HP2C

Community network in plasma physics, astrophysics and multiscale fluid dynamics

UZH, EPFL, UBA, ETHZ

3 former HP2C projects: cosmology, gyrokinetic, supernova
+ 1 project from CSE Lab at ETH

We share common algorithmic needs and similar computational and scientific methodologies

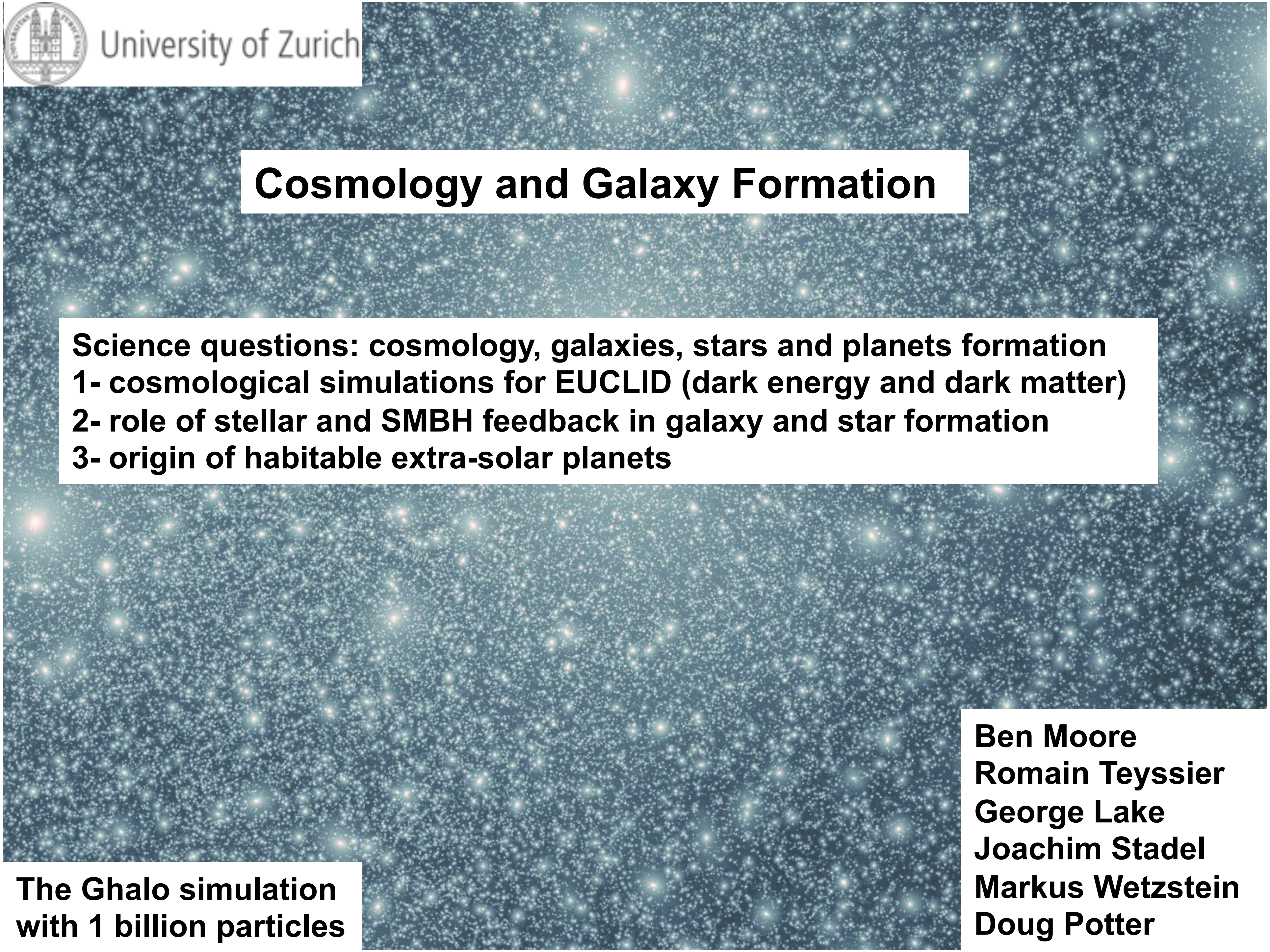
- **Magnetized turbulence and compressible hydrodynamics**
- **Hybrid schemes (particles and cells)**
- **Multiscale technique (adaptive meshes and time steps, wavelets)**
- **Non local phenomena: electromagnetic fields, gravity, radiation and neutrinos transport**

Activities:

