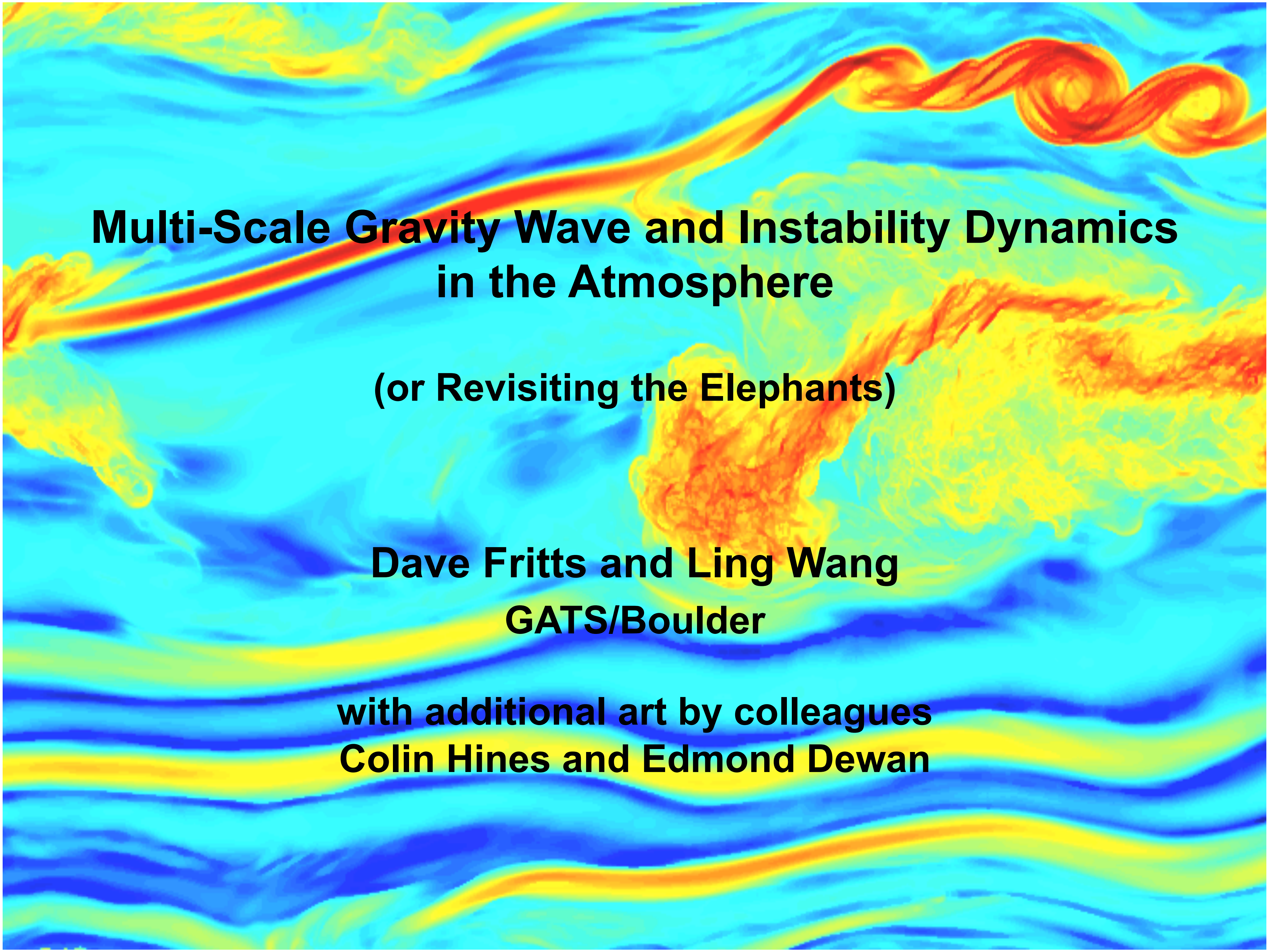


Multi-Scale Gravity Wave and Instability Dynamics in the Atmosphere

(or Revisiting the Elephants)

Dave Fritts and Ling Wang

GATS/Boulder

with additional art by colleagues
Colin Hines and Edmond Dewan

Background

The dynamics controlling the evolution and shape of the GW spectrum have been debated vigorously for ~30 years

"nonlinear diffusion" – spectral transfers

(Weinstock, Zhu, Medvedev/Klaassen, Gardner)

"linear saturation" - local instability/dissipation

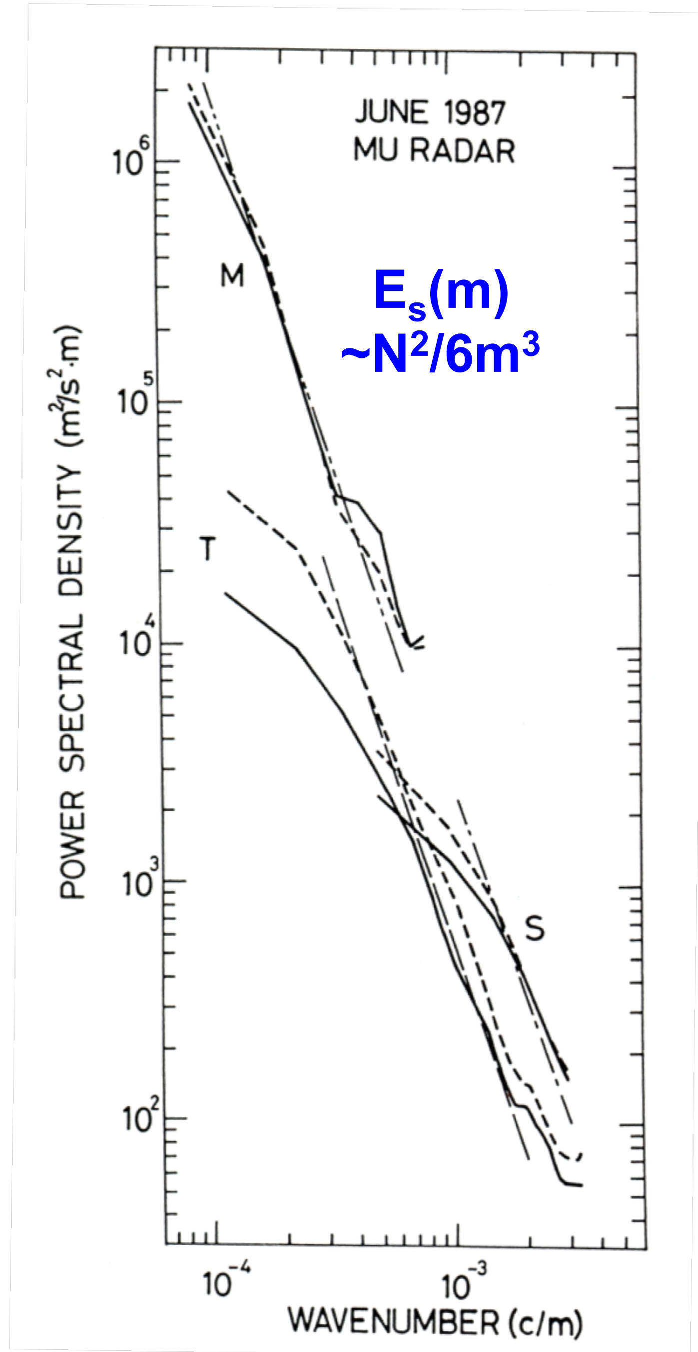
(Dewan/Good, Smith/Fritts/VanZandt, Warner/McIntyre)

