Advantages of the Ritchey–Chrétien Telescope Design
vs CDK (The Complete Story!)

You may have read promotional brochures or viewed websites that compare the CDK design to the Ritchey–Chrétien telescope design. After reading this literature it's possible that you believe the CDK design is superior to the RC. *That is far from the truth.* Read on for an accurate and comprehensive approach to this comparison. If you're in a hurry, you can jump to the summary.

History

Ritchey–Chrétien (RC)

The RC design was created by George Ritchey & Henri Chrétien in 1910, and is a variant of the Cassegrain telescope. The RC uses a hyperbolic primary mirror and a hyperbolic secondary mirror. Perhaps less well-known is the fact that the RC's two-mirror design has the smallest off-axis aberrations of any two-mirror design. It is the design most commonly used in professional telescopes including the Hubble Space Telescope, the Keck I & Keck II telescopes, and the ESO Very Large Telescope.

Dall Kirkham (DK)

The Dall Kirkham design was created by Horace Dall in 1928 and uses an elliptical shaped primary and pure spherical secondary mirror. These mirrors are easy and inexpensive to produce. The 'CDK' design that we will discuss later therefore represents a corrected Dall Kirkham telescope.

Apples-to-Oranges Comparison…

The CDK promotional literature compares a corrected Dall Kirkham to an uncorrected Ritchey–Chrétien. Any conclusions drawn from this comparison are quite frankly, not useful. Meaningful comparisons we will explore include:

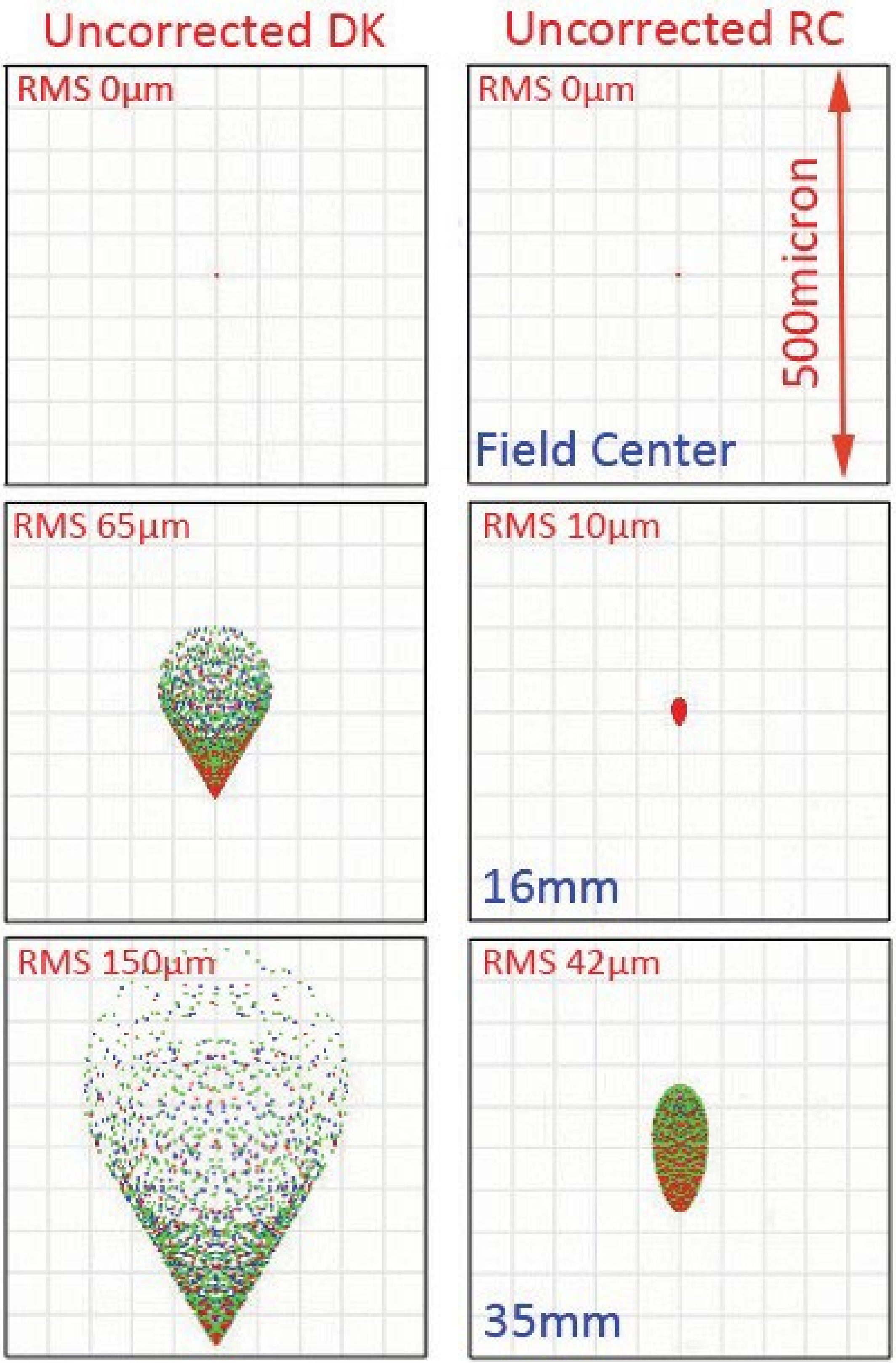
- an uncorrected Dall Kirkham and an uncorrected Ritchey–Chrétien
- a CDK and a corrected RC*

*Please note that ASA routinely supplies our Ritchey–Chrétien telescopes with a two-lens corrector. The corrector is optional with an RC, while the corrector is effectively mandatory with the CDK! Read on to find out why…

Comparison One: Uncorrected Dall Kirkham vs. Uncorrected Ritchey–Chrétien

The example below is calculated with an f/2.93 primary mirror and f/6.5 system focal ratio (similar to the design values used by our competition). As we will demonstrate later, this optical configuration is less than ideal as it requires a large central obstruction. For now, we will use this design for comparison purposes and suggest better design later.

