The Hunt for Massive Stars Hiding in the Milky Way

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Brief Background

Or, How I Became a Massive Stars Guy Without Really Trying
Bow shocks: Stellar winds meet moving gas

Povich et al. (2008)
Bow shocks:
Stellar winds meet moving gas

Spitzer “Color Code 1”
IRAC 3.6 µm • stars, PAHs
IRAC 4.5 µm • stars, shocked/ionized gas
IRAC 8.0 µm • PAHs [+hot dust]

Shock Fronts in the Omega Nebula (M 17)
NASA / JPL-Caltech / M. Povich (Univ. of Wisconsin)

Spitzer Space Telescope • IRAC
ssc2008-21a
Everett & Churchwell (2010): **Dust** must be continuously replenished within N49.

Draine (2011): 20 cm shell in N49 shaped by radiation pressure and winds.
The Chandra Carina Complex Project (CCCP)

Candidate X–ray Emitting OB Stars
(Povich et al. 2011a)
CCCP Collaboration

16 papers published in a May 2011 Special Issue of ApJS!
Available at http://cochise.astro.psu.edu/Carina_public/special_issue.html

Penn State Core Group
Leisa Townsley – Mighty Leader
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Konstantin Getman
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Richard Townsend
Barbara Whitney
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PLUS: About 50 other people!
Hubble Space Telescope image of Herbig-Haro jets and pillars in the Carina Nebula
Hubble Space Telescope

~6′ × 12′ mosaic of the Great Nebula in Carina
The Great Nebula in Carina

- Carina is a “starburst region,” an example of the large-scale star formation seen in starburst galaxies.
- Carina contains at least 200 O and early-B stars, including the prototype O2 I star, +WRs +Eta Car.


D ~ 2.3 kpc, 10’ ~ 6.7 pc, Bipolar, proto-superbubble!
Carina’s stellar population is a cluster of clusters. The 3 most massive clusters, Tr 14, 15, and 16, dominate the bright central region of the nebula.

**The Great Nebula in Carina**

- Carina’s stellar population is a cluster of clusters. The 3 most massive clusters, Tr 14, 15, and 16, dominate the bright central region of the nebula.


D ~ 2.3 kpc, 10' ~ 6.7 pc.

Bipolar, proto-superbubble!

2MASS JHK, ~28' x 28'
The Vela–Carina Survey
PI S. R. Majewski
Chandra

0.50 – 0.70 keV
0.70 – 0.86 keV
0.86 – 0.96 keV

Townsley et al. (2011)
• Spectral energy distribution (SED) fitting uses all available photometric data.
• Fit reddened spectra to data, using an extinction law characterized by $R_V = A_V/E(B-V)$. Note standard diffuse ISM law has $R_V = 3.1$. (See Cardelli et al. 1989, Indebetouw et al. 2005, Robitaille et al. 2007.)
Note degeneracy of $A_V$ and $T_{\text{eff}}$.

**Secure OB candidate**

**Marginal OB candidate:**

$L_{\text{bol}}(\text{MS}) = 10^4$ L$_{\odot}$

Pre-main-sequence degenerate case
The best-studied regions of the Carina Nebula are **not obscured**, but much of the nebula has been hidden by dust.

This wide-field image could fit 4 full Moons and contains over 50,000 stars.

*There are many places for massive stars to hide!*
Known massive, O and B–type stars

The Carina Nebula: Central 1°

Visible Light
Digitized Sky Survey

Near–Infrared
Two–Micron All–Sky Survey

Mid–Infrared
Spitzer Space Telescope

140 known high–mass stars, located in the less–obscured regions and in the well–studied, famous clusters.
Known massive, O and B–type stars

Candidate massive, O and early B–type stars

The Carina Nebula: Central 1°

Visible Light
Digitized Sky Survey

Near–Infrared
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Mid–Infrared
Spitzer Space Telescope

- 140 known high-mass stars, located in the less-obscured regions and in the well-studied, famous clusters.

