Upscale and forward treansfer of kinetic energy: Impact on giant planetary jet and vortex formation

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25.05.2022, EGU General Assembly 2022, Session NP0.1

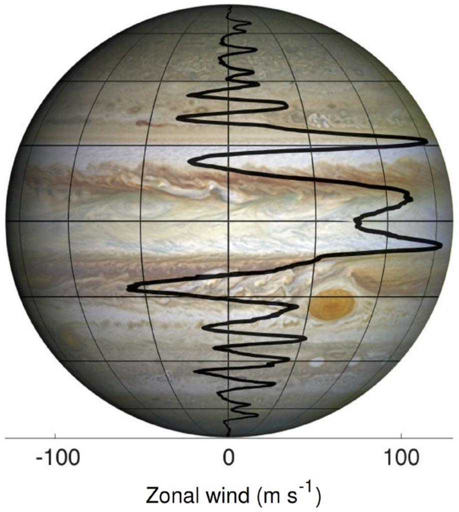
Image: NASA/Juno

Motivation: Jet and large-scale vortex formation on giant planets

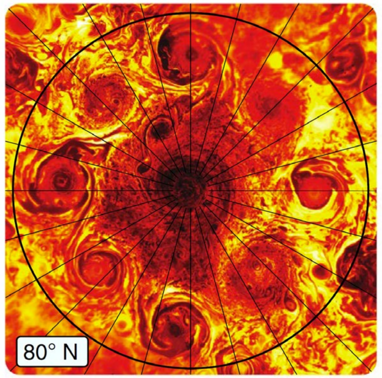
Motivating question: How do jets (=zonal winds) and large-scale vortices form?

- **Inverse cascade is a possible mechanism for feeding jets and large-scale vortices** (e.g., Rhines 1975, Vallis & Maltrud 1993, Rubio,+2014, Favier,+2014, Young & Read 2017).
- **Missing: Analysis of numerical simulations of rapidly-rotating convection in a deep spherical shell.**

Jupiter's surface zonal wind profile (Fig. 1 from Kaspi,+2020)



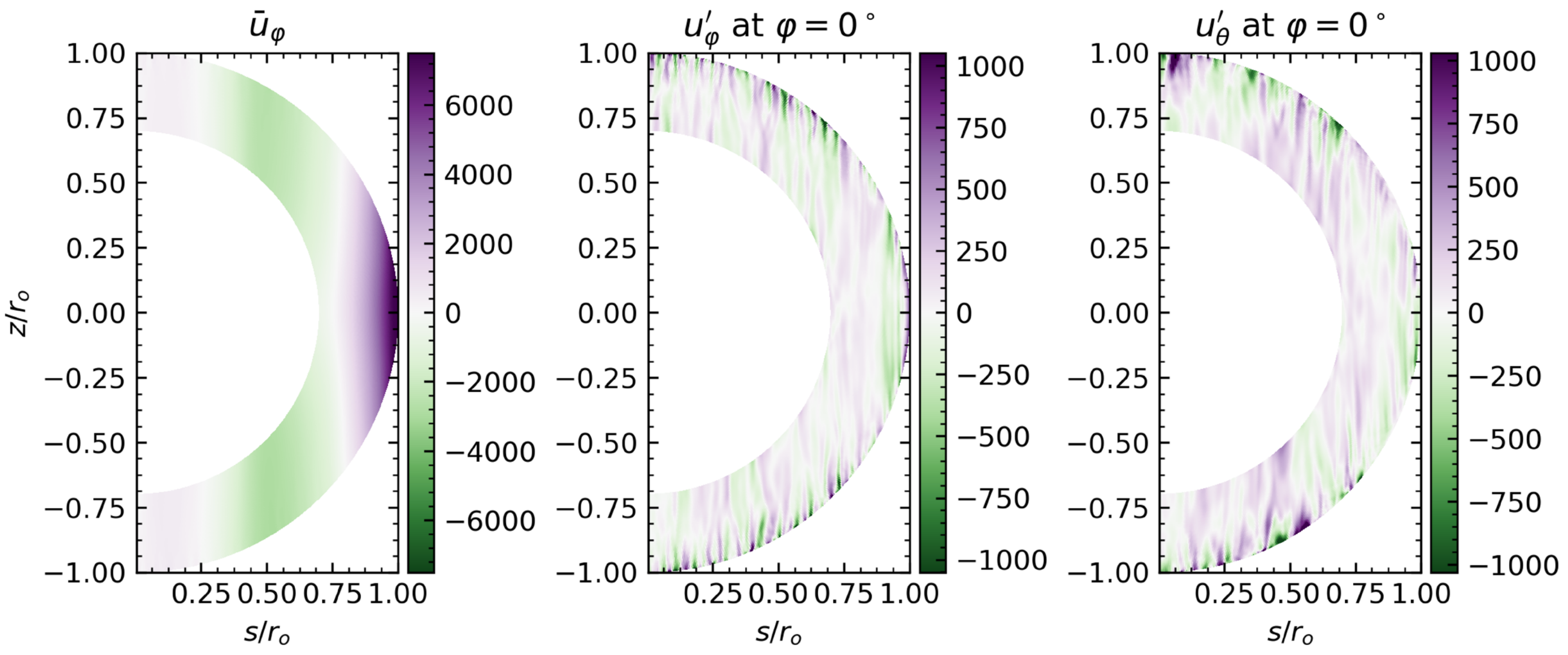
Jupiter's north pole (Fig. 1 from Gavriel,+2021)



