Some facts about RC versus CDK

Recently, a customer showed us an advertising brochure promoting a telescope with a CDK Design. It also included a comparison versus the Ritchey Chretien Design. After reading through this pamphlet, the customer thought that a CDK is superior to a RC, which is very far from the truth, so we thought it might be interesting to shed some light on the facts.

History

Ritchey Chretien (RC)

The RC was invented by 2 Astronomers (Ritchey and Chretien 1910. It uses a hyperbolic primary mirror and a hyperbolic secondary mirror. Since it is THE 2 mirror design with the smallest off-axis aberrations it is the most common telescope design used in professional telescopes (Hubble Space, VLT etc…)

Dall Kirkham (DK)

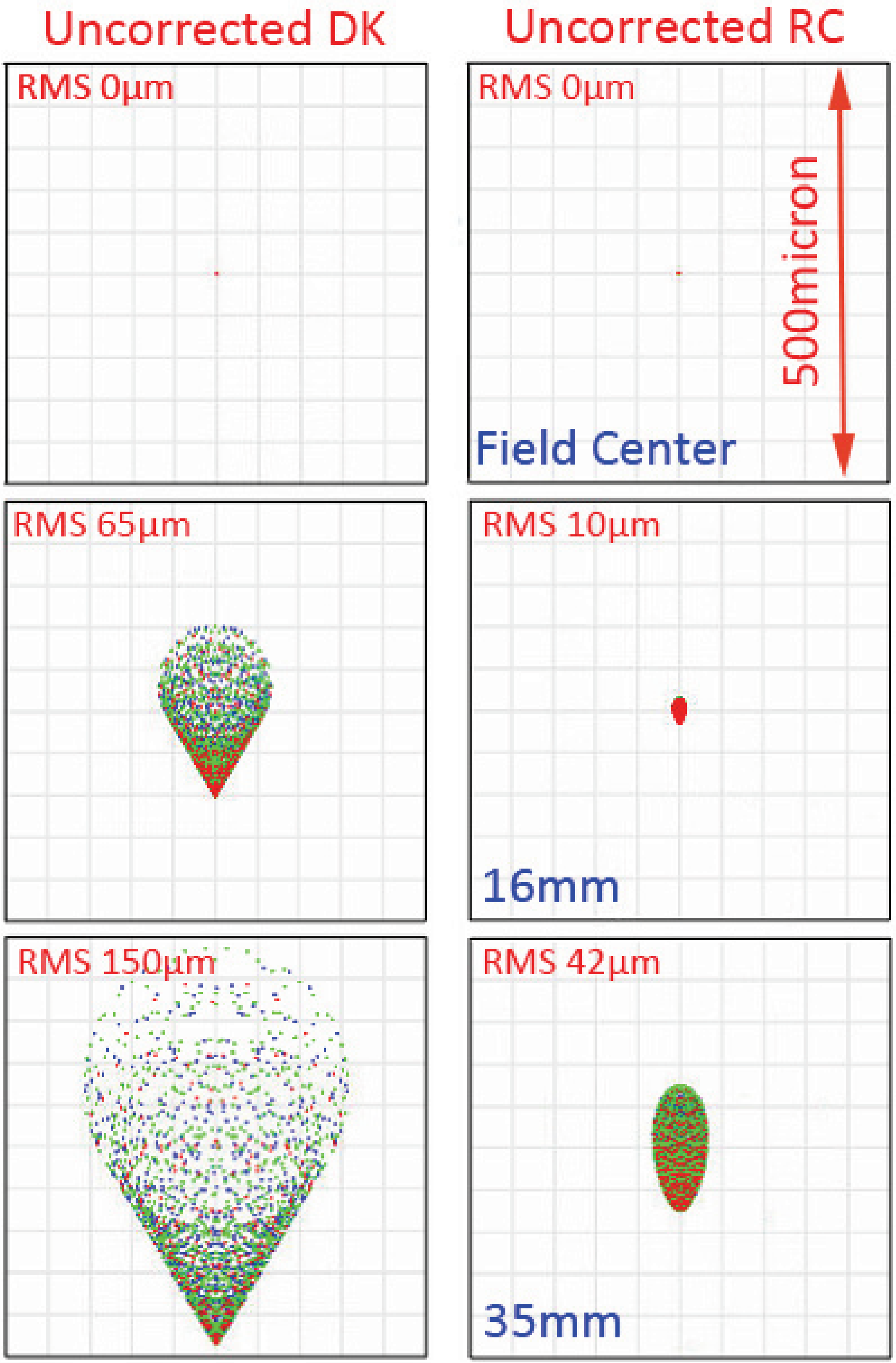
The CDK is a corrected Dall Kirkham telescope. The Dall Kirkham was first used in 1928 and uses an elliptical shaped primary and pure spherical secondary mirror, which can be produced easy and cheap.

The CDK brochure compares a CDK(thus a corrected Dall Kirkham) with an uncorrected Ritchey Chretien. The only fair comparison is of course between an uncorrected DK vs. an uncorrected RC and corrected DK vs. corrected RC because it is as easy to add a 2 lens corrector to a RC as it is to add one to a DK. This is what we are going to do in the following chapters.

So let us now first compare the performance of an uncorrected RC with an uncorrected DK.

The example is calculated with an f/2.93 primary mirror and f/6.5 system focal ratio, close to the design values a competitor used. As we will analyze later, this is a very unfortunate choice causing a large central obscuration but let's stay with this design for now to allow a 1:1 comparison. We will present better designs later.

