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ROWE-ACKERMANN
F/2.2 SCHMIDT ASTROGRAPH

Big! Fast! Wide! Sharp!

The Story of the Rowe-Ackermann Schmidt Astrograph

By Richard Berry and the Celestron Engineering Team

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1. Introduction

Astronomers building the mighty 200-inch Hale telescope on Palomar Mountain took an unprecedented step. In addition to the giant telescope, they included two additional telescopes: wide-field survey telescopes. First on the mountain in 1936 was the 18-inch Schmidt camera. It was a radically different instrument: a sharp, wide-field camera designed to survey the sky. With a focal length of just 36 inches, it covered a field 8.75° in diameter on a 6-inch "cookie" of photographic film. And its f/2 focal ratio meant that exposure times were short compared to any other telescope in the world.

Fig. 1: Using the Palomar 18-inch Schmidt camera, the innovative astronomer Fritz Zwicky proved the value of high-étendue survey telescopes to the stodgier scientists of his day. Courtesy of the Archives, California Institute of Technology

Cal Tech astronomer Fritz Zwicky promptly put the new Schmidt to work. Instead of zeroing in on tiny areas of the sky as astronomers had done traditionally, he mapped for the first time the full extent of clusters of galaxies, finding too little visible mass in the galaxies to hold the clusters together. Zwicky's investigations were the first hints that the Universe is dominated by dark matter and dark energy rather than the ordinary matter of stars, galaxies, and people.

Impressed by the success of the 18-inch Schmidt giant, astronomers began construction of a larger Schmidt in 1938, but World War II intervened, so it was not until 1948 that the 48-inch Schmidt and the 200-inch Hale telescope began nightly work. Although the 200-inch had an enormous light grasp, its field of view was minuscule. With it, an astronomer could photograph a single galaxy, take a spectrum of a single star, or construct an H-R diagram for a single globular cluster. Time on the 200-inch telescope was precious, tightly focused, doled out to a small, select cadre of astronomers.

In sharp contrast, the much smaller 48-inch "Big Schmidt" became, quite possibly, the most productive telescope on Earth. From 1949 until 1958, a sizable portion of the Schmidt's dark-sky time was devoted to making the first comprehensive photographic survey of the sky in two colors. With an aperture of 48 inches and a focal length of 120 inches, the Big Schmidt captured 6°×6° chunks of sky on 14-inch square glass plates. Each field was recorded in blue light and in red light, and after careful inspection, full-size photographic prints were distributed to subscribing observatories around the world. For a tiny fraction of the cost of a small professional telescope, the National Geographic Society-Palomar Observatory Sky Survey (or POSS for short) placed deep images of the entire northern sky at the fingertips of every working astronomer in the world.

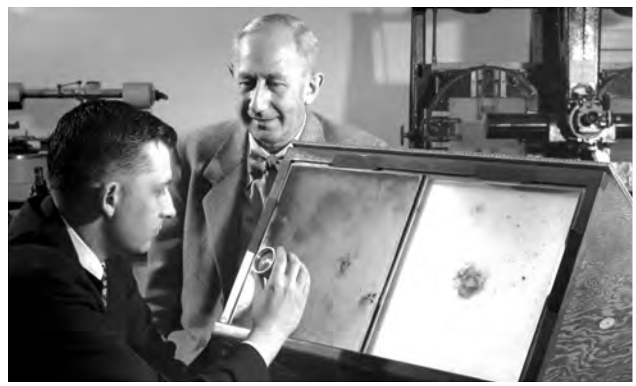


Fig. 2: The "Big Schmidt" served as a virtual finder telescope for an entire generation of astronomers. Its large glass plates were reproduced on paper and distributed to observatories around the world. Courtesy of the Archives, California Institute of Technology

Fast-forward to 1990. The Hubble Space Telescope is in orbit, CCDs have replaced photographic plates at ground-based observatories, and computers are ready and waiting to handle Big Data. New large telescopes have been built or are under construction at observatories in the Andes, the Canaries, and Hawaii – and cosmology has become the driving force behind astronomical research. Cosmology required surveying the sky again and again in search of supernovae to tie down the cosmic distance scale and calibrate the rate of expansion of the Universe. So too did the search for asteroids – their numbers building into the thousands and then tens of thousands – with their potential to deliver a civilization-ending impact. The need was also growing to monitor the number of artificial satellites and amount of space debris in orbit around the Earth. Comprehensive sky surveys provided the targets for the orbiting observatories and the great ground-based telescopes. What the world needed was a new generation of powerful wide-field survey telescopes, what the telescope designers and builders called telescopes with high étendue.

2.What is Étendue?

Among optical workers, étendue is a familiar concept: it is the energy flowing through an optical system. In a movie projector, for example, étendue is the product of the area of the lamp filament and the solid angle intercepted by the projector's condensing lenses. Because étendue is conserved in a system of lenses and mirrors, there is no way to increase the amount of light thrown on the movie screen by clever optical tricks; the only way to increase the light on the screen is a larger lamp filament or larger solid angle.

Although a telescope collects light rather than projects light, the principle is the same: the étendue is the product of the collecting area of the objective times the solid angle of light captured. The étendue, ε, is therefore:

$$\varepsilon = A\Omega$$

where A is the collecting area and Ω is the solid angle of the field of view. When evaluating the étendue of a large astronomical telescope, the collecting area is usually measured in square meters and the field of view in square degrees. Thus, étendue is measured in units of $m^2 deg^2$. For example, a telescope with a collecting area of one square meter ($A = 1 m^2$) that captures images that one degree on a side ($\Omega = 1 deg^2$) has an étendue of 1.00 $m^2 deg^2$. The 48-inch Big Schmidt had an étendue of 46 $m^2 deg^2$.

Étendue is a useful metric for survey-type telescopes because a large étendue requires that both the aperture and the field of view be large, or if one is small, the other must be very large. The hidden dimension in high-étendue telescopes is time: the time required to examine a tract of sky. The Palomar Observatory Sky Survey required exposing 936 pairs of plates (20 minutes for the blue plates and 40 minutes for the red) each covering a 6°×6° field of view – and took eight years to complete. If the Schmidt's aperture had been only 24 inches, reducing the area by a factor of four, the exposures could have been correspondingly lengthened, and the survey would have taken 32 years. To complete the survey with the same aperture but a 2°×2° field of view would have required 72 years (and would still be in process today). In short, the speedy (for those days) completion of the POSS was the result of the high étendue of the 48-inch Schmidt.

Of course, telescopes can do more than survey the sky. Many and perhaps most telescopes have been designed to zero in on specific selected star, quasar, asteroid, comet, supernova, or galaxy to make detailed images, measure brightness, or obtain a spectrum. What matters is a large light collecting area and sharp images; the telescope's narrow focus does not matter to the astronomer. Astronomical advances often come from studying relatively faint, rare, unusual, or transient objects and events. To find those objects or catch those events in progress, the lure of giant narrow-field telescopes was hard to resist. Not until the 21st century was well underway did astronomers recognize and fully embrace the need for deep, comprehensive surveys with high-étendue telescopes.

Technical Note about Étendue

As presented in this white paper, we have defined the étendue, ε , of a system as:

$$\varepsilon = A\Omega$$

where A is the collecting area and Ω is the solid angle of the field of view. However, this formulation fails to account for the sensitivity of the image sensor and the angular resolution of the optics. To include these factors, we write:

$$\varepsilon = A\eta\Omega \,/\, \mathrm{d}\Omega$$

where η s the quantum efficiency of the image sensor and $\mathrm{d}\Omega$ is the solid angle of one resolution element on the sky. While η for the best photographic emulsions was only about 3%, modern CCDs have broadband quantum efficiencies around 80%. The product $A\eta$ is the effective collecting area of the system, while the fraction $\Omega / \mathrm{d}\Omega$ is a measure of the total count of "spots" resolved on the sky by the telescope. To gather data rapidly, an astrograph needs a large collecting area over a large number of resolution elements.

For large survey telescopes, $\mathrm{d}\Omega$ is often limited by seeing, while short-focus wide-angle optics like the RASA are likely limited by pixel size. The classic photographic surveys were limited by the graininess of the photographic emulsions in use at the time. When the relevant factors are taken into account, today's CCD-equipped Oschin Schmidt is at least 100 times more effective than it was in the days of pre-digital photography.

3. The Era of High-Étendue Telescopes

"The Universe is so vast," thinks the astronomer, "and my telescope is so small." The job of the growing number of survey instruments is to inventory the contents of the Solar System, our Galaxy, and the Universe. Asteroids in particular pose a potential danger to our planet. Well over 250,000 are currently known, and still more that are 100 meters or more in diameter – civilization killers – have yet to be found. Among stars, it's those with planets that hold particular interest. These systems are to be found by watching millions of stars for the few telltale hours when a planet blocks a tiny bit of starlight. To gauge the expansion of the Universe, astronomers patrol for rare supernova explosions that serve as "standard candles" for calibrating distance and cosmic expansion.

To spy out such elusive quarries, a telescope must have a large aperture to see faint objects, a short focal length to match the pixels on a CCD sensor, and it must produce sharp images over a wide field of view: in short, it must have high étendue. Table 1 lists a sample of current sky surveys. Perusing this list we find the 48-inch Oschin Schmidt equipped with the massive Zwicky Transient Factory camera with sixteen 36-megapixel CCDs covering a total of 47 square degrees. Although the Oschin Schmidt is one of the smaller instruments, its wide field coverage means that every night it snaps hundreds of deep images that are searched immediately by computer for "transients" – that is, anything that's changed since the previous night.

Even more powerful is the Vera C. Rubin Observatory, which houses the Simonyi Survey Telescope, in the Chilean Andes. With an 8.4-meter primary mirror and covering a field of view 3.5 degrees across (9.6 square degrees) and a camera with 189 16-megapixel CCDs for a total of 3.2 gigapixels per exposure. Each night it produces 30 terabytes of data that is processed immediately and made available to the world.

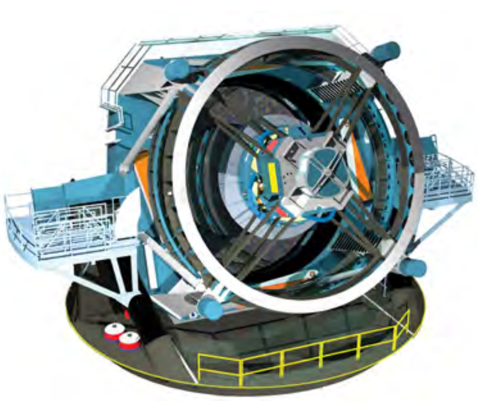


Fig. 3: The Simonyi Survey Telescope at the Vera C. Rubin Observatory surveys the entire sky twice a week over and over again, turning up thousands of potentially interesting objects every night it operates.

Table 1: Wide-Field Sky Surveys

Survey Telescope	Effective Aperture (meters)	Ω (deg^2)	Étendue $A\Omega$ (m^{2}deg^2)
USAF Linear	1.0	2.0	1.5
Catalina Schmidt	.68	9	3.6
Sloan Digital Sky Survey	2.5	3.9	6.0
CFHT Megacam	3.6	1	8.0
SUBARU-SuprimeCam	8.1	0.2	8.8
ATLAS Project	1.0	54	42
Oschin-ZTF	1.2	47	56
Pan-STARRS	3.7	7	60
LINEAR Space Surveillance Telescope	3.5	6	70
Simonyi Survey Telescope at Vera C. Rubin Observatory	6.5	9.6	319

4. Richest-Field Telescopes: Étendue for the Amateur Astronomer

Scouring the sky for elusive objects has long been one of the preoccupations of the astronomical amateur, tyro and expert alike. Charles Messier, that tireless 18th century seeker of comets, found 13 comets and more than a hundred faint, non-cometary glows in the heavens, the "Messier objects" we know now as galaxies, star clusters, and nebulae. Caroline Herschel, sister of the astronomer William Herschel, and an astronomer in her own right, found at least seven comets using a special short-focus, low-power telescope known as a "comet seeker." Comet seekers, or "richest-field telescopes", are the visual observer's equivalent of the high-étendue astrograph. They combine a short focal length, large objective, and low-power eyepiece to deliver the highest concentration of light to the retina of the observer's eye. This enables the seeker of comets to survey many fields quickly by sweeping the sky looking for the out-of-place, slow-moving fuzz-ball.

The 19th century ushered in the search for asteroids. On Jan 1, 1801, Giuseppe Piazzi spotted asteroid (1) Ceres, triggering a race among both amateurs and professionals to find more "minor planets" orbiting between Mars and Jupiter. In 1891, professional astronomer Max Wolf began photographic searches for comets, asteroids, novae, and whatever else was new in the sky using a 16-inch f/5 astrographic reflector that had, for its time, a remarkably high étendue. His efficient searches and surveys churned up stars with high proper motion, supernovae, dark nebulae, and many faint emission nebulae, leaving the amateur asteroid-seekers far behind.

As astronomy grew as hobby, however, the easy-to-use Schmidt-Cassegrain dominated astroimaging despite a low étendue. The classic SCT had a slow f/10 focal ratio and small field of view. For visual observers, however, the Dobsonian revolution ushered in an era of high étendue deep-sky exploration. With apertures starting around 12 inches extending upward of 36 inches combined with focal ratios of f/4 to f/5 and short-focus low-power wide-field eyepieces, the visual observers searched out and viewed many previously difficult deep-sky objects. The visual deep-sky revolution inspired, in turn, renewed interest in deep-sky imaging, and the introduction of new high étendue astrographs for amateur astronomy.

5. Celestron's Schmidt, Fastar, and HyperStar

The value of Schmidt cameras had long been evident to amateur and professional astronomers alike. In the 1970s, Celestron introduced two Schmidt cameras for use with 35mm photographic film. The first had an aperture of 5.25 inches and a focal ratio of f/1.65, and the second an aperture of 8 inches with a focal ratio of f/1.5. In the 8-inch version, each exposure covered a 4.5° × 6.5° field of view. At these very short focal ratios, deep-sky images could be captured on fine-grain films in a mere 30 minutes! These cameras took advantage of Celestron's ability to manufacture the tricky Schmidt corrector plate at an affordable price. In a Schmidt camera, the focal surface is curved and the images are formed inside the tube halfway between the corrector plate and the primary mirror. A special film holder that gently bent the film to the correct curvature was suspended on spider at the proper location. Although cutting, inserting, and developing small "chips" of film had to be performed in complete darkness, more than a few amateurs became proficient in these manipulations, taking splendid wide-field deep-sky images on super-fine-grain film known as Kodak Tech Pan.

Fig. 5: Celestron's 8-inch f/1.5 Schmidt camera gave amateurs access to fast, sharp, wide-field astrophotography on Kodak's remarkable Tech-Pan film. Photo by Kent Kirkley.

In the amateur world, in the 1990s, as film gave way to smaller but more sensitive CCDs, Celestron introduced another forward-looking product: the Fastar camera. The Fastar was a hybrid instrument created by removing the secondary mirror from a standard C8 Schmidt-Cassegrain and replacing it with a system of lenses mounted on the corrector plate. Celestron's image sensor was a CCD camera: the PixCel 255. By 1999, the original PixCel was obsolete, and replaced by SBIG's ST-237 CCD camera. With a focal ratio of f/2, the Fastar system was as fast as a Schmidt camera, allowing amateurs to reach sky-limited exposures in just a few minutes. But the CCDs of the day were very small: the PixCel 255 had a 320 × 240 pixel array, and the ST-237 had a 640 × 480 array measuring 4.7 × 3.6mm and covering a field 40 × 30 arcminutes on the sky (this was considered "wide-field" in its time).

Fig. 6: The 8-inch f/2 Fastar carried a PixCel CCD camera ahead of the corrector plate. In a fast telescope, it turns out that the best place for a compact image sensor is at the prime focus.

