Digitizing the Universe
From Your Backyard

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http://www.princeton.edu/~rvdb
Why Astrophotography?

Long Exposures, Permanent Record, Digital Enhancement, Light Pollution!
Some Pictures
Crab Nebula
Lagoon Nebula
Hercules Globular Cluster
Swan Nebula
Dumbbell Nebula
Orion Nebula—Close Up
Running Man 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: $6.45 \times 6.45$ microns
- Pixels: 1392 x 1040
- Quant. Eff.: $\sim 65\%$
- Readout Noise: $\sim 7$ electrons
- Cooling: $\sim 30^\circ$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 H$\alpha$

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).

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.
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
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
Eagle Nebula
Whirlpool Galaxy
Whirlpool Galaxy—Supernova
Ring Nebula
Little Dumbbell Nebula
Owl Nebula
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. H\(_\alpha\), 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