## Lunar Imaging


"When the Moon is out, shoot the Moon."
Van H. McComas

## Equipment

Introducing telescopes, cameras, filters and more fancy gear.


## Sample Images

Captured with an 8-inch telescope and a small planetary camera.


## Lunar Facts

Knowing our Moon and why lunar imaging is so rewarding.


## Foreword

Frankly, I am a novice amateur astronomer who is still learning the ropes. Largely limited by weather, astrophotography cannot be practiced every day in that gaining experience is a journey through perseverance, but highly rewarding.

This photo brochure exhibits a choice of lunar images taken through an 8-inch telescope and discusses equipment for lunar imaging

Feedback, preferably constructive criticism, is heartly invited to benefit further updates.

Wishing you all best health, stay safe by all means, and what's more..

## Clear skies!

December 2021 (first release)


Crater Brenner next to the better known crater Janssen in the rugged lunar southeast.


My "Royal Ryukyu Observatory". What's more, tomatoes to the left, bananas to the right, snakes below (rarely) and clouds above (most of the time).

"This work is dedicated to my wonderful little dog "Sun" who passed away on November 16th 2021 at the age of 12 years, ten months and six days after a long, brave fight against an unknown mouth disease. Sun's battle name was "Sirius". He used to guard my scope and continues to be the brightest star in my life."


## Contents

6 Summary
7 The Moon
16 Equipment188-inch Telescope
20 Cameras
21
Focal Length
22 Comparing Sensors
32
Filters
34 Image Capture
38 Sampling
40 Processing
42 Benchmark
44 Drizzle
46 Lunar Mosaics
47 Mineral Moon
50
Barlows54 Hints
62 Imaging Events

Equipment which you may need, at a glance.

A description of the Moon's photogenic attractions and its history.

Suitable telescopes, sturdy mounts, lunar-planetary cameras, filters, computer and software.
The Celestron 8 XLT, an 8 " SchmidtCassegrain, is one of many telescopes ideal for lunar imaging.

Who are the vendors, a color camera or going for monochrome?

Less is more, wisely chosen magnification and image scaling.

IMX290 versus IMX178 monochrome sensors.

Cut infrared or let only infrared pass? Imaging in visual or near-infrared.

About color spaces, file formats and settings for acquisition.

Splitting hairs about image scaling and resolution.

The basic steps for post-processing an image stack file in Photoshop CS2, for example.

Measuring the speed of stacking videos with Autostakkert!4.

Drizzle or not to drizzle. Best applied to undersampled images.
Just a few points to bear on mind for stunning posters.

Create a "mineral moon" with carefully saturated colors.

Does it make sense to use high power barlow lenses for more details?

Hopefully useful ideas and recommendations and how to determine effective system focal length.

Rewarding imaging events thanks to libration and lunar phases.



## 65 <br> Documentation

Ghost Craters

Add value to your images with correct descriptions and acquisition details.

A list of ten lunar features often remaining unvisited.

Odds and evens with too high magnification.

Attractive wide field imaging targets.

A lunar Sinus is a bay shaped (part of a) mare, one them is huge.

Well known Rima, Rupes and Vallis. One representative example each.

Lunar features of Curiosity, magnetism, two craters and a Mons.

Craters eroded by volcanic lava flooding.

Impressively high mountain ranges and isolated peaks.

The most widely imaged popular craters and their locations on a lunar map.

Annotated map from the Lunar Reconnaissance Orbiter Camera.

Close up views and crew photos of all Apollo missions courtesy NASA/LRO.
List of image sensors, recent products, free Android App and web tools.



Lunar libration angles were $4.282^{\circ}$ in longitude and $6.684^{\circ}$ in latitude, age 5.4 days, size 32.3 ', distance $369,454 \mathrm{~km}$.

Once you took a photo of the
Moon you are dpne. Not
exactly, because of the lunar phases changing illumination angles from either east or west;
cast various shadows giving lunar regions a different face of this enticing tafget every time. Achievable image quality strongly depends on atmospheric' condition in that you can atmost always improve ovér your previous images on a later date. The Moon is receding from Farth at a rate of 3.78 cm or 1.5 inches, per year, so it won't run alway.


As Apollo 11 astronaut Buzz Aldrin marvelled, "It's a bleak beauty".
'A color mosaic saturated so as to obtain a "mineral moon". Blue, orange and brownish colors indicate volcanic lava flows with various mineral deposits in the soil. Very roughly, the blue hues reveal mainly titanium while orange-red areas are richer of iron.

Summary
A telescope with at least five inches ( 127 mm ) aperture, typically a reflector type, Newtonian or Cassegrain.

A CMOS camera designed for lunar and planetary imaging, one or two barlow lenses plus IR-cut and infrared pass filters.

A sturdy mount with electronic tracking (equatorial or altitudeazimuth mount) and capable of shouldering the weight of the telescope.

A computer running image capture software, such as "SharpCap" or "FireCapture", software for image stacking, such as "Autostakkert!3" or "Registax6", plus software for post-processing, such as "Photoshop" or "GIMP". Since imaging involves recording of uncompressed video at fast frame rates, a fast SSD disk is required for smooth recordings.

It is matter of budget, but the wider the aperture of the telescope the more details can be captured. A large telescope is heavy hence requiring a sturdy mount which again burdens the budget.

Details about necessary equipment are provided on following pages.

Celestron C8 XLT and ASI462MC with UVIIR-Cut filter. Exposure 5ms, gain 120, 138 frames per second (fps).

If not credited all images are the author's taken through a Celestron 8 XLT Schmidt-Cassegrain telescope and planetary cameras housing IMX178 / IMX290 / IMX462 / IMX585 image sensors from Sony, unless otherwise noted. The author is not affiliated with any manufacturer or dealer mentioned in this issue.



Without the moon stabilizing Earth's rotation axis hence keeping the seasons in place while further caring for the tides, humans, perhaps life in general, would not exist.

## Physical

Diameter: 3474.8 km Angular size: 29.3' to 34.1 Distance: $384,400 \mathrm{~km}$ (mean) Magnitude: -12.74 (full) Eccentricity: 0.0549 Escape velocity: $2.38 \mathrm{~km} / \mathrm{s}$ Rotation period: 29.53 days Axial tilt: $1.542^{\circ}$ to ecliptic Inclination to orbit: 6.687 Inclination to Earth's equator: $24^{\circ}$



The Moon
...continued from previous page

## Fascinating Features

The Moon is about a quarter the diameter of Earth but exhibits extreme natural and geological dimensions. Some peaks of the rugged mountain chain Montes Apenninus rise as high as 5 kilometers (3 miles) casting long shadows. Crater Copernicus is 3.8 kilometers ( 2.36 miles) deep as are many more, wide or small. Rupes Altai is an escarpment located south of Mare Nectaris stretching over 420 kilometers ( 260 miles). Most craters contain a dozen or more craterlets and have central peaks casting shadows. Under favorable illumination and timing stunning pictures of such features are possible -- the exciting side of lunar photography.

Libration


Thanks to the moon's libration (wobbling effect), $59 \%$ of its surface is observable from Earth (of course $50 \%$ at a time). The maximum libration angle is: $1.54^{\circ}$ (equator to ecliptic inclination) plus $5.15^{\circ}$ (ecliptic to orbital plane inclination) $=6.69^{\circ}$. Libration occurs in both lunar latitude and

- Mare Humboldtianum at the eastern limb. longitude and at times shifts far side features or parts of them into view, such as the entire Mare Humboldtianum at the northeastern edge above the better known Mare Crisium. In the southern hemisphere crater Bailly and the eastern features of Mare Orientale come into view. Maximum librations occur about a week after perigee and apogee. Libration is a lunar rock'n roll motion.


## Varying Distance

Since the lunar orbit around Earth is of elliptical shape its distance to Earth changes strictly speaking every second (orbital speed $=1.022 \mathrm{~km} / \mathrm{sec}$ ). When reaching its closest orbit location the distance is around 356,300 kilometers ( 221,395 miles) while the farest point is at around 406,700 kilometers ( 251,903 miles), after all a difference of 50,400 kilometers ( 31,318 miles), or 14.5 times, or $7 \%$ the lunar diameter. When nearest, the Moon shines intrinsically brighter allowing shorter exposure times (the full moon then is around $30 \%$ brighter than average). When nearest the Moon is also apparently larger and therefore better positioned for imaging, however, we may be splitting hairs since seeing is the more dominant factor influencing the resolution and quality of our images. Driving on a straight
line at $100 \mathrm{~km} / \mathrm{h}$ it would take about 160 days to get to the Moon at its mean distance, or about 8 years on foot.

## Eclipses

The Moon's apparent size is about the same as that of the Sun which is 400 times further away but also 400 times larger. The distances of both vary in that the Moon can cover the Sun almost completely during a total solar eclipse or partly during an annular eclipse. During a partial solar eclipse, the Moon obstructs only part of the Sun's disk. A lunar eclipse occurs when the Earth moves in between and on the line of sight of the Sun and the Moon, in other words, when the Moon moves into the Earth's shadow. During such an event sunlight is being blocked by the Earth while the only light reaching the Moon is sunlight refracted by Earth's atmosphere band-passing reddish color.


- 'Super Moon' Lunar eclipse of May 26, 2021.

- A direct size comparison: "Super Moon" (perigee) and "Micro Moon" (apogee). At the times of capture the distances were not exactly the nearest and farest, but close.


## Lunar Facts

■ About 4.5 billion years ago, the Moon was probably formed after a collision between the premordial Earth and another perhaps Mars-sized protoplanet which has been named Theia. The debris from this "giant impact" gathered (accreted) in an initially low orbit around Earth to form the Moon in relatively short time. The so obliterated Theia is assumed to have formed near Earth explaining the similarity between lunar and terran rock.

■ The mean orbital speed of the Moon is 3,680 kilometers per hour ( 2,287 mph ) and is moving away from Earth at a rate of 38 mm (1.5 inches) per year.

- The dark patches on the lunar surface are not oceans like on Earth but cooled down molten lava which surfaced after asteroid impacts and volcanic activities about 3.9 billions of years ago. In fact once they were seas, but seas of molten rock. The "mare" appear darker because of lower light reflectivity (albedo). In November 2020, NASA announced that it has confirmed water molecules, $\mathrm{H}_{2} \mathrm{O}$, in sunlit areas of the Moon, indicating that water is widely distributed across the lunar surface though the Sahara Desert has 100 times the amount of water than what was detected by the SOFIA mission.
- Compared with the Earth, the Moon contains less iron and only few volatiles that evaporate easily, such as water and others, but it has more of aluminum and titanium (perhaps from the impactor), which are the cause of notable color hues on the lunar surface in contrast with lunar rock.

■ In view of the large size of the Moon relative to Earth, the Earth-Moon system is often referred to as a double-planet. Since the center of gravity currently lies 1700 km inside Earth, it does not satisfy the definition of a double planet. The Moon is almost as wide as the Australian continent (4000km), of course not in terms of surface area.

■ The Moon shows only one side because it rotates once around its axis while orbiting once around Earth (tidally locked). However, due to wobbling effects as a result of orbital inclinations not being zero (lunar libration) we can observe $59 \%$ ( $50 \%$ at a time) of its surface as it shifts in perspective.

■ The temperature difference between a lunar day and night is $300^{\circ} \mathrm{C}$, i.e., $+127^{\circ} \mathrm{C}$ during daytime and $-173^{\circ}$ during night time. The moon is exposed to 327.5 hours of sunlight and 327.5 hours of darkness during its orbital period of 27.3 days. Its gravity is 0.165 that of Earth.

■ The Earth's axial tilt is $23.45^{\circ}$ which results in our seasons. The Moon's tilt is $1.54^{\circ}$ in that there are hardly any seasonal changes. There are regions which remain in permanent shadow, mostly crater floors at the south pole. This is where frozen water is assumed to occur in 'large' quantities.

■ Due to ancient lava flows, there are large scale caves "pits", lava tubes and caves which entrances are called "skylights", or geological doorways to underground tunnels, wide enough to contain a city -- after filling with air and closing the entrance. Marius Hills, a region inside Oceanus Procellarum, is home to a series of lava tubes several kilometers long. Lava tubes have been found on both sides of the Moon.

■ The far side of the Moon has no large dark Mare and is heavily cratered. The only exception is Mare Moscoviense in the northwest. This is because the surface of the far side is about 30km thicker in that asteroid impacts did not open the crust to allow lava to flow over the surface. After forming, the Moon was much closer to Earth and tidally locked with one side always facing the scorching hot premordial Earth which heated the lunar surface up keeping it volcanologically active and thin.

$\triangle$ Artist's concept of the impact of Theia. Courtesy NASA.


- Crater Antoniadi, near the south pole on the far side, contains the lowest point on the Moon. Courtesy: NASA/USGS/LRO.

- Photographed by Apollo 11 from 18,520 km when homeward bound. Courtesy: NASA.

- The 450 million years young crater Aristarchus attracts with its high abedo and is deeper than the Grand Canyon, 2.7km, and 40 km across. Close-up inset by the Apollo 15 mission.

- An entrance (skylight) to a lava cave in Mare Ingenii on the rear side. Courtesy: NASA/Goddard/Arizona State University.


## The Moon

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The Moon is not as dead a body as was long assumed. Astro-geologists even assume it once was planet-like with a core, a molten mantle, a, crust plus a magnetic field and an atmosṕhere. All known lunar materials are also found on the Earth, therefore the Moon is geochemically almost identical, or a twin of Earth, Moons of other planets are made of elements largely different from their hosts.

With the exception of the Pluto-Charon (double planet) system with its barycenter some 960 km off Pluto and an orbital period of 6.387 days, no other moon in the solar system is a quarter the size of its host planet.


As seen from the surface of Pluto ( $\varnothing 2377 \mathrm{~km}$ ), Charon ( $\varnothing 1212 \mathrm{~km}$ ) spans about four degrees in the sky which is eight times wider than the apparent size of the Moon as seen from the Earth. The mean distance between Pluto and Charon is $19,596 \mathrm{~km}$ whereas the Moon orbits at a distance of $384,400 \mathrm{~km}$ in average away from the Earth both center-to-center.


A moon which once was planet-like..
A magnetic field persisting longer than assumed...
A shrinking moon torn by long seismic shocks..
A moon that will be a component of a double planet...

## Volcanic Activity

Three billion years ago the moon was covered by oceans of lava for several hundred million years. The glowing lava could have been observed from Earth because of the closer distance at that time. Erupting huge amounts of gasses streamed to the surface, such as water vapor, carbon monoxide and other toxic gases which may have formed a thin atmosphere under which water deposited on the surface while storing heat. In such an environment life may have formed though water deposites were not as abundant as Earth's oceans. More likely, bacterial life forms may have come from Earth as a result of asteroid impacts. However, water and heat on the Moon did not exist for long. When the lunar volcanoes could no longer supply sufficent gases, the low lunar gravitation could not hold the atmosphere any longer. Within a few million years all water escaped into space, the volcanoes extinguished and the Moon cooled down while its magnetic field disolved alongside any potential life. From that point onwards Earth and the Moon took different directions in their further lives.

## Moon Quakes

Apollo astronauts installed seismographs on the lunar surface. Within one year they measured 28 strong shock waves classified as moon quakes up to magnitude 5 on the Richter scale. Since quakes usually occur by tectonic activity on a molten

$\triangle$ Astronaut Scott collects samples near the Hadley Rille. In his visor is astronaut Irwin.
mantle, the origin must lie below the lunar surface. The lunar crust is 60 to 100 km thick, its solid mantle is about 1000 kilometers deep, while the lower mantle is likely molten. The Moon is

cooling off and therefore shrinking. Under this high pressure the collapsing surface causes quakes. Since the Moon is a dry body and its crust much thicker than that of Earth, further in absence of a molten mantle, lunar quakes can last longer than ten minutes as seismic waves easily propagate through dense dry stone. Earth's mantle and outer core as well as its oceans are liquid in that seismic waves are relatively quickly absorbed.

## Magnetic Field

In 2017, new analyses of material brought back by the Apollo 15 mission indicated signs of a magnetic field which should have entirely disappeared as the Moon cooled off and hardened while receding from Earth, however, the collected stones indicate that a magnetic field existed until a billion years ago. A magnetic field is generated by a molten core moving under a surface of crust. A molten core forms when tidal forces flex a body. At the time the Moon formed it orbited the Earth at a distance of some $20,000 \mathrm{~km}$ in that Earth's gravitation compressed and kneaded the Moon, generating heat by friction. This could explain why its magnetic field existed longer than assumed and leave traces of it in rocks and stones. Today, due to the longer distance, Earths pulls are too weak to keep the Moon's mantle molten. The magnetic field felt apart as all motions stopped and the Moon's surface was exposed to solar wind leaving a bleak surface. The Moon has not currently an active global magnetic field.


- Located west of crater Kepler, Reiner Gamma is unlike any other lunar feature. Looking like a painted swirl it is 70 km long, does not cast shadows and has a high albedo. Some sort of miniature magnetosphere that spans over 360 km with a 300 km thick region of plasma where the solar wind flows around without weathering the surface over Reiner Gamma is evident. This explains the higher albedo.


## Double Planet?

The Earth and the Moon are often called a double planet, so it would seem, however, the common center of gravity (barycenter) lies 1700 kilometers inside Earth in that by definition the system is not a double planet like Pluto and Charon. Since the Moon is gradually moving away from Earth (currently about four centimeters a year), it will be a double planet in distant future, say in 4 billion years. When receding, the Moon pulls on Earth and slows down its rotation until a day on Earth will be as long as a lunar orbital period, over 600 hours. Then, both bodies will be double tidally locked and show each other the same face. The Moon is tidally locked on Earth ever since its existence and strongly contributes to Earth's stable axis rotation and tilt which results into seasons and a stable environment for development of life.

## Size of the Earth

As the distance of the Moon to the Earth varies over its elliptical orbit its apparent angular size too varies. So does the size of the Earth as observed from the lunar surface. How big an Earth are we talking? In principle,

The equatorial diameters are...
Earth $=12756.2$ km
Moon $=3476.2 \mathrm{~km}$
factor $=3.67$

Assuming a given distance of $362,236 \mathrm{~km}$ (January 30, 2022, 07:00 UTC) the lunar size is 32.98 arc minutes. Then, the size of the Earth as seen from the center of the Moon is about 32.98 * $3.67=121.04 \mathrm{arc} \mathrm{min}=2.017^{\circ}$.

Since the lunar angular size is usually given for the center distances of the two bodies, we may wish to calculate the angular size of the Earth as seen from the surface of the Moon, say on its equator which is one lunar radius away from the center. Since the size is an angle, though small, it involves simple trigonometry for best precision:

Earth size = Atan(earth diameter / (em_distance - lunar radius)) * radians [in ]

Earth size $=$ Atan(12756.2km / (362236km - 1738.1km)) * $57.296=2.027^{\circ}=121.62^{\prime}=7297{ }^{\prime \prime}$

For the eyeball, the equations hardly make any difference. If you wish to calculate the size of the Earth on any lunar latitude multiply the lunar radius with the cosine of the latitude. For instance, on a latitude of $45^{\circ}$ the size of the Earth would be $2.022^{\circ}$.

## Lunar Pole Stars

The coordinates of the lunar north pole are $266.86^{\circ}$ in right ascension and $65.64^{\circ}$ in declination. The position is best visualized on a star chart. As we can see, the Moon does not have a bright northern Pole Star.



