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Parallel in time and object storage with CORTX

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CORTX Architect series Talk 6 May 2021

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- Introduction – Fusion and UKAEA – who we are?
- Parallel in Time schemes
- Exascale, Tiered storage and CORTX

Take home message:

Data is a big challenge in Plasma fusion and tiered object storage such as CORTX can provide a solution.

Energy requirement

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1) **The world uses a lot of energy** – average power consumption is 2,350 Watts per person

(world energy [electricity] market ~ $4.5 trillion [$1.5 trillion] pa)

2) **World energy use is expected to grow 50% by 2030**

- growth necessary in developing countries to lift billions of people out of poverty

3) **80% is generated by burning fossil fuels**

→ *climate change & debilitating pollution*

- *which won't last for ever*

Need major new sources of clean energy - this will require fiscal measures, regulation and new technology

Thanks: Christopher Llewellyn Smith

Deaths per year (1000s) caused by indoor air pollution (biomass 85% + coal 15%); total is 1.5 million – over half children under five

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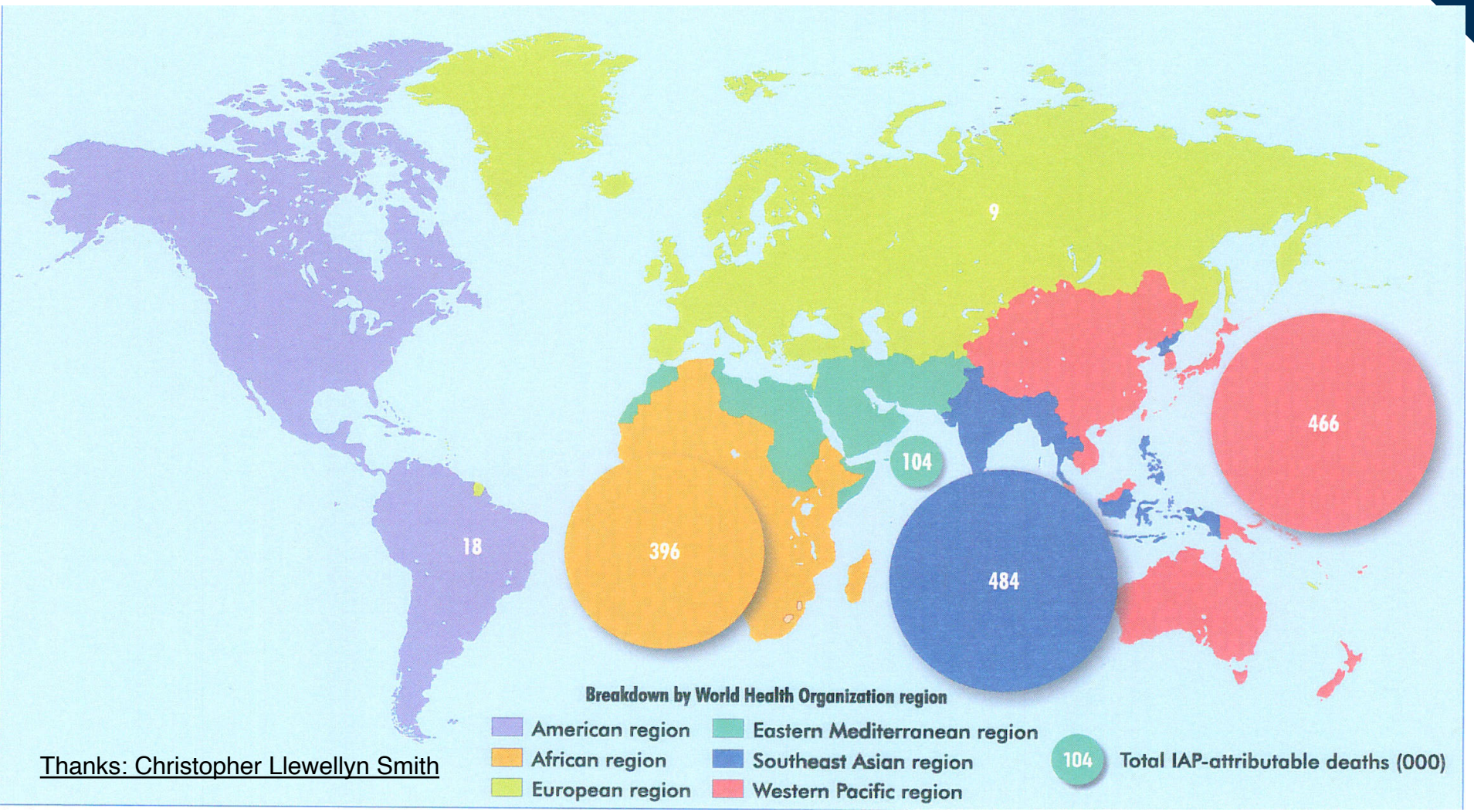

Thanks: Christopher Llewellyn Smith

Energy sources

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World's primary energy supply (approximate):

- 80 % - burning fossil fuels (44% oil, 31% coal, 26% natural gas)
- 10% - burning combustible renewables and waste
- 5% - nuclear
- 5% - hydro
- 0.5% - geothermal, solar, wind, . . .

Fossil fuels:

*** generating debilitating pollution**

(300,000 coal pollution deaths pa in China (World Bank estimated in 1995)

*** and driving potentially catastrophic climate change**

*** and will run out sooner or later**

Thanks: Christopher Llewellyn Smith

Fusion: source of energy

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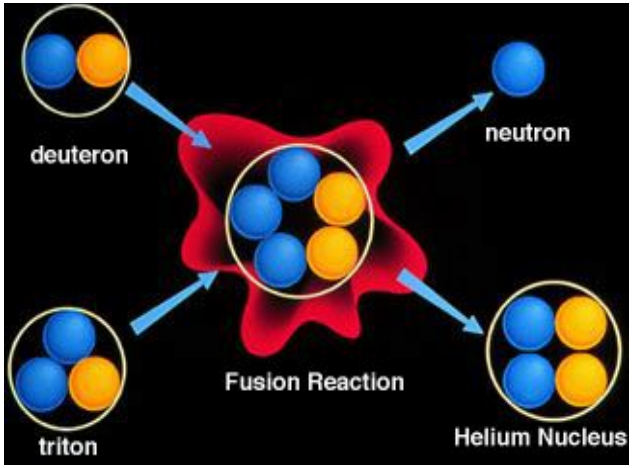
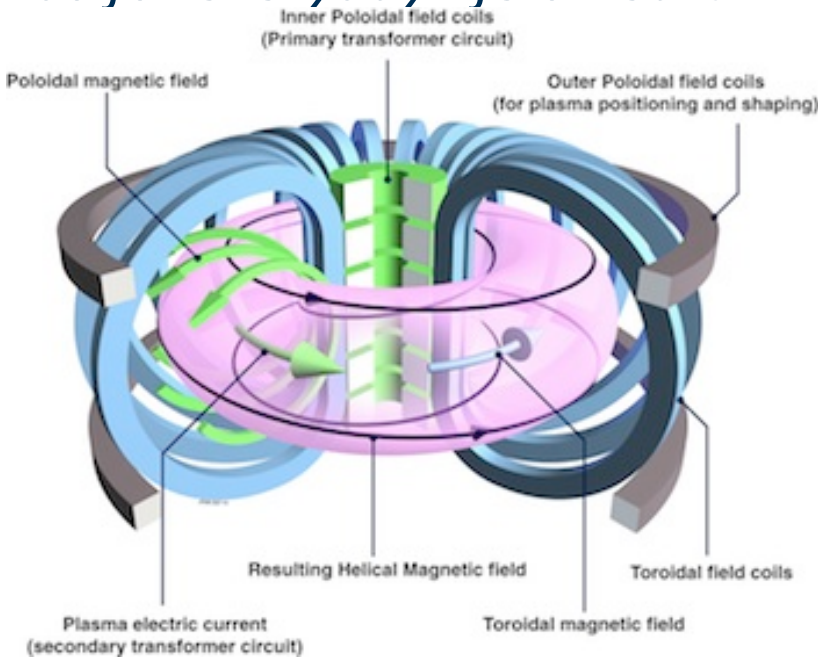


Fusion: power generation in the stars.

Possible in laboratories? **Yes**

Possible on grids for everyday life on earth?



