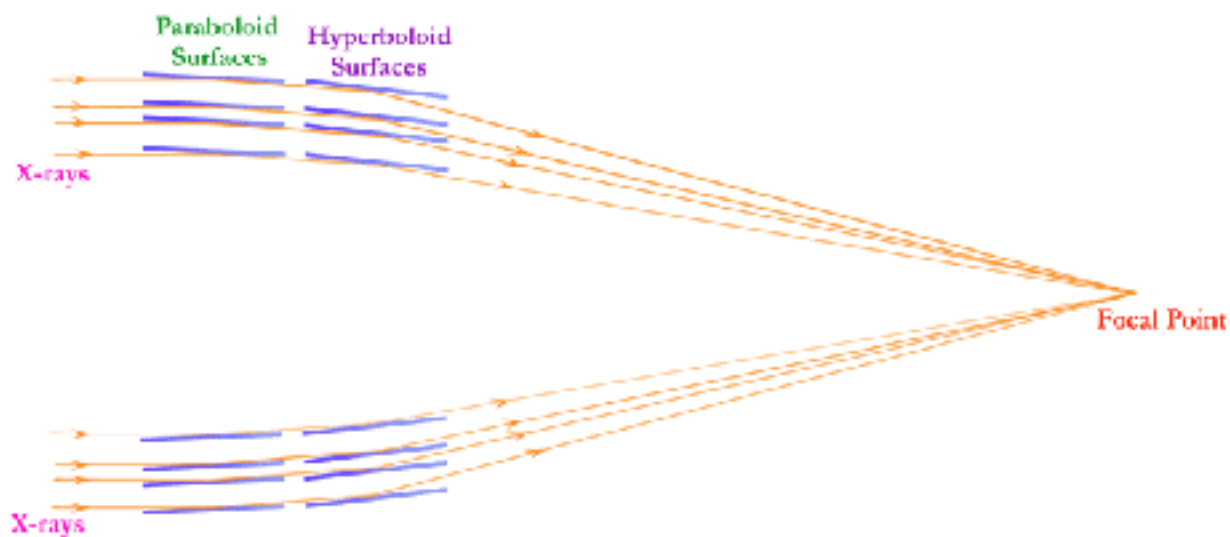


# Chandra Telescope Optical Axis

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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:

- To determine the Optical Axis, Focal Point and Aimpoint is one of the on-orbit calibration tasks.
- The current nominal Optical Axis was determined from the raster scan measurements made with HRC-I in September 1999 (Maxim Markevitch).
- The current 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 Oct. 2004)

Date	Source	Detector	Sim-Z
1999-09-02	HR 1099	HRC-I	91.8655 mm
1999-10-03	Ar Lac	HRC-I	126.9855 mm
1999-12-09	Ar Lac	HRC-I	126.9855 mm
2000-12-12	Ar Lac	HRC-I	126.9855 mm
2000-12-20	Ar Lac	HRC-S	250.4660 mm
2001-05-14	Ar Lac	HRC-S	250.4660 mm
2002-01-26	Ar Lac	HRC-S	250.4660 mm
2002-01-26	Ar Lac	HRC-I	126.9855 mm
2002-08-09	Ar Lac	HRC-S	250.4660 mm
2003-02-22	Ar Lac	HRC-S	250.4660 mm
2003-02-22	Ar Lac	HRC-I	126.9855 mm
2003-09-01	Ar Lac	HRC-S	250.4660 mm
2004-02-09	Ar Lac	HRC-S	250.4660 mm

## SIM Translation Table

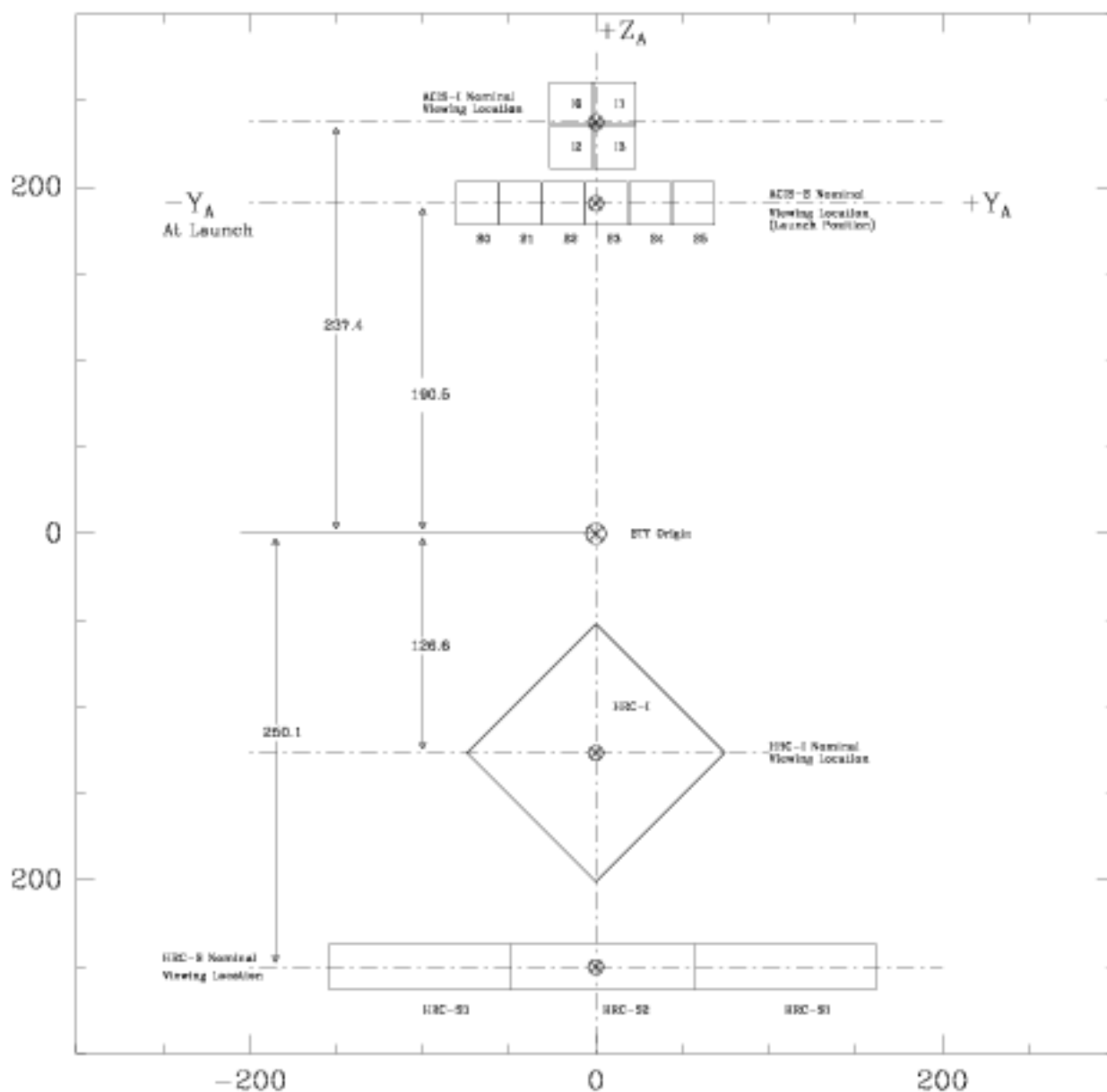


Figure 1: The Chandra SIM Translation Table, showing the flight focal plane instrument to scale. Distance in mm. Coordinate system is AXAF-STT-1.0. (credit: Jonathan McDowell)

## 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:

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

where  $i = 10\% - 99\%$ .

- By definition, optical axis is located at (ChipX, ChipY) where  $r_{EE_i}$  reaches minimum.

