Astrophotography

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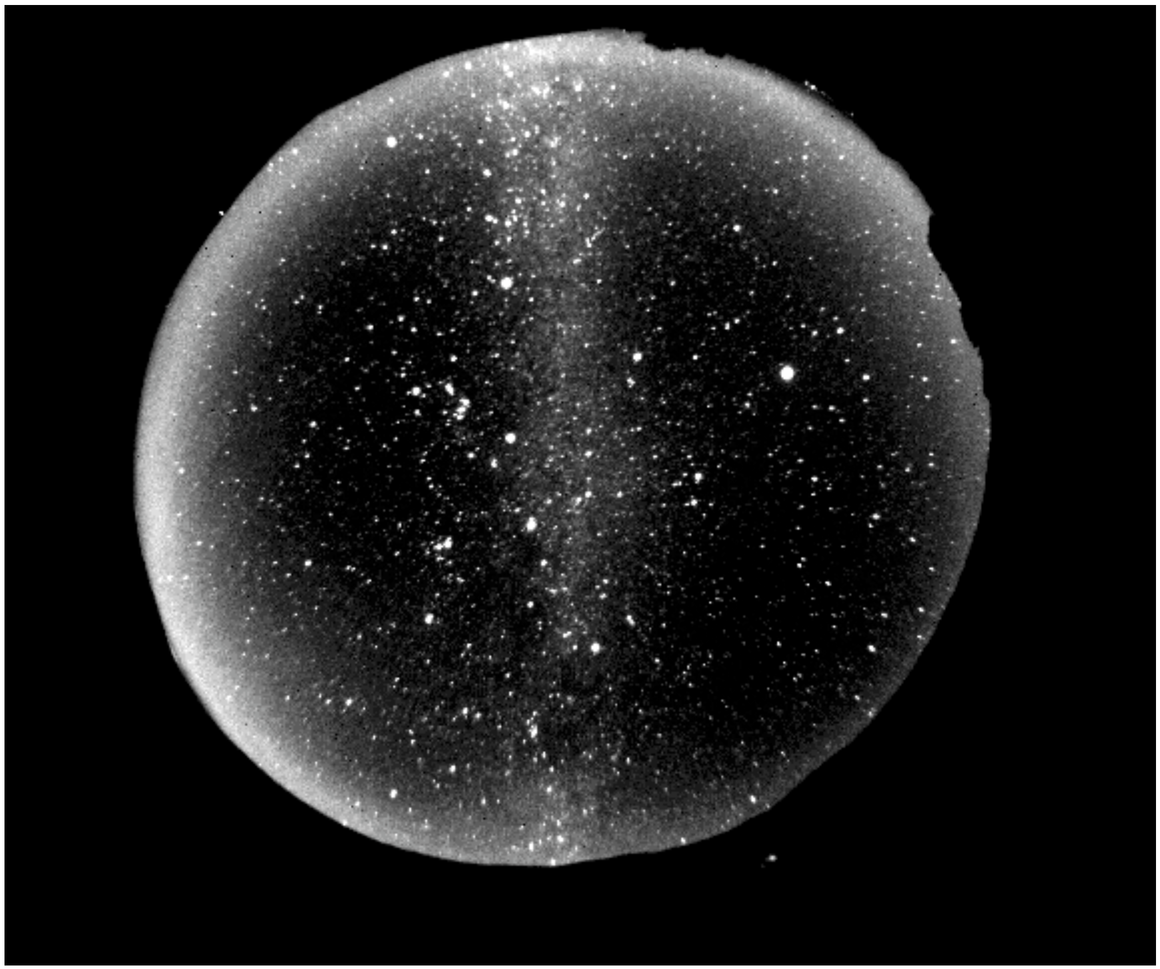
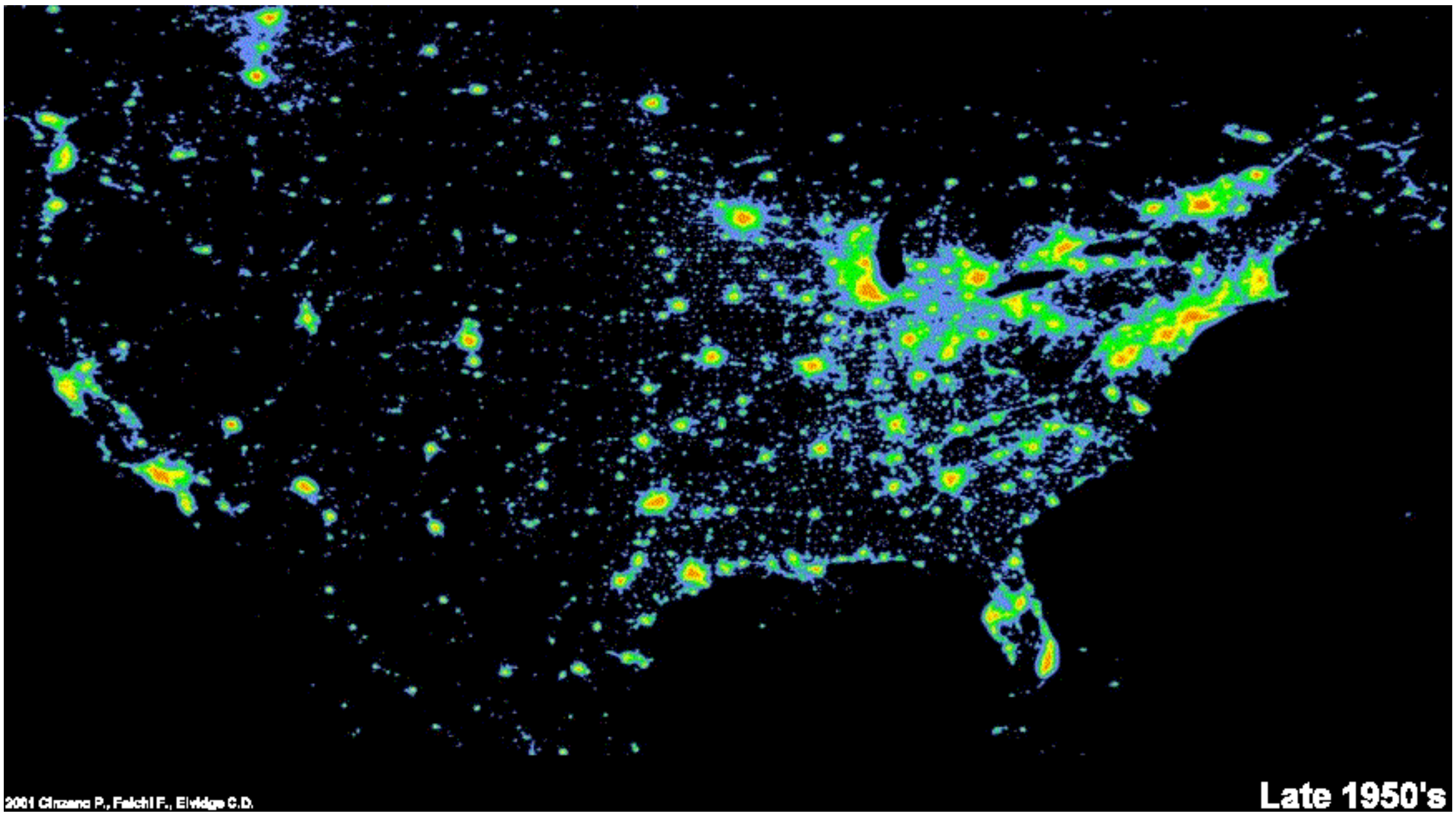
What’s different about astrophotography?

