TURBULENT AT HIGH AND LOW ROTATION RATES: EULERIAN AND LAGRANGIAN STATISTICS

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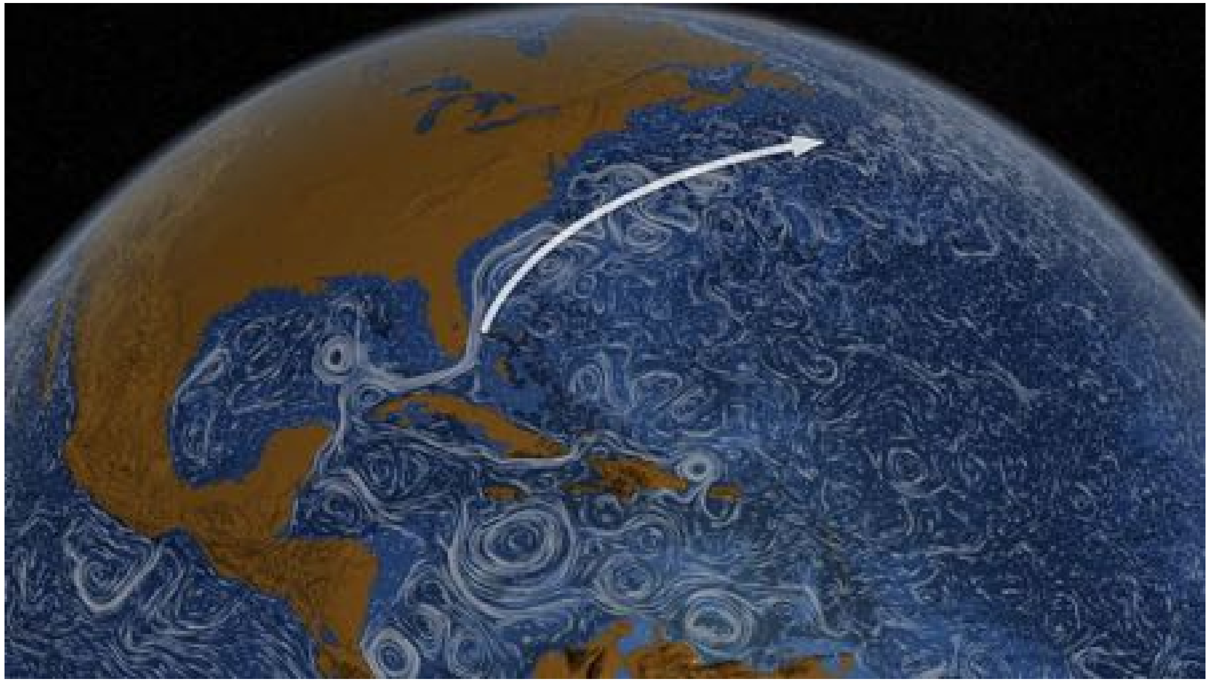
UWI 19° JAN 2017



F.Bonaccorso, I.Mazzitelli (Rome, Italy)
M.Hinsberg, F. Toschi (Eindhoven, The Netherlands)
A.Lanotte (Lecce, Italy)
S. Musacchio (Nice, France)
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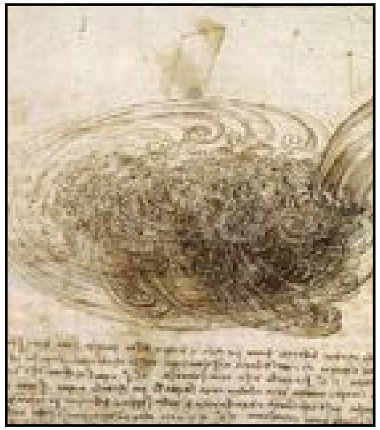
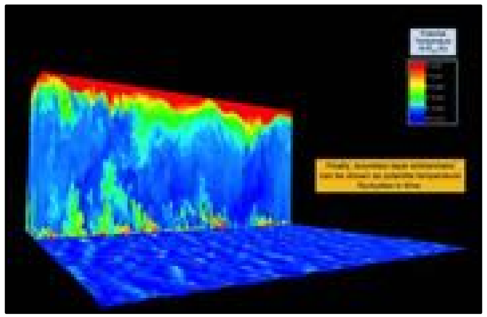
PRACE 09_2256
ROTATING TURBULENCE
2015 – 55MH

WHERE/WHAT IS THE PROBLEM?

- Too many turbulences?
- Can we disentangle universal from non-universal properties?
- Can we understand universal properties ?
- Does 'computing' mean 'understanding'? (Computo ergo sum?)
- Can we use computation to make experiments that cannot be done on a lab?





Turbulence or Turbulences?

$$\begin{cases} \partial_t v + v \cdot \partial v = -\partial P + \nu \partial^2 v \quad + F(\boldsymbol{B},\boldsymbol{B}) \quad + \boldsymbol{g}\theta \quad + \sum_i c_0(\boldsymbol{u}_i, \boldsymbol{v})\delta(\boldsymbol{r} - \boldsymbol{r}_i) \quad + f \\ \partial_t \theta + \boldsymbol{v} \cdot \boldsymbol{\partial}\theta = \chi \partial^2 \theta \\ \partial_t \boldsymbol{B} + \boldsymbol{v} \cdot \boldsymbol{\partial B} = \boldsymbol{B} \cdot \boldsymbol{\partial v} + \chi \partial^2 \boldsymbol{B} \\ \Delta P = -\partial_i \partial_j v_i v_j \end{cases}$$

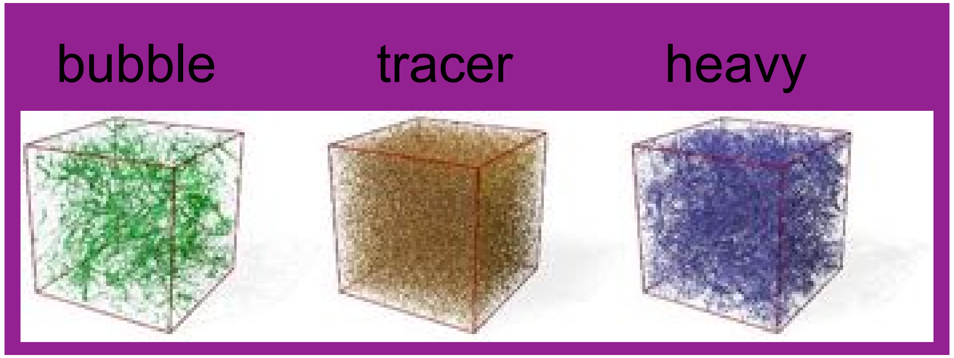
+ boundary conditions

temperature

magnetic field

$$\begin{cases} \frac{d\boldsymbol{u}_i(\boldsymbol{r}_i, t)}{dt} = -\rho_f |\boldsymbol{u}_i - \boldsymbol{v}|(\boldsymbol{u}_i - \boldsymbol{v}) \\ +\rho_f (\frac{D\mathbf{v}}{Dt} - \frac{D\boldsymbol{u}_i}{Dt}) + (\boldsymbol{u}_i - \boldsymbol{v}) \times \boldsymbol{\omega} \end{cases}$$

small particles: drag, added mass, lift force, etc...



Flows with additives:

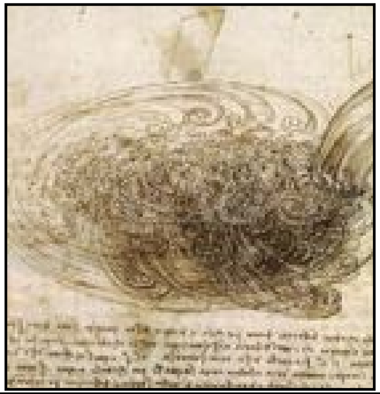
Advection-diffusion-reaction of passive scalar/vectors (temperature, magnetic field, chemical reactions, etc...)

Advection-diffusion of active scalars/vectors (convection, magnetic dinamo)

Polymers (drag reduction)

Bubbles/Droplets (two phase flows, rain formation, etc...)

Swimmers (cooperative hydrodynamical interactions)



Leonardo da Vinci (~ 1500): "doue la turbolenza (turbulence) dell'acqua si genera (is produced); doue la turbolenza dell'acqua si mantiene (is transferred); doue la turbolenza dell'acqua si posa (is dissipated)"

R.P. Feynman (1970): "Certainly. I've spent years trying to solve some difficult problems without success. The theory of turbulence is one. In fact, it is still unsolved."

J. Von Neumann (1949) "[…] The entire experience with the subject indicates that the purely analytical approach is beset with difficulties, which at the moment are prohibitive. […] Under these conditions there may be some hope to "break the deadlock" by extensive, but **well-planned** computational efforts.

Sir H. Lamb (1932): "I am an old man now, and when I die and go to Heaven there are two matters on which I hope enlightenment. One is quantum electrodynamics (QED) and the other is turbulence of fluids. About the former, I am really rather optimistic."

THE HYDROGEN ATOM OF TURBULENCE

$$\partial_t v + v \cdot \partial v = -\partial P + \nu \partial^2 v \ \ + f$$

$$\Delta P = -\partial_i \partial_j v_i v_j$$

\+ periodic boundary conditions

- -homogeneous
- -isotropic
- -Gaussian
- -white-noise in time
- -large-scale

HOMOGENEOUS TURBULENCE

3D CASE: MAINLY UNSOLVED!

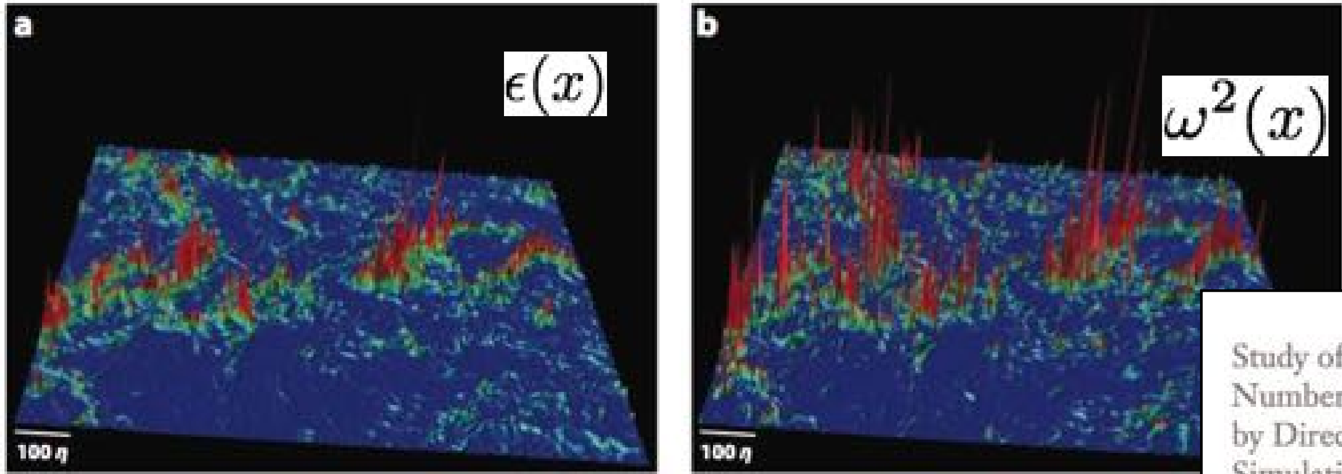


Figure 4

Snapshot of the intensity distributions of (*a*) the energy-dissipation rate $\tilde{\varepsilon} = \varepsilon/(2\nu)$ and (*b*) the enstrophy $\Omega = \omega^2/2$ on a

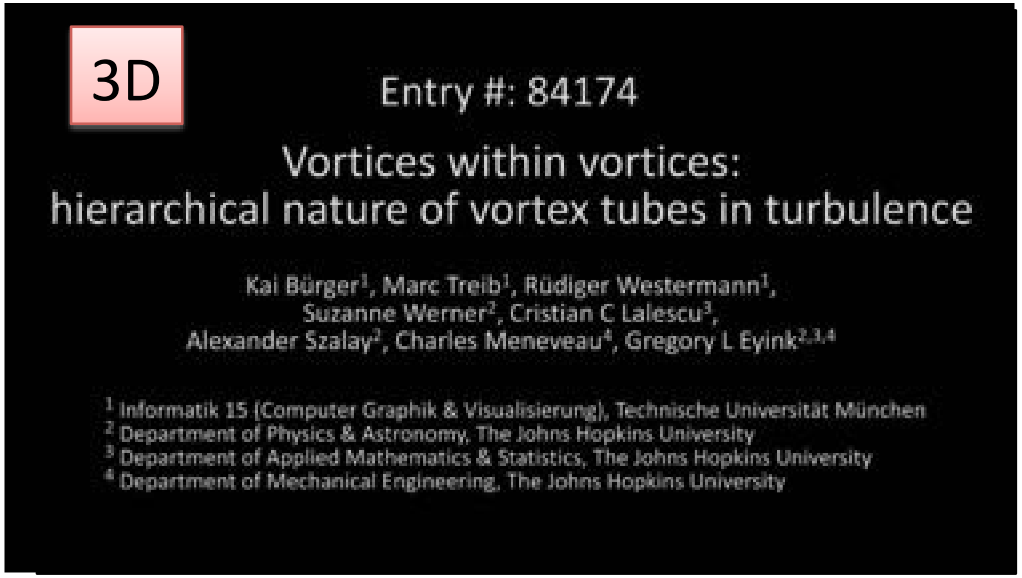
DNS-ES at $R_\lambda = 675$ in arbitrary units.

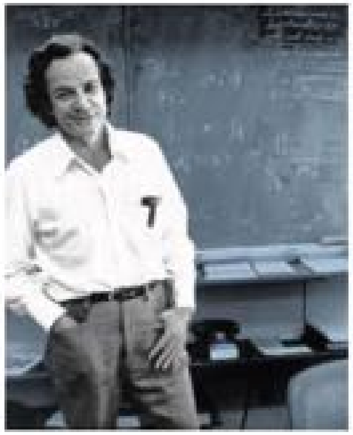
Study of High–Reynolds Number Isotropic Turbulence by Direct Numerical Simulation

Takashi Ishihara,[1] Toshiyuki Gotoh,[2] and Yukio Kaneda[1]

(NASA/Goddard Space Flight Center Scientific Visualization Studio)

NAVIER-STOKES 3D-2D





"With turbulence, it's not just a case of physical theory being able to handle only simple cases—we can't do any. We have no good fundamental theory at all." (Feynman, 1979, Omni Magazine, Vol. 1, No.8).

