# Exploring the Limits

## Digging Out Faint Structures in Astrophotographs

CEDIC 2019

Dr. Fabian Neyer

# Our goal: from this…

*Cooperation with Robert Pölzl*

# … to this

*Cooperation with Robert Pölzl*

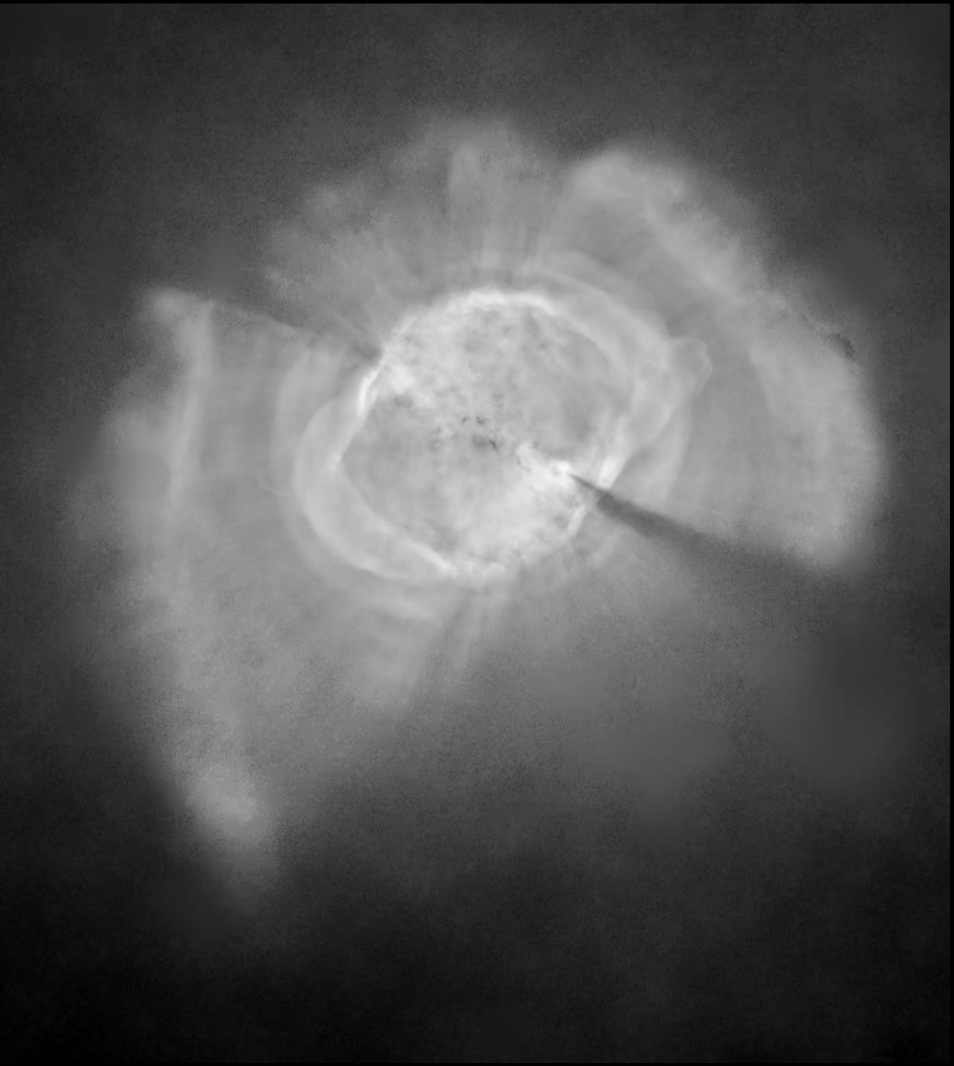
# Principle approach

1) creating a starless image
2) using the starless image as a mask for stretching

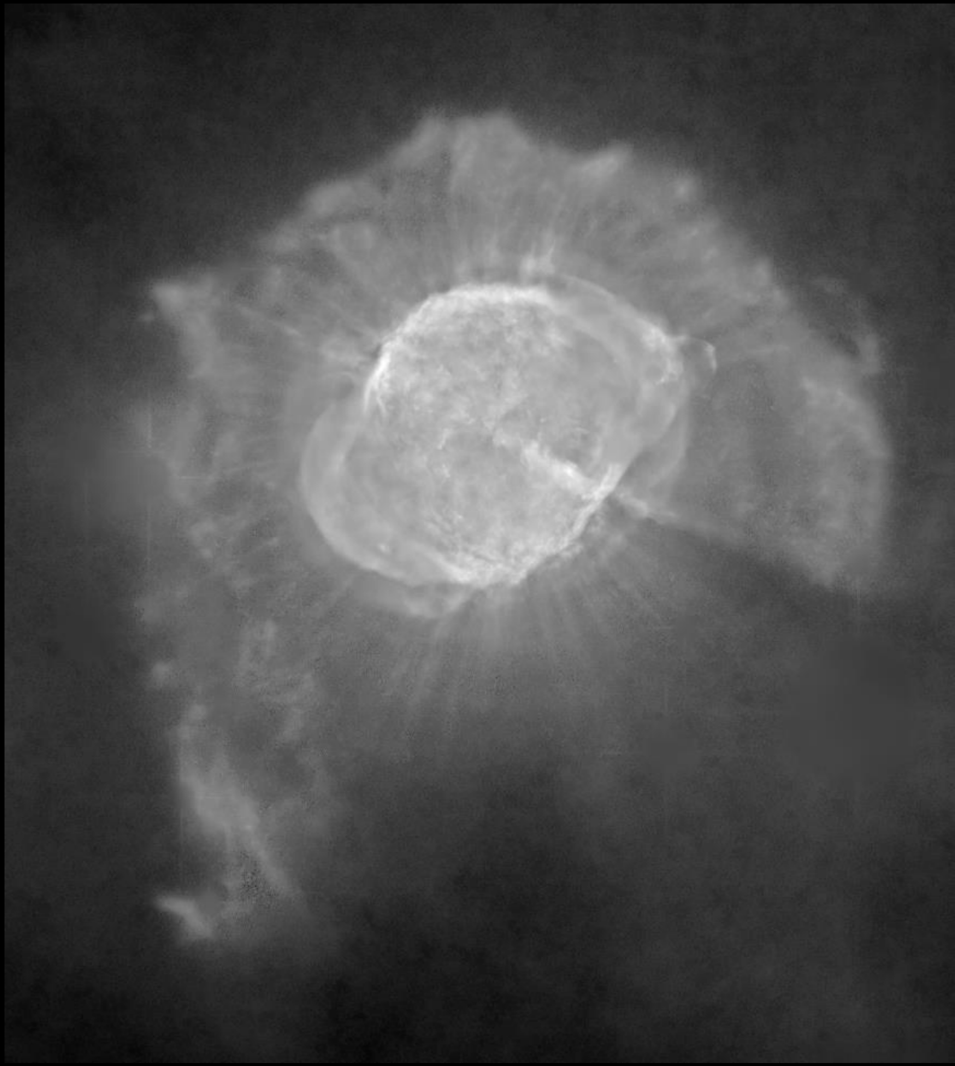
*standard stretch*

*masked stretch*

# principle approach



22.5h OIII @ f3.8



38.5h HII @ f3.8

# Overview

1) What to think about first…

2) Available Tools

3) Effects of stars and what the Pro's do

4) An amateur approach

    3.1) Star intensities
    3.2) Removal of stars and their halos
    3.3) Filling gaps
    3.4) Noise reduction

    } practical example

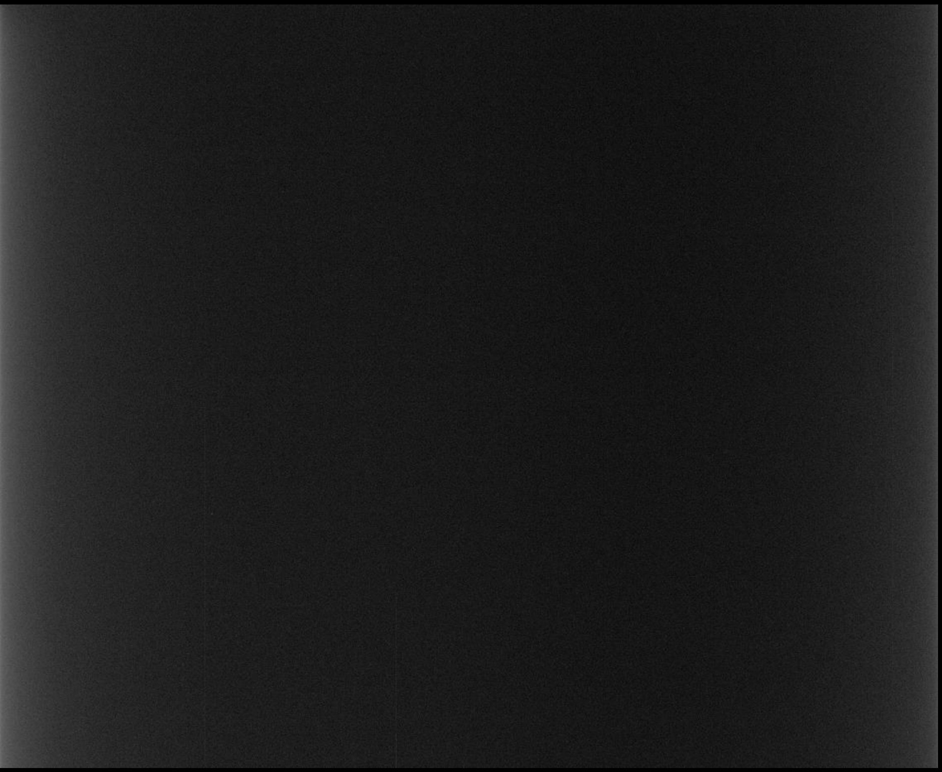
5) Stretching

# Aspects of Flat-Fielding

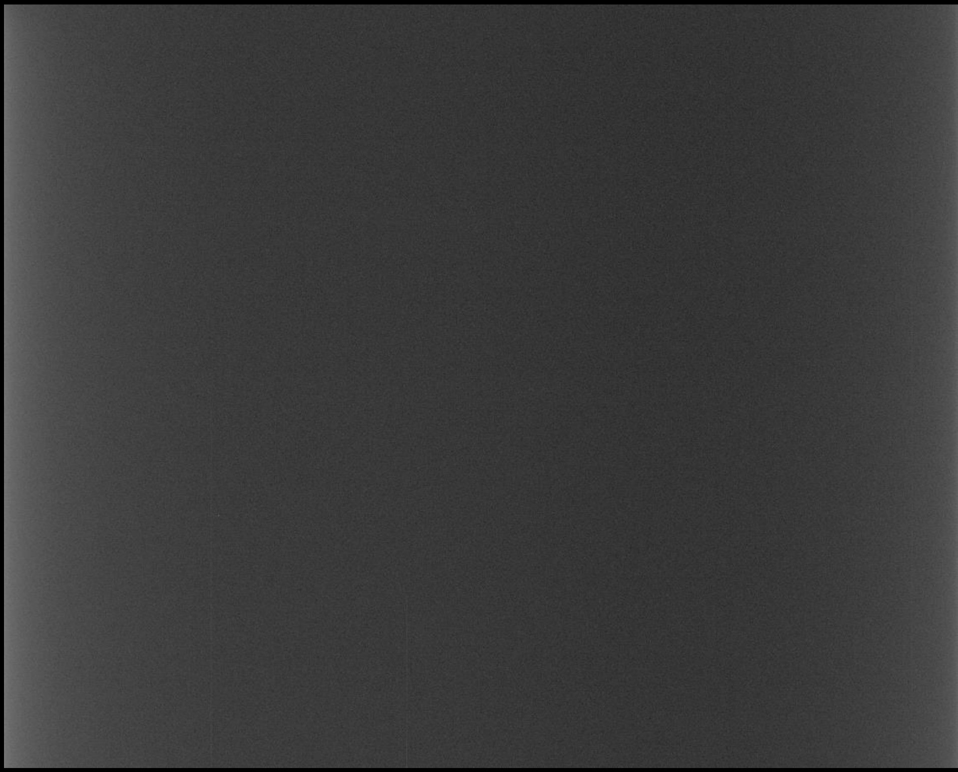
- Flats are crucial but also the most problematic calibration frames. What we need is:
  - Homogeneous Illumination
  - Intensities must be in the linear sensor response regime
  - Correctly calibrated by (Bias / Dark / Overscan)
  - Known accuracy of filter wheel repositioning
  - Minimum internal reflections
  - Awareness of shutter effects
  - Awareness of spectral effects
  - No light leakage, no directional dependency

