Thesis defense

Simulating multi-wavelength observations from low-resolution spectrographs

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22/1-2020

Aarhus University

Outline

- Motivation
  - Exoplanetary atmospheres
- Simulation
  - Step-by-step walkthrough
- Using the simulator
- Future work

Motivation

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- Search for alien life

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- Biosignatures and indicators

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  - Water, CO_2, oxygen

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- Search for alien life
- Biosignatures and indicators
  - Water, CO_2, oxygen
- Atmospheres

Exoplanetary atmospheres

Exoplanetary atmospheres

How to detect them:

- Direct imaging
- Transit method

Exoplanetary atmospheres

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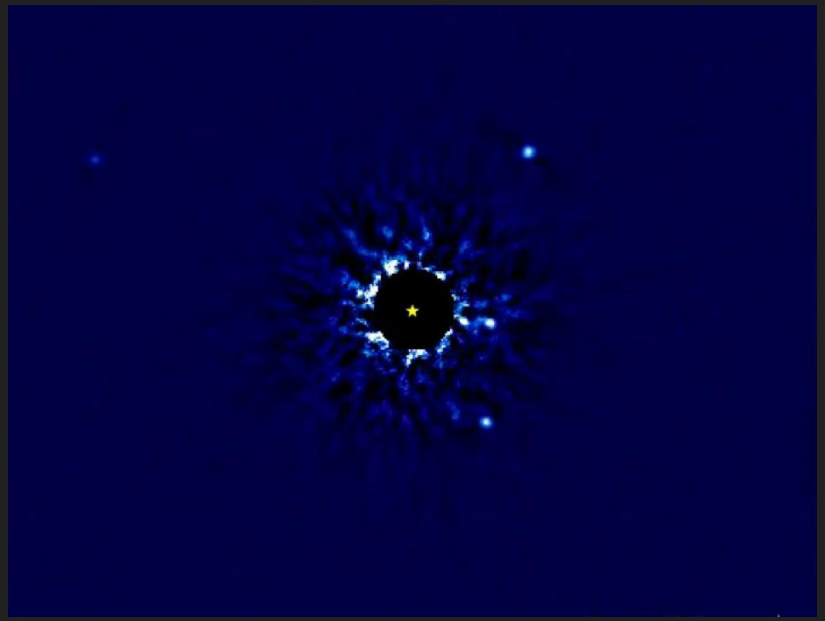
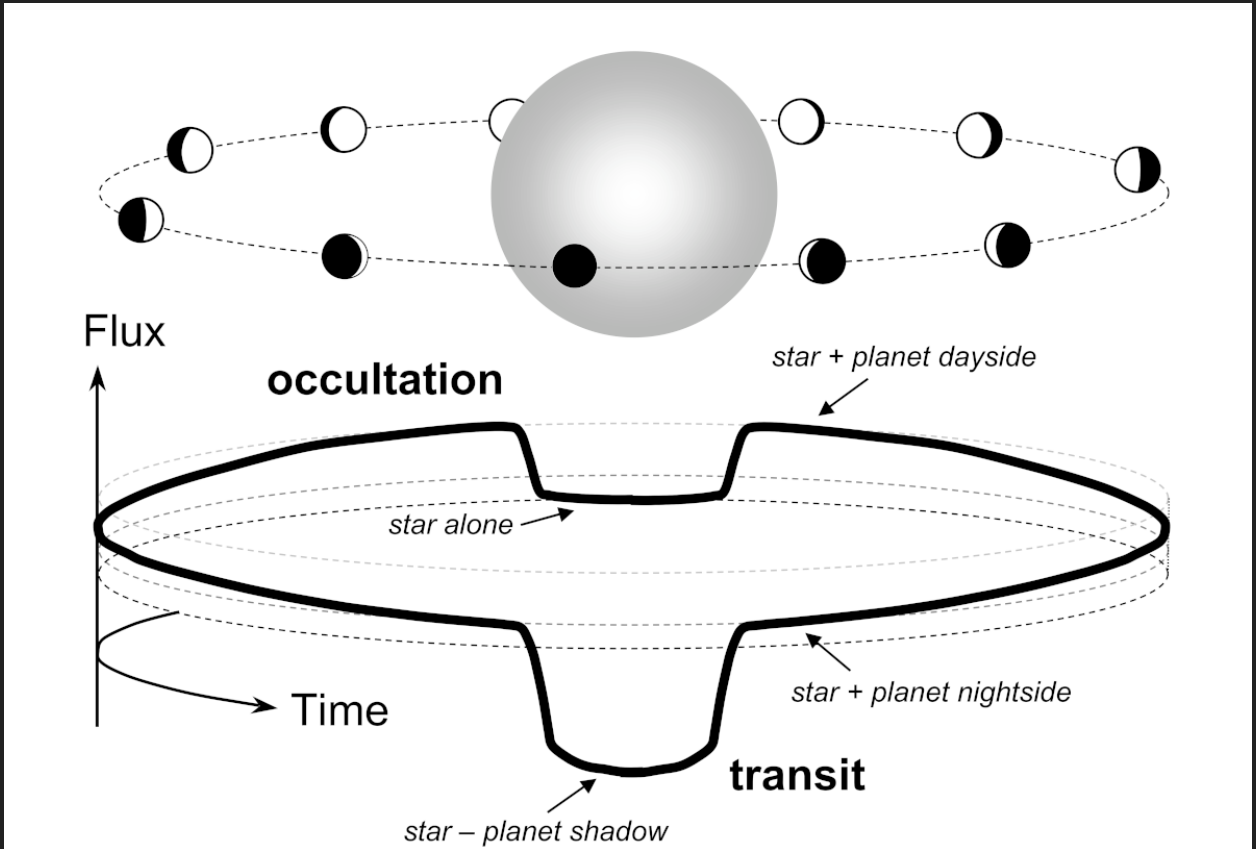