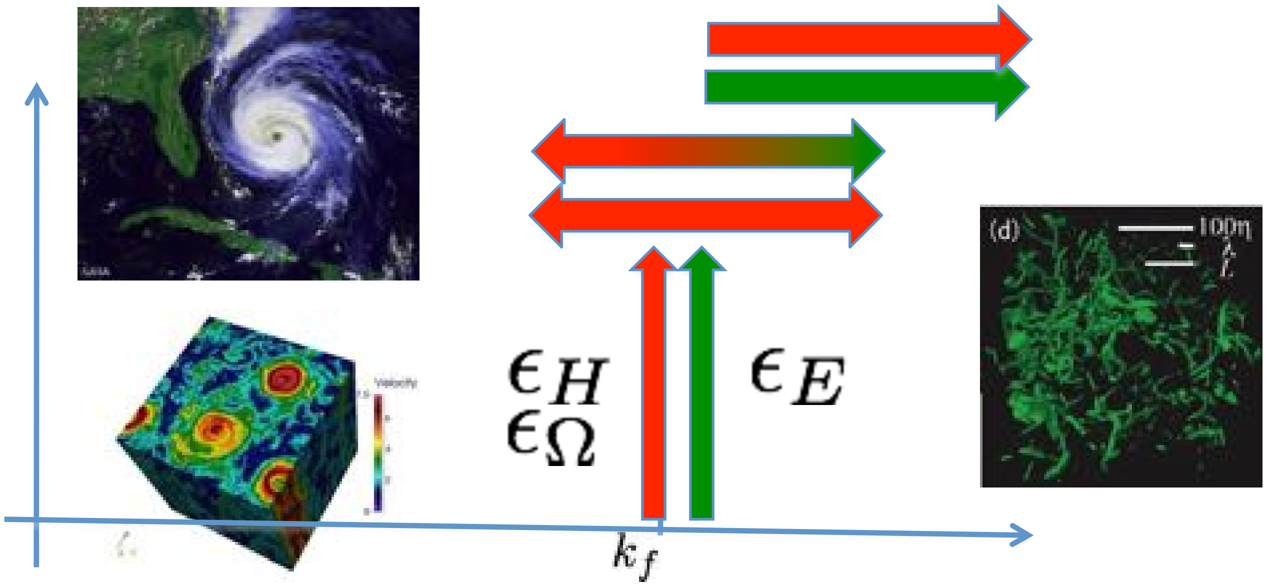
MOTIVATIONS:

A TALE ABOUT TRANSFER PROPERTIES OF INVISCID CONSERVED QUANTITIES, KINETIC ENERGY, HELICITY ENSTROPHY, MAGNETIC HELICITY ETC...

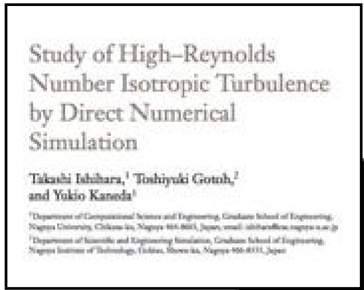
Q1: HOW TO PREDICT THE DIRECTION OF THE TRANSFER (FORWARD/BACKWARD) AND ITS ROBUSTNESS UNDER EXTERNAL PERTURBATION (FORCING/BOUNDARY CONDITIONS)?

Q2: HOW MUCH THE FLUCTUATIONS AROUND THE MEAN TRANSFER ARE INTENSE AND SELF-SIMILAR (INTERMITTENCY AND ANOMALOUS SCALING) ?

AS A MATTER OF FACT, FOR 3D NAVIER STOKES EQUATIONS, WE DO NOT KNOW HOW TO PREDICT NEITHER THE SIGN OF THE MEAN ENERGY TRANSFER NOR THE INTENSITY OF THE FLUCTUATIONS AROUND IT.



3D HOMOGENEOUS AND ISOTROPIC TURBULENCE FLUCTUATIONS: SMALL-SCALES INTERMITTENCY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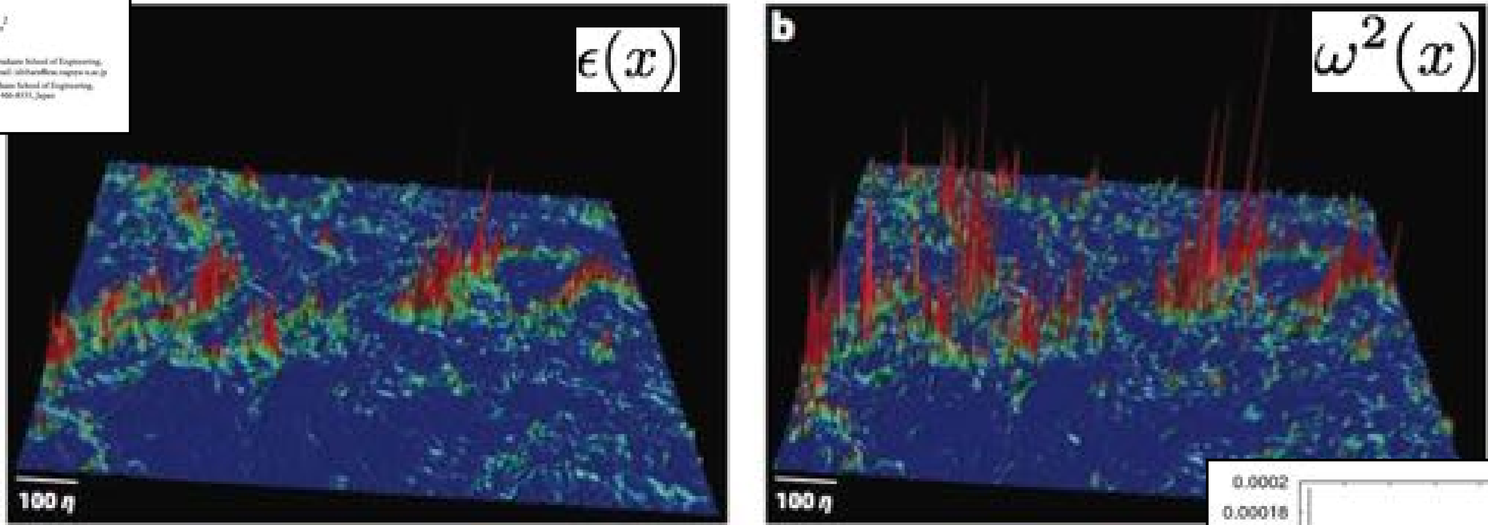
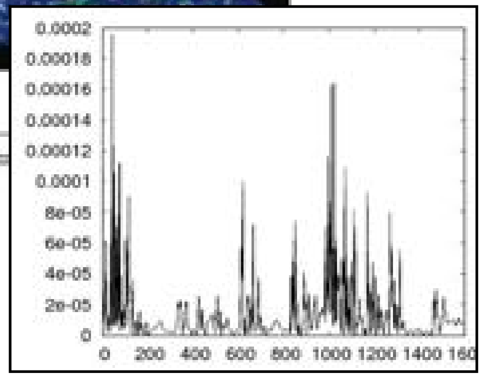
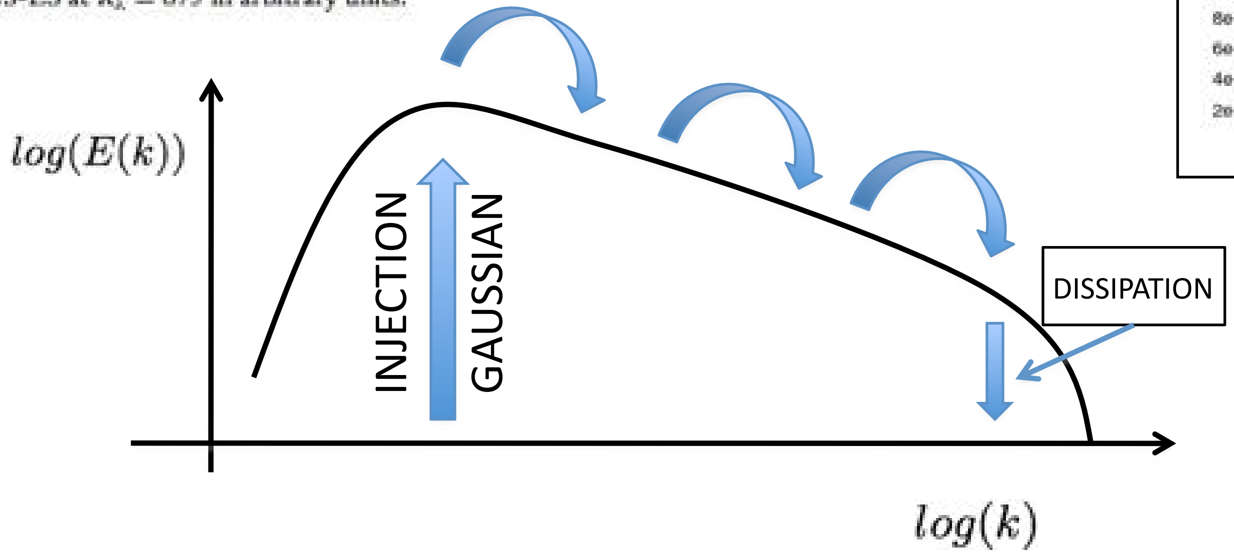


Figure 4

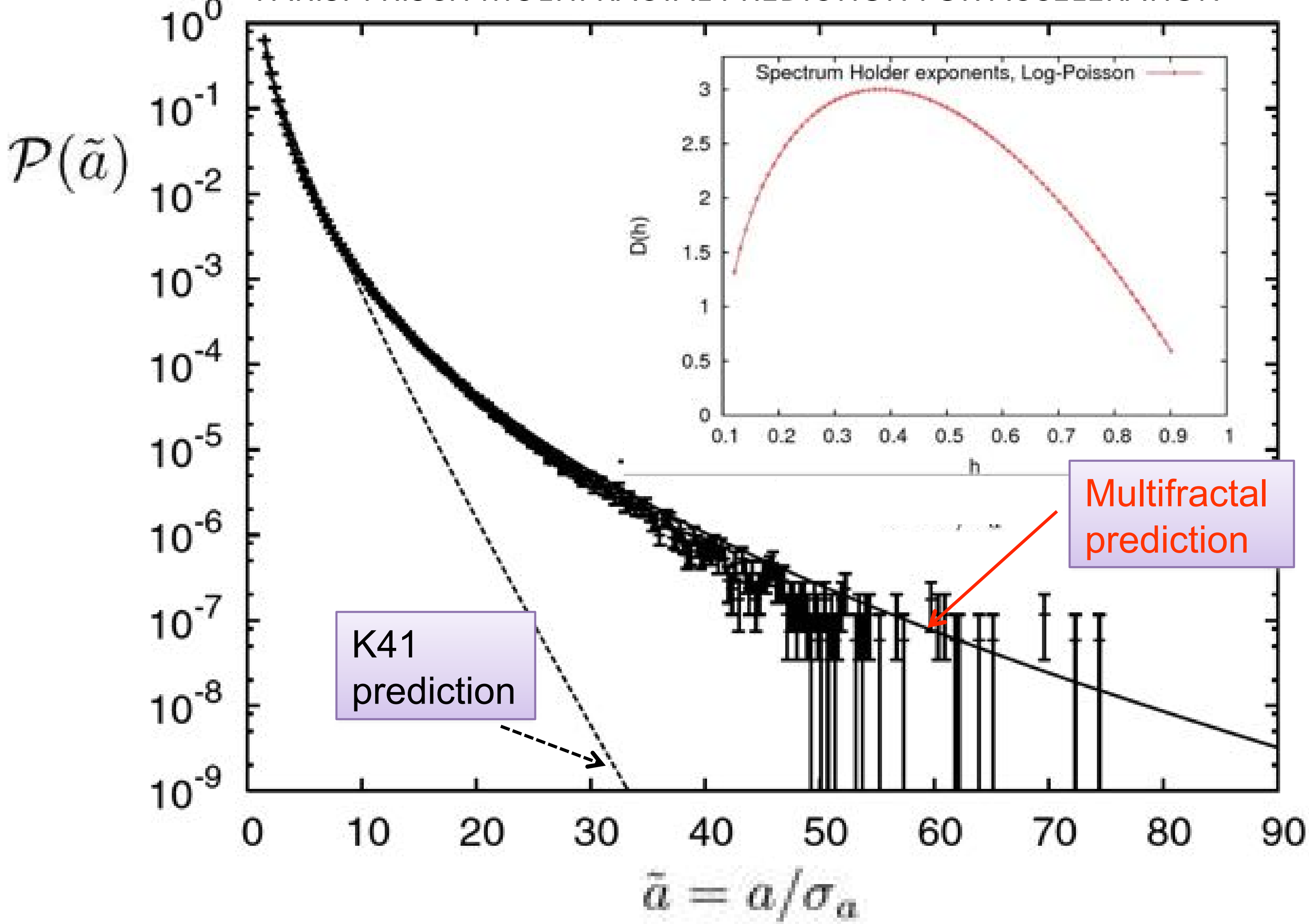
Snapshot of the intensity distributions of (*a*) the energy-dissipation rate $\bar{\varepsilon} = \varepsilon/(2\nu)$ and (*b*) the enstrophy Ω =
DNS-ES at $R_\lambda = 675$ in arbitrary units.





L. B., G. Boffetta, A. Celani, B. Devenish, A. Lanotte and F. Toschi *PRL* **93**, 064502, 2004

PARISI-FRISCH MULTIFRACTAL PREDICTION FOR ACCELERATION



$$\mathcal{P}(a) \sim \int_{h\in I} \mathrm{d}h\, a^{\frac{h-5+D(h)}{3}}\, \nu^{\frac{7-2h-2D(h)}{3}}\, L_0^{D(h)+h-3}\, \sigma_v^{-1} \times \exp\left(-\frac{a^{\frac{2(1+h)}{3}}\, \nu^{\frac{2(1-2h)}{3}}\, L_0^{2h}}{2\sigma_v^2}\right)$$

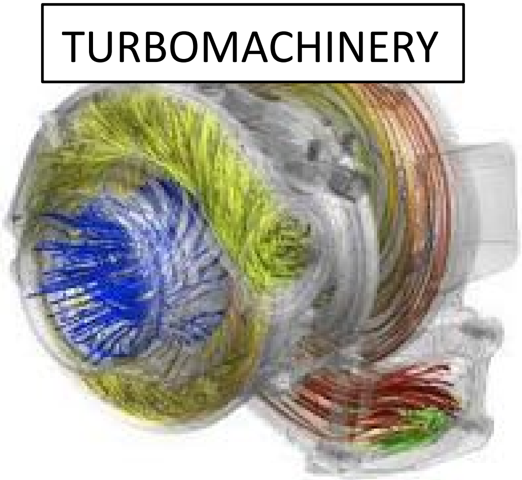
- MOTIVATION: WHY ROTATING TURBULENT FLOWS ARE IMPORTANT
- DIRECT AND INVERSE ENERGY TRANSFERS (2D-3D PHYSICS)
- OUR DNS (DIFFERENCES WRT PREVIOUS STUDIES)
- EULERIAN STATISTICS (MEAN SPECTRAL PROPERTIES)
- EULERIAN STATISTICS (LARGE FLUCTUATIONS)
- LAGRANGIAN STATISTICS (EFFECTS OF CORIOLIS AND CENTRIFUGAL FORCES)
- LAGRANGIAN STATISTICS (SINGLE PARTICLE DISPERSIONS)
- CONCLUSIONS

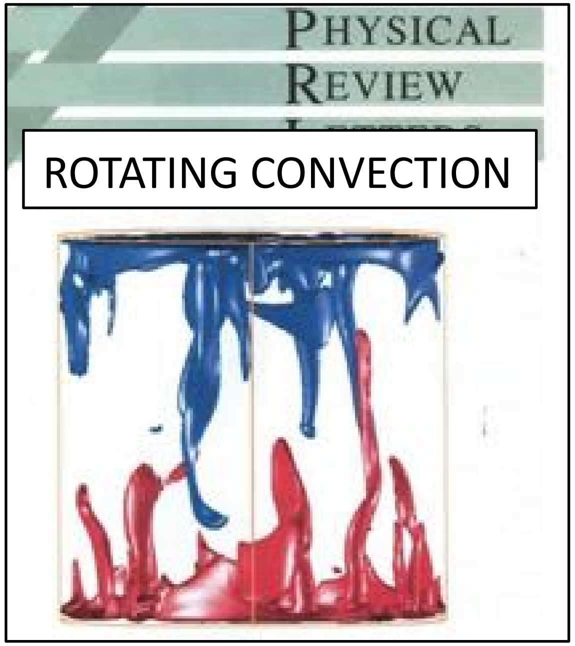
TAYLOR-COUETTE

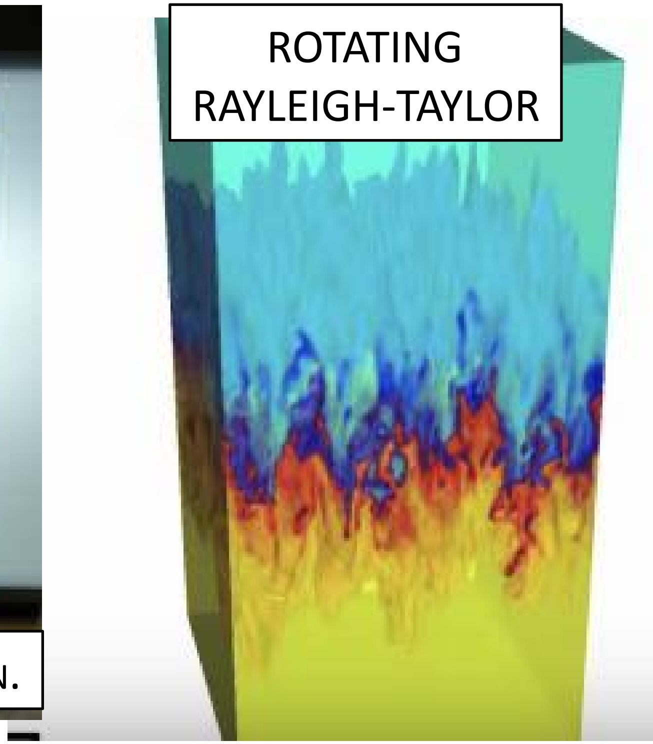
ROTATING CONVECTION (+ STRATIFICATION + MHD)

ROTATING RAYLEIGH-TAYLOR

Recent reviews/books by Lohse, Boffetta, Cambon, Clercx, Davidson etc...







