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Efficient Structure-Aware Selection Techniques for 3D Point Cloud Visualizations with 2DOF Input

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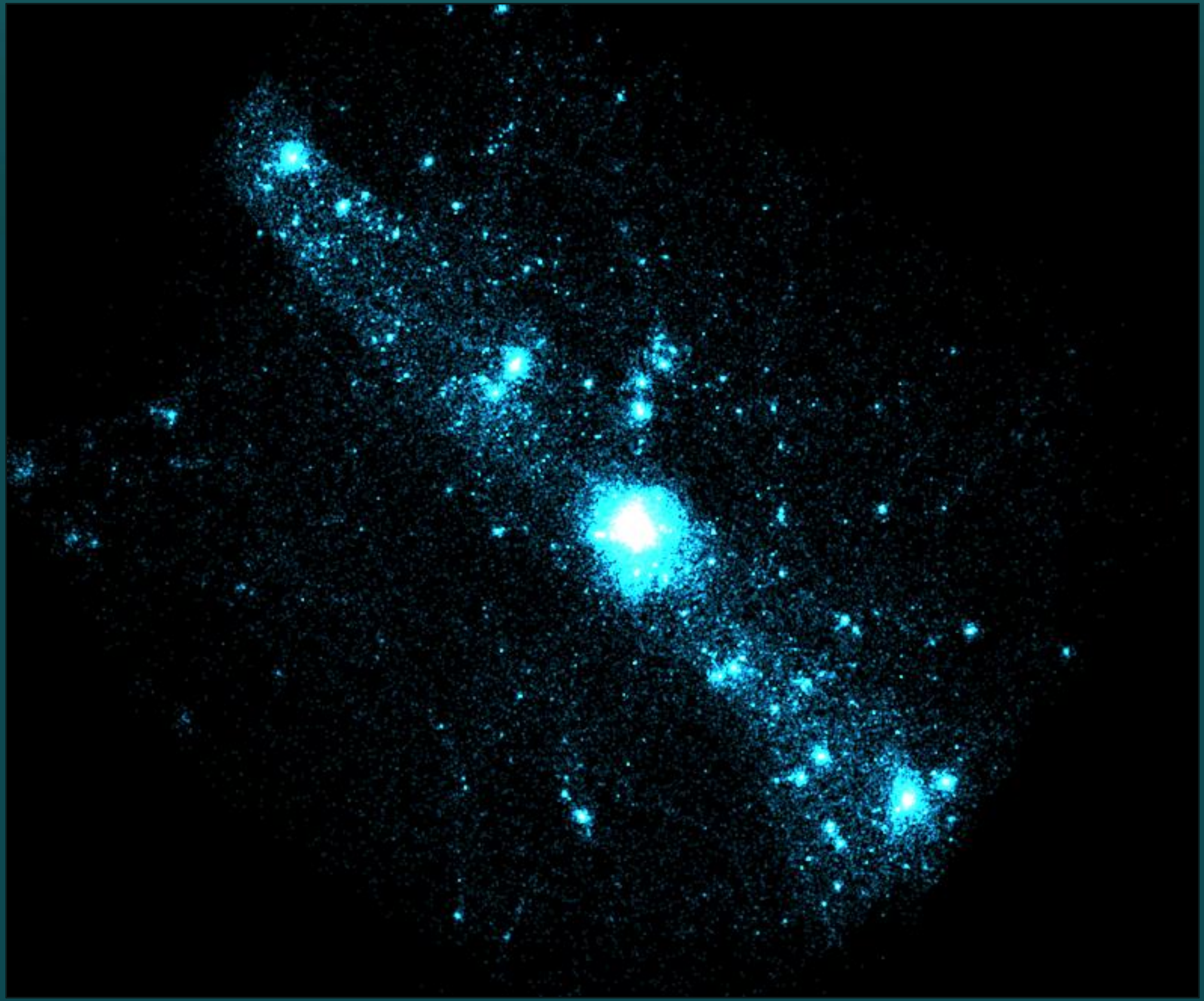
The Problem: Selection of 3D Subspaces

- 3D spatial data—basis of many visualization research questions
- **problem:** why/how to efficiently select subspaces in 3D?



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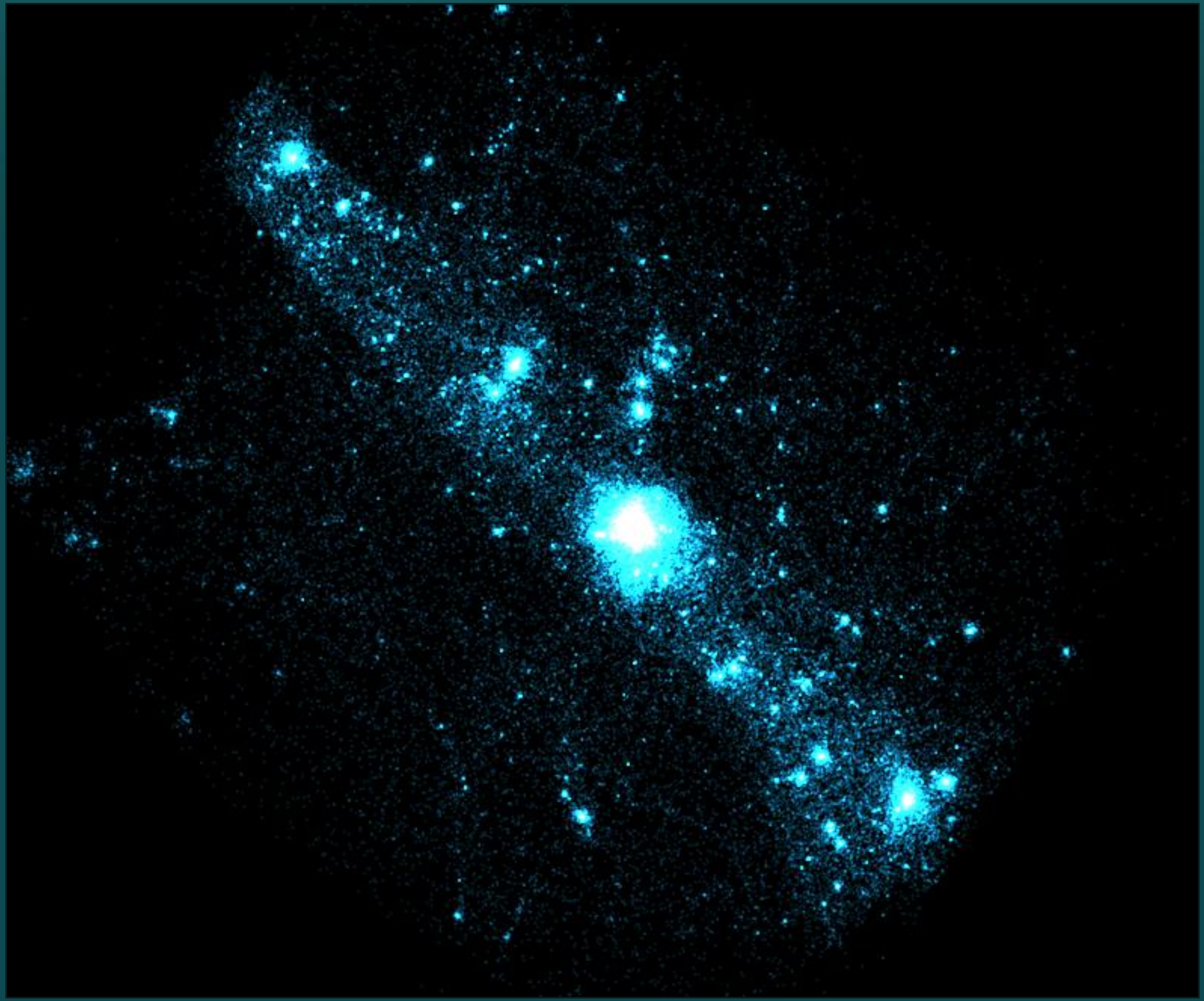

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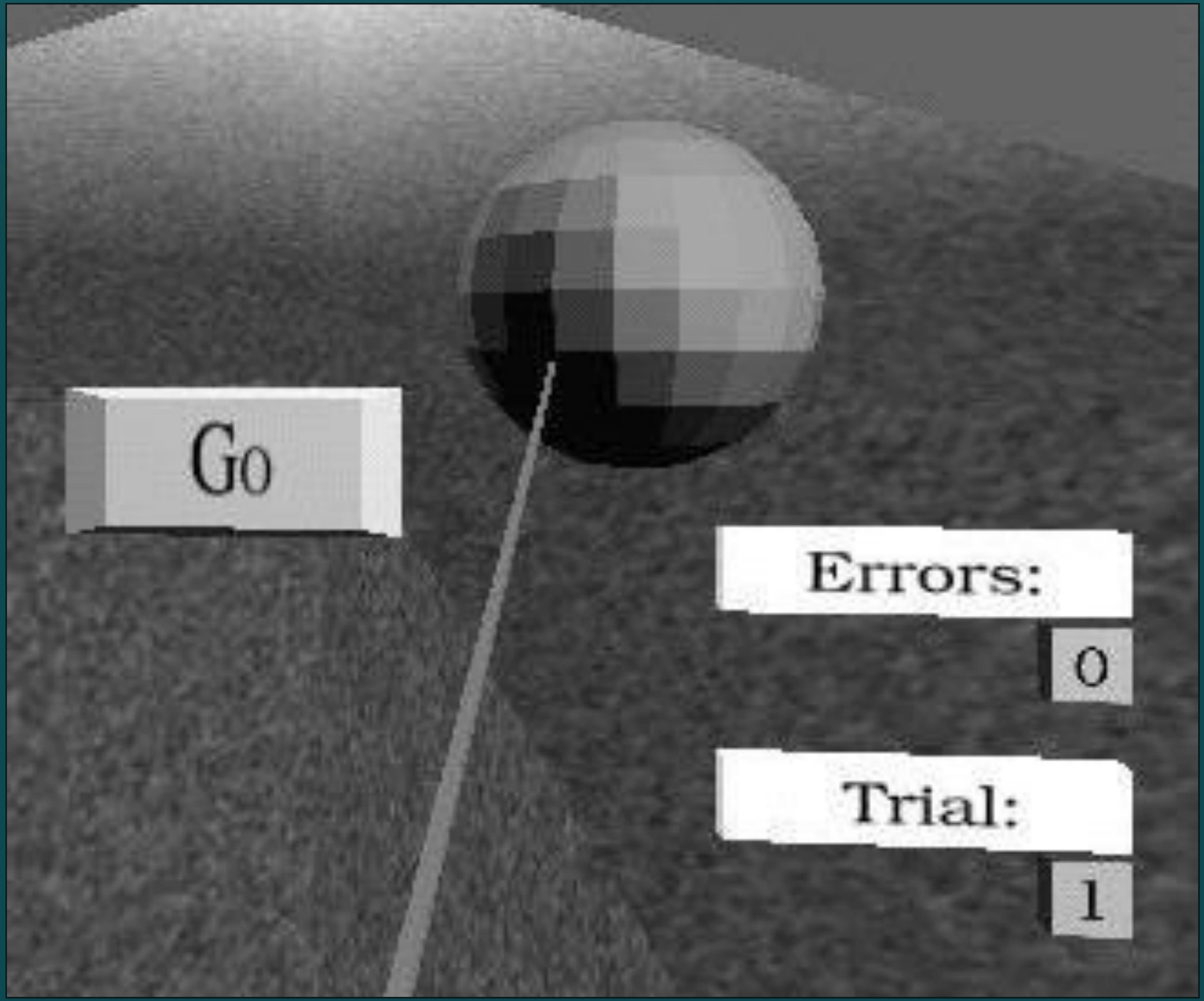

[Wingrave & Bowman, 2005]

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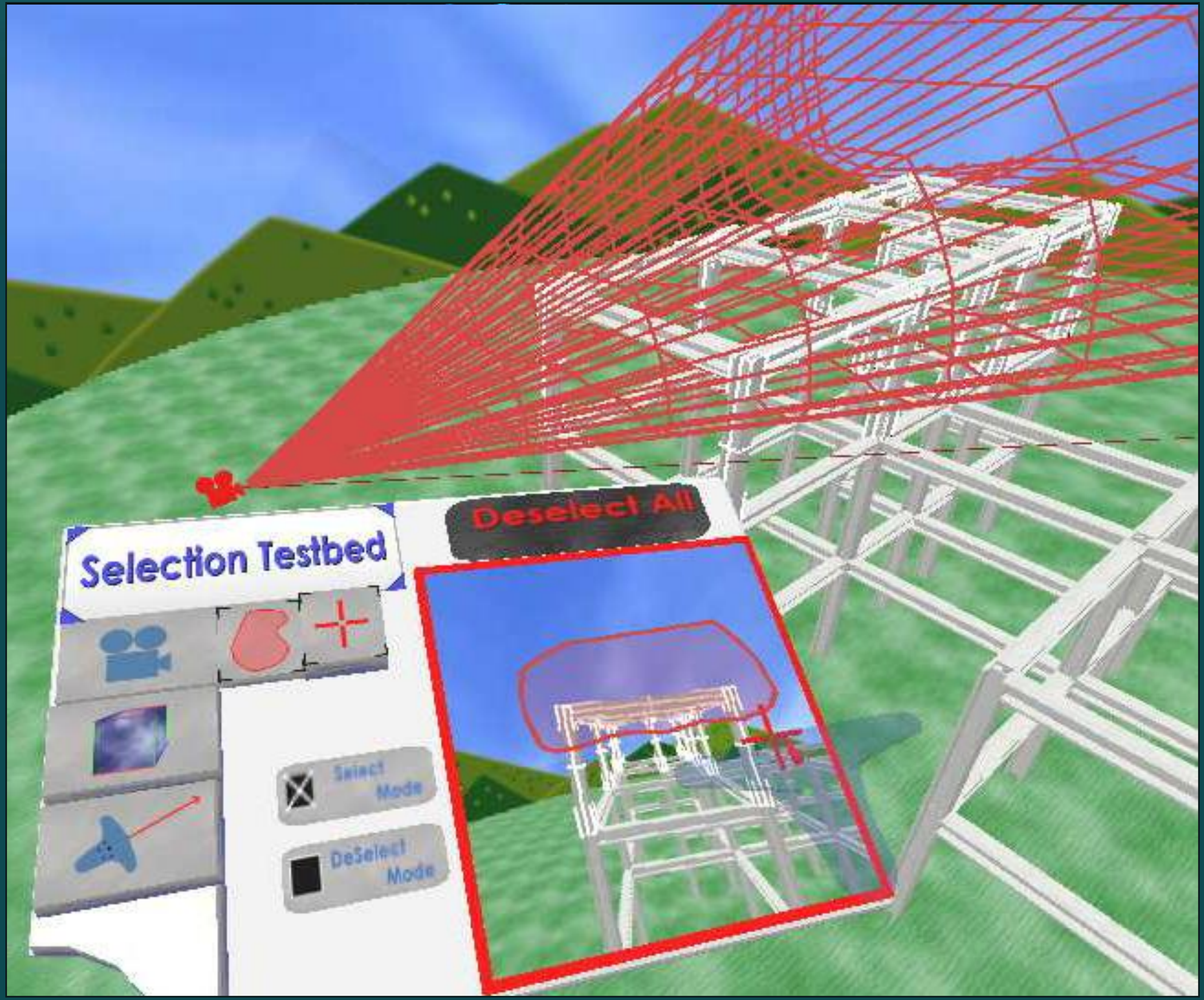

[Lucas & Bowman, 2005]

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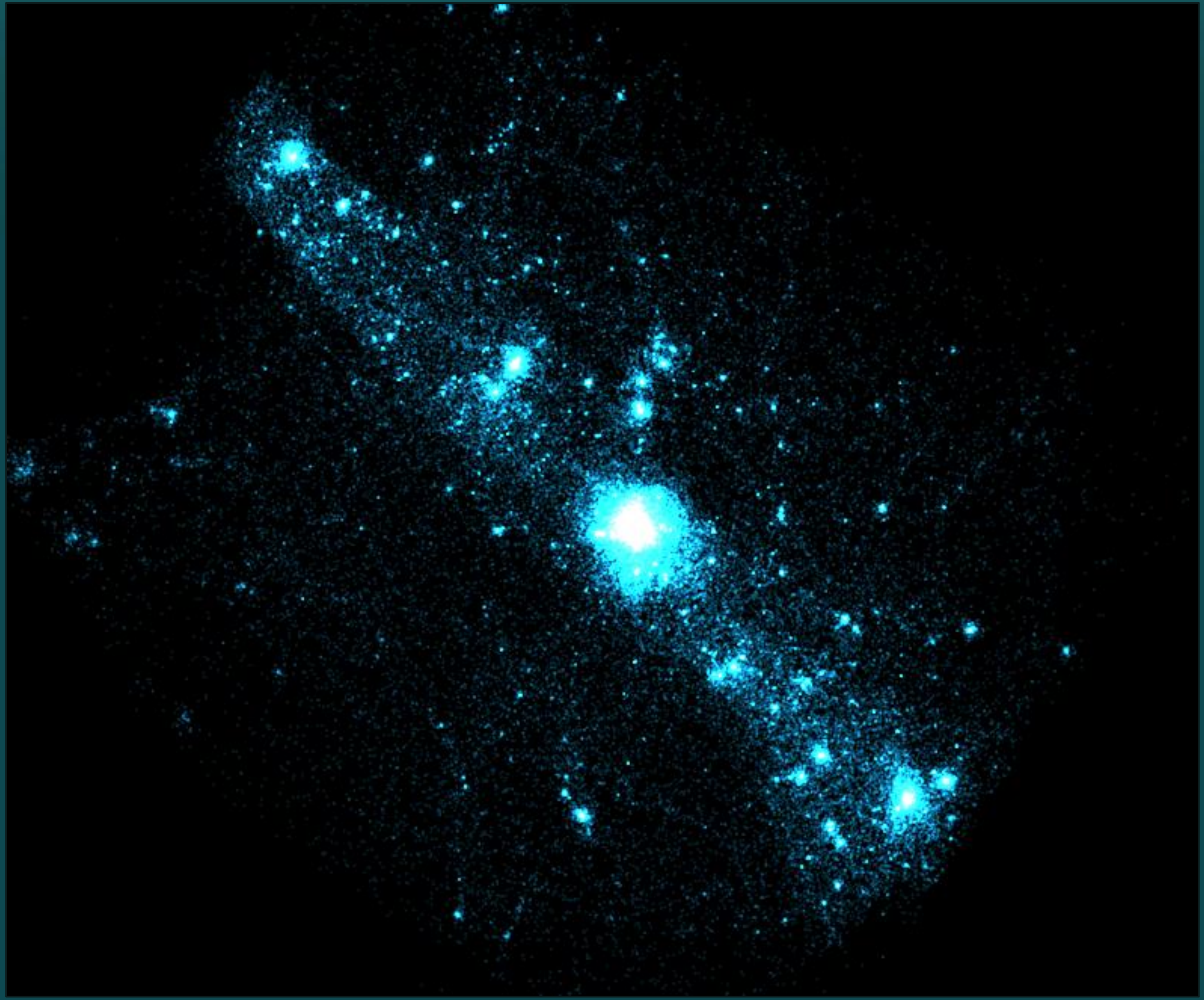

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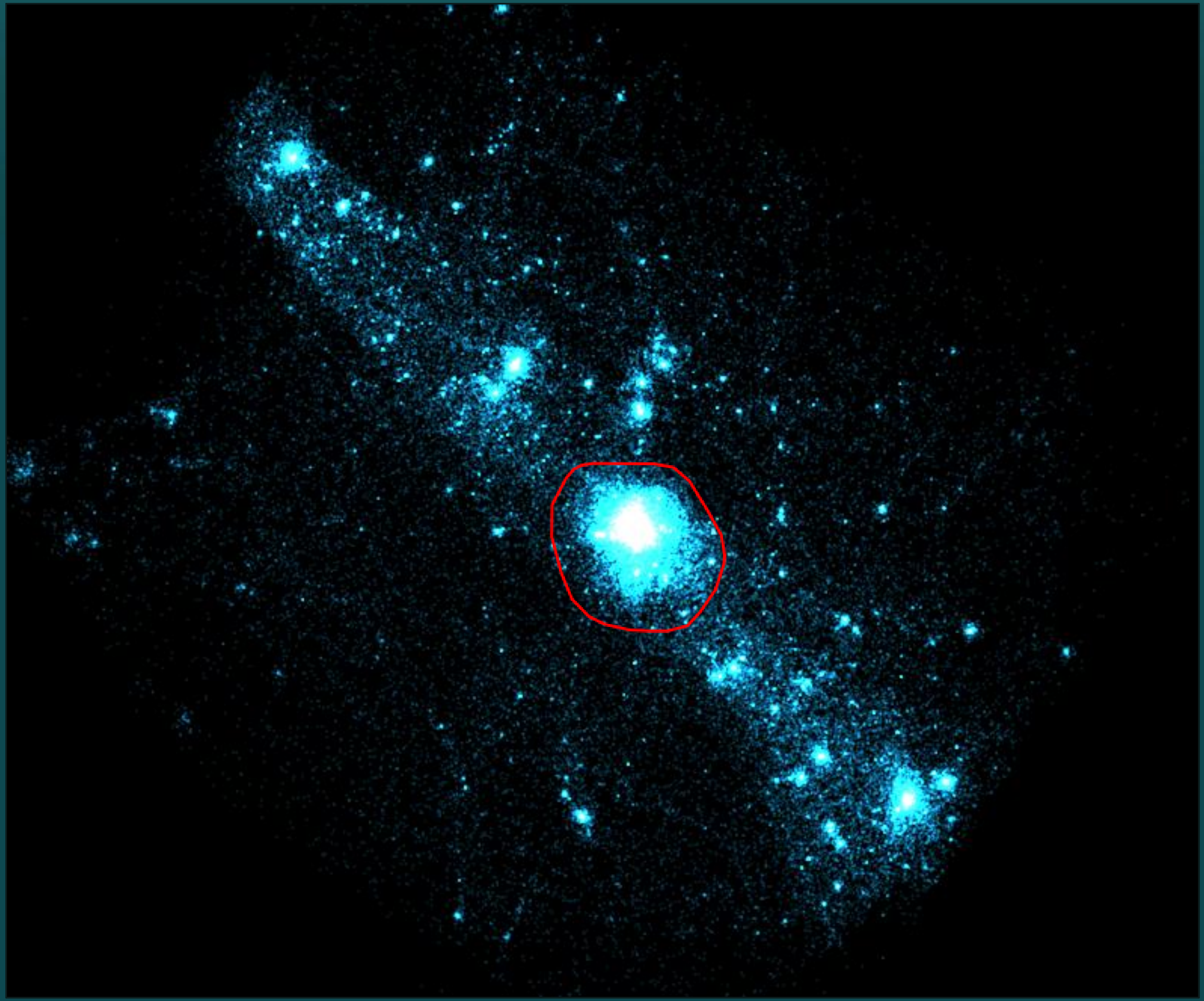

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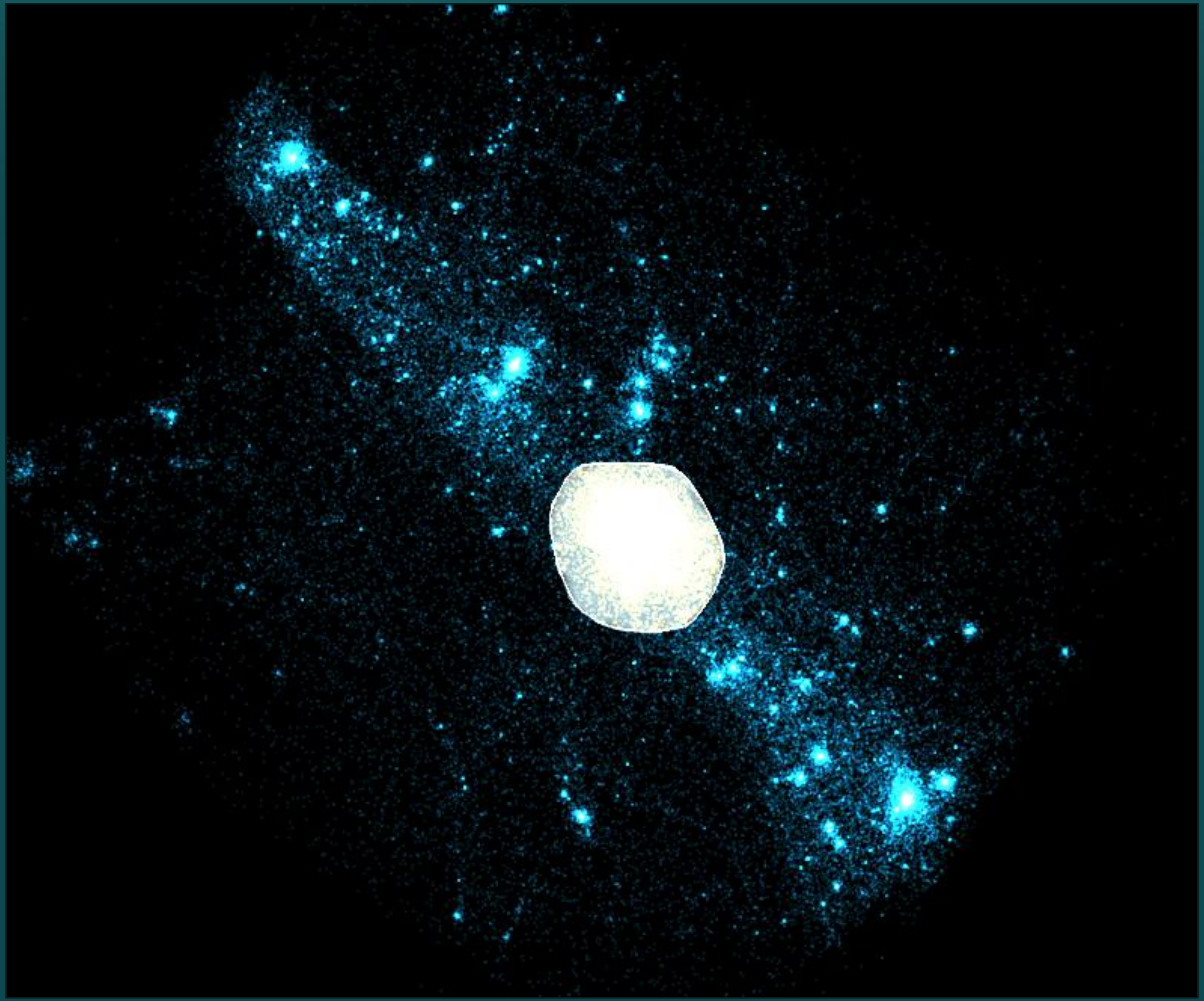

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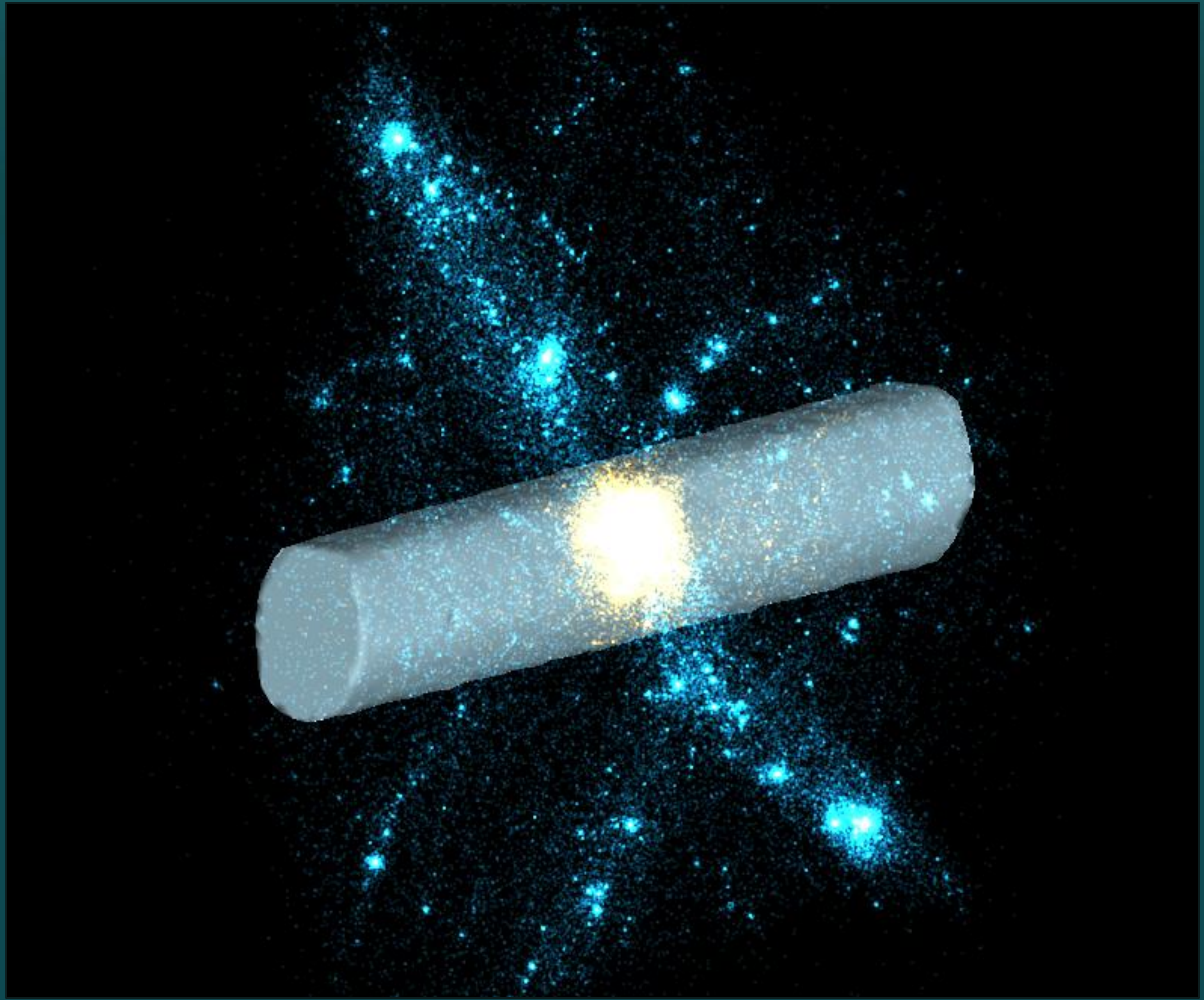

