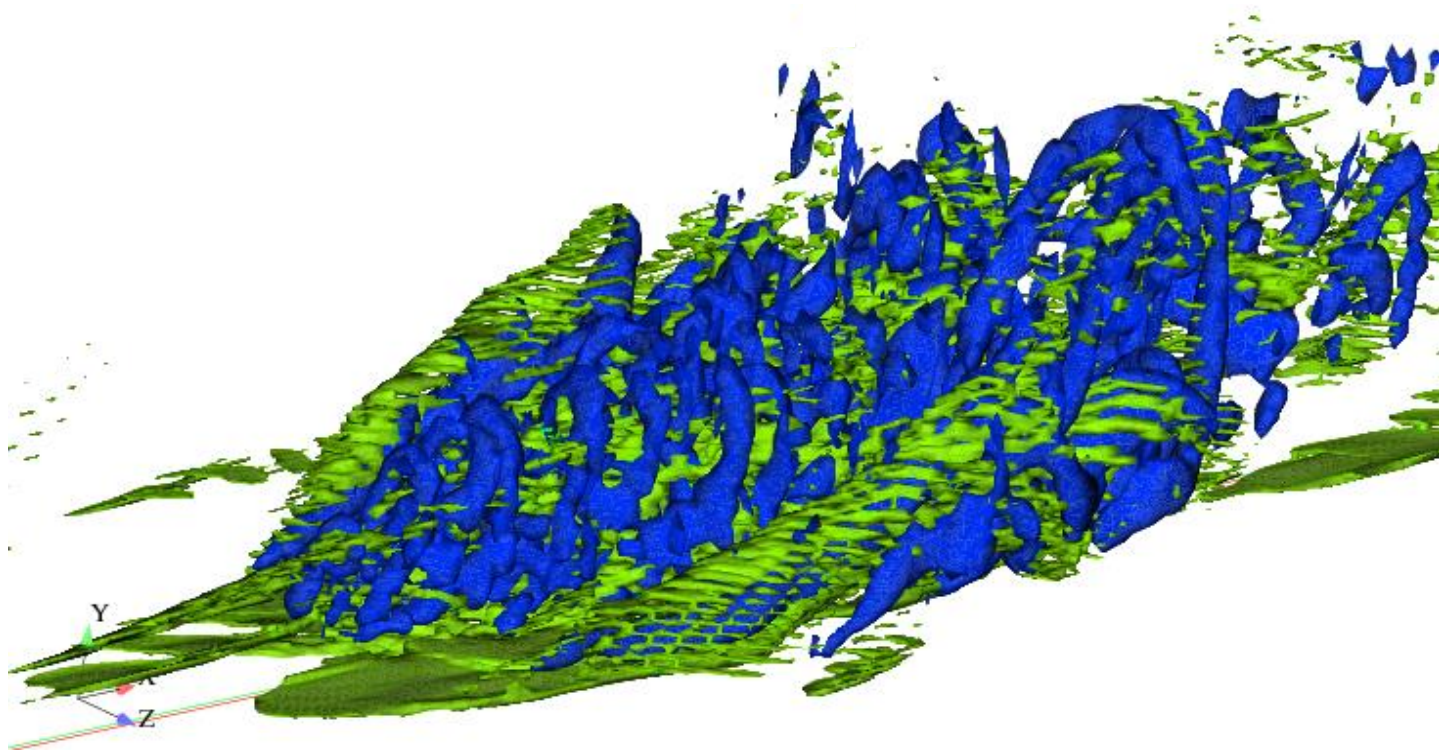
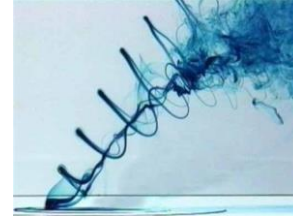
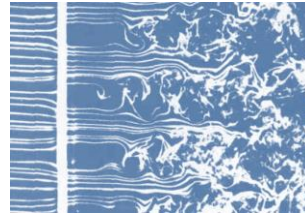


The Elusive Onset of Turbulence And the Laminar-Turbulence Interface

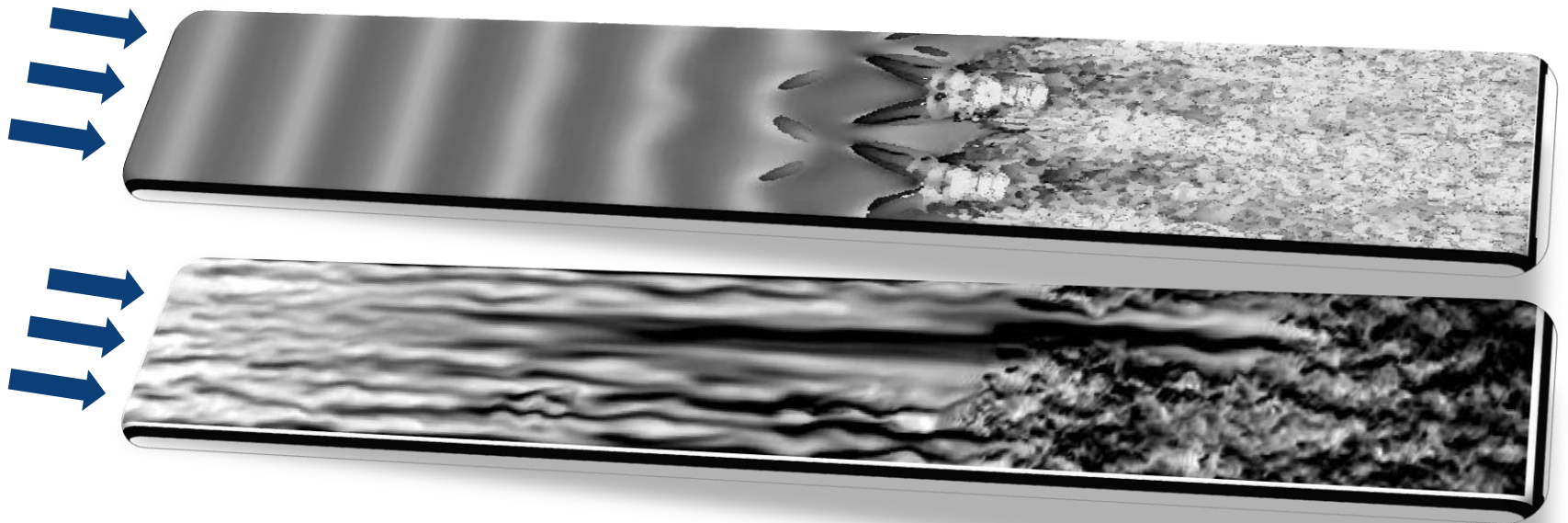


Transition to turbulence

- Breakdown of organized *laminar* motion into chaotic flow, or *turbulence*, is an intriguing phenomenon.

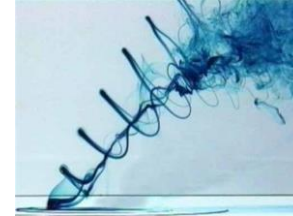
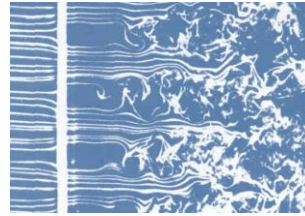


- The path to turbulence is not unique...
- ...even in the same flow configuration

