Advanced Methods in Digital Astrophotography

November 27th 2024

NED-24

Krabi/Thailand

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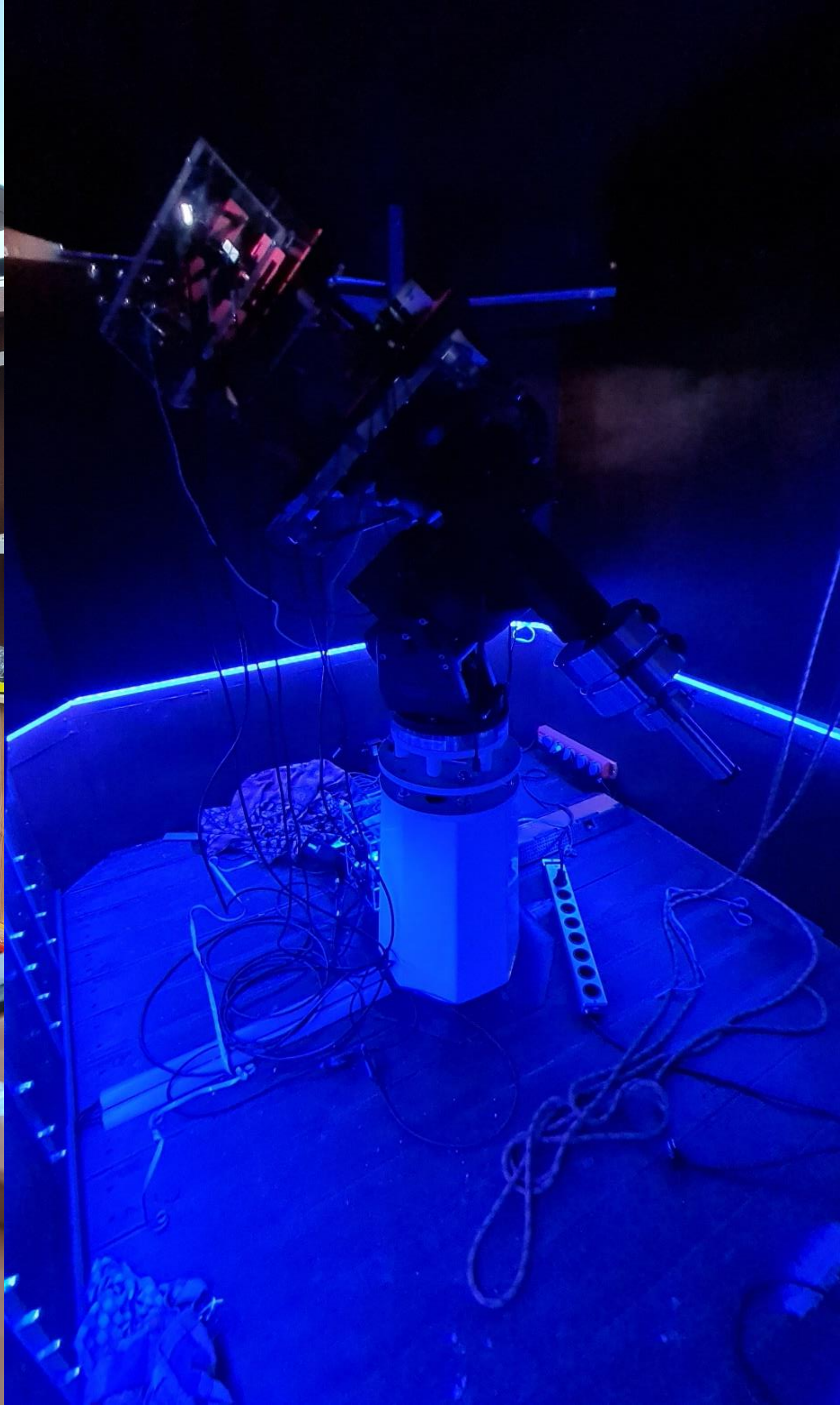
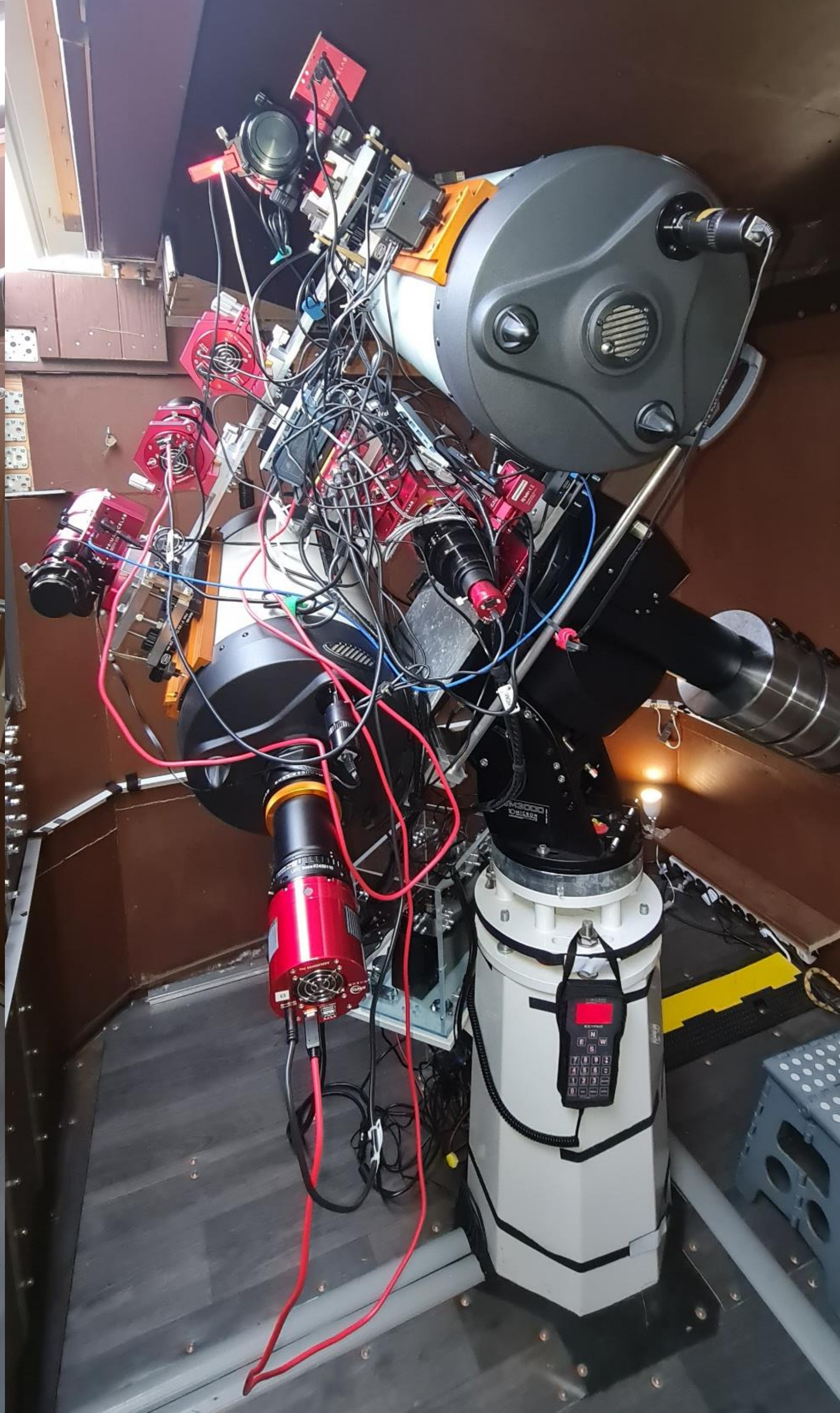
Ground Breaking
April 2021

Construction of base


Trockenbeton

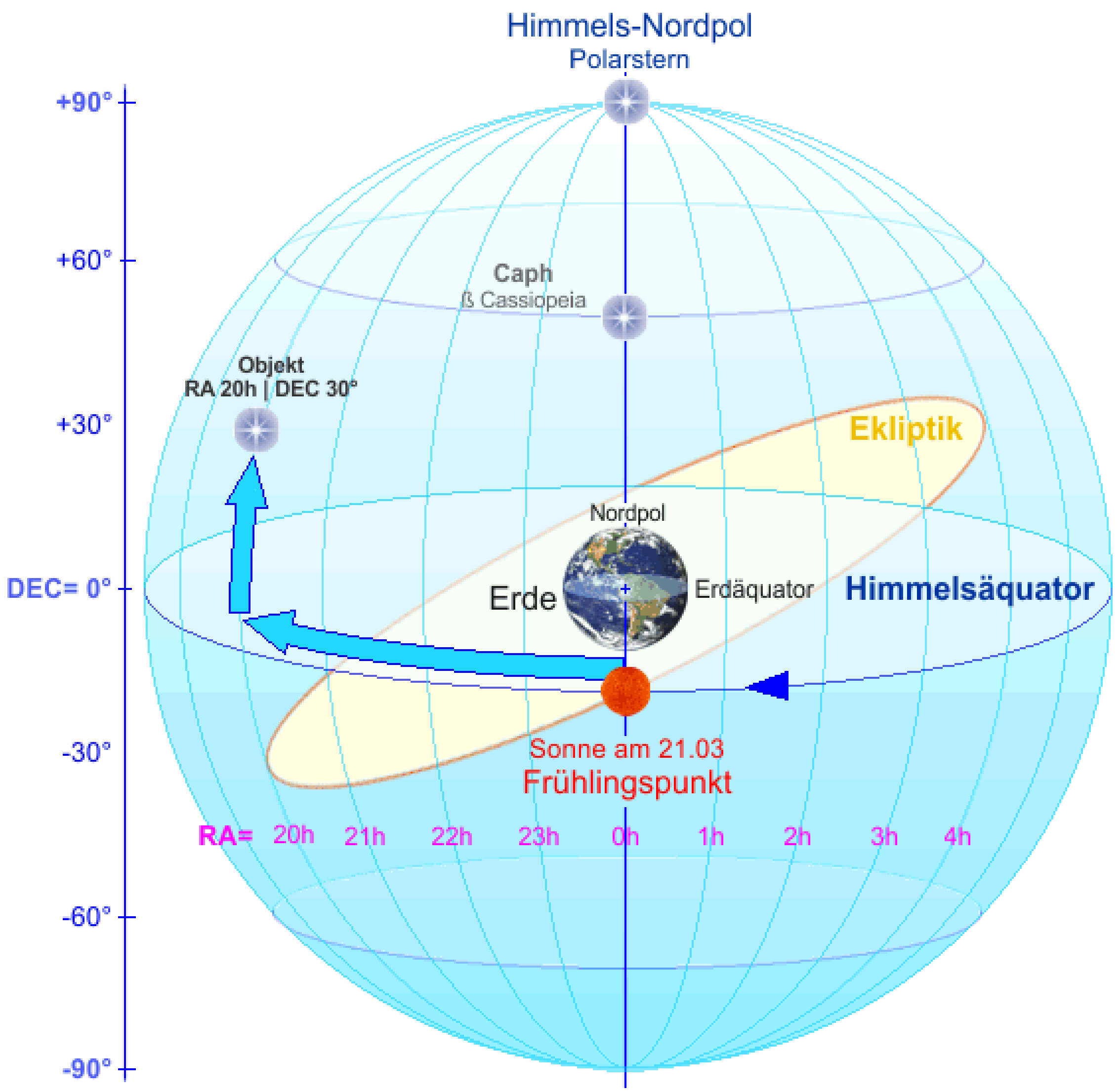


HPS




EAGLE

Celestial Coordinates



Astro.GoBlack.de

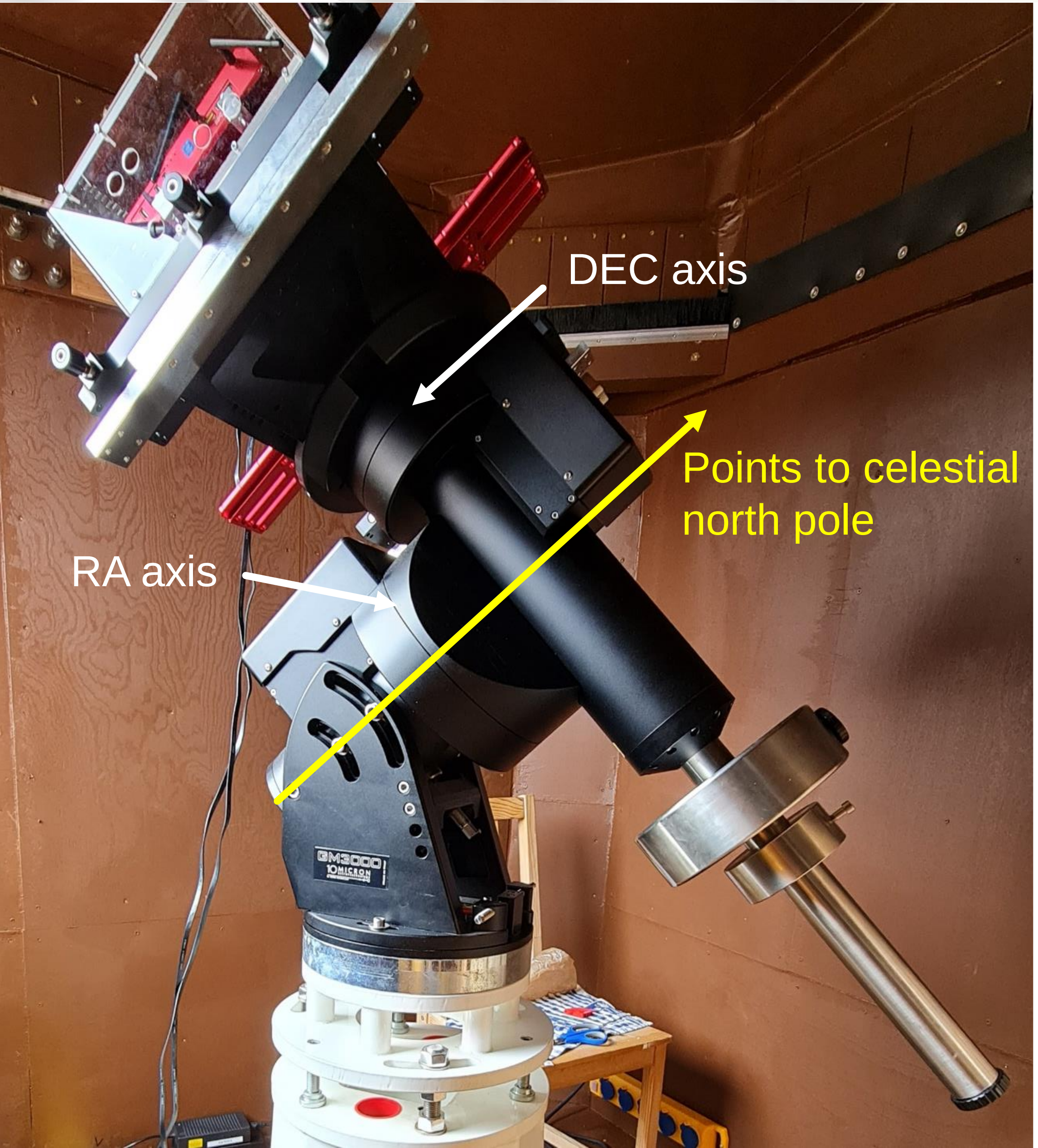
The most common coordinate system is **the rotating equatorial system**.

The **point of origin** is the point where the **celestial equator meets the ecliptic (Spring Point)**

Declination: angular distance from equator [-90°,+90°]
Right Ascension: angular distance from spring point [0h,24h]

Every point in the sky has a unique combination of DEC and RA values independent from time and location on earth.

For astro photography we have to compensate earth rotation



Equipment

10Micron GM3000 HPS equatorial mount

If everything is perfectly aligned and without atmospheric refraction only the RA axis is needed to compensate earth rotation.

- Payload: 100 kg
- Weight: 65 kg plus 100 kg counter weights
- Absolute encoders
- WLAN, GPS
- Automatic correction of atmospheric refraction
- 100 stars pointing error model

Equipment

Rowe Ackerman Schmidt Astrograph (RASA)
279/620 mm, f/2.2

C1100 EHD, Schmidt Cassegrain
279/2800 mm f/10 plus reducer 0.7x

TS Apochromat Triplett with corrector
74/370 mm

2x Sharpstar Apochromat Triplett with reducer
61/270 mm

2x Zeiss Milvus 100mm/f2.0

Mount + Optics

Color Camera

Broadband Filter

Data Processing

+

+

+

+

Monochrome Camera

Narrowband Filters (Ha, OIII, SII)

Basics of Digital Astrophotography

Goal

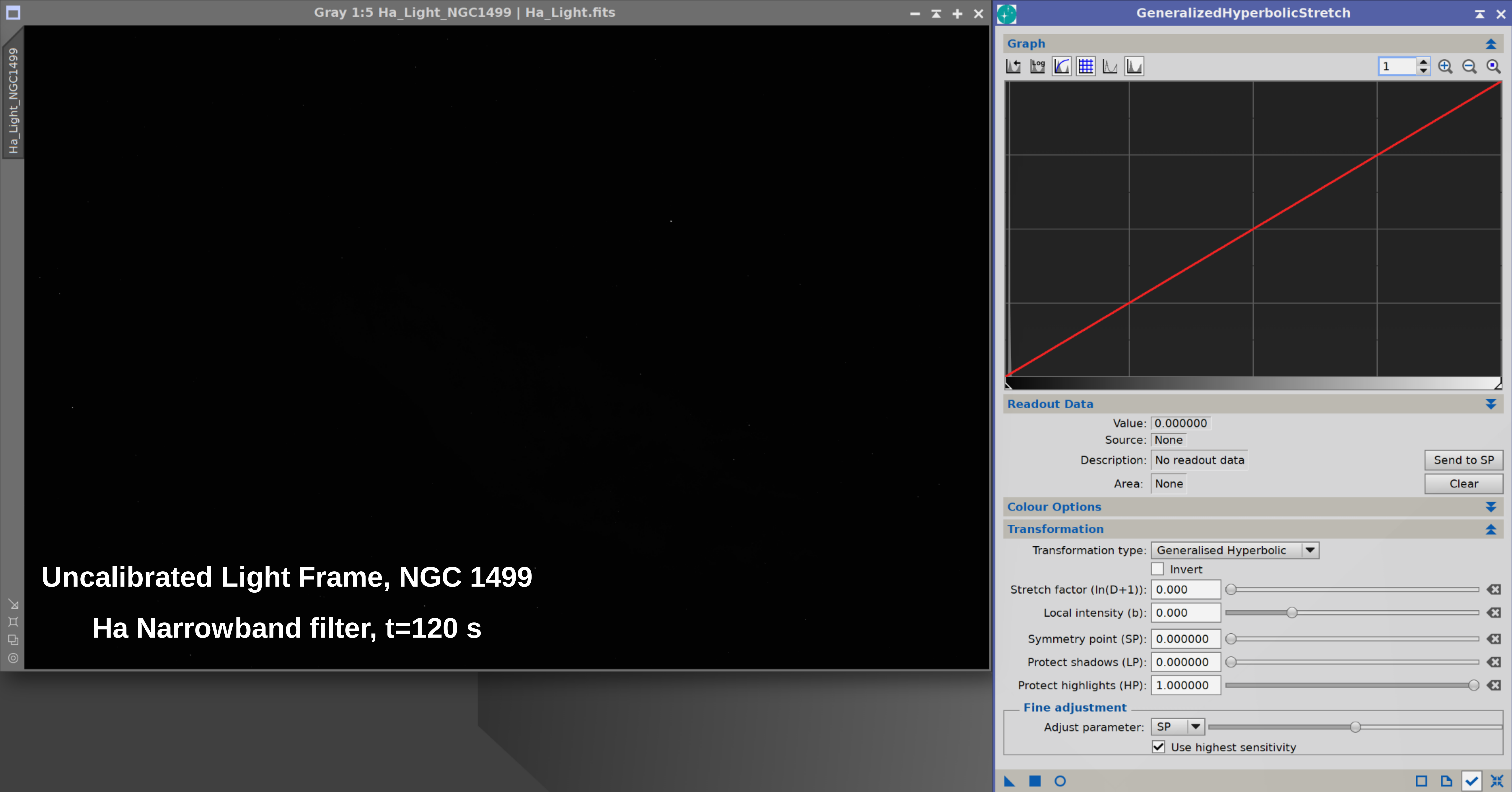
Low Noise pictures with lots of details

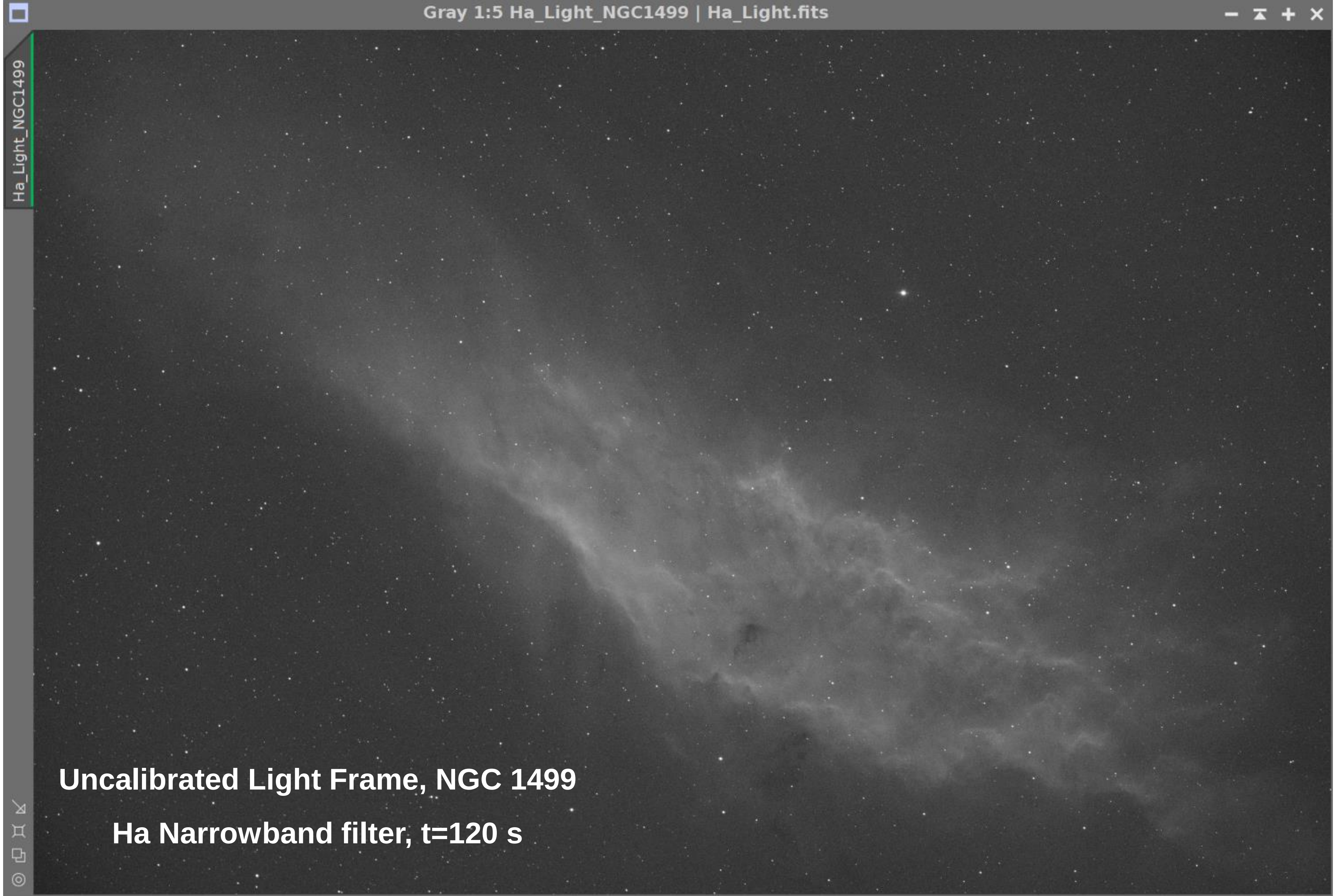
Your enemies

- Unwanted light (moon, artificial light, air glow) → Filters
- Vignetting → Flat frames
- Dust on sensors → Flat frames
- Atmospheric refraction → Mount with correction
- Geometric aberrations → Deconvolution (to a certain extend)
- Guiding errors → Good polar alignment
- **NOISE** → Calibration frames + long exposure + many frames

