PSTI UCLA
Plasma Science and Technology Institute

Computational plasma physics at the exascale: Goals, obstacles, and new ideas

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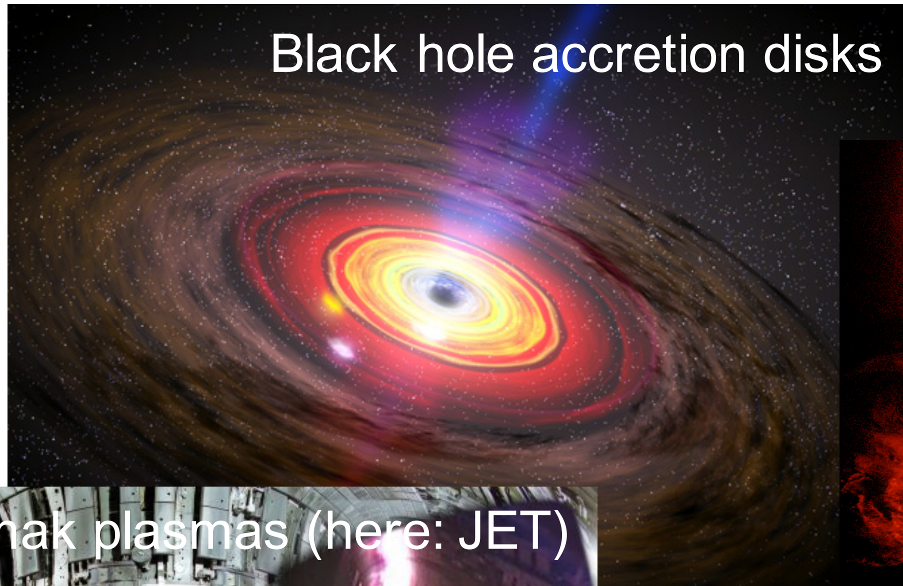
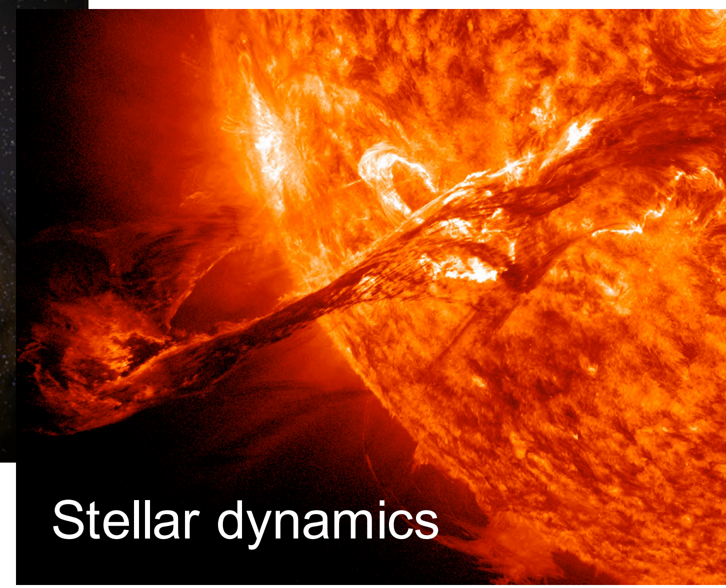
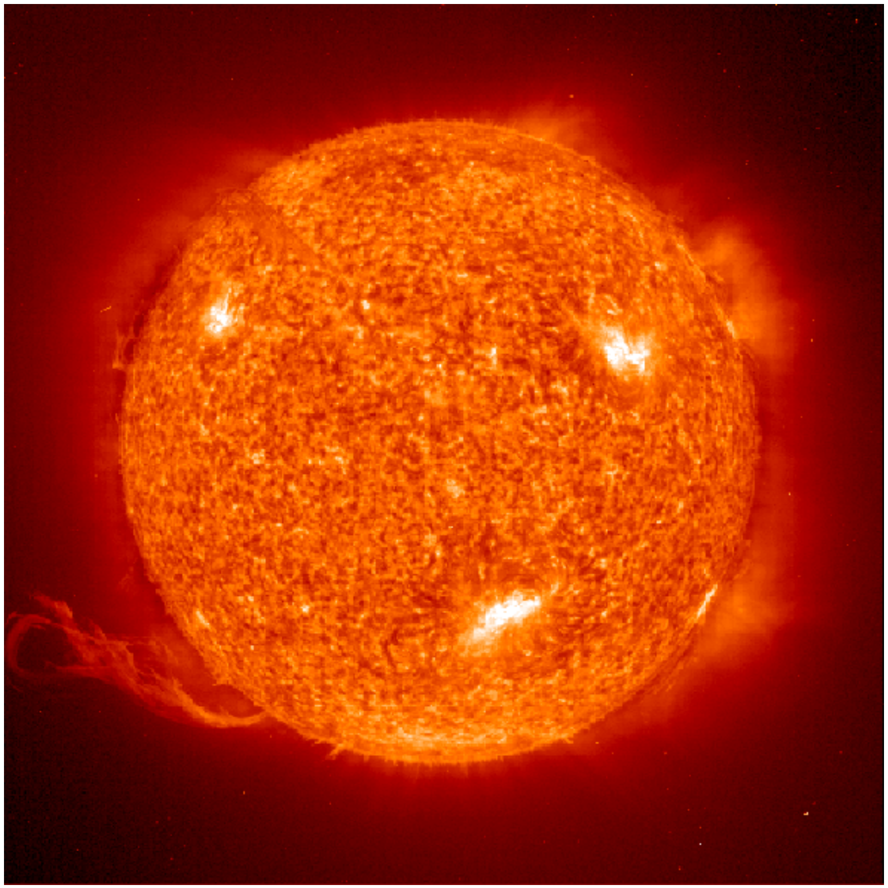
Our plasma universe: More than 99% of the visible universe is in a plasma state



