A visual interface for the analysis of turbulent structure statistics

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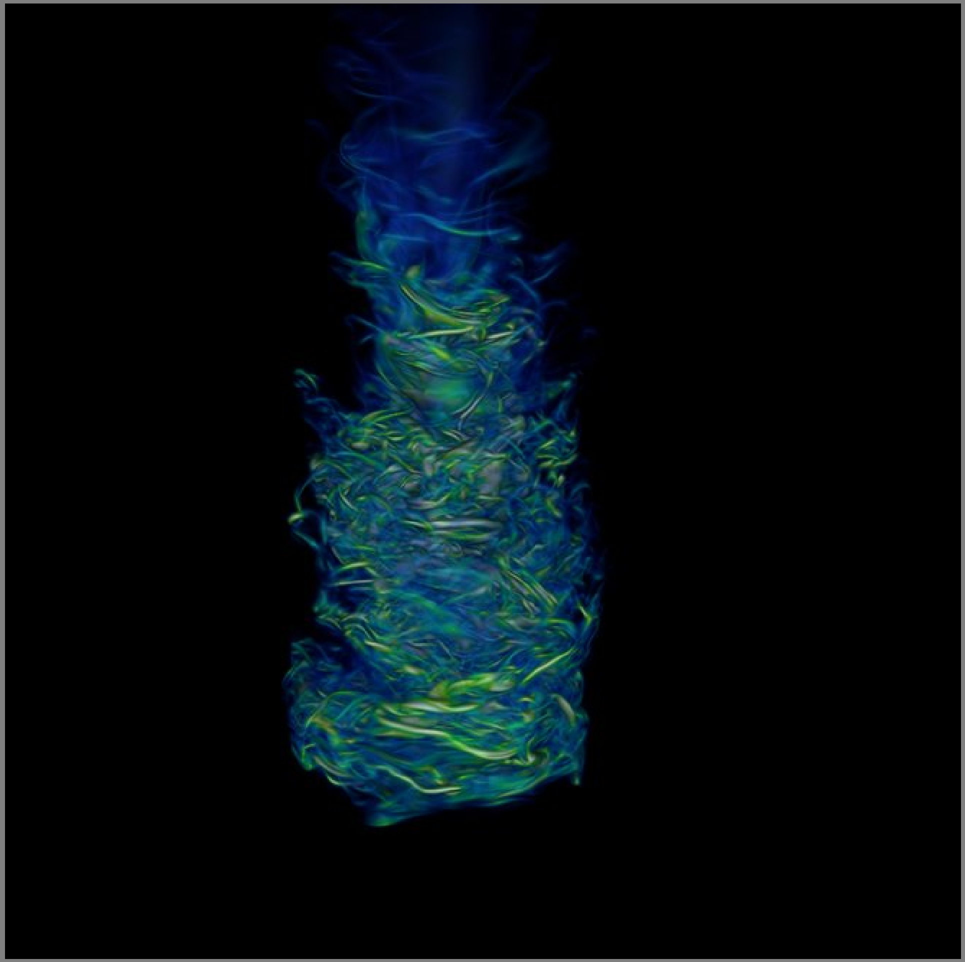
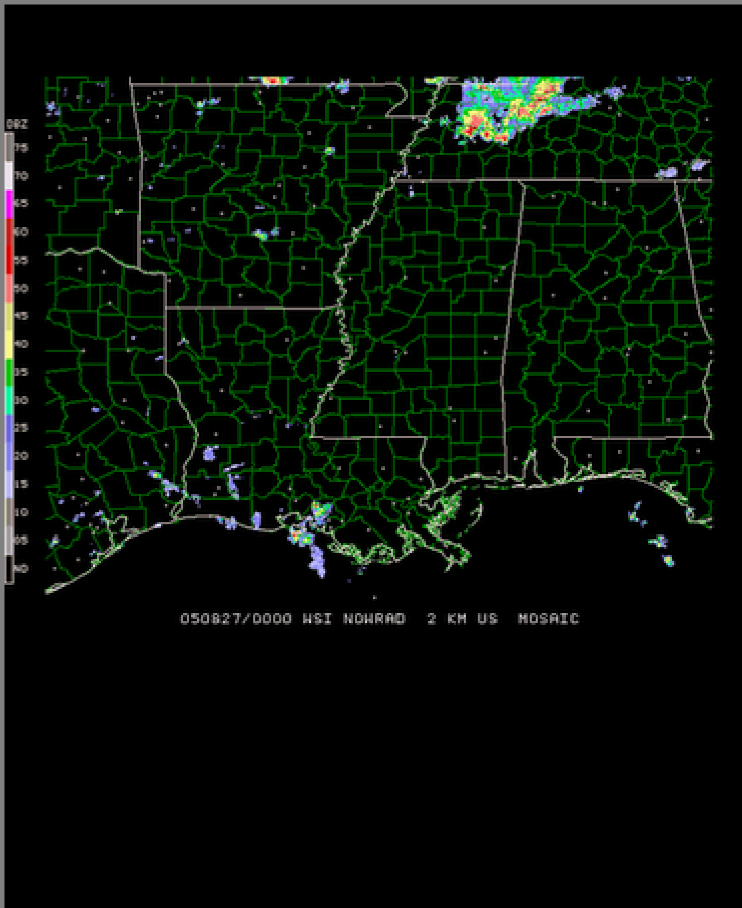
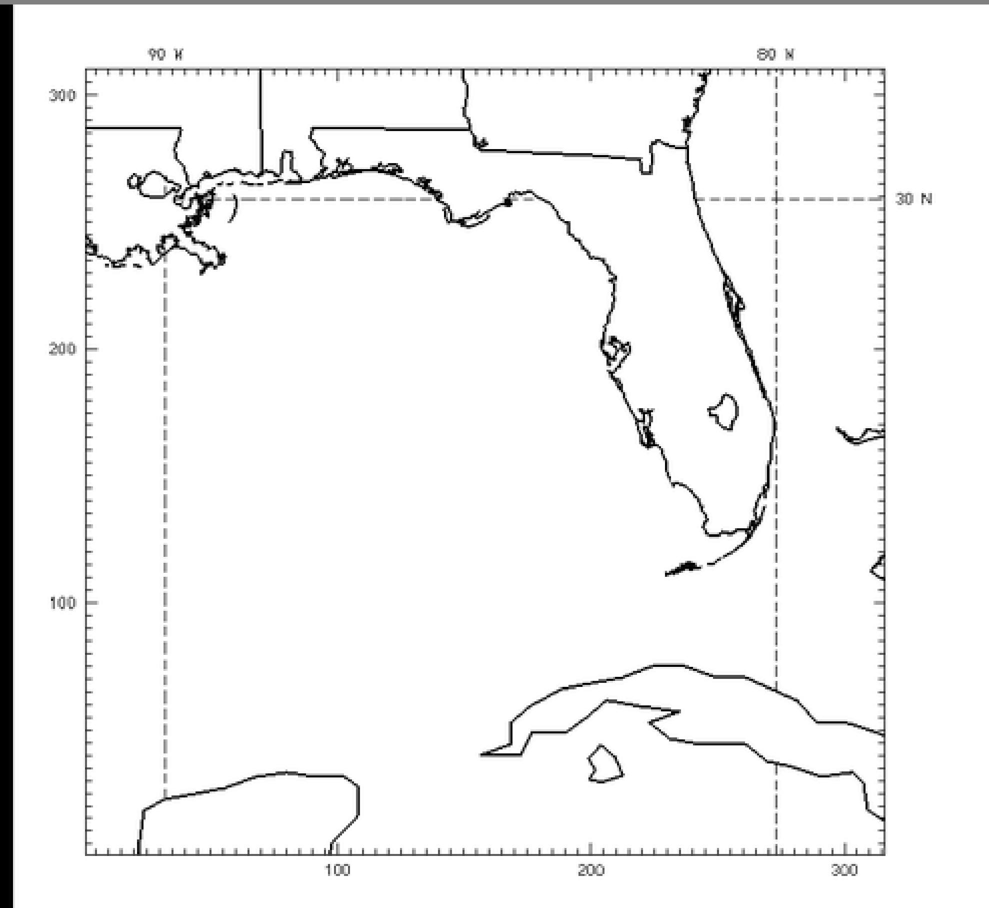