# Overscan

without overscan correction



with overscan correction



- correcting the bias signature of a CCD image
- overscan region is a dummy area without any physical pixels
- in its most simple form: a subtraction of a constant value

# Correctly calibrate the flats

- Flat Normalization

correctly calibrated

| | |
|---|---|
| 10 | 8 |
| 16 | 6 |

$\times \frac{1}{mean} =$

| | |
|---|---|
| 1.00 | 0.80 |
| 1.60 | 0.60 |

offset error (+2)

| | |
|---|---|
| 12 | 10 |
| 18 | 8 |

$\times \frac{1}{mean} =$

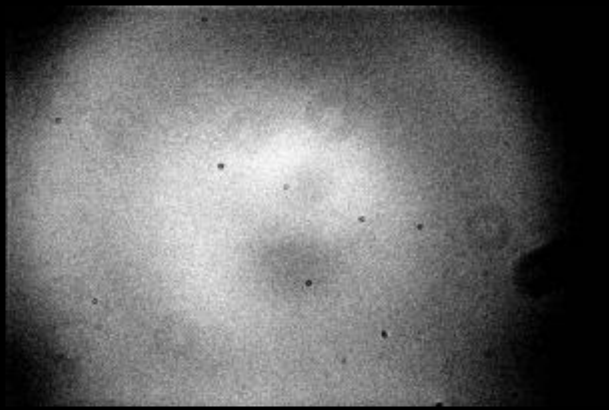
| | |
|---|---|
| 1.00 | 0.83 |
| 1.50 | 0.67 |

- relative error:

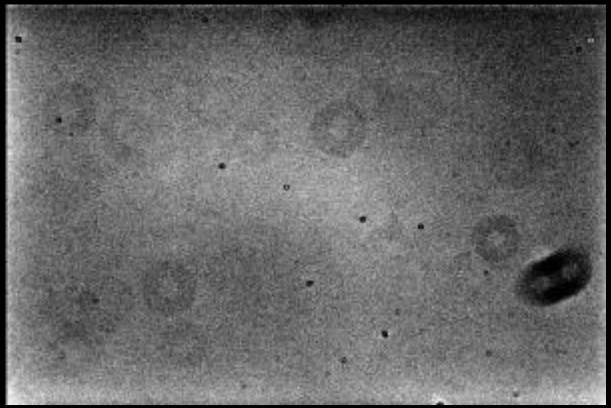
| | |
|---|---|
| 0% | 4.2% |
| 6.3% | 11.1% |

→ overcorrection!

# Minimize internal reflections

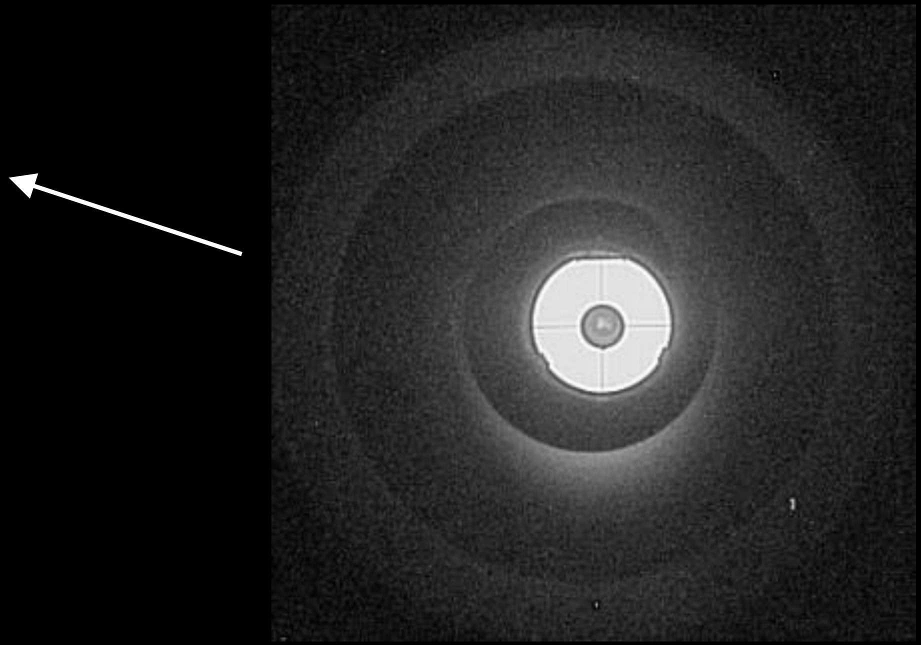


effect



after minizing int. reflections
same optics

internal reflections

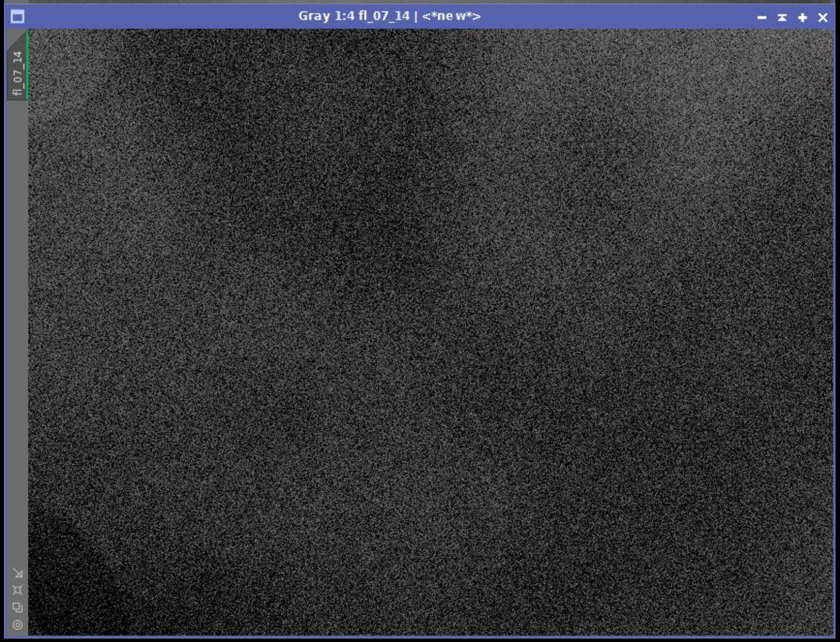


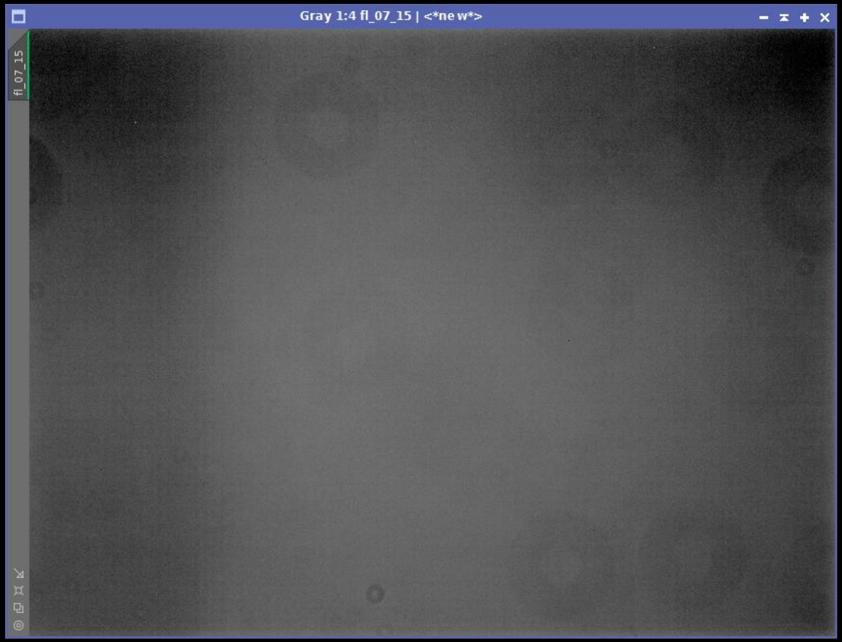
Depends on wavelengths!

# Minimize internal reflections

Remote observatory (Spain), 2 Masterflats, 1 day appart

*data acquired by Robert Pölzl*

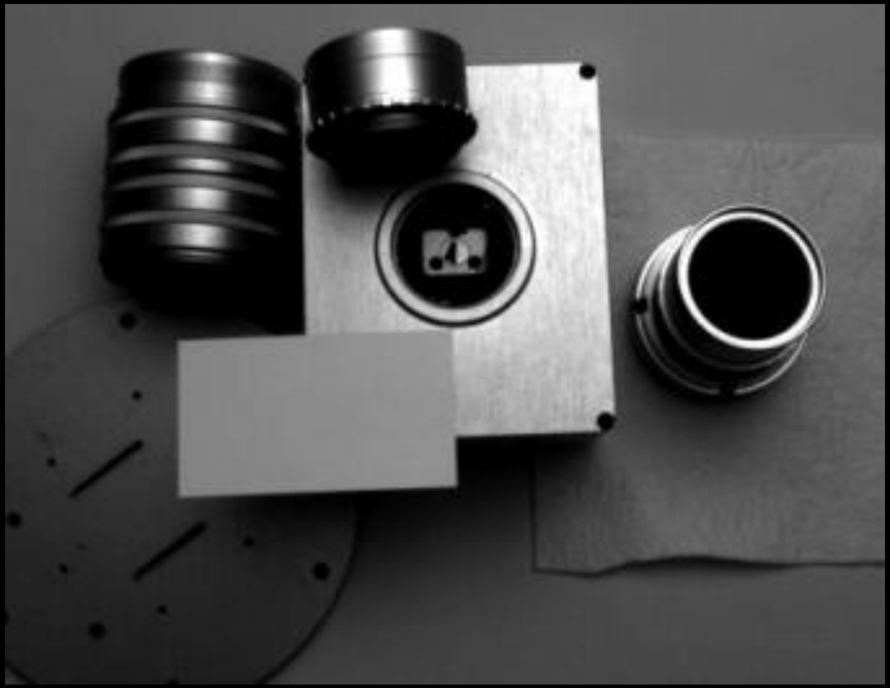




*Flat-fielded Flat*

*(Sky-Flats)*

# Internal reflections depend on wavelengths



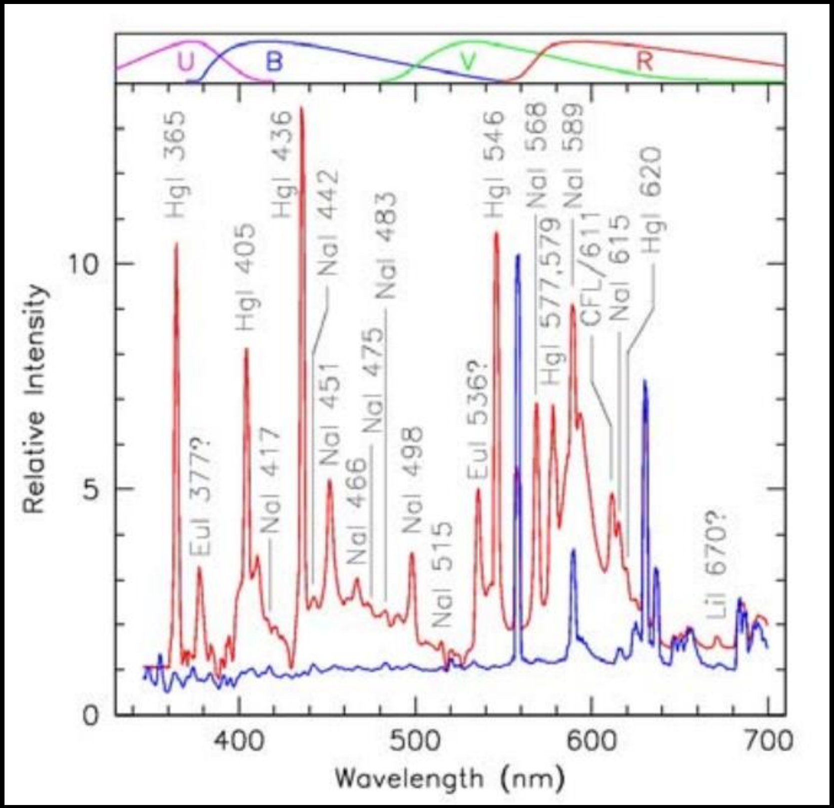
Black components in infrared light (940nm)
*Bild: Alan Holmes*

