High-Performance Outlier Detection Algorithm for Finding Blob-Filaments in Plasma

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Outline

What is an outlier ?

An outlier is a data object that deviates significantly from the rest of the objects, as if it were generated by a different mechanism.[1]

- Outliers could be errors or noise to be eliminated
- Outliers can lead to the discovery of important information in data

Outlier detection is employed in a variety of applications:

- fraud detection
- time-series monitoring
- medical care
- public safety and security

[1] Jiawei Han and Micheline Kamber, *Data Mining, Southeast Asia Edition: Concepts and Techniques*, Morgan kaufmann, 2006.

Our goal

Outlier detection is an important task in many safety critical environments.

- An outlier demands to be detected in real-time
- A suitable feedback is provided to alarm the control system
- The size of data sets need fast and scalable outlier detection methods

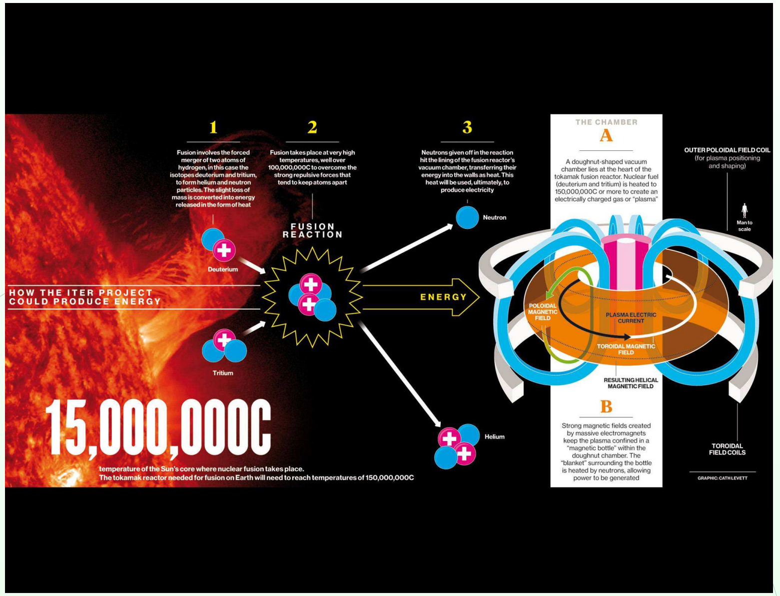
Our goal: apply the outlier detection techniques to effectively tackle the fusion blob detection problem on extremely large parallel machines

- Massive amounts of data are generated from fusion experiments / simulations
- Near real-time understanding of data is needed to predict performance

Blobs in fusion

What is fusion & Why fusion?

- Fusion is viable energy source for the future
- Fossil fuels will run out soon; Solar and wind have limited potential
- Advantages of fusion: inexhaustible, clear and safe



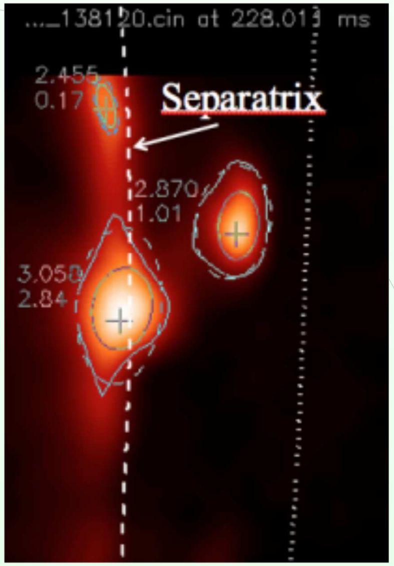
Blobs in fusion

Blobs are intermittent bursts of particles near the edge of the confined plasma

$\Rightarrow$ Driven by turbulence

Blobs are bad for fusion performance because they:

- Transport heat and particles away from the confined plasma
- May damage the main chamber wall
- Lead to increased levels of neutrals and impurities, bypassing control mechanisms