W.M. Keck observatory, J. Wang, C. Marois

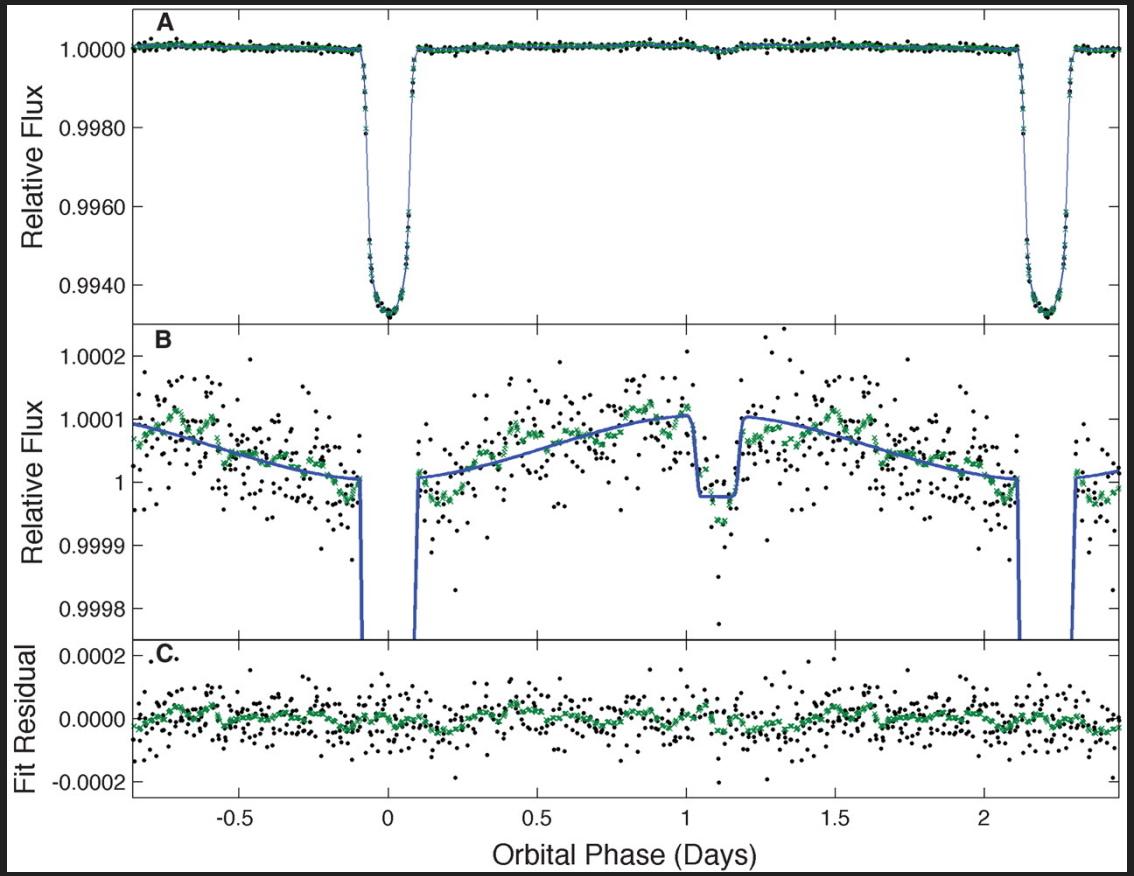
Transit method

Transit method



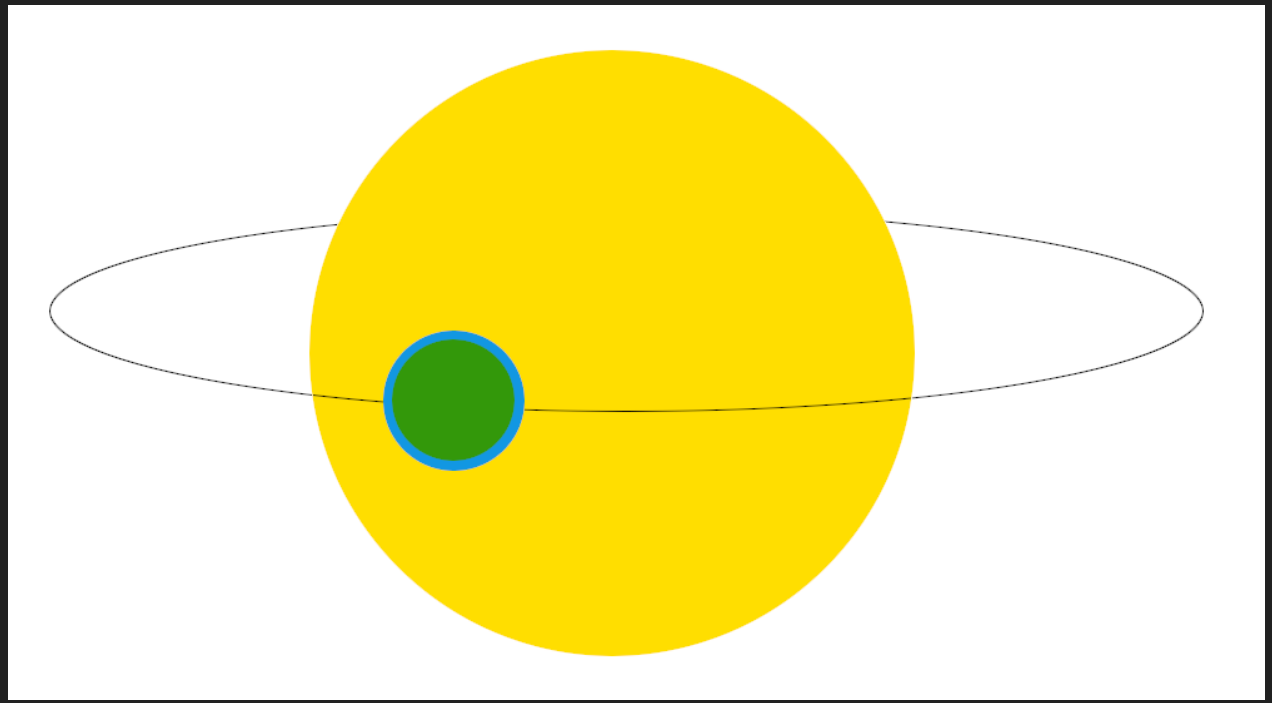
Winn 2014

Transit method



Borucki et al. 2009

Transit method



Transit method + spectroscopy

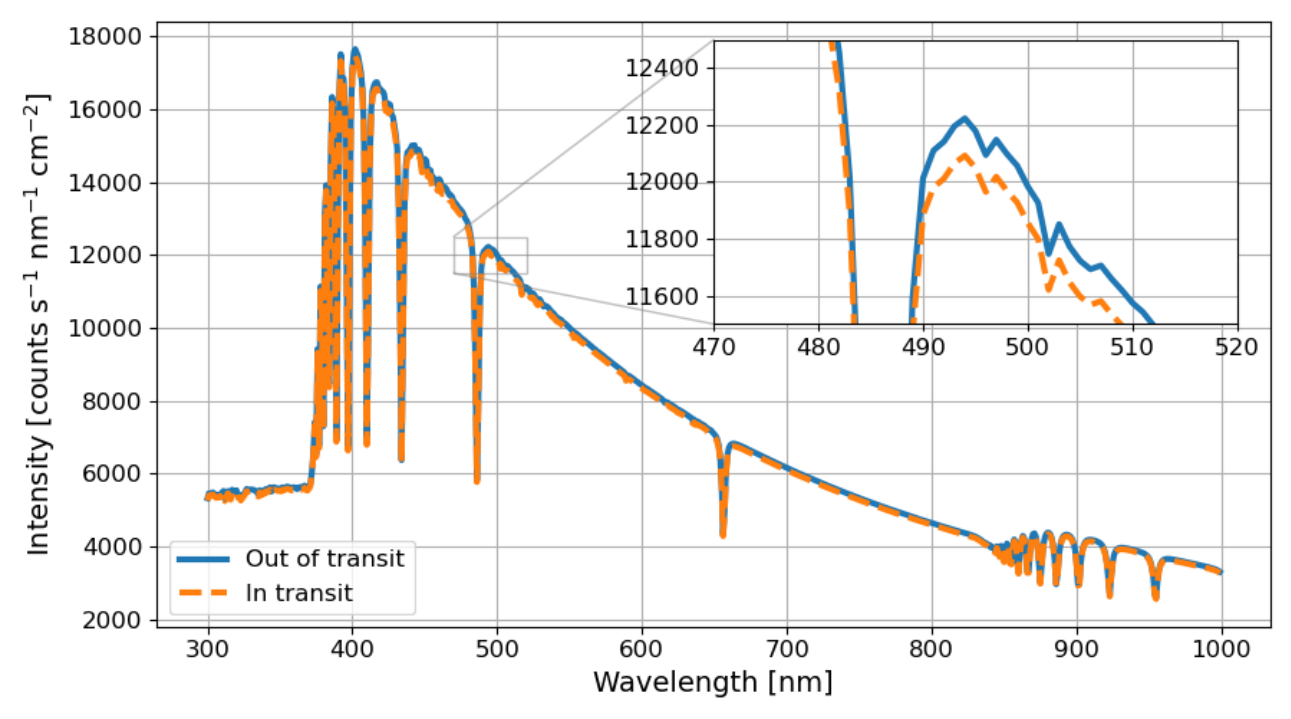


Fig. 8.1

Transit method + spectroscopy

Transit method + spectroscopy

Transmission spectrum:

Transit method + spectroscopy

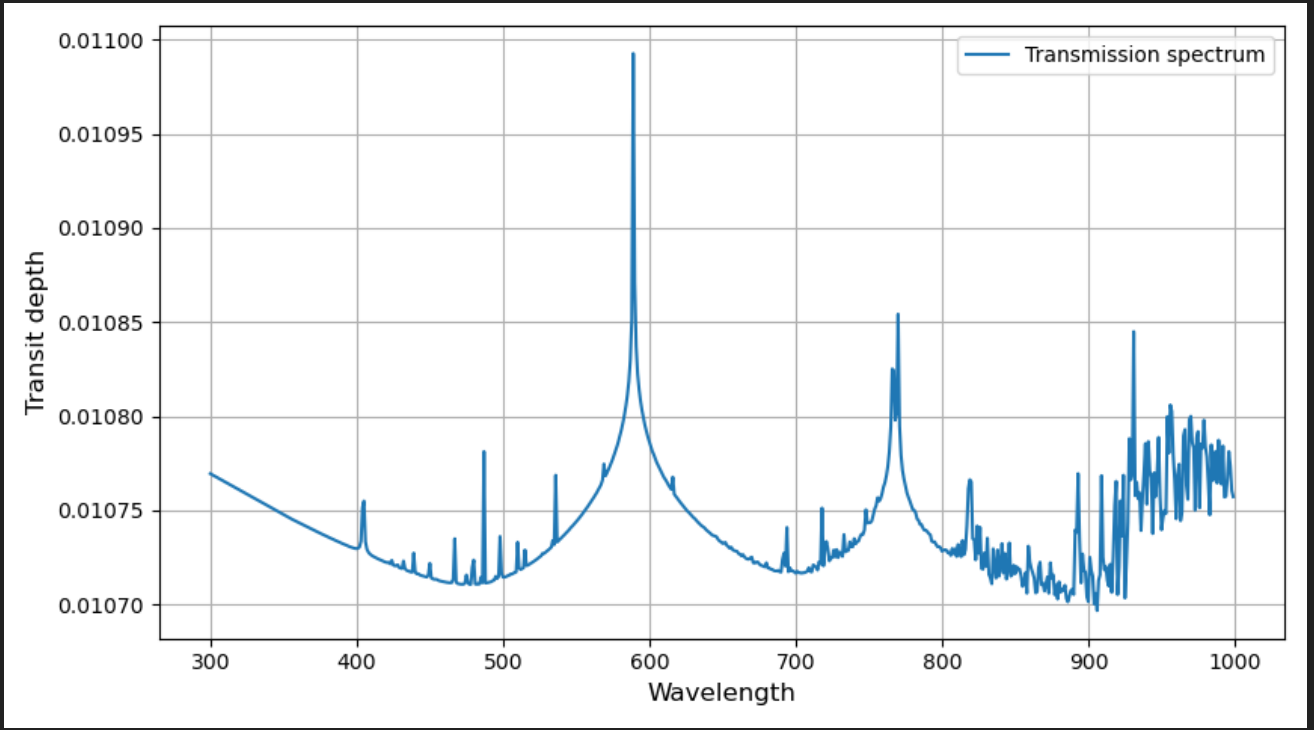
Transmission spectrum:

Transit method + spectroscopy

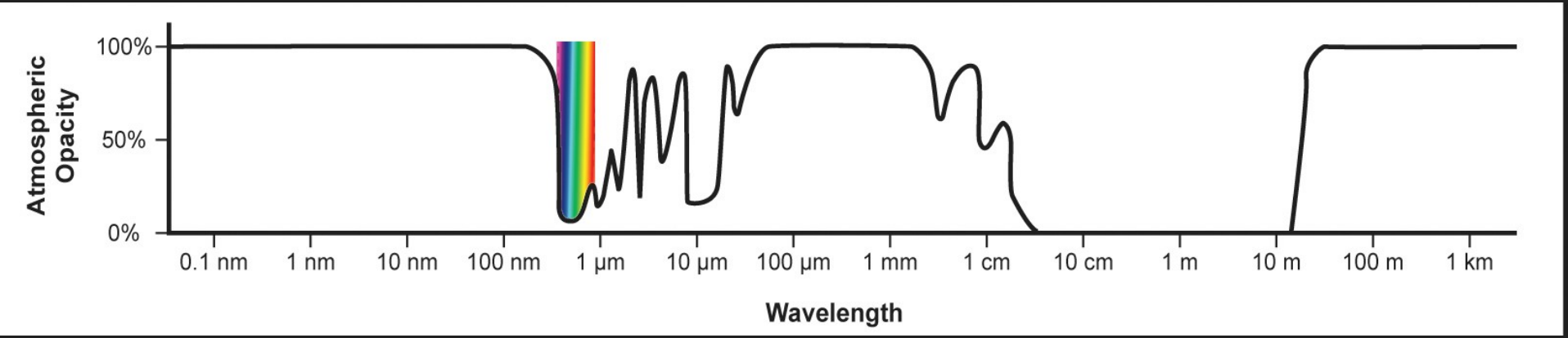
Transmission spectrum:

$$S_{Transmission} = \frac{\left(S_{in} - S_{out} \right)}{S_{out}}$$

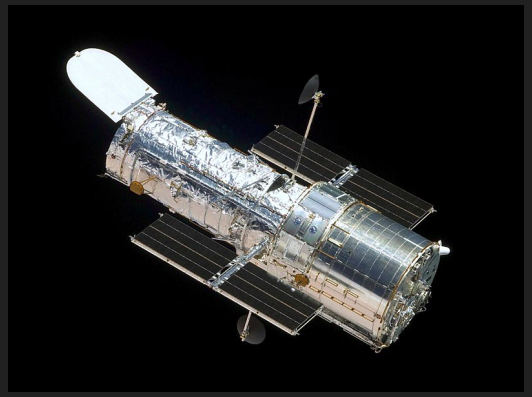
Transit method + spectroscopy



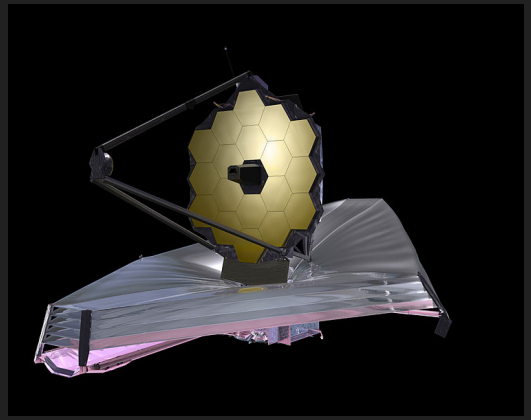
Another atmosphere...



Satellite-based spectroscopy



NASA



NASA

ESA

Simulator

- HIDRA: Hyperspectral Instrument Data Resemblance Algorithm
  - Modular simulator for low-resolution spectroscopy
  - Written in Python

- 1 nm spectral resolution $(\Delta\lambda)$

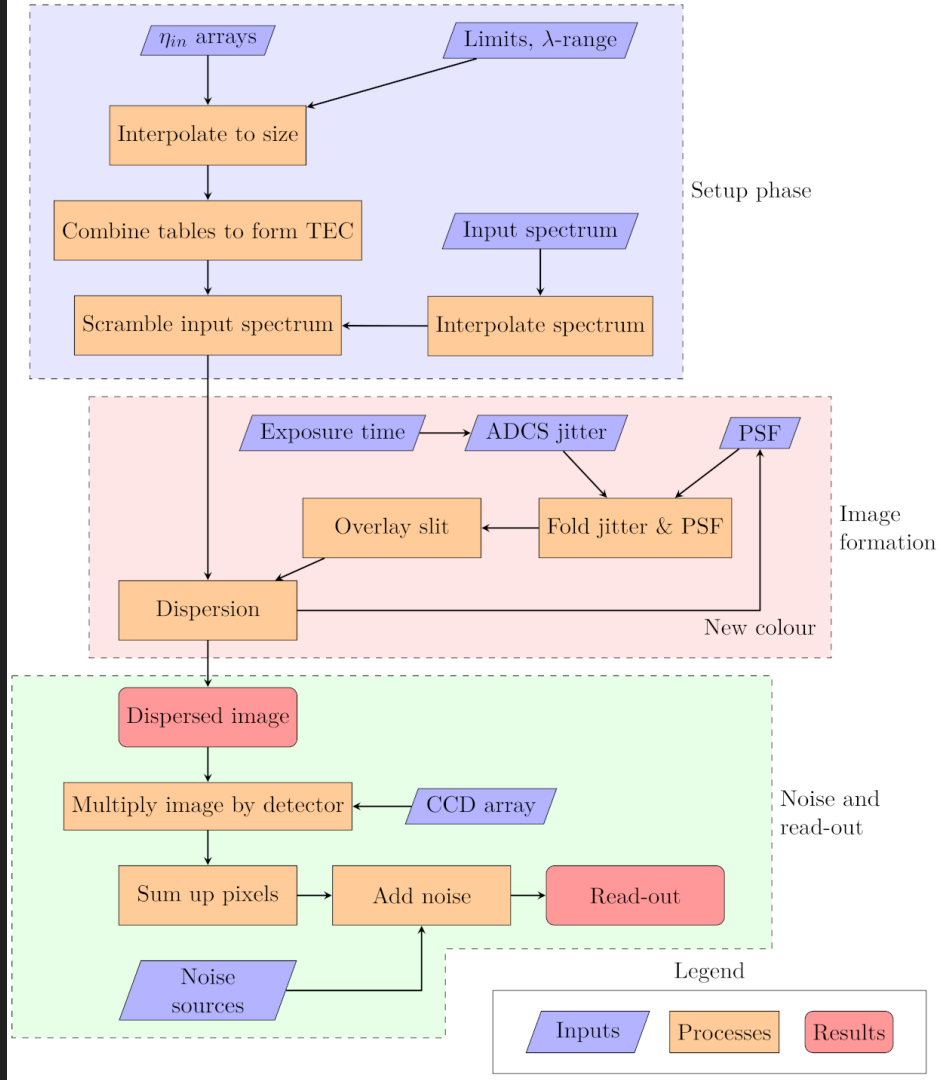

η_{in} arrays
Limits, λ-range
Interpolate to size
Combine tables to form TEC
Input spectrum
Scramble input spectrum
Interpolate spectrum
Setup phase
Exposure time
ADCS jitter
PSF
Overlay slit
Fold jitter & PSF
Image formation
Dispersion
New colour
Dispersed image
Multiply image by detector
CCD array
Noise and read-out
Sum up pixels
Add noise
Read-out
Noise sources
Legend
Inputs
Processes
Results