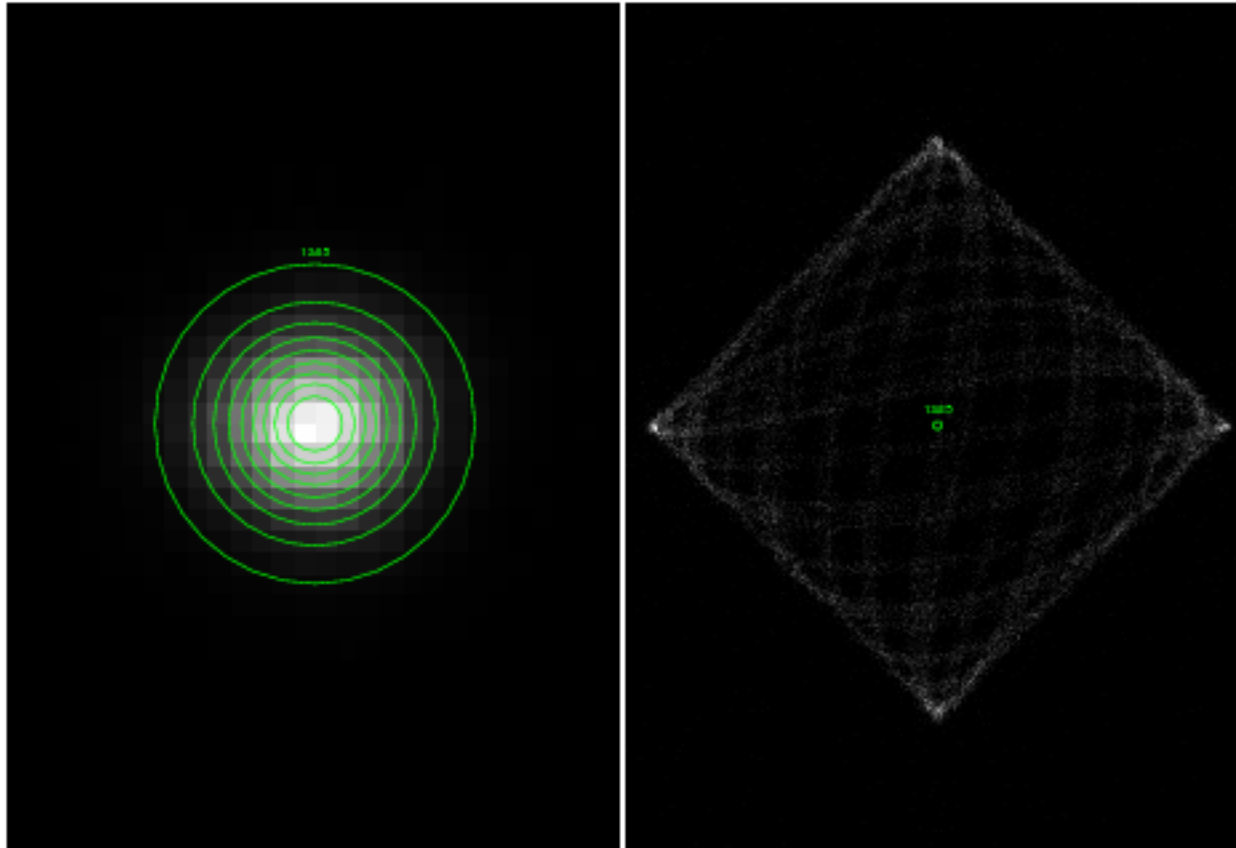


Figure 2: HRC-I observation of Ar Lac with 19ks exposure time and zero Y and Z offsets (obsid 1385). Left: image in sky coordinates with 10% – 90% encircled energy circle overlay. Right: image in chip coordinates with the centroid of the dither pattern marked. The centroid is at the center of the Lissajous dither pattern.

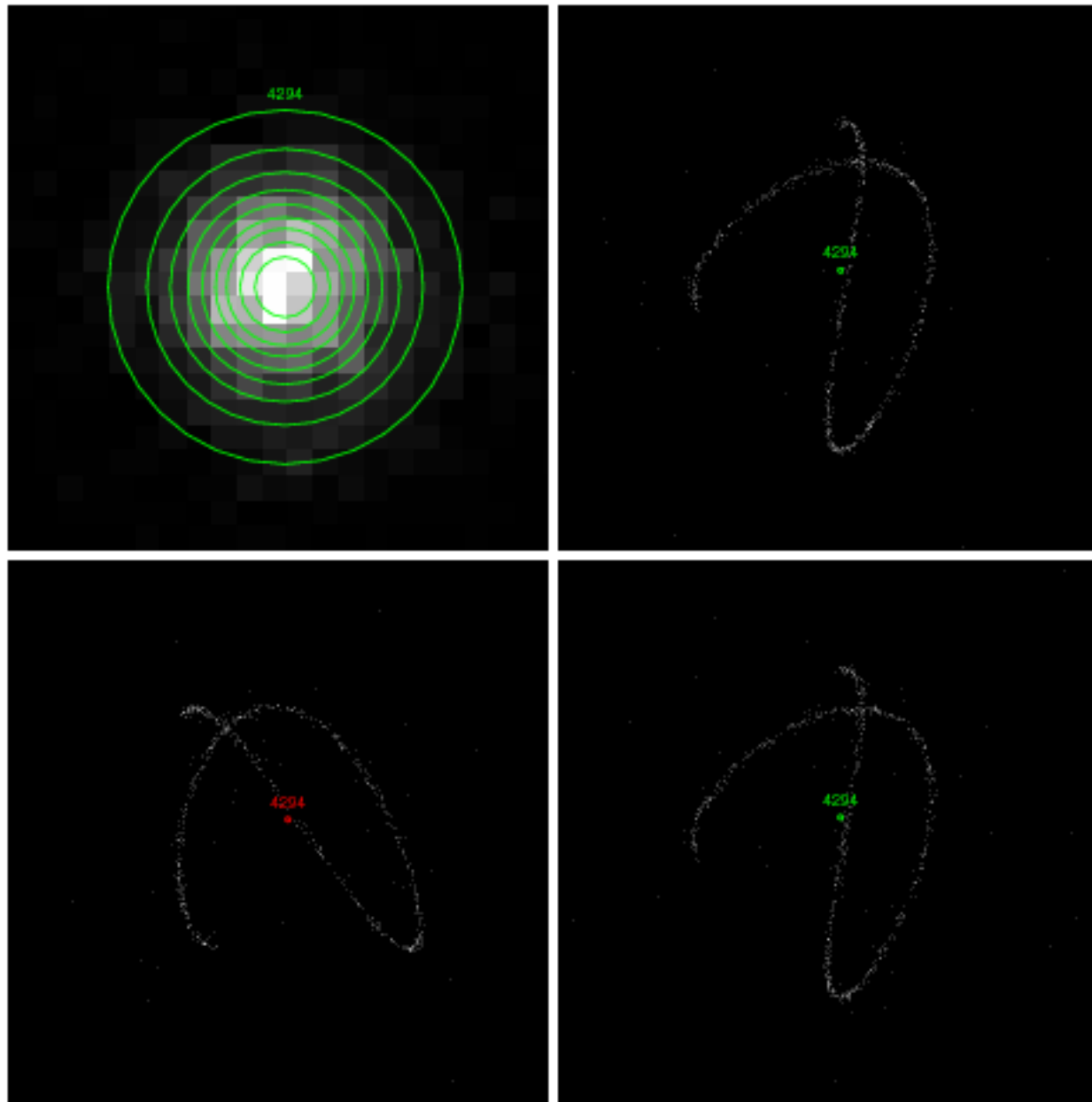


Figure 3: HRC-I observation of Ar Lac with 1ks exposure time and zero Y and Z offsets (obsid 4294). UL: image in sky coordinates with 10% - 90% encircled energy circle overlay; UR: image in chip coordinates with the centroid of the dither pattern marked; LL: image in det coordinates with the centroid of the dither pattern marked; LR: image in tdet coordinates with the centroid of the dither pattern marked.

