DE LA RECHERCHE À L'INDUSTRIE

Spatial Propagation of Turbulence & Formation of Mesoscopic Structures in Plasma Turbulence

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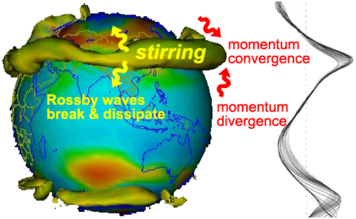
Status of our understanding w.r.t staircase formation
❺ how is it generated ?

A short detour on Earth [atmospheric jets, ocean currents]: [McIntyre '11]

- single field "$\mathcal{PV}$" $[\equiv \nabla^2\phi]$ system invariant satisfies: $\frac{\mathrm{d}\mathcal{PV}}{\mathrm{d}t} = \text{forcing} + \text{dissipation}$
  - ↳ $\mathcal{PV}$ expresses the advective nonlinearity
  - ↳ evolution of the $\mathcal{PV}$ field captures everything about the advective nonlinearity (!)
- single time derivative: one-way only propagating wave
  - ↳ rotating earth: westwardly propagating Rossby waves of atmosphere–ocean dynamics
  - ↳ horizontally stratified atmosphere: mixing of PV along stratification surfaces
- Taylor identity: $\langle \tilde{v}\widetilde{\mathcal{PV}}\rangle = -\frac{\partial\langle\tilde{u}\tilde{v}\rangle}{\partial y}$ [Taylor '15, Bretherton '66, Dickinson '69]
  - ↳ flux of $\mathcal{PV}$ linked to (pseudo)momentum carried by the Rossby waves $\mathcal{P}$: $\langle \tilde{v}\widetilde{\mathcal{PV}}\rangle = \frac{\partial \mathcal{P}}{\partial t}$
  - ↳ one-wayness of Rossby waves sets sign of $\mathcal{P}$:

> *« the central result that a rapidly rotating flow, when stirred in a localised region, will converge angular momentum into this region »* [Held '01]



  - ↳ strongly nonlinear, jet self-sharpening
  - ↳ jets seen as "Rossby waveguides"

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  - ↳ $\mathcal{PV}$ expresses the advective nonlinearity — $\mathcal{PV} \equiv \nabla^2\phi$ in H–W ; f in GK
  - ↳ evolution of the $\mathcal{PV}$ field captures everything about the advective nonlinearity (!)
- single time derivative: one-way only propagating wave — drift-wave
  - ↳ rotating earth: westwardly propagating Rossby waves of atmosphere–ocean dynamics
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  - ↳ flux of $\mathcal{PV}$ linked to (pseudo)momentum carried by the Rossby waves $\mathcal{P}$: $\langle \tilde{v}\widetilde{\mathcal{PV}} \rangle = \frac{\partial\mathcal{P}}{\partial t}$
  - ↳ one PV flux ↔ RS [Diamond '11] of $\mathcal{P}$:

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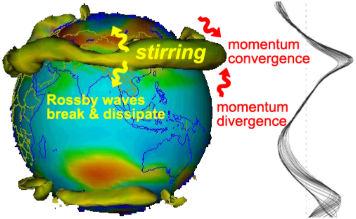

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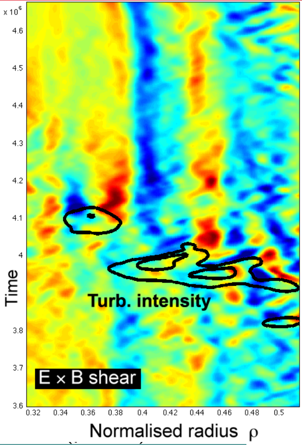

A short detour on Ea… …rents]: [McIntyre '11]

