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SPACE SCIENCE INSTITUTE

University of Colorado Boulder

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3D Simulation of electron scale turbulent currents in reconnection outflows

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Acknowledgments

AIDA

HORIZON 2020

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH UNITED STATES AIR FORCE

NASA

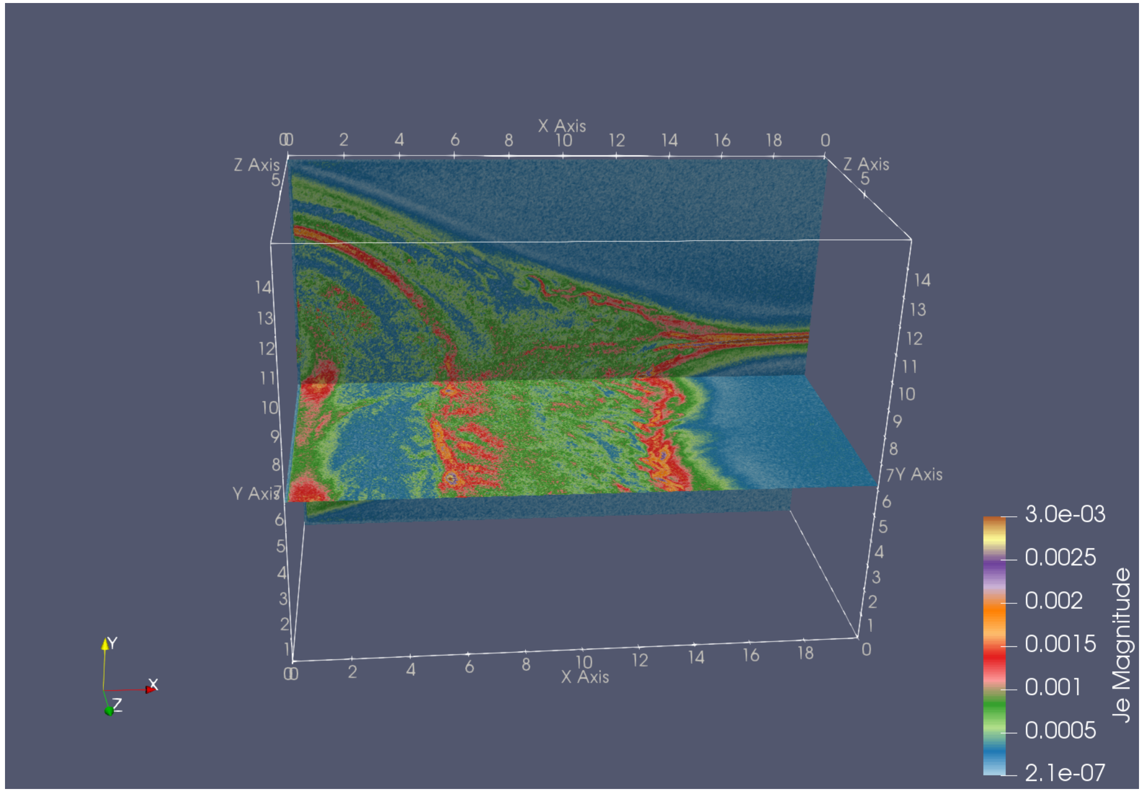
NERSC

PRACE

