INTRODUCTION TO ASTROPHOTOGRAPHY

Jan Buytaert

Introductory remarks

- Many thanks for this invitation !
- Great initiative to make a bridge between our two clubs. Maybe this will lead to some common activity ?
- This presentation is inevitably a little biased by my specific interest centres in astrophotography.
  - Deep sky objects (larger focal length 500-2000mm)
  - Only recently started short focal length (135mm) with DSLR.
  - ... I like the technical side of the hobby.
- The aim of this presentation is to introduce you to
  - the important issues in astrophotography in general
  - and use of DSLR cameras.

CERN Astro Club

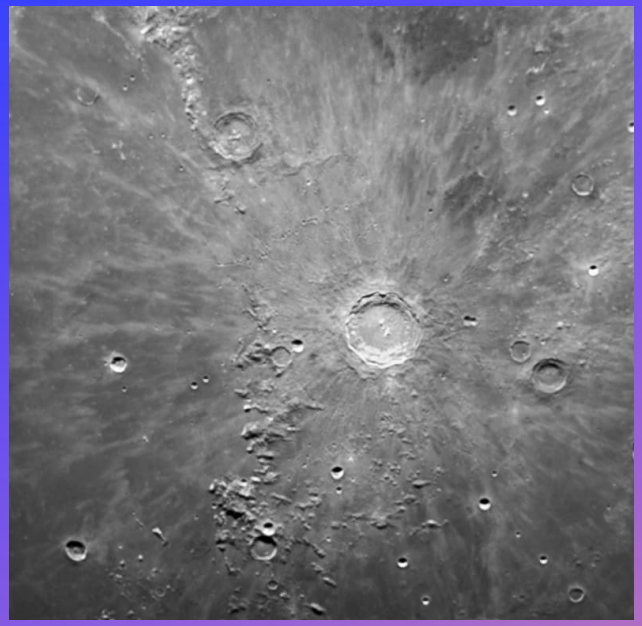
- Rather small club, 17 Members in 2024.
- Looking for a good model for the club.
  - Trying to attract new members (many active members recently left or are about to leave on retirement)
  - Local observation becomes more and more difficult by increasing light pollution.
  - (Astro)photography can be a very ‘individualistic’ hobby and often people don’t realise the advantages of being member in a club.
- We have a nice variety of good instruments for visual, solar/lunar, deepsky observations/photography.
- Our club barrack in CERN Prevessin, “decent spot”, no direct light.
- If you are interested to join a few observations, email me.
- Website : https://astro.web.cern.ch/welcome
- Pictures :https://www.flickr.com/groups/cern-astro-club/

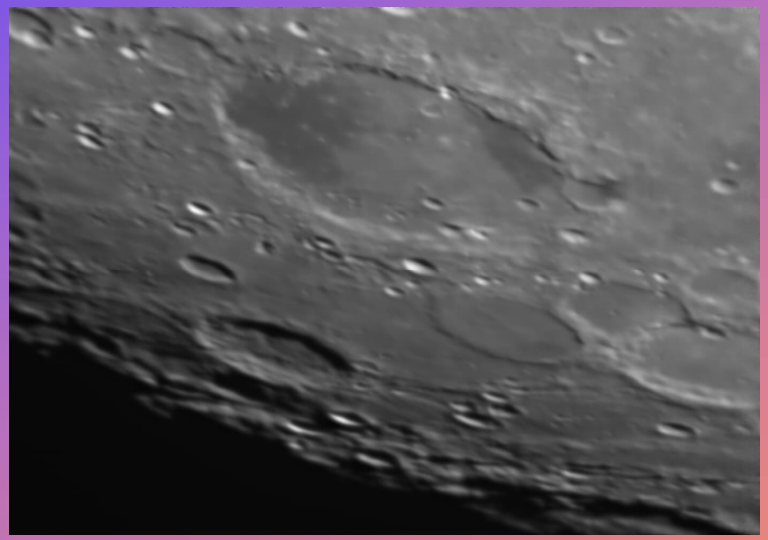
Astrophotography

- It is a very diverse field : too many objects to photograph in a lifetime !
  - Milky way, Moon, planets, sun, large interstellar molecular clouds, nearby supernova remnants, galaxies, galaxy clusters, open star clusters, globular clusters, emission nebula, dark nebula,…
  - Each will require different equipment (telescope, mounts, camera, filters) and different acquisition and processing techniques.
- Recent progress in technology is creating a 'golden age' for amateur astronomy:
  - Sensors
    - with 80% quantum efficiency and more affordable larger sizes (APS, FF)
  - Informatics:
    - automated and remote control of observation sessions.
    - Very sophisticated software for image processing
  - High quality optics and telescope mounts are much more affordable (China …)
- Look at www.astrobin.com (main image repository for amateur astrophotography

EXAMPLES OF VARIOUS OBJECTS

My pictures






Jan Buytaert

Comets C/2020 F3 (NEOWISE)
and C/2022 ZTF (Zwicky).

