# Ideas from the year-long Warwick Turbulence Symposium

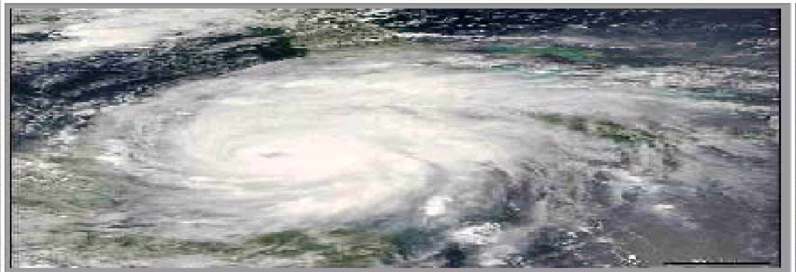
*Sergey Nazarenko, Warwick, UK*

http://www.maths.warwick.ac.uk/~snazar/turb_symp/WTS.html

WARWICK

# Warwick Turbulence Symposium

## *2005/2006 Academic Year-Long*



WTS 2005/2006

Warwick Mathematics Institute WMI

| | |
|---|---|
| Principal organiser: | Sergey Nazarenko |
| Local co-organisers: | Dwight Barkley<br>Robert Kerr<br>Oleg Zaboronski |
| **CO-organisers of Joint Events:** | Quantum/Cosmological turbulence: **Peter McClintock, Grisha Volovik, Martin Wilkens**<br>Environmental/Geophysical turbulence: **Ian Castro (Soton), Darryl Holm & Christos Vassilicos (ICL)**<br>MHD turbulence: **Sergei Molokov, Andre Thess, Thierry Alboussiere and Mike Proctor** |
| *Sponsored by EPSRC.* | *Hosted by the Mathematics Research Centre* |

http://www.maths.warwick.ac.uk/~snazar/turb_symp/events.html

*Turbulence Prelude* (April 25, 2005) Organiser: Sergey Nazarenko.

## Workshops.

These workshops form the backbone of the symposium.

*Singularities, coherent structures and their role in intermittent turbulence (September 9-17, 2005), organisers: Xinyu He, Bob Kerr, Sergey Nazarenko and Oleg Zaboronski.*

*Dynamical Systems, Fluid Dunamics and Turbulence, organised by Dwight Barkley* and Laurette Tuckerman *(October 31 to November 2, 2005)*

*Universal features in turbulence: from quantum to cosmological scales (December 5-10, 2005) Organisers: STOCHDYN: Peter McClintock, Warwick: Sergey Nazarenko, COSLAB: Grisha Volovik, QUDEDIS: Martin Wilkens*

*Environmental Turbulence: from clouds through the ocean (March 13-18, 2006), joint with the EPSRC Platform grant on Turbulence, ONR Global, NERC. Organsers: Ian Castro (Southampton), Darryl Holm (Imperial), Bob Kerr (Warwick), Sergey Nazarenko (Warwick) & Christos Vassillicos (Imperial).*

*Joint Workshop and Graduate summer school: Instabilities and Turbulence in MHD flows; (26th June - 1st July 2006) organised* ***by Sergei Molokov, Sergey Nazarenko, Andre Thess, Thierry Alboussiere and Mike Proctor***

*Non-equilibrium statistical mechanics & turbulence (LMS/EPSRC course: 10-14 July, workshop: July 15-21, 2006), organisers Sergey Nazarenko and Oleg Zaboronski.*

## Follow-up events.

*Continuing Euler (Sept 1, 2006); organised by Bob Kerr.*

**Navier-Stokes Data Analysis (October 2006)** Organisers: Robert Kerr and Xinyu He

# Plan

- Pick ideas relevant to our discussion.
- Classical turbulence: low dissipation in crucial in a broad range of important problems, e.g. geophysical (convection, stable stratification, rotation), singularity/reconnection/intermittency.
- Quantum turbulence: poorly studied fundamental mechanisms of forcing, cascade and dissipation (K41, reconnections, Kelvin waves, phonon radiation).
- Desperate need for better numerics, finer experimental insturmentation.

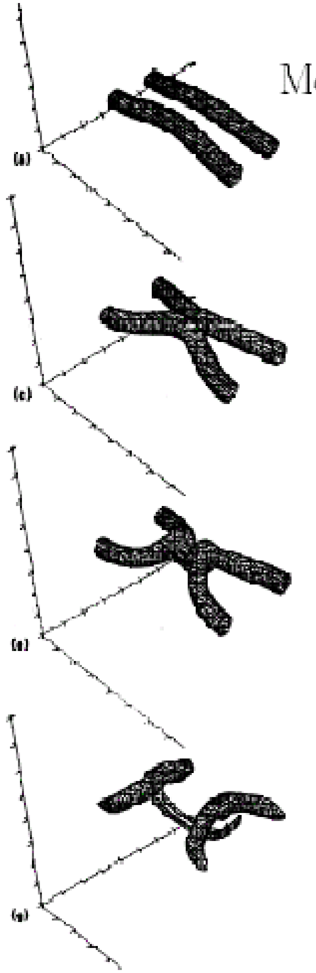
# Sept 2005: Singularities and Coherent structures in turbulence

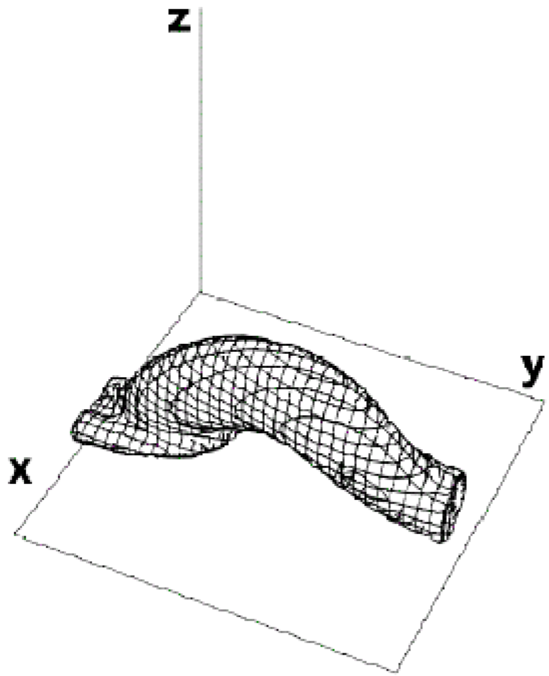
# Relevant problems?

- Classical fluids: singularity formation & vortex reconnections.
- Quantum fluids: reconnection of singular vortices and sound radiation; vortex annihilation and creation of coherent phase/condensate; strings and cosmological (electro-weak) phase transitions.

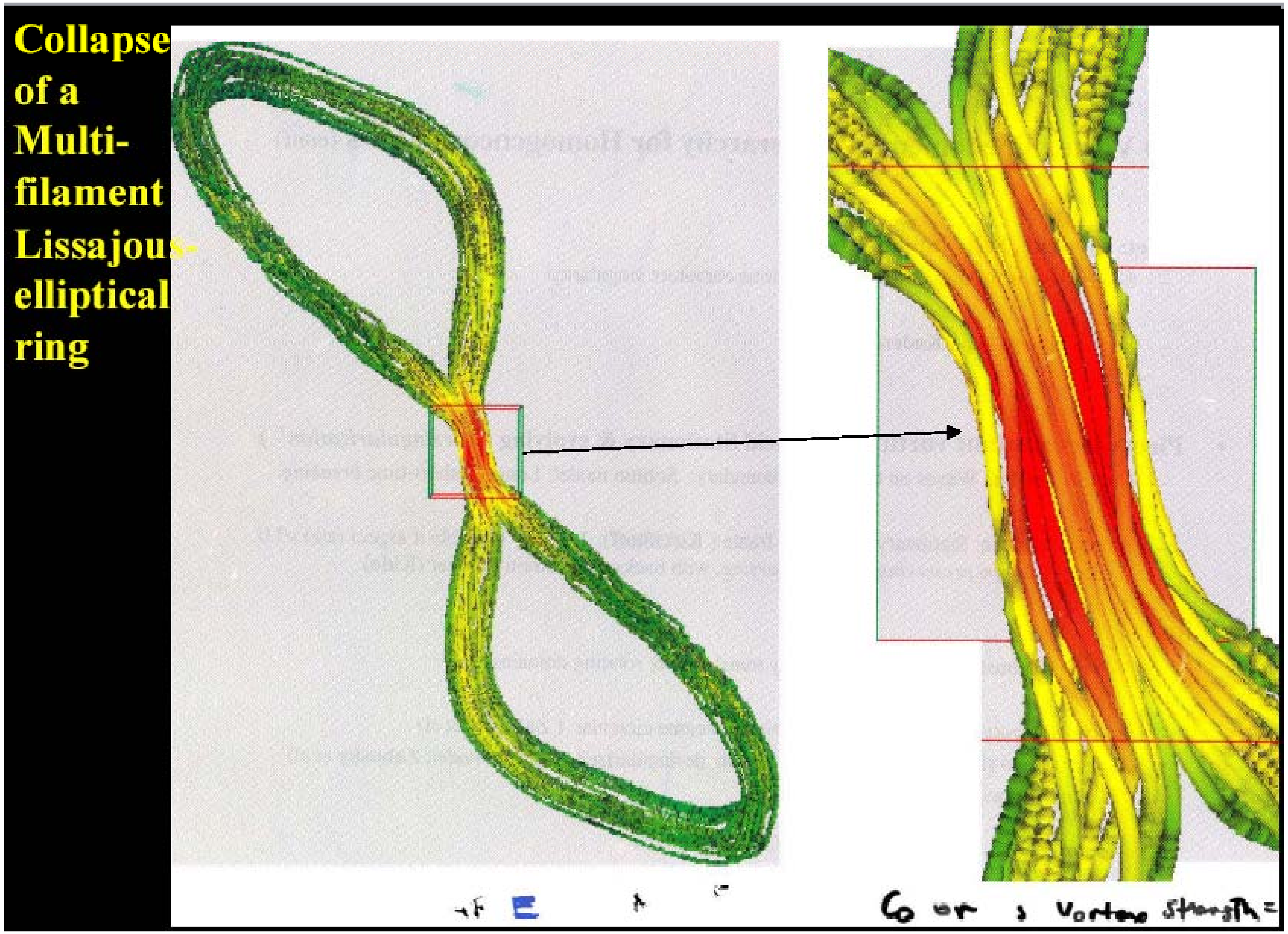
# Classical vortex reconnection

Melander and Hussain, 1989.