- The lunar north pole during favorable libration in latitude ( $+6^{\circ}$ ) Celestron 8, IR642nm, ASI290MM, 5ms, gain 130, 170fps, 600 frames.

The lunar south pole coordinates are $266.86^{\circ}-180^{\circ}=$ $86.86^{\circ}$ and $-65.64^{\circ}$ in declination. The star chart shows a fairly bright star near the lunar south pole which is delta Doradus, a 4th magnitude star some 150 light-years away and located just above the Large Magellanic Cloud.



Source: NASA/Bill Dunford

We always see the same side of the moon, because as the moon revolves around the Earth, the moon rotates so that the same side is always facing the Earth. But the moon still looks a little different every night. Sometimes the entire face glows brightly. Sometimes we can only see a thin crescent. Other times the moon seems to disappear entirely. As the bright parts of the moon appear to change shape during the month, each stage of the change is called a phase, and each phase carries its own name.

This chart above shows why this happens. The center ring shows the moon as it revolves around the Earth, as seen from above the north pole. Sunlight illuminates half the Earth and half the moon at all times. But as the moon orbits around the Earth, at some points in its orbit the sunlit part of the moon can be seen from the Earth, and at other points, we can only see the parts of the moon that are in shadow. The outer ring shows what we see on the Earth during each corresponding part of the moon's orbit.

## Lunar Orbit

## Sidereal Period: Synodic Period:

relative to the stars, it takes the Moon 27.32 days for a $360^{\circ}$ orbit around Earth. the interval between two subsequent new moons, 29.53 days (a lunar day from sunrise to sunrise is 708.72 hours).

The durations are different because the Earth is moving while orbiting the Sun, $30^{\circ}$ during 27.32 days in that the Moon must move $30^{\circ}$ more, which are another 2.21 days on its orbit to catch up with the Earth. The moon age is the number of days since new moon, from 0 (new moon) to 29.53 days (next new moon), another expression of lunar phases.

Super Moons in 2023

Time:
Phase:
Diameter:
Distance:
Right Ascension:
Declination:
Constellation:
Sub-Earth Longitude:
Sub-Earth Latitude:
Position Angle:
Time:
Phase:
Diameter:
Distance:
Right Ascension:
Declination:
Constellation:
Sub-Earth Longitude:
Sub-Earth Latitude:
Position Angle:

August 1, 2023, 14:00 UT
99.8\% (14d 19h 28m)
2003.5 arcseconds
$357,738 \mathrm{~km}$ (28.08 EarthØ)
20h39m03s
-23³3'44"
Capricorn
$-1.320^{\circ}$
$6.467^{\circ}$
$345.4^{\circ}$
August 31, 2023, 01:00 UT
99.9\% (14d 16h 22m)
2005.8 arcseconds

357,323 km (28.04 EarthØ)
22h39m40s
-12º3749"
Aquarius
$1.254^{\circ}$
$5.023^{\circ}$
$339^{\circ}$

Lunar Eclipses in 2023
May 5, 2023 17:23 UTC
Penumbral Lunar Eclipse

Visibility: South/East Europe, Much of Asia, Australia, Africa, Pacific, Atlantic, Indian Ocean, Antarctica.

Duration: 4 hours, 18 minutes.


## October 28, 2023 14:00 UTC <br> Partial Lunar Eclipse

Visibility: Europe, Asia, Australia, Africa, North America, North/East South America, Pacific, Atlantic, Indian Ocean, Arctic, Antarctica.

Duration: 4 hours, 25 minutes.
A Total Lunar Eclipse occurs when the Sun, Earth, and Moon align together in an exact straight line. When the alignment is not exact, and the Moon is partly in Earth's shadow, then the event is a Partial Lunar Eclipse. When only Earth's outer shadow casts on the Moon, then the event is called a Penumbral Lunar Eclipse. When the Earth blocks sunlight, the entire or a part of the Moon will be in Earth's shadow and reflect only the received reddish light refracted by Earth's atmosphere while shorter light wavelengths are scattered hence blocked. For this reason a total lunar eclipse is also called a Blood Moon.


The lunar eclipse of November 19th, 2021 has been praised an "almost total eclipse". In fact, at greatest eclipse the obscuration by Earth's shadow was $97 \%$ and with an overall duration of 6 hours and 2 minutes the longest partial lunar eclipse in 580 years, not seen since the 1440s, said AccuWeather. November 2021's Beaver Moon was also a "micromoon" as its distance to Earth was $21,000 \mathrm{~km}$ farther away from its mean distance.

The individual images were taken with a DSLR in order to get the entire Moon into the field of view. Image stacking is problematic since the Earth's shadow is gradually moving during frame acquisition. For each individual image the author captured about 60 frames with intervals of a few seconds (to allow the DSLR sensor to cool down a bit), but no more than 10 frames could be stacked in Autostakkert!3 without stripes and other distortions.

## Equipment

## Telescope

In the interest of good resolution, a telescope with at least 5 -inches ( 127 mm ) aperture, Newtonian or Cassegrain, will be fine. A Newtonian is most affordable and 'fast' with a typically F5 focal ratio sufficing with short exposure times, but is quite heavy therefore requiring a sturdy mount. More costly than Newtonians, Schmidt-Cassegrains come with a focal ratio of F10 and a long native focal length. A popular Cassegrain variation, the Maktsutov, has a slower focal ratio of around F12 to F15 and is said to produce sharp images. Cassegrains have a shorter tube and weigh less than comparably sized Newtonians. Owing to its design, the aperture of reflectors is obstructed by a secondary mirror. Consequently, a 6 -inch scope is a little over true 5 inches. If you choose an 8 -inch scope you will get true 6.5 to 7 inches depending on the size of the secondary mirror. Note that a Newtonian mirror has the larger area as compared with a Cassegrain of the same aperture as in Cassegrains a baffle


- Example: Sky-Watcher's 150PDS, a 6 inch, 750mm, F5 Newtonian.
goes through the center of the mirror. Please be aware that large telescopes do not only collect more light but also more air turbulences as compared with smaller telescopes. With 10 and more inches aperture you depend a lot on seeing, but when seeing is excellent the obtained images will pay. Telescopes from 5 to 8 inches, too, can produce remarkable images. Refractors can as well be used but are quite expensive with growing aperture. So-called "field flatteners" (for refractors) and "coma correctors" (for reflectors) are not essential because the sensor of a 'planetary' camera is typically small.


## Tracking Mount

The most important gear is an electronic equatorial mount capable of accurate tracking. The heavier the telescope the sturdier a mount is required. High magnifications typically required for lunar imaging call for accurate tracking. The mount should be specified for a payload of, say, 1.3 times the weight of your complete imaging gear.


- Example: The GoTo Orion Sirius mount is made for a payload of 13.6 kg .


## Camera

The ZWO ASI290MM is a monochrome CMOS camera with a 5.6 x 3.2 mm sensor comprising 1936 x 1096 pixels, same as the ZWO ASI462MC color camera which is highly sensitive to infrared. A "planetary" astro-camera records uncompressed videos containing thousands of frames from which a certain percentage (typically the best $10 \%$ to $20 \%$ ) are used for stacking. Planetary cameras sport small


Example: ZWO ASI290MM with bundled 1.25 " nose piece and all-sky wide CCTV lens.
sensors resulting in a narrow field of view which is desirable for imaging the Moon and the planets. Color cameras make it easy to image
painlessly within short time. Monochrome cameras offer higher resolution and sharpness. In order to produce a color image with a monochrome camera a set of three color filters is required significantly extending imaging and post-processing time. A filter set including wheel costs about the same as a color camera in that ownership of both a color and a monochrome camera is most efficient. Cameras containing the Sony IMX290/IMX178 (mono) or IMX462/ IMX464/IMX585 (color) sensors are ideal for lunar and planetary imaging tasks.

## Filters

Two types of filters are essentially required because a CMOS camera is sensitive to both visual and near infrared wavelengths. If used without filters images will look notably smeared. An infrared cut filter passes visual light only. It is indispensible for color photography. An infrared pass filter blocks visual light and can be used with both color and monochrome cameras while such images are usually converted to gray scale. When the atmosphere is turbulent, an IR-pass filter can help reduce the effect of blurring. IR-pass filters are available with opening wavelengths


- Example: Manual Filter Wheel.
between about 640nm and 850nm. With increasing wavelength the camera's response drops in that filters with long wavelengths require longer exposure times while also trading resolution which deteriorates with longer wavelengths. Color cameras containing the Sony IMX462, IMX464 or IMX585 sensors are highly sensitive to near-infrared, therefore hardly compromising exposure time when using IR-pass filters up to 750 nm . When frequently imaging in both wavelength domains, a filter wheel can help make imaging life easier but extends the distance to the camera's sensor.


## Computer

Consider a laptop with SSD disk and powered USB-3.x port since mechanical hard disks are often too slow resulting in intermediate buffering of frames in memory, then saving the buffered frames to hard disk. This can significantly reduce frame rate and extend recording duration. Since we are saving
 several Gigabytes per video file (ex.: 6000 frames, 8 -bit depth $=12 \mathrm{~GB}$ ) the capacity of the hard disk should be generous, at least, say, 512 Gigabytes. Note that you can elegantly remote control a PC via WiFi with another PC or a miniPC using the TeamViewer software.

- Example: The low-end, low cost Lenovo Thinkpad E590 sports an Intel i5-8265U CPU and a fast internal SSD disk. The author tested it with up tp 300 frames per second video recording without any issues. The product is discontinued but may be available second-hand, or look for a sucessor or a similar product from other manufacturers.


## Software

Capture: Please look for SharpCap or FireCapture or applications offered by camera manufacturers, such as ASIStudio from ZWO for ZWO cameras.

Stacking: Though Registax6 is a fine stacker, please look at Autostakkert!4 which is the preferable choice.

Sharpen: Although Autostakkert!4 can sharpen image stacks, Registax6 is popular for its wavelet sharpening. Also consider Y-Cittert sharpening of AstroSurface.

Post-processing: GIMP, Photoshop or similar.
Mosaic: For image stitching, among other choices, $M S-I C E$ is an accurate, fast and simple-to-use application. Unfortunately, MS-ICE is abandonware.

## Other

A table and a chair, power supply for the laptop and the telescope mount, an LED head light, tools, a mobile phone. Let friends or relatives know where you are out imaging. In the field, a quick-cover for laptop and telescope (in case of a sudden rain shower) can protect your gear. Else needed may be accessories, such as a dew shield, dew heater tape. Further... adequate clothing, food, drinks, medicine, first aid kit, bug repellant, etc.

## The ideal telescope for the Moon

A refracting telescope without a central obstruction maximizes the advantage of its aperture, however, large color-corrected refractors tend to cost a fortune. Low-cost achromatic refractors are available with up to 5 inches aperture but are not corrected for false colors. Yet they may be useful since the sensor of planetary cameras are very small and available in monochrome.

A reflector has a secondary mirror which obstructs the primary, thus sacrificing contrast and resolution. The secondaries are often made large to accommodate wide image sensors such as found in DSLRs. As planetary cameras sport small sensors, a "moon-tailored" reflector would suffice with a small secondary mirror, say for sensors up to 0.6 inch or 16 mm in diagonal. Since, unlike SCTs and MKTs, Newtonians do not have a baffle going through their primary mirror they provide optimized resolution for their aperture and are cheaper than any other design. However, since the optical path is not folded by means of internal reflections, Newtonian tubes (OTA) are nearly as long as their focal length which hardly exceeds 1000 mm thus requiring a barlow lens for lunar work. For this reason, a short-tube "light path folding" Cassegrain-type is most widely used for lunar and planetary imaging, though not exactly ideal.


You may wish to look for similarly sized SchmidtCassegrain telescopes from Meade, or Maktsutov Cassegrain telescopes from Sky-Watcher and others.

This Schmidt-Cassegrain telescope, SCT, is a real workhorse and an excellent compromise in terms of size, weight and cost. It sports a primary mirror 8 inches across. The primary mirror is $\mathfrak{f 2 . 0 \text { fast. The secondary }}$ mirror magnifies $5 x$, resulting in a f10 scope with a short tube.


The secondary mirror obstructs the primary by 64 mm or $31 \%$ in diameter. The overall obstruction is $35 \%$ or $10 \%$ by area. The tube weighs only 5.7 kg and sits comfortably on a medium sized equatorial mount, such as the iOptron CEM28, Orion Sirius, Sky-Watcher EQ5, or similar. The tube comes with a convenient grab handle at the back.

Thanks to its short tube the setup is sturdy and less prone to wind shake. It is a closed optical design in that it can take some time to thermal equilibrium, say an hour before action. In turn, the primary mirror is protected against contamination, while the corrector plate can be easily removed and cleaned. In humid nights the corrector plate will dew up quickly, in that a dew tape is indispensable, and be sure it is a 12 V tape (or a small hair dryer).

The aluminum optical tube offers 2032 mm of focal length and a focal ratio of $f / 10$, which is ideal for lunar and planetary imaging tasks at native focal length with popular CMOS cameras. Of course, the use of reducers to reduce or barlows to extend focal length is possible, but within limitations, such as given by seeing, pixel (image) scale and resolution. As a rule of thumb, going beyond a focal ratio of $5 \times$ camera pixel size will not yield any further resolution. For instance, an IMX290 based camera has $2.9 \mu \mathrm{~m}$ pixels. Multiplied by $5=$ about $\mathrm{f} / 15$, in other words, a $1.5 x$ barlow for the C8 would be optimal for close-up imaging but not really more because the theoretical resolution limit of the C 8 mirror is 0.56 seconds of arc.

In spite of many improvements over the classic C8, the visual back is still the 1.25 " sized with two screws to hold accessories, such as cameras and star diagonals. A modern, sturdy upgrade is the "Baader Clicklock" which accepts 1.25or 2-inch accessories that can be fastened with a single, well, "rotation clicklock". It should be a standard feature.

An SCT focuses by moving the primary mirror. Since the motion changes the distance of the primary to the secondary mirror, the focal length, too, changes. The closer the mirrors, the longer is the resulting focal length. The nominal back focus is about 127 mm from the rear surface of the baffle nut (the focal length of 2032 mm is specified for this point). Since the focus travel is very long, extension tubes can be used to manipulate the focal length to a considerable extend.

Owing to mirror curvature, a SCT is prone to off-axis aberration that makes stars away from the center look like little comets. Sensors of planetary cameras are usually too small to get into the outward area where aberration occurs, yet adjustment of the optical axis is crucial.

Celestron's standard $0.63 x$ reducer/flattener replaces the visual back for deep sky imaging. The optimal back focus to the camera sensor is about 105 mm . The reducer does
 not cover APS-C sensors leaving coma and field curvature beyond a corrected circle of 20 mm . Alternatively, a 1.25 " reducer, typically $0.5 x$, can be threaded to the nose piece of a CMOS planetary camera if a wider field at less resolution is wanted.

A rough collimation is made easy with three Phillips-head screws on the secondary mirror until a, say, defocused 2nd magnitude star is concentric with identical diffraction patterns on either side of focus. Replacing the three collimation screws, "Bob's Knobs" are thumb screws making collimation even easier without need for a tool.

A truly useful focusing assistant is a dual-speed $10: 1$ and 100 mm long Crayford focuser with 25 mm focus travel which threads to the visual back of an SCT. It accepts 1.25 " and 2 " imaging gear including a $\varnothing 48 \mathrm{~mm}$ filter thread. It provides way finer focusing and is an alternative to the
 standard visual back or the above introduced "Baader Clicklock", both of which can be threaded onto the $0.63 x$ reducer. The Crayford focuser then adjusts the camera's position to the reducer's back focus.

Celestron calls its coating technology 'StarBright XLT', with multi-layer mirror coatings and multiple layers of magnesium and hafnium fluoride on the corrector plate. Celestron specifies an overall transmission of $85.3 \%$ for their XLT design.


The Aristarchus Plateau with Vallis Schröteri.
The planets are inserted to image scale.


This image hăs won an USD 450.00 awaird in the "60th Anniversary Sightron Japan Astrophotography Contest 2021", and is featured in the largest Japanese monthly astronomy magazine TENMON GUIDE, issue December 2021, page 39 bottom.

This image has also been selected by the jury for Sightron Japan's 2022 calendar.

Alongside great images of 11 other winners this image has been exhibited at the Sightron Japan booth at the world premiere show for cameras and images "CP+2022" in Yokohama.

The currently best-known sources of planetary CMOS cameras are "QHYCCD" and "ZWO Company". In April 2021, "Player One Astronomy" joined the competition. The expert companies, now also including "Svbony" are adopting the same image sensors from Sony, in that except for electronic hardware and housing, the performance is about the same in that which to go for is principally a matter of how you like the camera body. For fairness this article refers to the part numbers of the Sony image sensors.

Now we are getting to the painful section, namely which camera to choose. As to the first hurdle, there are monochrome and color cameras. Fundamental difference being, monochrome cameras are sharper and reveal more details than color cameras, the latter coming with a "Bayer Matrix" which splits light into a pattern of colors, thus sacrificing resolution. Interestingly, monochrome cameras carry higher price tags. Simple reason being, Sony and others sell more color sensors than monochrome in that the mass production cost of color cameras is much lower.

The moon is a target inviting both monochrome and color imaging. If you own a monochrome camera, you can add optional color filters and a filter wheel, then take images each through a red, a green and a blue filter in addition to a luminance image through an IR-cut or IR-pass filter to add contrast. A so composed color image is as finely resolved as a monochrome image, however at the expense of longer recording time and additional filter set. A mechanical filter wheel and a filter set (1.25 inch) cost about as much as a "one-shot color" camera, OSC.

The following images showcase the form factors of three suppliers:


- Background images in color (left and middle) with ZWO ASI462MC and Svbony IR-Cut filter, monochrome (right) with ZWO ASI290MM camera and 640nm IR-pass filter. Celestron 8 XLT telescope at native focal length.


## Monochrome Camera

Cameras housing the monochrome IMX290 sensor are great for lunar imaging. The sensor's sensitivity peaks at 600 nm wavelength and is still $95 \%$ at 640 nm and $75 \%$ at 740 nm (both near-infrared), allowing for short exposure times and high frame rates (170fps max. at full resolution). The IMX290 camera sensor measures $5.6 \times 3.2 \mathrm{~mm}$ with $2.9 \mu \mathrm{~m}$ pixels, a total of 1936 x 1096 effective pixels. The IMX290 color version has been discontinued.

IMX290 / IMX462

## Color Camera

A recommendable color camera comes with the IMX462 sensor which has the same dimensions as the IMX290. The IMX462 excels with high infrared sensitivity peaking at about 800 nm . Its maximum frame rate is 138 fps at full resolution. Since sensor and pixel size are the same, both the monochrome IMX290 and color IMX462 supplement each other. The larger, but else identical IMX464 is twice the size of the IMX462 by sensor area.

The IMX485 is four times the size by area but with the characteristics that of the IMX290 color sensor (discontinued) and does not provide the high infrared sensitivity of the IMX462 and IMX464 sensors. Like all cameras, the IMX485 can be binned $2 \times 2$, i.e., four pixels can be combined into one (by the capture software) to obtain the pixel count of the IMX290 sensor with a pixel size of $5.8 \mu \mathrm{~m}$. Advantages of larger pixel size include higher sensitivity and less noise. The drawback is lower image resolution. Update July 2022: IMX585 ( $2.9 \mu \mathrm{~m}, 3840 \times 2160$ pixels) replaces IMX485 with higher QE and full-well.