- **Networking to define common computational dwarfs (kernels)**
- **Develop common strategies for code optimization, code porting and algorithmic developments**
- **Code support, maintenance and promotion within user community**

University of Zurich

Cosmology and Galaxy Formation



Science questions: cosmology, galaxies, stars and planets formation
1- cosmological simulations for EUCLID (dark energy and dark matter)
2- role of stellar and SMBH feedback in galaxy and star formation
3- origin of habitable extra-solar planets

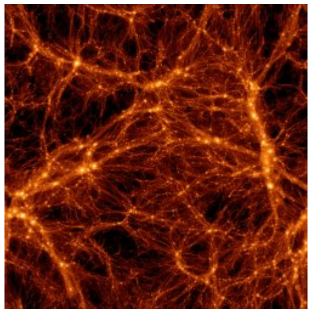
The Ghalo simulation with 1 billion particles

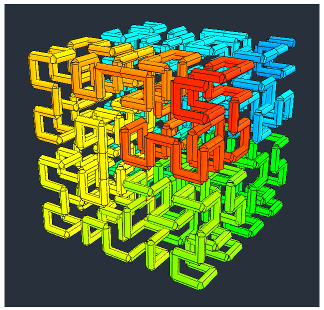
Ben Moore
Romain Teyssier
George Lake
Joachim Stadel
Markus Wetzstein
Doug Potter

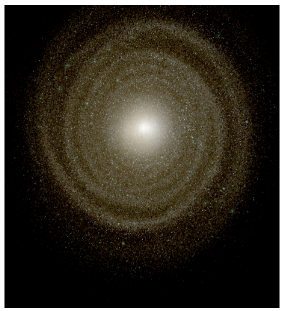
PKDGRAV: N body code with Fast Multipole Method
Gravity kernel used SSE/AVX and GPGPU acceleration
Smoothed Particle Hydrodynamics under development
Evolution of the older GASOLINE code.

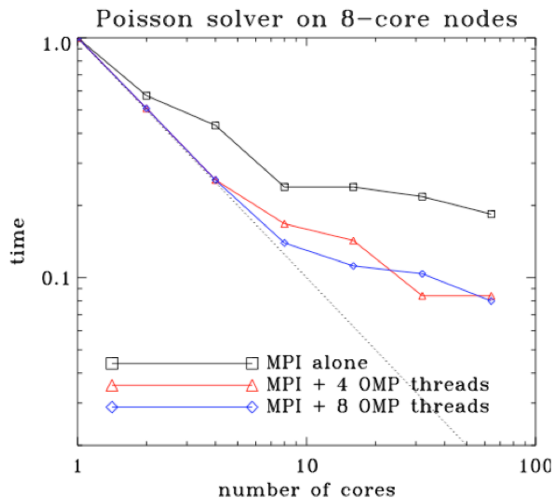
RAMSES: Adaptive Particle Mesh with Multigrid Poisson solver
Magneto-Hydrodynamics with a Godunov Scheme
Radiative transfer with moment scheme and GPU acceleration
Hybrid MPI/OpenMP: improved 2x load balancing issues

Spatial adaptivity (octree AMR, tree code), time adaptivity
MPI domain decomposition based on the Peano-Hilbert curve
Hybrid data structure (particles and cells)









Computational tools of the supernova node

- FISH

A 3D MPI/OpenMP parallelized magneto-hydrodynamics code for astrophysical applications.

Grid-based code using second-order total variation diminishing advection and constrained transport of magnetic fields [Käppeli et al. 2011].

- IDSA

An efficient spectral approximation to detailed neutrino transport in core-collapse supernovae.

The IDSA module implements 3D diffusion and interpolates to spectral streaming of the neutrinos including detailed reaction rates [Liebendörfer et al. 2009, Berninger et al. 2012].

- PARDISO

A parallel solver for large sparse symmetric and unsymmetric systems of linear equations

(main author Olaf Schenk from USI, Lugano). The solver is widely used by thousands of researchers at international scientific laboratories and universities with a wide range of applications.