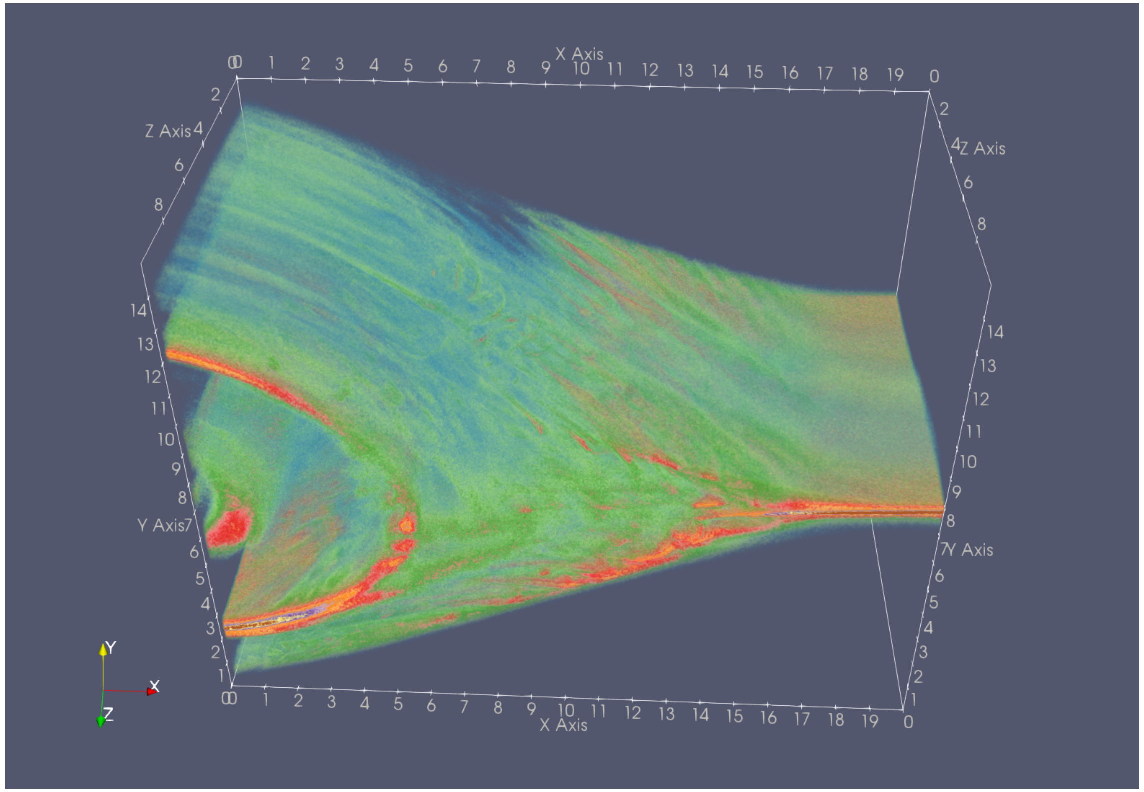
VSC Vlaams Supercomputer Centrum

3D reconnection leads to very non laminar outflows

Mi/me=256
B_g=1/10
Grid:1200x450x300
Resolution $\Delta x = d_e/2$
Resolution $\omega_{ce} \Delta t = 1/30$



Electron Current Density – Magnitude - Cuts



Electron Current Density – Magnitude –Volume rendering

Lapenta, G., et al. "Local regimes of turbulence in 3D magnetic reconnection." *The Astrophysical Journal* 888.2 (2020): 104.