NAVIER_STOKES EQS IN A ROTATING FRAME (NO BOUNDARIES)

DNS: A. Pouquet, P. Mininni, A. Alexakis, S. Chen, G. Eyink ....

$$\partial_t \mathbf{v} + \mathbf{v} \cdot \nabla \mathbf{v} + \mathbf{\Omega} \times \mathbf{v} = \nabla P + \nu \nabla^2 \mathbf{v} + \mathbf{F} - \alpha \mathbf{v}$$

$\mathbf{\Omega}$ =rotation

$$P = P_0 + \frac{1}{2} |\mathbf{\Omega} \times \mathbf{r}|^2$$

$\mathbf{F}$ =large scale Forcing

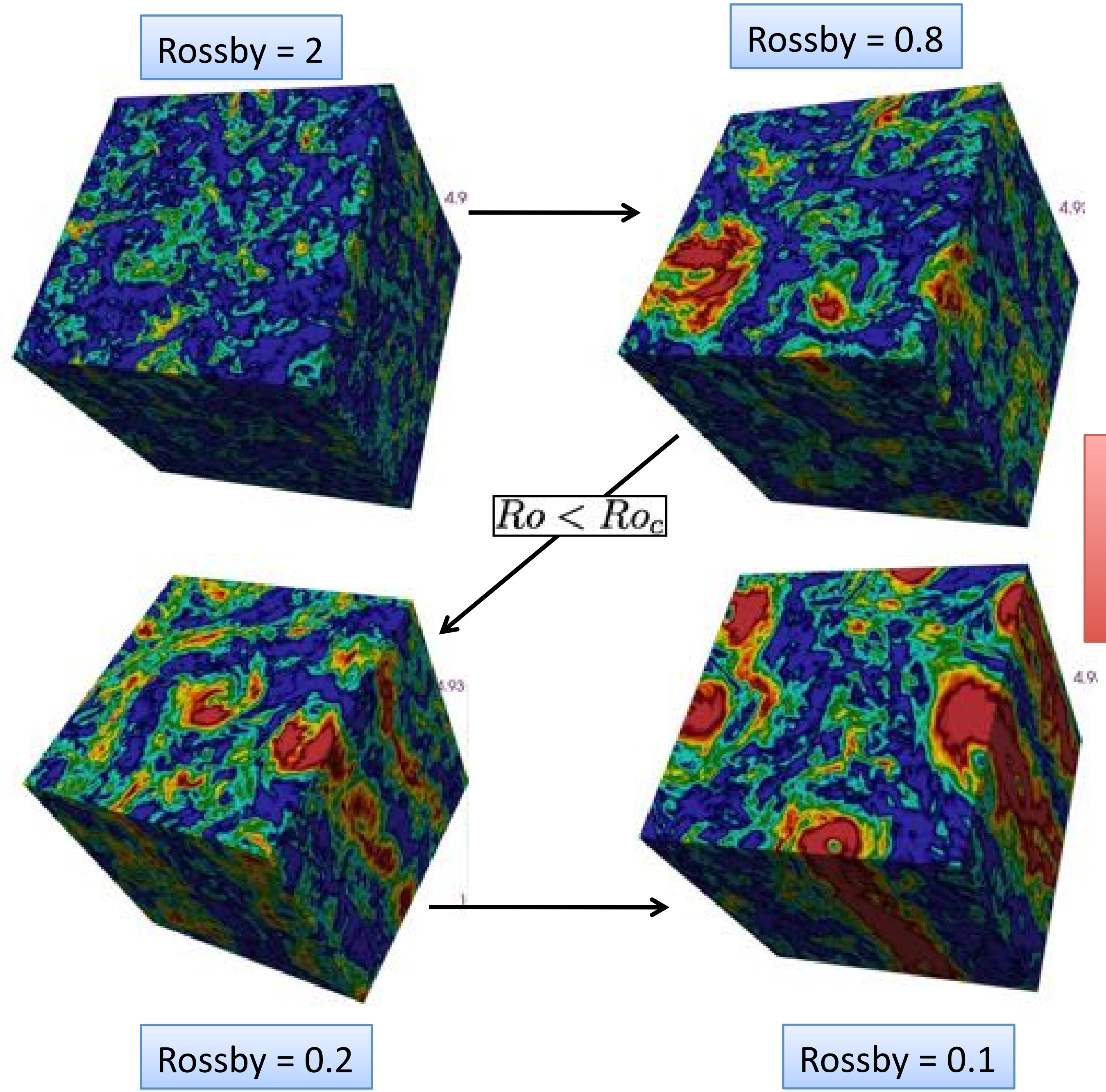
$\alpha =$ large scale energy sink

ROSSBY NUMBER ~ NON-LINEAR/ROTATION

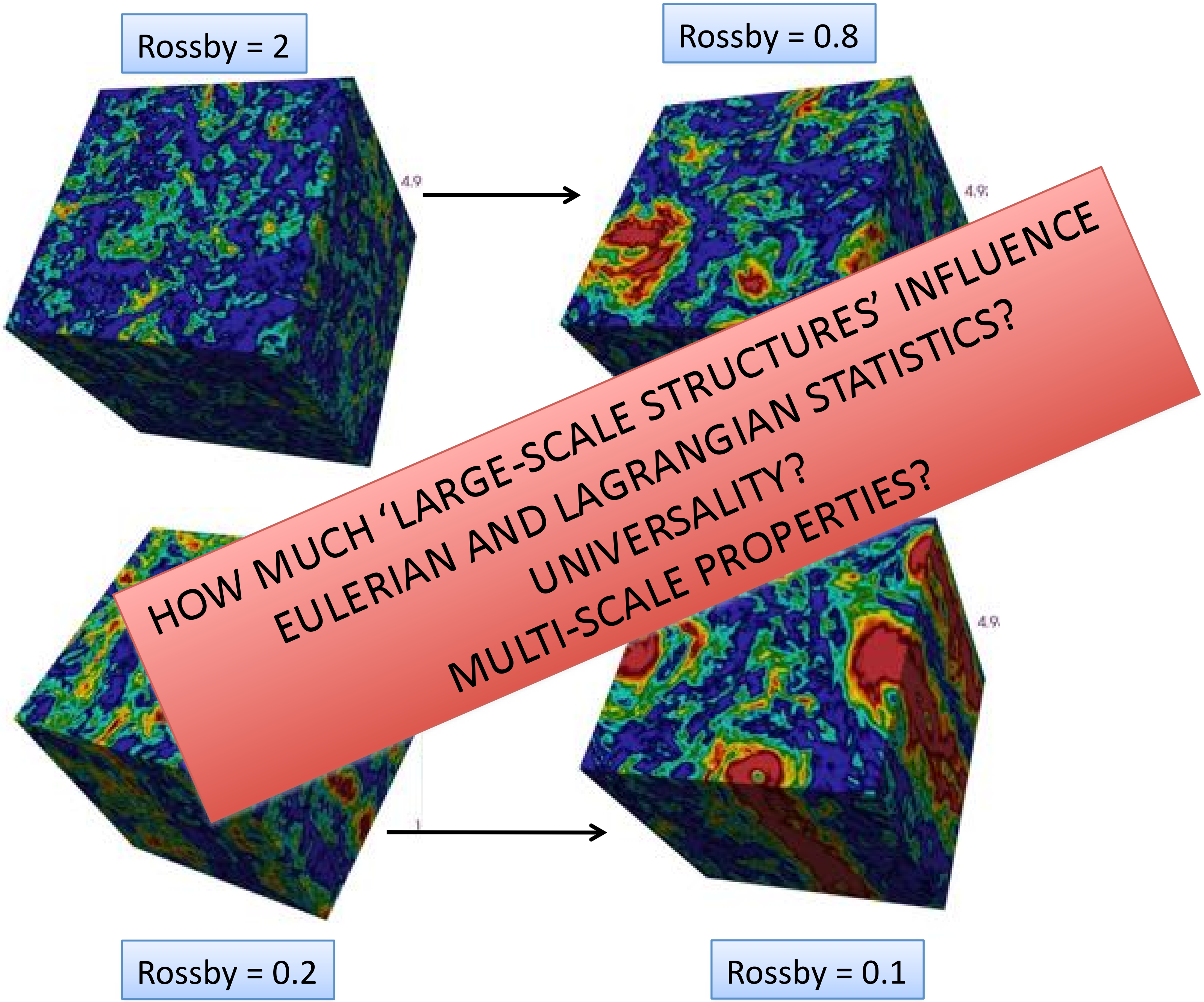
$$\mathrm{Ro} \sim \frac{v_0}{\Omega\, L_0}$$

$\mathrm{Ro} \geq Ro_c \rightarrow$ FORWARD ENERGY TRANSFER

$\mathrm{Ro} \leq Ro_c \rightarrow$ FORWARD & BACKWARD ENERGY TRANSFER



HOMOGENEOUS
ANISOTROPIC
2D & 3D PHYSICS
CHOERENT -STRUCTURES


Rossby = 2
Rossby = 0.8
HOW MUCH 'LARGE-SCALE STRUCTURES' INFLUENCE
EULERIAN AND LAGRANGIAN STATISTICS?
UNIVERSALITY?
MULTI-SCALE PROPERTIES?
Rossby = 0.2
Rossby = 0.1

OUR DNS DATA-BASE (EULERIAN + LAGRANGIAN)

NEW FEATURES:

1) IDEAL FORCING MECHANISM (AS NEUTRAL AS POSSIBLE: ISOTROPIC; NON HELICAL, TIME-COLORED) + LARGE SCALE FRICTION
2) UNPRECEDENTED NUMERICAL RESOLUTION/SCALE SEPARATION (**UP TO 4096^3**)
3) LAGRANGIAN STATISTICS (MILLIONS OF TRACERS AND INERTIAL PARTICLES)

N	Ω	ν	ϵ	ϵ_f	u_0	η/dx	τ_η/dt	Re_λ	Ro	f_0	τ_f	T_0	α
1024	4	7×10^{-4}	1.2	1.2	1.05	0.67	120	150	0.78	0.02	0.023	0.17	0.0
1024	10	6×10^{-4}	0.46	0.59	1.6	0.76	294	580	0.24	0.02	0.023	0.25	0.1
2048	4	2.8×10^{-4}	1.2	1.2	1.05	0.67	380	230	0.76	0.02	0.023	0.17	0.0
2048	10	2.2×10^{-4}	0.45	0.64	1.7	0.72	550	1170	0.25	0.02	0.023	0.3	0.1
4096	10	1×10^{-4}	0.46	0.65	1.7	0.78	1010	1600	0.25	0.02	0.023	0.3	0.1

TABLE I: Eulerian dynamics parameters. N: number of collocation points per spatial direction; Ω: rotation rate; ν: kinematic viscosity; $\epsilon = \nu \int d^3x \sum_{ij} (\nabla_i u_j)^2$: viscous energy dissipation; $\epsilon_f = \int d^3x \sum_i f_i u_i$: energy injection; $u_0 = 1/3 \int d^3x \sum_i u_i^2$: mean kinetic energy; $\eta = (\nu^3/\epsilon)^{1/4}$: Kolmogorov dissipative scale; $dx = L_0/N$: numerical grid spacing; $L_0 = 2\pi$: box size; $\tau_\eta = (\nu/\epsilon)^{1/2}$: Kolmogorov dissipative time; $Re_\lambda = (u_0\lambda)/\nu$: Reynolds number based on the Taylor micro-scale; $\lambda = (15\nu u_0^2/\epsilon)^{1/2}$: Taylor micro-scale; $Ro = (\epsilon_f k_f)^{1/3}/\Omega$: Rossby number defined in terms of the energy injection properties, where $k_f = 5$ is the wavenumber where the forcing is acting; f_0: intensity of the Ornstein-Uhlenbeck forcing; τ_f: decorrelation time of the forcing; $T_0 = u_0/L_0$: Eulerian large-scale eddy turn over time; α: coefficient of the damping term $\alpha\Delta^{-1}\boldsymbol{u}$.

