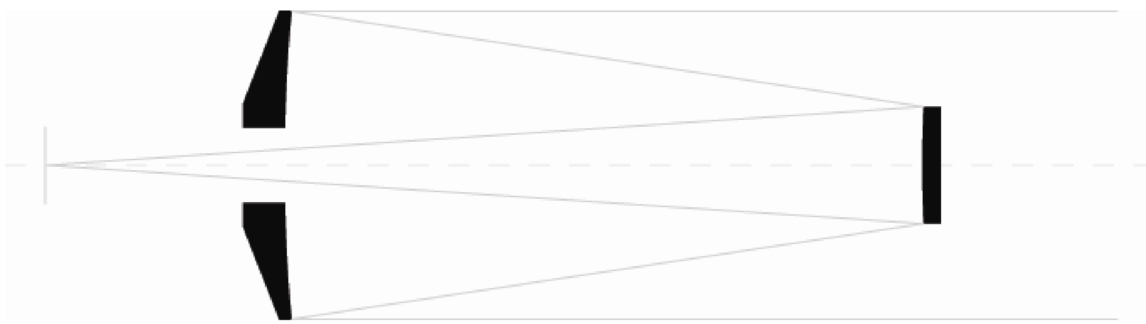
The Meade RCX-400: What is it?

Introduction

The RCX-400 telescope from Meade Instruments Corporation is advertised as an "Advanced Ritchey-Chrétien Optical System". Here, we will explore these claims and compare the optical performance to that of previous Schmidt-Cassegrain (SCT) designs and a true Ritchey-Chrétien (RC) design, as defined in the literature.

What is a Ritchey-Chrétien design?

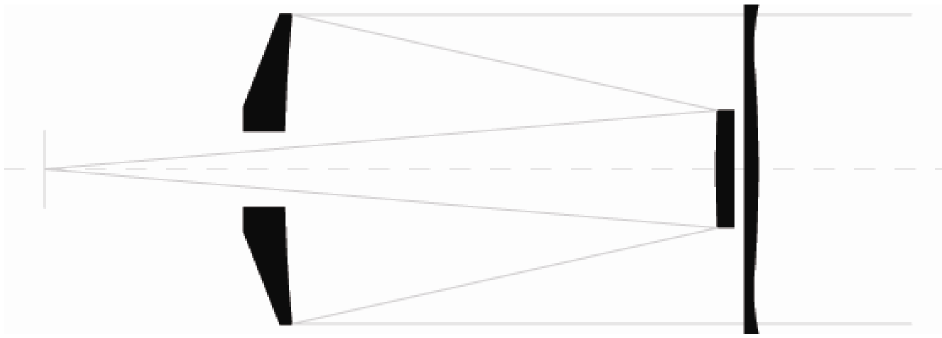


The RC design is actually a special case of the Classical Cassegrain (CC) two-mirror reflecting telescope design. In this design, a primary and secondary mirror is arranged so that the light collected by the primary is reflected to the secondary and then back through a hole in the primary to a focus behind the primary. The CC is defined by the curvature of the mirrors to be a parabolic primary and a strong hyperbolic secondary. By proper choice of mirror curves, the telescope can be made to have zero spherical aberration. "Spherical aberration occurs when light rays parallel to the optical axis entering a system come to a focus at different points along the axis"[1]. However, the next aberration that is significant is coma, which "occurs in an oblique bundle of light when the intersection of the rays is not symmetrical but is shifted with respect to the axis of the bundle"[2]. By using a hyperbolic primary and a hyperbolic secondary, and with proper mirror spacing, both spherical aberration *and* coma can be minimized.

Again, this is a reflecting telescope design with no refractive elements. Refractive elements are to be avoided if chromatic aberration is to be minimized. Chromatic aberration occurs when different light wavelengths come to focus at different points, due to the refractive nature of glass. If there is no refractive element, there is no chromatic aberration.