‘black’ components of your imaging equipment reflect light depending on its wavelengths,

An objects appears brighter in one wavelength than it does in another

# Internal reflections depend on wavelengths





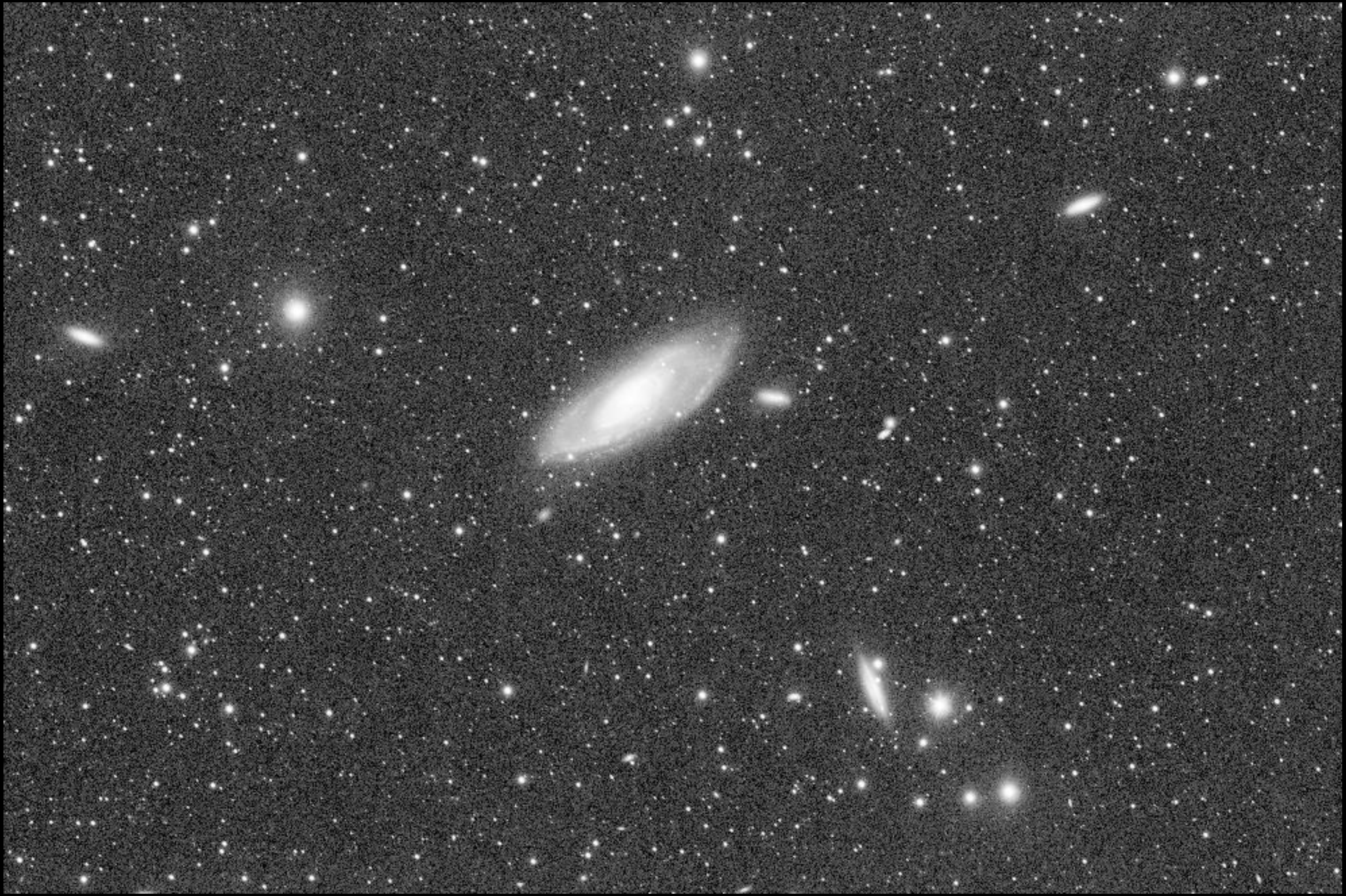

Spectrum of natural night sky (blue) and light polluted night sky (red) F. *Patat, IAU/ESO*

# Internal reflections depend on wavelengths

standard flat

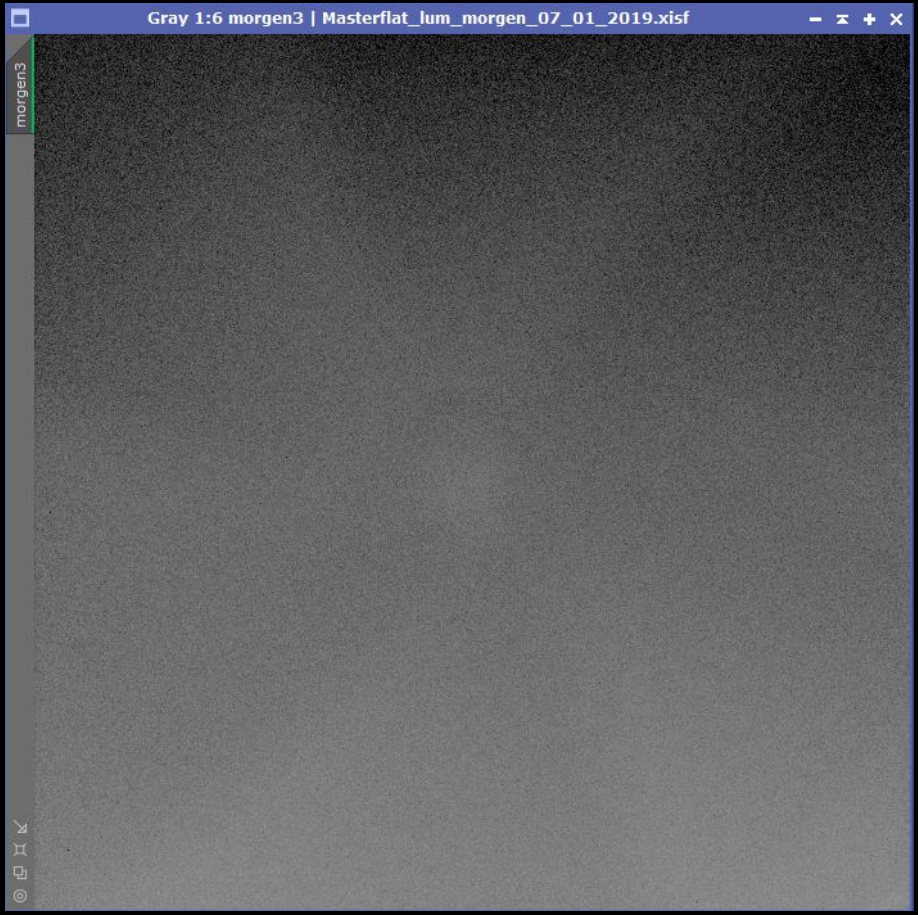
# Internal reflections depend on wavelengths

improved flat



# Awareness of shutter effects

Effects seen: Shutter + gradient




effects seen: Shutter + filter wheel / particles

# Lacerta Flatfieldbox

- can be controlled via APT
- illuminates after a certain delay
- real sensor exposure = delay + flat exposure + delay

- brightness range 1 – 100%
- ***very*** even illumination
- relatively homogeneous spectrum

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   3.4) Noise reduction
5) Stretching

# Available tools: “Straton”

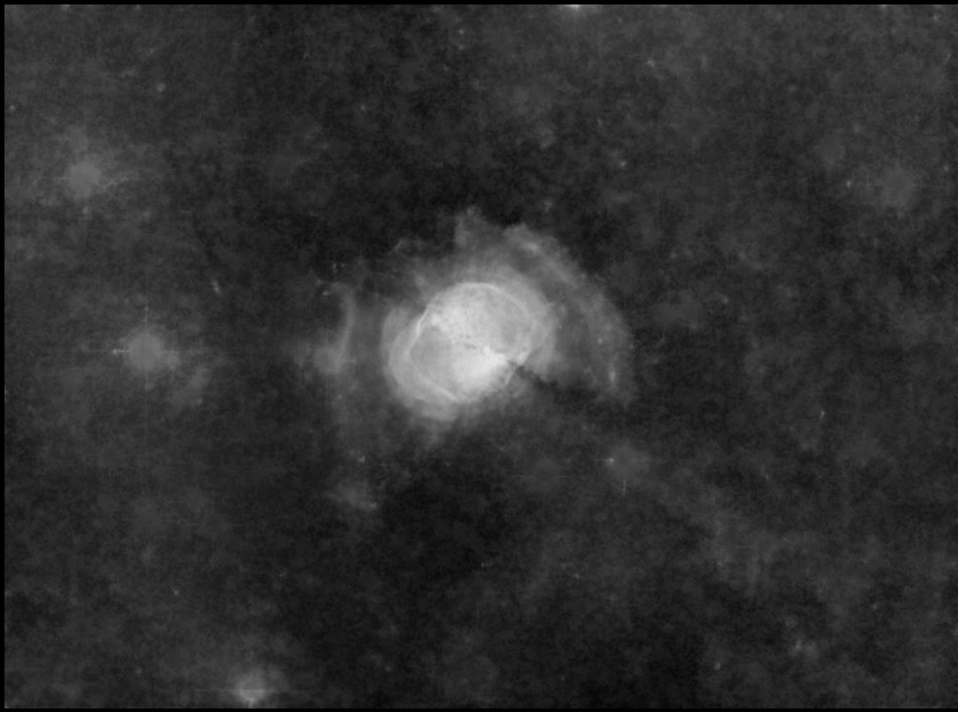
- Introduced in 2013 ( https://zipproth.com/#Straton )
- Works with linear & non-linear images
- Works well for narrowband images with tight stars
- More artefacts for non-linear images, specially in dense star fields

