Project Plans for Deblending

Fred Moolekamp

The Problem

Space is big… but it's filled with stuff

from HSC COSMOS
courtesy Nate Lust

“Deblending” Crowded Stellar Fields

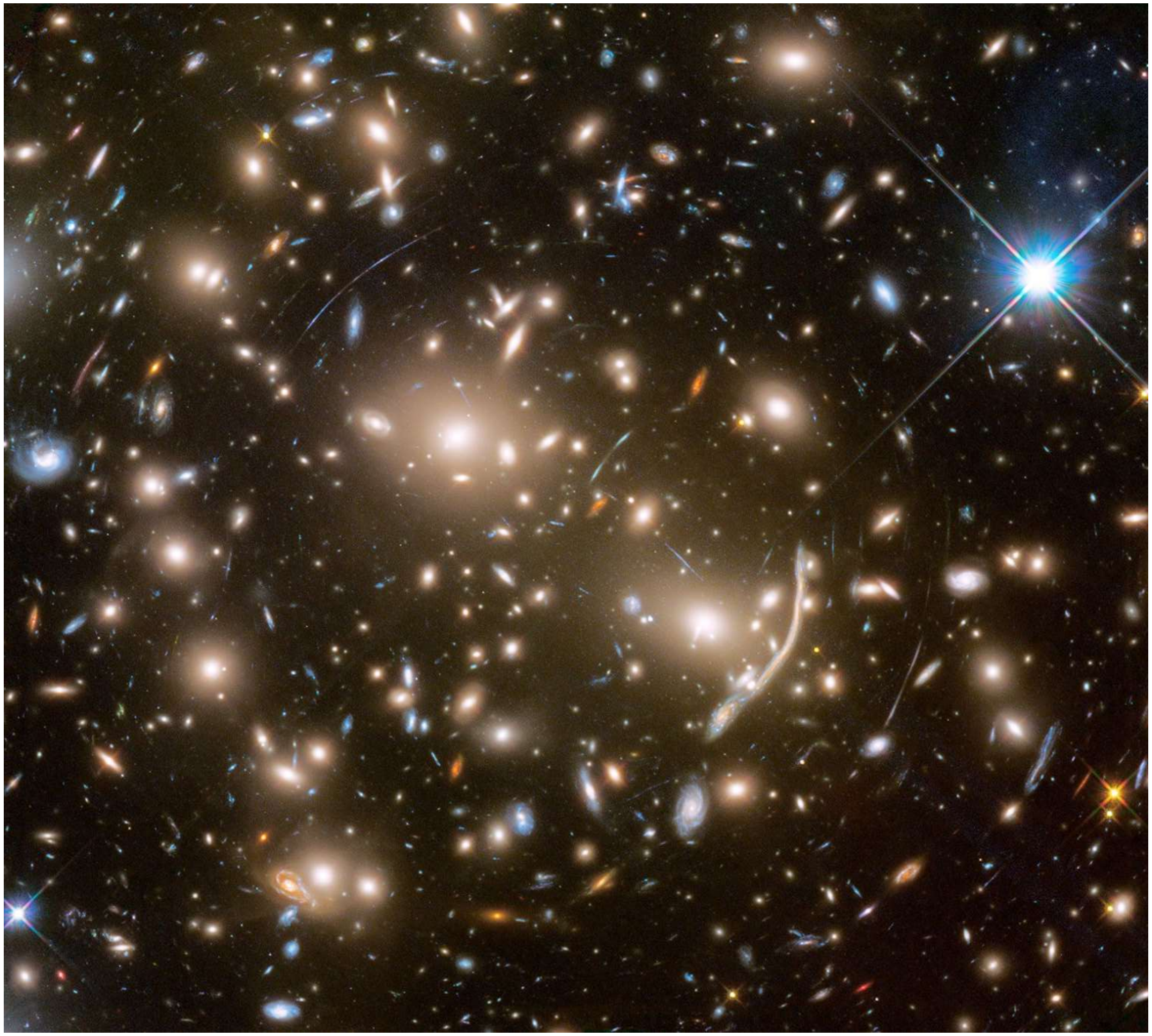
M22
Image credit:
Giuseppe Donatiello

“Deblending” Crowded Stellar fields

- (mostly) a solved problem (see Colin’s talk on Thursday!)
  - Stars are point-like (so we can model them)
- Iterative solution:
  1. Model a subsampled PSF (can be tricky)
  2. Model each source as a multiple of the PSF, with varying amplitude and position
  3. Subtract off the sources that have been modeled
  4. Detect new sources in the residuals (tougher than it sounds)
  5. Repeat steps 2-4 until no new sources are detected and the residual of the image is mostly noise

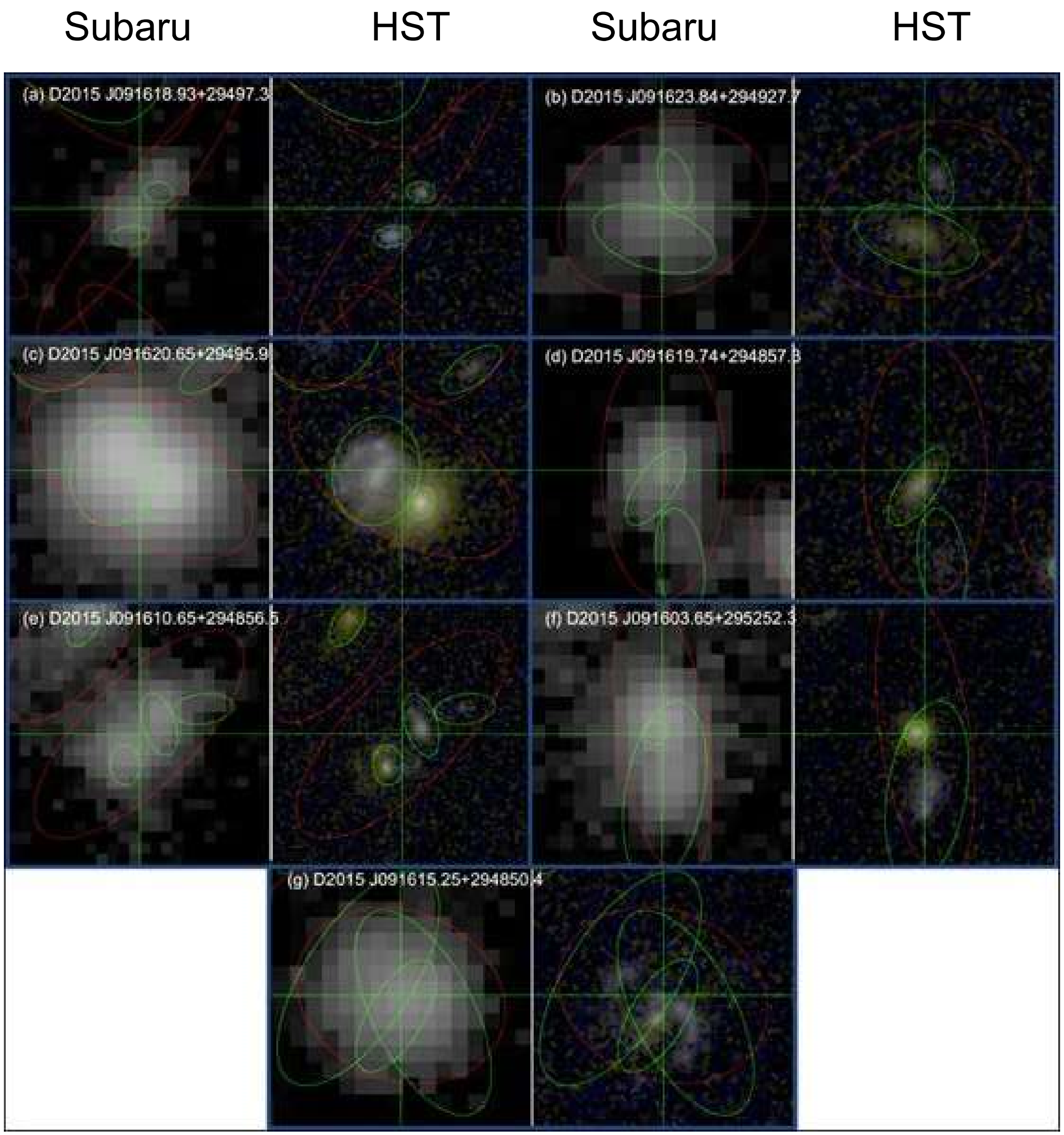
Things that make deblending galaxies impossible

Galaxies vary in morphology with no sharp edges



Abell 370 from HST: courtesy NASA and STScI

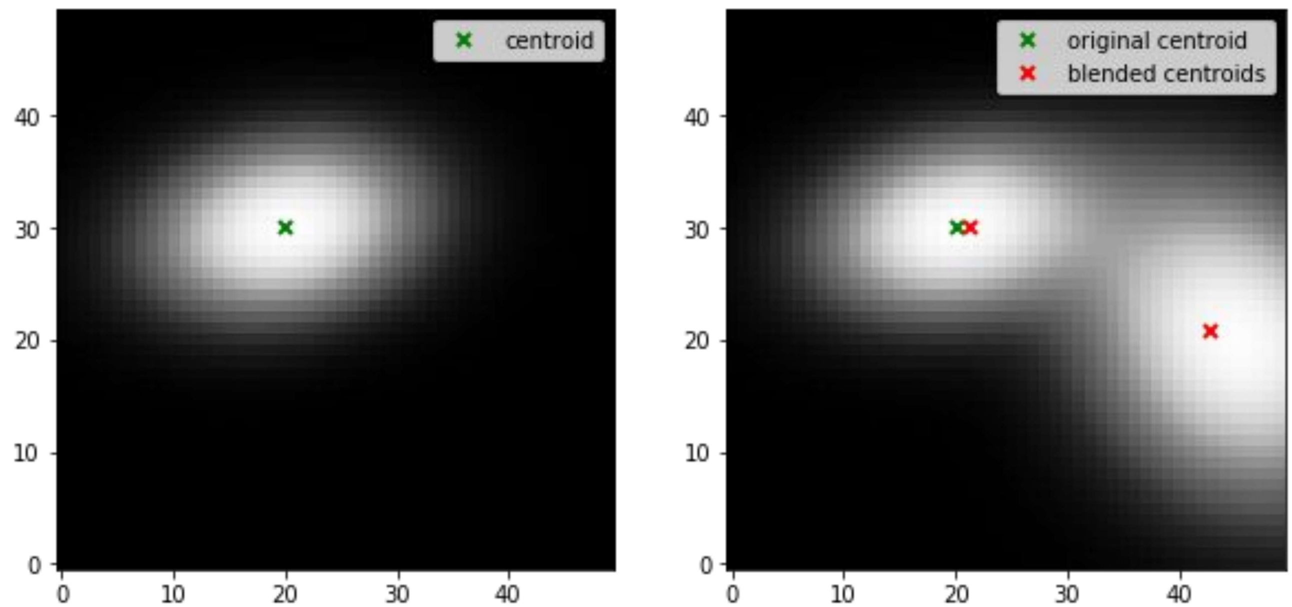
Ground-based PSF makes blending worse



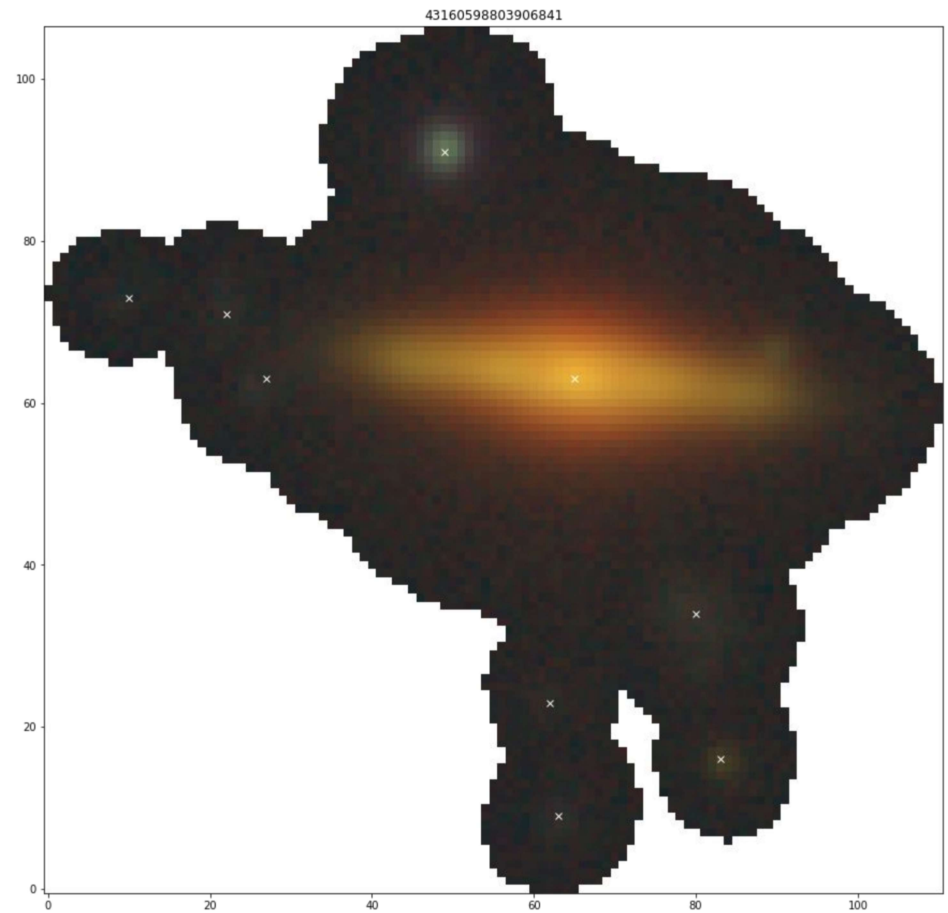
[Dawson et al. 2016]

Instrumental and Astrophysical Backgrounds Exist

Center of flux is shifted due to neighbors



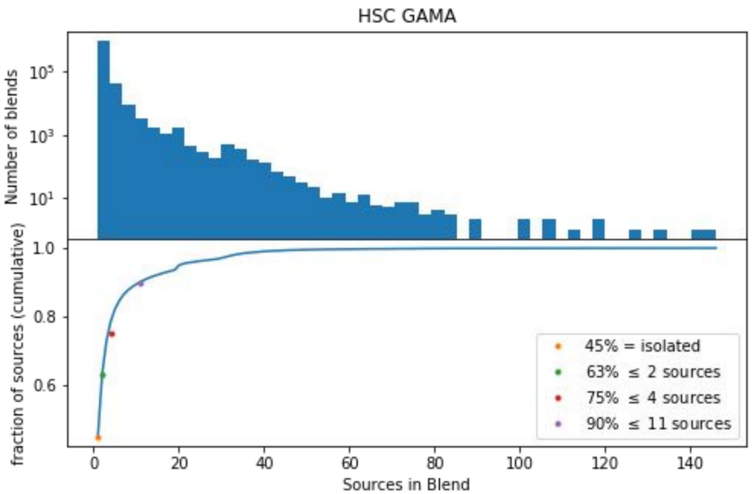
Galaxies can have optically thick regions

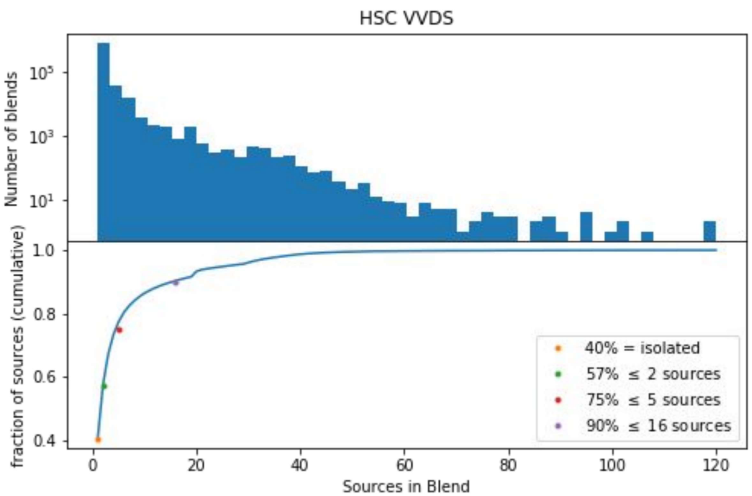


from HSC COSMOS

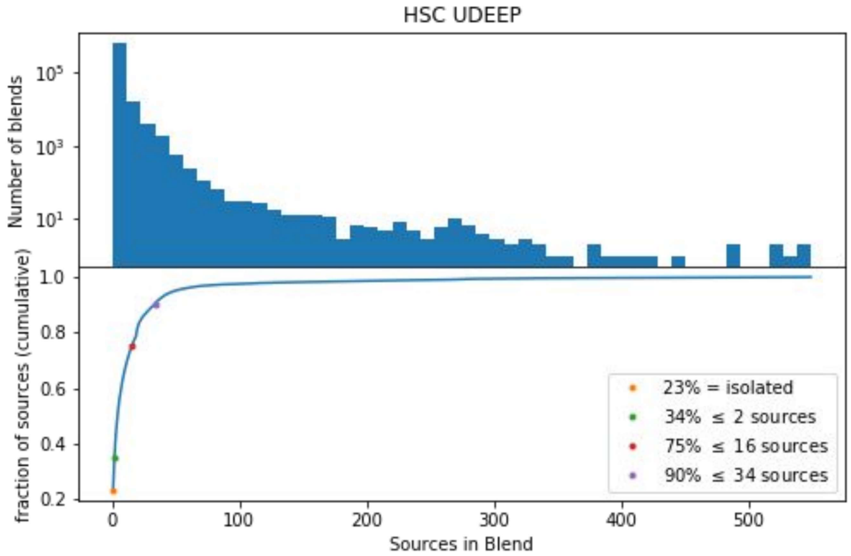
How bad is the problem?