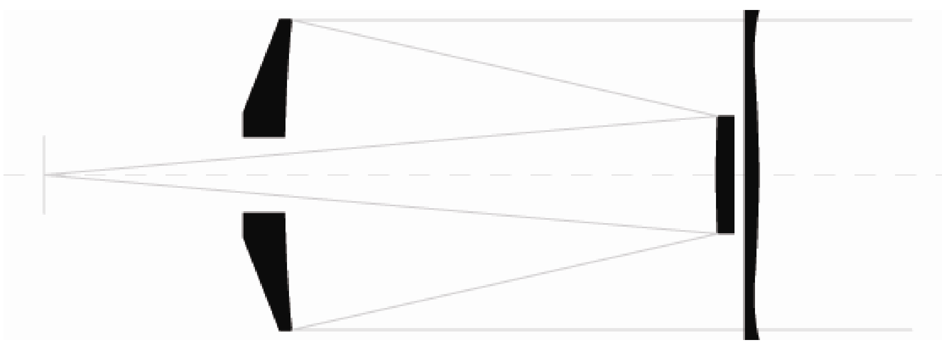
[1,2] Rutten and van Venrooij, *Telescope Optics Evaluation and Design* (1988), Willmann-Bell, Inc.

What is a Schmidt-Cassegrain design?



The SCT design is essentially a two-mirror Cassegrain design with a Schmidt corrector located in the plane of the spherical secondary mirror and supporting the secondary mirror. This correcting refractive element is used to reduce axial spherical aberration. Of course the addition of this refractive element adds chromatic aberration.

What is the RCX-400 design?



The RCX-400 is a two-mirror Cassegrain design with a Schmidt Corrector plate located in the plane of the secondary mirror and supporting the secondary mirror. The RCX-400 claims to reduce coma by use of a combination of a primary mirror and corrector plate that perform as a hyperbolic primary. However, the presence of the refractive corrector plate is a source for chromatic aberration. The stronger the corrector plate, the greater is the chromatic aberration.

The Differences

It has been clearly accepted in the optical design community that a Classical Cassegrain and its special case, the Ritchey-Chrétien, consist of a two-mirror system with no refractive element in the path. The RCX-400 has the elements of a Schmidt-Cassegrain design with a carefully chosen primary curvature and corrector plate to approach coma-free performance. In fact, this exact point is contemplated in a discussion of SCT design. "The correction of coma and astigmatism is possible only for specific combinations of power and position of the Schmidt corrector and certain shapes of the primary and secondary mirrors"[3]. Because The

[3] *ibid.*

RCX-400 has a Schmidt Corrector plate, it is clearly not an RC but an aplanatic SCT or aSCT. Based on this and the technical literature, it should more properly be called an "Advanced Schmidt Cassegrain Optical System" as being more technically accurate.

