High-Resolution Astrophotography of the Moon: Amateur Astronomers

Pedro Ré
http://pedroreastrophotography.com/

ABSTRACT: Amateur astronomers have been imaging the moon with video cameras since the 1960s. Video offers a certain number of advantages over traditional emulsion-based photography and CCD imaging using refrigerated astronomical cameras. Specialized digital video cameras coupled to a telescope produce excellent high-resolution images of the moon. A high-resolution image can show the finest details of a celestial object independently of the instrument used. The recent advent of CCD cameras that can be operated in a video mode, taking 10 or more images per second for periods of up to a few minutes, can be used with excellent results. Atmospheric turbulence (seeing) affects all high-resolution images. Usually a video file with 1000 or more snapshot images is obtained. This video file includes frames seriously degraded by seeing and others that are less affected. Image processing software (freeware) can be used to stack and align the best frames to produce a low noise high-resolution image. The best amateur images of the moon have resolutions of 300-500 m. These images are far better that some professional Earth-based telescopic atlases.

André Couder (1897-1979) wrote that "*The worst part of the telescope is the atmosphere*"[1]. The atmosphere is a constant source of perturbation exhibiting inhomogeneity, due to winds, eddies, and differences in temperature. The air refractive index varies with temperature causing an irregular wavefront that reaches the objective of the telescope. The magnitude of these irregularities determines the quality of the astronomical seeing. Seeing is usually measured taking into account the diameter of a star's Airy disk.[2] With small and medium size telescopes (10 to 50 cm aperture) the seeing disk of star at the focal plane of a telescope varies from 0.3" to 3". The seeing varies with the wavelength of light and distance to the zenith.[3] The best seeing conditions are usually found at mountain top observatories.

Jean Texereau (1984)[4] describes in detail different types of turbulence that can affect the astronomical seeing:

1. *High-level atmospheric turbulence*: high frequency temperature fluctuations of the atmosphere and the mixing of air "parcels" of different temperatures/densities;
2. *Local turbulence*: caused by the immediate environment related to the diurnal heating of the telescope followed by night-time radiation;
3. *Instrumental turbulence*: produced inside the telescope tube.

Many astronomical seeing scales were described over the years. Eugène M. Antoniadi (1870-1944) and William H. Pickering (1858-1938) seeing scales are familiar to many visual observers, however with the advent of CCDs and webcams other seeing scales were described (*e.g.* Damian Peach's *modern scale of astronomical seeing for imagers*[5]):

1. *Excellent Seeing*: A solid stable star disk with good contrast. Minor Lunar and Planetary details are held for long periods. No significant undulation or fuzziness;

---

[1] Danjon, A. and A. Couder (1935). *Lunettes et Telescopes*. Paris : Editions Revue d'Optique.
[2] The Airy disk and Airy pattern are descriptions of the best focused spot of light that a perfect telescope lens can produce, limited by the diffraction of light.
[3] Short wavelengths are more affected by the seeing. Atmospheric thickness also plays an important role as far as dispersion is concerned. Dispersion is the 'smearing out' of light of different colours due to differential refraction as it passes through our atmosphere.
[4] Texerau, J. (1984). *How to make a Telescope.* Willmann-Bell.
[5] http://www.damianpeach.com/seeingscale.htm

2. *Good Seeing*: A mostly solid stable star disk with good contrast. Minor details are frequently seen though not held for long periods;
3. *Fair Seeing*: Slight or moderate undulation or fuzziness. Reasonable contrast. Minor lunar and planetary details occasionally seen;
4. *Poor*: Very Poor seeing: Severe undulations or fuzziness. Poor contrast. Large scale detail poorly defined. Minor details invisible;
5. *Extremely Poor seeing*: Severe undulations or fuzziness. Very poor contrast. Little detail visible.

