Daniel E. Harris (1934 - 2015)

Slugs and Snails and Puppy Dog Tails: jets from an unconventional angle was the title of Dan Harris' review article presented at the IAU 313 Symposium held in September 2014 at the Galapagos Islands. The symposium was partly dedicated to Dan's work in the area of extragalactic jets and also a celebration of his 80th birthday. He presented a short review of jet properties, the "agents" that carry jet power, synchrotron jets, jet variability and quasar jets. The presentation covered questions that Dan had researched and focused on the *Chandra* discoveries of ubiquitous X-ray jets. Dan had studied extragalactic radio sources since the time of his PhD project in the late 1950's. He had experienced the evolution of X-ray astronomy and contributed to many aspects of modern X-ray astronomy research. This review was Dan's final publication. He died on December 6, 2015.

On March 19th, the day before the spring 2016 equinox, Dan's colleagues, family and friends gathered at the Center for Astrophysics in Cambridge to celebrate Dan's life. Many of us were unaware of the broad interests Dan had and how much he had accomplished in his life outside of astronomy. The title of his IAU review paper conveys Dan's view of the world, connecting many aspects of life, especially art and science. Dan was a researcher in the full meaning of the word. He was an astronomer, explorer, poet, bicyclist, soccer player, carpenter, musician and an activist. He was also a husband, father and grandfather, and devoted a great amount of time to his family who followed him around the world on his many adventures. The proceedings of the IAU 313 Symposium include numerous details of Dan's scientific and personal life, and note his curiosity about the world.

Dan was born in 1934. He graduated from Caltech in 1961 with a PhD thesis titled "The continuous spectra of radio sources with particular reference to non-thermal galactic sources". Since then, he has studied the nature of radio sources using radio and X-ray data. Working with the *Uhuru* and *Einstein* X-ray data, he calculated and discussed the importance of the inverse Compton scattering of cosmic microwave background radiation in these sources. In particular, his 1979 paper, in collaboration with Josh Grindlay, stated the importance of X-ray studies of radio sources by using the inverse Compton process to determine the magnetic field of the source, its electron spectrum and the density content of the cosmic ray reservoir. In 1987 he published a detailed spatial analysis of the *Einstein* HRI image of the quasar 3C273—the highest resolution X-ray image at that time—to locate the X-ray emission associated with the quasar jet. He applied the inverse Compton scattering of cosmic microwave background photons to the relativistic jet electrons (IC/CMB) model to explain the observed X-ray intensity of that jet. At that time, only a few resolved jets had been detected in X-rays, i.e. M87, Centaurus A and 3C273. Later, the ROSAT High Resolution Imager resolved the X-ray emission from the hotspots of Cygnus A which Dan reported in a Letter to Nature in 1994. He argued that the X-ray emission of these hotspots was due to inverse Compton scattering of radio photons on the relativistic electrons, i.e. synchrotron self-Compton (SSC) process.

Chandra discoveries of X-ray jets made the last 15 years of Dan's research very exciting. He started compiling the data for X-ray jets on a designated web site. He used the numerous observations of X-ray jets to systematically study jet emission processes in detail. In 2002 he published a paper summarizing the processes responsible for X-ray emission in relativistic jets and later, in 2006, reviewed work on X-ray jets in Annual Reviews of Astronomy and Astrophysics.

