Stronger Local Dissipation for Stronger Waves In *Fluid and MHD Turbulence*

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Pouquet et al., Atmosphere **14**, *1375 (2023)*

A few questions on energy dissipation in turbulence, with or w/o waves: Rotating stratified flows, MHD, solar wind, galaxies …

- 1- How much **global** energy dissipation in a turbulent fluid (with or w/o magnetic field) ?
  - *Role of exact laws to measure dissipation, and role of bi-directional cascades*
- 2- How much **global** energy dissipation in **wave** turbulence ?
- 3- How much **local** energy dissipation in a turbulent fluid in the presence of waves *(intensity vs. localization)* ?
- 4- Statistical properties of kinetic energy dissipation: a link between its third- and fourth- order moments

Equations & definitions: rotating stratified flows

$$\partial_t \mathbf{u} = -(\mathbf{u}\cdot\nabla)\mathbf{u} - N\theta \mathbf{z}^\star + \nu\nabla^2\mathbf{u} + 2\mathbf{u}\times\boldsymbol{\Omega} - \nabla p + \mathbf{F}_u \;, \quad \nabla\cdot\mathbf{u} = 0$$

$$\partial_t \theta = -(\mathbf{u}\cdot\nabla)\theta + Nw + \kappa\nabla^2\theta + F_\theta$$

$\varepsilon_V = D_t <u^2> = - p<u^3> + \ldots$

$\varepsilon_\theta = D_t <\theta^2> = - q<u\,\theta^2> + \ldots$

$$Re = \frac{U_{rms}L_{int}}{\nu} \;,\; Ro = \frac{U_{rms}}{fL_{int}} \;,\; Fr = \frac{U_{rms}}{NL_{int}} \;;\; R_\lambda = \frac{U_{rms}\lambda_T}{\nu} \;,\; R_B = ReFr^2 \;, Ri_g = \frac{N(N-\partial_z\theta)}{[(\partial_z u)^2 + (\partial_z v]^2]}$$

$f = 2\Omega$, $\lambda^2 = < u^2 > / < \omega^2 >$, $\omega = \nabla\times\mathbf{u}$

Skewness and excess kurtosis (both 0 for a Gaussian distribution):

$$S_V = \left\langle V^3 \right\rangle / \left\langle V^2 \right\rangle^{3/2}, \; K_V = \left\langle V^4 \right\rangle / \left\langle V^2 \right\rangle^2 - 3 \;; \quad K_V(S_V) = a_V S_V^2 + b_V$$

range	Dissipation estimate (Eq.)	symbol	definition	assumption
dissipative sub-range	instantaneous (3)	ϵ_0	$2\nu(s_{ij}s_{ij})$	
	(local) volume average (4)	$\langle\epsilon(\boldsymbol{x},t)\rangle_R$	$\frac{3}{4\pi R^3}\iiint_{\mathcal{V}(R)}\epsilon_0(\boldsymbol{x}+\boldsymbol{r},t)\mathrm{d}\boldsymbol{r}$	SHI
	(longitudinal) gradient (6)	ϵ_G	$15\nu\left\langle\left(\frac{\partial u_1'(\boldsymbol{x})}{\partial x_1}\right)^2\right\rangle$	SHI
	2nd-order SF (dissipation range) *	ϵ_{D2}	$15\nu D_{LL}(r)/r^2$	SHI, $r \lesssim \eta_K$
	zero-crossings *	ϵ_+	$15\pi^2\nu\langle u_1'^2\rangle N_L^2$	SHI
inertial sub-range	4/5 law * ((7), $n=3$) *	ϵ_{I3}	$-5/4D_{LLL}(r)/r$	SHI, K41
	2nd-order SF (inertial range) ((7), $n=2$)	ϵ_{I2}	$(D_{LL}(r)/C_2)^{3/2}/r$	SHI, K41
	spectral (9)	ϵ_S	$\left(\frac{\kappa_1^{5/3}E_{11}(\kappa_1)}{18/55C_K}\right)^{3/2}$	SHI, K41
	cutoff filter *	ϵ_C	$\left(\frac{2}{3}\frac{2\langle u_C'^2\rangle}{18/55C_K\left(\kappa_{1,\mathrm{low}}^{-2/3}-\kappa_{1,\mathrm{up}}^{-2/3}\right)}\right)^{3/2}$	SHI, K41
energy injection scale	scaling argument (10) *	ϵ_L	$C_\epsilon\sigma_{u'}^3/L_{11}$	SHI
	global mean (5)	$\langle\epsilon\rangle$	$\lim_{R\to\infty}\langle\epsilon_0(\boldsymbol{x},t)\rangle_R$	SHI

Schroder+2023

Strain: $S_{ij}=[\partial_i u_j+\partial_j u_i]/2$

SHI: Stationary, Homogeneous, isotropic

Exact Kolmogorov (1941) law

- **Starting point: Invariants** (ν=η=0): total energy, magnetic helicity & cross-helicity in 3D-MHD, …
- **Assumptions:** homogeneity, stationarity and large Reynolds number, together with finite dissipation ε, as well as incompressibility and full isotropy ***(but not always: Galtier-Banerjee)***
  - Fluids: *Kolmogorov 1941; Antonia+ 1997; 2D: Lindborg-99. Passive scalar: Yaglom, 1949*
  - MHD: *Politano+1998ab, Banerjee+* 2016, 2017; 2D: Caillol, *unpublished*.
  - Compressible: *Banerjee+'13,14, Kritsuk 23, …*
  - **Helical** laws for fluids, MHD & Hall-MHD: *Gomez+ 00, Politano+ 03, Banerjee+ 16,17*
    - Helical sub-invariants (Alexakis, 2017)
    - Helical MHD case ?
  - **Non-linear models** of small-scale dynamics: EDQNM (fluids: *Briard+17*), *alpha*-models for fluids & MHD: *Graham+ 2006, 2008.*
  - *MHD closure case ?*

** Beyond Hall & e-MHD: 2D-3C; 2-fluid; extended MHD ?*

$$\delta u_L(r) = u(x+r) - u(x)$$
$$S_3(r) = < \delta u_L^3(r) > \rightarrow$$

*

Seven points

(1): Exact

(2), ESS: high-order structure functions scaling with r ←→ Y_H

$$S_3(\mathbf{r}) = -\frac{4}{5}\epsilon^V r$$

+

(3): cascade direction

(4) **measure** ε

(5) +: add terms (model, viscous, force)

(6): Non-Gaussianity, *but not necessarily intermittency (cf. the 2D case)*

(7): More laws when **more invariants**?

** How do they inter-connect?*

** Role of cross-correlations?*

Laboratory experiments on decaying fluid flows

R_λ up to 5779

Active grids

Kuchler+2023

$R_\lambda = u\lambda/\nu$

$\lambda^2 = \langle u^2 \rangle / \langle \omega^2 \rangle$

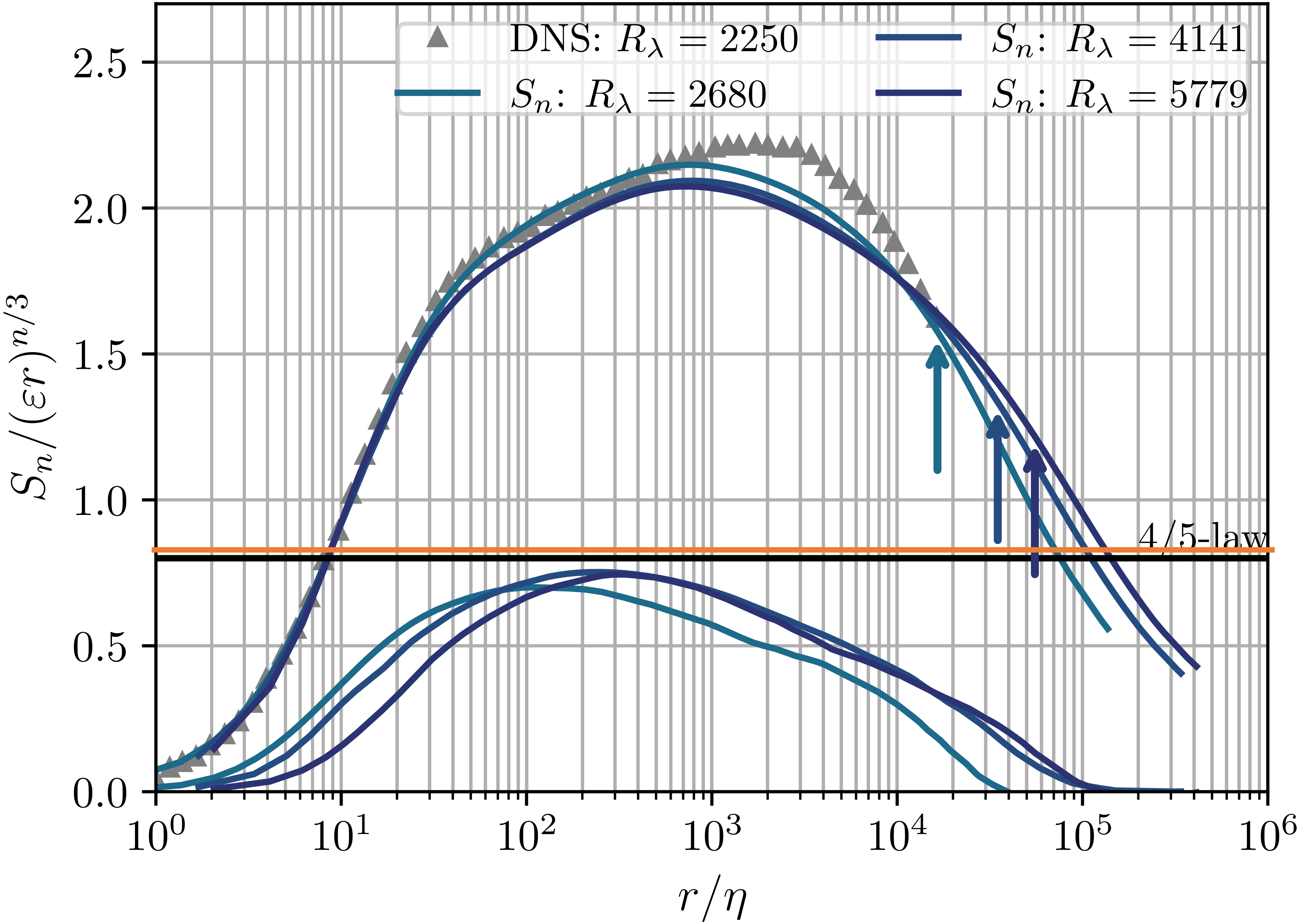
$\omega = \nabla \times \mathbf{u}$

Kolmogorov dissipation length η_k:

$\eta = [\epsilon/\nu^3]^{-1/4}$

Local slope: $\zeta_2(r)$

$\delta u^2(r) = r^{\zeta_2}$

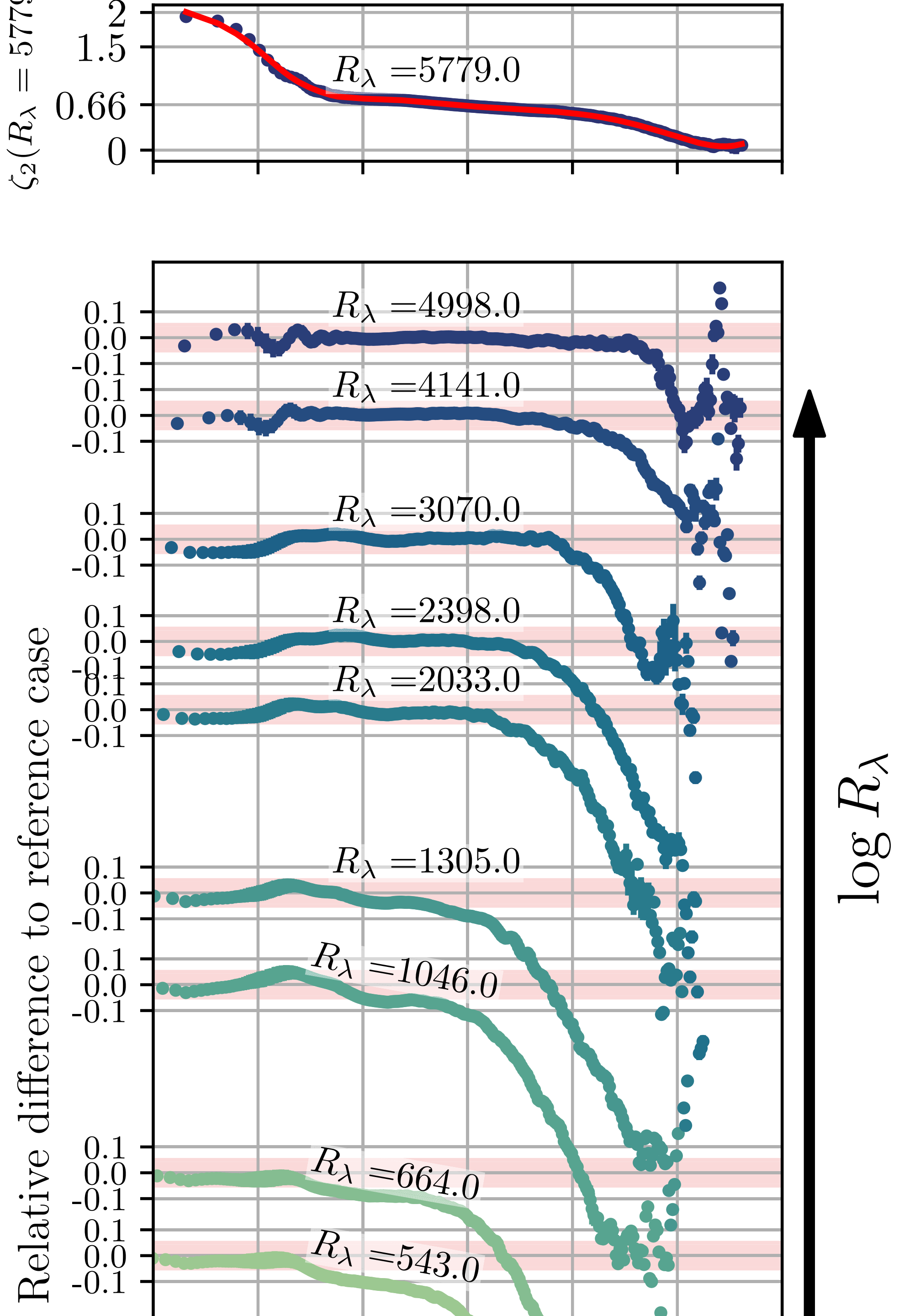


Laboratory experiments on decaying fluid flows

R_λ up to 5779

Kuchler+2023

Compensated energy spectra



Exact laws in MHD

Review: Marino+ 2023

$$\langle \delta v_L \delta v_i^2 \rangle + \langle \delta v_L \delta b_i^2 \rangle - 2 \langle \delta b_L \delta v_i \delta b_i \rangle = -(4/d)\, \varepsilon^T r$$

$$- \langle \delta b_L \delta b_i^2 \rangle - \langle \delta b_L \delta v_i^2 \rangle + 2 \langle \delta v_L \delta v_i \delta b_i \rangle = -(4/d)\, \varepsilon^C r$$

E^T AND H^C

$\varepsilon^T = - d_t E^T$,

$\varepsilon^C = - d_t E^C$

- Also in terms of **$Y^{\pm}$** fluxes of Elsasser variables, with energy dissipation rates $\varepsilon^{\pm}$

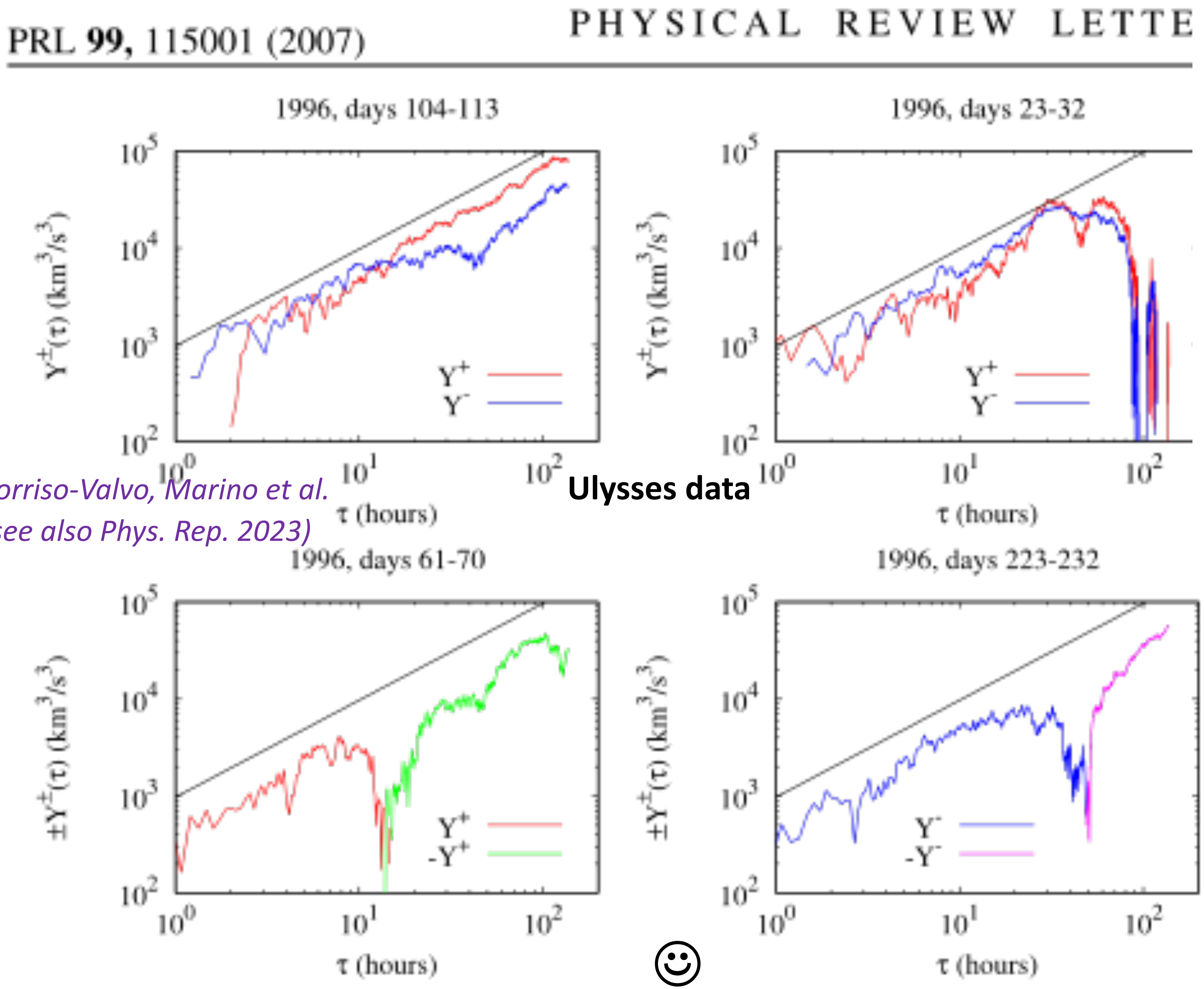
- **Three** regimes: v-dominated *vs.* B-dominated *vs.* Alfvénic (**v ~ b**) *(cf. Ting et al 1986)*

- ***Dynamical role of the correlation*** *between v & b in the mixed regime* (Politano+ *GRL* ***25****, 1998;* *also Boldyrev, 2006):*
  $\varepsilon^x = 0$ for exact solutions such as (nonlinear) Alfvén waves.

- When such laws apply, the input/dissipation rates $\varepsilon^{T,C}$ & $\varepsilon^{\pm}$ can be measured, *e.g. in the solar wind for different conditions.* *What about plasma regimes?*

Politano+1998ab; Banerjee+2017

vKH in MHD: *Chandrasekhar 1950*



Sorriso-Valvo, Marino et al.
(see also Phys. Rep. 2023)

Ulysses data

☺

MacBride+ 2005

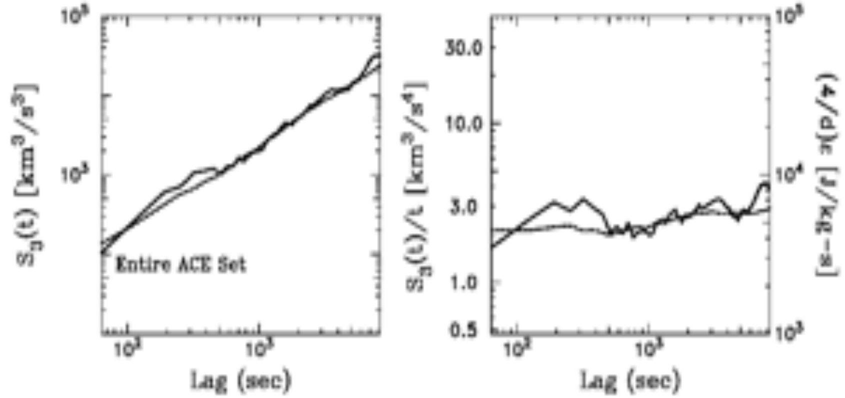


Figure 4. (left) The third moment of fluctuations as a function of lag for the hydrodynamic (dashed) and magnetohydrodynamic (solid) forms spanning years 1998 through 2004. (right) An estimate for ϵ.

$$\langle |\Delta z^{\pm}|^2 \Delta z_{\parallel}^{\mp} \rangle = Y^{\pm}(r) = -\frac{4}{3}\epsilon^{\pm} r$$

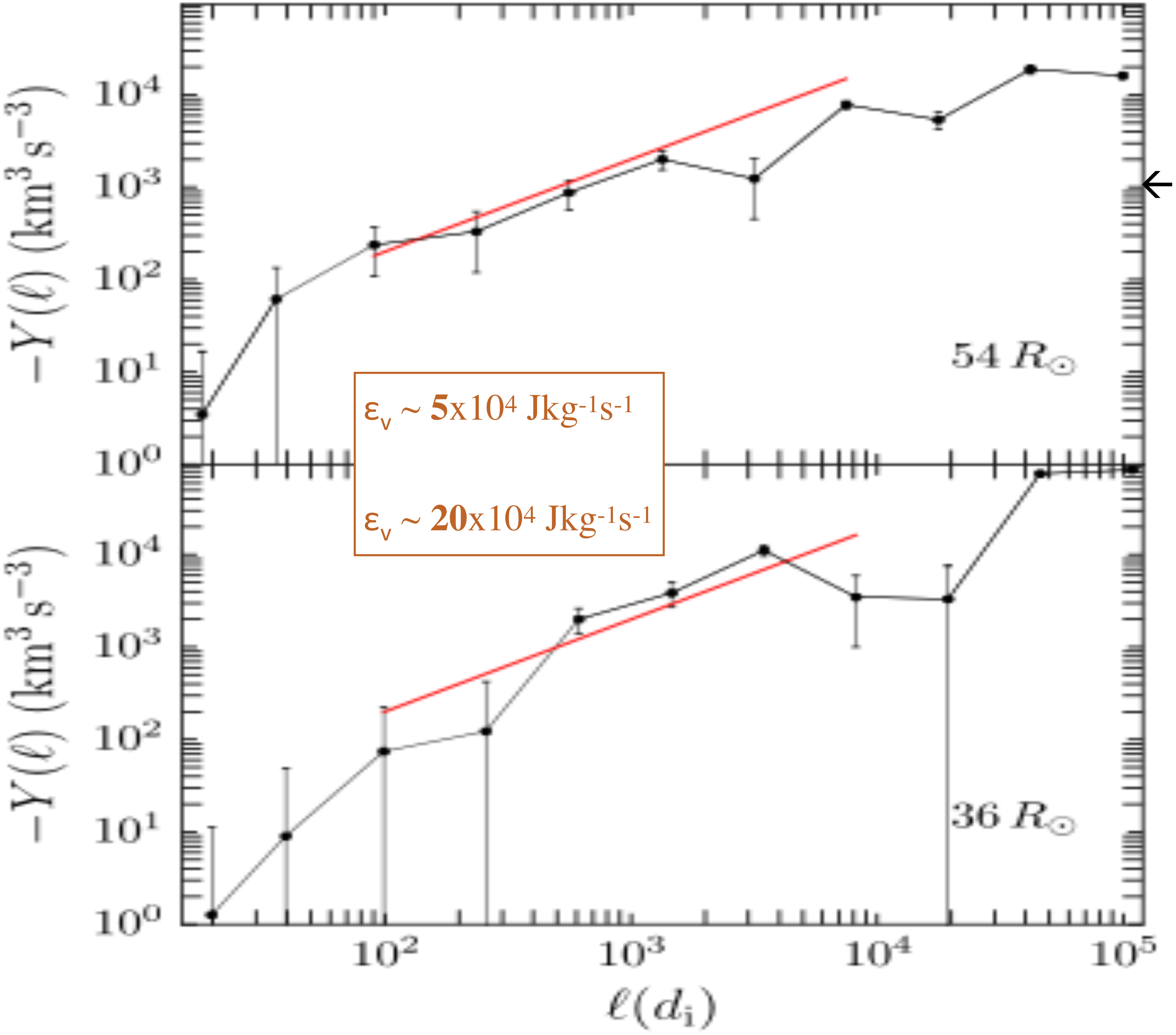
$\mathbf{Z}^{\pm} = \mathbf{v} \pm \mathbf{b}$, $Z_{//} = \mathbf{Z} \cdot \mathbf{r} / |r|$

$\Delta Z(r) = Z(x + r) - Z(x)$

Note:

$\delta z^+ \delta z^+ \delta z^- \sim (\delta v + \delta B)^2 (\delta v - \delta B) \sim \varepsilon^+$

But it does not always work ….



Bandyopadhyay+ 2020

Parker Solar Probe, inner heliosphere

← $Y = [Y^+ + Y^-]/2$

$$\langle |\Delta z^{\pm}|^2 \Delta z_{\parallel}^{\mp} \rangle = Y^{\pm}(r) = -\tfrac{4}{3}\epsilon^{\pm} r$$

+ Hall terms

$\mathbf{Z}^{\pm} = \mathbf{v} \pm \mathbf{b}$

$Z_{//} = \mathbf{Z} \cdot \mathbf{r} / |r|$

$\Delta Z(r) = Z(x + r) - Z(x)$

Larger energy dissipation rate closer to the Sun

Vorticity dynamics for fluid turbulence

$D_t\omega = \partial_t \omega + \mathbf{v}.\nabla\omega = \quad \omega.\nabla\mathbf{v} \quad + \nu\nabla^2\omega \quad + \nabla\times\mathbf{F}$

advection *stretching by velocity gradients* *+ dissipation* *+ forcing*

Model:

$D_t\omega = \omega.\nabla\mathbf{v}$ —> $\nabla\mathbf{v}$ **is** O(1) at early times: exponential growth of vorticity

Buaria+2018-22, strain-vorticity amplification in [12k]³ DNS

But: $\omega \sim \nabla\mathbf{v}$ so:

$D_t\omega = |\omega|^2$: explosive growth

Is there a role for the geometry of structures?

