Finding Mass-Loss Rates Using Stellar-Wind Bow Shocks: Converting IR Intensities into Gas Densities

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Introduction

Massive, O- and B-type stars can lose a significant fraction of their mass over the course of their existence, which can impact their stellar evolution. We used IR stellar-wind bow shocks from previously-compiled catalogs (Kobulnicky et al. 2016, Jayasinghe et al. 2019), to determine the mass-loss rates (in solar masses per year) of their driving stars (Kobulnicky et al. 2018) using the equation:

$$\dot{M} = 1.67 \times 10^{-28} \frac{R_0^2 D V_a^2 I_v}{V_w j_v \ell}$$

The focus of my research was on the method to estimate the depth of each bow shock nebula by measuring the *chord lengths* (ℓ) assuming rotational symmetry. Other variables in the equation include standoff distance (R_0), distance to star (D), velocity of the surrounding ISM (V_a), peak IR intensity of the bow shock nebula (I_v), terminal wind velocity of the star (V_w), dust emission coefficient per nucleon j_v.

Background and Spectroscopy

Presented are the visible-light spectroscopy for 2 bow shock driving stars. Observations made using the Wyoming Infrared Observatory 2.3m telescope (WIRO) and Apache Point Observatory 3.5m telescope with the KOSMOS spectrograph.

Figure 1:

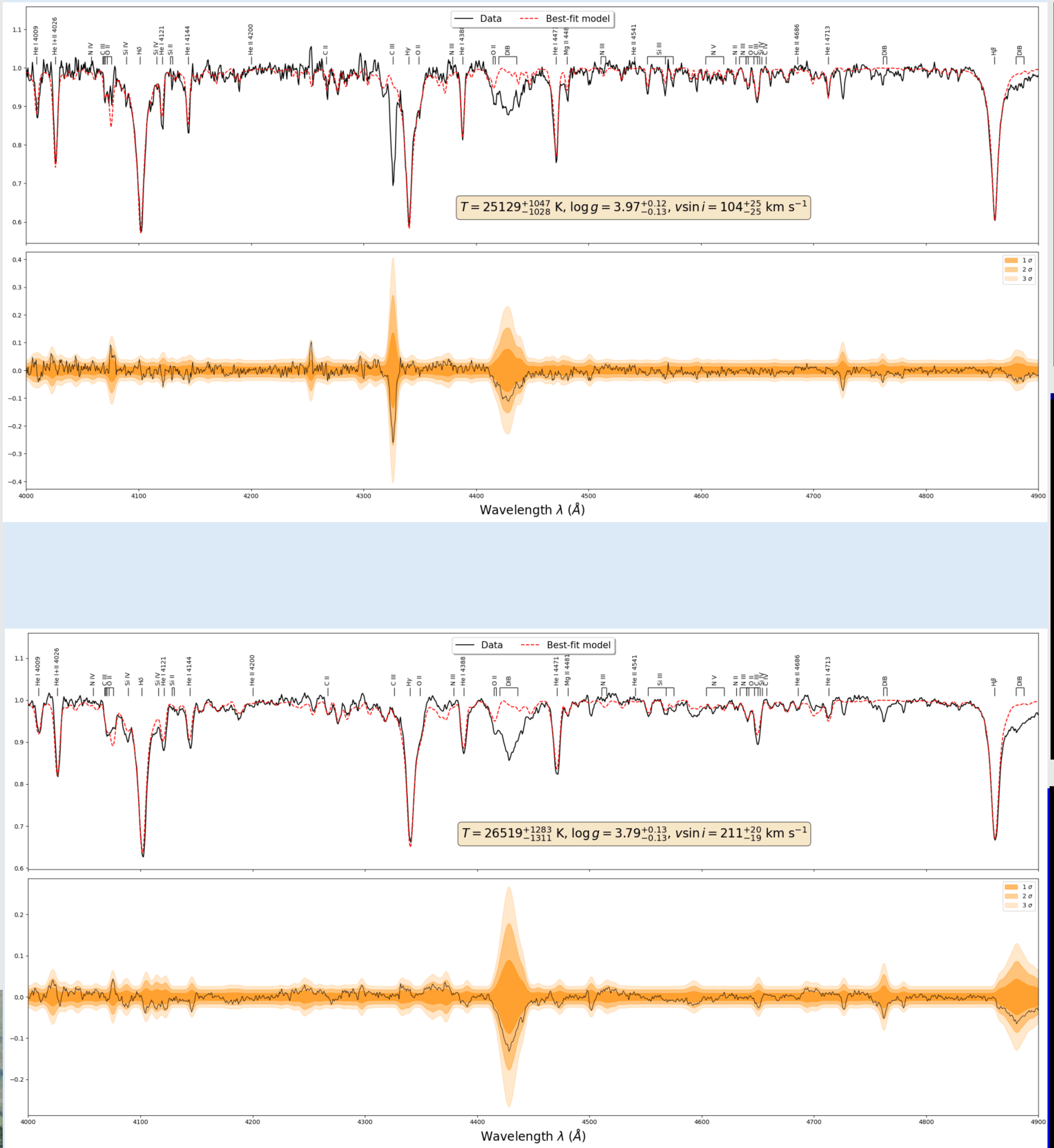

Figure 1: All spectra were recorded in the 4000-5000 Å range. The red curves in top panels represent the model's best fit compared to the data (the black curve). The residuals are shown bottom panels. The spectra shown here, from top to bottom, are targets BS150 and BS288 respectively.