WIDE





DEEP



What deblending is (and isn't)

Is

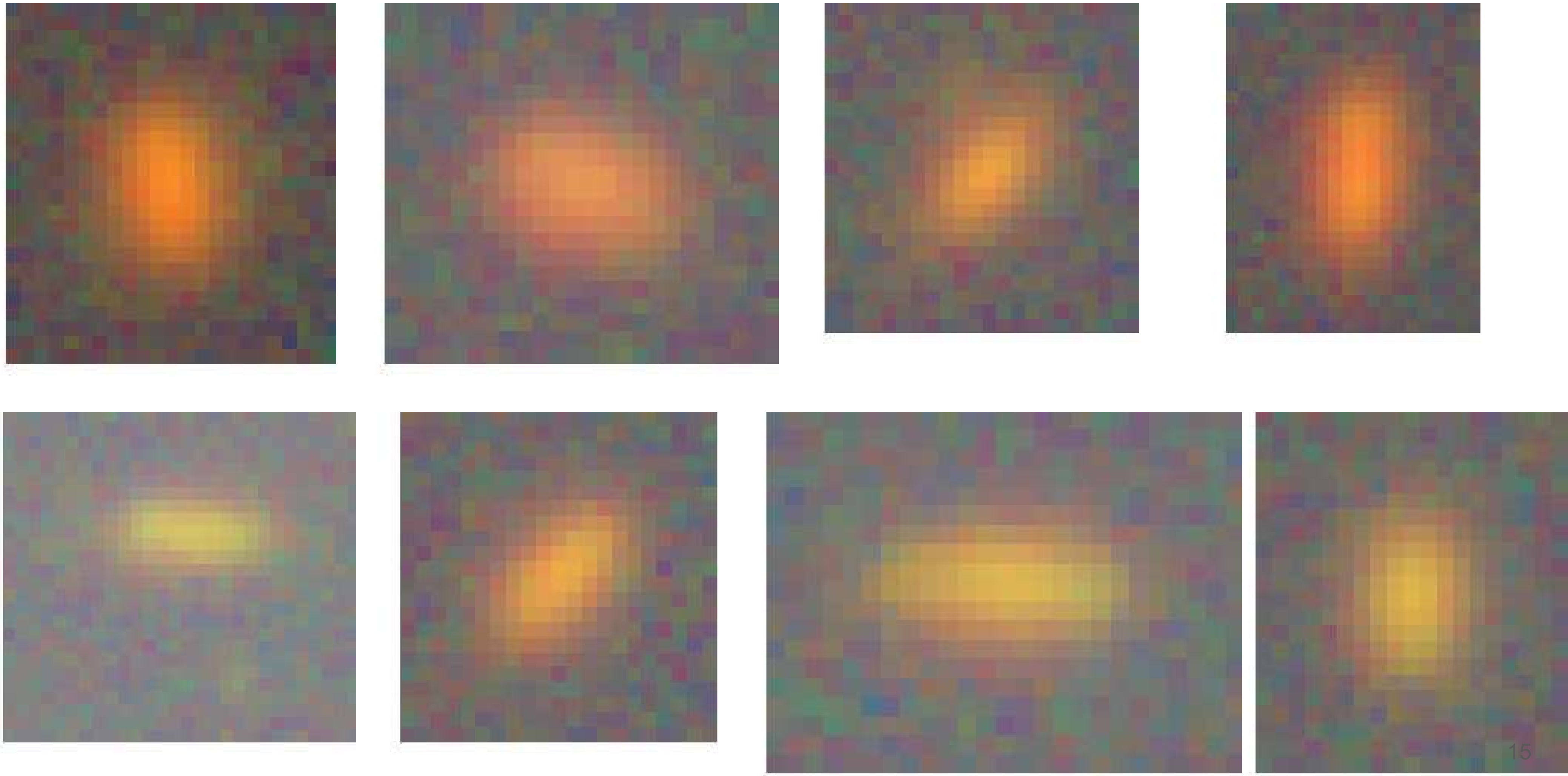
- An algorithm way to separate flux in pixels with flux from multiple sources
- Dependent on what we want to optimize
    - Photometric measurements for the *majority* of simple blends (< 5 sources lightly blended)
    - Reducing the number of outliers (at the cost of slightly degrading the majority)
    - Something else?
- Application of minimal assumptions on galaxy compositions to avoid biases

Is not

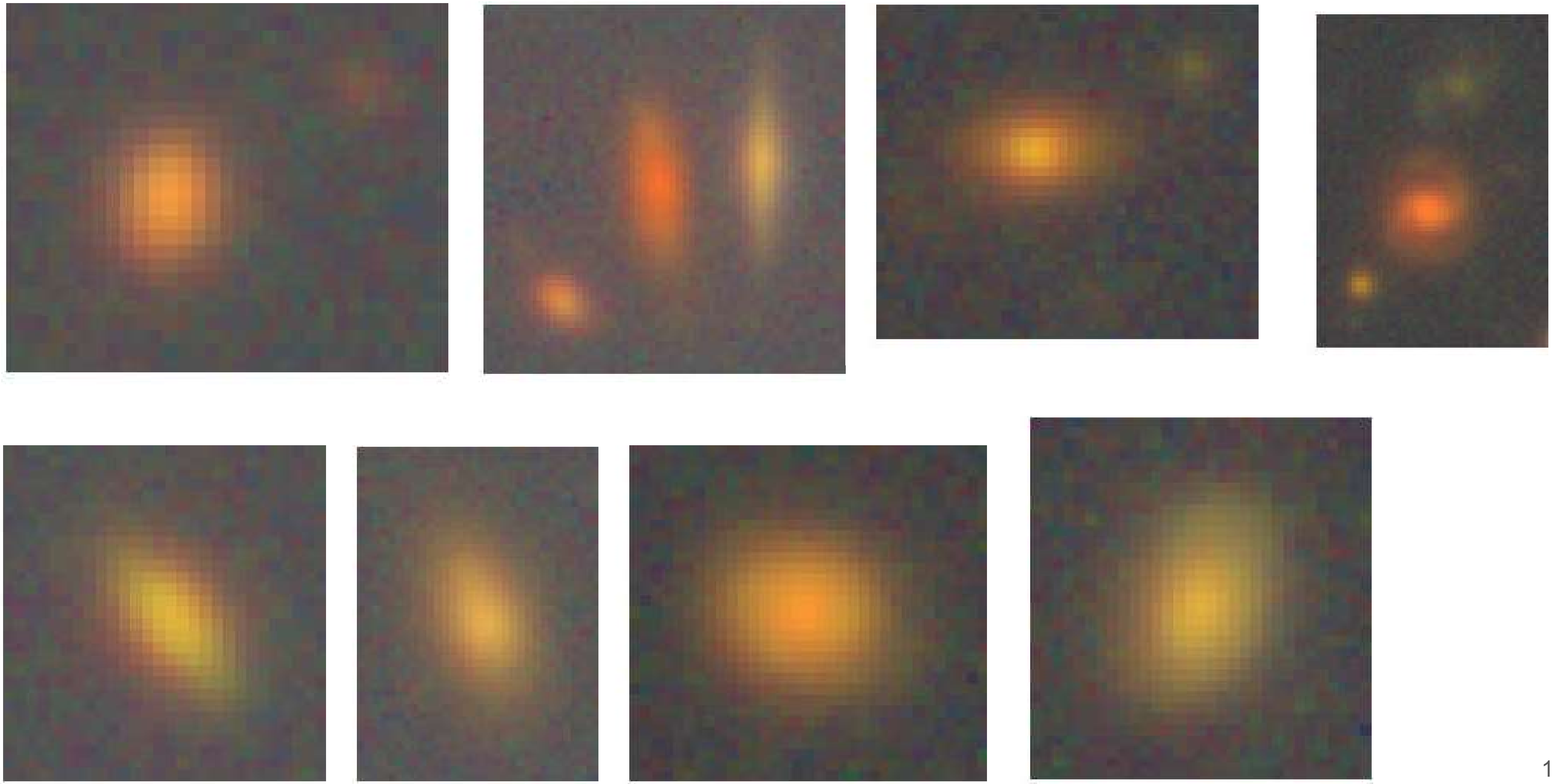
- A unique solution
- Expected to perfectly recover the flux of blended galaxies

Deblending in the Current Stack: meas_deblender (a cousin of the SDSS deblender)

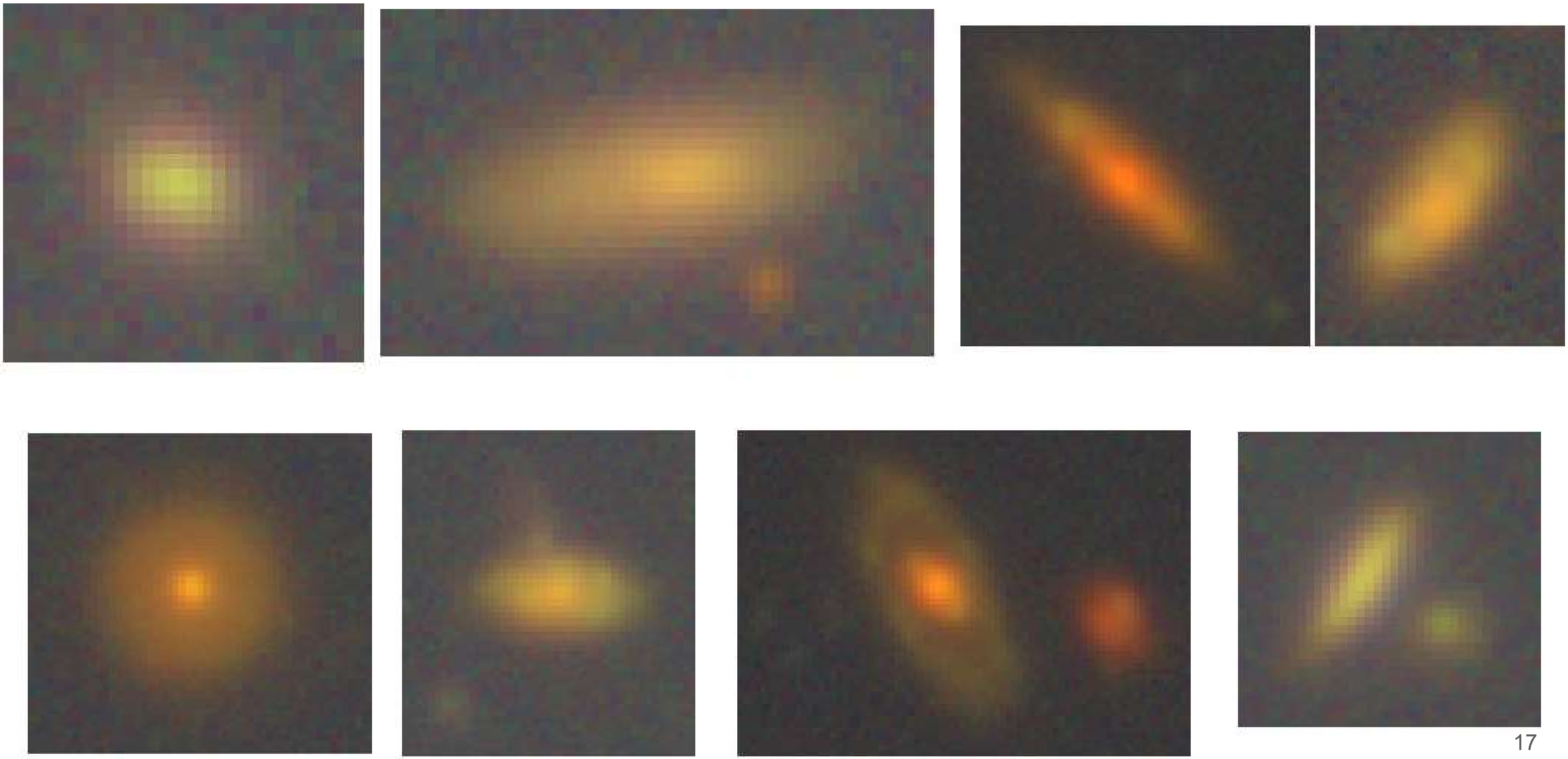
Sample of Galaxies from a single HSC field



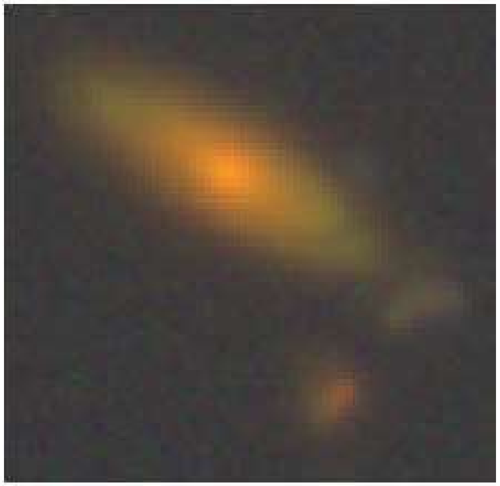
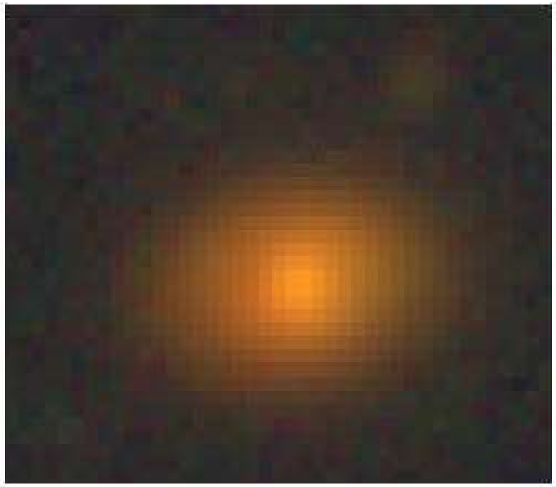
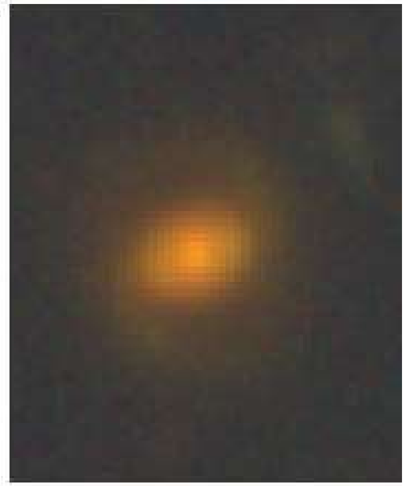
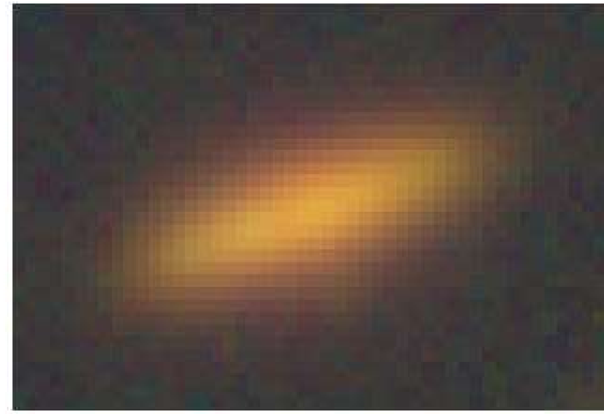
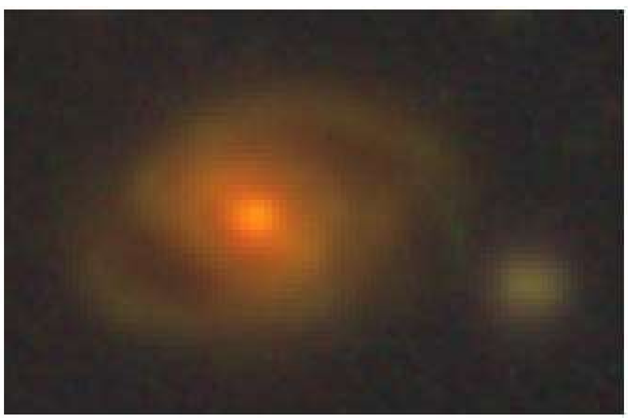
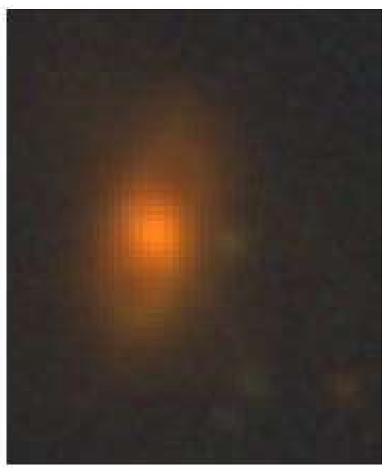
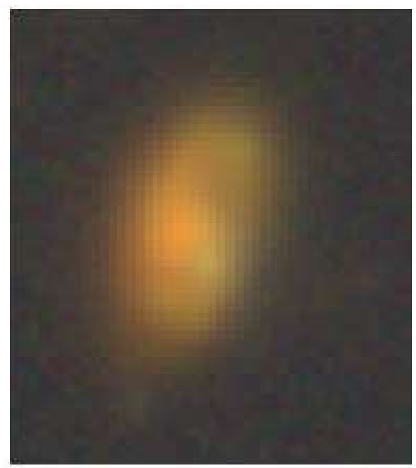
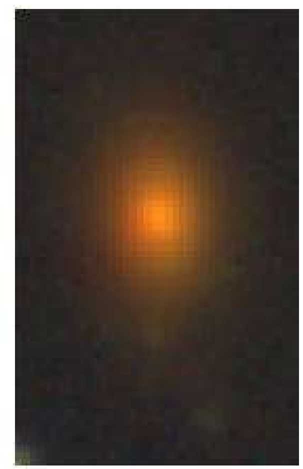
Sample of Galaxies from a single HSC field



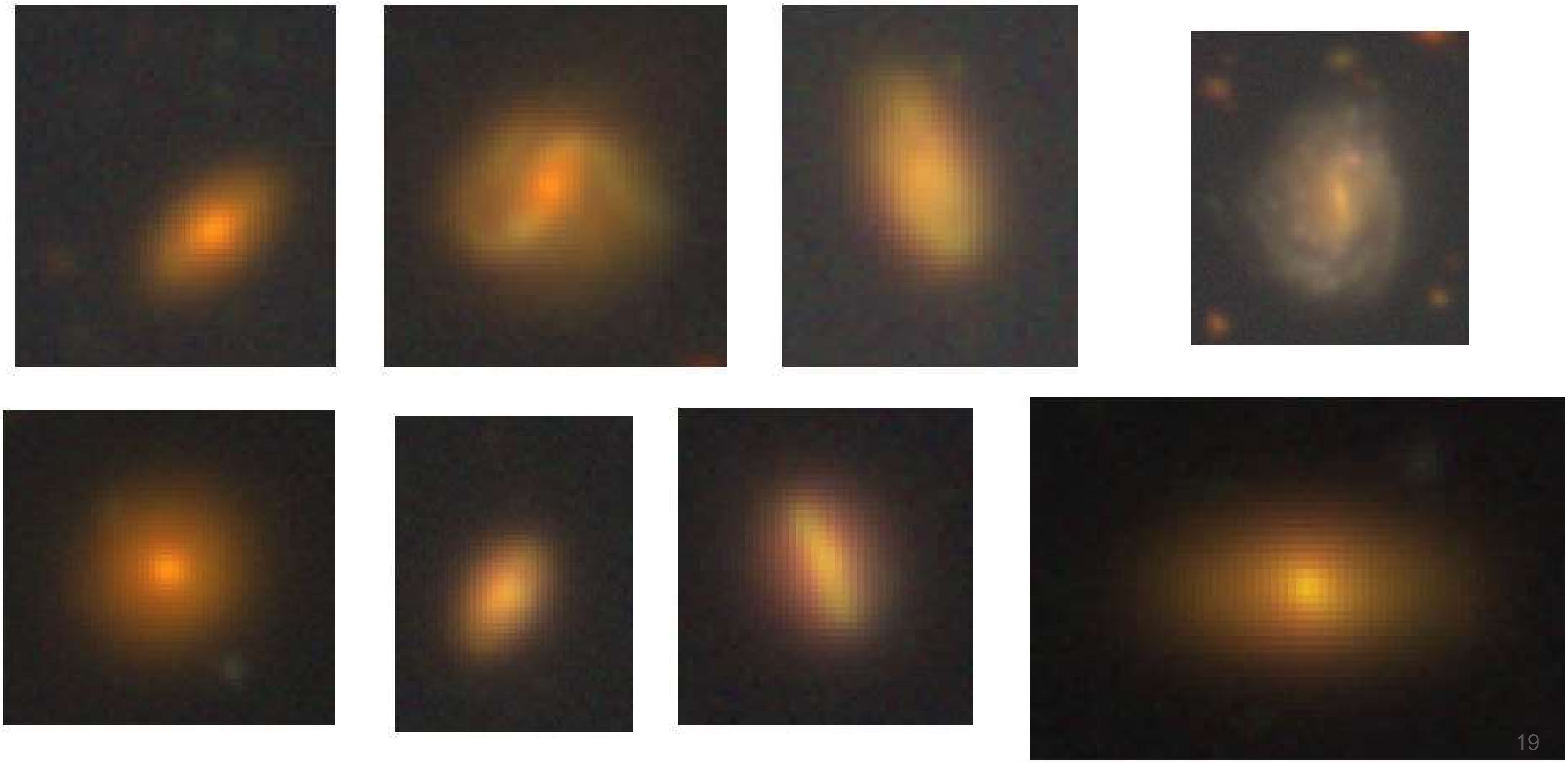
Sample of Galaxies from a single HSC field