Fig. 6.1

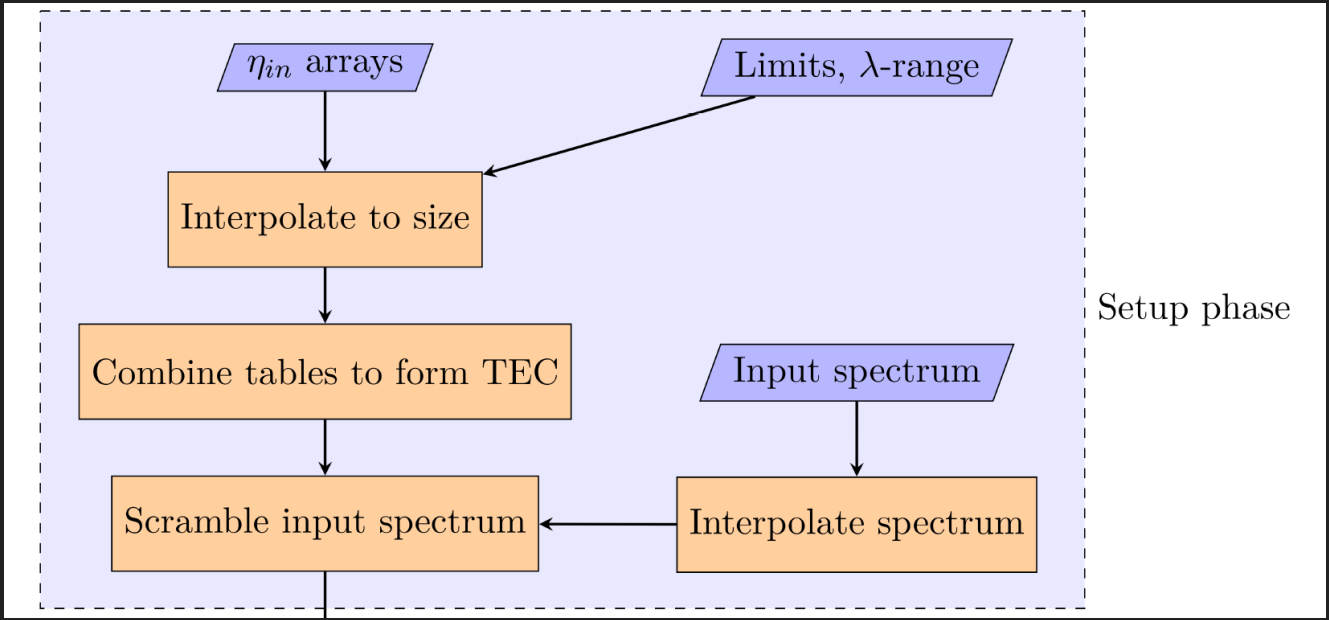
Inputs

- Input spectra
  - In and out of transit
- Spectral throughput, η_{in}
  - CCD QE, spectral response of optics, etc.
- Pixel size, plate scale, etc.

Parameter	Value
in_spec	See figure 8.1
wl_ran	300-1000
col_area	200 cm^2
img_size	1000×100
pl_scale	355.63 arcsec mm^{-1}
pix_size	13.5 µm
exp	300 s
PSF FWHM	3 pix. @300 nm
sub_pix	10 $pixel^{-1}$
eta_in	See figure 8.2
slit	variable
jitter	1.3 arcsec (RMS)

Tab. 8.1

Step 1: Setup and interpolate



Step 1: Setup and interpolate

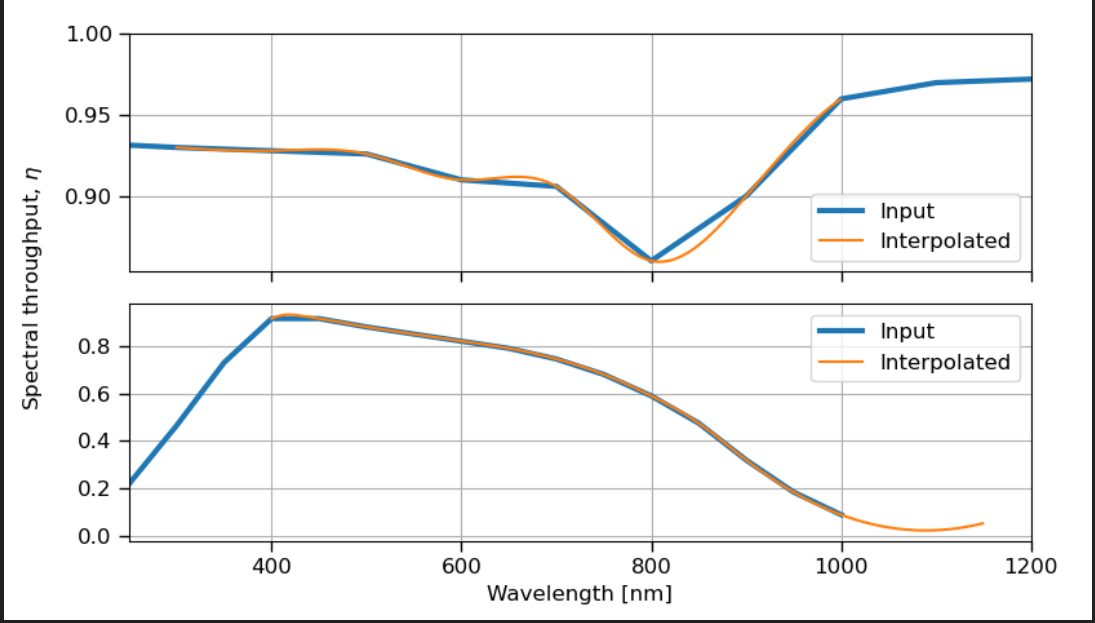


Fig. 7.1

Step 1: Setup and interpolate

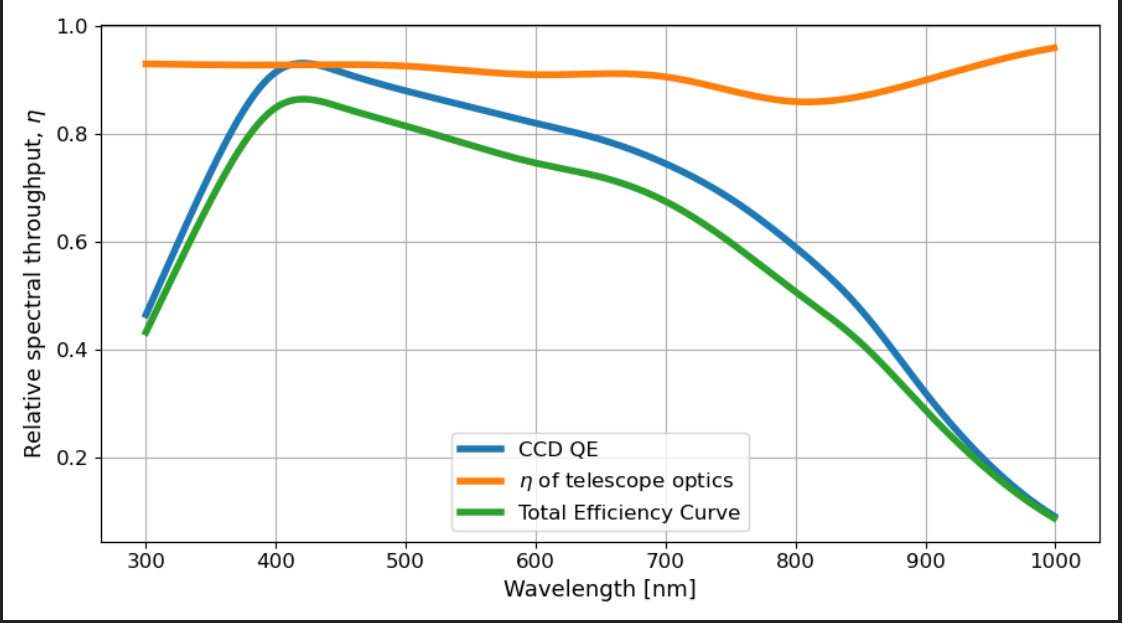
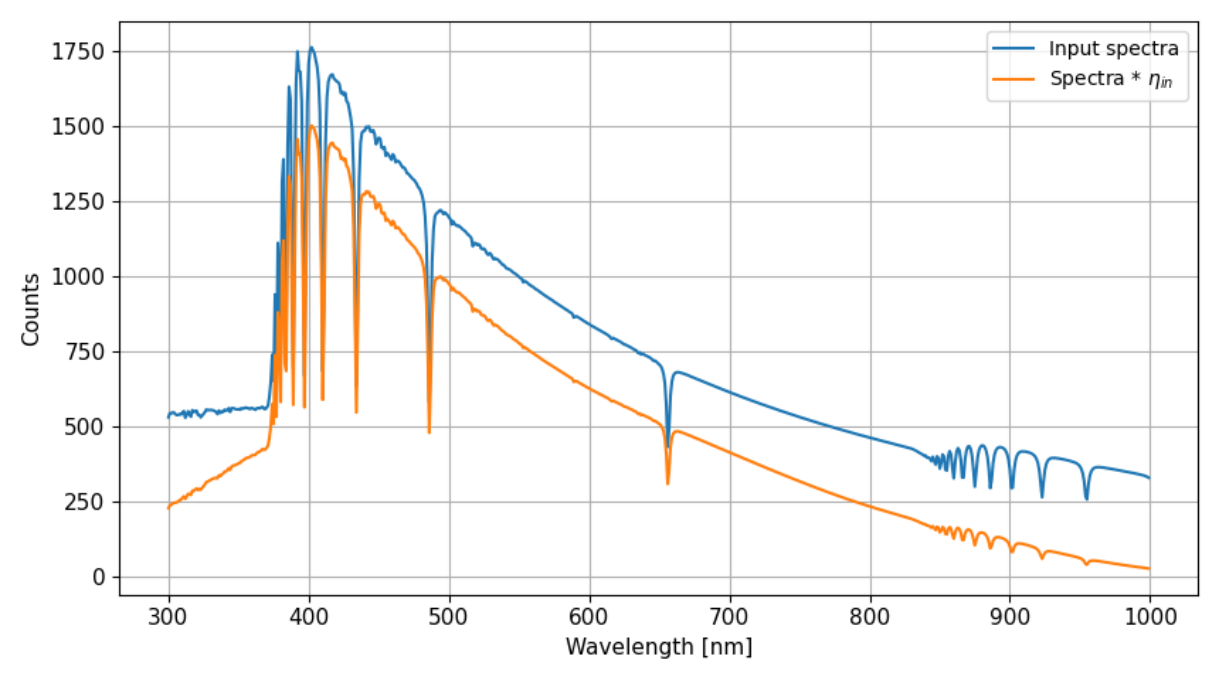
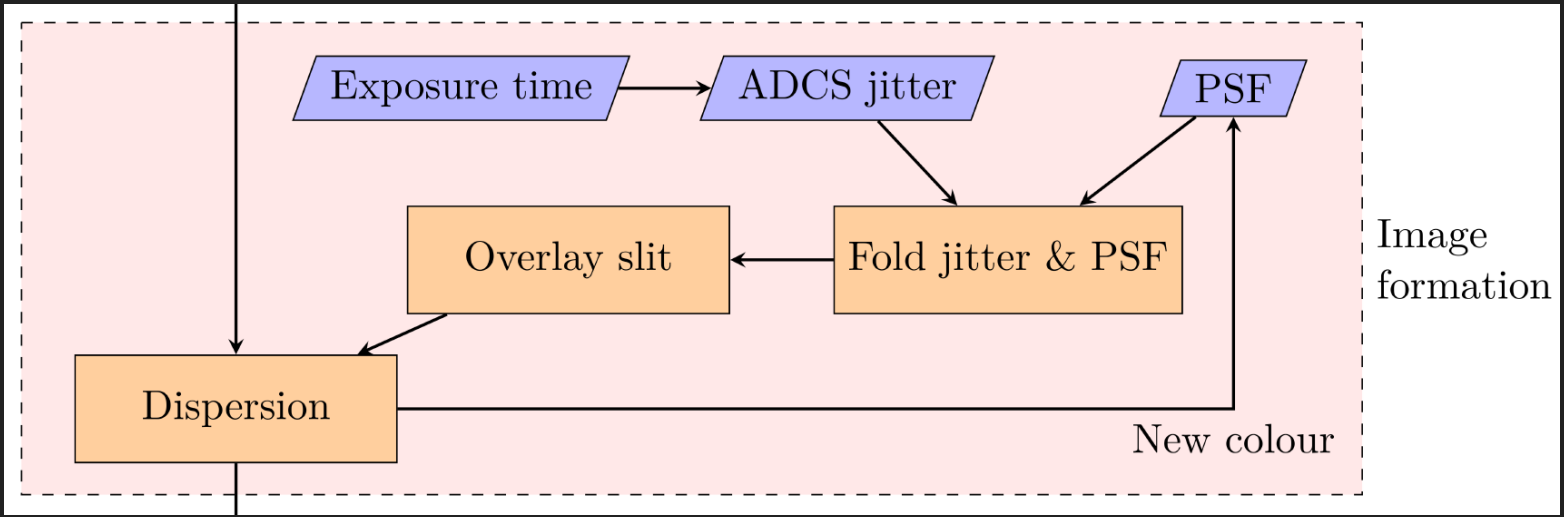


