

Bows around OB stars in the Orion Nebula

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ABSTRACT

The interaction of OB stars with a moving medium will form a bow-shaped nebula that emits strongly in the mid-infrared. Depending on the strength of the stellar wind and the optical depth of the nebula, these may either be hydrodynamic bow shocks or radiation-supported bow waves. We investigate the case of two such nebulae within the star forming region of the Orion Nebula: the Ney–Allen nebula around the B0.5V star θ^1 Ori D in the core of the Trapezium Cluster, and the nebula around the B1.5V star LP Ori on the periphery of the region. We find that the Ney–Allen nebula is a wind-supported bow shock in fully ionized gas, whereas the LP Ori nebula is radiation-supported bow wave, interacting with neutral/molecular material.

Key words: circumstellar matter – radiation: dynamics – stars: winds, outflows

1 OBSERVATIONAL CASE STUDIES

In observational studies of bow-shaped arcs around OB stars, it is frequently assumed that all such objects are wind-supported bow shocks (e.g., Kobulnicky et al. 2016). Our results from § ?? show that this is indeed a fair assumption in the absence of gas-grain decoupling, so long as the ambient density is less than about 100 cm^{-3} (see Fig. ??). In other words, most OB stars interacting with the diffuse interstellar medium are probably in the wind bow shock regime. Therefore, to find examples of radiation-supported bow waves and bow shocks it is necessary to look at arcs inside H II regions and star-forming clouds, where the ambient densities are much higher.

1.1 Evidence for radiation-supported bows

One potentially promising sample is the Carina mid-infrared bow shocks (Sexton et al. 2015), which are in a high density environment, 1000 cm^{-3} , so they may be bow waves. There seems to be spectral types for most of them: B0 (but supergiant) to O7. Sizes are 3 to 12 arcsec, which at Carina (2.3 kpc) is 0.033 pc to 0.134 pc.

Amazingly, the size/density combination gives regions that overlap with the dust wave region for both the $20 M_{\odot}$ and $40 M_{\odot}$ case. And implying velocities of 30 km s^{-1} to 50 km s^{-1} . This is more believable than the 10 km s^{-1} that they quote, since that would not give a shock at all. This would imply $\tau > \eta \approx 0.1$, so the bow luminosity should be 10% of the star luminosity, so getting on for $10^4 L_{\odot}$.

Two small bows in M42:

β 1D (Ney–Allen nebula) (Robberto et al. 2005)

LP Ori: B1.5V star, like our $10 M_{\odot}$ example. Radius about $3''$, so 0.005 pc . With $v = 80$ that would clearly be a dust wave and would require 100 cm^{-3} to 1000 cm^{-3} . Gaia distance (408 ± 11) pc

Ones that Ochsendorf claims are dust waves (Narrator: they aren't).