"Doppler spreading" – wave-wave interactions

(Hines)

"saturated cascade" – interactions & instabilities

(Dewan)

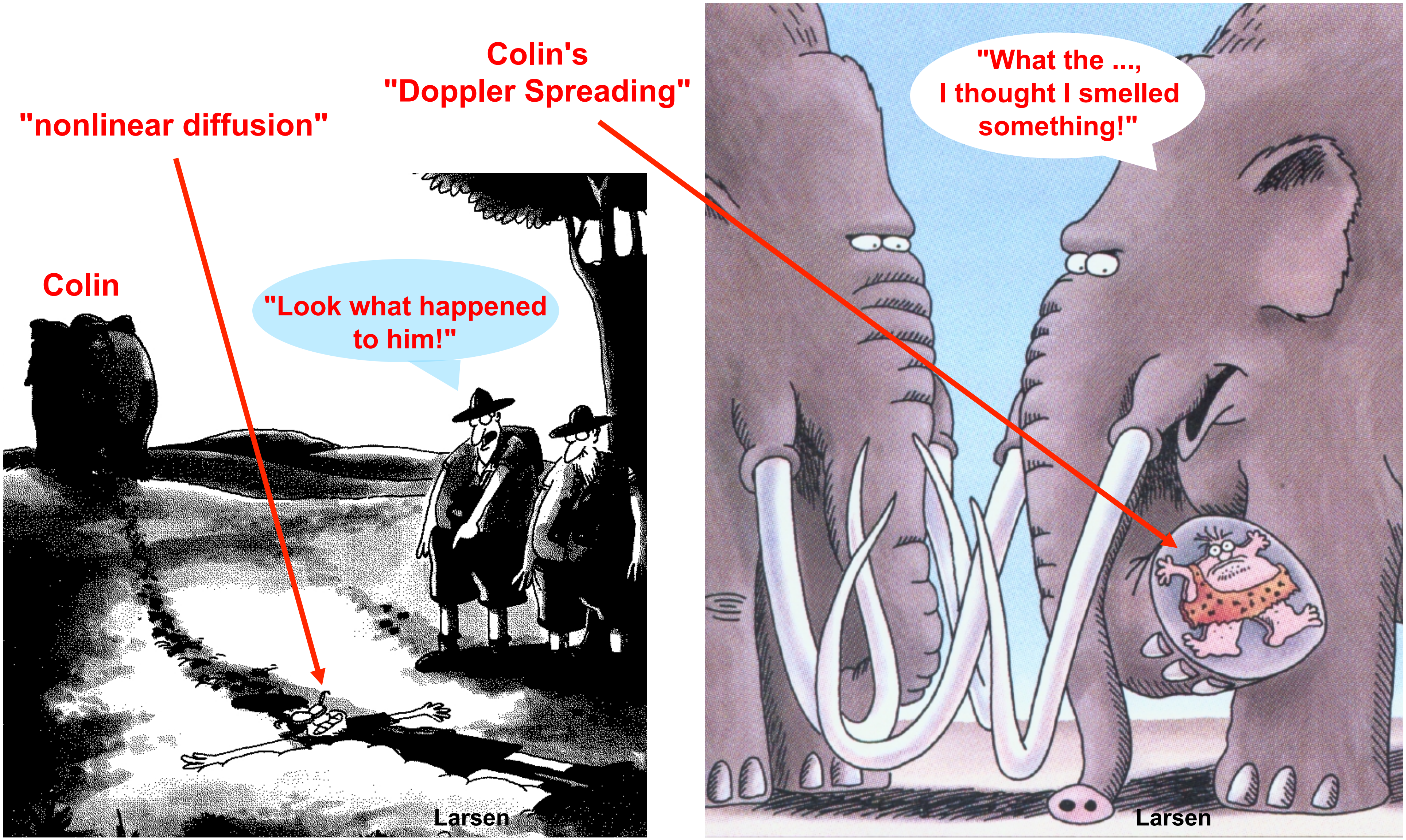


Tsuda et al. (1989)

The debate was nicely illustrated with elephants ...

Colin did not embrace the initial GW saturation theories

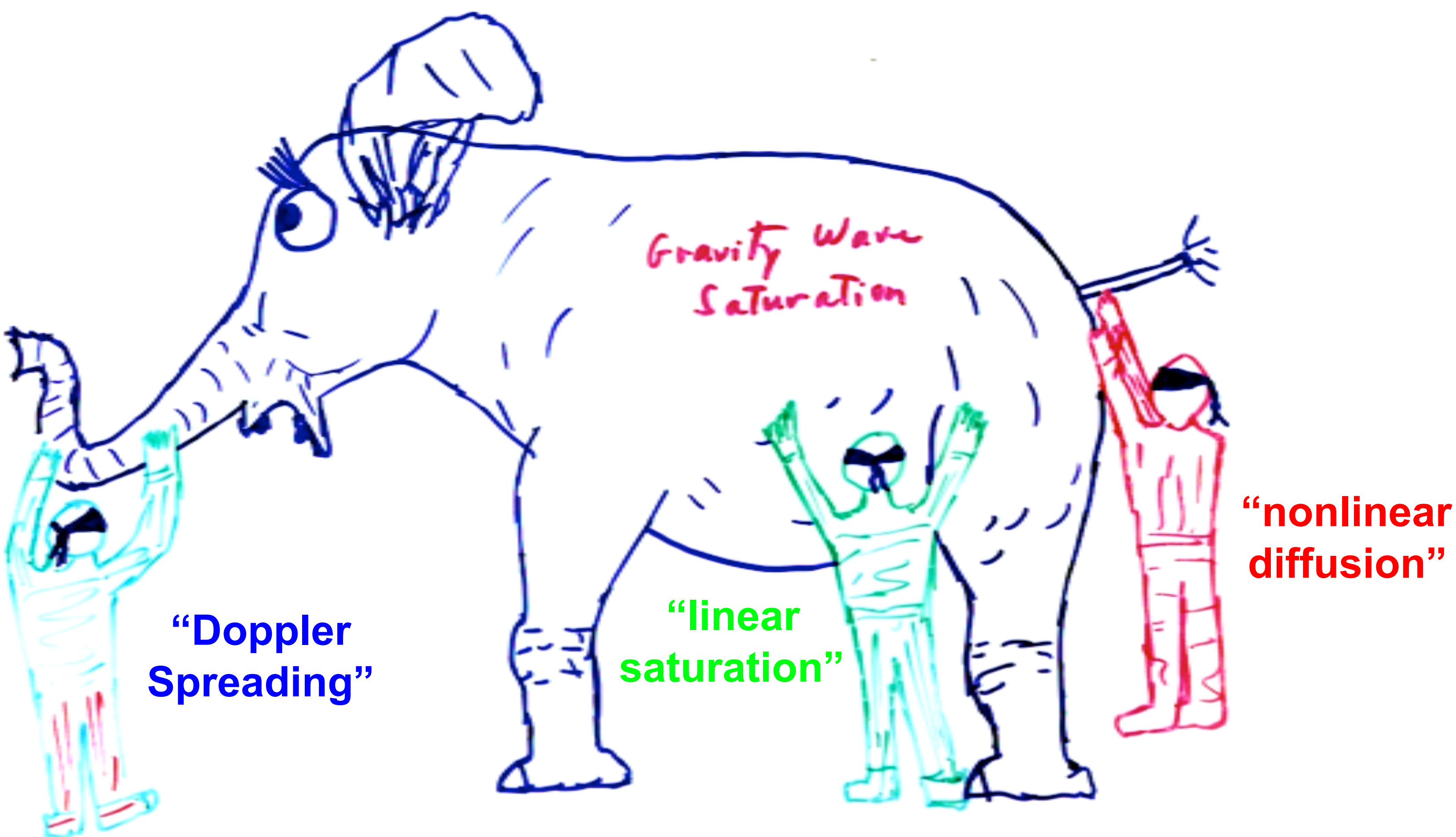
but modelers also found Colin's needed assumptions to be distasteful ...