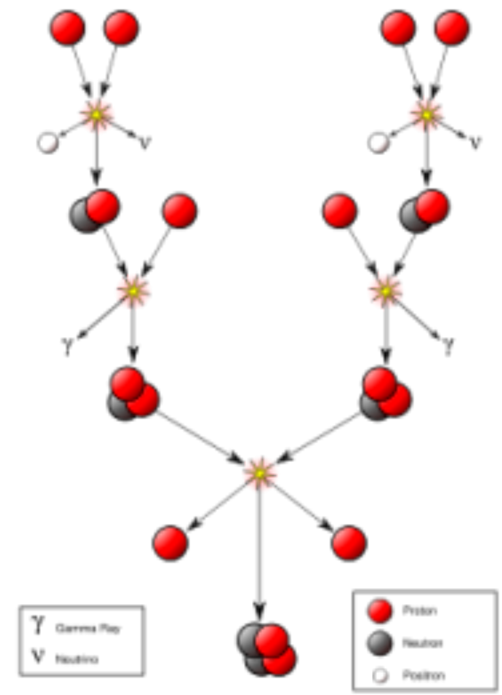


Turbulence is widely recognized as an **important open problem** in modern physics & astrophysics

How the Sun shines: Fusion energy



Fusion of 4 protons in several stages



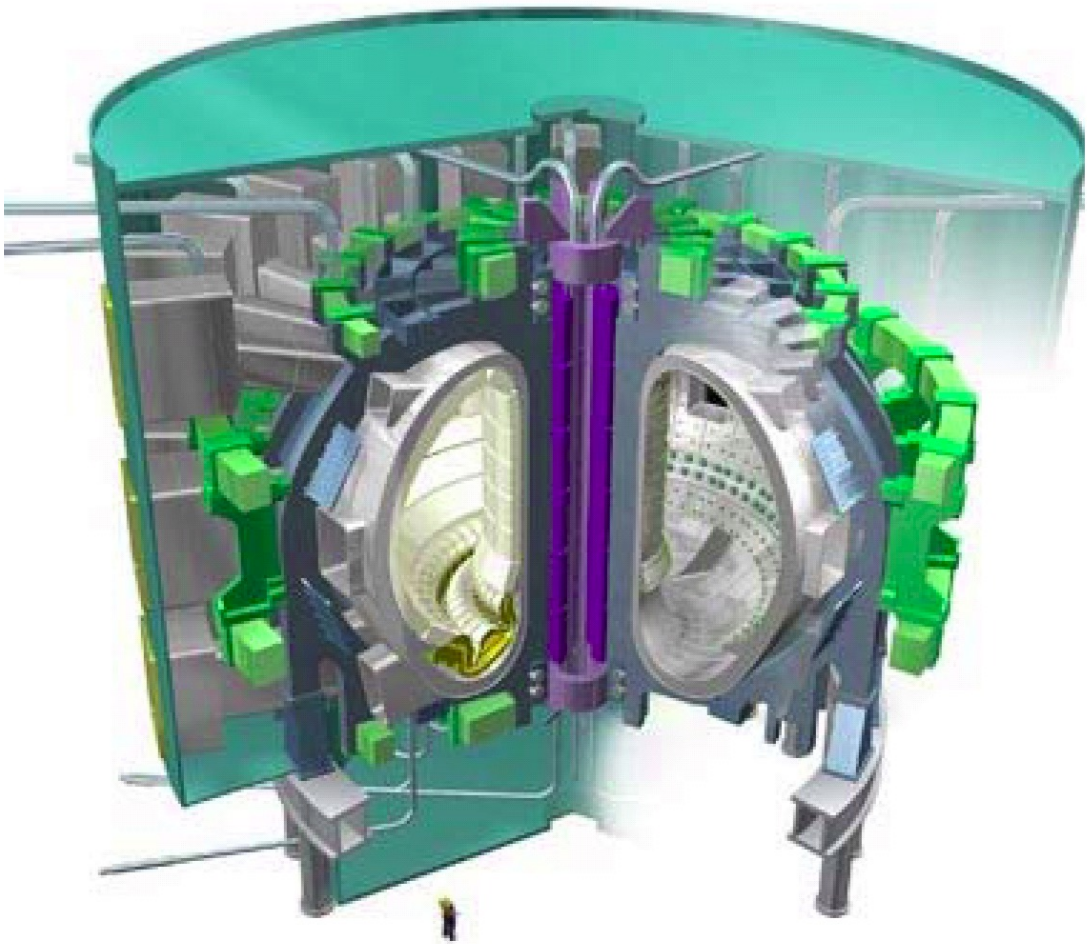
Idea: D-T fusion as a new source of CO_2 free energy for the 21st century and well beyond

The resources for fusion energy are practically unlimited

Deuterium in a bath tub full of water and Lithium (to produce Tritium) in a used laptop battery suffice for a family over 50 years