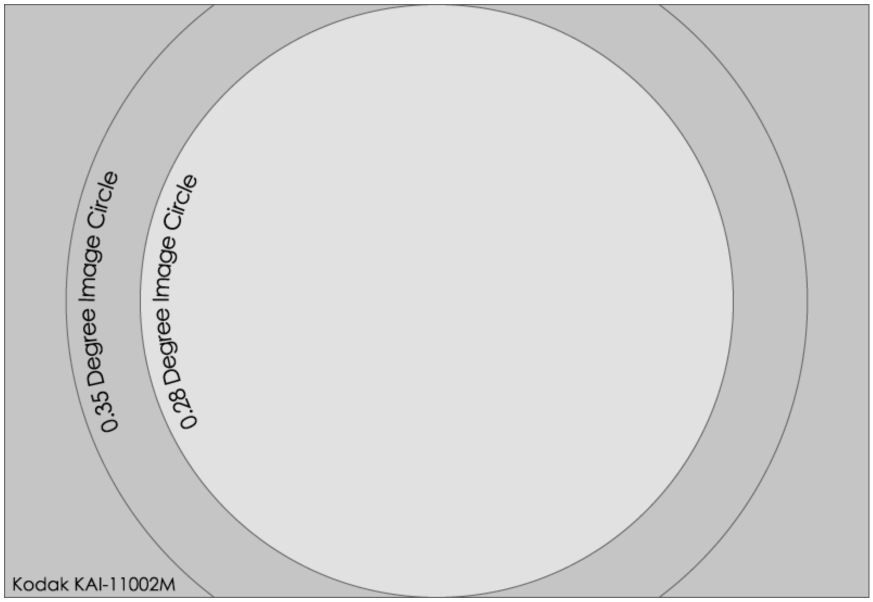
Measurements

In addition to the above discussion, some additional insight can be gained by investigating the optical performance of the three designs – SCT, aSCT and RC – to see how they deal with spherical aberration, coma and chromatic aberrations. Since all well-designed optical systems should have good on-axis performance, it is instructive to investigate off-axis performance. In order to analytically compare measurements, optical prescriptions are required. The prescriptions for the RC and SCT are well known. The aSCT prescription needed to be determined.

The secondary was determined to be a slightly overcorrected parabola by using a Hindle Sphere Test. We lined up the radius of curvature of the Hindle Sphere and the radius of curvature of the secondary, and then used a small refractor telescope of 3.25" aperture. We used a Ronchi grating with a light source at the focus of the refractor which would turn the beam into a collimated beam through the hole of the Hindle Sphere and onto the secondary which would expand the beam to the Hindle Sphere and then back to the secondary and then back to the telescope to focus. We got straight lines with the Ronchi which would mean that the secondary was a parabola. In the ray tracing program, we set up so that the program would optimize for no coma and gave it the radius of curvature of the primary and secondary with a back focus of 12". The program came back with a conic of 1.3 for the secondary with 1 being a parabola. It turns out that a Classical Cassegrain design with these parameters would have a conic of 2.79, and an RC would have a conic of 3.17.

The optimum design for the RCX-400 is very close to a parabola. Now to explain how the correction between the secondary and the primary corrector-combination works, is easier done using the Dall-Kirkham principle. All Schmidt Cassegrain designs are essentially Dall-Kirkham designs with the RCX-400 system being the exception. A Dall-Kirkham has a spherical secondary with an ellipsoidal primary. The next step up is a Classical Cassegrain which has a parabolic primary with a hyperbolic secondary. The Ritchey-Chrétien has a hyperbolic primary with a greater hyperbolic secondary. The way this works is the secondary subtracts correction from the primary to zero out the spherical aberration. The primary is corrected for its f ratio, in this case f2, which makes it way overcorrected for an f8 system. The secondary has the opposite correction to take a percentage of the correction away from the primary so you zero out spherical aberration. The RCX-400 falls between the Dall-Kirkham and the Classical Cassegrain system which means it would have an ellipsoidal primary corrector combination which is nowhere near a hyperbola.

As a representative point to measure, consider the CCD imaging sensor manufactured by Kodak, the KAI-11002. At a physical size of 24 mm x 36 mm, this sensor approximates the size of 35 mm film, is in wide use in the imaging community and is of an intermediate size, compared to larger sensors. It also represents an area one might achieve with a smaller chip and a focal reducer.



With this sensor as a reference, any off-axis aberrations will be clearly visible in its field of view (FOV). Assuming a nominal telescope of 14" aperture at F/8, the corresponding focal length is 2845 mm. With a quality circle equivalent to the height of the sensor, the effective off-axis angle is .24 degrees. The corner of the imaging chip represents an off-axis angle of .43 degrees.

Coma

Recall that coma is a measure of how much the spot grows from its diffraction-limited value as we move off-axis. The following table summarizes that geometrical spot size measurement at .35 degrees off-axis:

	Spot size (microns)
RC	9.8
aSCT	17.4
SCT @ .29°	140

Table 1: 0.35 degrees off-axis spot size

While the aSCT improves considerably over the SCT, it is clearly seen that the RC design is superior to both the aSCT and SCT due to its smaller spot size.