Uncorrected Dall Kirkham vs. uncorrected Ritchey–Chrétien



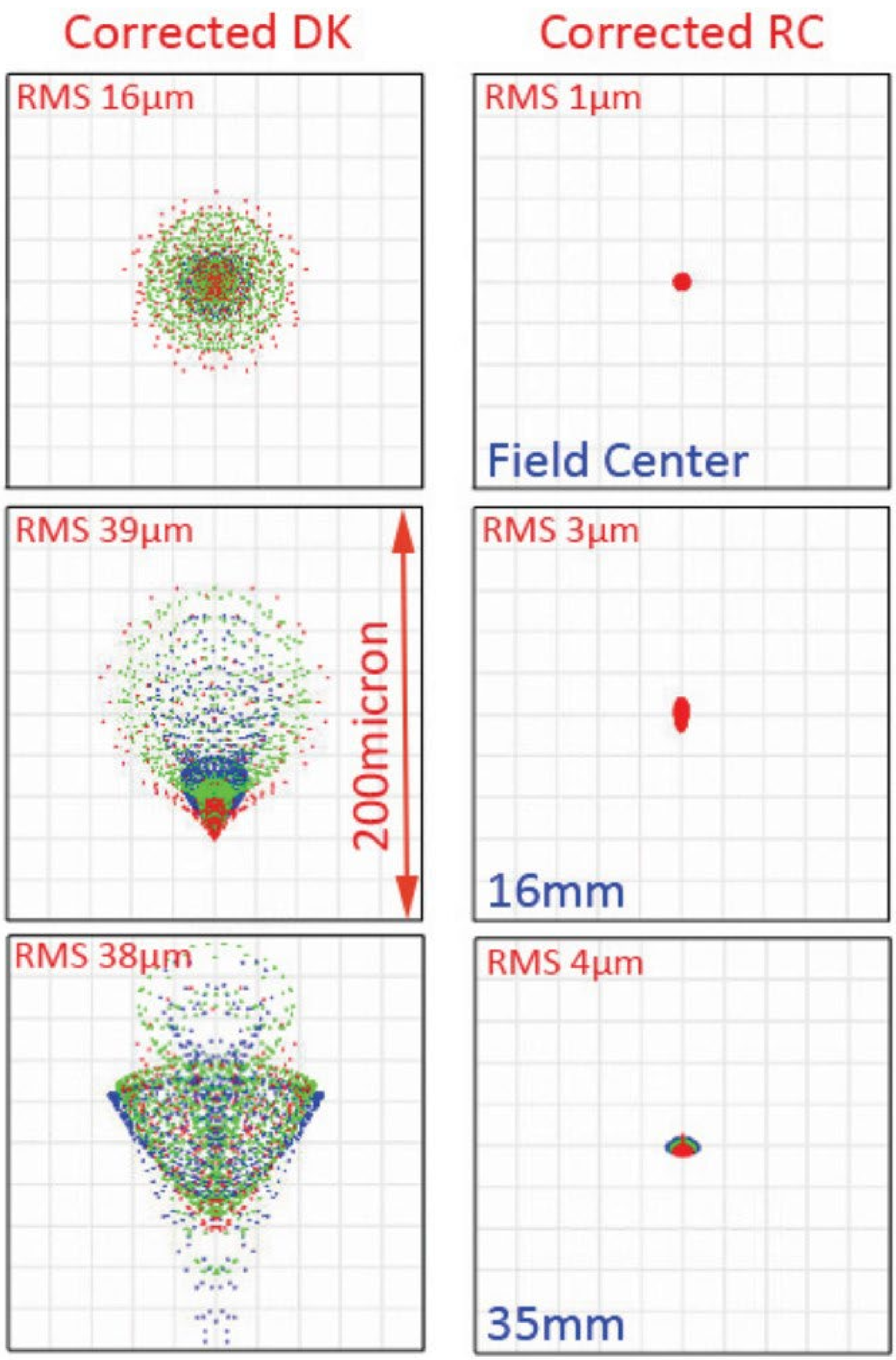
In the above comparisons, the small box size represents 50 microns and the large box size, 500 microns (0.5mm). The RMS Values are RMS radius. This the radius where appr. 80% of the light is contained. 10 micron equals 0.5 arc sec. at 4540mm focal length. Wavelengths used for the spot diagrams have been 430nm, 555nm and 700nm.

Results:

- Both systems perform perfect in the field center (assumed the optics are perfectly finished)
- The off-axis performance is 6x better for the RC
- The DK off-axis performance is completely useless even for small field sizes and CCD
- RC can be well used for CCD sensors up to 40mm diameter without a corrector

Comparison Two: Corrected DK (CDK) vs. Corrected RC (CRC)

As a first step we will now add a two-lens corrector to the two systems above and examine their performance again. With a modern Raytracing Software like Zemax you can choose a glass catalogue like Schott, define the location for the corrector and Zemax needs less than a minute to find the optimum solution. The quality depends a little bit on the location of the two-lens corrector so we assumed the optimum location.


Corrected DK
Corrected RC
RMS 16µm
RMS 1µm
Field Center
RMS 39µm
200micron
RMS 3µm
16mm
RMS 38µm
RMS 4µm
35mm

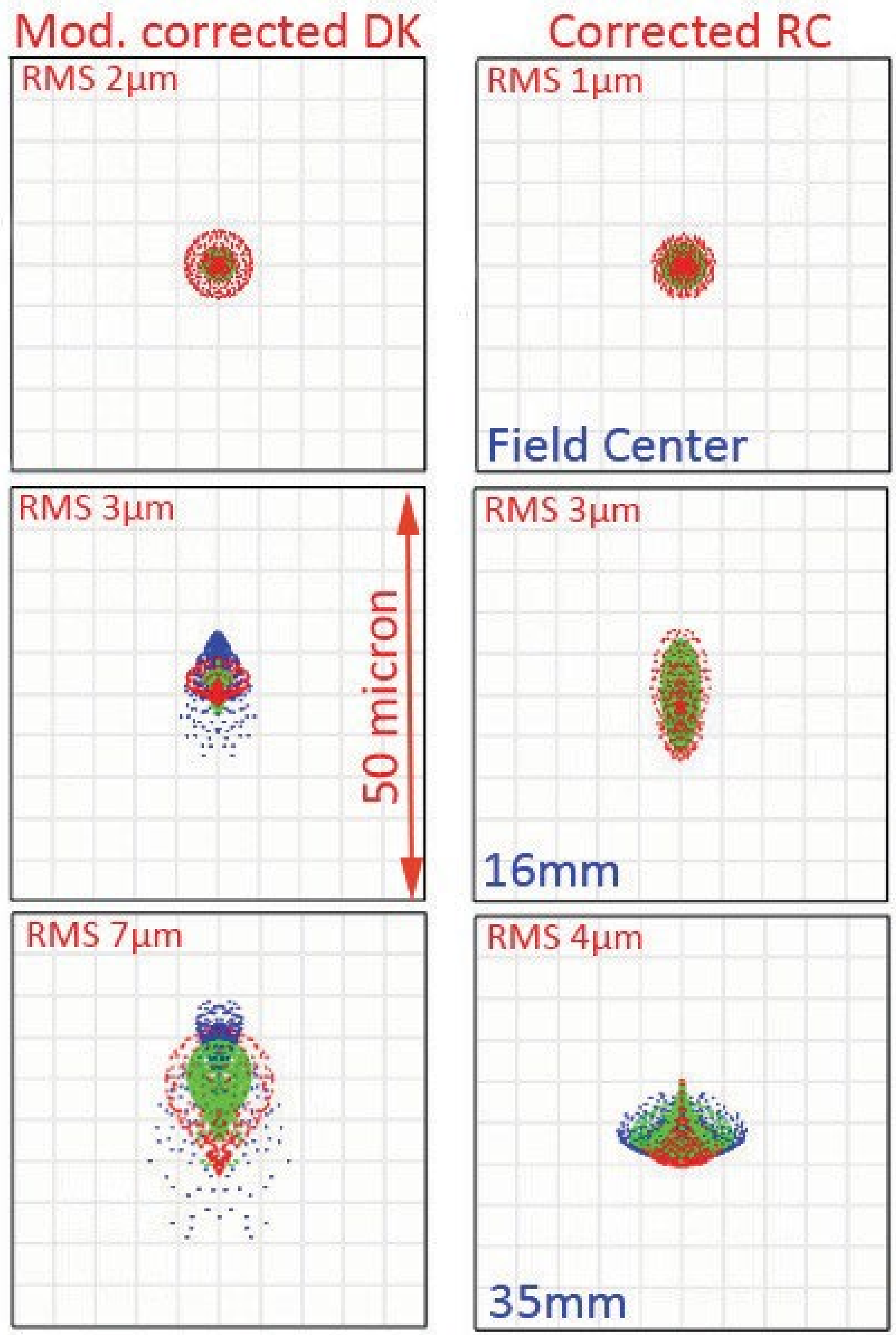
The off-axis errors of the original Dall Kirkham are too large to be corrected effectively with a two-lens corrector. The RC on the other hand, provides seeing-limited performance over a 70mm diameter field, with a simple two-lens corrector.

The overall off-axis performance of the corrected Dall Kirkham can be improved if the elliptical shape of the primary mirror is changed while maintaining the inexpensive spherical secondary. This is what some companies undertake to reach a sufficient off-axis performance. Below, we will examine such a system against an RC with two-lens corrector (the same RC system as described in Comparison Two). In this case we will reduce the box size to 50 microns to magnify the errors. The CDK in Comparison Three has a corrector that **cannot be removed as the system will not work without it even in the field center.**

Please note that systems with permanent correctors installed have several disadvantages:

1) The wavelength range is limited due to chromatic errors but also due to the transmissivity of the optical glasses used which blocks wavelengths below 400nm. These systems cannot be used in UV!
2) Every lens in the light beam reduces contrast and adds ghost images even if the coating is perfect.
3) If the field flattener cannot be removed, it is more difficult (and compromising) to add a dedicated reducer.