At the right are the field of views with a Celestron 8 telescope, $\mathrm{FL}=2030 \mathrm{~mm}$.


IMX464


IMX485 / IMX585



A barlow lens extends the focal length of a telescope hence increasing magnification. In almost all cases the effective magnification is not as printed on the barlow, because the factor depends on where in the optical train the barlow is placed. Also, a Schmidt-Cassegrain telescope focuses by moving its primary mirror thereby changing its native focal length.


A tubeless barlow from William Optics threads to the camera's $1.25^{\prime \prime}$ nose piece and is therefore positioned near the camera's sensor resulting in less magnification than imprinted. The distance can be increased with an extension tube or a filter wheel.


- Measuring the approximate effective magnification with Jupiter's equatorial diameter in pixels.



## Comparing Sensors

There is no way around, the more aperture the more details a telescope can resolve. The ability of an objective lens or mirror to resolve is the so called "Dawes Limit" specified in seconds of arc which marks the theoretical angle below which no further details can be obtained. The maximum meaningful focal length in connection with a given camera strongly depends on the pixel size of the camera's sensor. As a rule of thumb, going beyond a focal ratio of $5 x$ (seeing dependent) camera pixel size in $\mu \mathrm{m}$ will not yield any further detail.

Large sensor pixels collect more light and gather less noise, however, at the expense of image resolution as compared with smaller pixels. While IMX290 sensors with $2.9 \mu \mathrm{~m}$ pixels are great for lunar and planetary imaging, the IMX178 sensor has even smaller pixels, namely $2.4 \mu \mathrm{~m}$ resulting in higher image resolution.

Hereafter, we will compare images captured with IMX290 and IMX178 monochrome sensors, represented by a ZWO ASI290MM camera and a Player One Neptune-M camera, respectively. The essential features are:


The frame rate is specified for the maximum field of view (region of interest, or ROI). The larger the image the longer it takes to transfer it. The sensor size of the IMX178 is three times larger than that of the IMX290 by area. Update: In June 2022, ZWO launched its ASI678MC, a camera with $2.0 \mu \mathrm{~m}$ pixels. In April 2023 QHYCCD introduced its QHY5III715C with $1.45 \mu \mathrm{~m}$ pixels. Unfortunately for lunar imaging both are color cameras.

The Neptune-M camera additionally sports internal 256MB buffer memory which helps avoid loss of frames when connected to a slow PC, a dead pixel suppression function and a HGC mode which automatically reduces readout noise at higher gain thus maintain a dynamic range which is comparable with low gain settings. The Neptune-M also has an adjustable plate to compensate for tilt in the optical axis or in the camera itself. It can also be binned up to $4 \times 4$.

The larger sensor size of the IMX178 entails a wider field of view with a given focal length of a telescope. A wider field allows mosaics with fewer tiles.


- Actual field of view at a focal length of 2030 mm . Also note the different aspect ratios.


FOV: $0.21 \times 0.14^{\circ}$, image scale: $0.244^{1 / p x}$, linear: 456 meters/px

Image scale is the theoretical resolution in arcsec per pixel. Linear scale is the theoretical resolution in meters per pixel and depends on the moon's distance while actual resolutions vary with seeing conditions, air turbulences and the telescope's resolving power. It might be both, fun and useful to add this data to image documentation in addition to capture time and employed gear.

## Glossary

Full well capacity (in electrons) is the amount of charge that can be stored within a single pixel before saturation. The larger a pixel the larger the full well capacity, like more rain is gathered in a large bucket.

Quantum efficiency is the ability of a sensor to convert received photons into electrons. There are no $100 \%$ efficient sensors.

Read noise is the electronic noise introduced as pixel charges are read out through an amplifier and an analog-todigital converter, ADC. "HGC mode" can reduce readout noise.

## Splitting Hairs

Though various pixel sizes entail various pros and cons the difference between $2.9 \mu \mathrm{~m}$ and $2.4 \mu \mathrm{~m}$ pixels is not that significant. Again, larger pixels collect more light in a given time interval and are therefore more sensitive, resulting in shorter exposure times, less noise and higher frame rates at a given ROI which can help freeze poor seeing conditions.

Smaller pixels collect less light and a larger noise portion, are more prone to seeing and tracking accuracy but provide a higher image resolution. Since the moon is a bright object, a higher resolution with more detail can be more desirable than higher sensitivity and lower noise level both of which can be compensated for by recording and stacking more frames.

Since the IMX178 sensor is larger by area its maximum frame rate is much lower than that of the smaller IMX290 sensor. However, when the IMX178 is set to the maximum ROI of the IMX290 (1920 x 1080 pixels), then the frame rates at the same exposure time are similarly fast but the image resolution will be the same.

## For comparison, the "telescope" of

 the LRO is an $f / 3.59$ Cassegrain (Ritchey-Chretien) design with a 195 mm primary mirror and 700 mm effective focal length. The "narrow angle" camera sports a Kodak KLI5001G image sensor resulting in a pixel scale of 0.5 meters/pixel at 50 km altitude.
## Painless Maths

Field of view, FOV, is obtained by:

```
FOV [degrees] = 2 * Atan(sensor size / 2 x telescope focal length) * 57.296
```

Sensor size can be horizontal, vertical or diagonal length in millimeters. Example: IMX178 sensor width and an 8 inch Schmidt-Cassegrain:

```
fov = 2 * Atan(7.4mm / 4060mm) * 57.296 = 0.21' or 12.6 minutes of arc.
```

Image scale is obtained by:
scale_img [arc sec/px] = 206.265 * pixel size [ $\mu \mathrm{m}$ ] / focal length [mm]
where 206.265 is a radian in arc seconds divided by 1000 to match the focal length unit in millimeters. Pixel size is that of the camera sensor.

Linear scale is obtained by:
scale_lin $[\mathrm{km} / \mathrm{px}]=$ image scale [arcsec/px] / moon size [arc sec] * 3476.28 [km]
The apparent diameter (size) of the Moon varies significantly with its distance from Earth. The mean value is 1860 arcsec. The physical equatorial diameter of the Moon measures 3474.2 kilometers. The angular diameter of the Earth as observed on the lunar equator is about $1.91^{\circ}$ ( 6876 arcsec) at mean distance.

## Frame Rate vs Exposure

When seeing is unfavorable, tracking inaccurate and clouds rolling in and out, short exposure times in the interest of fast frame rates are crucial for lunar imaging. The values in the following table in fps have been measured with SharpCap4 at 1920 x 1080 pixels ROI, mono8, 10-bit ADC, USB speed 100\%.

|  | ASI290MM | Neptune-M |
| :---: | :---: | :---: |
| 5 ms | 170 | 118 |
| 6 ms | 166 | 118 |
| 7 ms | 142 | 118 |
| 8 ms | 124 | 118 |
| 9 ms | 111 | 110 |
| 10 ms | 100 | 99 |
| 11 ms | 91 | 90 |
| 12 ms | 83 | 83 |
| 13 ms | 77 | 76 |
| 14 ms | 71 | 71 |
| 15 ms | 66 | 66 |
| 20 ms | 50 | 50 |
| 25 ms | 40 | 40 |

At maximum ROI (3096x2080 pixels), the Neptune-M records at 60 fps with exposure times up to 16 ms . Longer exposures would anyway not freeze the images when the air is turbulent. This gives much room for balancing exposure and gain without sacrificing frame rate, also considering that the lunar surface brightness can vary significantly with phases.

## Storage Requirement

For example, when video-recording 6000 frames at maximum ROI, the ASI290MM writes 12.5 Gigabyte files, while the Neptune-M writes 37.7 GB , or roughly three times more which corresponds to its three times larger pixel count. Accordingly, stacking in Autostakkert! 4 takes more time (about 25 minutes for 600 of 4000 frames with an i 5 CPU at 1.8 GHz and 16 GByte memory *). Overnight batch stacking of similarly taken images will help save time.

When imaging the Moon with the Neptune-M a large capacity SSD, say 1 Terabyte may help avoid premature ending of a recording session. We recall that capture software records uncompressed video. On the other hand, a lunar mosaic requires less panels with the Neptune-M because its larger sensor delivers a wider field of view.

* Drizzle $=$ OFF, Double Stack $=$ OFF, Improved Tracking = ON.

Personal judgement: after weighing all pros and cons against my imaging purposes, and if I were forced to pick one model, I would go for a camera sporting the IMX290 sensor.

## Conclusion

The smaller pixels of the Neptune-M deliver higher resolution, but collect less light thus requiring a bit more exposure time while the portion of noise in the signal is larger.

The larger sensor provides a wider field, which is great for lunar full disk mosaics, but trades off frame rate.

To avoid sampling issues the focal length of the telescope should not go too far. Larger sensors are more prone to optical errors, such as poor telescope collimation and axial tilt.


Age: 6.1 days ..in Aquarius
Magnitude: -10.8
Phase: 43\%
Diameter: 31.2 arc min Distance: 382770 km Longitude Earth: $7.9^{\circ}$ Latitude Earth: $6.7^{\circ}$
Position angle: $338^{\circ}$


Celestron 8 XLT, $2 \times$ tubeless barlow, ASI290MM, Astronomik IR642nm filter, $8 n \mathrm{~s}$, gain 220, 124fps, 600 frames, mono8, 10-bit ADC.

The ROI for the ASI290MM image is $1888 x$ 1032 pixels after cropping of stacking artifacts.


The ROI for the Neptune-M image is 2800 x 2008 pixels after cropping of stacking artifacts

The ratio of pixel sizes is $2.9 \mu \mathrm{~m} /$ $2.4 \mu \mathrm{~m}=1.21$. The smaller image (ASI290MM, top) is 1888 pixels wide, in that we need to crop the larger image (Neptune-M, bottom) to 2285 pixels wide and shrink it to the same width on this page in order to visually compare the image resolutions.


Celestron 8 XLT, $2 x$ tubeless barlow, Neptune-M, Astronomik IR642nm filter, 8 ms , gain 250, 60fps, 600 frames, mono8, 10 -bit ADC.





2022-12-04 12:58 UTC
Celestron 8 XLT, ASI290MM, Astronomik IR642nm filter, 5ms, gain 220, 170fps, 1000 frames, mono8, 10-bit ADC, 3-panel mosaic Mars imaged on the same night at 14:09 UTC is inserted to image scale.


## Filters

The aim is to produce videos at shortest possible exposure time and fast frame rate in particular when seeing is poor and persistently rolling in clouds are disturbing. Equally important is low noise. Noise can be reduced by choosing the lowest meaningful gain and a large number of frames to stack. Naturally, imaging the Moon at good seeing is the best guarantor of success.

Infrared pass filters (precisely nearinfrared) compensate a lot for poor seeing but need longer exposure times as the camera's infrared response is lower than its visual color response. In case of the ASI290MM, the exposure time with an IR640nm pass filter is about half that of an IR740nm filter -- a notable benefit when seeing is not that bad. When using infrared pass filters on color cameras you would typically record in monochrome. Infrared pass filters are mostly used with monochrome cameras.

Because the resolution in infrared diminishes with increasing wavelength (Rayleigh criterion: 1.22 * wavelength / aperture), it is advisable to choose the filter in accordance with seeing. A red filter is often used when seeing is good or a green filter when seeing is exceptional. Both provide sharper and more detailed images with short exposure times. Unwanted edge diffraction, aka ringing, worsens with increasing wavelength in that imaging in visual is wiser when seeing is good and the atmosphere calm. Since ringing occurs where sharpening messes up abrupt transitions from dark to light the effect in infrared is worse the better the seeing.


- Captured during calm air with an IR642nm band pass filter. A red or green filter would have provided a bit more resolution. Celestron 8, 1.6x tubeless barlow and ASI290MM camera.

Quality IR-cut filters for recording in visual wavelengths pass more than $95 \%$ of the light hence hardly sacrificing exposure time. It is a dance on a rope. Either you record in visual light resulting in the shortest possible exposure times and fastest frame rates, or in infrared with longer exposures and slower frame rates, but less prone to poor seeing. When your time and clouds allow, image in both domains and select the keepers after post-processing.


- The response in near infrared is higher than in color, a unique characteristic which helps reduce exposure times for infrared imaging.

- The response in near infrared drops past 600 nm and is around $50 \%$ at 850 nm but it is still high with 640 nm to 740 nm IR-pass filters.


4 The $11.2 \times 6.2 \mathrm{~mm}$ dimensioned IMX585 is an 8.3 megapixels 4 K color sensor with $3840 \times 2160$ pixels, $2.9 \mu \mathrm{~m}$ each sporting four times the chip area of the IMX290 resulting in twice the field of view. In 2x2 binning mode the pixel size doubles to $5.8 \mu \mathrm{~m}$ while still providing HD resolution. Succeeding the IMX485, the IMX585 peaks a QE of $\sim 91 \%$ with a full-well
capacity of $38.8 k-e$.

## Filter Test



- This equally processed image trio compares the results with various filters under turbulent air. Test equipment: ZWO ASI290MM camera set to mono-8 and 10-bit ADC, Ø150mm f5 Newtonian with $2 x$ barlow ( $F L=1500 \mathrm{~mm}, \mathrm{f10}$ ). Obviously, the differences are subtle. Short exposure times freeze the frames while infrared is less prone to poor seeing. The IR640nm pass filter allows short exposure times while contributing to the infrared advantage. For up to 8 inches aperture an IR640nm filter is a good bet for infrared imaging, else an IR740nm compensates poor seeing better.


## Band-Pass Filters

Narrow-band filters are indispensable for deepsky imaging providing a narrow window around a wavelength of interest, such "Hydrogen Alpha", H $\alpha$ at 656.28 nm . The "spectral window" can be as narrow as 3 nanometers. For lunar imaging we will need a wider window in order to obtain shortest possible exposure times while making use of the filter's advantages.

Player One's ERF filter is originally designed to assist solar imaging but can serve as a Red filter with 125nm spectral window and high transmittivity, providing better sharpness with monochrome cameras when seeing is favorable (when exceptional a Green filter will perform a bit better).


The resolving power of a telescope, for example an 8 -inch ( 20.3 cm ) f10 SCT, is better at short wavelengths. This relates to the Rayleigh criterion:

### 1.22 * wavelength / aperture

Consequently, at 470 nm (blue):
1.22 * $470 \mathrm{~nm} / 20.3 \mathrm{~cm}=0.28$ " at 850 nm (infrared):
1.22 * $850 \mathrm{~nm} / 20.3 \mathrm{~cm}=0.52$ "


This is the minimum angular separation of two light sources, such as stars (= diffraction limit measured in seconds of arc), which can just be resolved by a lens or a mirror (in an optical system a beam of light always spreads out). In our example blue light is 1.8 times better resolved than infrared.

Shorter wavelengths can be better distinguished by a given lens. This advantage can be benefitted from when the air mass is quiet. If not, infrared pass filters opening at longer wavelengths, such as 640 nm or 740 nm , are employed to reduce the effect of turbulent air trading against resolving power. The equation also shows why larger apertures provide finer resolution. The science behind is way more complex, but reference to a simplified formula is sufficient for lunar imaging. The formula is theoretical and merely a starting point for limitations in an optical system. In catalogs the specified resolving power of a telescope is based on the "Dawes" limit, which, irrespective of wavelength, is roughly quantified as 115.824 / aperture [ mm ] in seconds of arc. Obstruction in reflecting telescopes should be accounted for. The obstruction factor is: 1 - (obstruction in \% * 0.01$)^{2}$.

The Astronomik ProPlanet 642nm has a 200nm spectral window from 642 nm to 842 nm , blocking not only visual wavelengths but also the longer near infrared.


This universal filter is well suited for daylight IR-imaging, it reduces seeing effects and enhances contrast when employed for lunar- and planetary imaging. Because it blocks longer IR, it reduces ringing effects while increasing sharpness. It is also an affordable $\mathrm{H} \alpha$ filter for getting started with imaging $\mathrm{H} \alpha$ regions, such as nebulae.


According to the manufacturer installing the ProPlanet 642 BP in front of an autoguider camera dramatically improves guiding quality, as image-motion from one frame to the next is minimized.

## Image Capture

## Color Spaces and Frame Rates

The keys to brilliant images next to good seeing are exposure time and consequent frame rate (fps) which need to be fast enough to freeze seeing but also long enough to fill up the camera's sensor pixels (full well) in the interest of best possible signal-to-noise ratio. The shorter the exposure the faster the resulting frame rate. The frame rate depends on various factors.

Monochrome cameras provide 8-bit or 16-bit Mono 'color spaces' where 8-bit yields the faster frame rate, about twice as fast as 16 -bit. Color cameras provide ' 8 -bit and 16 -bit Raw', 'RGB24', and '8-bit Mono'. 8-bit Raw yields twice the frame rate of 8-bit Mono.

The camera can use either a 10-bit ADC (high speed mode ON) or 12-bit ADC (high speed mode OFF). The 10-bit ADC provides 1024 brightness levels (faster frame rate) while the 12-bit ADC provides 4096 levels hence the better contrast and detail but at about half the frame rate. There is hardly any difference in the frame rate when the exposure time exceeds about 10 ms (as found with an ASI290MM). For the moon and planets 8-bit depth with 10-bit ADC is basically sufficient as with 12 -bit you would just be recording the atmospheric noise inherent to seeing, unless the air is steady which is hardly the case.

Reduction of the image size (ROI = Region of Interest) too results in faster frame rates. While for the Moon the maximum size is desirable, planets do not require that much space around. Often an ROI of $320 \times 240$ pixels is quite sufficient for planets. IMX290 sensor based cameras provide a frame rate of 170 fps at maximum ROI and can exceed 300 fps with $640 \times 480$ pixels or 700 fps with $320 \times 240$ pixels through the camera's 10-bit ADC and 8 -bit data.

NOTE: 16-bit mono and 16-bit raw provide 65,536 brightness values, however, the camera's 12-bit ADC outputs 4,096 steps maximum, ignoring or rather wasting the upper 4 bits which is fair enough though as 8 -bit are quite sufficient for solar system imaging.

## File Formats

All cameras can save videos as *.AVI or *.SER. While AVI (8-bit only) can be played in numerous applications, SER is more robust and less error-prone as specifically concepted for astronomy image capture. The choice of SER is recommended and fully compatible with the Autostakkert!4 stacking software.


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## Acquisition

Since we are always imaging through the Earth's atmosphere it is desirable to "freeze" turbulent air with short exposure times. As the camera's gain is turned up shorter exposure times can be realized but image noise increases noticeably. This can be compensated for with ten thousands of frames to stack, but involves much longer processing time. A good compromise for an IMX290 sensor based camera is a gain between 150 and 200 for a low noise level that requires way less frames for stacking, say, a few thousand. When using an IR-pass filter a gain of 200 is better since the camera's sensitivity lowers as the wavelength increases. Please remember that an IR-pass cuts better through bad seeing but sacrifices some resolution.

It depends on the camera's specification, but around 15 ms exposure and 80 fps are a good compromise in terms of speed and noise. Nevertheless, if tracking is not at its best and clouds rolling in and out you may wish to achieve the maximum possible frame rate and expose under 10 ms . The author has obtained great results with 5 ms exposures resulting fast frame rates at 170 fps with an ASI290MM, thus outsmarting clouds and turmoil air.

