Chandra Telescope Optical Axis and Aimpoint

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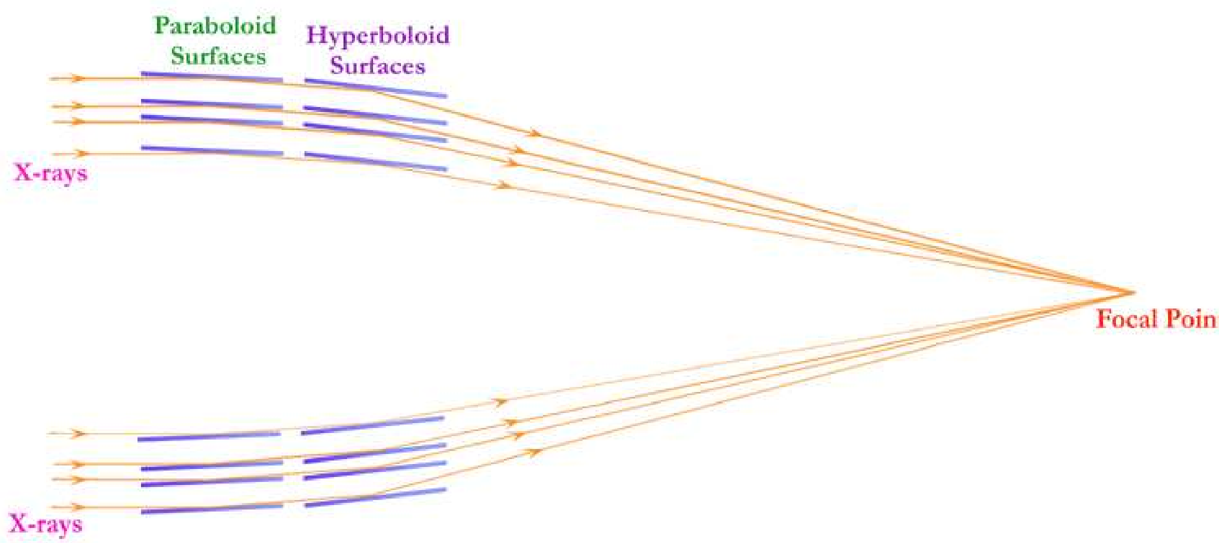

Optical Axis, Focal Point and Aimpoint

Definition:

- Optical Axis: Axis that perpendicular to the focal plane at the Focal Point.
- Focal Point: Point on the focal plane where the sharpest PSF is located.
- Aimpoint: Point on the focal plane where the image of a source with zero Y and Z offsets is located.

For ideal Wolter-I X-ray Mirrors:

- Optical Axis is the mathematical axis of both paraboloid and hyperboloid mirror surfaces; and it passes through both Focal Point and Aimpoint (i.e. Focal Point and Aimpoint is the same point).

For the actual HRMA:

- The Focal point and the Aimpoint were not the same point after Chandra launch, and they have been drifting since.
- The positions of the Optical Axis, Focal Point and Aimpoint have been monitored continuously.
- The nominal Optical Axis was determined from the raster scan measurements made with HRC-I in September 1999 (Maxim Markevitch).
- The nominal Aimpoint was determined from the absolute pointing measurements made with ACIS-S from September 1999 to April 2000 (Tom Aldcroft).
- Based on the above measurements, the Focal Point and Aimpoint were separated by $\sim 18.6''$.
- Where have they been since then? – the motivation of this study.

On-orbit calibration of the Optical Axis

The calibration was made by raster scans of offset Y and Z for bright point sources (HR 1099 and Ar Lac) with detectors HRC-I or HRC-S. The position of the Optical Axis has been monitored continuously since the Chandra launch.

Optical Axis Calibration data (until Nov. 2005)

Detector: HRC-I

Date	Source	Sim-Z
1999-09-02	HR 1099	91.8655 mm
1999-10-03	Ar Lac	126.9855 mm
1999-12-09	Ar Lac	126.9855 mm
2000-12-12	Ar Lac	126.9855 mm
2002-01-26	Ar Lac	126.9855 mm
2003-02-22	Ar Lac	126.9855 mm
2004-11-25	Ar Lac	126.9855 mm
2005-09-27	Ar Lac	126.9830 mm

Detector: HRC-S

Date	Source	Sim-Z
2000-12-20	Ar Lac	250.4660 mm
2001-05-14	Ar Lac	250.4660 mm
2002-01-26	Ar Lac	250.4660 mm
2002-08-09	Ar Lac	250.4660 mm
2003-02-22	Ar Lac	250.4660 mm
2003-09-01	Ar Lac	250.4660 mm
2004-02-09	Ar Lac	250.4660 mm
2004-11-28	Ar Lac	250.4660 mm
2005-02-10	Ar Lac	250.4660 mm
2005-09-01	Ar Lac	250.4660 mm

