Principled inference from images, part II

In which we do a measurement.

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June 13, 2023

Where did we leave off last time?

- What is a psf?
- How do I measure the brightness of a star?
- Tradeoffs between model and aperture photometry
- Using GalSim to create simulated images.

What will we do today?

- Discuss how and why to do model-fit photometry of galaxies
- Try to deal with some of the ‘normal’ complexity of measurement in images.
- Obtain some Legacy Surveys imaging data for stars and galaxies
- Perform a measurement.

Extended sources in images

$$g(\mathbf{u}) + s(\boldsymbol{u})$$

There is a source on the sky, ***g***. There is other light, ***s***, not associated with our source.

Extended sources in images

$$g(\mathbf{u}) + s(\boldsymbol{u})$$

$$\int d^2\mathbf{u}\,(\,g(\mathbf{u}) + s(\mathbf{u})\,)\,p(\mathbf{u} - \mathbf{x})$$

This light is smeared out by the telescope psf, ***p***.

Extended sources in images

$$g(\mathbf{u}) + s(\boldsymbol{u})$$

$$\int d^2\mathbf{u}\,(\,g(\mathbf{u}) + s(\mathbf{u})\,)\,p(\mathbf{u} - \mathbf{x})$$

$$I_i = \int d^2\mathbf{x}\,\Pi(\mathbf{x} - \mathbf{x}_i)\,\int d^2\mathbf{u}\,(\,g(\mathbf{u}) + s(\mathbf{u}\,)\,)\,p(\mathbf{u} - \mathbf{x})$$

Light that falls on the detector is recorded by the pixels. Each pixel's area, Π, projects onto a different patch of sky.

Π is not necessarily regular, and it is not necessarily normalized to unity.

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The telescope and sensor can introduce additional non-astrophysical signals, ***A***.

Extended sources in images

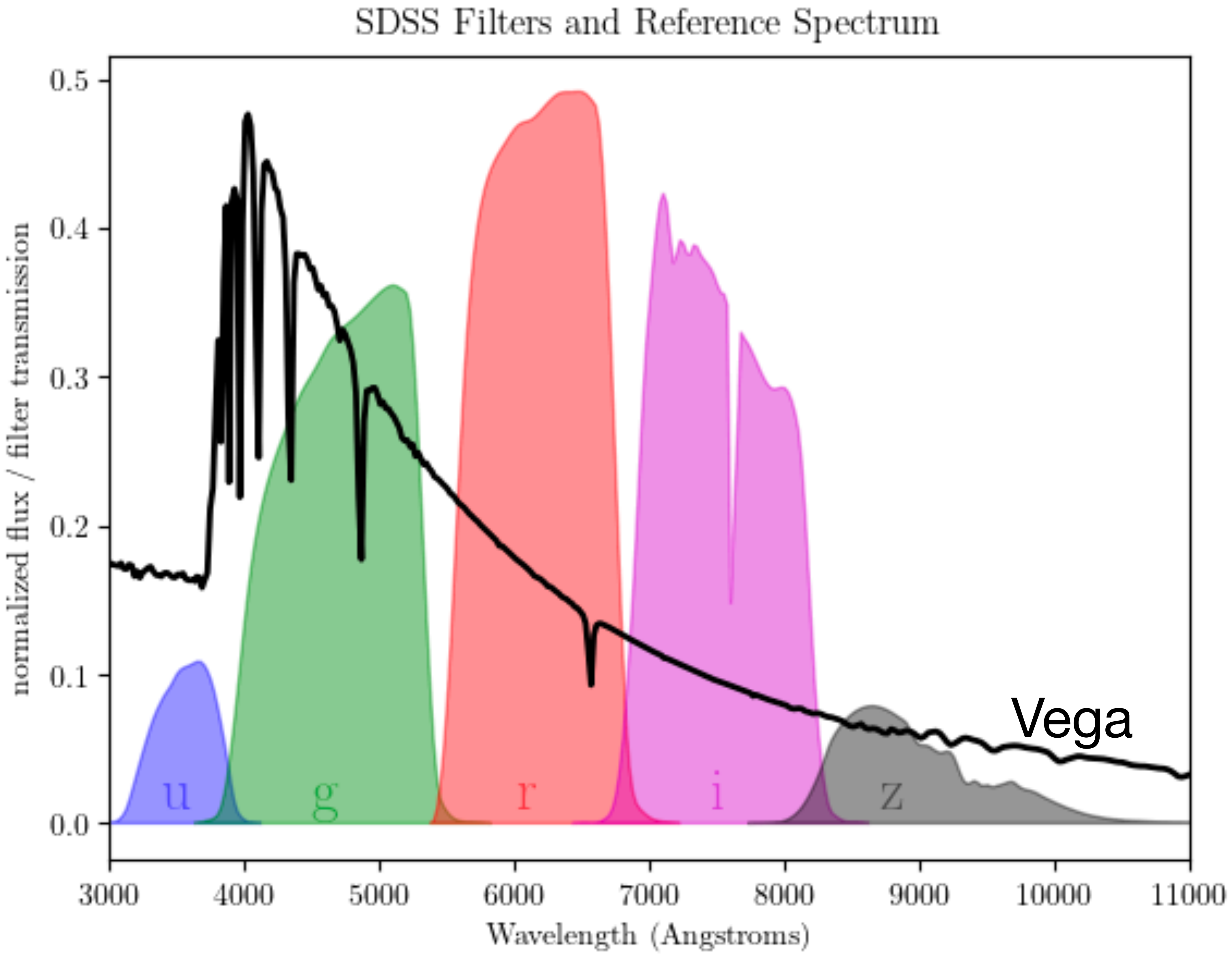
Interpreting the measured flux

$$g(\mathbf{u}) = \int dt \int d\lambda \frac{\lambda}{h\,c} I(\mathbf{u}, \lambda, t)\, r_{\mathrm{atm}}(\mathbf{u}, \lambda, t)\, r_{\mathrm{tel}}(\lambda, \mathbf{u}, t)$$

What we *actually* measure is the total number of photons integrated over our bandpass.

Typically, we compare the measured flux to a known reference spectrum.

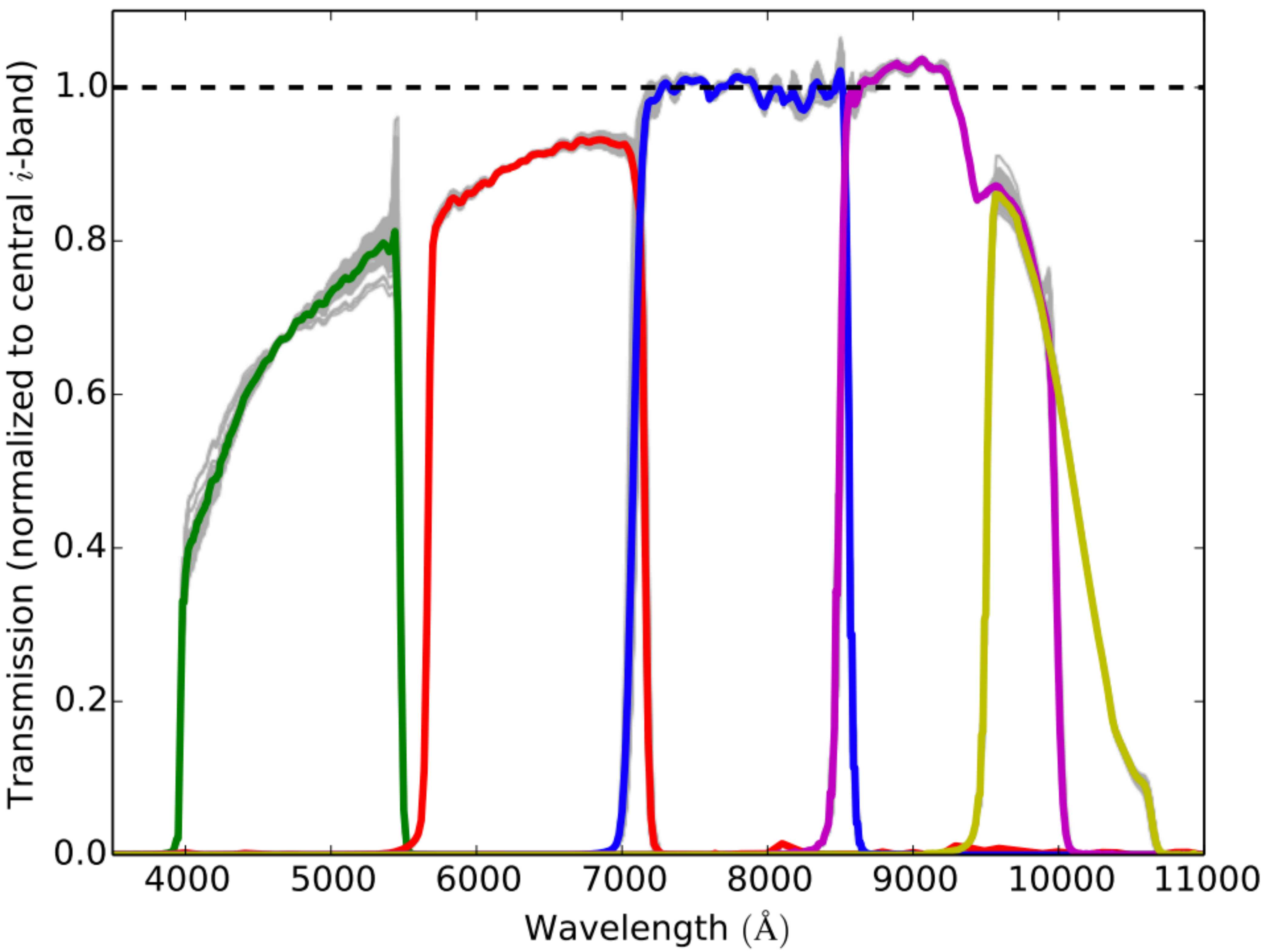
But we cannot interpret the result as a flux without assuming a spectrum for ***g***.