Fusion:

a) Reaction requires temperatures ~10^8 K,

b) Virtually unlimited – Deuterium abundant in sea water. Tritium produced from lithium which is also abundant in nature.

c) Held together by magnetism.

d) Relatively environmentally friendly : Waste with radioactive toxicity < 100 years

Fusion

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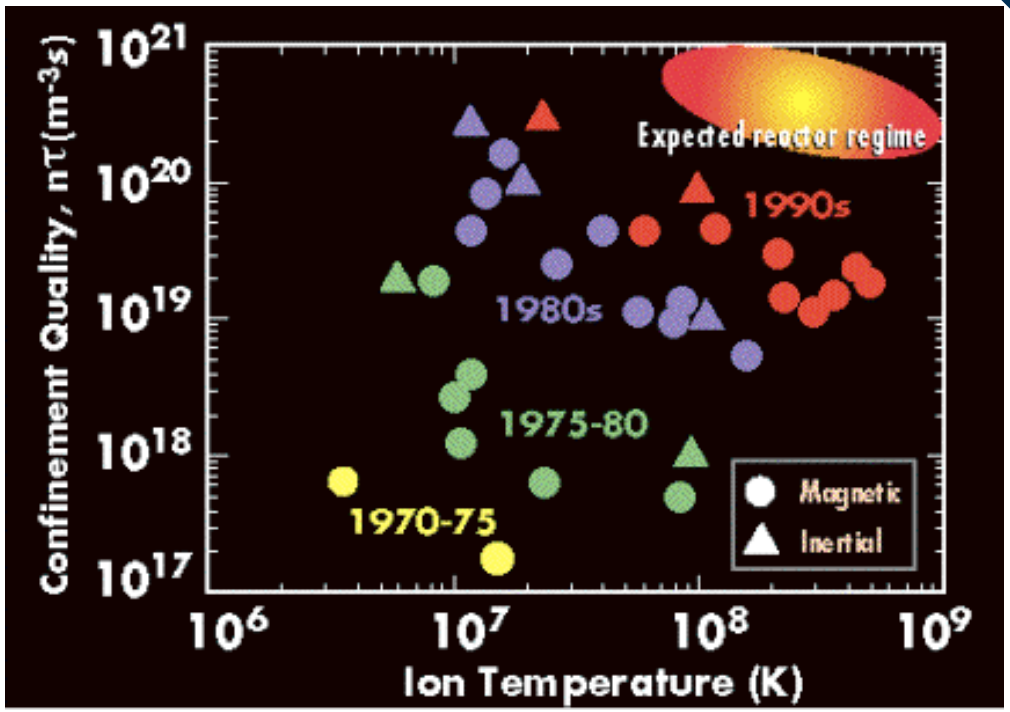
- Typically, plasma at 100 million K
- Maximize nTτ (Lawson criterion)

Density

Confinement Time

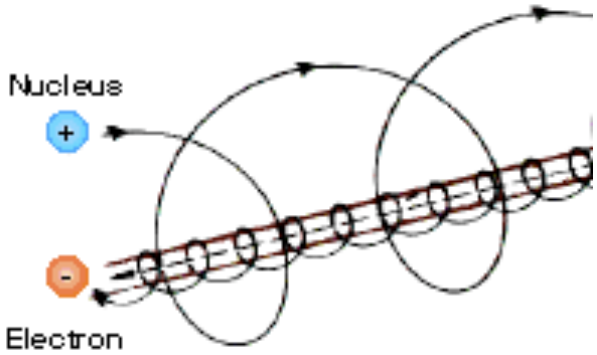
Temperature



Confinement :

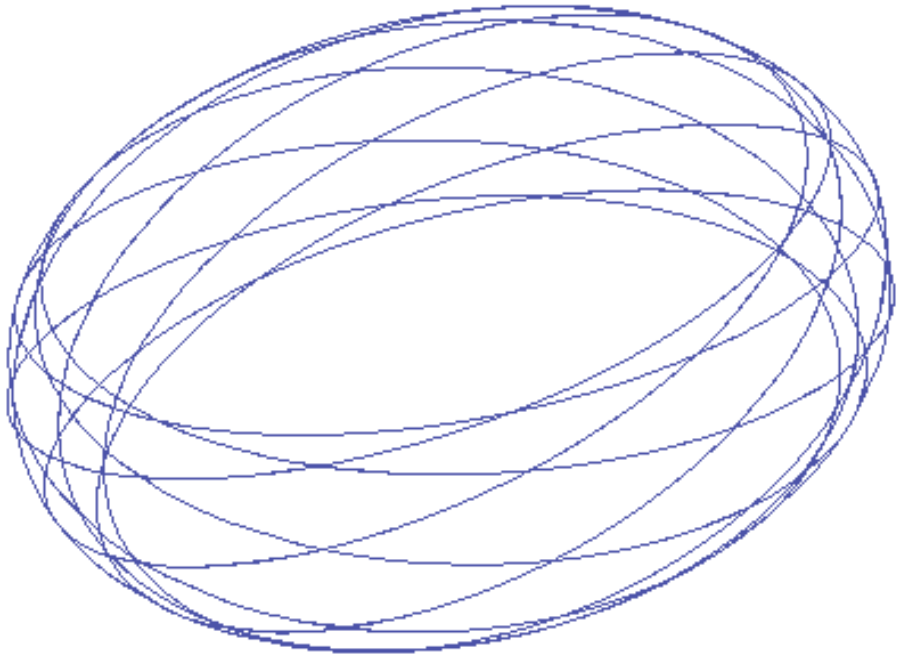
- Gravitational confinement - as in stars
- Magnetic Confinement of plasma
- Inertial confinement

Magnetic Confinement



http://ffden-2.phys.uaf.edu/

Most devices are toroidal shaped.



Used in ITER, DIII-D, JET, JT-60 ...

JET – biggest TOKAMAK in the world

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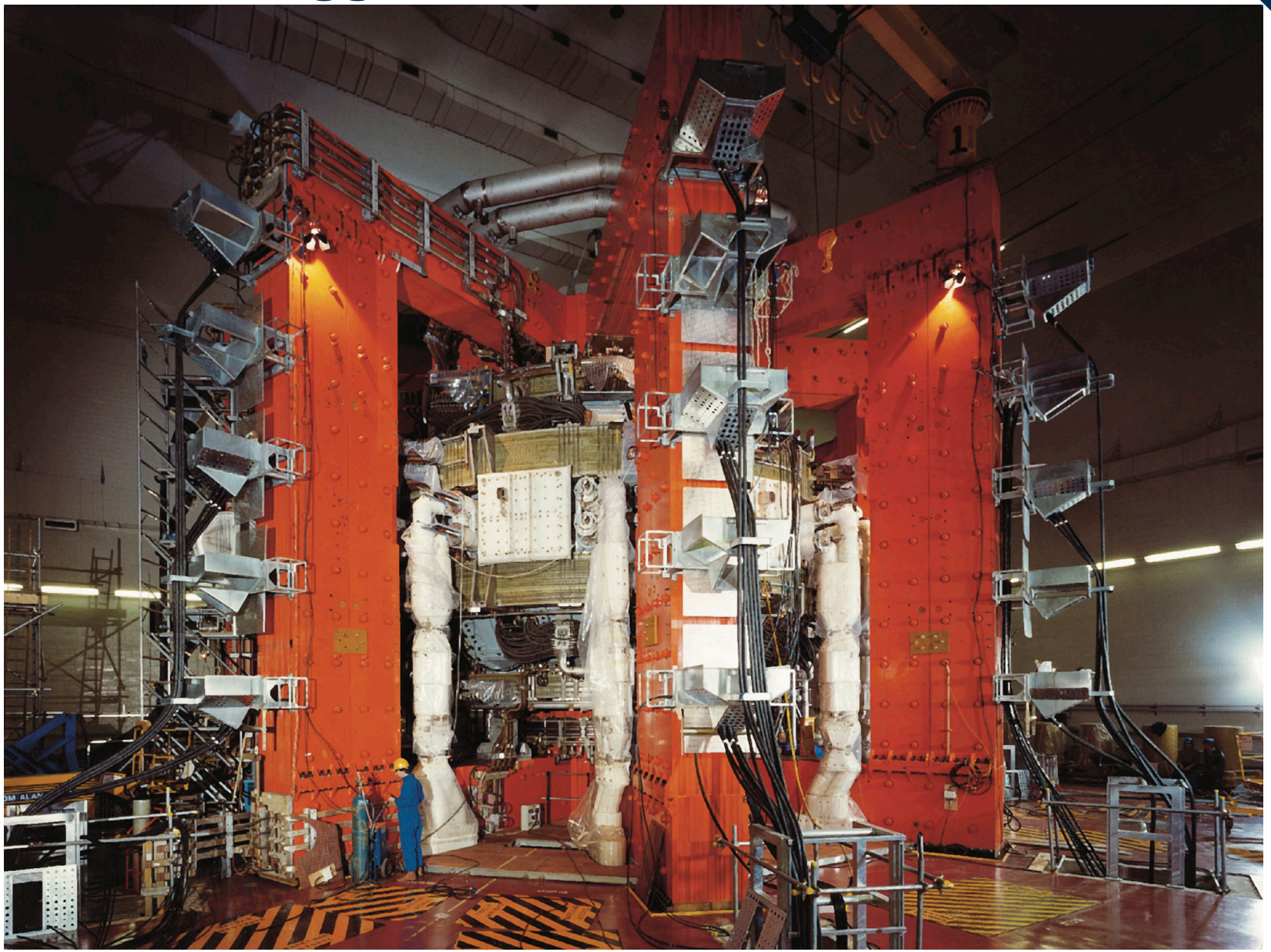
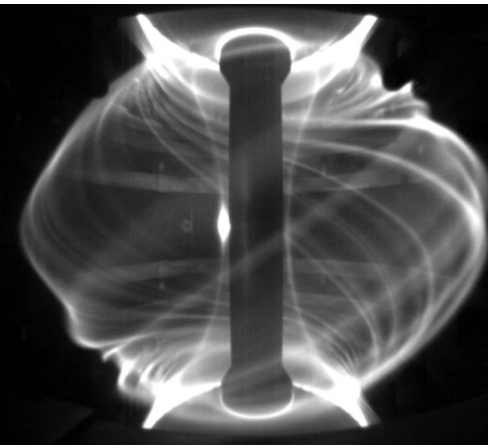
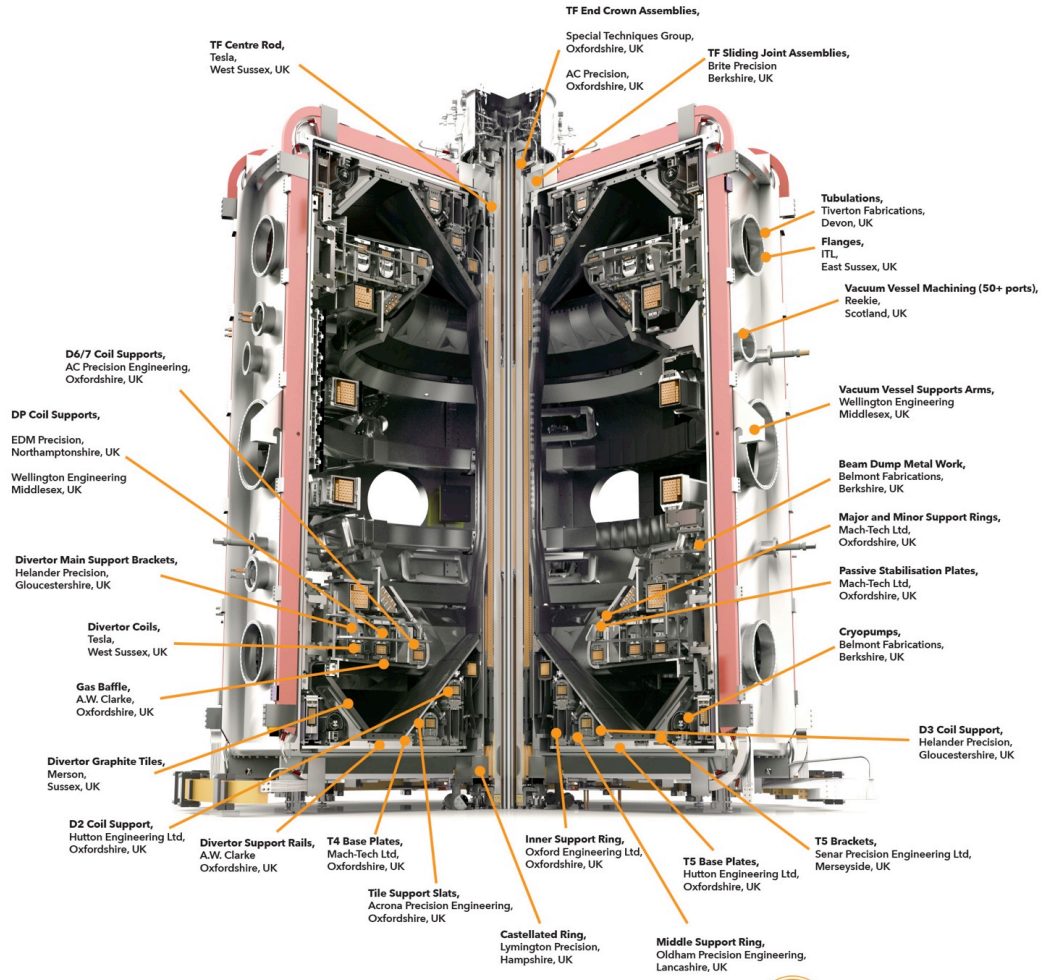