Chromatic Aberration

Recall chromatic aberration is the difference is spot size as a function of the wavelength (color) of light. White light consists of a mixture of red, green and blue light. If a spot or star is to be accurately represented off-axis, all colors of light must come to focus at the same size. The following tables summarize the measurement at .35 degrees off-axis:

	Blue (450 nm)	Green (550 nm)	Red (650 nm)
RC	7.0	7.0	7.0
aSCT	172	29	37.8
SCT @ .29°	158	132	143

Table 2: 0.35 degrees off-axis spot size in microns

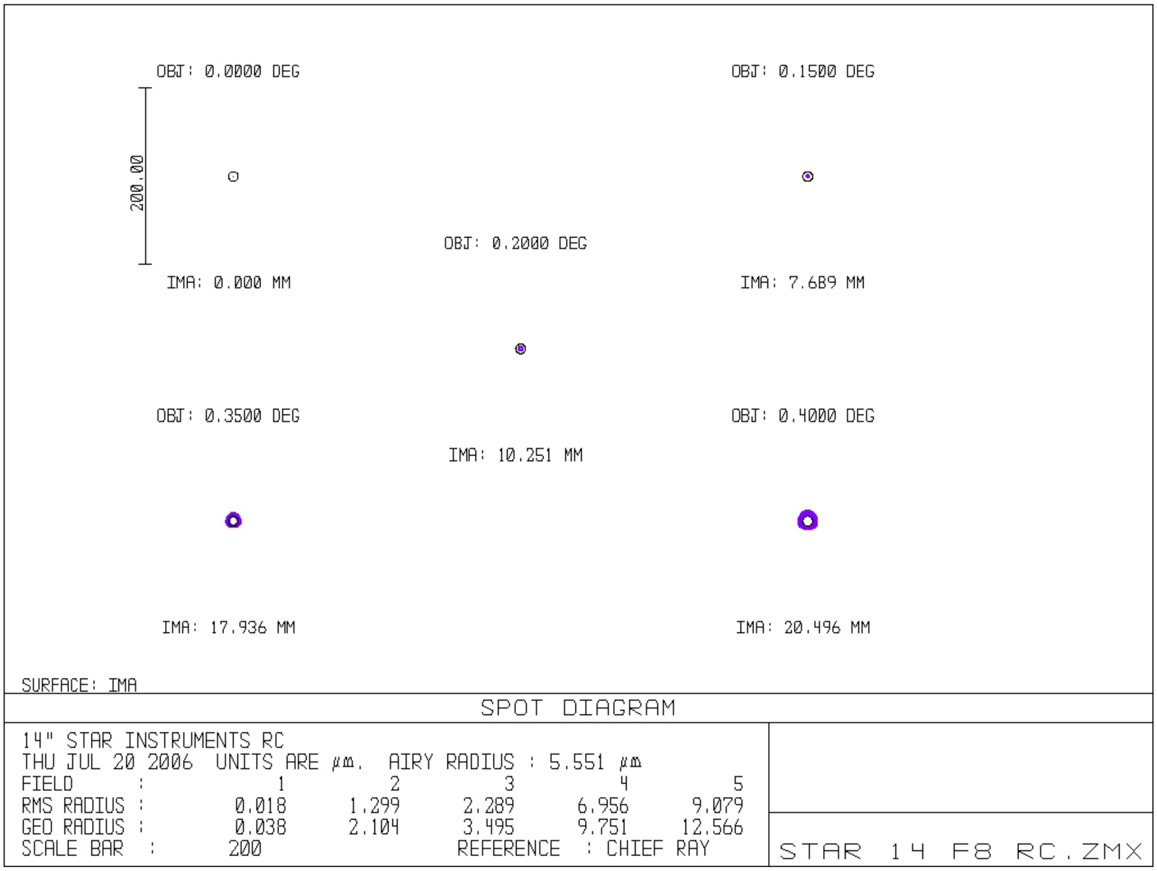
Once again, the difference is apparent. The SCT has somewhat uniformly large spot sizes. With the aSCT and when focused on green, we can expect blue haloes around fine detail. Only the RC design, being a pure reflective design with no refractive element shows zero chromatic aberration.