MAX RESOLUTION

$$\partial_t \mathbf{v} + \mathbf{v} \cdot \nabla \mathbf{v} + \boldsymbol{\Omega} \times \mathbf{v} = \nabla P + \nu \nabla^2 \mathbf{v} + \mathbf{F} - \alpha \mathbf{v}$$

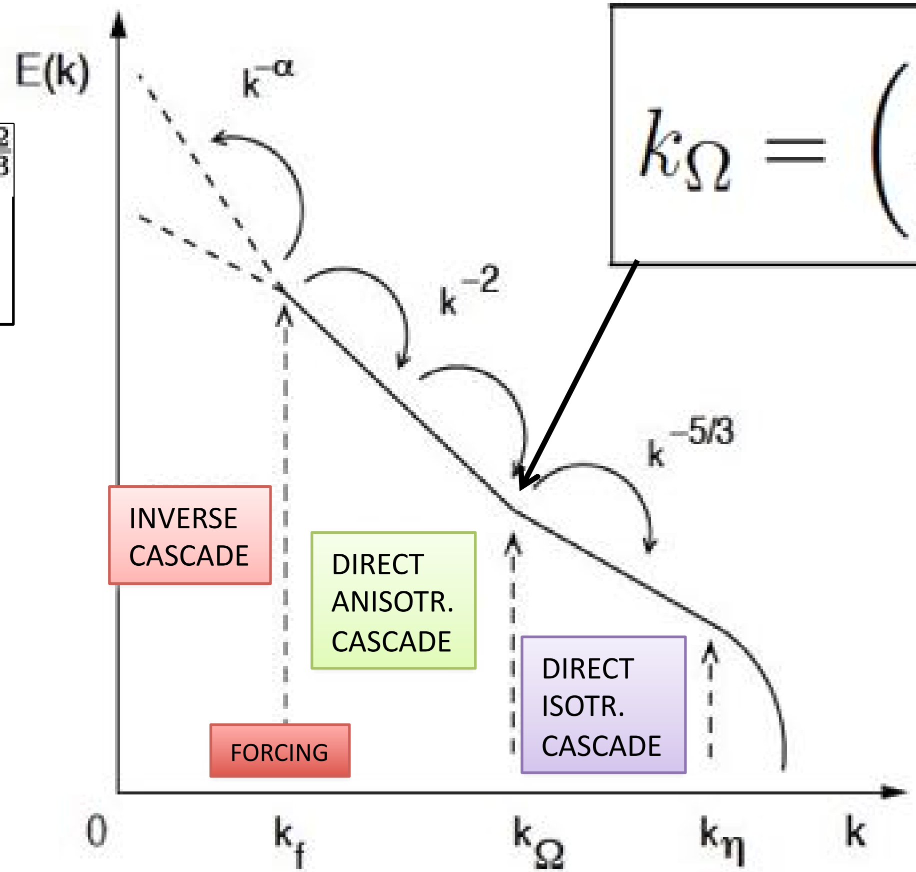
DIMENSIONAL PHENOMENOLOGY

- $k > k_\Omega \longrightarrow E(k) \sim \varepsilon^{2/3} k^{-5/3}$
- $k_f < k < k_\Omega \longrightarrow E(k) \sim (\varepsilon\Omega)^{1/2} k^{-2} \longleftrightarrow \tau_{tr}(k) \sim \frac{\tau_{nl}(k)^2}{\tau_\Omega}$
- $k < k_f \longrightarrow E(k) \sim \Omega^2 k^{-3} \overset{?}{\longleftrightarrow} E(k) \sim k^{-5/3}$

TWO TIME SCALES

$$\tau_{nl}(k) \sim \epsilon^{-\frac{1}{3}} k^{-\frac{2}{3}}$$

$$\tau_\Omega \sim 1/\Omega$$



$$k_\Omega = \left(\frac{\Omega^3}{\varepsilon}\right)^{1/2}$$

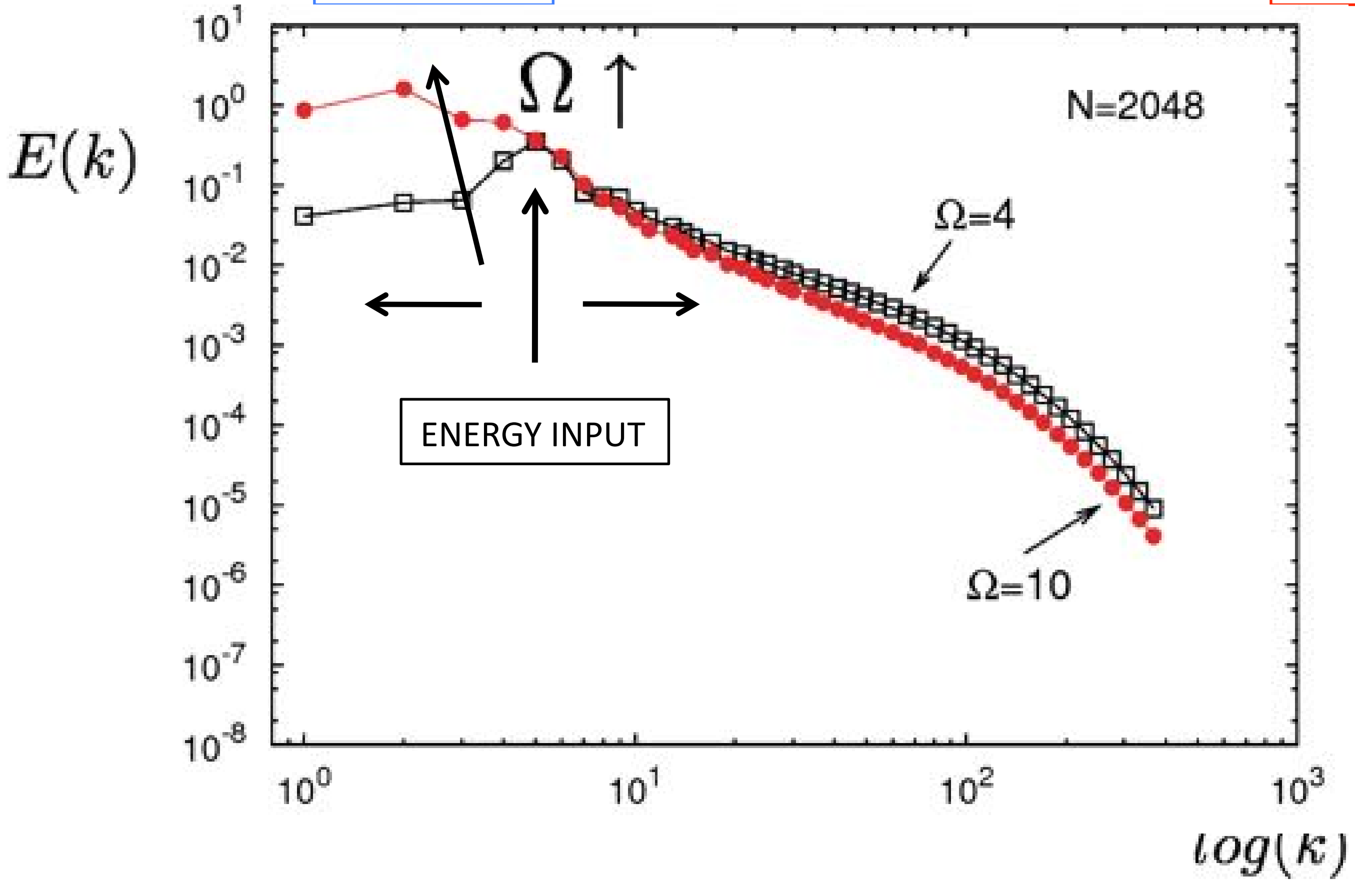
ZEEMAN SCALE

HOMOGENEOUS-ANISOTROPIC

$$\partial_t \mathbf{v} + \mathbf{v}\cdot\nabla\mathbf{v} + \boldsymbol{\Omega}\times\mathbf{v} = \nabla P + \nu\nabla^2\mathbf{v} + \mathbf{F} - \alpha\mathbf{v}$$

ROTATION

DAMPING:



FORCING: 2°-order OU-PROCESSS: ISOTROPIC, HOMOGENEOUS **NOT** DELTA-CORRELATED

1 WHAT ARE THE INTERACTIONS/MECHANISMS RESPONSIBLE FOR THE INVERSE ENERGY CASCADE, 2D-3D?

2. WHAT ABOUT THE SMALL-SCALES VELOCITY STATISTICS IN PRESENCE OF A LARGE SCALE INVERSE ENERGY TRANSFER: EFFECTS OF CHOERENT VORTEX STRUCTURES

Commun. Math. Phys. 115, 435–456 (1988)

The Beltrami Spectrum for Incompressible Fluid Flows

Peter Constantin[1,*] and Andrew Majda[2,**]

The nature of triad interactions in homogeneous turbulence

Fabian Waleffe
Center for Turbulence Research, Stanford University–NASA Ames, Building 500, Stanford, California 94305-3030

(Received 24 July 1991; accepted 22 October 1991)

$$\boldsymbol{u}(\boldsymbol{k}) = u^+(\boldsymbol{k})\boldsymbol{h}^+(\boldsymbol{k}) + u^-(\boldsymbol{k})\boldsymbol{h}^-(\boldsymbol{k})$$

$$\boldsymbol{h}^\pm = \hat{\boldsymbol{\nu}} \times \hat{\boldsymbol{k}} \pm i\hat{\boldsymbol{\nu}}$$

$$\hat{\boldsymbol{\nu}} = \boldsymbol{z} \times \boldsymbol{k}/||\boldsymbol{z} \times \boldsymbol{k}||.$$

$$i\boldsymbol{k} \times \boldsymbol{h}^\pm = \pm k\boldsymbol{h}^\pm$$

$$\begin{cases} E = \sum_{\boldsymbol{k}} |u^+(\boldsymbol{k})|^2 + |u^-(\boldsymbol{k})|^2; \\ H = \sum_{\boldsymbol{k}} k(|u^+(\boldsymbol{k})|^2 - |u^-(\boldsymbol{k})|^2). \end{cases}$$

$$u^{s_k}(\mathbf{k},t) \quad (s_k = \pm 1)$$

$$\frac{d}{dt}u^{s_k}(\mathbf{k}) + \nu k^2 u^{s_k}(\mathbf{k}) = \sum_{\mathbf{k}+\mathbf{p}+\mathbf{q}=0} \sum_{s_p, s_q} g_{\mathbf{k},\mathbf{p},\mathbf{q}}(s_p p - s_q q) \times [u^{s_p}(\mathbf{p}) u^{s_q}(\mathbf{q})]^*. \quad (15)$$

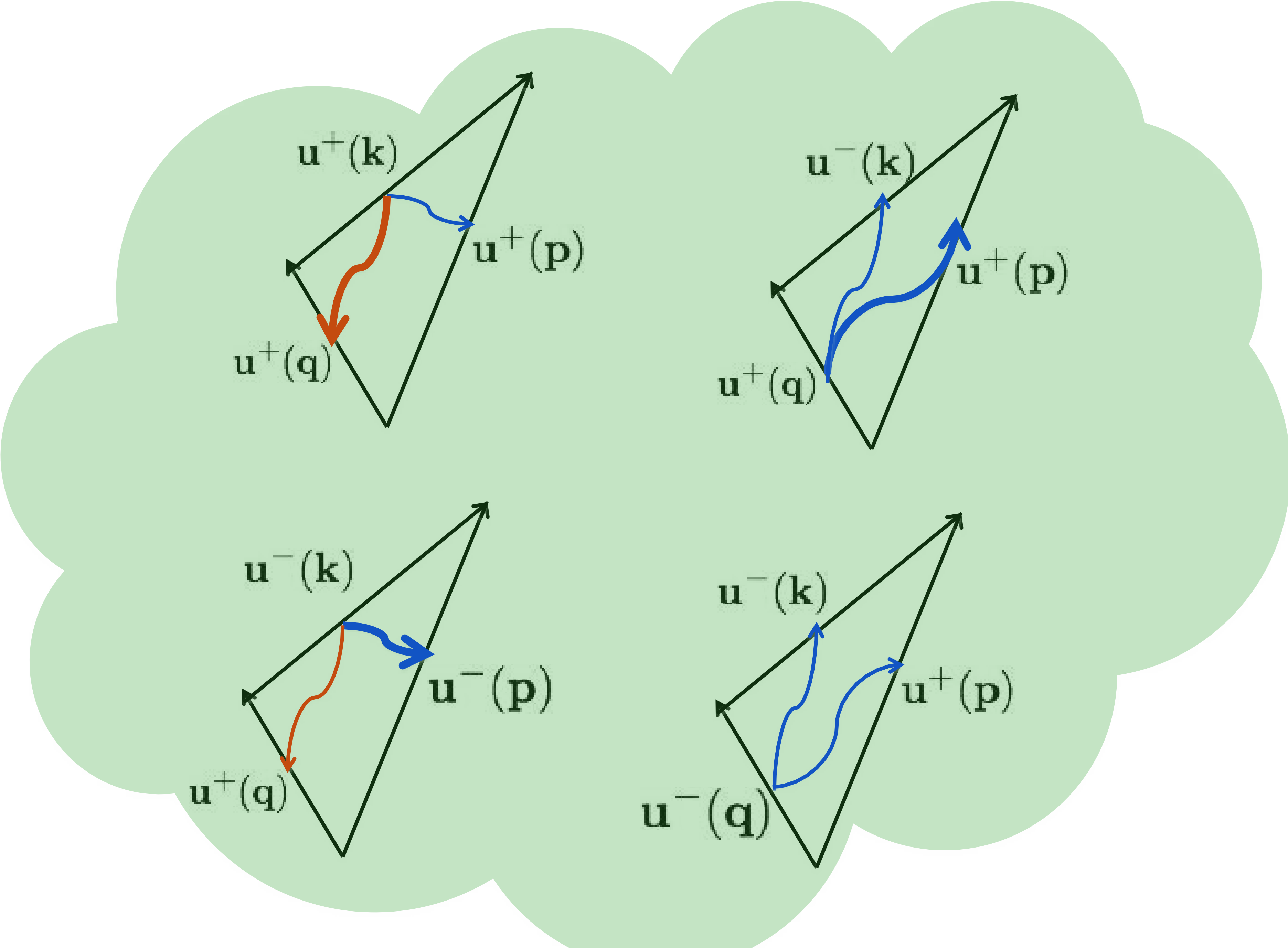
Eight different types of interaction between three modes $u^{s_k}(\mathbf{k})$, $u^{s_p}(\mathbf{p})$, and $u^{s_q}(\mathbf{q})$ with $|\mathbf{k}| < |\mathbf{p}| < |\mathbf{q}|$ are allowed according to the value of the triplet (s_k, s_p, s_q)

$$\dot{u}^{s_k} = r(s_p p - s_q q)\frac{s_k k + s_p p + s_q q}{p}(u^{s_p} u^{s_q})^*,$$

$$\dot{u}^{s_p} = r(s_q q - s_k k)\frac{s_k k + s_p p + s_q q}{p}(u^{s_q} u^{s_k})^*,$$

$$\dot{u}^{s_q} = r(s_k k - s_p p)\frac{s_k k + s_p p + s_q q}{p}(u^{s_k} u^{s_p})^*.$$