Light Frames

NGC 1499 Ha Light Frame – Histogram with GHS


Gray 1:5 Ha_Light_NGC1499 | Ha_Light.fits
Ha_Light_NGC1499
Uncalibrated Light Frame, NGC 1499
Ha Narrowband filter, t=120 s
GeneralizedHyperbolicStretch
Graph
1
Readout Data
Value: 0.000000
Source: None
Description: No readout data
Area: None
Send to SP
Clear
Colour Options
Transformation
Transformation type: Generalised Hyperbolic
Invert
Stretch factor (ln(D+1)): 0.000
Local intensity (b): 0.000
Symmetry point (SP): 0.000000
Protect shadows (LP): 0.000000
Protect highlights (HP): 1.000000
Fine adjustment
Adjust parameter: SP
Use highest sensitivity

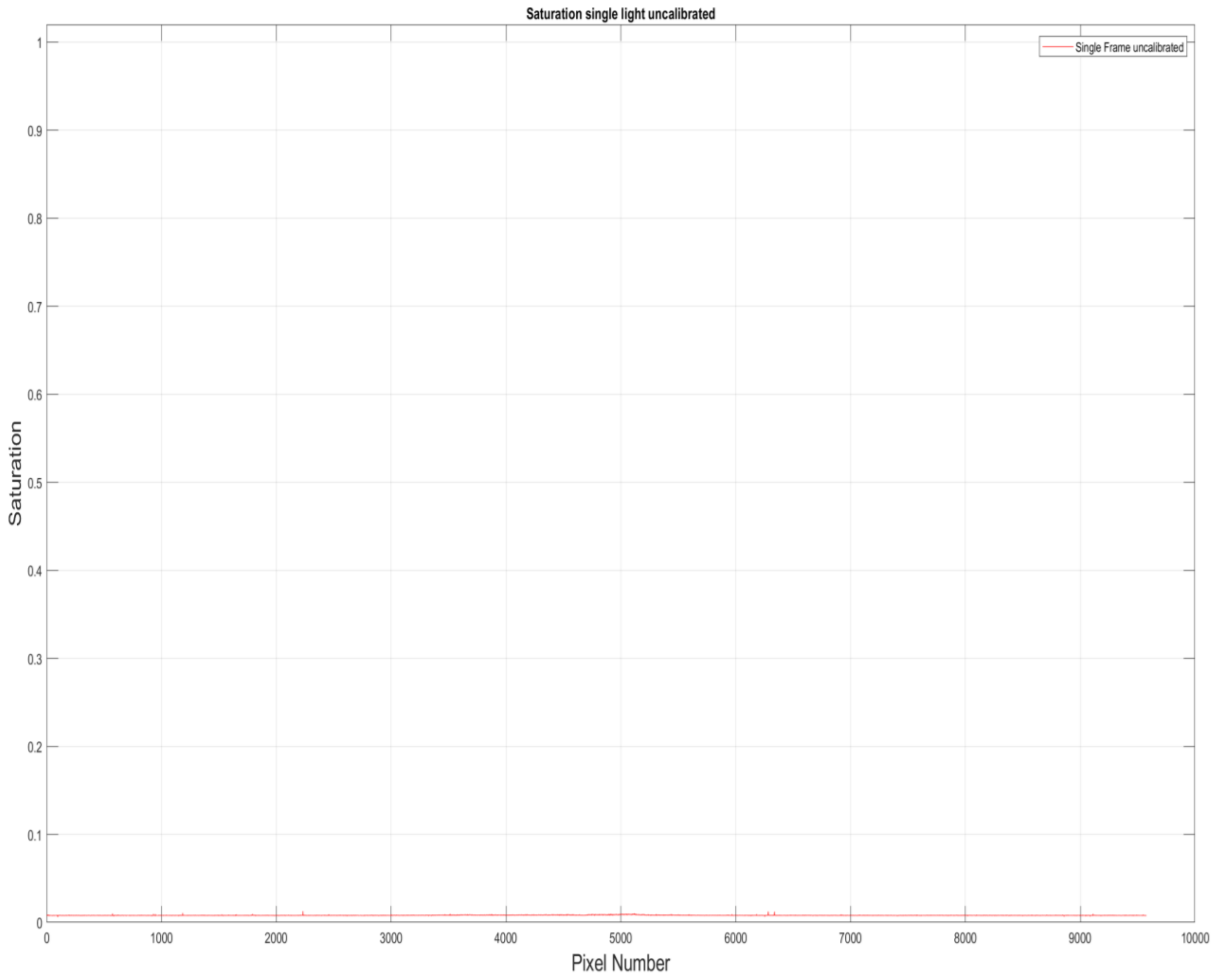


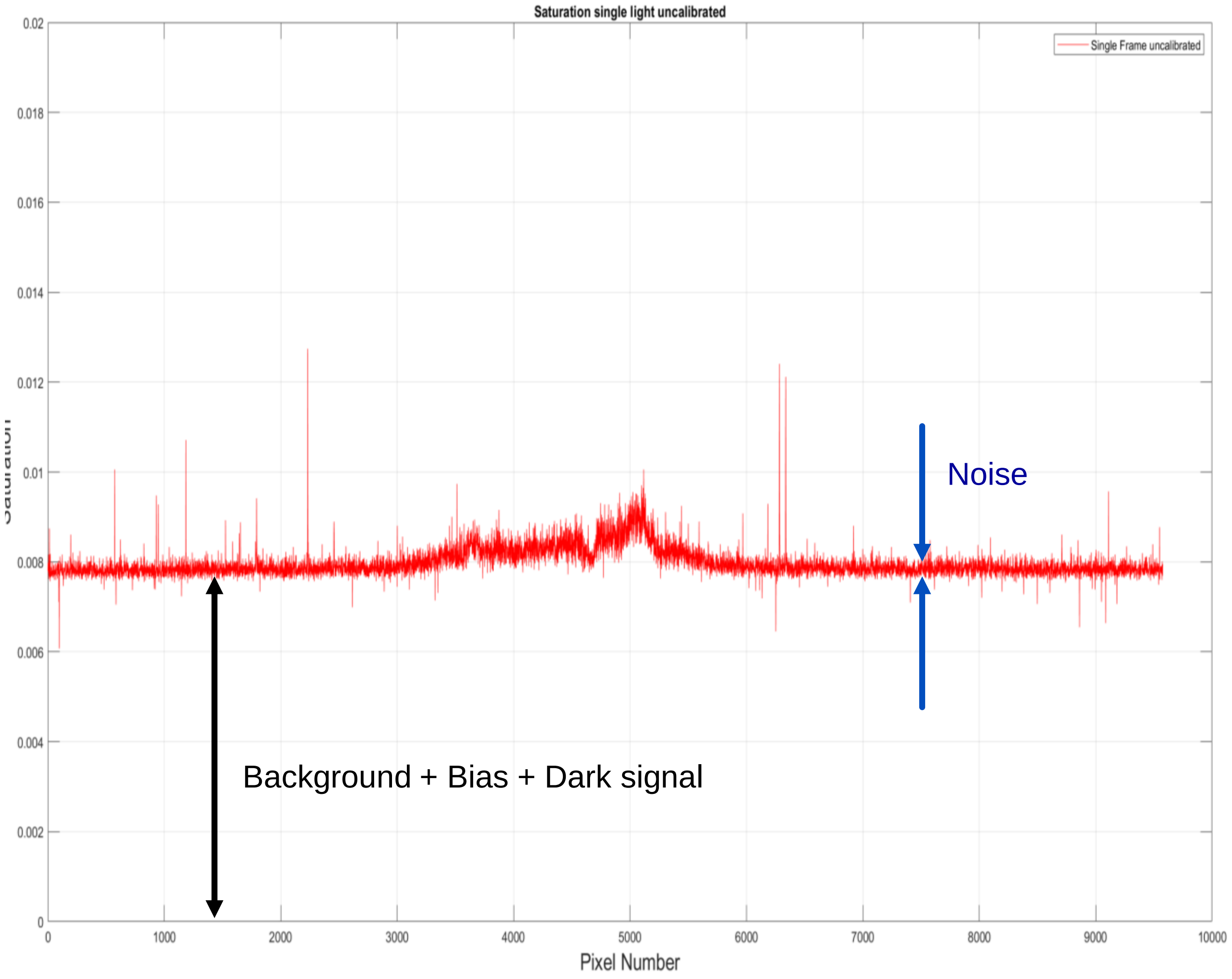
Uncalibrated Light Frame, NGC 1499

Ha Narrowband filter, t=120 s


Gray 3:1 Ha_Light_NGC1499 | Ha_Light.fits
Ha_Light_NGC1499
Noise, background, hot pixels
Uncalibrated Light Frame, NGC 1499
Ha Narrowband filter, t=120 s

Saturation Light Frame (uncalibrated)





Noise/Unwanted Signal

There are several unwanted signals with noise in the Light Frames:

- **Bias Signal with Noise**
- **Thermal Signal (Dark Current) with Noise**
- **Noise of Object because of low saturation statistical variations of number of excited electrons**
- **Background (skyglow, light pollution)**

Golden Rule: Long total exposure time, calibration and data processing

Noise

Every pixel has a certain signal

Object signal + unwanted signal and noise

To fight noise, the pixels of many independent frames must be averaged (stacking or image integration)

$$g_{ave}(x,y) = \langle \boldsymbol{f}_{xy} \rangle = \frac{1}{N}\sum_{i=1}^{N} f_i(x,y)$$

$$\sigma_{g_{ave}} = \frac{\sigma_{f_i}}{\sqrt{N}}$$

Light Frames

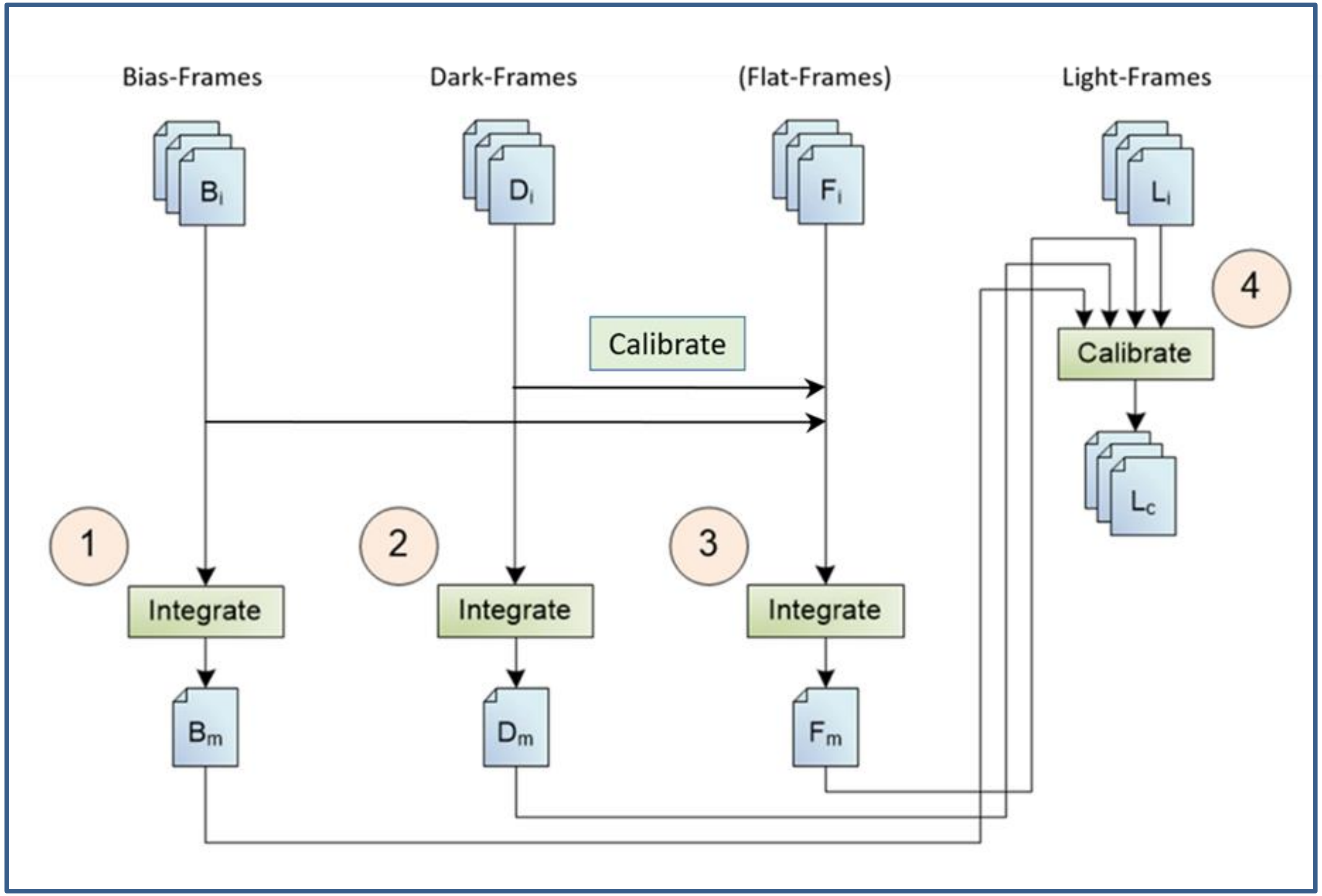
Light frames are the **actual pictures** of the object

Typical exposure times (deep sky objects) between 30 and 500 s

Number of light frames depends on available time (N>>10)

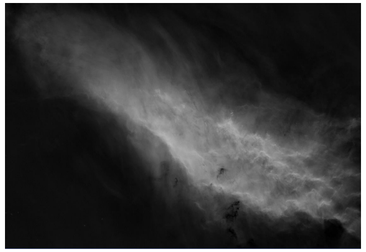
To be calibrated with Master-Bias, Master-Dark and Master Flat

Calibration

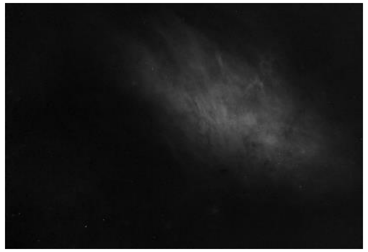


Integration → Master

Ha



OIII



SII

single calibrated Light Ha

Uncalibrated Light Frame

Calibrated Light Frame

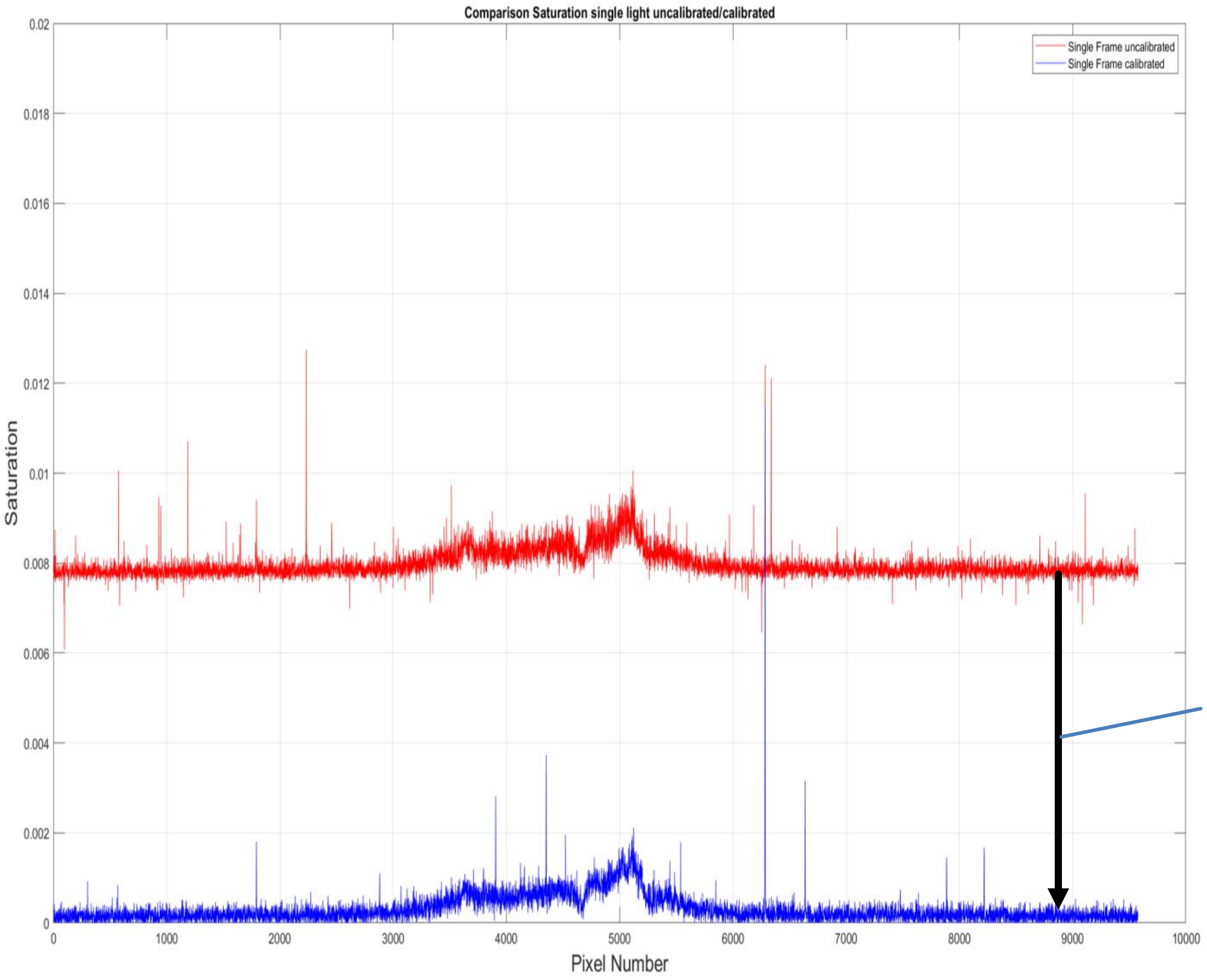
Individual automatic histogram stretch

Uncalibrated Light Frame

Calibrated Light Frame

Stretch of calibrated Frame applied to uncalibrated frame

Calibrated Light Frame



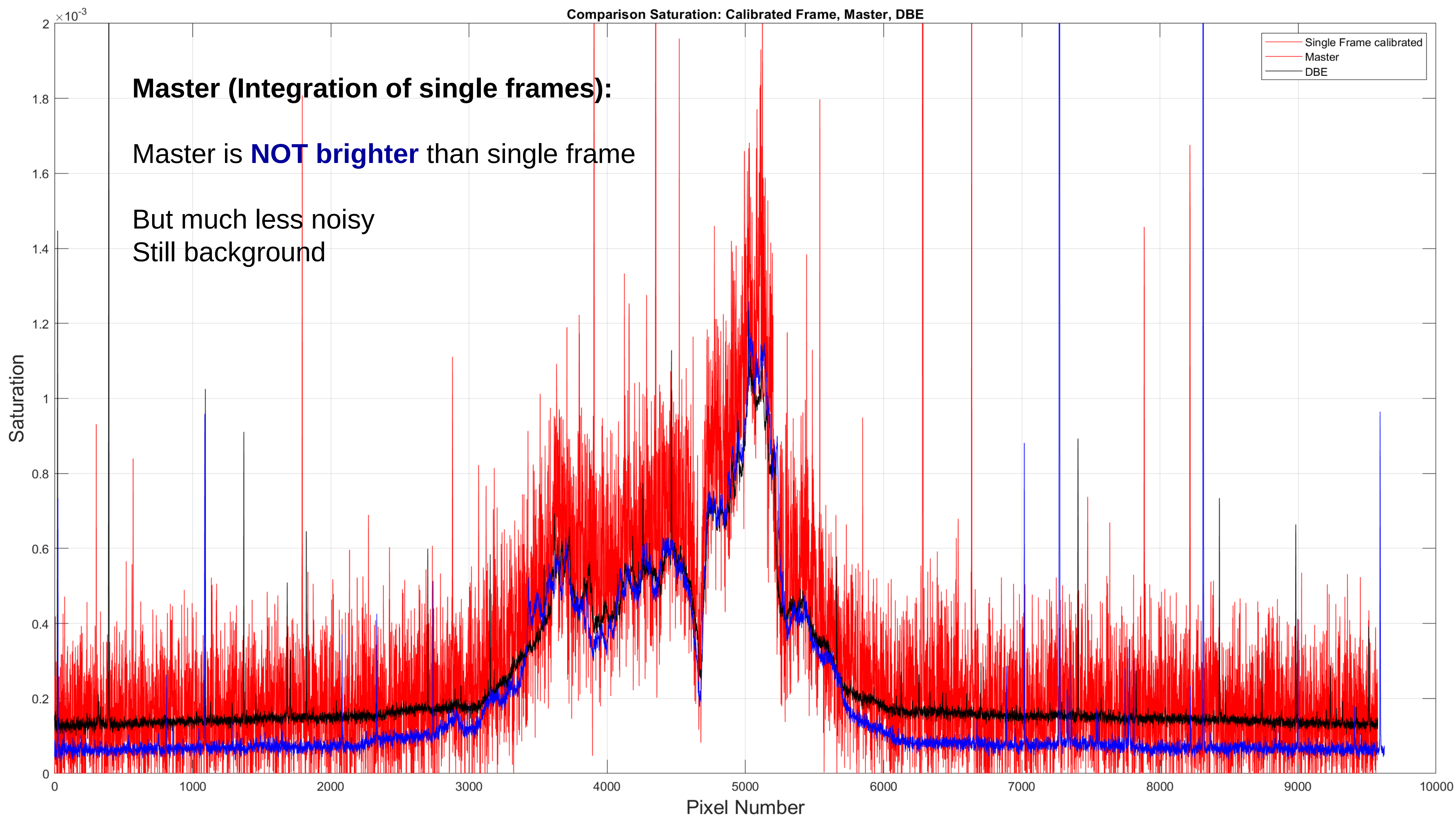
Reduction of unwanted signal by a factor of 10

