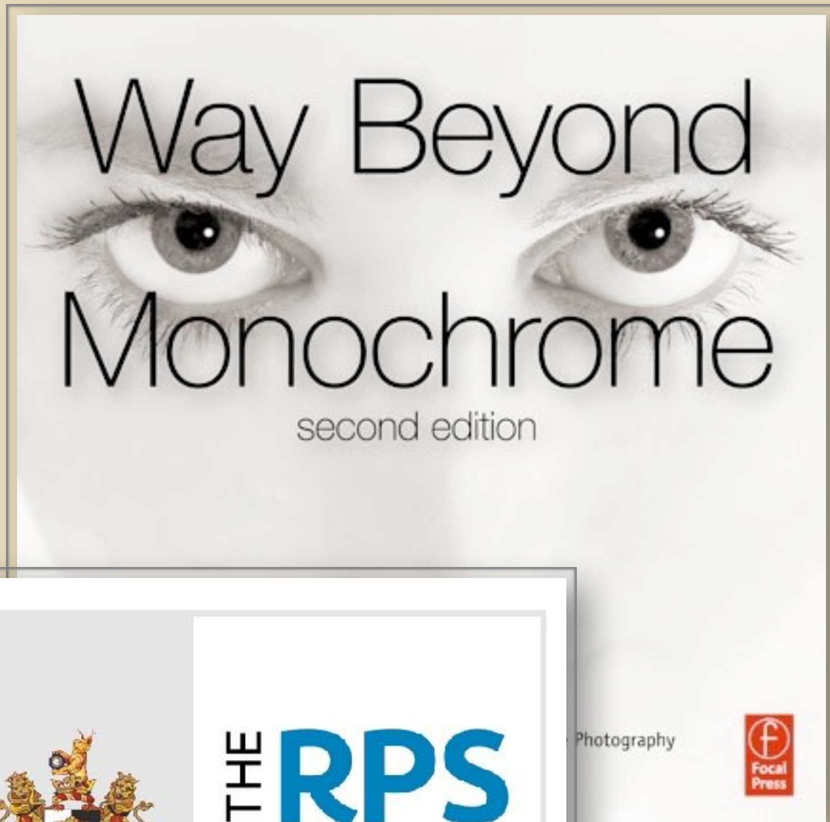
ASTROPHOTOGRAPHY

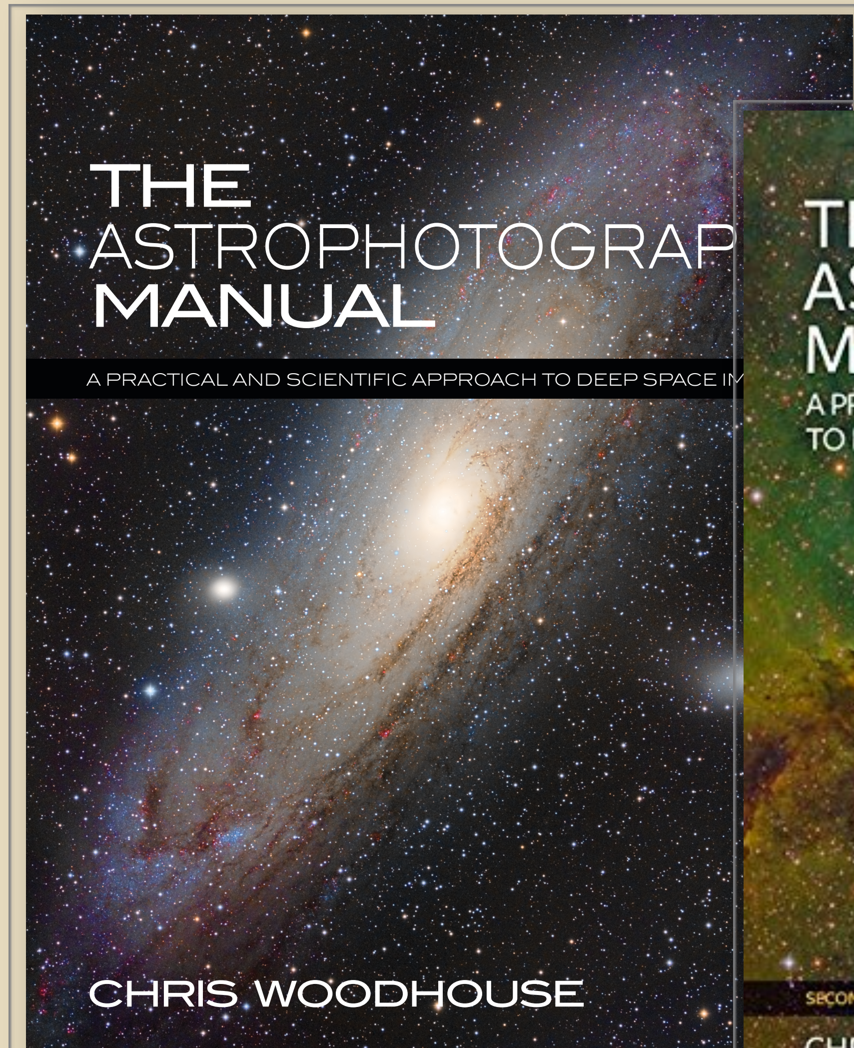
(taking it to infinity)

