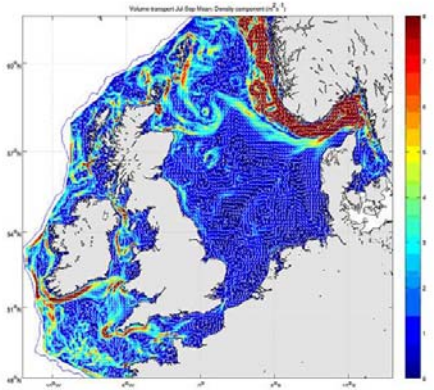

Exploring Extreme Scalability in Scientific Applications

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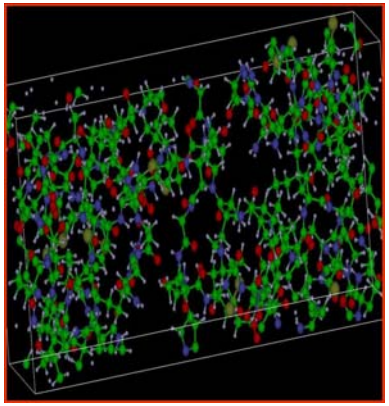
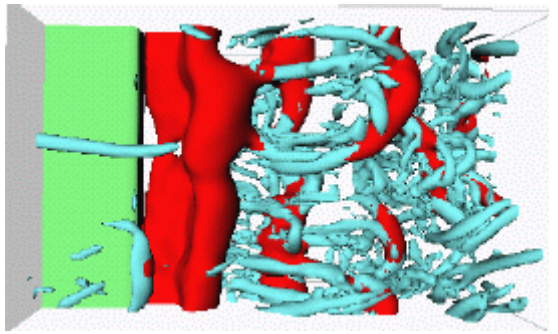




Outline

- Why explore extreme scalability?
- How are we doing this?
- What have we found so far?
- Where are we going next?

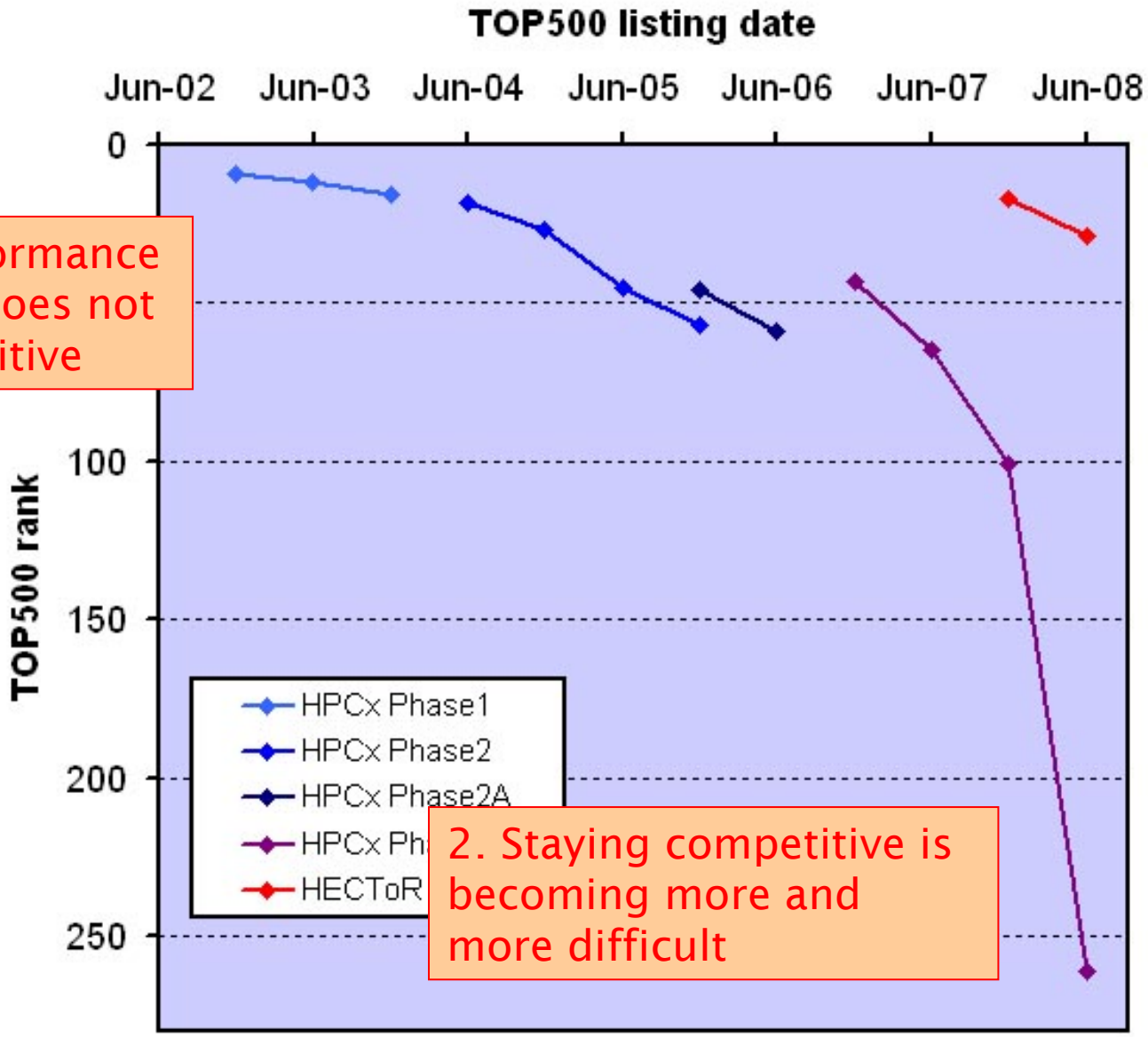
HPC Strategy in the UK

HPC Strategy Committee:

"… the UK should aim to achieve sustained Petascale performance as early as possible across a broad field of scientific applications, permitting the UK to remain internationally competitive in an increasingly broad set of high-end computing grand challenge problems."

… *from* A Strategic Framework for High-End Computing

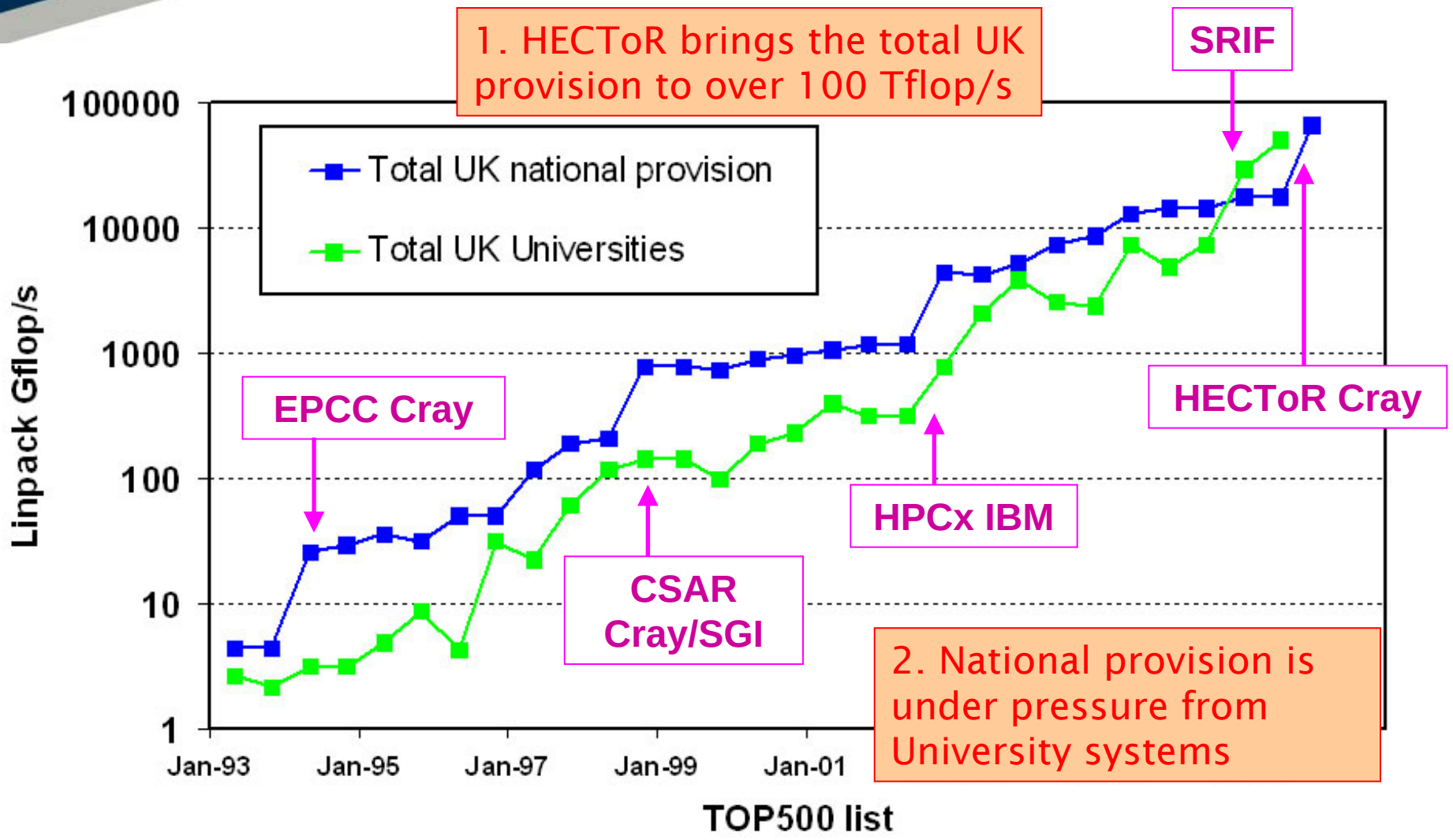
Remaining Competitive?



1. Doubling performance every two years does not keep you competitive

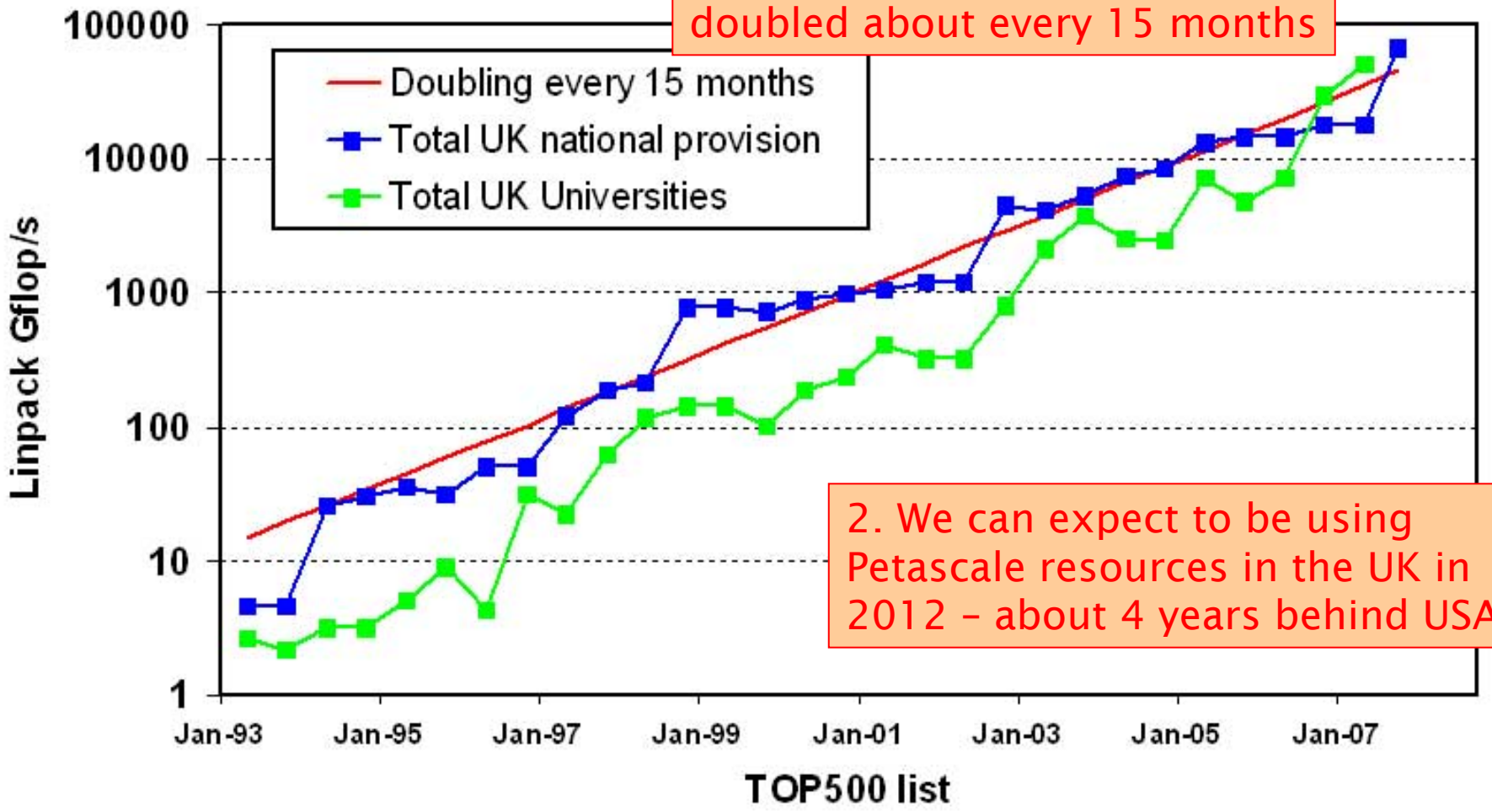
2. Staying competitive is becoming more and more difficult

UK Academic Provision I



UK Academic Provision II

1. The total computing power available to UK academia has doubled about every 15 months



2. We can expect to be using Petascale resources in the UK in 2012 – about 4 years behind USA

What will a Petascale system look like ?