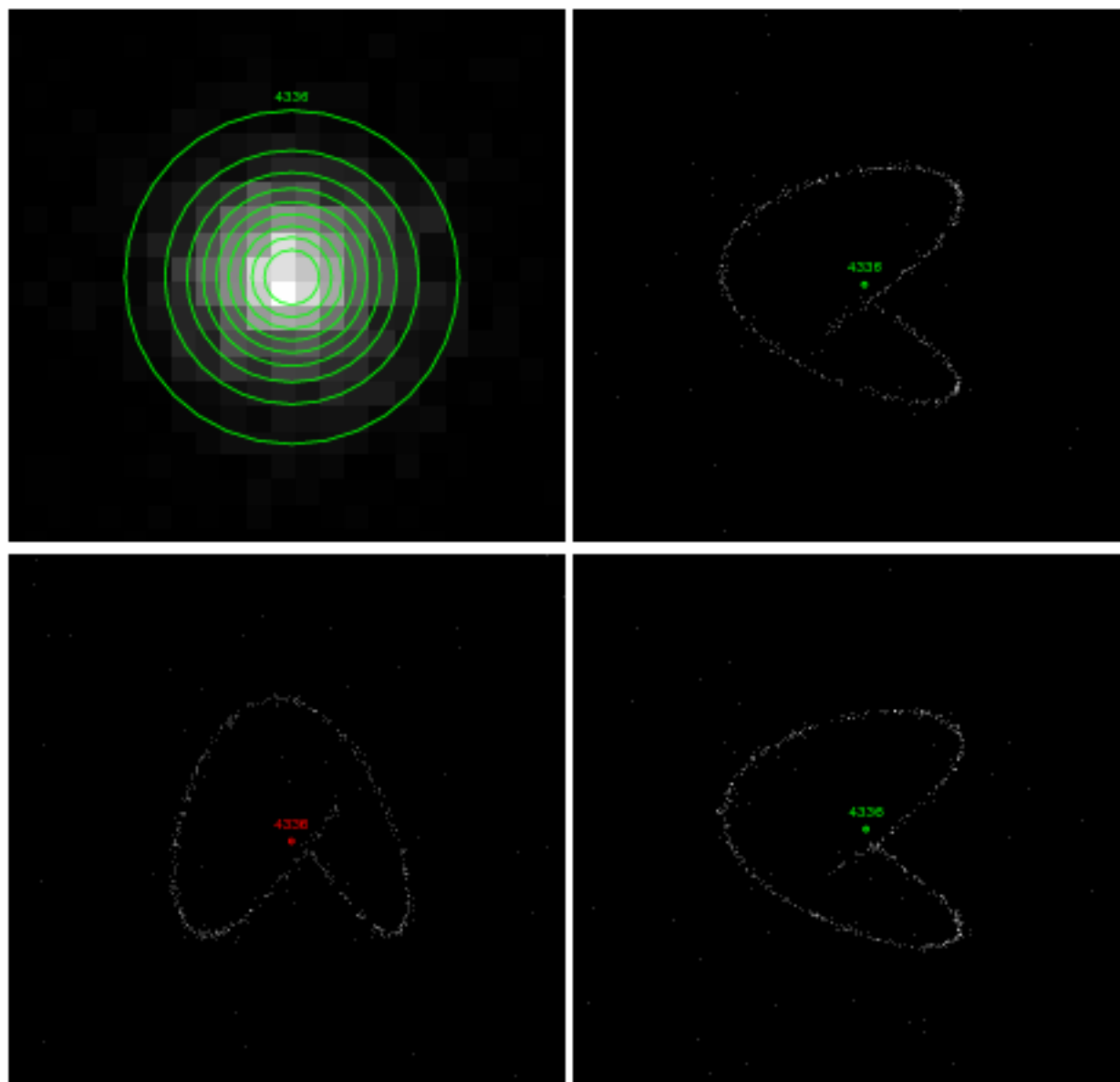


Figure 4: HRC-S observation of Ar Lac with 1ks exposure time and zero Y and Z offsets (obsid 4336). UL: image in sky coordinates with 10% - 90% encircled energy circle overlay; UR: image in chip coordinates with the centroid of the dither pattern marked; LL: image in det coordinates with the centroid of the dither pattern marked; LR: image in tdet coordinates with the centroid of the dither pattern marked.



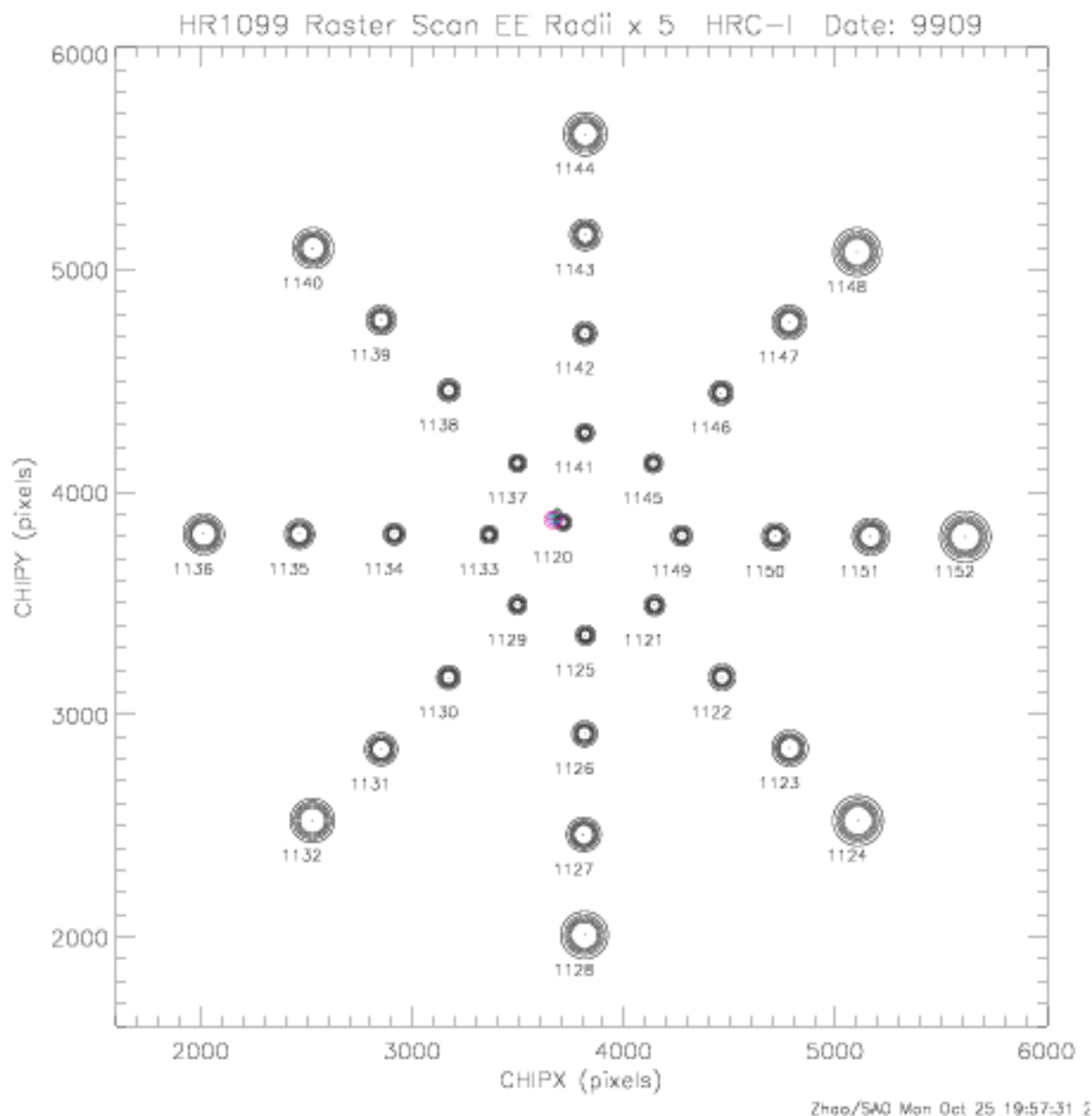


Figure 5: HRC-I raster scan observation of HR 1099 with 1ks exposure time for each scan point (Date: 1999-09-02). Circles around each observation point are the 50% - 90% EE circles  $\times 5$ .