Aim: Determine role of inverse cascade in simulations

Aim: Determine whether an inverse cascade plays a role in simulations.

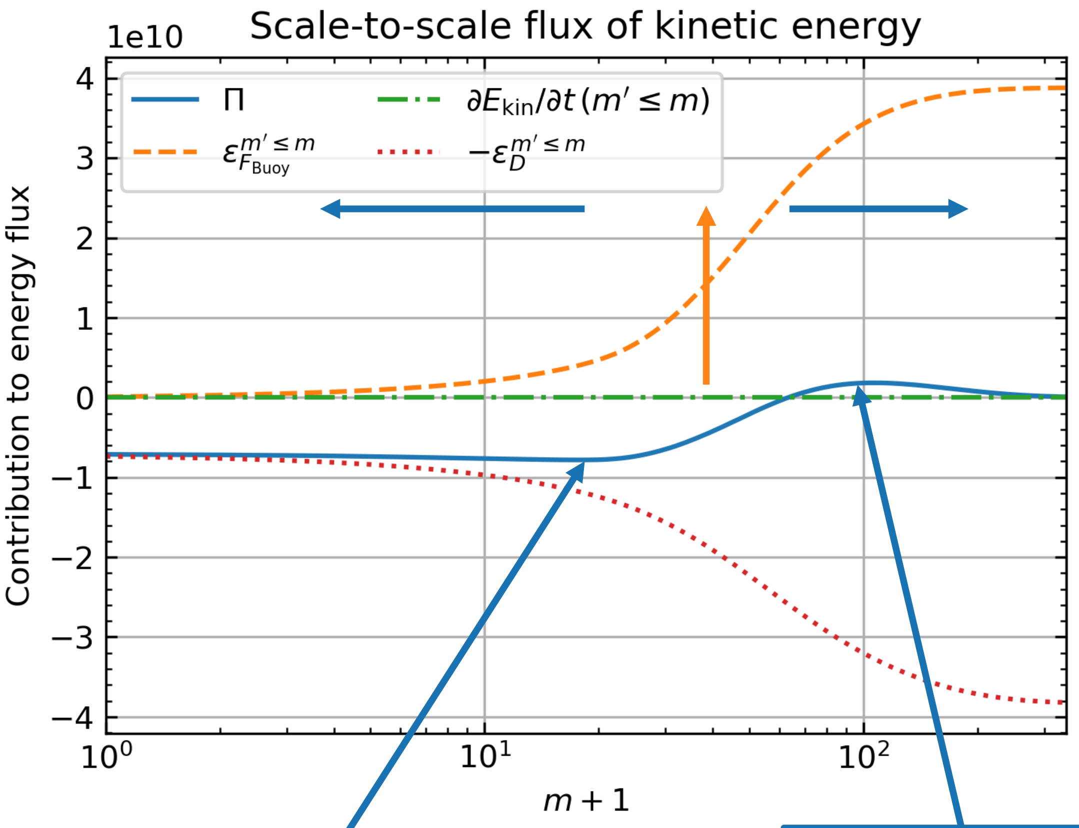
- **We use the anelastic MagIC code** (Wicht 2002, Lago,+2021).
- **Simpler than a real planet, but capture essential physics:**
  - 2 prograde jets, 1 retrograde jet, large-scale vortical structures
  - „moderate parameters“ $(Ek = 3 \times 10^{-5},\ Ra = 3 \times 10^{8},\ Pr = 0.5,\ N_\rho = 1.8)$



