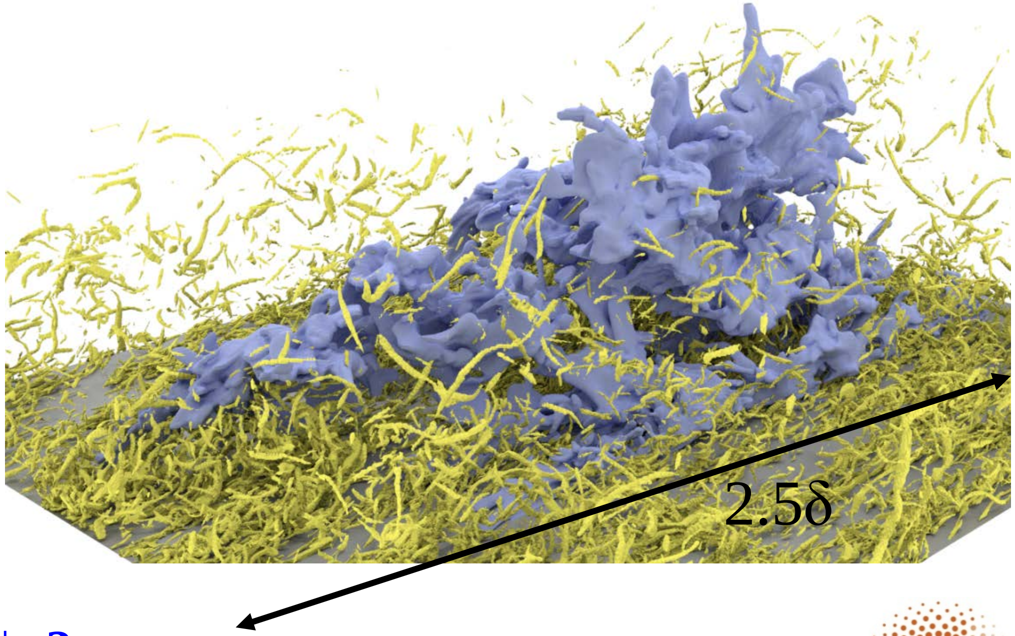
(So called) inertial eddies in turbulence

Javier Jiménez & al.

School of Aeronautics, Madrid



TBL: Re_τ=1800, u'^+=2
J.A. Sillero

'Cascades'

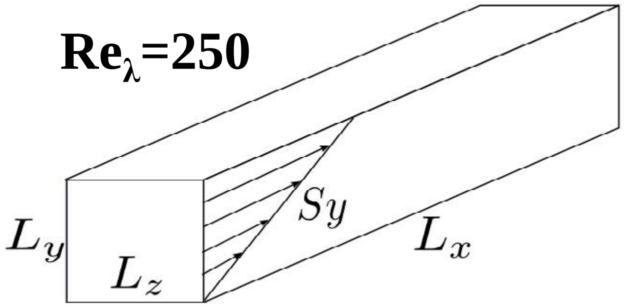
The flux of a conserved quantity across a range of scales

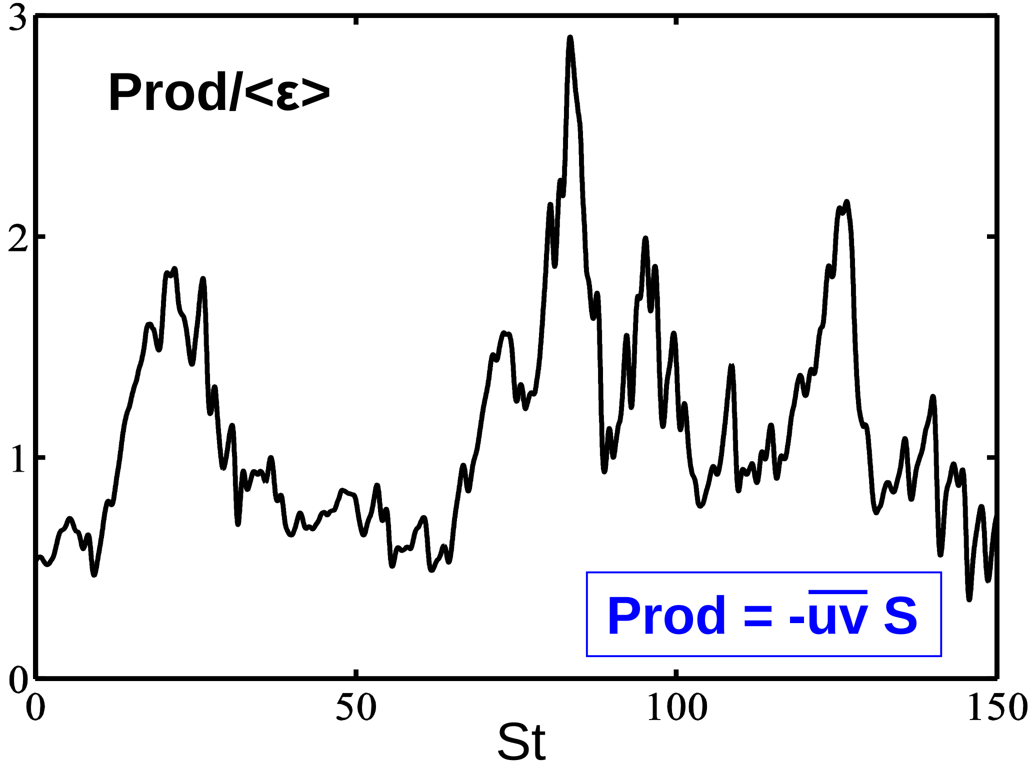
e.g.

- **Energy in Homog. Turbulence**
- **Momentum in shear flows**

The energy cascade

Homogeneous Shear Flow



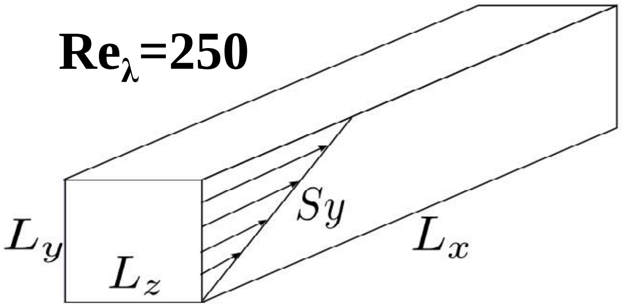


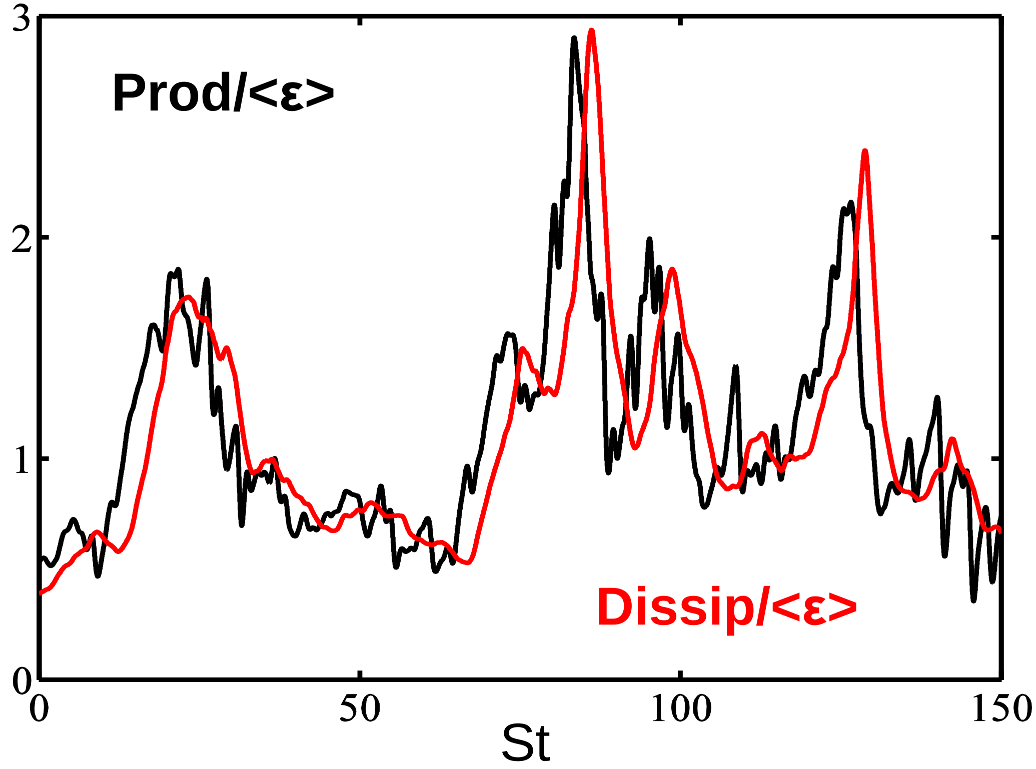
Dong, Sekimoto & J, 2012

The energy cascade takes time

Large to Small

Homogeneous Shear Flow



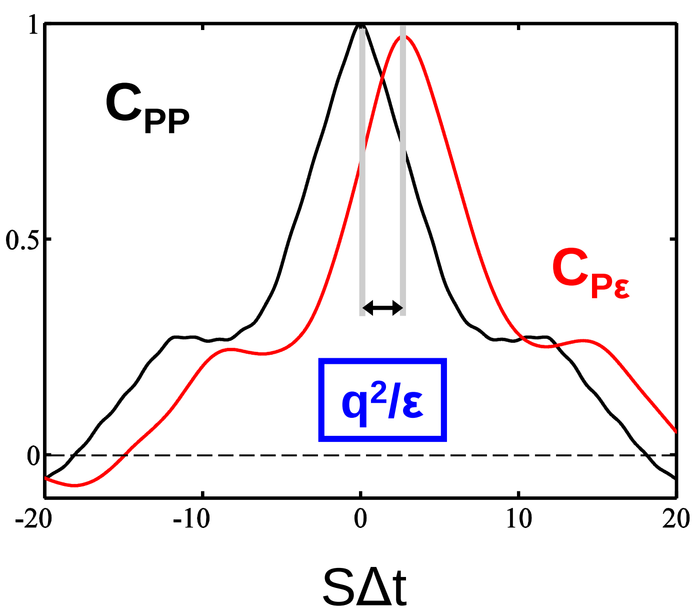


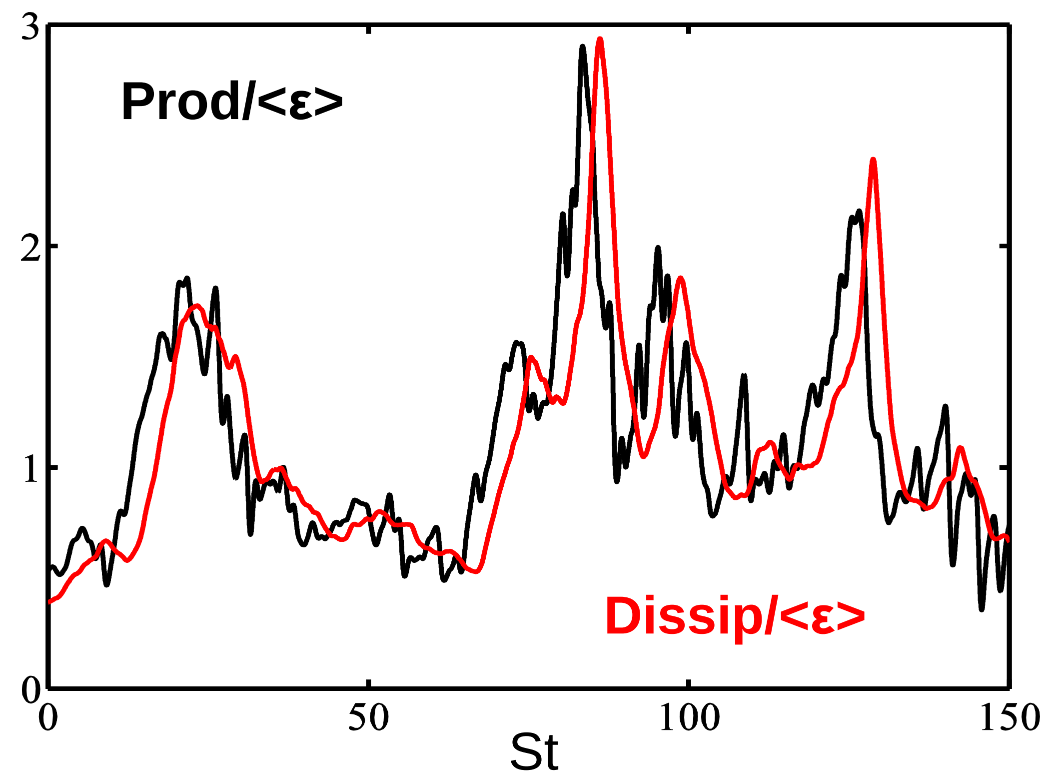
Dong, Sekimoto & J, 2012

The energy cascade takes time
Large to Small

Homogeneous Shear Flow

Temporal cross-correl.





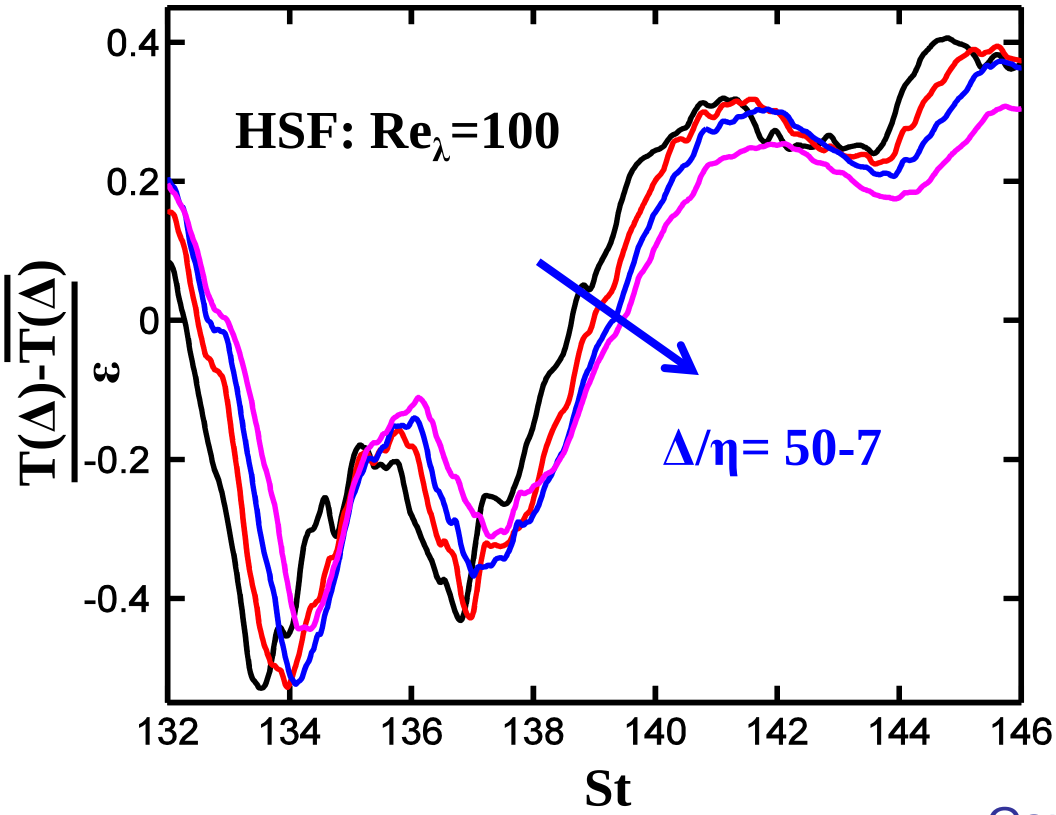
Dong, Sekimoto & J, 2012

The cross-scale energy **flux**

$u = \bar{u} + u'$; $\bar{u} = G * u$; $G \sim \exp[-(x_1^2+x_2^2+x_3^2)/\Delta^2]$

$$\left(\partial_t + \overline{u}_j \partial_j\right) \frac{1}{2} \overline{u}_i \overline{u}_i = -\partial_j \left(\overline{u}_j \overline{p} + \overline{u}_i \tau_{ij} - 2\nu \overline{u}_i \overline{S}_{ij} \right) - 2\nu \overline{S}_{ij} \overline{S}_{ij} + \overline{S}_{ij} \tau_{ij}$$