Methods for Finding Chord Length

Chord lengths and intensities were measured using 24 μm images taken from MIPSGAL, Cygnus-X, or other Spitzer/MIPS images available on IRSA. For bow shocks not imaged by Spitzer, we substituted WISE 21 μm.

Figure 2:

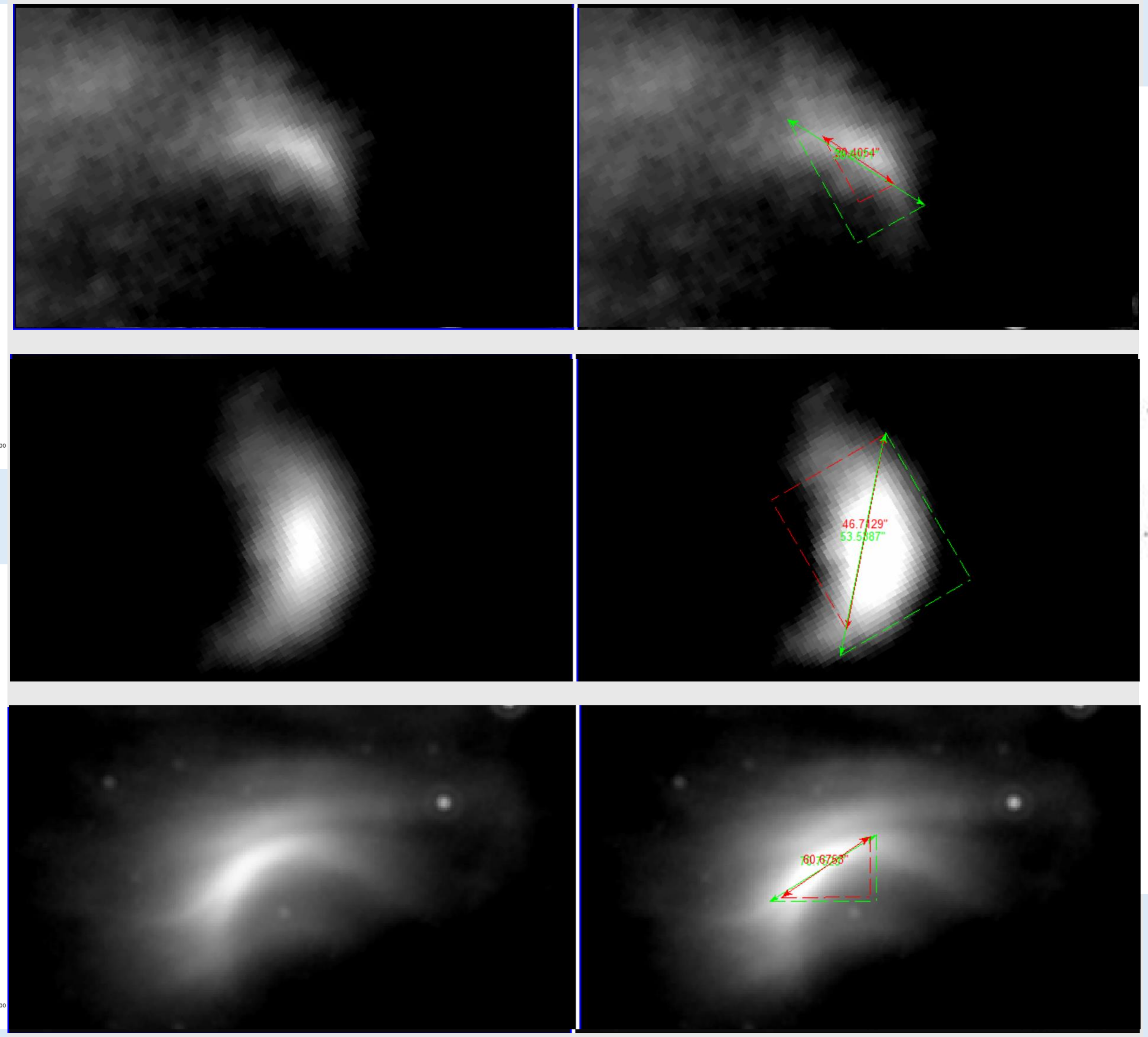

Figure 2: Each pair of IR images above (targets BS288, BS306, BS634) shows the same bow shock without (left) and with (right) the annotations used to measure chord lengths. The green and red lines represent the outer/innermost measurements. To measure the intensities of these bow shocks, the targets were viewed in the same 24 μm and 21 μm images in SAOImage ds9. Peak intensities (P_{24}) for each of the bow shock were measured using the brightest pixel intensity values. A nearby off-nebula location was sample to estimate the background intensity (B_{24}). Then: $I_{24} = P_{24} - B_{24}$.