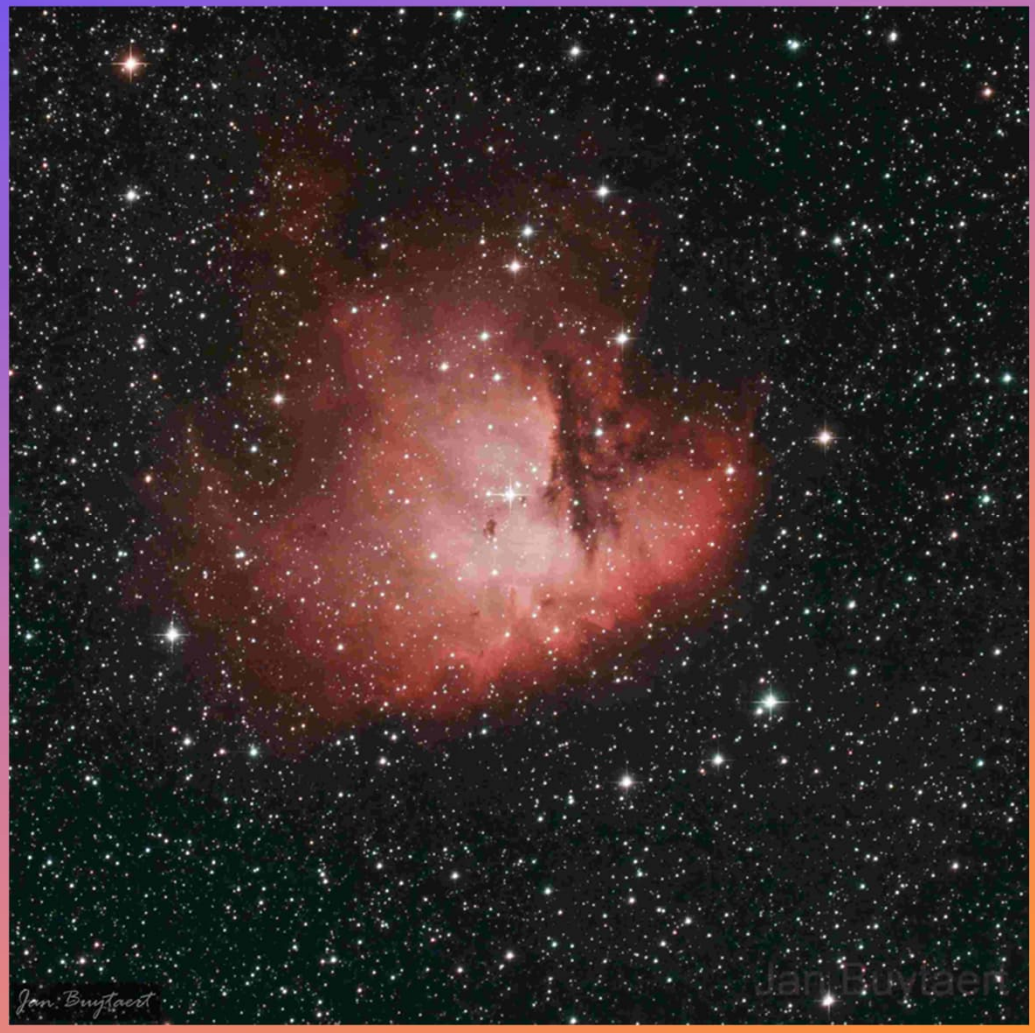
M57 ring nebula

supernova remants

M27 dumpbell nebula

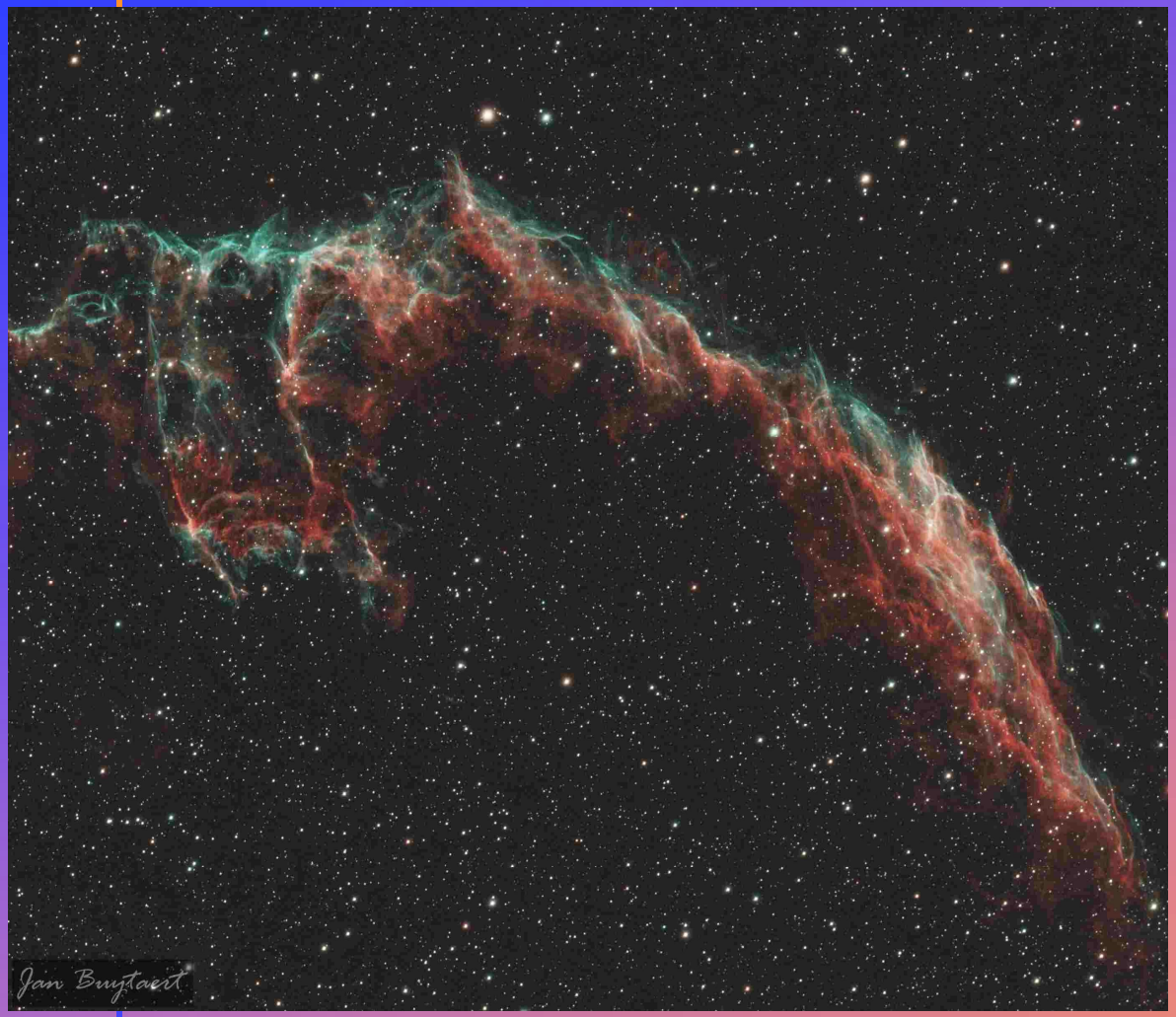
Emission nebulae

Horsehead and flame nebulae



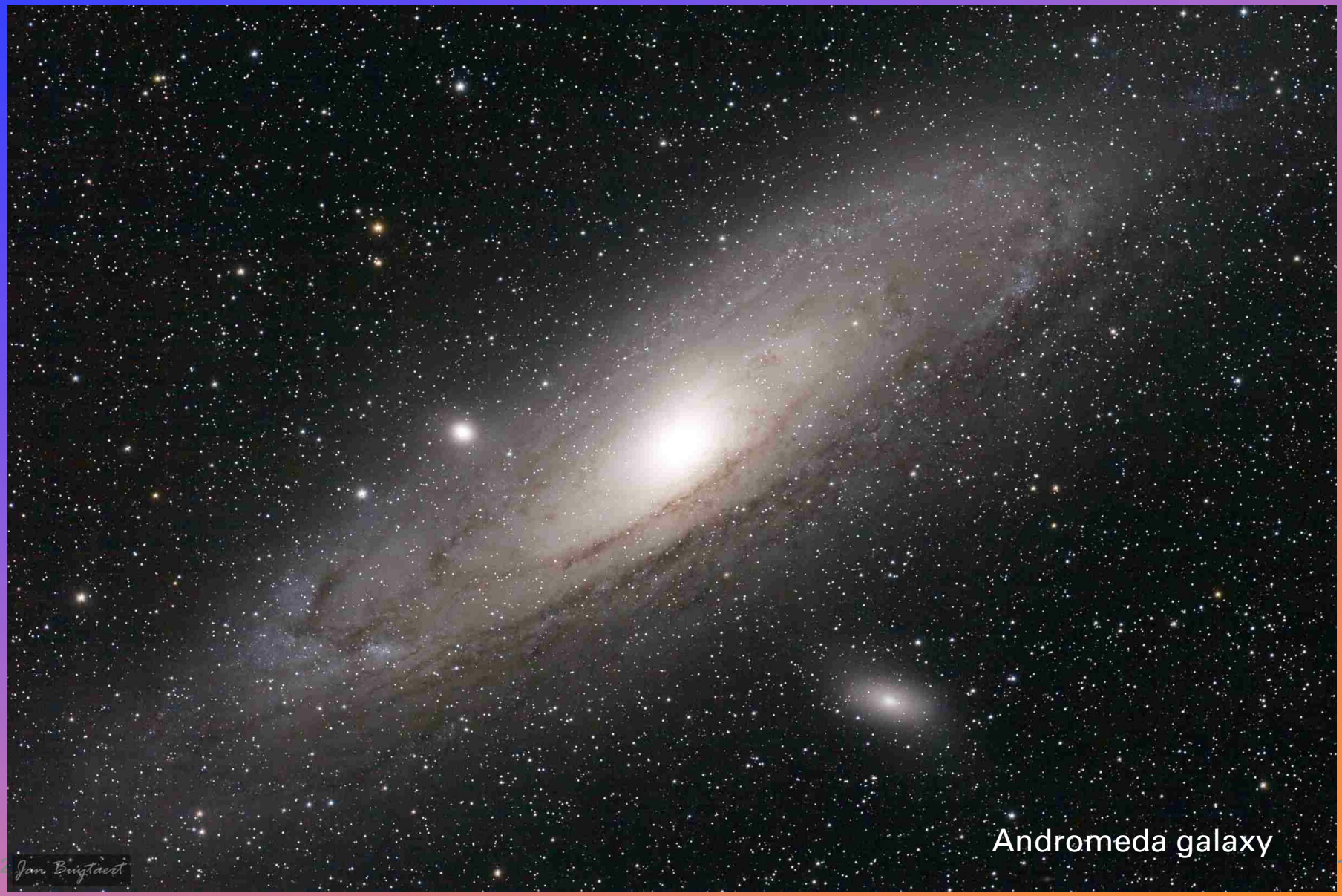
Pacman nebula (red is from Halpha line)

supernova remants



Eastern veill nebula

Crescent nebula



Andromeda galaxy

Needle galaxy

M51 whirlpool galaxy

Specificities (or challenges…)

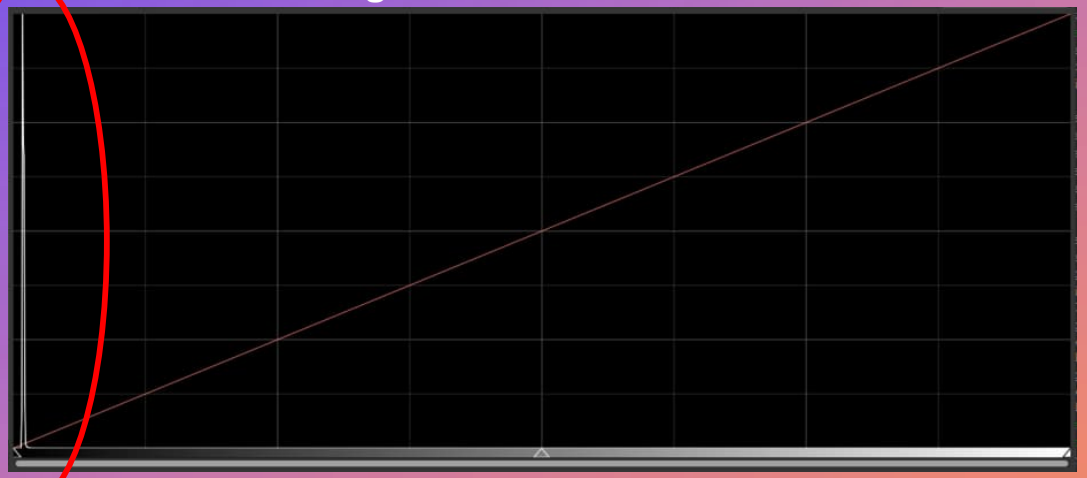
- Objects are very dim (except sun, planets, moon)
  - Collecting very few photons in a pixel even for long exposures ! Typical exposure times are 5 minutes or more.
  - Control of noise is crucial.
- Objects are moving due to earth rotation.
  - This requires very high mechanical stability and tracking at level of arcseconds (1 arcsec = angle sustained by a pea at a distant of 1 km)
- Objects are optically very demanding. Stars are (mostly) white points
  - chromatic and geometric aberrations are immediately noticeable.
  - A star field is the best test for assessing performance of any lens !
- Objects have very small structure,
  - requiring very high spatial resolution at arcseconds or few pixel level.
- One can spend entire nights outside (mostly winter..)
- One is always striving for better performance…

Dim objects:

- Single 30s exposure, linear viewing mode.