When Celestron discontinued Fastar, they did not abandon the idea of a wide-field camera at the prime focus of their Schmidt-Cassegrain. Celestron continued to make SCTs with removable secondary-mirror assemblies, and they passed the baton to the Starizona HyperStar. Unlike the small-sensor Fastar, HyperStar was designed to cover a fairly sizable 27mm diameter field found in APS-C digital SLR cameras at a focal ratio near f/2 on HyperStar-compatible C6, C8, C9.25, C11, and C14 SCTs. Starizona provides conversion kits for non-HyperStar SCTs and camera adapters for a wide variety of CMOS, DSLR, and mirrorless cameras.

Fig. 7: The Starizona HyperStar worked extremely well with APS-C DSLR cameras. By combining fast optics, short focal length, and a wide field, it paved the way for the Rowe-Ackermann Schmidt Astrograph.

Although Fastar was first, it fell to HyperStar to introduce fast, wide-field imaging to amateur astronomy. In the decade since its introduction, Hyperstar carved a niche for short-exposure wide-angle, deep-sky imaging. But HyperStar was an add-on component rather than a fully integrated part of the system. Forced to meet constraints imposed by a pre-existing corrector plate, primary mirror, component spacing, hole diameters, and mounting points, it was a necessary compromise solution. Would a dedicated optical design provide bigger fields, sharper stars, less vignetting, and greater mechanical stability?

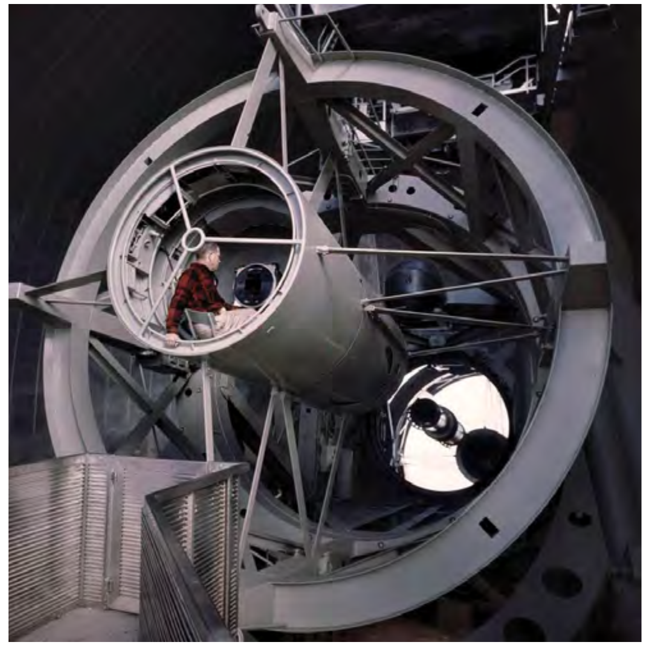


Fig. 8: Back in the days of the Hale 5-meter telescope, the observer photographed the sky from the prime focus. Today, on amateur astronomers' telescopes, a CMOS camera occupies prime focus. Photo: LIFE

6. The RASA Is Conceived

The name of the Rowe-Ackermann astrograph acknowledges David Rowe and Mark Ackermann, the two astronomer/inventors who conceived and refined its optical design. Back in 2012, Rowe had been consulting for Celestron, so he had met regularly with Celestron's product gurus. "I told them I thought they should offer a telescope like a Schmidt camera with a flat focal surface," Dave says, "but I felt that it absolutely had to have the image outside the telescope tube."

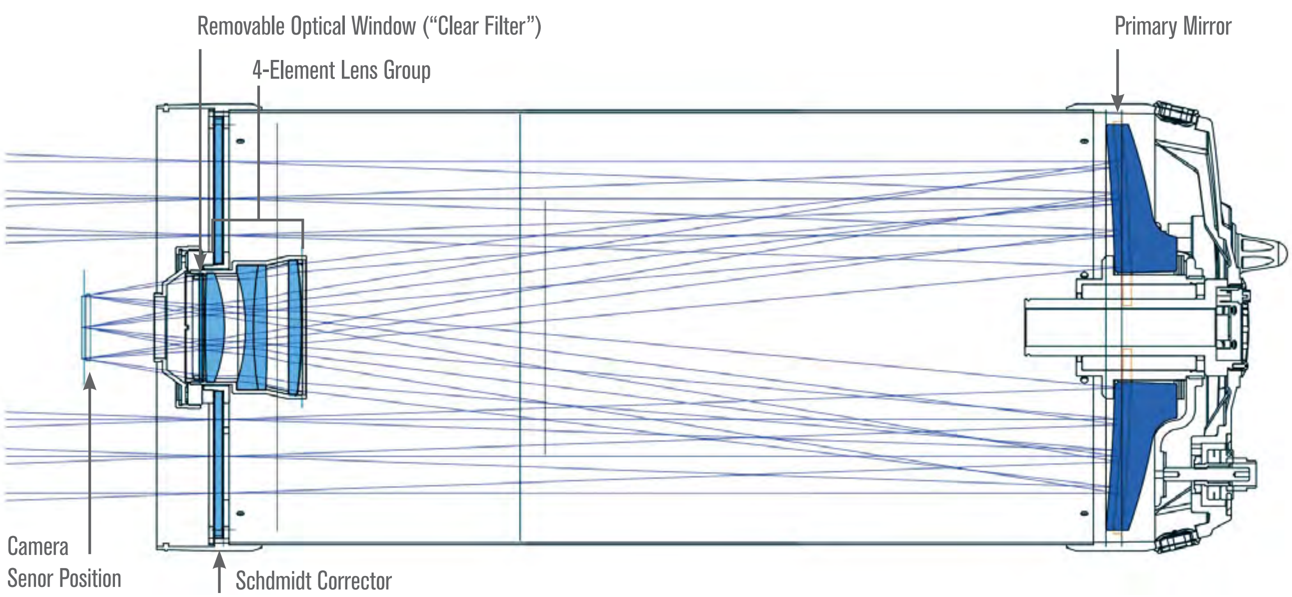


Fig. 9: Celestron's Rowe-Ackermann Schmidt Astrograph consists of a Schmidt corrector plate, primary mirror, and a four-element corrector lens. Light enters from the left, passes through the corrector plate to the primary mirror, then reflects back through the corrector lens and comes to focus in front of the corrector lens.

Matrix Spot Diagram (18 µm box size)

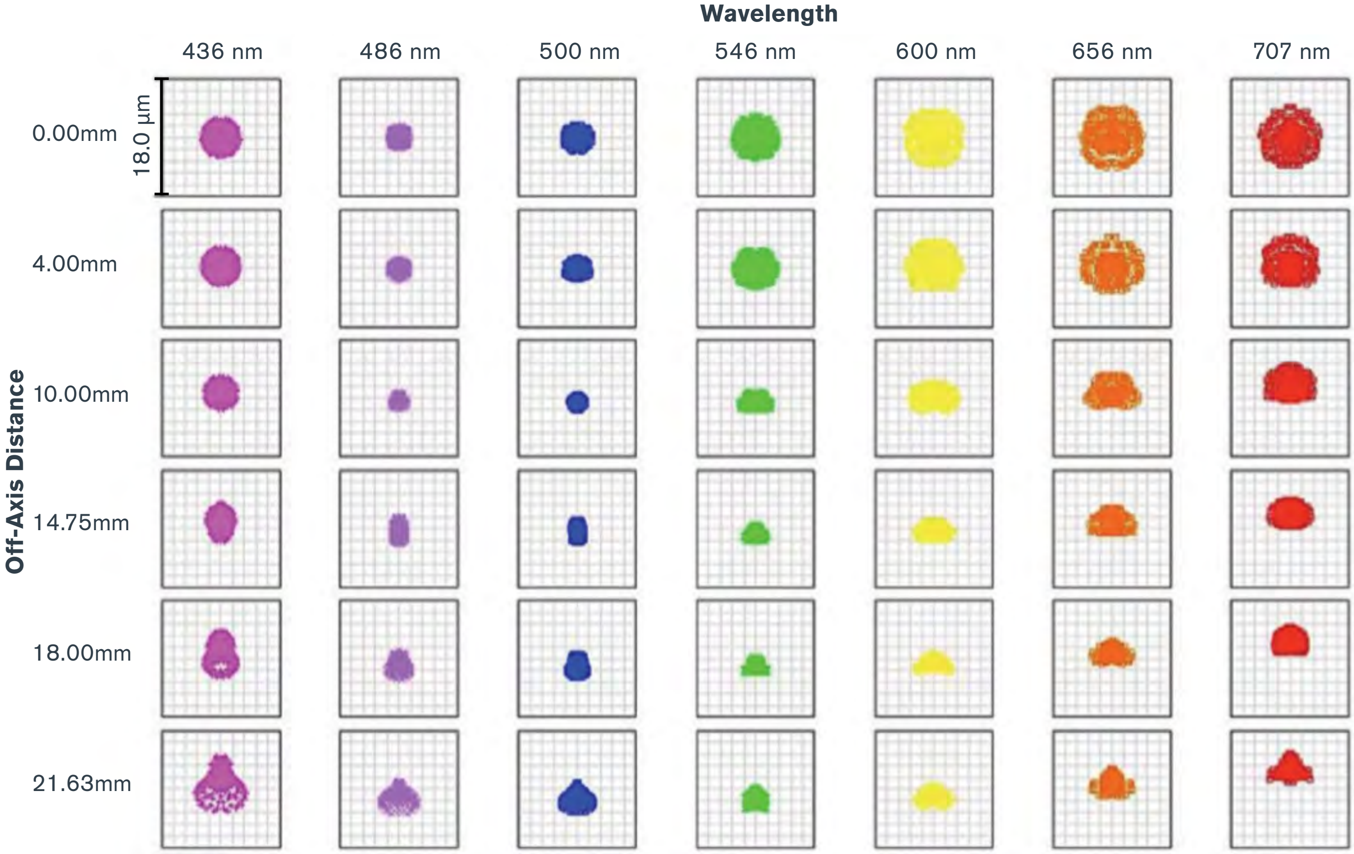


Fig. 10: The RASA's matrix spot diagram reveals that it forms remarkably tight star images across the entire visible spectrum from deep violet (430 nm) to near infrared (700 nm), from the center of the field to more than 21mm off axis. In practice, a field of view 52mm diameter is practical. The boxes are 18 microns on a side.

In the classic Schmidt camera, the image is formed inside the tube halfway between the corrector plate and the primary mirror. "There are all sorts of problems putting a CCD camera inside a closed tube, and with most DSLRs it would not work. Although a diagonal mirror like a Newtonian's diagonal sounds like a good idea, it's just not practical. The Schmidt is so fast that the diagonal has to be huge, and it blocks way too much light."

Rowe fired up his computer and started kicking around ideas. Placing a two-element correcting lens just ahead of focus would flatten the curved field of the classic Schmidt camera, but the focus was inside the tube. By placing the focus in front of the corrector plate, as Hyperstar did, the focus fell outside the tube. "I discussed it with Corey Lee and Eric Kopit at Celestron, and we all felt that an 8-inch astrograph was too small for a DSLR. The camera body would block too much light. The design had to be based on standard 11-inch SCT optics." Rowe went back to his computer and began tracing rays through the optics in search of a good solution.

A month later, he had a design consisting of a Schmidt corrector plate, a spherical mirror, and a three-element correcting lens with the focus in front of the corrector plate. To get the best performance, however, the design required a corrector plate with more optical power. "Celestron did not want to change the corrector," Rowe noted, "because they mass-produce corrector plates that are perfect for their SCTs. Instead, they suggested I should see what I could do with their C-11's standard corrector plate and a different spherical mirror." A mirror with a longer radius of curvature would be straightforward to produce using the same glass blanks as the regular C11 SCT. Retaining the standard corrector plate would keep the cost to the consumer down and also guarantee excellent optical quality.

"So I worked up a new design that used a longer primary mirror, the standard C11 corrector plate, with a three-element correcting lens using common glass types. It produced a well-corrected 43mm field at f/2.2 with a 55mm back focus distance compatible with DSLR cameras, and I left it at that."

A year later, Dave walked into Celestron's offices to find they had a working prototype of the RASA!

Unknown to Dave, Celestron had asked Mark Ackermann (Sandia National Laboratories, University of New Mexico) to look over the design. "It was Dave's idea," said Mark, "and when Celestron asked me to design a production version, I took on the project." An amateur astronomer by night, by day Mark is an expert on space surveillance systems. Used to thinking about apertures measured in meters, Mark was intrigued by Dave's small-aperture, high étendue design: it might turn out to be ideal for surveilling space debris and fast-moving satellites in LEO (low Earth orbit), tasks best accomplished by large numbers of small telescopes.

"I pushed the design outside the original box," he mused, "I optimized it to cover a wider spectral range – the whole visible spectrum from 400 nm to 700 nm – and specified that the correcting lens have four elements rather than three, and I employed special low-dispersion optical glass for sharper star images. For a small increase in the cost of manufacture, we got star images smaller than 4.5 microns RMS everywhere in a field 43.3mm across." In addition, Ackermann increased the diameters of the optical elements to reduce internal vignetting. "It's a university-quality system," he said, "a system with lots of capability at a very attractive price point."

7. How the RASA Works

The RASA is a modification of the Schmidt camera, the optical system in the pioneering 18-inch and Oschin Schmidt cameras, adapted to modern high-sensitivity CMOS sensors. Schmidt cameras are based on an optical property of spherical mirrors: that light passing through the center of curvature of the mirror forms an equally good image regardless of the direction of the incoming light. This means that spherical mirrors can form images over a wide field of view, but spherical mirrors do not bring incoming rays from a given direction to a perfect image. The Estonian optician Barnard Schmidt realized, however, that by placing a thin lens at the center of curvature, he could "tweak" the incoming rays to converge to make an excellent image.

Schmidt's thin lens, the "Schmidt corrector plate," is a weak positive lens in the center and a weak negative lens at the edges. Schmidt not only recognized the principle, but he also worked out a way to grind and polish the glass surface of the lens to a polynomial curve. The spherical mirror formed its images inside the tube halfway between the corrector plate and the spherical mirror, and a photographic film held at that location captured the image. A decade later, the Schmidt camera had begun to revolutionize observational astronomy.

Fig. 11: The Schmidt corrector plate is not a simple optical window, it is actually an aspheric lens. Celestron's founder, Tom Johnson, revolutionized the manufacture of this optical element with his patented process, and the Schmidt corrector in the RASA is made in this same way.

As the 21st century began, film became obsolete. It was either inconvenient or impossible to place the bulky electronic package around the digital sensor inside the tube. As Dave Rowe had recognized, the best place to put the camera was at the front of the optical tube. With careful design, the camera would block very little light, and optically, at least, it was the best design solution.

When the RASA is pointed at the sky, light rays from each star arrive traveling in parallel paths. As they pass through the Schmidt corrector plate, the rays receive a small refractive tweak so that after they have been reflected from the spherical primary mirror, they converge to focus to a star image. As the rays approach focus, they pass through the four-element lens assembly. On-axis rays are barely affected, while off-axis rays are refracted slightly to form tight, clean star images. By design, the RASA's star images are formed on a plane surface ahead of the RASA, where the image sensor is located. The sensor captures and stores the photoelectrons generated by each star's light until, at the end of the exposure, they are read out, converted to a digital signal, and transferred to your computer.

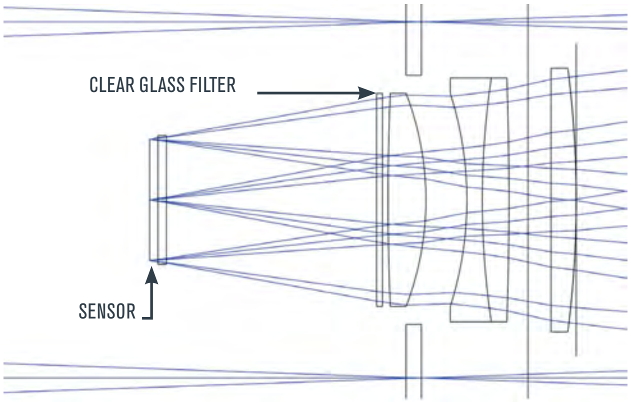


Fig. 12: This geometric ray trace shows how light from the RASA's correcting lens travels to focus on the sensor. Note that any obstruction in the space between the clear glass filter and the sensor blocks light and results in vignetting.