The Cloudy model for LP Ori

REFERENCES

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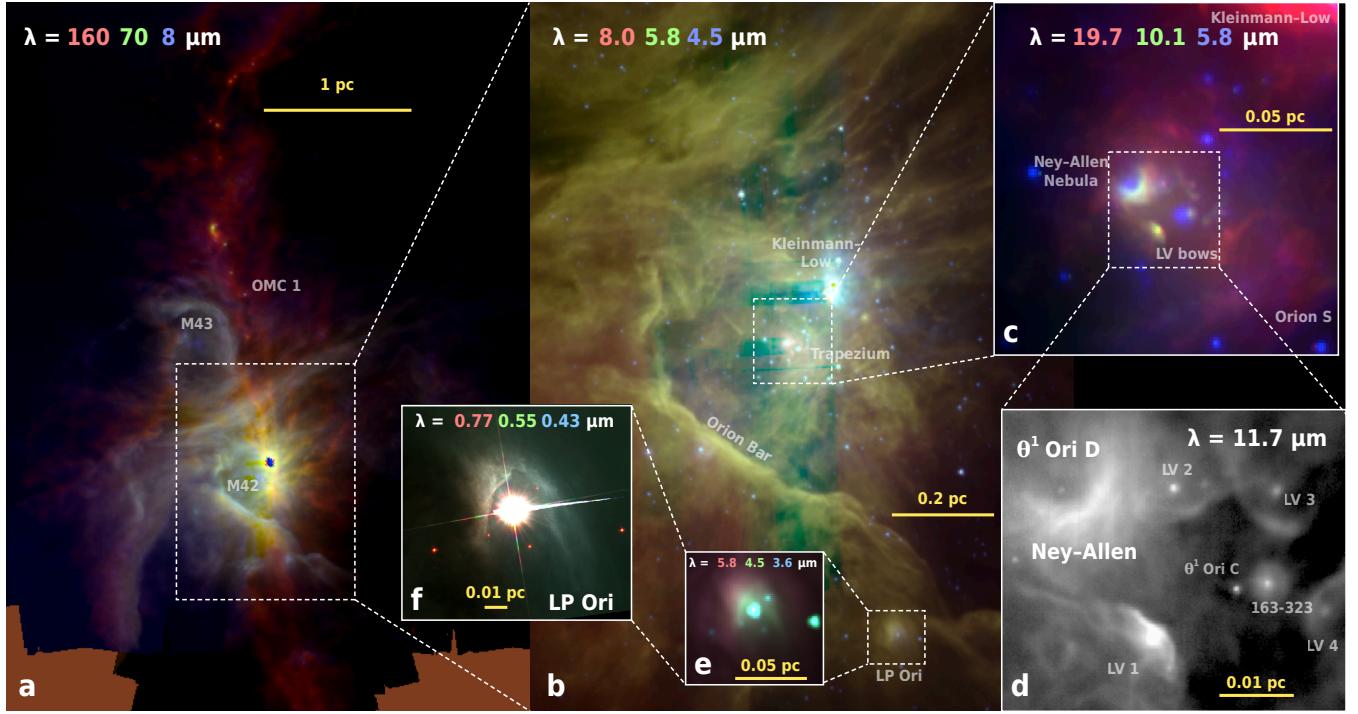


Figure 1. Bows driven by the OB stars θ^1 Ori D and LP Ori in the Orion Nebula. (a) Large-scale infrared view of the Orion Molecular Cloud. Red, green, and blue intensities show respectively Herschel PACS observations at $160\,\mu\text{m}$ and $70\,\mu\text{m}$, and Spitzer IRAC observations at $8\,\mu\text{m}$. Red traces thermal emission from cool dust ($T < 30\,\text{K}$) in the dense molecular filament. Green traces thermal emission from warmer dust ($T \approx 40\,\text{K}$) in the neutral PDR, which is heated by far-ultraviolet radiation from the OB stars in the cluster. Blue traces emission from PAH $7.6\,\mu\text{m}$ and $7.85\,\mu\text{m}$ bands in the same neutral PDR plus thermal emission from hotter dust ($T > 100\,\text{K}$), which is found inside the ionized H II region. (b) Zoom on the central parsec of the Orion Nebula (M42), showing short-wavelength mid-infrared emission from Spitzer IRAC observations ($8.0\,\mu\text{m}$, $5.8\,\mu\text{m}$ and $4.5\,\mu\text{m}$). Red shows the same as blue in panel a. Green show predominantly the $6.2\,\mu\text{m}$ PAH band. Blue shows mainly stellar photospheric emission, plus a minor contribution due to the Br α emission line from ionized gas. Some major components of the nebula are labelled: the Trapezium cluster, which contains the majority of the massive stars; the Kleinmann-Low reflection nebula, illuminated by massive stars embedded in the molecular filament; the Orion Bar, a prominent edge-on ionization front and PDR. (c) Zoom on the central $0.1\,\text{pc}$ of the Trapezium cluster, showing longer wavelength mid-infrared emission from UKIRT MAX ($19.7\,\mu\text{m}$ and $10.1\,\mu\text{m}$). In this central zone, these wavelengths (shown in red and green) are dominated by warm ($100\,\text{K}$ to $300\,\text{K}$) silicate grains, while the IRAC $5.8\,\mu\text{m}$ emission (blue) shows stellar photospheres and the very warmest dust.

