Ricoh Theta S in Astronomy

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The Theta S camera is a valuable tool for a multitude of applications in astronomy and astrophotography.

The Ricoh Theta S is a completely new type of camera. With two fisheye lenses it records a 360° full-sphere panorama in only one single shot. The recorded images can be further processed and viewed either with the player provided by the manufacturer or with any third-party panorama viewer or web service that supports full-sphere panoramas. When used stand-alone, the camera works only in automatic mode. Controlling the camera with the provided app on a mobile device gives the user much more options: Long exposures, timed exposure series, HDR shooting, image download, immediate viewing as a sphere on the mobile device, etc. For a more thorough introduction to the camera system and to view some terrestrial sample shots, visit the manufacturer's Theta S website theta360.com.
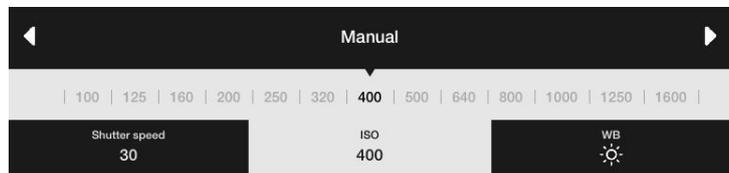

Image: Ricoh press release

Night Sky Suitability of the Theta S

Before we discuss some astronomical applications in more detail, here are the basic facts about the camera's suitability for night sky photography: First of all, to use the manual mode and to set exposure time, ISO and white balance individually (as it is required for night sky photography) the camera must be controlled by the provided app running on a smartphone or tablet. This procedure is straightforward, the camera connects with the mobile device via Wi-Fi and the app is easy to understand and simple to use. For

night sky photography the camera must be mounted on a tripod - for this, the camera provides a standard 1/4" thread in the base. The extremely fast focal ratio of f/2 of the two f=1.31mm fisheye lenses is a great benefit for astronomical applications. One would believe that this fast focal ratio must result in catastrophic aberrations. Luckily,

The exposure values can be set manually when operating the camera via the provided app.

this is not the case. Although star images show some chromatic aberration and distortions especially in the field edges of the fisheyes, the images are surprisingly nice. Noise, on the other hand, is as strong as the small pixel size of the tiny chips would imply. The camera allows ISO settings from 100 up to 1600. Above ISO 400, noise increases considerably. ISO 800 might be of use in some cases, but in our opinion it is best to avoid the ISO 1600 setting. With the highest ISO setting too much detail, like small stars, gets lost in the noise.


The camera's performance at different ISO settings. With values higher than ISO 400, noise increases considerably. The 100% crops were somewhat stretched to make the noise better visible.

To keep the ISO setting as low as possible, it comes in handy that the maximum exposure time of the camera can be used to its full 60 seconds duration for night sky photography. Experiments revealed that 30 second exposures show no significant signs of star trailing. In 60 second exposures some trailing begins to show in areas near the celestial equator but is still tolerable. After each shot the camera automatically stitches the two fisheye shots to one full-sphere image. This is done remarkably well. Stitching is seamless and the camera even retouches itself out of the picture. The images are EXIF time stamped by the camera's internal clock, which is updated every time the cam is connected to a mobile device. The reliable time stamp is of great value when analyzing the images later. When you download the resulting image to your smartphone, tablet or desktop computer you get a 5376 x 2688 pixel wide equirectangular panorama image in JPEG format. The term equirectangular refers to the projection that is used to store the spherical 360° data in a flat image, see underline explanation equirectangular. The images downloaded via Wi-Fi onto a mobile device are somewhat compressed and tend to show banding. However, downloads via USB to a computer retrieve the uncompressed original images. Once downloaded, the images may be further enhanced and labeled with any image processing software such as Photoshop. Whether the original images are modified or not, they can be dragged and dropped into the desktop software, explored interactively as a 360° sphere and uploaded for sharing on the Theta S website.