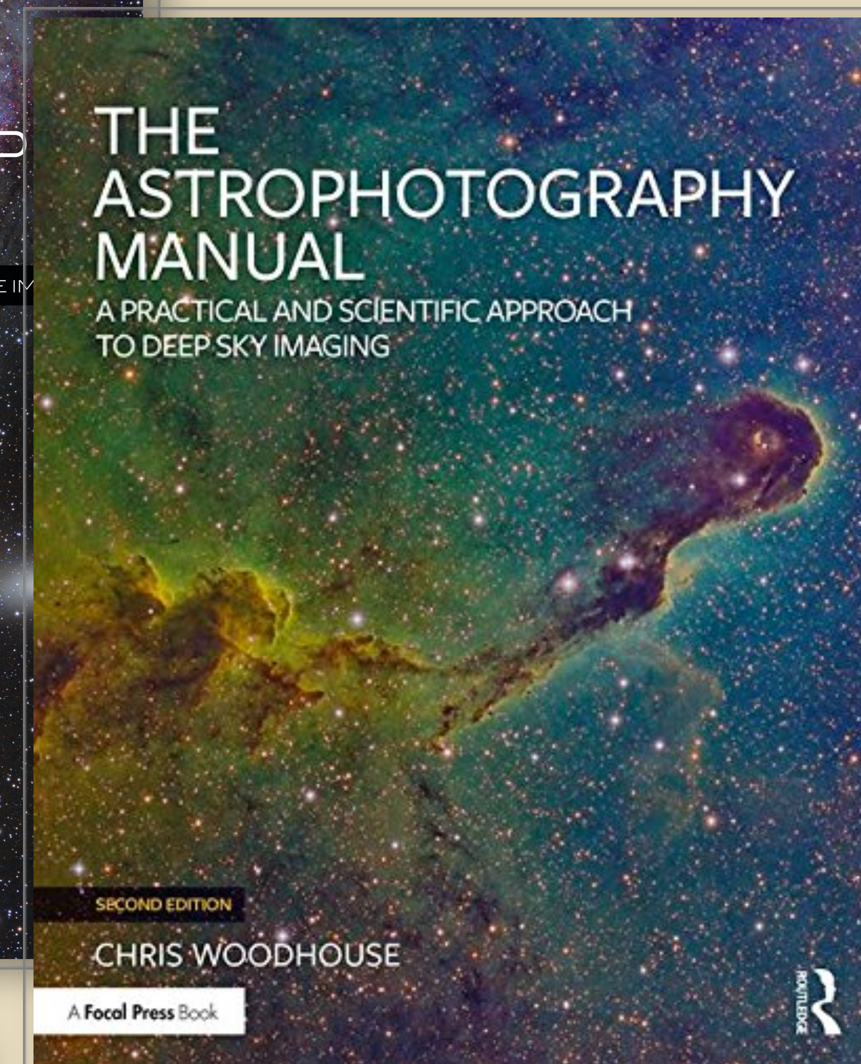
Camera Club Presentation

- a bit about me
  - living on the edge
    - break
      - solutions
        - questions