MAST Upgrade – UK industry benefits



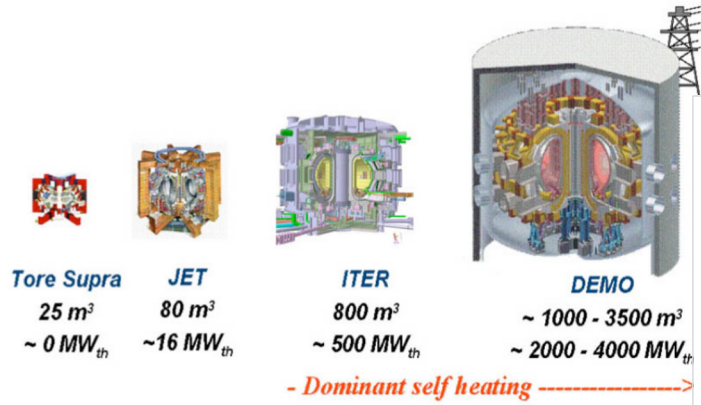
Stainless Steel 316L Outokumpo, South Yorkshire, UK
Plate Flatness Grinding Hoverdale UK Ltd, Leicestershire, UK
Material Heat Treatment Bodycote, Cambridgeshire & Special Techniques, Oxfordshire, UK
In-Vessel Fasteners T.R. Fastenings, East Sussex, UK

CP515.65

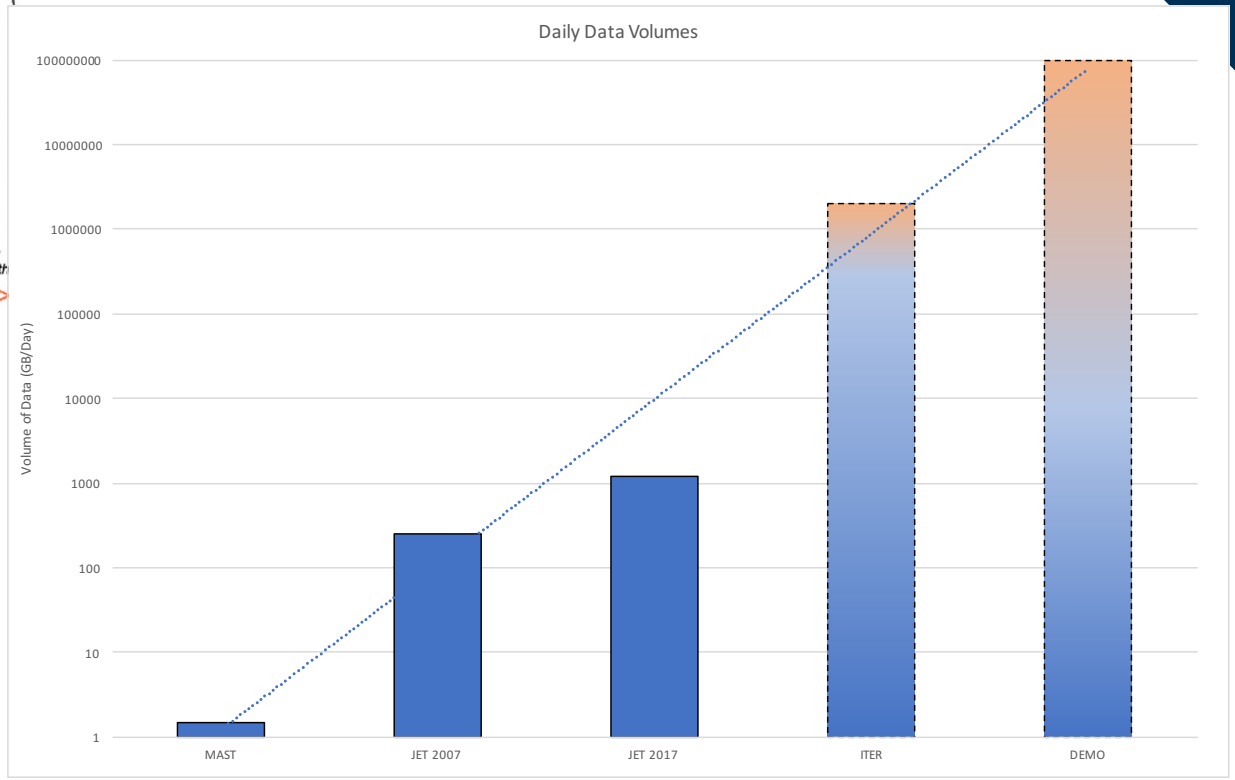
MAST UPGRADE

CCFE CULHAM CENTRE FOR FUSION ENERGY

Data Challenge

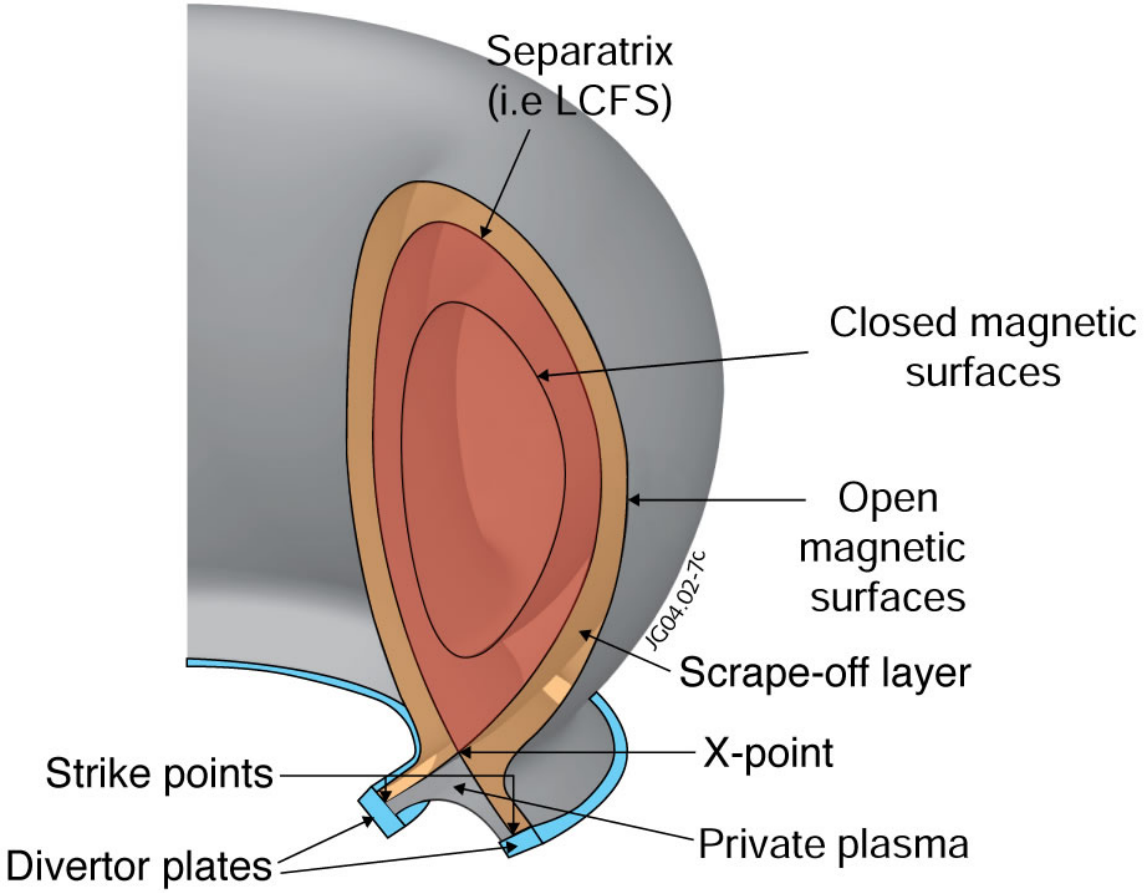


- ITER is Fusion's First Global Experiment
  - EU, Japan, USA, India, Russia, China, Korea
  - Will produce more data in 1 day than the total generated by JET in 35 years



