The PlaneWave Instruments CDK

An Insider's View of the Origins of PlaneWave Instruments and Its CDK Telescopes

By Richard Hedrick

At PlaneWave Instruments we engineer and manufacture the Corrected Dall-Kirkham (CDK) telescope. This is a wonderful optical design which provides beautiful performance across a large focal plane from a system of remarkably simple optical elements.

The design utilizes an ellipsoidal primary mirror, a spherical secondary mirror, and a two-element lens group near the focal plane of the telescope as shown in **Image 1**. All of these components are optimized to work in concert in order to create superbly pinpoint stars across the entire focal plane.

This is not simply a Dall-Kirkham with a corrector. Rather the CDK is an optical system of its own in which each component is optimized to work in concert with the others to best cancel spherical aberration, off-axis coma and astigmatism, and to create a flat field.

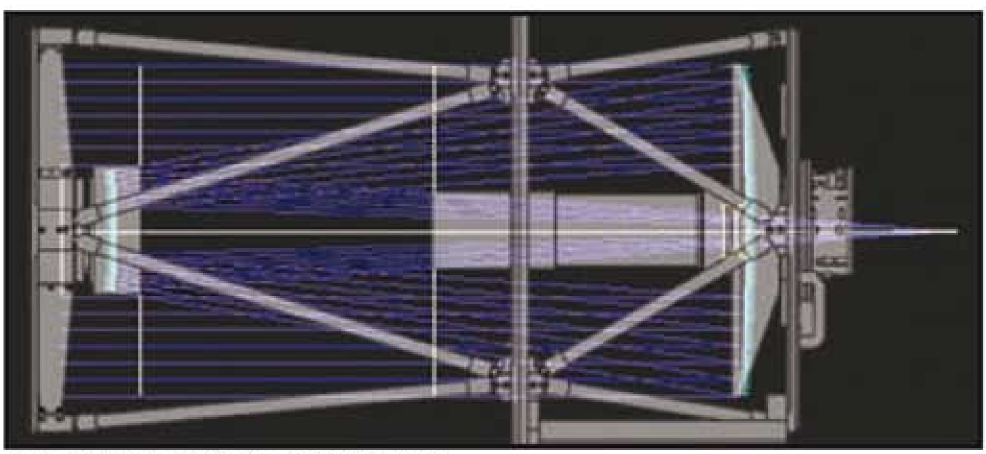

Image 1: The layout of the CDK telescope.

CDK History

The path by which the CDK design came to be is an interesting one. There may be others who have independently come up with this optical design, but I will tell the story of how the CDK was discovered for PlaneWave Instruments. The first design was made for visual use as a hobbiest project.

In 1991 a group of us started a telescope making class at El Camino College in Torrance, California, and quickly developed full-blown telescope making fever. Many great telescopes were made in the class, ranging in apertures from 6 inches to 28 inches, but eventually the core group of telescope makers in the class decided to make a large

Image 2: First light for the CDK 42-inch Dobsonian telescope in front of PlaneWave Instruments.

telescope. This group consisted of Joe Haberman, Jason Fournier, Don Quok, and me, and was lead by the professor of the class, Perry Hacking.

Perry wanted to build a really big telescope for visual use and wanted to do it all by hand. Of course, we spent a great deal of time talking about what the perfect size telescope would be. The question eventually came down to how big of a telescope we could fit into two standard-size pickups, versus what was the largest amateur-made telescope that we knew of at the time: a 41-inch Newtonian. So naturally we decided to make ours "1" bigger, a 42-inch Newt. It didn't hurt that "42" was also the answer to "the life, the universe, and everything" in the popular series, *The Hitchhikers Guide to the Galaxy*.

The problem with a big Newtonian is that the ladder required can be frighteningly tall, especially when used in the dark. So we thought of making a very fast Newtonian – f/3.3. The problem in turn with such a fast Newtonian is off-axis coma, so we started looking at correctors for the Newtonians and eventually settled on a Wynne corrector similar to that used by Palomar. That was our starting point and we optimized the design for our system.