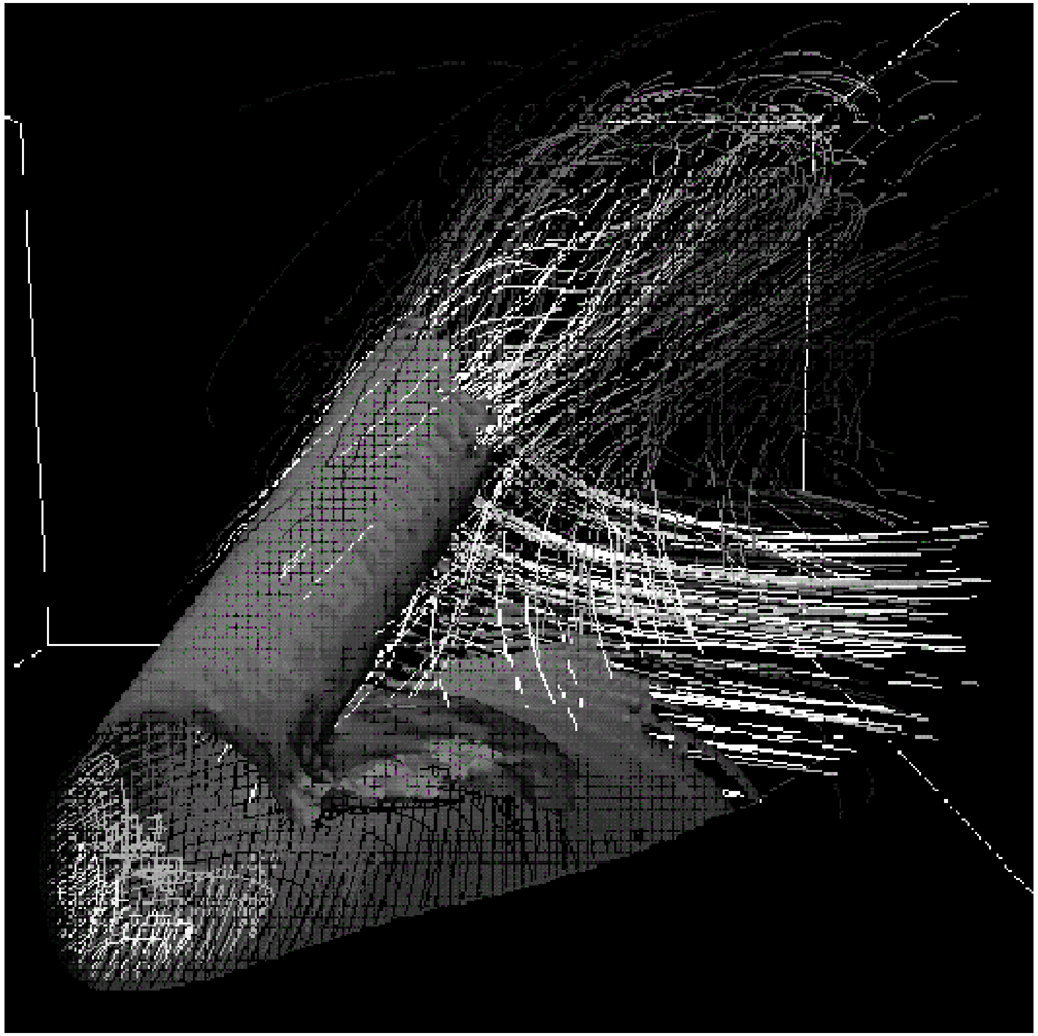




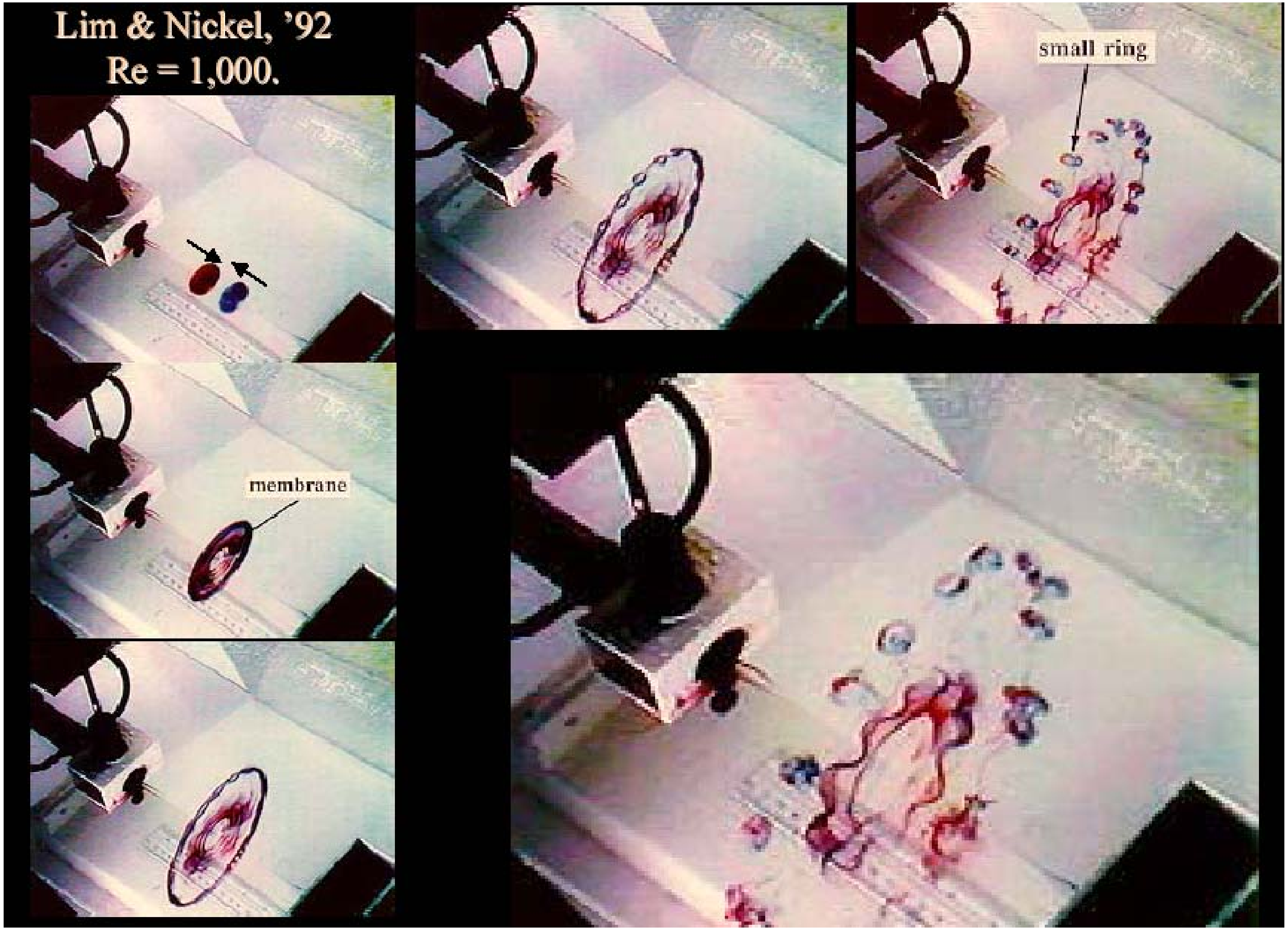
# Zabusky's talk. Bio-Savart simulations



# Kerr’s talk

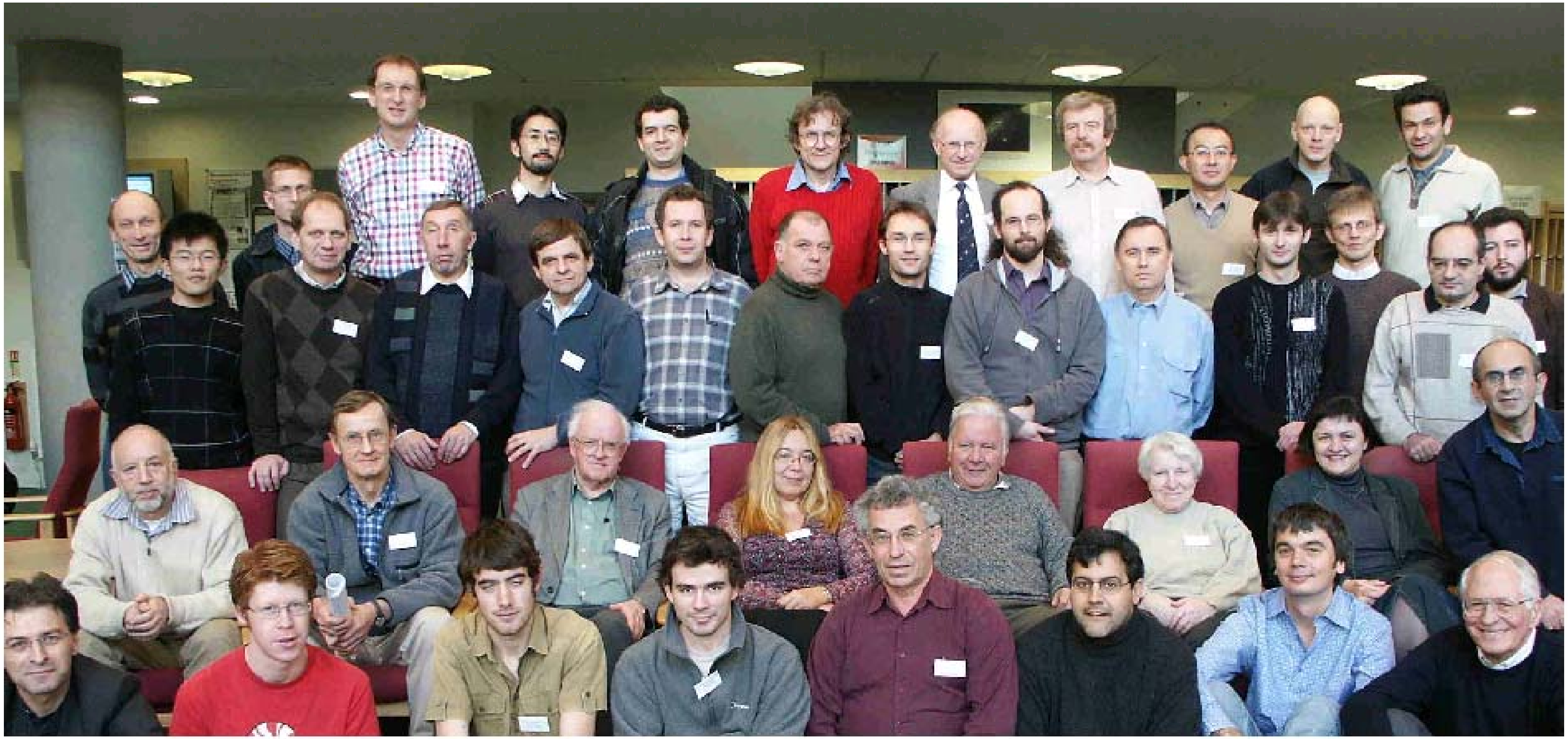


Ongoing controversy pro and contra singularity (Kerr vs Hou).