Thanks: Shaun de Witt

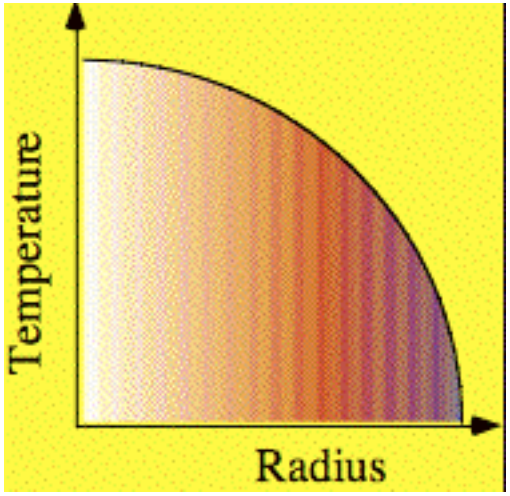
Fusion simulations: multiple



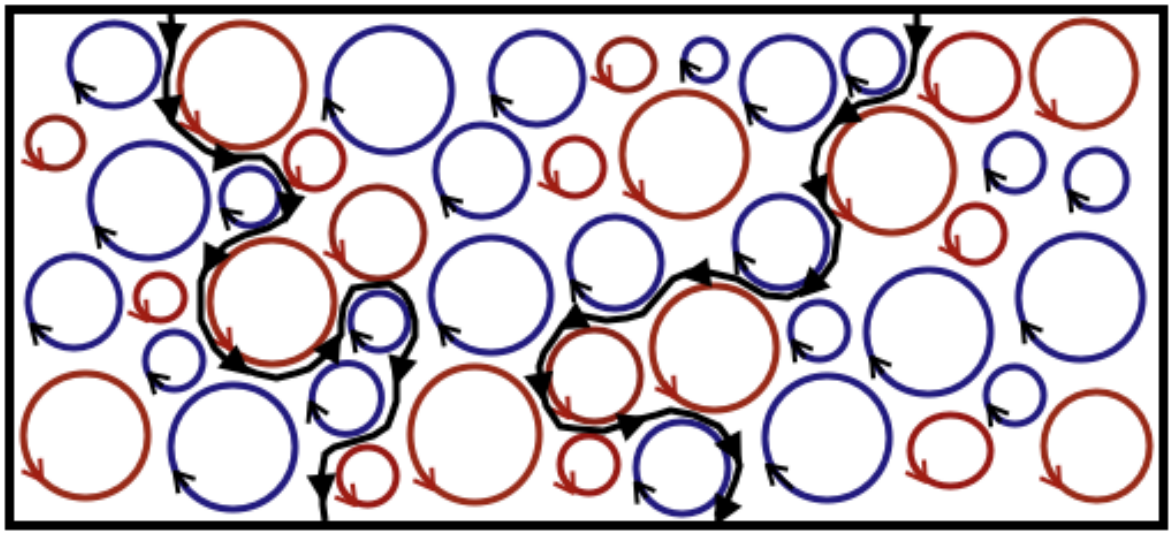
Some examples:

a) Turbulence
b) Impurity transport
c) Instabilities
d) Plasma exhaust
e) Energetic particle transport

Example problem



Hot core, cool walls - but nature abhors gradients

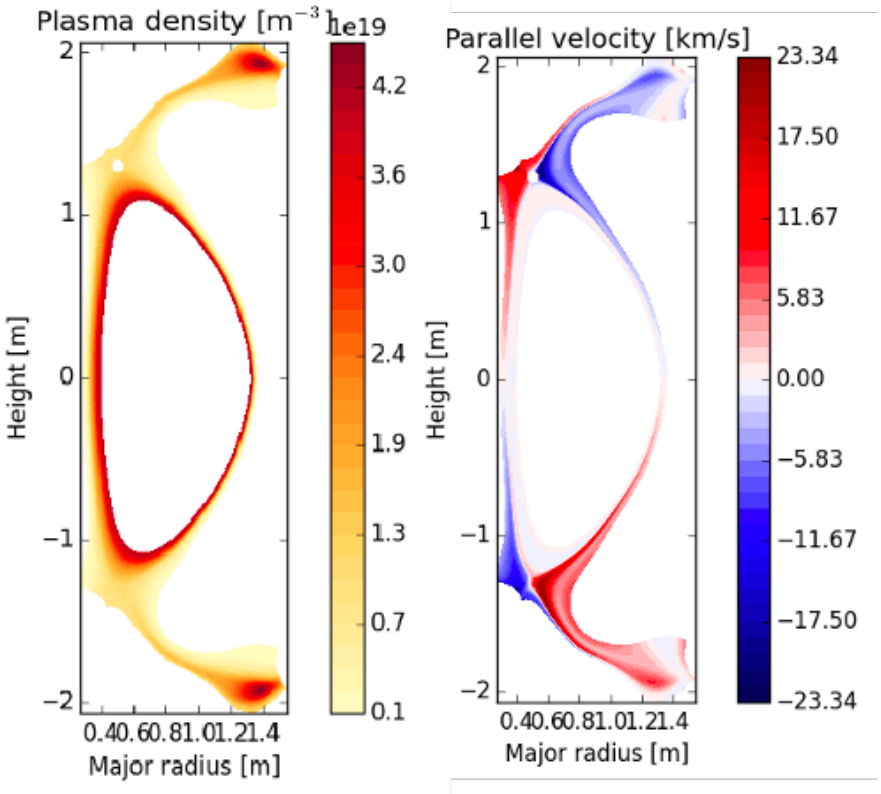


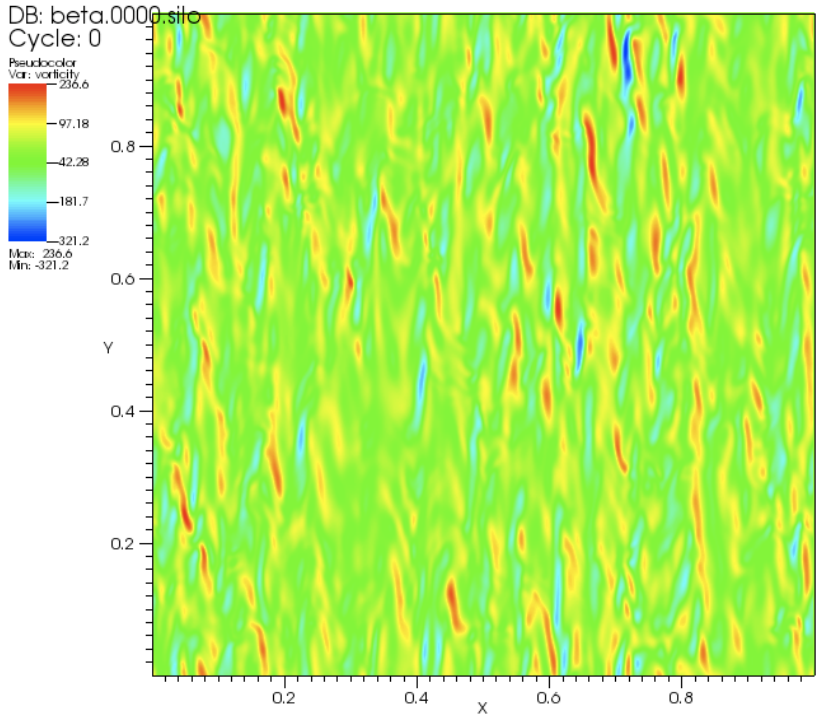
Turbulence relaxes the gradient.

Turbulent transport reduces confinement time.

Challenge : TO CONTROL THE TURBULENT TRANSPORT

Turbulent transport in tokamak plasmas is computationally intensive.