A bit about me







THE RPS
ROYAL PHOTOGRAPHIC SOCIETY

ROYAL ASTRONOMICAL SOCIETY
QUICQUID NITET NOTANDUM
1820

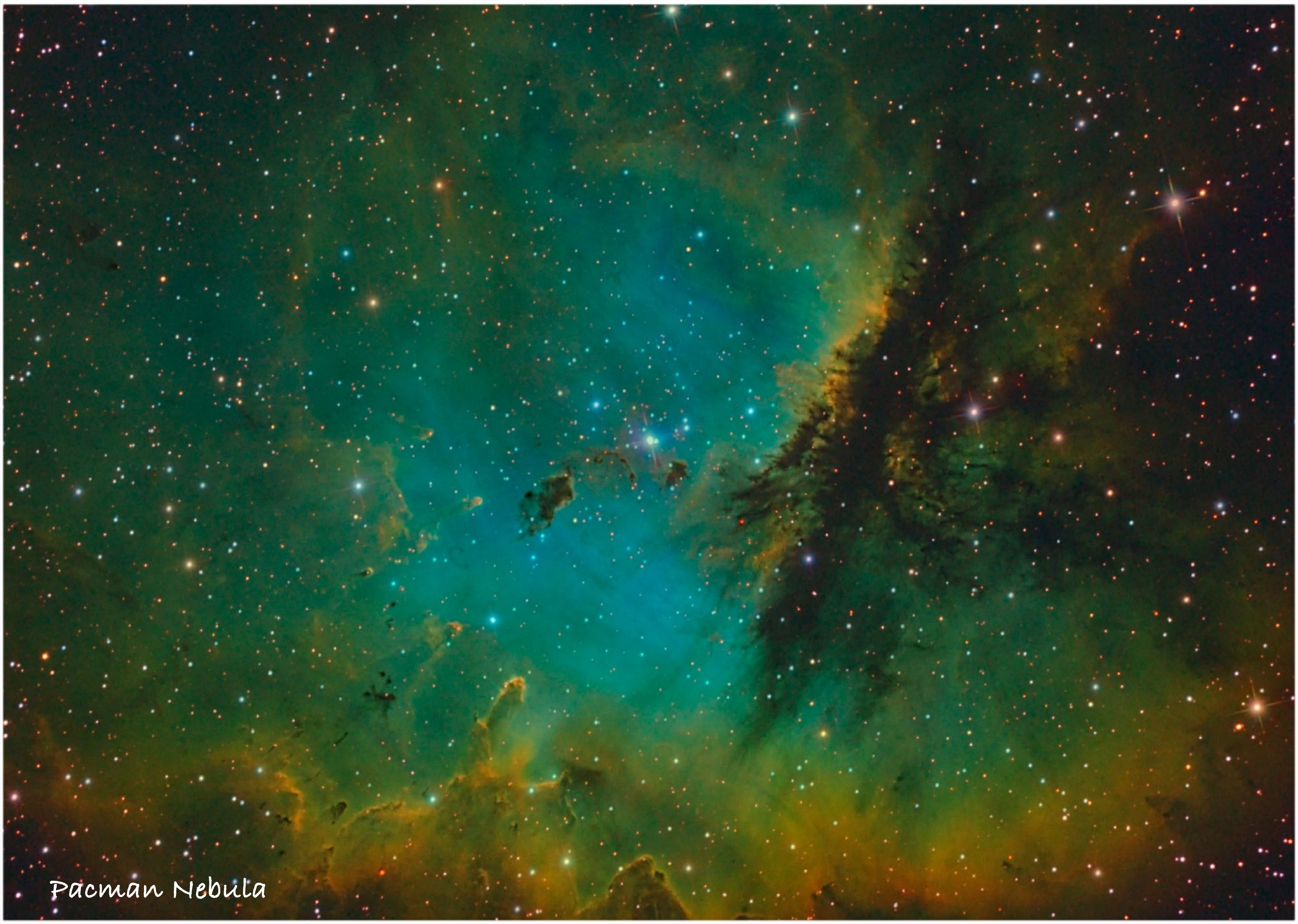
living on the edge

Digital Photography

difficult, confusing, expensive?

Pah!

That is *nothing* compared to astrophotography.


Pacman Nebula

living on the edge

Meet the challenges:

- finding something invisible
  - incredibly low light levels
    - image noise
      - everything is moving
        - weather
          - light pollution

M31 Andromeda Galaxy Canon EOS, 300mm L f/4






meet the neighbours
M31 Andromeda Galaxy:

3 degrees wide (Moon is 0.5 degrees)
focal length 400 mm

Exposure:
4 hours luminance
4 hours through separate R, G & B filters

8 hours total, 240 exposures
over several weeks


M31 Andromeda Galaxy

finding something invisible

Stellar Catalogs -
Stars:
GSC
UCAC
...

Non Stellar:
Messier
Caldwell
Herschel
...

Millions of catalog entries, descriptions, size, intensity, position and colour information.

Sortable by database and visible in planetarium.

finding something invisible

Requires:

- accurate time and location
- accurate Polar alignment
- alignment to three stars
- robotic mount
- catalog coordinates

gets within ~0.25 degrees

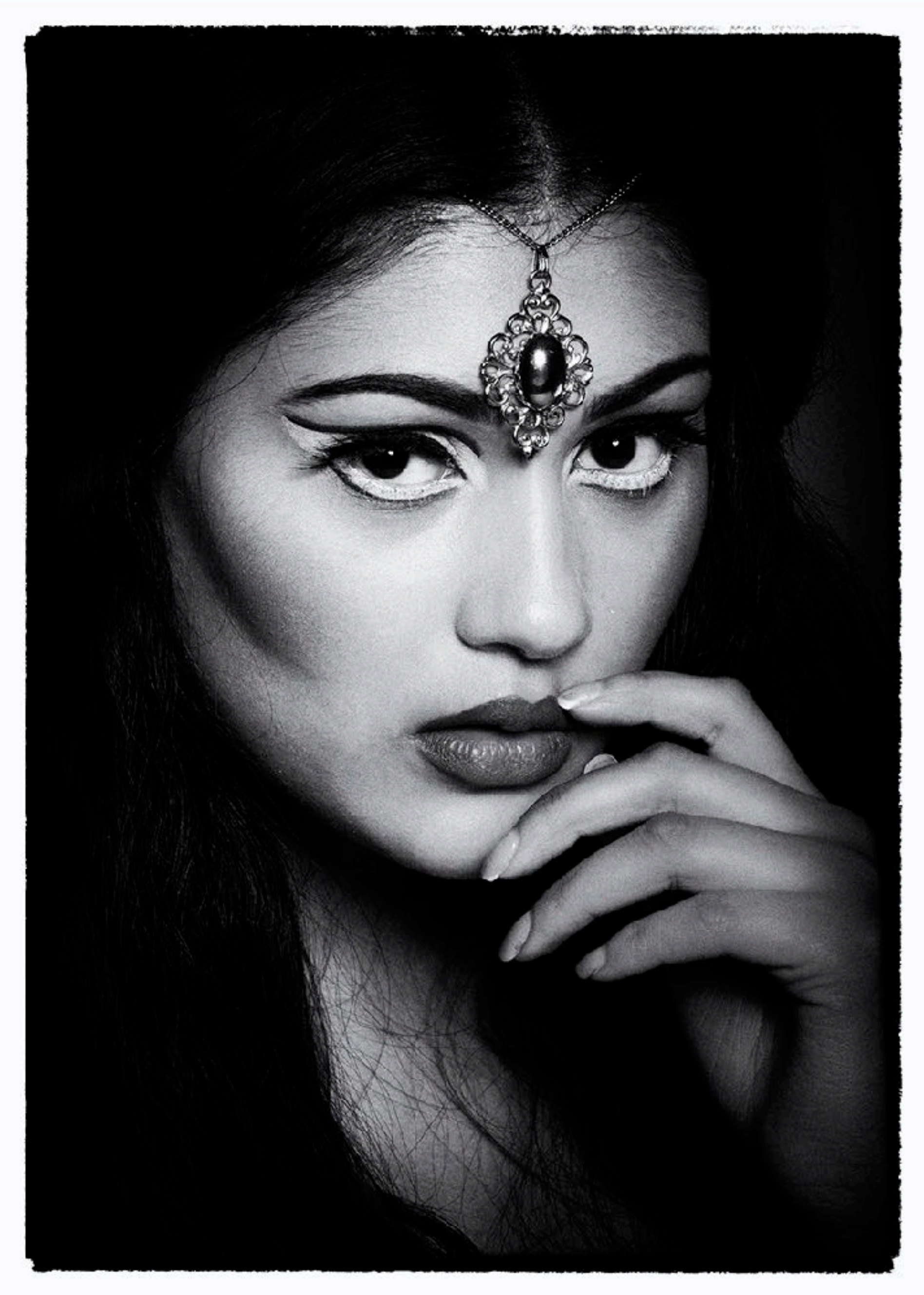

Heart of the heart nebula

incredibly low light levels (1)

compare a studio portrait:

- EOS CMOS sensor, ISO 250
- 1/2,000 second exposure
- 16-bit face value of 40,000
- about 80,000 photons

=1 photon/pixel every <u>6 nS</u>

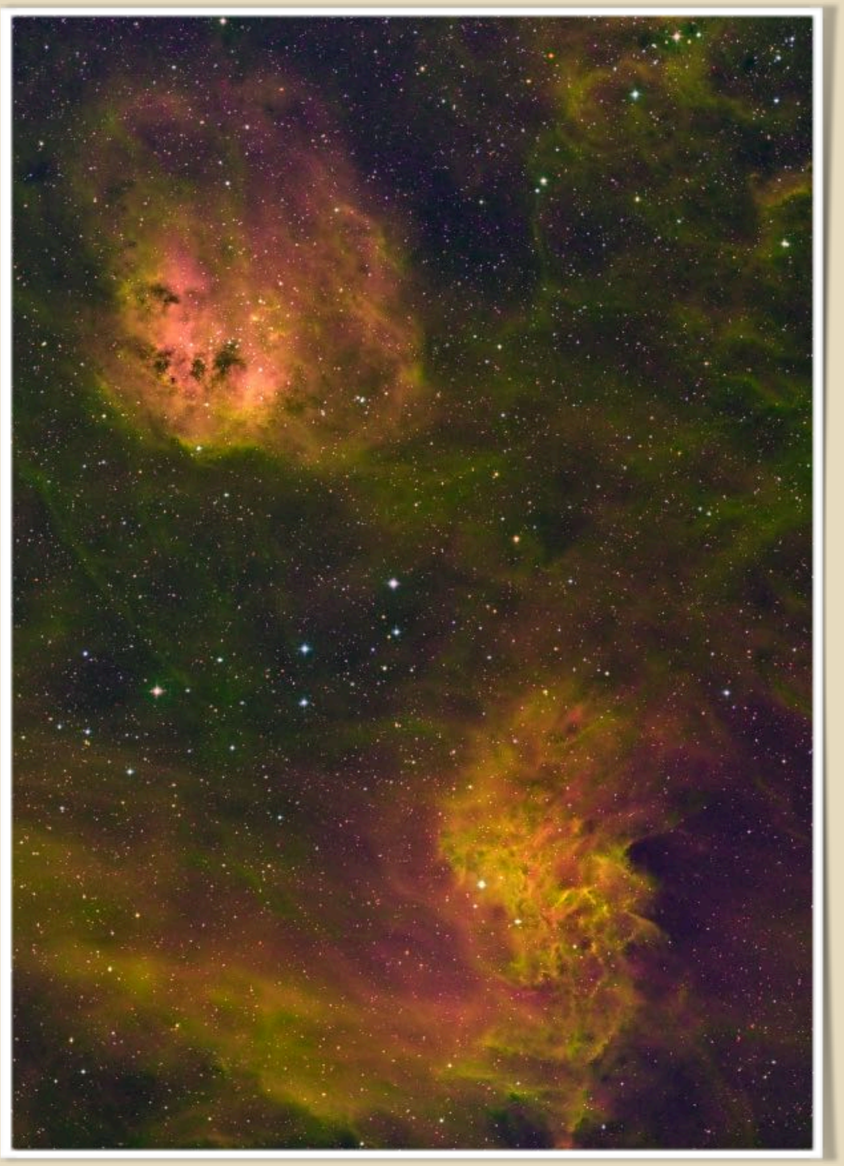


incredible low light levels (2)

with a typical nebula image:

- 15-year old 8 MP CCD sensor
- 20-min exposure @-20°C
- 16-bit pixel value of 65
- about 30 electrons, or 50 photons
  =1 photon/pixel every <u>24 seconds</u>

~4,000 million times dimmer!



incredible low light levels (3)

nothing there after 30 seconds!

Elephant Trunk Nebula

focal length 900 mm,132 mm aperture
Exposure: multiple 20-minute exposures
40 hours with Ha, SII and OIII filters
+5 hours through separate R,G & B filters

45 hours total, 180 exposures
(over two months)


Elephant Trunk Nebula- single 20 minute exposure


Elephant Trunk Nebula- 45 hours later

Lenses

- aperture ratio (f/stop) has little relevance
- physical aperture diameter (mm) is everything
- more aperture = more photons
- more aperture = higher resolution
- telescope optics are often 'diffraction limited' **

**(our atmosphere limits resolution to ~2 arc seconds)

M13 Globular Cluster

focal length 2,000 mm, 250 mm aperture

130 x 5-minute exposures
through separate RGB filters.

~11 hours over 3 weeks


M13 Globular Cluster

image noise

noise is everything in an image we don't want.