The first high-resolution astrophotographs of the Moon were obtained from 1890 to 1900 with two different telescopes: i) 91 cm Lick Observatory and ii) 60 cm Paris observatory refractors.[6] These first photographs had a low resolution.[7] High-resolution images obtained with the Mount Wilson Hooker 2.5 m telescope in the 1920s were not much better[8]. Planetary images obtained with the 60 cm Clark refractor of the Lowell observatory had a resolution of 0.6", decidedly a big step forward (1905 to 1930). Similar resolutions (0.4" to 0.6") in planetary images were recorded by several French astronomers working at Pic du Midi observatory (1940s). The best lunar and planetary images from this period had an average resolution of 0.5".

With the introduction in the 1990s of Kodak Technical Pan (TP-2415), amateur astronomers were able to produce lunar and planetary images with details as small as 0.3", a resolution obtained only by the best professional observatories. The extremely fine grain and high resolving power, coupled with high-contrast development of this film, permitted reproduction of very fine detail on objects in the solar system.[9]

TP-2415 is the derivative of Technical Pan SO-115, developed by Kodak for solar patrol photography. Hypered[10] Tech-Pan was universally accepted as the film of choice for astrophotography (both in high-resolution and deep-sky photography).

In 1969, Willard Sterling Boyle and George Elwood Smith of Bell Laboratories invented the *charge-coupled device* (CCD), a solid-state semiconductor. Boyle and Smith were investigating new ways of imaging with solid-state, silicon methods to develop the Picture phone. This method turned out to be an incredible innovation that changed imaging away from vidicon-type TV tubes and from emulsion-based photography.[11]

The first Boyle & Smith paper[12] began with the following words:

A new conductor device concept has been devised which shows promise of having wide applications (…)

A CCD array consists of a thin wafer of pure silicon subdivided into a grid of picture elements or pixels.[13] The pixels act as light sensors like the tiles in a mosaic. As photons strike a given

6 Vaucoulers, G. (1958). *La photographie astronomique.* Paris, Albin Michel.
7 The finest details recorded could be easily observed with a 10 cm telescope.
8 The smallest lunar features were easily visible in an amateur-sized 20 cm telescope.
9 TP-2415 was a "miracle film" for many astrophotographers because it combined speed, high contrast, resolving power and fine grain.
10 Film hypersensitazion or htypering is the process of making film more sensitive by baking it in an atmosphere of 8 % hydrogen and 92 % nitrogen forming gas. Hypersensitazion can also be achieved by freezing the film to near-cryogenic temperatures.
11 The 2009 Nobel Prize in Physics was awarded to W.S. Boyle and G.E. Smith "*for the invention of an imaging semiconductor circuit – the CCD*".
12 Boyle, W.W., G. E. Smith (1970). Charge Couple semiconductor devices. *The Bell System Technical Jornal*, 49 (40: 587-593.
13 "Pixel" is the contraction of **PICt**ure **EL**ment.

pixel, they generate an electrical charge with a magnitude proportional to the intensity of the incident light. Each picture element acts as a tiny capacitor accumulating a charge for a given time interval or integration time.

CCDs have many advantages over other electronic and photographic imaging devices. CCDs are remarkably efficient light detectors[14], linear in their response to light and exhibit an excellent sensitivity over a wide range of wavelengths.

Amateur astronomers basically use three different types of digital cameras:

1- Digital SLR Cameras (DSLR)
2- Dedicated, Cooled Astronomical CCD Cameras (CCD)
3- Webcams and astronomical digital video cameras

DSLR and Cooled Astronomical CCD cameras are mainly used for shooting Deep-Sky objects. Webcams and specialized high-end digital video cameras are better suited to imaging the moon, sun, and planets.

The recent advent of CCD cameras that can be operated in a video mode, taking 10 0r more images per second for periods of up to a few minutes, can be used with excellent results for high-resolution imaging.[15]

Webcams[16] and astronomical digital video cameras are equipped with a color or a black & white CCD or CMOS.[17]

They can be operated with different interfaces: USB 1.0, UBS 2.0, USB 3.0, FireWire, and GigE. These cameras can capture several hundred to thousands of individual images (frames) in rapid succession and store them in popular video formats[18]. This video file includes frames seriously degraded by seeing and others that are less affected.