Current indicators:

- TOP500 #1 LANL *Roadrunner* 1.026 Pflop/s
  - 122,400 processors, attached Cell processors
- TOP500 #2 LLNL Blue Gene L 0.478 Pflop/s
  - 212,992 processors, dual-core nodes
- TOP500 #3 ANL Blue Gene P 0.450 Pflop/s
  - 163,840 processors, 2xdual-core nodes
- ORNL late-2008 upgrade to Cray XT4 ~1 Pflop/s
  - ~120,000 processors, quad-core nodes
- Japanese Petascale project
  - Smaller number of ~100 Gflop/s vector processors

Most likely solution for the UK is O(100,000) processors using multi-core components or attached processors

Challenges at the Petascale

Scientific:

- What new science can you do with 1000 Tflop/s ?
- Larger problems, multi-scale, multi-disciplinary

Technical:

- How will existing codes scale to 10,000 or 100,000 processors ? Scaling of time with processors, time with problem size, memory with problem size
- Data management, incl. pre- and post-processing
- Visualisation
- Fault tolerance

Daresbury Petascale project

Scaling analysis of current codes

Performance analysis on O(10,000) procs

Forward-look prediction to O(100,000) procs

Optimisation of current algorithms

Development of new algorithms

Evaluation of alternative programming models

Machines

Machines

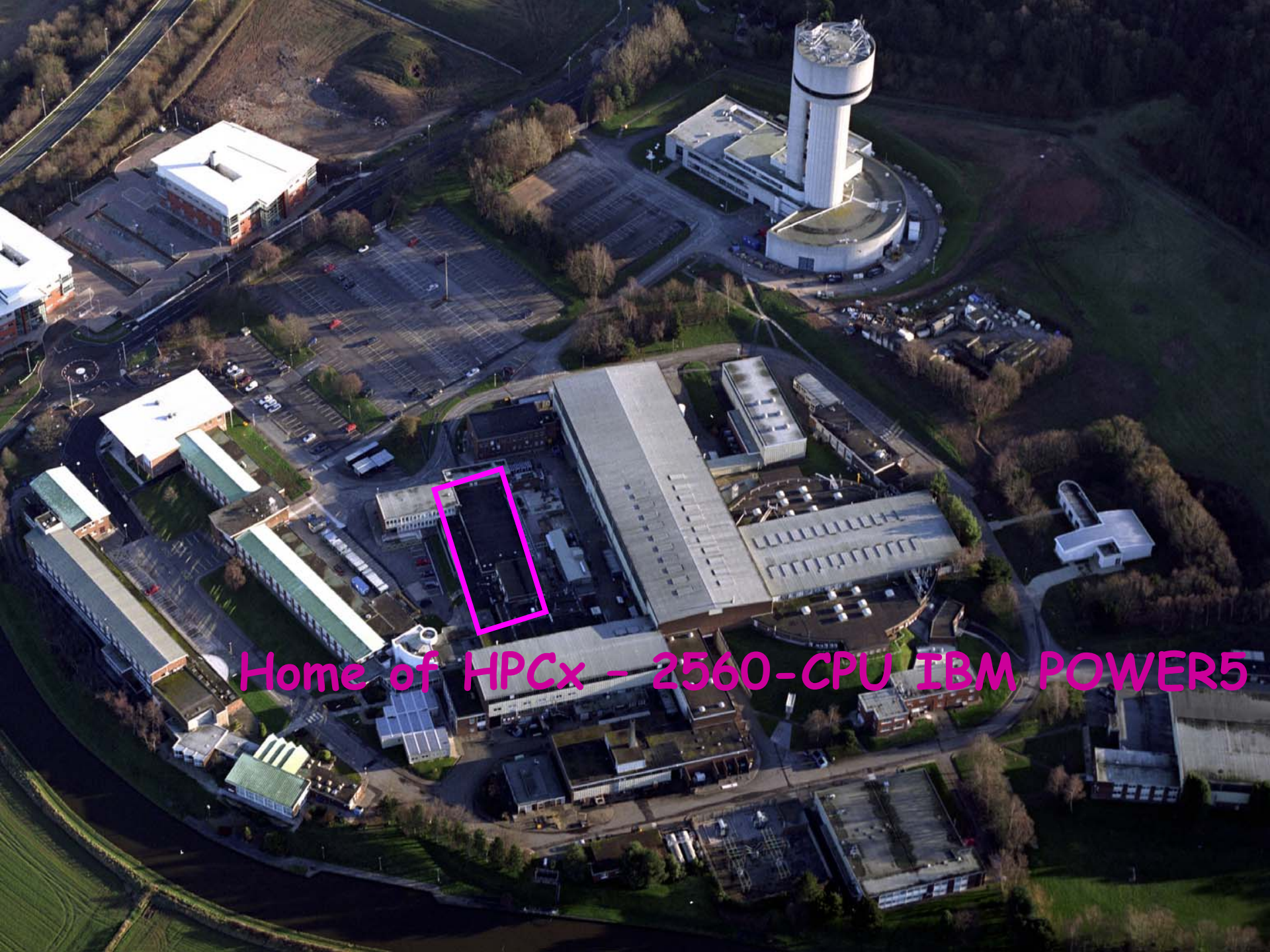
Cray XT4 *HECToR*
- DC 2.8 GHz Opteron 11328 cores

Cray XT3/XT4 *old-jaguar*
- DC 2.6 GHz Opteron ~12,000 XT4 cores

Cray XT3 palu CSCS
- DC 2.6 GHz Opteron 3328 cores

IBM p5-575 *HPCx*
- DC 1.7 GHz POWER5, HPS, 2560 cores

IBM BlueGene/L *jubl*
- DC 700 MHz PowerPC, 16384 cores


Home of HPCx - 2560-CPU IBM POWER5

Applications

Applications

PDNS3D/SBLI
- Direct numerical simulation of turbulent flow

POLCOMS
- Coastal-ocean finite difference code

fd3d
- Earthquake simulation finite difference code

DL_POLY3
- Molecular dynamics code

CRYSTAL
- First principles periodic quantum chemistry code

What is a processor?

A processor by any other name …

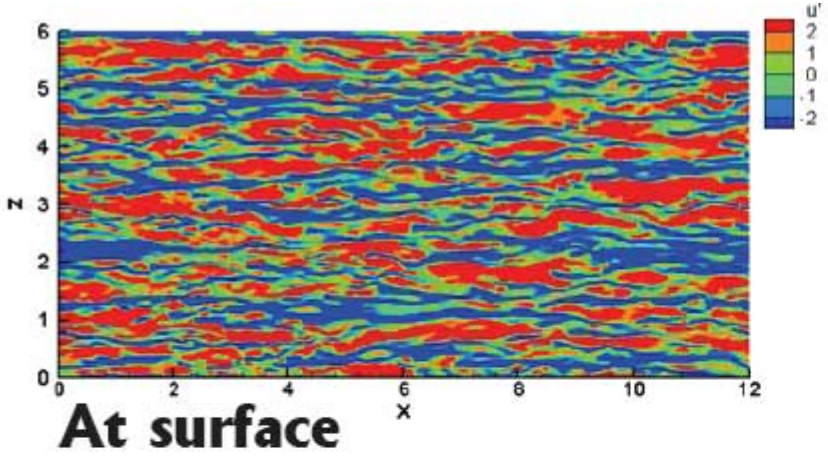
An applications view …

A processor is what is has always been …

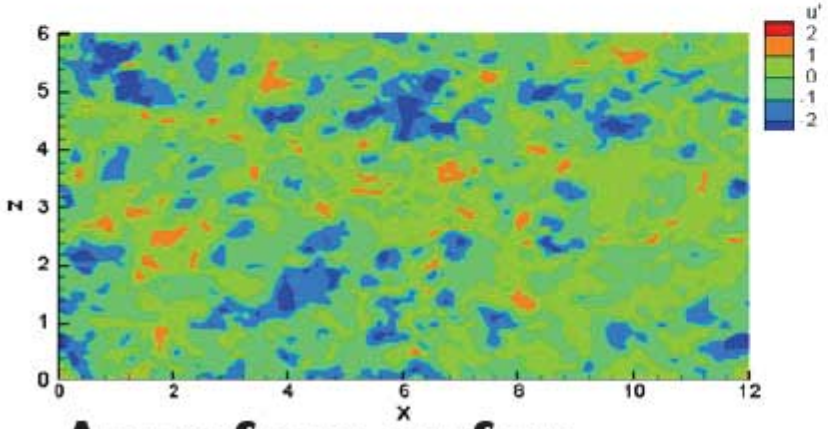
- A short name for Central Processing Unit
- Something that runs a single instruction stream
- Something that runs an MPI task
- Something that runs a bunch of threads (OpenMP)