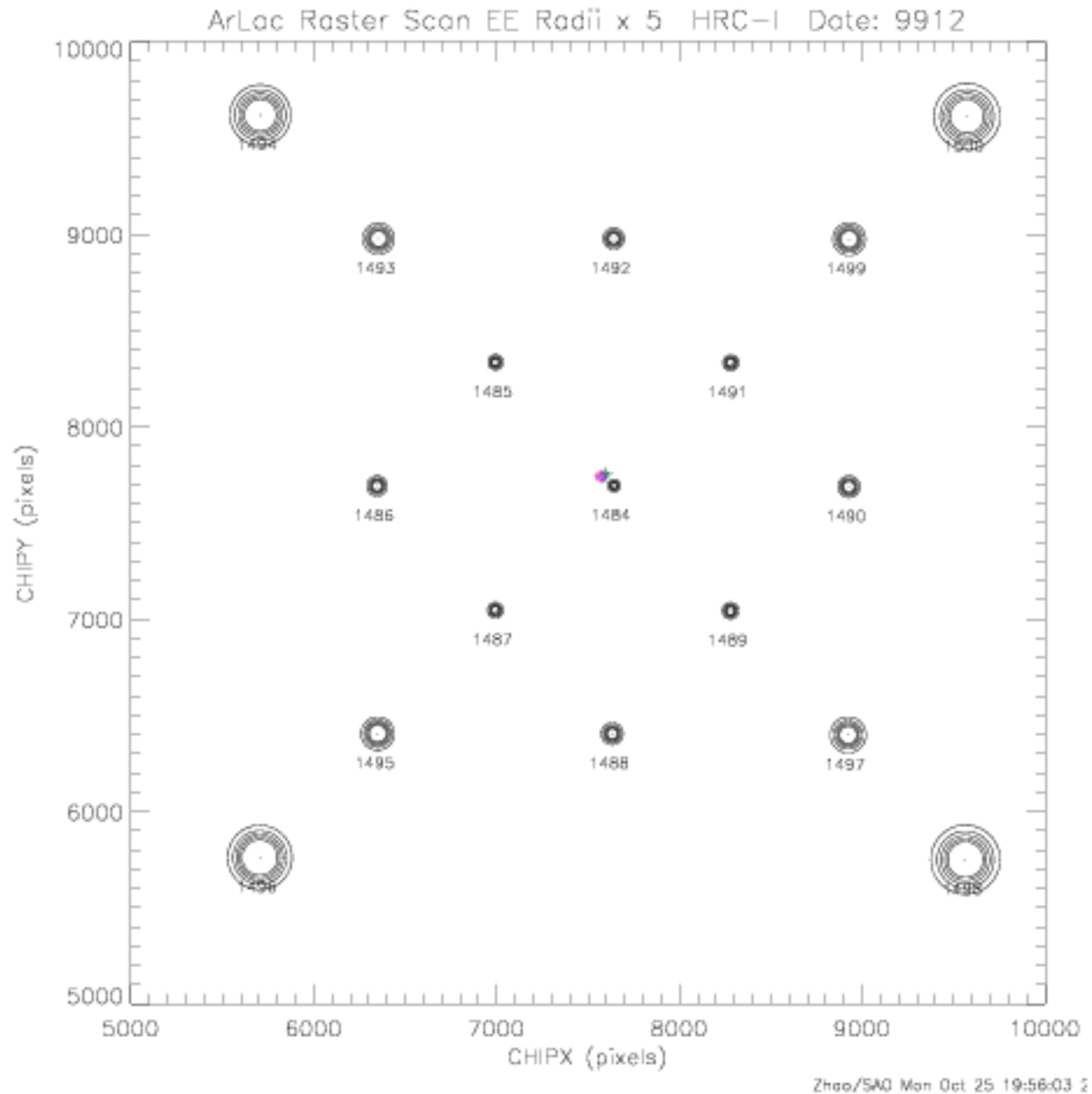


Figure 6: HRC-I raster scan observation of Ar Lac with 1ks exposure time for each scan point (Date: 1999-12-09). Circles around each observation point are the 50% - 90% EE circles  $\times 5$ .

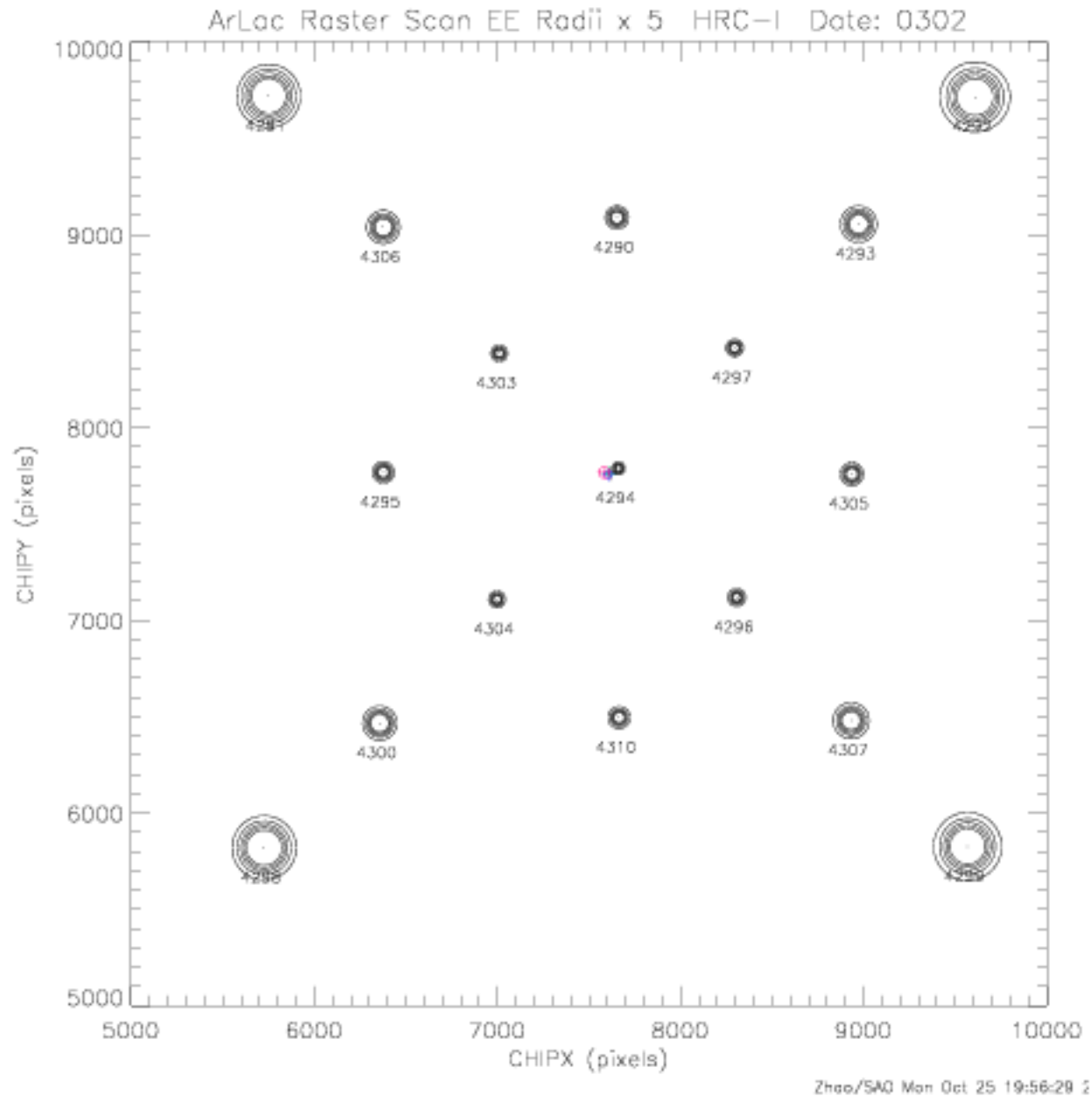


Figure 7: HRC-I raster scan observation of Ar Lac with 1ks exposure time for each scan point (Date: 2003-02-22). Circles around each observation point are the 50% - 90% EE circles  $\times 5$ .