Vorticity, strain and dissipation in fluid turbulence

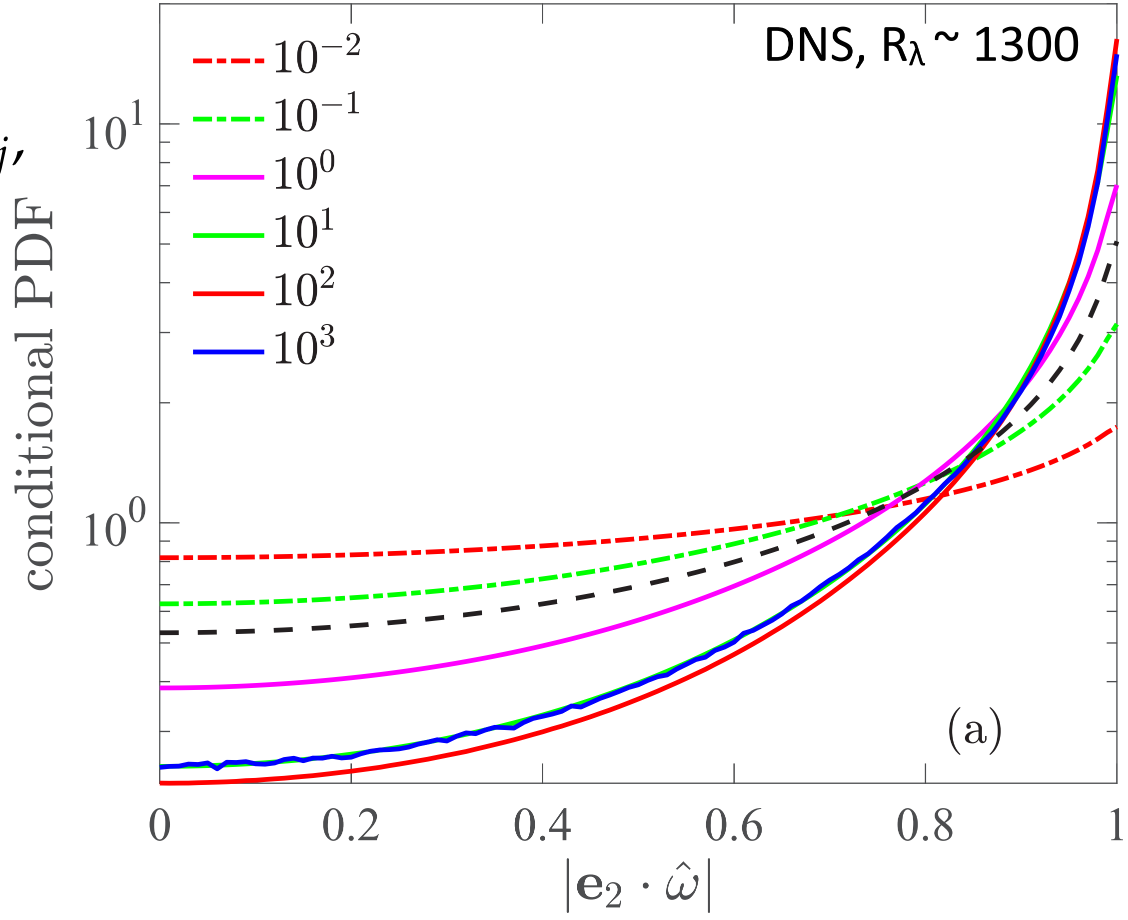
$\omega = \nabla \text{x} u, \quad \epsilon = 2\nu S_{ij} S_{ij}, \quad \text{where } S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right), \qquad 2\Omega_{ij} = \partial_j u_i - \partial_i u_j$

$$\frac{D\omega_i}{Dt} = \omega_j s_{ij} + \nu \nabla^2 \omega_i,$$

$$\frac{DS_{ij}}{Dt} = -S_{ik}S_{kj} - \frac{1}{4}(\omega_i\omega_j - \omega_k\omega_k\delta_{ij}) - \Pi_{ij} + \nu\nabla^2 S_{ij},$$

Betchov 1956: $< |\mathbf{S}^2| > = < \omega^2 > /2$

Buaria+ 2018-2022: strain-vorticity amplification in 12k^3 DNS



Bradshaw+2019, Johnson 2020, Rafner+2021

Strain and vorticity, local and nonlocal, amplitude and geometry

Vorticity dynamics: geometry

$$\partial_t \omega = \nabla \times (\mathbf{v} \times \omega) + \nu \nabla^2 \omega + \nabla \times \mathbf{F}$$

$D_t\omega = \partial_t \omega + \mathbf{v}.\nabla \omega =$ $\omega.\nabla\mathbf{v}$ $+ \nu \nabla^2 \omega$ $+ \nabla \times \mathbf{F}$

advection *stretching by velocity gradients* *+ dissipation* *+ forcing*

Model:

$D_t\omega = \omega.\nabla\mathbf{v}$, with $\nabla\mathbf{v}$ O(1) : exponential growth of vorticity at early times

But. $\omega \sim \nabla\mathbf{v}$ so:

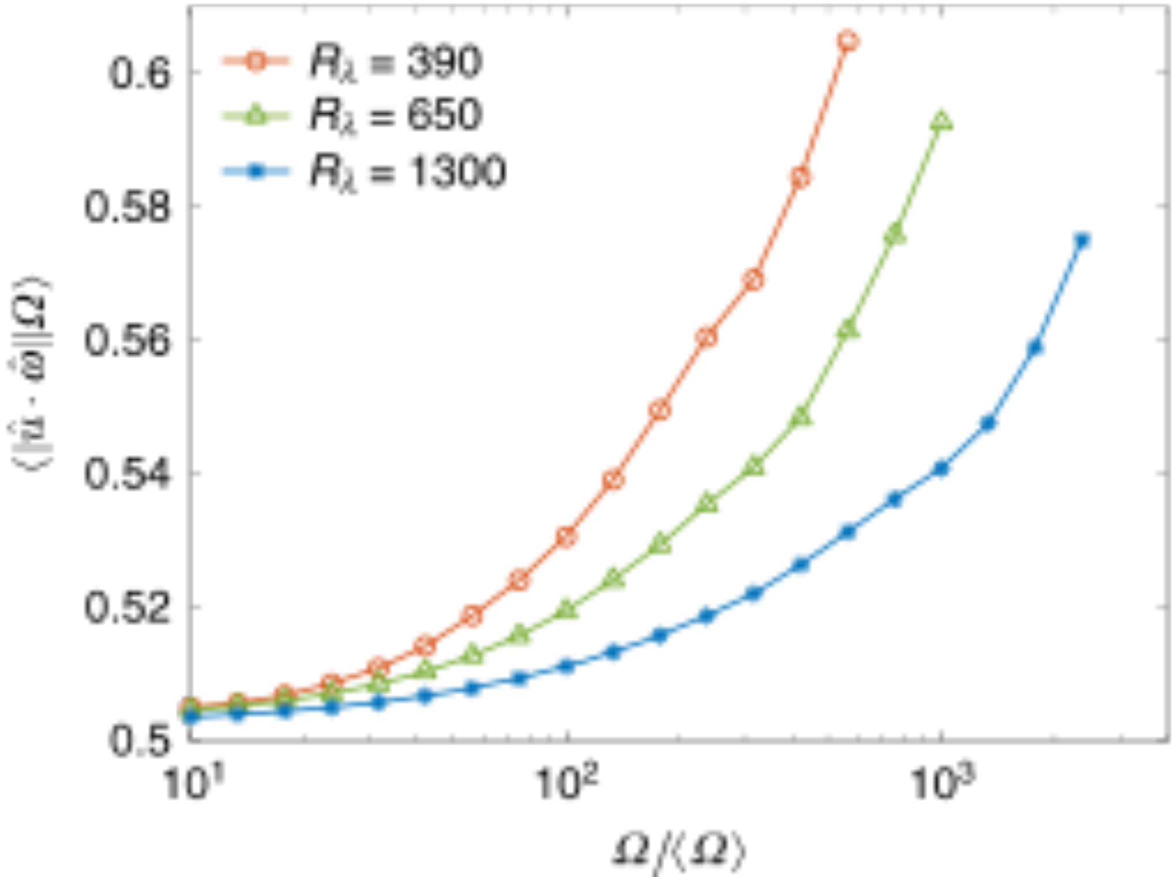
$D_t\omega = |\omega|^2$: explosive growth

Is there a role for the geometry of structures?

Yes when $\mathbf{v} // \omega$ (vortex filament)

→ locally weak nonlinearities and long-lived coherent structures

Review: Bradshaw+2019

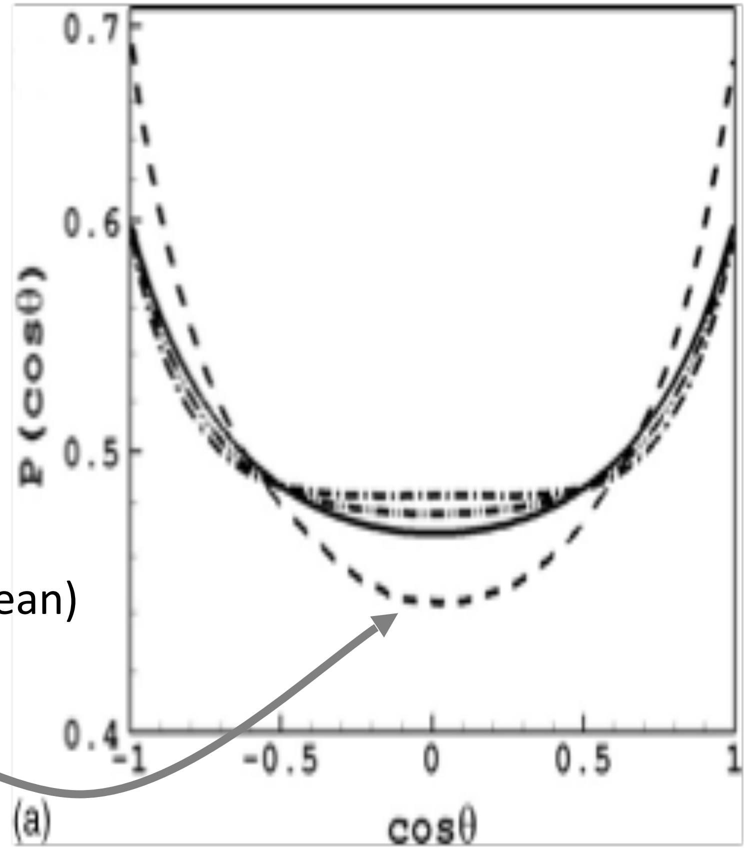


Buaria+ 2020

Lamb vector u x ω alignment

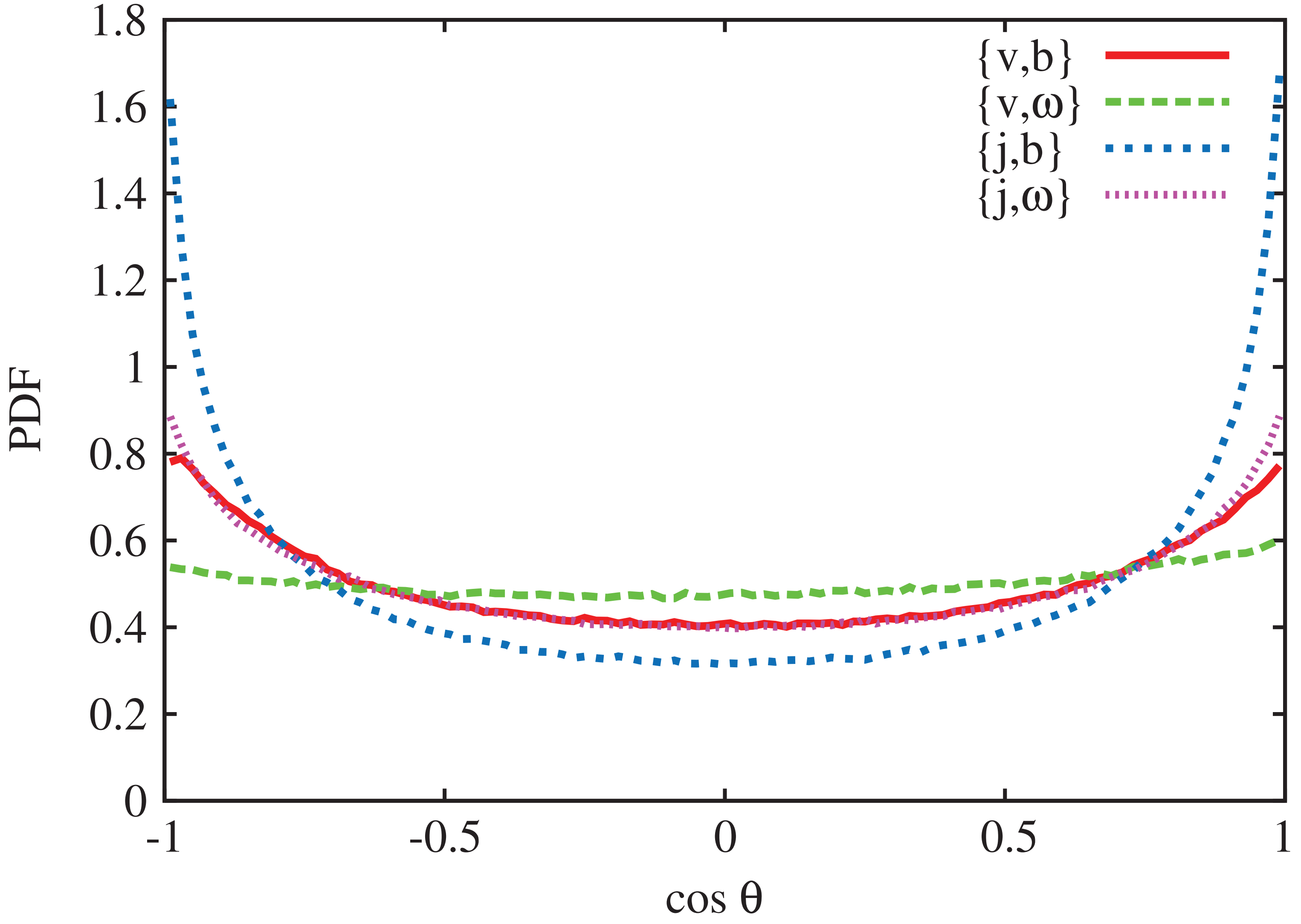
Choi+09

Relative helicity
conditioned by
level of enstrophy:
Total (solid), and
1-4; 4-16;
16-64 (dash, in terms of mean)



Other alignments

MHD, 128^3 grids, flat initial distributions

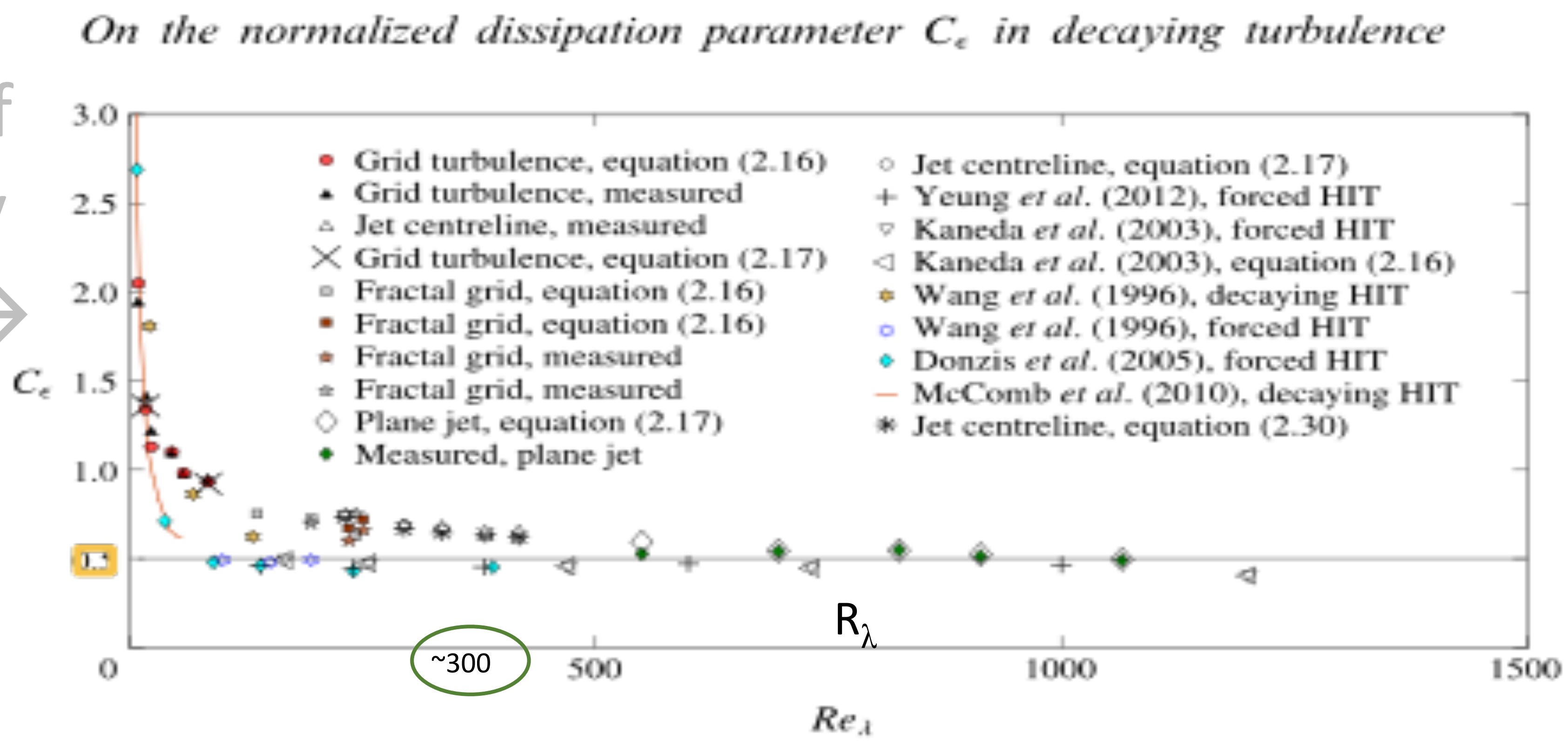


Alfvenic state
Beltrami waves
Force-free Taylor field
… no-name

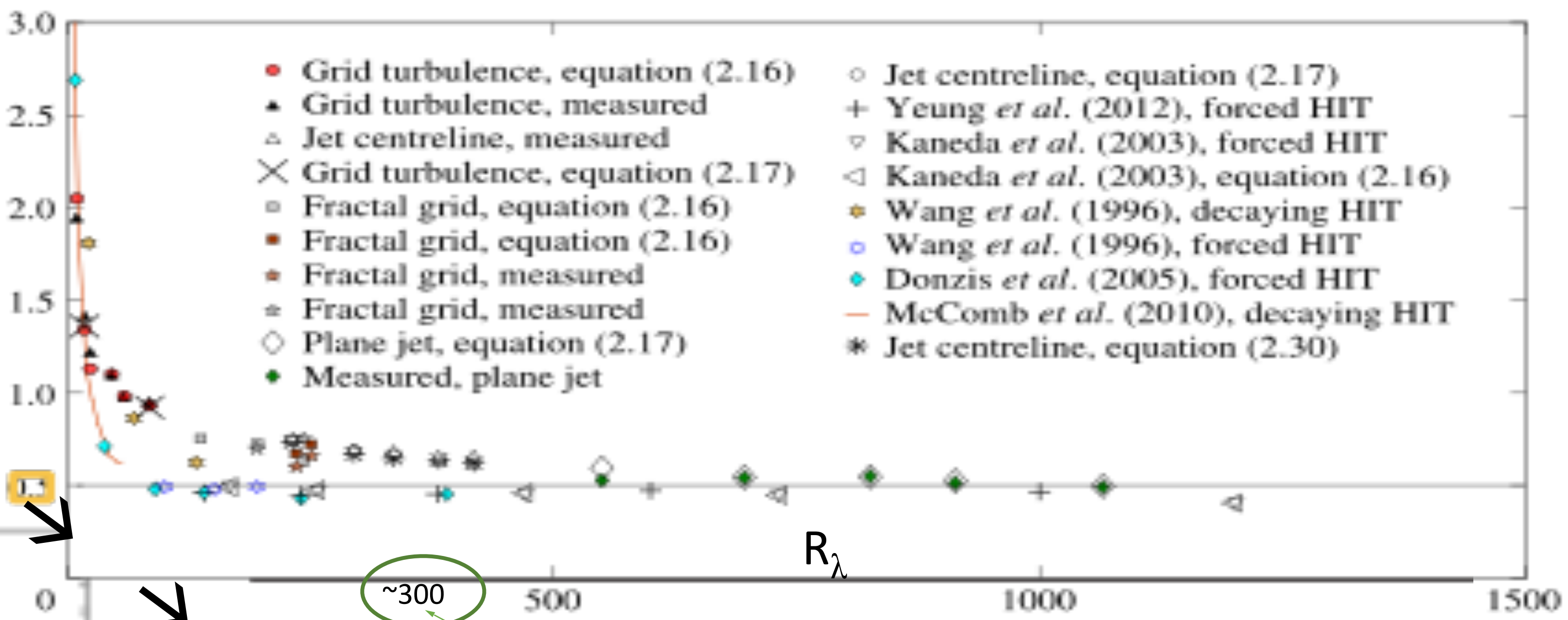
$$\cos\theta = \frac{\mathbf{f}\cdot\mathbf{g}}{|\mathbf{f}||\mathbf{g}|}$$

Servidio+ PRL 2008

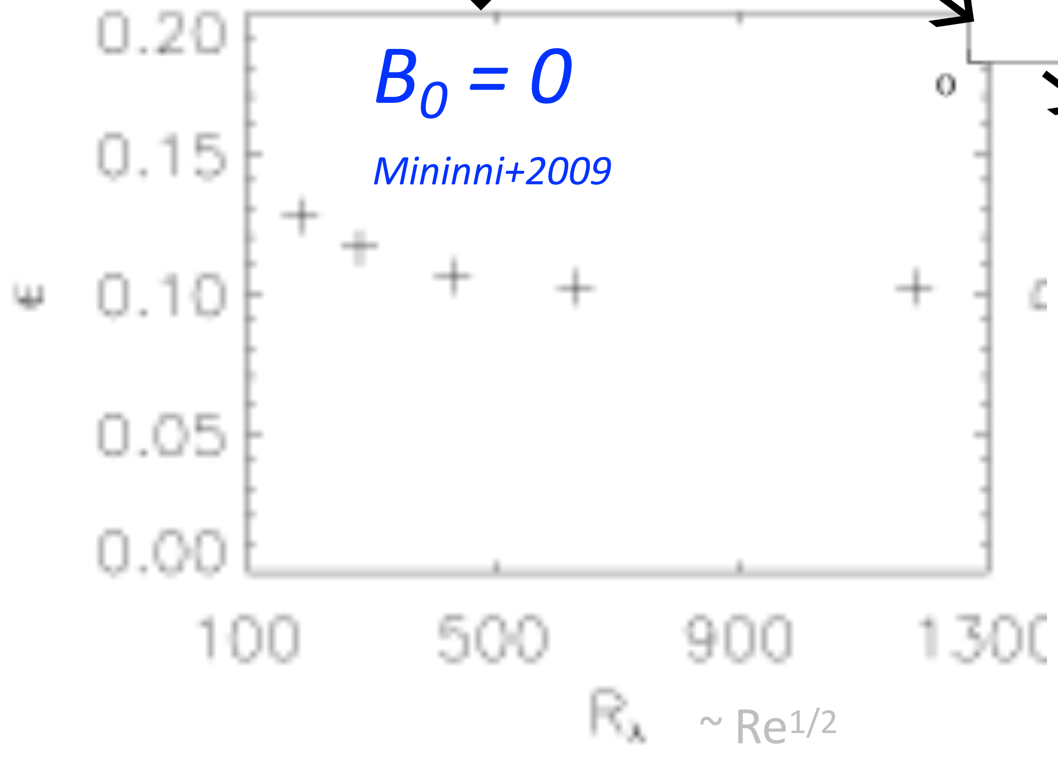
Saturation with Re of dissipation efficiency in fluids *(Djenidi 2017)* →