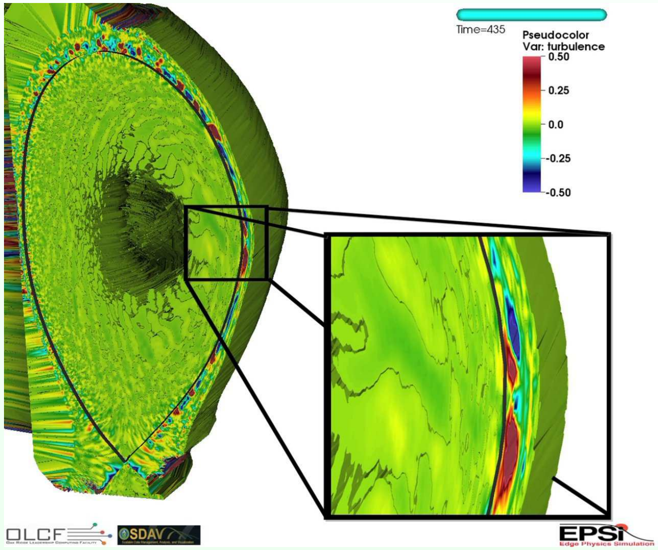


Blob detection is a very important task!

Big data challenges in fusion energy

Fusion experiments generate massive amounts of data:

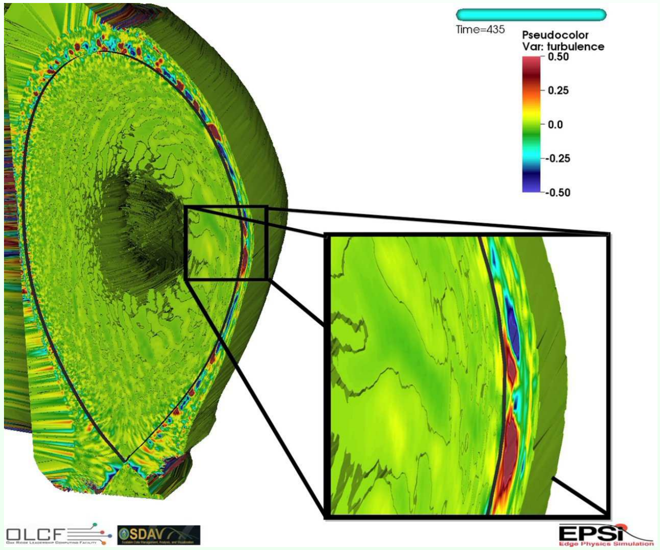
- Diagnostics measuring lasts from a few to several hundred seconds generating large amounts of data, $\sim$ Gigabytes to Terabytes!
- Large-scale fusion simulation generates $\sim$ a few tens of Terabytes per second!



Big data challenges in fusion energy

Difficulties in large-scale data analysis:

- Existing data analysis is often a single-threaded, slow, and only for post-run analysis
- Fusion experiments demand real-time data analysis
- E.g. ICEE aims to apply blob detection for monitoring health of fusion experiments in KSTAR



Real-time blob detection is a very challenging task!

