Enhancing Subaru Telescope science productivity with new noise-based detection algorithm

Mohammad Akhlaghi & Takashi Ichikawa

With great thanks to:
Robert Lupton, Anu More, Keiichi Umetsu, John Silverman, Masayuki Tanaka, Masami Ouchi, Nobunari Kashikawa, Jim Bosch, David Spergel, Marcin Sawicki and many more

Subaru Users' Meeting FY 2015
19 January 2016

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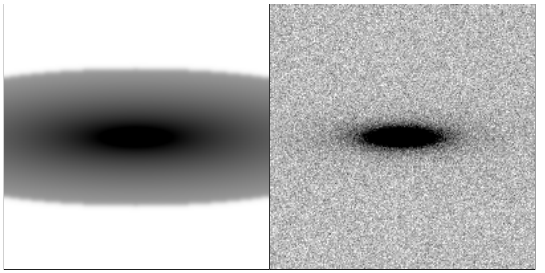
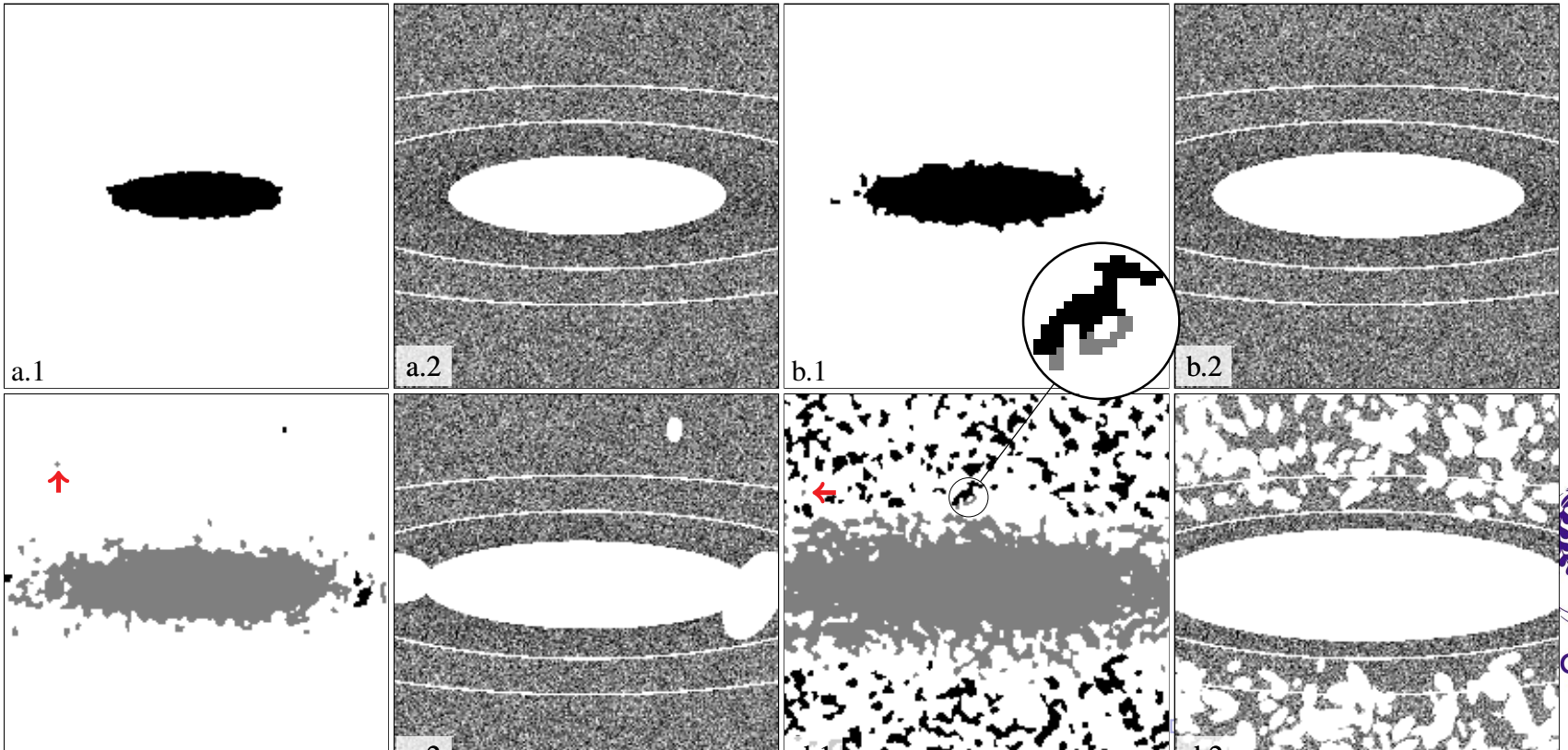
Growing and the Kron radius (r_k):

Kron (1980) radius: $r_k = \frac{\sum rI(r)}{\sum I(r)}$.

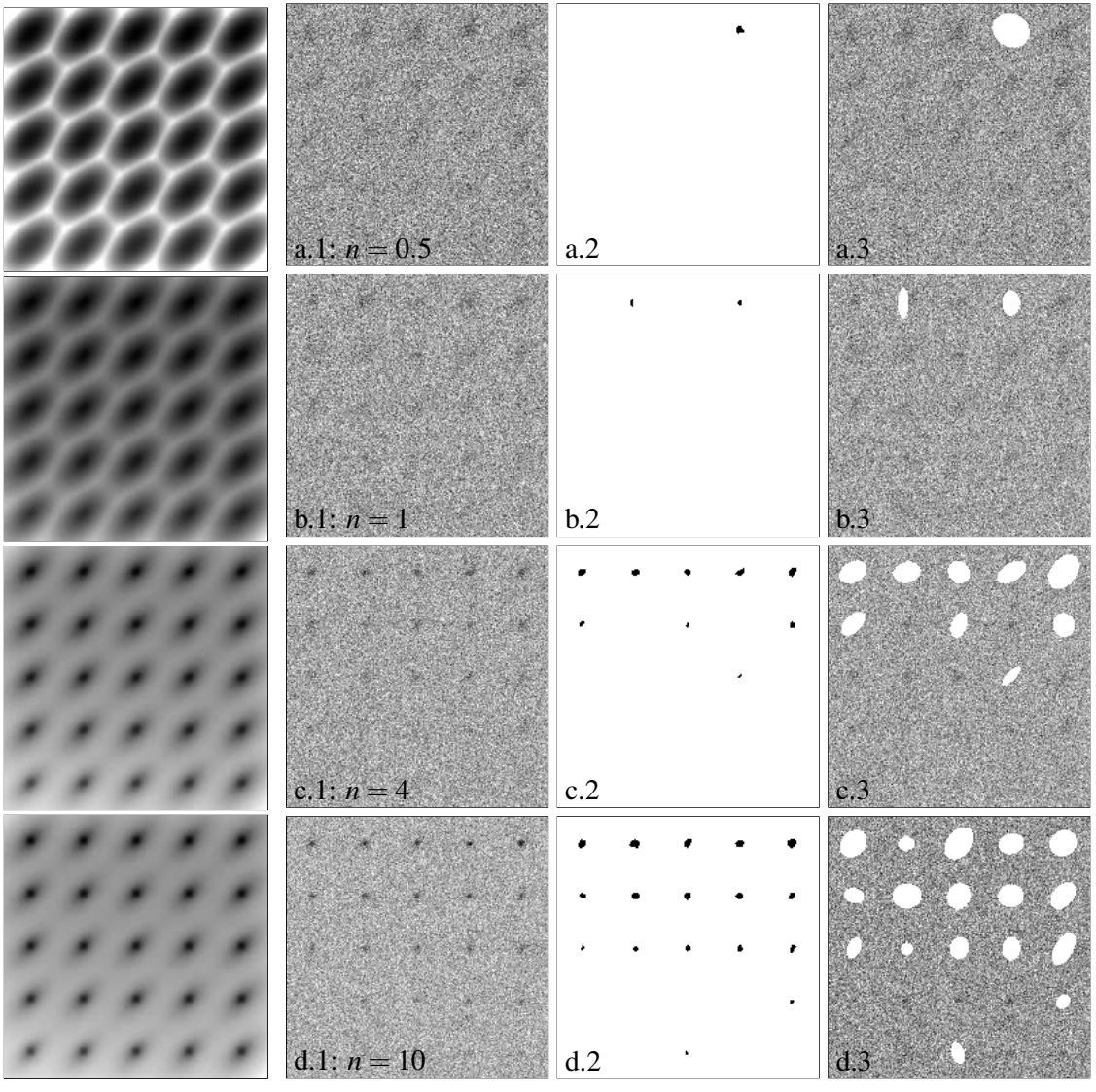


- Assumes a circle/ellipse.
- Depends on the region above the threshold.
- Masked below: $3 \times r_k$ (hardly reaches 90% of flux for $n = 4$ profile).