Sample of Galaxies from a single HSC field

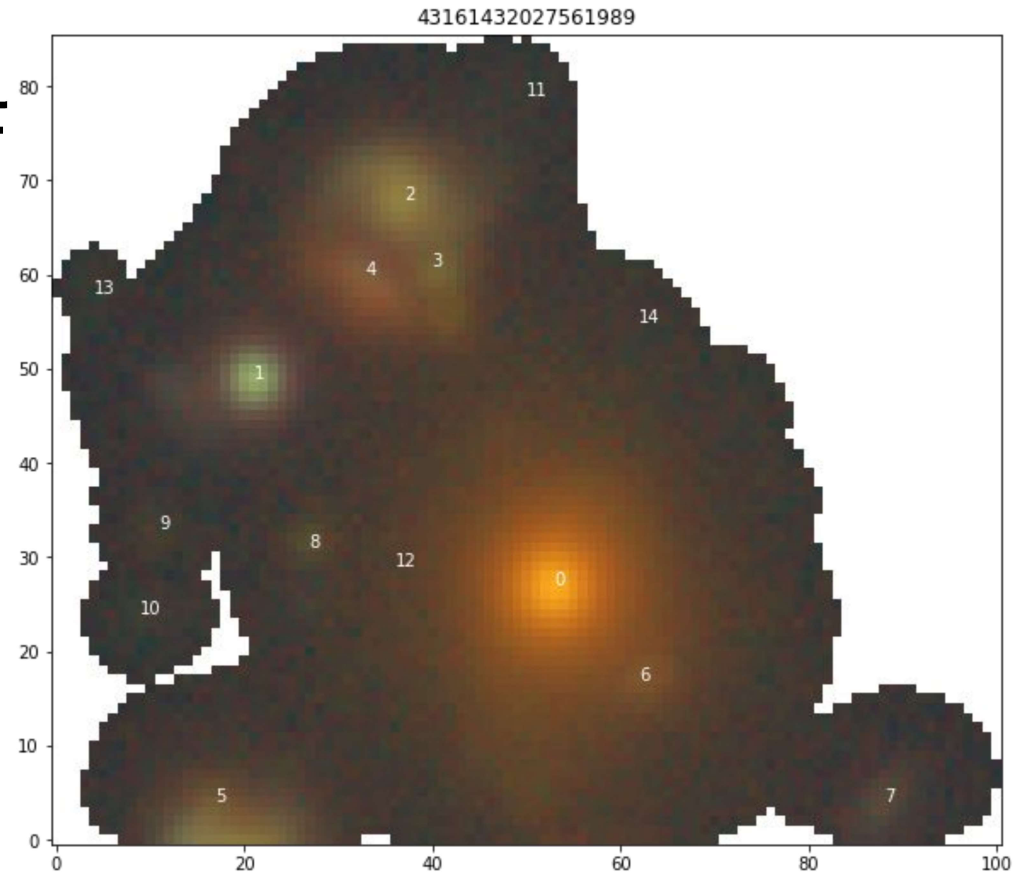









Sample of Galaxies from a single HSC field



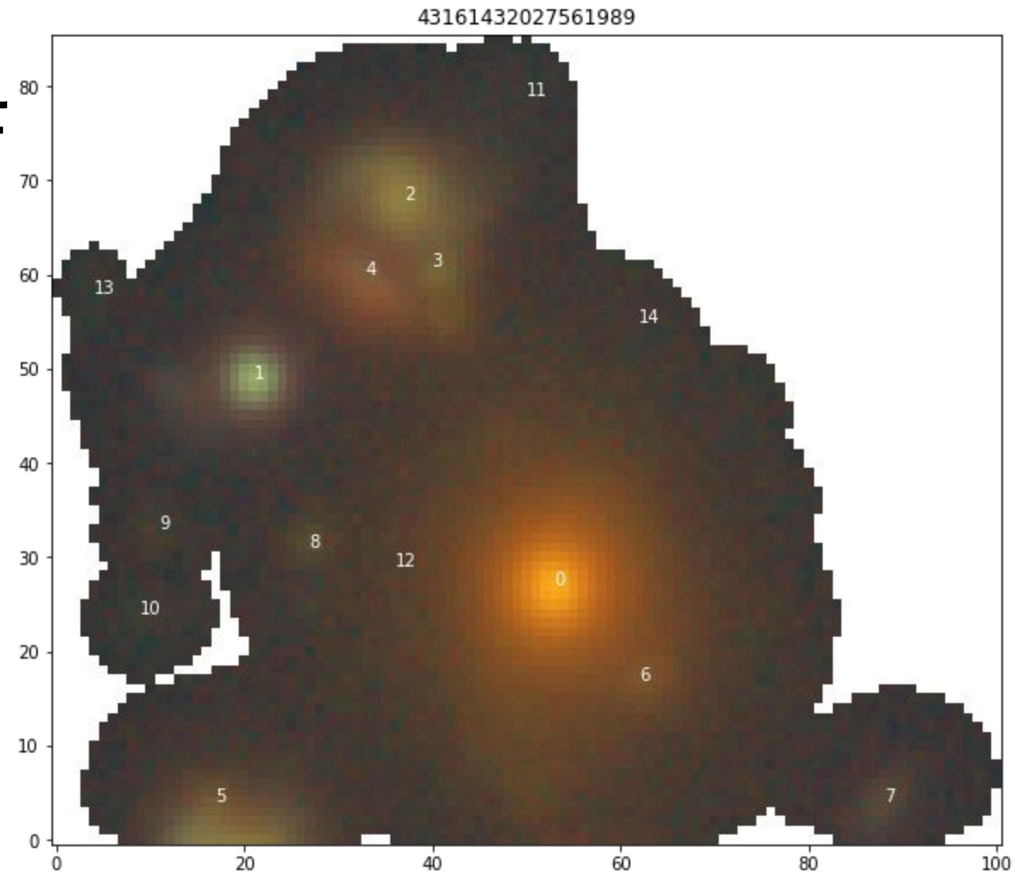
1. Fit each peak to the PSF

- Takes advantage of the ease of modeling point sources
- Fit the amplitude and center of all peaks along with a linear sky model (in a box the size of the PSF, ~41x41, around each source)
- If χ^2 <1.5 per DOF (with or without recentering)
  - Source = point source
  - Skip to step 6: Apportion Flux for all point sources



1. Fit each peak to the PSF

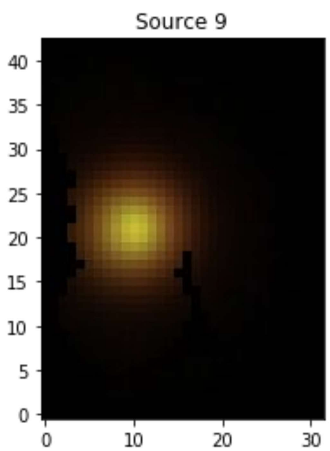
Filter	PSF matches
g	6,8,9,10,11,12
r	9,10,11,12,13,14
i	9,11,13,14
z	9,11,13,14
Y	6,8,9,10,11

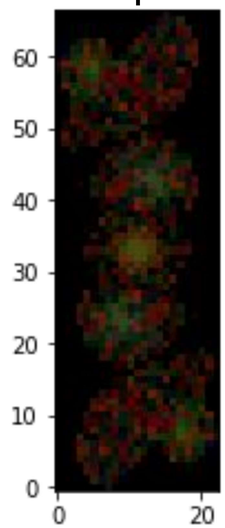


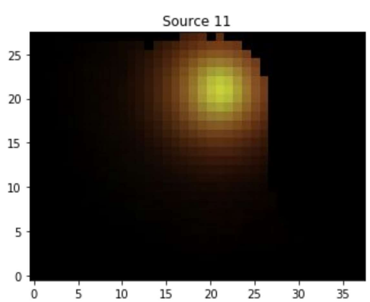
1. Fit each peak to the PSF

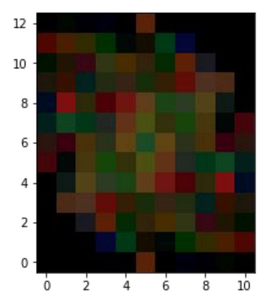
PSF
model

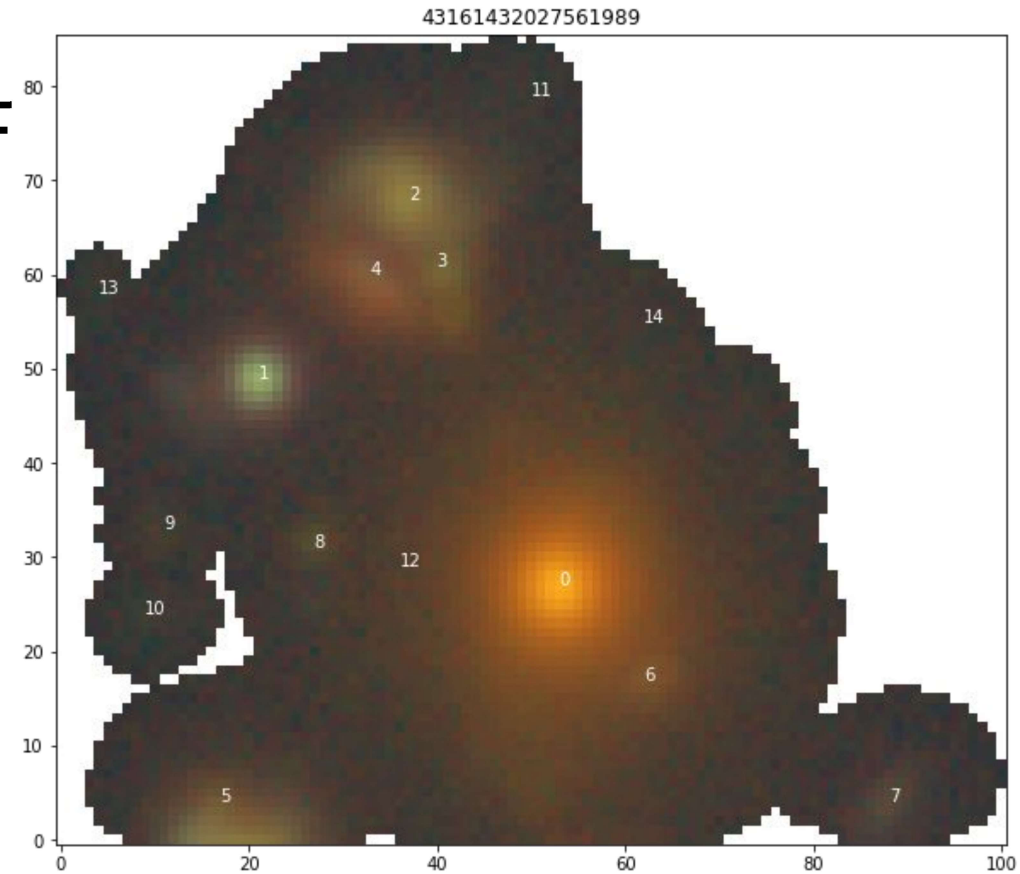
template





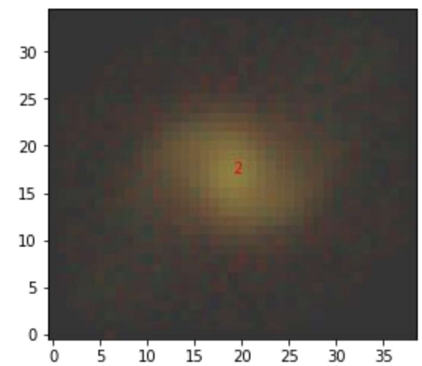


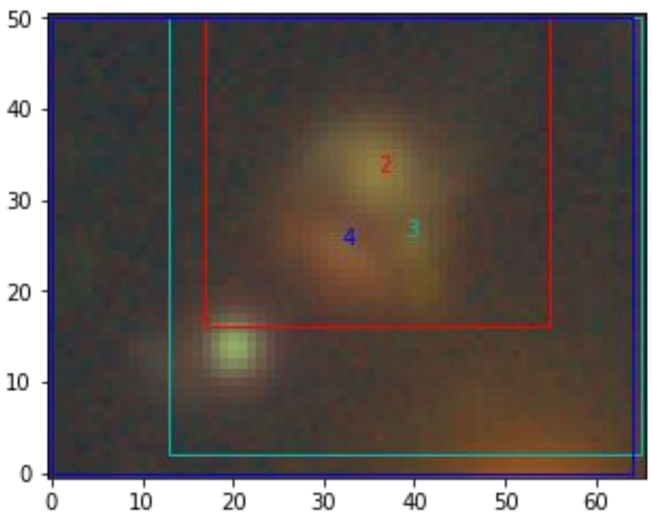


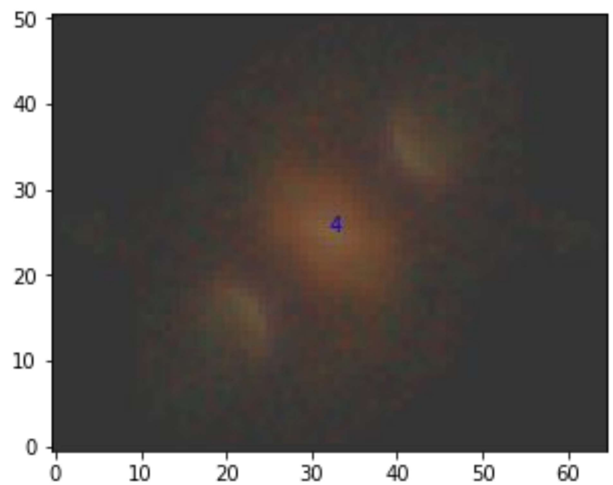


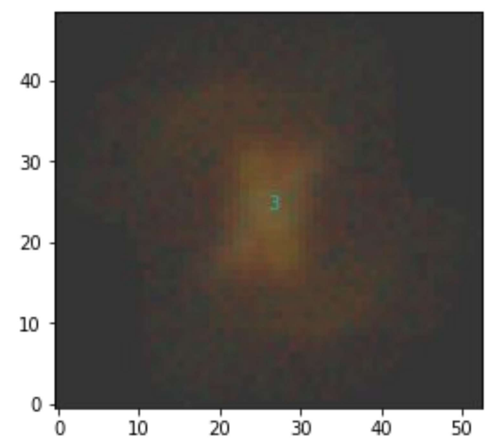
2. Build a symmetric template for remaining sources

- Templates use 2 fold rotational symmetry
  - Use the minimum value for each pixel and its symmetric partner



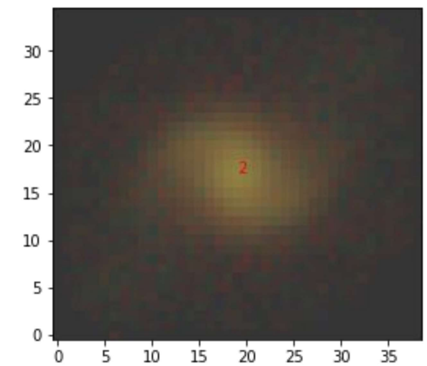




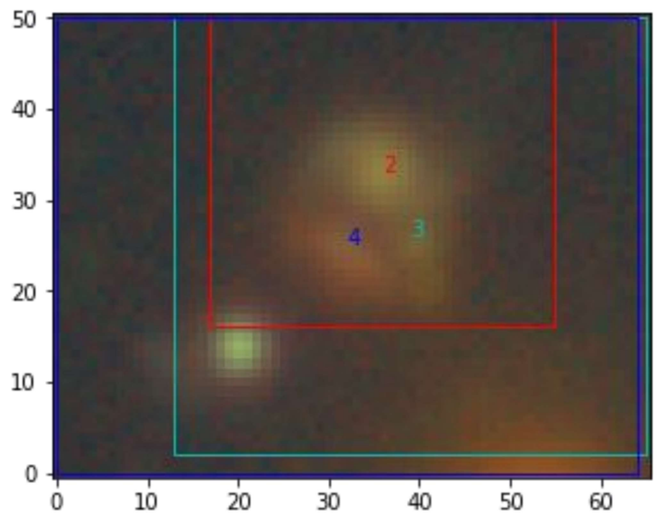


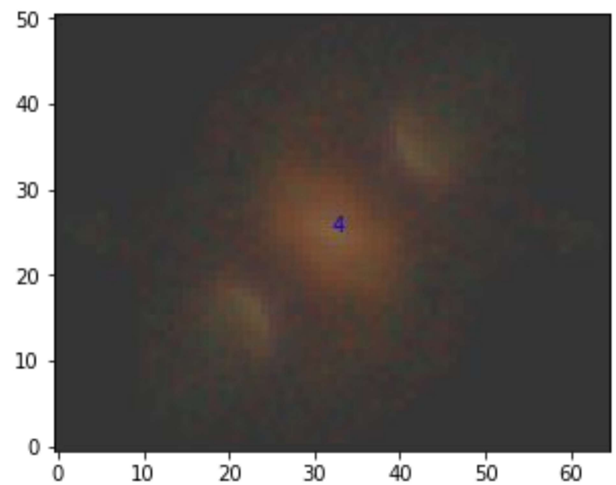
3. Ramp flux at footprint edges

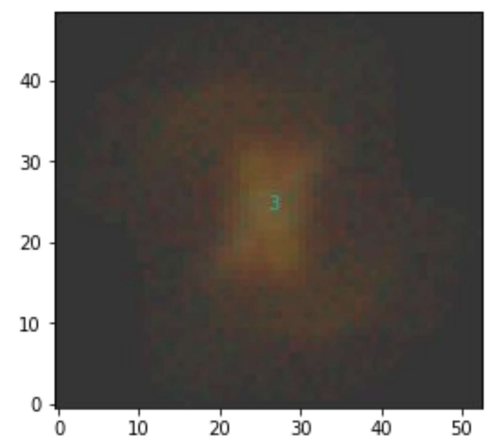
- Footprints within 1.5 * PSF FWHM of an edge are grown
- Flux is ramped to zero at the edge using the PSF model
- Template is made symmetric



(no changes in this blend)

