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SkyWave

Alignment of Ritchey–Chrétien Telescopes

RCT

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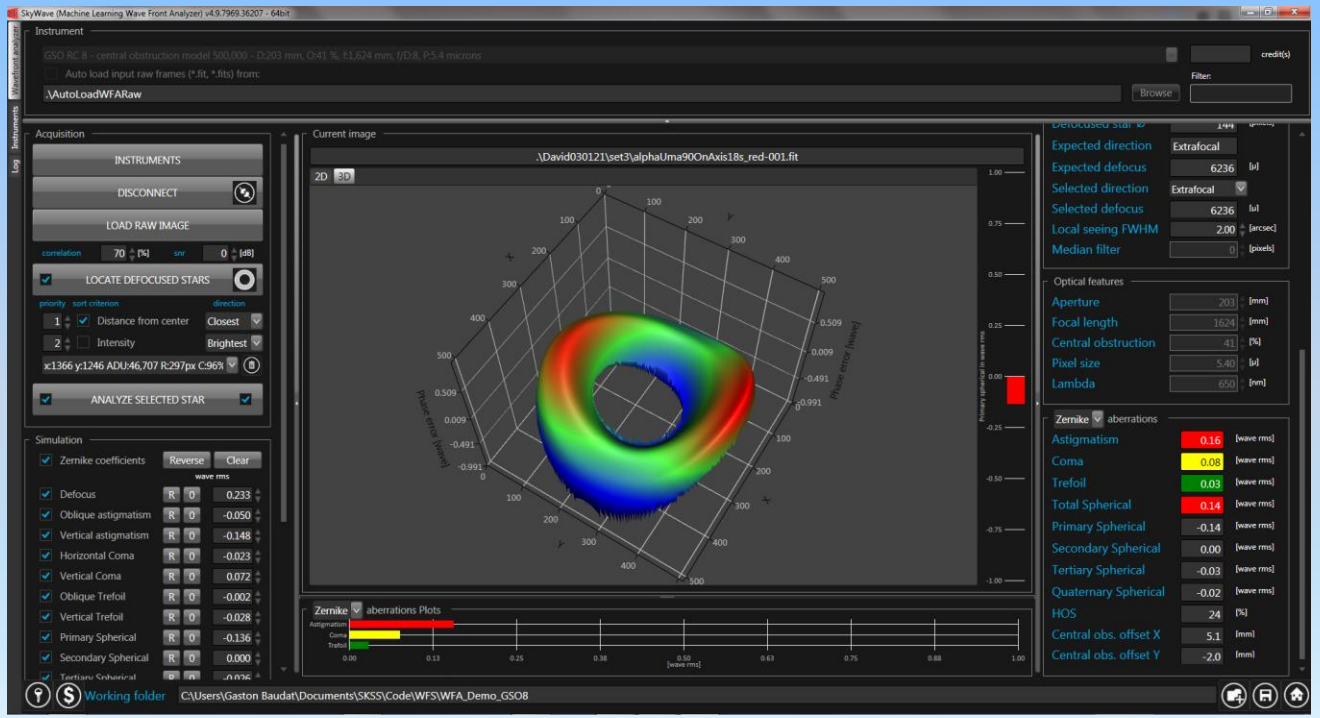
SkyWave (SKW)

SKW engine uses our patent pending AI based wavefront sensing technology. The wavefront and related aberrations are determined from a single defocused star even under seeing limited conditions.



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Goal & Content

- This presentation describes how to align a Ritchey–Chrétien telescope (RCT) using SKW.
- First, we discuss basic concepts and definitions before looking at an example (a 8” RCT).
- Telescope optical alignment requires two steps:

1. Alignment of the mirror optical axes. Both axes need to be superimposed. Defined as congruence in this presentation.
2. Setting the correct distance between both mirror vertices. Defined as spacing in this presentation.

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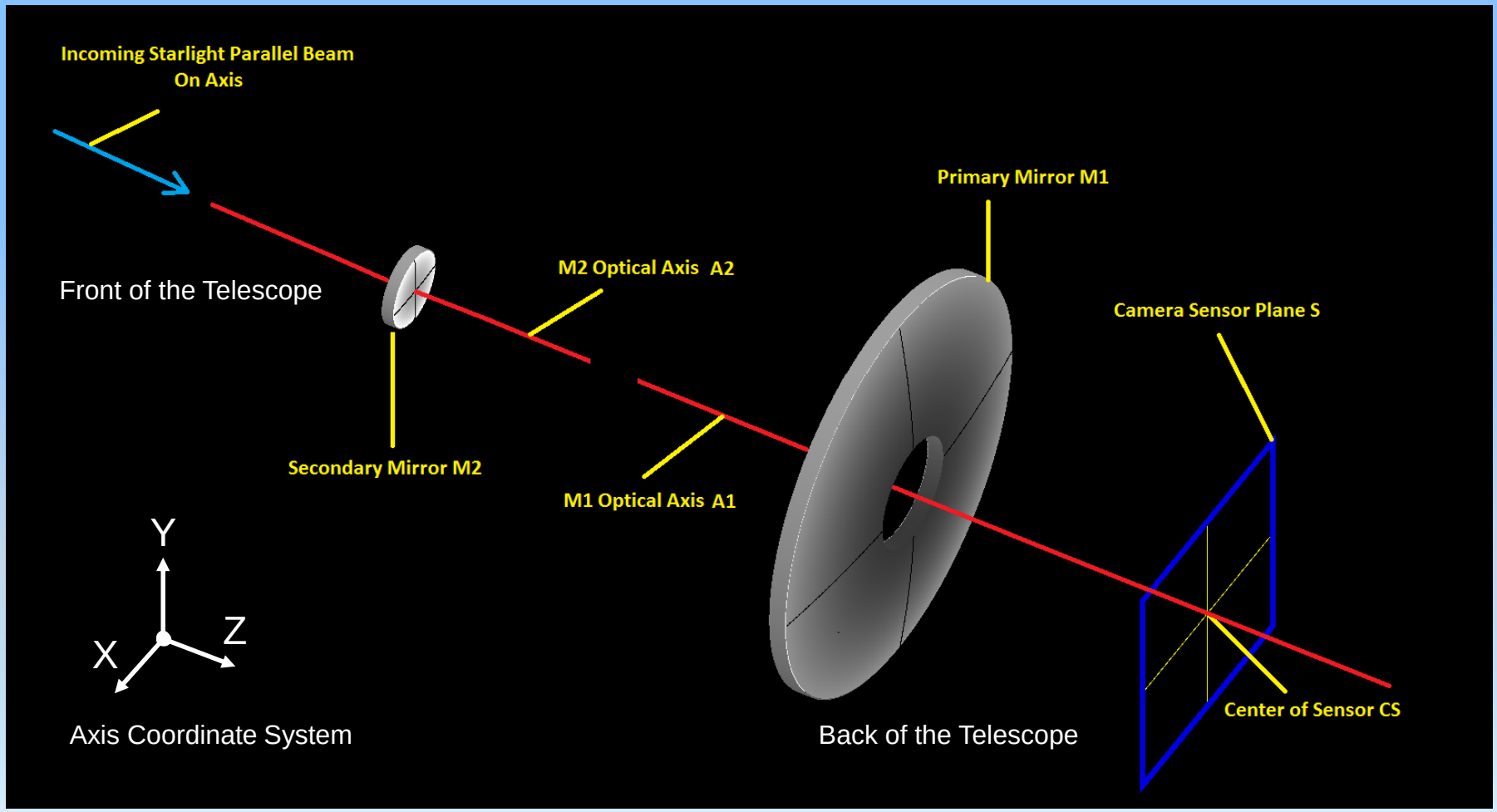
Some Definitions