Fig. 8.2

Step 1: Setup and interpolate

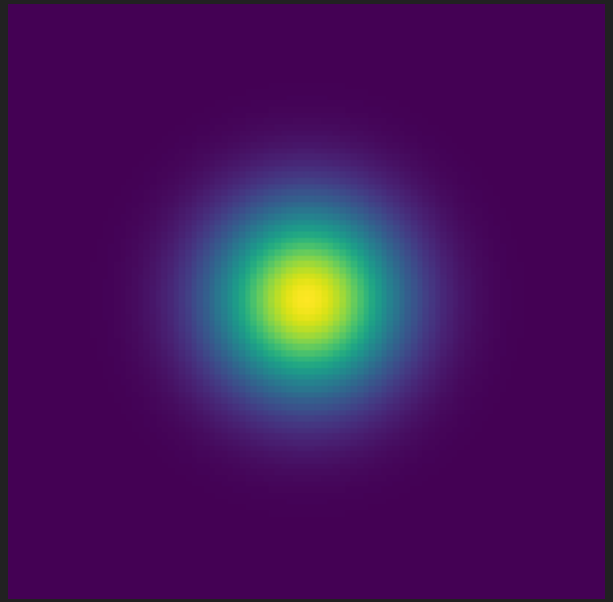


Step 2: Image formation



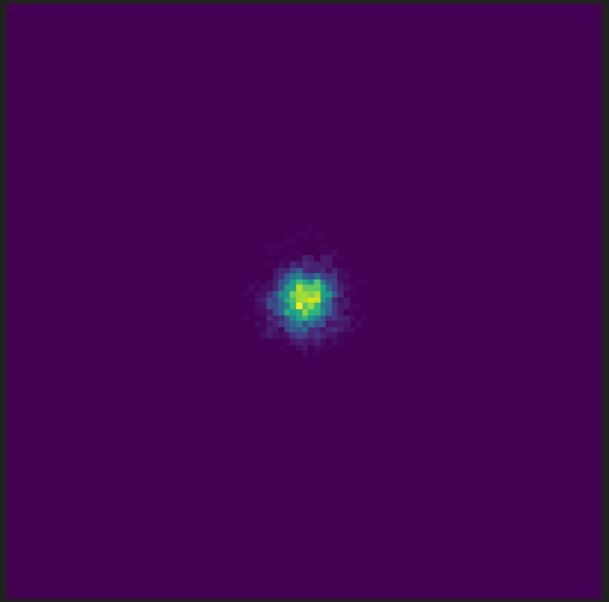
PSF & Jitter

Point Spread Function



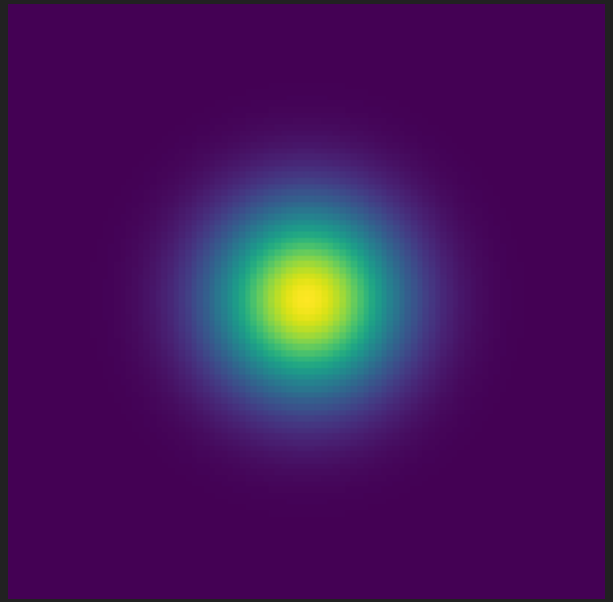
Convolution

Spacecraft jitter / seeing



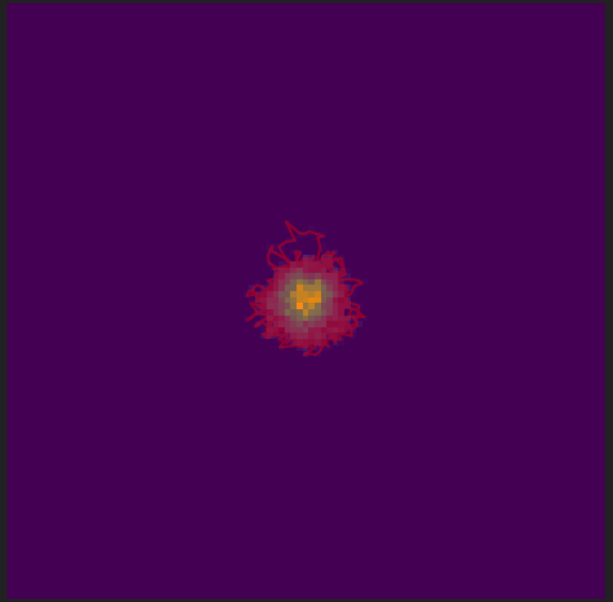
PSF & Jitter

Point Spread Function



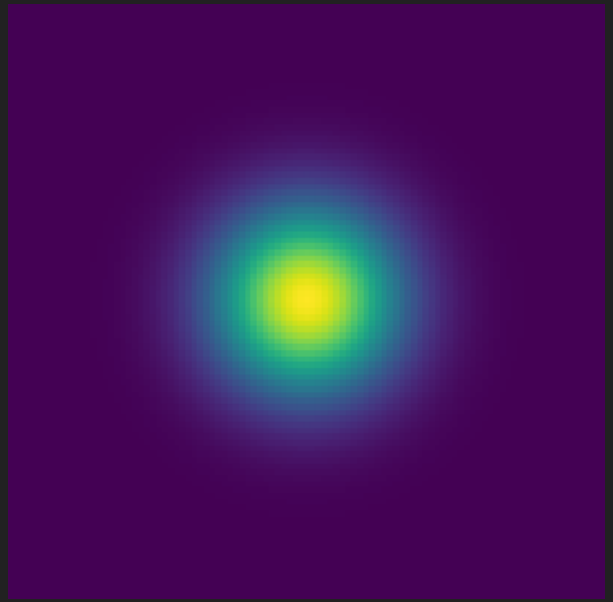
Convolution

Spacecraft jitter / seeing



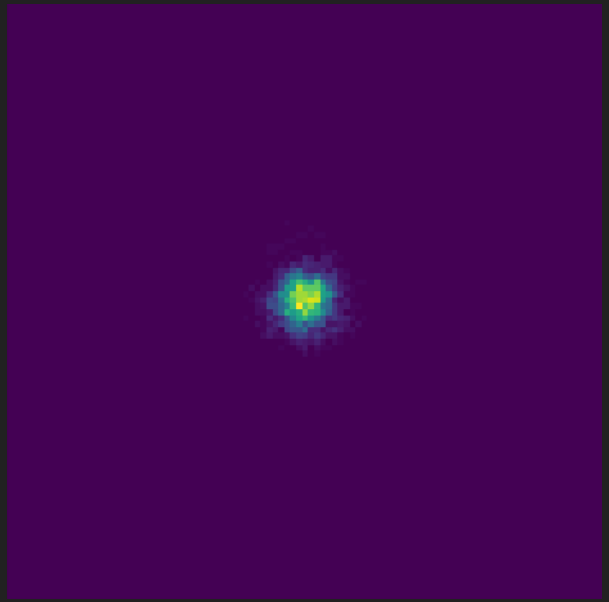
PSF & Jitter

Point Spread Function

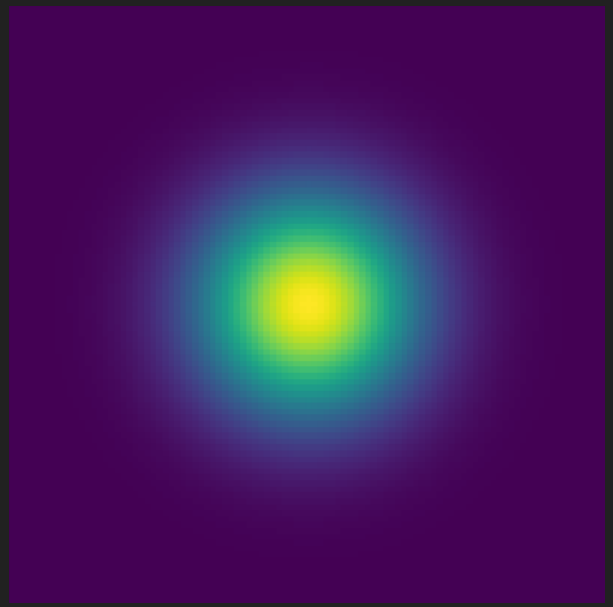


Convolution

Spacecraft jitter / seeing



PSF & Jitter



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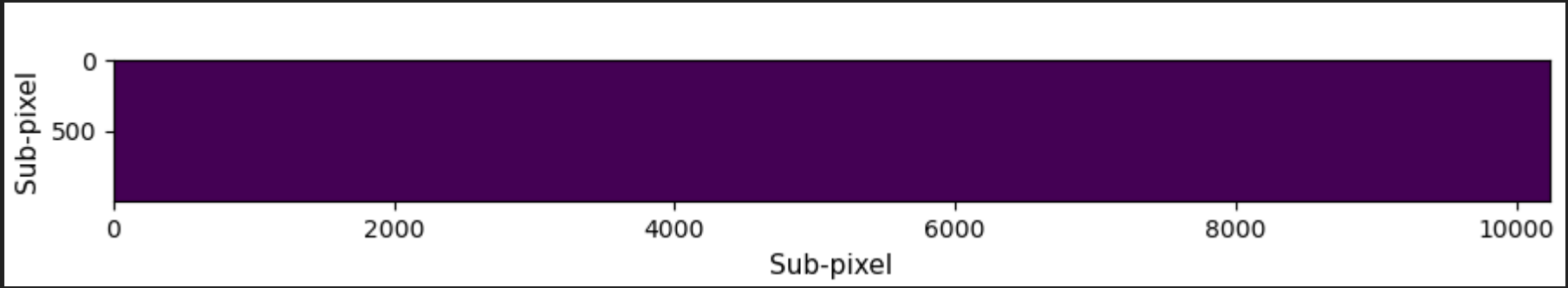