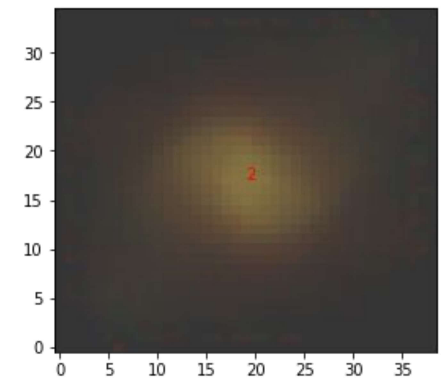


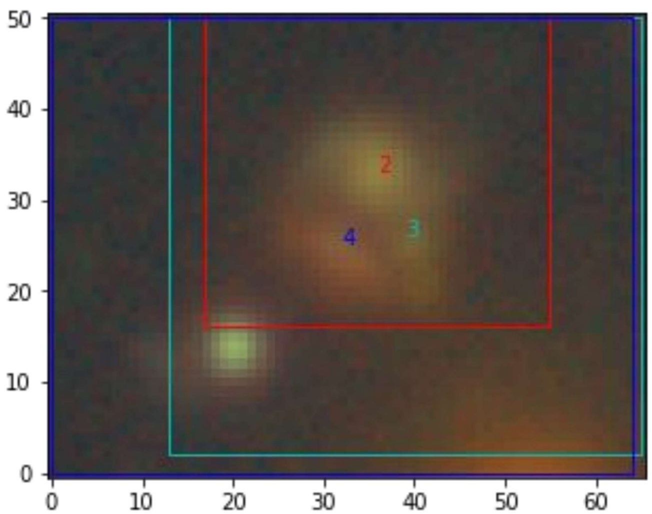


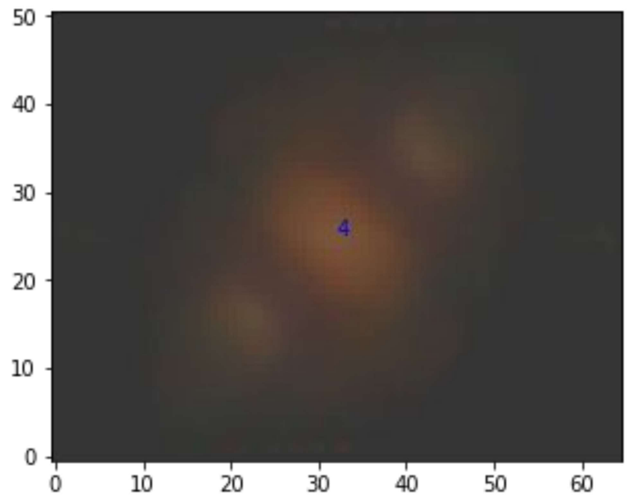


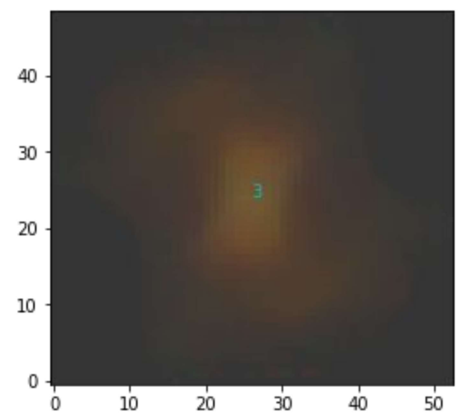
Median Smoothing

- Each pixel is updated with median of 5x5 box centered on itself
- Edges are not smoothed
- Not used in SDSS deblender

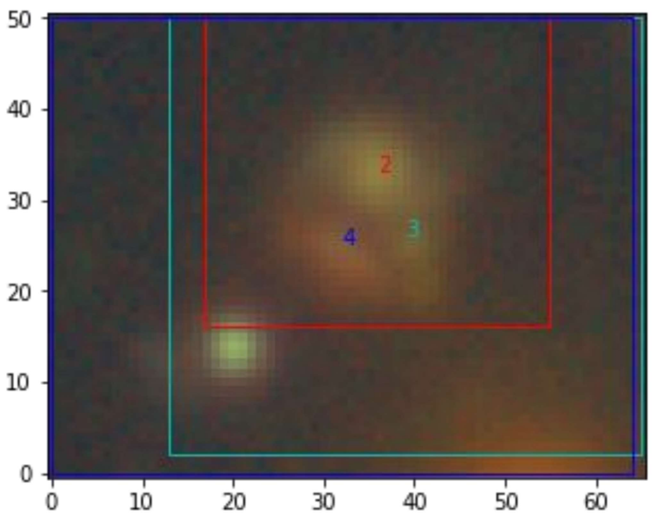


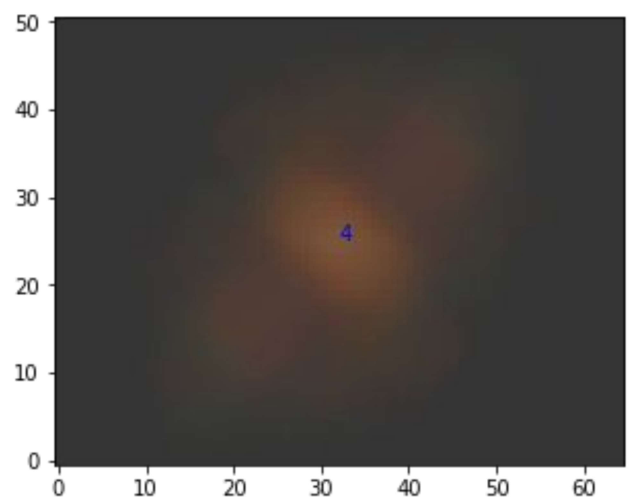


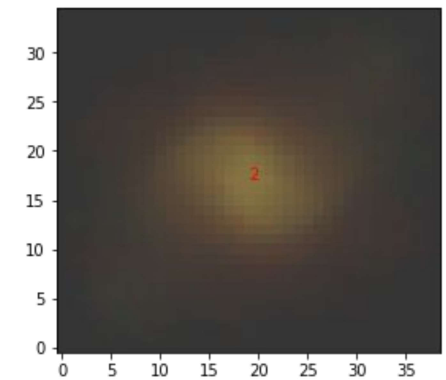


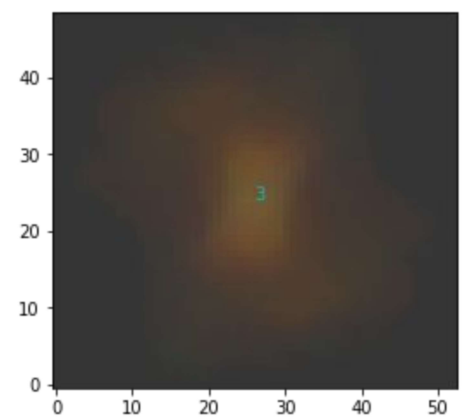


Make flux monotonically decrease from peak





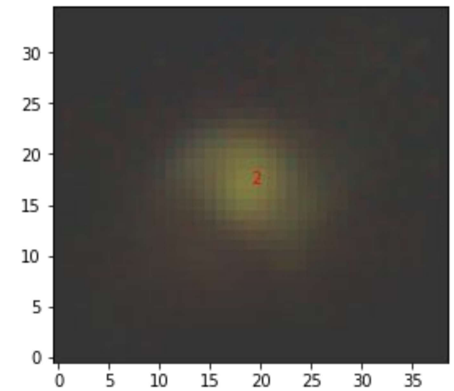


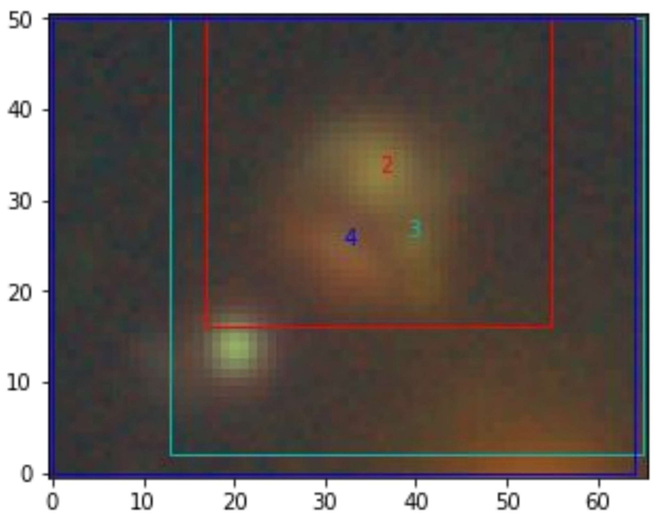


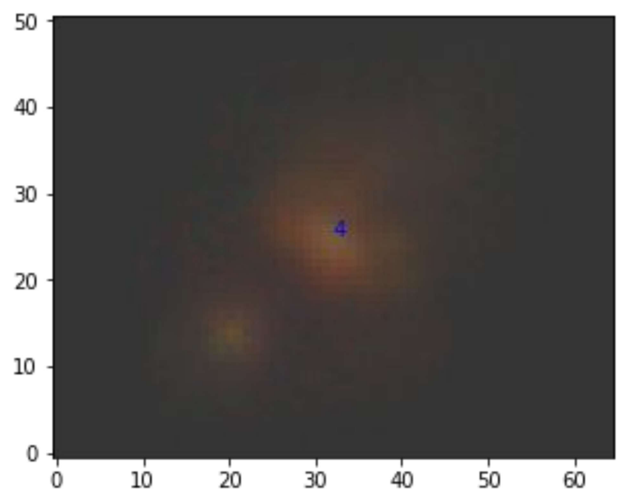
* different than SDSS deblender

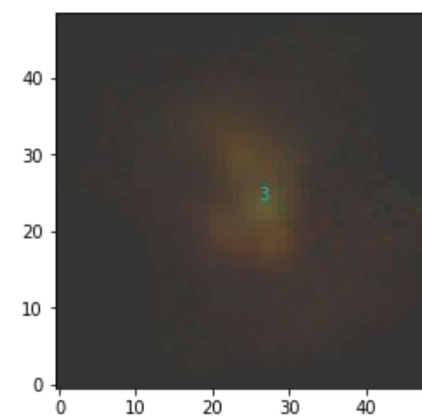
6. Apportion Flux

- Divide image flux to sources based on PSF model (step 1) or templates (steps 2-5)
- Stray flux is not included in any sources (but can be if the config is changed)*

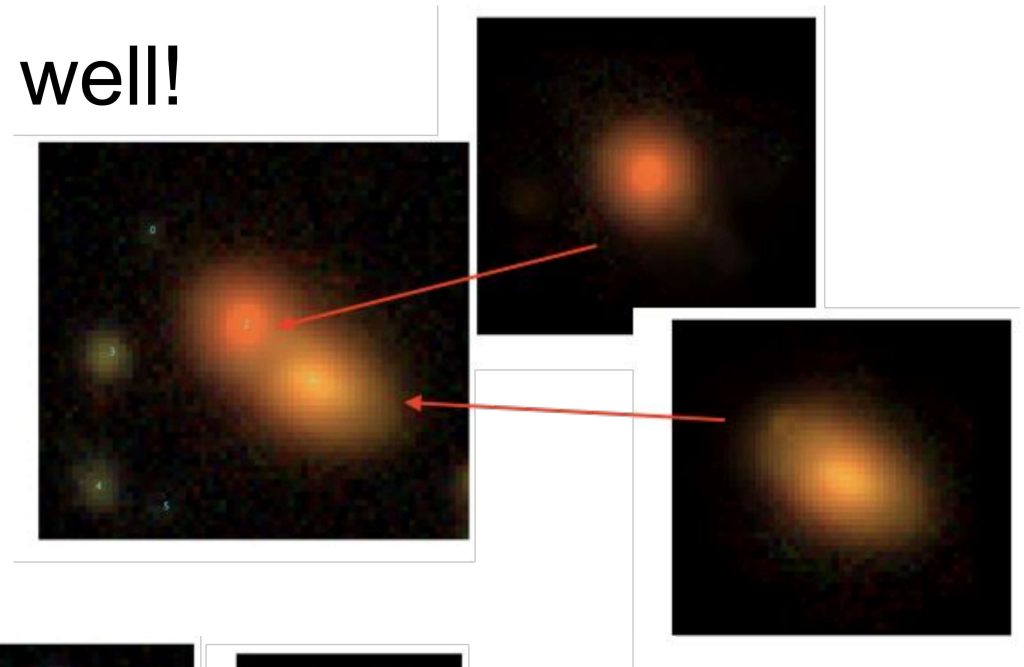


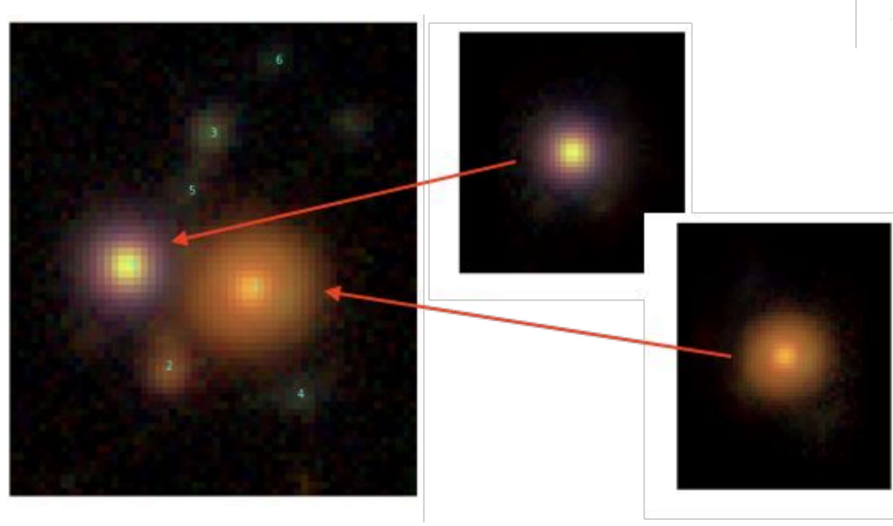






This works shockingly well!



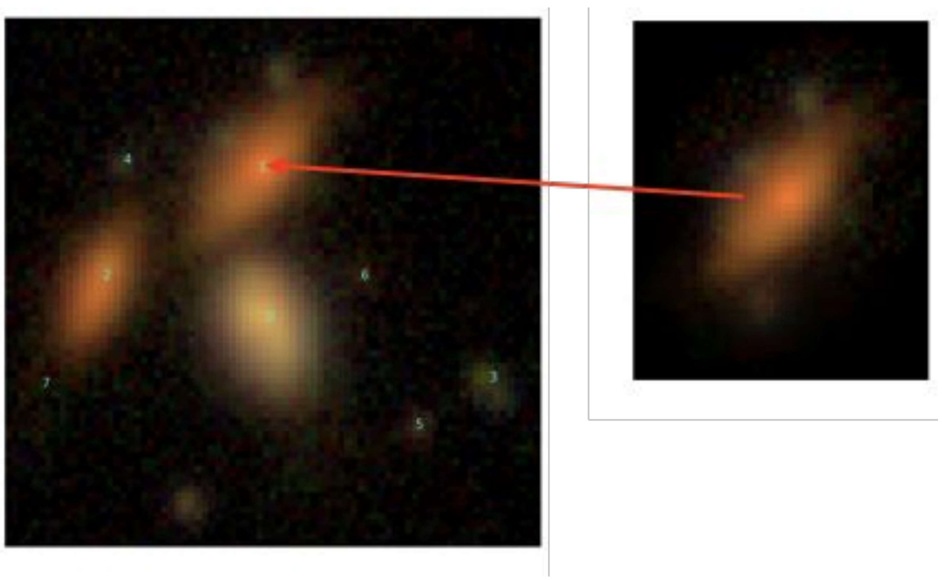


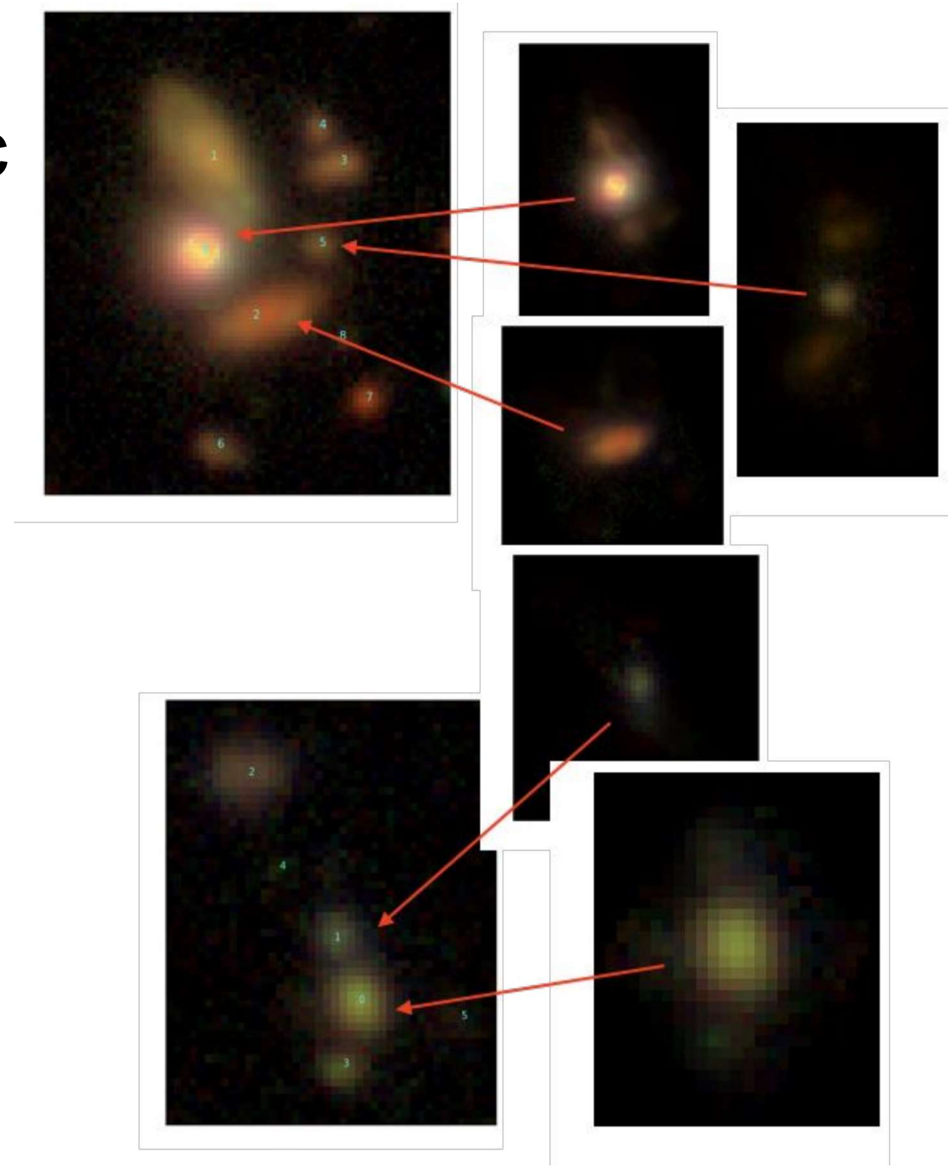
Problems with this algorithm

- PSF fit is not consistent across bands *
- Galaxies are not actually symmetric (and they have dust)
  - Can result in poor re-apportioning in blended regions
  - Outer regions of asymmetric galaxies are ignored as “stray flux” *
  - “Three in a row” problem increases as images become deeper
- Undetected sources are included in flux measurements
- No residuals = No hierarchical deblending
- One poorly deblended object will steal flux from multiple neighbors

* different than SDSS deblender

“3 in a row” is catastrophic





Other Deblending Methods

SExtractor

- Performs detection
- Does not really deblend
- Segments the image based on pixel ratios
  - All of the flux from any given pixel is attributed to only a single object
- Works well for sparse exposures without a lot of dynamic range