Parallelization options: time

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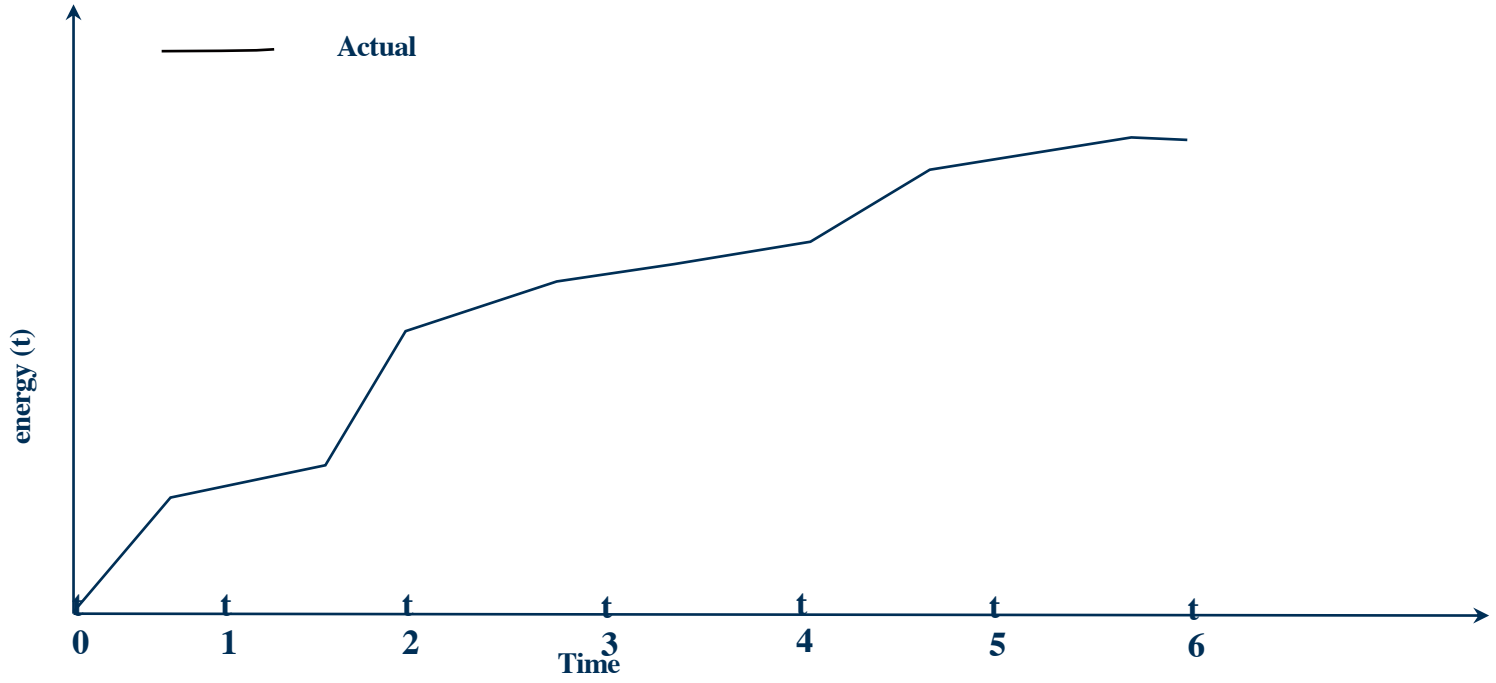
Problem with simulations – extremely long computational time.

But first let's focus on the solution to achieve the parallel simulation.

F is a propagator evolving the function (energy(t)) from initial time, t_0, to a later time ...



Parallelize time – solve multiple time slices simultaneously

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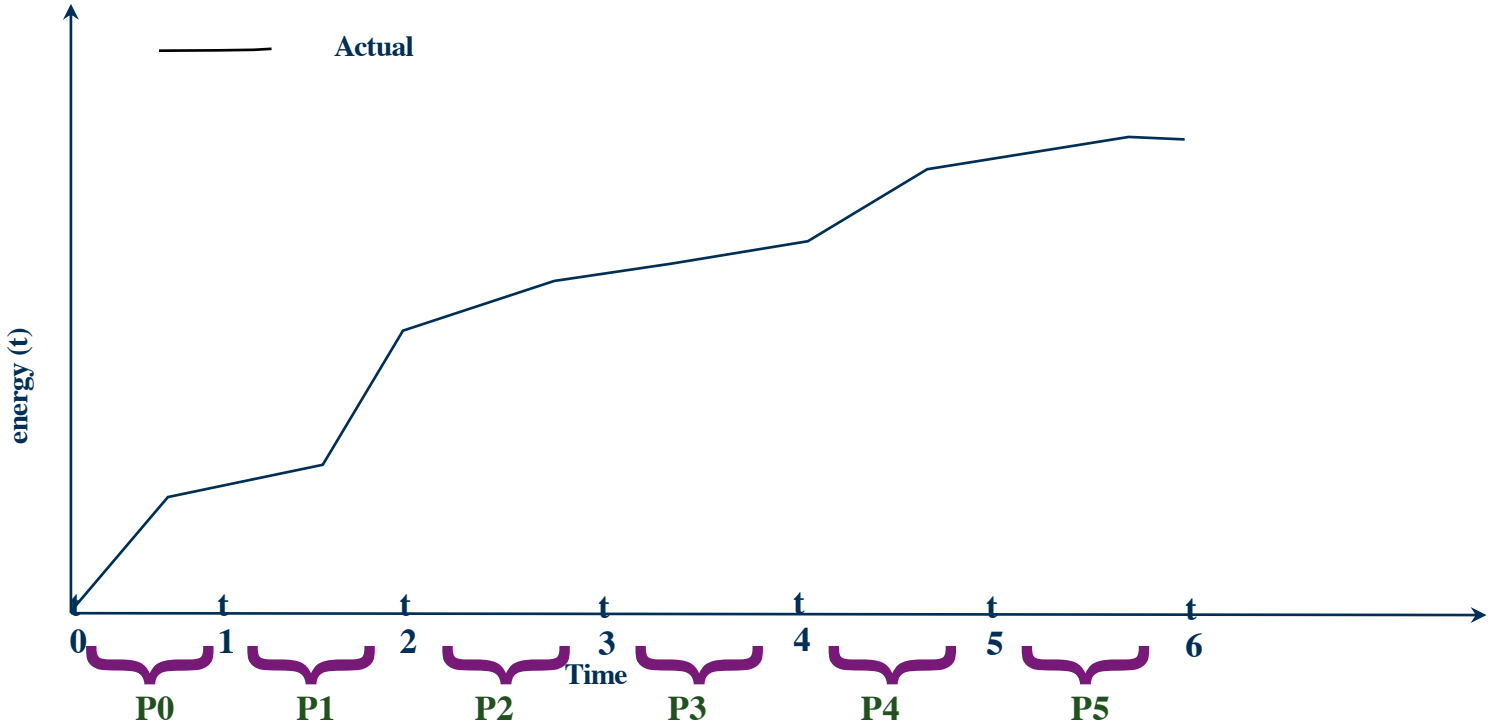
F is a propagator evolving the function (energy(t)) from initial time, t_0, to a later time ...



Various algorithms exist for this purpose

- **RIDC**
- **Parareal**
- **PFASST**

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- **RIDC**
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Use a predictor-corrector technique

Various algorithms exist for this purpose

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- RIDC
- Parareal
- PFASST

Use a predictor-corrector technique

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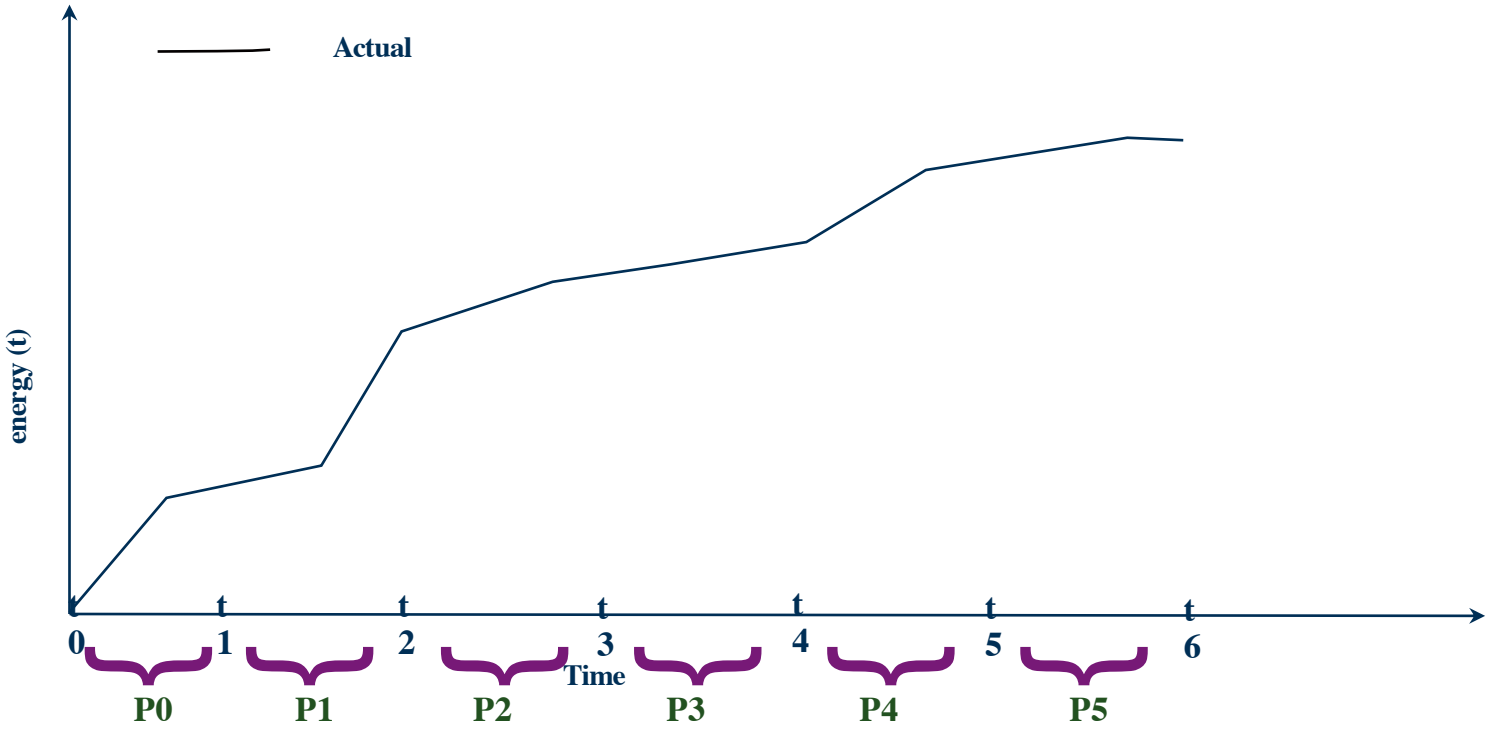
Overview of the Parareal Algorithm ...