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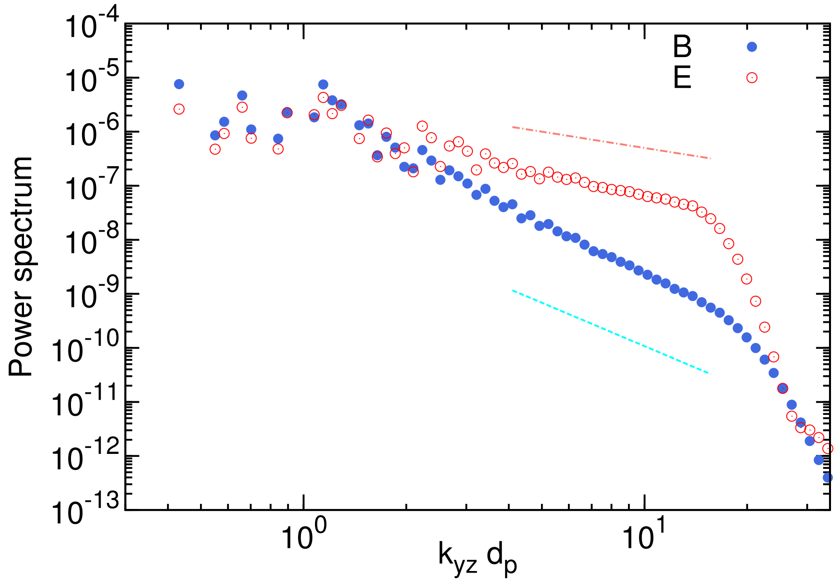
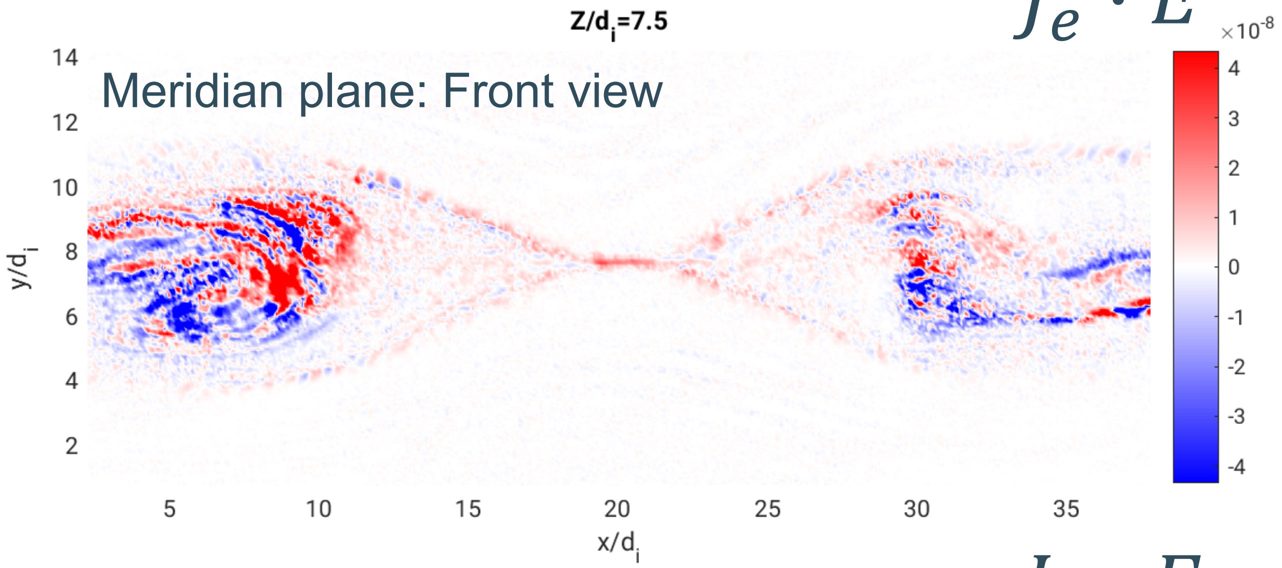
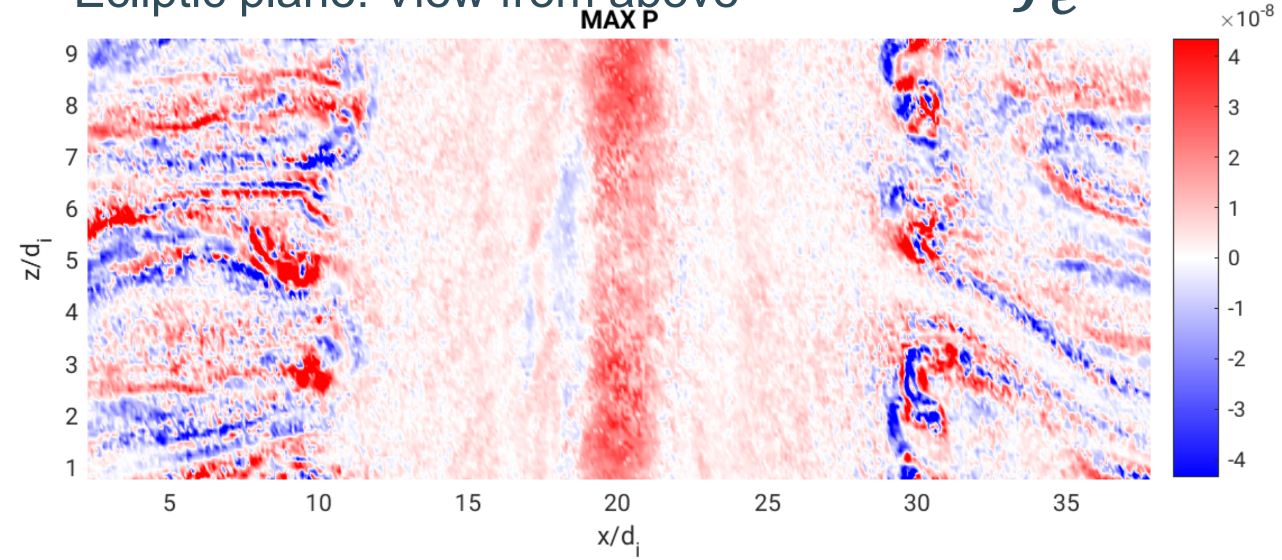
The conditions are turbulent and electron scale currents are formed