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Part 1: Congruence

- The goal is to superimpose both optical axes A1 and A2 to make them congruent.
- A1 is the reference axis. For an aspherical mirror, it is its axis of revolution.
- By definition, a star is on-axis when its incoming beam is parallel to A1, even if its image is not located at CS.
- When the axes are congruent, the star image on the sensor plane is the telescope's optical center (OC) location.
- In practice, when the axes are congruent, we can reasonably assume that OC is close enough to CS.

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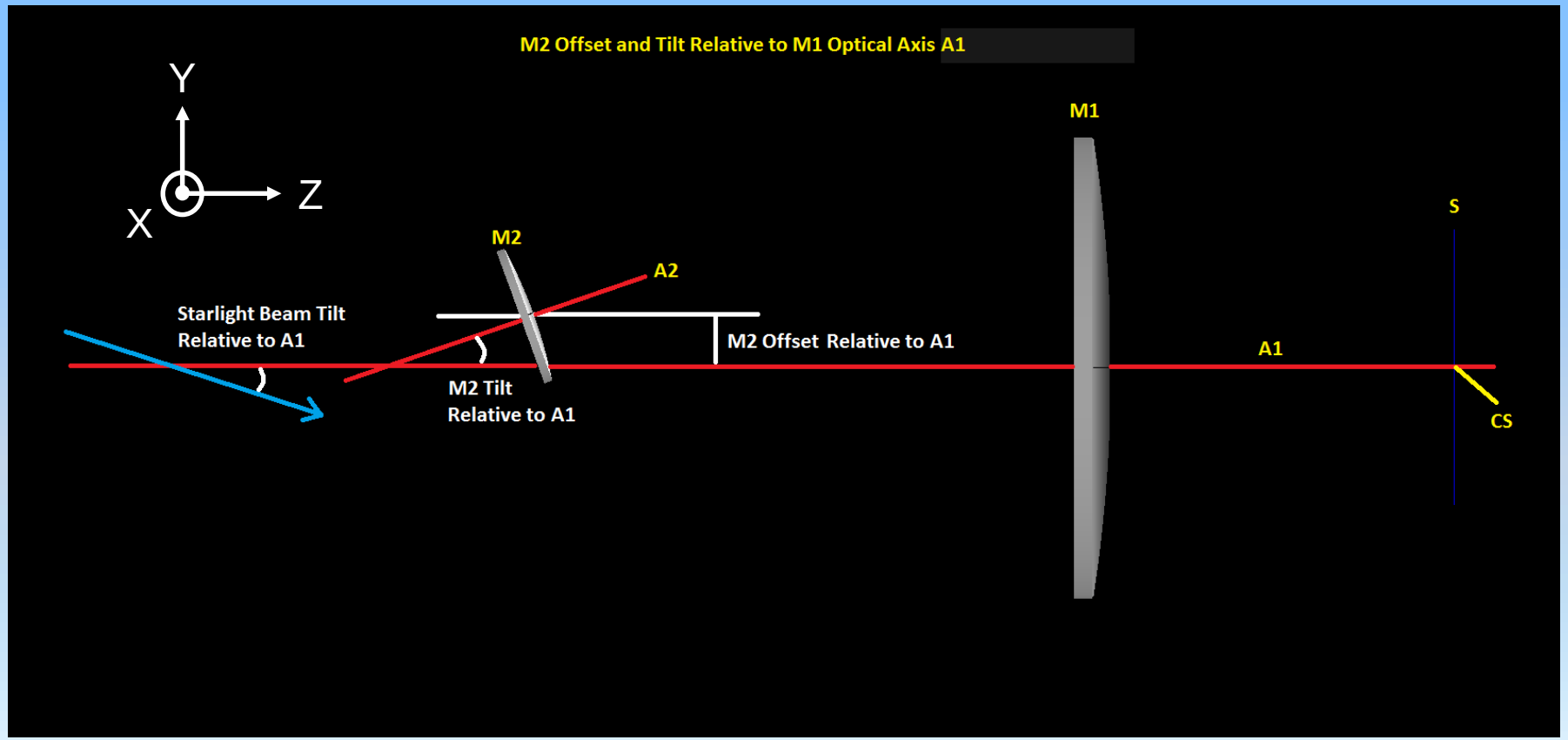
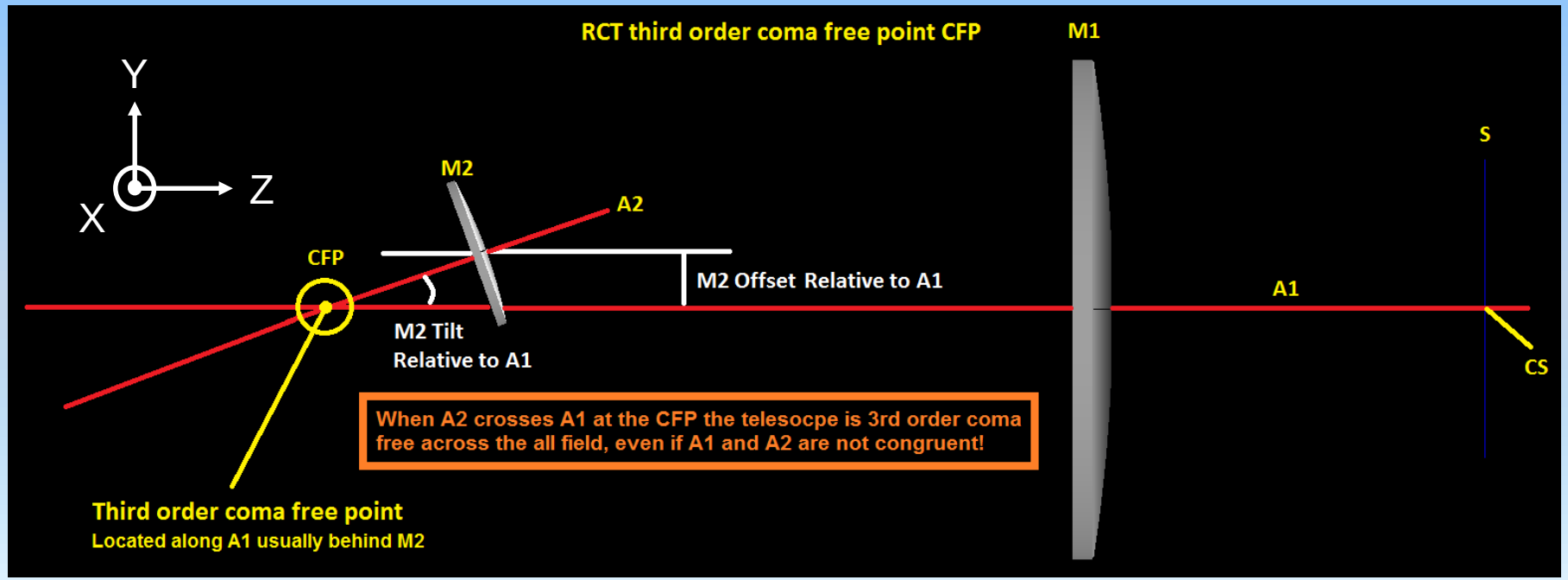
Congruence
Degrees of freedom