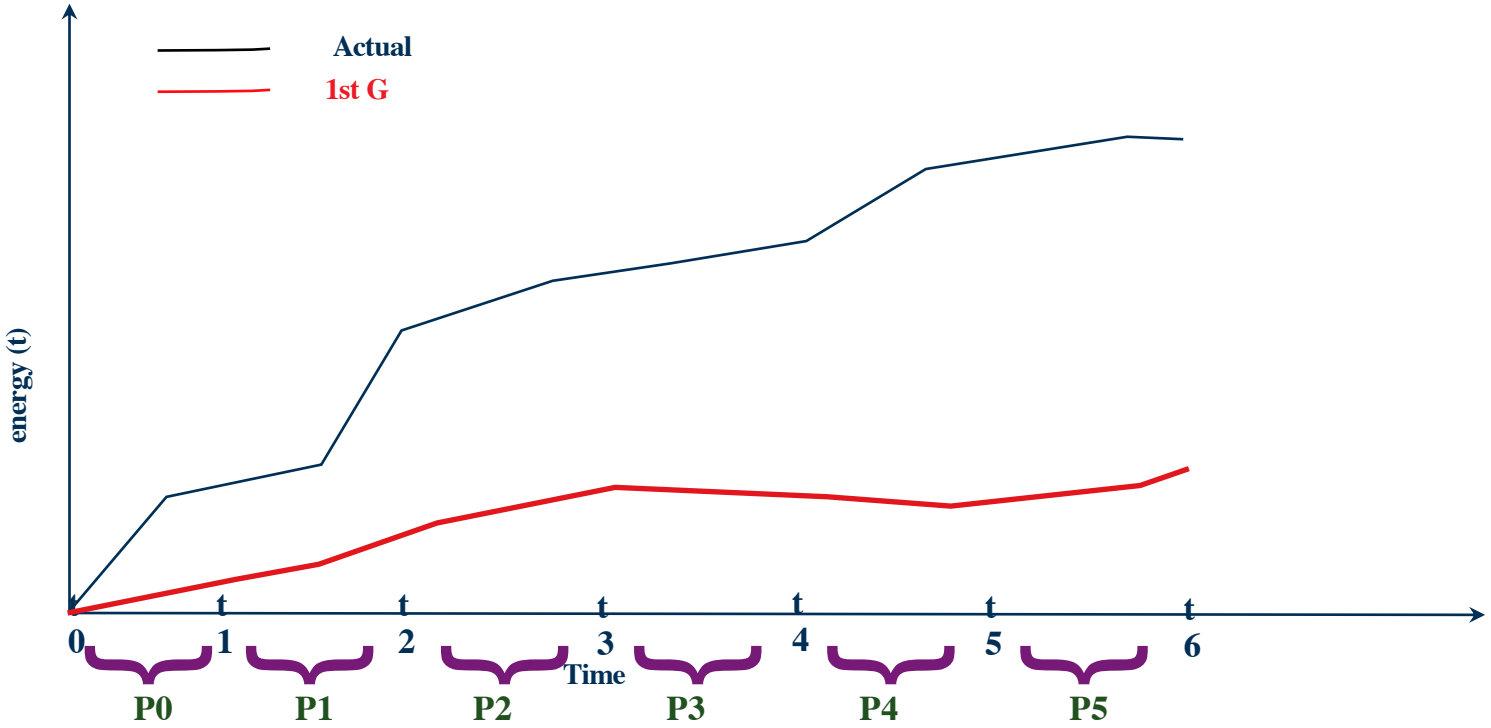
F is a propagator evolving the state, λ. The function, energy(λ,t) thus changes from initial time, t_0,to a later time ...



$$\lambda_{i+1}^{k+1} = G_{\Delta t}\left(\lambda_{(i)}^{k+1}\right) + F_{\Delta t}\left(\lambda_{(i)}^{k}\right) - G_{\Delta t}\left(\lambda_{(i)}^{k}\right)$$

F is a propagator evolving the state, λ. The fu… energy(λ,t) thus changes from initial time, t_0,to … later time …

G - faster but inaccurate propagator



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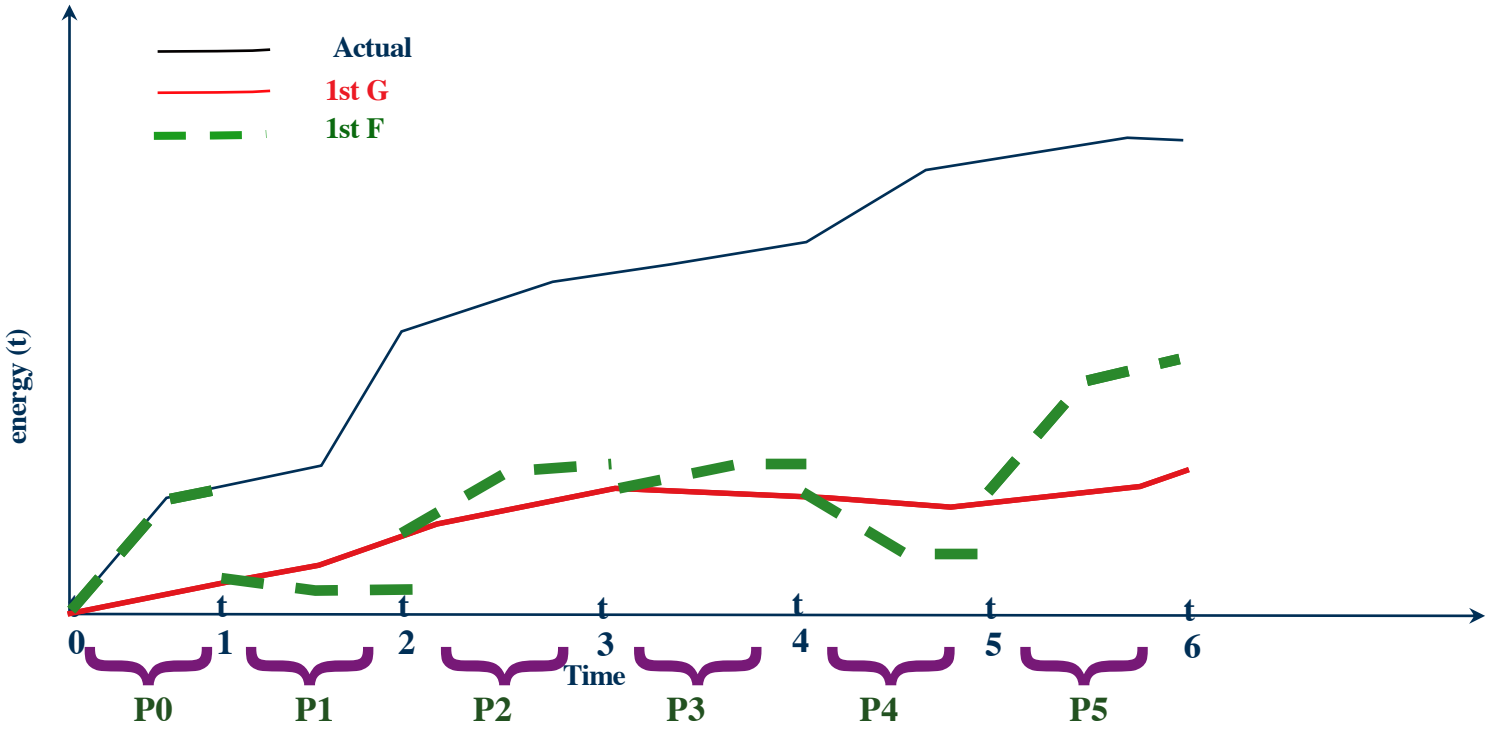

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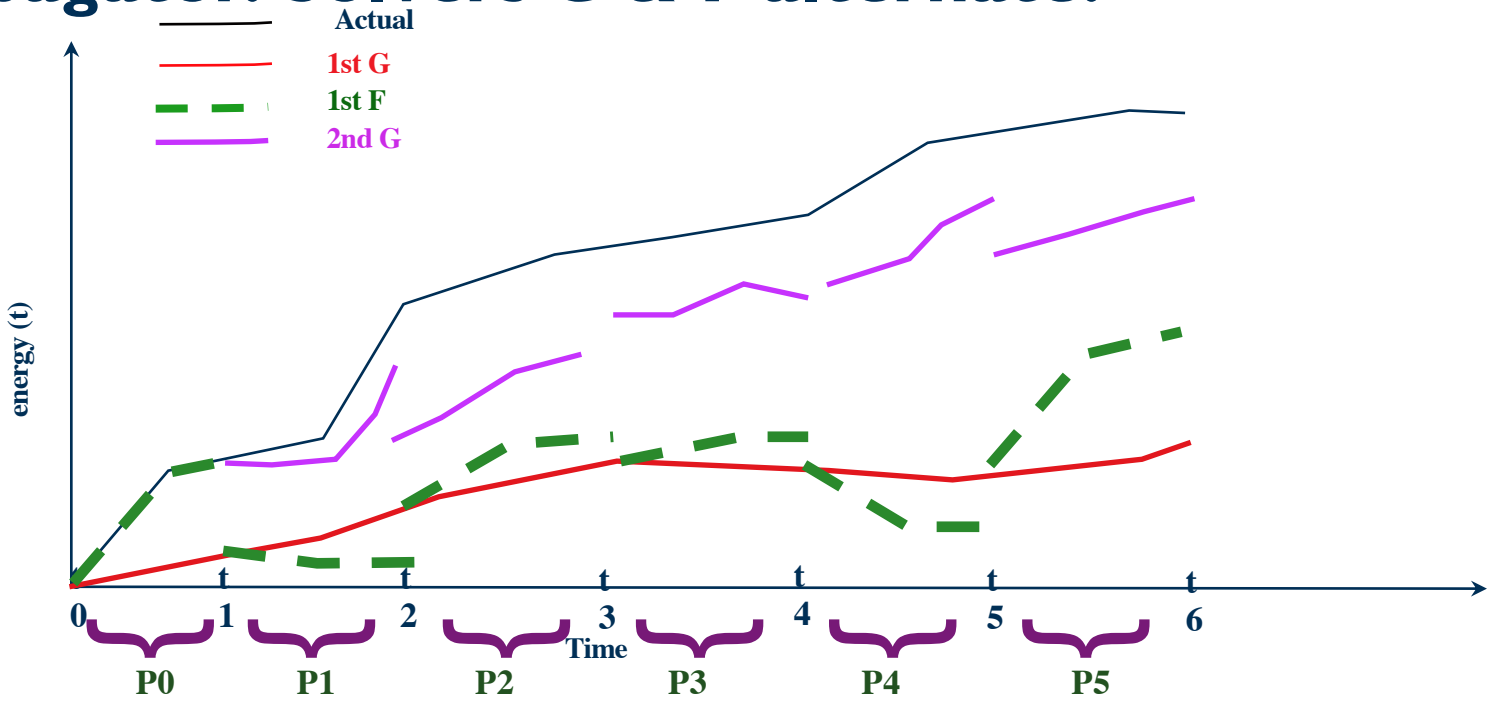
F is a propagator evolving the state, λ. The function, energy(λ,t) thus changes from initial time, t_0,to a later time ... G - faster but inaccurate propagator. Solvers G & F alternate.