Interpreting the measured flux

Why does the photometric calibration change?

- dust accumulates on the optical surfaces, and is cleaned off periodically.
- the mirror gradually loses reflectivity, and is re-aluminized from time to time
- the transparency of the atmosphere varies from night to night.
- the transparency of the filter varies with incidence angle of the light.



Variation in DECam passbands over the first three years of the Dark energy survey.

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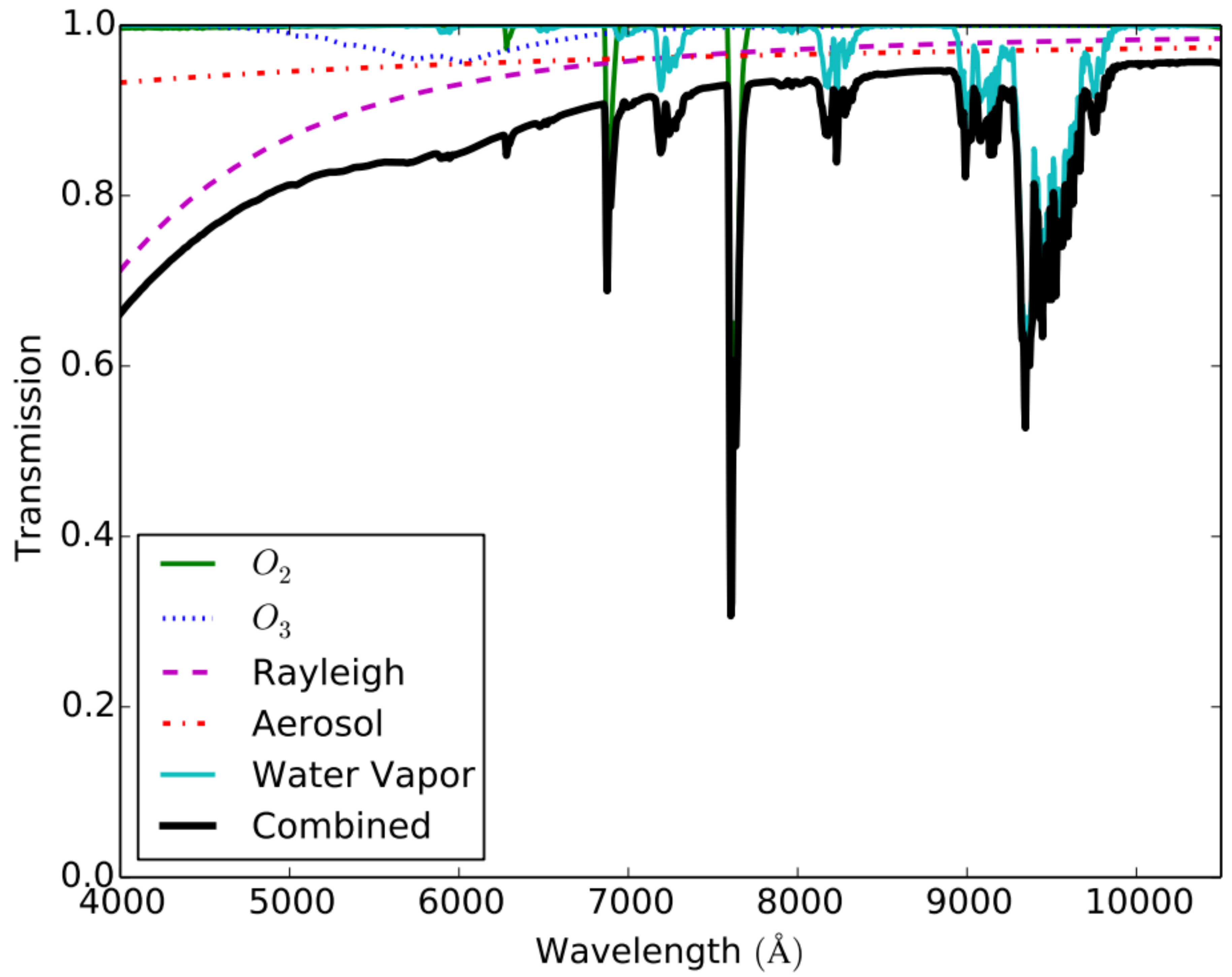

Components of atmospheric transparency.
These can vary independently over time.

