Separating detection and catalog production,

a step towards Algorithms for Large Databases and Vice-versa.

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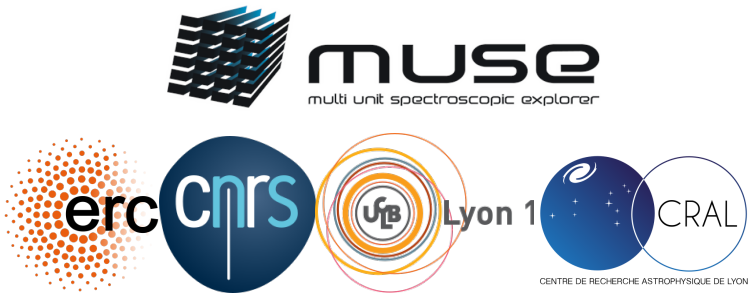
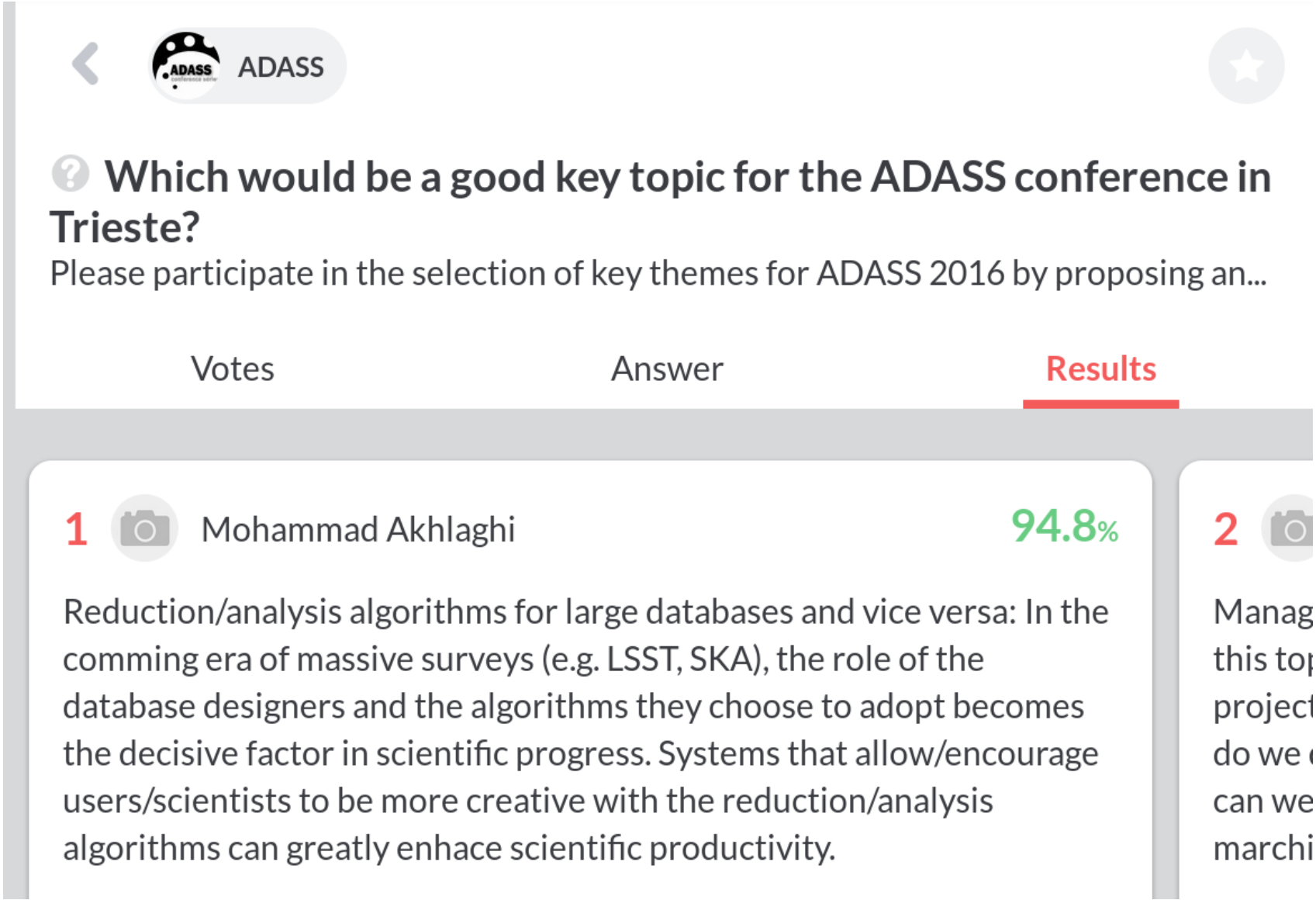


October 19th, 2016. 26th ADASS. Trieste, Italy.

A vote for the key topic

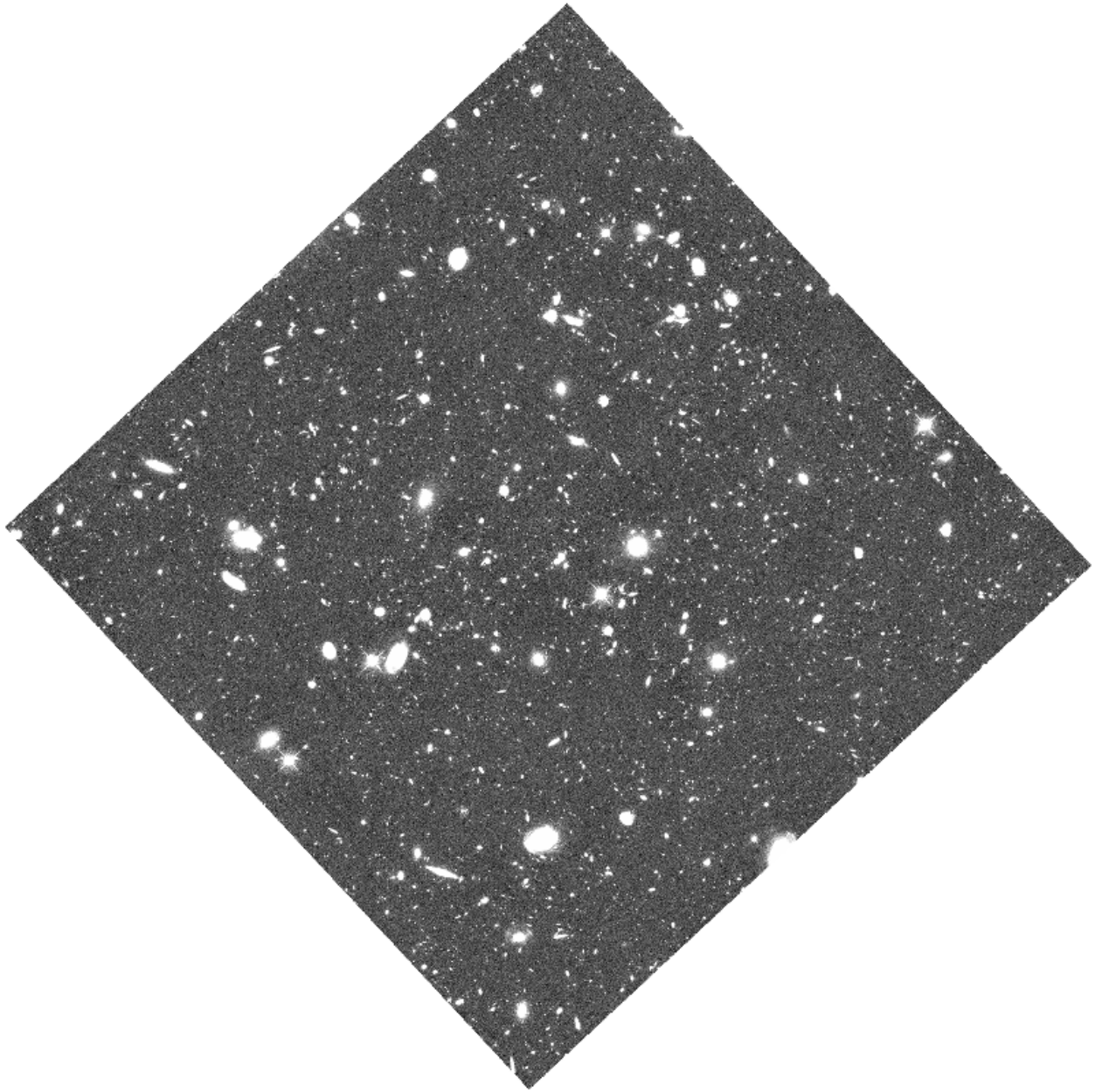


https://app.appgree.com/#!talk/9272279064034058 25/1659496956281499649

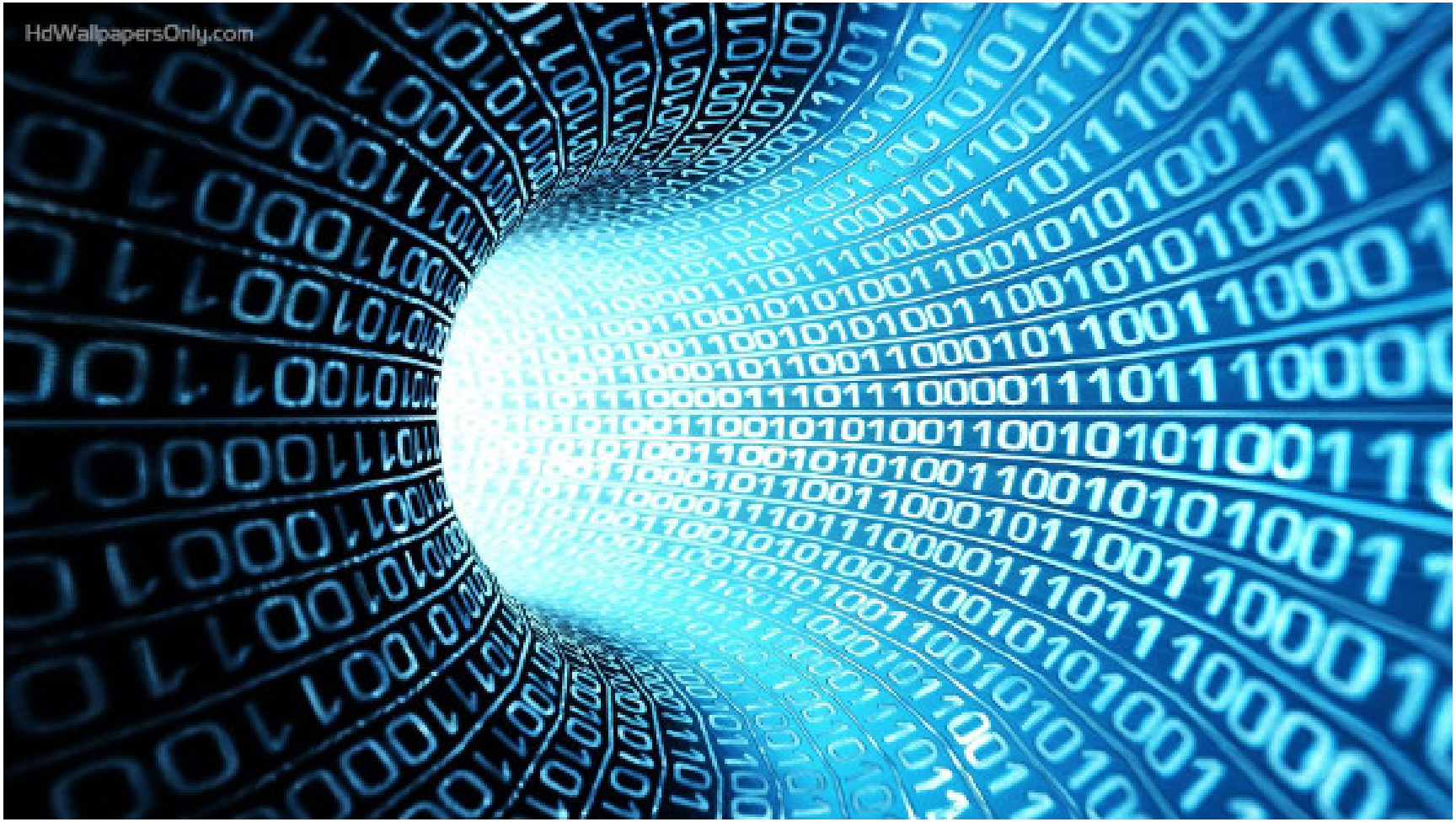
Raw data is not directly usable for analysis.