Comparison Three: Modified Corrected DK (CDK) vs. Corrected RC (CRC)



Result: Both systems will perform well on this CCD size with some slight advantages for the RC.

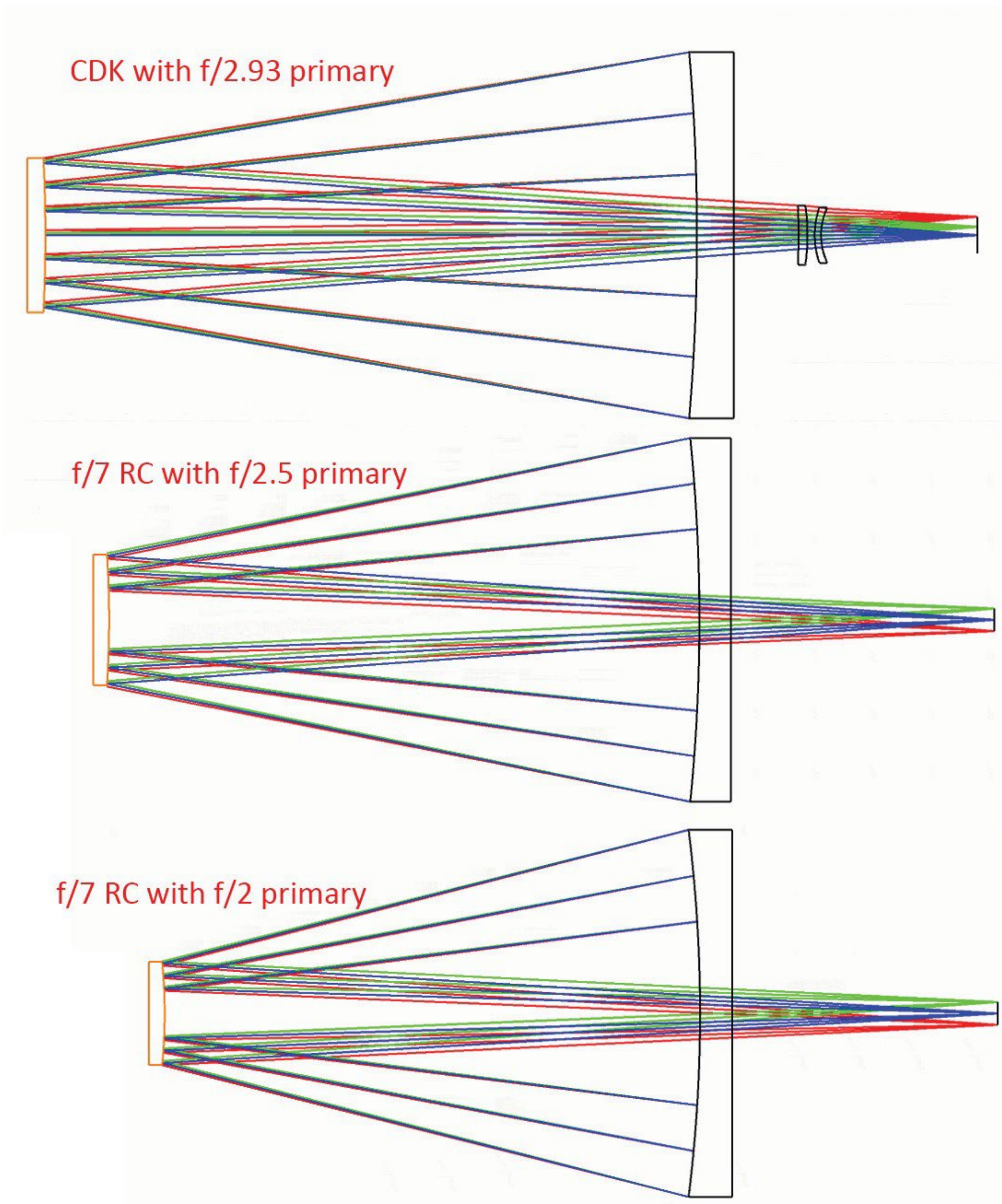
The significant disadvantage of the modified Corrected Dall Kirkham (left side) is the fact that it will not be possible to use it without corrector. In this case, since the shape of the primary has been changed, the system will suffer from severe spherical aberration in the field center if you remove the corrector. If you have such a system, you can try it without the corrector and you will not find a satisfying focus.

The RC on the other hand can be always be used without a corrector. The versatility of the RC is that it can be used for high resolution planetary targets and imaging objects without spectral restrictions, or wide-field imaging with a reducer when need appropriate. An RC with a removable corrector is the best of both worlds.

Primary mirror ROC (Radius of Curvature)

Although we have calculated the examples thus far with an f/2.93 primary design, a shorter focal length primary mirror is always preferred. Depending on the system we use an f/2 or f/2.5 primary mirror.

Physical Attributes Comparison: Below you can see the scaled comparison between the different optical layouts.

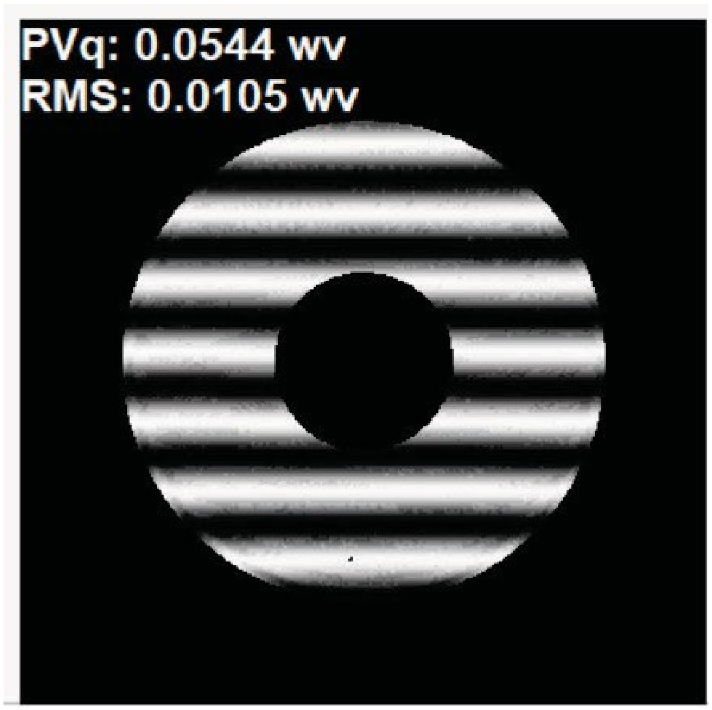


ASA's OTAs with a short primary ROC are compact, allowing for smaller enclosures (domes) and smaller secondary mirrors. Our OTA central obstructions are 36% with an f/2 primary, and 40% with an f/2.5 primary. Compare this to the 47% central obstruction in the CDK with an f/2.93 primary. It is well known that larger central obstructions produce lower contrast images. They also reduce the *effective* focal ratio.

An f/6.5 system with a 47% central obscuration has an effective focal ratio of only f/7.4. This is hardly any faster than the f/7 – f/2 RC system which reaches a f/7.5 effective f-number.

Why ASA can make it - and others choose not to?