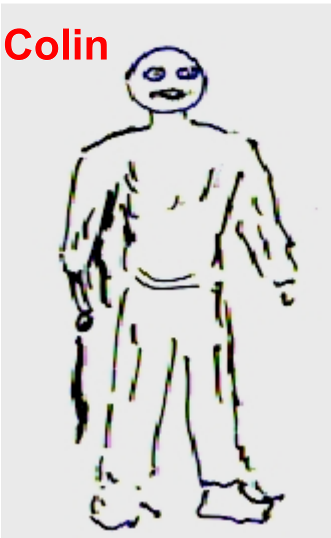
And the elephants continued ... but without Gary Larsen's artistry!

Theorists in search of Truth

(Fritts, IAGA 1995)



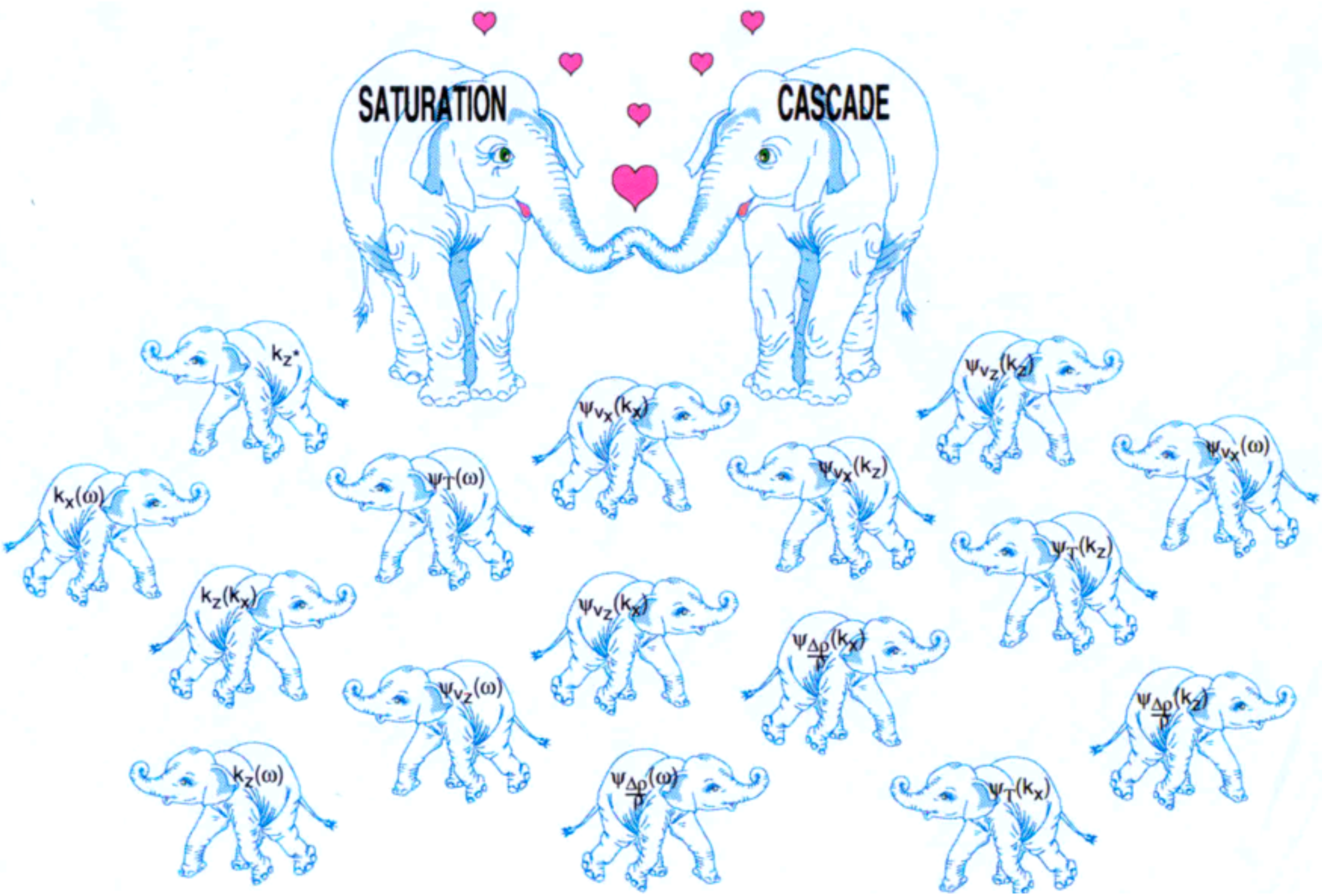
Colin had his own view of the truth, and of yet another theory…



Theorists in search of Truth

Revisions: Colin Hines

Edmond Dewan advocated a harmonious alternative:
- a blend of wave-wave interactions and local instabilities



The debate has lessened for lack of a quantitative understanding of the nonlinear dynamics.

So key questions remain:

"What NL interactions and instabilities control the GW spectrum and its evolution with altitude and time?"