Regions of upscale and forward spectral flux

m=10,…,100:
driving by buoyancy
(convection)

- Decomposition in azimuthal wavenumber m (Fourier transform in longitude), with jets being m=0.
- **Cascade definition** (e.g., Frisch 1995, p.104)**:**
  1. scale-invariant dynamics (incl. constant scale-to-scale flux): OK!!!
  2. transfer is local in spectral space: ??? (→ multiple steps in cascade, not only one or a few steps)



upscale flux (negative):

m=0 (to jets)
m=1,…,20: (to large eddies)

forward flux (positive):

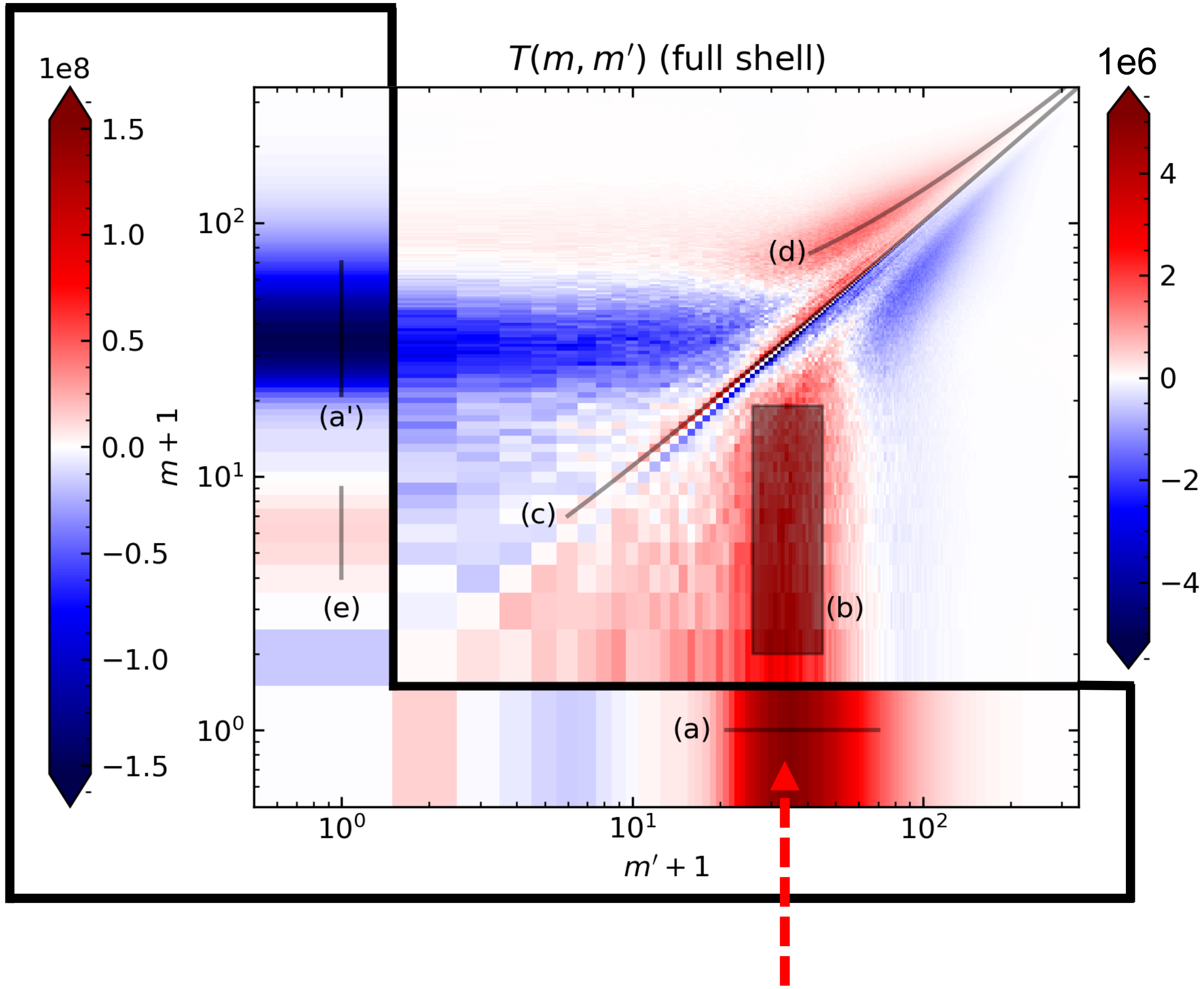
m>80
(to classical dissipation scales)

