

# CCD Astrophotography: with a 3.5" Questar

Robert J. Vanderbei

Stella-Della/Q-Fest  
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Princeton University

<http://www.princeton.edu/~rvdb>

# My Location—Belle Mead, NJ



# My Telescope—3.5" Questar



## Pros:

Superb Optics  
No mirror flop  
Built-in flip-mirror

Fork mount  
Counterweight

## Cons:

F/16

# Why Do CCD Imaging?

How M13 Looks Visually w/ Small Telescope Under Light-Polluted Skies



# Choosing a Camera

## Two Fundamental Facts

$$\text{Field of View} \propto \frac{\text{Dim of CCD chip}}{\text{focal length}}$$

$$\text{Exposure time} \propto \frac{F^2}{\text{Area of pixel}}, \quad \text{where } F = \text{focal ratio} \\ = \text{focal length/aperture}$$

3.5" Questar at f/16 vs. 7" Telescope at f/8

- Same Field-of-View.
- Quadrupled exposure times.

**Conclusion:** Look for a lightweight camera with large pixels.

# My Camera—Starlight Express MX-916



- Approximate equivalent ASA (ISO): 20,000
- Linear response—no reciprocity failure (prior to saturation)
- Quantum efficiency:  $\approx 50\%$

# My Observatory



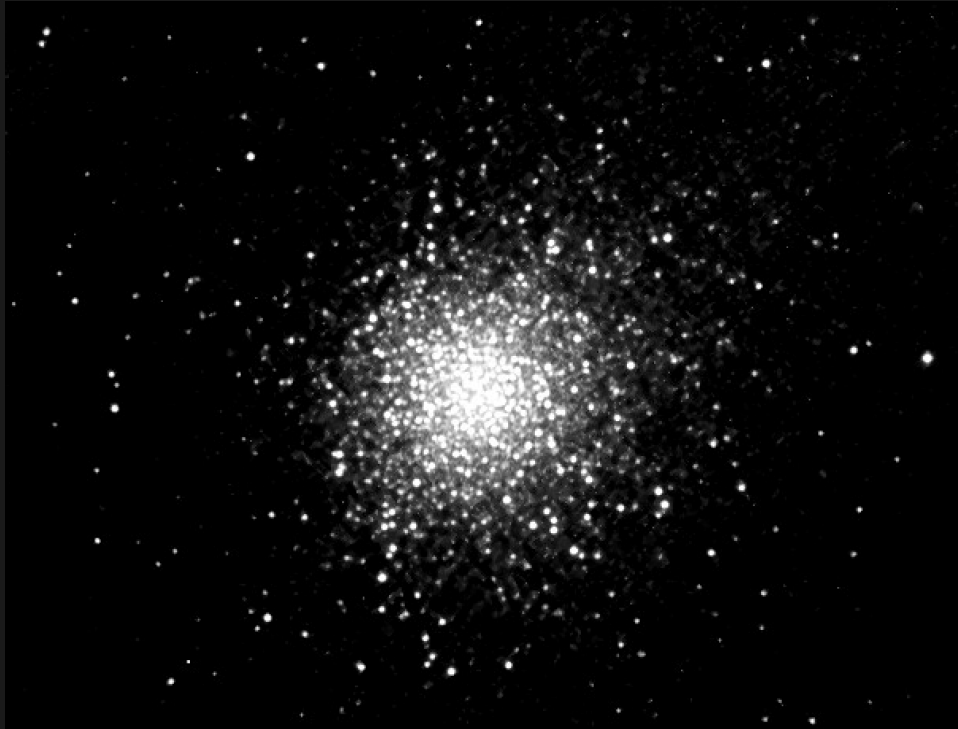
# Why Do CCD Imaging?

How M13 Looks Visually w/ Small Telescope Under Light-Polluted Skies



# Why Do CCD Imaging?

How M13 Looks After Subtracting Sky Glow, Stretching, and Sharpening



# When to Image?

M5 with a Full Moon Nearby



# When to Image?

M5 on a Dark Moonless Night—After Midnight



# Comparison to Other Images

3.5" Questar w/ MX-916



LearnWhat'sUp



2 Micron All Sky Survey (2Mass)

The globular cluster Messier 5



10" LX-200 at f/6.3 w/ MX-916



# Polar Alignment

Polar alignment is important.  
It is critical if doing short unguided exposures.  
There are lots of methods.  
Find one that is quick and accurate.  
Here's what I do...

- Set Dec=90. Lock it.
- Adjust mount to center NCP in eyepiece.



# Focusing

CCD cameras having fast downloads are easy to focus.

Pick a camera with a USB port interface.

A Hartman mask, or other focus aid, is useful.



# Finding Faint Fuzzies

Many of the targets of interest are completely invisible visually.

An accurate method of pointing is critical.

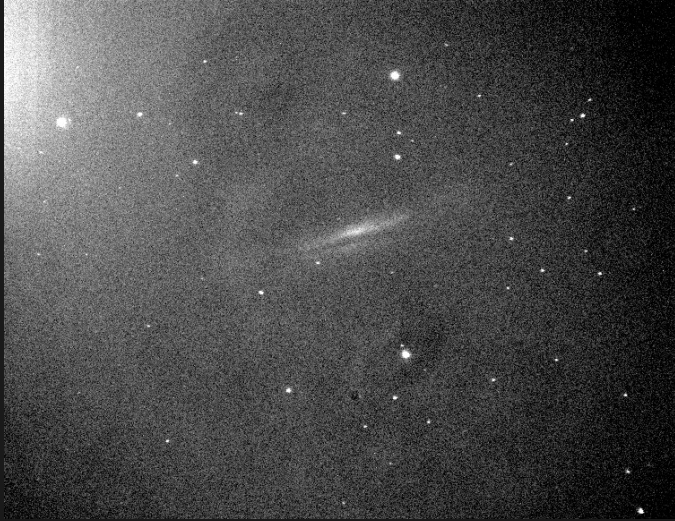
Helpful accessories:

- Telrad/QuickFinder
- Flip mirror system w/ parfocal eyepiece
- Digital setting circles
- On-computer planetarium program
  - Image can be flipped and/or mirrored and resized to match the eyepiece view or the camera image as needed

# Image Processing

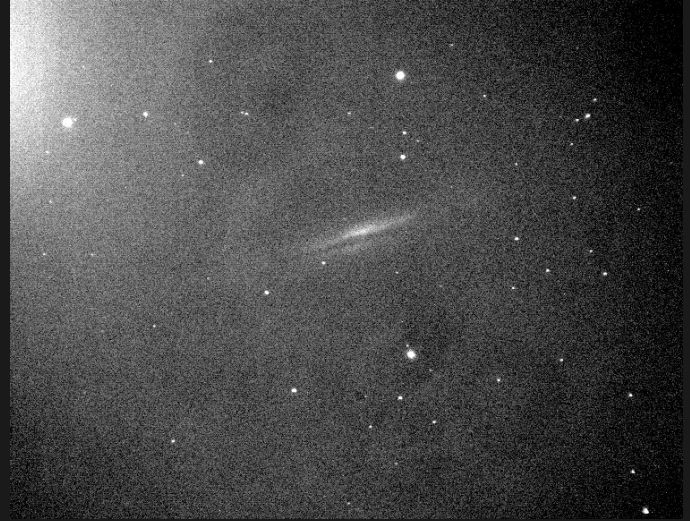
# Raw Image Frames

A 6-minute raw image of NGC3628



R=2760-25987, V=2803-2914 Log

Another 6-minute raw image



R=2767-24719, V=2810-2923 Log

Images consist of multiple signals:

photons from space,  
photons from sky glow,  
thermal photons,  
readout.

Plus:

noise,  
shadows from dust on the optics,  
vignetting.

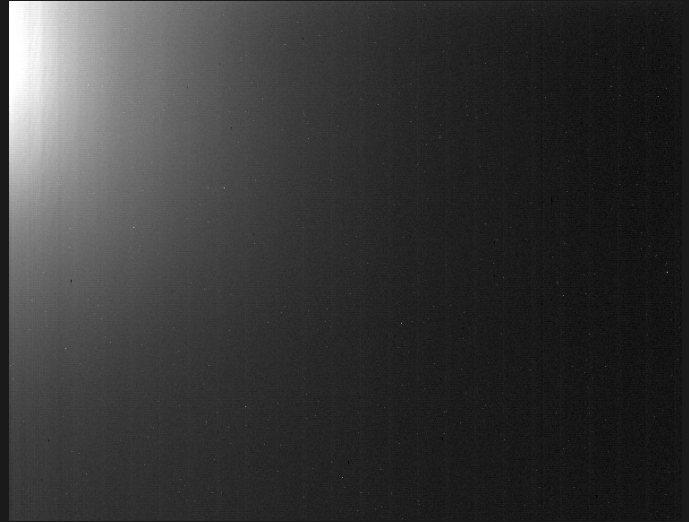
# Dark Frames

One 6-minute dark frame



R=2614-4802, V=2636-2755 Log

Thirty 6-minute dark frames averaged



R=2634-3424, V=2639-2758 Log

## Thermal photons

Accumulate over time. Two parts:

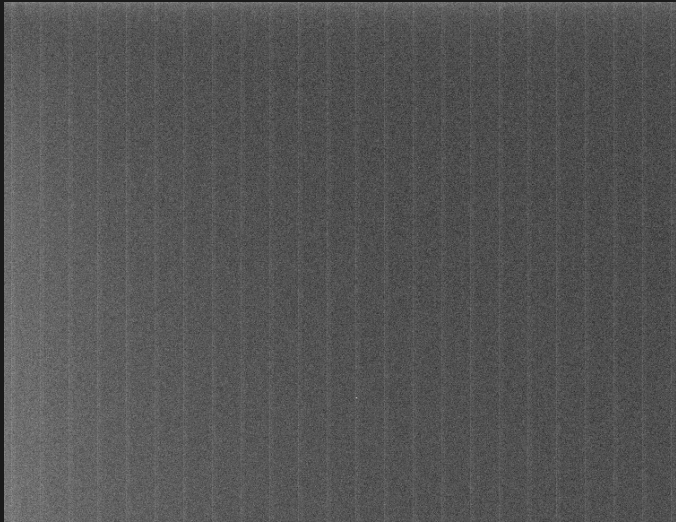
- Amplifier glow—indep of temp.
- Other thermal photons

## Readout signal

Fixed value (pedestal) plus random component. Characteristic is vertical bands.

# Bias and Flat Frames

Forty 0-second bias frames averaged



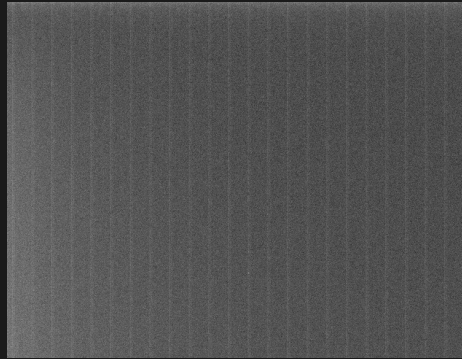
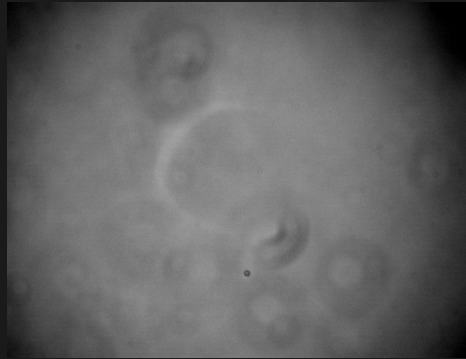
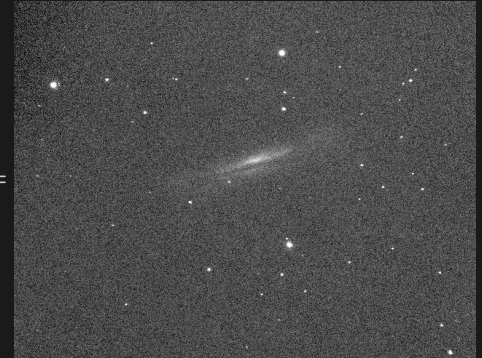
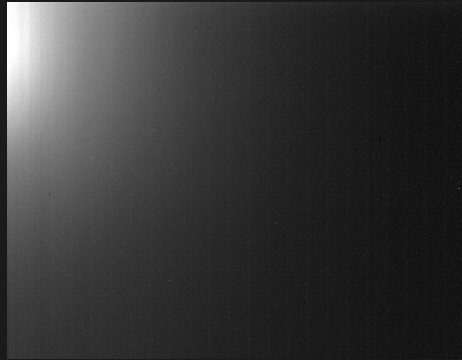
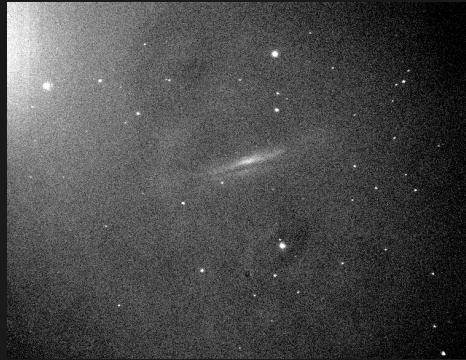
R=2633-2657, V=2631-2650 Log

Flat frame



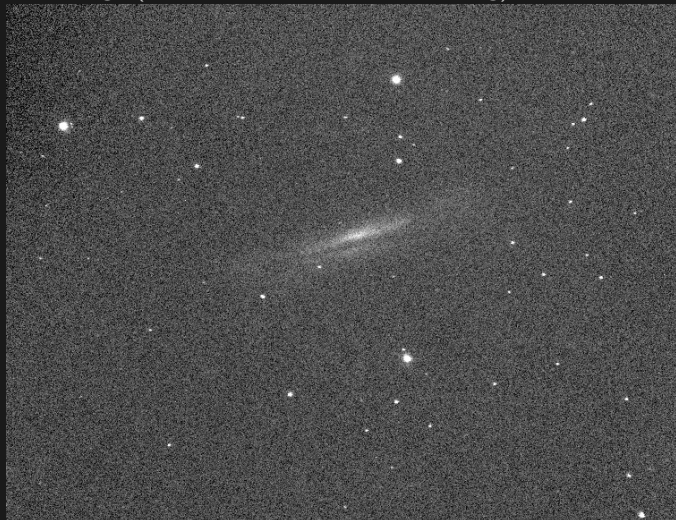
R=26317-33722, V=27451-36920 Lin

# Image Calibration



Next step is Stacking...

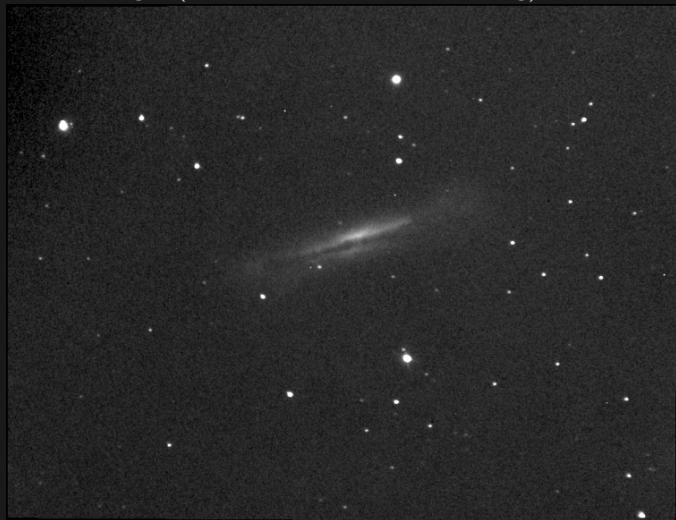
One image (R=218-23768, V=251-362 Log)



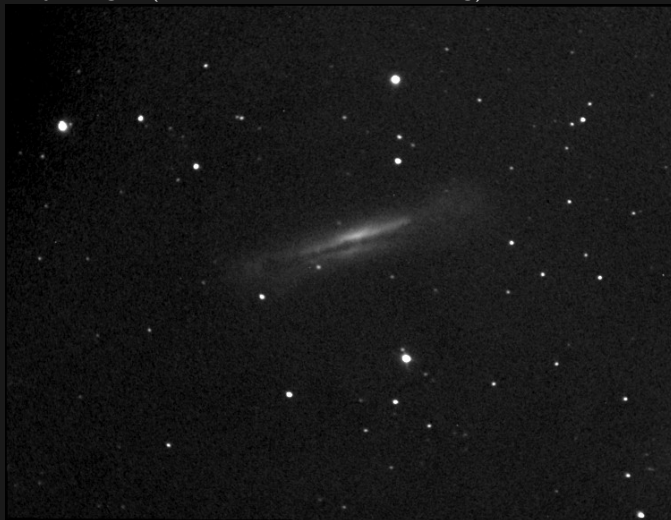
Five images (R=48-13827, V=251-362 Log)



Fifteen images (R=16-10372, V=248-359 Log)



Fifty images (R=5-9048, V=244-355 Log)

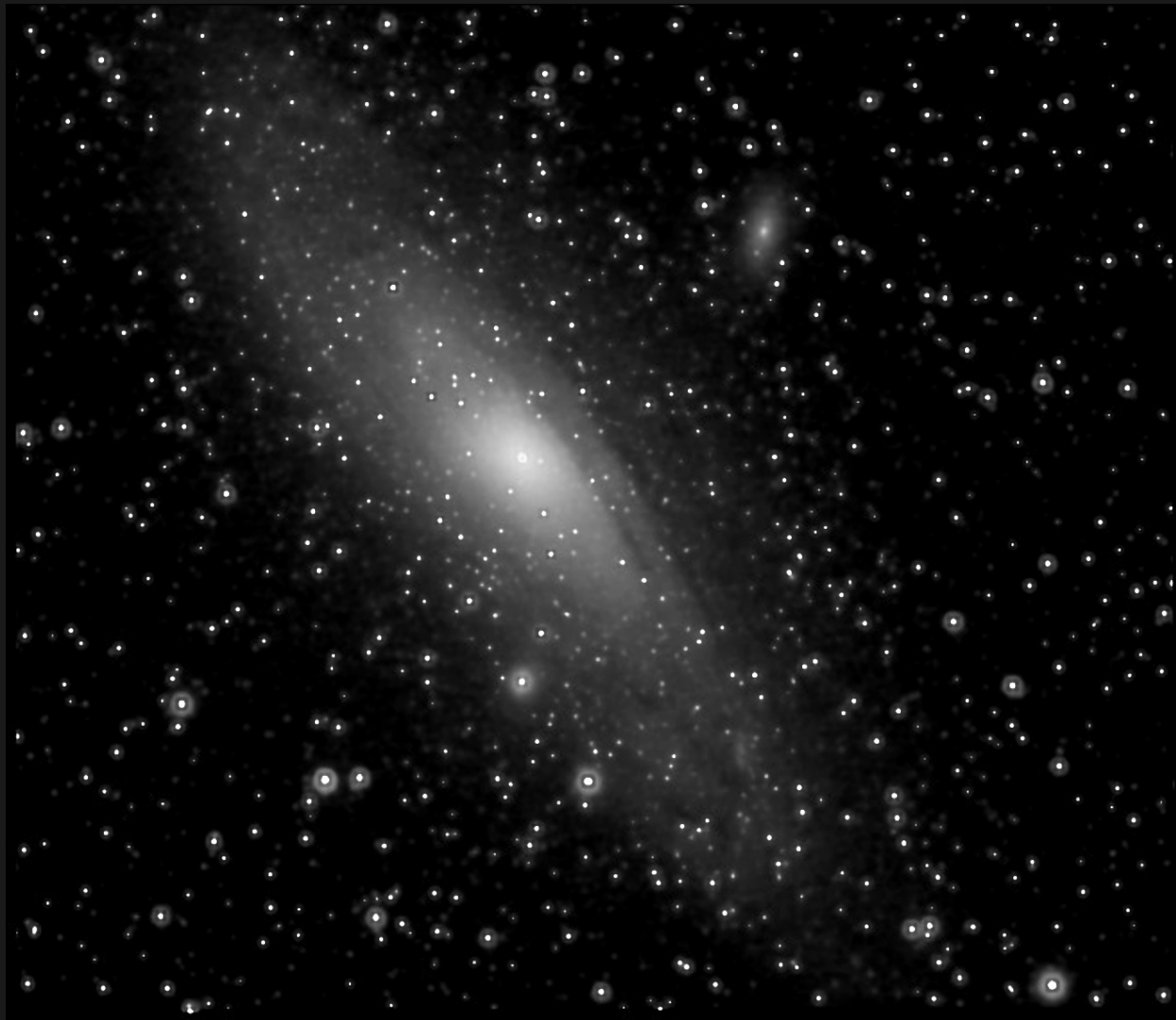


# Gradient Correction



# Fast, Wide-Field Imaging—Telephoto Camera Lenses

- Tracking/guiding issues are minimized
- Polar alignment is not critical
- Exposures are relatively short
- Piggyback setup requires careful balancing

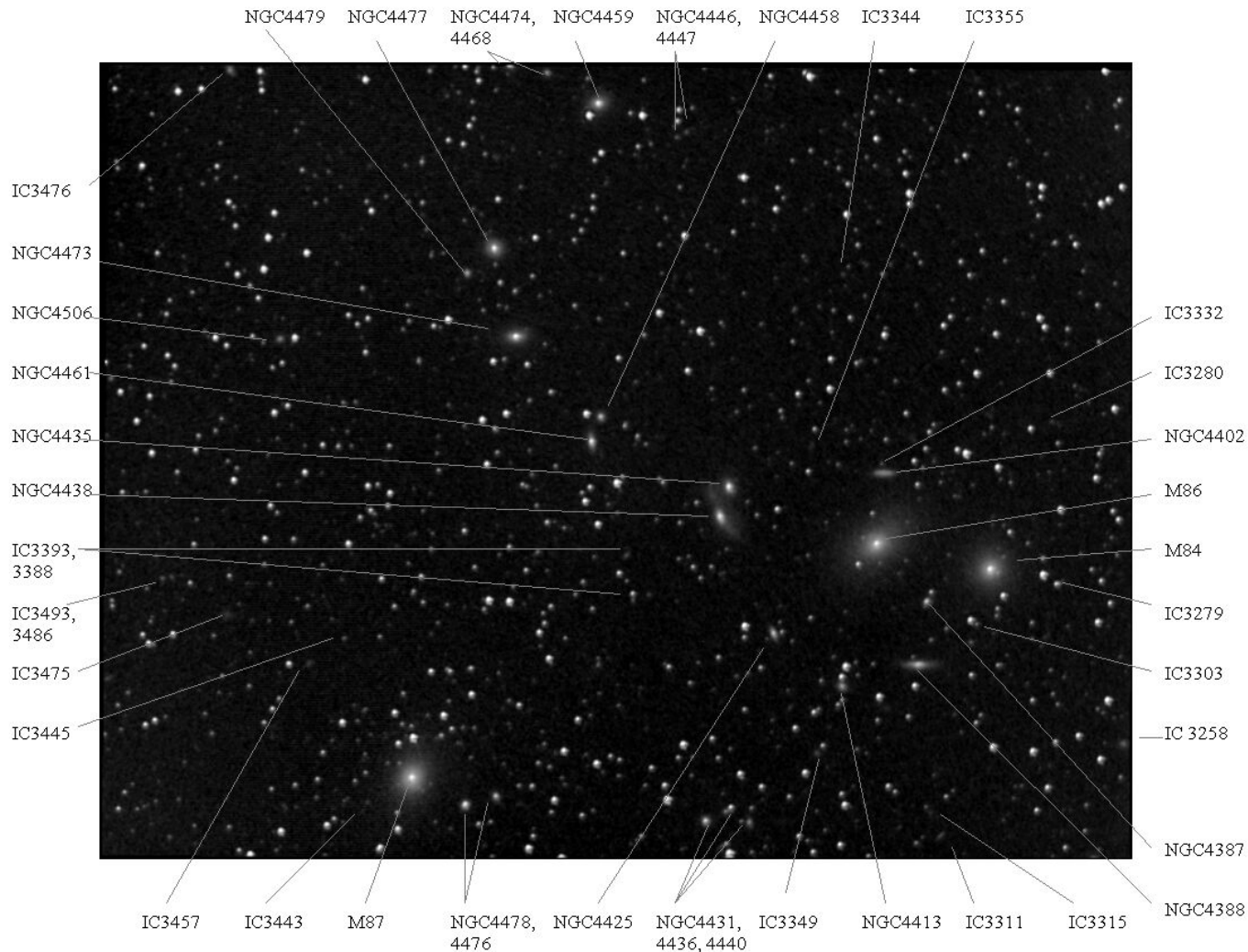


















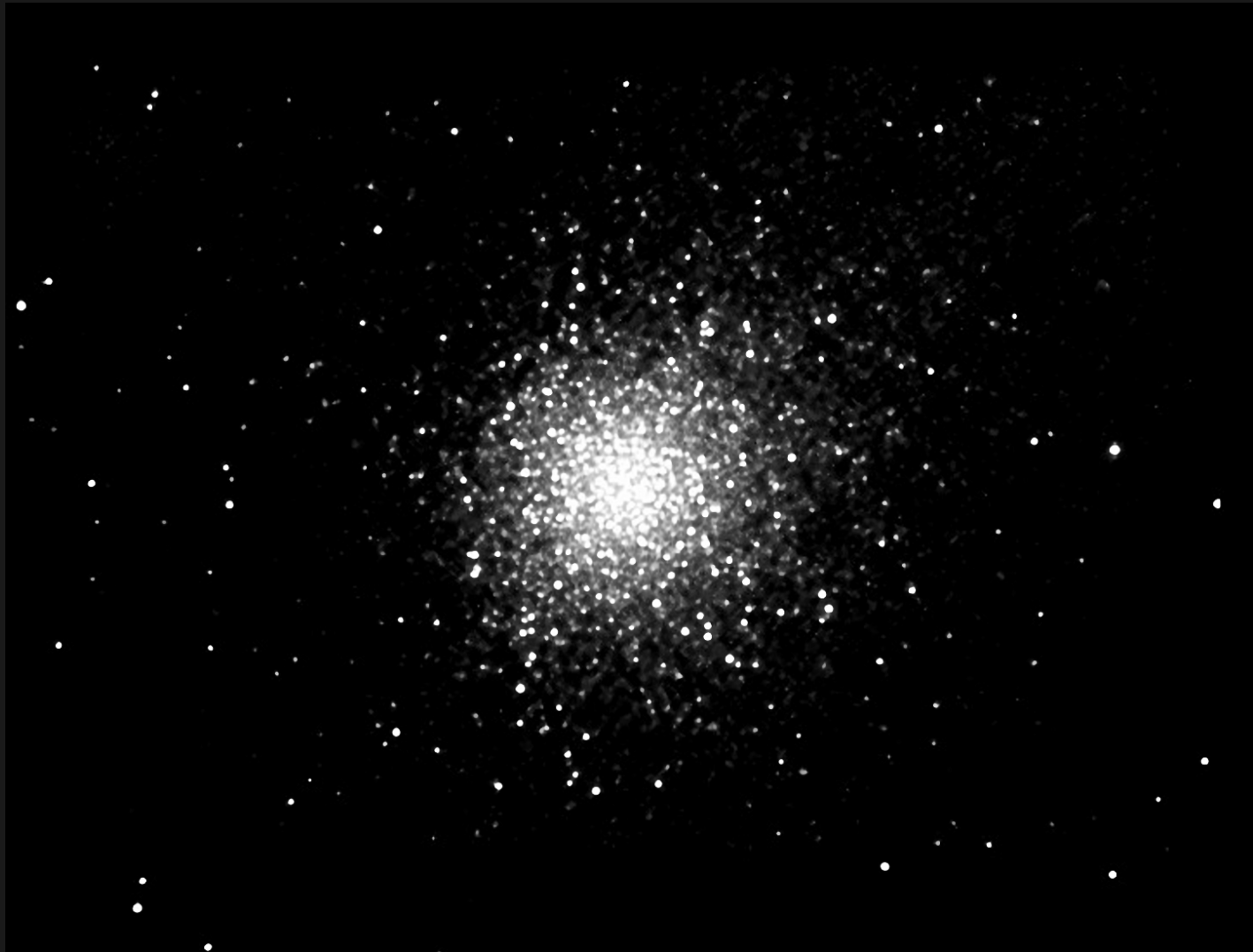
# Star Clusters

- Stacking short unguided exposures (40 6-second) produces best results
- Quality of tracking drive is important
- Polar alignment need not be very precise
- Process with “Digital Development”











# Small Nebulae

- Longer total exposure times (1 hour or more)
- Stacking 200 18-second exposures is tedious
- Stacking 10 (or 20) 6-minute guided exposures is easier
- Starlight Express cameras feature “self-guiding”







# Large Nebulae

- Use a focal reducer.
- Converts from  $f/16$  to  $f/10$  or even  $f/8$ .
- Field of view has four times the area.
- Signal-to-noise is doubled for same exposure time.





# Comparison to Other Images

3.5" Questar w/ MX-916  
3 hours



Tim Puckett's  
24" Ritchey-Cretien w Apogee Ap-7  
1 minute











# Galaxies

- Longer total exposure times (4 hours, or more!!)
- Stacking 800 18-second exposures is VERY tedious
- Stacking 40 (or 80) 6-minute guided exposures is easier
- Set it up and go to bed











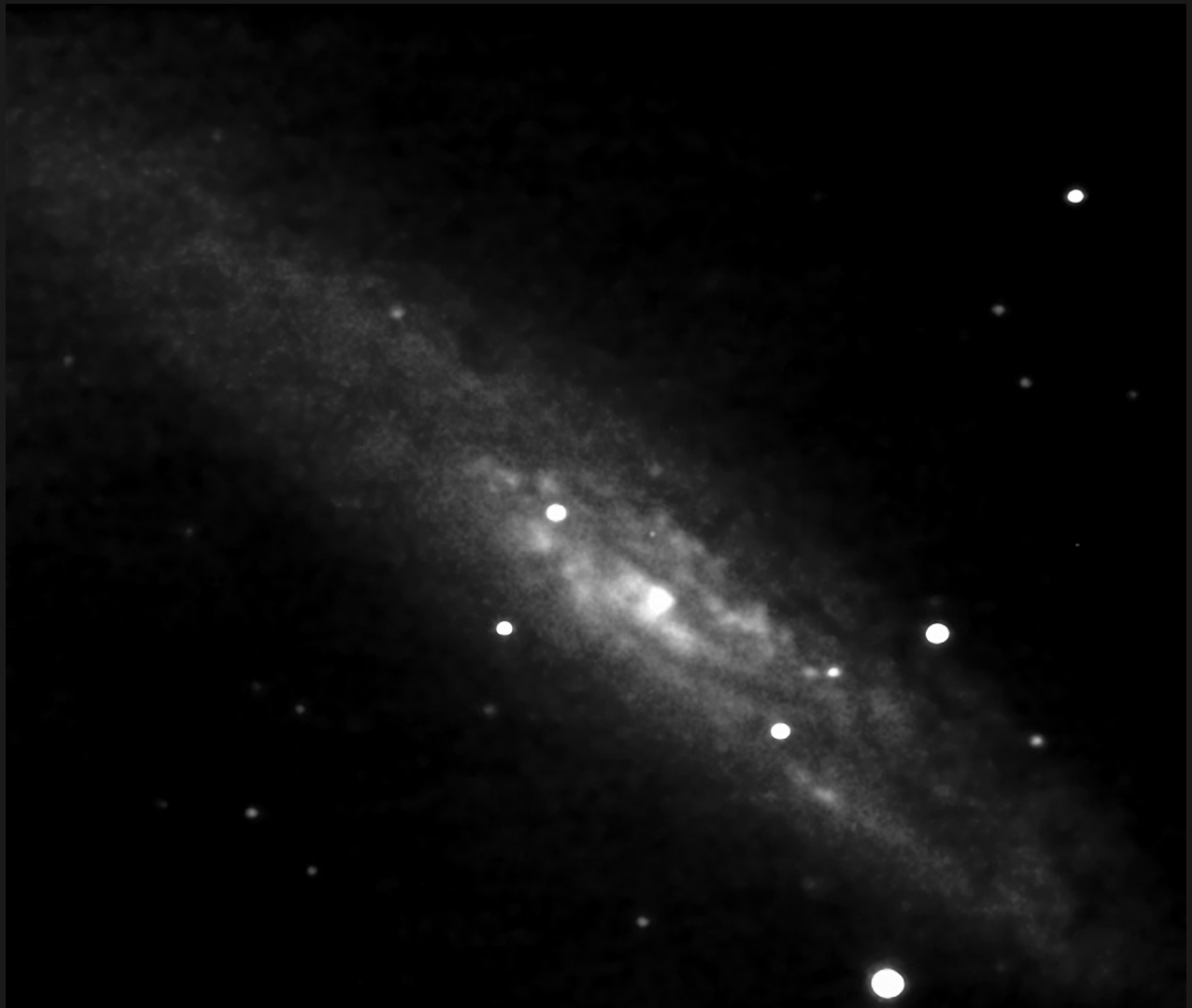


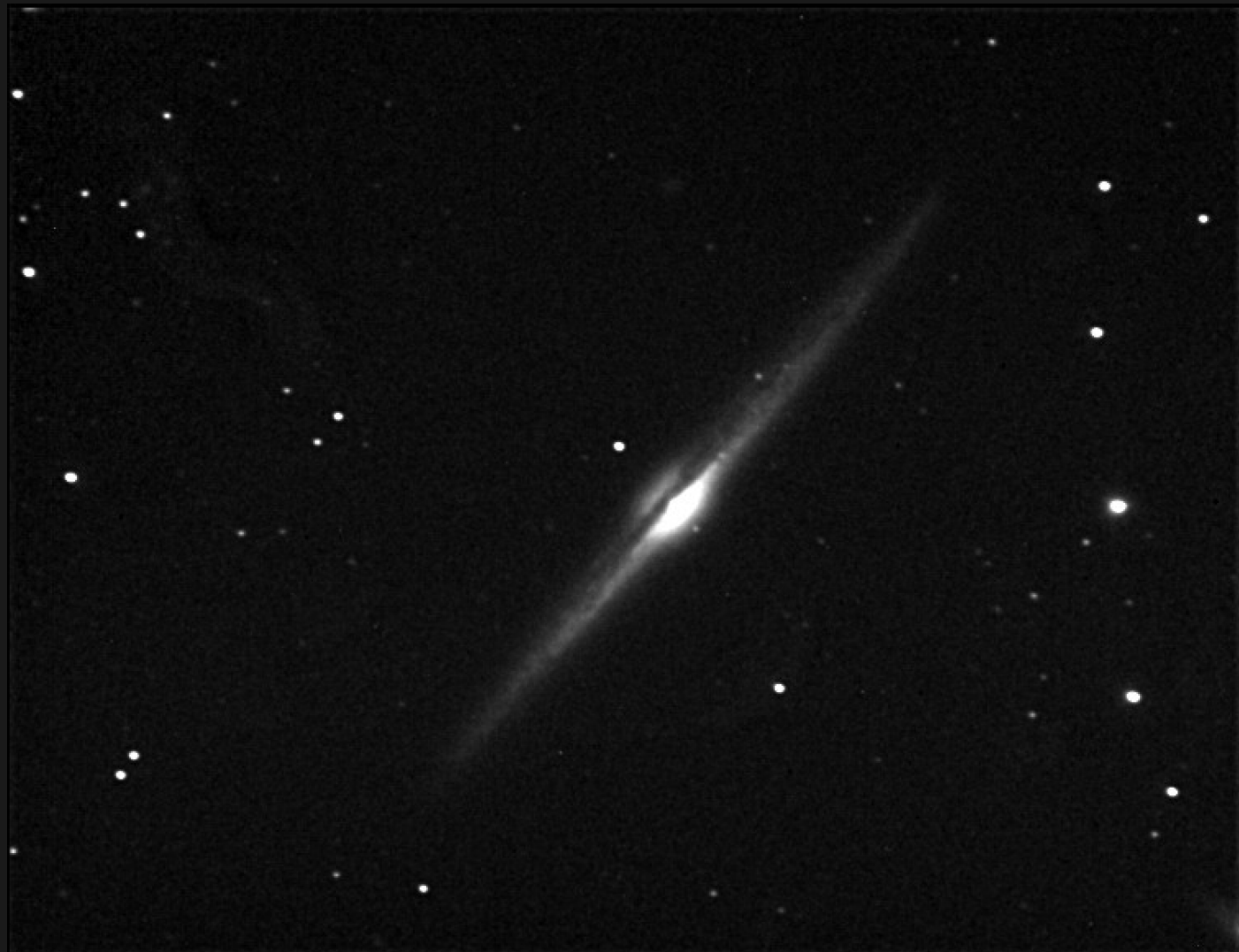








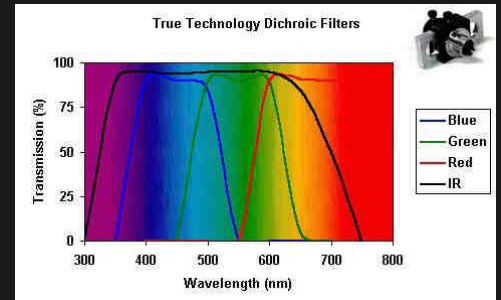






# Color

- Long “luminance” exposure is combined with short R, G, and B exposures
- Use dichroic RGB filters with IR-blocking
- Most filter sets are parfocal





























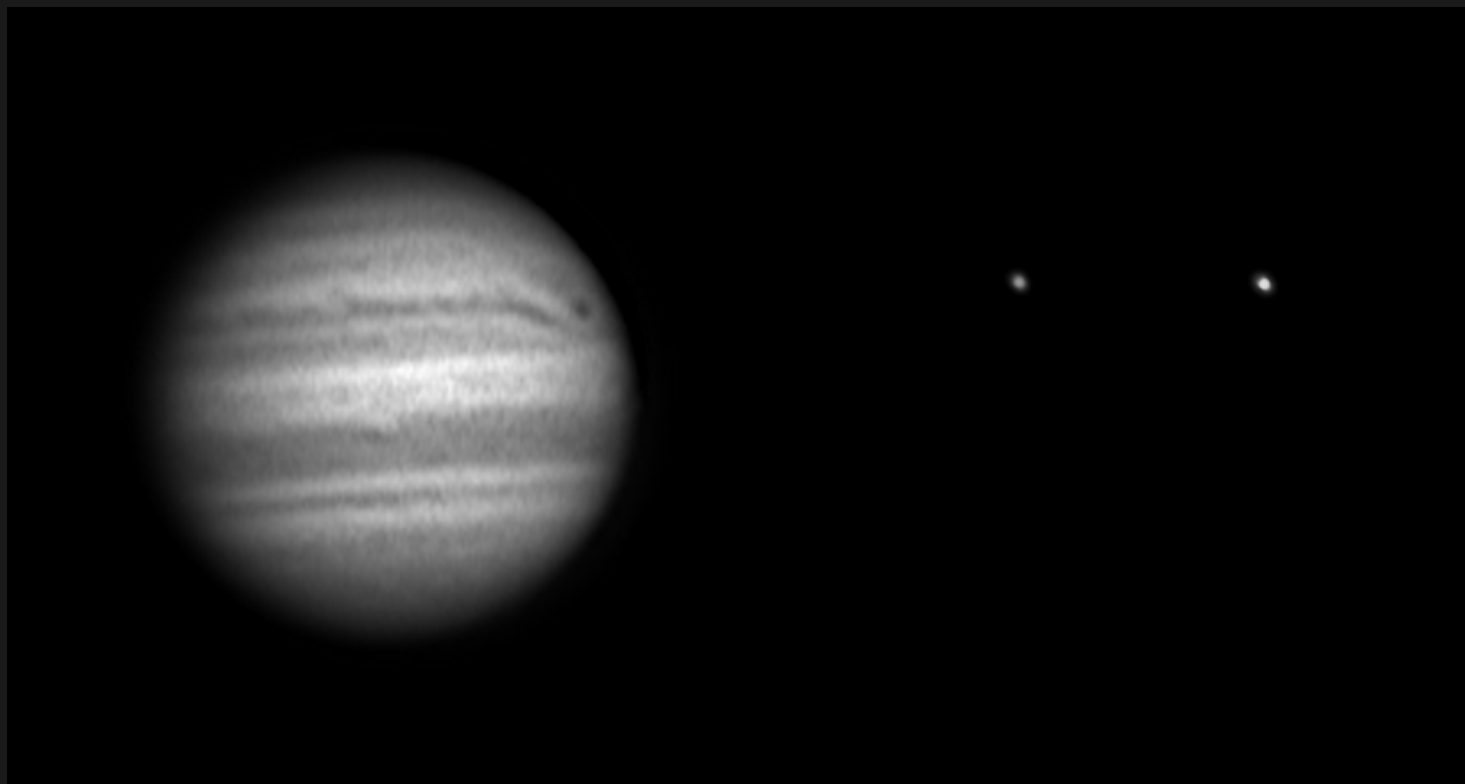




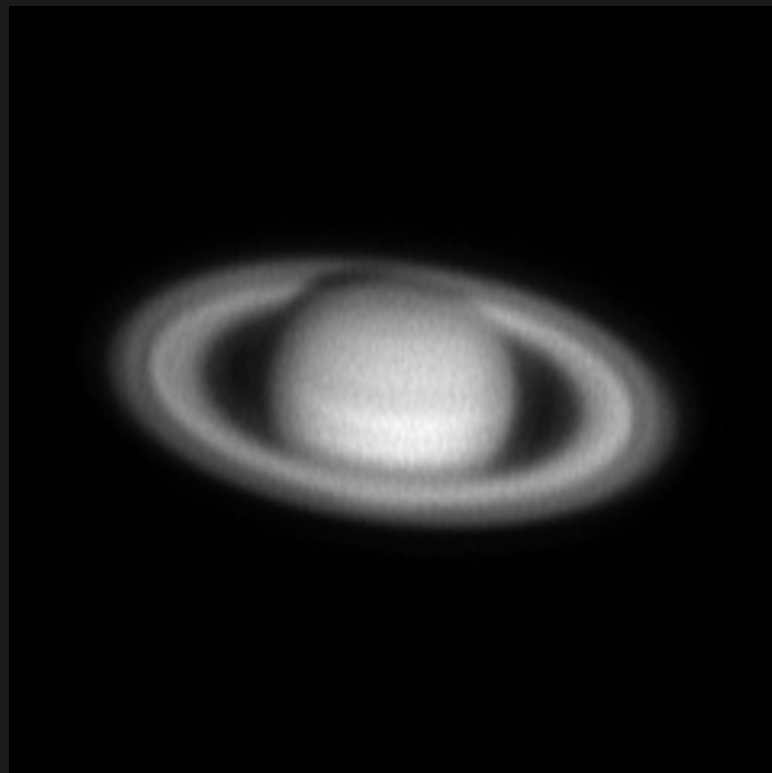


# Planets—Eyepiece Projection

- CCD chip positioned about 2" beyond 8mm eyepiece
- Converts F/15 to about F/90
- Flat fields are critical for dust donut removal
- Accurate polar alignment is critical
- Accurate pointing system is critical
- Accurate motor drive is critical
- Stack (best of) many short exposures
- VanCittert deconvolution miraculously removes blurring caused by bad seeing





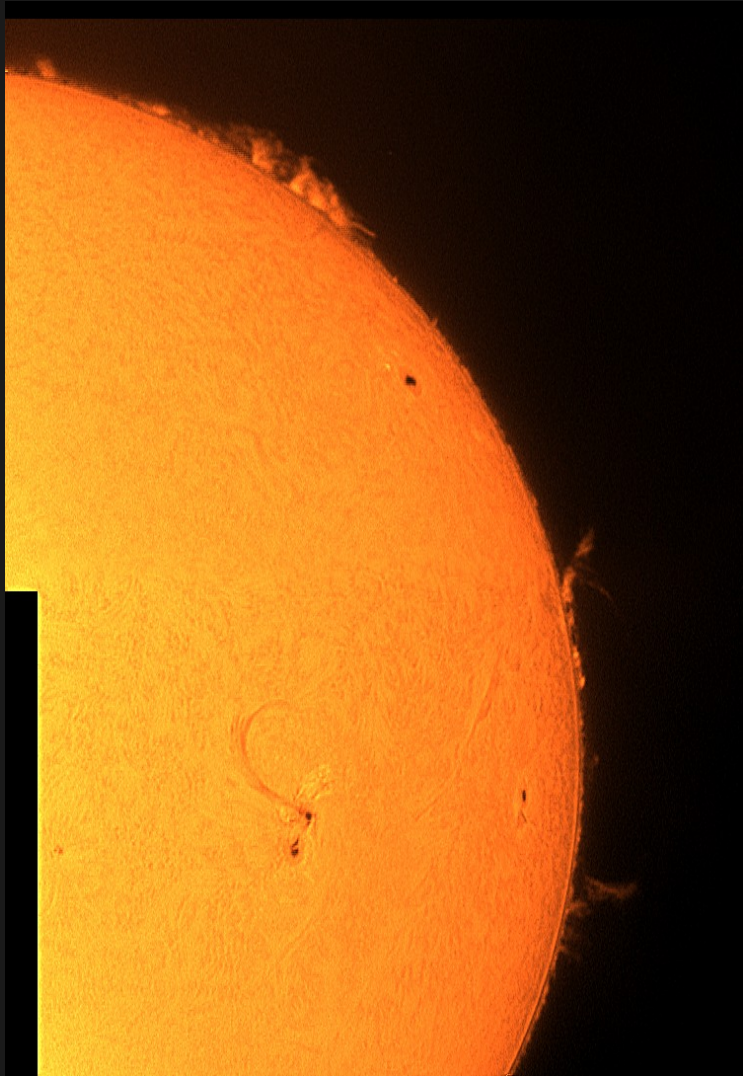








# Sun and Moon









# Movies