Interpreting the measured flux

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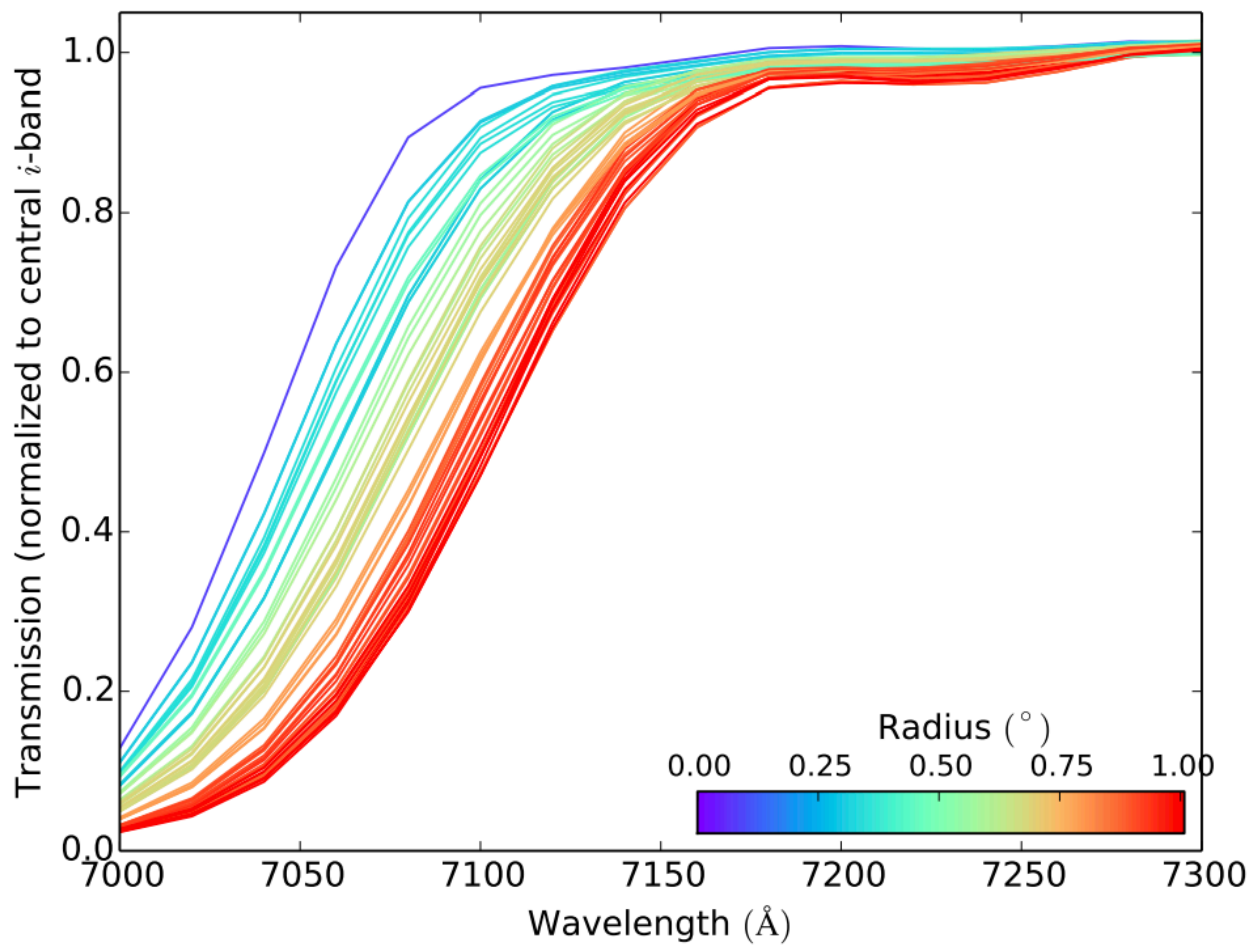
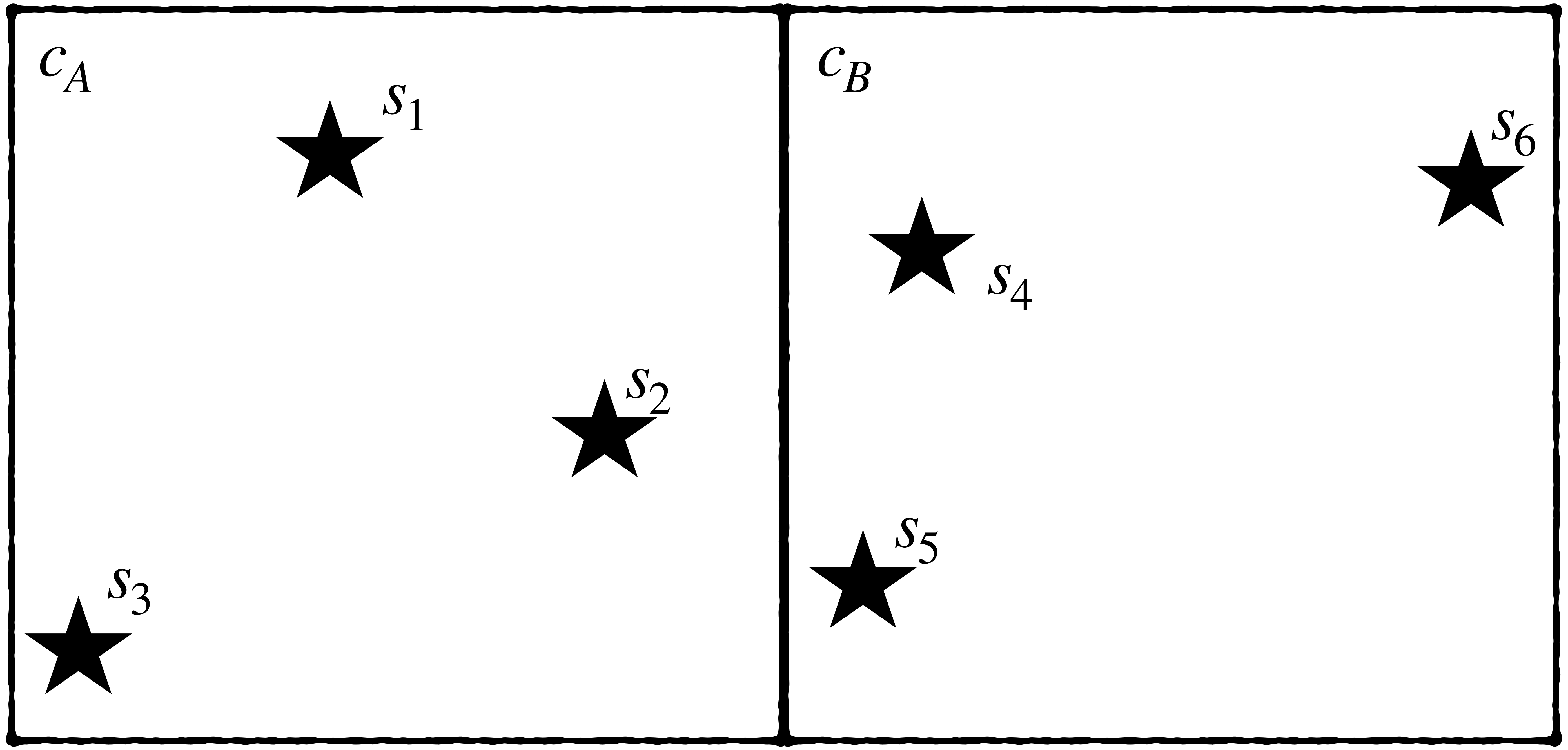


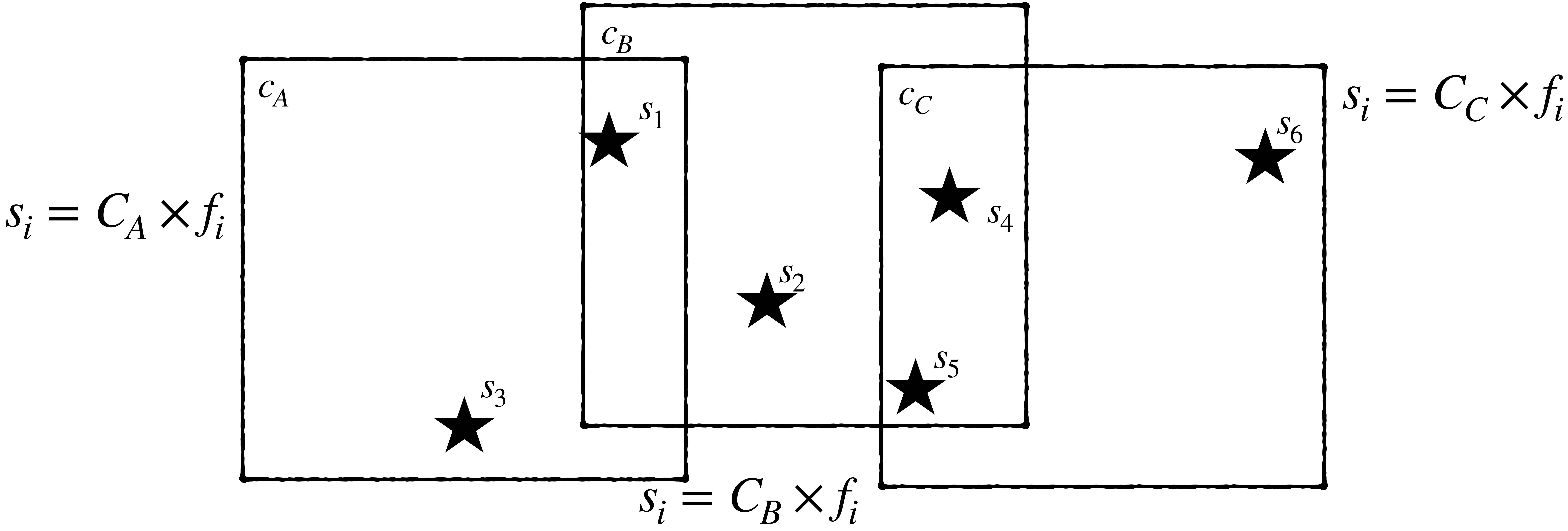
Variation in DECam i-band blue edge transmission over the field of view.

Self-consistency and ‘ubercalibration’

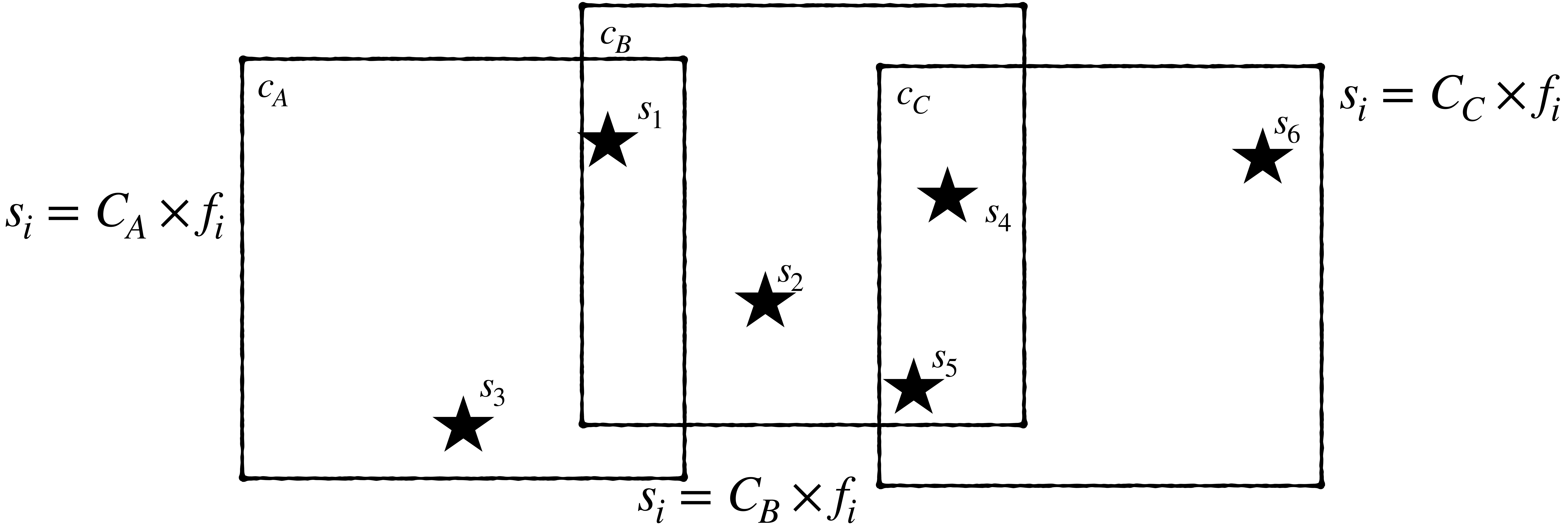


$s_i = C_A \times f_i$ $\quad$ $s_i = C_B \times f_i$

Self-consistency and ‘ubercalibration’