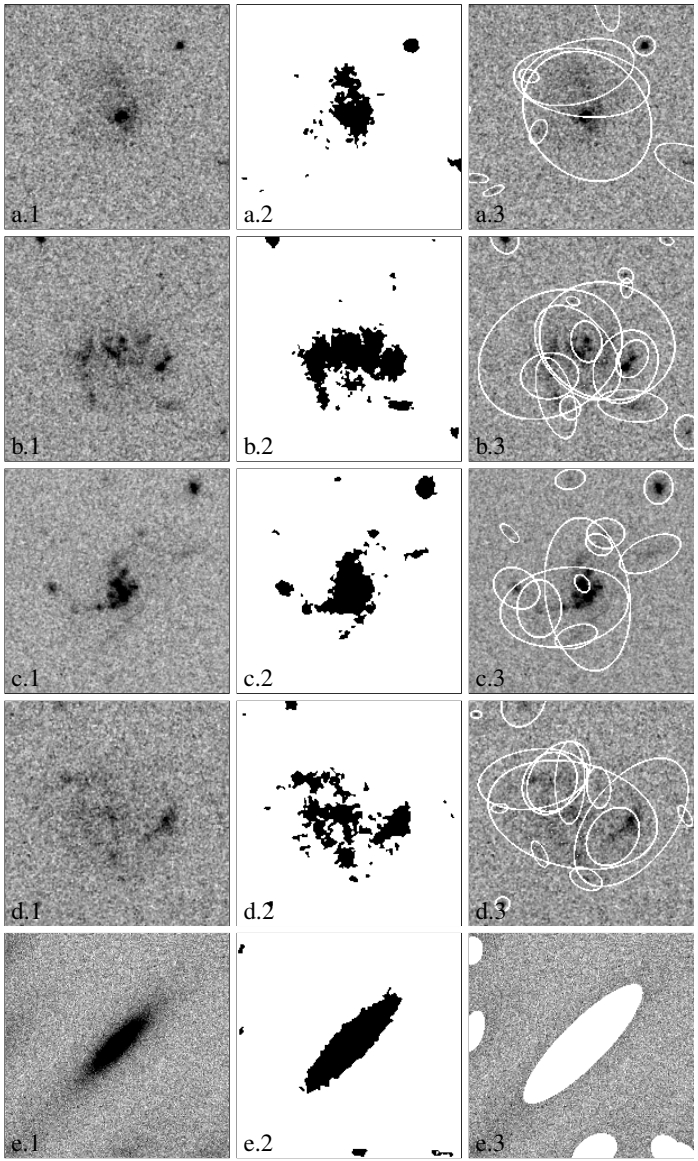
`DETECT_THRESH` is 2, 1, 0.5 and 0.1 respectively.



SExtractor: Sensitivity Test



SExtractor: Real



Real objects (images):

- Are not a clean ellipse.
  - Can be clumpy.
  - Can be diffuse.
  - Can have spiral arms.
  - Can be on the edge of the image.
- Do not necessarily have a uniform radial profile.

The existing method fails since such objects do not satisfy its *a priori* assumptions.

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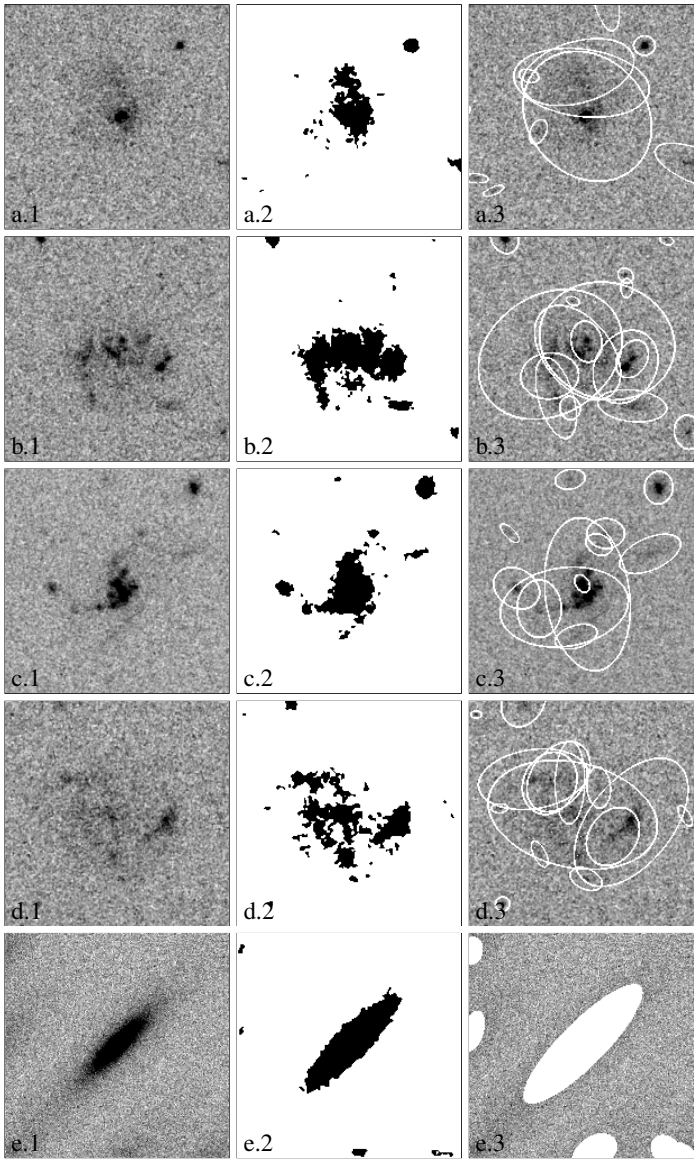
SExtractor: Real



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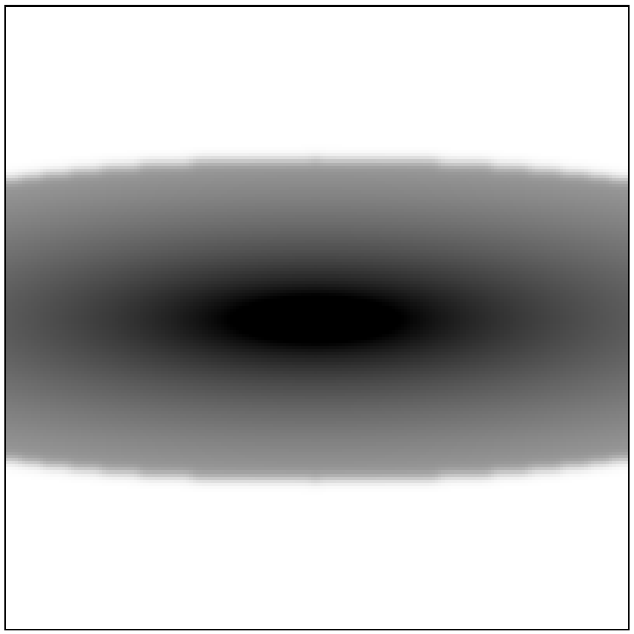
higher redshifts → more clumpy
(e.g., Murata et al. 2014)

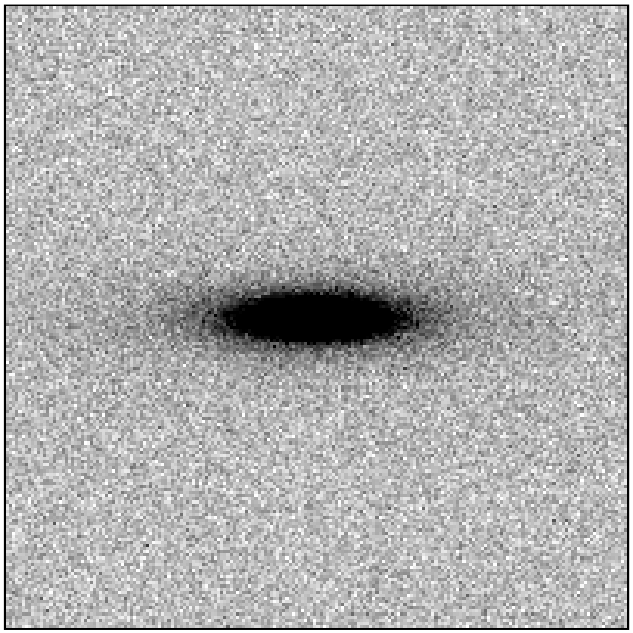
NoiseChisel – Detection – Basics

Aims:

- Threshold must be independent of the Sky.
- Impose negligible assumptions on signal.
- Accurately remove false detections.
- Use the actual data, not *a priori* models.

Model profile for demonstration:





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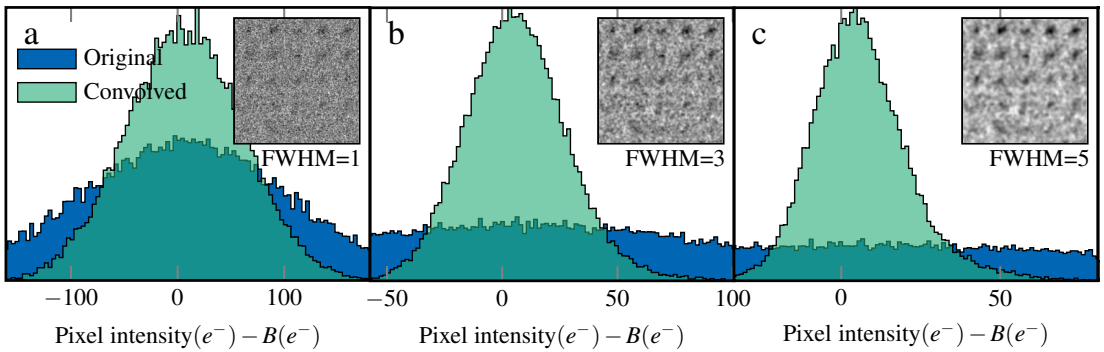
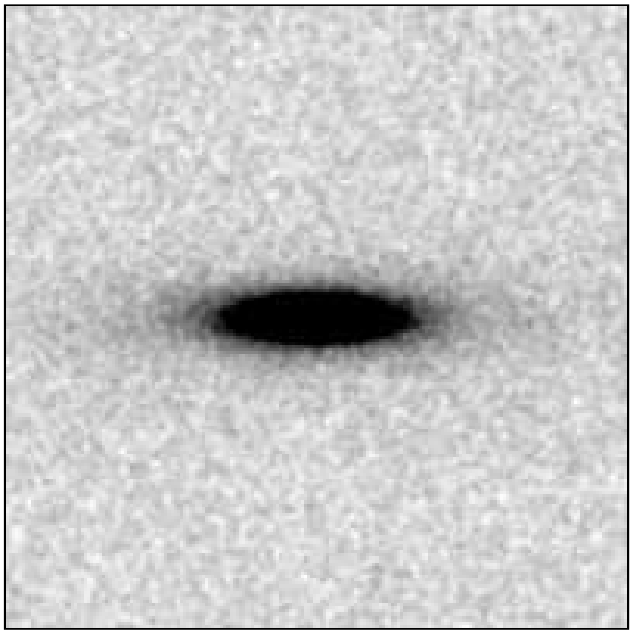
NoiseChisel – Detection – Convolution

- Convolution decreases dynamic range.
- **So:** Gaussian kernel, FWHM= 2pixels.





