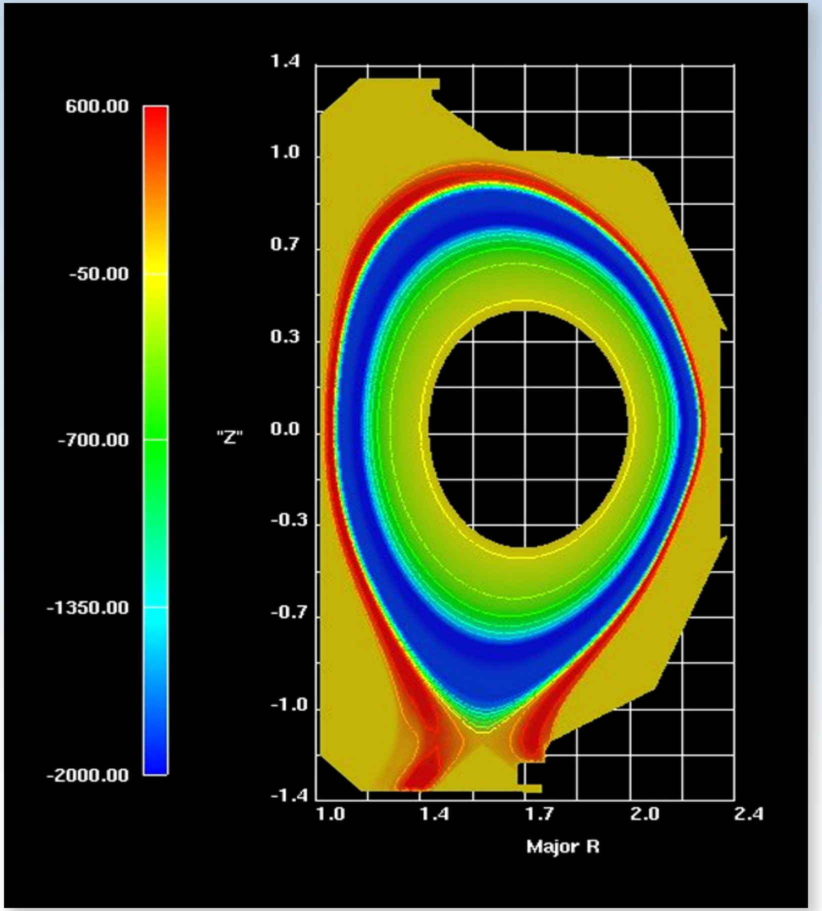
- 131 M ions and 131 M electrons, 200 K nodes
- Peak performance with 2048 cores, using strong scaling results
- Working with team members to increase peak performance to 18%

Routine	Time %	Peak performance
Total	100%	6%
Poisson	7%	~1.5%
Pushing	37%	~8%
Charging	50%	~4%

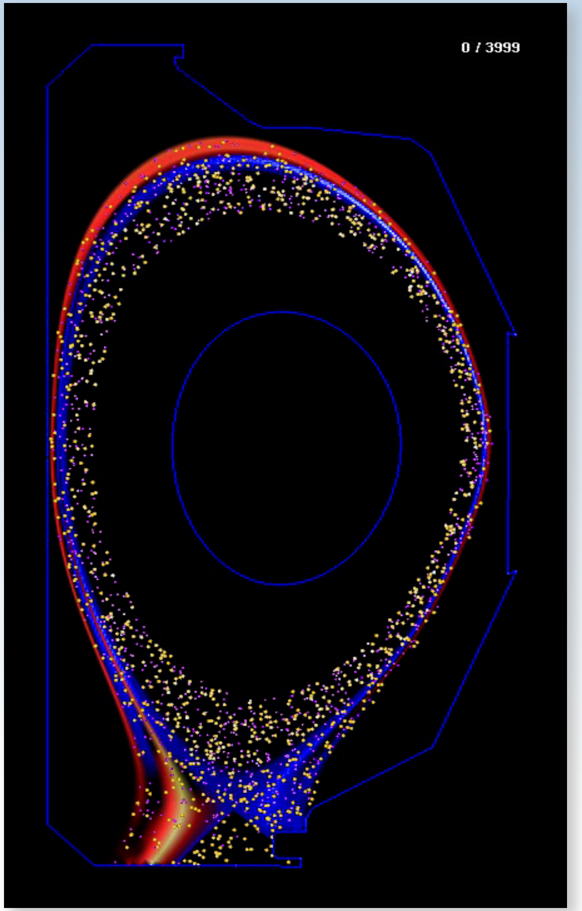
Scalability of XGC1 on Jaguar: Near linear scaling for weak scaling