<u>sensors have noise</u>

- pixel variations (pattern)
- read noise (pattern and random)
- thermal noise (average and random)

<u>light has noise</u>

- light pollution (unwanted background)
  + shot noise (random noise)
- deep sky (wanted signal)
  + shot noise (random noise)

light has noise

Photons are like raindrops; random in nature.
If you measure and compare the accumulated photons on each pixel you will find:

The randomness (noise) between like pixels, increases with the average amount, defined by:

shot noise = $\sqrt{}$ mean pixel value

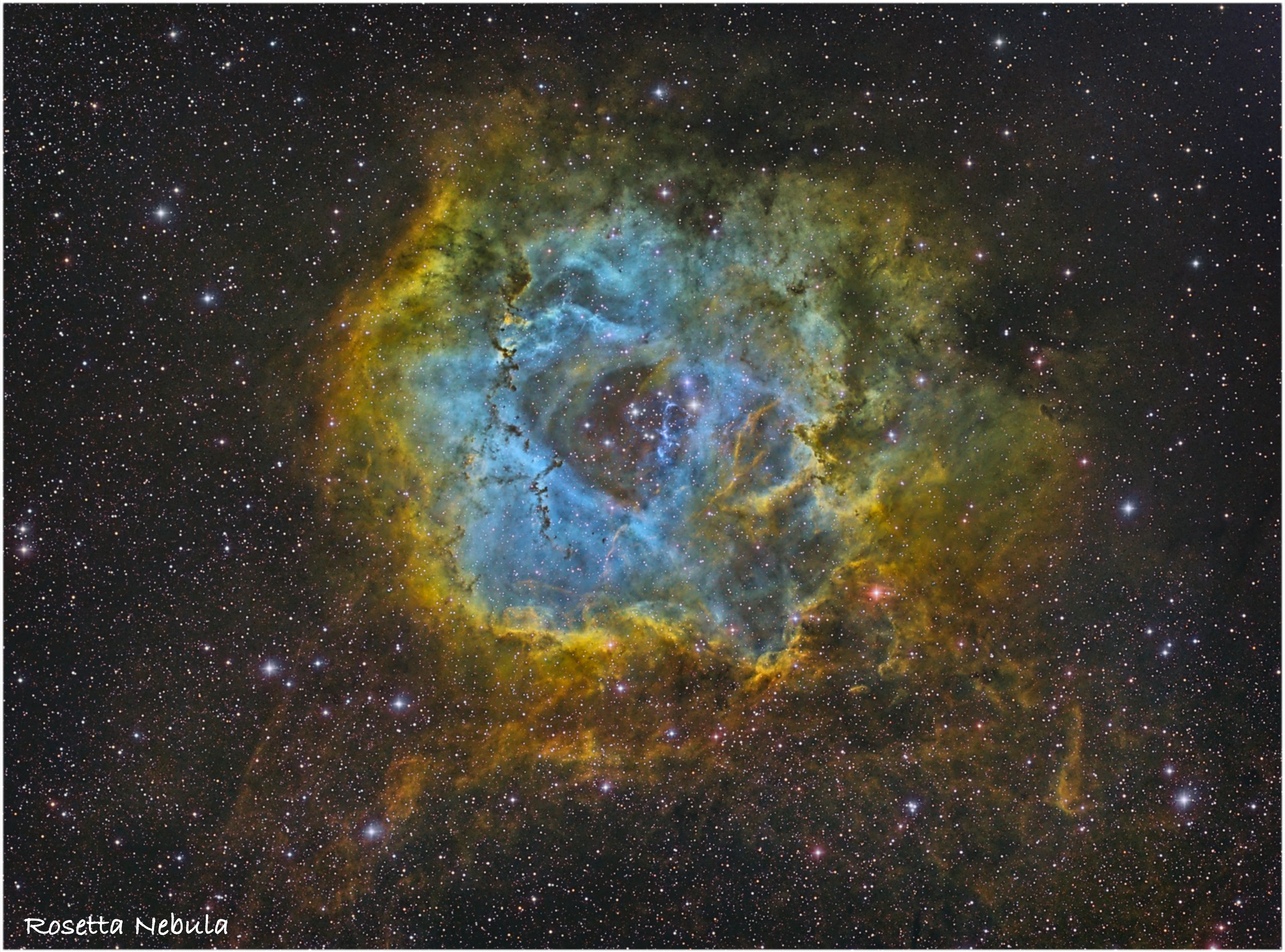
Compare noise level of bright scene and a dim one:
$\sqrt{40{,}000} = 200$, $1/200^{th}$ of mean value
$\sqrt{400} = 20$, $1/20^{th}$ of mean value

Rosette Nebula

focal length 350 mm, 85 mm diameter

imaged in narrowband Ha, SII, OIII

40 hours exposure over 3 months


Rosetta Nebula

SNR = Signal to Noise Ratio

comparing portrait with deep sky portrait

1/1000th sec SNR = 200

(almost 100% shot noise)

single narrowband 1,200 sec SNR = 3

(20% shot noise, 80% sensor noise)

average of 36 x 1,200 sec SNR = 24

Sunflower Galaxy

focal length 2,000 mm

130 x 5-minute exposures
through separate R, G & B filters.

~11 hours over 3 weeks


M63 Sunflower Galaxy

Break


Digital
Astrophotography

welcome back

Horsehead Nebula, natural colour

everything is moving

- everything is moving in relationship to everything else!

- principle apparent movement is from Earth's rotation every 23h 56m

  = 1 degree (3,600 arc seconds) every 4 min

  = 15 arc seconds every second

  compared to a star width ~ 1.5 arc seconds

everything is moving

telescope is fitted to a mount which rotates with the stars, with incredible accuracy and stability

mechanical tolerances achieve:

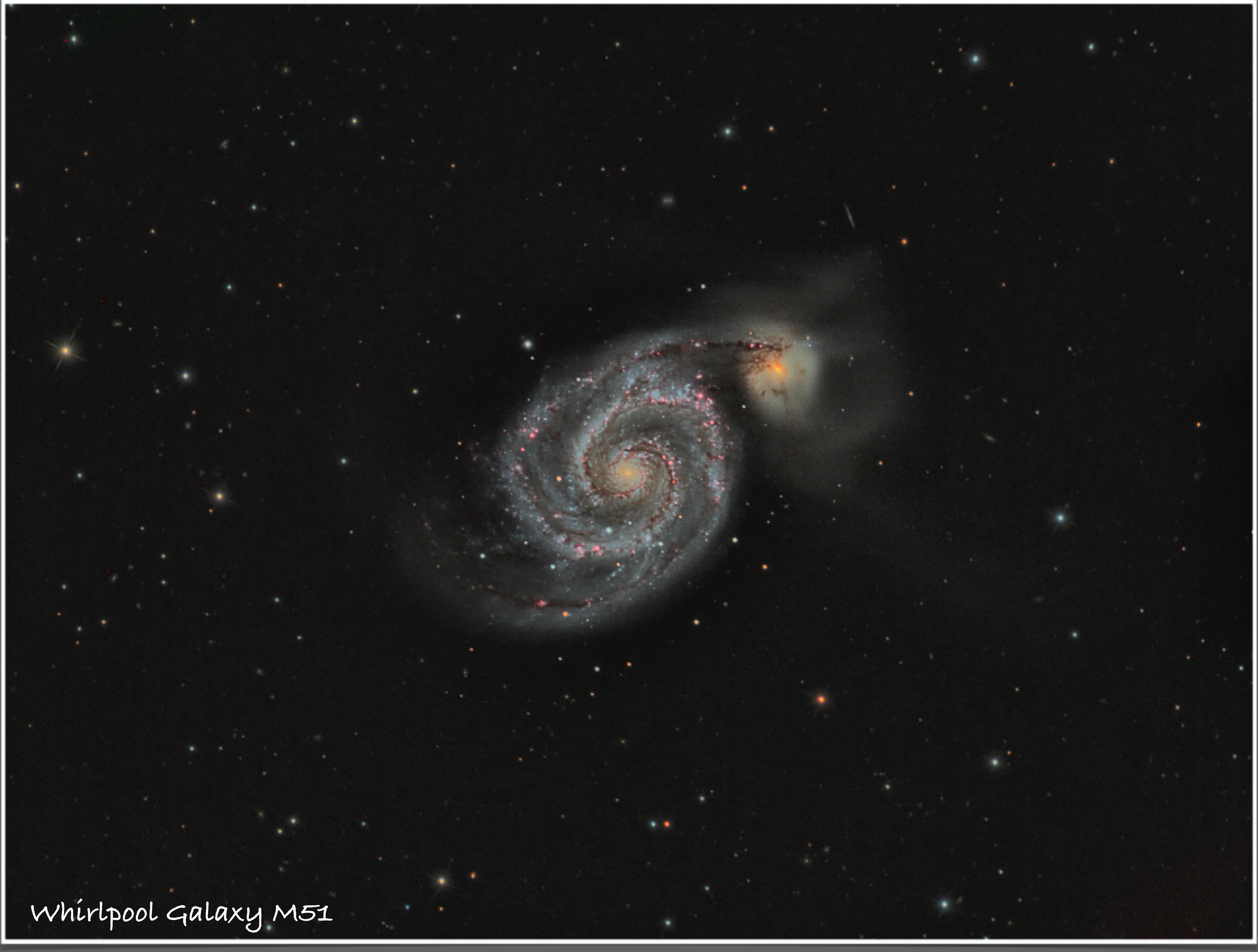
±2 to ±15 arc seconds

… not good enough

solution

- remaining errors fixed by continual monitoring and adjustment on both axes-improves tracking to:

  0.5 arc seconds (1/7,000th degree)


Whirlpool Galaxy M51

wet weather? - solution: take up fishing


Eastern Veil Nebula

noise solutions

- take up oil painting
- add more exposure
- calibrate the image files
- find a darker site and use filters
- cool the sensor
- advanced image processing
- add even more exposure

add more exposure

SNR is improved with more exposure

1. lengthen each exposure (but do not clip)
2. take more exposures and average them

Each time you double the exposure count, the averaged image exposure has 40% less noise.


M101 PinWheel Galaxy

calibrate each exposure

Why?
If you average thousands of image files, you will still have sensor pattern noise, hot pixels, dust shadows and vignetting in each image. This 'noise' is constant but still annoying.

Calibration uses dark frames, zero-exposure frames and images of featureless T-Shirts to create an image of pattern noise to subtract from each image and normalize with another, which makes all pixels behave the same.


M45 - Nebula 35 hours exposure

sensor calibration

calibration typically requires:

- 50 averaged zero-length exposures of nothing
- 50 averaged exposures of nothing at image exposure time and temperature
- 50 averaged exposures of a flatly lit uniform subject
- 50+ exposures of the image itself

calibrated image = (image - dark) x (normalized flat)