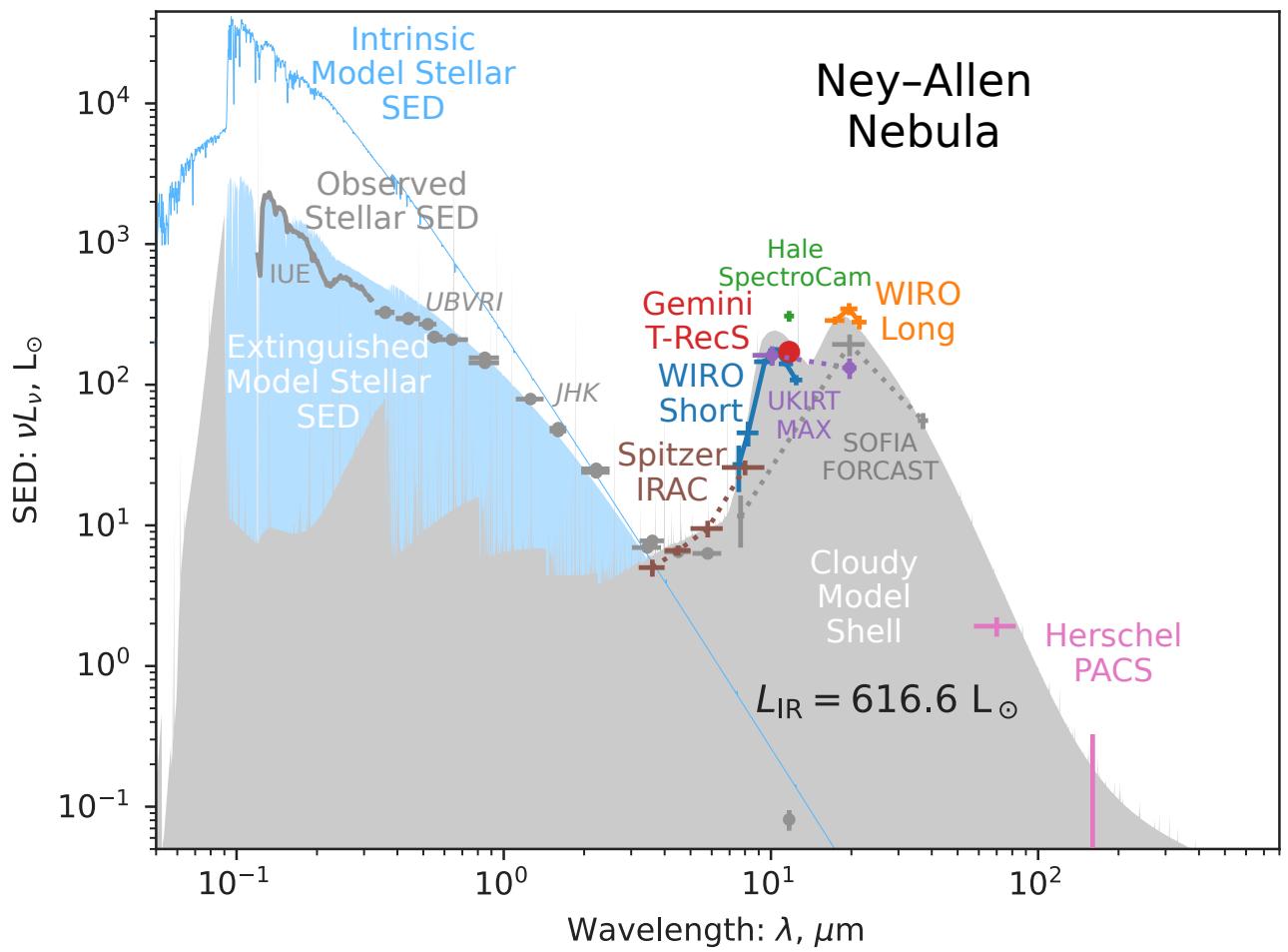


Figure 2. Ultraviolet-to-infrared spectral energy distribution of the Ney–Allen nebula that surrounds θ^1 Ori D.