Data Analysis

- **Encircled energy radii (10% – 99%) of each raster scan images (in sky coordinate) were calculated.**
- **The centroids of ChipX and ChipY were calculated for each point.**
- **The EE radii vs. (ChipX, ChipY) was fit to a quadratic function:**

$$r_{EE_i}(x, y) = c_0 + c_1x + c_2y + c_{11}x^2 + c_{12}xy + c_{22}y^2 \qquad (1)$$

  where $i = 10\% - 99\%$.
- **By definition, optical axis is located at (x_0, y_0) where r_{EE_i} reaches minimum.**
- **Aimpoint positions were calculated for each set of raster scan, using the script provided by Jonathan McDowell.**

Optical Axis and Aimpoint Positions

Detector	SIM-Z (mm)	Point	Nominal[a] ChipX	Nominal[a] ChipY	Actual[b] ChipX	Actual[b] ChipY	Current[c] ChipX	Current[c] ChipY	Current(HRC-I)[d] ChipX	Current(HRC-I)[d] ChipY
HRC−I	126.985	opax	7529.90	7745.00	7551.08	7725.13	7574.03	7730.78	7574.03	7730.78
		aimp	7669.00	7721.00	7669.00	7721.00	7638.84	7796.56	7638.84	7796.56
HRC−S	250.456	opax	2201.53	8976.27	2200.42	8947.27	2279.87	8904.08	2179.91	8934.76
		aimp	2119.88	8861.03	2119.88	8861.03	2129.13	8912.34	2087.42	8935.69
ACIS−I	−233.592	opax	984.34	994.80	984.05	987.02	—	—	978.57	983.64
		aimp	962.47	963.79	962.47	963.79	951.00	974.00	953.75	983.80
ACIS−S	−190.133	opax	220.73	531.80	228.51	531.50	—	—	231.86	526.01
$\Delta Y=0''$		aimp	251.64	509.93	251.64	509.93	235.00	497.00	231.63	501.22
$\Delta Y=-20''$		aimp	292.32	509.93	—	—	275.68	497.00	272.313	501.22
$\Delta Y=+10''$		aimp	231.30	509.93	—	—	214.66	497.00	211.288	501.22

[a] **Nominal (default) positions based on measurements made in September 1999, on HRC-I (optical axis) and ACIS-S (aimpoint). These are the numbers in the Calibration Database and POG since 1999.**

[b] **Actual optical axis positions based on the same measurements but taking into account of the HRC-I clocking angle — the angle between +ChipX and −Sim-Z is 44.70419°, instead of 45°. The aimpoints are the same as Nominal.**

[c] **Current optical axis and aimpoint positions, based on measurements made in September 2005 for HRC-I and HRC-S, and in September 2004 for ACIS-I and ACIS-S. Values for ACIS-I and ACIS-S are already in the Cycle 7 POG, Table 6.3 (p.87), but not yet in the *geom* file. (POG ACIS chapter Figure 6.1 still gives the old values.)**

[d] **Current optical axis and aimpoint positions, based on measurements made in September 2005 for HRC-I and translated onto other detectors using the *dmcoords* and the current *geom* file in the Calibration Database.**

Issues for Discussion

1. **What could cause both optical axis and aimpoint to shift?**
   - Possible a change in the geometry of the spacecraft, such as a bending of the optical bench, causing the SIM module to shift with respect to the HRMA.
2. **Do we want to re-define nominal SIM-Z positions to compensate the shift?**
   - Detector chips are tilted to match: 1) the curved surface of the best HRMA focus for ACIS-I; and the Rowland torus for the ACIS-S and HRC-S. We want to put the optical axis near the designed positions on the detector so that best fit can be achieved.
   - Do we want to put the optical axis or aimpoint on any particular pixel of the detector to, say, avoid the dithering falls off the edge of the chips (ACIS-I)?
3. **Do we want to re-define the telescope Y and Z offsets so that the aimpoint can be (almost) on the optical axis?**
4. **Do we want to apply a $+20''$ (or $+10''$) offset, instead of the current $-20''$ offset, for the ACIS-S observation, so that the dithered flux from an (almost) on-axis point source is entirely in node 0, instead of node 1, of ACIS-S3?**
5. **What are the positive and negative impacts by making any of the above changes?**
6. **What software and database changes do we need to make in order to implement any of the above changes?**
   - For example, *geom* file needs to be updated.
   - For example, by definition, the (nominal) optical axis is at the center of the (DETX, DETY) coordinates for each detector. Since the optical axis has moved, the derived (DETX, DETY) do not give the true off-axis angle and so PSFs derived from them will not be correct.