T



Cardesa et al., 2014

The cross-scale energy flux

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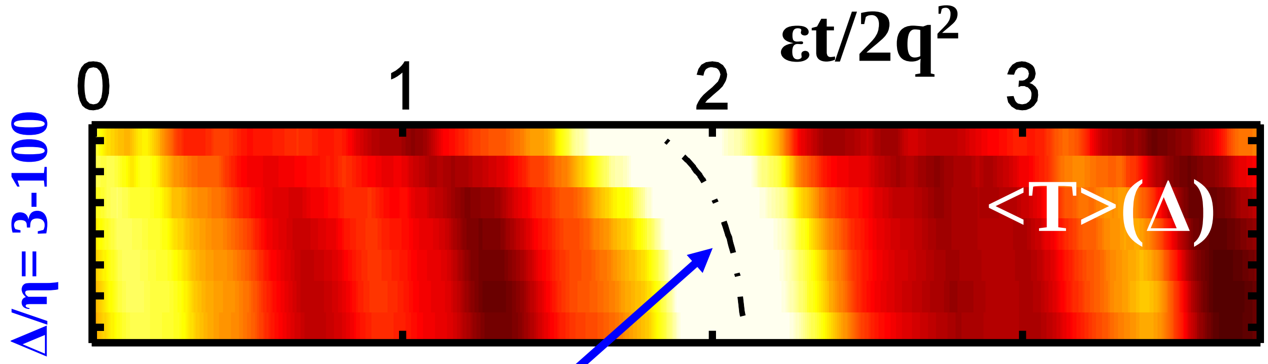
T

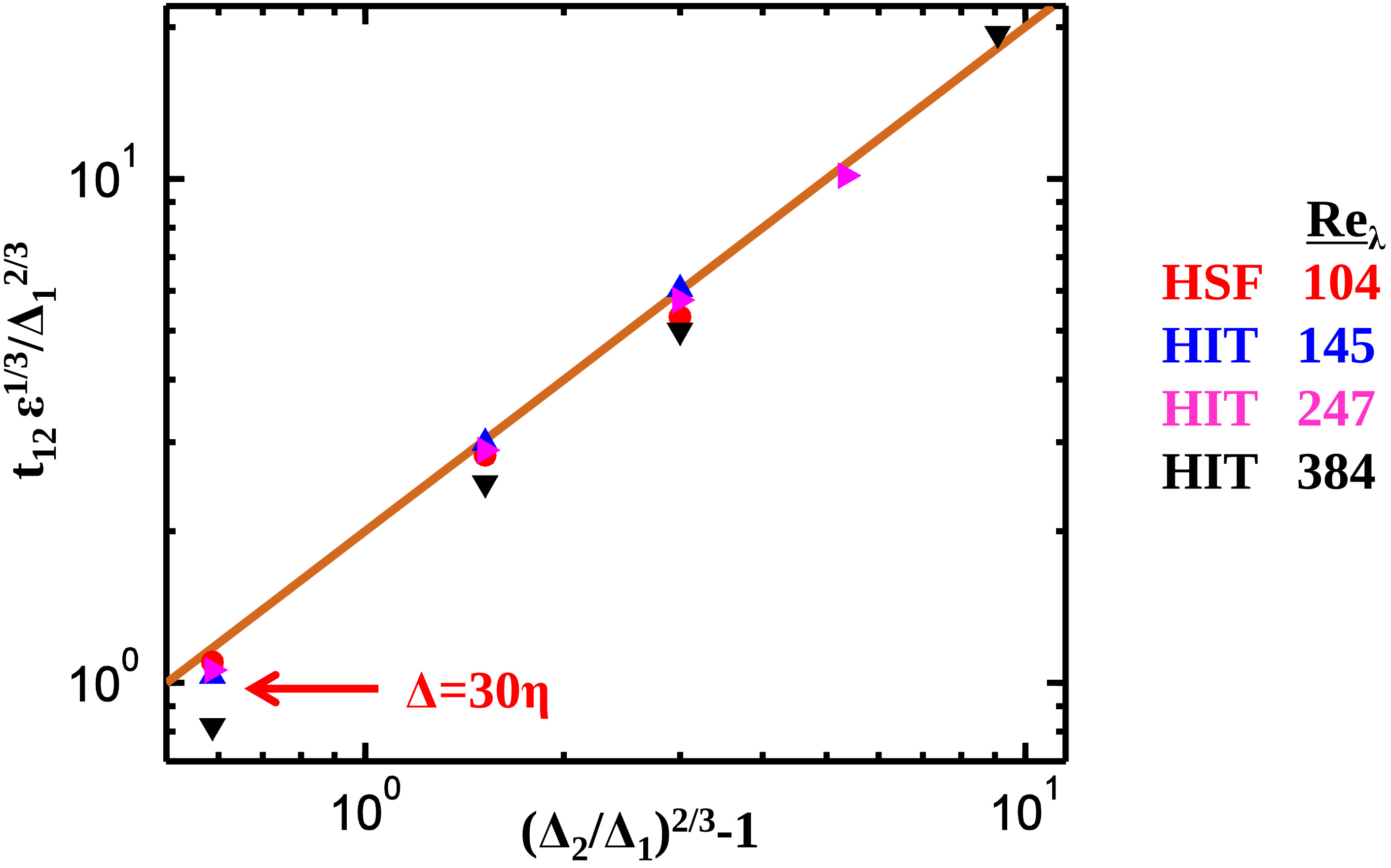


$\Delta t \approx \text{const.} - \varepsilon^{-1/3} r^{2/3}$

HIT: Re_λ=384

Cardesa et al., 2014

The 'velocity' of the cascade



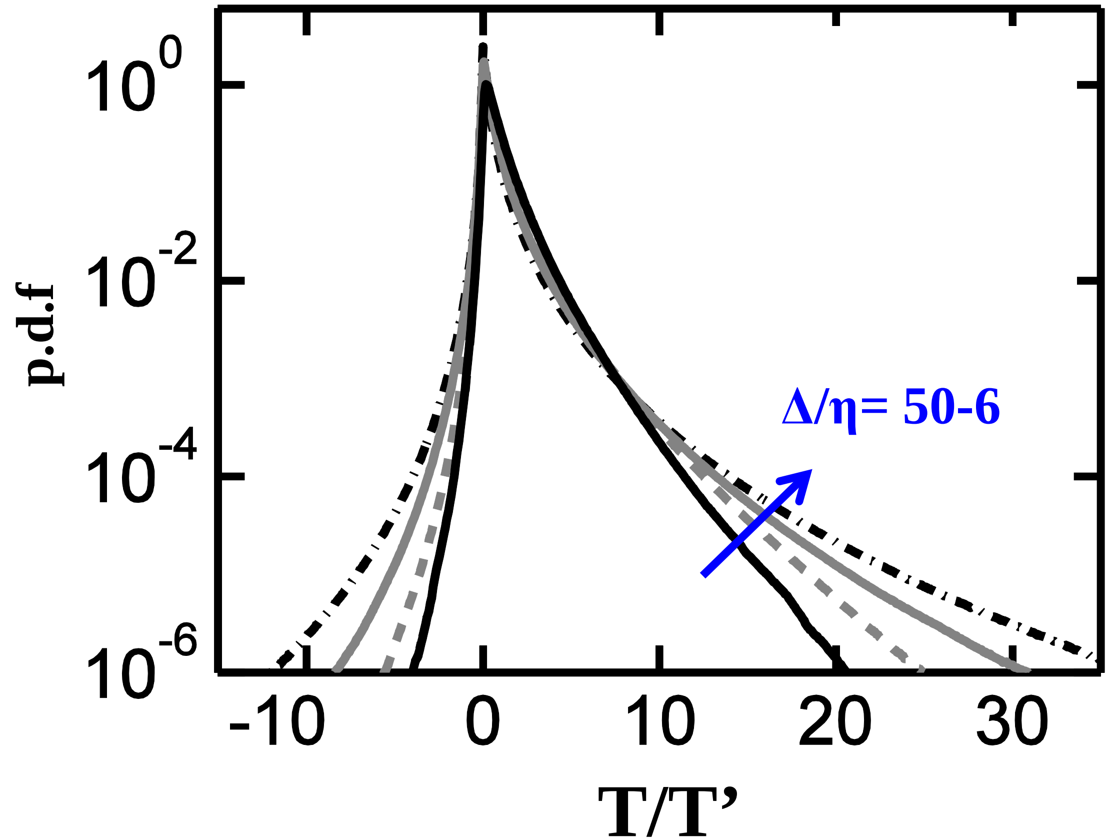
Cardesa & J, 2014

The energy flux is intermittent

$u = \bar{u} + u'$; $\bar{u} = G*u$; $G \sim \exp[-(x_1^2+x_2^2+x_3^2)/\Delta^2]$

$$\left(\partial_t + \overline{u}_j \partial_j\right) \frac{1}{2} \overline{u}_i \overline{u}_i = -\partial_j \left(\overline{u}_j \overline{p} + \overline{u}_i \tau_{ij} - 2\nu \overline{u}_i \overline{S}_{ij} \right) - 2\nu \overline{S}_{ij} \overline{S}_{ij} + \overline{S}_{ij} \tau_{ij}$$

T

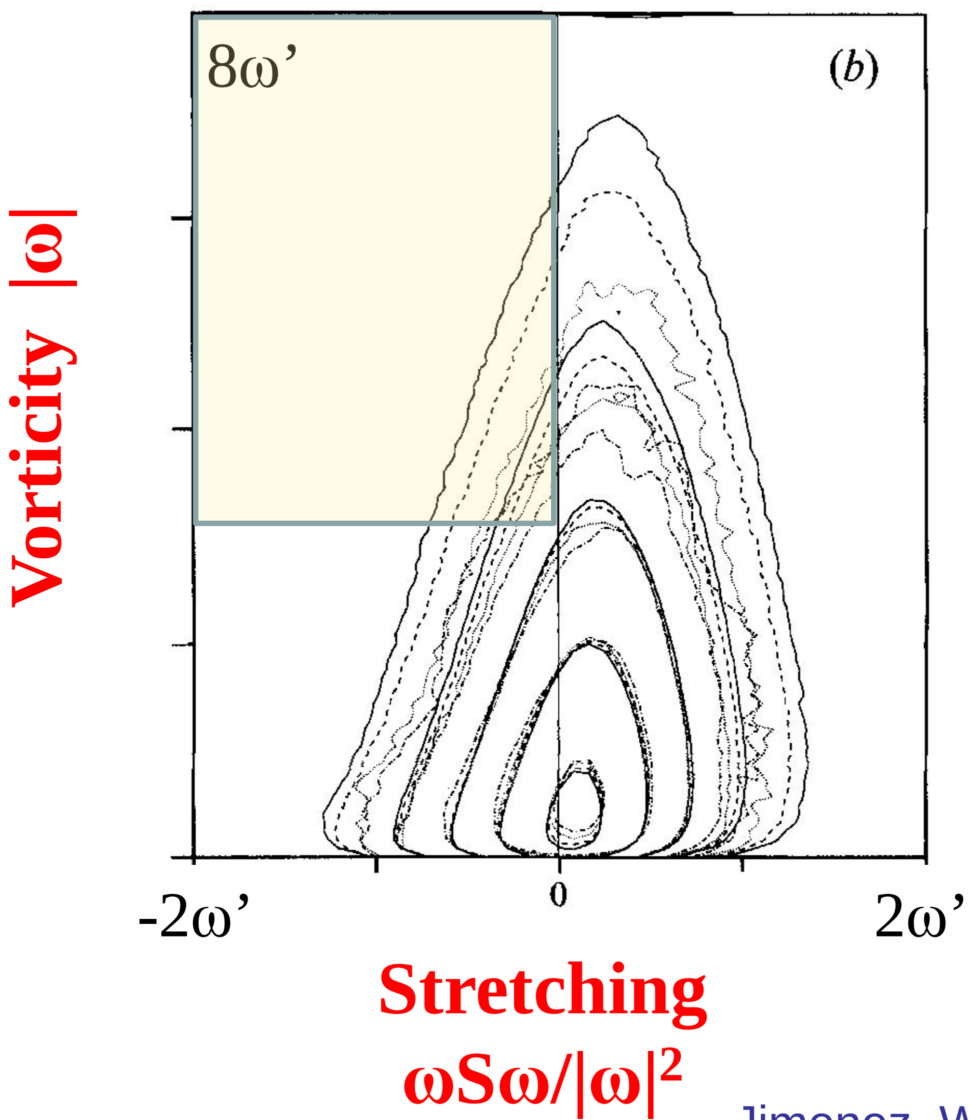


HSF: Re_λ=100

Cardesa et al., 2014

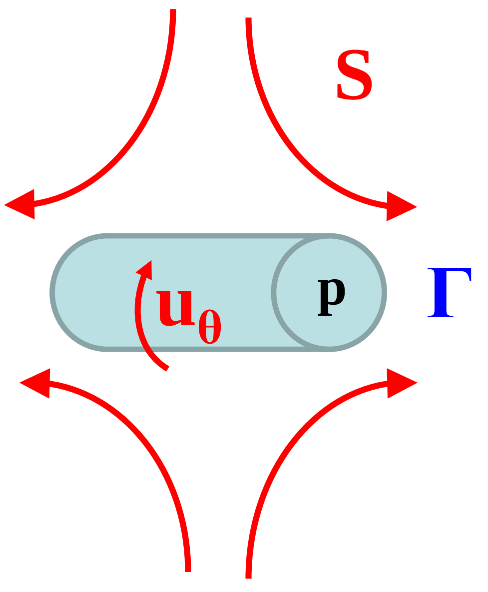
Stretching in turbulence

HIT, Re=60-200



Jimenez, Wray, Saffman, Rogallo (1993,98)