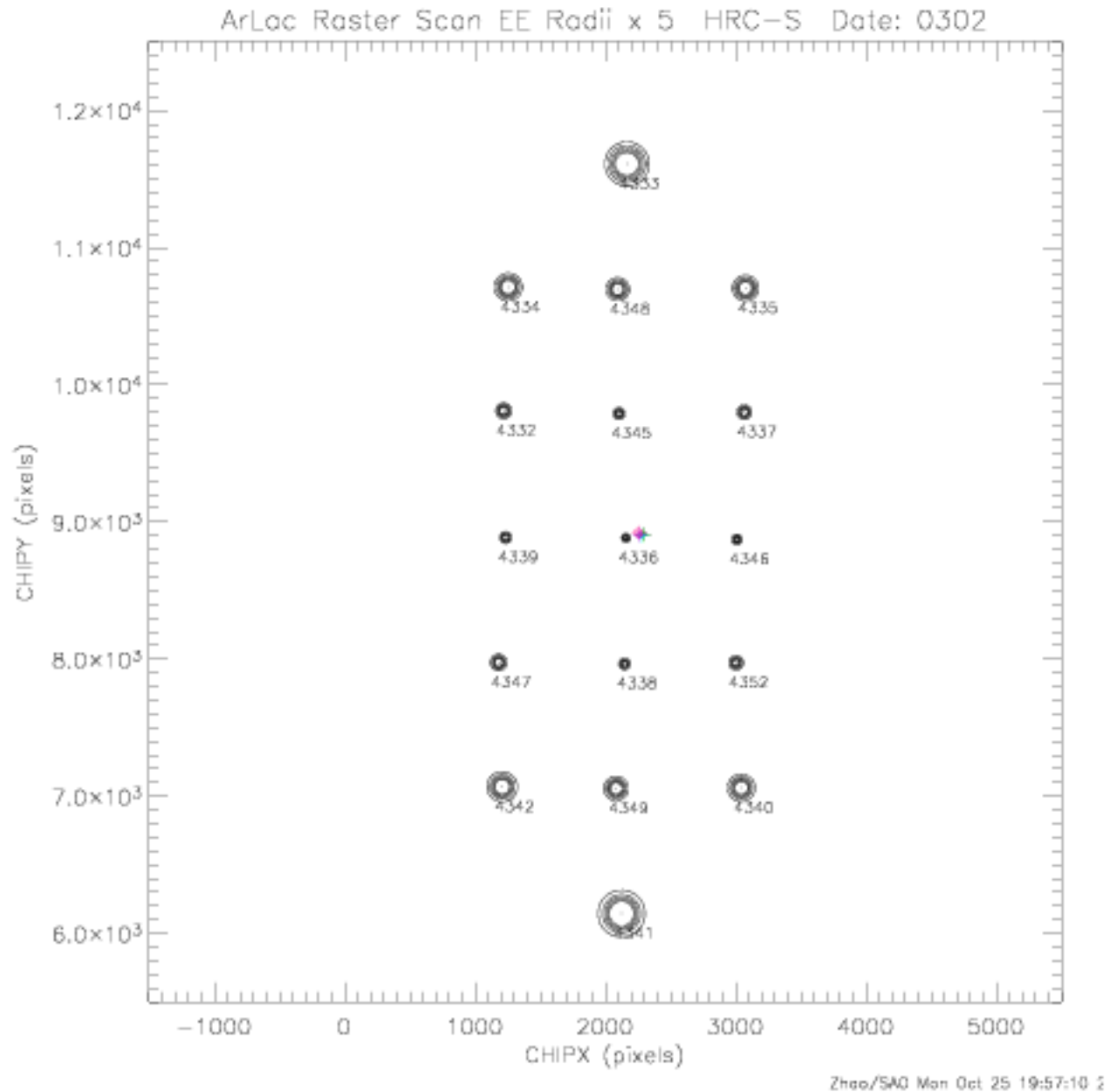


Figure 8: HRC-S raster scan observation of Ar Lac with 1ks exposure time for each scan point (Date: 2003-02-22). Circles around each observation point are the 50% - 90% EE circles  $\times 5$ .

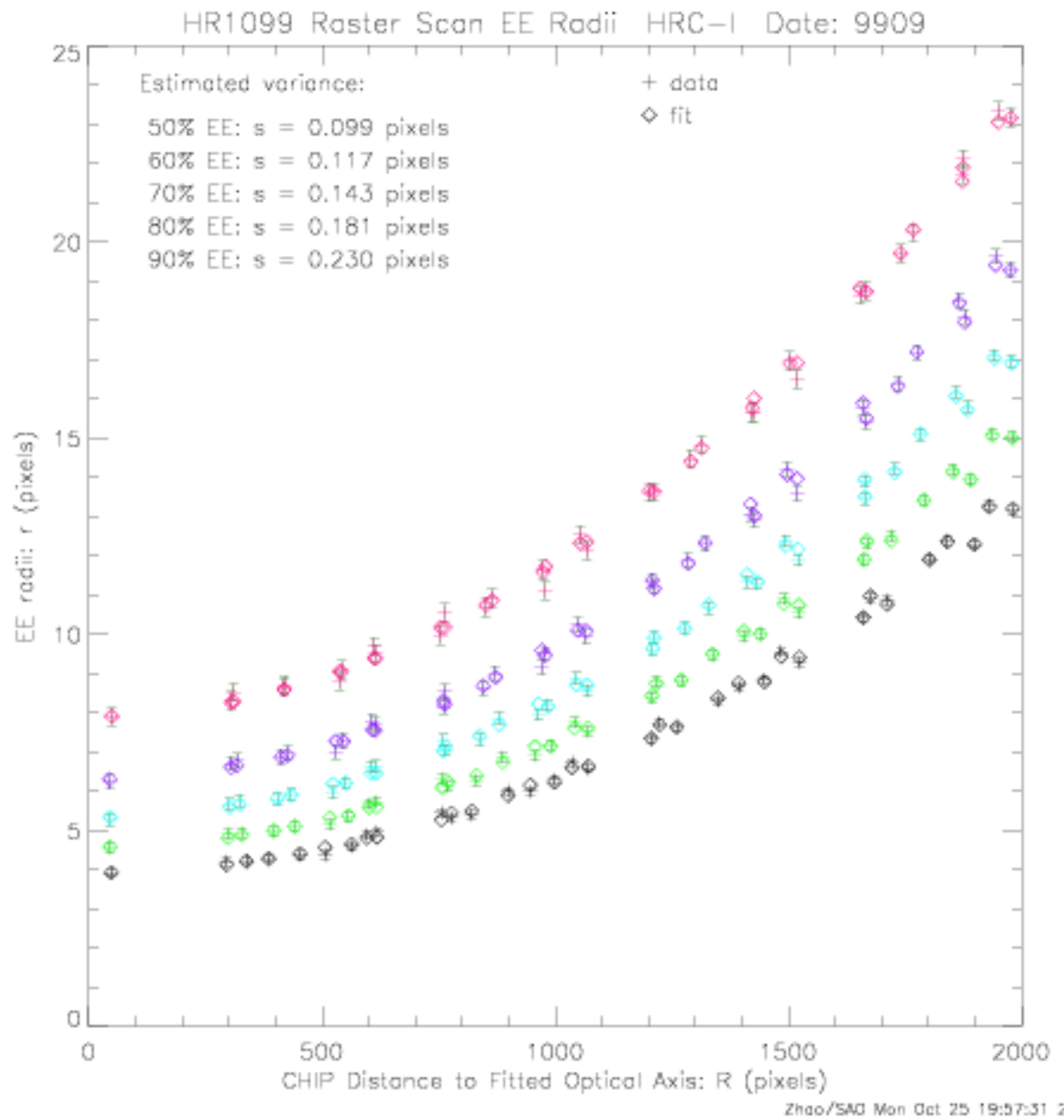


Figure 9: Quadratic fit of HRC-I raster scan observation of HR 1099 (Date: 1999-09-02).

