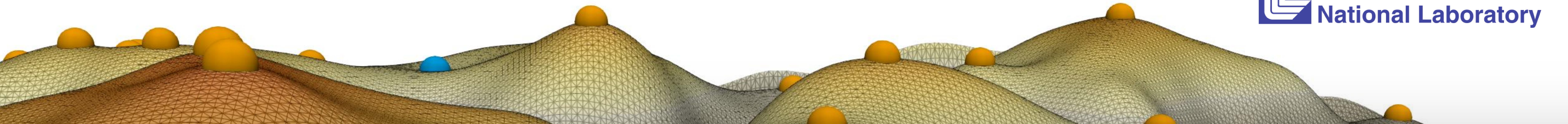
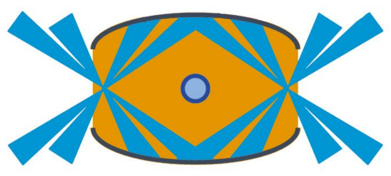
Topological Data Analysis of 3D Ablative Rayleigh-Taylor Instability Dataset for Automatic Segmentation



Fabien Vivodtzev, Alexis Casner, Laurent Masse, *French Atomic Energy Commision*
Luke Ceurvorst, *Laboratory of Laser Energetics,* **Shahab Khan, Vladimir Smalyuk** *Lawrence Livermore National Laboratory*

