Astronomy

From visual …

… To the photo

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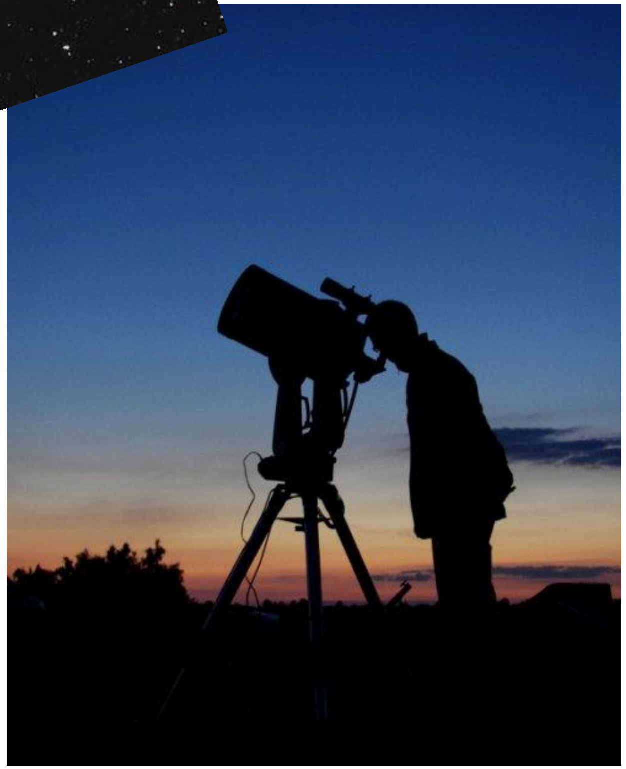
06/13/2019

Summary

- Introduction
- Light pollution
- Visual observation
- Astrophotography
- Advanced Techniques
- Similarities with optical remote sensing
- What materials for what budgets?
- Information helpful



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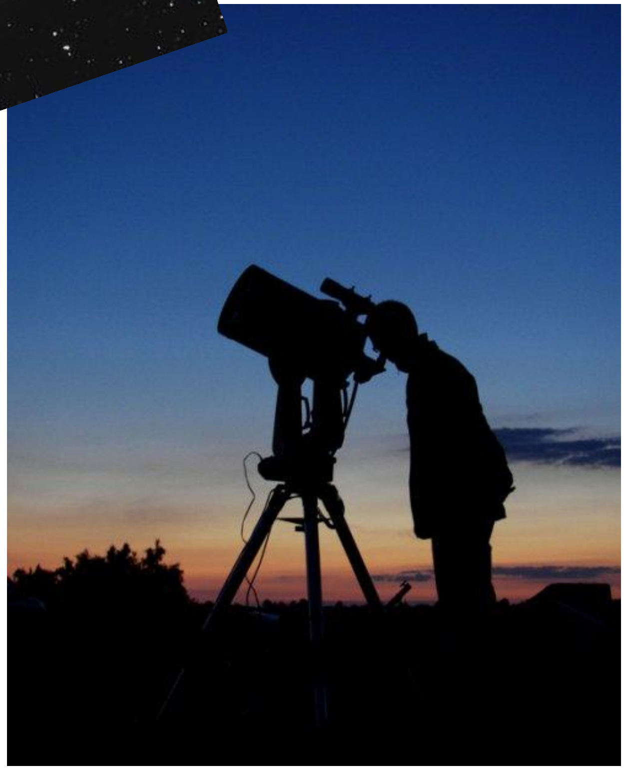
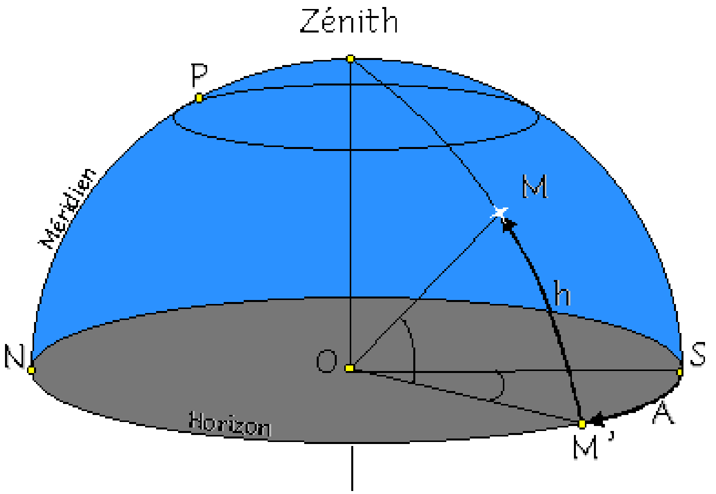


Some key dates

- 1543: Copernicus: The Earth is not the center of the universe!
- 1609: Kepler: Planetary motion lows
- 1610: Galileo: 1st refractor + Observation of Jupiter satellites
- 1687: Newton: 1st reflector + Gravitation lows
- 1860: Huggins: Spectroscopy => Birth of Astrophysics
- 1905: Schwarzschild: Prediction of black holes
- 1916: Einstein: General Relativity theory
- 1929: Hubble: Expansion of the universe
- 1931: Jansky: Radio transmission => birth of radioastronomy
- 1948: Gamow: Big Bang theory
- 1970: Rubin: Dark matter hypothesis
- 1975: Hawking: Black holes evaporation
- 1995: Mayor and Queloz: Discovery of the first extrasolar planet
- 2015: First detection of gravitational waves
- 2019: First image of a black hole

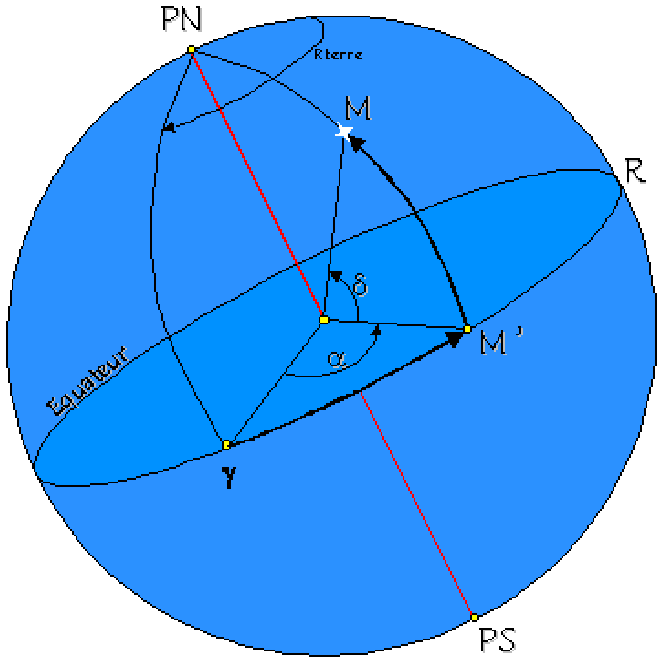
Coordinate systems and Magnitude

- Coordinate system
  - The observer on Earth is at the center of the coordinate system
  - Imaginary lines are represented on the celestial sphere



- Azimuth Type: depends on the place and time!
  - Azimuth : Origin South = [0 ° 360 °]
  - Height : Original Horizon = [0 ° to 90 °]

- Equatorial Type: Uniform system
  - Declination (⇔Projected latitude): Original = celestial equator [-90° to 90°]
  - Right Ascension (⇔Projected Longitude): Original = Vernal Pt [0° 360°] (Intersection of the ecliptic and the celestial equator)



- Apparent Magnitude
  - Used to measure the brightness of a celestial object
  - The more it is high and the less it is light (log scale inverse)
  - Polaris = 2.09 ; Vega = 0 ; Sirius = -1.46 ; Sun = -26.78