more is not enough

Heart Nebula

Shot with SII, $H\alpha$ and OIII filters

120 x 20 minute exposures SHO
60 x 5 minute exposures RGB

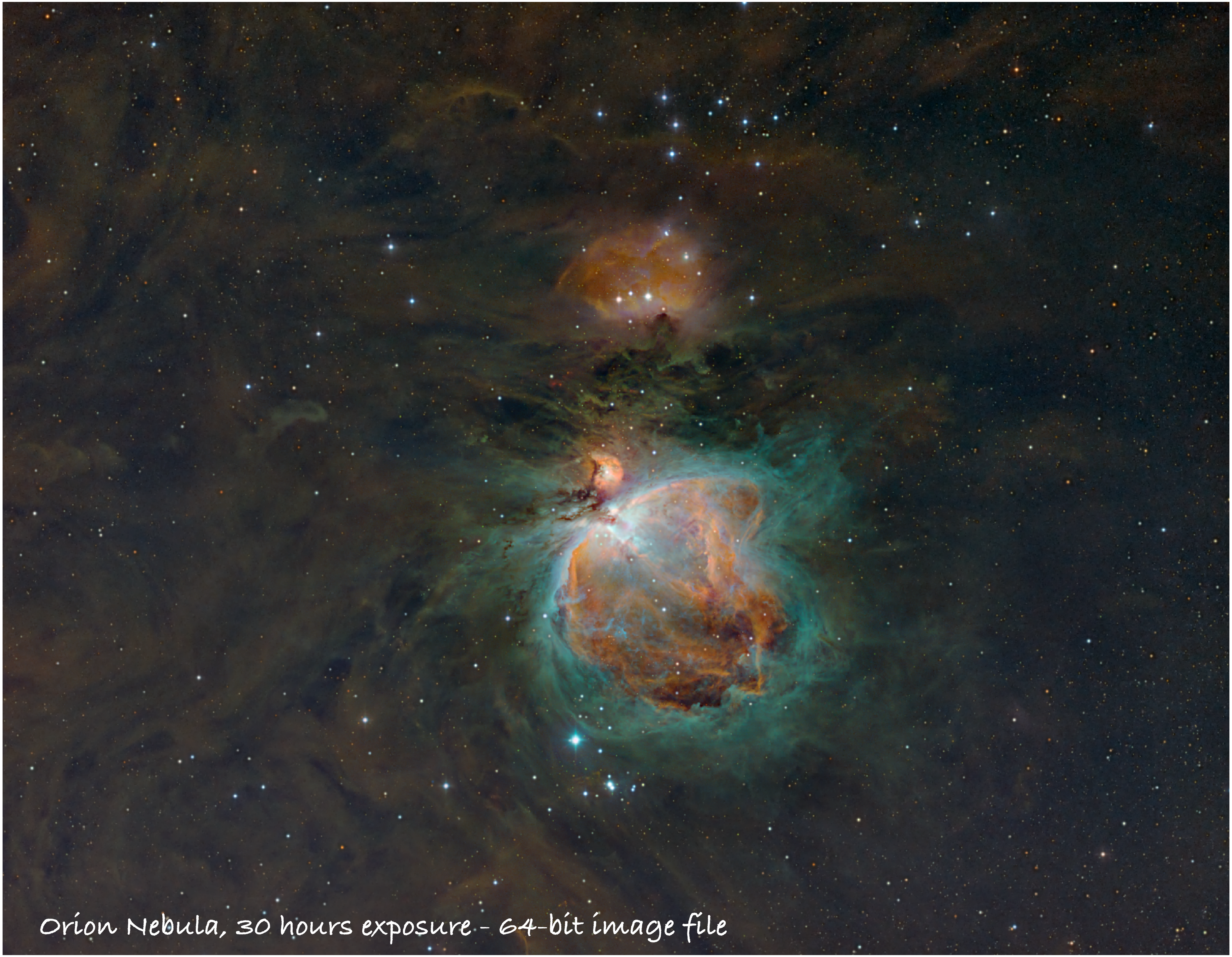
45 hours over two months


Heart Nebula SH2-190

deep exposure and dynamic range

increasing the exposure count also increases the dynamic range, a stop for every quadrupling

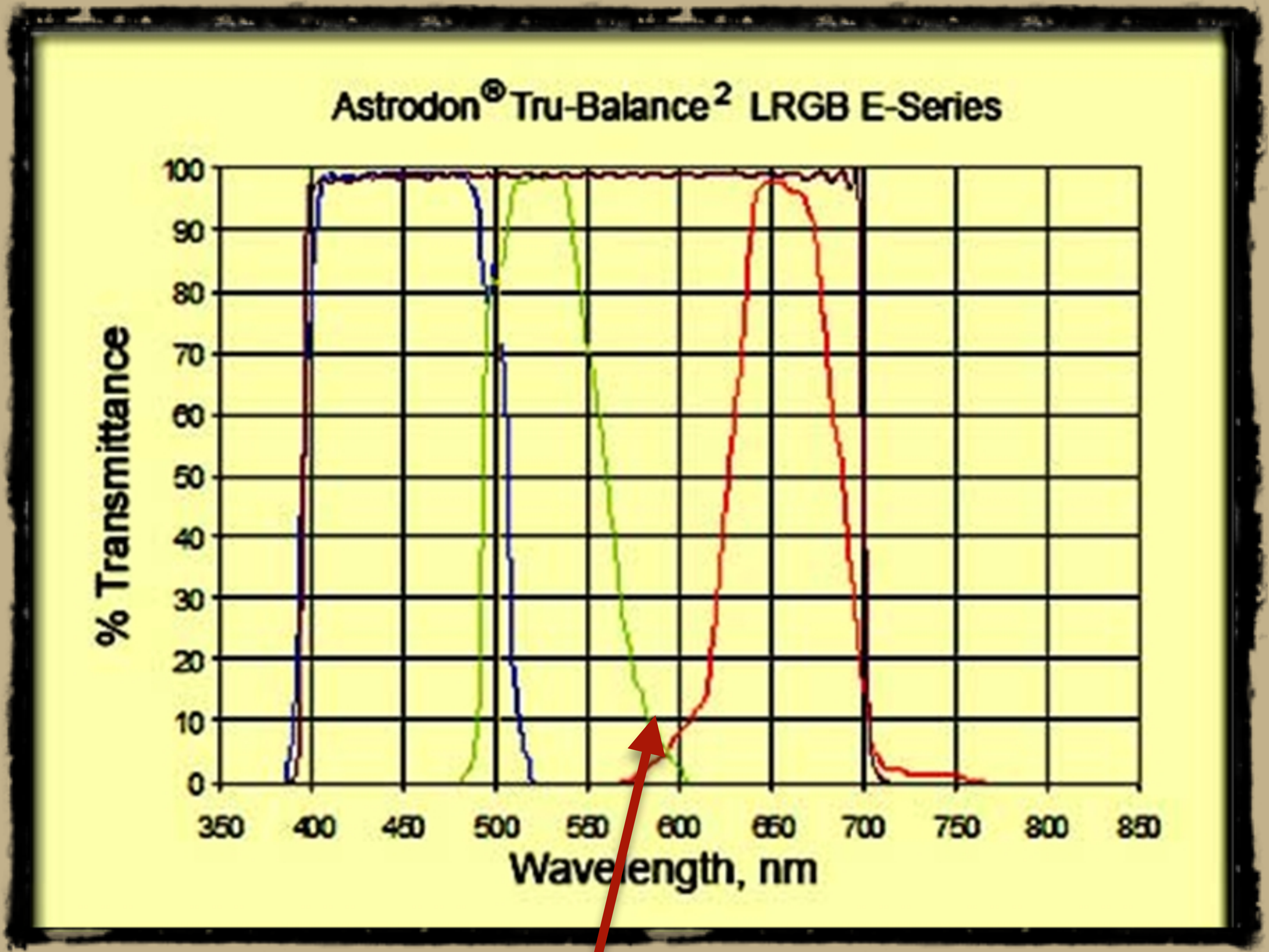
example: Orion Nebula - particularly tricky
10 hours Hα in 30, 120, 300 second exposures
8 hours SII in 120, 300 second exposures
8 hours OIII in 120, 300 second exposures
4 hours RGB for stars
acquired over 10 nights (due to low altitude)