Each data element (pixel) only has a position and a value.

Example image: HST UDF field in F775W (Illingworth+2013).



So, we reduce the low-level data ...



... into high-level constructs

Each row is one identified subject (group of pixels).

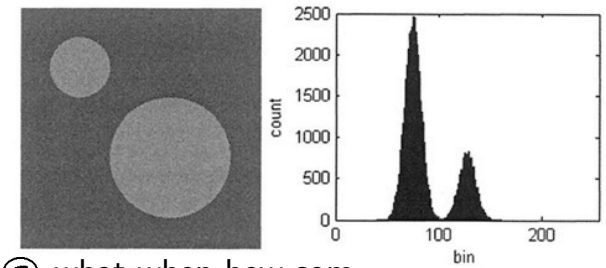
Each column is one derived property (e.g., position, magnitude, or ellipticity).

6471	4100	53.12683058	-27.79520847	9037.4350	4796.1560	-99.000	-99.000	-99.000	27.204	27.250	27.355	27.310	26.913	26.890	-99.000	26.233	0.000	0.000	0.000	0.042	0.031	0.038
6472	56335	53.12598492	-27.78574278	9127.1750	5932.0420	99.000	29.153	29.437	29.679	29.440	29.183	29.267	29.722	28.377	-99.000	28.694	30.673	0.918	0.745	0.192	0.117	0.103
6473	4127	53.16524586	-27.79547032	4959.4940	4763.9610	99.000	29.594	30.092	29.519	29.114	29.169	29.285	28.128	27.815	27.894	27.867	29.951	0.952	0.916	0.159	0.080	0.091
6474	4147	53.14908463	-27.79545415	6675.0760	4766.3820	-99.000	-99.000	-99.000	30.703	30.004	30.006	30.120	30.027	29.788	29.661	29.792	0.000	0.000	0.000	0.269	0.109	0.126
6475	4133	53.16230185	-27.79545453	5272.0120	4765.9610	-99.000	-99.000	-99.000	30.342	29.706	29.453	29.219	29.164	28.980	28.533	28.343	0.000	0.000	0.000	0.453	0.201	0.183
6476	4112	53.12417517	-27.79548546	9319.3190	4762.9240	-99.000	-99.000	-99.000	28.368	28.226	28.232	28.460	27.650	27.500	-99.000	28.252	0.000	0.000	0.000	0.079	0.049	0.055
6477	5962	53.19749054	-27.78650845	1535.9310	5837.7530	-99.000	-99.000	-99.000	28.492	27.299	26.134	25.370	24.861	24.343	-99.000	23.970	0.000	0.000	0.000	0.168	0.043	0.017
6478	6476	53.15332715	-27.78565732	6224.4220	5941.8980	-99.000	-99.000	-99.000	31.269	30.783	30.705	30.827	30.314	29.749	29.755	29.256	0.000	0.000	0.000	0.391	0.198	0.208
6479	4135	53.14968689	-27.79548315	6611.1440	4762.8880	-99.000	-99.000	-99.000	30.369	30.293	29.358	28.613	28.187	28.268	27.966	27.806	0.000	0.000	0.000	0.335	0.234	0.120
6480	9760	53.15723140	-27.75770472	5808.9900	9296.1020	99.000	29.352	29.995	29.060	28.263	28.211	28.448	28.367	28.235	-99.000	27.750	30.082	0.955	1.080	0.121	0.044	0.047
6481	6366	53.17182501	-27.78616468	4260.6440	5880.3780	-99.000	-99.000	-99.000	29.347	29.486	29.431	29.482	28.072	28.188	28.364	27.802	0.000	0.000	0.000	0.239	0.196	0.212
6482	4129	53.13494109	-27.79548130	8176.4720	4763.3600	-99.000	-99.000	-99.000	30.464	29.440	29.342	29.893	29.166	99.000	-99.000	99.000	0.000	0.000	0.000	0.289	0.089	0.090
6483	6297	53.15471075	-27.78620184	6077.5500	5876.5180	-99.000	-99.000	-99.000	30.151	28.551	27.805	27.912	27.760	27.739	27.702	27.752	0.000	0.000	0.000	0.407	0.079	0.046
6484	4588	53.15318829	-27.79347772	6239.3960	5003.4540	27.967	27.865	27.723	27.309	27.034	26.582	26.342	26.201	26.100	26.130	26.053	0.370	0.313	0.171	0.039	0.022	0.017
6485	4152	53.15466929	-27.79548426	6082.2410	4762.6290	-99.000	-99.000	-99.000	31.311	31.121	31.140	31.590	30.780	30.011	30.154	30.289	0.000	0.000	0.000	0.256	0.162	0.185
6486	6309	53.15272612	-27.78626920	6288.2470	5868.4880	99.000	99.000	28.387	27.868	28.039	28.331	28.415	28.239	28.242	27.956	27.806	29.544	29.491	0.347	0.046	0.039	0.058
6487	56355	53.13533923	-27.78574961	8134.0880	5931.1590	29.598	99.000	99.000	30.239	30.446	30.682	31.009	30.393	30.915	29.893	30.278	1.032	30.572	31.058	0.200	0.173	0.245
6488	6572	53.19020612	-27.78506074	2309.1710	6011.9260	-99.000	-99.000	-99.000	99.000	30.408	29.467	29.345	99.000	28.789	-99.000	99.000	0.000	0.000	0.000	31.707	0.217	0.116
6489	6405	53.18899153	-27.78575288	2438.1620	5928.9400	99.000	99.000	29.346	28.215	28.060	28.196	28.235	27.663	27.751	-99.000	27.460	29.240	29.324	0.893	0.060	0.038	0.051
6490	6196	53.16047727	-27.78629732	5465.3620	5864.8870	26.125	25.785	25.653	25.589	25.379	24.756	24.451	24.188	24.027	23.995	23.978	0.129	0.088	0.050	0.017	0.010	0.006
6491	6320	53.15545801	-27.78626722	5998.2210	5868.6520	99.000	29.036	29.958	29.575	28.692	28.743	28.977	28.656	28.256	28.123	28.083	30.377	0.658	0.986	0.174	0.059	0.070
6492	4098	53.12901124	-27.79553694	8805.9500	4756.7300	-99.000	-99.000	-99.000	31.379	28.776	28.533	28.959	27.909	28.761	-99.000	27.996	0.000	0.000	0.000	0.661	0.058	0.052
6493	4098	53.12912217	-27.79556408	8794.1740	4753.4730	-99.000	-99.000	-99.000	30.611	29.558	29.232	29.040	29.060	28.729	-99.000	99.000	0.000	0.000	0.000	0.412	0.126	0.109
6494	4088	53.13706605	-27.79553126	7950.8990	4757.3400	-99.000	-99.000	-99.000	30.435	29.680	29.797	29.833	29.077	99.000	-99.000	29.159	0.000	0.000	0.000	0.256	0.099	0.123
6495	4125	53.13728748	-27.79552769	7927.3930	4757.7660	-99.000	-99.000	-99.000	30.835	30.434	30.660	30.691	29.506	99.000	-99.000	99.000	0.000	0.000	0.000	0.297	0.156	0.216
6496	4128	53.14300811	-27.79552547	7320.1250	4757.9460	-99.000	-99.000	-99.000	31.285	30.704	30.468	31.016	29.605	30.336	30.029	99.000	0.000	0.000	0.000	0.401	0.186	0.169
6497	4122	53.17232195	-27.79553444	4208.3400	4755.9860	-99.000	-99.000	-99.000	30.798	29.900	29.859	29.788	29.529	29.898	29.459	29.521	0.000	0.000	0.000	0.352	0.119	0.131
6499	6378	53.18153224	-27.78565751	3230.0630	5940.7870	99.000	99.000	99.000	28.179	27.907	28.006	28.061	27.915	27.493	27.478	27.150	29.857	29.935	30.447	0.145	0.083	0.103
6500	6427	53.15363590	-27.78571246	6191.6450	5935.2730	99.000	99.000	29.311	28.745	27.908	27.884	28.061	27.533	27.227	27.130	27.025	30.004	29.945	0.890	0.123	0.043	0.048
6501	6465	53.17551754	-27.78559076	3868.6030	5949.0870	99.000	28.962	99.000	29.598	29.286	28.838	28.536	28.034	27.976	27.858	27.868	30.291	0.805	30.878	0.241	0.135	0.102
6502	9986	53.15597372	-27.75779009	5942.5470	9285.8940	-99.000	-99.000	-99.000	29.954	30.018	29.930	29.962	28.579	29.375	-99.000	99.000	0.000	0.000	0.000	0.232	0.178	0.189
6503	4109	53.13160447	-27.79554853	8530.6680	4755.3230	-99.000	-99.000	-99.000	30.149	29.315	29.003	29.241	29.011	99.000	-99.000	28.495	0.000	0.000	0.000	0.227	0.080	0.069
6504	4090	53.18466386	-27.79555816	2898.1970	4752.5450	-99.000	-99.000	-99.000	28.891	28.493	28.720	28.581	28.710	28.671	-99.000	27.801	0.000	0.000	0.000	0.082	0.042	0.059
6505	56463	53.20231083	-27.78543210	1024.1110	5966.5950	-99.000	-99.000	-99.000	28.809	27.079	25.592	24.706	23.687	22.736	-99.000	22.270	0.000	0.000	0.000	0.279	0.043	0.013
6506	6299	53.15541566	-27.78635410	6002.7200	5858.2270	28.086	28.738	28.897	29.223	28.645	28.867	28.306	27.797	27.561	27.670	27.592	0.471	0.904	0.684	0.230	0.104	0.143
6507	5922	53.13151988	-27.78642864	8539.5700	5849.7100	25.709	25.269	25.397	25.271	25.084	24.393	24.016	23.728	23.524	-99.000	23.415	0.196	0.139	0.097	0.019	0.011	0.007
6508	6325	53.16161490	-27.78633660	5344.5890	5860.1360	-99.000	-99.000	-99.000	30.452	99.000	29.180	27.741	27.545	27.451	27.512	27.493	0.000	0.000	0.000	0.616	31.132	0.185
6509	4104	53.19234925	-27.79556925	2082.3620	4750.7770	-99.000	-99.000	-99.000	99.000	29.952	29.648	29.582	29.663	29.127	-99.000	99.000	0.000	0.000	0.000	31.922	0.120	0.110
6510	4131	53.14730403	-27.79559643	6864.0970	4749.3480	-99.000	-99.000	-99.000	31.095	30.876	30.606	30.512	30.956	30.474	99.000	29.586	0.000	0.000	0.000	0.454	0.291	0.266
6511	6432	53.13528732	-27.78585466	8139.6000	5918.5530	-99.000	-99.000	-99.000	30.762	30.411	30.345	30.584	30.170	30.178	30.211	30.368	0.000	0.000	0.000	0.341	0.191	0.198
6512	6657	53.17808141	-27.78478449	3596.3690	6045.7190	99.000	99.000	99.000	29.137	28.675	28.666	28.554	28.482	28.462	28.445	28.149	30.355	30.398	30.902	0.161	0.078	0.087
6513	4108	53.19692308	-27.79559973	1596.8330	4746.8360	-99.000	-99.000	-99.000	29.597	29.729	29.907	30.419	99.000	99.000	-99.000	99.000	0.000	0.000	0.000	0.115	0.094	0.127
6514	6409	53.14781419	-27.78586195	6809.7030	5917.4750	-99.000	-99.000	-99.000	30.688	29.406	29.024	29.491	29.204	29.228	28.845	28.759	0.000	0.000	0.000	0.470	0.121	0.098
6515	4101	53.13577271	-27.79563710	8088.1940	4744.6550	-99.000	-99.000	-99.000	30.601	29.821	30.030	30.406	99.000	99.000	-99.000	28.739	0.000	0.000	0.000	0.291	0.111	0.150
6516	4115	53.19144757	-27.79561505	2178.0820	4745.3350	-99.000	-99.000	-99.000	29.785	29.840	30.296	30.159	28.981	28.325	-99.000	99.000	0.000	0.000	0.000	0.145	0.111	0.186
6517	56263	53.15234975	-27.78619611	6328.2020	5877.2690	-99.000	-99.000	-99.000	31.687	31.012	30.765	30.490	30.146	29.725	30.201	29.437	0.000	0.000	0.000	0.595	0.270	0.251
6518	6295	53.14929275	-27.78611953	6652.7410	5886.5320	99.000	28.521	28.938	28.601	28.438	27.511	27.314	27.003	26.837	26.836	26.766	29.954	0.887	0.828	0.117	0.073	0.037
6519	56294	53.14588767	-27.78589868	7014.2300	5913.1070	-99.000	-99.000	-99.000	30.544	30.258	30.355	29.930	29.102	29.021	28.879	29.008	0.000	0.000	0.000	0.351	0.210	0.254
6521	6353	53.18543148	-27.78619325	2816.1380	5876.2930	-99.000	-99.000	-99.000	99.000	99.000	30.141	29.505	28.837	29.043	-99.000	99.000	0.000	0.000	0.000	31.599	31.962	0.214
6522	6504	53.13743798	-27.78523322	7911.2690	5993.1000	99.000	99.000	99.000	27.500	26.680	26.516	26.629	26.348	26.273	26.133	25.878	29.377	29.300	29.803	0.048	0.016	0.016
6523	4102	53.17361933	-27.79565626	4070.6240	4741.3110	-99.000	-99.000	-99.000	29.830	28.929	29.453	29.846	29.382	29.536	28.952	28.489	0.000	0.000	0.000	0.348	0.120	0.210
6524	6348	53.15673109	-27.78596990	5863.0570	5904.2940	99.000	99.000	27.977	28.265	28.465	27.499	27.508	27.239	26.878	26.864	26.859	29.903	29.835	0.376	0.112	0.097	0.046
6525	56327	53.14645508	-27.78590786	6953.9920	5911.9940	-99.000	-99.000	-99.000	99.000	30.566	30.694	30.826	30.235	30.043	99.000	30.111	0.000	0.000	0.000	32.051	0.182	0.232

(UVUDF catalog, Rafelski et al. 2015)

So, how is the image reduced to a catalog?