The next step for fusion research: ITER

Key challenge: Plasma confinement



Magnetic confinement in a large tokamak

Goal: 500 MW of fusion power

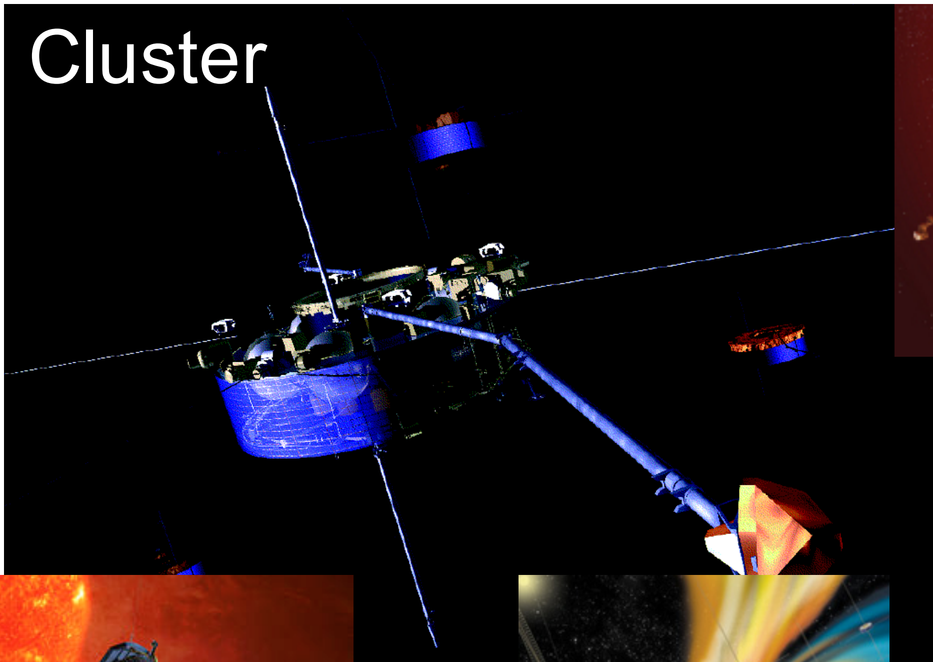
Problem: Turbulent transport

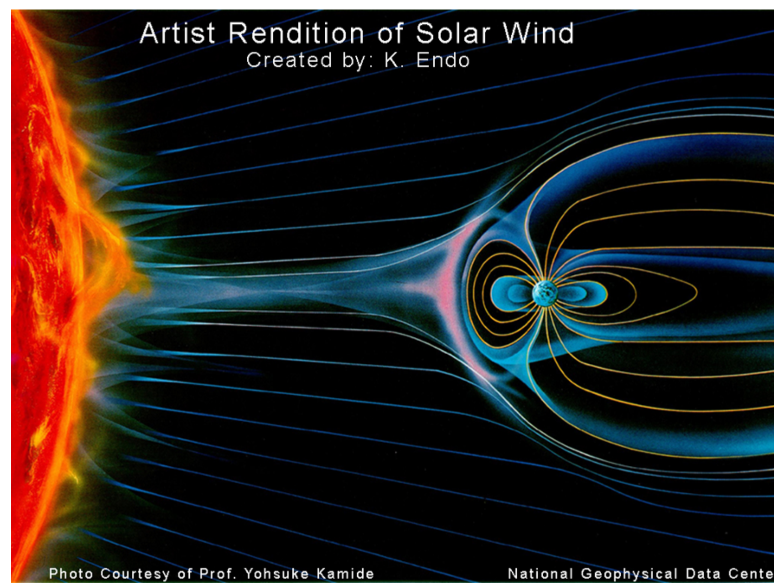
www.iter.org

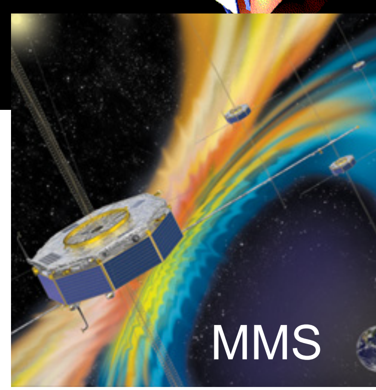
Gyrokinetic plasma turbulence (GENE)