Results for Mass Loss Rates

Here are the results of the mass loss rates when compared to theoretical calculations. Figure 3 shows that stars with higher surface temperatures and lower surface gravities have higher mass loss rates.

Figure 3:

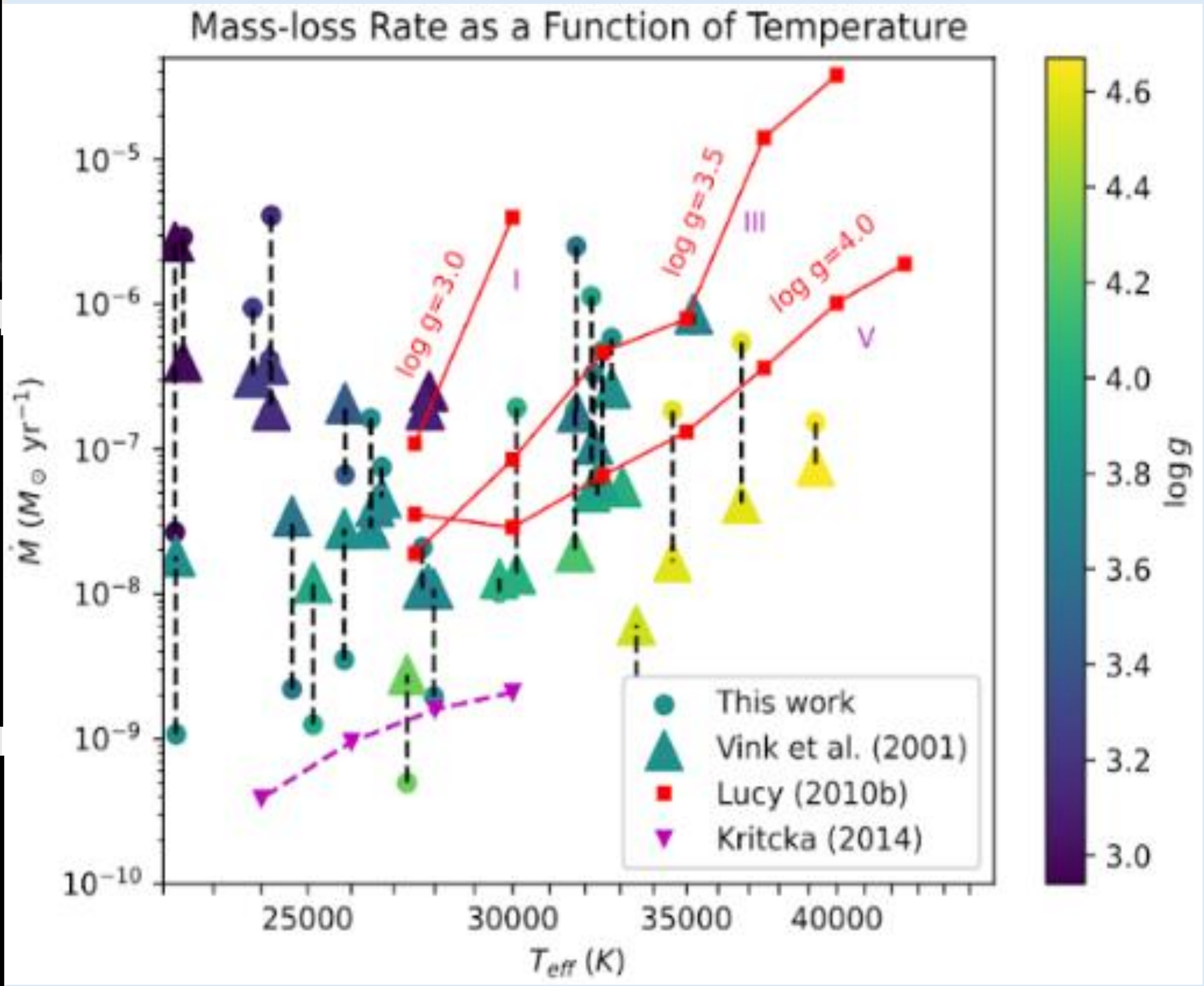

Figure 3: All the targets that my research group and I did are included as points on the plot. In total there were 34 targets evaluated for this project and currently more targets are under investigation. From our analysis the results we produced ended up being within 1 magnitude of theoretical calculations which is better than other current methods for measuring mass loss rates, but only for massive O and B type stars.

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Image of the Wyoming Infrared Observatory provided by http://physics.uwyo.edu/~WIRO/