Simulation:



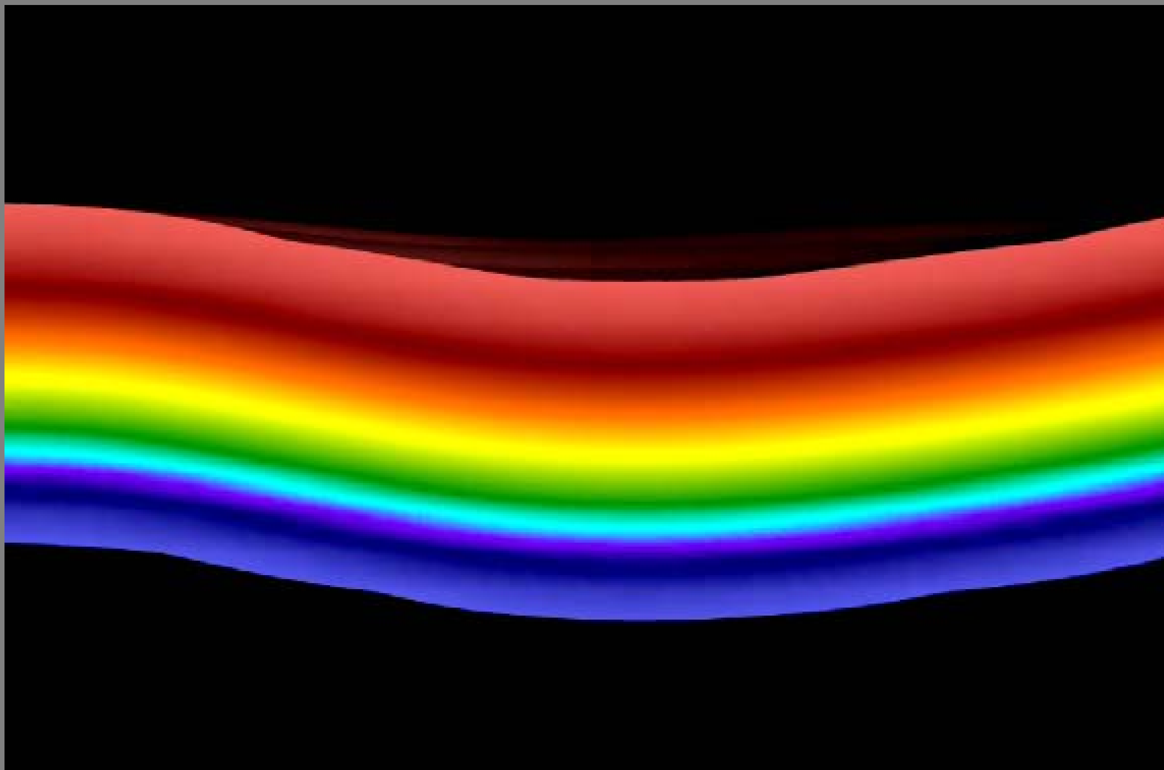


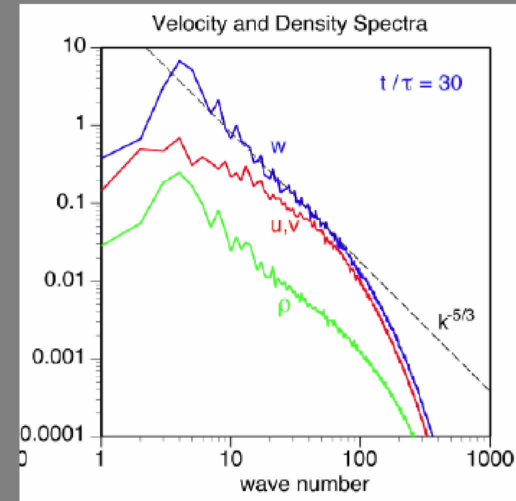
Visualization for operation.

NCAR's Advanced Research version of the Weather Research and Forecasting model (WRF)

- Two-dimensional projection sufficient (e.g. surface pressure, temperature, rainfall).

Global analysis:





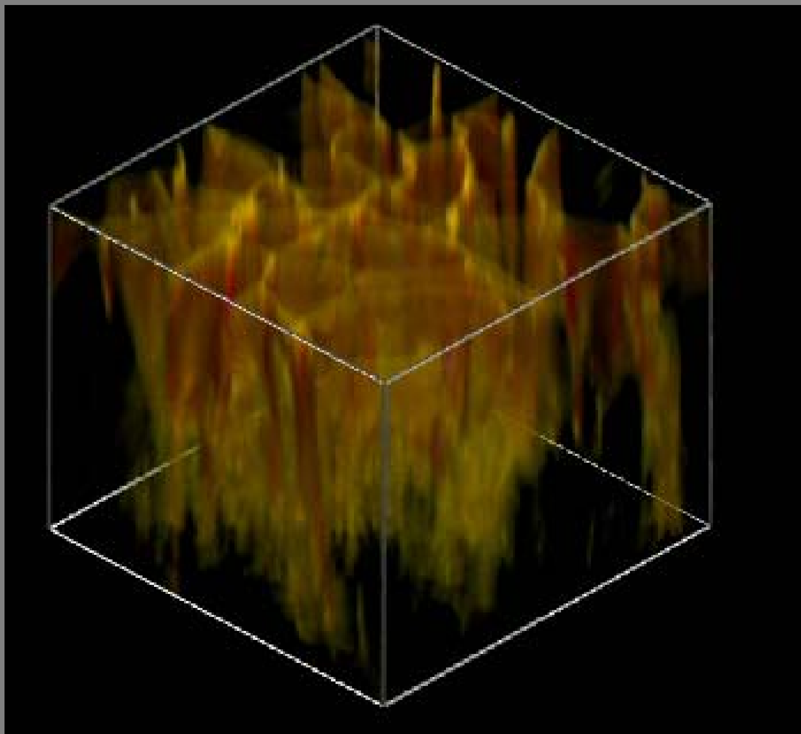
Rayleigh-Taylor instability

Lawrence Livermore
National Laboratory (2006)

Visualization for impression.

- Full data volume movies few in number, and not interactive.
- Analysis problem is reduced from three spatial to one or two statistical dimensions (even the largest problem provides no significant data management challenges).

Experimental physics:

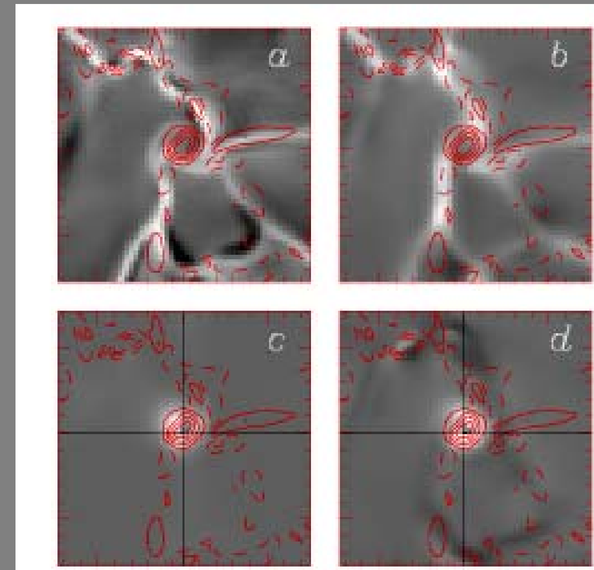


Supersonic ionizing convection (1999)

256^2 x 248

$$-\nabla_{H} \cdot \rho u$$

$$-\frac{\partial p}{\partial z} + \rho g$$



$$\frac{u_\theta^2}{r}$$

$$\frac{1}{\rho}\frac{\partial p}{\partial r}$$

Sites of supersonic downflow are also those of very high vertical vorticity. The cores of the vortex tubes are evacuated, with centripetal acceleration balancing that due to the inward directed pressure gradient. Buoyancy forces are maximum on the tube periphery due to mass flux convergence.