# Can you do this in Helium?

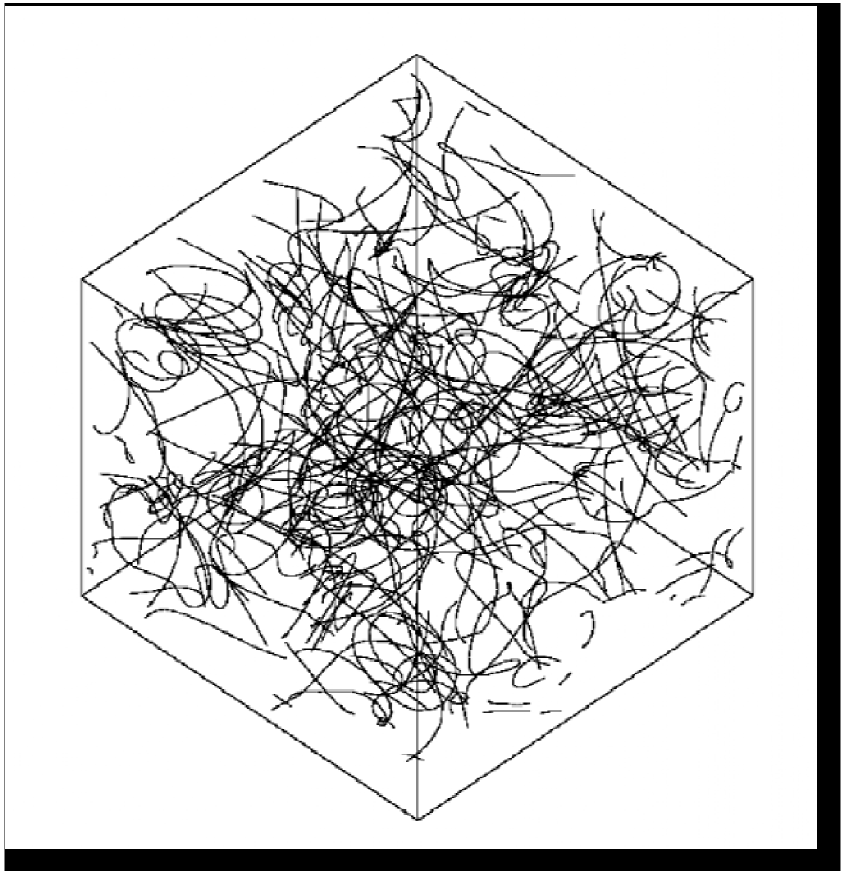
# Dec. 2005:
# Universal features in turbulence, - from quantum to cosmological scales



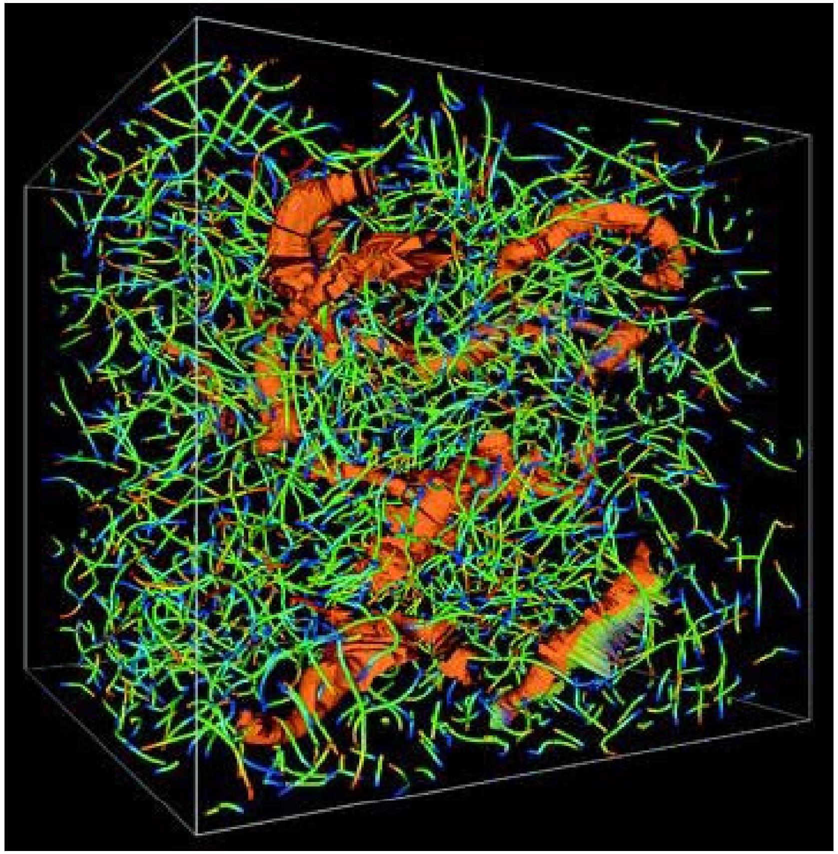
Workshop Timetable

# Barenghi's talk. Challenges in numerics (also Kivotides)

Superfluid turbulence

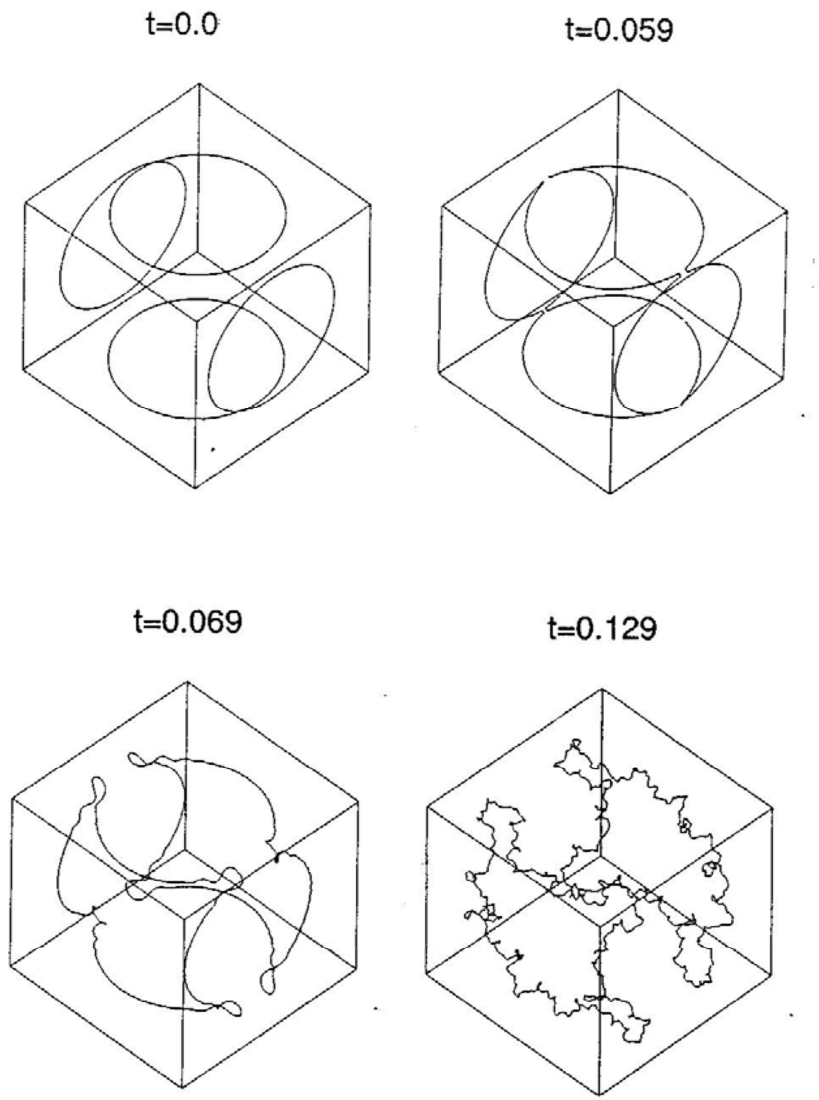


Classical turbulence



(Kida)

# Kelvin waves cascade




reconnections

↓

cusps

↓

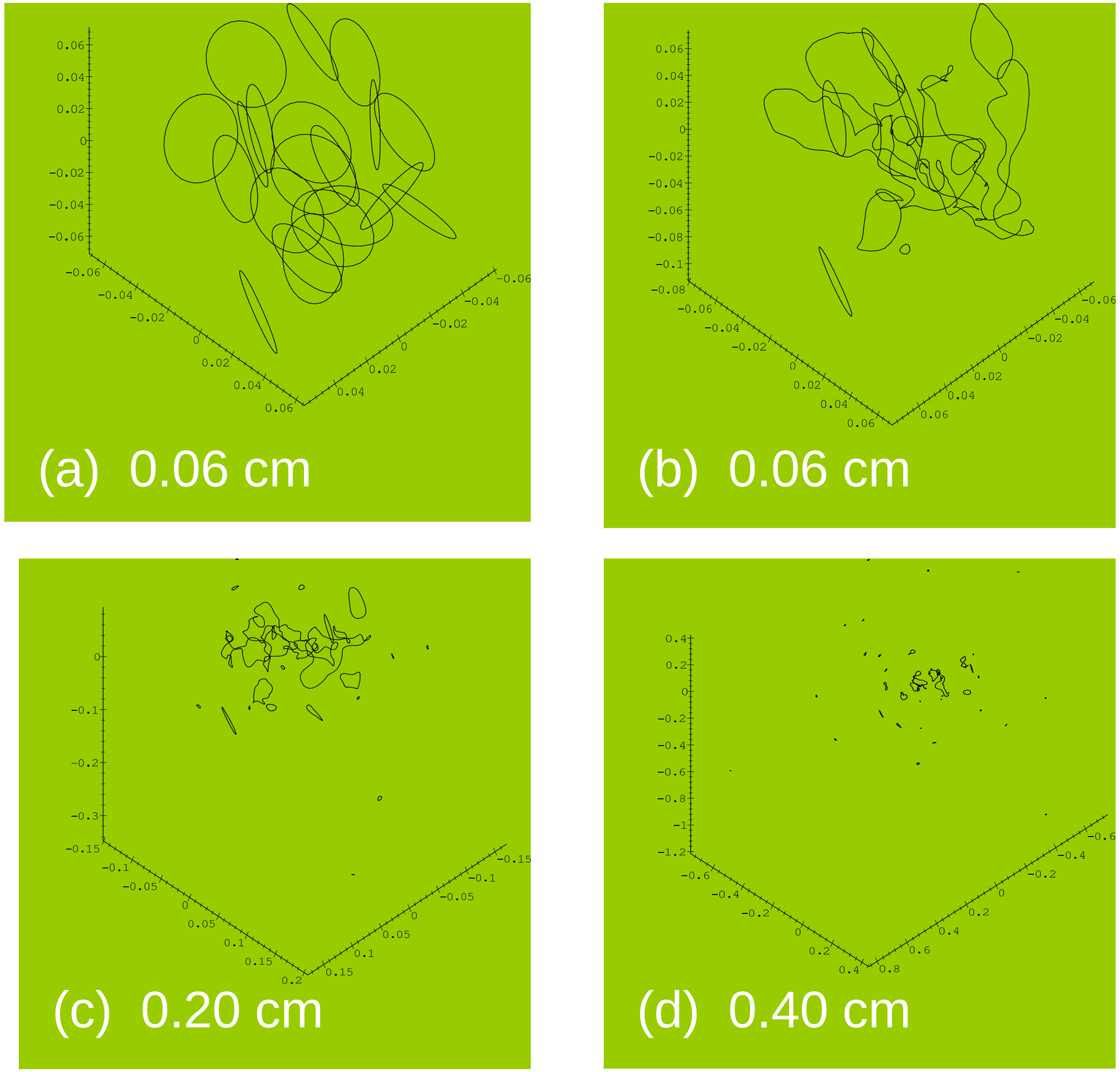
high k

↓

sound

Kivotides, Vassilicos, Samuels & Barenghi,
Phys. Rev. Lett. 86, 3080 (2001)
Vinen, Tsubota & Mitani,
Phys. Rev. Lett. 91, 135301 (2003)
Kozik & Svistunov,
Phys. Rev. Lett. 92, 035301 (2004)

