Massive stars in Cygnus (especially in Cyg OB2)

Jesús Maíz Apellániz

Keele University, Thursday 1 February 2018
Talk structure

1. Cygnus in context.
   ★ Overview.
   ★ Cygnus and Carina.


3. The massive star census.

4. A bit about extinction.

5. The future.
   ★ WEAVE.
   ★ GALANTE.
Why is Cygnus important for massive stars?

Massive stars by Galactic octant

(Maíz Apellániz et al. 2018)

O-star extinction by Galactic octant

(Maíz Apellániz & Barbá 2018)
The Cygnus complex is... complex
The Cygnus complex is... complex
The Cygnus complex is... complex
The Cygnus complex is... complex
The Cygnus complex is... complex
The Cygnus complex is... complex
The Cygnus complex is... complex

Confirmed O stars
Confirmed WR stars
Confirmed B stars + A supergiants
Other massive stars

F861M + F660N + F515N
Piercing the Galaxy
Piercing the Galaxy

Cyg OB2 ~1.5 kpc
Perseus arm ~5.5 kpc
Outer arm ~9.5 kpc
Cyg OB2 ~1.5 kpc

Massive stars in Cygnus
Jesús Maíz Apellániz
Keele University, Thursday 1 February 2018
Massive stars in Cygnus

Piercing the Galaxy: Carina
Piercing the Galaxy: Cyg OB2
The history of massive stars in Cyg OB2

- Johnson & Morgan (1954), Morgan et al. (1954).
- Schulte (1958).
- Walborn (1973), Walborn et al. (2002).
- Sota et al. (2011, 2014), Maíz Apellániz et al. (2016).
A HEAVILY OBSCURED O-ASSOCIATION IN CYGNUS

H. L. JOHNSON AND W. W. MORGAN
Lowell Observatory; Varenna Observatory
Received October 7, 1933

ABSTRACT

The clustering of blue giant stars near γ Cygni discovered at the Tenementiolar Observatory by L. Münch and Morgan has been observed photometrically and spectroscopically. It is shown to be an O-association of considerable interest because of the large number of O stars and the great interstellar absorption; the latter reaches a value of between 6 and 7 mag. on the V system of Johnson and Morgan. The distance of the association is around 1500 parsecs.

Photometric and Spectroscopic Data

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* The mean value of the distance modulus is 10.5.
† Eclipsing binary; magnitude corrected by +0.7 mag. for duplicity.
NOTES FROM OBSERVATORIES

A VERY RED STAR OF EARLY TYPE IN CYGNUS

W. W. MORGAN, H. L. JOHNSON, AND NANCY G. ROMAN
Yerkes and McDonald Observatories, Lowell Observatory

In the course of observing the cluster of blue supergiants recently discovered northeast of γ Cygni, an exceedingly red star was found about midway between Numbers 9 and 5 of the cluster and slightly south of the line joining the two stars (Fig. 1). Because of its proximity to the clustering of O stars it seemed possible that the star, which appears visually to be considerably redder than star No. 9, might be of unusual interest.

Several spectrograms were obtained with the 82-inch refle-
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Several spectrograms were obtained with the 82-inch reflec-

Fig. 1.—Region of the very red star of early type in Cygnus. North is at top; east is at left. The numbered stars are from the paper by Johnson and Morgan. The brightest star in the field (upper left center) is BD +40° 4225; No. 5 is BD +40° 4220; No. 8 is BD +40° 4227. The new red star is marked by an arrow and is given the number 12.
NEW MEMBERS OF THE ASSOCIATION VI CYGNI. II 1958

D. H. SCHULTE
Yorkes Observatory
Received February 3, 1958; revised March 3, 1958

ABSTRACT

The existence of twelve additional reddened early-type stars in the O-association VI Cygni has been confirmed by $(U, B, V)$ photoelectric observations with the 82-inch McDonald telescope. This brings to thirty-one the total number of such stars, determined either from slit spectrograms or photoelectrically.