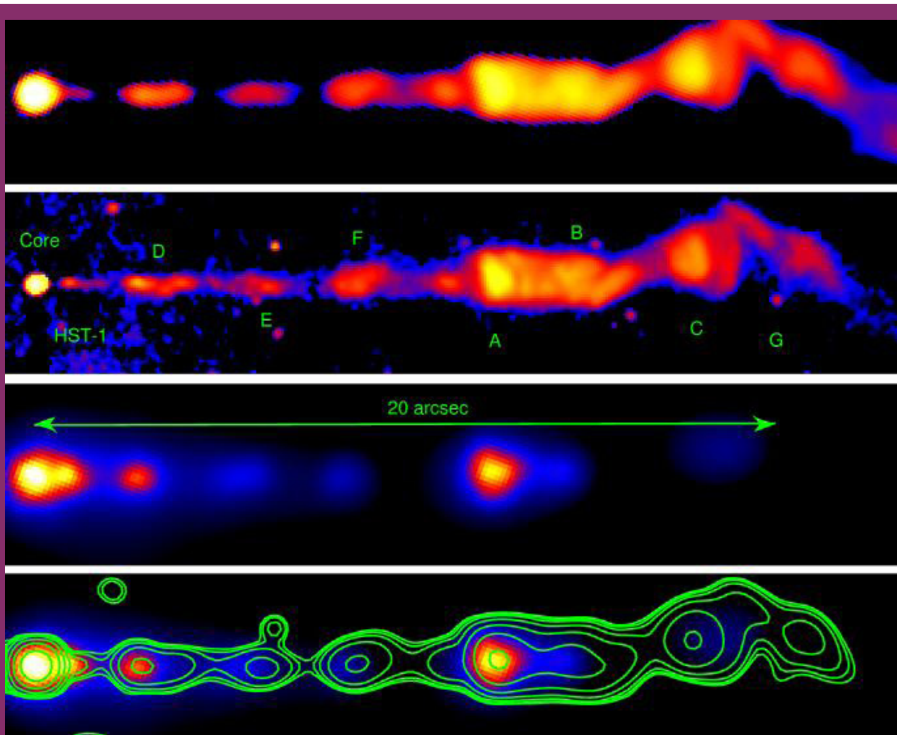

Figure 1: M87 jet in three bands, rotated to a horizontal orientation (from Marshall et al. 2002). First panel (top to bottom): VLA image at 14.435 GHz with spatial resolution ~0.2 arcseconds. Second panel: The HST Planetary Camera image in the F814W filter from Perlman et al. (2001). Third panel: Adaptively smoothed Chandra X-ray image. Fourth panel: Smoothed Chandra image overlaid with contours of a Gaussian-smoothed HST image matching the Chandra PSF. The HST and VLA images have a logarithmic stretch to bring out faint features, while the X-ray image scaling is linear.

Dan had been monitoring the M87 jet, studying its multi-band variability and was rewarded by detecting a huge X-ray flare that did not originate in the core of the galaxy, but from a knot in the jet. *Chandra*'s high angular resolution allowed for a clear detection of the X-ray flare from the HST-1 knot of the M87 jet (Harris et al. 2003, 2006). This was a most exciting and important discovery because the knot variability indicated that particle acceleration can occur at large distances from the nucleus. HST-1 was the first jet knot clearly resolved from the nuclear emission by *Chandra* and was the site of the huge flare. In a 2009 paper, Dan presented evidence that the multi-band decrease in the knot intensity was caused by synchrotron cooling, and estimated that the magnetic field strength was consistent with the equipartition field. The *Chandra* X-ray light curve of HST-1 also showed quasi-periodic oscillation on a time scale of six months in the two years prior to the huge flare. The *Chandra* data indicated that the X-ray variability of the nucleus appeared to be at least twice as rapid as that of the HST-1 knot, but still longer than the shortest TeV variability (1-2 days) reported by the H.E.S.S. and MAGIC gamma-ray telescopes. In 2011 Dan described an experiment to locate the site of the TeV variability using *Chandra* and Veritas telescopes and reported that the TeV flares are more likely to originate in the nucleus of M87. The *Chandra* monitoring program is on-going and per-

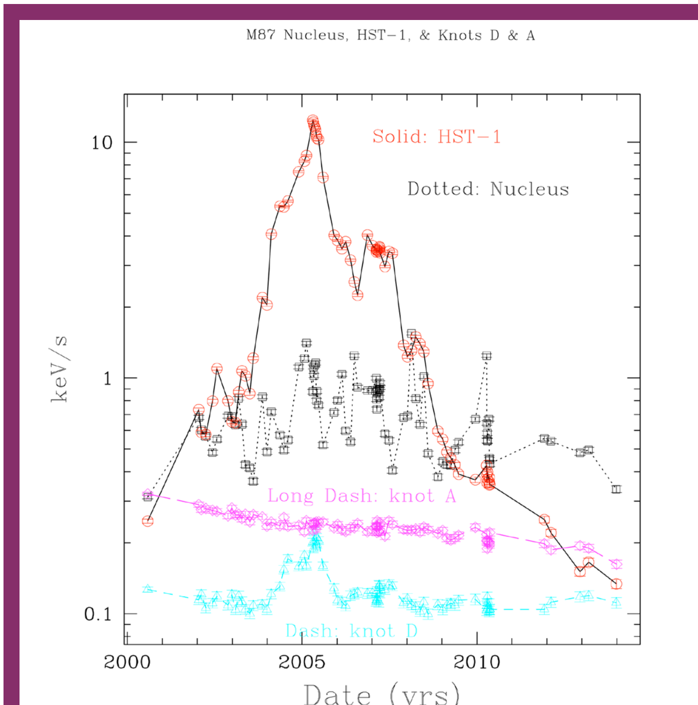

Figure 2: M87 X-ray in outburst. X-ray lightcurve of M87 nucleus and three knots HST-1, A, D collected over 13 years of Chandra monitoring program led by Dan Harris (Harris et al. 2009). The count rate is shown on the logarithmic scale. A strong and long-lasting outburst of HST-1 knot dominates the lightcurve. The nucleus shows the short-term variability during the same time. During the time HST-1 was peaking, severe pileup corrupted the PSF so that both the nucleus and knot D photometric apertures were collecting only a fraction of HST-1 events.

haps his colleagues will be able to locate the site via future observation of flares.

Dan had been working in the High Energy Astrophysics Division at the SAO for more than 30 years. He was a member of the *Einstein*, ROSAT and *Chandra* support teams. He worked on the catalogs of X-ray sources using *Einstein* and ROSAT observations. His work in the *Chandra X-ray Center* was focused on source detection and user support. He semi-retired in early 2000, but remained involved with his astrophysical research. ▪

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Prepared by Aneta Siemiginowska and Dan Schwartz