- 94 new candidate high-mass stars, located in the more-obscured regions and outside the famous clusters.
Correcting for selection biases, candidate OB stars could **double** the massive stellar population.
OB search in M17

Heather Busk (PSU grad student)

OB candidate from X-ray/SED method

Candidate is known OB star

ACIS Pointing 3: 40 ks

Pointing 1: 320 ks

Pointing 2: 96 ks
Bolometric luminosities and reddening of known Carina OB stars: SED fitting method compared to $B - V$ photometric method.

Late O and B dwarfs
Early O dwarfs and OB (super)giants

- $B - V$ method: more vulnerable to photometric errors; more sensitive to $R_V$.
- SED method systematic: What’s up with the OB (super)giants?
Spectral models matter!

- ATLAS9 LTE, plane-parallel atmosphere (Kurucz 1994).
- CMFGEN non-LTE, line-blanketed, expanding atmosphere (Hillier & Miller 1998).

OB supergiant winds produce IR excess emission that should be detectable with Spitzer photometry. Can spectroscopy + IR SED fitting better constrain mass-loss rates in spectral models?
Lessons from the CCCP

- Extrapolating IMF from known massive star content of Carina Nebula underestimates total stellar population by a factor $>2$.
- Candidate obscured, X-ray-emitting OB stars could increase known massive stellar population by up to a factor of $\sim2$.
- SED modeling not simply a means for identifying new OB stars. It also provides improved measurements of extinction, bolometric luminosity, and (hopefully) soon mass-loss rates.
The Milky Way Project

Citizen scientists in search of Galactic H II regions
The human eye–brain combination is still the best pattern-recognition system in the known universe!
THE MILKY WAY PROJECT TEAM

Kim Arvidsson » Postdoctoral researcher at Adler Planetarium.

Robert Benjamin » GLIMPSE team member and Professor of Physics, University of Wisconsin-Whitewater.

Eli Bressert » PhD student at ESO and the University of Exeter researching star formation and star clusters.

Ed Churchwell » Professor Emeritus at the University of Wisconsin-Madison, Principal Investigator of the GLIMPSE I&II surveys and team member on all other GLIMPSE Surveys.

Chris Lintott » Astronomer and Zookeeper normally in Oxford but currently at Adler Planetarium, Chicago.

Sarah Kendrew » Postdoctoral researcher at the Max Planck Institute for Astronomy, Heidelberg.

Sarah Maddison » Associate Professor of Astrophysics at Swinburne University, Australia.

Matthew Povich » NSF Postdoctoral Fellow at Pennsylvania State University.

Kevin Schawinski » Einstein Fellow at Yale University.

Reid Sherman » Millimeter-wave observational astronomer, graduate student at University of Chicago.

Arfon Smith » Technical lead of the Zooniverse. He used to know lots of things about astronomy but these days spends most of his time thinking in code.

Robert Simpson » Zooniverse Researcher and Developer at Oxford University. PI of the Milky Way Project.

Barbara Whitney » Senior Scientist at University of Wisconsin and Space Science Institute.

Grace Wolf-Chase » Astronomer, Adler Planetarium & Senior Research Associate, University of Chicago.

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Infrared Images of H II Region “Bubbles”

Spitzer Color Code 2:
- STARS
- DUST and molecules outlining bubbles
- WARM DUST inside bubbles
Example $3^\circ \times 2^\circ$ GLIMPSE+MIPSGAL Mosaic
Centered @ $(l,b) = (12.0^\circ,0.0^\circ)$
ALL user drawings
“Cleaned” user drawings $\rightarrow$ Bubbles catalog
ALL user drawings
ALL user drawings
ALL user drawings—masked @ threshold “hit rate.”
“Heat maps” highlighting PDRs
The Milky Way Project: First Results

• >4,000 bubbles in catalog, a factor of ~7 increase over existing catalogs (Churchwell et al. 2006, 2007). The vast majority are H II regions.

• “Heat map” masks highlight PDRs and provide a roadmap for Galaxy-wide study of star formation triggered by expanding H II regions.

Simpson, Povich et al. (in prep)