Image processing software can then be used to stack and align the best frames to produce a low noise high-resolution image.

Individual frames of the video are analysed, and the sharpest frames selected using dedicated software. These good frames (less affected by the seeing) are stacked together to produce a high-resolution image in the form of a single still picture. The composite images have less noise, higher contrast, and better resolution than a single exposure.

The pioneers in composite image stacking were two Lowell Observatory astronomers: Earl C. Slipher (1883-1964) and Harold L. Johnson (1875-1969). These astronomers developed and improved astronomical photographic techniques that became standard and are now used in the digital age.

This technique was known as integration printing. The method consisted of capturing many high-resolution photographs of a planet and then aligning and exposing these plates on a single

---

[14] The sensitivity or quantum efficiency of a CCD can be as high as 90%. By comparison, the fastest photographic emulsions are 10 times less efficient. The detector quantum efficiency of the human eye is only 5%.

[15] Some high-end video cameras have high-speed data transfer of up to 120/s (USB 3.0, GigE and FireWire interfaces).

[16] The first webcams were mainly used as video conferencing devices.

[17] Complementary metal–oxide–semiconductor (CMOS). In the recent past CMOS technology proved inferior to CCD as far as capturing high-resolution images of the Sun, Moon and Planets. Modern CMOS detectors have a better overall quality and are considerably cheaper to produce.

[18] 8-bit avi files, 12-bit ser files.

print. The result was a photographic print with less film grain than a single negative could produce (better signal-to-noise ratio).

This method of integration printing has evolved into what we now know as staked-video imaging.

Amateur astronomers today regularly capture images of the Sun, Moon and planets that rival those taken by professional astronomers. These images often constitute valuable scientific contributions[19].

Specialized software[20] align, sort and stack hundreds to thousands of images, automatically producing a low noise composite image.[21] These images can be processed using aggressive image processing tools to bring out hidden detail.[22]

The best amateur high-resolution images of the moon have resolutions of 300-500 m. These images are far better that some professional Earth-based telescopic atlases.

In 2009, several well-known astrophotographers[23] created an image, which has eclipsed any other so far taken of the Moon by ground-based astronomers.[24] This world record image was part of an ambitious project to create the largest ground-based mosaic image of the Moon.[25]

The Moon was imaged using high-end astronomical video cameras coupled to different large amateur telescopes. Each telescope targeted a small portion of the lunar surface. These high-resolution images were assembled in a giant mosaic of the gibbous Moon (9-day old).

Almost 1000 different areas were imaged, corresponding to 1.2 million captured video frames and 1.1 terabytes of data. The 288 individual image panes were selected based on their overall quality and assembled in final high-resolution 87.4-megapixel mosaic.[26]

---

[19] Sun activity (*e.g.* flares), Moon transient phenomenon (video impact monitoring), Atmospheric activity of Jupiter, Saturn, and Mars.

[20] Registax - http://www.astronomie.be/registax/, Autostakkert - http://www.autostakkert.com/, Avistack - http://www.avistack.de/

[21] Images are aligned using hundredths to thousands of reference points. The best resolution images are then staked producing a high signal to noise ratio final composite image.

[22] Usually wavelet-based image restoration algorithms.

[23] Ten different astrophotographers used a range of 9.25-inch to 14-inch Schmidt –Cassegrain Telescopes working between 5.5- and 7.8-meter focal length and high frame rate digital astronomical video cameras to create the world record lunar mosaic image.

[24] http://www.lunarworldrecord.com/image.php

[25] The mosaic Moon image was submitted to the 2010 Guinness World of Records, http://www.lunarworldrecord.org/

[26] The resolution of the mosaic image is better than 1 km on the Moon surface.