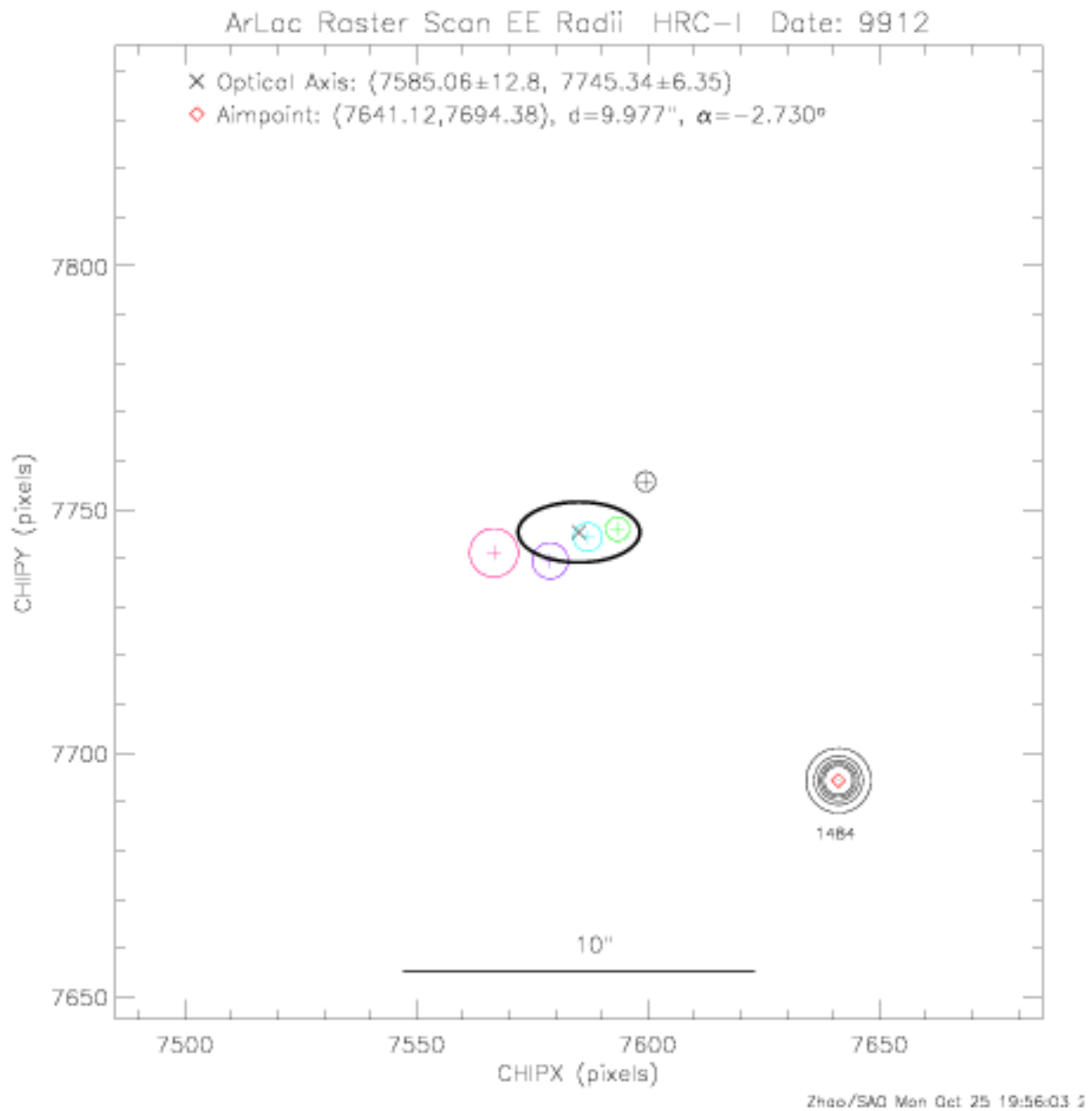


Figure 10: Optical Axis and Aimpoint position on HRC-I chip coordinates, based on raster scan measurements made on 1999-12-09.

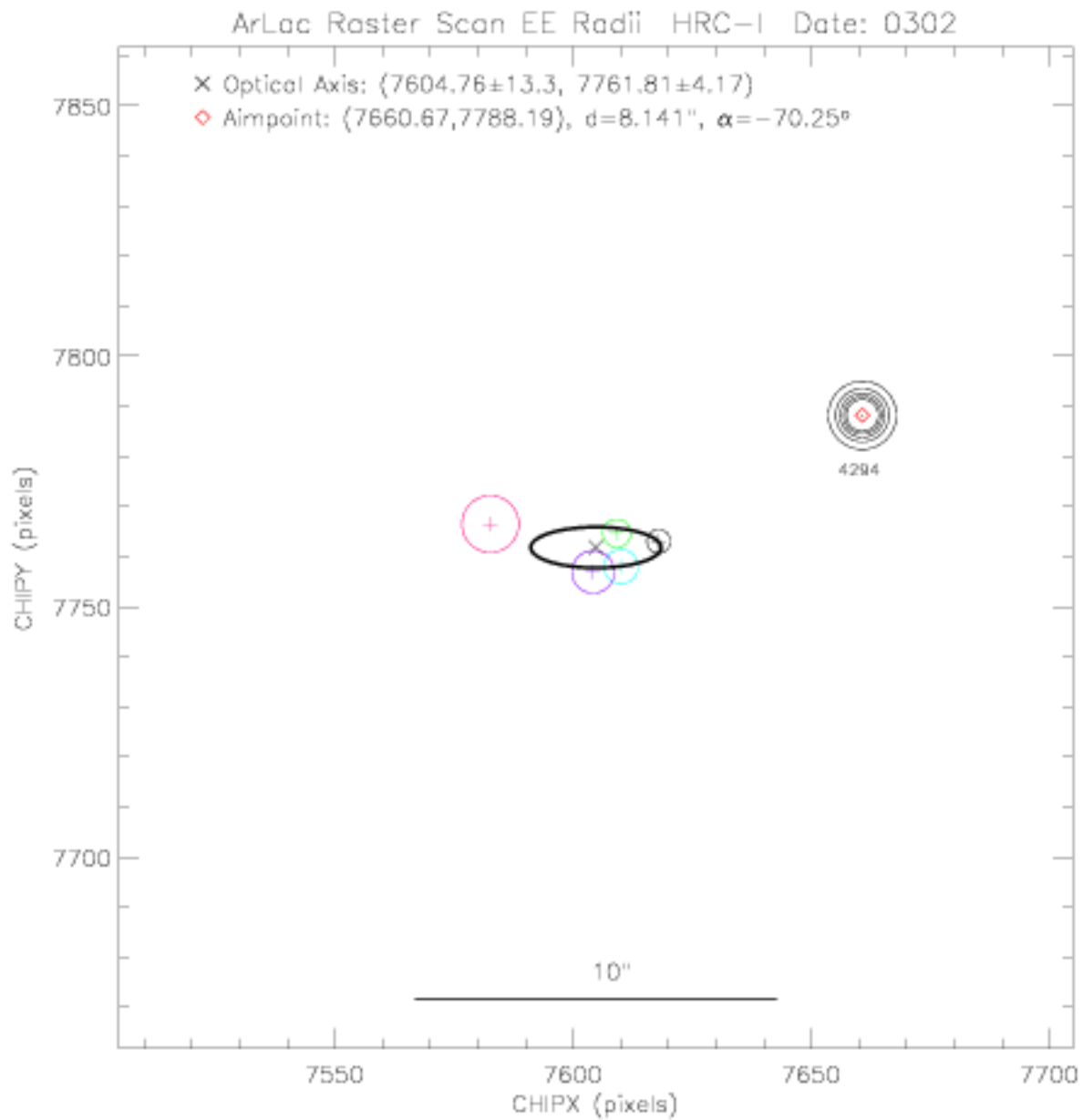
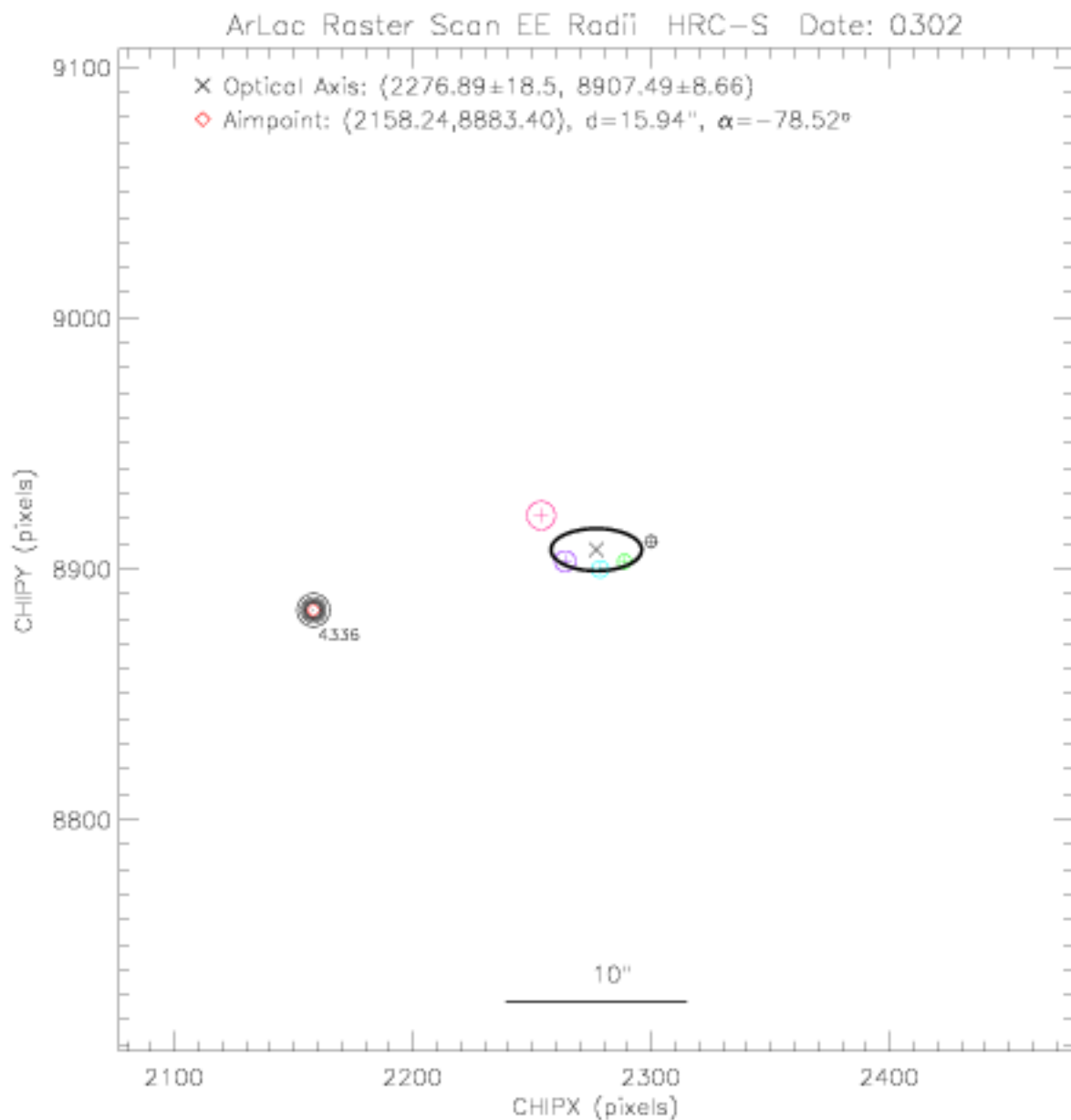


Figure 11: Optical Axis and Aimpoint position on HRC-I chip coordinates, based on raster scan measurements made on 2003-02-22.



