Digitizing the Universe From Your Backyard

Robert J. Vanderbei

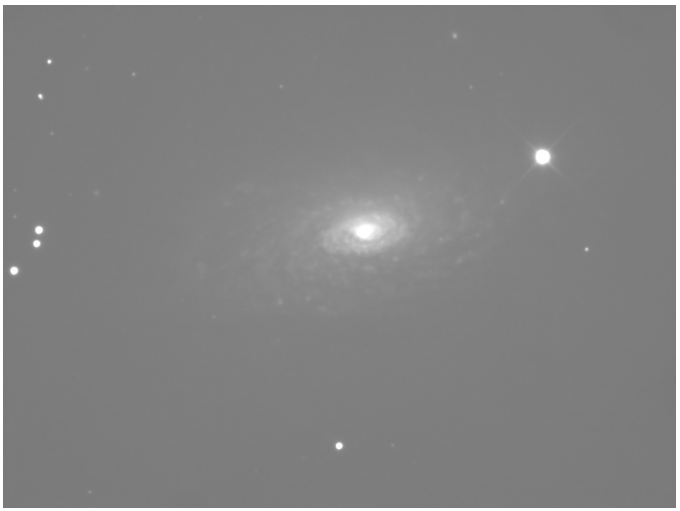
2008 February 27

http://www.princeton.edu/∼rvdb

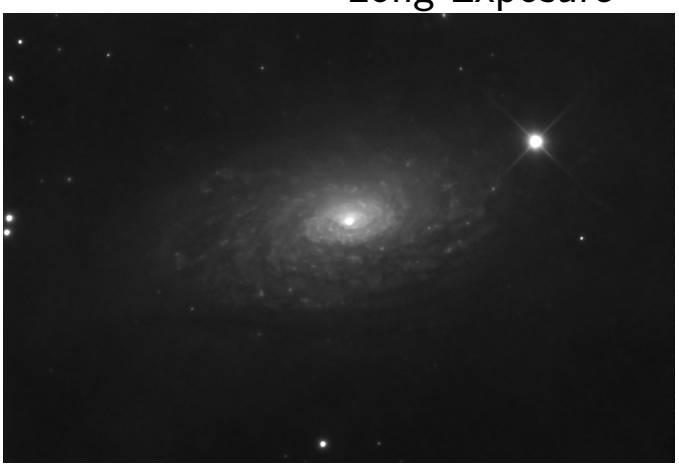
Why Astrophotography?

Long Exposures, Permanent Record, Digital Enhancement, Light Pollution!

Visual Experience



Long Exposure



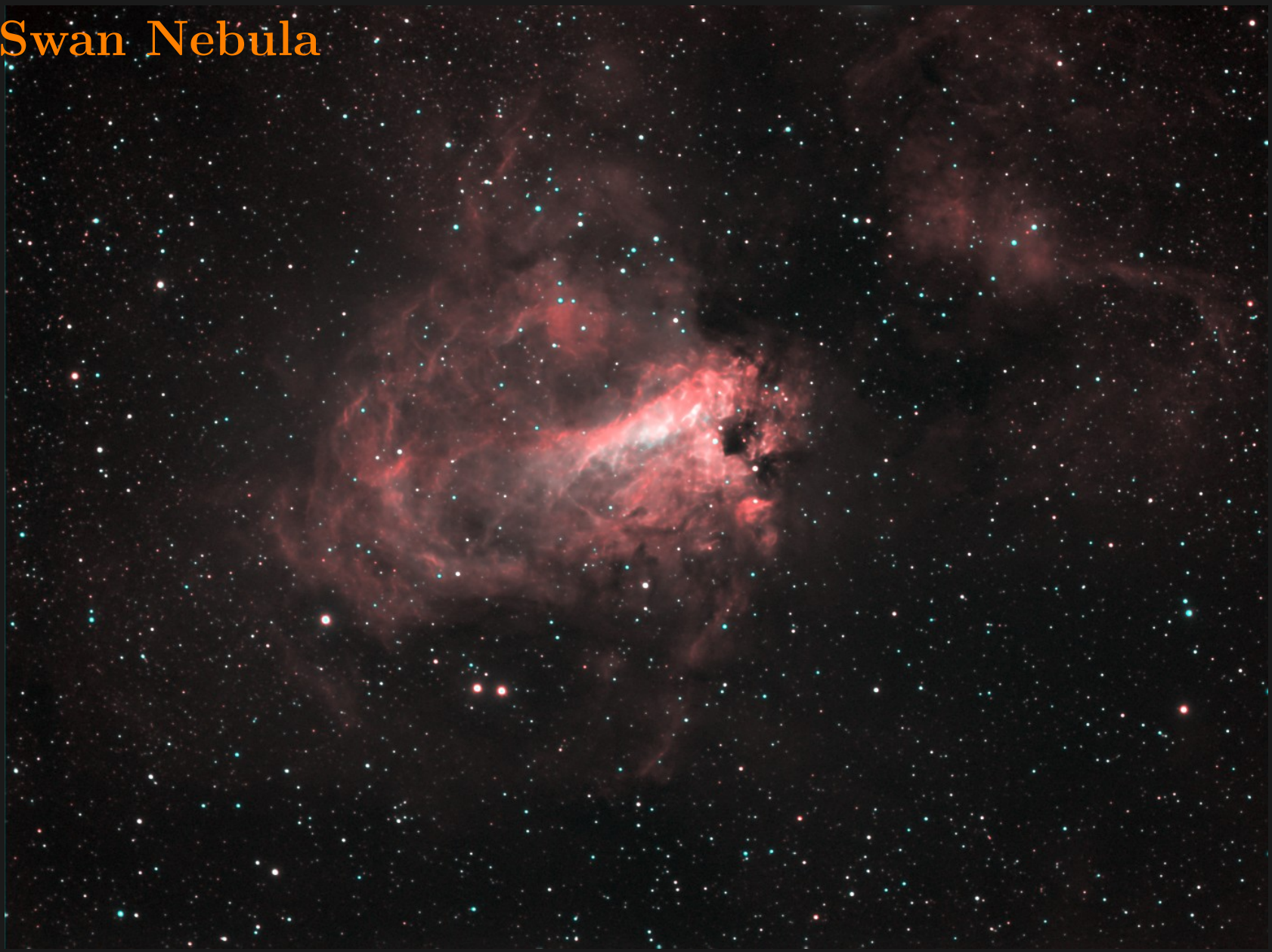
Light Pollution Subtracted

Some Pictures


Crab Nebula


Lagoon Nebula

Hercules Globular Cluster


Swan Nebula


Dumbbell Nebula

Orion Nebula

Orion Nebula—Close Up


M82 and M81

Running Man Nebula

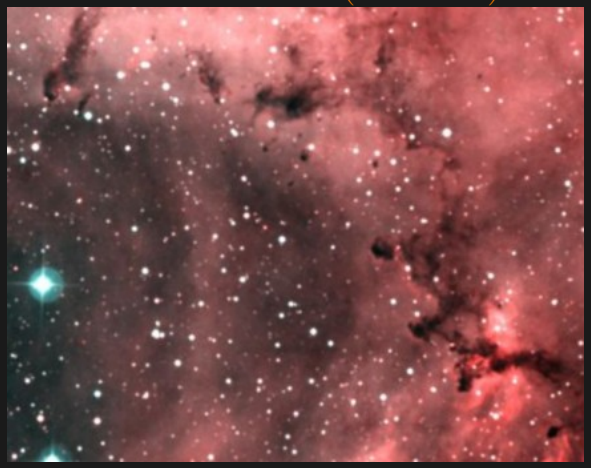

Rosette Nebula

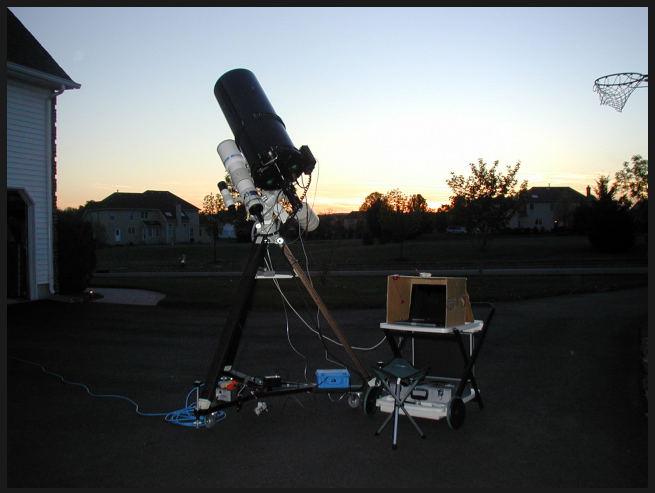
Rosette Nebula—Widefield

Rosette Nebula—Driveway vs. Mt. Palomar

Driveway

Mt. Palomar (48-inch)






Pleiades

Equipment

In order of IMPORTANCE...

1. Mount
2. Camera
   Computer
   Software
3. Telescope (OTA)

NOTE: This talk is about *deep sky* astrophotography.
For imaging the moon and the planets, the order would be reversed.