Summary: Is an automobile's V6 engine an "Advanced V8 System"?

In reviewing both the technical definition and performance, it can be clearly seen that the RCX is in reality an aplanatic SCT, that has been manufactured for a number of years and whose improvement over the SCT was contemplated in 1988, if not sooner. It still suffers, albeit to a lower degree, to the shortcomings of a conventional SCT. Further, the actual achieved performance of the RCX, while better than the SCT, is a far cry from that of a true Ritchey-Chrétien. To say that the RCX-400 is an "Advanced Ritchey-Chrétien System" is totally incorrect both from a theoretical and performance perspective and totally misleads the market place.

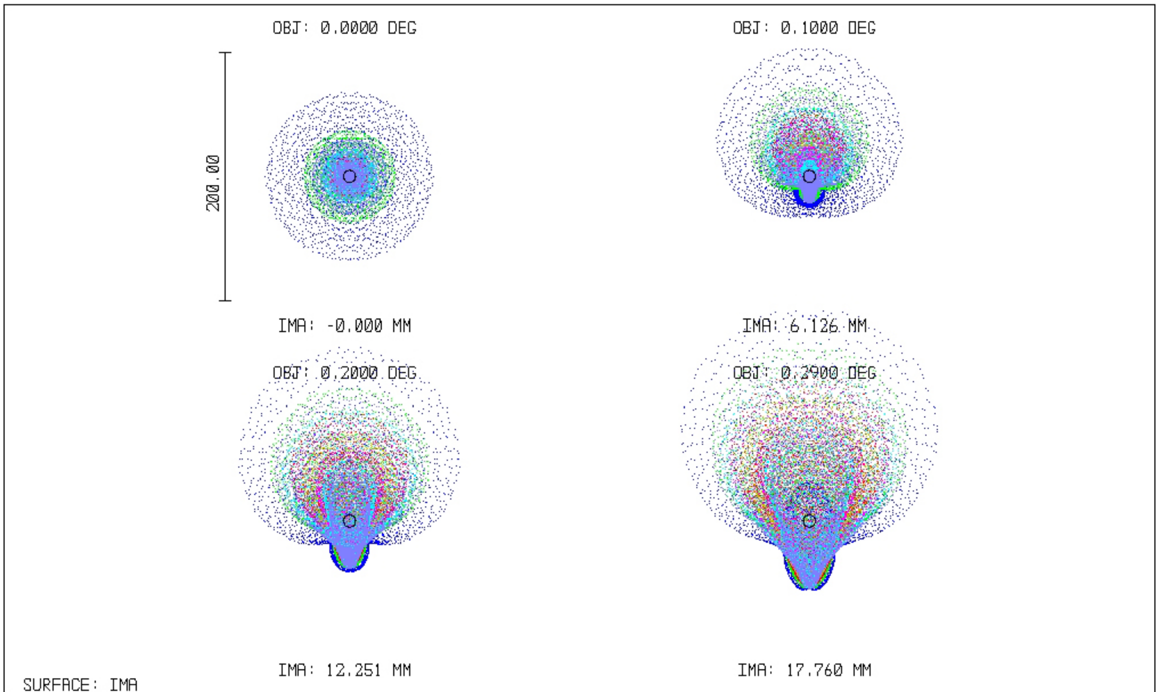
Appendix

The three optical designs under consideration were modeled in an optical design program called ZeMax. The optical curvatures were measured from representative samples. Spot size plots were done for off-axis amounts of 0 to 0.4 degrees. Plots of the effect of wavelength (color) were also done.



