When excellent on-axis performance is not good enough

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Optical nodal-aberration theory enables detailed characterization of optical aberrations affecting three-mirror telescope design.

In this United Nations-endorsed international year of astronomy, during which we celebrate the 400th anniversary of the development of the astronomical telescope, a major evolution is occurring in telescope design: the introduction of innovative three-mirror astronomical telescopes. The performance of these instruments is determined by new misalignment-induced aberration fields that we have described only recently.

A characteristic of a misaligned telescope is the appearance of an on-axis comatic image (resembling a comet with tail). On-axis coma is an excellent indicator of alignment problems for amateur astronomers. They are mostly restricted to using Cassegrain-type telescopes (equipped with parabolic mirrors) because of cost considerations. For a Cassegrain telescope that is out of alignment, we still observe a well-defined point in the image field that is unaffected by coma. It is, however, simply no longer located in the center of the field of view. When aligning a Cassegrain telescope, one must therefore return the point of zero coma to the center of the field. However, it is little known that the absence of on-axis coma is not a good indicator of satisfactory alignment for professionals. Observing a seeing-limited image at the center of the field of view of a science-grade telescope built after approximately 1920—which generally means that it is not a Cassegrain configuration—does not assure that the instrument is properly aligned.

For a Ritchey-Chrétien telescope the effects of optical aberrations are somewhat different. Because it is corrected for third-order coma by using a slightly nonparabolic primary mirror, misalignment again results in the appearance of axial coma, but now the aberration appears everywhere in the field with the same magnitude and orientation. This is the first example of a family of ‘misalignment-induced aberration fields.’ Alignment results in removal of coma at all field points simultaneously. The aligned and misalignment-induced aberration fields for coma in two-mirror astronomical telescopes are shown in Figure 1.

In a Ritchey-Chrétien telescope that has been aligned to remove coma, a new misalignment-induced aberration field is introduced, which was originally discovered by Roland Shack: binodal astigmatism (see Figure 2). We found that the aligned telescope represents a degenerate case where the two characteristic misalignment-induced aberration-field nodes have coalesced to overlay each other at the on-axis field point. We recently discussed in detail the important implications of this discovery for alignment of astronomical telescopes built in the 1900s.

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At the present time, astronomers have discovered the three-mirror anastigmatic telescope (TMA), a family of optical forms that is corrected for all third-order aberrations that provide the most fundamental limits to the fields of view of astronomical telescopes. With three mirrors, each can provide a degree of freedom to accomplish correction of a third-order aberration type. The James Webb Space Telescope currently under development is an example of this family of optical forms.\footnote{5}

We recently discovered that while a misaligned TMA telescope will initially signal its imperfect state by exhibiting axial coma, removal of this aberration (which then results in excellent on-axis imagery) does not guarantee that the telescope is properly aligned. The reason for this is that TMA telescopes display a new form of misalignment-induced aberration field: field-linear, field-asymmetric astigmatism.\footnote{1} The resulting misalignment-induced astigmatism over the field dominates the telescope’s performance (see Figure 3).

A key advantage of nodal-aberration theory is that it provides an extensible, independent, self-consistent model for understanding precisely how a particular telescope design will respond to misalignments. In particular, knowing that there is a specific, intrinsic, field-asymmetric behavior is important for engineers attempting to interpret off-axis performance measurements, especially those based on Zernike-component reductions of measured wavefront data over a limited set of measurement points in the field of view. We will next aim to employ nodal-aberration theory to substantial advantage in planning the alignment of the emerging family of TMA telescopes.

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**References**