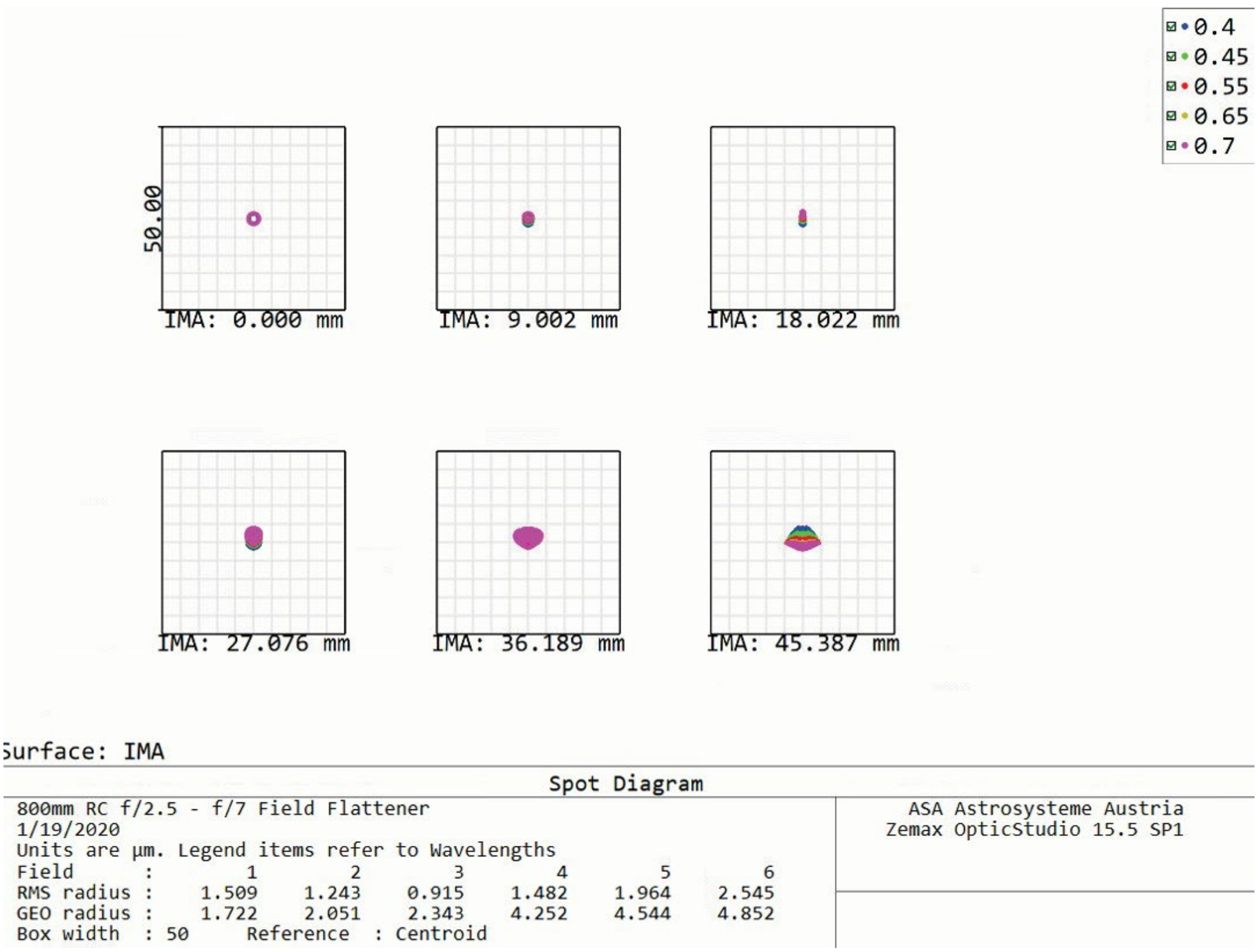
Designing and fabricating short focal length primary mirrors places a sizable emphasis on the required optical expertise a company must possess. It is not only the hyperbolic secondary, the optical finesse necessary to make an f/2 hyperbolic primary RC mirror is massive when compared to the f/2.93 elliptical shaped CDK primary. While the maximum deviation from sphere is only 4 microns in the case of the 700mm CDK primary, it is 27 microns in the case of the f/2 hyperbolic RC primary. We therefore understand, why some optical shops hesitate to produce f/2.5 primary mirrors or faster - even if they understand the advantages in the telescope design and performance. ASA has developed special polishing tools and techniques to succeed in these steep aspheric surfaces and we can reach up to 99 Strehl while keeping an ultra-smooth surface at the same time.



Interferogram of a f/2 hyperbolic primary manufactured in the ASA optical shop.

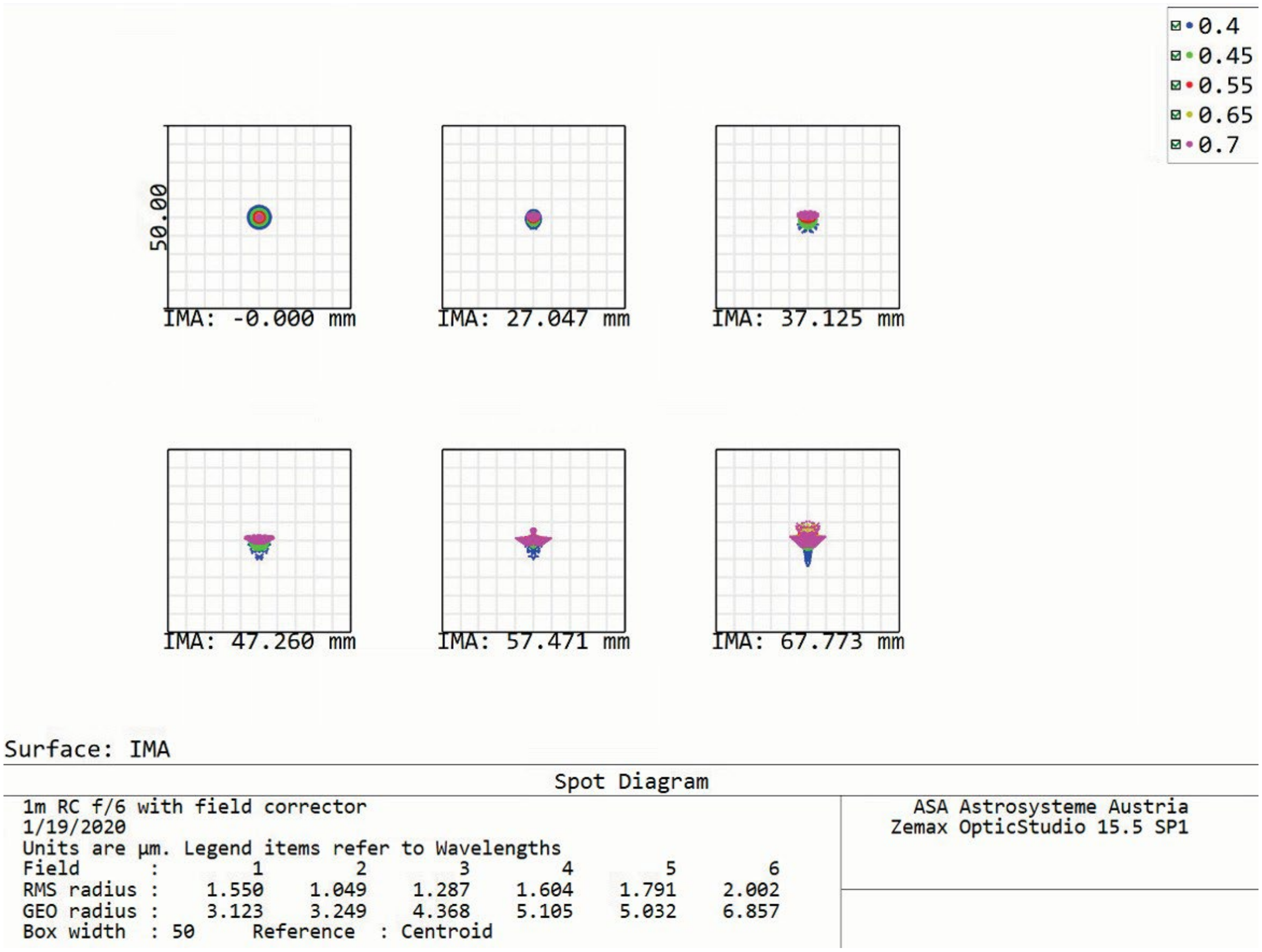
ASA corrector examples

Below you are spot diagrams of our 800mm f/7 – f/2.5 RC with our standard field flattener. As you can see, we are also using 400nm in our wavelength calculation because most blue filters have a cutoff there and not at 430nm.



