Nature vs. Nurture: Identical "Twin" Luminous Blue Variable Stars with Contrasting Nebulae

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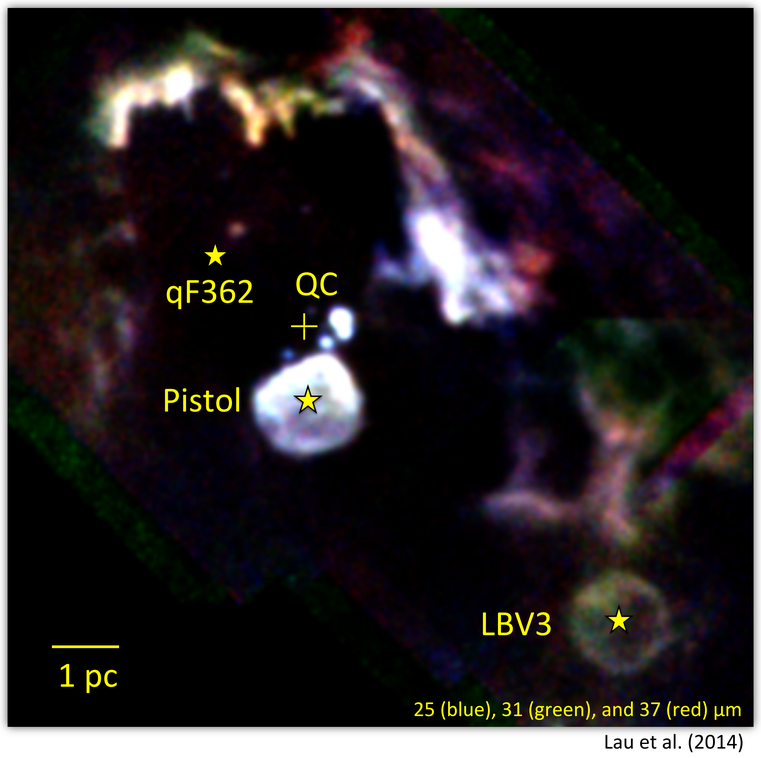
SOFIA/FORCAST Observations of the Pistol and LBV3 Nebulae



Lau et al. (2014)

Luminous Blue Variables (LBVs) in and near Massive Stellar Clusters at the Galactic Center

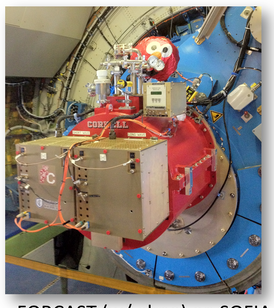
- LBVs exist in a very brief (< 10^5 yrs) evolutionary phase nearing the end of their lifetimes and are extremely rare. Only ~ 10 have been confirmed within the Milky Way[1]
- Three LBVs are located in the vicinity of the Quintuplet Cluster (QC) at the Galactic Center, a site of recent massive star formation: qF362[2], the Pistol star[3], and G0.120-0.048[4] (LBV3)
- We characterize the LBV nebulae surrounding the Pistol star and LBV3 to trace their evolution and study the influence of their different environments

The Faint Object Infrared Camera for the SOFIA Telescope (FORCAST)

- Images of the Pistol nebula at 19, 31, and 37 μm were obtained using FORCAST[5] on the 2.5 m Telescope aboard the Stratospheric Observatory for Infrared Astronomy (SOFIA) on June 8, 2011 (alititude ~ 43,000 ft)
- Follow-up observations with FORCAST of both the Pistol and LBV3 nebulae were obtained on July 1, 2013 (altitude ~ 39,000 ft) at 19, 25, 31, and 37 μm