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SPECTRAL CLASSIFICATION OF OF STARS IN VI CYGNI
(CYGNUS OB2)

NOLAN R. WALBORN*

David Dunlap Observatory, University of Toronto,
Richmond Hill, Ontario, Canada

Received 1972 November 16

ABSTRACT

Two-dimensional spectral classifications have been obtained for seven O stars in the interesting association VI Cygni. One of them, star No. 7, is of type O3 II*; it is the second known member of this new category, and the first in the northern hemisphere. Its spectrum is illustrated. A distance of 1800 pc to the association is derived.

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MASSIVE STARS IN Cyg OB2¹

PHILIP MASSEY AND A. B. THOMPSON

Kitt Peak National Observatory, National Optical Astronomy Observatories,² P. O. Box 26732, Tucson, Arizona 85726-6732

Received 16 October 1990; revised 7 December 1990

ABSTRACT

The galactic OB association Cygnus OB2 contains a wealth of heavily reddened O and B stars, including VI Cyg No. 12, one of the most luminous and heavily reddened stars known. We have studied this association using CCD $UBV$ photometry and spectroscopy. The photometry has allowed us to isolate the intrinsically blue stars: spectroscopy has then provided accurate MK spectral types for determining effective temperatures and hence bolometric corrections. We show how the two-color diagram can be used to separate foreground from association memberships by using the large minimum reddening [$E(B-V) > 1.2$]; galactic associations with more moderate reddening will suffer confusion of foreground F and G stars with reddened stars of mid-to-late B type. The resulting H–R diagram shows a well-defined, clean main sequence, with a few slightly evolved supergiants of lower mass, suggesting that star formation was not strictly coeval, similar to what is seen in OB associations in the Magellanic Clouds. The initial mass function of Cyg OB2 is found to have a slope of $\Gamma = -1.0 \pm 0.1$, considerably flatter than that previously found for massive stars in the Galaxy and for most regions studied in the Magellanic Clouds. Finally, we discuss the nature of the very luminous star VI Cyg No. 12. This star is the most visually luminous star known in the Galaxy and lies in a position of the H–R diagram well above the upper luminosity cutoff found by Humphreys & Davidson [ApJ, 232, 409 (1979)]. It is also the most heavily reddened star known optically ($A_V \approx 10$ mag). Data presented here and elsewhere suggest that the star is slightly variable both photometrically and spectroscopically, and we speculate that it is an incipient Hubble–Sandage variable (i.e., a Luminous Blue Variable), and that the high luminosity coupled with high extinction is in fact not a coincidence, but evidence of a previous episode of mass loss.

Photometric [MT91] XXX (1-789) e.g. [MT91] 59 = Cyg OB2-1
On the massive star contents of Cygnus OB2*

F. Comerón\textsuperscript{1}, A. Pasquali\textsuperscript{2}, G. Rodighiero\textsuperscript{3}, V. Stanishev\textsuperscript{4}, E. De Filippis\textsuperscript{5}, B. López Martí\textsuperscript{6}, M. C. Gálvez Ortiz\textsuperscript{7}, A. Stankov\textsuperscript{8}, and R. Grebel\textsuperscript{9}

\textbf{Abstract.} We present a near-infrared spectroscopic survey of a large area centered on the Cygnus OB2 association aimed at constraining its massive star contents. Our goal is to establish a nearly complete list of O-type members of the association, both to examine recent claims based on star counts that suggest a richer content than previously thought, and to provide a suitable database for further studies of the entire high-mass end of one of the richest associations of the Galaxy. \textbf{The target selection is based on the JHK photometry published in the 2MASS all-sky survey.} We identify 46 new early-type candidates, most of them expected to be O-type stars, plus 16 new stars with emission in Br\textgamma and often in other lines as well, characteristic of evolved massive stars undergoing intense mass loss. We also present spectra of three luminous stars with CO overtone emission, one of them having also intense H\textsubscript{2} emission and being associated with compact nebulosity. By considering our findings, those of other authors, and plausible completeness corrections, we estimate the number of O-type stars or stars having evolved from an O-type progenitor to be 90–100, slightly below, but compatible with, most recent star counts estimates by Knödlseder (2000, A&A, 360, 539). These results support the notion that Cygnus OB2 may be considered as a young globular cluster. The lists of new members that we provide, in particular those with emission lines, should be a useful resource for future investigations of Cygnus OB2 itself, as well as of very massive stellar evolution by providing a nearby, abundant sample of stars sharing a common environment.