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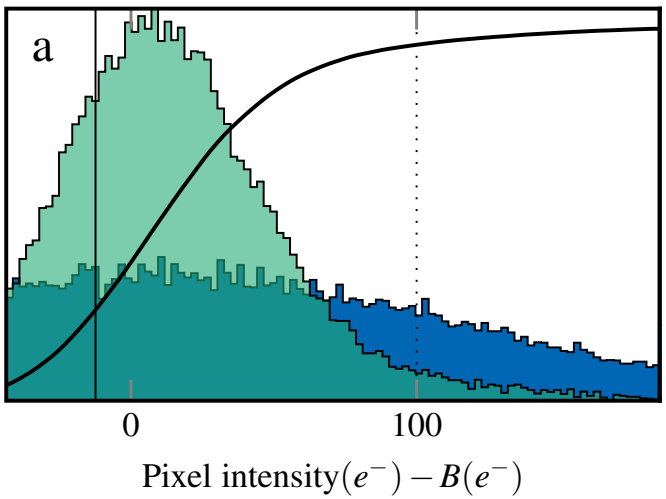
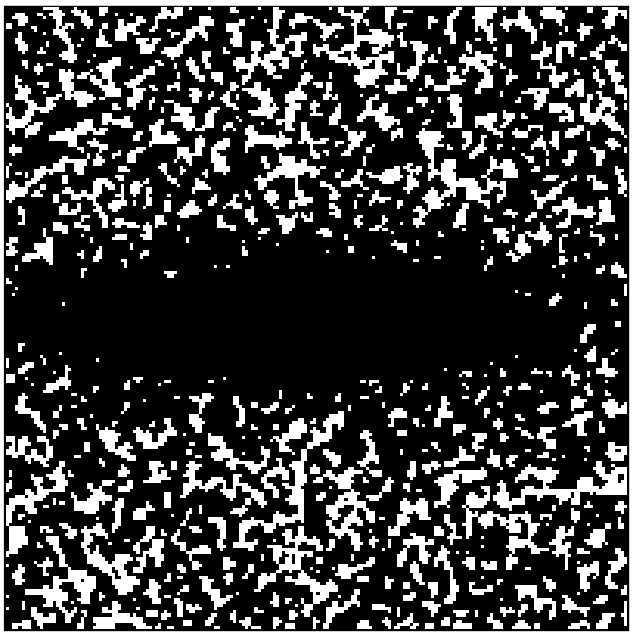
NoiseChisel – Detection – Threshold

- Use the cumulative pixel distribution.
- The threshold is set to the 0.3 quantile of the image.





Since the threshold is now independent of Sky, we can accurately estimate the Sky once detection is complete.

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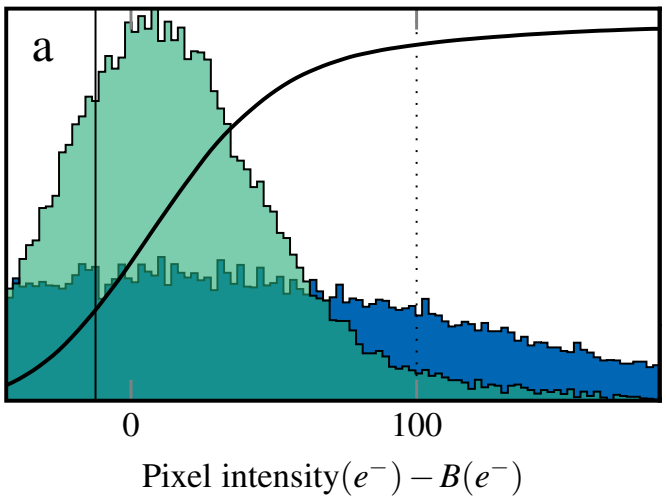

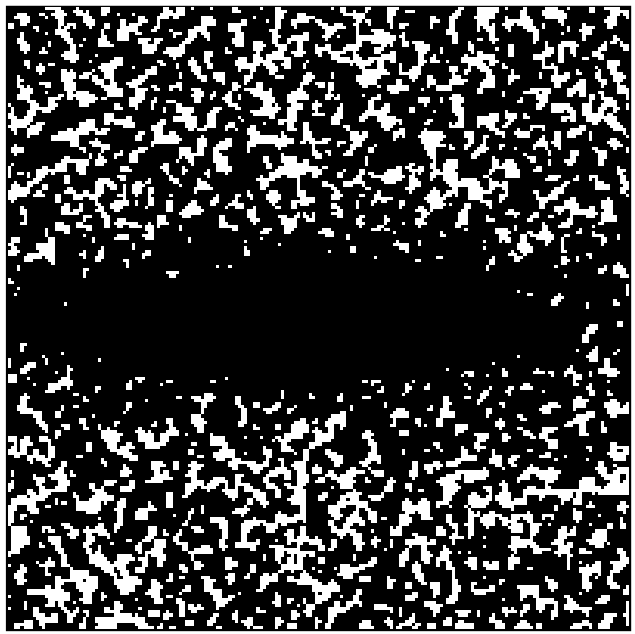

Since the threshold is now independent of Sky, we can accurately estimate the Sky once detection is complete.

Threshold no longer defined by Sky.

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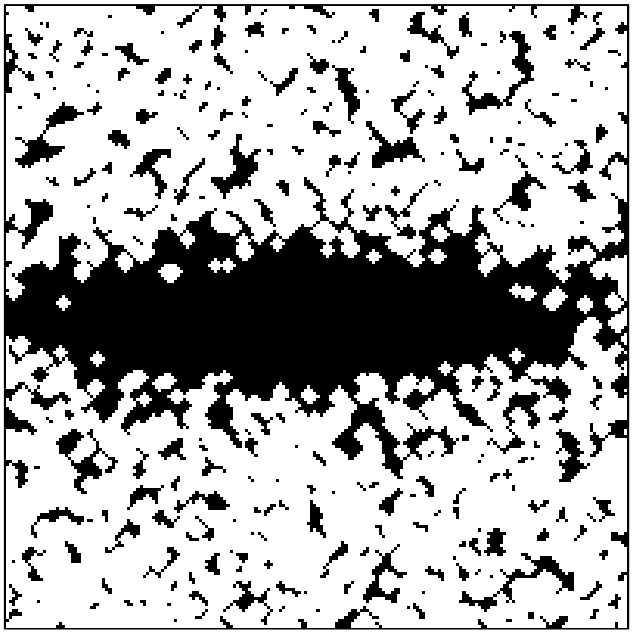
NoiseChisel – Detection – Erode

Erosion: Foreground becomes background if touching.

- **Or:** we expand the holes.
- **Or:** we carve off the signal.

NoiseChisel name: a tool to carve off noise



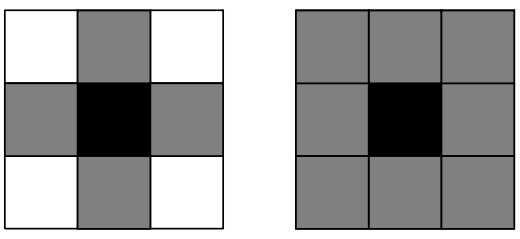
NoiseChisel – Detection – Open

Definitions:

- **Dilation:** Inverse of erosion.
- **Opening:** Erosion followed by dilation.

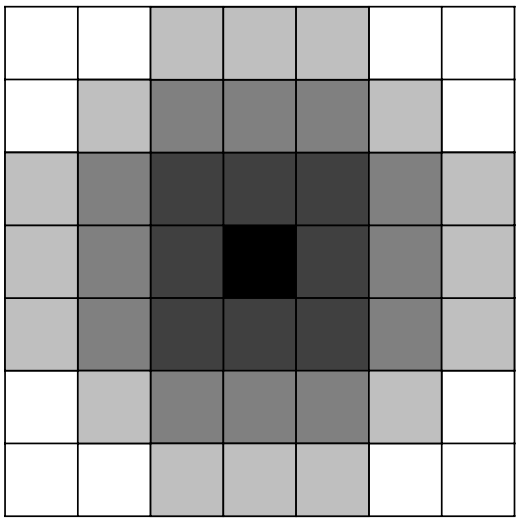
In practice:

- Separates all the steps below.
- We use eight connectivity here (and four connectivity in the previous step.)