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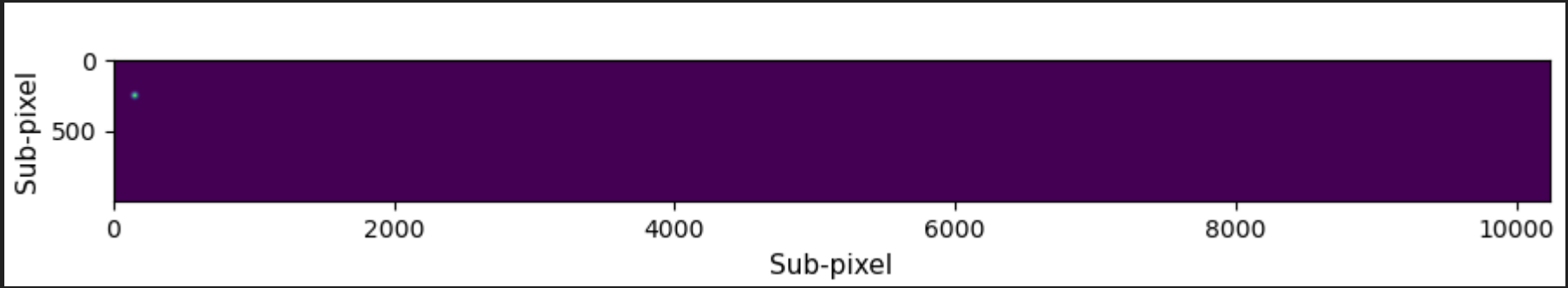

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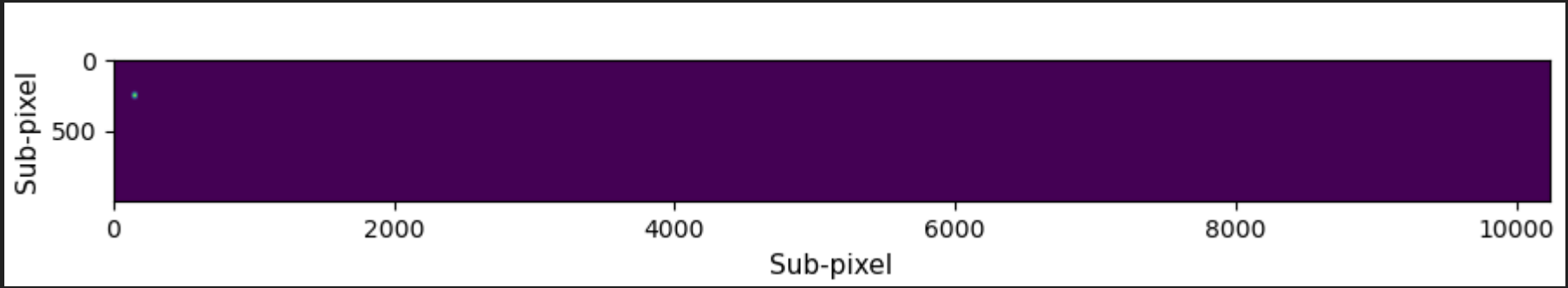

Step 2: Image formation

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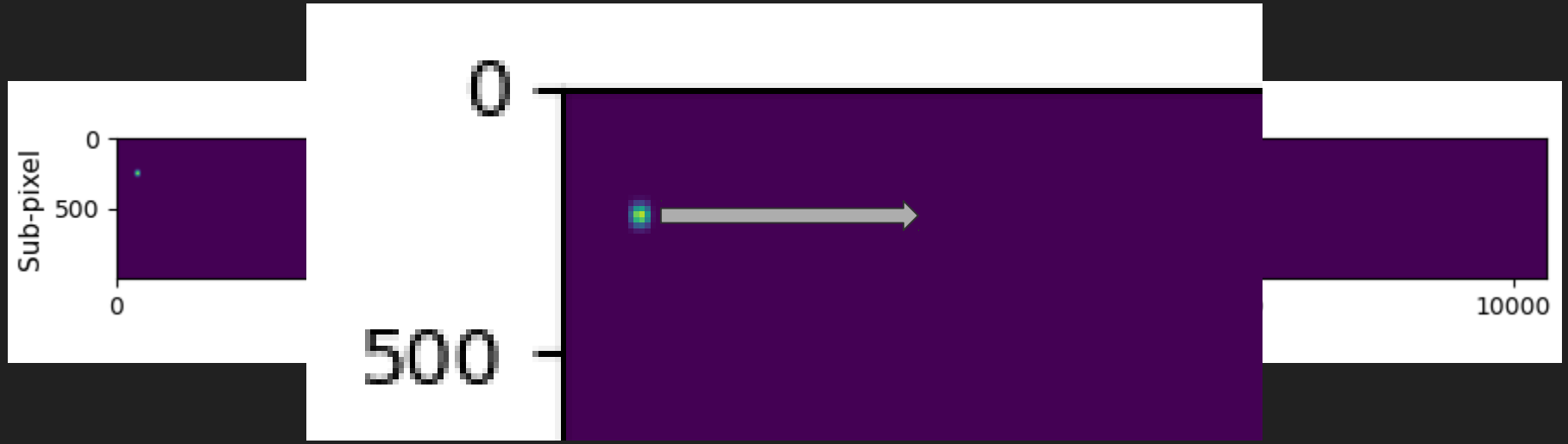
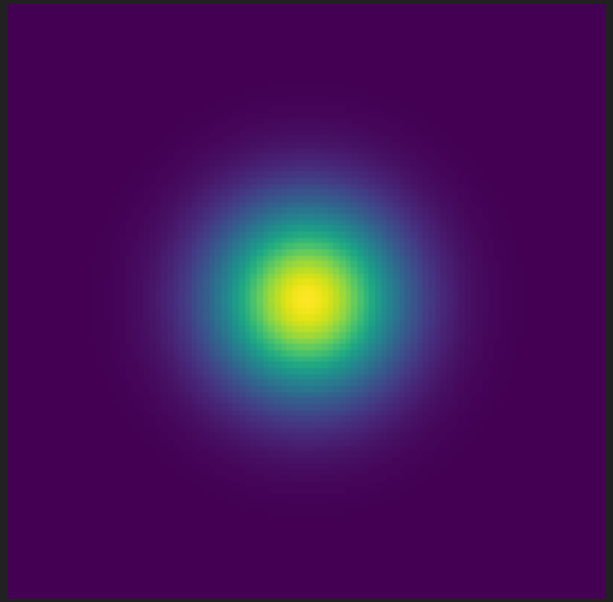