single 30s exposure, linear intensity scale

Histogram, vertical axis linear scale

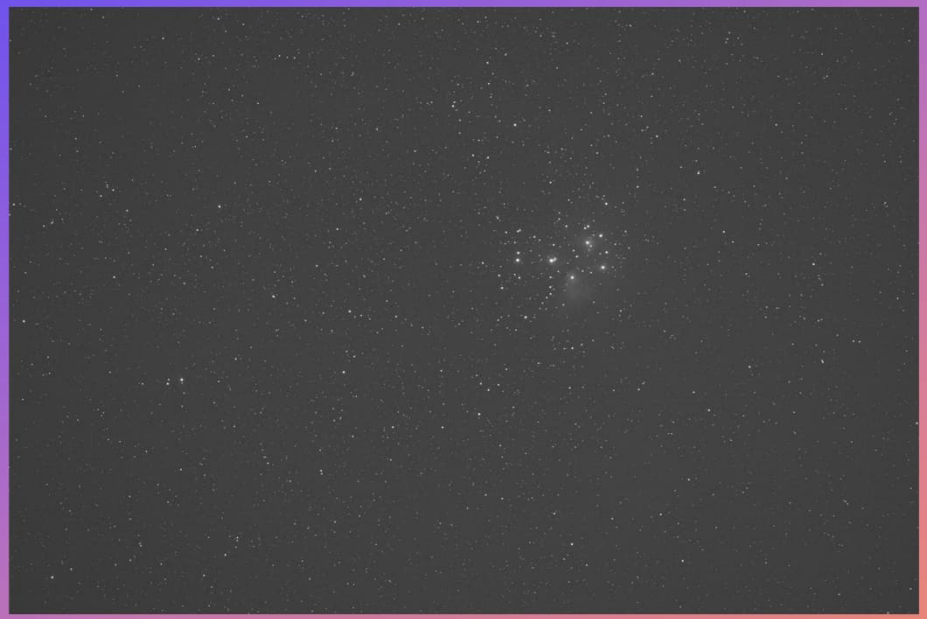


Histogram vertical axis logarithmic scale

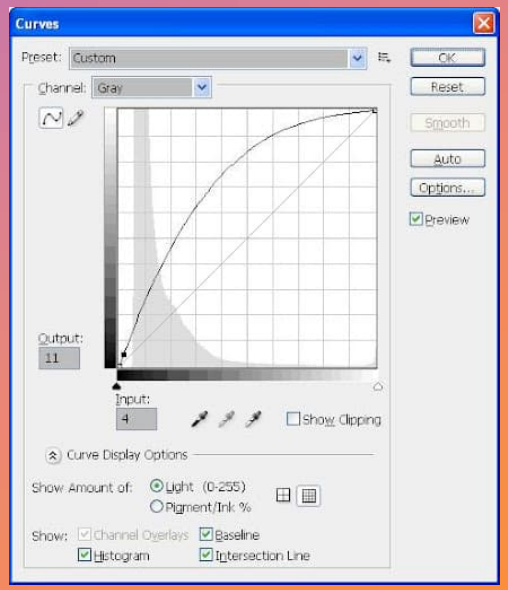
(Gain (ISO) should have been been x 2[4]...)

Dim objects

- Applying a non-linear intensity transformation ("arcsinh","histogram", ...) creates a"stretched" image



Like 'curve' in PS



Earth rotation.

- If using static camera : to avoid star trails use "500 rule"
  - Max exposure-time= 500s /focal length(mm). 10s for 50mm.
  - Depends on elevation (worse if closer to zenith)
  - Depends on azimuth (worse near North and south meridians)
  - Or try
- For longer exposure times, you will need a small motorised equatorial mount.
  - "Polar alignment" : make rotation axis of the mount parallel to the earth rotation axis. I.e. point toward north polestar.
  - Many brands available…
- But: it is better to make many short exposures then ione single long exposure !!!! (see later)

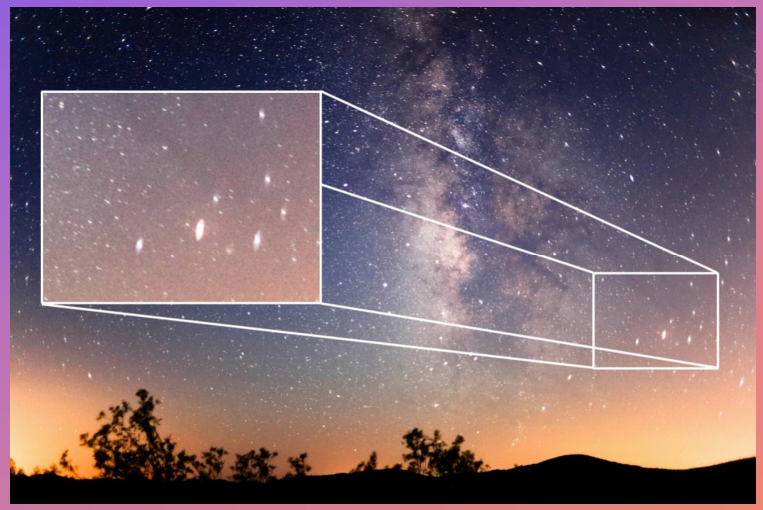
Ioptron Skytracker Pro
~500Euro

Skywatcher Star Adventure
~400 Euro

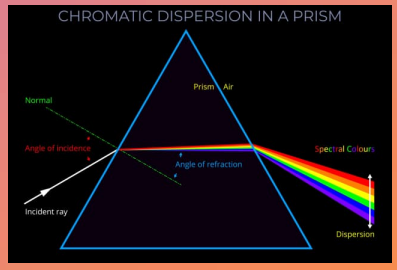
Omegon minitracker
~300Euro

Optical distortions

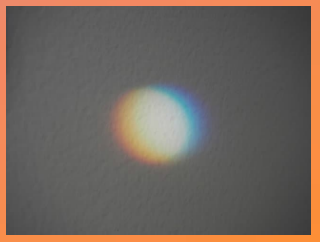
- Only solution : high quality lens (or telescopes ‘astrographs’).
  - fixed focal length gives best performance. Avoid zoom lens.
  - Samyang has good price/performance.
- Choose targets at high elevation,
  - i.e. not near the horizon (> 40 degree)
  - to reduce chromatic dispersion due to the atmosphere. Atmosphere acts like a prism…



Spherical and chromatic aberration



Stars have color gradient



Spatial resolution.

- not an issue for small focal length (F< 300mm), lenses.
- at high F, the resolution is limited by the aperture
  - by light diffraction caused by the aperture of the telescope:
    - Airy disk radius = 1.22 x λ x F-number. with F-number = (focal length) / diameter)
- Ultimately by atmospheric turbulence ~ 1 arcsec.
  - At best conditions 0.5 arcsec
  - video showing turbulence