PDNS3D / SBLI

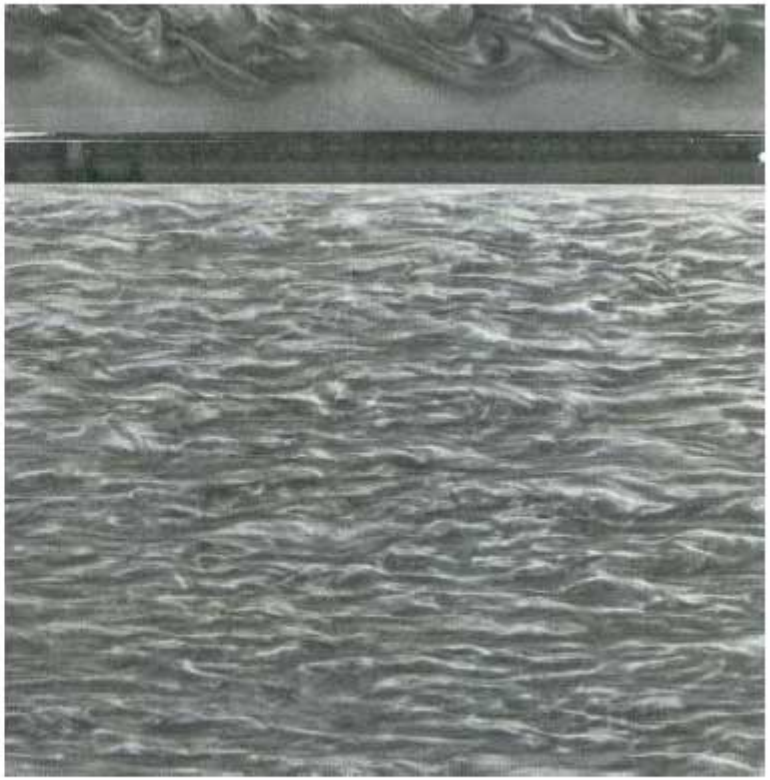
DNS results of near-wall turbulent flow



At surface



Away from surface



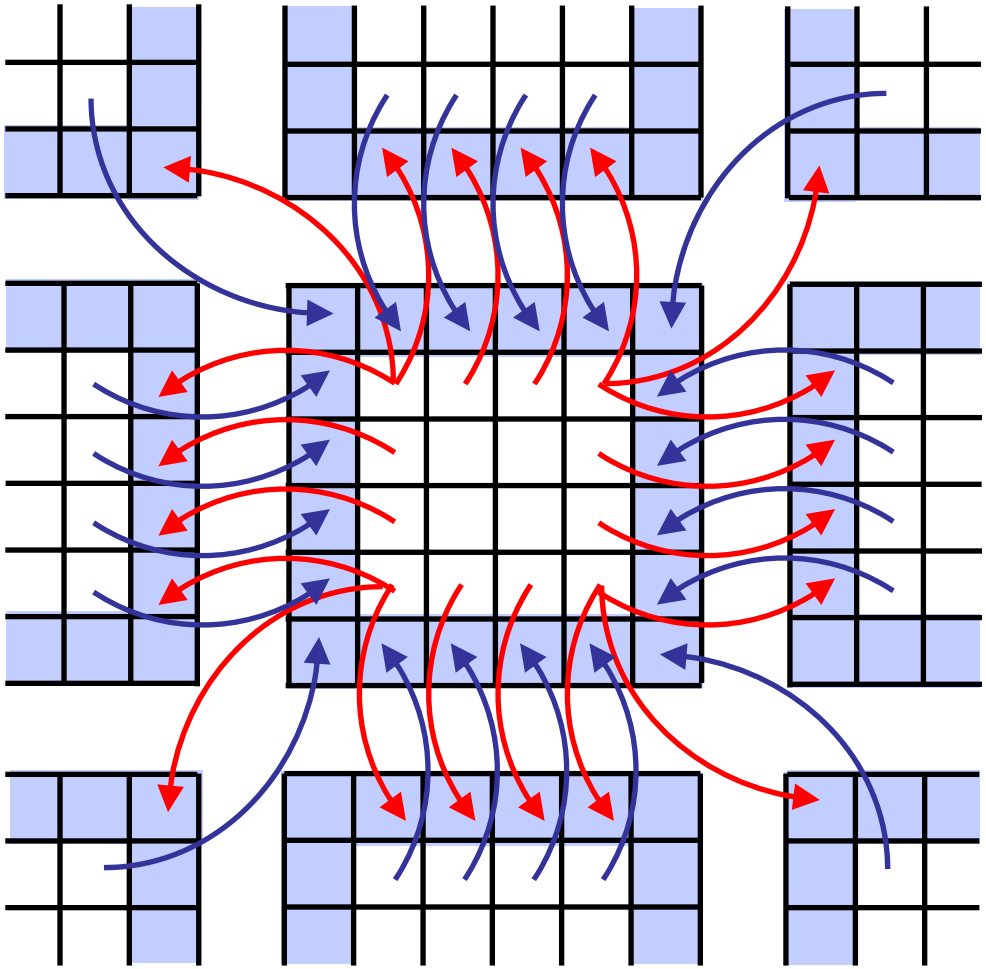
Experiment

3D grid partitioning with halo cells

calculation cost:
scales as n^3

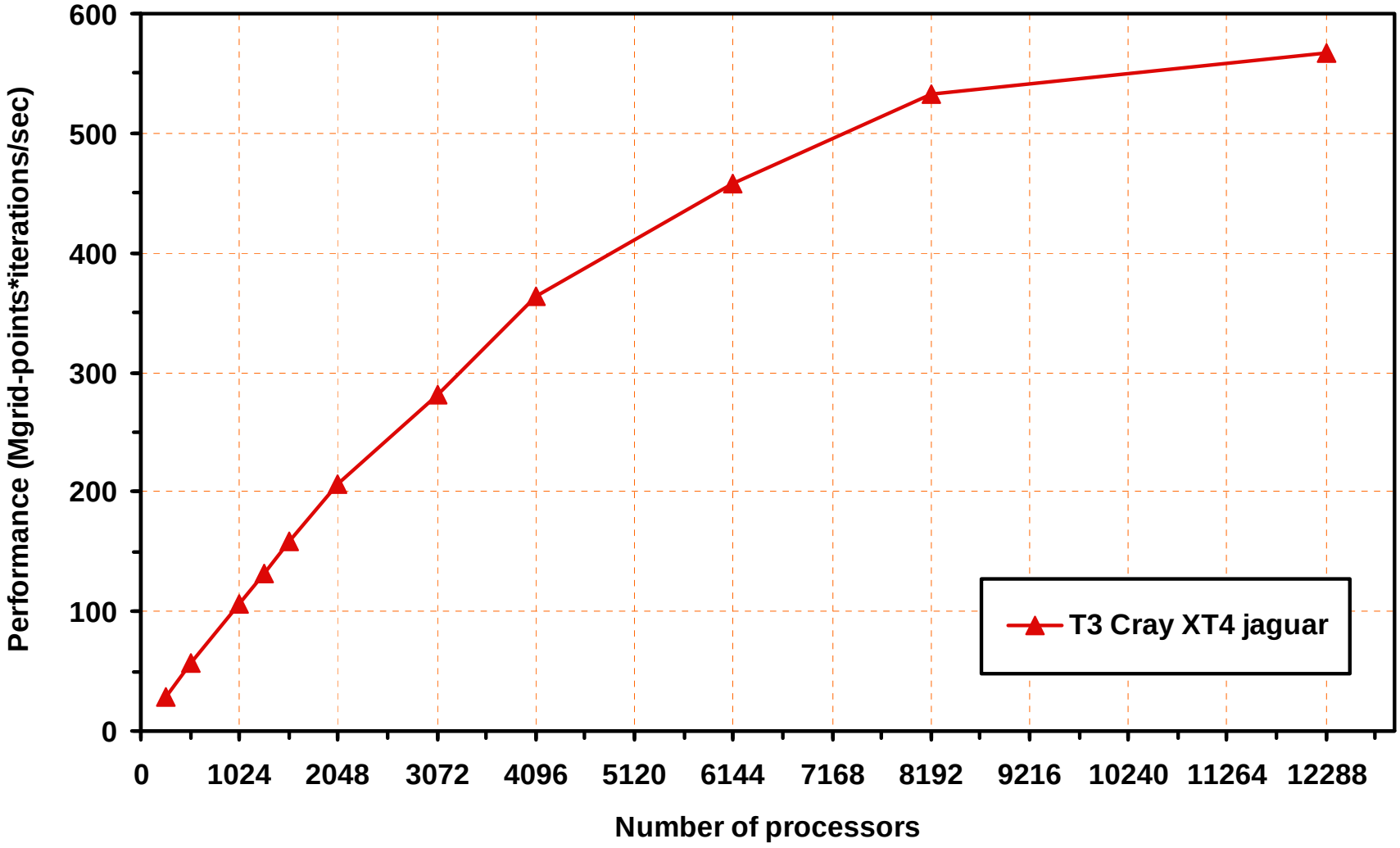
communication cost:
scales as n^2

strong scaling:
increasing P
decreasing n
comms will dominate



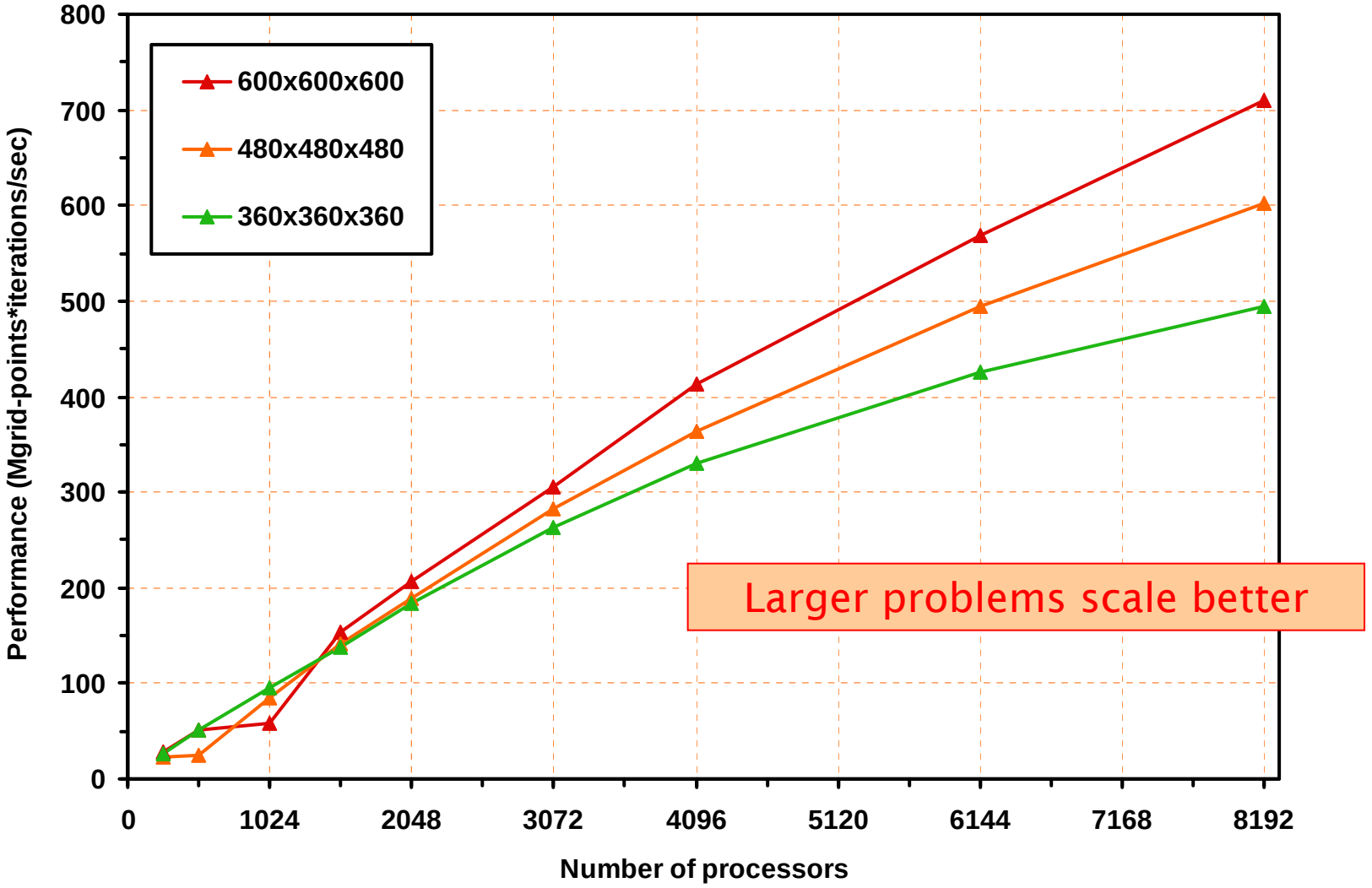
SBLI on jaguar

Turbulent channel flow benchmark



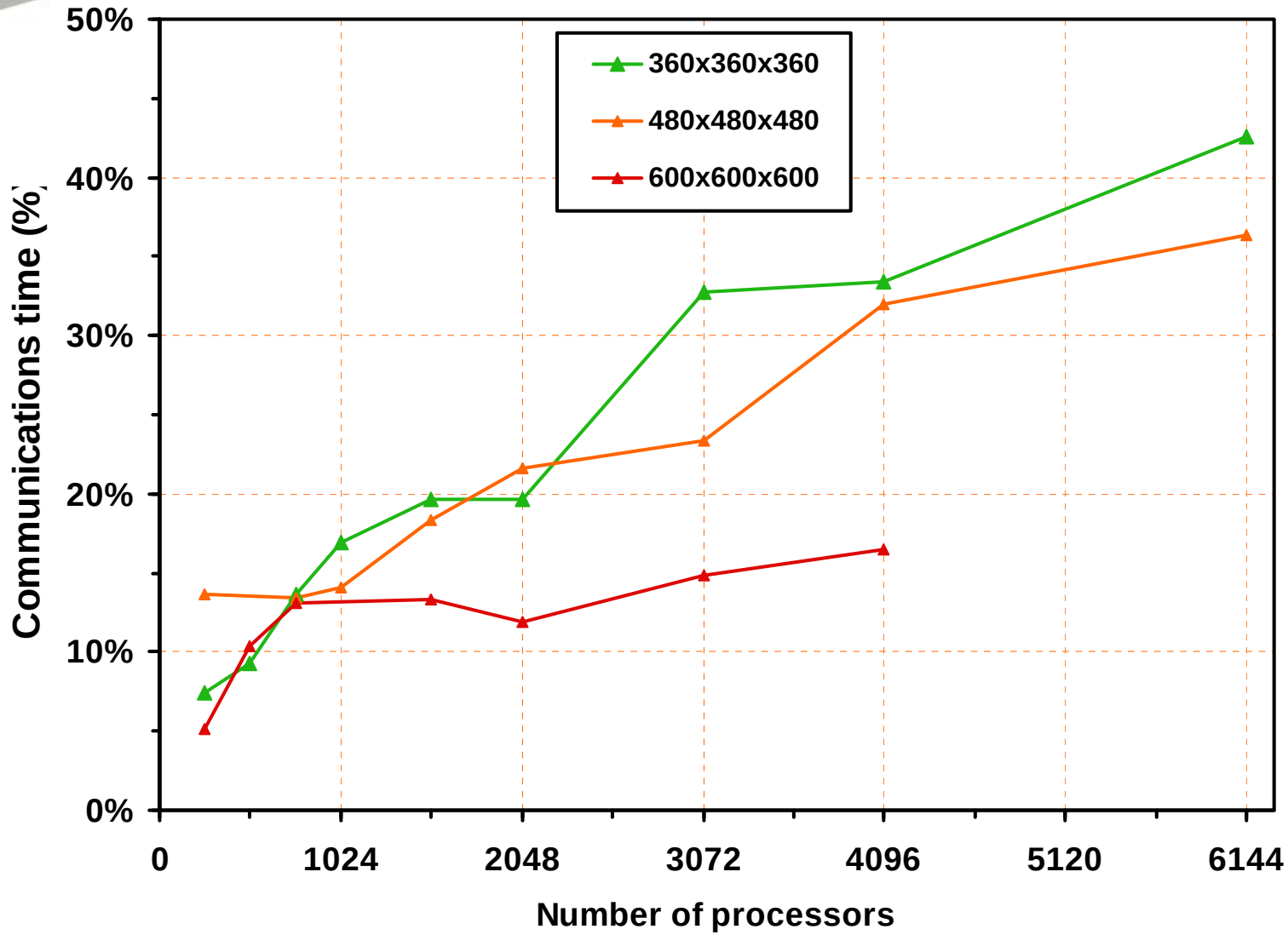
SBLI on Cray XT4

Turbulent channel flow benchmark



Larger problems scale better

% comms time from craypat



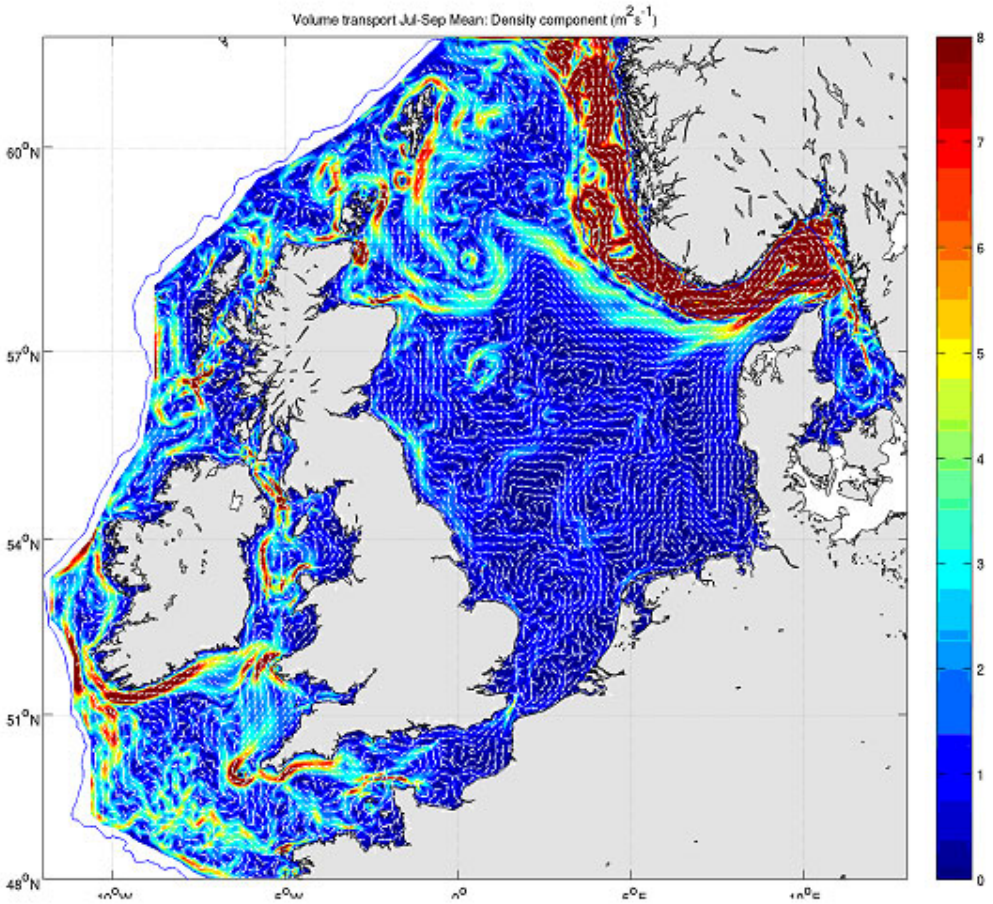
POLCOMS

High-Resolution Coastal Ocean Modelling