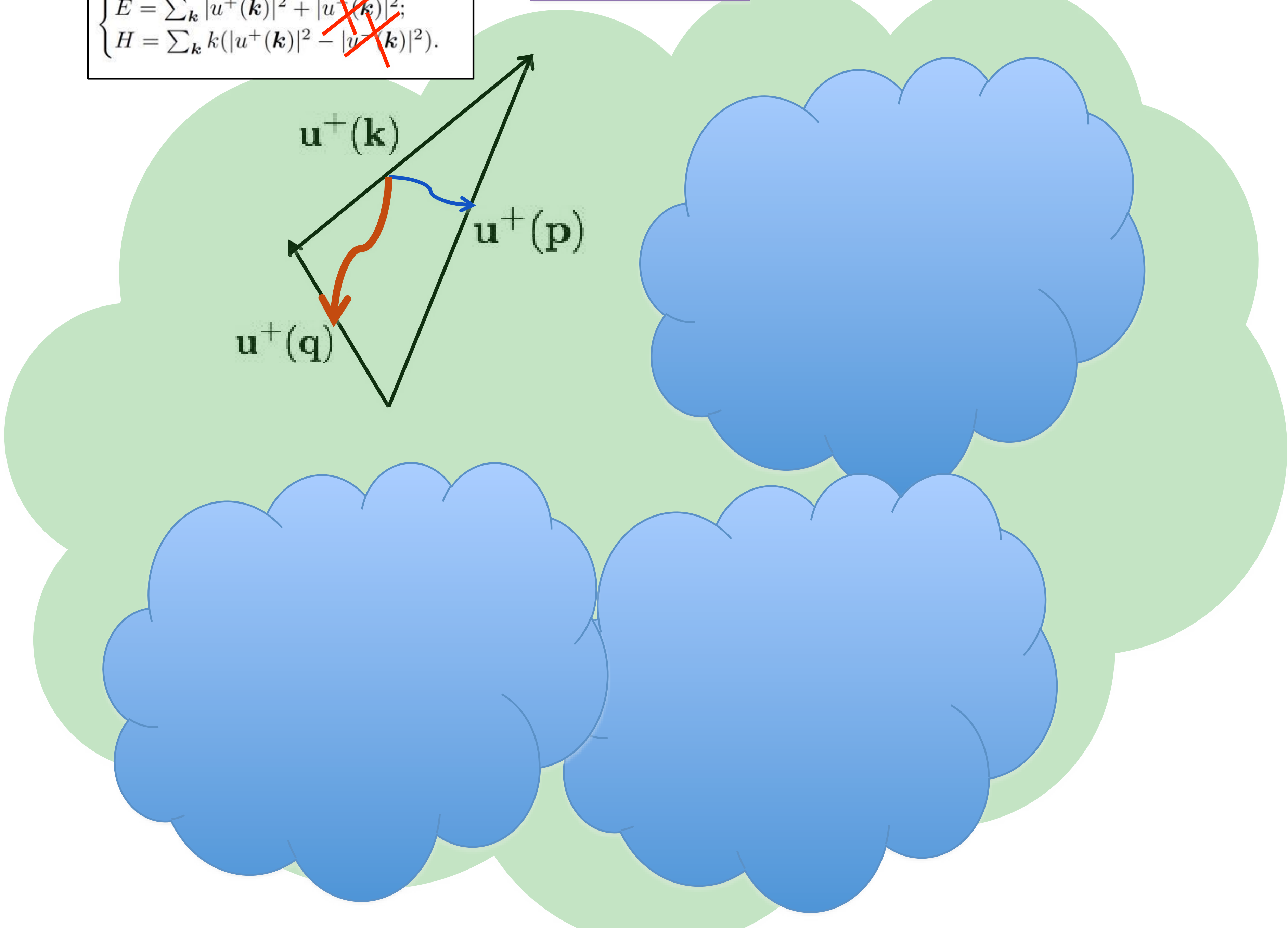
HELICAL TRIADIC INTERACTION IN THE NAVIER_STOKES EQS



TRIADIC INTERACTION IN DECIMATED NAVIER_STOKES EQS

HOMOCHIRAL

$$\begin{cases} E = \sum_{\boldsymbol{k}} |u^{+}(\boldsymbol{k})|^2 + |u^{-}(\boldsymbol{k})|^2; \\ H = \sum_{\boldsymbol{k}} k(|u^{+}(\boldsymbol{k})|^2 - |u^{-}(\boldsymbol{k})|^2). \end{cases}$$



HOMOCHIRAL 3D NAVIER STOKES EQS.

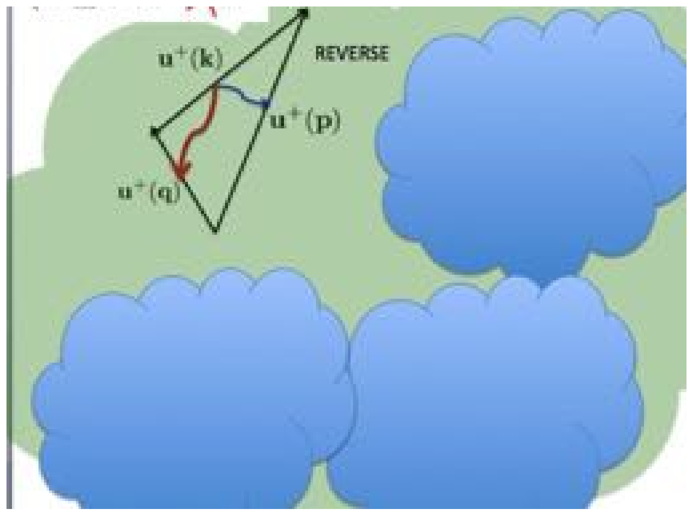
$$\mathcal{P}^{\pm} \equiv \frac{\boldsymbol{h}^{\pm} \otimes \overline{\boldsymbol{h}^{\pm}}}{\overline{\boldsymbol{h}^{\pm}} \cdot \boldsymbol{h}^{\pm}}. \qquad \boldsymbol{v}^{\pm}(\boldsymbol{x}) \equiv \sum_{\boldsymbol{k}} \mathcal{P}^{\pm} \boldsymbol{u}(\boldsymbol{k});$$

$$\boldsymbol{u}(\boldsymbol{k}) = u^{+}(\boldsymbol{k})\boldsymbol{h}^{+}(\boldsymbol{k}) + u^{-}(\boldsymbol{k})\boldsymbol{h}^{-}(\boldsymbol{k})$$

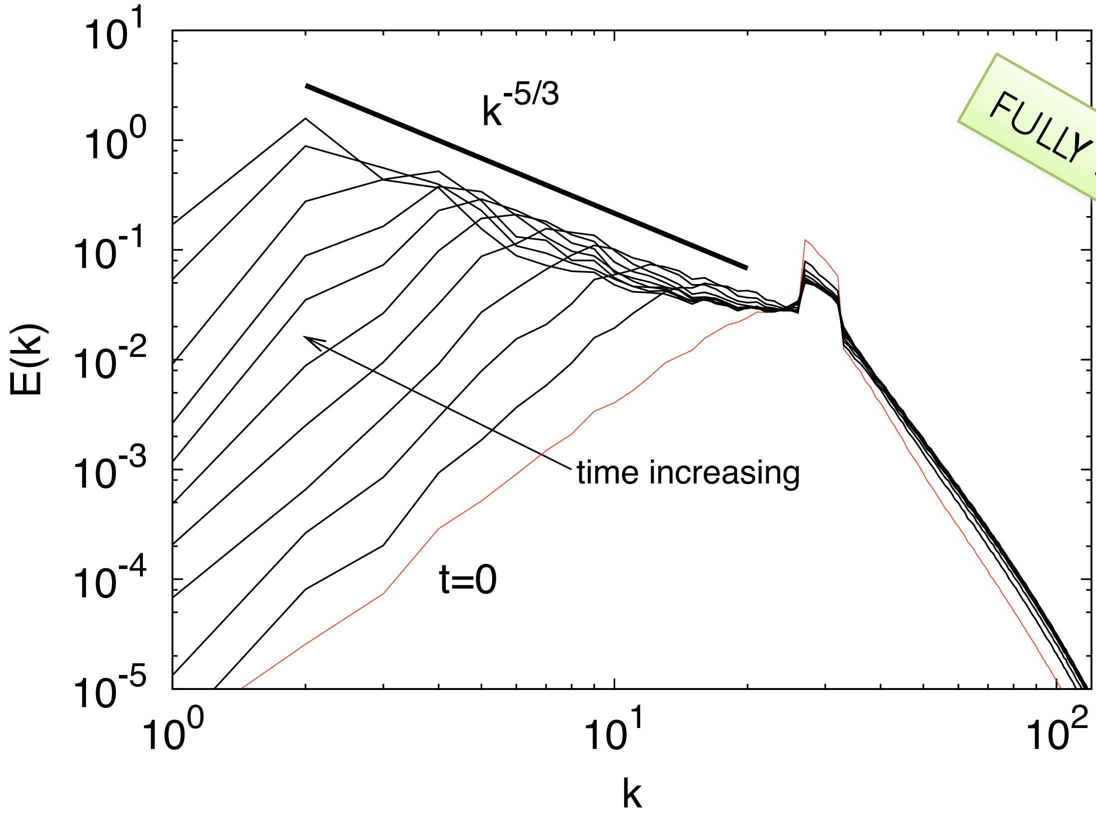
LOCAL BELTRAMIZATION (IN FOURIER)

$$\partial_t v^{+} + \mathcal{P}^{+} B[v^{+}, v^{+}] = \nu \Delta v^{+} + \mathbf{f}^{+}$$

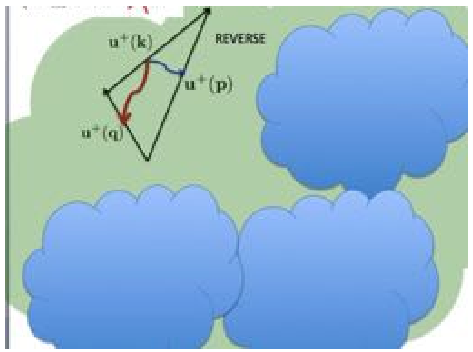
decimated-NSE



$$\begin{cases} E = \sum_{\boldsymbol{k}} |u^+(\boldsymbol{k})|^2 + |u^-(\boldsymbol{k})|^2; \\ H = \sum_{\boldsymbol{k}} k(|u^+(\boldsymbol{k})|^2 - |u^-(\boldsymbol{k})|^2). \end{cases}$$



FULLY 3D AND ISOTORPIC



L.B., S. MUSACCHIO & F. TOSCHI Phys. Rev. Lett. 108 164501, 2012.

PHYSICS OF FLUIDS VOLUME 11, NUMBER 6 JUNE 1999

Transfer of energy to two-dimensional large scales in forced, rotating three-dimensional turbulence

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$$\mathbf{u}(\mathbf{k}) = u^{+}(\mathbf{k})e^{+it\omega^{+}(\mathbf{k})}\mathbf{h}^{+}(\mathbf{k}) + u^{-}(\mathbf{k})e^{+it\omega^{-}(\mathbf{k})}\mathbf{h}^{-}(\mathbf{k})$$

$$i\boldsymbol{k} \times \boldsymbol{h}^{\pm} = \pm k\boldsymbol{h}^{\pm} \qquad \omega^{\pm}(\mathbf{k}) = \pm 2\Omega\frac{k_z}{k}$$

$$\frac{d}{dt}u^{s_k}(\mathbf{k}) + \nu k^2 u^{s_k}(\mathbf{k}) = \sum_{\mathbf{k}+\mathbf{p}+\mathbf{q}=0}\ \sum_{s_p,s_q} g_{\mathbf{k},\mathbf{p},\mathbf{q}}(s_p p - s_q q)$$

$$e^{i(\omega^{s_k}+\omega^{s_p}+\omega^{s_q})t/Ro} \times [u^{s_p}(\mathbf{p})u^{s_q}(\mathbf{q})]^{*}. \qquad (15)$$

TRIADIC WAVE-INTERACTIONS

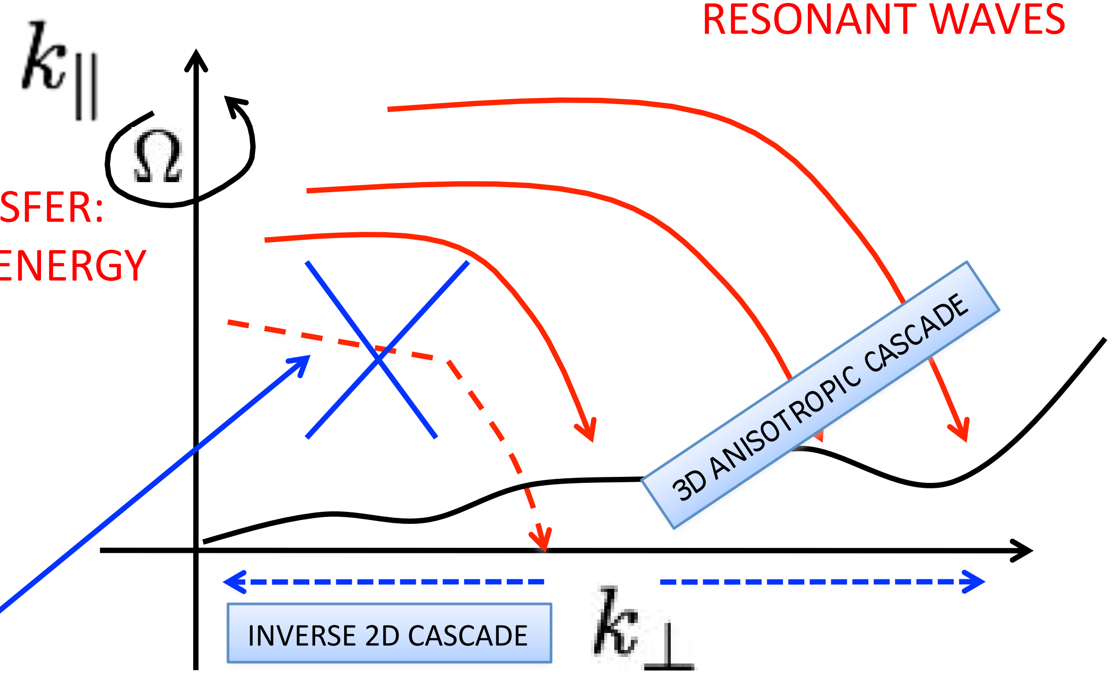
$$\omega^{s_k} + \omega^{s_p} + \omega^{s_q} = 0$$

$$Ro \to 0$$

$$Ro \rightarrow 0 \qquad \omega^{s_k} + \omega^{s_p} + \omega^{s_q} = 0$$

RESONANT WAVES

ANISOTROPIC ENERGY TRANSFER:
WAVES TEND TO TRANSFER ENERGY
TOWARD THE $k_\perp$ BUT ...