When there are sharp and high S/N edges, a sufficiently high threshold can *avoid* the noise $\rightarrow$ Signal-based detection.



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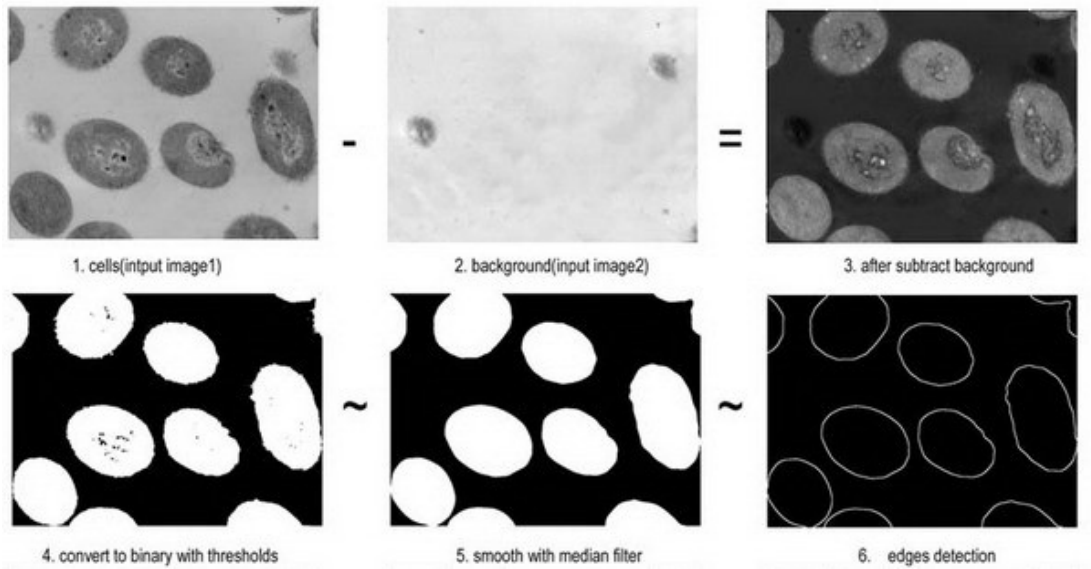

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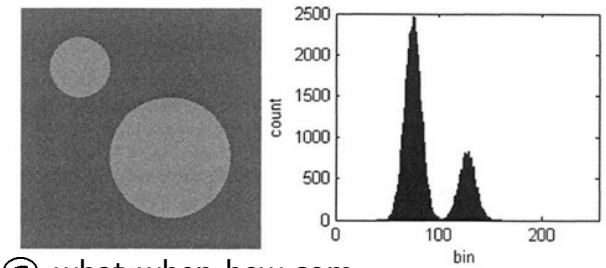

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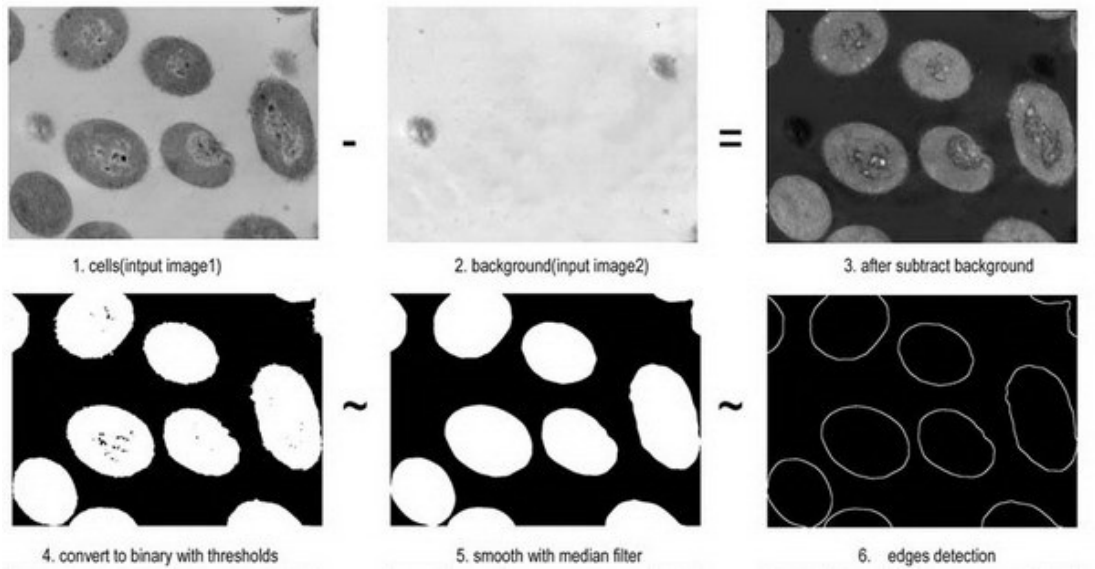

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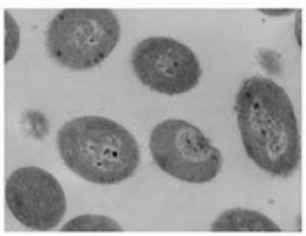
Outline is:



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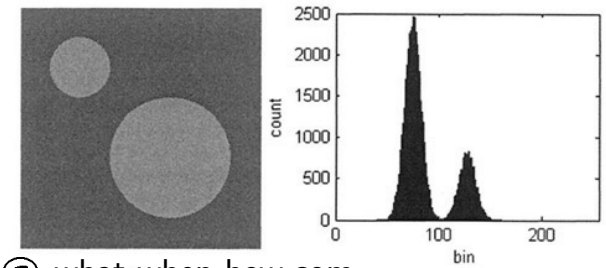

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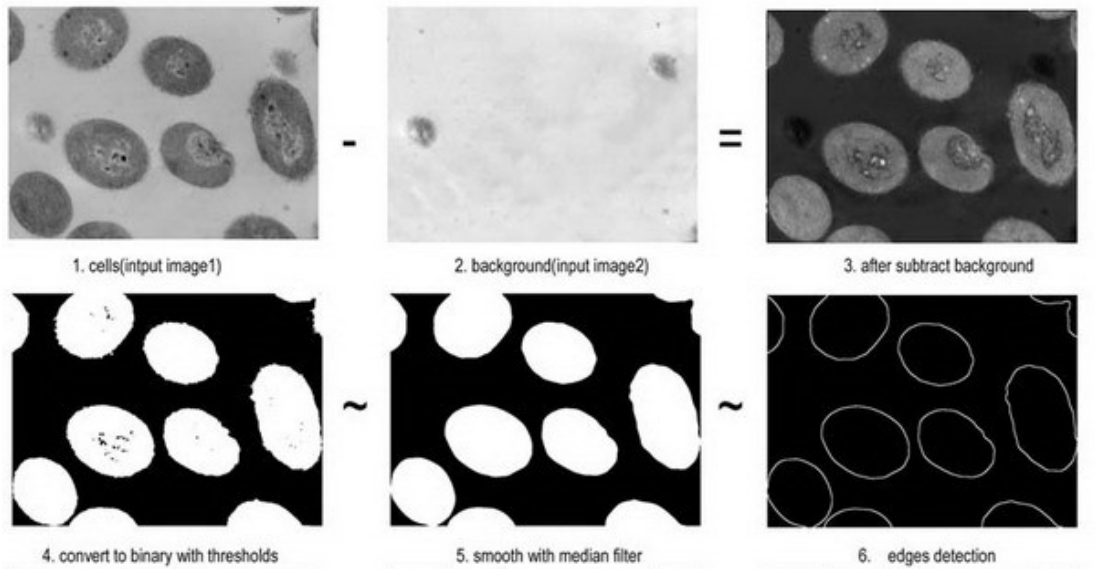

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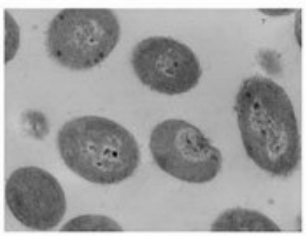
Outline is:



$\rightarrow$ Software $\rightarrow$

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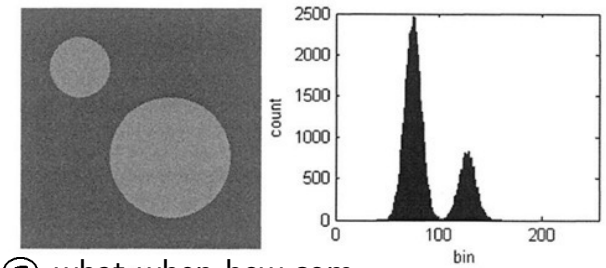

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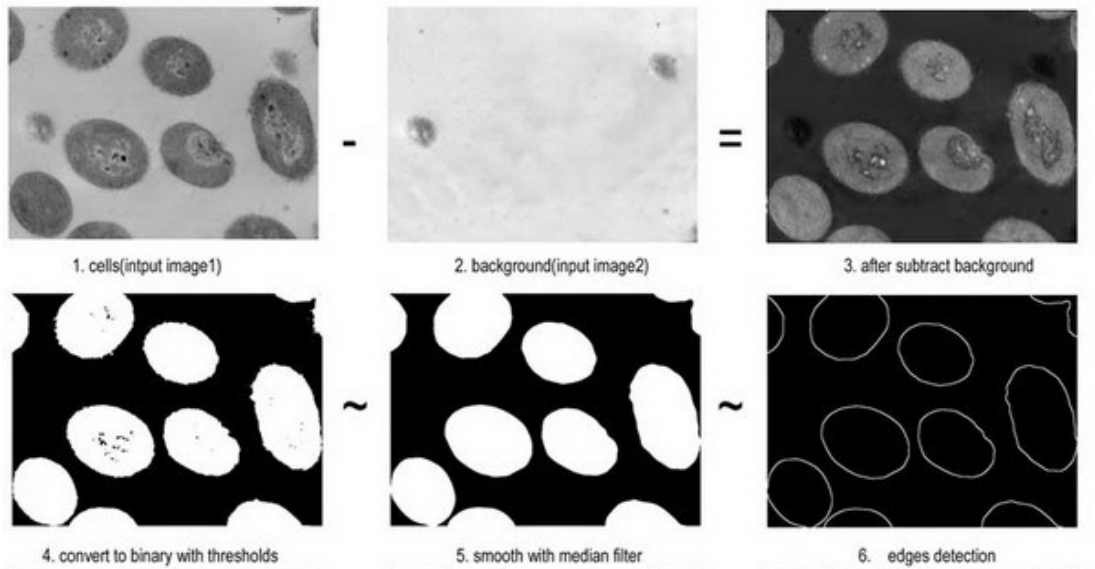