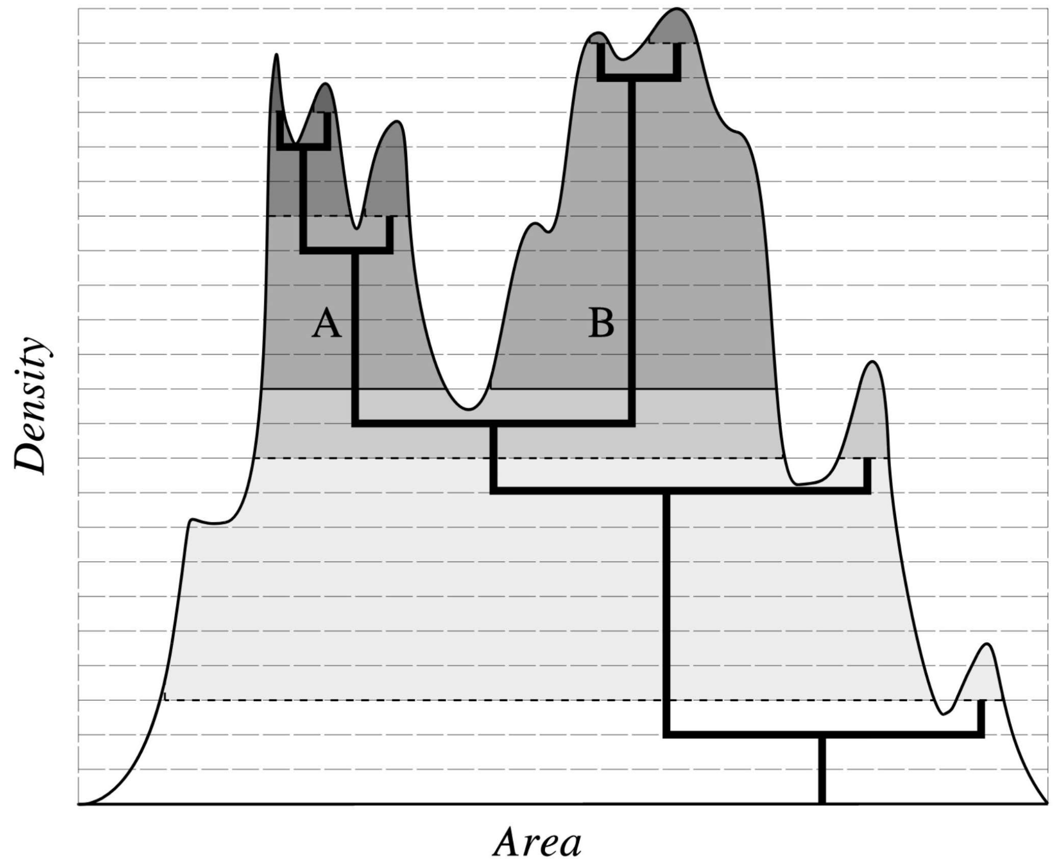
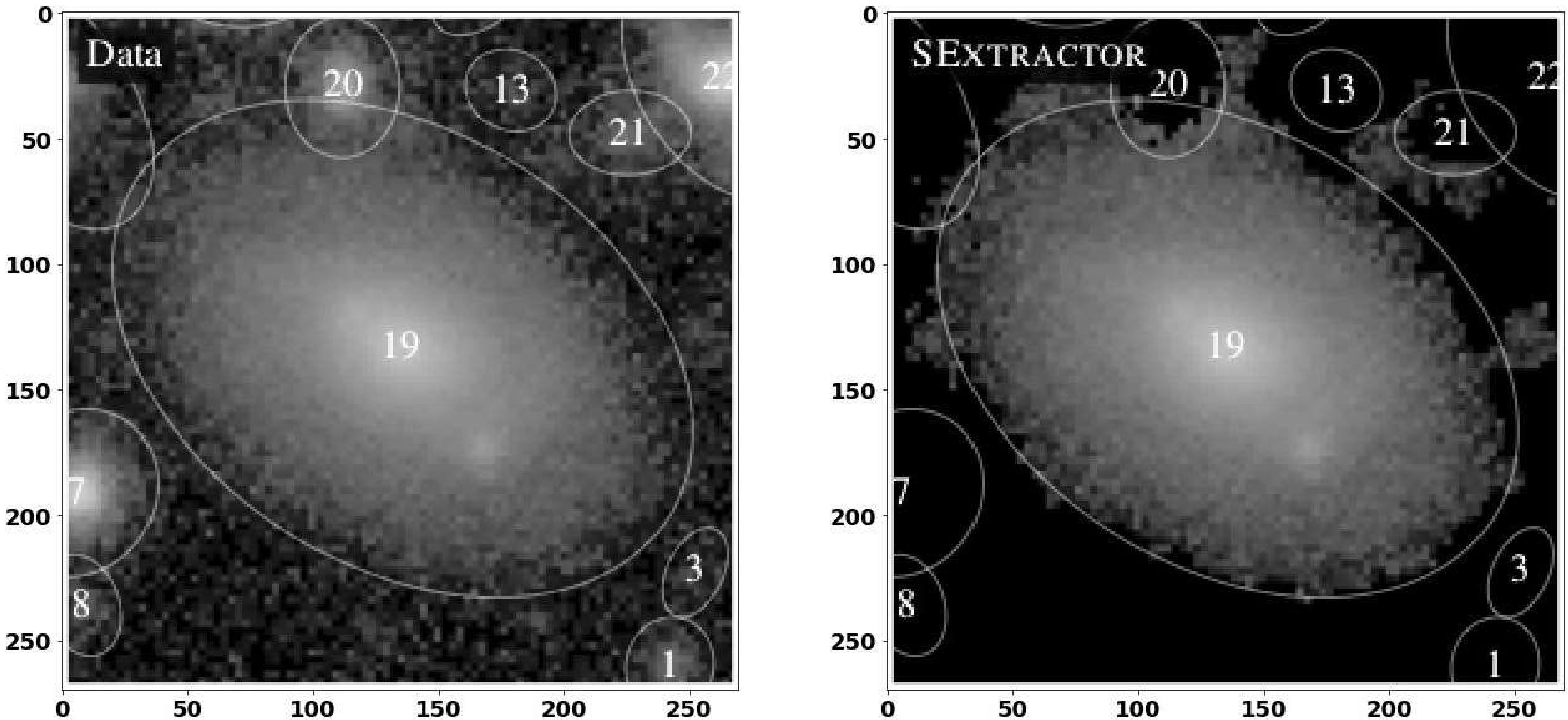


Image credit: Bertin, [unpublished manual]

SExtractor



Melchior and Moolekamp et al. 2018

Sersic Model Approaches

- Elliptical galaxies can be expressed as Sersic models:

$$I(R) = I_e \exp\left(-b_n\left(\left(\frac{R}{R_e}\right)^{1/n} - 1\right)\right)$$

- Two components:
  - Bulge: often n=4 (de Vaucouleurs)
  - Disk: n = 1
- Similar to crowded field photometry
  - Fit radial parameters, ellipticity, angle

galfit

- Parametric model
- In addition to Sersic profiles also includes other radial profiles
- Additional models to attempt to model spirals and more complicated morphologies

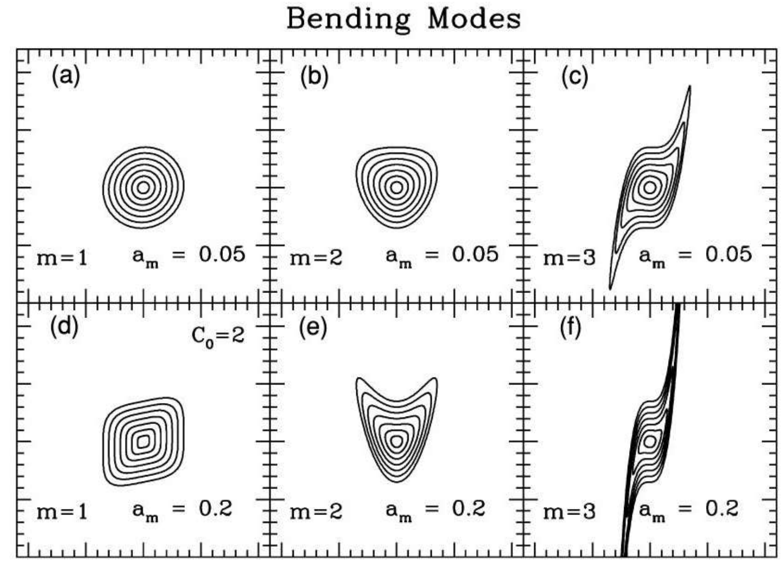
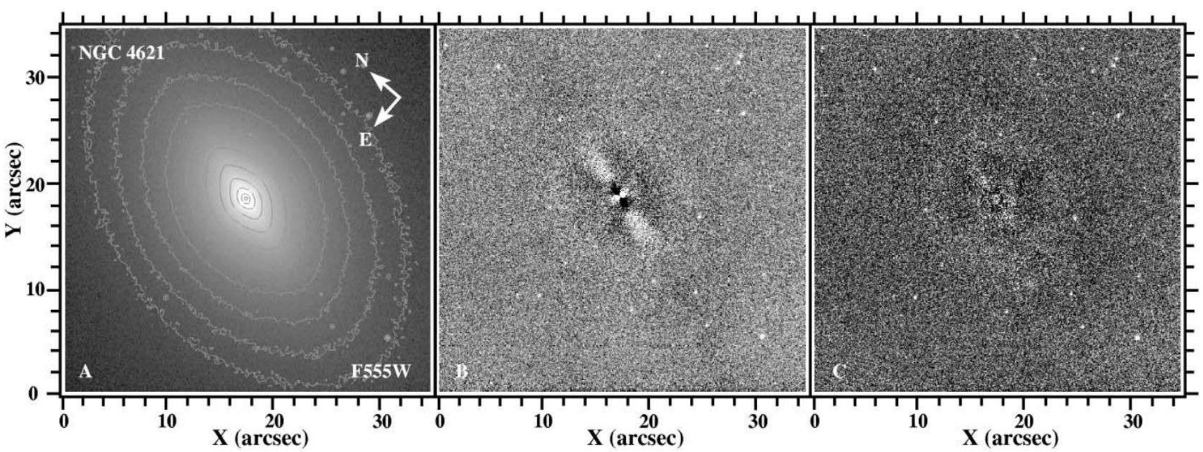


Figure 10. Examples of bending modes modifying a circular profile ($q = 1.0$) with $C_0 = 0$ (unless indicated otherwise). Top row: low-amplitude ($a_m = 0.05r^m_{\rm scale}$) bending modes. Bottom row: high-amplitude ($a_m = 0.2r^m_{\rm scale}$) bending modes. Bending modes can be combined with Fourier modes to change the higher order shape.

Peng et al. 2010



Peng et al. 2002

Example: Multi-Object Fitter (MOF)

- Used in the Dark Energy Survey Y3 processing
- Uses bulge-disk model with gaussian mixtures for each component
- Doesn’t work well in crowded regions

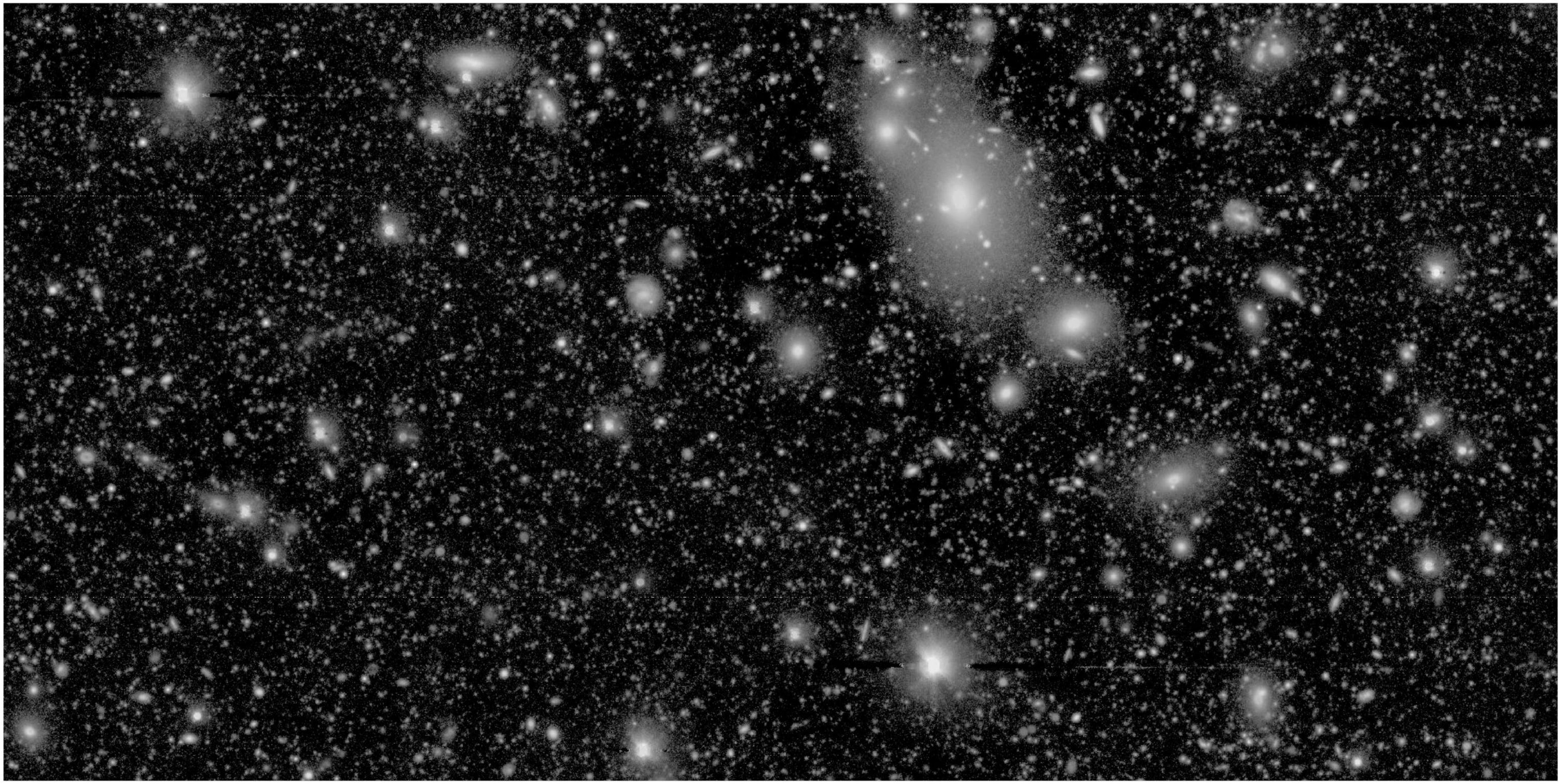
Thanks to Erin Sheldon for help on these slides

Example: The Shredder

- Used in the Dark Energy Survey Y6 processing
- Multiband model of galaxies as N free gaussians with fixed centers
- Works in more crowded regions
- neighbors are subtracted and the resulting cleaned image fed into a more precise modeling code

Thanks to Erin Sheldon for help on these slides

Leading DM Pipeline Candidate: Deblending with scarlet

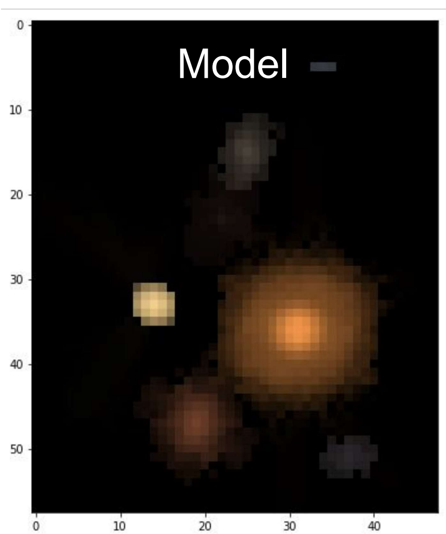


HSC I-band

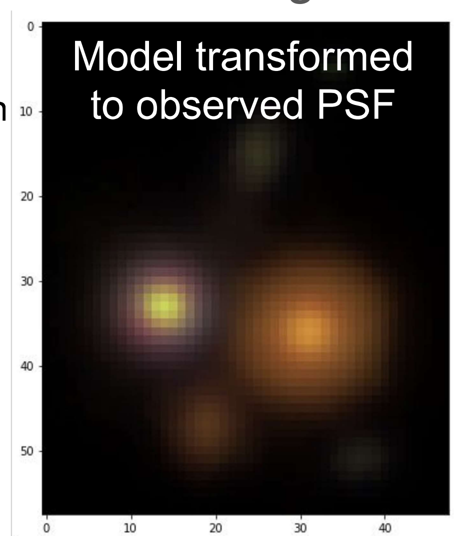
HSC GRI-bands

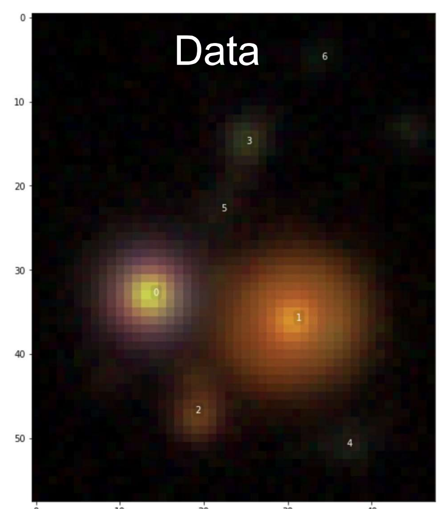
How scarlet works

1. The user defines an initial multiband model
   - The blend model exists in a frame with a narrow (but nyquist sampled) PSF
2. The blend model is convolved to the observed PSF in each band
3. AdaProx (Melchior et al. in Prep) implementation of ADAM is used to apply constraints and priors to the models and calculate the gradient step
4. The gradients are back-propagated to update the model
5. Steps 2-4 are repeated until convergence



Convolution in each band





Models: Basic Model

Data

Rendered Model

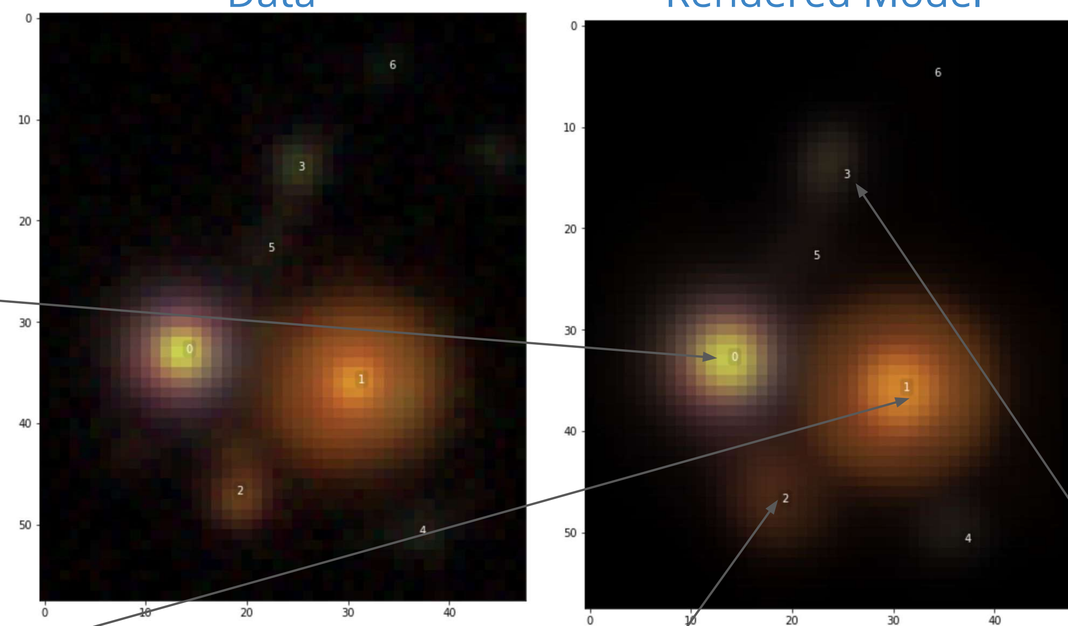
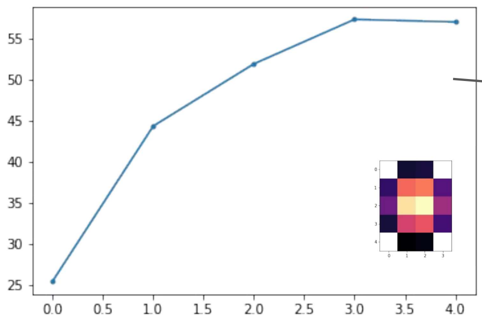
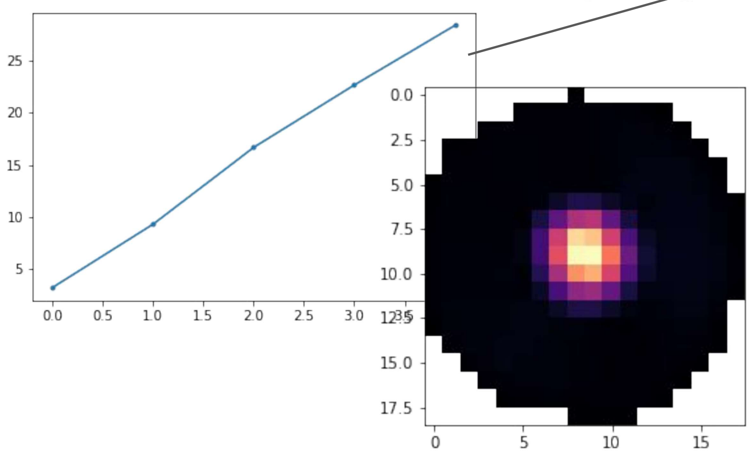