Upscale transfer to jets is mostly non-local

- Main result: transfer function of kinetic energy, T(m,m‘).
- Red color means transfer from m‘ to m. Upscale transfer is red below the diagonal.

- **Transfer function is dominated by non-local transfer to jets (m=0) from convective structures (m‘ = 20,…,70)**
- **The greatest part of the upscale flux is due to this non-local transfer.**

→ **Jets are not driven by an inverse cascade !!!**



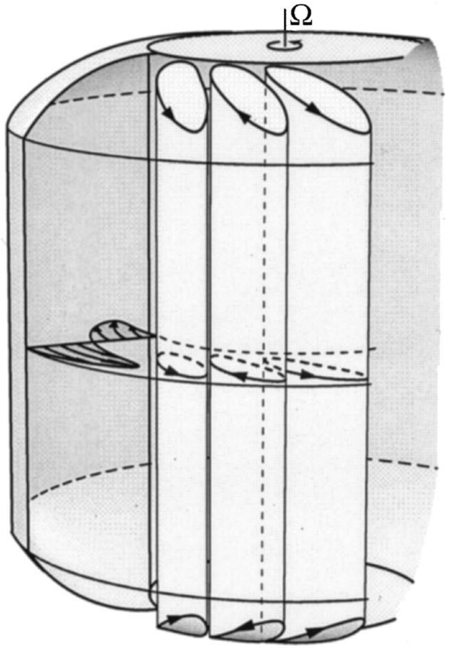
My impression from literature search (see Maltrud and Vallis 1993, Frisch 1995 p. 251, Xiao et al. 2009): True inverse cascades can only exist in an infinite spatial domain or if the largest-scale modes are artificially damped. Discussion welcome: boening@mps.mpg.de

Jet growth is due to effect of rotation on flow patterns

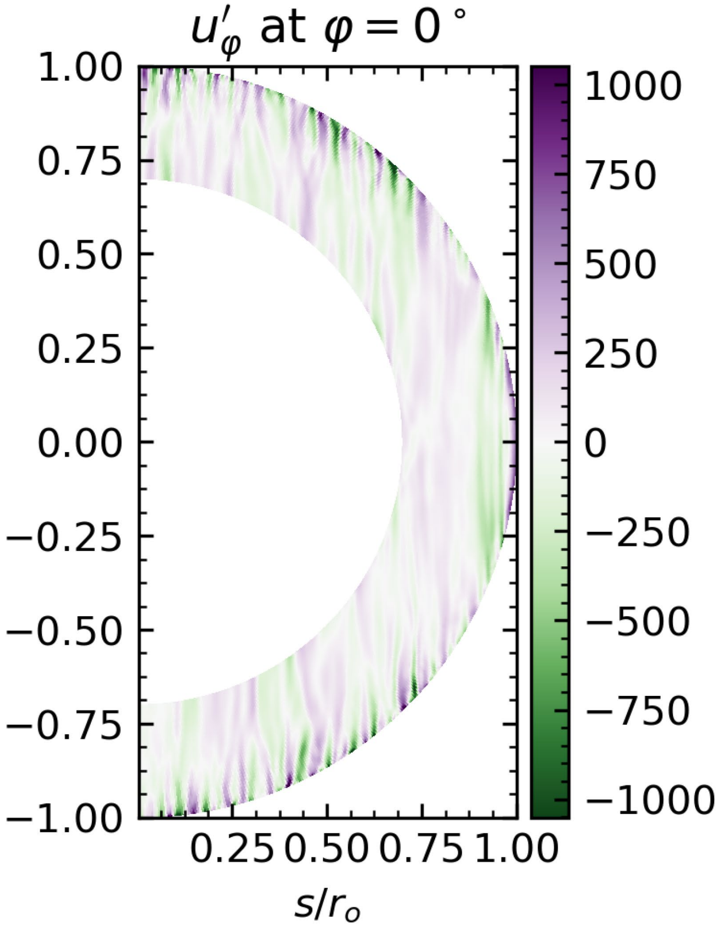
- Mathematically, transfer to jets (T(m,m') for m=0) is due to statistical correlations of different flow components.

