Characterizing the Circumstellar Envelope of AGB star RX Bootis

Juan P. Cardenas$^{1,2}$, Lynn D. Matthews$^1$

$^1$MIT Haystack Observatory, $^2$Cornell University

Summary: We detected H I 21 cm line emission associated with the circumstellar envelope of the asymptotic giant branch star, RX Boo. The morphology of the circumstellar envelope’s H I emission reveals a bow shock and tail structure, implying that it is strongly interacting with the interstellar medium. The envelope morphology spatially mirrors the far-ultraviolet emission from the GALEX satellite.

Background

What are Asymptotic Giant Branch (AGB) Stars and Circumstellar Envelopes?

AGB stars are old post-core helium burning descendants of stars with initial mass of $\sim$0.8-8 M$_\odot$. Their contracting inert C-O core raises core temperature and therefore pressure inside the star. To maintain hydrostatic equilibrium, star’s radius enlarge to of order 1 AU and the temperature drops to $\sim$2000-3000 K. The low surface gravity and strong pulsations, along with dust-driven winds, cause substantial outflows of gas and dust produces extensive circumstellar envelopes (CSE).

Why Study the Circumstellar Envelope?

Learning about the chemistry and morphology of the CSEs can give insight into (1) the mass-loss process of AGB stars and (2) how they recycle gas into the galactic environment. AGB stars are major contributors of dust and heavy elements to the galactic environment, producing at least 50% of such material in our galaxy. The H I 21 cm line is a unique tracer since it can probe into distances $\geq$10$^3$ (151 AU) away from the star and reveals how it is affected by the interstellar medium (see Fig. 1).

Observations

The radio observation of RX Boo was performed by the Karl G. Jankelyn Very Large Array (JVLA) in the 21 cm line on August 21st, 2014, for 6 hours. The VLA was in the D configuration with a baseline of up to 1 km for resolving the structure of the CSE on the scale of arcminutes and maximum sensitivity. The spatial resolution at natural weighting was 55.79” × 53.25”. For this analysis, the data were calibrated and examined using the Astronomical Image Processing System (AIPS).

An ultraviolet observation was performed by the Galaxy Evolution Explorer (GALEX) on May 6th, 2009. The data were retrieved from the Mikulski Archive for Space Telescope (MAST) database.

Fig. 3: FUV image of RX Boo taken by the GALEX satellite. The “x” represents the position of RX Boo, the arrow represents the direction of motion, and the circle encloses a sp. 4.8 H II. The image was processed using DSS imaging software with gaussian smoothing set to a radius of 13.5’.

Complementary Results from GALEX

FUV emission from CSEs are theorized to be caused by the excitation of molecular hydrogen from impacting hot electrons in shocked gas (Martin et al. 2007).

Key results:

- Surprisingly, both radio and FUV data (Fig. 2 & Fig. 3) almost mirror each other, a rare feature amongst CSEs. RX Boo’s CSE is most visible as a right-side up bowl structure south of RX Boo and diffuse emission along the northwest direction of the star in both figures.
- The size of the CSE in radio and FUV emission are similar at approximately 0.85 pc and 0.94 pc in diameter, respectively.
- No radio continuum emission was detected from RX Boo or its bow shock.

CSE Morphology and Limitations

Spatially resolved H I emission from the CSE is detected from channel V$_{LLR}$ = -3.1 km/s to -2.6 km/s. Unfortunately, contamination from a foreground gas cloud complicates the determination of the total H I mass.

Key results:

- A bow and diffuse H I shell is detected in contours $\geq$2.5 km/s along with a ring or half-line-structures at LSR velocities 1.5 km/s to -1.8 km/s. RX Boo’s LSR velocity of 3.86 km/s is at the upper edge of LSR velocities with CSE emission.
- The high systemic velocity of RX Boo of 43.9 km/s with a sky position angle 130° from the vertical (shown in Fig. 2), likely displaced the shell through the interstellar medium. This is supported by a diffuse tail end northwest of the star’s position in a few of the central channels and the shell is offset in the same direction.
- Fringe structure from an unresolved gaseous cloud along the line-of-site is present in velocity channels 0.7 km/s.
- Discerning the CSE from the fringe structure becomes difficult for velocity channels $\leq$2.4 km/s.

Spectral Analysis

Table 1: Stellar Parameters

<table>
<thead>
<tr>
<th>Star</th>
<th>$d$ (pc)</th>
<th>$m_\odot$ (M$_\odot$)</th>
<th>$L$ (L$_\odot$)</th>
<th>$V_{LLR}$ (km/s)</th>
<th>$M$ (M$_\odot$)</th>
<th>$M_L$ (M$_\odot$)</th>
<th>$T_{kin}$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RX Boo</td>
<td>156</td>
<td>19.873</td>
<td>-48.615</td>
<td>3.86</td>
<td>5.197</td>
<td>0.01364</td>
<td>3120</td>
</tr>
</tbody>
</table>

Notes: Column Explanations: (1) Name of star; (2) Distance; (3) Proper motions; (4) Infrared and ultraviolet; (5) Stellar mass from Oloffson et al. 2002; (6) Effective temperature from Takeuti et al. 2013.

Table 2: Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Beam (arcsec)</th>
<th>$f$ (GHz)</th>
<th>$f_V$ (GHz)</th>
<th>$f_M$ (GHz)</th>
<th>Processing</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>GALEX</td>
<td>20</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>SLFIT</td>
<td>5.85x4.5</td>
</tr>
</tbody>
</table>

Notes: Column Explanations: (1) Instrument for RX Boo observations; (2) Frequency range; (3) Calculated heading; (4) Observation time for RX Boo; (5) Spatial resolution of velocity weighting in radio and angular resolution in UV.

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