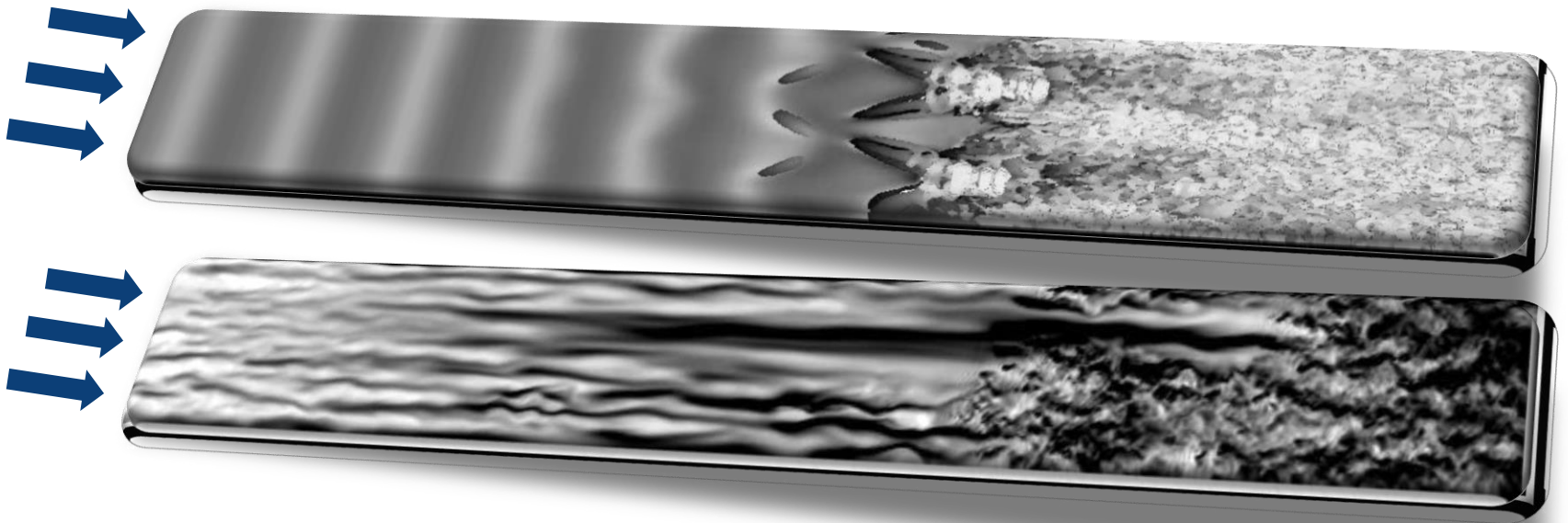


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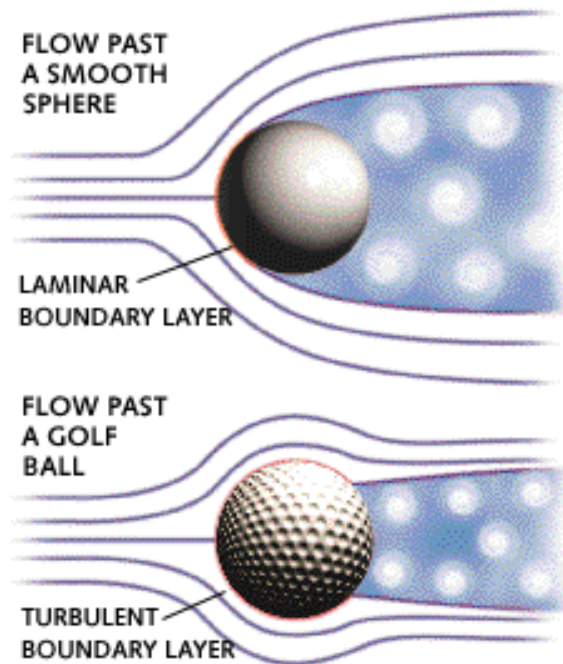


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Characteristics

- **Transition to turbulence**
 - enhances mixing
 - enhanced momentum transport

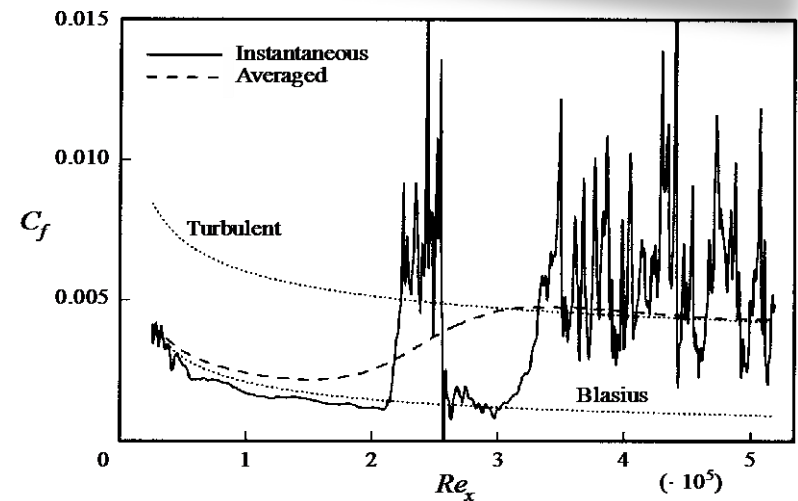
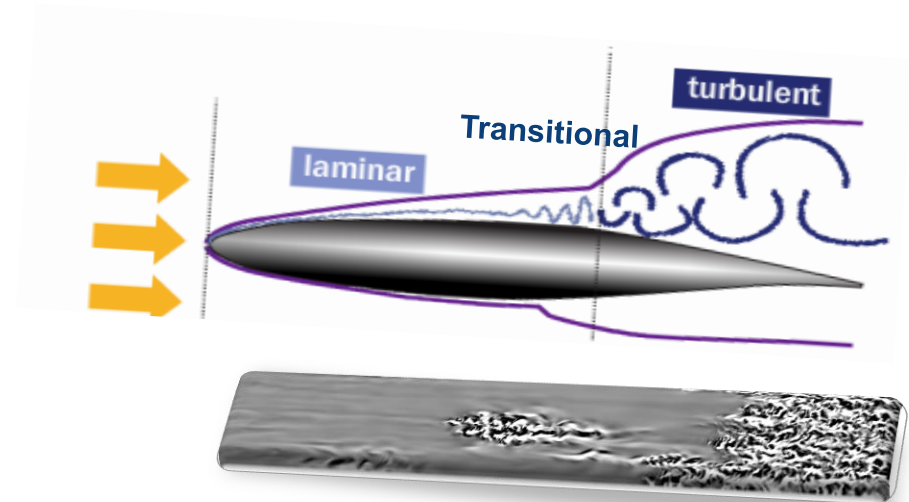
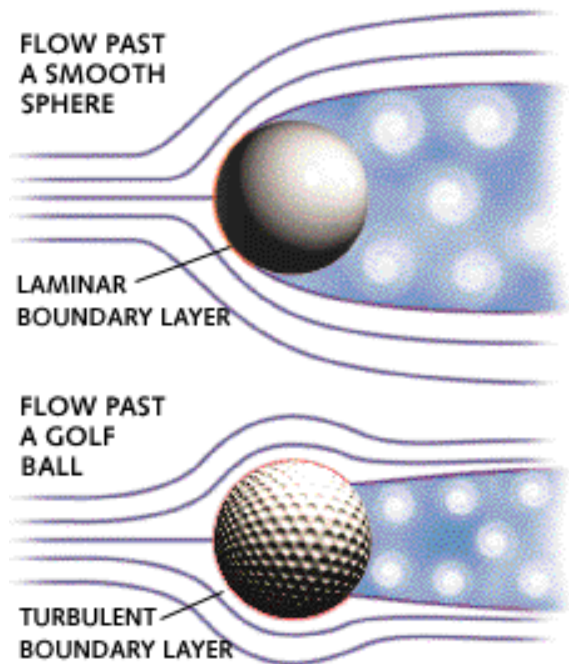