# “Evaporation” of a packet of vortex loops

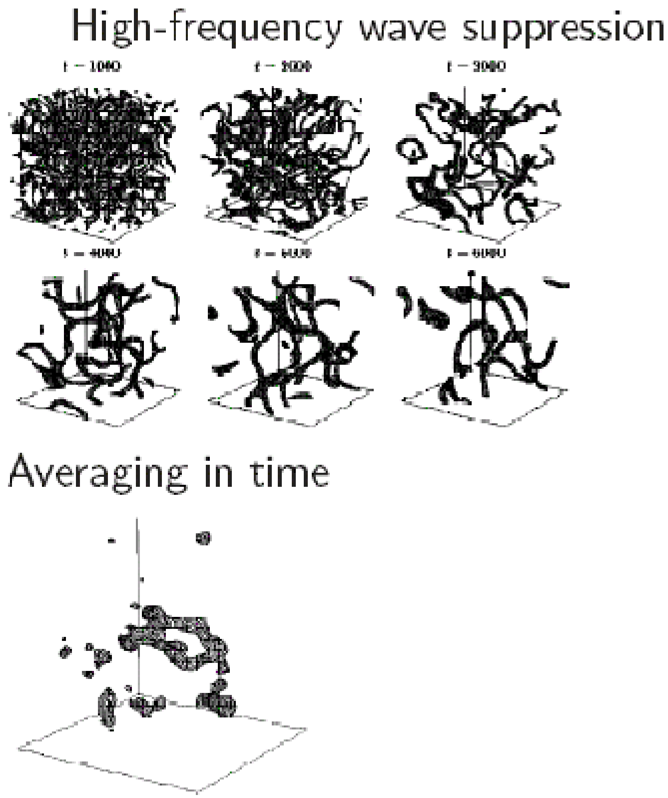


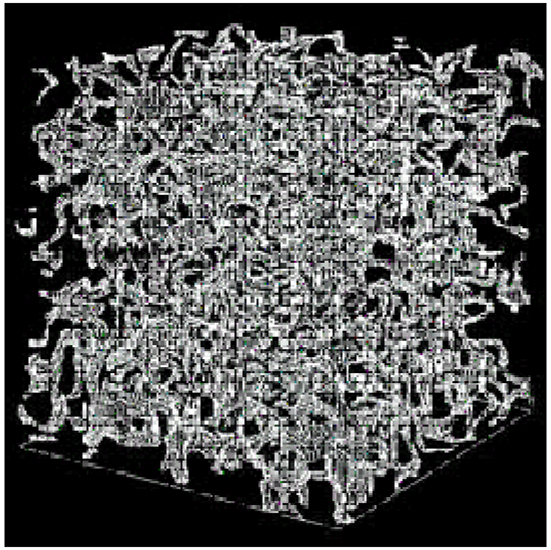

Radius of vortex cloud vs time agrees with experiment at Lancaster

Barenghi & Samuels, Phys. Rev. Lett. 89, 155302 (2002)

Berloff’s talk: vortex annihilation & formation of coherent phase. Kibble-Zurek phase transition. Cosmic strings. (also Volovik, Pickett, Nazarenko, Golov)

**Evolution of topological defects**

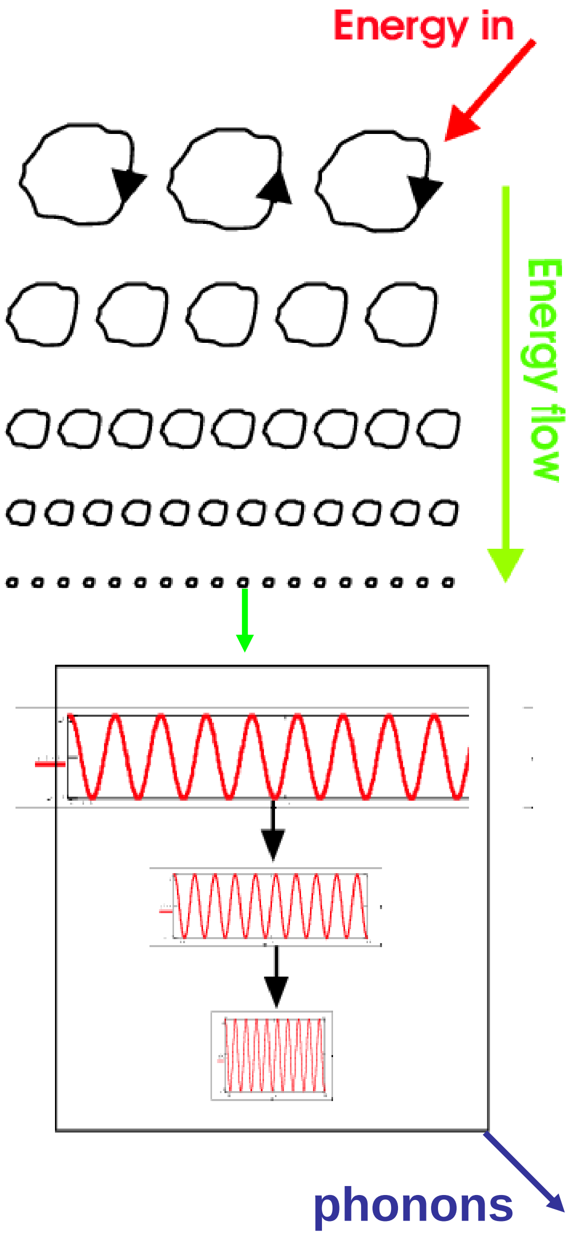


- Can we study this in a large volume of Helium?

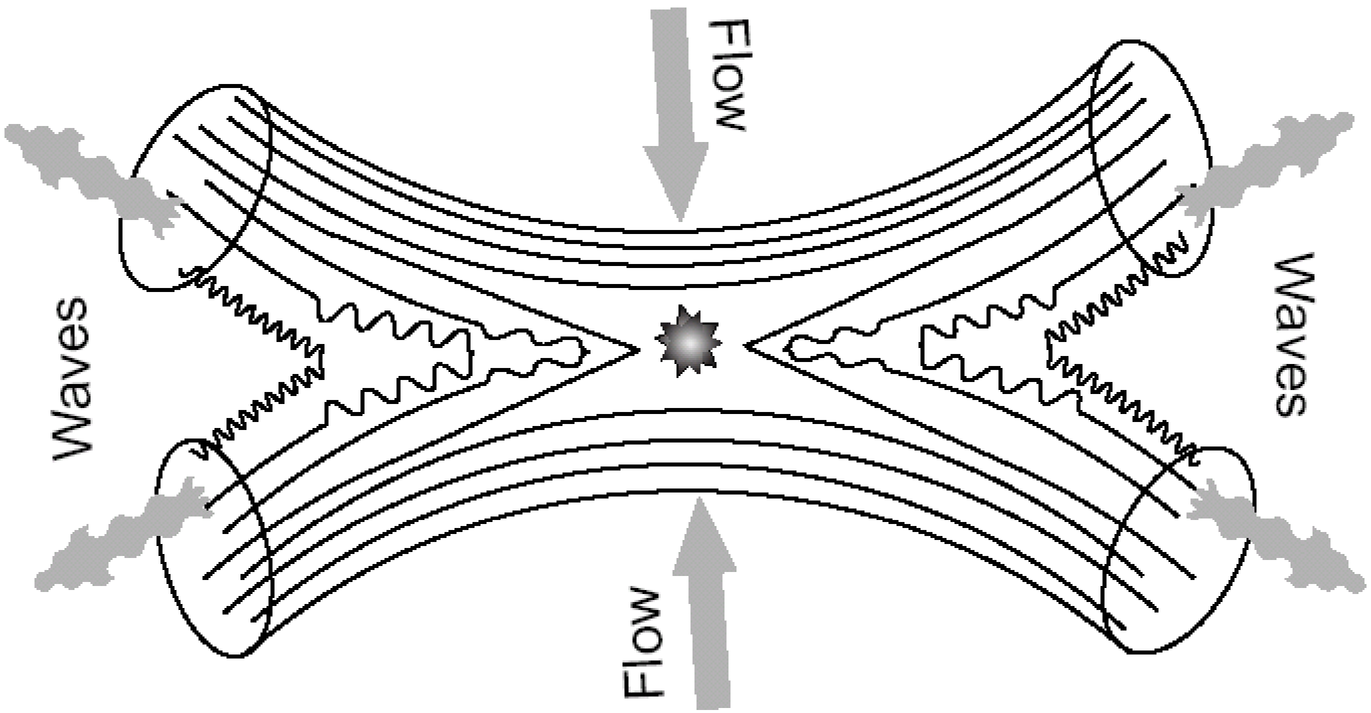
# Vinen's talk. The overall picture (of quantum turbulence)?

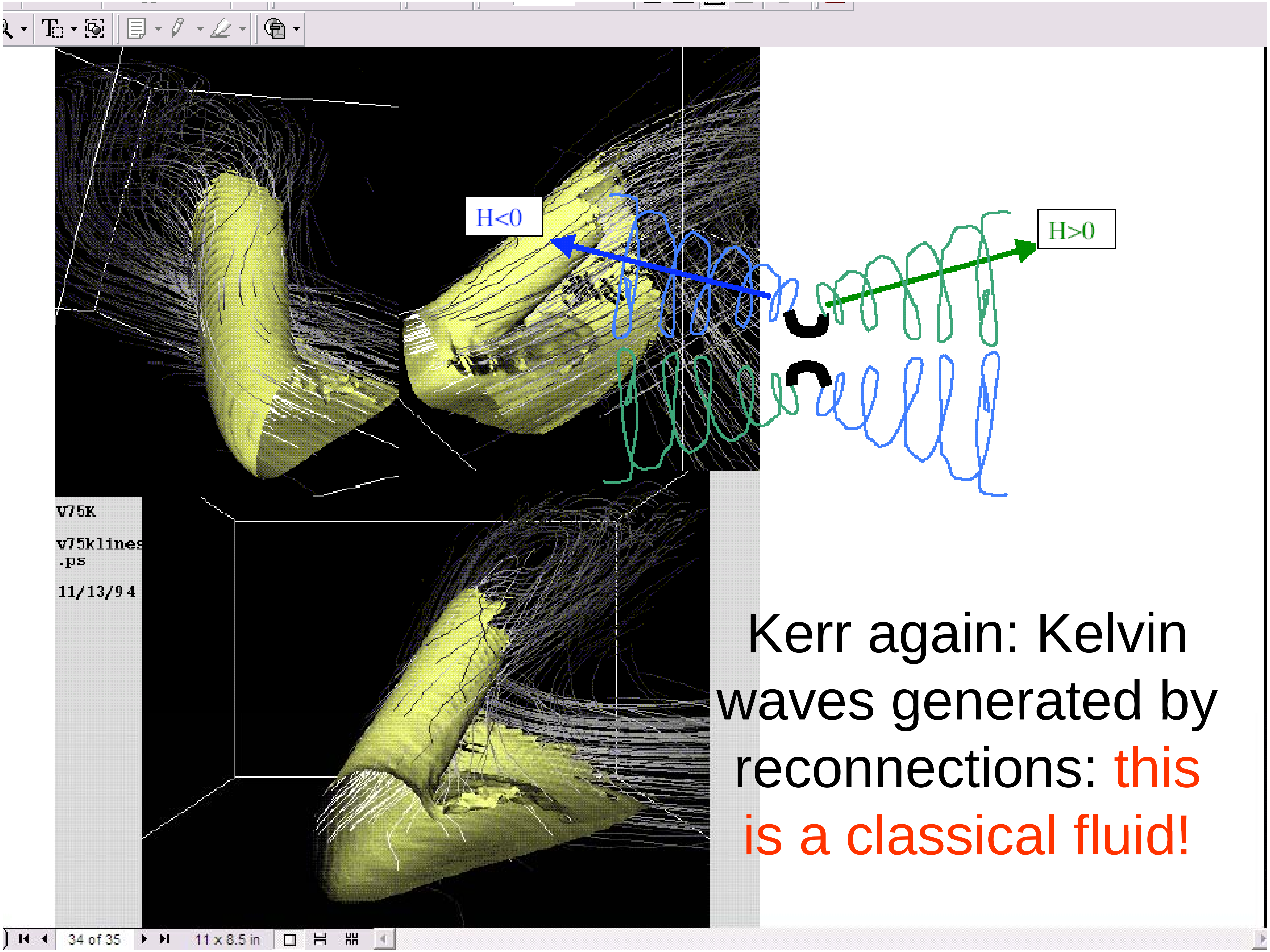
- So perhaps we have the following picture of the evolution of turbulence in superfluid $^4$He at a very low temperature.  Energy flows to smaller and smaller length scales:
  - First in a classical Richardson cascade
  - Followed by a Kelvin-wave cascade
  - With final dissipation by radiation of phonons
  - The length scale (= vortex spacing) at which we change from Richardson to Kelvin-wave cascades adjusts itself automatically to achieve the correct dissipation.
- $^3$He-B may be similar except that energy can be lost from the Kelvin waves into quasi-particle bound states in the cores of the vortices (Caroli-Matricon states),  which do not exist in $^4$He.  This occurs at a frequency much smaller than that required for phonon radiation.