Grand Challenge: Turbulent dynamics

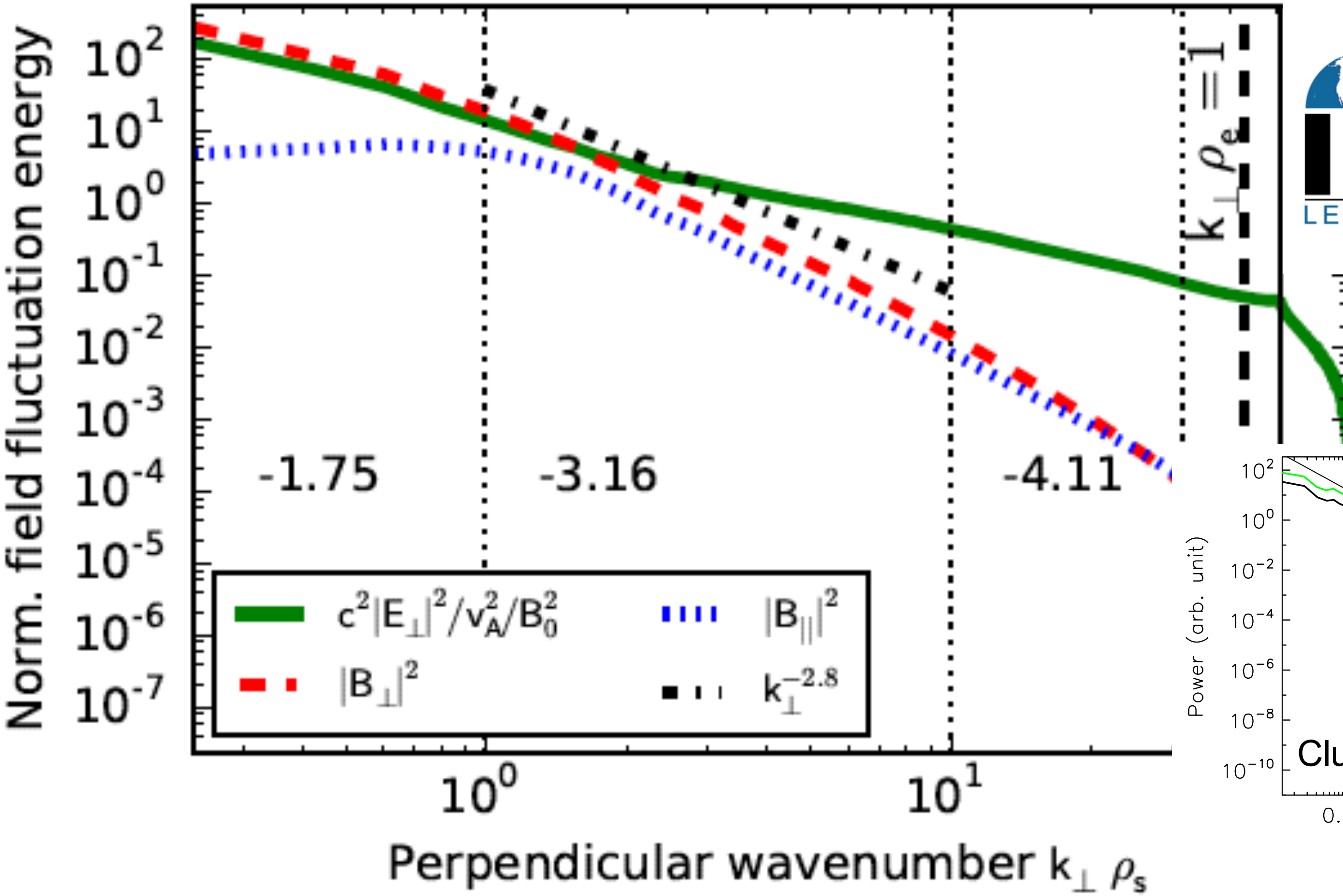
„The understanding of the small-scale termination of the turbulent energy cascade in collisionless plasmas is nowadays one of the outstanding unsolved problems in space plasma physics" (Bruno & Carbone, 2013)







Dissipation in KAW turbulence (GENE)



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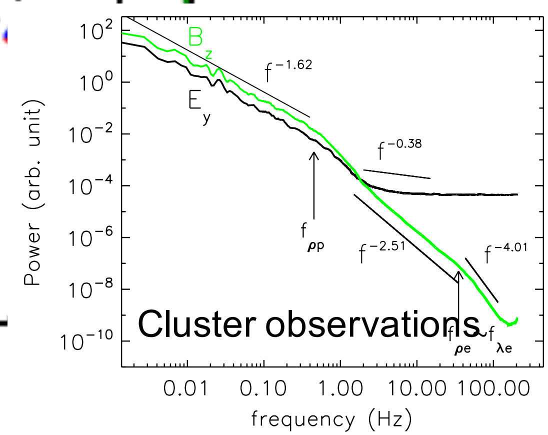
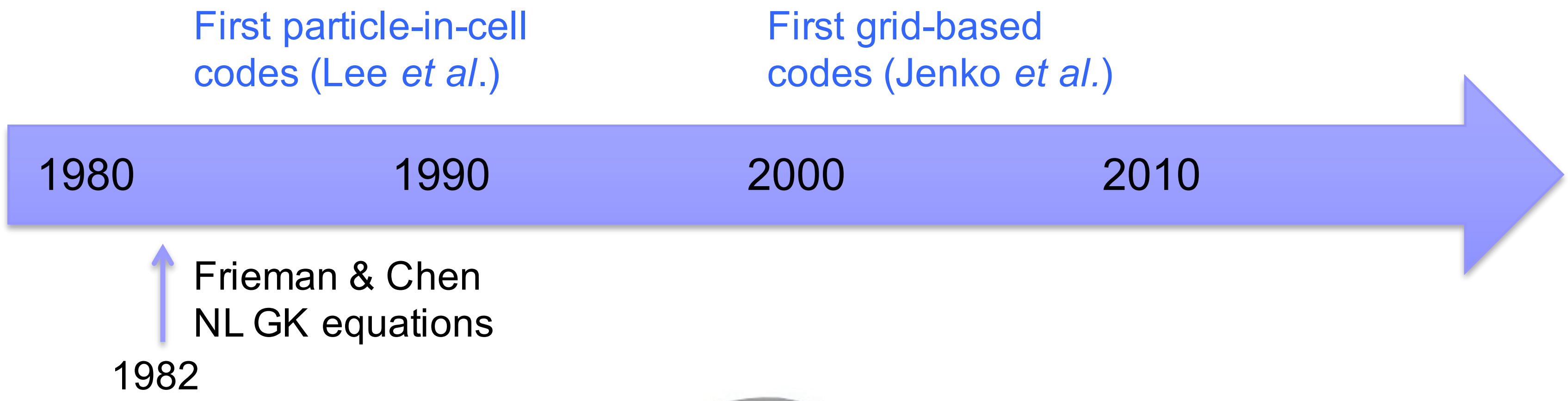