In April 1998 we placed an order for a light-weight 42-inch Pyrex mirror blank. Since we were associated with a college we got a good deal on the blank, but that also meant getting knocked back in the line for delivery – all told, it took 4.5 years to get the blank. Meanwhile, we had concluded that it would be too difficult for us to make the corrector lenses as Wynne correctors feature some very thin lenses with extremely short radii.

Then a local amateur telescope maker, Dave Rowe, happened by. Dave lived nearby and had heard of the telescope making class. One evening, while dining at the Mexican restaurant across from El Camino, Perry explained our efforts to Dave and on the way out, Dave asked whether we had considered a Cassegrain. Perry explained that the secondary mirror of a Classical Cassegrain was too difficult for us to make – Perry said he found it scary (and still does) – so Dave asked about a Dall-Kirkham and Perry concluded that the off-axis performance of that design was too poor.

The next weekend Dave was back again, asking suspiciously leading questions, as if an idea was brewing. One question Perry particularly recalls was: "If you were to place a corrector in front of the focal plane of a Dall-Kirkham, where would you guess would be the best place?" Perry ventured that something around 200 mm seemed a good trade between surface curvatures and the diameters of the elements, at which point Dave revealed that he had an idea to make a fairly simple corrector for a D-K. Perry recalls being very excited at the idea.

At the next weekly meeting, Dave delivered the optical prescription. Apparently Dave already had a basic design he had originally come up with back in 1996 and had optimized it for our project. The result was an incredible design that gave wonderful off-axis performance from lenses that were nevertheless relatively easy to make, and with the aid of a tertiary mirror the eyepiece would only be about six feet off the ground. Eureka! The CDK was born and Dave became a member of the team.

The CDK 42 is only now being completed. By the time we'd finished the optics, everyone's lives had gotten busy (kids, work, etc) and so the telescope sat for many years. Only recently, in April

Image 3: The prototype CDK18 made by Celestron. Pictured are Bob Peasley, mechanical engineer, Joseph Lupica, President of Celestron, and Richard Hedrick, then VP of Engineering at Celestron. The photo was taken in 2003.

of 2009, did we finish putting it together and perform the first star test (**Image 2**).

During the grinding and polishing of the 42-inch primary, we had a lot of time to talk about "the perfect imaging telescope," and Dave Rowe and I discussed possible designs for a flagship telescope for Celestron where I was then VP of Engineering.

After much brainstorming, I brought the idea to Celestron and it was decided that it would make a prototype CDK. The first one we constructed was the 18-inch seen in **Image 3**. After more planning and strategizing with the sales and marketing departments, as well as with Celestron's distributors, we decided on production of a 20-inch CDK. At that point, Celestron hired Joe Haberman, the best mirror maker in the telescope making class, who had also by then started a small optics company called Haberman Optics.

After Celestron's announcement of the C20 and shipment of two units, several events culminated in the conclusion that it no longer made sense to produce the telescope. Joe and I were, of course, extremely disappointed – it was such a wonderful design and we knew it was only a matter of time before others produced the telescope.

During this time the company was sold and the C20 was officially dead. Celestron's president and I discussed the possibility of my independent production of the C20 since Celestron no longer wanted too. Furthermore, a university had placed an order that Celestron would not be able to fill, so Celestron gave Joe and me permission to produce the telescope needed to fill that order. That was the beginning of PlaneWave Instruments. Within six months, Joe and I left Celestron to pursue PlaneWave full time. Celestron was gracious enough to convey the drawings of the C20, now called the CDK20, so we didn't have to start from scratch. Thank you to Joe Lupica, President, and to David Shen, owner of Celestron – both have been very supportive of our new venture.