"What environmental parameters influence these dynamics?"

and

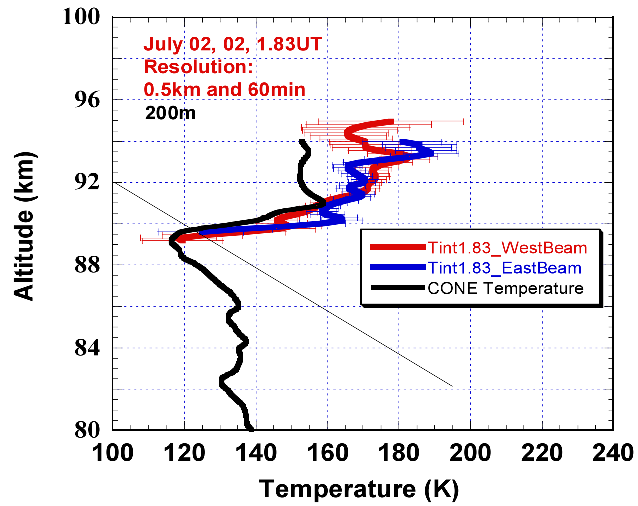
"What can we learn from high-resolution numerical simulations that describe all nonlinear GW dynamics for idealized flows?"

Motivations

GWs and multi-scale dynamics are ubiquitous throughout atmosphere

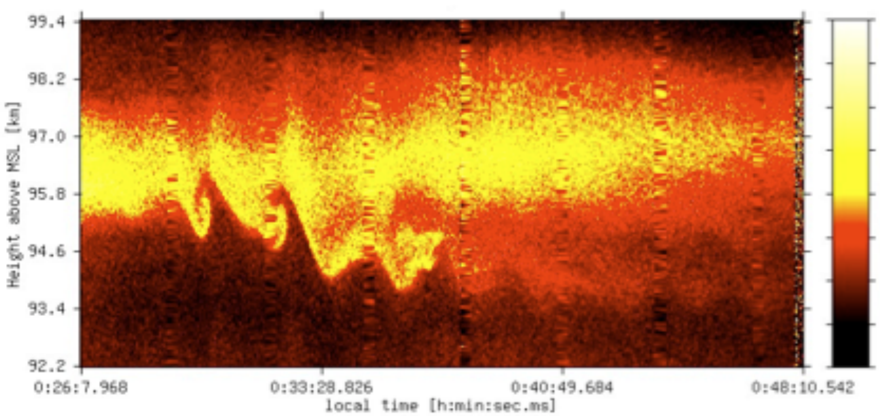
- scales increase by ~1000 from SBL to MLT
- instabilities are intermittent everywhere

multi-scale structures in T(z)

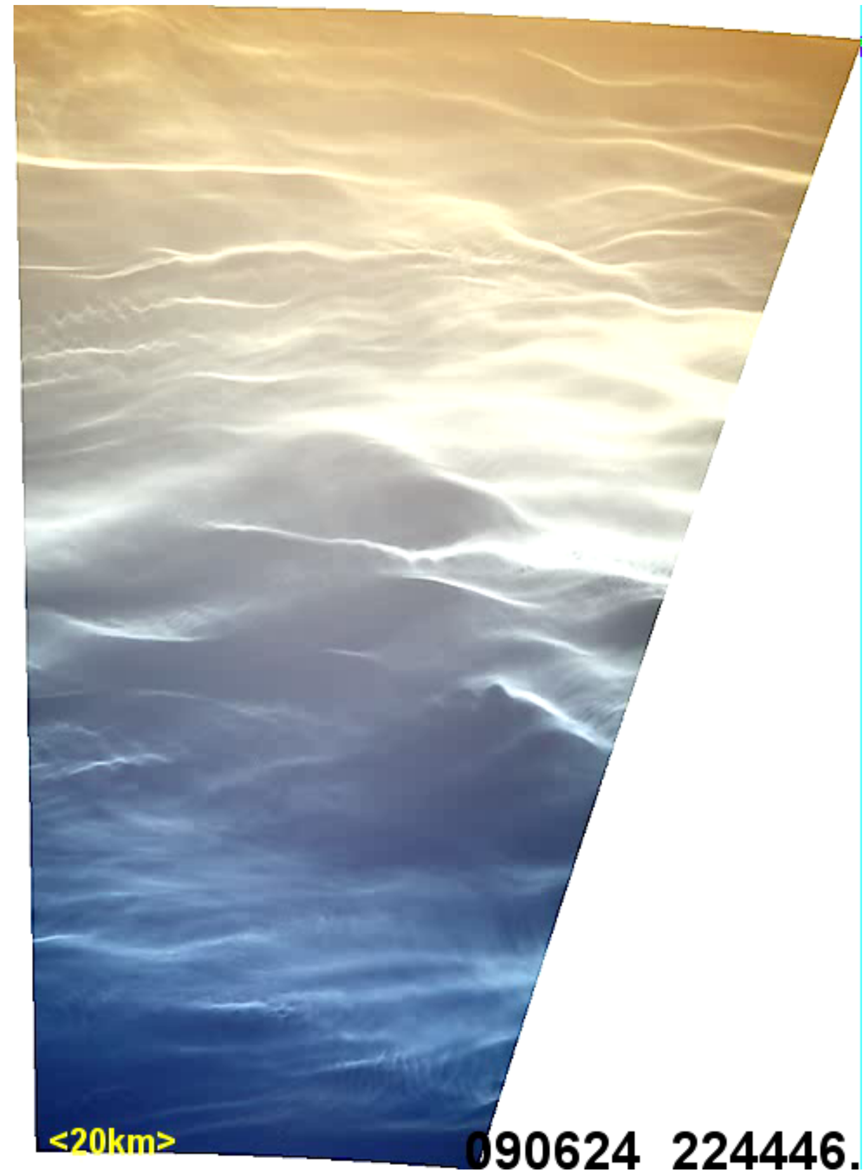


Fritts et al. (2004)

KHI likely initiated by GWs in the MLT



Pfrommer et al. (2009)