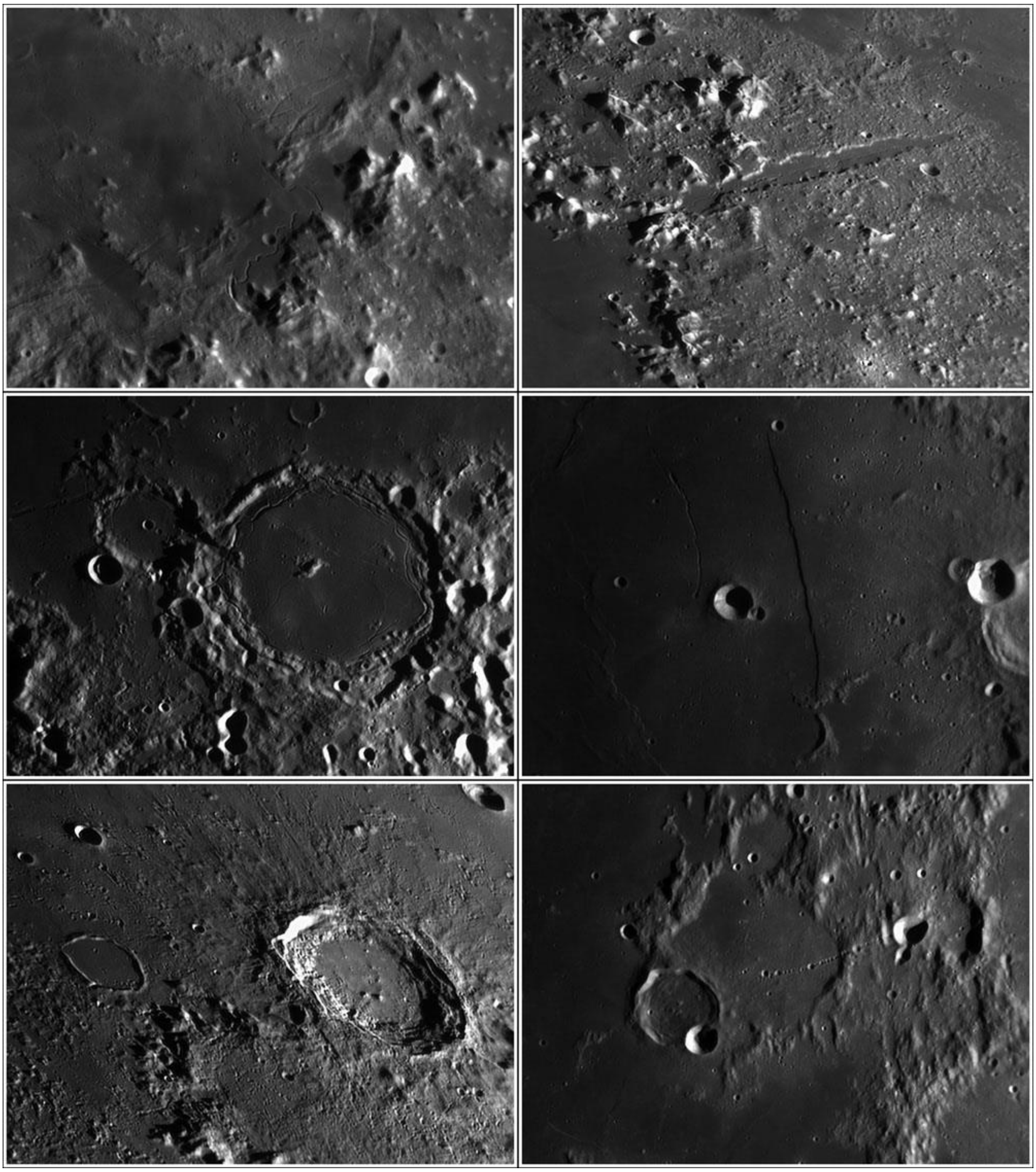

Figure 1- High-resolution images of the Moon. António Cidadão, Meade 14” F/10 Schmidt Cassegrain, SKYnyx CCD cameras.