- Force and energy balance at precise locations in domain of interest
- Visualization and quantitative analysis on interactive time scales needed
- Secondary quantities are not a priori determinable

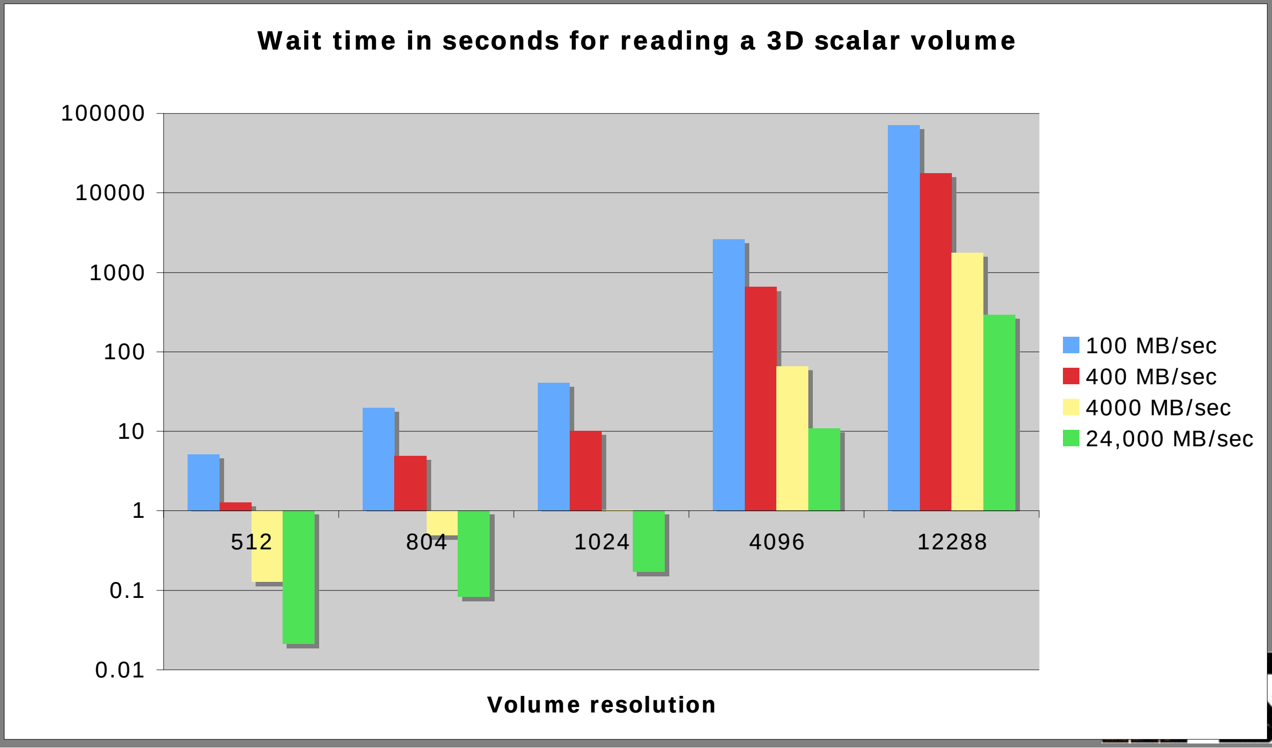
Visualization for investigation.

What is meant by *interactive* analysis?

Definition: A system is *interactive* if the time between a user event and the response to that event is short enough maintain my full attention

If the response time is…

- 1-5 seconds : I'm engaged
- 5-60 seconds : I'm tapping my foot
- 1-3 minutes : I'm reading email
- > 3 minutes : I've forgotten why I asked the question!

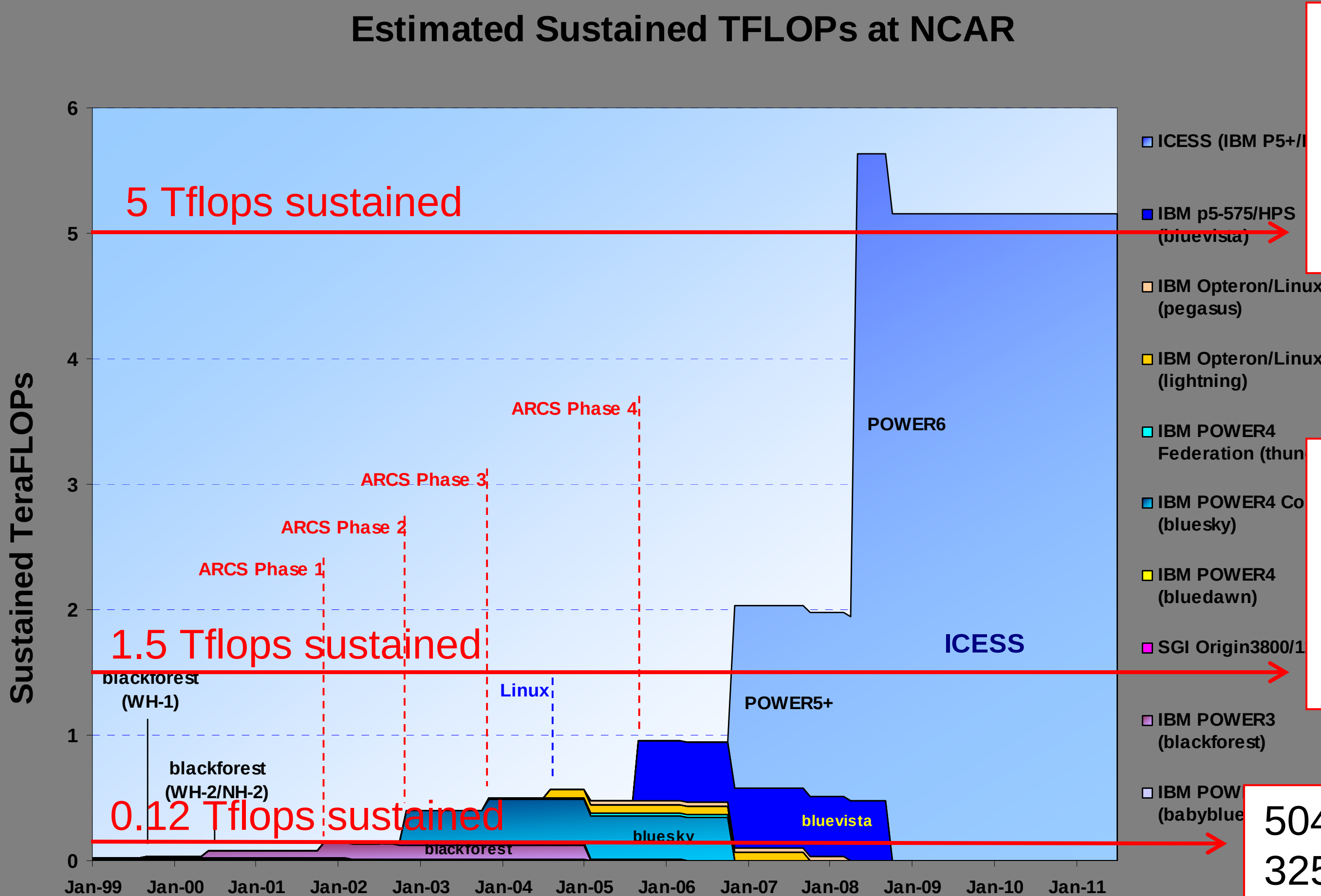


The postdoc class problem (sustained effort on 1/10 of the machine):

1 Pflop sustained

8200^2 x 65536
145,000,000 pe hrs
(50,000/500,000 6.0GHz pe,
4 - 16 months)
85000TB data 16394^3