Self-consistency and ‘ubercalibration’



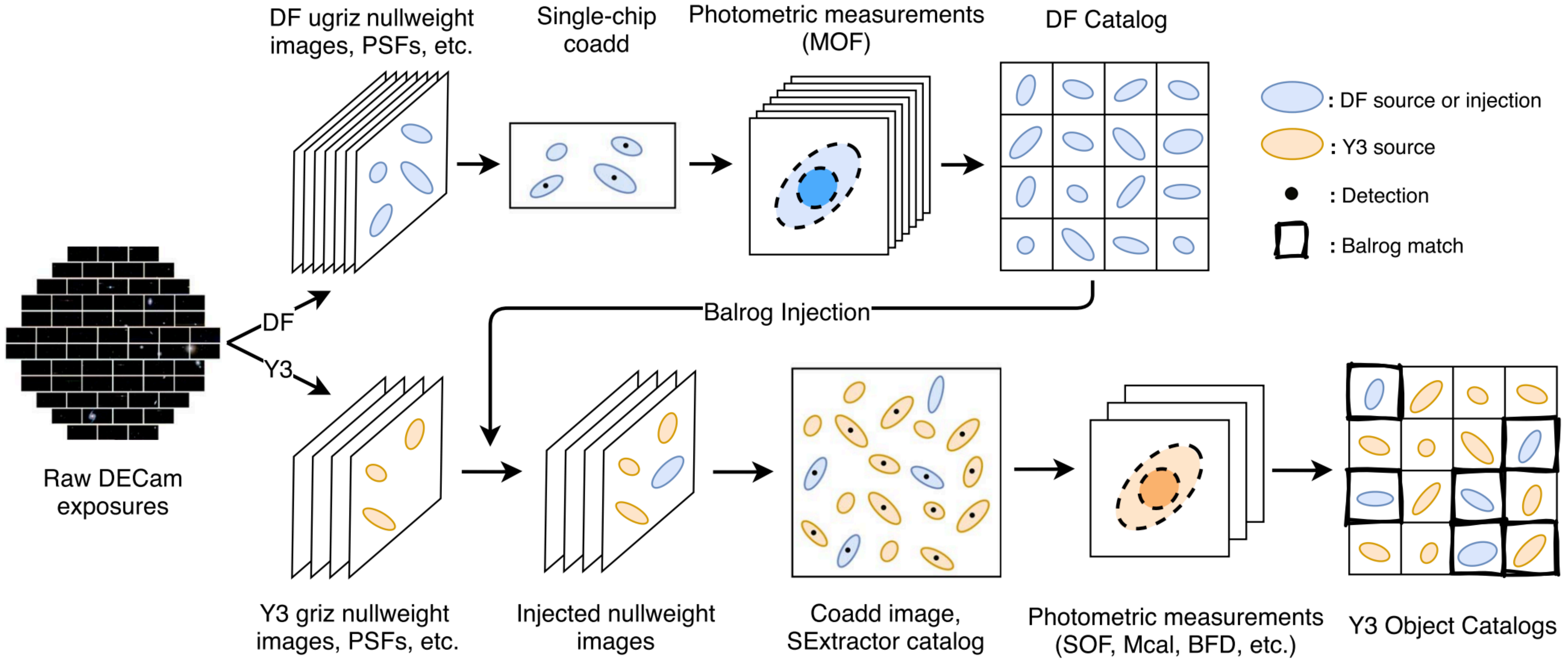
With overlap, we need more images, but with common measurements we can find the ratios $\frac{C_A}{C_B}$ and $\frac{C_B}{C_C}$.

Source injection

Measurement is very complicated.

It's actually extremely difficult to predict every possible systematic effect.

It's easier to just add known galaxies to the signal chain, and re-measure them afterwards.



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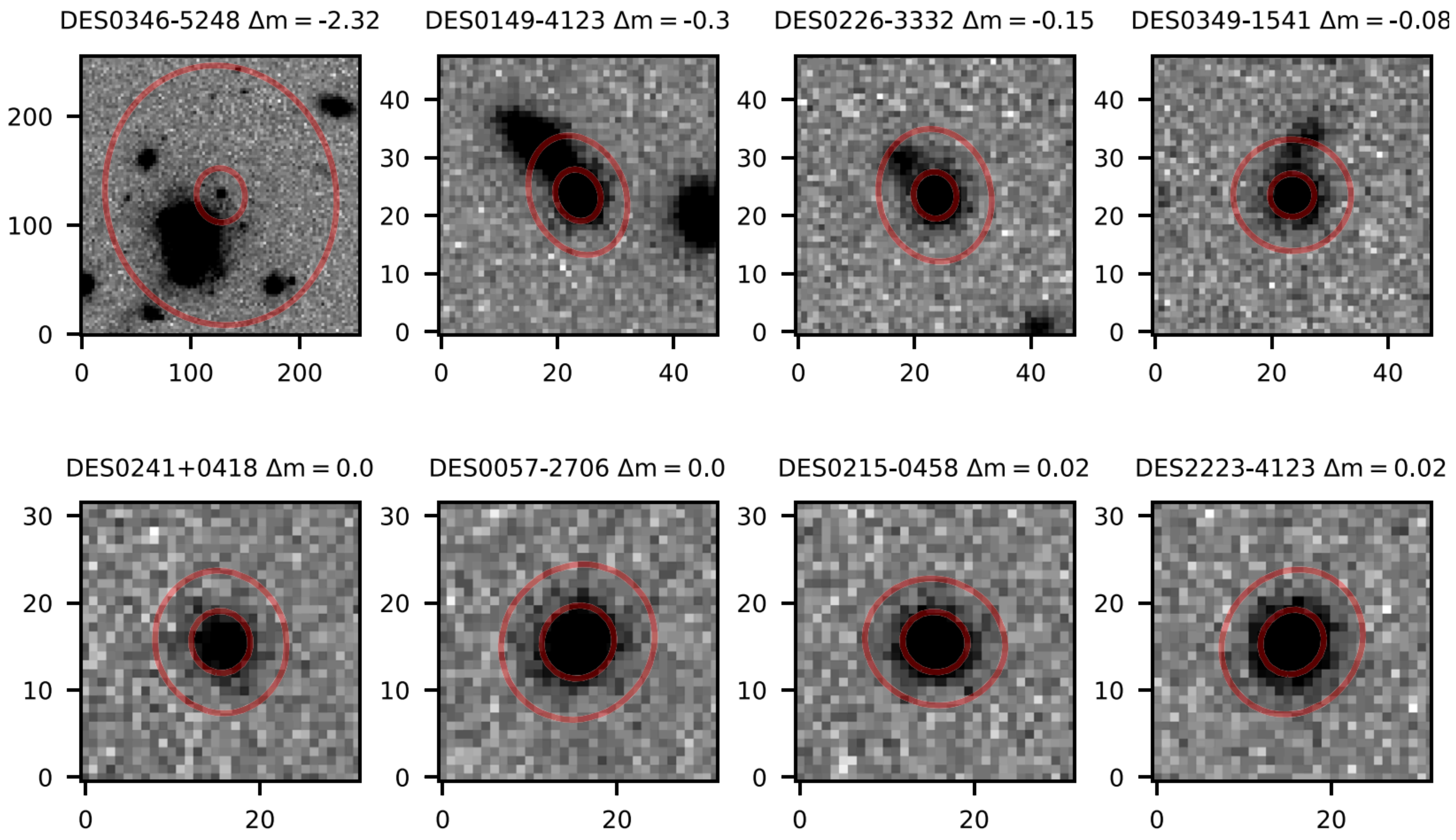