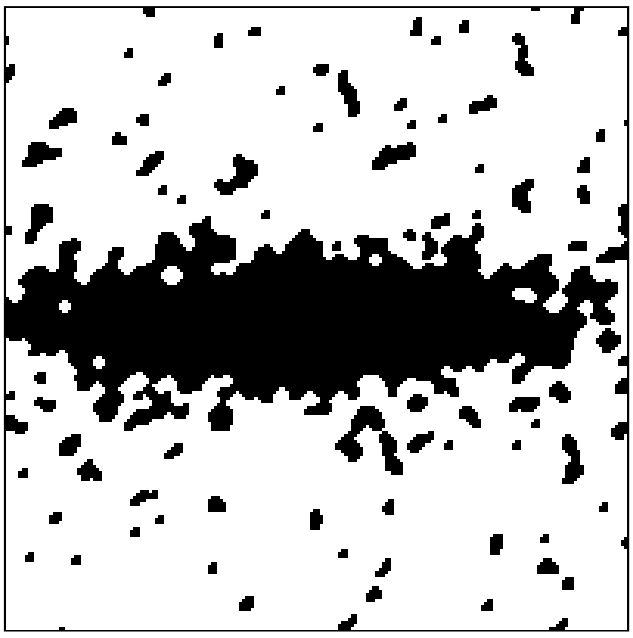


a

b

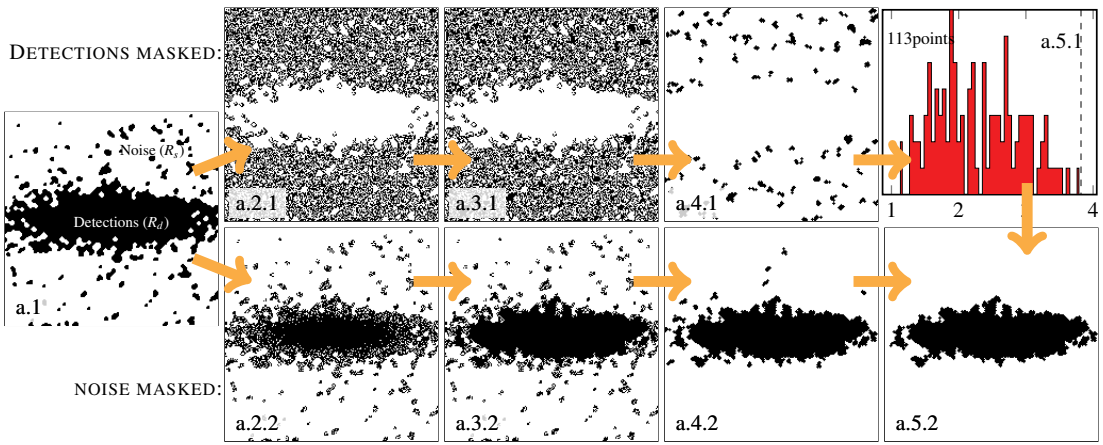


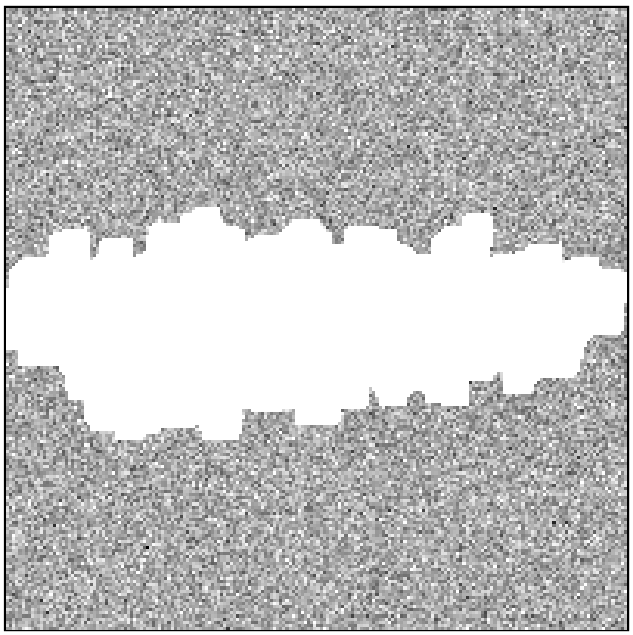
c



NoiseChisel – Detection – Remove false detections

- Use the ambient noise as a reference.
- The S/N of definite false detections is used:





False detections are successfully removed with high accuracy.

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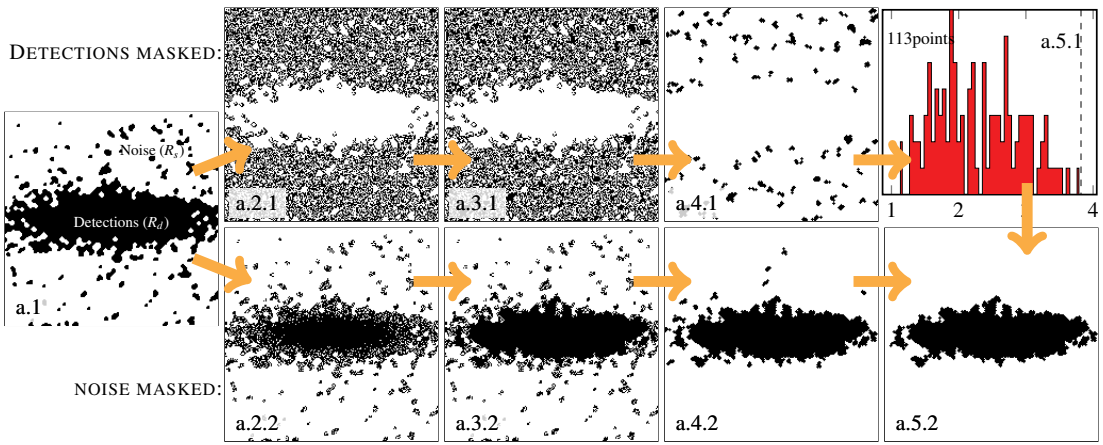

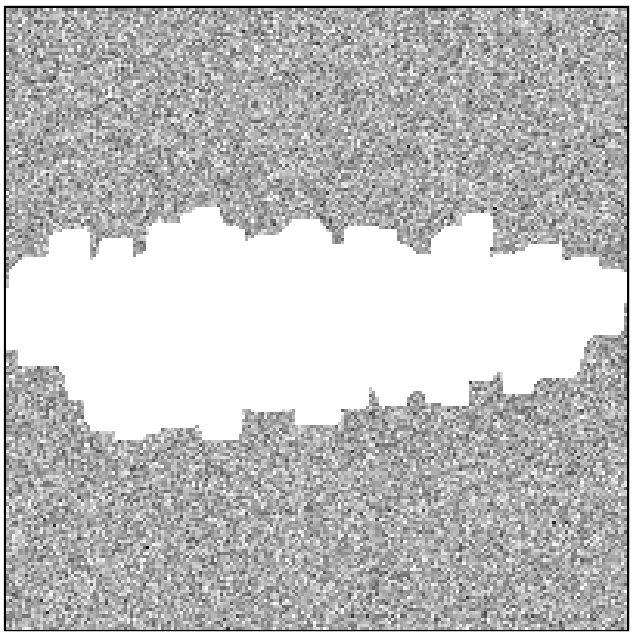

False detections are successfully removed with high accuracy.

False detections are now identified for any image without hand-input values.