Three approaches for blob detection

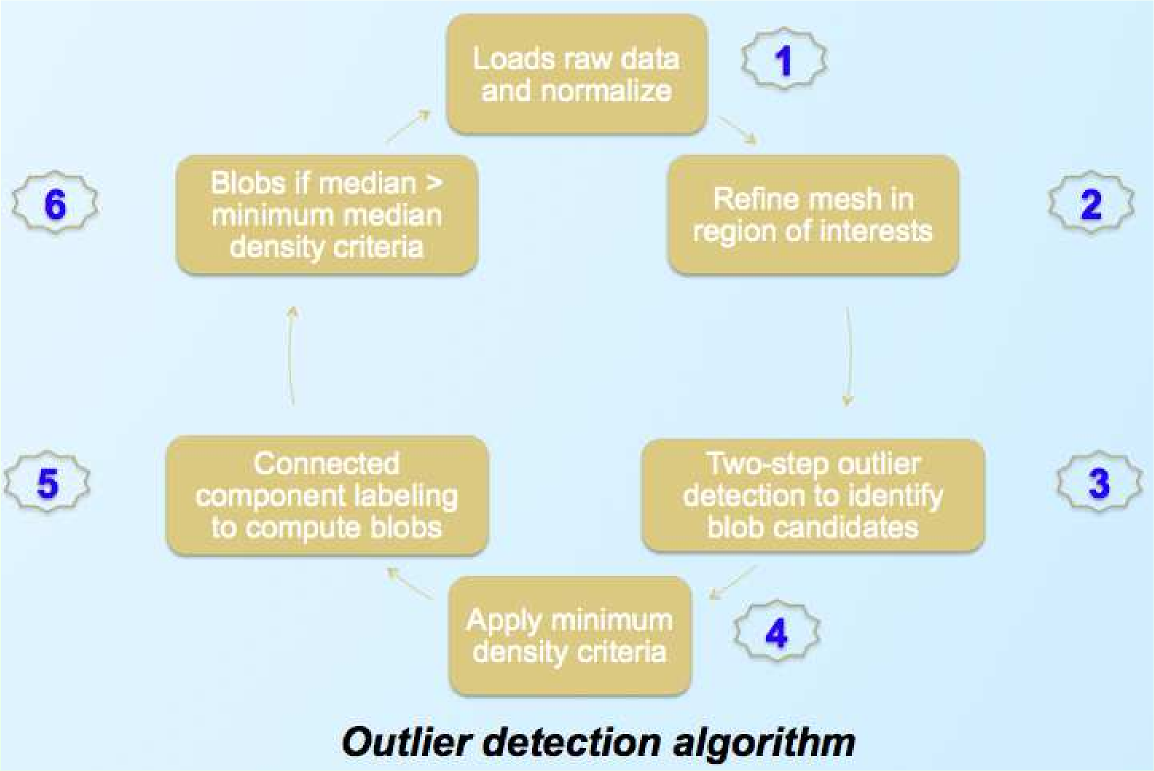
Approach	Drawbacks
Single threshold & conditional averaging	• The exact criterion varies • Averaging may destroy important information
Image analysis techniques	• Very sensitive to the setting of parameters • Hard to use generic method for all images
Contouring method & thresholding	• Can not be a real-time blob detection • May miss detecting blobs at the edge • Is still post-run-analysis

An efficient blob detection approach

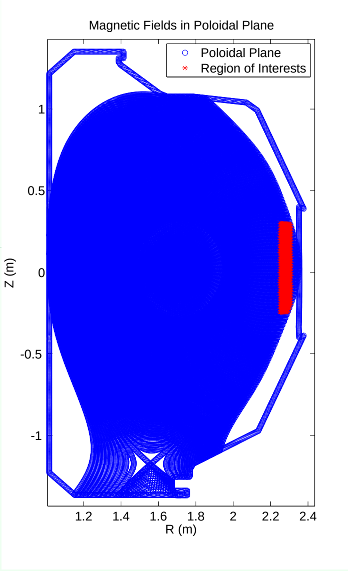
- Our approach: an outlier detection algorithm for efficiently finding blobs in fusion simulations / experiments
  - Two-step outlier detection with various criteria after normalizing the local intensity
  - Leverage a fast connected component labeling method to find blob components based on a refined triangular mesh
- Contributions:
  - A new method not missing detection of blobs in the edge of the region of interests compared to contouring method
  - Targeting for more challenging in-shot-analysis and between-shot-analysis
  - The first research work to achieve blob detection in a few milliseconds

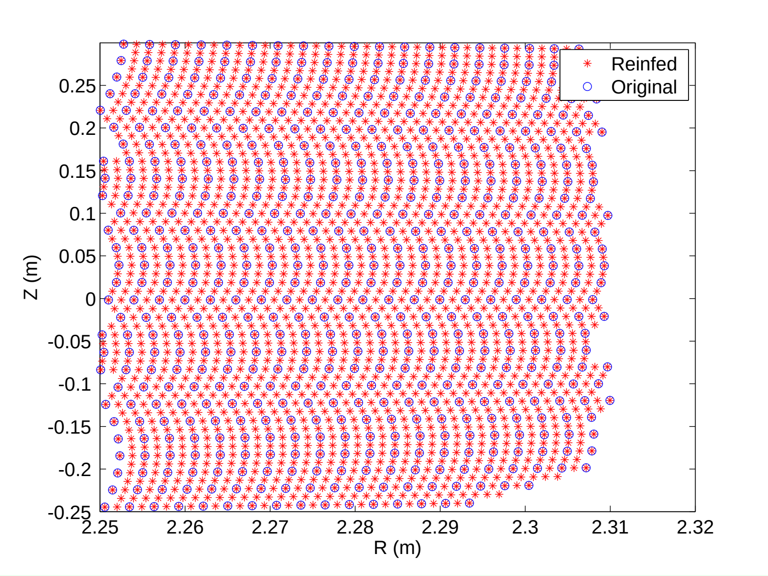
Outlier detection algorithm for finding blobs