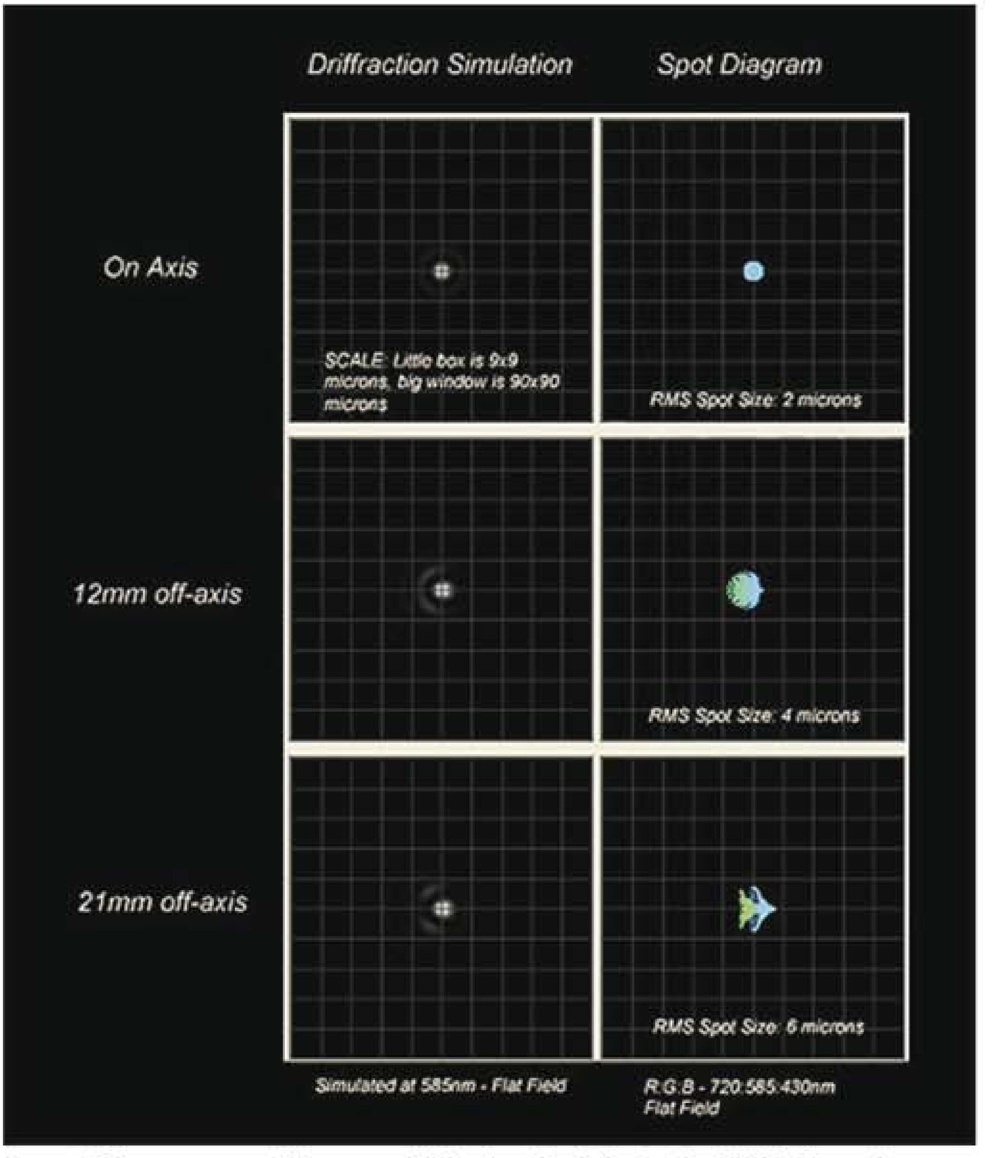

Image 4: Shown are a spot diagram and diffraction simulation for the CDK20. The performance 21 mm off-axis is 6 micron rms spot sizes. 21 mm off-axis is the corner for a full-frame CCD.

CDK Performance

PlaneWave Instruments currently manufactures the CDK in three apertures: the CDK20, the CDK17 and the CDK12.5, with apertures of 20, 17 and 12.5 inches respectively, selling for $32,500, $22,000 and $9990.