- SPHYNX

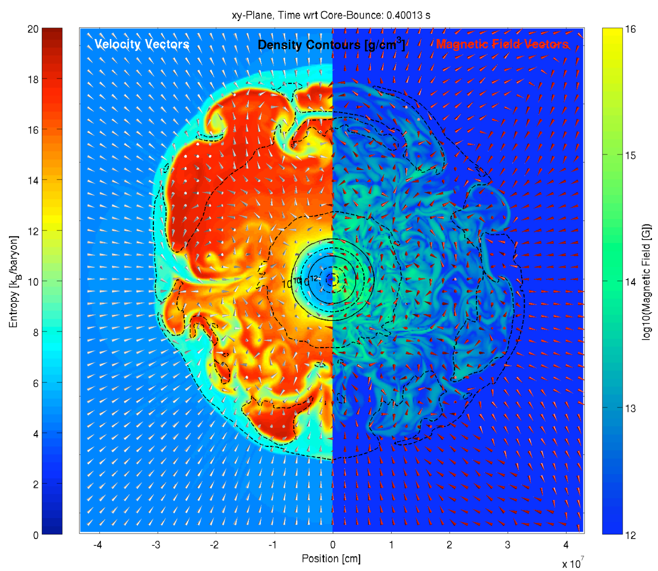
A new smooth particle hydrodynamics code complementing the grid-based approach.

(main author Ruben Cabezon from UniBas).

- Ruben Cabezon BS
- Martin Gander GE
- Roger Käppeli ETHZ
- M. Liebendörfer BS
- O. Schenk USI
- F.-K. Thielemann BS

Supernova explosion: which mechanism?

Gravitational binding	Heat and neutrino production	Neutrino radiation and fluid instabilities	Neutrino heating in outer layers	Shock revival and yield ejection
Gravitational binding	Rotational and magnetic energy	magnetic field growth and fluid instabilities	Magnetic pressure and heat from dissipation	Shock revival and yield ejection



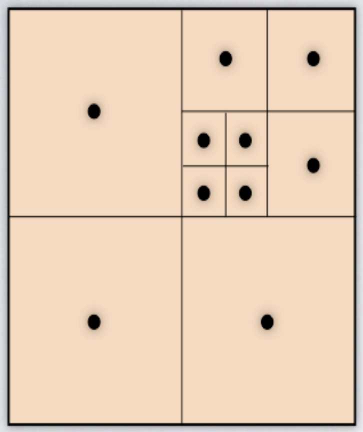
Detailed computational supernova models involve 3D turbulence and rely on high performance computing

Observations:

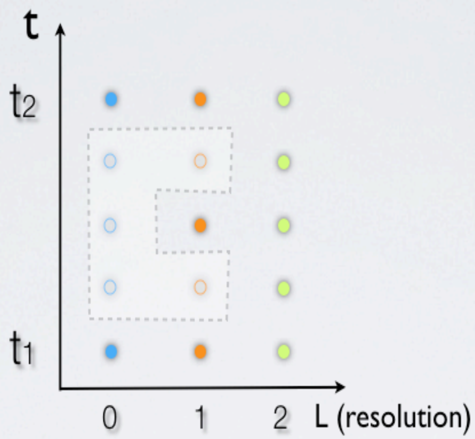
- Lightcurve, other elmag spectrum
- Energy and asymmetry of Explosion
- Ejecta composition and velocity (source of heavy elements!)
- Neutron star and remnant properties
- Neutrinos (SN1987A)
- potentially Gravitational waves

Wavelet-based Multiresolution Adaptive Grids (MRAG)

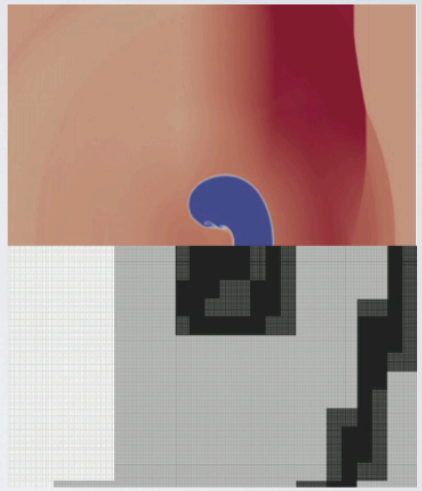
Spatial Adaptivity



Local Time-Stepping (LTS)



2D Shock-Bubble Interaction



Multiphase Compressible Flows

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

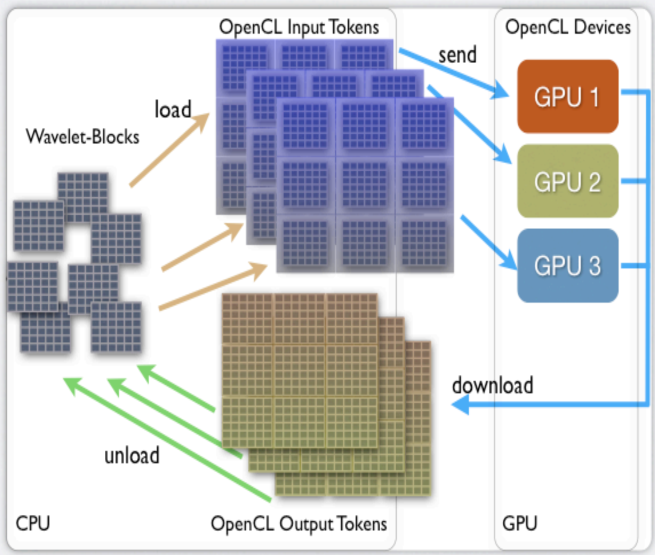
$$\frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}^{\mathbf{T}} + p\mathbf{I}) = 0$$