Simple Astronomical Applications for the Theta S

Many possible shooting scenarios for the Theta S in an astronomical context require no additional accessories. We expect a lot of these images to appear in the near future. For example, the Theta S will be a wonderful tool to capture twilight phenomena, auroras, noctilucent clouds, total solar eclipses, solar and lunar halos, constellations, planetary conjunctions, fireballs and the brighter parts of the Milky Way. Even the social aspects of stargazing might be captured with this little gadget: Imagine using the Theta S on a star party, during observing sessions or inside an observatory dome. All you have to do is put the tiny cam on a tripod, connect via the app and shoot away.
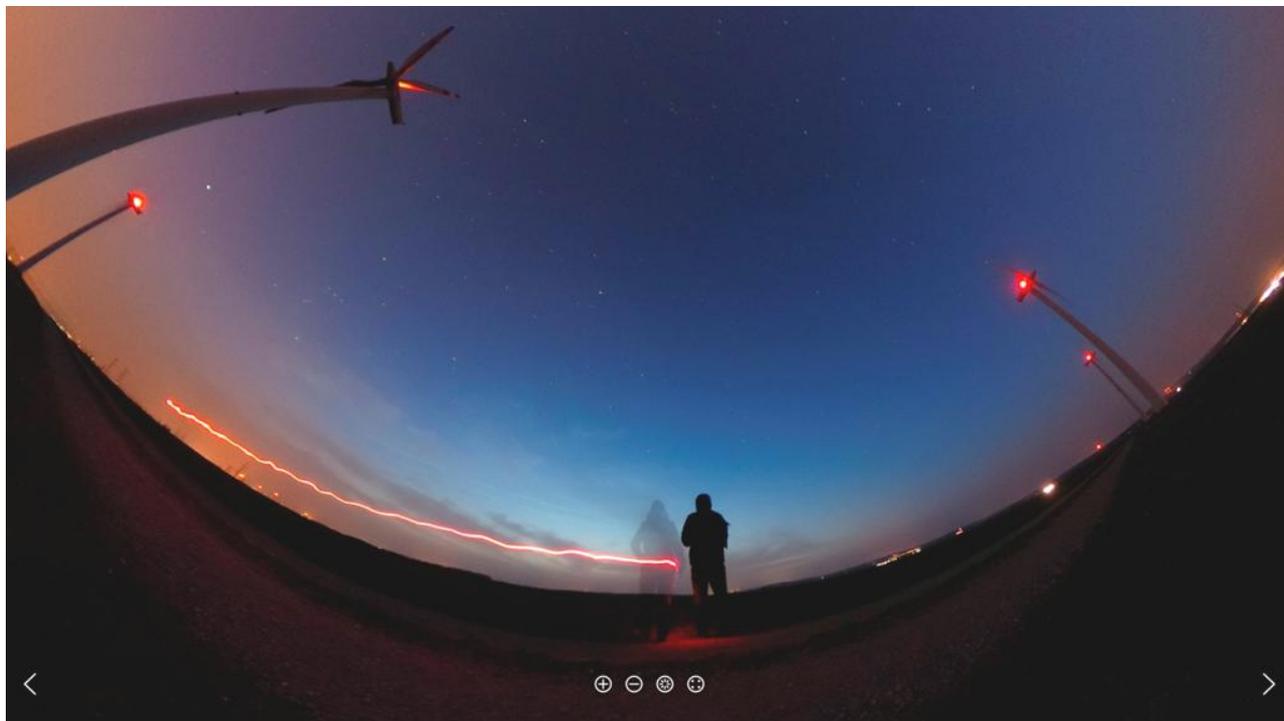
Fun shot during a short observing session at a wind farm. The picture was exposed 30 seconds at ISO 100. This is a screen shot of the panorama displayed with the Theta S desktop player. To experience the 360° scene yourself, explore the panorama on our website.

Aligning the Images

Besides the fun images mentioned above, there are some more advanced astronomical applications of the Theta S. Two of these applications are described later in the text. With these applications it is possible to measure azimuth and elevation angles of objects directly on the images. To do so, the images must be recorded with the camera aligned in the horizontal system. Meaning, the mathematical horizon of the imaged scene must appear as a straight horizontal line crossing the equirectangular image exactly in its middle. This is never the case when the vertical alignment of the camera is done by simple eyeballing.