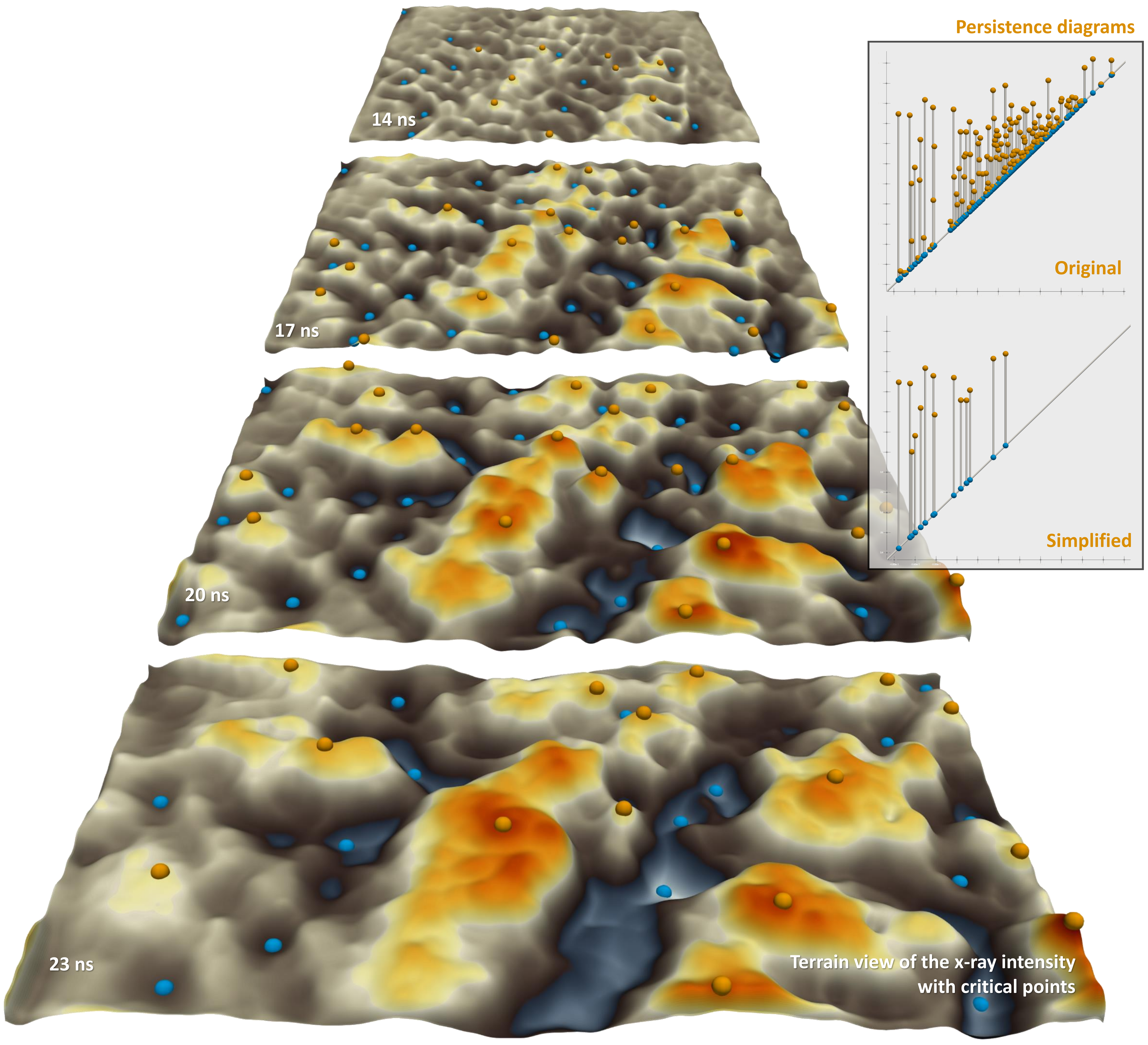
HYDRODYNAMICS INSTABILITIES ON THE NIF



National Ignition Facility [19] used to drive Dedicated Discovery Science campaigns [6] in order to better understand the growth [5] and possibly control mechanisms of Hydrodynamics instabilities.

Hydrodynamics instabilities [4] present in Inertial Confinement Fusion (ICF) capsules are one of the major drawbacks [15] on the road towards higher energy gains [1] necessary for future Inertial Fusion energy powerplants.

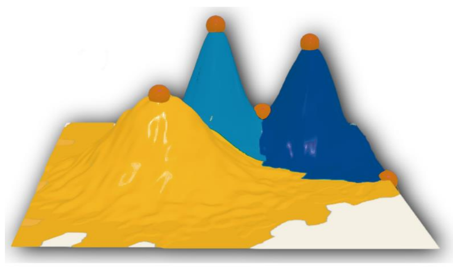
Ablative Rayleigh Taylor instability gives birth at its highly nonlinear stage to complex 3D patterns when starting from imprinted perturbations imposed by the laser focal spots [7]



Terrain view of the x-ray intensity with critical points

TOPOLOGICAL DATA ANALYSIS

Watershed segmentation and threshold of the input images traditionally [8,17] rely heavily on parameters defined by the observers.



Topological Data Analysis [9, 20] helps to identify hidden patterns in the structure of the data and ease the comparison between members of ensembles. Especially, Persistent Homology [10] measures topological features of shapes and of functions by tracking topological changes of a changing space. The utility of TDA has been already demonstrated in many fields [13], with examples of successful applications in medical imaging [18], fluid dynamics [16] or combustion [12].

The persistence diagram [9] which represents the birth and death of specific features of interest along a filtration. **Merge and contour trees** [2] describe the connectivity evolution of level sets. **The Morse-Smale complex** [11] is another structure using integral lines to describe area of a manifold regarding to its monotonic behavior.