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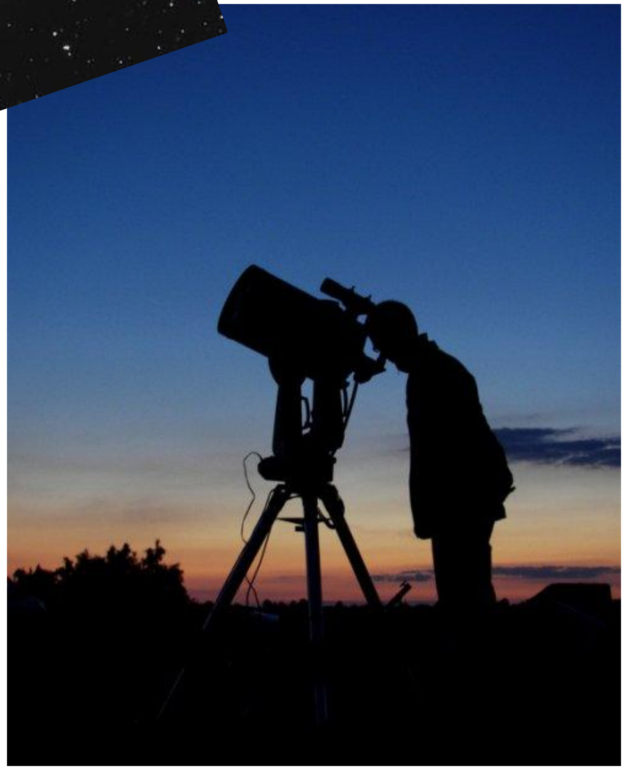
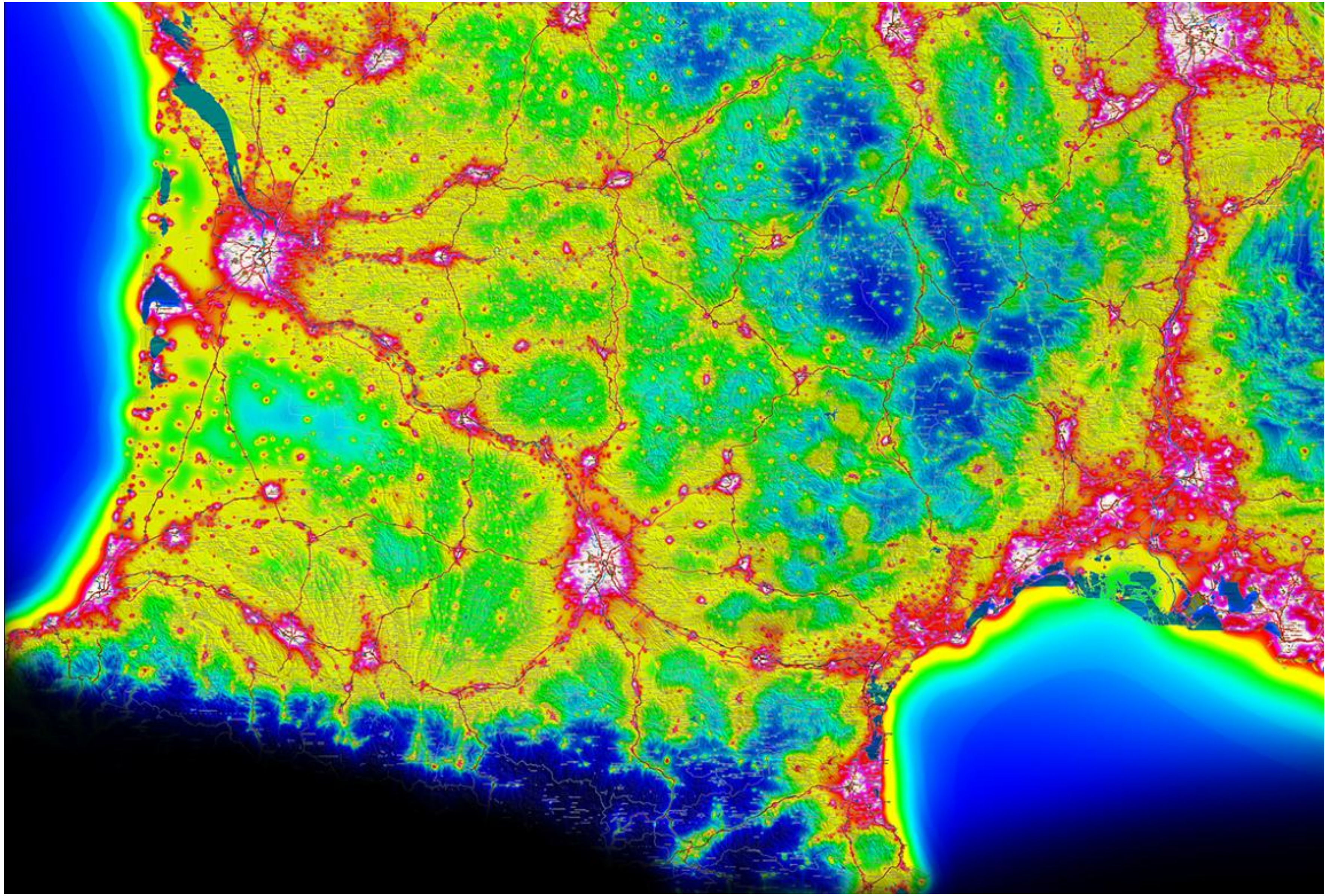


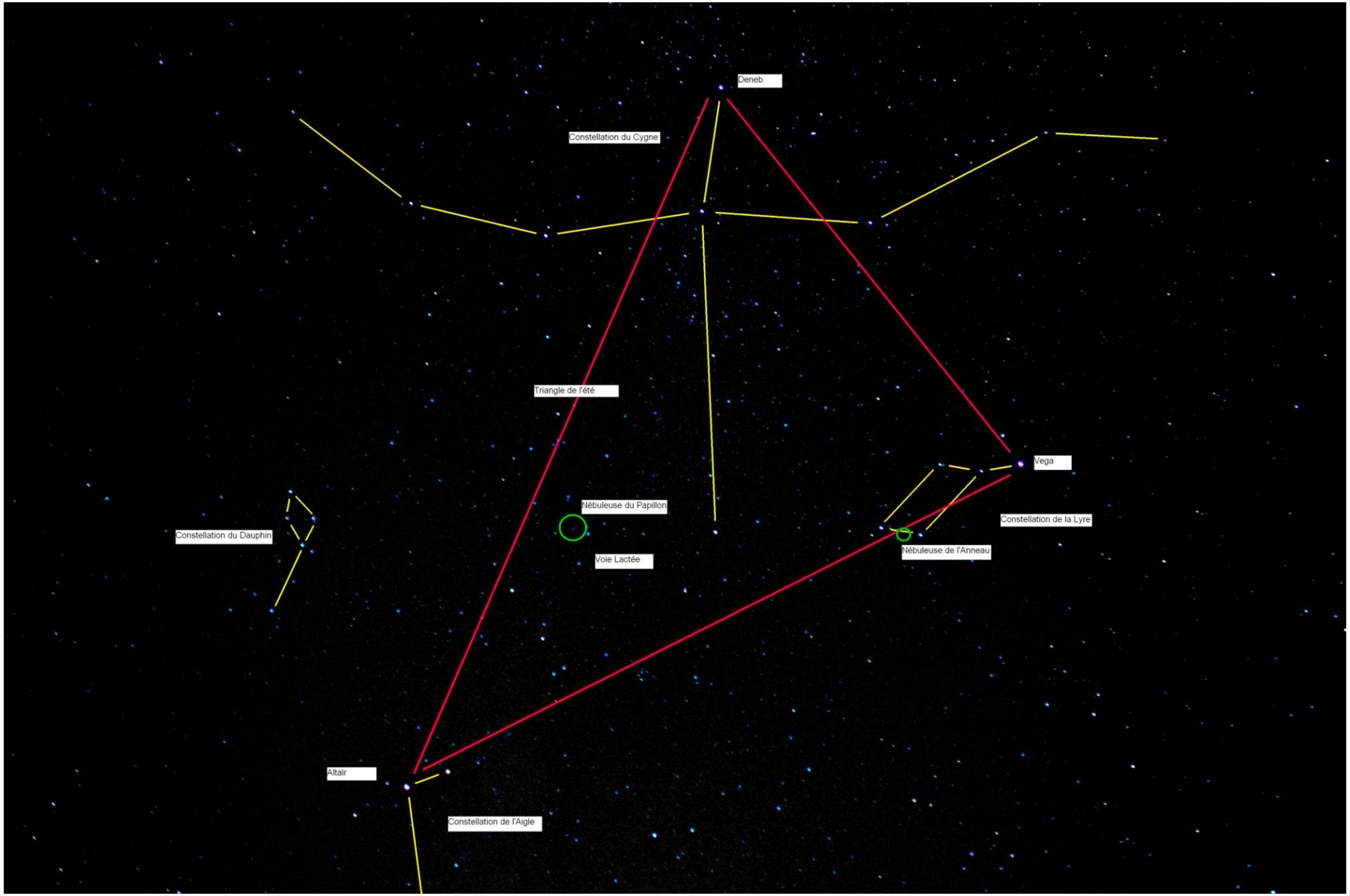
The real Star Wars: Light pollution!



Example with campaign sky (simulation)

Example with suburban skies of a medium city (simulation)