In general a mis-aligned A2 exhibits, relative to A1, offsets and tilts in 2 directions X & Y for a total of 4 degrees of freedom. Spacing omitted (Z).



Congruence
3rd Order Coma Free Point

There is a point along A1, known as the coma free point (CFP), such when A2 crosses A1 at the CFP the RCT is 3rd order coma free across the all field, even if both axes are not congruent. Therefore, a coma free RCT is not necessarily aligned yet, large unbalanced off-axis astigmatism may still exist!



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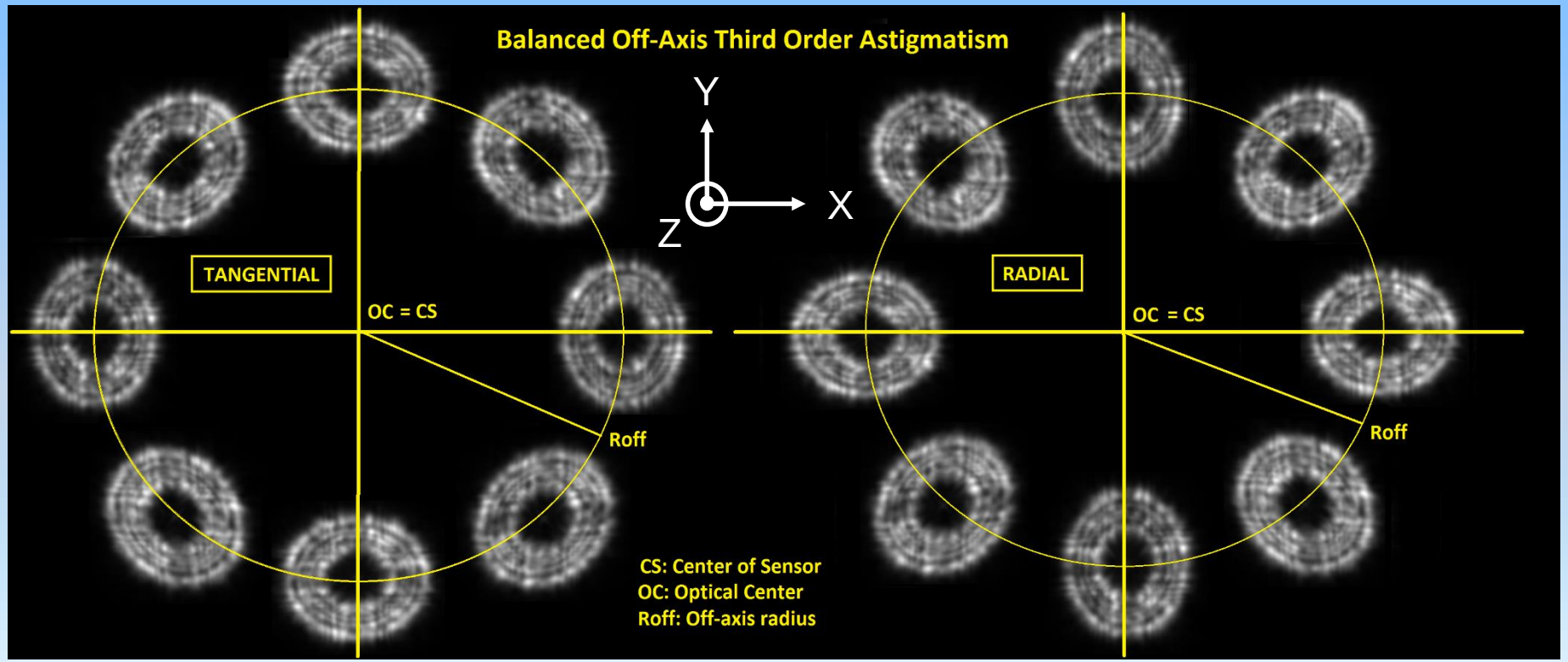
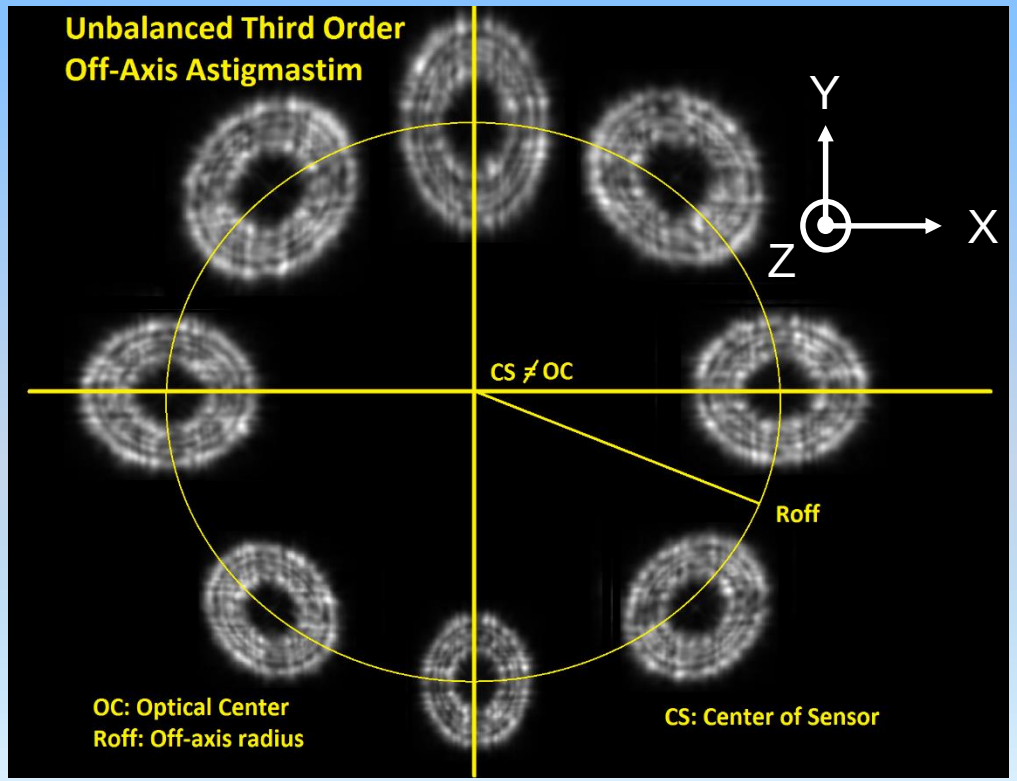
Congruence
Balanced Off-Axis Astigmatism