Neoclassical potential and flow of edge plasma from XGC1

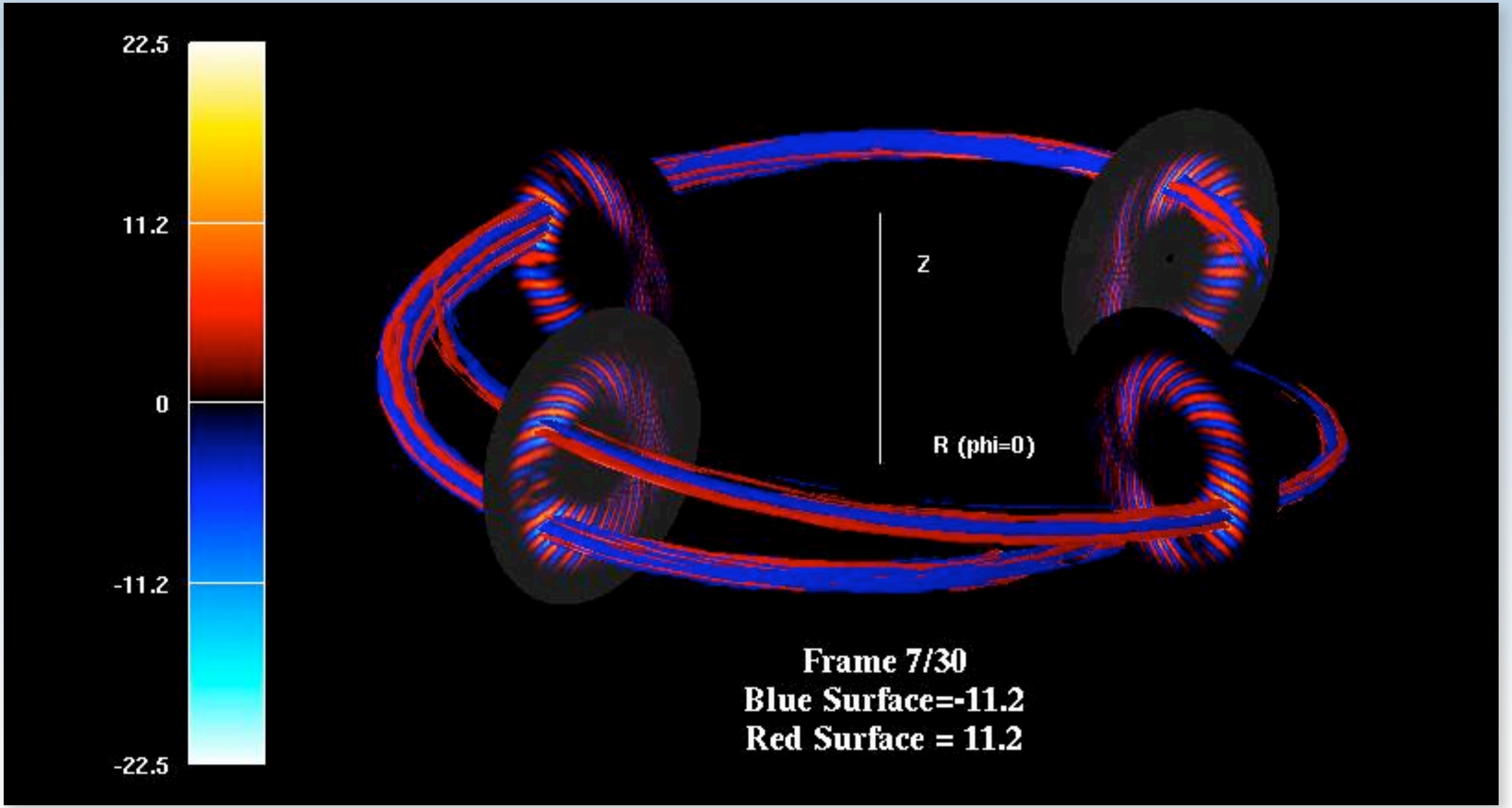


Electric potential



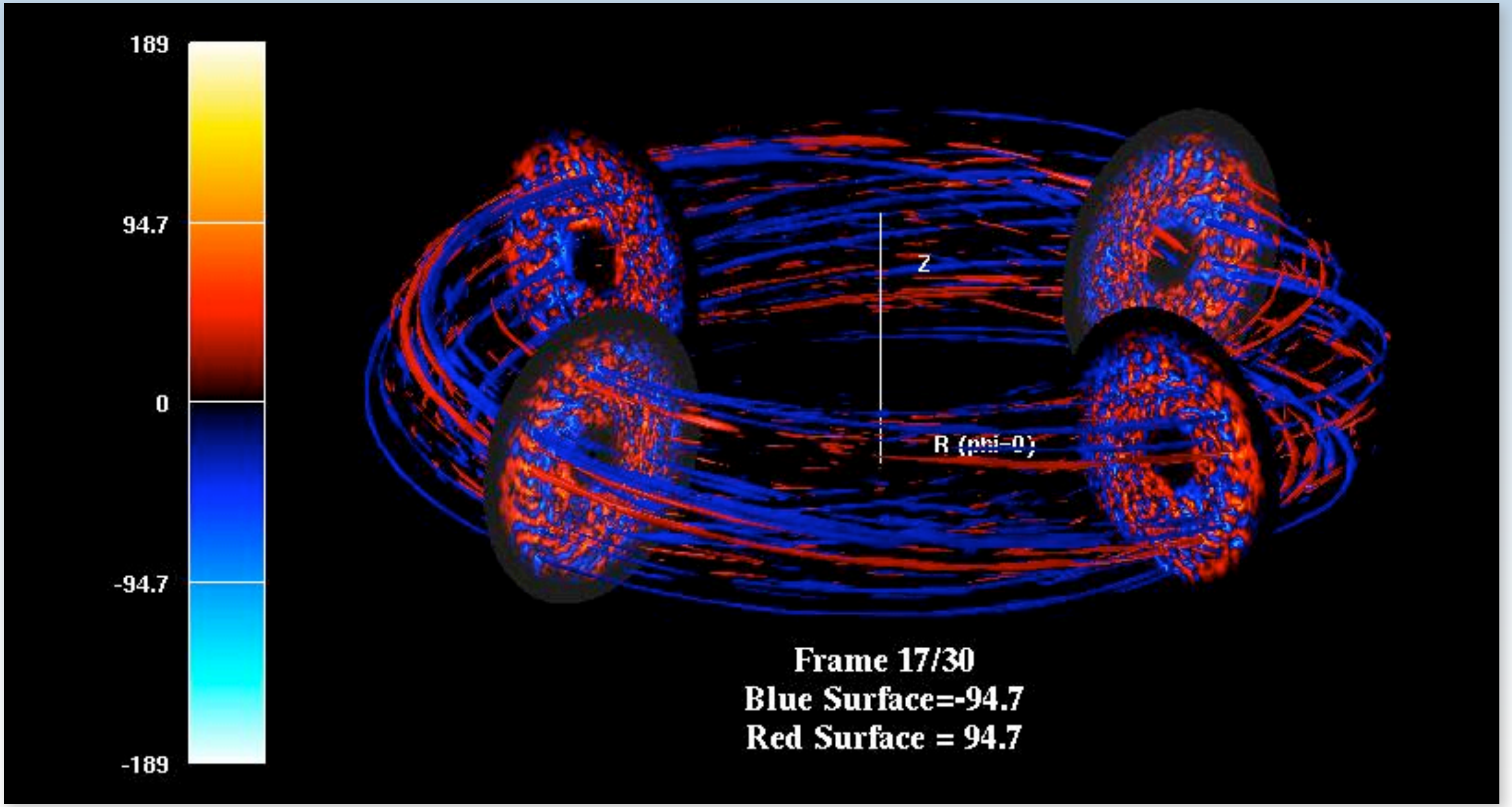
