The Randall Harper Award

A *Chandra* X-Ray Study of Herbig-Haro Objects: HH 184 & HH 300

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1. Introduction & Motivation

In recent years it has become apparent that jet phenomenon is a common and essential element in astrophysics. Jet outflows are widely interpreted as Nature's way of solving the angular momentum problem in contracting or collapsing environments. Highly collimated jets occur in a wide variety of astrophysical environments, including young newborn stars, high- and low-mass X-ray binaries, planetary nebula nuclei, supersoft X-ray sources, and active galactic nuclei. The global presence of jets in such different environments and scales may suggest common underlying fundamental processes.

Herbig-Haro (HH) jets are an important component of star-forming regions, which provide 'fossil' records of the formation history of young stars and insights into star formation that cannot be obtained by any other means. Recent data obtained by the *Chandra X-ray Observatory* has demonstrated that the jet launch and collimation region of prostellar jets contain high-temperature X-ray emitting plasma (Bally et al. 2003); an unknown astrophysical property from low frequency studies. This recent observational evidence adds a new dimension to the relationship between X-rays and HH jets, suggesting that prostellar jets may serve as strong X-ray emitters.

2. Research Program

This complex research effort consisted of performing many lengthly processes, which required intelligent and careful decision making. The effort included the analysis of large *Chandra* data sets, requiring the use of many UNIX- and web-based programs. Therefore, only the fundamentals processes and results of this effort will be summarized.

Herbig-Haro objects, HH 184 and HH 300, were observed with the Imaging Array of *Chandra's* Advanced CCD Imaging Spectrometer (ACIS-I), in single pointings of $\sim$ 25 ks. The raw pipelined data were filtered and cleaned using several lengthly filtering techniques (Grade, Status, and GTI) and corrected for CCD charge transfer inefficiency (caused by radiation damage at the beginning of the mission). The event positions were also refined, using a subpixel positioning algorithm, to improve the effective resolution of the ACIS detector. Over 200 X-ray point sources were detected across both fields using a wavelet-based algorithm. Point source extraction and spectral analysis were performed using *ACIS Extract* (AE), a sophisticated IDL based code. Trial extractions were performed to determine the probability that the extracted counts (photons) exist purely from Poisson variations (noise) in the local background. Point sources exhibiting probabilities less than the carefully chosen threshold were promptly eliminated leaving 100 acceptable sources. Spectral fitting was then performed on sources using a single thermal plasma model with a single absorption component. Deciding on the correct probability and error methods (C-Statistic, χ^2-Statistic, Churazov) posed problems during the fitting process. The uncertainty of choice required several collaborative discussions and direct comparisons upon reaching a decision.

We find that the HH 300 source exhibits a highly absorbed and luminous X-ray spectrum (typical of protostars); suggestive of typical low-mass protostellar X-ray emission. Whereas, the HH 184 sources possesses a relatively hard and unabsorbed spectrum, which may originate from an inner jet component as the spectrum exhibits a soft excess and a median energy of 1.5 keV. The HH 184 source also appears spatially coincident with the protostar rather than offset as in Bally et al. (2003); apparently, the geometry of this complex system deserves further investigation.

REFERENCES

Bally, J., Feigelson, E., & Reipurth, B. 2003, ApJ, 584, 843