8. The RASA is Born: Manufacturing a Breakthrough Product

To bring out the RASA as a practical instrument for the amateur market, Celestron's optical and mechanical engineers faced some tough challenges. Although broadly similar to the Celestron Fastar models, the RASA had significant differences. The radius of curvature of the primary mirror was longer than that of a standard SCT. The tube would therefore be longer. Although the corrector plate was the same as the standard Celestron SCT, it was required to support a hefty four-element correcting lens assembly inside the tube, and outside the tube it needed a mounting for the adapter that would hold a camera. The fast focal ratio also meant that the depth of focus was much narrower than F/10 designs, which is more demanding of the focuser mechanism to prevent the optical system's potentially pinpoint star images from appearing out of focus.

"We worried a bit about supporting the weight of the correcting lens and a camera on the corrector plate," said Celestron's Eric Kopit. "So we did a test. We set up a corrector plate and hung heavier and heavier weights on it." The corrector plate finally failed when it had been loaded with 80 pounds. "After that," he said, "we did not worry."

"We improved the primary mirror focusing system by improving tolerances and using different materials," said Kopit. "The new system works on the same principles as that in the EdgeHD tubes," he said. "But because we didn't need a hollow Cassegrain baffle tube, we could use a tube with thicker walls, which permits a more consistent fit tolerance." Also, the surface that the primary mirror "slider" moves on is brass, rather than aluminum, which provides a smoother bearing.

In 2020, Celestron released a V2 of the RASA 11-inch, which utilizes a redesigned focuser, called the Ultra-Stable Focus System (USFS). This revision to the focuser's mechanical design further minimizes both

Fig. 13: The optional Celestron Focus Motor is compatible with the RASA 11-inch focuser.

focus shift and mirror flop. At the heart of this system is a precision linear ball bearing, which rides on a high-precision steel shaft; the linear ball bearing essentially replaces the brass slider from the original focuser. With the new USFS design, the motion of the primary mirror is better constrained and unwanted lateral motion is further minimized.

The RASA is focused by rotating the focus knob, which moves the primary mirror. The focus knob is compatible with the Celestron Focus Motor, thus providing a convenient solution for both precise and motorized focusing. The focus motor also allows observers to focus the RASA remotely. "In many search-based observing programs," Kopit noted, "a RASA would be in use all night, every night, so remote focusing capability is not a luxury, but really a necessity."

For best performance, cooling optics inside the optical tube is also a necessity. Kopit explained, "Putting a cooling fan in the Cassegrain location at the base of the tube made a lot of sense. The fan pulls air down the tube so it flows around the primary mirror. We reengineered the vent mesh to optimize airflow." During an observing session, the fan would normally be run continuously so the tube and optics are always in equilibrium with the ambient air.

Fig. 14: The 12VDC MagLev fan along with improved venting allows for good airflow within the optical tube. This helps cool the telescope to ambient temperature.

Fig. 15: All RASA primary mirrors are tested on an optical bench by means of laser interferometry. In the picture, stacks of polished primary mirrors await testing.

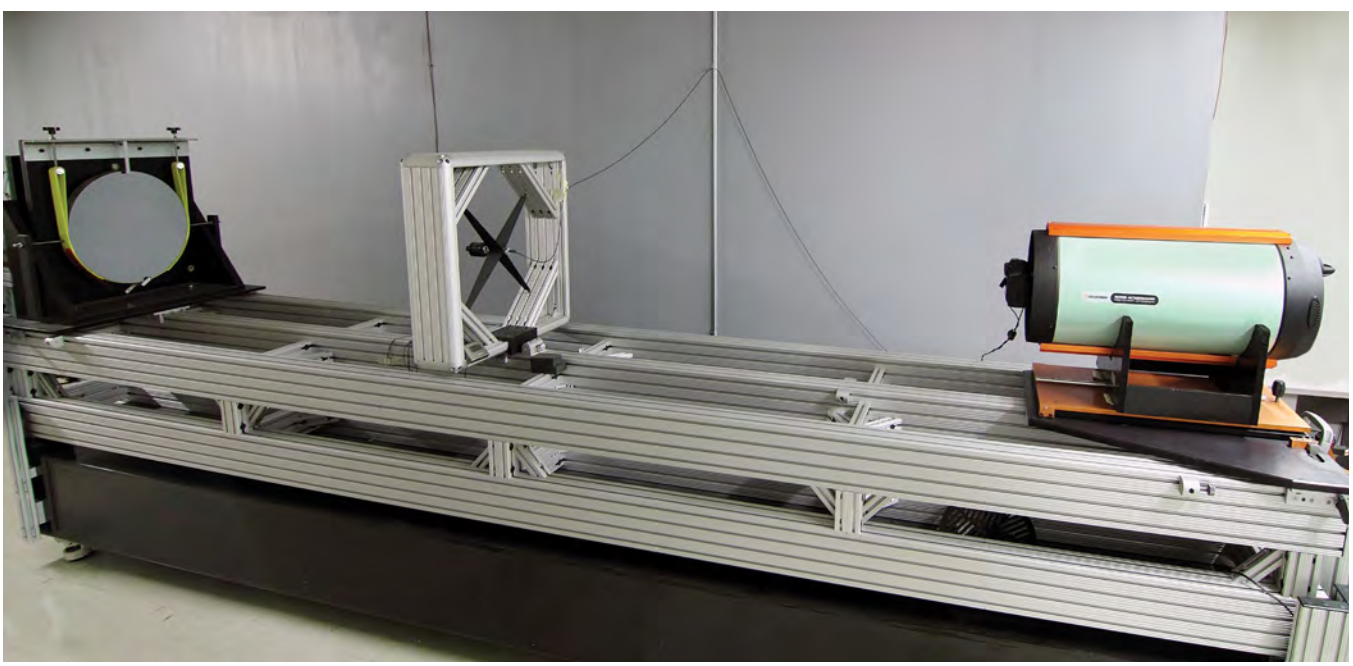
Manufacturing the optical system was also a new experience for Celestron. "In our standard and EdgeHD SCTs, we make the corrector plates and primary mirrors as accurately as possible, but there are always slight variations. So we set up the primary and corrector plate in a test stand and hand-figure the secondary mirror to attain diffraction-limited imagery," explained Kopit. "The RASA is a different ballgame. We test the primary mirror with an interferometer, so it is bang on. We test each of the eight surfaces in the correcting lens assembly using match plates, so they are well within a tight tolerance."

With everything meeting tight tolerances, there's nothing left to match. "The RASA uses the same Schmidt corrector plate as the EdgeHD, but the EdgeHD corrector plates are hand-matched in the finished telescope by making small corrections to the secondary mirror. Because the RASA does not have a secondary mirror, the RASA design cannot be matched in this way. Instead, we set aside those Schmidt corrector plates that our testing shows will give the best performance in the RASA," he said. In this respect, manufacturing the RASA is more like manufacturing a high-quality camera lens than making a telescope: because each component meets tight specifications, hand matching becomes unnecessary.

The housing for the correcting lens assembly is a case in point: "We machine the metal barrel to very tight specs, and hold lens diameters and thicknesses to close tolerances," Kopit noted. Finally, the primary, corrector plate, and correcting lens assembly are installed in an optical tube and aligned using a laser fixture.

Before it can leave the factory, every RASA must pass its Final Acceptance Test. This test is carried out on an optical bench. In fact, it is the same fixture Celestron uses to test its EdgeHD SCTs. "We use a camera with a full-frame sensor. We focus on an artificial star image at the center of the field," Kopit explains, "then point the RASA being tested so the image falls in each of the four corners of the frame. The center and all four corner images must be virtually identical." If the corner images

Fig. 16: The Final Acceptance Test ensures that every Rowe-Ackermann Schmidt Astrograph leaves the factory aligned and producing tight, sharp star images across the full field of view.



are not as sharp and tight as the center image, the tilt of the correcting lens assembly is adjusted so the on-axis and off-axis star images appear sharp at the same focus point. "When a RASA leaves the factory, it's in good alignment," said Kopit. "Although the user can adjust the tilt of the correcting lens assembly, it's usually not necessary."

9. The RASA as a High Étendue Optical System

Astronomers measure the flux gathering capability of an optical system using a parameter known as étendue. Étendue, designated by ε, the product of the collecting area of the optical system, A, times the field of view of the image sensor, Ω, that is, $\varepsilon = A\Omega$. A telescope's étendue is an effective measure of its power to both gather light and survey the sky.

How do telescopes commonly used by amateur astronomers compare for deep-sky imaging? In Table 2, you will find a list of astrographic telescopes used by amateur astronomers for deep-sky imaging, and for each system, the aperture, focal length, the field of view covered by a full-frame 36mm × 24mm sensor, and the calculated étendue of the system.

Table 2: Étendue of Amateur Astronomers' Telescopes

Telescope	Aperture (mm)	Focal Length (mm)	Area Coverage* (deg^2)	Étendue** cm^2deg^2
36 cm RASA	356	790	9.506	10120
11-inch RASA	279	620	7.380	4779
10-inch Imaging Newtonian	250	1000	2.837	1662
6-inch Imaging Newtonian	150	750	5.043	1064
FSQ 106ED	106	530	10.099	1135
TSA 102S	102	610	7.624	793
AT 115EDT	115	805	4.378	579
10-inch Ritchey-Chretien	250	2000	0.709	395
11-inch Edge HD	279	2788	0.365	253
Classic C8	203	2032	0.687	252
14-inch Edge HD	356	3857	0.191	242

* Coverage in square degrees for a 36mm x 24mm "full frame" sensor, except 14-inch RASA, with 49.1mm x 36.8mm KAF-50100 sensor.

** Étendue is measured in cm^2deg^2. Aperture area has been corrected for central obstruction. To convert to m^2deg^2, divide by 10,000.

The RASA's winning combination of large aperture and wide field of view place it at the very top. Below the RASA are imaging Newtonians equipped with a coma correcting lens; they rank high because they offer generous aperture plus a moderately wide field. Although apochromatic refractors may offer a wide field of view, their small aperture means they lack the RASA's light-gathering power, resulting in multi-hour exposure times. Traditional Ritchey-Chrétiens and Schmidt-Cassegrain telescopes afford plenty of light-gathering power, but their long focal lengths and resulting high focal ratios dictate much smaller fields of view. Neither aperture by itself nor field of view alone can produce an instrument with high étendue. The RASA's unique combination of large aperture plus wide field of view places it at the top of the list.

The choice of image sensor is therefore critical in high étendue imaging. The physical dimensions of the camera's sensor determine the angular field of view and therefore control the étendue of the system. If you use the RASA with a small sensor, the result is a lower ability to search and survey the sky – but you still have the full benefit of the RASA's large aperture and fast focal ratio. And, as desirable as a large sensor might be, larger sensors cost more than small sensors. Because the 11-inch RASA offers so much optical capability at such a low price, it is hardly surprising that "big-chip" cameras able to exploit the RASA's full capacity and capability often prove to be more expensive than the RASA itself.

10. Adapting Image Sensors to the RASA

In an ideal world, it would seem a simple task to locate an image sensor at the focal plane of the RASA. In the real world, it's a bit more complicated. The image sensor must be solidly mounted in the correct place, and light from the RASA needs to travel from the correcting lens assembly to the sensor without being blocked. Potential difficulties occur when the structures that support the image sensor intrude, preventing light from reaching the sensor, and resulting in vignetting that can range from mildly annoying to quite severe. To interface the image sensor optimally, think of the external volume between the RASA and the sensor as a "Do Not Obstruct" zone.

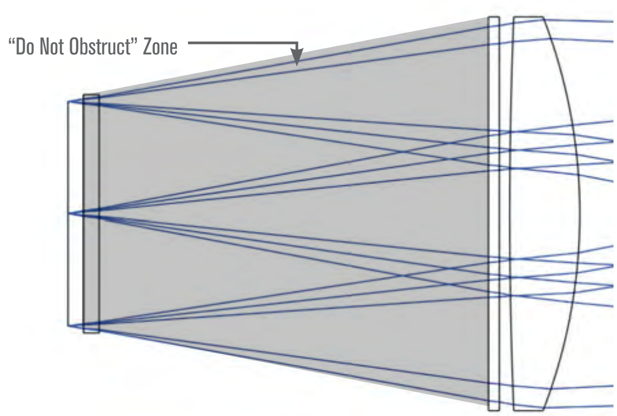


Fig. 17: The "Do Not Obstruct" zone is the region between the corrector lens and the image sensor. Anything that obstructs light passing through this volume causes light loss.

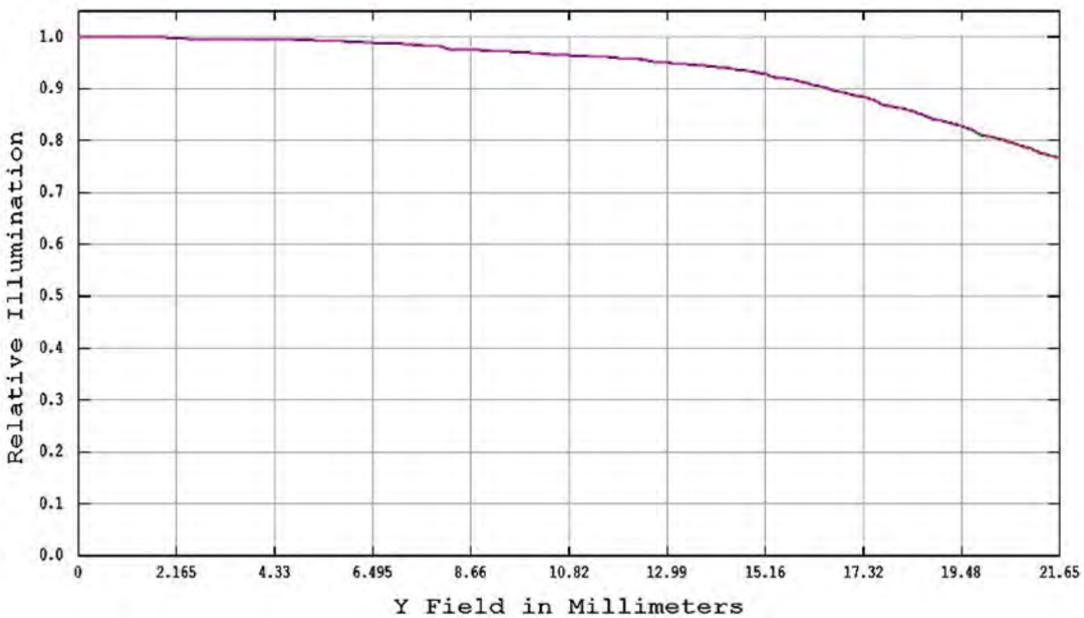


Fig. 18: With no external obstructions, the RASA displays a smooth and modest light loss to vignetting, amounting to 23% in the corners of a full-frame sensor. External obstructions will produce a sharp drop in the right-hand side of the curve.

“Aesthetic Imaging” with the RASA

What does the RASA offer you that other astrographs with the same focal length don’t offer? The RASA gives extremely sharp images across a wide, flat field of view. The same is true of a high-end apochromatic flat-field astrograph. An imaging Newtonian with a coma corrector provides acceptable performance over most a full-frame format, too. The RASA’s color correction might be a bit better, and its off-axis images a touch sharper, but in the end, any optic with a 620mm focal length is an optic with a 620mm focal length. Isn’t that right?

We invite you to carry out an experiment with your DSLR camera and a good-quality camera lens with a 28 to 55mm focal length. We suggest using the same lens you use for taking wide-angle pictures of the Milky Way. Place the camera on a tracking mount, select an ISO setting of 1600, and set the lens to f/2.5. (Although the RASA is f/2.2, its central obscuration makes it slightly slower. This is called the “T-number;” it’s just like an “f-number,” but it also takes optical transmission into account. The RASA is T/2.5.) Focus carefully, and then take a 60 second exposure. You will capture splendid picture showing star clouds, clusters, nebulae, dark rifts – and your picture will be fully and properly exposed.