Parallel flow and particle positions

ITG turbulence simulation in concentric circular geometry



3-D electric potential of linear growth phase

ITG turbulence simulation in concentric circular geometry



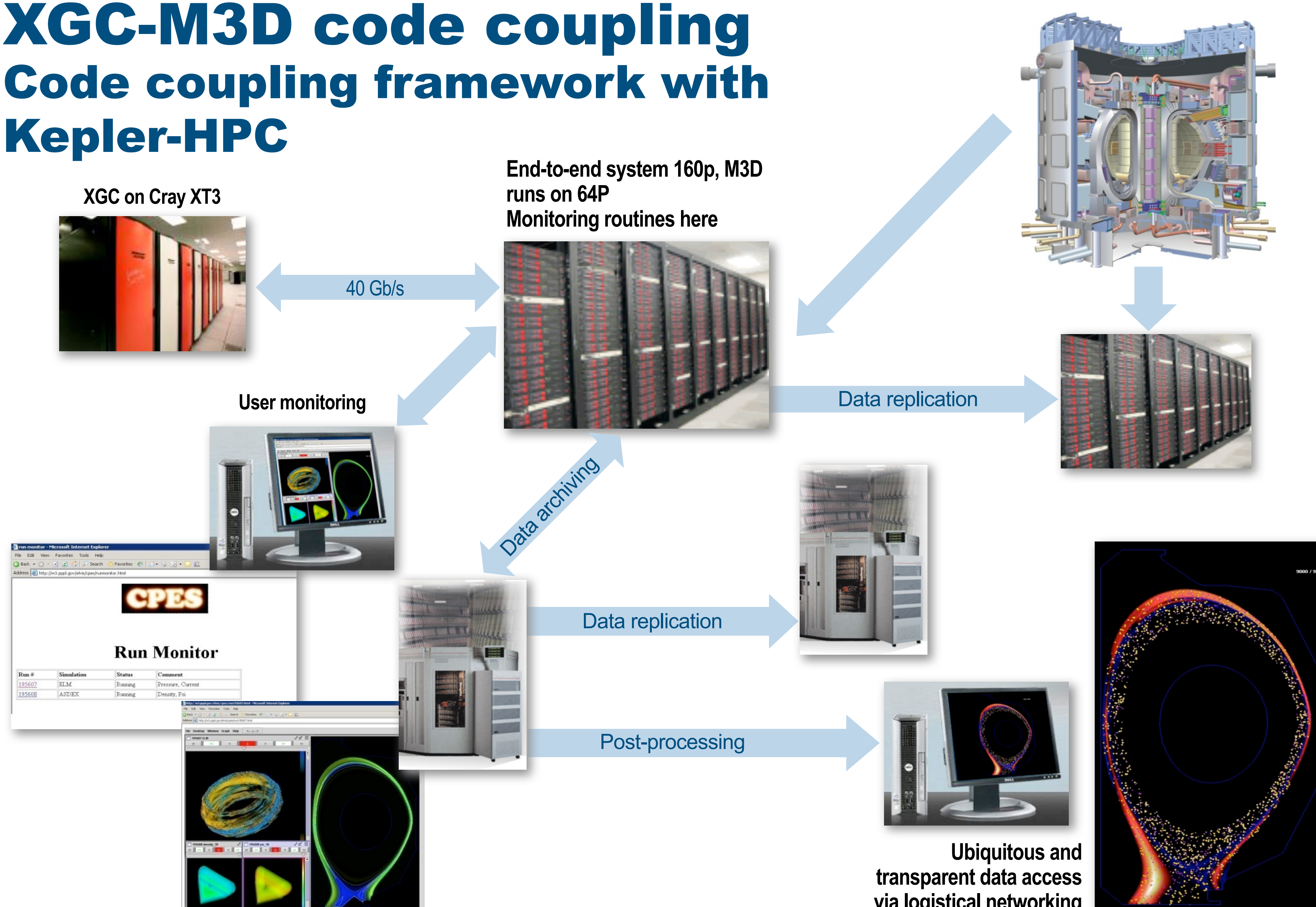
3-D electric potential of turbulent phase