New members of the massive stellar population in Cygnus\textsuperscript{*,***,****}

F. Comerón\textsuperscript{1} and A. Pasquali\textsuperscript{2}

\textsuperscript{1} ESO, Karl-Schwarzschild-Strasse 2, 85748 Garching bei München, Germany
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Received 12 February 2012 / Accepted 17 April 2012

\textbf{ABSTRACT}

\textbf{Context.} The Cygnus OB2 association and its surroundings display the richest collection of massive stars in our nearby Galactic environment and a wealth of signatures of the interaction between these stars and the interstellar gas.

\textbf{Aims.} We perform a magnitude-limited, homogeneous census of O and early B-type stars with accurate spectral classifications in the blue, in a 6' x 6' region centered on Cygnus OB2 that includes most of the Cygnus X complex, a sizeable fraction of the adjacent Cygnus OB9 association, and a large area of the field surrounding these complexes.

\textbf{Methods.} By using reddening-free indices based on \textit{V}IJK magnitudes from the USNO-B and 2MASS catalogs, we are able to produce a highly complete, highly uncontaminated sample of O and early B stars, which nearly duplicates any previous census of the region for the same range of spectral types. We provide the spectral types of 60 new O and B stars, as well as a list of an additional 60 candidates pending spectroscopic confirmation. In addition, the \textit{UBV} imaging of the surroundings of three apparently isolated O stars is used to investigate the possible presence of small clusters of young stars around them.
A RADIAL VELOCITY SURVEY OF THE CYG OB2 ASSOCIATION

DANIEL C. KIMINKI,1 HENRY A. KOBUŁNICKI,1 K. KINEMUCHI,1 JENNIFER S. IRWIN,2 CHRISTOPHER L. FRYER,3,4 R. C. BERRINGTON,1 B. UZEN,1 ANDY J. MONSON,1 MICHAEL J. PIERCE,1 AND S. E. WOOSLEY5

Received 2006 July 7; accepted 2006 September 27

ABSTRACT

We conducted a radial velocity survey of the Cyg OB2 association over a 6 yr (1999–2005) time interval to search for massive close binaries. During this time we obtained 1139 spectra on 146 OB stars to measure mean systemic radial velocities and radial velocity variations. We spectroscopically identify 73 new OB stars for the first time, the majority of which are likely to be association members. Spectroscopic evidence is also presented for a B3 Iae classification and temperature class variation (B3–B8) on the order of 1 yr for Cyg OB2 No. 12. Calculations of the initial mass function with the current spectroscopic sample yield τ = −2.2 ± 0.1. Of the 120 stars with the most reliable data, 36 are probable and 9 are possible single-lined spectroscopic binaries. We also identify three new and eight candidate double-lined spectroscopic binaries. These data imply a lower limit on the massive binary fraction of 30%–42%. The calculated velocity dispersion for Cyg OB2 is 2.44 ± 0.07 km s⁻¹, which is typical of open clusters. No runaway OB stars were found.