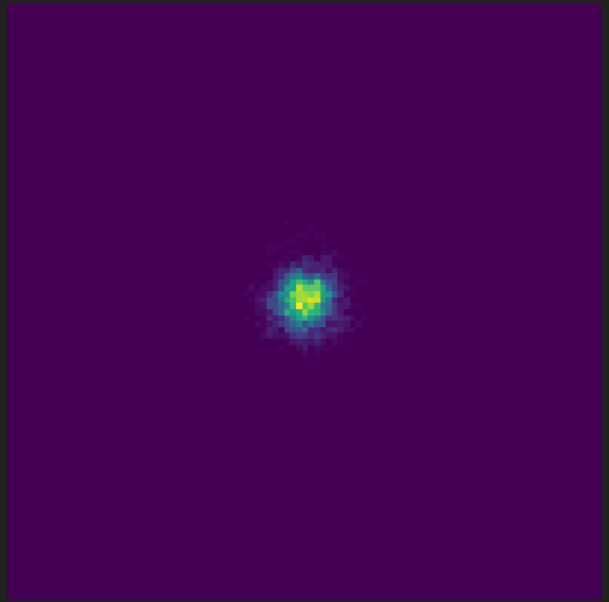
PSF & Jitter

Point Spread Function - Next color

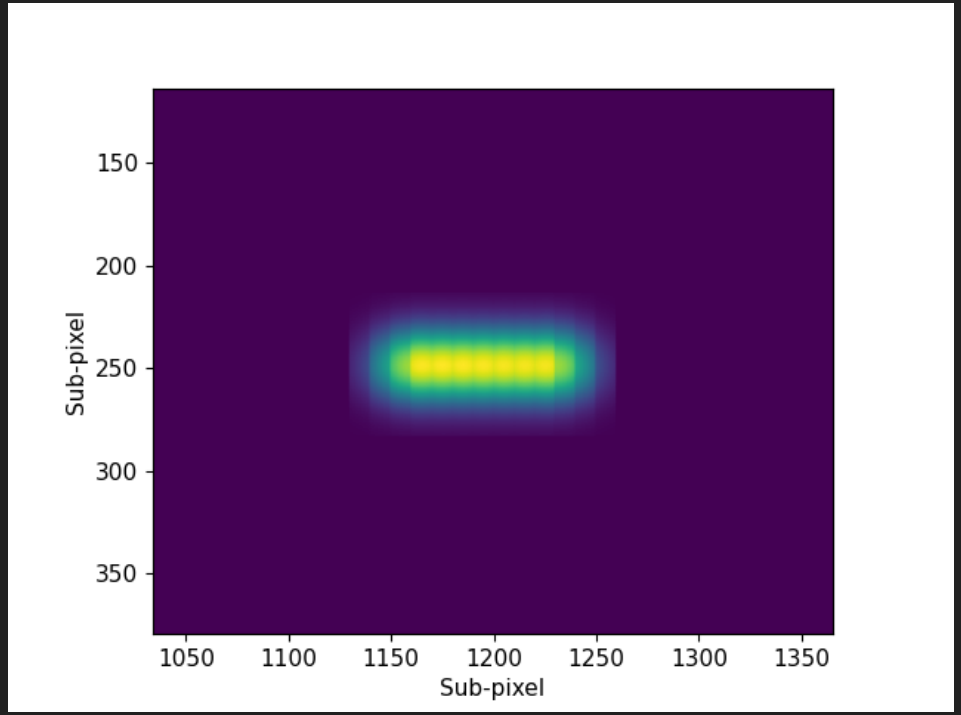


Convolution

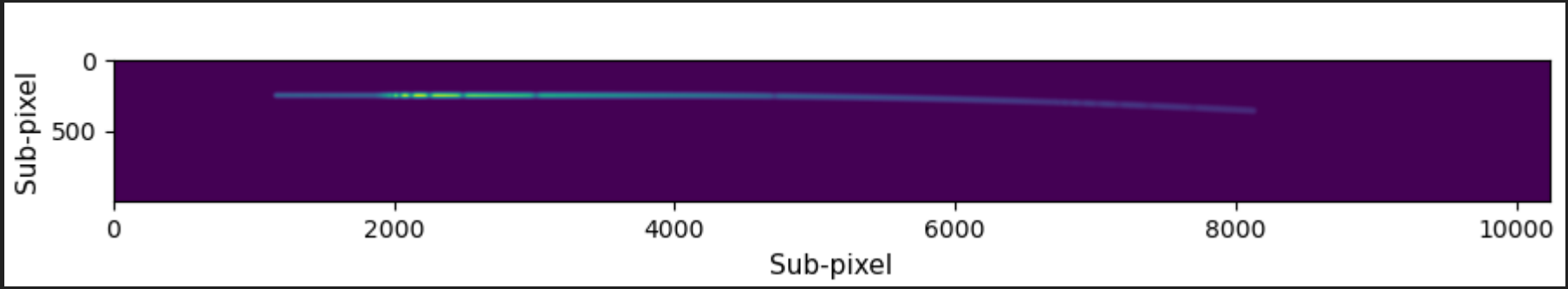
Spacecraft jitter / seeing



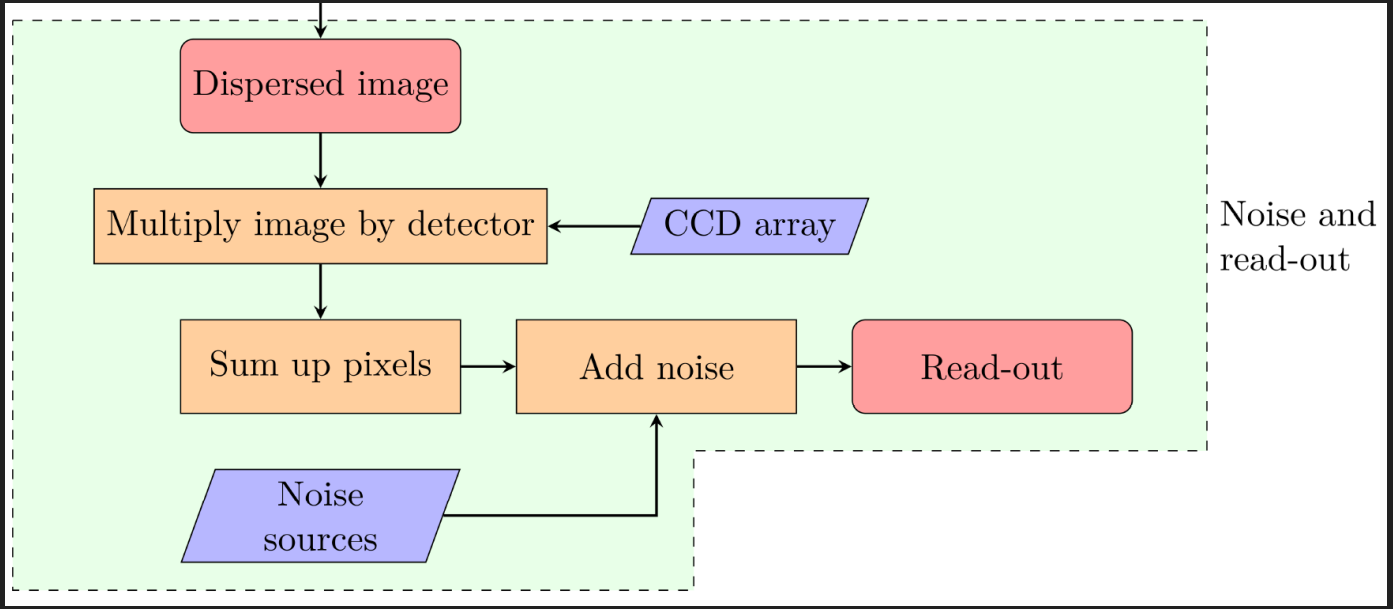
Step 2: Image formation



Step 2: Image formation



Step 3: Noise and read-out



Multiply by CCD

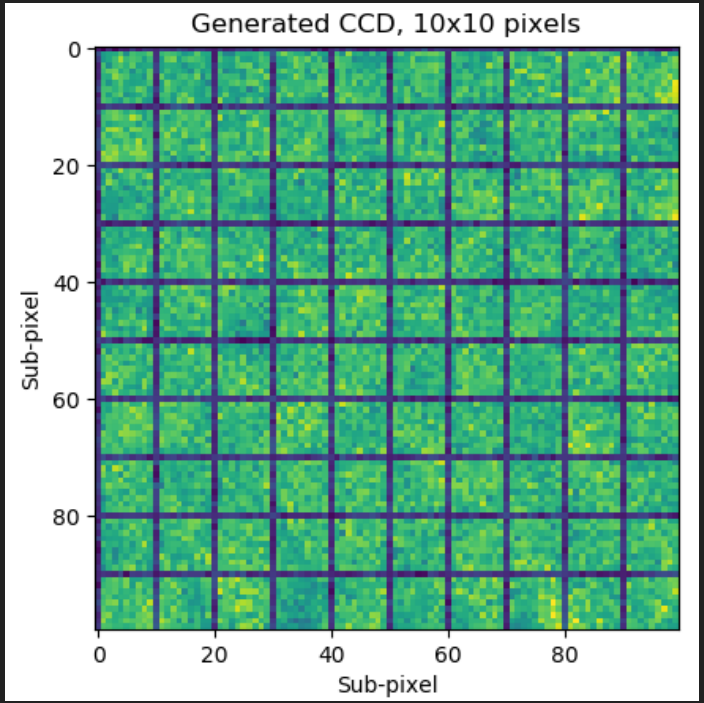


Fig. 6.7

Multiply by CCD

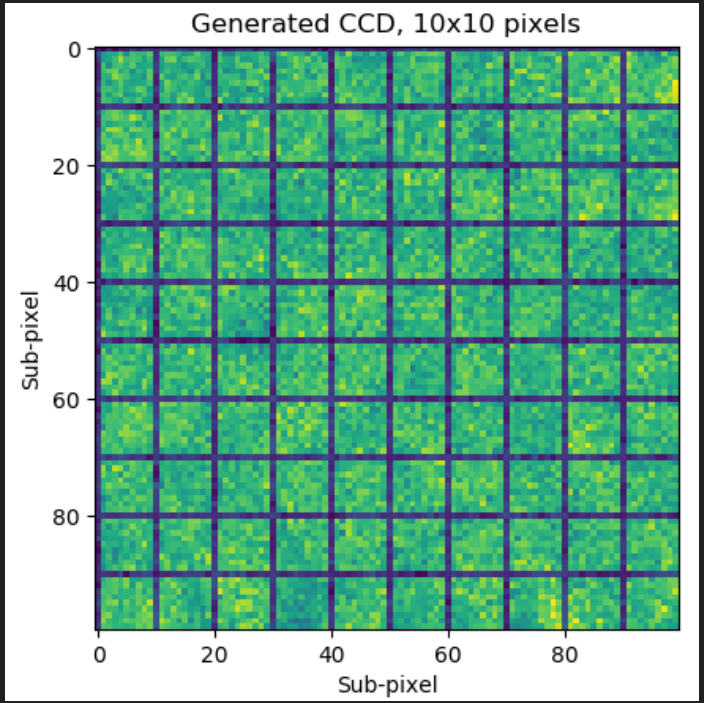
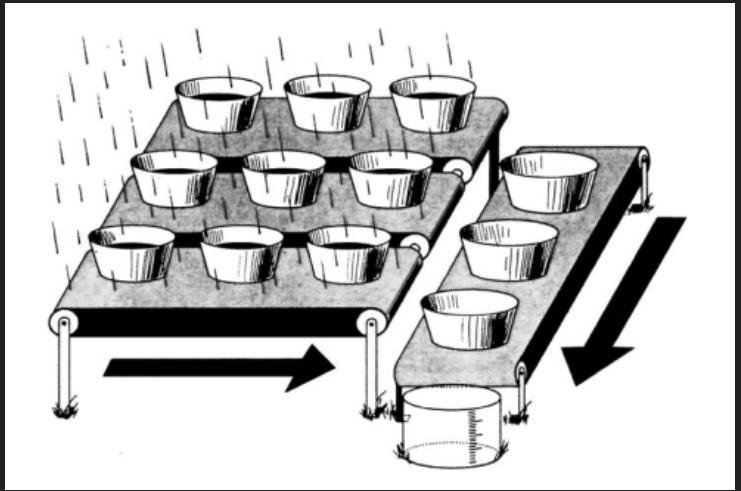


Fig. 6.7



Janesick & Blouke 1987

Sum up pixels

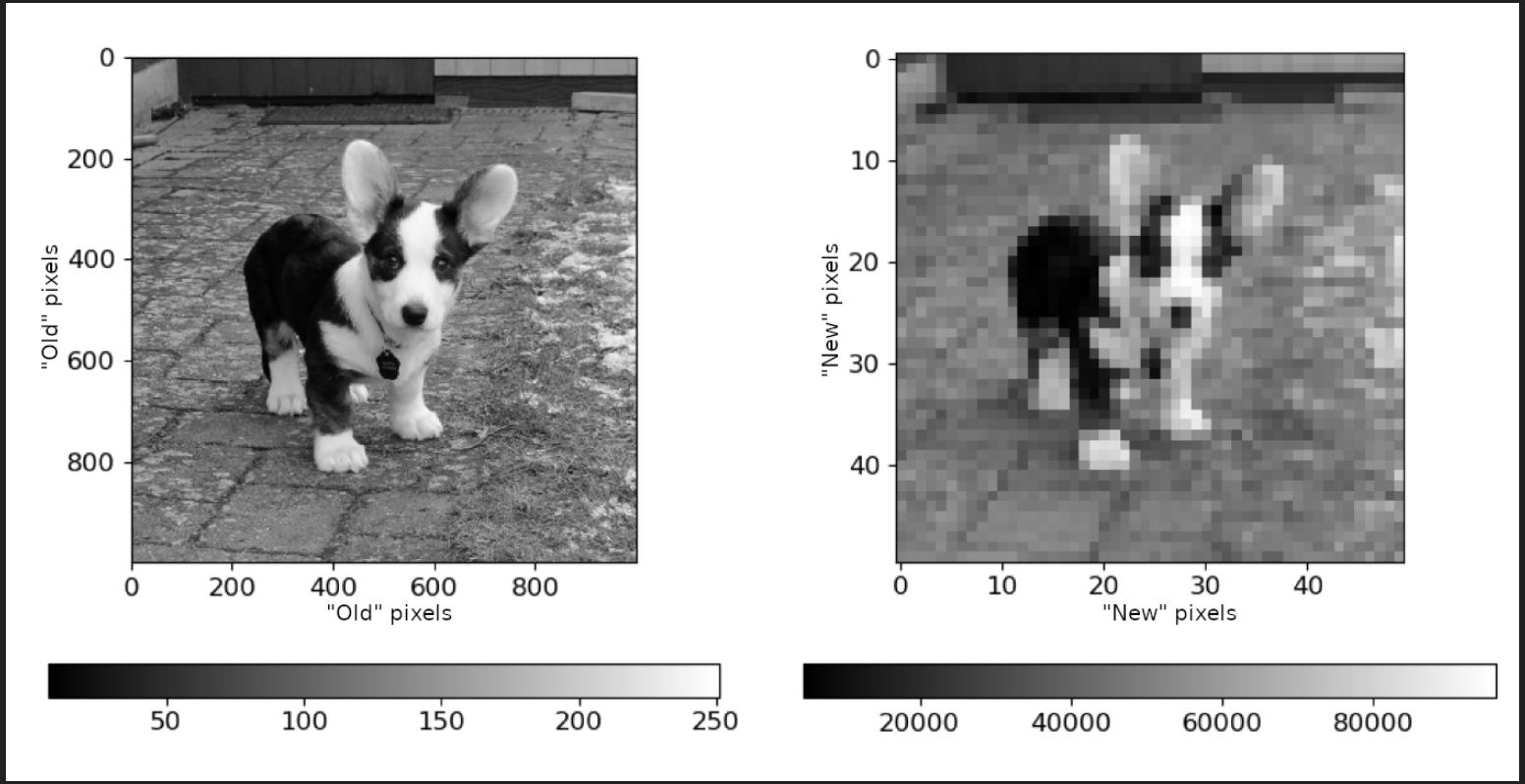
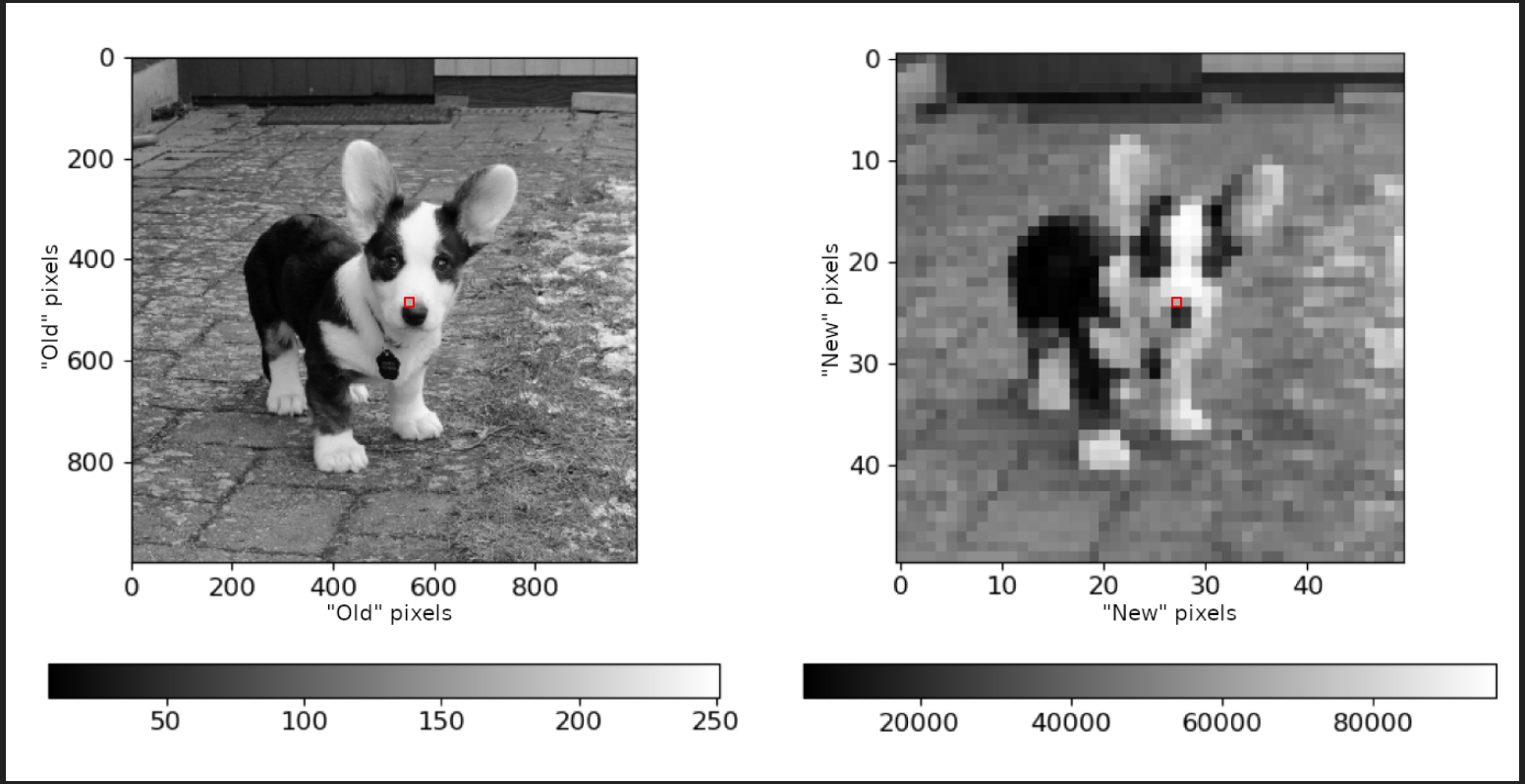