Uncorrected DK vs. uncorrected RC



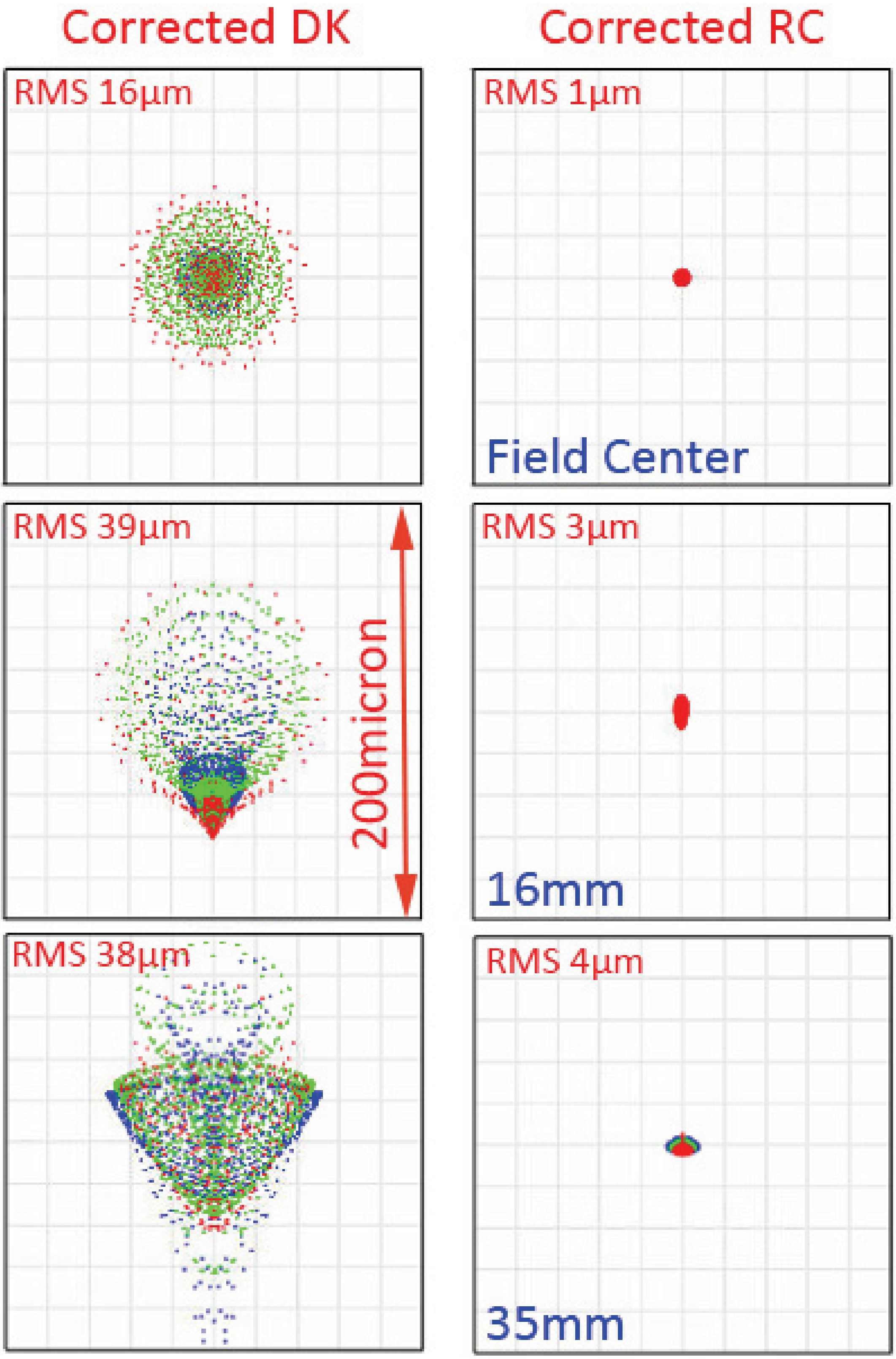
The Small Box Size is 50microns, the large box size 500 microns (0.5mm). The RMS Values are RMS radius. This the radius where appr. 80% of the light is contained. 10 micron equals 0.5 arc sec. at 4540mm focal length. Wavelenghts used for the spot diagrams have been 430nm, 555nm and 700nm.

Result:

- 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 any corrector

Corrected DK (CDK) vs. corrected RC (CRC)

As a first step we will now add a 2 lens corrector to the 2 above systems and examine the 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 1 minute to find the optimum solution. The quality depends a little bit on the location of the 2-lens corrector so we assumed the optimum location.

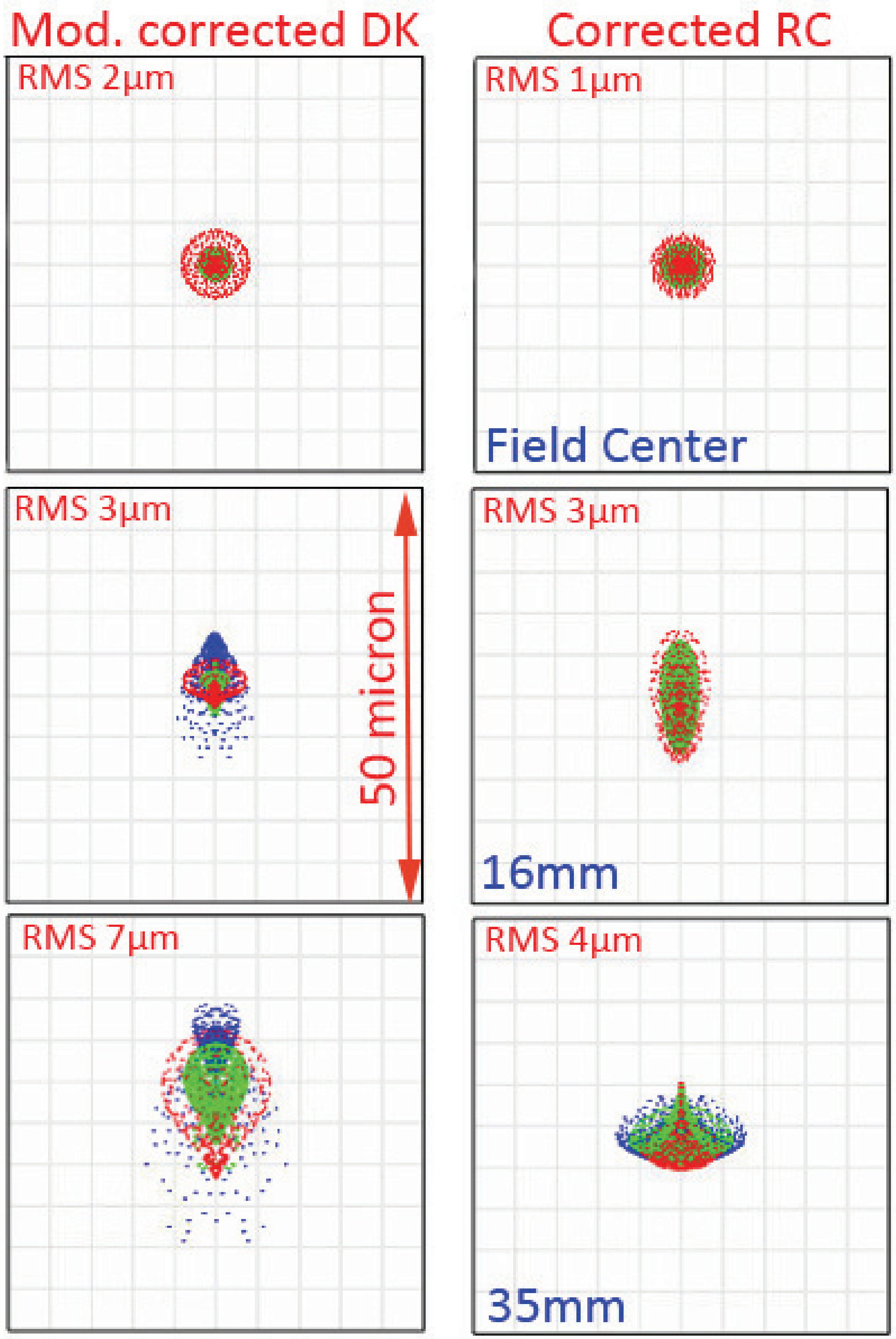

Corrected DK
Corrected RC
RMS 16µm
RMS 1µm
Field Center
RMS 39µm
200micron
RMS 3µm
16mm
RMS 38µm
RMS 4µm
35mm

The off-axis errors of the original Dall Kirkham are too large to be corrected effectively with a 2 lens corrector while the RC with a simple 2 lens corrector shows a seeing limited performance over a 70mm diameter field.

Both above systems can be used without corrector. Permanent correctors in systems have certain disadvantages. Firstly, the wavelength range is limited not only due to chromatic errors but also due to the transmissivity of the optical glasses used which blocks mostly below 400nm. So these systems cannot be used in UV.
Secondly, every lens in the light beam reduces contrast and adds ghost images even if the coating is perfect. Thirdly, if it is possible to remove the field flattener it is much easier to add a dedicated reducer.

The overall off-axis performance of the corrected Dall Kirkham can be improved, if the elliptical shape of the primary mirror is changed while keeping the cheap spherical secondary. This is what some other companies undertake to reach a sufficient off-axis performance and thus we will now examine such a system against an original unchanged RC with 2-lens corrector, the same system as before. Only the box size was reduced to 50 micron to magnify the errors.

Please note that in this CDK system, the corrector cannot be removed as the system will not work without it even in the field center.