POLCOMS is the finest resolution model to-date to simulate the circulation, temperature and salinity of the Northwest European continental Shelf

important for understanding of the transport of nutrients, pollutants and dissolved carbon around shelf seas

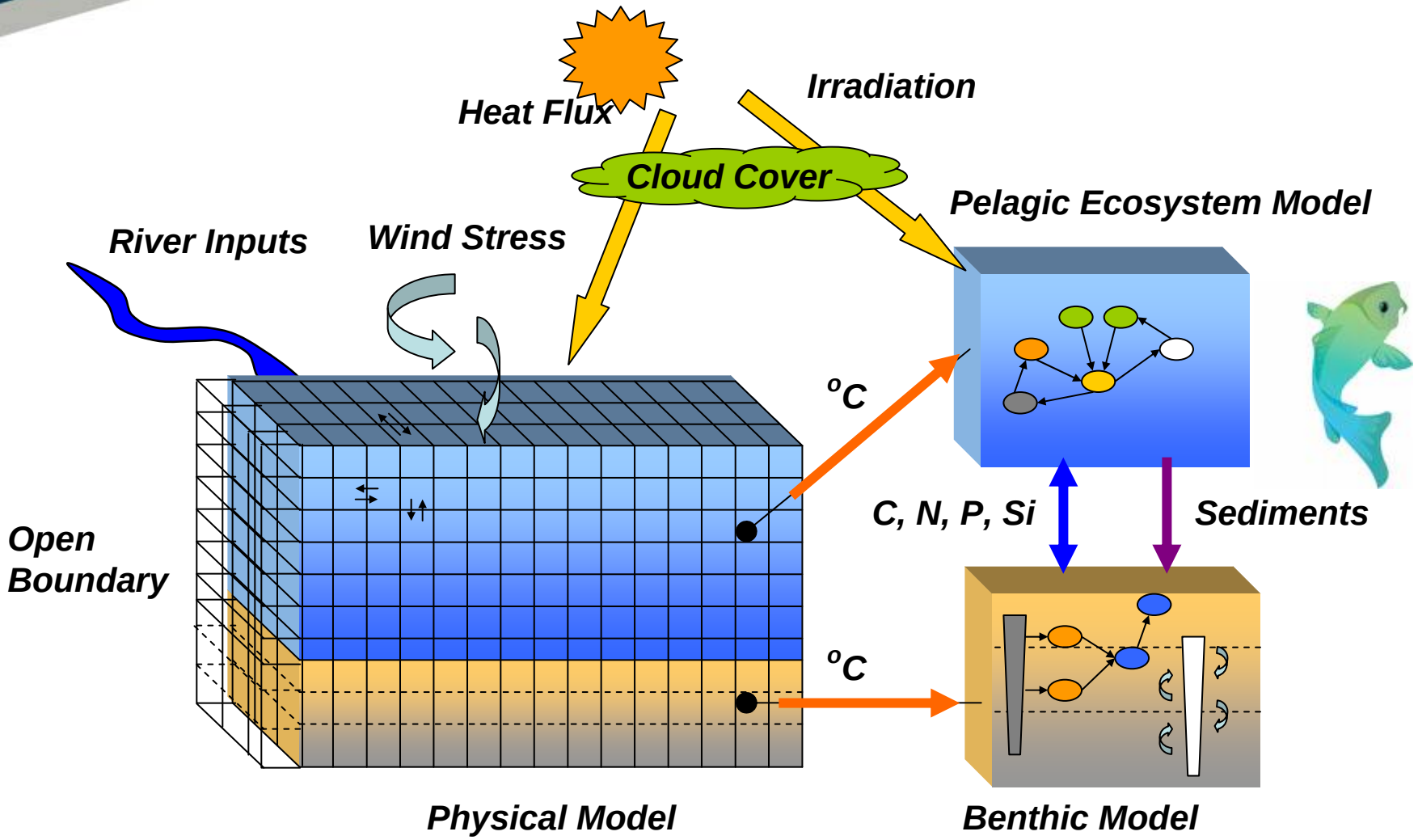
We have worked with POL on coupling with ERSEM, WAM, CICE, data assimilation and optimisation for HPC platforms



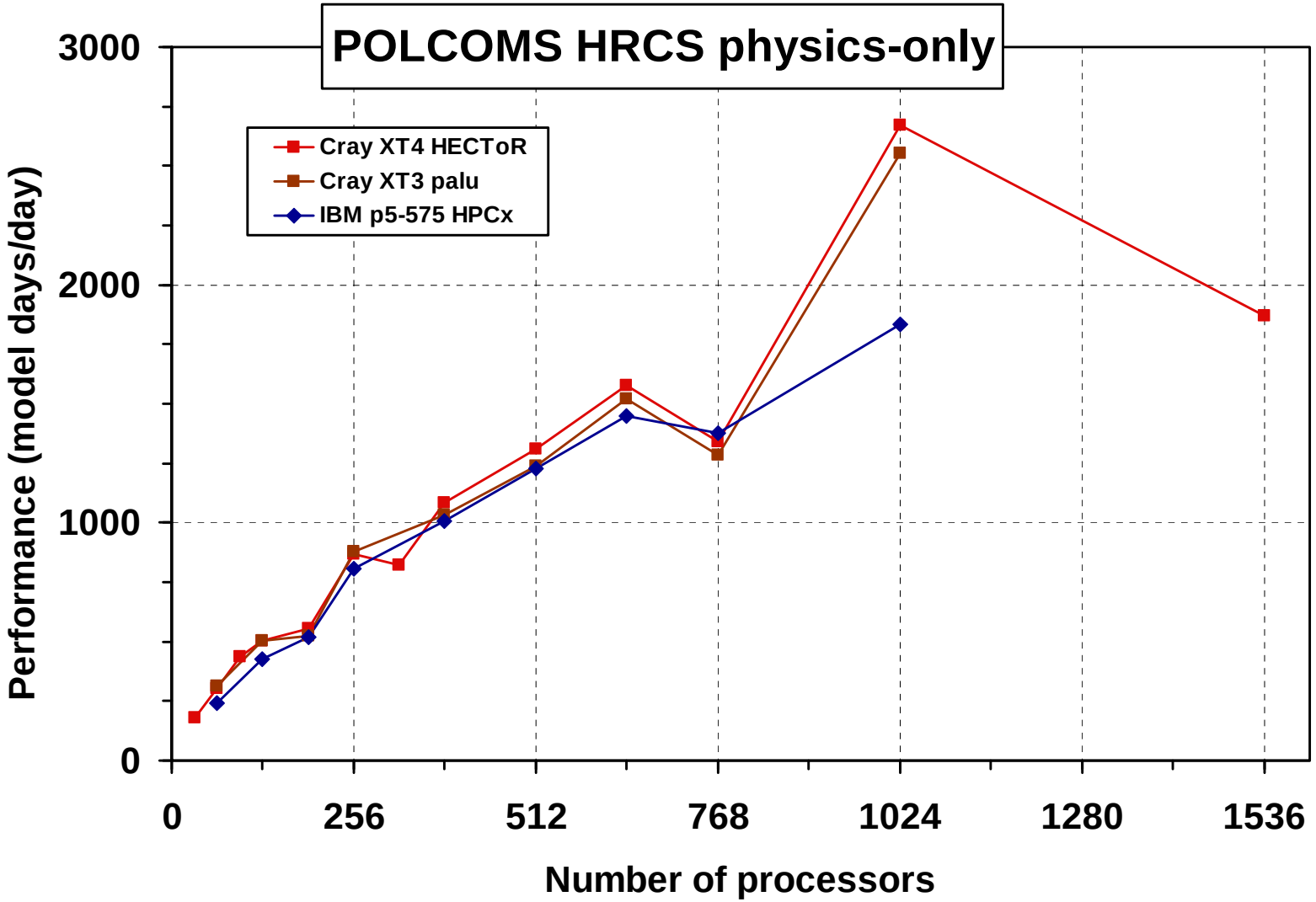
Volume transport Jul-Sep mean

Advective controls on primary production in the stratified western Irish Sea: An eddy-resolving model study, JT Holt, R Proctor, JC Blackford, JI Allen, M Ashworth, Journal of Geophysical Research, 109, 2004, p. C05024

