Active optics: pushing x-ray astronomy to its limits

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Piezo-controlled x-ray optics could be the answer for probing the first epoch of star formation in the Universe.

X-ray astronomy, so far, is nowhere near the limits set by physics. Even the superb Chandra X-ray Observatory1 mirrors could have made 20 times sharper images, before hitting the diffraction limit, because the thermal lines emitted by x-ray hot plasmas are 20 times narrower than the best available spectra. To reach these limits, and be able to image those first objects in the Universe, will require a ‘super-Chandra’ and a major advance in x-ray optics.

The high angular resolution of the Chandra X-ray Observatory has revolutionized x-ray astronomy, and wide areas of astrophysics. But Chandra is a small telescope because its mirrors have to be heavy—around 18×10^3 kg m^−2—in order to maintain their accurately fabricated figures during the rigors of launch. How can we beat Chandra resolution at much lower mass per unit area? The answer may be to adjust the mirror configuration, once the telescope is in orbit, using piezoelectrically controlled ‘active x-ray optics’.

A NASA ‘Vision Mission’, called Generation-X, aims to go from the 1/7200 of a degree HPD (half power diameter) images of Chandra to ones of less than 1/36,000 HPD, and to do so with 1000 times the Chandra area. These goals can only be met with some new x-ray mirror technology, and active x-ray optics looks like a promising candidate. The grazing incidence geometry, essential to broadband x-ray telescopes, precludes copying the approach used for optical telescopes. That method consists of actuators pushing directly on the back of the mirror, which would block the incoming x-rays. Our solution2 is to use thin piezoelectric actuators on the back of the x-ray mirrors to bend the mirrors to their correct shape.

Active x-ray optics add complications, but come with advantages: simpler ground calibration, easier launch-stability requirements, and an operating temperature that need not be the same as for the ground calibration. Such optics would only need to be adjusted every few months, compared with the approximately 10Hz correction rate for ground-based adaptive optics. However, at the one-degree-grazing-incidence angle of x-ray optics, each square meter of collecting area requires nearly 100m^2 of reflecting surface, all of which must be controlled. This implies many actuators (10^4 − 10^6) per square meter.

The three major challenges to be overcome include sensing misalignments, calculating adjustments, and applying the corrections. Sensing the misalignments of all these sensors can be done using a far out-of-focus image of the converging x-ray beam (see Figure 2). Twenty of more celestial x-ray sources provide 1000 counts per second per square meter, so an alignment observation will take a only a few hours to few days. Unless the patches are very small, several cycles of correction can be done during each alignment campaign.

Calculating the required figure adjustments is not difficult: the Keck telescope3 adjusts 349 actuators at 1−10Hz. If the

Figure 1. The arrangement of piezoelectric actuators on a Wolter I x-ray optic.

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mirrors of choice for almost all x-ray astronomy missions. Rapid development of active x-ray optics is an urgent, and reasonable, short-term goal for x-ray astronomy. Diffraction-limited x-ray telescopes may now be on the horizon.

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Martin Elvis has been an x-ray astronomer from the early days of satellites up through the Chandra era. He discovered that active galaxies are powerful sources of x-rays. He went on to explain their variety by the effects of obscuration, their atomic emissions and absorption features, as the effects of a wind from the accretion disk surrounding their central black holes.

References


Figure 2. In a Chandra ‘ring focus’ image, the detector was placed forward of the focus in the converging beam from the mirror shells, each of which produces a separate ring that is azimuthally resolved. For active x-ray optics, the image would be further out of focus to give a radially extended image that also separates each axial segment.