The obvious solution would be to transform such non-aligned images later on by using the data that is provided by the camera's internal alignment sensor. This sensor monitors the orientation of the camera during the exposure and determines how much it deviates from the vertical position. The sensor's value is stored with the image in the JPEG data. Sadly, the precision of the sensor is not high enough. During our tests transformations performed with the Theta S desktop software based on the values provided by the sensor worked only to an accuracy of ±2°, even if the camera had been steadily mounted on a tripod for the shot. For accurate vertical alignment the internal sensor is a dead end.

So, obviously some means is needed to put the camera in a reliable vertical position during shooting. At first, we tried to align the camera with the tiny bull's eye spirit levels that can be found on many tripod heads and ball heads. Still no luck, again the accuracy was too low.

Finally we came up with a solution that really works. It consists of a quick release plate with a two-axis spirit level and a compass mounted on it. The compass is for pointing the camera roughly in a north-south direction. This is only for convenience and the compass could have been left out, but the two-way bubble level is the indicator that really matters. The Theta S is mounted on the quick release plate and the whole contraption goes onto the tripod. Before shooting, we orient the camera roughly north-south with the compass and then adjust the tripod head until the bubble levels indicate sufficient vertical alignment of the camera. This simple solution allows alignment to a repeatable accuracy better than ±0.5°. This means that horizontal coordinates of objects on the images can be measured to the same accuracy.

A simple leveling plate turns the Theta S into a powerful full-sphere surveying tool. With a two-way bubble level the camera is vertically aligned for the exposures. On images shot with this setup, the horizontal coordinates of celestial objects, light pollution domes, horizon lines etc. can be measured directly.

In Theta S images shot with this setup it is possible to measure horizontal coordinates of objects on the images to an accuracy of ±0.5°. This can be used for many purposes, including two typical applications we describe on the following pages. It may also be used as an educational tool, for example with students who are in the process of familiarizing themselves with the apparent motions of celestial objects and the usage of spherical coordinate systems.

Surveying an Observing Site's Horizon

A question that often arises is: "Can I watch or photograph a certain celestial object or event from my observing site or will it be obstructed by the local horizon?" For example, a conjunction of Venus and the crescent moon low in the western sky might be hidden behind a nearby group of trees. Or there may be some hills on the horizon that just block a star cluster with a southern declination from view. Or the long awaited partially eclipsed sun may hide itself behind a group of buildings in the east, etc. To avoid such disappointments, astrophotographers and visual observers alike often prepare for an upcoming event by driving to their preferred observing site to check out the visibility of objects. Other amateurs even make panoramas of their favorite observing locations by carefully photographing the horizon in several images and stitching them together. This has never been done frequently, because until now the process to produce such a panorama took hours. With the Theta S this changed dramatically.

To demonstrate how the Theta S can be used to survey an observing site's horizon, we did an exposure at Star Meadow, the endpoint of the Grossmugl Star Walk. For the shot, we aligned the camera vertically as described above. Since the Theta S delivers equirectangular images, azimuth circles and elevation parallels are simple parallel lines on the image. To add a grid of horizontal coordinates to the image, we prepared an overlay image that includes lines for the horizon, parallels for different height angles, verticals at the cardinal points, azimuth labels every 10 degrees and a mark for the celestial pole. We used Photoshop to insert the overlay image as a layer in the original Theta S image. Since the horizon line is exactly in the middle of the equirectangular image, the layer with the grid only has to be oriented left-right until it matches north on the image. It is easy to use the celestial pole to do so. Once we had the overlay oriented, we flattened the layers and saved the image again as a JPEG. It is now possible to open the image in the Theta app or the Theta desktop viewer and simply read off the height of the horizon at any azimuth to an accuracy of ±0.5°.

Equirectangular image of an observing location in moonlight at the endpoint of the Grossmugl Star Walk. In the image, coordinate lines of the horizontal system (azimuth, height) were added in Photoshop. Exposure of the original Theta S image was 60 seconds at ISO 100.

Our experiments showed that it is best to do the shots to survey a horizon line with the Theta S under a gibbous moon. During this lunar phase, the surroundings of the observing site are plainly visible on the image. With a gibbous moon the night sky is not too bright from moonlight, so major light pollution sources can be identified on the picture, too.

