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Bow shocks, bow waves, and dust waves. VI. Compact bows in M42

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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 $100\,\mathrm{cm}^{-3}$ (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). are in a high density environment, $1000\,\mathrm{cm}^{-3}$, 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 $20\,\mathrm{M}_\odot$ and $40\,\mathrm{M}_\odot$ case. And implying velocities of $30\,\mathrm{km\,s}^{-1}$ to $50\,\mathrm{km\,s}^{-1}$. This is more believable than the $10\,\mathrm{km\,s}^{-1}$ 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 $10^4\,\mathrm{L}_\odot$.

Two small bows in M42:

þ1D (Ney–Allen nebula) (Robberto et al. 2005)

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

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

The Cloudy model for LP Ori

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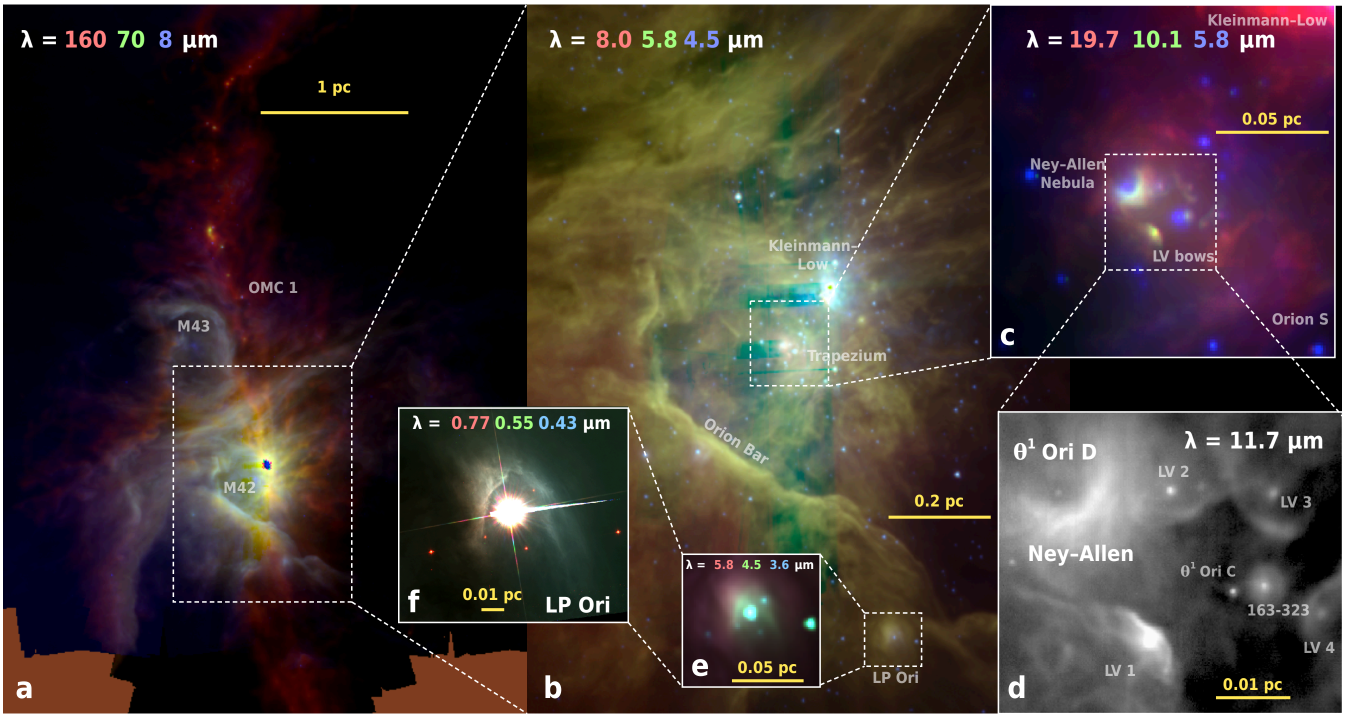

Figure 1. Bows driven by the OB stars θ^1 Ori D and LP Ori in the Orion Nebula. (a) Large-scale infrared view of the Orion Molecular Cloud. Red, green, and blue intensity show respectively Herschel PACS observations at 160 µm and 70 µm, and Spitzer IRAC observations at 8 µm. Red traces thermal emission from cool dust ($T < 30$ K) in the dense molecular filament. Green traces thermal emission from warmer dust ($T \approx 40$ 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 µm and 7.85 µm bands in the same neutral PDR plus thermal emission from hotter dust ($T > 100$ 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 µm, 5.8 µm and 4.5 µm). Red shows the same as blue in panel a. Green show predominantly the 6.2 µm 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 pc of the Trapezium cluster, showing longer wavelength mid-infrared emission from UKIRT MAX (19.7 µm and 10.1 µm). In this central zone, these wavelengths (shown in red and green) are dominated by warm (100 K to 300 K) silicate grains, while the IRAC 5.8 µm emission (blue) shows stellar photospheres and the very warmest dust.