Zhao/SAG Mon Oct 25 19:57:11 2

Figure 12: Optical Axis and Aimpoint position on HRC-S chip coordinates, based on raster scan measurements made on 2003-02-22.



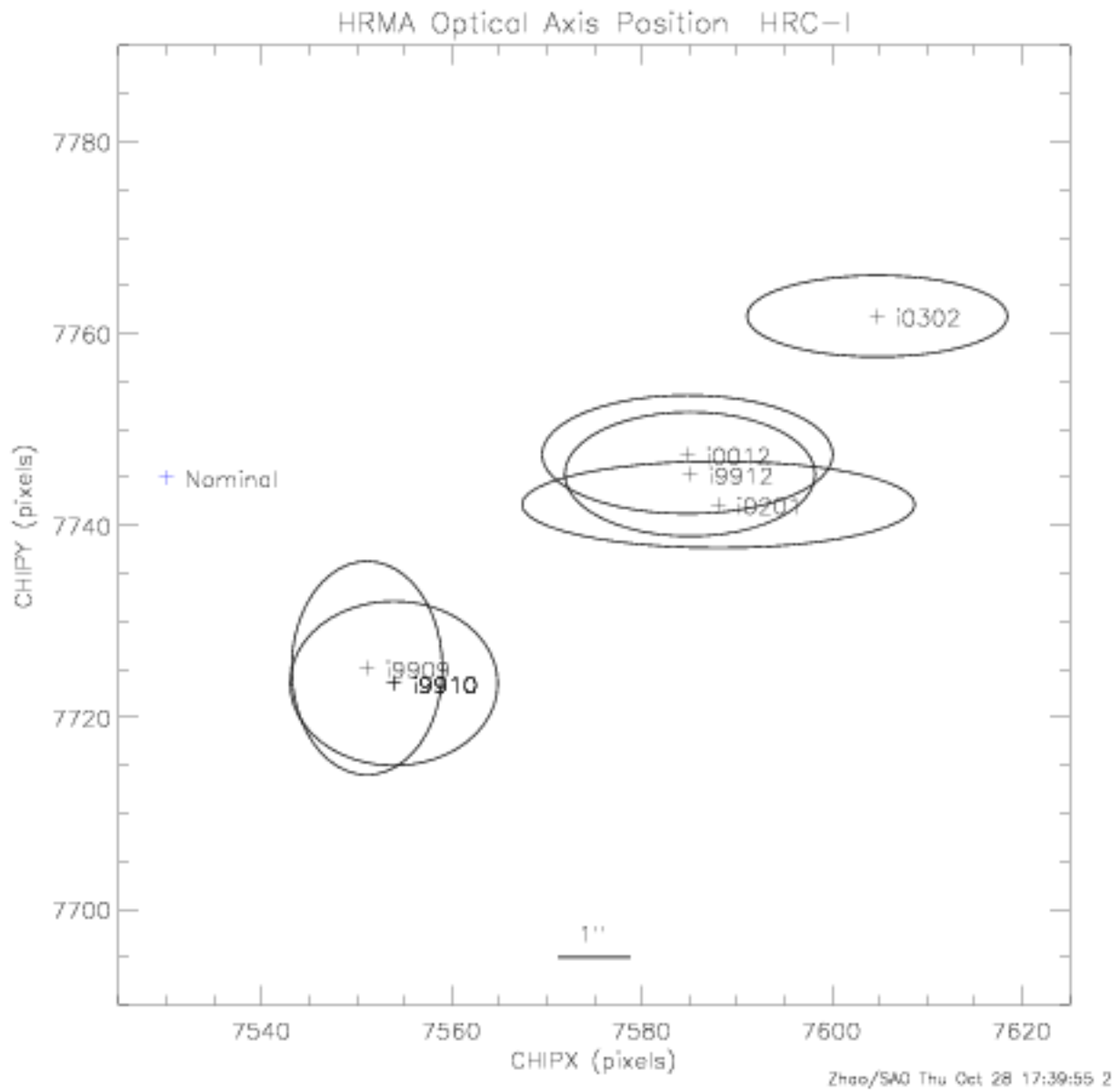


Figure 13: Optical Axis positions from all the HRC-I measurements.

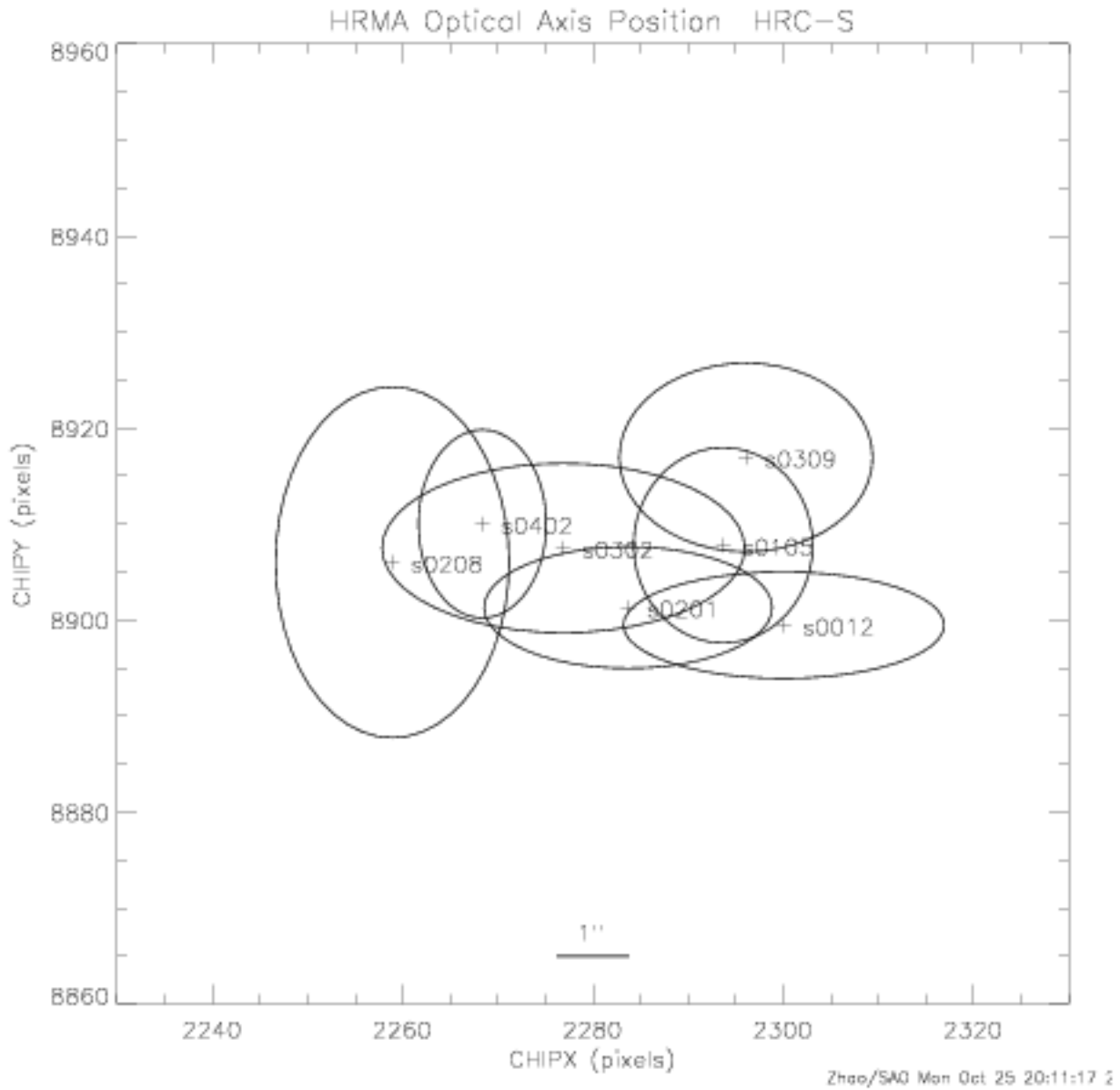


Figure 14: Optical Axis positions from all the HRC-S measurements.