Subject headings: binaries: close — binaries: general — binaries: spectroscopic — stars: early-type — stars: kinematics — surveys — techniques: radial velocities

Online material: machine-readable tables

2007

TOWARD COMPLETE STATISTICS OF MASSIVE BINARY STARS: PENULTIMATE RESULTS FROM THE CYGNEUS OB2 RADIAL VELOCITY SURVEY

HENRY A. KOBUŁNICKI1, DANIEL C. KIMINKI2, MICHAEL J. LUNDQUIST1, JAMISON BURKE1,3, JAMES CHAPMAN1,4, ERICA KELLER1,5, KATHRYN LESTER1,6, EMILY K. ROLEN1,7, ERIC TOPEL1,8, ANIRBAN BHATTACHARJEE1, RACHEL A. SMULLEN1, CARLOS A. VARGAS ÁLVAREZ1, JESSIE C. RUNNOE1,9, DANIEL A. DRAKE1, AND MICHAEL M. BROTHERTON1

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ABSTRACT

We analyze orbital solutions for 48 massive multiple-star systems in the Cygnus OB2 association, 23 of which are newly presented here, to find that the observed distribution of orbital periods is approximately uniform in log P for P < 45 days, but it is not scale-free. Inflections in the cumulative distribution near 6 days, 14 days, and 45 days suggest key physical scales of 0.2, 0.4, and 1 A.U. where yet-to-be-identified phenomena create distinct features. No single power law provides a statistically compelling prescription, but if features are ignored, a power law with exponent β ≈ −0.22 provides a crude approximation over P = 1.4–2000 days, as does a piece-wise linear
THE MASSIVE STAR-FORMING REGION CYGNUS OB2. I. CHANDRA CATALOG OF ASSOCIATION MEMBERS

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Constraints on massive star formation: Cygnus OB2 was always an association

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The massive star population of Cygnus OB2

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ABSTRACT
We have compiled a significantly updated and comprehensive census of massive stars in the nearby Cygnus OB2 association by gathering and homogenizing data from across the literature. The census contains 169 primary OB stars, including 52 O-type stars and 3 Wolf–Rayet stars. Spectral types and photometry are used to place the stars in a Hertzsprung–Russell diagram, which is compared to both non-rotating and rotating stellar evolution models, from which stellar masses and ages are calculated. The star formation history and mass function of the association are assessed, and both are found to be heavily influenced by the evolution of the most massive stars to their end states. We find that the mass function of the most massive stars is consistent with a ‘universal’ power-law slope of $\Gamma = 1.3$. The age distribution inferred from stellar evolutionary models with rotation and the mass function suggest the majority of star formation occurred more or less continuously between 1 and 7 Myr ago, in agreement with studies of low- and intermediate-mass stars in the association. We identify a nearby young pulsar and runaway O-type star that may have originated in Cyg OB2 and suggest that the association has already seen its first supernova. Finally we use the census and mass function to calculate the total mass of the association of $16.500_{-600}^{+600} M_\odot$, at the low end, but consistent with previous estimates of the total mass of Cyg OB2. Despite this Cyg OB2 is still one of the most massive groups of young stars known in our Galaxy making it a prime target for studies of star formation on the largest scales.
ABSTRACT

We present the first installment of a massive spectroscopic survey of Galactic O stars, based on new, high signal-to-noise ratio, $R \sim 2500$ digital observations from both hemispheres selected from the Galactic O-Star Catalog of Maíz Apellániz et al. and Sota et al. The spectral classification system is rediscussed and a new atlas is presented, which supercedes previous versions. Extensive sequences of exceptional objects are given, including types PrC, ON/OC, Onfp, Ofp, Oe, and double-lined spectroscopic binaries. The remaining normal spectra bring this first sample to 184 stars, which is close to complete to $B = 8$ and north of $d = -20^\circ$ and includes all of the northern objects in Maíz Apellániz et al. that are still classified as O stars. The systematic and random accuracies of these classifications are substantially higher than previously attainable, because of the quality, quantity, and homogeneity of the data and analysis procedures. These results will enhance subsequent investigations in Galactic astronomy and stellar astrophysics. In the future, we will publish the rest of the survey, beginning with a second paper that will include most of the southern stars in Maíz Apellániz et al.