With the labeled image in the Theta S player, we now have a 360° full-sphere model of the observing site on our hands. It can be viewed interactively and will be of great help for planning images and observing events at Star Meadow. The panorama is available in the tests section of our website.


Screenshot of the spherical display of the image in the Theta iPad app. To view the interactive 360° scene yourself explore the panorama on our website.

When comparing this technique to the conventional way of generating panoramas from several images the Ricoh Theta S clearly wins. To survey the horizon line of an observing site with this little cam it takes only one shot and the grid overlay can be inserted and aligned within minutes. The whole process takes 15 minutes max. We are planning to make similar surveys of all our favorite observing and astro shooting locations.

Documenting Light Pollution at an Observing Site

The same technique can be used to document the light pollution at an observing site. To do so, the exposure has to be made after the end of astronomical twilight and with no moon in the sky.
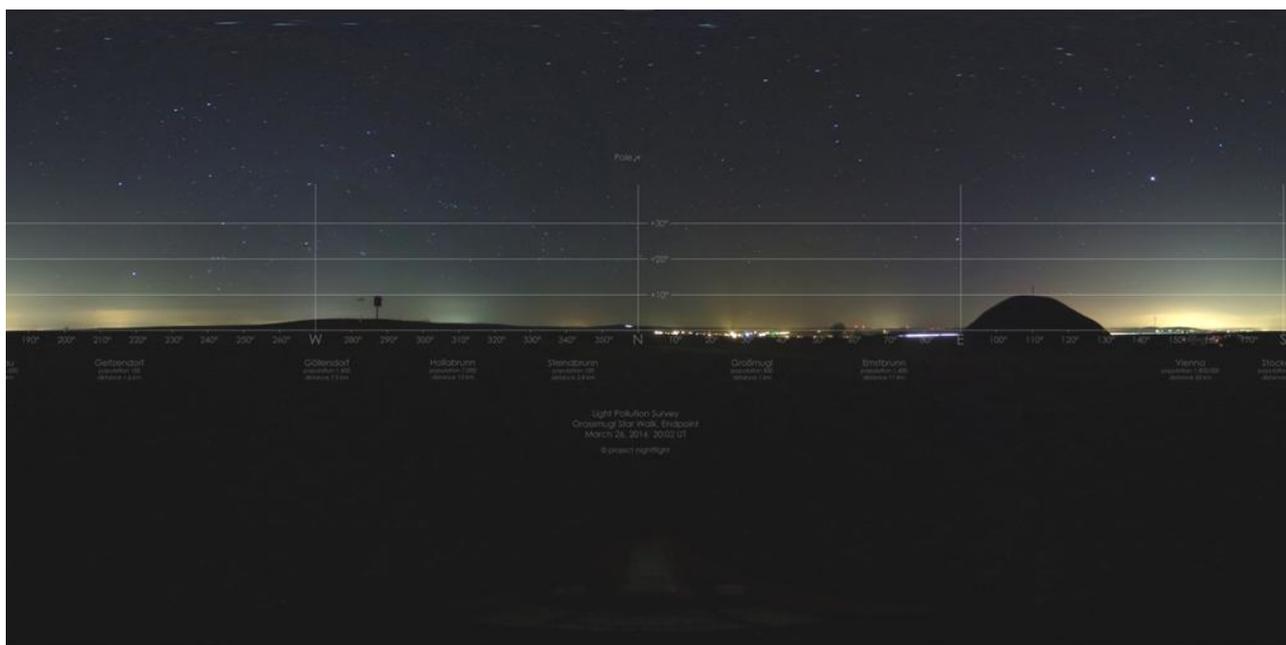
Equirectangular image of the light pollution at Star Meadow, the endpoint of the Grossmugl Star Walk. In the image, coordinate lines of the horizontal system (azimuth, height) were added in Photoshop. Exposure of the original Theta S image was 60 seconds at ISO 200.