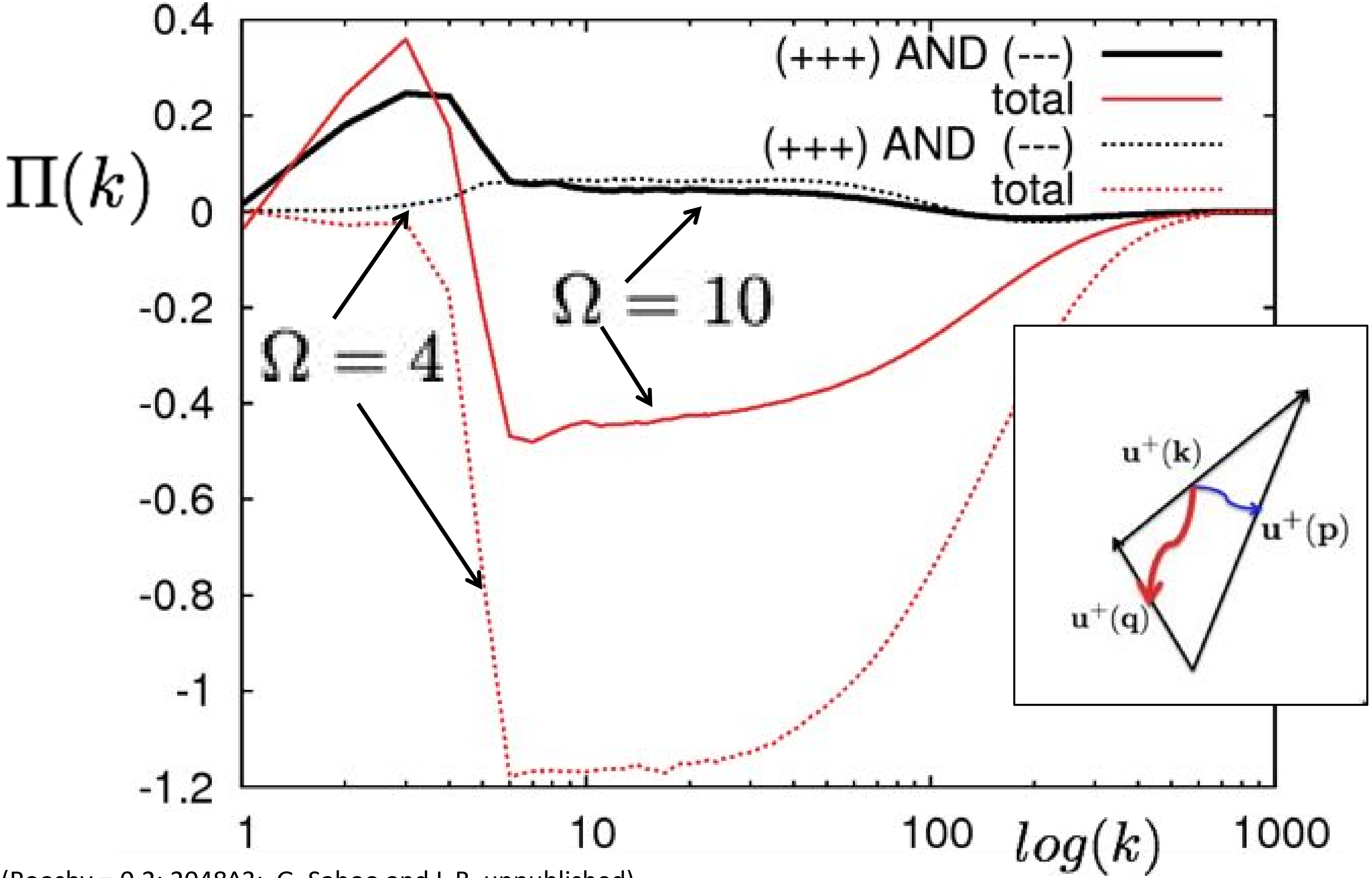


FORBIDDEN !!!
NO DIRECT TRANSFER FROM 3D RESONANT WAVES TO 2D MODES

THERE EXISTS A BUFFER REGION IN THE K-SPACE CLOSE TO THE 2D MODES WHERE TRIADIC RESONANT WAVES ARE LESS AND LESS EFFICIENT:

-) O(Ro) INTERACTIONS
-) QUARTET-INTERACTIONS
-) TURBULENCE

CONTRIBUTION TO THE INVERSE ENERGY FLUX MAINLY FROM TRIADS WITH SIGN-DEFINITE HELICITY



(Roosby = 0.2; 2048^3; G. Sahoo and L.B, unpublished)

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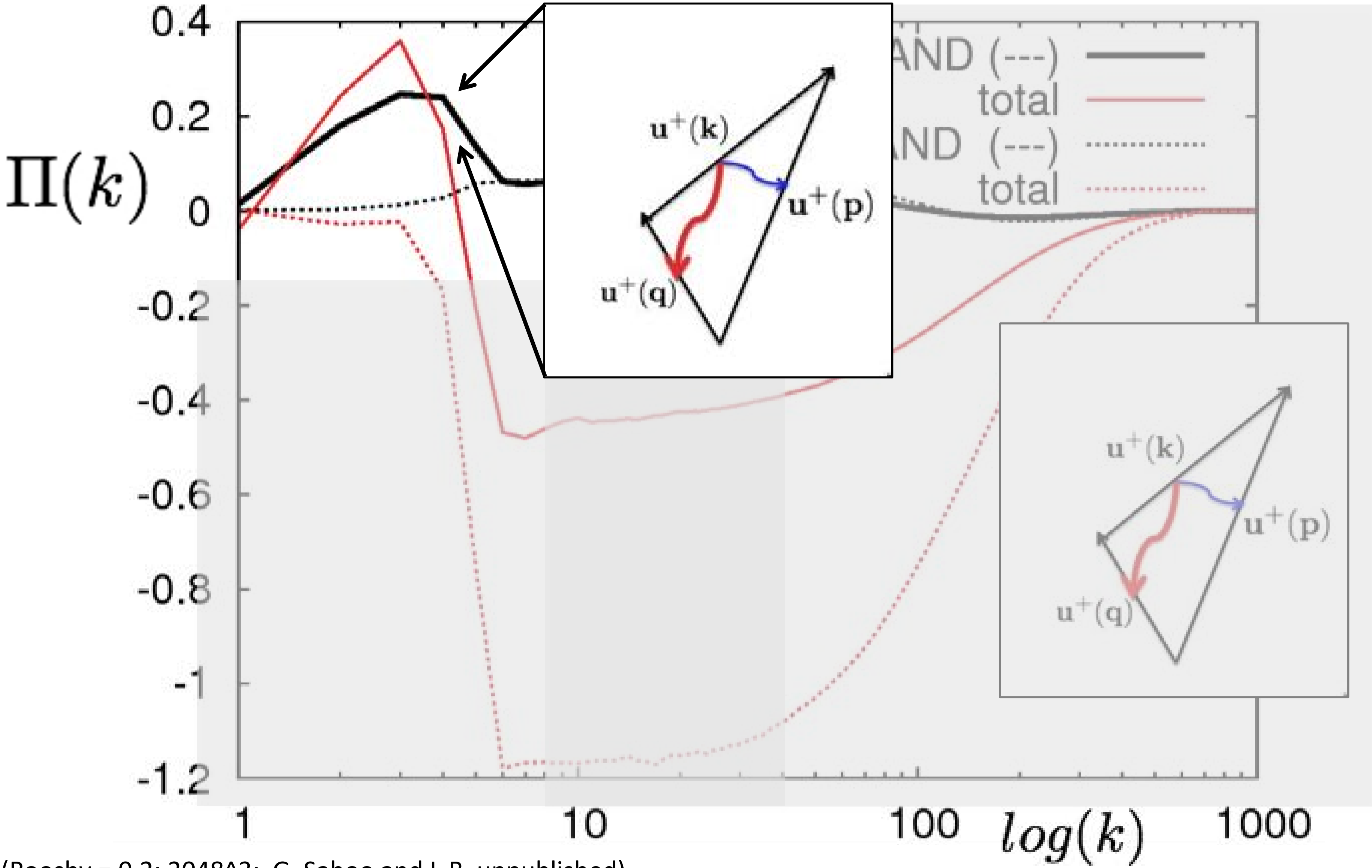

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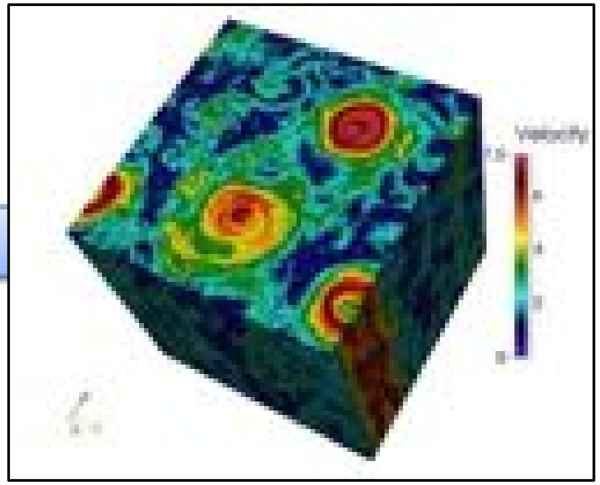
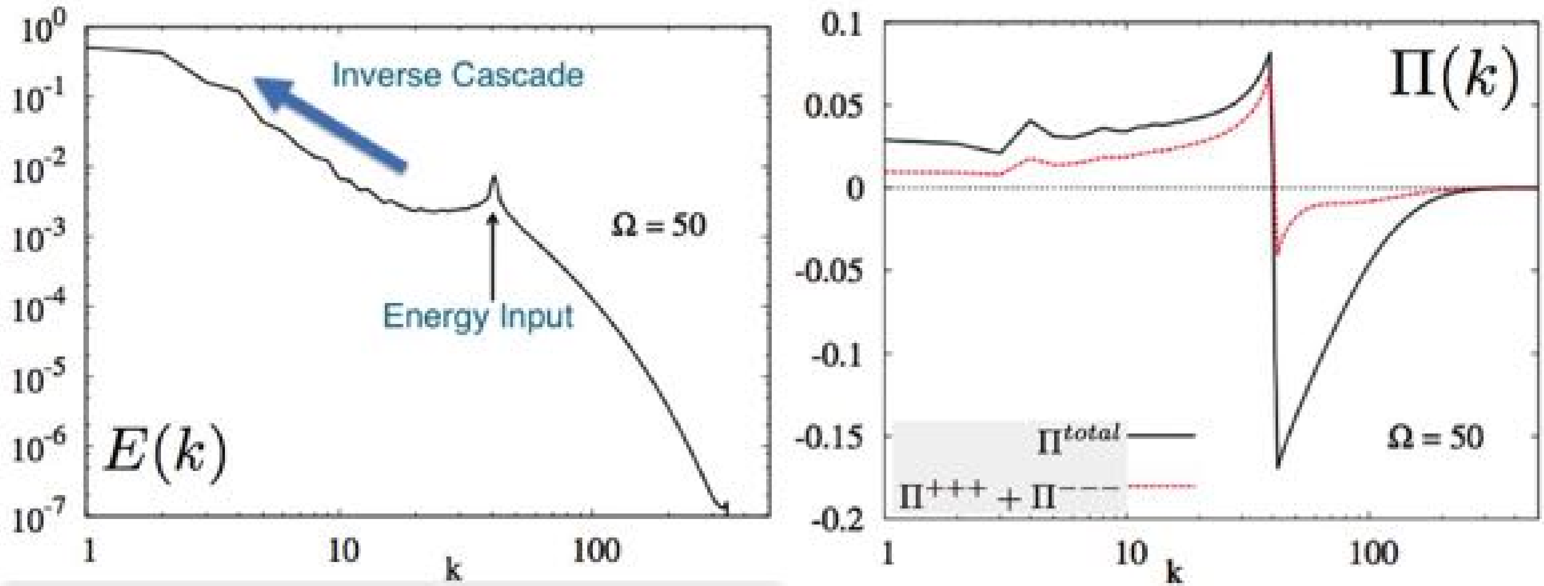
Inverse cascade at Ω = 50

Inverse flux is brought mainly by +++ and --- triads.



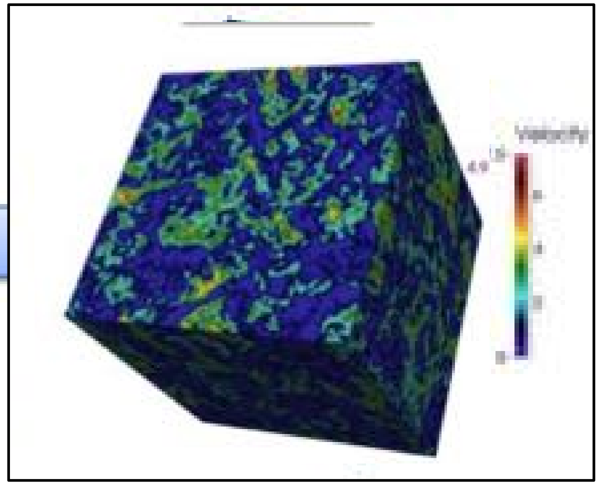


$$\Pi^{(+++)}(k) = \langle u^{+}_{<k} N(u^{+}, u^{+}) \rangle$$

$$Ro \sim 0.15$$

WITH G. SAHOO AND P. PERLEKAR (unpublished)

Inverse cascade at Ω = 50



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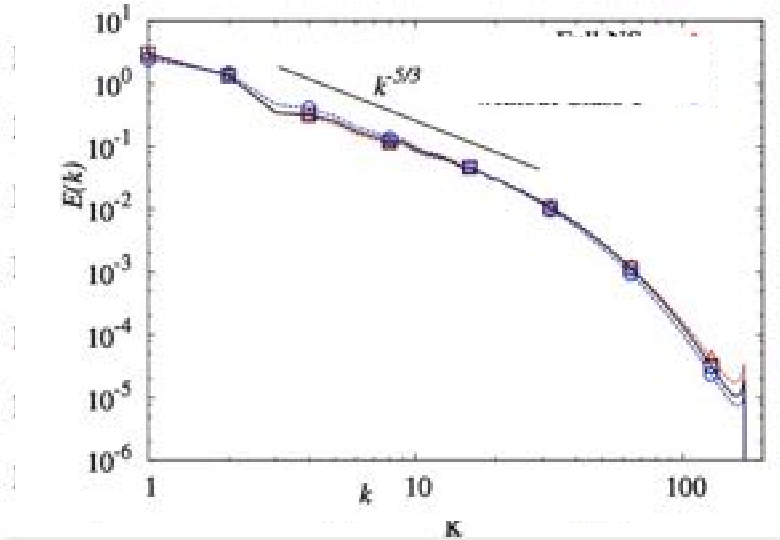