- The reconnection outflows drives the formation of electron currents down to the electron scales (electron gyroradius and electrons skin depth
- Reconnection there happens via electron processes leaving ions largely unaffected







Pucci, Francesco, et al. "Properties of turbulence in the reconnection exhaust: numerical simulations compared with observations." ApJ 841.1 (2017): 60.

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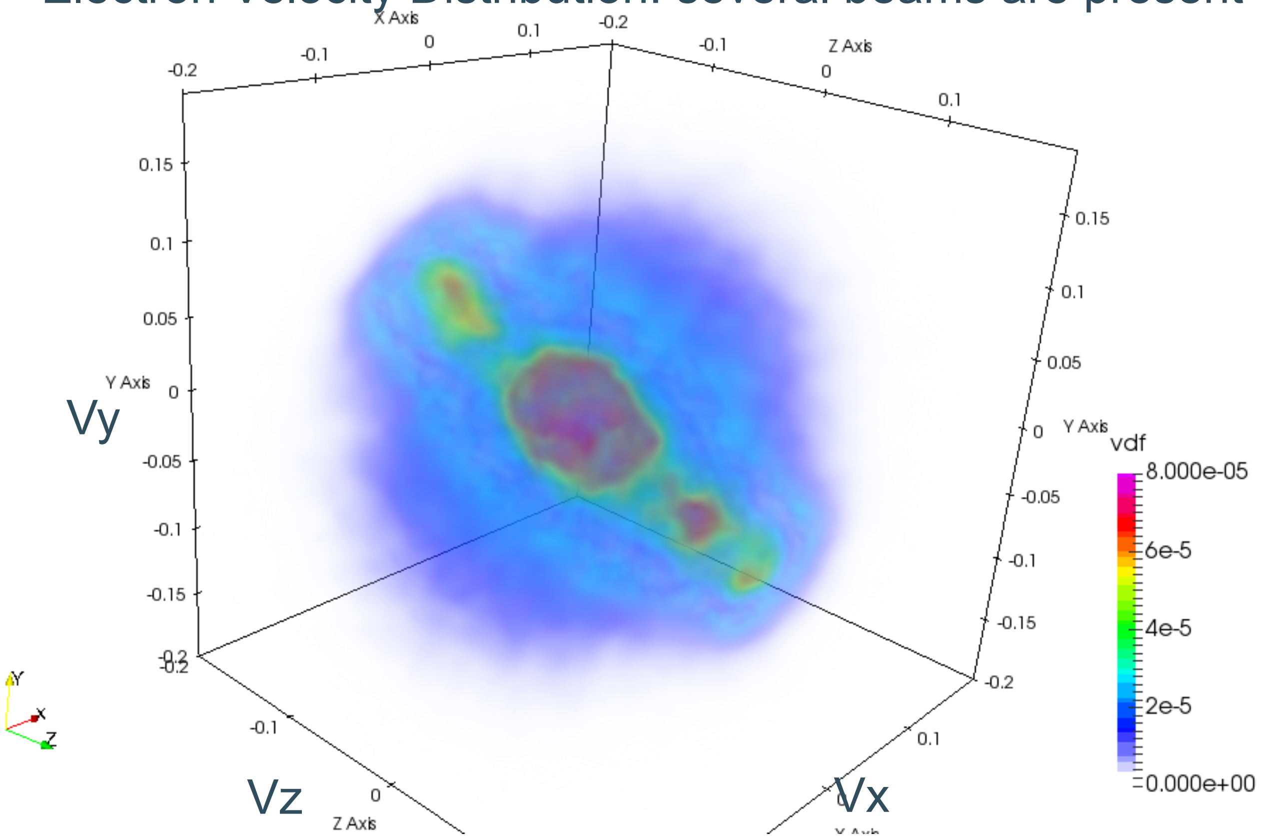
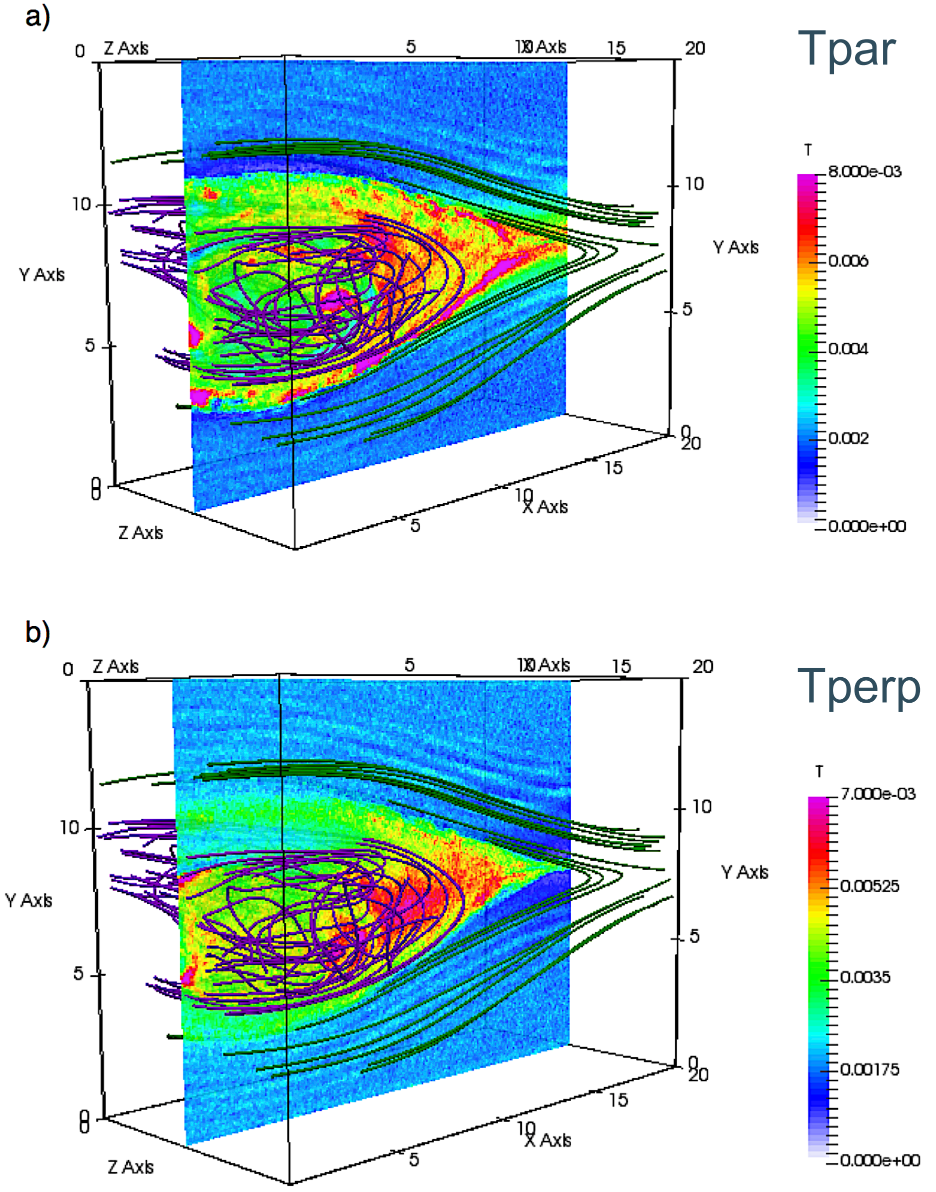
Electron energization leads to non Maxwellian distributions