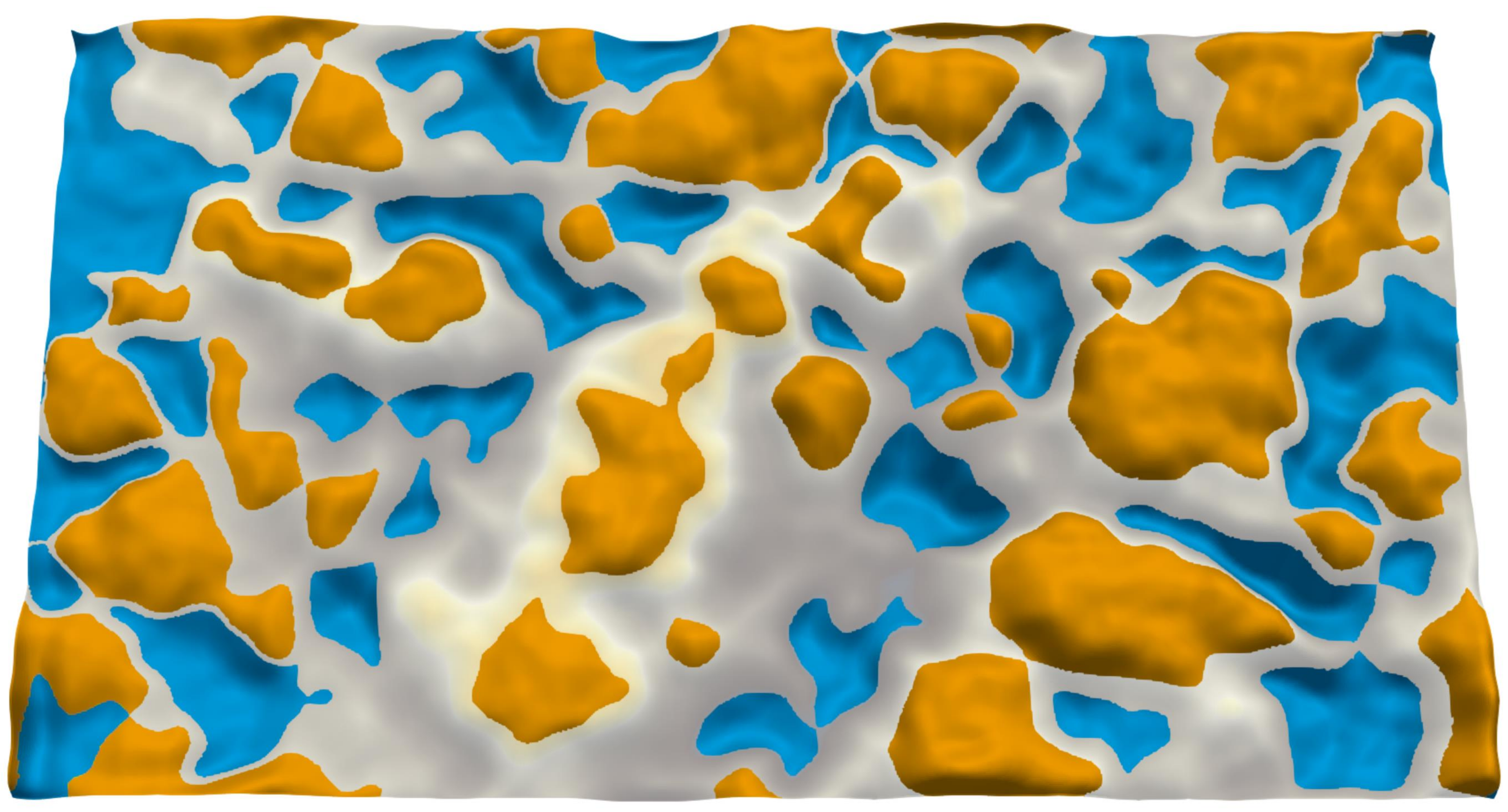
Paraview [3] and the **Topology Toolkit** [21] used to explore dataset (NI180212, NI180213) trough different visualization pipelines. TTK allow us to extract all the necessary topological structures.

CONTRIBUTIONS

Correlation between the **x-ray pixel intensity** and the bubble structure created during the Rayleigh-Taylor instability development. Pixels of the original image discretized as a **manifold triangle mesh**. Cell centered pixel values interpolated at the nodes define a **discrete scalar field**.

Topological simplification based on the **persistence** of pair of critical points using the persistence diagrams (shown above) and a persistence threshold (0.2). All pairs close to the diagonal of the diagram are removed on the simplified diagram.

Contour-tree built on the scalar field and only the leaves of the tree are kept to segment the valleys (blue regions) and the peaks (orange regions) of the corresponding terrain.



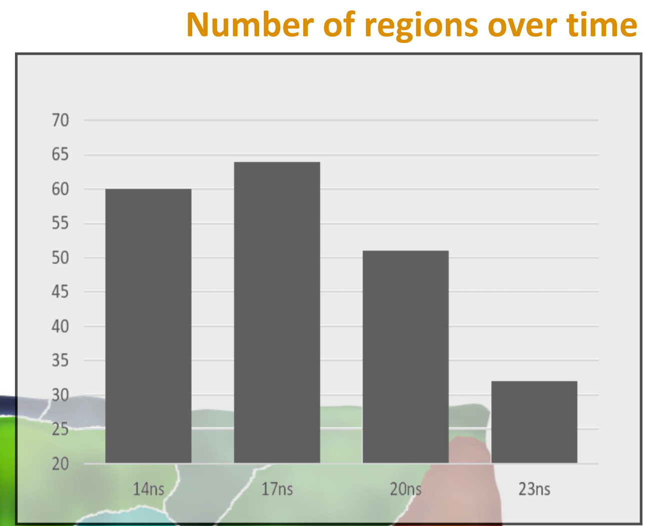
Segmentation by leaves of a simplified contour tree