Still noise (width of curve)

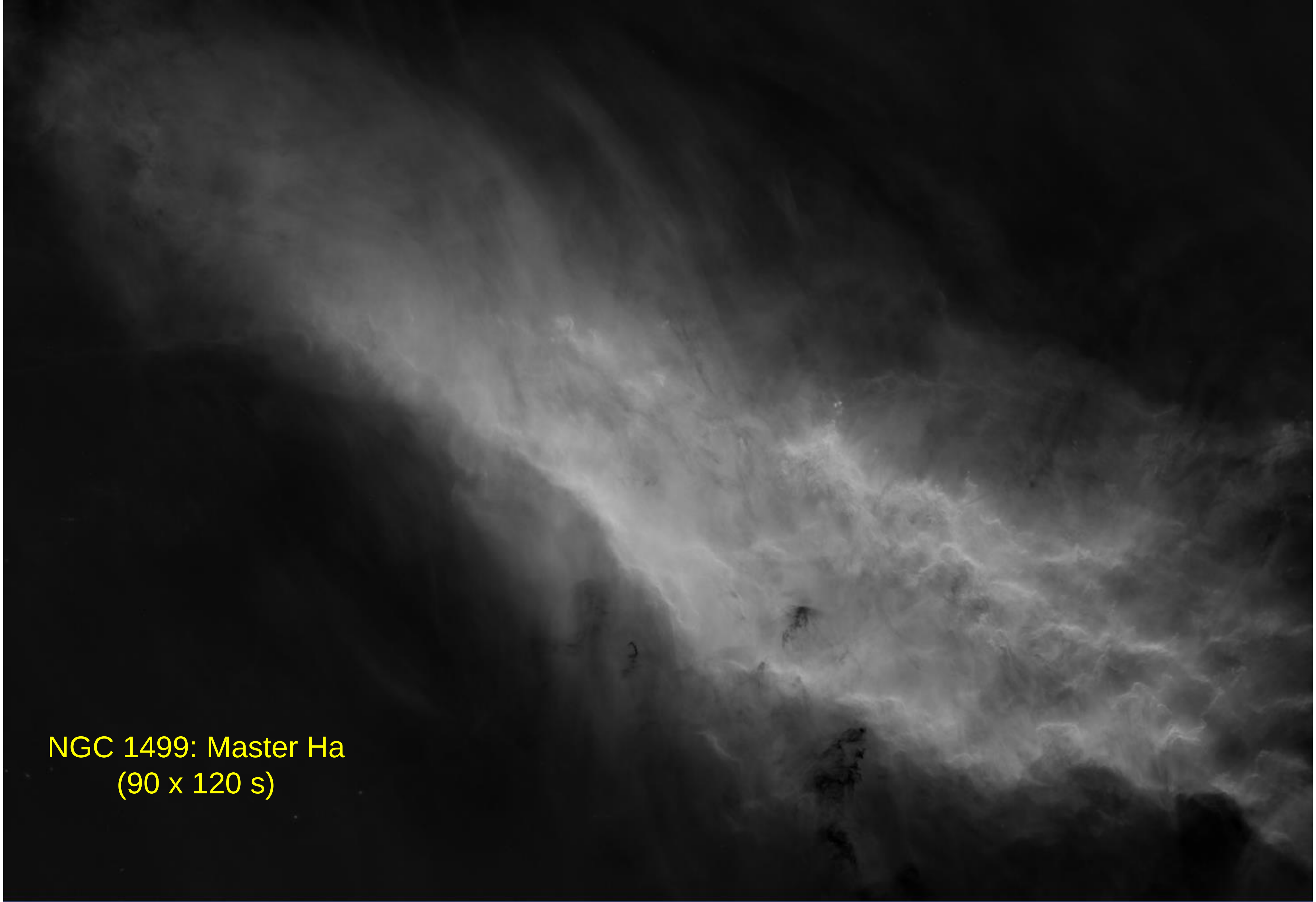
Increased Signal to Background Ratio

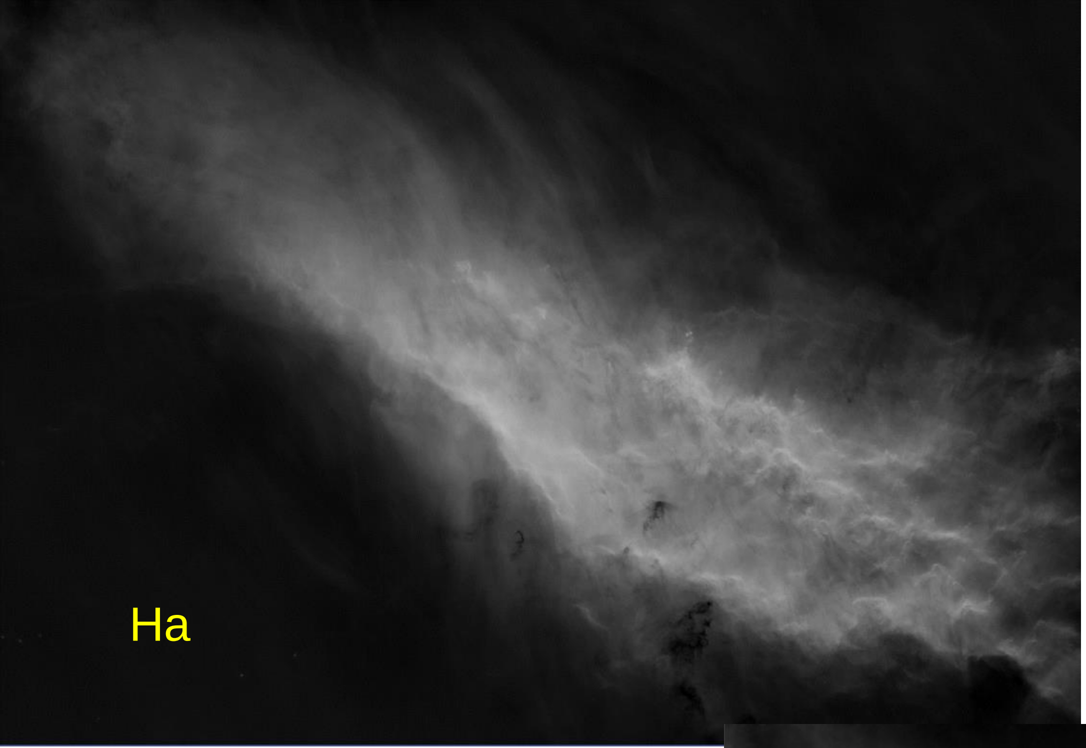
Reduction Bias and Dark signal

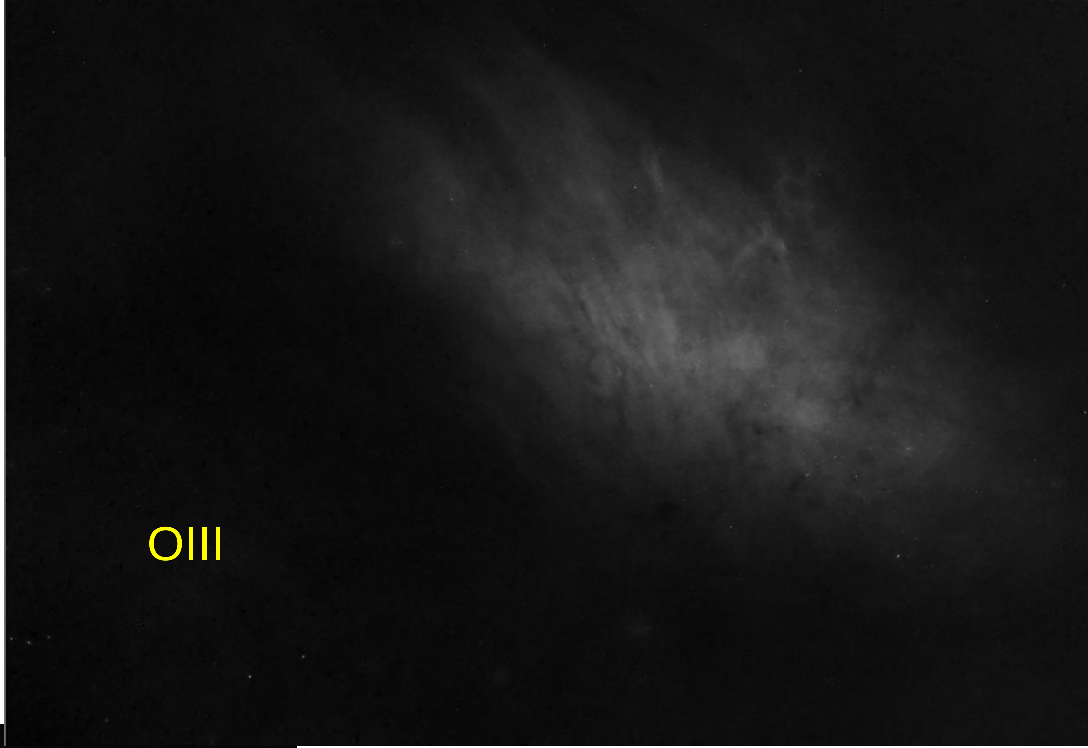
Finally (after several other steps), integration of light frames to create Master



Comparison Saturation: Calibrated Frame, Master, DBE
×10^-3
Single Frame calibrated
Master
DBE
Master (Integration of single frames):
Master is NOT brighter than single frame
But much less noisy
Still background
Saturation
Pixel Number

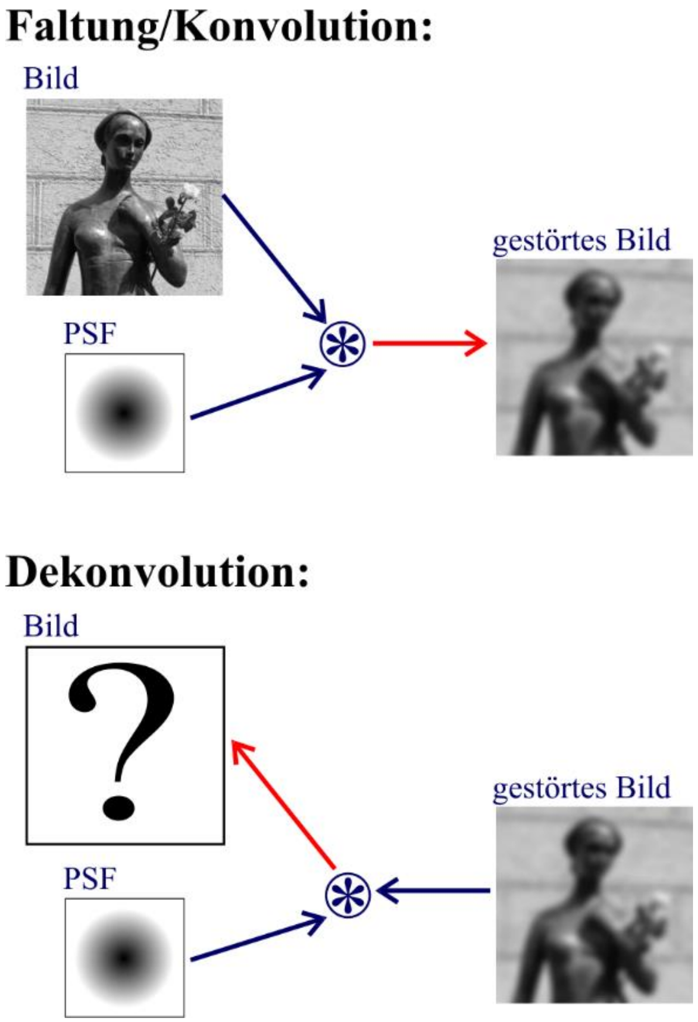

NGC 1499: Master Ha
(90 x 120 s)





Master Files

Deconvolution

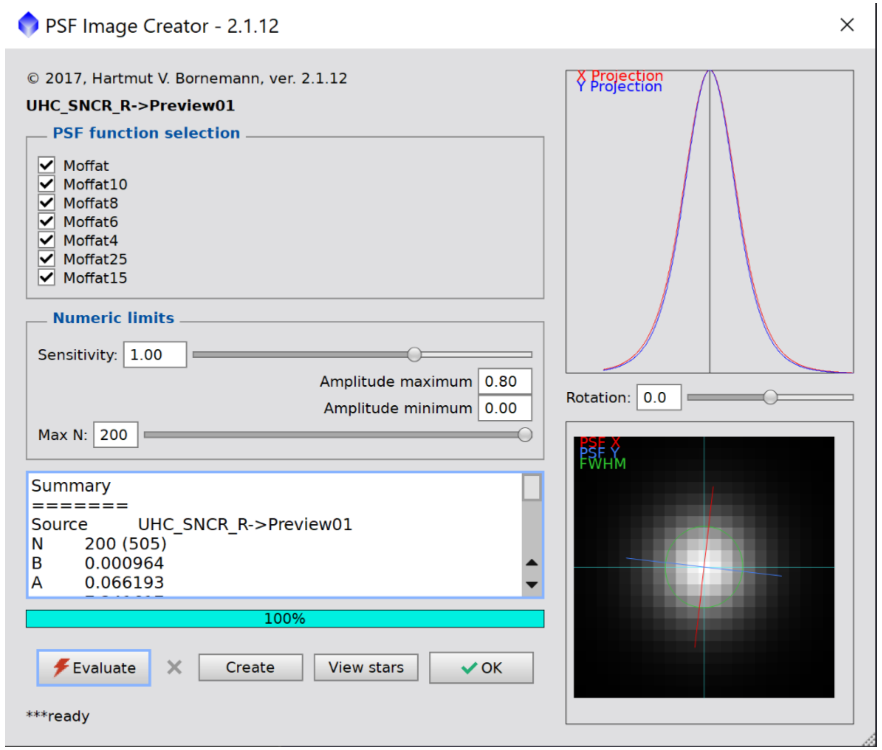


Deconvolution is a mathematical process (inverse of convolution) to improve images

Disturbances (imperfect optics, guiding errors, temperature and pressure changes, weak focusing, seeing…) lead to a degradation of the image (reduced contrast of small scale details)

If we can measure the pertubance we can deconvolute the image

Deconvolution



Stars are punctual but represented by diffractions disks (Airy Disk)

These diffraction discs (Stars intensity profile) are described by Moffat Functions

$$M(x,y) \quad = \quad B + A\left(1 + \frac{(x-x_0)^2}{\sigma_x^2} + \frac{(y-y_0)^2}{\sigma_y^2}\right)^{-\beta}$$

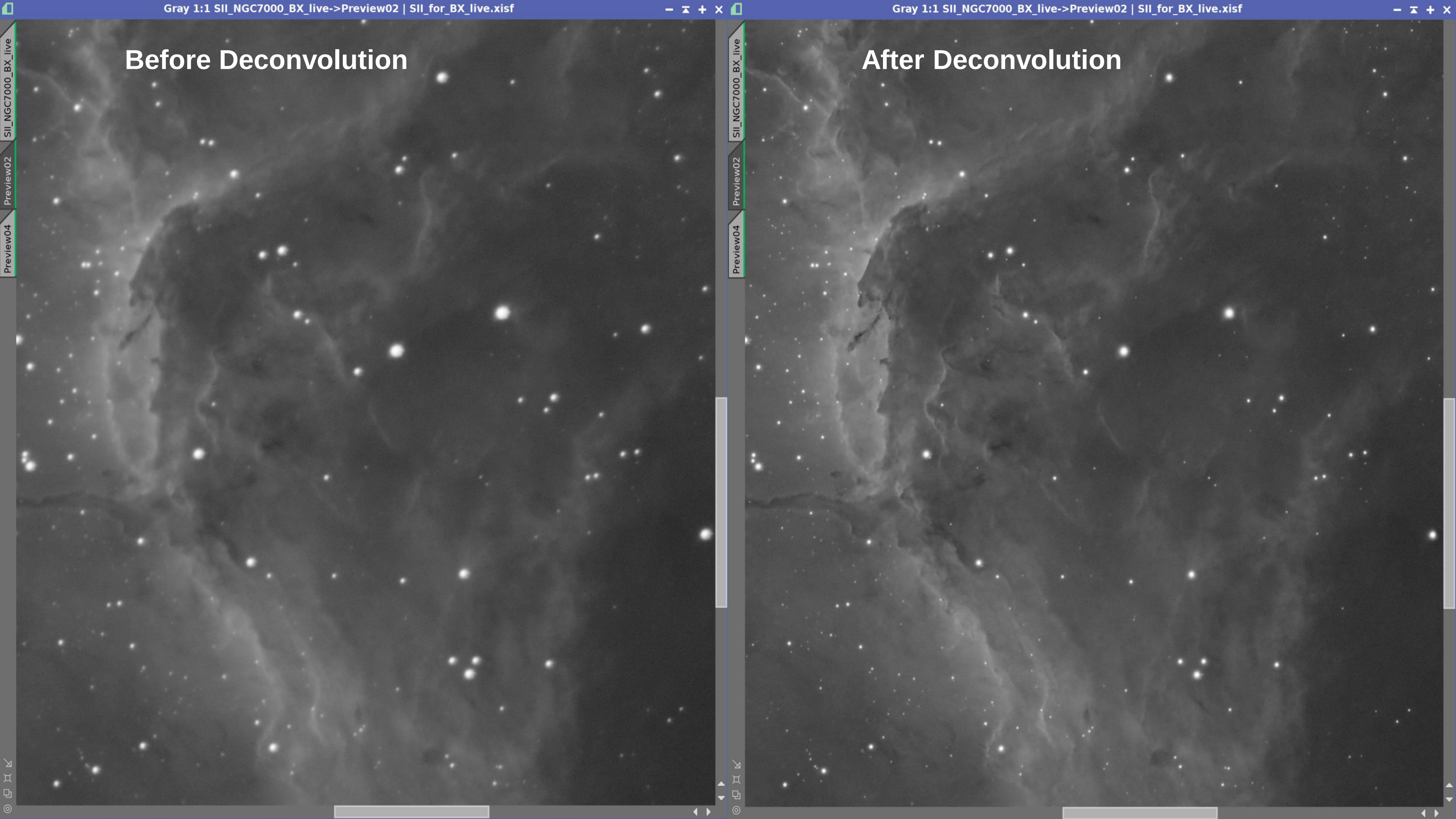
We can measure the density functions and calculate the deviation from the theoretical distribution → PSF (even non-stationary PSF)

The measured PSF will differ from the ideal PSF without errors

It is **not only sharpening** but **real information restoration** to the refraction limit

Deconvolution

Blur Xterminator with SII Master NGC 7000


Gray 1:1 SII_NGC7000_BX_live->Preview02 | SII_for_BX_live.xisf
Before Deconvolution
SII_NGC7000_BX_live
Preview02
Preview04
Gray 1:1 SII_NGC7000_BX_live->Preview02 | SII_for_BX_live.xisf
After Deconvolution
SII_NGC7000_BX_live
Preview02
Preview04