85 petabytes



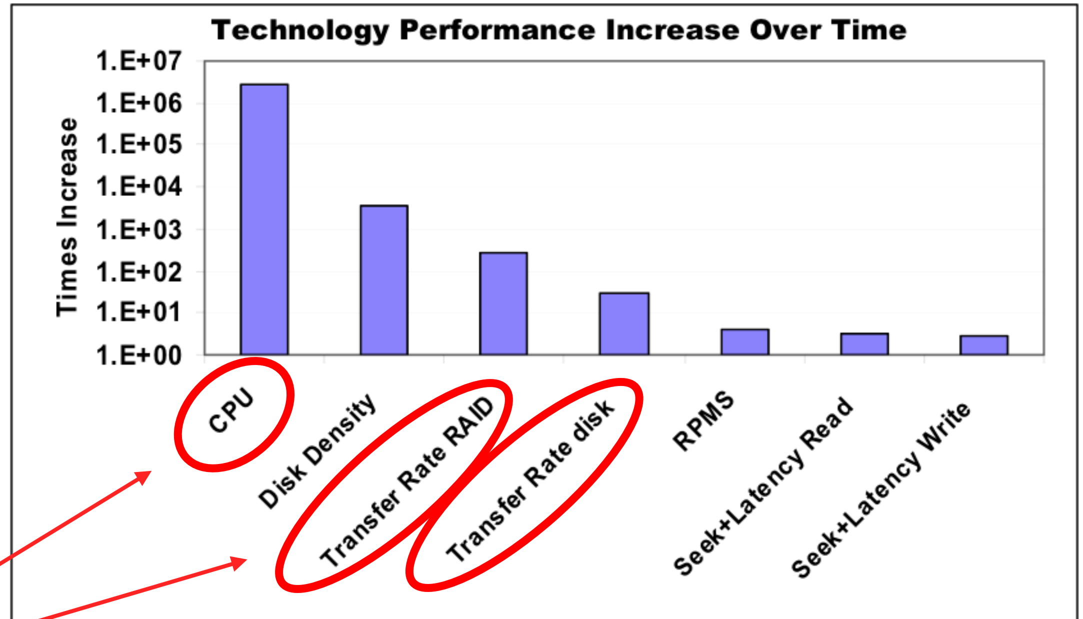
1650^2 x 8192
930,000 pe hrs
(320/3200 4.0GHz pe,
4 - 16 months)
430TB data 2814^3

1260^2 x 4096
460,000 pe hrs
(160/1600 1.9GHz pe,
4 - 16 months)
125TB data 1866^3

504^2 x 2048 (483 time steps)
325,000 pe hrs
(112/1160 375MHz pe,
4 - 16 months)
10TB data 804^3

Not all technologies advance at the same rate:

Technology performance increases from 1977 to 2006



Increases in processor speed and disk density have both grown at alarming rates while disk transfer rates have only grown modestly and disk agility has hardly improved at all.

High End Computing Revitalization Task Force (HEC-RTF), Inter Agency Working Group (HEC-IWG) File Systems and I/O Research Workshop 5

Orders of magnitude difference between improvements in CPU speed and IO bandwidth

Balance between compute and IO is changing rapidly

A posteriori analysis and visualization of the data volumes can not keep up with batch capabilities:

- Multi/*insanely-large-number* processor simulation vs. single/dual/quad/*small-number* processor analysis and visualization

THE HOPELESS SITUATION THEOREM:
Doubling the resources available to a batch execution will increasingly overload a corresponding doubling of the resources available for interactive *analysis* and visualization.

Data decimation before/during analysis/visualization is essential.

Caveat:
For petascale computations, data decimation BEFORE batch output may be essential.

16384^3 simulation will require decimation by factors of about 32^3 for interactivity

VAPOR
Visualization & Analysis Platform

Clyne, J. and Rast, M. "A prototype discovery environment for analyzing and visualizing terascale turbulent fluid flow simulations", in proceedings of Visualization and Data Analysis 2005, pp. 284-294, January 2005.

http://www.vapor.ucar.edu/

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Capabilities:

- 3D volume rendering
    - interactive transfer function editor
- Bidirectional coupling to analysis software
- Vector field lines: static and time dependent
- Time series animation
- Viewpoint and lighting control
- Two-dimensional contour at arbitrary angle, iso-surface
- Planar/one-d image probe at arbitrary angle
- Lagrangian tracer – spot noise field advection

Data grid types:

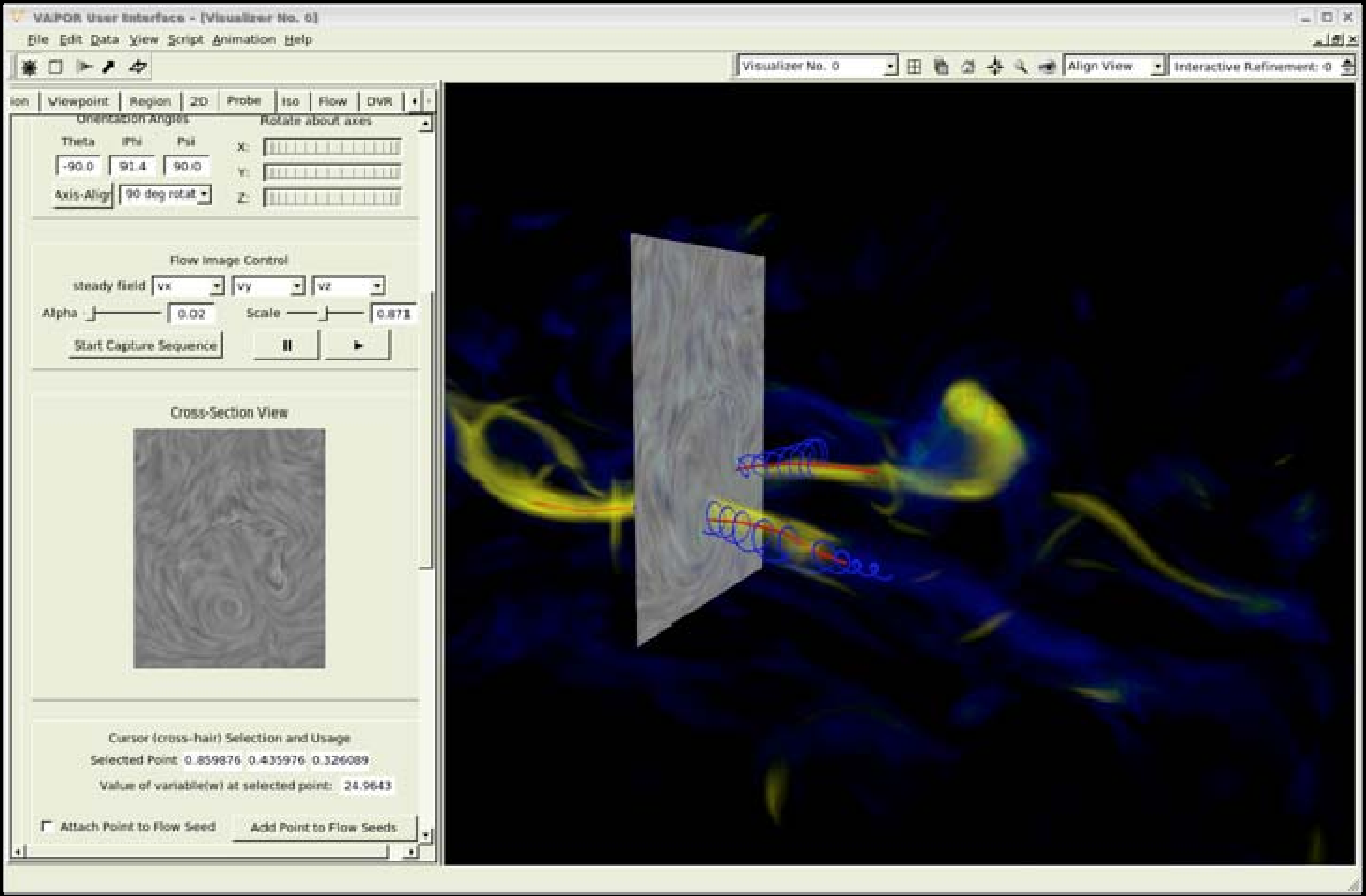
fully supported:
- Cartesian
- Terrain following/non-uniform *z* (WRF)
- Block structured AMR

prototype:
- Spherical
- Berger & Colella AMR (ENZO)