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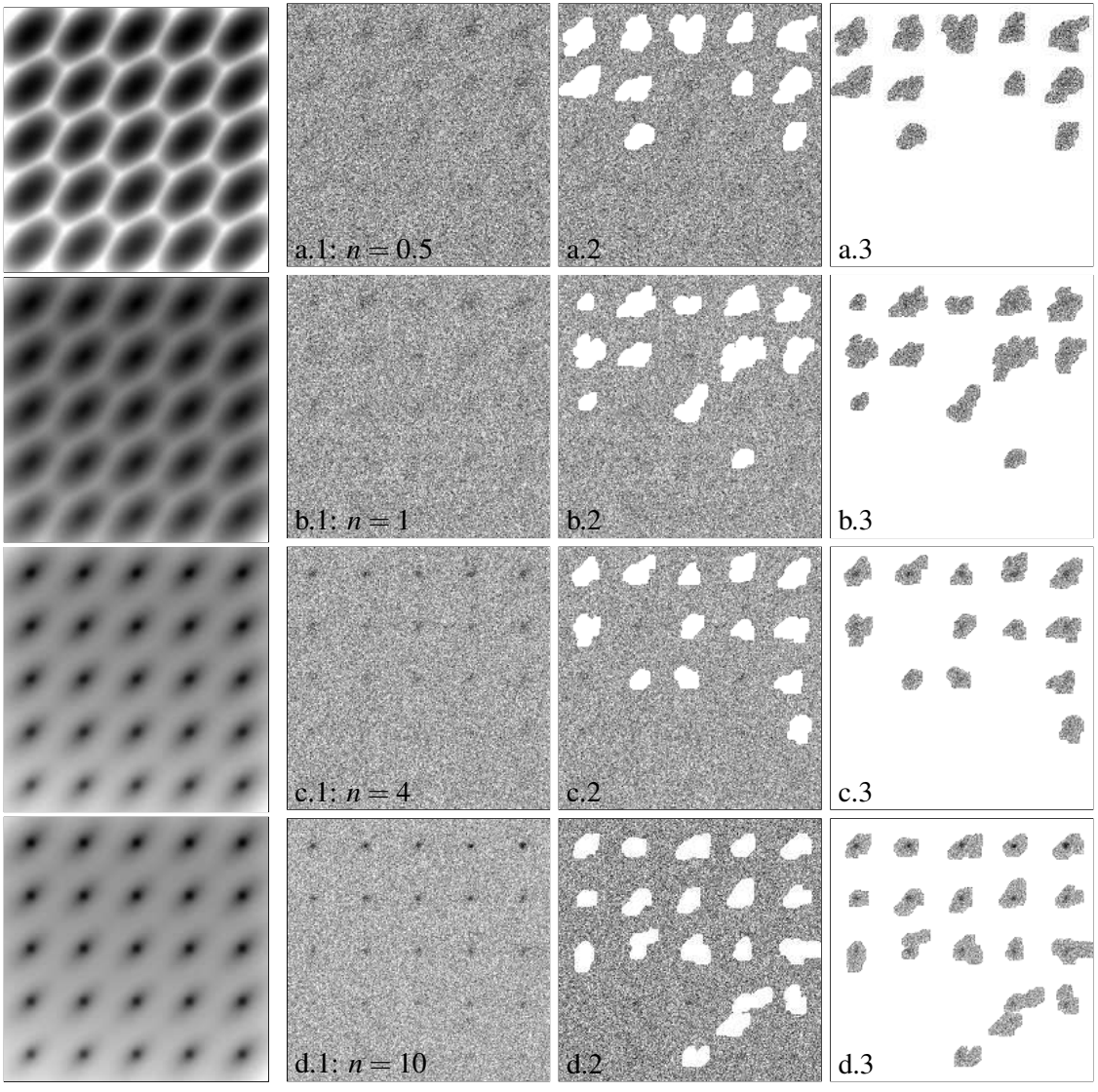
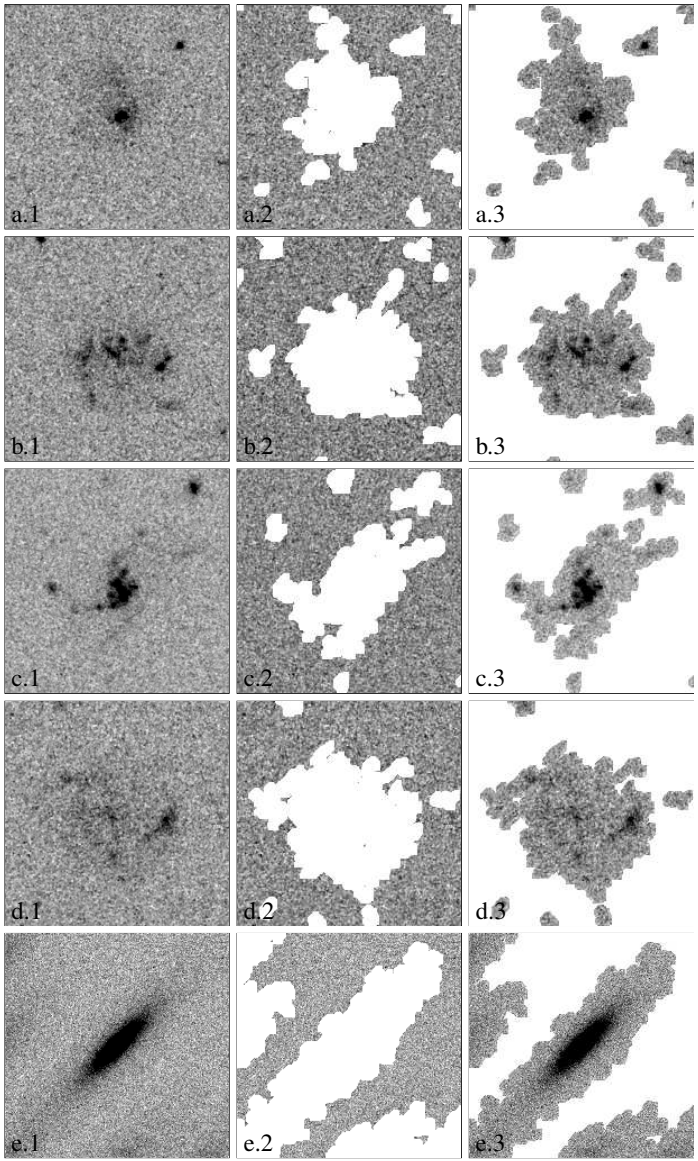
NoiseChisel – Detection – Sensitivity Test



NoiseChisel – Detection – Real HST Images



Noise-based detection: Works on any image with any target shape.

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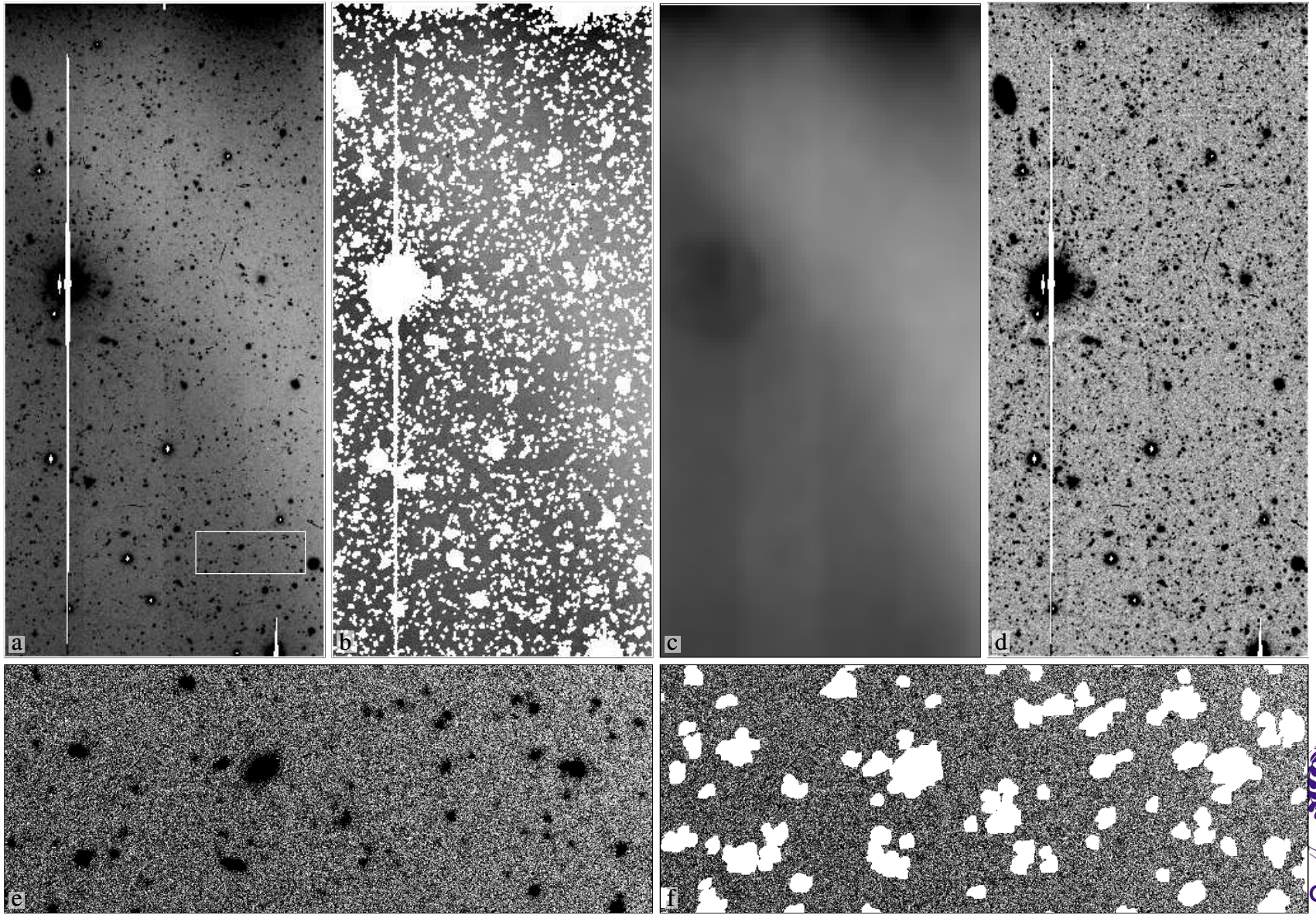
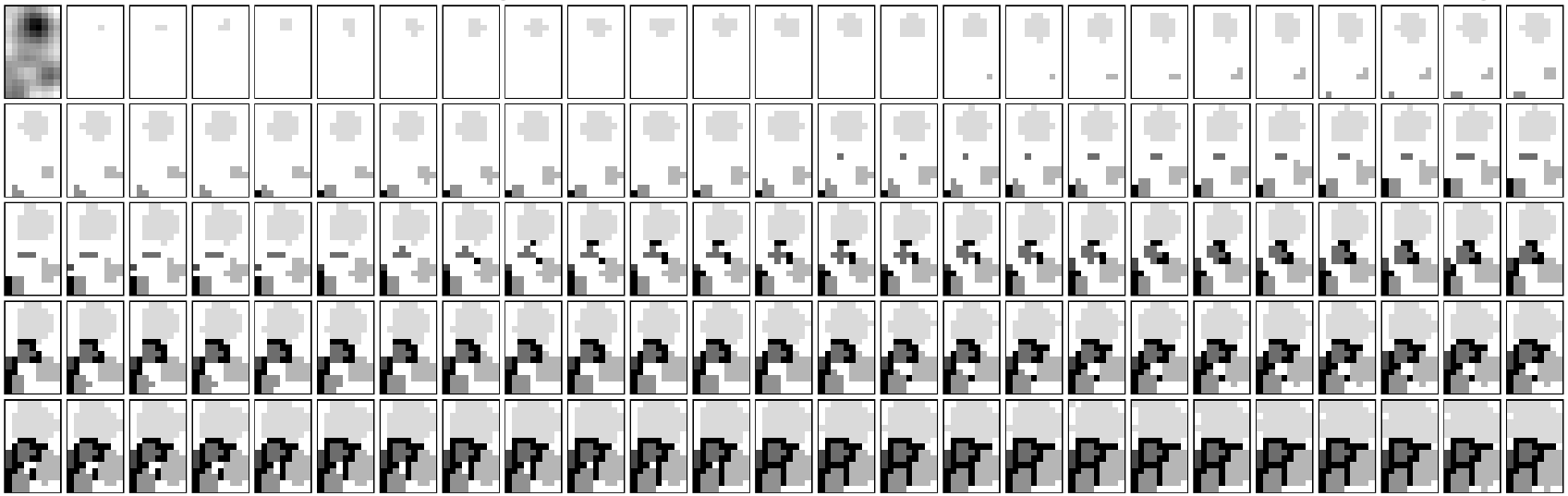
NoiseChisel – Detection – Large real images