Fig. 7.5

Sum up pixels



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Sum up pixels

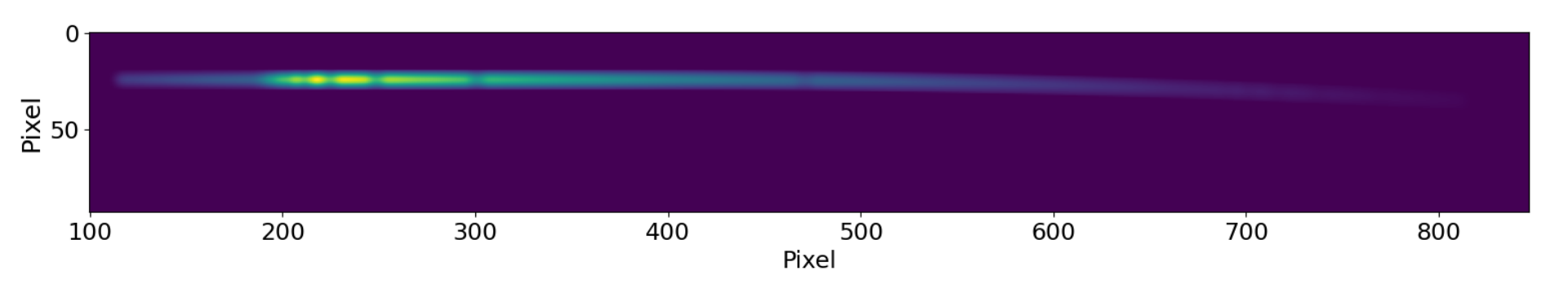
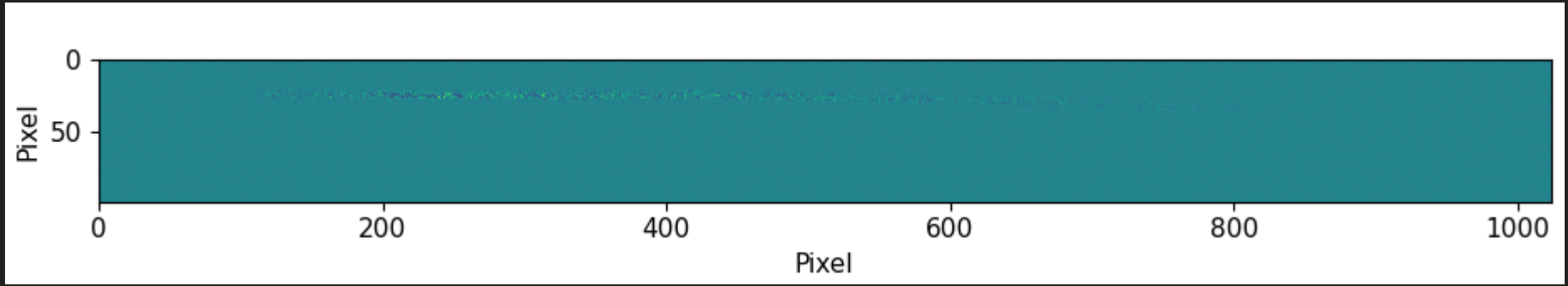


Fig. 8.3

Adding noise

$$noise_{i,\,j} = \left(\sqrt{N_{i,\,j}} + RON\right) \cdot \mathcal{N}(\mu = 0,\ \sigma = 1)$$



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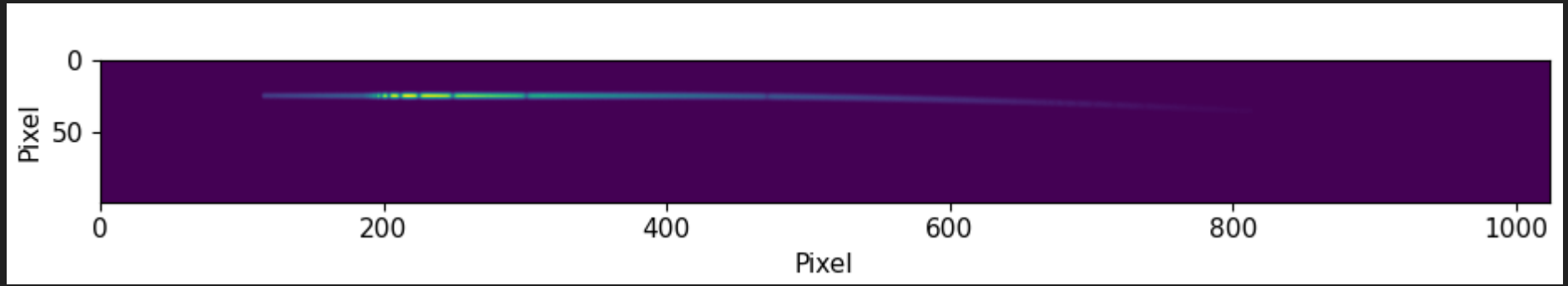
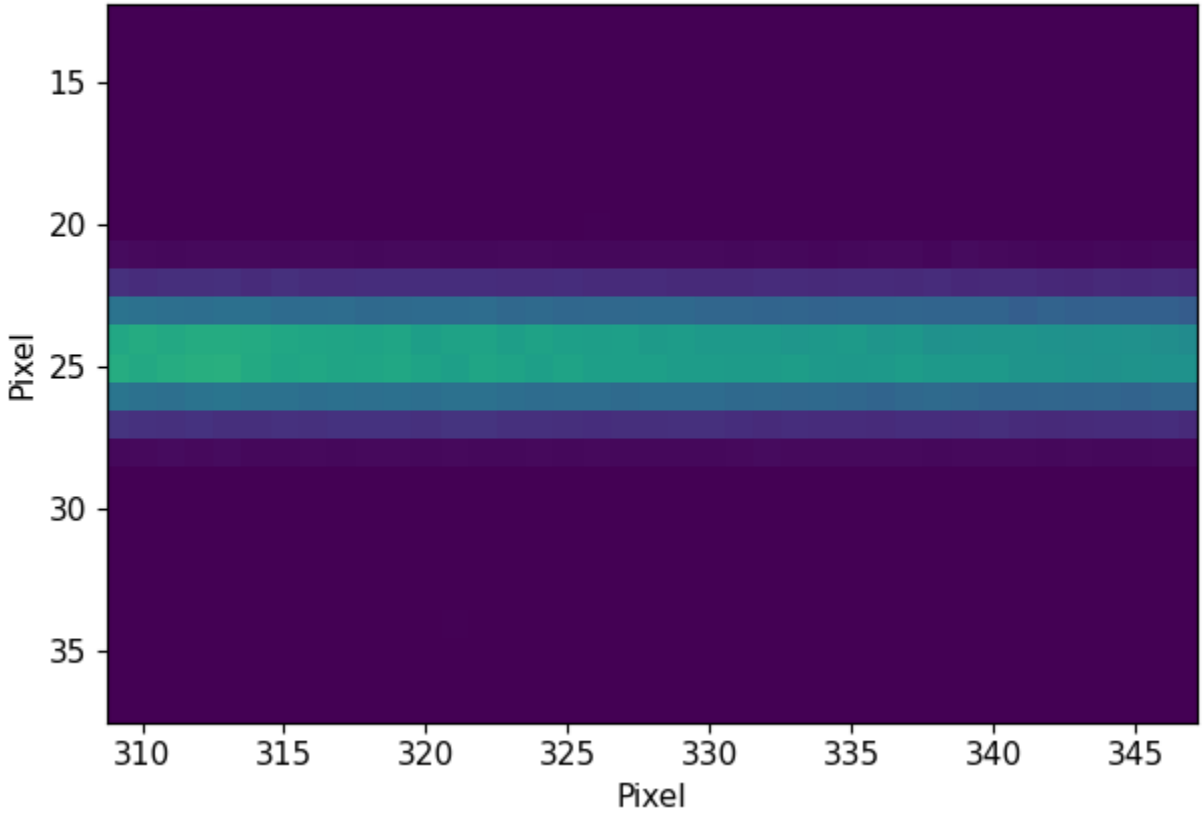
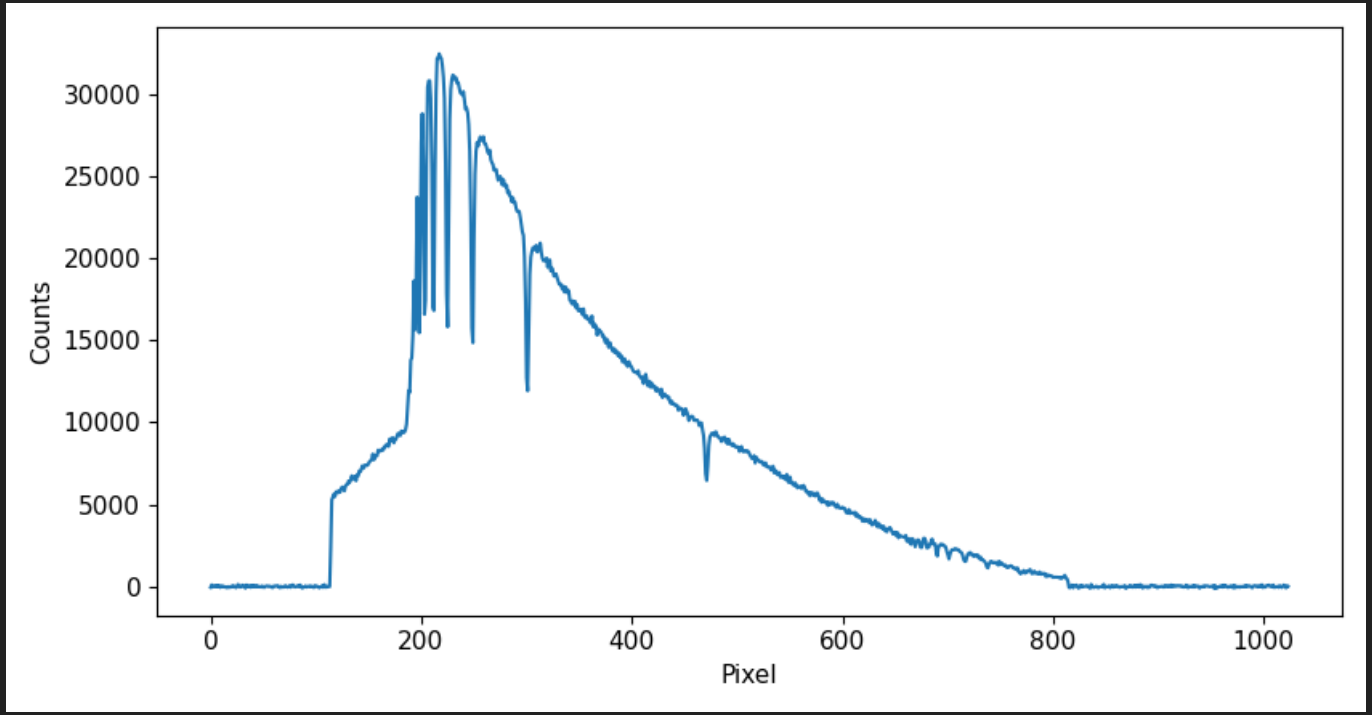