example: non-linear, green channel

# Available tools: “Starnet++” (Nikita Misiura)

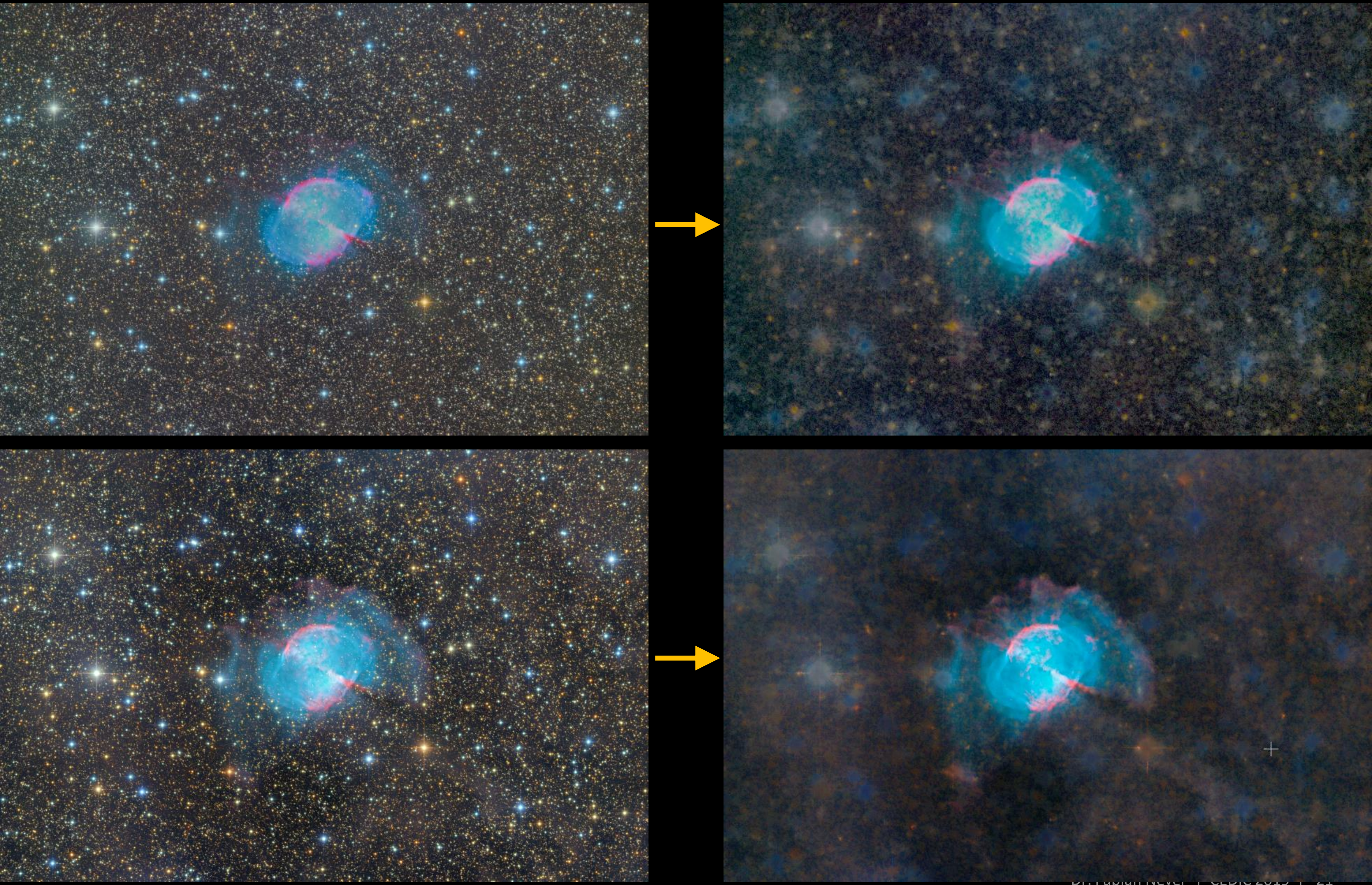
- Introduced in 2018 ( https://sourceforge.net/projects/starnet/ )
- Based on neural network training
- Works better for images taken with refractor telescopes (training data)
- Can be trained on your data to perform better!
- BUT: Results will never be better than the training data you provide!

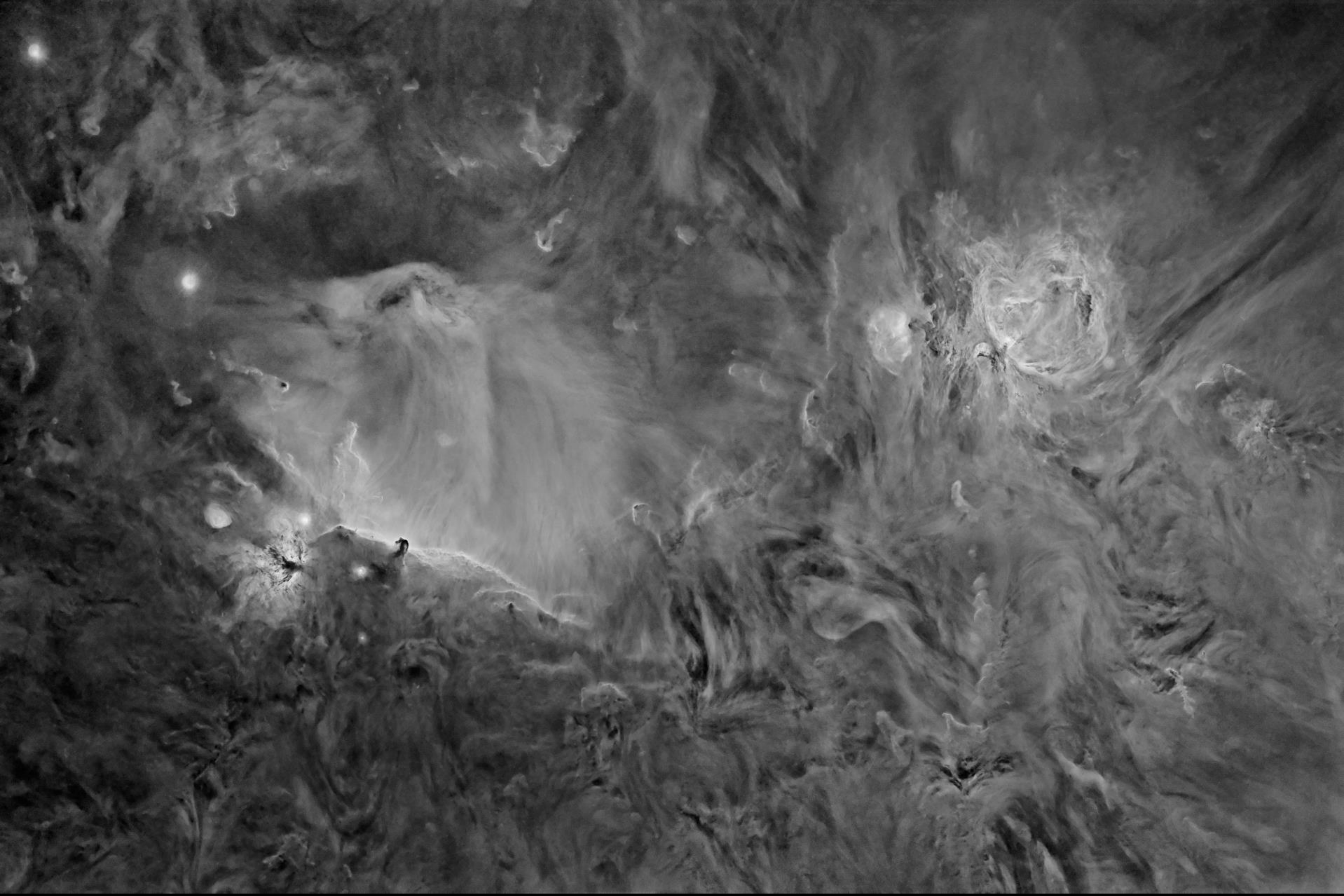
straton



starnet++

# Available tools: “Starnet++”





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# (2) Effect of stars and what the Pro's do

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## REMOVING INTERNAL REFLECTIONS FROM DEEP IMAGING DATASETS

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Department of Astronomy, Case Western Reserve University, Cleveland, OH.
*Draft version September 18, 2009*

ABSTRACT

We present a means of characterizing and removing internal reflections between the CCD and other optical surfaces in an astronomical camera. The stellar reflections appear as out-of-focus images and are not necessarily axisymmetric about the star. Using long exposures of very bright stars as calibration images we are able to measure the position, size, and intensity of reflections as a function of their position on the field. We also measure the extended stellar point-spread function out to 1°. Together this information can be used to create an empirical model of the excess light from bright stars and reduce systematic artifacts in deep surface photometry. We then reduce a set of deep observations of the Virgo cluster with our method to demonstrate its efficacy and to provide a comparison with other strategies for removing scattered light.
*Subject headings:* Data Analysis and Techniques

### 1. INTRODUCTION

Deep wide-field imaging is widely used to study extended, diffuse objects such as low surface brightness galaxies (McGaugh et al. 1995; Sprayberry et al. 1996; Marshall 2004), the diffuse interstellar medium (Sandage 1976; Gordon et al. 1998; Witt et al. 2008), the outer disks and faint stellar features around bright galaxies (Malin & Carter 1983; Pohlen et al. 2002; Martínez-Delgado et al. 2009), the diffuse intracluster light in galaxy clusters (Uson et al. 1991; Gregg & West 1998; Feldmeier et al. 2004; Gonzalez et al. 2005; Mihos et al. 2005), and the extragalactic background light (Bernstein 2007). Accurately measuring faint surface brightnesses places stringent demands on the minimization of systematic effects, including large scale flat fielding, accurate sky subtraction, scattered light from nearby objects, and internal reflections in the telescope/camera system. All of these effects, if not treated carefully, can imprint a spatially varying pattern of light onto the image, which can significantly contaminate measurements of the low surface brightness astronomical object being studied.

In particular, internal reflections of bright stars in the field represent a significant source of this type of contamination. Light coming to focus can reflect off the CCD and back up the optical path, reflect again off optical elements such as the dewar window, filter, or any reimaging optics, and come back down to the CCD. The longer path length results in multiple out-of-focus stellar images (one for each reflection) being added to the image. These defocused stars are essentially extended images of the telescope's entrance pupil, and have complex spatial structure due to obstructing objects such as the Newtonian mirror and its support spider. As we show below, the position of these reflections relative to their central star changes across the field of view, making characterization and subtraction difficult. They also complicate the measurement of the extended stellar PSF, making the subtraction of the low surface brightness wings of stars problematic. The complex pattern of overlapping reflections and stellar wings can then plague efforts to accurately model and subtract sky from the images.

Some of this contamination can be reduced in hardware, through careful baffling of the telescope to reduce scattered light, minimization of optical elements to reduce the number of reflecting surfaces, and the use of aggressive anti-reflective coatings on the optical surfaces to reduce the intensity of the reflections. A particular example of this kind of effort is our optimization of Case Western Reserve University's Burrell Schmidt for deep surface photometry. This 24/36-inch Schmidt telescope is located at Kitt Peak and was originally designed for wide field imaging with photographic plates (Nassau 1945). The telescope was subsequently converted to Newtonian focus with a flat Newtonian mirror and a CCD imaging camera located on the side of the telescope tube.

The telescope is particularly well-suited to deep surface photometry by its original design, and in addition we have made additional upgrades to increase its sensitivity. The telescope's closed-tube design and the use of a Newtonian focus severely limits the amount of stray light that reaches the detector. Recent upgrades to the telescope include a redesign of the Newtonian mirror and its mounting structure to reduce vignetting and flexure, an installation of light-absorbing material to the inside of the telescope tube to reduce scattered light, the installation of a wide field 4Kx4K CCD ($1.65° \times 1.65°$ on the sky), a combining of the dewar window and field flattener to reduce optical surfaces, and the use of filter-specific anti-reflective coatings on the filter and dewar window/field flattener (see Appendix A). With these improvements, the telescope has been able to detect extremely faint structure in the intracluster light of Virgo (Mihos et al. 2005).