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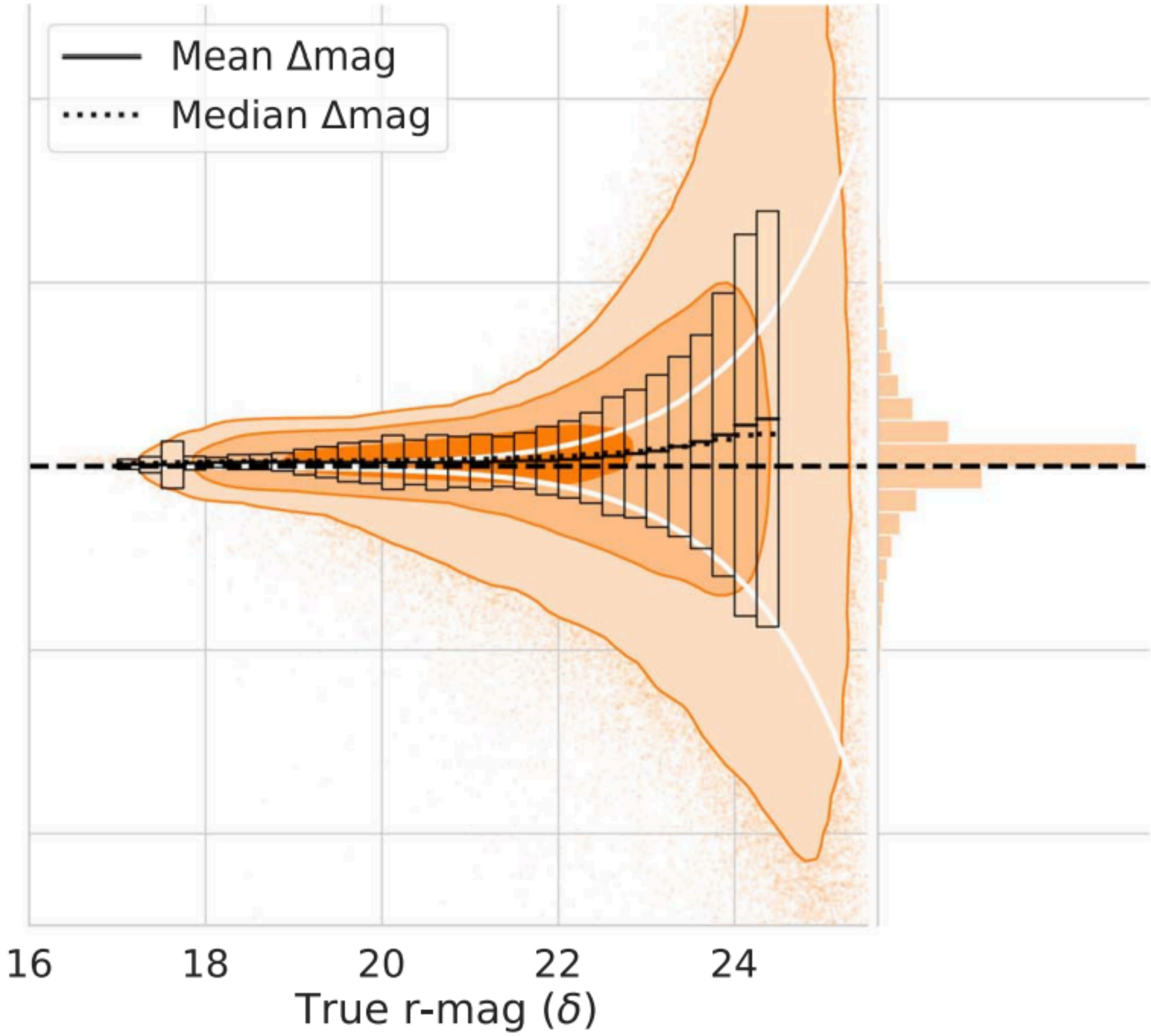

Galaxy photometry with complications

Let's talk about the meaning of g and s.

$$g(\mathbf{u}) + s(u)$$

Subaru intra-group light, from Martínez-Lombilla et al. 2022

Decomposing the light into 'source' and 'background' or 'interloper' components is a modeling choice.

Constructing a model to fit to galaxies.

$$I_i = \int d^2\mathbf{x}\,\Pi(\mathbf{x}-\mathbf{x}_i)\;\int d^2\mathbf{u}\,(\,g(\mathbf{u}) + s(\mathbf{u}\,)\,)\,p(\mathbf{u}-\mathbf{x}) + A$$

The star or galaxy we care about.

Other nearby galaxies.
Sky background
Diffuse extended light

Problem: We cannot simply construct T.

Solution:

- convert the question into a parameter estimation problem.

- add nuisance parameters to describe your model uncertainties.

Constructing a model to fit to galaxies.

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Since we don't have a 'template' for our target, we should build and fit a model.

General considerations:

- Model flexibility: can it actually fit any configuration of signal?
- Computational tractability: can we actually compute a model prediction?
- Degrees of freedom: can we actually constrain the model parameters?

Parameterized functional forms for galaxy light.

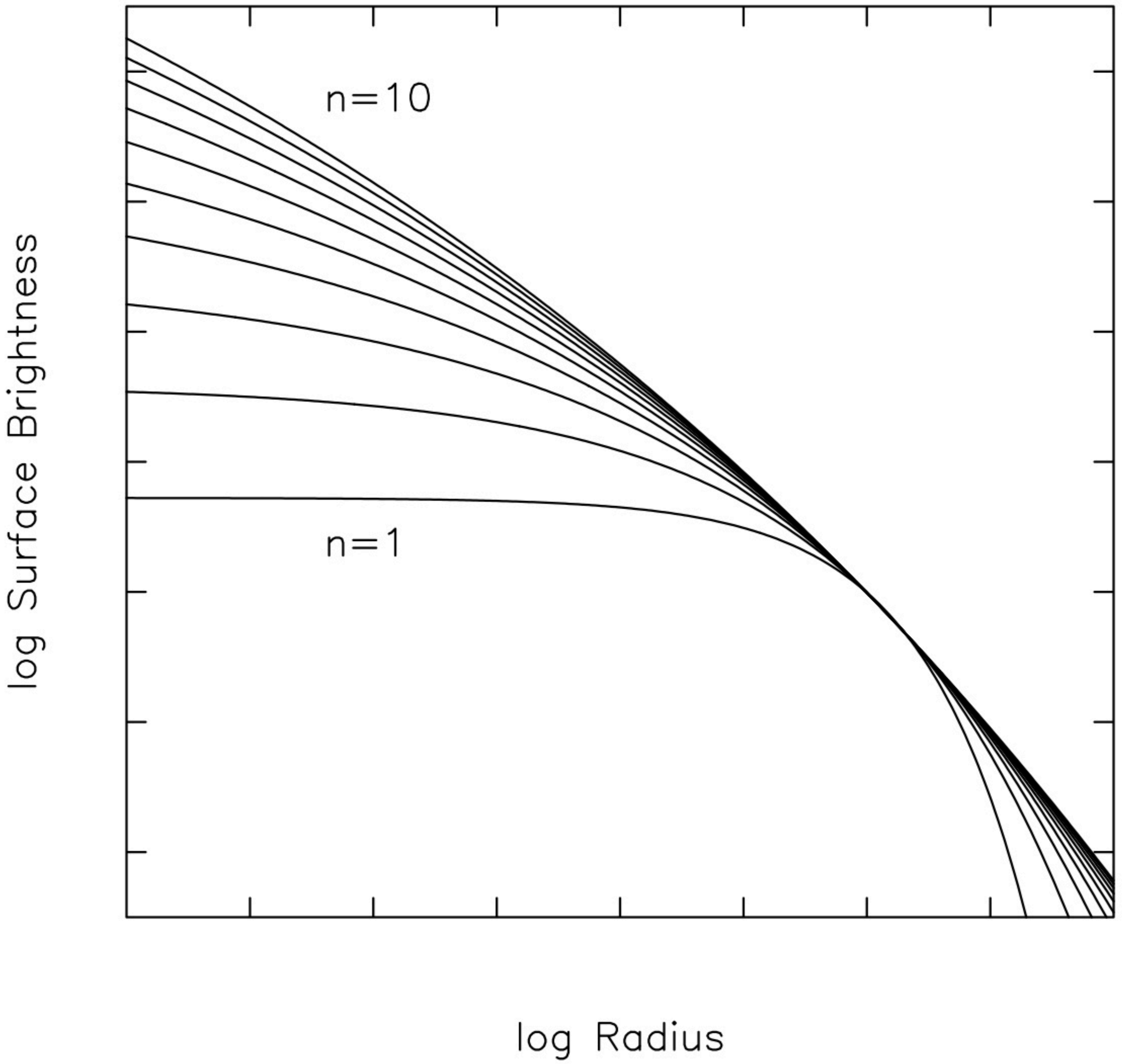
$$I_i = \int d^2\mathbf{x}\,\Pi(\mathbf{x}-\mathbf{x}_i)\int d^2\mathbf{u}\,(\,g(\mathbf{u}) + s(\mathbf{u}\,)\,)\,p(\mathbf{u}-\mathbf{x}) + A$$

$$I = I_0\, e^{-b_n\left[\left(\frac{r}{r_e}\right)^{\frac{1}{n}} - 1\right]}$$

The Sérsic profile is a common parameterization for galaxy surface brightness.