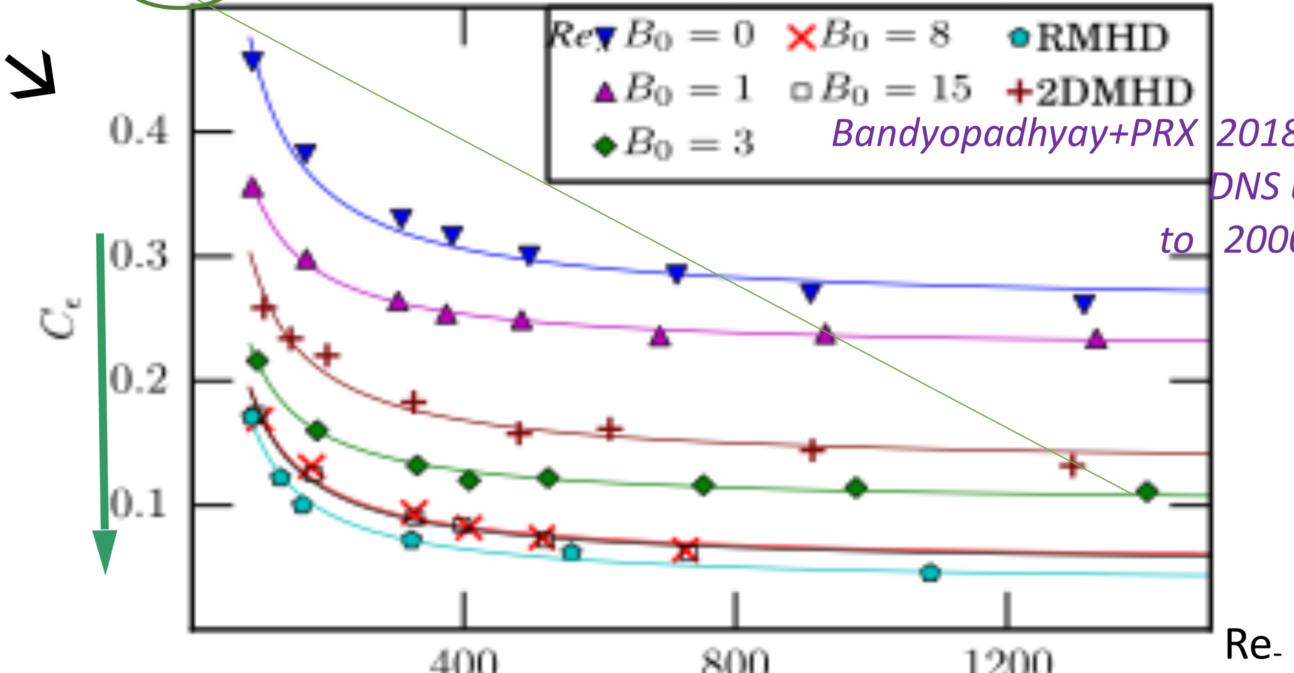


Saturation with Re of dissipation efficiency in fluids (Djenidi 2017) →

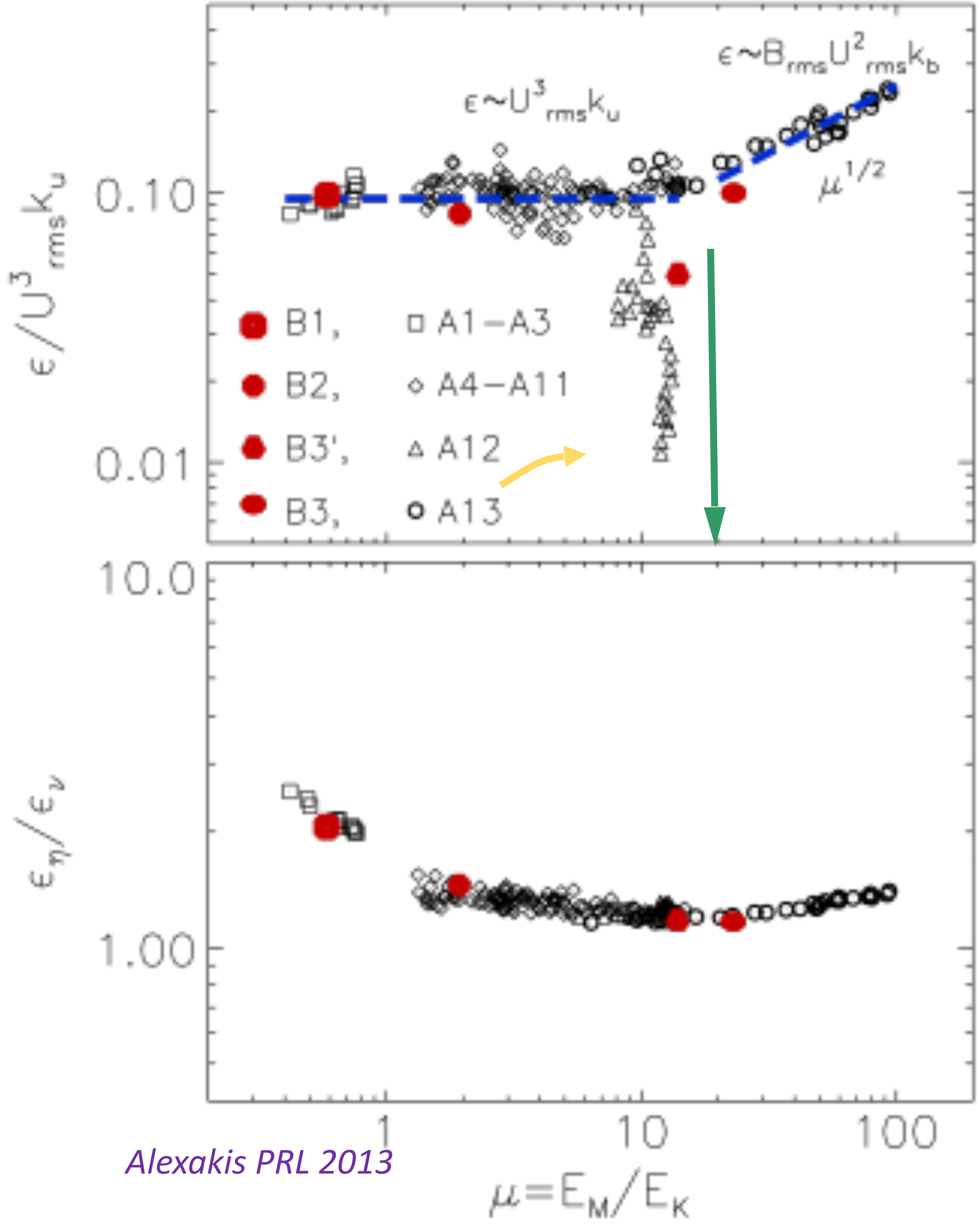


And 3D-MHD, $B_0=0$ ↓↓ or $B_0 \neq 0$





Bandyopadhyay+PRX 2018
DNS up to 2000^3

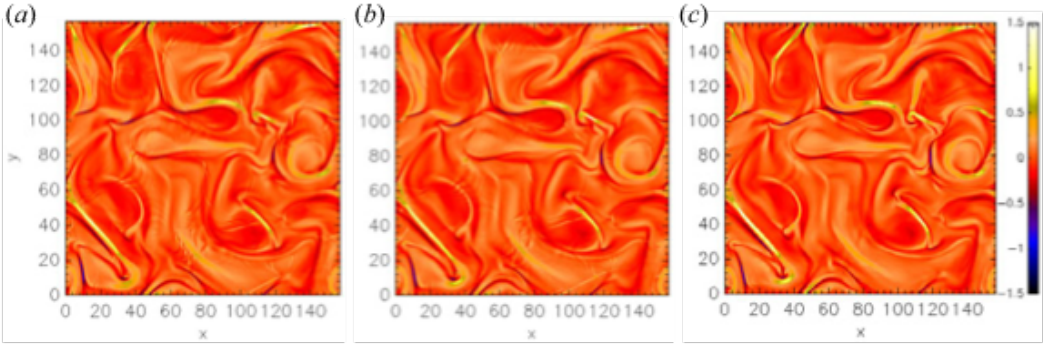


Alexakis PRL 2013

Dissipation in MHD

DNS up to 1024^3 points

Change of regime for dominant magnetic energy and for fully helical forcing, with *more* dissipation



Vasconez+21 **J_z** *H-MHD* *Landau fluid* *Hybrid Vlasov Maxwell*

Landau fluid: **V**, P_{perp}, $P_{//}$, ϱ, **B**, heat flux Q_{perp} & $Q_{//}$. Hybrid Vlasov Maxwell: ions are PIC, *e* are isothermal, quasi-neutrality*;* Two-fluid: ion-electron conservation laws

→Aspect ratio: L_0 / l_d

→Non-locality of interactions

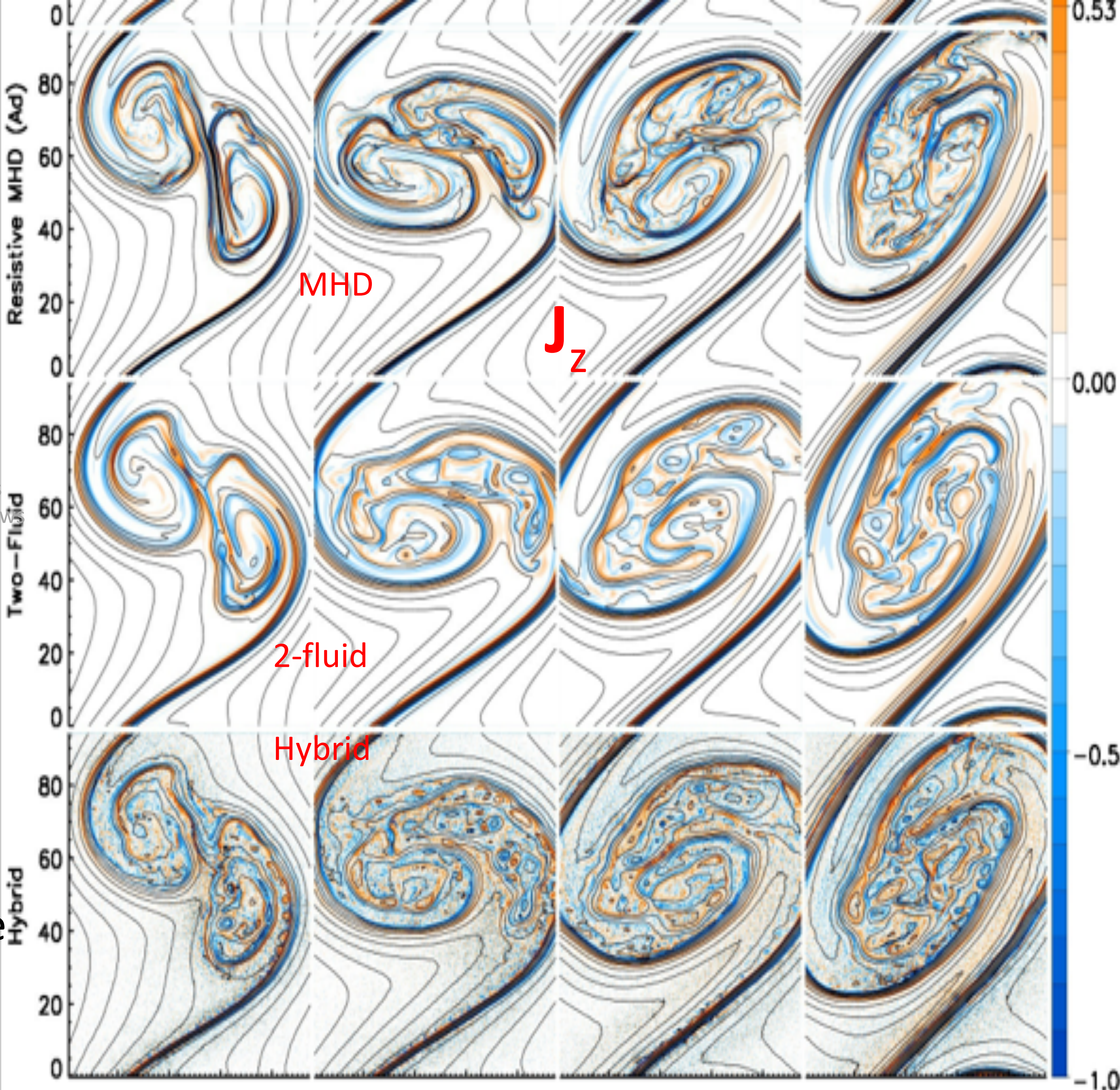
→Intermittency, non-Gaussian vorticity and current PDFs,

as well as sometimes v & b

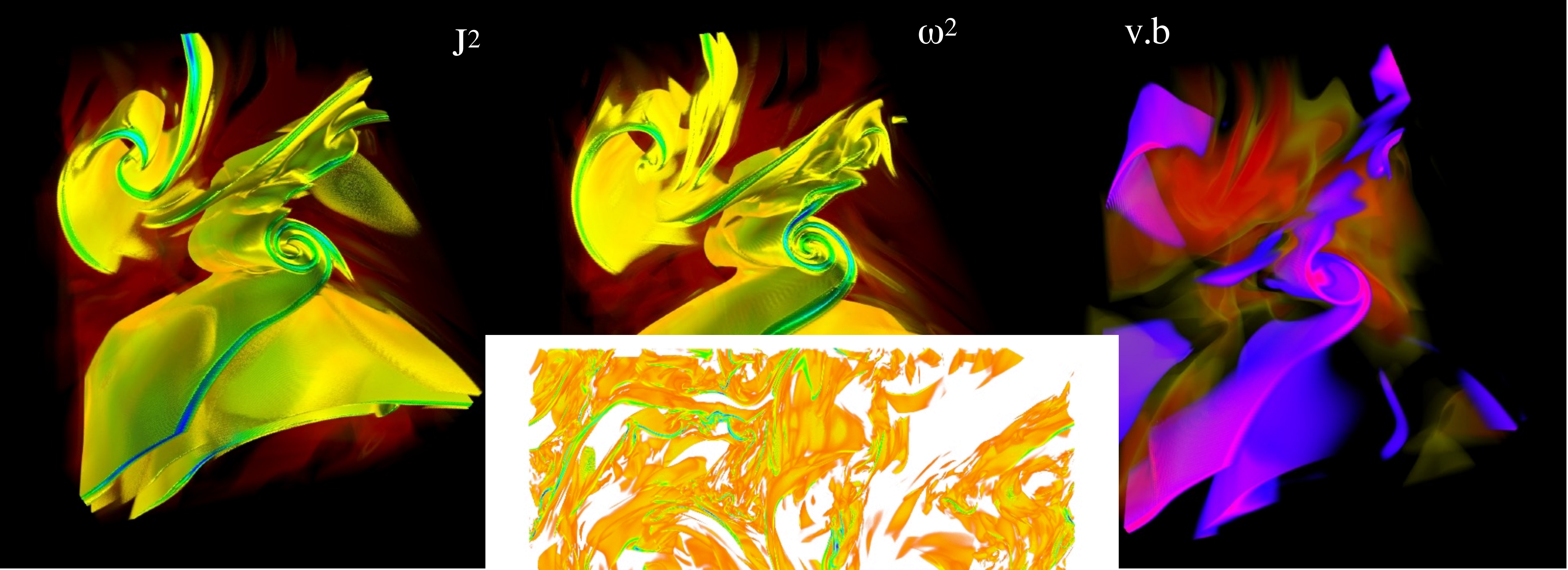
Vortex filaments in superfluid turbulence

Current sheets and filaments in MHD+

Internal small-scale structures

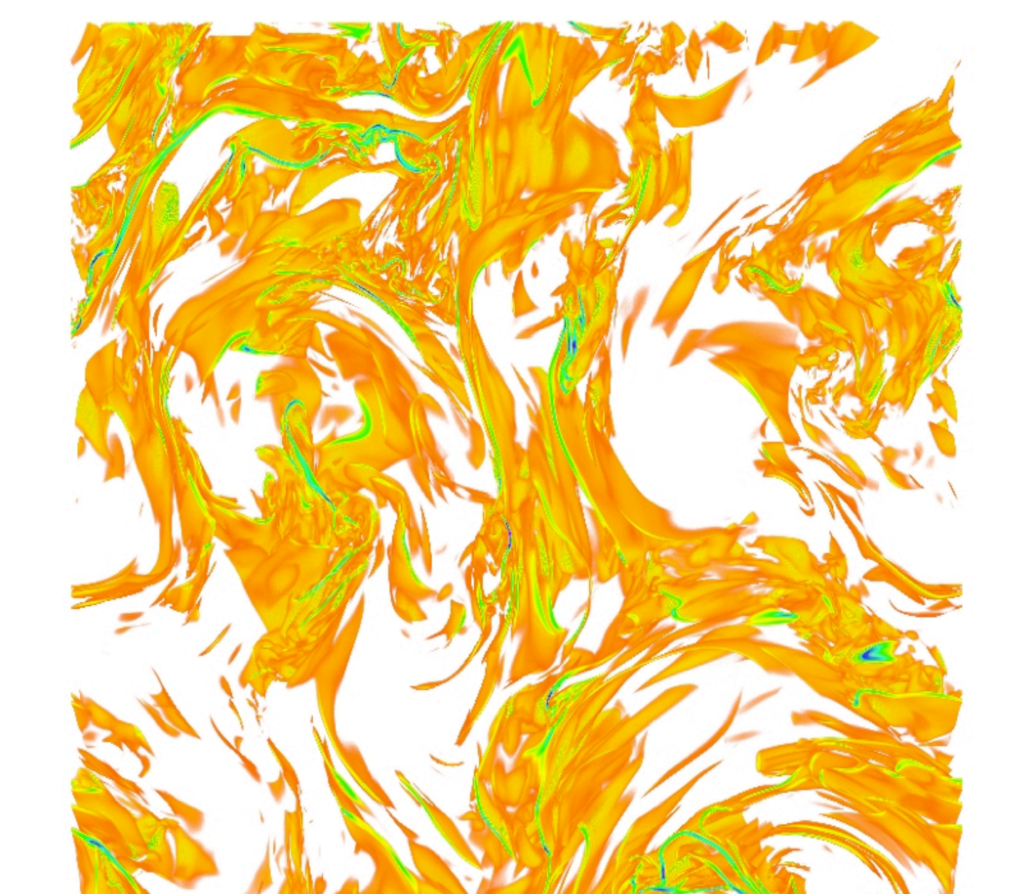


Henri+2013



Global current at early times

And at later times →

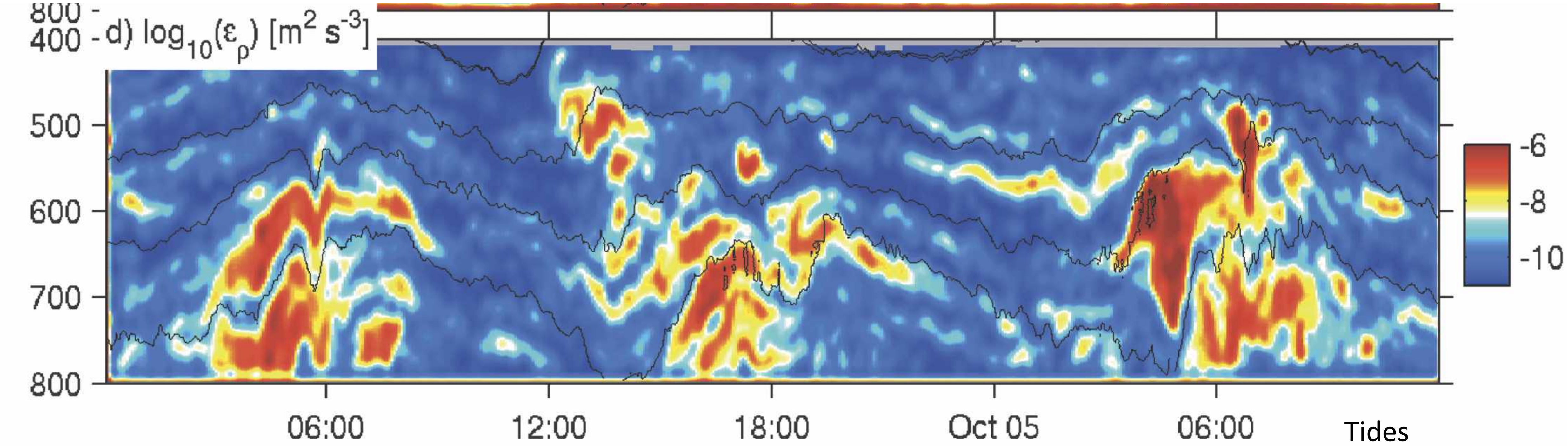


Mininni+ 2006

Ocean, measured dissipation rate ε in the Hawaiian ridge *(Klymak+2008)*

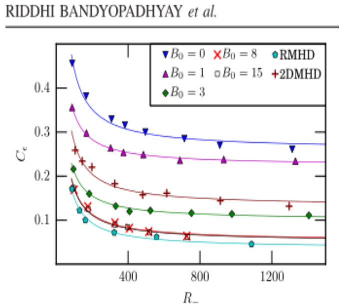
U=0.1ms^{-1}, Re ~ 10^8, L_0 ~ $10^3 m$, **$<\varepsilon_V>$ ~ 10^{-10}** —> **$\tau_{NL}=L_0/U$ ~ 2.8 *hr***

Brunt-V frequency N=0.001s^{-1} → Fr ~ 0.1 **Active sites:** $\varepsilon_V \sim 10^{-6} \sim \varepsilon_D \sim U^3/L_0$



Tides

Dissipation efficiency <u>in rotating stratified **turbulence**</u>, Ro,Fr<1



1024^3 DNSs, Reynolds nb., Re ~ 8000
Froude number Fr = U/[LN],
Rossby nb. Ro = U/[Lf], variable N/f>2
*Pouquet+ JFM **844**, 2018; PoF **31**, 2019*

$\beta \equiv \varepsilon_V/\varepsilon_D \sim Fr$ *with* $\varepsilon_D = U^3/L$

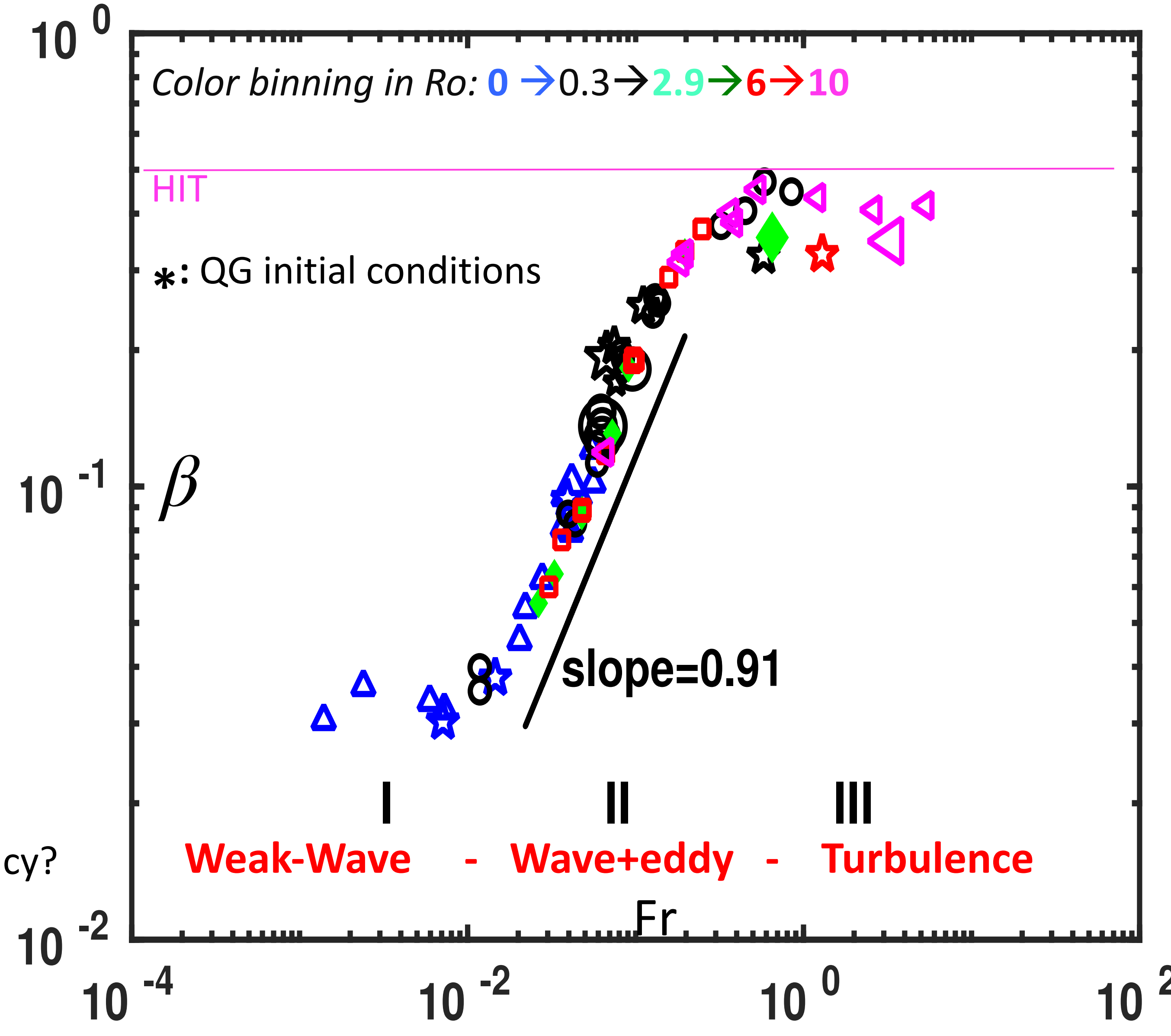
*Weak (wave) turbulence ****phenomenology*****

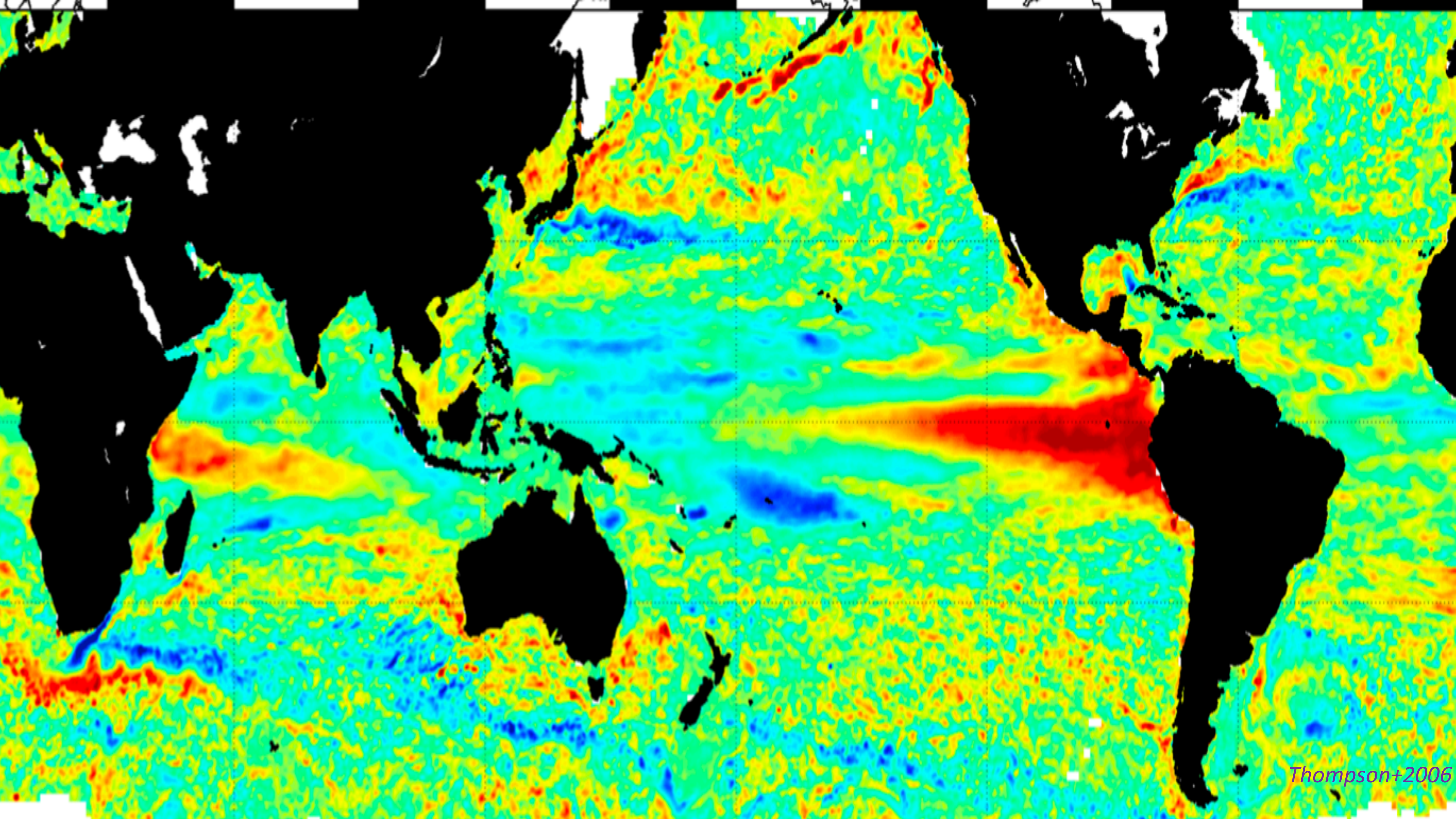
$$\tau_{transfer} = \tau_{NL} * [\tau_{NL}/\tau_{wave}] = \tau_{NL}/Fr$$

$$\beta = \varepsilon_V/\varepsilon_D = [U^2/\tau_{transfer}].[L/U^3] \sim Fr$$

0.91 *vs.* 1 slope: Insufficient data? Anisotropy? Intermittency?