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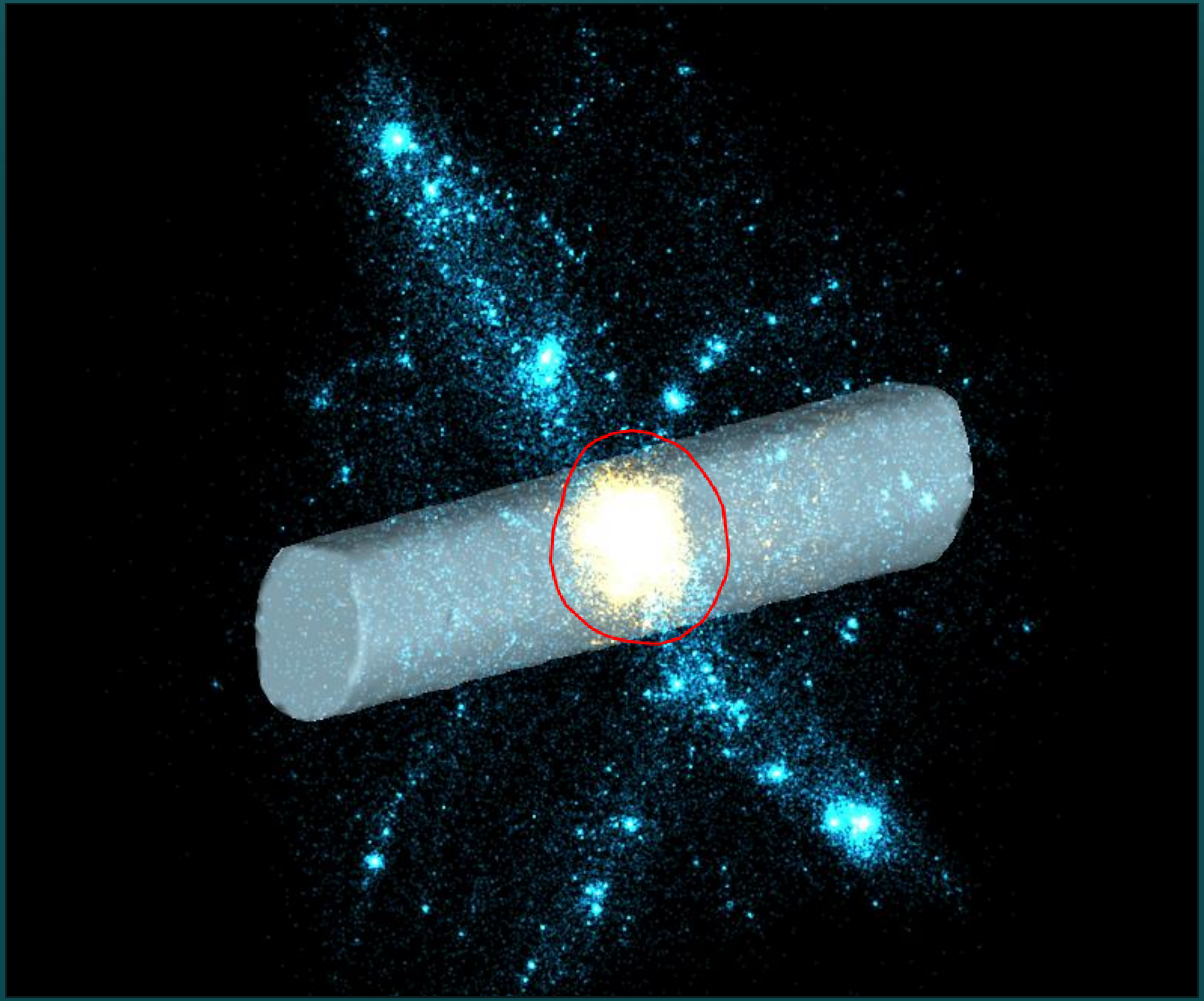

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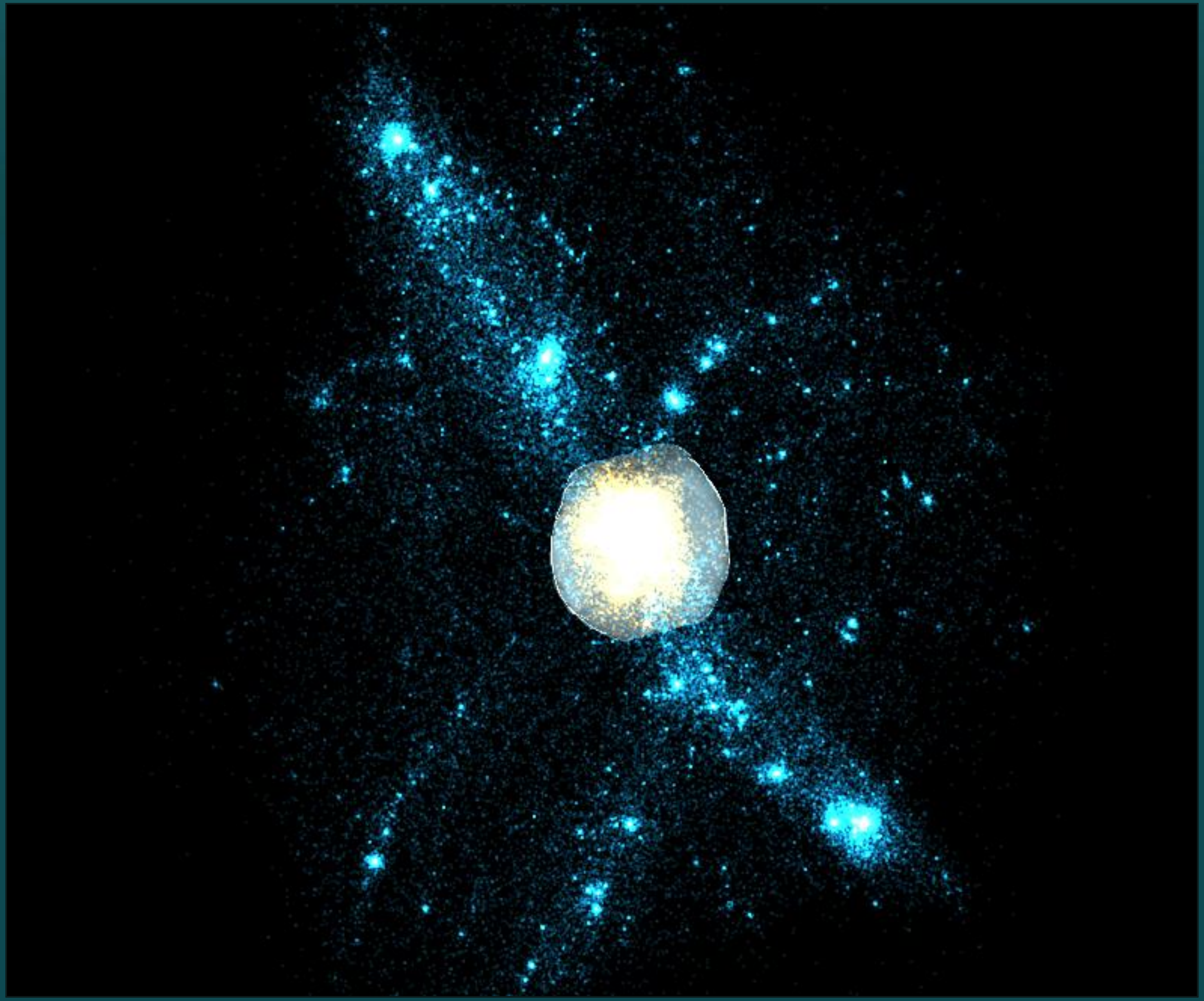

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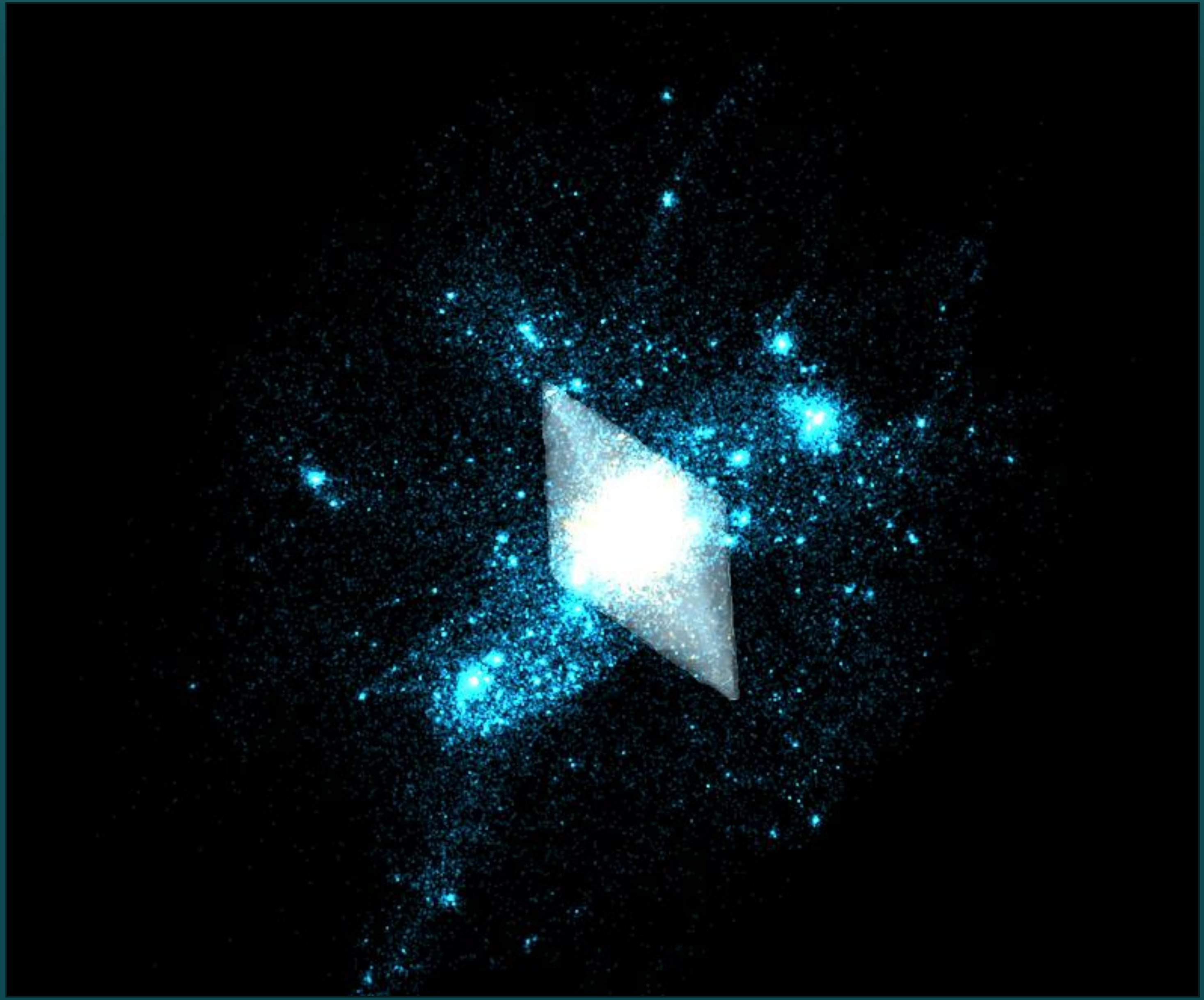

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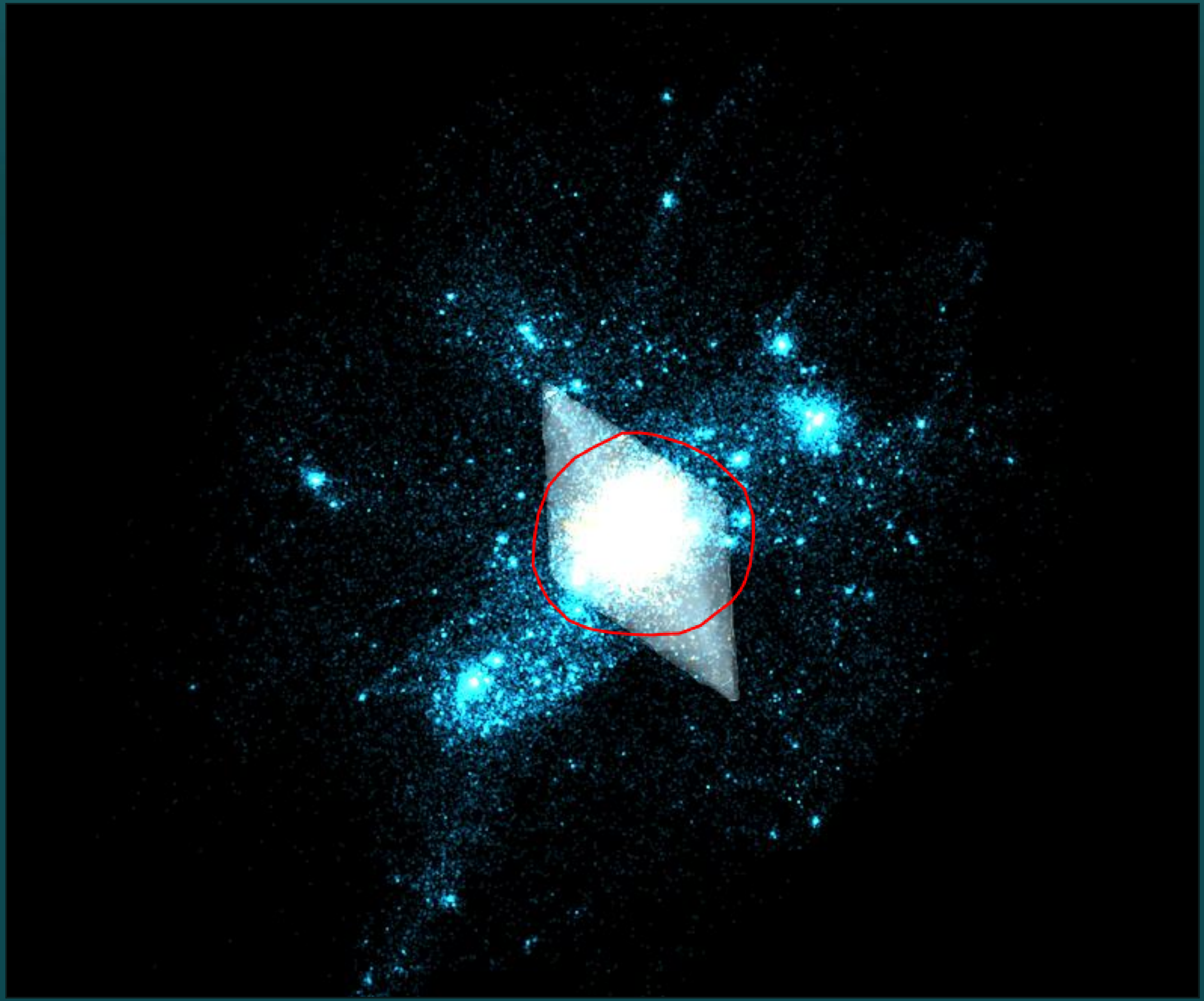

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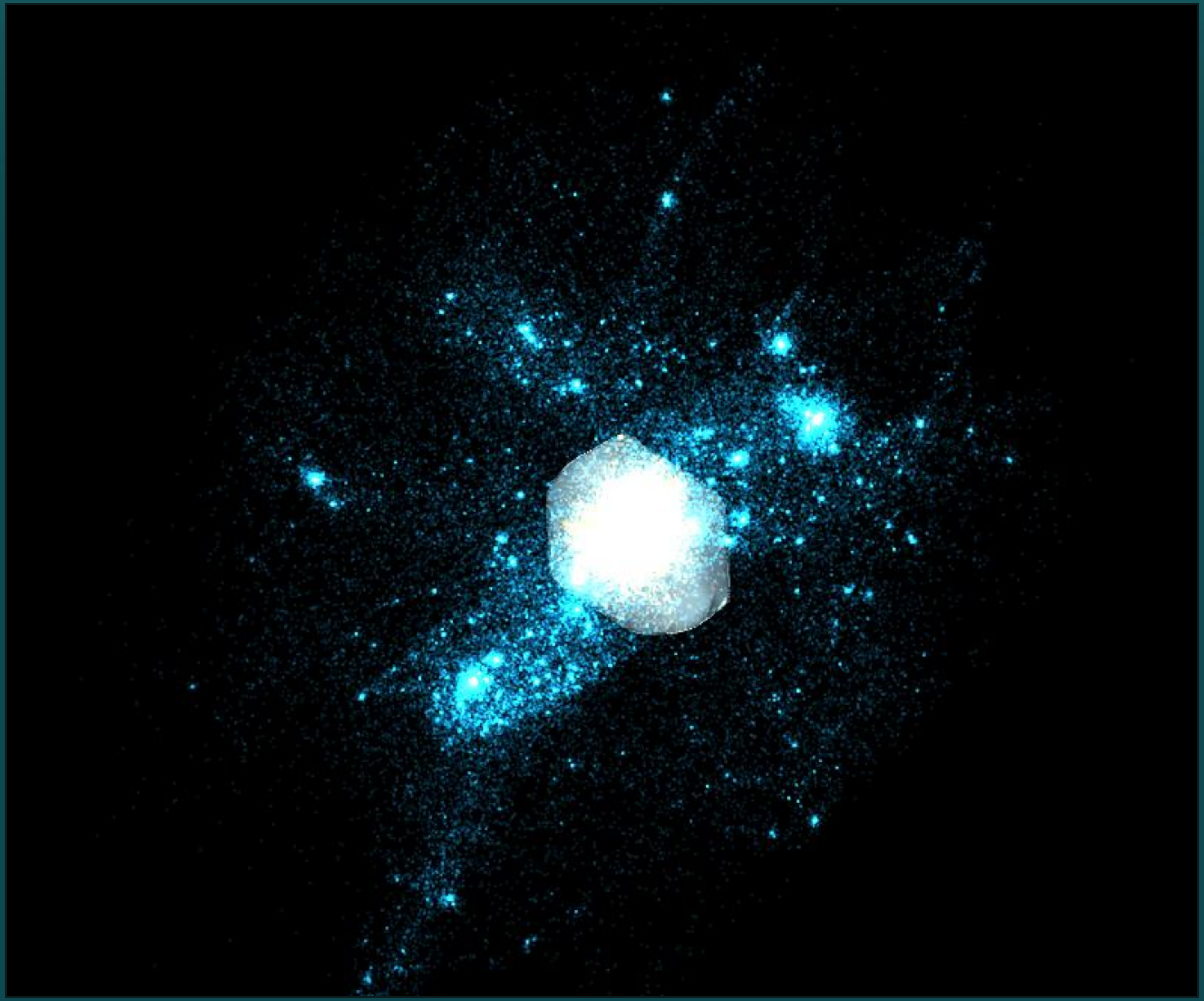

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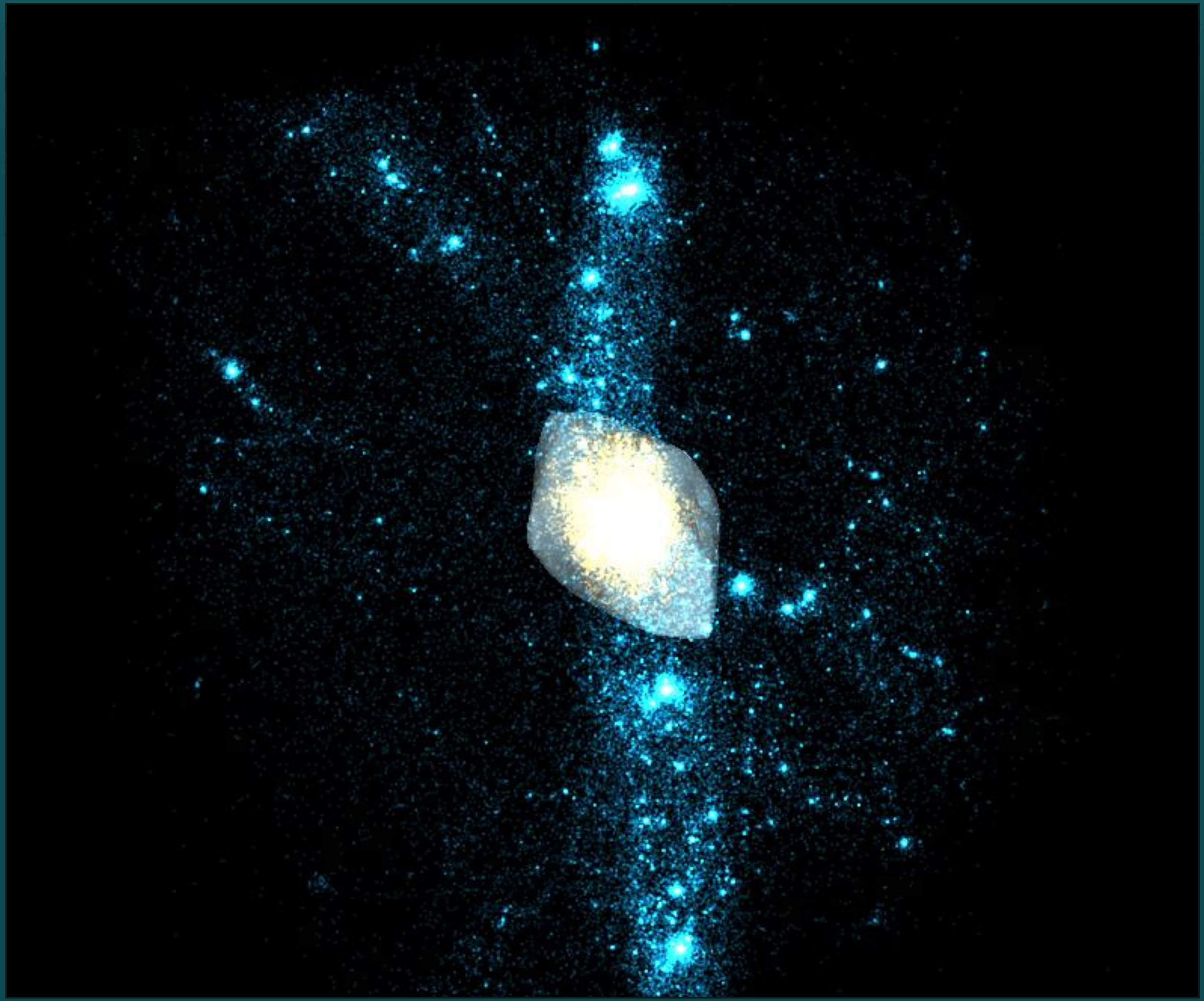
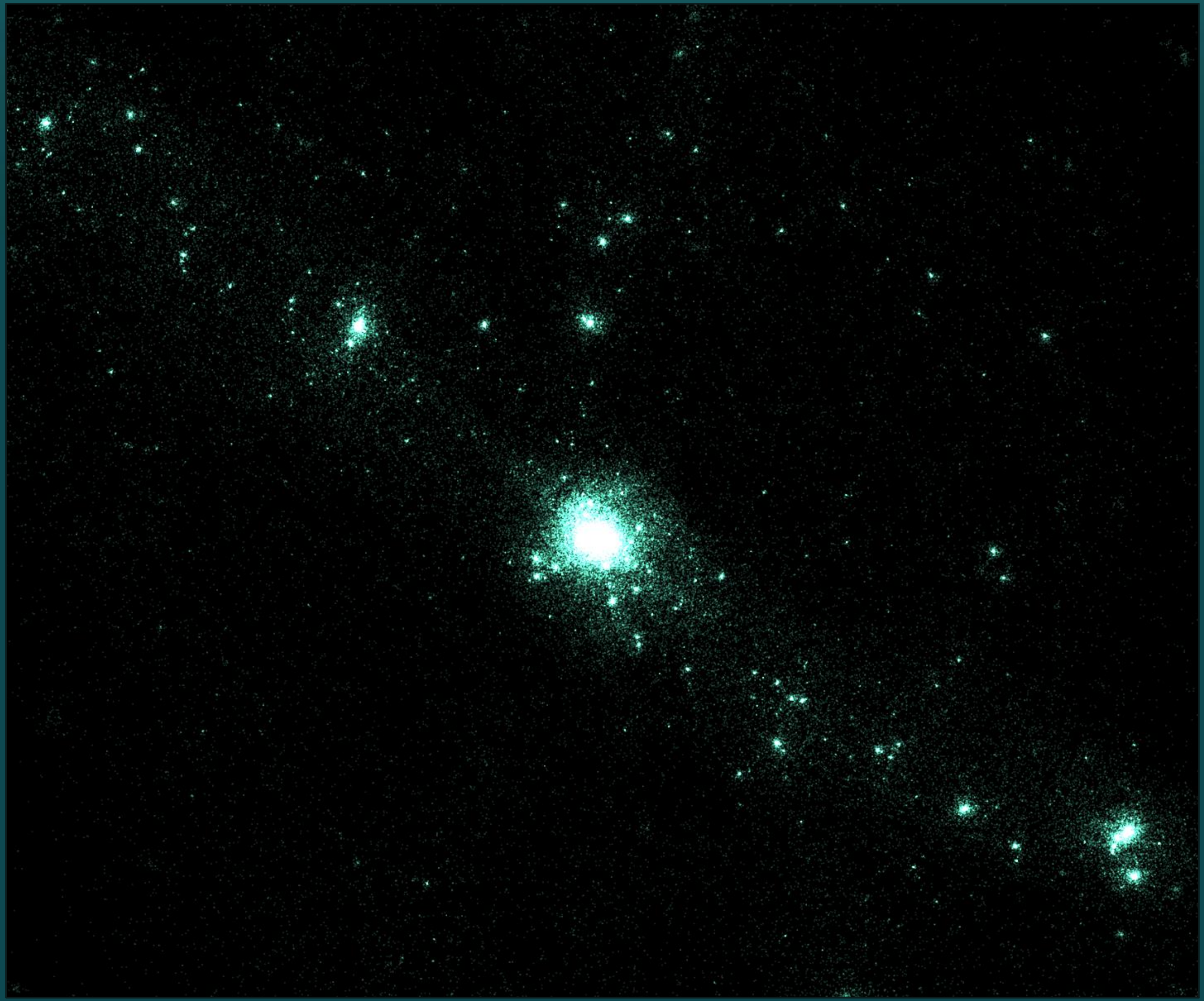


A New Interactive Selection Technique

- ***spatial selection*** rather than object-based selection
- ***two-dimensional input*** (PC, touch displays)
- ***2D lasso*** interaction: ***intended*** selection
- ***structure-aware selection*** in 3D depth