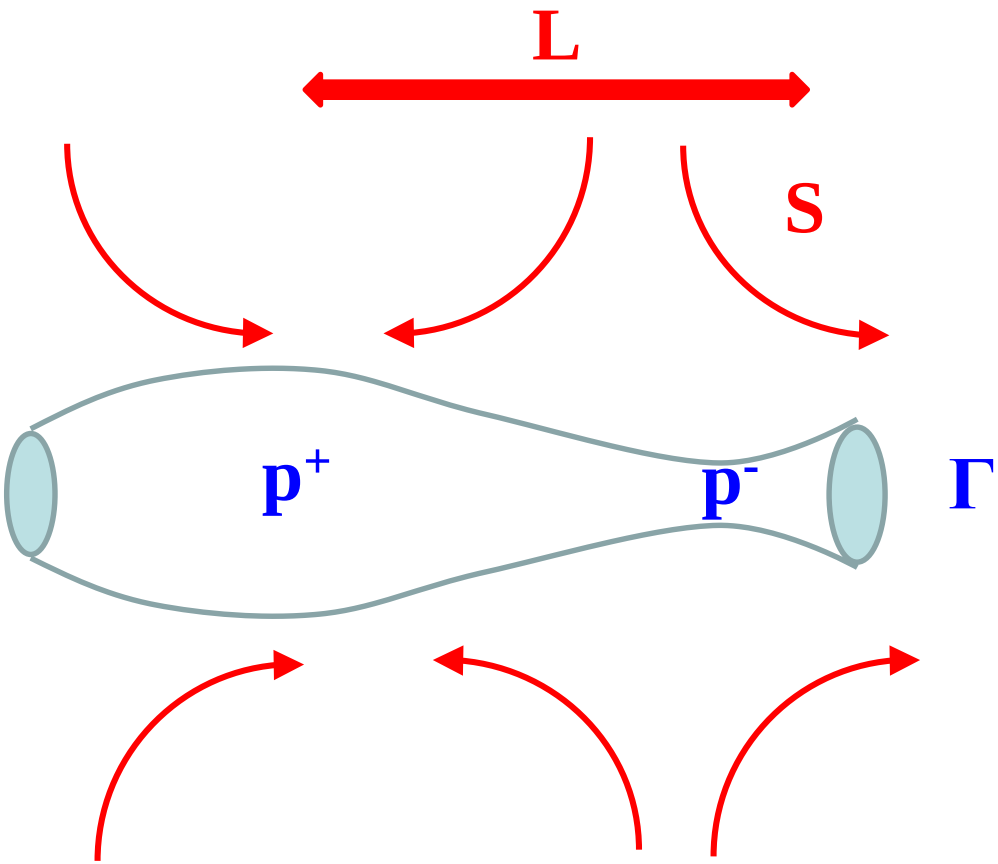
Stretching an infinite vortex



$$u_\theta = \Gamma \, (S/\nu)^{1/2}$$

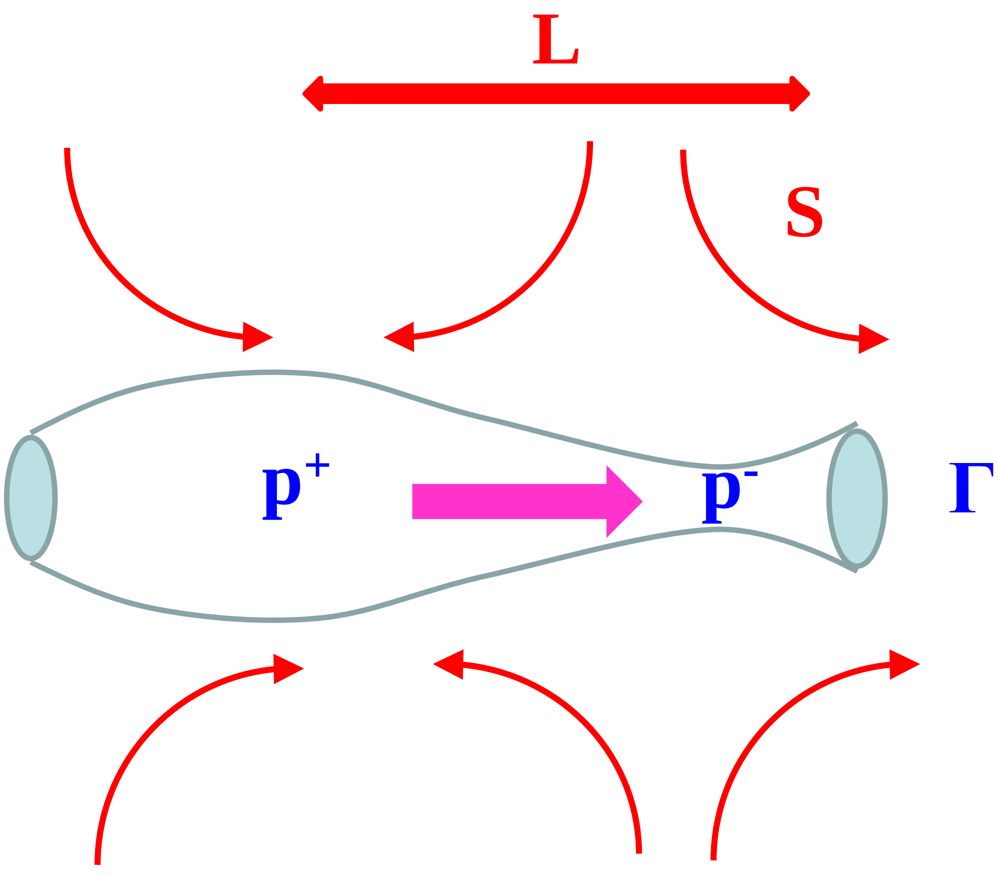
$$p \approx - u_\theta^2$$

Stretching an finite vortex



Verzicco, Jimenez, Orlandi (1995, 1999)

Stretching an finite vortex



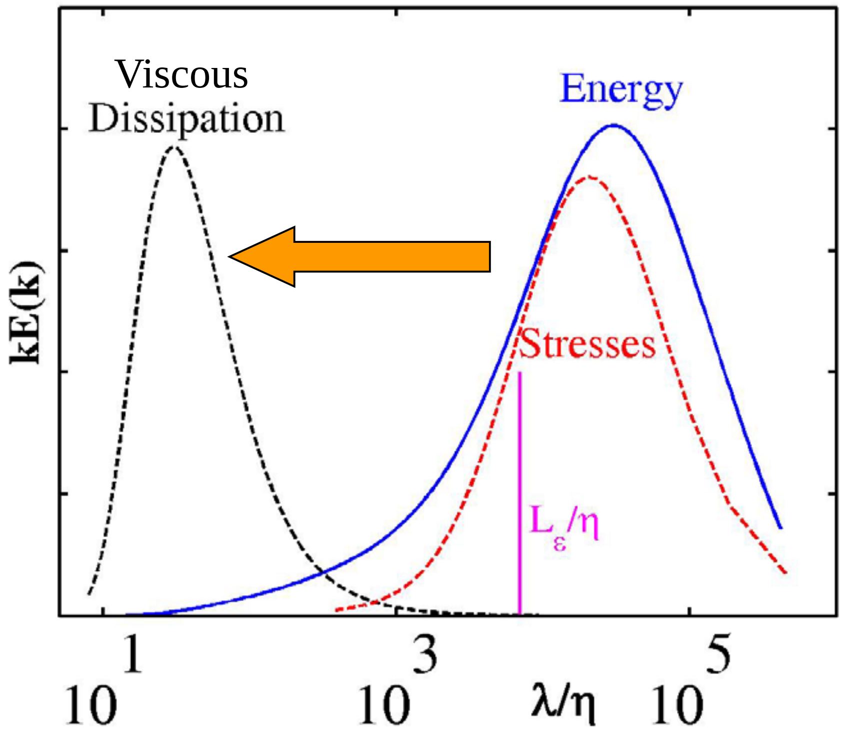
$u_\theta \approx SL$

$\Delta u_\theta \approx u'$?

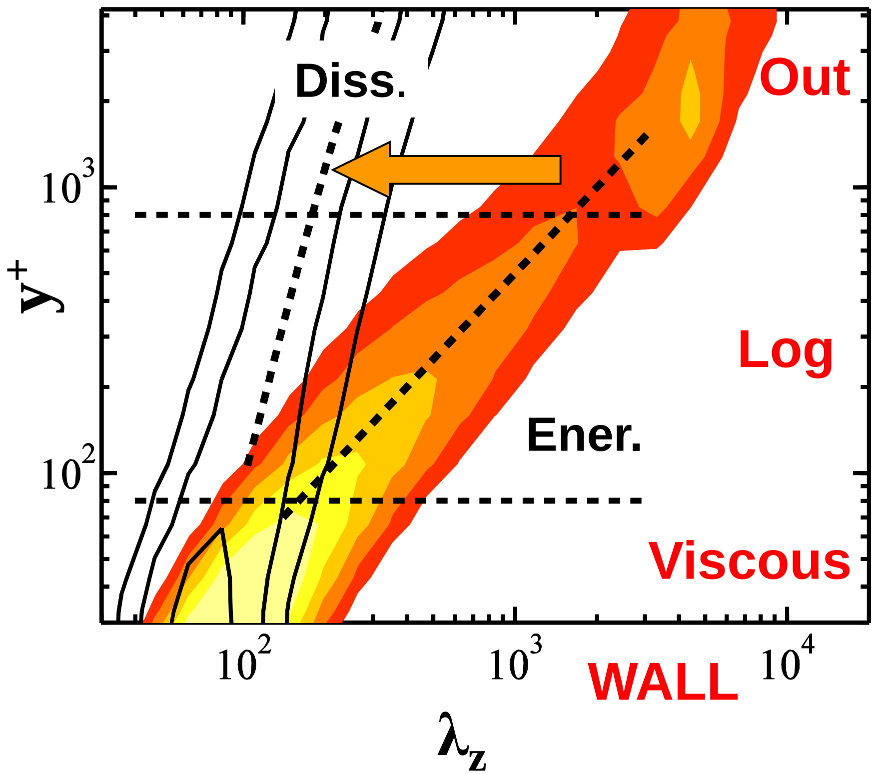
Verzicco, Jimenez, Orlandi (1995, 1999)

Wall-bounded Flows

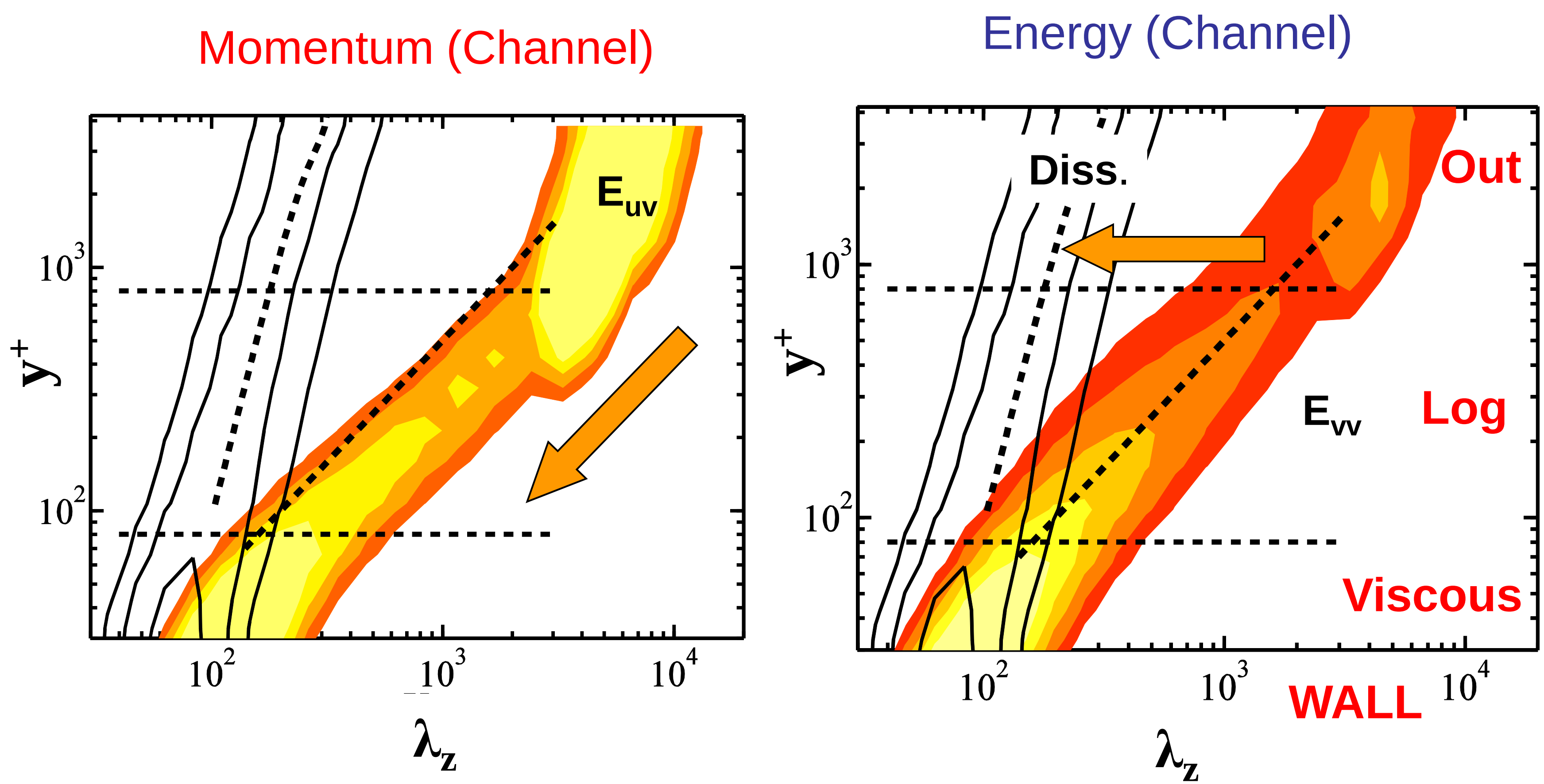
Homogeneous Turbulence



Wall Turbulence (Channel)



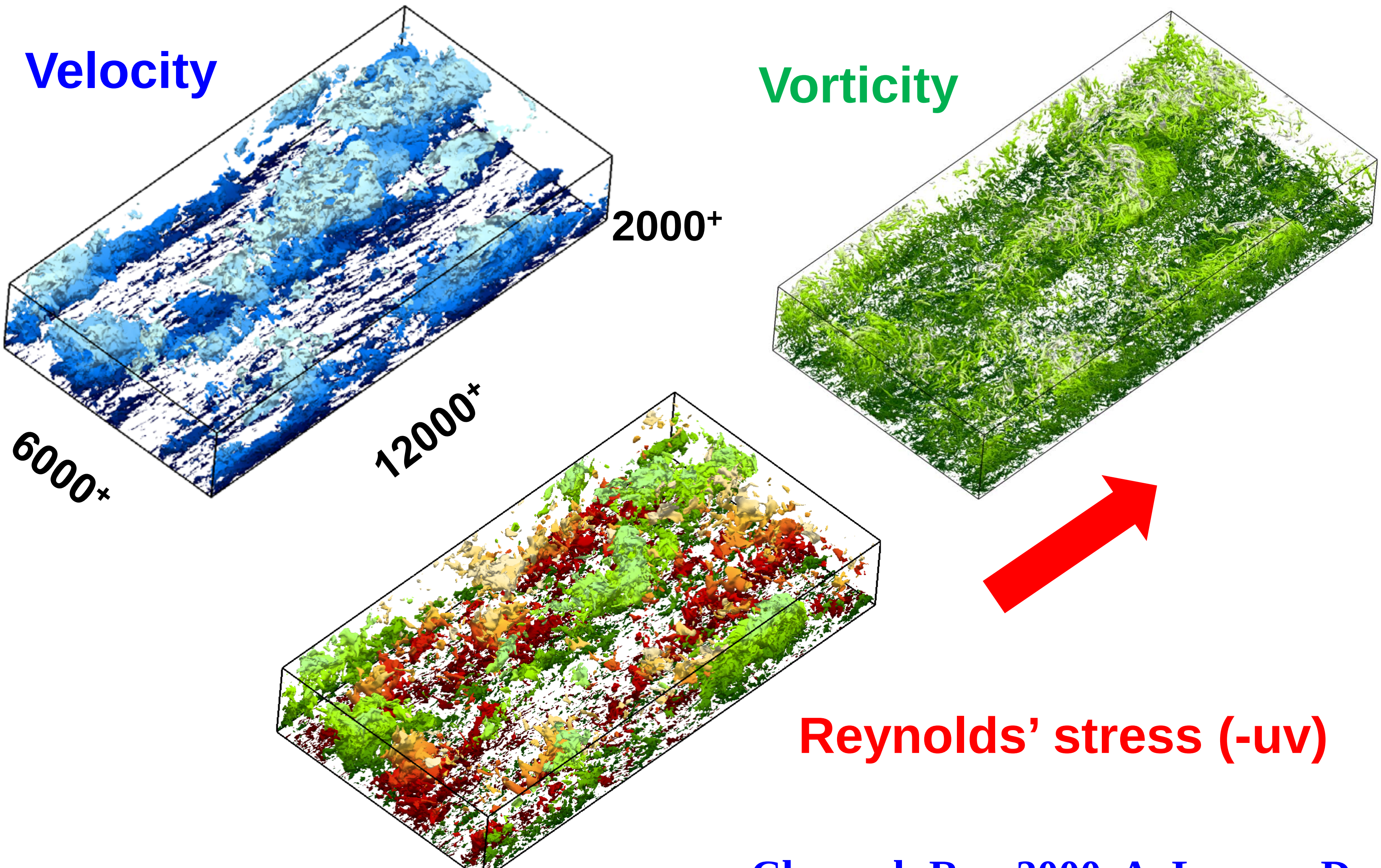
Momentum Flux Cascade



$$\partial_t U + \partial_x P = \partial_y \langle -uv \rangle + O(Re_\tau^{-1})$$