Sketch the proposed outlier detection algorithm:



Refine mesh in the region of interests

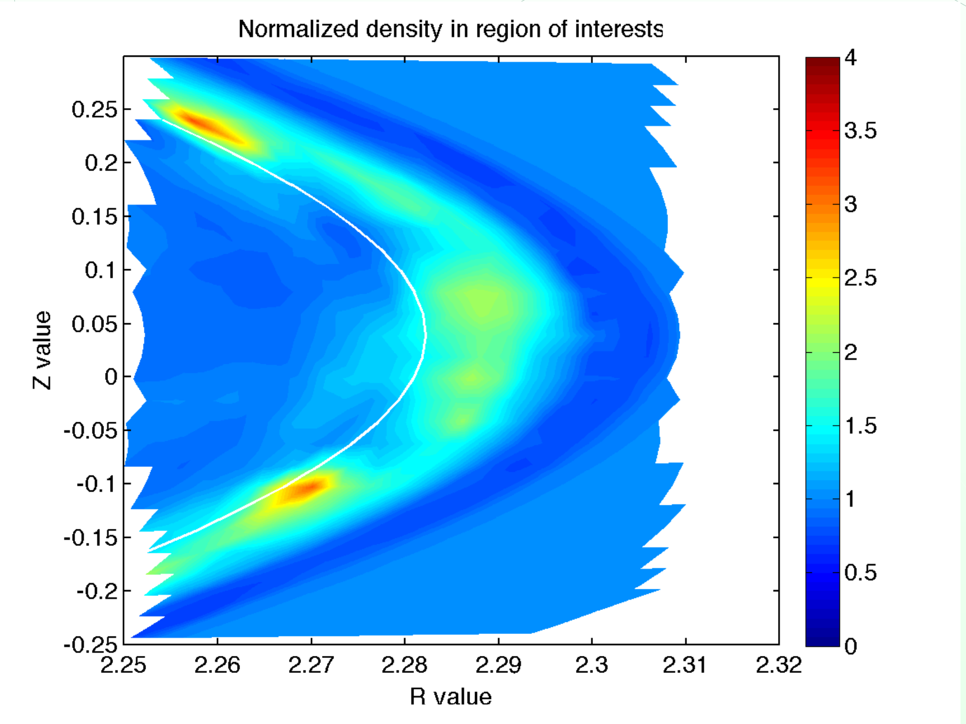




- Compute 4 times more triangles by creating new vertexes with the three middle points of original edges
- Apply recursively until reaching the desired resolution
- Depend on specified data set and demanded resolution

Two-step outlier detection to identify blobs

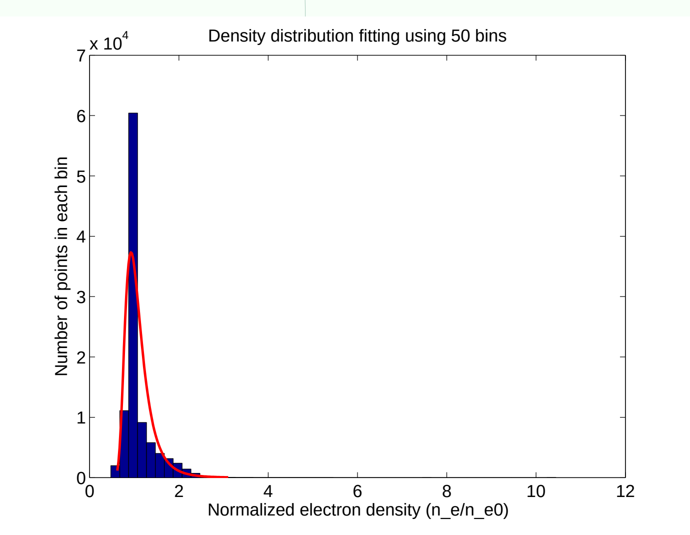
Motivation for two-step outlier detection for finding blobs:



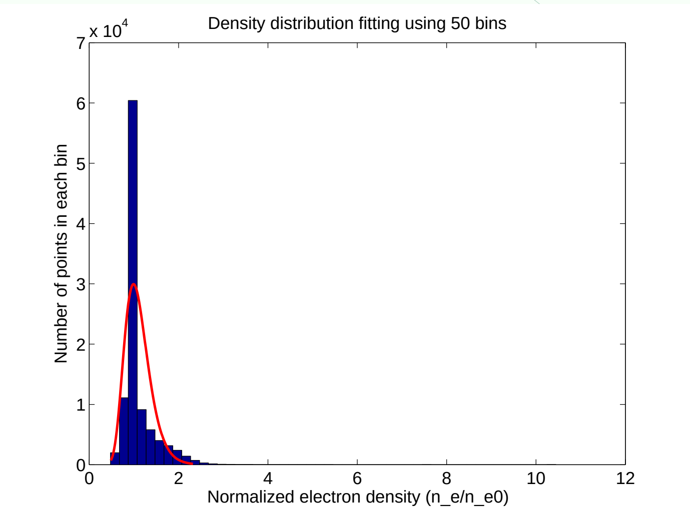
A contour plot in the region of interests

Two-step outlier detection to identify blobs

Apply exploratory data analysis to analyze the underlying distribution of the local normalized density:



(a) Extreme Value Distribution



(b) Log Normal Distribution

$$\left[\begin{array}{c} N(r_i, z_i, t) - \mu > \alpha * \sigma, \forall (r_i, z_i) \in \Gamma, \\ N(r_i, z_i, t) - \mu_2 > \beta * \sigma_2, \forall (r_i, z_i) \in \Gamma_2. \end{array} \right]$$

A fast connected component labeling algorithm

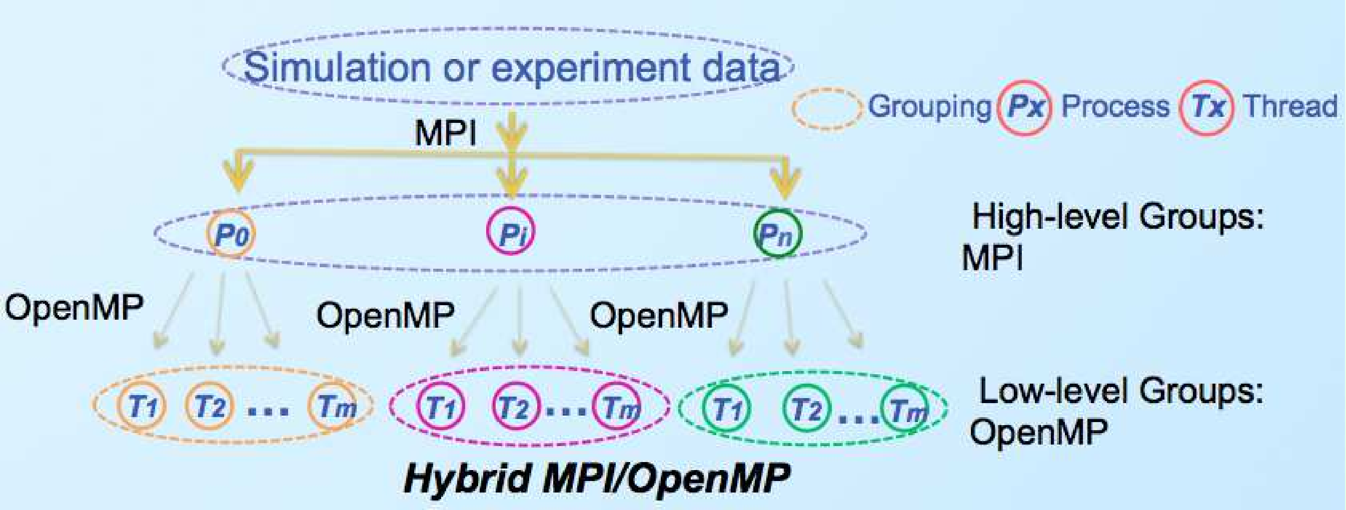
We apply an efficient connected component labeling algorithm on a refined triangular mesh to find blob components:

- This is a two-pass approach and each triangle is scanned firstly
- Reduce unnecessary memory access if any vertex in a triangle is found to be connected with others
- After the label array is filled full, we need flatten the union and find tree
- Second pass is performed to correct labels and all blob candidate components are found