When A1 & A2 are congruent a RCT exhibits balanced off-axis astigmatism. At a given off axis radius astigmatism is either tangential or radial symmetric with a constant magnitude. Field lenses (corrector) may reduce it to a minimum.



Congruence
Unbalanced Off-Axis Astigmatism

When A1 & A2 are not congruent. A RCT exhibits unbalanced off-axis astigmatism. At a given off axis radius astigmatism is neither tangential nor radial symmetric and it has variable magnitude.



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Congruence
A Two Steps Alignment Procedure

- RCT telescopes are 3rd order coma free across the all field when aligned, the converse is not necessarily true.
- Both M1 and M2 tilt/tip adjustments are necessary for reaching congruence.
- Failing to follow the proper alignment procedure leads to an ever-increasing off-axis astigmatism even in the absence of coma.
- Step #1: Adjusting (tilt/tip) M1 to remove on-axis coma.
- Step #2: Adjusting (tilt/tip) M2 to balance off-axis astigmatism.
- Repeat step #1 and #2, in this order, until the on-axis coma is removed, and the off-axis astigmatism is balanced. Convergence takes usually 2 to 3 iterations.

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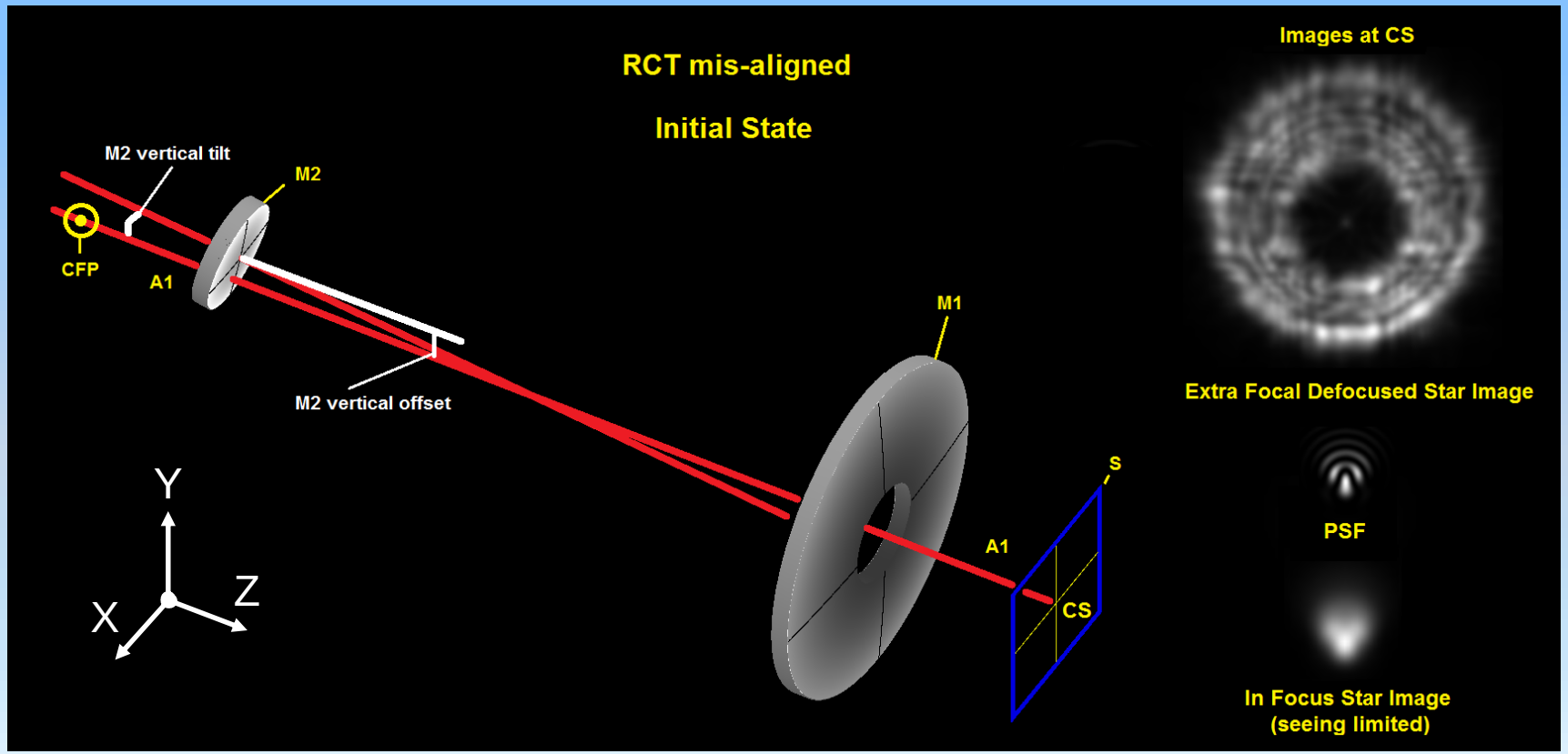
Congruence
Example with a 8” RCT
Initial State

In this example A2 is tilted back vertically by 0.1° and offset up by 0.5mm, not at scale. The star at the CS is overwhelming dominated by alignment induced coma, here 0.2 wave rms.