Astronomical CCD camera

- Pixel size: 6.45×6.45 microns
- Pixels: 1392 x 1040
- Quant. Eff.: $\sim 65\%$
- Readout Noise: ~ 7 electrons
- Cooling: $\sim 30°$C below ambient
- Download: 3.5 seconds
- Format: 16 bit
- Weight: 350g

Example

"Telescope": 200mm f/3.5 Vivitar lens ($30)

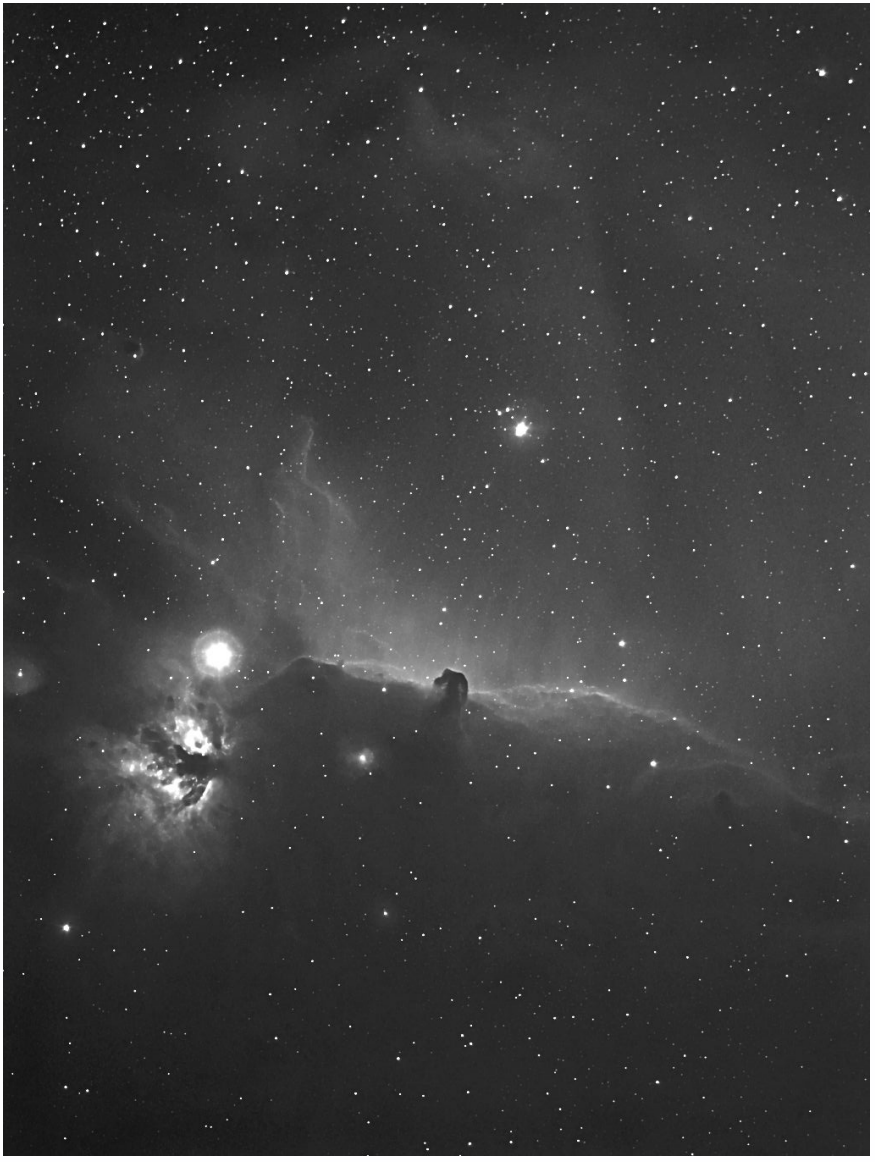
Mount: Questar

Camera: Starlight Express SXV-H9

Filter: Dichroic Hα

Fundamental Principles

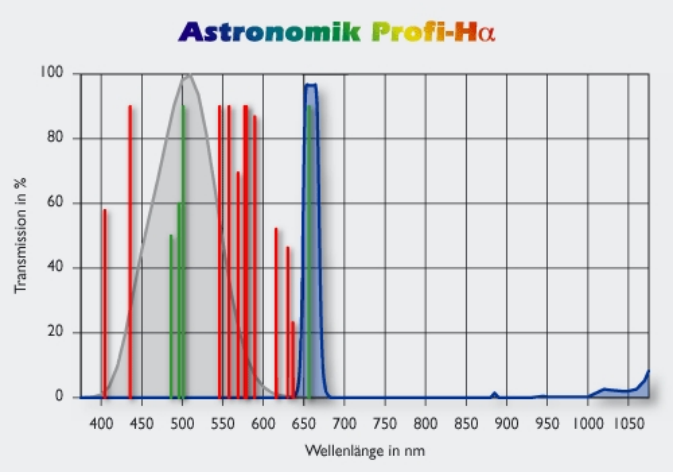
- *Focal length* determines *field of view*
- *F-ratio* determines *exposure time*

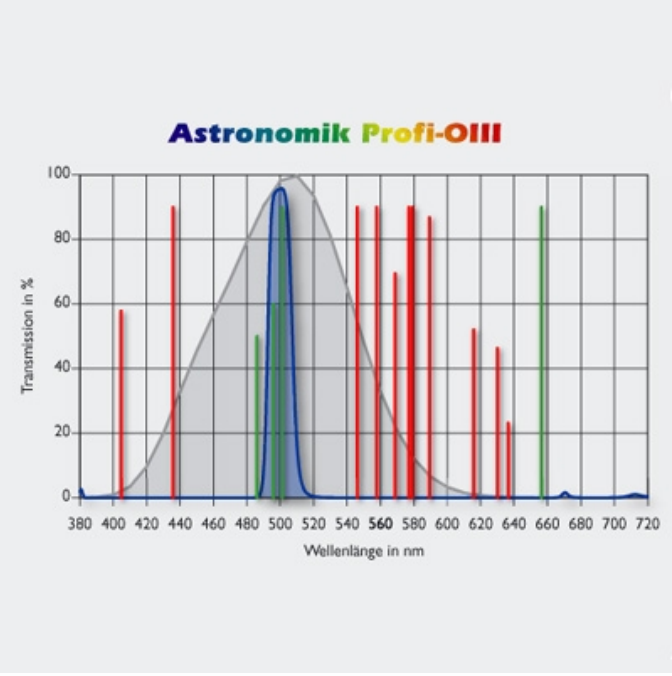


Total exposure time $= 156$ mins. Field of view $= 2.5°$.

Combatting Light Pollution

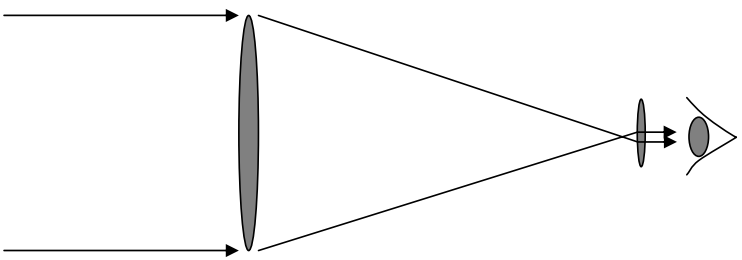
Narrow-Band Filters





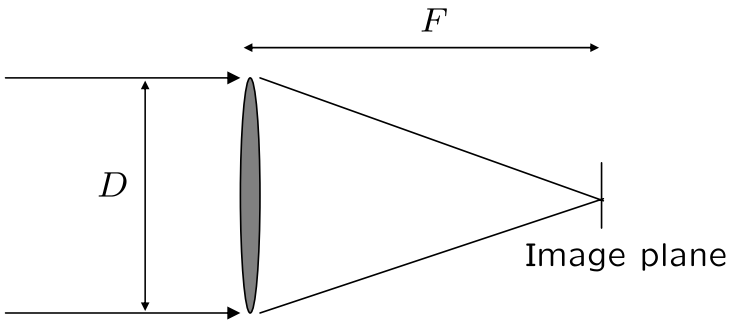
Visual Astronomy vs. Astrophotography

Visual astronomy is complicated.



- *Aperture* determines *photon flux*

Astrophotography is easier!