The summer triangle



Some towns switch off their lights at night: **before**

Some towns switch off their lights at night: **after**

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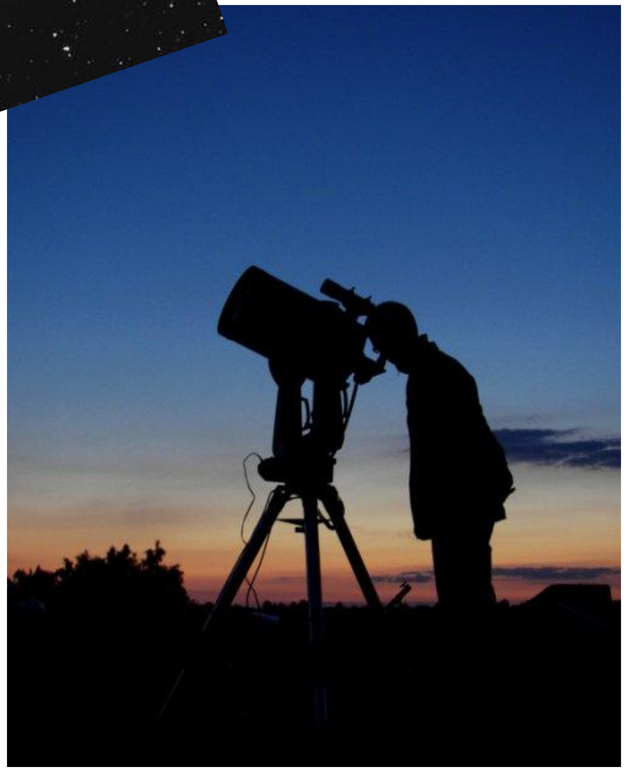
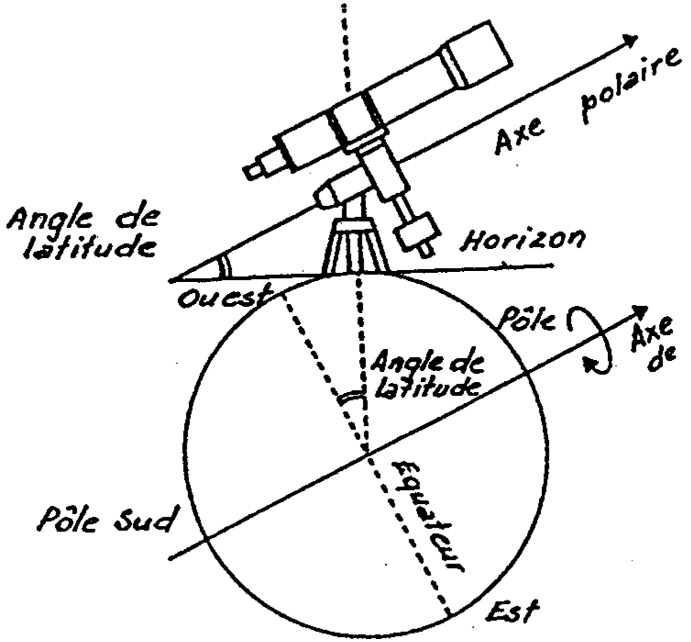


The setting station

- Advantage of the equatorial mount
  - The axis of rotation of the earth is (almost) aligned with the polar star
  - Simply align the "AD" axis of the mount on the Polar star
  - The equatorial mount has just to follow the earth's rotation to track on a pointed celestial object (sidereal rate via a motor)

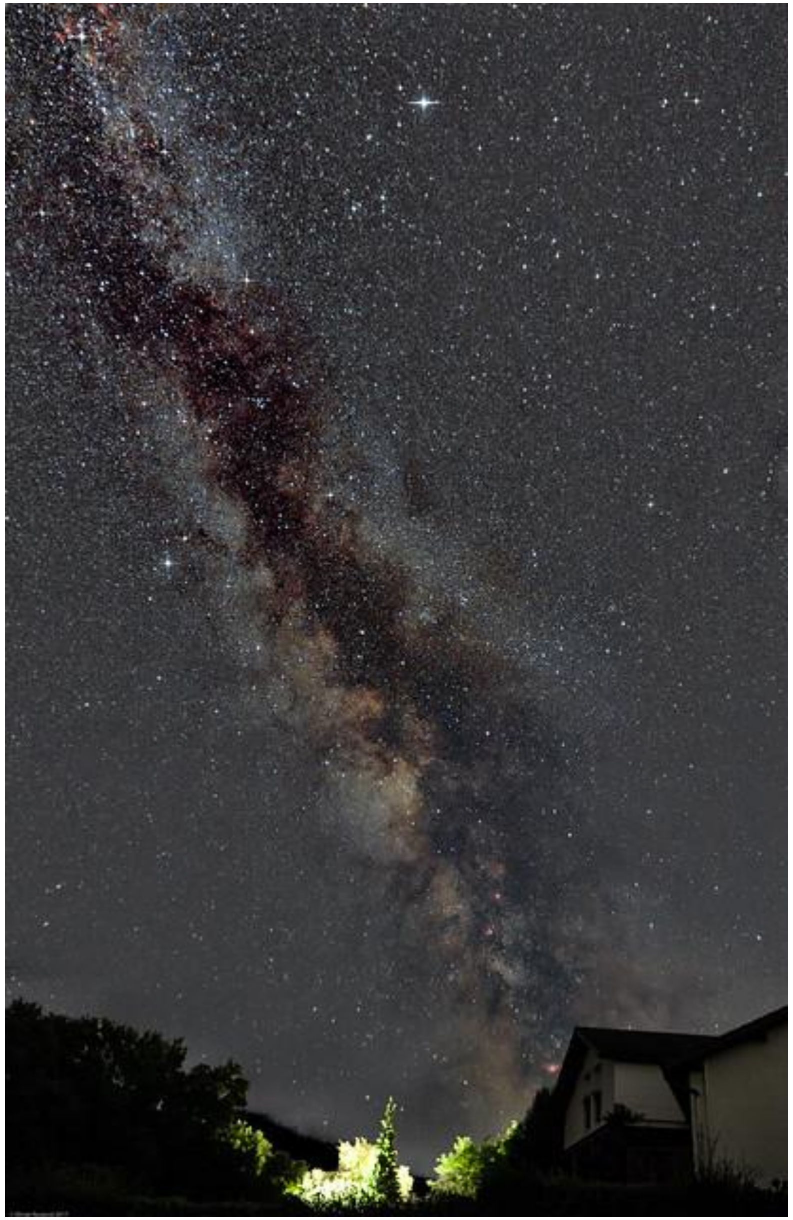


- Setting station of the equatorial mount
  1. The tripod mount must be level
  2. Polar Alignment using the polar finder
  3. Updating GPS coordinates of the observation place
  4. Alignment on 3 bright stars through the racket or a software on a PC connected to the mount (correction by triangulation)
  5. Saving registration points for not redo everything
  6. The mount is ready to find and track a celestial object (GoTo)

Visual observation: the more accessible

- **The eyes**
  - Wait about 10 minutes to adapt to darkness
  - You have to spot from the Big Dipper => Polar star
  - We can see :
    - The Milky Way
    - Constellations and some stars clusters (Pleiades)
    - The Andromeda Galaxy
    - The planets
    - Shooting Stars

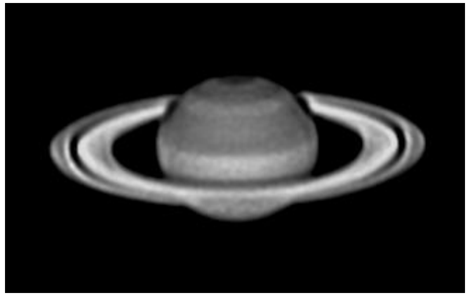
- **The Twins**
  - Preferably use a tripod to a have a stabilized view
  - Adjust each eyepiece separately on a bright star
  - Lets have a "3D" effect
  - We can see :
    - The open star clusters (Double Perseus cluster)
    - The bright nebulae (Orion)
    - Jupiter and its satellites



Visual observation: refractor and reflector

▪Refractor or reflector ?

- The both used to see everything but depends on the diameter
- The brightness of instrument depends on the focal / diameter ratio
  - ➢ F / D> 10: ideal for bright objects like planets
  - ➢ F / D <5: ideal for faint objects like galaxies
  - ➢ F / D small ideal for the photo because decreases the exposure time
- The resolution and magnification increases with the diameter
  - ➢ Magnification Max of instrument ~ = 2.5 × Diameter
  - ➢ Magnification = Instrument focal / ocular focal
  - ➢ If M > M max then the image will be blurred!



▪Factors differentiating

- The price of a refractor is higher with equivalent diameter
- The reflector needs to be "collimated" regularly
- The refractor provides more contrast images
- The reflector is bulkier to carry
- Prioritize the diameter of the instrument : reflector (cheaper price)

Visual observation: accessories


- **Eyepieces : 3 focals enough**
  - Large field: f> 20 mm
  - medium field: f E [10 mm; 20 mm]
  - Strong magnification: f <10 mm but with wide angle (>60°)

- **Barlow lenses**
  - Increases the eyepiece focal and thus the magnification
  - The multiplier coefficients range from 2x to 5x
  - Some also have a field corrector


- **Filters**
  - Moon: variable polarizing
  - Sun :
    - ➢ Sun filter for sunspots
    - ➢ H-Alpha filter for the protrusions (but very expensive)
  - Deep sky: anti-light pollution filter (UHC or CLS type)
  - Planets: different colors in order to improve the contrast according to the planet to observe