LASP

APS

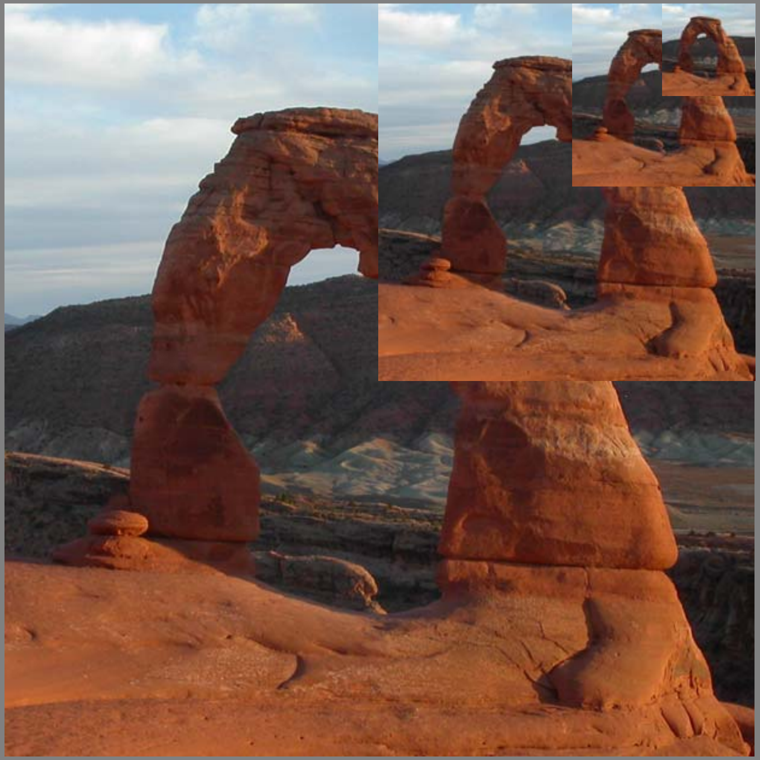
GUI Interface:



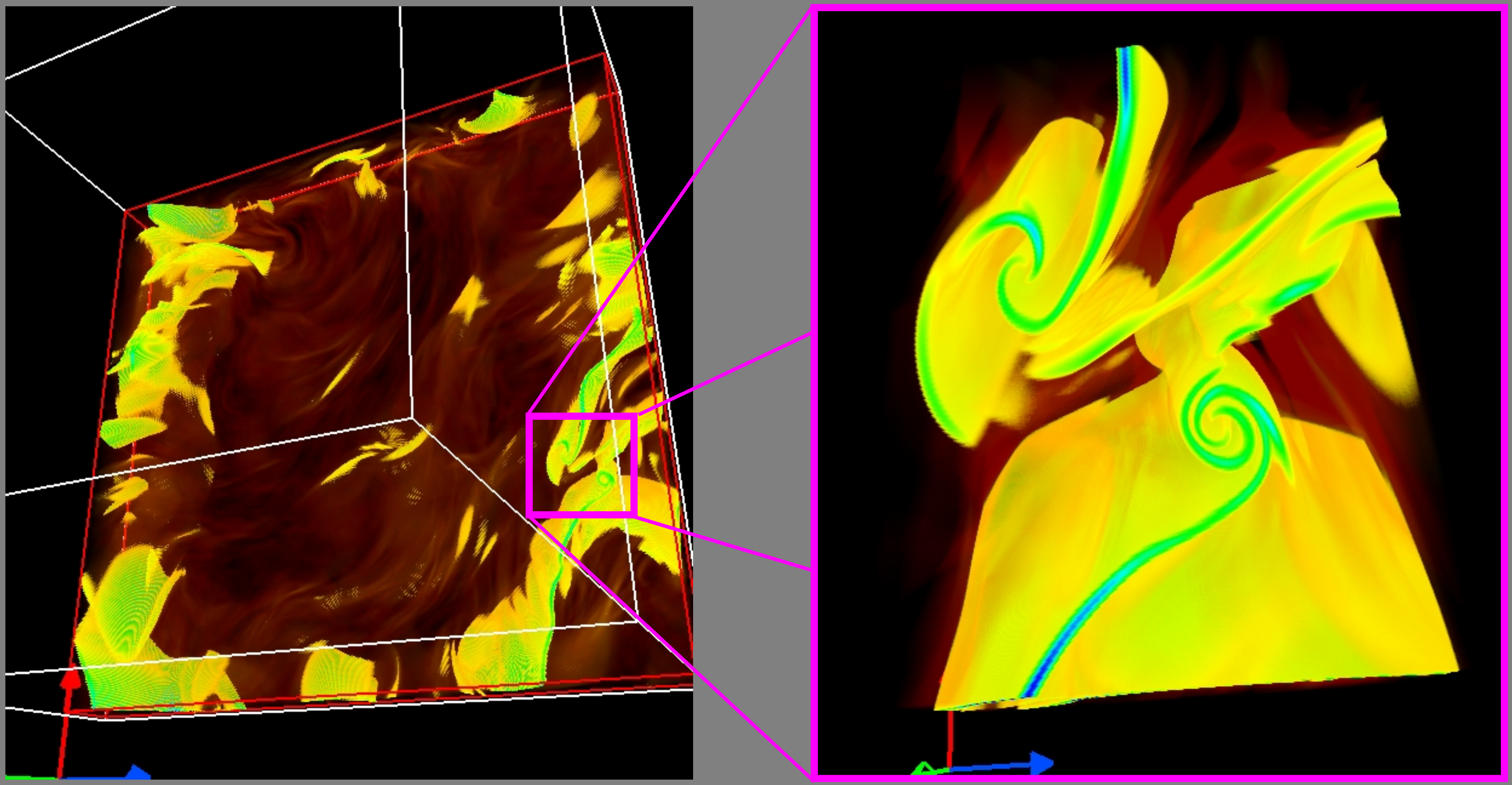
Data decimation strategies:

1. Multi-resolution data access via wavelet representation

- Wavelet properties:
  - Permit hierarchical data representation
  - Invertible and lossless (subject to floating point round off errors)
  - Numerically efficient (*O*(n))
    - forward and inverse transform
  - No additional storage cost



2. Efficient region of interest extraction



Full domain, 1/64th resolution

1536^3 MHD

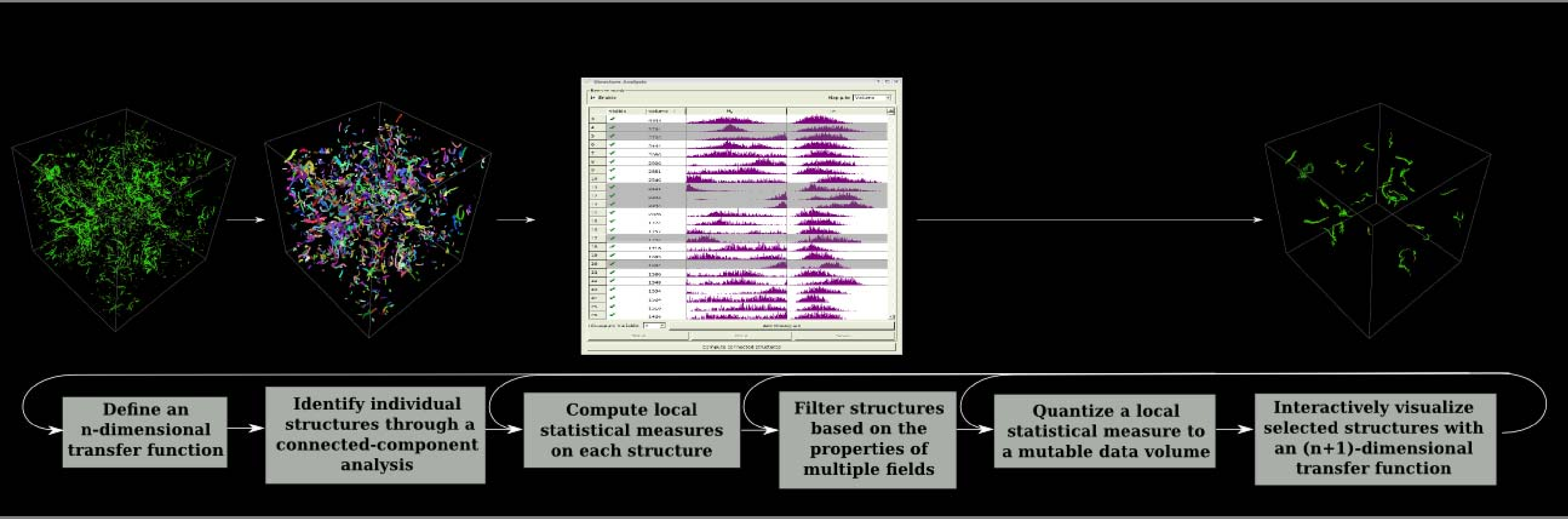
Mininni, 2006

Sub-domain, full resolution

Often full grid resolution is only required for a small spatial/temporal region of the domain