Key words: binaries; general – stars: early-type – stars: emission line, Be – stars: Wolf-Rayet – surveys

1. The Galactic O-star Spectroscopic Survey (GOSSS), II. Bright Southern Stars

THE GALACTIC O-STAR SPECTROSCOPIC SURVEY (GOSSS). III. 142 ADDITIONAL O-TYPE SYSTEMS

We present the first installment of a massive spectroscopic survey of Galactic O stars, based on new, high signal-to-noise ratio, $R \sim 2500$ digital observations from both hemispheres selected from the Galactic O-Star Catalog of Maíz Apellániz et al. and Sota et al. The spectral classification system is rediscussed and a new atlas is presented, which supercedes previous versions. Extensive sequences of exceptional objects are given, including types PrC, ON/OC, Onfp, Ofp, Oe, and double-lined spectroscopic binaries. The remaining normal spectra bring this first sample to 184 stars, which is close to complete to $B = 8$ and north of $d = -20^\circ$ and includes all of the northern objects in Maíz Apellániz et al. that are still classified as O stars. The systematic and random accuracies of these classifications are substantially higher than previously attainable, because of the quality, quantity, and homogeneity of the data and analysis procedures. These results will enhance subsequent investigations in Galactic astronomy and stellar astrophysics. In the future, we will publish the rest of the survey, beginning with a second paper that will include most of the southern stars in Maíz Apellániz et al.

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Key words: binaries; general – stars: early-type – stars: emission line, Be – stars: Wolf-Rayet – surveys
The Galactic O-Star Spectroscopic Survey (GOSSS)

- Long-slit (+fiber bundle) spectroscopy of OB stars with $R \sim 2500$ and $S/N > 200$ in 3900-5100 Å.
- Initial selection from the Galactic O-Star Catalog (GOSC).
- Telescopes and spectrographs:
  - OSN 1.5 m (Albireo): $\delta > -20^\circ$, $B < 11$
  - LT 2.0 m (FRODOspec): $\delta > -35^\circ$, $B < 11$
  - CAHA 3.5 m (TWIN): $\delta > -20^\circ$, 11 < $B$ < 14
  - WHT 4.2 m (ISIS): $\delta > -35^\circ$, 11 < $B$ < 14
  - GTC 11.4 m (OSIRIS): $\delta > -30^\circ$, 14 < $B$ < 17
  - LCO 2.5 m (B&C): $\delta < +20^\circ$, $B < 13$
  - SOAR 4.1 m (GHTS): $\delta < +20^\circ$, 13 < $B$ < 15
  - Gemini South 8.1 m (GMOS): $\delta < +20^\circ$, 13 < $B$ < 16
- 2737 stars (4347 spectra) processed (+ ~900 unproc.), compl. for $B < 8$.
The massive star census in Cyg OB2

<table>
<thead>
<tr>
<th>Type</th>
<th>Wright et al. (2015)</th>
<th>GOSSS</th>
<th>Total</th>
</tr>
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<td>I+II+III</td>
<td>Observed and processed</td>
<td>GOSC to do + unprocessed</td>
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<td>3</td>
</tr>
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<tr>
<td>OB</td>
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<td>61</td>
<td>61</td>
</tr>
</tbody>
</table>

1 square degree circular area around 20:33:16 41:18:45
Spectral type refers to primary (systems, not stars, counted)
The massive star census in Cygnus

<table>
<thead>
<tr>
<th>Type</th>
<th>GOSSS</th>
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<tr>
<td>OB</td>
<td>61 97</td>
<td>61 97</td>
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</tr>
</tbody>
</table>

White: 1 square degree circular area around 20:33:16 41:18:45
Yellow: 68 < $l$ < 98, -7 < $b$ < +11
Spectral type refers to primary (systems, not stars, counted)
Some interesting massive stars in Cygnus

- Cyg OB2-7 + Cyg OB2-22 A: only two O3 If* in the north.
- Cyg OB2-12: B5 Ia supergiant, heavy extinction.
- Cyg OB2-4 B: Be + neutron star binary.
- Cyg X-3: WR + neutron star binary.
- Cyg X-1: O O9.7 labp var + black hole binary.
- Bajamar Star: O3.5 III(f*) + O8:, ionizing star of North America Nebula.
- LS III +46 11: O3.5 If* + O3.5 If*. 