# Reconnecting vortex bundles emitting Kelvin waves.

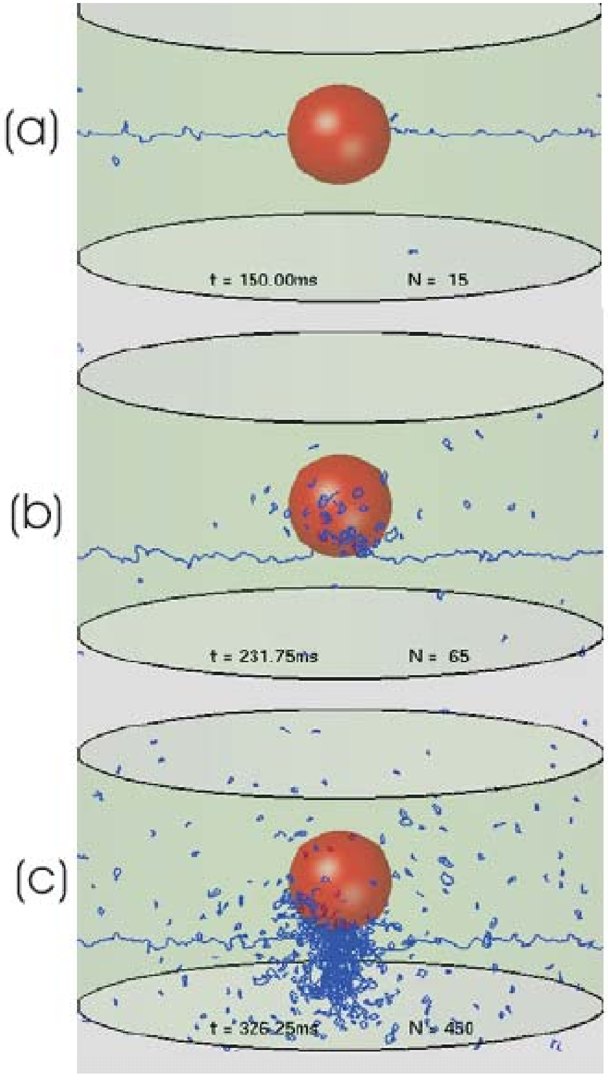
Polarised vortex tangles generated by “classical” means have never been computed before: numerical challenge





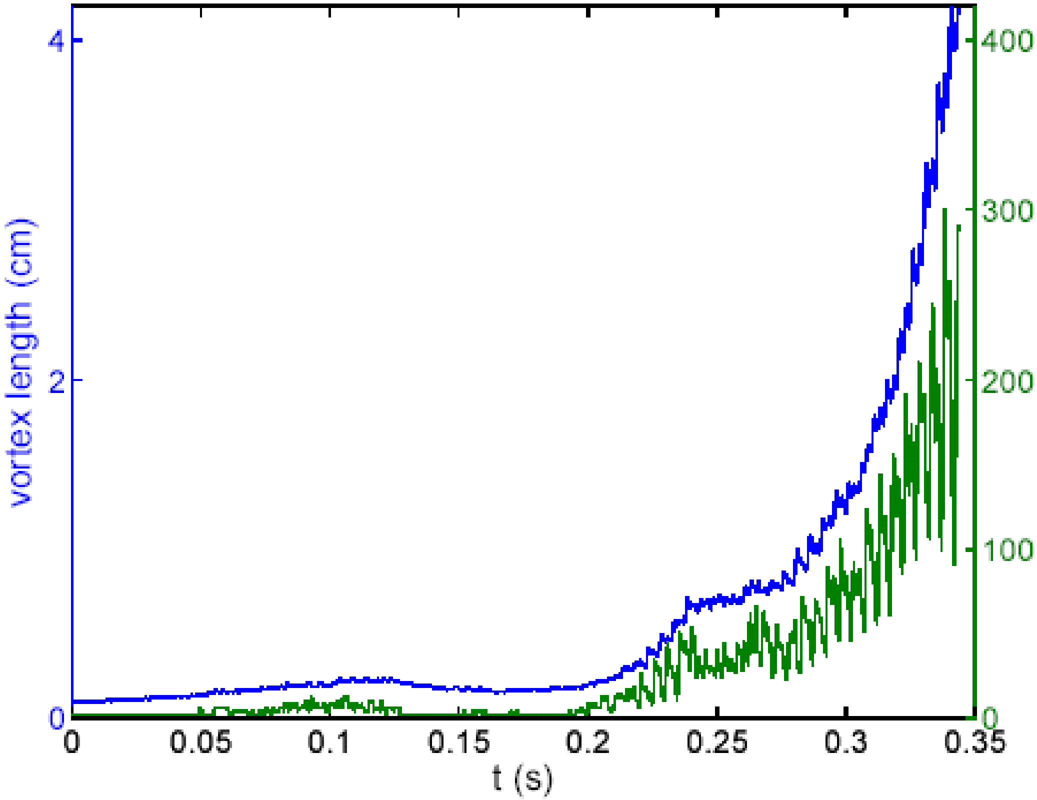

Kerr again: Kelvin waves generated by reconnections: this is a classical fluid!