Note that even at short exposure times the frame rate can drop significantly with 12-bit ADC and 16bit data and that it takes way more time and disk space for recording, while also demanding higher tracking accuracy for keeping the image centered during several minutes of recording.

For a lunascape 8-bit mono or 8-bit raw will suffice and result in faster recording time and smaller file sizes. When choosing 8-bit color spaces, then the camera's "high speed mode" (10-bit ADC) can be used without sacrifices.

As you will obtain way more frames with 8-bit data within a given time, stacking will cancel much more noise and allow for more aggressive sharpening.

## Capture Parameters

Camera setting parameters which require special attention are exposure time (frame rate) and gain.

Short exposure times freeze poor seeing and turbulent air while allowing for fast frame rates. If the mount does not track well or clouds are rolling in and out then fast recording is helpful.

Gain is not the same as sensitivity. An image sensor has a fixed sensitivity which is its ability to convert collected photons into electrons (quantum efficiency, QE). Gain is software-controlled and directly related to dynamic range and noise therefore often requiring a compromise.

The four plots at the right showcase the reationship between gain and sensor performance for the IMX178 monochrome sensor as an example. The maximum gain specified here is 400 , but this depends on the image sensor.

The only parameter which benefits of higher gain is readout noise but all other performance features worsen as gain increases.

Full well and dynamic range are directly related. As gain increases the sensor pixels will reach saturation sooner thus decreasing dynamic range. A low dynamic range has a higher portion of image noise and lacks contrast as well as resolution while making post-processing a real pain in the neck.

Capture software, such as SharpCap limits the gain setting to a reasonable range. When recording planets or the lunar surface at high gain the larger noise portion can be compensated for by increasing the number of frames for the final image stack - to some extend.

An in-depth description of the impact of gain would lie way beyond the scope of this edition as this subject alone can fill a thick expert book.


- Plots by Player One Astronomy for its Neptune-M (IMX178) camera. The data can differ noticably by image sensors.

Please appreciate that SharpCap supports Player One cameras since version 4 while earlier versions won't recognize the cameras.


Nevertheless, please also check the sensitivity curve of your camera since short exposure times at high frame rates are equally important for "freezing" air turbulence.

Consequently, the most rewarding imaging opportunity is when the air is calm and the camera equipped with an IRCut or a Red filter (580~670nm) or an infrared pass filter with a short opening wavelength, say 640 nm , when seeing is good to average. Longer pass wavelengths only make sense with large aperture telescopes which compensate with their higher resolving power for the loss in detail at longer wavelengths. However, large apertures are more susceptible to atmospheric effects because they capture not only more detail but also more turbulences. It is a dance on a rope.


When seeing is exceptional a
telescope can amaze with its real resolving power and sharpness. This image of the rugged lunar south is a stack processed and sharpened in Autostakkert!3 software with only a slight Curve adjustment in Photoshop.


2023-03-31 10:12 UTC
Celestron 8 XLT, ASI290MM, Crayford focuser, no barlow,
focal length 2130 mm , ERF filter, 6 ms , gain 180,166fps, mono8, 10-bit ADC
Image scale: 0.281"/pixel, image FOV: $9.1 \times 5.1$ arcmin, linear resolution: 524 meters/pixel, $1.5 x$ drizzled.

This chapter assumes the use of an 8 -inch SCT with 2030 mm focal length. Resolving power (theoretical) is the ability of the telescope to seperate two white stars of equal brightness in absence of air and is determined by:
resolving power = 115.8 / aperture [mm] ("Dawes limit")
For an 8-inch SCT this is: 115.8 / 203mm = 0.57 arcseconds (hereafter: ")
Ability to resolve is much more affected by seeing conditions. Likewise, the human eye has a resolving power of about 2 arcminutes, but depends on visual acuity. The angular image scale in "/pixel indicates how well the camera's sensor samples and is a function of pixel size and focal length: image scale $=206.265$ * pixel size[ $\mu \mathrm{m}] /$ focal length[mm]

For an 8-inch SCT and an IMX178 sensor this is:
$206.2655^{*} 2.4 \mu \mathrm{~m} / 2030 \mathrm{~mm}=0.244$ " per pixel
with an IMX290 sensor this is 206.265 * $2.9 \mu \mathrm{~m} / 2030 \mathrm{~mm}=0.295$ " per pixel, both of which being better than the Dawes limit.

The image scale must at least be equal to $1 / 3$ rd of the resolving power. IMX178: 0.244 " * $3=0.732$ " achieved resolution versus 0.57 " which is well sampled. The value for the IMX290 is 0.885 ", also unobjectionable.

When the image scale is known, the focal length can be found by:
$F L=206.265$ * pixel size[ $\mu m$ ] / image scale[px/"]
In order to achieve an exact match the focal length should be 206.265 * $2.4 \mu \mathrm{~m} / 0.577^{*} 3$ = 2600mm (1.3x barlow) for the IMX178.

The value for the IMX290: 3150mm (1.6x barlow), or 6300mm when binned.
Longer barlows will not contribute to detail. For instance, a $3 x$ barlow on a Celestron 8 with an IMX290 camera would result into a focal length of about 6000 mm and an image scale of $0.11 / \mathrm{px}$ which is better than the telescope's optical resolving power. When binned $2 \times 2$ the image scale is $0.2 " / p x$ matching the optical resolving power (Dawes limit) in terms of sampling.

A rule of thumb is: optimum focal ratio = camera pixel size $[\mu m]$ * 5 .
IMX178: $2.4 \mu \mathrm{~m}$ * $5=\mathrm{f} / 12$, and $\mathrm{f} / 15$ for the IMX290.
which largely agrees with the theory. The useful barlow magnification is:
$G=5.15$ * pixel size[ $\mu \mathrm{m}]$ * aperture[mm] / focal length[mm]
The linear image scale in km/px is obtained by angular image scale / 1860 * 3476.28 (at mean lunar distance) Here the angular size of the moon is 1860 " and 3476.28 km the lunar diameter.

The size of the smallest lunar feature which a given telescope can resolve is: 115.8 / FL * 3476.28 / 1860 [km] (at mean lunar distance)

An 8-inch SCT can theoretically resolve features 0.11 km long or across (at perfect seeing or outside the atmosphere).

For smaller telescopes, pixel sizes of $2.4 \mu \mathrm{~m}$ or $2.9 \mu \mathrm{~m}$ are too large to satisfy the theory. For instance the Dawes limit of a 90 mm scope is 1.33 arcseconds. Given a focal length of 600 mm , the image scale with an IMX178 is 0.825 "/px * $3=$ ca. $2.5^{\prime \prime}$ which is the limiting factor. Cameras capable of binning can enlarge but cannot reduce pixel size by software. Fortunately, Autostakkert! 4 provides an $1.5 x$ drizzle algorithm which arithmetically reduces the pixel size by $55 \%$. Then, image scale $=206.265^{*} 2.4 \mu \mathrm{~m} * 0.55 / 600 \mathrm{~mm}=0.45$ " per pixel. The resolution limit then is 0.45 " * $3=1.35$ "/px which matches the Dawes limit of $1.33^{\prime \prime}$. For an IMX290 the limit is $1.65^{\prime \prime}$ which is slightly over.


- Two just separated stars. The angular pitch (distance) is the resolving power of a telescope hence its resolution limit.

- Seeing is "good" when an 8-inch telescope reveals the four largest craterlets inside crater Plato, while "good" is relative.

Telescopes always show stars as small disks of light (called Airy disks, after British Astronomer Royal Sir George Airy, 1835-1892). The disks are surrounded by faint rings of light called diffraction rings. The size of the Airy disk is determined by the aperture of the telescope - the larger the aperture, the smaller the Airy disk, and the higher the resolving power.


[^1]The theories here are always questioned by seeing and guiding accuracy, Since the lunar surface is a linear object sampling is not that a critical issue.

## In 1965, nASA's Ranger 9

delivered lunar surface images of the highest resolution available at that time. Below is the Ranger 9 image of Alphonsus crater (diameter 108 km ) from a distance of 442 km , taken about 3 minutes before impact in the upper right portion of the crater. At left is the northeastern edge of Mare Nubium. The crater adjacent to Alphonsus at the bottom is the 39 km diameter Alpetragius. Davy crater is at upper left. North is at 12:30. Ranger 9 impacted the Moon on 24 March 1965 at 14:08:20 UT.


## Detriments

Rather than splitting hairs about sampling challenge lunar imaging when the atmosphere is highly transparent, calm and steady. Heavily twinkling stars are a reliable indicator of poor seeing and turbulent air as are flickering artificial lights near the horizon. The intensity of twinkling stars can hint on where the jet stream passes. If overhead, the seeing is no good at all. When the Moon is on low altitude you would image on a longer path through the atmosphere while more air mass acts like a prism dispersing largely reflected blue light way more than red (also explaining our blue sky).

Wait until the Moon has assumed maximum elevation or near. Avoid places near asphalt and buildings which dissipate heat they absorbed during daytime. If the Moon does not rise high enough, remember that you can image the Moon during twilight or daylight with an IR-pass filter.

56 years later, the image below was taken on 14 October 2021 with an 8" SCT and an IMX290 camera from a distance of $378,430 \mathrm{~km}$ through a polluted air mass (atmosphere).

The telescope as well needs attention. Especially for closed OTA designs such as SCTs, it takes time to assume thermal equilibrium, often more than an hour. In an attempt to minimize the risk of tube currents it helps to tip the scope with the visual back sticking straight up. Then replace the camera with a vacuum cleaner filter to allow the warmer air inside the OTA to escape out the top.

Collimation of the optical axis is often ignored because planetary cameras have small sensors, but accurate optical alignment is crucial for details and finest possible resolution.


- The defocused star Bellatrix in a roughly collimated SCT. The rings are largely concentric but the blotch that runs from about 12 to 4 o'clock can be caused by a tube current or dew on the corrector plate. Accurate collimation with the airy disk of a focused star makes sense when seeing is excellent which was not the case when this image was taken.

By default an SCT comes with three plus driver screws that hold the secondary mirror. They are also used for collimation. You may wish to get "Bob's Knobs" to replace them.


- The result of a poorly collimated telescope. The right side of the image is smeared and defocused while the left side is razor sharp.

Finally, and in order to rule out all detrimental wrongdoings, be sure to use an air blower (bulb) to remove dust particles on barlow, filter and camera sensor which cast shadows of "donuts" and "rings". A little contamination on the corrector plate does not severely impact image fidelity as you never focus on it.

In case you envy people using large telescopes, 6 or 8 inch scopes are way less prone to turbulent air in that often the smaller buckets produce the more detailed images. When seeing is excellent, then, indeed, you do have reason to envy the big brothers.

## Processing

There are certainly more professional and time-consuming procedures while the quality of unprocessed image stacks vary. The following table contains the basic steps employed by the author. Please remember, "less is more". This processing example provides a pre-sharpened image stack output by Autostakkert!4.

Depending on selected stacking parameters it can take quite a while for an image stack to complete. When seeing and tracking was good you can shorten the process by deselecting "Improved Tracking". Also, drizzle slows down as do too small and too many alignment points. Note that Autostakkert!4 supports batch processing that can be run, say, overnight while resting from the imaging session.

Hint: Purposely under-expose the SER video a little bit to avoid saturation during processing. Then, in Photoshop:

## Image/Adjustment/Curves

If need be, raise the Curve to brighten the image, then, crop away stacking artifacts and duplicate the layer.

Actually, every step described hereafter should best be done on a duplicated layer and when completed select Layer/Merge Down.

## Filter/Other/High Pass

Apply high pass filter (100\%) to the layer and blend the layer and background with Soft Light. This adds sharpness, contrast and lets the image look more dimensional. You can adjust the opacity of the layer if need be. Next, select Layer/Merge Down.

## Filter/Blur/Gaussian Blur

If the image is noisy apply a Gaussian Blur (Radius 0.5 pixels) to smooth noise. Note that a small amount of 'grain' will not harm the overall image quality. To some extend noise can also be treated with Filter/ Noise/Despeckle or Filter/Noise/Dust \& Scratches. Set the radius to 1 and threshold to 0 in order to avoid loss of detail. Let us recall that less camera gain and a larger number of frames to stack significantly relaxes noise treatment.


## Filter/Sharpen/Unsharp Mask

If the image is not not sharp enough after stacking apply a light Unsharp Mask (radius 1-2 pixels), and, if need be, another Gaussian Blur (do not overdo sharpen).

## Filter/Noise/Reduce Noise

In case of a color image (this is not for monochrome), open "Reduce Noise" and disable all adjustments except "Reduce Color Noise". Pull the slider between 50\% and 100\% depending on how much color noise is present.

## Image/Adjustments/Hue/ Saturation'

If you wish to create a mineral moon, duplicate as layer and set the blend mode to Luminosity, then select the original image and go to Image/ Adjustments/Auto Color menu. This will align the color channels but will hardly be noticable on the image. Next, increase saturation in several small steps of say 20 per step until colors emerge to your liking. Then reduce color noise again as in the previous step and merge the layer down or flatten the image.

## Image/Mode

Autostakkert!3 saves files in RGB color or grayscale 16-bit format. Reduce to 8-Bits/Channel when the SER/AVI video is was recorded in 8bit color space. Select Grayscale if you are processing monochrome or infrared images. This will significantly reduce file size.


Reduce Noise $\times$


## Benchmark

Software: Autostakkert! 4 V4.0.11 (x64) Camera: ASI290MM, $1920 \times 1080$, 8-bit mono SER Video File: 12.5GB AS!4 Settings: Stacked 600/6000 frames, Sharpened 10\%, Drizzle 1.5x, Improved tracking, Cropped, Laplace 5, 573 APs (auto), AP size 104, Multi-Scale, memory buffering.

## 1. NEC PC-VKX64T1AR

(Tablet Windows 11 Home) Intel(R) Atom(TM) x7-Z8750 @1.6GHz, 4C/4T, 4GB RAM, 128GB eMMC.

| $\checkmark$ | Surface Stabilization | 3204.2 sec. |
| :--- | :--- | :--- |
| $\checkmark$ Be8.4 |  |  |
| $\checkmark$ Beffering and Analysis | 130.2 sec. |  |
| $\checkmark$ Reference Frame | 123.1 sec. | min |
| $\checkmark$ Alignment | 355.8 sec. |  |
| $\checkmark$ Stacking | 1295.8 sec. |  |
| $\checkmark$ MAP Analysis | 36.6 sec. |  |
| $\checkmark$ MAP Recombination | 156.3 sec. |  |

Total: 5302 sec

## 3. Fujitsu AH Series

(Windows 11 Home)
AMD Ryzen 75700 U @1.80 GHz, 8C/16T, 16GB RAM, 512GB SSD.

| $\checkmark$ Surface Stabilization | 122.9 sec | 5.2 |
| :--- | :--- | :--- |
| $\checkmark$ Buffering and Analysis | 34.2 sec. | min |
| $\checkmark$ Reference Frame | 33.4 sec. |  |
| $\checkmark$ Alignment | 43.1 sec. |  |
| $\checkmark$ Stacking | 100.9 sec. |  |
| $\checkmark$ MAP Analysis | 1.4 sec. |  |
| $\checkmark$ MAP Recombination | 8.1 sec. |  |

Total: 310 sec

Processing time naturally increases with image dimensions while also color images and 16-bit images take longer.

## Autostakkert! 4

Developed and distributed by Emil Kraaikamp from The Netherlands, AS! 4 is software for the purpose of stacking individual light frames or frames contained in a video file. The Moon is usually recorded in a video file containing a few thousand frames from which typically the best 10$20 \%$ are stacked with selectable parameters. The tool is the defacto standard for stacking "Lucky Imaging" videos of the planets and the lunar/solar surface.

## 4. GMKtec Mini PC

(Windows 11 Pro)

(Windows 11 Pro)
Intel(R) N100 @3.8GHz, 4C/4T

- The Settings screen for the benchmark test.

8GB RAM, 128GB eMMC, added 512GB SSD (M. 2 2280).

| Surface Stabilization | 30.4 sec . |
| :---: | :---: |
| Buffering and Analysis | 39.2 sec . |
| Reference Frame | 40.7 sec . |
| $\sqrt{ }$ Alignment | 90.7 sec . |
| $\checkmark$ Stacking | 298.1 sec. |
| $\checkmark$ MAPAnalysis | 4.7 sec . |
| $\checkmark$ MAP Recombination | 22.5 sec . |

Total: 526 sec

Intel(R) Core(TM) i7-1260P @4.70GHz, 16C/16T 16GB RAM, 1TB SSD.

| Surface Stabilization | 17.7 sec. |
| :--- | :--- |
| Buffering and Analysis | 13.7 sec. |
| Reference Frame | 21.8 sec. |
| Alignment | 19.1 sec. |
| Stacking | 100.5 sec. |
| MAPAnalysis | 1.7 sec |
| MAP Recombination | 8.4 sec |

Total: 183 sec


## 2. HiMeLE 4C Overclock

30.4 sec
39.2 sec
40.7 sec 298.1 sec . 4.7 sec . 22.5 sec .


## Bottlenecks

The major time consuming settings include:

## Image Stabilization: Improved Tracking

Reference Frame: Double Stack Reference Advanced Settings: 1.5x or 3.0x Drizzle / Resample

Improved Tracking is recommended for shaky videos. When disabled, Surface Stabilization is completed about 10 times faster.

Developed for the Hubble Space Telescope, Drizzle is a fix for under-sampled images to improve resolution, but is also often applied for obtaining larger final image sizes. When set to Off stacking is about 5 times faster.

Resample enlarges the image using interpolation, which is a hardly used option.

When opting for Double Stack Reference, the images will be aligned and stacked twice in an attempt to generate an improved reference frame which takes about 1.3x longer than when unchecked.

Further, the more alignment points, AP, the slower the process. A good guess depends on the size of the video. In case of $1920 \times 1080$ (HD) pixels a few hundred APs at size 104 will be sufficient. APs can be set automatically or manually. If the image contains the lunar terminator auto often does not set APs over faint details in that they should be placed manually after an automatic placement in order to avoid blurring of faint lunar features. This test was carried out with 448 APs, size 104, multi-scale. When increased to 2181 APs, size 48, Stacking took about 1.7 times longer without tangible gain in quality.

In case of a larger image, say $3840 \times 2140$ ( 4 K ) pixels, the number of APs should be around four times as many. Of course an image four times the area that of an $1920 \times$ 1080 image takes longer to process, and even much longer for a color image. In Surface mode the process can further be accelerated by limiting the image size while keeping centered on an object of interest.

## miniPC for Astro



## Drizzle

When stacking a video in say, Autostakkert!4 software you can opt to drizzle 1.5 or $3 x$. $1.5 x$ drizzle is just $3 x$ drizzle and then reduced down by $50 \%$ in AS!3. Drizzle won't do any good if there isn't some movement (dithering) between frames, fortunately there is always some movement between frames in a video from tracking inaccuracy and seeing. This movement only needs to be a few pixels to work for drizzle. Drizzle is basically recommended for linear reconstruction of under-sampled images and generates a final stacked image that is 1.5 or 3 times the size in each dimension. Most lunar surface images are over-sampled because of typically long focal length and small camera pixels below $4 \mu \mathrm{~m}$.