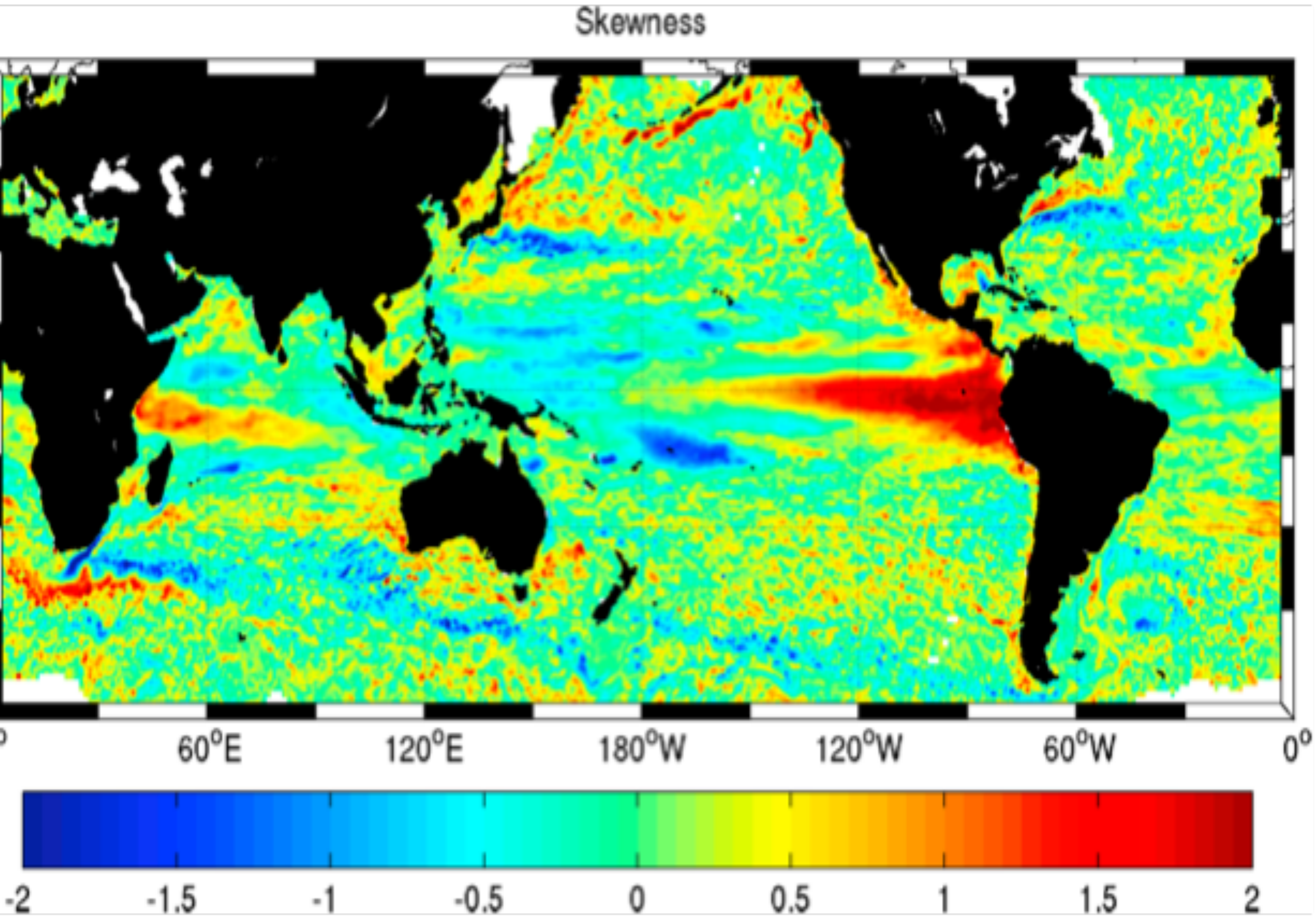
Rotation? Re? Or is it a critical scaling?



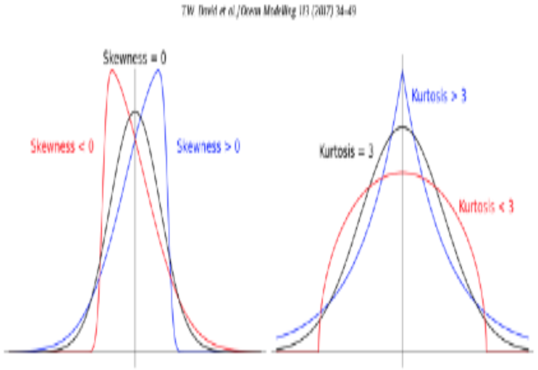


Thompson+2006

JGR 111 THOMPSON AND DEMIROV: SKEWNESS OF SEA LEVEL VARIABILITY 2006 C05005



Weekly-gridded 7 years data
Topex-Poseidon+
1/3 degree res.
Error in skewness ~ 0.2
El Niño 1997-98
Meso-scale variability



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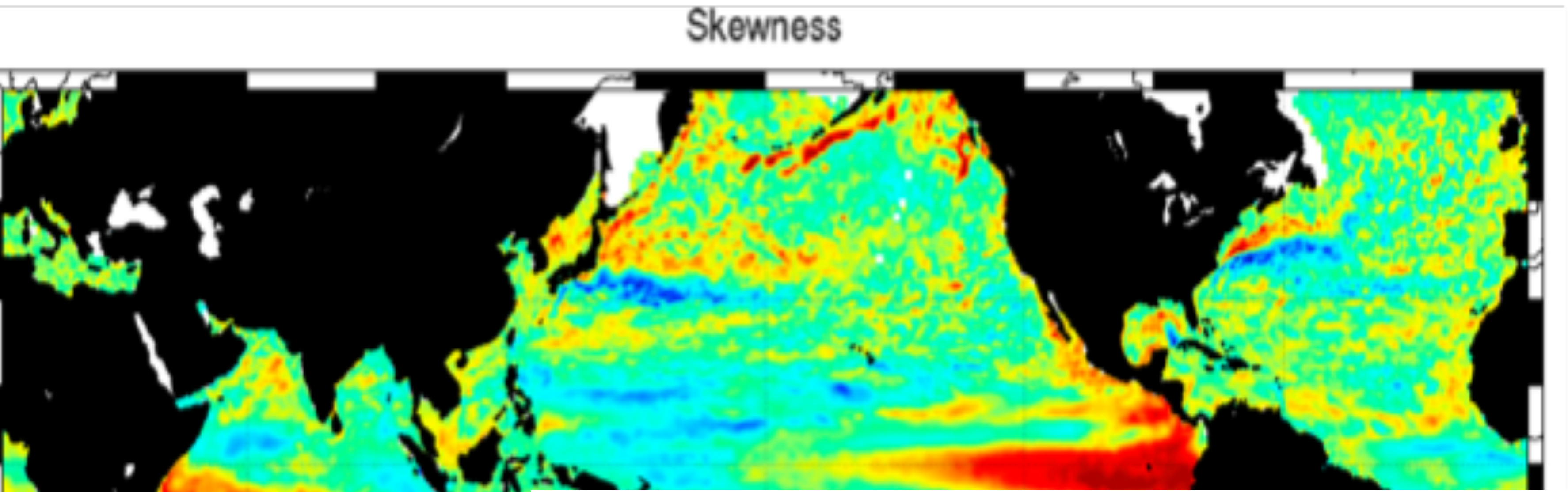
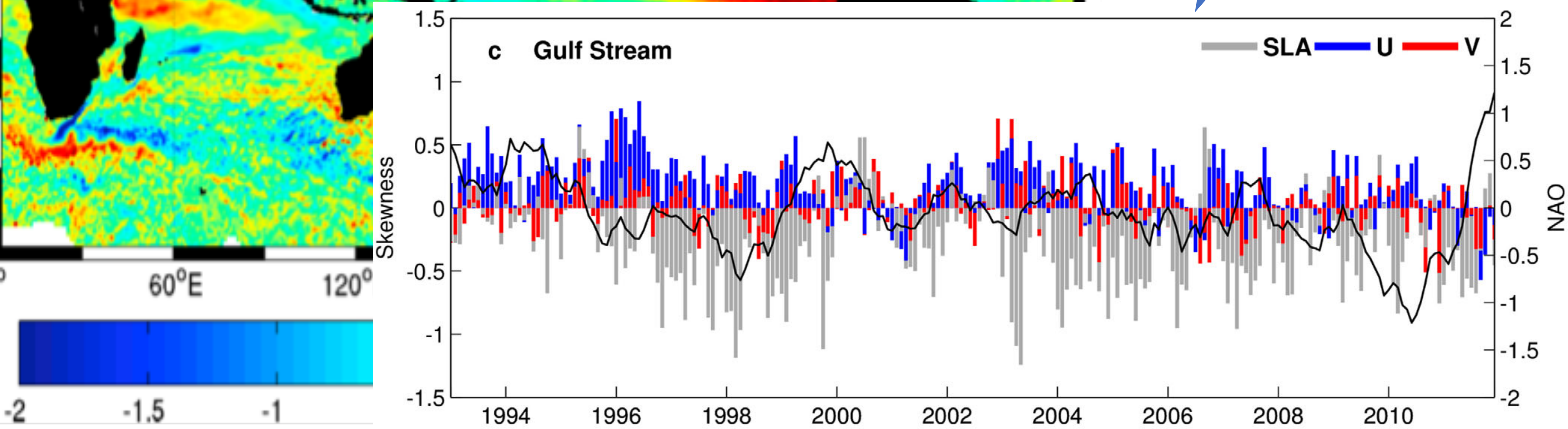


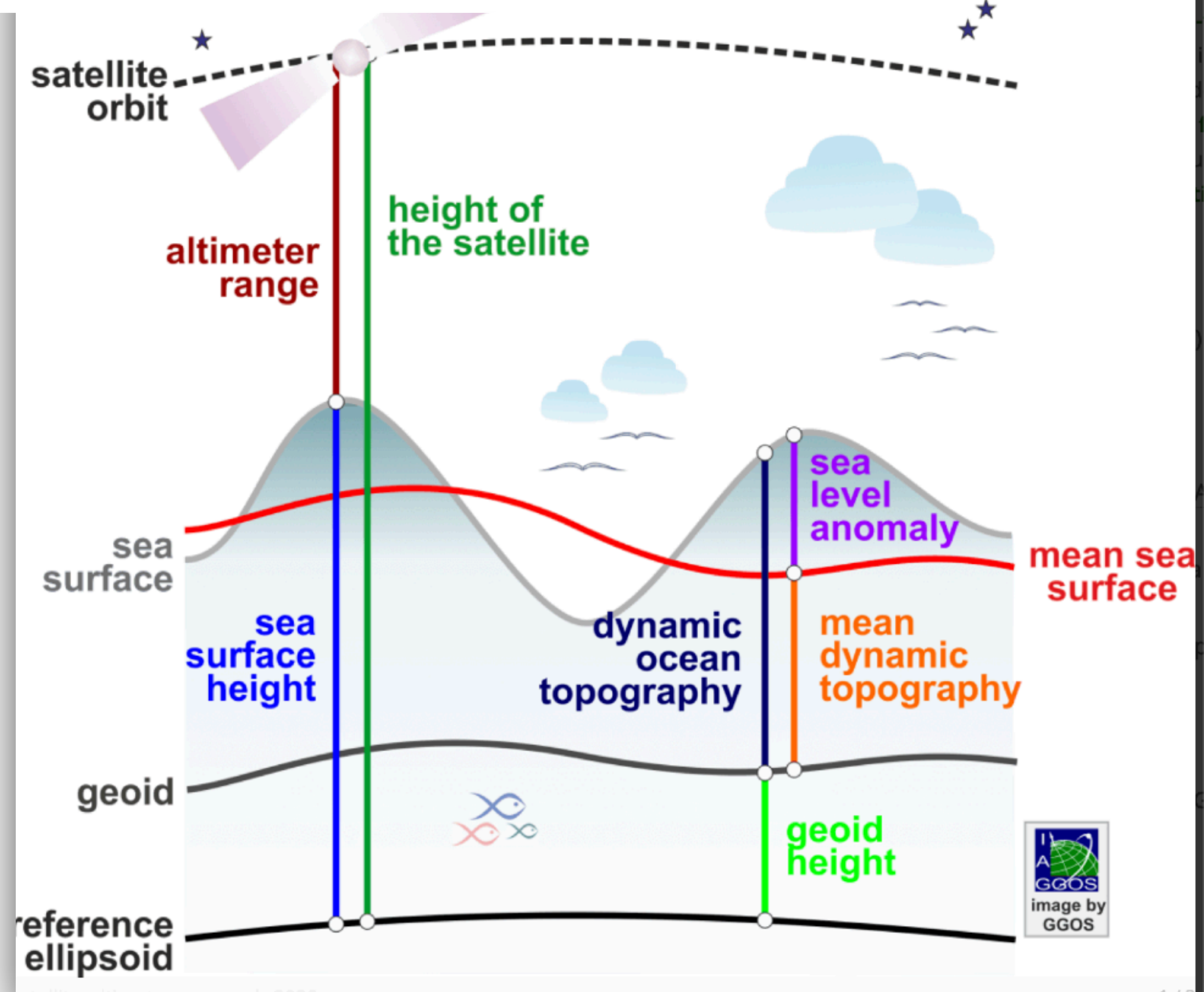
Biri+2015

Skewness for SLA (sea level anomaly) & horizontal velocities

& ___North-Atlantic Oscillation



Satellite altimetry systems are designed to map the sea surface. These systems **measure the satellite-to-sea surface** round-trip travel time of radar or light pulses to determine the height of the satellite (altimetric range) above the instantaneous sea surface. The difference between the satellite altitude above a reference surface and the altimetric range provides the sea surface height with respect to the same reference surface. The range from the satellite to the sea surface is **corrected for various components** of the atmospheric refraction and to mitigate effects caused by instrumental biases and sea state induced systematics. A number of corrections due to different geophysical effects are also taken into account. **Different products are distinguished**:

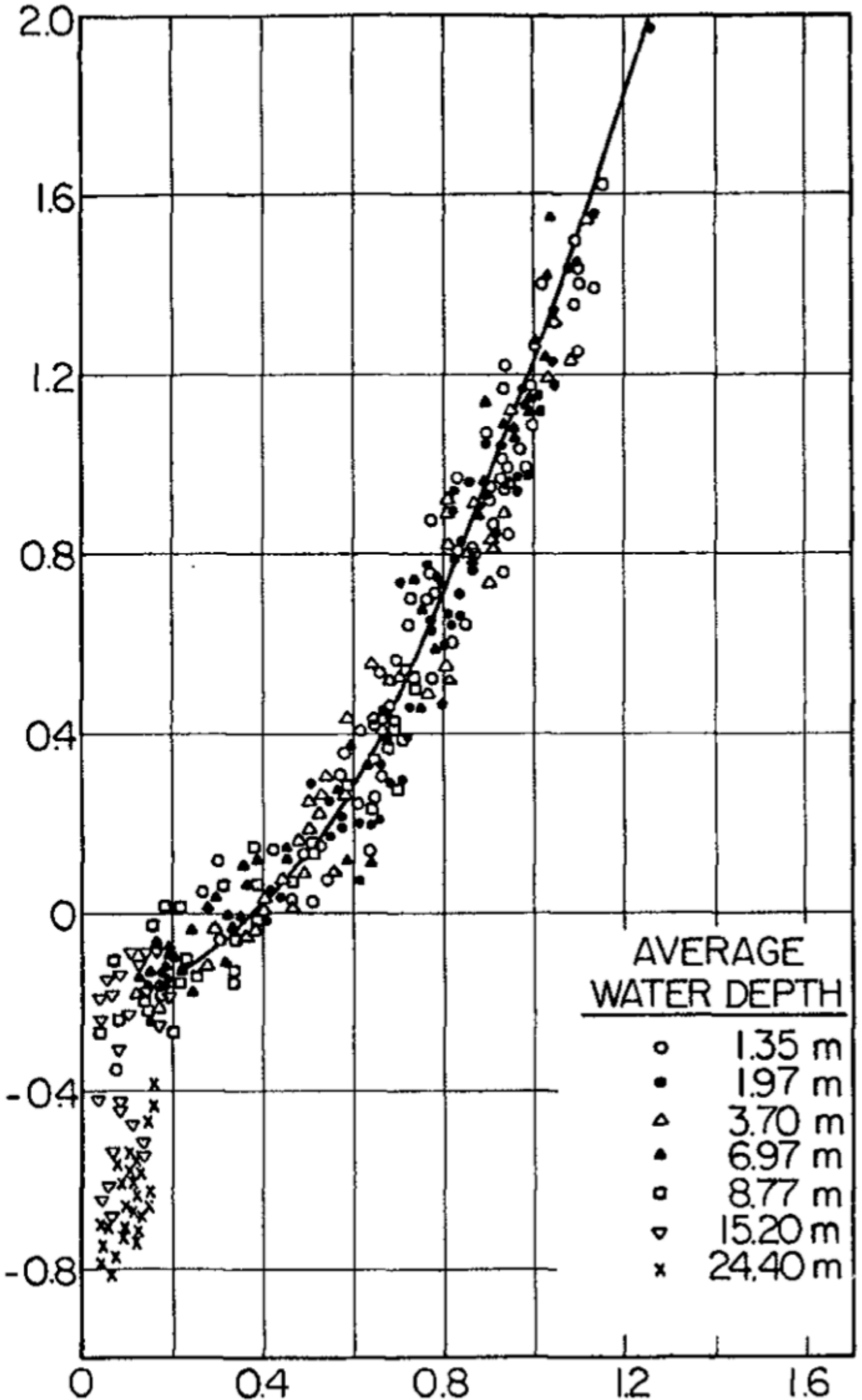


Breaking waves on a sloping beach

Longuet-Higgins 1963

K(S) for sea surface deviation

Ochi 1984 →

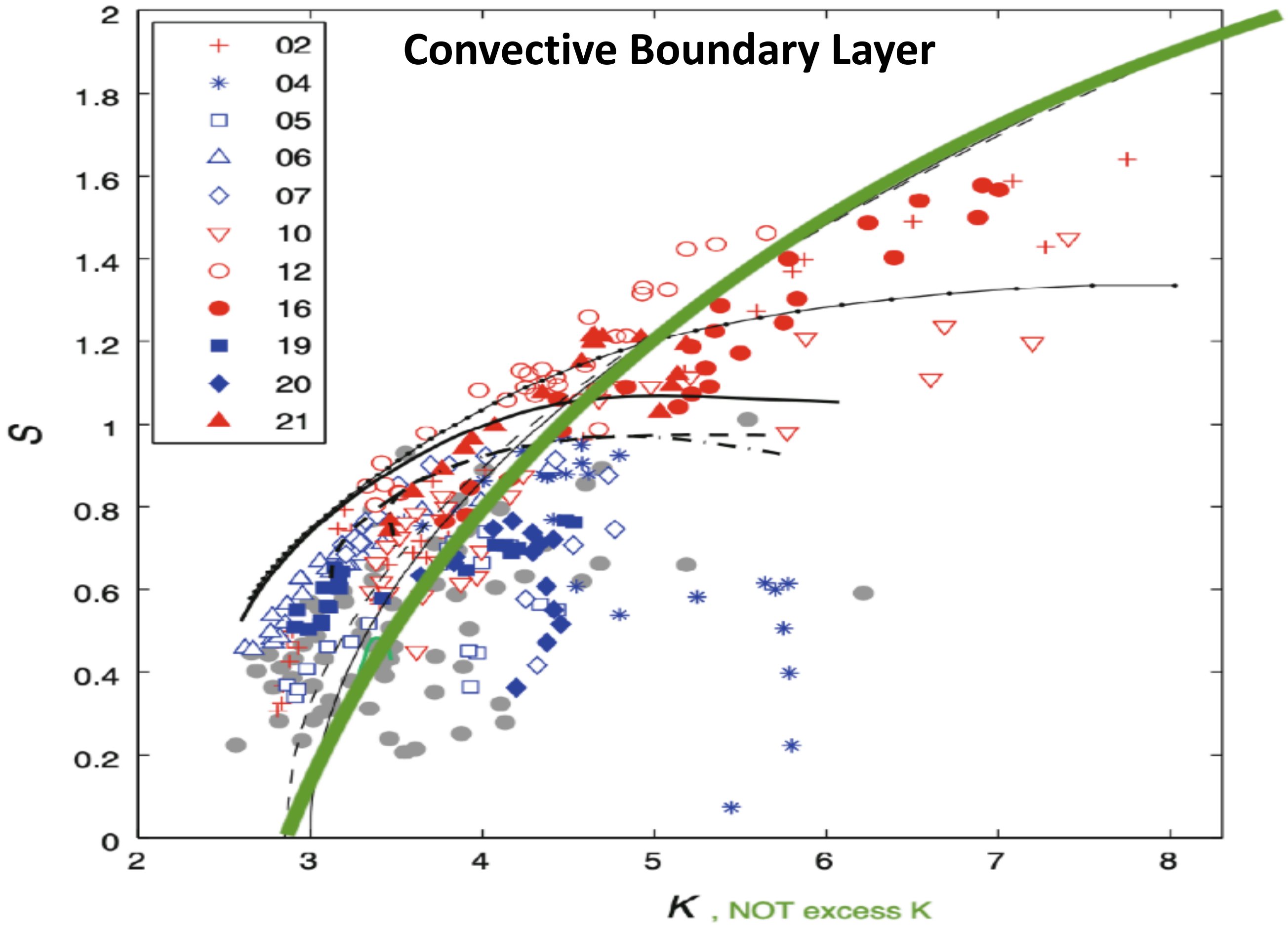


Lenschow+, 1994: PDF = G + αG^2 , G Gaussian.

Large α: PDF~ $3(S^2/2 + 1)$, S_{max}~ 2.83, K_{max}~ 1

Convective Boundary Layer, S(K) →

Lenschow+'12: Measurements and LES



Fit

K – 3= K_{excess}

~ $1.4S^2$ - 0.15

Lines: LES

Circles: Data

(LIFT, AMMA)

Lidar In Flat Terrain, 1996

African Monsoon, 2006

Lenschow+, 1994: PDF = G + αG^2 , G Gaussian.