However, in practice many of these solutions are generally unavailable to the observer on a multi-user, multi-instrument telescope, and even with such solutions in place, faint reflections still persist. In these situations, software solutions must be implemented to correct for these reflections in the reduction process, after the data has been taken. In this work we present a way of

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"Accurately measuring faint surface brightnesses places stringent demands on the minimization of systematic effects, … scattered light from nearby objects, and internal reflections in the telescope/camera system"

"…the position of these reflections relative to their central star changes across the field of view, making characterization and subtraction difficult"

"…a generative model of the reflections can be built and used to remove the scattered light"

"…observation of a small number of bright stars in order to characterize the sizes, intensities, and positions of the reflections"

*Salter et al. 2009: Removing Internal Reflections From Deep Imaging Datasets*

# (2) Effect of stars and what the Pro's do

14 Slater, Harding, and Mihos

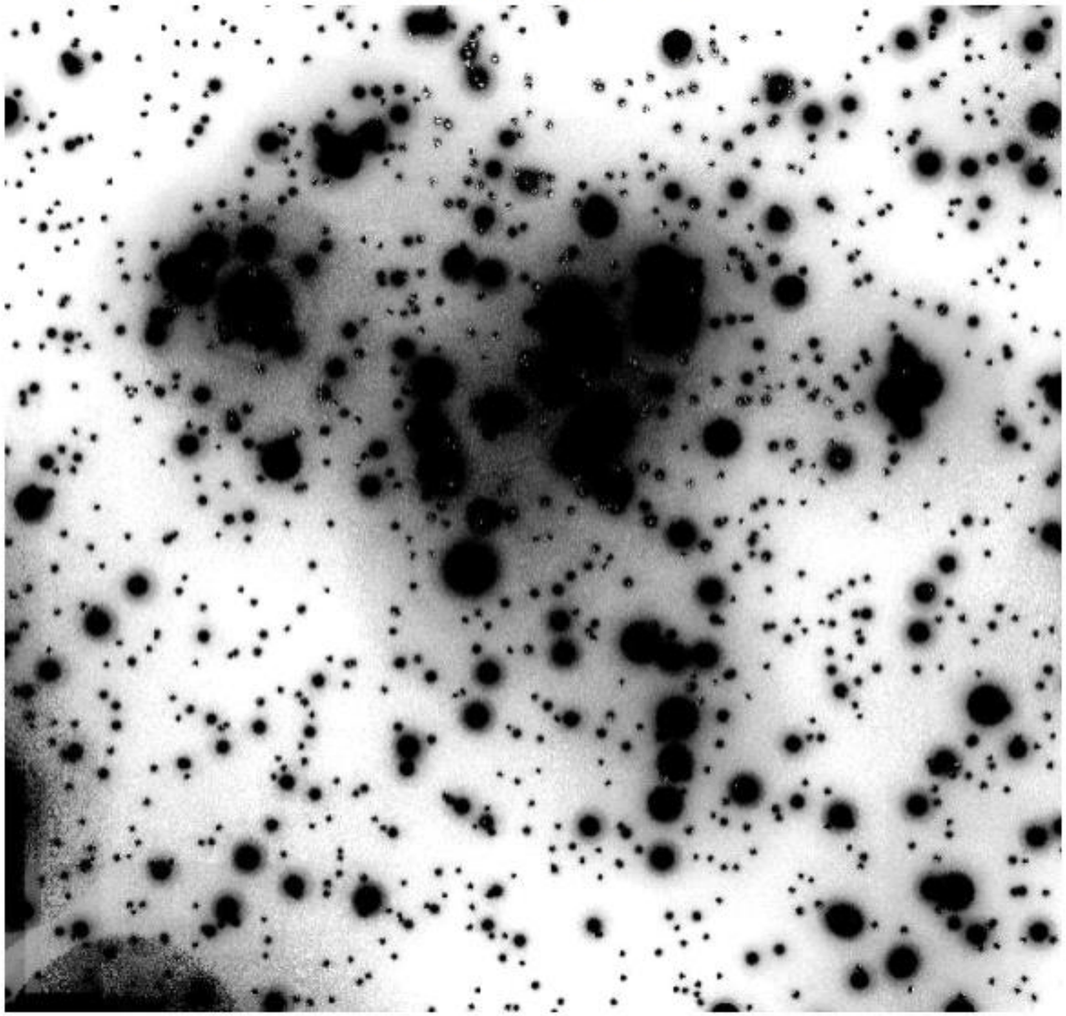


FIG. 10.— This image is the difference between the reduction with no star subtraction and the image with the fully modeled reflection and PSF subtraction. Black indicates an excess of light in the image without star subtraction, and saturates at 2.5 ADU ($\mu_V = 27.8$).

24/36-inch Burrell Schmidt telescope, Kitt Peak

Illustrated here: Scattered light effects of stars

# (2) Effect of stars and what the Pro's do

# (3) An amateur approach

Principle Idea:

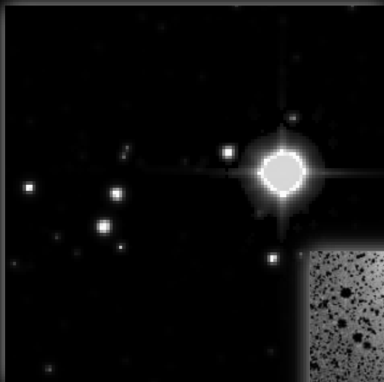
- Replacing stars by local background
- Reducing star halos by iterative subtraction and convolution

Assumptions:

- Stars with equal intensities produce equal halos, independent of their image location
- Halo extentions can reasonably well be estimated by visual inspection

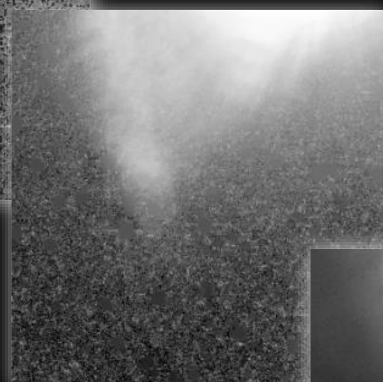
→ works only for linear images

# (3) An amateur approach



1) star intensities

2) removal of stars and their halos



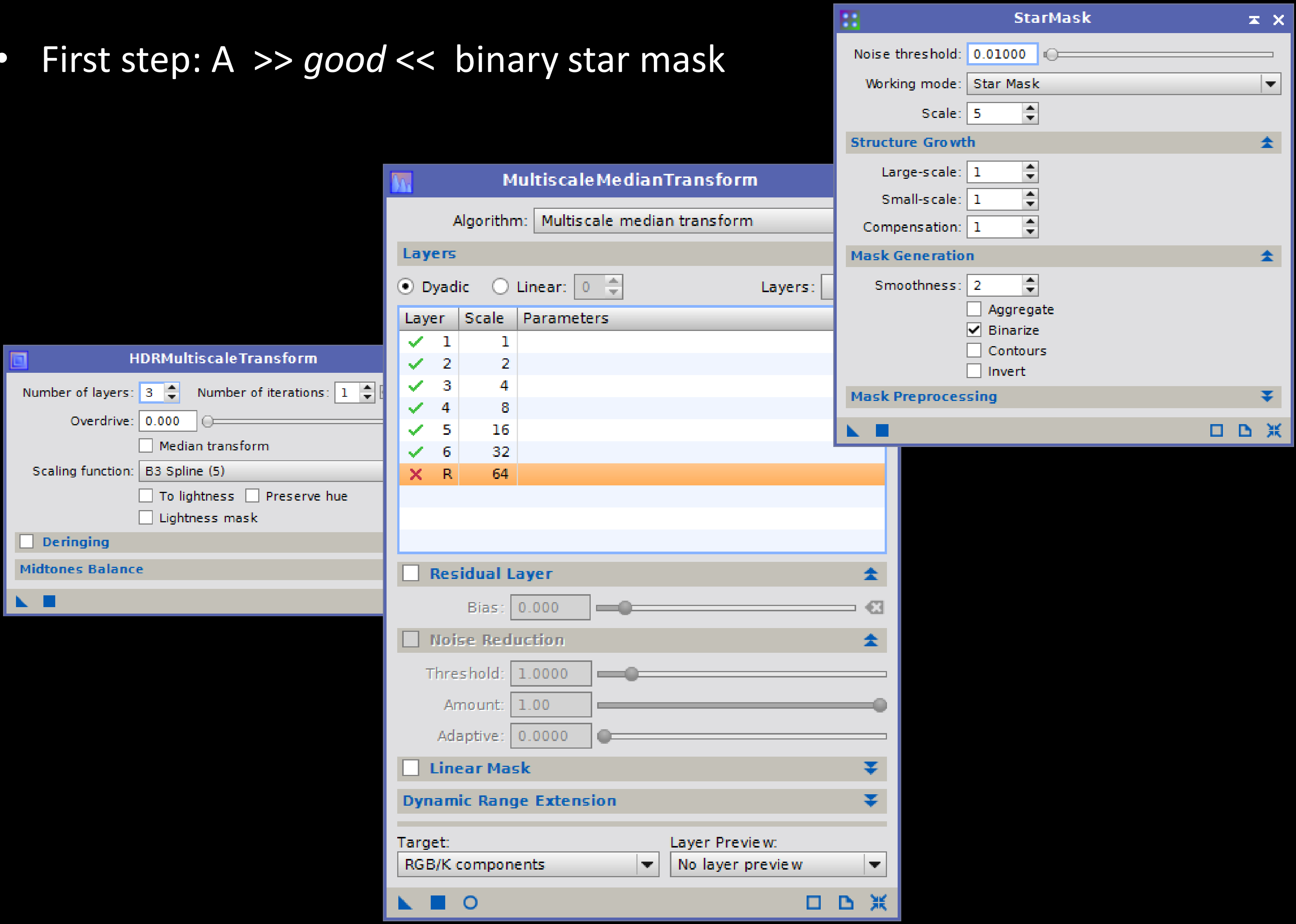
3) filling gaps

4) noise reduction

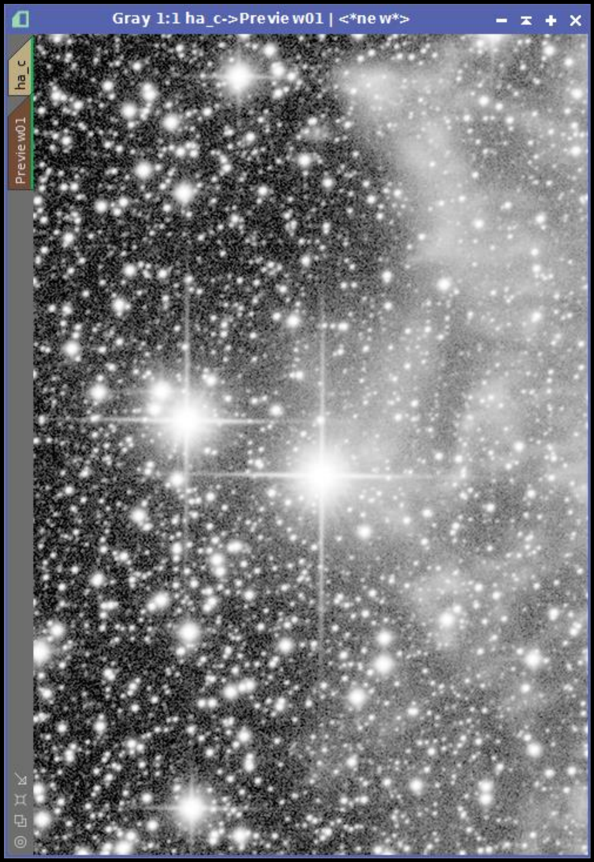
PixInsight

# (3.1) Star intensities

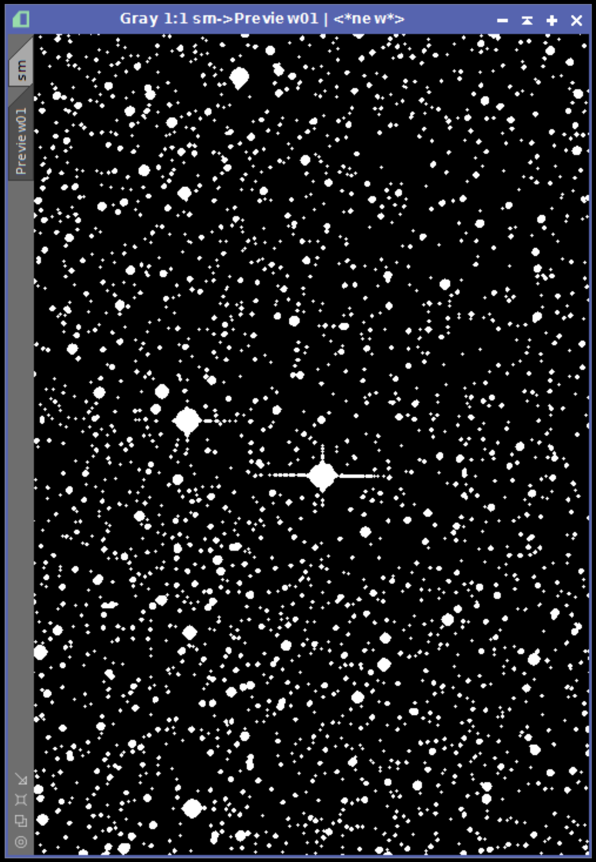
- First step: A >> *good* << binary star mask