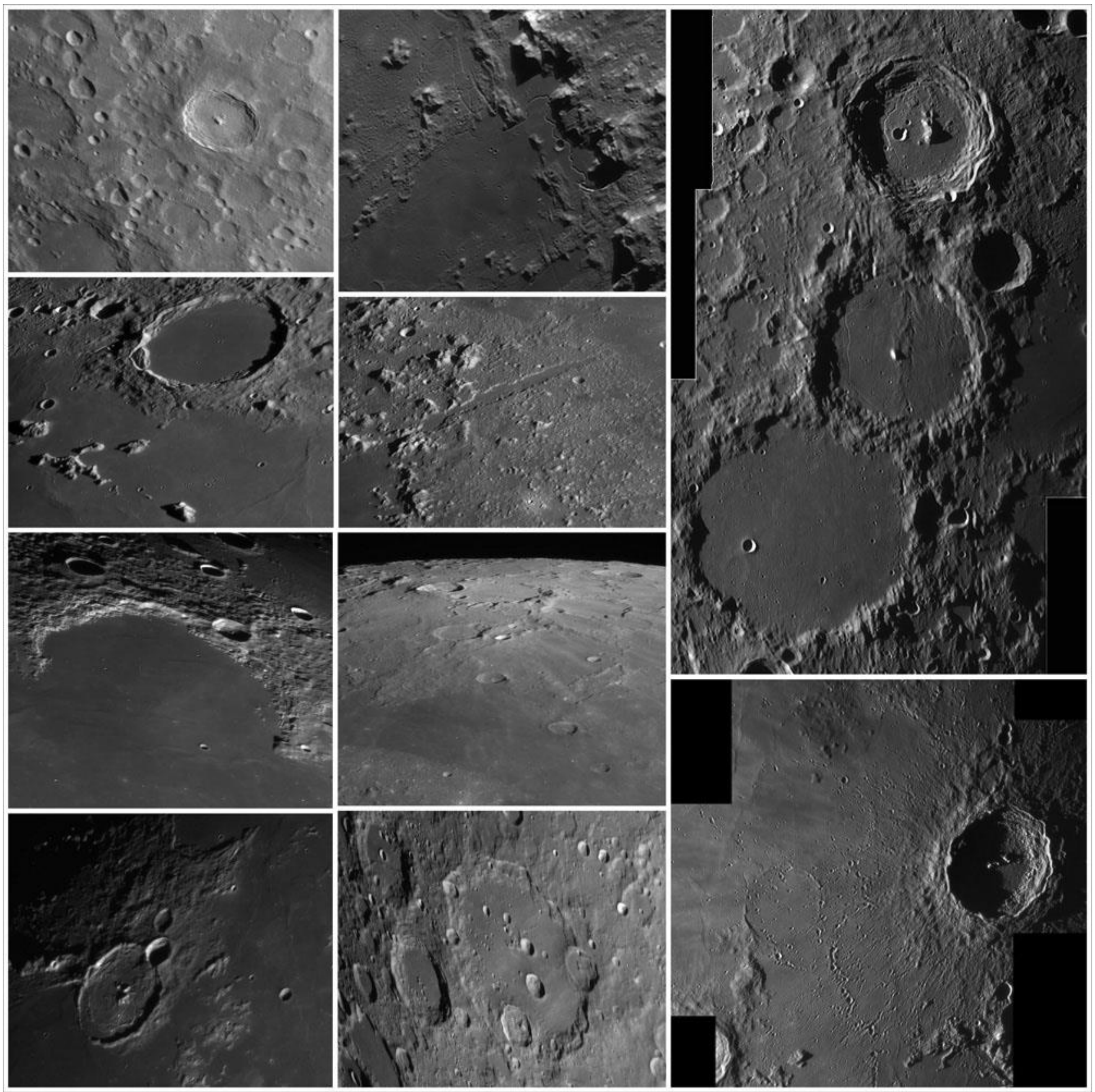

Figure 2- High-resolution images of the Moon. Luís Campos, 300 mm reflector, PG Chamaleon and DMK CCD cameras.