The result is seeing-limited performance even in Paranal Seeing conditions up to 90mm field size.

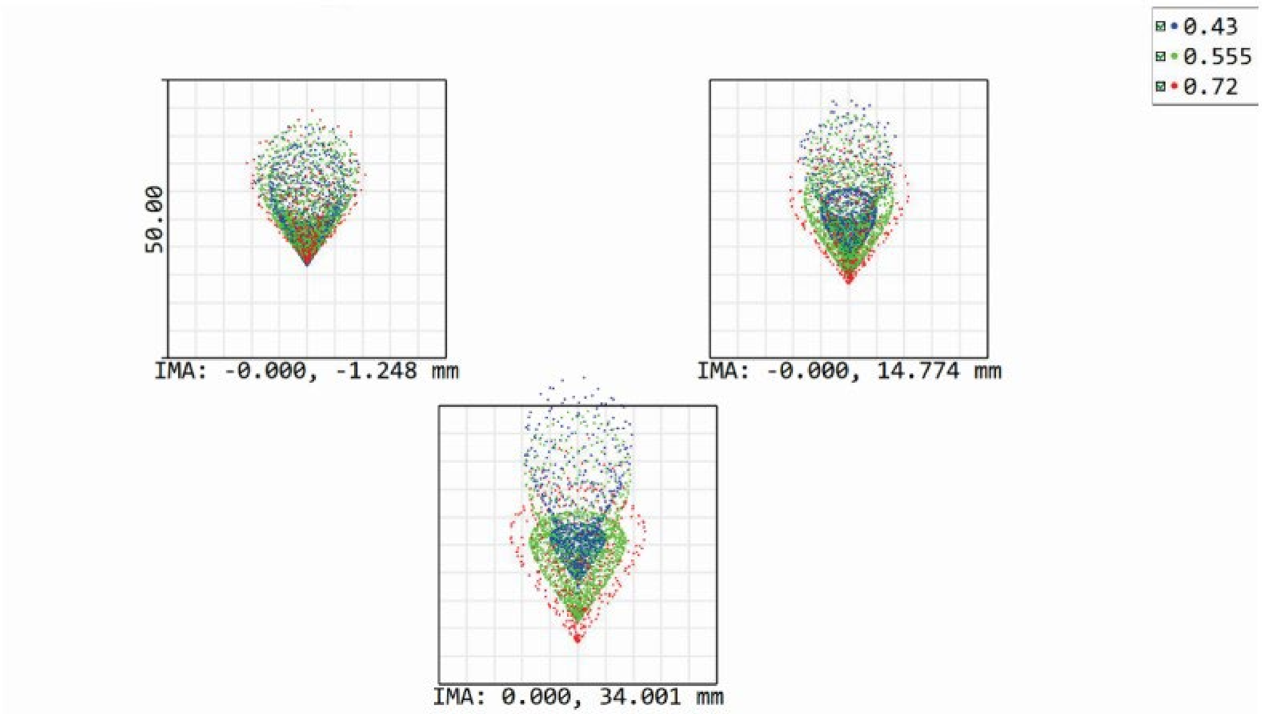
The next example is of a system we offer for the next generation of large CCD cameras and which has been delivered and commissioned already, it is a 1m system with a modified RC design and a 3-lens corrector:



The seeing-limited field size is 135mm. You will not reach this performance if you limit the optical design with a spherical secondary mirror used in a Dall Kirkham system.

More Myth Busting

Another myth you may have heard mentioned is the RC's higher sensitivity to collimation errors. Let's also shed some light on this myth as well:



Surface: IMA

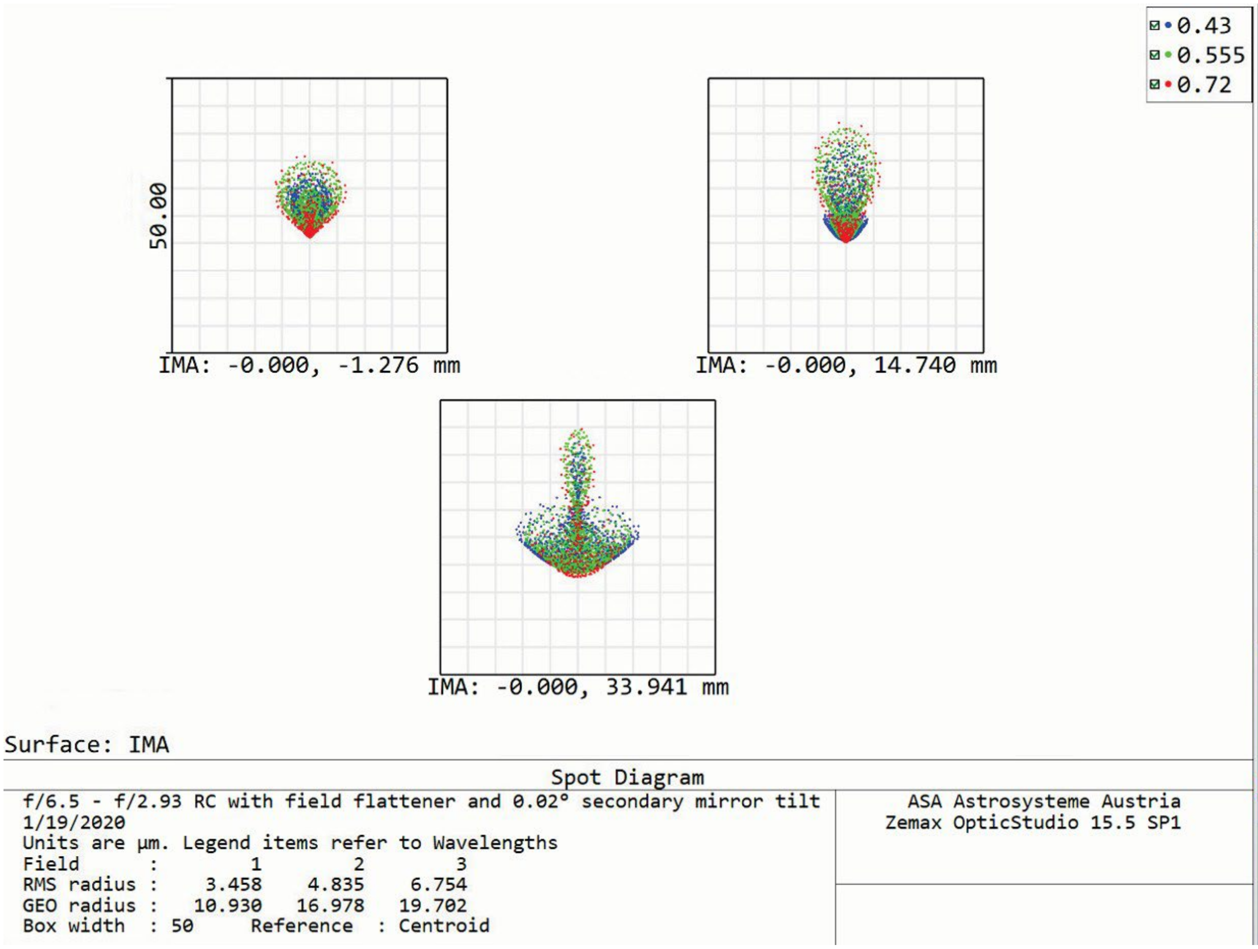
Spot Diagram

CDK with 0.02° secondary tilt
1/19/2020
Units are µm. Legend items refer to Wavelengths

