Differential Proper-Motion Measurements of The Cygnus Egg Nebula; The Presence of Fast Equatorial Outflows

Rachael Tomasino[1], Dr. Toshiya Ueta[1], Brian Ferguson[2]

[1]*University of Denver, Denver, CO;* [2]*Des Moines University Medical School, Des Moines, IA*

Cygnus Egg Nebula

The Cygnus Egg Nebula (V1610 Cyg, RAFGL 2688) is one of the first infrared sources ever discovered with an optical reflection bipolar nebulosity (Ney et al. 1975). This object consists of the central star in the post-asymptotic giant branch (post-AGB) phase of evolution and the circumstellar envelope that resulted from mass-loss processes during the preceding AGB phase

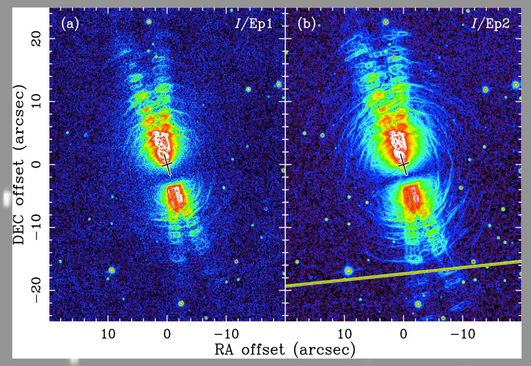

Figure 1: The "Roberts' Cross" edge-enhanced Stokes I maps. The structure of the lobes and arcs are enhanced while ambient scattered light is significantly reduced. The plus symbol at the center indicates the location of the illumination source.

One of the most peculiar characteristics of the circumstellar shell structure of the Egg Nebula is the co-presence of the nebula's signature bipolar lobes and rather circular concentric arcs superposed on top of each other (Sahai et al. 1998). These concentric arcs are qualitatively perceived as some manifestations of spherically symmetric mass-loss processes that took place in early AGB mass-loss phases. However, there is no consensus among researchers on their origins.

Previous Research

We have already performed differential proper-motion measurements of the bipolar lobes and the structures seen in the apparent equatorial plane using NICMOS imaging-polarimetric data taken 5.5 years apart (Ueta et al. 2006). The apparent expansion was translated to the distance to the Egg Nebula, 420 ± 60 pc. It was also recognized that the entire nebula experiences its own proper motion at (13.7 ± 2.0, 10.2 ± 2.0) mas/yr.

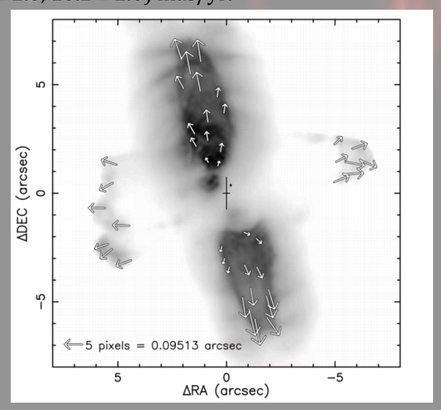

Figure 2: Stokes I image of the Egg at 2μm overlaid with proper-motion vectors of the selected local structures in the past 5.5 yr. The larger plus sign at (0, 0) indicates the origin of the outflow determined from these vectors, while the smaller plus sign at (0.2, 0.4) marks the origin of the polarization vector pattern derived by Weintraub et al. (2000).