3. "Structure" extraction and analysis

- Defined via multivariate transfer function
- Extracted as connected components
- Statistical property interface
- Interactively iterate
- Export geometry or statistics for further analysis



1024^3 Taylor-Green Flow (courtesy Pablo Mininni)

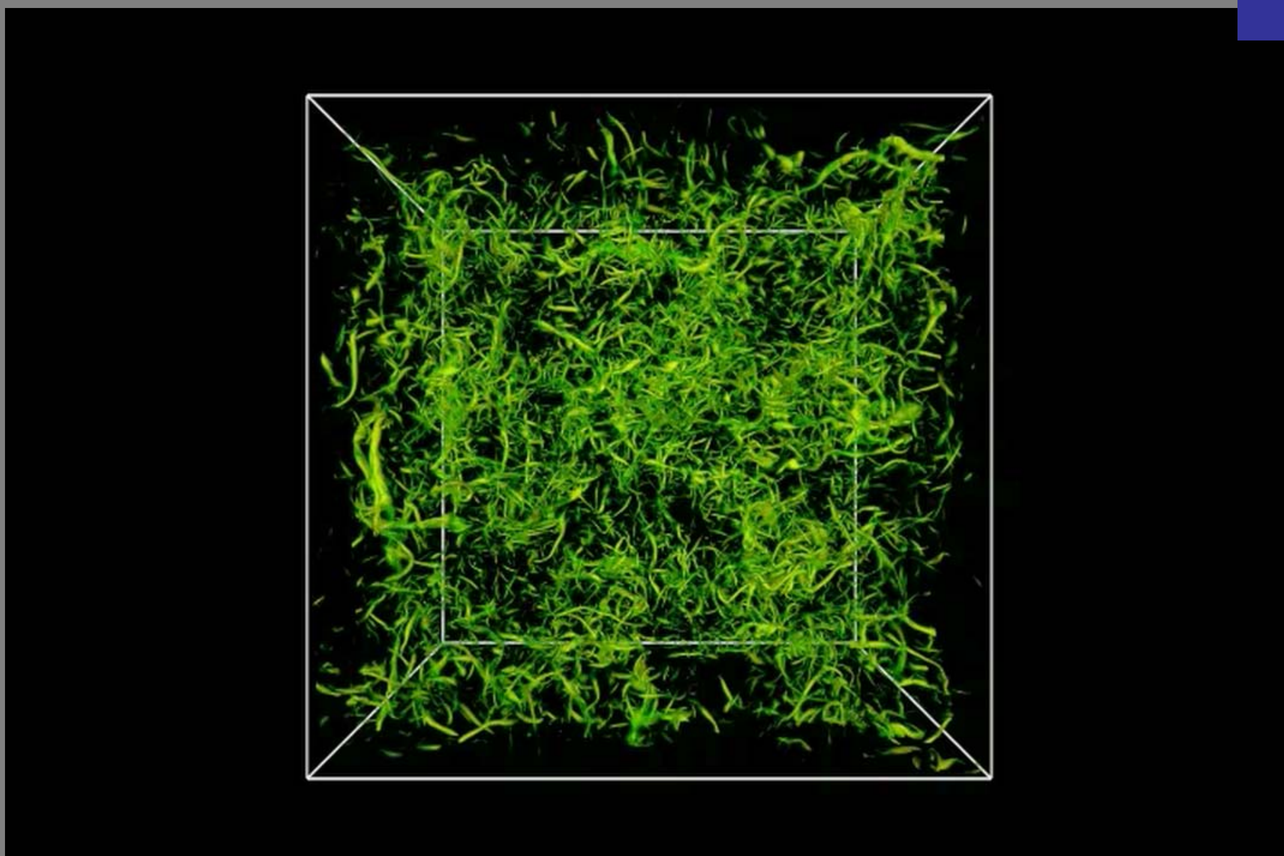
$R_\lambda \sim 1300$

Incompressible Navier-Stokes:

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + \vec{u}\cdot\nabla\vec{u}\right) = -\nabla p - \nu\nabla^2\vec{u} + \vec{f}$$

Taylor-Green Flow:

$$f_x = f_0 \sin(u_x)\cos(u_y)\cos(u_z)$$
$$f_y = -f_0 \cos(u_x)\sin(u_y)\cos(u_z)$$
$$f_z = 0$$