There has been a lot of talk about naming telescope designs and I want to be accurate with ours. We call it a CDK – short for "Corrected Dall-Kirkham." But in truth, this is not simply a Dall-Kirkham with a corrector added. While, the design does start as a Dall-Kirkham, to which a lens group is added near the focus, it is then optimized – the system is optimized as a whole. It might be more accurate to call it a "Modified Corrected Dall-Kirkham," but "MCDK" seems like a bit much.

Spot Diagrams

With any high performance telescope, I consider it important to demonstrate optical performance with meaningful spot diagrams and **Figures 4 through 6** provide those for the CDK12.5, the CDK17, and the CDK20. These spot diagrams are shown in three wavelengths and are for a flat field. The spot diagrams are presented on the right side of each figure and diffraction simulations on the left. The small squares are 9 by 9 micron – the same size as a typical CCD pixel. The spot diagrams show how light travels through the optical design if behaving as a ray and the diffraction simula-

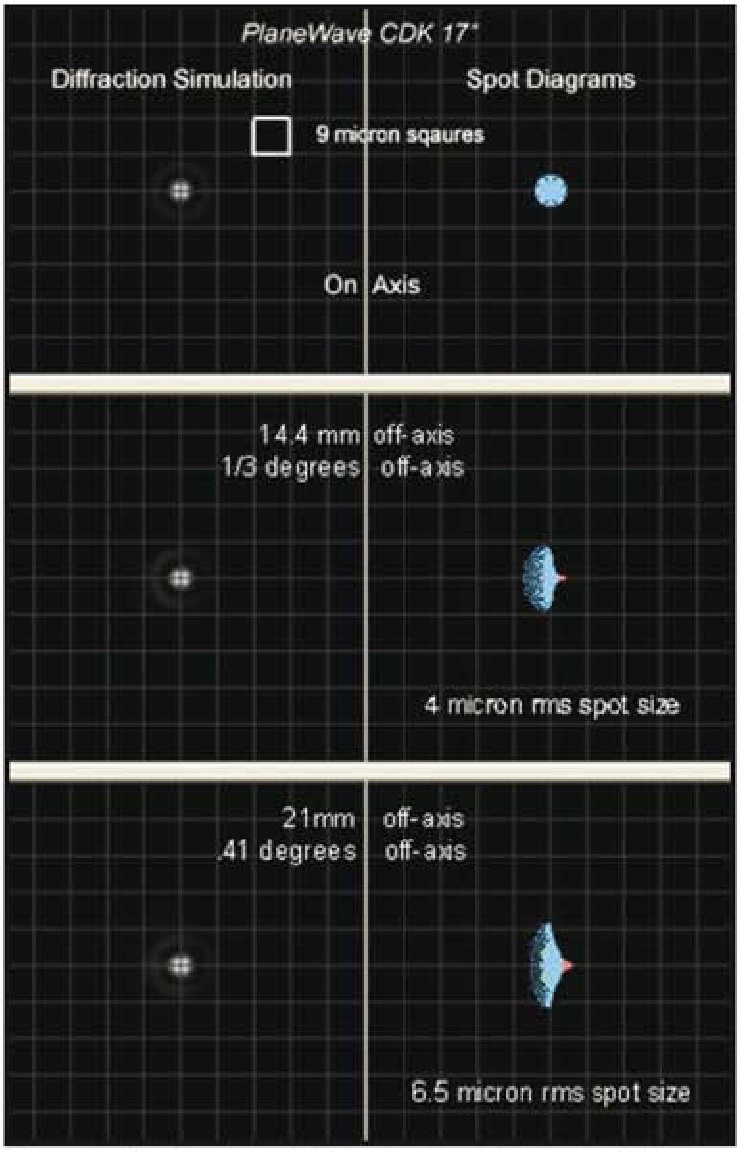

Image 5: Spot diagram and diffraction simulation for the CDK17. The performance 21 mm off-axis is 6.5 micron rms spot sizes. 21 mm off-axis is the corner for a full-frame CCD.