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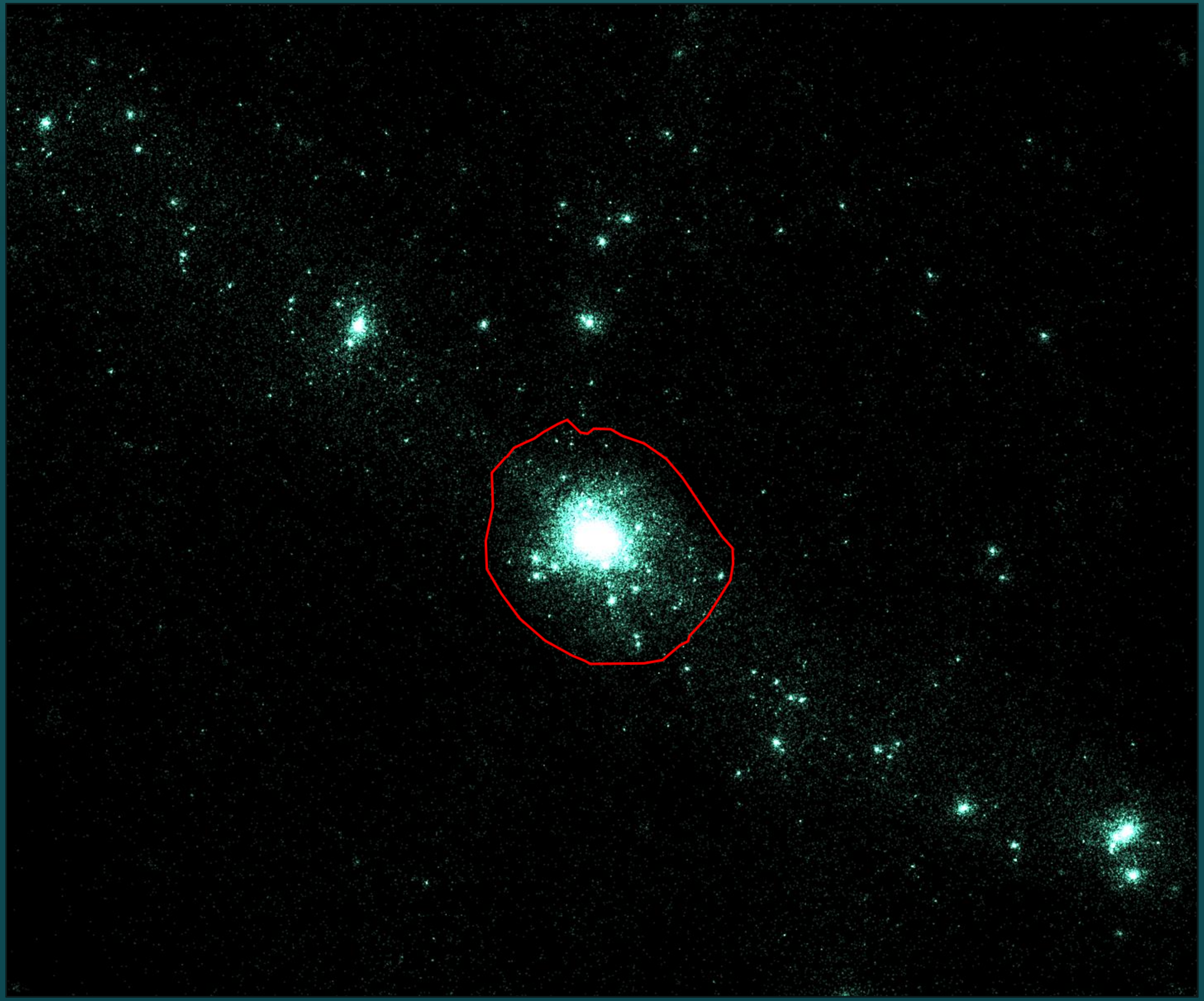

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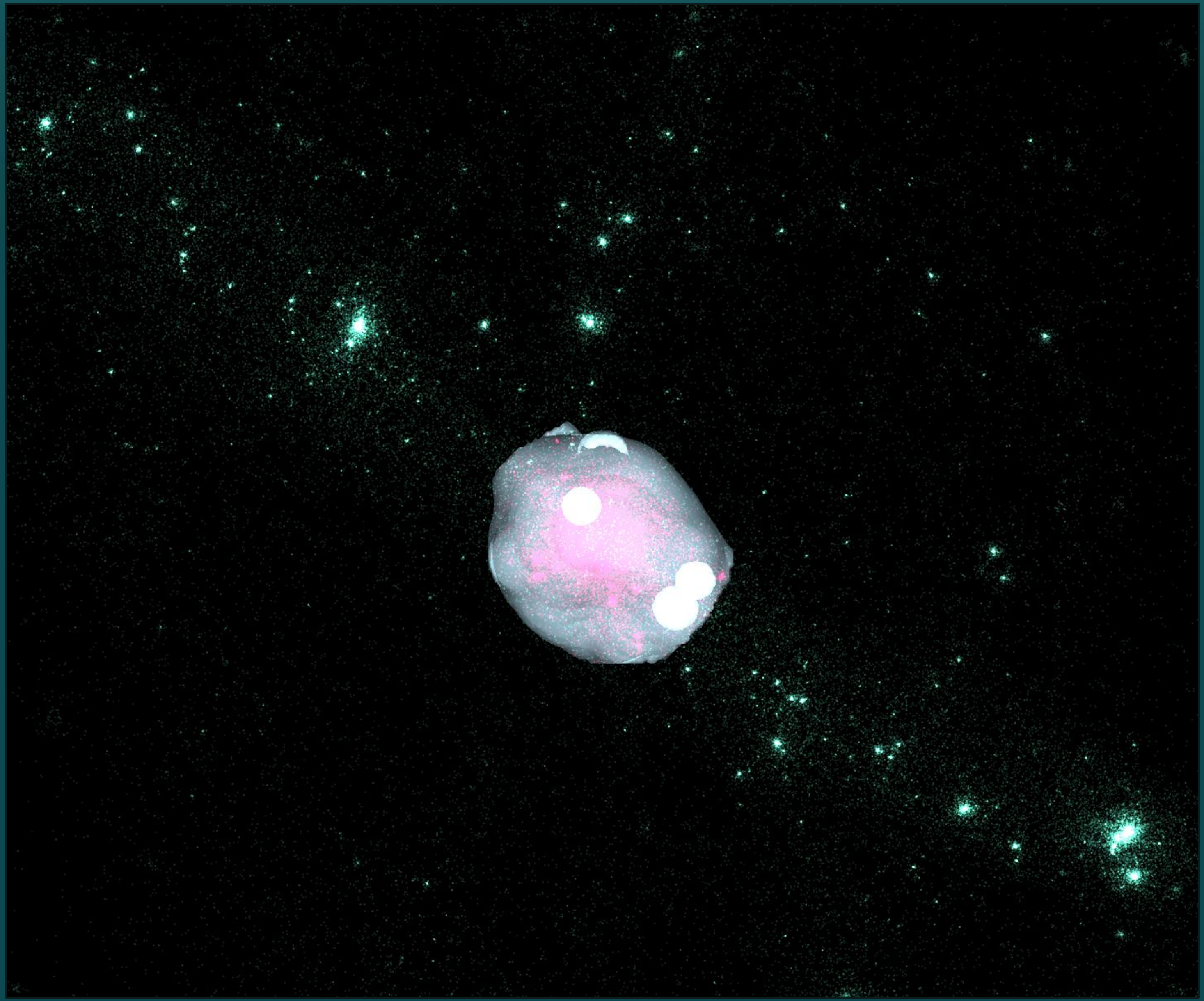

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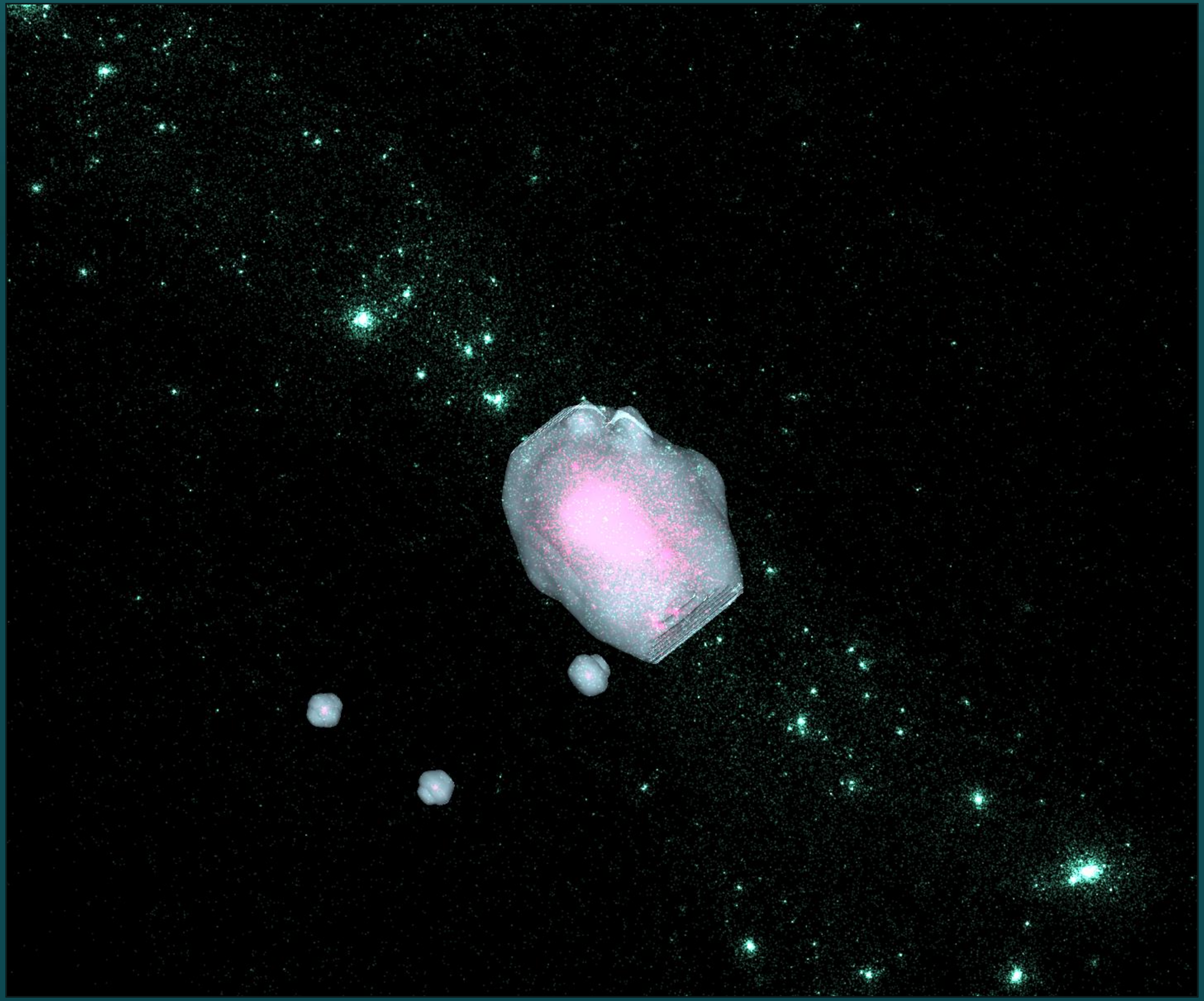

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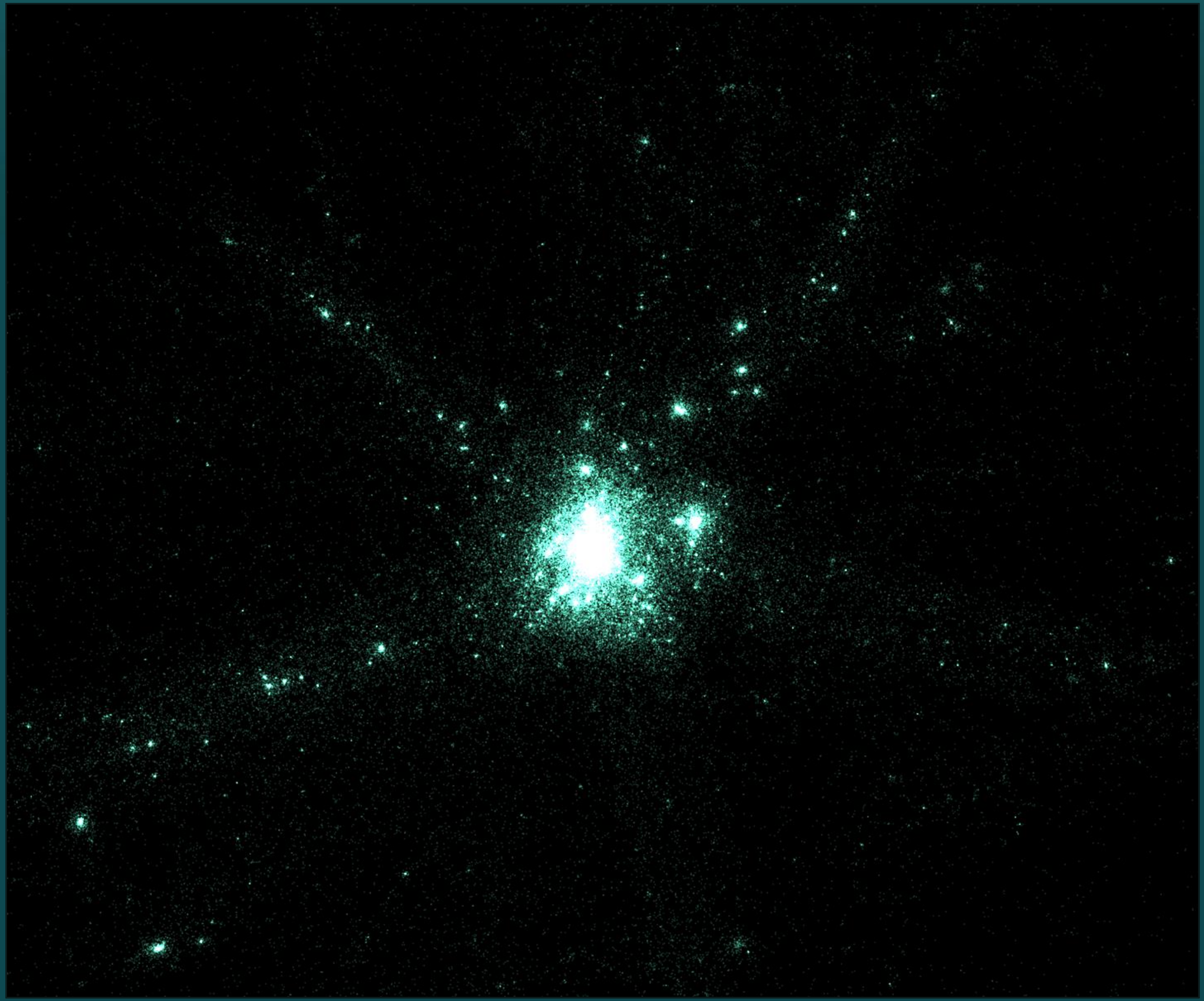

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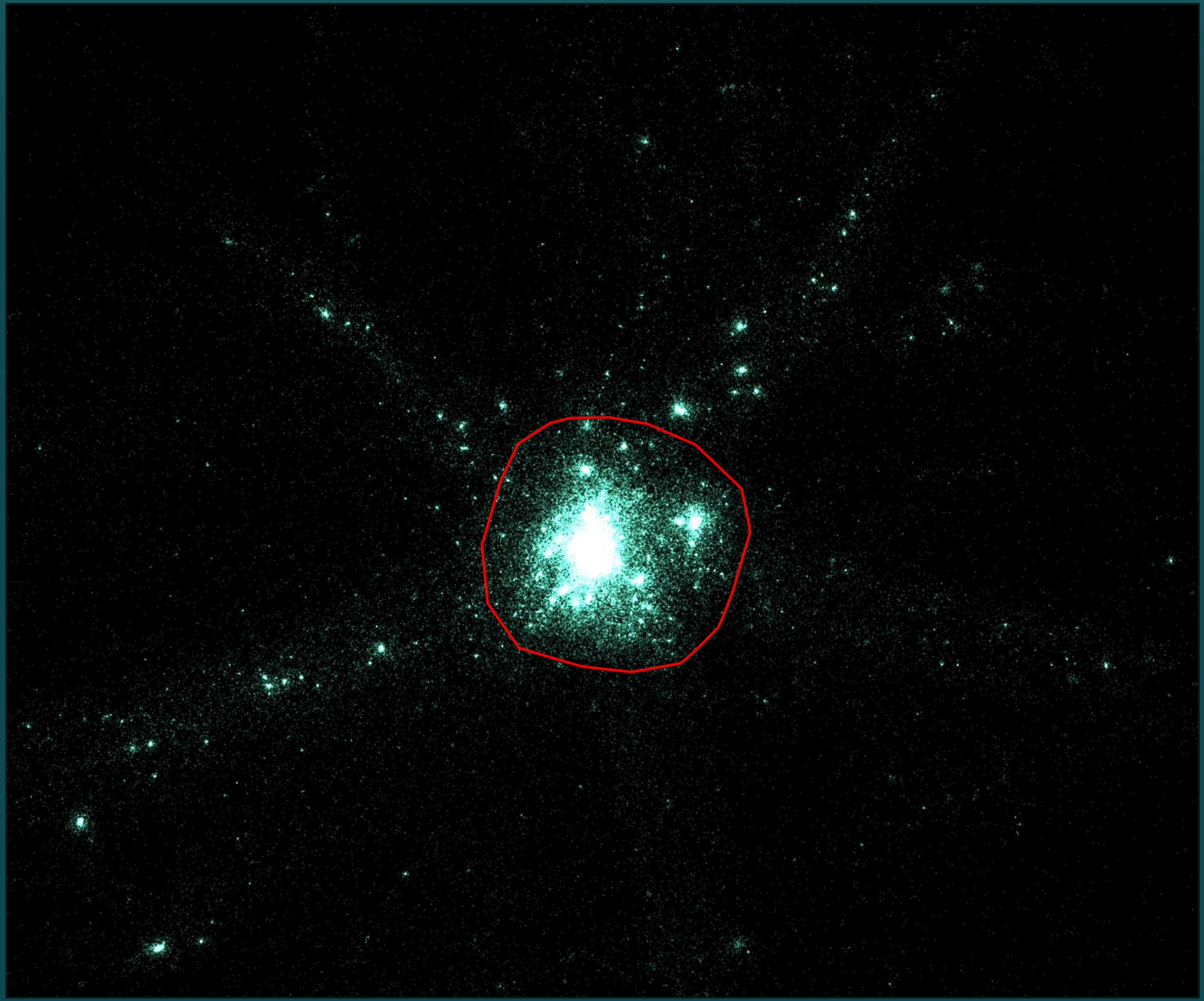

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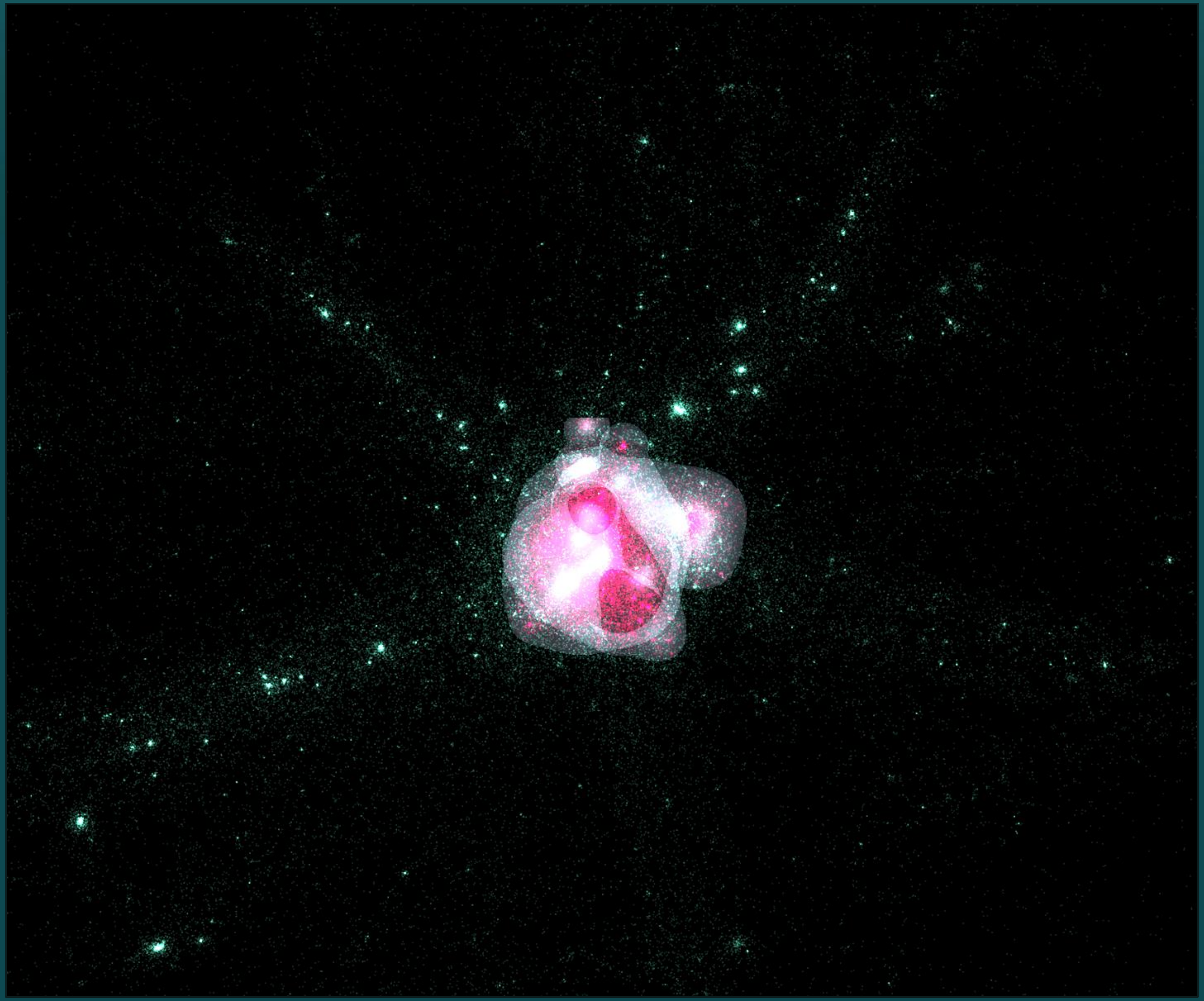

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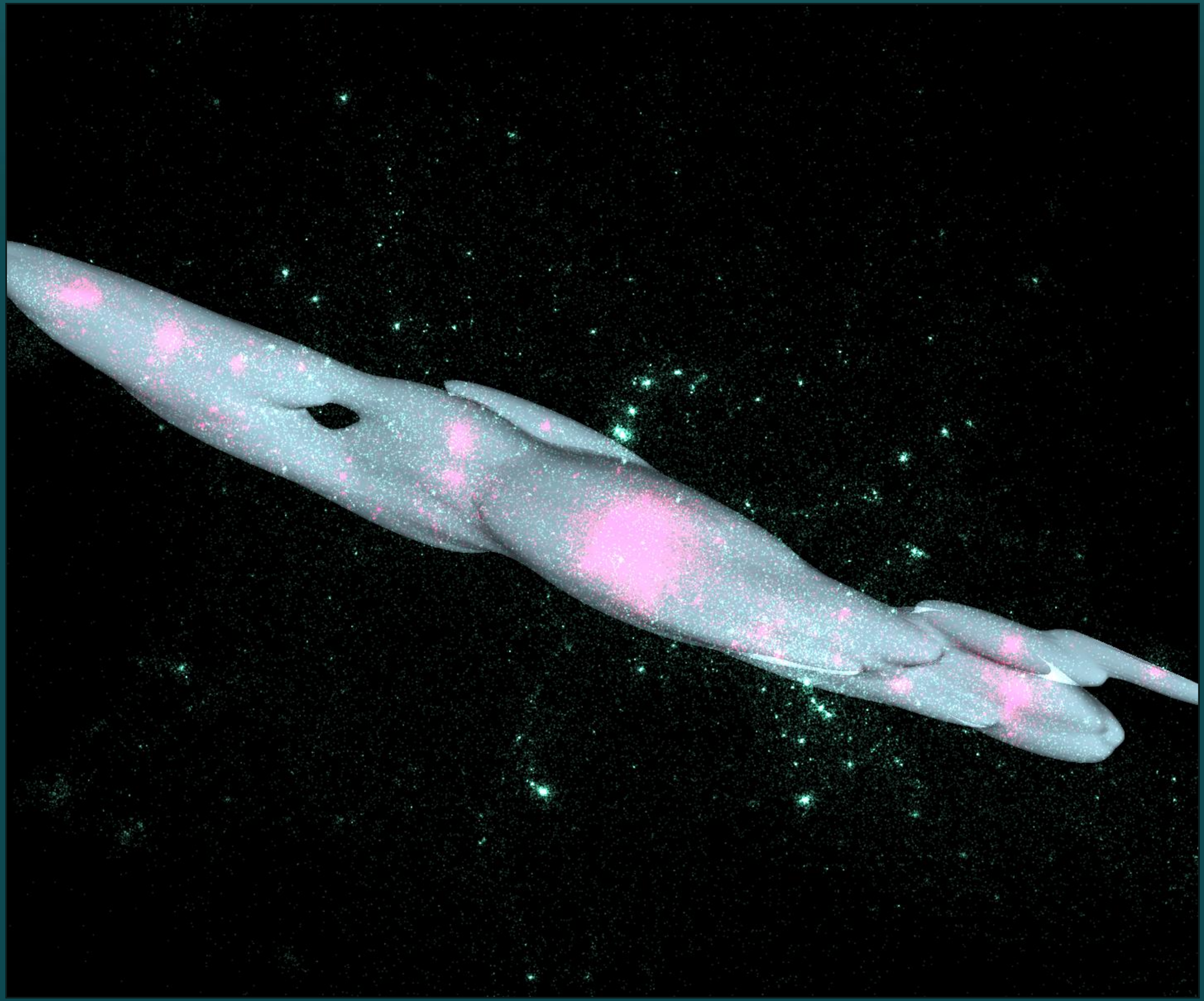

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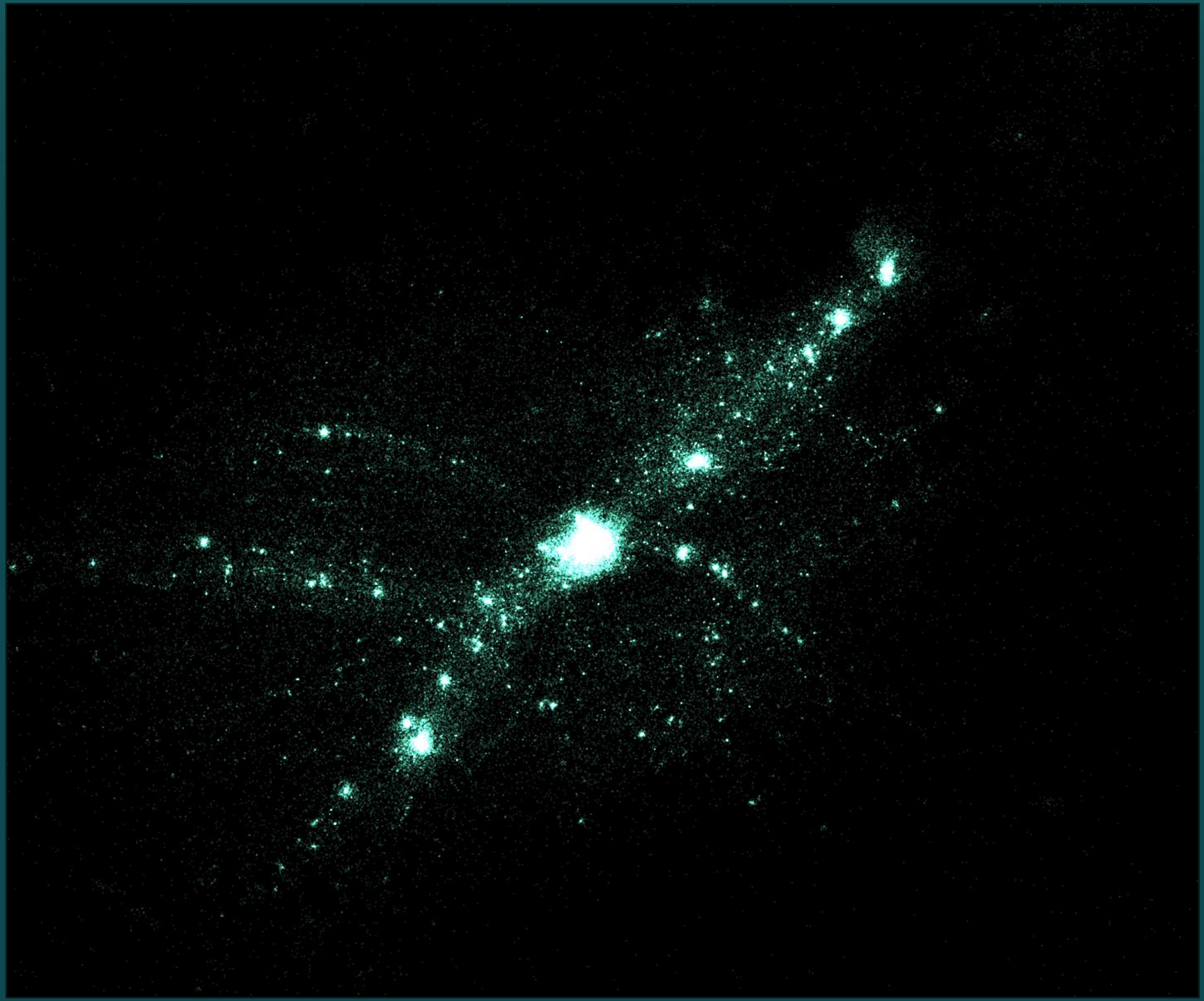