Field :	1	2	3
RMS radius :	6.837	7.163	8.873
GEO radius :	19.600	21.375	30.101

Box width : 50 Reference : Centroid

ASA Astrosysteme Austria
Zemax OpticStudio 15.5 SP1

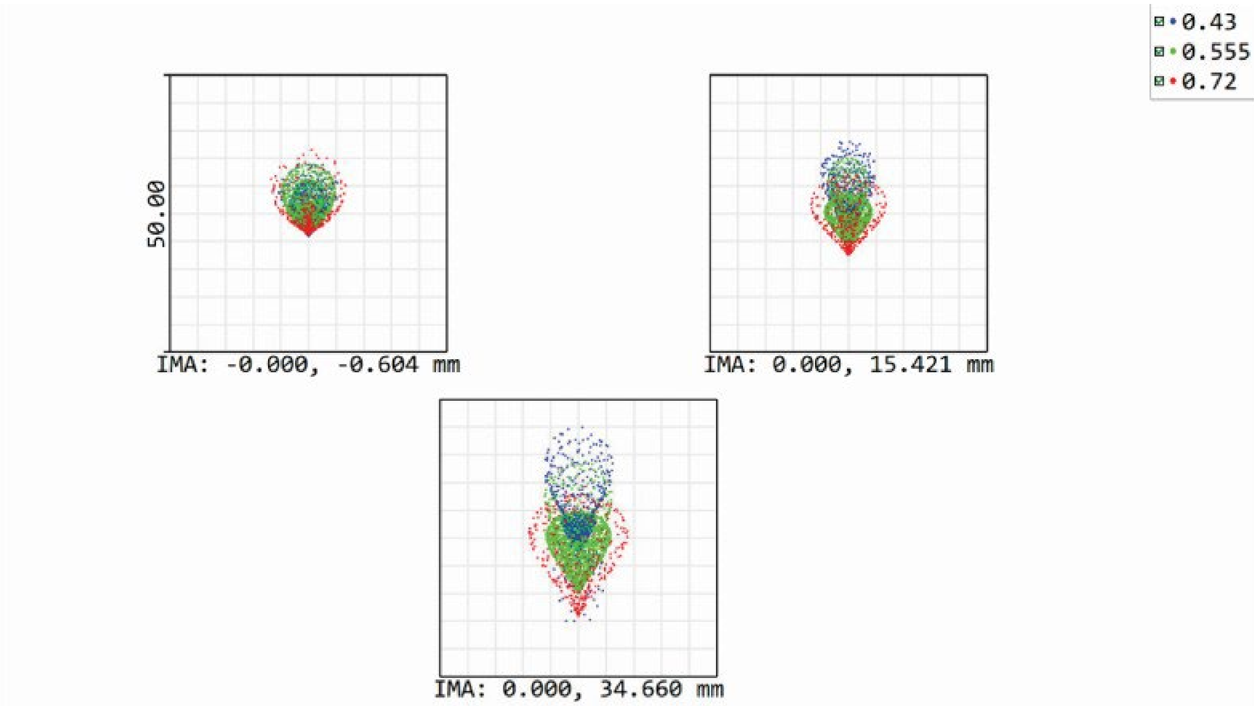


In above examples we have used the:

- f/6.5 – f/2.93 CDK with an optimized elliptical primary
- f/6.5 – f/2.93 RC with corrector

In this case we have tilted the secondary mirror by 0.02°. If we assume a 300mm diameter secondary, this means a tilt of 0.1mm at one side. The result may surprise some people but it's an indisputable optical fact: the RC with corrector is *less sensitive* to the secondary tilt than the CDK.

It is also useful to examine the centering error. Let's consider a secondary centering error of 0.5mm.



Surface: IMA

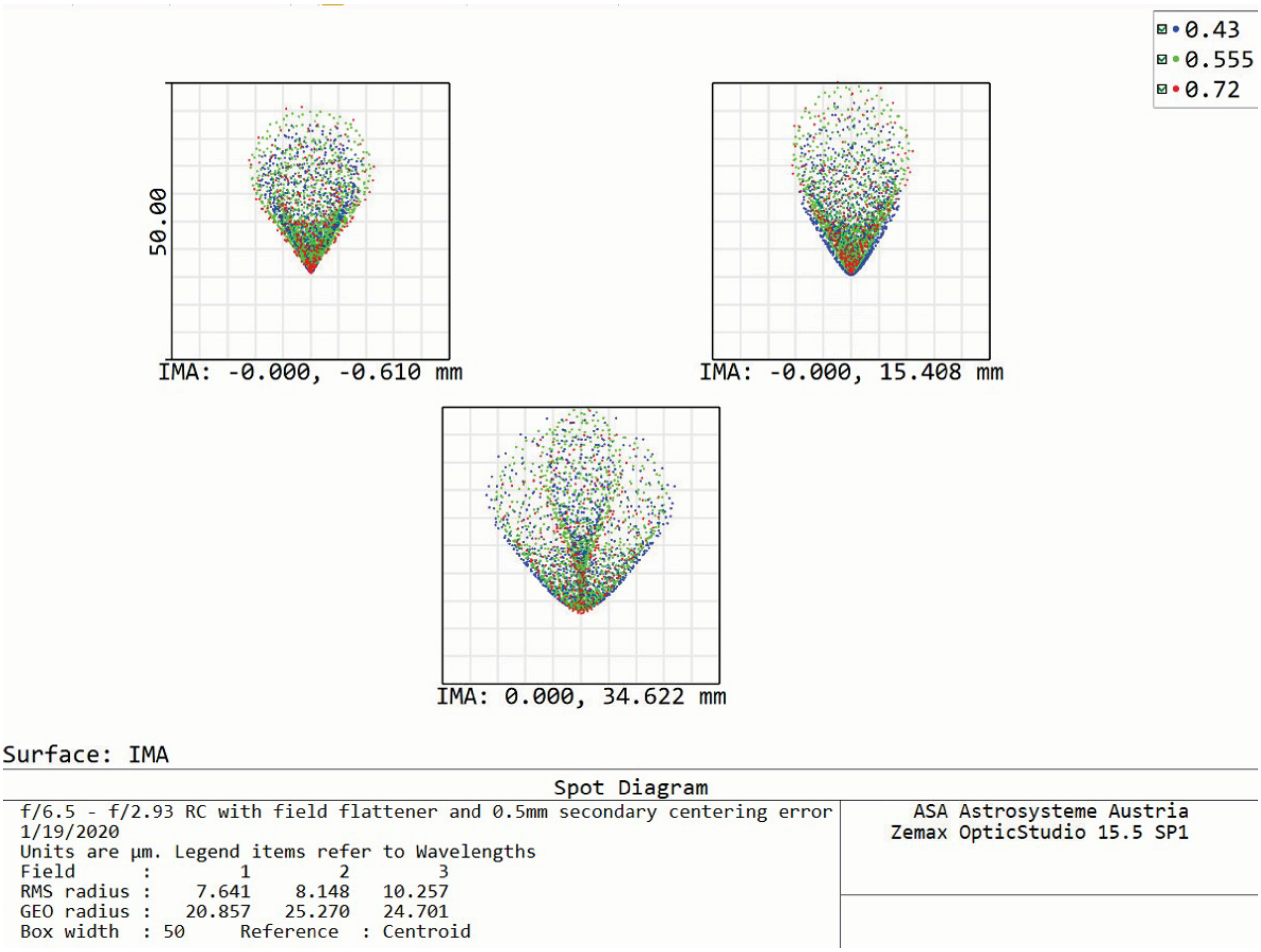
Spot Diagram

CDK with 0.02° with 0.5mm secondary decenter
1/19/2020
Units are µm. Legend items refer to Wavelengths