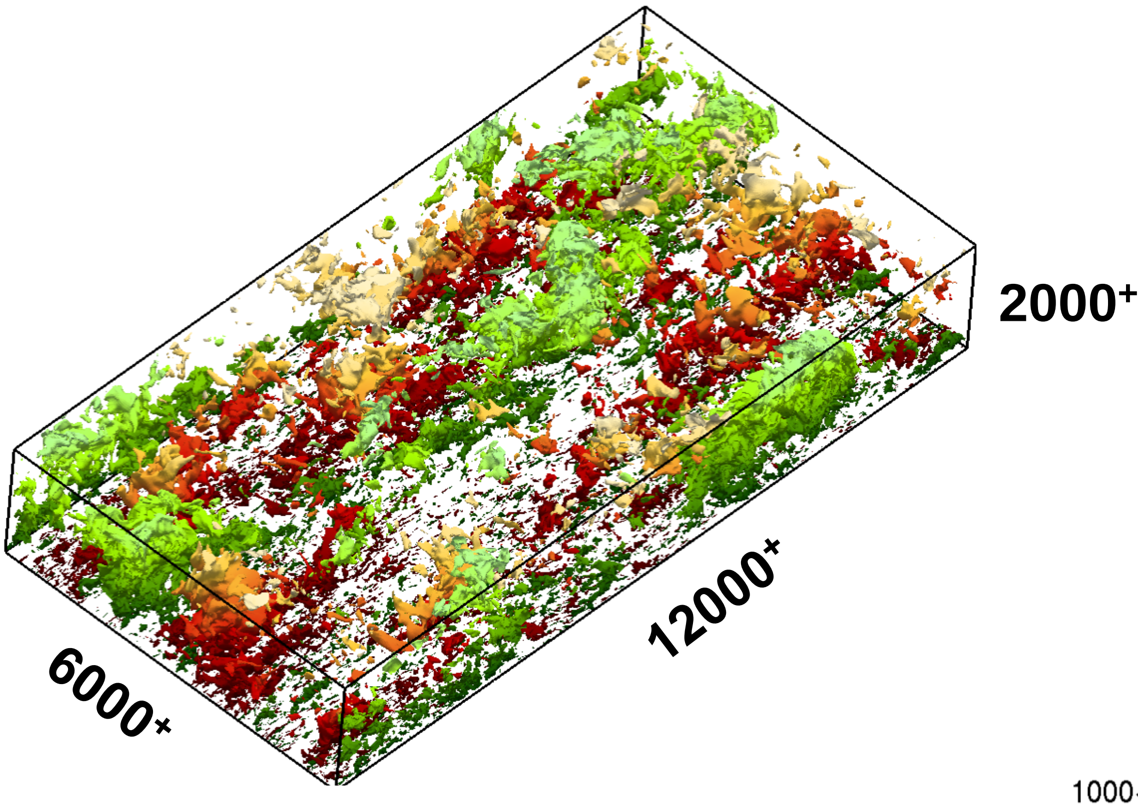
$$\tau = -uv$$ Momentum flux

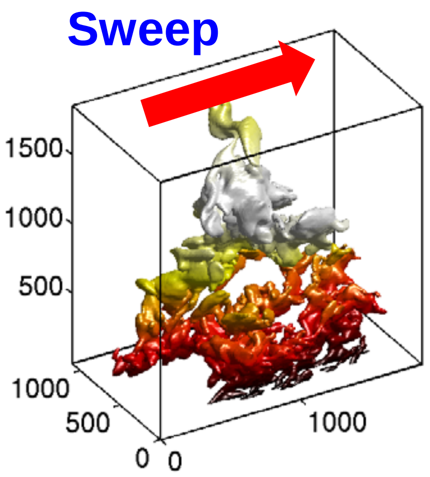
Flow fields of the Logarithmic layer

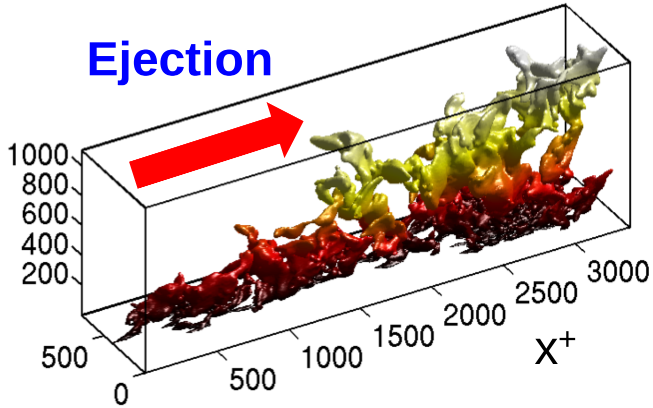


Channel: Re_τ=2000. A. Lozano-Durán

Momentum Structures of the Logarithmic layer





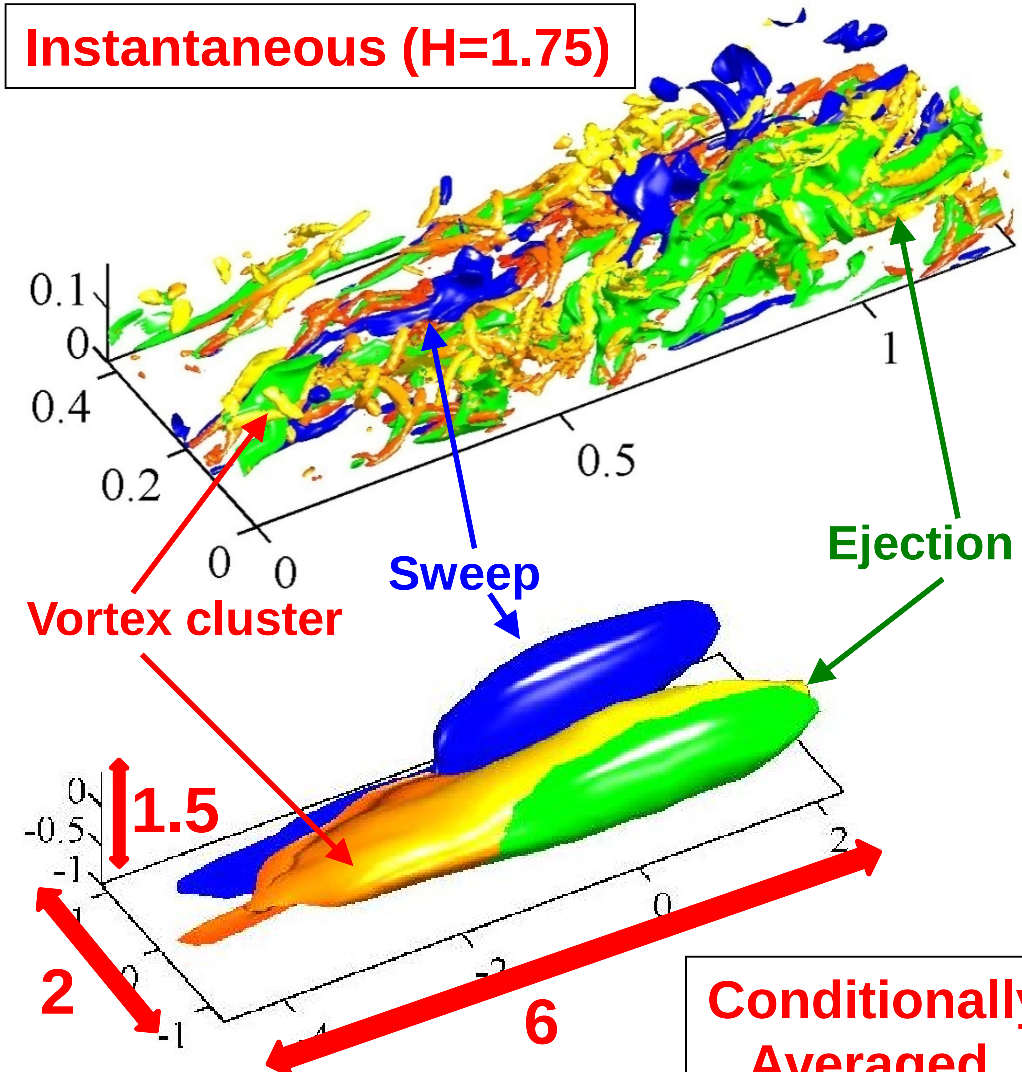


-uv > 1.75 u'v'

Channel: Re_τ=2000. A. Lozano-Durán

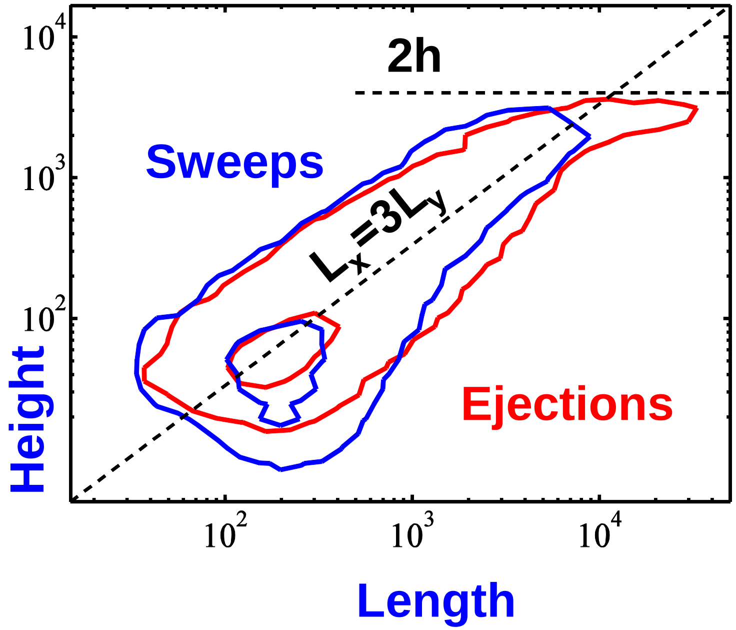
Attached Sweeps and Ejections

Instantaneous (H=1.75)



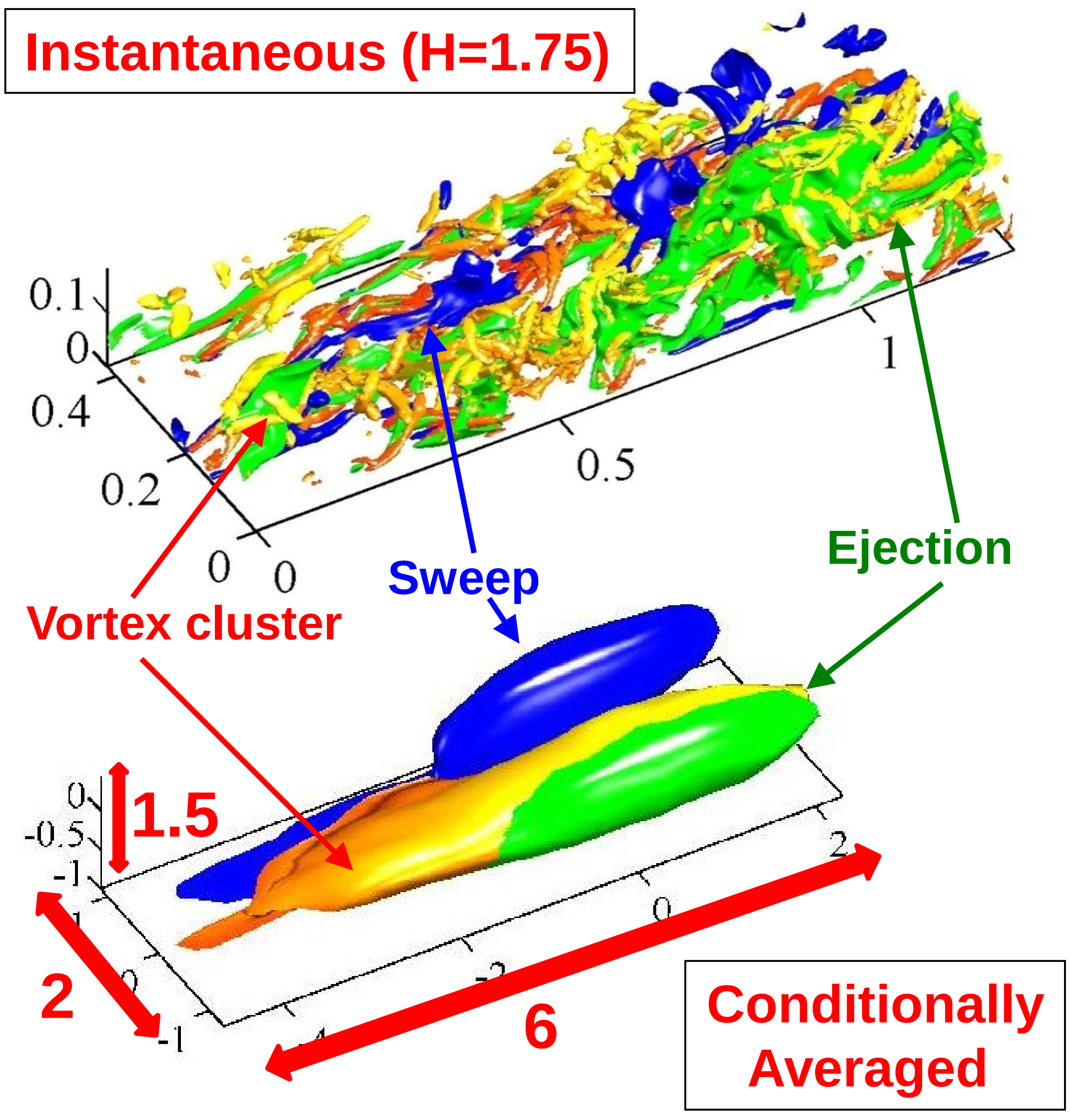
Conditionally Averaged

Momentum Transfer is self-similar

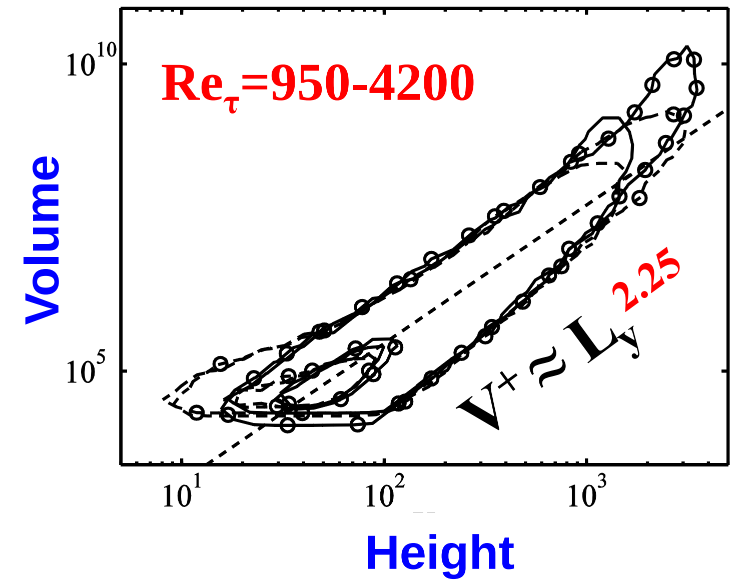


Lozano-Duran, Flores & J (2012)