Now repeat the process, but this time set the focal ratio of your camera to the focal ratio of your favorite imaging telescope. Give your optics the benefit of the doubt, and don’t correct for their central obscuration. For a typical imaging Newtonian, try shooting at f/4.5, for the apochromatic astrograph, take your pick among f/5, f/6, and f/7. For the Ritchey or the SCT, set the aperture to f/8, f/10, or f/11. Make the same 60-second exposure. You will have a picture that may be sharp, it may be well tracked, but it will definitely be underexposed. You can compensate, but an ISO setting of 6400, 12800, or 25,600 just don’t give you the noise-free picture you hoped for. What to do?

Obviously, you can increase the exposure time. Try exposures of 120 seconds, 180 seconds, 300 seconds, and 600 seconds. You will find it takes 180 seconds at f/4.5 to get the same full exposure you got at f/2.5. At f/5.5, you need 300 seconds to reach full exposure, and at f/10, you’re in for a 15 minute exposure time. In other words: the focal ratio matters.

This RASA 11” image of the Heart Nebula (IC 1805) was taken by Jimmy Walker, using an FLI Microline 11002 color camera. The image comprises of twelve 5-minute exposures stacked together.

When you put a good-quality DSLR at the focus of the 11-inch RASA, you can cruise around the sky shooting nicely exposed images of the famous deep-sky objects in 60 seconds. You don’t even need to guide! Drop the ISO setting to 400, get good polar alignment, expose for five minutes, and you’ll get a deep, grain-free image of almost any deep-sky object you can name. Go for broke and shoot a dozen five-minute exposures, stack them, and you have an image that would have taken three hours to capture with an f/4.5 optic, five hours with an apochromatic refractor, and two entire nights with the conventional R-C astrograph or SCT.

That’s what the RASA really offers the aesthetic deep-sky imager: efficient and effective use of the limited number of clear nights you get under a dark sky. The RASA’s extraordinary light-gathering power – the combination of a fast focal ratio and a large aperture – puts lots of photons on the focal plane for your image sensor to capture. The RASA cannot do more than other optical systems of the same focal length and field of view, but it can do the same thing much faster. Five minutes with the RASA gets you an hour’s worth of light collected by a top-of-the-line apochromatic refractor. And RASA images are tight, sharp, and free of color everywhere in the full-frame format field.

Internally, the RASA's optical system exhibits mild vignetting. After passing through the corrector plate, a small amount of off-axis starlight misses the rim of the primary mirror, and another small amount of light converging toward the correcting lens assembly gets clipped by the correcting lens housing. This vignetting is part of the RASA design; it falls off smoothly and is readily countered by standard flat-fielding methods. Even at the corners of a full-frame sensor (21.65mm off-axis), vignetting amounts to a modest 23%. Figure 18 graphs the RASA's smooth "native" vignetting profile.

The location of the image sensor is external to the RASA optics and its placement should satisfy three conditions:

1. The sensor must be 72.8 ± 1mm from the tilt collar on the RASA.
2. The sensor should be perpendicular to the optical axis of the RASA to 0.01° or better.
3. Light rays from the RASA optics should reach the sensor without encountering any obstacles.

The first two conditions are fairly easy to satisfy. If the components of the adapter are machined from metal, the necessary distance is a matter of design, and perpendicularity is assured by the machining process. The RASA end of the adapter should be similar to that of the adapters supplied by Celestron with every RASA, and the sensor end should be threaded, or have a dovetail or bayonet mount matching that of the camera body that holds the sensor.

The third condition is considerably more difficult to meet. At f/2.2, the light cone from the RASA's optical system is wide where it exits the correcting lenses, so the skinny cylindrical extensions typical of the adapters on refractors and SCTs simply will not do. Instead, the inside of the adapter should be as open as possible to avoid blocking light and causing vignetting; it should take the form of a squat, stout cylinder or broad, truncated cone.

The following points summarize adapter types for major camera and sensor types:

A. DSLRs

DSLR camera bodies have a built-in obstruction that is impossible to change: the reflex mirror. The mirror is housed in a deep, narrow structure called the "mirror box". Standard camera lenses sit immediately in front of the mirror, so light from the lens diverges and avoids being blocked by the mirror. In contrast, RASA's broad converging light cone is clipped on all four edges, and most strongly clipped along the side with the reflex mirror. Celestron provides two DSLR-oriented adapters with each RASA.

B. MILCs

Mirrorless interchangeable-lens cameras have no mirror; instead, the sensor is read out continuously and displayed on a screen on the camera body. Because there is no mirror, the camera body can be thinner, and can provide much more open access to the image sensor. MILCs can be mounted on a RASA using standard adapter (with some vignetting) or custom adapters (with little or no vignetting).

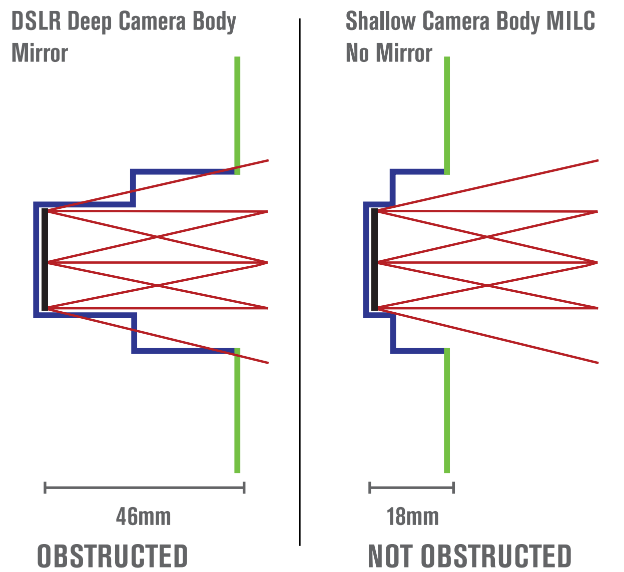


Fig. 19: The DSLR, with its deeply recessed sensor and obstructing mirror box, will block some of the RASA's light from reaching the edges of a full-frame sensor. The MILC does not have this problem.

C. Astronomical CMOS Cameras

Without a doubt, cameras designed for long-exposure deep-sky astronomy most fully exploit the RASA's potential. They offer the highest quantum efficiency, the lowest noise, and the best options for dark current subtraction and flat-fielding. Astronomical CMOS cameras are available in both monochrome and one-shot-color formats. CMOS cameras with relatively small sensors can be mounted using Celestron's standard DSLR adapters. If you have a CMOS with a sensor larger than 16mm diagonal, use it with a custom adapter. If the image sensor is mounted near the front of the camera housing, you should be able to obtain an adapter that causes little or no external vignetting.

Celestron includes two general purpose adapters with each RASA. One adapter is for T-system cameras. Many cameras use the T-system: a standard 42mm × 0.75mm female thread with a standard 55mm flange-to-sensor distance. The adapter has a matching 42mm × 0.75mm male thread. Any T-system camera mounted on the adapter will be at the correct back-focus distance. However, the small inside diameter of the T-system barrel intrudes into the “Do Not Obstruct” zone and prevents some light from reaching the corners of the image sensor.

The second Celestron adapter is similar to the T-system adapter, but has a “T-wide” 48 × 0.75mm (M48) male thread. The larger diameter opening reduces, but does not entirely eliminate, vignetting from the adapter.

Other standard adapters including T-mount, T-wide, T-to-C, and C-mount, as well as adapters for specific astronomical CMOS cameras are available from astronomical equipment dealers.

For custom adapters, consult the manufacturer of the CMOS camera you are considering. The design and dimensions needed to mount CMOS cameras vary considerably from maker to maker. PreciseParts (www.preciseparts.com) offers a custom design and machining service with their on-line “Build an Adapter” application. The required part is made to your specifications and shipped directly to you.

As handy as it may be, do not accept the first software-designed adapter design you get. Analyze how light from the RASA optics flows through the adapter, and make sure nothing intrudes into the RASA’s external “Do Not Obstruct” zone. Non-obstructing adapters will, as a general rule, be hollow cylindrical or bell-shaped structures with a RASA flange at one end and, at the image-sensor end, as wide open as the camera’s flange, bayonet, or threads will allow. Refer to page 24 for more details.

11. Imaging with the RASA

For amateur astronomers, the RASA’s fast focal ratio and wide field of view favor imaging colorful hydrogen-rich nebulae and intense star-forming regions. The Pleiades, Orion Nebula, the Trifid and the Lagoon, Markarian’s Chain in Virgo, Eta Carinae, and the Large Magellanic Cloud are calling for your attention!

For imaging deep-sky objects with the RASA, here’s what every potential imager must consider:

A. Obscuration

Because the camera is mounted on the front of the telescope, the camera should be compact. The correcting lens assembly of the RASA acts as an obscuration 114mm in diameter, so cameras that fit within a 114mm circle will block no additional light. However, even bulky DSLR cameras that protrude outside the 114mm circle add little additional obscuration. CMOS sensors mounted in slender cylindrical camera bodies (up to about 125mm diameter) are best, and add little or no additional obscuration.

B. Obstruction

The adapter that holds the camera body should intrude as little as possible into the “Do Not Obstruct” zone (see Figure 17). A well designed adapter will introduce no more vignetting than absolutely necessary.

C. Sensor format

One-shot-color and monochrome CMOS cameras are good, especially those housed in a slender camera body. Full-frame or APS-C DSLRs and MILCs work well. Vignetting affects full-frame DSLRs far more than it does the smaller APS-C format, so many users will prefer the lower cost and greater ease of use of the APS-C format despite its reduced field of view.

Table 3: Image Sensor Formats with the RASA-11

Format	Dimensions (mm)	Area (mm^2)	Angular Field	Field Area
35mm “Full Frame”	36.0 x 24.0	864	3.3° x 2.2°	7.4°
APS-C (Nikon, Sony, ...)	23.6 x 15.7	370	2.2° x 1.5°	3.2°
APS-C (Canon)	22.2 x 14.8	329	2.1° x 1.4°	2.8°

D. Imaging by wire

All astronomical CMOS cameras are controlled remotely via USB cable. With DSLRs and MILCs, it is possible but not practical to operate the camera manually. Instead, the observer should be able to operate the camera from a PC or Mac via USB interface cable. The camera control software should support Bulb exposures (that is, exposures of any length), intervalometer shooting (multiple exposures at a pre-set interval), and Live View (displaying a continuous video image from the camera). Many cameras come with suitable remote imaging software. You can download excellent and inexpensive aftermarket remote-operation programs for Canon and Nikon cameras.

E. Power

If possible, operate the camera with external power. A serious imaging session can easily run six to eight hours. The camera’s batteries must be able to operate the camera reliably for at least this long. If you must operate on camera battery power, have several extra fully charged batteries on hand.

F. Dew Shield

It’s a must-have! It is important to shield the camera body from stray light that can enter the optics and fog images. A dew shield at least 30 cm (12 inches) long will help to prevent dew from forming on the dew-vulnerable corrector plate of the RASA. The Celestron Aluminum Dew Shields, introduced in 2022, are compatible with the RASAs, and are a great choice for dew prevention.

G. Dew Heater

In addition to a dew shield, a few watts of heat from a dew heater will prevent dew from fogging the corrector plate during an imaging run. It is better to prevent dew from forming than to try to remove it once the corrector plate is dewed or frosted.

The Celestron Dew Heater Rings, introduced in 2022, are compatible with the RASAs. They replace the astrograph's retaining ring, integrating seamlessly into your setup. We highly recommend them along with the Smart DewHeater and Power Controller for a complete dew prevention and power management solution. Third-party heating strips will also work to prevent dew, but will not contact the Schmidt corrector directly.

Of course, you must also be able find targets, so a GoTo mount and/or a good finder telescope are necessities. If you wish to make long exposures, it's easy to mount a guide telescope and guide camera on the top dovetail that's included with the RASA. Once set up, however, the RASA's fast optical system keeps exposure times short, so capturing great images with it remains a pleasure.

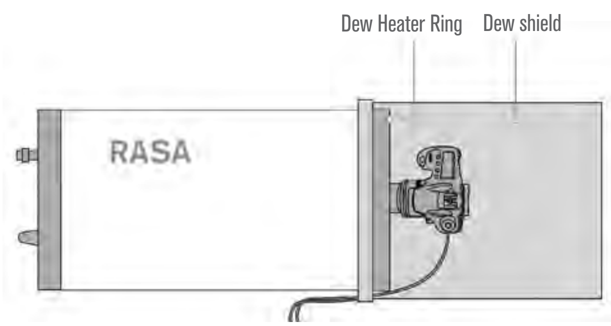


Fig. 20: The dew shield serves three important roles: 1) it prevents dew from forming on the corrector plate, 2) it shields the camera from stray light that can be reflected into the RASA, and 3) it prevents skylight outside the field of view from reducing image contrast.

12. Imaging with a DSLR Camera

On the RASA, ordinary APS-C DSLRs perform extremely well. Although "modding," that is, removing the infrared cutoff filter that also reduces Hα light, improves a camera's sensitivity to Hα, standard non-modded DSLRs render objects such as the Andromeda galaxy, reflection nebulae such as dust enveloping the Pleiades, star clusters like the Double Cluster in Perseus, and galaxies in the Virgo Cluster exactly the same as a regular DSLR would. Furthermore, an off-the-shelf DSLR renders gaseous nebulae with greater subtlety than a modified camera does: nebular gases appear a natural "electric pink" in color, rather than the saturated "crimson" hue of a modded sensor. Before spending the money and voiding your DSLR's warranty, shoot some "baseline performance" images with the RASA. You will not regret it.

Fig. 21: A DSLR connected to the RASA. Note the dovetail bar on top of the optical tube, which provides a mounting platform for optional imaging equipment.

13. Imaging with MILCs

All DSLRs have a reflex mirror that flips out of the light path just before the camera makes an exposure. Mirrorless cameras instead capture the image continuously and display it on a viewing screen. By allowing interchangeable lenses, MILCs offer the advantages of using different lenses without the drawbacks of the DSLR's deep camera body and moving reflex mirror.

For astronomical imaging, a popular choice is the full-frame format Sony A7S. The A7S (or α7S) has a 12 megapixel sensor and rather than burying the sensor 45mm deep inside camera body, the flange-to-sensor distance is only 18mm. With a suitable adapter, vignetting caused by the camera body and reflex mirror can be eliminated or greatly reduced. Although the pixel count is small by modern standards, its 8.4-micron pixel size is actually well matched to the spot size of the RASA. The stock α7S body can be modified for enhanced sensitivity to Hα.

14. Imaging with One-Shot-Color CMOS Cameras

CMOS cameras come in two flavors: monochrome and one-shot-color. In a monochrome CMOS camera, pixels on the sensor array are all the same. To make a color image, three exposures are made through color filters. The images are monochrome (i.e., black-and-white) and must be combined to produce color. In one-shot-color CMOS cameras, the sensor is covered with an array of tiny red, green, and blue color filters called a Bayer array. Adjacent pixels capture different wavelength bands, so that afterwards a full-color image can be reconstructed from the matrix of differently filtered pixels.

The selling point of one-shot-color cameras is they capture a color image in a single exposure. Their image acquisition software reconstructs a full-color image from the mosaicked Bayer-array data. The primary disadvantage of one-shot-color cameras is that the Bayer array filters reduce the amount of light reaching the CMOS sensor, necessitating longer exposure times–but the RASA's f/2.2 focal ratio means that exposures seldom exceed five minutes, and the image obtained in that time is deeper and richer than slower astrographs capture in an hour's worth of stacked exposures.

For imaging at sites with heavy light pollution, the RASA's internal clear glass filter (located inside the tilt collar) can be replaced with a special light pollution reduction filter offered by Celestron. The filter is an exact replacement for the clear filter, except that it reduces the effect of city lights without distorting the color balance of your one-shot-color images.