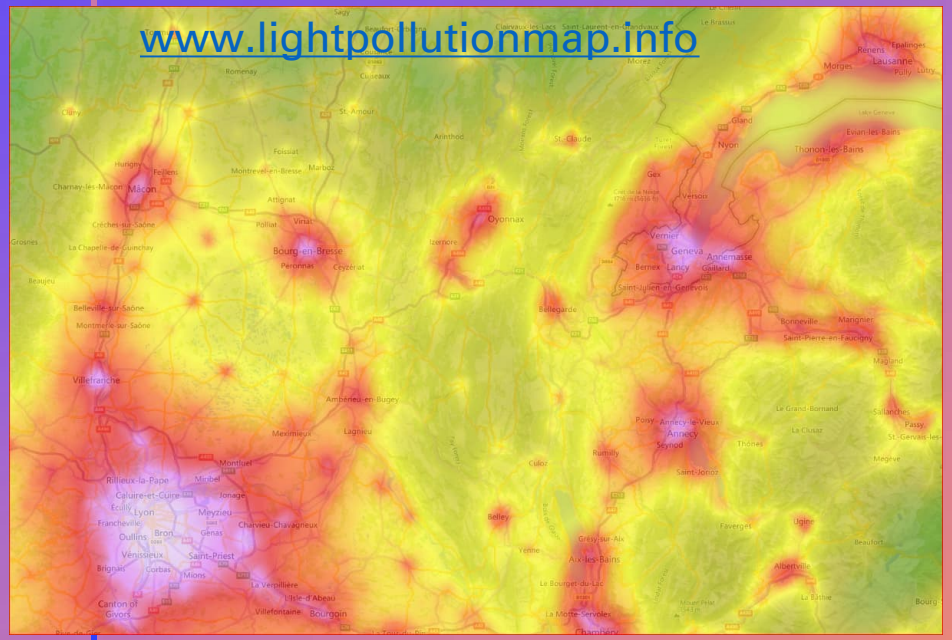
Focusing

- Use manual focus.
  - Auto focus won't work very well on stars.
  - You do not want focus to change unexpectedly during the session.
- Don't trust the infinity indicator.
- Difficult to find optimal focus at night. Best technique:
  - use live-view, very high ISO and short exposure time.
  - look at very faint stars to become brightest.
  - (Minimum size of stars is no very easy to detect).
- Or prepare infinity focus during day light and don't touch any more

- In general, turn of all automatic features of your camera (noise reduction, file compression,…).
- Use as much as possible original ('native') data from pixel matrix.

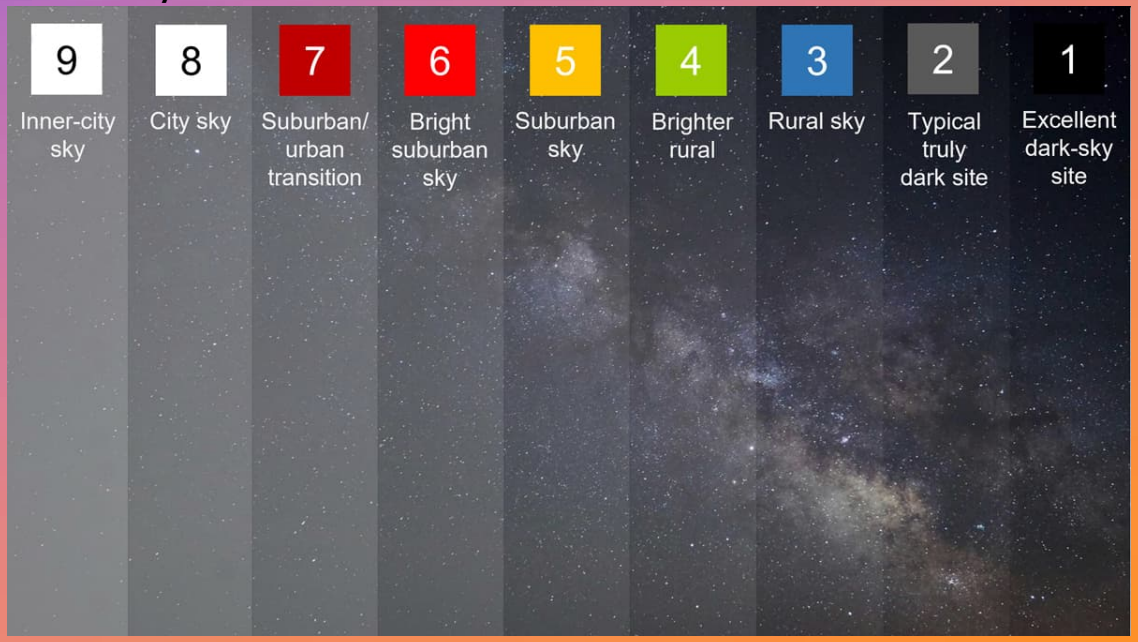
Dark sites

- If possible, choose a site with low light pollution!
  - Final image quality will be much better ! Light pollution background can be removed, but not the noise that it generates.



‘Bortle scale’

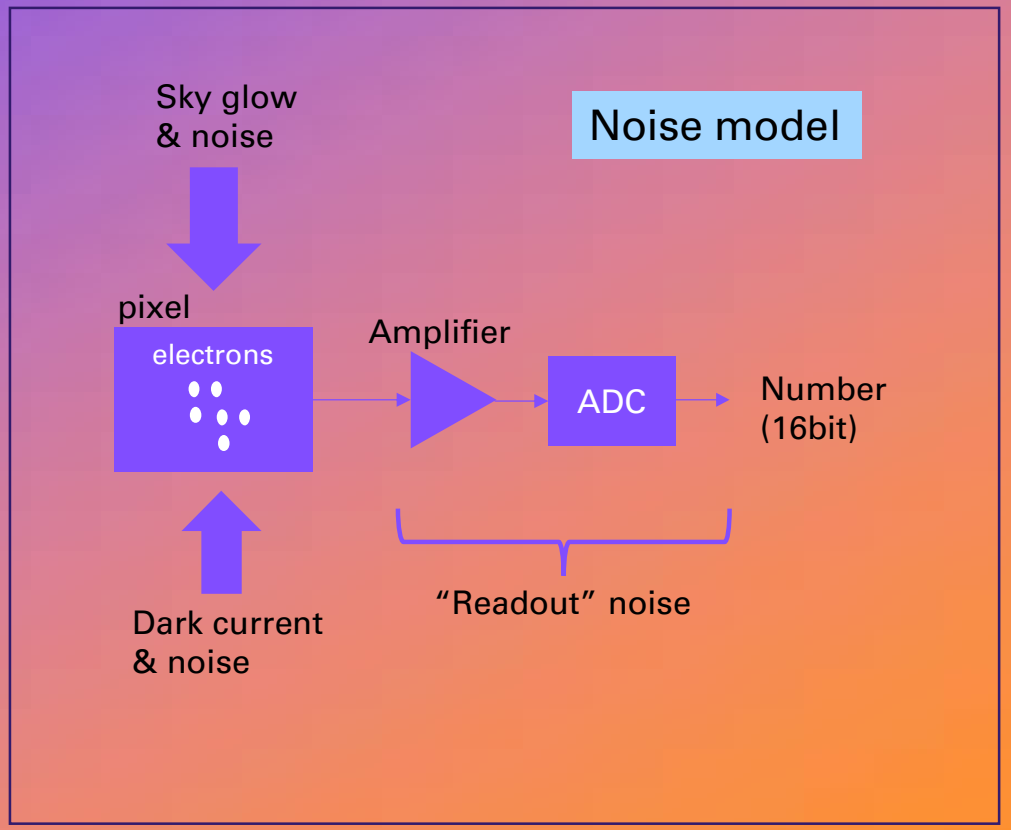
Pays de Gex=6/5 Jura=5/4. Best France=3/2



Noise.