Attached Sweeps and Ejections



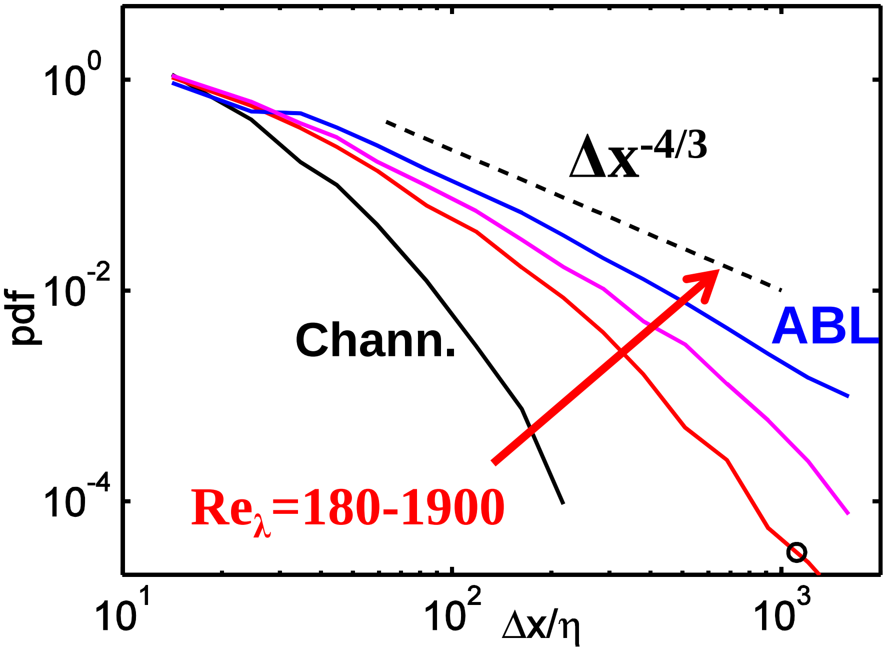
Momentum Transfer is Fractal



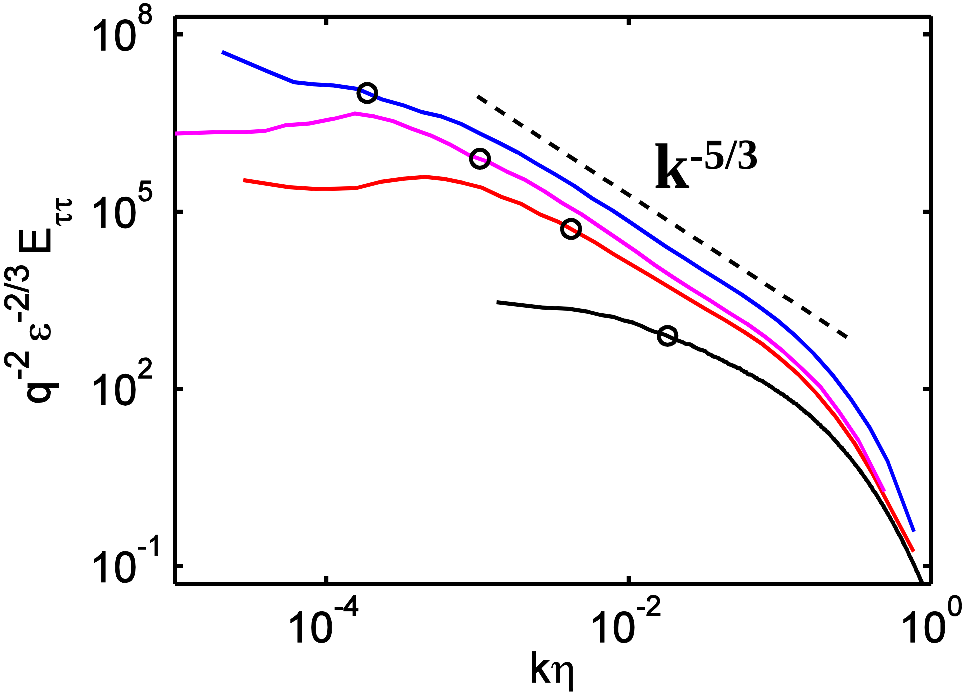
Lozano-Duran, Flores & J (2012)

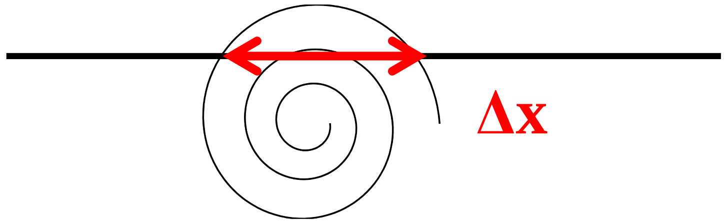
Momentum Transfer is "Universal"

Length of (uv)



Spectrum of (uv)

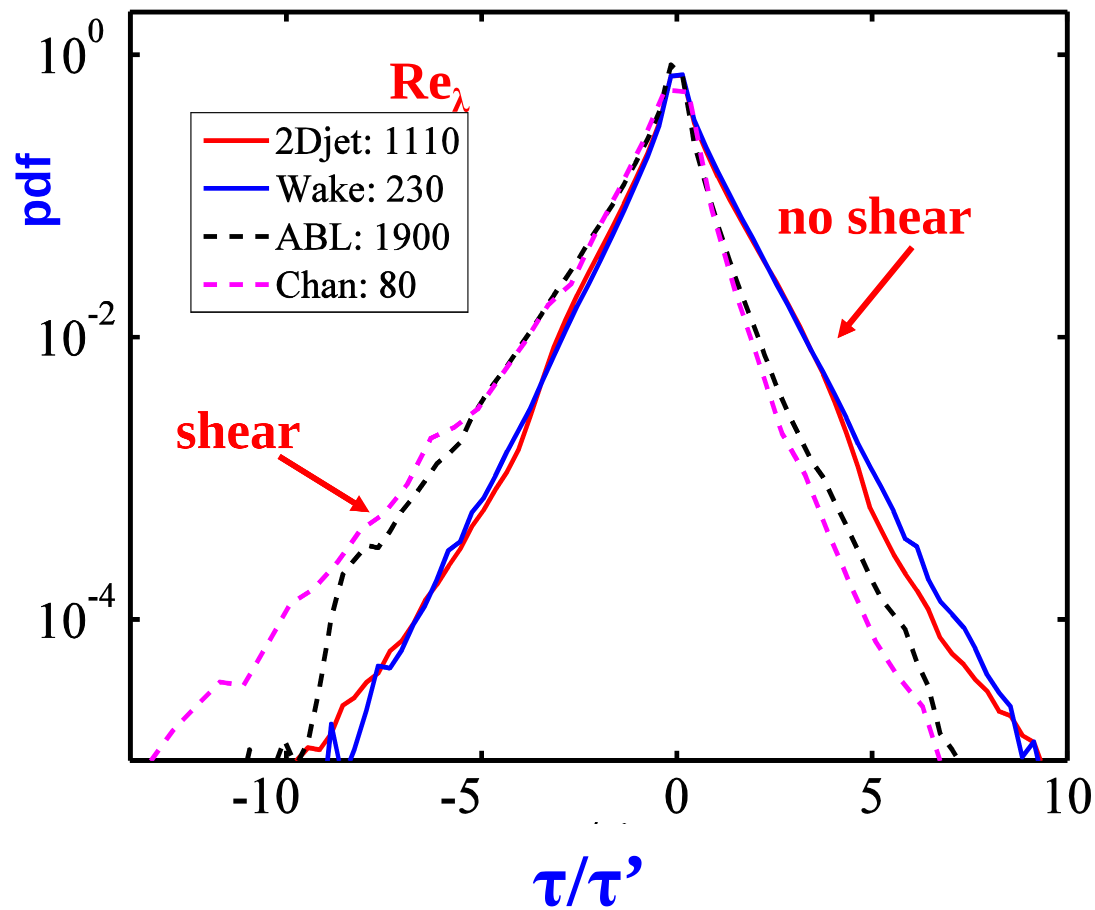




Lozano-Duran, Flores & J (2012)

