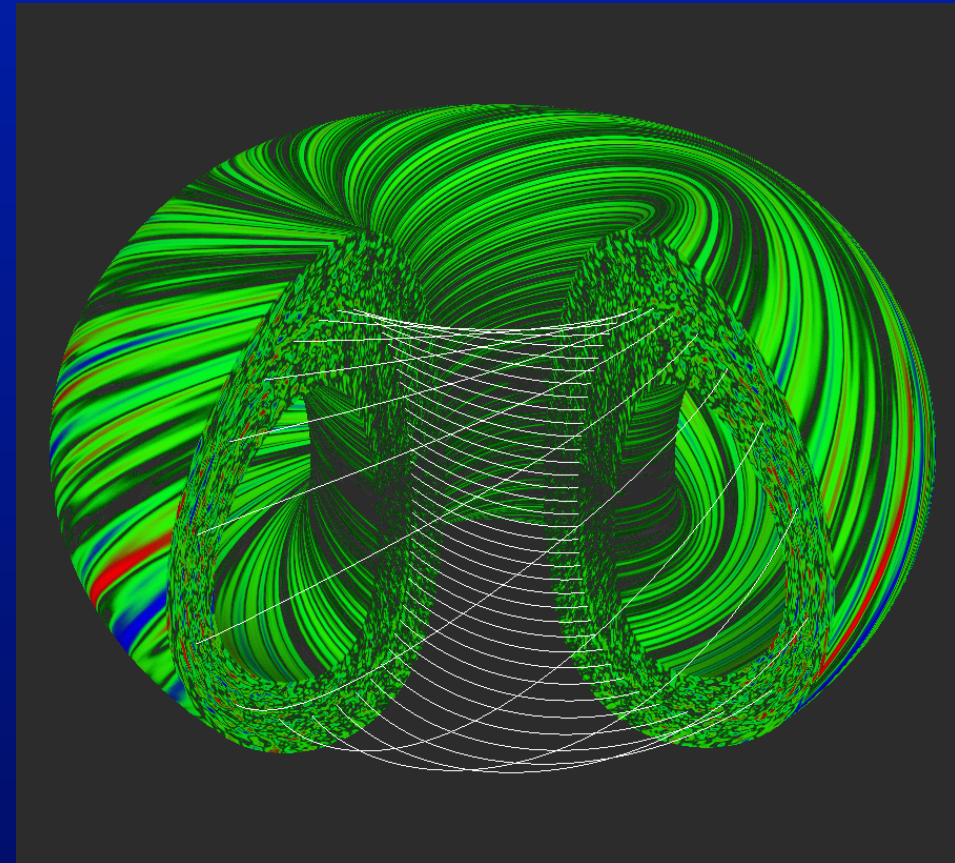


Computational Plasma Physics: Examples from Turbulence Research

W Dorland
University of Maryland

With images from:

W M Nevins	D Applegate
G W Hammett	G D Kerbel
B I Cohen	G G Howes
UKAEA	J Stone
J Candy	R E Waltz



Advancing Science with Simulations

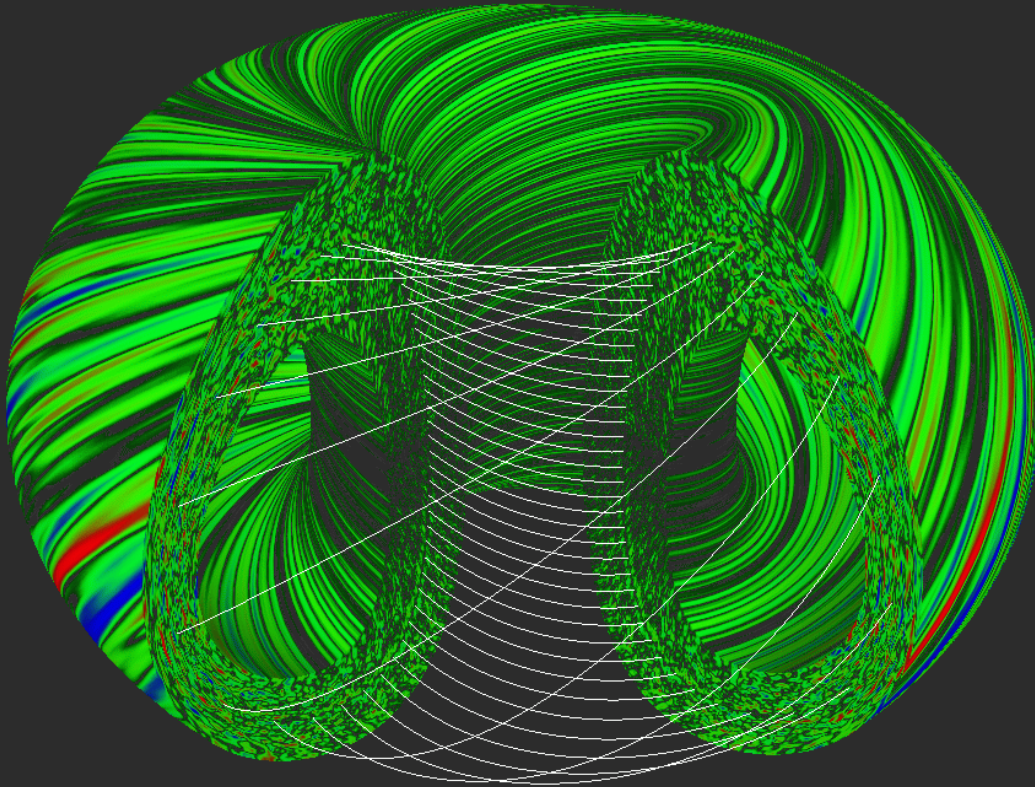
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**Wide range of
problems in plasma
physics**

Plasma from START, courtesy Culham Lab, UKAEA

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**Wide range of
algorithms and codes**