Coupled Marine Ecosystem Model



POLCOMS HRCS performance



POLCOMS

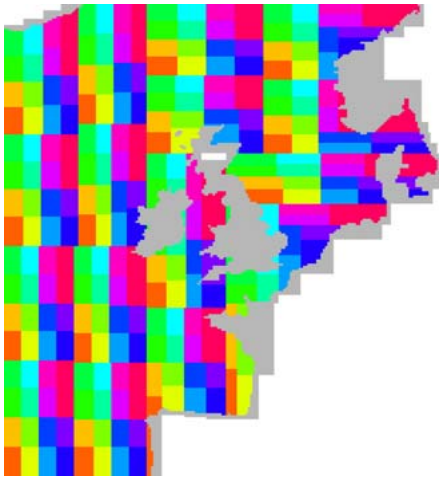
Structured-grid finite difference code from POL

Sophisticated advection scheme to represent, fronts, eddies etc in the shelf seas

Halo-based partitioning

Complicated by land/sea issue

Performance dependent on partitioning



Known issue with communications imbalance – new version under test

Largest domain size limited by I/O through master

Efficient parallel I/O is essential for this code

fd3d

fd3d earthquake simulation code

Seismic wave propagation

3D velocity-stress equations

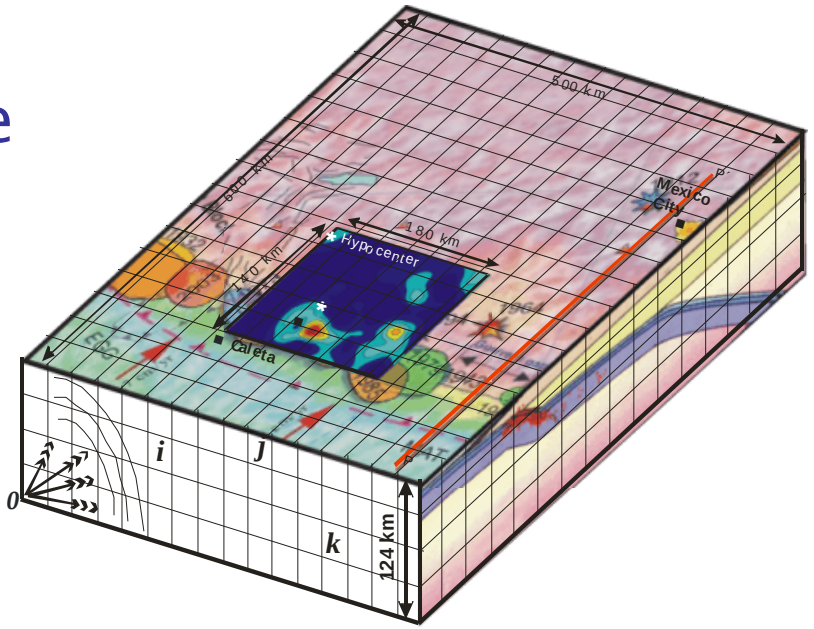
Structured grid

Explicit scheme

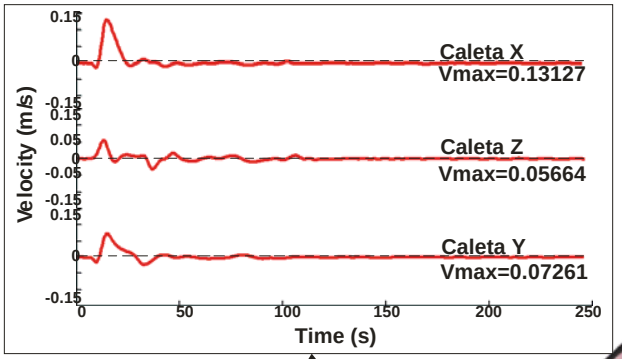
- 2nd order accurate in time
- 4th order accurate in space