Largest such simulations to date: Told, Jenko, TenBarge, Howes, and Hammett, PRL 2015

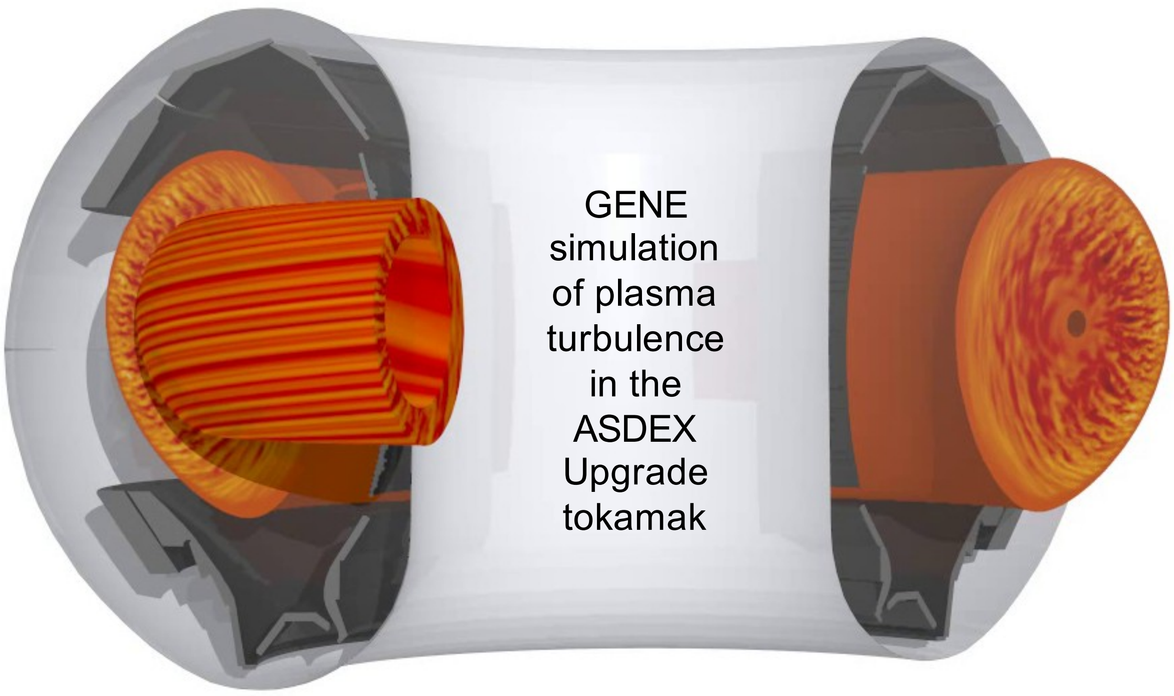
Evolution of gyrokinetic simulations



Hot, dilute plasmas are collisionless (i.e., kinetic)

Grid-based gyrokinetic codes use a **grid in a 5D configuration-velocity space**

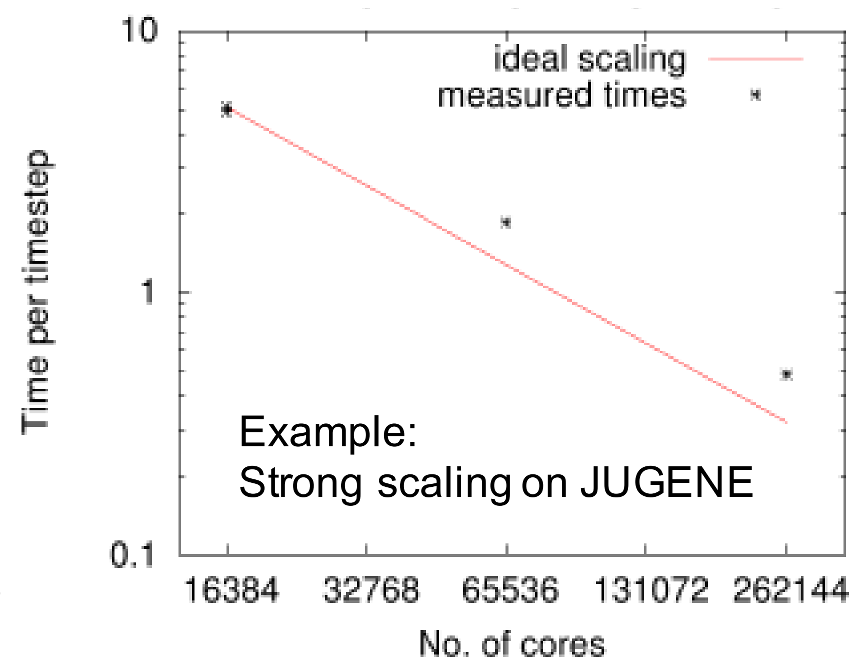
One starts to feel the "curse of dimensionality"



GK Vlasov code GENE (Jenko *et al*., 1999 –)

http://genecode.org

- Modes of operation: **delta-f & full-f; flux-tube & full-torus**
- Unique combination of various finite difference/volume & spectral methods (CFD)
- Comprehensive physics
- Publicly available, world-wide user base
- Output to date: ~150 papers (~20 PRLs)
- Scales well on leading HPC systems, is part of the *Unified European Application Benchmark Suite* (PRACE Research Infrastructure