Simulation courtesy G D Kerbel and W Dorland

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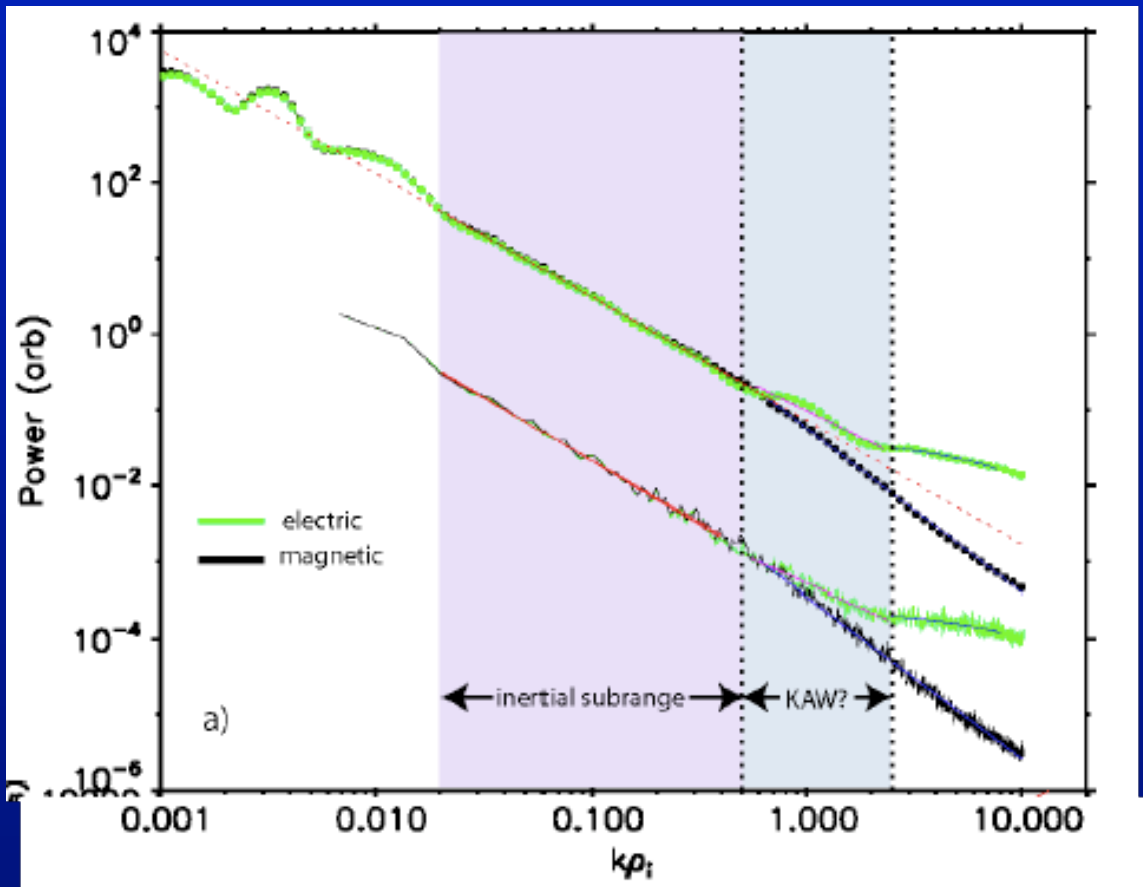


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Turbulent accretion flow courtesy J Stone

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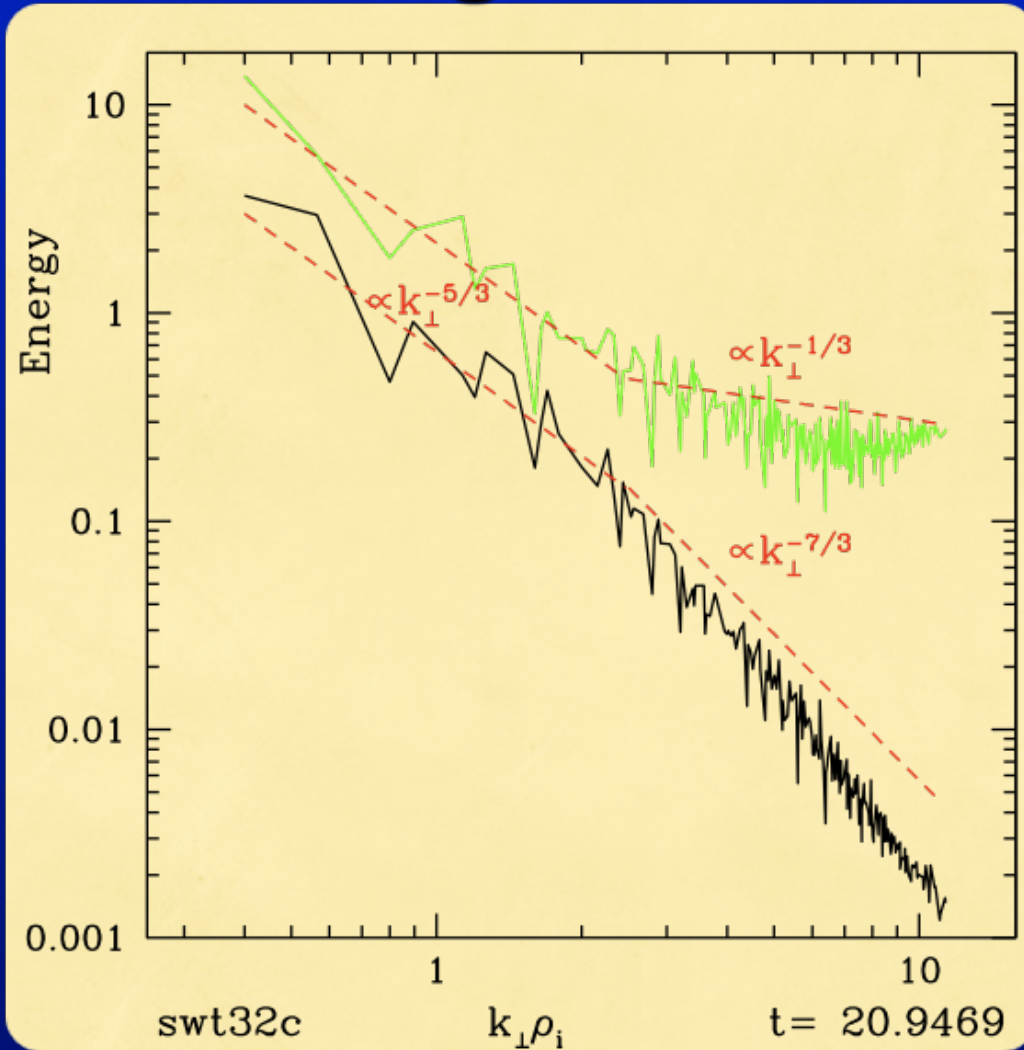


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***Turbulent fluctuations in solar wind
Courtesy of S Bale, UC-Berkeley***

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**Wide range of
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**What do we have in
common?**

Gyrokinetic simulation of MHD turbulence

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Common Denominator:

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How does one use supercomputers to advance science?

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I will address this question with examples from my research area.

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Answer: Turn it off!