Orion Nebula, 30 hours exposure - 64-bit image file

light pollution and sky noise

individual RGB filters and a monochrome sensor exclude more light pollution than a color sensor.



the red and green exclude sodium lamp yellow (@ 590 nm)

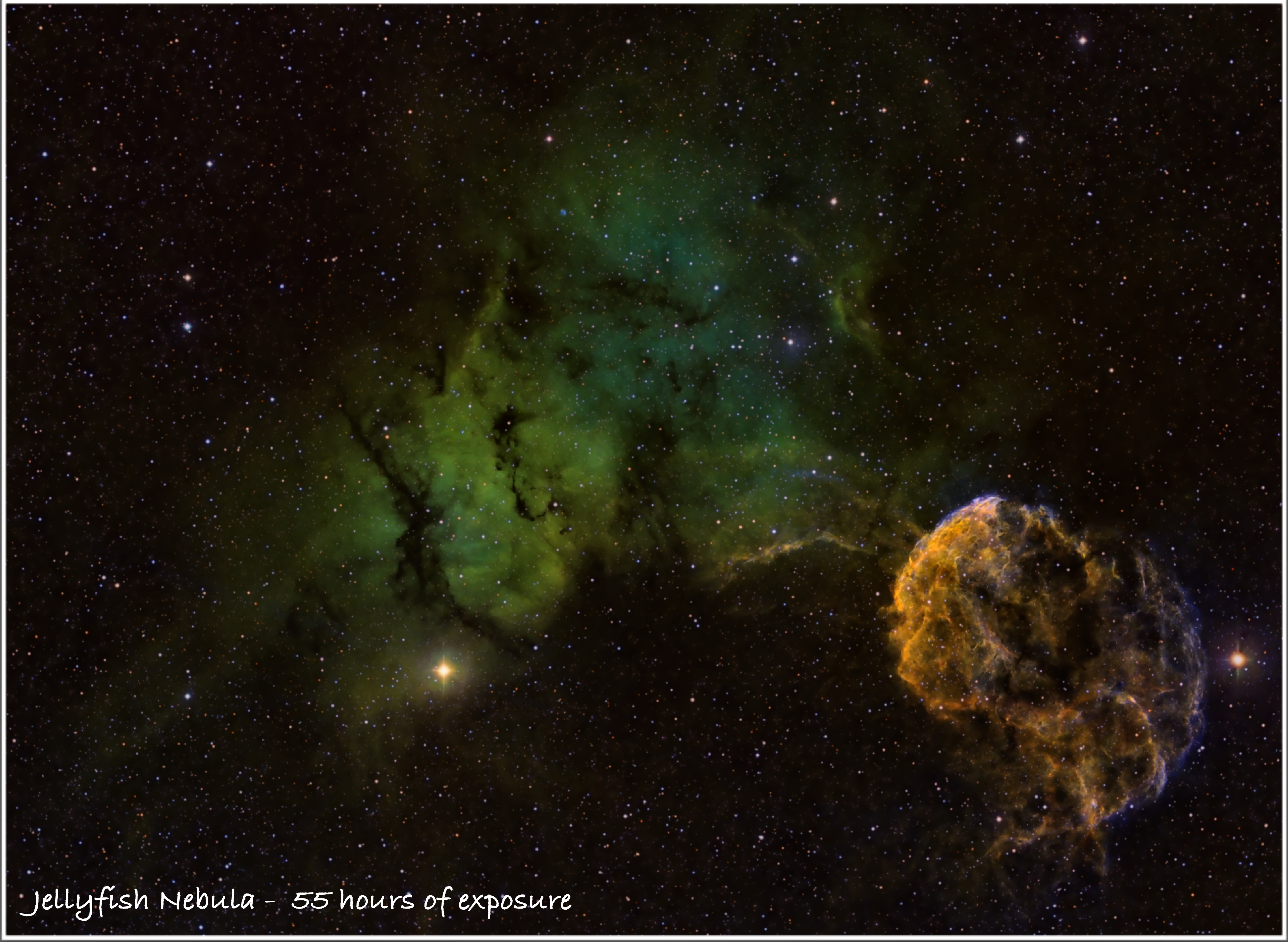
M33 - Triangulum Galaxy

light pollution and sky noise

or… virtually exclude light pollution and its noise with narrowband filters - tuned to ionised gas emissions

advanced image processing

these are the same image, before and after 32-bit processing in PixInsight (Photoshop cannot handle this)


Jellyfish Nebula - 55 hours of exposure

All-night, automated,
remote imaging from Essex

QUESTIONS?