Drizzle in Autostakkert! 4 fills in missing information between pixels across frames and can help produce a higher resolution final image by ensuring it reproduces fine detail in edges despite the effects of stacking transformations. A differ-ence in pixelation is visible with smoother edges in the drizzled image. Note that drizzling can add noise and cause artefacts.

Drizzle exploits the fact that dithering (movement between frames) is a form of spatial sampling. The data that drizzle extracts is wholly contained within the dithered data, meaning that nothing is interpolated.

IMPORTANT: Once you have pre-processed your video in, say, the PIPP utility you can't go back and drizzle in Autostakkert!4 as the PIPP has already registered (aligned) the video frames, leaving no movement.

NOTE: Drizzle was originally developed for use with the Hubble Space Telescope and its first camera, the Wide Field \& Planetary Camera 1 (WFPC1) which, given Hubble's resolution, produces under-sampled images.


Pixelation at crater walls (1.5x drizzled)


Pixelation at crater walls (not drizzled)



## - Crater Clavius

2023-05-01 13:12 UTC
Celestron 8 XLT, ASI290MM camera (IMX290), 2.5x Powermate, ERF
filter, 7 ms , gain 270,142fps, 600 frames, mono8, 10-bit ADC. Image scale $0.112 " / p x$, FOV: $3.62 \times 2.04$ arc min.

The images on the facing page are taken through a telescope with 0.57 " resolving power. The effect of seeing deteriorates resolving power to say, 1.5 ". The image scale is $0.112^{\prime \prime} /$ pixel. According to the sampling theorem: $0.112^{\prime \prime}$ x $3=0.336$ "/pixel, meaning over-sampled. Nevertheless, pixelation is smoothend in the $1.5 x$ drizzled image. The difference is really subtle but when viewed at actual size
the undrizzled image appears slighty sharper and detailed for which reason drizzle is recommended for undersampled data. The IMX290 sensor has $2.9 \mu \mathrm{~m}$ pixels. Mated with a native focal length of 2030mm the image scale is about 0.3 " per pixel which matches the telescope's theoretical resolution power which, however, can never be achieved due to seeing conditions, in that images taken at native focal length are still over-sampled, hence calling for larger sensor pixels or, trading against resolution and photo size, binning (less noise and shorter exposures).


## Lunar Mosaics

Advanced stitching software makes it easy to build lunar mosaics up to poster size. The Micosoft Image Composite Editor (ICE) is an accurate and seamlessly stitching application but, sadly, has been retired in that updates are no longer available, but there are alternatives.

Since clouds may roll in, or air condition may change, or just for memory economy, the aim is to suffice with a minimum of single panels, however with the required overlapping of at least $20 \%$. When after the session you are not sure whether you have covered the entire lunar surface record spare videos of regions you believe you have missed. Often people use patches from earlier images which fix to some extend, but in most cases it will leave seams or result in a mess. Crop panels if overlapping too much.

Rotate the camera on the telescope so as the Moon will move on a horizontal or vertical line. Depending on the illumination phase the Moon should be so aligned as to avoid taking panels which are mostly dark. This is because the stacking software, such as AS! 3 cannot accurately align images with too dark reference points, resulting in blurred panels which will ruin the final mosaic. In our example, the Moon is best aligned vertically (top right).

Equally critical is exposure time as the Moon has bright regions as well as dark regions along the terminator. Set the exposure time so as the brightest regions won't be saturated. This will likely result in underexposed regions elsewhere. When the mount moves to a dark region, the exposure time can be increased by one or two milliseconds because the MS-ICE will detect and adjust different brightness levels if not too aggressive. It is not a good idea to increase gain because in most cases this will result in more noise which the MS-ICE cannot handle. Several thousands of frames can be recorded to minimize noise, but this takes more time and storage.

The larger the camera sensor, the wider the field of view and the less panels required to complete a full mosaic, but sacrificing frame rate as larger images take longer to transfer to the PC via USB. However, if the sky is clear and the mount tracking accurately, this should not bother. On the other hand, small sensors provide faster recording, but need more panels in that at the end of the day (night) it won't make a big difference.

There is software, such as the "MoonPanoramaMaker" which steers a mount to optimally select sunlit regions, overlap properly and shoot an automated sequence of panels.

Atmospheric condition may change during a mosaic session. A blurred part of a panel overlapping another can render an entire region unsharp or ringed. Also, too much black space overlapping will prevent MS-ICE from stitching all panels or leave black lines. In such events each panel should be trimmed individually in Photoshop, GIMP, etc.


The region around Vallis Snellius (above) is an extremely bright spot on the Moon and often oversaturated. Captured with a Celestron 8 XLT, ASI462MC, 1.5 ms , gain 80, 138fps. The short exposure time is thanks to a $0.5 x$ reducer. Even harder to tackle is the floor of crater Aristarchus below.



Mineral Moon

A mineral moon is a lunar image with saturated colors for exhibiting various material deposits in lunar soil (regolith). Bluish regions are rich in titanium and iron while reddish areas lack these elements. This is best facilitated with photo processing software capable of using layers, such as Photoshop or GIMP. The job is not done by merely dragging the saturation slider towards $100 \%$ which will look rather ugly and artificial. We need to protect the base image (background) with a luminosity layer which holds back any adverse artefacts that could manifest themselves as a result and produce "unknown" minerals, yet it is a simple process in 10 steps.

Workflow

1. Load the lunar color image.
2. Duplicate it as layer.
3. Select the new layer.
4. Under the layers tab select Luminosity to blend over.
5. Select the lower image.
6. Apply Auto Color to align the color channels.
7. Remove color noise (no other settings).
8. Increase saturation in a few steps of $+20 \sim 30 \%$.
9. Flatten the image.
10. Save with a different file name.

# Âristarchus in saturated color 

The lunar impact crater Aristarchus and geologically diverse Aristarchus plateau, including the neighboring crater Herodotus and the Vallis Schröteri rille, is a must for imaging in color. The prominent crater, Aristarchus, is 40 km across, up to 3.5 km deep and 450 million years old. It is the brightest lunar formation and therefore a photo-


Lunar Reconnaissance Orbiter image of the central peak.

## -2.5x Zoom on Aristarchus

2023-03-04 11:23 UTC
Celestron 8 XLT, Uranus-C camera (IMX585), 2.5x Powermate, Baader UVIIR-Cut CMOS optimized, 5 ms , gain 286,46fps, 400 frames, raw8.


The lens of a tubeless, short barlow sits closer to the focal plane such as an image sensor.


## Does it make sense to use a Barlow?

The answer is yes, but with restrained power.
The shorter (faster) the focal length the less exposure time and gain is needed, vice-versa for longer (slower) focal length. More gain results in less dynamic range consequently in a larger portion of image noise.

By rule of thumb the maximum focal ratio for a camera is is pixel size $\times 5$, or pixel size $\times 6$ when seeing is excellent.

Given the ASI290MM with $2.9 \mu \mathrm{~m}$ pixels the optimum focal ratio is roughly between $1 / 15$ and $f / 18$. Theoretically, this means that a with given telescope aperture no further details can be recorded. For this focal ratio range a Celestron 8 would need a $1.5 x$ or a $1.8 x$ barlow. These are uncommon magnifications but with tubeless barlows the magnification factor can be adjusted by changing the distance of the barlow lens to the focal plane. For instance a $2 x$ tubeless barlow magnifies $1.45 x$ depending on the flange back distance.

The image at the top of the facing page has been taken without barlow at $\mathrm{f} / 11$ (Crayford focuser adds FL) and zoomed in to 200\%.

The image at the bottom zoomed to $100 \%$ has been taken with a TeleVue $2.5 x$ Powermate at around $\mathrm{f} / 26$ which is contrary to the rule of thumb.

The images show craters north of Cleomedes, Burckhardt and Geminus (the left and larger of both), each a stack of 600 frames (10\%) and 1.5x drizzled. The air was turbulent but transparent and changing during the recordings. In other words, both images were acquired under nearly the same condition and the same short exposure time of 5 ms in an attempt to freeze turbulences. Since the focal length of the bottom image is $2.5 x$ longer the gain was increased to 240 resulting in background noise which would need to be compensated for with more frames to stack or longer exposure at less gain.

As for the ASI290MM, its sweet spot of gain is about 80 where it performs with a high dynamic range of 12 stops at half of its full-well capacity and notably lower readout noise.

Comparing both images it is apparent that the bottom image taken with a Powermate does not show any more detail than the zoomed-in top image taken at native focal length. However, at higher magnification the optical path is more prone to air turbulences. A bit more detail may surface at better or excellent seeing. Of course an image taken without barlow too would benefit from better seeing.


【 2023-02-07-151 Sutc-asi290mm-2000mm-5ms-g240-600x-..e 100\% (Gray/8)


## 2024-03-16 09:42 UTC

Celestron 8 XLT, ASI290MM, Crayford focuser, $2 x$ Ortho barlow,


In December 2023, Takahashi launched its new 1.25" 2x Ortho Barlow composed of a group of two lenses. According to Takahashi It is so designed as not to add achromatic aberration and peripheral coma, all across the field. It has a 31.7 mm sleeve and a male M42 P0.75 T-ring screw for a planetary camera. The lens unit is removable and has an M28.5x0.6 thread at both ends in that it can be attached to a nose piece of a camera with a 1.25 " filter threaded at the telescope facing end.

The photo above was taken with the barlow at $2 x$ magnification while the photo below was taken with only the lens unit attached to the nose piece of the camera resulting in a 1.6x magnification due to the shorter distance to the camera's sensor.



## Sharpen with AS!3

"Sharpened, Blend Raw in for..." (at the right of the right column).

The often overlooked sharpen mode of Autostakkert! 4 is awesome. The lower the percentage the stronger the sharpen effect. A few tests are recommended for finding the optimal value which depends on the focal length and whether the stack is drizzled or not. AS! 4 will save a raw stack file plus a sharpened file which includes the sub-string "_conv" in the file name. The so pre-sharpened image can then be fine-tuned in your favorite image processing software, such as Photoshop or GIMP.

Using a Stock DSLR


Since a DSLR has a large sensor it is a good choice for shooting the entire moon disk without need for stitching a mosaic. For example, the moon fits nicely into the view of a Celestron 8 at native focal length and a full-frame DSLR. If the DSLR comes with the smaller crop sensor (APS-C) then a $0.63 x$ reducer will embrace the full lunar disk while flattening the field for better focus in the image corners.

Alternatively, a smaller telescope with shorter focal length will be fine provided high resolution is not the aim. For instance, the legendary C90 spotting scope acts as a large telephoto lens embracing a full moon entirely at its 1000 mm focal length.

A telescope should have a native focal length of at least 1000 mm to avoid need for a barlow which adds glass, possibly also aberration to the optical train hence deteriorating image fidelity and resolution if the barlow is of low optical quality.


Also consider the latest version of "AstroSurface" featuring Van Cittert Deconvolution for sharpening.

## Optical Train

Keep the parts count attached to the telescope's focuser as low as possible. Every part, such as a filter wheel, a flip mirror or an extension tube increases the risk of tilt in the optical axis which can result in partly blurred images.


- Field of view with Celestron 8 and $0.63 x$ reducer/flattener.


## AR Window

Since a camera's built-in AR window attenuates light above 650nm (see graph) it may be a good idea to remove it when using an IR-pass filter. A permanently attached external filter can protect the sensor as well.


- Example: ZWO anti-reflection (AR) window.

- Field of view with Celestron 8 without reducer at native focal length.

If the DSLR supports simultaneous recording of RAW and JPEG, select the highest image quality, highest ADC, ISO200-400, disable all noise reductions, then shoot, say, a hundred photos and stack them all including sharpen in Autostakkert!3 without drizzling. RAW files need to be converted to TIF or PNG for AS!3, but JPEG will do almost as well while keeping the processing simple. Then load the stack file into Photoshop, GIMP or other photo editors and tune the image to your liking.

Precise focusing is crucial and can make a significant difference.
Since DSLRs are color cameras the images can be used for creating a "mineral moon" by increasing color saturation carefully in small intervals, best implemented on a separate layer, again, in Photoshop or GIMP, etc.

Since modern DSLR cameras sport sensors with $6000 \times 4000$ pixels and more, they can produce large scale images of high resolution ready for, say, little poster prints or calendars.

## Mysterious Focal Length

The focal length of a given optical path is the distance between an objective lens or primary mirror all the way up to the image sensor and determines the field of view of a camera with a given sensor size. Often, accessory is used between the telescope and camera, such as a filter wheel or a barlow lens, all of which change the focal length which is therefore difficult to measure accurately. Even worse, a SchmidtCassegrain telescope is focused by moving its primary mirror thus changing its effective system focal length every time focus is adjusted. The only simple means of measuring focal length is with the help of the final image itself.

The image is composed of pixels which span over a given angular (arc seconds per pixel) or linear (km or miles per pixel) distance. This is the "image scale", sc, a value which varies by pixel size and system focal length:
sc $=206.265$ * pixel size / focal length (206265 = arcseconds in one radian)

Now, if the image scale is known, while the camera's pixel size anyway is, then the effective system focal length can be calculated by:
focal length $=206.265^{*}$ pixel size $/$ sc
If the image scale is unknown the focal length can be determined with the help of the raw image (not drizzled and not altered in size).

Measure the number of pixels which the object (full moon or planet) covers, obj [px], multiply by the pixel size of the camera and by 206.265, and divide the result by the angular size of the object obj ["]:
focal length $=$ obj $[p x]$ * pixel size [ $\mu m]$ * 206.265 / obj ["]
obj $[p x]$ can be determined by loading the image into Photoshop or GIMP, etc., and measure the width or height of the object in pixels. The camera's pixel size is usually known and found in its specifications. obj ["] can be found using planetarium software or online tables which typically provide equatorial size.


For example, we have an image of the moon and measured the number of pixels the full lunar dusk covers, such as 7140 . Then determine the angular size of the moon's disk by providing date and time of capture to a planetarium application. The example image was taken on 2021-12-10 at 10:14 UTC. According to Stellarium the lunar disk was $31^{\prime} 36^{\prime \prime}=$ 1896 arc seconds wide. The camera's pixel size is $2.4 \mu \mathrm{~m}$. Consequently, the focal length was about

7140 * 2.4 * $206.3 / 1896=1864 \mathrm{~mm}$

In analogy, we determine the focal length at which Jupiter was taken with an ASI290MM camera:
obj [ $p x$ ] $=400$ pixels
pixel size $=2.9 \mu \mathrm{~m}$
obj ["] = 48.5 arc seconds
400 * 2.9 * $206.3 / 48.5=4933 \mathrm{~mm}$
...which makes sense as a $2.5 x$
Powermate barlow was used.
Both examples were taken through a Celestron 8 SCT with a variable, mean native focal length of 2030 mm .


The previous calcuation is fine but only for images embracing the full lunar disk. What if we do not have an image showing the full lunar disk but a surface close-up?

If the image scale, sc in arc seconds per pixel, is known while the camera's pixel size anyway is, then the effective system focal length can be determined by converting the formula for the image scale:
image scale $=206.265$ * pixel size /
focal length
to
focal length $=206.265$ * pixel size $/$ sc
(206265 = arcseconds in one radian)
If focal length is unknown, then the image scale needs to be determined otherwise, namely by the Moon's angular size which varies by its distance to the Earth. The average value is 31.2 arcmin, or 1860 arc sec. The Moon's equatorial diameter is 3476.2 kilometers linear.

Since the moon is a round object the best location for a measurement image is Sinus Medii which lies in the center of the lunar disk. Do not drizzle the image.


The linear distance between two points ( $x 1 / y 1$ and $x 2 / y 2$ ) on the lunar surface is basically determined as:
$D i=\sqrt{(x 2-x 1)^{2}+(y 2-y 1)^{2}}$
or $D i=\sqrt{a^{2}+b^{2}}$

Example: First we need to determine the angular distance between two points on the surface image. Visit https://quickmap.Iroc.asu.edu/ and resize the moon disk as shown in the picture below in full screen mode.

Next, make a screenshot and load it into a Paint program to measure the width of the lunar disk in pixels (here Dm = 2290 pixels).

Then mark the points $\mathrm{x} 1, \mathrm{y} 1$ and $\mathrm{x} 2, \mathrm{y} 2$ on both the screen shot and the surface image and calculate the distances in pixels (2290 on the screen shot and 970 on the surface image).

Next, open planetarium software and set the date and time of the surface image, here 2021-12-15 11:30 UTC, and check the lunar diameter for the given date which is

Ms = 1775 arc seconds.

The camera's sensor pixel size is given as
$P s=2.9 \mu \mathrm{~m}$.
Ms / Dm * $D p=217$ arc sec,
then, 217/ Di $=0.224$ arc sec/pixel
Finally the sought focal length is:
$F L=206.265$ * Ps $/ 0.224=2670 \mathrm{~mm}$
Obviously, this method is too rough for a precise measurement but fine for most purposes.




## The Moon against the Sky

This picture simulates an occultation of the Pleiades by the Moon. At its mean distance of 384400 kilometers the apparent angular size of the Moon spans $0.52^{\circ}$ of the sky. The background image of the Pleiades measures $1.37^{\circ} \mathrm{x}$ $0.76^{\circ}$ or $3737 \times 2081$ pixels which translates to 1.32 seconds of arc per pixel.

Full Moon:
TS-71SDQ ( $\varnothing 71 \mathrm{~mm} / 450 \mathrm{~mm}$ ), Uranus-C, $600 \times 5 \mathrm{~ms}$ at gain 180.

Pleiades:
TS-71SDQ (Ø71mm/450mm), Uranus-C, $149 \times 60 \mathrm{sec}$, gain 200.

## Imaging the Moon during Daylight

No special gear is required for imaging the Moon during daylight or twilight. All you need is your IR-pass filter which is designed to cut visible light. The images at the right are from August 13th, 2021 taken around 6:50 PM near civil twilight with a Celestron 8 XLT, ASI290MM planetary camera and an Astronomik ProPlanet IR642nm band pass filter. When imaging during bright daylight an IR-pass filter with a longer wavelength, say 740 nm , will cut more of the visible light, therefore increasing contrast. A filter with a higher wavelength, say 850 nm , won't do any better and only require longer exposure time resulting into slower frame rates. Please recall that longer near-infrared wavelengths compensate for poor seeing but sacrifice image resolution and contrast, though not always eyeball-apparent. For daylight lunar imaging an IR-pass filter is indispensible but let's use the shortest meaningful wavelength to obtain best possible resolution while keeping an eye on contrast. It is an act of balance also shaken by seeing. Often, the air is calming during twilight allowing for sharper images.


Mare Crisium with a tubeless $1.6 x$ barlow, $6 m s$, gain 200, 166fps. The planets, taken with an ASI462MC, are inserted to image scale.


Lunar northeast: with a tubeless $1.6 x$ barlow, 8 ms , gain 200, 124 fps.


The "planets season" is when the planets are observable during sociable evening hours, an unique opportunity for capturing the Moon and the planets to the same image scale of their apparent sizes, meaning imaging at the same focal length on a same night. The individual images can then be arranged to taste in Photoshop or GIMP, etc.

The sample above is a composite of individual images taken with a Celestron 8 XLT and an ASI462MC color camera. The planets are captured in the same way as the Moon, namely in video files and stacked in Autostakkert!4. The wavelet sharpen function in the "Registax6" or "AstroSurface" software is a wise choice for sharpening planets while also offering cosmetic fixes such as deringing.