Characteristics

- **Transition to turbulence**

- enhances mixing
- enhanced momentum transport

- increases skin friction drag
- Increases heat transfer rates

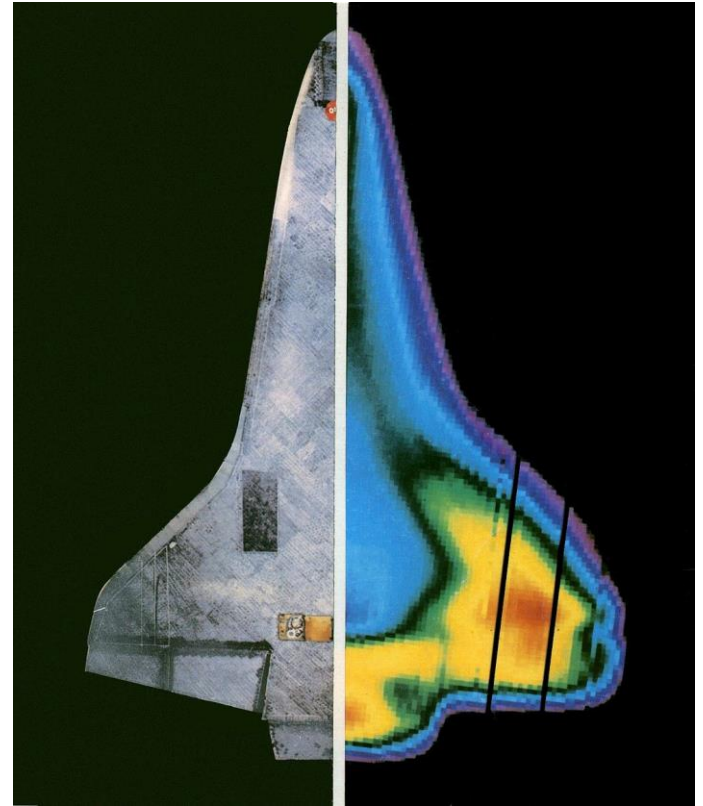


Hypersonic flight



Hypersonic flight

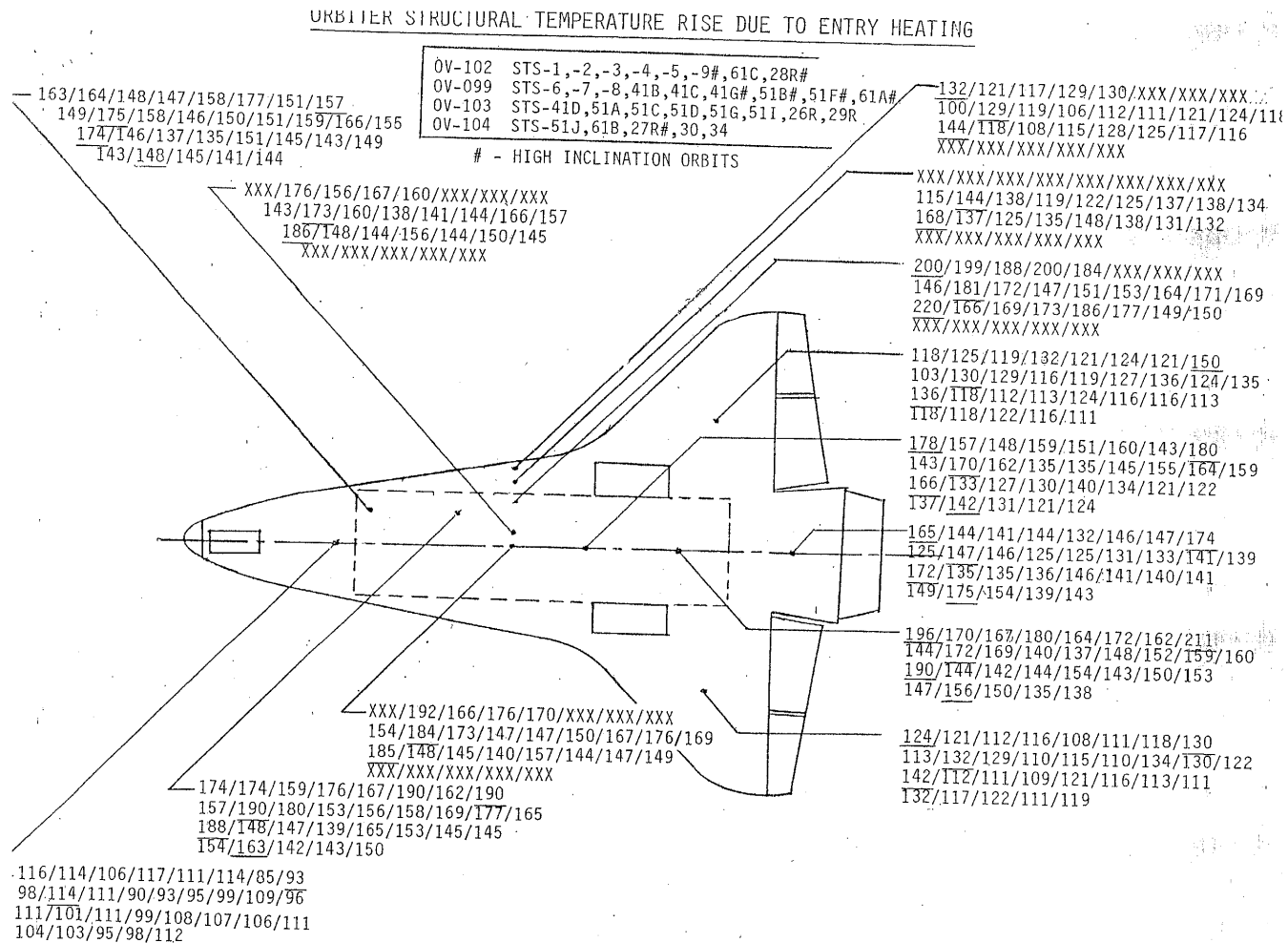
- **Columbia: STS 28R (8th flight)**
 - Thermal image from earlier mission (STS 3) shows the effect of turbulent heating.
 - Post-flight analysis of STS-28R discovered unusual heating of the thermal protection system (TPS) during re-entry “caused potentially by an early transition to turbulent flow around the vehicle”.
 - Columbia STS 107 (28th flight)
- **Discovery STS 114**
 - First "Return to Flight"
 - Nearly 2.5 years after Columbia



Infrared image of Columbia STS 3

Hypersonic flight

STS-28 R Early Boundary Layer Transition



Hypersonic flight



Johnson Space Center- Houston, Texas

STS-28R Early Boundary Layer Transition

Structures and Mechanics Division

J. A. Smith

December 1989

Background

• Boundary Layer Transition from Laminar to Turbulent Flow

• Will Always Occur

- Function of many parameters : Reynolds number (air **density**, **velocity**, **viscosity**); geometry (configuration, angle of attack, **location** on vehicle, vehicle **roughness**); boundary layer (heat transfer); freestream disturbances; vehicle vibrations
- Time of transition (for same entry trajectory) primarily dependent on vehicle roughness
- Roughness, commonly referred to as K_{eq} or, "equivalent roughness", is divided into two types:
 - **Discrete** roughness - One single large protuberance results in boundary layer transition
 - **Distributed** roughness - Many small protuberances results in boundary layer transition

Hypersonic flight



Johnson Space Center- Houston, Texas

STS-28R Early Boundary Layer Transition

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- STS-28 (Continued)

- Questionable "Double Transition" Data and Transition Time (V07T9478, Centerline and V07T9480 port side at same X location) (See Next Page)

- (1) - If data is "good" during this time interval, it shows that transition from laminar to turbulent flow occurred at approx. 900 seconds, then went back to laminar flow at 1000 seconds for V07T9478 and 950 seconds for V07T9480, then returned to turbulent flow.

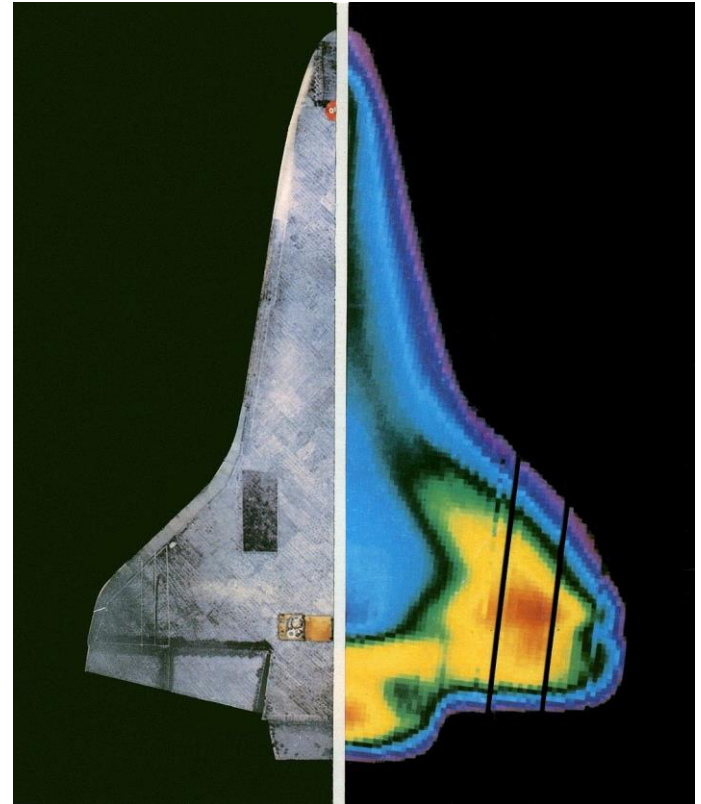
- May possibly result from protruding AMES gap fillers, causing the first transition to occur; then (after burning out or softening the RTV) the gap filler layed over, allowing return to laminar flow before the final transition to turbulent flow

OR - (2) - If the data is "not good", but really reacts as shown by dashes, it negates the first transition time

BUT Laminar peak temperatures would be higher than ever recorded in these locations and, Thermal Analysis shows that structural temperatures would not correlate with the higher laminar temperatures

Hypersonic flight

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Hypersonic flight

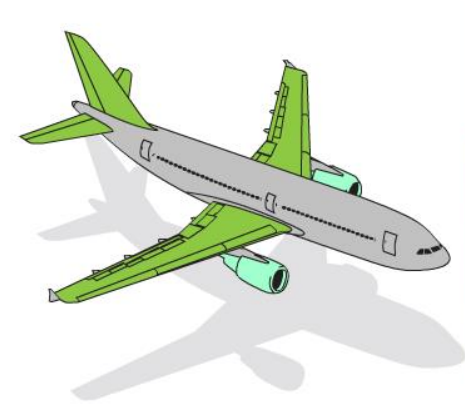
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Civil aviation

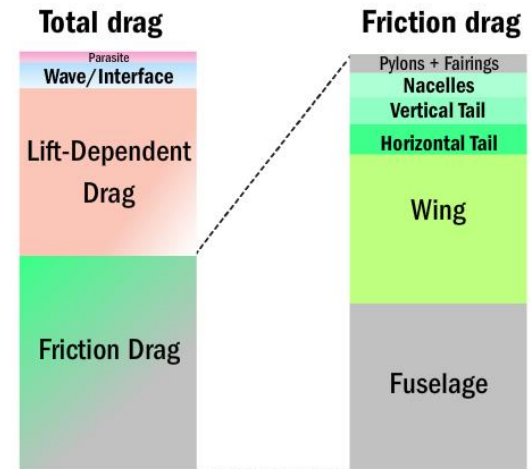
- **Civil aviation**

- Skin friction is 30-50% of total drag
- The wings offer highest potential for friction-drag reduction
 - Laminar flow over 50% of suction surface translates into 5-7% total drag reduction
- Reduction goals for 2020
 - Aircraft drag by 10%, wing drag by 20%