Image from HSC Deep Field

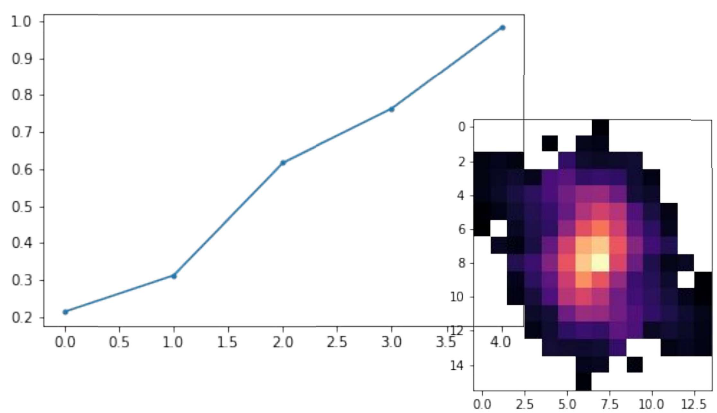
Source 0



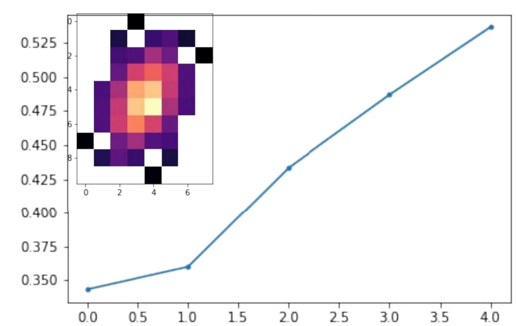
Source 1



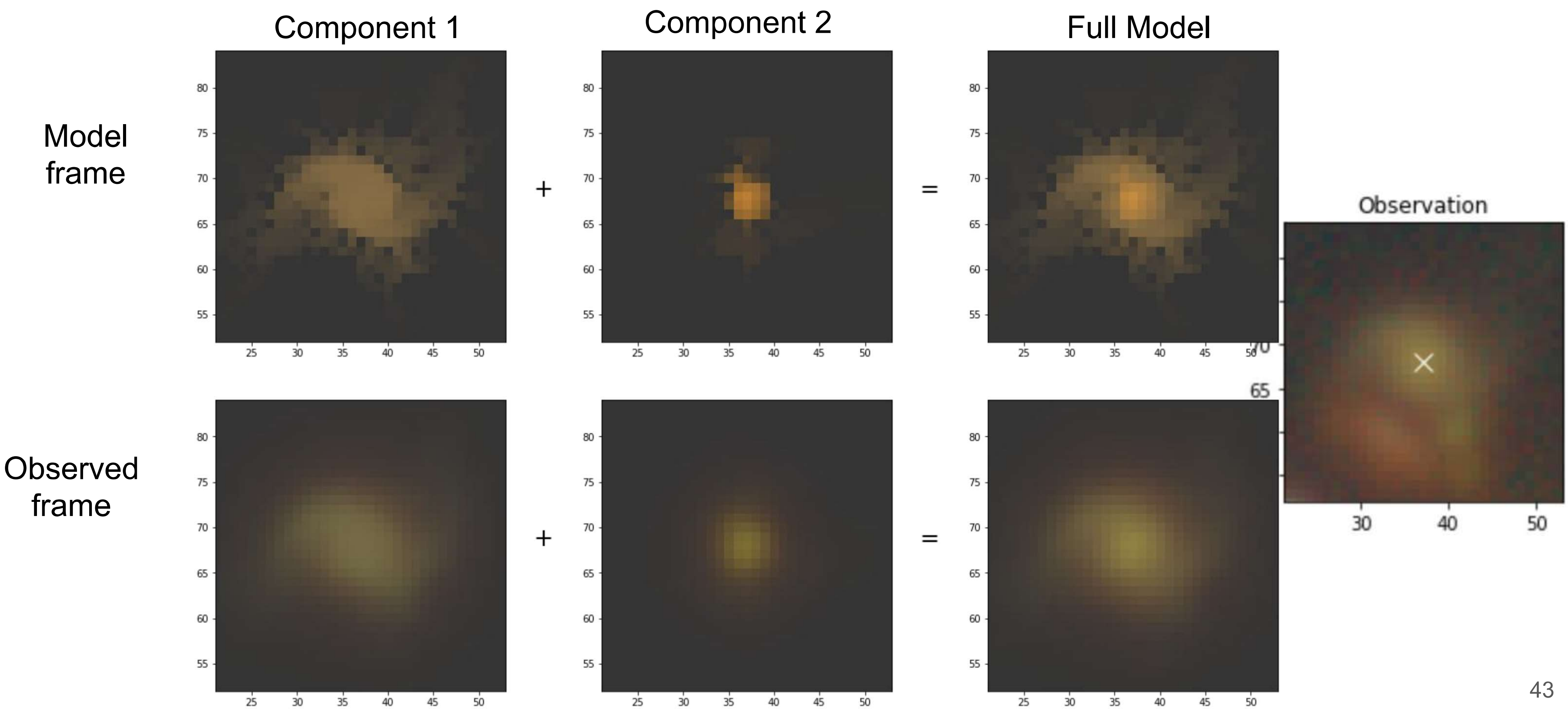
Source 2



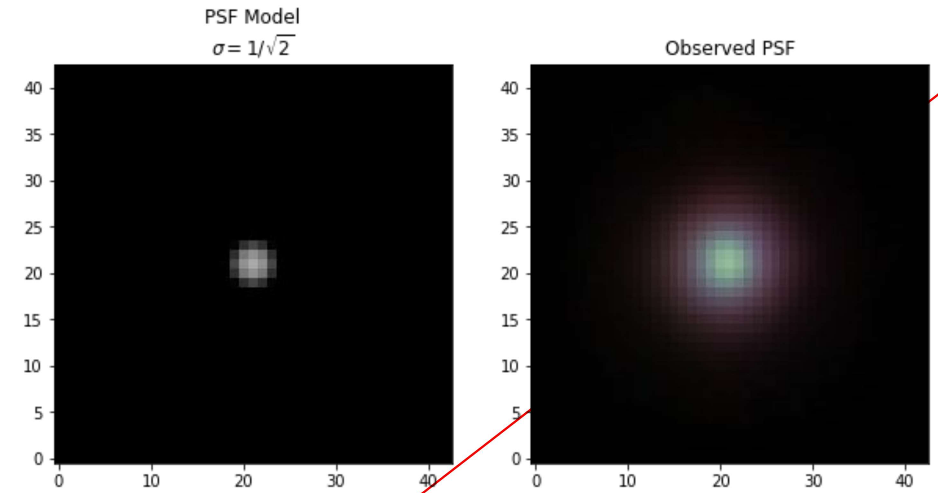
Source 3

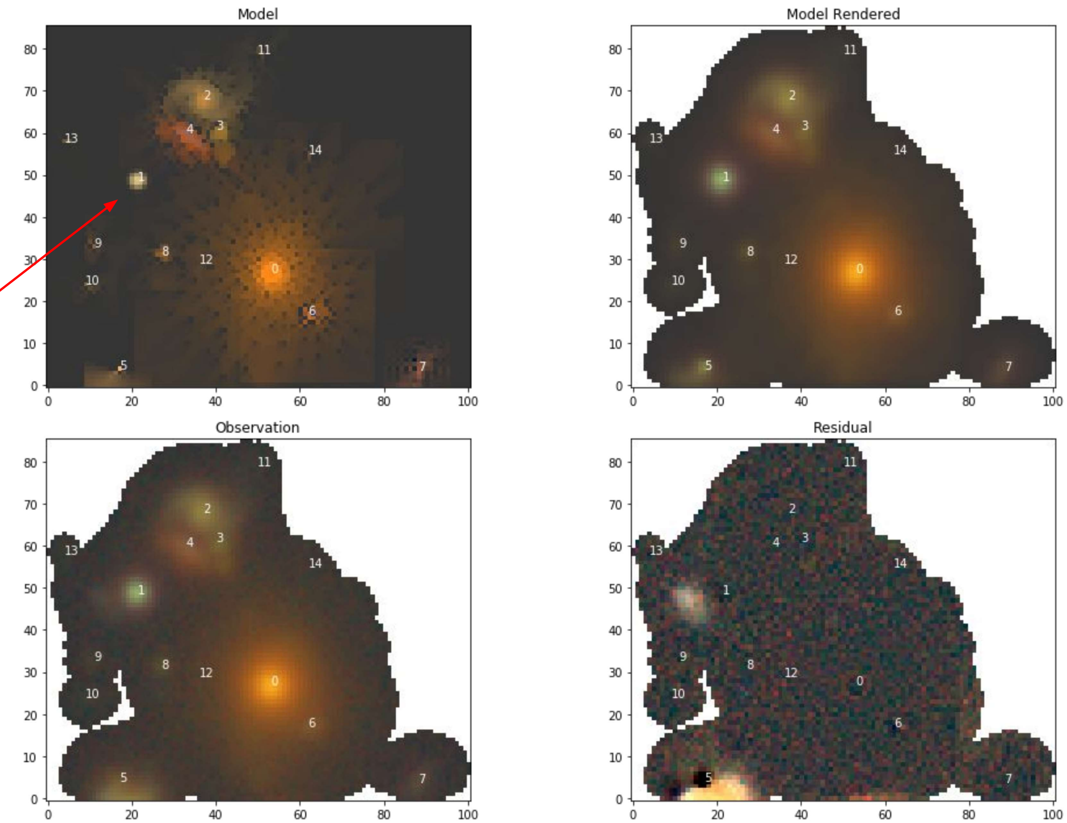


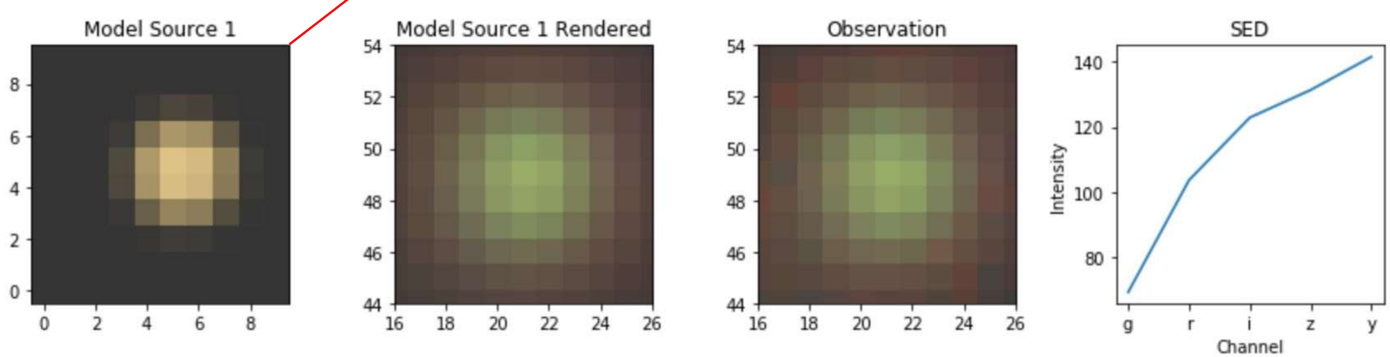
Models: Multiple Components



Models: Point Source

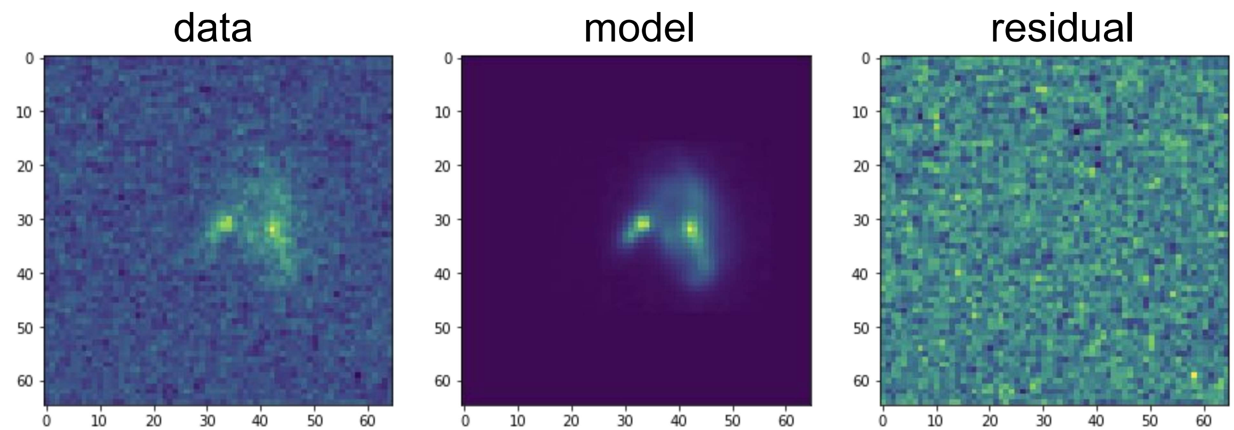


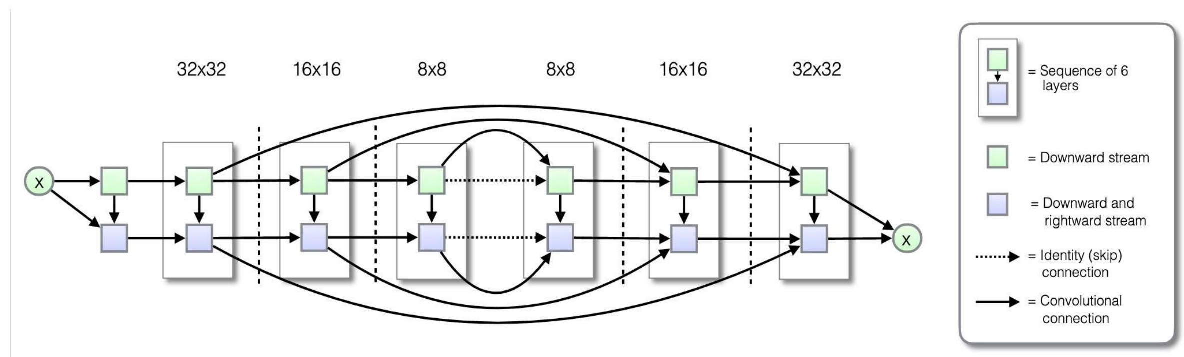




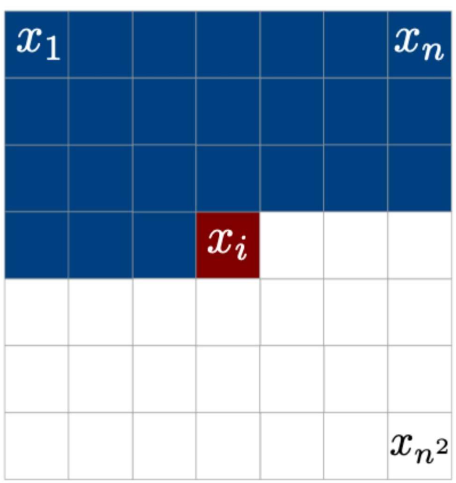
Models: Pixel CNN

- Pixel CNN network trained on isolated real galaxy templates
- Still in development by François Lanusse