# Vinen's talk: need to study and parametrize forcing of quantum turbulence



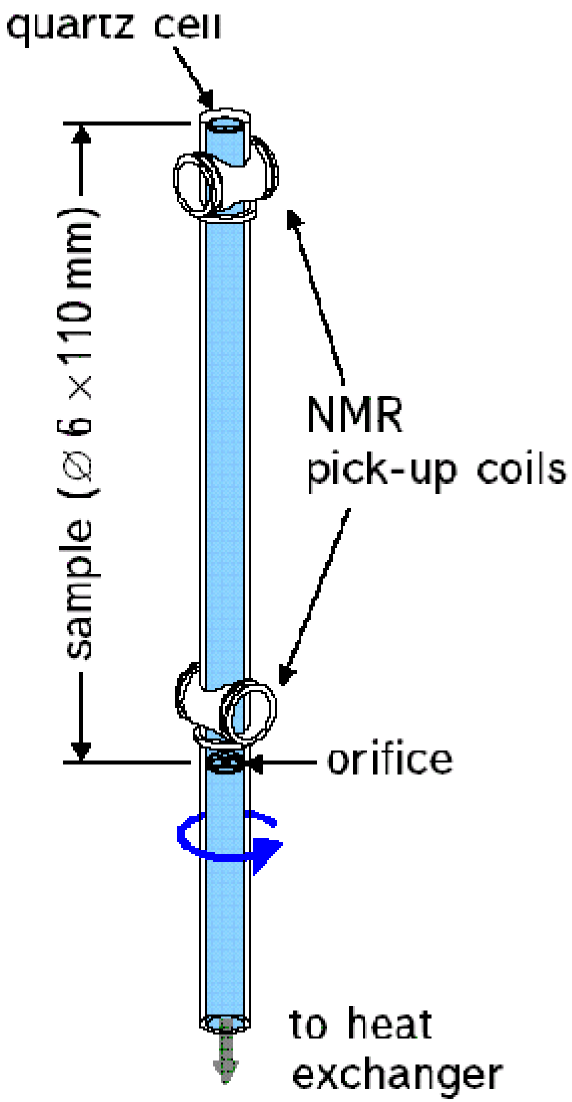

Vortices generated by oscillating sphere

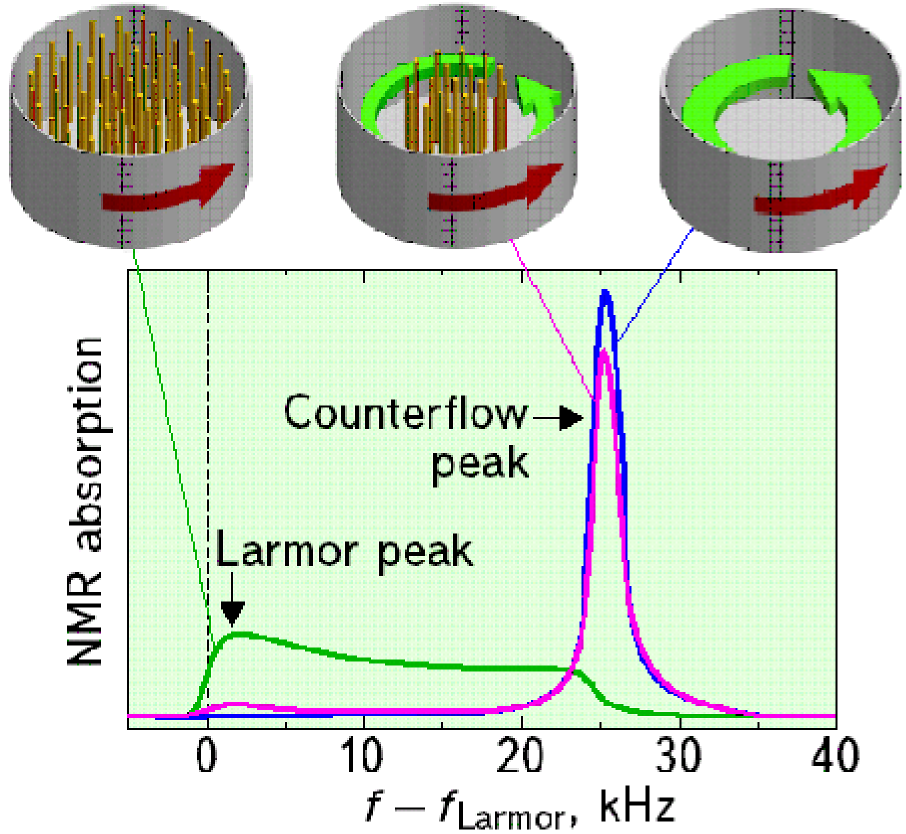
Hanninen, Tsubota, Vinen, 2006

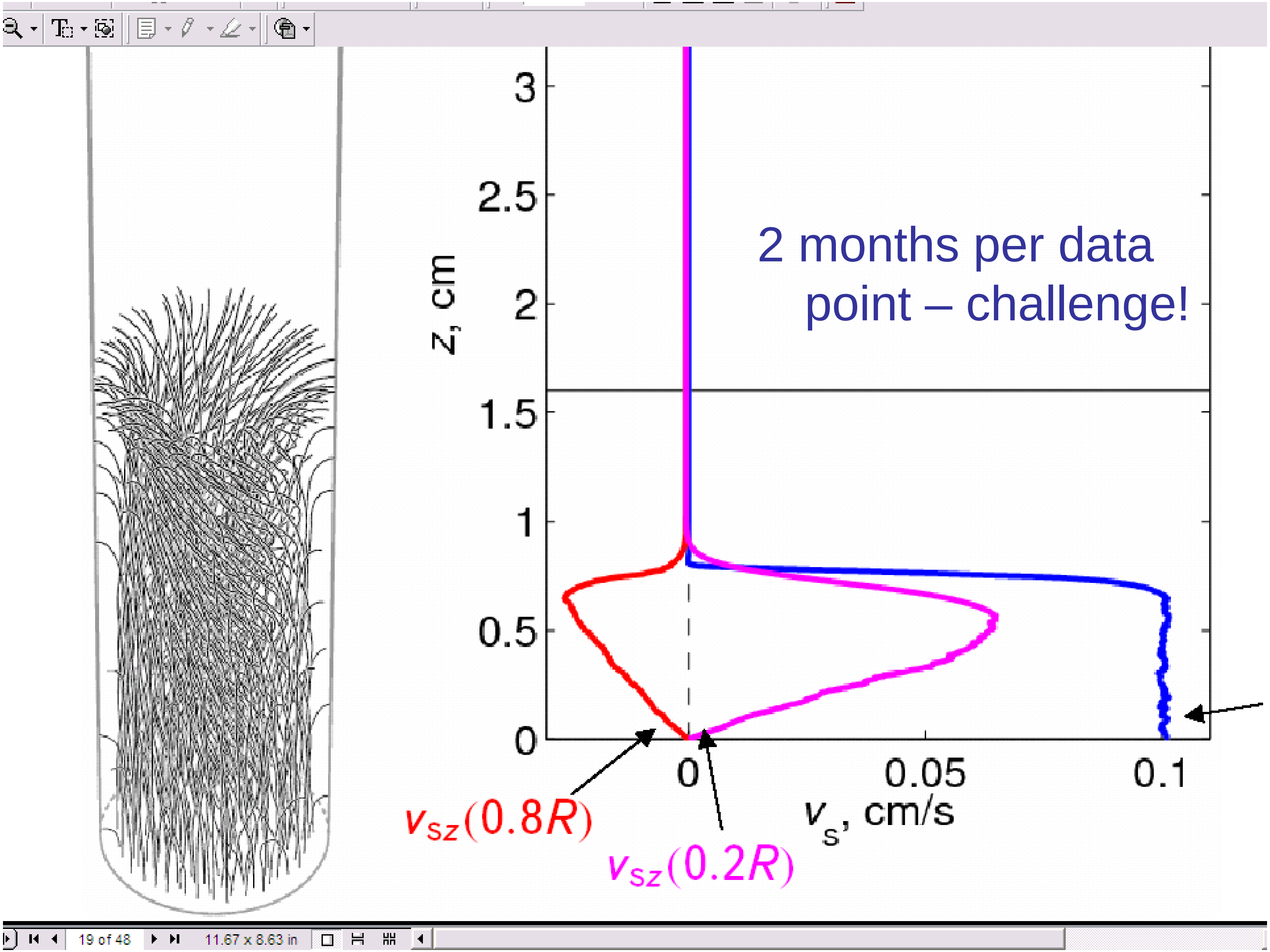



No steady state reached: numerical challenge

# Eltsov, Krisius & Volovik talks.





19 of 48
11.67 x 8.63 in
3
2.5
2
1.5
1
0.5
0
z, cm
0
0.05
0.1
$v_s$, cm/s
2 months per data point – challenge!
$v_{sz}(0.8R)$
$v_{sz}(0.2R)$

March 2006: Geophysical turbulence (no photo – sorry!)

Also June 2006 (plasma turbulence) & July 2006 (stat mech & turbulence)

# June 2006

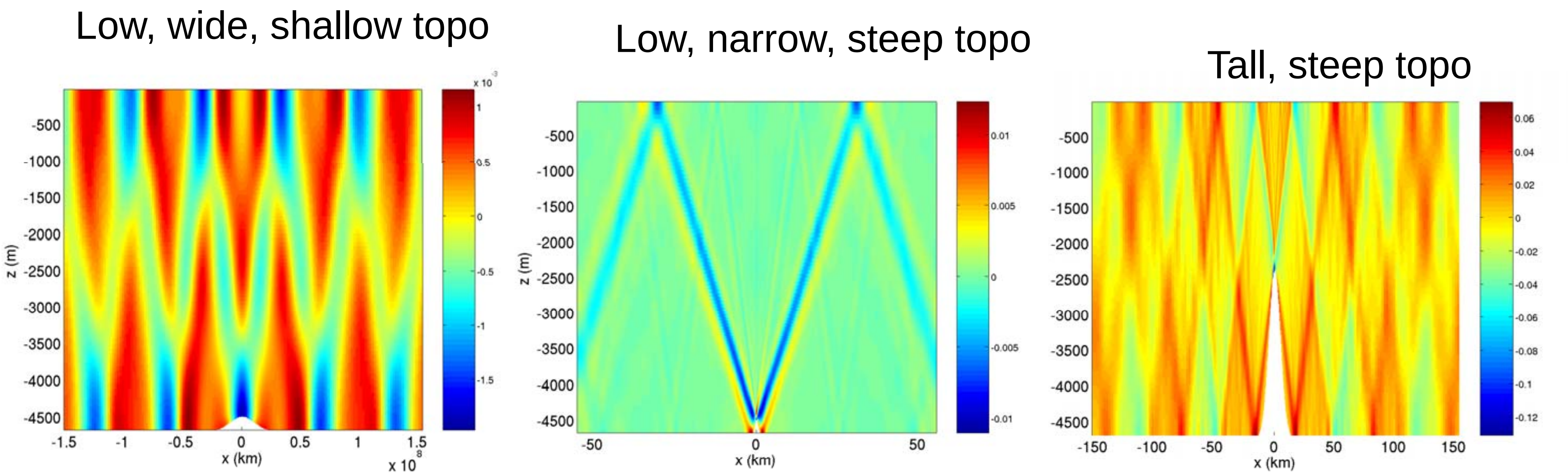
# Rotating & stratified geophysical systems. Climate & weather.

- Internal gravity waves (IGV) in stratified fluid: ocean mixing (upwards) as a part of the “conveyor belt”.
- Role of IGV in atmospheric turbulence. Validity of the geostrophic balance assumption.
- Rotation – Rossby waves and zonal flows (also inertial waves).

# Legg's talk: IGV generated by tidal flow over topography.

Key questions for parameterization development:

1. Do theoretical predictions hold for large amplitude flows?
2. How much of converted energy is dissipated locally v. radiated away?



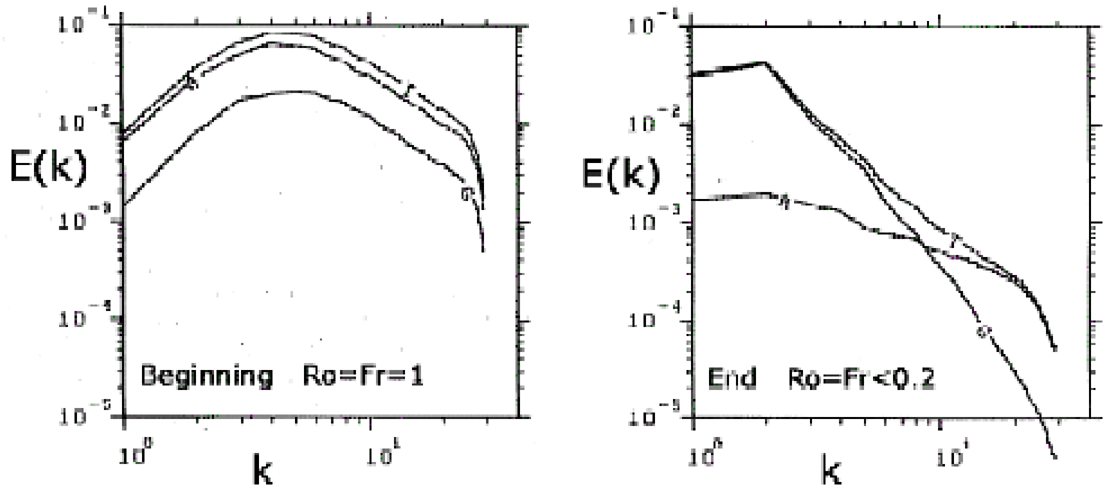

Baroclinic velocity snapshots from simulations of tidal flow over Gaussian topo with forcing amplitude U0=2cm/s (Legg and Huijts, 2006; using MITgcm).

Steep topography leads to generation of internal tide beams: energy concentrated on wave characteristics.

# Bartello's talk: role of IGW in atmospheric turbulence. Geostrophic balance.

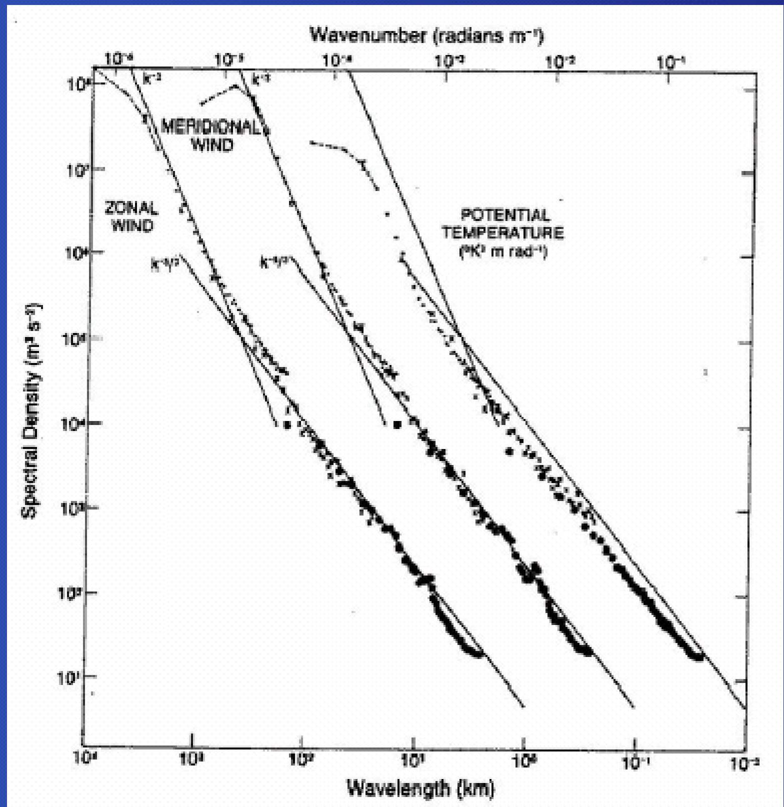
**1. Strong rotation and strong stratification**

Rotational ($G$ for geostrophic) and wave-mode ($A$) spectra




Get it? They cross.