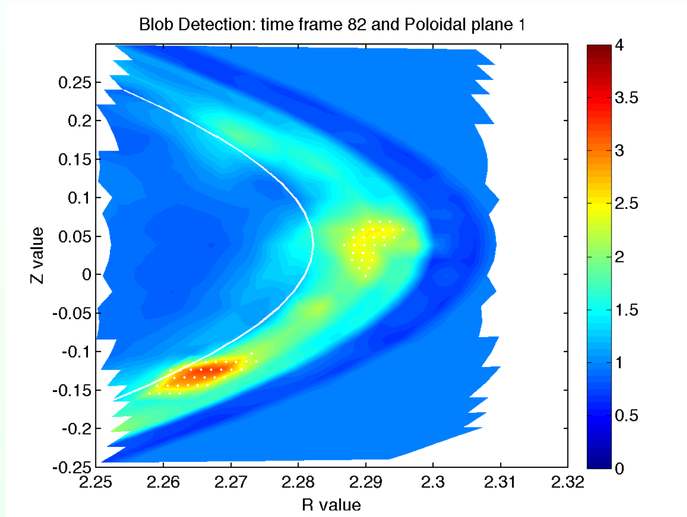
Parallelization of blob detection approach

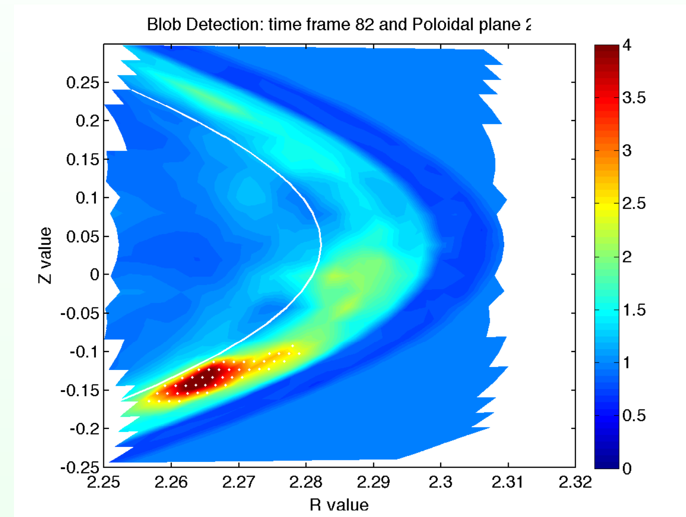
A hybrid MPI/OpenMP parallelization on many-core processor architecture:

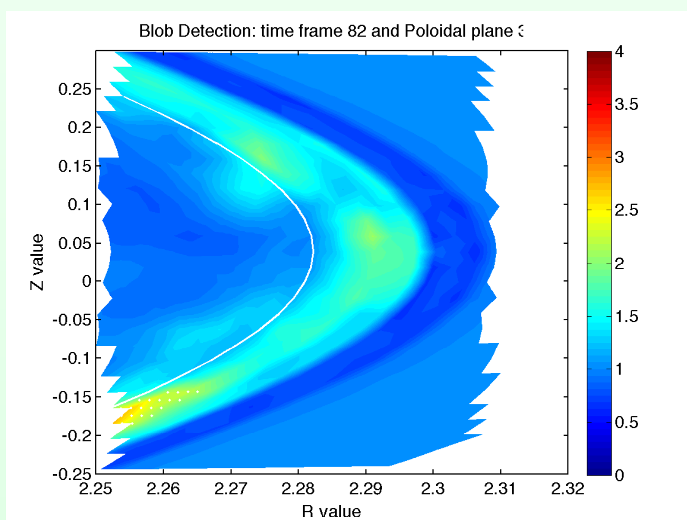
- High-level: use MPI to allocate n processes to process each time frame
- Low-level: use OpenMP to accelerate the computations with m threads