XGC-MHD coupling plan

Phs-0: **Simple coupling:** with M3D and NIMROD	XGC-0 grows pedestal along neoclassical+anomalous diff root MHD checks instability and crashes the pedestal The same with XGC-1 and 2
Phs-2: Kinetic coupling: MHD performs the crash	XGC supplies closure information to MHD during crash
Phs-3: Advanced coupling: XGC performs the crash	M3D supplies the B crash information to XGC during the crash

Black: Developed • Red: To be developed

XGC-M3D code coupling
Code coupling framework with Kepler-HPC



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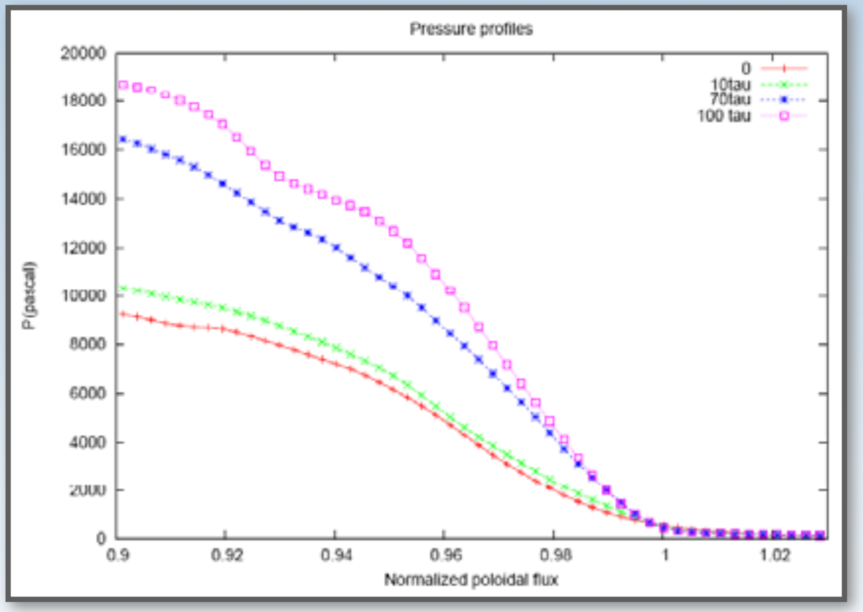
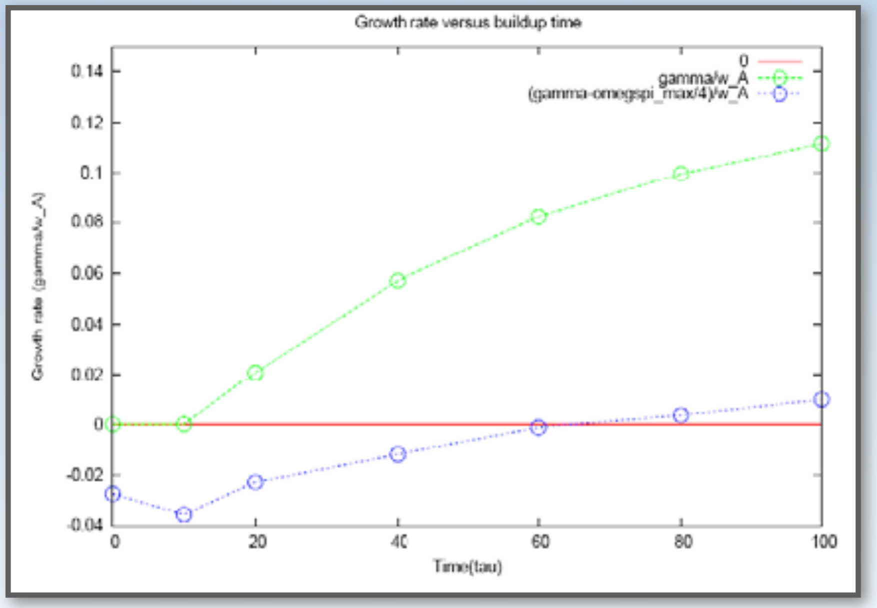
XGC0–Elite coupling:
Pressure profile hits the linear stability boundary