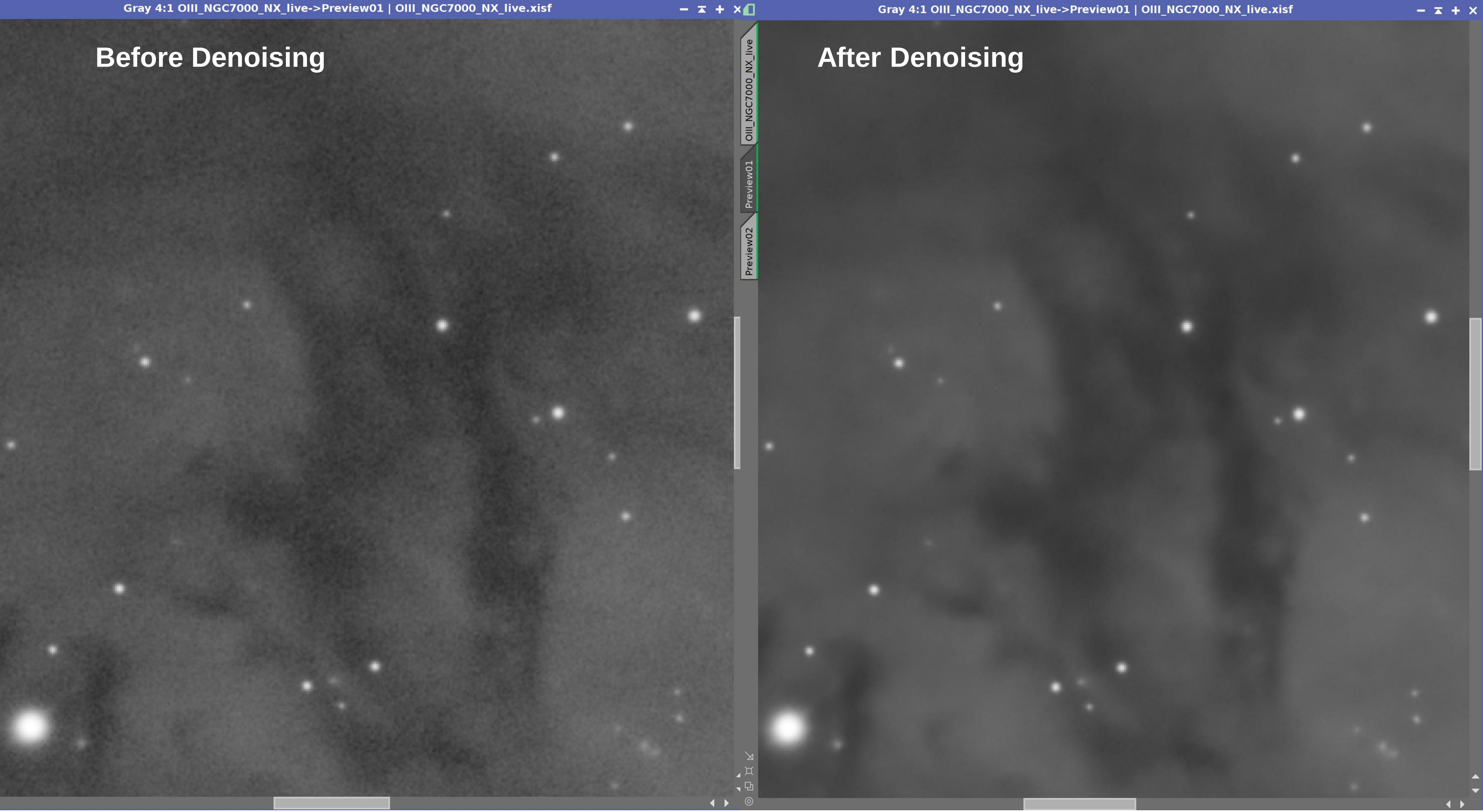
Noise Reduction

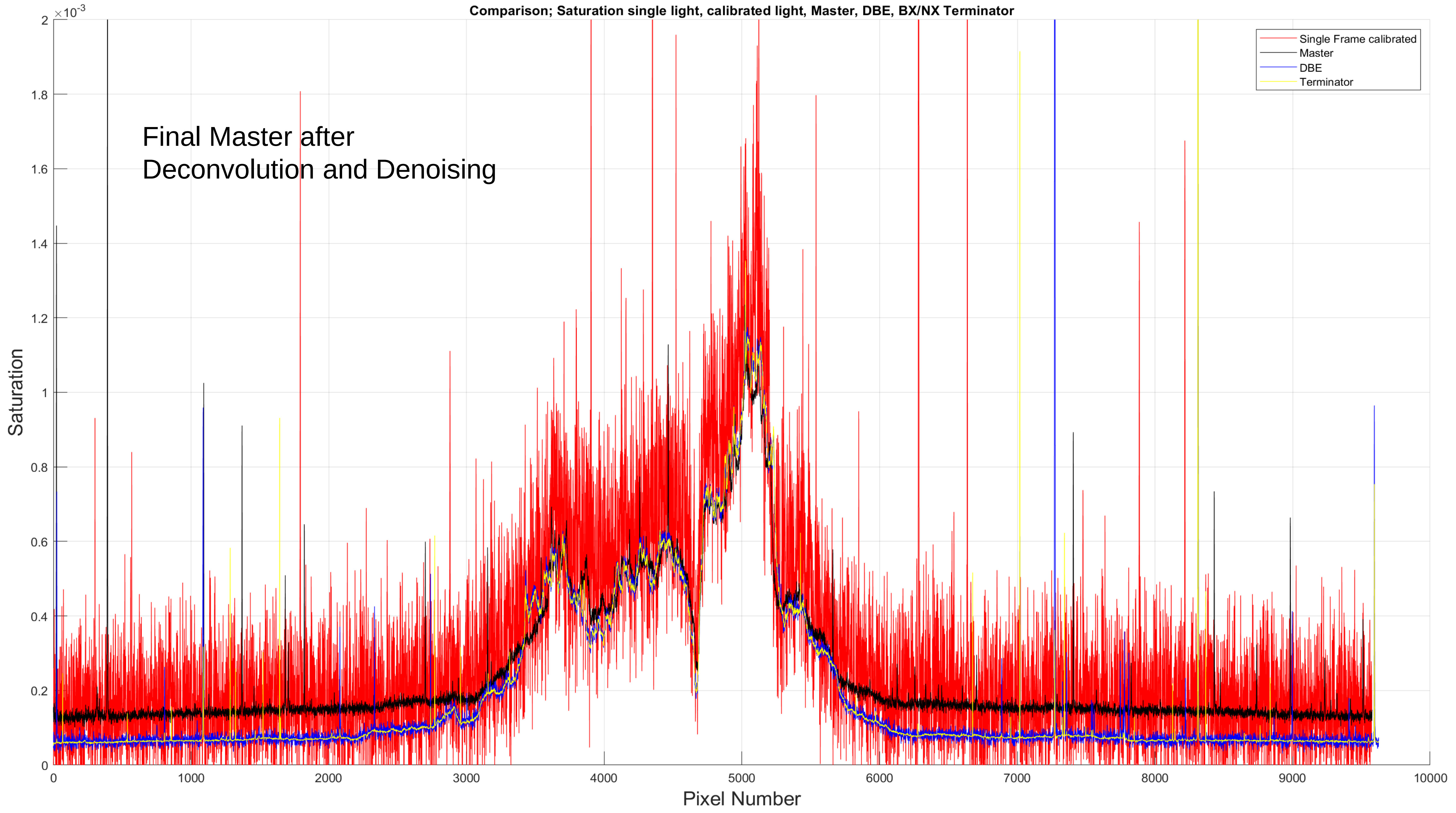
Even with many frames and calibration there is residual noise

Several processes are available to reduce noise

- TGV Denoise (Total Generalized Variation)
- ACDNR (Adaptive Contrast Driven Noise Reduction)
- MLT (Multiscale Linear Transform)
- MMT (Multiscale Median Transform)
- SCNR (Substractic Chromatic Noise Reduction)
- **Noise Xterminator (AI based)**

Noise Xterminator with OIII Master NGC 7000


Gray 4:1 OIII_NGC7000_NX_live->Preview01 | OIII_NGC7000_NX_live.xisf
Before Denoising
OIII_NGC7000_NX_live
Preview01
Preview02
Gray 4:1 OIII_NGC7000_NX_live->Preview01 | OIII_NGC7000_NX_live.xisf
After Denoising



Comparison; Saturation single light, calibrated light, Master, DBE, BX/NX Terminator
×10^-3
Single Frame calibrated
Master
DBE
Terminator
Final Master after
Deconvolution and Denoising
Saturation
Pixel Number
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

Institut für Angewandte Physik
LINAC AG

Stretching of Frames – Generalised Hyperbolic Stretch

All **raw frames** as light frames or Master-files are **linear** pictures.

Every pixel has collected a certain number of electrons.

If the brightness is proportional to the signal, the picture is **linear.**

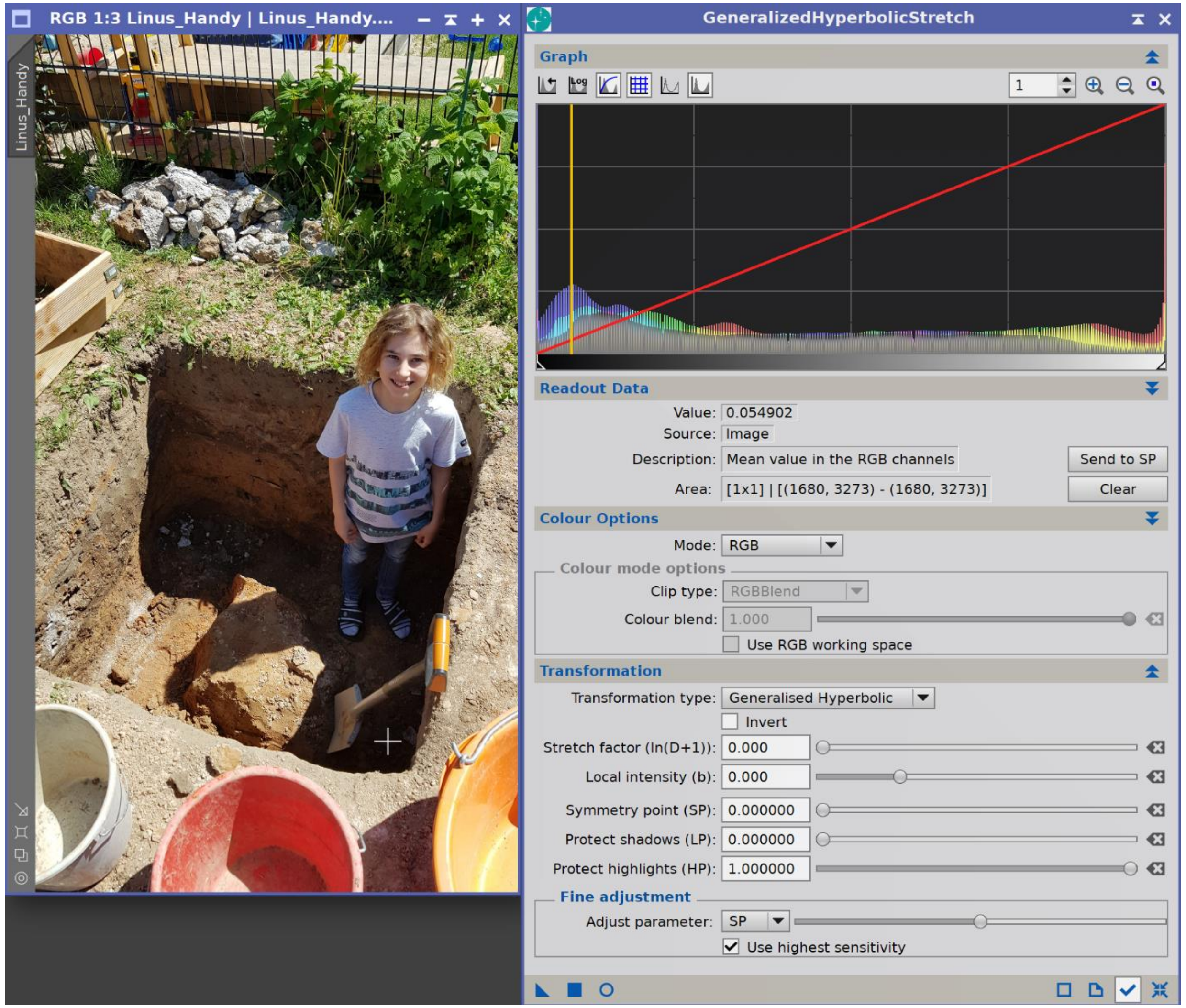
Applying a non-linear function to the picture will stretch it und enhance the contrast locally.

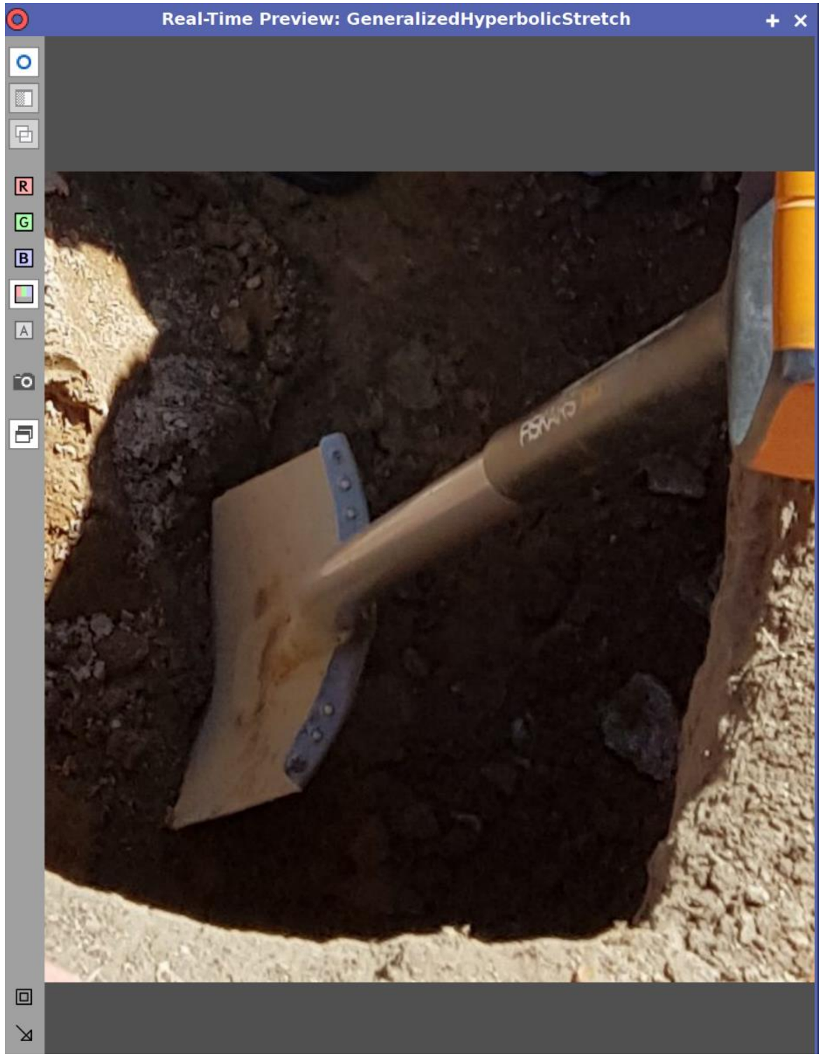
Histogram with cell phone picture

Histogram with Ha-Master

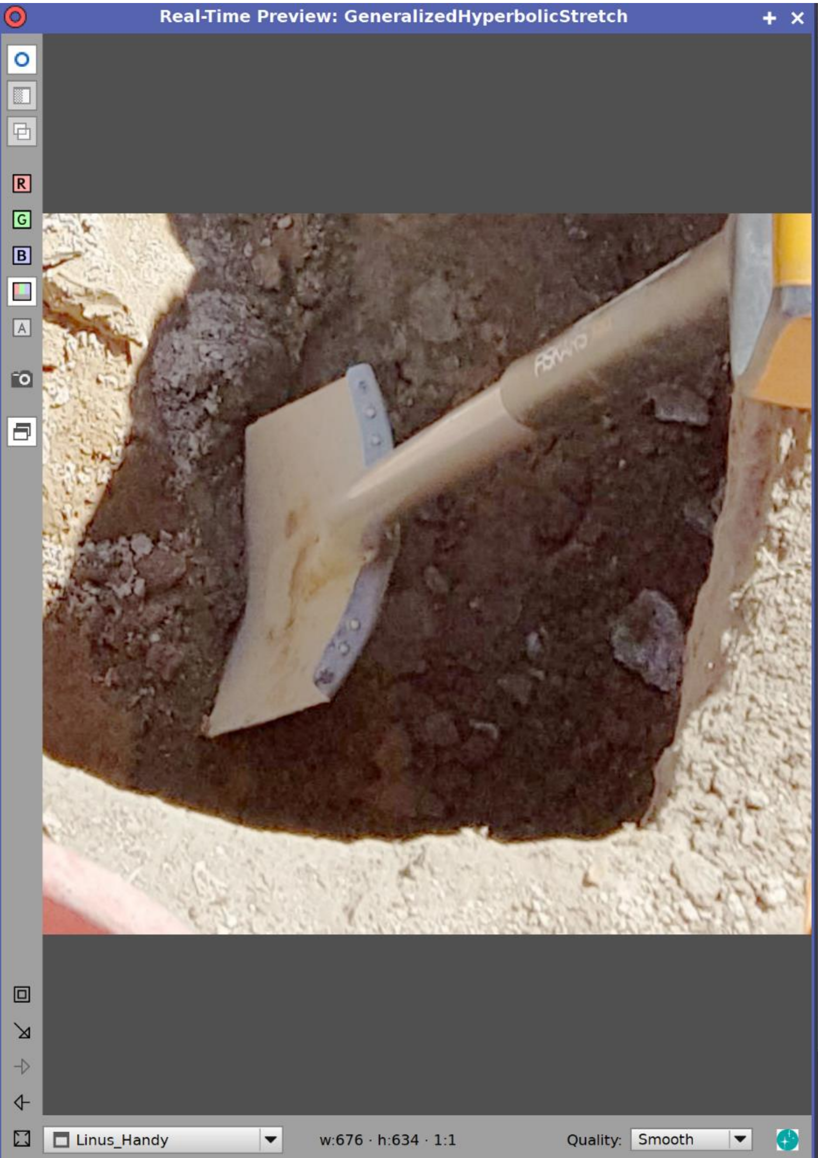
GHS Stretching (Gradient Picture and Ha)

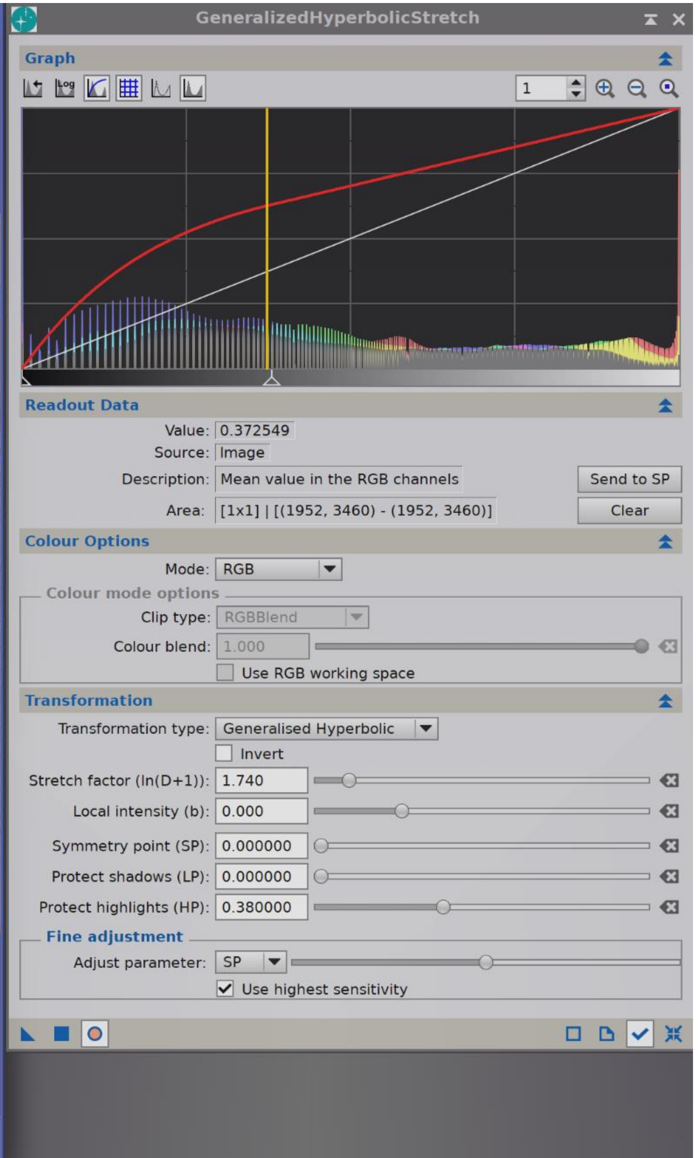
Stretching of Frames – Generalised Hyperbolic Stretch

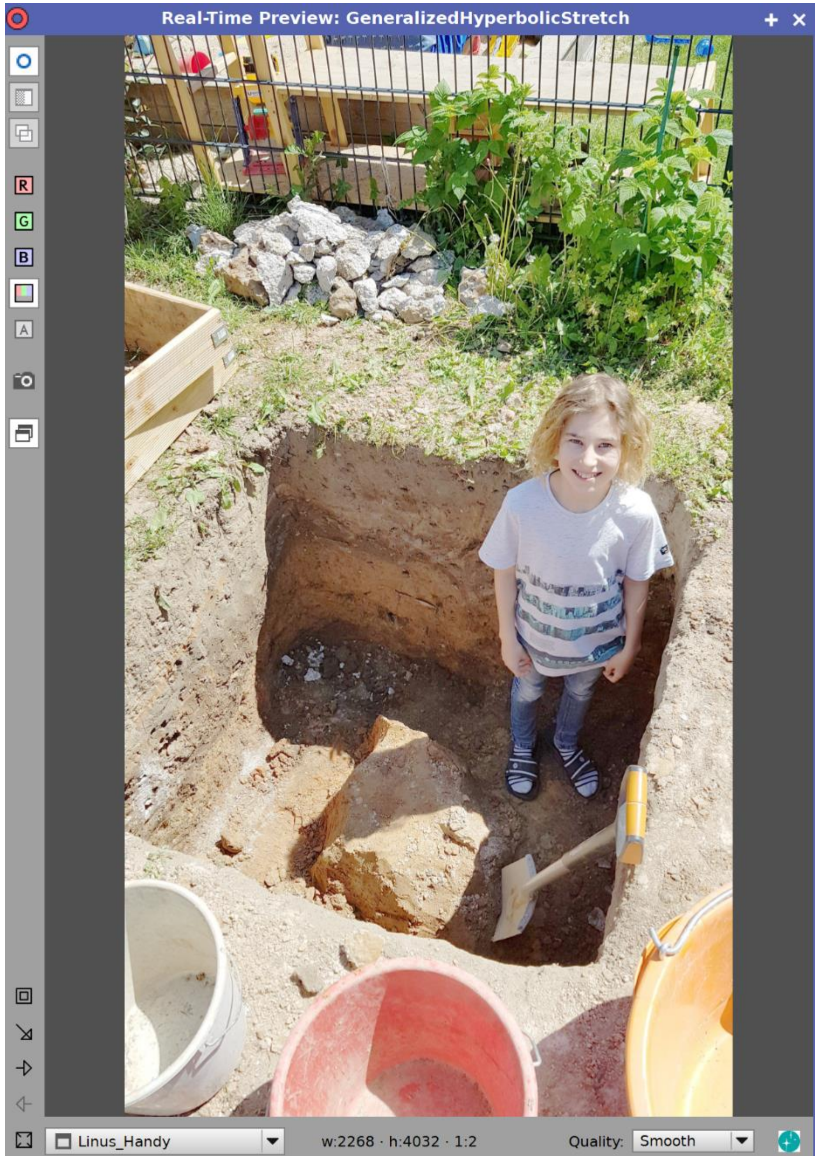




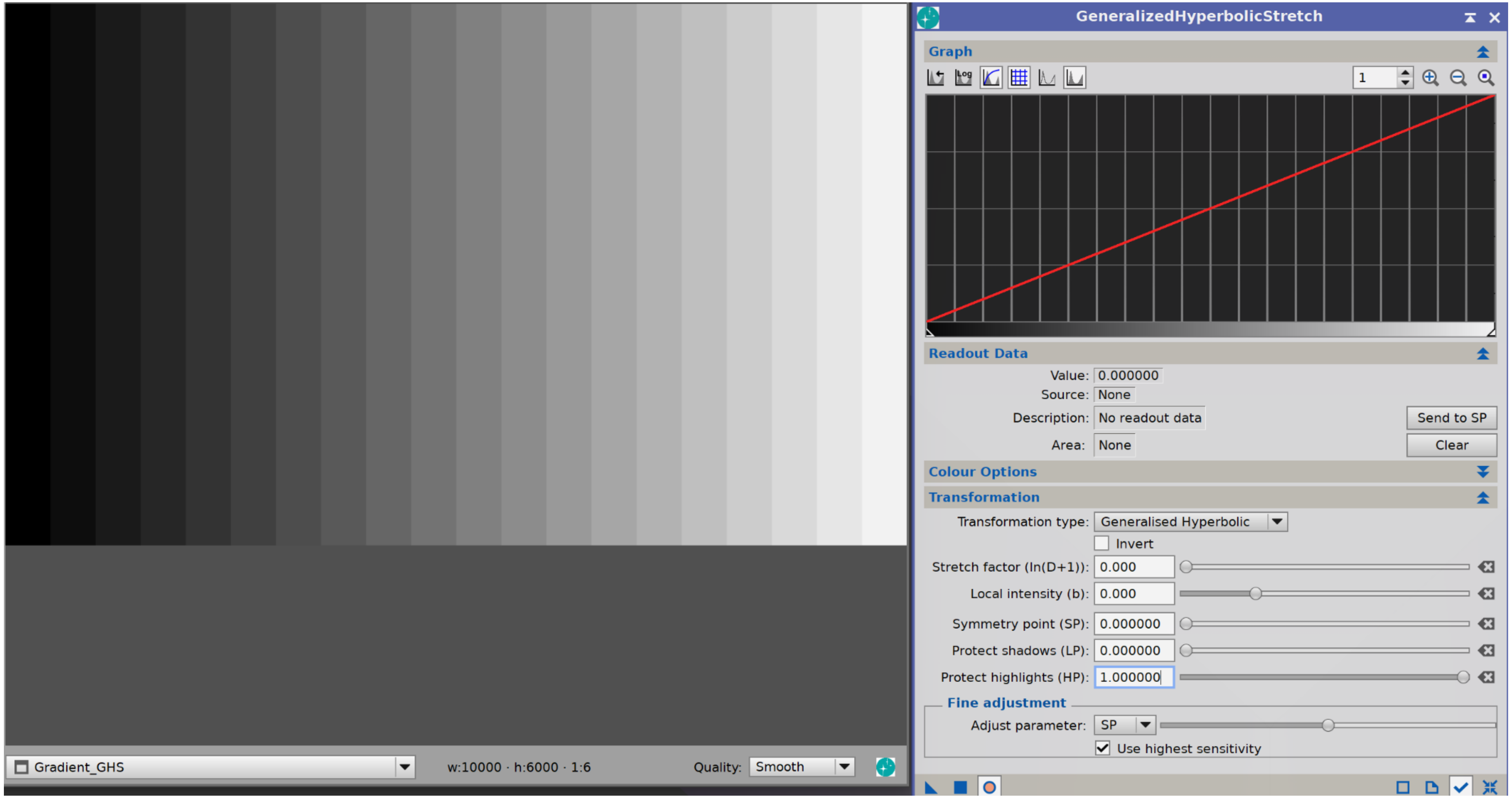
Stretching of Frames – Generalised Hyperbolic Stretch