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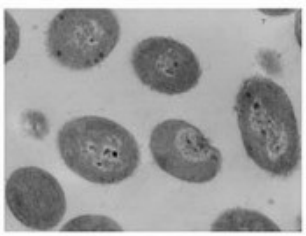
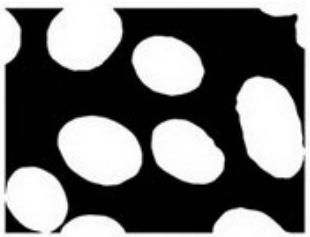


$\rightarrow$ Software $\rightarrow$



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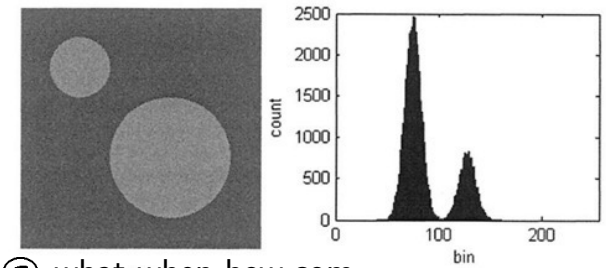

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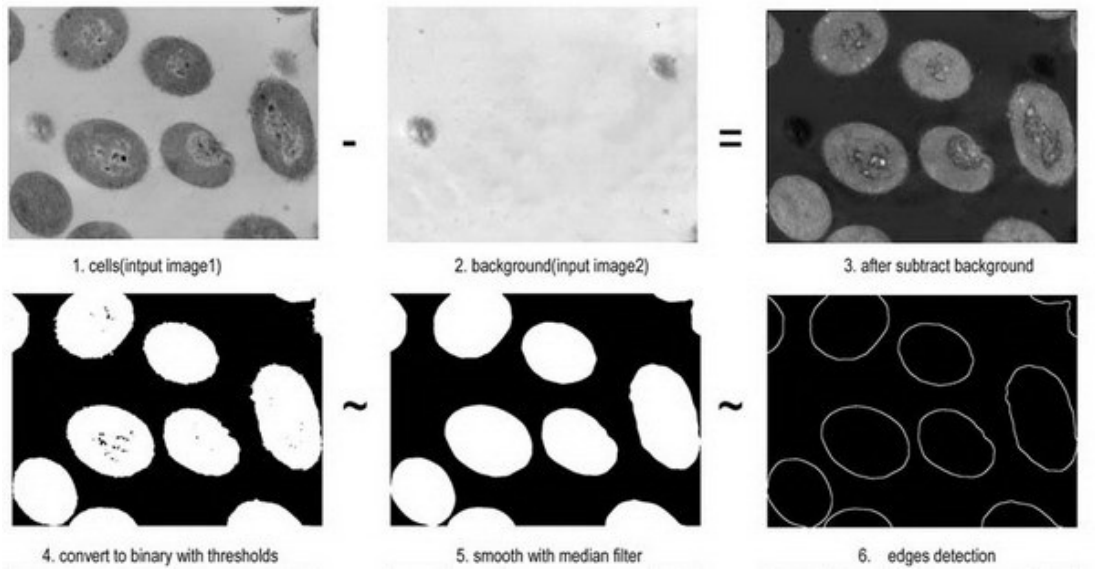
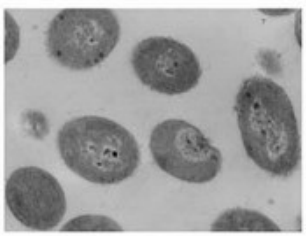
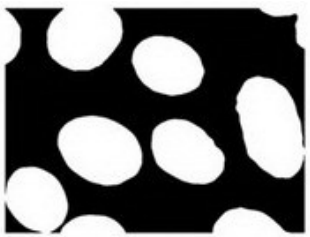


© OriginLab.com

Outline is:



$\rightarrow$ Software $\rightarrow$



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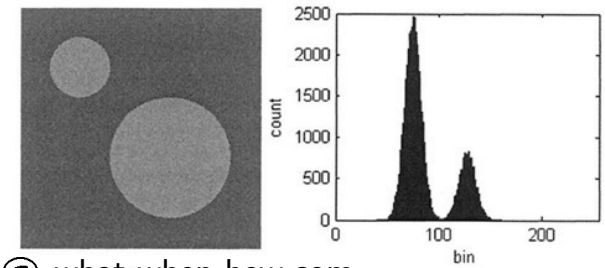

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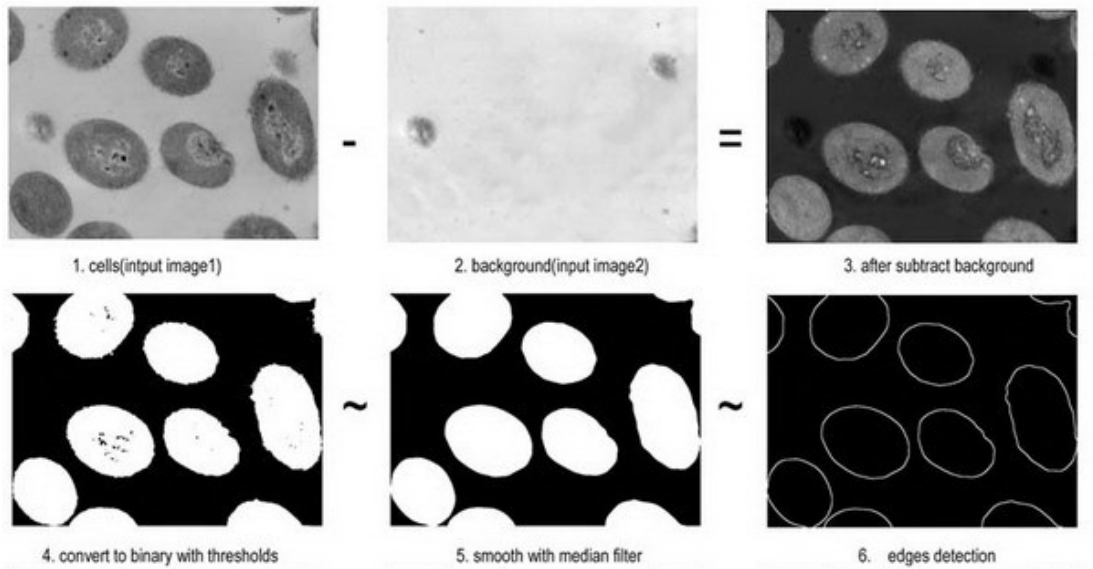

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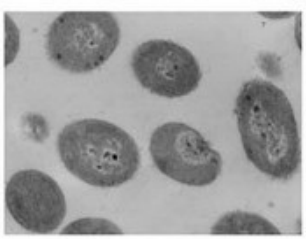
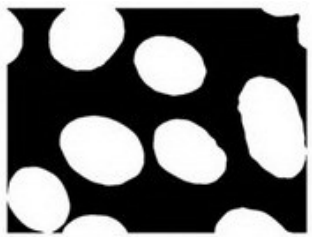
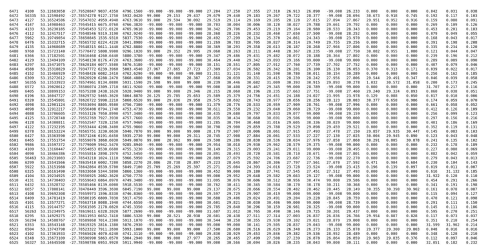


→ Software →

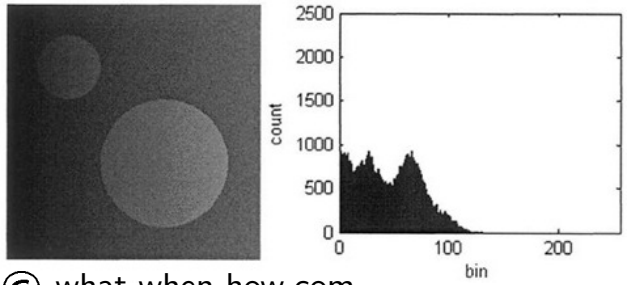


→ Software →



But astronomical objects ...

... don't have such sharp edges.
... can have a huge diversity of shapes and sizes.



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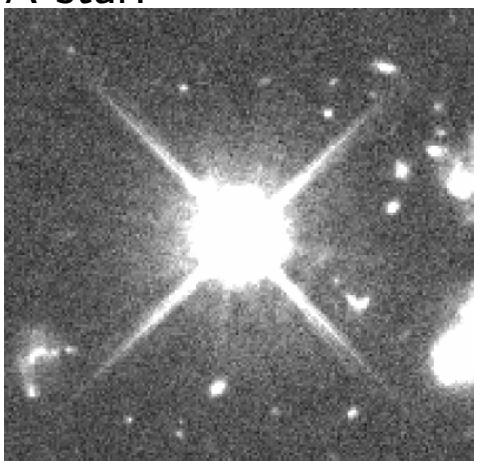
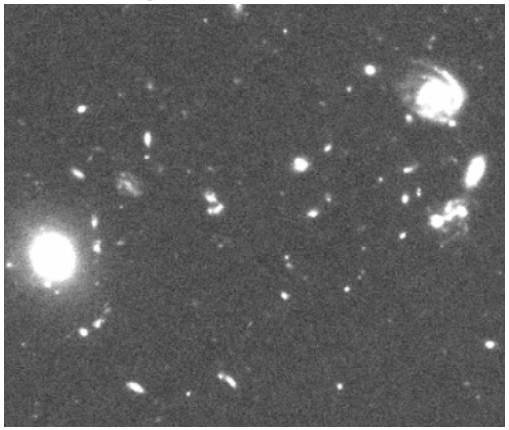
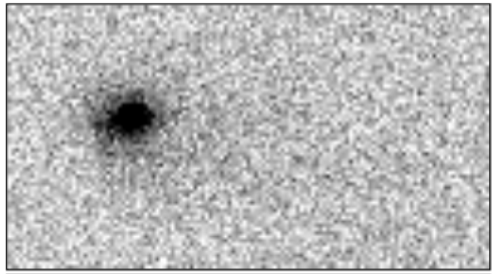
A star:



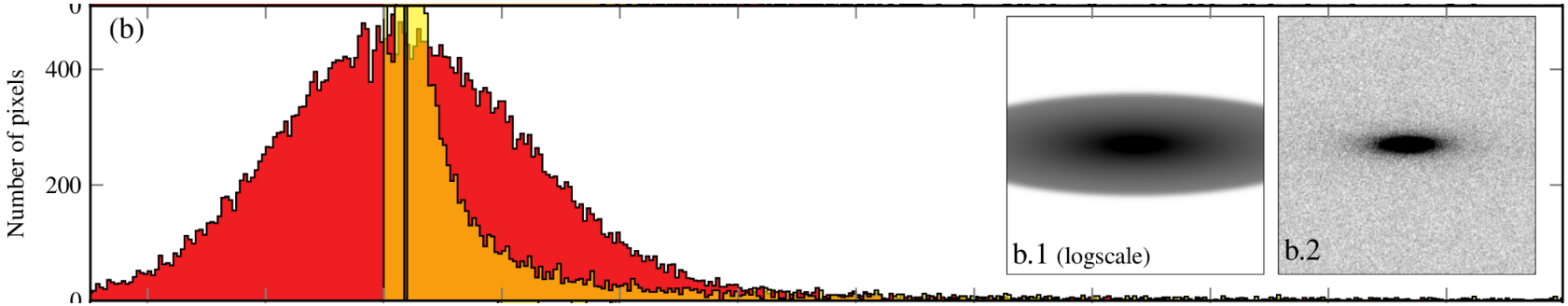
Some galaxies:



A main-belt comet:



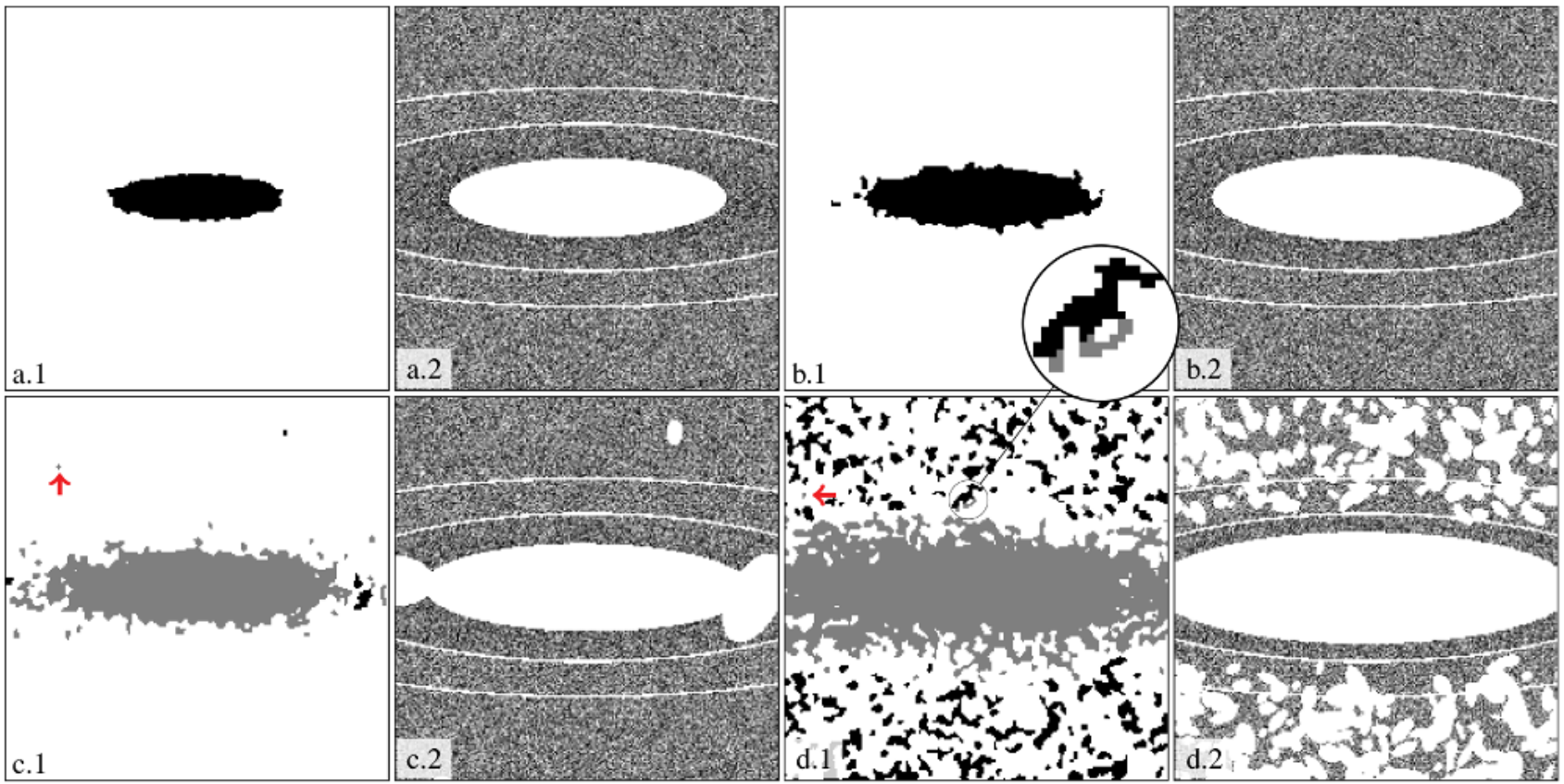
A mock galaxy: (Yellow/left-image: only signal. Red/right-image: signal and noise.)



So for astronomical objects ...

... a threshold designed to avoid the noise (signal-based detection) will miss a lot of the signal. Decreasing the threshold will result in many false detections.

So our only hope is to try modelling the brighter parts.



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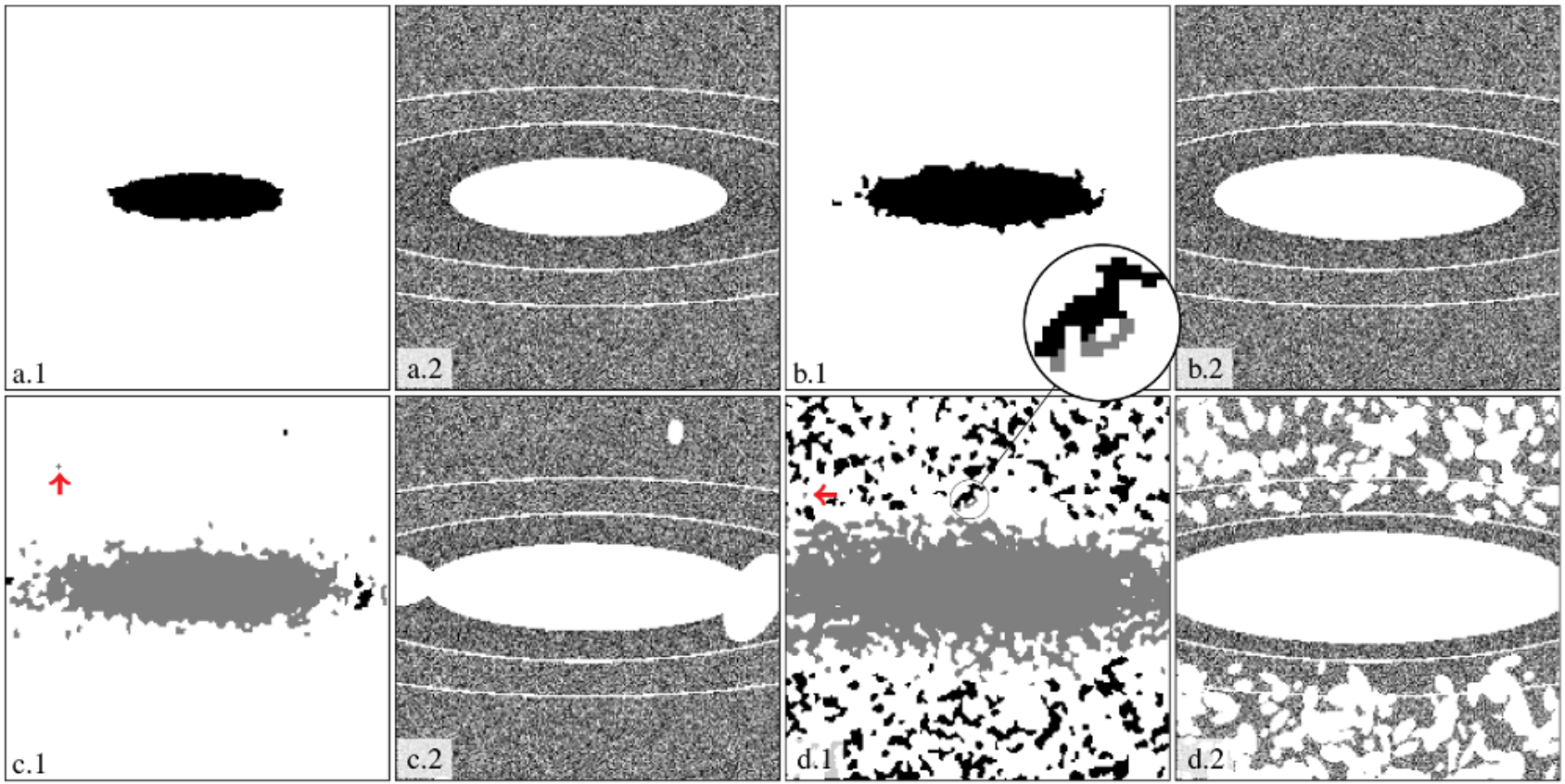
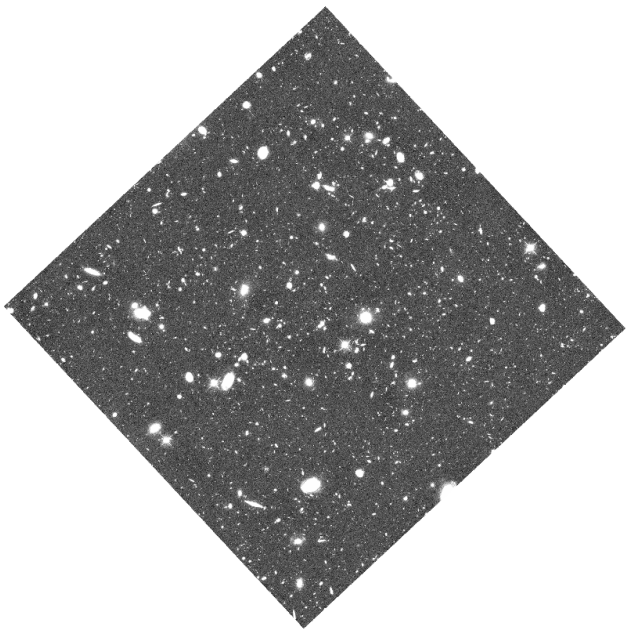


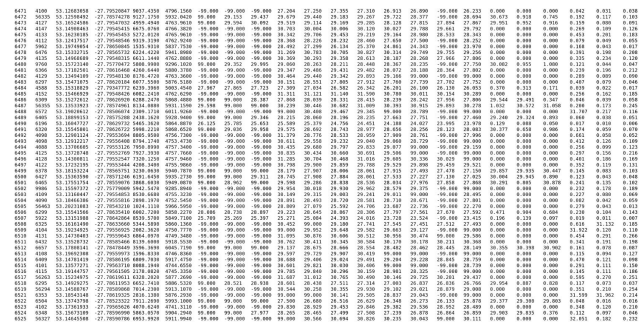
Detection and catalog production heavily intertwined through the parametric models.

Outline of most common software

So this is the most common procedure:



→ Software/Pipeline →

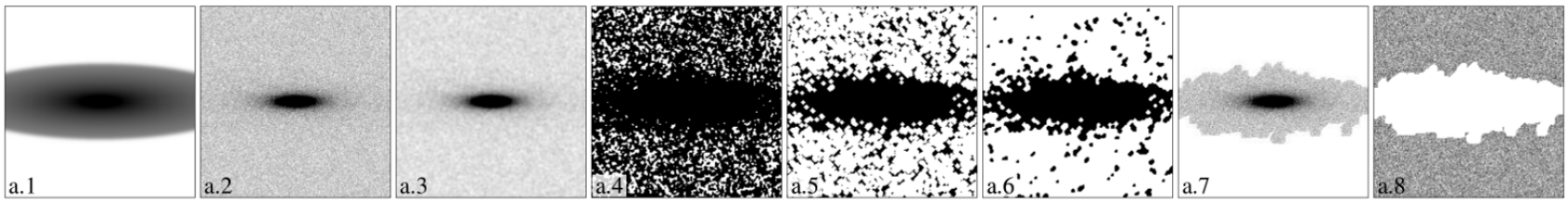


As a result:

- Catalog production is computationally expensive.
- Decreases modularity, or creativity.

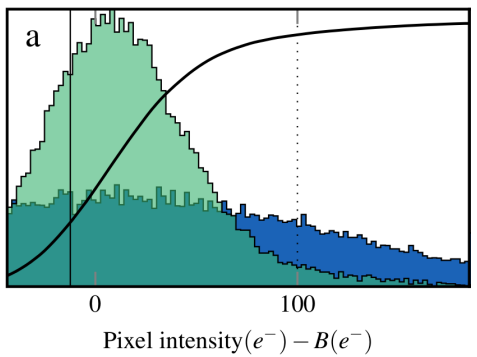
Noise-based detection

In Sydney (25th ADASS), we introduced a new noise-based detection. The threshold is below the Sky value ($\sim -0.5\sigma$, not designed to avoid the noise). Noise is separated from signal (detection) by exploiting the signal's contiguity.



The threshold is the solid vertical line:

(In this mock image, the Sky value is on 0)



See:
Akhlaghi and Ichikawa (2015, ApJS 220, 1. arXiv: 1505.01664).