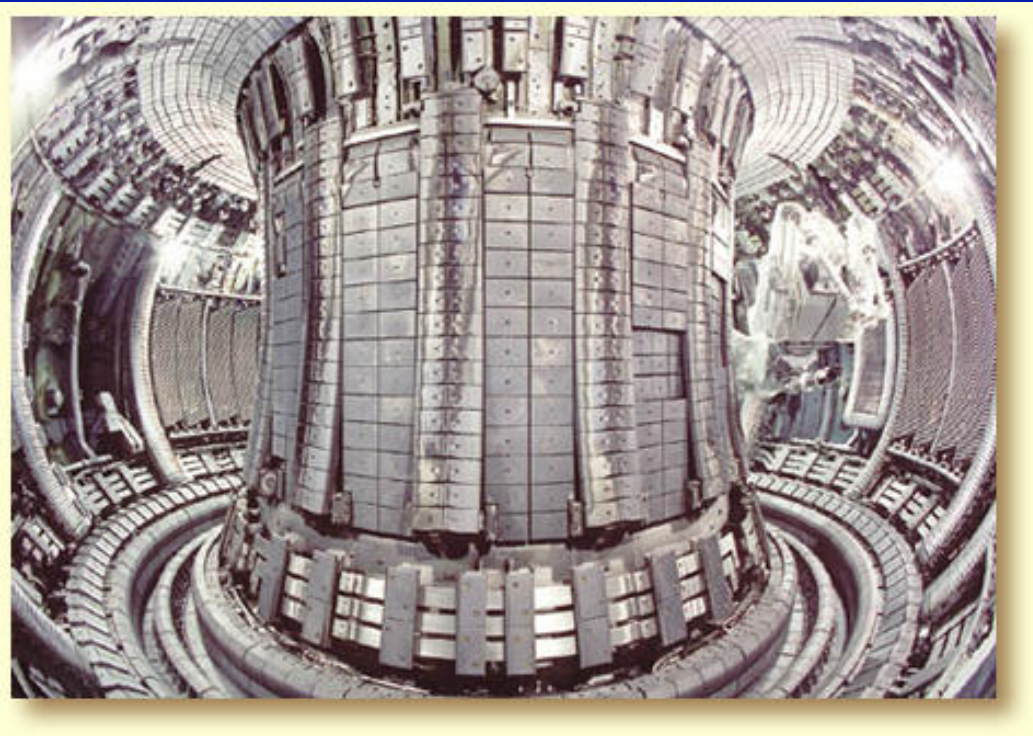
Tokamaks 101

A tokamak is a toroidal magnetic chamber to confine plasma

Stable equilibria demonstrated for hours on superconducting machines

Problem is rapid transport of energy, momentum and particles out of machine by turbulence.

One major goal of fusion program: understand and control this turbulence. Understanding comes from studying simulations...



JET tokamak

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- 5. “Turn off” the computer**

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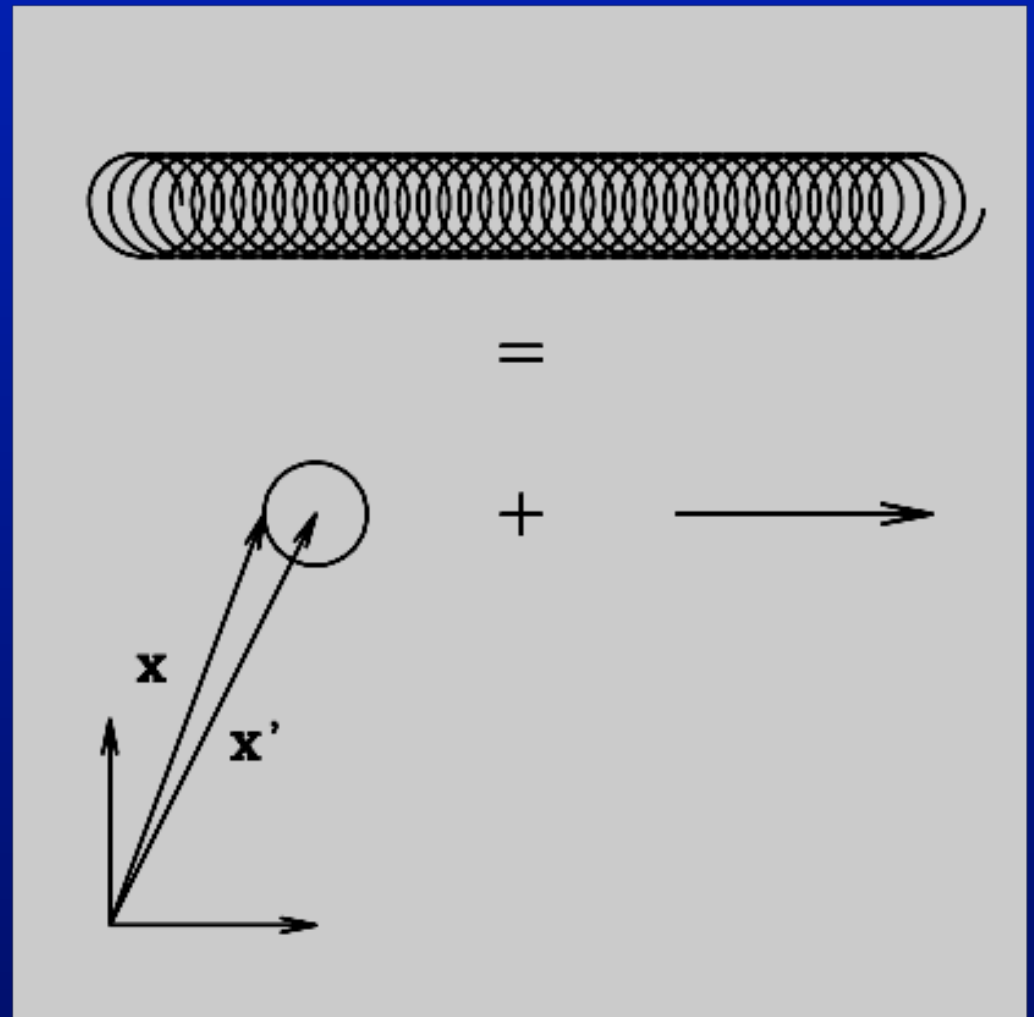
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Plus Maxwell's Eqs to get gyro-averaged potential:

$$\bar{\Phi} = \frac{1}{4\pi} \int \frac{\mathbf{k} \cdot \mathbf{r}}{|\mathbf{k}|} \Phi \int \frac{d^3 \mathbf{k}}{(2\pi)^3} \frac{\mathbf{k} \cdot \mathbf{r}}{|\mathbf{k}|} e^{i\mathbf{k} \cdot \mathbf{r}} \Phi^0 \cos \xi \Phi$$