- 3 noise sources :
  - Noise from dark current.
    - Dark current : depends on temperature. Reduces by ½ every 6 C.
    - Noise ~ sqrt(dark current).
    - Cool camera to -10C or lower.
  - Noise from light pollution signal.
    - Signal depends on 'sky glow'
    - Noise ~ sqrt(sky glow).
    - Goto dark site and/or add light pollution filter.
  - Readout noise:
    - All noise caused by electronic processing chain (amplifier and ADC)
    - See next slides

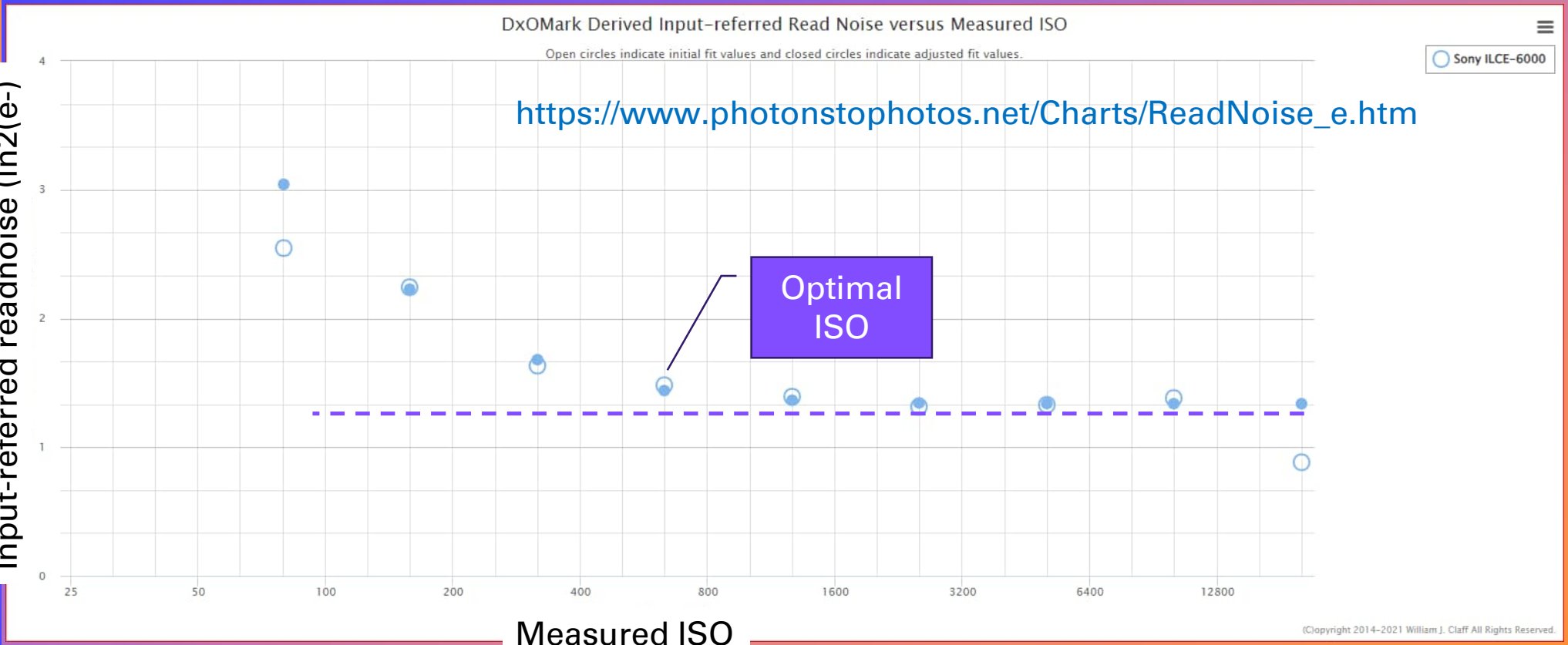
Usually dark current << skyglow.



Readout noise

- noise contribution on each exposure.
- It is not depending on exposure time.
- It is depending on ISO (gain of amplifier)
  - Decreasing (!) with higher ISO,
    - if referred to the input !
  - At a certain ISO it flattens (“ISO invariance” or “ISOless”)
    - No further gain of S/N
    - But loss of dynamic range.
  - Check your camera best ISO in https://www.photonstophotos.net/Charts/ReadNoise_e.htm

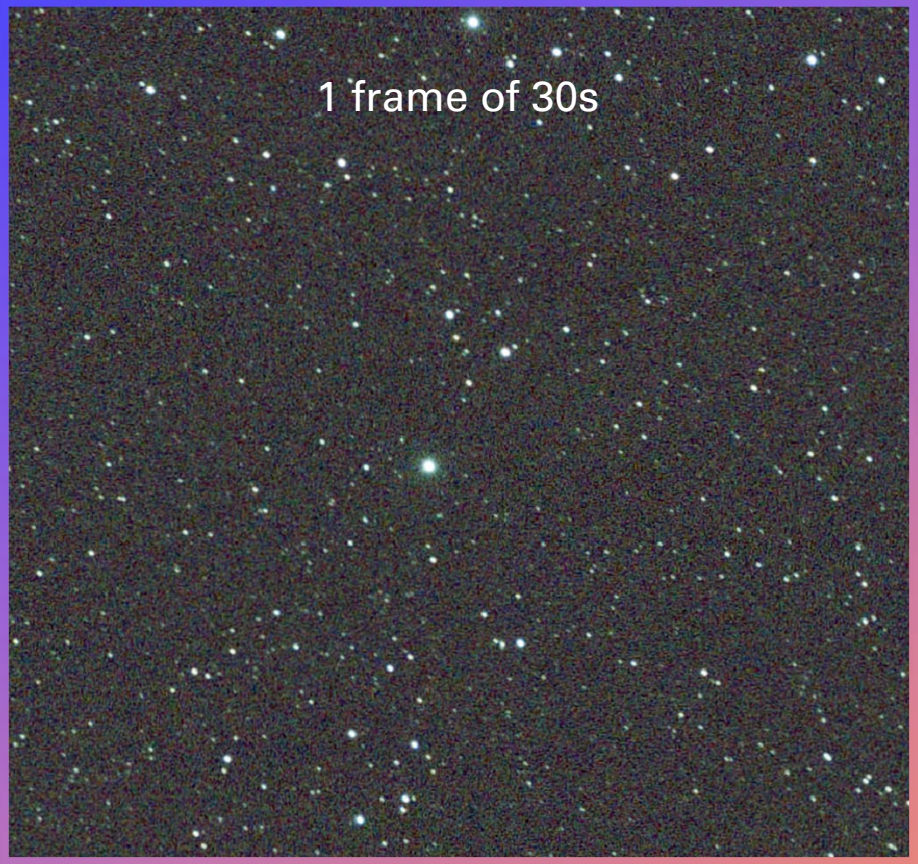
Readout noise



Noise reduction:

- Can be reduced significantly by multiple exposures !
- 1 exposure of N minutes VERSUS addition (“stacking”) of N exposures of 1 minute ?
  - The total collected signal will be the same,
  - but “readout noise” will decrease as 1/sqrt(N).
  - => S/N will increase as sqrt(N).
    - Take 20x 5” rather then 1x100” ! S/N will be sqrt(20)= 4.5 better !
  - Also, this will also help in reducing star trails due to earth rotation.
- Modern CMOS cameras are now much better than CCD camera’s and are still improving.

Example of stacking



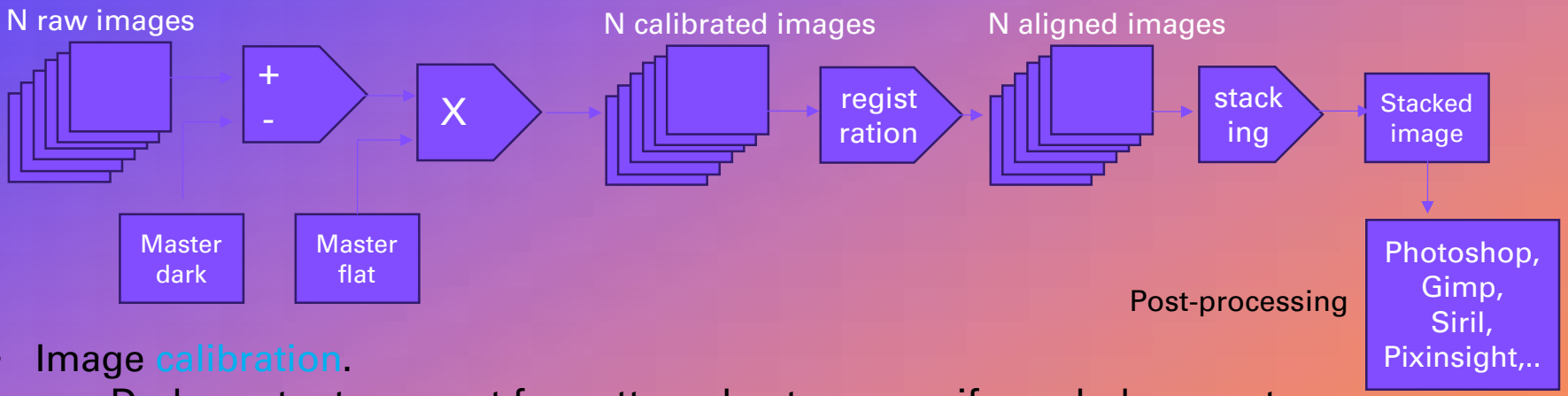
Huge increase of Signal/Noise ! x13 (=sqrt(175)

Noise : summary

- Use optimal ISO setting for your camera.
  - https://www.photonstophotos.net/Charts/ReadNoise_e.htm
- Take multiple exposures to increase S/N.
- Cool your camera. (Winter is better than summer).
- Goto dark site or use light pollution filter.
- Take targets at high elevation (horizon is more polluted) or in direction away from city lights .

Image processing.

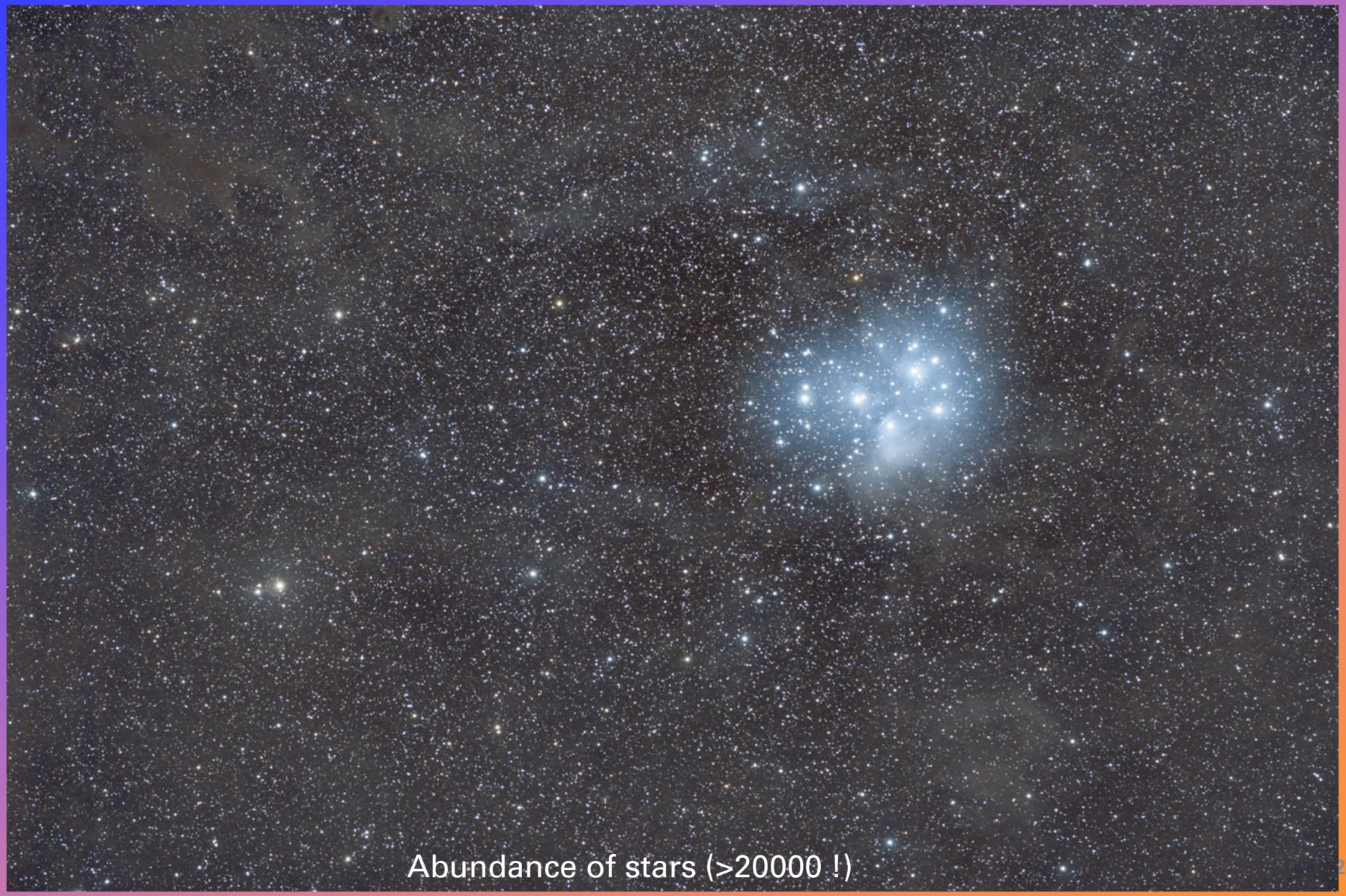
- preprocessing software, e.g. SIRIL, Pixinsight, …