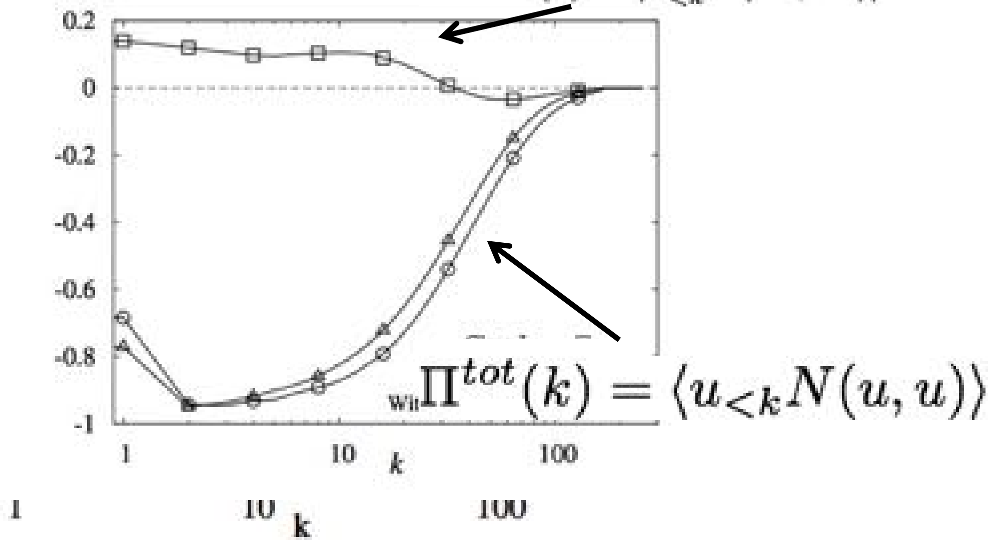

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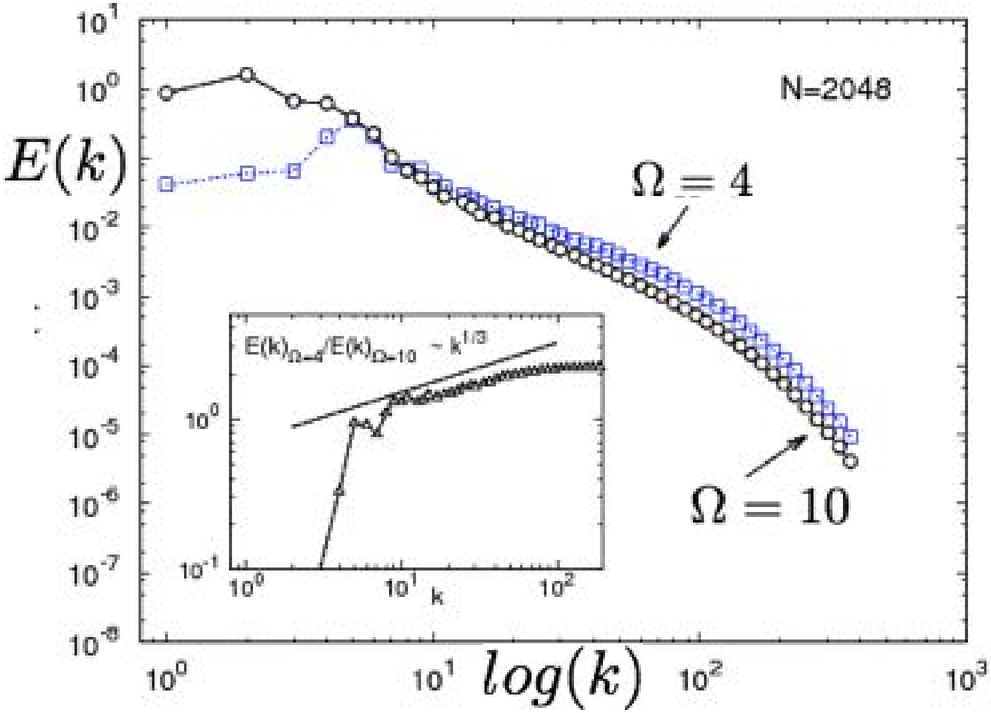
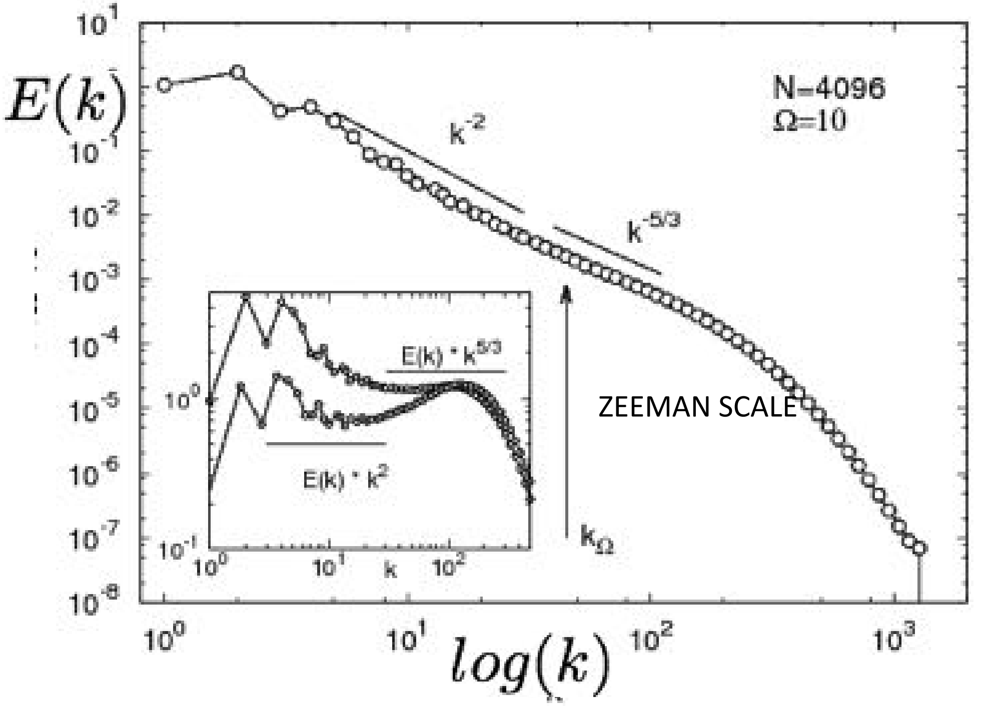
WITH G. SAHOO AND P. PERLEKAR (unpublished)

1 WHAT ARE THE INTERACTIONS/MECHANISMS RESPONSIBLE
FOR THE INVERSE ENERGY CASCADE, 2D-3D?

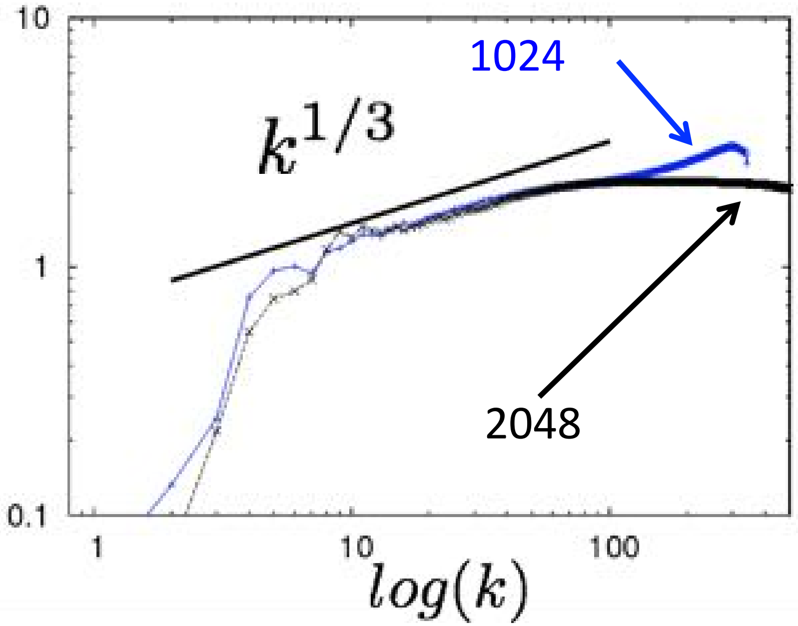
2. WHAT ABOUT THE SMALL-SCALES VELOCITY STATISTICS IN PRESENCE OF A LARGE SCALE INVERSE ENERGY TRANSFER: EFFECTS OF CHOERENT VORTEX STRUCTURES

MEAN SPECTRAL PROPERTIES

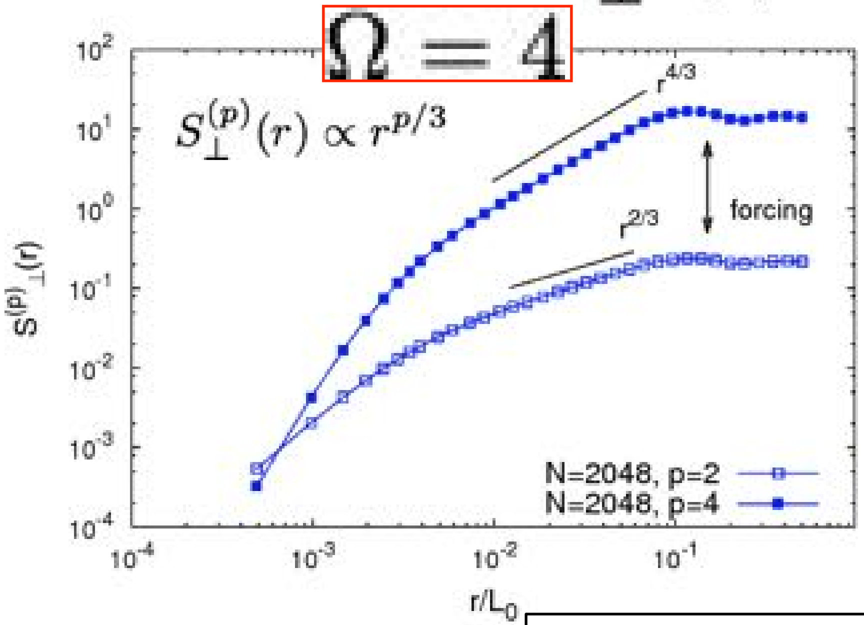


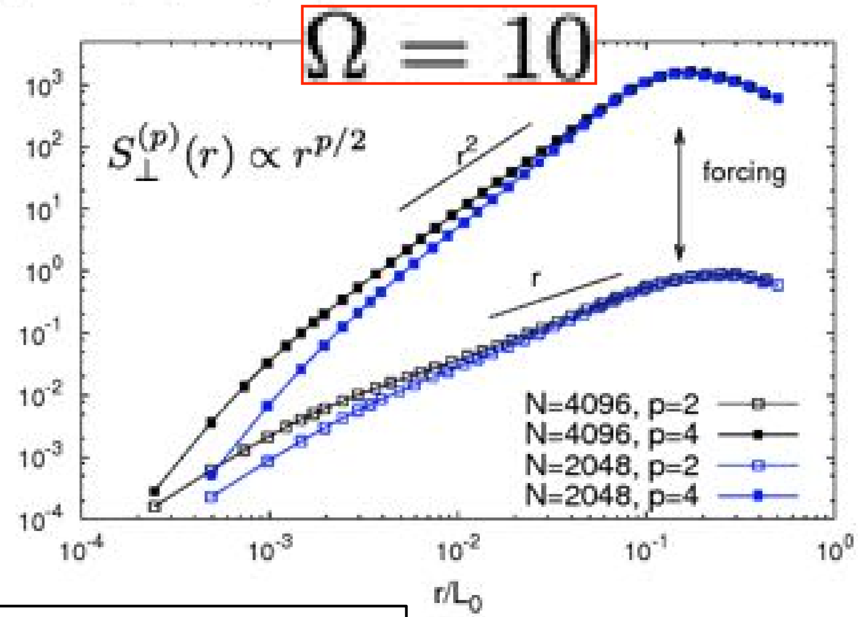


$$E_{\Omega=4}(k)/E_{\Omega=10}(k)$$

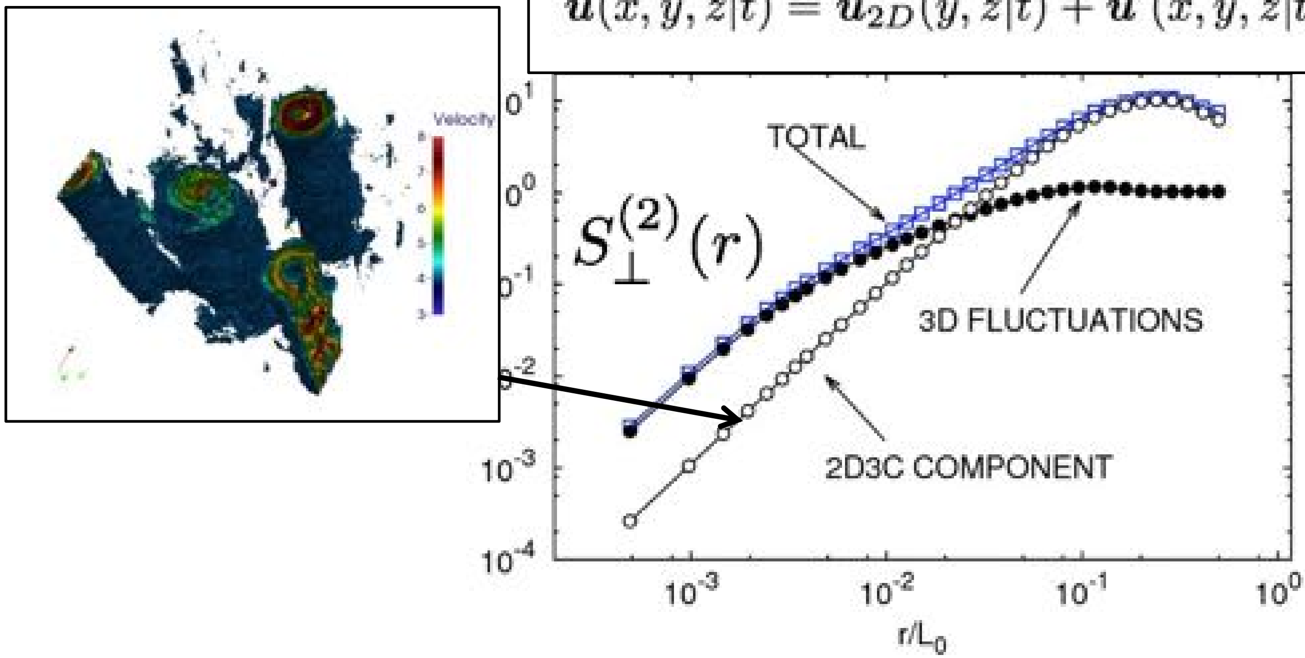


$$S_{\perp}^{(p)}(r) = \langle(\delta u(r)_{\perp})^p\rangle$$



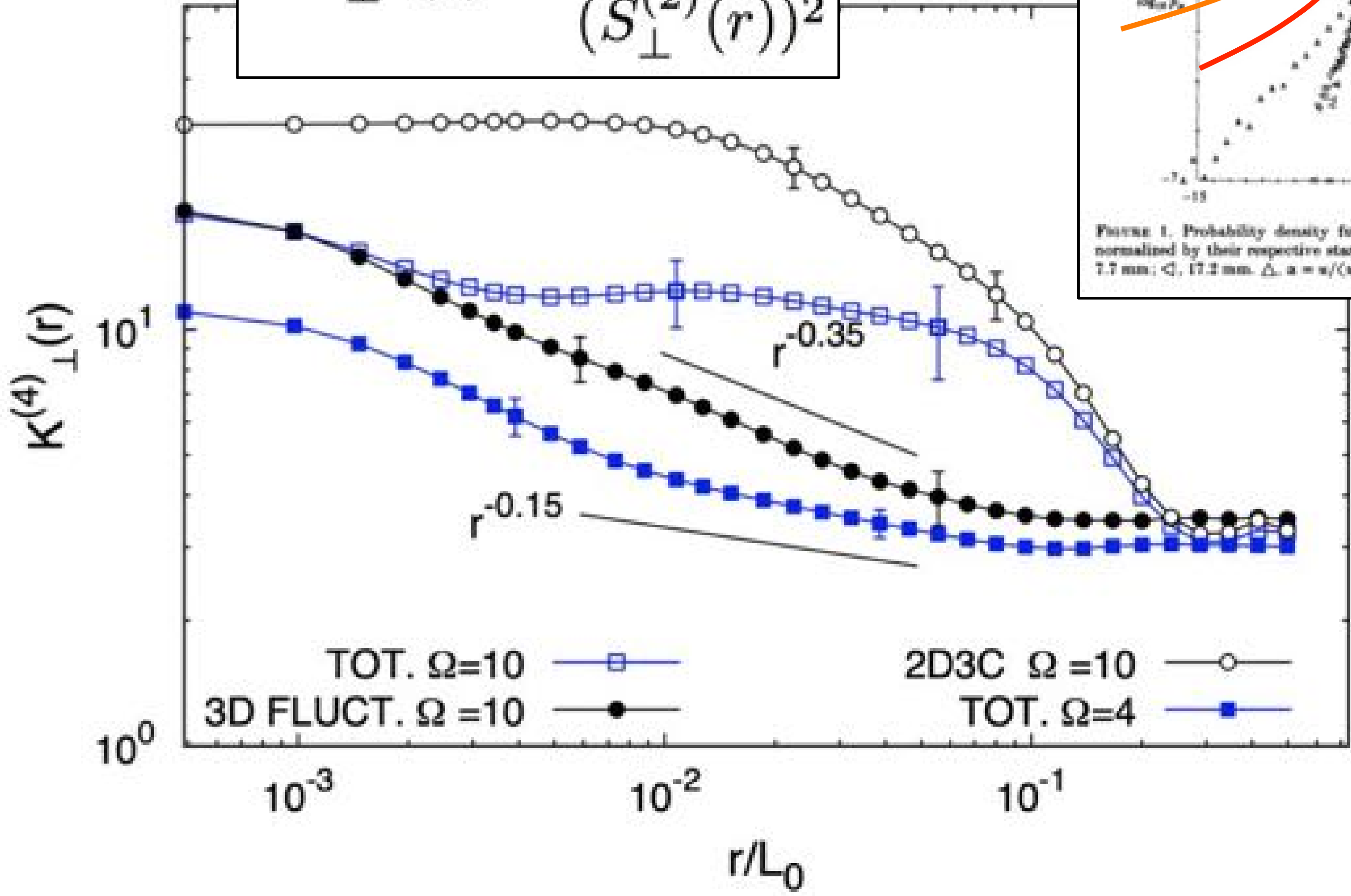


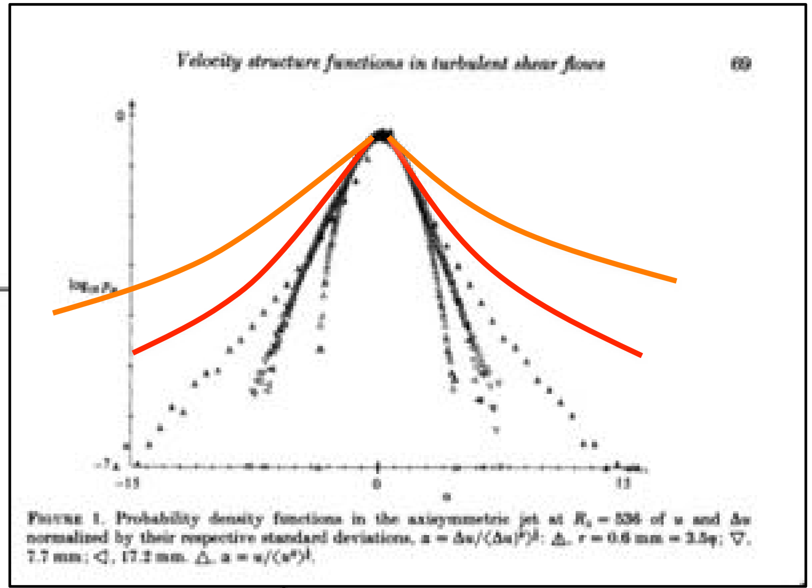
$$\boldsymbol{u}(x,y,z|t) = \boldsymbol{u}_{2D}(y,z|t) + \boldsymbol{u}'(x,y,z|t)$$