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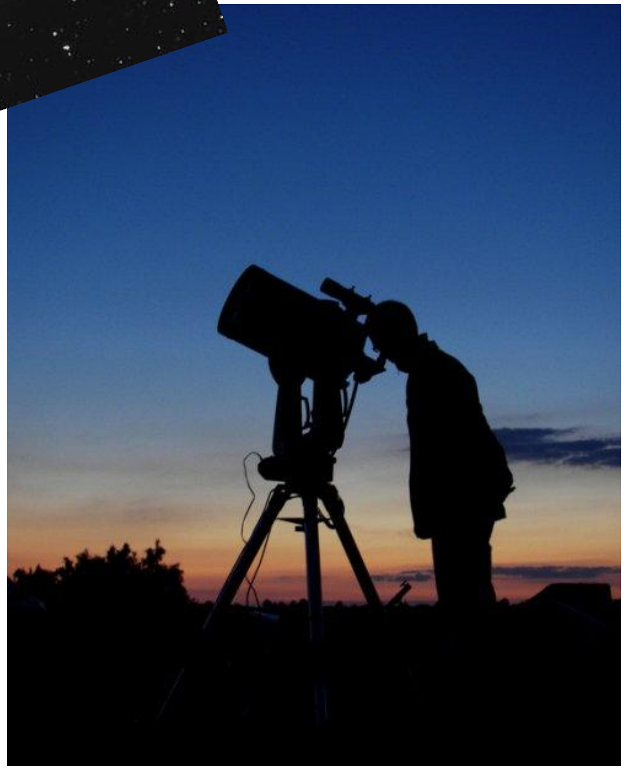
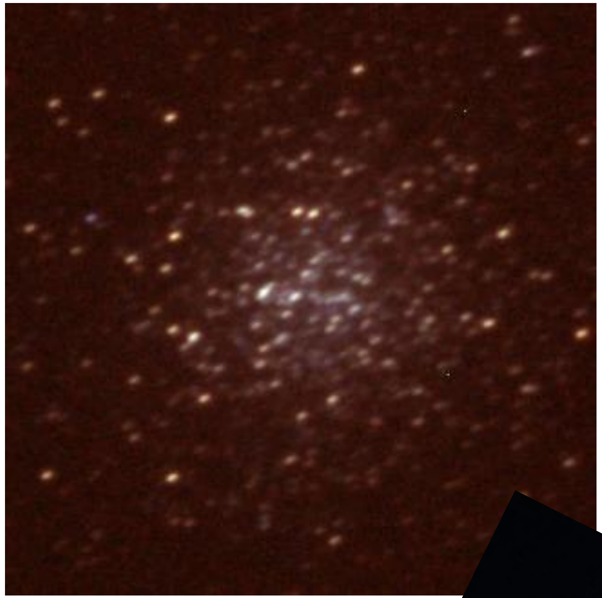
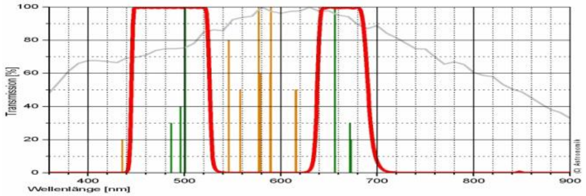
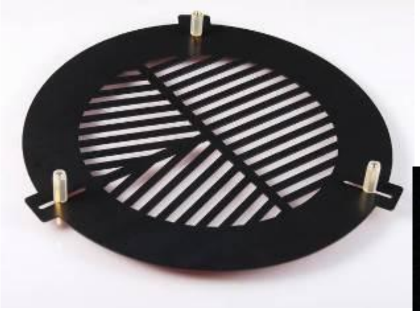


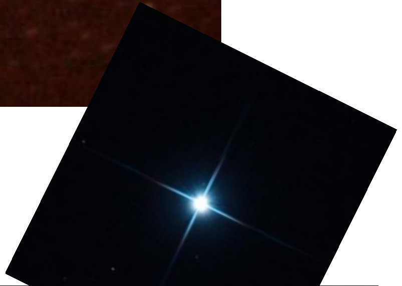
Astrophotography: difficulties begin!

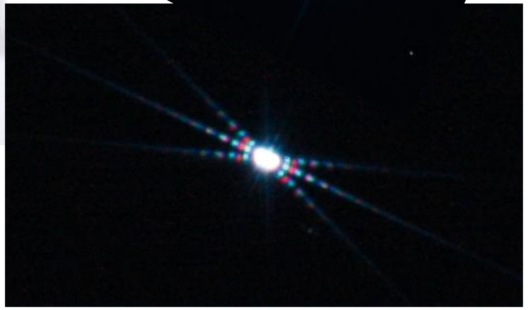


- **Problems**
  - Low light => long exposure time => stability required
  - The mount stationary is not perfect => the tracking drifts
  - The mount tracks the subject but there are mechanical games
    => Periodic error is large (worm)
    => The photo is blurry!
  - Light pollution is high => orange picture!
  - The focus is not quite accurate => sharpness problem!
  - The photo is too noisy => 'grains' in the photo!
  - There is dust and hot pixels in the photo







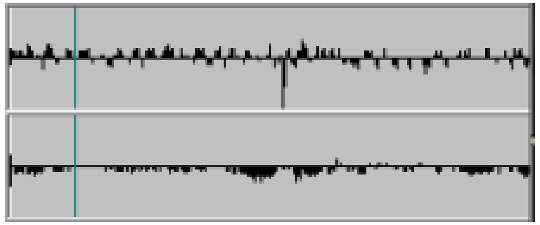


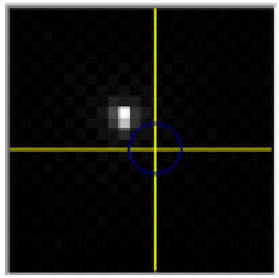
- **Workarounds**
  - Focus performed using a Bahtinov mask
  - Setting up an automatic tracking: Auto Guidance
  - Adding a light anti-pollution filter
  - Noise reduction in the picture: you stack multiple photos
  - Removal of dust and hot pixels with "flats" and "darks"

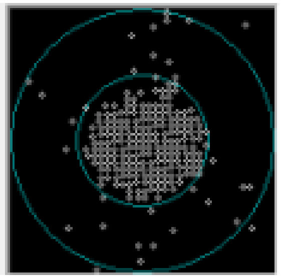
Astrophotography: Auto Guidance

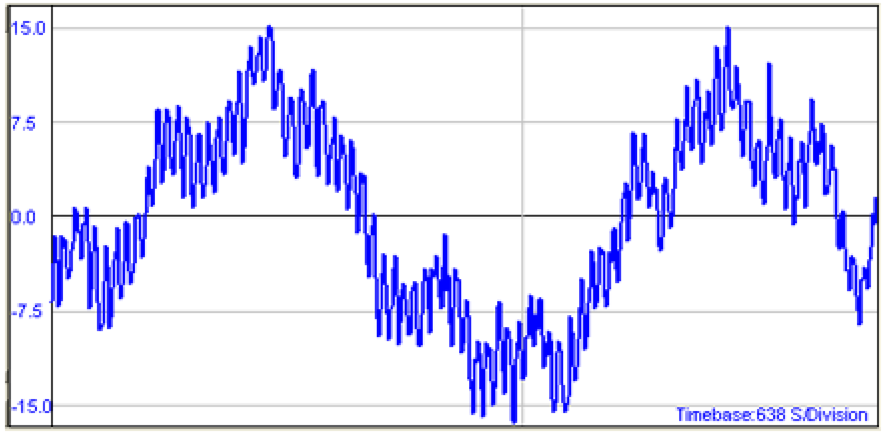
▪Principle

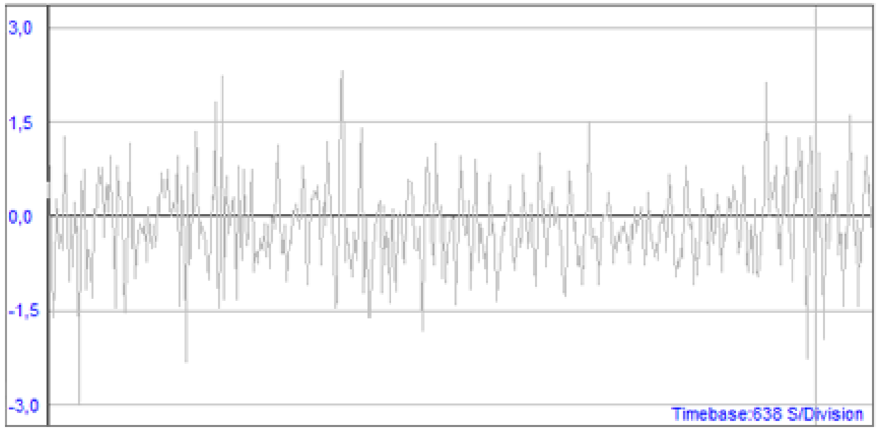
- Measure the tracking error / initial position
- Monitoring deviates from the tolerance?
- If yes, send orders + or - to the mount
- Error lower than tolerance error?
- If yes, stop sending orders







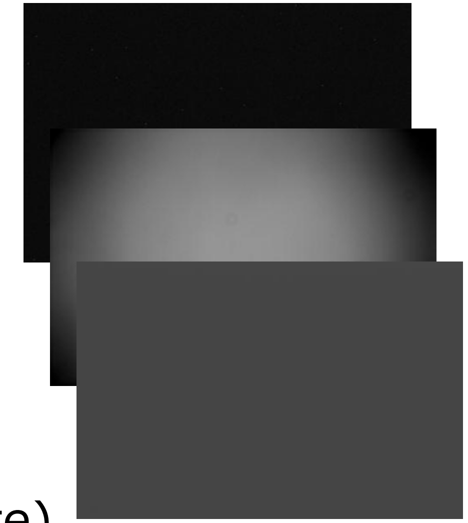




▪Set up

1. Add in parallel a small refractor to the instrument
2. Mounting a monochrome camera on the refractor
3. Select a "guide" star near the object to be imaged
4. Use a guidance application (Guidemaster or PHD2)
5. Adjust the focus and make a calibration on the chosen guide star
6. Lock tracking mount on the guide star
7. The application then sends track orders to the mount