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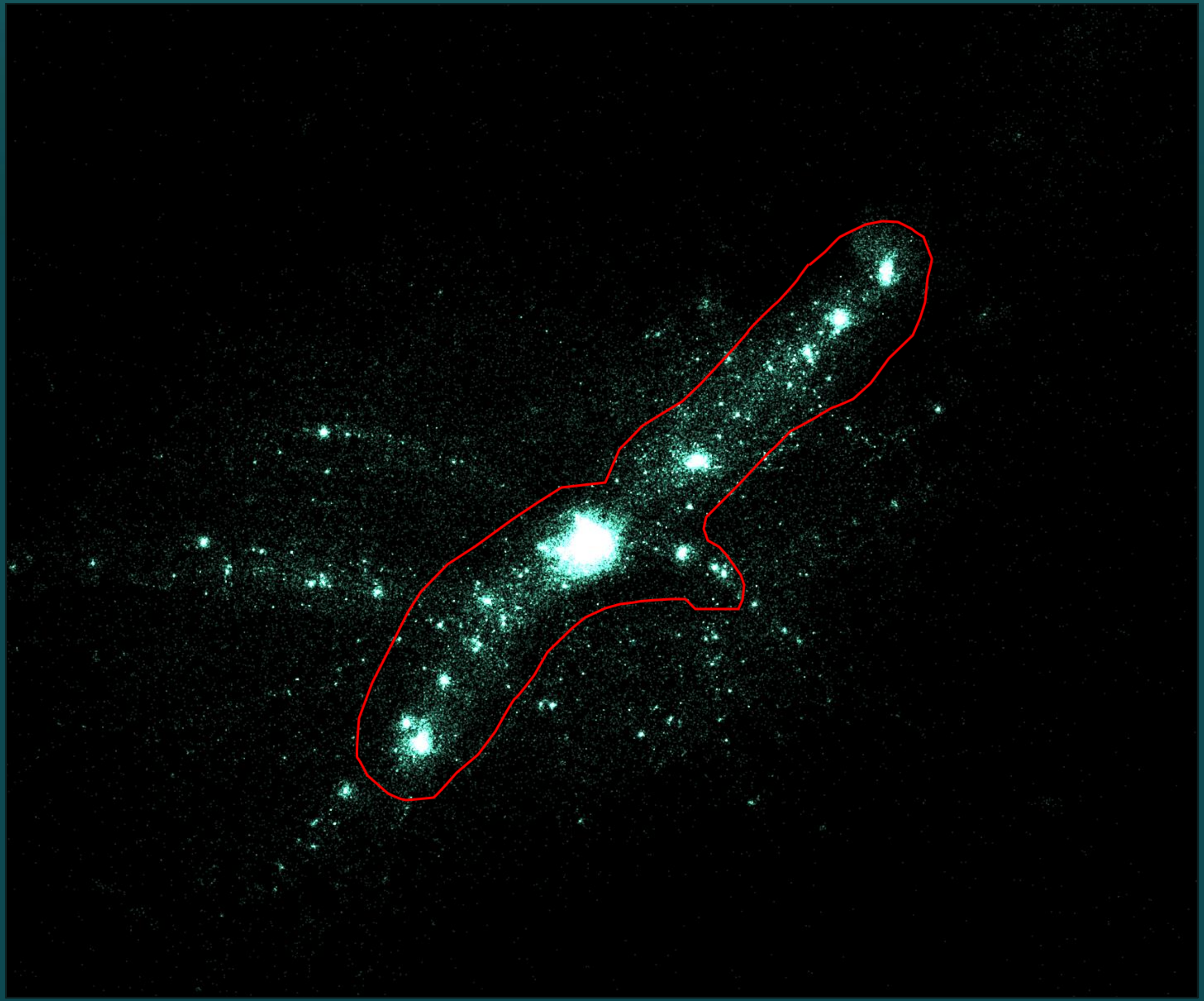

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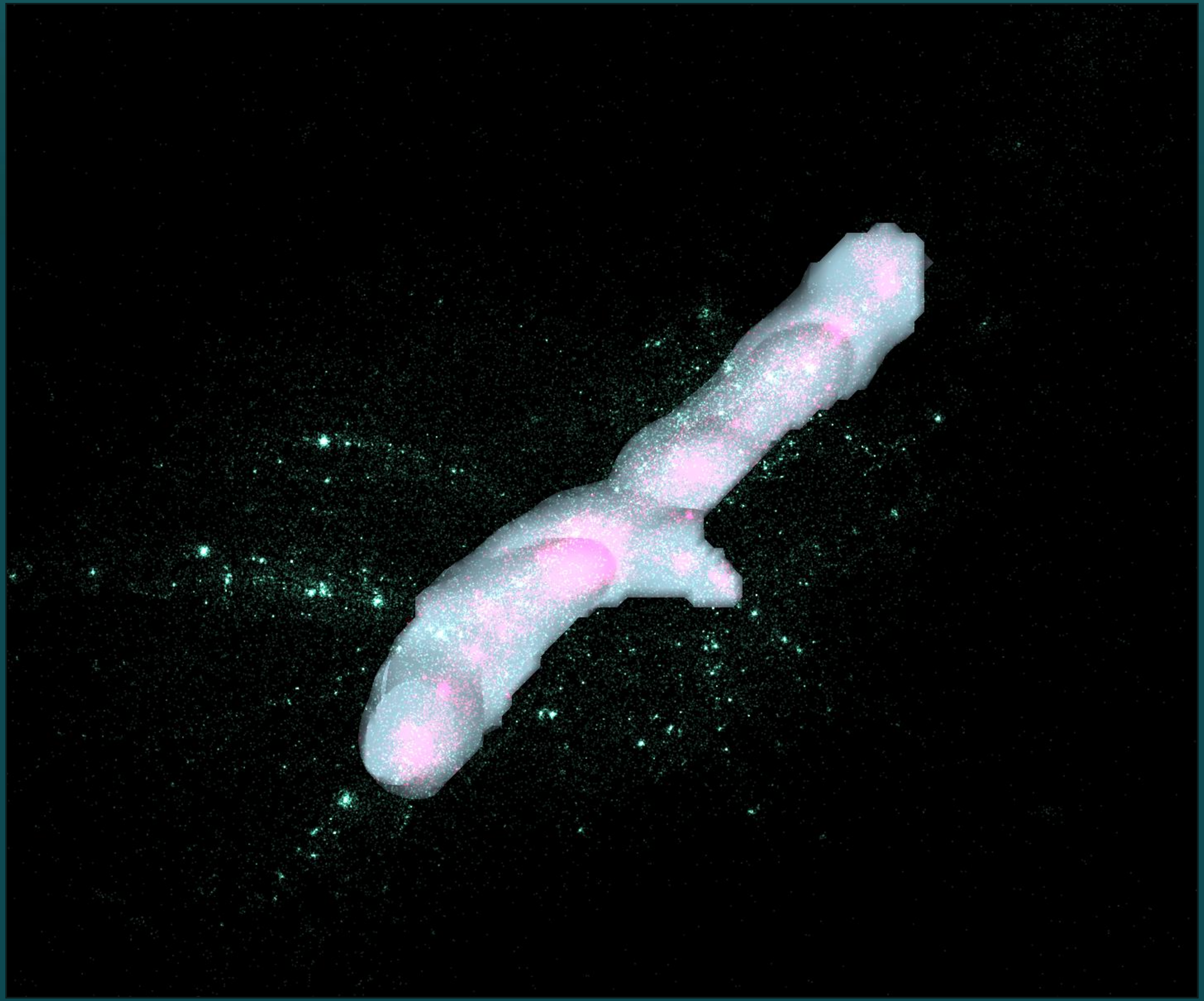

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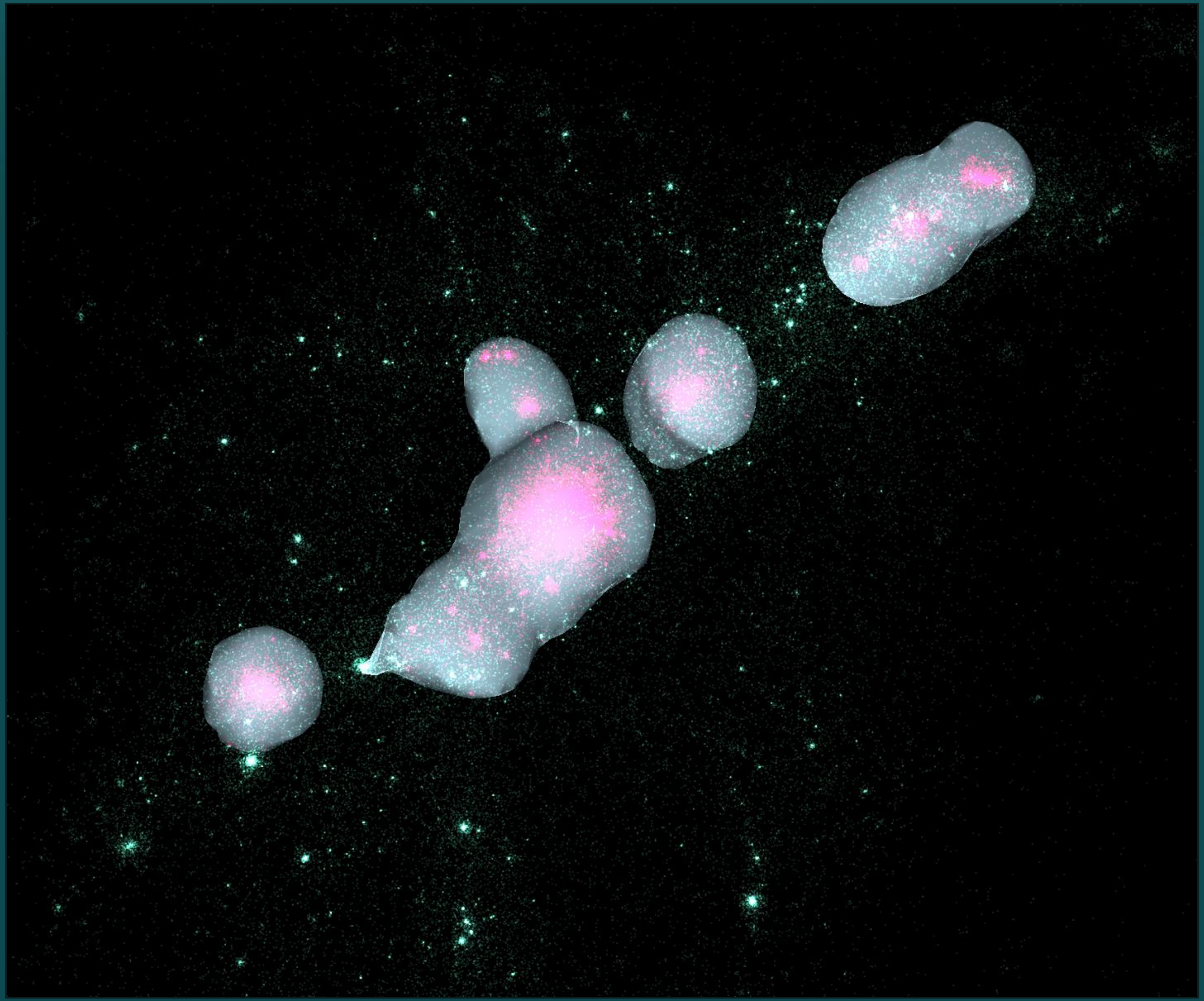


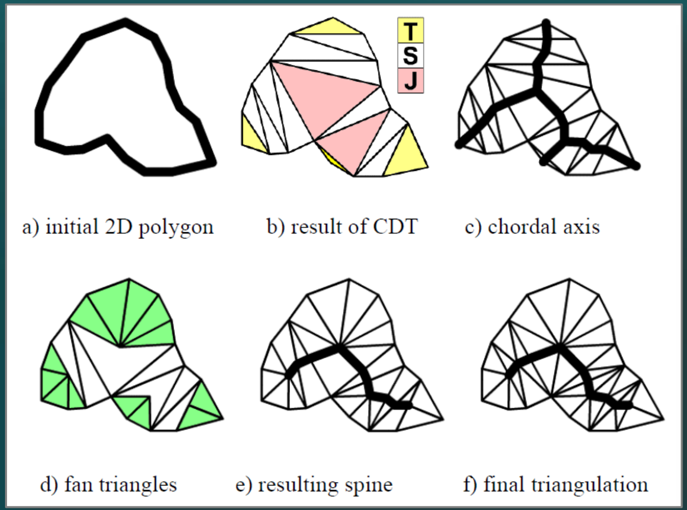
A New Interactive Selection Technique

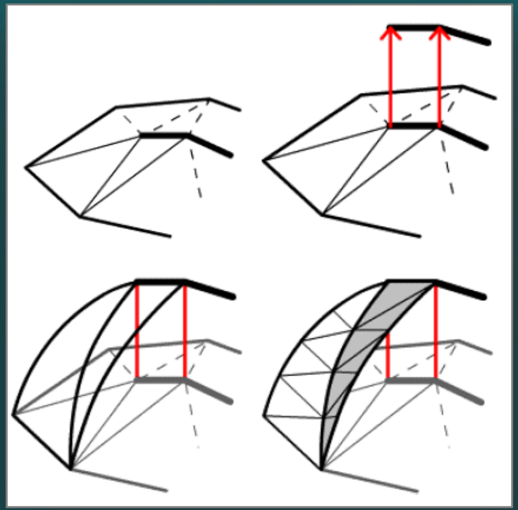
- observation: similar constraints as in sketch-based modeling:
  → definition of 3D space based on 2D input

[Igarashi et al., 1999]

TeddySelection

- sketch-based modeling:
  Teddy by Igarashi et al. [1999]
  - model in 3D based on sketched outline
  - not directly usable for selection





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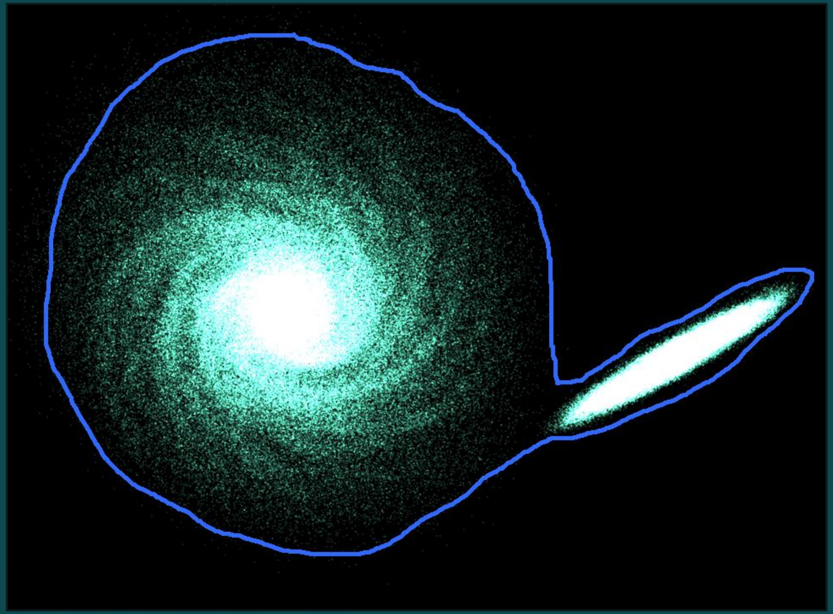
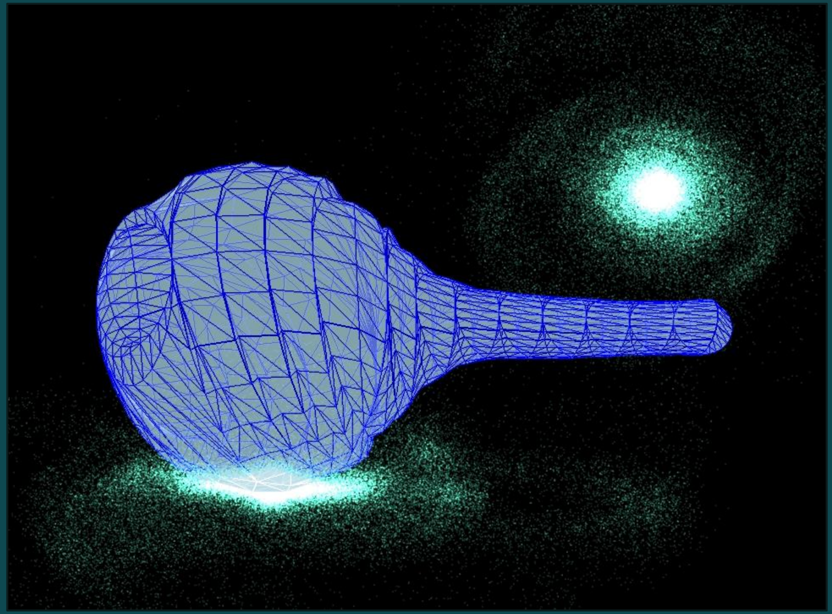
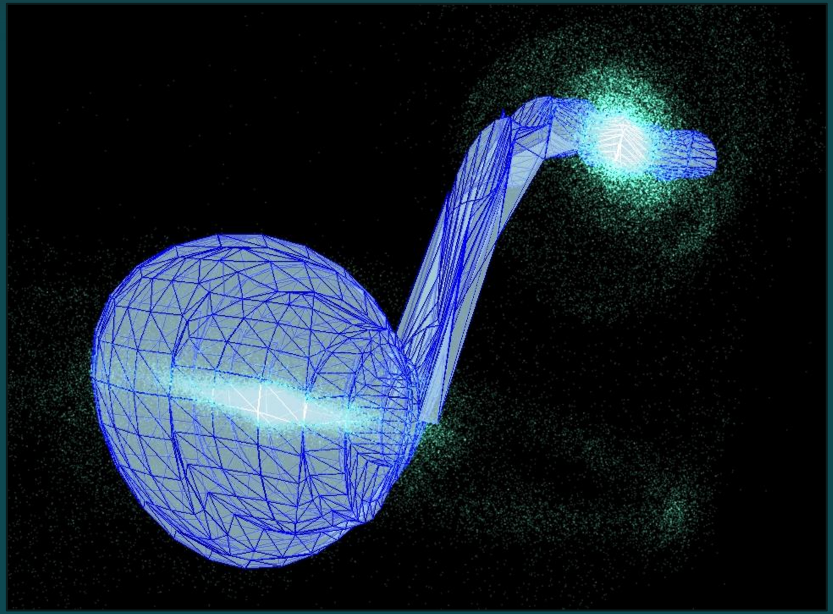
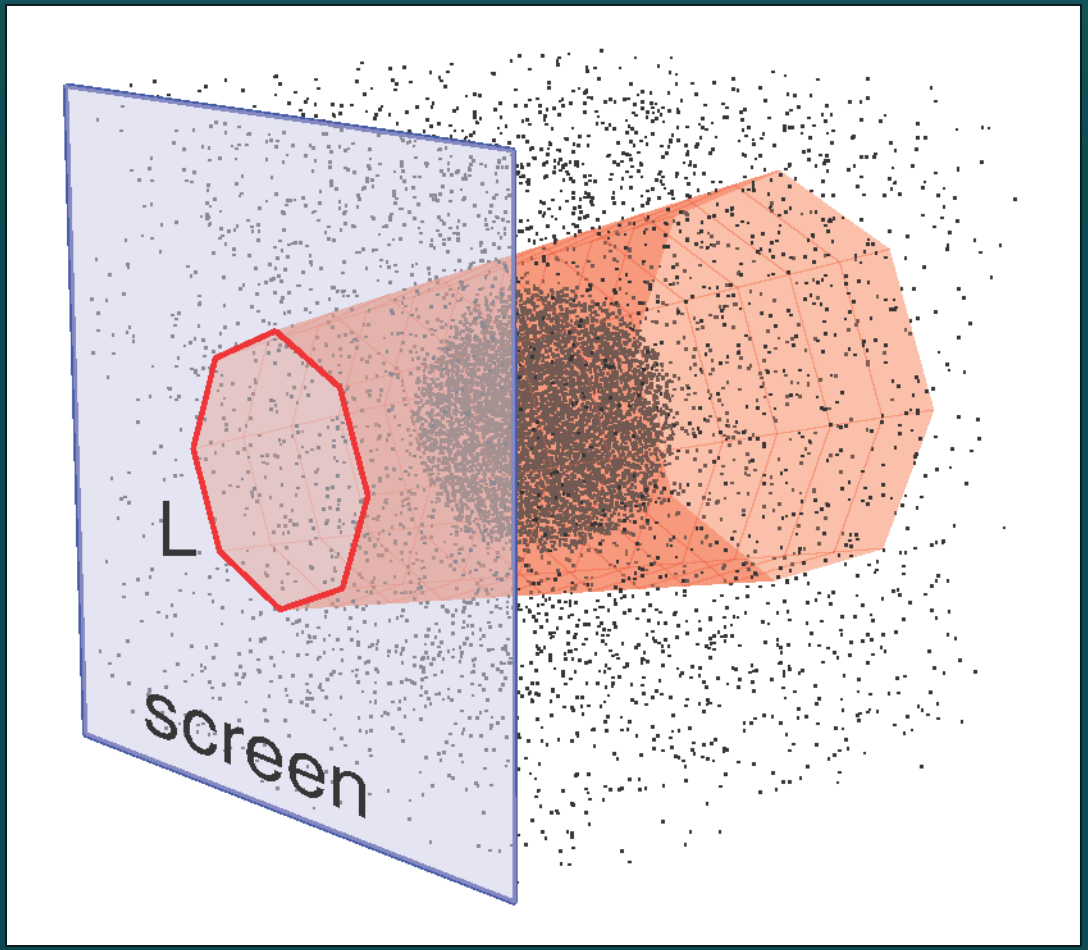






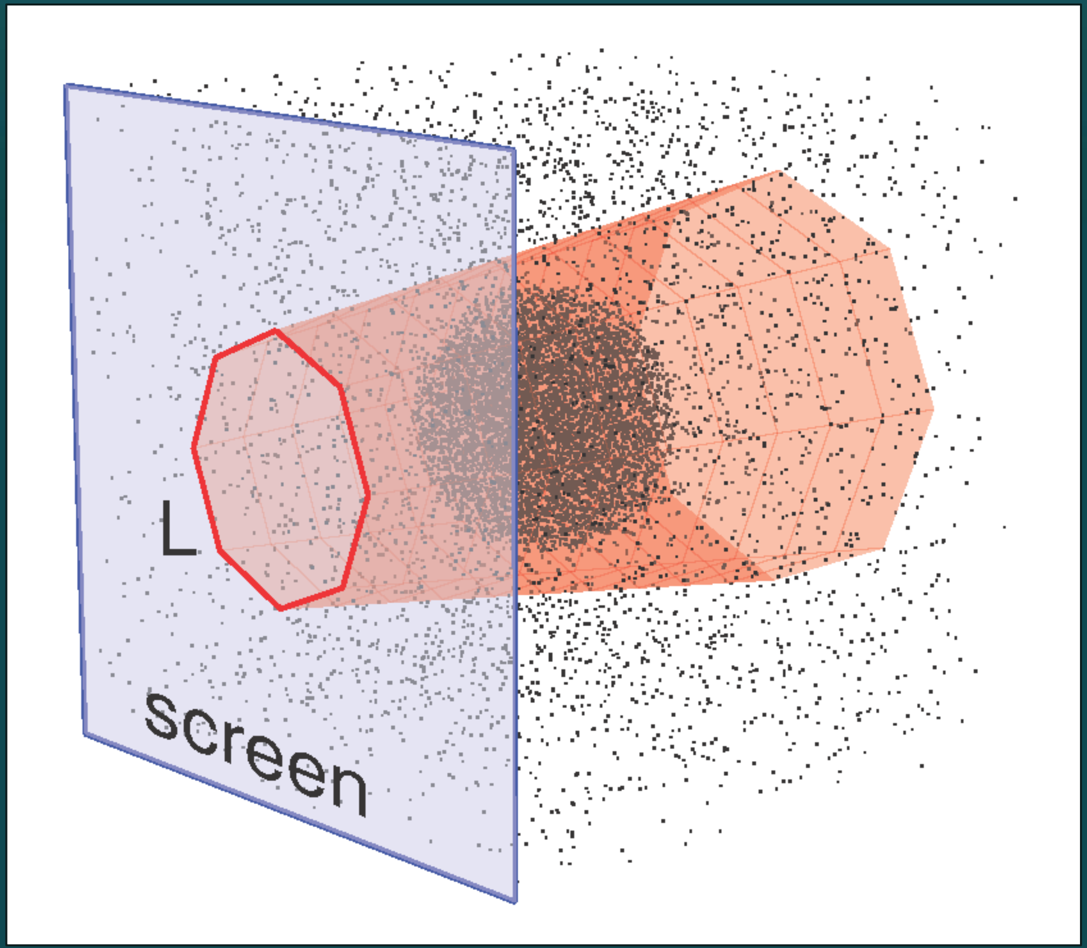
TeddySelection: Principle

1. draw lasso



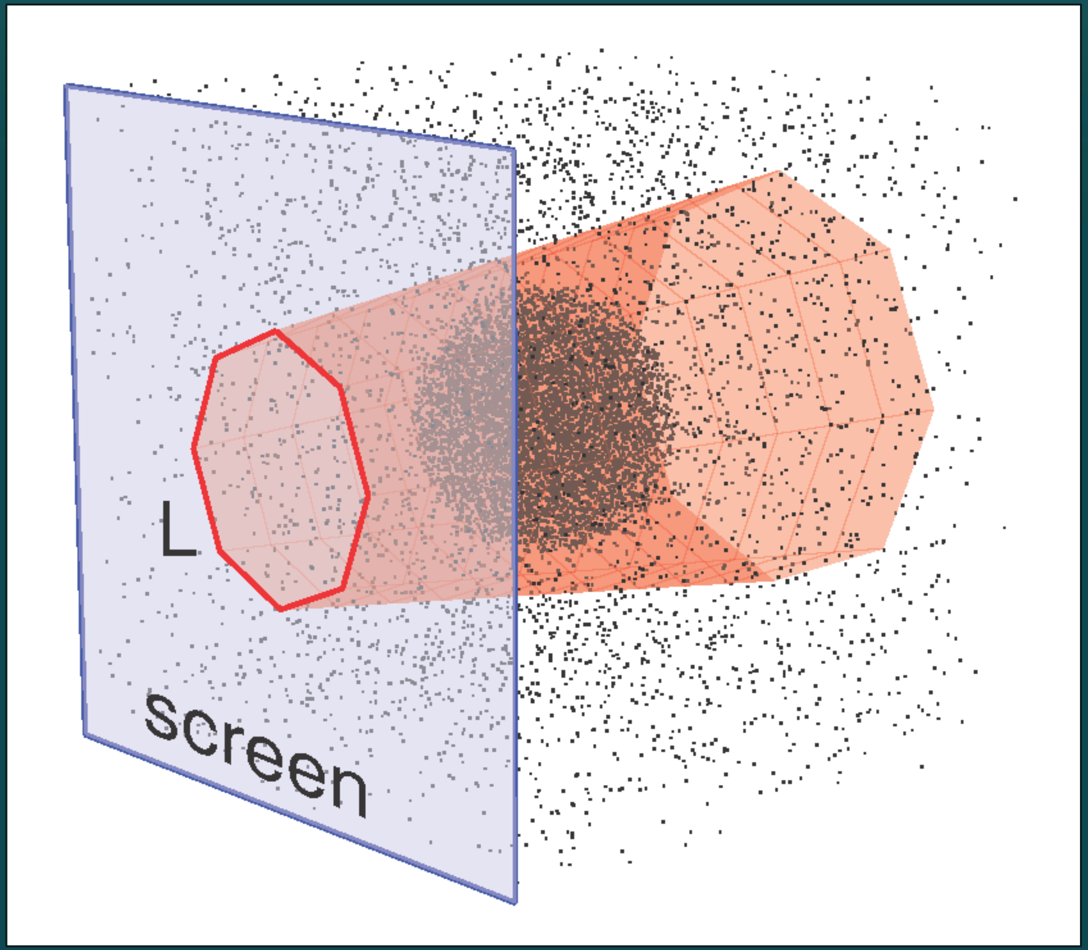
TeddySelection: Principle

1. draw lasso
2. input polygon triangulation



TeddySelection: Principle

1. draw lasso
2. input polygon triangulation
3. mapping particles to triangles



TeddySelection: Principle

1. draw lasso
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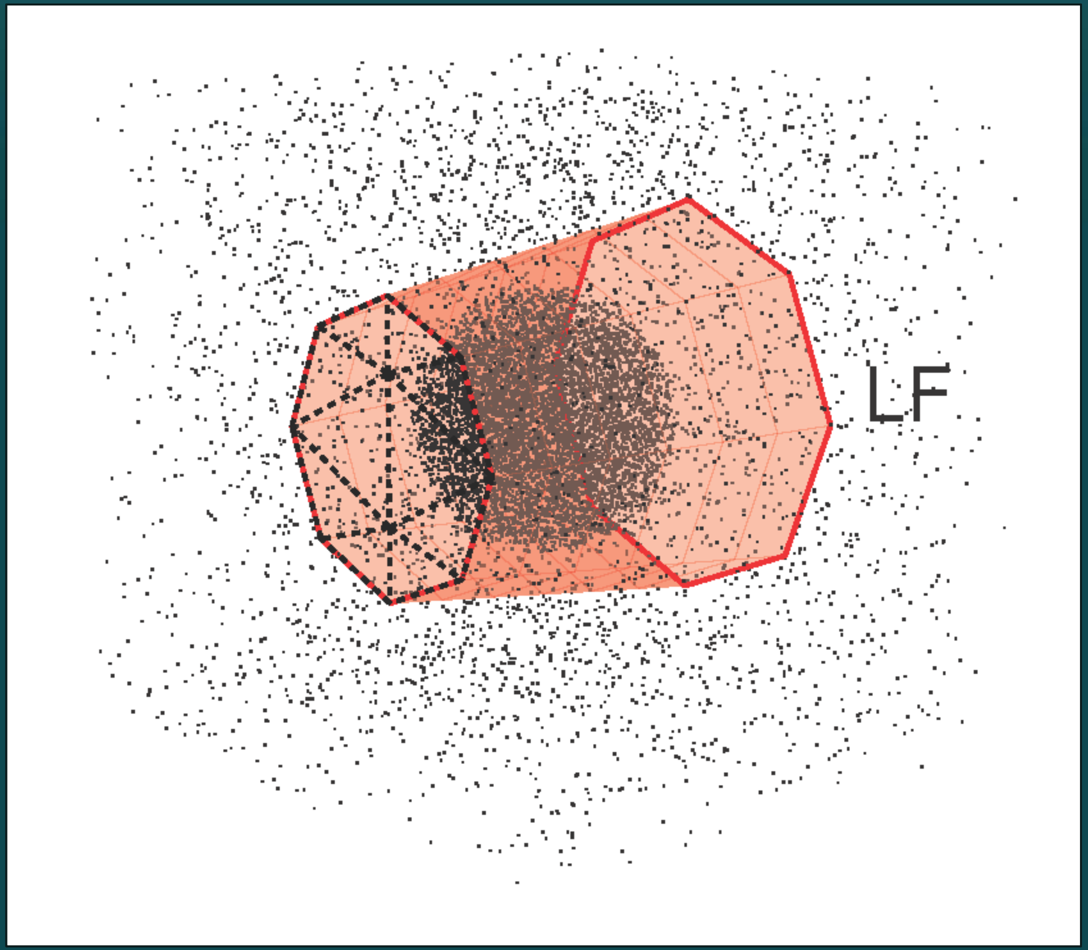
3. mapping particles to triangles
4. selection mesh construction
   - 1st binning to fit generalized cylinder to data