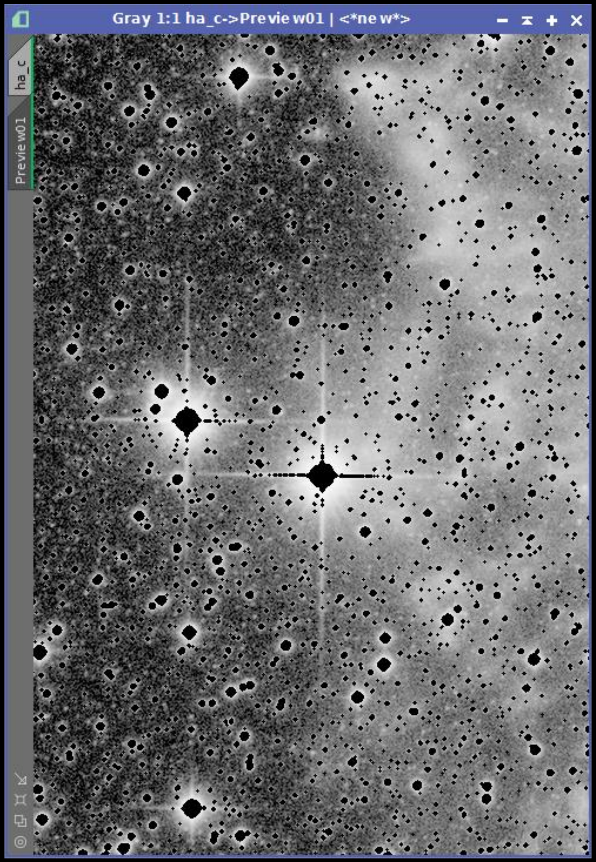
# (3.1) Star intensities




original




starmask

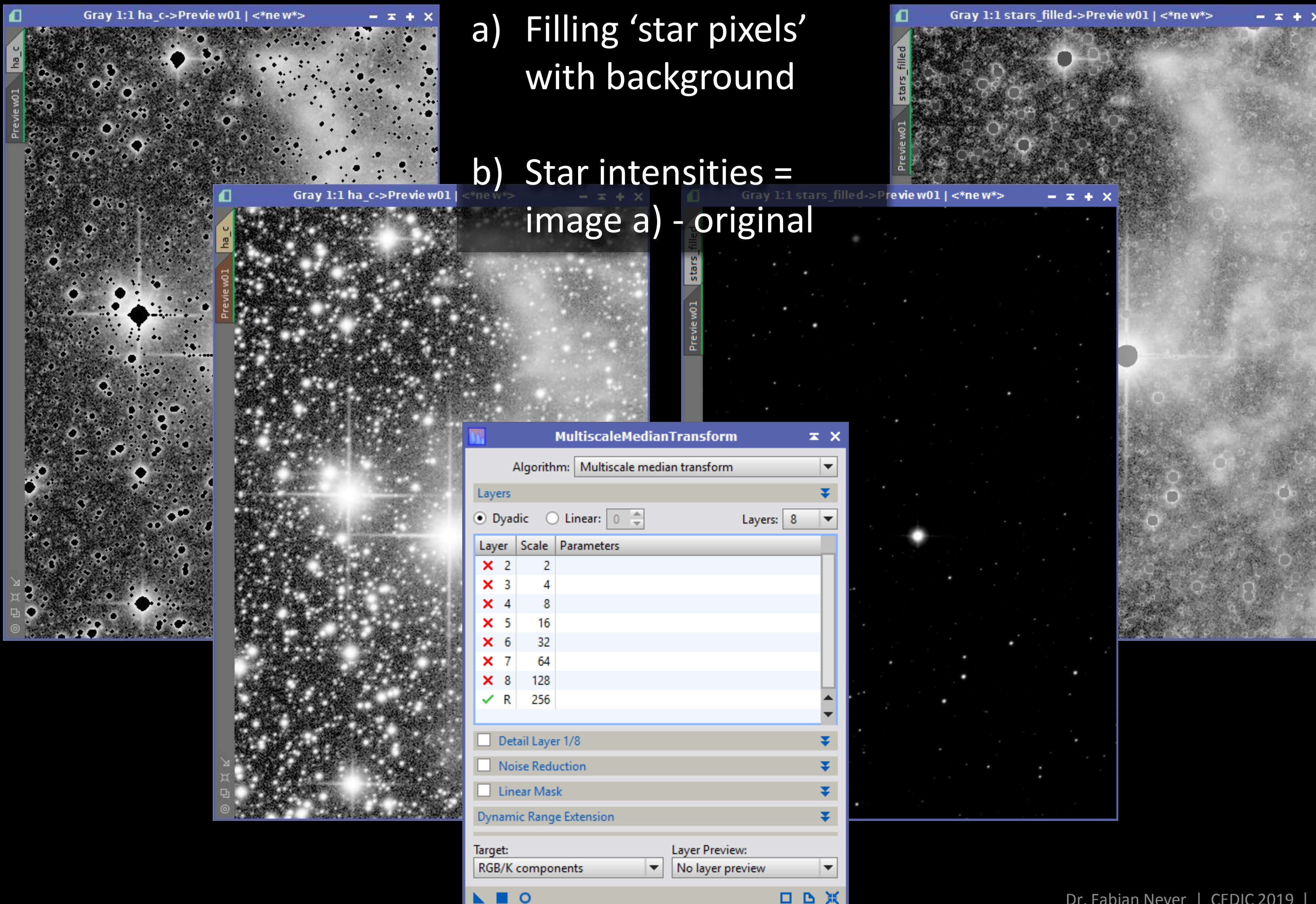



original *0
(mit aktiver starmask)

# (3.1) Star intensities

a) Filling ‘star pixels’ with background

b) Star intensities = image a) - original



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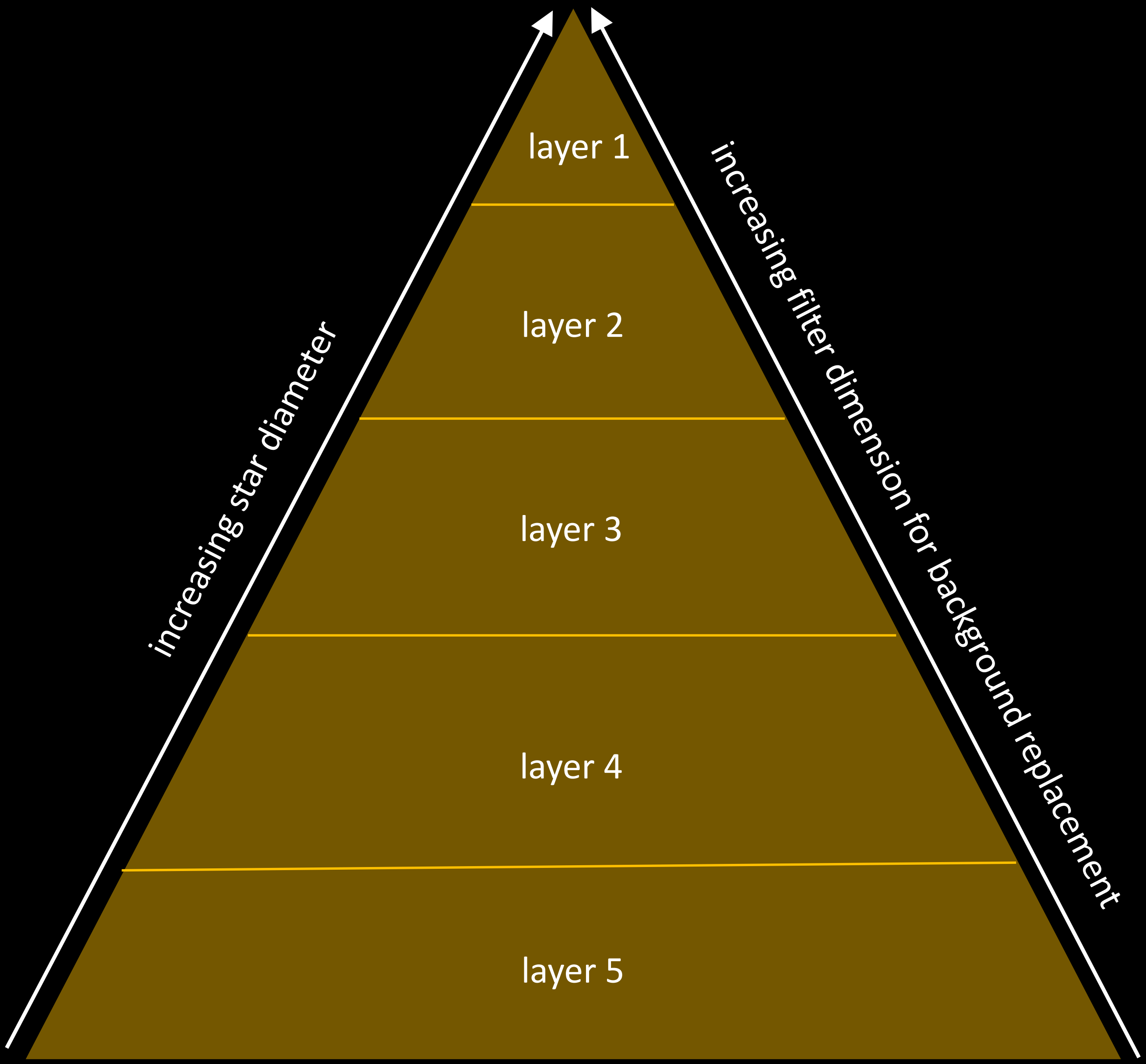