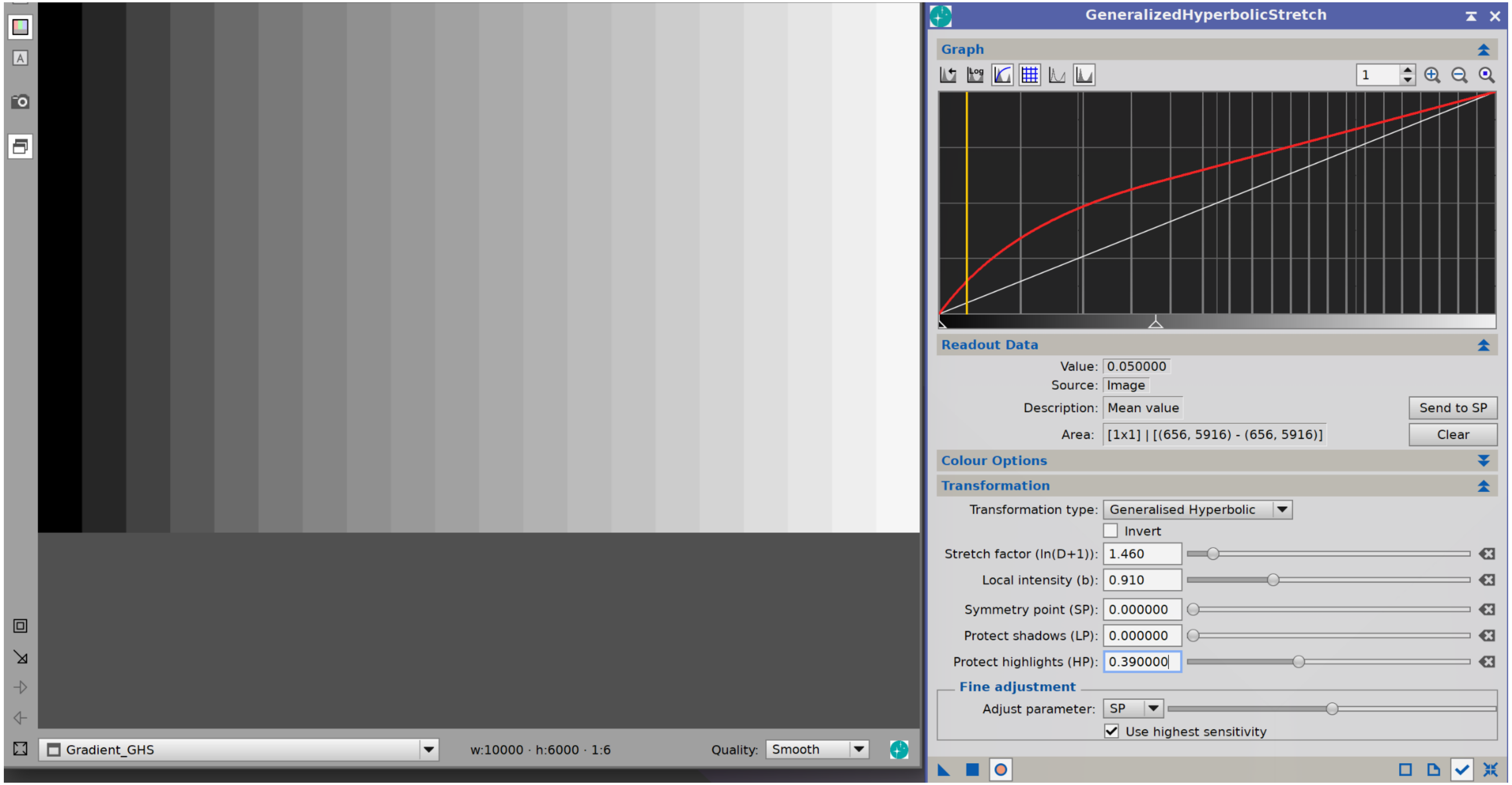




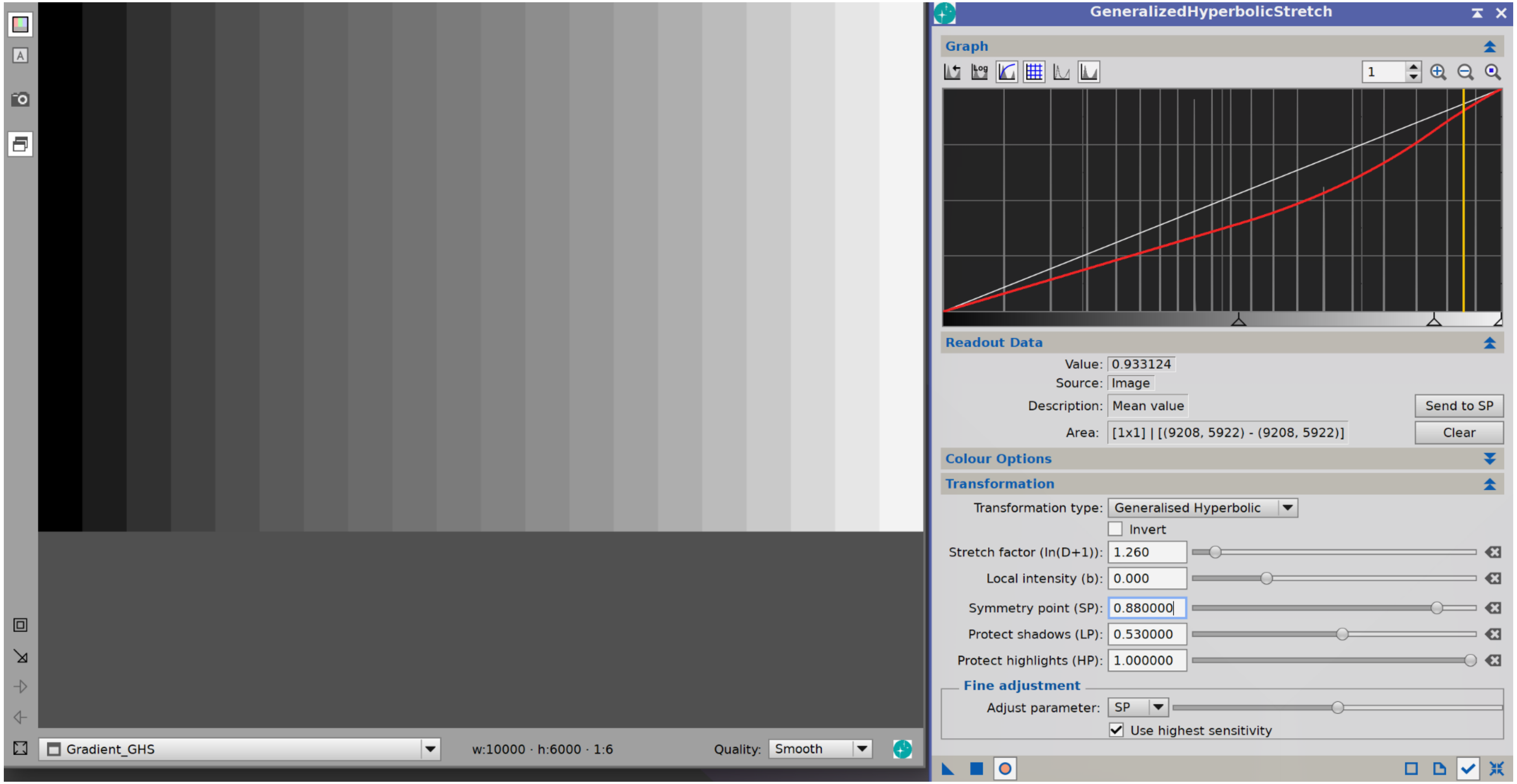
Stretching of Frames – Generalised Hyperbolic Stretch



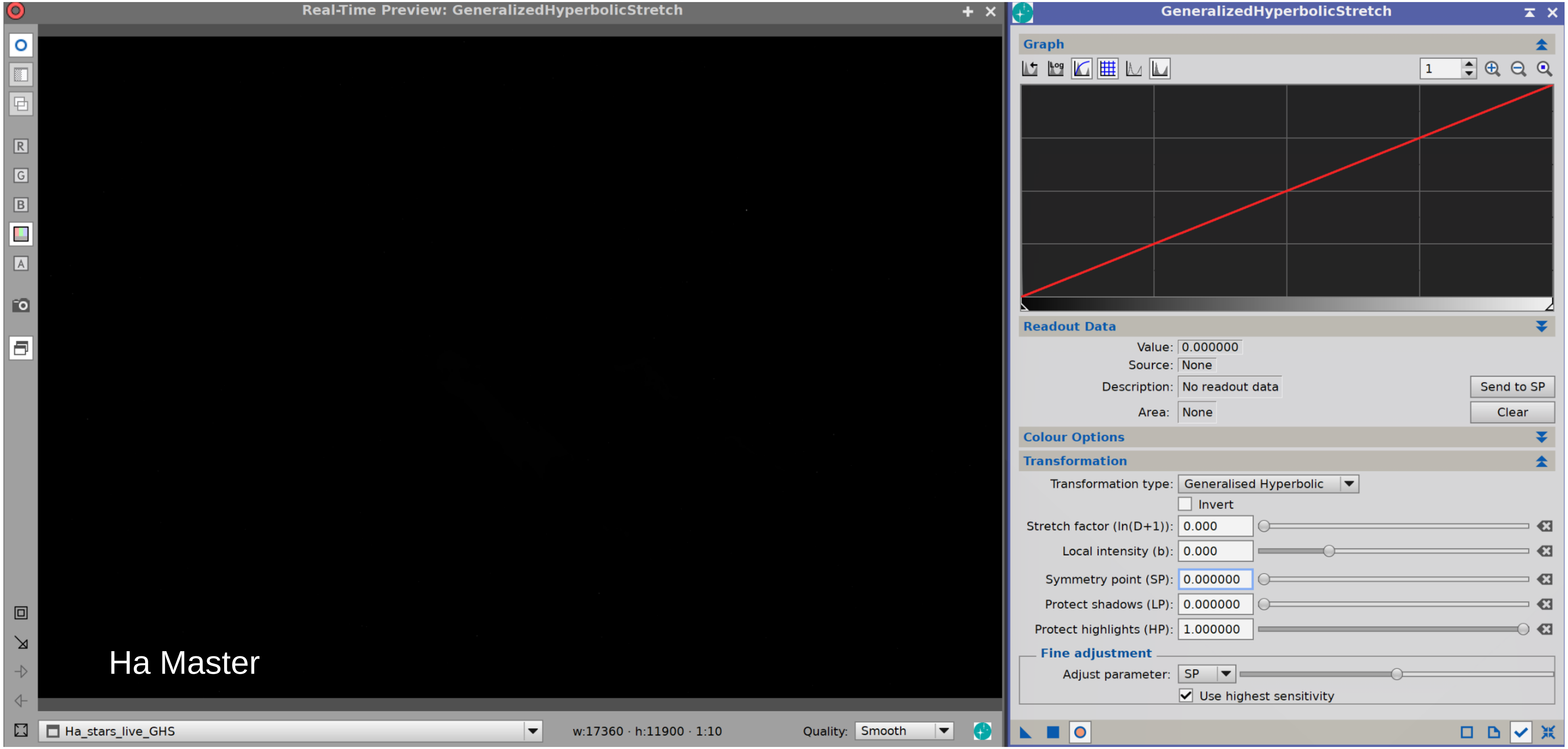
Stretching of Frames – Generalised Hyperbolic Stretch



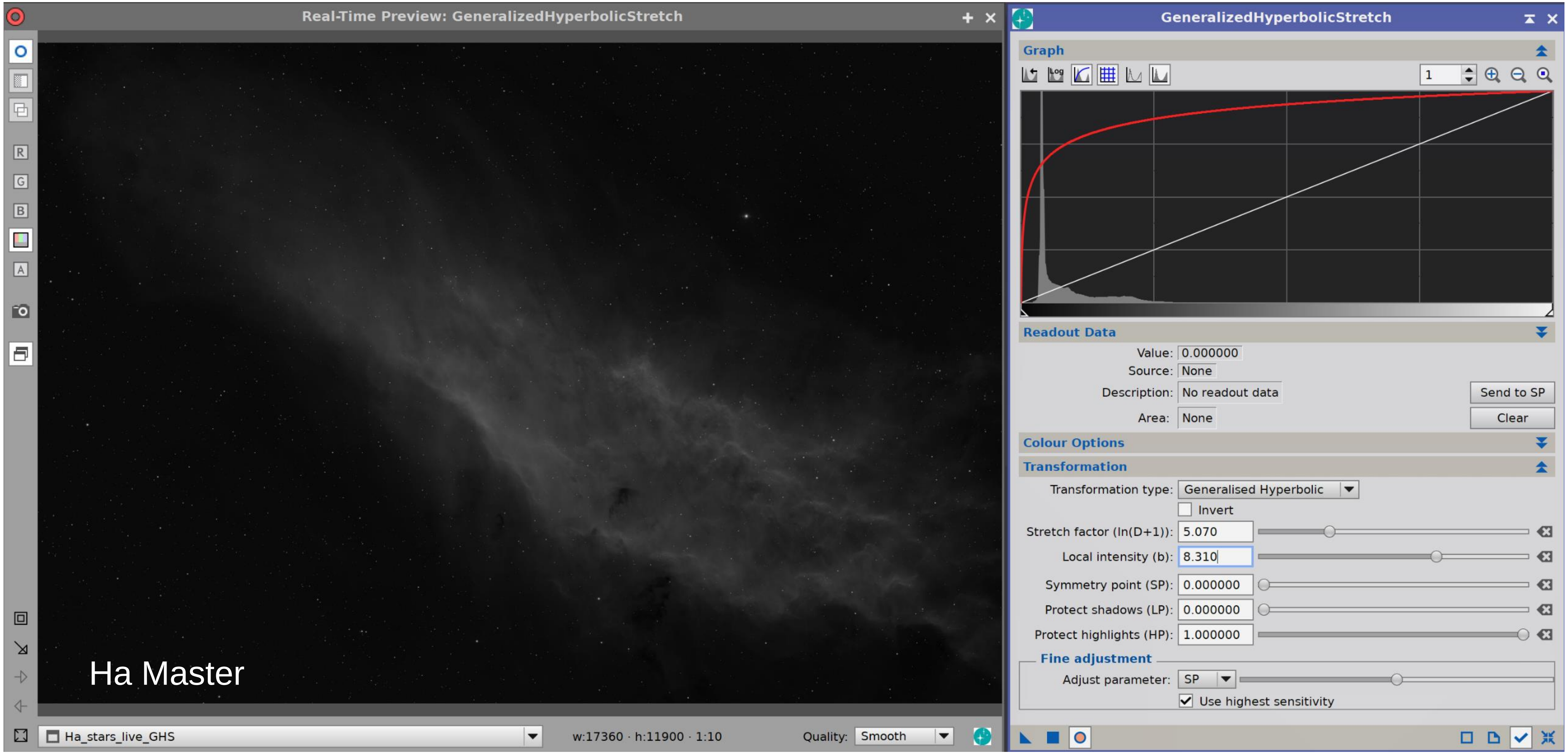
Stretching of Frames – Generalised Hyperbolic Stretch



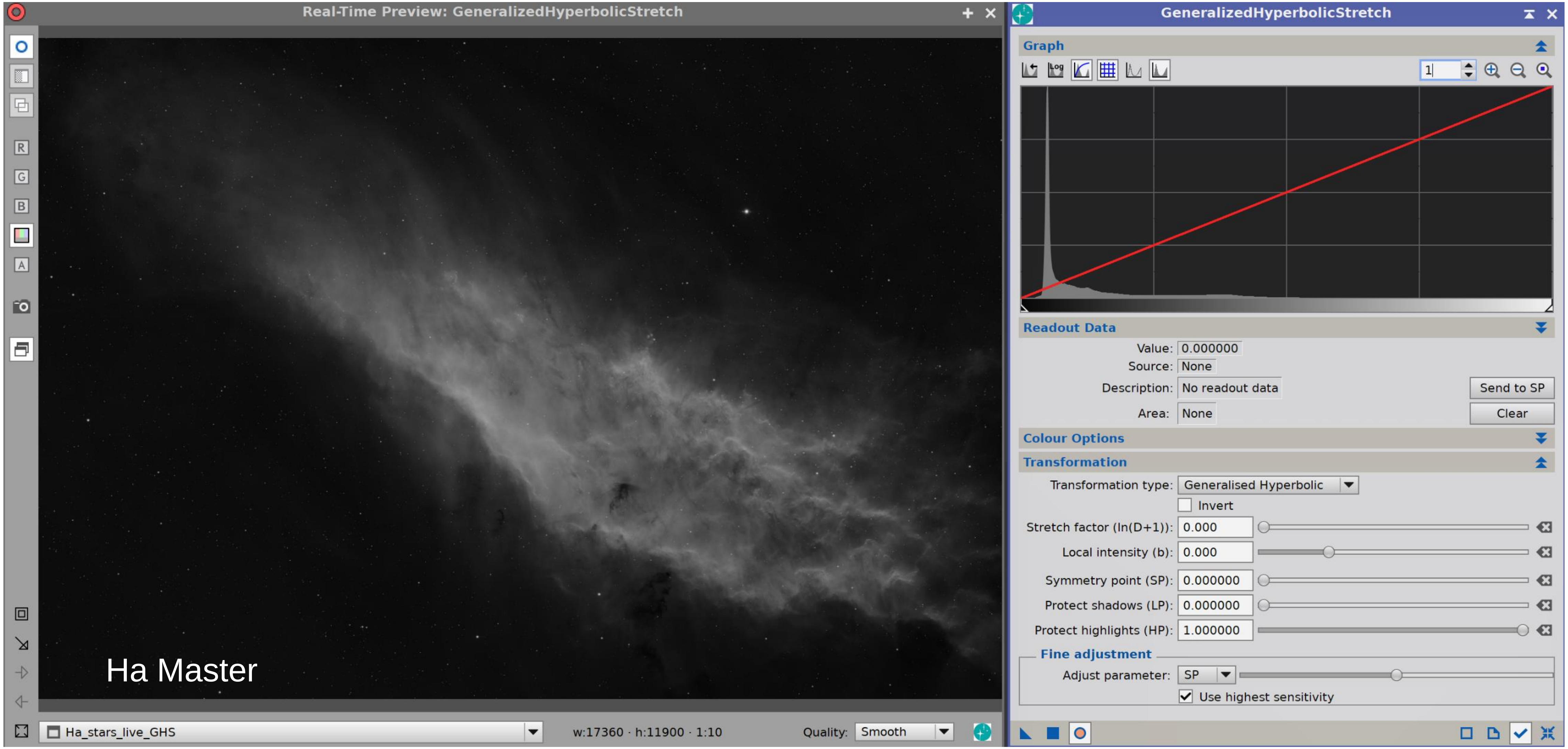
Stretching of Frames – Generalised Hyperbolic Stretch