Salimans et al 2017

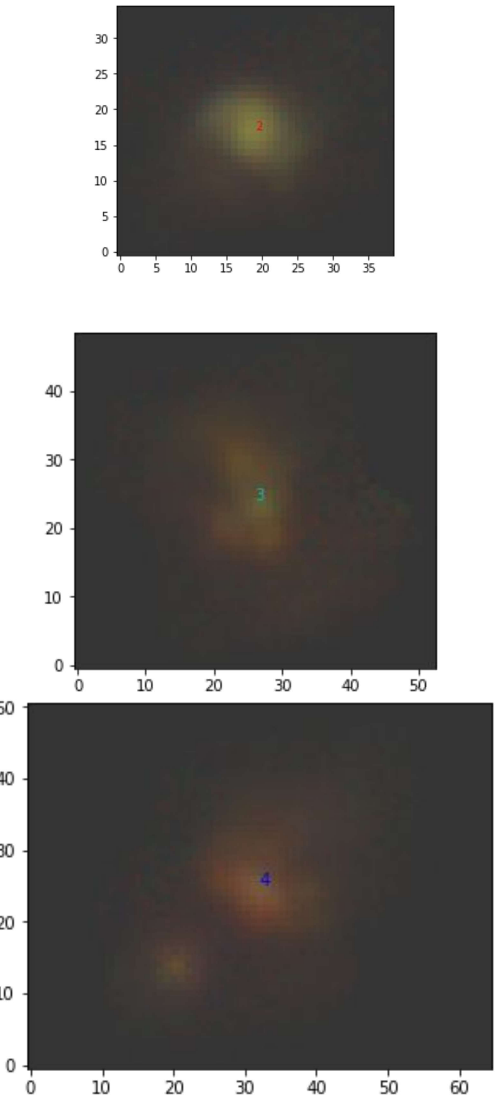


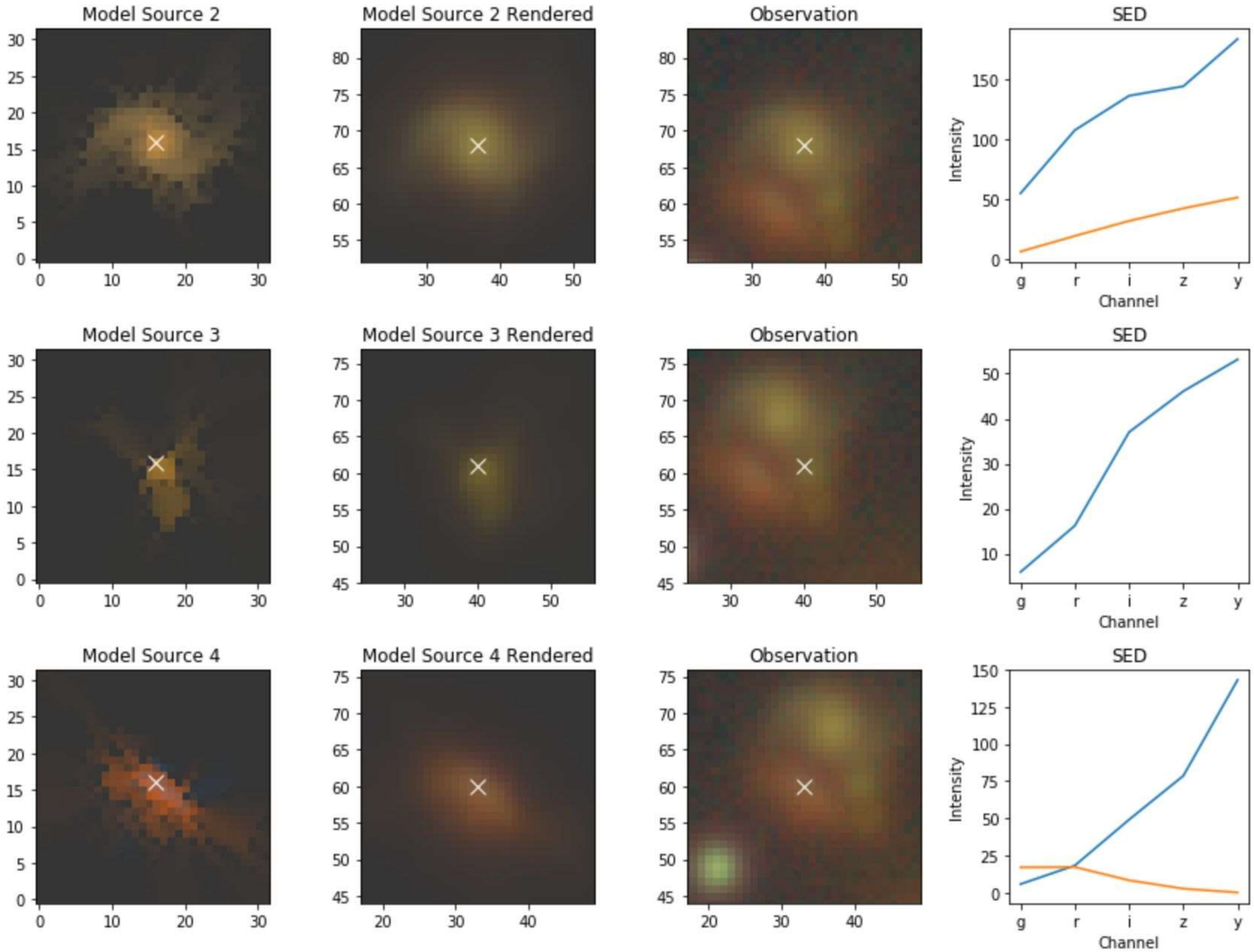
van den Oord et al 2016

Other Possible Models

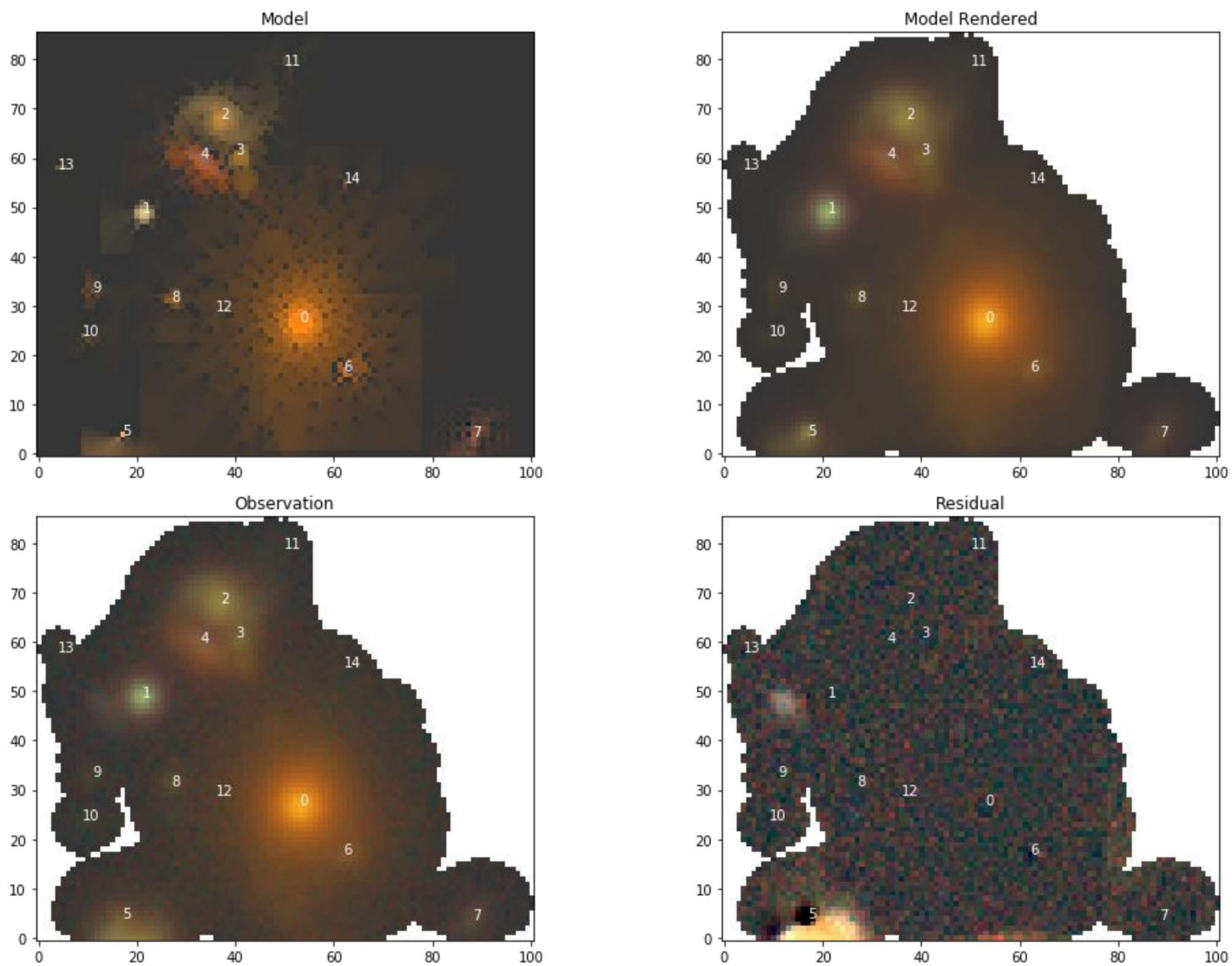
- Parametric Models (e.g. Sersic Bulge with Exponential disk)
- Gaussian Mixture
- Multiplicative dust model
- Custom models defined by the user

Stack deblender

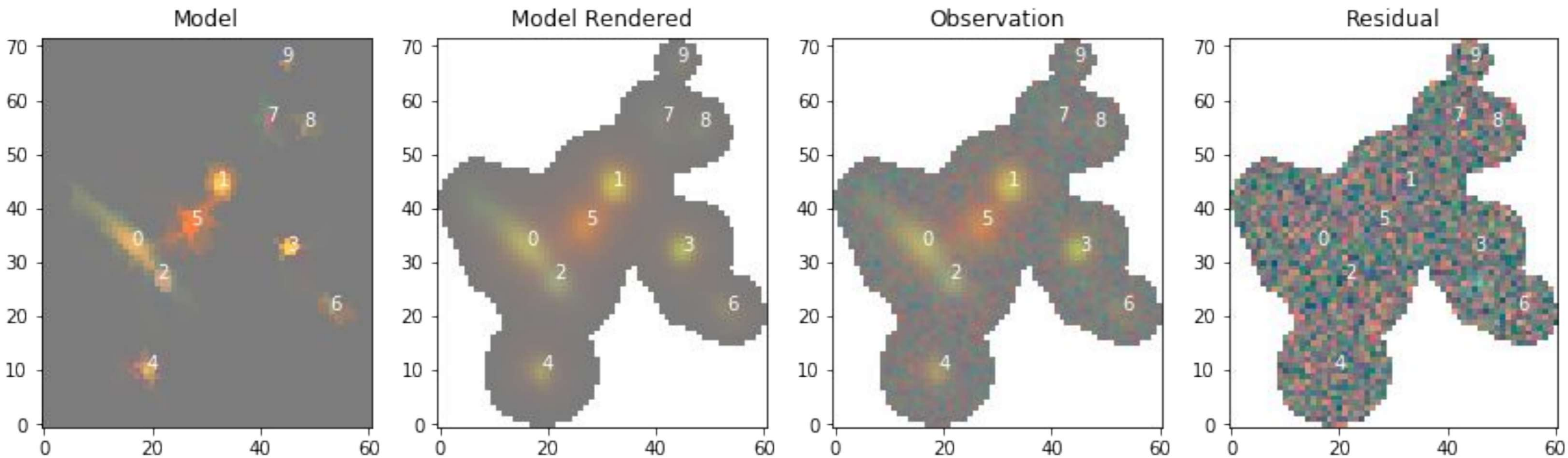


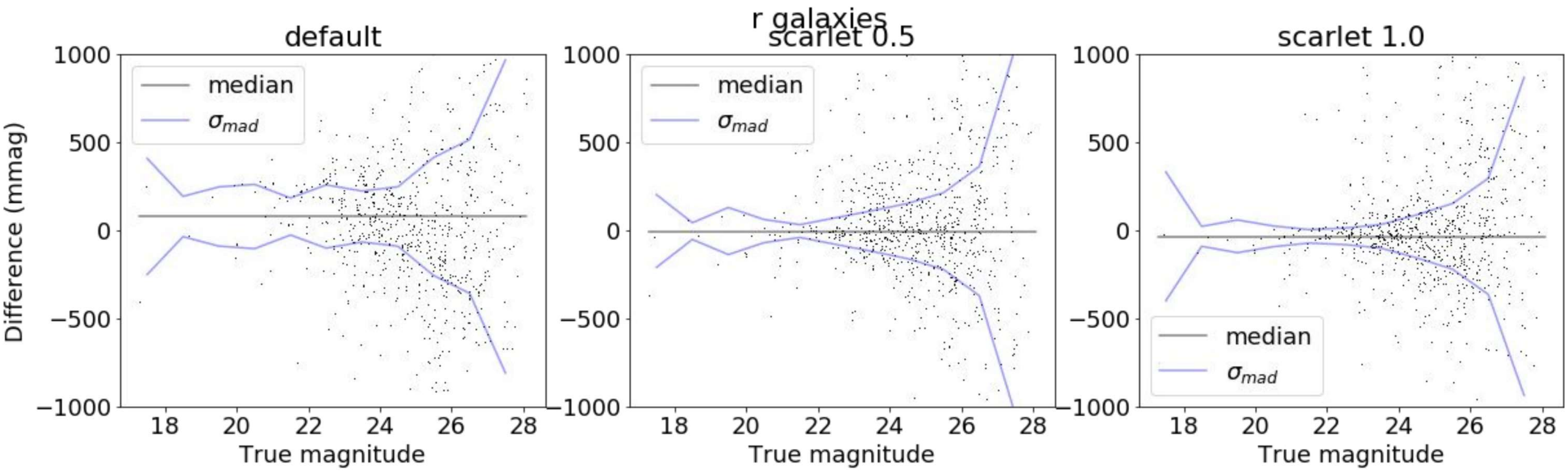


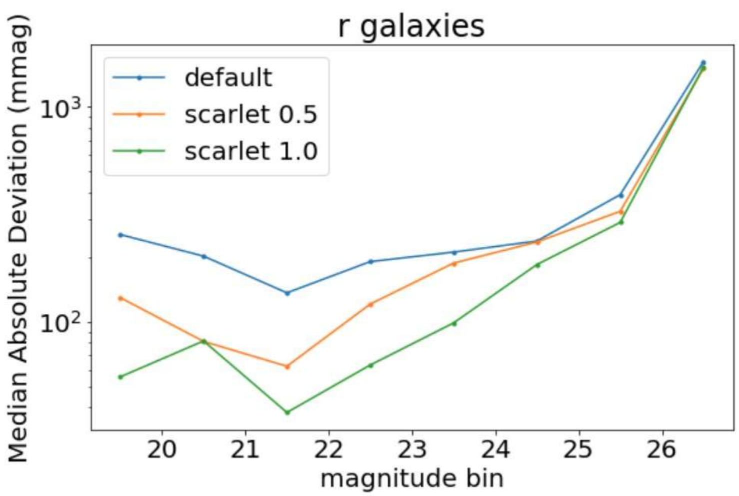
scarlet residuals can be useful!

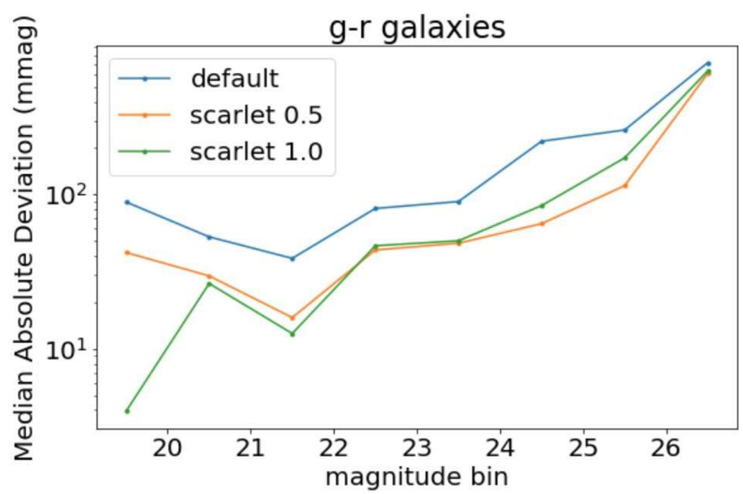


Another example




r galaxies
default
scarlet 0.5
scarlet 1.0
median
σ_{mad}
Difference (mmag)
True magnitude
1000
500
0
−500
−1000
18
20
22
24
26
28


r galaxies
default
scarlet 0.5
scarlet 1.0
Median Absolute Deviation (mmag)
magnitude bin
10^3
10^2
20
21
22
23
24
25
26


g-r galaxies
default
scarlet 0.5
scarlet 1.0
Median Absolute Deviation (mmag)
magnitude bin
10^2
10^1
20
21
22
23
24
25
26

Upcoming Improvements

- Better identification of source type for initialization and model choice (P, R)
- Analytic convolutions (faster back-propagation) (P, R?)
- Analytic gradients (M, P)
- Multi-scale detection and deblending (R)
- Improved constraints (P, R)
- New models (dust, LSB, jets, etc)

R = improves robustness, P = improves CPU performance,
M = improved memory usage

More distant improvements

- It may be that the deblender we use in Y10 is not the same one as Y1
- Preventing detection/deblending from shredding large spirals is non-trivial
- Model PSF during crowded-field deblending
- Train and test deep learning solutions
  - Ex. Francois Lanusse Pixel-CNN prior (Lanusse et al. 2019), Variational Auto-Encoder (Arcelin et al 2020, in review), etc.
  - Requires a robust training and validation sample and testing on real images
  - Not likely to be implemented until mid-survey at the earliest

Different Types of Deblenders (from Robert Lupton)

- Deblender
  - Algorithm to produce images which can be further analyzed
  - Philosophy: “There are measurements we want to make that must be made on data, not models”
    - Gini coefficients
    - Petrosian magnitudes
  - Ex. SExtractor, SDSS Deblender, current stack deblender
- Simultaneous Fitter
  - Simultaneous model fitting and measurement of multiple sources
  - Philosophy: “We need to have a model to know what we are measuring”
    - Flux
    - Colors
    - Shapes
  - Ex. MOF, galfit, Crowded stellar field codes, scarlet

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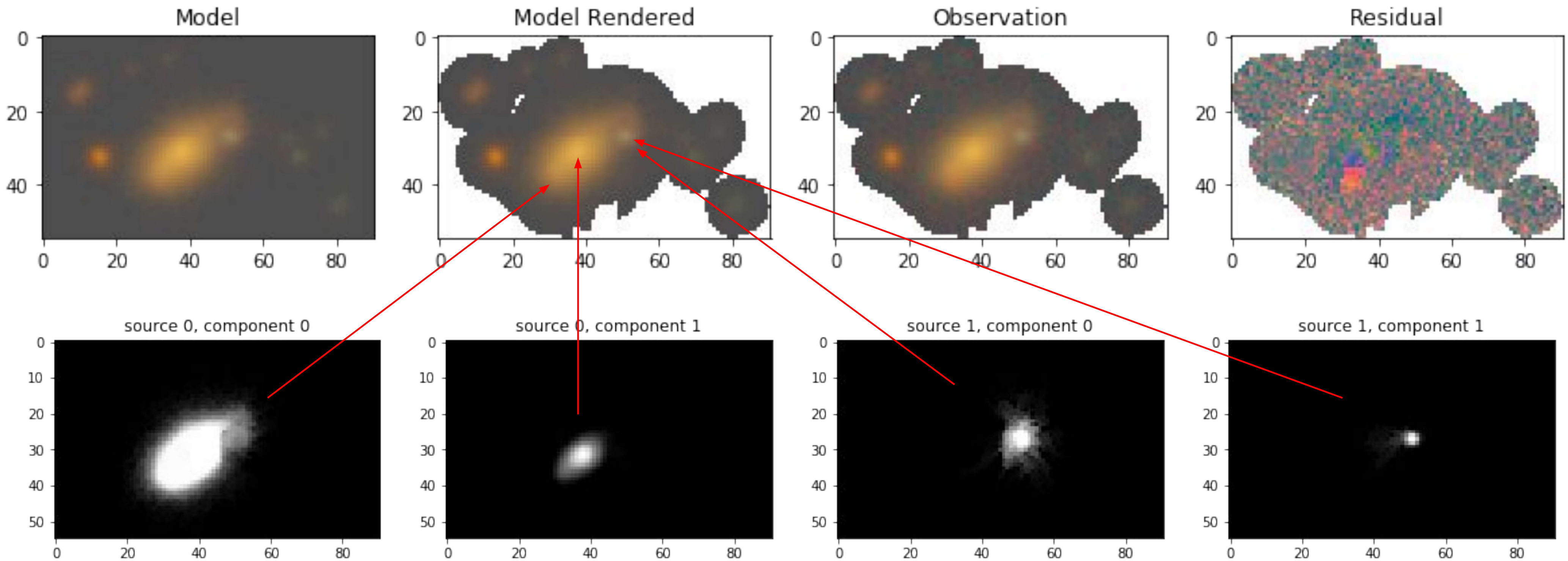
We may need both!