- **Jet engines**

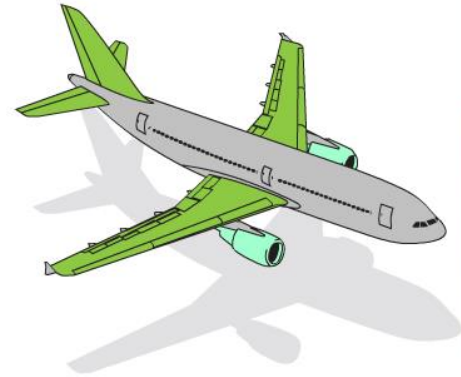
- Compressor aerodynamics
 - Flow separation can lead to catastrophic stall
 - Transition to turbulence mitigates stall risk
- Turbine
 - 20-30% of engine weight
 - 50% of the airfoil chord is transitional flow
 - More aggressive designs for light weight have transition as a key design parameter



Civil aviation

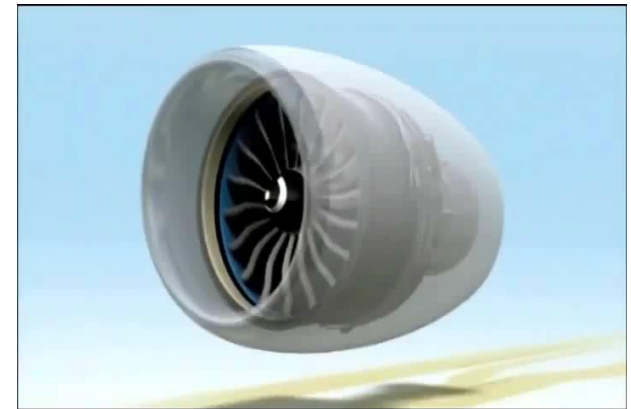
- **Civil aviation**

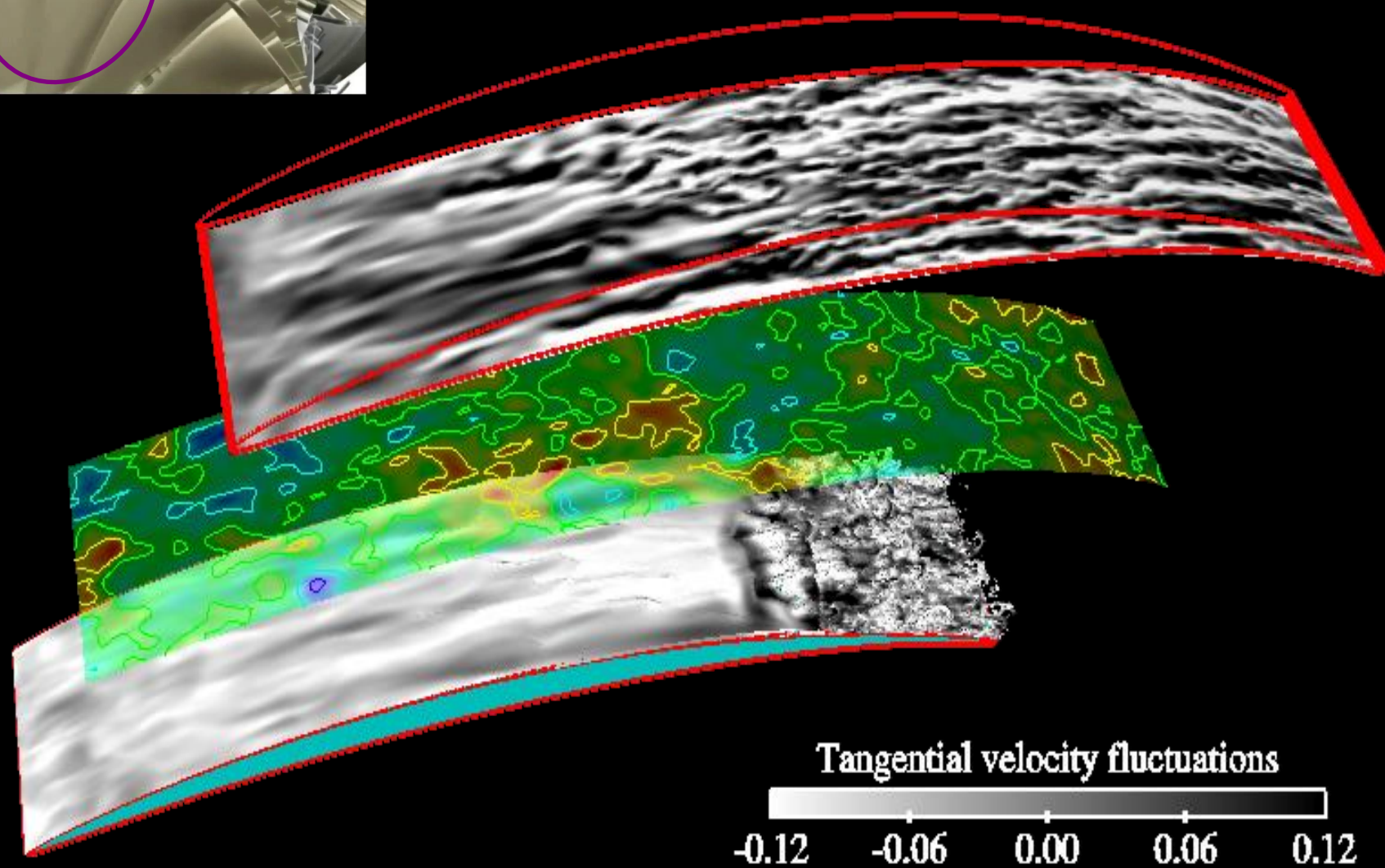
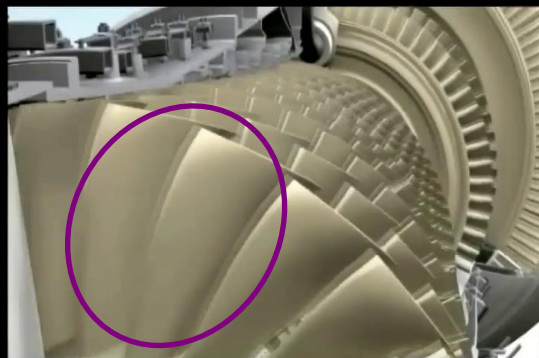
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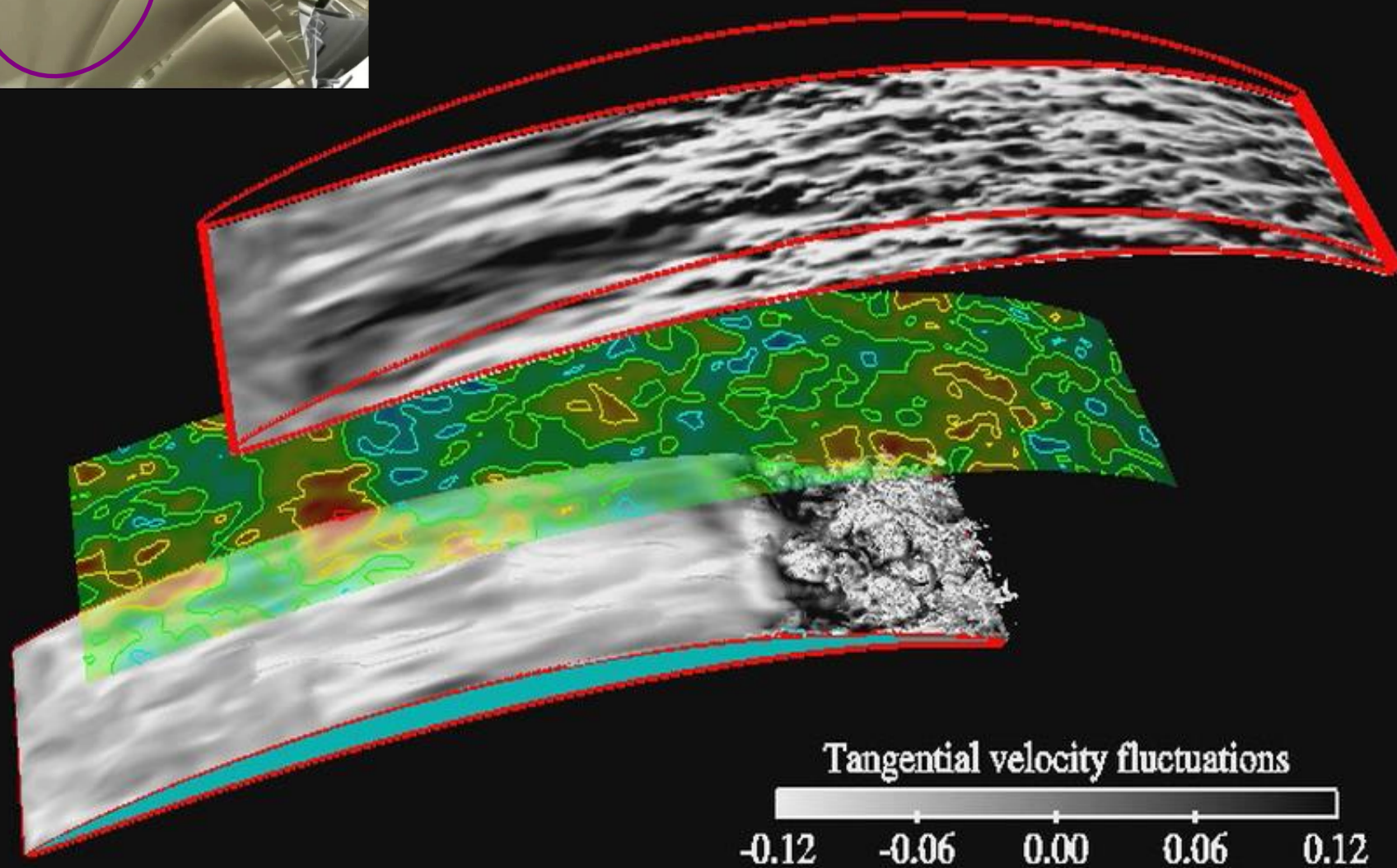
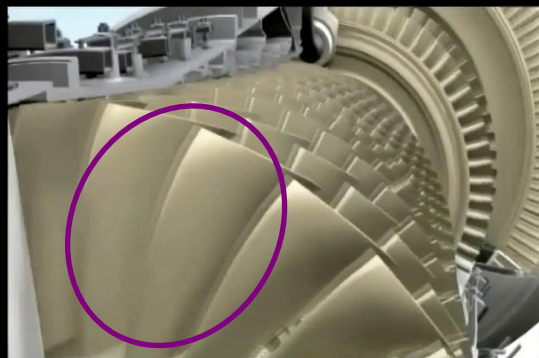