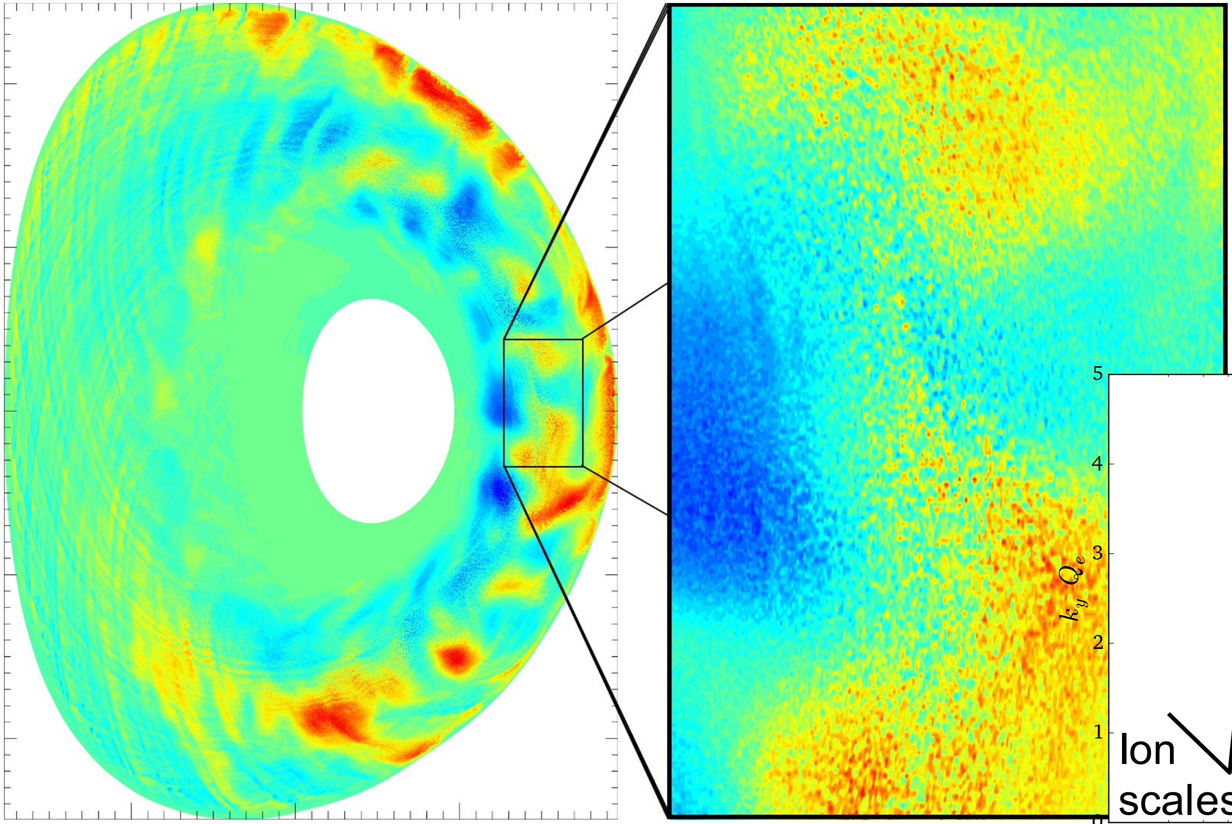
Gyrokinetic Electromagnetic Numerical Experiment

Goals, obstacles, and new ideas

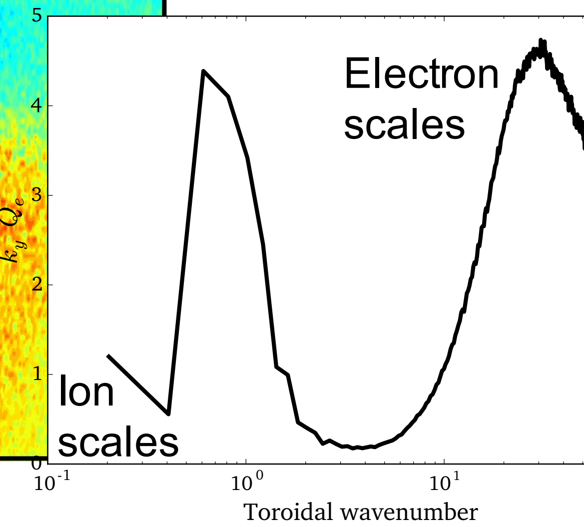
Challenge 1: Multiscale, multiphysics runs

First simulation **from system size to *electron* gyroradius** with *real* (D) mass ratio for a moderate-size tokamak (TCV) > 10^7 core-hours (single run)