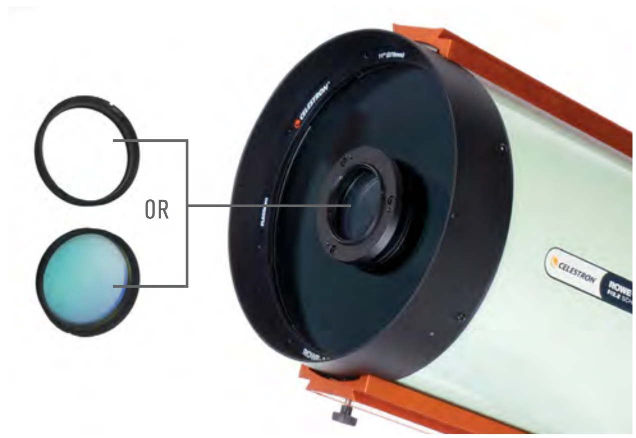


Fig. 22: The RASA's integrated clear filter ensures optimal optical performance. It should be removed when using another filter in the light path. It can also be replaced with an optional light pollution filter.

Manufacturers of one-shot-color CMOS cameras include Atik, QHYCCD, ToupTek, Player One, and ZWO. Since the RASA design is optimized to produce a full-frame 43.3mm diameter image with a modest 23% vignetting in the very corners of the image, if you can afford a full-frame format camera, you'll be able to capture a large chunk of sky in a single exposure. Even better, in a single night you could shoot a mosaic with a dozen images that covers the region from the Belt Stars to the Horsehead to the diffuse nebulosity south of the Orion Nebula!

15. Imaging with Monochrome CMOS Cameras

Monochrome CMOS cameras offer greater sensitivity than one-shot-color cameras because there is no light-absorbing Bayer filter mask on the sensor. With no filter, the CMOS sensor responds to light from the near ultraviolet through the visible spectrum and into the near infrared. For applications that demand the greatest space-penetrating power in the shortest time –such as searching for comets or imaging orbiting space debris – a monochrome CMOS camera with a readily accessible sensor and a compact camera body is the way to go.

Five-Minute Exposures!

The images shown here are 5-minute exposures taken with a Nightscape CCD camera on an 11-inch RASA telescope. With the RASA, lengthy exposures are a thing of the past. Deep-sky images are easy, fun, and quick!

Pleiades Star Cluster, M45

Andromeda Galaxy, M31

Rosette Nebula, NGC 2237

Images by Richard Berry

To make color images with a monochrome CMOS camera, the usual technique is to shoot images through broadband red, green, and blue filters, or to shoot using narrowband OIII, SII, and HA filters. Because the RASA's optics are designed for a single 2mm thick filter in the optical path, if you wish to use another filter, remove the internal clear glass filter located inside the RASA's tilt collar. If two filters are in the optical path at the same time, the RASA's performance will be affected.

Observing programs that require a filter usually require more than one filter, so the filters are mounted in a filter rotating wheel. A small motor turns the wheel so that different filters can be inserted into the light path without manual intervention. All too often though, the filter wheel is considerably larger than the camera body itself, and when placed at the focus of a RASA, the filter wheel blocks a considerable amount of light. There is currently no easy solution to the filter-wheel dilemma, although custom solutions do exist. For example, filters can be mounted in a sliding drawer and manually inserted into the light path.

16. Big! Fast! Wide! Sharp!

Celestron's telescope testing observatory is located at their headquarters in Torrance, CA, a place not known for pristine dark skies. In fact, these semi-urban skies are typical of the skies many Celestron owners experience on a nightly basis. "If we did all of our testing under perfect skies," said former Celestron Product Manager of Astronomy, Bryan Cogdell, "we would not be serving our customers well. It's important that we know and understand how our telescopes operate under the typical suburban and urban skies."

"For those who are new to astronomical imaging, as well as those who have learned astroimaging the hard way, the RASA comes as a revelation," said Cogdell. "The newcomers have heard stories about hours-long exposure times," he said, "and the old-timers have experienced those all-night sessions imaging at f/8 and f/10. Those guys have done it all: polar alignment, lengthy exposures, autoguiding, and stacking! They have paid their dues."

For them, the RASA comes as new experience. "With the ISO of their camera set to 6400, old-timers make a single 15-second exposure at f/2.2 and see a creditable image. They are totally amazed! If they drop the ISO to 1600 and expose for 60 seconds, they see an image that would have taken 20 minutes at f/10." There's no need to guide for just 60 seconds; quick polar alignment is good enough. "With minimal complexity," noted Cogdell, "veterans can apply their hard-won skills, shoot a dozen five-minute exposures at ISO 400, stack them, and get rewarded with the finest images they've ever taken."

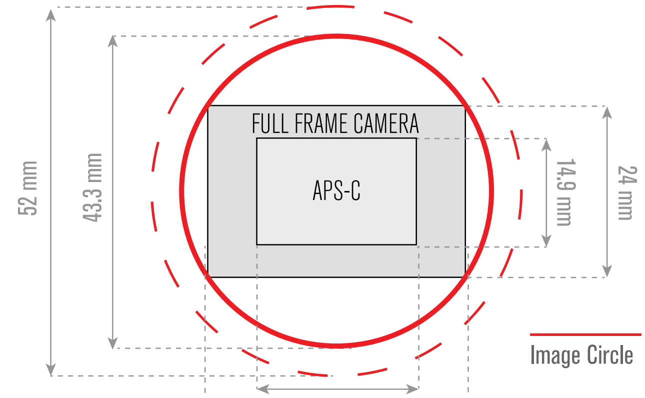


Fig. 23: Larger CMOS sensors work well with the RASA 11".

As the party responsible for testing and evaluating the RASA from the first, Cogdell said he was consistently impressed. "With the RASA," he said, "we have given observers the ability to do fast imaging, but we also need to make people aware that 'real time astronomical imaging' is now possible with a high-étendue telescope. Using high-sensitivity CMOS sensors enables capturing and watching deep sky objects on a computer screen in 'almost real time'. It's going to be great for group viewing and public star nights. You press 'go-to M51' and everyone sees the Whirlpool as it glides into view."

Another new technology is image live stacking. You watch as the image grows stronger and the noise drops away. The focal length of the RASA gives you a field of view perfectly suited to viewing the Messier objects," Cogdell explained. Software takes care of image alignment and stacking, even when the telescope is not perfectly polar aligned. "High étendue gives the RASA a big advantage. With other telescopes, you need focal reducers; with the RASA, you're ready-set-go at f/2.2."

For serious aesthetic imaging," said Cogdell, "I am anxious to try multi-frame mosaics. Advanced amateurs are doing mosaics now, but with conventional low-étendue systems, it takes forever to gather the necessary number of images." With the RASA, everything you need for a multi-frame mosaic can be captured in a single night. "For some imagers, the seven square degrees of sky you get in a RASA frame is simply not enough! But gather 30 minutes of data with your RASA for each field, and you can complete a two-by-three six-panel mosaic in a couple of hours! Stitch the images together and you create a new perspective on the greater Perseus area."

"For beginners," said Cogdell, "the adapters we include with every RASA make it easy to attach any DSLR camera with an APS-C format sensor and get great results right from the start. That's probably the best way to start using the RASA." But, as Cogdell admitted, "it's easy to outgrow what the DSLR can do. For aesthetic imaging under good to excellent skies, you probably can't beat the power and simplicity of a good full-frame one-shot-color CMOS camera mounted on a non-obstructing adapter." The combination of high-étendue optics with an easy-to-use sensor produces amazing deep-sky, wide-field color images in less than an hour's exposure time. "In the hands of an experienced amateur astronomer," declared Cogdell, "the RASA is the ultimate astrograph."

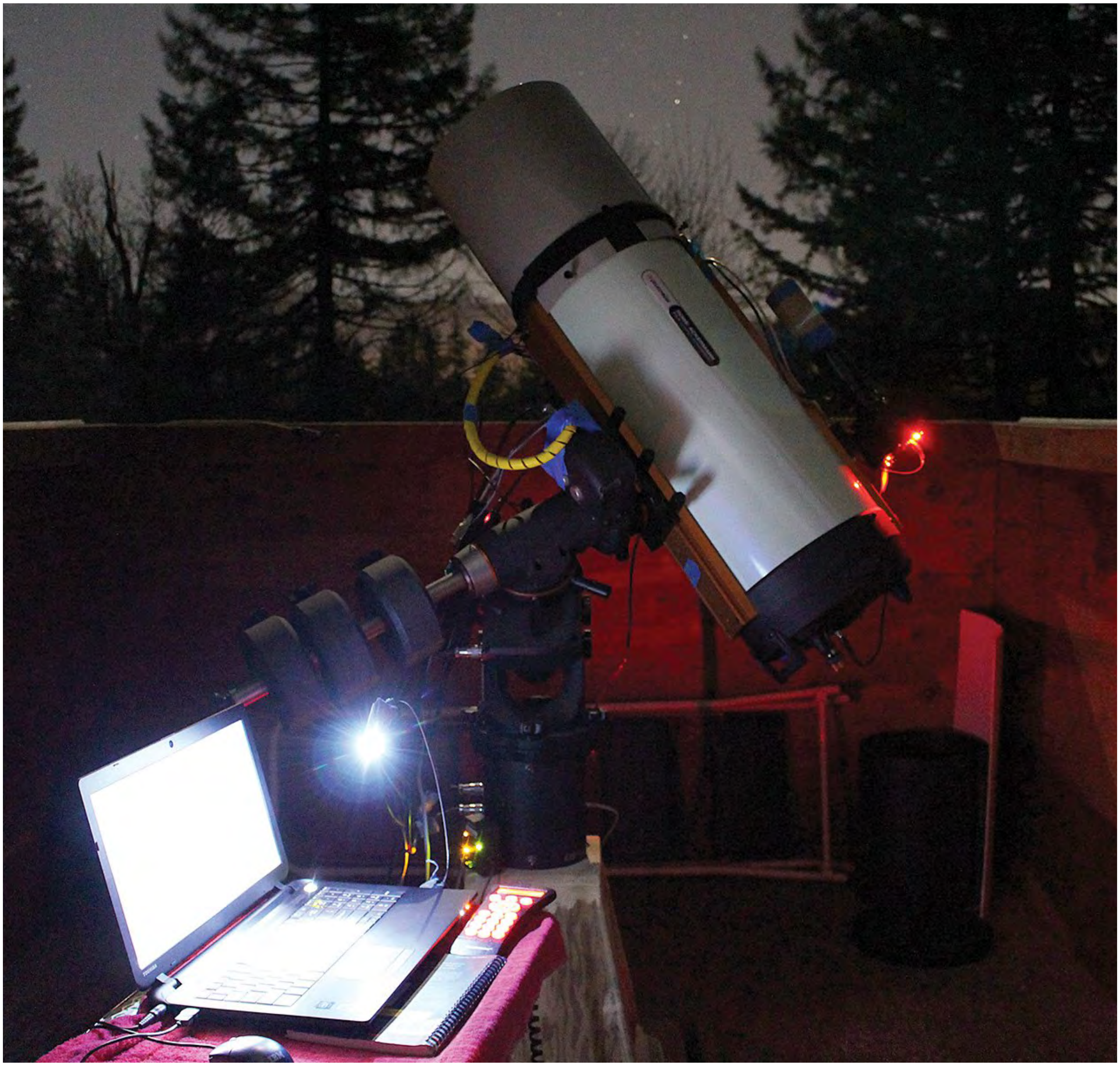


Fig. 24: The truest satisfaction with an astrograph comes when you're under the stars. As this photo was taken, the RASA was busy capturing images of Comet Catalina.

Fig. 25: Bryan Cogdell enjoying a night of imaging with the RASA 11" from a dark sky location.

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RASA 11-inch vs. Palomar Sky Survey

How do images taken with an 11-inch f/2.2 RASA compare the famous Palomar Sky Survey? At left is a stack of twelve 5-minute exposures versus a 30-minute red-filtered photograph made for the POSS II survey with the 48-inch f/2.5 UK Schmidt Telescope on the right. The RASA has better SNR (Signal-to-Noise Ratio) and has a deeper limiting magnitude, but UKSTU's 120 inch focal length provides better spatial resolution than does the RASA's 24 inches focal length. It's a dramatic demonstration of how much better the tools of the astronomers have become. The nebula is IC359 in Taurus.

279mm f/2.2 Rowe-Ackermann

1200mm f/2.5 UK Schmidt Telescope

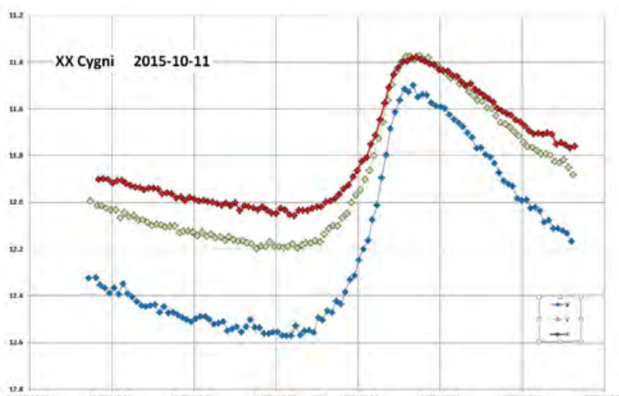
APPENDIX A: Science with the RASA

Because of its high étendue, the RASA is an exceptionally science-capable optical system. The combination of large aperture, fast focal ratio, and wide field combine to the benefit of the science observer. This is especially true in programs that require large numbers of images or large swaths of sky to be taken and searched rapidly.

Variable Star Photometry

One of the strongest contributions to science from amateur astronomers is through photometry of variable stars. The American Association of Variable Star Observers (AAVSO), the Center for Backyard Astrophysics (CBA), and the British Astronomical Association (BAA) are among the organizations that run active variable-star programs. The advent of CCDs increased both the number and precision of the work done by these groups.

To make an observation, the telescope points to a field containing a program star, makes a series of images through one or more color filters, then moves to the next program star. One telescope can visit hundreds of stars per night, or it may dwell on a single star all night long. The images are then calibrated and the magnitude of the stars are measured relative to comparison stars in the same field of view.



The star XX Cygni goes through a complete pulsation is just over three hours. XX Cygni has been followed for over 100 years. To check for ongoing changes in the period of the star, the observer used the versatile 11-inch RASA to make alternating 15-second CCD images through photometric B, V, and R filters. Plotting the light curve gave the time of maximum light to better than a minute.

Asteroid Photometry

Amateur astronomers have made significant contributions to science by making light curves of asteroids. From a light curve, it is possible to determine the rotation period and pole orientation of the asteroid. The wide field of RASA combined with the large aperture makes it possible to follow an asteroid for multiple nights while using the same set of comparison stars, resulting in more homogenous data.

Comet Science

Although professional observatories using telescopes similar to the RASA have largely supplanted amateur comet searches, amateurs continue to contribute by following comets and measuring their changing brightness. The light curve of a comet during an apparition may hold surprises as the comet brightens (or fails to brighten) and undergoes outbursts of activity.

Novae and Supernovae Searching

So much sky and so few telescopes! Novae pop up unexpectedly in rich Milky Way fields, while supernovae appear in and around distant galaxies. Regular surveillance programs carried out by amateur astronomers can and do turn up both types of exploding stars.