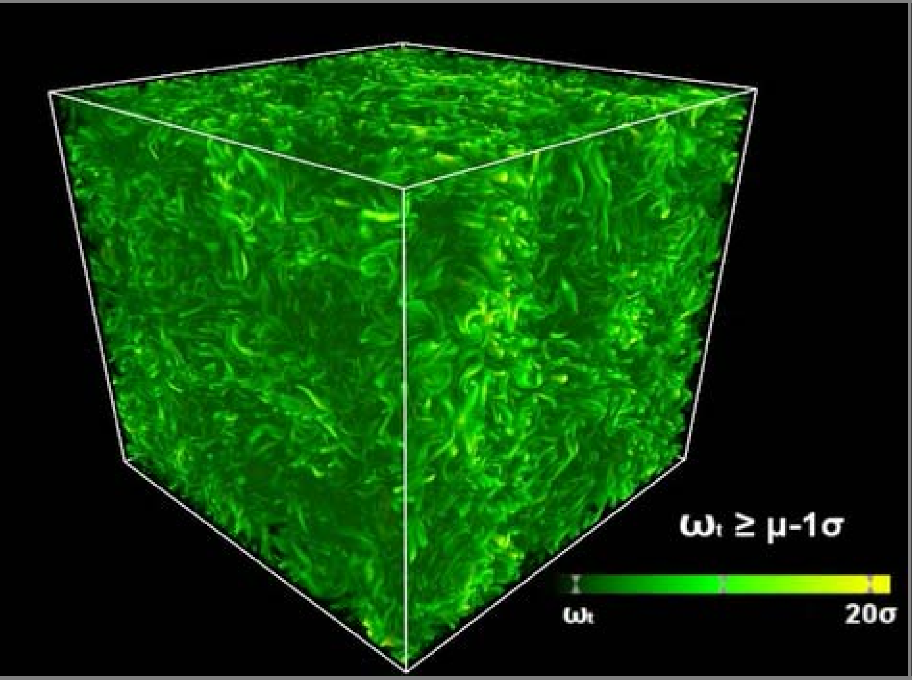


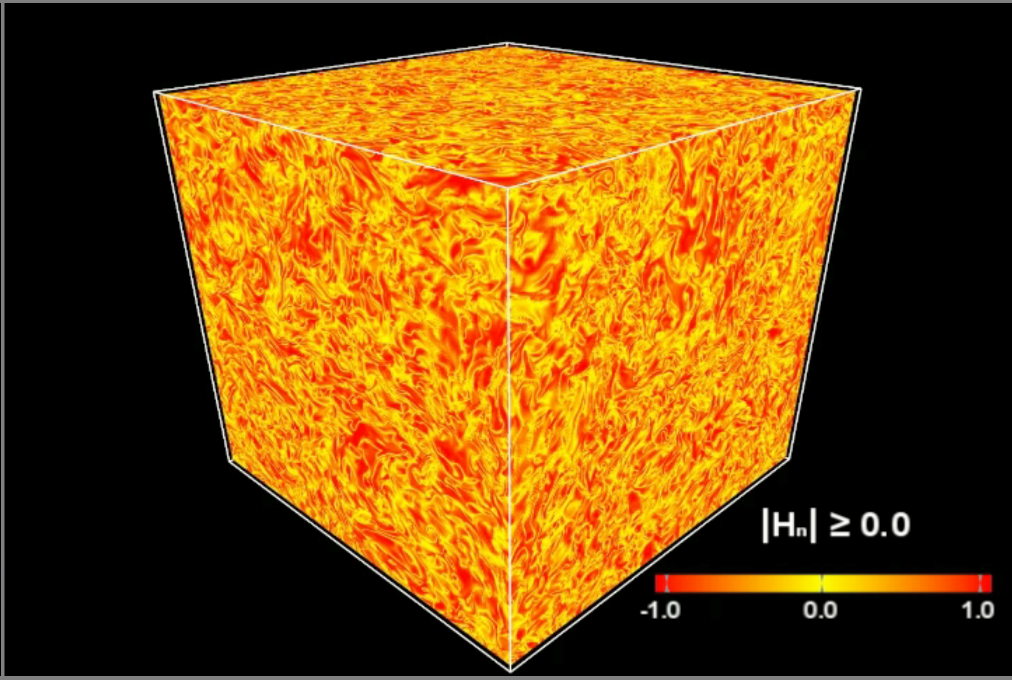
Vorticity:

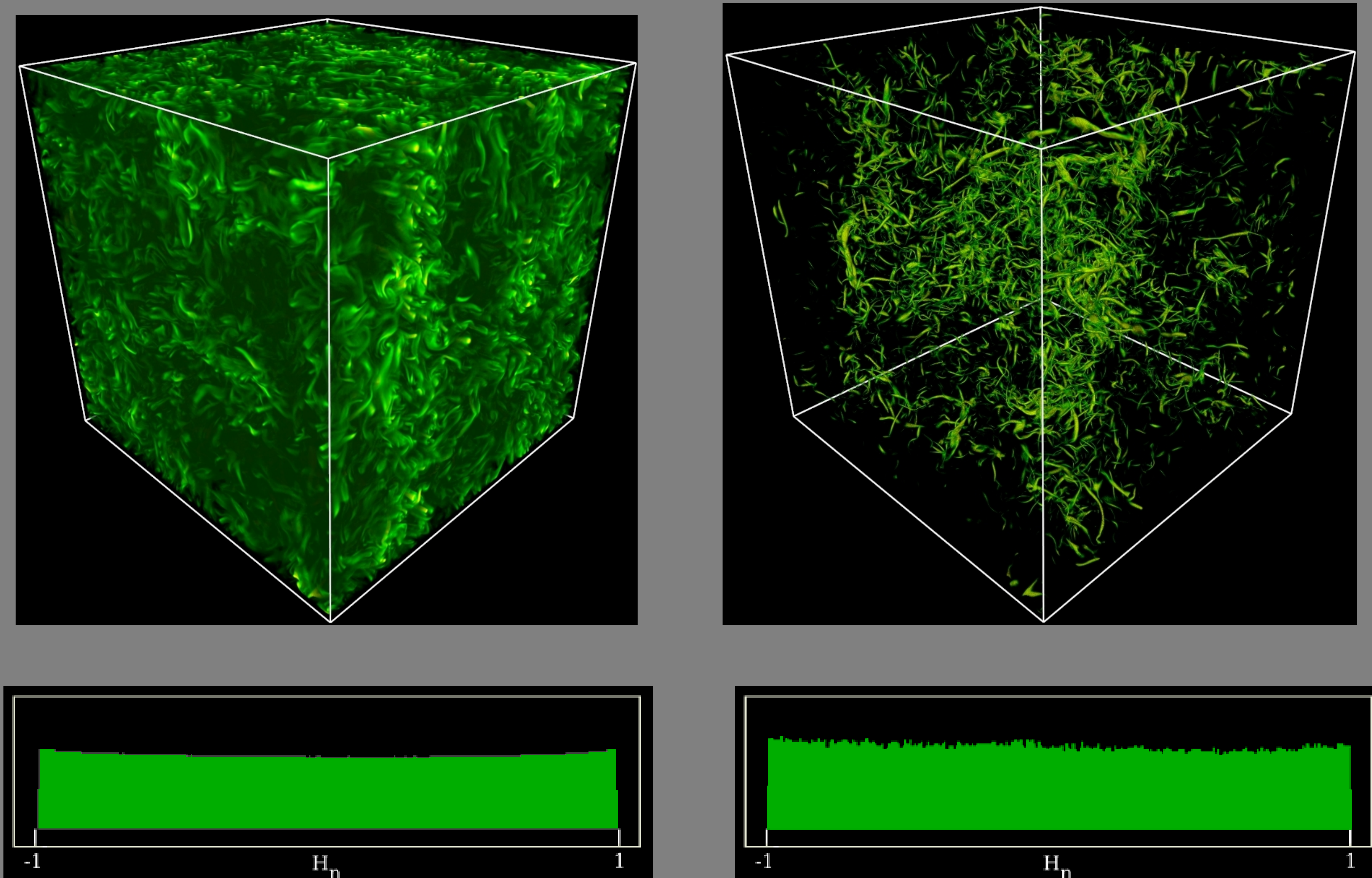
$$\vec{\omega} = \nabla \times \vec{v}$$

Helicity:

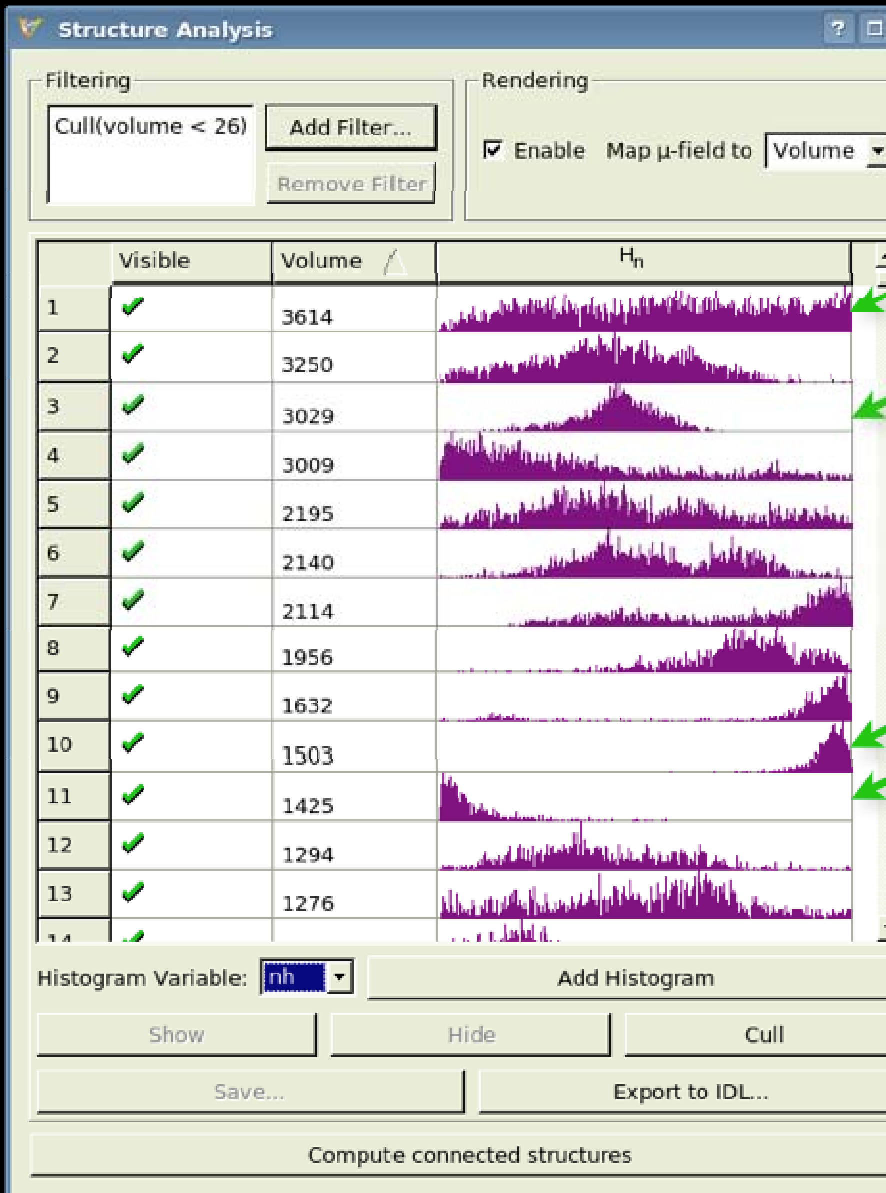
$$H_n = \frac{\vec{v} \cdot \vec{\omega}}{|\vec{v}||\vec{\omega}|}$$