Addin

$noise_{i,}$



Read-out


30000
25000
20000
15000
10000
5000
0
Counts
0
200
400
600
800
1000
Pixel

Results

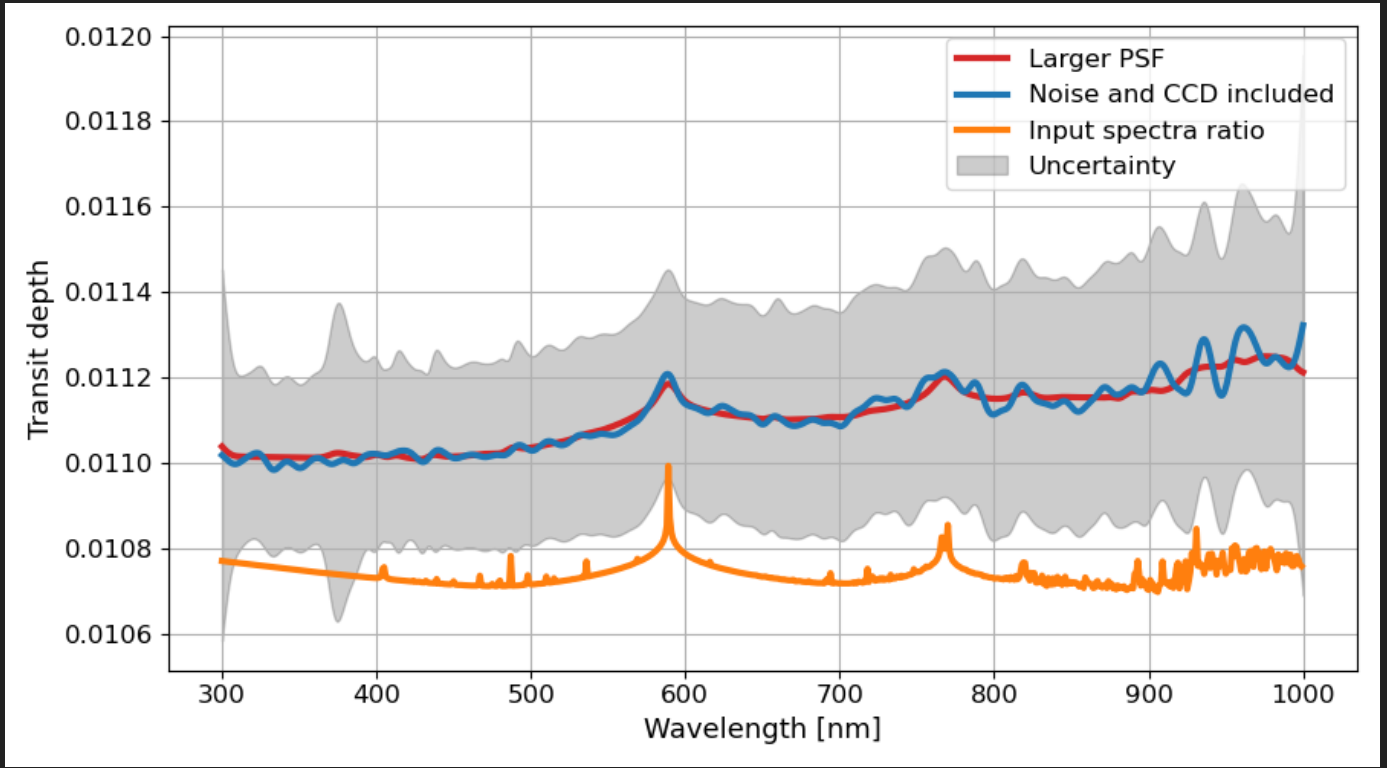


Fig. 8.11

Results

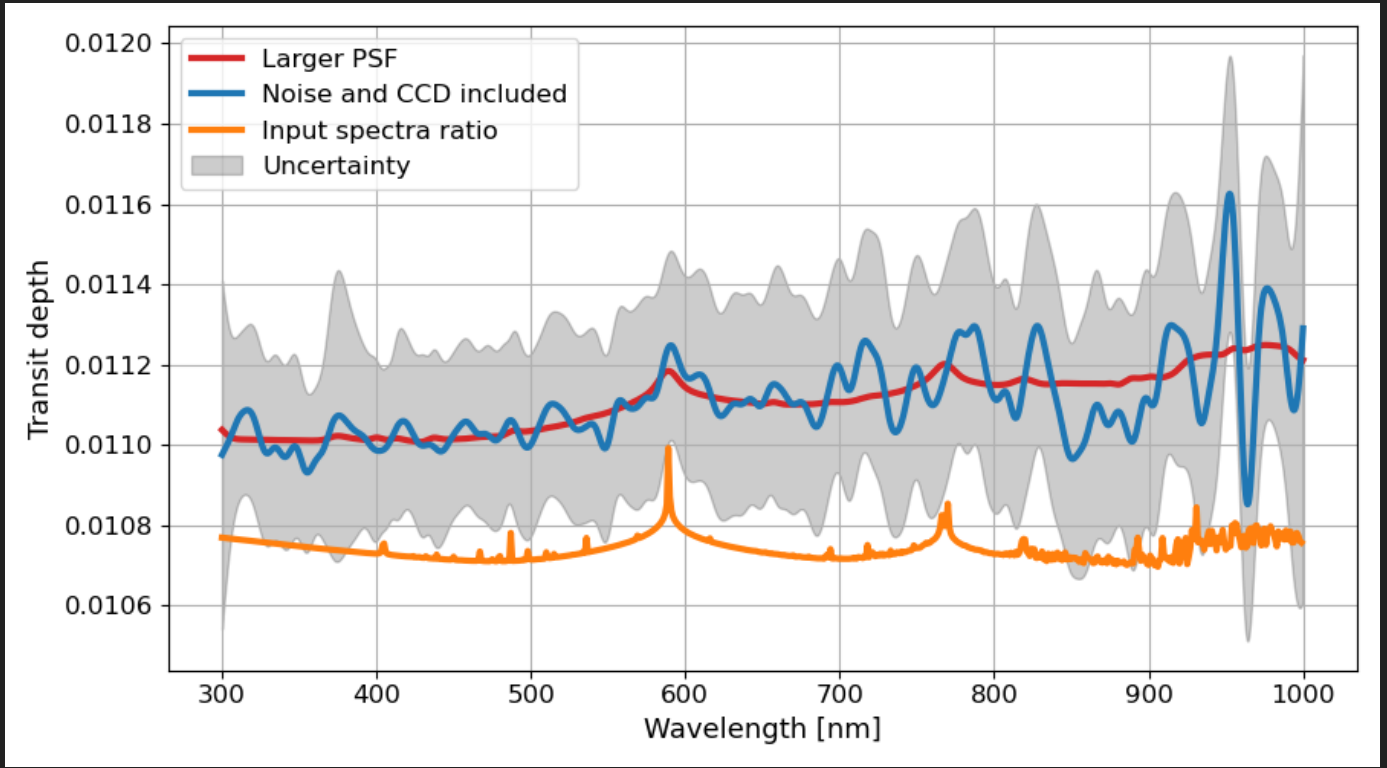


Fig. 8.12

Using the simulator - misalignment

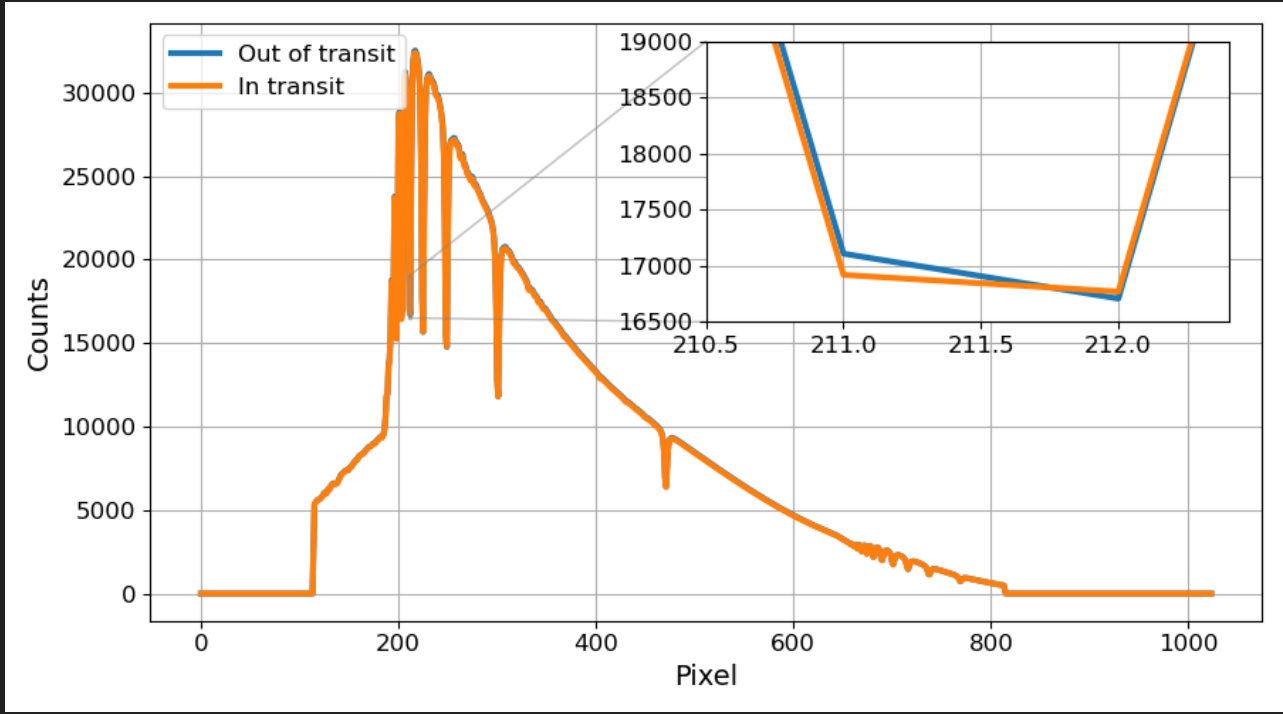
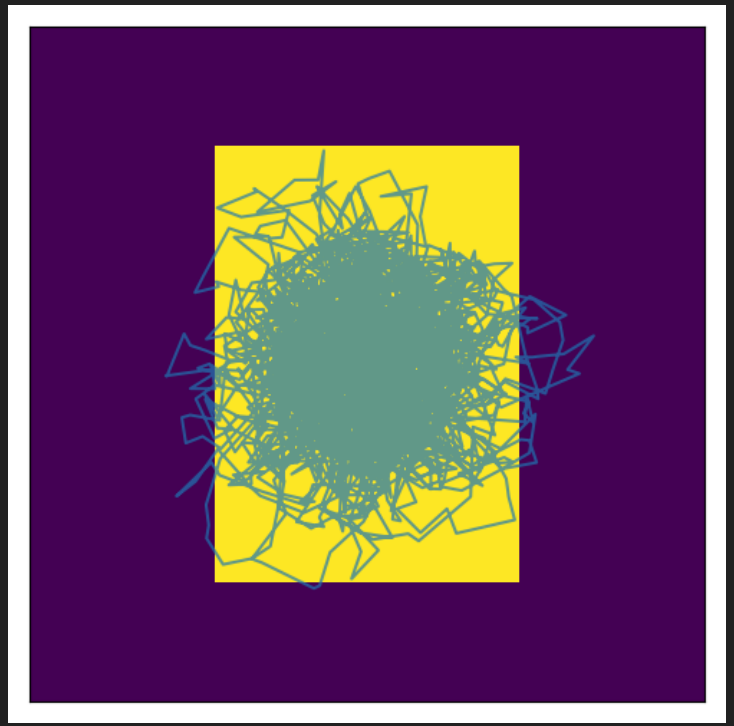


Fig. 8.5

Using the simulator - jitter



Future improvements

- Faster run-time
- Higher spectral resolution
- Secondary light sources / background stars
- Improved format checking during setup

Conclusion

- Goals of this thesis:
  - Create a simulator for low-resolution spectroscopy
    - Tests were conducted
- Realistic input values were used to conduct a “real-life test”
  - Jitter is a major obstacle!
- Future improvements
  - Faster, more robust, and with higher spectral resolution