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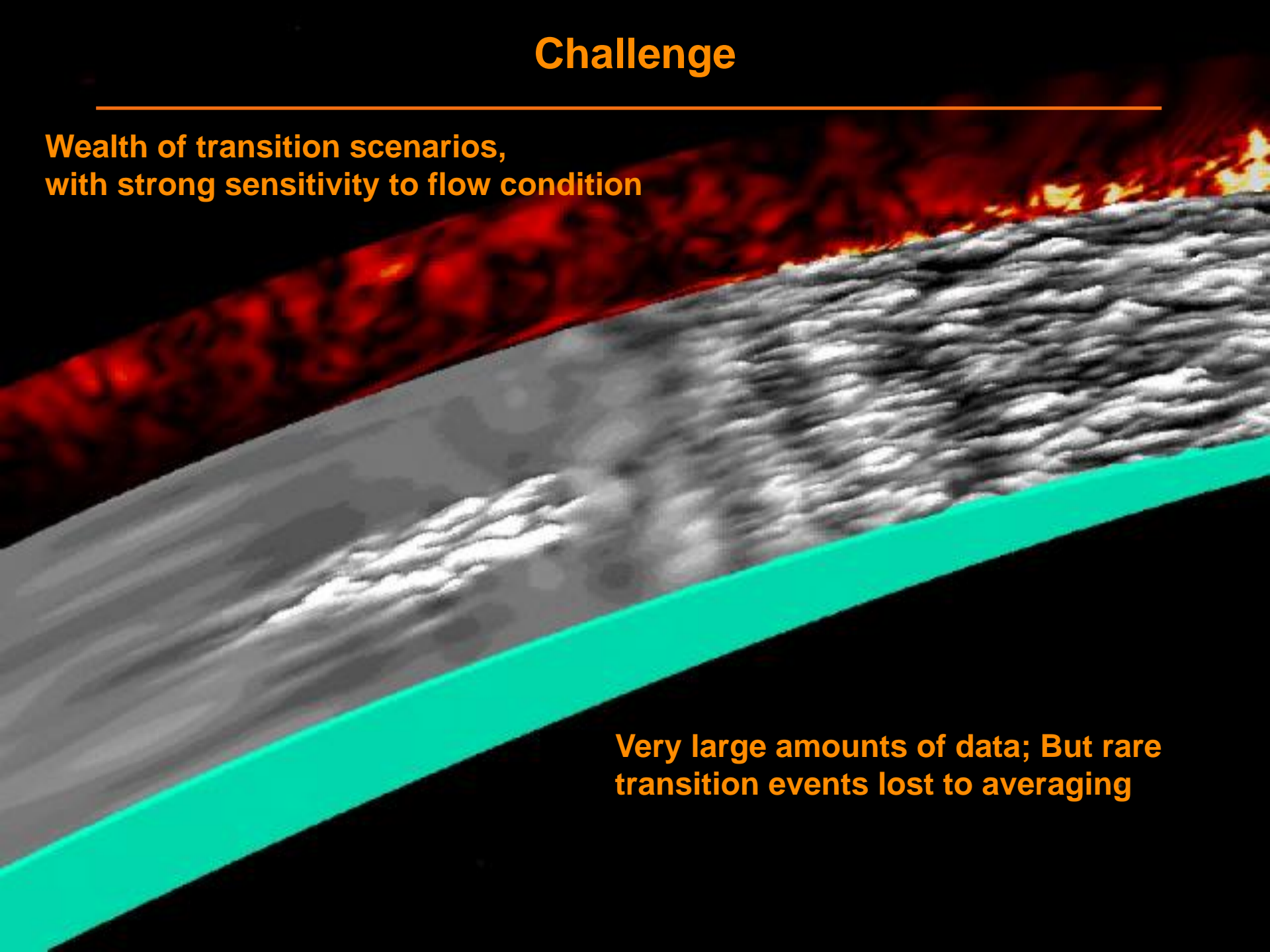




Challenge

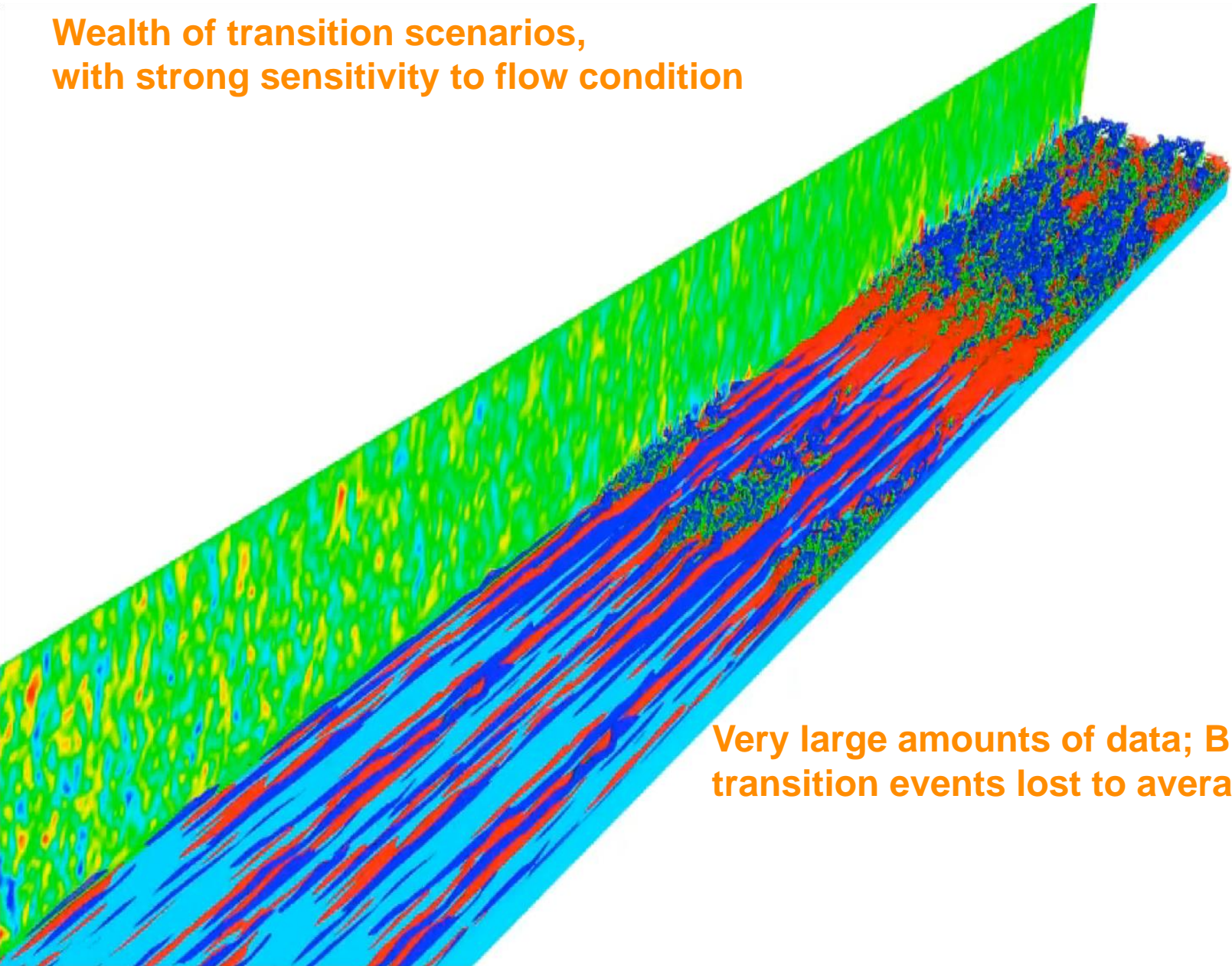
Wealth of transition scenarios,
with strong sensitivity to flow condition