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Again, we shot our example image at Star Meadow, the endpoint of the Grossmugl Star Walk. The image was made on an evening with average sky conditions, on March 26, 2016. We inserted the grid with the horizontal coordinate lines as explained above and additionally labeled the sources responsible for the light pollution. As the result shows, the sky at Grossmugl is still rather nice for being so close to a major city (Vienna with its 1.800.000 inhabitants is only 33 kilometers away). We will also use this data to plan our imaging sessions at the Star Walk. As can be seen on the sphere, in the directions facing away from Vienna's awful light dome the Grossmugl sky will allow long exposures down to a height above horizon of about 30 degrees.
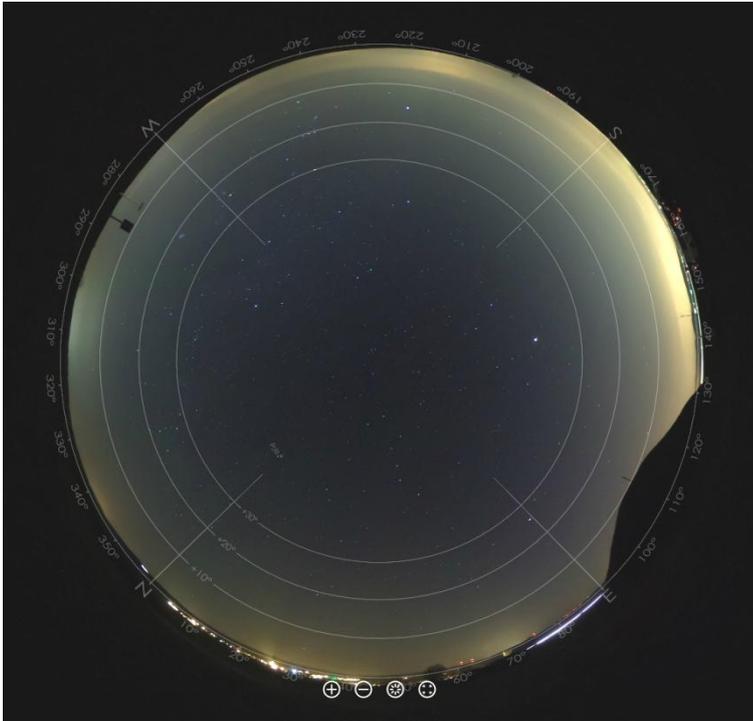
Screenshot of an all-sky view of the image in the Theta desktop viewer. To view the interactive 360° scene yourself explore the panorama on our website.

We want to emphasize how useful this technique is to document and visualize light pollution. With the Theta S, it takes only one shot to capture the light pollution situation at a site and the horizontal grid is added in no time. Since it is so easy to do this kind of documentation a larger number of sites can be covered, and with high frequency. For example, the increase of light pollution (or hopefully the decrease at some sites) may be documented over several consecutive years. The Ricoh Theta S even provides a website where it is possible to share the results among fellow stargazers and with the general public. Given all this, we can all turn the Theta S into a new and highly valuable tool in the struggle against light pollution.

For those of you interested in doing sky brightness measurements, here's some additional information: It is obvious that the Theta S cannot be used to make absolute measurements of the sky brightness. At present (April 2016), accessing the RAW image data of the camera is not possible. Therefore, the images cannot be calibrated and analyzed for sky brightness values. There is a chance that this will change over time, since a lot of third-party developers are asking Ricoh to give them access to the RAW data. We are not sure this will ever happen - what's sure is that at the moment sky brightness measurements cannot be done with this cam. For this purpose, the SQM (Sky Quality Meters) from Unihedron are a much better choice. They are highly recommended by the International Dark Sky Association (IDA) and are widely used in IDA campaigns for data acquisition on a global scale.

Although measured sky brightness values are very useful, a typical SQM result like "20.7 magnitudes per square arcsecond" will mean absolutely nothing to someone outside the astronomical community. Numbers are not easy to comprehend for everyone and that's where the Theta S can come in. It will doubtlessly excel in the visualization of light pollution. The camera is a very easy-to-use tool to

demonstrate the impact of light pollution on the night sky at a given location. The presence of light pollution domes on the horizon can be proven and the sources can easily be identified. Even some quantitative analysis of the images is possible, since the horizontal and vertical extension of light pollution domes can be measured directly from the image. Changes over time might be documented as well. But the greatest strength of the Theta S spherical images is the fact that they are extremely instructive - they can be viewed full screen, panned, zoomed, auto rotated, played with etc. This will be very useful to demonstrate the effects of light pollution to people not involved in astronomy, such as politicians, local government officials or media people.