- single field "$\mathcal{PV}$" … …isfies: $\frac{d\mathcal{PV}}{dt}$ = forcing + dissipation
  - ↳ $\mathcal{PV}$ expresses … $\mathcal{PV} \equiv \nabla^2\phi$ in H–W ; f in GK
  - ↳ evolution of t… …about the advective nonlinearity (!)
- single time derivat… …vave drift-wave
  - ↳ rotating earth… …/ waves of atmosphere–ocean dynamics
  - ↳ horizontally st… …PV along stratification surfaces
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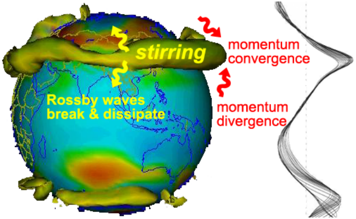
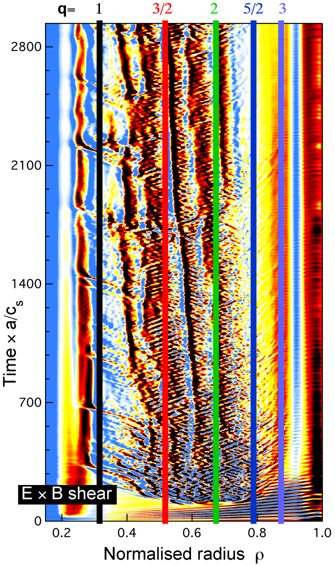
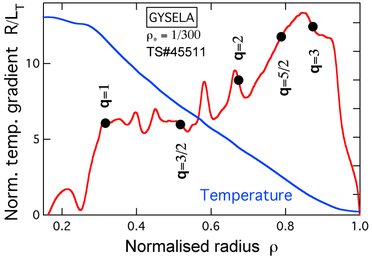
  - ↳ stro… connection to stirring …rpening
  - ↳ jets seen as "Rossby waveguides"



❼ an ongoing [interesting ?] observation





staircase generation seems largely independent of low-order q rationals

yet, cores of the jets meander. . .
↳ . . .staircases halt on rational q ?

❹ ...and through an interplay with avalanches

- non-locality is not exactly a new idea
  [Garbet '94, Diamond '95, Carreras '96, Politzer '00, Beyer '00, Hahm '05, Sanchez '05, Zaslavsky '05, Dif-Pradalier '10, Ghendrih '12, Gurcan '13, Bufferand '13, Ida '13]

- What's new: connection between stochastic avalanches & mean flow pattern step

$$Q = - \int \mathcal{K}(r, r') \nabla T(r') \, \mathrm{d}r'$$

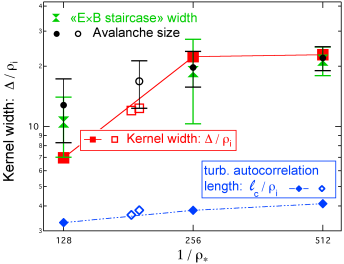
[Dif-Pradalier '10]

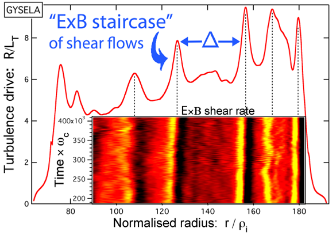
➠ $\mathcal{K}(r, r') = \frac{S}{\pi} \frac{\Delta/2}{(\Delta/2)^2 + (r - r')^2}$

➠ $\Delta \sim$ avalanche scale $\gg \ell_c$ correl. length

beyond « local-like, $\rho_\star$, gyro-Bohm »paradigm

- self-organisation: a continuum of scales
- no staircase: scale-invariant avalanches fill-in most of the plasma column
- staircase: scale-invariance "elastically" arrested at mesoscales





...a long history of traffic modeling [Whitham '74, Payne '79, Helbing '01, Flynn '09]

basic hypotheses:

- traffic flow is not modeled as individual vehicles ➽ continuum second order traffic models [Payne-Whitham '79, Aw-Rascle'00] for the vehicle density & velocity

$$\partial_t \rho + \partial_x(\rho u) = 0$$

$$\partial_t u + u\partial_x u + \frac{1}{\rho}\partial_x p = \frac{1}{\tau}(\bar{u} - u)$$

  - $\tau \equiv$ relax. time $\equiv$ "response" time of the drivers
  - $1/\rho\partial_x p \equiv$ "anticipation" term: drivers' reaction to traffic situation in their surrounding, partly compensating for the time delay τ

- ubiquitous shock-like solutions [linearly unstable for ρ large enough]

  Option#1: inviscid models $\equiv$ no momentum exchange btw neighboring vehicles

  ➽ jam cluster spreading backwards through the traffic interpreted as a shockwave

  Option#2: some « $\partial_{xx} u$ » smears out shocks. Dynamics in those cases depend non-trivially on the form of the dissipation [Kerner '93, Kurtze '95].

- models are purely deterministic, all drivers behave according to the same laws.

Early staircase constitution somewhat consistent with jamiton growth ➠ what happens non-linearly ?