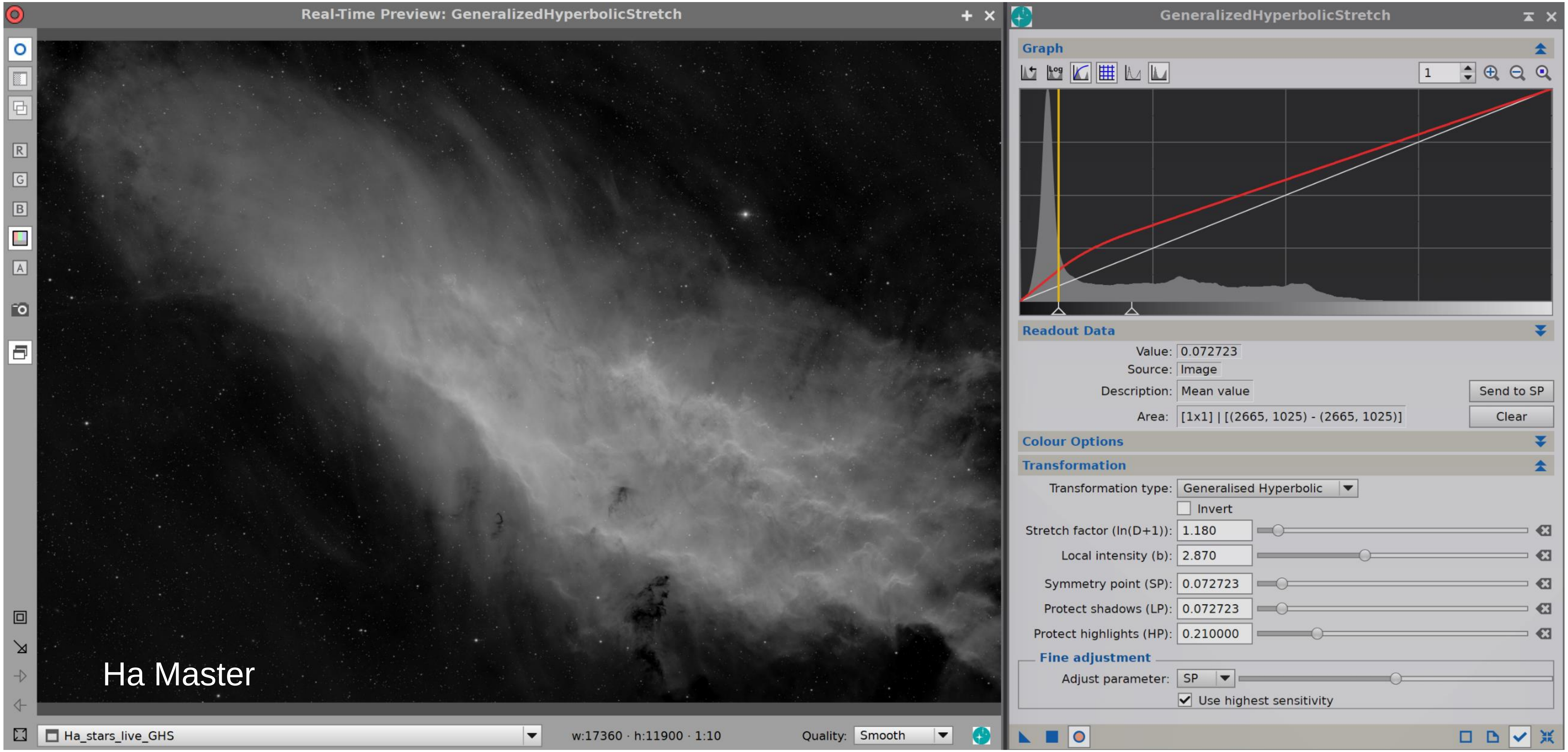
Stretching of Frames – Generalised Hyperbolic Stretch



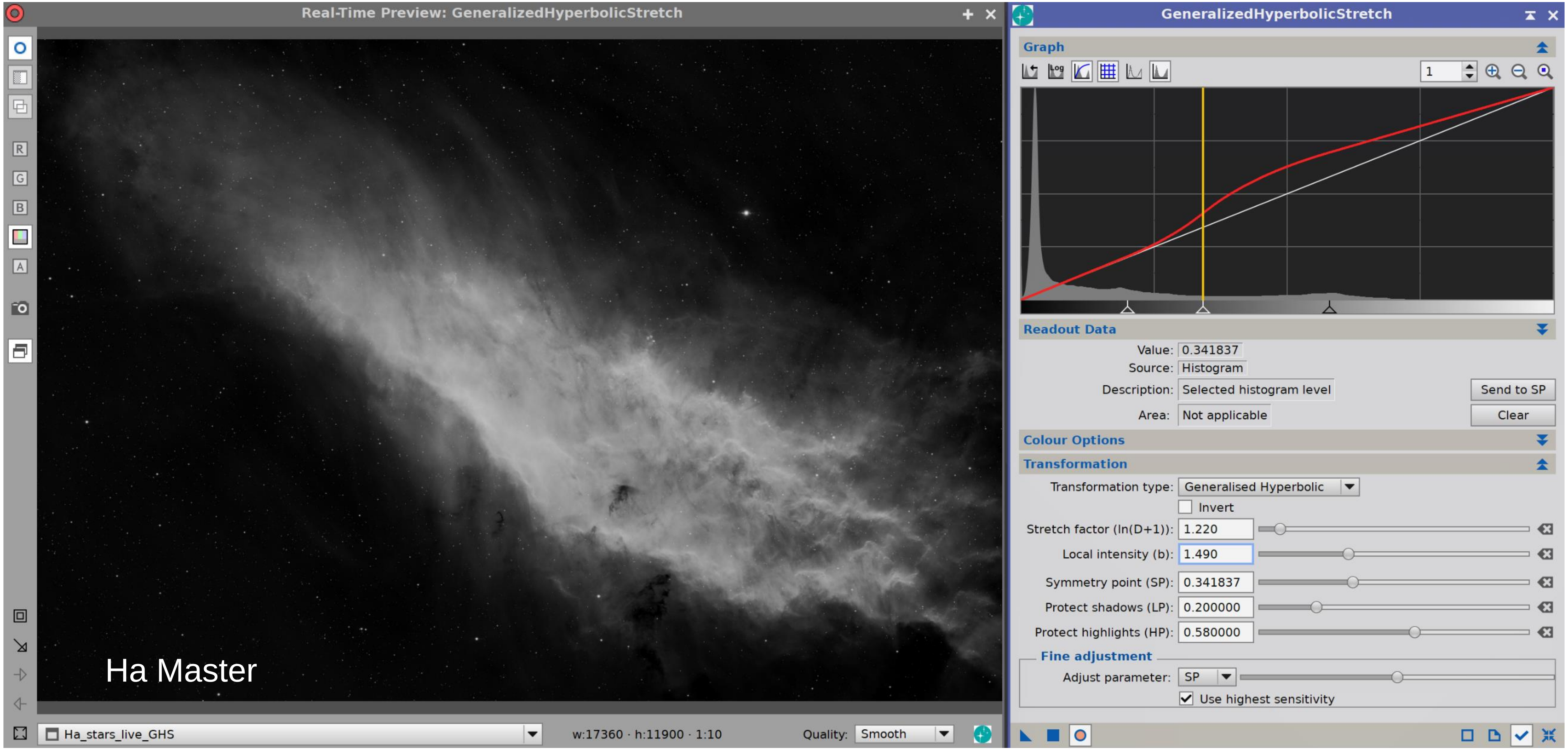
Stretching of Frames – Generalised Hyperbolic Stretch



Stretching of Frames – Generalised Hyperbolic Stretch

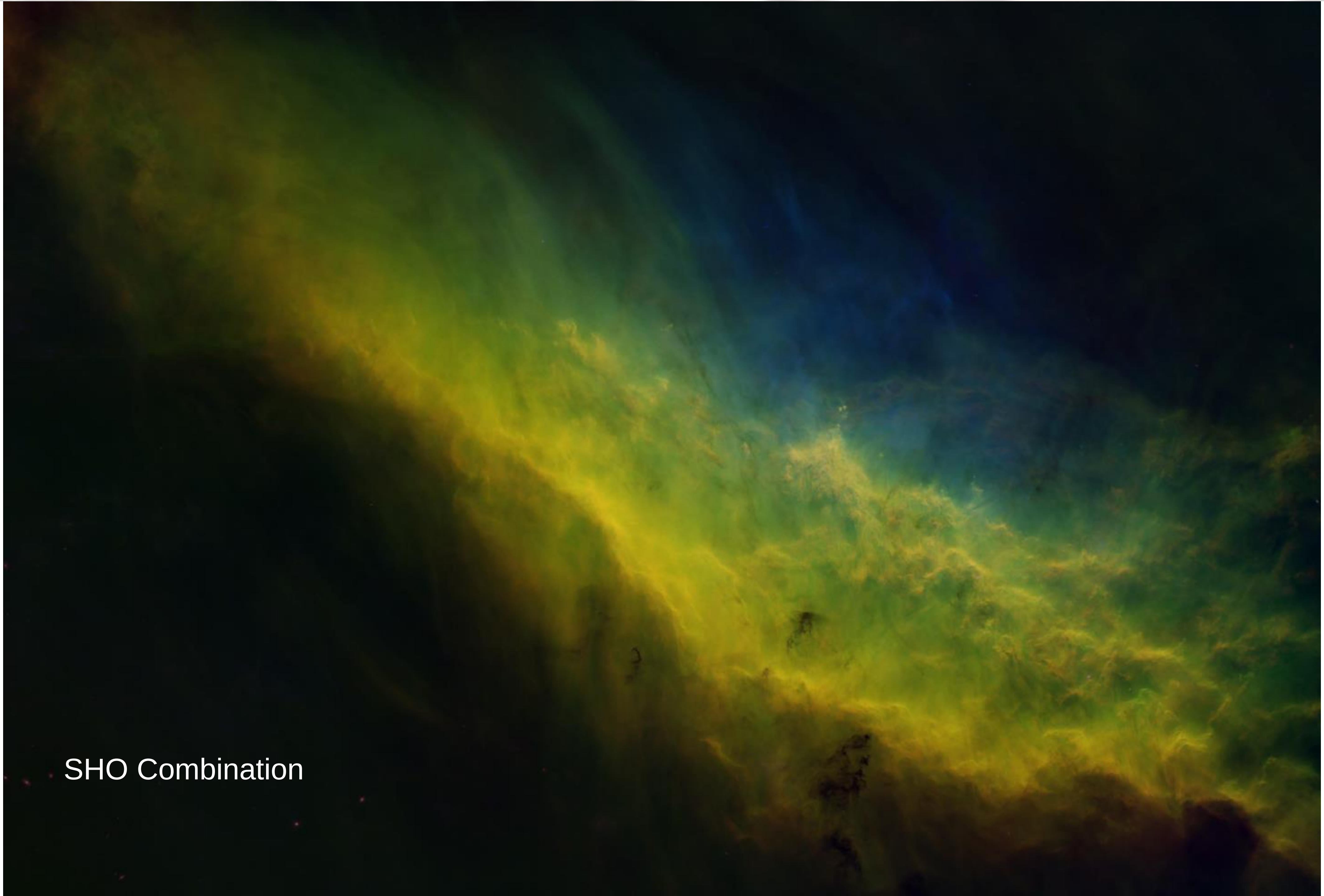


Stretching of Frames – Generalised Hyperbolic Stretch



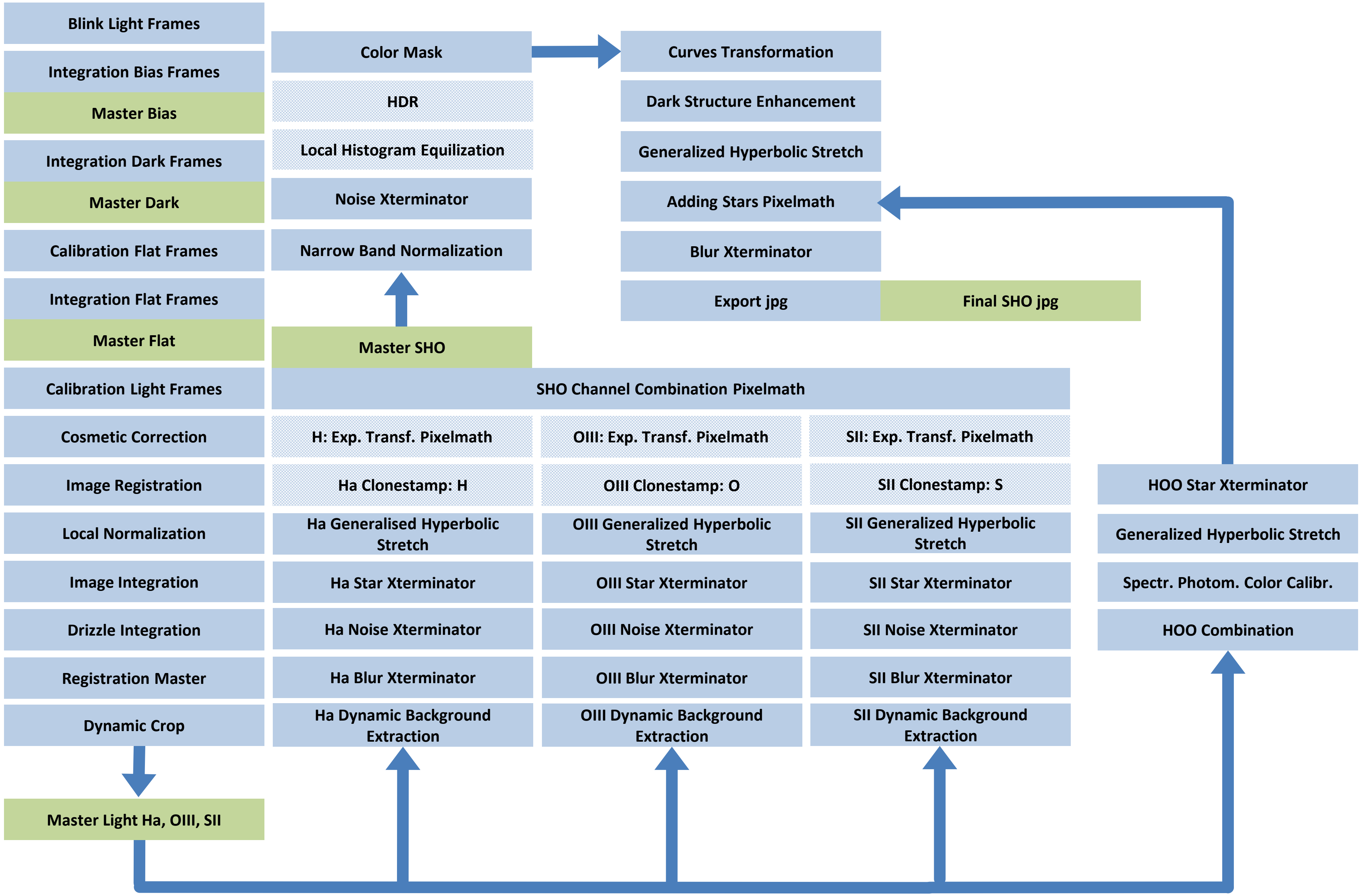
Channel Combination

SHO + HOO + HSS combination Pixelmath

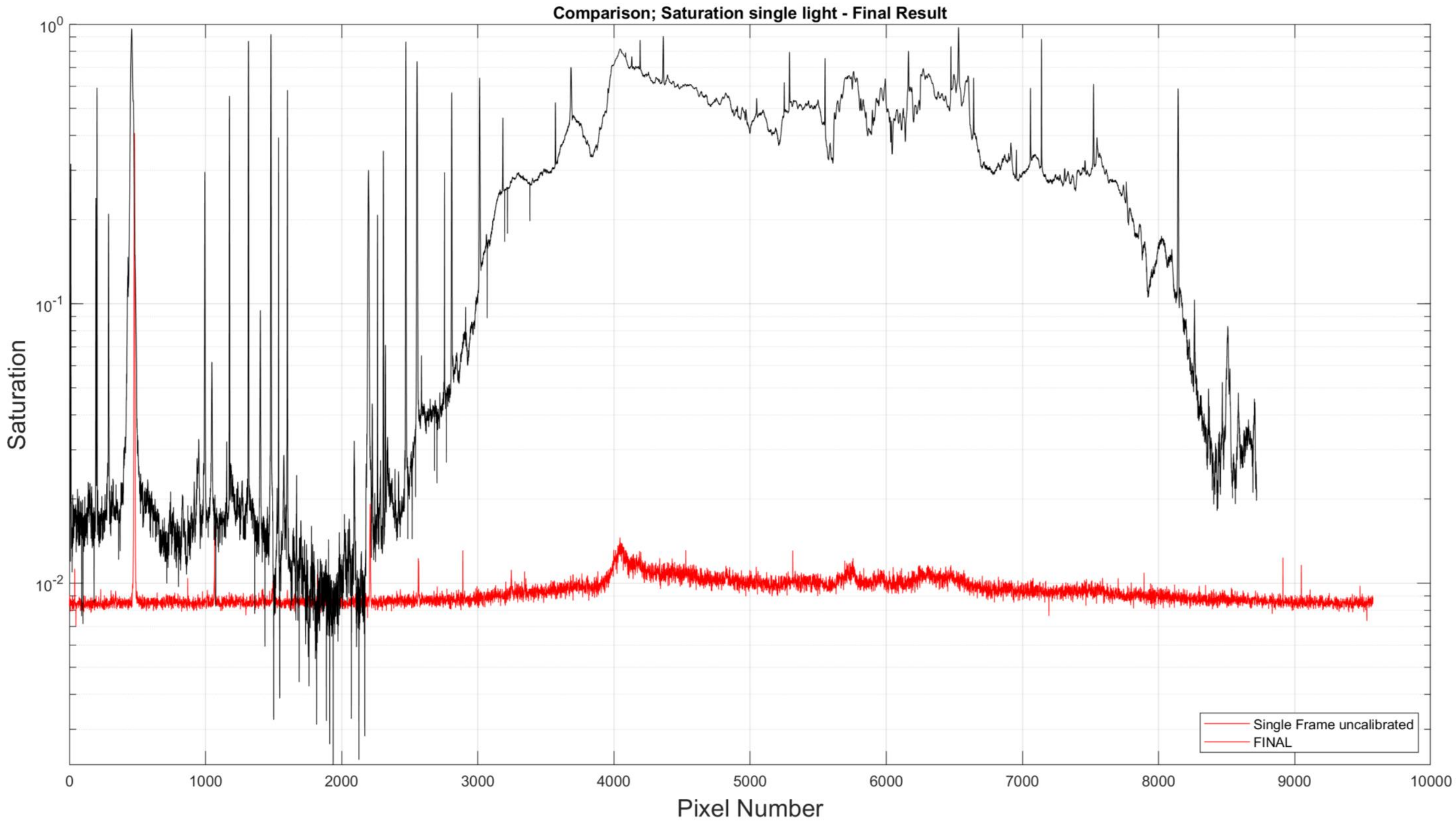

SHO Combination


HSS Combination

Workflow SHO




SHO Palette Final


Comparison; Saturation single light - Final Result
Saturation
Pixel Number
10^0
10^{-1}
10^{-2}
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Single Frame uncalibrated
FINAL

Exponential Transformations

A picture is in principle a (n x m)-Matrix

Each pixel is a matrix element with values between 0 and 1

→ Mathematical operations with this matrix

$$C_{ij} = A_{ij} + B_{ij} \qquad \forall\, i = 1 \ldots n, \qquad j = 1 \ldots m$$

S=0.4

+

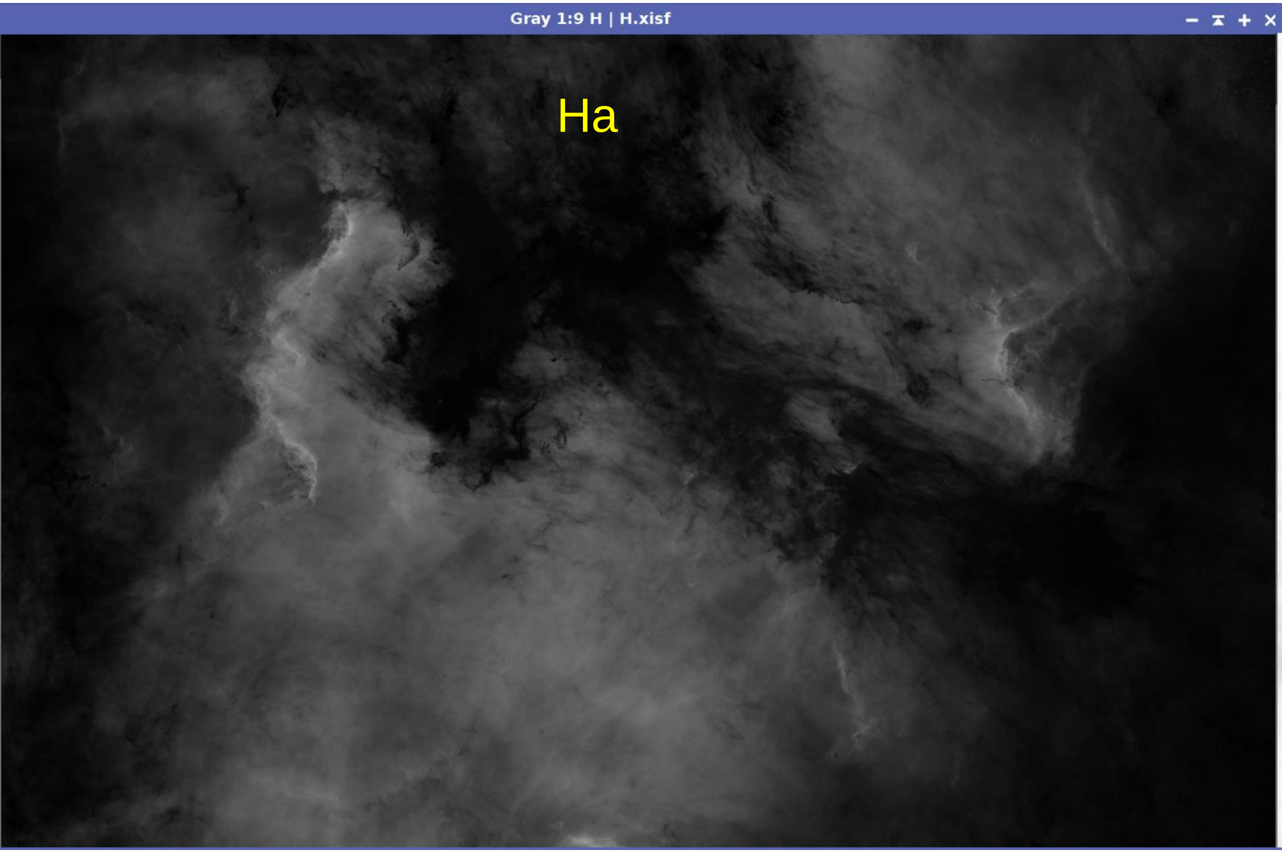
S=0.3

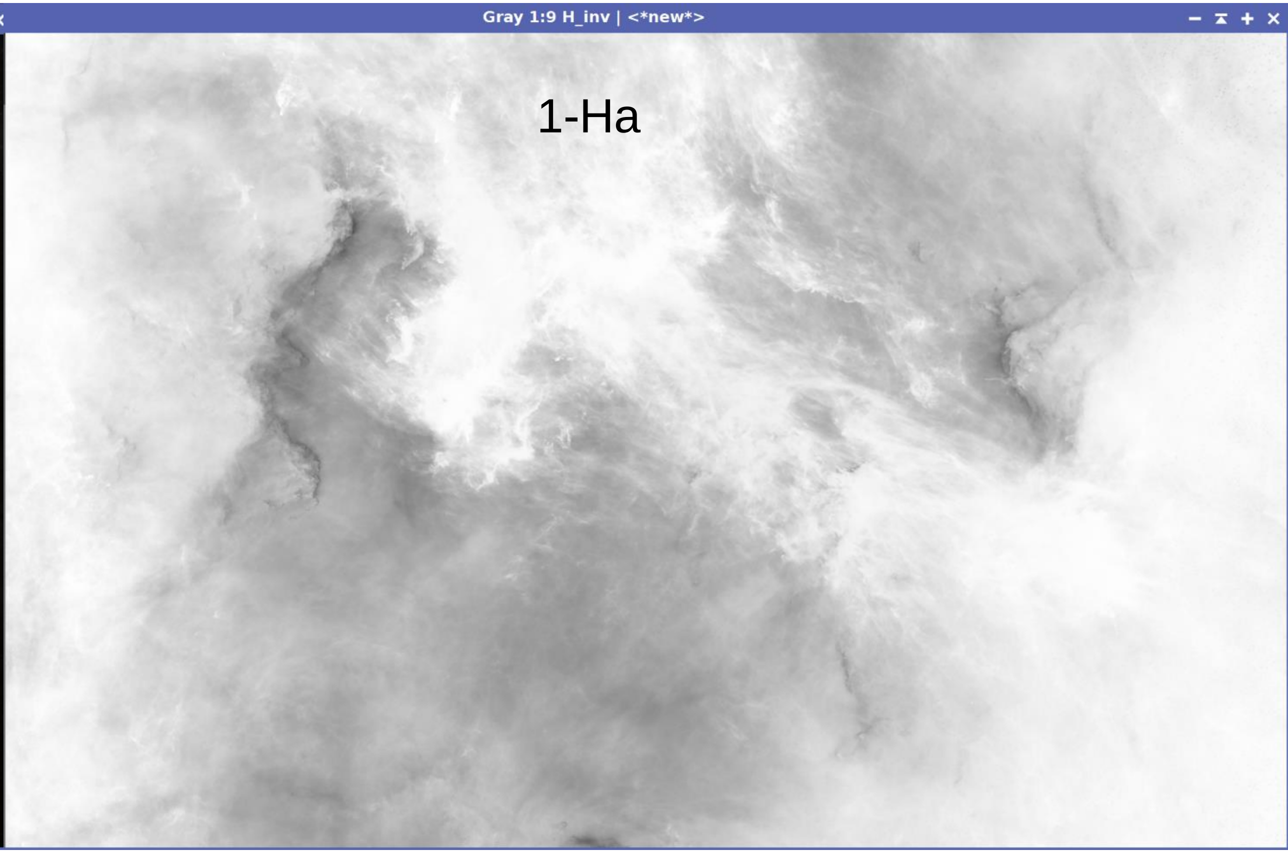
=

S=0.7

Exponential Transformations

The inverse of a picture C is (1-C)