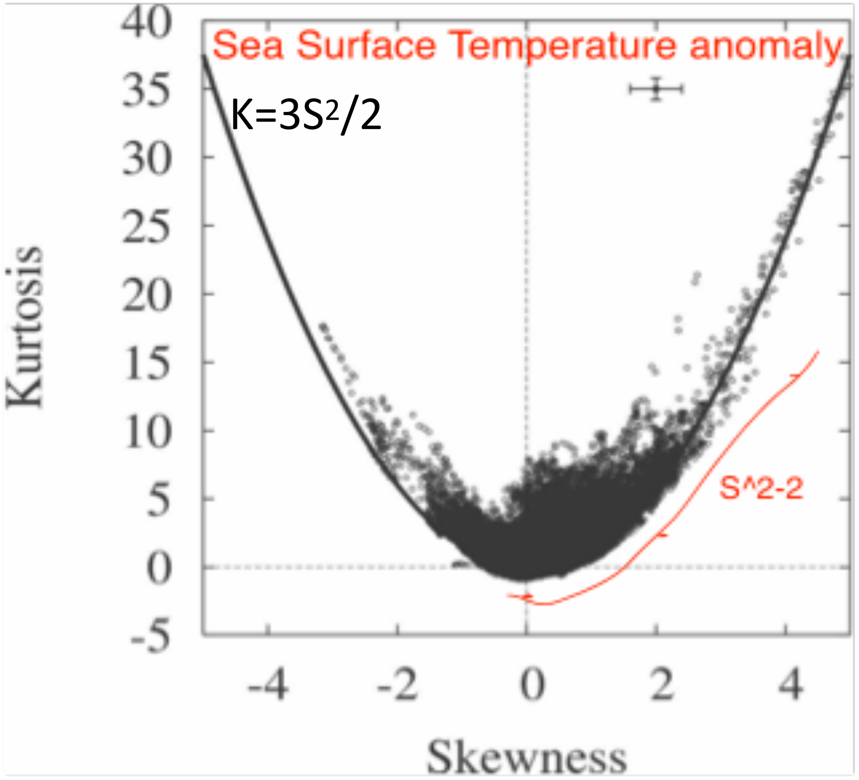
Large α: PDF~ $3(S^2/2 + 1)$, S_{max}~ 2.83, K_{max}~ 1

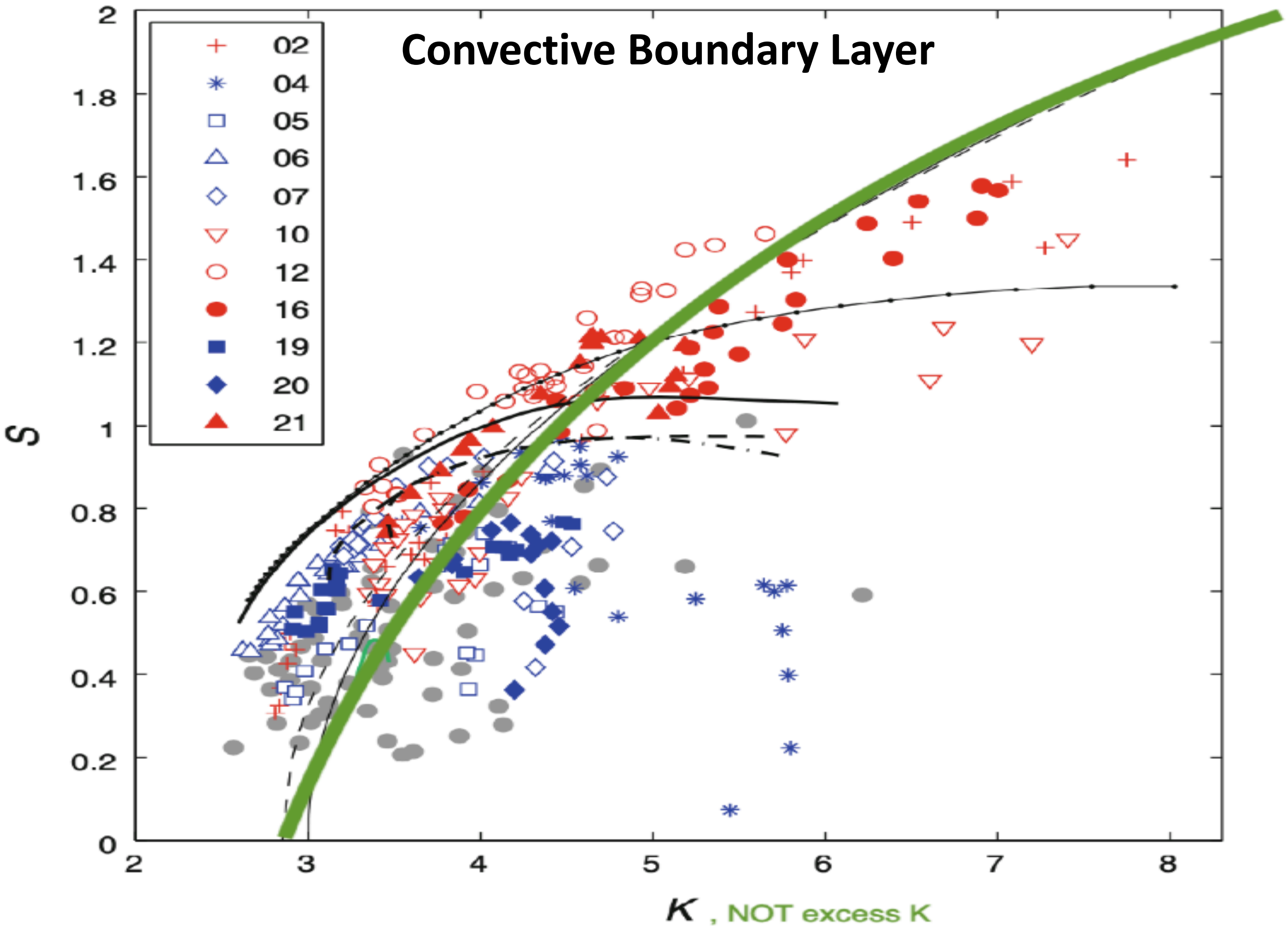
Convective Boundary Layer, S(K) →

Lenschow+'12: Measurements and LES

Sea-Surface Temperature anomaly

Sura+2008





Fit

K – 3= K_{excess}

~ 1.4S² - 0.15

Lines: LES

Circles: Data

(LIFT, AMMA)

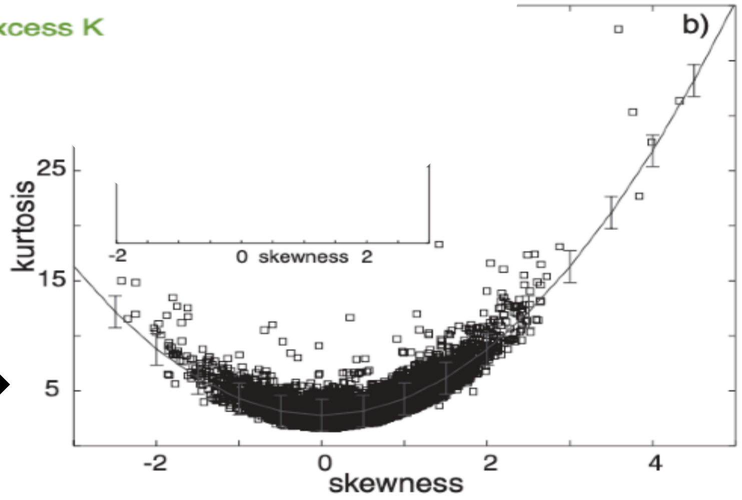
Lidar In Flat Terrain, 1996

African Monsoon, 2006

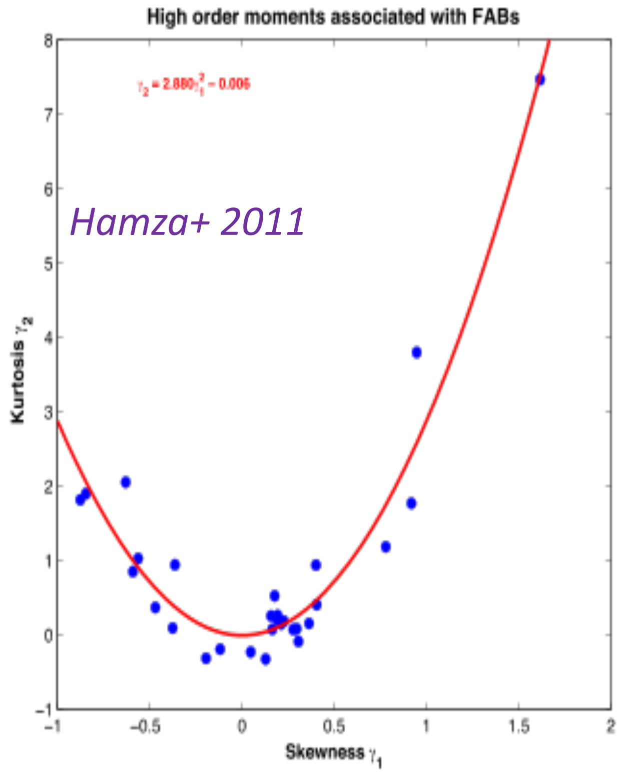
K(S)

Toroidal magnetized plasma

Labit+2007 →

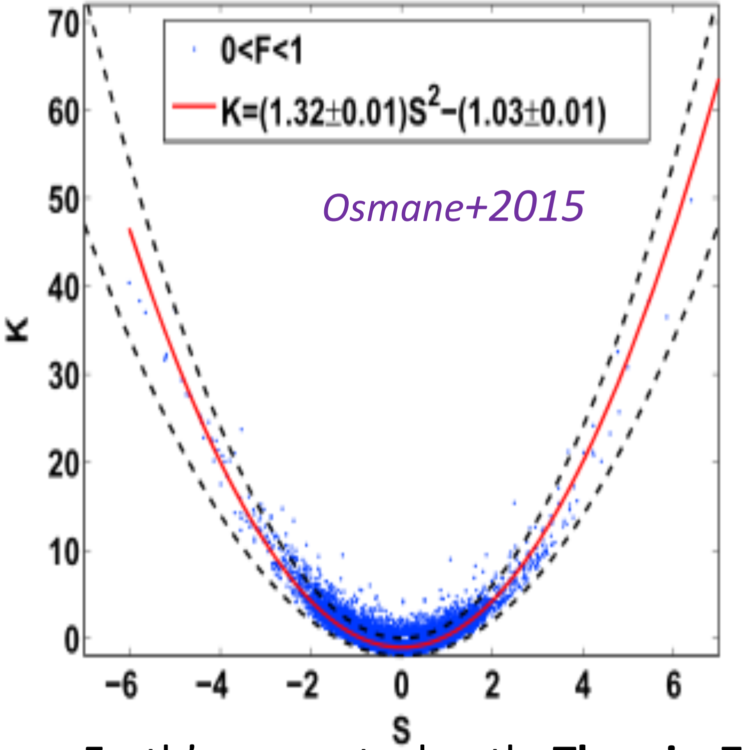


K(S)



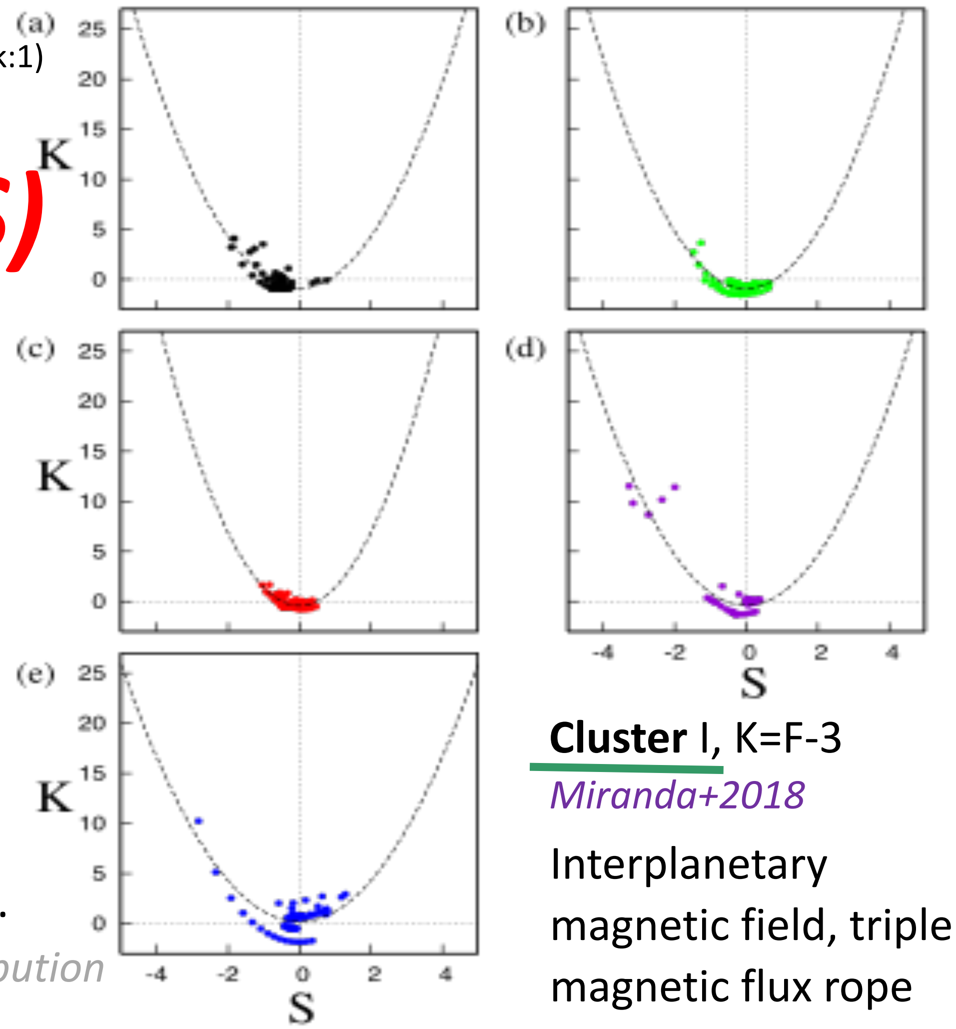
Ion distribution, **Cluster**
Quasi-perp. bow shock

Fractional distance (magnetopause:0; bow-shock:1)



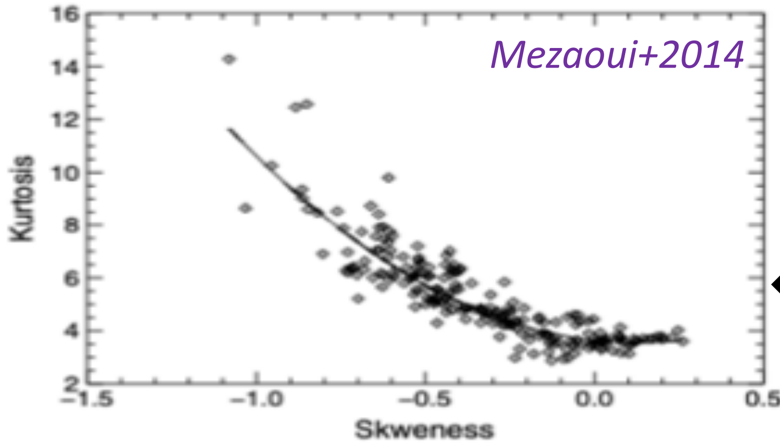
Earth's magnetosheath, **Themis**, 7 years,
~ 50000 points, mirror modes fluctuations.

Black dots: constraints for β distribution



Cluster I, K=F-3
Miranda+2018
Interplanetary magnetic field, triple magnetic flux rope

Interval	$K = \alpha S^2 + \beta$	
R_1	$K = 1.29S^2 - 0.86$	*interior*
I_{12}	$K = 1.42S^2 - 0.92$	*interface*
R_2	$K = 1.82S^2 - 0.42$	
I_{23}	$K = 1.26S^2 - 0.40$	
R_3	$K = 1.03S^2 + 0.17$	



← High-latitude ionospheric turbulence
Power fluctuations of electron density
K ~ 5.5 S^2+ …

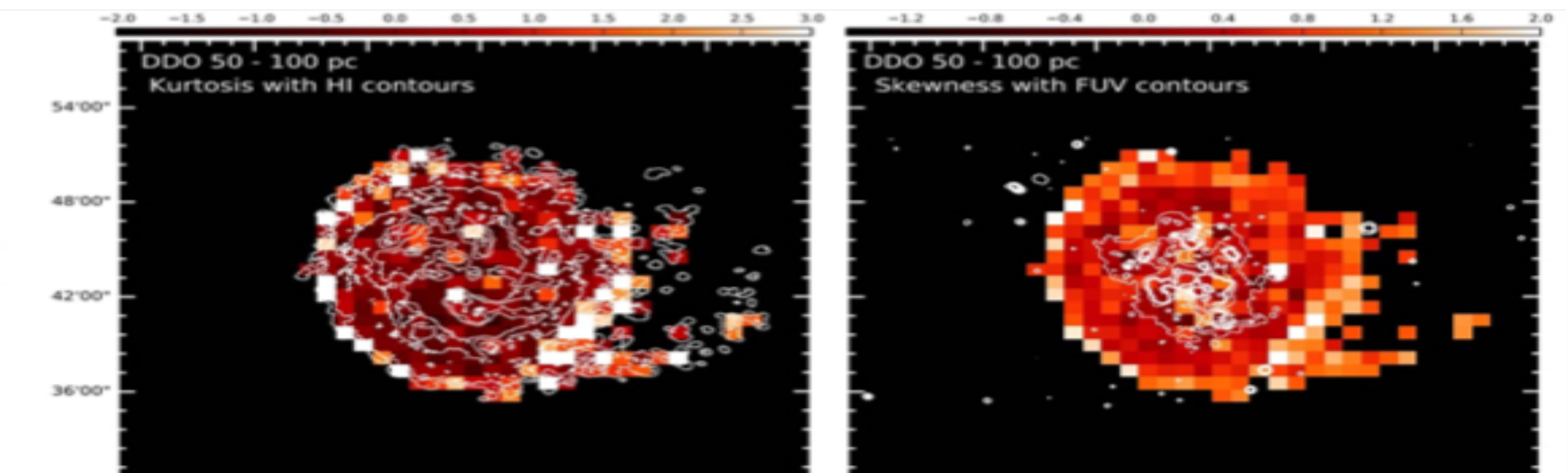
Maier+2017 : LITTLETHINGS dwarf irregular galaxies ISM

Characteristics of turbulence through 3rd and 4th-order normalized moments of H I

Local Irregulars That Trace Luminosity Extremes: The H I Nearby Galaxy Survey

Integrated HI column density, Very Large Array

Kurtosis Skewness

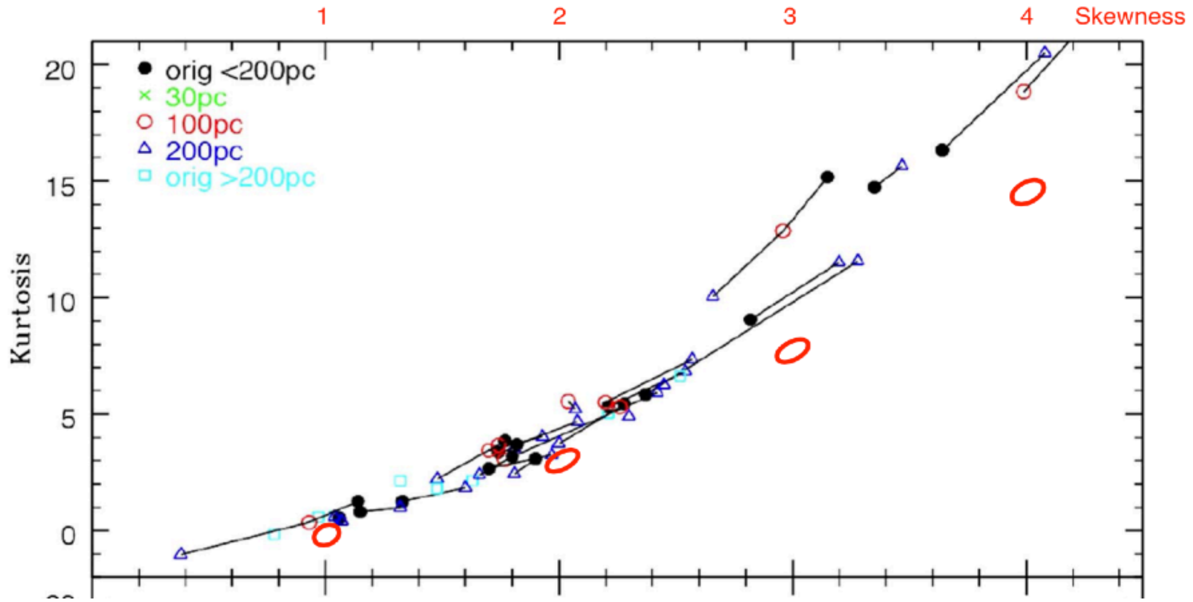


Maier+2017 : LITTLETHINGS dwarf irregular galaxies ISM

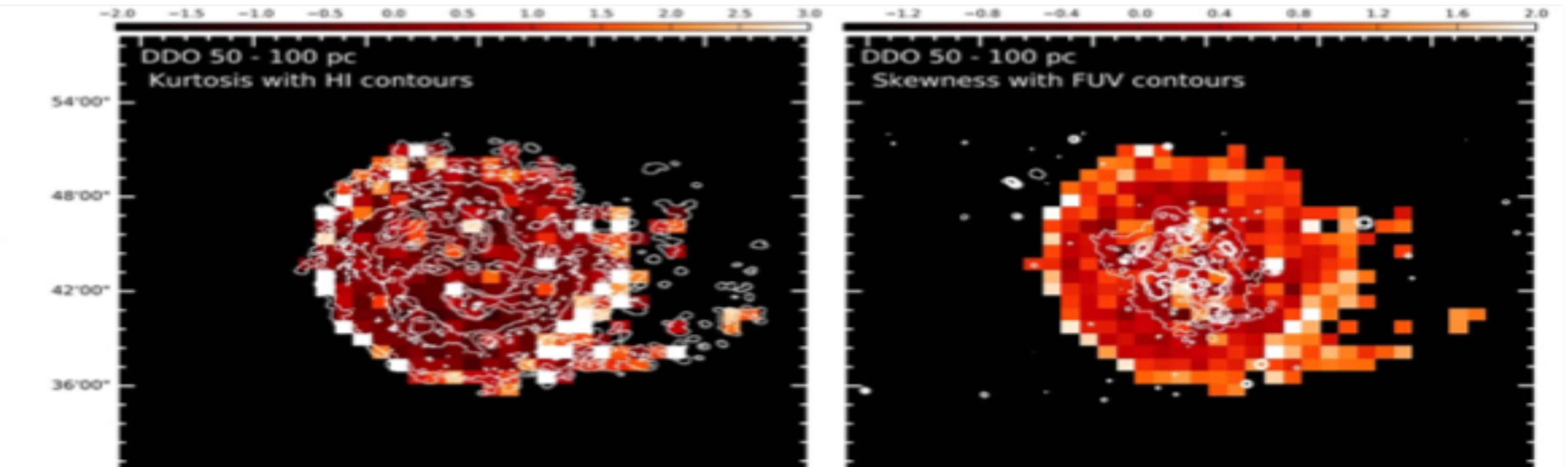
Characteristics of turbulence through joint 3rd and 4th-order normalized moments of H I

$K = aS^2 + b$ *[Cauchy-Schwarz: $K \geq S^2 - 3$]*

$K \geq S^2 - 6/5$ *(Klaassen+2000, unimodal symmetric)*



AL JOURNAL, 153:163 (35pp), 2017 April



Maier+2017 : LITTLETHINGS dwarf irregular galaxies ISM

Characteristics of turbulence through joint 3rd and 4th-order normalized moments of H I

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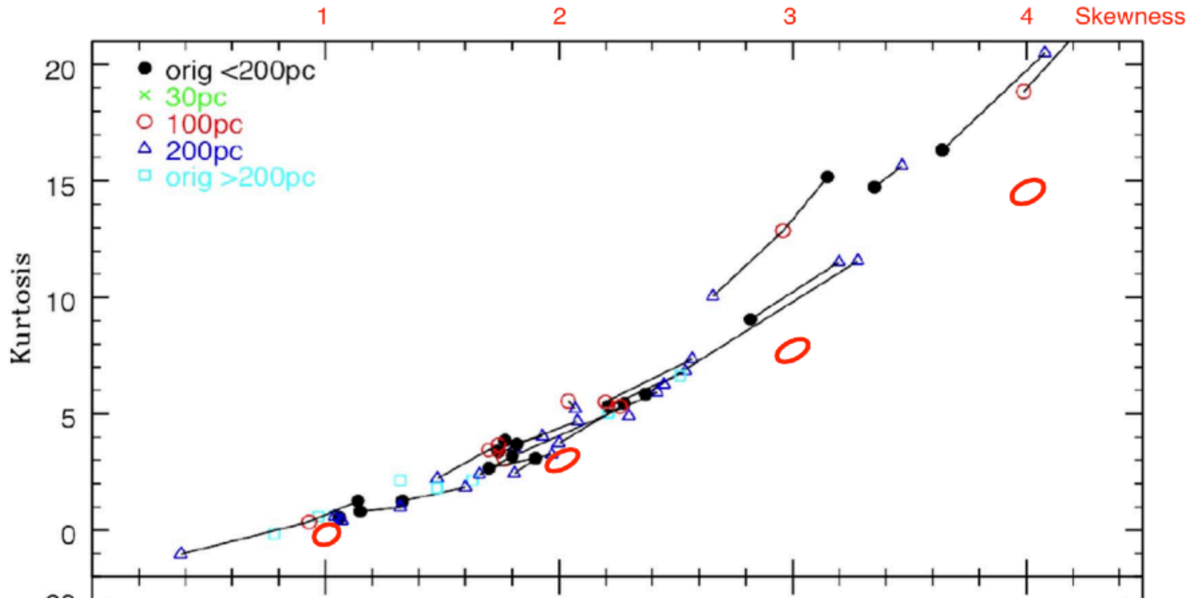

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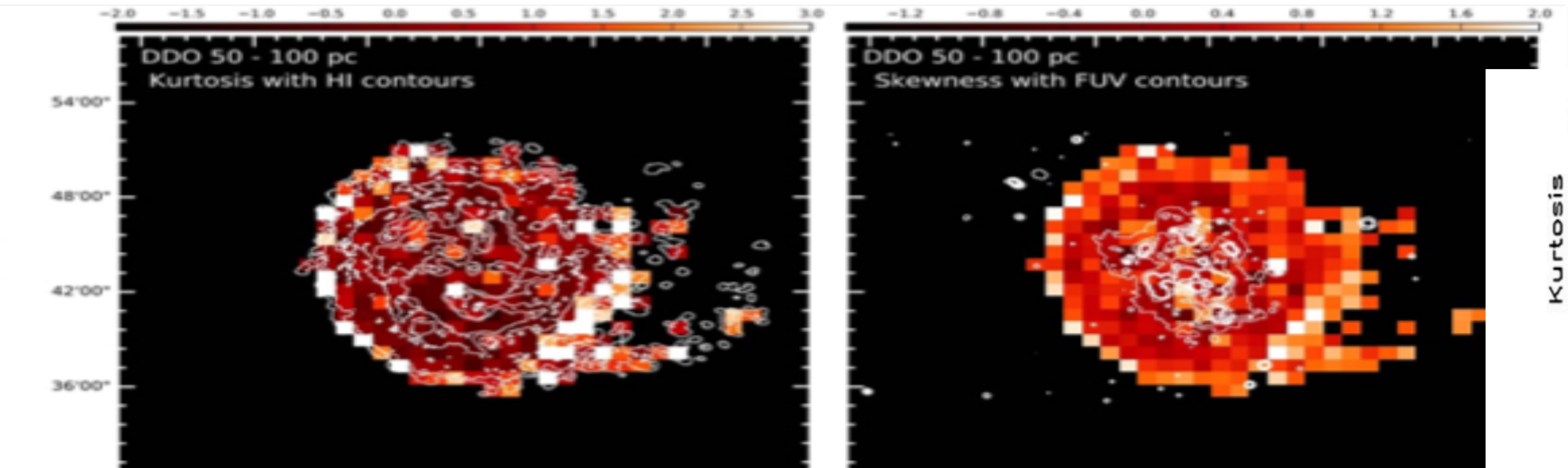
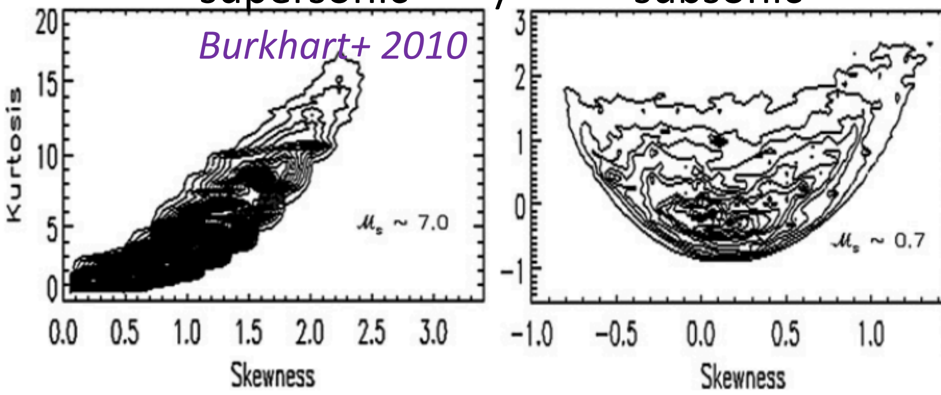