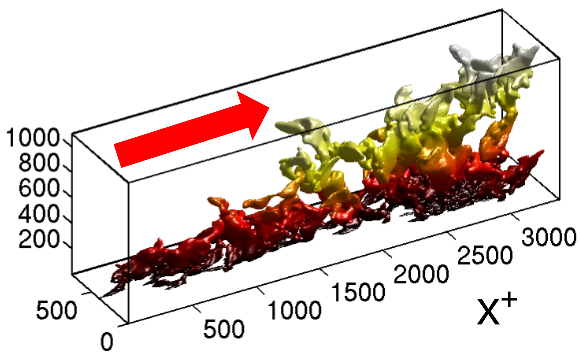
Sweeps and Ejections

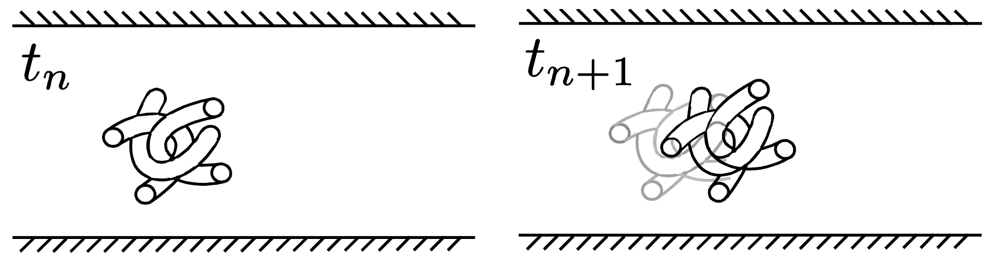
Momentum Transfer is NOT Intermittent

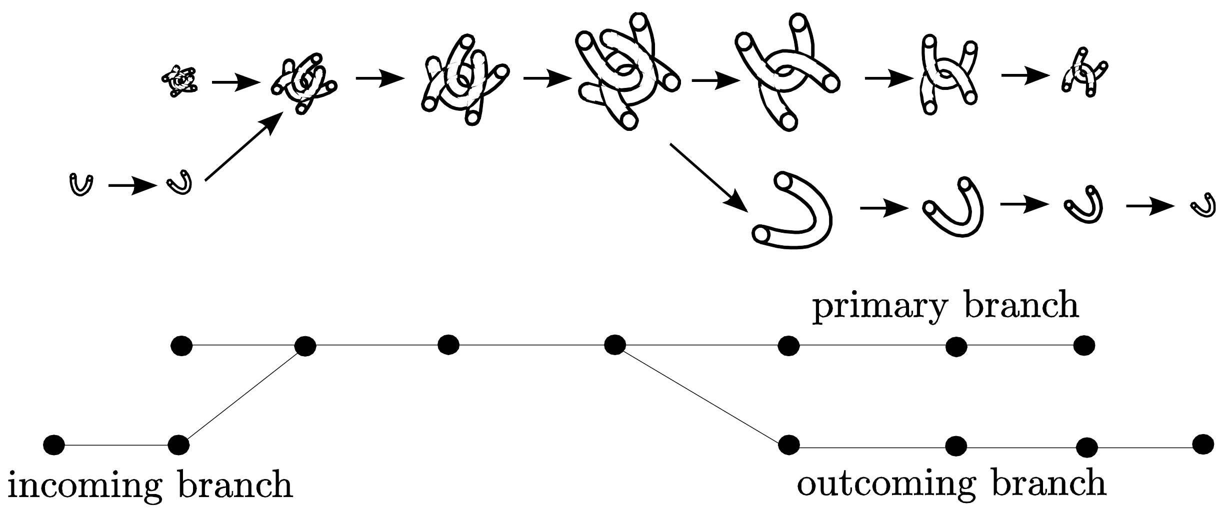


Data: R.A. Antonia

Tracking Eddies in Time

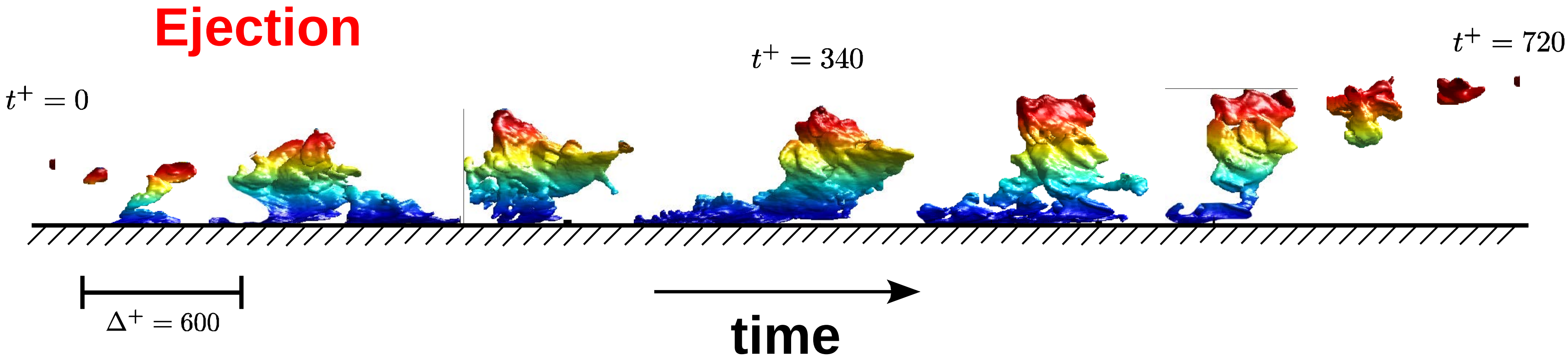


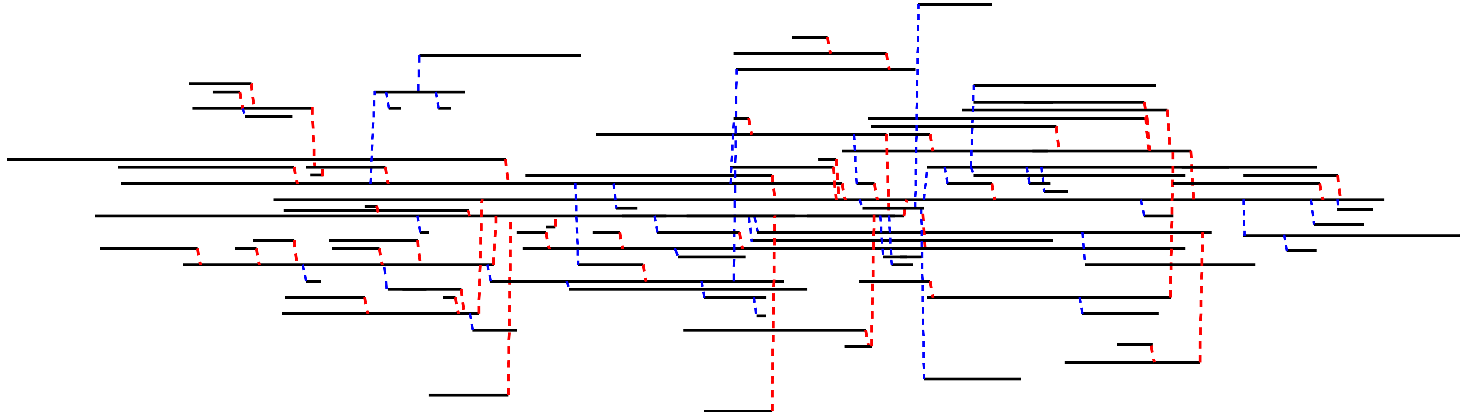




A. Lozano-Durán & J (2010)

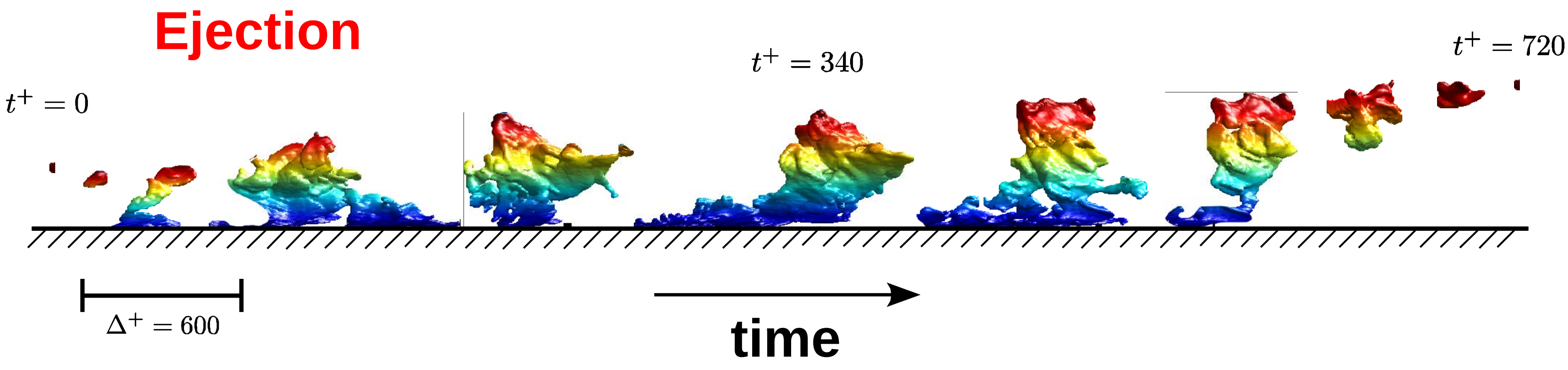
Tracking in Time

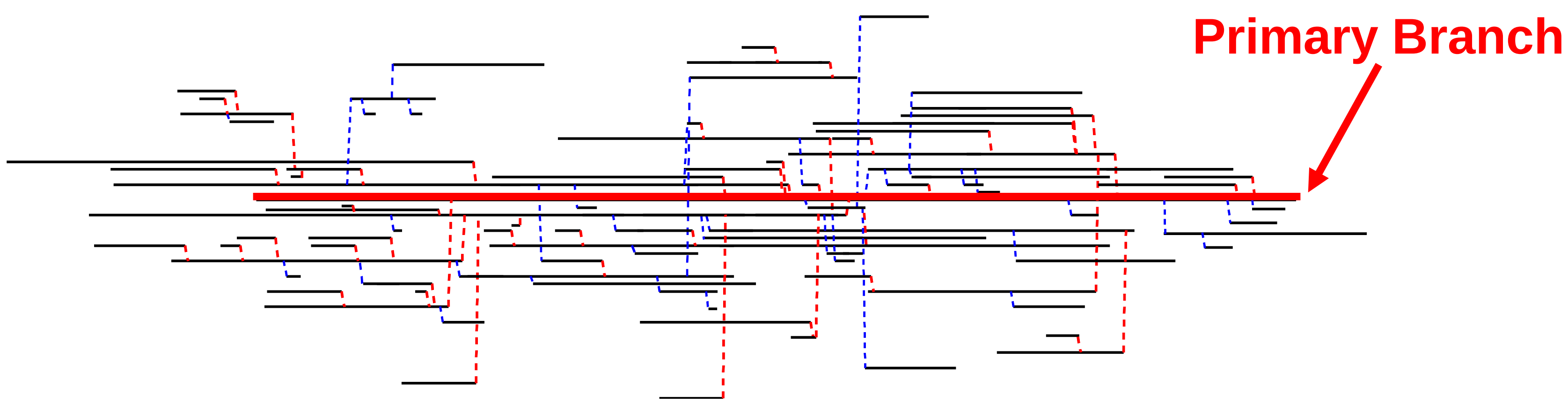




Channel: Re_τ=4200. A. Lozano-Durán

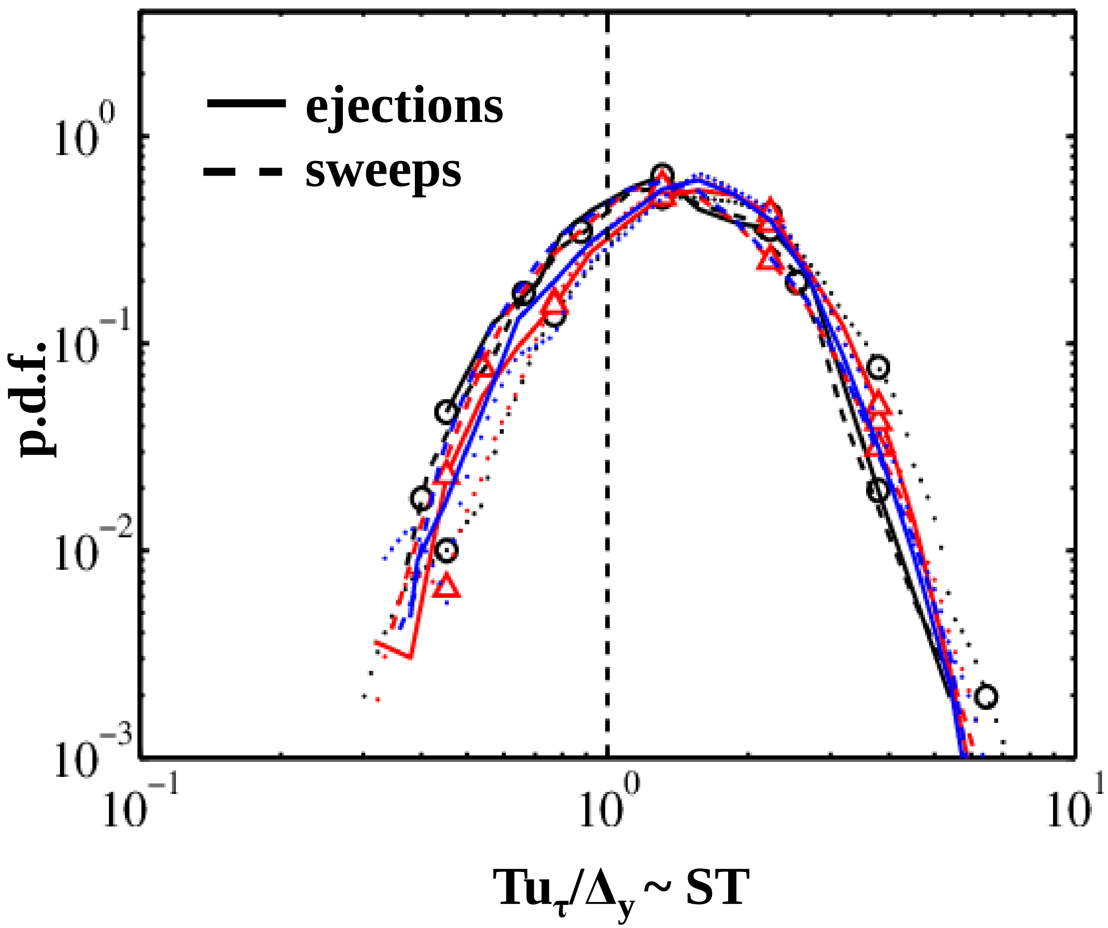
Tracking in Time

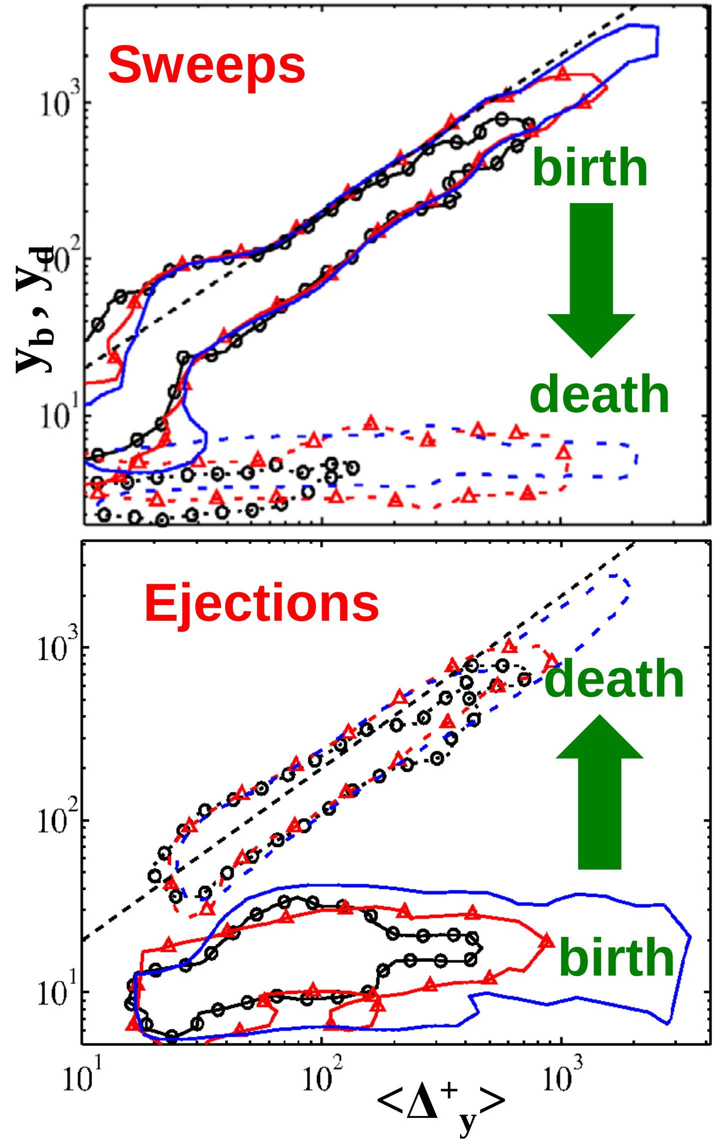




Channel: Re_τ=4200. A. Lozano-Durán

Lifetimes: Attached Sweeps and Ejections

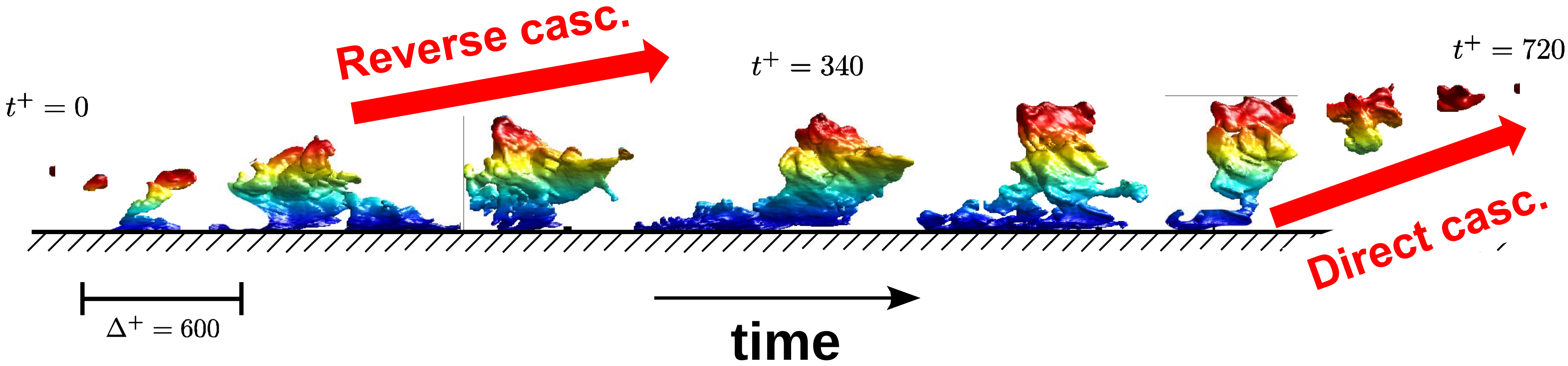


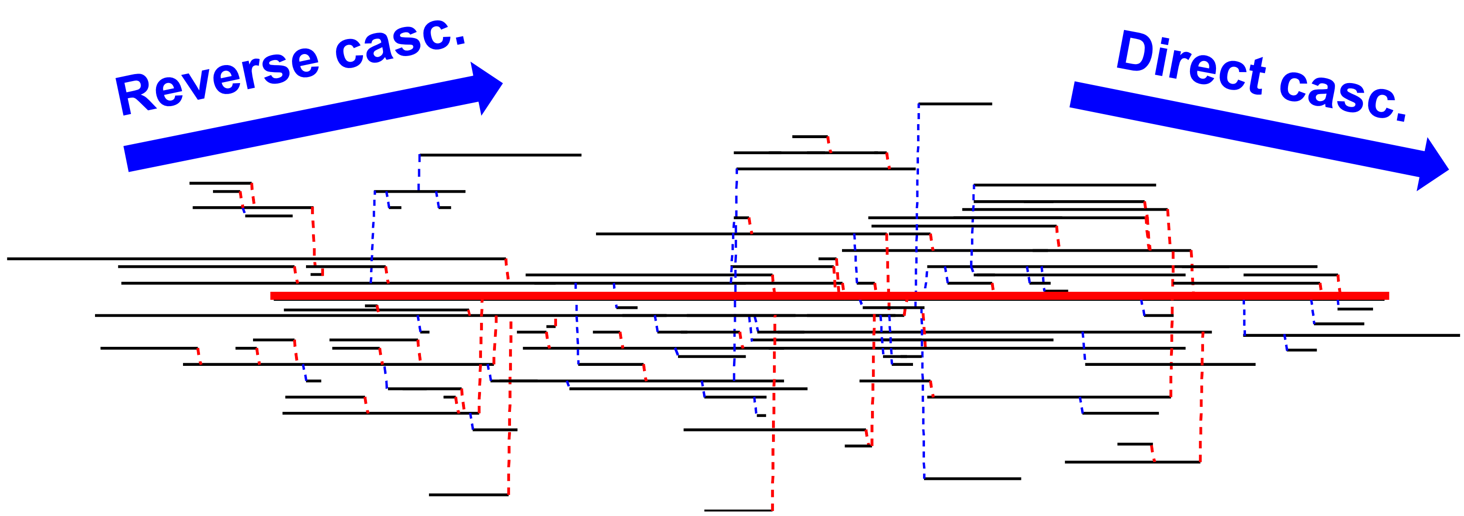


Channels: Re$_\tau$ = 950-4200

Lozano-Durán & J (2014)

Scale Change in Time

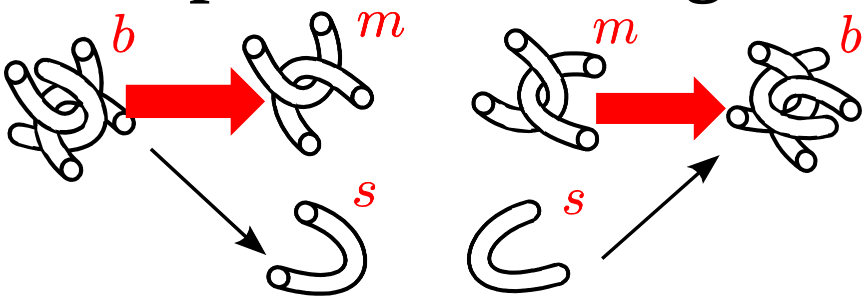




Channel: Re_τ=4200. A. Lozano-Durán

Splits and Mergers

Split **Merger**



$$V_b \approx V_m + V_s$$

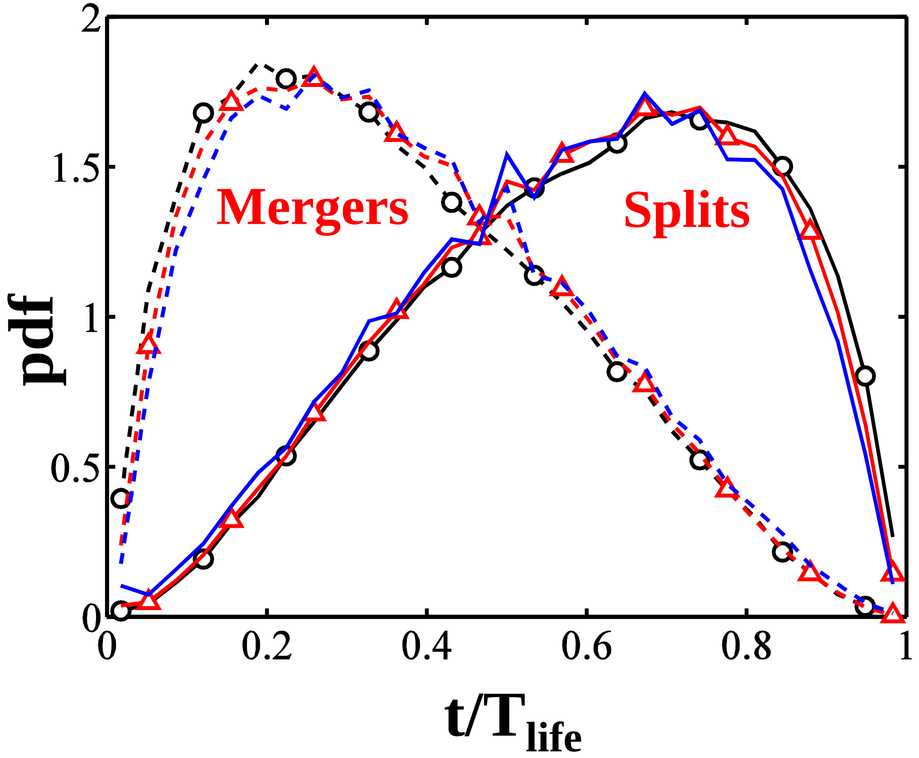
$$\Delta V_{BRANCH} = \Sigma\, |\Delta V| \approx \Sigma\, V_s$$