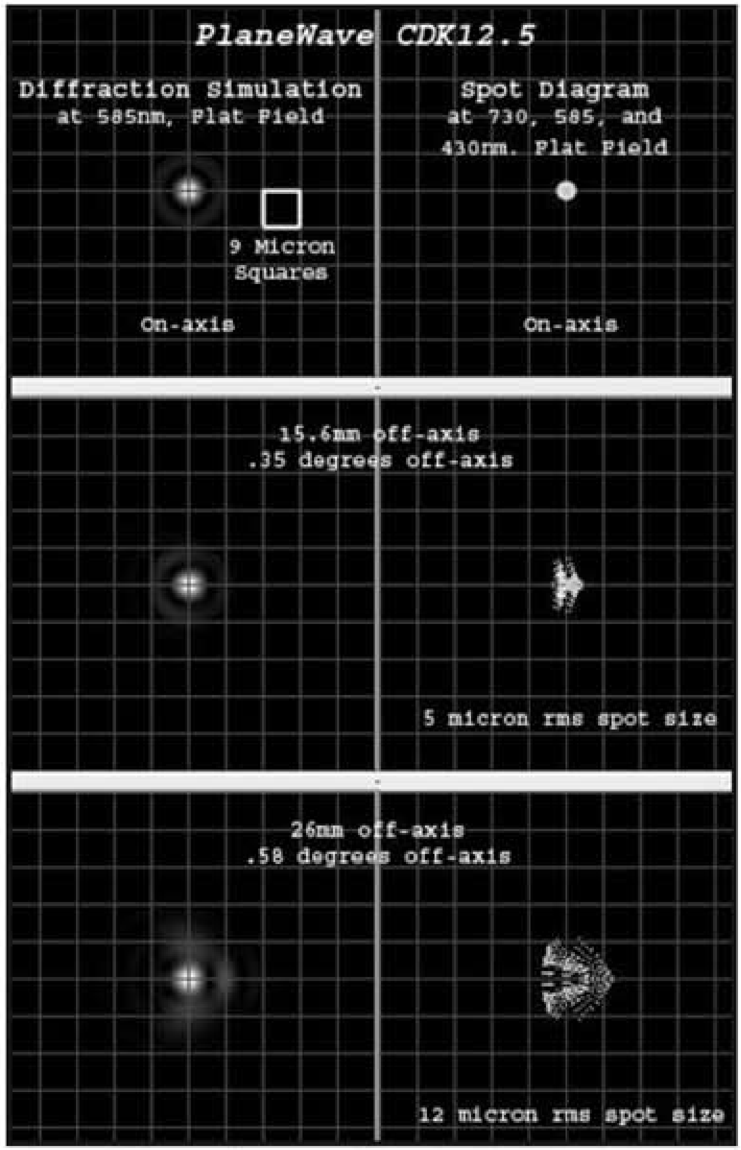

Image 6: The spot diagram and diffraction simulation for the CDK12.5. The performance 21 mm off-axis is 12 micron rms spot sizes. 21 mm off-axis is the corner for a full-frame CCD.