Field	1	2	3
RMS radius	3.533	4.011	6.189
GEO radius	11.532	13.042	19.982

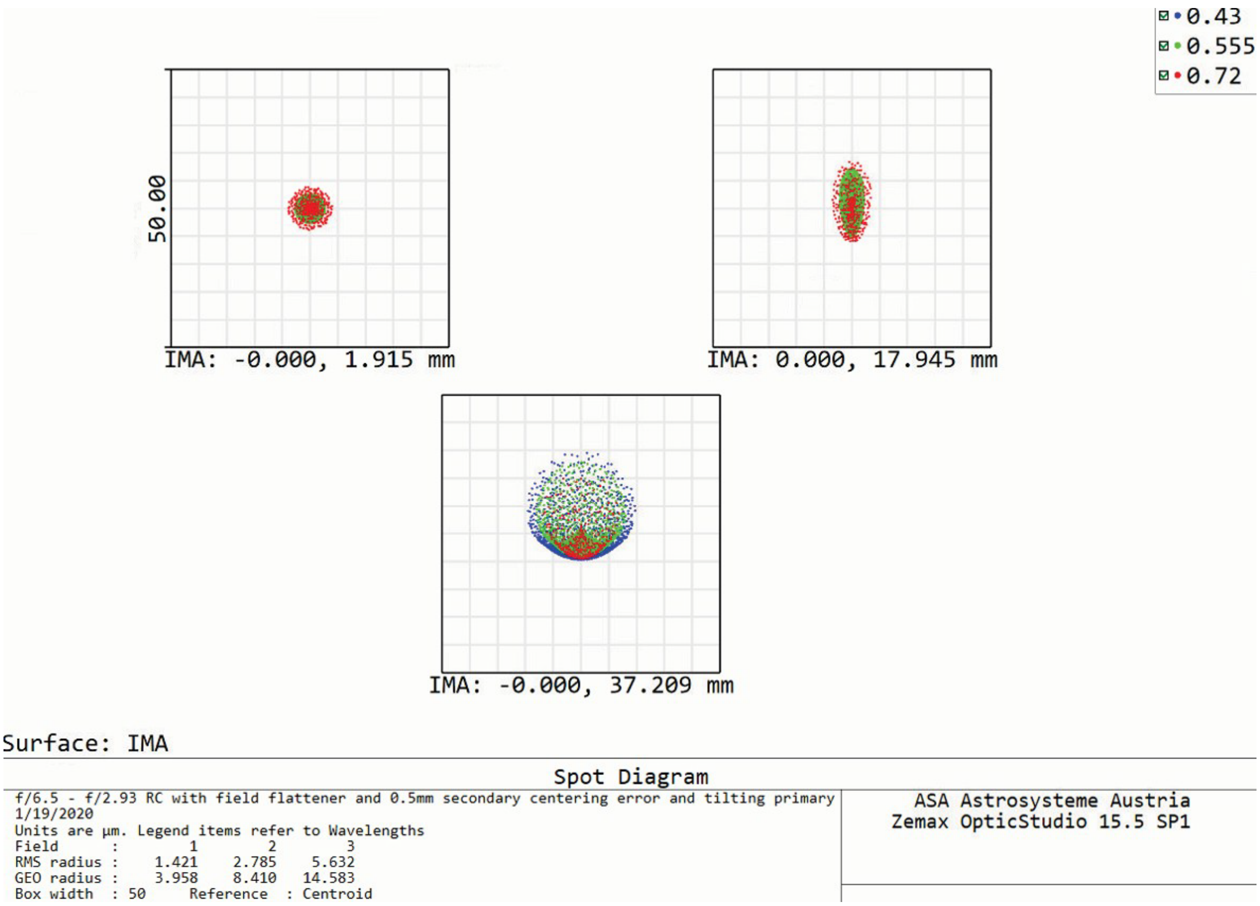
Box width : 50 Reference : Centroid

ASA Astrosysteme Austria
Zemax OpticStudio 15.5 SP1



In this case we can see a larger error in the case of the RC telescope. (It is however, nowhere near the 5x factor mentioned by our competitor.)

Even more interesting - Most of the secondary center and tilt errors can be compensated by the final main mirror collimation with a star (looking at the in and out of focus images). Every owner of a Newtonian telescope is used to this procedure. Most customers need only 1-2 minutes to perform the final collimation.

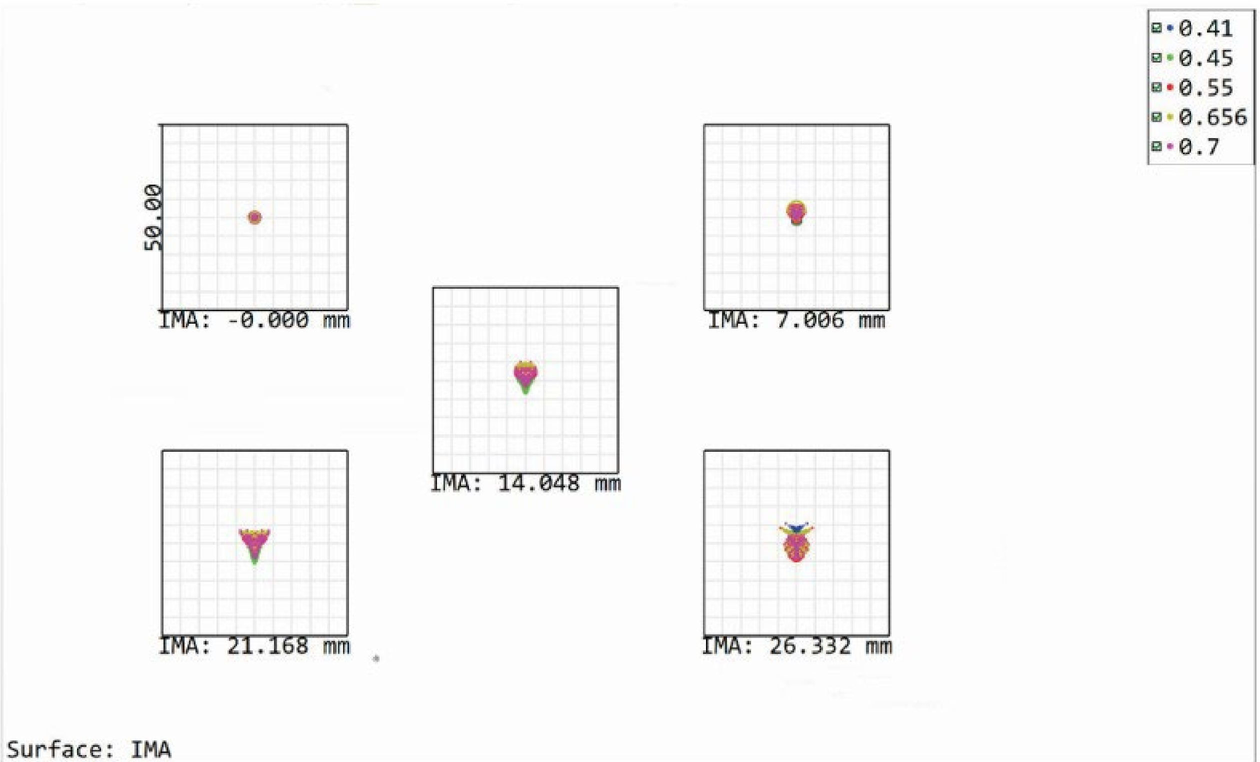


For example: to correct the secondary centering error, the main mirror would be tilted by 0.015°. This is shown in the above spot diagram. It proves that all the collimation errors can finally be corrected by ONE optical element (unless the errors would be huge, like 5mm secondary centering error). This happens completely automatically and is straightforward if the customer removes the coma by centering the central obscuration visible in the in and out of focus images. Every RC can be collimated in 5 minutes with a simple laser collimator and a star. Just as important – our mechanical implementation of the RC design has stable collimation over time!

Corrector flexibility and Reducer quality

With the RC design, you can optimize the reducer with the least number of lenses without having to take a corrector into account. ASA would never use a reducer behind our field flattener. Unfortunately for the customer - this is what an optical designer has to do if he has to put a reducer in a CDK with fixed lens corrector.

The next example is our standard 0.65x reducer for the 800mm f/7 - f/2.5 RC. This is a mid-size reducer that we offer for this telescope and it will work with image diagonals of 55mm. At ASA, the customer has the choice between three different reducers for different sized CCDs.