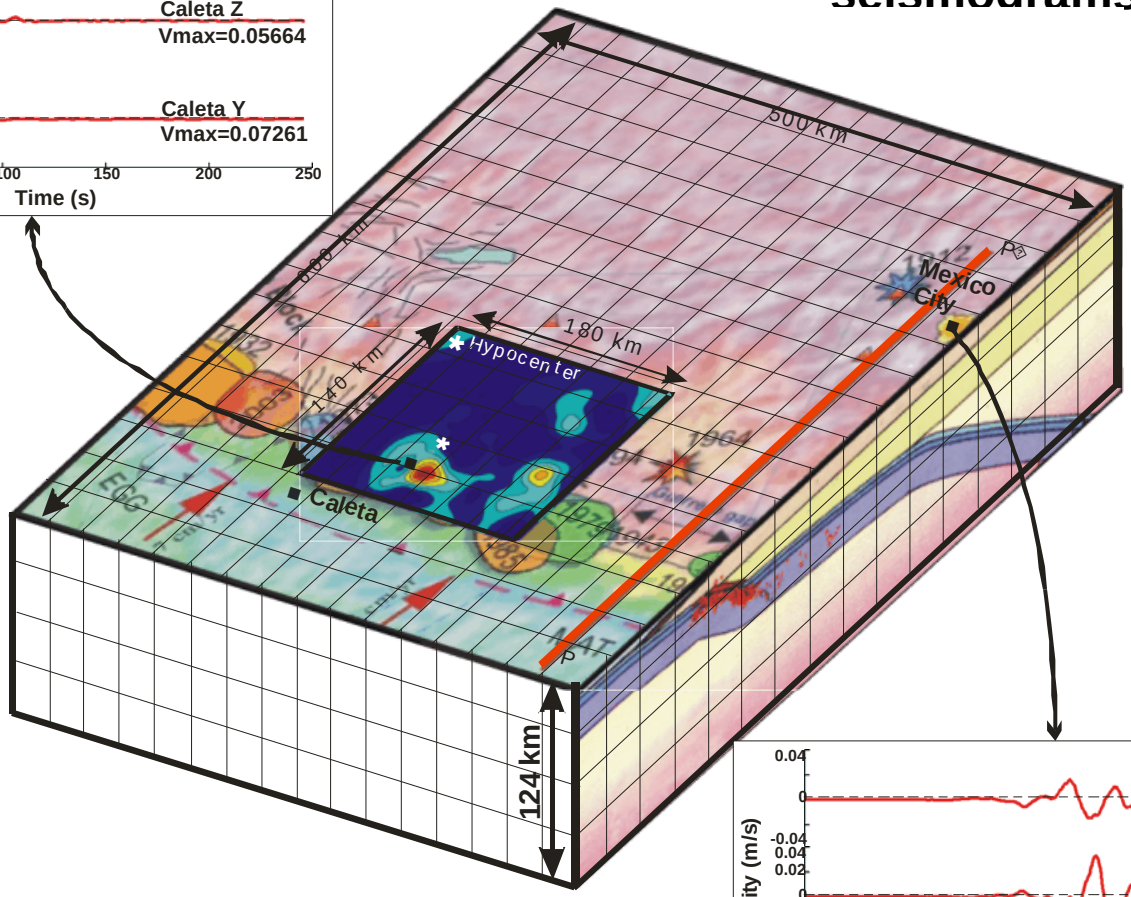
Regular grid partitioning

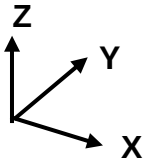
Halo exchange

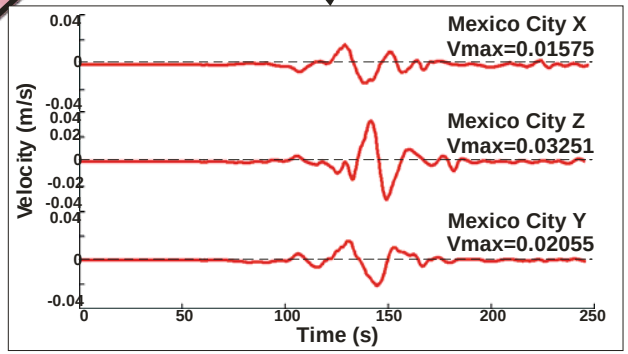


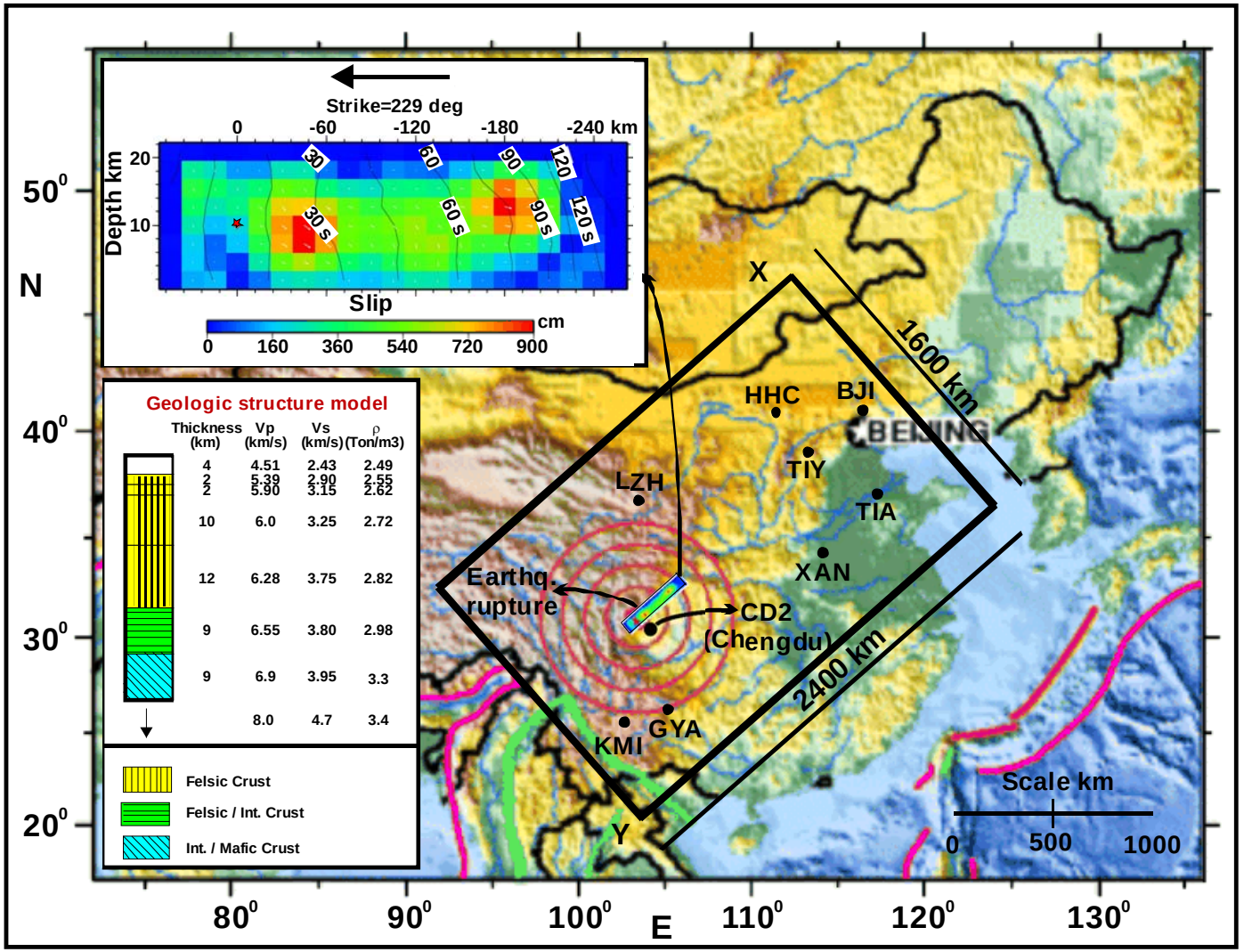
fd3d output: synthetic seismograms





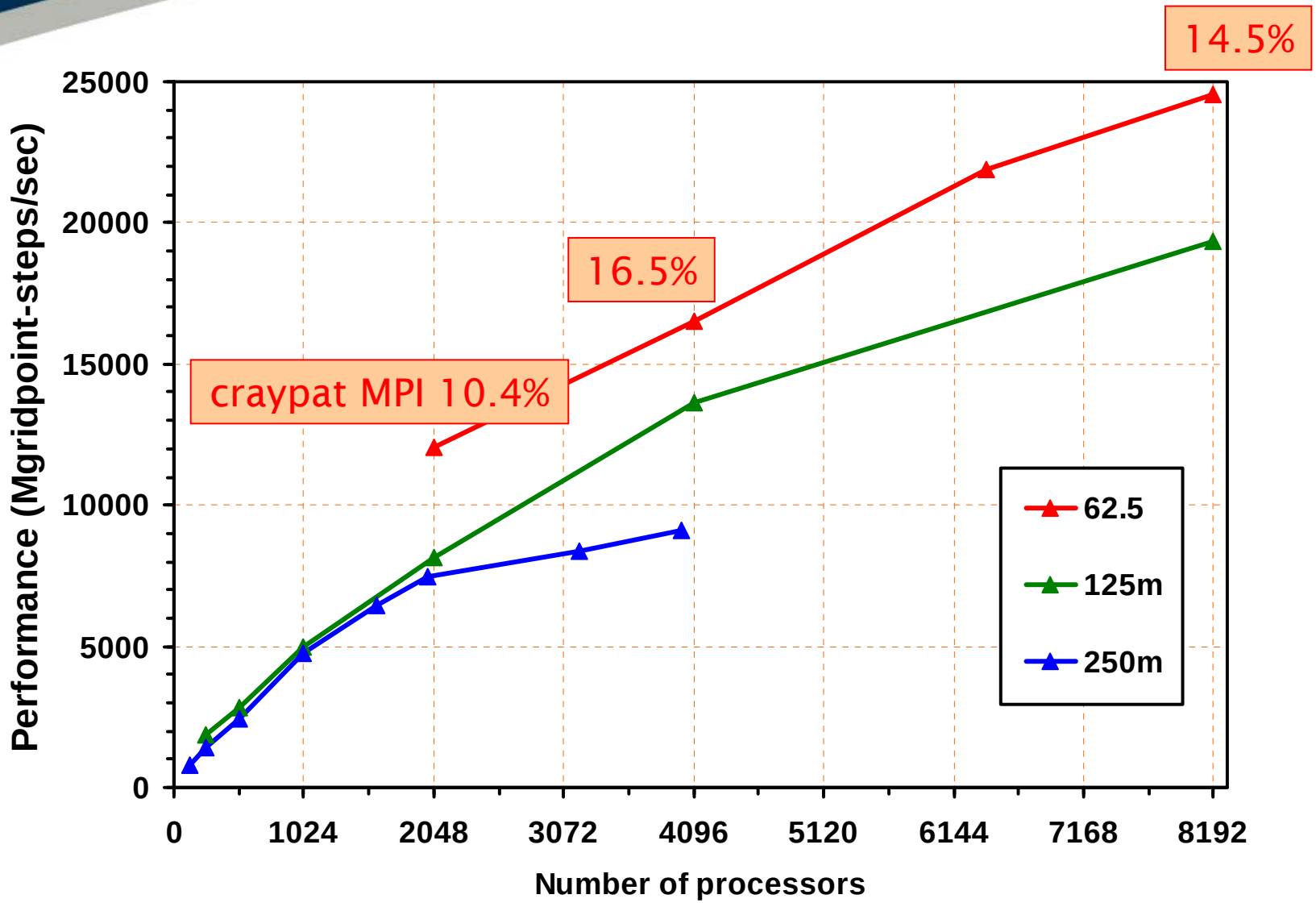






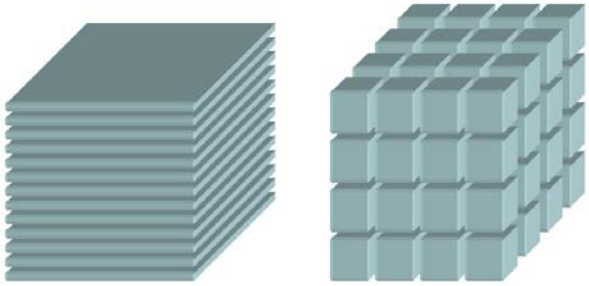
Locations of: a) the epicenter (red dot) of the 12 05 2008 Sichuan Ms 7.9; b) its rupture area and its kinematic slip; c) 9 seismographic stations sites (black dots) of the China Seismographic Network; d) the surficial projection of the 2400 x 1600 x 300 km3 volume used to discretize the region of interest; f) the geologic structure adopted for the volume

fd3d on Cray XT4 HECToR



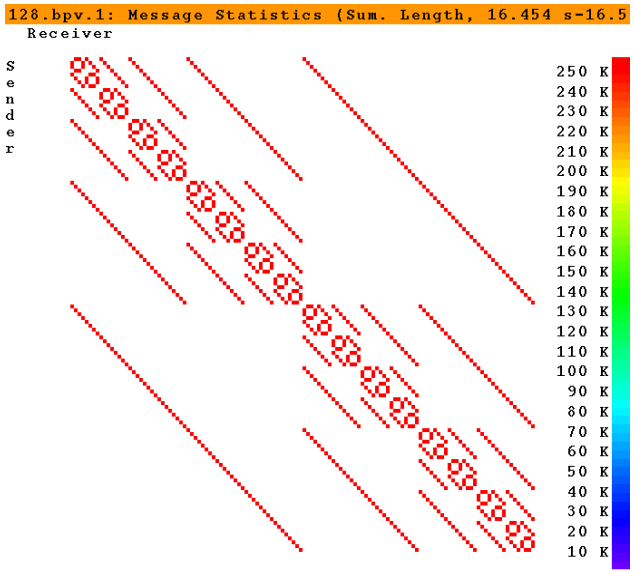
DL_POLY

Migration from Replicated to Distributed data DL_POLY3: Coulomb Energy Evaluation



Planes **Blocks**

Conventional routines (*e.g.* fftw) assume plane or column distributions. A global transpose of the data is required to complete the 3D FFT and additional costs are incurred re-organising the data from the natural block domain decomposition.

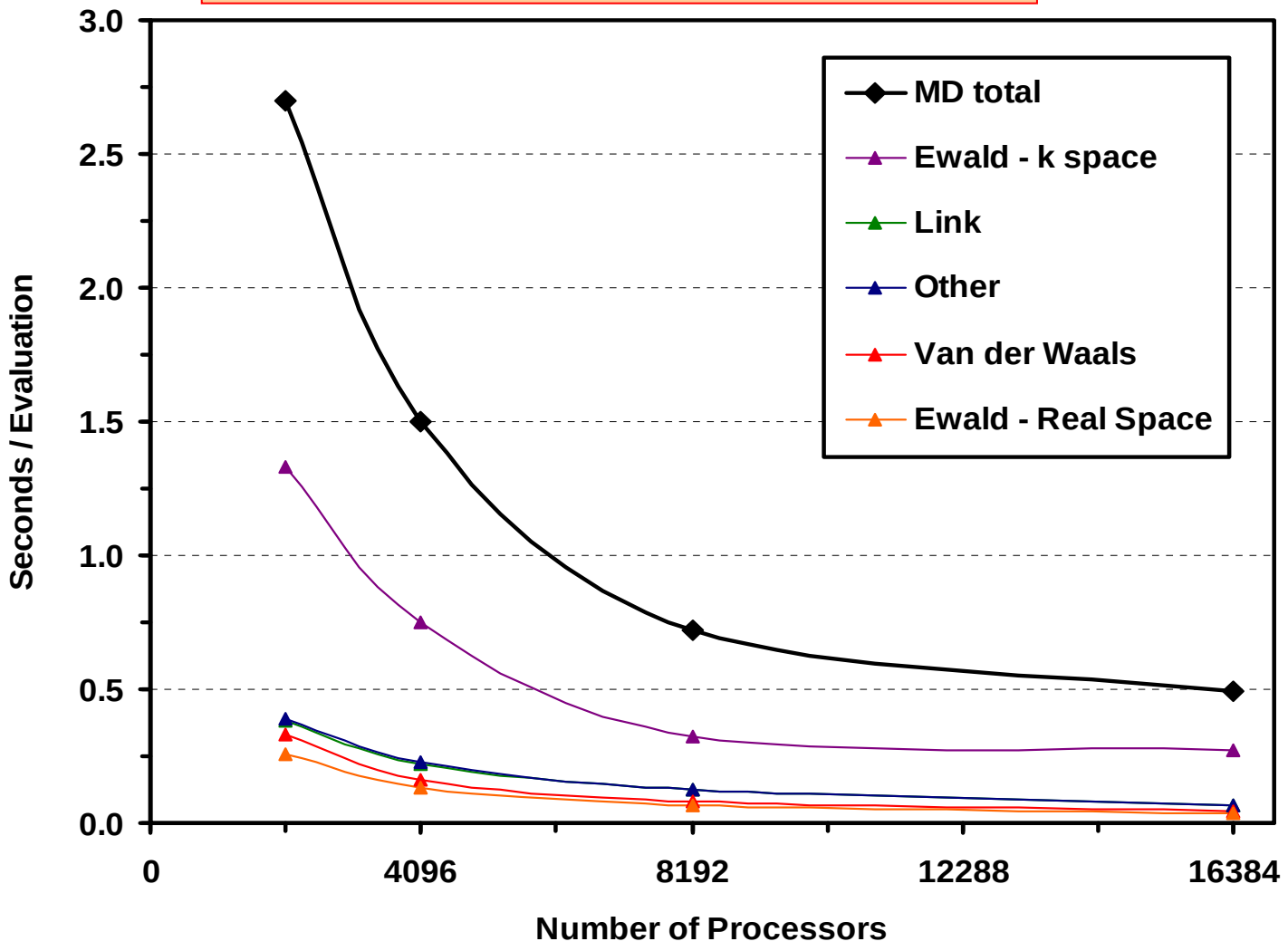


An alternative FFT algorithm has been designed to reduce communication costs.