Astrophotography: pretreatment is essential



- **Goal**
  - Reduce noise in the image
  - Remove defects: dust and hot pixels

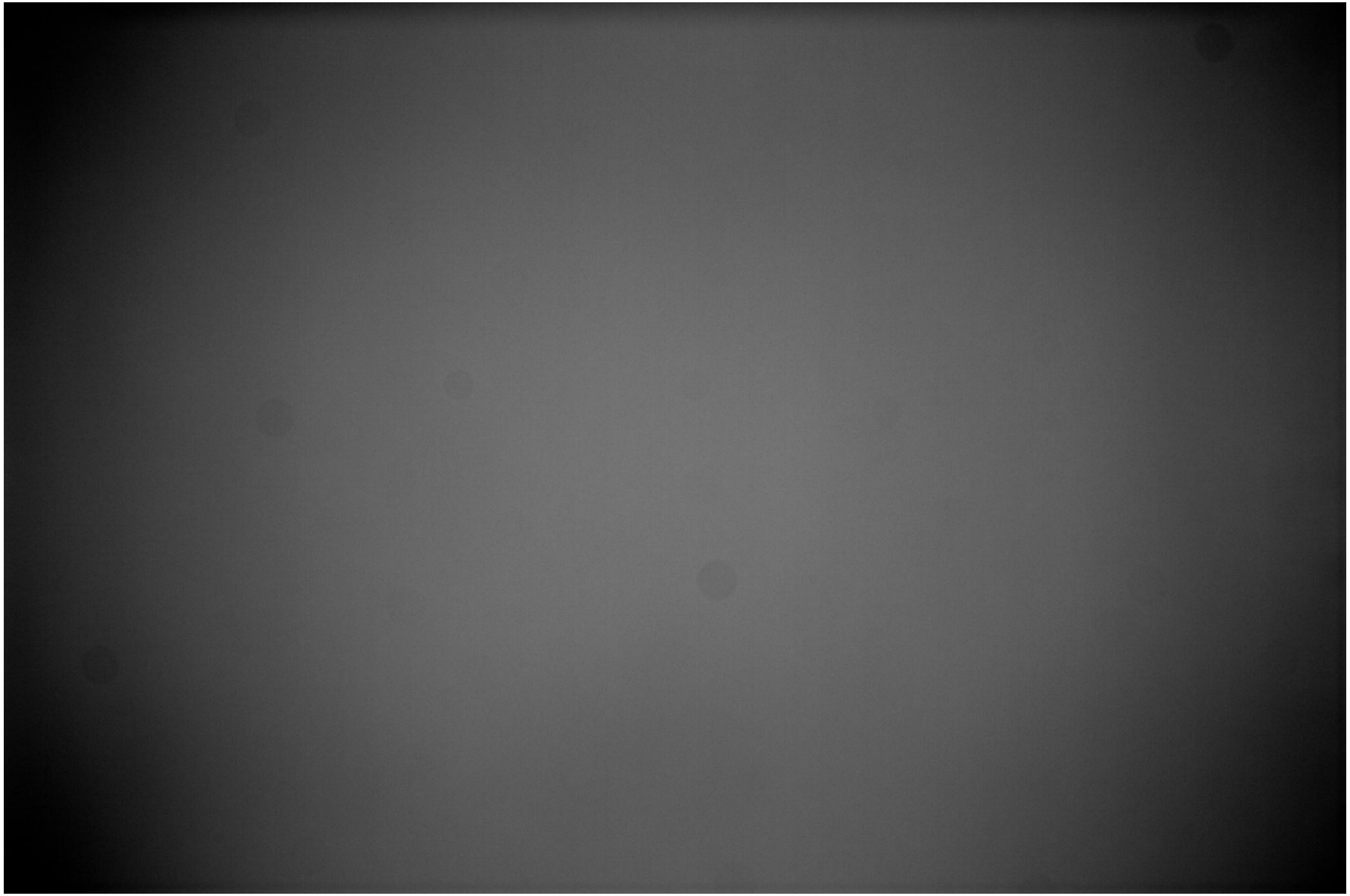
- **Method: make calibrations** (As for spatial imaging)
  - Making « bias" photo with closed shutter and exposure time as short as possible (measuring the darkness current)
  - Making "flats" picture with the same focus on a uniform background (white)
  - Make "darks" photograph with shutter closed and with the same exposure time as the object (measurement of thermal noise)
  - Make several raw images of the object (> 10)

- **Procedure**
  1. Create the calibration images 'master': median stack of each calibration
  2. Create raw images pretreated with the following formula:
     pretreat_raw = (raw – master_dark) / (master_flat – bias_master)
  3. Align all raw pretreated (geometric transformation from the stars)
  4. Stack all the raw pretreated in a single image

Exemple of pre-treatment: **Raw** (240 s / 800 iso)

Exemple of pre-treatment: **Stacking of 27 photos pretreated**

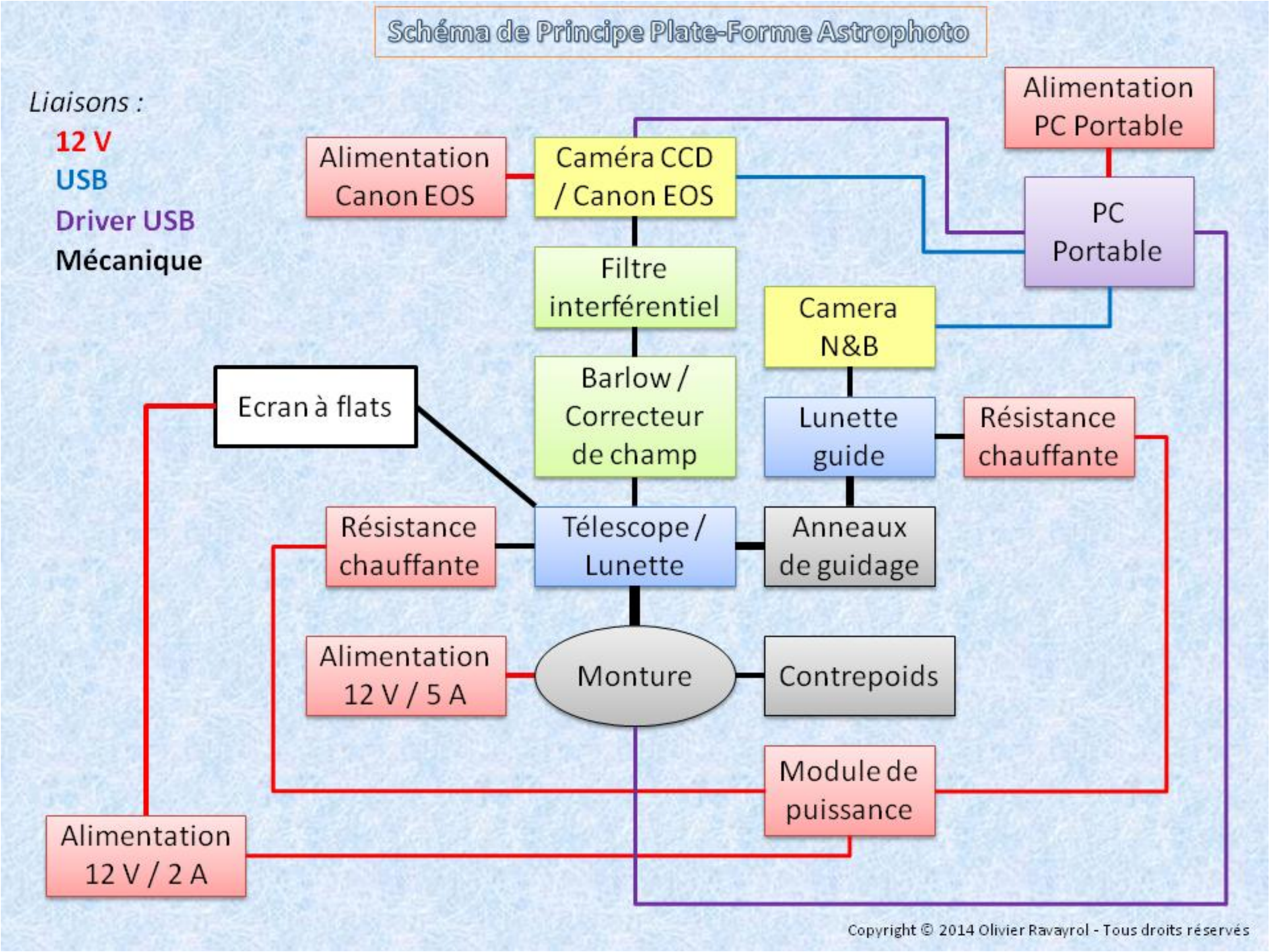
Exemple of pre-treatment: **Master flat** (1 / 6s - 800 iso)