Congruence
Alignment using SKW
Step #1: Removing coma

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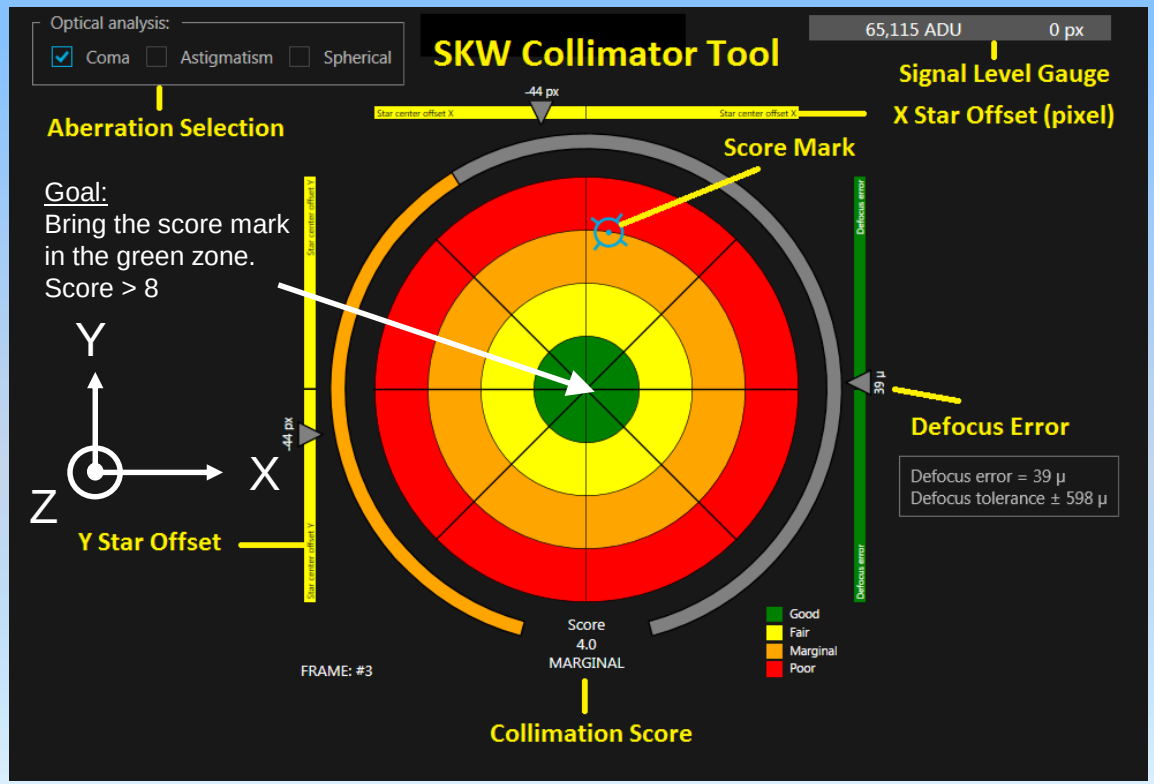
The SKW features a tool named collimator for alignment which displays a score mark inside a target. Coma only should be selected. The mark is oriented toward the point where **M2** is the most tilted forward (in this RCT example the +Y direction).

SKW collimator provides angular information in relation with the axis coordinate system used in this presentation.



Corrective action:
Pull **M1** at the position indicated by the SKW score mark angular direction

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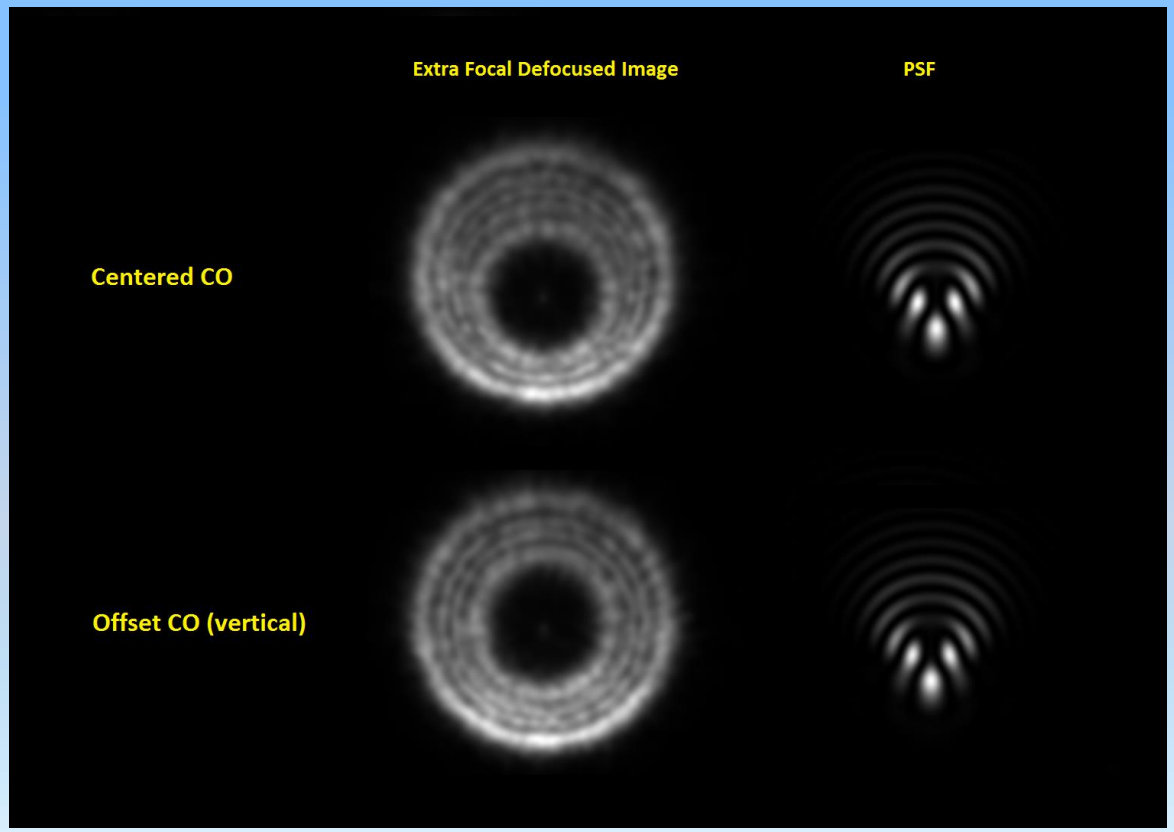
Congruence
Effect of Central Obstruction Offsets

The defocused star image is strongly affected by any M2 central obstruction (CO) offset for any reason, while the in-focus image is not. SKW provides quantitative aberrations independently of such offset.