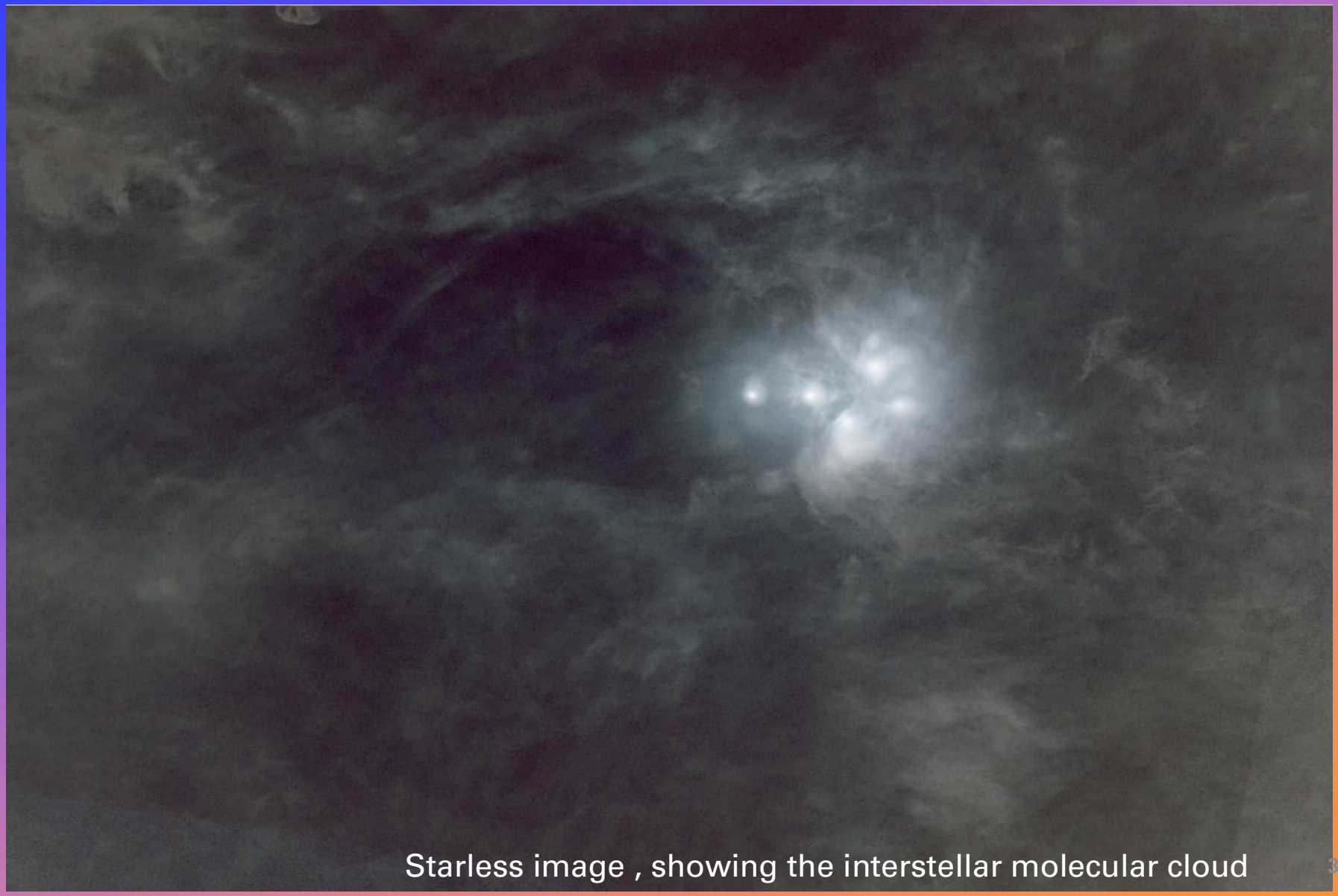
- Image calibration.
  - Dark master to correct for pattern due to non-uniform dark current.
  - Flat master to correct for vignetting and dust/scratches
- Image 'registration' :
  - calculate translation, rotation per image to align all images to each other
- Image stacking:
  - calculate average per pixel , with rejection algoritm (remove satellite, airplanes,etc…

EXAMPLE

- Taken with Sony alpha A6000 and 135mm Samyang.
- Pleiades with dark molecular clouds, field of view 10deg x 7deg.
- Stack of 175 exposure x 30s
- 1h26m total



Abundance of stars (>20000 !)



Starless image , showing the interstellar molecular cloud

Moon/Solar/planetary photography.

- We want to see very small surface features < 1arcsec.
- Try to ‘eliminate’ effect of atmospheric turbulence (which limits resolution).
- Videos of turbulence on moon, star twinkling, speckles.
- Use technique of “lucky imaging”:
  - These are very bright objects.
  - Take thousands of short exposure (1ms) frames at highest possible framerate (200 frame/s).
  - Use program “Autostakkert3” to select ~10% best images (least affected by turbulence)
  - Stack images and (lots of) processing.

Picture of Jupiter from a club member

Picture of sun from a club member

Useful links

- Conference "Initiation aux techniques de l'astrophotgraphie du ciel profond". Xavier Peillon. CERN April 2023.
  - https://indico.cern.ch/event/1258032/contributions/5316667/
  - Recording : https://cds.cern.ch/record/2855818
- Bastien Foucher. Tutorials.
  - https://www.bastienfoucher.com/tutoriels
  - Excellent pdf book at 15 Euro.
- Astrophotography. Thierry Legault. 3rd edition. Excellent !
- Stellarium, Skysafari apps .

THANK YOU