**Bessel functions represent
averaging around particle gyro-orbit**

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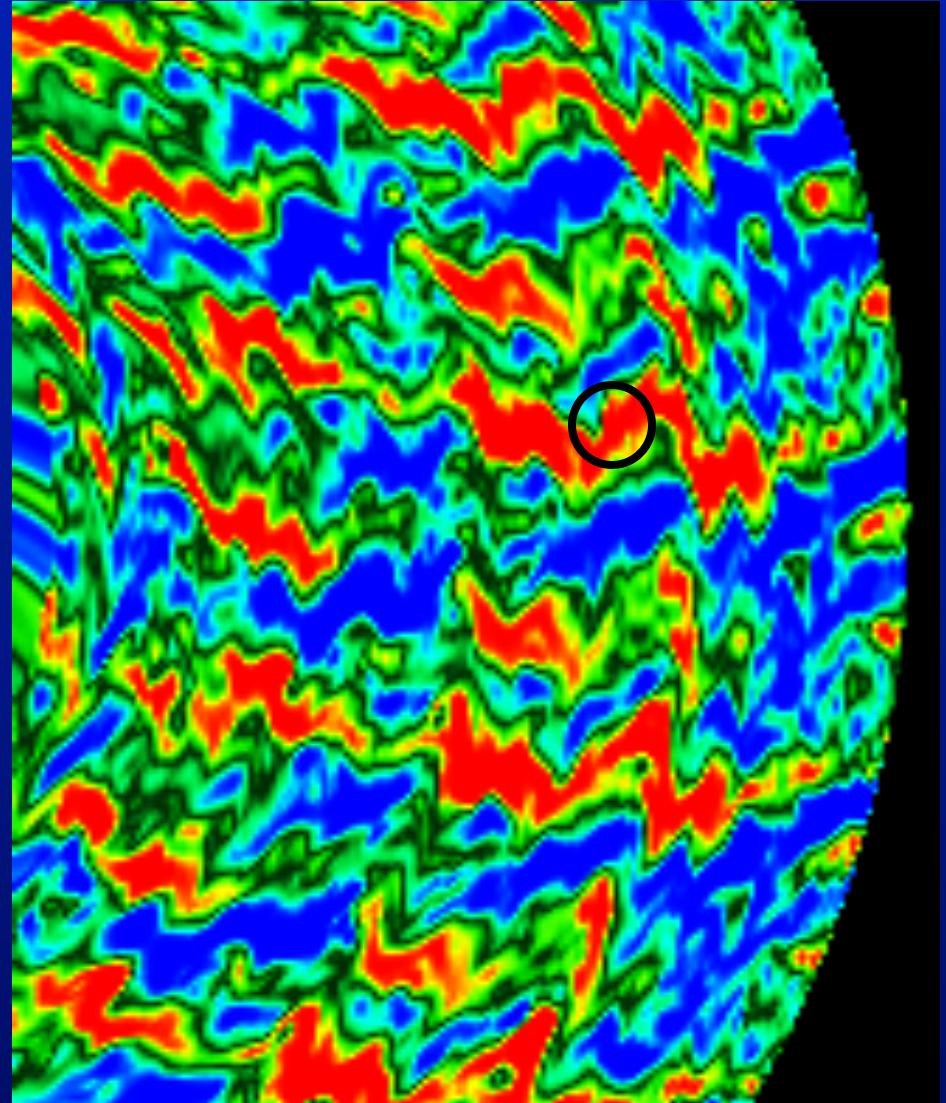


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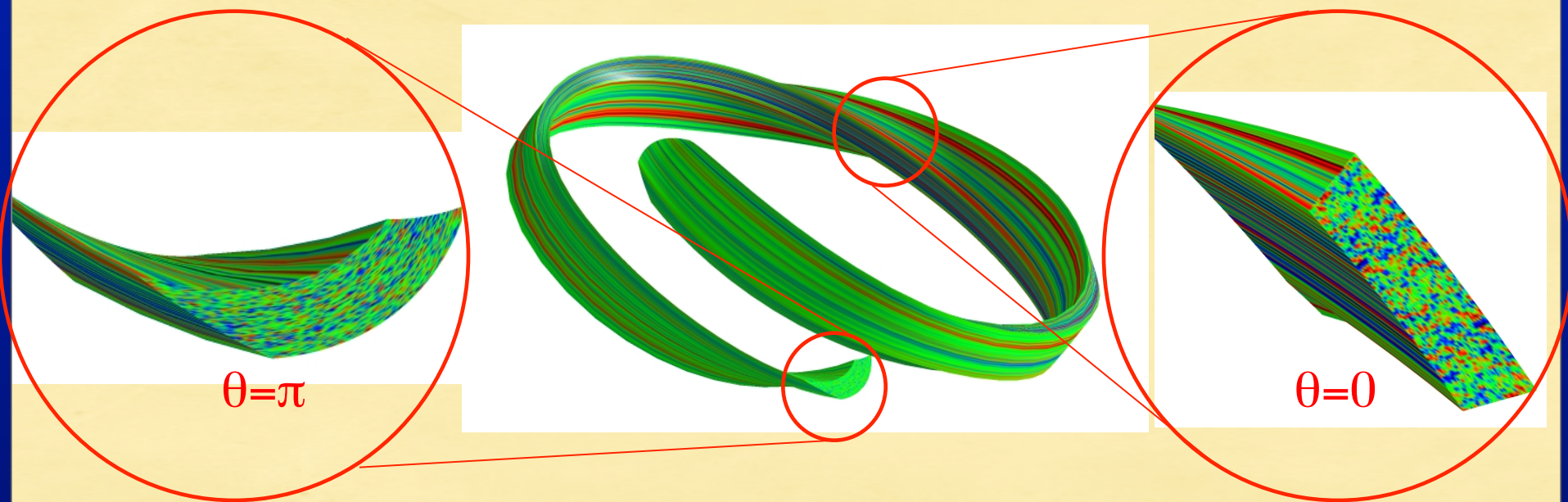
$$\overline{\Phi}_k = J_0 \left(\frac{k_{\perp} v_{\perp}}{\Omega} \right) \Phi_k$$

Easy to evaluate in pseudo-spectral code.

Fast multipoint Padé approx. in other codes.