Electron Velocity Distribution: several beams are present





Lapenta, G., Pucci, F., Olshevsky, V., Servidio, S., Sorriso-Valvo, L., Newman, D., & Goldman, M. (2018). *Journal of Plasma Physics, 84*(1), 715840103.

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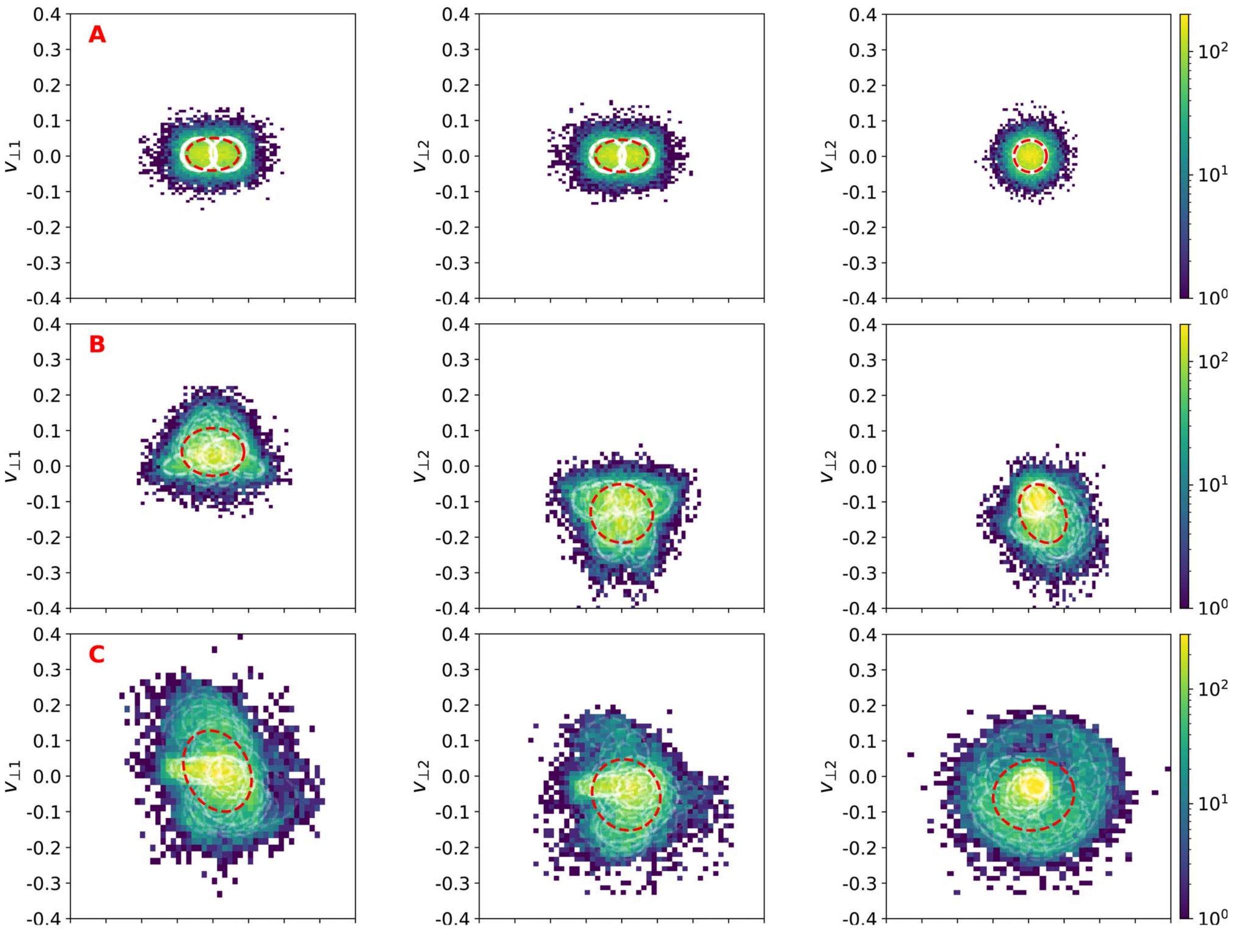
Gaussian Mixture Model (GMM): Different distributions