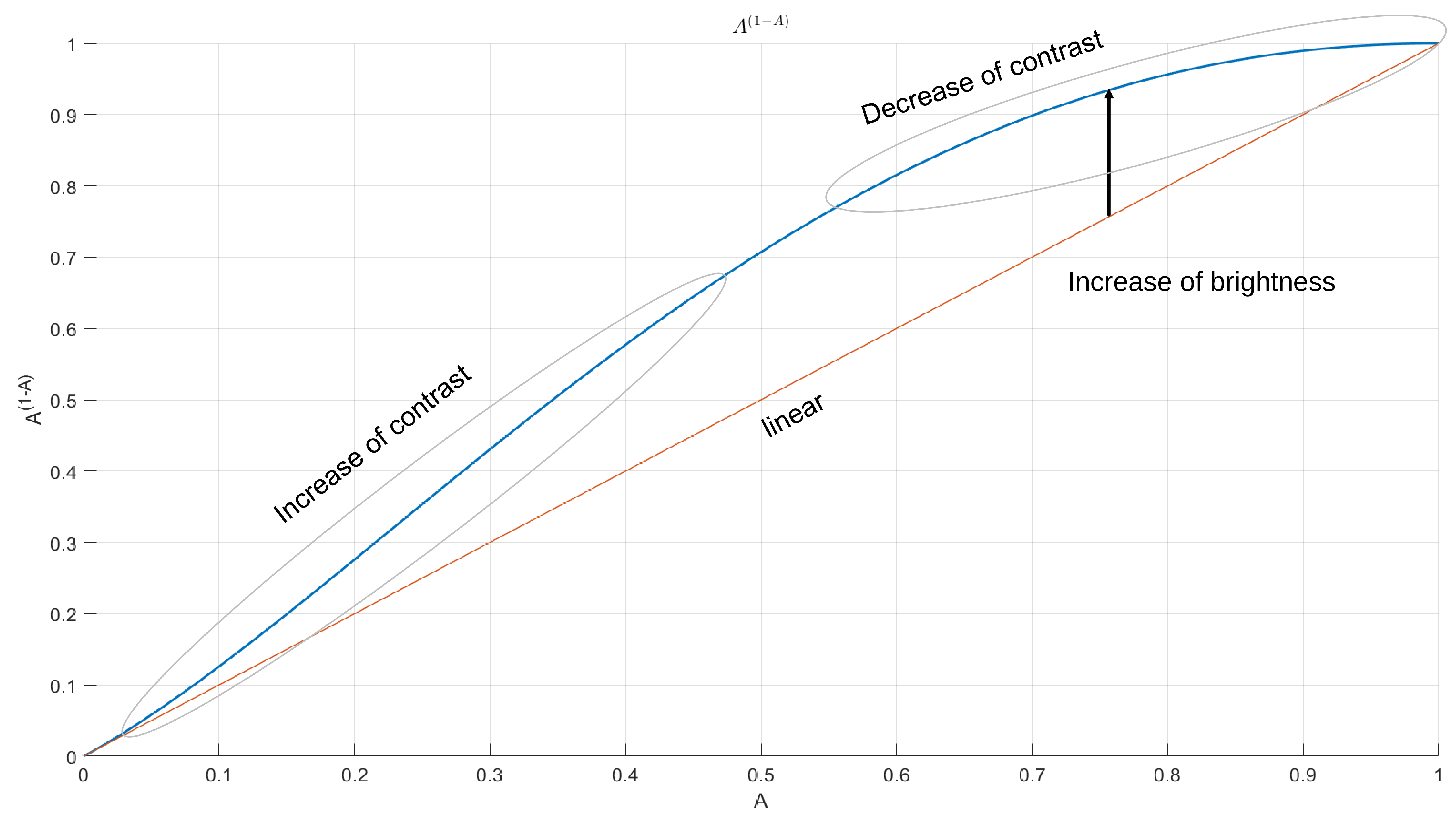
Exponential Transformations

A picture can be raised to the power of its inverse

$$A = A_0^{f(1-A_0)}$$

A	1-A	A^{1-A}
0.01	0.99	0.0105
0.05	0.95	0.058
0.1	0.9	0.126
0.5	0.5	0.710
0.9	0.1	0.990
0.99	0.01	0.999

- All pixel are raised in brightness (but NOT linearily)
- This transformation ensures that no pixel will reach full saturation



$A^{(1-A)}$
Decrease of contrast
Increase of brightness
Increase of contrast
linear
$A^{(1-A)}$
A
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Exponential Transformations

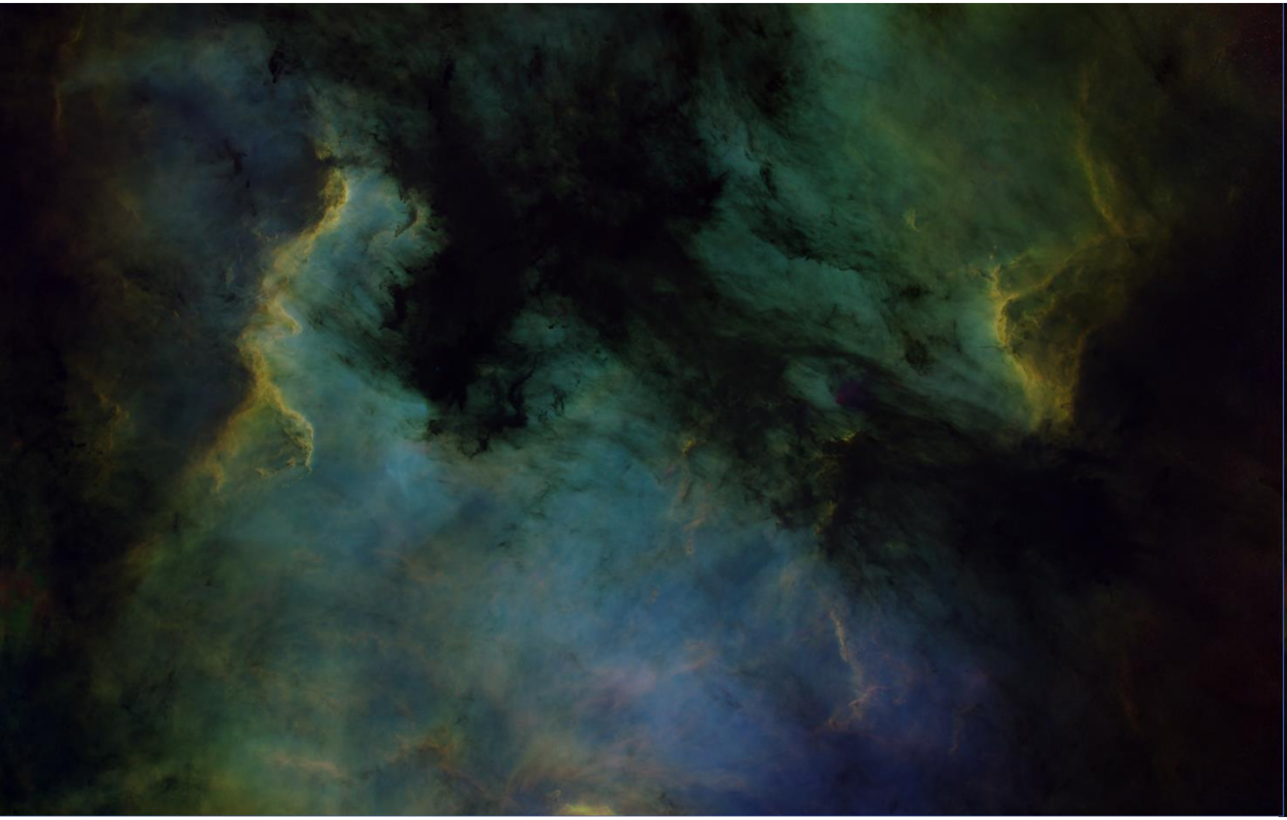
H

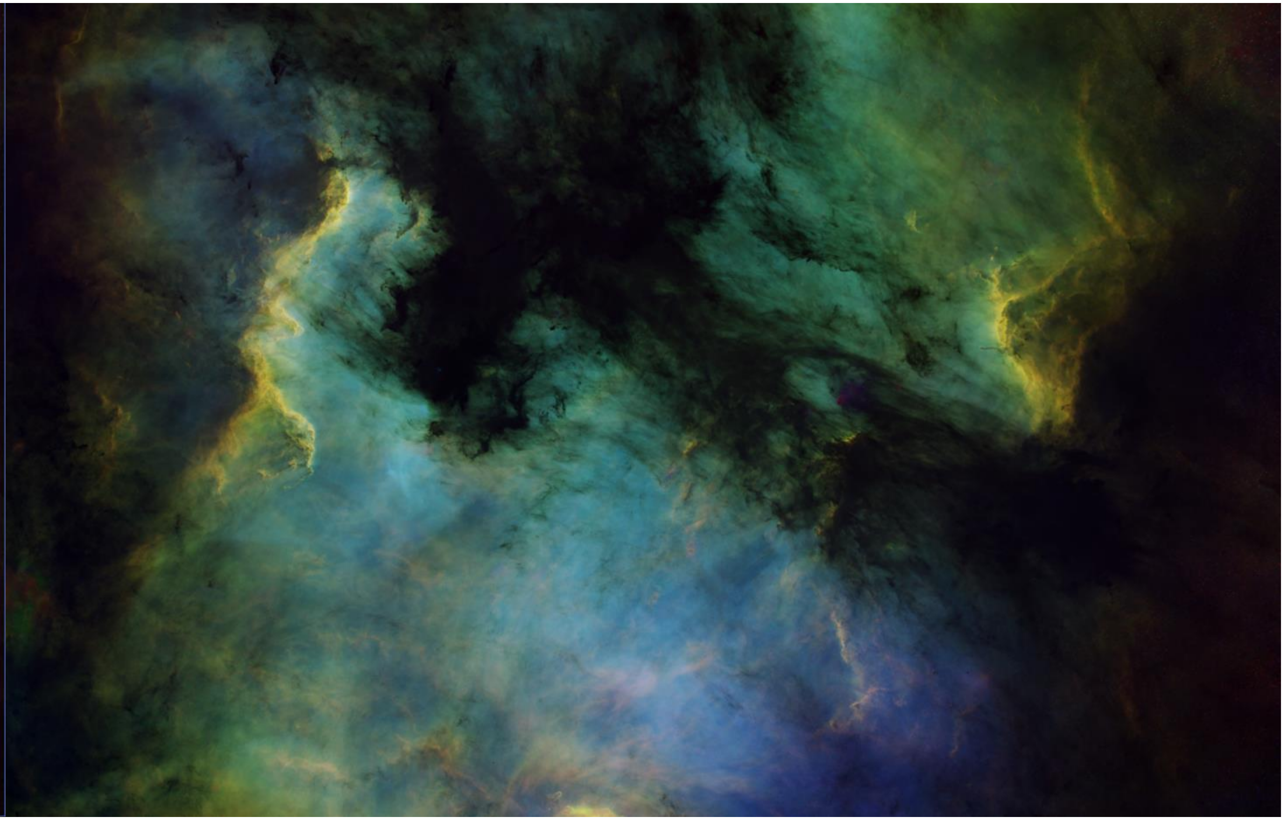
$H1=H^{(1-H)}$

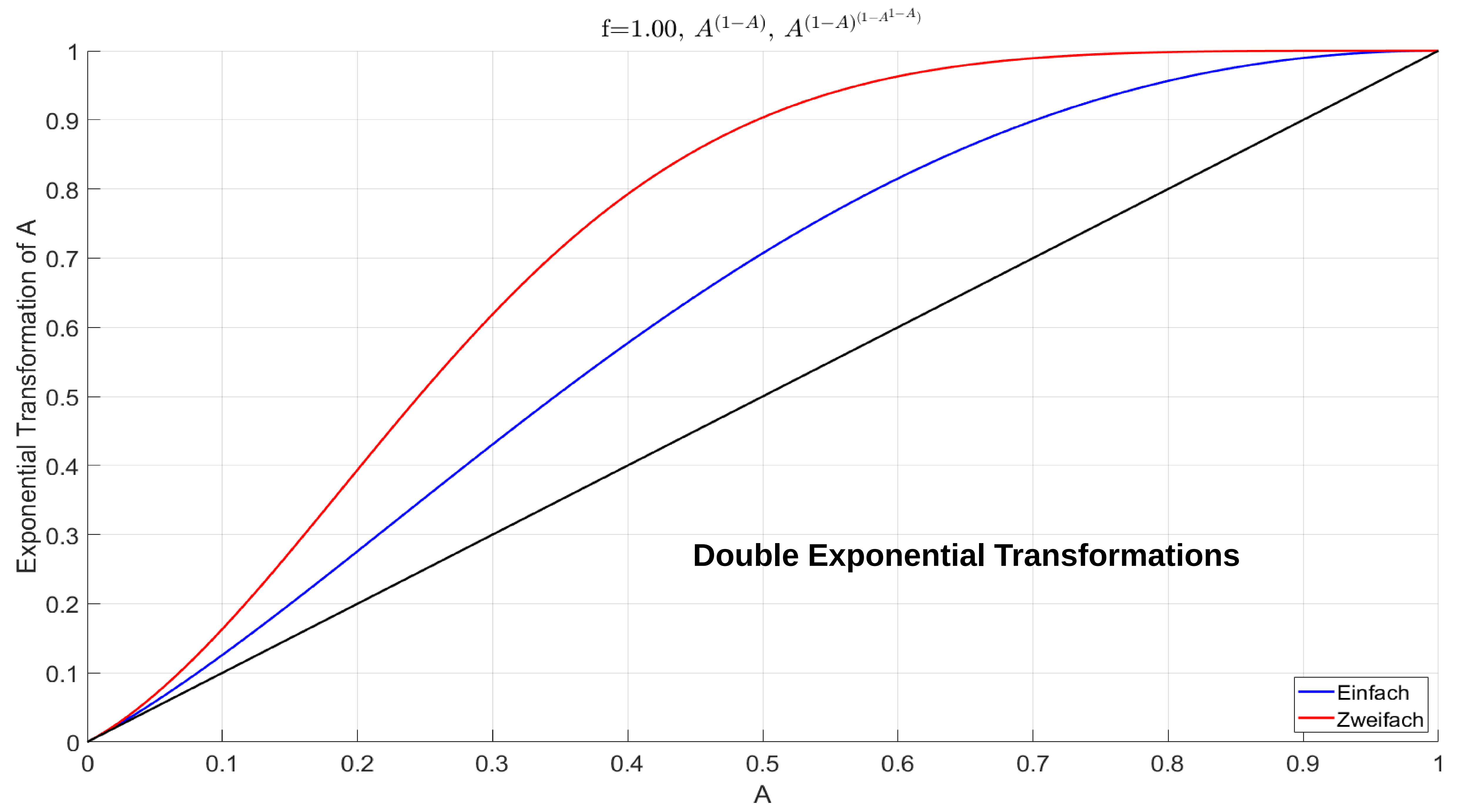
Exponential Transformations

$$\begin{aligned} R &: S \\ G &: H \\ B &: O \end{aligned}$$

$$\begin{aligned} R &: S^{1-S} \\ G &: H^{1-H} \\ B &: O^{1-O} \end{aligned}$$





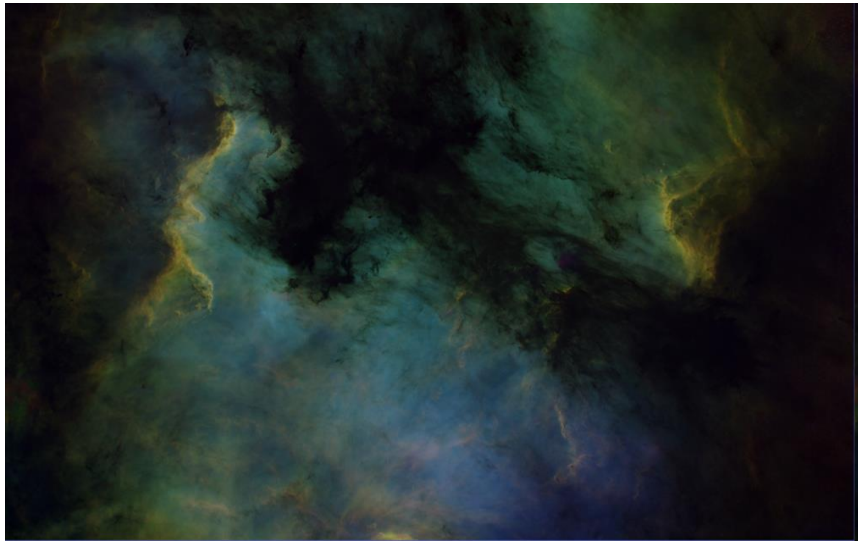
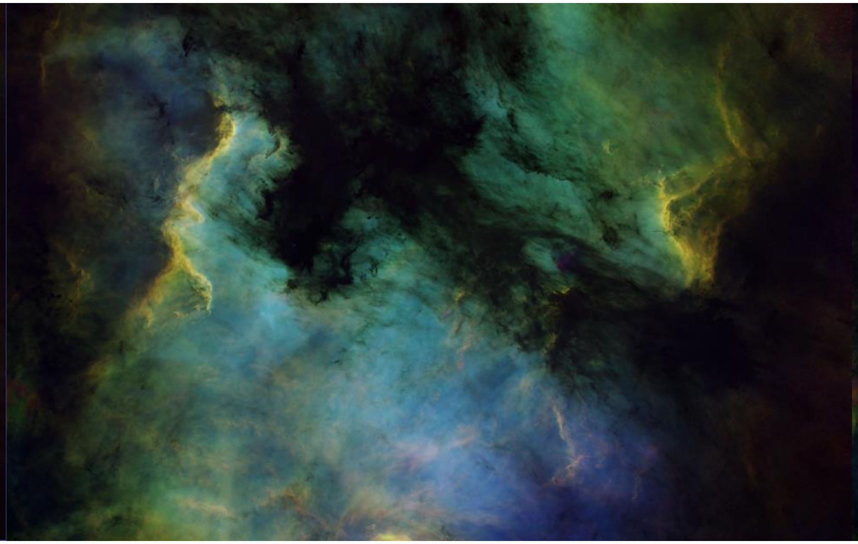
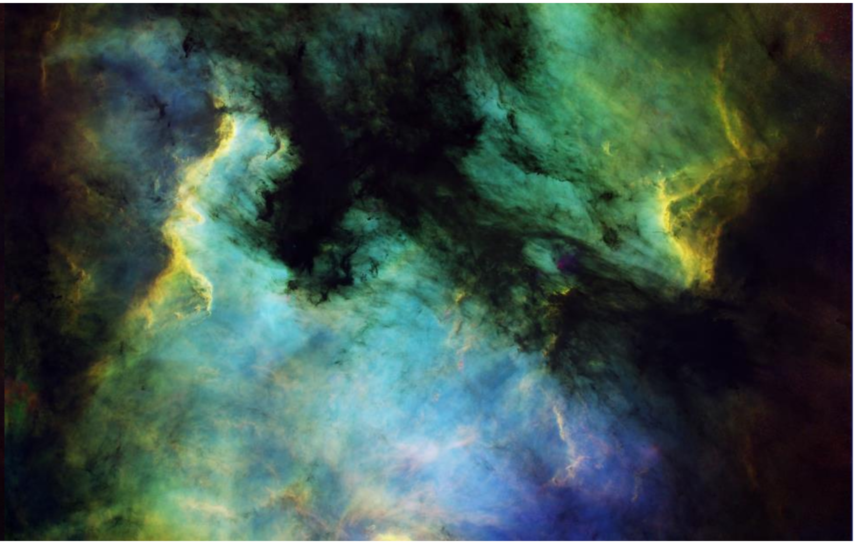

f=1.00, $A^{(1-A)}$, $A^{(1-A)^{(1-A^{1-A})}}$
Exponential Transformation of A
Double Exponential Transformations
Einfach
Zweifach
A
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Exponential Transformations

$$\begin{aligned} R &: S \\ G &: H \\ B &: O \end{aligned}$$

$$\begin{aligned} R &: S^{1-S} \\ G &: H^{1-H} \\ B &: O^{1-O} \end{aligned}$$

$$\begin{aligned} R &: (S^{1-S})^{(1-S^{1-S})} = S^{(1-S)(1-S^{1-S})} \\ G &: (H^{1-H})^{(1-H^{1-H})} = H^{(1-H)(1-H^{1-H})} \\ B &: (O^{1-O})^{(1-O^{1-O})} = S^{(1-O)(1-O^{1-O})} \end{aligned}$$