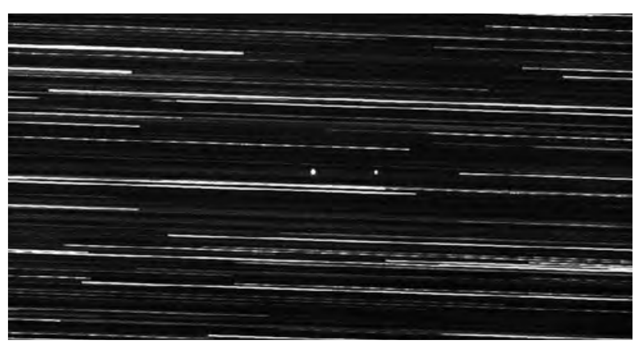
Low Earth Object (LEO) Spotting

Spotting and following Earth-orbiting satellites has become an exoteric hobby among space enthusiasts. National governments track their satellites with fast, wide-field optics similar to the RASA, so it's only natural that amateur space hobbyists have turned to the RASA. Their targets include spy satellites, discarded booster rockets, space observatories, debris from satellite collisions, and assorted debris down to the basketball size range. To spot objects in LEO, the search instrument stares into space making short exposures, while a dedicated computer processes images looking for moving objects. Pairs of such imaging systems located a few kilometers apart can locate objects in space and determine their orbits.

Search for Near Earth Objects (NEO)

Our planet has been and will be hit again by a class of asteroids called Near Earth Objects. NASA and other space agencies are actively surveying the skies to identify and classify all objects that pose a danger to life here, and they are using instruments like the RASA to do so. The Catalina Sky Survey, Pan-STARRS, LINEAR, Spacewatch, NEOWISE, and the PS1 Consortium all employ fast, wide-angle optics in search of these objects. Of course, their optics may be fancier – an aperture measured in meters, a many-degrees field of view, and gigapixel CCD cameras – but there will never be enough eyes watching the sky.

"Amateur satellite trackers need the wide field and large aperture of an instrument like the RASA. Satellites move quickly, so you need to capture their light in seconds," noted optical designer Mark Ackermann, "and with exposure times of a minute or two, you can catch Earth-crossing asteroids and comets." The RASA's high étendue also makes it suited for supernova searches. In each case, the name of the game is to cover lots of sky in a short time, then cover it all again a few nights later to look for changes. The ATLAS Project, funded by a $5M NASA grant, will search using two 500mm aperture f/2 telescopes with fields 7.4 degrees on a side. A 36 cm version of the RASA could, for $15,000, do the same, and falling not far behind in capability, at a tiny fraction of the cost."



With the RASA pointed to a location in the sky (and no equatorial tracking), satellites in geosynchronous orbit will stay stationary in the field of view while stars will appear as streaks. Image by Richard Berry.

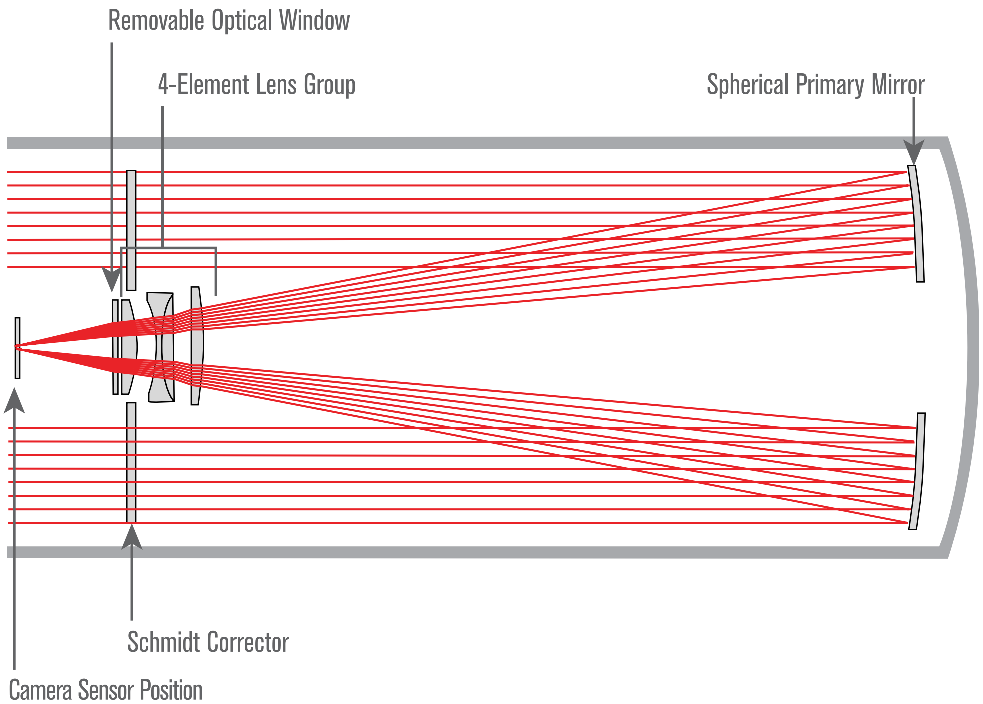
APPENDIX B:
11" Rowe-Ackermann Schmidt Astrograph Specifications

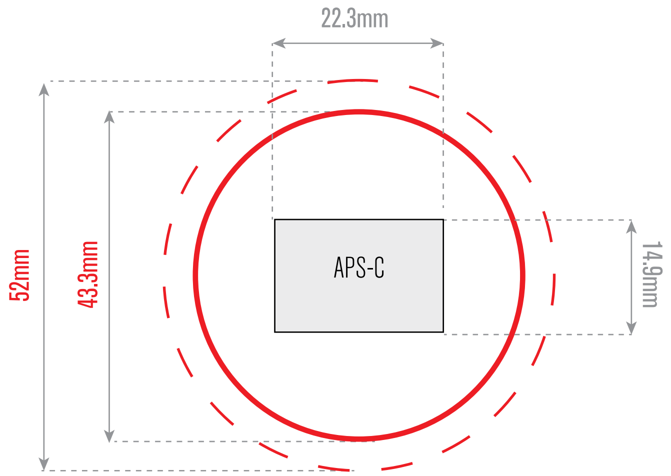
#91076

Optical Design	Rowe-Ackermann Schmidt
Aperture	279mm
Focal Length	620mm
Central Obscuration	114mm (41% of aperture diameter)
Focal Ratio	f/2.2
Design Wavelength Range	400 to 700 nm
Design Linear Field of View	43.3mm
Design Angular Field of View	4.00 degrees
Aperture Collecting Area	50900mm²
Back Focus, M42 Camera Adapter	55.0mm
Back Focus, from Reference Surface	72.8mm
On-Axis RMS Spot Size	< 4.00 microns diameter
Everywhere RMS Spot Size	< 4.50 microns diameter
Encircled Energy(400-700 nm)	> 90% inside 7.5 micron circle
Clear Optical Filter, clear aperture	68mm
Clear Optical Filter, diameter	72mm
Clear Optical Filter, thickness	2.1mm
Clear Optical Filter, coating	Broadband AR multi-coated
Optical Filter, thread dimensions	M75 x 0.75
Image Scale (arcseconds per pixel)	0.33 x pixel size in microns
Vignetting, Relative Illumination	100% at 5mm off-axis 96% at 10mm off-axis 93% at 15mm off-axis 80% at 20mm off-axis 77% at 21.65mm off-axis (edge of field design)
Optical Coating, Primary Mirror	StarBright XLT reflective coatings
Optical Coating, Schmidt Plate	StarBright XLT anti-reflective coatings
Optical Coating, Corrector Lenses	Broadband AR multi-coated
Focuser	Ultra-Stable Focus System (USFS)
Focuser Rate	0.75mm/turn
Focuser Direction	CCW moves mirror forward
Cooling Fan	12 VDC, tip polarity + (positive)
Maximum Camera Weight	10 kg (22 pounds)
Total Weight, Telescope Kit	20 kg (43 pounds)
Optical Tube Length	840mm (33 inches)
Optical Tube Diameter	315mm (12.4 inches)
Mounting	Heavy-duty CGE dovetail rails top and bottom

OPTICAL DESIGN

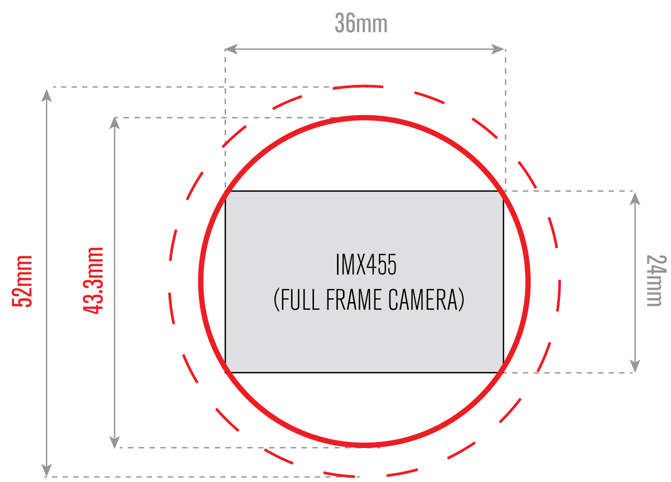
- 11-inch aperture
- f/2.2 focal ratio
- 4.0° field of view
- 43.3mm image circle
- < 4.4 µm RMS spot size across field of view

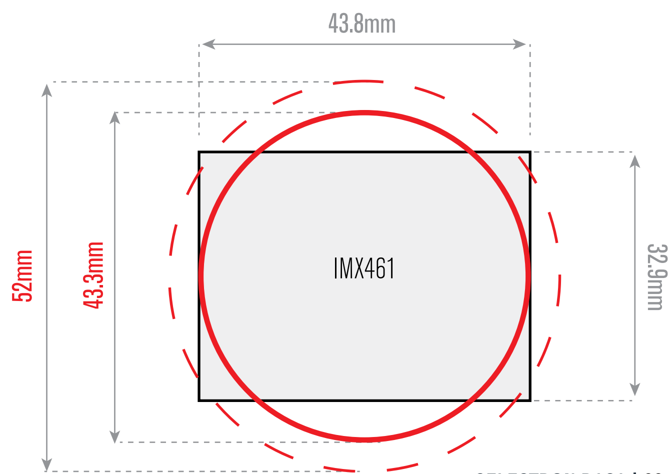




Usable Field (52mm)

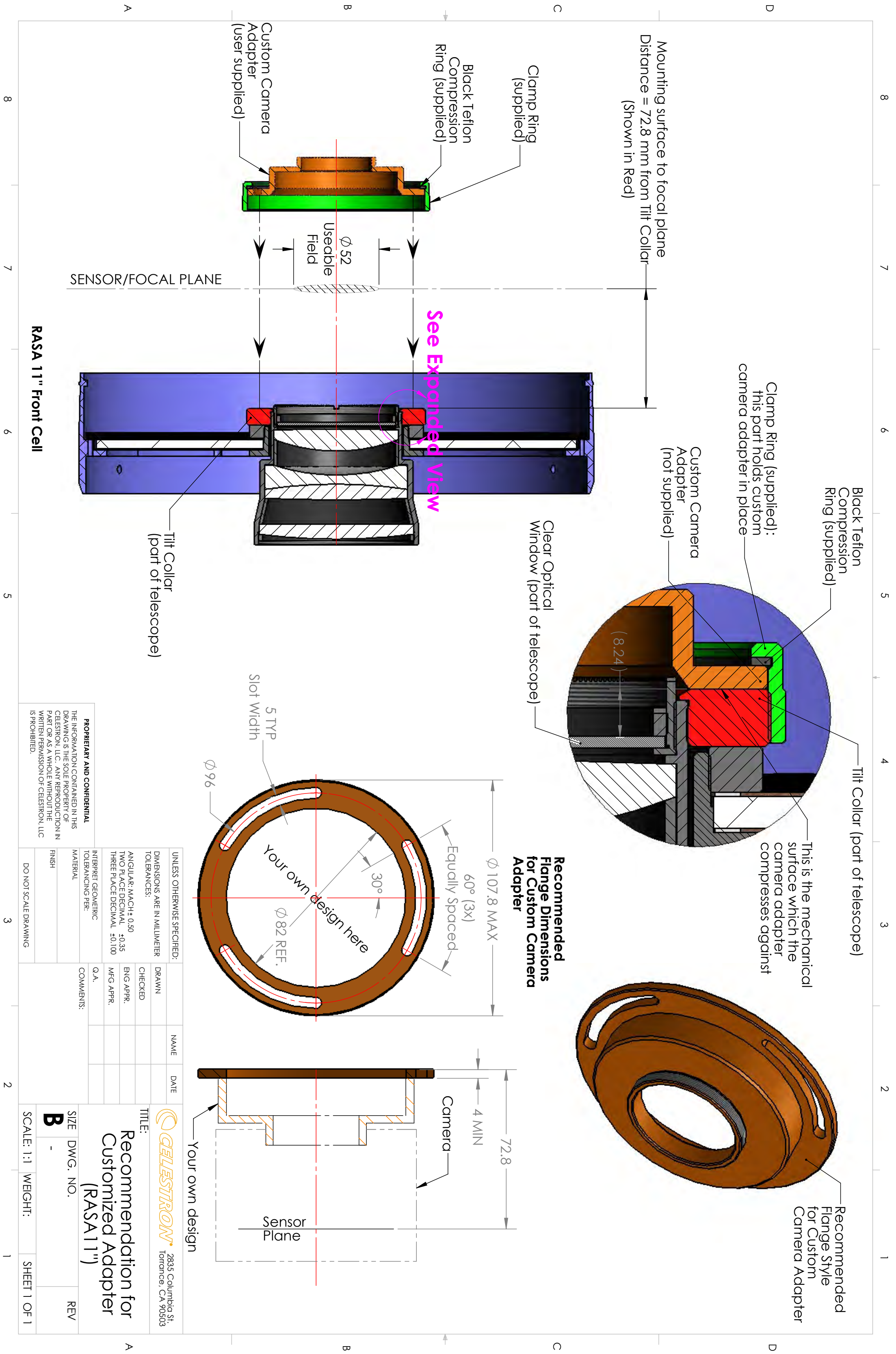
Image Circle (43.3mm)





Matrix Spot Diagram
(Refer to page 6)

Custom Camera Adapter Design Considerations



APPENDIX C:
36 cm Rowe-Ackermann Schmidt Astrograph

Shortly after the design of the RASA 11 was completed, Celestron began work on a 14” aperture version of the RASA. This model was primarily inteneded to be used for Space Situational Awareness (SSA) and other space surveillance applications, where a large area of sky needs to be scanned in a short amount of time to detect very small and faint objects. The 14” version of the RASA would be too large to be portable, so it was intended to be housed in a small observatory. Since most telescopes created for professional use have metric designations, the name of the design was called the RASA 36cm to indicate that it is a professional-class instrument.

Key to the optical design was making the RASA 36cm compatible with the next generation of large sensors. Using a large sensor for SSA work is mandatory, as it increases the field of view (and étendue) captured with each image. At the time, the largest sensor available was the KAF-50100, which has a 60.1mm diagonal sensor size, so it was decided to optimize the design across a huge 60.1mm image circle. In fact, if larger sensors become available, the RASA 36cm can handle a sensor with up to a 70mm diagonal!

Another unique feature of the RASA 36cm is the extended spectral range. Since most professional CMOS cameras have good spectral response in the near-infrared region of the spectrum (i.e. from 700-900 nm), extending the spectral performance of the RASA 36cm results in more of the object’s light being sharply focused within the image. This yields a brighter signal, which can result in detecting slightly fainter (i.e. smaller) objects during SSA sky surveys.

In SSA work, constantly halting data collection to refocus the telescope wastes valuable time during an observing run. That’s why we redesigned the RASA 36cm V2’s entire focusing mechanism to minimize focus shift and mirror flop. The V2 version has an improved “Ultra-Stable Focus System” (USFS) with focuser mechanics that constrain unwanted lateral motion of the primary mirror. At the heart of the USFS is a precision linear ball bearing riding on a tight tolerance steel shaft. This makes a precise focus even easier to achieve and more stable throughout the observing session.

Since the field of view of the RASA is so large, the diameter of the removable optical window is also is quite large (104mm clear aperture). Because of this, a custom filter (not offered by Celestron) will be required to fit inside the RASA 36cm in place of the optical window. Otherwise, an external filter drawer between the camera and camera adapter (not offered by Celestron) can be employed to use filters with the RASA 36cm.