FLUCTUATIONS: FLATNESS

$$K_{\perp}^{(4)}(r) \equiv \frac{S_{\perp}^{(4)}(r)}{(S_{\perp}^{(2)}(r))^2}$$

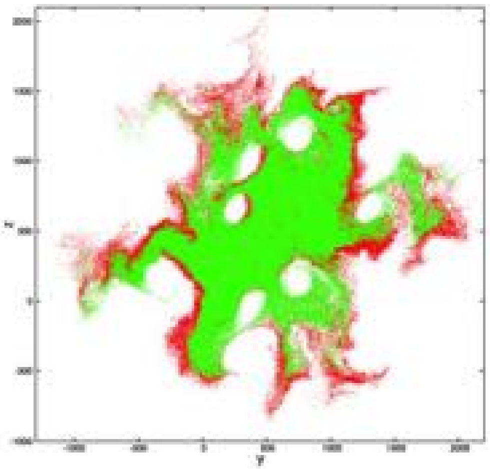




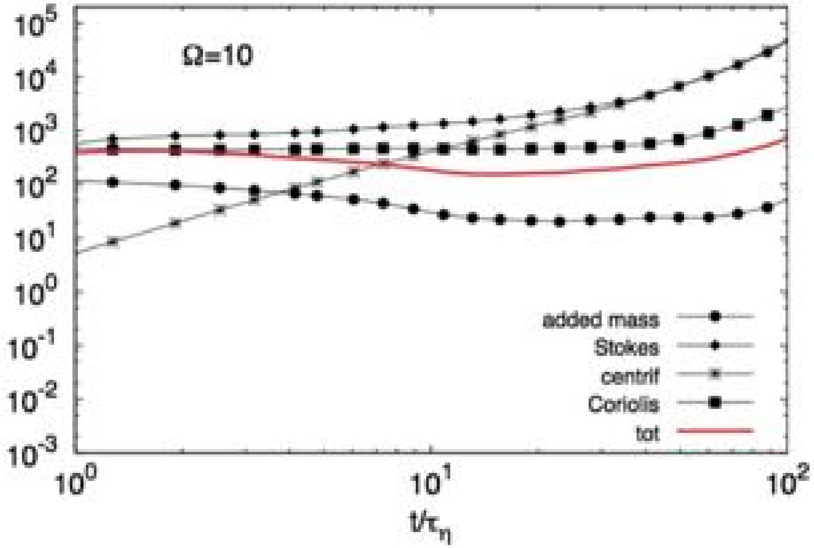
- NON-GAUSSIAN PROPERTIES DEPEND ON THE WAY YOU DECOMPOSE THE FIELD
- AFTER FILTERING THE 2D3C COMPONENT: SCALING PROPERTIES ARE BACK (BUT NOT HIT!)

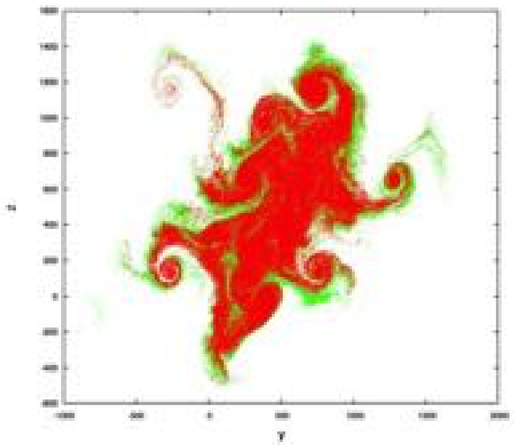
RMS FORCES ALONG TRAJECTORIES

$$\frac{d\mathbf{v}}{dt} = \beta\frac{D\mathbf{u}}{Dt} - \frac{1}{\tau_p}(\mathbf{v}-\mathbf{u}) + 2(\mathbf{v}-\beta\mathbf{u})\times\boldsymbol{\Omega} - (1-\beta)\boldsymbol{\Omega}\times(\boldsymbol{\Omega}\times\mathbf{r})$$

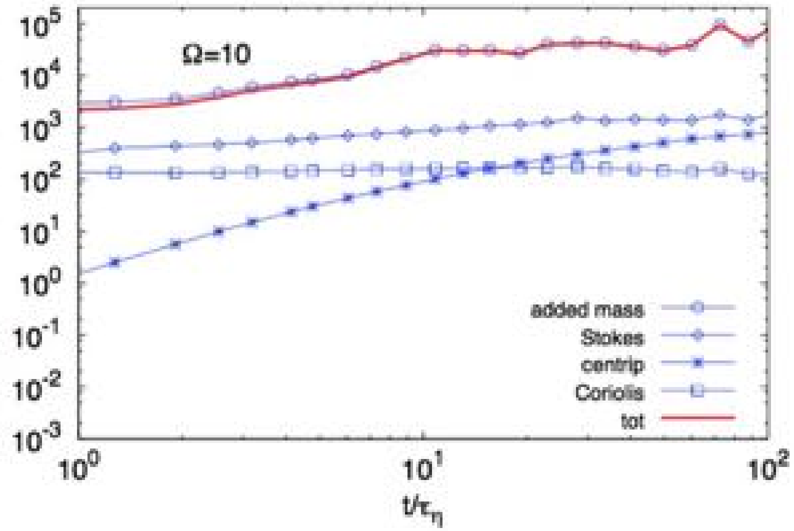


HEAVY



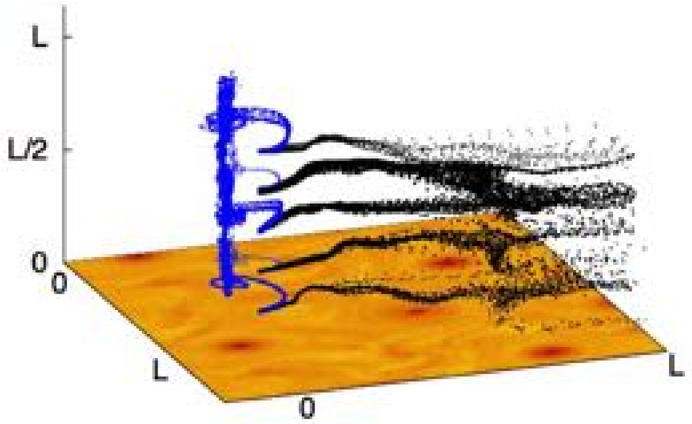


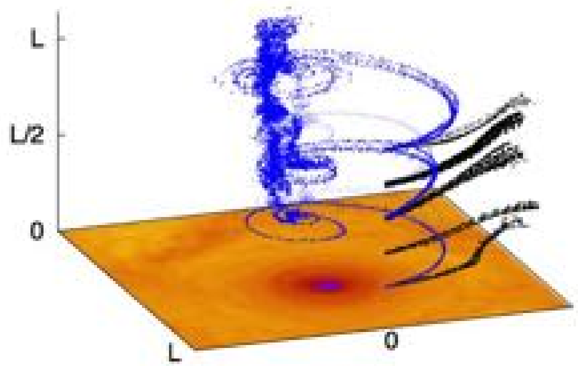
LIGHT

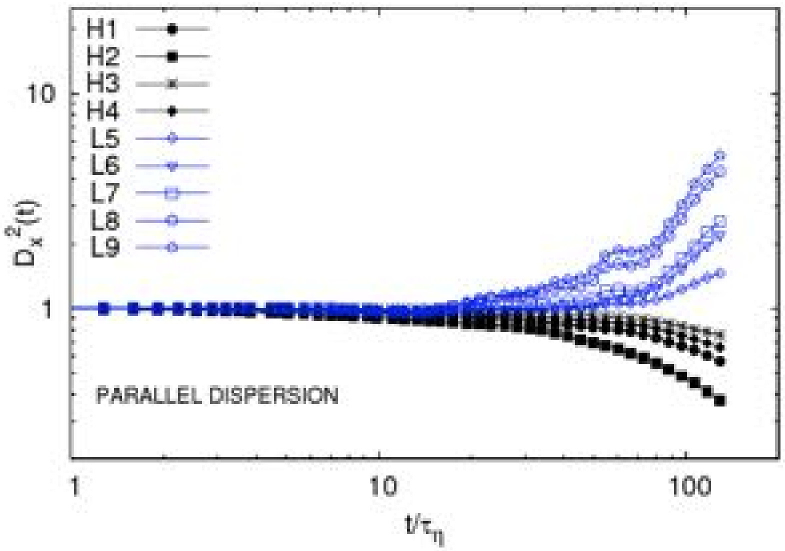


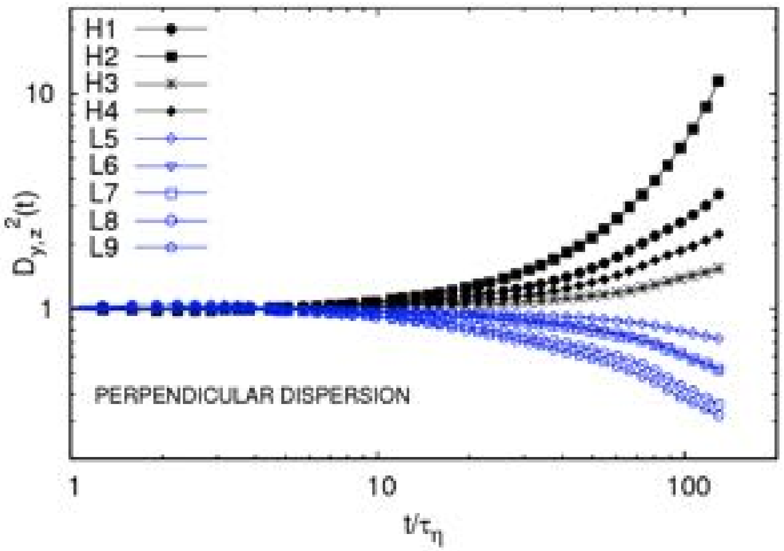
INERTIA: SINGULAR EFFECT ON SINGLE PARTICLE DISPERSION

$$D^i_{St,\beta}(t) = \frac{\langle (r^i_t - r^i_0)^2 \rangle_{St,\beta}}{\langle (r^i_t - r^i_0)^2 \rangle_{tracer}}$$









CONCLUSIONS

-HIGH RESOLUTION ROTATING TURBULENCE: FIRST ATTEMPT TO CONTROL SIMULTANEOUSLY EULERIAN & LAGRANGIAN STATISTICS

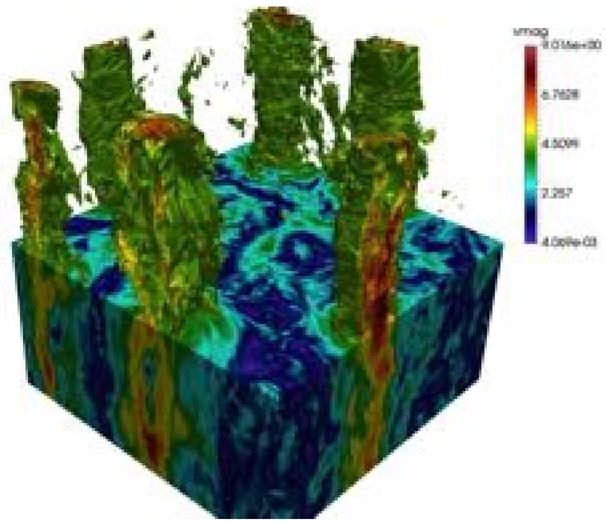
-IDEAL SET-UP (1): HOMOGENEOUS AND ISOTROPIC TIME-COLORED FORCING

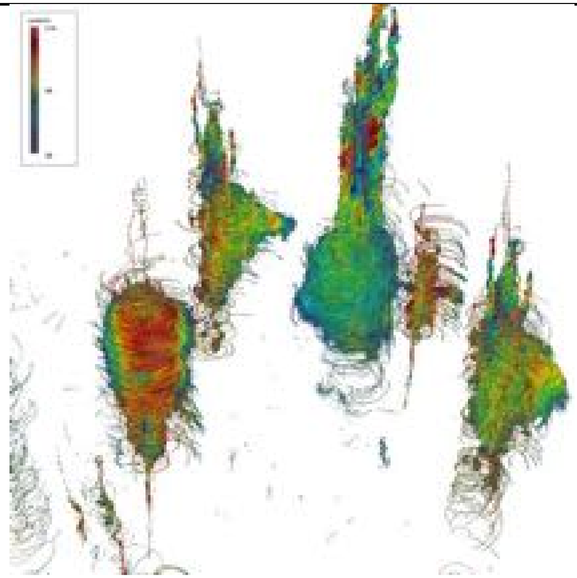
-IDEAL SET-UP (2): SCALE-SEPARATION

-STRONG INFLUENCE OF LARGE-SCALE (NON-UNIVERSAL?) VORTICAL STRUCTURES

-DEPARTURE FROM GAUSSIANITY (DEPENDING ON HOW YOU MEASURE IT: 2D3C-3D3D)

-EFFECTS OF LARGE-SCALE STRUCTURES ON PARTICLES' DISPERSION





L.B., F. Bonaccorso, I. Mazzitelli, A. Lanotte, S. Musacchio, P. Perlekar, F. Toschi and M. Hinsberg, PRX **6** 041036 (2016)