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

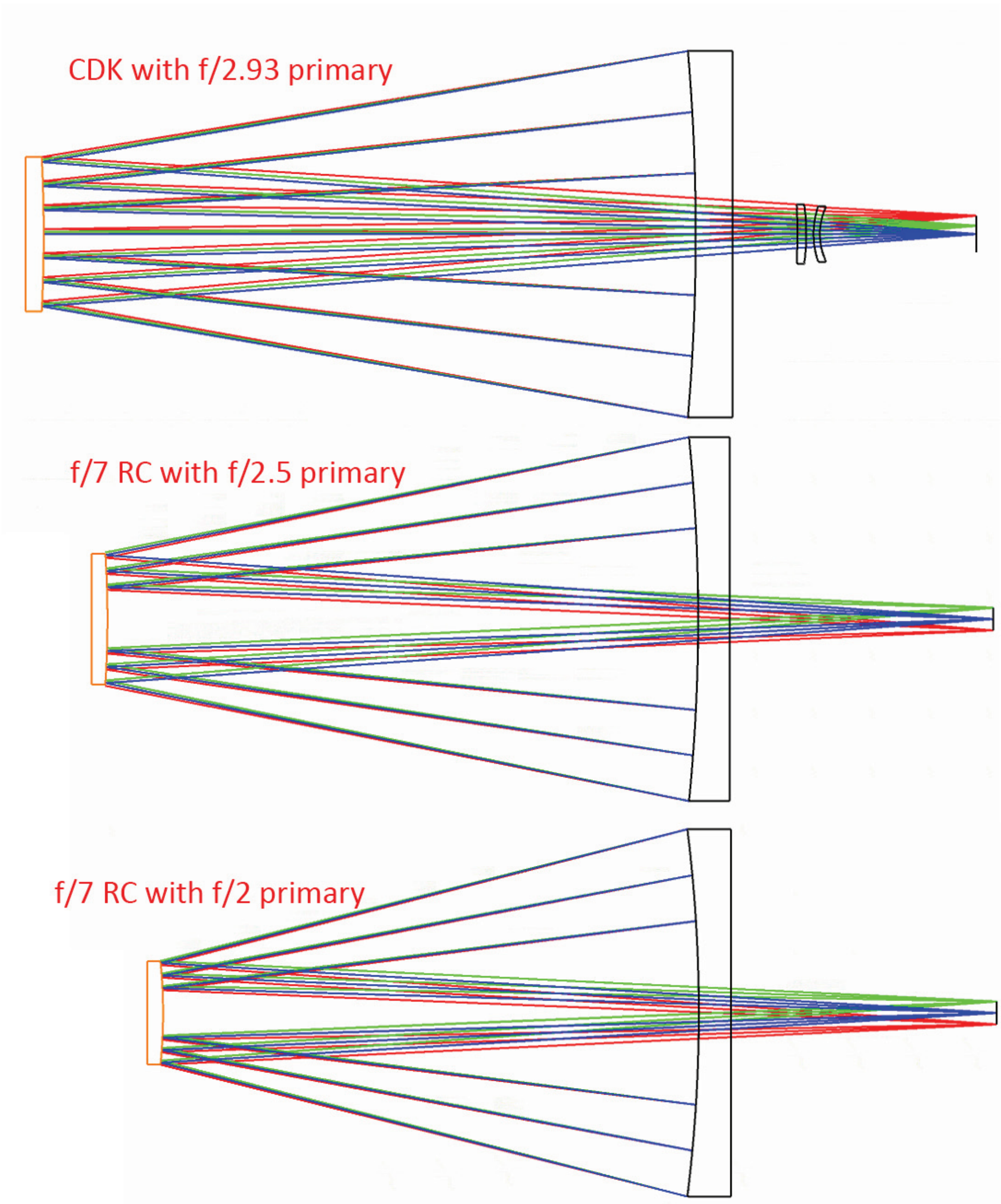
The huge disadvantage of the corrected DK (left side) is the fact that it will not be possible to use it without corrector. Since the shape of the primary has been changed, the system will suffer from severe spherical aberration in the field center if you remove the corrector. If you have such a system, you can try. You will not find satisfying focus.

The RC on the other hand, can also be used without the corrector, making it much more suitable for high resolution planetary imaging, a wider spectral range and more versatile when using a reducer. A RC with a removable corrector combines the best of both worlds, a high resolution planetary visual telescope without corrector and a wide field machine for large CCD areas with a dedicated corrector.

Primary mirror ROC (Radius Of Curvature)

Although we have calculated the examples with a f/2.93 primary design, we prefer a shorter focal length main mirror, so depending on the system we use f/2 primary mirrors or f/2.5 primary.

Below you can see the scaled comparison between the different optical layouts:

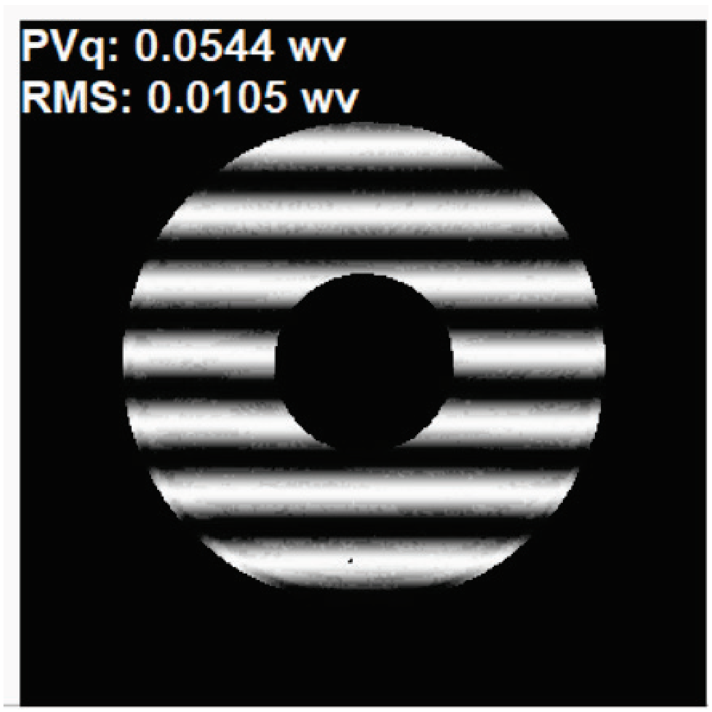


The ASA systems with the short primary ROC are not only much more compact (resulting in a considerable smaller dome size), but they also use a smaller secondary mirror, especially the f/2 primary systems. The central obscuration is 40% with the f/2.5 primary and only 36% with the f/2 primary, compared to 47% in the discussed CDK with an f/2.93 primary. It should be well known, that such large central obscurations moves light from the airy disc in the first diffraction ring and is especially problematic on weak contrast objects like planets. Also, they reduce the effective focal ratio. An f/6.5

system with a 47% central obscuration has an effective focal ratio of only 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 can't