Shooting the Milky Way

Besides documenting light pollution and surveying observing sites, the Theta S is capable of capturing quite dim objects, too. Under a dark sky, exposures of 60 seconds easily capture the Milky Way or the zodiacal light. However, since these objects require settings of ISO 800 or higher, the images turn out somewhat noisy. To get rid of the unwanted noise, it is possible to shoot several images and later combine them with a stacking software. During the imaging sequence the Theta S has to be tracked for the sky's motion, otherwise the equirectangular images cannot be stacked properly. For tracking the Theta S, any motorized equatorial mount or sky tracking device will suffice. Simply mount the camera piggyback on your telescope or on your sky tracker and use the Theta app's interval timer to expose a sequence of images. When using ISO 800 we recommend shooting at least 16 individual images. These are imported later into a stacking software like Deep Sky Stacker and combined to a single noise-free picture.
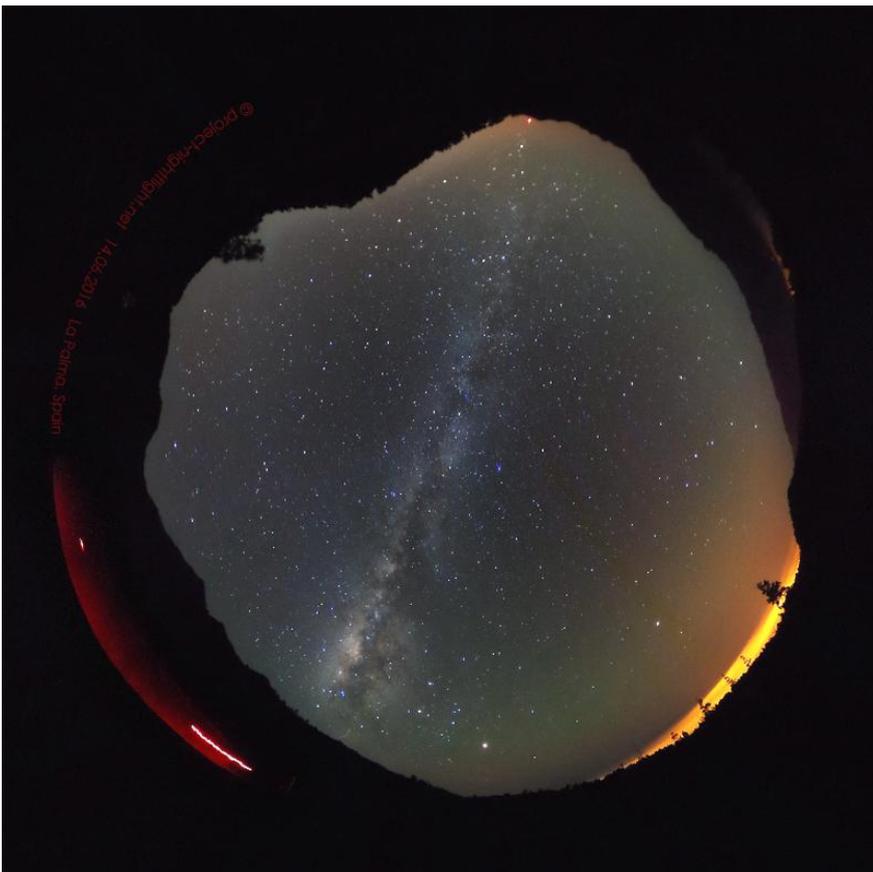
Screenshot of an all-sky view of a tracked and stacked Milky Way image in the Theta iPad app. To view the interactive 360° scene yourself explore the panorama on our website.

To demonstrate what's possible with this technique we obtained an image of the Milky Way on La Palma island. We used an Astrotrac TT-320X AG to track the sky and shot 25 exposures of 60 seconds at ISO 800. Another sequence of 25 untracked exposures was made to get an unblurred image of the landscape. Both sequences were stacked with the freeware Deep Sky Stacker. The two resulting noise-free images of the sky and of the landscape were combined with Photoshop. Finally, some minor improvements like a white balance correction and a subtle contrast improvement were applied.