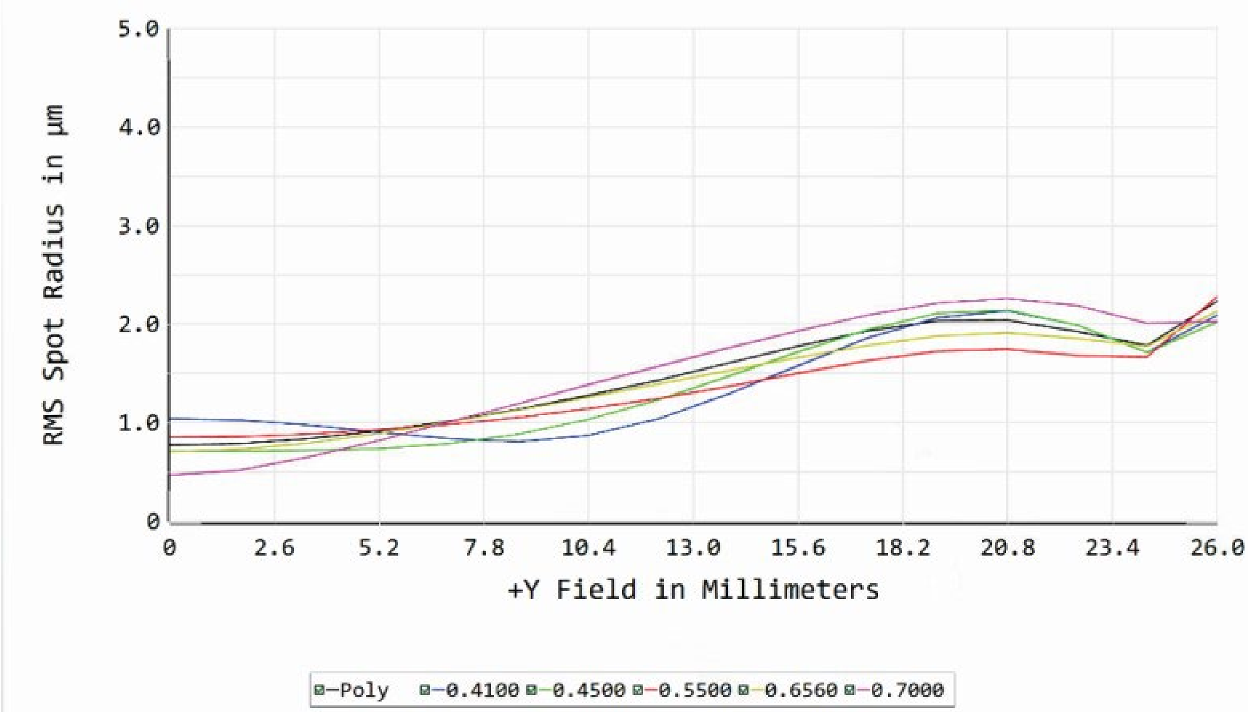
Spot Diagram

RC f/7 to f/4.5
1/20/2020
Units are µm. Legend items refer to Wavelengths

ASA Astrosysteme Austria
Zemax OpticStudio 15.5 SP1

Field :	1	2	3	4	5
RMS radius :	0.750	1.112	1.787	2.207	2.361
GEO radius :	1.542	4.502	5.213	5.470	6.037

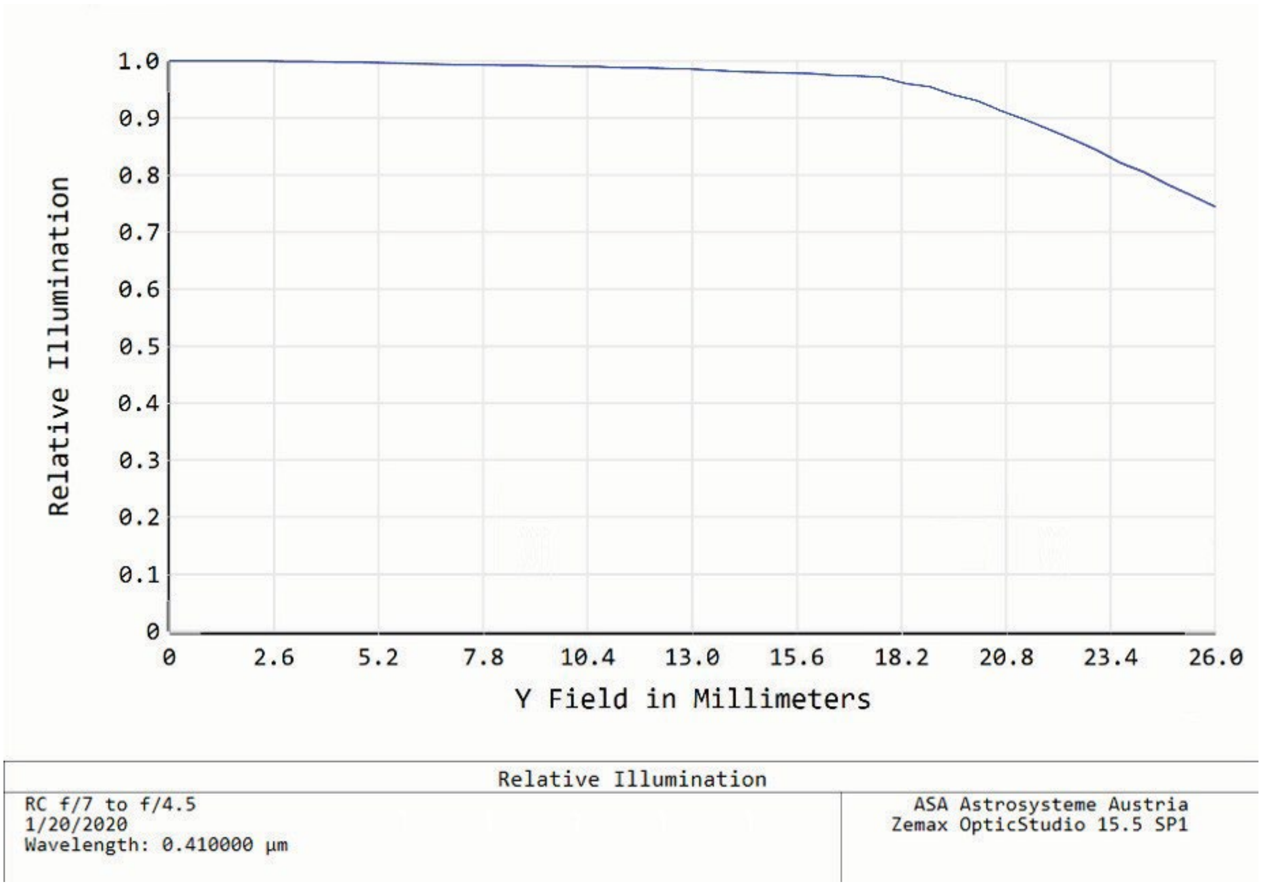
Box width : 50 Reference : Centroid



RMS Spot Radius vs Field

RC f/7 to f/4.5
1/20/2020
Legend items refer to Wavelengths
Reference: Centroid

ASA Astrosysteme Austria
Zemax OpticStudio 15.5 SP1



The largest lens has a diameter of 118mm but it is not possible to design a 3" reducer with 55mm field without causing excessive vignetting. With our 5" reducer, vignetting is less than 30%, which can be easily corrected by flat fields.

Conclusion(s)

- The RC (with corrector) is slightly more sensitive to secondary centering than the CDK.
- The CDK is more sensitive to secondary tilt than the RC.
- The RC OTA is shorter and more compact than the CDK – allowing for smaller observatories.
- The RC has a smaller central obstruction than the CDK.
- The RC produces higher contrast images than the CDK.
- The RC telescope is more versatile than the CDK. It can be used 1) without a flattener, 2) with a flattener, or 3) with a high-performance reducer.

Summary

	ASA f/7 f/2.5 RC	CDK
On axis planetary performance without corrector	☺	not possible
On axis planetary performance with corrector	☺	☺
Off axis performance with corrector	☺	☺
Off axis performance without corrector	☺	☹
Central obscuration	☺	☹
Spectral range without corrector	☺	☹
Can be upscaled to very large fields	☺	😐
RC technology in affordable price/performance ratio	☺	😐