Δ_y/η	Inertial $\Delta_s > 100\eta$	Viscous $\Delta_s < 100\eta$	Smooth Growth
0-50	0%	23%	77%
50-200	28%	23%	49%
200-400	54%	8%	38%
>400	94%	5%	1%

$Re_\tau = 4200$; "detached"

Lozano-Durán & J (2014)

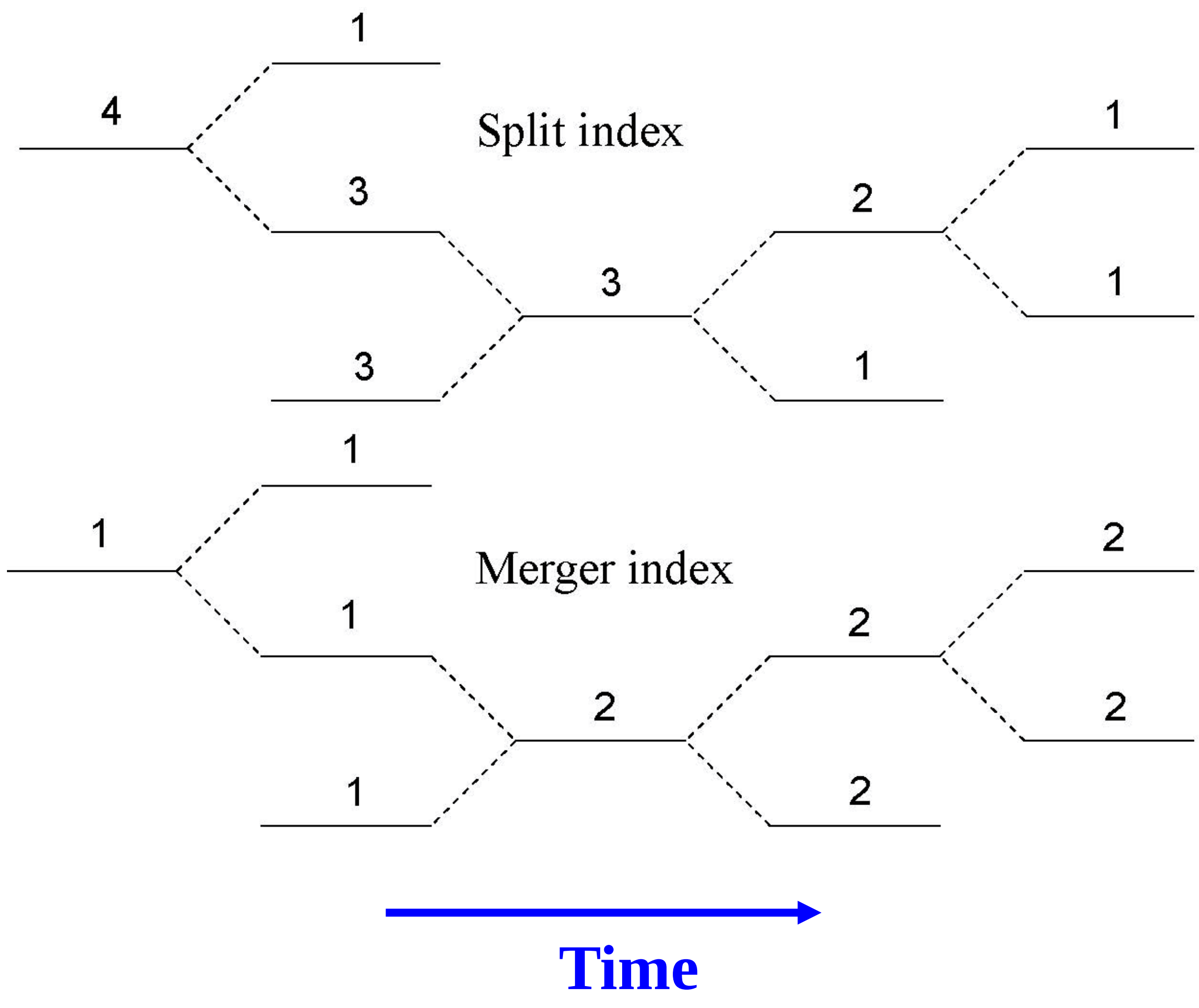
Growth and Decay



Re_τ= 950-4200

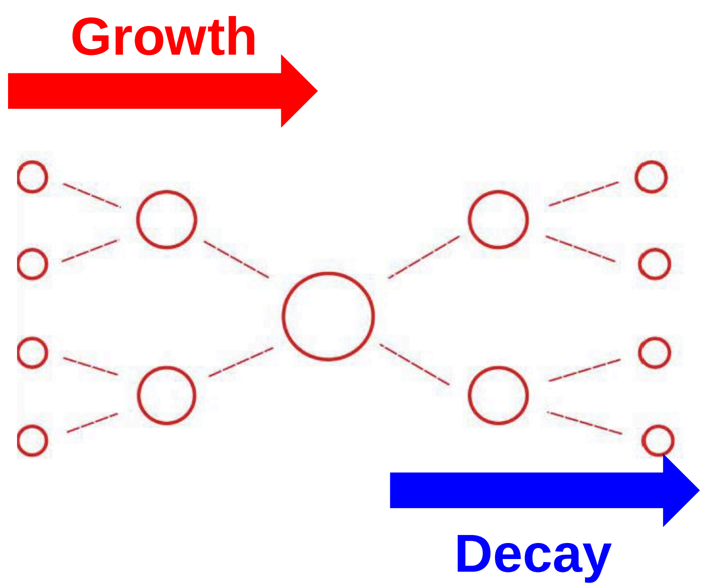
Lozano-Durán & J (2014)

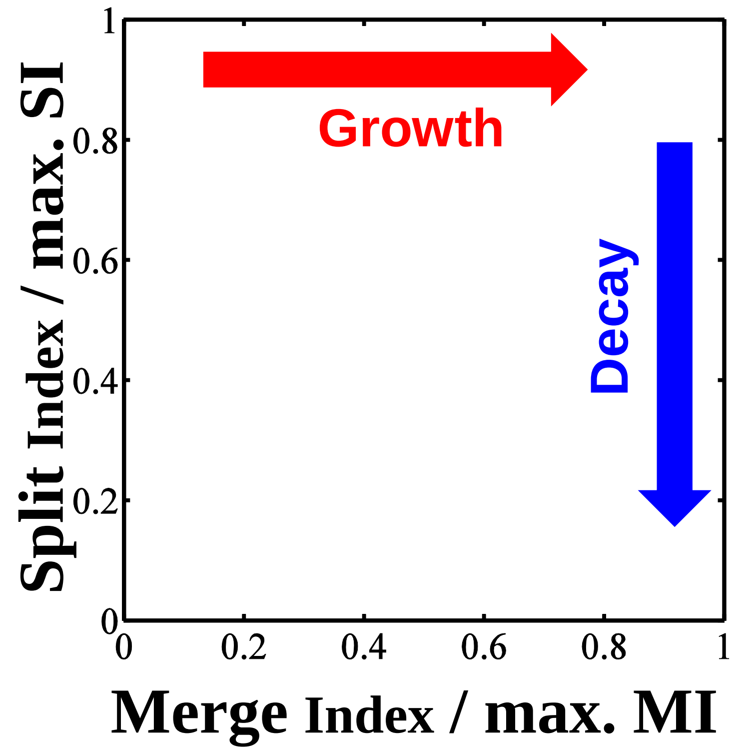
Merger and Split Indices



Huertas-Cerdeira & J (2014)

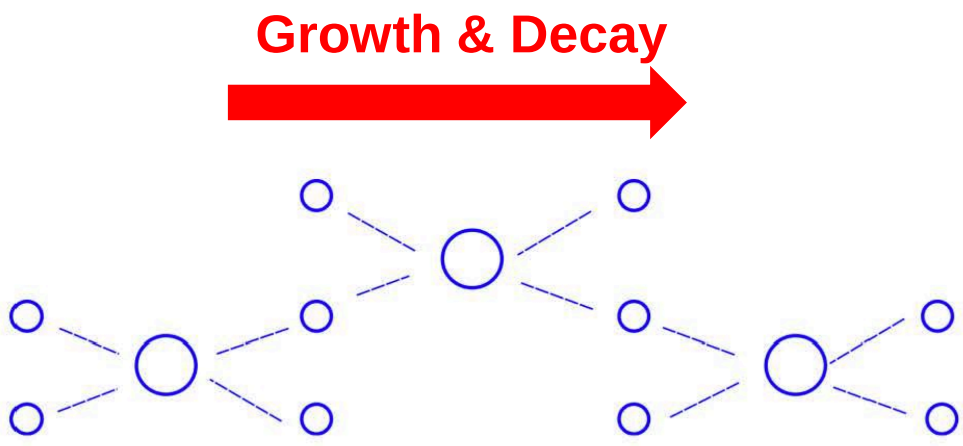
Growth and Decay (the theory)

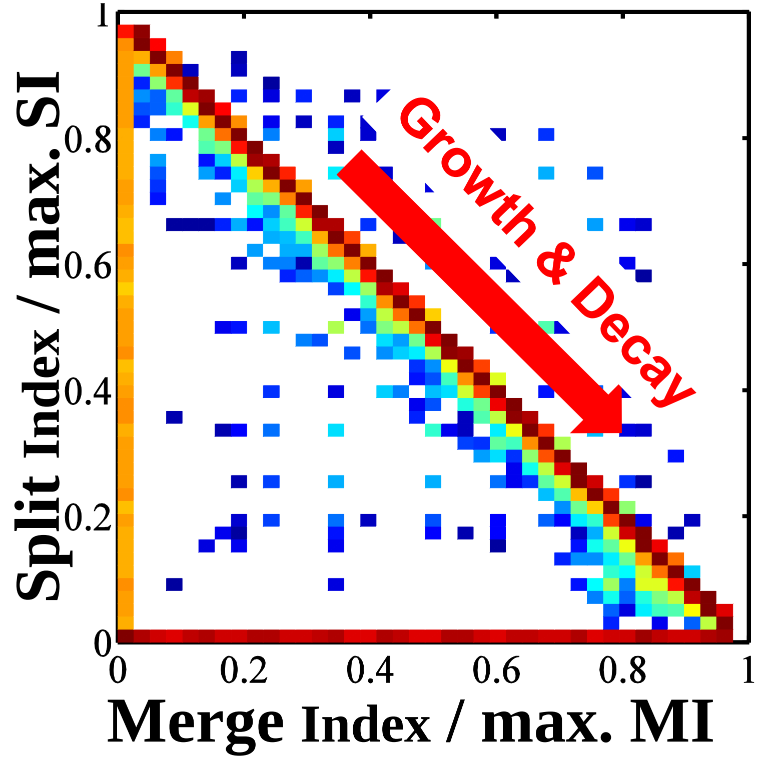




Huertas-Cerdeira & J (2014)

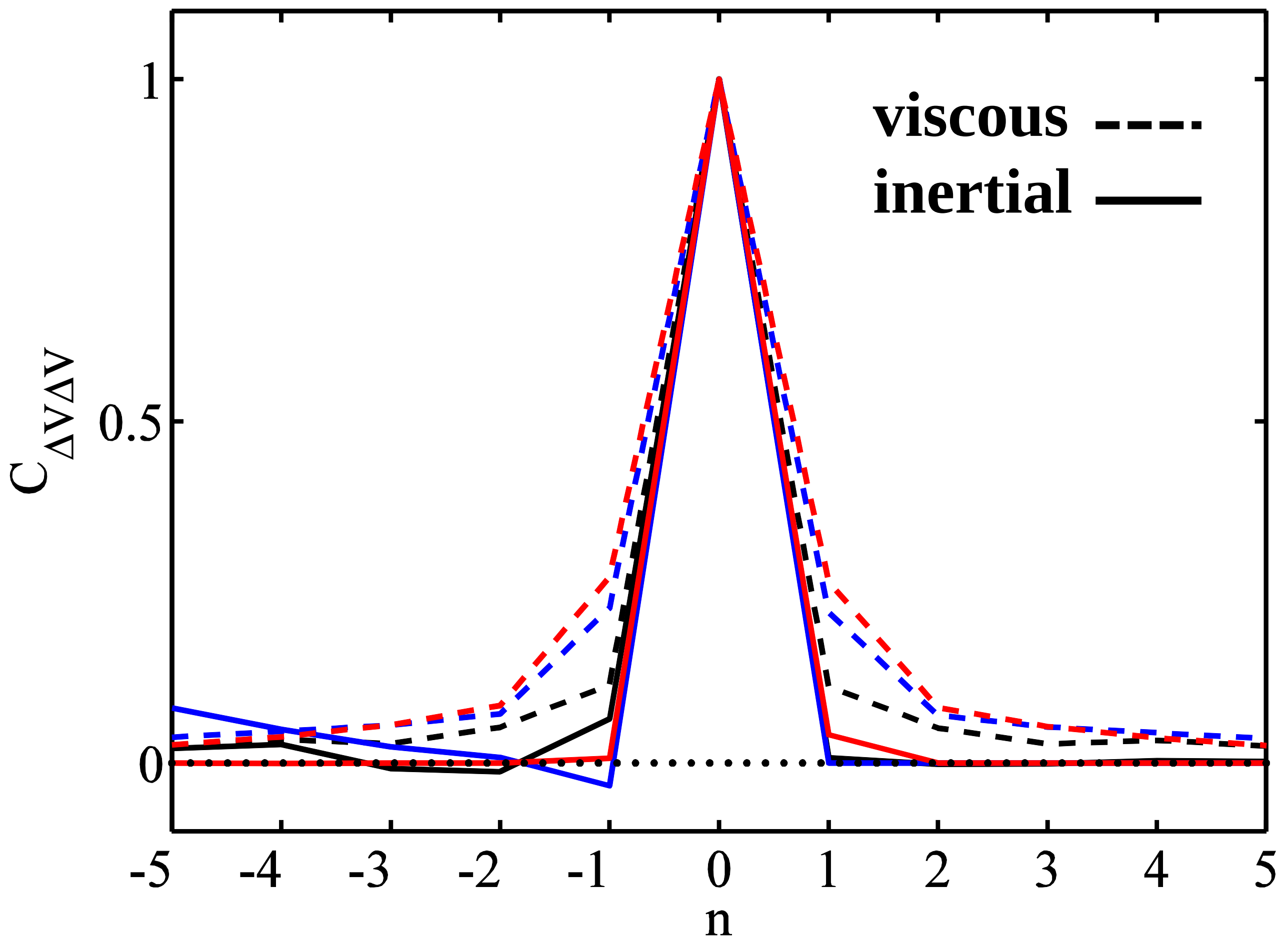
Growth and Decay (the data)





Huertas-Cerdeira & J (2014)