While Mars, Uranus and Neptune are rotating at a relaxed velocity, Jupiter and Saturn are spinning around their axes in just over 9.93 hours and 10.55 hours, respectively, in that we need to keep video recording time short so as not to smear details in our images. The longer the focal length (magnification) the more prone to smearing over time. As a rule of thumb, one minute for Jupiter and 1 min 30 sec for Saturn.

Jupiter is the brighter planet and suffices with very short exposure times, say 5 ms at gain 300 . With an ROI reduced to $800 \times 600$ pixels the ASI462MC will record at 200 fps thus collecting 12,000 frames in a minute of recording which is quite sufficient. The better the seeing the more frames can be stacked, on average $25 \%=3000$ frames.

Saturn requires longer exposure time or more gain, say, 15 ms at gain 350 which translates to 66 fps with the same equipment as used to image Jupiter. However, during 1.5 minutes we will obtain merely 6000 frames. At 12 ms exposure 83 fps can be achieved (about 7500 frames in total). It is a compromise. The author has obtained good results with 3-minute videos of Saturn at $55 \mathrm{fps}=9,900$ frames -- not too bad.

The software "WinJupos", among other useful functions, is capable of de-rotating several videos or images in that longer exposures are made possible. WinJupos computes the position of the central meridian for a given instant and compensates for rotation. However, if the purpose is merely for decoration of lunar images, then, the previously discussed simple, fast way is preferable. All planets inserted into lunar images in this brochure have been captured effortlessly to short videos in no time.

A small camera ROI helps increase the frame rate, however, when tracking is inaccurate the planet may shift out of a narrow field, in that precise polar alignment is crucial, also considering the high magnification at which planets are usually imaged. Of course, it is possible to keep the planet centered using the mount's slowest manual steering control, but a stable position of the planet inside the ROI will benefit the quality of the final image stack. Since it is no trouble at all the author often uses autoguiding to hold the position of a planet. This is useful for instance when you are producing a video sequence.

Stable atmospheric conditions provided a video sequence, say, the motion of the GRS, can easily be implemented by taking videos of say 30 seconds length each in 5 minute intervals, stack and save them as images files. The capture software also allows scheduling and automation of capture sequences. For this purpose it is important that the planet stays centered in the camera's field of view. Then use software capable of creating animations, such as "PIPP" which additionally corrects, fixes and trims videos before conversion to a target file format.

There is a handful of software applications, actually masterpieces, which magically compensate for poor imaging conditions, yet, the best piece of advice is, go out to image the Moon and the planets when seeing is good, the air transparent and the object on high elevation near culmination, and use a telescope mount which tracks well.


- 2023-11-28 13:10 UTC, Jupiter at 12:24 UTC

Celestron 8 XLT, 2.5x Powermate, Uranus-C, Baader UV/IR-Cut CMOS optimized, 5ms, gain 314, 46fps, 400 frames, raw8.

Examples of Jupiter inserted into lunar images to scale. Moon and Jupiter in the image above are taken with a $2.5 x$ Powermate (barlow). The image below is taken without barlow at native focal length (Jupiter transited by its moon Ganymede). Both, lunar surface and Jupiter are taken in the same evening.

The Uranus-C (IMX585) color camera was used for both objects. The lunar surface has been slightly color saturated. Cameras using the IMX585 sensor are good for the moon, planets and bright deepsky objects.

- 2023-11-03 15:40 UTC, Jupiter at 14:40 UTC

Celestron 8 XLT, no barlow, Uranus-C, Baader UV/IR-Cut CMOS optimized, 5 ms , gain 229, 46 fps , 400 frames, raw8.



- 2023-10-29 14:32 UTC, Jupiter at 14:0 UTC

Celestron 8 XLT, 2.5x Powermate, Uranus-C, Baader UV/IR-Cut CMOS optimized, 8 ms , gain 280, 124fps, 600 frames, raw 8.

For the composite above the ROI of the Uranus-C camera has been reduced to $1920 \times 1080$ pixels in order to obtain a faster frame rate at short exposure time as the air was turmoil. Jupiter is placed above crater Endymion and Mare Humboldtianum.

In contrast, the composite image below is made of a monochrome lunar image (with an ASI290MM camera providing higher resolution than color) and Jupiter in color. The image scale is the same as both cameras have the same pixel size, namely $2.9 \mu \mathrm{~m}$.

- 2023-11-23 10:59 UTC, Jupiter at 11:28 UTC

Celestron 8 XLT, no barlow, ASI290MM, ERF filter, 5ms, gain 131, 170fps, 600 frames, mono8, 1.5x drizzled.



The planets taken a few hours earlier are inserted to image scale for decoration only.

- Celestron 8 XLT, ASI290MM, focal length 2030mm, IR642BP filter, 6ms, gain 220, 166fps, mono8, 10-bit ADC.

Image scale: 0.295 "/pixel, image FOV: $9.57 \times 5.53$ arc min, linear resolution: 550 meters/pixel.

## Imaging Events

The images have been captured under turbulent air on a humid early morning with the moon at low altitude of $32^{\circ}$ in the constellation of Leo. On the preview in the capture software the surface looked like seen through flowing water. Yet the Autostakkert!4 stacking software output a sharp and clear image stack because the short exposure time of 5 ms froze each frame. Turbulent, but else clear air is no reason for giving up.

In the same morning, the lunar libration in longitude was near $7^{\circ}$ west and $6^{\circ}$ south in latitude in that part of the rear side of the moon was visible, for instance the eastern walls of Mare Orientale and the entire crater Bailly region at the bottom right. The widest crater on this image is Schickard at the center top. Shown on the image below is Mare Orientale at the lunar western limb (west is top). The wide crater at the right is Grimaldi.


Age: 25.3 days Magnitude: -8.5 Phase: 21\%
Diameter: 31.5 arc min Distance: 378813 km Tidal force: 1.044x Longitude Earth: -6.91 Latitude Earth: -6.65º Position angle: $22.6^{\circ}$


Mare Orientale as imaged by NASA's LRO.


Craters Bailly as imaged by NASA's LRO. About 300 km wide, Bailly is the largest impact basin on the near side.

The 25.3 days old moon, a mosaic of twelve panels.
Celestron 8 XLT, ASI290MM, focal length 2030mm, IR642BP filter, 6ms, gain 200, 166fps, mono8, 10-bit ADC.
Image scale: 0.295"/pixel, image FOV: 15.13 x 19.45 arc min, linear resolution: 550 meters/pixel.

## Shadow Effects



- Celestron 8, ASI290MM, $2 x$ barlow, focal length 2880mm, IR642nm filter, 5ms, gain 200, 170fps, mono8, 10-bit ADC. Image scale: 0.208 "/pixel, image FOV: $6.71 \times 3.80$ arc min, linear resolution: 388 meters/pixel.

The sub-Earth longitude and latitude (changing with libration) were $-5.536^{\circ}$ (south) and $-5.870^{\circ}$ (west), respectively, bringing more westerly and southerly craters into view. An eye-striking shadow play appears like a Vshaped trench at the horizon (on the image south is up). The path leads from the large craters Clavius via Moretus and Short to the up to 5 kilometers tall Malapert crater rim (aka "peak of eternal light") near the lunar south pole marked by the crater Shackleton (not seen on the image). Most of the interior of the Malapert craters remain in eternal shadow. Length and direction of shadows also change with the libration angles as does the elongated shape of craters, most prominently at higher latitude.

2021-10-31 around 17:00 UTC

## Like an Orbit View



[^2]
## Increasing Contrast

No shadows cast in this region of the 11.6 days old Moon, yet floors and surroundings is enhanced, achieved with a twice applied high pass filter in Photoshop. At the center right lies Mare Humboldtianum and crater Endymion to its left.

- Celestron 8, ASI290MM, focal length 2030mm, IR642BP filter, 5ms, gain 100, 170fps, mono8, 10-bit ADC. Image scale: 0.295 "/pixel, image FOV: $9.39 \times 5.26$ arc min, linear resolution: 550 meters/pixel.

2021-11-16 around 11:00 UTC

## Documentation



Example of image data
Astronomical images are nice to swipe forth and back on a tablet that may be connected to a large monitor. Image data can be contained coded or readable in the file name, such as

2021-11-24-1707utc-asi290mm-2000mm-5ms-g200-600x-170fps-mono8-10bit-ir642-2xbs-drizzle15.png

Good documentation can add value to your images. The most flexible means is a website with underlaying database and routines computing data of interest upon uploading images. Next to image data it is good knowing the ephemeris of the moon at capture time which can help with the interpretation of the image related to libration, shadows, resolution, and more. This can be best implemented by means of a pop up window.


An individual solution requires knowledge of programming, including for instance, HTML, CSS, Javascript, PHP and MySQL. A specilized platform tailored to astronomical images, such as AstroBin eliminates need for programming. Besides uploading images and data AstroBin computes data and plots star charts and plate solving charts wherever meaningful. Also provided are text communication with fellow users and forum access for groups with specific interests. AstroBin does not display unrelated ads while the community is solely focused on astrophotography, lunar, solar, planetary and deepsky.

Certainly, images can be uploaded to common social networks, however, for sharing only while computations, such a lunar ephemeris and image scales cannot be performed with your data. Social networks also modify images for optimized storage economy and download speed.


## Less Known Features



Guericke
Type: Crater Remnant

1

| Latitude: | $-11.5^{\circ}$ south |
| :--- | :--- |
| Longitude: | $-14.1^{\circ}$ west |
| Diameter: | 63 kilometers |
| Depth: | 700 meters |

Prinz
Type: Crater Remnant

| Latitude: | $25.5^{\circ}$ north |
| :--- | :--- |
| Longitude: | $-44.1^{\circ}$ west |
| Diameter: | 46 kilometers |

An arc shaped lava-filled


Located at the northern tip of Mare Nubium, the rim of crater Guericke has been heavily worn. The floor is covered with basalic lava. At the southern edge lies the largest 21 kilometers wide satellite craterlet Guericke F.
remains of an impact crater with rims up to 1 km high at its north-eastern wall. The western region is marked by rays and craterlets attributed to the bright crater Aristarchus at the left. Rima Prinz, an 80 km wide system of rilles lies to the north of Prinz.



Brenner
Type: Eroded Crater

| Latitude: | $-39.0^{\circ}$ south |
| :--- | :--- |
| Longitude: | $39.3^{\circ}$ east |
| Diameter: | 93 kilometers |
| Depth: | 3.3 kilometers |



An old impact crater located west of crater Metius. The formation was subsequently eroded by massive impacts leaving only the western part looking crater-like. There are 16 satellite craters, the largest being Brenner A at the southern rim.



## Montes Recti <br> Type: Mountain Range

| Latitude: | $48.3^{\circ}$ north |
| :--- | :--- |
| Longitude: | $-19.7^{\circ}$ west |
| Length/width: | $90 / 20$ kilometers |
| Elevation: | 1.8 kilometers |

4


Located between crater Plato and Sinus Iridium, this is a rarely seen linear formation of irregular ridges streching from west to east. Alongside neighboring mountains Montes Recti is a remnant of the formation of Mare Imbrium some 3.85 billion years ago. The crater in the eastern edge is 7.3 km wide.

Bürg
Type: Crater

| Latitude: | $45.0^{\circ}$ north |
| :--- | :--- |
| Longitude: | $28.3^{\circ}$ east |
| Diameter: | 40 kilometers |
| Depth: | 1.8 kilometers |



Impact crater Bürg poses in an arch-shaped lava-flooded eroded crater formation, the 150km wide Lacus Mortis which hosts a 100 km long rille system, the Rimae Bürg. Crater Bürg cores a twin central peak and has two satellite craters, 12 and 6 kilometers across.

## Descartes

Type: Eroded Crater

| Latitude: | $-11.7^{\circ}$ south |
| :--- | :--- |
| Longitude: | $15.7^{\circ}$ east |
| Diameter: | 48 kilometers |
| Depth: | 900 meters |



A heavily worn impact crater with a high albedo region at its outer rim which is a strong magnetic anomaly deflecting solar wind particles. The patch surfaces well on images after color-saturation. Apollo 16 landed about 50 km to the north in the 'Descartes Highlands'.


Lunar Eastern Tip (east is up)
Celestron C8 XLT, ASI290MM, IR640nm filter, 4ms, gain 100, 170fps,
mono8, 10-bit ADC, three panel mosaic.


## Rimae Sirsalis Type: Rille

Latitude: $\quad-15.7^{\circ}$ south Longitude: Length: Width: $-61.7^{\circ}$ west 426 kilometers 2~3 kilometers


Named after a young nearby crater Rimae Sirsalis is a 426km long rille stretching from crater Darwin all the way up to the Sirsalis crater family crossing craters, hills and other small rilles. It formed by rising magma and could be the source of the strong magnetic field measured in the region.

Rima Hadley
Type: Rille

| Latitude: | $26.13^{\circ}$ north |
| :--- | :--- |
| Longitude: | $3.63^{\circ}$ east |
| Length: | 80 kilometers |
| Width: | 1.21 kilometers |
| Depth: | 180 to 370 meters |



Located at the foot of the Montes Apenninus, the sinuous rille was formed by volcanism and lava flow. Crater Bela, likely a volcanic vent, marks the southernmost point, crater Hadley C the middle. Apollo 15 landed east of the northern curve of the rille.


## More Less Known Features



Cleomedes
Type: Crater
Latitude:
$27.7^{\circ}$ north
Longitude:
$55.5^{\circ}$ east
Diameter:
Depth:
126 kilometers
2.7 kilometers


Situated to the north of Mare Crisium, this is an impact crater with worn, eroded walls and a flat floor with a low central peak, four major craterlets and 17 satellite craters, two of which lie inside Mare Crisium. A rille crosses the northern floor.

Meton
Type: Merged Craters
Latitude: $\quad 73.8^{\circ}$ north
Longitude: $19.2^{\circ}$ east
Length: 122 kilometers
Depth: 2.6 kilometers

The formation consists of
 several merged craters, later flooded with lava and finally resembling the shape of a clover leaf. The flat floor is dotted with craterlets. Eight satellite craters are assigned to Meton. Because of its northerly location Meton appears elongated.


Left: The less known Maria at the east edge of the near side, located east of Mare Crisium are best visible at large eastern libration above 6 degrees.

Mare Marginis, the "Sea of the Edge", measures 358 km in diameter, Mare Smythii is 373 km wide and Mare Undarum and Mare Spumans are 245 km and 140 km across, respectively. Crater Neper spans over 132 km and is 2 km deep.

## Big Challenges

The arithmetical image scale is 0.12 " per pixel equivalent to a theoretical linear resolution of 225 meters per pixel, here obviously not achieved, also because of poor seeing.

The hereafter introduced images are taken through a Celestron 8 XLT telescope and an ASI290MM monochrome CMOS camera with an IR640nm pass filter and a Vixen $2 x$ barlow resulting in an effective focal length of 4930mm. They are challenges because a focal length exceeding 4000 mm is beyond the resolving power of an 8-inch Schmidt-Cassegrain telescope. However, when seeing is good and the air calm then satisfactory results can be achieved, though often not the desired details.


Imaging at a long focal length requires longer exposure times (slower frame rate) and/or higher gain (more noise). It can be, compensated for by stacking more frames and accurate tracking.


## To Drizzle or not to Drizzle

Drizzling is basically recommended for upscaling only when an image is undersampled to improve resolution. Undrizzled images are a bit more detailed and slighly


10 ms , gain 200, 99fps, no drizzle.
sharper, while on the other hand 1.5 times larger images are better suited for HD videos and slide show productions. The images show the famous Sinus Iridum.


Small Maria

## A lunar Mare (plural: Maria) is a plain of solidified volcanic lava with a lower albedo than other lunar surface features.

## Overview

1. Mare Vaporum 2. Mare Nectaris
2. Mare Cognitum
3. Mare Humorum
4. Mare Insularum 6. Mare Crisium

All images with a Celestron 8 XLT and ASI290MM camera with 640nm IR-pass filter.


Mare Orientale


Mare Marginis (top left) and Mare Smythii


Mare Humboldtianum

Small maria are attractive for imaging because they easily fit into a field of view of small to medium aperture telescopes armed with a planetary camera. There are a lot more small maria, such as Mare Humboldtianum ( 230 km ), Mare Marginis ( 358 km ) and Mare Smythii ( 373 km ), but they are located at the far east limb of the near side and largely visible only during favorable libration. The same applies to Mare Orientale (294km), the antipode of Mare Marginis, located at the far southwestern limb.


4 Mare Vaporum is 242 km wide, about $55000 \mathrm{~km}^{2}$ in area and is flanked to the northeast by the mountain range Montes Apenninus and the rugged foothills called Marco Polo.


To its right lies crater Manilius (38km across), to the south Rima Hyginus, a 220km long rille, as eye-catching landmarks. In the northern part of the Mare Vaporum is a triangular shaped 71 km wide bay named Sinus Fidei.

the basin as is the crater Theophilus to the north west. On its southern periphery, the north wall of crater Fracastorius is engulfed by the lava that formed the mare. The largest crater, Rosse, has a high albedo, is 12 km wide and 2.4 km deep.


4 The featureless Mare Cognitum is 376 km wide and about $73000 \mathrm{~km}^{2}$ in area. In November 1969, Apollo 12 landed near the north shore of Mare Cognitum. In February 1971, Apollo 14 landed at the crater Fra Mauro ( 97 km ) situated at the north east. Astronauts noted the amount of glass contained in the mare's regolith. In the mare's center lies crater Kuiper, 12 km wide and 2.4 km deep.

- Mare Humorum is an almost circular lunar sea, 450 km wide, about $87000 \mathrm{~km}^{2}$ in area and 2.24 km deep. The basalt layer at its center is about 3.6 km thick. It is located in a 825 km wide impact basin with surrounding mountain ranges likely caused by an asteroid collision flooding the mare with lava from subsequent volcanic activity. To the north lies the large impact crater Gassendi (111km). Ridges at the north near the southern rim of Gassendi exhibit fields with high albedo boulders.


4 Mare Insularum is 512 km wide and about $200,000 \mathrm{~km}^{2}$ in area. It ranges between the craters Copernicus and Kepler, their rays protruding into the mare which extends to crater Fra Mauro and Mare Cognitum in the south east. The largest central craters contained are Reinhold, Lansberg and Gambart. Sinus Aestuum forms a northeastern extension (not in view of the image) at the east of Copernicus. In between lies the crater remnant Stadius.

- Easy to spot with the naked eye, Mare Crisium is 556 km wide and about $176,000 \mathrm{~km}^{2}$ in area. It has a flat floor with a ring of folded ridges (dorsa) at its periphery. During the solidification of the lava plain, concentric ripples appeared inside which are traces of moonquakes. The three notable craters to the west are Yerkes, Picard and Peirce. Several former Soviet Luna probes landed here with Luna 24 remaining the last probe to land controlled on the Moon in 1976 before the landing of the Chinese probe Chang'e 3 in 2013.


## Mare Crisium

## Lunar Bays

## A lunar Sinus is a bay-shaped area of solidified volcanic lava with a lower albedo than other lunar surface features.

All images with a Celestron 8 XLT and ASI290MM (IMX290) or Player One Neptune-M (IMX178) camera with 640 nm IR-pass filter.