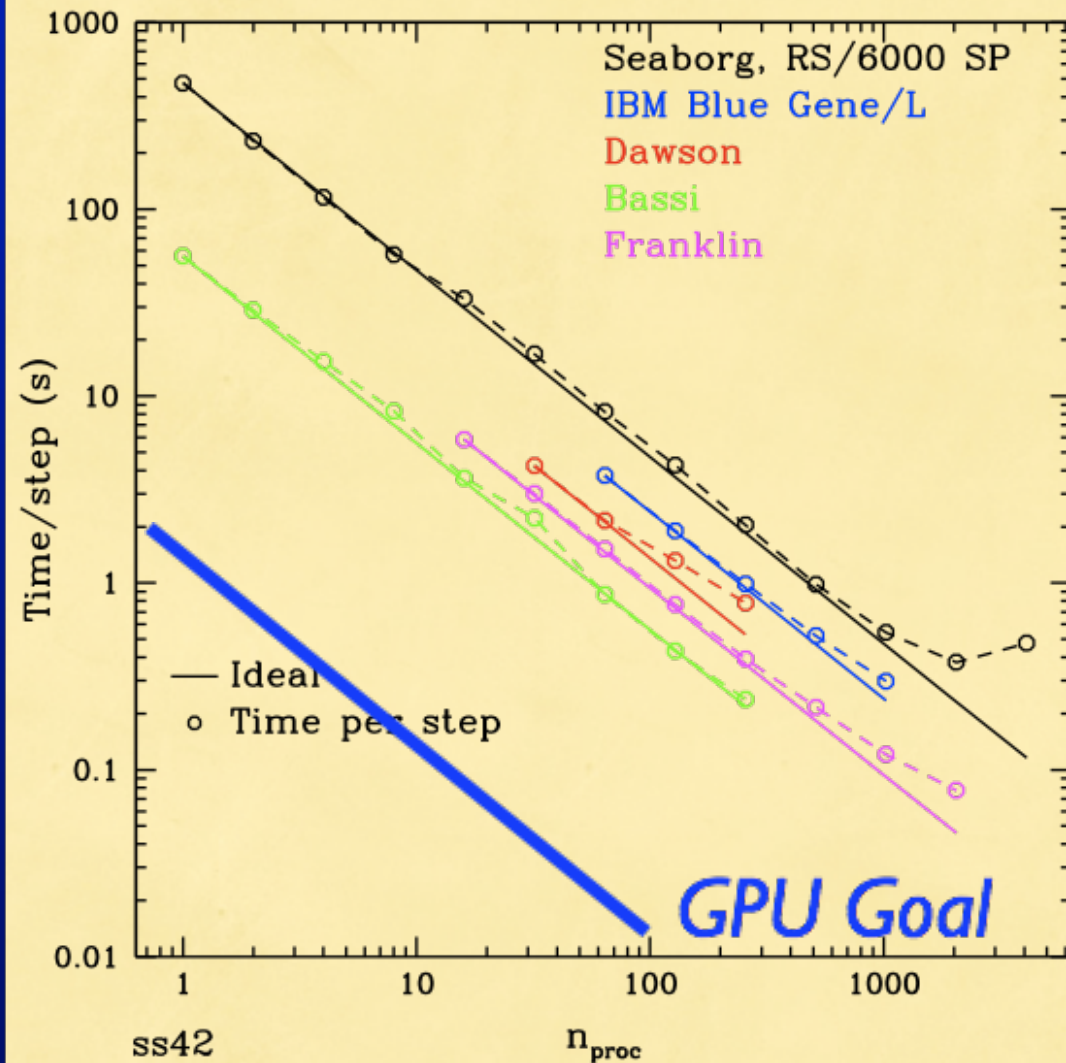


Highly Anisotropic Structures with Long Mean Free Path



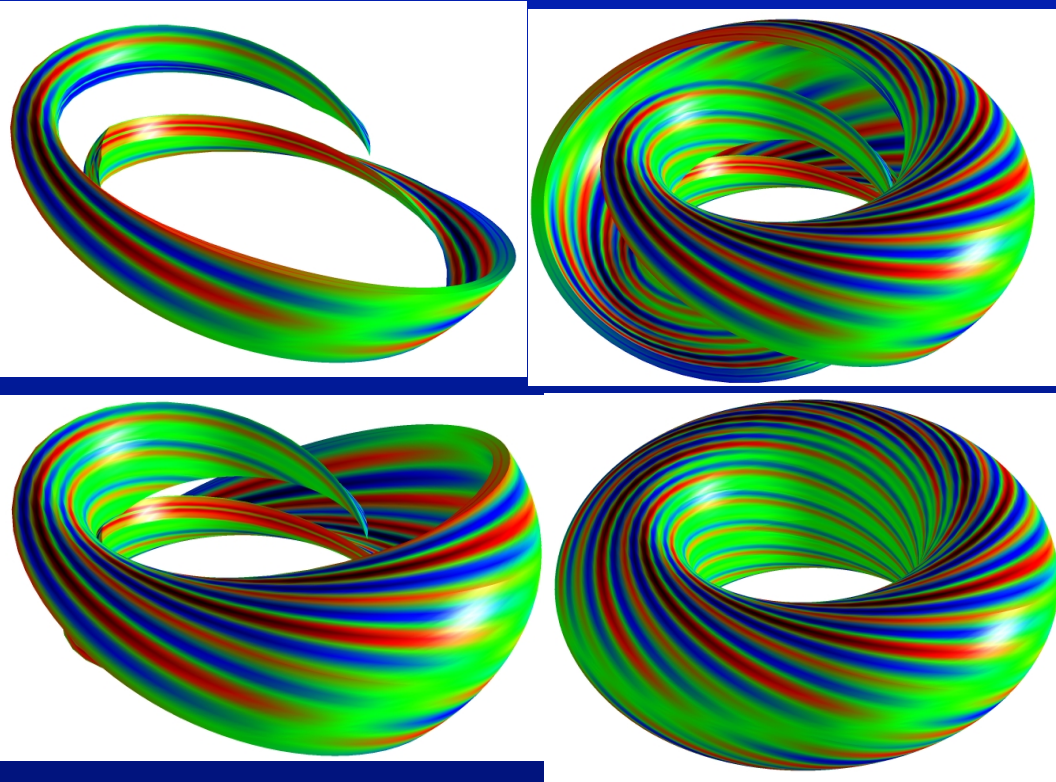
Independently Develop Multiple Algorithms and Codes