$$\lambda_{i+1}^{k+1} = G_{\Delta t}\left(\lambda_{(i)}^{k+1}\right) + F_{\Delta t}\left(\lambda_{(i)}^{k}\right) - G_{\Delta t}\left(\lambda_{(i)}^{k}\right)$$

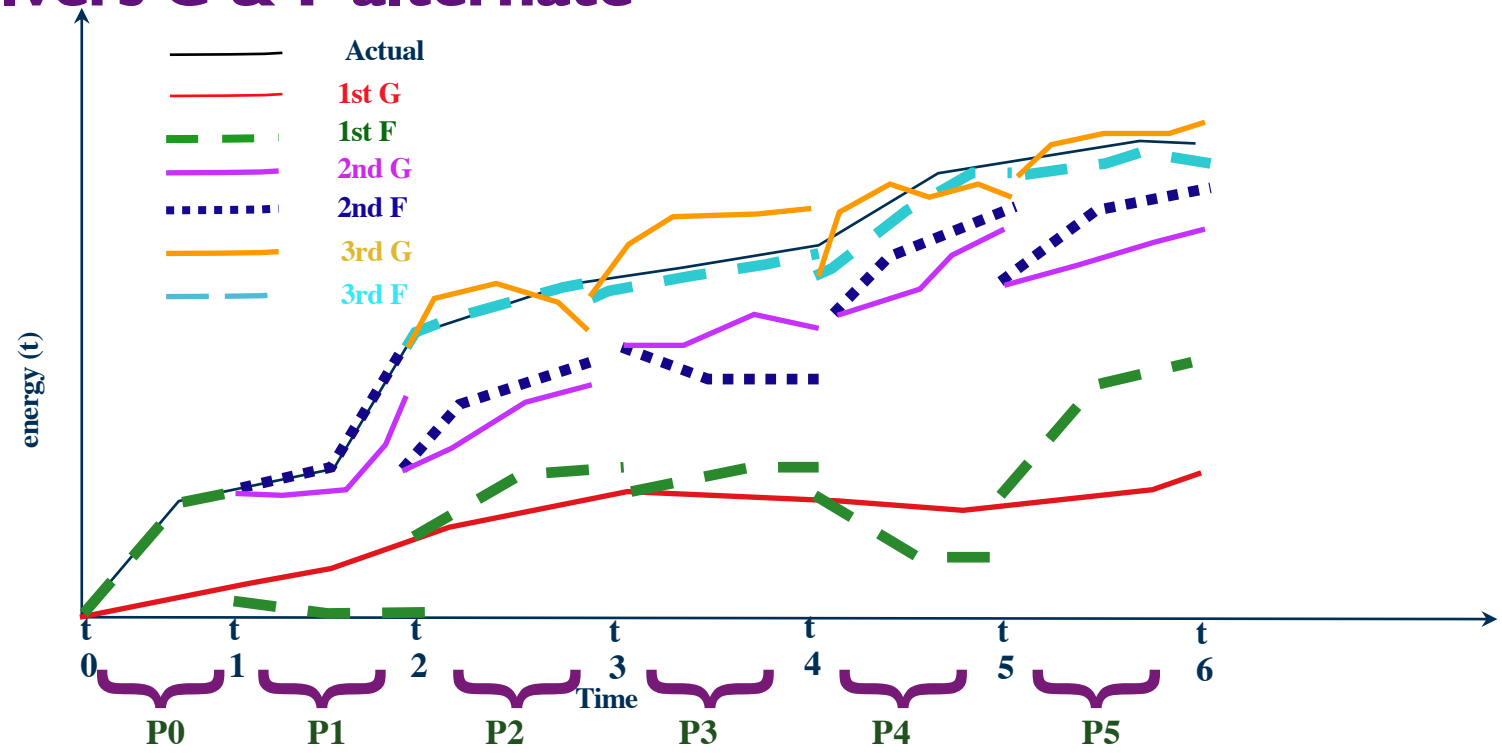
New G

Old G

F is a propagator evolving the function (energy(t)) from initial time, t_0, to a later time ...

G - faster but inaccurate propagator

Solvers G & F alternate



$$\lambda_{i+1}^{k+1} = G_{\Delta t}\left(\lambda_{(i)}^{k+1}\right) + F_{\Delta t}\left(\lambda_{(i)}^{k}\right) - G_{\Delta t}\left(\lambda_{(i)}^{k}\right)$$

New G

Old G

Success of Algorithm Depends on Multiple Factors

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Algorithm always converges if k=N.

★ **But, success in achieving significant speedup if k<<N**

★ **G is much cheaper than F.**

★ **"Good" G: Solutions converge**

★ **"Bad" G: Solutions diverge**

★ **No "fixed recipe" for G !**

✓ **Despite solutions being very sensitive to initial conditions for - it is possible to choose G.**

Selecting Optimum Coarse Solver is Important

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Different approaches can/should be explored to find G. Any one of them, or a combination of them, may work :

- **Some of the physics may be ignored when solving with G, to achieve speedup.**
- **G can be same as F, but may be solved over a coarser k-mesh (or spatial grid).**
- **G may be same as F, but may be solved with a larger timestep (dt) and less accuracy.**
- **Use a different G.**

Advantages of using the IPS Framework

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- portable parareal framework (L.Berry, W. Elwasif, ORNL) –written in python.
- exploring multiple cases with relative ease.
- hybrid parallelization (space + time).
- Less focus on numerics of parareal scheme.
- Prime focus on coarse solver.
- Reuse of processors already having attained convergence.

Event driven parareal dramatically improves computational gain

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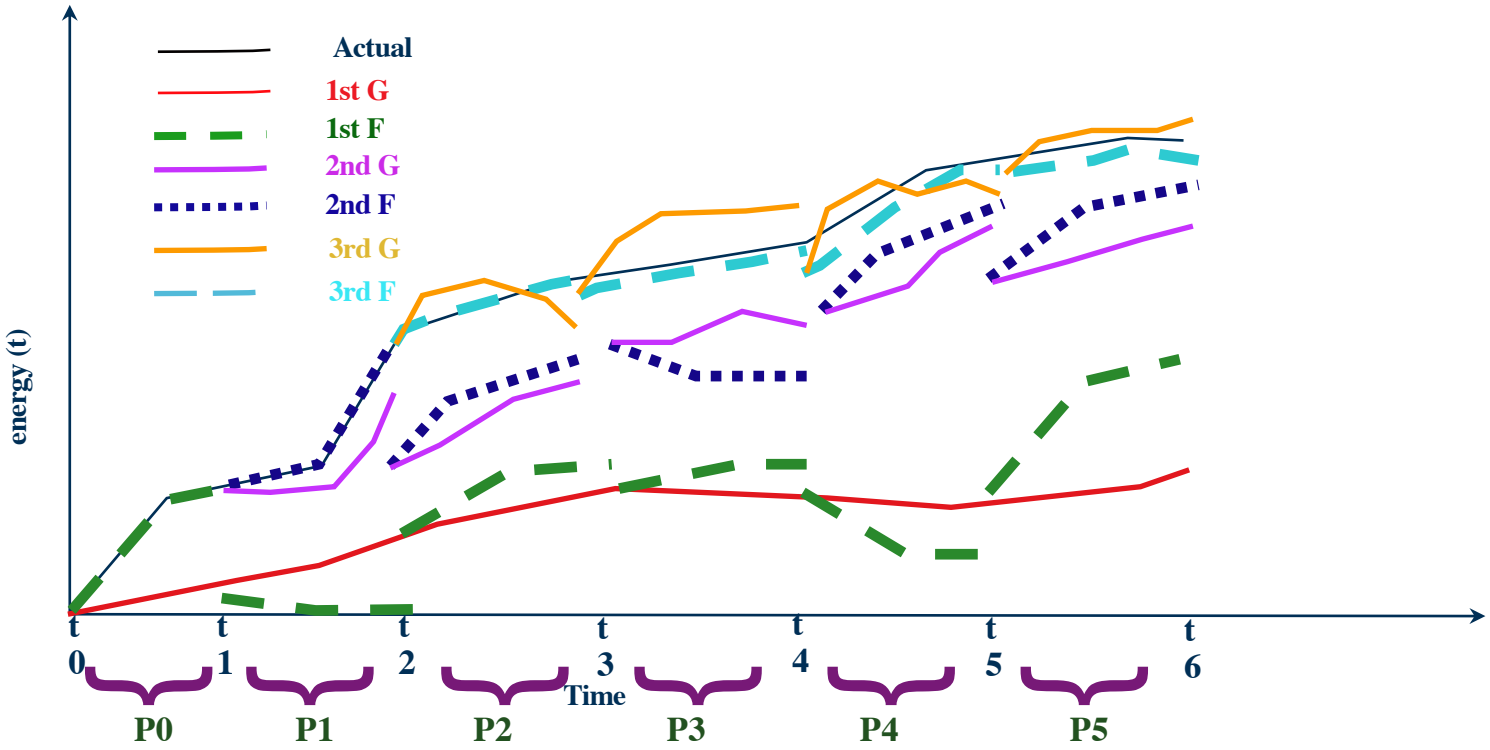

$$\lambda_{i+1}^{k+1} = G_{\Delta t}\left(\lambda_{(i)}^{k+1}\right) + F_{\Delta t}\left(\lambda_{(i)}^{k}\right) - G_{\Delta t}\left(\lambda_{(i)}^{k}\right)$$

New G

Old G

But, what about managing the data?