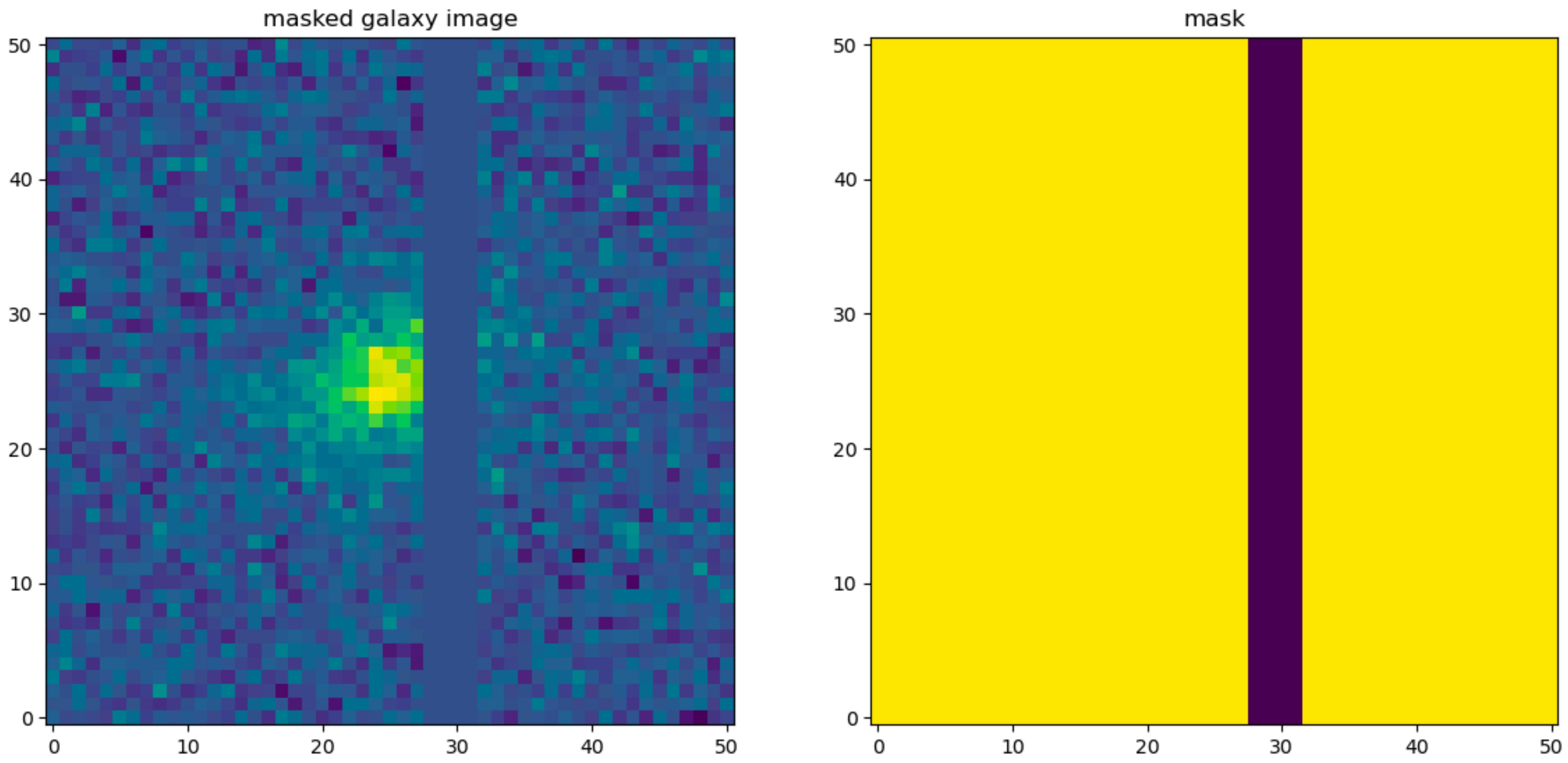
n — index setting slope of profile
r_e — half-light radius
I_0— Intensity at $r = r_e$

b_n is a function of *n,* roughly equal to $2n - \dfrac{1}{3}$



Things you can do once you can fit a model.

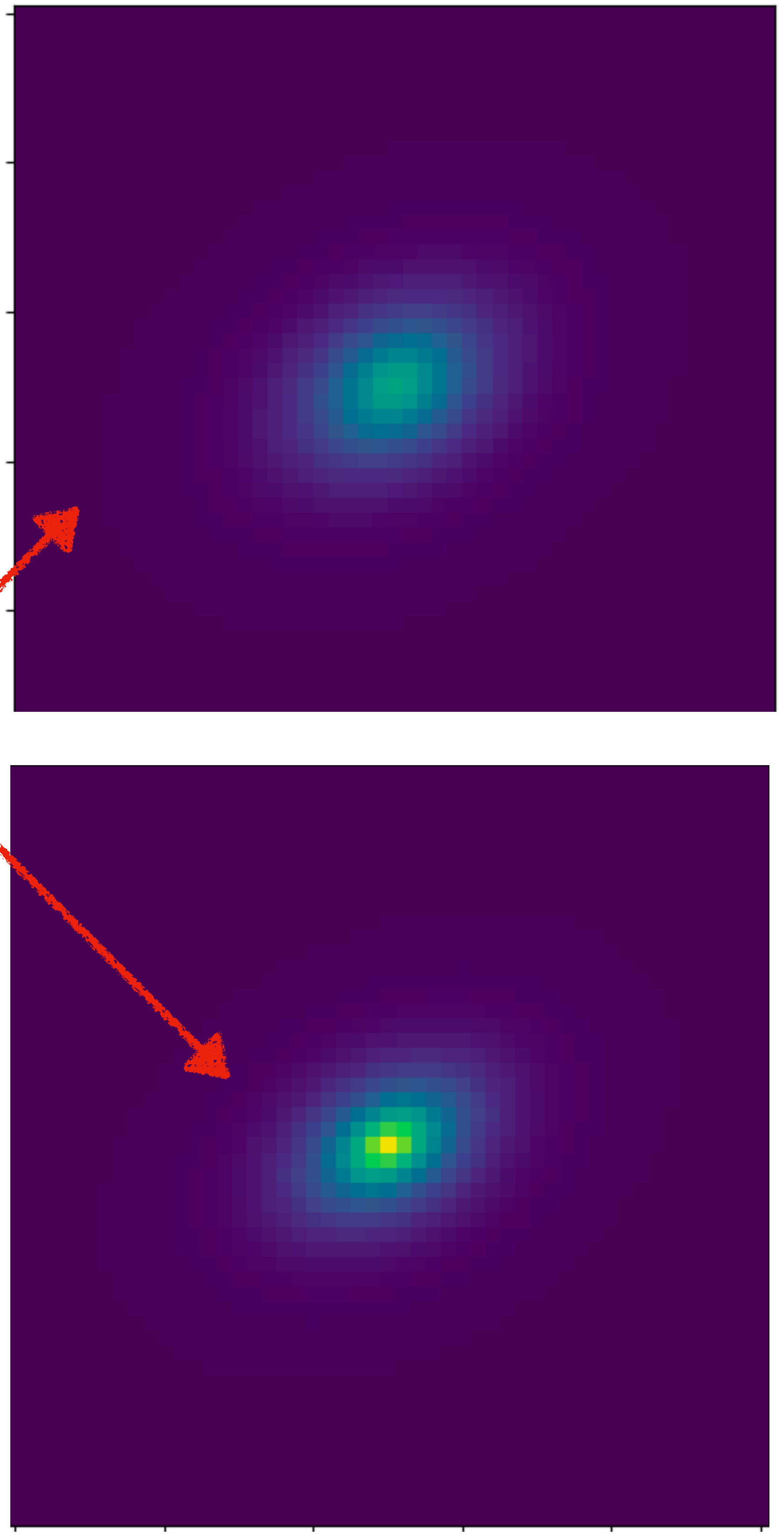
- Handle *masked* data



Things you can do once you can fit a model.

- Handle *masked* data
- Combine data with different PSFs

Same galaxy, different psf!



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- Combine data with different PSFs
- deblend overlapping galaxies.

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- Make measurements of galaxies you can't see (forced photometry)