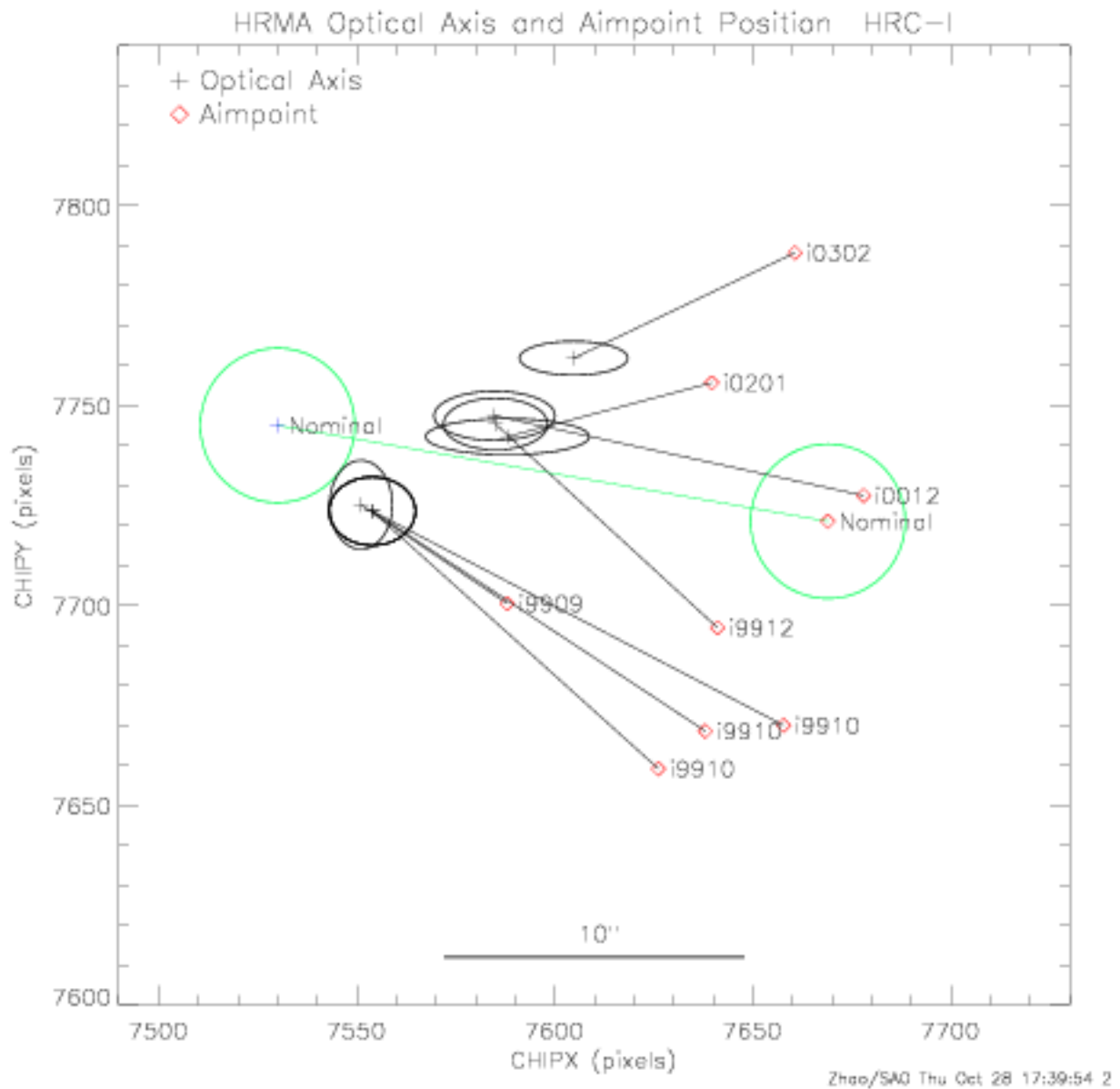


Figure 15: Optical Axis and Aimpoint positions from all the HRC-I measurements.

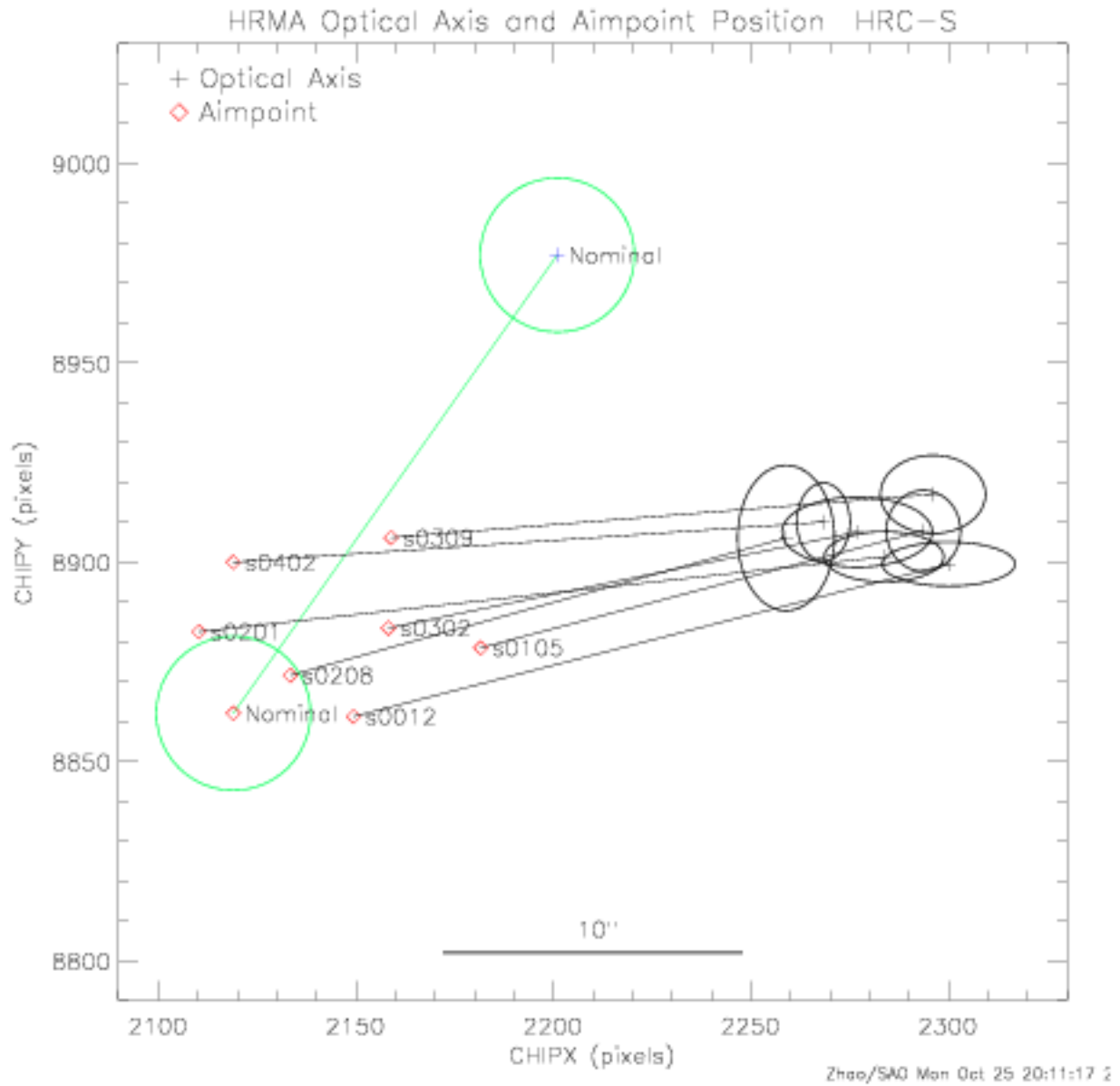


Figure 16: Optical Axis and Aimpoint positions from all the HRC-S measurements.