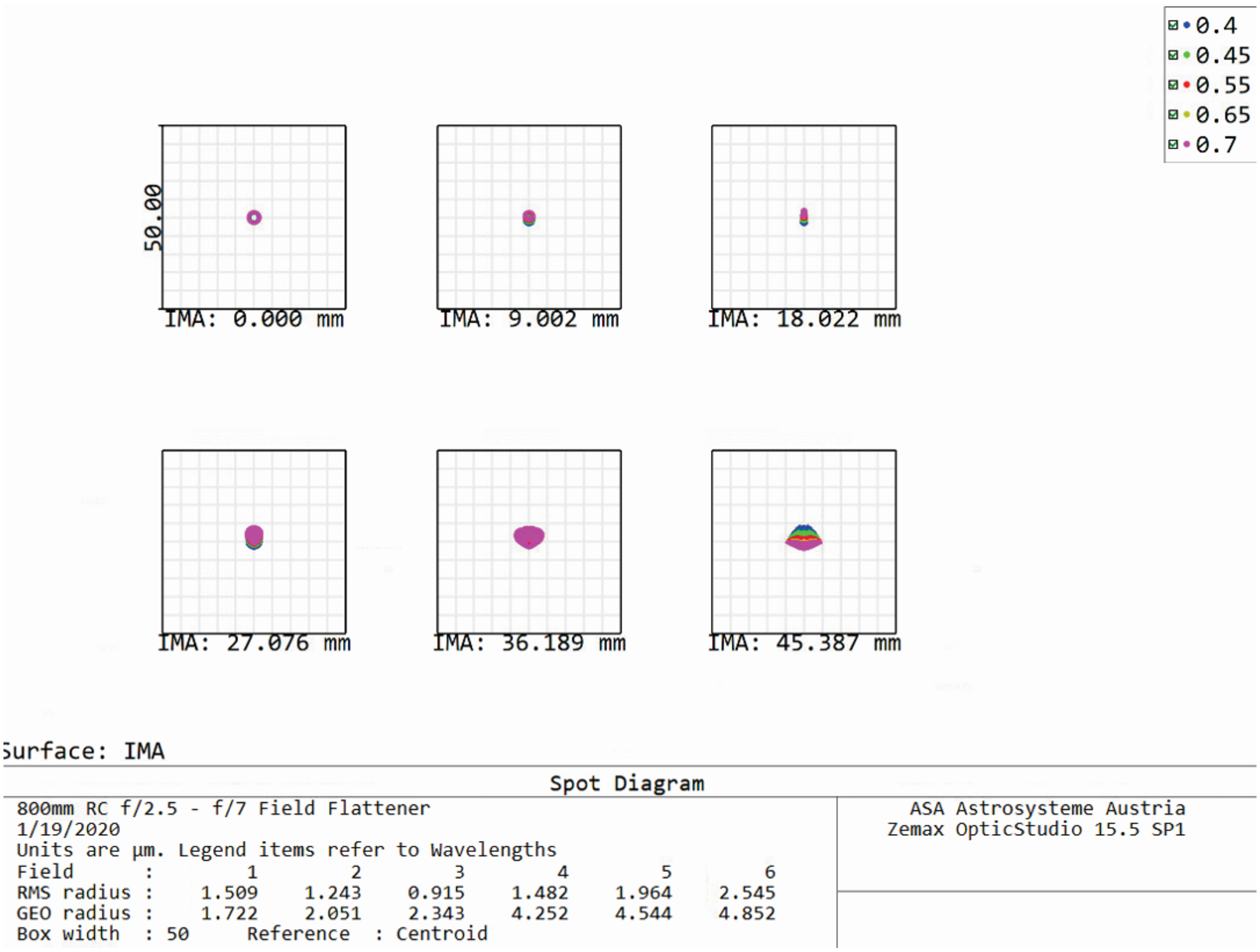
Using such short focal length primary mirrors has some consequences for the optical production. It is not only the hyperbolic secondary, the challenge to make an f/2 hyperbolic primary RC mirror is huge compared to the f/2.93 elliptical shaped CDK primary. While the maximum deviation from sphere is only 4 microns in the case of the 700mm CDK primary, it is 27 micron in the case of the f/2 hyperbolic RC primary. We therefore understand, why some optic shops hesitate to produce <=f/2.5 primary mirrors even if they offer such advantages in the telescope design and performance.
But 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 a ultra smooth surface at the same time.



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

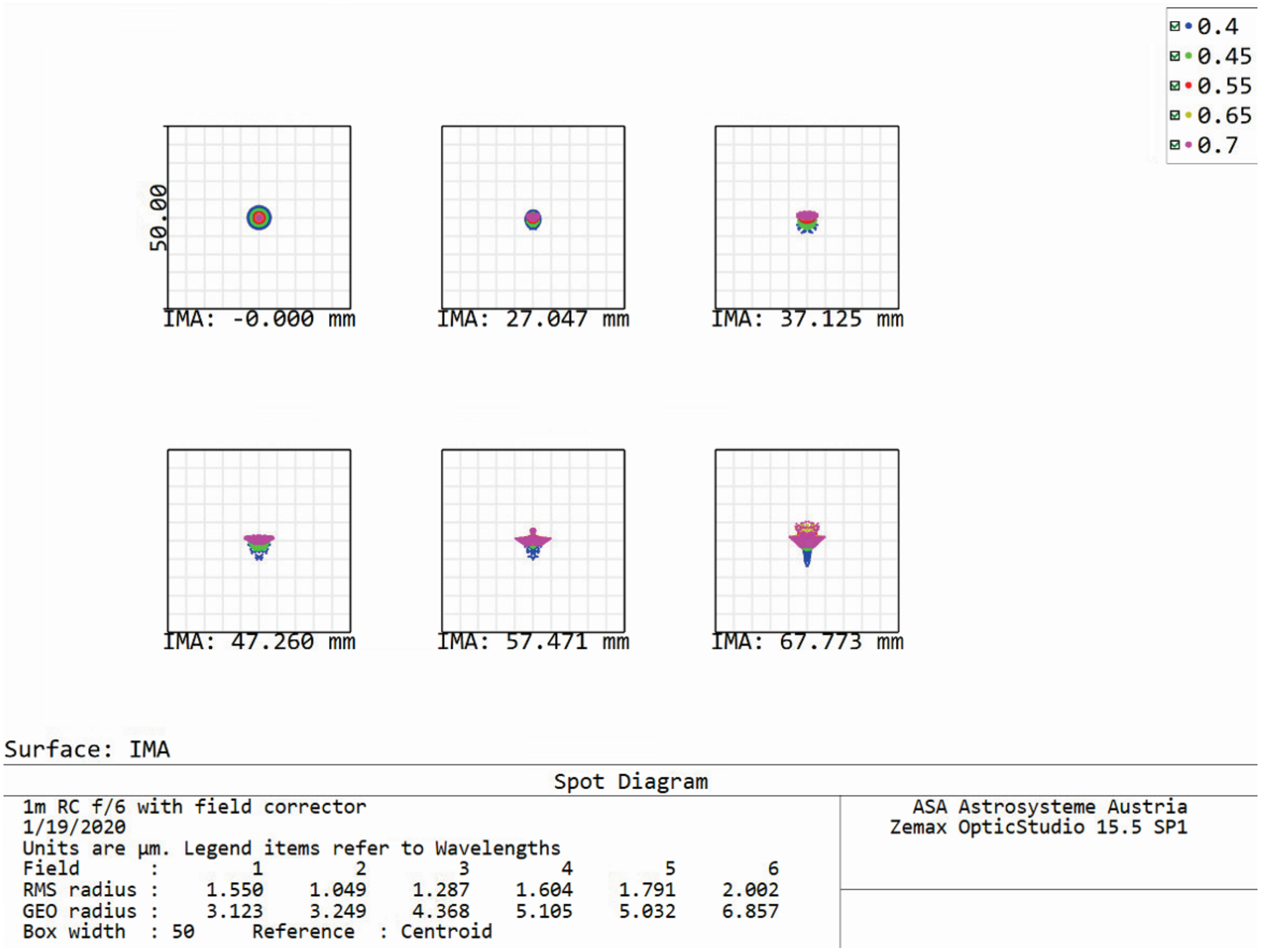
ASA corrector examples

Below you can see a spot diagram 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 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:

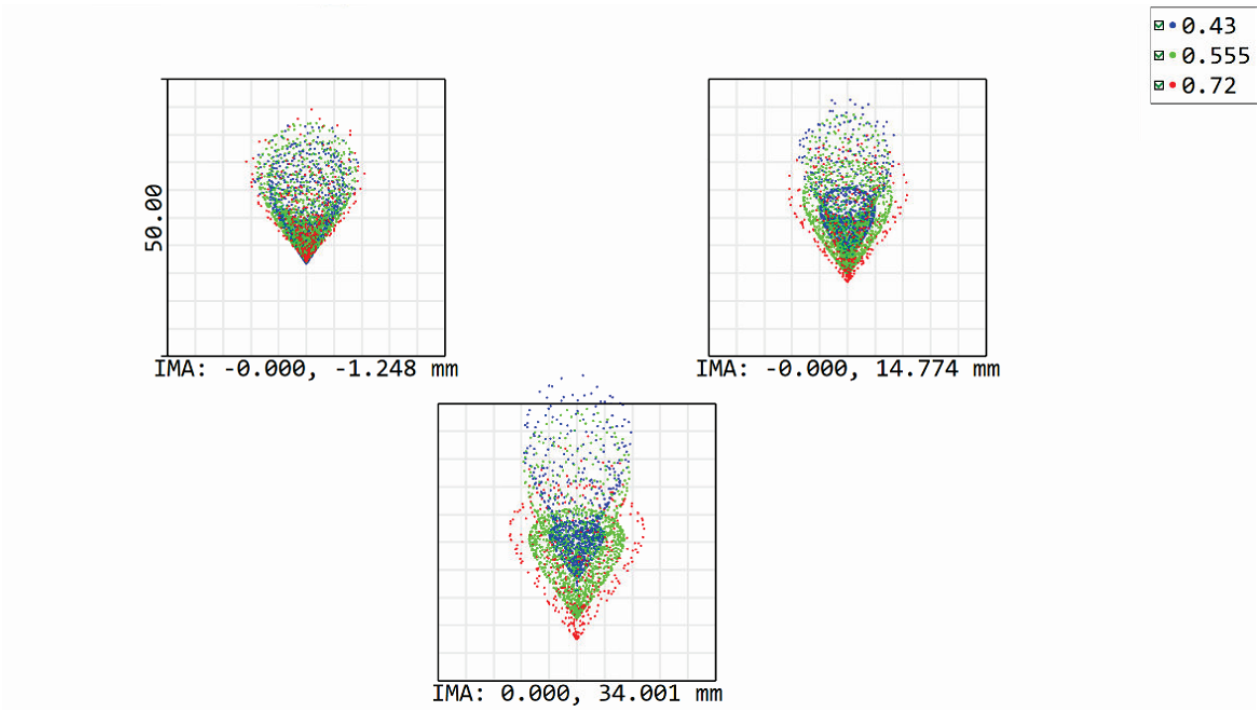


The seeing limited field size is 135mm.

You will not reach this performance if you limit the optical design with a spherical secondary mirror used in a Dall Kirkham system.

Some more Myth Busting

The next myth you may have heard is the larger RC sensitivity against collimation errors. Let us also shed some light on this as well:



Surface: IMA

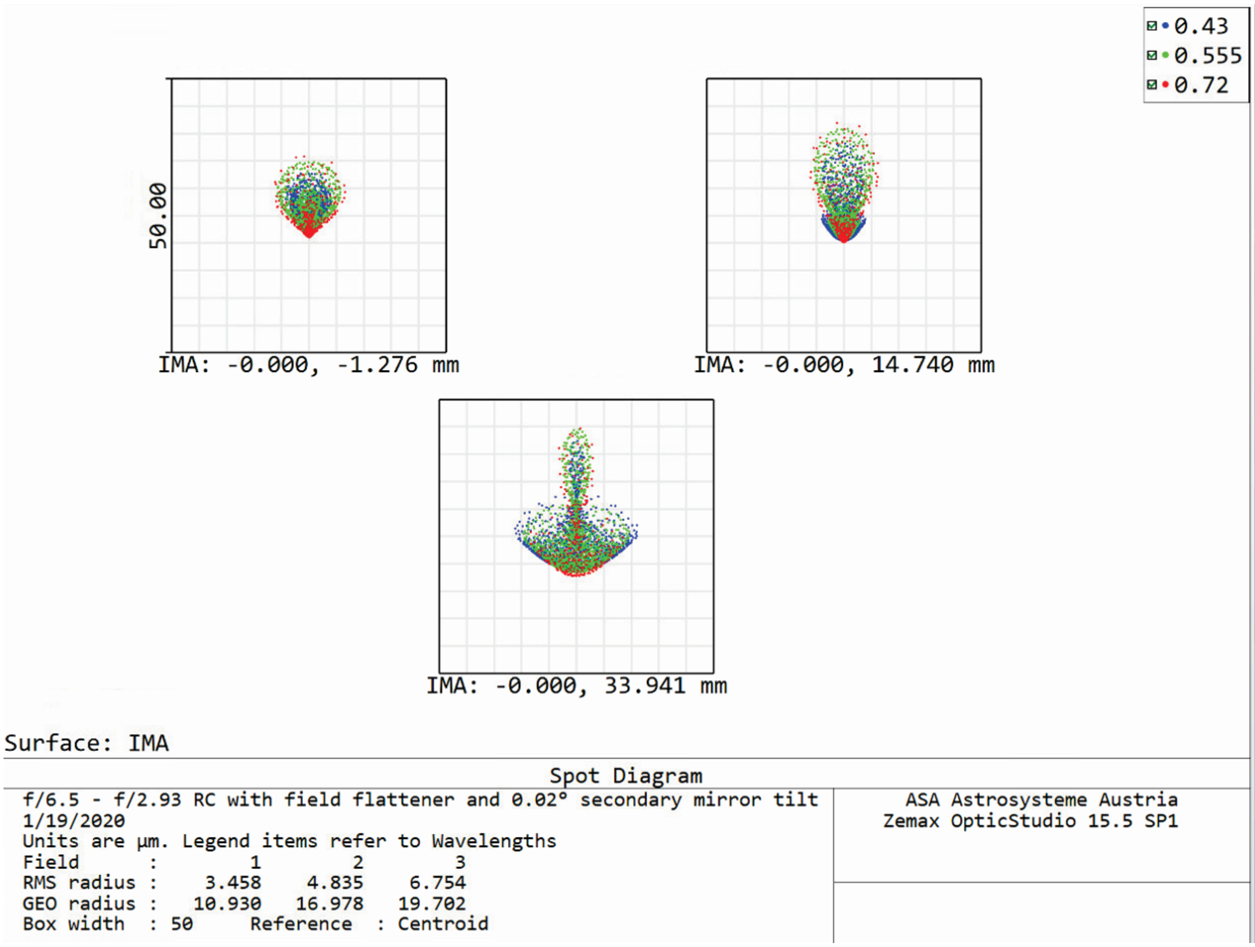
Spot Diagram

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

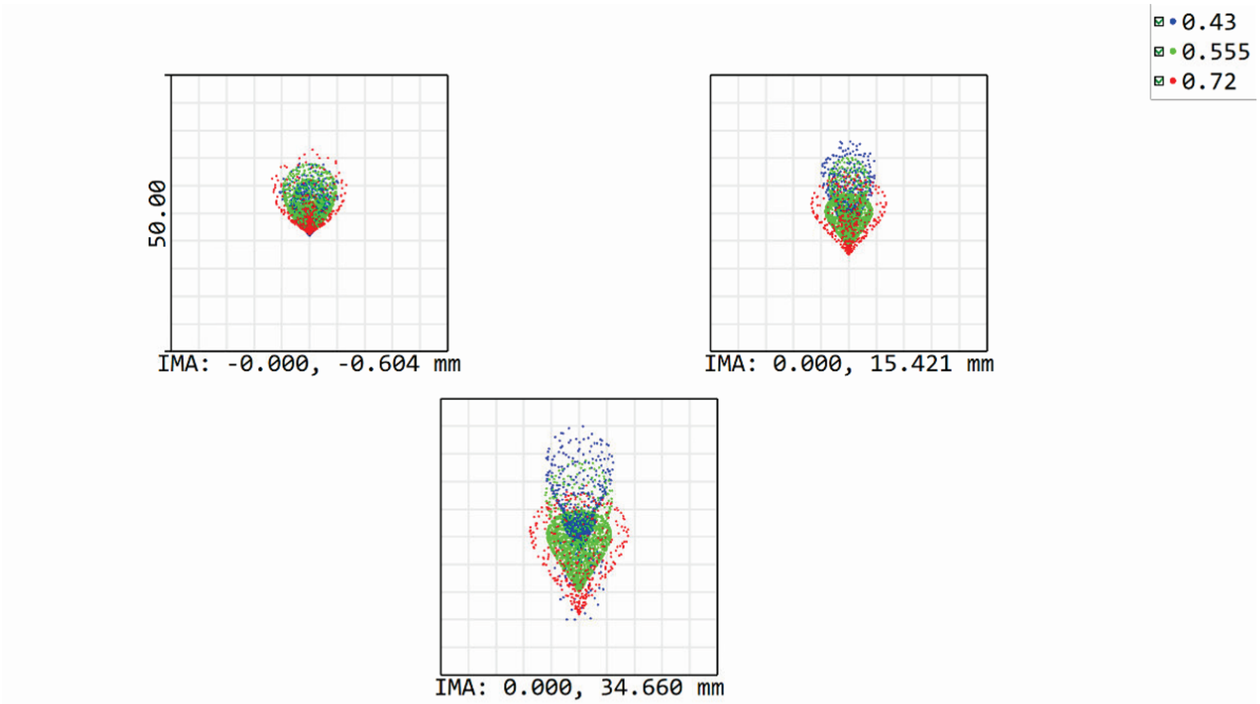
Box width : 50 Reference : Centroid

ASA Astrosysteme Austria
Zemax OpticStudio 15.5 SP1



In above examples we have again used the f/6.5 – f/2.93 CDK with an optimized elliptical primary and the f/6.5 – f/2.93 RC with corrector and 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, that the RC with corrector is less sensitive to the secondary tilt than the CDK.
Apart from the tilt it might also be interesting to examine the centering error. Now we look at a secondary centering error of 0.5mm.