Note: The spot diagrams above are for curved fields.

The RC has a 14.87" radius versus the RCX400 which has an 11.54" radius.



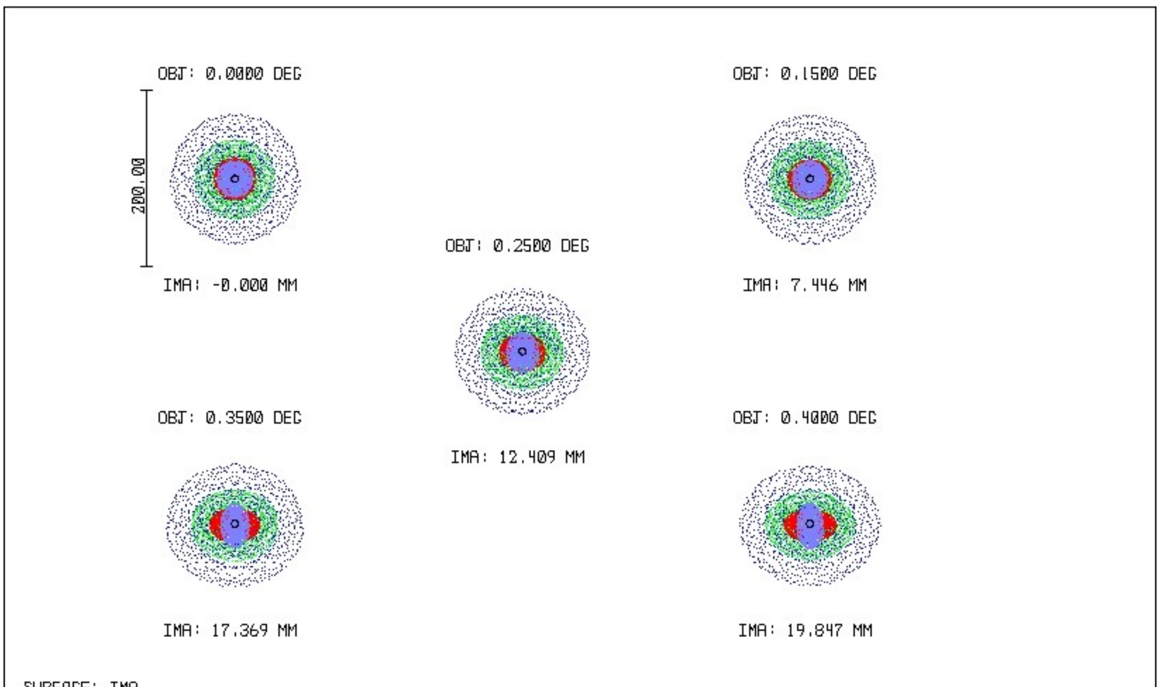
SPOT DIAGRAM

14 F/10 SCT 400 - 700 MICRON SPECTRAL BAND
TUE JUL 25 2006 UNITS ARE µm. AIRY RADIUS : 4.9 µm

FIELD :	1	2	3	4
RMS RADIUS :	15.117	21.353	33.734	46.239
GEO RADIUS :	67.767	103.257	139.758	170.299

SCALE BAR : 200 REFERENCE : CENTROID

14 F10SCT.ZMX



SPOT DIAGRAM

14 F/8 APLANATIC SCT 400 - 700 MICRON SPECTRAL BAND
THU JUL 6 2006 UNITS ARE µm. AIRY RADIUS : 3.908 µm

FIELD :	1	2	3	4	5
RMS RADIUS :	17.102	17.100	17.167	17.455	17.663
GEO RADIUS :	74.107	75.002	76.313	77.966	79.540

SCALE BAR : 200 REFERENCE : CENTROID

14 F8 APLANATIC SCT.ZMX