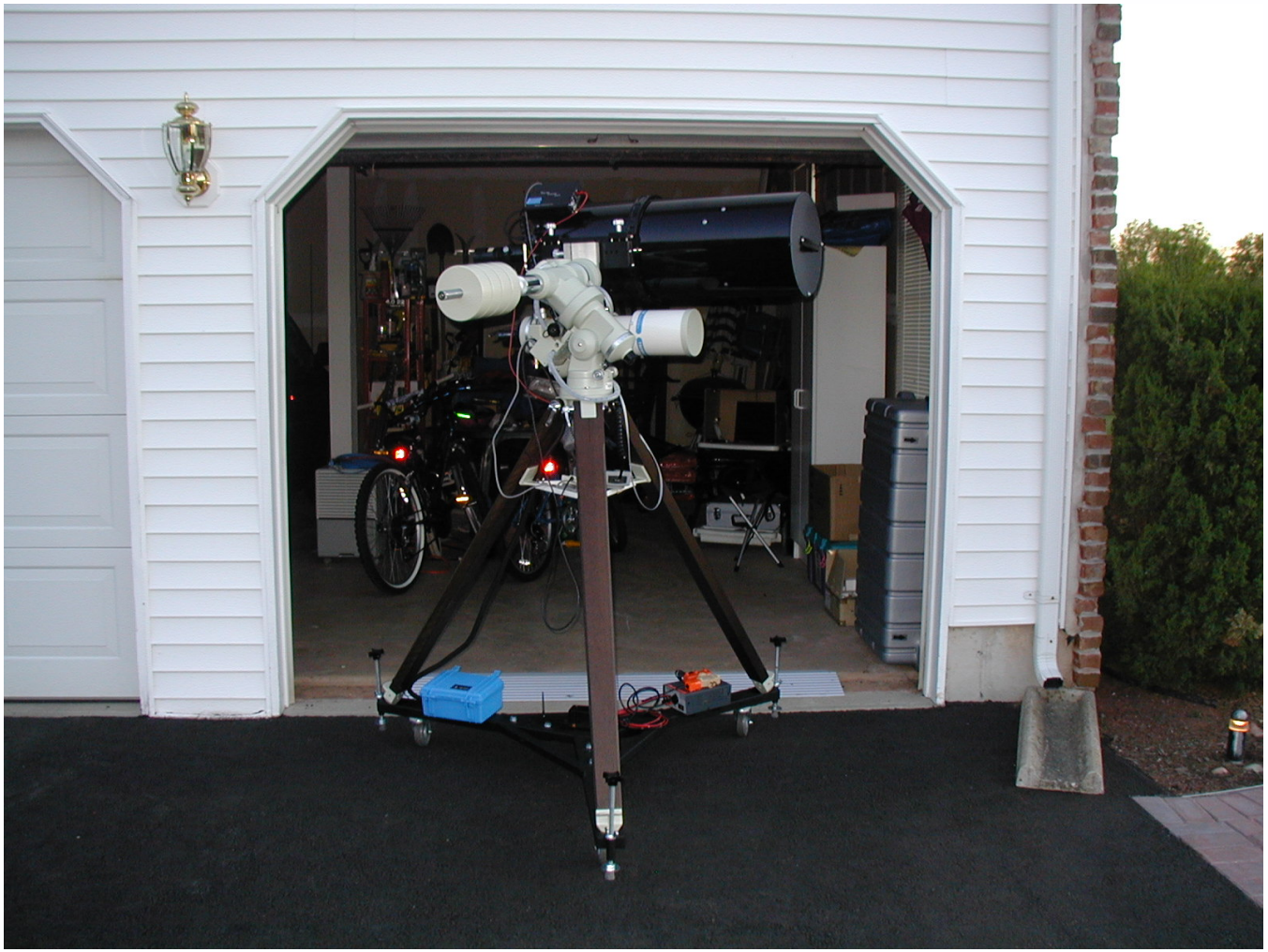


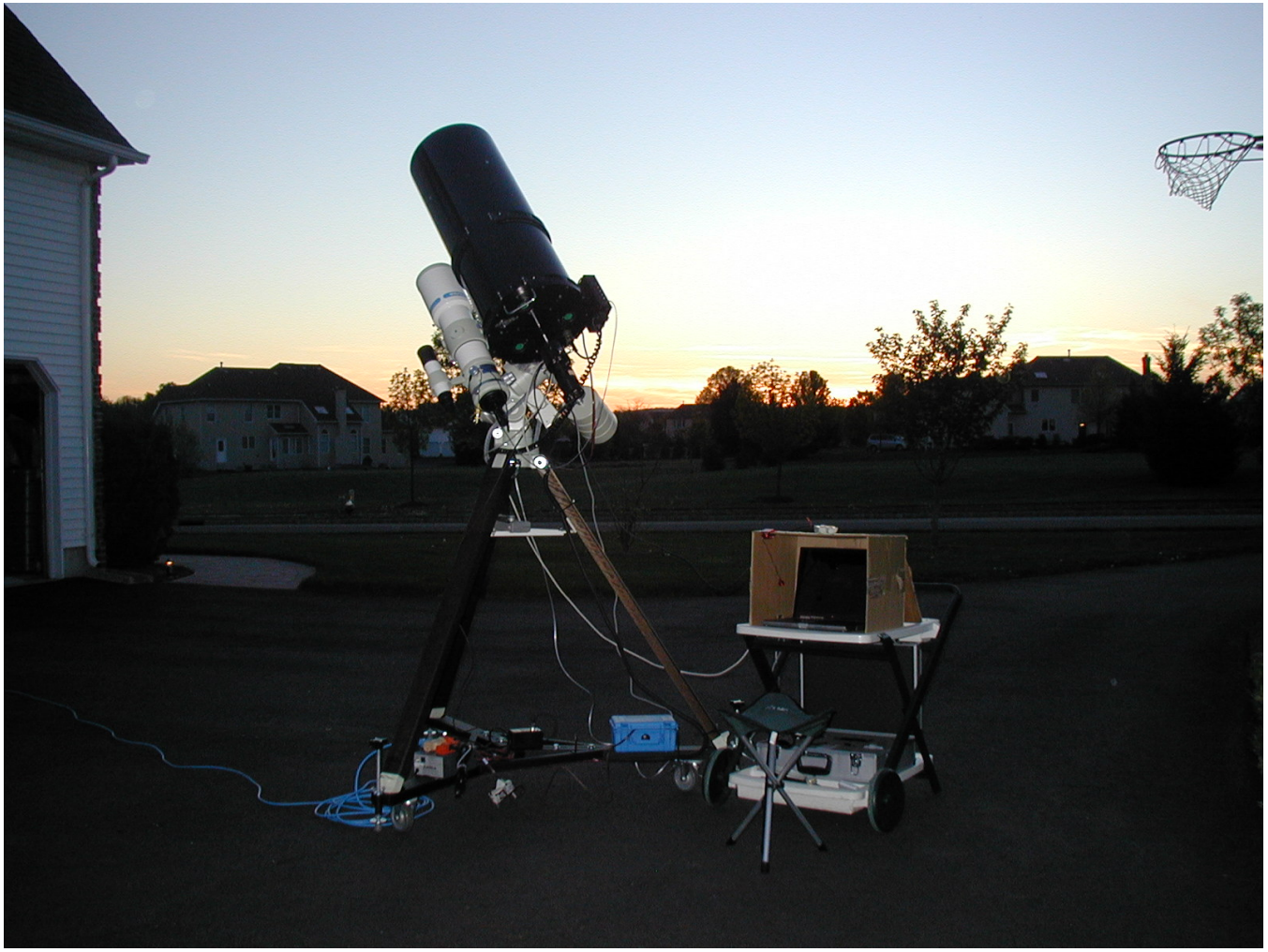
- *Focal length* determines *field of view*
- *F-ratio* determines *exposure time*

Image Acquisition

1. Move equipment outside (3 minutes). Let cool (in parallel).
2. Polar align (2 minutes).
3. Manually point at a known star (1 minute).
4. Fire up MaximDL, my image acquisition software (0 minutes).
5. Focus on bright star (3 minutes).
6. Center star in image (1 minute).
7. Fire up Cartes du Ciel, my computer's planetarium program (0 minutes).
8. Sync on star (1 minute).
9. GoTo desired target (1 minute).
10. Center (1 minute).
11. Select guide star. Calibrate and start guider (5 minutes).
12. Initialize imaging sequence (1 minute).
13. Go inside (1 minute), watch TV (hours).
14. Go outside. Pack everything up (15 minutes).

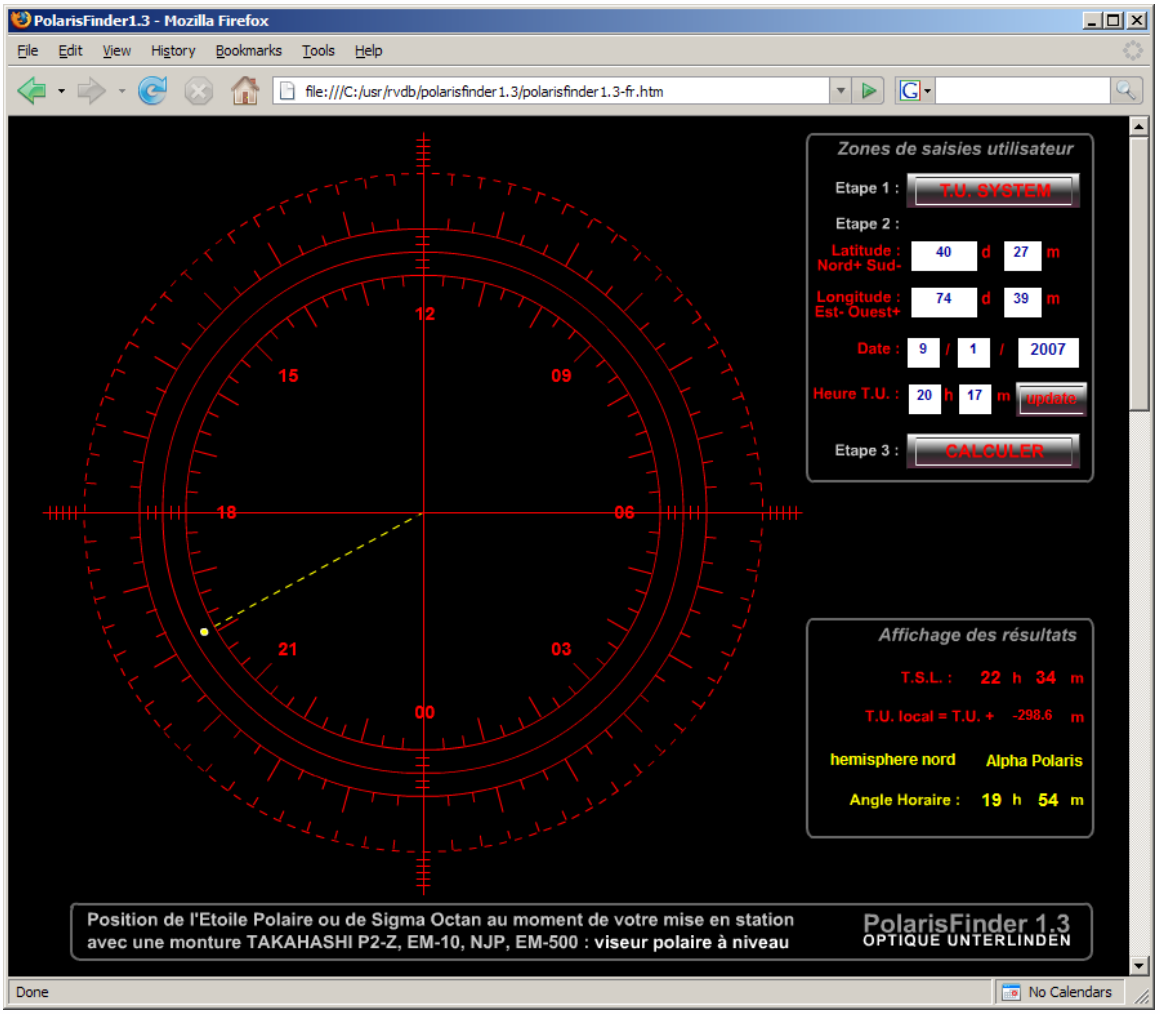
Move equipment outside (3 minutes). Let cool (in parallel).