→ **Our results similar to zonal flow instability picture of Busse (2002) with tilted convective columns:**

- **Initial correlations are due to the effect of uniform background rotation and geometry on convective structures**
- **and correlations evolve with growth of the jets until a steady state is reached.**
- **Our case is more turbulent and these columns and correlations are statistical features.**



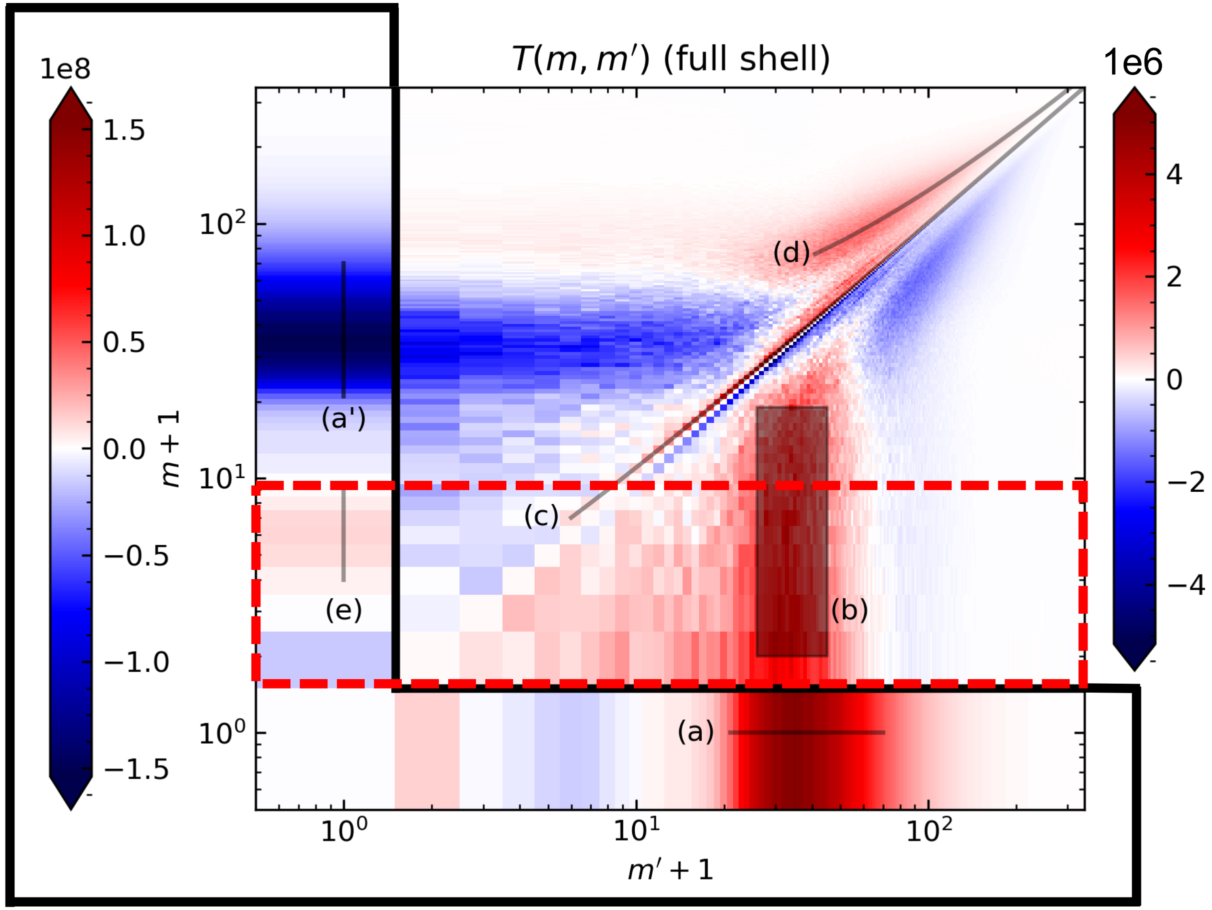
Busse (2002)