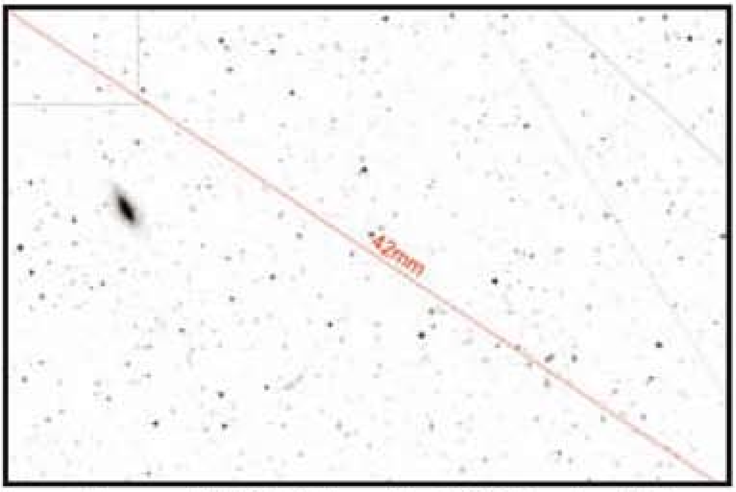

Image 7: Image of NGC7331 taken with a CDK12.5 and an SBIG STL11000 camera. This is a single 600-second image that has been dark subtracted and flat fielded. The image is 42 mm on the diagonal and is meant to show the pinpoint stars across the entire field.

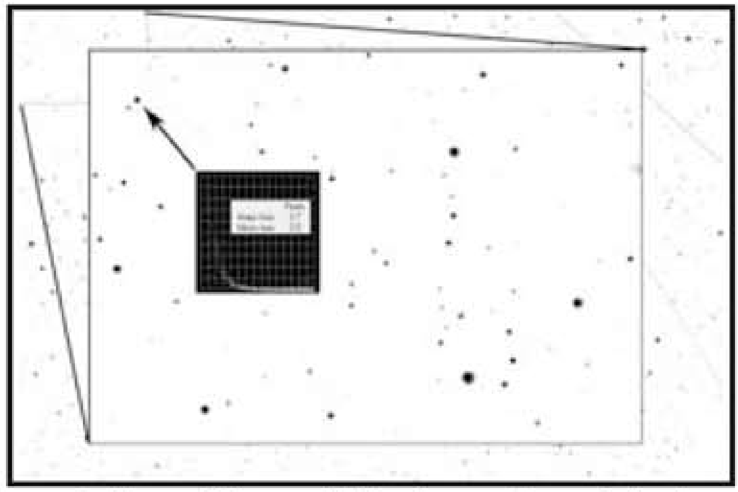

Image 8: Blow up of the upper left-hand corner of Image 7 showing the pinpoint stars 21 mm off-axis of the CDK telescope.

tions demonstrate how the optical design performs if you treat light as a wave. Both are useful tools in understanding how a telescope will perform.

But spot diagrams can be misleading. Many companies demonstrate spots of only one wavelength making it impossible to tell how it will perform under different wavelengths. Some diagrams also hedge bets by showing performance for a curved field. If the telescope is to be used only visually, that may not be a problem because the eye can compensate for some amount of field curvature. But, if the telescope is used for imaging, then such reports can be misleading. If a telescope has a curved field, stars in the center will be in focus and stars at the field edges will be out of focus. If the spot diagram is displayed for a curved field, off-axis stars will look much better in the diagram than the system will deliver when imaging.