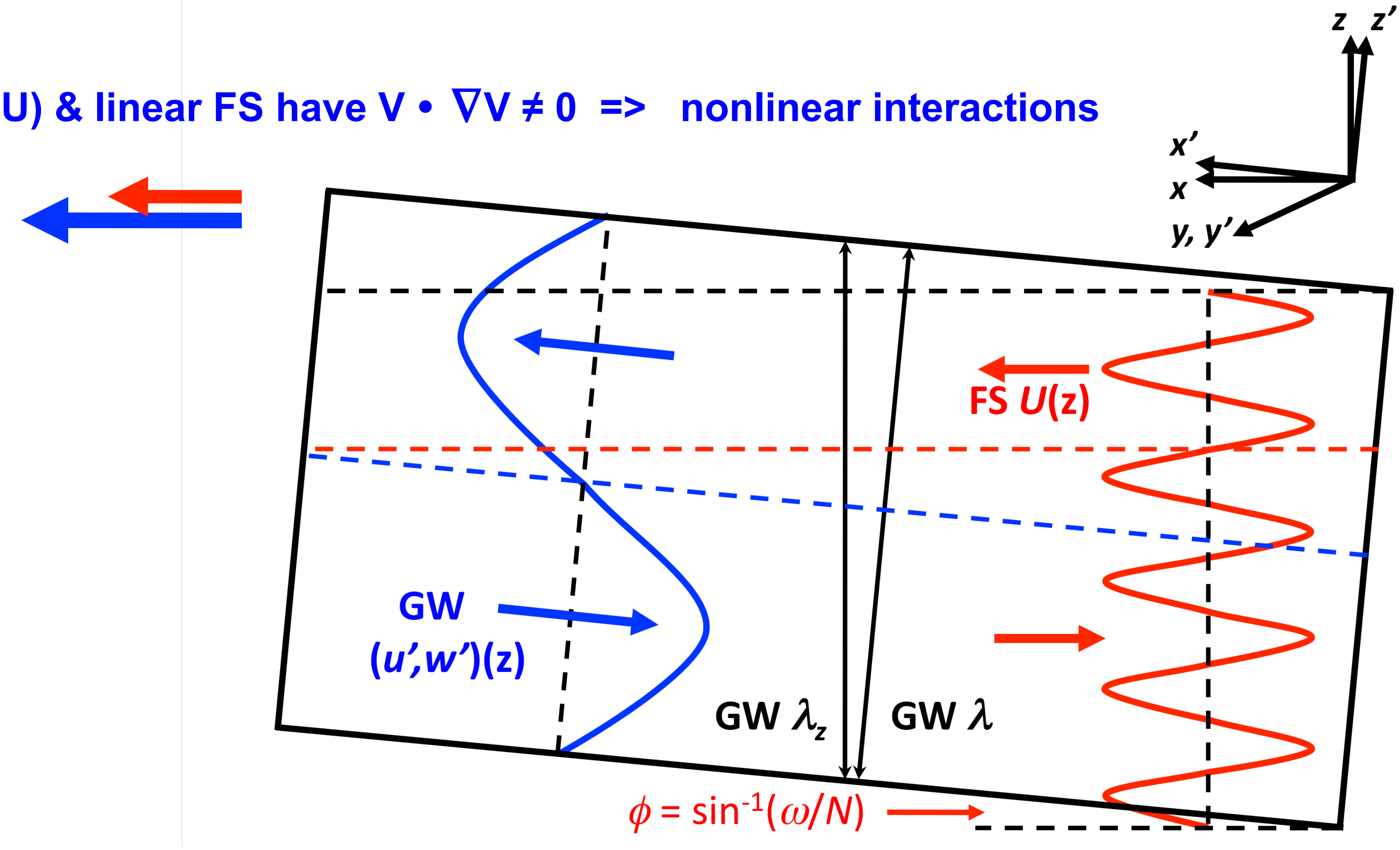


(courtesy G. Baumgarten, 2013)

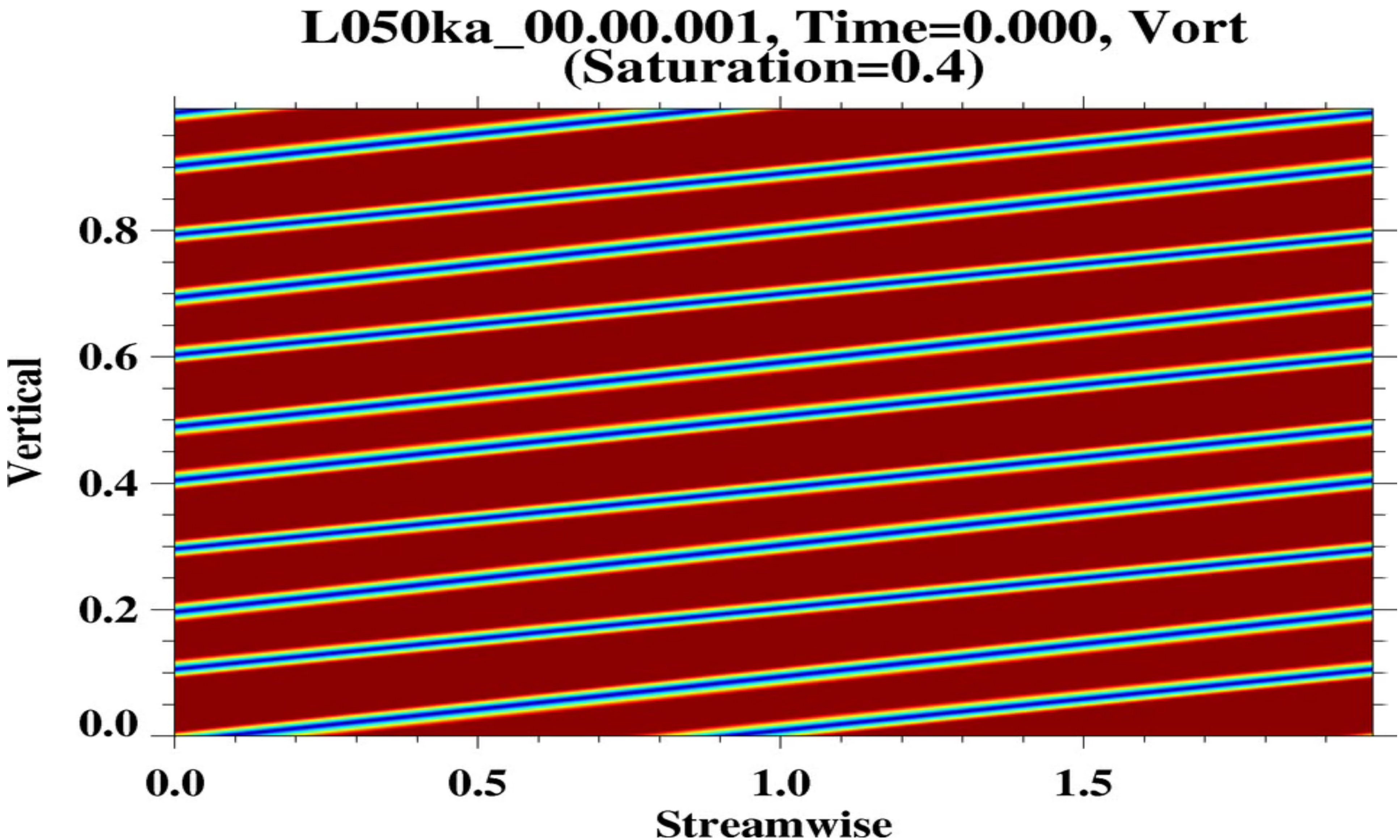
Examine one "simple" DNS of a superposition of

- GW with $a = u_0'/(c-U) = 0.5$, $\omega = N/10$, $m\ (= 2\pi/\lambda_z) = 1$, $Re = \lambda_z^2/T_b\nu = 50{,}000$
- oscillatory fine-structure (FS) shears with $dU_{FS}/dz = 2N$, $m \sim 5$