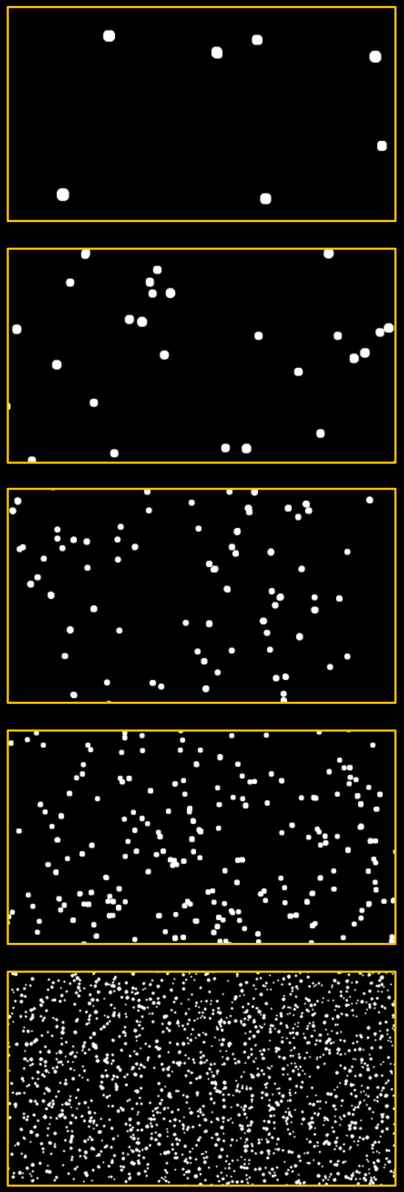

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5) Stretching

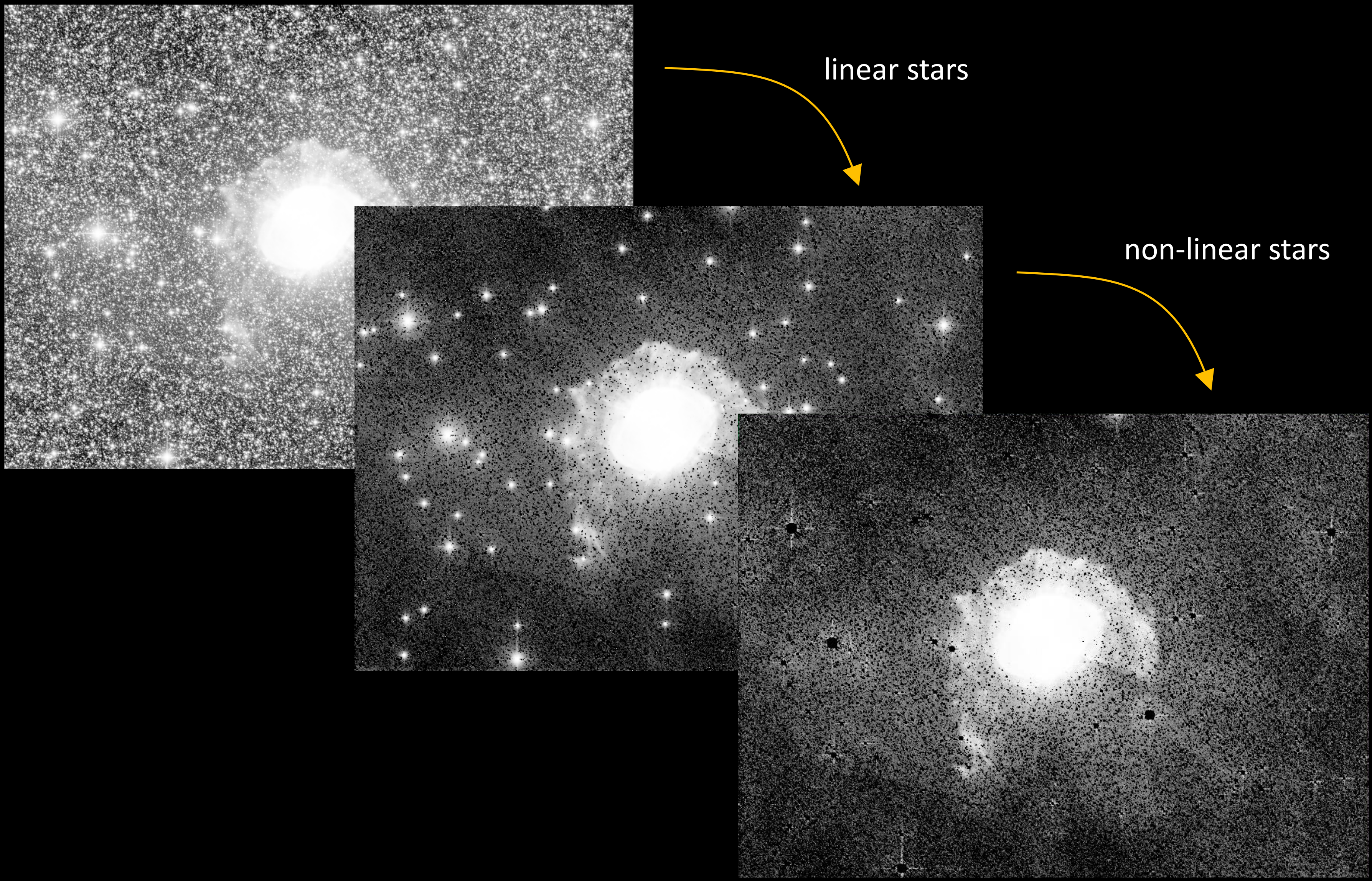
# (3.2) Removal of stars and their halos

Procedure:

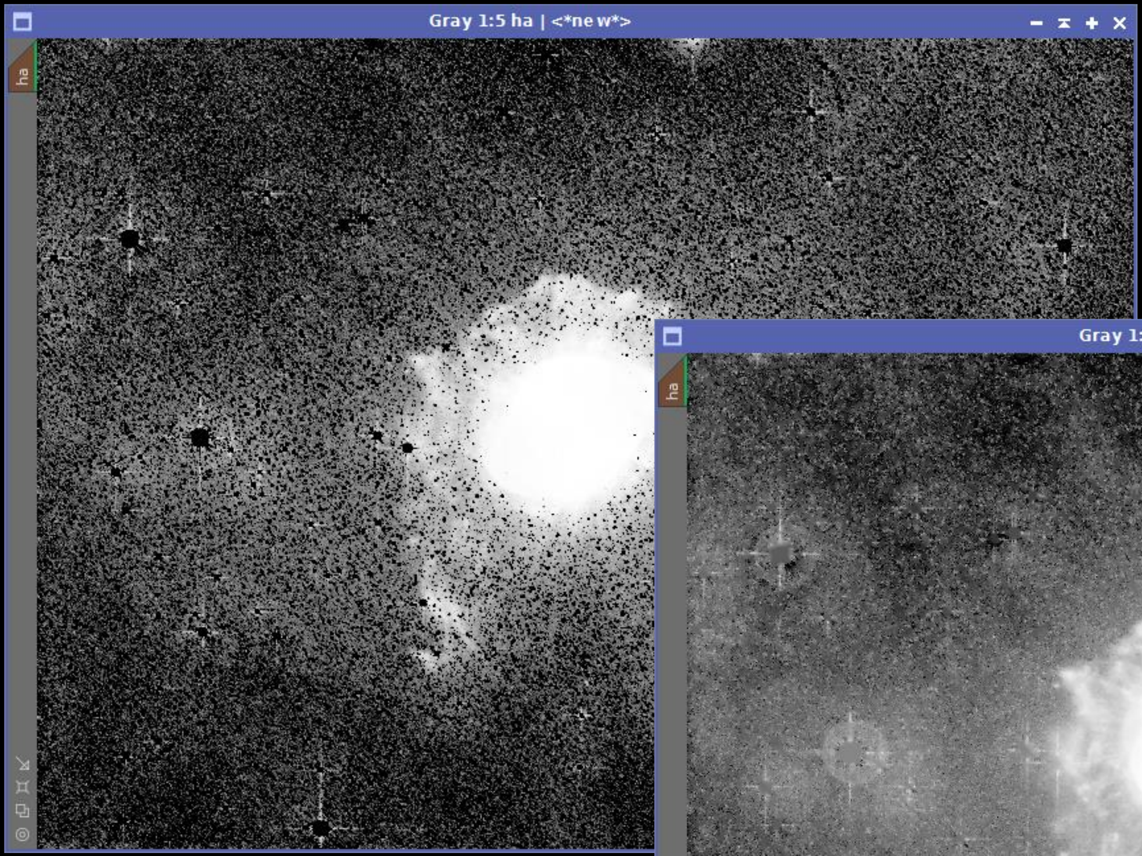
1) Blur (*convolution with gaussian kernel*) the 'star' image
2) Subtract the blurred image from the original (usually only a fraction of the blurred image)
3) Increase convolution kernel size (larger StdDev)
4) Start again at 1)

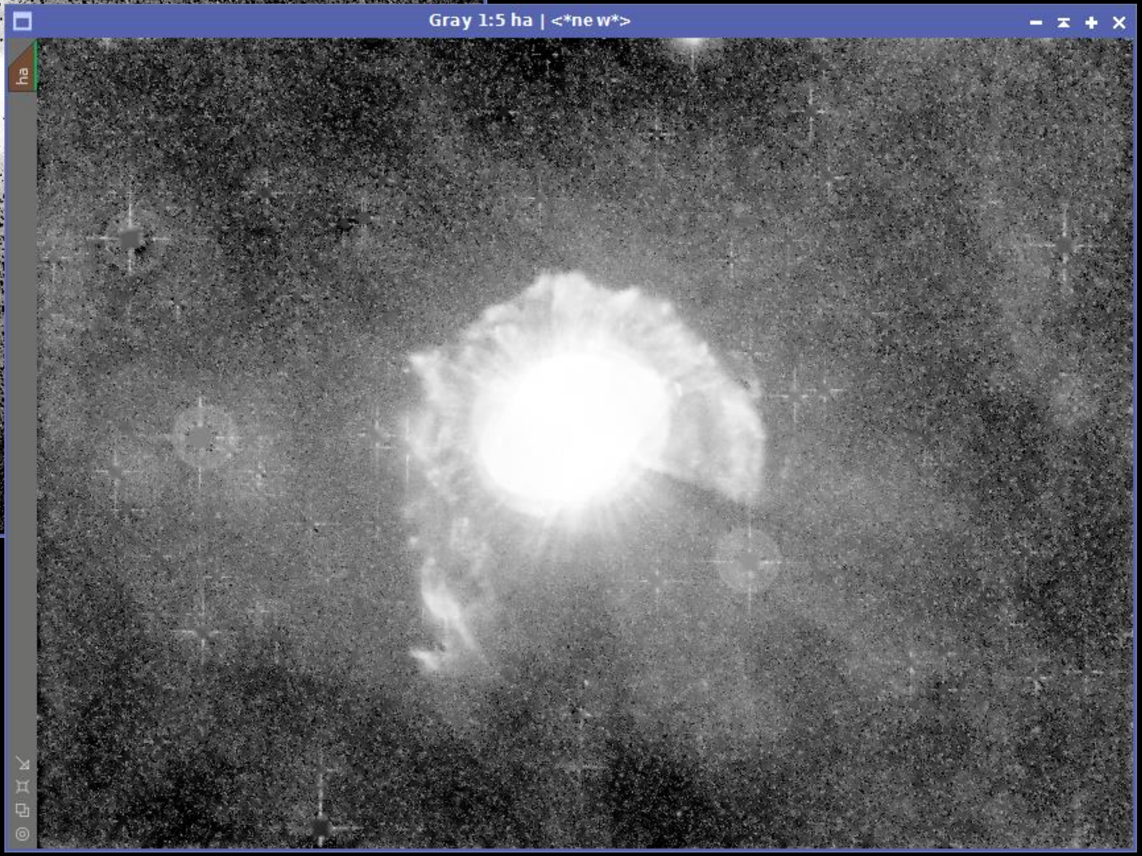
Usually works very well for stars in the linear regim. Stars in the non-linear sensor response domain need separate treatment