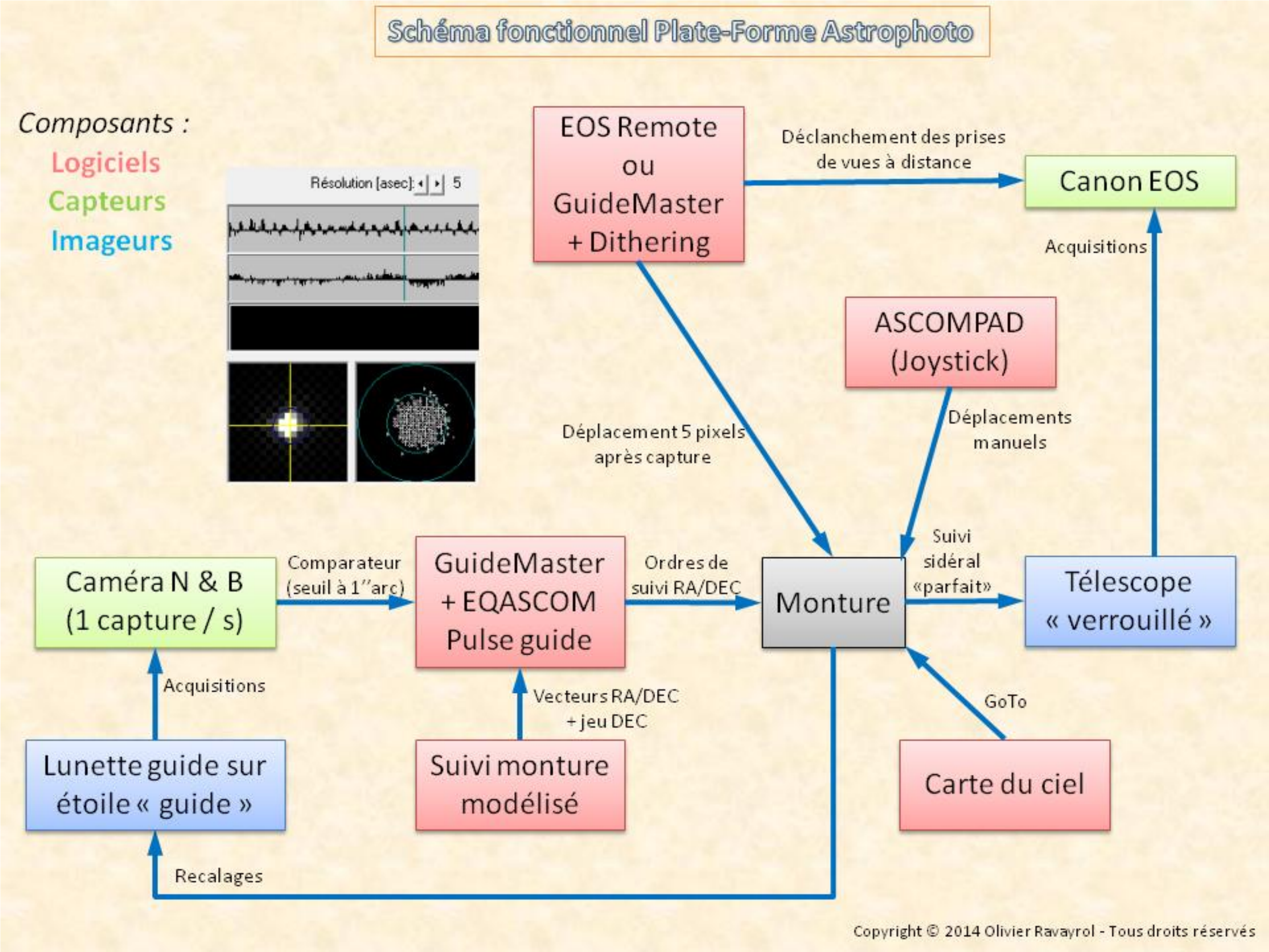
Exemple of pre-treatment: **Without flat**

Exemple of pre-treatment: **With flat**

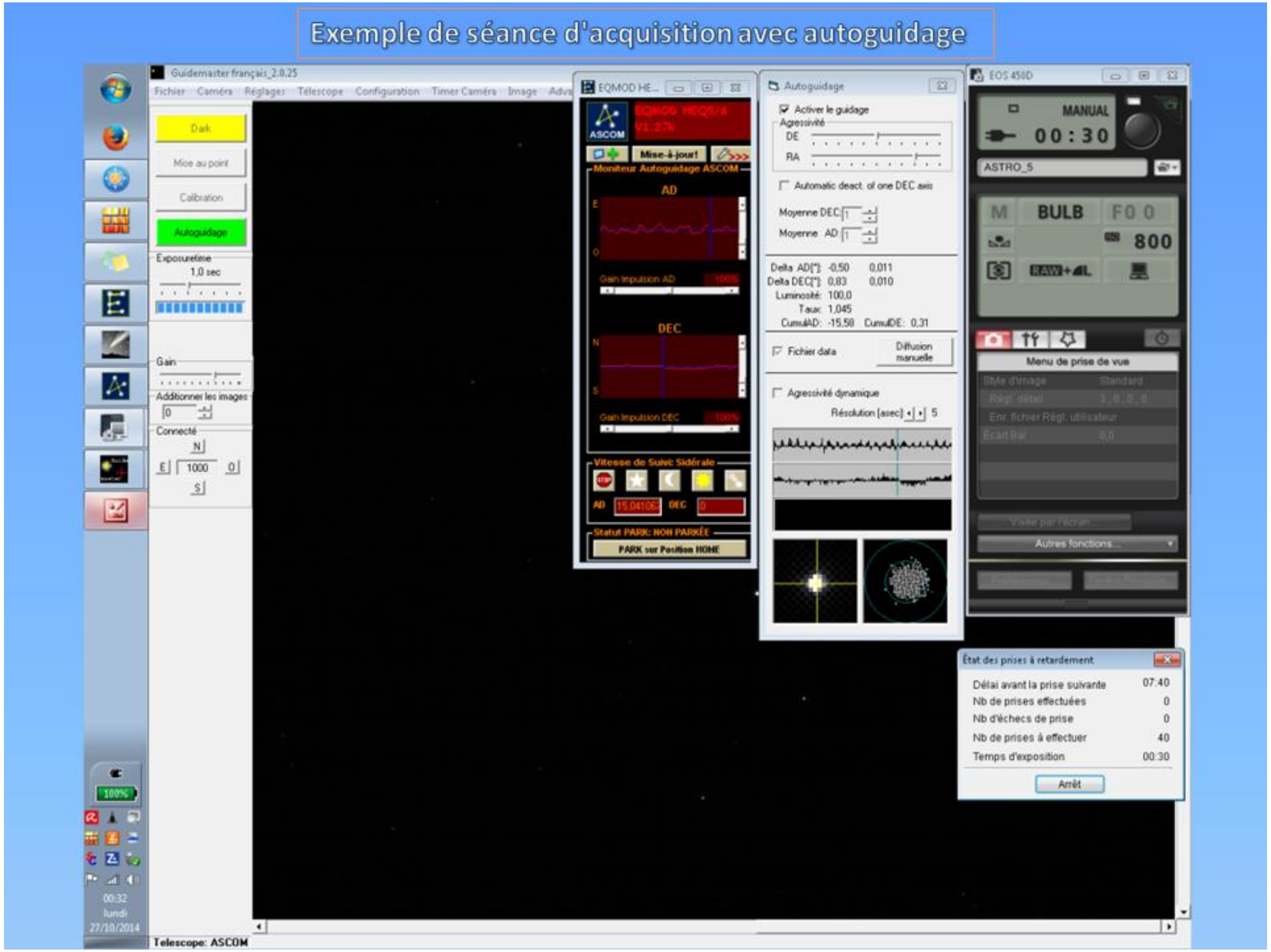
Principle diagram of my platform dedicated to photography



Functionnal diagram of my platform dedicated to photography



Supervision of remote acquisitions via WiFi (Remote control)



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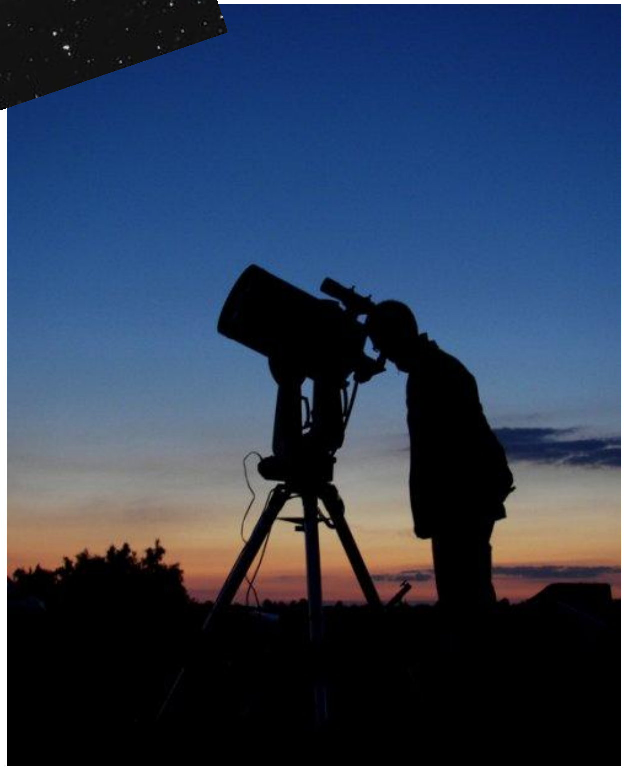
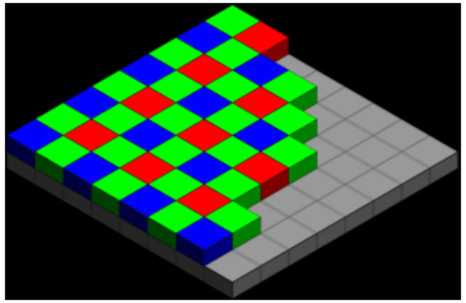
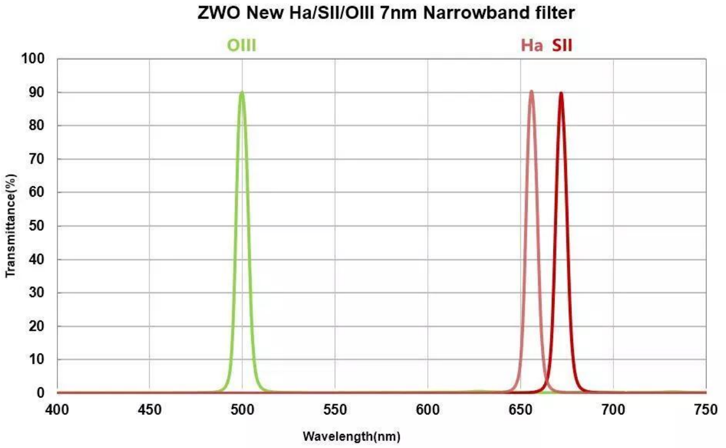