Density fluctuation contours from GENE



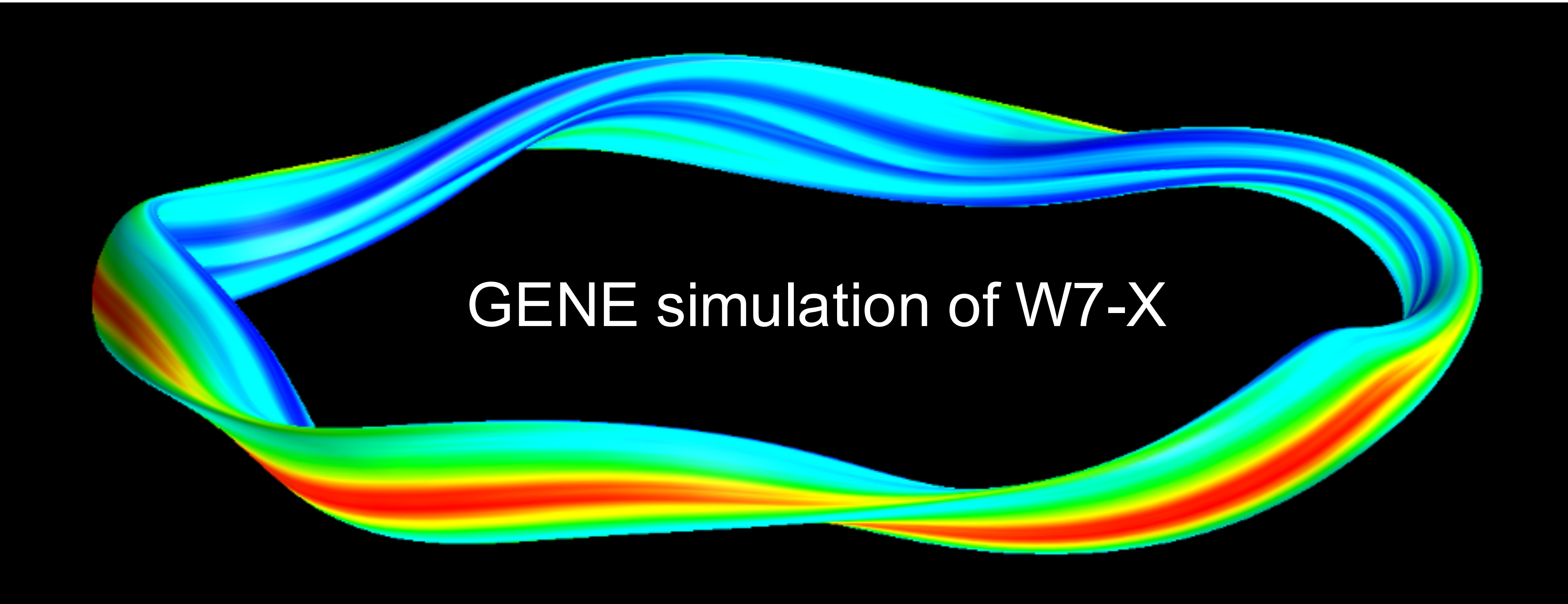
Electron heat flux



Challenge 2: Comprehensive validation

Need to test our capablities over a wide range of devices

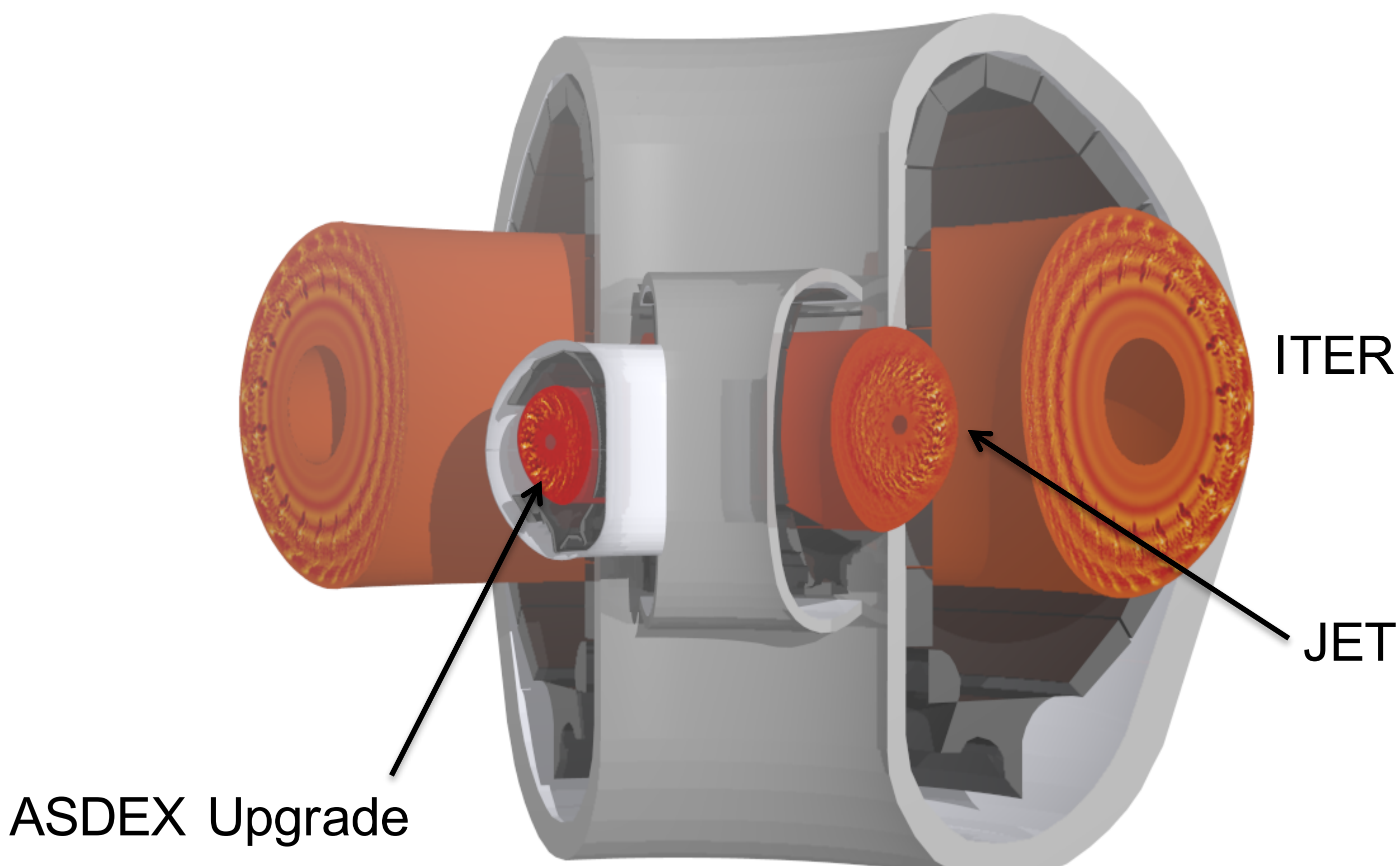
Example: W7-X is a $1 billion project at Greifswald which started operation a few weeks ago; it will be a great testbed for our predictive capabilities