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GS2: continuum, flux tube

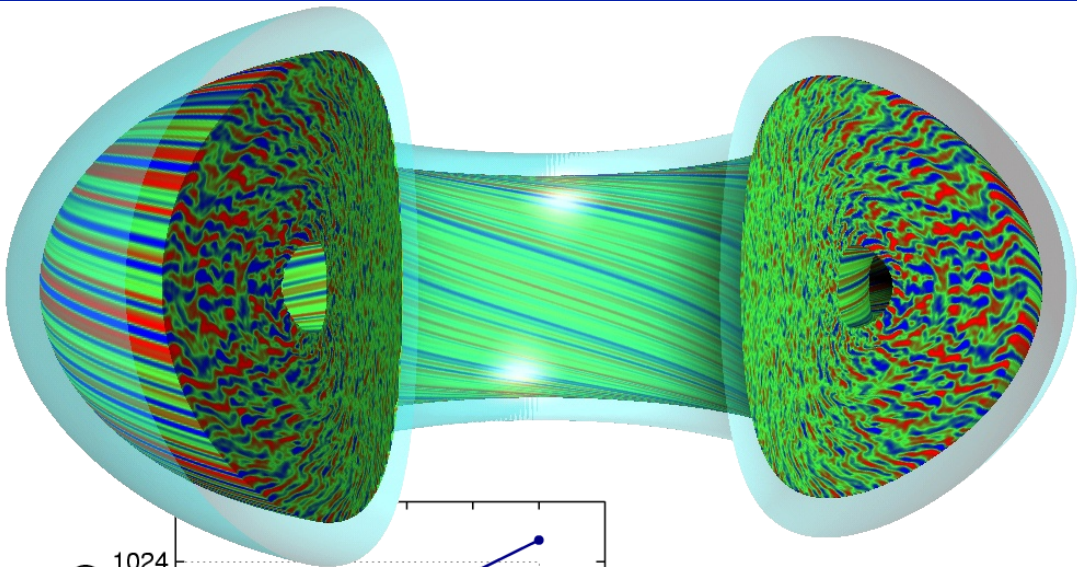
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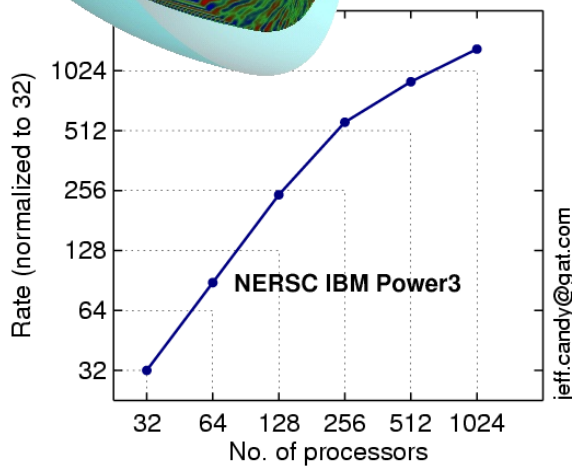
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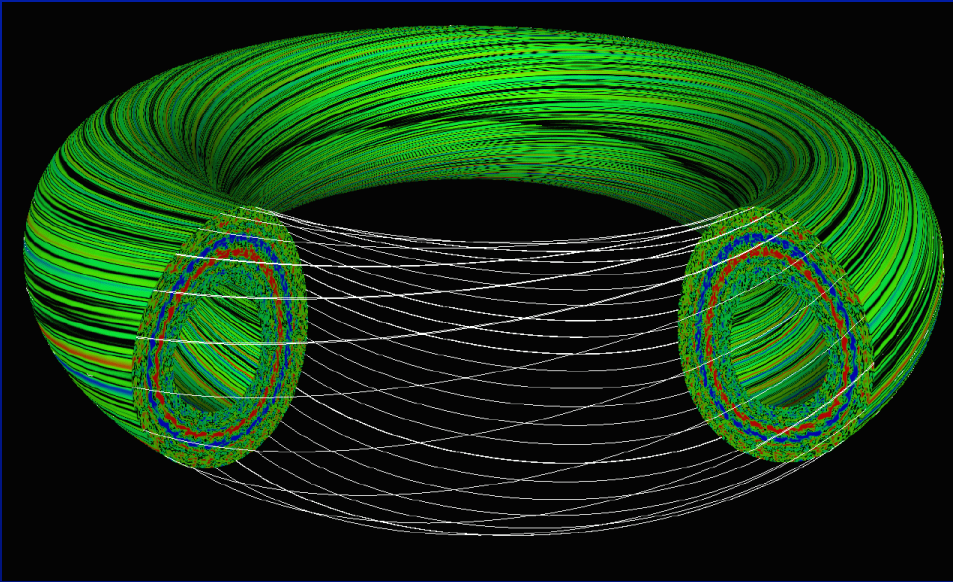
GYRO: continuum, global



GYRO gives superlinear
scaling up to 1024
processors on FIXED
problem size.