Overview of Sample Images

For those who want to delve further into spherical astrophotography here is an overview of the astronomy related full-sphere images we made so far with the Theta S. You can browse them, feel inspired, get some ideas for your own astrophoto projects or share them with other people interested in astronomy and astrophotography. Just click the links below and enjoy.

Stacked Images:
Milky Way on La Palma Island, Spain
Stargazing Events:
Sunset with a group at the Grossmugl Star Walk installation, Austria
Dusk with a group at the Grossmugl Star Walk installation, Austria
Starlight Picnic with a group at the Grossmugl Star Walk installation, Austria
Austrian Science Night public stargazing at Vienna Observatory, Austria
Simple Nightscapes:
Dusk at a Wind Farm in Lower Austria, Austria
Dusk in the Mountains of La Palma Island, Spain
Dusk at an Astronomical Viewpoint, Mirador Del Jable, La Palma, Spain
Moonlit Scenery at an Astronomical Viewpoint, Mirador De Las Ventas, La Palma, Spain
Horizon Surveys:
Moonlight Horizon Line Survey at the Endpoint of the Grossmugl Star Walk, Austria
Daylight Horizon Line Survey of the Astronomical Viewpoint Mirador Del Jable, La Palma, Spain
Daylight Horizon Line Survey of the Astronomical Viewpoint Mirador De Las Ventas, La Palma, Spain
Light Pollution Documentation:
Light Pollution Documentation at the Endpoint of the Grossmugl Star Walk, Austria

Conclusion

The Theta S has tremendous potential for astronomical usage and is a definite "Buy!" for every astronomy and nature enthusiast. Besides, the app that comes with the cam will not be the end of the story. Ricoh provides a programming interface and information for third-party developers, so there are new interesting apps for the Theta S to be expected. But already today the camera opens up a whole new world for astronomy aficionados. Whether you want to shoot fun pictures at a star party, record an observing event, capture extended celestial scenes, survey observing sites or document light pollution, the Ricoh Theta S is a great investment.

The authors **Karoline Mrazek** *and* **Erwin Matys** *are founding members of the astrophotography group project nightflight. Check out their images, tests and tools at their* underline website.

For technical specs of the Theta S see appendix on next page.

Appendix - Ricoh Theta S Technical Data

Here is a compilation of the technical data on the Theta S that is relevant for astrophotography. It is based on information from Ricoh, various web resources and our own findings. This information is supplied without any liability.

Camera Size	13 x 4.4 x 2.3 cm	
Camera Weight	0.13 kg	
Lenses	f/2, f=1.31mm	Fixed aperture, fixed focus
Focus Range	10 cm ... infinity	
Sensor Type	CMOS	
Sensor Size	6.17 x 4.55 mm	
Bayer Matrix	RGBG	
Capturing	stills, videos	
Exposure Time	1/6400 ... 60 seconds	Star trailing begins to show in exposures > 30 sec
ISO Range	100 ... 1600	For astrophotography we recommend using 100 ... 400
White Balance	auto & several presets	The typical variety: Daylight, Cloudy, Tungsten, Incand...
Modes	auto, manual & others	For astrophotography we recommend manual mode
HDR Shooting	yes	Only in auto mode
Intervalometer	yes	Only with app, but with all modes
Self-timer	yes	Stand-alone and with app
Image Format Stills	JPEG	Equirectangular full-sphere panorama
Image Size Stills	5376 x 2688 pix	
Color Space Stills	sRGB	
EXIF Data	yes	
Videos	MP4, 1920 x 1080 pix	In our opinion not useable for astrophotography
Memory	built-in, 8GB	
Memory Capacity	approx. 1.600 stills	
Tripod Adapter	1/4" thread in base	
Image Transfer	USB, Wi-Fi	Images transferred via Wi-Fi are somewhat compressed
Power	built-in Li-Ion battery	
Charging	USB 5V	Camera can be used during charging

Customer reviews are available [here](#).