Surface: IMA

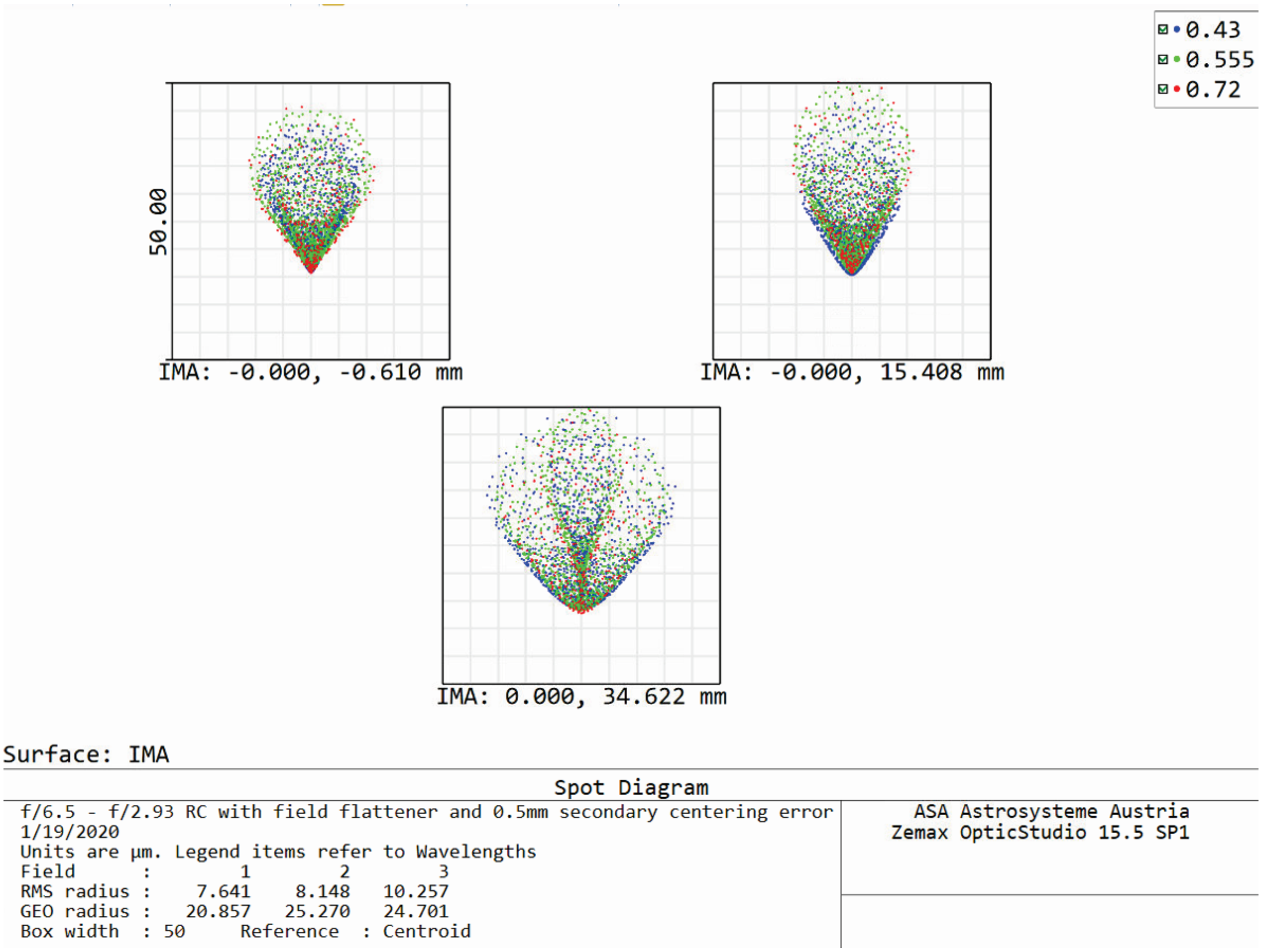
Spot Diagram

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

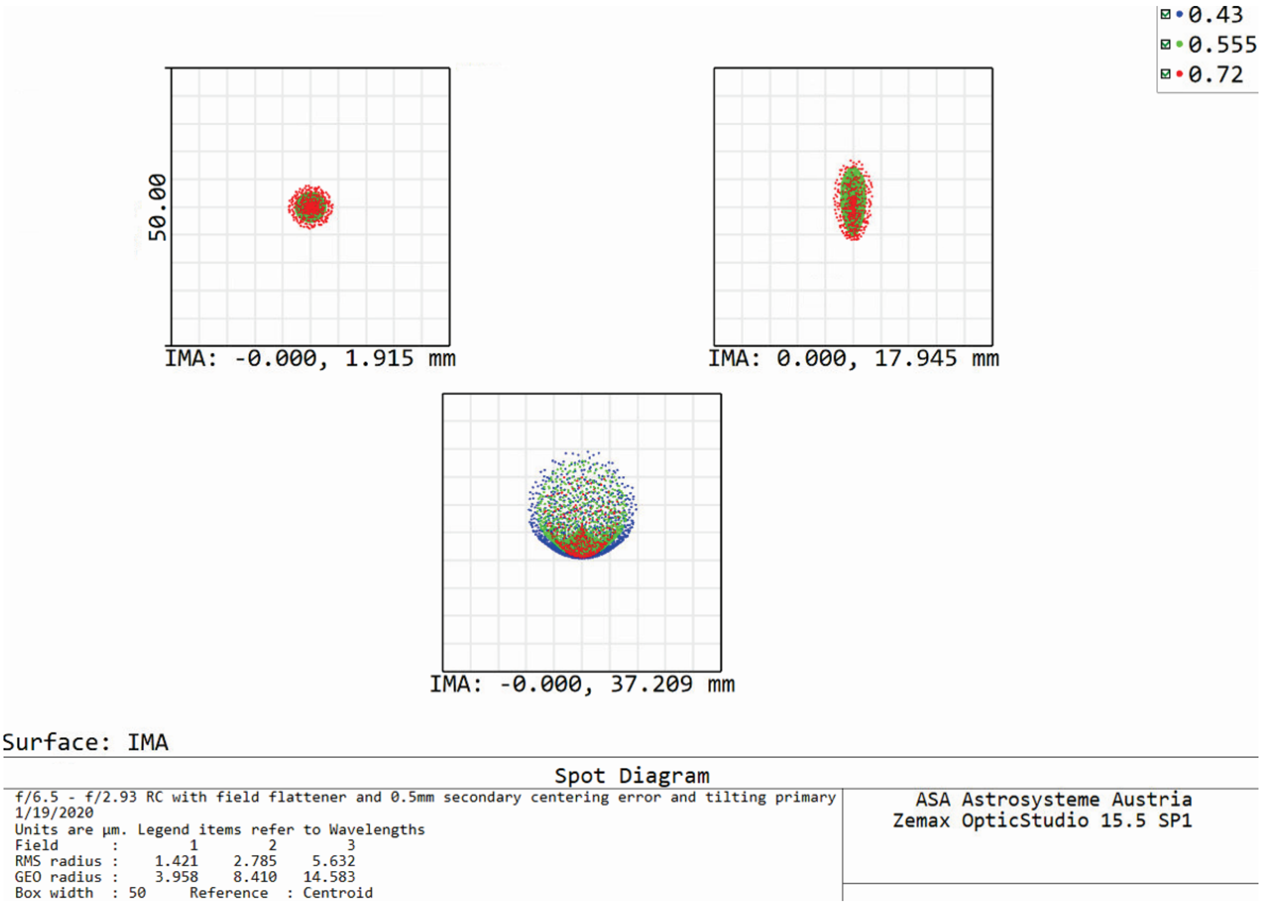
ASA Astrosysteme Austria
Zemax OpticStudio 15.5 SP1



In this case we can see a larger error in the case of the RC telescope. But it is nowhere the factor 5 which was mentioned by some competitor.

This is not even the most interesting point.

The fact is that people have to understand that 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). This is so easy that most customers need only 1-2 minutes to perform the final collimation.

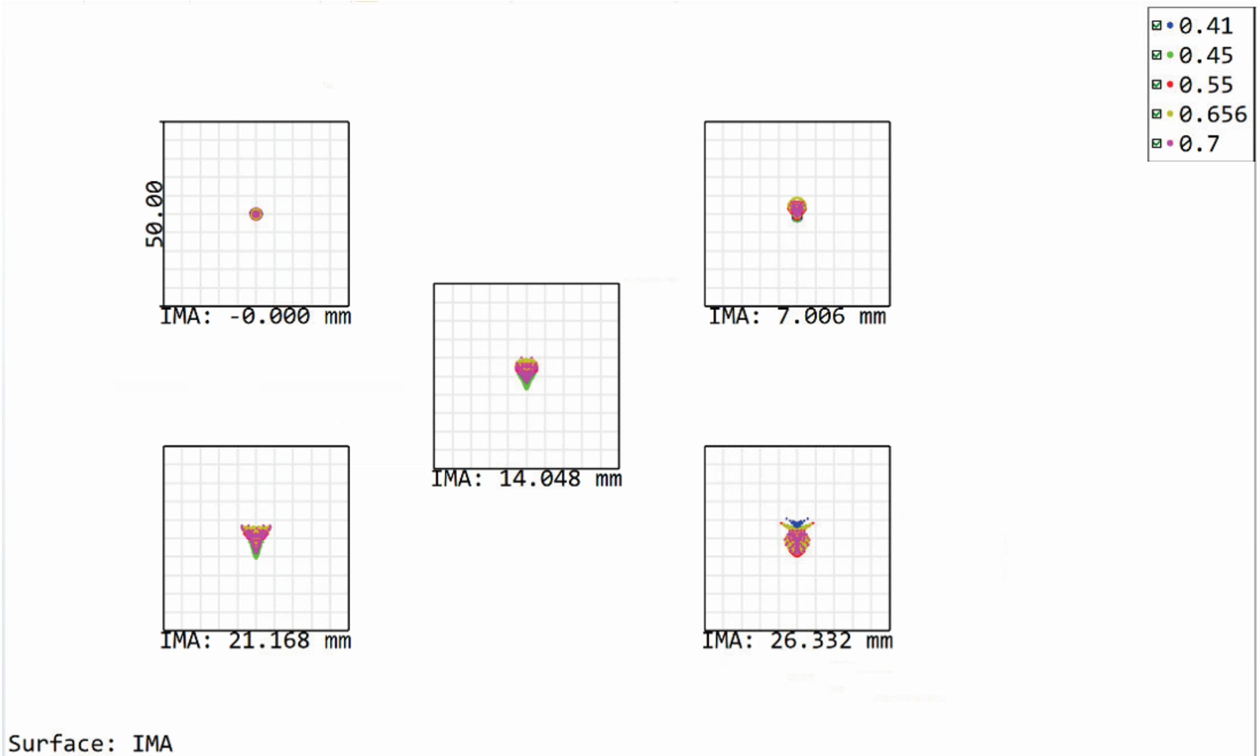


For example, to correct the secondary centering error the main mirror would be tilted by 0.015°. This is shown in above spot diagram and it proves, that all the collimation errors can finally be corrected by ONE optical element (unless the errors would be huge, like 5mm secondary centering error). This happens completely automatic and straight forward 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.

Corrector flexibility and Reducer quality

In the RC, you can optimize the reducer with the smallest amount of lenses without having to take a corrector into account. We would never try to use a reducer behind our field flattener, but this is what an optical designer has to do if he has to put a reducer in a CDK with fixed lens corrector.

Here is an example of our standard 0.65x reducer for the 800mm f/7 - f/2.5 RC. This is the middle size reducer which we offer for this telescope and it can work with image diagonals of 55mm. At ASA, the customer has the choice between 3 ! different reducers for different sized CCD.