# (3.2) Removal of stars and their halos



# (3.3) Filling gaps

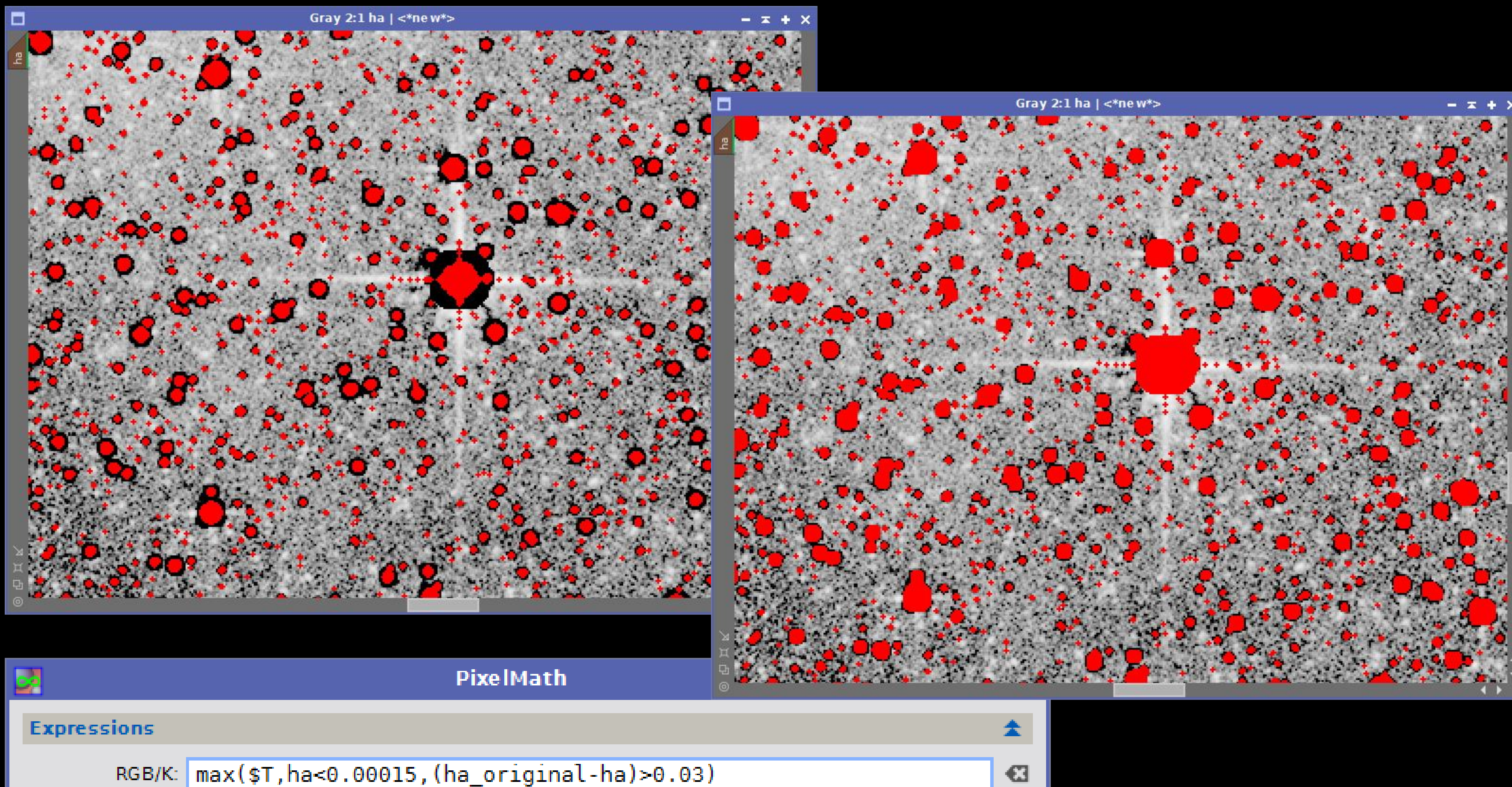



Iterative closing and interpolation of 'black' pixels

# (3.3) Filling gaps

Include black areas that appear after the star halo removal

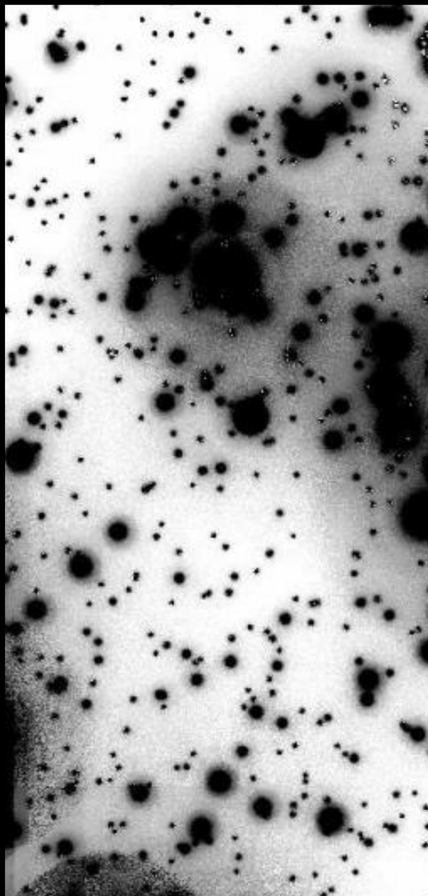



original starmask

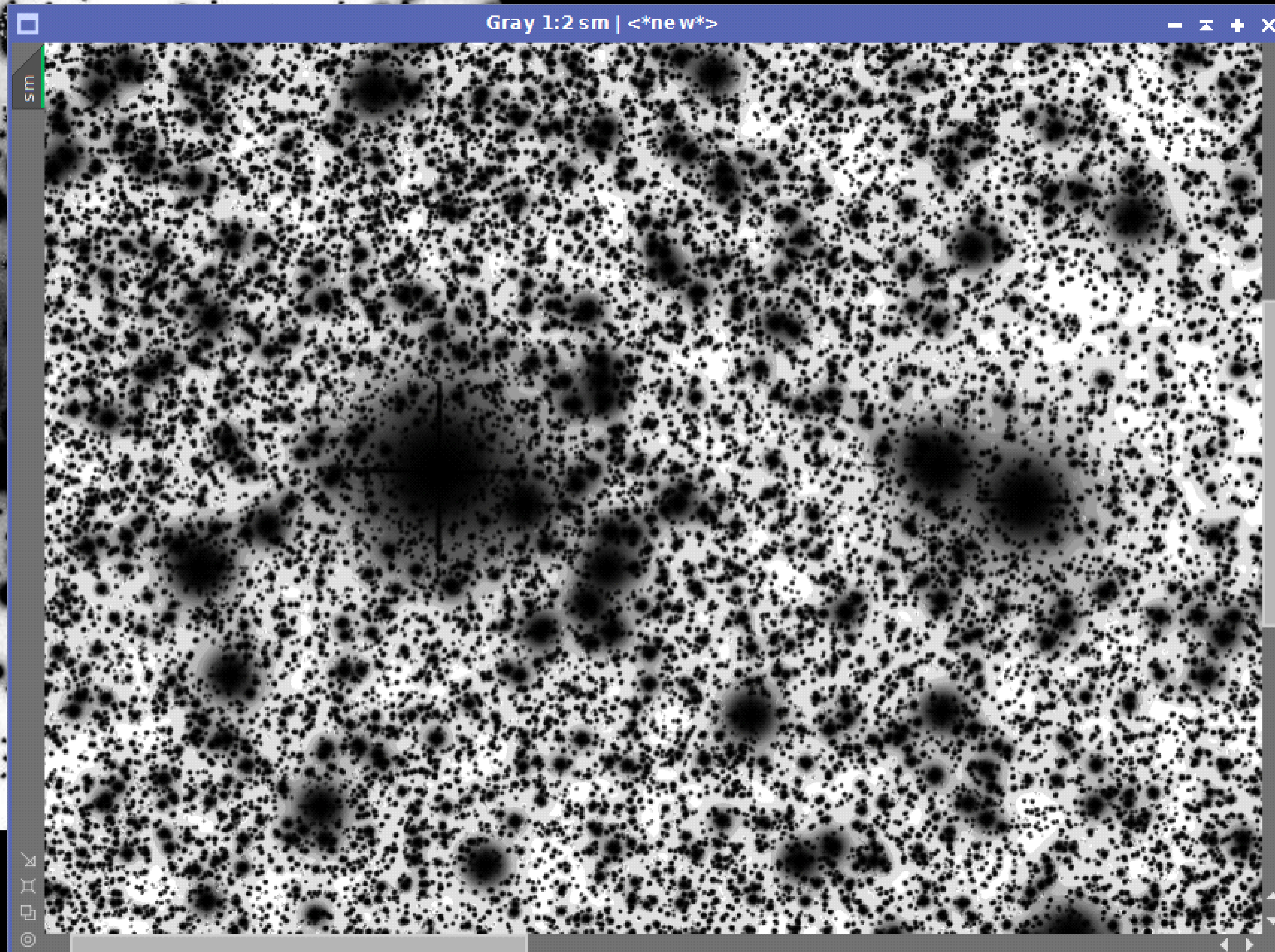
threshold ('ha' image)

threshold of differences

# (3.3) Filling gaps



*Salter et al. 2009*




*our model*

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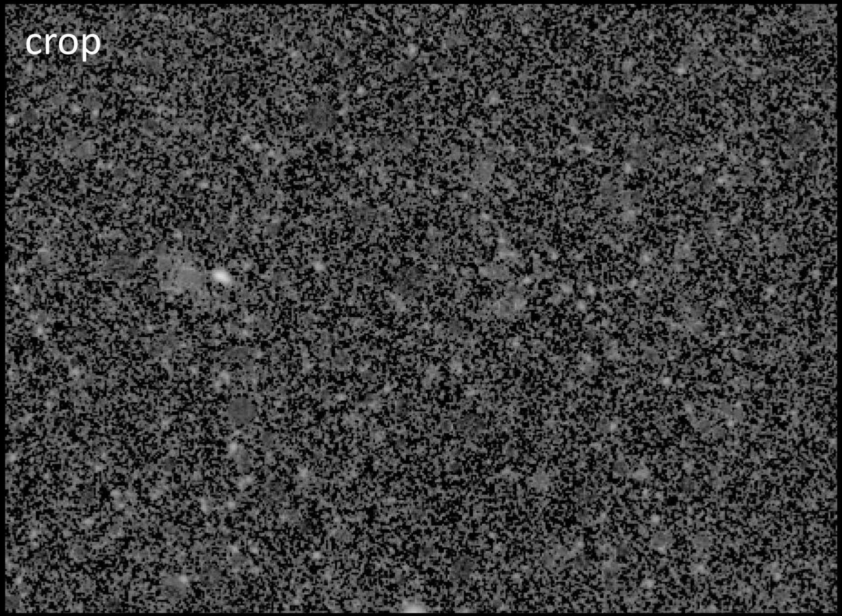
# (3.4) Noise reduction

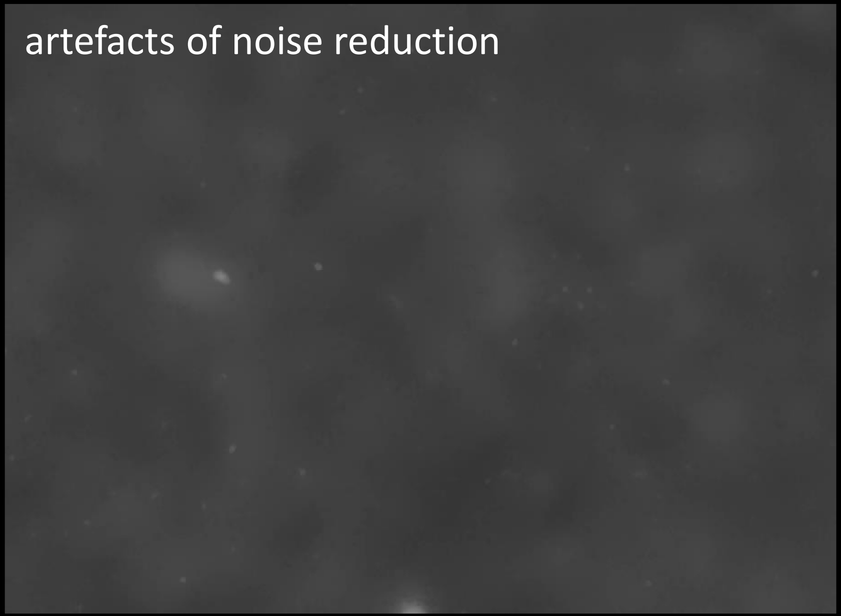
Create a good mask from the starless image requires noise reduction
Noise reduction is also 'dangerous':

- can create artificial halos around brighter structures
- can create continuous  soft structures through effects of multiple small but distinct structures

Iterativ noise reduction

- heavily depends on image S/N and residual structures in the background
- MMT, ACDNR
- always with masks



# (4) Stretching

# (4) Stretching

# Take home messages

1) Analyse your calibration procedure, especially your flats

2) Experiment with star reduction, be creative and systematic

3) Keep an eye on *starnet++*, eventually use your starless images for training your specific configuration


Thank you!
www.starpointing.com