Independently Develop Multiple Algorithms and Codes



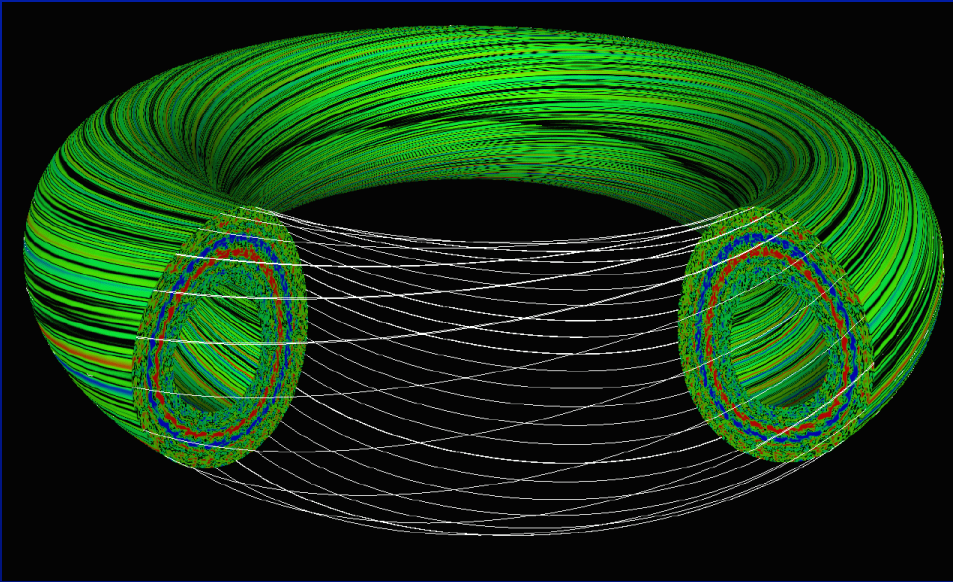
GS2: continuum, flux tube

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GYRO: continuum, global

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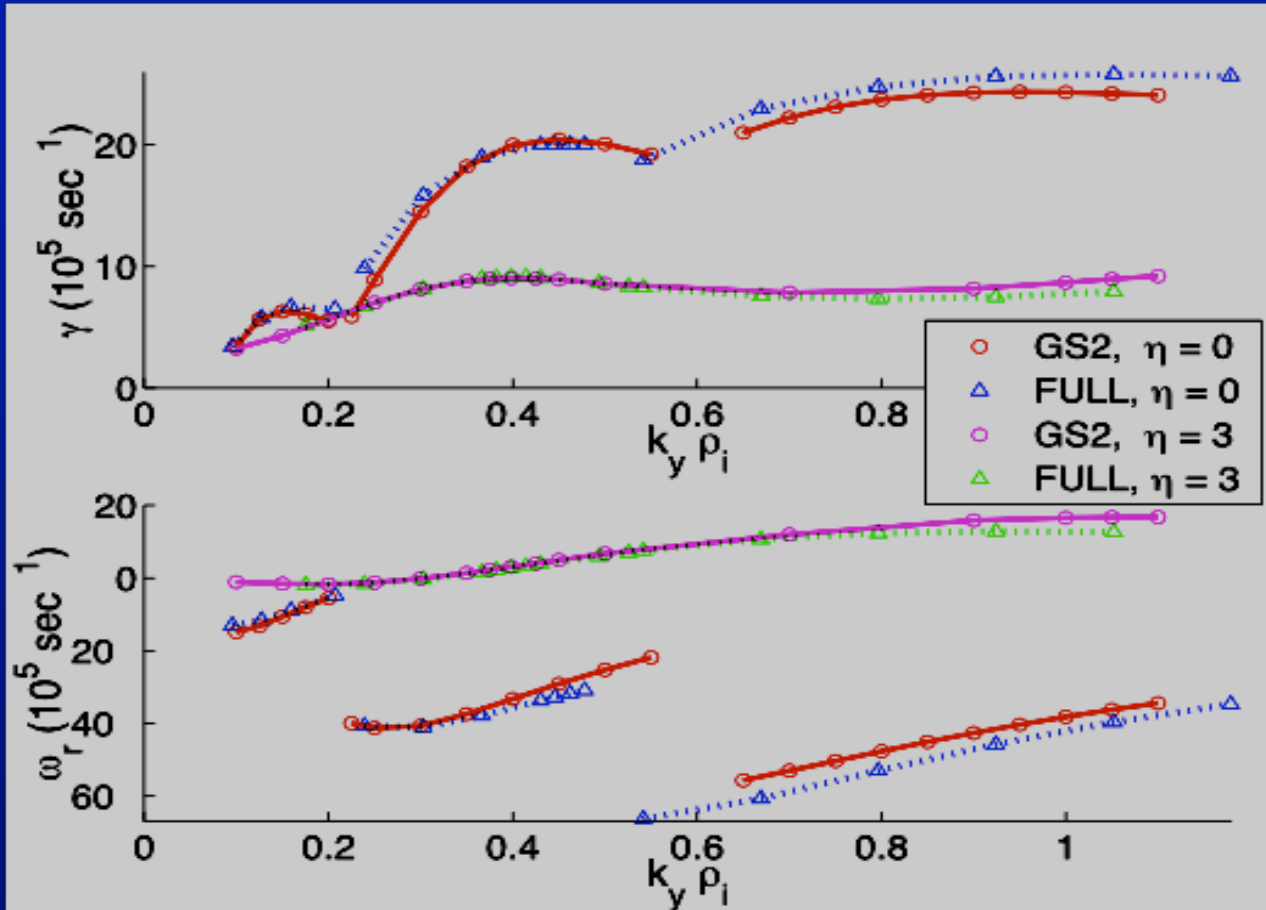
GYRO: continuum, global

**GENE: continuum, flux
tube**

FULL: continuum, linear

Benchmark Codes in Simple Limits and *Against Each Other*

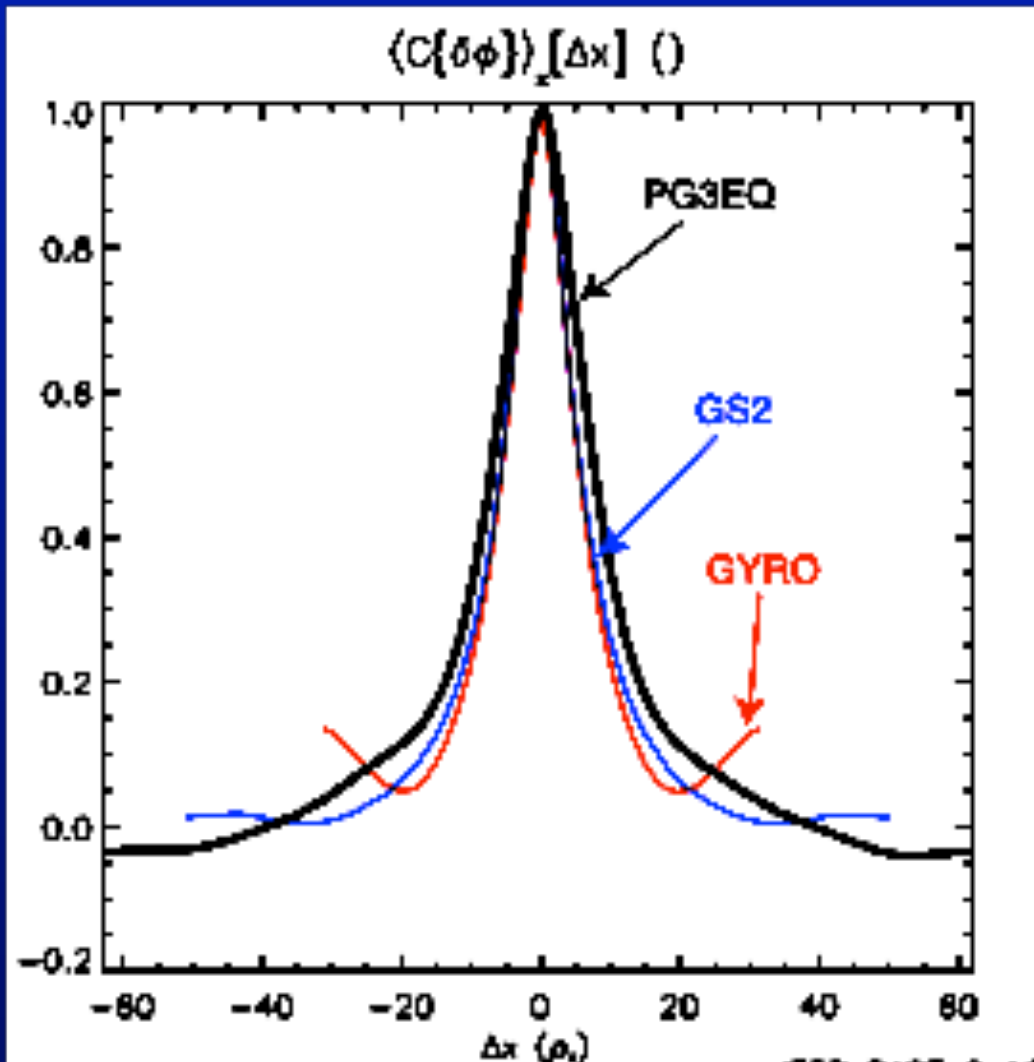
Benchmark Codes in Simple Limits and Against Each Other



Linear micro-stability calculations for NCSX stellarator with GS2 and FULL agree: very challenging linear benchmark