GW (U) & linear FS have $V \cdot \nabla V \neq 0$ => nonlinear interactions



Multi-scale superposition: GW with *a* = 0.5, FS with $dU_{FS}/dz = 2N$



different instabilities contribute at different times

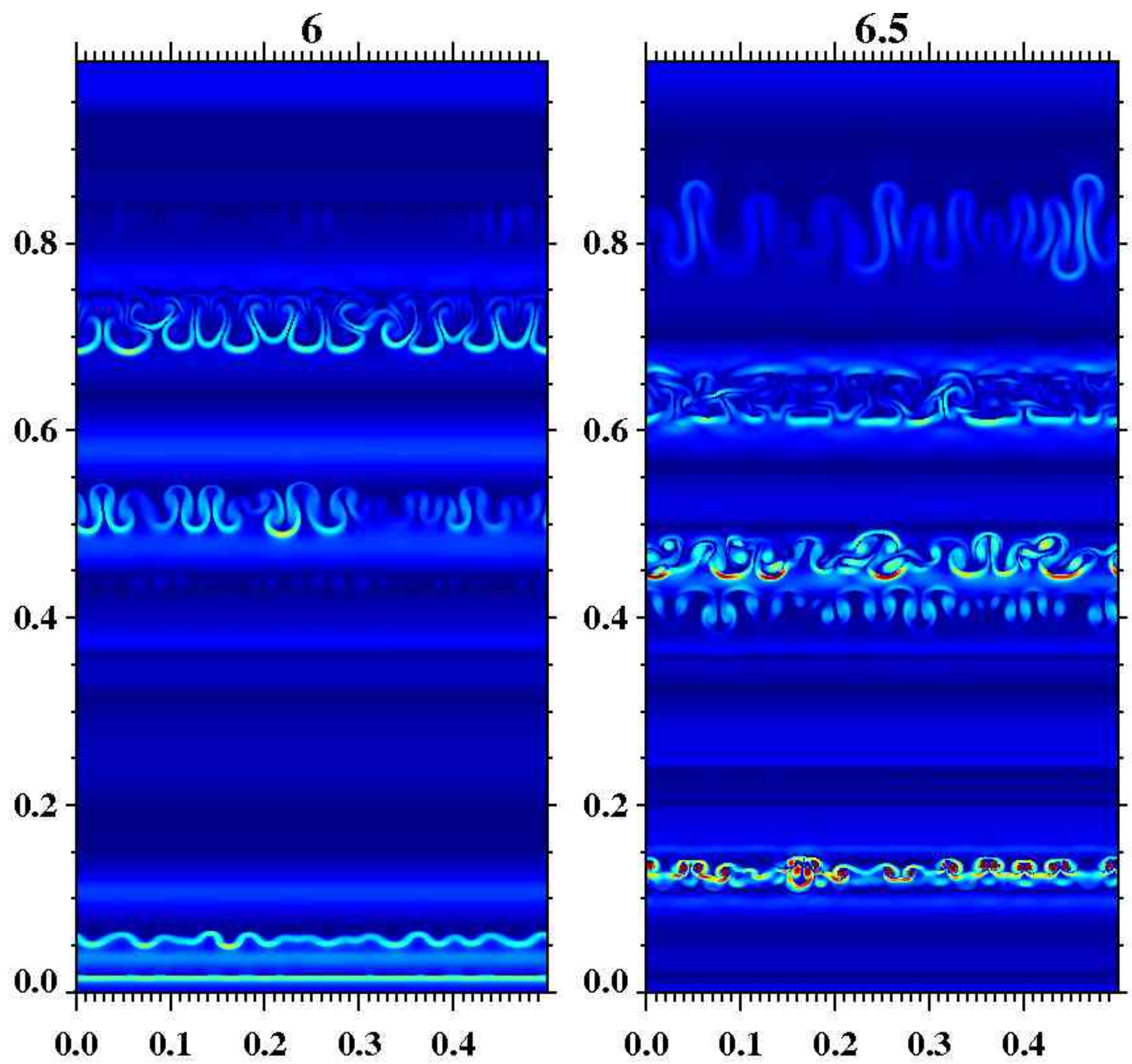
initial instabilities comprise counter-rotating streamwise-aligned vortices where FS advection yields local overturning

similar instability structures are also observed in

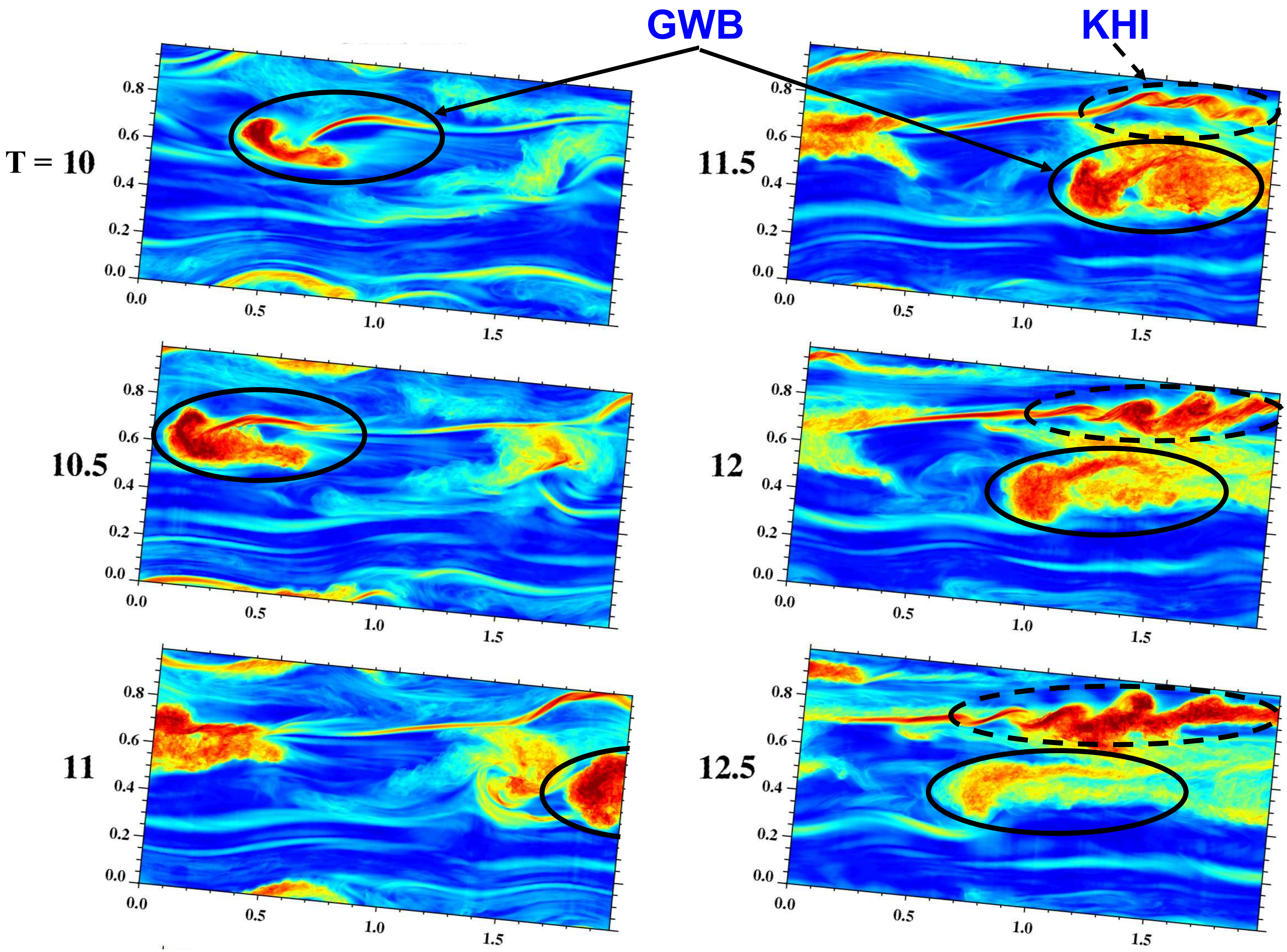
- secondary instabilities in Kelvin-Helmholtz (KH) billows