Electron velocity distributions

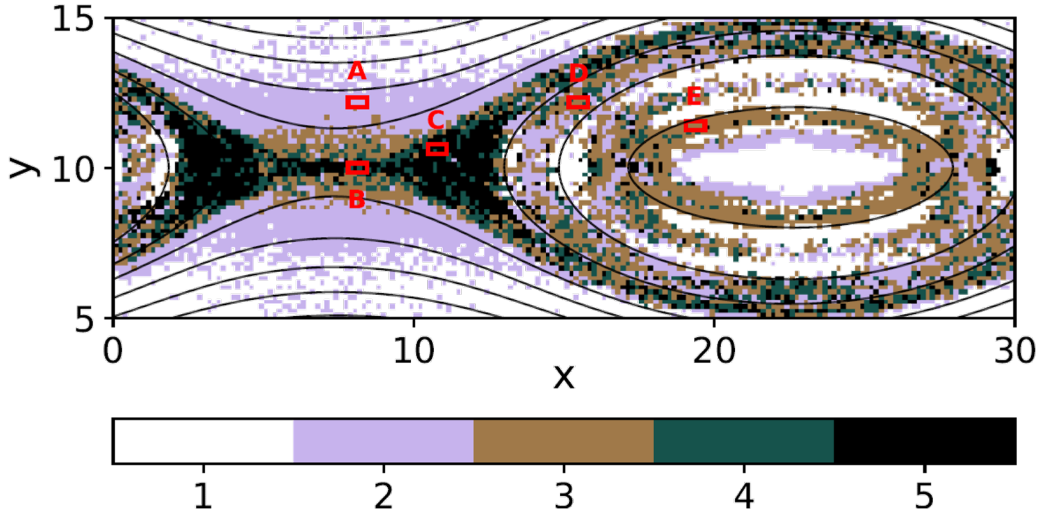


$$p(\boldsymbol{x}|\boldsymbol{\Phi}) = \sum_{k=1}^{K} w_k \,\mathcal{N}(\boldsymbol{x}|\boldsymbol{\theta_k})$$

Determination of the number of Gaussians:

- ➢ Akaike information criterion (AIC): 2*k* - 2 ln(*L*)
- ➢ Bayesian information criterion (BIC): ln(*n*)*k* - 2 ln(*L*),

k = number of Gaussians; L = likelihood



Dupuis, R., et al.(2020). ApJ, *889*(1), 22.