You need long exposures from a rotating platform (the Earth!),



What's different about astrophotography?

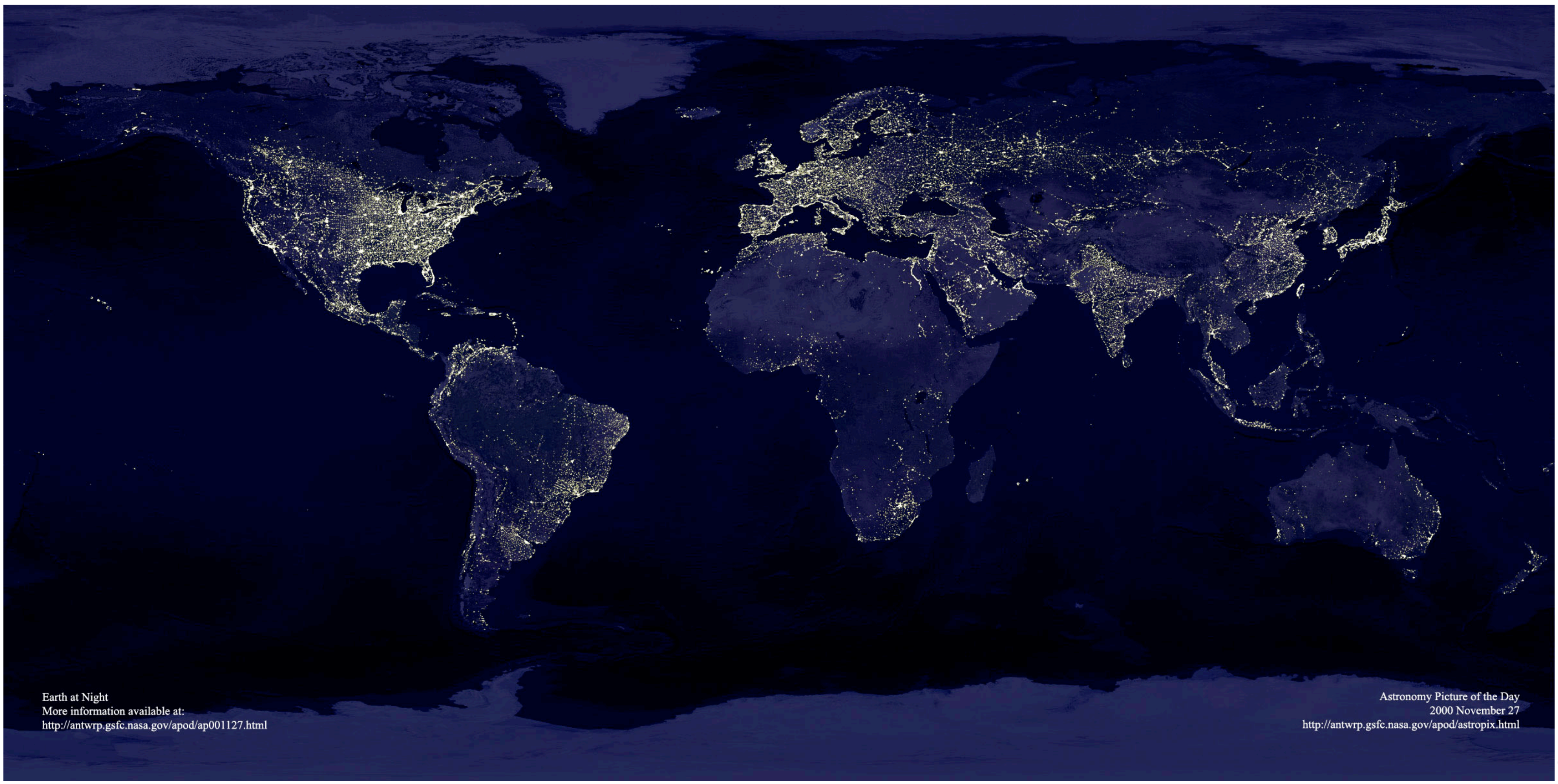
You need long exposures from a rotating platform (the Earth!), which has growing light pollution



www.darksky.org

What’s different about astrophotography?

You need long exposures from a rotating platform (the Earth!), which has growing light pollution



NASA

What's different about astrophotography?

You need long exposures from a rotating platform (the Earth!), which has growing light pollution and an active, mildly refractive (n =~ 1.0003) atmosphere.

What’s needed for astrophotography?

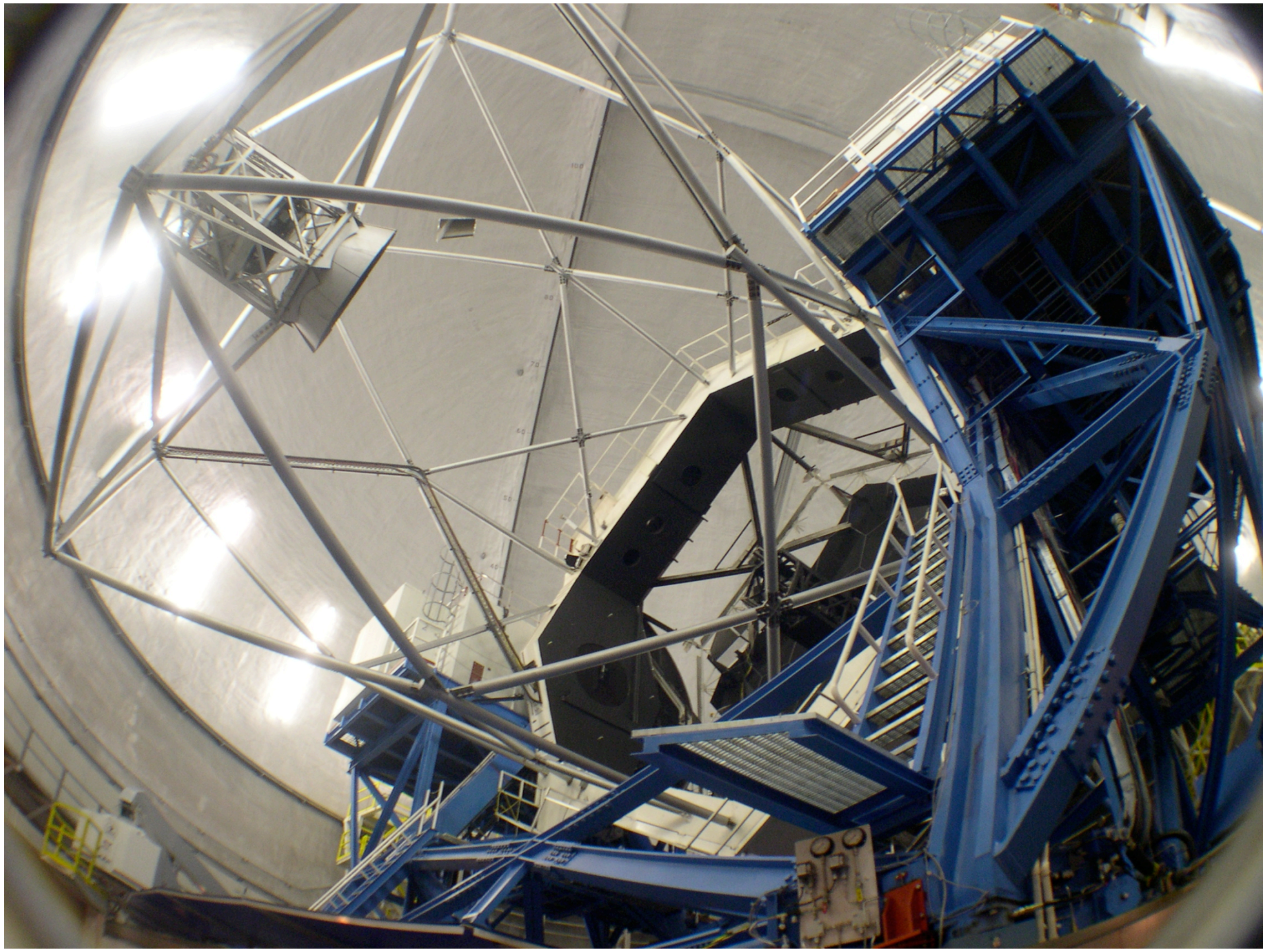
You also need very long focal length telescopes (200mm

http://superwasp.org/

The Superwasp program uses 200mm f/1.8 Canon lenses with cooled, back-thinned monochrome CCDs for extra-solar planet detection.

What's needed for astrophotography?

You also need very long focal length telescopes (200mm to 50m)



http://www.keckobservatory.org/

Keck primary – 10m, focal length varies with instrument and lightpath. This is the world's largest telescope – all large instruments have mirrors.

What's needed for astrophotography?

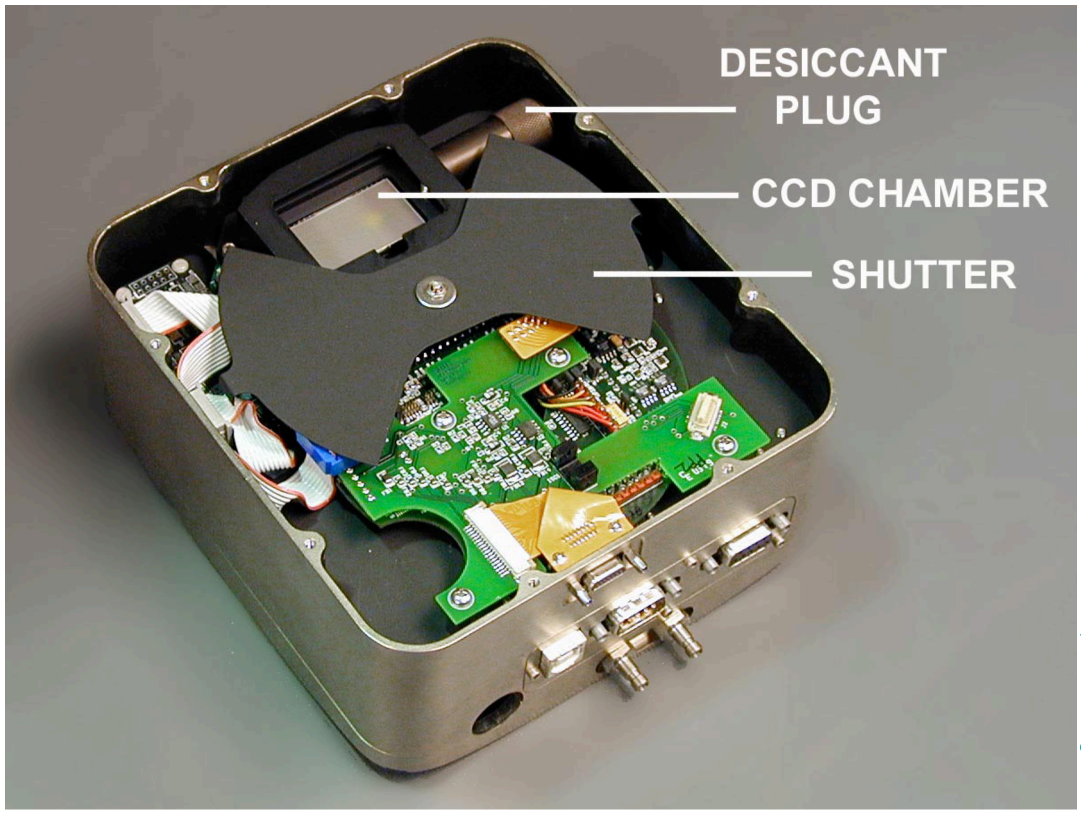
You also need very long focal length telescopes (200mm to 50m) with as large an aperture as practical, a stable tracking mount with the ability to find your target, and …

http://www.astro-physics.com/

Astro-Physics' 1200GTO mount; robotic tracking with than 5 arcsec of periodic error.

What's needed for astrophotography?

A camera! Most astronomical cameras are CCD-based, cooled, front-illuminated or back-thinned monochrome cameras.



http://www.sbig.com/

SBIG's STL-11k, cooled 11-megapixel KAI-11000M based CCD camera with integrated self-guiding head.

What’s needed for astrophotography?

A camera! Most astronomical cameras are CCD-based, cooled, front-illuminated or back-thinned monochrome cameras. A filter wheel is required to take narrow-band or color images.

http://www.sbig.com/

RGBL filterset for SBIG STL-11k

Know your sensor!

Example - a Kodak KAI-11000M based camera

Understand gain, readout noise, dark current and QE
This helps you plan exposure lengths, understand how to balance color and calibrate your images.

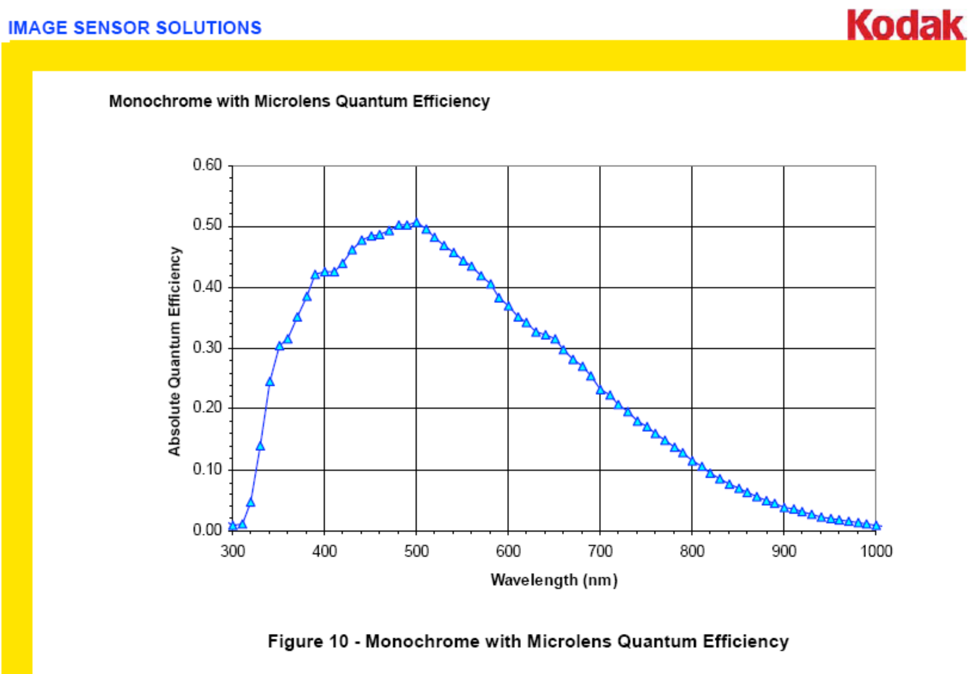
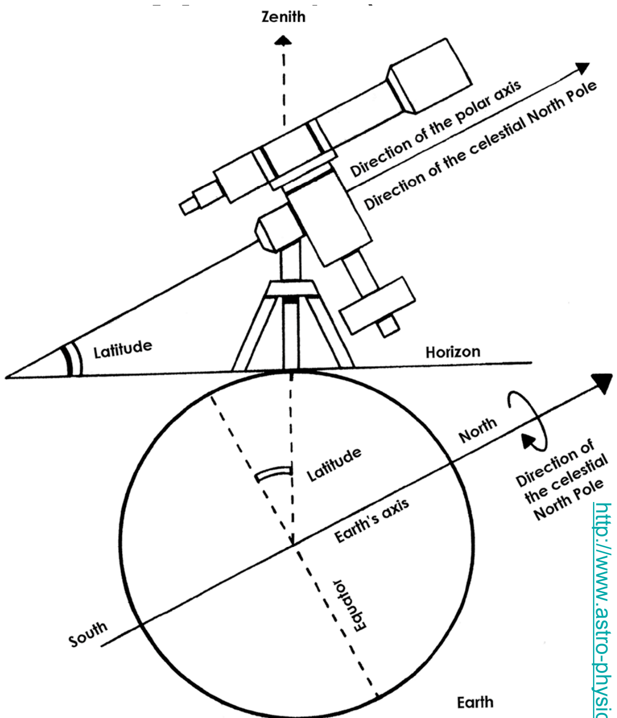


Figure 10 - Monochrome with Microlens Quantum Efficiency

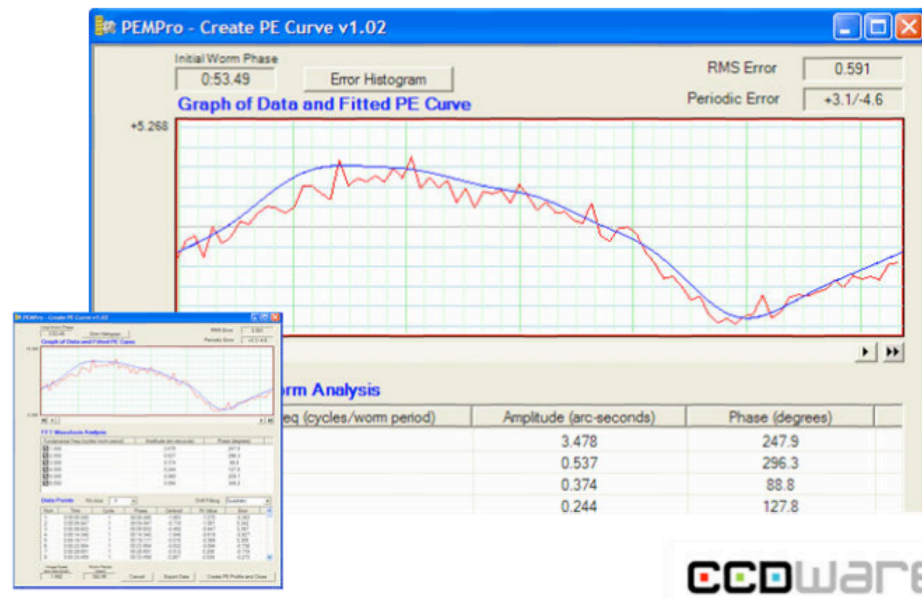
~9 e- readout noise
0.82 e-/ADU gain
50k e- full well depth

Processing an astrophoto

- Let’s say we have our setup fully tuned and working:
  - Mount is balanced, polar aligned, homed (if necessary), periodic error correction (PEC) and mechanics well-profiled (Tpoint,



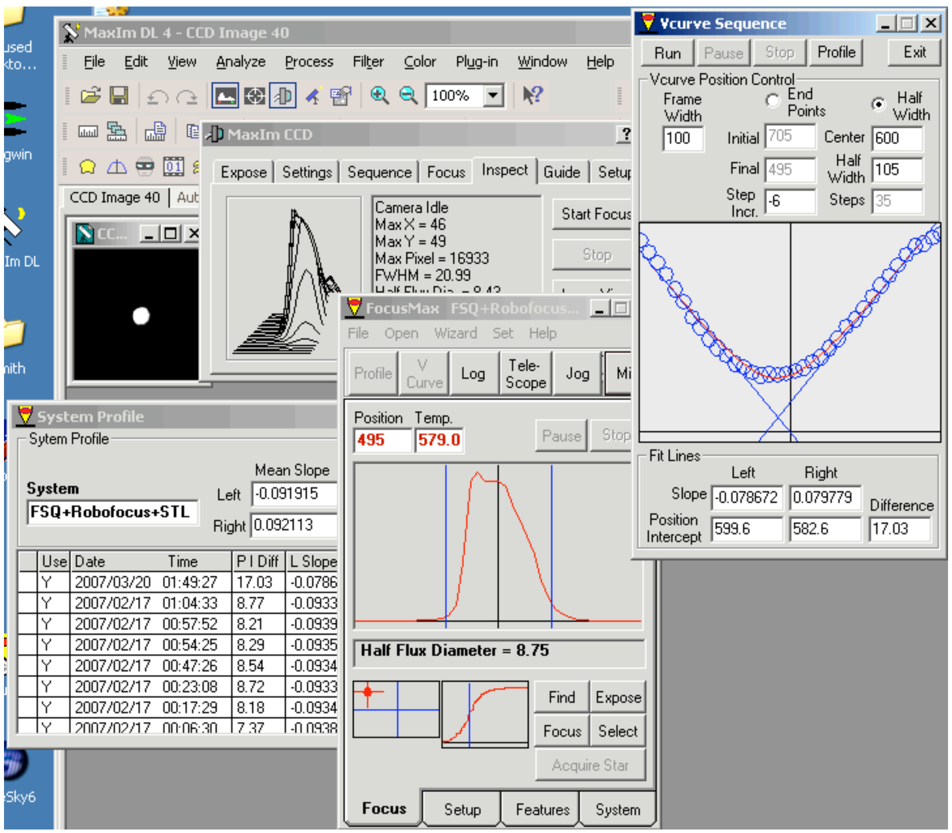
http://www.astro-physics.com/

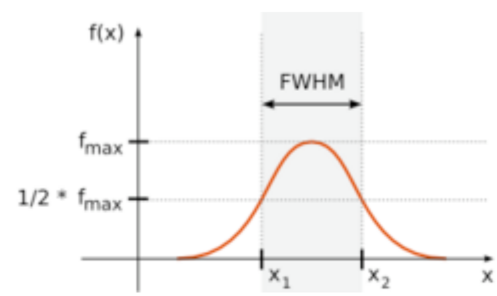


PEMPro by Ray Gralak http://www.ccdware.com/

Processing an astrophoto

- Let’s say we have our setup fully tuned and working:
  - Telescope is focused perfectly – no room for error with point sources

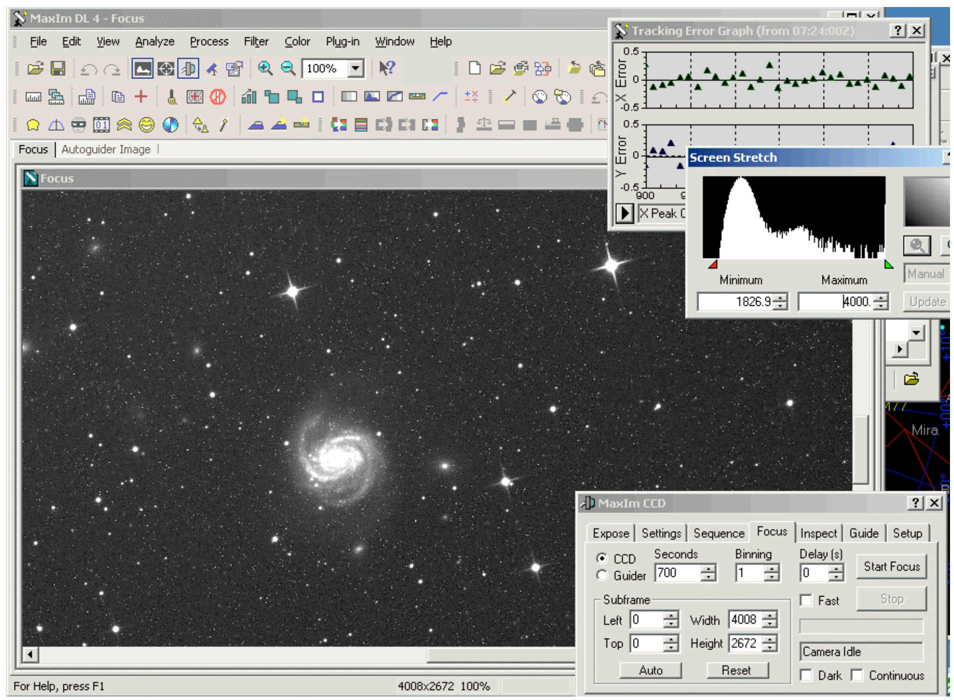




Processing an astrophoto

- Let’s say we have our setup fully tuned and working:
  - Planetarium software, CCD control software, focusing control, etc. configured
  - Autoguiding/adaptive optics calibrated and giving us high-quality tracking and dithering

One 700s frame taken with good guiding.



Processing an astrophoto

- Need 3 master calibration frames
  - Dark Master
  - Bias Master
  - Flat Master (one for each filter)
- And our light frames (monochrome, or RGB/other filter combination)

What's in an ADU?

ADU = Bias + (Dark Current + Readout Noise + Signal)/Gain

- Bias – ADUs added to readout to prevent negative counts – not actually on the sensor

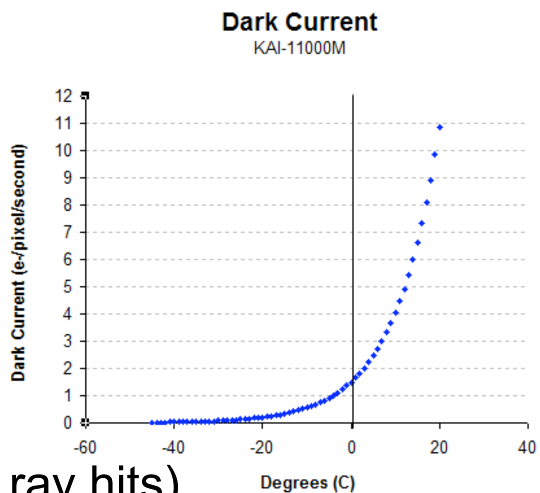
- Dark current – relatively predictable thermal signal

- Readout noise – shot noise, no escape from this

- Signal – ADUs from the target's photons

Processing an astrophoto

Dark Frames



- Dark signal accumulates fairly predictably

- Take lots of dark frames at
    - The temperature of your light frames
    - The length of your light frames

- Combine, throwing away outliers (like cosmic ray hits)

- Signal adds with each exposure, noise increases with the square root of the signal, so each frame in the master dark increases overall S/N

- Subtract the master dark from each light frame, pixel-by-pixel

$$ADU = Bias + (Dark\ Current + Readout\ Noise + Signal)/Gain$$
$$- (Bias_{master} + (Dark\ Current_{master})/Gain)$$

$$ADU_{+dark\ calibration} = (Readout\ Noise + Signal)/Gain$$

Processing an astrophoto

Bias Frames

What is bias?

- Added into readout to prevent using bits for signed integers

How do we calculate it (do we need to)?

- Take shortest possible exposures
- Or just take the manufacturer’s word

Why do we need it?

- For frame scaling, specifically flat frames (and possibly darks)

Processing an astrophoto

Flat Frames

Acquisition – uniformly illuminate every pixel (ideally with light whose spectrum matches that of your subject)

This can be challenging – use a light box or the twilight sky

Take a lot of flat frames with enough exposure to fill the wells to about 2/3 depth (stay linear, but good S/N; these exposures are too short to benefit from dark subtraction)

Subtract additive bias and combine by normalizing and then averaging to create flat master

Finally, apply the flat master to all light frames by doing a pixel-by-pixel division (*light pixel/flat master pixel*)

Processing an astrophoto

Flat Frames

Net result – each pixel is scaled to reflect the amount of signal it received, nothing more. No:

- Vignetting
- Dust shadows from coverslip, optics or filters
- Pixel-to-pixel QE inconsistencies

Critical for scientific astrophotography and often the difference between a good and a great astrophoto.

Try flat-framing terrestrial photos as well, and dark-subtracting long shots.

Processing an astrophoto

Signal ("Light") Frames

After applying the dark and flat frames, each signal sub-exposure is the cleanest representation of the data we have.

Take a lot and combine them!

$$S/N = Signal / (\sqrt{\ } Signal + Noise_{Readout\ +\ frame\ combines})$$

Since

$$S >> Noise$$

And $\sqrt{\ }$ *Signal* >> *Noise* (for exposures with enough signal, our goal)

$$S/N =\sim Signal / \sqrt{\ } Signal = \sqrt{Signal}$$

Each additional sub-exposure increases the *S/N* by about $\sqrt{\ }$ *Signal*

Processing an astrophoto

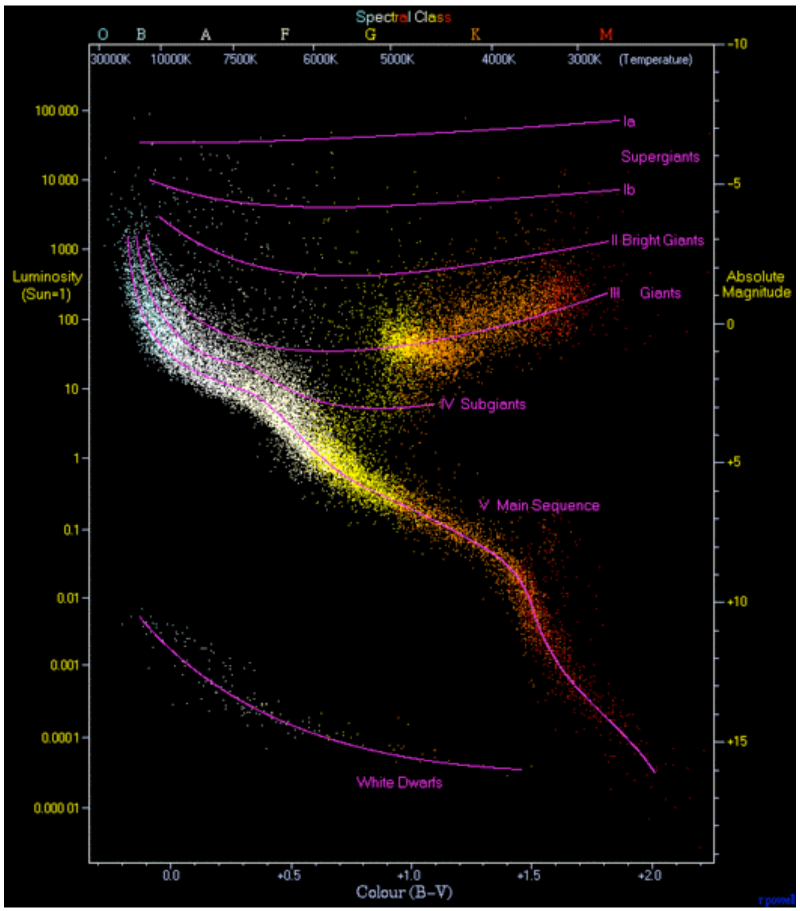
Signal ("Light") Frames

No substitute for *S/N*! Sky glow, readout noise set the floor for practical, achievable *S/N*, but typically a *lot* of exposure is needed to get there.

For example, the Hubble Deep Field has 42 hours of exposure.

Processing an astrophoto

Combining Color Frames

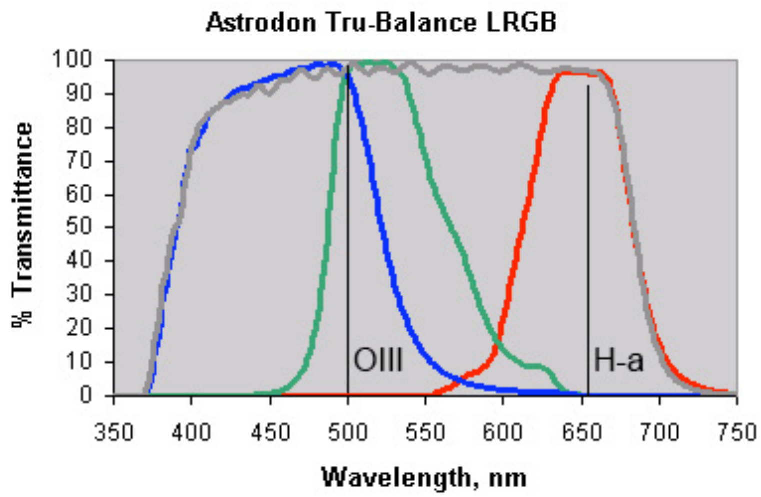


White balance – find a white star close to target, and balance R G and B on it.

It is important to make sure that the star is not saturated in any of R, G B or L or else the color will be skewed. Either scaling the bias-subtracted signal frames, or taking different length sub-exposures will suffice for ensuring the right amount of each color.

Processing an astrophoto

Combining Color Frames



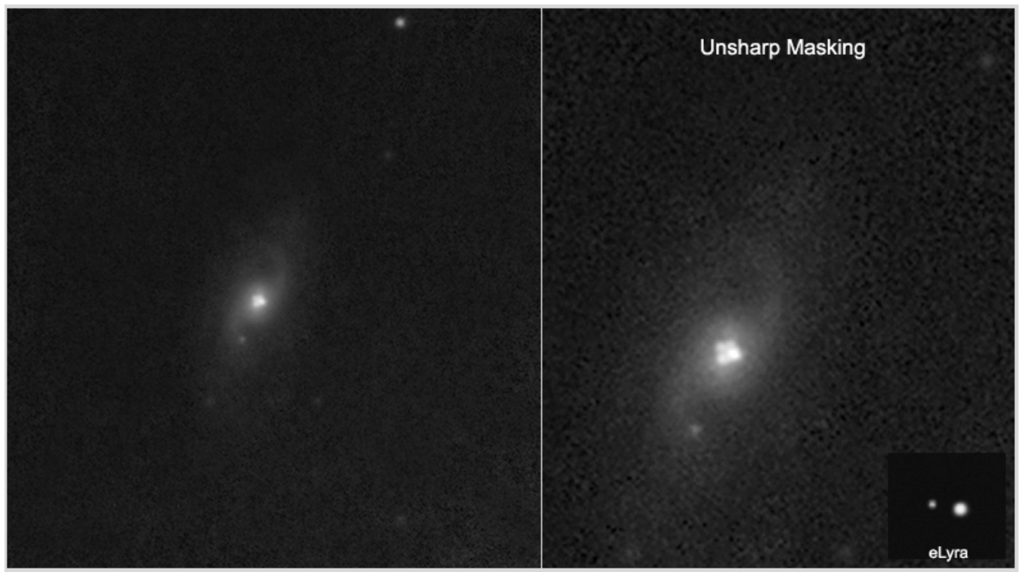
http://www.astrodon.com/

Astronomical filters are designed so there is sufficient bandpass at some of the most common wavelengths in the universe (OIII and H-a), though highly redshifted targets can move spectral lines and require more specific filters.

It is also common to have narrowband filters; many nebula glow brightly in H-a.

What kind of images can an amateur take?

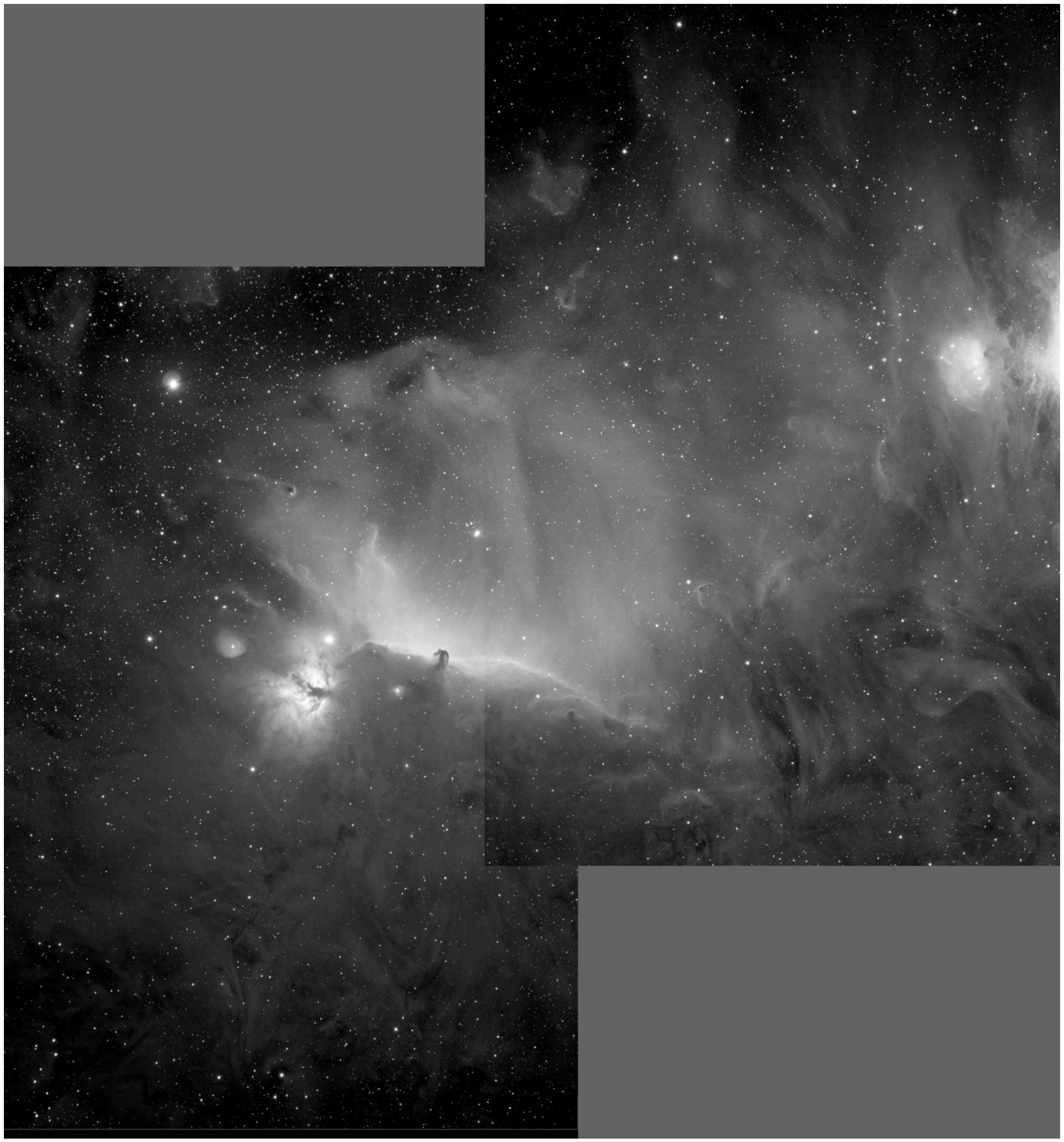
Einstein's Cross – Gravitational lensing of a quasar



10-hour exposure with a 10" Mak-Cass
Photo, telescope and mount by Roland Christen of Astro-Physics

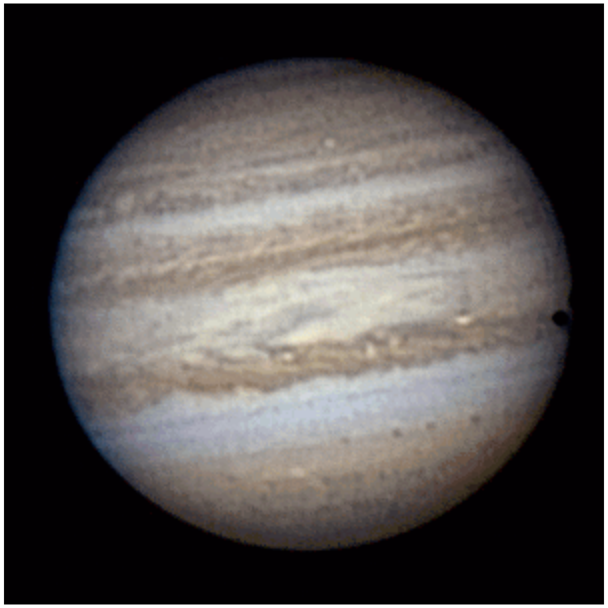
Images used with permission

What kind of images can an amateur take?

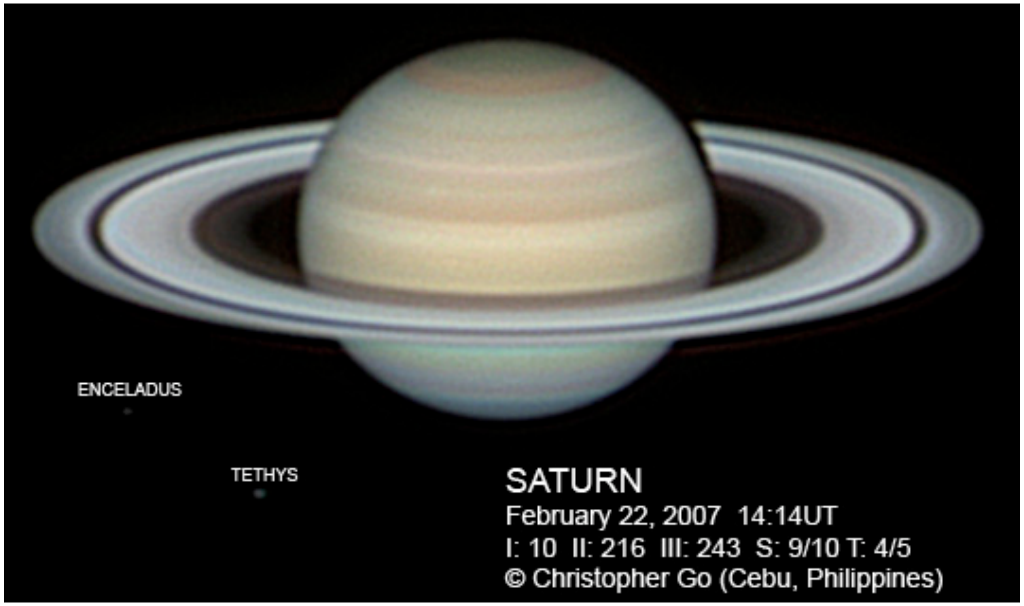


~20 hours, through
a 4” f/5 refractor and
a 6nm bandpass H-a
filter on a KAI-11k based
SBIG camera @ -22C.

What kind of images can an amateur take?



http://jupiter.cstoneind.com/



http://saturn.cstoneind.com/

Both images by Chris Go – also discovered Red Spot Jr!
(11” SCT + IEEE1394-based, high-speed monochrome video camera)

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