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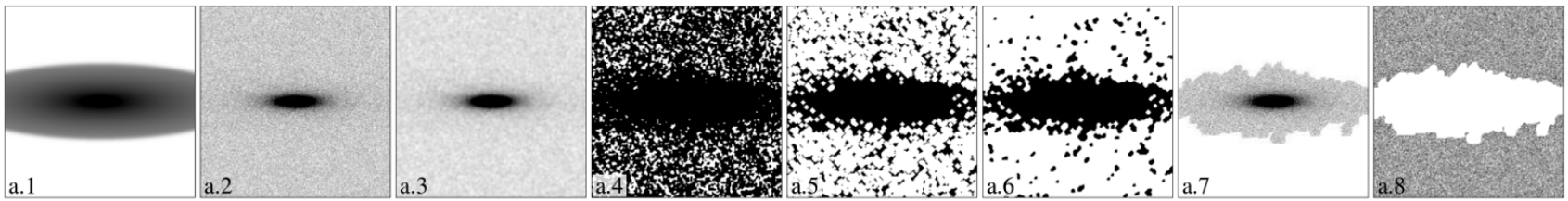

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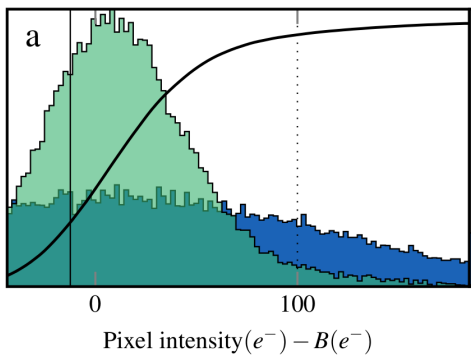
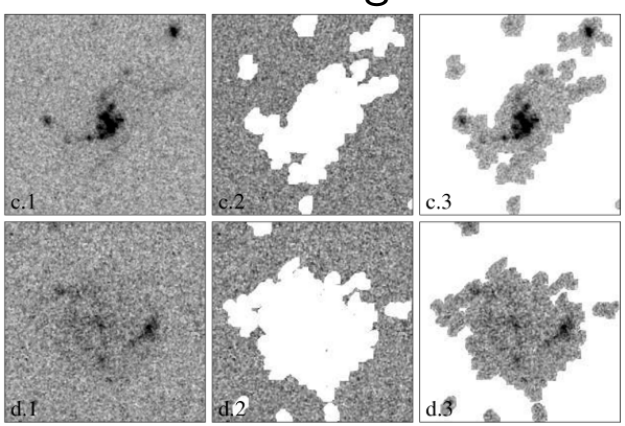


Results: real galaxies:



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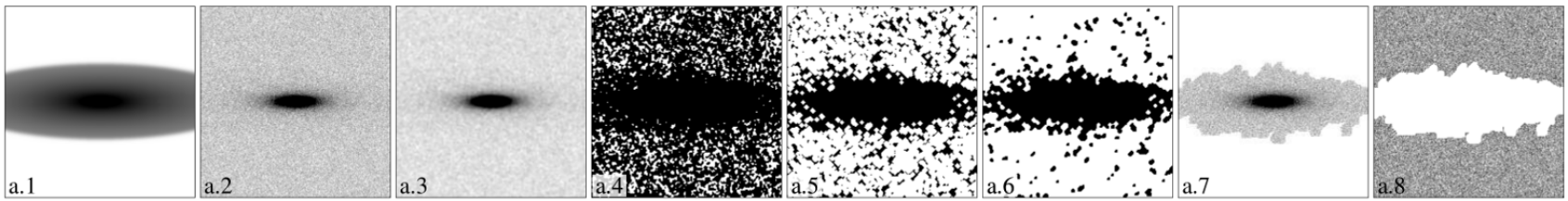

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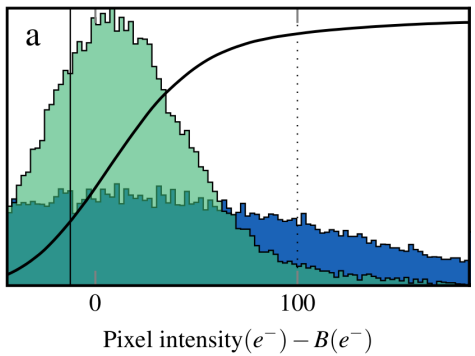

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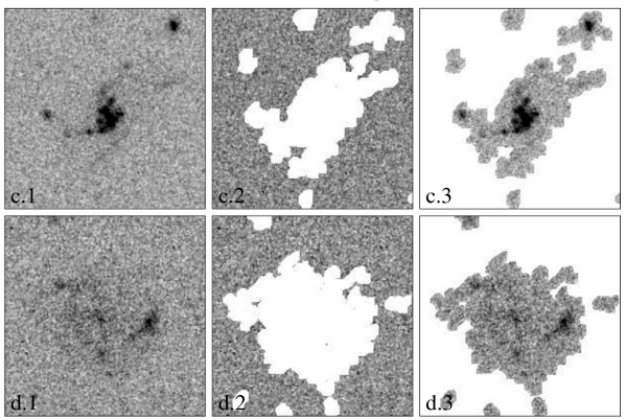
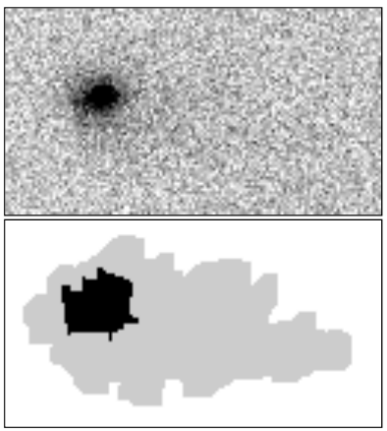


A comet (Hsieh+2013):



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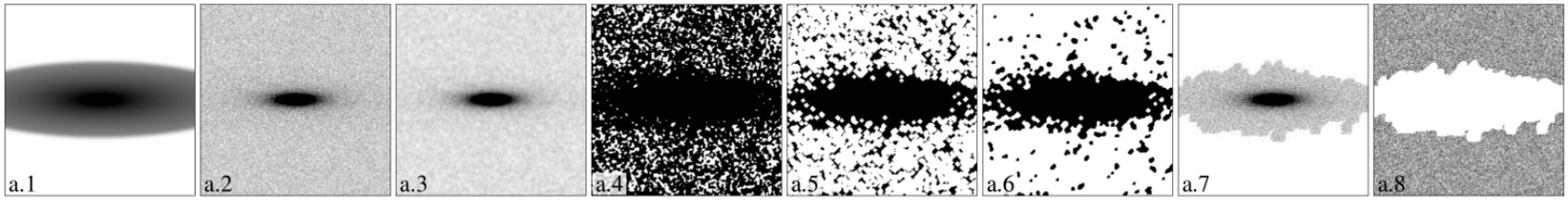

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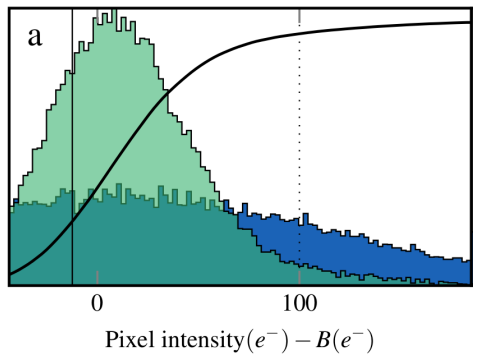

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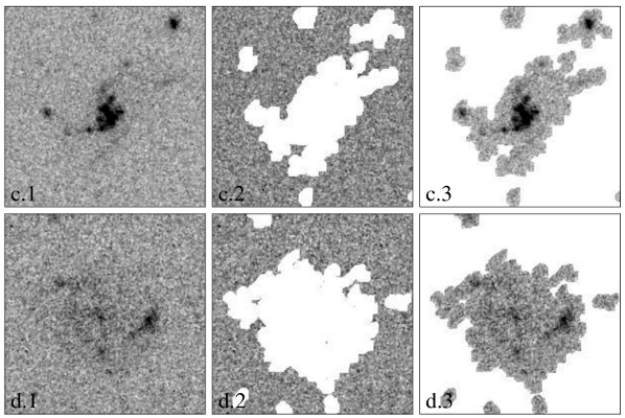

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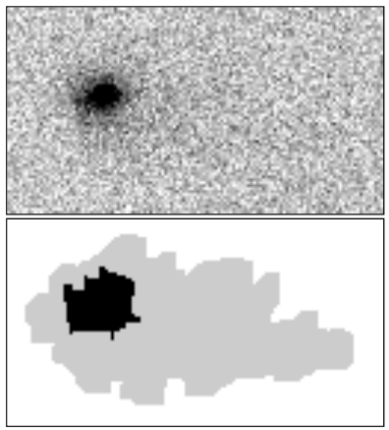
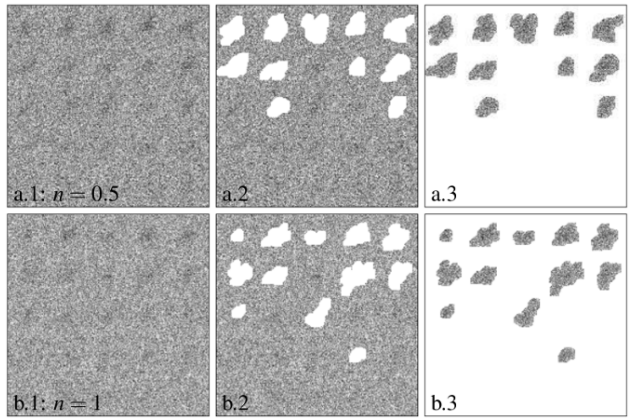
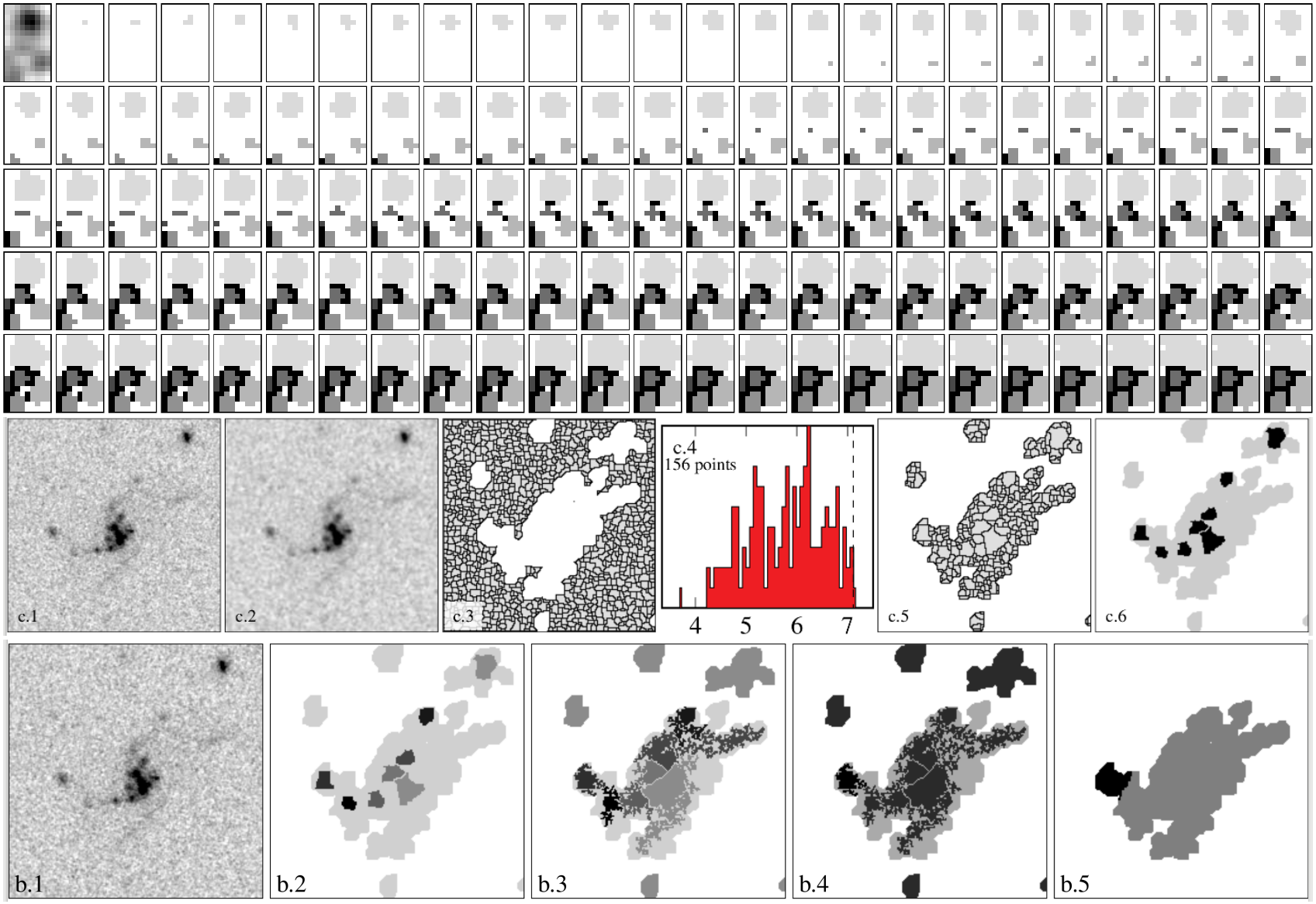


Mock faint/small galaxies

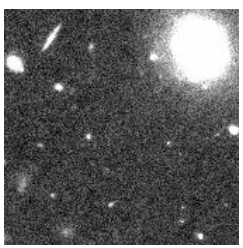


Finding true peaks and segmentation



NoiseChisel and MakeCatalog in GNU Astronomy Utilities (Gnuastro)

In Gnuastro, NoiseChisel is only in charge of the detection (creating a labeled image), and MakeCatalog is in charge of creating a catalog from that input.