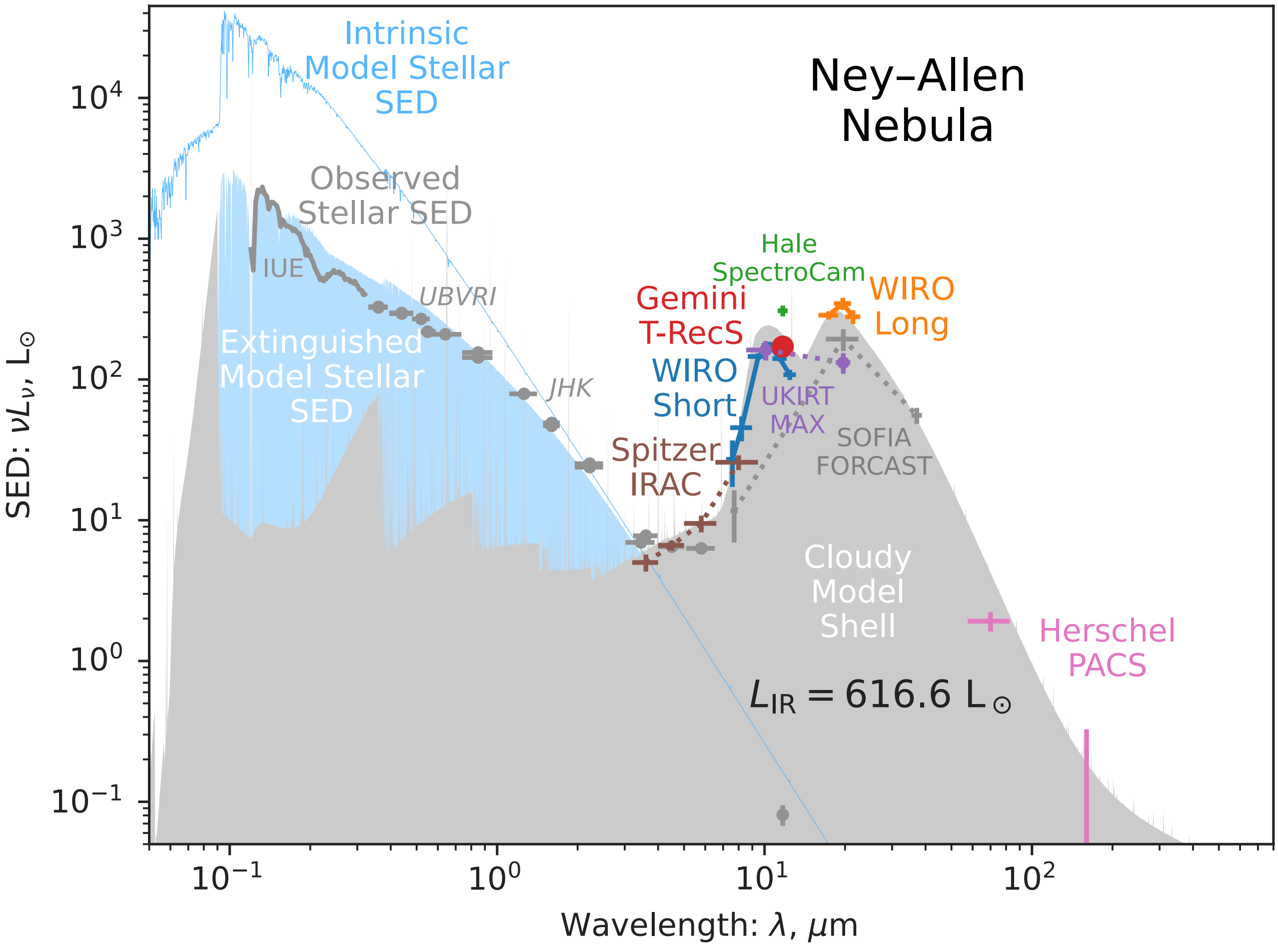

Figure 2. Ultraviolet-to-infrared spectral energy distribution of the Ney–Allen nebula that surrounds θ^1 Ori D.