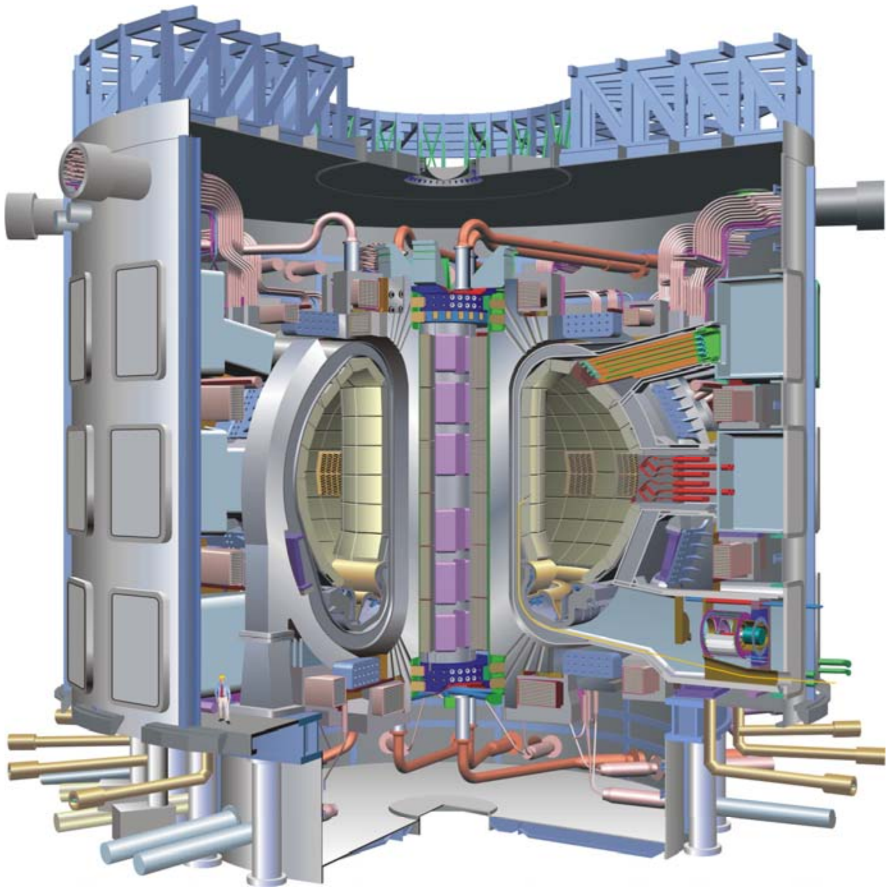
# Nastrom-Gage spectrum



# Diamond, Shats, talks. Also Galperin, Reed

Drift waves in fusion devices

**Rossby waves** in atmospheres of rotating planets

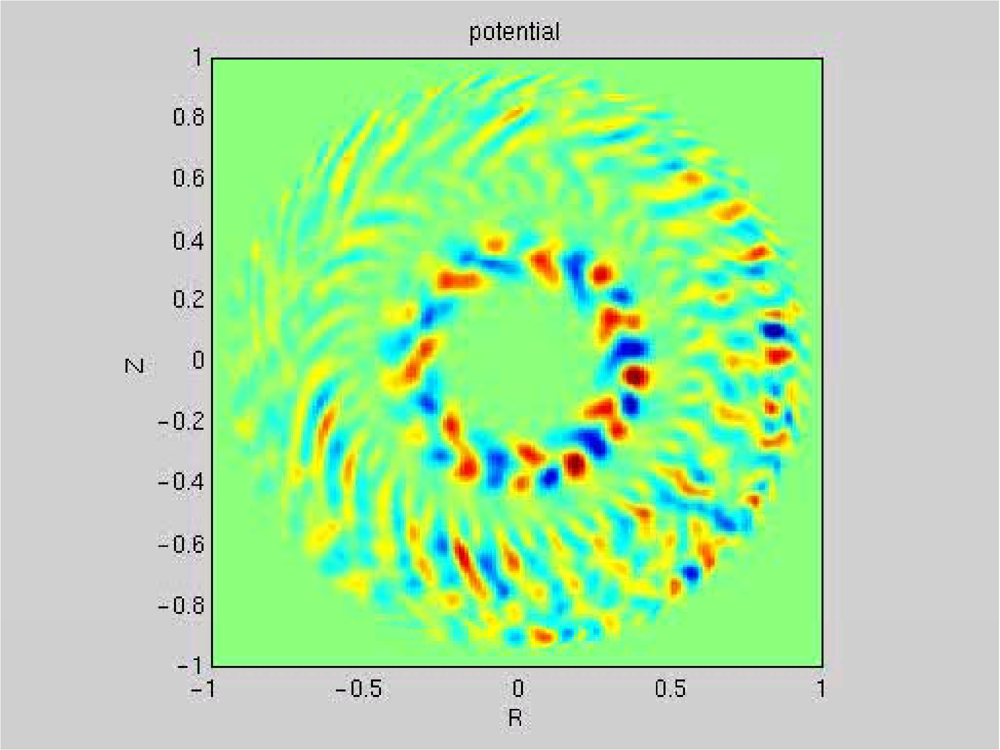


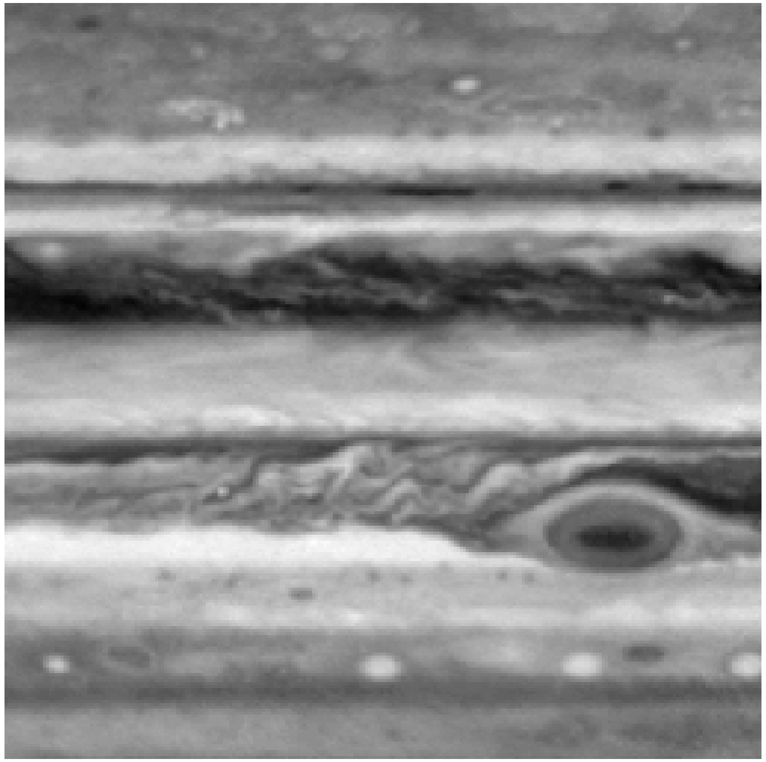
# Charney-Hasegawa-Mima equation

$$\frac{\partial}{\partial t}(\rho^2 \Delta\psi - \psi) - \beta\frac{\partial\psi}{\partial x} + \frac{\partial\psi}{\partial x}\frac{\partial\Delta\psi}{\partial y} - \frac{\partial\psi}{\partial y}\frac{\partial\Delta\psi}{\partial x} = 0$$

- $\Psi$ -- electrostatic potential (stream-function)
- $\rho$ -- ion Larmor radius (by $T_e$) (Rossby radius)
- $\beta$ -- drift velocity (Rossby velocity)
- $x$ -- poloidal arc-length (east-west)
- $y$ -- radial length (south-north)

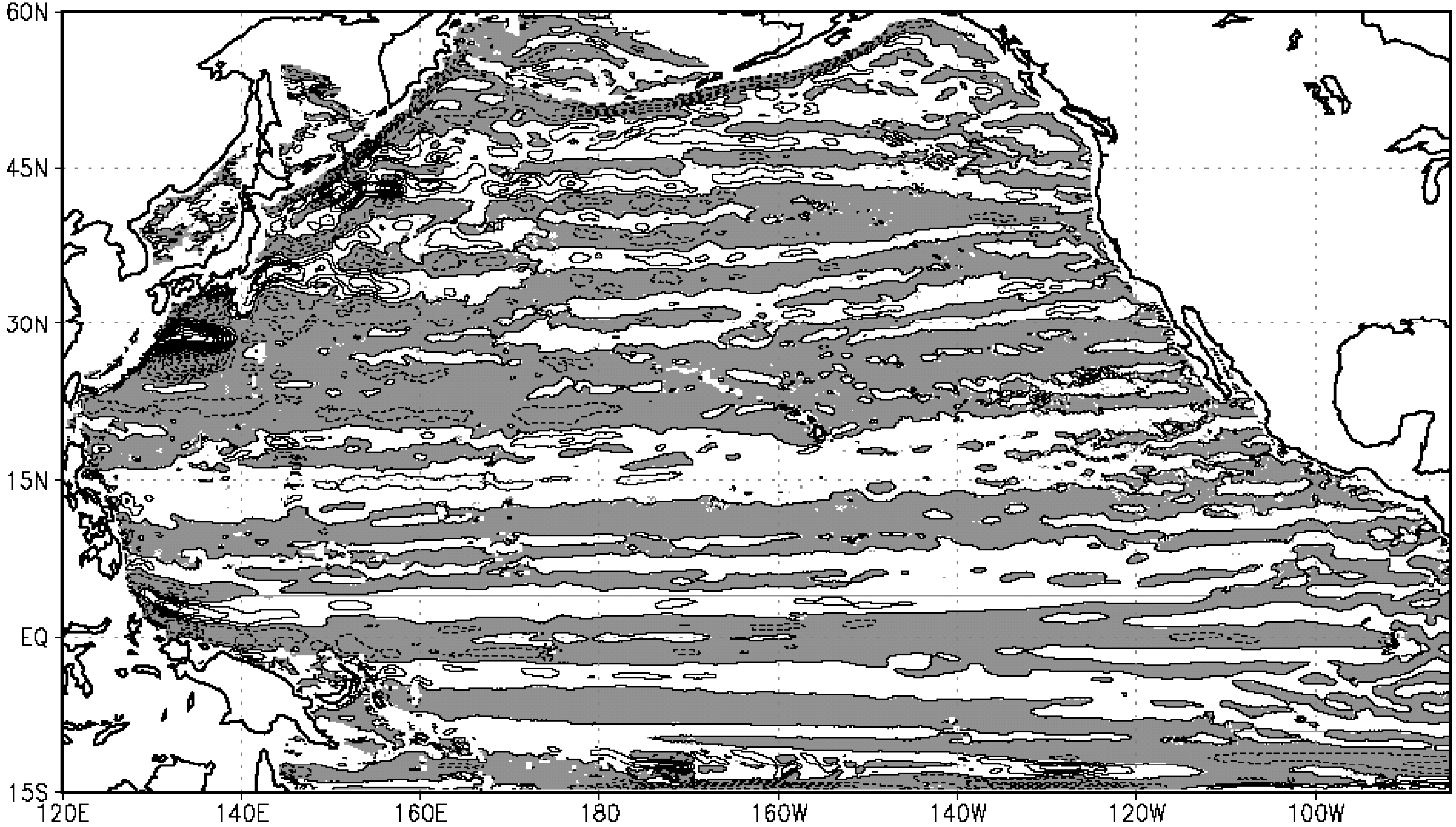
# Ubiquitous features in Drift/Rossby turbulence