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1. draw lasso
2. input polygon triangulation
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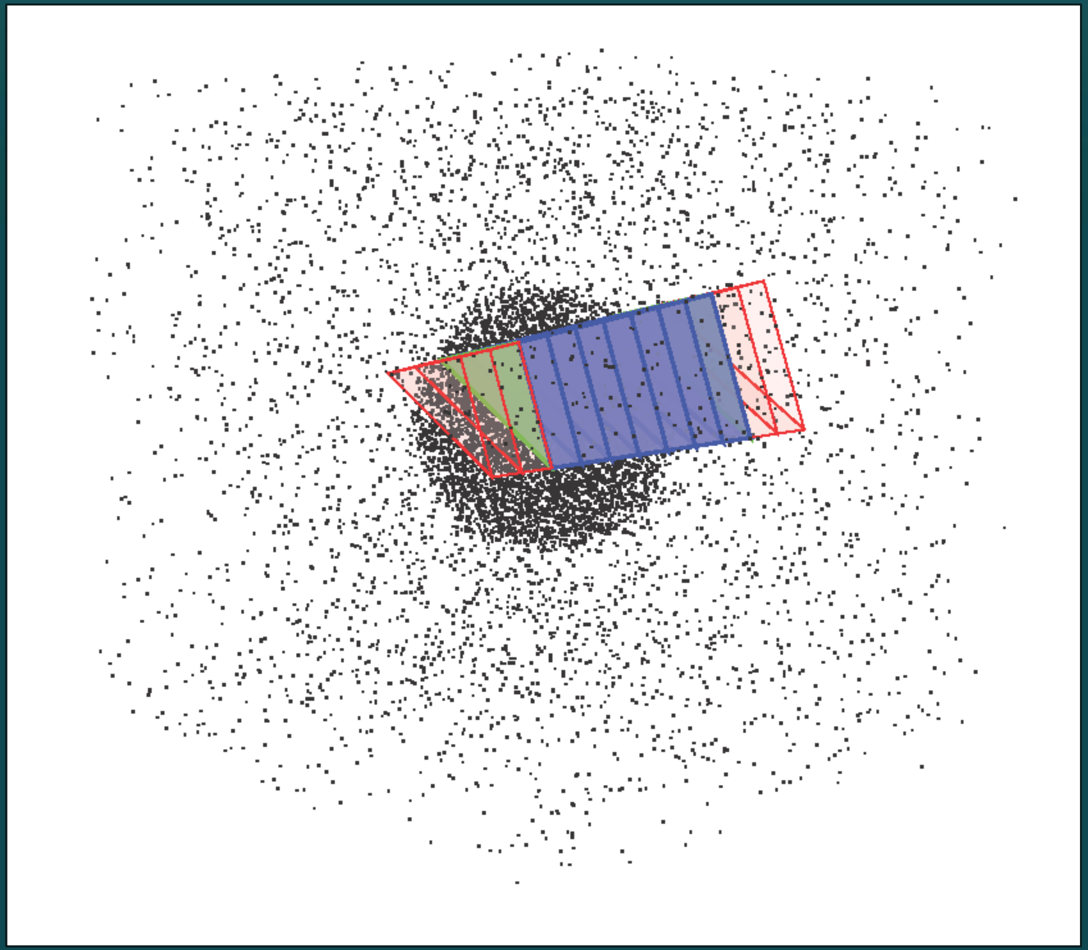
   - 1^{st} binning to fit generalized cylinder to data
   - 2^{nd} binning per triangle, find closest/furthest dense bin (density > 4 • expected density)



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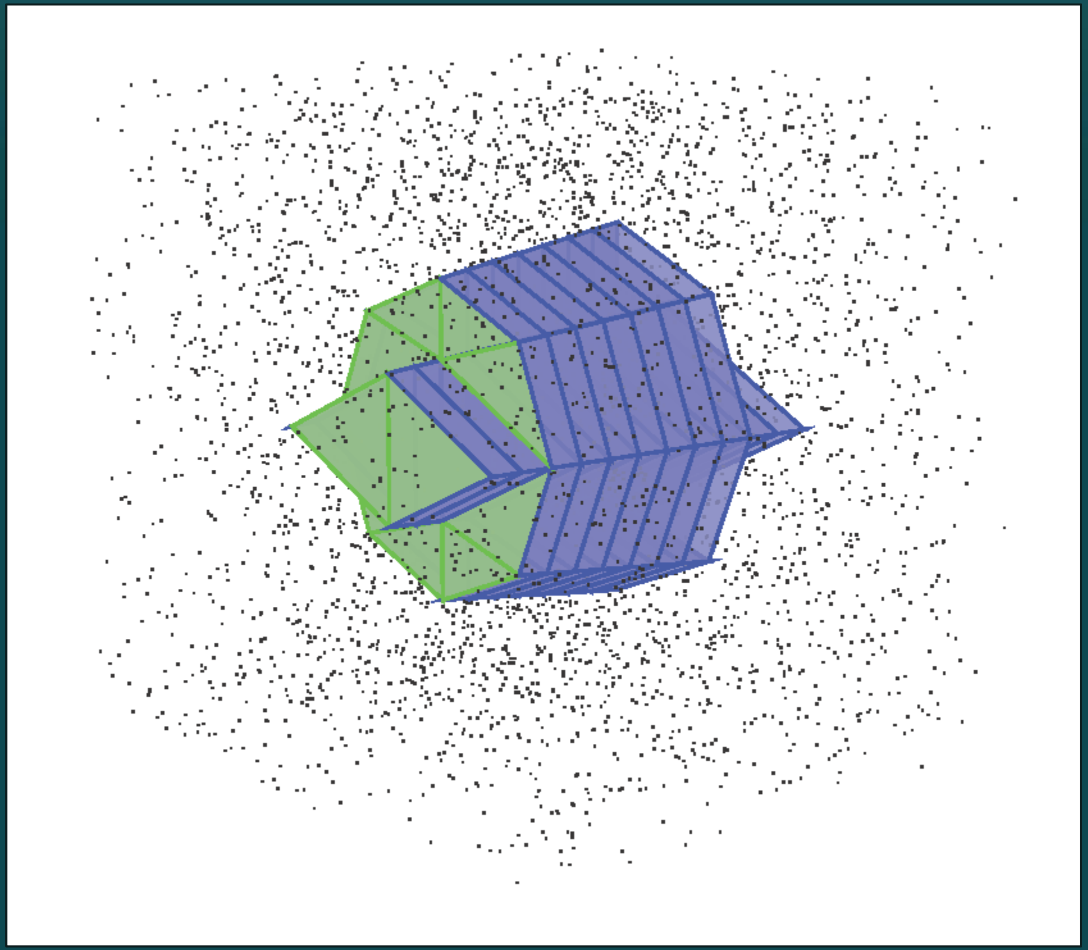

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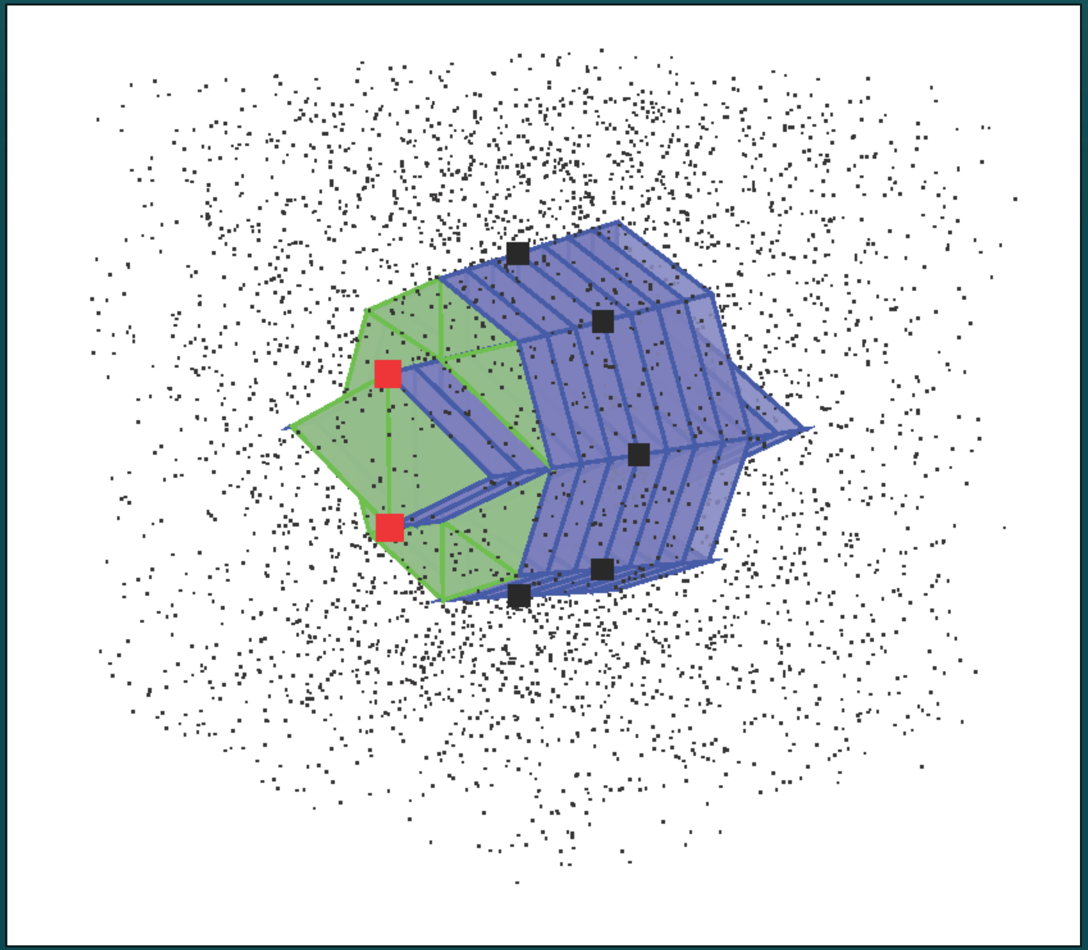

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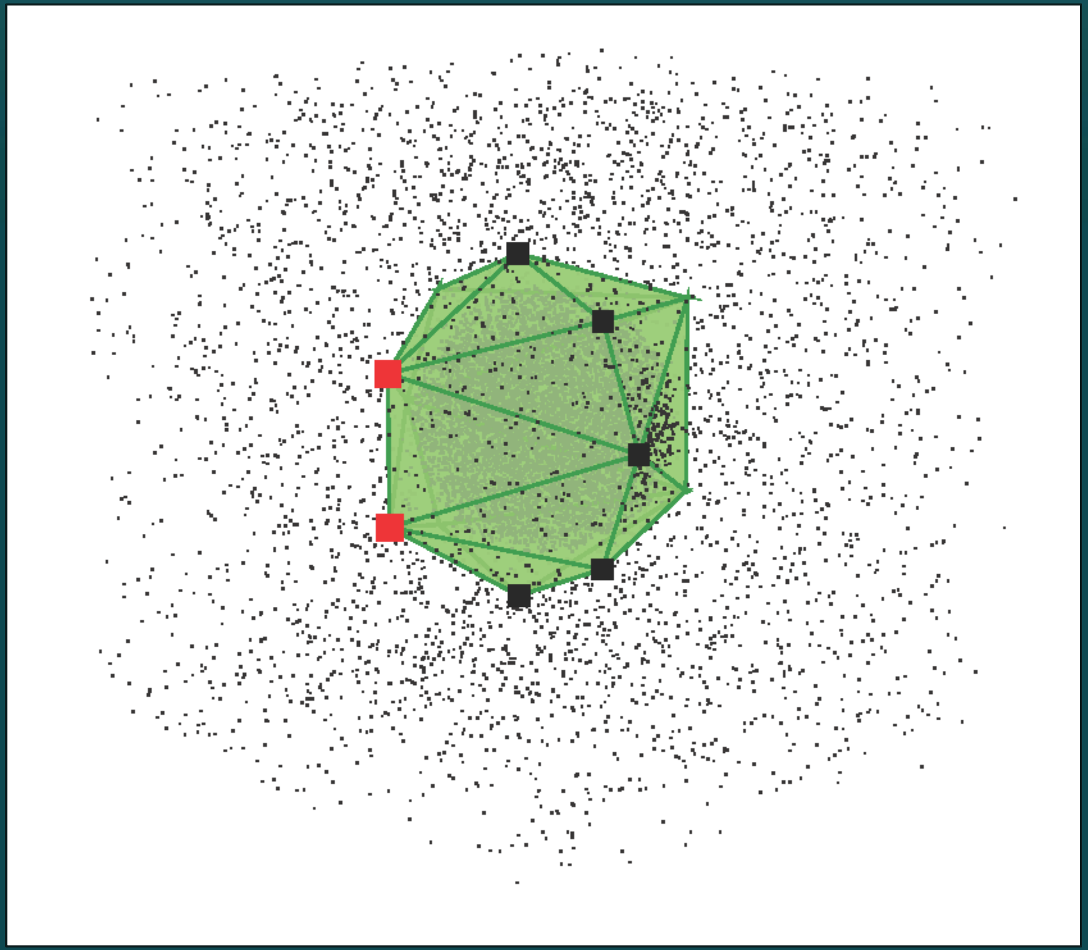
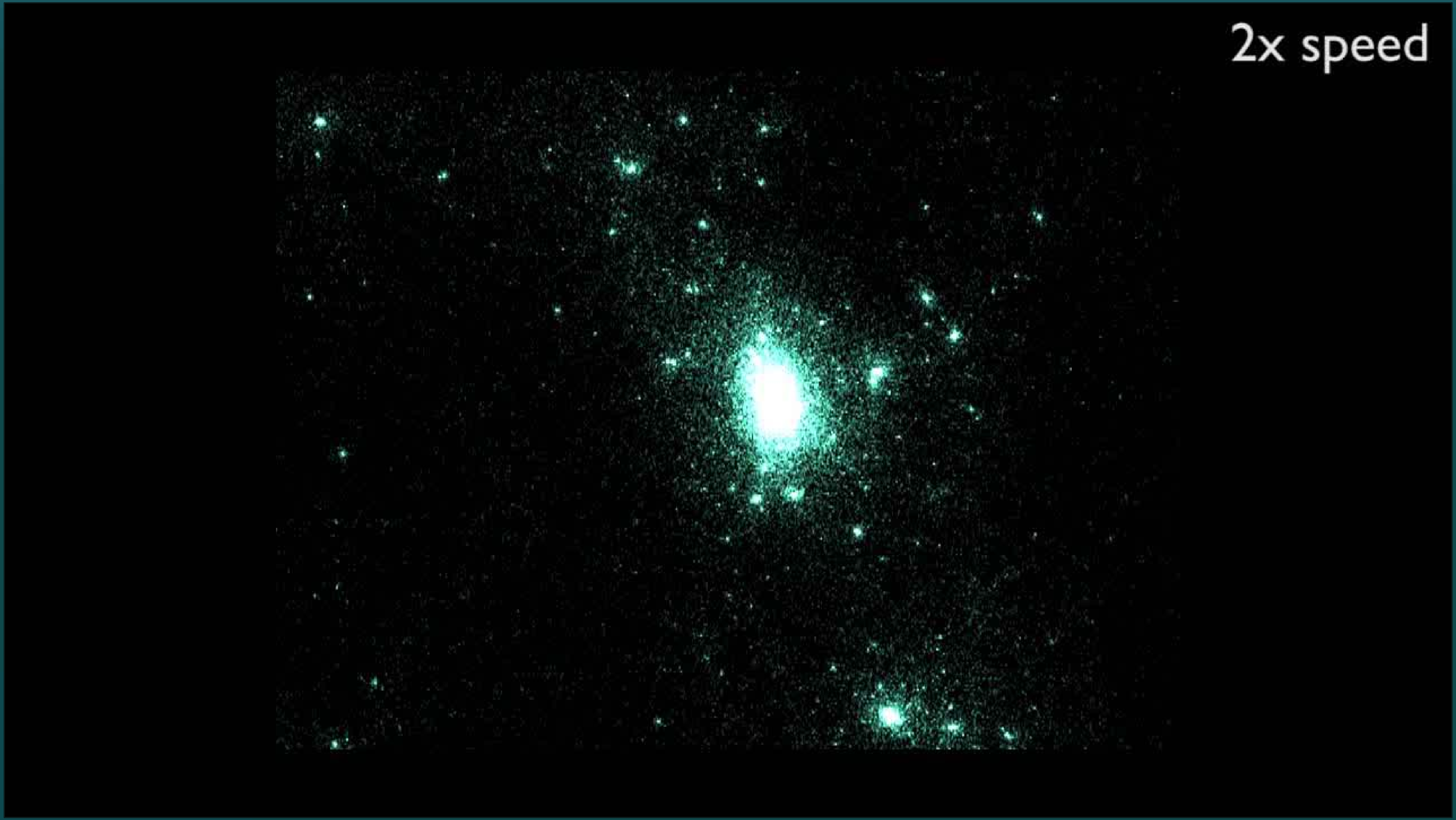
   - place outline vertices at average distance
   - inflate 2D mesh based on binning data

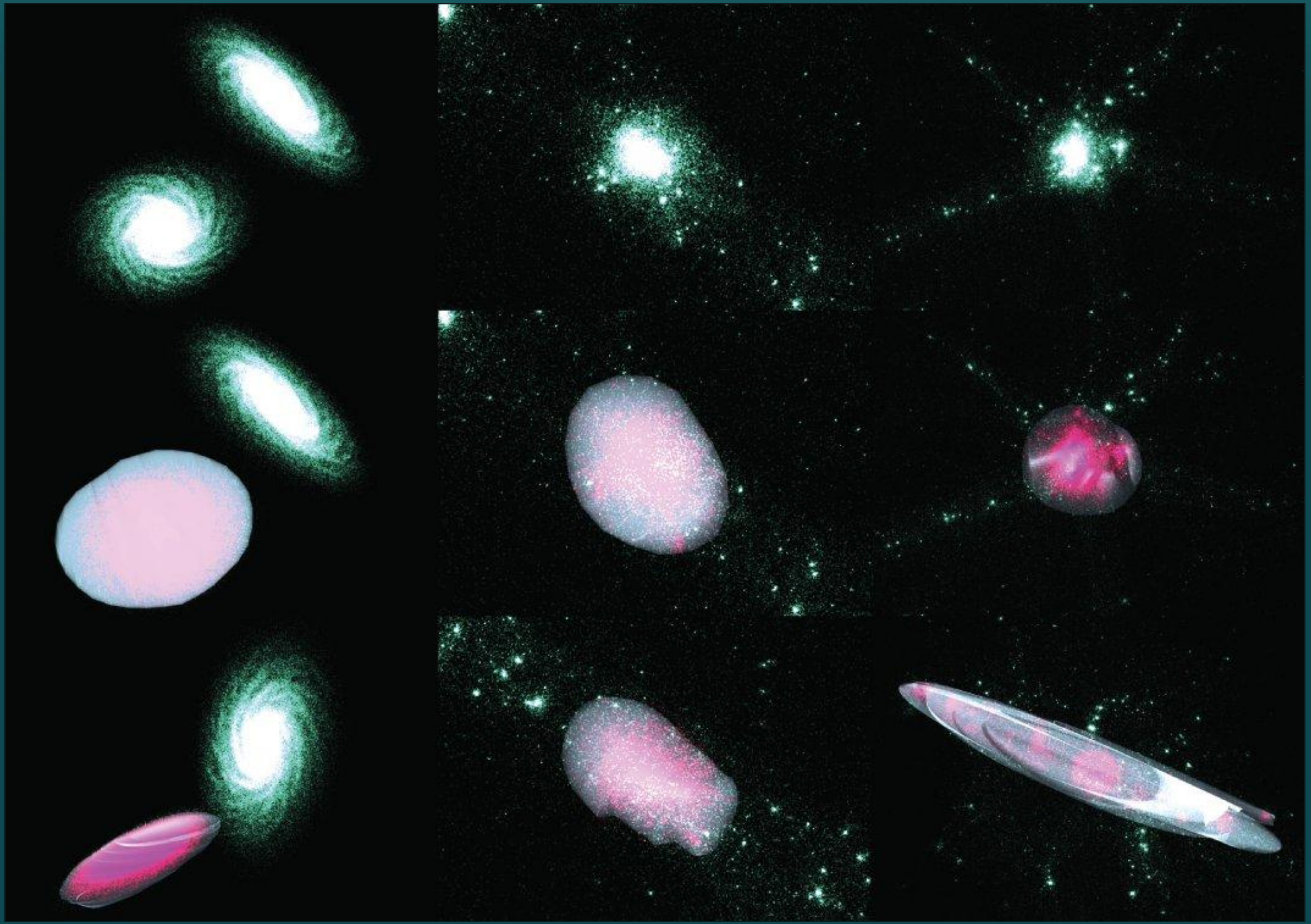


Video: TeddySelection



TeddySelection: Pros & Cons

- benefit
  - structure-aware selection
  - compact selection volume
  - fast selection (≈ 0.2 sec.)
- criticism
  - problems in sparse regions
  - volume always connected, does not work well for many small clusters



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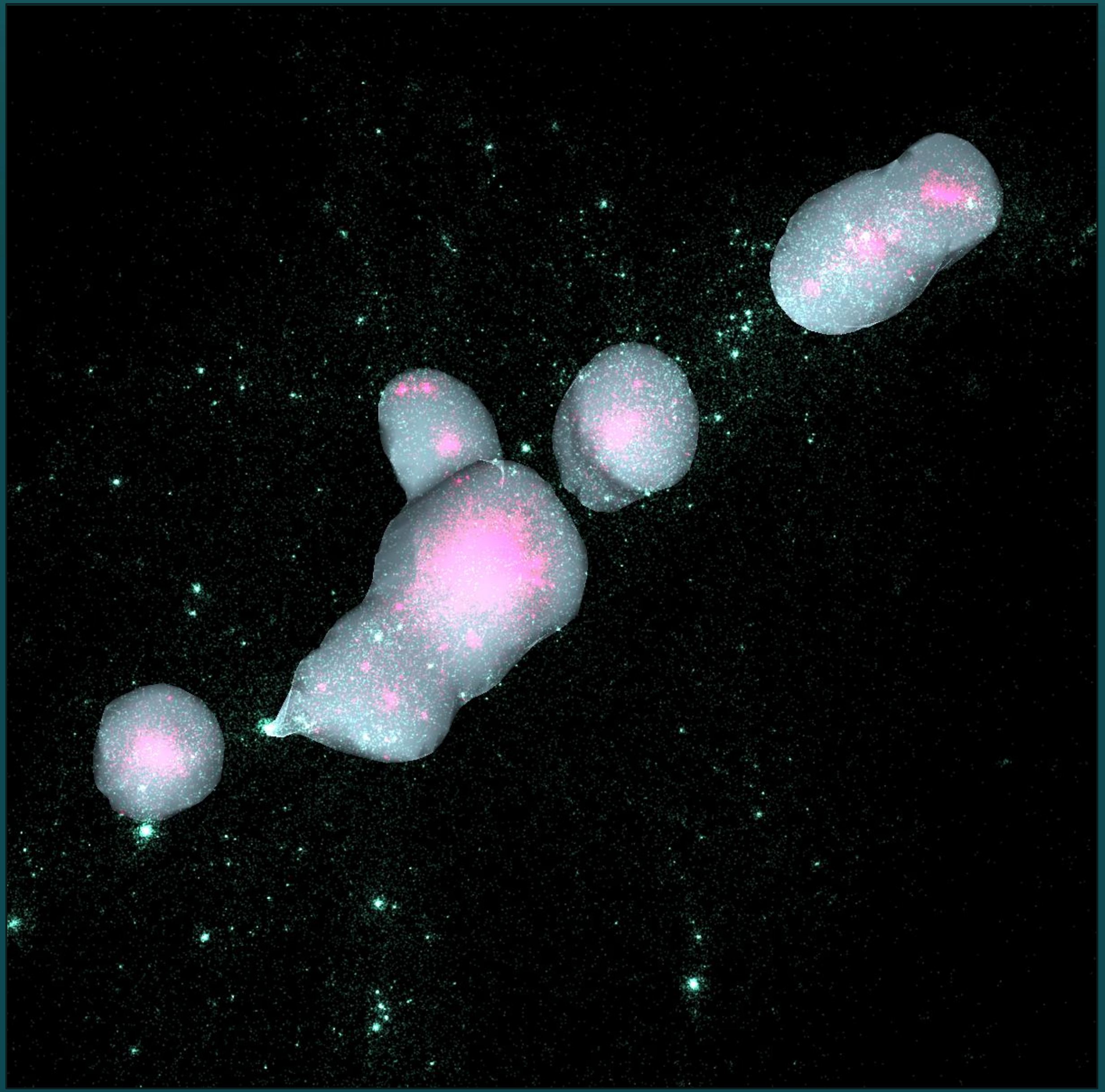
CloudLasso