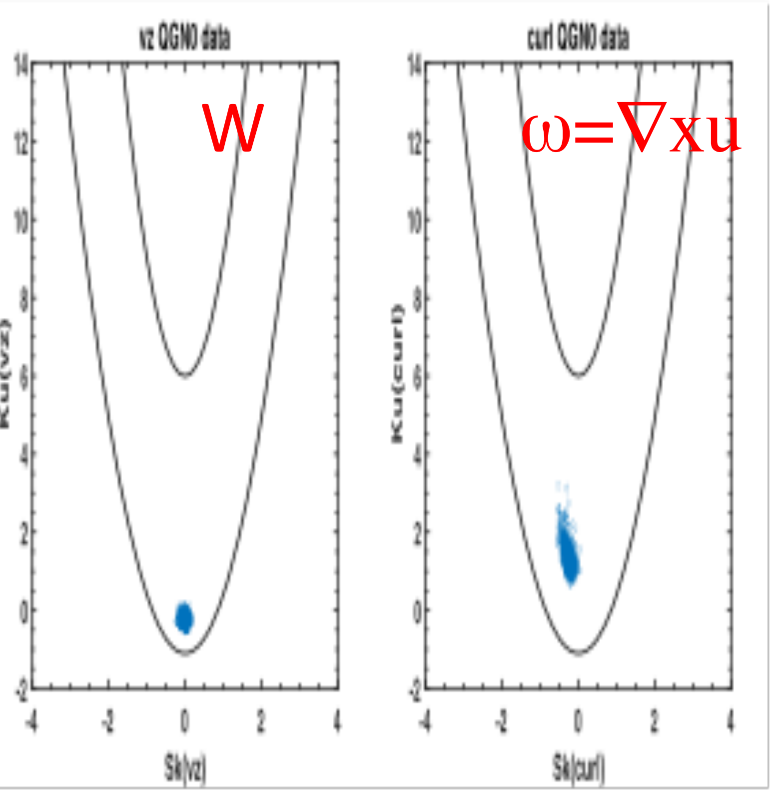
K(S) for HI, isothermal runs for SMC

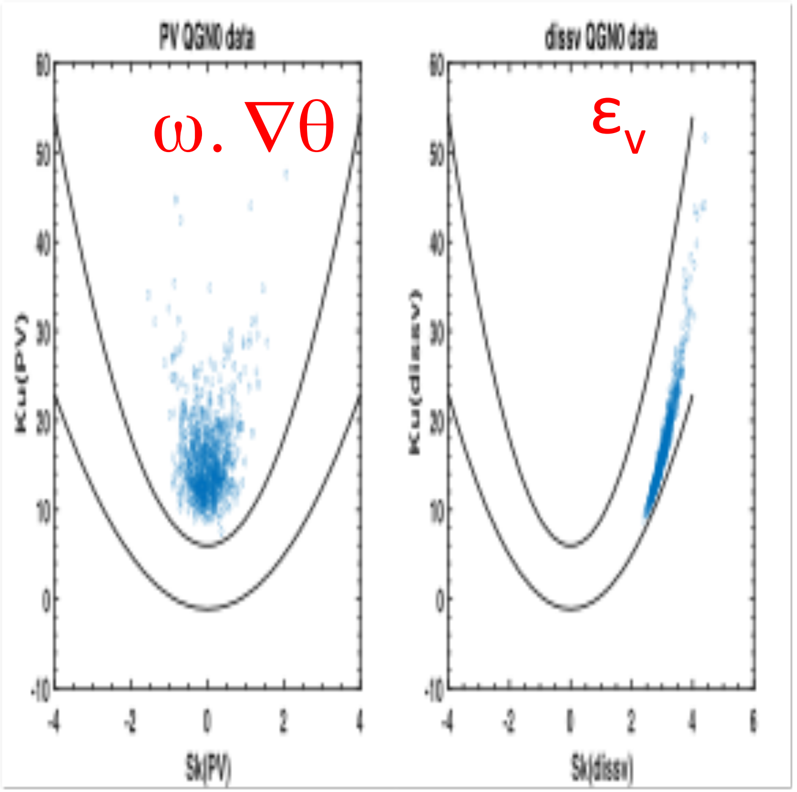
supersonic / subsonic

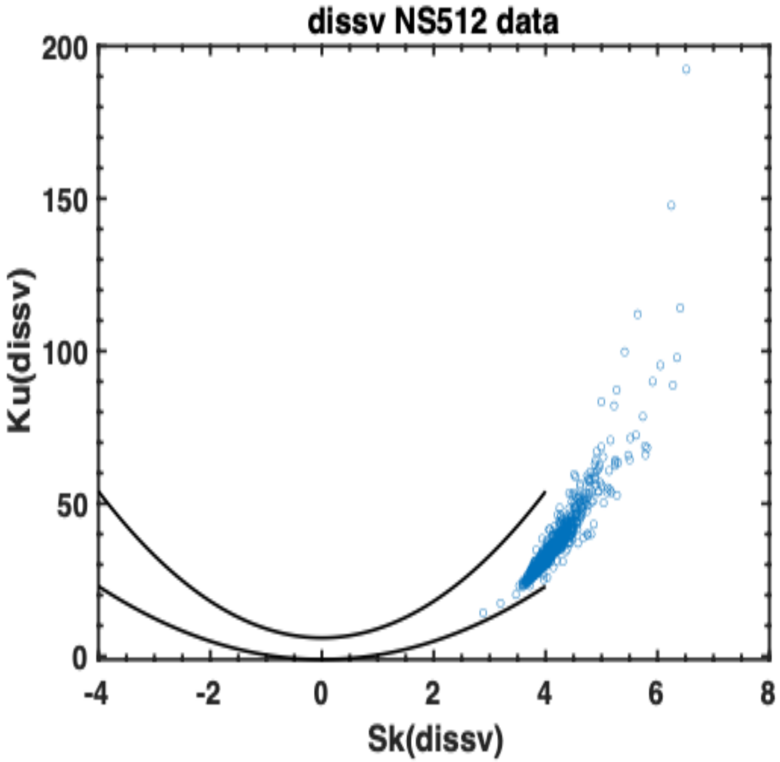
Burkhart+ 2010



Navier-Stokes: 128^3, Re~200, R_λ~28, $800\tau_{NL}$ & 512^3, Re~800, R_λ~ 53, $80\tau_{NL}$







K_W K_ω K_{PV} K_ε K_ε - 512 run

$$\partial_t \mathbf{u} + (\mathbf{u}\cdot\nabla)\mathbf{u} = -\nabla p - N\theta \mathbf{z}^{\star} + 2\mathbf{u}\times\boldsymbol{\Omega} + \nu\nabla^2\mathbf{u}$$
$$\partial_t \theta + (\mathbf{u}\cdot\nabla)\theta = Nw + \kappa\nabla^2\theta$$

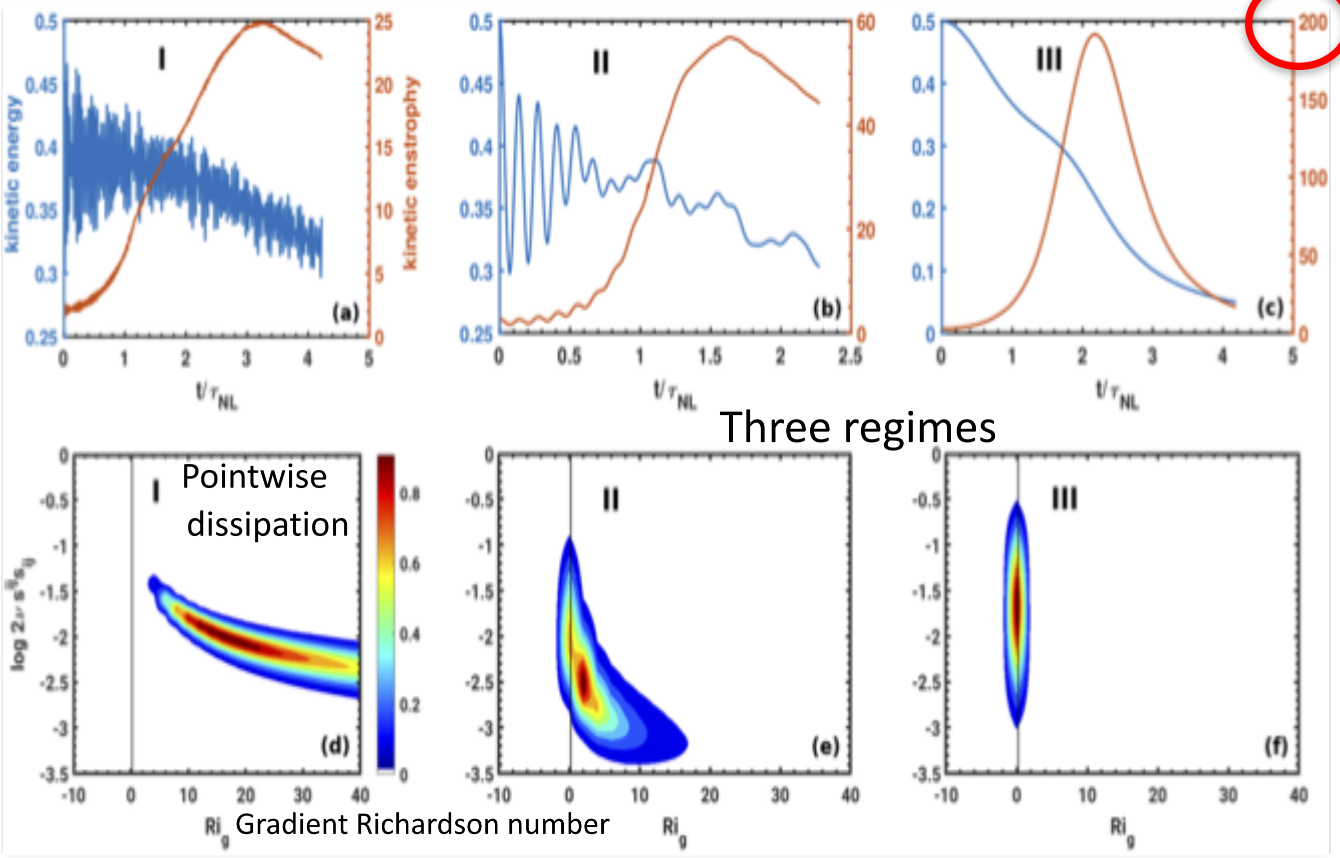
Rotating stratified turbulence, no forcing

Kinetic energy and dissipation

N/f=31, Re=14000; Fr=0.007, R_B= 0.75

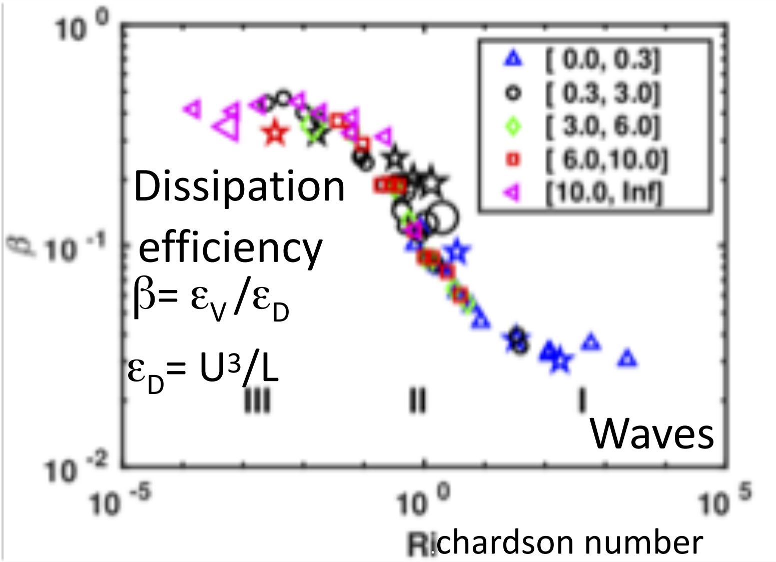
N/f=42, Re=12000; Fr=0.07, R_B=65

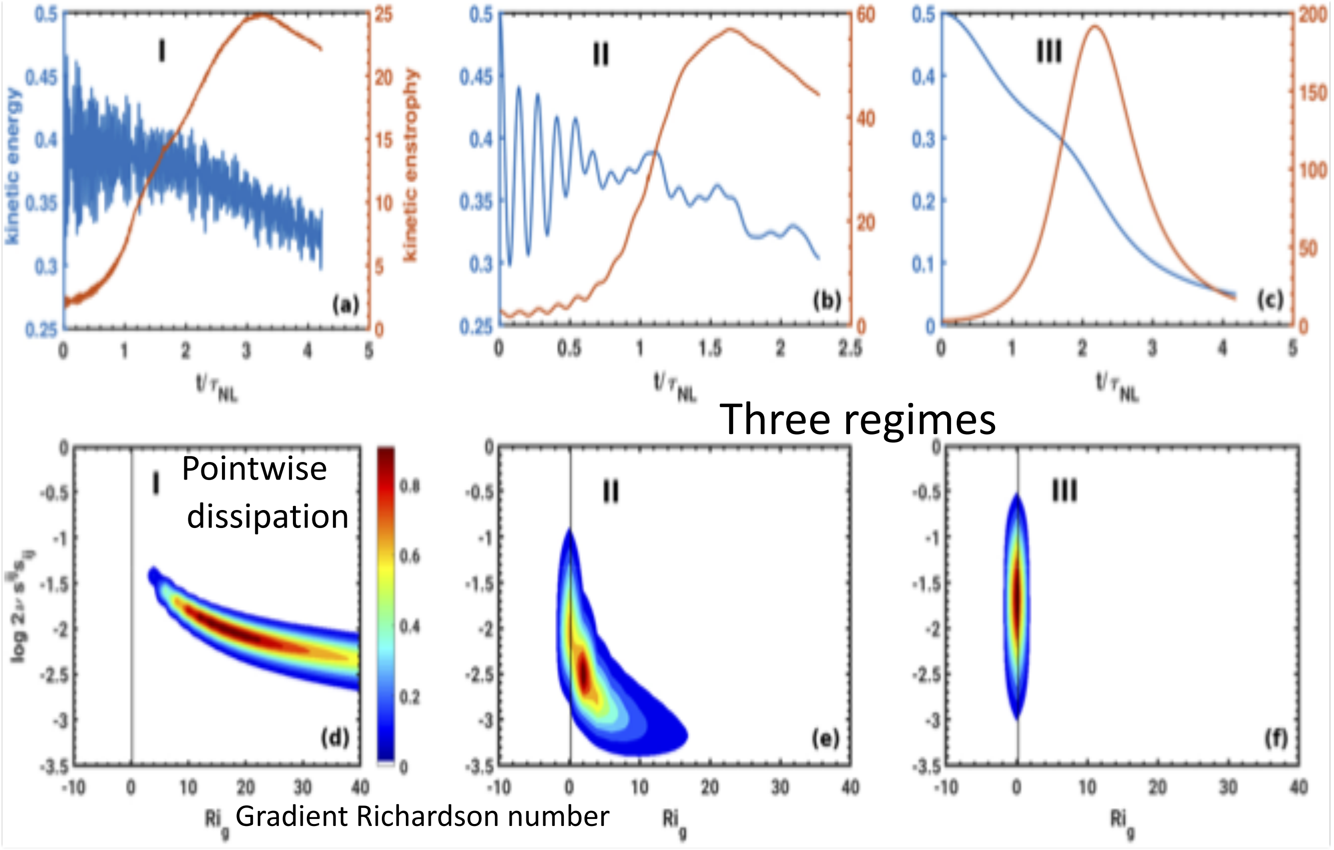
N/f=2.5, Re= 4700 Fr=0.89, R_B= 3760



Pouquet+2019

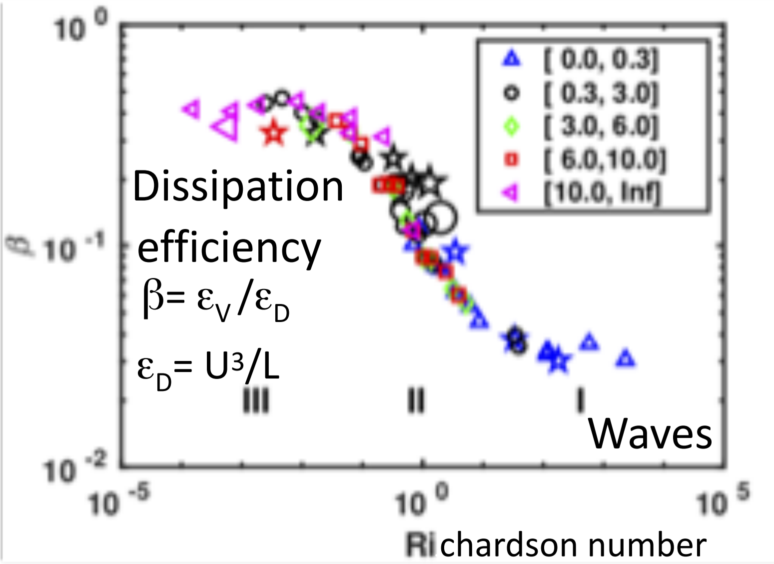
Rotating stratified turbulence

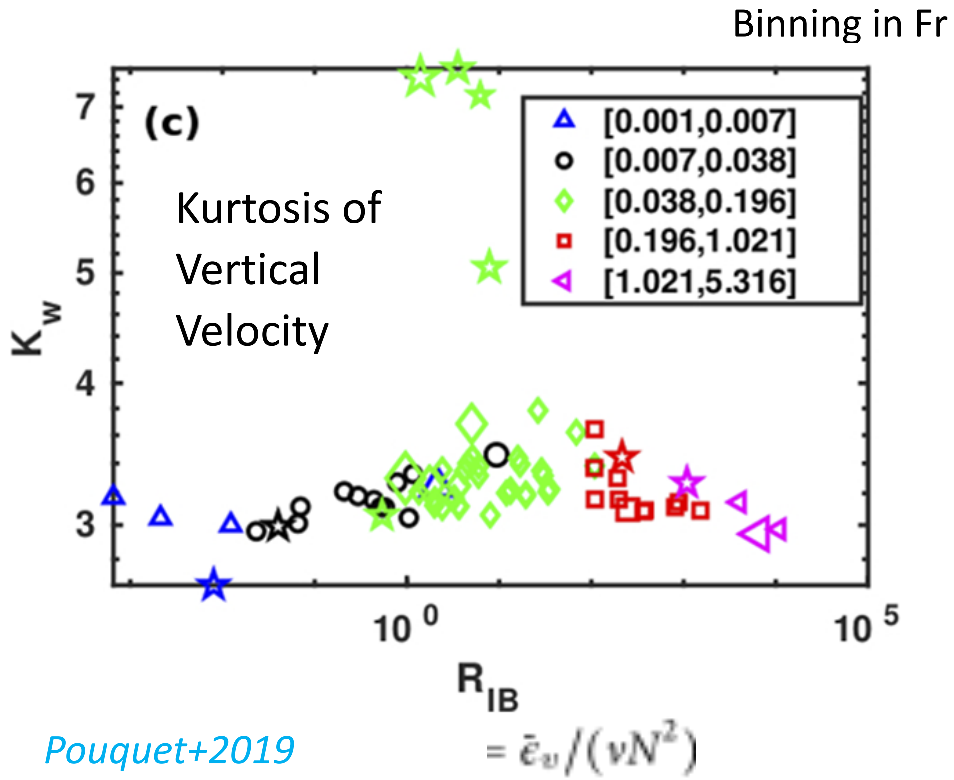


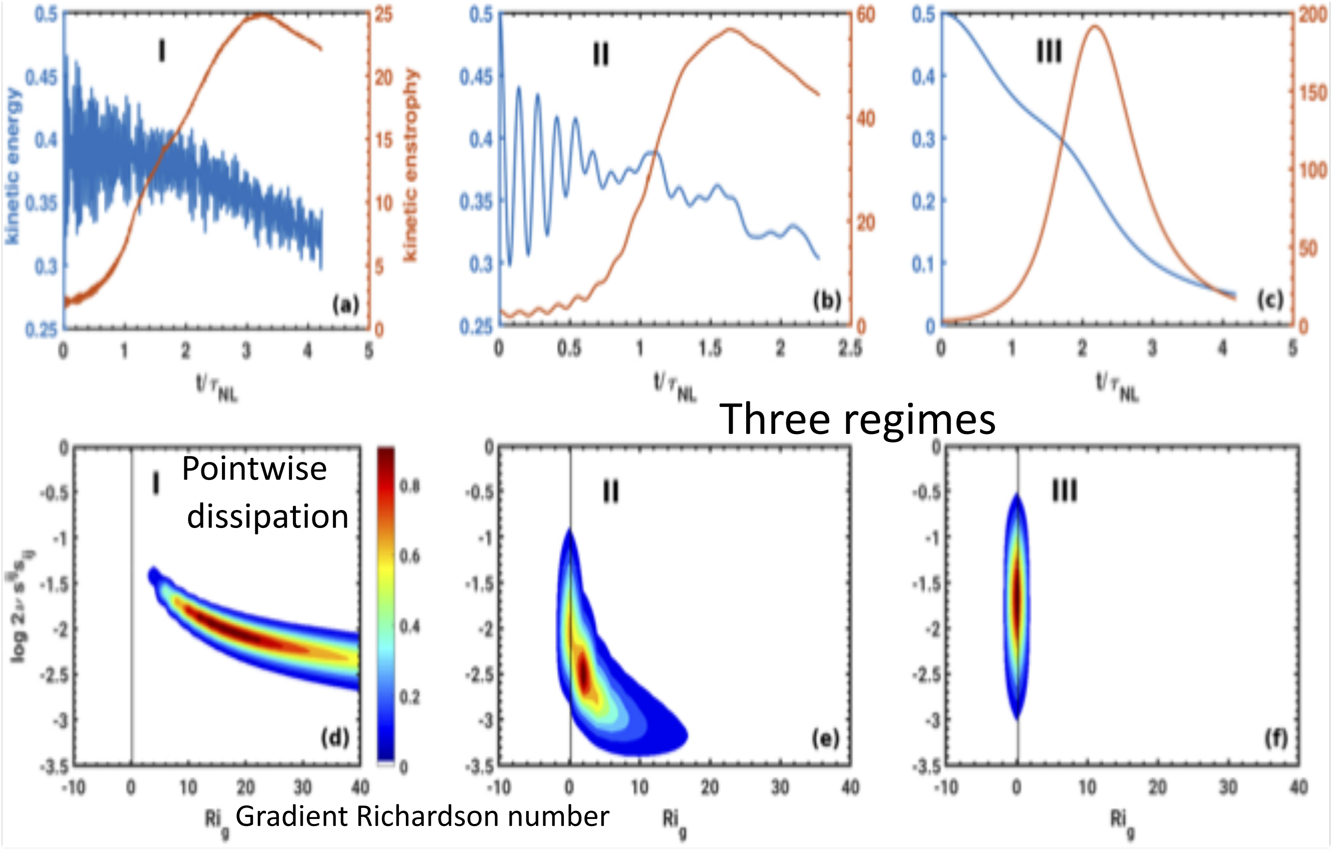


Pouquet+2019

Rotating stratified turbulence

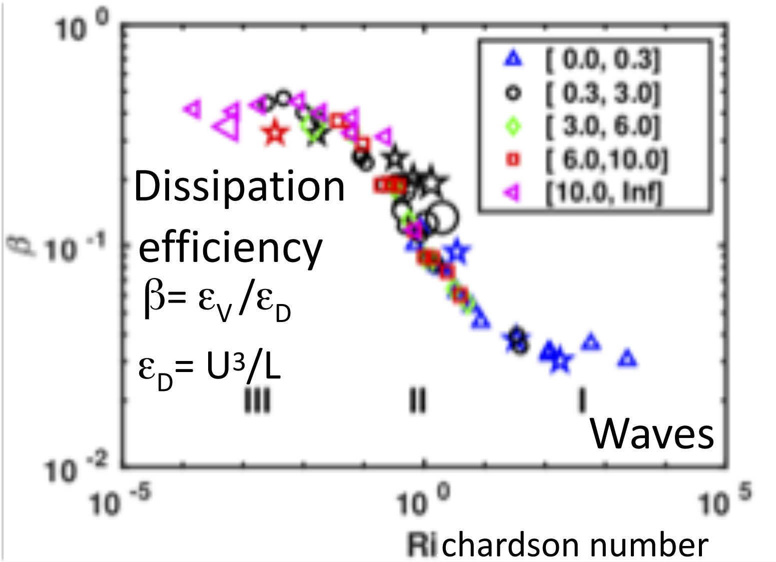




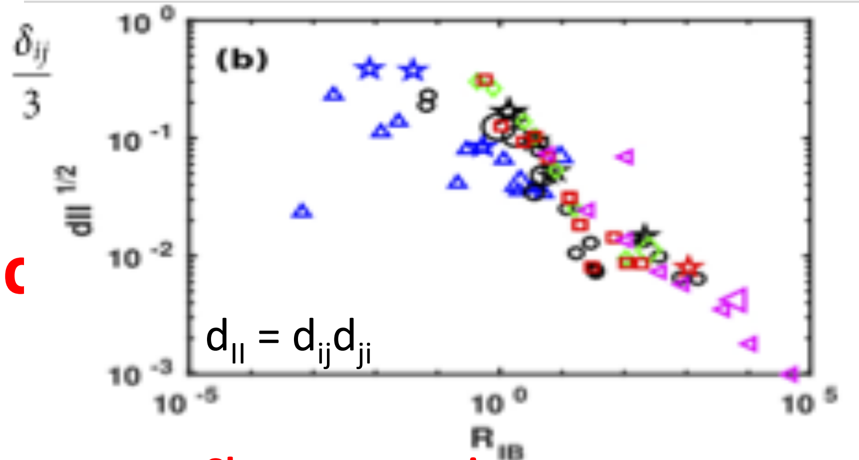


Pouquet+2019

Rotating stratified turbulenc

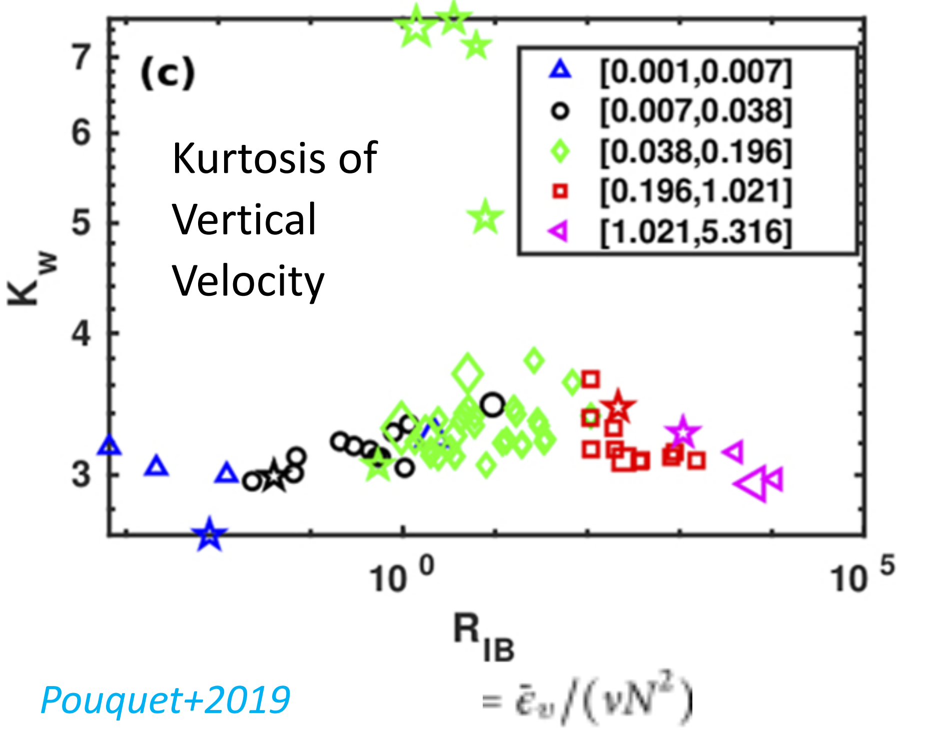


$$d_{ij} = \frac{\langle \partial_k u_i \partial_k u_j \rangle}{\langle \partial_k u_m \partial_k u_m \rangle} - \frac{\delta_{ij}}{3}$$