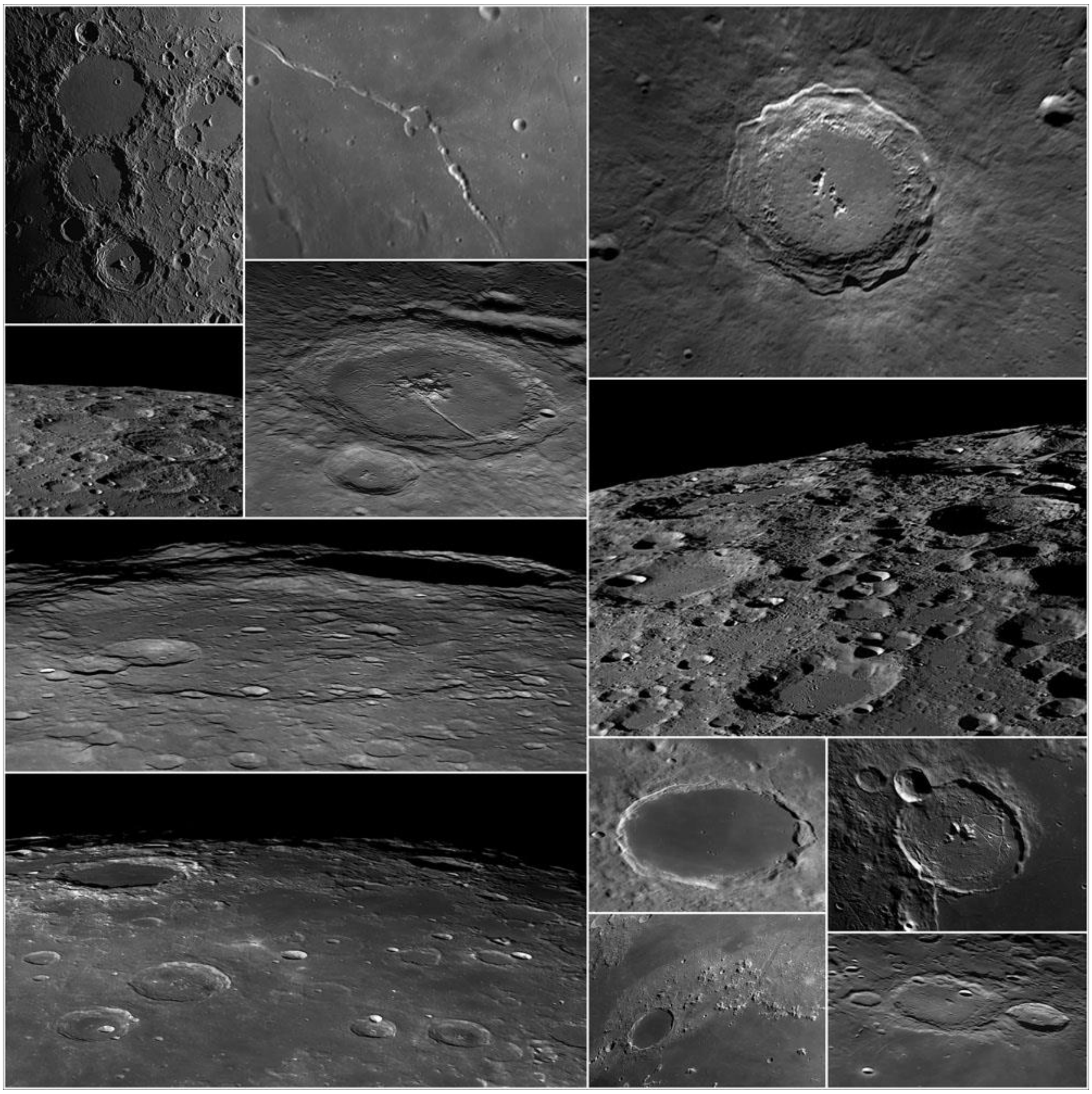

Figure 3- High-resolution images of the Moon. Paulo Casquinha, C14, SKYnyx2-0 CCD camera.