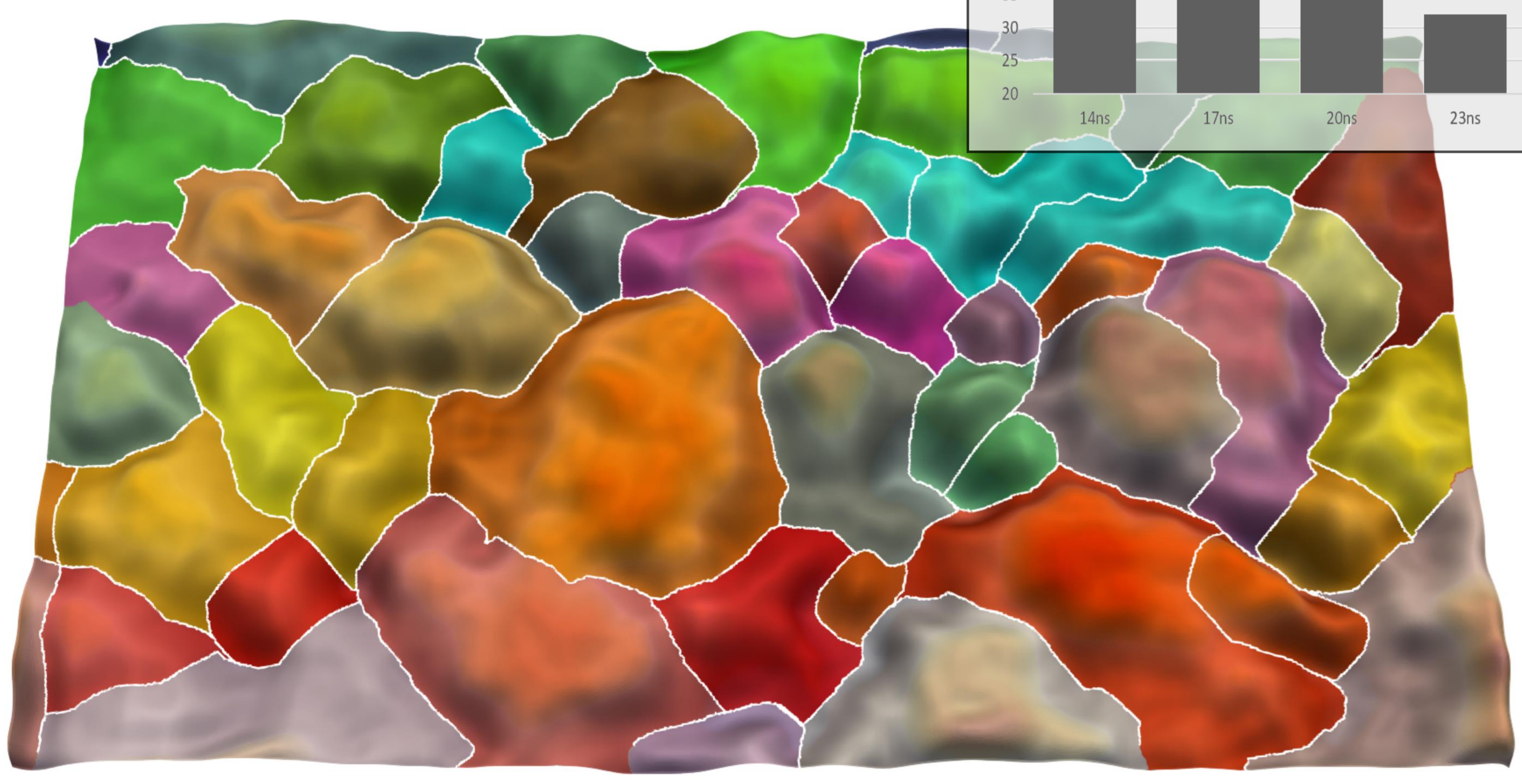
Segmentation based on a **Morse-Smale complex**. The 1-separatrices of the ascending Morse-Smale complex leads to a promising segmentation. The bubbles area are well captured according to the persistence threshold.

Experimental studies based on watershed algorithms show that the number of features segmented at each iteration tends to decrease.

Morse-Smale segmentation successfully captures the expected **decreasing number of bubbles** of the instability over time as shown on the histogram.

Number of regions over time





Segmentation by a simplified ascending Morse-Smale complex

CONCLUSION AND FUTURE WORK

TDA of 3D Rayleigh-Taylor experimental x-ray is a promising approach to automatically analyze complex patterns in ICF. Contour Trees and Morse-Smale complexes extracted from a simplified x-ray based on persistence give promising segmentations.

Work on progress on **bubble association** over time with algorithms based on various distances such as a **distance between merge trees** or the **Wasserstein distance** between persistence diagrams. Extension of the feature tracking strategies to other experimental results and to 3D complex numerical simulations.

ACKNOWLEDGMENTS

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