Pressure profile development from XGC0 at 0, 10, 70, and 100 toroidal transit times

Elite growth rates showing an approximate stability boundary near 65τ after the diamagnetic ω∗ stabilization

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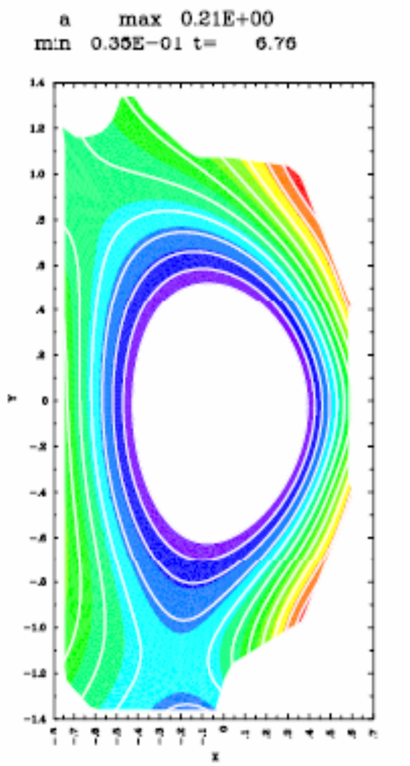
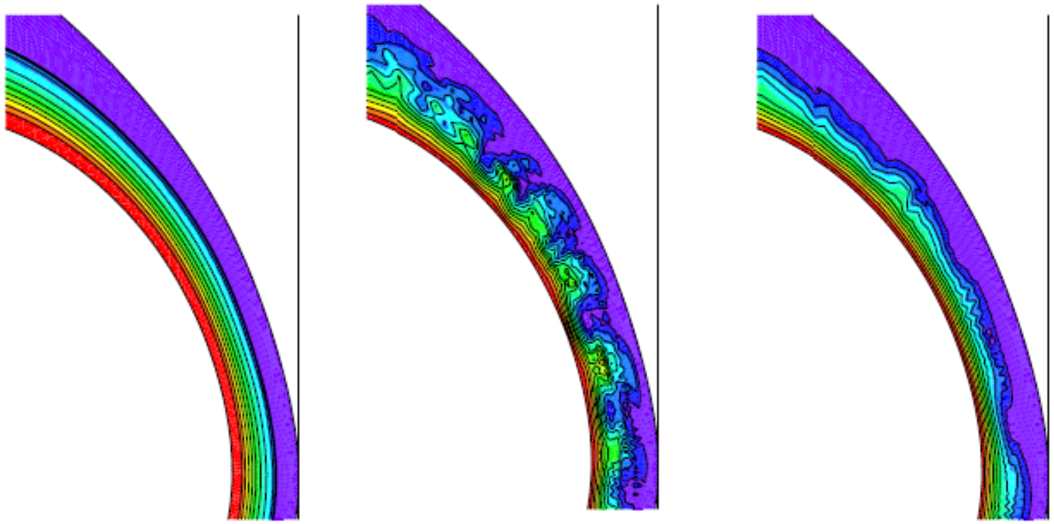
M3D simulation :
Time development of ELM crash



Equilibrium poloidal
Magnetic flux

time development of ELM
after saturation pressure smooths out



t = 27
Initial p

t = 67
ELM

t = 106
relaxation

Contact

Scott A. Klasky
Lead, End-to-End Solutions
National Center for Computational Sciences
(865) 241-9980
klasky@ornl.gov