NoiseChisel – Segmentation – clumps

A clump is found using the maximum resolution of the convolved image:



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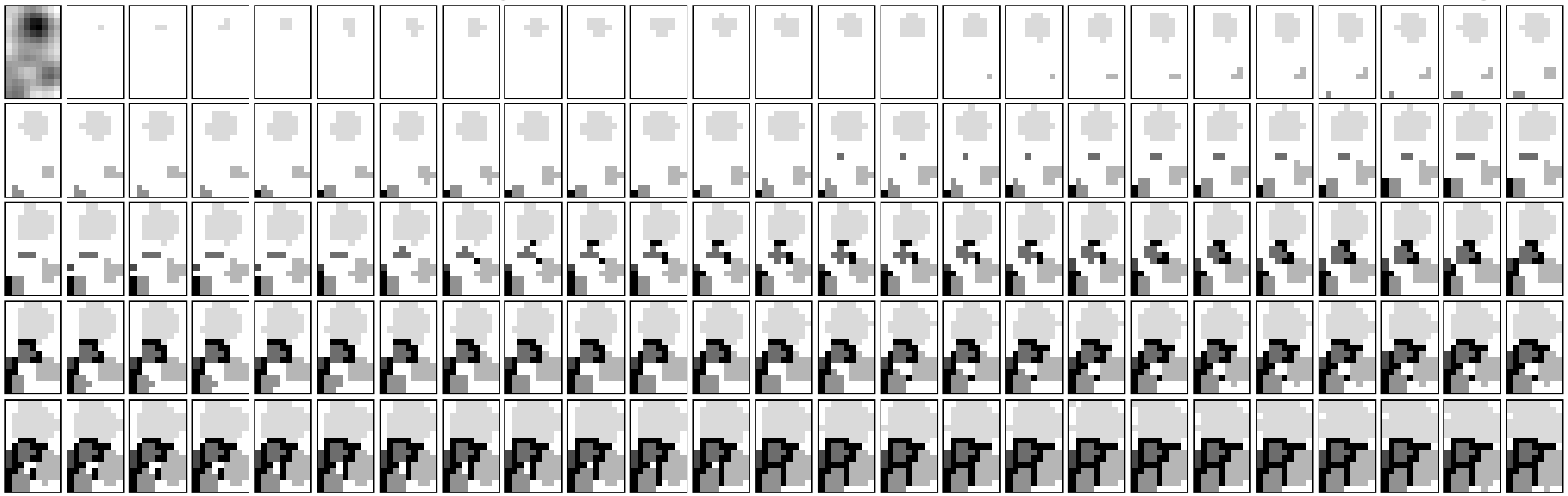
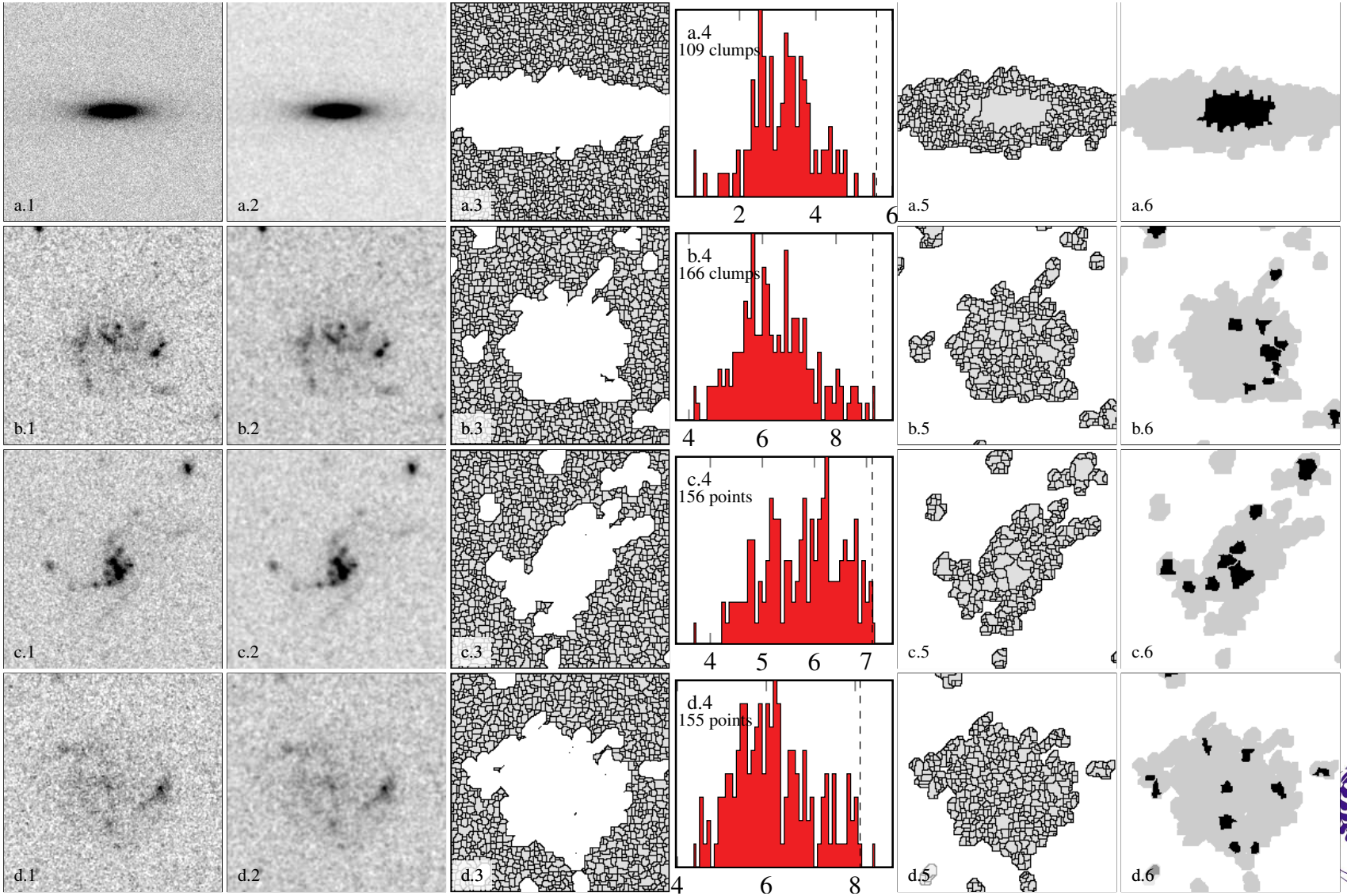
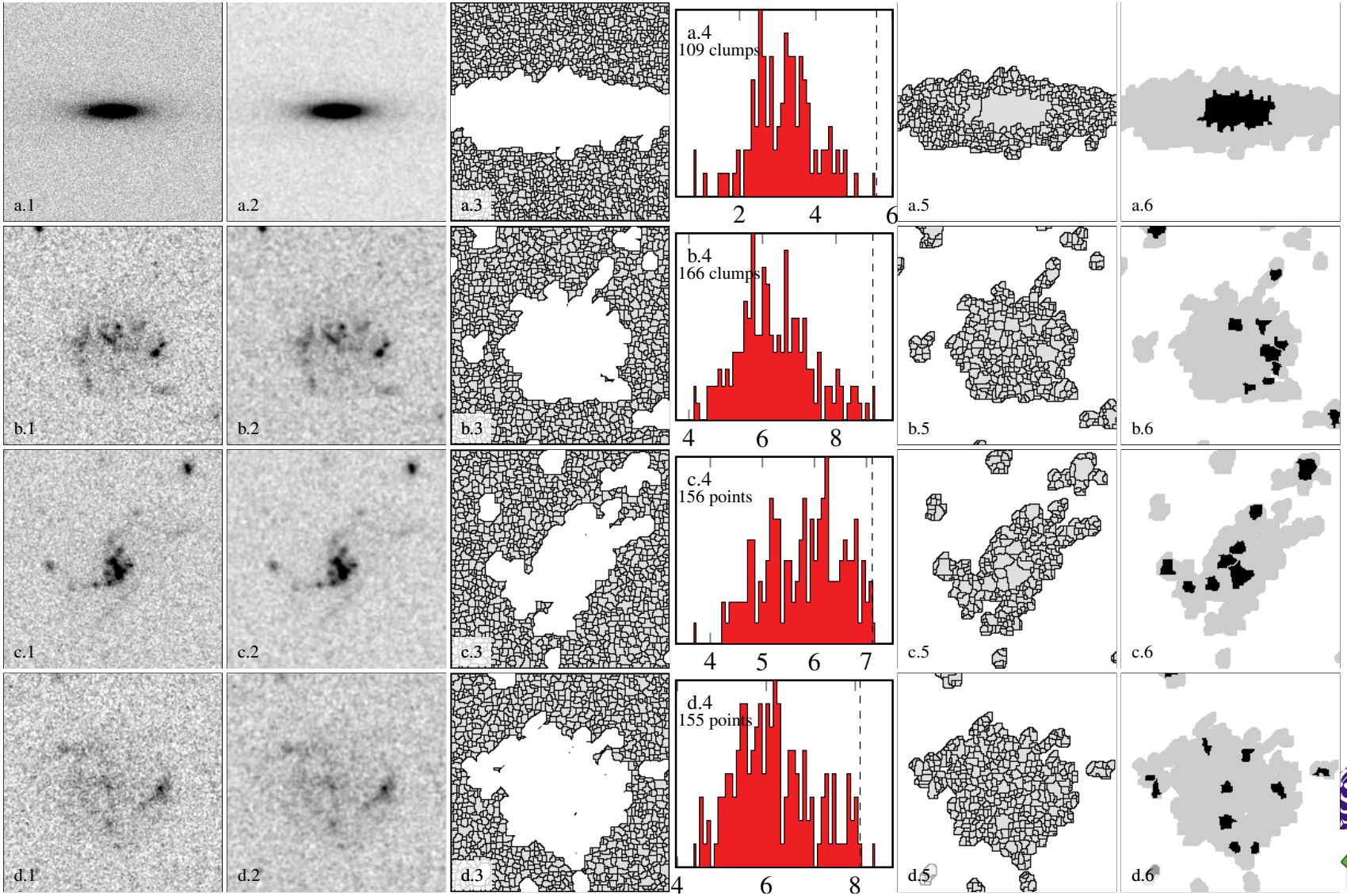