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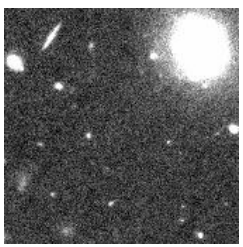

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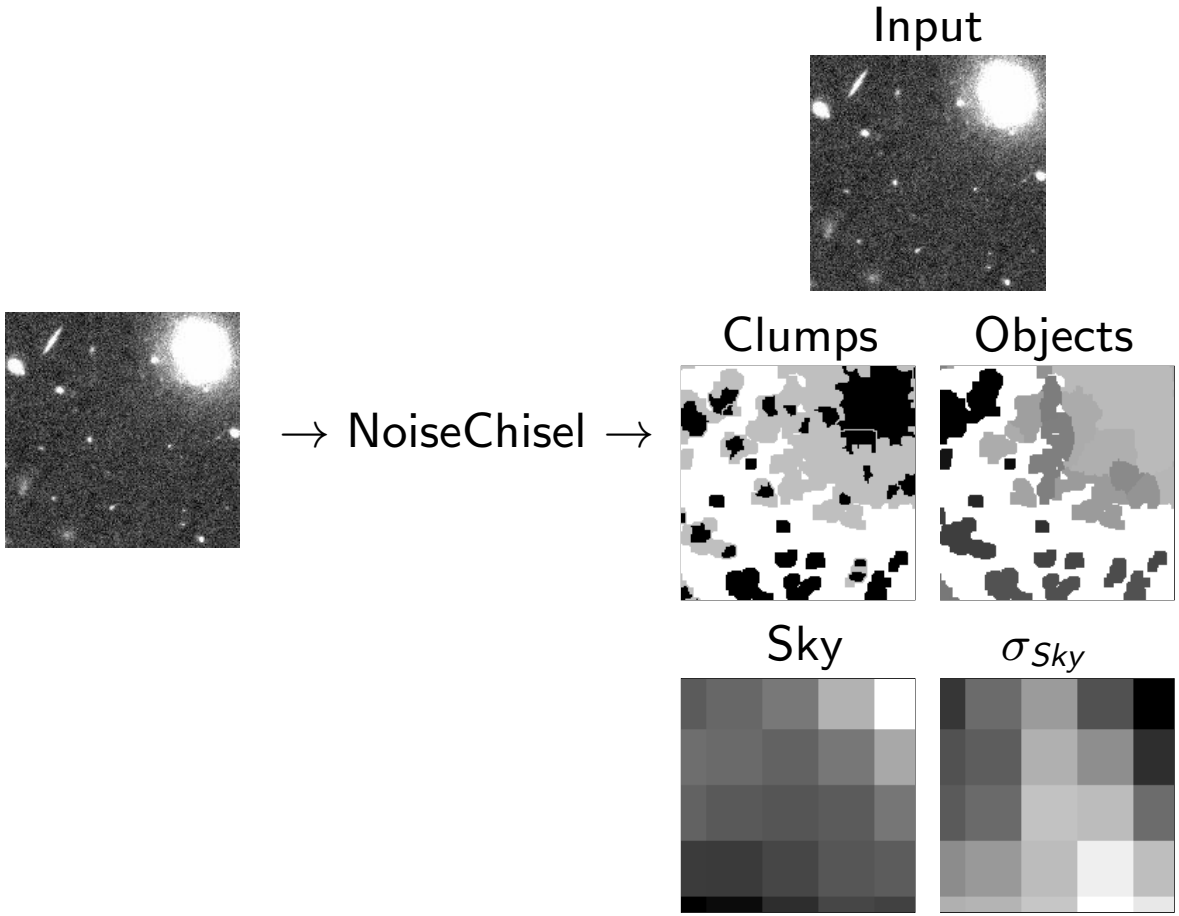

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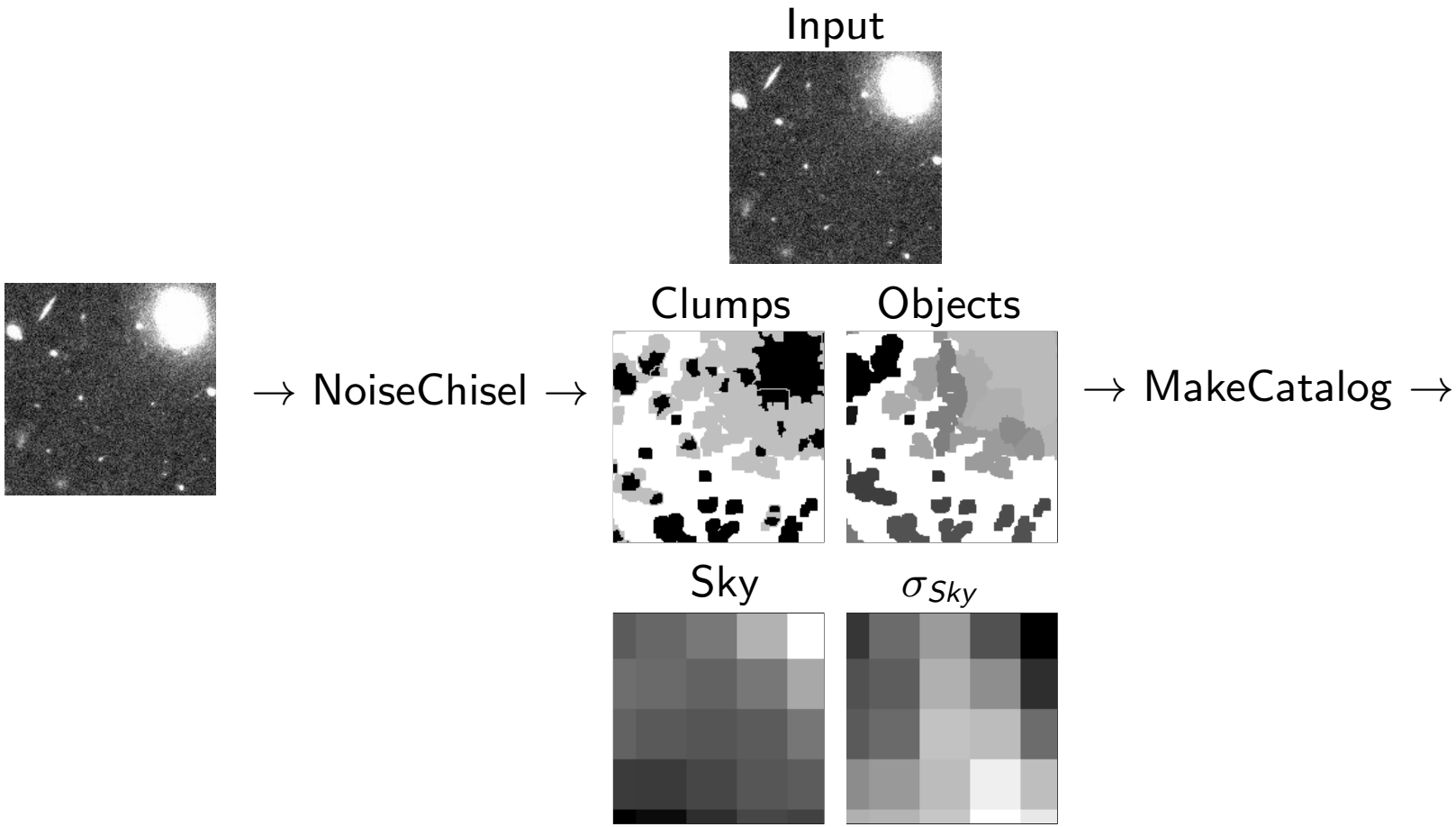

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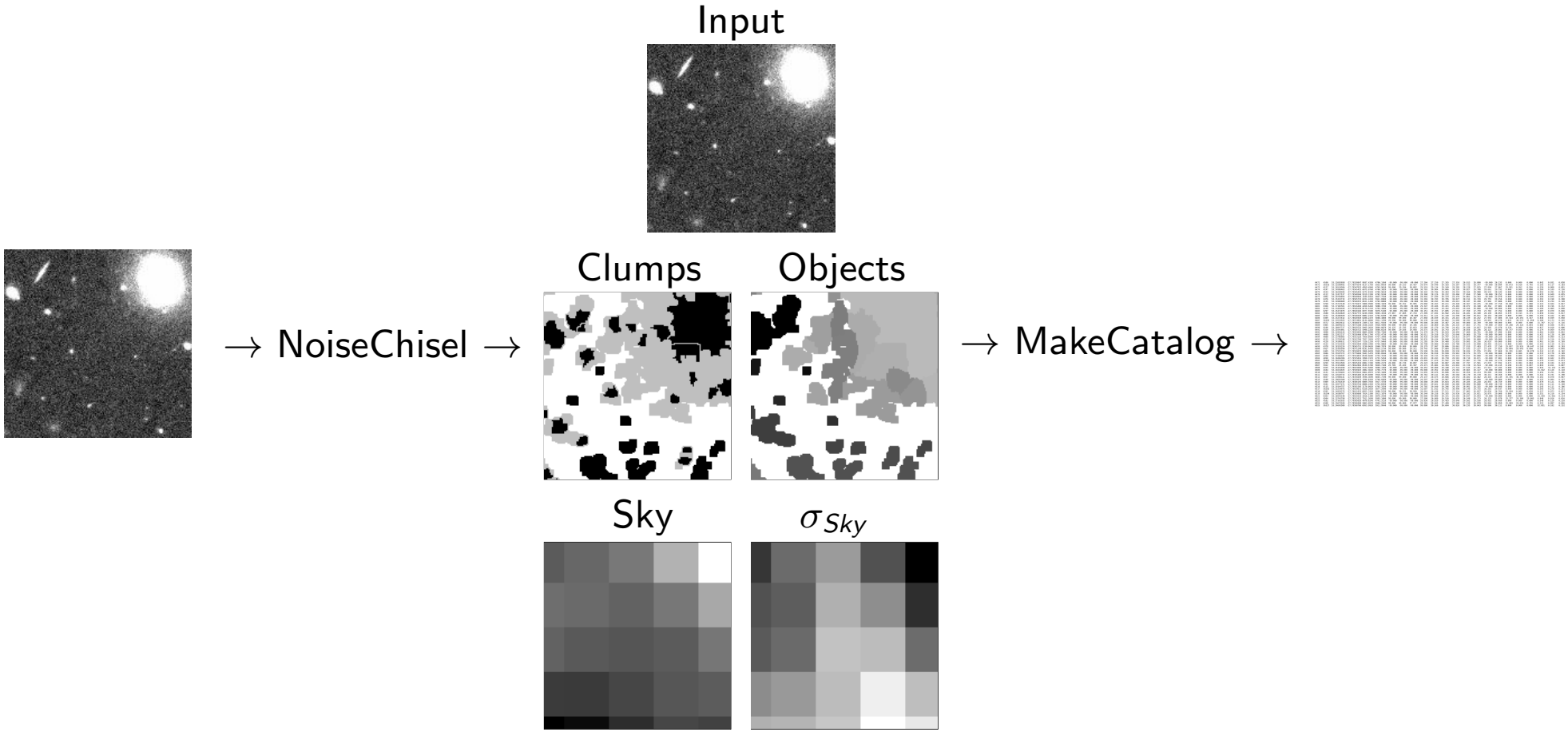

Basic idea:

Each image (input, Clumps, Objects, Sky, and σ_{sky})
is a separate input into MakeCatalog.
(The Clumps are optional)

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The modularity (separating detection from catalog production)
greatly simplifies pipeline development.

And, most importantly ...

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The modularity (separating detection from catalog production)
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And, most importantly ...

empowers the users in using the data-base as they please.

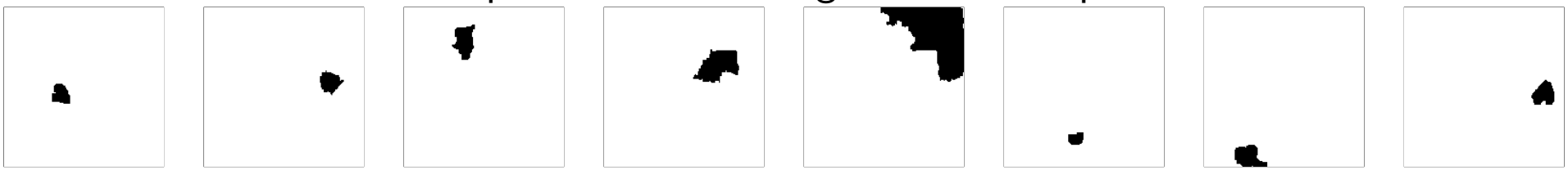
The separate segments can be cropped

Initial objects segmentation map ...