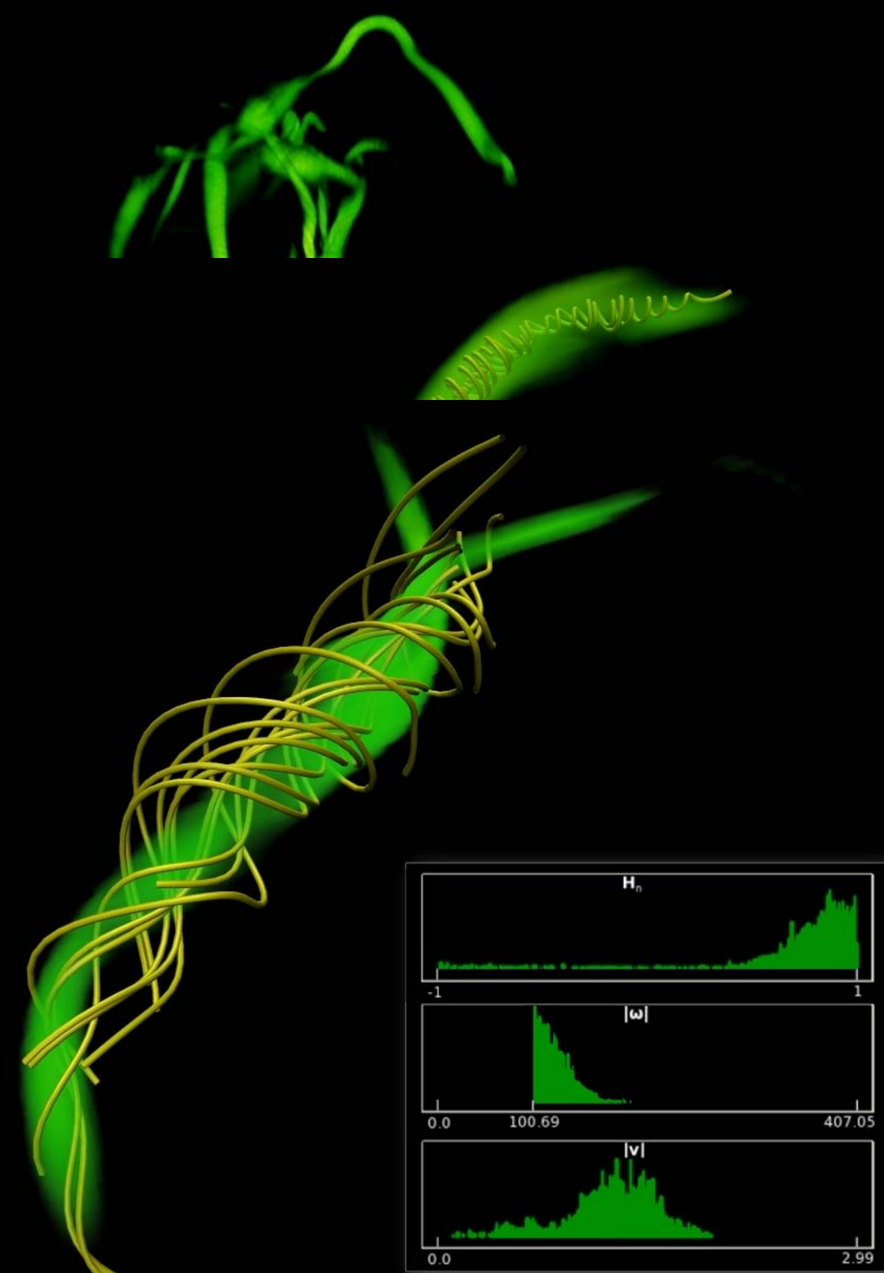




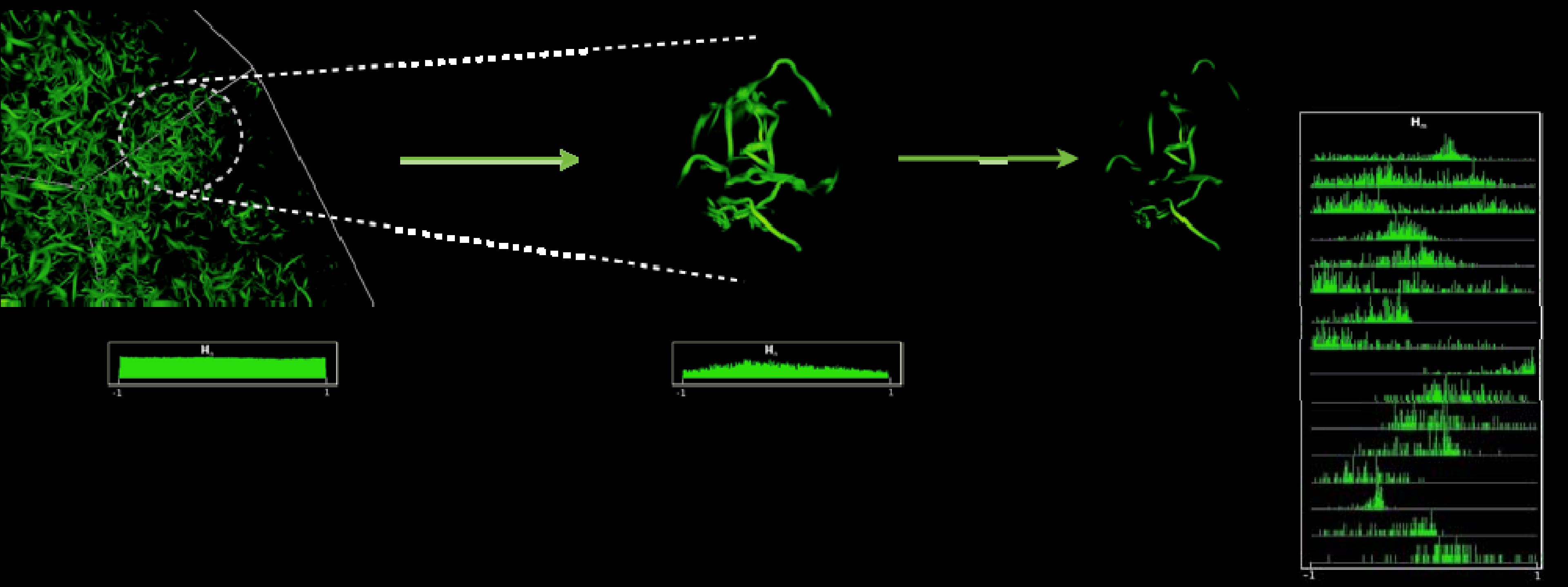

-1
H_n
1
-1
H_n
1

Feature local histograms:





Progressive refinement of data structures and analysis of properties



Stellar dynamo simulations
Toroidal magnetic field
(courtesy Ben Brown)