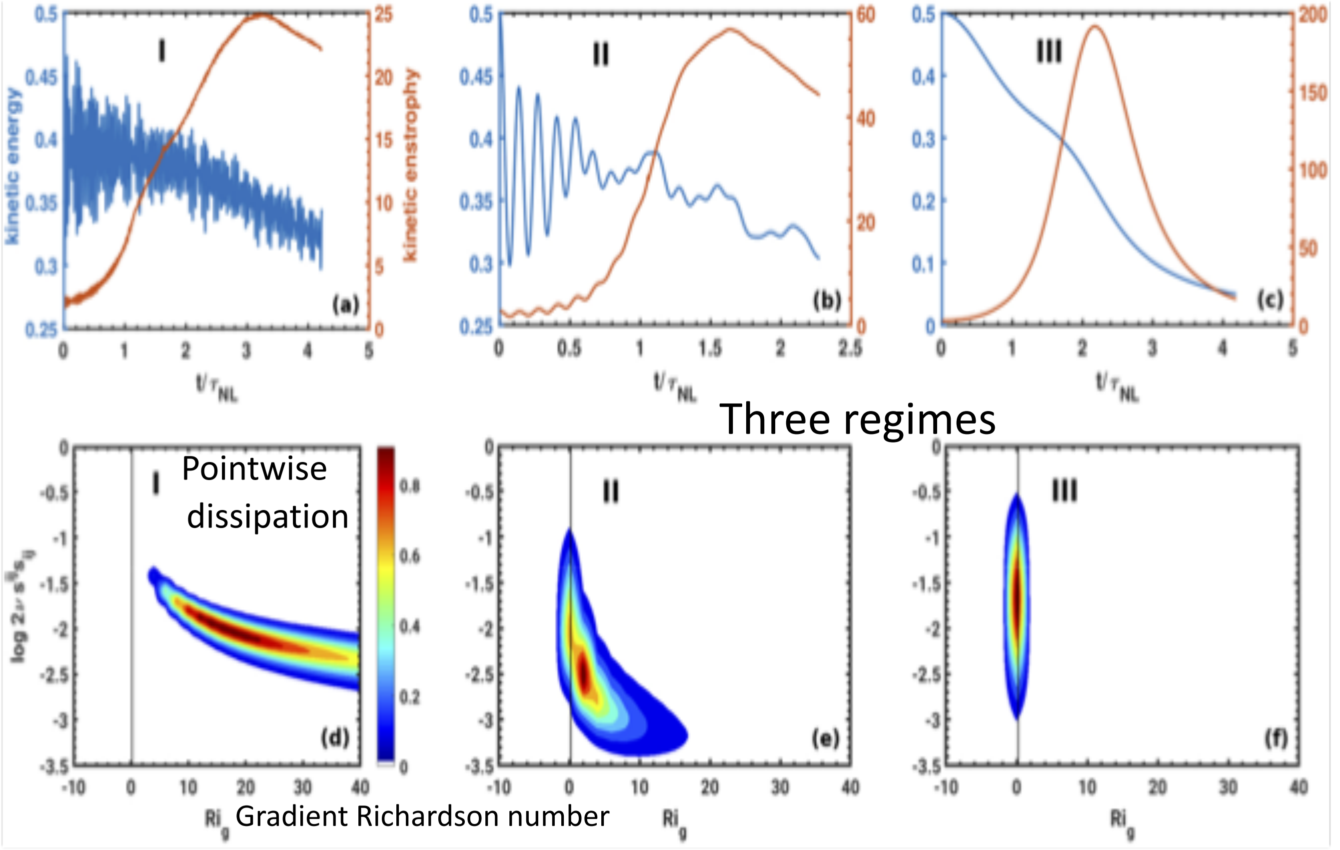


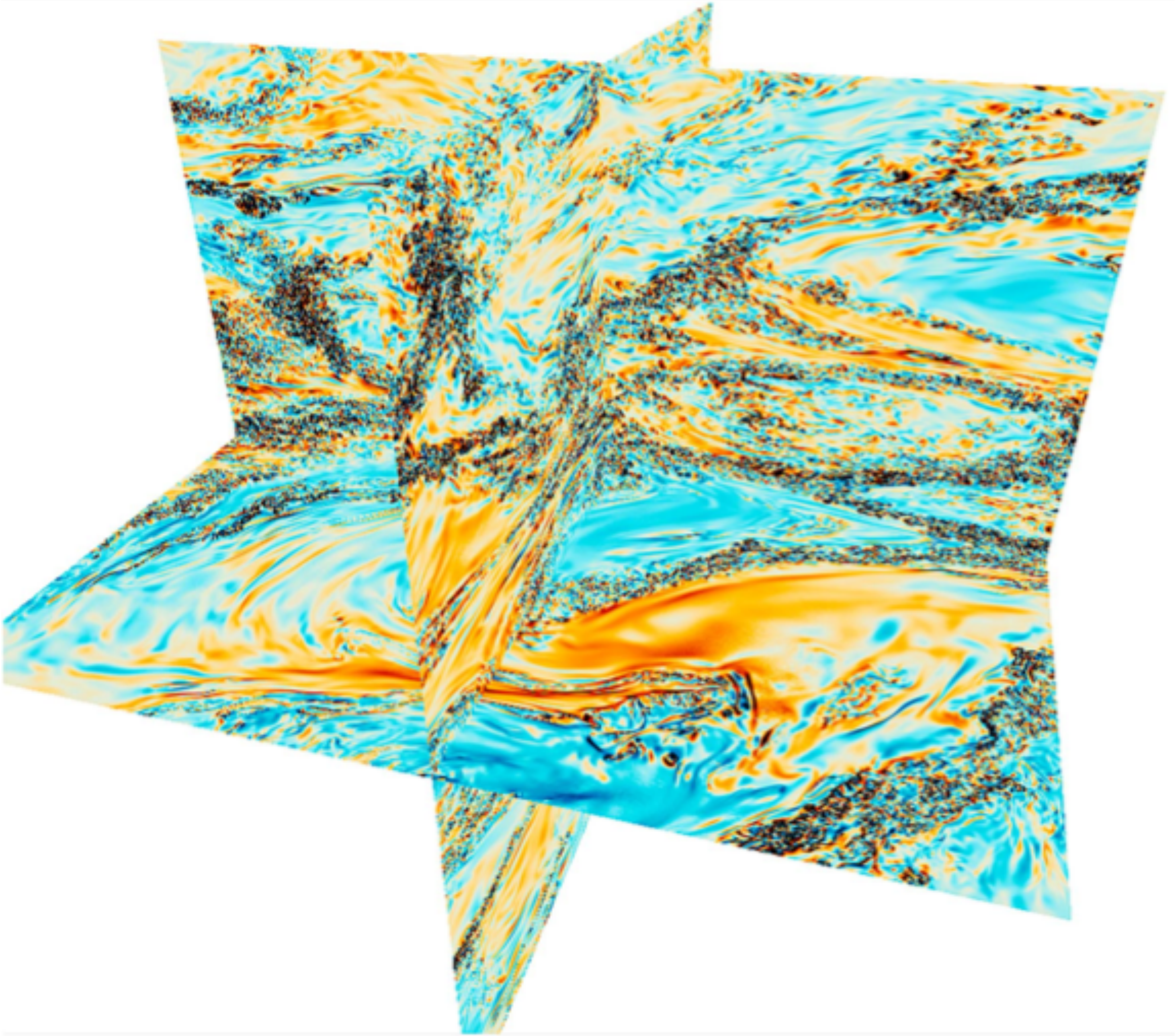
Slow return to isotropy

Binning in Fr



Pouquet+2019





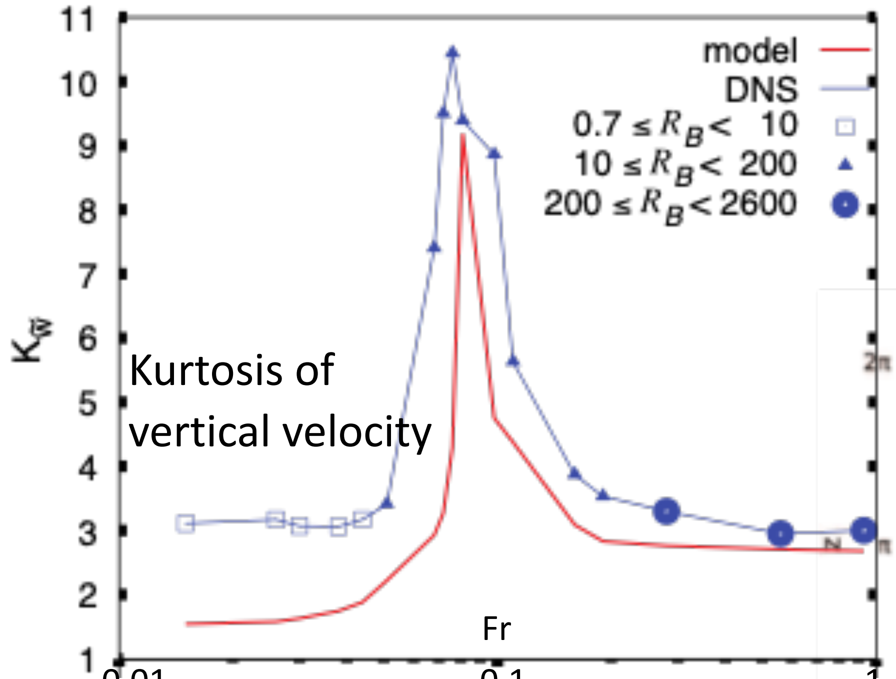
4096^3 , N/f=5, Re=55000, R_B =32
Unforced rotating stratified turbulence

Vorticity magnitude, 3D projection

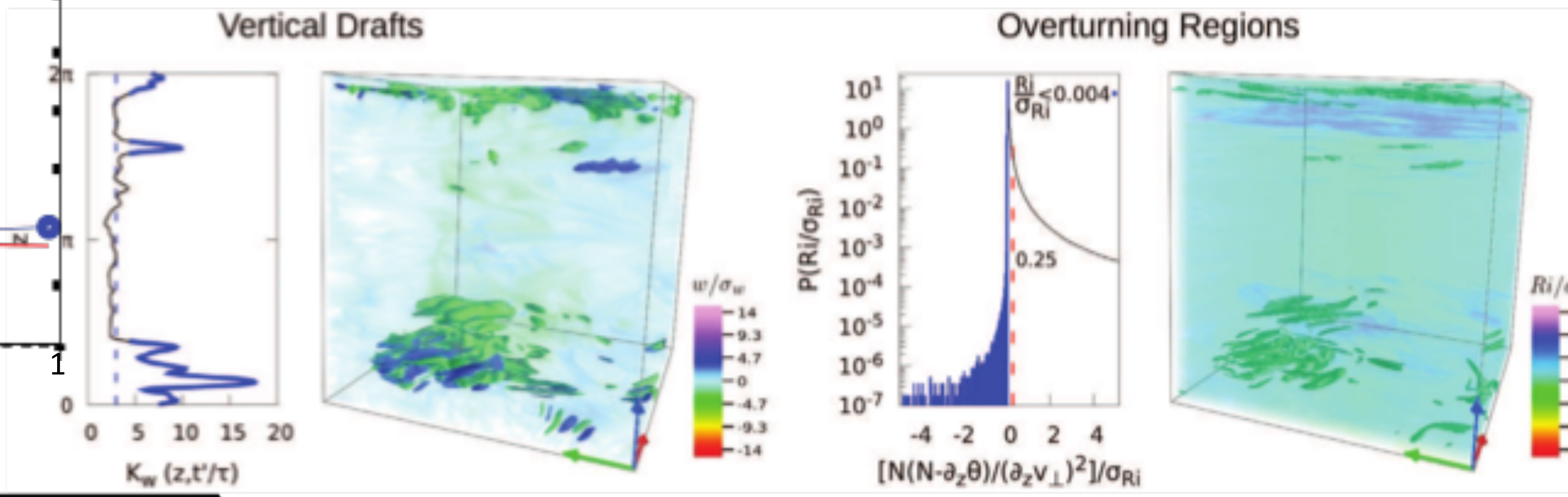
Co-existence of large eddies
(a signature of inverse transfer),
.and strong small-scale eddies

Stratified turbulence

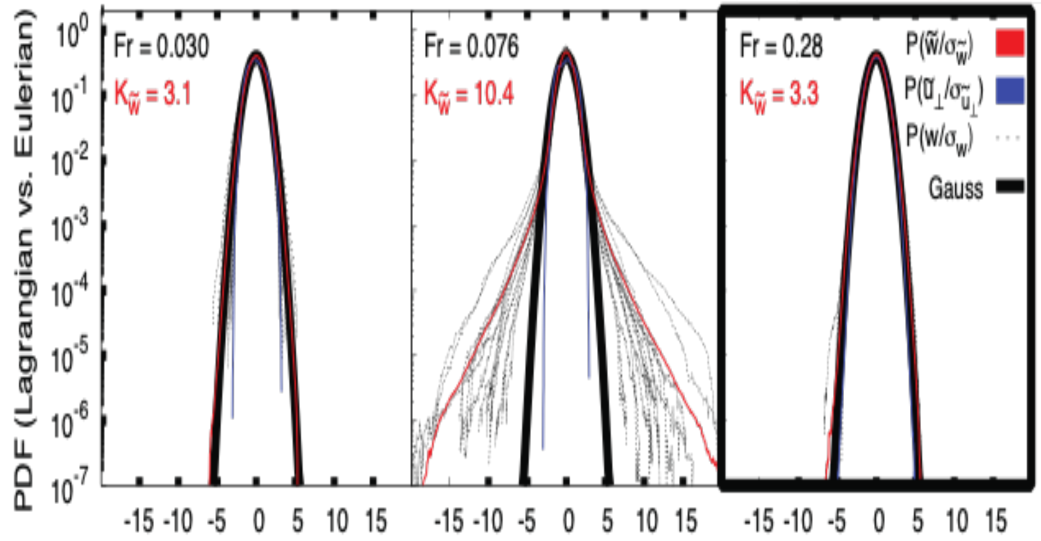
Efficiency of dissipation in volume @ the 50% level
at different times



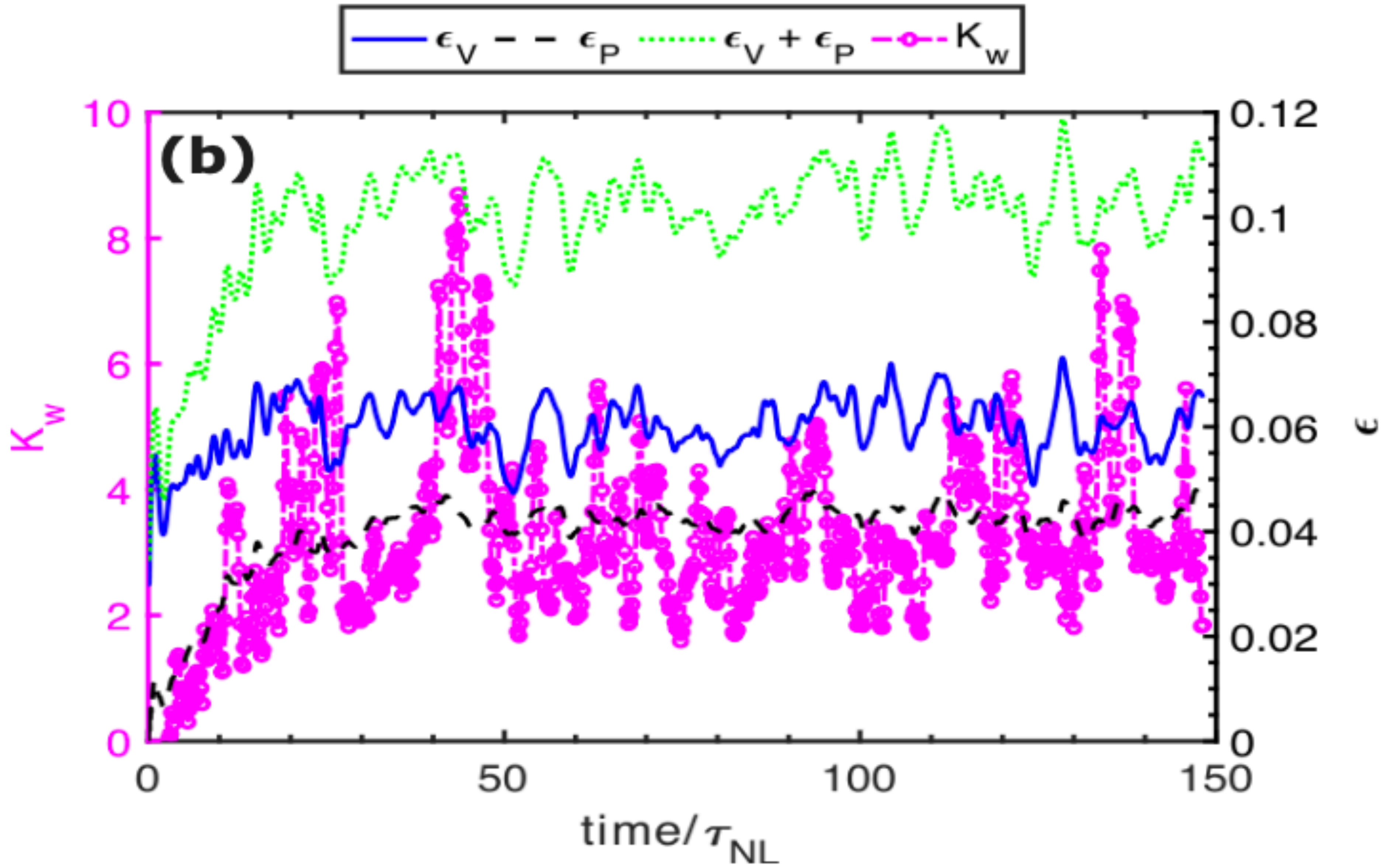
Feraco+ 2018



Marino+ PRF 2022



Overall kurtosis of vertical velocity at different times, forced flows



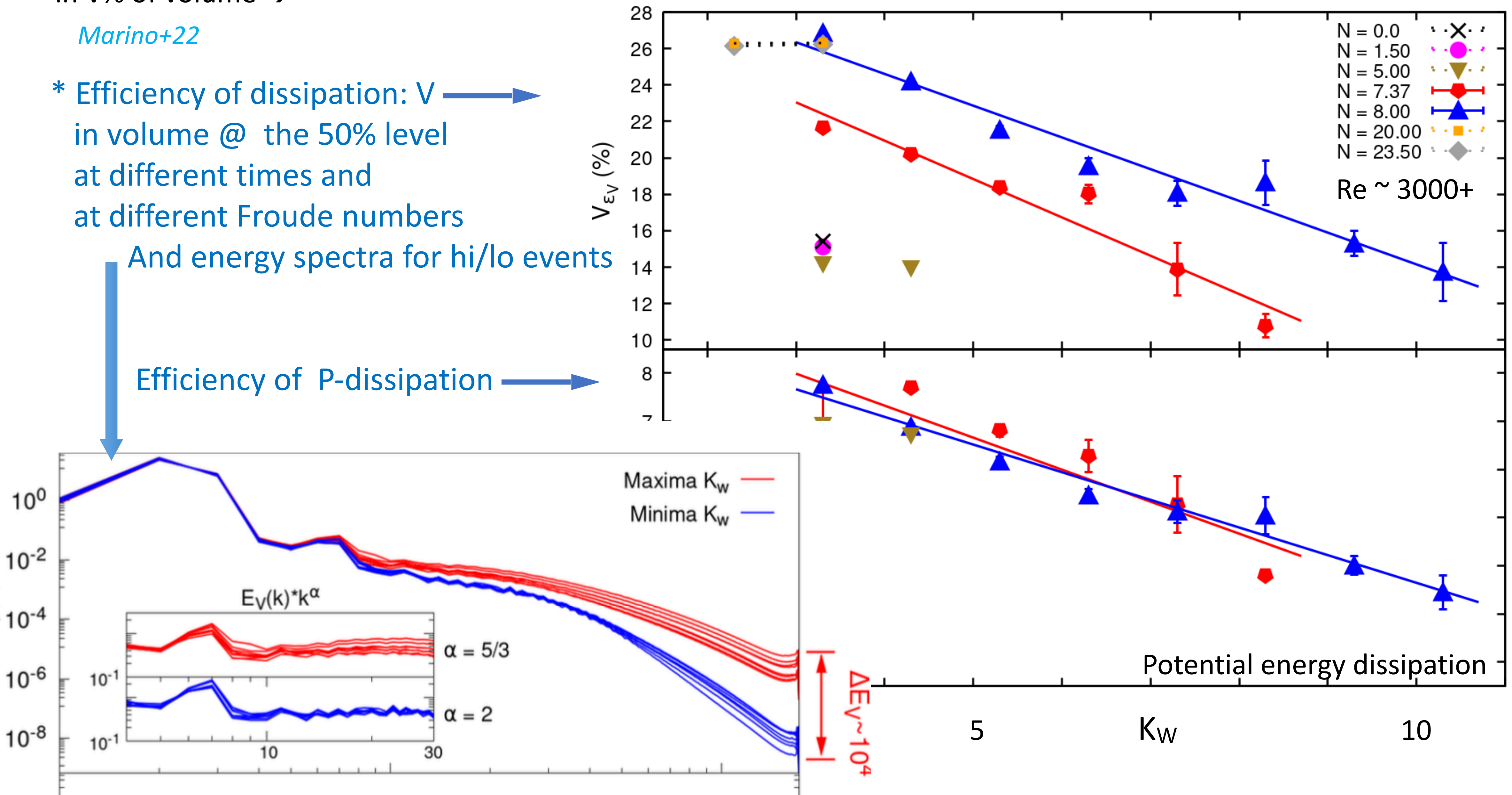
ϵ_V
ϵ_P
$\epsilon_V + \epsilon_P$
K_w
(b)
K_w
ϵ
0
2
4
6
8
10
0
0.02
0.04
0.06
0.08
0.1
0.12
0
50
100
150
time/τ_{NL}

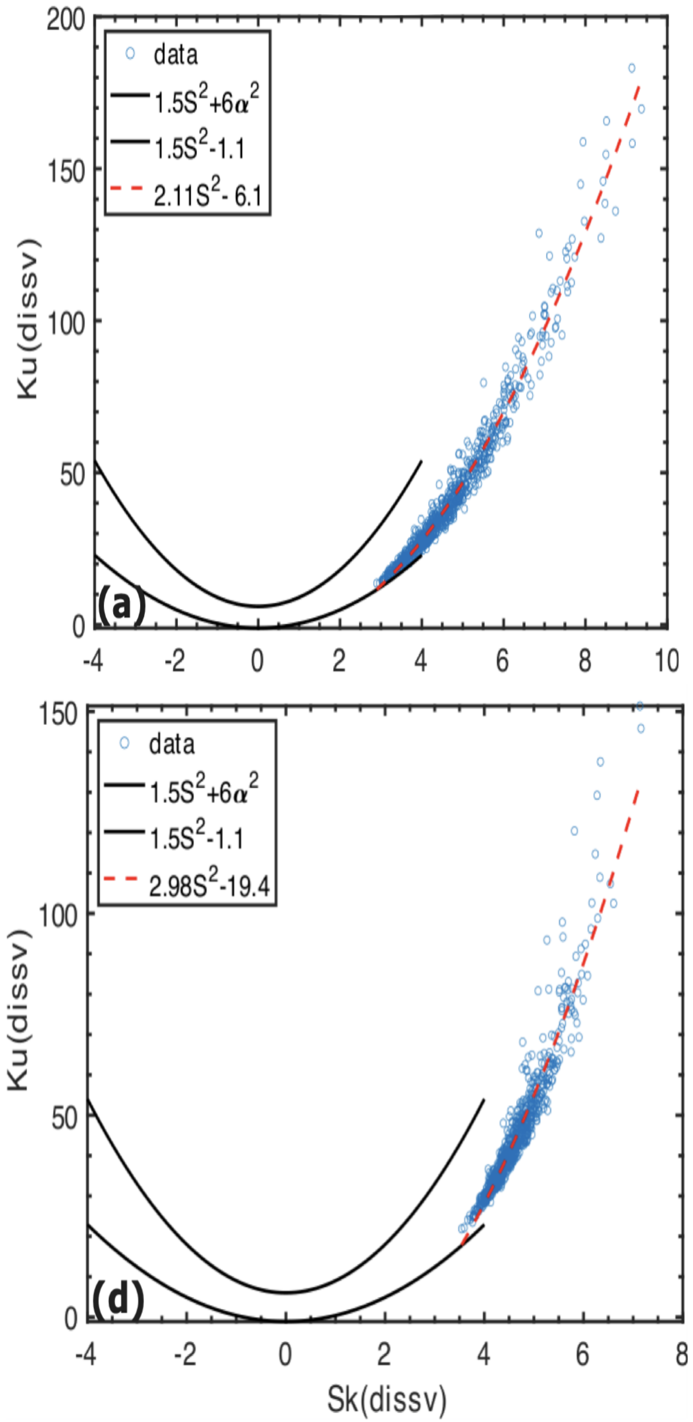
Stratified flows, no rotation
50% of dissipation
in V% of volume →