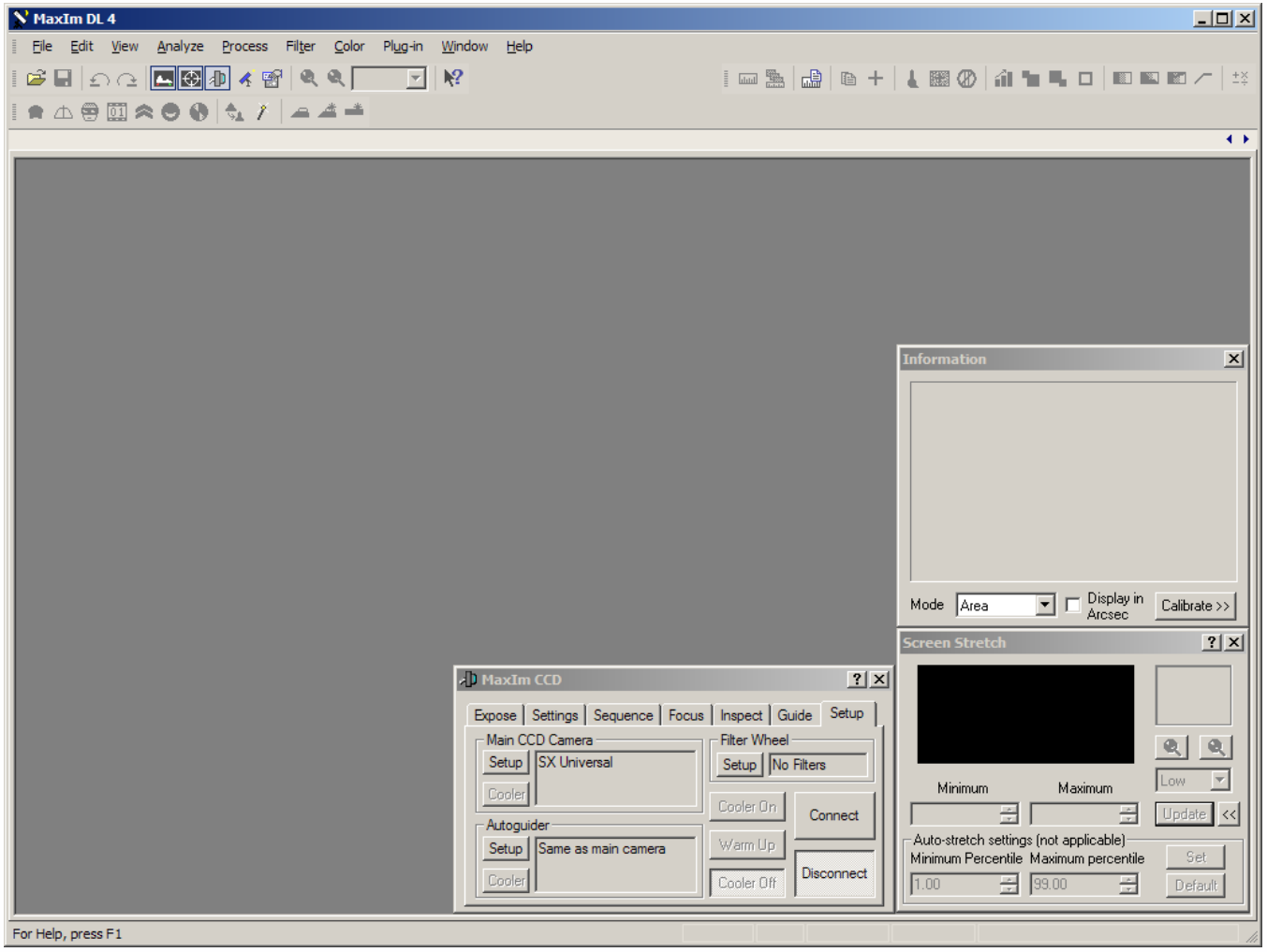


Polar align (2 minutes).

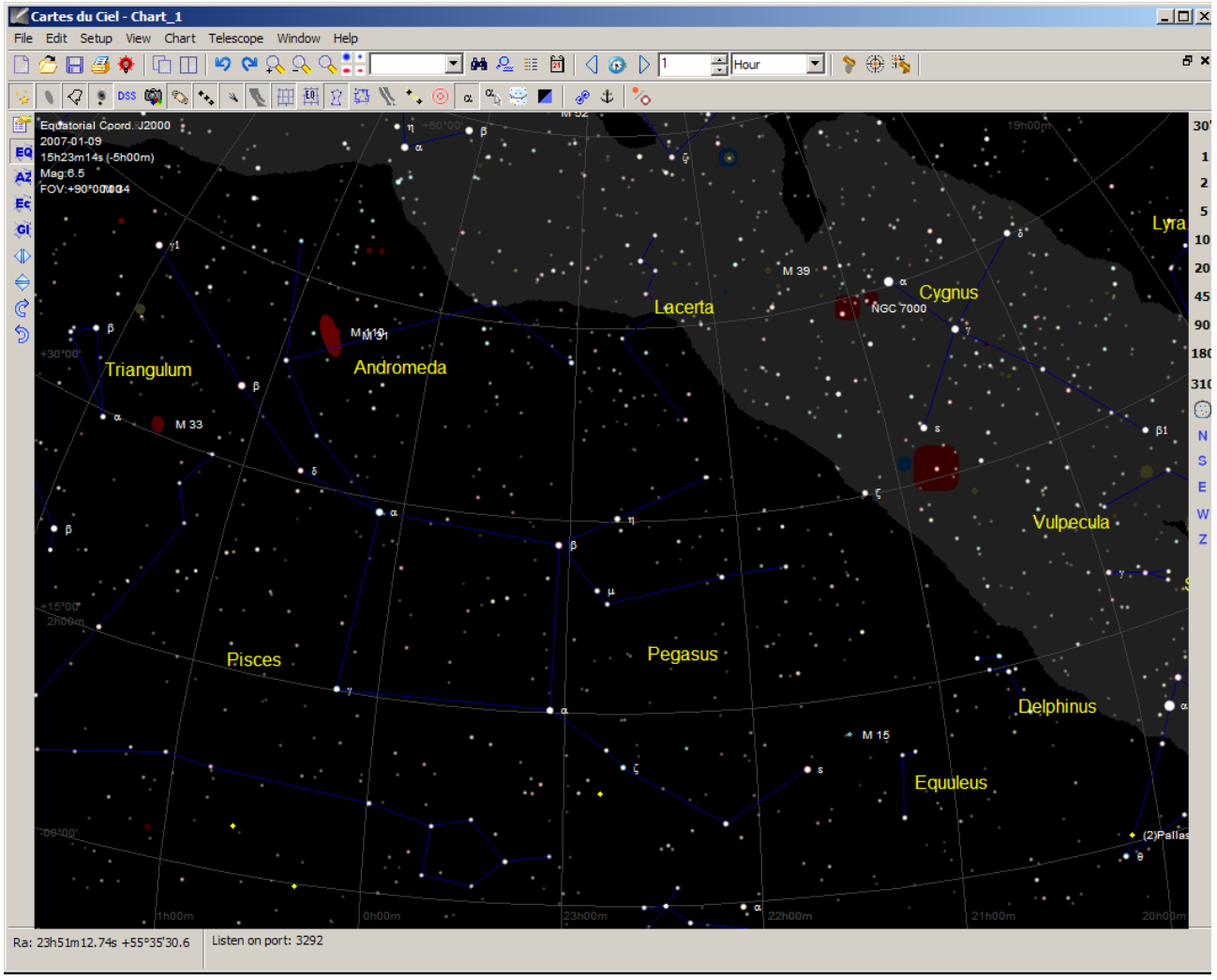
Equatorial mount!



Manually point at a known star (1 minute).
Fire up image acquisition software (0 minutes).
Focus on bright star (3 minutes).



Center star in image (1 minute).
Fire up computer's planetarium program (0 minutes).
Sync on star (1 minute).



GoTo desired target (1 minute).

Center (1 minute).

Select guide star. Calibrate and start guider (5 minutes).
Here there be dragons!

Initialize imaging sequence (1 minute).

Go inside (1 minute), watch TV (10 minutes), sleep (hours?).

Me watching TV.

Go outside. Pack everything up (15 minutes).

Image Processing

- Calibrate (flats, darks, etc.).
- Align.
- Stack.
- Color combine.
- Enhance.

Darks

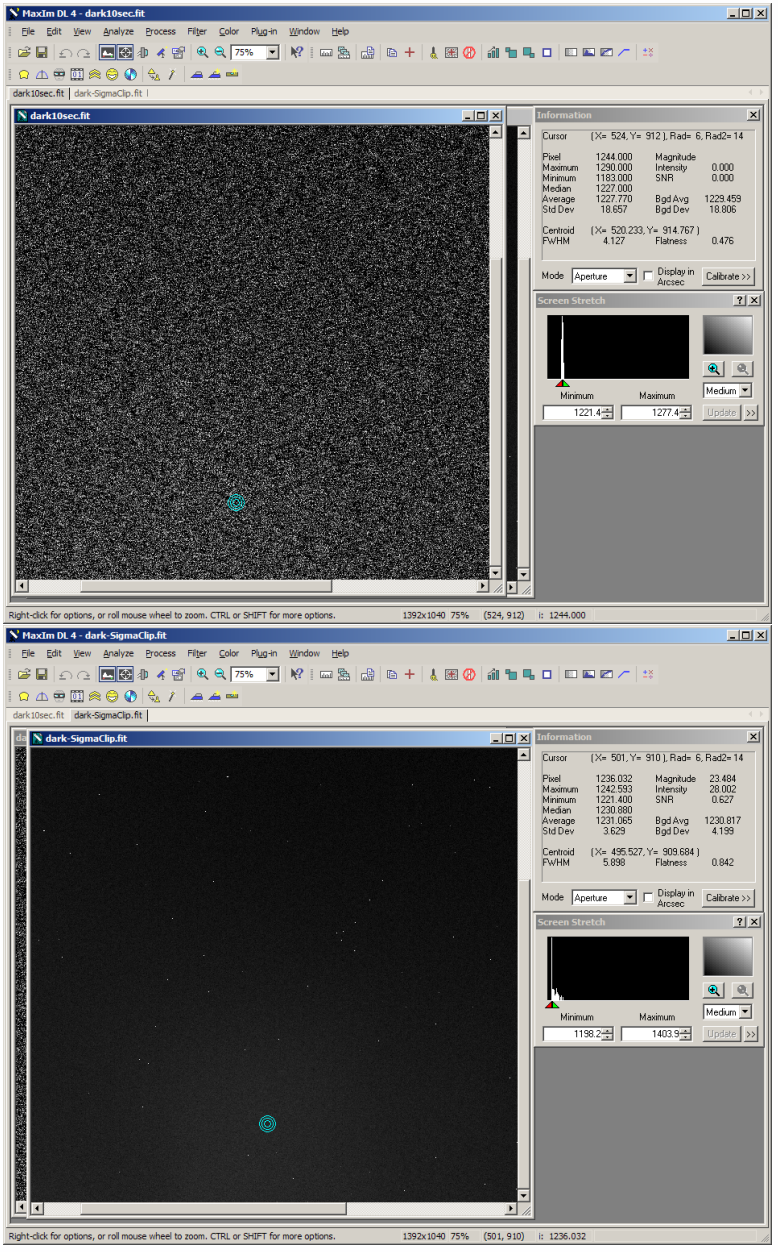
Idea: Take several images of a completely black field (obtained by closing the "shutter" to the camera). Subtract this "dark" image from the "light" images.

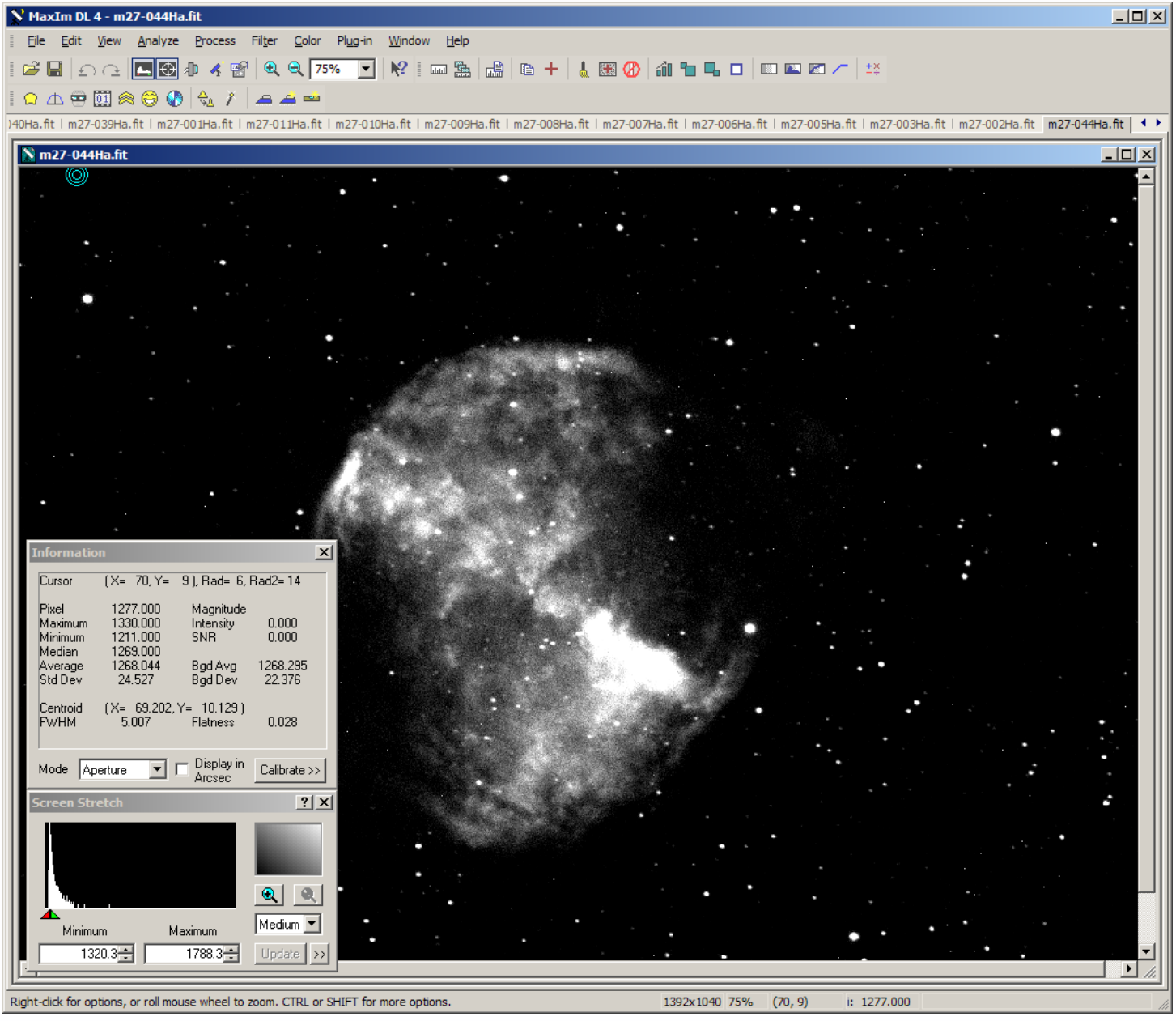
Darks correct for dead, warm, and hot pixels as well as "heat" photons.

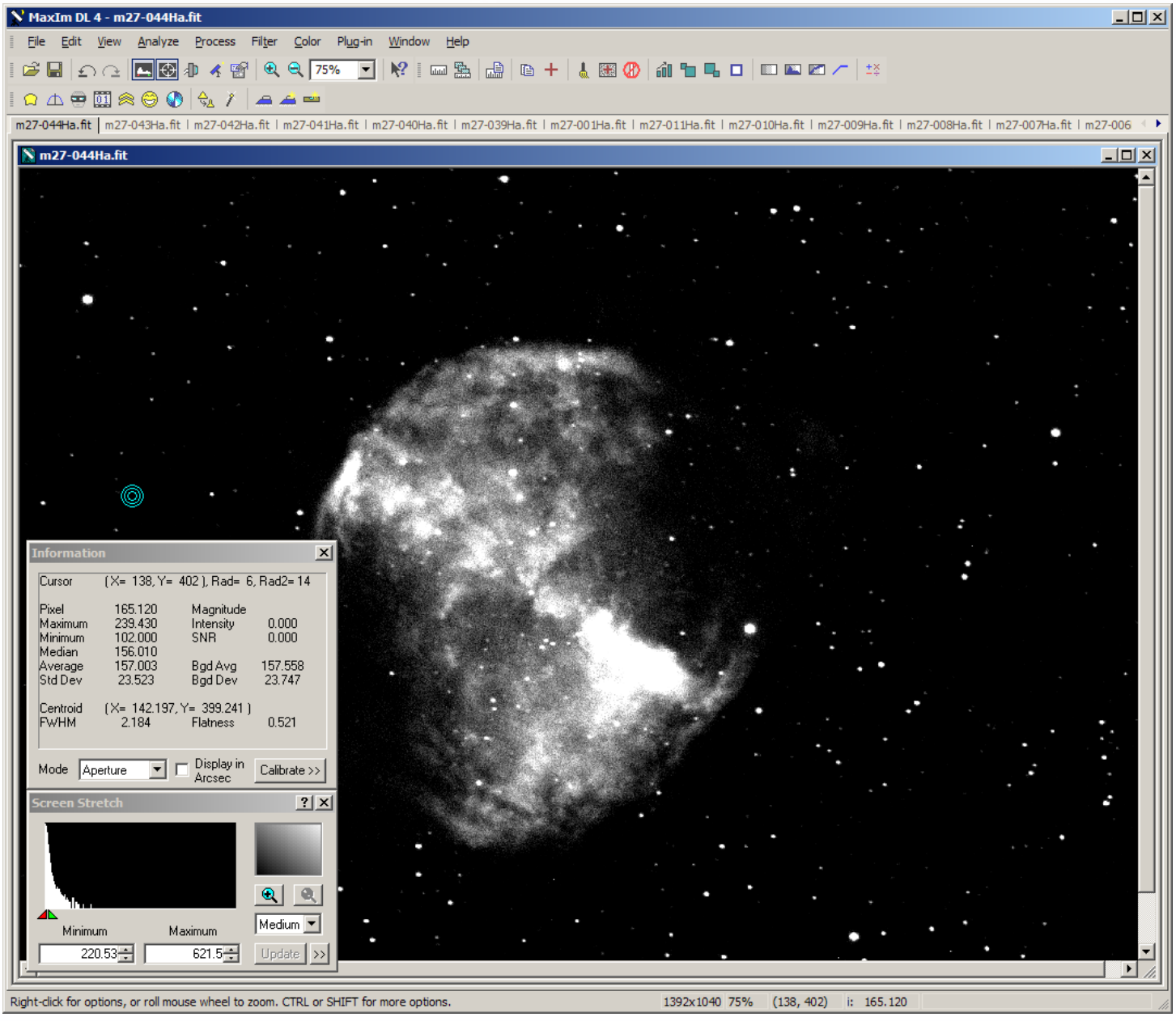
Most CCD chips are cooled and hence heat glow is not a significant problem.

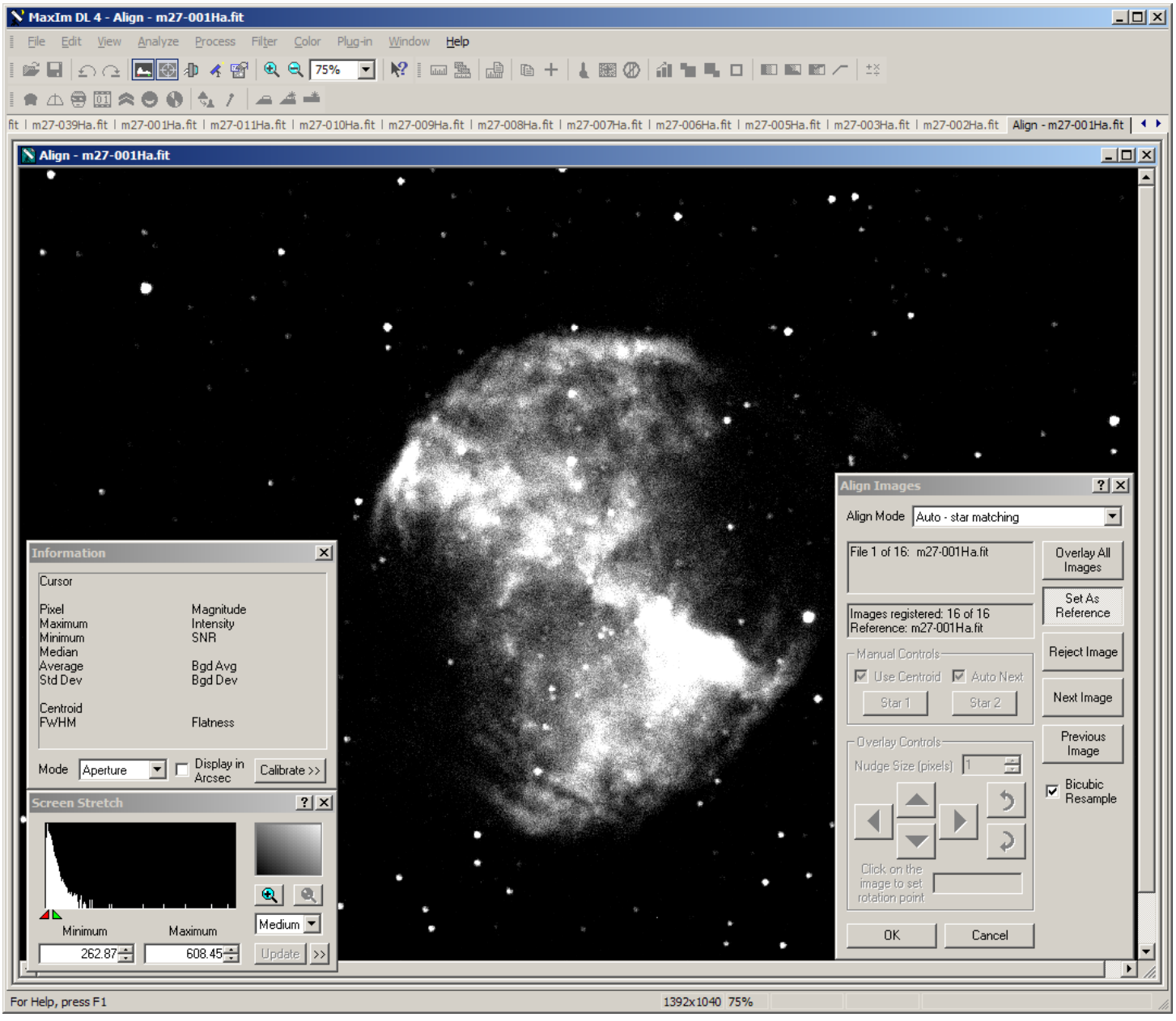
Newer CCD cameras have better "dark".

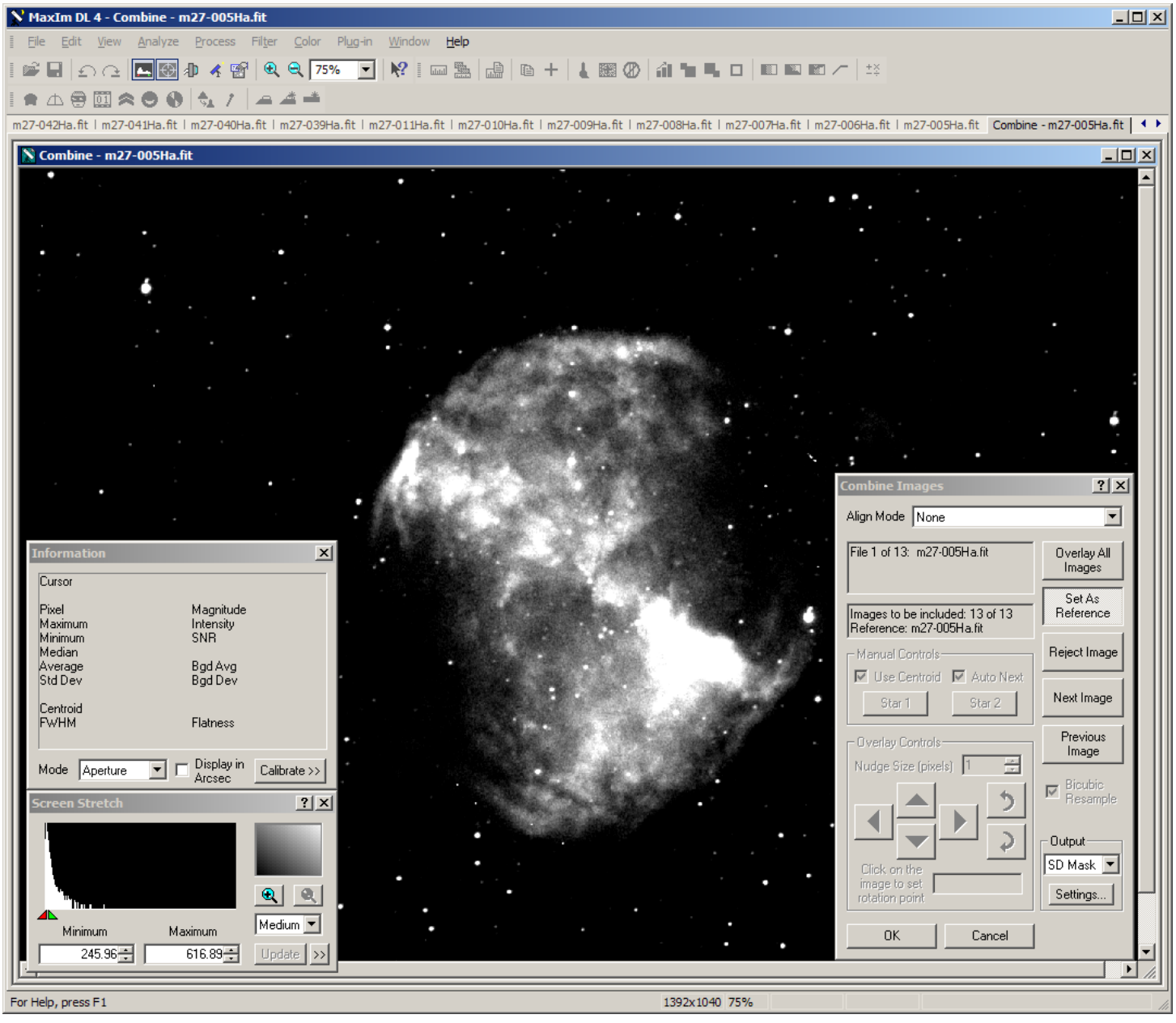
Dead, warm, and hot pixels are better handled by software.

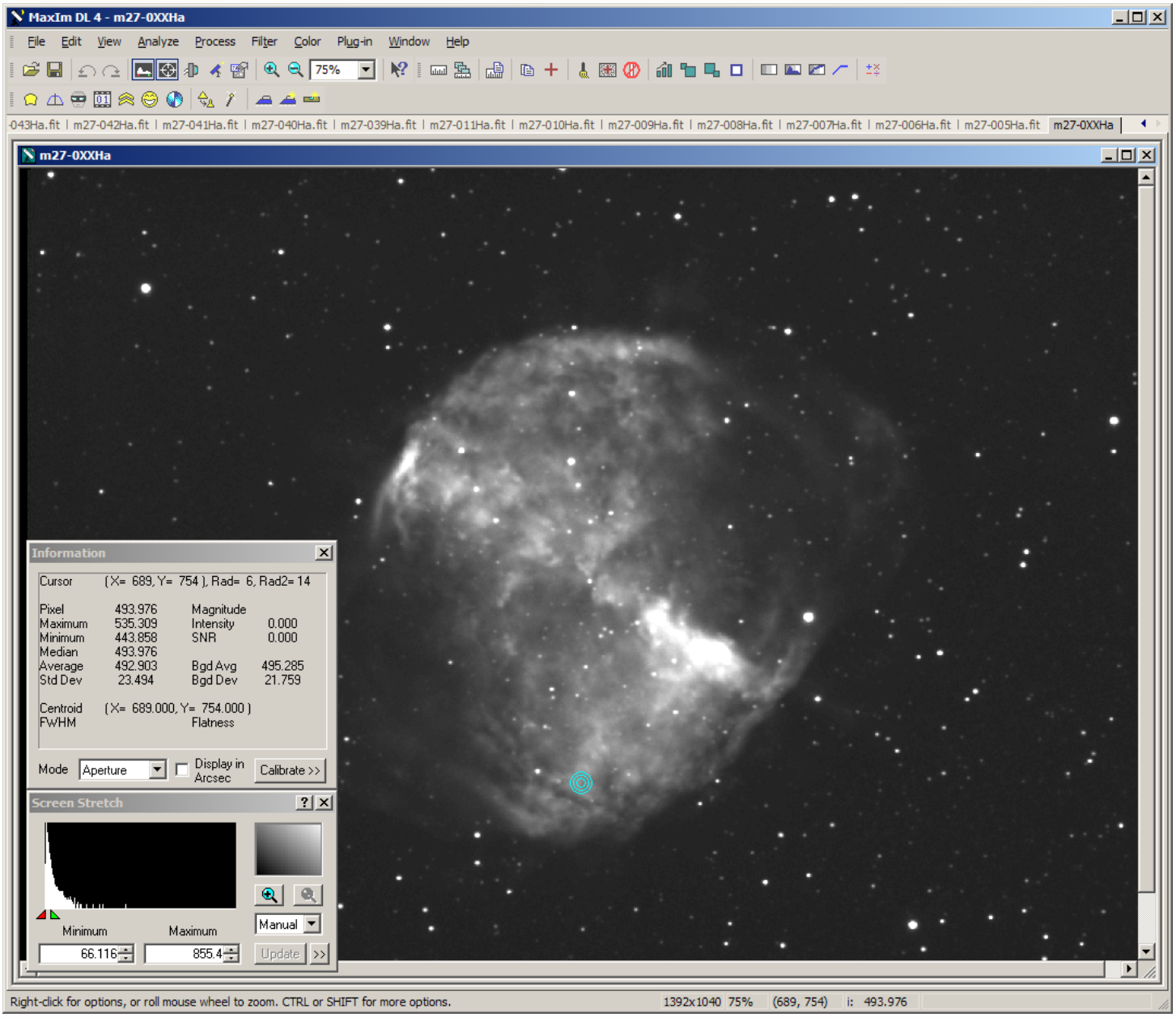



MaxIm DL 4 - m27-044Ha.fit
File Edit View Analyze Process Filter Color Plug-in Window Help
75%
m27-039Ha.fit | m27-001Ha.fit | m27-011Ha.fit | m27-010Ha.fit | m27-009Ha.fit | m27-008Ha.fit | m27-007Ha.fit | m27-006Ha.fit | m27-005Ha.fit | m27-003Ha.fit | m27-002Ha.fit | m27-044Ha.fit
m27-044Ha.fit
Information
Cursor (X= 70, Y= 9), Rad= 6, Rad2= 14
Pixel 1277.000 Magnitude
Maximum 1330.000 Intensity 0.000
Minimum 1211.000 SNR 0.000
Median 1269.000
Average 1268.044 Bgd Avg 1268.295
Std Dev 24.527 Bgd Dev 22.376
Centroid (X= 69.202, Y= 10.129)
FWHM 5.007 Flatness 0.028
Mode Aperture
Display in Arcsec
Calibrate >>
Screen Stretch
Minimum
Maximum
1320.3
1788.3
Medium
Update
>>
Right-click for options, or roll mouse wheel to zoom. CTRL or SHIFT for more options.
1392x1040 75% (70, 9) i: 1277.000


MaxIm DL 4 - m27-044Ha.fit
File Edit View Analyze Process Filter Color Plug-in Window Help
75%
m27-044Ha.fit | m27-043Ha.fit | m27-042Ha.fit | m27-041Ha.fit | m27-040Ha.fit | m27-039Ha.fit | m27-001Ha.fit | m27-011Ha.fit | m27-010Ha.fit | m27-009Ha.fit | m27-008Ha.fit | m27-007Ha.fit | m27-006
m27-044Ha.fit
Information
Cursor (X= 138, Y= 402), Rad= 6, Rad2= 14
Pixel 165.120 Magnitude
Maximum 239.430 Intensity 0.000
Minimum 102.000 SNR 0.000
Median 156.010
Average 157.003 Bgd Avg 157.558
Std Dev 23.523 Bgd Dev 23.747
Centroid (X= 142.197, Y= 399.241)
FWHM 2.184 Flatness 0.521
Mode Aperture
Display in Arcsec
Calibrate >>
Screen Stretch
Minimum
Maximum
220.53
621.5
Medium
Update
>>
Right-click for options, or roll mouse wheel to zoom. CTRL or SHIFT for more options.
1392x1040 75% (138, 402) i: 165.120


MaxIm DL 4 - Align - m27-001Ha.fit
File Edit View Analyze Process Filter Color Plug-in Window Help
75%
m27-039Ha.fit | m27-001Ha.fit | m27-011Ha.fit | m27-010Ha.fit | m27-009Ha.fit | m27-008Ha.fit | m27-007Ha.fit | m27-006Ha.fit | m27-005Ha.fit | m27-003Ha.fit | m27-002Ha.fit | Align - m27-001Ha.fit
Align - m27-001Ha.fit
Information
Cursor
Pixel
Maximum
Minimum
Median
Average
Std Dev
Centroid
FWHM
Magnitude
Intensity
SNR
Bgd Avg
Bgd Dev
Flatness
Mode Aperture
Display in Arcsec
Calibrate >>
Screen Stretch
Minimum
Maximum
262.87
608.45
Medium
Update
>>
Align Images
Align Mode Auto - star matching
File 1 of 16: m27-001Ha.fit
Images registered: 16 of 16
Reference: m27-001Ha.fit
Manual Controls
Use Centroid
Auto Next
Star 1
Star 2
Overlay Controls
Nudge Size (pixels) 1
Click on the image to set rotation point
Overlay All Images
Set As Reference
Reject Image
Next Image
Previous Image
Bicubic Resample
OK
Cancel
For Help, press F1
1392x1040 75%


MaxIm DL 4 - Combine - m27-005Ha.fit
File Edit View Analyze Process Filter Color Plug-in Window Help
75%
m27-042Ha.fit | m27-041Ha.fit | m27-040Ha.fit | m27-039Ha.fit | m27-011Ha.fit | m27-010Ha.fit | m27-009Ha.fit | m27-008Ha.fit | m27-007Ha.fit | m27-006Ha.fit | m27-005Ha.fit | Combine - m27-005Ha.fit
Combine - m27-005Ha.fit
Information
Cursor
Pixel
Maximum
Minimum
Median
Average
Std Dev
Centroid
FWHM
Magnitude
Intensity
SNR
Bgd Avg
Bgd Dev
Flatness
Mode Aperture
Display in Arcsec
Calibrate >>
Screen Stretch
Minimum
Maximum
245.96
616.89
Medium
Update
>>
Combine Images
Align Mode None
File 1 of 13: m27-005Ha.fit
Images to be included: 13 of 13
Reference: m27-005Ha.fit
Overlay All Images
Set As Reference
Reject Image
Next Image
Previous Image
Manual Controls
Use Centroid
Auto Next
Star 1
Star 2
Overlay Controls
Nudge Size (pixels) 1
Bicubic Resample
Output
SD Mask
Settings...
Click on the image to set rotation point
OK
Cancel
For Help, press F1
1392x1040 75%


MaxIm DL 4 - m27-0XXHa
File Edit View Analyze Process Filter Color Plug-in Window Help
75%
043Ha.fit | m27-042Ha.fit | m27-041Ha.fit | m27-040Ha.fit | m27-039Ha.fit | m27-011Ha.fit | m27-010Ha.fit | m27-009Ha.fit | m27-008Ha.fit | m27-007Ha.fit | m27-006Ha.fit | m27-005Ha.fit | m27-0XXHa
m27-0XXHa
Information
Cursor (X= 689, Y= 754), Rad= 6, Rad2= 14
Pixel 493.976 Magnitude
Maximum 535.309 Intensity 0.000
Minimum 443.858 SNR 0.000
Median 493.976
Average 492.903 Bgd Avg 495.285
Std Dev 23.494 Bgd Dev 21.759
Centroid (X= 689.000, Y= 754.000)
FWHM Flatness
Mode Aperture
Display in Arcsec
Calibrate >>
Screen Stretch
Minimum
Maximum
66.116
855.4
Manual
Update
>>
Right-click for options, or roll mouse wheel to zoom. CTRL or SHIFT for more options.
1392x1040 75% (689, 754) i: 493.976

Color Combining

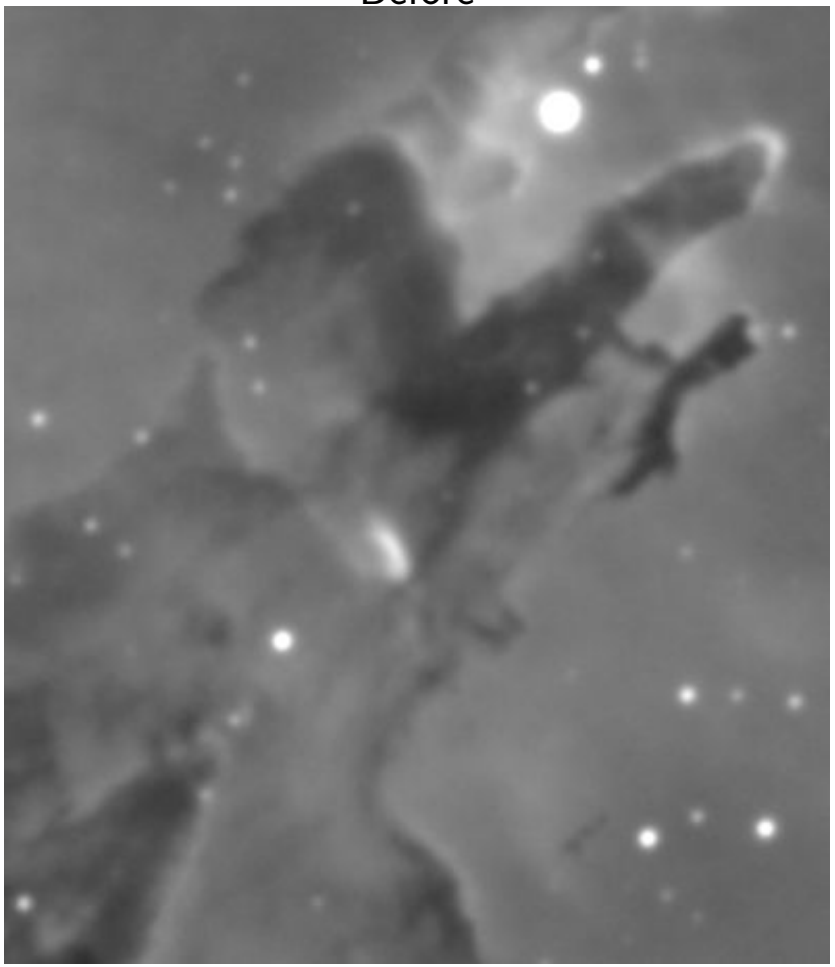
Left. Red = Hα.

Right. Green & Blue = O-III.

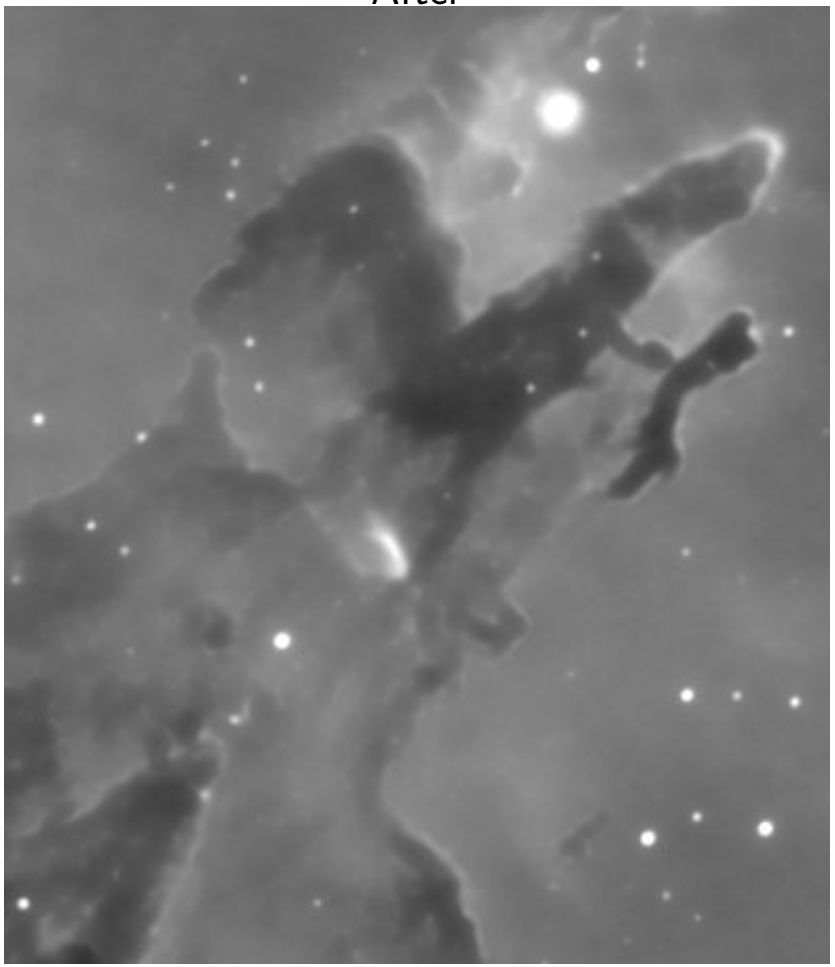
Bottom. Color.

Sharpening w/ Richardson-Lucy Deconvolution

Before



After



http://www.cyanogen.com/products/maxim_extras.htm
http://www.princeton.edu/~rvdb/images/deconv/deconv_MaximDL.html

Digital Development: Being Gentle vs. Overprocessing

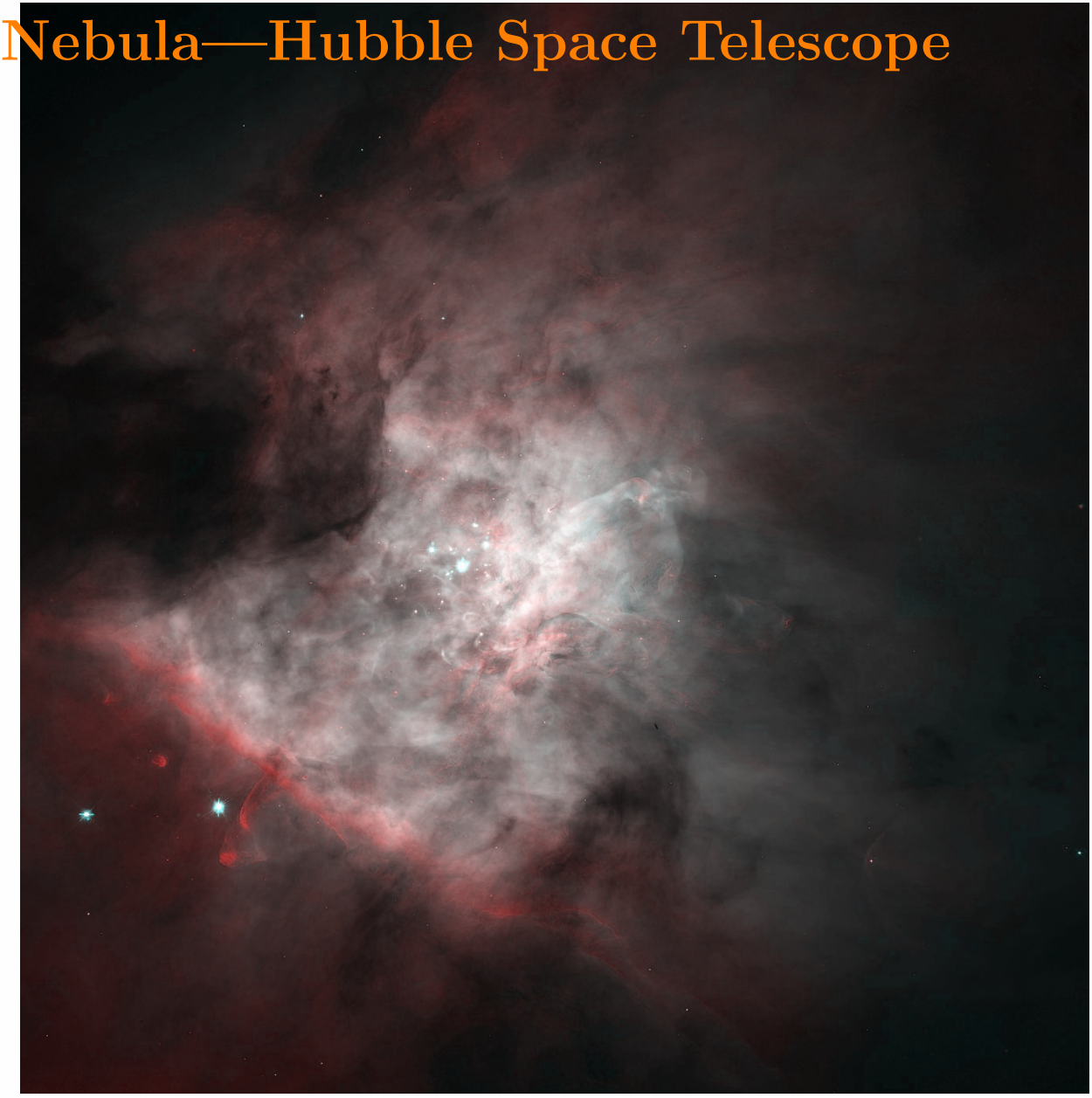
Left. Log stretch.

Right. Digital development.

Bottom. Half & Half.

Orion Nebula—Driveway Version

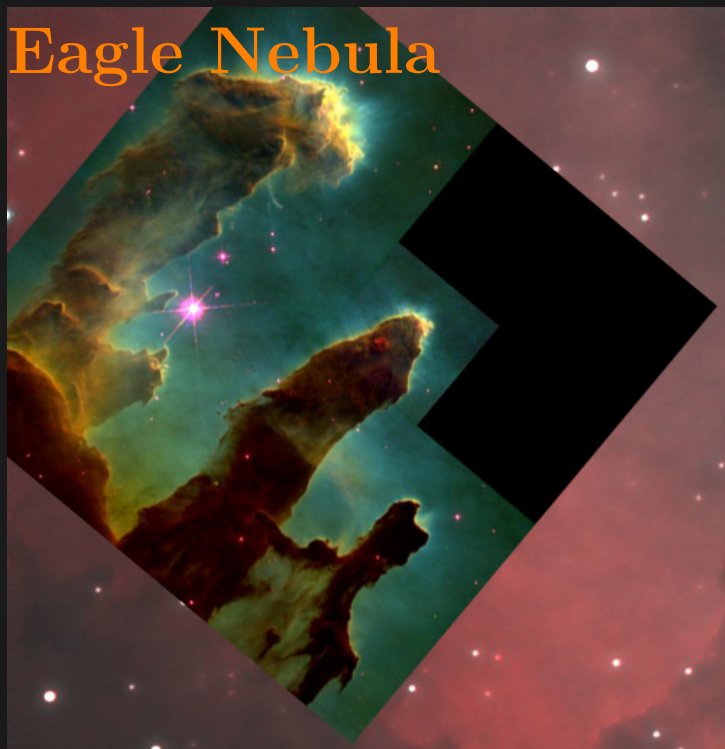
Orion Nebula—Hubble Space Telescope



Some More Pictures


M15

Eagle Nebula



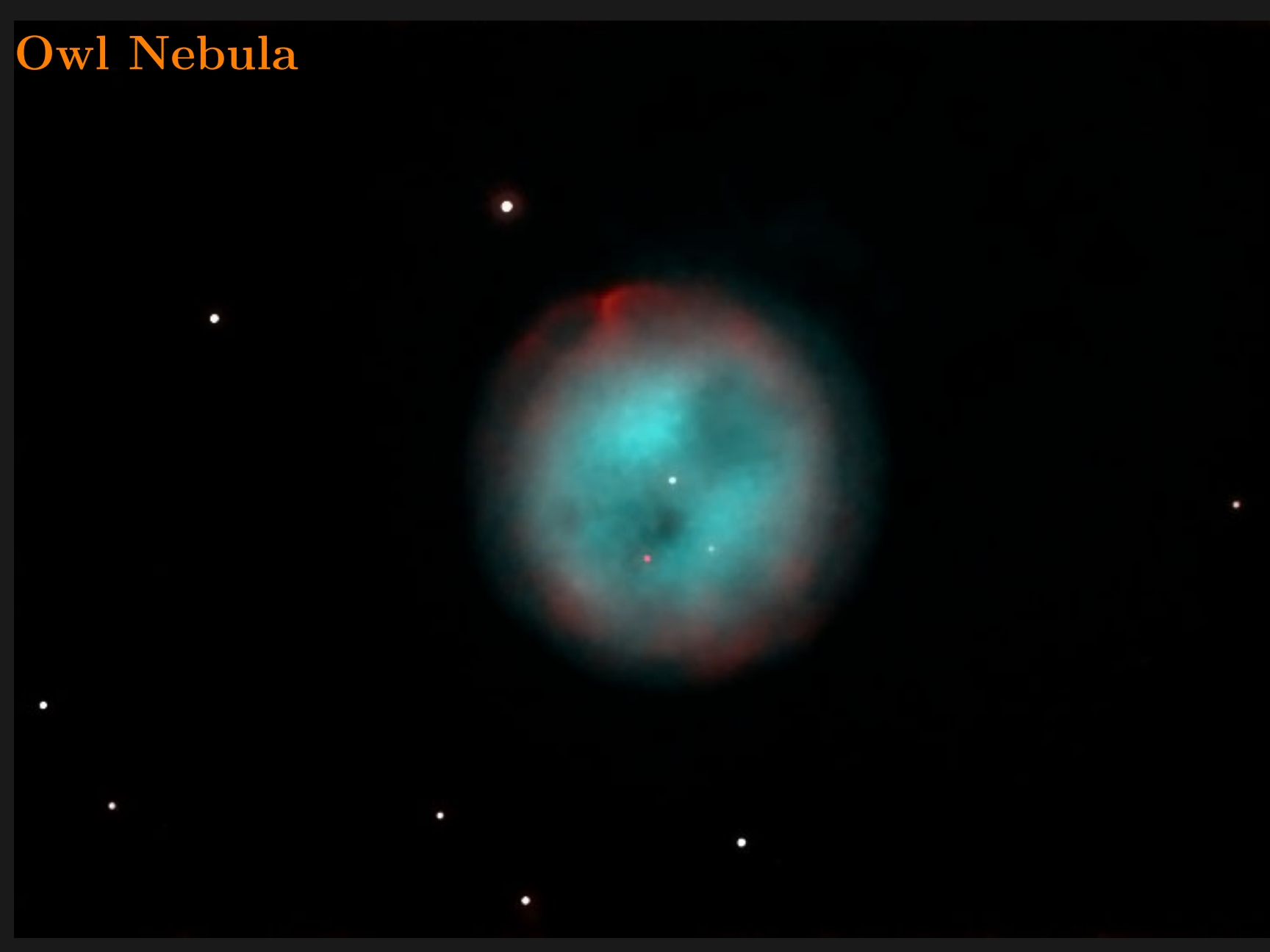
Whirlpool Galaxy


Whirlpool Galaxy—Supernova

Ring Nebula


Little Dumbbell Nebula

Owl Nebula




Sombrero Galaxy


Pacman Nebula

Eskimo Nebula

NGC 4565


Deerlick Galaxy Cluster


Crescent Nebula


Veil Nebula


Bubble Nebula

Horsehead Nebula

Jupiter and Saturn

Final Suggestions

Telescope. Low f-ratio, flat field.

Mount. Equatorial, low periodic error, controllable, stable.

Camera. Cooled, b&w, low noise.

Filters. ESSENTIAL. Dichroic. Hα, O-III, R,G,B.

Computer. Laptop.

Software.

Image Acquisition. MaximDL or AstroArt.
Planetarium. CartesDuCiel or TheSky.
Image Processing. MaximDL or AstroArt. Maybe Photoshop.

Backup Slides

Biases