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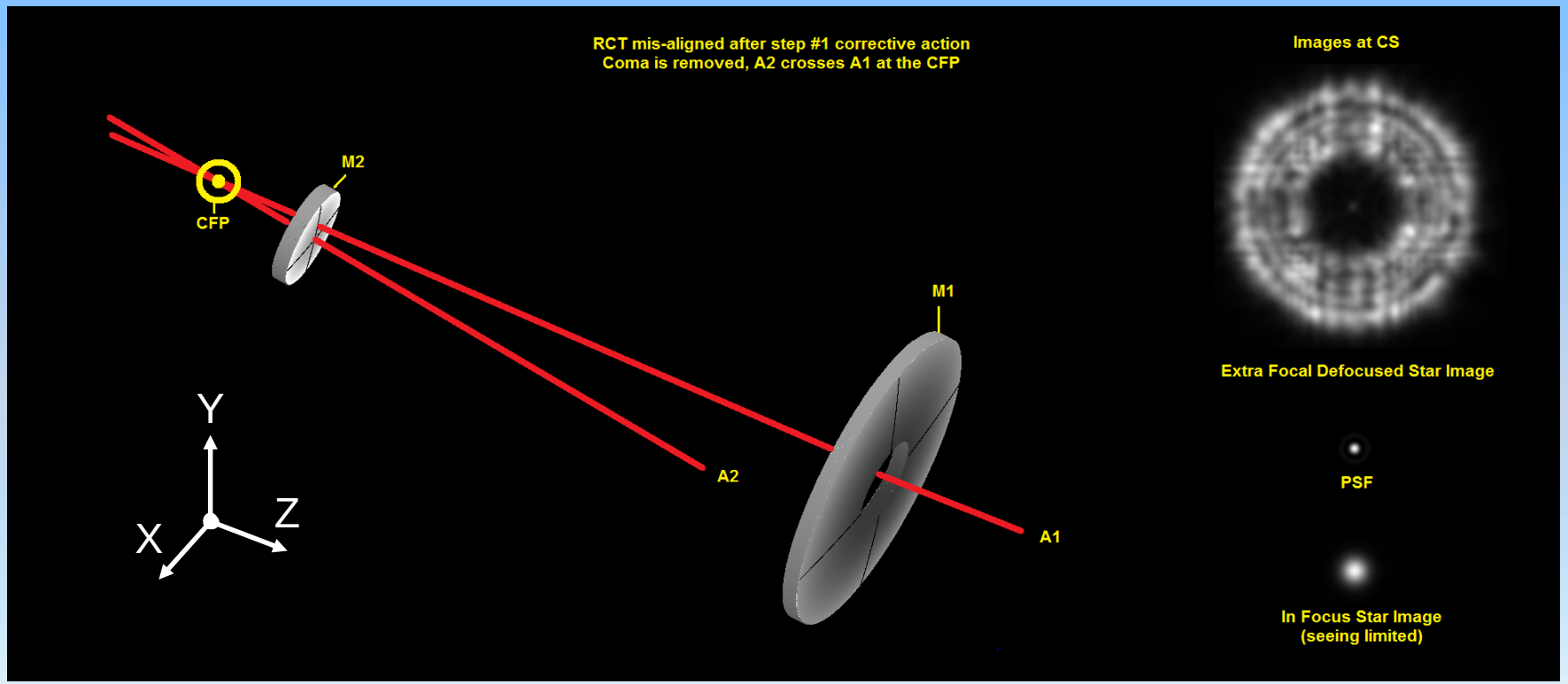
Congruence
Example with a 8" RCT
After Step #1 Corrective Action

Coma has been removed across the all field. Image at CS, near the OC, is DL (SR>99%). A1 crosses A2 at the CFP. However A1 & A2 axes are not congruent yet, they are still tilted leading to unbalanced off-axis astigmatism.



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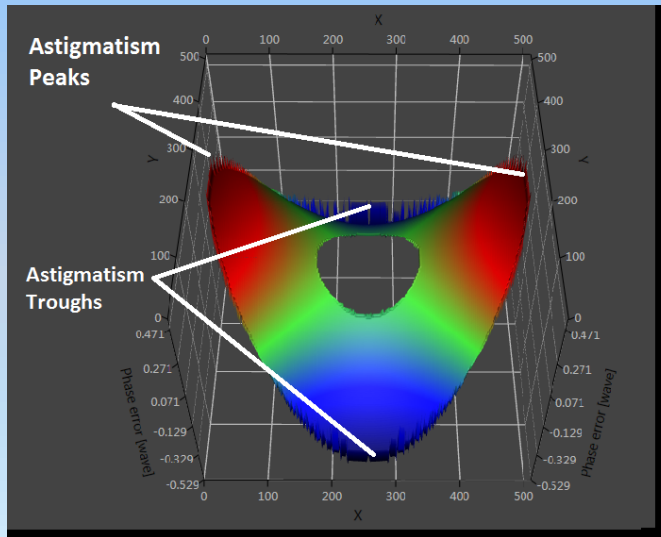
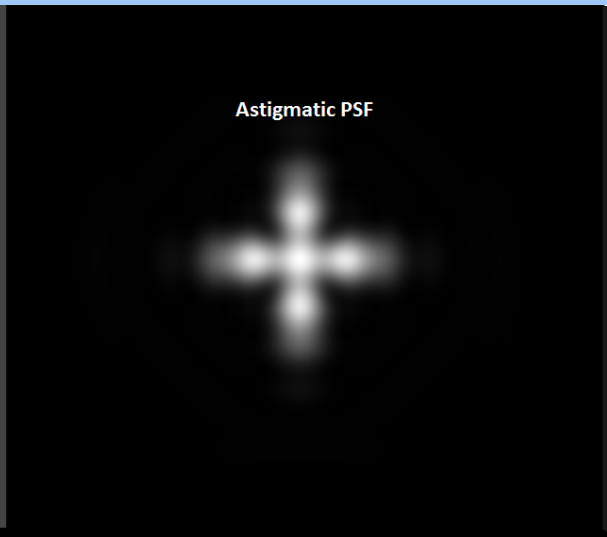
Congruence
Understand SKW Astigmatism Score

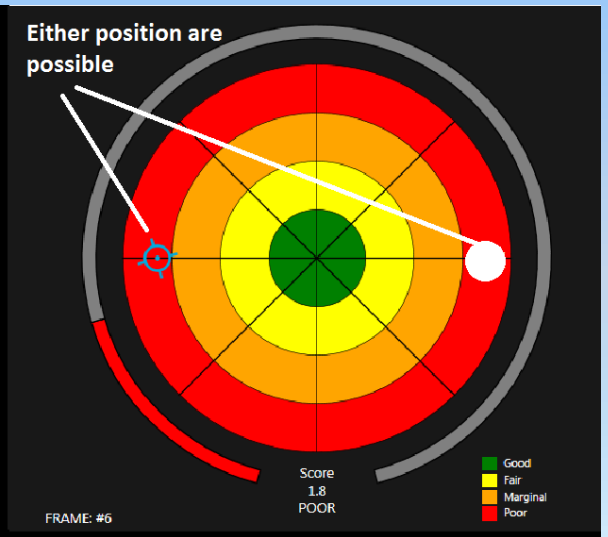
The astigmatism aberration used in SKW features two identical maximums and minimums on the wavefront phase error.
As a result, the SKW collimator score mark, for a given magnitude, could be at any of two opposite positions along the same axis. We shall mainly focus on the score magnitude for the step #2 RCT congruence alignment.