- goals
  - same selection procedure as before
  - overcome limitations of TeddySelection
    $\rightarrow$ be able to treat clusters
- concept
  - base the selection volume on
    global particle density estimation
  - i.e., selection mesh based on density field
    $\rightarrow$ marching cubes algorithm



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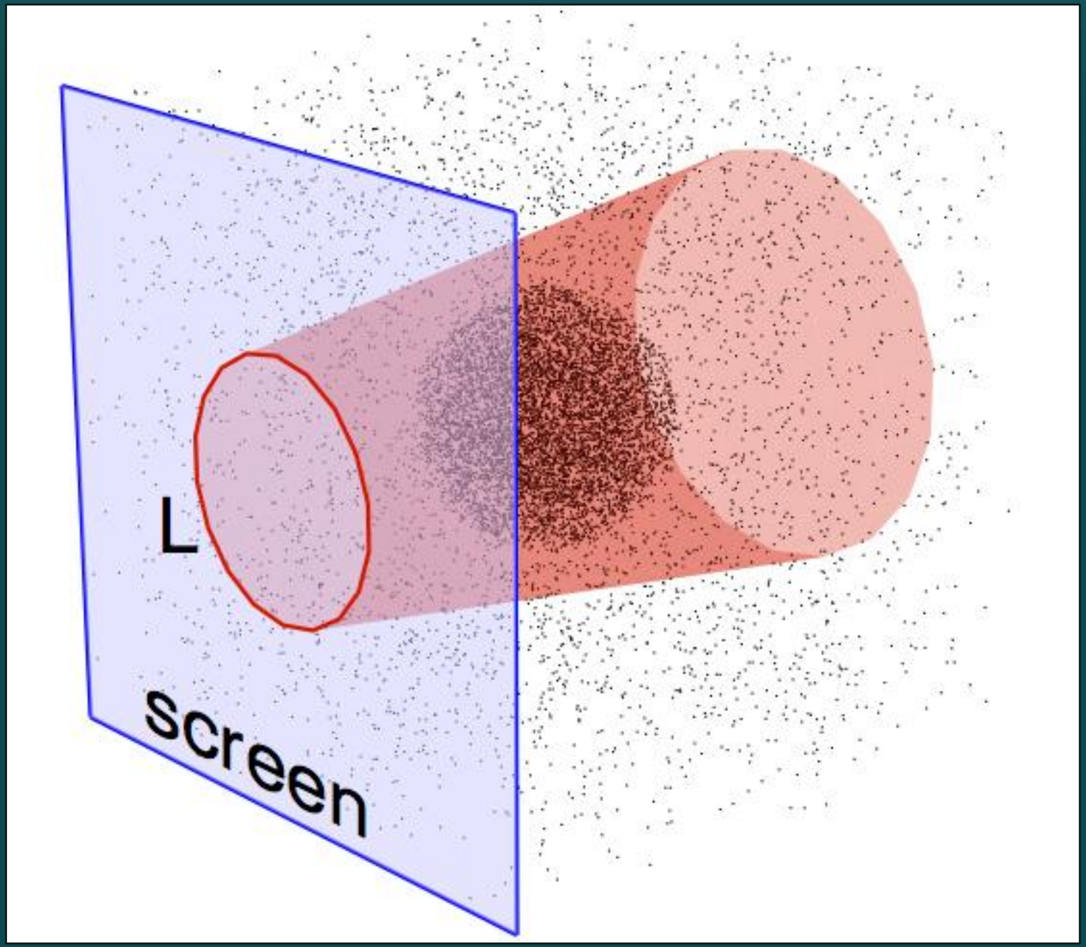

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1. draw lasso
2. selection mesh construction
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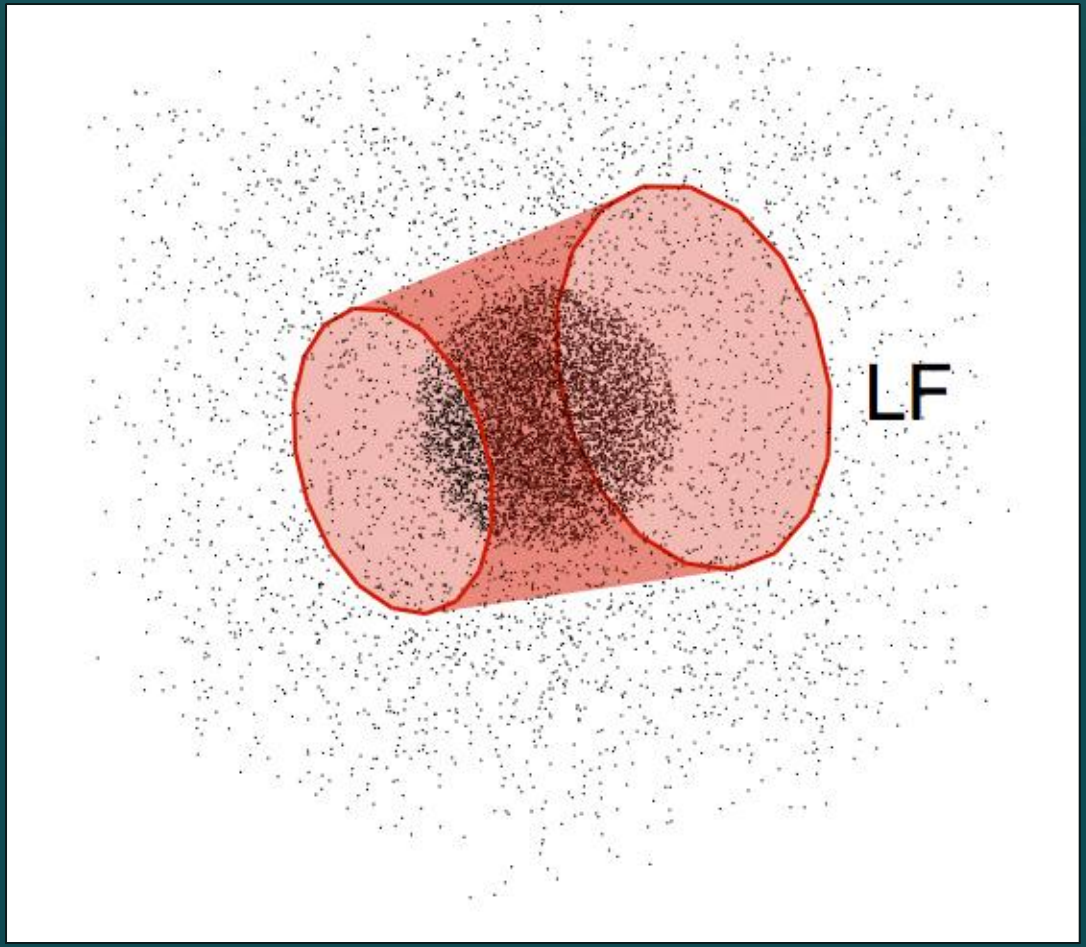
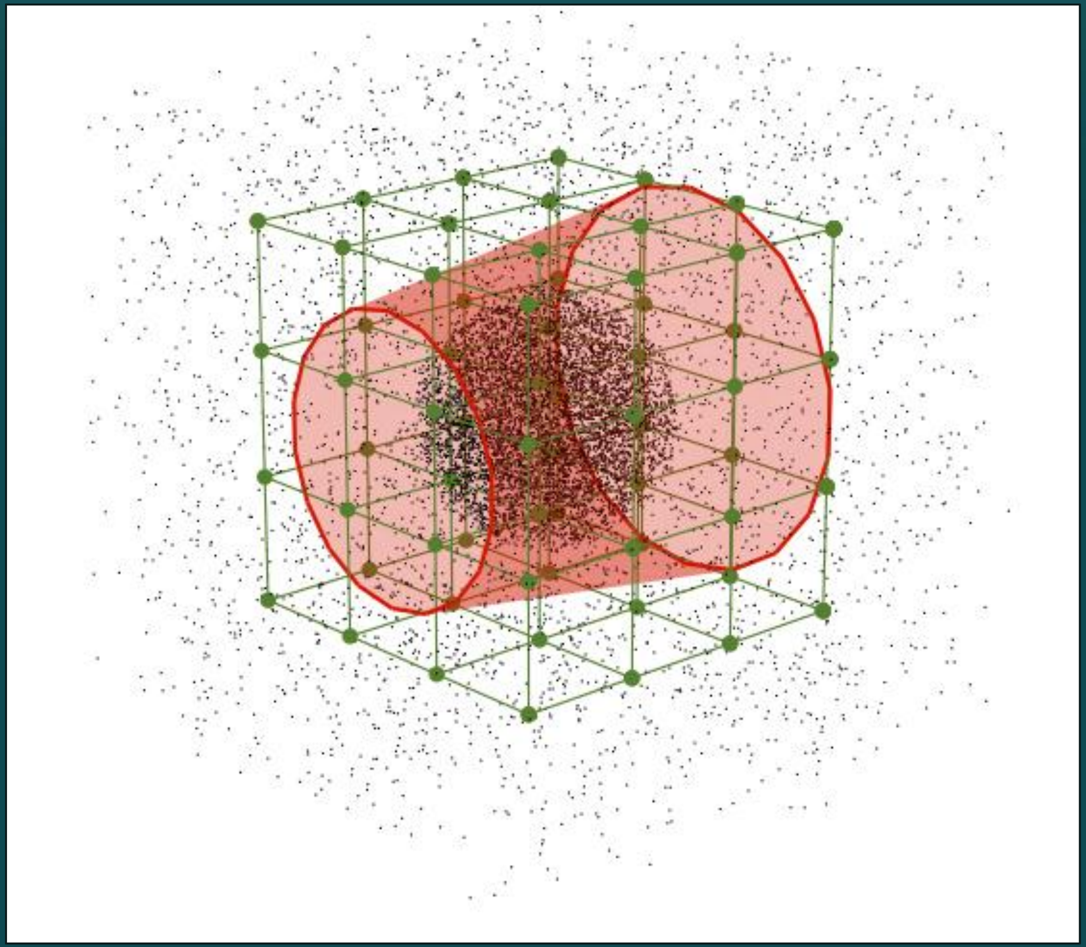


CloudLasso: Principle

1. draw lasso
2. selection mesh construction
   - 1^{st} binning to fit generalized cylinder to data
   - fit regular grid ($64 \times 64 \times 64$) to enclose the lasso frustum



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1. draw lasso
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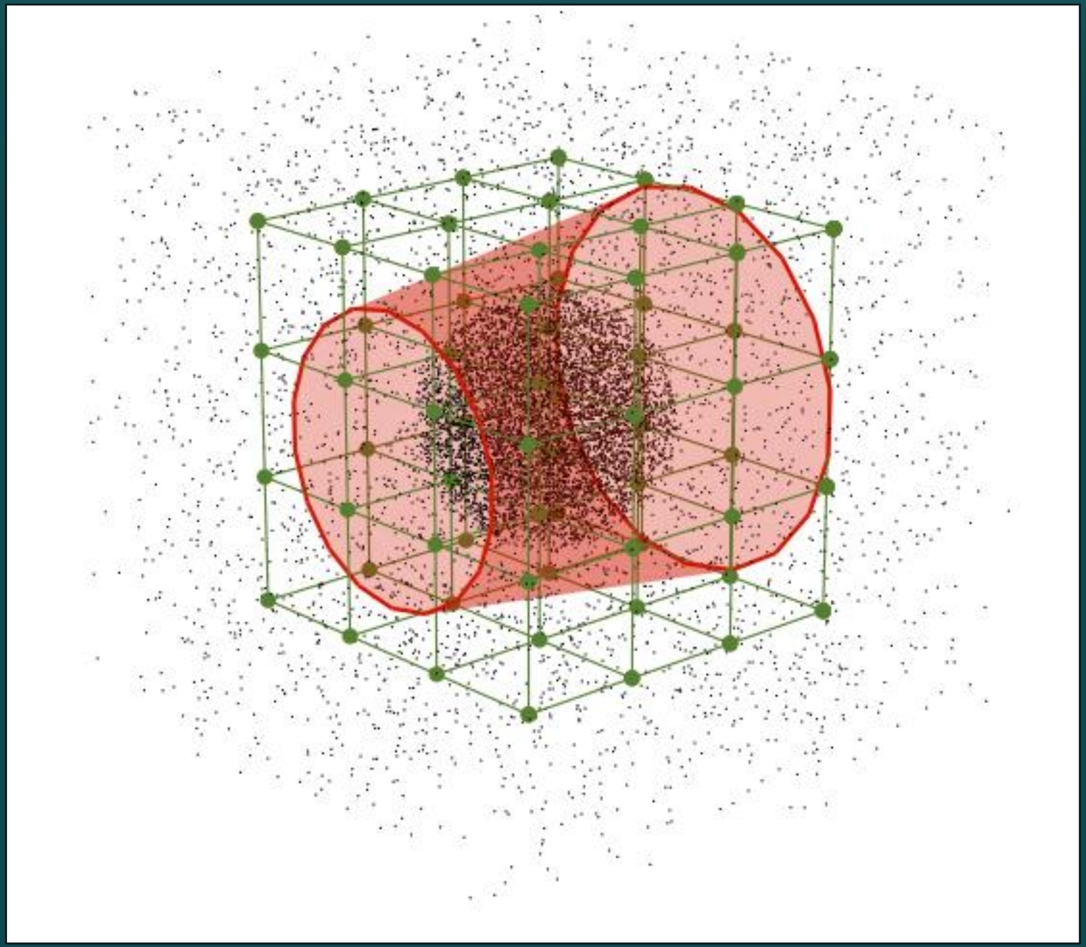
   - fit regular grid ($64 \times 64 \times 64$) to enclose the lasso frustum
   - use kernel density estimation on grid



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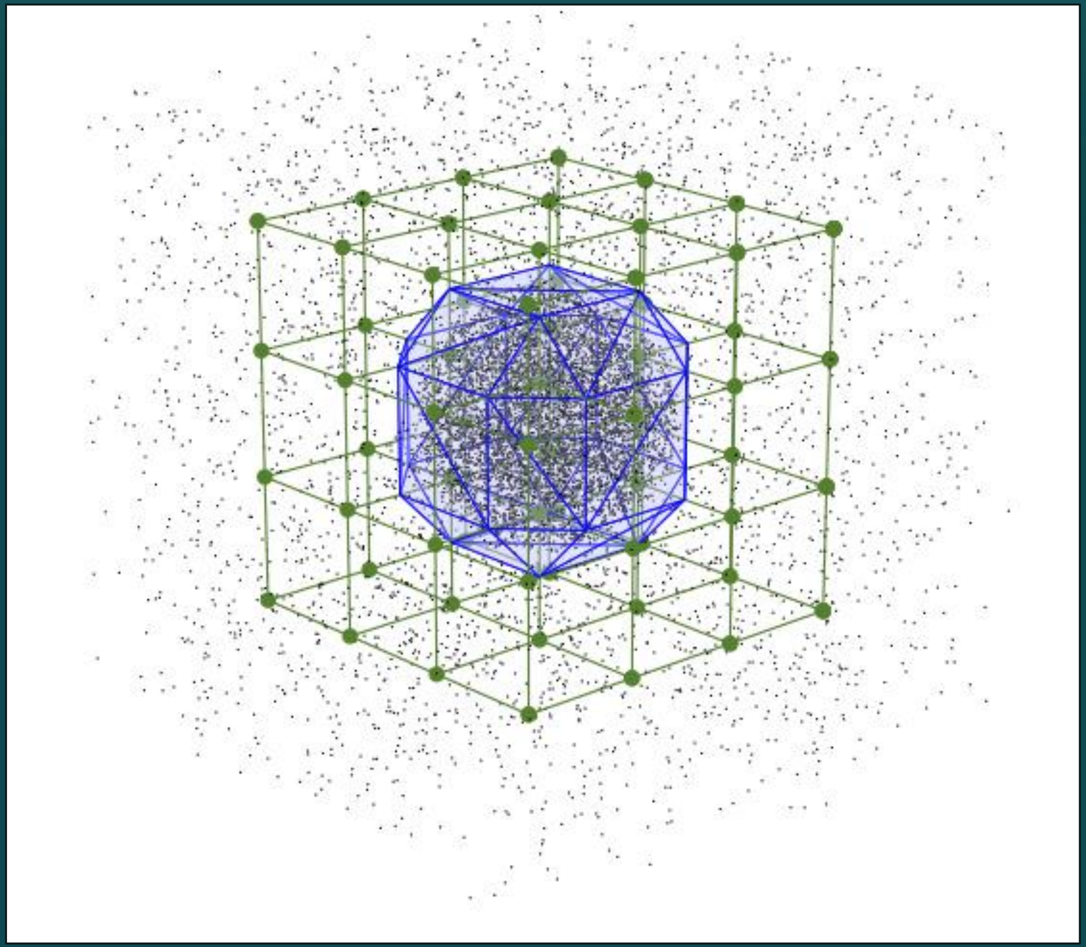
   - 1^{st} binning to fit generalized cylinder to data
   - fit regular grid ($64 \times 64 \times 64$) to enclose the lasso frustum
   - use kernel density estimation on grid
   - run marching cubes algorithm, but ensure to ignore parts outside lasso

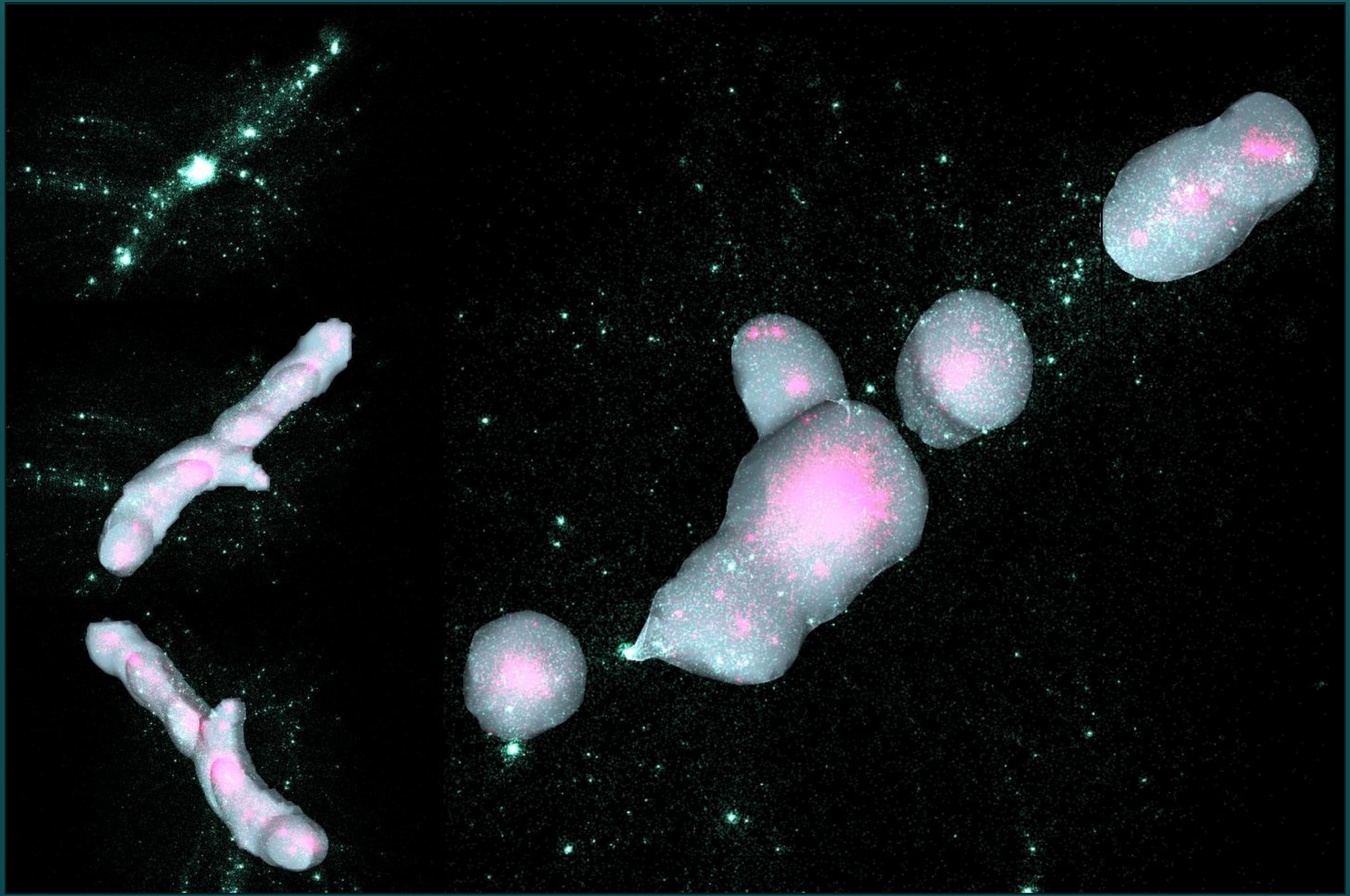


- threshold adjustment possible interactively

CloudLasso: Results

- structure-aware selection
- separate clusters
- interactive adjustment of selection threshold

- performance:
  Marching Cubes: ≈ 0.4 sec.
  density estimation:
  4–6 sec. for ≈ 2 • 10^5 particles



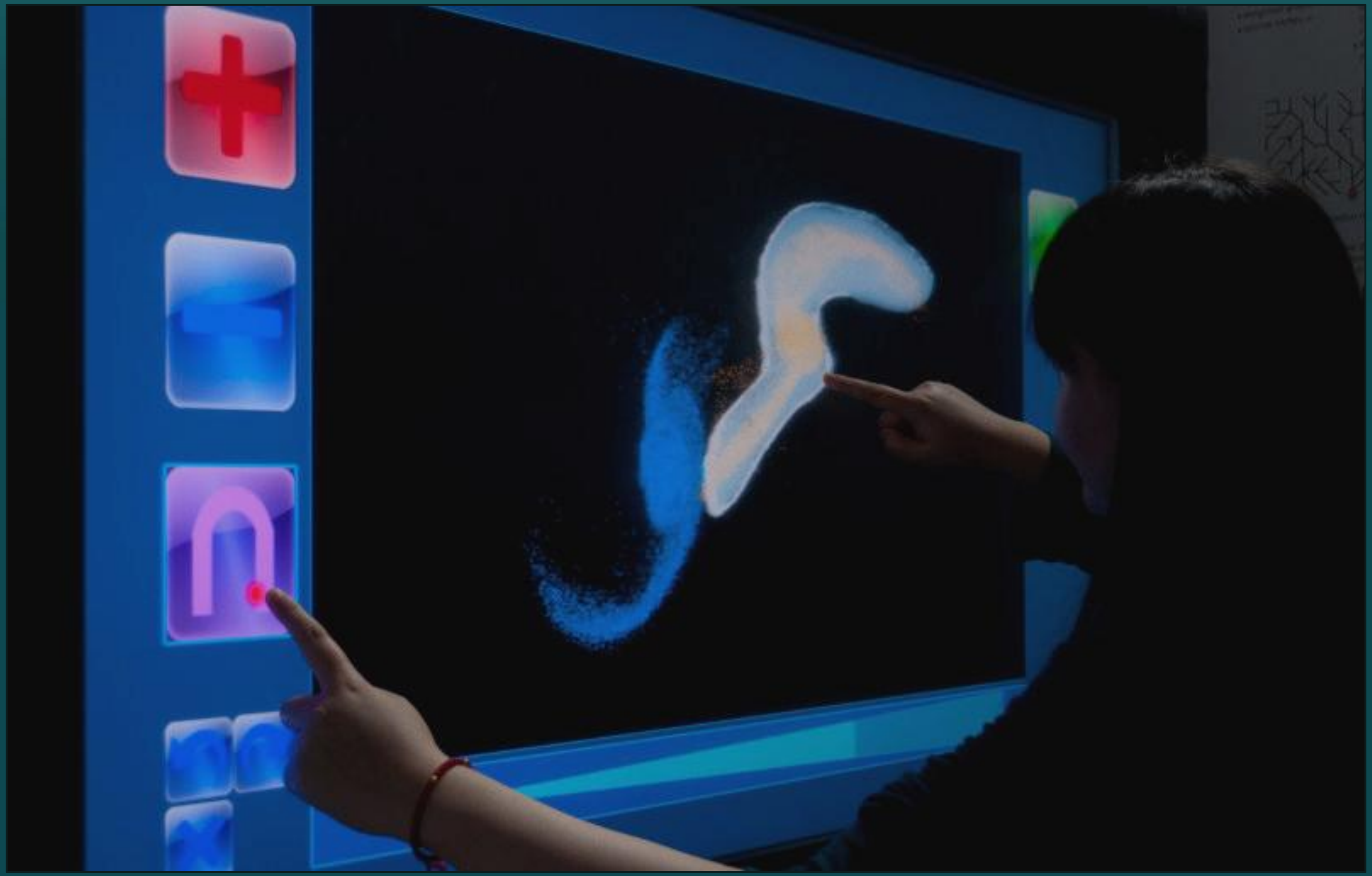
Video: CloudLasso Selection & Interaction

Evaluation & Validation: User Study

- informal feedback positive
- quantitative study to confirm
- restriction to 2 selection methods:
  CylinderSelection
  - base line (Tablet Freehand Lasso)