Very large amounts of data; But rare
transition events lost to averaging



Opportunity

Wealth of transition scenarios,
with strong sensitivity to flow condition

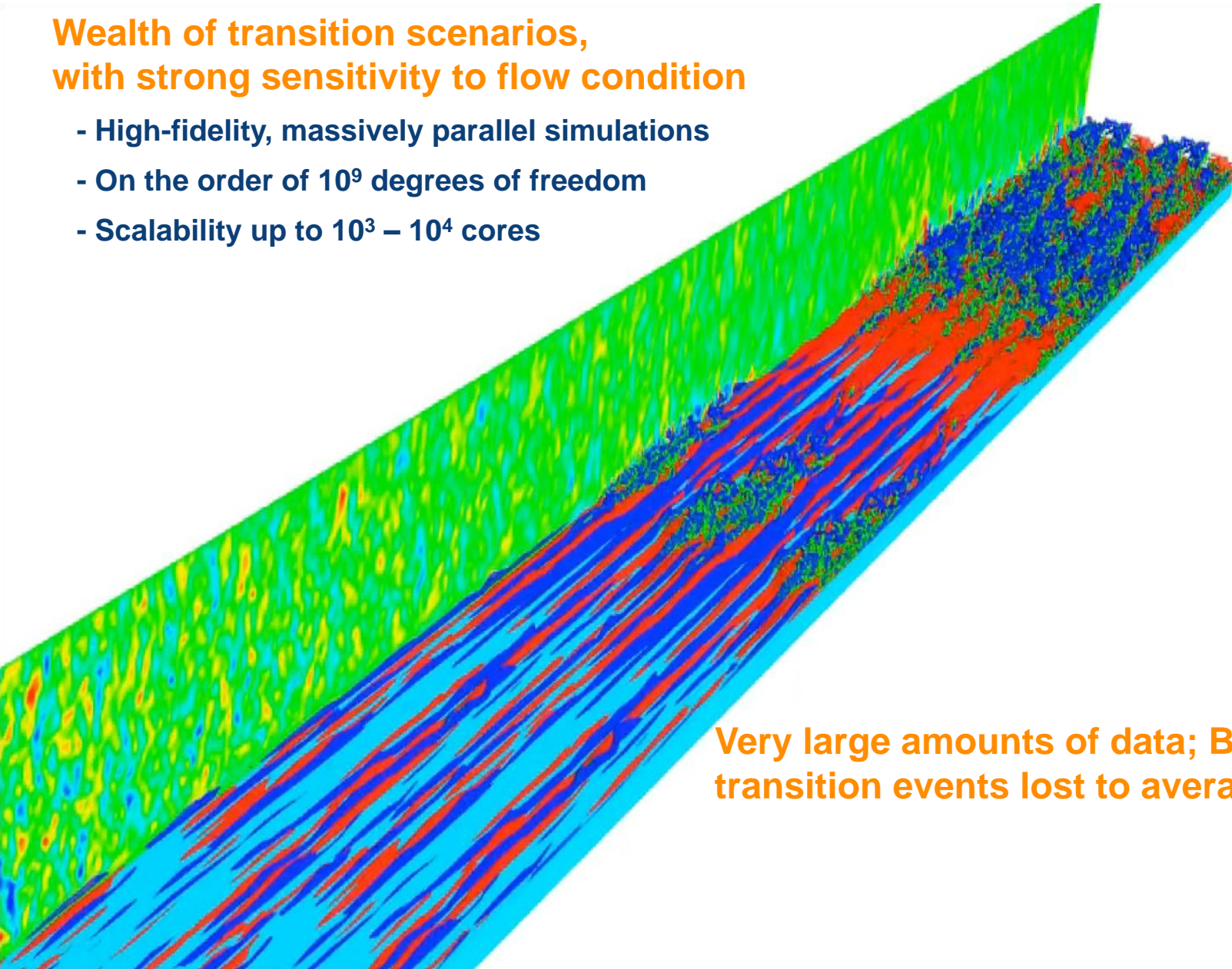


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Opportunity

Wealth of transition scenarios,
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- High-fidelity, massively parallel simulations
- On the order of 10^9 degrees of freedom
- Scalability up to $10^3 - 10^4$ cores