Wavefront Phase Error



PSF (no seeing)



SKW Collimator Tool

Congruence
Alignment using SKW
Step #2: Balancing off-axis astigmatism

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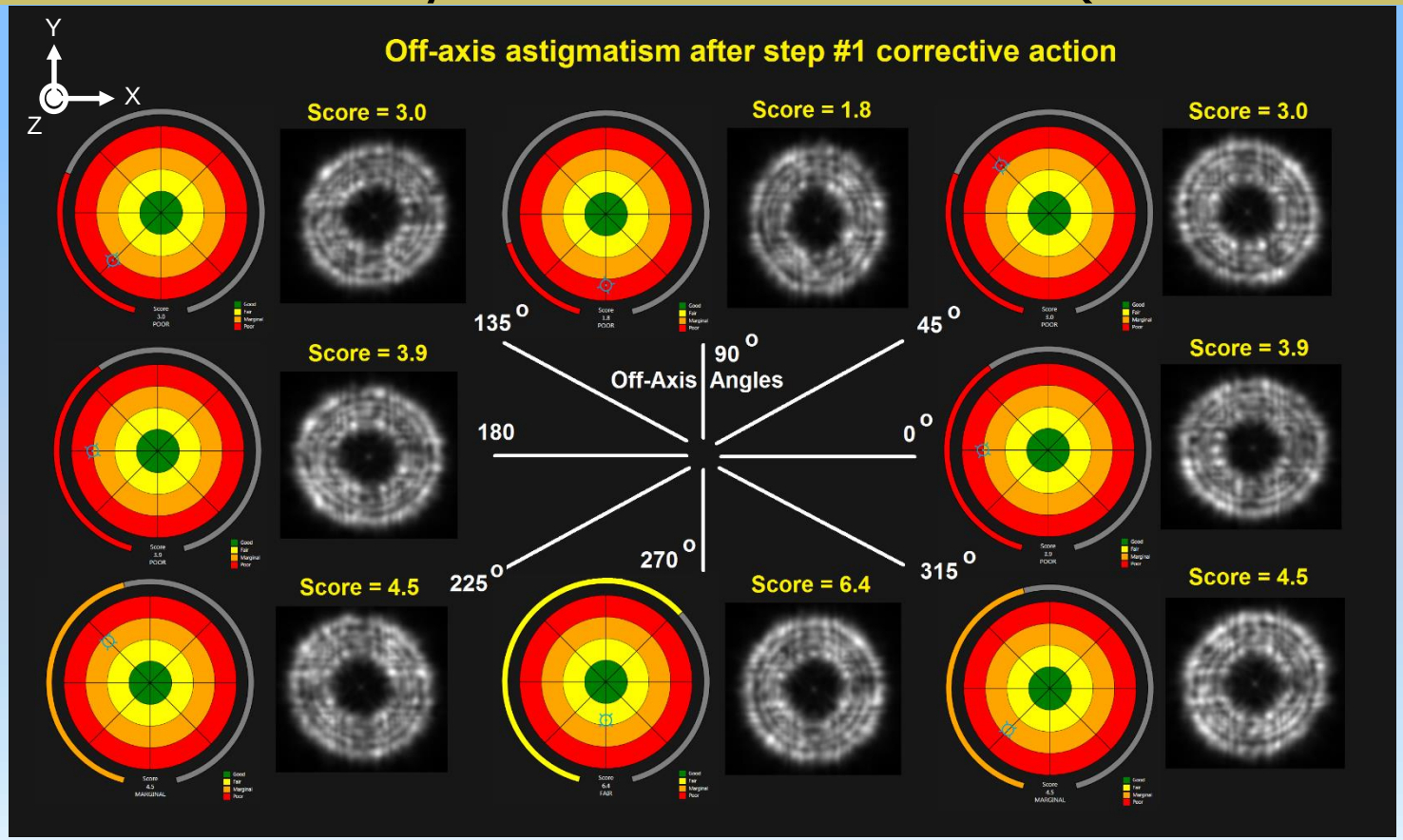
Analyze stars at a given off-axis radius. Astigmatism only should be selected. Corrective Action: Pull **M2** at the angular position indicated by the lowest SKW score (here at 90° , +Y)



Congruence
Example with a 8" RCT
After Step #2 Corrective Action

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For a given off-axis radius (here 14mm from CS) astigmatism has been balanced by adjusting **M2** only until the SKW off-axis scores are close to each others. Some mixt of tangential & radial astigmatism is acceptable if the scores are alike. This RCT does not have a corrector leading to some native off-axis astigmatism when A1 & A2 are at, or near, congruence.

Off-Axis Astigmatism Scores

135° off-axis SCORE = 4.8	90° off-axis SCORE = 4.8	45° off-axis SCORE = 4.8
180° off-axis SCORE = 4.9	"On-axis" at CS near OC SCORE = 10.0	0° off-axis SCORE = 4.9
225° off-axis SCORE = 5.0	270° off-axis SCORE = 5.0	315° off-axis SCORE = 5.0

On-Axis Coma Score

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Part 2: Spacing

- The goal is to set the distance **d** between both mirror vertices to its optimal value **d0**.
- Departure from **d0** leads to mainly primary spherical aberration and defocus. The telescope focal plane moves.
- For most telescope optical design prescriptions, the spherical aberration increases quite slowly with **d**.
- Therefore, a large primary spherical aberration may very well be related to the scope optics itself not its alignment.
- Since SKW retrieves and uses the wavefront data, the spherical aberration is computed independently of any other aberrations, such as coma or astigmatism.