Differential Proper-Motion Analysis

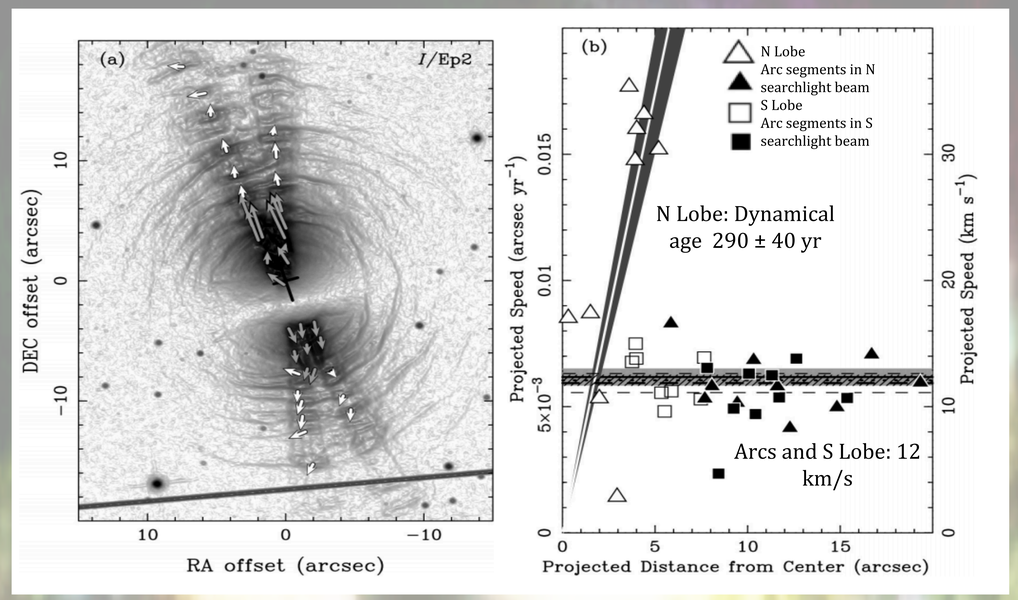

Figure 3: (a) The edge-enhanced I map (epoch 2) overlaid with proper-motion vectors of some local structures in the past 7.25 yr: lobes = gray vectors; arc segments in the searchlight beams = white vectors. (b) The plot of proper-motion vs. radial distance for these structures. The best-fit lines: N lobe = white solid line with the gray zone of uncertainty, S lobe = black solid line with the light gray zone of uncertainty, arc segments in the N beams = thick dashed line with the zone bounded by the thin dashed lines, and arc segments in the S beams = thick dotted line with the cross-hatched zone.

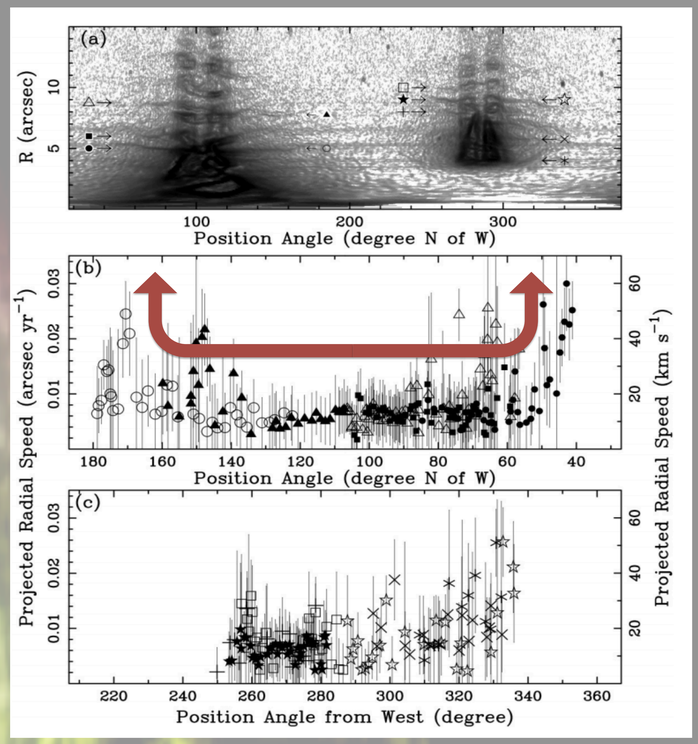

Figure 4: (a) The edge-enhanced I map (epoch 1) in polar coordinates; (b, c) the measured projected radial speed vs. position angle plots, showing the distribution of the measured radial speed with respect to the bipolar axis (at 107°and 287°). The plots show a strong trend of an increasing radial speed toward the equatorial plane.

Conclusions

1. Via differential proper-motion analysis of notable structures in the nebula we partially corroborate our own earlier finding of Hubble-flow-like expansion in the N lobe with projected velocities near the tip of the lobe reaching 30 to 35 km/s (adopting the distance of 420 pc). This finding yielded an interpretation that **the lobes were curved-out cavities caused by this Hubble-flow-like wind along the poles impinging onto an initial spherical outflow** that started excavation about 290 yr ago.

2. Via differential radial-motion analysis of the concentric arcs, we have revealed that (1) arc segments found along the searchlight beams move at similar projected speed around 12 km/s (suggesting the dynamical age of the arcs of 4500 yr) and (2) the radial velocity field of the concentric arcs show a **colatitudinal dependence** in which the **radial expansion velocity increases toward the equatorial regions** roughly by a factor of two.

This is the first time that the colatitudinal variation of the radial expansion speed in the circumstellar shells of post-AGB star was measured directly via differential proper-motion analyses, and provides major observational evidence for the **binary modulation** of the spiral-shocked shells predicted by Morris & Mastrodemos (1999).

Acknowledgements

Support for this work was provided by NASA through a grant HST-AR-12157.01-A from the Space Telescope Science Institute and by the University of Denver through a professional research opportunities for faculty (PROF/2007) grant. We would like to thank Dr. R. E. Stencel and Dr. D. Ladjal for their feedback throughout this research and Dr. D. A. Weintraub for thoroughly explaining his method of locating a central illumination source.

References

Mastrodemos, N., & Morris, M. 1999, ApJ, 523, 357
Ney, E. P. et al. 1975, ApJ, 198, L129
Sahai, R. et al. 1998, ApJ, 493, 301
Ueta, T. et al. 2006, ApJ, 641, 1113
Weintraub, D. A. et al. 2000, ApJ, 531, 401

Scan for preprint.
http://urizen-physics.nsm.du.edu/~tueta/Egg/egg_preprint201301.pdf