Multiband monitoring and X-ray brightening of Be X-ray binary PSR J2032+4127/MT91 213 on its approach to periastron

Wynn C. G. Ho,1,2* C.-Y. Ng,3 Andrew G. Lyne,4 Ben W. Stappers,4 Malcolm J. Coe,2 Jules P. Halpern,5 Tyrel J. Johnson6† and Iain A. Steele7
Optical-NIR dust extinction towards Galactic O stars

J. Maíz Apellániz¹ and R. H. Barbá²

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ABSTRACT

Context. O stars are excellent tracers of the intervening ISM because of their high luminosity, blue intrinsic SED, and relatively featureless spectra. We are currently conducting the Galactic O-Star Spectroscopic Survey (GOSSS), which is generating a large sample of O stars with accurate spectral types within several kpc of the Sun.

Aims. We aim to obtain a global picture of the properties of dust extinction in the solar neighborhood based on optical-NIR photometry of O stars with accurate spectral types.

Methods. We have processed a carefully selected photometric set with the CHORIZOS code to measure the amount \([E(4405 - 5495)]\) and type \([R_{5495}]\) of extinction towards 562 O-type stellar systems. We have tested three different families of extinction laws and analyzed our results with the help of additional archival data.

Results. The Maíz Apellániz et al. (2014, A&A 564, A63) family of extinction laws provides a better description of Galactic dust that either the Cardelli et al. (1989, ApJ 345, 245) or Fitzpatrick (1999, PASP 111, 63) families, so it should be preferentially used when analyzing samples similar to the one in this paper. In many cases O stars and late-type stars experience similar amounts of extinction at similar distances but some O stars are located close to the molecular clouds left over from their births and have larger extinctions than the average for nearby late-type populations. In qualitative terms, O stars experience a more diverse extinction than late-type stars, as some are affected by the small-grain-size, low-\(R_{5495}\) effect of molecular clouds and others by the large-grain-size, high-\(R_{5495}\) effect of \(\text{H}\ II\) regions. Late-type stars experience a narrower range of grain sizes or \(R_{5495}\), as their extinction is predominantly caused by the average, diffuse ISM. We propose that the reason for the existence of large-grain-size, high-\(R_{5495}\) regions in the ISM in the form of \(\text{H}\ II\) regions and hot-gas bubbles is the selective destruction of small dust grains by EUV photons and possibly by thermal sputtering by atoms or ions.
O-star extinction

The graph shows the relationship between $E(4405-5495)$ and $R_{5495}$ for different combinations of observations: Jo+2M+Ga, Jo+2M+Ga+Ty, Jo+2M+Ga+St, and Jo+2M+Ga+Ty+St.
O-star extinction

$E(4405 - 5495)$ vs. $R_{5495}$

- Jo+2M+Ga
- Jo+2M+Ga+Ty
- Jo+2M+Ga+St
- Jo+2M+Ga+Ty+St
- Cyg OB2
- Cyg other
The future: WEAVE

- OBA-stars-centered survey with ~7% of WEAVE survey time.
- Also ISM in emission, Cepheids, evolved low-mass stars, and other young stars.
- \( R \sim 5000 \), whole optical range.
- Galactic Plane with longitudes from 20 deg. to 225 deg.
- 1200 sq. deg.
- \( 5 \cdot 10^5 \) targets
The future: the GALANTE survey

- Northern Full Galactic Plane.
- ~3 nights/month in the T80+S80.
- 1.4° x 1.4° FOV, 0.55” px, no gaps.
- Exp. times from 0.1 to 50/100 s.
  - Saturation at mag ~3 (PSF to ~0).
  - S/N ~100 at mag 17 (det. to ~19).
- Seven filters:
  - F348M + F420N + F450N.
  - F515N + F861M.
  - F660N + F665N.
The GALANTE survey
GALANTE T80 images
Cyg OB2 with GALANTE
Cyg OB2 with GALANTE
GALANTE T80 images
GALANTE T80 images
GALANTE T80 images

F861M + F515N + F348M