- GW breaking

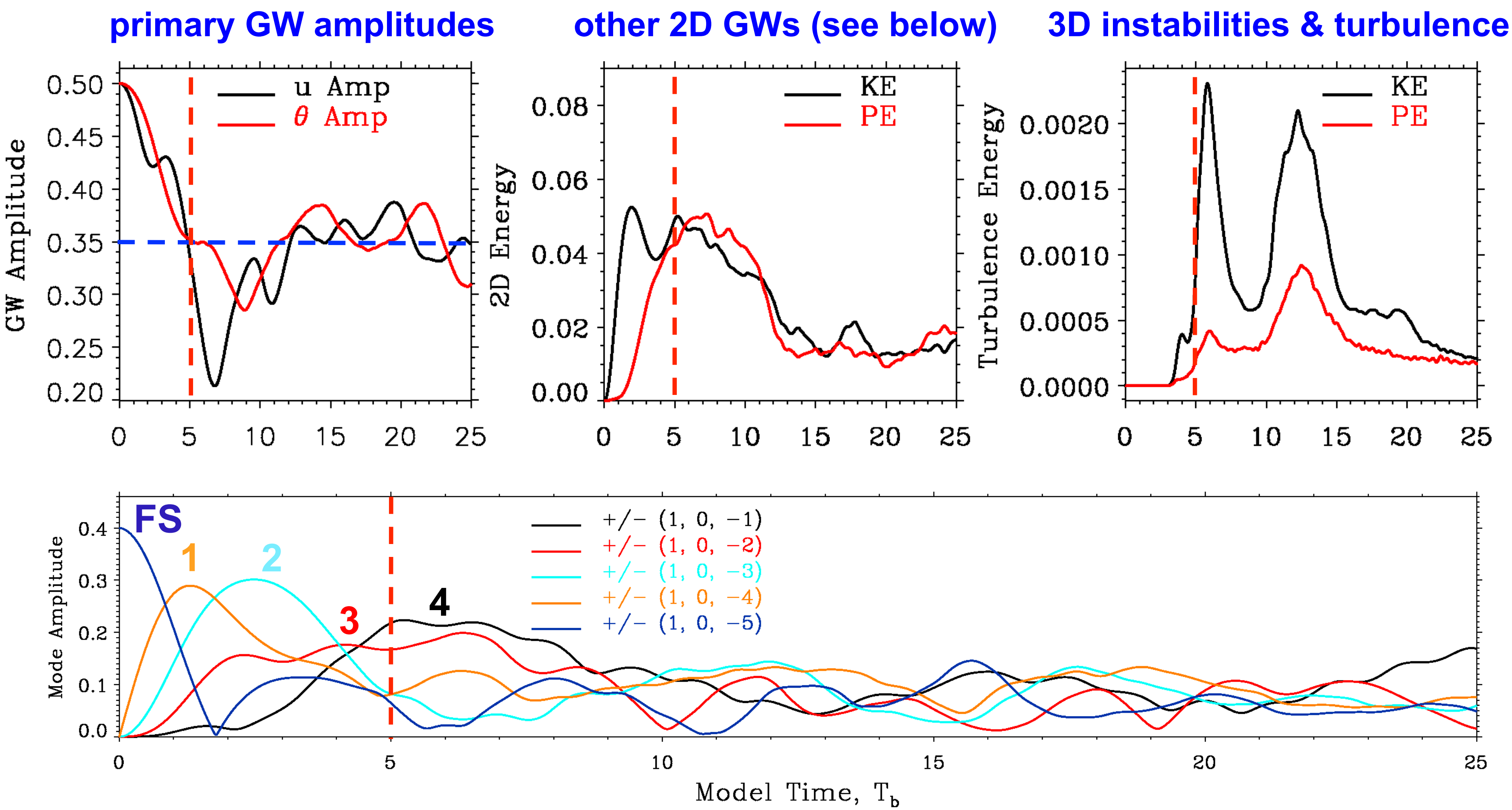
- sheared convective boundary layers



at later stages GW breaking (or intrusions) and KHI dominate
(shown in energy dissipation rate, ε)



GW – FS interactions =>
2D (wave-wave interactions) and 3D (local instabilities) compete