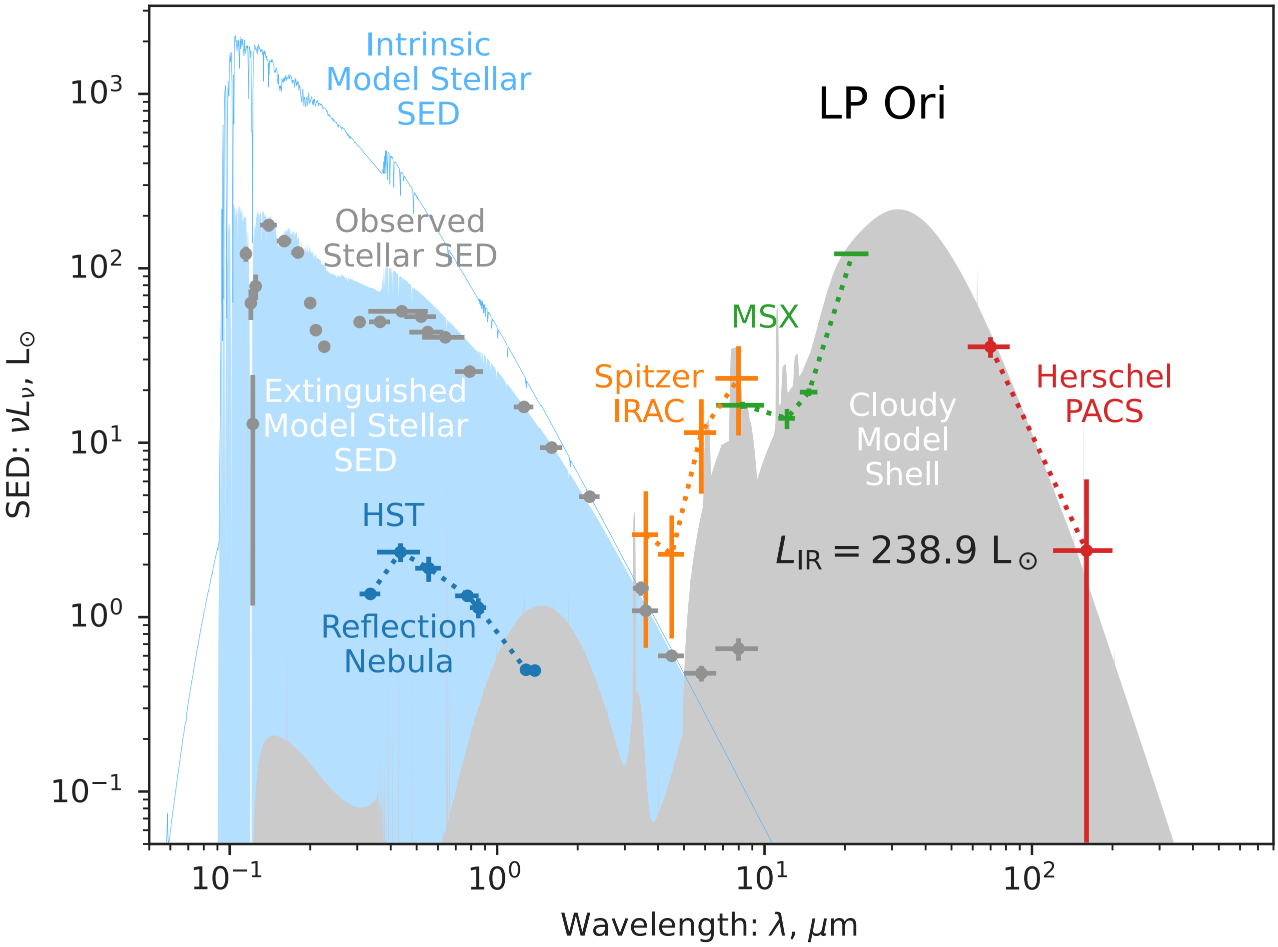

Figure 3. Ultraviolet-to-infrared spectral energy distribution of LP Ori and associated nebula.

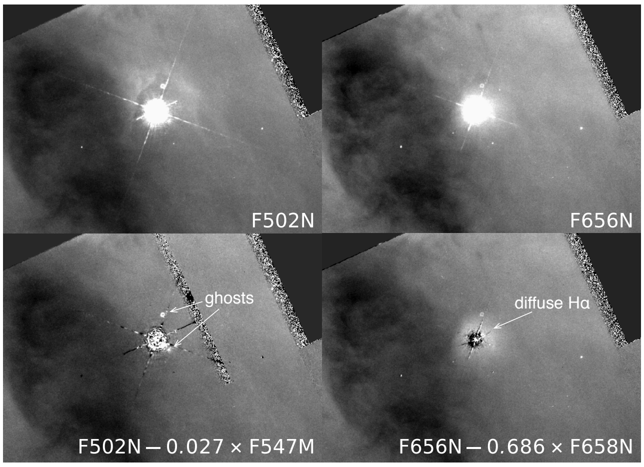

Figure 4. Narrow-band images of LP Ori nebula