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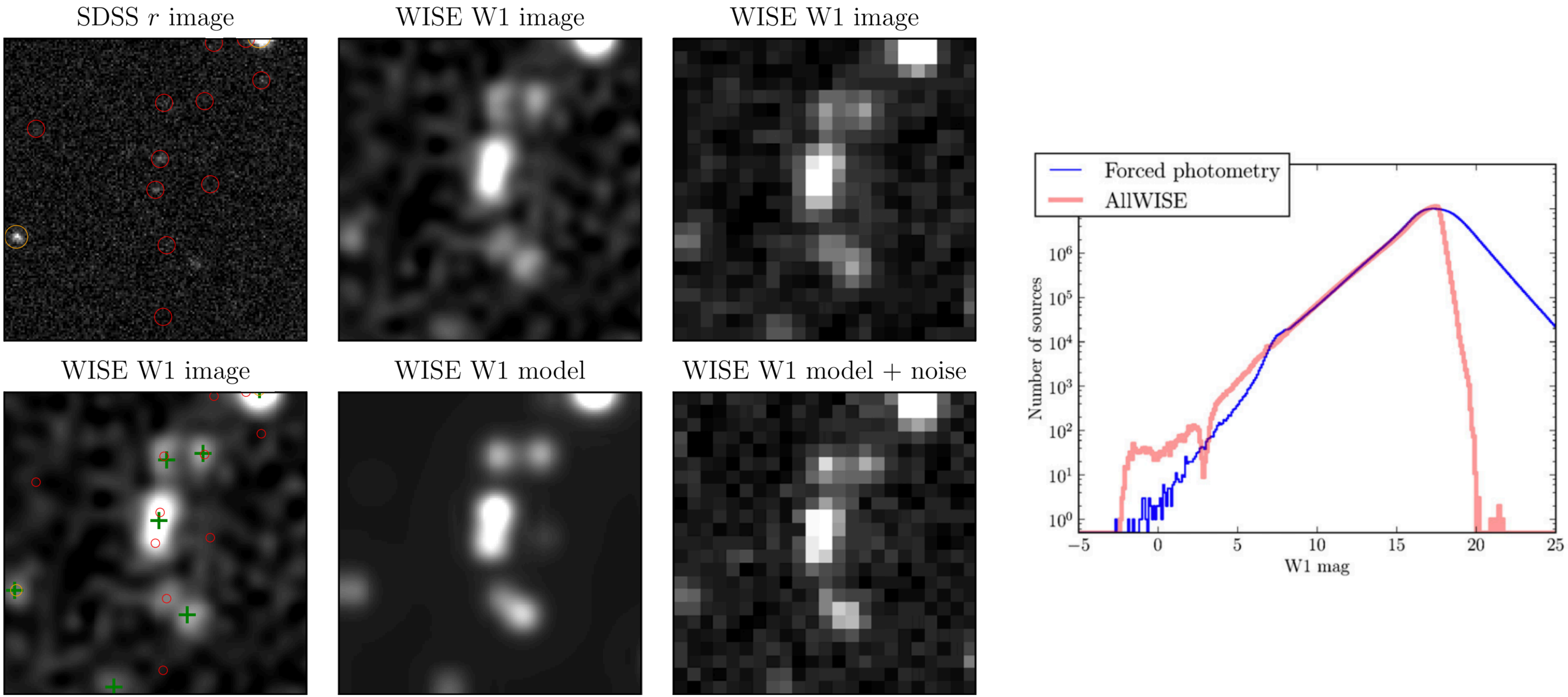
The Astronomical Journal, 151:36 (12pp), 2016 February Lang, Hogg, & Schlegel



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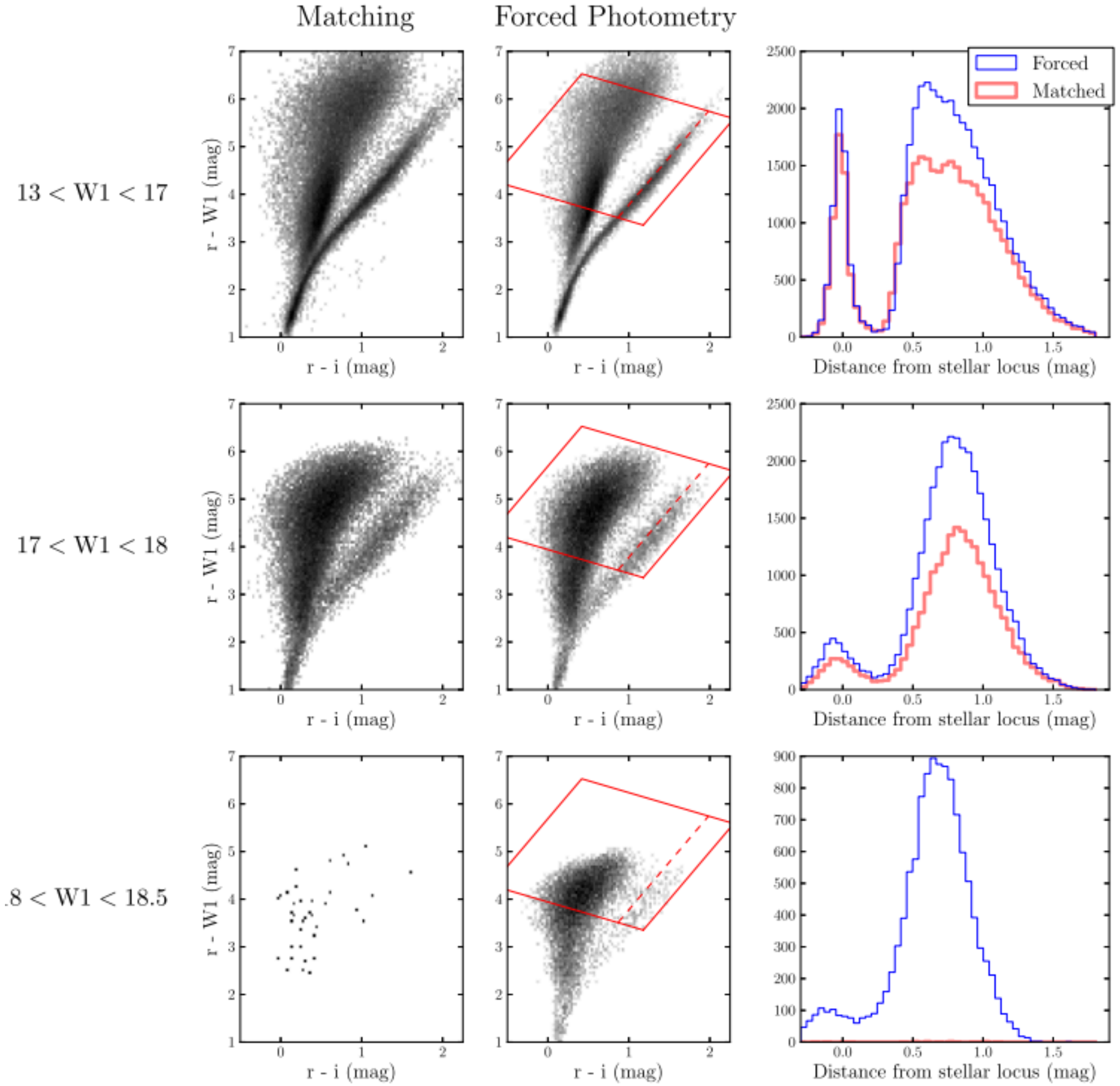
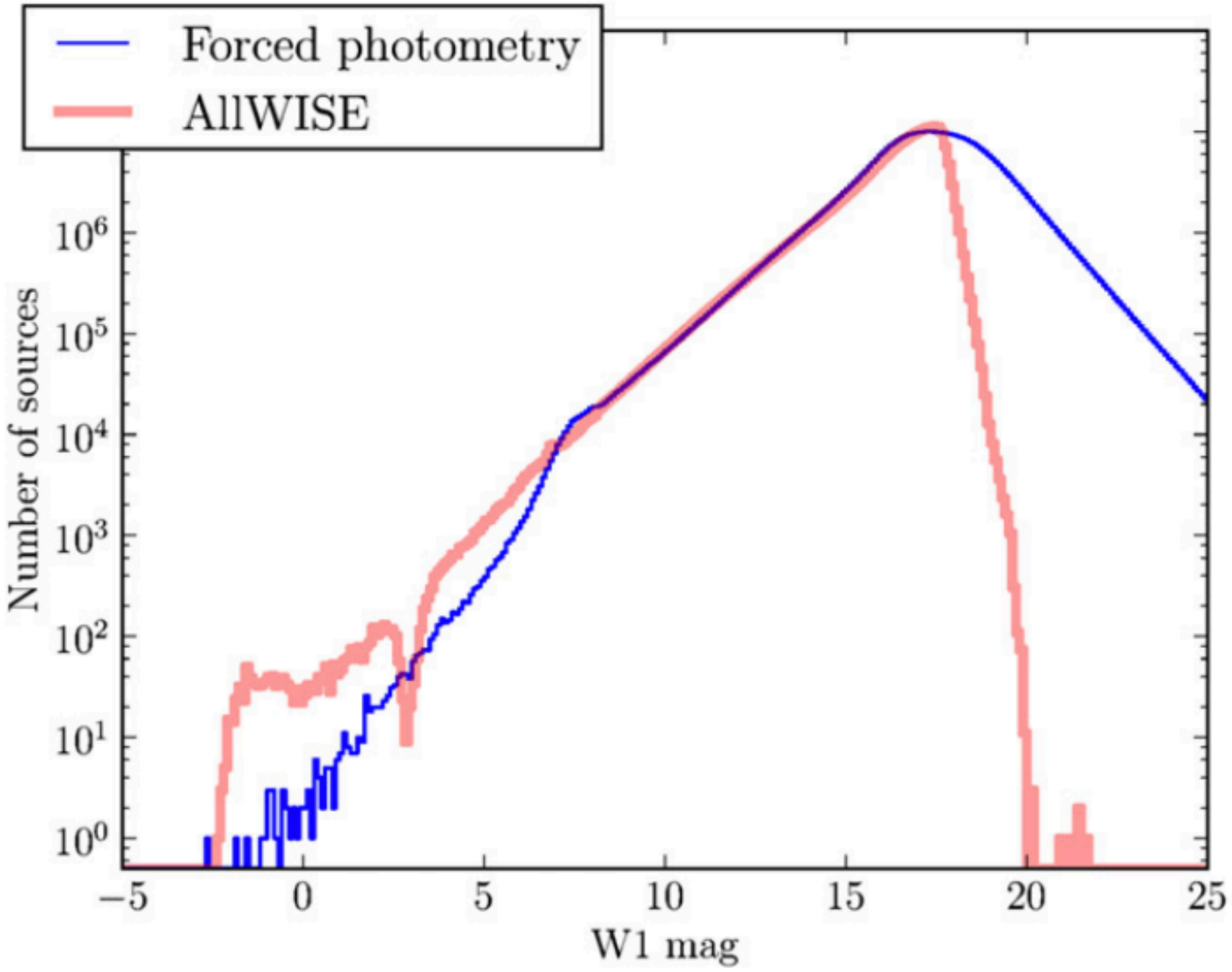
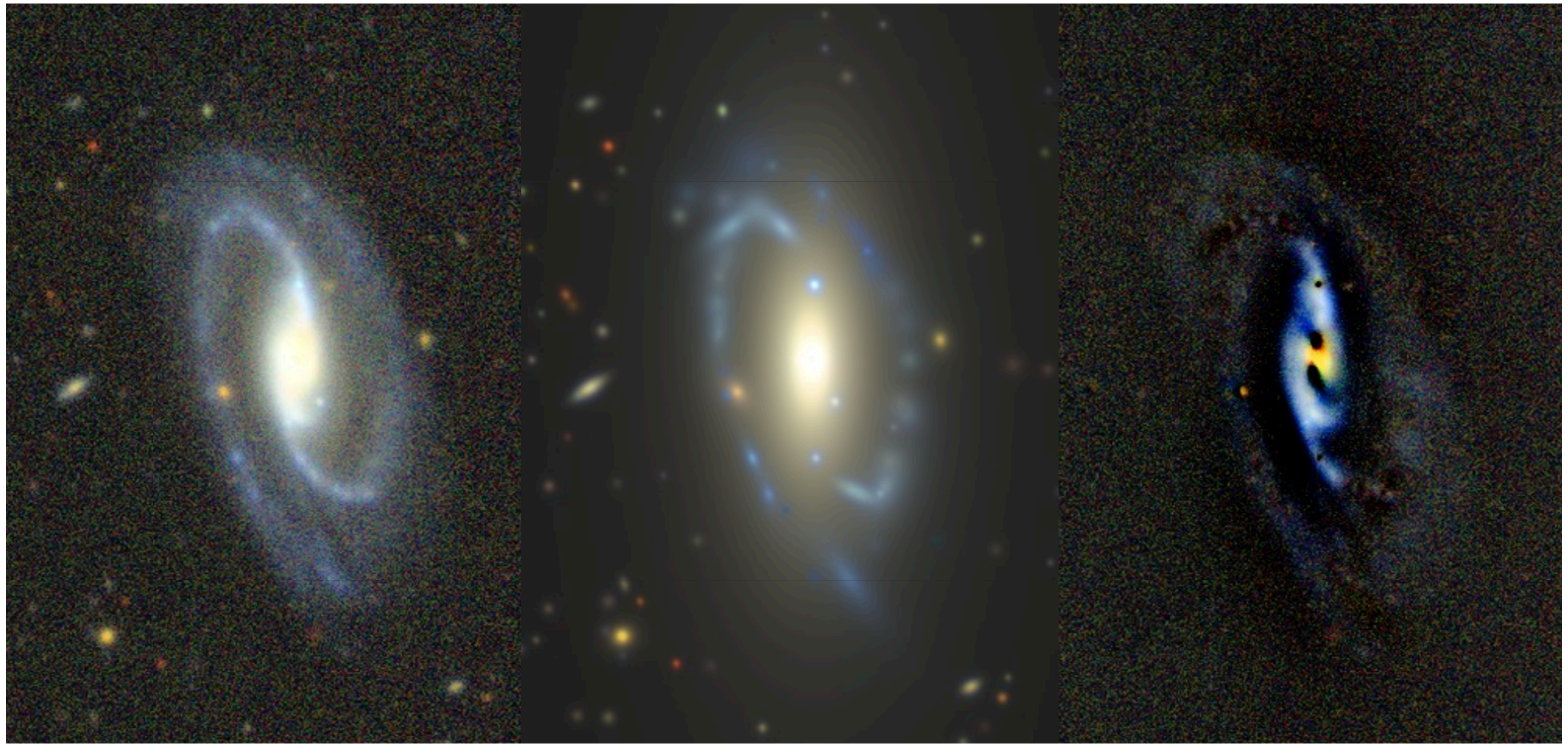