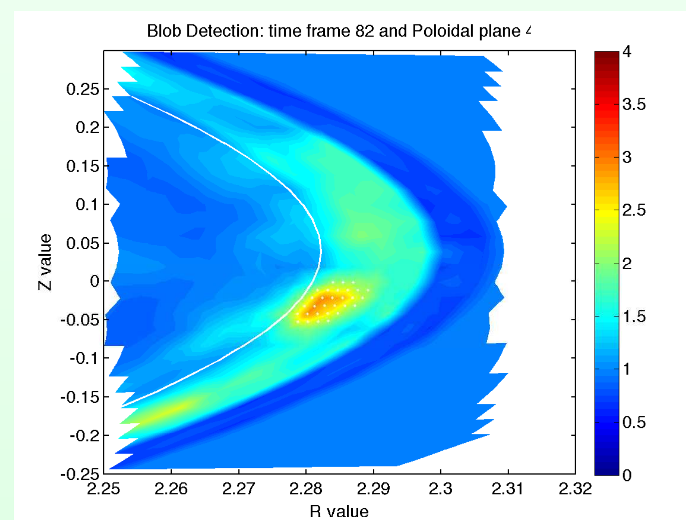


Results: same time frame + four planes

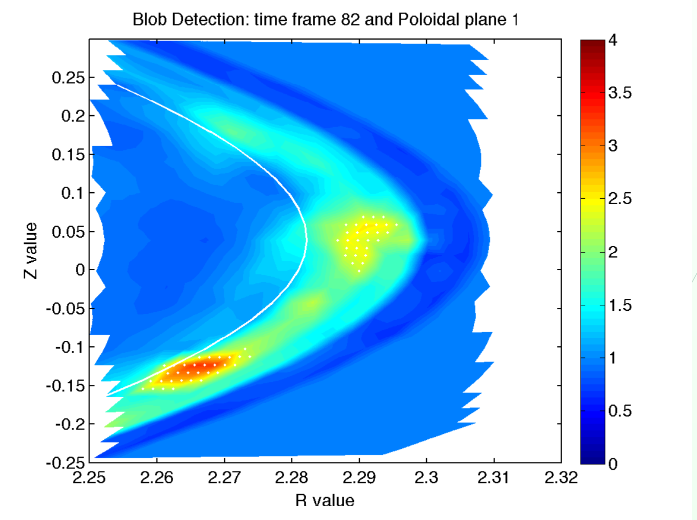


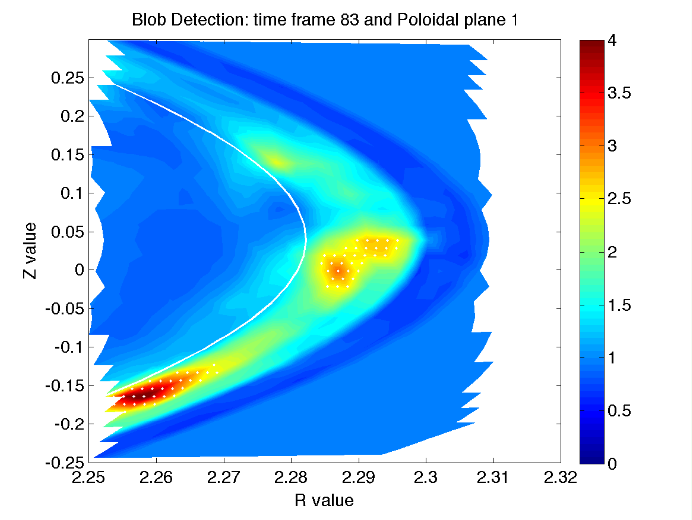


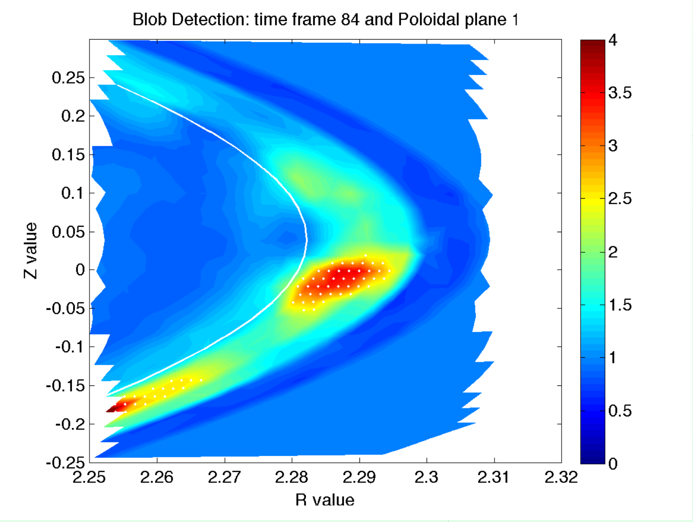


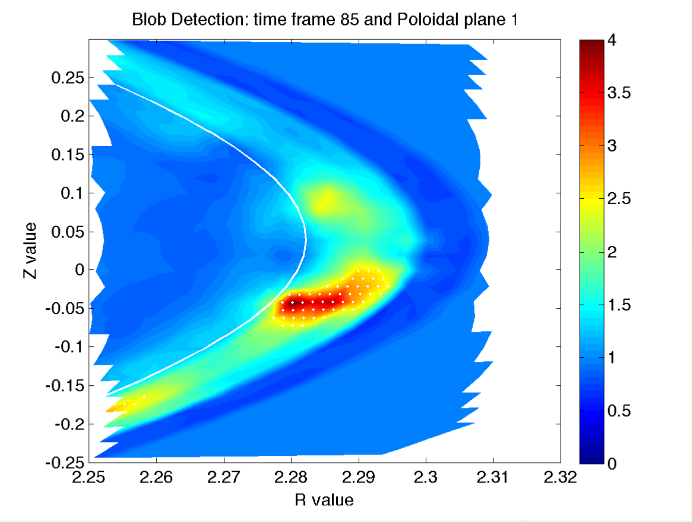


Results: same plane + four time frames

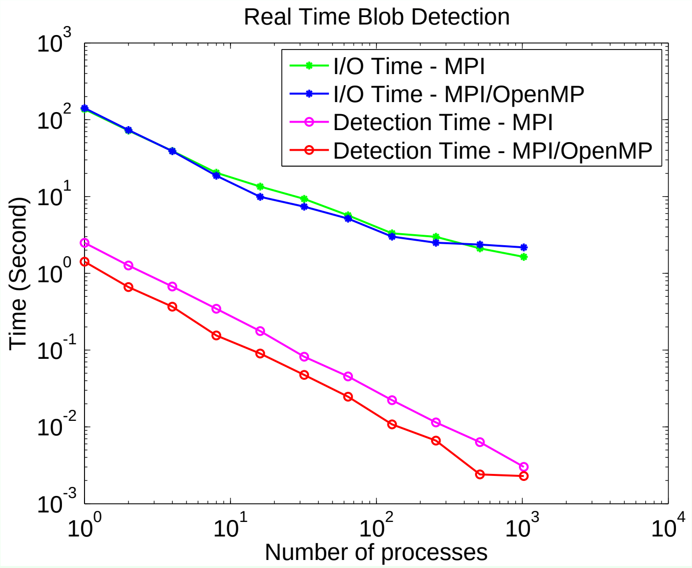


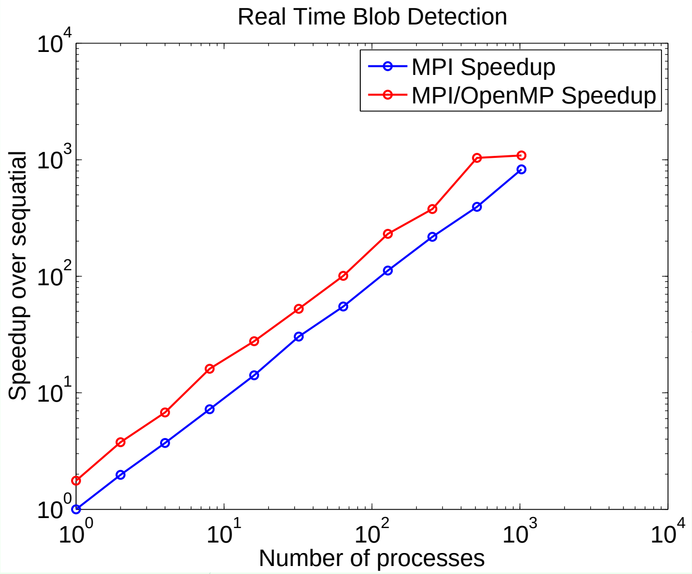






Results: real-time blob detection





- Complete blob detection in around 2 ms with MPI/OpenMP using 4096 cores and in 3 ms with MPI using 1024 cores
- MPI/OpenMP is two times faster than MPI
- Linear time speedup in blob detection time and slightly more in I/O time

Conclusion and future work

We present for the first time a real time blob detection method for finding blob-filaments in real fusion experiments or numerical simulations.

- Key components:
  - Two-step outlier detection with various criteria
  - A fast connected component labeling method
  - Hybrid MPI/OpenMP parallelization
- Future work:
  - Test the detection algorithm to experimental measurement data from operating fusion devices
  - Develop a blob tracking algorithm