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

$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = 0$$

$$p = (\gamma - 1)\rho(E - 0.5|\mathbf{u}|^2)$$

CPU/GPU cooperation



Performance

Spatial Adaptivity	LTS
10x acceleration 40x compression	20x acceleration

Multithreading	CPU/GPU
13x speedup (over 16 cores)	3x acceleration

CSE LAB
Computational Science & Engineering Laboratory

[Hejazialhosseini et al., J. Comp. Phys., 2010, Rossinelli et al., SIAM J. of SC, 2011]

High Performance 3D Compressible Flow Solver (MRAG/CUBISM)

3D Shock-Bubble Interaction

- Medical application I: Extracorporeal shockwave lithotripsy (EWSL)
- Medical application II: Targeted cell destruction

Software Optimization

core & node

AVX intrinsics
Data/computation reordering
1.5/2.5 ulps operations
Thread pinning
NUMA-aware optimizations

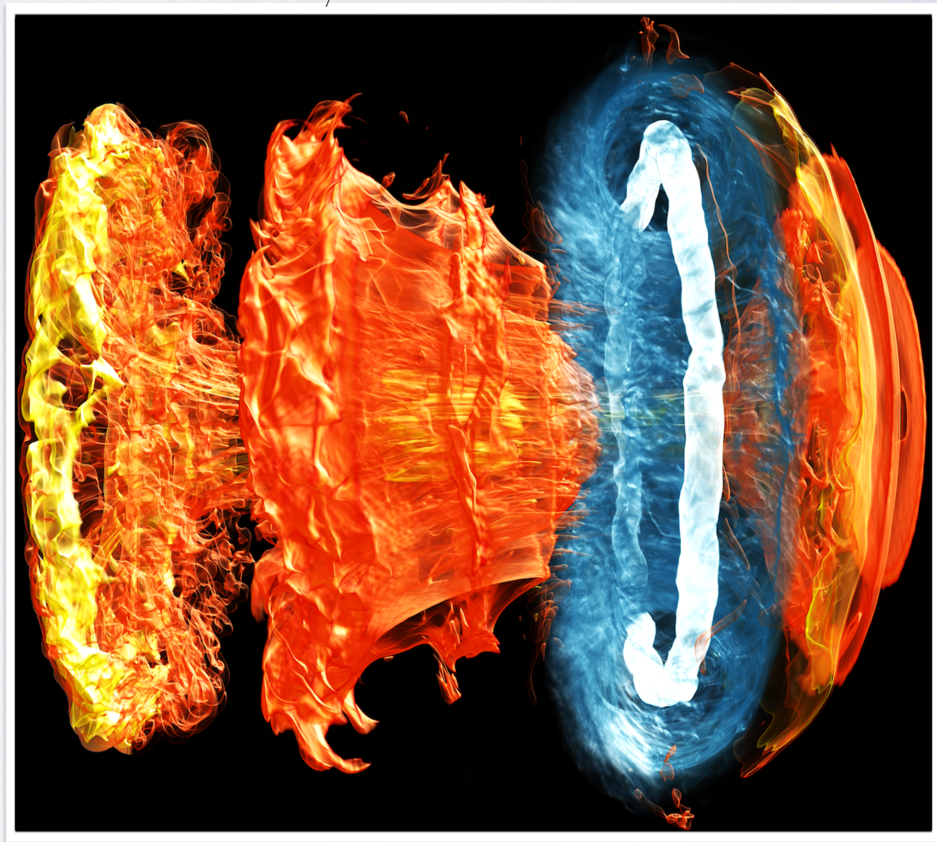
cluster

Asynchronous communication
Genuine C/T overlap

Performance

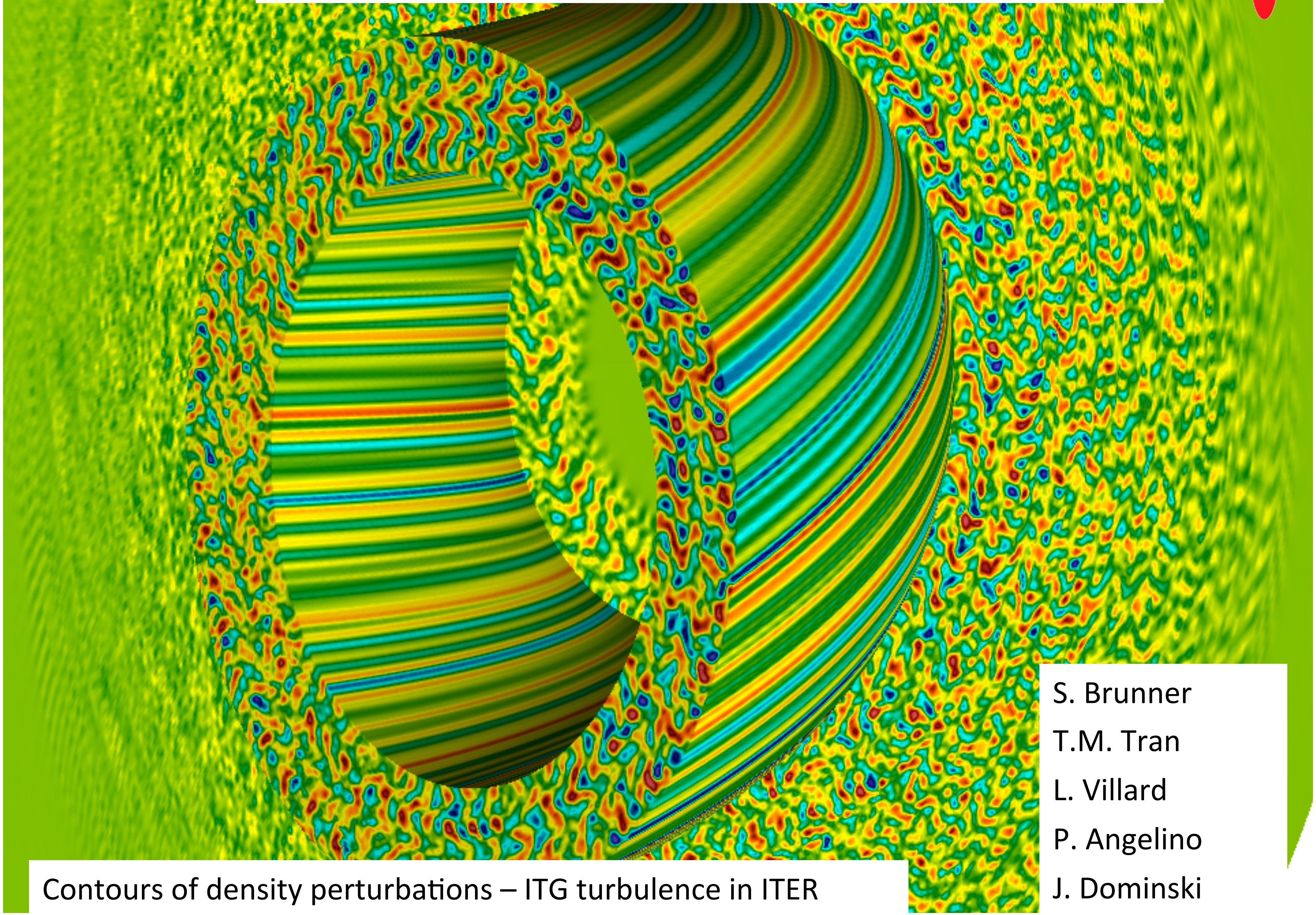
- 250 billion elements
- 47'000 cores, Cray XE6 Monte Rosa
- **0.25 PFLOP/s**, **30%** of the nominal peak

Density field of late time shock-bubble interaction at Mach=3



[Hejazialhosseini et al., SC '12]

Turbulence in magnetic fusion reactors



Contours of density perturbations – ITG turbulence in ITER

S. Brunner
T.M. Tran
L. Villard
P. Angelino
J. Dominski

Turbulence in magnetic fusion reactors

ORB5 code

Gyrokinetic, PIC, finite elements, control variates

Simulations of ITER:

- 10^9 particles (5D phase space)
- 10^9 grid points (3D field solver)

Developped by CRPP-EPFL + several labs in EU (Max-Planck IPP, Uni Warwick, etc)

Runs on several HPC platforms, incl. Rosa@CSCS, HELIOS@IFERC (Japan, 1.5 PetaFlops)

Present HP2C project → parallel scalability substantially increased, performance improvement factor 2 (for ITER simulations)

Common kernels: data treatment, visualization (incl particle data), field solver, parallel data transpose, etc.