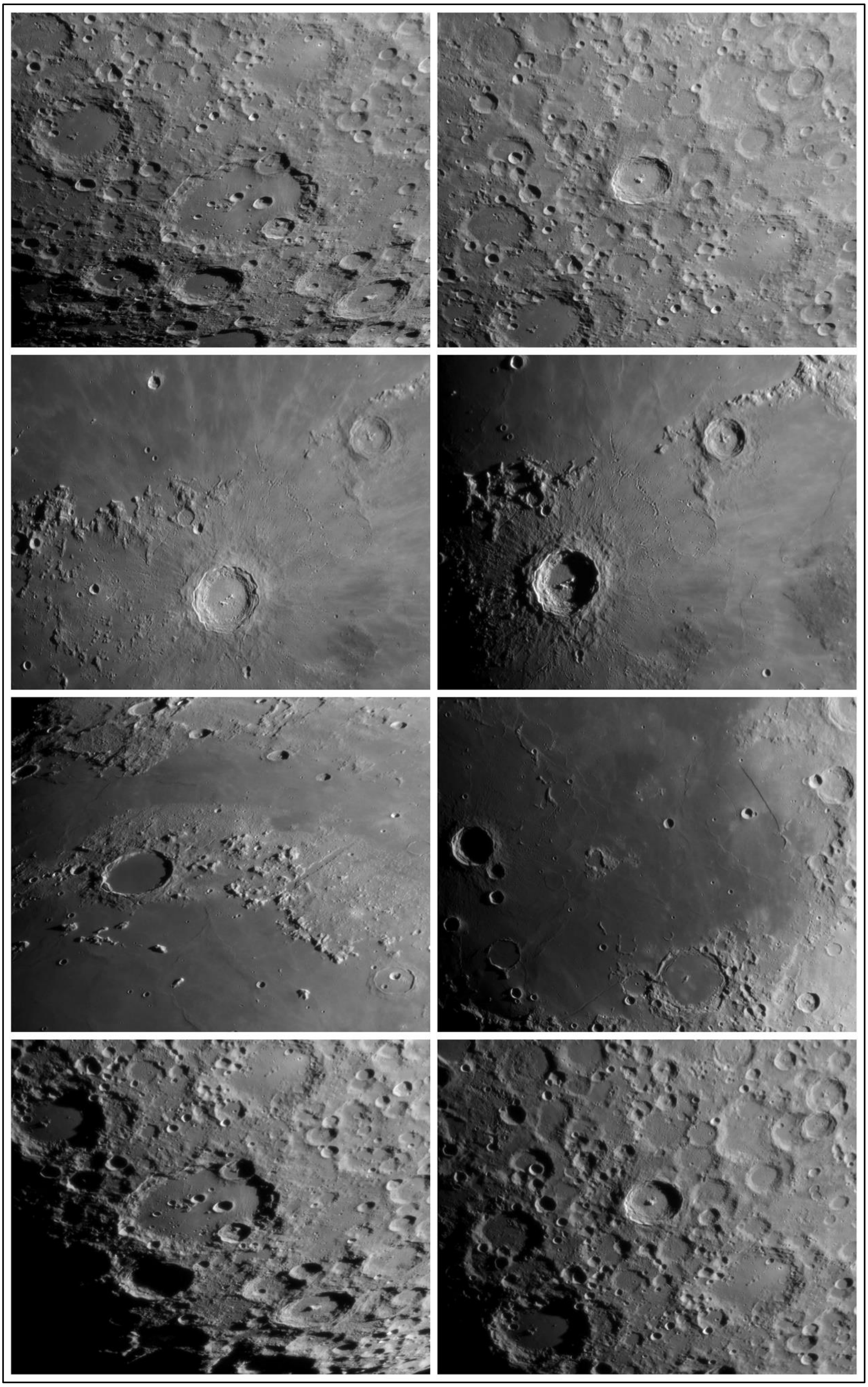

Figure 4- High-resolution images of the Moon. Pedro Ré, TEC140, ASI ZWO 174MM CMOS camera.