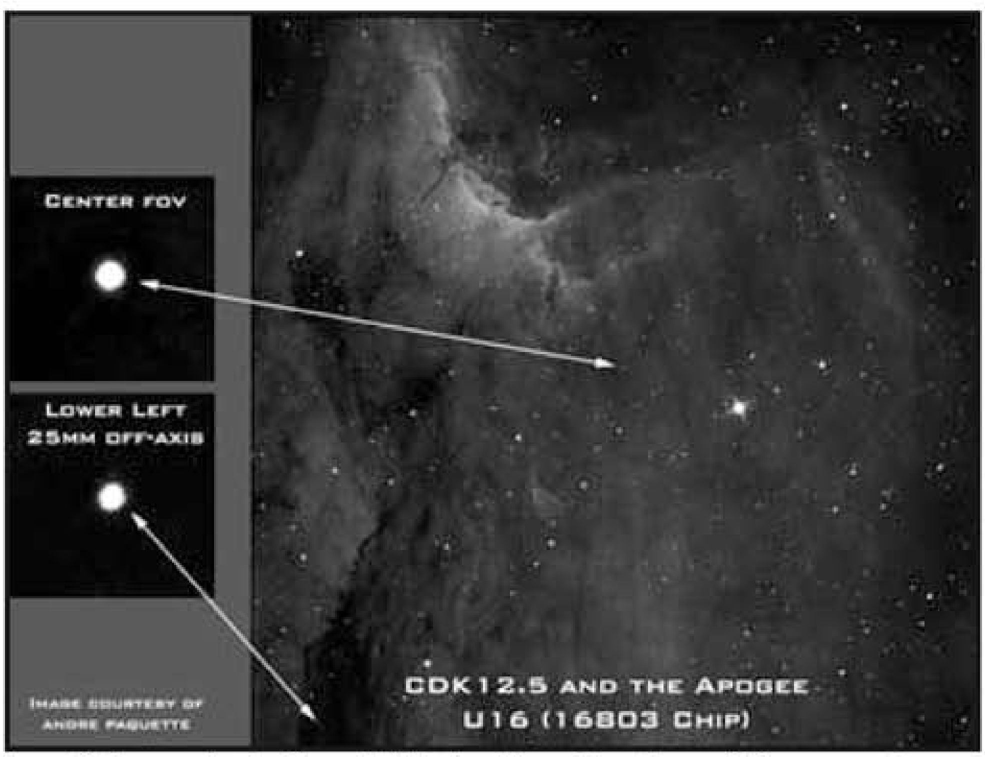

Image 9: An example of a 52-mm field of view taken with an Apogee U16 camera and a CDK12.5. On the left is a star near the center of the field and on the right a star near the lower left corner of the field 25 mm off-axis.

Another way to hedge spot diagrams is to conceal the scale or spot size. Such a diagram may show a favorable comparison against a relatively poorly performing design, while not allowing meaningful comparison to high-performing designs for lack of meaningful spot scale.

This is why we try to provide the fullest meaningful disclosure of our optical design. Our spot diagrams reflect performance on a flat focal plane and are shown in three wavelengths so you are getting the complete story. We also provide a scale to compare against as well as the RMS spot size of off-axis stars (typically the point of interest as on-axis spots are going to be limited by diffraction).

Image Performance

So, in our efforts to explain the merits of the CDK design, we provide what we know to be meaningful spot diagrams. But, the more we show people these spot diagrams, the more we realize that they fail to convey the full story. We eventually con-

Image 10: M33 taken with an Apogee U16 with a 52-mm field corner to corner taken on a CDK20. Notice the perfect stars across the entire field. Image courtesy of Andre Paquette.

cluded that showing actual results of stars on and off axis was a much better way to go (**see the examples in Images 7, 8, and 9**). Image 7 presents a full frame of NGC7331 – the field is 42 mm on the diagonal. Image 8 shows a blow up of the upper left hand corner of that image and demonstrates the pin-point stars produced at the edge of the field. Image 9 was taken with a CDK12.5 with an Apogee U16 camera that has a 52-mm field on the diagonal. The image presents a star near the center of the field and a star near the corner of the field, again best illustrating the incredible performance of the optical design.

PlaneWave CDK Features

The PlaneWave CDK is not just a high performance optical design, it is also a well-engineered instrument. As explained earlier, the features start with the optical performance. The design has a flat, coma-free field, with no off-axis astigmatism over a 52-mm focal plane. The system is f/6.8 for the CDK17 and the CDK20, and f/8 for the CDK12.5. The CDK17 and CDK20 come with a 3.5-inch ID focuser that can be manually rotated 360 degrees, and the CDK12.5 features a 2.75-inch ID focuser which can also be rotated. Both focusers run on a lead screw so there is no slipping or movement as the angle relative to gravity changes.

The primary mirrors are conical shaped and thus have lower thermal mass, so equilibration is fairly fast. The primary mirrors are glued to the mirror cell at the center of mass so no external torques act on the mirror as the gravity vector changes. The mirrors are also laser aligned to the mirror cell so their optical axes are true to the mechanical axis. This ensures that you won't end up with a tilted field at the focal plane and makes collimation surprisingly easy for such a high-performance imaging platform. Since the secondary mirror is spherical, collimation is accomplished by tip-tilt of the secondary only. There is no need to go to great the lengths necessary to center the secondary over the optical axis of the primary as with an R-C design.