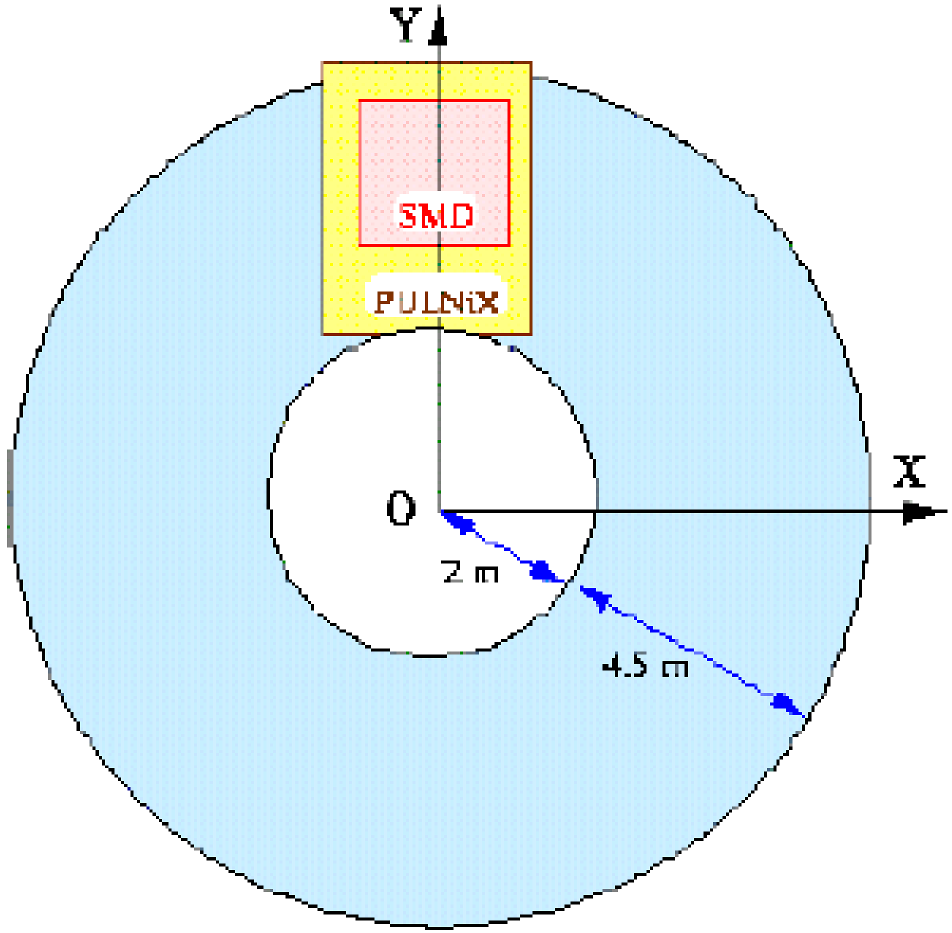
- Drift Wave turbulence generates zonal flows
- Zonal flows suppress waves
- Hence transport barriers, Low-to-High confinement transition

# Ocean simulation of Nakano and Hasumi, 2004.
# 5-year average from 58-year simulation;
from Galperin et al 2004.

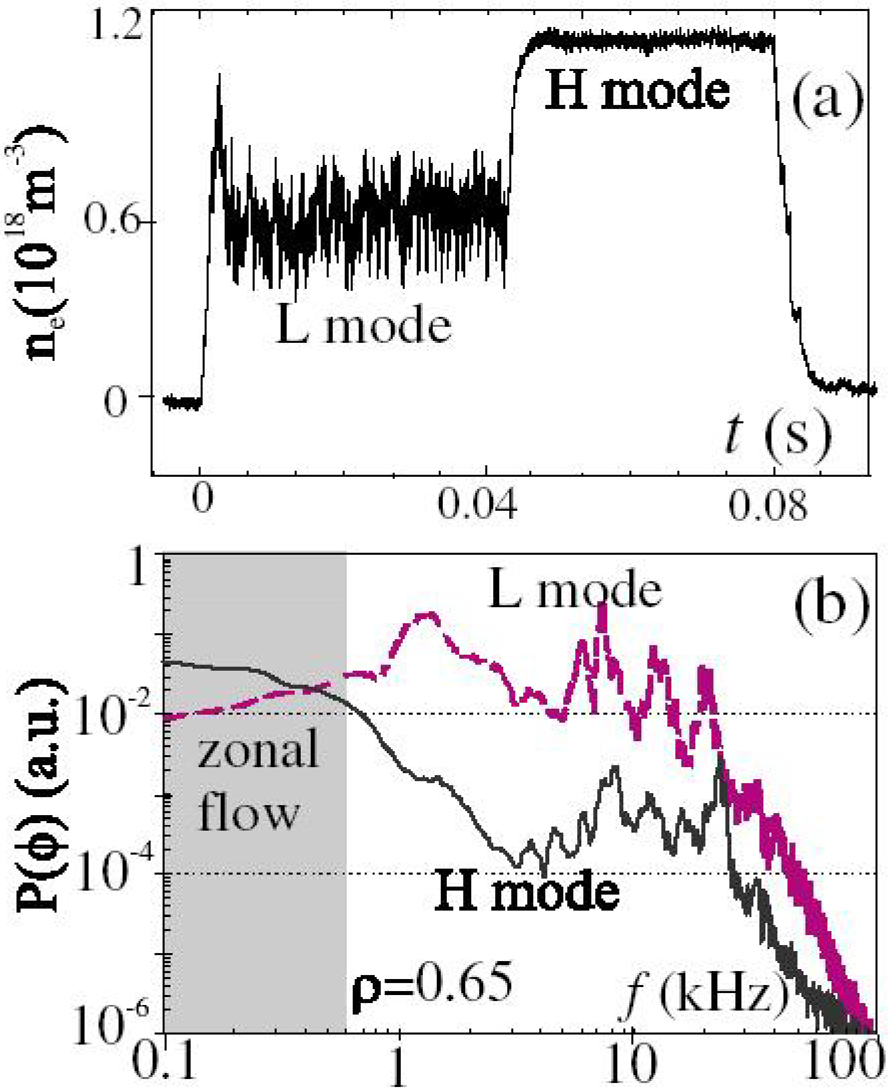


# Reed’s experiment @ Coriolis turntable

The water depth is the shallowest (20 cm) along the inner boundary and deepest (55 cm) at the outer wall.



# Shats plasma experiment




- L-H transition
- ZF generation
- DW suppression

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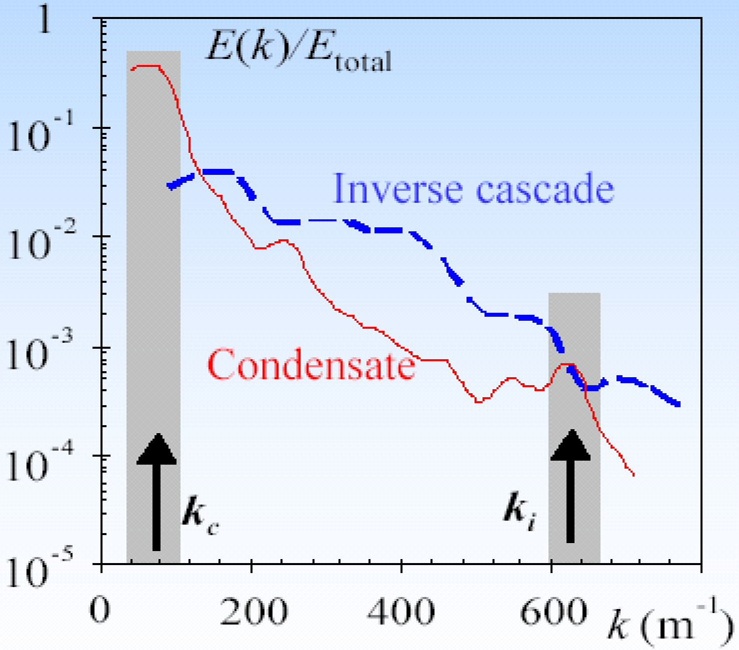
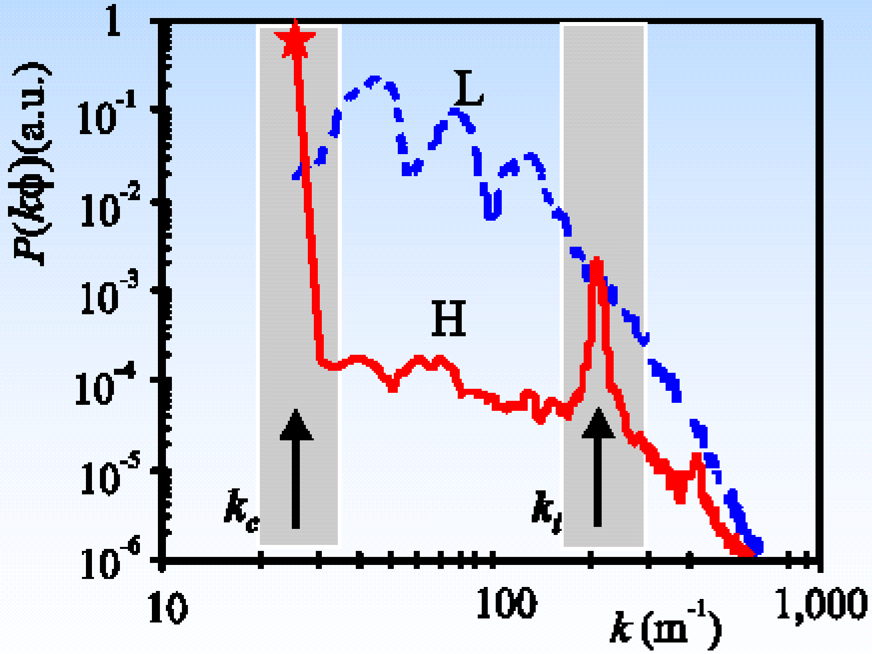
# Spectral condensation as a paradigm for confinement transitions in plasma

**Spectral condensation in 2D fluid**

**?**

**Spectra evolution from L to H mode**



# Non-local spectral transfer in plasma

[Balk, Zakharov, Nazarenko JETP (1990), Physics Letters A (1990)

Dyachenko, Nazarenko, Zakharov Phys. Letts. A (1992)]:

**Hypothesis of a nonlocal nature of drift-wave turbulence =>**

Inverse energy cascade enhances spectra at large scales;

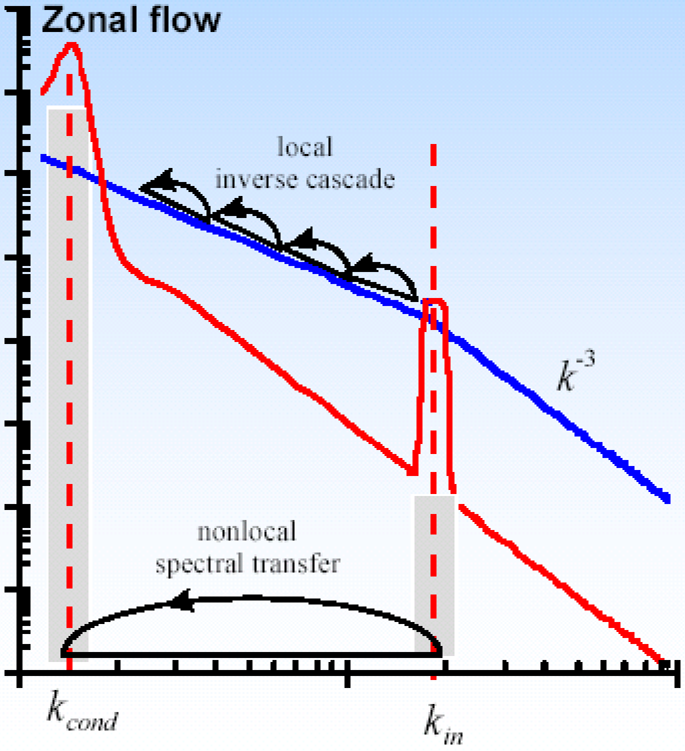
Turbulence becomes nonlocal;

Spectral energy is pumped from the small-scale jet into a zonal flow ;

Intermediate scales are reduced;

Two spectrally unconnected components: ZF($\boldsymbol{k}_{ZF}$) and jet ($\boldsymbol{k}_{inj}$)

Spectral energy delivered from $\boldsymbol{k}_{inj}$ **to** $\boldsymbol{k}_{ZF}$ is sufficient to overcome damping of zonal flow



# Summary

- Classical turbulence:

a) Reconnections
b) Geophysical systems with stratification or/and rotation. Climate and weather.

i. Mixing by IGW.
ii. Transport blocking by zonal jets.
iii. Shallow convection.

- Quantum turbulence:

a) Study and parametrize the forcing of quantum turbulence
b) Study polarised vortex tangles, cross-over of Richardson cascade to the Kelvin wave cascade.
c) Need more numerical power and finer spatial resolution of experimental probes.