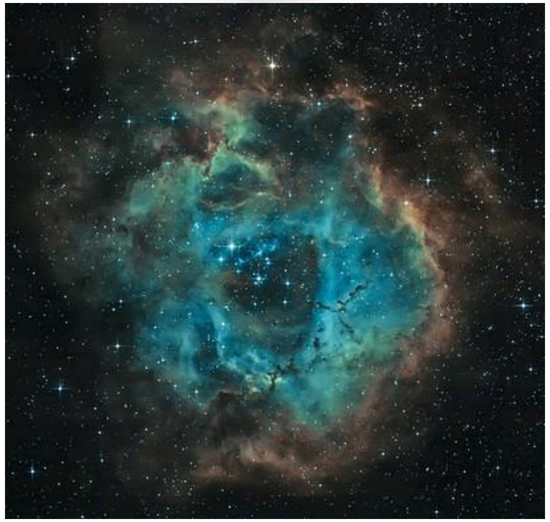
Astrophotography Advanced: sensors & filters

▪sensors

- Monochrome CCD cooled camera : the best but expensive
- Monochrome CMOS cooled camera : good price/quality (noise well controlled)
- APN (CMOS uncooled):
  - ➢ color sensor => 3x less sensitive than a monochrome sensor (Bayer matrix)
  - ➢ Need to be refiltered in order to see better in the red!
  - ➢ Uncooled sensor => biggest noise on long exposures







▪The narrowband filters

- Reduces light pollution
- Passes only the nebulae emission ray for improved contrast: essentially « H-Alpha », « Oxygen 3 », « Hydrogen Sulfide 2 » bands
- Allows you to create false color images also called "Hubble colors

Astrophotography Advanced: The trichromatic

- The monochrome sensors are 3x more sensitive
- You have to take 3 aligned photos to make a color photo, choice:
  - 4 filters: Luminance, Red, Green, Blue => « Photo L-RGB »
  - 3 filters: H-alpha, OIII, SII => photo « Ha-SHO »

Astrophotography Advanced: luminance and color

- Luminance layer: corresponds to the useful signal of the object
  - Monochrome image without filter or with the most detailed layer (Ha)
  - Must contain most of the useful signal
  - Must be the least noisy as possible
  - Must be as detailed as possible
- Color layer: allows colorizing the luminance layer
  - Corresponds to RGB or SHO layers seen previously
  - The presence of noise is less annoying
  - The detail is less important

Example with nebulae M8 & M20: Luminance

Example with nebulae M8 & M20: RGB Color

Example with nebulae M8 & M20: L-RGB

Example with nebulae M8 & M20: Luminance

Example with nebulae M8 & M20: Luminance Ha

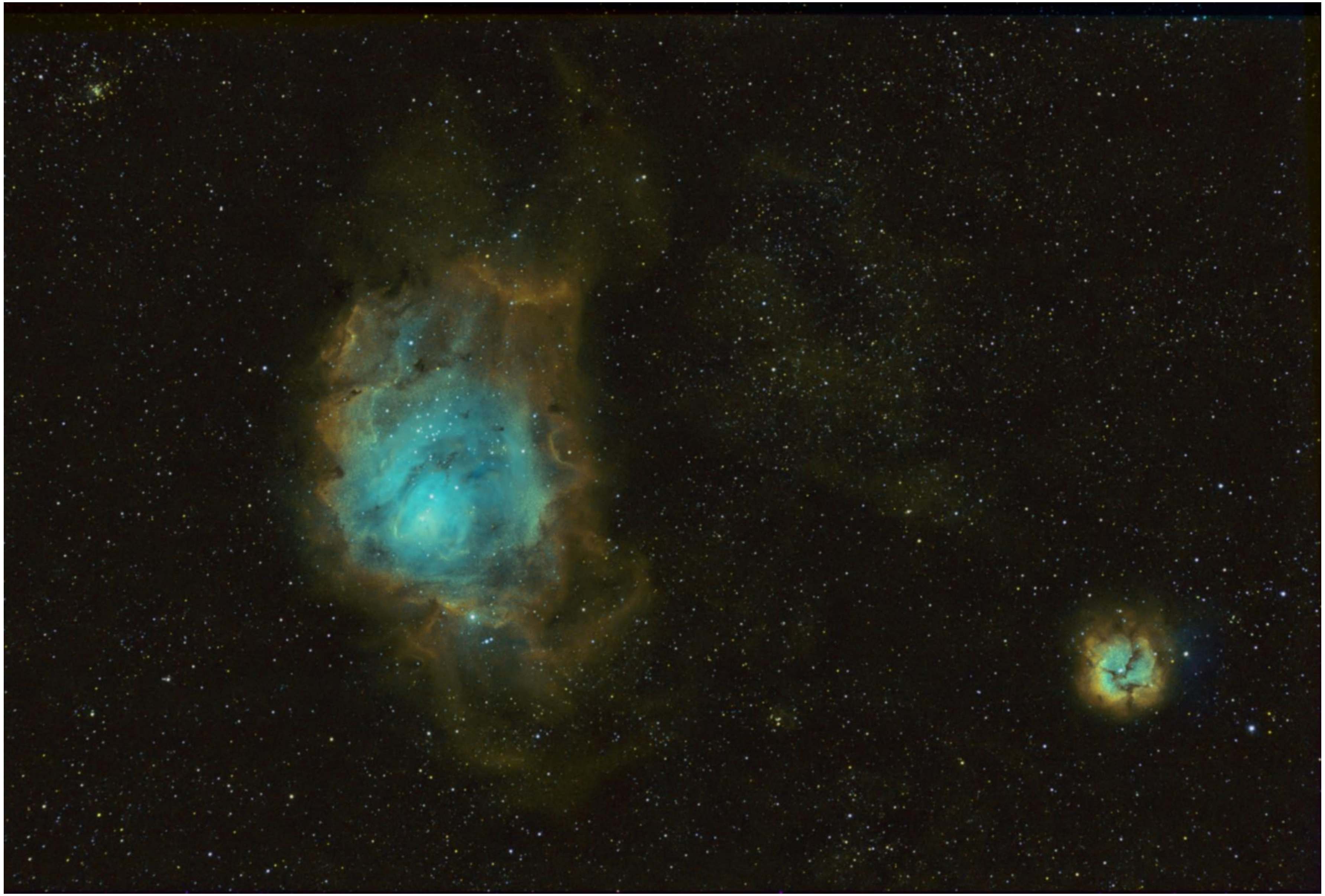
Example with nebulae M8 & M20: RGB Color

Example with nebulae M8 & M20: Ha-RGB

Example with nebulae M8 & M20: L-RGB

Example with nebulae M8 & M20: Luminance Ha

Example with nebulae M8 & M20: Color SHO



Example with nebulae M8 & M20: Ha-SHO

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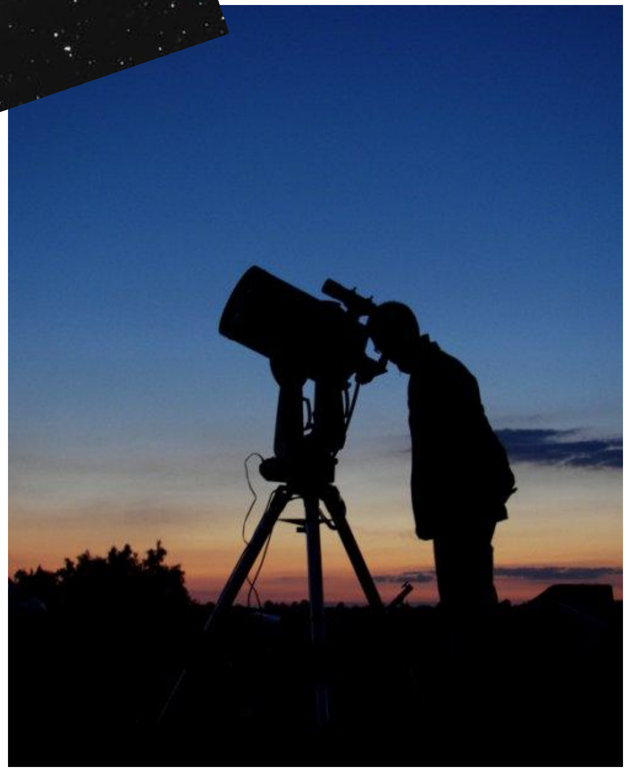

Similarities with optical remote sensing (Space imaging)