Transfer to large-scale vortices is both upscale and forward

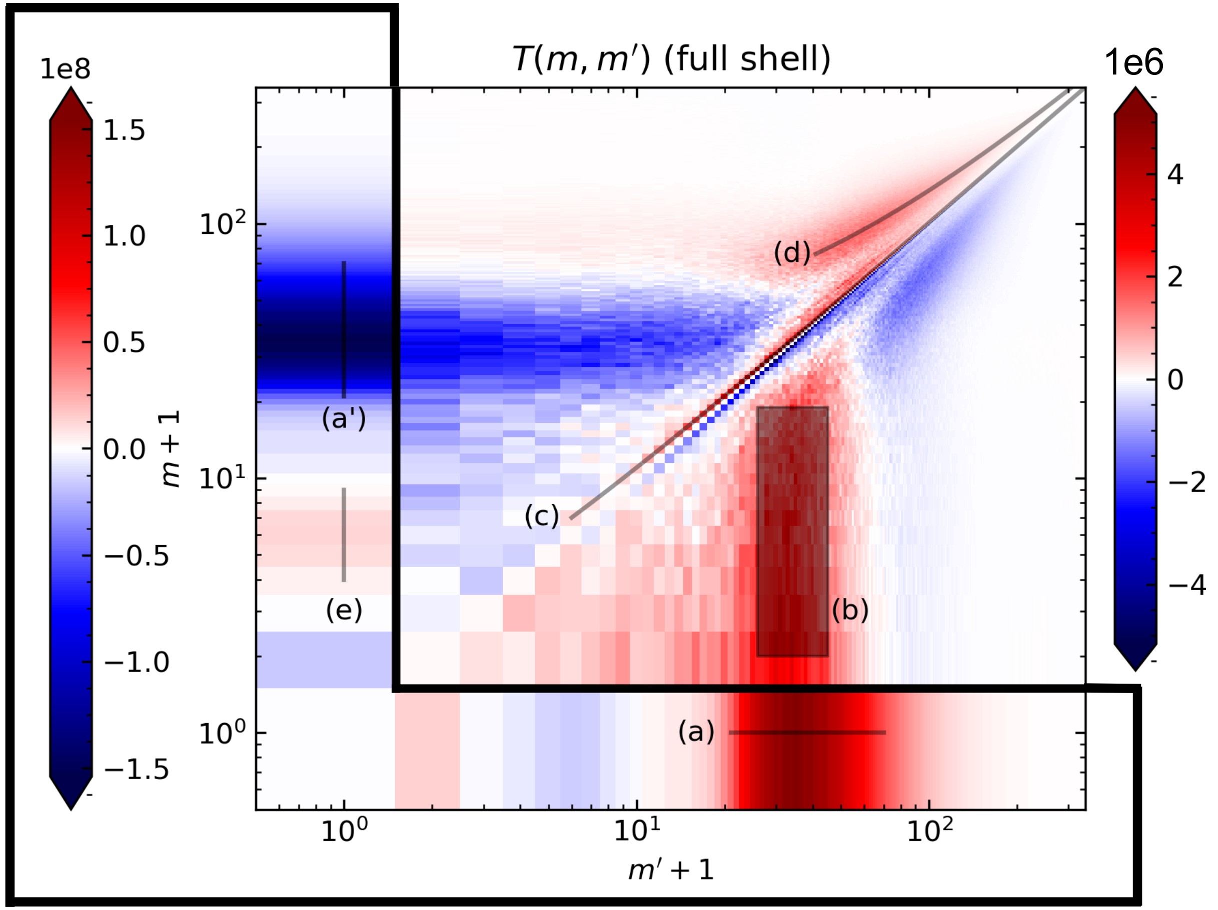
- Large-scale structures: m=1,…9
- **Upscale transfer (b) is rather non-local → likely not a cascade either.**
- **Transfer from the jets to large-scale vortices (e) is a forward transfer, likely due to an instability of the jets.**

→ **Jet instability could be a mechanism for feeding large-scale vortices.**



Summary for our simulation:
Jet and vortex formation are likely not due to an inverse cascade.

1. Jet and vortex formation are likely not due to an inverse cascade.
2. Rather due to effect of rotation on flow pattern (labels a+b).
3. We propose jet instability as an alternative mechanism for feeding large-scale vortices (label e).



Thanks for your attention!

Image: NASA/Juno