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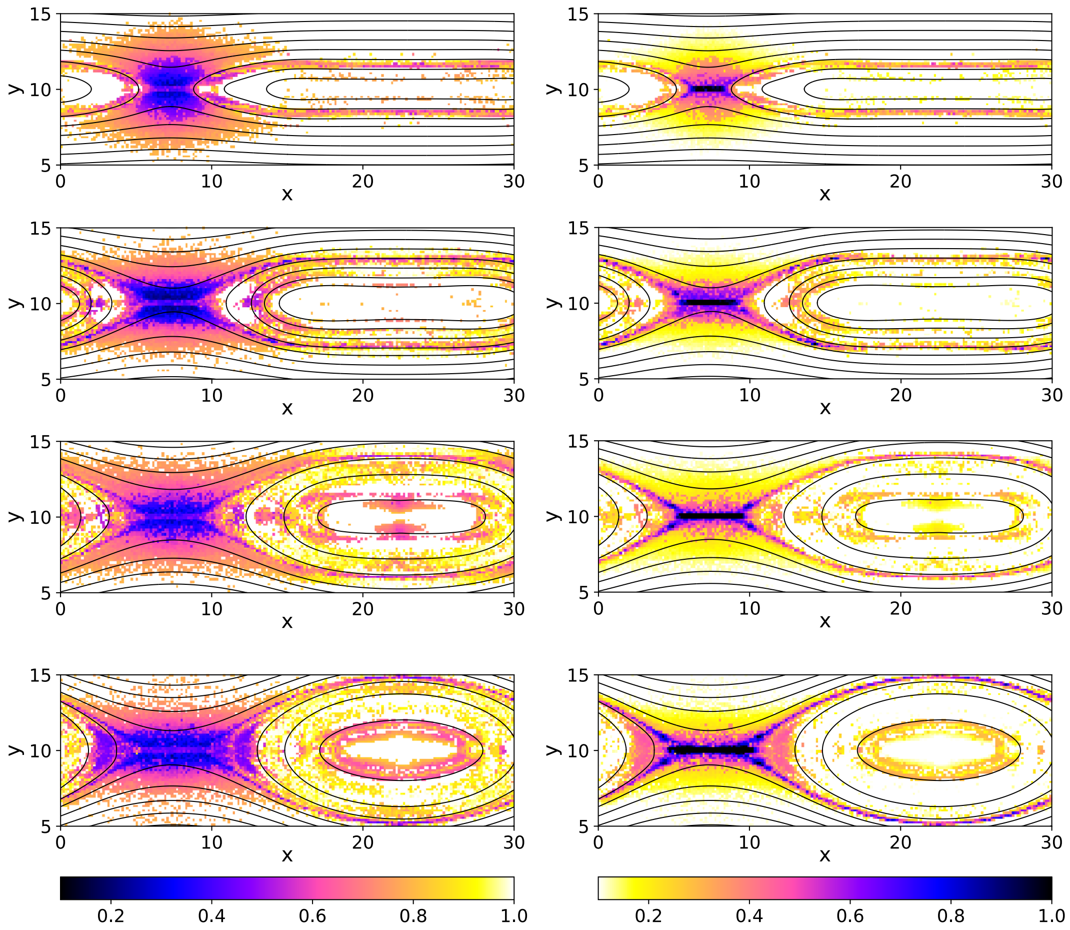
Effect on the definition of thermal energy

Thermal energy drop   Pseudo ("false") thermal en.

$$E_{\rm drop} = \frac{E^{(K)}_{\rm thermal}}{E_{\rm thermal}}.$$

$$E^{(K)}_{\rm dev}$$



- Fluid thermal energy:

$$E_{\rm thermal} = \frac{1}{N_p}\sum_{i=1}^{3}\left[\sum_p (\boldsymbol{V_p} - \langle \boldsymbol{V_p}\rangle)^2\right]_i, \text{ with } \langle \boldsymbol{V_p}\rangle = \sum_p \frac{\boldsymbol{V_p}}{N_p}.$$

- Multibeam thermal energy

$$E^{(K)}_{\rm thermal} = \frac{1}{2}\sum_{i=1}^{3}\sum_{k=1}^{K} w_k^2 [\boldsymbol{\sigma}_{\boldsymbol{k}}^2]_i.$$

- Drop in thermal energy

$$E_{\rm drop} = \frac{E^{(K)}_{\rm thermal}}{E_{\rm thermal}}.$$

- Pseudo ("false") thermal energy

$$E^{(K)}_{\rm dev} = \sum_{i=1}^{3}\left[\sum_{k=1}^{K} w_k (\boldsymbol{\mu_k})^2 - \left(\sum_{k=1}^{K} w_k (\boldsymbol{\mu_k})\right)^2\right]_i.$$

Dupuis, R., et al.(2020). ApJ, *889*(1), 22.
Goldman et al.(2020), arXiv:2005.09113, submitted to JGR