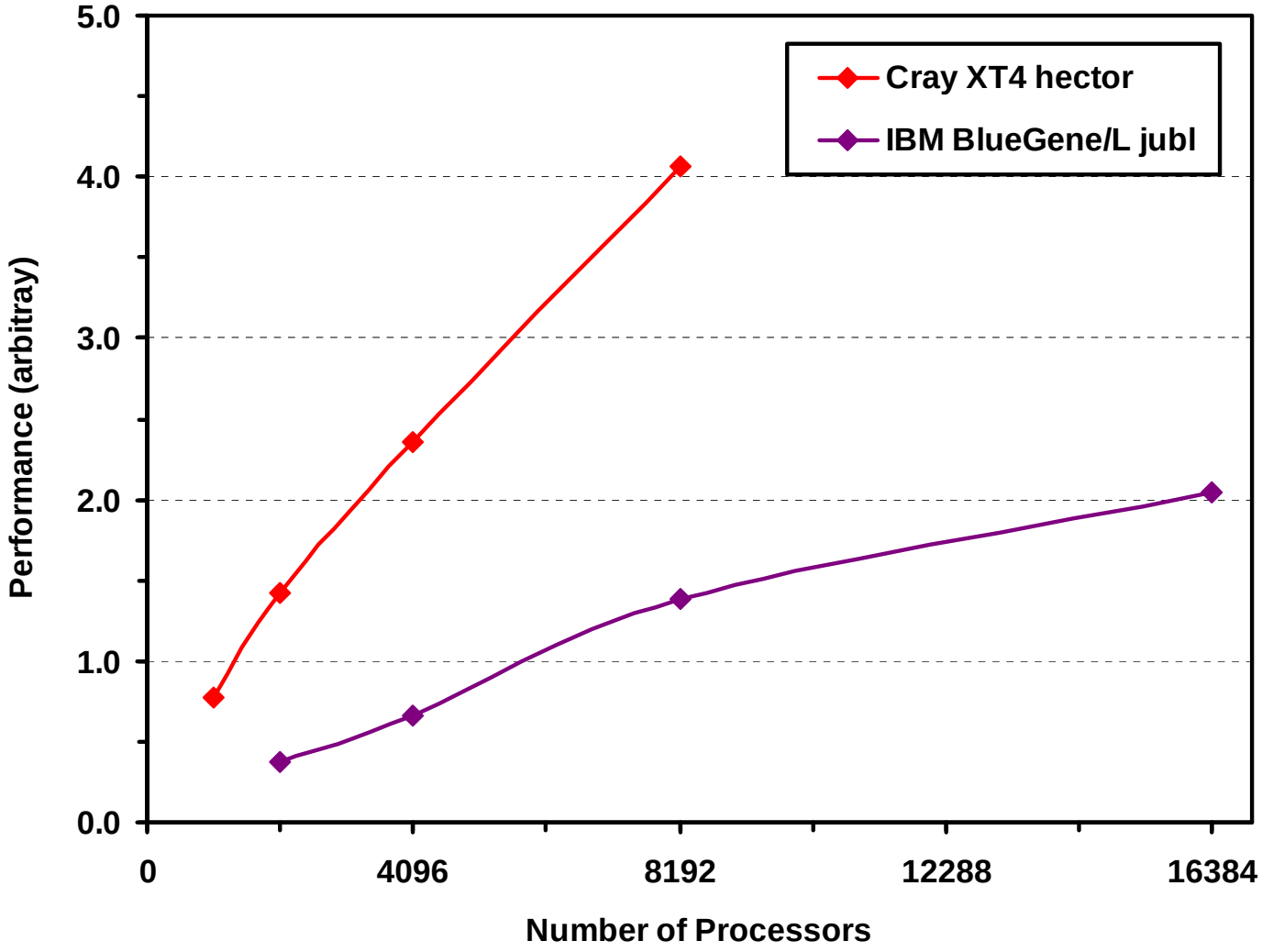
- the 3D FFT is done as a series of 1D FFTs, each involving communications only between blocks in a given column
- The data distribution matches that used for the rest of the DL_POLY energy routines
- More data is transferred, but in far fewer messages
- Rather than all-to-all, the communications are column-wise only (see sparse comms structure, left)

BlueGene/L times

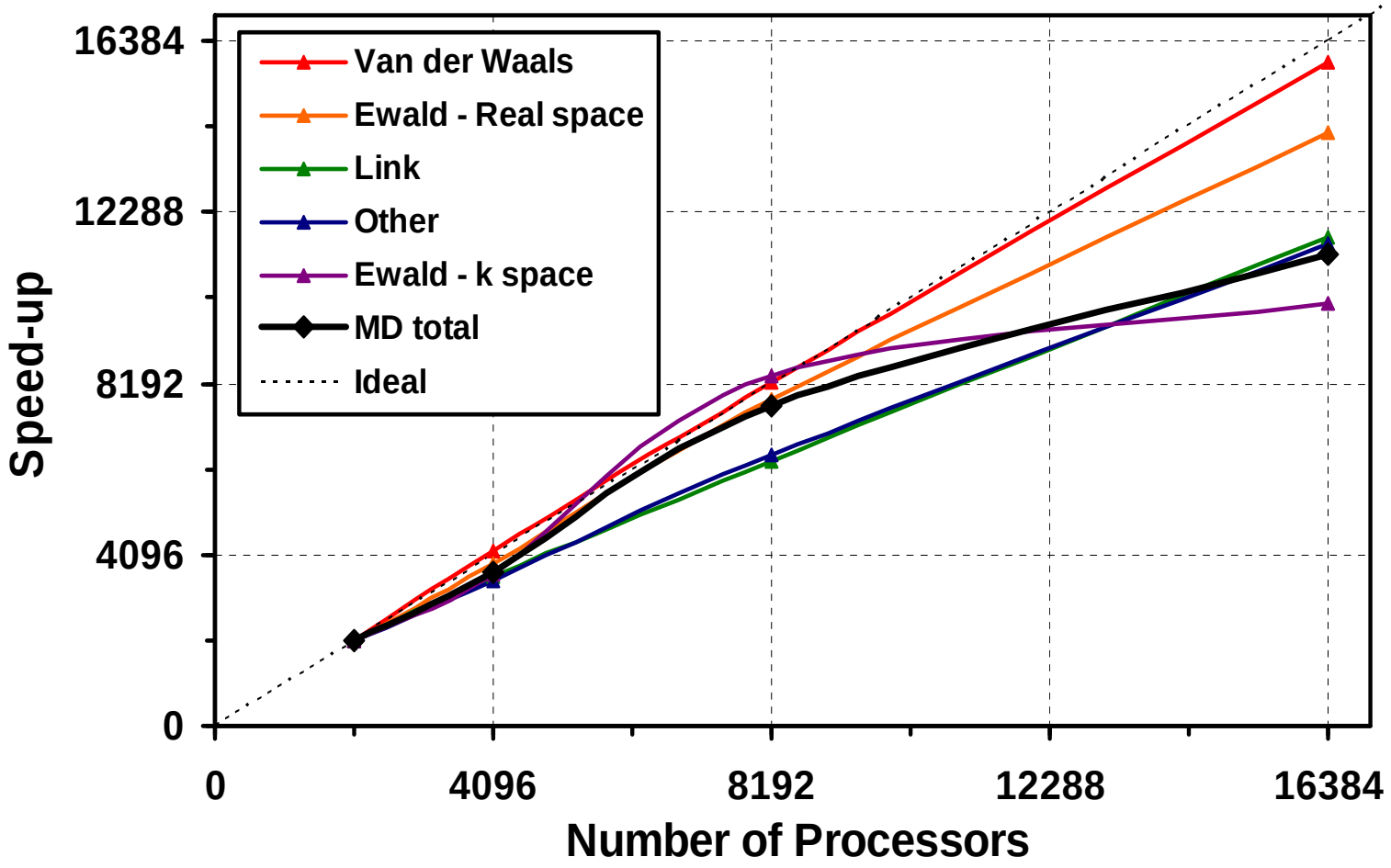
14.6 million particle $Gd_2Zr_2O_7$ system



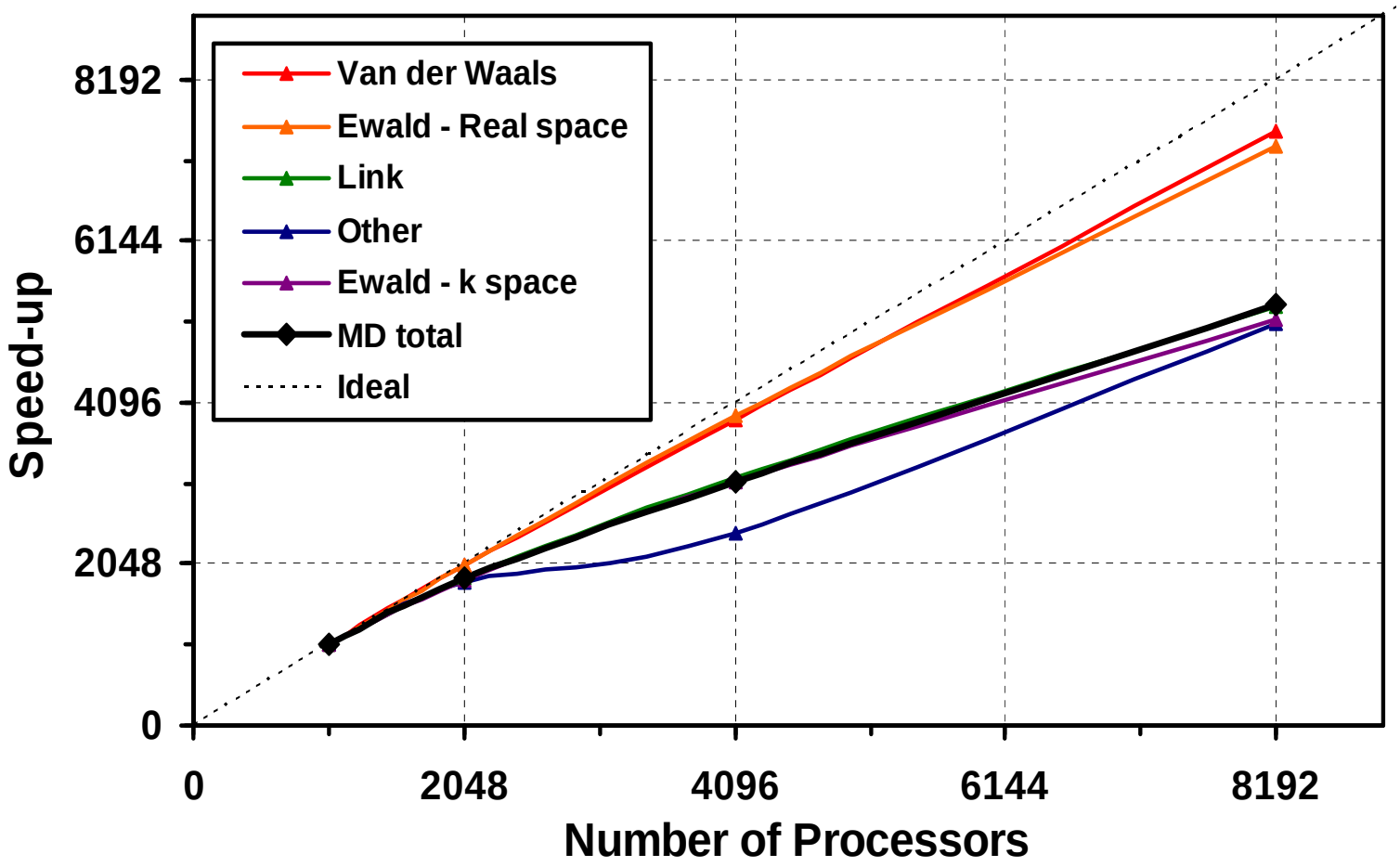
Cray XT4 & BGL performance



Scaling analysis BGL



Scaling analysis XT4



DL_POLY

Excellent scaling with >~1000 particles per processor

Scalability limited by long-range forces

Can use force-shifted Coulomb electrostatics

Fast multipole electrostatics for even larger systems

I/O is a major bottleneck

Efficient parallel I/O is essential for this code

Plus tools to handle & visualize large output datasets

"The Need for Parallel I/O in Classical Molecular Dynamics", Ilian Todorov, CUG 2008

CRYSTAL

Crystal

Electronic structure and related properties of periodic systems

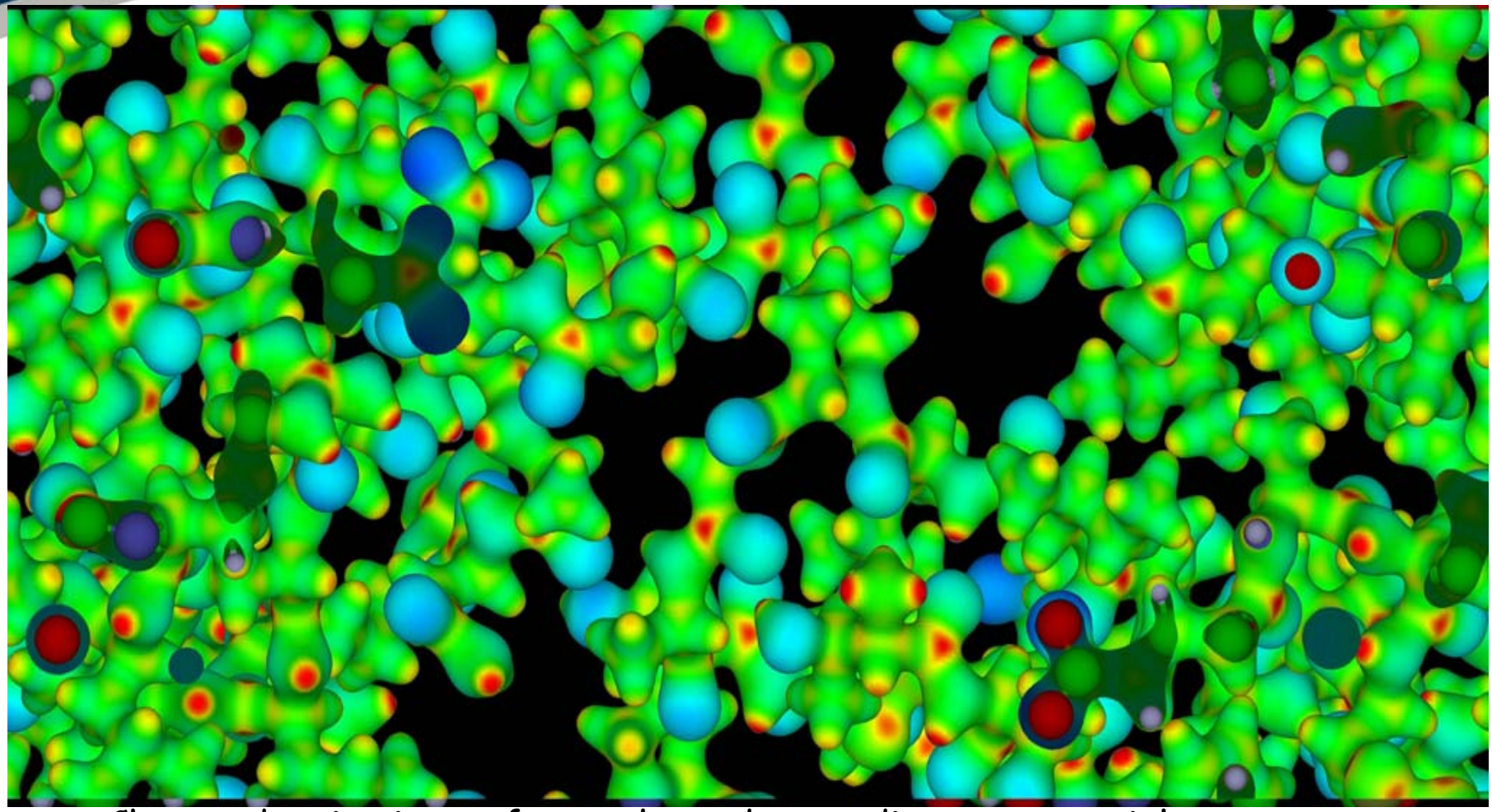
All electron, local Gaussian basis set, DFT and Hartree-Fock