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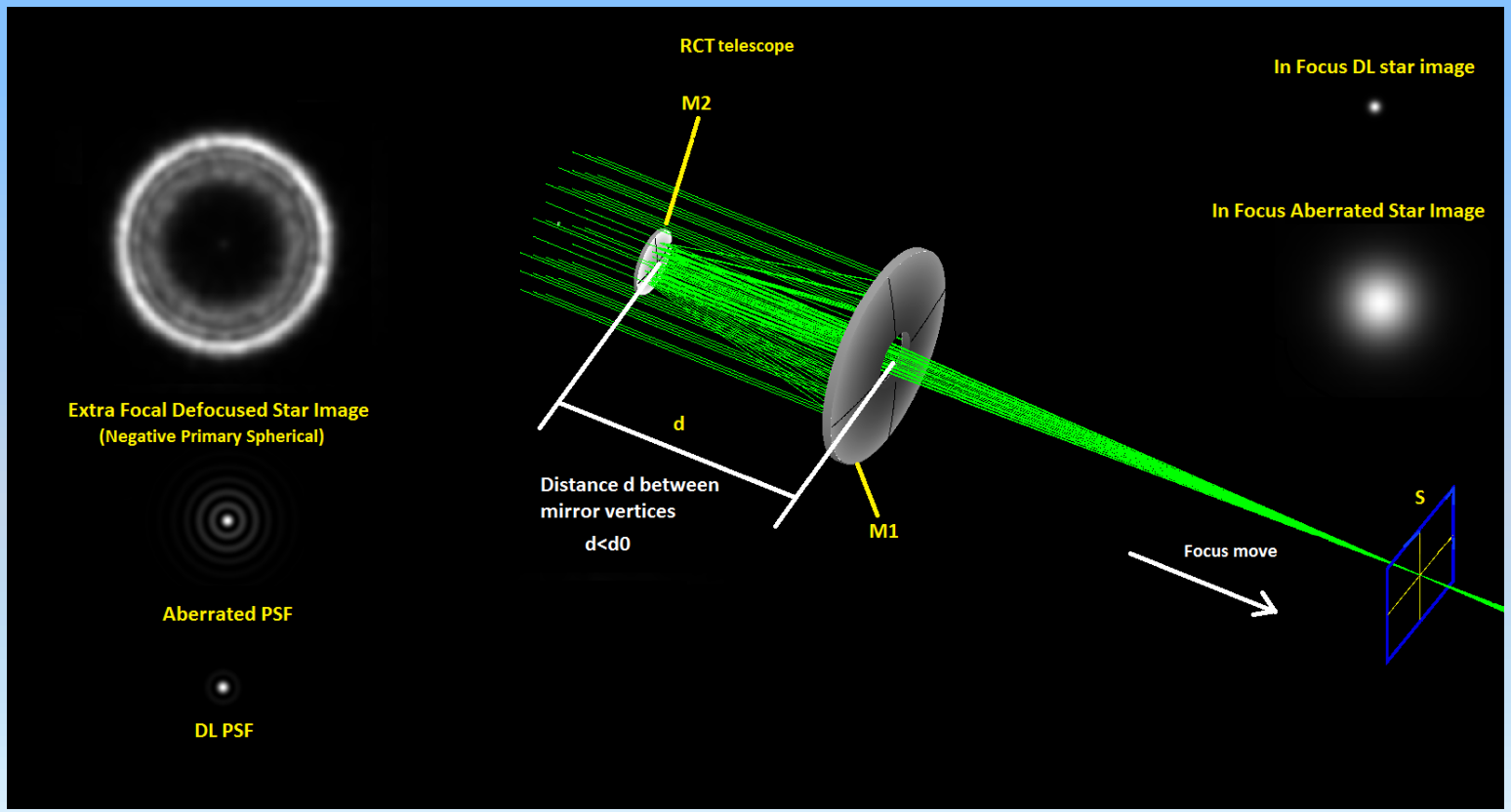
Spacing
Example with a 8” RCT

In this example **d<d0** by -11mm leading to -0.14 wave rms of negative primary spherical aberration.
The focus shifts forward by 178mm with this RCT optical design.



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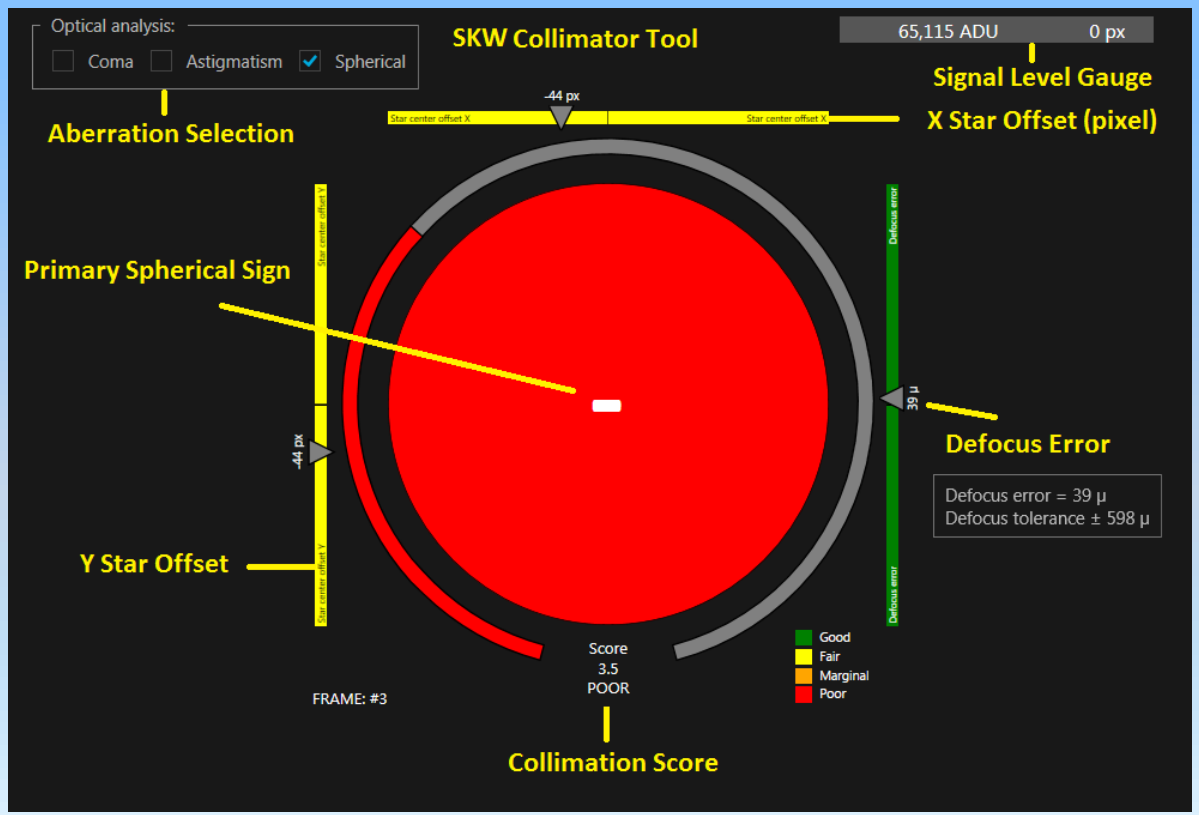
Spacing
SKW Collimator Tool

The SKW collimator tool displays the score and the sign of the primary spherical aberration. Spherical only should be selected. A negative sign implies that **d<d0**, a positive one that **d>d0**.



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Conclusions

- SKW determines wavefront allowing for an accurate and fast quantitative optical alignment of telescopes using the relevant aberrations. Score goal ≥ 8, the green zone.

Step #1 Congruence using **coma only**

Pull M1 at the position indicated by the SKW score mark angular direction.

- Step #2 Congruence using **astigmasim only**

Pull M2 at the angular position indicated by the lowest SKW score of the off axis defocused stars.

REPEAT

2. Spacing using **spherical only**

Increase the mirrors spacing if the SKW spherical aberration sign is negative, decrease it if positive.

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Thank you!