## Overview

1. Sinus Iridum
2. Sinus Medii
3. Sinus Aestuum
4. Sinus Amoris
5. Sinus Concordiae
6. Sinus Honoris
7. Sinus Asperitatis

249km (Bay of Rainbows) 287 km (Bay of the Center) 290km (Bay of Heat) 190km (Bay of Love) 142 km (Bay of Harmony) 112 km (Bay of Honor) 206km (Bay of Roughness)

4 Sinus Iridum is a wide plain of basaltic lava situated at the north west of Mare Imbrium and flanked by Montes Jura from north east to south west. The two protruding mountain capes (promontorium) are Heraclides at the west and Laplace at the east of the "rainbow", however, no gold-filled buckets detected so far. The bay's surface is largely level with a number of wrinkle ridges (dorsa). The bay is most popular among observers for its beautiful shape and telescopic view.

- Sinus Concordiae is located at the east edge of the Mare Tranquillitatis and borders with Palus Somni in the north.

- Sinus Honoris is flanked by uneven terrain to the north and southwest. Rille systems extend from the north and south.

- Sinus Asperitatis spans from Mare Tranquillitatis southwards to Mare Nectaris. At its western and eastern sides are regions of irregular terrain.


(Sinus Amoris is 190 km wide bay located to the north east of Mare Tranquillitatis. To the north of the bay are the Römer craters and the peaks of Montes Taurus. The central part of the bay includes a few low ridges, but is almost flat and featureless. At the bay's exit to the south where it meets Mare Tranquilitatis lies Mons Esam, a lower elevation between several small lunar domes. To the northwest are the Littrow craters, the landing site of Apollo 17.


## - Sinus Medii is located at the

 intersection of the Moon's equator and prime meridian, for which reason it has been named the "Bay of the Center". As observed from inside the bay, the Earth would always shine directly overhead. At its west lies Mare Insularum, at its north Mare Vaporum. A series of rille systems are found in the eastern region while the rille Rima Hyginus (220km long) lies further out northeast and another rille, Rima Ariadaeus (also 220km long), lies at the far eastern end. The craters inside the bay are Bruce and Blagg, the larger crater to the northeast is Triesnecker.

4 Sinus Aestuum is a flat and largely featureless region with a few small impact craters and wrinkle ridges. The solidified basalt lava is almost circular measuring 290 x 250 km . To its north are the southern ranges of the Montes Apenninus and situated to the northwest is crater Eratosthenes, the flooded crater remnant Stadius is located at its west. Further southwest is the Mare Insularum (not in view of the image). To the utmost east lies a about 90 km long unnamed rille like a border line between the Bode and Marco Polo craters.

# Rima, Rupes E Vallis 

A Rima is a rille, a Rupes is a fault and a Vallis is a valley.<br>All images with a Celestron 8 XLT and ASI290MM (IMX290) camera with 640nm IR-pass filter.

Located at the east of Mare Nubium, Rupes Recta (Straight Wall) is a linear fault or fracture. It measures 110 km in length, is 2~3 km wide, and raises up to 450 meters above the western floor. Although it appears like a large cliff to the eyeball, its slope is rather low between $10^{\circ}$ and $15^{\circ}$.

Rupes Recta formed when a portion of Mare Nubium collapsed due to underground pressures in the lunar crust and bulged out.

When the Moon is about 8 days after new moon, the Sun illuminates Rupes Recta at an oblique angle. Then, it casts a wide shadow that gives it an appearance of a sharp, dark line or a steep cliff, but actually, it is a slope. In the last quarter phase, Rupes Recta is lit up by reflecting bright sun light shining from the west. As the sun rises the shadow gets shorter and finally blends into the Nubium soil. Whether at sunrise or sunset, Rupes Recta is always a dramatic view in Mare Nubium.

Situated to the west are Rima Birt ( 50 km long and 1.5 km wide) with its "Cobra Head" at the north and crater Birt (17km wide, 3.5 km deep).

- Situated near the center of the Moon and formed by faulting of a former lava tube (collapse of underlying structure) Rima Hyginus, precisely, is a Graben (trench) and thought to be a region of active volcanism.

It is about 220km long and up to 3 km wide. Near its middle crater Hyginus, 11 km across and 800 meters deep, bisects the Rima into a north and a southeastern wing.

Many "craters" are found inside the Rima, including crater Hyginus. They are believed to be of volcanic origin because they lack a raised outer rim. Therefore, strictly speaking, they are calderas, not craters. Dark sediments also suggest volcanic explosions.

In the vicinity of Hyginus are two further Rimae, Rima Ariadaeus to the southeast and Rimae Triesnecker to the southwest.

When the Moon is about 7 days past new moon a small light beam flooding the floor of "crater" Hyginus can be observed and imaged. The beam widens as the moon ages.

Image: moon age 19.75 days.



## Features of Curiosity

## Magnetism, Craters, Mons and Domes.

All images with a Celestron 8 XLT and ASI290MM (IMX290) camera with 640nm IR-pass filter.


- Located west of crater Kepler, Reiner Gamma is unlike any other lunar feature. Looking like a painted swirl it is 70 km long, does not cast shadows and has a high albedo. Some sort of miniature magnetosphere that spans over 360km with a 300km thick layer region of plasma where the solar wind flows around without weathering the surface over Reiner Gamma is evident. This also explains the higher albedo but the nature of lunar swirls is not yet completely understood.
- Located in the southern region of Mare Fecunditatis, Messier (9 x 11km, 1300 m deep) and Messier $A$ ( 13 km wide, 2250 m deep) are oblong shaped craters in east-west orientation formed during the Copernican period about 1.1 billion years ago by a low angle impact. The first strike ejected material at Messier perpendicular to the direction of impact. Then the impacter bounced back and struck again to leave behind Messier A. The low angle of impact could explain the asymmetric beam system. Both crater floors exhibit dark streaks in their centers and have a higher albedo than surrounding area. There are six satellite craters ( 3.7 km to 11 km wide), including Messier A. The crater pair is known for eye-catching linear rays extending over 100 km southwestwards from crater Messier A towards the west edge of the Mare. To the northwest of Messier A lies Rima Messier, a 100km long narrow rille. This crater was named in honor of the French astronomer Charles Messier (17301817)


- Mons Rümker is a young volcanic formation located in the northern part of Oceanus Procellarum. The plateau is 70 kilometers wide and rises to an altitude of 900 m to the west, about $1,100 \mathrm{~m}$ to the south, and about 650 m to the east. Mons Rümker is a gathering of 30 dome shaped structures, a few of them have a craterlet at their peak, but its surface
is largely uniform. A dome is made of slowly solidified ejected lava. The soil around the Mons is almost a billion years younger than all material that has been returned by any Apollo mission, meaning that the formation has been volcanically active until the "recent past", also considering that the lava covered surface lacks


Overview

1. Reiner Gamma
2. Crater Messier
3. Mons Rümker
4. Crater Webb

70km long 13 km wide 70 km wide 22 km wide

craters. Eight satellite craters between 3 and 6.8 km wide are assigned to Rümker. On December 1st. 2020, the Chinese Chang'e 5 mission landed east of satellite crater Rümker K on a young lava plain to the northeast of Mons Rümker. Named after German astronomer Carl Rümker (1788-1862).


## Ghost Craters

Crater remnants obliterated and submerged by basaltic lava flow.
All images with a Celestron 8 XLT and ASI290MM (IMX290) camera with 640nm IR-pass filter.

- Situated between the well known craters Copernicus and Eratosthenes lies a remnant of an ancient crater, the 69 km wide Stadius, which is almost completely eroded by basaltic lava flows. A chain of eleven satellite craters spans in linear formation to the northwest into Mare Imbrium. Stadius' floor is largely level, contains a number of craterlets and lacks a central peak. Stadius has been allocated a total of 20 satellite craters between 3 and 7 km wide, the largest of them situated at the border to Mare Imbrium. Crater Stadius was named after Flemish astronomer Johannes Stadius (1527-1579).


4 Catena Davy is a crater chain connecting craters Davy and Davy G. Crater Davy, 34km wide and 1400 m deep, and the chain are located in the northeastern region of Mare Nubium and southwest of the well known crater Ptolemaeus. The chain consists of 23 small craterlets with a length of about 50 km . Six of them have been named. They have probably been formed by a single impacter which broke apart prior to collision while volcanic origin has not been ruled out entirely. Crater Davy has seven satellite craters between 3 and 70 km wide. The catena lies inside the widest satellite crater, Davy Y. The craters have been named after British physicist Humphry Davy (1779-1828).

- Located inside the north of Mare Nectaris, flooded and obliterated by basaltic lava, Daguerre is a 46 km wide impact crater and shaped like a horseshoe owing to a gap in the southwest wall. Though almost submerged in lava the remaining rim has a height of 1500 meters but is difficult to image given its low relief. The crater floor shows a symmetry of rays extending from 2 km wide crater located near the west wall. A long ray extends from the neighboring crater Mädler to Daguerre's western wall. Five satellite craters between 3 and 5 km wide are assigned to Daguerre. The crater was named after French photographer Louis Daguerre (1787-1851).




## Overview

1. Crater Stadius
2. Crater Davy
3. Crater Daguerre
4. Crater Wolf
5. Crater Taruntius
6. Crater Flamsteed

69 km wide 34 km wide 46 km wide 26 km wide 56 km wide 21 km wide

- Located on the border between Mare Tranquillitatis and Mare Fecunditatis, Taruntius is a 56 km wide and 1000 m deep impact crater. It features a number of ghost craters and other lave-flooded features largely to the southwest. The heavily worn rim is of circular shape but broken in the northwest by the 11 km wide crater Cameron. The level floor is fractured owing to material uplift from beneath while a few slim concentric rilles, Rimae Taruntius, are also found. The middle of the floor is marked by a low central peak complex. Taruntius emits a 600km wide ray system and has 14 satellite craters between 5 and 23 km wide. Named after ancient Roman Lucius Tarutius Firmanus.
- Wolf is a 26 km wide impact crater located in the southern half of Mare Nubium. Its floor is lavaflooded with only a broken rim sticking out 700 meters. The crater rim is of irregular shape with outward bulges. Wolf B, a satellite crater protrudes into Wolf at its southeastern rim, now resembling a single formation. There are nine satellite craters between 2.3 to 30km wide. Named after German astronomer Max Wolf (1863-1932).



4 The Flamsteed crater is a conventional small 21 km wide and 2200 meters deep, nearly circular shaped impact crater with a rugged but largely even floor showing signs of only little erosion and hardly any traces of impacts but there is a circular array of small central ridges. The inner slope of the sharp wall edge has a high albedo. The crater rim raises 750 m above surrounding terrain. What strikes the eye is a ring of hills a large eroded basaltic lava-flooded round formation 112 km across and designated satellite crater Flamsteed P, a ghost crater and a relict of low ridges and hills. Flamsteed $G(46 \mathrm{~km})$ is another such remnant. Including Flamsteed $P$ and G, there are 18 satellite craters between 2 and 24 km ( P and G excluded). In 1966, the Surveyor 1 spacecraft landed about 50km to the NNE of Flamsteed. Named after British astronomer John Flamsteed (1646-1719).

## Montes and Mons

## Mountain Ranges and Mountains.

All images with a Celestron 8 XLT and ASI290MM (IMX290) camera with 640nm IR-pass filter.


The Moon is smaller than the Earth, but its mountain summits are comparatively high, up to 5000 meters. Many named mountains are part of a mountain range.


Overview

| 1. Montes Spitzbergen | 70 km long |
| :--- | ---: |
| 2. Montes Riphaeus | 190 km long |
| 3. Montes Carpatus | 360 km long |
| 4. Montes Argaeus | 65 km long |
| 5. Montes Tenerife | 112 km long |
| 6. Montes Apenninus | 600 km long |

4 Montes Riphaeus is an irregular mountain range which landmarks the nortwestern edge of Mare Cognitum. The formation stretches over about 190 km , is 30 to 50 km wide and contains slim ridges and lava-flooded valleys largely in its northern region. The impact crater to the west is 12 km wide and 1300 meters deep Euclides. Its eight satellite craters are scattered all around Montes Riphaeus with Euclides $P$ being a lava-flooded ghost crater 66km across.

- Montes Carpatus is a 360 km wide rugged mountain range located 100 km away to the northwest of crater Copernicus and stretches from east to west. The formation has an average width of 60 km , with several peaks of up to 2400 meters high. It consists of peaks and rises separated by flat valleys flooded with lava from Mare Imbrium. The area north of the mountains is nearly level, with only occasional ridges or smaller craters. To the south the terrain is slightly rougher although largely covered with lava. The outer ridges of crater Copernicus extend to the foot of Montes Carpatus. The Montes are the raised rim of the Imbrium Basin which a giant impact left behind about 3.85 billion years ago.

- Mons Argaeus is a some 65km long mountaneous massif located at the northern top of Mare
Tranquillitatis, about 60km southwest of the Taurus-Littrow Valley, the landing site of Apollo 17. The massif raises up to 2500 meters above the surrounding two Maria. The highest peak of the range is located in its northwest casting a long shadow on the lunar plain. At the southern wall lies the 1.5 km wide crater Fabbroni.



4 Montes Tenerife is located in the northern part of Mare Imbrium, some 95km southwest of the wall of crater Plato. The mountains are a system of isolated peaks scattered over an area 112 km long, 56 km wide and raises up to 2400 meters about the mare's plain. The range is one part of surviving fragments of the inner ring formed by an impact that caused the formation of the Mare Imbrium basin some 3.85 billion years ago. Rock material raised during the impact probably contain a significant amount of titanium and iron. To the southeast is the equally 2400 meters high Mons Pico.

- With a total length of 600km Montes Apenninus is the largest lunar mountain range with summits peaking up to 5000 meters. It ranges from crater Eratosthenes in the west to Montes Caucasus to the northeast. Several named Mons (mountains) are part of the Apenninus chain, such as Ampère, Bradly, Huygens, Hadley and Wolff. Apollo 15 landed near the geologically diverse Hadley rille. The massif is extremely steep to the Mare Imbrium side. On the other side to the south lie the rugged foothills home to the Marco Polo crater family. A most popular target for lunar imagers.




## ular <br> Targets

## n 8 XLT, ASI290MM, IR-pass filter




Petavius

Tycho



## Map of $t$

## Northern

Lunar Reconna

Gateway, shown with spacecraft Orion approaching, will be an outpost orbiting the Moon that provides vital support for a long-term human return to the lunar surface, as well as a staging point for deep space exploration (credit: NASA/Alberto Bertolin).


## ne Moon

## lemisphere

issance Orbite




# Apollo Landing Sites 

16-24 July 1969
Mare Tranquillitatis
Columbia / Eagle
8 days 3 hours

## Crew

Neil Armstrong
Michael Collins
Edwin "Buzz" Aldrin


Astronauts Neil Armstrong and "Buzz" Aldrin landed the Apollo 11 Lunar Module (LM) in Mare Tranquillitatis [0.67416 N, $23.47314^{\circ}$ E], at 20:17:40 UTC 20 July 1969. They spent a total of 21.5 hours on the lunar surface, performing one Extra-Vehicular Activity (EVA) and collecting 21.5 kg of lunar samples. Astronaut Michael Collins orbited the Moon in the Lunar Command Module (LCM), awaiting the return of Armstrong and Aldrin from the surface.

LRO Featured Lunar Sites, Apollo 11 Landing Site
Credit: http://lroc.sese.asu.edu/featured_sites/view_site/1

LROC Image ID:
Longitude:
Latitude:
Incidence Angle:
Phase Angle:
Pixel Scale:
Original Pixel Scale:
Time:
Local Solar Time:

M111443315R
$23.4731^{\circ}$
$0.6742^{\circ}$
$26.24^{\circ} \mathrm{E}$
$27.17^{\circ}$
$0.50 \mathrm{~m} / \mathrm{pix}$
0.52 m/pix

2009-10-29 UTC
10:16


14-24 November 1969
Lansberg Formation
Yankee Clipper / Intrepid 10 days 4 hours


Crew
Charles (Pete) Conrad
Richard F. Gordon Jr.

Alan Bean


Astronauts Pete Conrad and Alan Bean landed the Apollo 12 Lunar Excursion Module (LEM) in Oceanus Procellarum, demonstrating precision landing by setting down the LEM near the Surveyor 3 lunar probe [3.0128 ${ }^{\circ}$ S, 336.57810 ${ }^{\circ}$ E]. Conrad and Bean landed at 06:54:35 UTC on 19 November 1969, and stayed for 1 day and 7.5 hours, during which they performed two Extra-Vehicular Activities (EVA) totaling 7.75 hours and collecting 35.34 kg of lunar samples.

LRO Featured Lunar Sites, Apollo 12 Landing Site
Credit: http://Iroc.sese.asu.edu/featured_sites/view_site/2

| LROC Image ID: | M175428601R |
| :--- | :--- |
| Longitude: | $336.5781^{\circ}$ |
| Latitude: | $-3.0128^{\circ}$ |
| Incidence Angle: | $45.16^{\circ} \mathrm{E}$ |
| Phase Angle: | $44.03^{\circ}$ |
| Pixel Scale: | $0.50 \mathrm{~m} / \mathrm{pix}$ |
| Original Pixel Scale: | $0.40 \mathrm{~m} / \mathrm{pix}$ |
| Time: | $2011-11-08$ UTC |
| Local Solar Time: | $08: 59$ |



## Apollo 14



31 Jan - Feb 91971
Fra Mauro Formation
Kitty Hawk / Antares 9 days 0 hours

Crew
Alan Shepard
Stuart Roosa
Edgar Mitchell


Astronauts Alan Shepard and Ed Mitchell landed the Apollo 14 Lunar Excursion Module (LEM) in the Frau Mauro formation [3.64589 ${ }^{\circ} \mathrm{S}, 342.52806^{\circ} \mathrm{E}$ ]. Shephard and Mitchell landed at 09:18:11 UTC on 5 February 1971, and stayed on the lunar surface for 1 day and 9 hours, during which they performed two Extra-Vehicular Activities (EVA) totaling 9.37 hours and collecting 42.28 kg of lunar samples.

LRO Featured Lunar Sites, Apollo 14 Landing Site
Credit: http://Iroc.sese.asu.edu/featured_sites/view_site/3

| LROC Image ID: | M150633128L |
| :--- | :--- |
| Longitude: | $342.5281^{\circ}$ |
| Latitude: | $-3.6459^{\circ}$ |
| Incidence Angle: | $59.90^{\circ} \mathrm{W}$ |
| Phase Angle: | $77.09^{\circ}$ |
| Pixel Scale: | $0.50 \mathrm{~m} / \mathrm{pix}$ |
| Original Pixel Scale: | $0.49 \mathrm{~m} / \mathrm{pix}$ |
| Time: | $2011-01-25$ UTC |
| Local Solar Time: | $15: 59$ |



26 Jul - Aug 71971
Hadley-Apennine Endeavor / Falcon 12 days 7 hours

## Crew

David Scott
Alfred Worden
James Irwin


Apollo 15


Astronauts David Scott and James Irwin landed the Apollo 15 Lunar Excursion Module (LEM) next to Hadley Rille in Mare Ibrium [26.13239 ${ }^{\circ}$ N, $3.63330^{\circ}$ E]. Scott and Irwin landed at 22:16:29 UTC on 30 July 1971, and stayed on the lunar surface for 2 days and 18 hours, during which they performed three Extra-Vehicular Activities (EVA) totaling 18.5 hours and collecting 77 kg of lunar samples. Apollo 15 was the first of the J Class Missions, which included the new Metric and Panoramic orbital camera systems, the Lunar Rover and additional surface experiments.