Summary

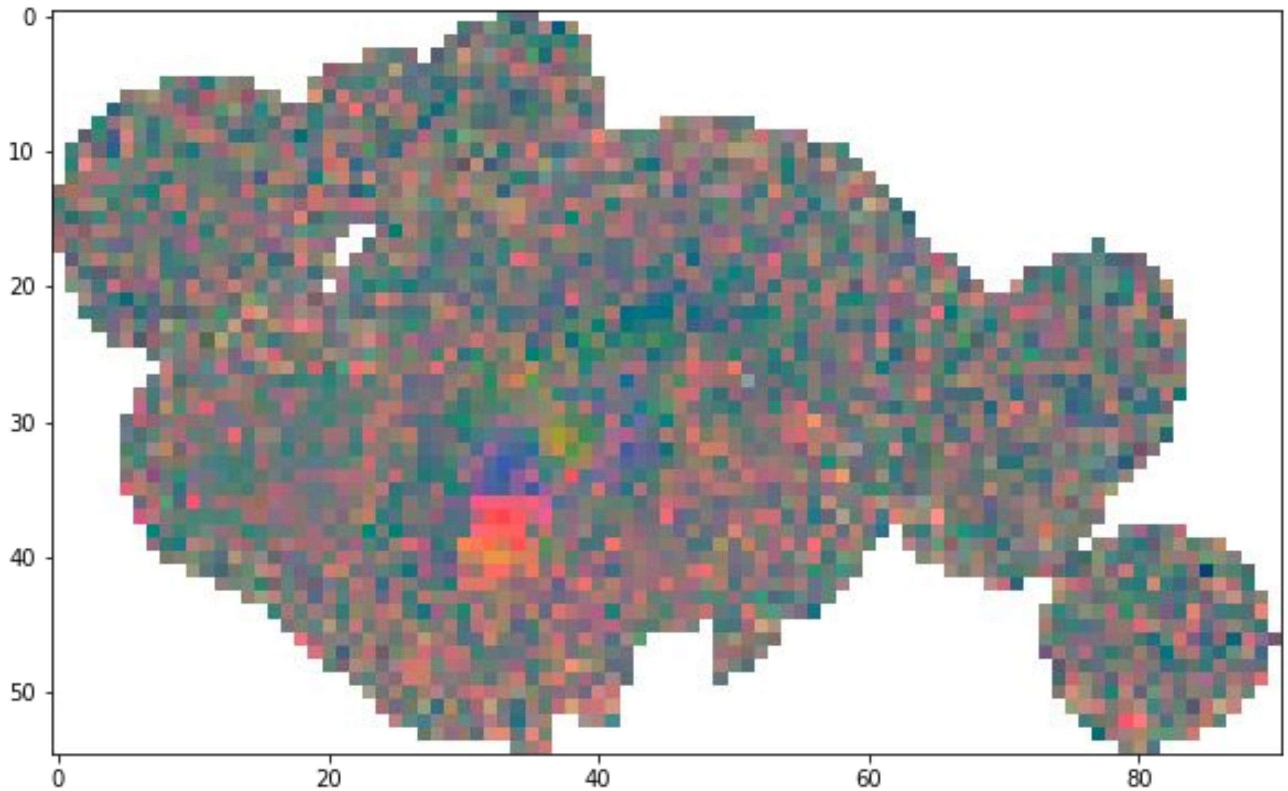
- Deblending is a hard problem
- The current deblender does well for simple blends
- We have been making a lot of progress in simultaneous fitting stars and galaxies using scarlet
- We need to run more extensive tests for shapes and biases, and comparison with MOF
- scarlet allows us to take advantage of new features added by Peter Melchiors group
- Run time for scarlet will always be more expensive than the current deblender, but may be partially offset by savings in measurement time
- The project will use whatever deblending solution works best that we have the compute power to support

Extras

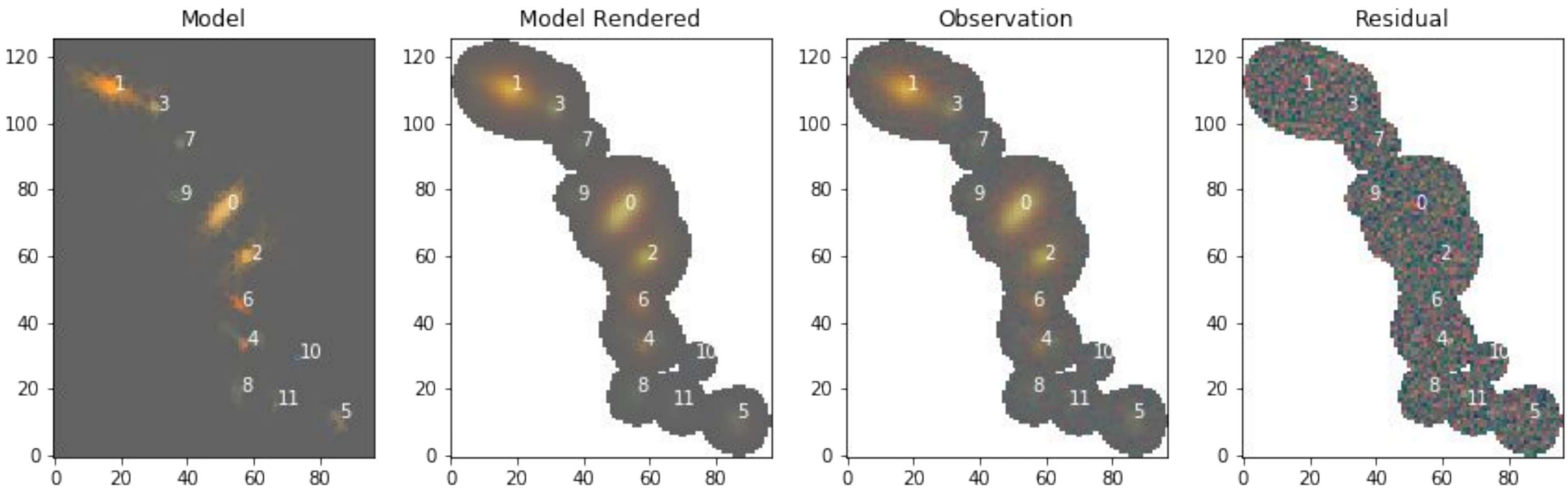
Examples


Model
Model Rendered
Observation
Residual
source 0, component 0
source 0, component 1
source 1, component 0
source 1, component 1

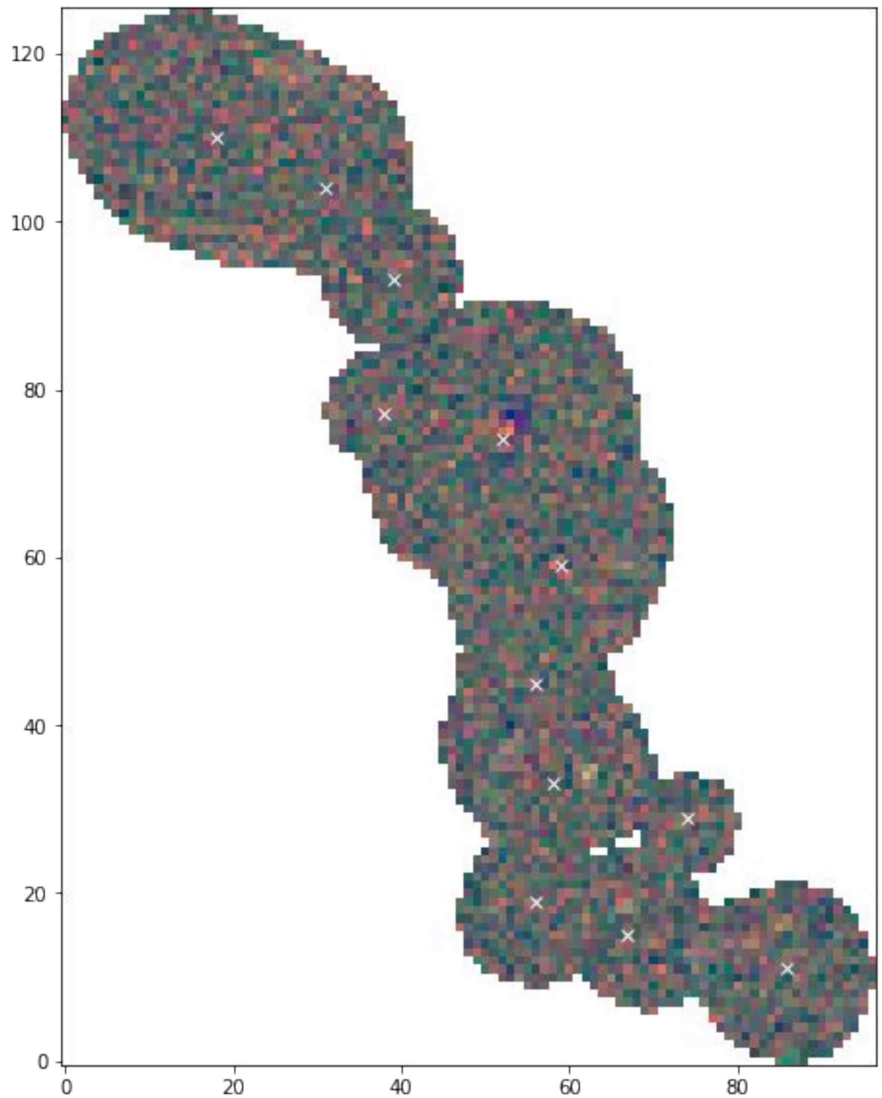
Examples



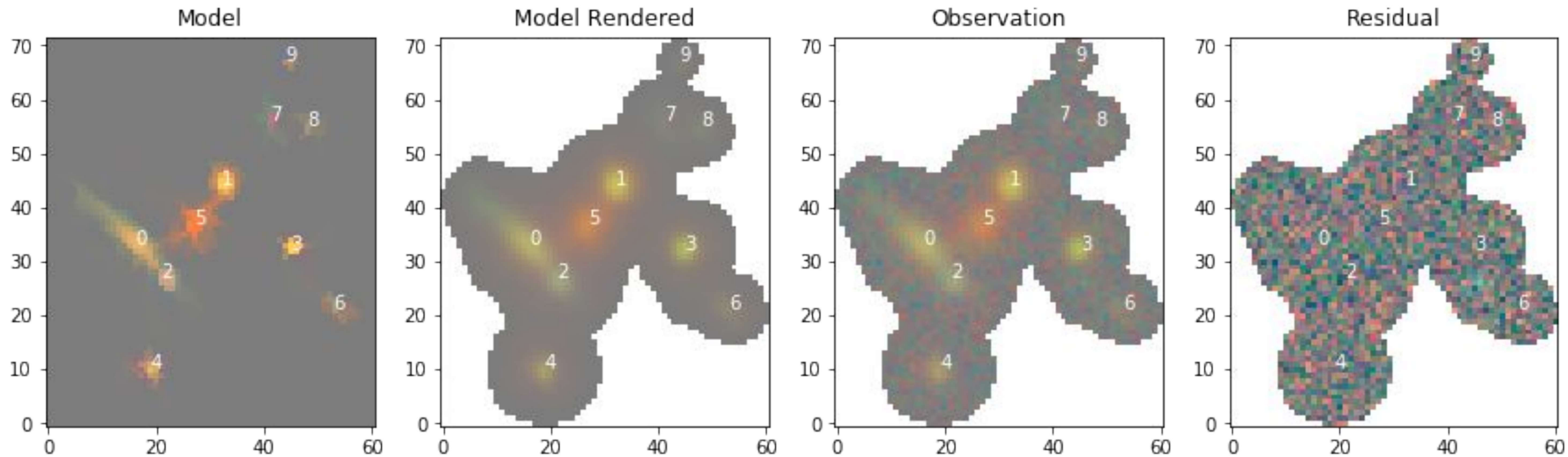
Examples



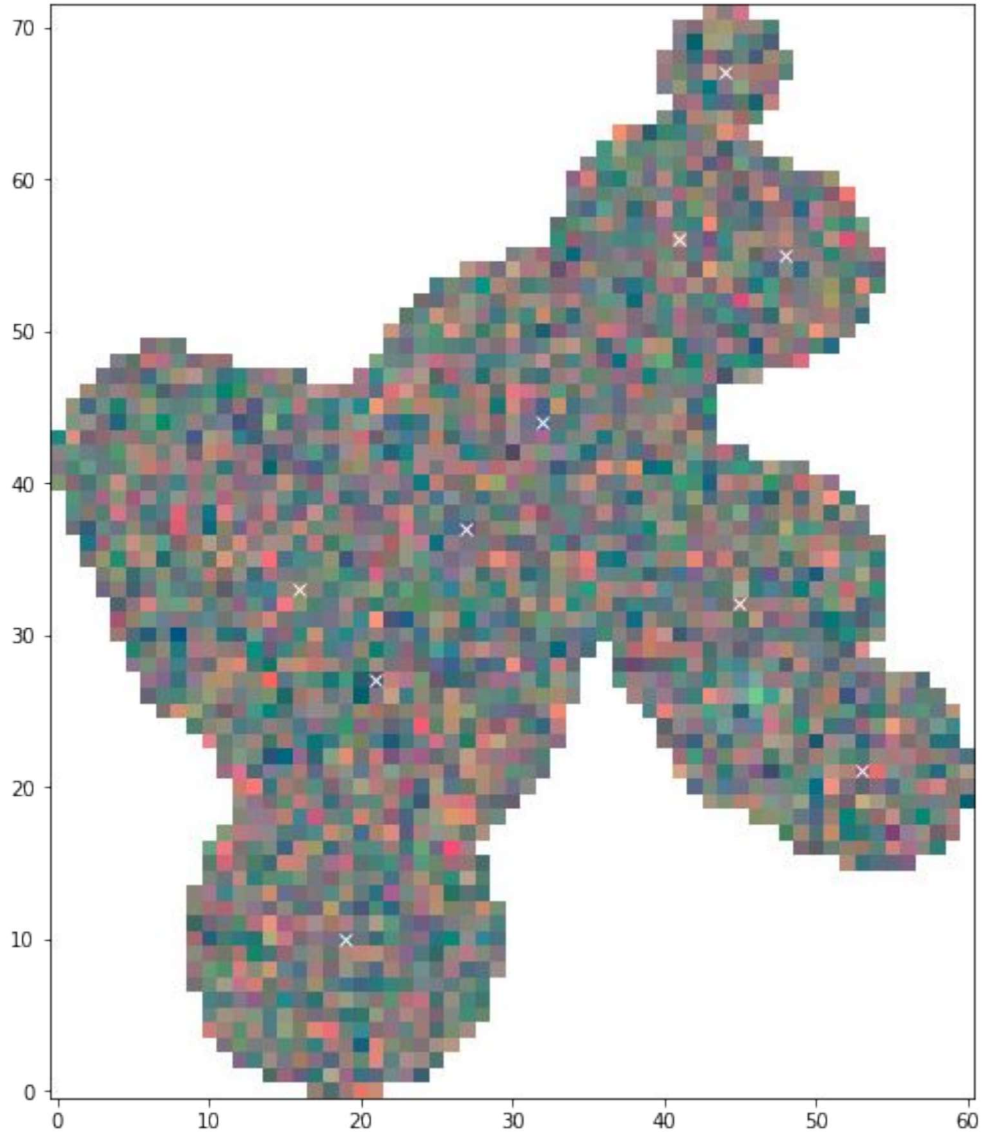
Examples



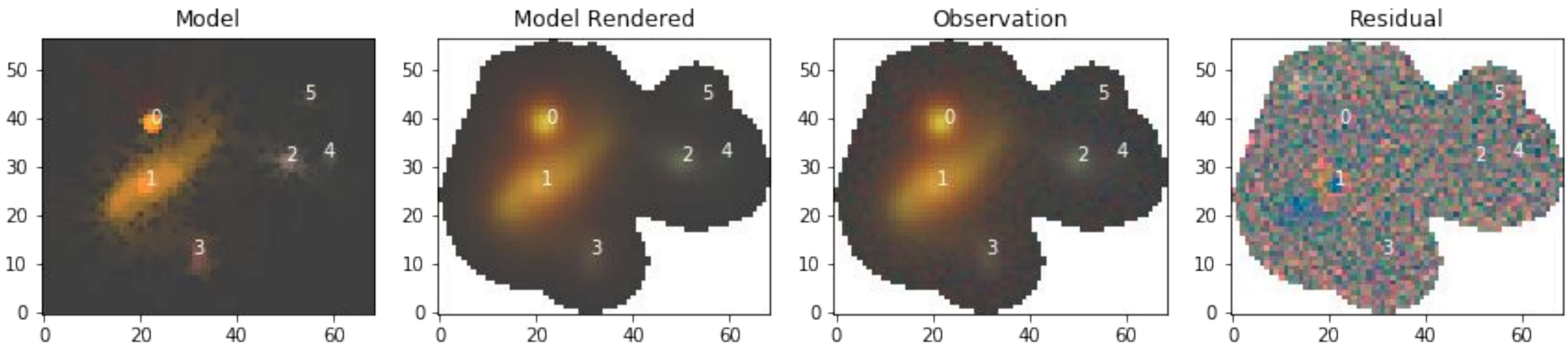
Examples



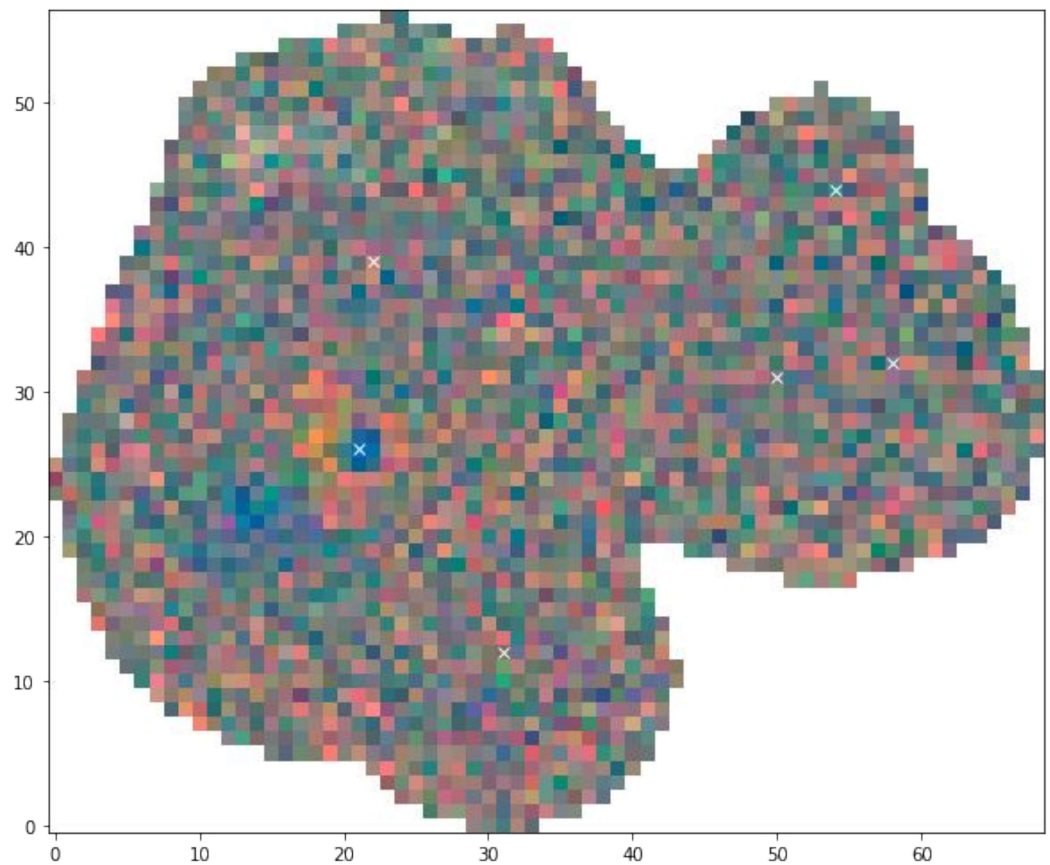
Examples



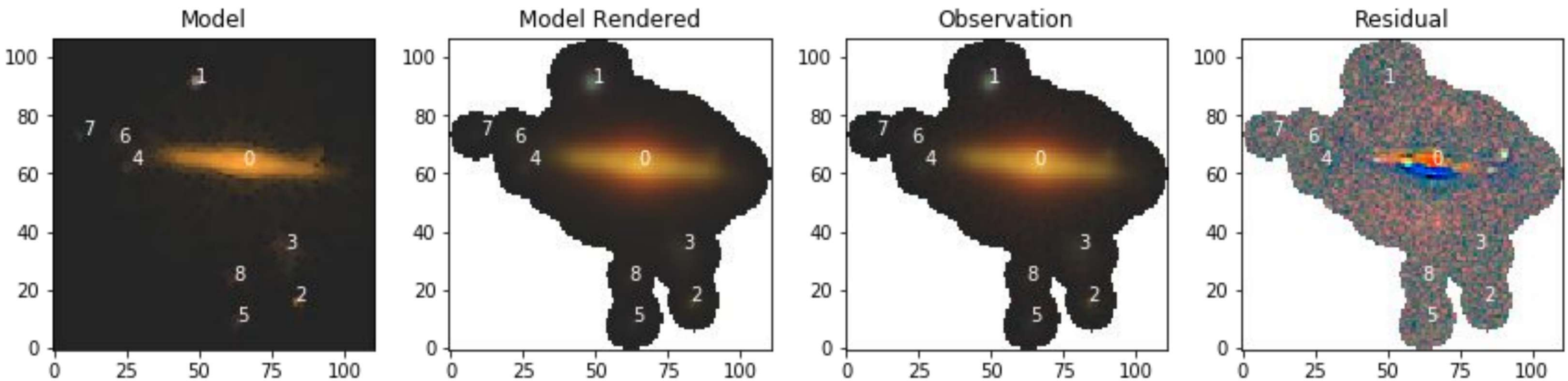
Examples



Examples



Examples


Model
Model Rendered
Observation
Residual
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
0
25
50
75
100

Examples