Data storage should provide ease in:

- Visualization
- Checkpointing
- Analysis of random variables

Data size is relatively manageable on current small runs

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Data size starts to become difficult with longer runs

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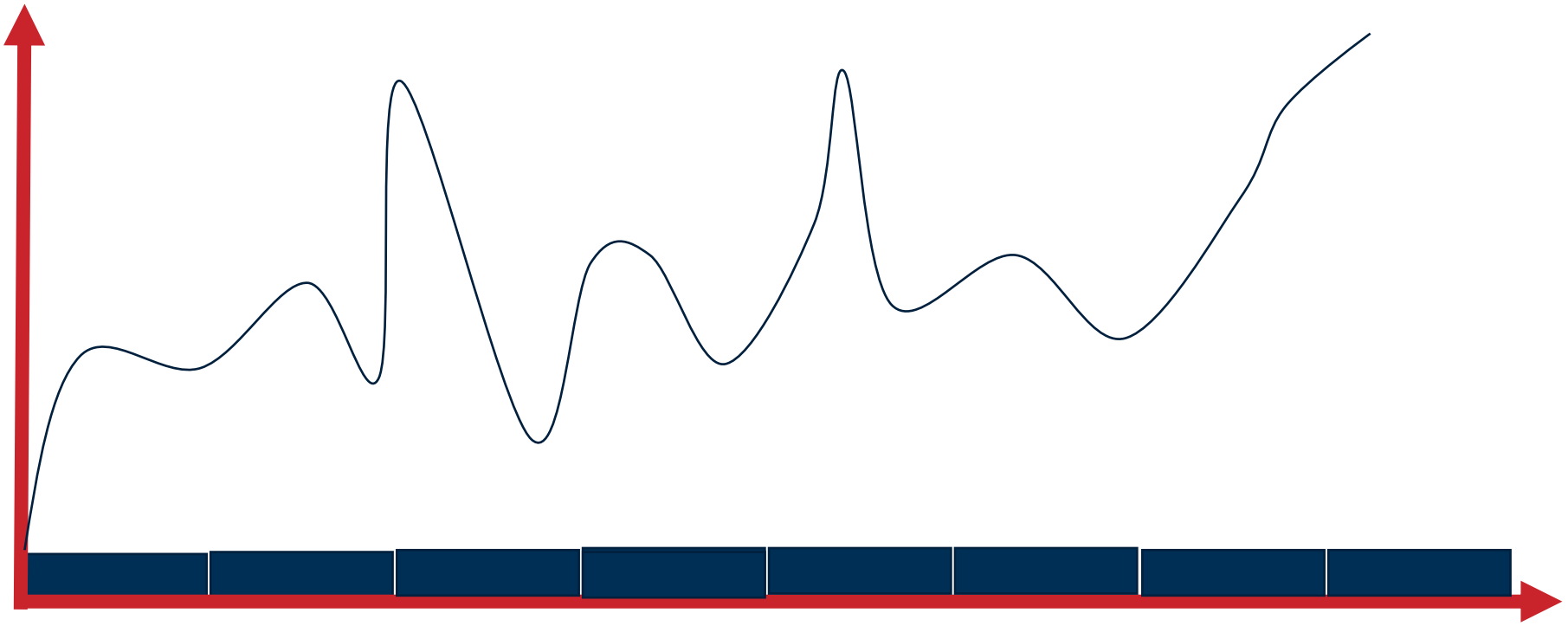

Data size is a challenge with parareal runs

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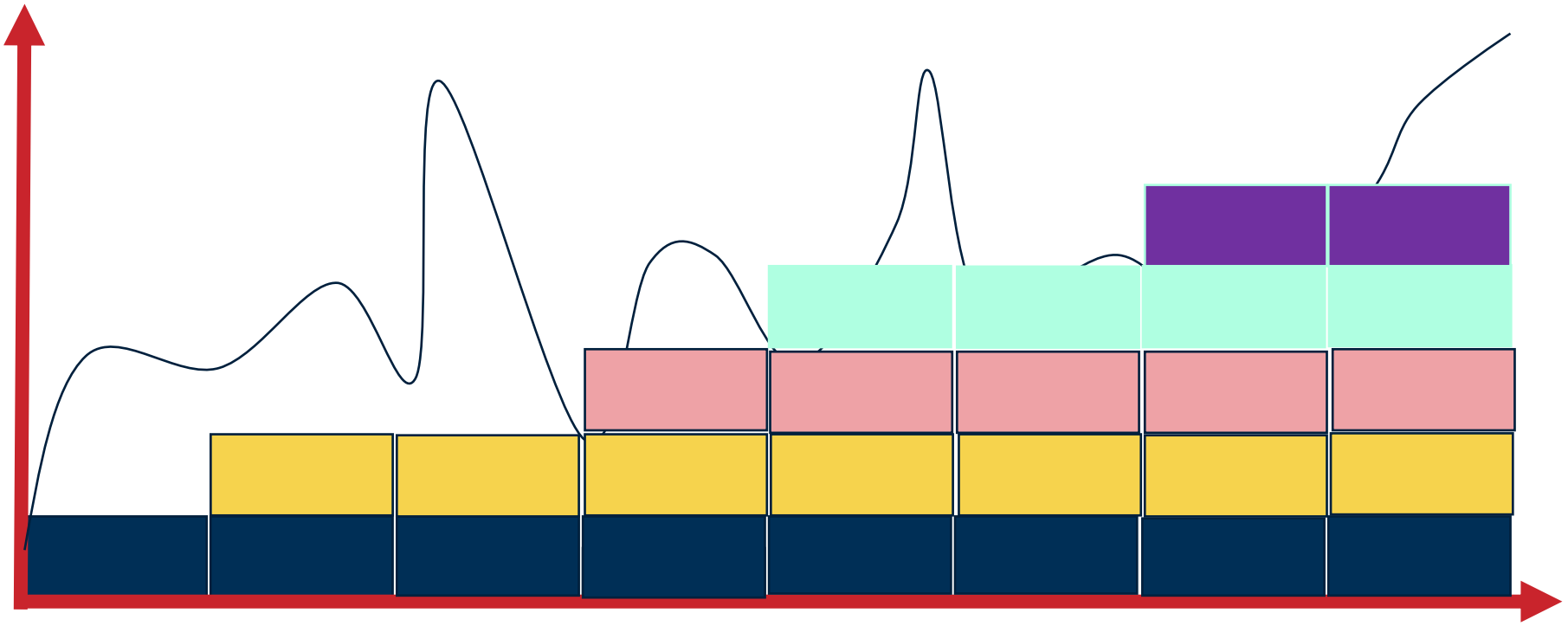

Data challenge in the Exascale

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A Parareal run will generate approximately 3 times data per timestep (G+F+corrected value).

Currently, about 100MB per timestep on a serial run. So, 100K timesteps will need 30TB using parareal (per iteration).

For complete physics- 3TB per timestep (So, 300000 TB per iteration). So, when talking of Parareal iteration, k=20(say), we are discussing Exabites.

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Current serial run: data retrieval is like looking for a sentence in a given page in a book in a book case.

Exascale simulation: Find the same page with the sentence hidden in a hole somewhere in a BIG city

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You first need a map!

How fast can you traverse through the map?!

Code snippet for CORTX I/O

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```
file_in=$1
file_out=$2
file_in_data=$1"_FineRun_data"
file_out_data=$2"_data"

id=$(awk 'NR==1{print $1}' $file_in )
echo "id for read in=" $id
addrl=$(awk 'NR==2{print $1}' $file_in)
addrh=$(awk 'NR==2{print $2}' $file_in)

/home/users/jusers/samaddar1/sage/Clovis/clovis-sample-apps_Sept2020/clovis-sample-apps/c0ct $addrl $addrh $file_in_data 4 $id

./2d_Cond_F $file_in_data $file_out_data
```

… Code snippet for CORTX I/O

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```
echo "Done F. Now c0cp output file and save ID & addresses"

c=$RANDOM
d=$RANDOM

/home/users/jusers/samaddar1/sage/Clovis/clovis-sample-apps_Sept2020/clovis-sample-apps/c0cp $c $d $file_out_data 4 -a 8 | awk '{print $2}' > $file_out

echo $c $d >> $file_out
```

Steps for porting code to tiered storage system.

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1. **Legacy serial code**

2. **Code in Parareal framework**

3. **Parareal version on Cortx**

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References:

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Thank you!