Things you can do once you can fit a model.

- Handle *masked* data
- Combine data with different PSFs
- deblend overlapping galaxies.
- Make measurements of galaxies you can't see (forced photometry)
- Interrogate the best-fit model



Exercise:

Open the *Simulated galaxy photometry.ipynb* notebook.

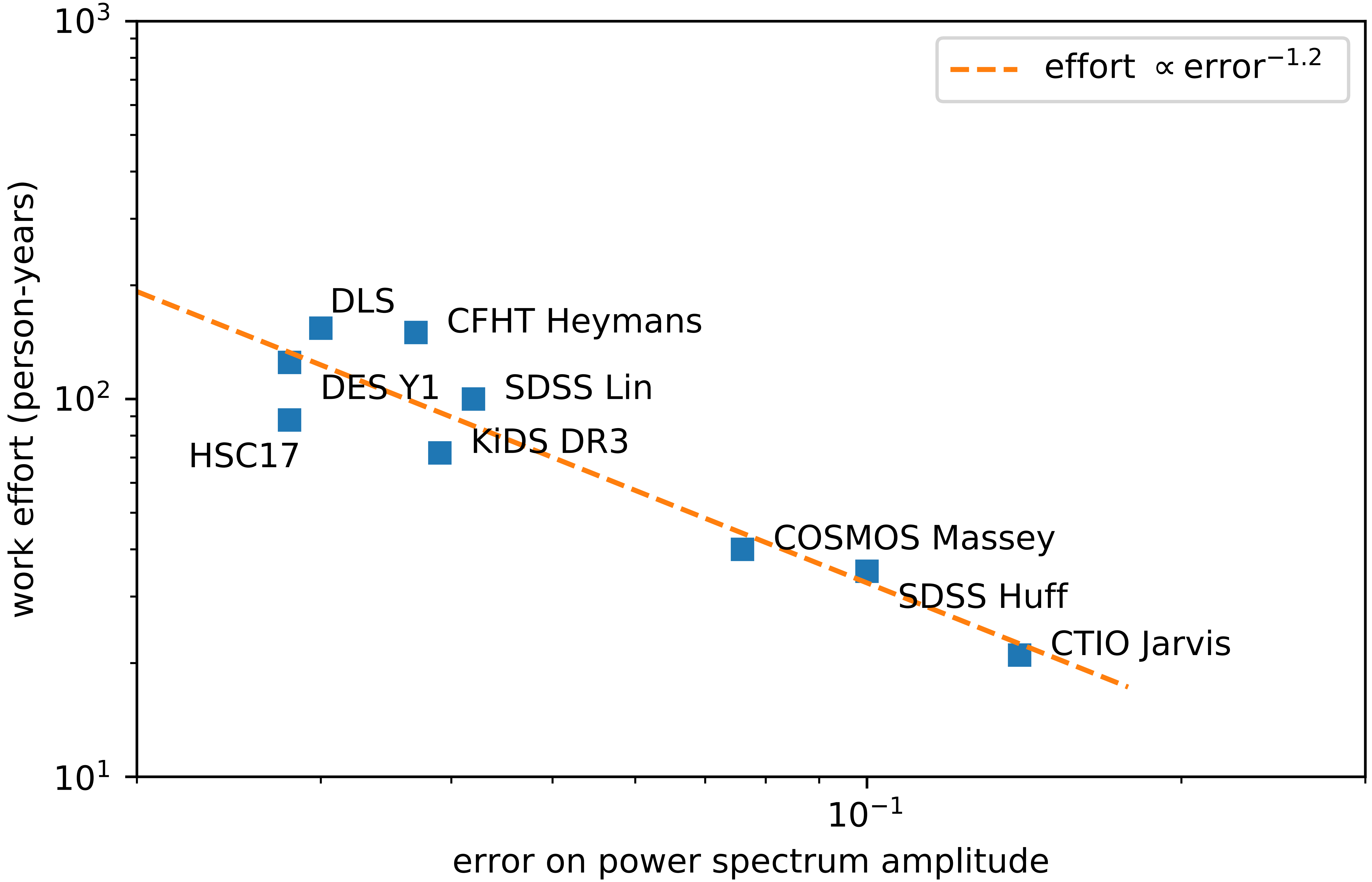
This will take us through the galaxy photometry model-fitting exercise.

Exercise:

Open the *Measurements with GalSim* notebook.

This will give you a measurement task on real data.

Larger context: precision science is hard!



Larger context: precision science is hard!