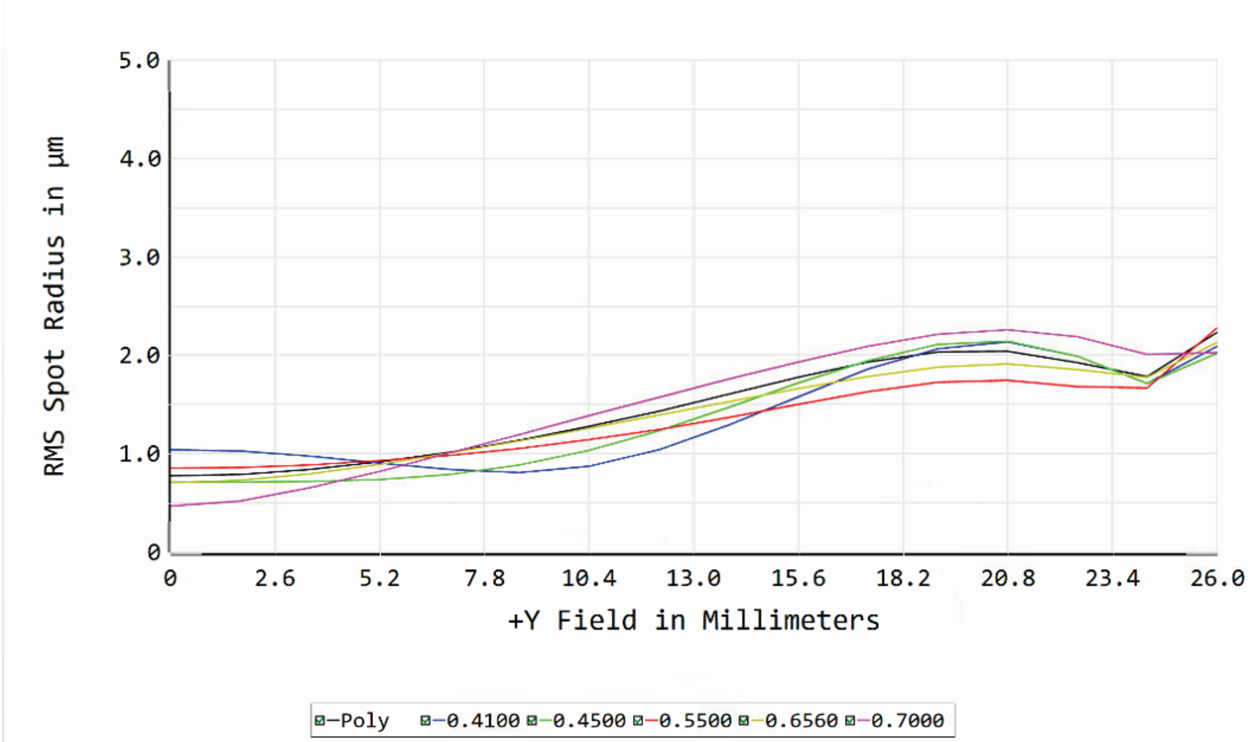
Spot Diagram

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

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

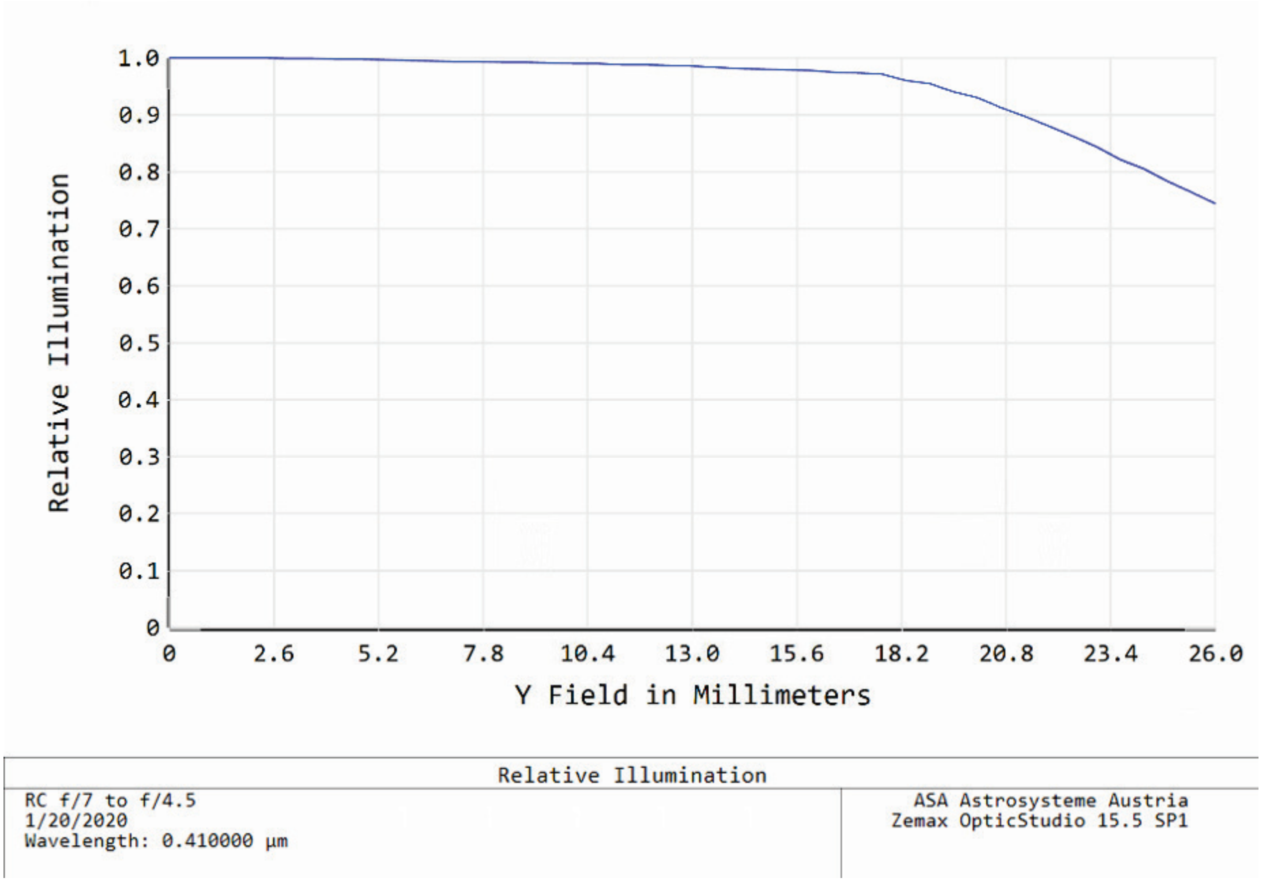
ASA Astrosysteme Austria
Zemax OpticStudio 15.5 SP1



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:

We have shown that, if you compare a CDK against a RC with a simple field flattener assuming the same optical data (main mirror ROC, focal length, tube length), the only remaining advantage of the CDK is the cheaper production costs of the secondary mirror since this is spherical. The collimation sensitivity is a myth which can be easily confound by performing raytrace calculations. The RC with corrector is slightly more sensitive in secondary centering, while the CDK is more sensitive in secondary tilt.

Since ASA has the optical capabilities of reducing the main mirror ROC to f/2.5 or even f/2 systems, you get much shorter and compact telescopes with less central obscuration.

RC telescopes are more flexible since they can be used without flattener for high performance visual or planetary work, with flattener and also with high performance reducers.

Summary

	ASA f/7 f/2.5 RC	CDK
Cheap and easy production	☹	☺
On Axis planetary performance without corrector	☺	not possible
Off Axis Performance with corrector	☺	☺
On Axis planetary performance with corrector	😐	😐
Central Obscuration	😐	☹
Spectral Range without corrector	☺	☹
Can be upscaled to very large fields	☺	😐