The separate segments can be cropped

Initial objects segmentation map ...

... can be broken up into individual segmentation maps for each label ...



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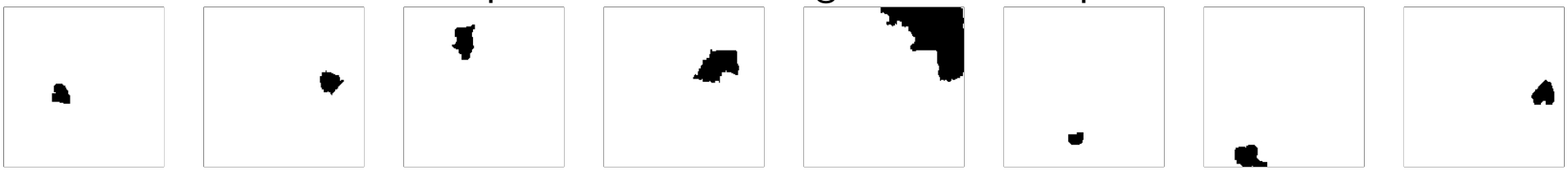

... and extra pixels can be removed.

The separate segments can be cropped

Initial objects segmentation map ...

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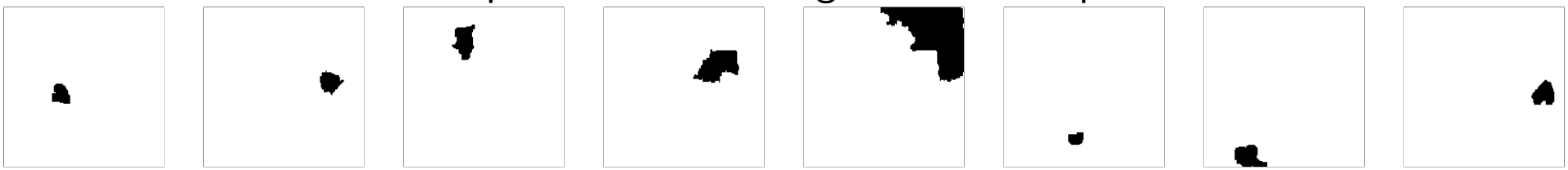
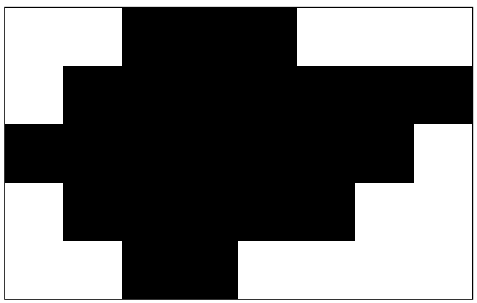


... and extra pixels can be removed.

These are binary images, for example:



$\rightarrow$

$$\begin{matrix} 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \end{matrix}$$

So, only one bit is necessary for each pixel.

Deblending and matching

Deblending (when necessary) can be defined as
1-byte (256 layers) or 2-byte (65536 layers) integers.

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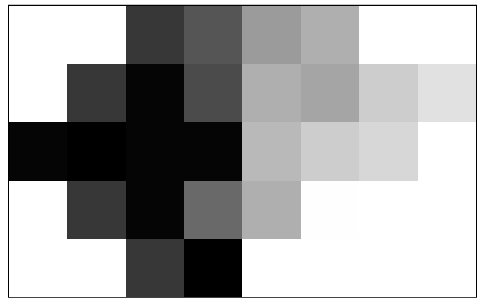
0	0	200	170	100	80	0	0
0	200	250	180	80	90	50	30
250	255	250	250	70	50	40	0
0	200	250	150	80	1	0	0
0	0	200	255	0	0	0	0



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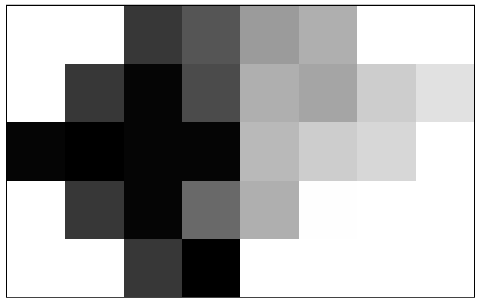
0	0	200	170	100	80	0	0
0	200	250	180	80	90	50	30
250	255	250	250	70	50	40	0
0	200	250	150	80	1	0	0
0	0	200	255	0	0	0	0

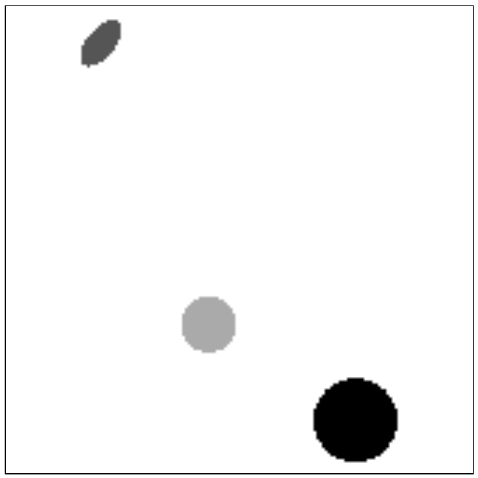


In a similar way, the pixel maps can be warped and/or convolved to match images with other pixel or spatial resolutions (from other surveys).

Aperture photometry

Aperture photometry only needs detection for the Sky and σ_{Sky}.

In Gnuastro, MakeProfiles is in charge of building profiles (apertures in this case) on an image.



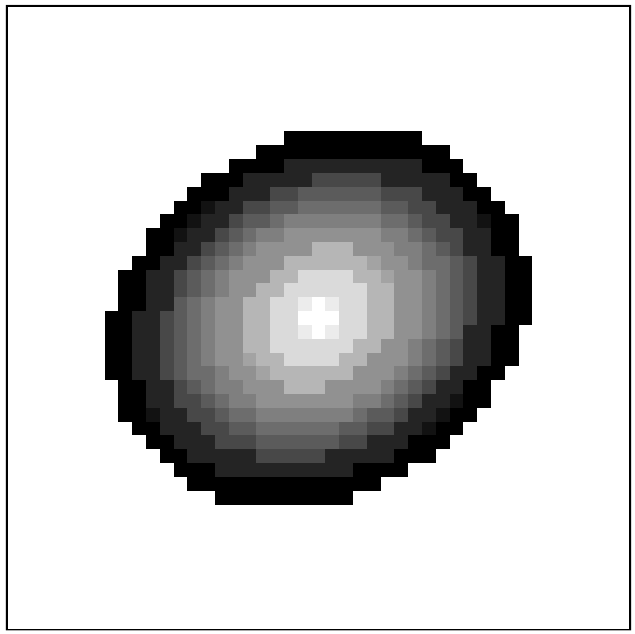
Curve of growth

Curves of growth segmentation maps (elliptical annuli)
can also be created easily with MakeProfiles.

MakeProfiles input (to define each annulus):

```
1  22  22  5  1  0  30  0.8  1  1
2  22  22  5  2  0  30  0.8  2  1
3  22  22  5  3  0  30  0.8  3  1
```

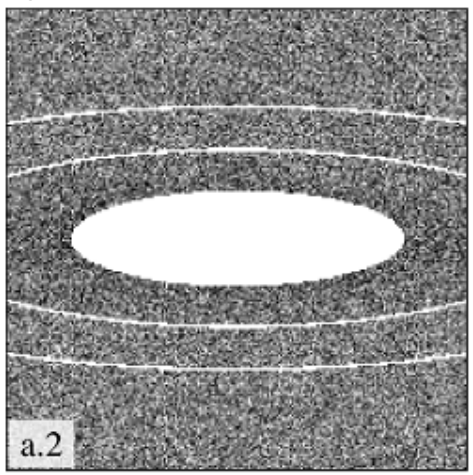
(Columns are: ID, X, Y, function, radius, func. param, PA, axis ratio, value, truncation)



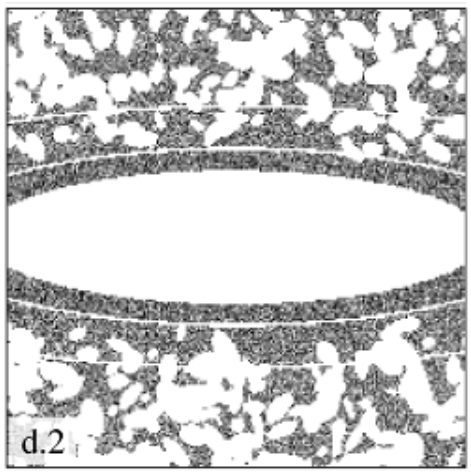
High completeness catalog in multi-band data

Completeness and purity (no contamination) are anti-correlated. For the image below, assume this is a real image with faint galaxies in the background.

Threshold: 2σ
High purity (no false detections)
Low completeness (faint objects lost)
Sky value over-estimated



Threshold: 0.1σ
Low purity (many false detections)
High completeness (faint objects detected)
Sky value under-estimated



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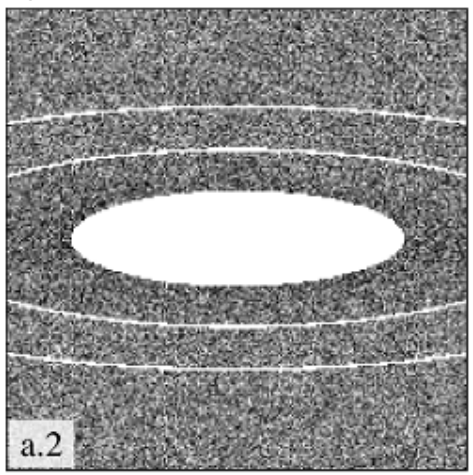

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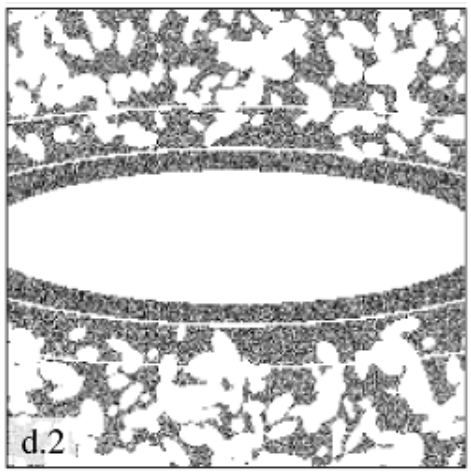
Sky value under-estimated



When the science needs multiple detections (like dropouts with detections in redder filters), the low purity will be corrected and we end up with a high completeness by taking this strategy:

Reasonable completeness and purity:
Sky and σ_{sky}.

High completeness:
Segmentation map(s).

Even more:

Custom columns:

- Each pixel only has position (x and y) and value (v).
- So new columns can be defined at runtime.
- Or MakeCatalog can link with dynamically loaded libraries (plugins) to define more columns by the users.

Over-lays

- The segmentation maps can be uploaded to online viewers like Visi*O*matic (Poster P8.4, Bertin et al.) for users to visually check their objects online.

Different methods to use clumps and objects

- NoiseChisel's segmentation is just one approach to using clumps. Other science cases can use them differently for other purposes.

It is not unique to Gnuastro

- This separation can greatly simplify any calculation, not just users of Gnuastro/MakeCatalog.

NEWS: GNU Astronomy Utilities (Gnuastro) 0.2 released

- Conforms with GNU Coding Standards.
- Now installs shared libraries (for C and C++).
  - Emphasis was mainly on robust build and documentation.
  - Most interesting functions are still locked within programs and will be liberated soon.
  - The quantity and quality of libraires will greatly improve with future releases.
  - Libraries will soon be changed to LGPL.
- Comes with 14 programs: Arithmetic, ConvertType, Convolve, CosmicCalculator, Header, ImageCrop, ImageStatistics, ImageWarp, MakeCatalog, MakeNoise, MakeProfiles, NoiseChisel, SubtractSky, Table.
- Complete documentation in various web, print and command-line formats.

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

Please come help us make it better for everyone.