Under continuous development since 1974

Distributed to over 500 sites world wide

Developed jointly by Daresbury and the University of Turin

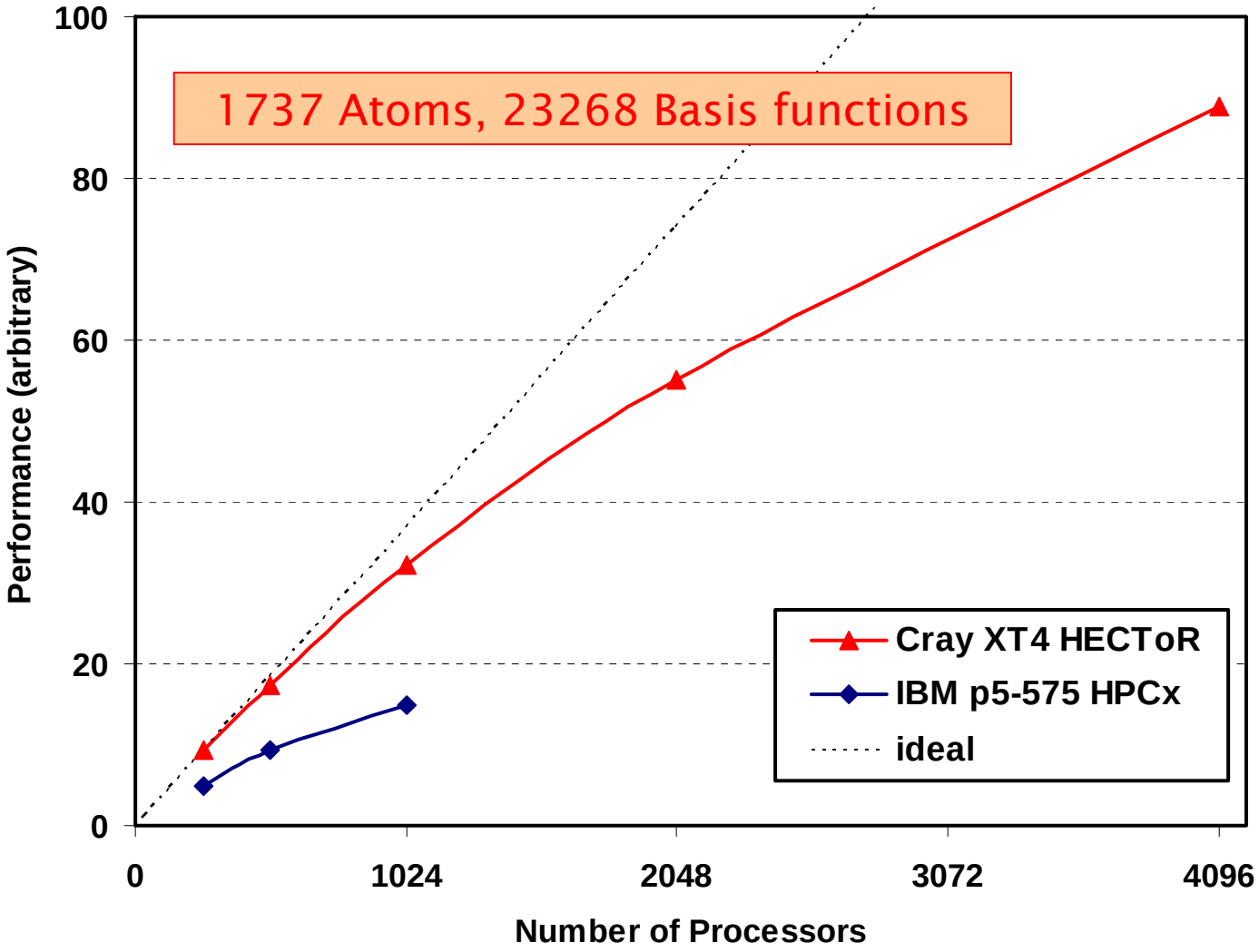
Crambin Results – Electrostatic Potential



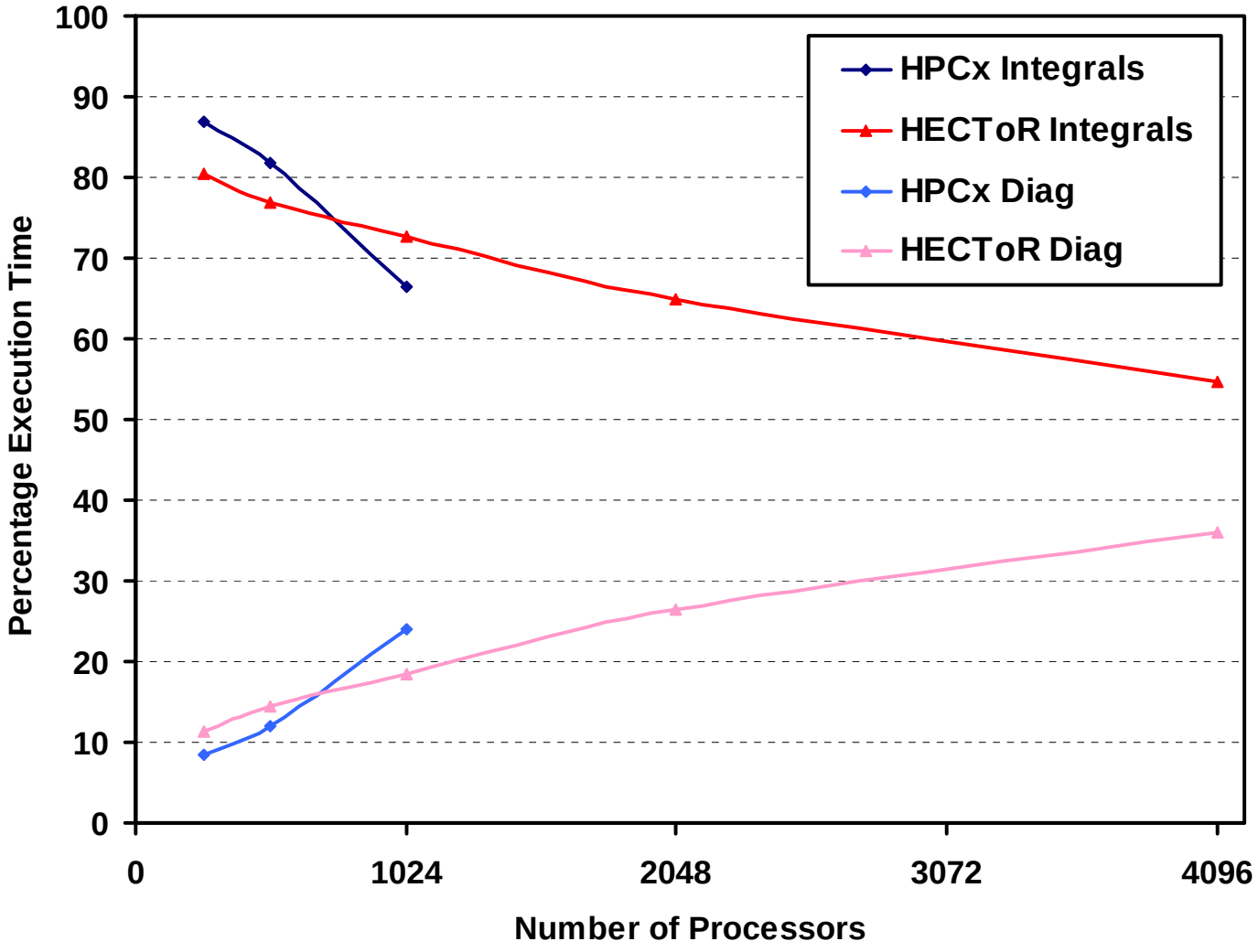
Charge density isosurface coloured according to potential

Useful to determine possible chemically active groups

SCF cycle scaling



SCF breakdown



CRYSTAL

SCF cycle dominated by two parts

Integral evaluation for the Kohn-Sham matrix

- Time scales linearly
- Difficult to distribute so poor scaling in memory

Dense linear algebra (diagonalization)

- Standard libraries (e.g. ScaLaPack D&C)
- Communications-heavy so poor scaling

Starts with integral evaluation dominating

For larger systems and larger number of processors the diagonalization dominates

Will need to look at diagonalization-less methods

"Investigating the Performance of Parallel Eigensolvers on High-end Systems", Andy Sunderland, CUG 2008

Applications conclusions

- We have looked at five codes up to 16384 procs
  - Mainly to 8192 on Cray XT4, also BlueGene/L and /P
- Most codes scale well to O(10,000) procs:
  - Need large problem sizes
  - Need efficient parallel I/O (in progress)
  - Need diagonalization-less methods for quantum chemistry
- Prospects look good to exploit higher numbers
  - Scaling isn't everything, need to look also at efficiencies – especially for quad-core, multi-core and beyond
  - Fortran+MPI works just fine (so far!)

ORNL Scaling Workshop, July 2007

Several speakers concluded that:

- The MPI send-receive model may hit limitations at very high processor numbers
- Hybrid programming e.g. MPI/OpenMP may help, only one MPI task per multi-core node, esp. for collectives , also saves memory
- Single-sided messaging may be needed and the PGAS languages (e.g. Co-Array Fortran, UPC) may be a good high-level interface

"Migrating a Scientific Application from MPI to Co-Arrays", Ashby & Reid, CUG 2008

Conclusions

Petascale computing will soon be available in the UK

Largely achieved by massive increases in the number of processors

Systems will be based on multi-core nodes

We need to look now at scalability and other issues on O(10,000-100,000) processors

We may need to look at alternatives/additions to the existing programming model (serial language + MPI)

New Opportunities

Computational Science is evolving very rapidly

Hardware is moving rapidly towards the Petascale

- Extreme scalability is required to 100k processors at beyond
- Clusters of multi-core SMP nodes

Scientific demands are also changing

- Multi-scale
- Multi-disciplinary

We need to deliver on the evolving aspirations of the community across a broad spectrum of scientific and engineering disciplines

The Hartree Centre

Strategic science themes incl. energy, biomedicine, environment, functional materials

10,000 sq ft machine room

10 MW power

£10M systems / two year cycle

The Hartree Centre will be a new kind of Computational Sciences institute for the UK that will:

- stimulate a step change in modeling capabilities for strategic science themes – Grand challenge projects
- multi-disciplinary, multi-scale, effective and efficient simulation
- **have at its heart the collaborative development, support and exploitation of scientific applications software – this is the key to real scientific and economic impact and will be Hartree's essential driver.**

If you have been …

… thank you for listening

Mike Ashworth

http://www.cse.scitech.ac.uk/