Key Results

- We propose that the Pistol and LBV3 are identical "twins" that exhibit contrasting nebulae due to the external influence of their different environments
- The Pistol nebula is composed of very small, transiently heated grains (< 60 Å) that are differentially decelerated and sputtered due to the winds from Wolf-Rayet Carbon (WC) stars in the Quintuplet Cluster to the north
- We suggest that the LBV3 nebula has a grain composition similar to that of the non-sputtered region of the Pistol nebula and is freely expanding
- Both Pistol and LBV3 nebulae share identical dynamical timescales (~10^4 yrs), mass-loss rates (~10^{-3} M_{Sun}/yr), and gas-to-dust mass ratios (~275)



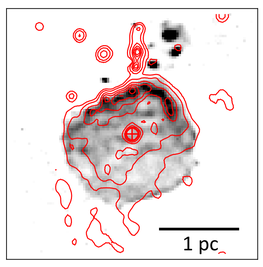
FORCAST (w/ elmo) on SOFIA

SOFIA in flight, courtesy of NASA

Pistol Nebula

Morphology:

- Shell-like with a radius of 0.5 – 0.7 pc
- Compressed and asymmetric about Pistol star
- Shaped by Wolf-Rayet Carbon (WC) star winds at the north



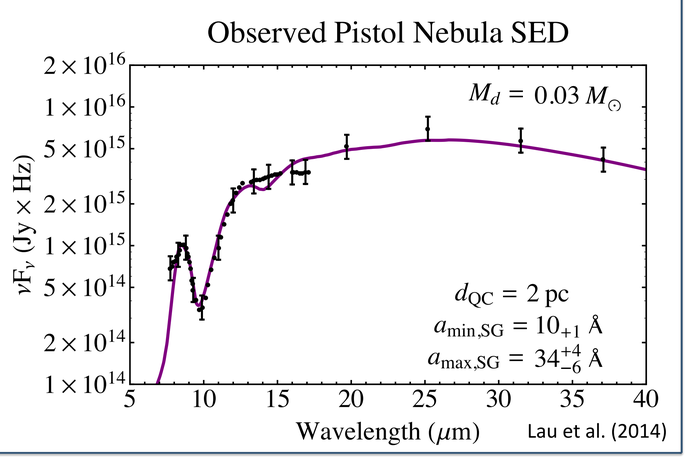
31 μm Flux with P-α Contours[6]

Ionization and Dust Energetics:

- Pistol star does not provide enough Lyman-continuum photons to ionize nebula
- Externally ionized by Quintuplet Cluster
- Dust heating dominated *externally* by *Quintuplet Cluster*

Dust Properties:

- Composed of silicates with a minimum size of 10 Å and maximum sizes 25 – 60 Å decreasing from south to north due to sputtering from WC star winds
- T_d ~ 120 K, M_d ~ 0.03 M_{Sun}, and L_{IR} ~ 5 x 10^5 L_{Sun}
- Gas-to-dust mass ratio of 275^{+46}_{-69}
- If the Pistol nebula has a separate distribution of large grains (~1000 Å) it would only be 20% of the total dust mass

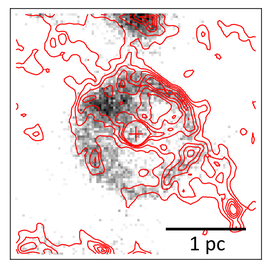


Lau et al. (2014)

LBV3 Nebula

Morphology:

- Shell-like with a radius of 0.7 pc
- Circularly symmetric about LBV3
- Freely expanding into surrounding medium



31 μm Flux with P-α Contours[6]

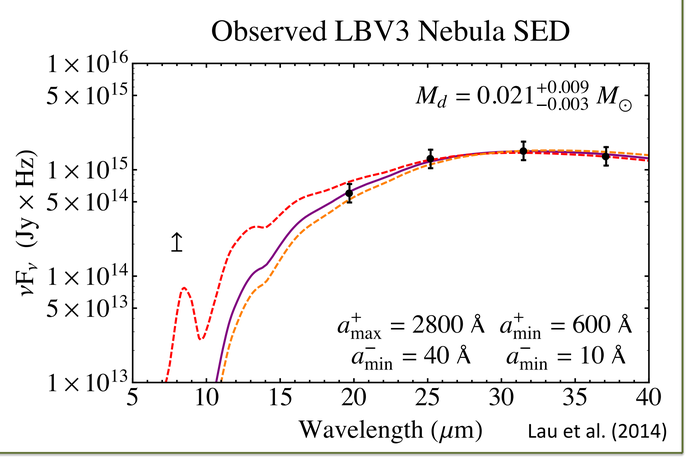
Ionization and Dust Energetics:

- LBV3 does not provide enough Lyman-continuum photons to ionize nebula
- Externally ionized by Arches Cluster and possibly the Quintuplet Cluster
- Dust heating dominated *centrally* by *LBV3*

Dust Properties:

- Composed of silicates with minimum grain size < 600 Å and maximum size 40 – 2800 Å
- T_d ~ 95 K, M_d ~ 0.02 M_{Sun}, and L_{IR} ~ 10^5 L_{Sun}
- Gas-to-dust mass ratio of 276^{+46}_{-95}
- If LBV3 has very small, transiently heated grains it would not be detectable by Spitzer/IRAC

SEDs modeled with DustEM[8]

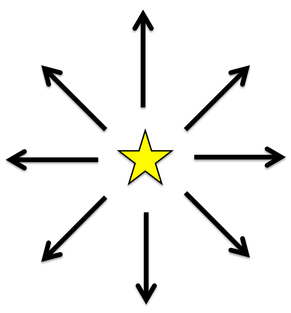


Lau et al. (2014)

Evolution of the LBV Nebulae

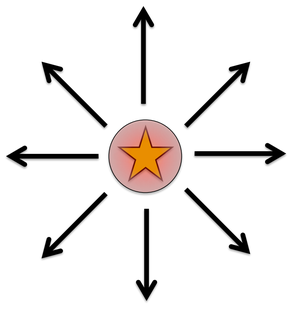
Formalism adopted from Kochanek (2011)

LBV enters an eruptive state



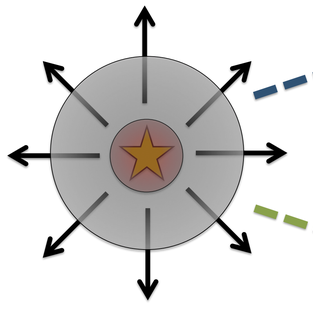
The mass-loss rate is greatly enhanced from ~10^{-5} M_{Sun}/yr (*quiescent*) to ~10^{-3} M_{Sun}/yr (*eruption*)

Forms a 7000K "pseudo photosphere"



The optically thick dense winds form a "pseudo photosphere" with an apparent temperature cooler than that of the star

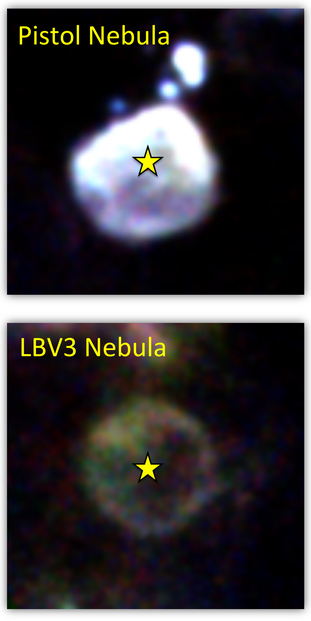
Dust condenses and grows collisionally



The optically thick winds shield the dust formation region (r ~ 10^{15} cm) from UV photons that would otherwise sublimate the grains

Pistol encounters WC star winds to the north

LBV3 freely expands



Summary of Pistol and LBV3 Nebulae Properties

	d (pc)	T_d (K)	L_{IR} (L_{Sun})	L_* (L_{Sun})[4]	M_g /M_d
Pistol	1.2 – 1.4	120	5 x 10^5	3.3 x 10^6	~275
LBV3	1.4	95	~10^5	4 x 10^6	~275

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