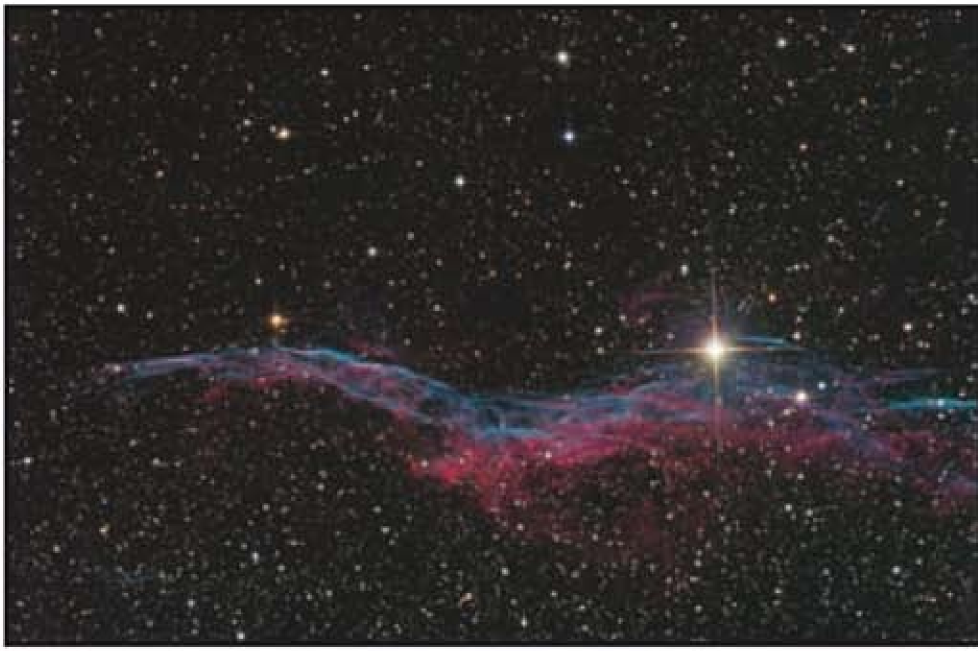

Image 11: A portion of the Veil Nebula taken with the CDK17 and the SLT11000 camera. It combines LRGBs of 20 minutes each and is courtesy of Johannes Schedler. With a 42-mm diagonal, this image is another example of the full-field performance of the CDK design.

The CDK17 and 20 optical tubes use dual carbon-fiber trusses to minimize thermal expansion and contraction and to provide a light-weight, stiff structure. The CDK12.5 uses a closed carbon-fiber tube. And the large dovetail used to mount the telescopes features an expansion joint to allow for the different thermal expansion of aluminum versus the carbon fiber structure.

These features, along with the benefits inherent to the CDK optical design, ensure that each PlaneWave telescope is a high-performing, well-engineered instrument.

What is New at PlaneWave

PlaneWave Instruments is currently working on several exciting new projects, including a 0.66 reducer we are soon introducing that will work with the CDK12.5, CDK17 and CDK20. We also have a CDK24 under design that is probably about six months away from production. It will have a focal ratio of around f/6.8 and will feature more back focus than the current models. It will also cover an even larger 70-mm focal plane.

We are also working on an observatory-class complete system designated the CDK700, a 0.7 meter alt-az CDK with Nasmyth focus and with direct-drive motors and high resolution encoders on each axis. The CDK700 will be around f/6.5 and will also cover a 70-mm field of view. The direct-drive motors have zero backlash and zero periodic and non-periodic error. This telescope is intended to bring the features and advantages of larger professional telescopes to a much wider market and we anticipate delivery of the first unit by the end of this year.

I invite you to visit www.planewaveinstruments.com for regular updates on these and other new products. ATT

CAD drawing of the CDK700. This is a Nasmyth focus 0.7 meter alt-az telescope.