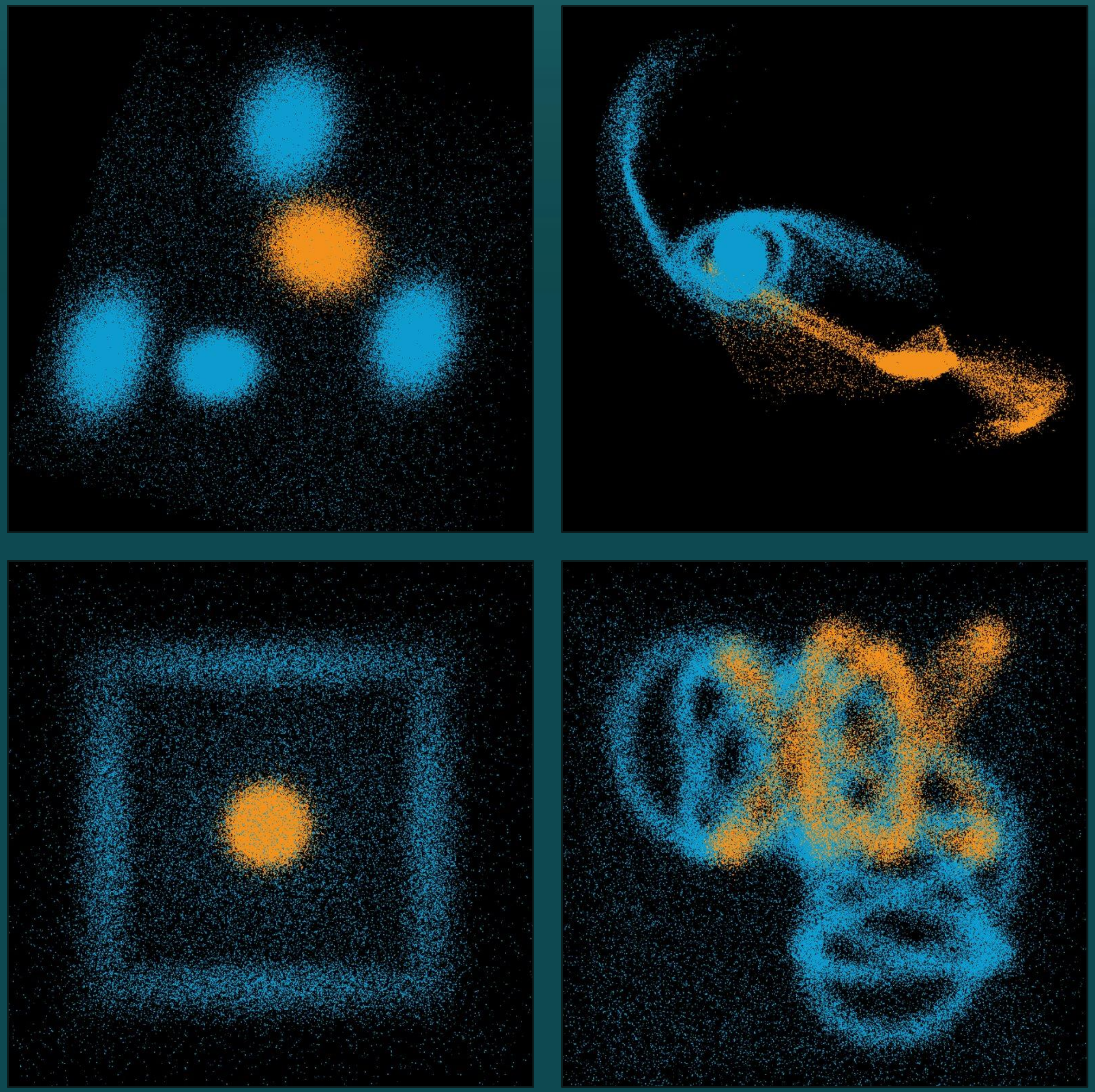
  CloudLasso
  - subjectively best results

  both could be fine-tuned
- Boolean operations possible

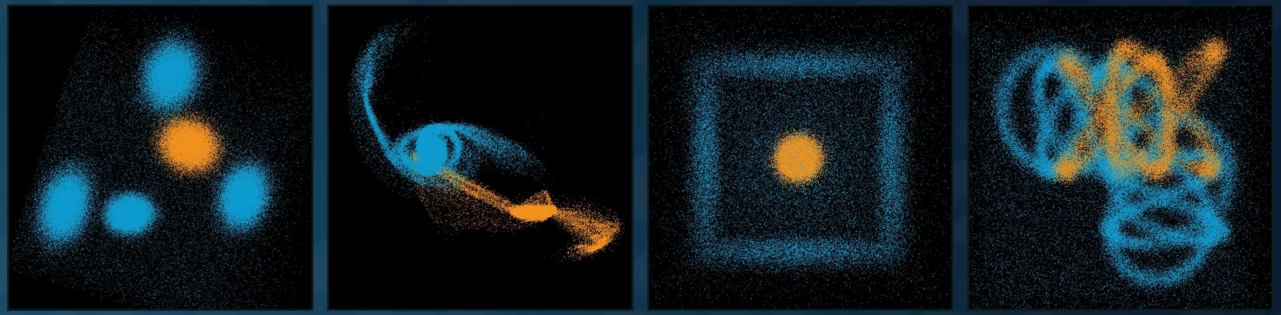


Study Design

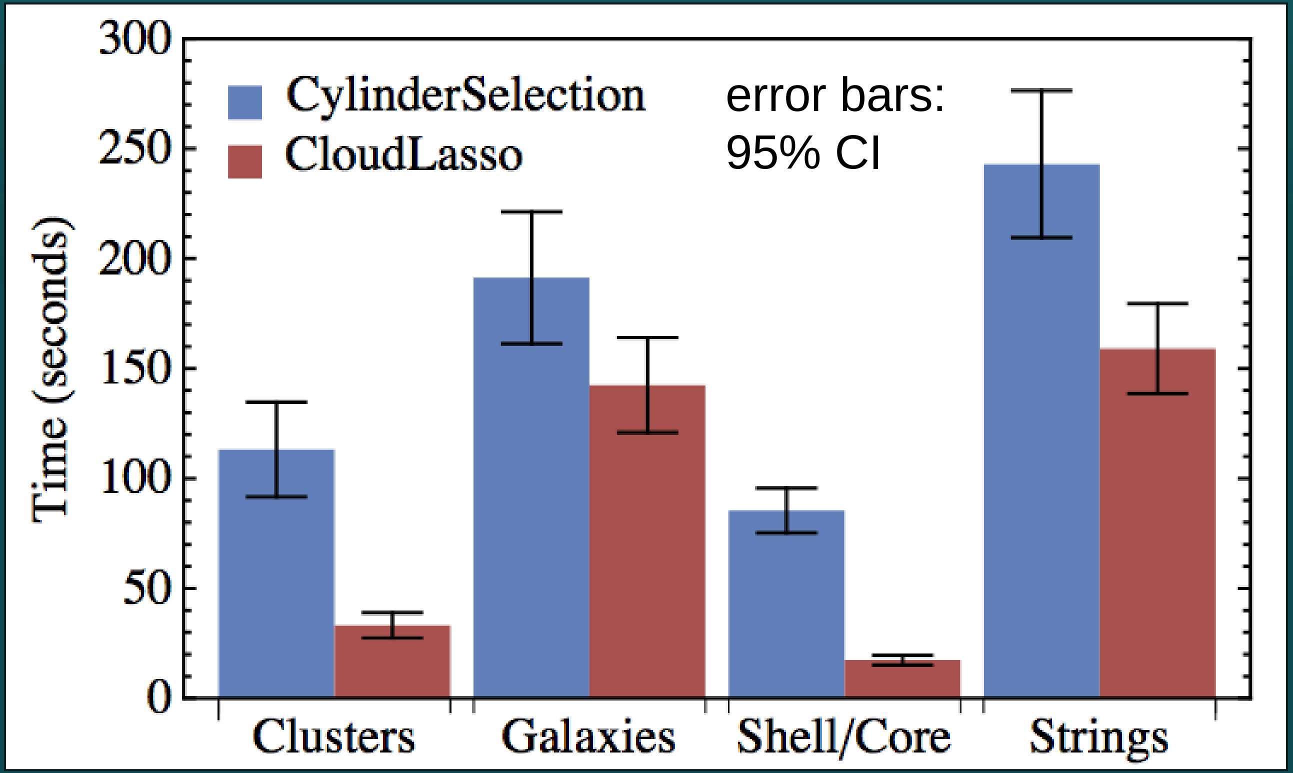
- 12 participants (4 female)
- 4 selection tasks (datasets)
- measurement of **time**, **error**, and **selection volume**
- questionnaire for subjective opinion



Study Results



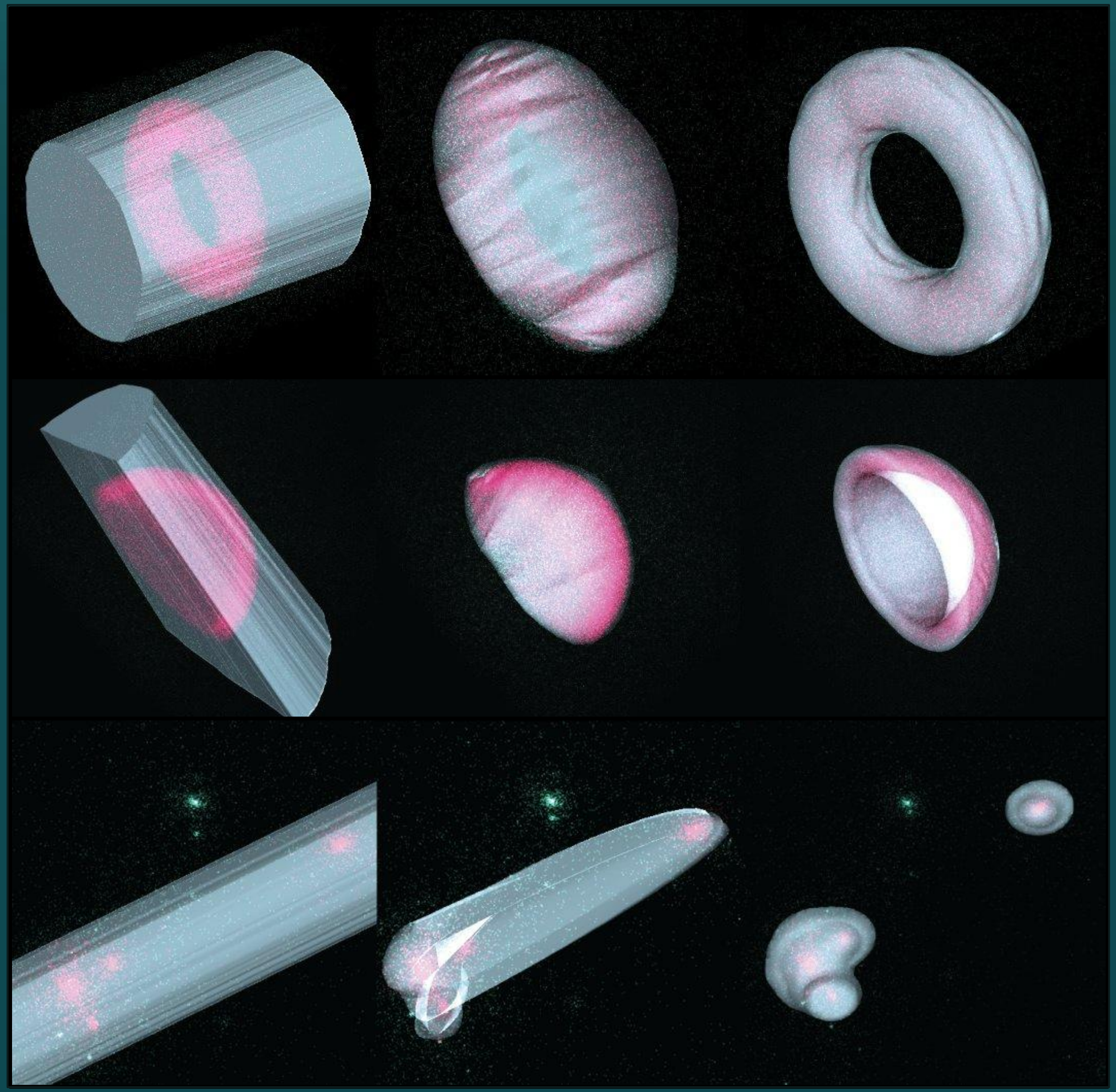
- CloudLasso (CL) always faster than CylinderSelection (CS)
  - significant except galaxies
- two error metrics F_1 & MCC
  - CloudLasso always less error than CS
  - F_1 significant except galaxies
  - MCC significant for clusters & shell/core



- CloudLasso volume always smaller, significant for strings dataset
- CloudLasso the preferred technique for all participants

Discussion: ClouldLasso vs. TeddySelection

- both **spatial** & **structure-aware** selection
- both based on lasso principle
- TeddySelection: connected selection
- CloudLasso: individual clusters
- CloudLasso can handle difficult cases
- both can be coupled with Cylinder-Selection using Boolean operations

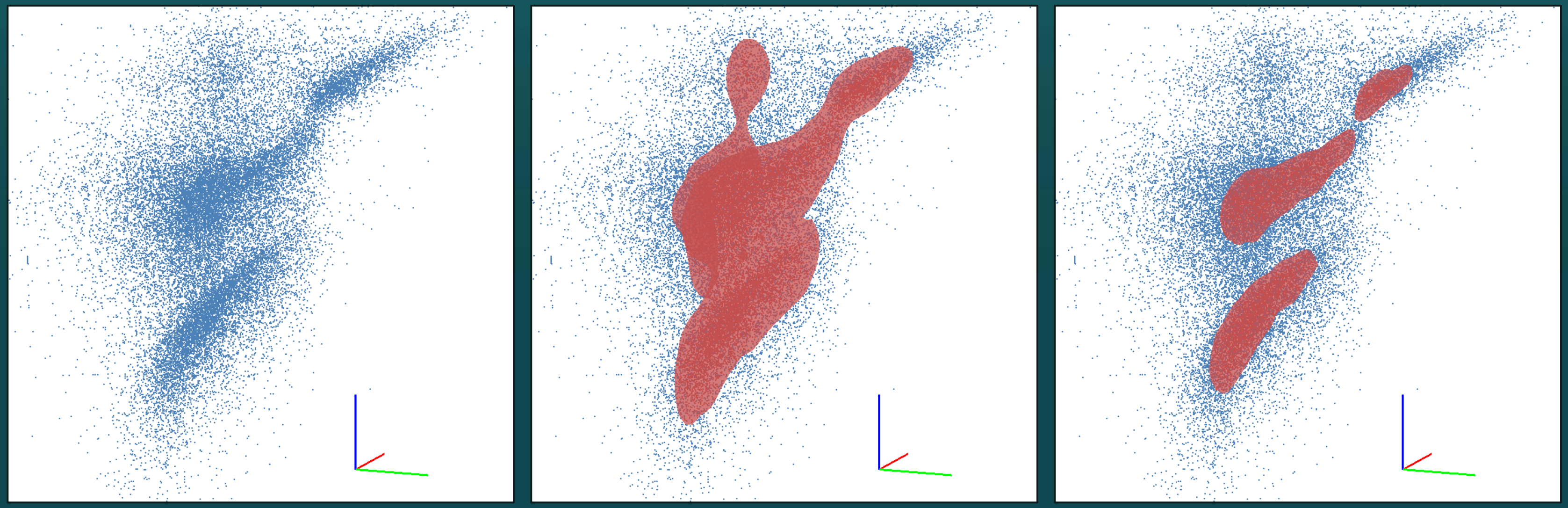


Limitations

- performance
  - CloudLasso requires grid-based density estimation
  - slower than interactive speeds (≈ 4–6 seconds for ≈ $2 \cdot 10^5$ particles)
  - but parallelizable / GPU; only needs to be computed once per scale level
- several parameter choices (e.g., # of bins)
  - parameters seem stable, not changed in our experiments
  - initial density threshold of CloudLasso suggested by algorithm
- set difference (subtraction) just with structure-aware selection not good
  - include operations with CylinderSelection results (e.g., for subtraction)

Application Domains / Future Work

- any particle-based dataset
- also abstract data such as 3D scatter plots
  $\rightarrow$ linked views



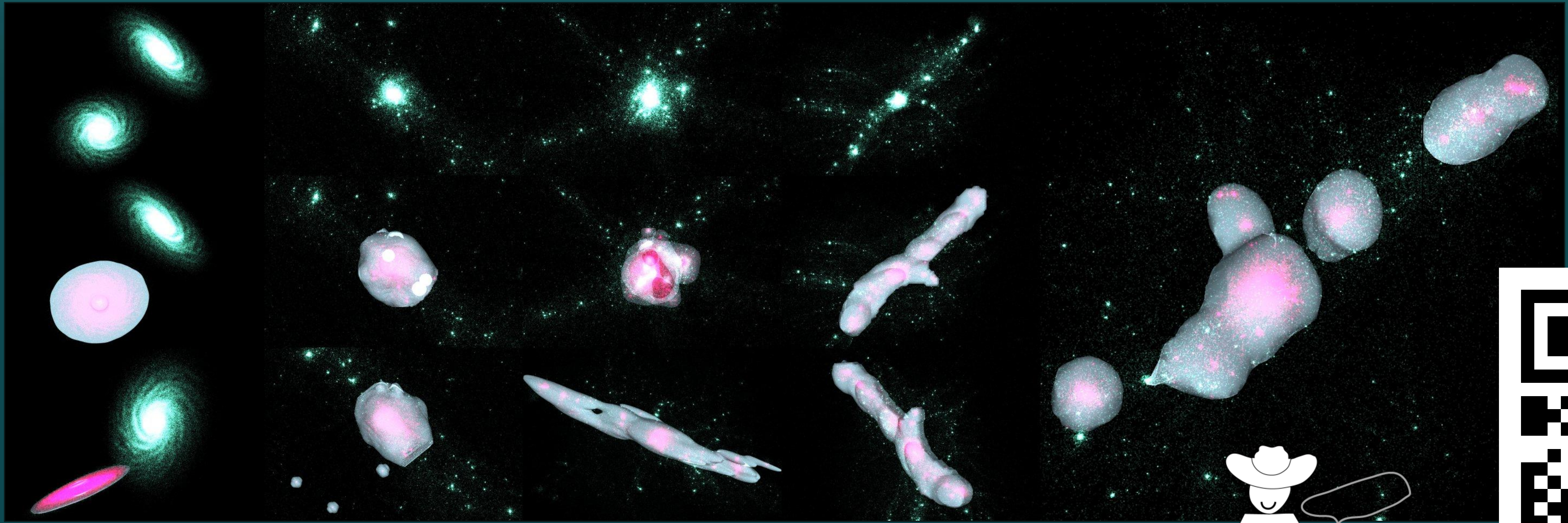
- huge datasets possible
- selection metrics other than density possible
- applicable to volume data with minor changes

Conclusion

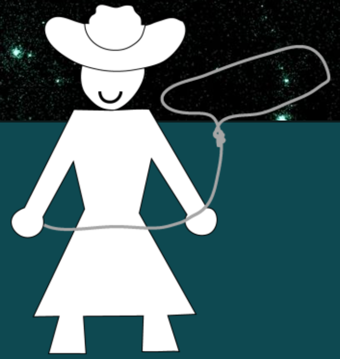
- TeddySelection & CloudLasso:
  new **spatial**, **structure-aware** 3D selection techniques
- input: lasso drawn in 2D; output: 3D subspaces
- support complex spatial selections
- applications in many fields of visualization
- study showed that CloudLasso is superior to the traditional cylinder-based selection both in performance and overall preference

- smart selection techniques essential for **interactive** visualization

Thanks for your attention!



Trivia: LingYun Yu's nick name is Yun which in Mandarin (云) means "cloud".
So it's really Yun's Lasso and she is the LassoGirl … ;-)



Video & demo:
http://tobias.isenberg.cc/VideosAndDemos/Yu2012ESA

What about HUGE datasets?

- interactive selection based on a well-chosen sample
- use of both LassoSelection and CylinderSelection
- generation of selection shapes, sequence of Boolean operations
- off-line application to the whole huge dataset (batch process)

Selection Shape 1 $\xrightarrow{\cap}$ Selection Shape 2 $\xrightarrow{\cup}$ Selection Shape 3 $\xrightarrow{\dots}$ … $\xrightarrow{\dots}$ Selection Shape N

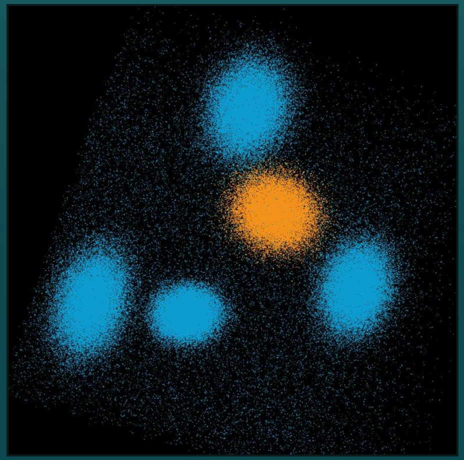
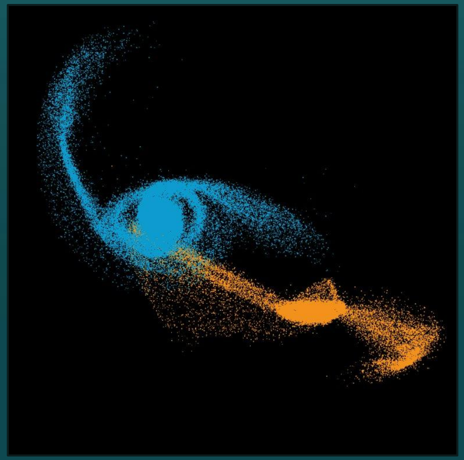
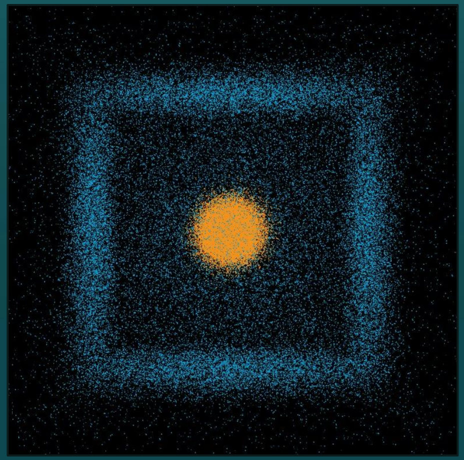
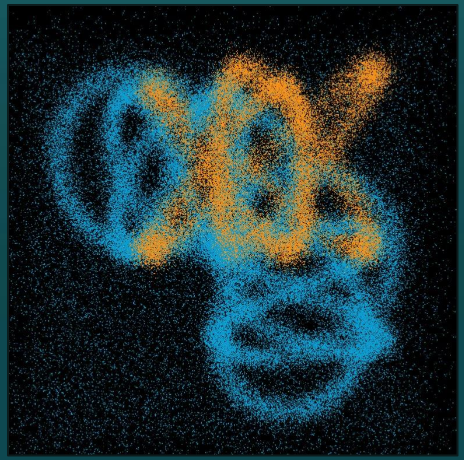
What about properties other than density?

- density makes most sense for particle data
- other properties may make sense, e.g., for volume data
- property needs to be defined continuously
- need means to compute property on a grid for CloudLasso
- output always a mesh that encloses a volume in 3D space
- particles/voxels inside that volume are selected

What about precision issues?

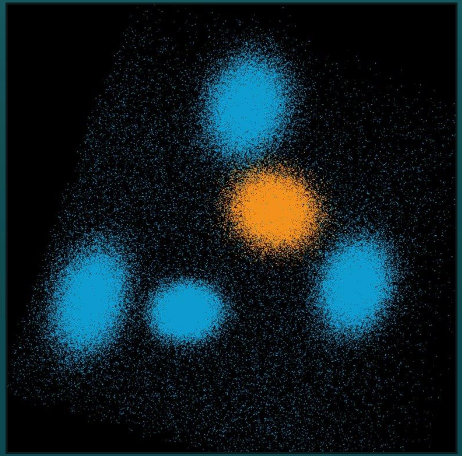
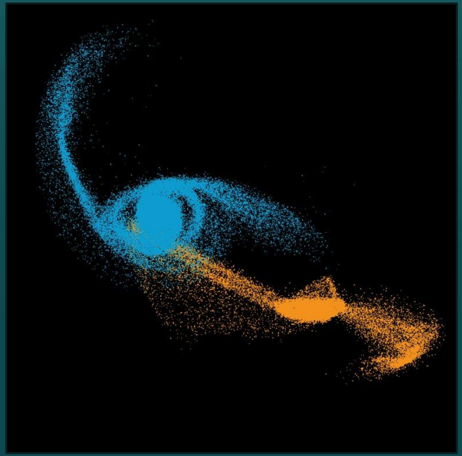
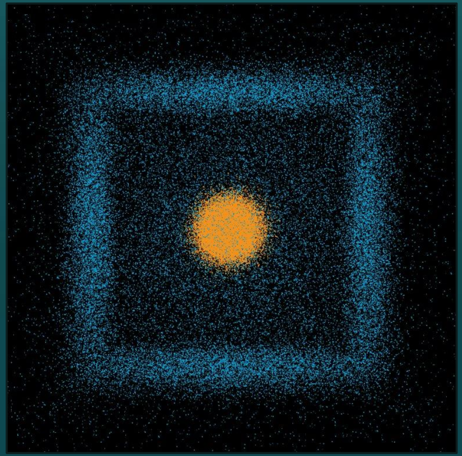
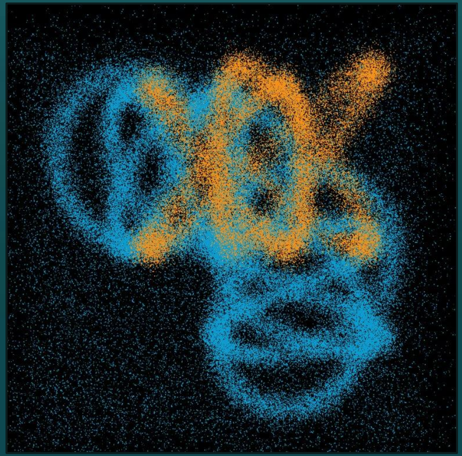
- precise input possible (mouse, pen, algorithmic)
- adjustment possible after selection operation
- iterative selections possible
- selection is structure-aware, thus needs less precision

Study Results – Errors: F_1

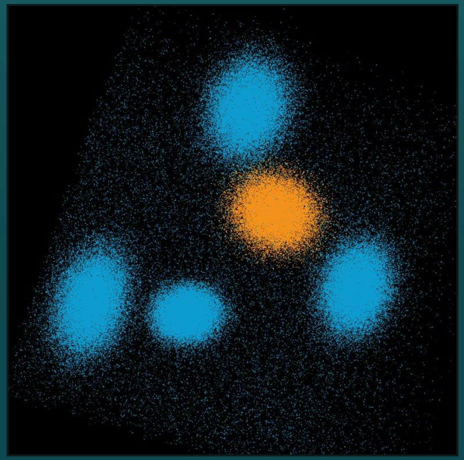
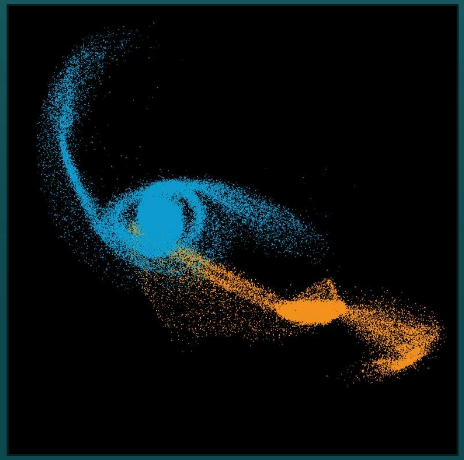
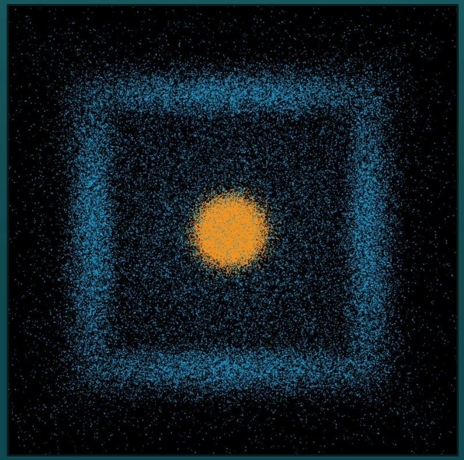
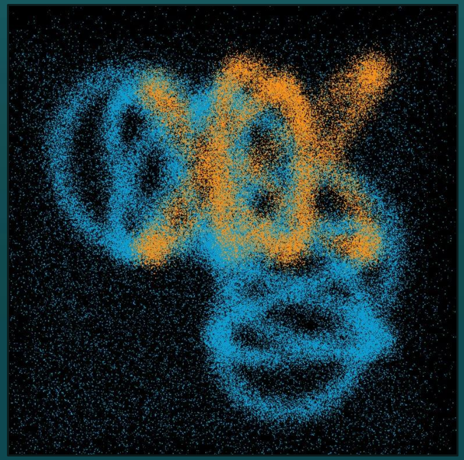
	Clusters	Galaxies	Shell/Core	Strings
CloudLasso	.9789	.9866	.9980	.7494
CylinderSelection	.9759	.9855	.9960	.7303
Z	2.67	0.71	3.06	2.04
p	**<.01**	.48	**<.01**	**.041**

Study Results – Errors: MCC

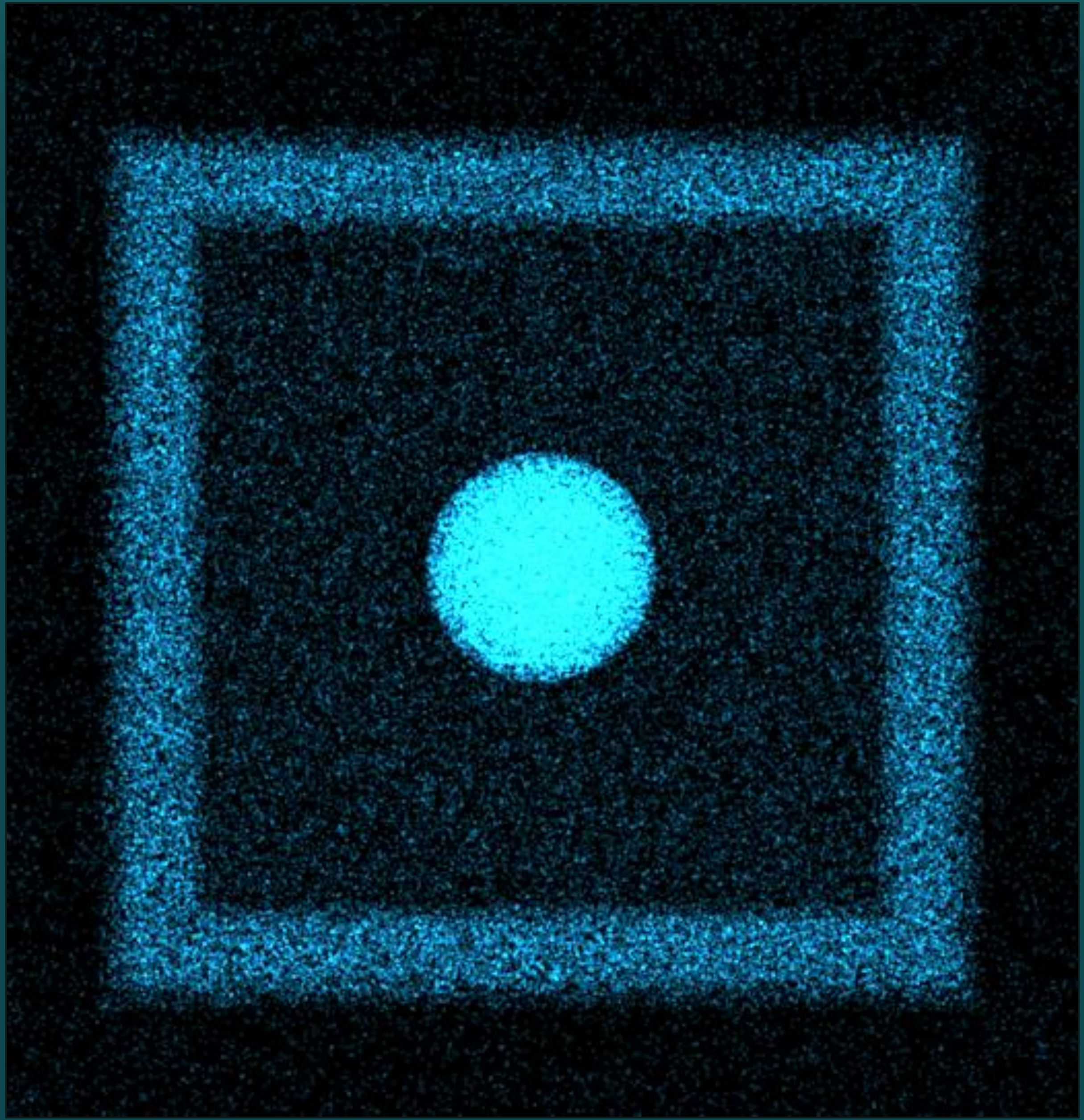
	Clusters	Galaxies	Shell/Core	Strings
CloudLasso	.9765	.9733	.9974	.6519
CylinderSelection	.9731	.9712	.9948	.6305
Z	2.75	0.78	3.06	1.89
p	**<.01**	.43	**<.01**	.06