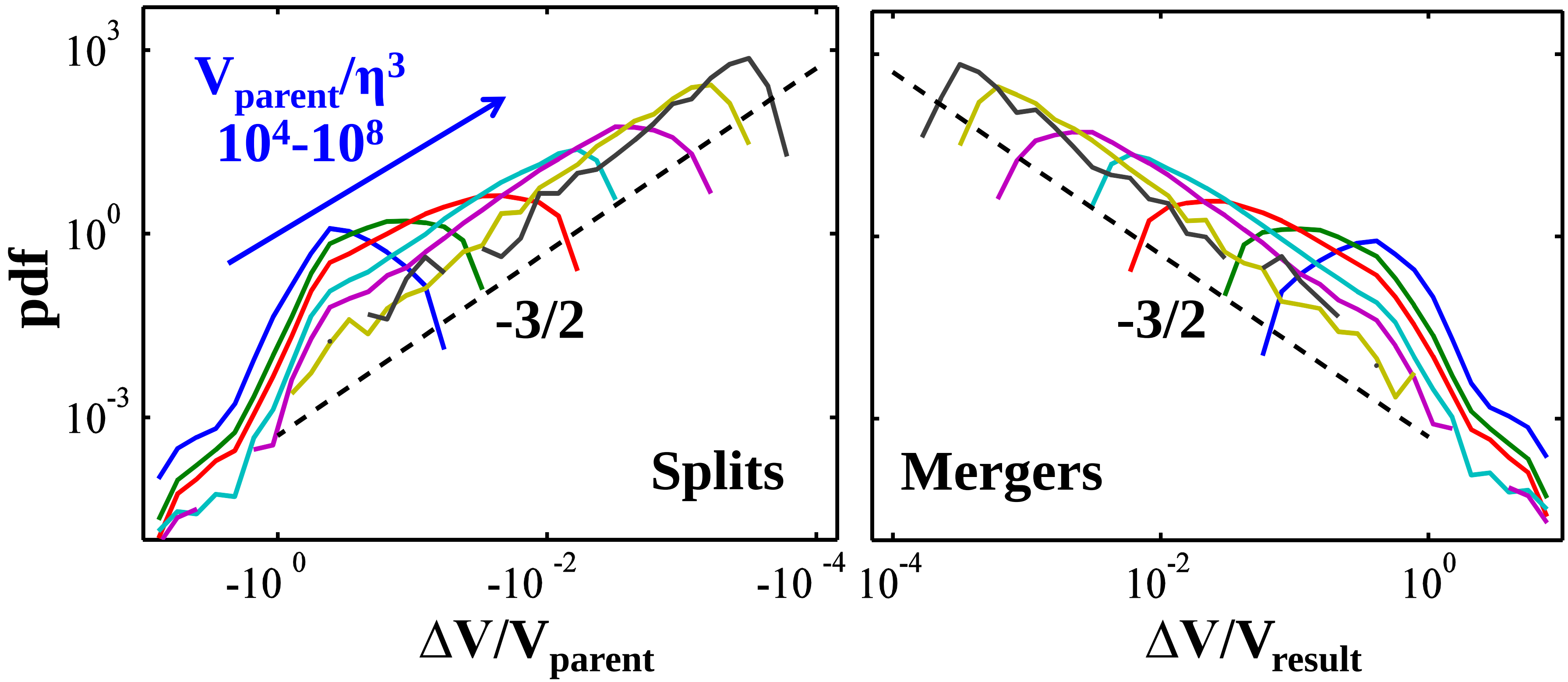
Mergers and Splits are Markovian



Re_τ= 950-4200; “detached”

Lozano-Durán & J (2014)

Relative Volume Increments

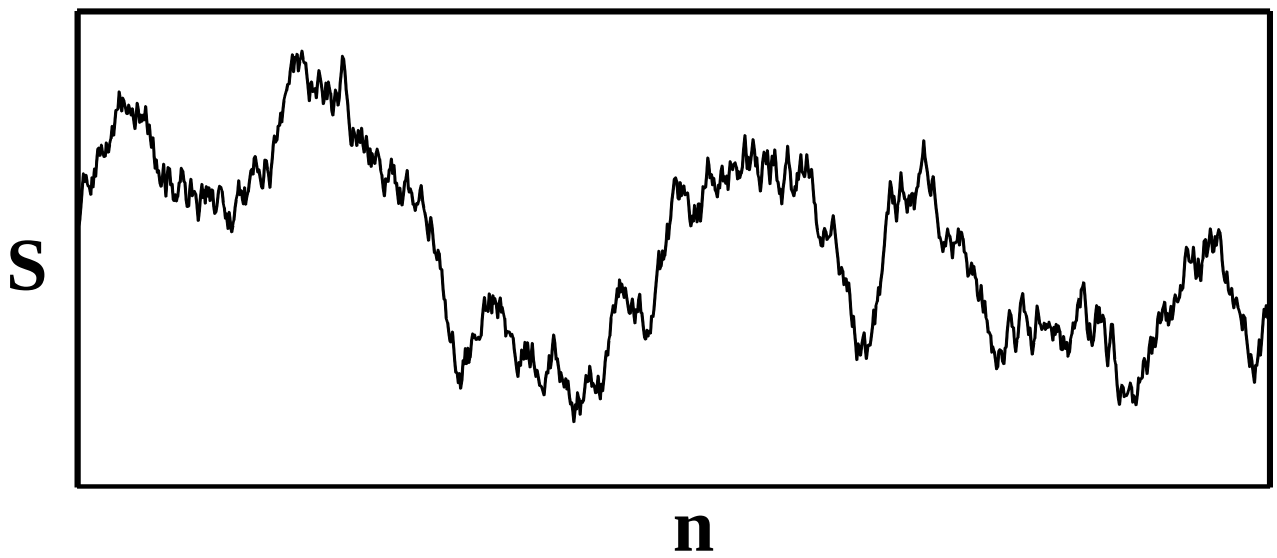


Re_τ= 4200; "detached"

Lozano-Durán & J (2014)

A fair coin toss
(martingale)

$$S_n = S_{n-1} \pm 1\$$$

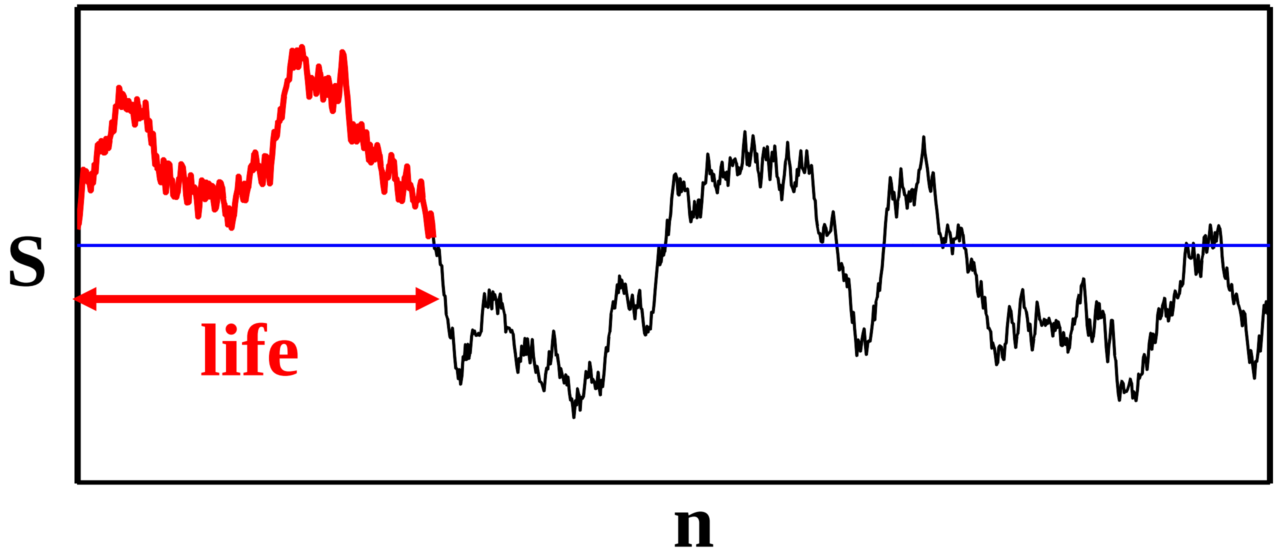


Lozano-Durán & J (2014)

A fair coin toss

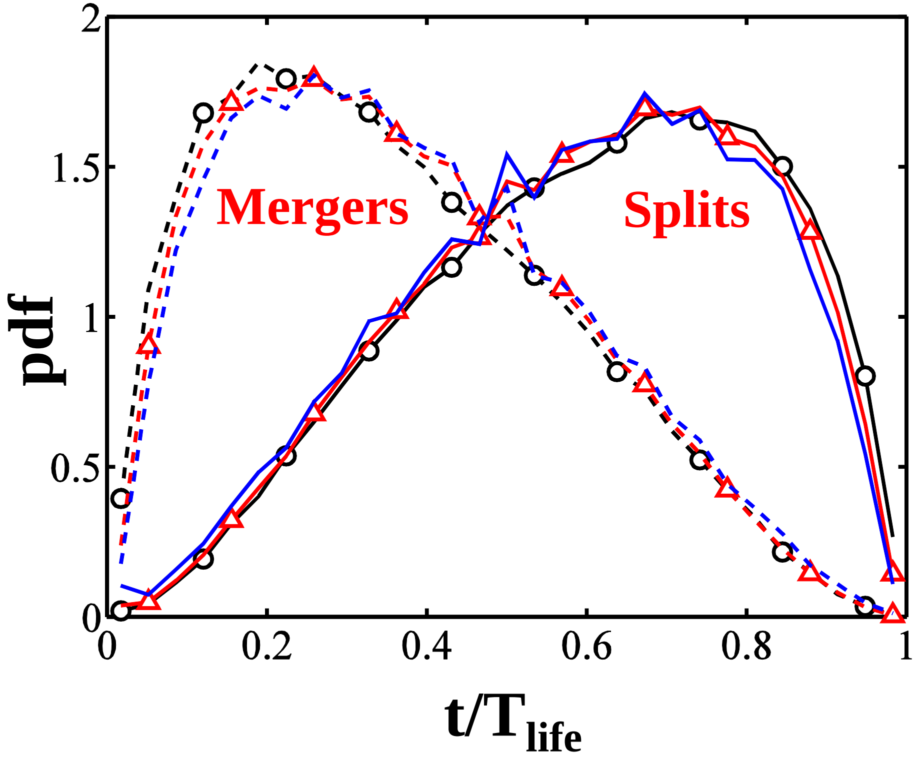
(martingale with ruin)

$$S_n = S_{n-1} \pm 1\$$$

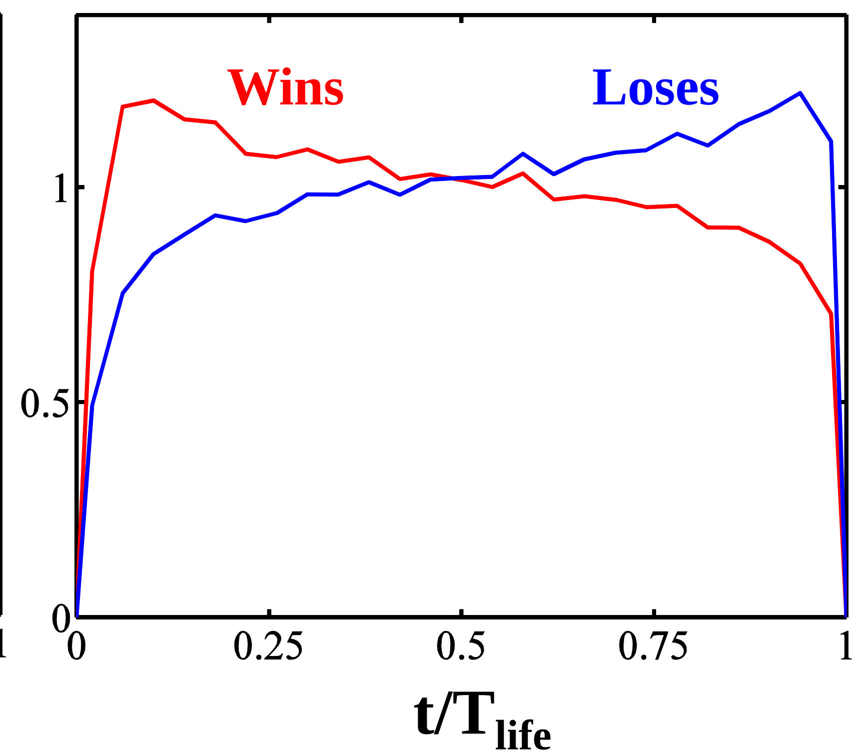


Lozano-Durán & J (2014)

Growth and Decay



Channel



Martingale

Lozano-Durán & J (2014)

Martingales with ruin

Additive: $S_{n+1} = S_n + r_n$

$$S_{max} \sim N_{max}^{1/2}$$

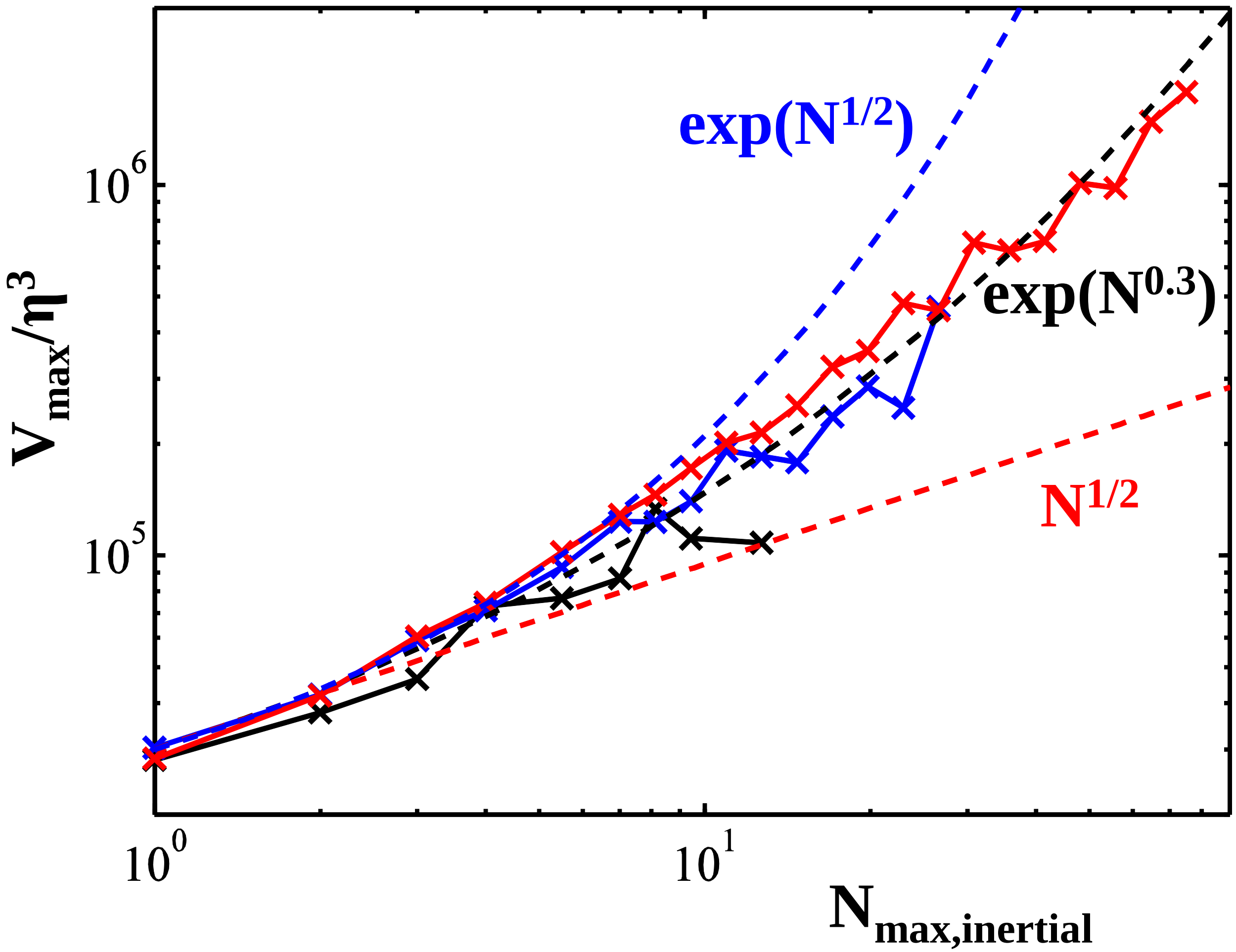
Multiplicative: $S_{n+1} = S_n * r_n$

$$\log(S_{n+1}) = \log(S_n) + \log(r_n)$$

$$S_{max} \sim \exp(N_{max}^{1/2})$$

Lozano-Durán & J (2014)

Volume versus Life



Re_τ= 950-4200; “inertial”

Lozano-Durán & J (2014)

Summary

- There is a forward energy cascade that takes time
- It crosses the inertial range incrementally
- Its velocity is given by the local eddy turnover
- It is intermittent (or $u_{max} \approx u'$)
- The momentum flux in channels also cascades
- It is not intermittent
- It can be followed in individual eddies
- It "resembles" a martingale with ruin

Thank you

The Viscous Layer is Small

Channel (U): Re_τ = 2000, y^+=15