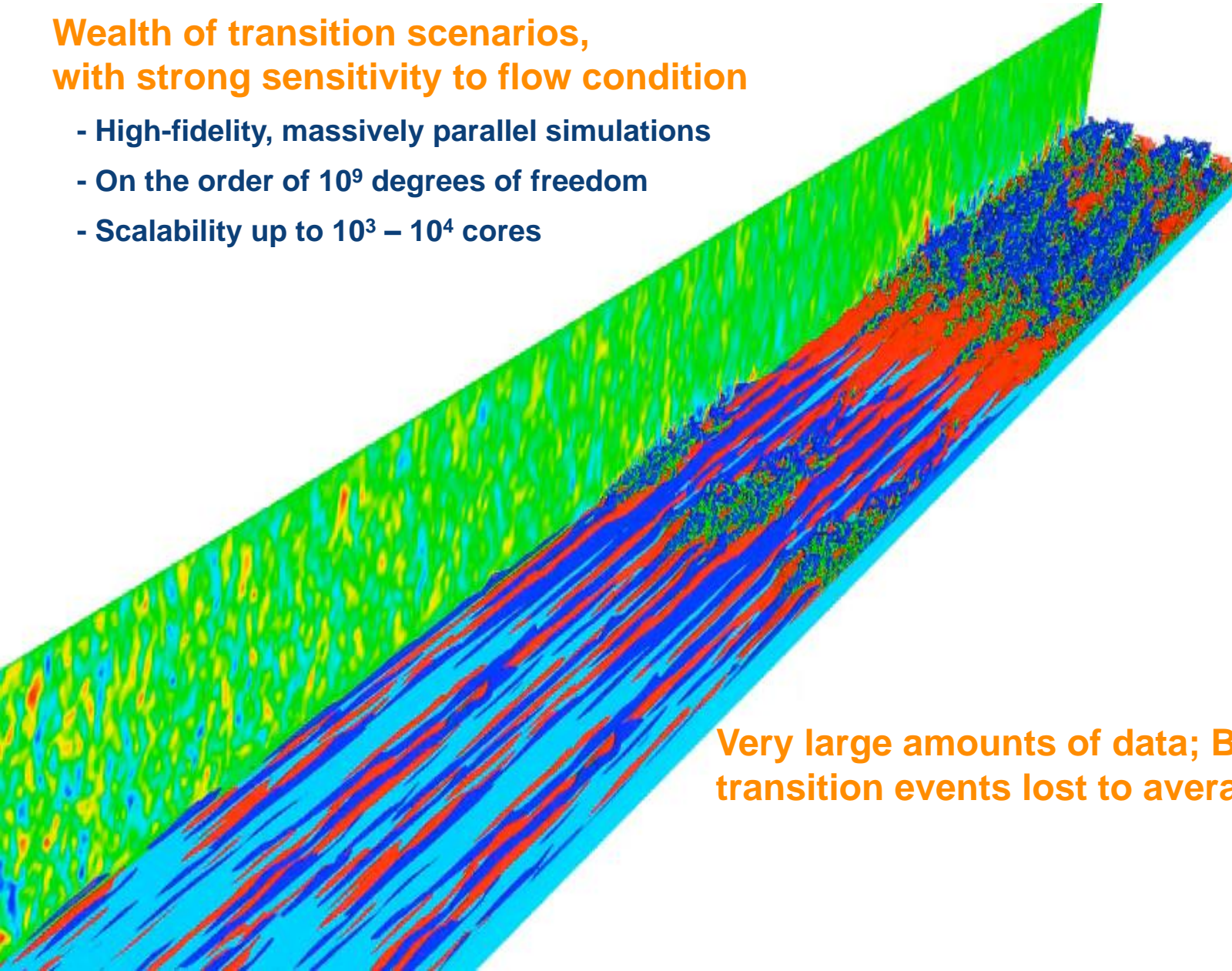


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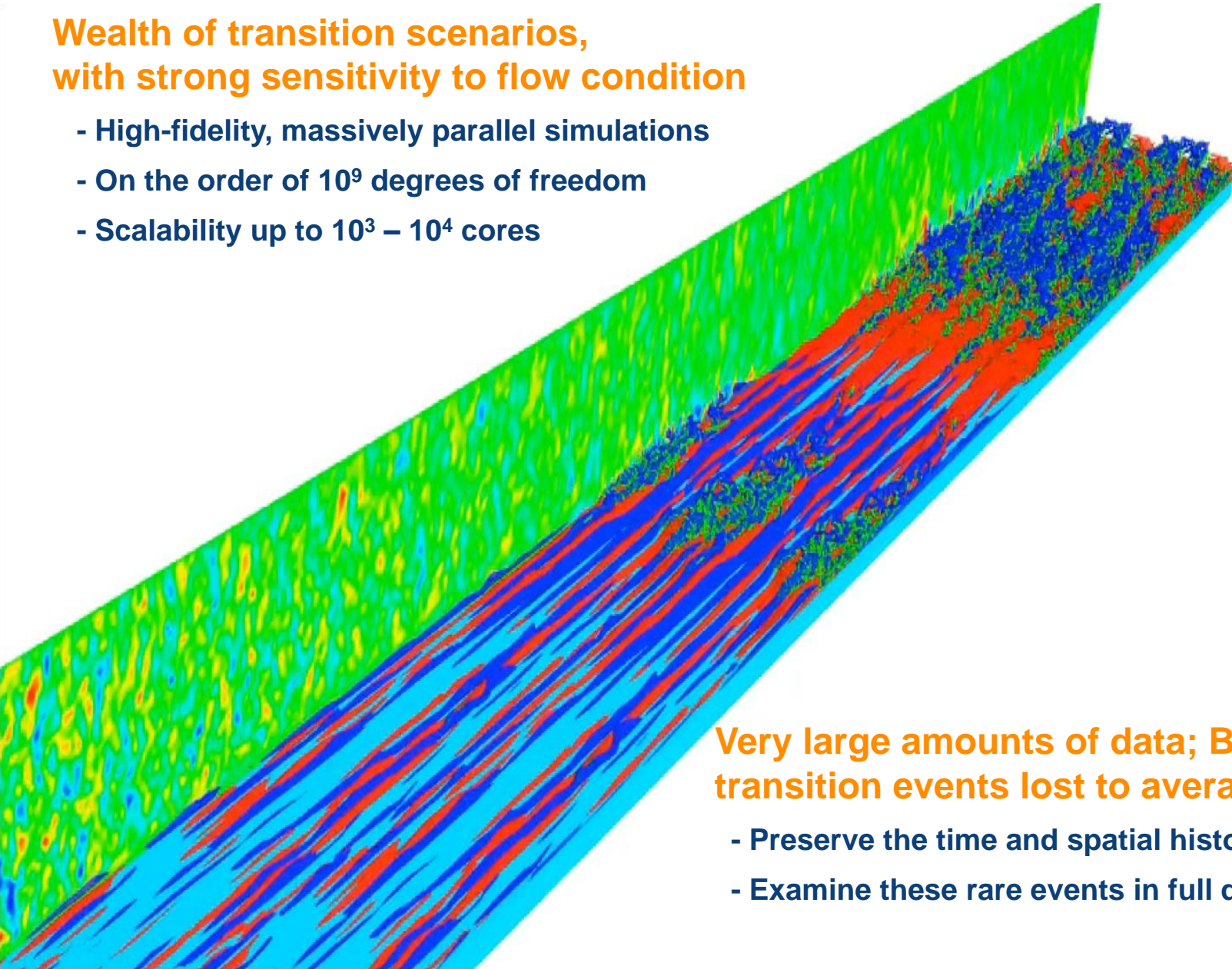


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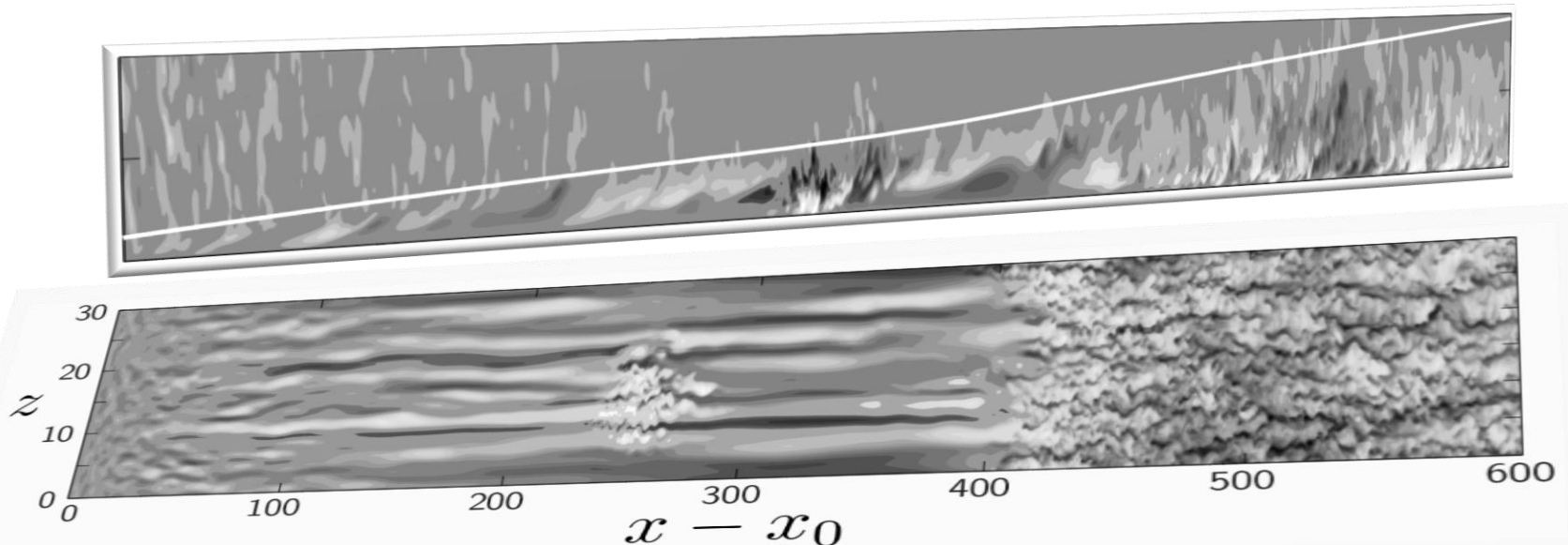


Very large amounts of data; But rare
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- Preserve the time and spatial history of the flow
- Examine these rare events in full detail

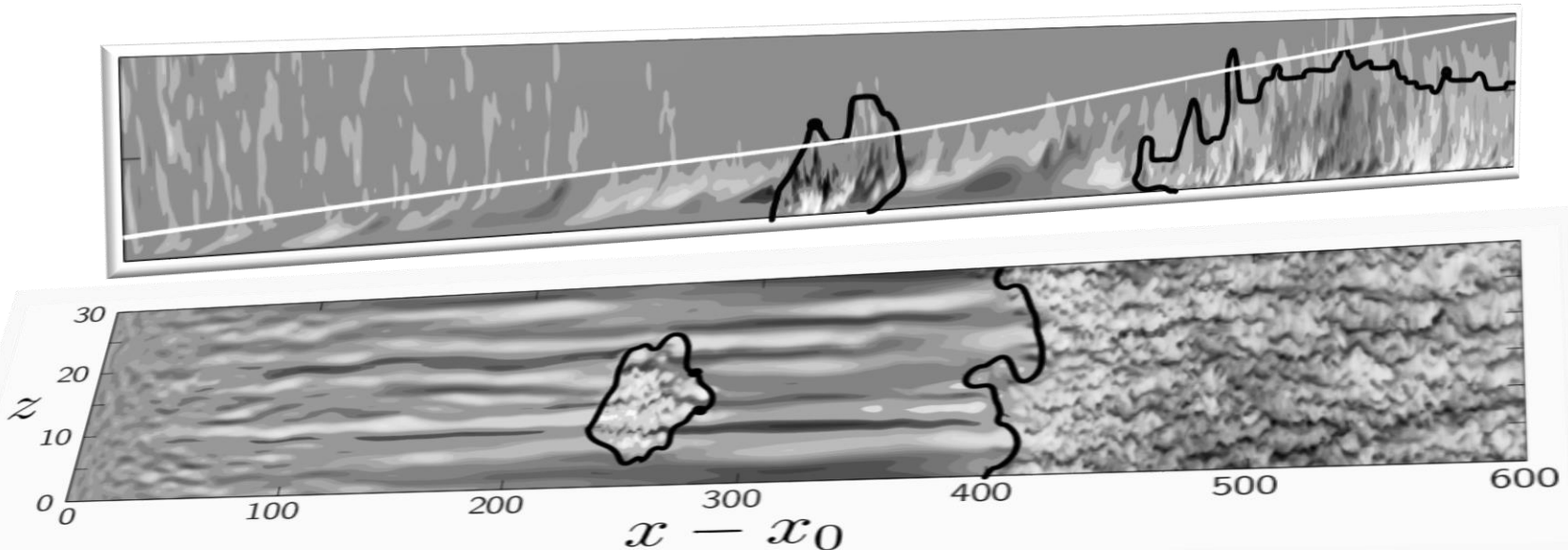
IDIES project

- An “observatory” for transition phenomena
 - First complete temporally and spatially resolved database of laminar-to-turbulence transition
 - The entire time history from laminar, through transition and into the turbulent regime (~100 TB)
 - On-demand access to transition events and their evolution
 - Probe the precursors on transition onset
 - Provide benchmark for predictive transition modeling