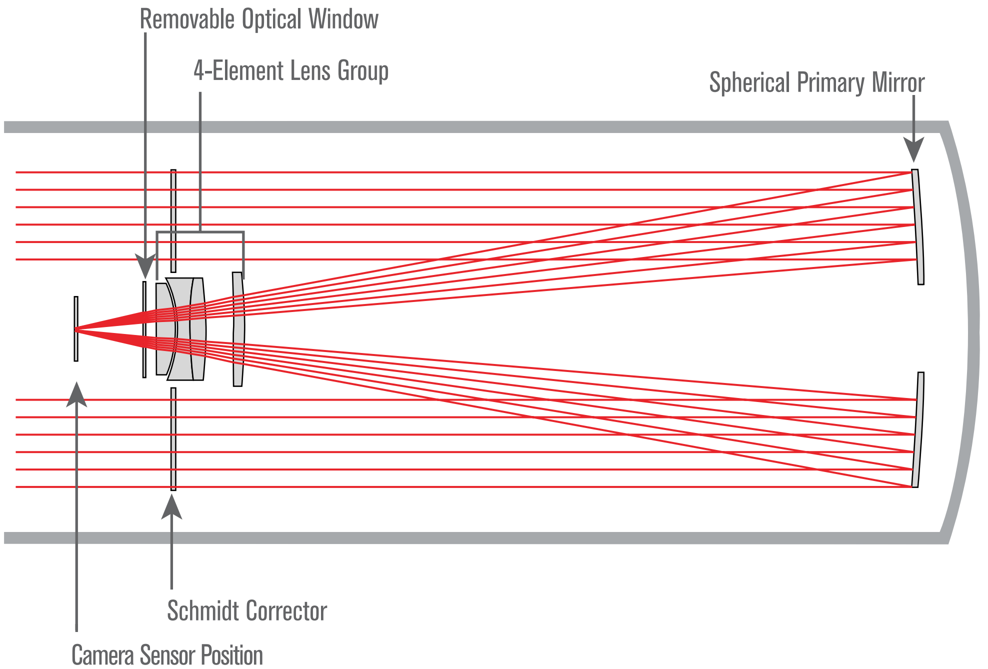
RASA 36 cm Specifications

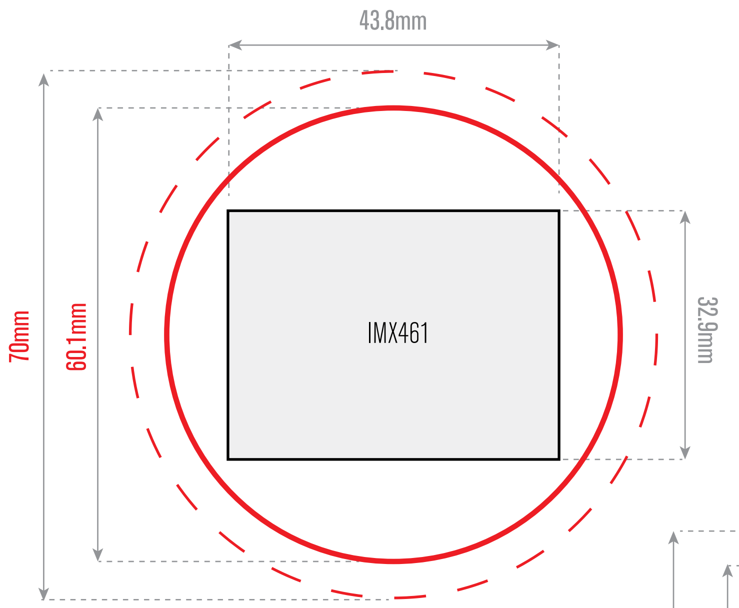
#91078

Optical Design	Rowe-Ackermann Schmidt
Aperture	355.6mm
Focal Length	790mm
Central Obscuration	164mm (46% of aperture diameter)
Focal Ratio	f/2.2
Design Wavelength Range	400 to 900 nm
Design Linear Field of View	60.1mm
Design Angular Field of View	4.3 degrees
Aperture Collecting Area	78200mm²
Back Focus, M42 Camera Adapter	55.0mm
Back Focus, from Reference Surface	77.5mm
On-Axis RMS Spot Size	< 5.5 microns diameter
Everywhere RMS Spot Size	< 6.3 microns diameter
Encircled Energy(400-900 nm)	> 80% inside 8 micron circle
Clear Optical Filter, clear aperture	104mm
Clear Optical Filter, diameter	108mm
Clear Optical Filter, thickness	3.0mm
Clear Optical Filter, coating	Broadband AR multi-coated
Optical Filter, thread dimensions	M110 x 0.75
Image Scale (arcseconds per pixel)	0.26 x pixel size in microns
Vignetting, Relative Illumination	99% at 5mm off-axis 97% at 10mm off-axis 94% at 15mm off-axis 92% at 20mm off-axis 88% at 25mm off-axis 67% at 30mm off-axis (edge of field design)
Optical Coating, Primary Mirror	Starbright XLT reflective coatings
Optical Coating, Schmidt Plate	StarBright XLT anti-reflective coatings
Optical Coating, Corrector Lenses	Broadband AR multi-coated
Focuser	Ultra-Stable Focus System (USFS), Improved design to further minimize lateral motion of the primary mirror
Focuser Rate	0.75mm/turn
Focuser Direction	CCW moves mirror forward
Cooling Fan	12 VDC, tip polarity + (positive)
Maximum Camera Weight	17 kg (38 pounds)
Total Weight, Telescope Kit	34 kg (75 pounds)
Optical Tube Length	1080mm (42.5 inches)
Optical Tube Diameter	406mm (16.0 inches)
Mounting	Heavy-duty CGE dovetail rails top and bottom

OPTICAL DESIGN

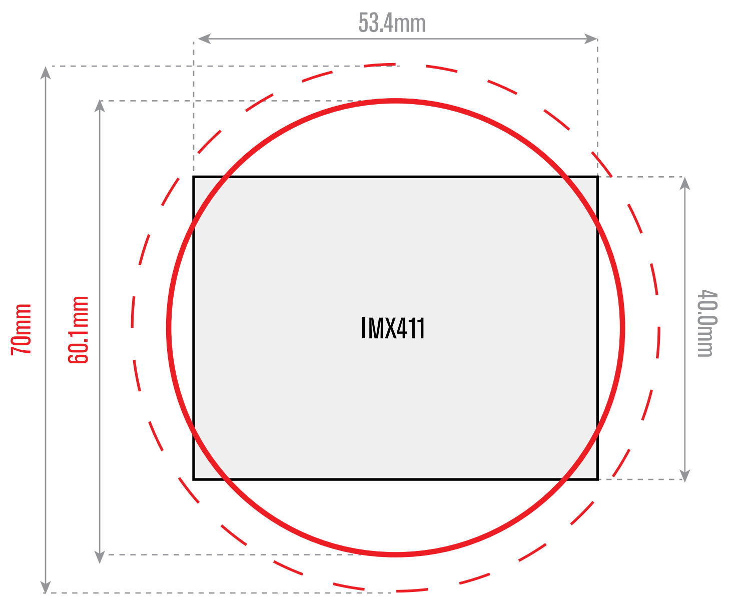
- 36 cm aperture
- f/2.2 focal ratio
- 4.3° field of view
- 60.1mm image circle
- < 6.3 µm RMS spot size across field of view



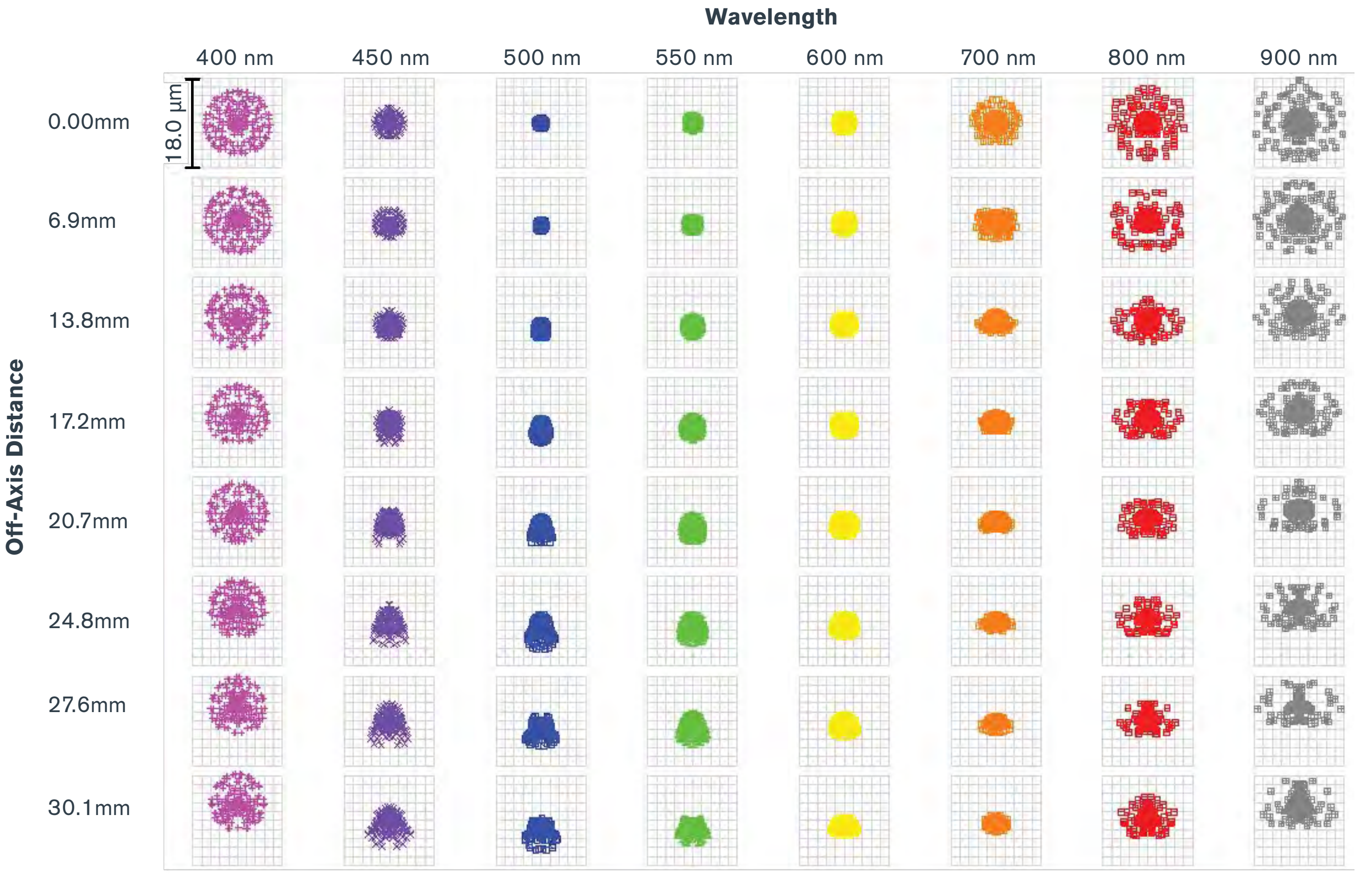


Usable Field (70mm)

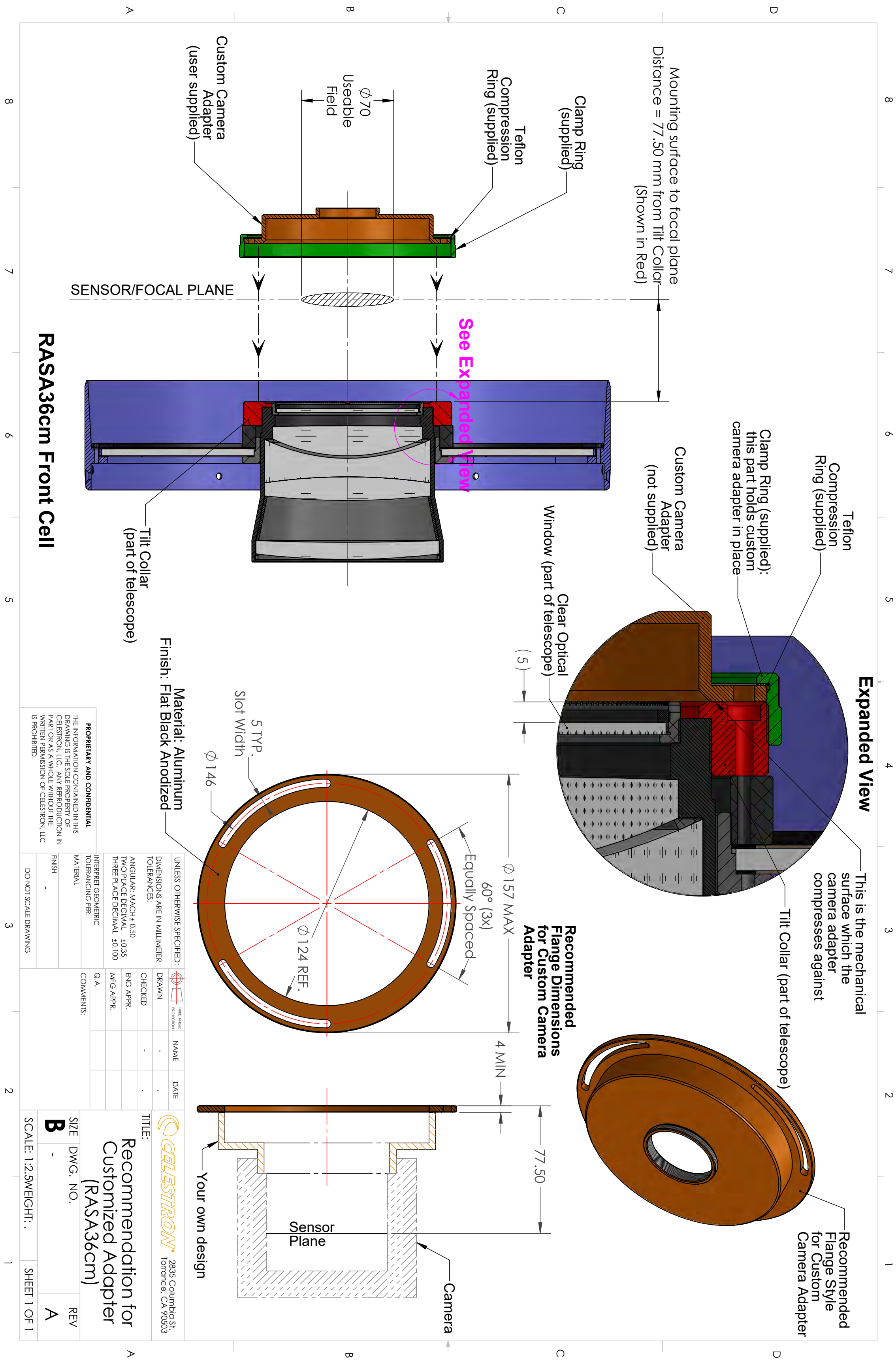
Image Circle (60.1mm)



Matrix Spot Diagram (18 µm box size)



Custom Camera Adapter Design Considerations



APPENDIX D:
8" Rowe-Ackermann Schmidt Astrograph

In late 2018, Celestron introduced the 8" version of the Rowe-Ackermann Schmidt Astrograph. This was intended primarily to be used for wide-field astronomical imaging of deep-sky objects by amateur astronomers.

When considering the design for a RASA 8, it became apparent that it would not be compatible with DSLRs, since the body of a DSLR would be much bigger than the desired central obstruction for a RASA 8; using a DSLR with a RASA 8 would result in reduced image brightness (due to the camera body blocking some of the incoming light) and irregular diffraction patterns (due to the camera body not being cylindrical). Since the DSLR has the longest backfocus distance (i.e., flange focal distance) requirement of all commonly used astroimaging cameras, the 55mm backfocus requirement could be considerably relaxed in order to meet other important optical design goals.