Marino+22

* Efficiency of dissipation: V →
in volume @ the 50% level
at different times and
at different Froude numbers
And energy spectra for hi/lo events

Efficiency of P-dissipation →





Rotating Stratified Turbulence

K(S) for QG runs

Kinetic energy dissipation ε_v

Top: Fr=0.07, Re=631

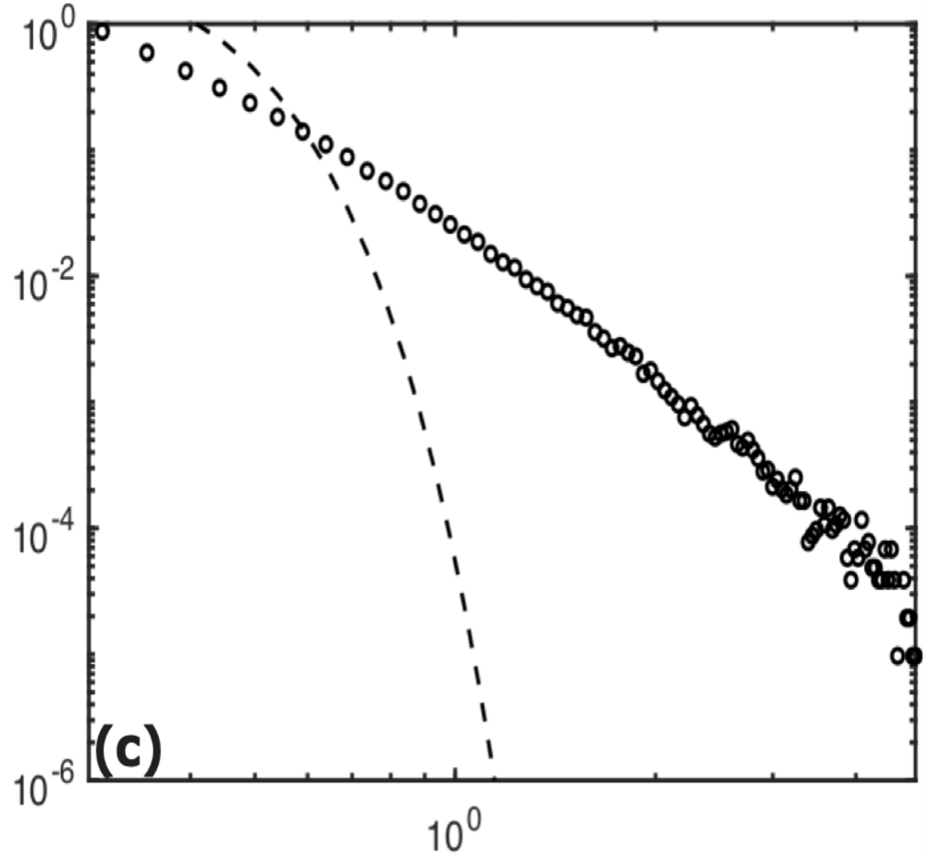
Ri=3.1, L_{Oz}/η_K=0.36

K(S) ~ $3.4S^2 + 16.5$

Bottom: Fr=0.36, Re=694

Ri=0.6, L_{Oz}/η_K=11.9

K(S) ~ $1.45S^2 + 6.2$

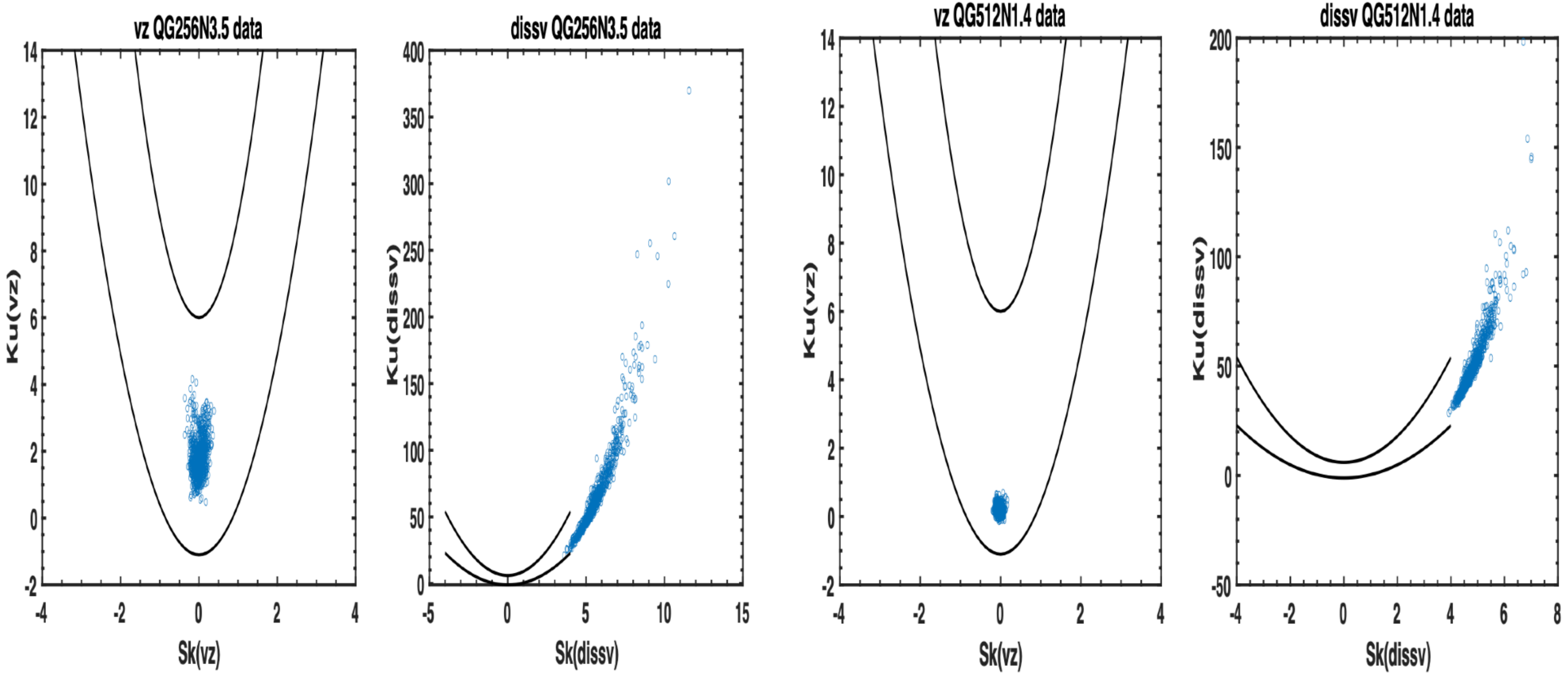


PDF of ε_v at maximum of K_w

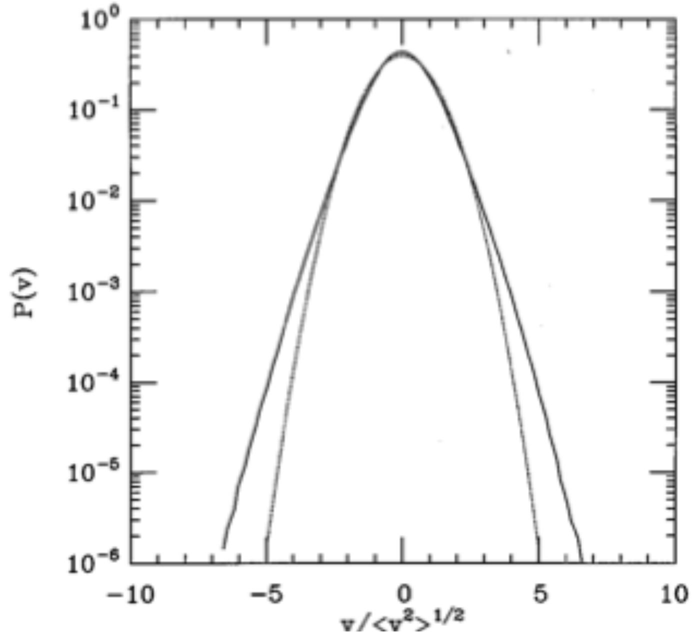
Fr=.29, Re=370, Ri=.9, L_{Oz}/η_K= 6.4

—> **Sharp transition** when isotropic K41 range begins to be present

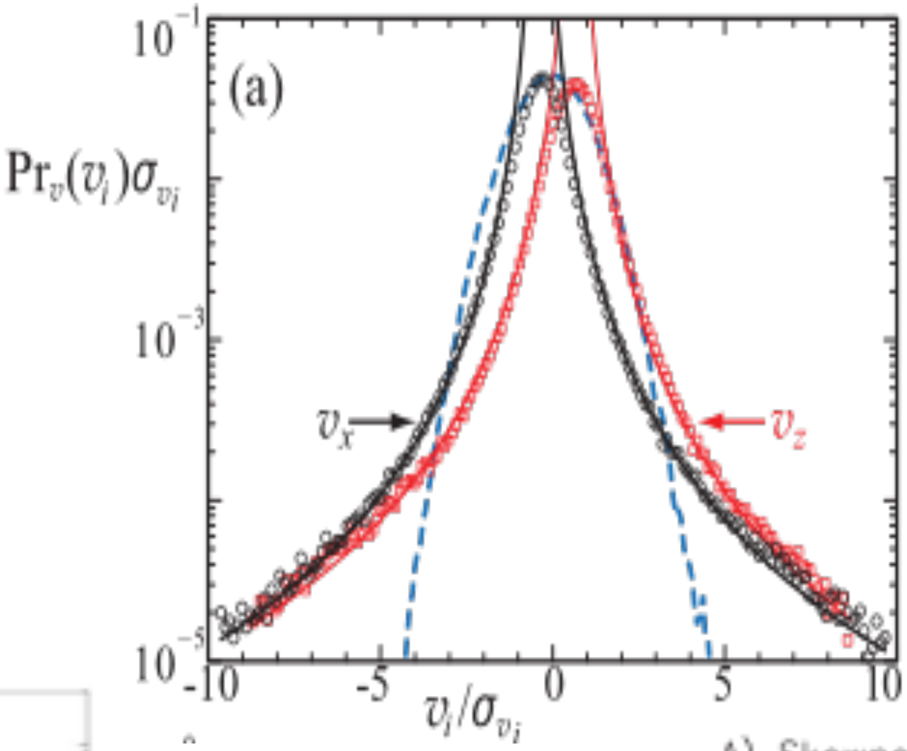
Rotating stratified flows at different Froude numbers, with N/f=5, 80 T_{NL} : w & ε_v



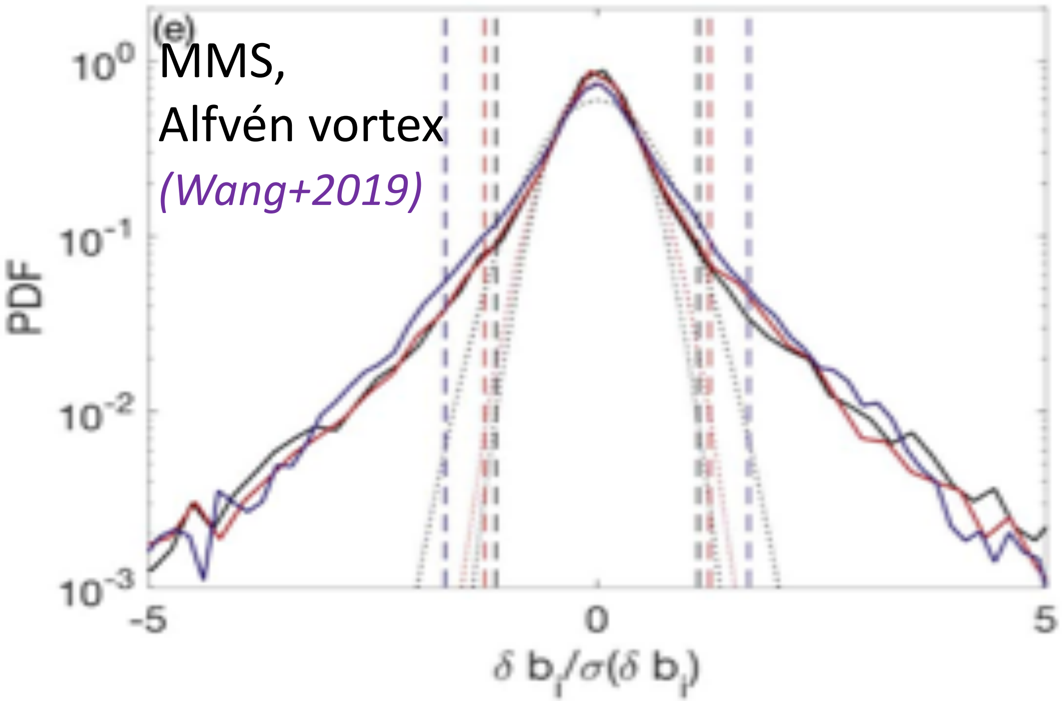
Fr ~ 0.11, Ro= 0.55, Re=942, $\mathbf{R_B=11}$, K~4.4S² and Fr ~ 0.4, Ro= 2., Re=10^3, $\mathbf{R_B=11}$, K~1.6S²



Shear flows
Pumir 1996
DNS

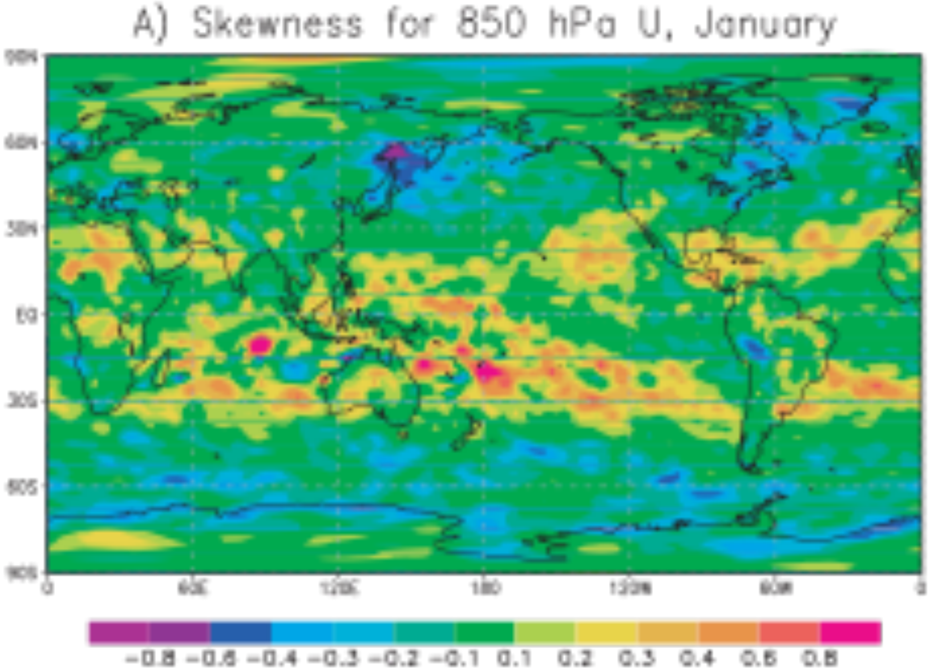


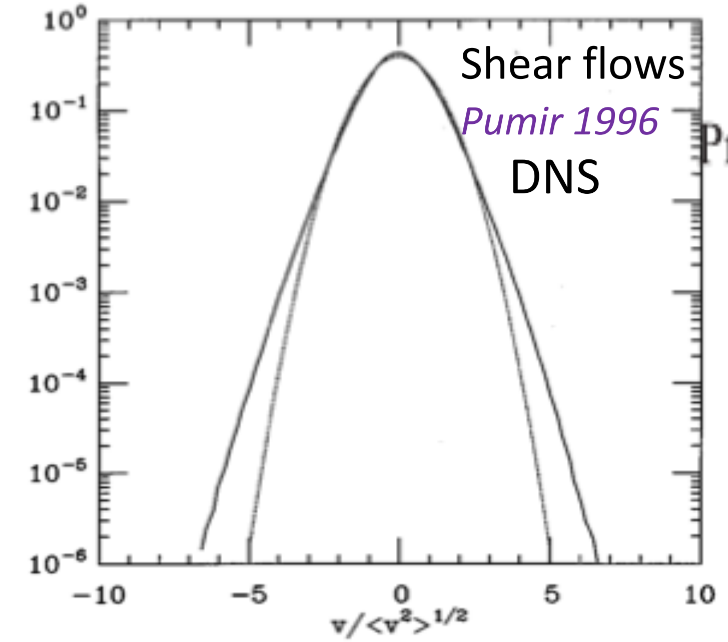
Paoletti+2008
Superfluid turbulence

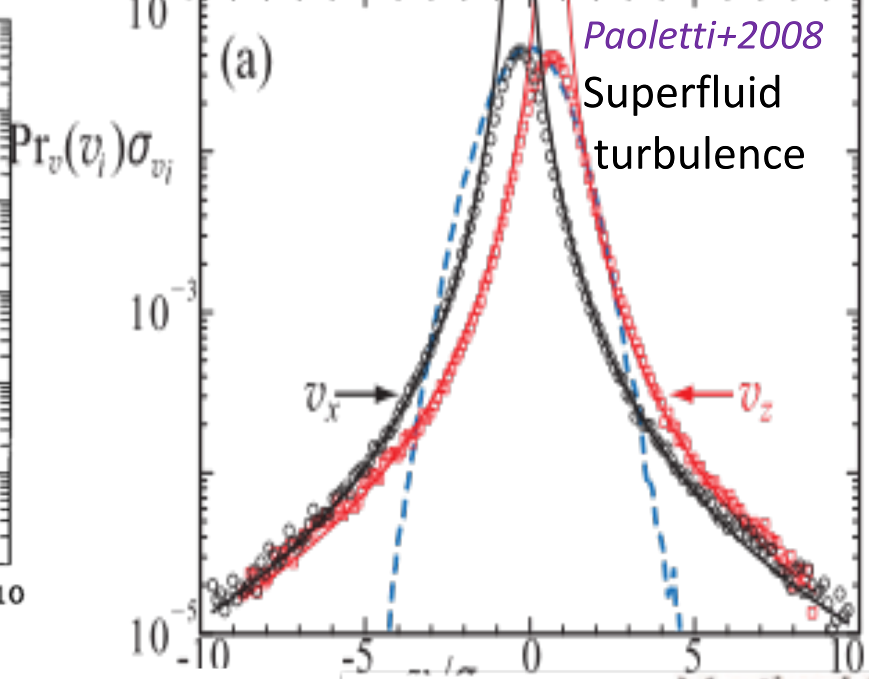


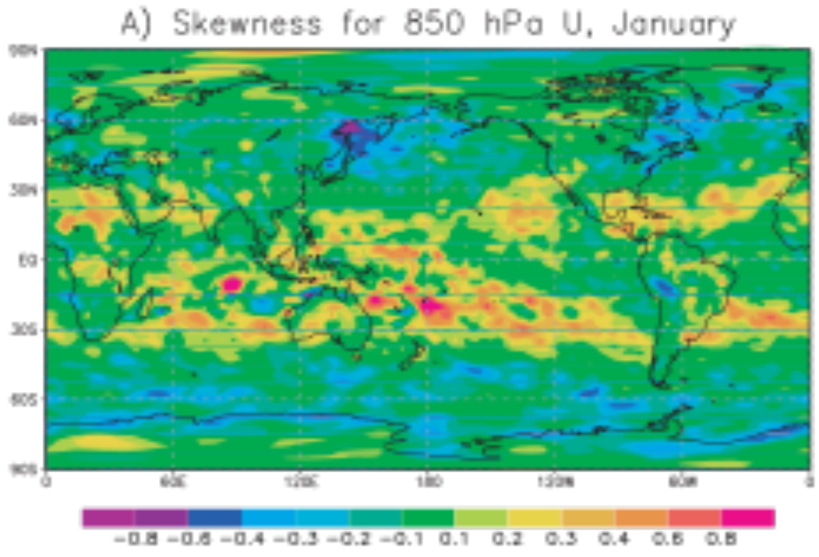
MMS,
Alfvén vortex
(Wang+2019)

Skewness of temperature
ERA40 data. *Petoukhov+ 08*

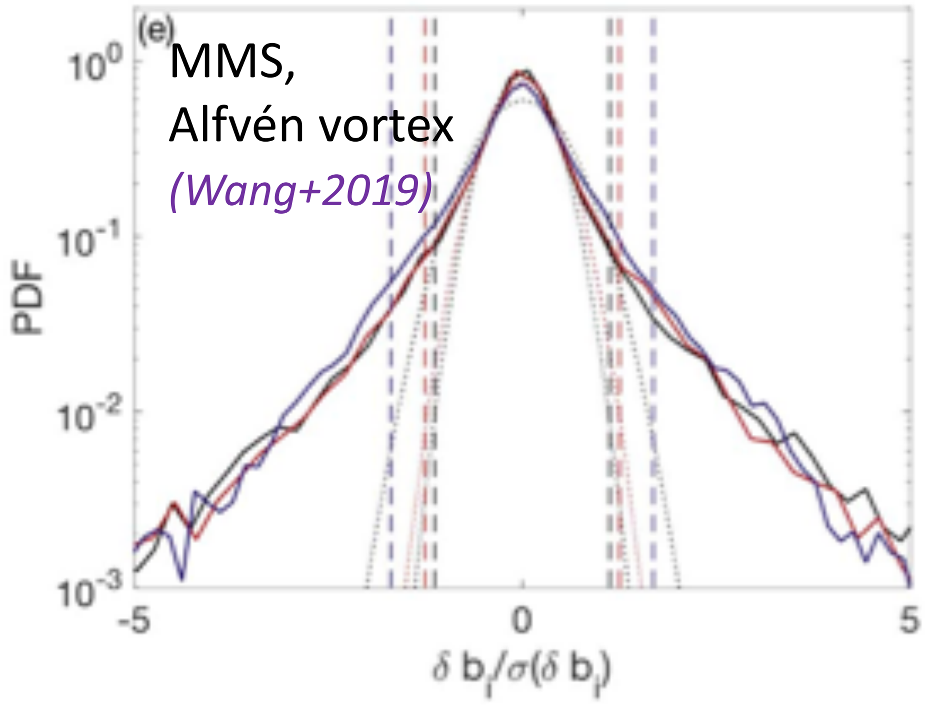


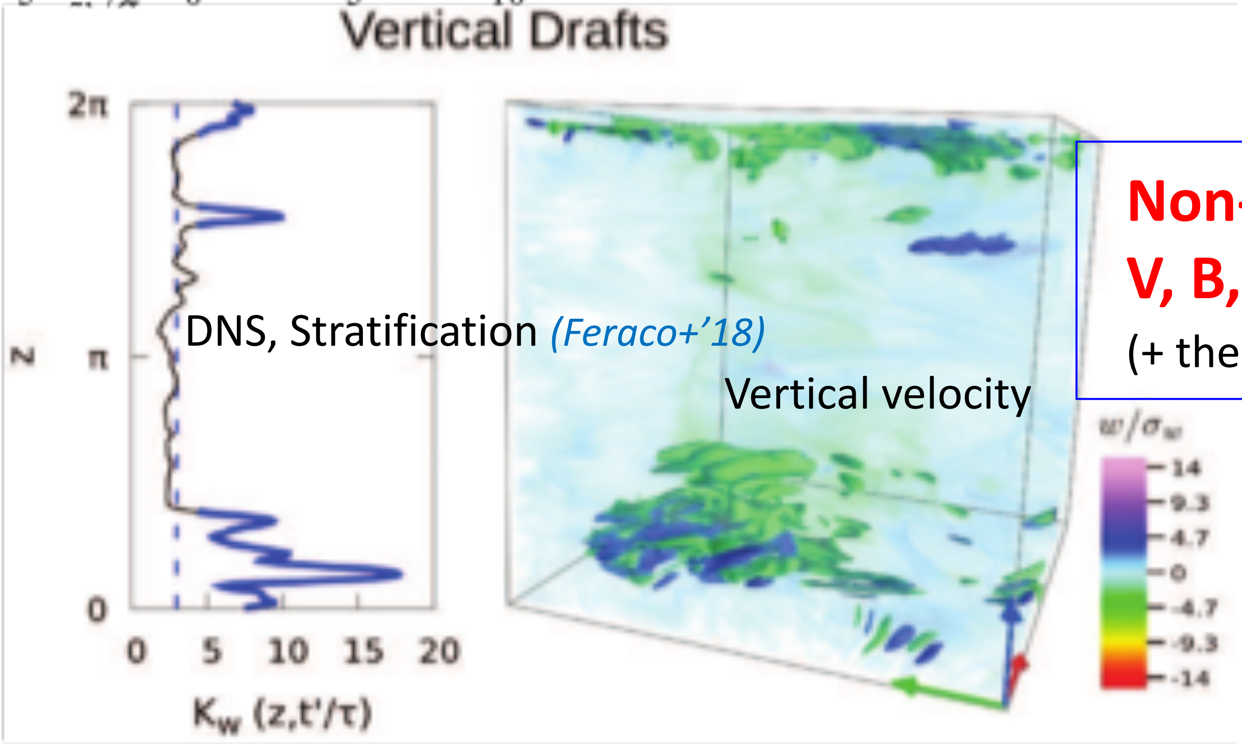






Skewness of temperature
ERA40 data. *Petoukhov+ 08*





Non-Gaussian
V, B, T
(+ their gradients)

Conclusions and perspectives

* Need for detailed explorations of dissipative structures in fluid, MHD and plasma turbulence (*e.g.*, sparseness scale as a function of dissipative scale)
* Dissipative structures not fully explored *(ongoing work in MHD)*

* Skewness *S* and excess kurtosis *K* as maps of nonlinear behavior
* *K(S)* laws in hydrodynamic turbulence, and (rotating) stratified turbulence
* Statistics: need for long-time integration, in excess of $5000^{+}\tau_{NL}$?

    * Scaling variation for different regimes? As a trace of what change in structures?
    * What intermittency do they correspond to *(ongoing work in MHD)*?
        * That of the dissipative range?
        * That corresponding to a critical shear instability
        * Or other: Langevin model, SOC, …

Thank you!

pouquet@ucar.edu