Exponential Transformations - FORAXX

Beside the simple allocation of the different masters to the color channels (SHO, HOO, HSS ,…) we can mix them:

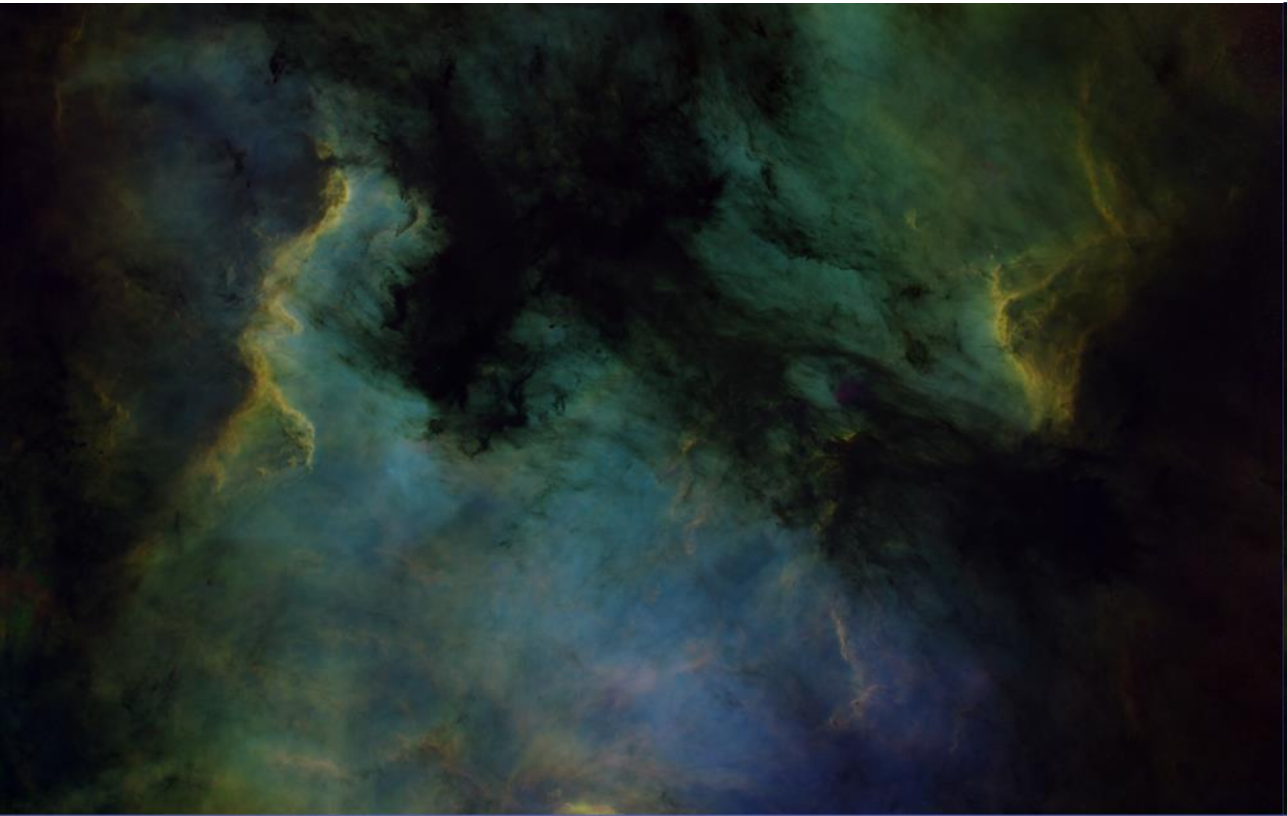
$$
\begin{aligned}
R &: \quad a \cdot S + (1-a) \cdot H \\
G &: \quad b \cdot H + (1-b) \cdot O \\
B &: \quad O
\end{aligned}
$$

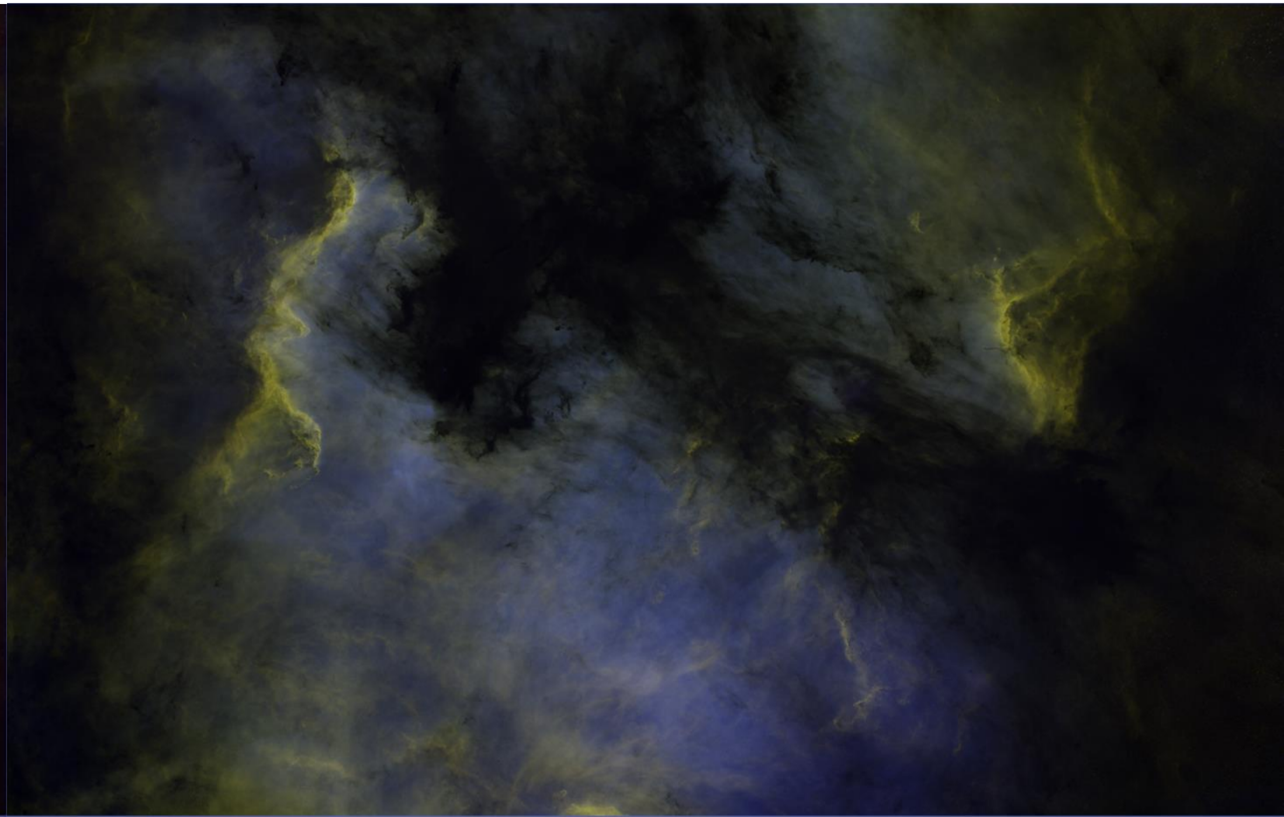
These **factors are static**, i.e. all pixel have the same amount of contributions from the different master files.

Exponential Transformations - FORAXX

$$
\begin{aligned}
R &: S \\
G &: H \\
B &: O
\end{aligned}
$$

$$
\begin{aligned}
R &: 0.7 \cdot S + 0.3 \cdot H \\
G &: 0.5 \cdot S + 0.5 \cdot H \\
B &: O
\end{aligned}
$$





Exponential Transformations - FORAXX

We can also define **dynamic factors** which are individual for each pixel und which depend only on the actual data:

$$a = O^{(1-O)}$$

$$b = (H \cdot O)^{(1-H \cdot O)}$$

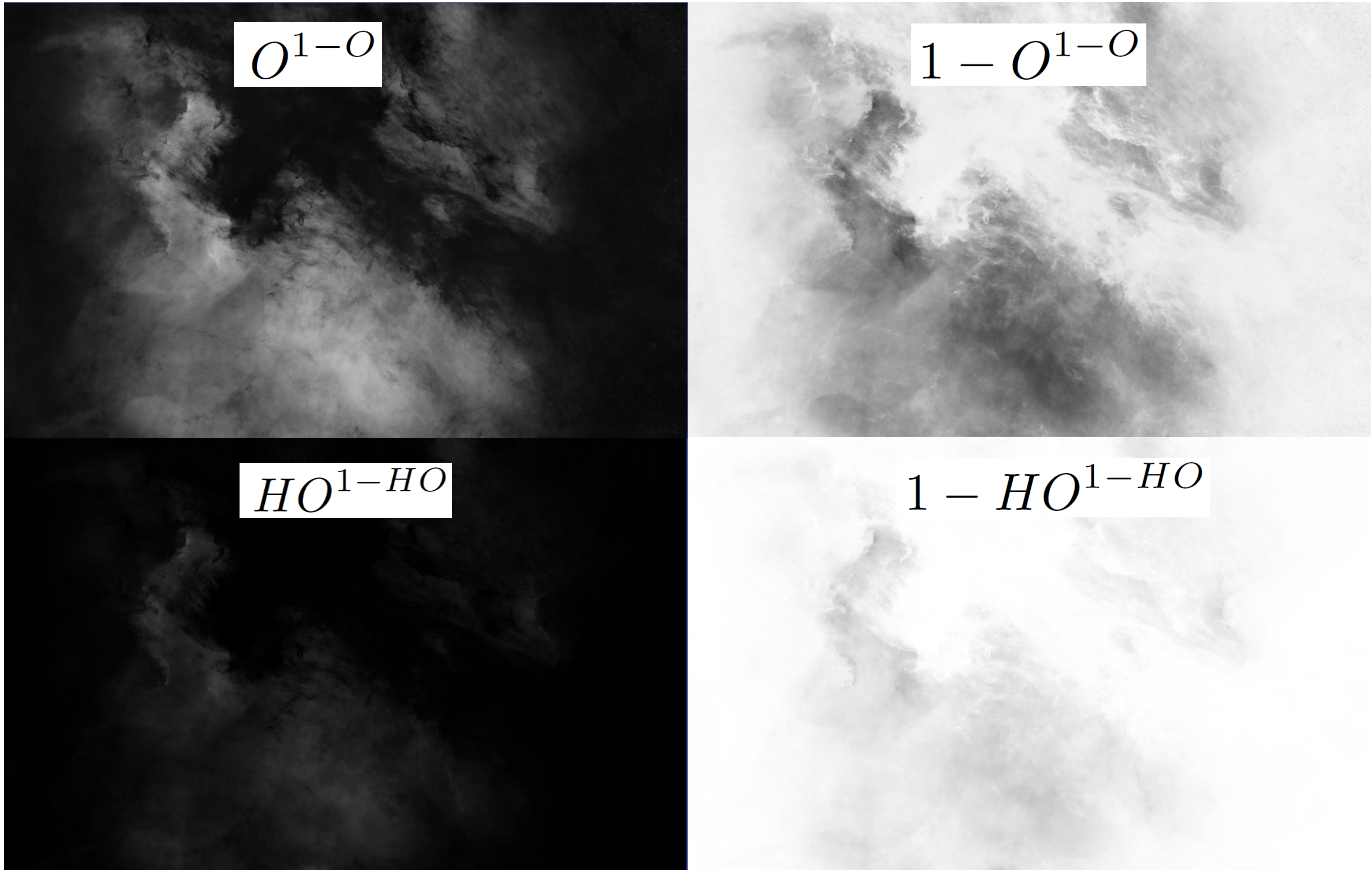
FORAXX Combination

$$R : O^{1-O} \cdot S + (1 - O^{1-O}) \cdot H$$

$$G : (H \cdot O)^{1-H \cdot O} \cdot H + (1 - (H \cdot O)^{1-H \cdot O}) \cdot O$$

$$B : O$$

Exponential Transformations - FORAXX



Exponential Transformations - FORAXX

$$
\begin{aligned}
R &: \quad O^{1-O} \cdot S + (1 - O^{1-O}) \cdot H \\
G &: \quad (H \cdot O)^{1-H \cdot O} \cdot H + (1 - (H \cdot O)^{1-H \cdot O}) \cdot O \\
B &: \quad O
\end{aligned}
$$

R: If there is a lot of O, the picture is dominated by S, otherwise by H

G: If the product of HO is large, the picture is dominated by H, otherwise by O

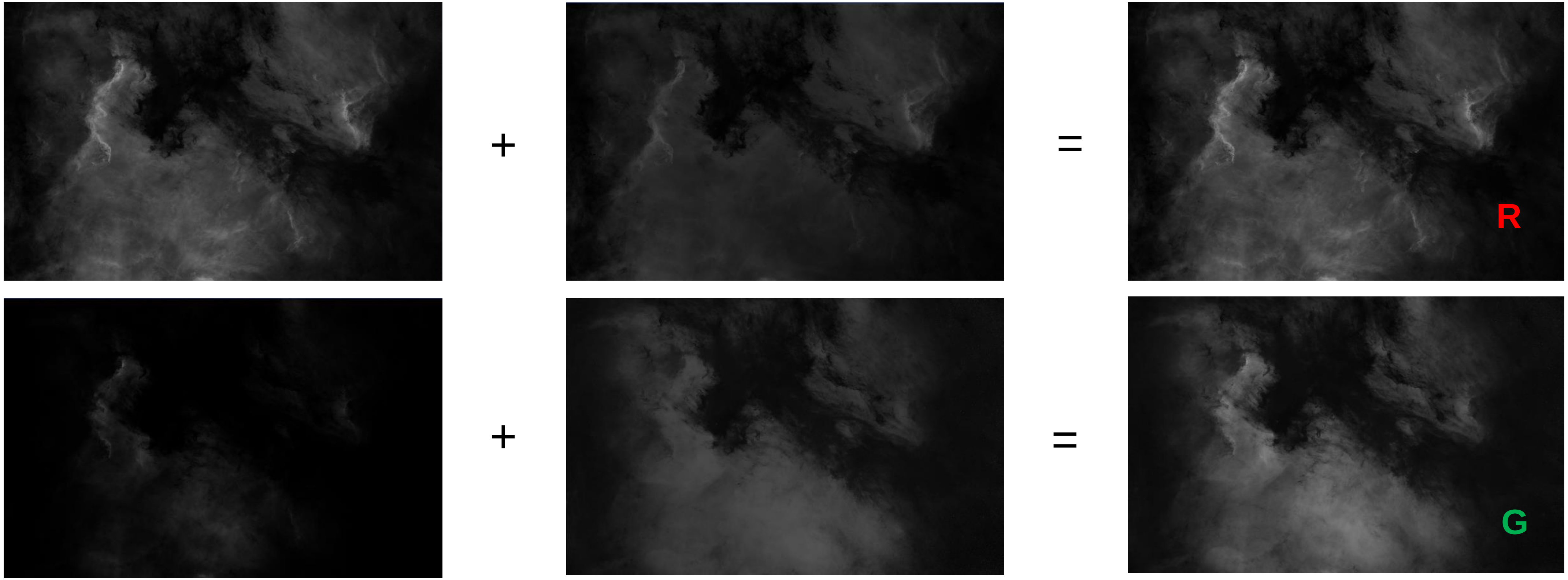
Depending on the data, we get locally a SHO and HOO combination.

Exponential Transformations - FORAXX

$$R \;:\; O^{1-O} \cdot S + (1 - O^{1-O}) \cdot H$$

$$G \;:\; (H \cdot O)^{1-H \cdot O} \cdot H + (1 - (H \cdot O)^{1-H \cdot O}) \cdot O$$

$$B \;:\; O$$




FORAXX

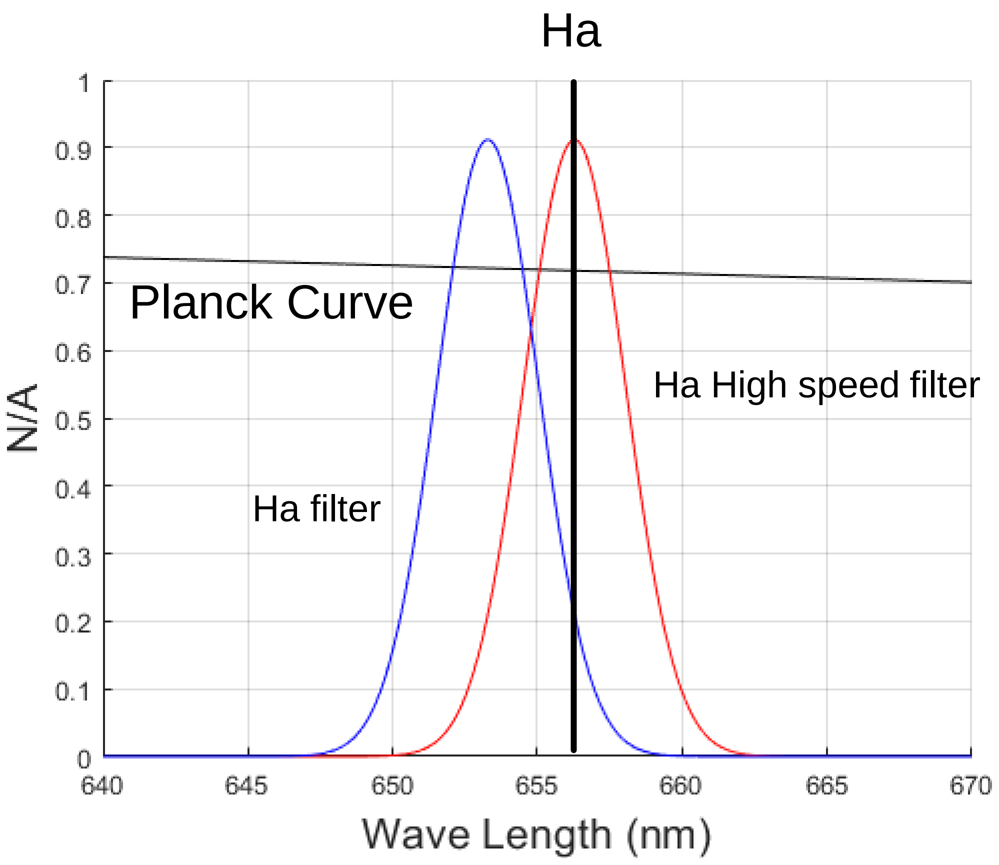
M31 – Andromeda Galaxy

A galaxy emittes mainly thermal radiation and Ha in some areas

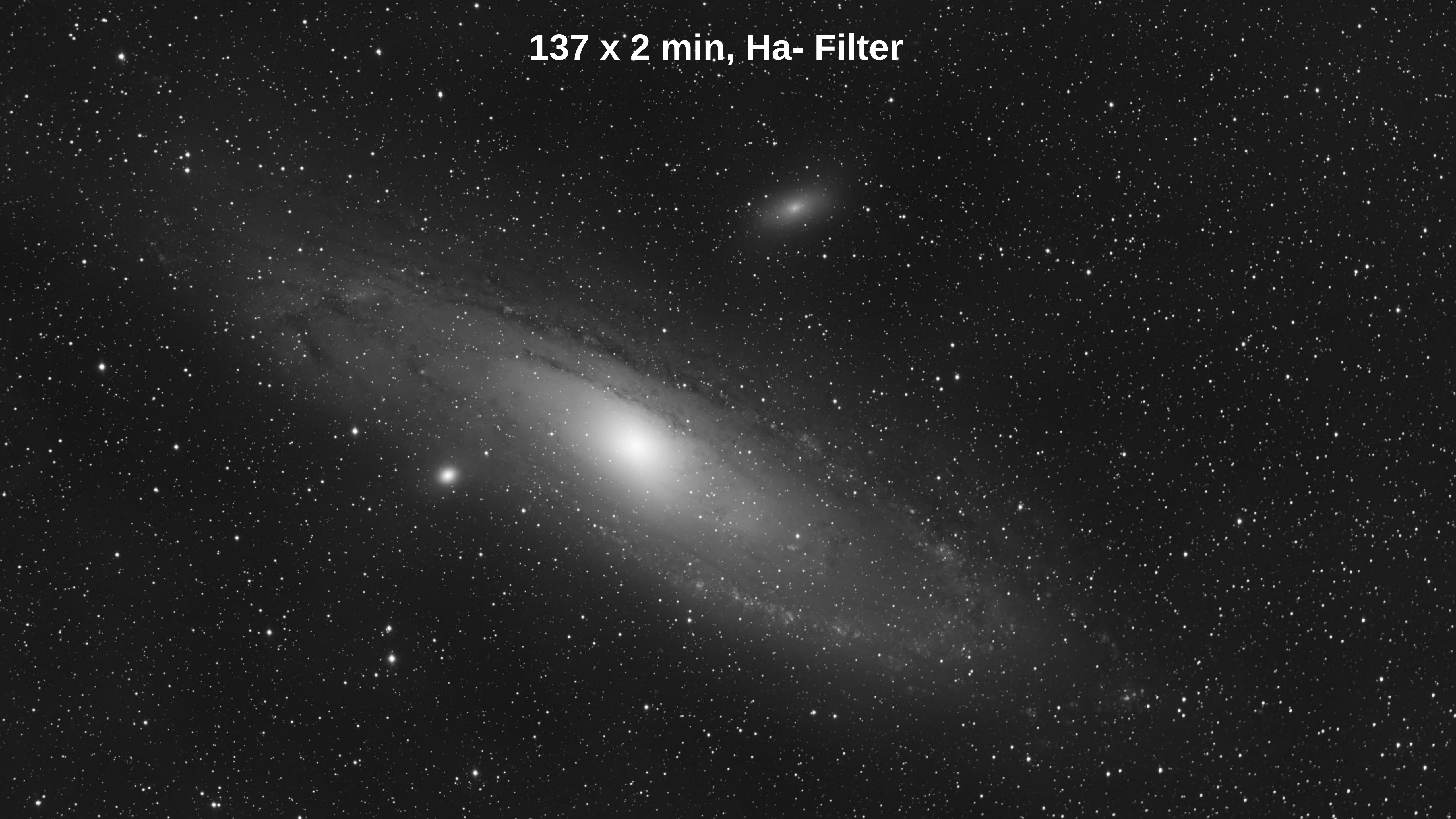
Both Ha-Filter transmit the thermal radiation

But only the High Speed Ha-Filter transmits also the narrow-band Ha-Light

By substracting both pictures it is possible to show the „pure“ Ha radiation of a galaxy



137 x 2 min, Ha- Filter



72 x 2 min, High Speed Ha- Filter