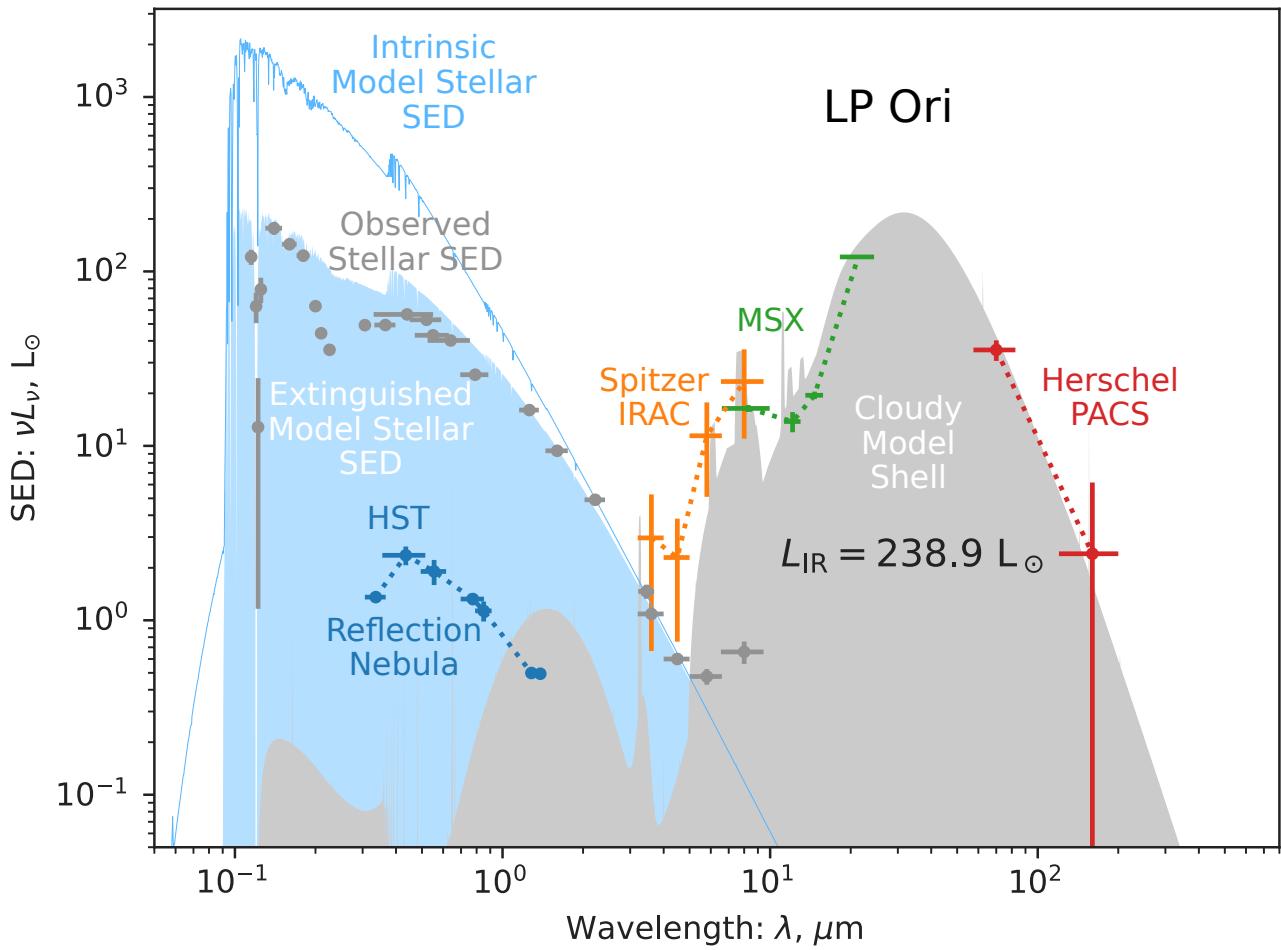


Figure 3. Ultraviolet-to-infrared spectral energy distribution of LP Ori and associated nebula.

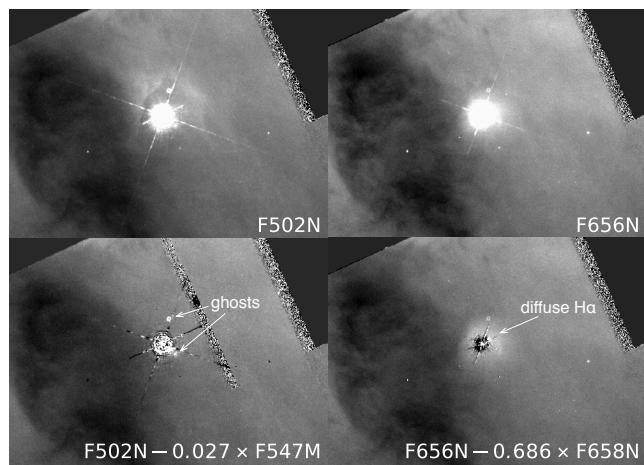


Figure 4. Narrow-band images of LP Ori nebula