No more layers

NoiseChisel – Segmentation – True clumps

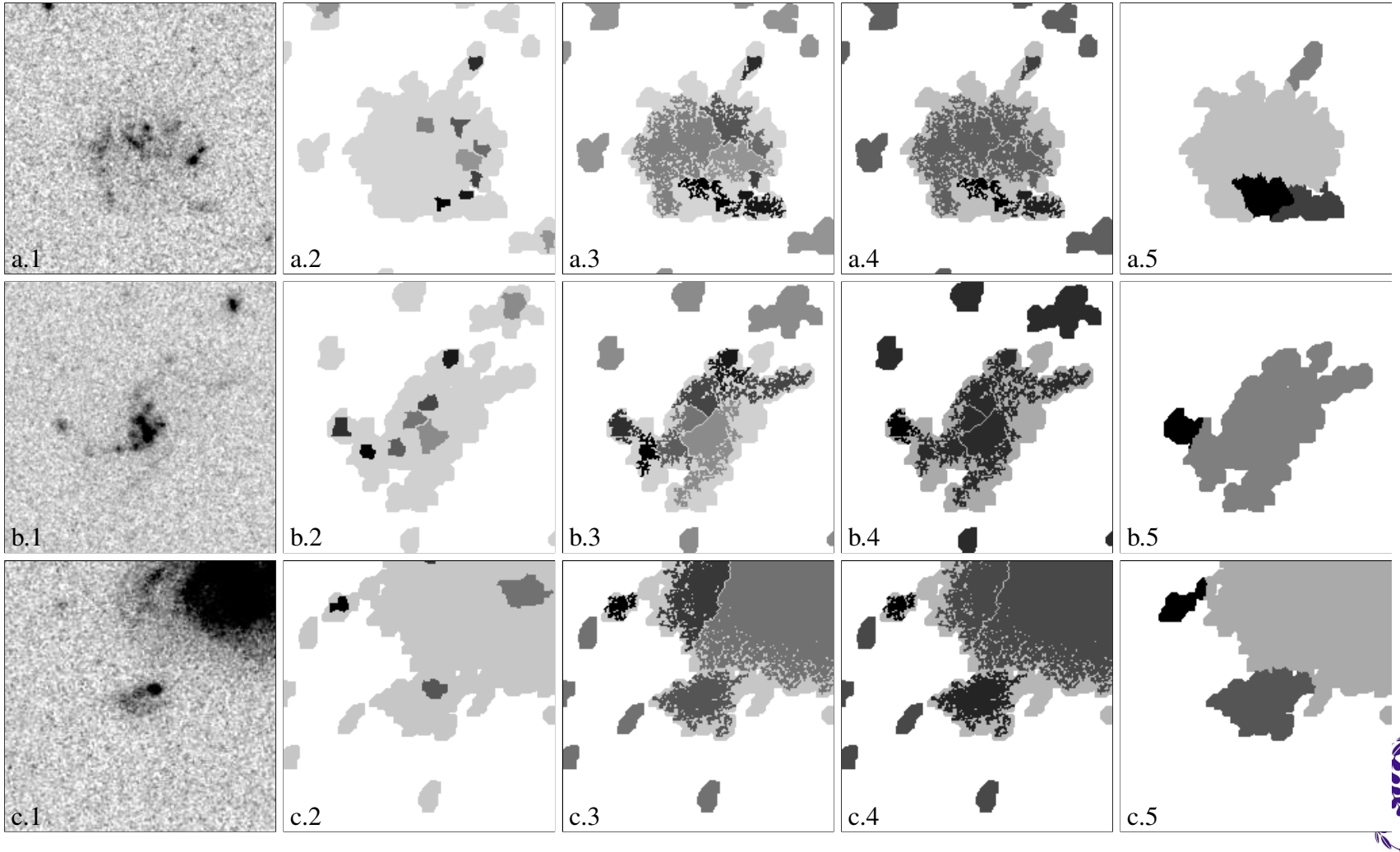


NoiseChisel – Segmentation – True clumps



clumps are found independent of user input.

NoiseChisel – Segmentation – Objects



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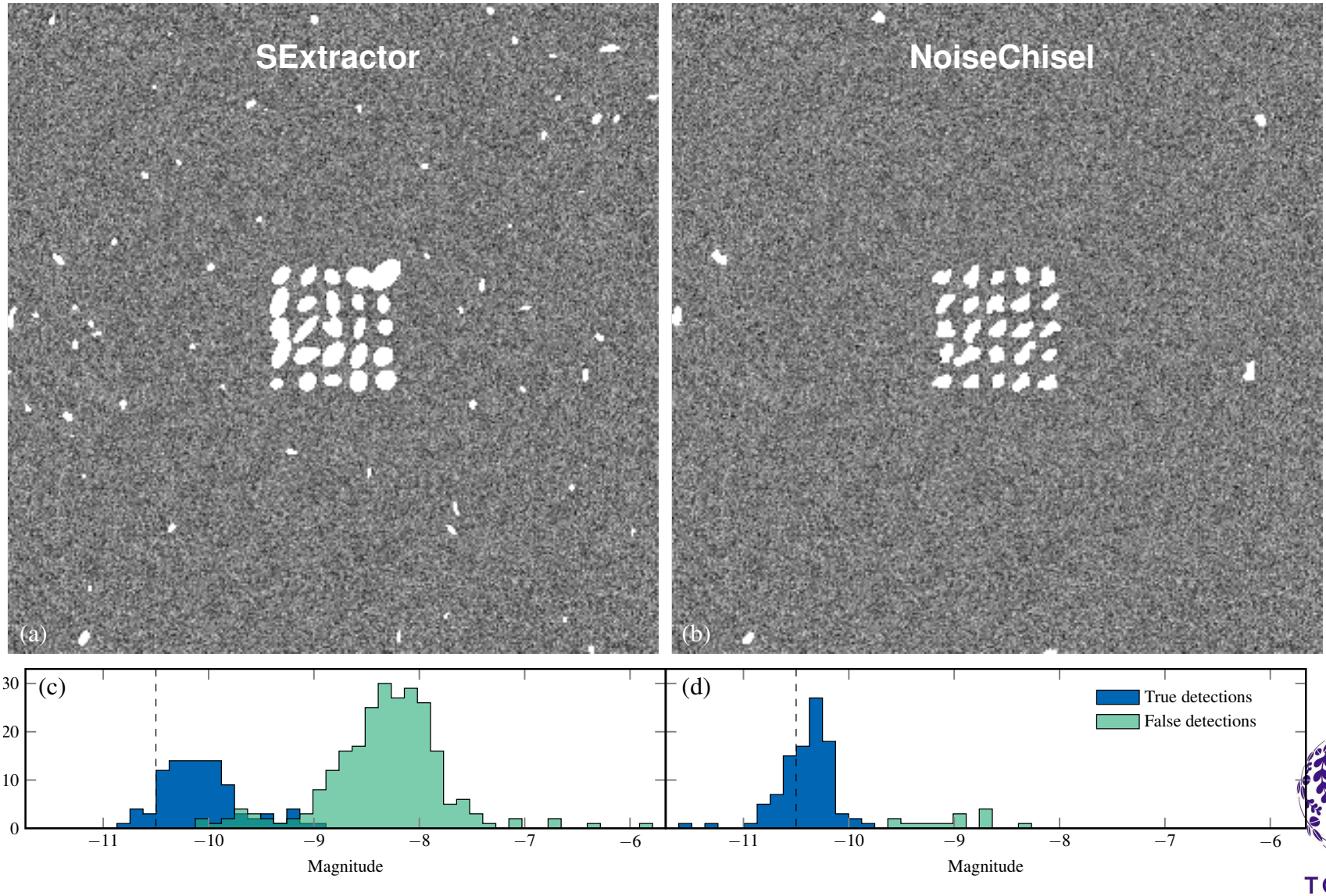
Purity and magnitude dispersion