Challenge 3: Truly predictive capability

Towards a „virtual tokamak“

To prepare and interpret ITER discharges, and to guide the development and optimization of future power plants, need to go from postdiction to prediction

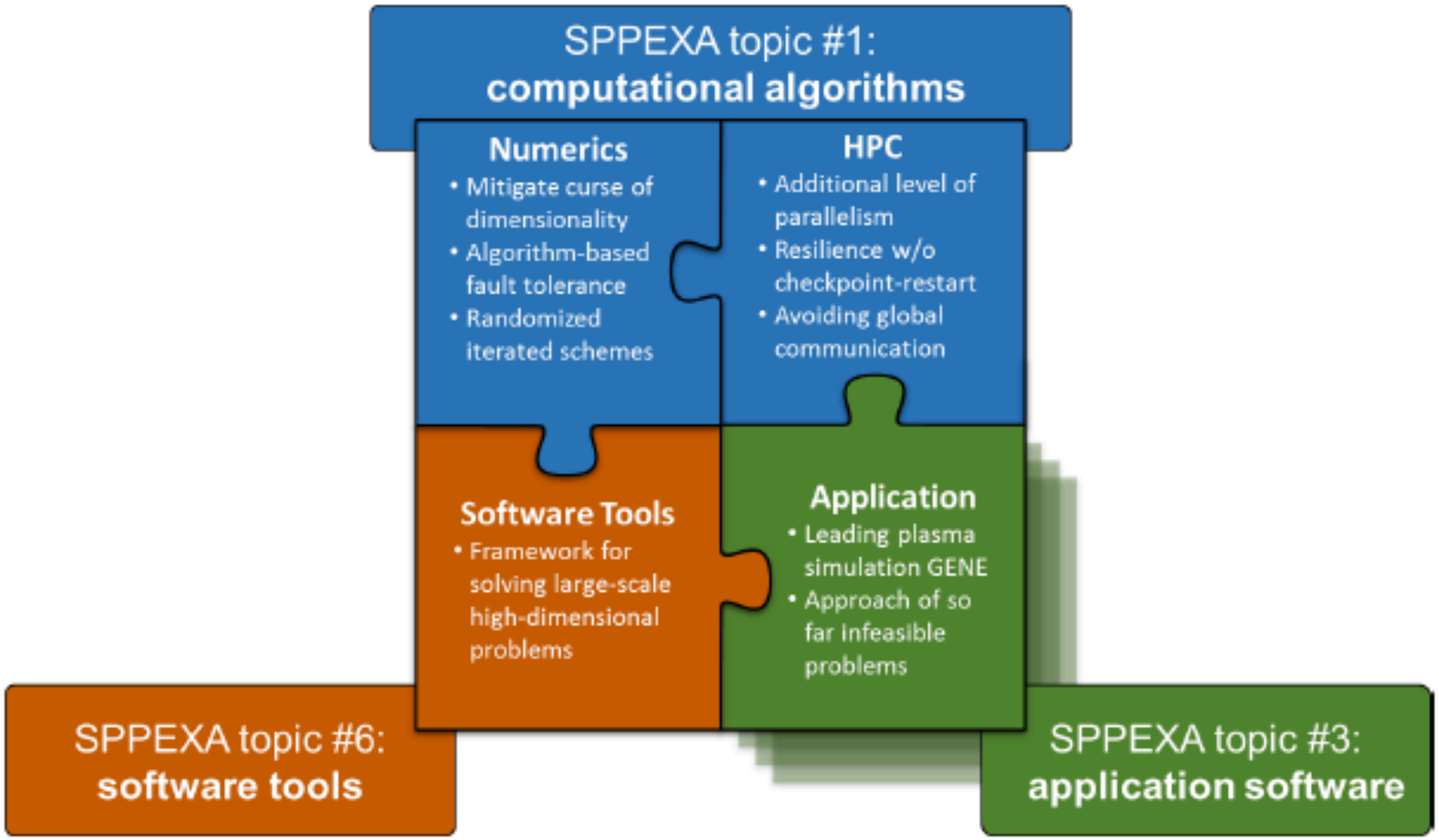


New ideas

Some important examples:

- Structure-preserving schemes
- Multiscale, multiphysics schemes
- Minimize time-to-solution (!)
- Efficient 5D grids (curse of dimensionality)
- Algorithmic approaches to resilience (exascale)
- **Sparse grid techniques...**

Summary



… and joint events and work with ExaFSA, ExaStencils, EXA-DUNE, and others …