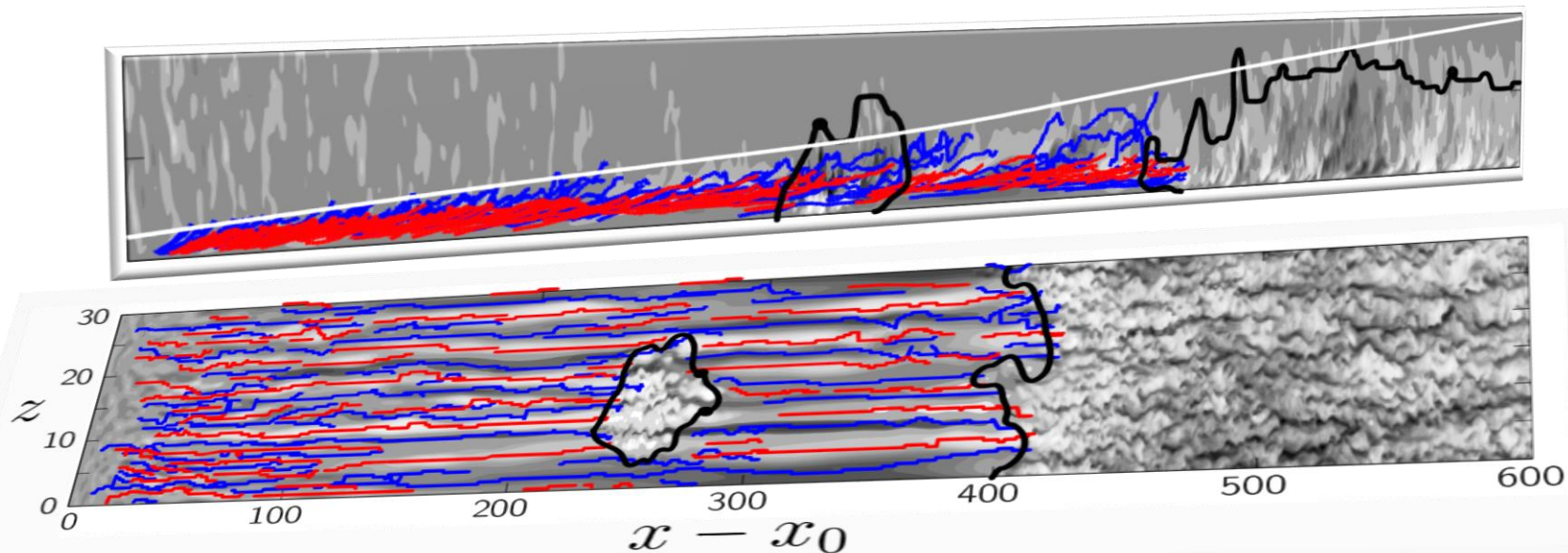
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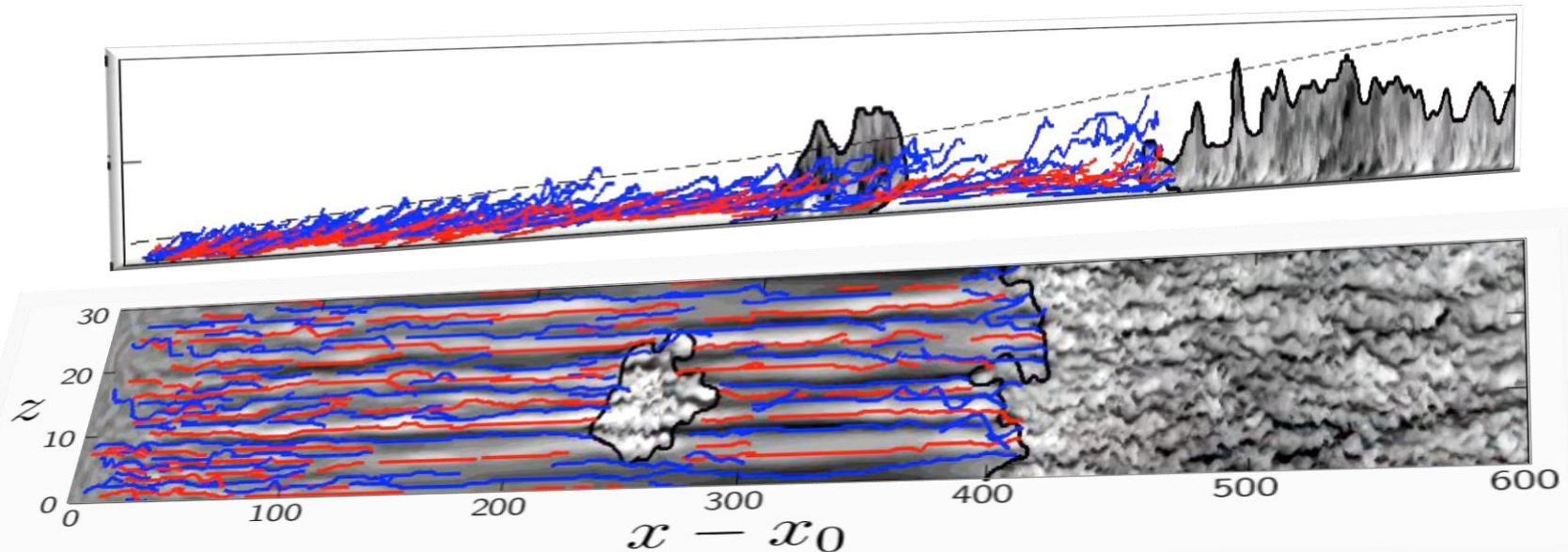
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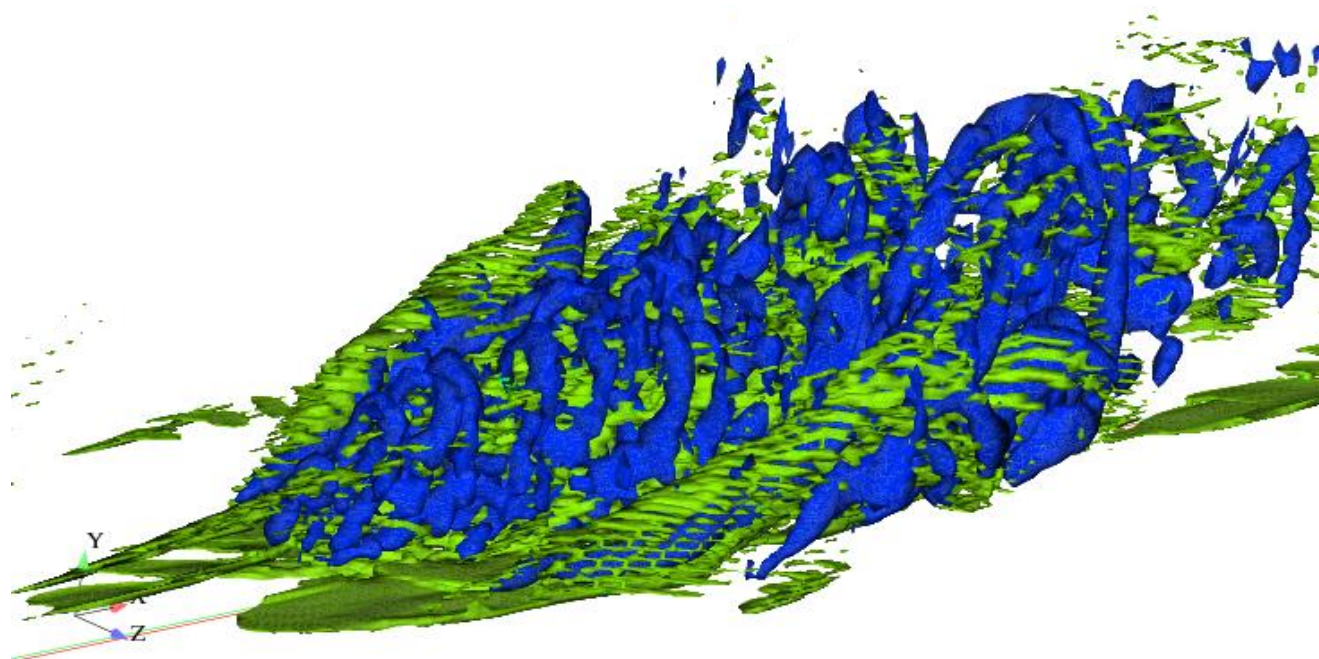
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