Lesson from history:

In 1900 (at the British Association for the advancement of Science): 5 years before special relativity and about two decades before quantum mechanics fundamentally changed Physics:

> There is nothing new to be discovered in Physics now. All that remains is more and more precise measurement.
>
> Lord Kelvin

At the dedication of Ryerson Physics Lab, University of Chicago in 1894:

> The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote.... Our future discoveries must be looked for in the sixth place of decimals.
>
> Albert. A. Michelson – Nobel prize winner in Physics (1907)

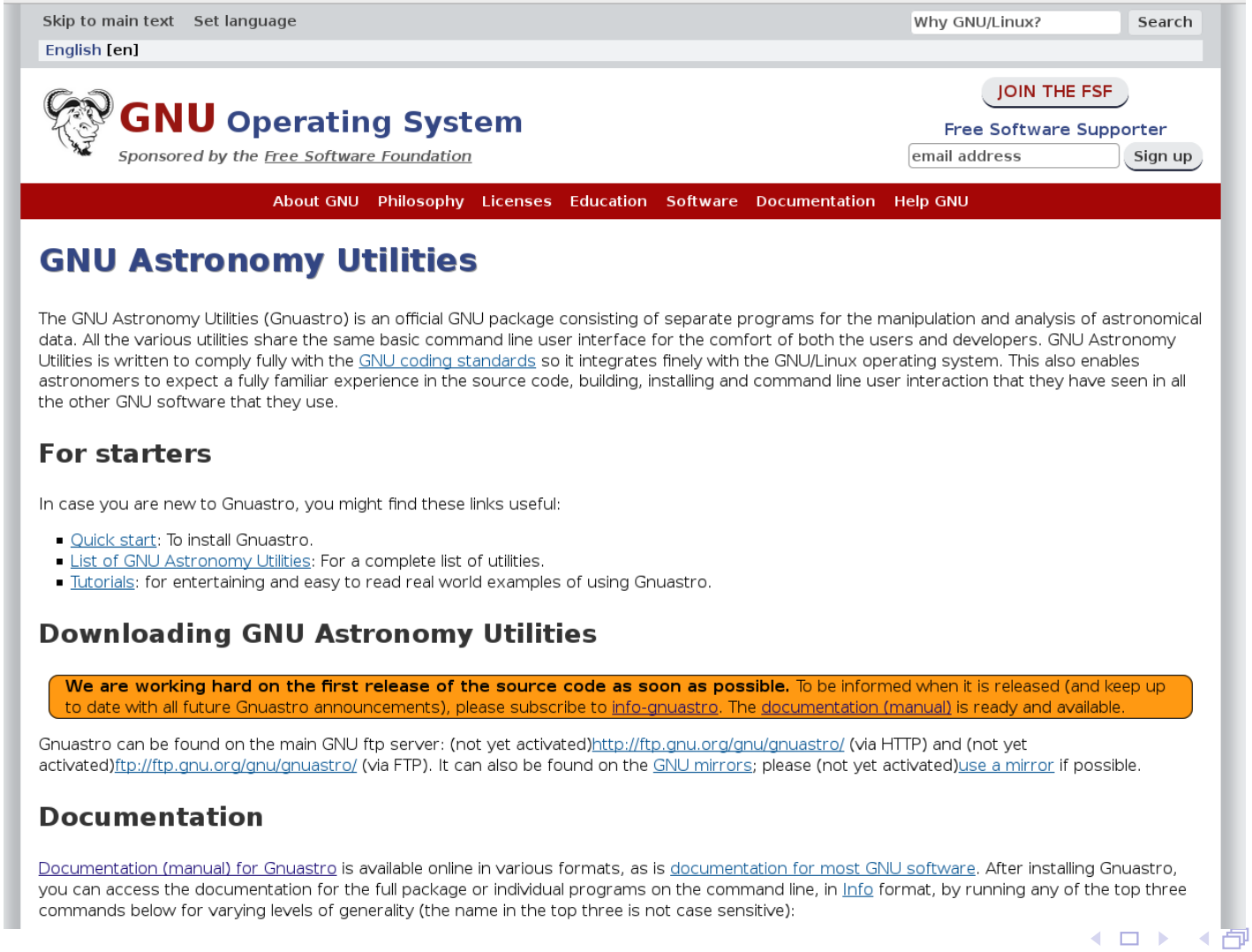
Progress in science:

> New data that we insist on analyzing in terms of old ideas (that is, old models which are not questioned) cannot lead us out of the old ideas. However many data we record and analyze, we may just keep repeating the same old errors, missing the same crucially important things that the experiment was competent to find.
>
> Edwin T. Jaynes, *Probability theory: the logic of science*

GNU Astronomy Utilities (Gnuastro)

NoiseChisel is part of the GNU Astronomy Utilities

- https://www.gnu.org/software/gnuastro/



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GNU Astronomy Utilities

The GNU Astronomy Utilities (Gnuastro) is an official GNU package consisting of separate programs for the manipulation and analysis of astronomical data. All the various utilities share the same basic command line user interface for the comfort of both the users and developers. GNU Astronomy Utilities is written to comply fully with the GNU coding standards so it integrates finely with the GNU/Linux operating system. This also enables astronomers to expect a fully familiar experience in the source code, building, installing and command line user interaction that they have seen in all the other GNU software that they use.

For starters

In case you are new to Gnuastro, you might find these links useful:

- Quick start: To install Gnuastro.
- List of GNU Astronomy Utilities: For a complete list of utilities.
- Tutorials: for entertaining and easy to read real world examples of using Gnuastro.

Downloading GNU Astronomy Utilities

We are working hard on the first release of the source code as soon as possible. To be informed when it is released (and keep up to date with all future Gnuastro announcements), please subscribe to info-gnuastro. The documentation (manual) is ready and available.

Gnuastro can be found on the main GNU ftp server: (not yet activated)http://ftp.gnu.org/gnu/gnuastro/ (via HTTP) and (not yet activated)ftp://ftp.gnu.org/gnu/gnuastro/ (via FTP). It can also be found on the GNU mirrors; please (not yet activated)use a mirror if possible.

Documentation

Documentation (manual) for Gnuastro is available online in various formats, as is documentation for most GNU software. After installing Gnuastro, you can access the documentation for the full package or individual programs on the command line, in Info format, by running any of the top three commands below for varying levels of generality (the name in the top three is not case sensitive):

Current Utilities

- ConvertType
- Convolve
- Header
- ImageCrop
- ImageStatistics
- ImageWarp
- MakeCatalog
- MakeNoise
- MakeProfiles
- NoiseChisel
- SubtractSky

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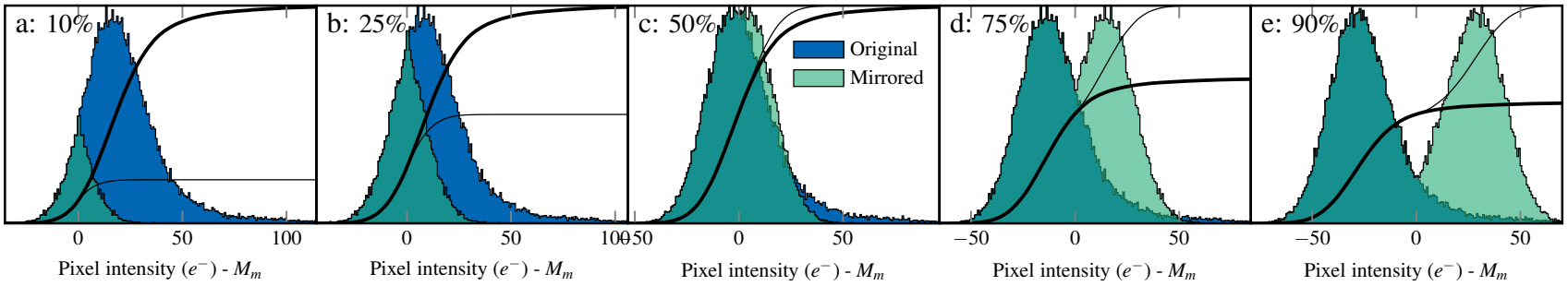
Reproducible science

See source of arXiv:1505.01664 (this paper) and/or `https://gitlab.com/makhlaghi/NoiseChisel-paper`.

- All the scripts and configuration files submitted to arXiv.
- Operation is managed by a Makefile.
- Data-generated numbers are LaTeX variables generated by the scripts.
- Input for all the plots are also generated by the scripts.
- Readers are encouraged to check/modify the parameters to see their effect.
- Everything fully explained in `reproduce/README`.

Finding the mode

- Data shifts the mode to the positive.
- The quantile is only comparable when the mode is.
- To find the mode, we define a "mirrored distribution" (green):



- The mode is where the cumulative frequency plot of the mirror distribution and original distribution are most similar: