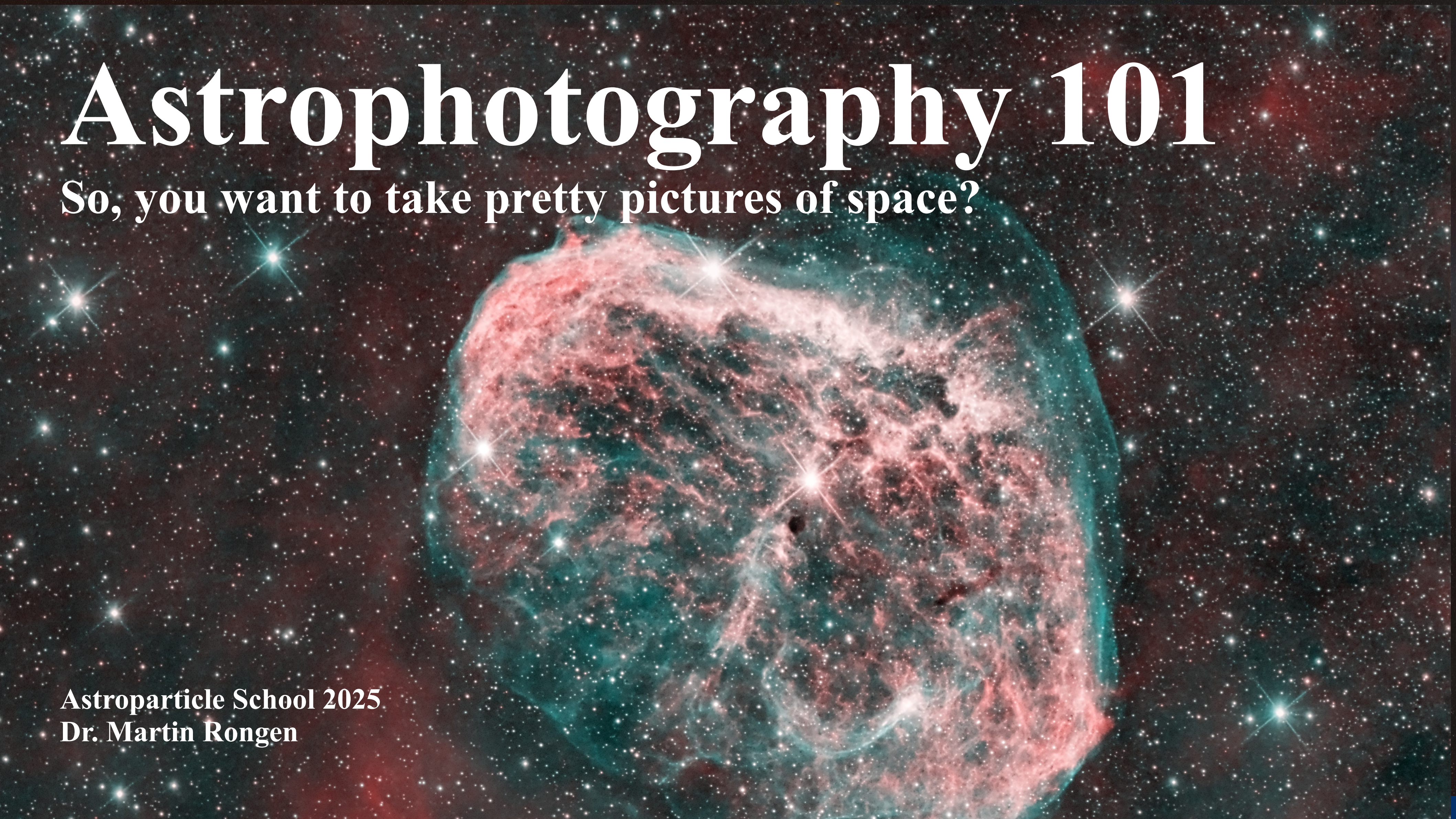


Astrophotography 101

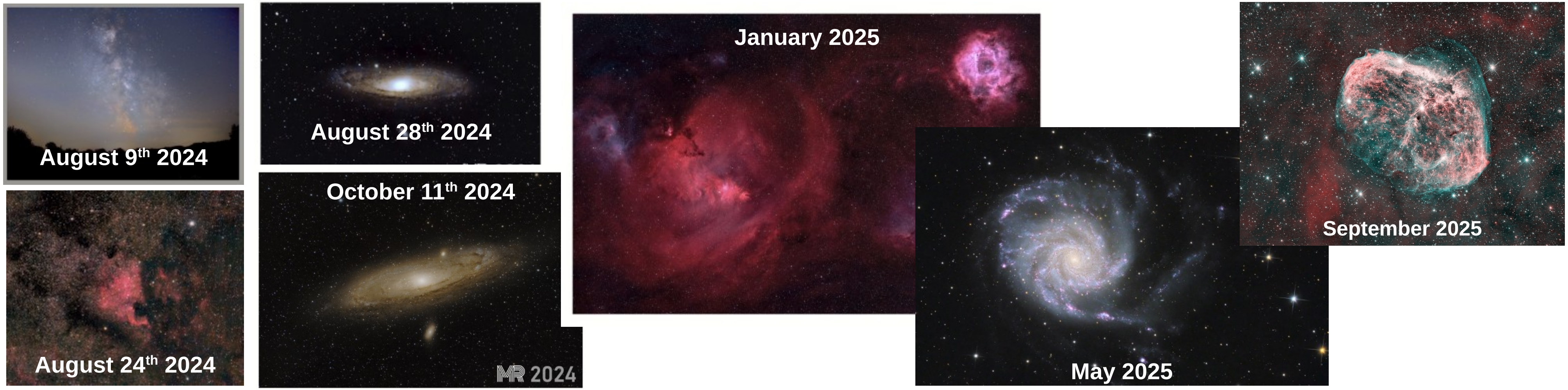
So, you want to take pretty pictures of space?

Astroparticle School 2025
Dr. Martin Rongen

Speaker introduction

- Astroparticlephysicist @ ECAP working on the IceCube Neutrino Observatory
  - 2019: PHD from RWTH Aachen
  - 2020-2023: Postdoc in Mainz
  - 2023: joined ECAP as habilitation candidate

- Started in astrophotography in August 2024 (so still rather new to all this...)



Astrophotography as your miniature science experiment

- Chose your science case

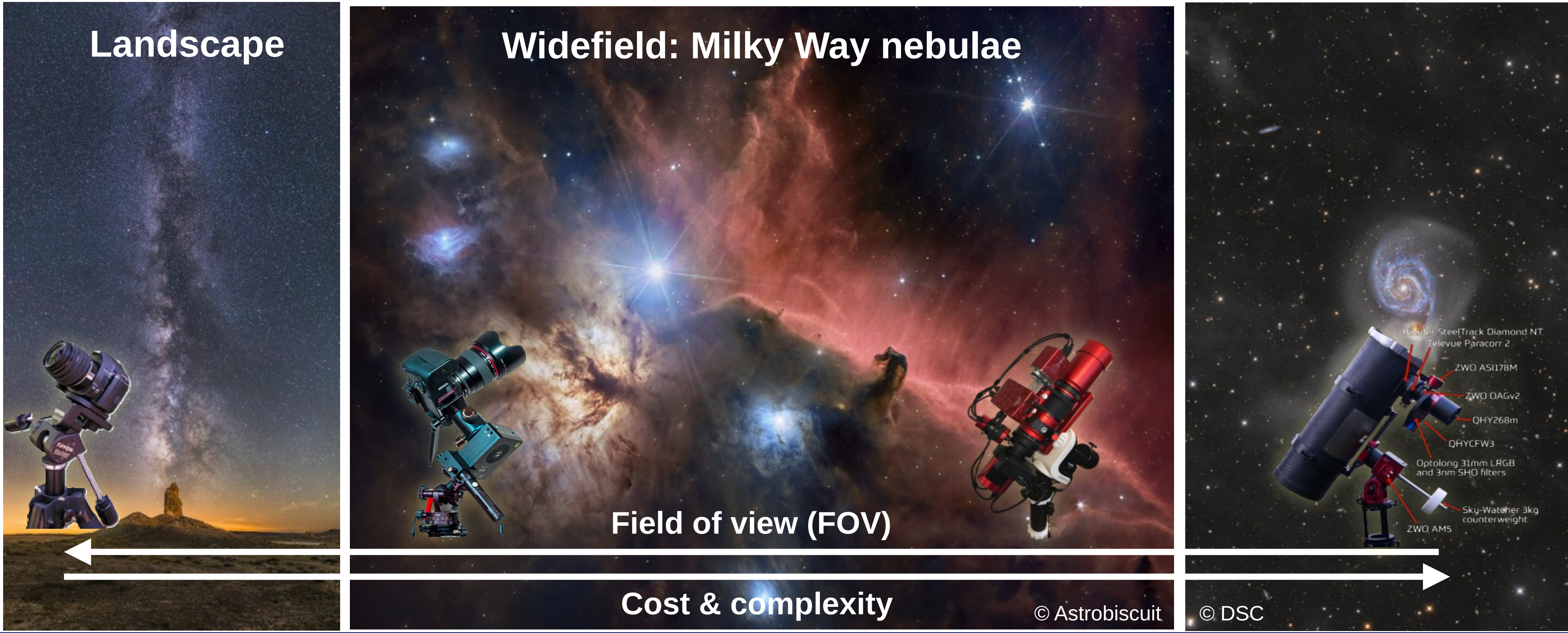
- Design, fund & build your experiment

- Gather the data

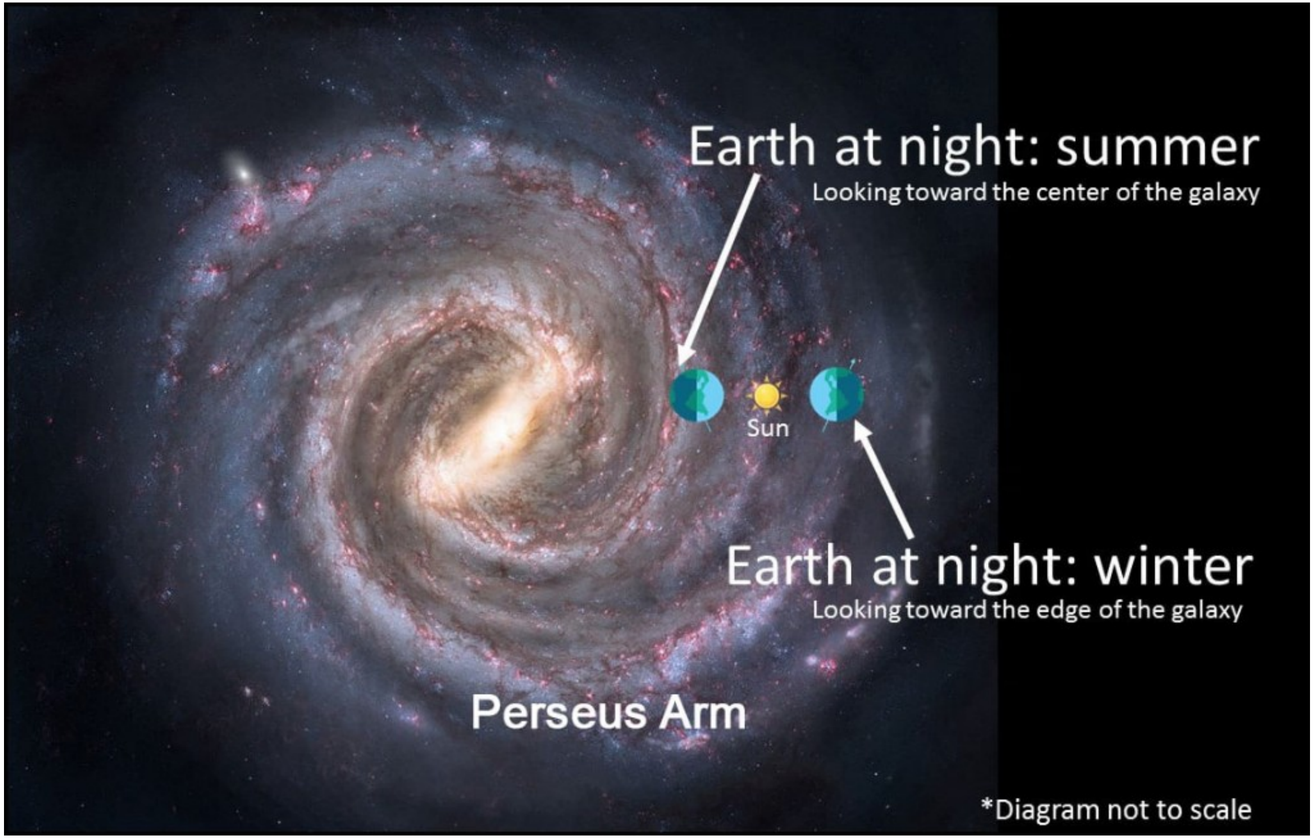
- Process the data

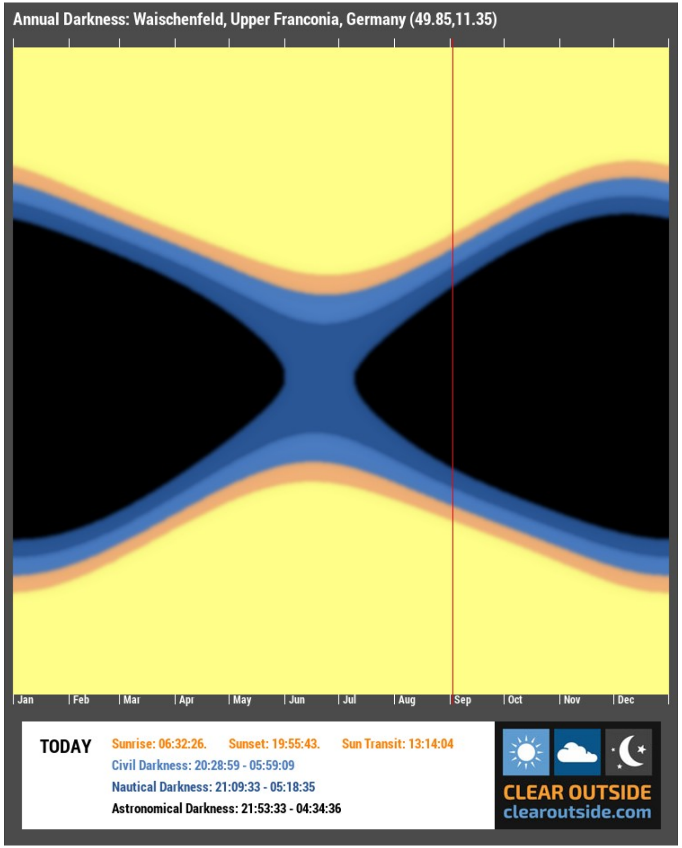
Types of astrophotography

DSLR & Tripod F500 Rule	Short Scope & Star Tracker	Long Scope & Heavy Mount



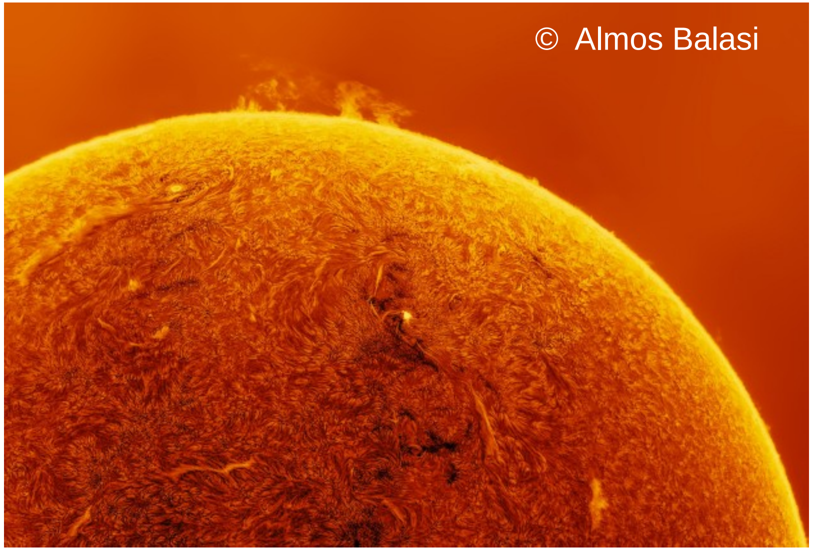
The seasons of astrophotography





Landscape / milky way nebulae astrophotography in summer & autumn.

Solar, lunar, planetary & satellites



Plenty of other specialized fields requiring unique techniques (e.g. lucky imaging) and equipment.

Equipment overview

Every setup consists of 3 major components:

- A sturdy mount (tripod – EQ mount)
- The optics (lens – telescope)
- A camera (DSLR – astro camera)

And lots and lots of little things:

- Power supplies
- Data storage
- Focusing masks ….

Untracked setup

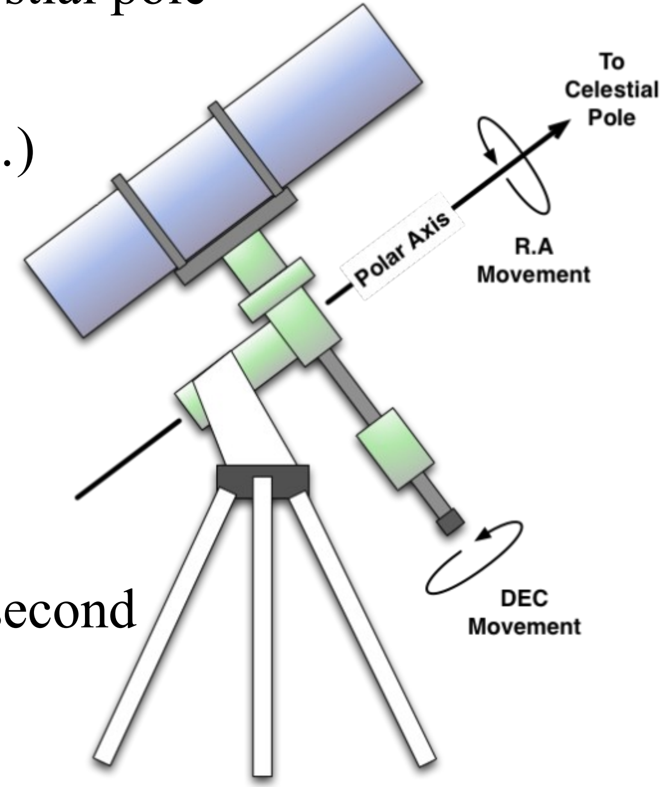
- Camera, Lens, Tripod, **Intervallometer**
- Landscape astrophotography sadly only makes sense with very little light pollution
- Long exposures yield star trails
- F500 rule for sharp stars:
  - Exposure: 500s/focal length[mm]
  - Modulo crop factor, …
    e.g. PhotoPills app for details
- Sensible focal length range:
  - 50mm: ~20° FOV
  - 135mm: ~7° FOV
    (moon is about 0.5° diameter)

Star trackers

- Same setup as before, but now adding one-axis constant-speed motor to compensate Earth rotation
- Exposure times limited by accuracy of tracker, generally around 30-45 seconds
- Focal length limited by maximum weight tracker can support, 135mm max still sane

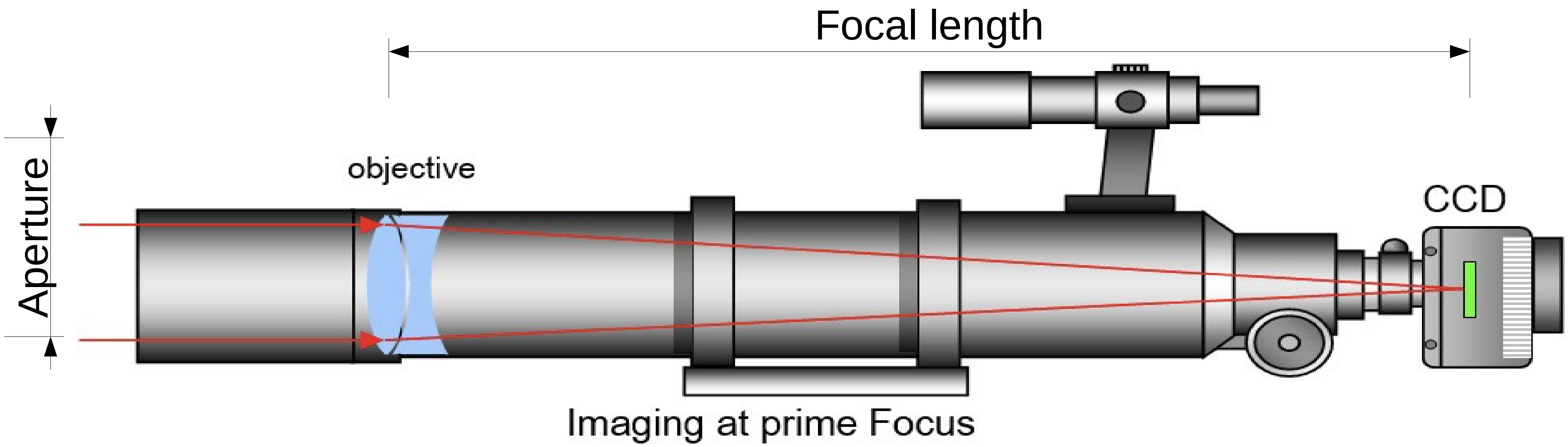
Equatorial mounts

- Telescope mounted rigidly and two axes to be able to slew to any direction
- Right ascension axis aligned with Earth rotation / celestial pole
  Declination axis at 90°
- Alt-Azimuth mounts have their specific uses (visual…)
  BUT are generally not preferred as they introduce
  field rotation (can keep target centered, but image rotates)



- Also allows for guiding:
  - While primary telescope is taking long exposures
  - Secondary guide telescope takes an image every second and sends correction signals to mount

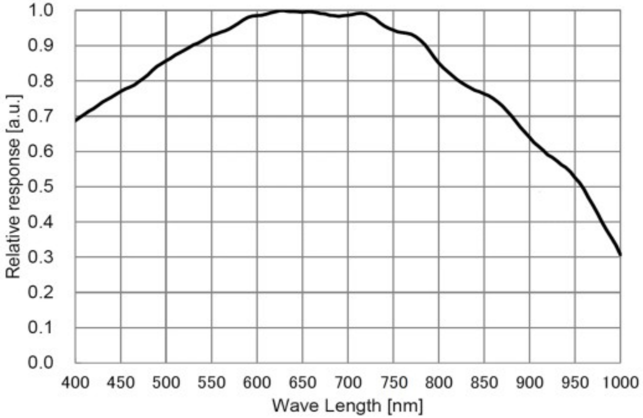
Optics basics: Focal length & aperture

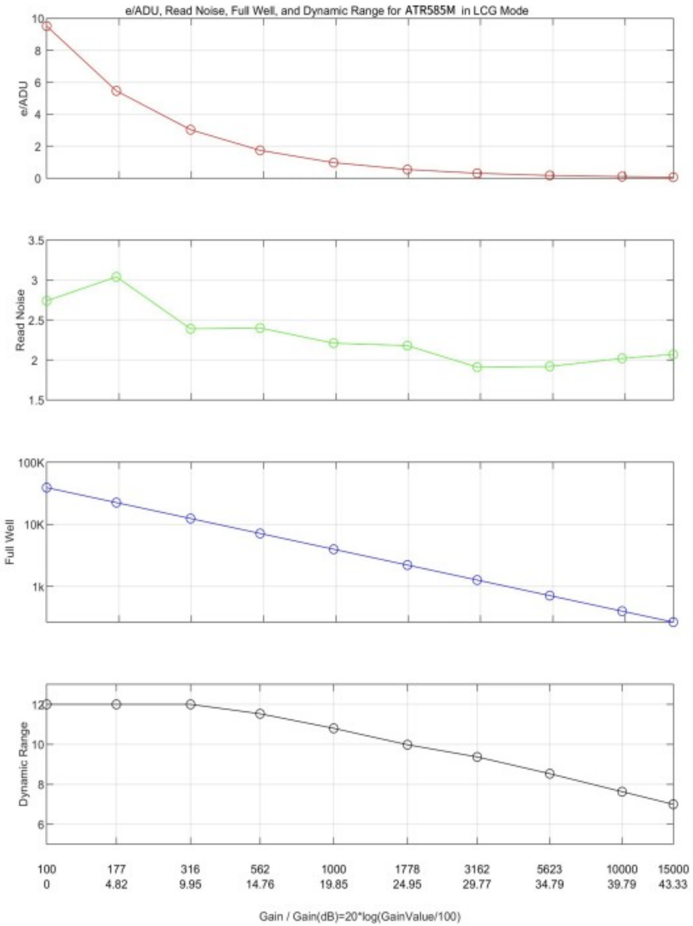


- Telescopes project an angular seperation onto a focal imaging plane
- Longer focal length → larger angular magnification → less intensity per unit area
- Larger aperture → more photons in total
- Image brightness given by **f-ratio: focal length/aperture**
- Slow scopes: Large f-ratio; Fast scopes: Small f-ratio

Camera basics: Pixel characteristics

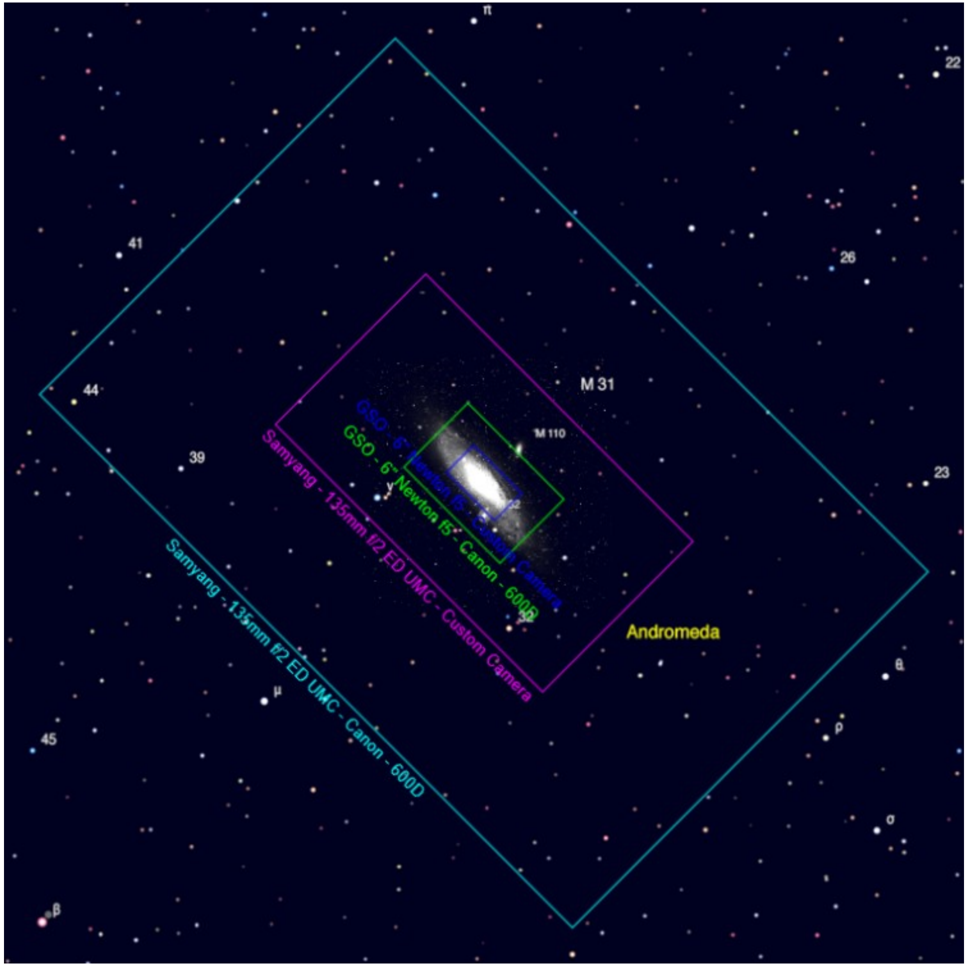
Sensor IMX585	1/1.2" 11.2×6.3mm	Resolution 3840×2160	ADC 12bit	FPS 47	Full well MC 40Ke/MM 38.7Ke
Read noise 0.7e	Cooling Tempe 35°C	DDR3 Buffer 512MB	USB 3.0	QE MC 88%/MM 91%	Pixel Size 2.9µm





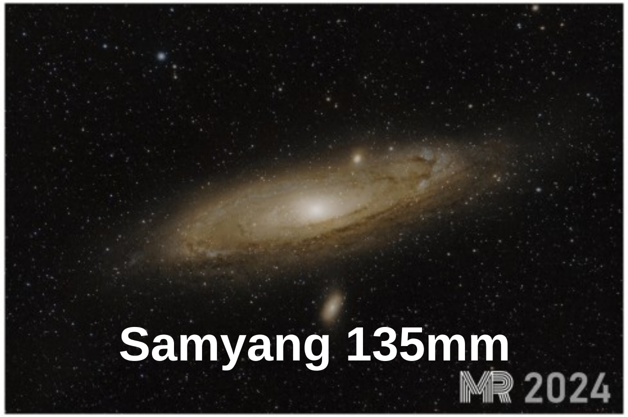
Angular resolution and FOV

- The telescope focal length and camera pixel size determines the per-pixel angular resolution
- Multiplied with horizontal and vertical number of pixels yields the FOV
  → needs to be matched to target
  (or dedicate to a mosaic)
- Actual resolution mostly limited by atmospheric seeing (typically 1“)
  - Oversampling does not improve image
  - Undersampling can increase SNR but degrade resolution
- Additional diffraction Rayleigh limit for small apertures
- Calculator @ https://astronomy.tools/calculators/ccd_suitability



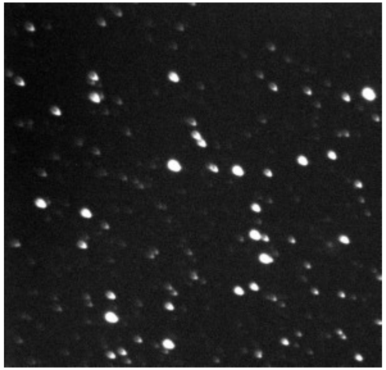
Refractors & lenses

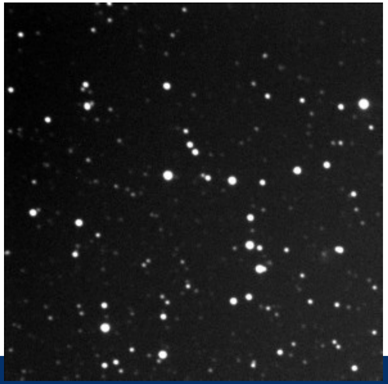
- Most camera lenses are BAD
  (Your stars are purple and large?? You have chromatic aberration….)
- Prime lenses can be good (well known Rokinon/Samyang 135mm f2)
  but often need to be stepped down (closing the aperture for larger f-ratio)
- Dedicated astro-lenses / refractos often use expensive
  fluorite optics

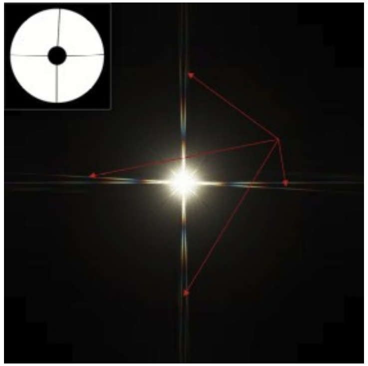


Reflectors (here only discussing Newtonians)

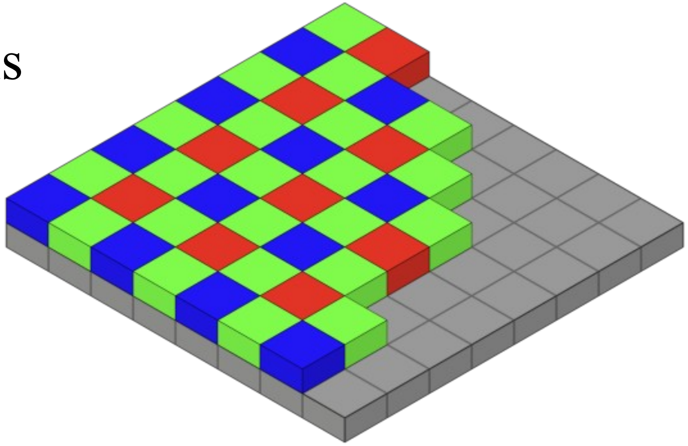
- Cheapest way to get a descent f-ratio at larger focal lengths
- But reflectors suffer from comatic abberation requiring another expensive piece of equipment (coma corrector)
- Newtonians also require alignment of the optical train (called collimation) (can even drift as telescope slews)
- And lots of fine-tuning for good optical quality
  (flocking, secondary spider alignment for symmetric diffraction splikes)







Color vs. Mono cameras



- Color cameras use Bayer color mask in front of pixels
  (2 green, 1 blue, 1 red to match human color perception)

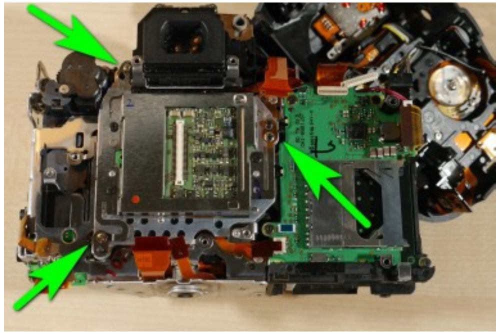
- „Real resolution“ only 50% of what is quoted
- Few things in sky actually green…

- Mono cameras do not feature Bayer mask
  - 3x photon count without filters (luminance)
  - Stacking images with color filters gives color image
  - Allows for efficient narrowband imaging

- Filter wheels allow for automatic cycling
  of filters during imaging session

DSLRs vs. Dedicated astro cameras

- DSLR:
  - Multi-purpose, often already on hand
  - Cheap when used (< 200€)
  - Low sensitivity, but UV-IR cutoff filters can be removed ….
  - uncooled → high noise (especially in Summer)



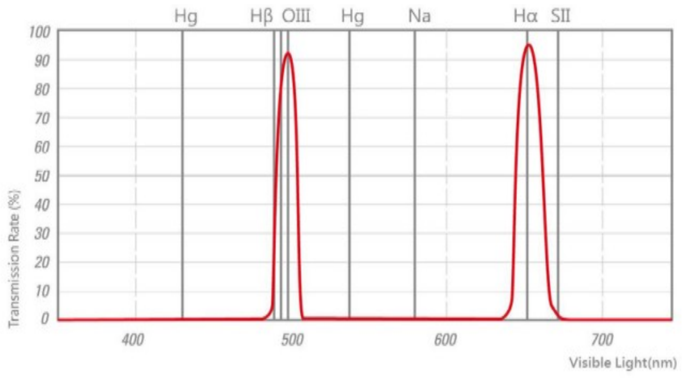
- Astrocameras:
  - Require dedicated PC to readout
  - Can be mono!!
  - Cooled and low noise

(Narrowband) filters and SNR

- Selecting discrete emission lines (non-thermal component)
  - Interesting to look at specific elements
  - Suppresses most light pollution → higher SNR

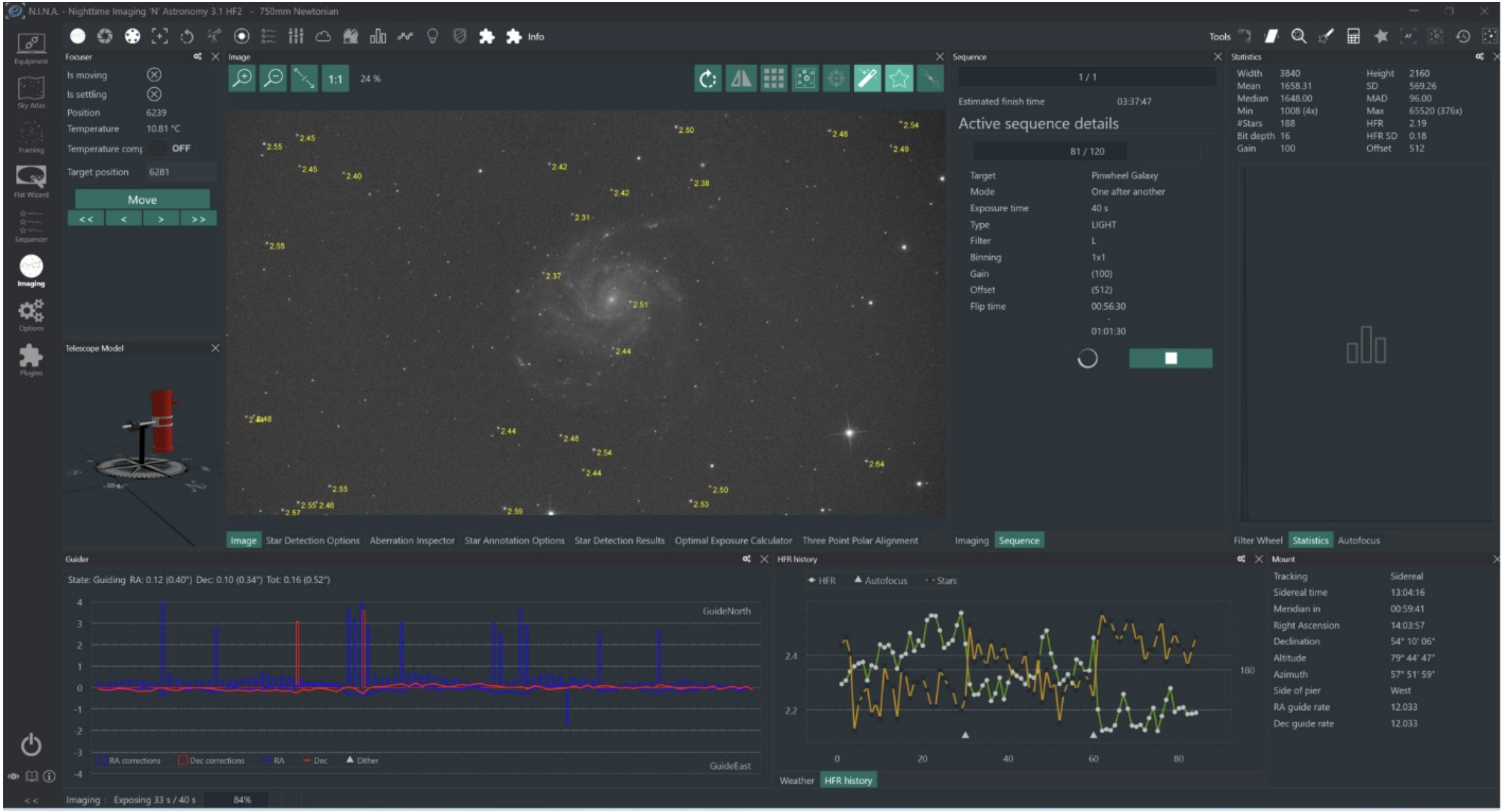
- Dual-narrowband (Ha, OIII) amazing for DSLRs

- Broad-band light pollution filters mostly not worth it



Aquisitions software (ASIair, NINA)

Central control hub for all systems



Smart telescopes

- Extremely good value for money
- Easy entry point into descent astrophotography, with imaging being fully controlled in phone ap
- To me not really interesting as I enjoy building and understanding my setup as much as using it….

Planning an astro-night

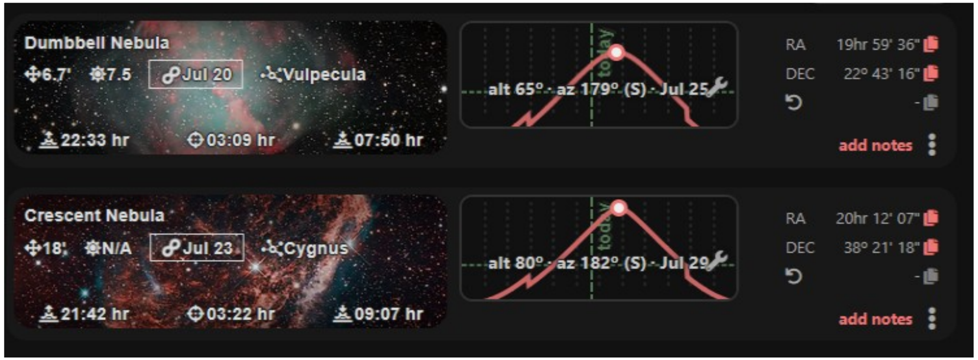
- Is the weather fine?
- What is the seeing like?
- What moon phase are we in?
- Which targets are high in the sky? (close to opposition)
- Want to drive to a dark site?

  → target selection
  (narrow vs broadband target)

- Pick and prepare equipment to match target

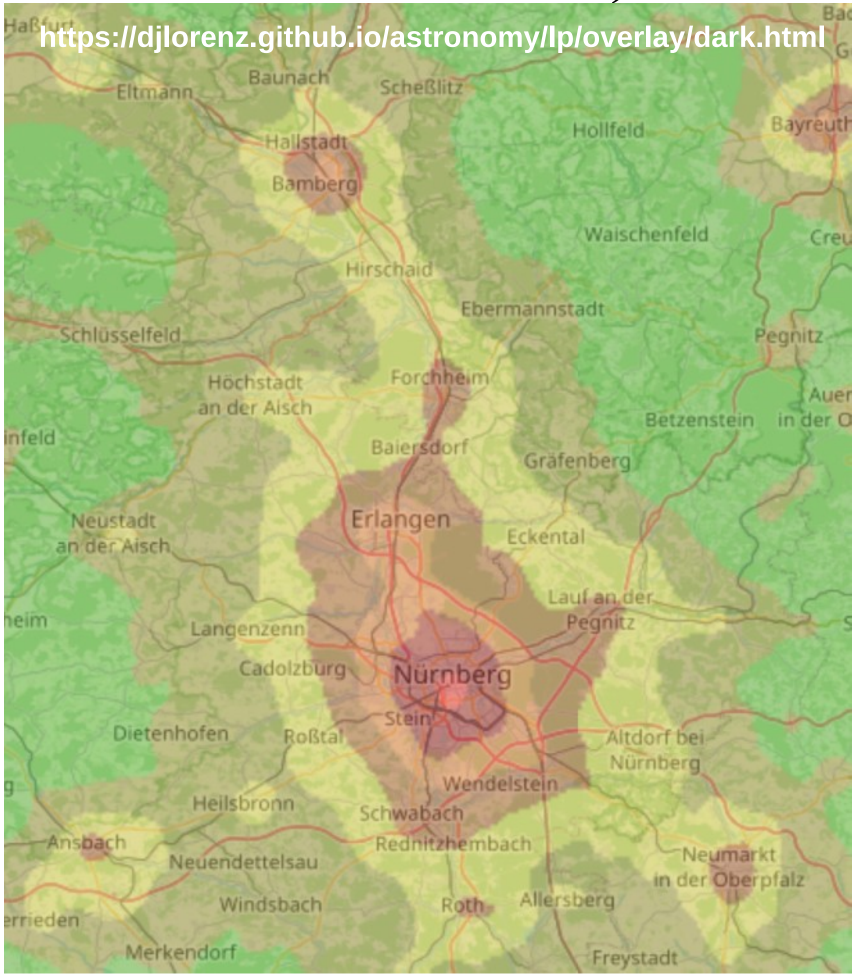
	Clouds				Index			Bad Layers			Ground		
🕓	Low	Mid	High	Arc Sec.	1	2	Jet Stream	Bot (km)	Top (km)	K/100m	Temp	Rel. Hum.	Celestial Bodies
23	0	0	0	1.35	5	5	15 m/s	01.6	02.6	0.6 K	18 °C	47%	---M-----
Sat 2025-06-21 sunrise: 05:11 sunset: 21:19 moonrise: 01:55 moonset: 16:52 moonphase: 21%													
0	0	0	0	1.32	5	5	15 m/s	01.6	02.6	0.6 K	17 °C	49%	---M----P
1	0	0	0	1.29	5	5	15 m/s	01.6	02.6	0.7 K	16 °C	52%	--------P
2	0	0	0	1.24	5	4	16 m/s	01.6	02.6	0.7 K	16 °C	55%	-----S-NP
3	0	0	29	1.19	5	4	16 m/s	01.6	02.1	0.8 K	15 °C	58%	L----S-NP
4	0	0	70	1.16	5	4	14 m/s	01.6	02.1	0.9 K	14 °C	61%	L-V--SUNP
5	0	0	100	1.14	5	4	13 m/s	04.4	05.1	0.5 K	14 °C	63%	L-V--SUNP
6	0	1	100	1.13	5	4	11 m/s	01.6	02.1	0.9 K	15 °C	60%	L-V-JSUNP
7	0	4	100	1.13	5	4	10 m/s	01.6	02.1	0.8 K	16 °C	56%	L-V-JSUNP
8	0	6	99	1.12	5	4	9 m/s	01.6	02.1	0.8 K	18 °C	50%	LMV-JSUN-
9	0	4	67	1.11	5	5	9 m/s	01.6	02.1	0.8 K	19 °C	46%	LMV-JSUN-
10	0	1	24	1.09	5	5	9 m/s	01.6	02.1	0.8 K	21 °C	42%	LMV-JSUN-
11	0	6	2	1.07	5	5	9 m/s	01.6	02.1	0.8 K	23 °C	38%	LMVMJSUN-
12	0	27	24	1.06	5	5	9 m/s	01.6	02.1	0.8 K	24 °C	33%	LMVMJSUN-
13	0	56	67	1.06	5	5	10 m/s	01.6	02.1	0.8 K	25 °C	31%	LMVMJ-UN-
14	0	77	98	1.05	5	5	10 m/s	01.6	02.1	0.8 K	26 °C	29%	LMVMJ-U--
15	0	83	100	1.04	5	5	10 m/s	01.6	02.1	0.7 K	26 °C	26%	LMVMJ-U--
16	0	81	99	1.02	5	5	10 m/s	01.6	02.1	0.7 K	26 °C	25%	LMVMJ-U--
17	0	71	86	1.01	5	5	10 m/s	01.6	02.1	0.7 K	26 °C	24%	-M-MJ-U--

01:55 05:11 21% 16:52



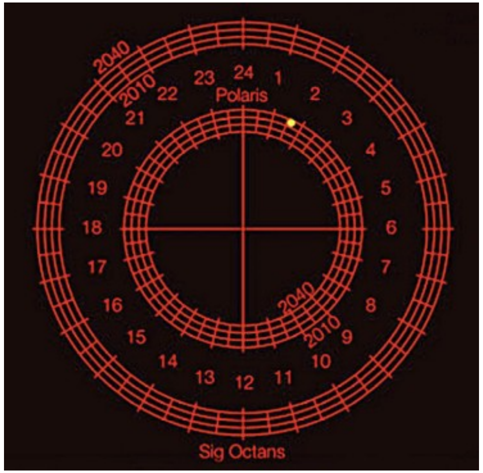
Light pollution (anthropogenic and the moon)

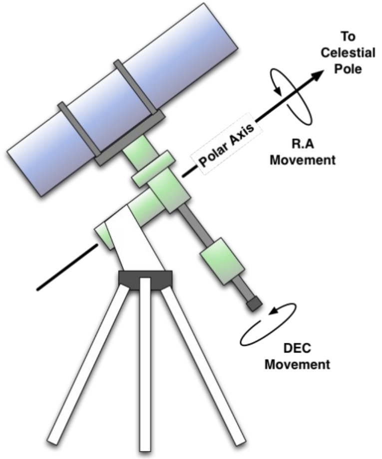
- Diffuse light background washes out targets
  (SNR more important than #photons)
- Full moon is ~bortel 7



Polar alignment

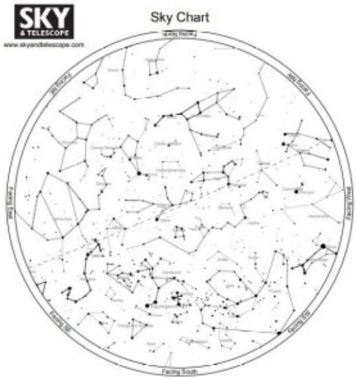
- Align R.A. axis to celestial pole
  via small telescope inside R.A. axis
- Polaris is close but not exact (~0.45° away)
- Star trackers sometimes feature lasers for rough alignment



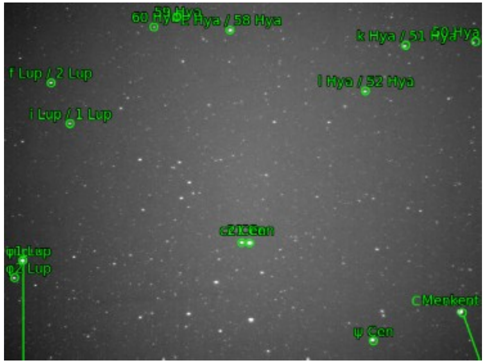


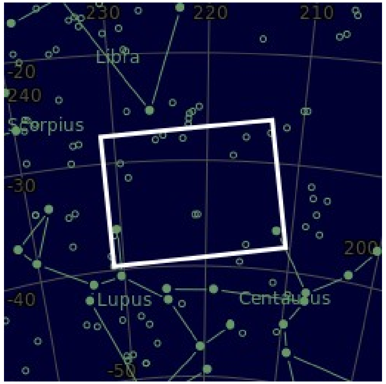
Finding the target I: Star hoping & plate solving (GPS in space)

- With a star tracker now you need to find the object by manually pointing the camera (while not knocking the tracker out of alignment)
- Star charts and phone planetarium software is helpful to go from constellation to constellation, star by star to the object
- This can be VERY frustrating and time consuming …
- Most of the time you will not even see your DSO in the image, here plate solving helps to iterate



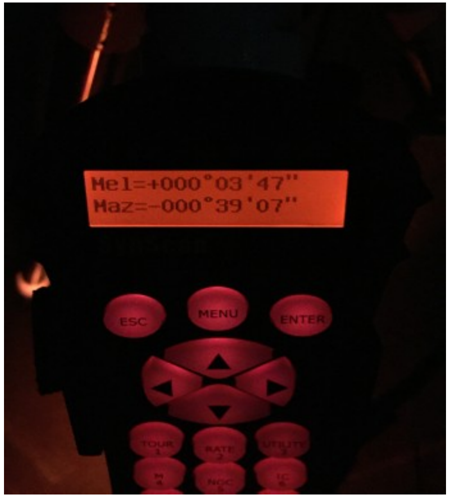
Astrometry.net



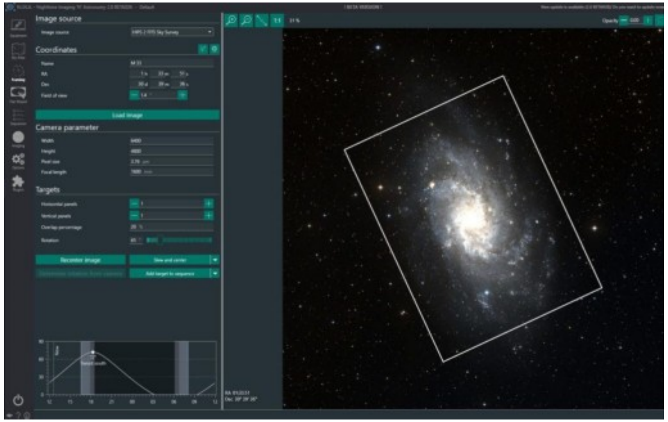


Finding the target II: Star alignment and automation

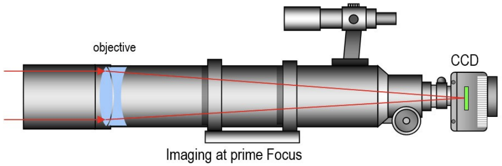
- Motorized go-to mounts feature star alignment methods
  - Mount slews to bright star
  - You manually center it in the FOV
  - Repeat 3x → mount knows orientation



- When software controlling all components (i.e. in NINA) software will plate solve every image and can automatically determine telescope orientation and slew to targets



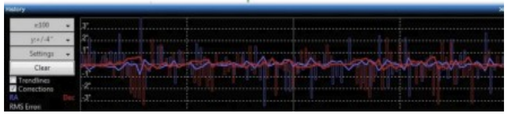
Guiding

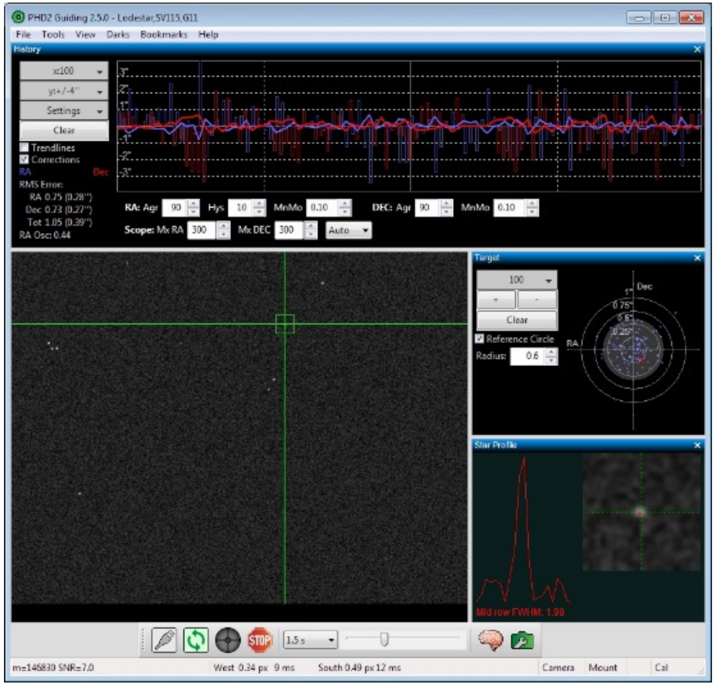


- Secondary guide scope takes an image every ~ second
- Software analyses star positions and sends correction signals to mount

  → can keep image stable to sub-arcseconds for minutes

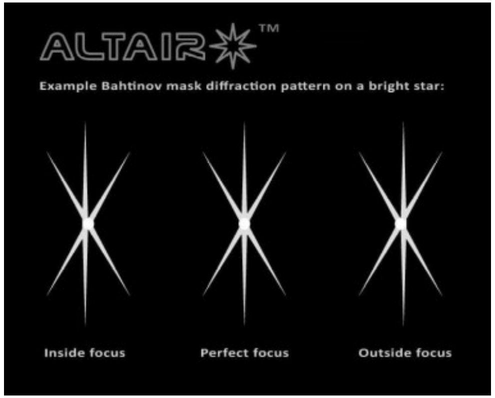
- Also allows for dithering:
  Sub-pixel resolution photography
  by randomly offsetting image by fractional pixel counts

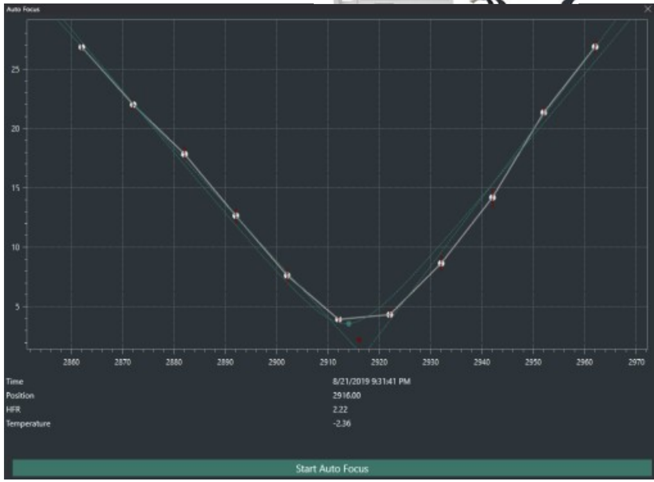




Focusing

Spherical aberration call spherochromatism
typical for camera lenses

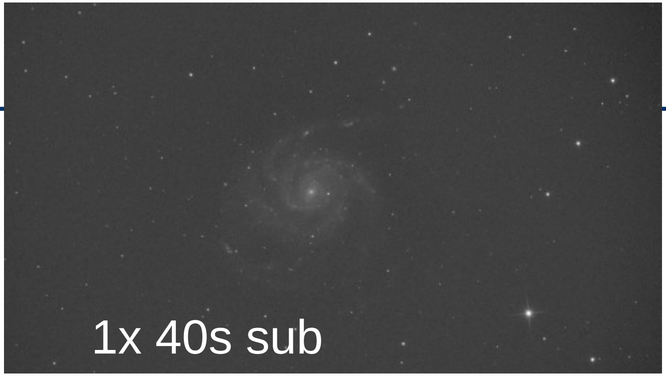


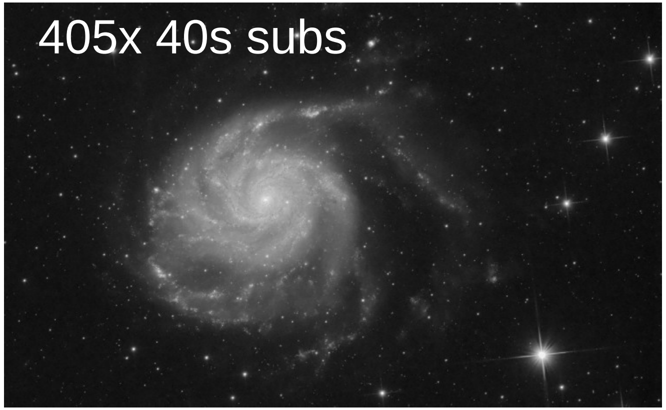


- Manual focusing aided by diffraction spikes of e.g. Bahtinov masks
- With a computer controlled setup can measure star size
(& with an electronic auto-focuser set focus position with um-accuracy)

Gathering subframes (subs)

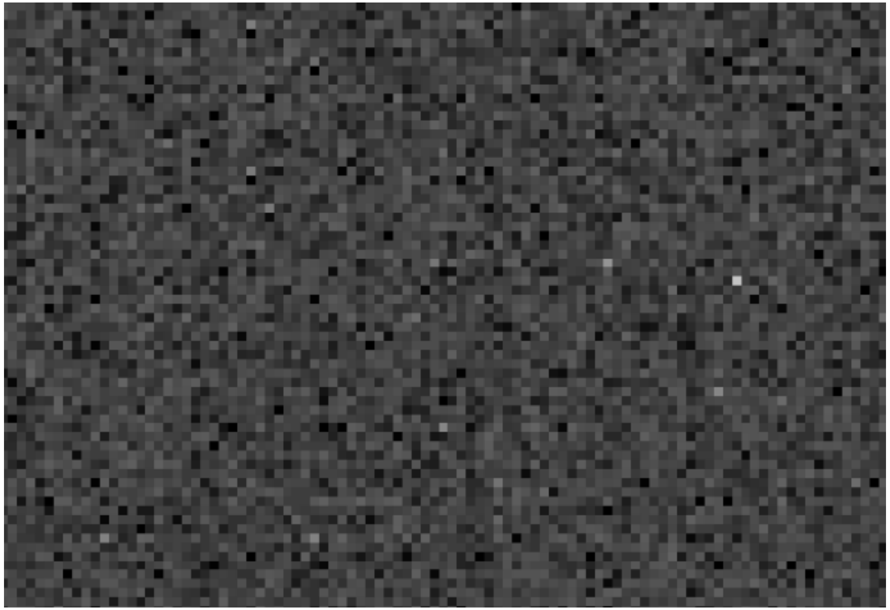
- Sub exposure time limited by:
  - Tracking / guiding stability
  - Camera dynamic range
    (keep stars unsaturated for true color)
  - Satellite trails
  - Can range between seconds
    to several minutes





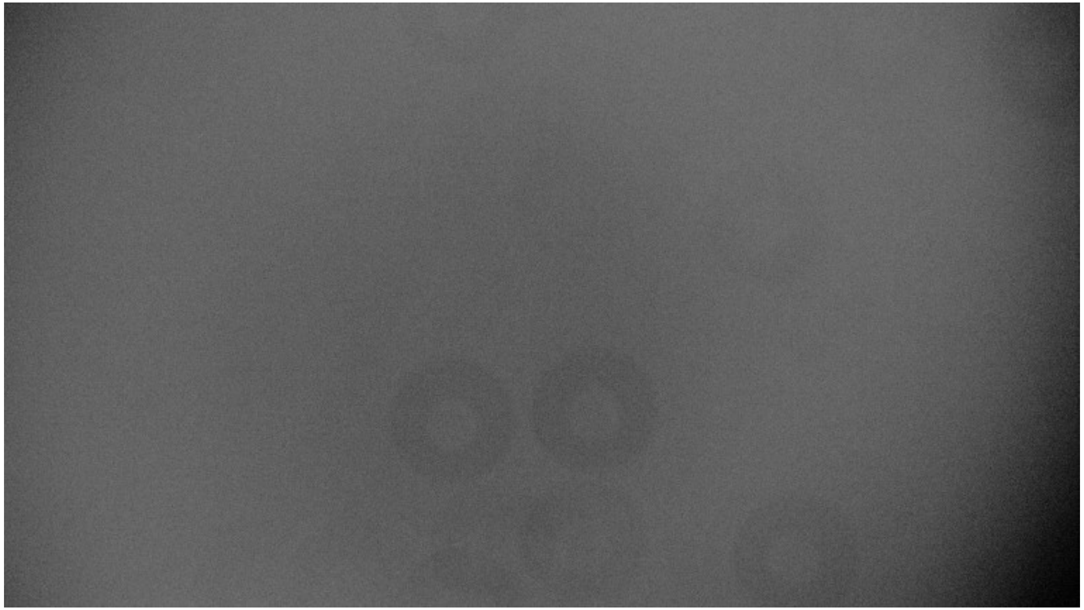
- Small project ~1h, serious projects starting at 10h, deep exposures can go to several hundred hours

Calibration frames – darks & flats



Camera image in perfect darkness not perfectly dark:

- ADC read-noise
- Thermal dark current
- Taken at same temperature & exposure settings



Not the same sensitivity everywhere in the image:

- Sensitivity falls of at large angles
- Dust particles (motes)
- Taken using LED panels or the sky at dusk/dawn with diffusor cloth sheets

Post-processing software

Siril
Open-source, very capable for both artistic and scientific imaging

my personal favorite

PixInsight
~400€
Supposed to be THE best in software.

Not tried myself yet...

AstroPixelProcessor
~200€, supposed to be quite good

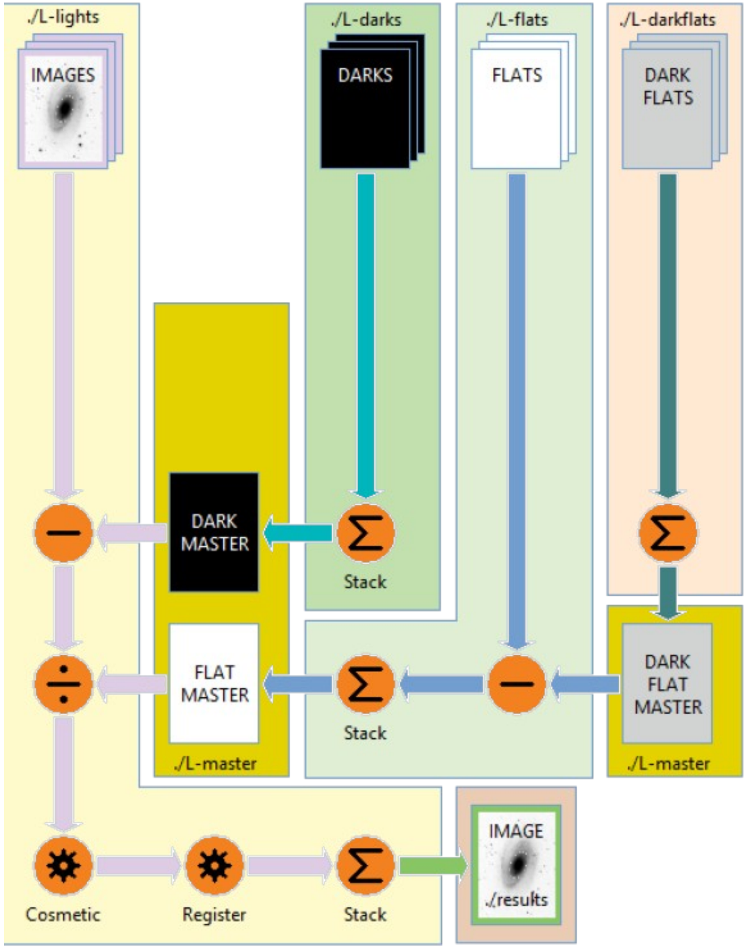
Sequator
Free, good for landscapes

SetiAstroSuite
Free, rapidly developing, strong AI integration

ASTAP
Free, great but technical, amazing plate solving

DeepSkyStacker
Free, a bit outdated

Stacking – calibrate, align & average subs



A tangent on SNR….

- Stacking is not about gathering more light, but about increasing the statistical uncertainty of the gathered light….
- Each pixel samples from a Poisson distribution of Target Flux + Sky flux
- We want to measure the Target Flux:

SNR = Target Flux * time / sqrt((Target Flux + Sky Flux) * time)

→ - SNR grows as the square root of time
- Time needed to reach a constant SNR growth linear with Sky flux

Cropping & Background extraction

- After stacking crop image to common region
- Fit and subtract low-order polynomial
  to remove sky flux / light pollution background
- (Or use AI models like GraXpert)

Sharpening & denoising (classic & AI)

- While there are limits to the obtainable resolution / sharpness images can be improved either by deconvolution (when knowing the PSF) or applying AI denoising/sharpening tools
- Best to go easy, as aggressive sharpening leads to artifacts

(Spectrophotometric) color calibration

Color in astrophotography is always tricky and often a matter of taste.

But initial color correction / white balancing often performed on catalog data of star colors (e.g. from the Gaia satellite mission)

Stretching

- Original image is „linear“: Twice the photon count = twice the image brightness
- We need to apply a transfer function to lift information from shadows into mid-tones and highlights
- Can be algorithmic (statisitcal stretches), guided (arcsinh, GHS) or manual
- Also referred to as histogram or curve transformations
- Be slow and go in steps, easy to over-do

Star processing (e.g. with StarNet++)



Foreground stars often a lot brighter compared to deep sky object.

Problem: Would want to stretch DSO strongly, but this clips stars….
Common solution: Use (AI) tools to seperate stars and DSO and process separately

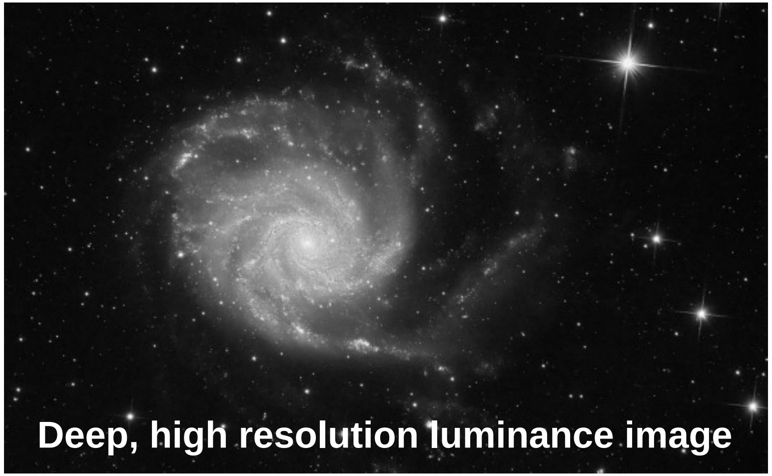
Layer based image editors

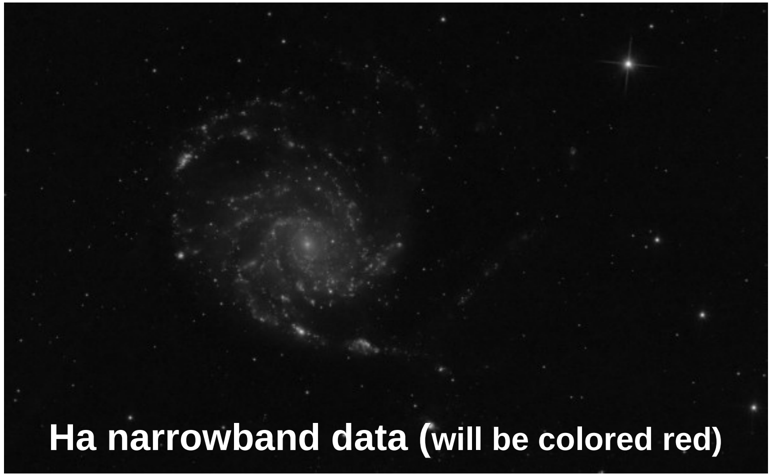
- After stretching images mostly further processed in classical layer based editors (Photoshop, Gimp)

- Narrowband color assignment (color pallet picking)
- L-RGB merging (based on L mask)
- Stars and starless blending

- Artistic touchups:
  - Color contrasts
  - Wavelet sharpening
  - Curve transformations
  - ….

Merging narrowband and/or L-RGB

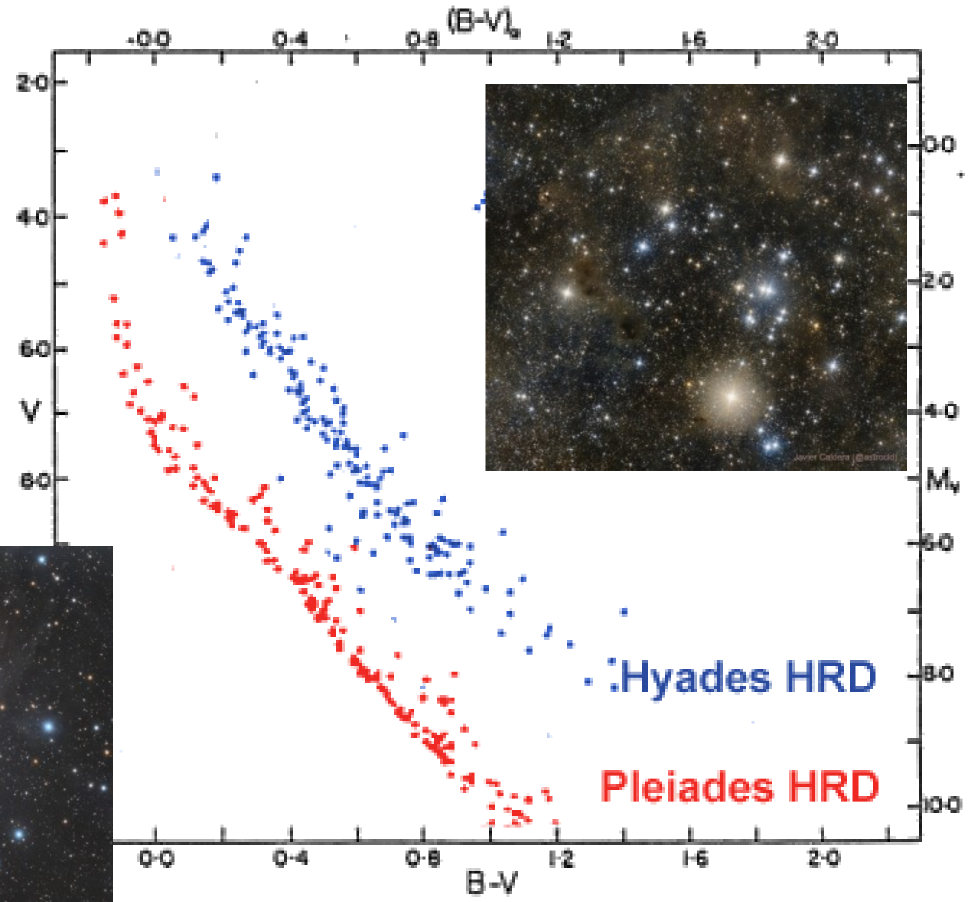




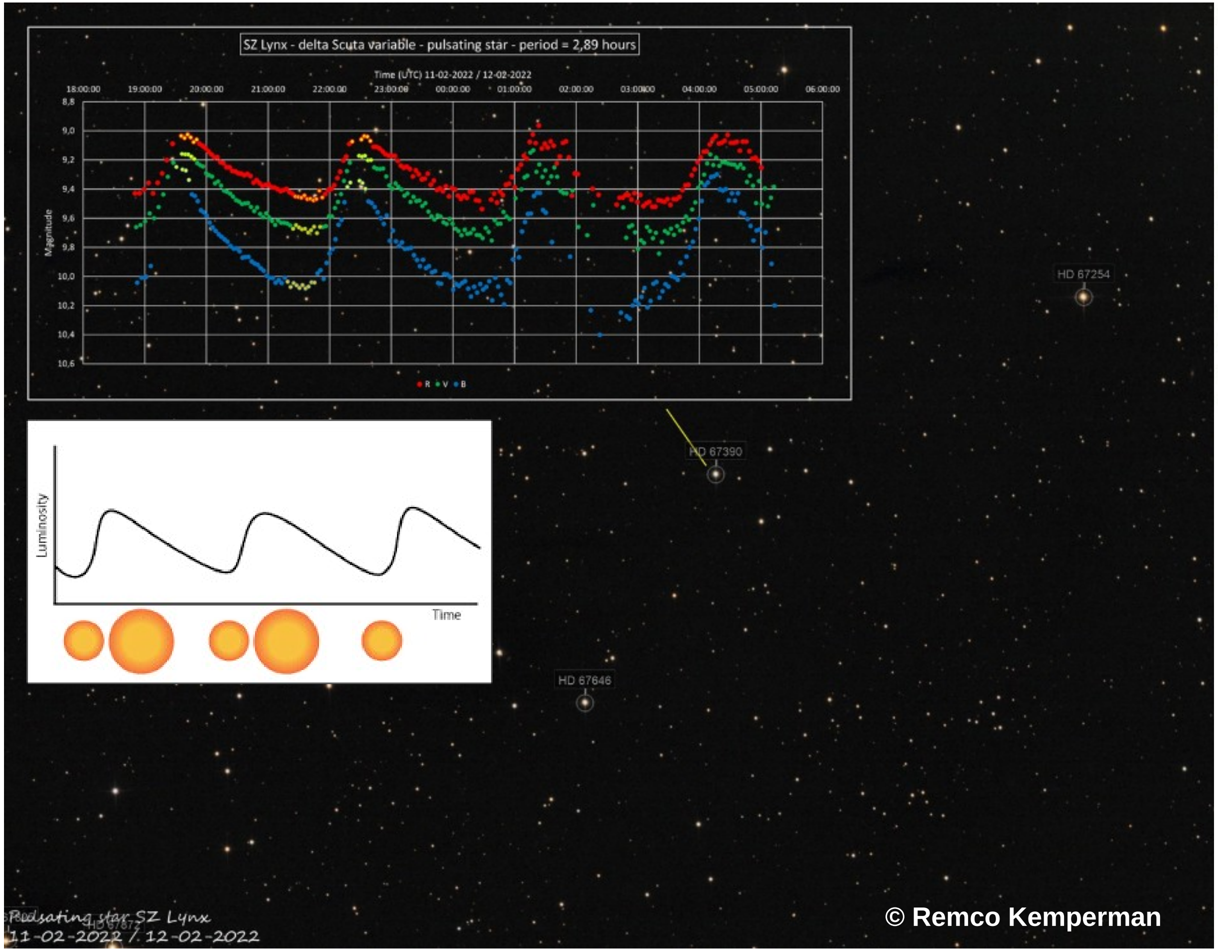
Scientific imaging: Photometry (HRD)

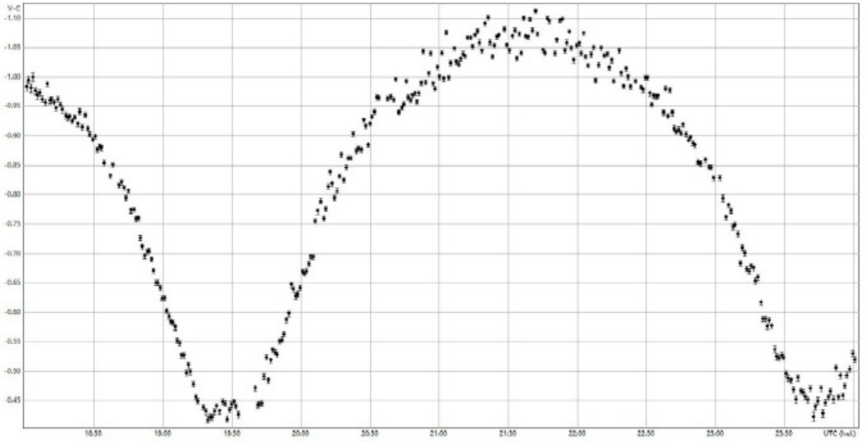
Images can also be used quantitatively.

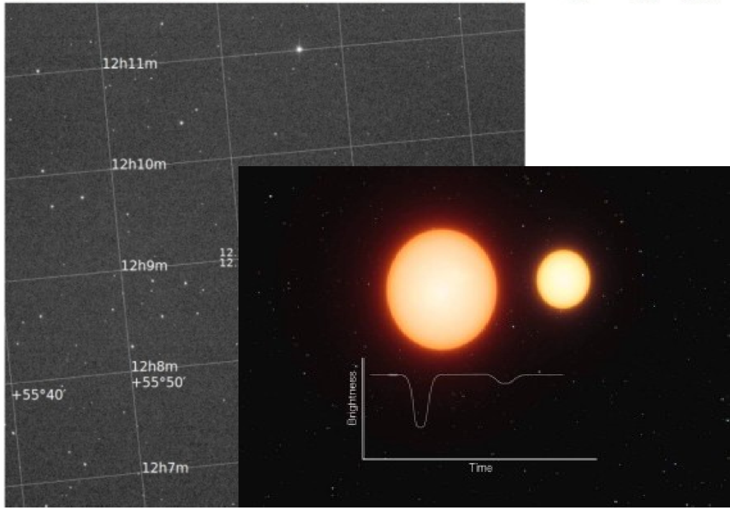
For example to measure star color and brightness, building „Hertzsprung-Russell diagram“ to see stellar evolution and for example measure relative distance of star clusters.



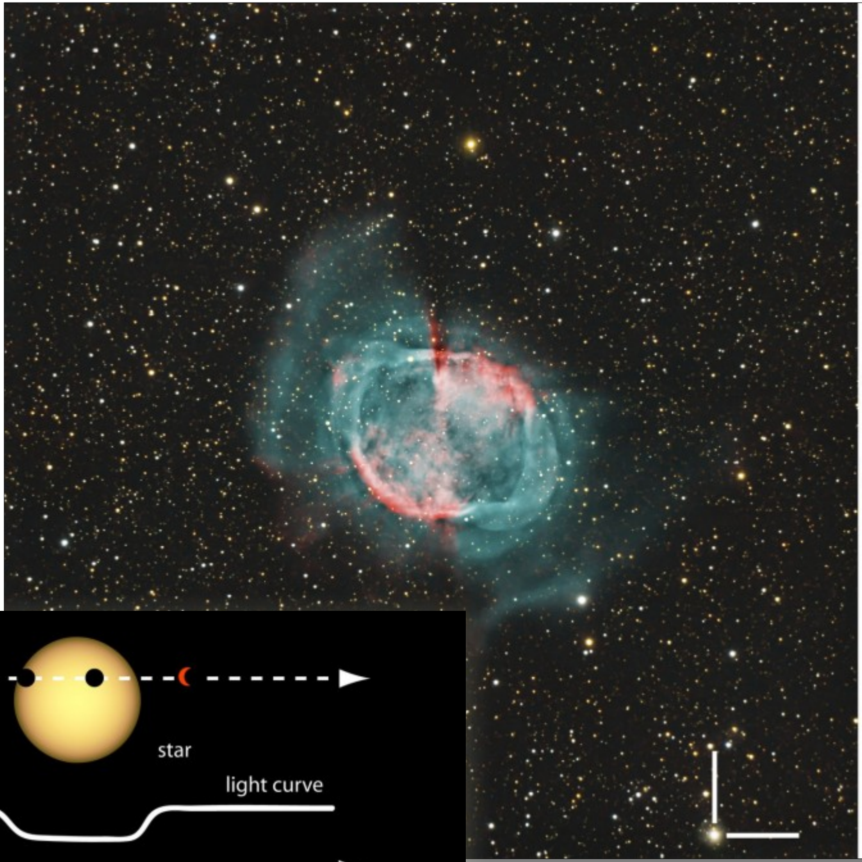
Scientific imaging: Variable stars

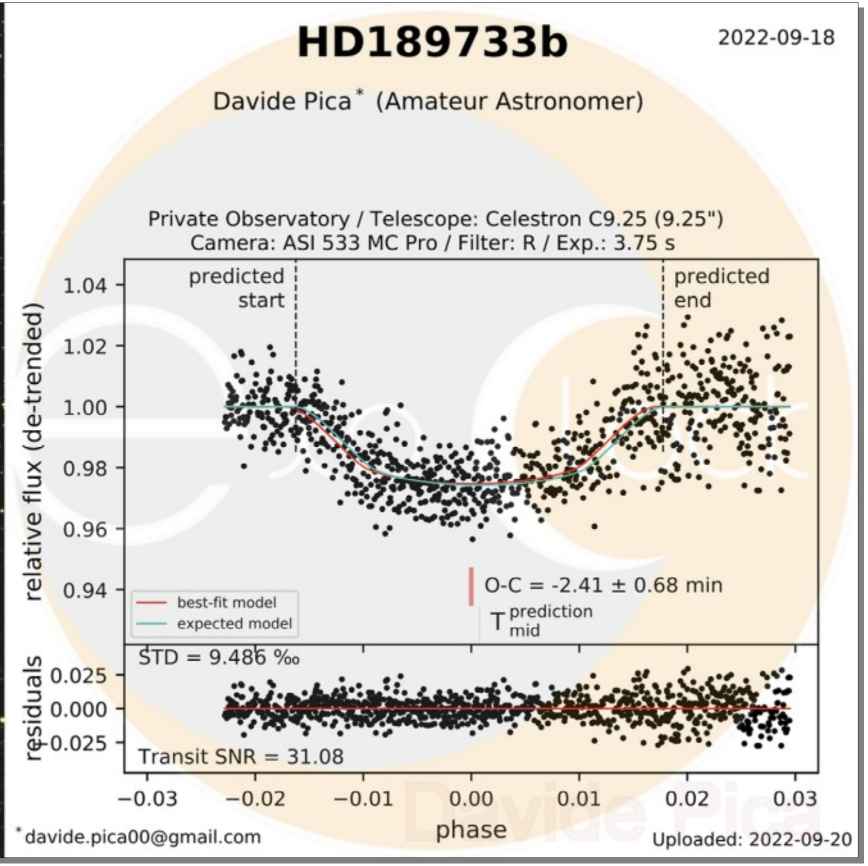


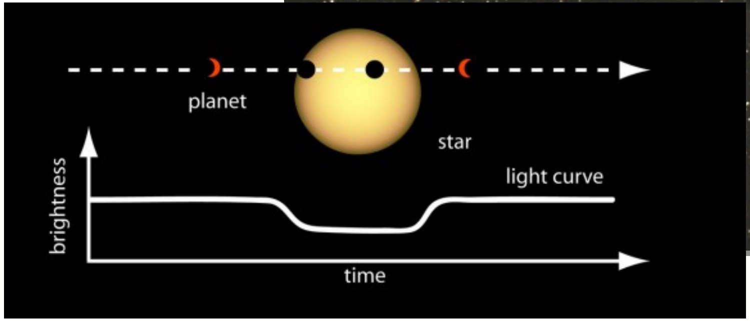




Scientific imaging: Exoplanet transients

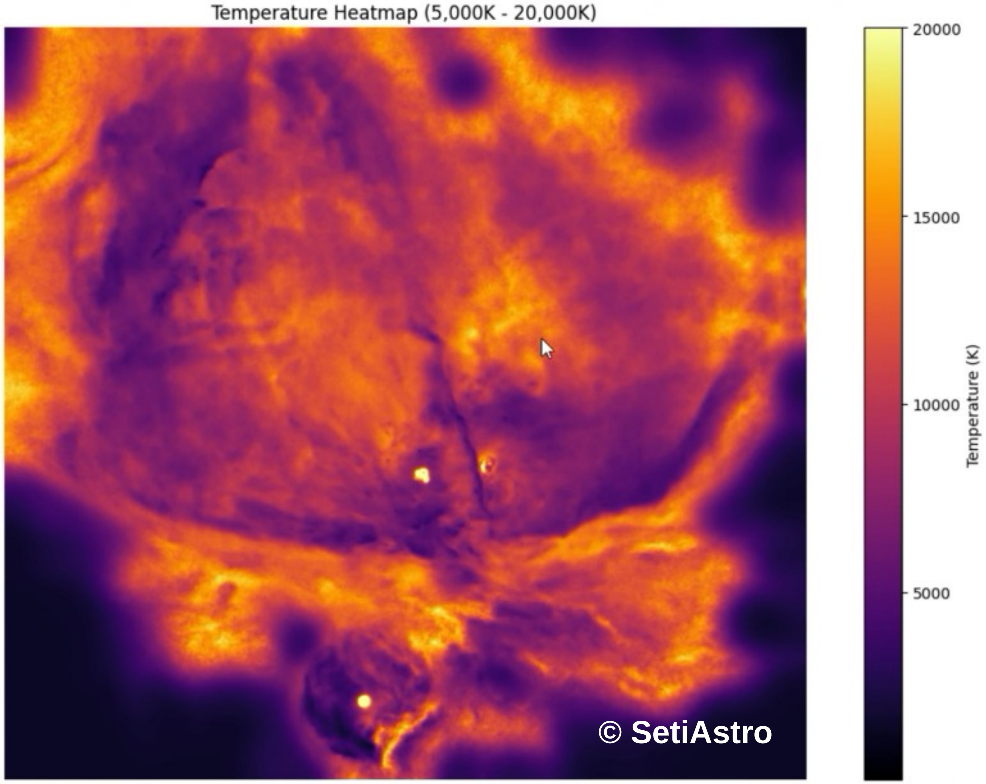




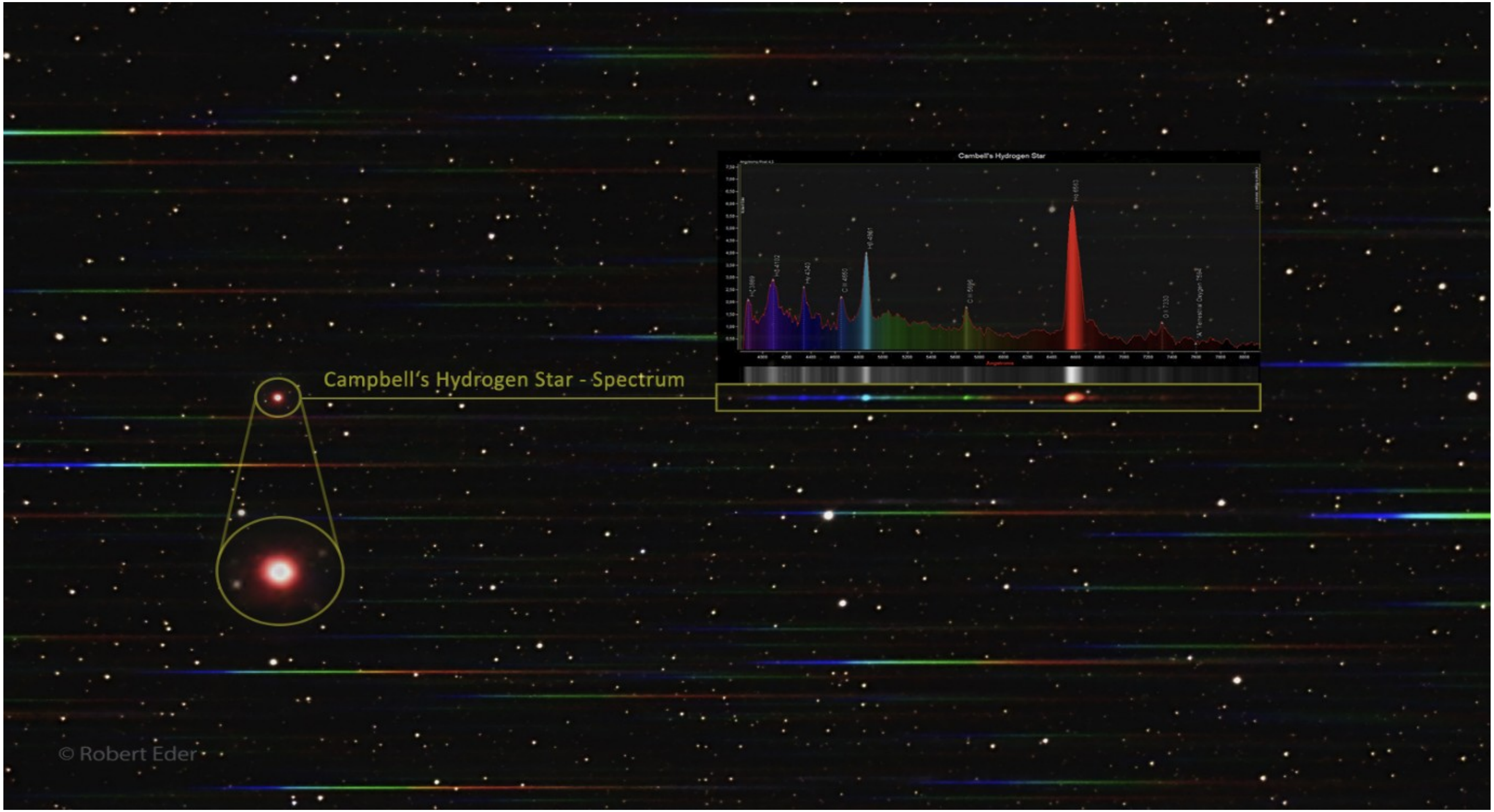


Scientific imaging: Balmar decrement imaging

Capturing the ratio of H-alpha (656nm) to H-beta (486nm) emission
to deduce hydrogen gas temperature



Scientific imaging: Spectroscopy



Astrophotography as an academic hobby

- We **can** get AMAZING results
- BUT there will **also** be better pictures than yours
- The hobby is mostly about learning to improve yourself and plenty of failing along the way
- So temper your expectations and enjoy the progression

Some more pictures

Thank you for your attention!

Questions?