Compared item	ASTROPHOTO	OPTICAL REMOTE SENSING (Example with Pleiades satellite)
Programming	Control applications / physical connections	Monitoring / control stations (+ antenna)
imager	Reflector (carbon tube) or refractor D = 150 to 250mm, F = 900 to 1200mm => F/D = 4 to 6	Carbon reflector F = 13 m, D = 650 mm => F/D = 20
Sensor	1 CCD or CMOS sensor (Avg 20M pixels, pixel size = 3-5 µm)	Panchro: 5 barrettes CCD (6000 pixels / array, pixel size = 13 µm) Color: 5 x 5 barrettes CCD (bands B0 to B3, 1500 pixels / array, pixel size = 52 µm)
Calibrations	Bias: measures obscurity signal Darks: measures thermal noise Flats: measures the defects of the optical	Radiometry essentially: on stars, Moon edge, deserts and ice on Earth
Focus	Bright star (with Bahtinov mask or Fwhm)	Known ground targets on Earth
Moving of the target	Belt / toothed wheel	Reaction wheels
Accuracy of the target	Aligning the stars Regular readjustments on target because of mechanical games	Recalibration of positions x, y, z on the orbit by laser telemetry or radiolocation Recalibration attitudes ϕ, Θ, ψ on known stars (star tracker)
Stability of the target	Mechanical games during the tracking of the Earth rotation Vibrations (wind, mechanical stress) => Servoing using a guidance refractor + camera	Microvibrations but under control (110 rad/s max)
Acquisition	1 acquisition / filter => 4 acquisitions / 4 filter for an L-RGB color image	1 image = 1 tile or 1 scan of several acquisitions (1 purchase = 25 images at once) Possibility of stereoscopy / tri-stereoscopic "Video" mode possible
Exposure time	3-7 min avg / acquisition for faint object (must acquire a maximum of photons!) (Luminance binx1, color binx2 => 1 pixel = 4 pixels => high sensitivity but resolution degraded => exposure time reduced)	Very short because of a ground speed high and very sensitive detector The surface is bright as sunlit and often acquired near the Nadir
Retrieving Images	Immediate each end of acquisition (few seconds) No compression	Storage in the onboard memory Image compression for optimizing the size of available onboard memory Emptying the memory each pass above the reception center (encrypted data)
Treatment	Gradient withdrawal related to light pollution Noise reduction Improvement of brightness of the object (stacking of a several exposures)	Radiometric correction (L1A) Geometric correction (L1) Atmospheric correction (L2)
Creating color image	Luminance or Ha filter (much resolved) + color bands or SHO (less resolved)	Panchro band (70 cm resolution) + colors B0-3 bands (2.8 m resolution)

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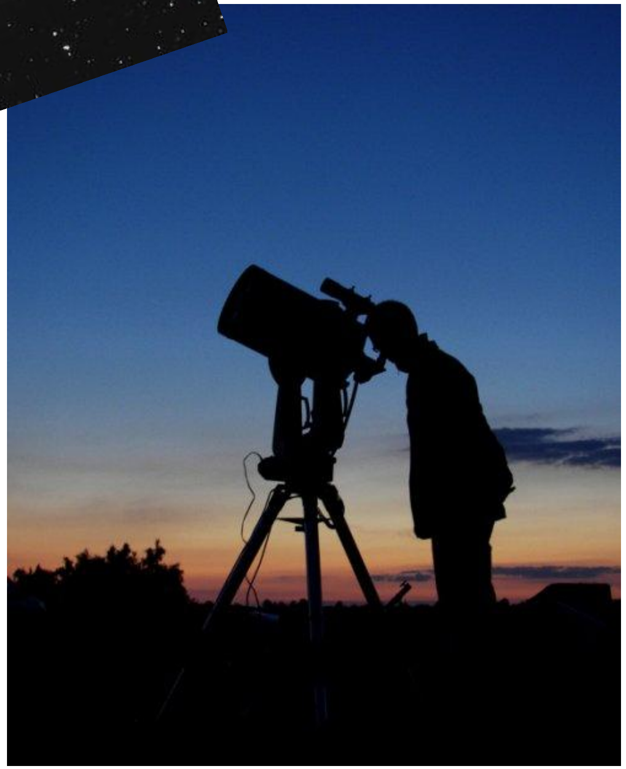

What material for what budget? Visual

Instrument	Model	Price at 2019/06 (€)	Remarks
Visual			
Camera tripod & ball	Maximum payload 15 kg (TS Optics)	150	Light (1.7 kg) and compact when folded
Binoculars	15 x 70	99	
Binoculars	20 x 80	180	
Achromatic refractor	120/600	375	With non-motorized mount AZ3 (1st prize)
Refector	200/1000	625	With mount NEQ5 motorisable (1st prize)
Dobson reflector	Skywatcher GoTo 300/1500	1080	Large diameter => the top for deep-sky visual! Removable for transport
Solar reflector	60mm / H-Alpha	1500	For observation of the Sun only H-Alpha can see the protuberances
Eyepiece	28mm	40	Large field
Eyepiece	20 mm / 62 ° field	90	Average field
Eyepiece	8 mm / 82 ° field	150	Zoom
Barlow Lens	3x	80	Increases the focal length and thus magnification to observe planets
Moon filter	Polarizing variable	40	Reduces excessive brightness of the Moon
Sun filter	Astrosolar safety film	25	A4 sheet to fix on the lens Lets see sunspots
Light pollution filter	visual UHC	99	Improves the contrast of deep sky objects in light pollution conditions

What material for what budget? Photo

Instrument	Model	Price at 2019/06 (€)	Remarks
Equatorial mount	Skywatcher HEQ5 Pro GoTo	1000	Photo payload max = 10 kg (very good quality / price / payload)
Equatorial mount	Skywatcher GoTo HEQ6-R Pro USB	1500	Photo payload max = 17 kg (mount heavy to carry)
Reflector	Skywatcher 200/1000 - F/D = 5	380	Small field / planets (9 kg)
Reflector	TS Optics 200/800 Carbon - F/D = 4	1100	Small field / planets (very good price / quality ratio) Light weight with 7.4 Kg
Refractor	Skywatcher 80/400	100	For autoguiding
Refractor	Skywatcher 72/420 (F/D = 6) APO doublet	330	Large field / mean field
Refractor	TS Optics 80/480 (F/D = 6) APO triplet	800	Large field / mean field (very good price/quality ratio)
DSLR camera	DSLR Canon EOS 1300D Filter replaced	680	Company "EOS For ASTRO" can make the refiltering operation Easy to use for beginners and versatile astronomical photography (Milky Way) Possibility of color Hubble with SHO filters
Astronomical CMOS Camera	Monochrome ZWO ASI 1600MM Pro	1500	Deep sky and planetary
Planetary CMOS Camera	Monochrome ZWO ASI 120MM	200	Planets / Autoguiding
Wide field objectif	Samyang 14mm (F/D = 2.8)	330	Milky Way and starry nightscapes
Reflector field corrector	Baader MPCC	160	Corrects coma stars for Newtonian reflectors
Filter wheel	Motorised 7 positions	350	Allows you to change the filter without removing and refocus
LRGB filters	1 luminance filter, 3 filters Red, Green, Blue	100	Allows you to create full-color images
SHO filters	3 filters D = 31.75 SII, H-alpha, OIII in 12nm	390	Allows you to create color Hubble images 12nm not enough in light pollution conditions or full moon
SHO filters	3 filters D = 31.75 SII, H-alpha, OIII in 6nm	600	Allows you to create color images Hubble 6nm more expensive than 12nm but much better if light pollution conditions
Barlow Lens	APM ED 2.7x with integrated coma corrector	170	Increases the focal length and thus magnification for the picture of the planets
Laser collimator for Newtonian reflector	Hotech	140	Lets collimating the Newton telescope easily (required before each session of acquisition)
Bahtinov masks	2 different diameters	50	Adjusts the point of focus easily on a bright star
Flat field screen	Diameter > to Newton	120	Allows creating calibration images of the defects from the optical
Budget picture with refractor		**2830**	**Mount HEQ5 + refractor TS Optics & guidance + guidance camera + EOS**
Budget photo with reflector		**3440**	**Mount HEQ5 + reflector TS Optics & guidance + guidance camera + EOS + Laser + Barlow**
Budget "pro" Photo		**6530**	**Mount HEQ6-R + Telescope & refractor TS Optics & Guidance + astro & guidance camera + Laser + Barlow + filters L-RGB & SHO**

Useful informations

- Training "La Ferme des Etoiles" (Gers state in France : www.fermedesetoiles.com)
- AIP: Association offering internships and many tutorials in astrophoto (http://www.astro-images-processing.fr)
- Recommended book: "Astrophotography" by Thierry Legault (http://www.astrophoto.fr/astrophotographie.html)
- Magazine Ciel & Espace: many articles and podcasts (http://www.cieletespace.fr/)
- Astronomy Store in Toulouse : http://laclefdesetoiles.com
  - Celine and Sebastien Vauclair (Dr in Astrophysics) will advise you ;-)
- On the Web :
  - Astrosurf : http://www.astrosurf.com
    - Forum covering all topics related to astronomy (many experience feedbacks)
    - Synthetic ephemeris software and major events
  - Webastro : French astronomy community (http://www.webastro.net)
  - French Astronomical Association: http://www.afastronomie.fr/
- Software:
  - Stellarium Planetarium (http://www.stellarium.org/fr/)
  - Virtual Moon Atlas: (http://ap-i.net/avl/fr/start)

More details on my website ...

https://www.astro-photo.fr

Questions / Answers