Understanding that the RASA 8 would not be compatible with DSLRs resulted in design goals that included making the optical system as fast as possible while keeping the central obstruction as small as possible, and providing great performance across at least a 4/3" format image sensor, which is the size used in many astronomical cameras and mirrorless cameras. Also, it was possible to extend the spectral range to 390-800nm in order to take advantage of popular consumer cameras that have decent response to wavelengths above the 700 nm limit of the visual spectrum. This means that some light outside the visual spectrum will be well-focused in RASA 8 images, creating detail not otherwise able to be seen. For telescopes not optimized for wavelengths beyond the visible spectrum, this light will be unfocused and can actually degrade images. This is why some other setups require IR-cut filters, so that the unfocused light outside the visible spectrum is blocked and doesn't reach the sensor. For the RASA 8, an IR-cut filter should not be required. This allows users to catch even more detail in their images, details that cannot normally be seen with the human eye.

Although the design was optimized for a 22mm diameter image circle, performance and field illumination is still quite good across a 32mm diagonal sensor. This makes the RASA 8 an excellent choice to use with APS-C size sensors, like those found in popular astronomical and mirrorless cameras.

In addition, Celestron also implemented the Ultra-Stable Focus System (USFS) into the RASA 8 to help further prevent focus shift and mirror flop. This provides easier focusing without the need to refocus as the astrograph is slewed across the sky. At the heart of this system is a precision linear ball bearing that the primary mirror moves on, which helps to constrain any unwanted lateral motion of the primary mirror. This was the first implementation of the USFS, and it worked so well and was so well received by users that this new focuser design was implemented into the RASA 11 in January 2020.

Like the other RASAs, the RASA 8 also utilizes a removable optical window, which is intended to be removed if any additional flat glass, like a filter or camera optical window, is added into the light path. This maintains the high-quality optical performance of the astrograph, since it is such a fast optical design. Celestron currently offers a Light Pollution Imaging Filter for the RASA 8; its transmission spectrum is the same as the LPI Filter for the RASA 11. Another option for filter use is to employ a "filter drawer" between the camera and RASA 8 camera adapter. These filter drawers are readily available from several manufacturers.

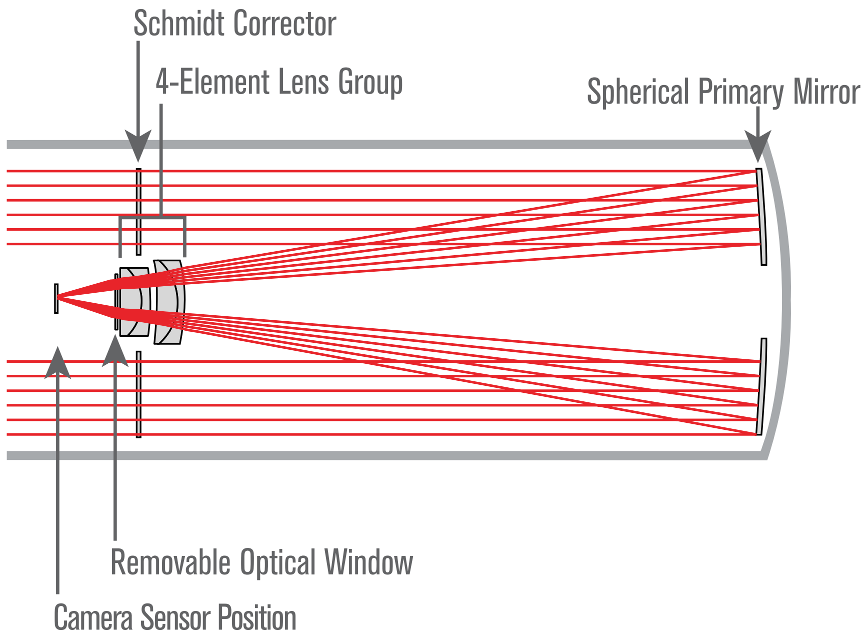
RASA 8 Specifications

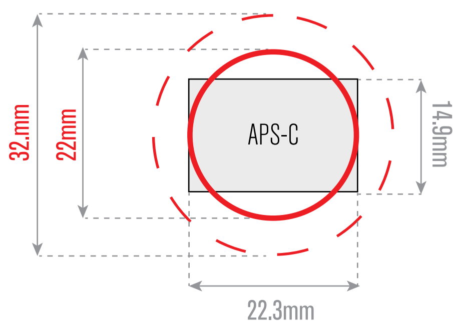
#91073

Optical Design	Rowe-Ackermann Schmidt
Aperture	203mm
Focal Length	400mm
Central Obscuration	94mm (46% of aperture diameter)
Focal Ratio	f/2.0
Design Wavelength Range	390 to 800 nm
Design Linear Field of View	22.0mm
Design Angular Field of View	3.2 degrees
Aperture Collecting Area	25400mm^2
Back Focus, M42 Camera Adapter	25mm
Back Focus, from Reference Surface	28.7mm
On-Axis RMS Spot Size	< 3.70 microns diameter
Everywhere RMS Spot Size	< 4.55 microns diameter
Encircled Energy (390-800 nm)	> 90% inside 8.4 micron circle
Clear Optical Filter, clear aperture	43mm
Clear Optical Filter, diameter	46mm
Clear Optical Filter, thickness	2.0mm
Clear Optical Filter, coating	Broadband AR multi-coated
Optical Filter, thread dimensions	M55 x 0.75
Image Scale (arcseconds per pixel)	0.51 x pixel size in microns
Vignetting, Relative Illumination	100% at 2mm off-axis 98% at 4mm off-axis 97% at 6mm off-axis 96% at 8mm off-axis 93% at 11mm off-axis (edge of field design)
Optical Coating, Primary Mirror	Starbright XLT reflective coatings
Optical Coating, Schmidt Plate	StarBright XLT anti-reflective coatings
Optical Coating, Corrector Lenses	Broadband AR multi-coated
Focuser	Ultra-Stable Focus System (USFS)
Focuser Rate	0.75mm/turn
Focuser Direction	CCW moves mirror forward
Cooling Fan	12 VDC, tip polarity + (positive)
Maximum Camera Weight	9.1 kg (20 pounds)
Total Weight, Telescope Kit	7.7 kg (17 pounds)
Optical Tube Length	630mm (24.8 inches)
Optical Tube Diameter	235mm (9.3 inches)
Mounting	Heavy-duty CGE dovetail rail

OPTICAL DESIGN

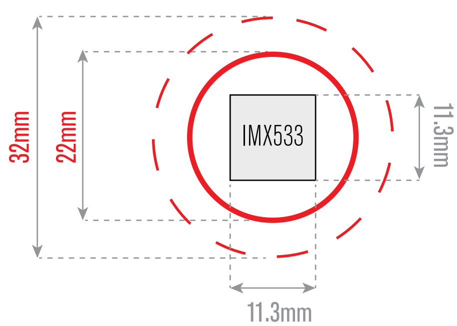
- 8-inch aperture
- f/2.0 focal ratio
- 3.2° field of view
- 22mm image circle
- < 4.55 µm RMS spot size across field of view

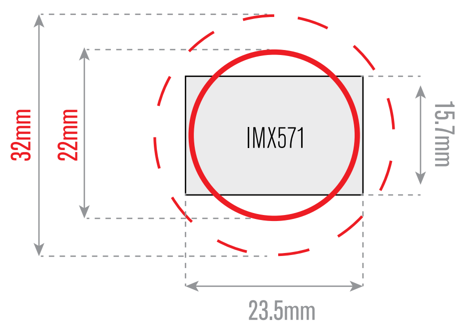




- - - Usable Field (32mm)

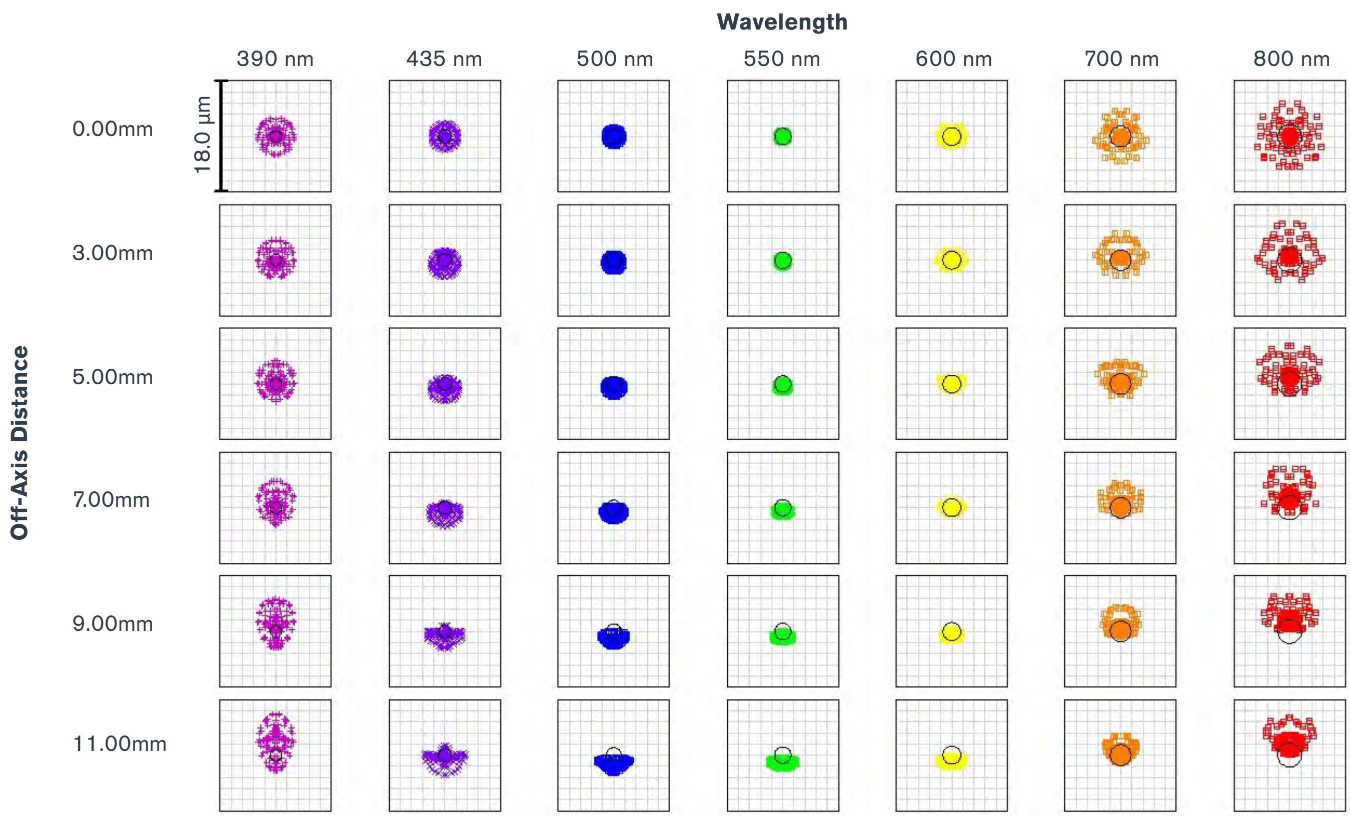
—— Image Circle (22mm)



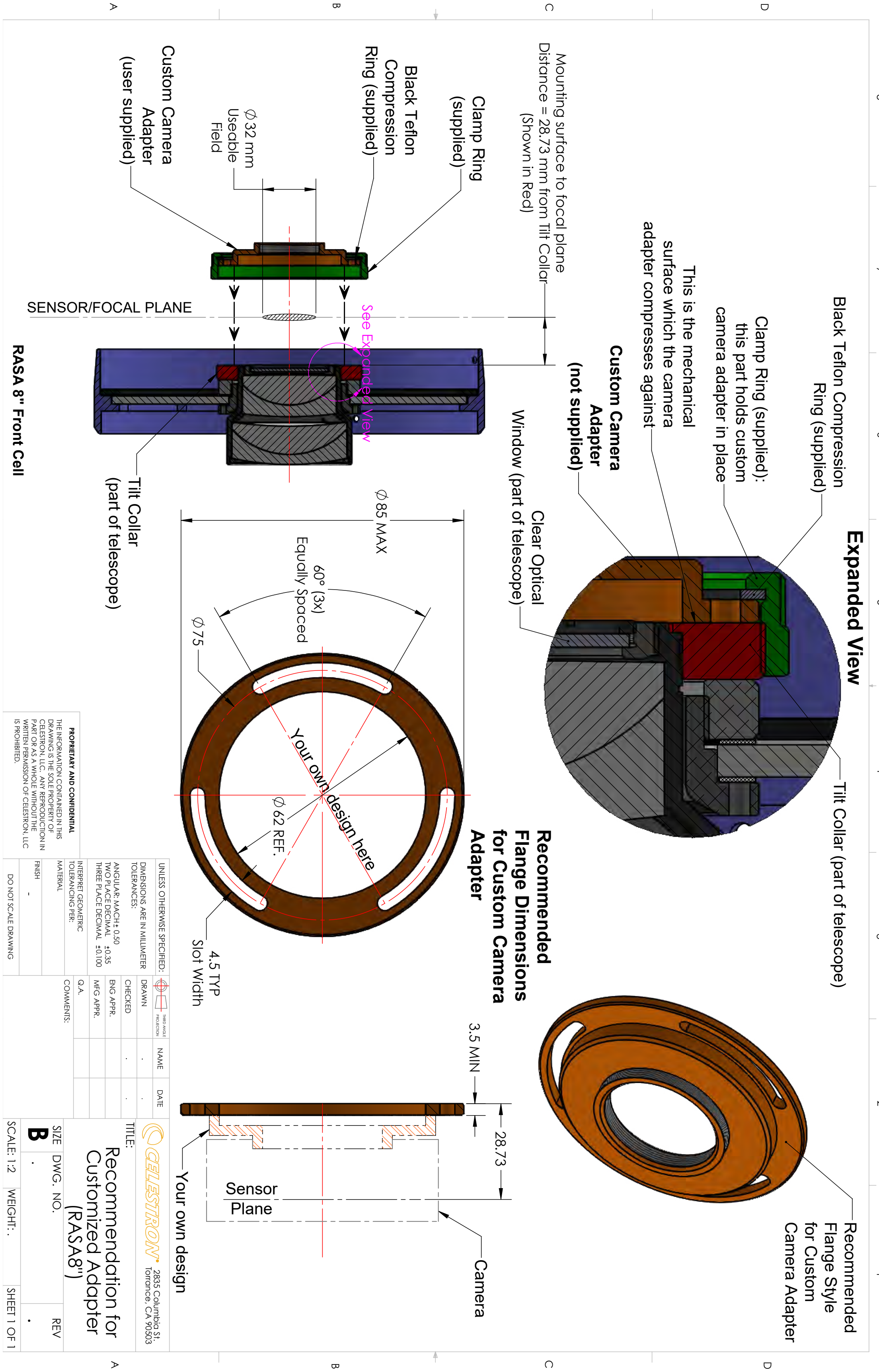


OBJECT: Barnard 33 & NGC 2024, Horsehead and Flame Nebulae
IMAGER: Michael Jäger
EQUIPMENT: RASA 8" f/2.0

Matrix Spot Diagram (18 µm box size)



Custom Camera Adapter Design Considerations



OBJECT: Barnard 33 & NGC 2024, Horsehead and Flame Nebulae
IMAGER: Michael Jäger
EQUIPMENT: RASA 8” f/2.0

FOR MORE INFORMATION:
VISIT: **celestron.com/RASA**
OR EMAIL: **RASA@celestron.com**

US Patent Number: US 9,635,223 B2

22 PAP Carta

Separate waste collection. Check your local municipal guidelines.
Raccolta differenziata. Verifica le disposizioni del tuo Comune.

CELESTRON

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UK: Unit 2 Transigo, Gables Way, Thatcham RG19 4JZ, United Kingdom
This product is designed and intended for use by those 14 years of age and older.
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