LROC Image ID:
Longitude:
Latitude:
Incidence Angle:
Phase Angle:
Pixel Scale:
Original Pixel Scale:
Time:
Local Solar Time:

M122184104R
$3.6333^{\circ}$
$26.1324^{\circ}$
$35.07^{\circ} \mathrm{W}$
$42.10^{\circ}$
$0.50 \mathrm{~m} / \mathrm{pix}$
$0.48 \mathrm{~m} / \mathrm{pix}$
2010-03-02 UTC
13:44

LRO Featured Lunar Sites, Apollo 15 Landing Site
Credit: http://lroc.sese.asu.edu/featured_sites/view_site/4


## 16-27 April 1972

Descartes Highlands Casper / Orion 11 days 1 hour

Astronauts John Young and Charles Duke landed the Apollo 16 Lunar Excursion Module (LEM) in the Descartes Highlands [8.9734 ${ }^{\circ}$ S, $15.5011^{\circ}$ E]. Young and Duke landed at 02:23:35 UTC on 21 April 1972, and stayed on the lunar surface for 2 days and 23 hours, during which they performed three Extra-Vehicular Activities (EVA) totaling 20.25 hours and collecting 95.71 kg of lunar samples.

LRO Featured Lunar Sites, Apollo 16 Landing Site
Credit: http://Iroc.sese.asu.edu/featured_sites/view_site/5

## Crew

John Young
Ken Mattingly
Charles Duke



7-19 December 1972
Taurus-Littrow
America / Challenger
12 days 13 hours

## Crew

Eugene Cernan
Ronald Evans
Harrison Schmitt


Astronauts Eugene Cernan and Harrison Schmitt landed the Apollo 17 Lunar Excursion Module (LEM) within the Taurus-Littrow Valley [20.1911 ${ }^{\circ}$ N, $30.7723^{\circ}$ E]. Cernan and Schmitt landed at 19:45:57 UTC on 11 December 1972, and stayed on the lunar surface for 3 days and 2 hours, during which they performed three Extra-Vehicular Activities (EVA) totaling 22 hours and collecting 110.52 kg of lunar samples. Apollo 17 was the last manned mission to the lunar surface.

LRO Featured Lunar Sites, Apollo 17 Landing Site
Credit: http://Iroc.sese.asu.edu/featured_sites/view_site/6

| LROC Image ID: | M168000580R |
| :--- | :--- |
| Longitude: | $30.7723^{\circ}$ |
| Latitude: | $20.1911^{\circ}$ |
| Incidence Angle: | $45.17^{\circ} \mathrm{W}$ |
| Phase Angle: | $68.50^{\circ}$ |
| Pixel Scale: | $0.50 \mathrm{~m} /$ pix |
| Original Pixel Scale: | $0.42 \mathrm{~m} /$ pix |
| Time: | $2011-08-14$ UTC |
| Local Solar Time: | $14: 42$ |



## Appendix

Planetary Camera Sensors

| Part Number | Pixel Sixe | Resolution [px] | Sensor Size | QE | Full-well | ADC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sony IMX174 | $5.86 \mu \mathrm{~m}$ | $1936 \times 1216$ | $11.3 \times 7.1 \mathrm{~mm}$ | $\sim 77 \%$ | 24.8 ke - | 12-bit |
| Sony IMX178 | $2.40 \mu \mathrm{~m}$ | $3096 \times 2080$ | $7.4 \times 5 \mathrm{~mm}$ | $\sim 81 \%$ | 15 ke - | 14-bit |
| Sony IMX183 | $2.40 \mu \mathrm{~m}$ | $5496 \times 3672$ | $13.2 \times 8.8 \mathrm{~mm}$ | $\sim 84 \%$ | 15 k - | 12-bit |
| Sony IMX224 | $3.75 \mu \mathrm{~m}$ | $1304 \times 976$ | $4.8 \times 3.6 \mathrm{~mm}$ | $\sim 75 \%$ | $19.2 \mathrm{ke-}$ | 12-bit |
| Sony IMX249 | $5.86 \mu \mathrm{~m}$ | $1920 \times 1200$ | $11.3 \times 7.1 \mathrm{~mm}$ | $\sim 77 \%$ | 32 ke - | 12-bit |
| Sony IMX290 | $2.90 \mu \mathrm{~m}$ | $1936 \times 1096$ | $5.6 \times 3.2 \mathrm{~mm}$ | $\sim 80 \%$ | 14.6 k e- | 12-bit |
| Sony IMX294 | $4.63 \mu \mathrm{~m}$ | $4144 \times 2822$ | $19.1 \times 13 \mathrm{~mm}$ | $\sim 90 \%$ | 66 k e- | 14-bit |
| Sony IMX347 | $2.90 \mu \mathrm{~m}$ | $2712 \times 1538$ | $7.86 \times 4.46 \mathrm{~mm}$ | TBA | TBA | 12-bit |
| Sony IMX385 | $3.75 \mu \mathrm{~m}$ | $1936 \times 1096$ | $7.4 \times 4.1 \mathrm{~mm}$ | $\sim 80 \%$ | $18.7 \mathrm{k} \mathrm{e-}$ | 12-bit |
| Sony IMX429 | $4.50 \mu \mathrm{~m}$ | $1944 \times 1472$ | $8.75 \times 6.6 \mathrm{~mm}$ | ~79\% | 25 k - | 12-bit |
| Sony IMX432 | $9.00 \mu \mathrm{~m}$ | $1608 \times 1104$ | $14.5 \times 9.9 \mathrm{~mm}$ | ~79\% | 97 k - | 12-bit |
| Sony IMX462 | $2.90 \mu \mathrm{~m}$ | $1936 \times 1096$ | $5.6 \times 3.2 \mathrm{~mm}$ | $\sim 80 \%$ | 14.6k e- | 12-bit |
| Sony IMX464 | $2.90 \mu \mathrm{~m}$ | $2712 \times 1538$ | $7.9 \times 4.5 \mathrm{~mm}$ | ~90\% | 12 ke - | 12-bit |
| Sony IMX482 | $5.80 \mu \mathrm{~m}$ | $1920 \times 1080$ | $11.1 \times 6.2 \mathrm{~mm}$ | $\sim 85 \%$ | 51.5 k e- | 12-bit |
| Sony IMX533 | $3.76 \mu \mathrm{~m}$ | $3008 \times 3008$ | $11.3 \times 11.3 \mathrm{~mm}$ | $\sim 91 \%$ | 73 ke - | 14-bit |
| Sony IMX568 | $2.74 \mu \mathrm{~m}$ | $2472 \times 2046$ | $6.7 \times 5.6 \mathrm{~mm}$ | TBA | TBA | 12-bit |
| Sony IMX585 | $2.90 \mu \mathrm{~m}$ | $3840 \times 2160$ | $11.2 \times 6.3 \mathrm{~mm}$ | ~91\% | 38.8 k e- | 12-bit |
| Sony IMX662 | $2.90 \mu \mathrm{~m}$ | $1936 \times 1100$ | $5.6 \times 3.2 \mathrm{~mm}$ | ~91\% | 37.8 ke - | 12-bit |
| Sony IMX664 | $2.90 \mu \mathrm{~m}$ | $2704 \times 1540$ | $7.4 \times 4.5 \mathrm{~mm}$ | $\sim 91 \%$ | 38.5 k e- | 12-bit |
| Sony IMX676 | $2.00 \mu \mathrm{~m}$ | $3536 \times 3536$ | $7.1 \times 7.1 \mathrm{~mm}$ | TBA | TBA | 12-bit |
| Sony IMX678 | $2.00 \mu \mathrm{~m}$ | $3840 \times 2160$ | $7.7 \times 4.3 \mathrm{~mm}$ | $\sim 83 \%$ | 11.27 k e - | 12-bit |
| Sony IMX715 | $1.45 \mu \mathrm{~m}$ | $3840 \times 2160$ | $5.6 \times 3.2 \mathrm{~mm}$ | $\sim 80 \%$ | 5.7 ke - | 12-bit |

Lunar Libration


Field of View Simulator

| Focal Length [mm] | 2032 |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| Sensor | Sony IMX178 |  |  | $\checkmark$ |
| Pixel Size | $2.4 \quad \mu \mathrm{~m}$ |  |  |  |
| Effective Pixels | $3096 \times 2080$ |  |  |  |
| Sensor Size [mm] | 7.43 | X 4.99 | I 8.95 |  |
| Field of View [ ${ }^{[1]}$ | 0.21 | $\times 0.14$ | I 0.25 |  |
| Pixel Scale | 0.24 | arc sec/p |  |  |
| Linear Resolution | 1.37 | km/pixel | theoretic |  |


https://www.astropical.space/moon/fovsim.php

## Interactive Lunar Map

## Interactive Map

Move the mouse over a feature, as the cursor changes to crosshairs
mouse or a touch pen recommended for tablets.


## Name: Aristarchus

Type: Crater
Size: 40km
Longtude: - $47.2^{\circ}$
Latitude: 23.71*
Aristarchus is an approximately 450 mililion years old impact crater with prominent rays located on an elevated rocky plateau in the midst of the Oceanus Procellarum. It measures 40 km in diameter and 3.7 km in depth, deeper than the Grand Canyon. The crater is known for its high albedo, a steep central peak being the brightest feature.
https://www.astropical.space/moon/interactive.php

## Lunar Imaging App

Compatible with Android 8 and higher smart-phones and tablets Lunar Imaging is a companion for visual Moon observers and imagers alike. It provides abundant lunar information for current and selectable dates, including positional, physical and ephemeris as well as libration data. The phase of the moon is represented by a 3D globe in 8 K resolution which can be swiped to change dates by one day back or forth. Its orientation can be toggled between upright and diurnal angles, while the phase shadow can be toggled on and off.

Further menu items include a Lunar Calendar and Lunar Atlas. The Camera Simulator is for imagers, the Scope Simulator for visual observers while its Polar Finder should please both. Annual Libration data is provided in form of a table. An Observatory Clock is a time keeper for your observatory. More information is made available via online links.


Age: 4.47 days Waxing crescent in Aquarius R.A., Dec: $22 \mathrm{~h} 15.7 \mathrm{~m},-15^{\circ} 59^{\prime}$ Ecliptic Iongitude: $330.1^{\circ}$ Max elevation: $48^{\circ}$ Phase: $54.55^{\circ}$ Illumination: 21\% Distance: $\mathbf{3 6 5 , 6 2 9} \mathrm{km}$ Tidal force: 1.162 Gravitational force: 1.105 Orbit velocity: 1044 m/s Radial velocity: $51.767 \mathrm{~m} / \mathrm{s}$ Angular Size: $32.68^{\prime}$ (1961") Light time: 1.214 sec Magnitude: -8.48
Earth angular size: $2.008^{\circ}$


Lunar information at a glance.


A few gorgeous gauges for the Moon.

The Lunar Atlas contains a rotatable lunar globe and a database of over 550 major lunar features (craters, dorsa, lacus, mare, montes, mons, oceanus, palus, planitia, sinus, rima, rupes, vallis and Apollo landing sites) half of them with image thumbnails.


Camera Simulator

## Sony IMX178

Focal Length [mm]
2030



PARAMETERS
Aperture
Focal length
Obstruction
Eyepiece focal length
Eyepiece apparent FOV
Barlow/Reducer Performance Plot

## Sensor Data

## Optical Performance

lar angular size is $32.66^{\prime}\left(0.544^{\circ}\right)$.

Current lunar angular size is 32.6
The simulator does does not take into account atmospheric seeing. Ideally, the image scale should be a third of the seeing but is often unrealistic.

The Camera Simulator helps choose a suitable camera for a given focal length and vice-versa. Pick an image sensor from a dropdown and enter the effectve focal length of your optical system to compute the resulting field of view, FOV, image scale and, for the moon only, the linear resolution. The apparent size of the moon changes with its distance to the Earth and is calculated for realtime for best accuracy. The simulator also has a few deepsky images against which to check the FOV. The data of a selected sensor is also available (right).

Pixel size: $2.9 \mu \mathrm{~m}$
Sensor size: $11.14 \times 6.26 \mathrm{~mm}$
Diagonal: 12.8 mm
Total pixels: 8.29 Mp
Effective pixels: $3840 \times 2160$
Diagonal: 4406 pixels
Aspect ratio (H/W): 0.563
Quantum efficiency: ~91\%
Full-well capacity: 38.8 k e
A/D converter: 12-bit
NOTE:
Succeeds IMX485
Player One: Uranus-C ZWO: ASI585MC
QHY: QHY5III585C
Svbony: SV705C

The aperture of a reflecting telescope is obstructed by its secondary mirror which is accounted for in Optical Performance data.

The Telescope Simulator is for visual observers. Against provision of telescope aperture and focal length as well as focal length and apparent field of view, AFOV, of the eyepiece (ocular) the simulator will provide the true field of view, TFOV, value and the simulated view through the specified eyepiece. Sine the apparent size of the moon changes with its distance to the Earth it is calculated for realtime for best accuracy. The TFOV can also be checked against an image of the southern region of Orion. The overall optical performance data is also available.

## Latest Planetary Camera

Player One Astronomy's hexagon shaped CMOS camera sports a 1/1.2" sensor, the IMX585 with a total of 3856 x 2180 pixels ( 8.3 megapixels), each $2.9 \mu \mathrm{~m}$ square, arrayed on an area of $11.2 \times 6.3 \mathrm{~mm}$. The camera surprises with $91 \%$ relative quantum efficiency (QE) and 38.8 k e full-well capacity, a.k.a. "well depth", which is 3 times improved over the previous sensor, the IMX485.

Inherent to the large image size at maximum resolution, the transfer rate is 47 fps (frames per second). This requires a fast control computer with USB-3. $x$ and an SSD disk, but on the other hand, the camera is equipped with 256 megabyte DDR buffer memory which smoothens the data transfer to slower computers. At HD resolution ( $1920 \times 1080$ pixels) the frame rate reaches speedy 187 fps outperforming cameras with native HD-size sensors.

The employed IMX585 sensor is highly responsive to near-infrared, opening gates to additional applications. The sensor has a dynamic range of 88 dB in a single exposure.

The Uranus-C also provides DPS (dead pixel suppression) function and incorporates passive cooling. It is free of "Amp-Glow" even after 300 seconds exposure time. Readout noise is below 1e at gain above 250.

With an optional T2 to C-mount adapter and an ultra-wide lens, the Uranus-C is ideal for all-sky monitoring. Its flange distance is 12.5 mm for CS lenses. A 5 mm thick, $\varnothing 25.4 \mathrm{~mm}$ extension is required for a $C$ lens (flange distance 17.5 mm ). The IMX585 sensor may be too large for some wide angle $C$ or $C S$ lenses.

IMX585 powered astro cameras are currently also offered by ZWO, QHY and Svbony. Meanwhile, Player One launched a TEC-cooled version, the Uranus-C Pro.

## TeleView 2.5x Powermate

Too much magnification does not yield more details because the resolving power of a telescope is limited by its primary's diameter. Yet, TeleVue's Powermates deliver fine lunar close-up images though depending on good seeing. The facing images were taken with an 8-inch SCT and a TeleVue $2.5 x$ Powermate at $\mathrm{f} / 26$ with an ASI290MM which has $2.9 \mu \mathrm{~m}$ pixels, a combination theoretically meaningful at around f/15 only. Composed of 4 elements in 2 groups, the $2.5 x$ Powermate uses a positive field lens that corrects the tilt of converging light beams directed toward the image plane and is virtually free of aberration, unlike an ordinary barlow lens. Since the optic is largely telecentric, the magnification remains almost unchanged regardless of the distance to a focal plane, such as an image sensor or an eyepiece.


- The hexagon-shaped camera body design symbolizes the manufacturer with a high recognition rate.

- The relative infrared response of the IMX585 looks impressive though no absolute curve has been published. In production since mid 2021. (Source: Sony).

- Vallis Rheita, 2023-02-07 15:26 UTC

Celestron 8 XLT, TeleVue 2.5x Powermate, ASI290MM, Baader UV/ IR-Cut optimized, 5ms, gain 220, 170fps, 600 frames, mono8, Image scale: 0.112 ", FOV: $3.53 \times 1.83$ arc min, turbulent but transparent air. - Crater Petavius, 15:06 UTC, gain 235, FOV: $3.41 \times 1.95$ arc min, else image data as above.


# Thank you for reading, and "sayonara" for now... 

- This breathtaking view of Earth rising over the Moon's horizon was taken from the Apollo 11 spacecraft by astronaut Michael Collins who remained with the Command and Service Module "Columbia" in lunar orbit while astronaut Neil A. Armstrong, commander, and Edwin E. Aldrin Jr., lunar module pilot, descended in the Lunar Module "Eagle" to explore the landing site in the northern region of the Sea of Tranquility.

The lunar terrain pictured is in the area of Mare Smythii on the eastern edge of the nearside over center coordinates $85^{\circ}$ east longitude and $3^{\circ}$ north latitude.

Credit: NASA

^ 2021-09-17 12:28 UTC, Celestron C8, ASI290MM, IR642nm band pass filter, 5 ms at gain 100, 170fps, 600 frames.

Libration in longitude $+4.6^{\circ}$, in latitude $+6.1^{\circ}$


## Lunar Reconnaissance Orbiter Camera

4 By combining LROC imagery, data, and historical data, Quickmap is an online visualization tool also available as mobile apps with interactive maps and much more, such as mosaics, topographic shaded relief models, and global features with amazing detail. Launched in June of 2009, the LROC, is a system of three cameras mounted on the Lunar Reconnaissance Orbiter (LRO) that capture high resolution black and white images and moderate resolution multispectral images of the lunar surface.
https://quickmap.Iroc.asu.edu/


Dragon fruits (pitahaya) bloom at night around
full moon and wilt during the same night.

## Fun Fact



## About the author

Born in July 1955, the author is a German national living in Japan since late 1996. Formerly a marketing communications manager for a Tokyo-based semiconductor company, he moved to Okinawa as a freelance web developer, now retired and stranded on the island with two wonderful dogs. A life long interested in astronomy, he started with astrophotography in late 2018 initially with a Vixen A80Mf and a DSLR on an old but working Orion Atlas EQ-G mount. His current workhorse is a Celestron C8 XLT telescope. He began with lunar and planetary imaging because persistent cloudy weather does not permit serious deepsky work.


[^0]:    - Lunar surface captured with a Celestron 8, 1.6x tubeless barlow and IR642nm band pass filter at 5 ms in mono-8, 10-bit ADC, gain 150 and maximum possible speed of 172 fps for $1920 \times 1080$ pixels sized frames. The planets taken with an ASI462MC and UV/IR-cut filter are inserted to image scale.

[^1]:    - Typical appearance of an Airy disk.

[^2]:    - Celestron 8, ASI290MM, focal length 2030mm, IR642BP filter, 5ms, gain 150, 170fps, mono8, 10-bit ADC Image scale: 0.295 "/pixel, image FOV: $9.49 \times 5.37$ arc min, linear resolution: 550 meters/pixel.