Study Results – Errors: $V_{selected} / V_{real}$

	Clusters	Galaxies	Shell/Core	Strings
CloudLasso	1.244	4.055	1.327	1.852
CylinderSelection	1.303	5.855	1.360	2.691
Z	0.94	1.49	1.57	2.98
p	.347	.14	.875	**<.01**

Problem with Structure-Aware Subtraction



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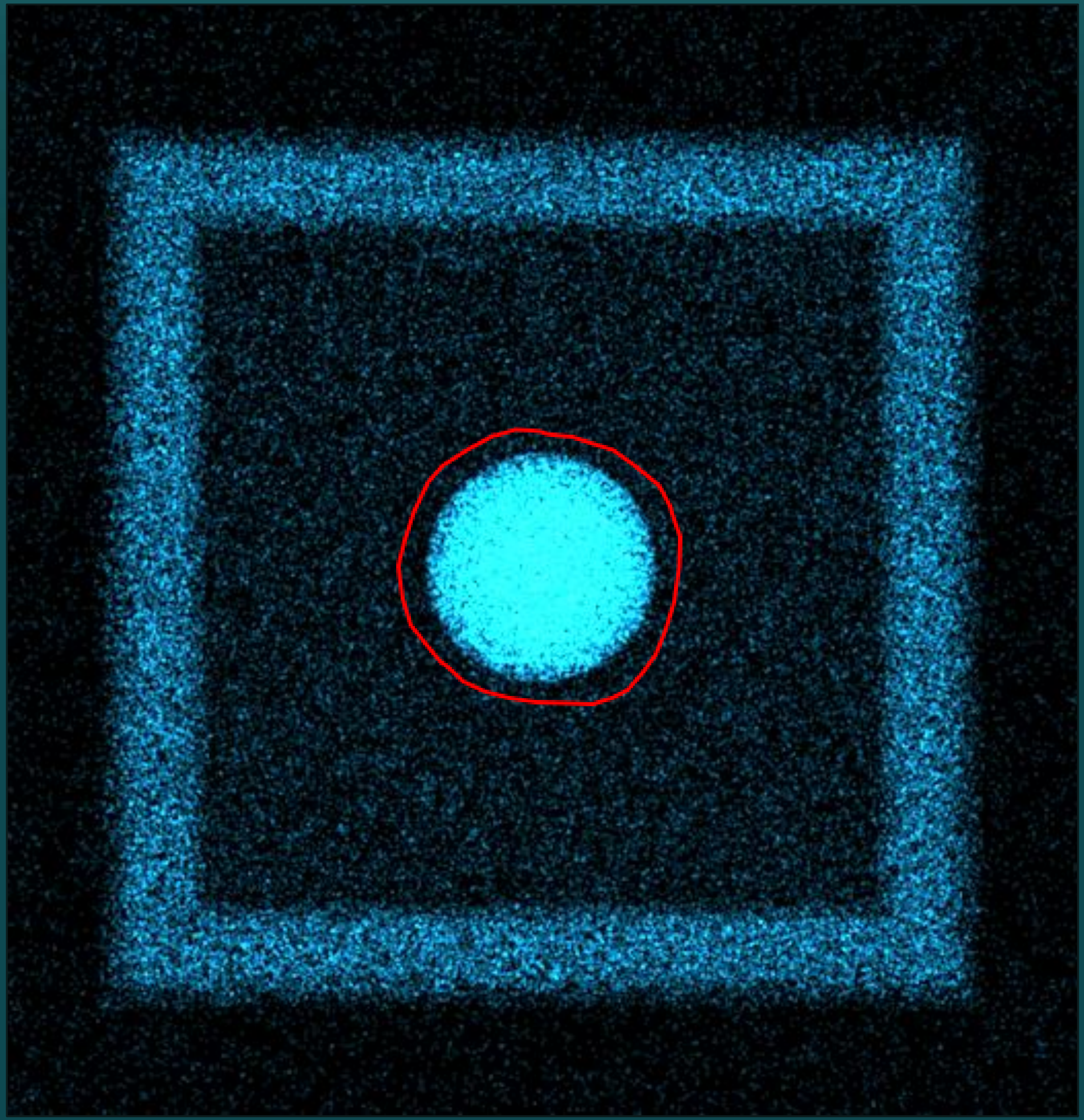

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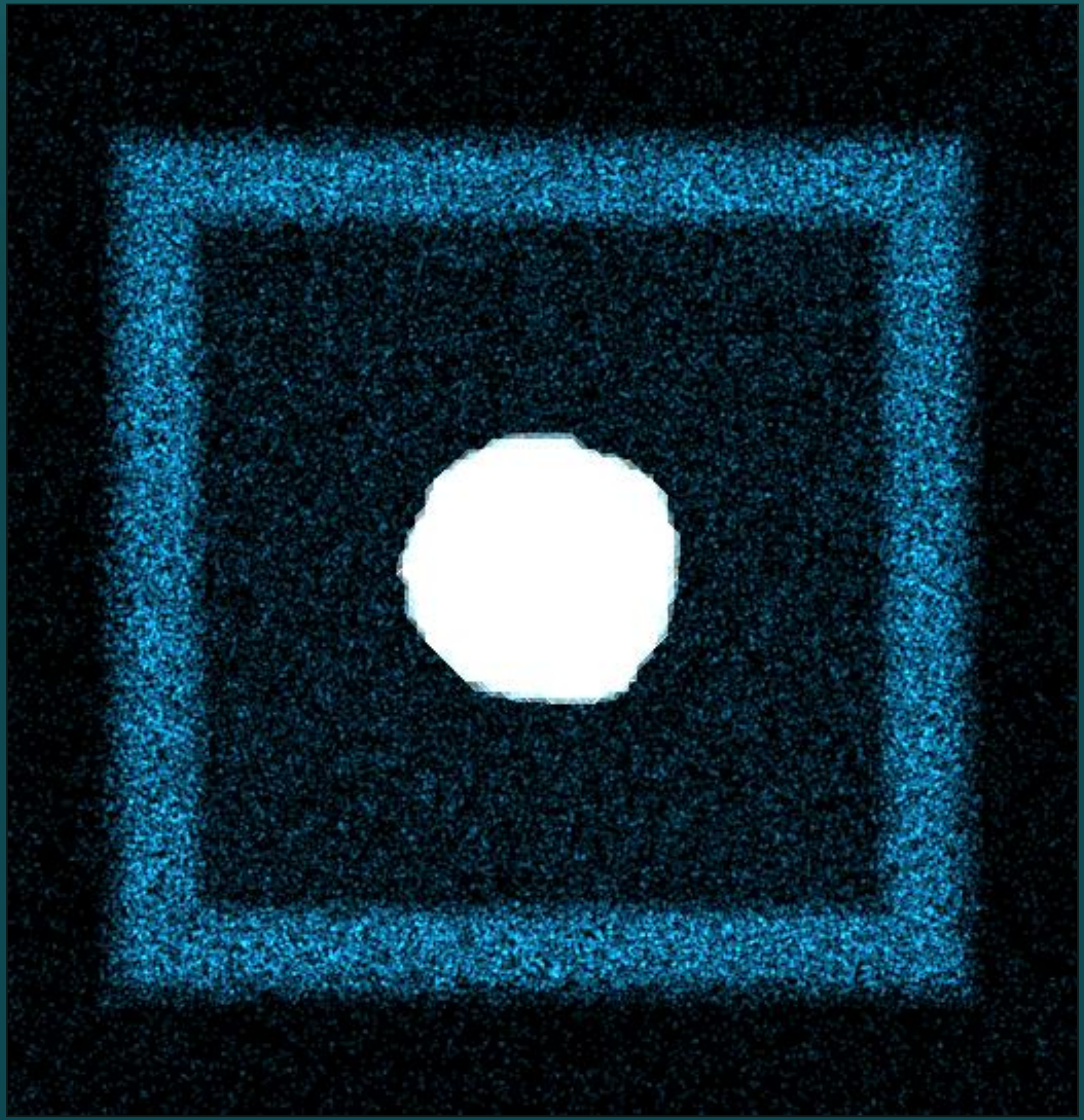

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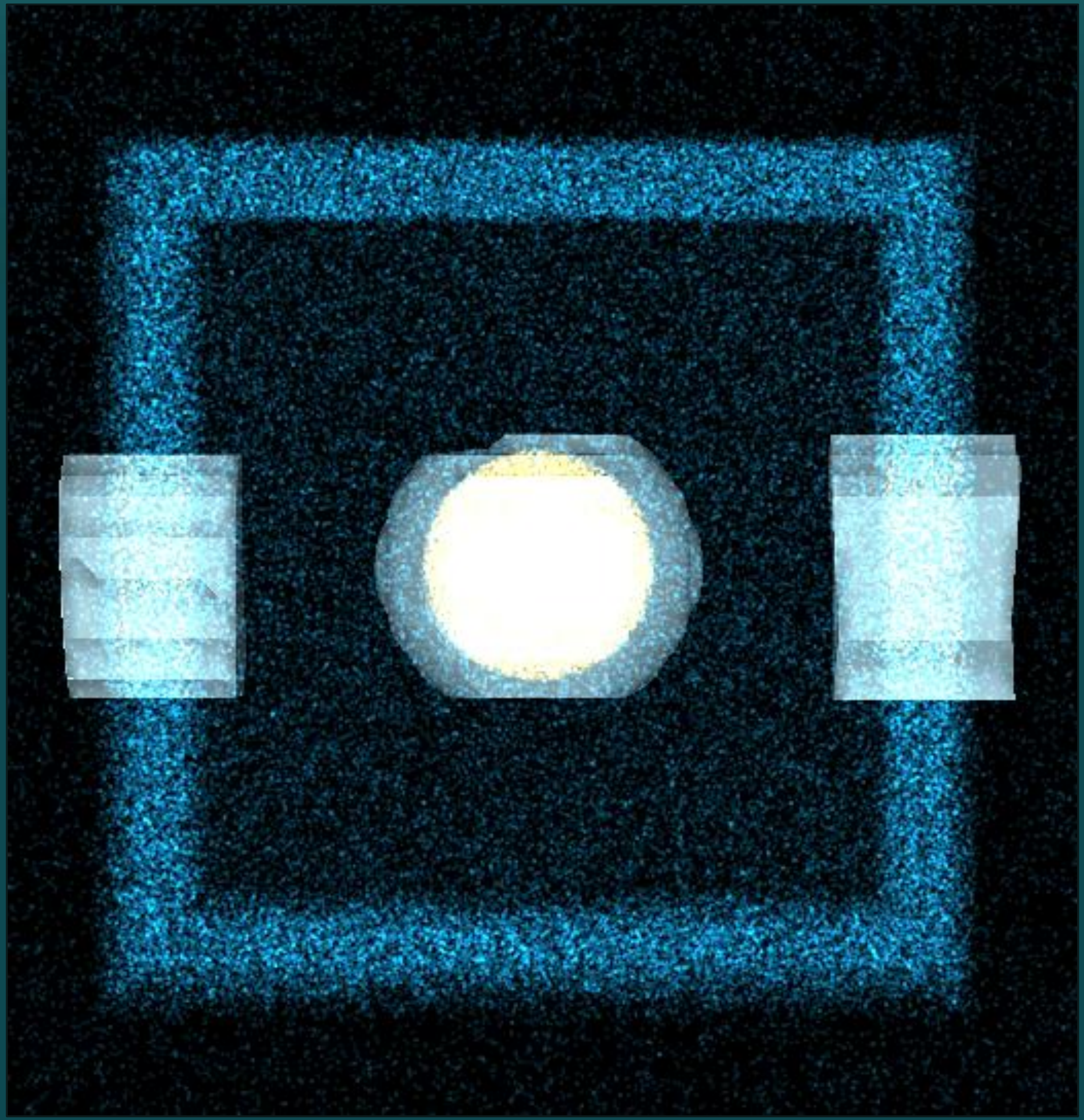
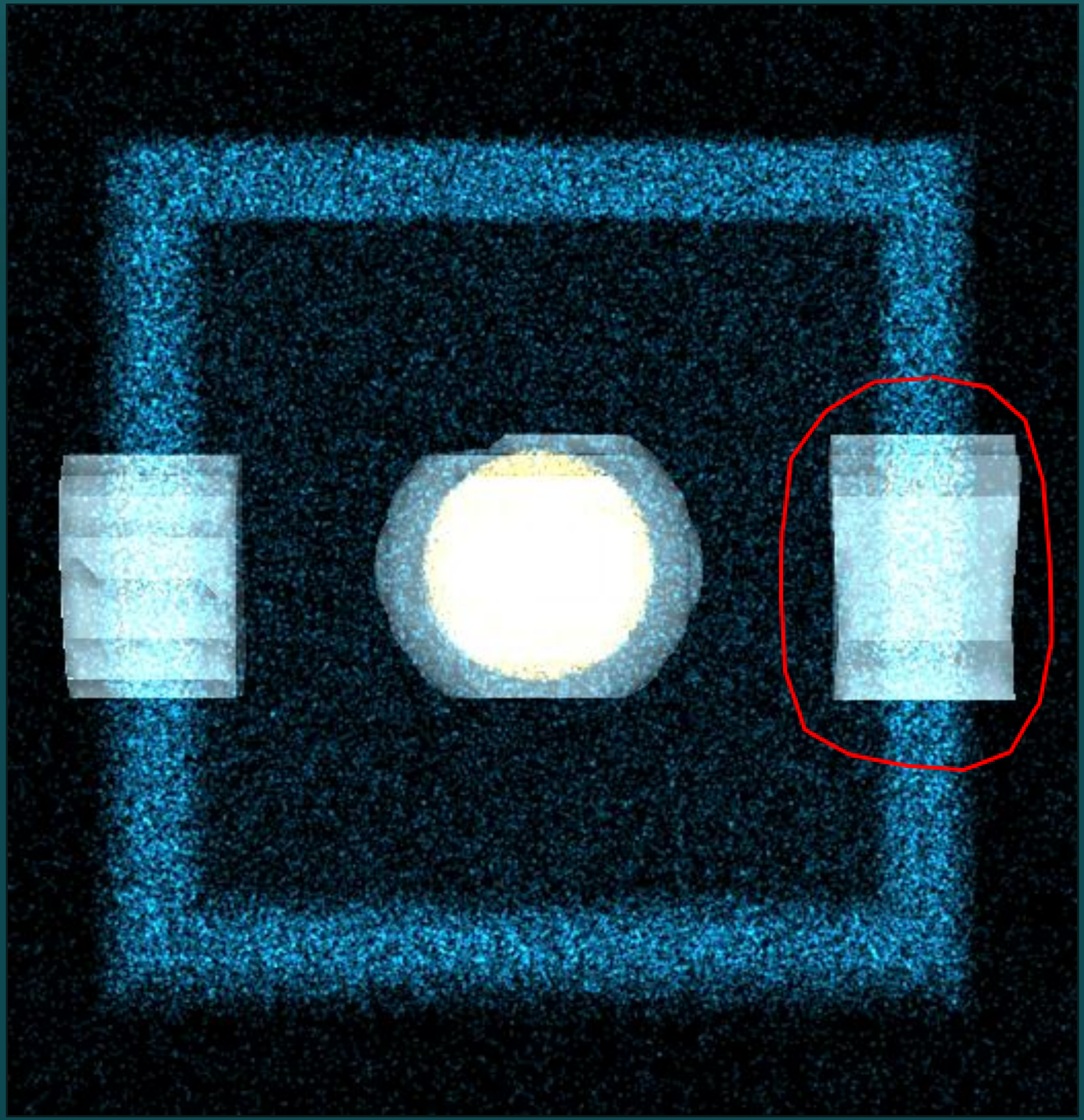


Problem with Structure-Aware Subtraction



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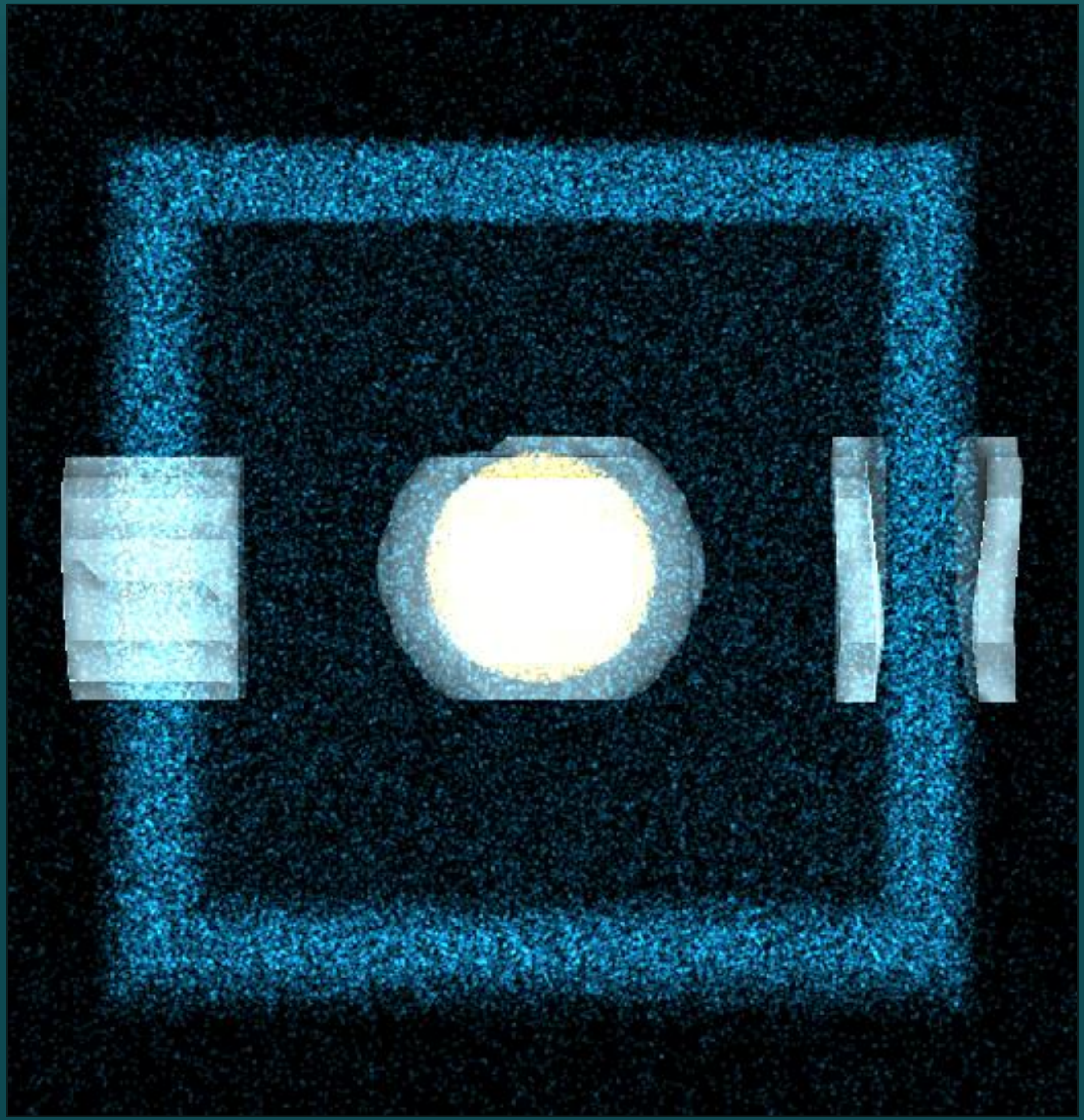

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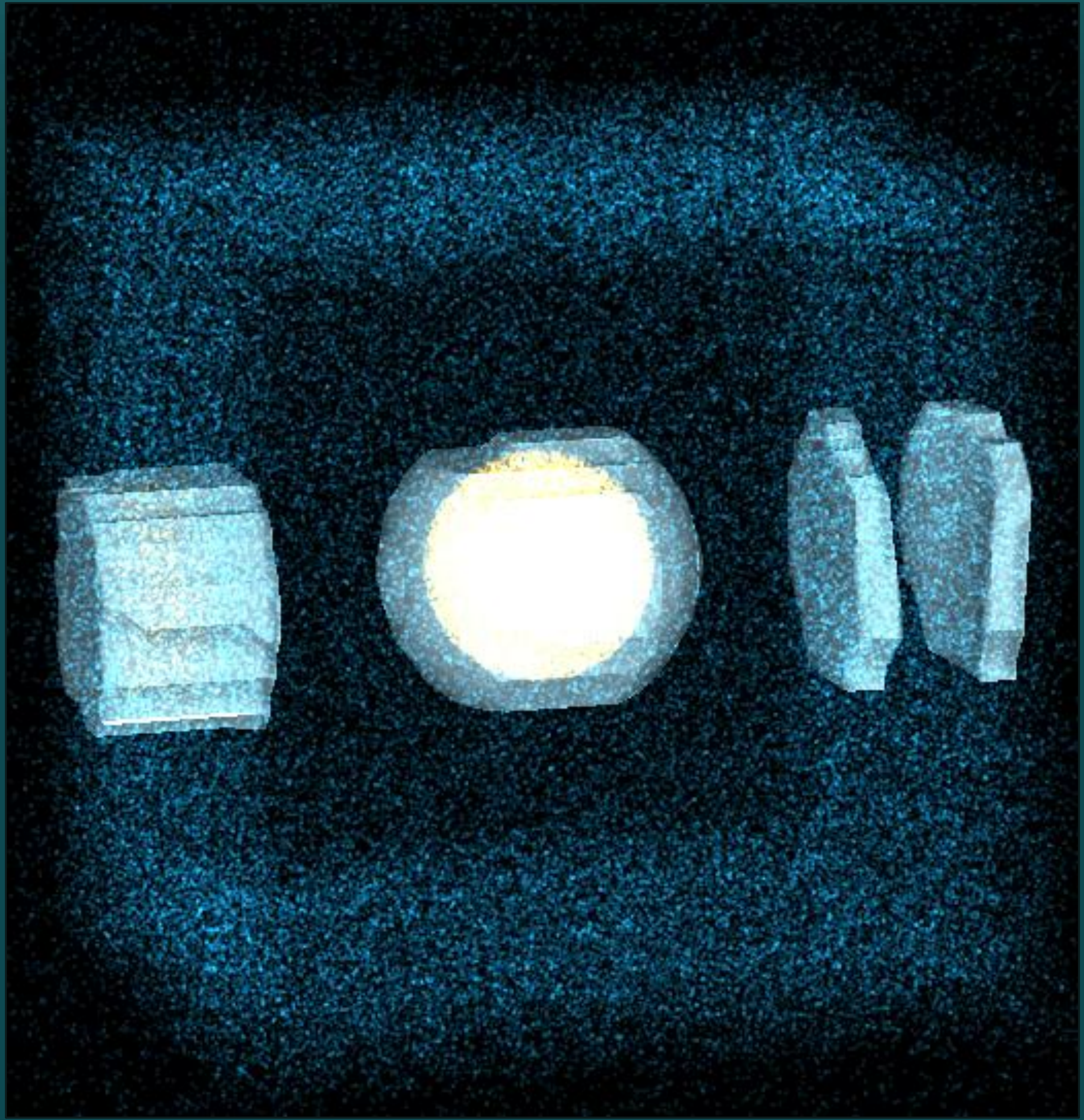

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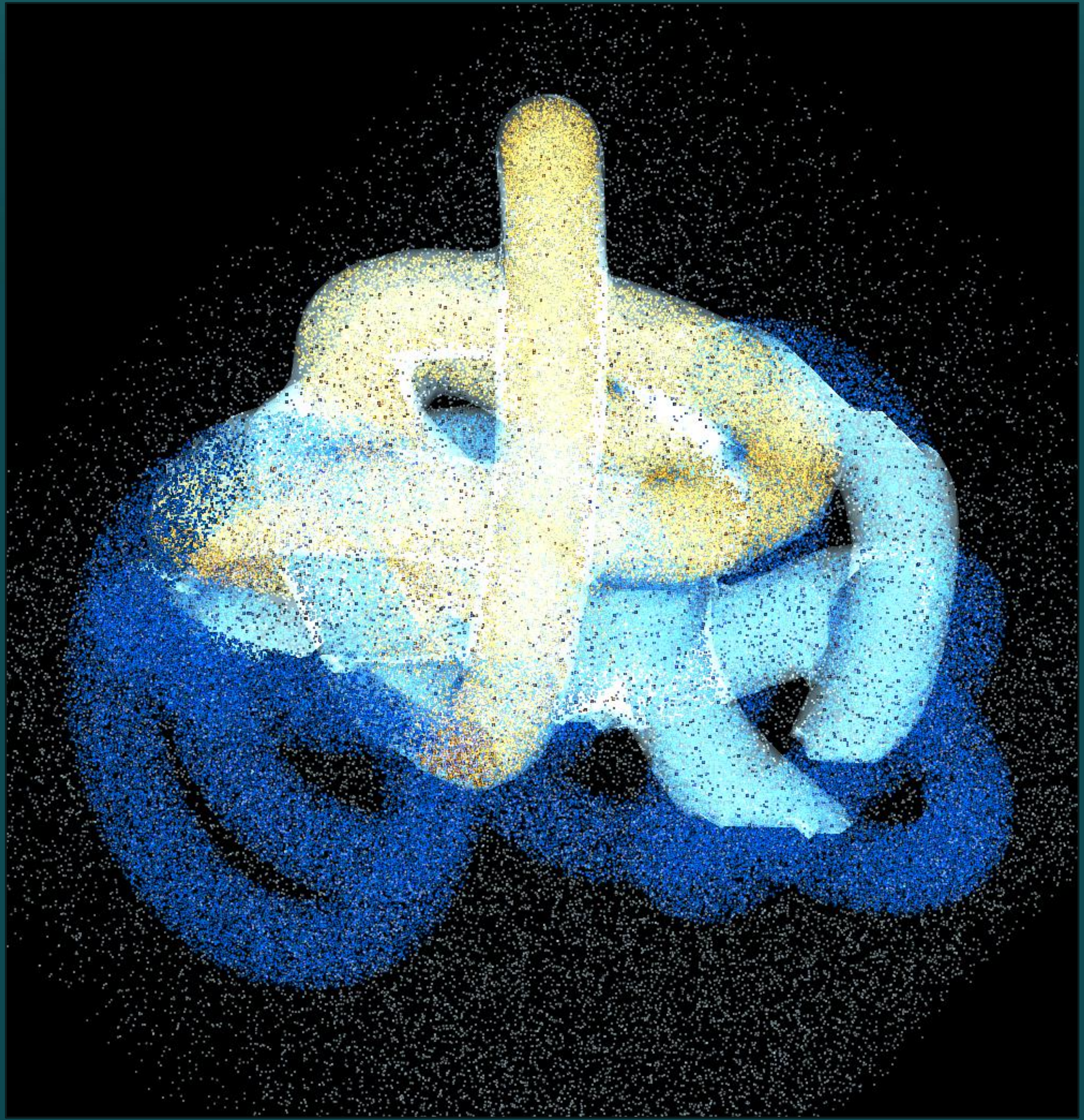

Problem with Structure-Aware Subtraction