Benchmarks by E Belli, G Rewoldt, Hammett and Dorland

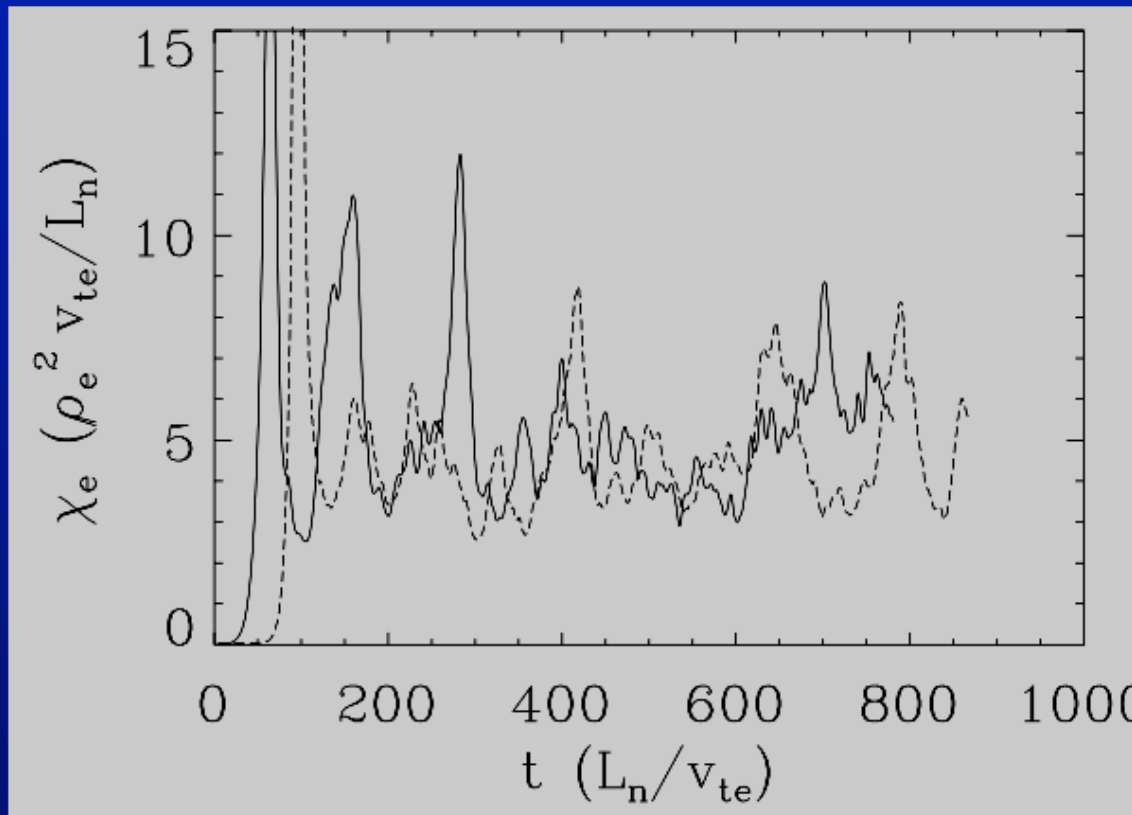
Benchmark Codes in Simple Limits and Against Each Other



Radial correlation functions from three independently developed gyrokinetic codes, run for identical physics parameters.

This was a difficult **nonlinear** benchmark.

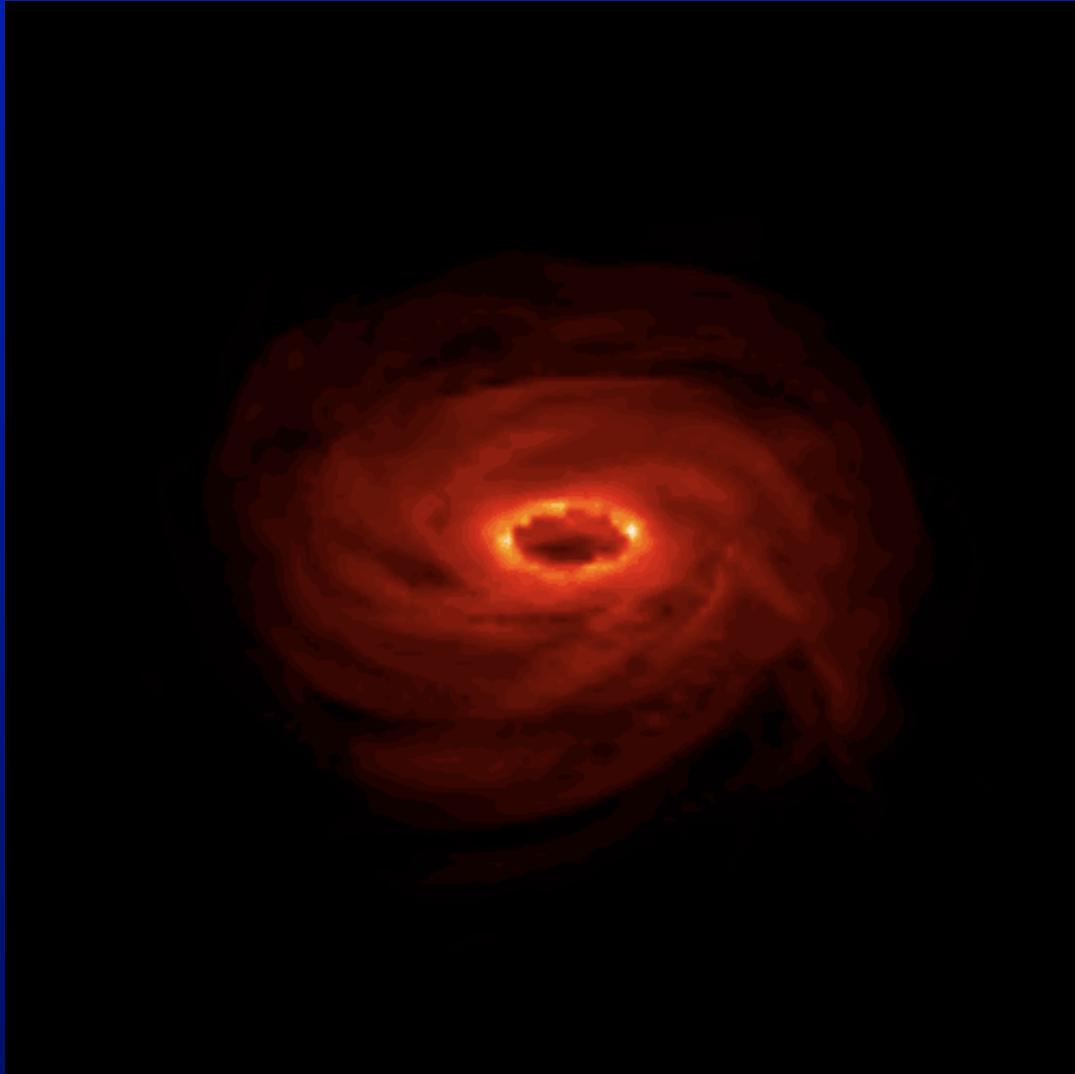
Benchmark Codes in Simple Limits and Against Each Other



GS2 and GENE (a European code by F Jenko) benchmark of **heat flux for toroidal ETG **turbulence****

Average value agrees well -- another example of **nonlinear benchmark**

Develop models of physical systems – and use them!



*Accretion flow luminosity model
[Goldston, Quataert,
Igumenshchev, 2005]*



Supernova 1987A



HUBBLESITE.org



Mosaic of The Crab Nebula



HUBBLESITE.org



Photograph by Norbert Rosing