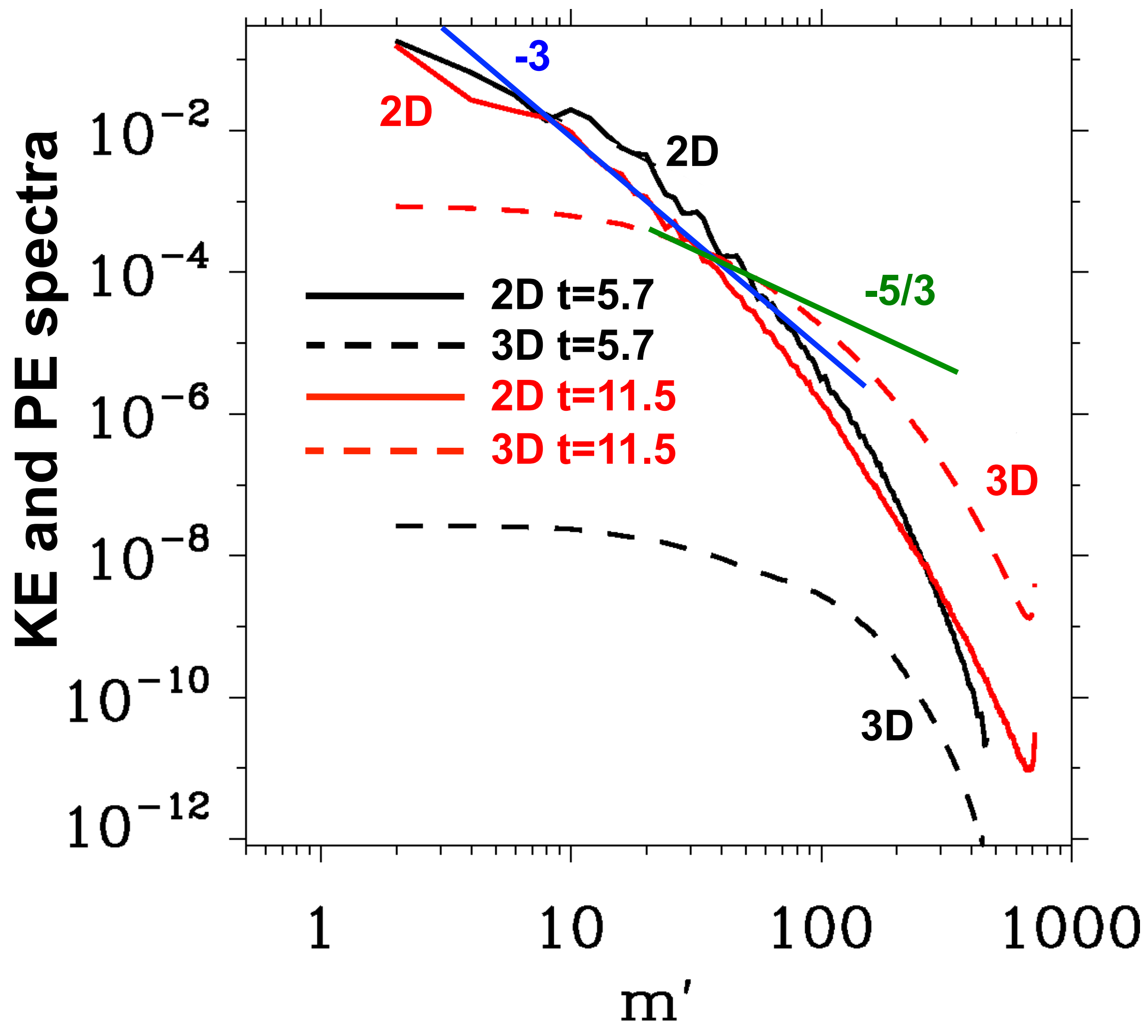
2D GW dynamics and 3D turbulence exhibit clear scale separations, very different spectral shapes

- black spectra show an early time before 3D instabilities and turbulence

- red spectra show a later time after 3D instabilities and turbulence have reduced 2D GW KE and PE

- GWs dominate spectral transfers and shape at large scales

- turbulence dominates at smaller scales

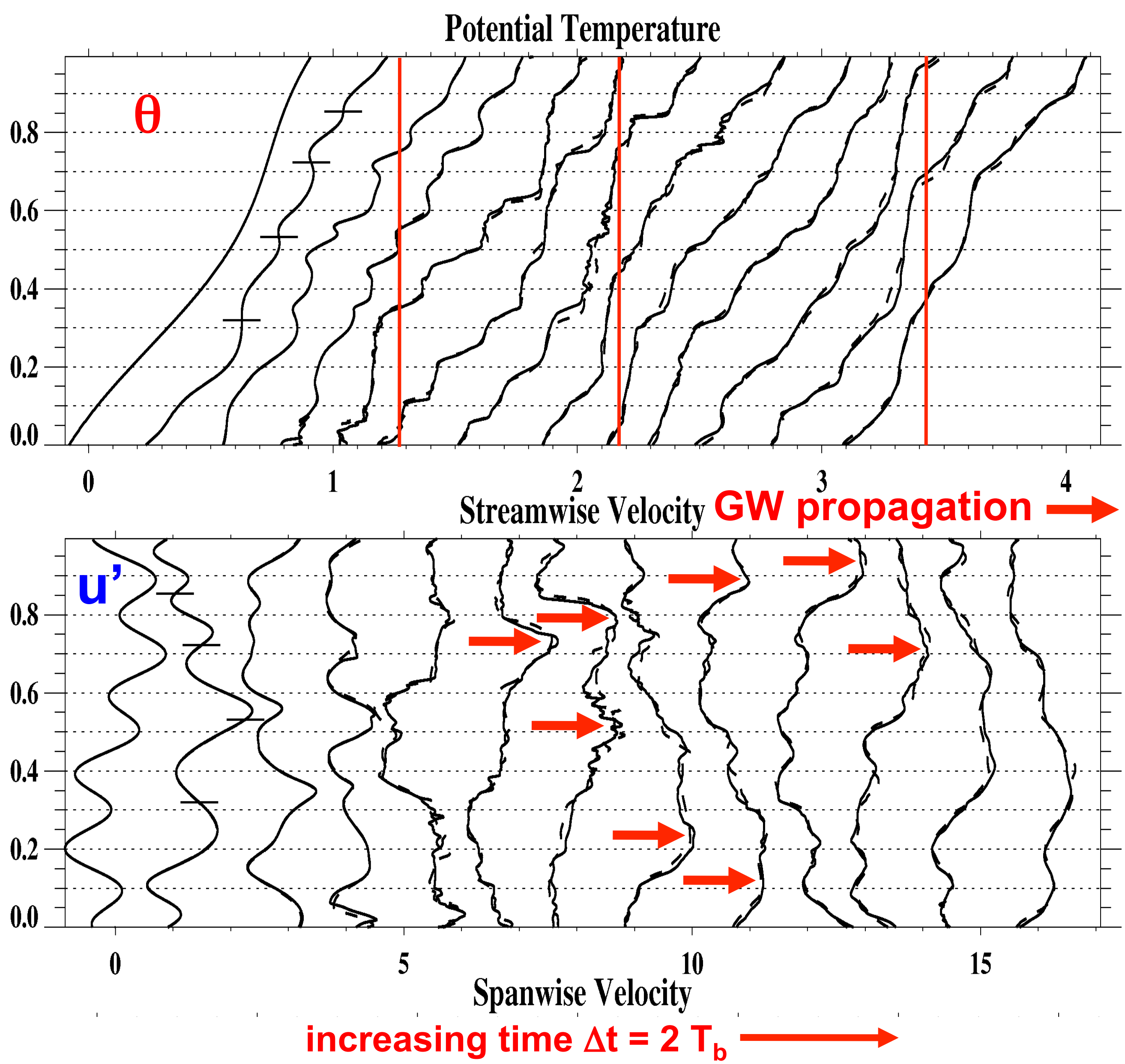


GW – FS interactions =>
complex, highly-structured flows due to sporadic turbulence & mixing

temperature profiles exhibit "sheet and layer" structure during active turbulence

major turbulence sources accompany maximum streamwise motions along GW propagation

velocity FS is major source of turbulence energy, decreases with time due to instabilities



Conclusions

- Multi-scale GW interactions are a major driver of GW spectral evolution and instabilities throughout atmosphere

- Both *wave-wave interactions* and *local instabilities* contribute, but in different ways and at different times

- *Wave-wave interactions* drive spectral energy transfers and a 2D m^{-3} spectrum

- *Local instabilities* cause turbulence and dissipation and a 2D m^{-3} spectrum

- Layered mixing yields persistent “sheet and layer” structures

- predicted energy dissipation rates are consistent with measurements throughout the atmosphere (not shown)