PROCEEDINGS OF SCIENCE

Preliminary results from the e-MERLIN Legacy Cyg OB2 Radio Survey

PoS(EVN 2014)058

Danielle Fenech*
Department of Physics & Astronomy, University College London, UK.
E-mail: `dmf@star.ucl.ac.uk`

Jack Morford
Department of Physics & Astronomy, University College London, UK.
E-mail: `jmorford@star.ucl.ac.uk`

Raman Prinja
Department of Physics & Astronomy, University College London, UK.
Email: `rkp@star.ucl.ac.uk`

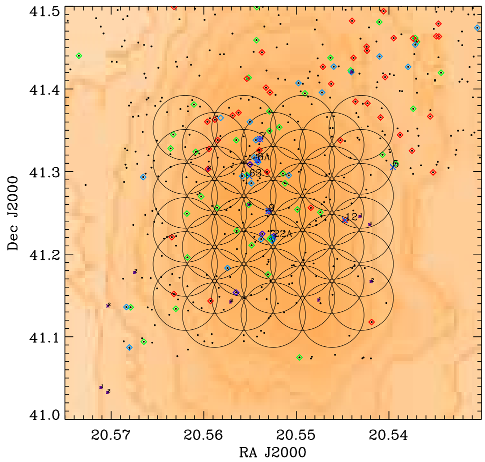
The e-MERLIN Cyg OB2 Radio Survey (COBRaS) is designed to exploit e-MERLIN's enhanced capabilities to provide substantial deep-field mapping of one of the most massive OB associations in our Galaxy, offering direct comparison to not only massive clusters in general, but also young globular clusters and super star clusters. COBRaS will address two major areas of study within massive stellar research which have far-reaching implications, the accurate determination of mass-loss and the presence of binary systems within the stellar association. This project has been awarded 300 hours of total observing time split between L- and C- bands. Observation of the ~42 hrs L-band allocation is now virtually complete and reduction is on-going. We present some preliminary results from these L-band observations of Cyg OB2 including the well-studied binary system Cyg #9.

12th European VLBI Network Symposium and Users Meeting,
7-10 October 2014
Cagliari, Italy

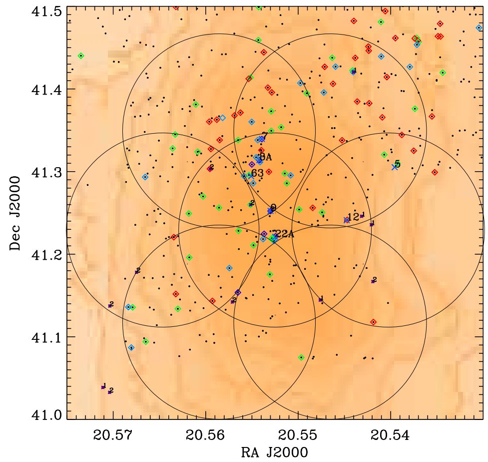
*Speaker.

1. An Introduction to COBRaS

The Cygnus OB2 Radio Survey (COBRaS) is an e-MERLIN Legacy project awarded a total allocation of 252 hours at C-band and 42 hours at L-band to study the Cygnus OB2 association. The aim of this project is to exploit the high-resolution capability and tremendous sensitivity of e-MERLIN to assemble the most substantial radio dataset of an important massive stellar population within our Galaxy. COBRaS will produce extensive radio mapping of the OB rich stellar cluster at both C and L-band utilising 42 and 7 mosaiced pointings whilst providing sensitivities of 3 and 8 μJy/beam respectively (see Fig. 1). This survey is expected to significantly increase the number of detected OB stars (by a factor of ~ 30). The COBRaS data will be combined with existing archival data and other multi-waveband surveys of the Cygnus X region, both current (IPHAS, Spitzer, and Chandra) and in future programmes (Herschel and JWST). This project will therefore not only yield substantial results within the main COBRaS science goals, but will also provide new perspectives for numerous additional archival studies in stellar and extragalactic astrophysics.



(a) C-Band Pointings



(b) L-Band Pointings

Figure 1: Background figure from [1], blue points indicate radio sources of O and WR stars (counts based on 2MASS survey).

2. The Cygnus OB2 association

Cyg OB2 is a young massive cluster located behind the Great Cygnus Rift at the core of the Cygnus X region. Cyg OB2 is therefore ideally studied at radio wavelengths which are unaffected by the large and non-uniform visual extinction (ranging from 4 to 10 mag [1]). This association is known to contain a rich population of massive stars [2] including $\sim 120 \pm 20$ O-type stars and 2600 ± 400 OB-type stars [1] and is not only very rich in stellar density but also in its diversity. Cyg OB2 lies at a distance of ~ 1.45 kpc [3] making it one of the closest young massive stellar clusters. With a total mass estimated to be 4-10 $\times 10^4$ $M_\odot$ and an estimated age of 2-3 Myr [4], Cyg OB2 can be considered more as a young globular cluster than an open OB association (similar to such clusters in the LMC; [5, 6]), and is believed to represent a smaller example of the super-star clusters found in star-forming galaxies.

3. The COBRaS science goals

Massive stars dominate the emergent spectra of active star forming galaxies; directly at optical-UV wavelengths and indirectly (due to reprocessing via dust and gas) at IR and radio wavelengths. Additionally, the stellar winds and SNe of massive stars provide a significant input of both mechanical energy and chemically enriched material into the wider galactic environment; acting in concert in young massive ‘super star clusters’. As a nearby proxy Cyg OB2 provides a unique opportunity to study a massive stellar environment and these processes in detail. In particular the COBRaS project will address two main science goals: mass-loss determinations in massive stars and the incidence of binary systems within the Cyg OB2 association.

3.1 Mass-loss

The greatest barrier to understanding massive stars is the nature and magnitude of their mass-loss, which has profound implications for many areas of astrophysics including stellar evolution. Recent results have strongly challenged the current models and it is now recognised that there is significant discord in our understanding of mass-loss results from clumped and/or porous radiation driven winds (e.g. [7, 8]). This has far reaching consequences for the evolution and fate of massive stars (which is largely determined by mass-loss) and for galactic chemical evolution (where mass-loss drives chemical and mechanical feedback on the interstellar medium).

OB stars emit radio radiation through (thermal) free-free emission, due to electron-ion interactions in their ionised wind. The considerable advantage of using free-free radio fluxes for determining mass-loss is that, unlike Hα and UV, the emission arises at large radii in the stellar wind, where the terminal velocity has been reached. The interpretation of the radio fluxes is more straightforward therefore and is not strongly dependent on details of the velocity law, ionisation conditions, inner velocity field, or the photospheric profile. However, the greater geometric region and density squared dependence of the free-free flux makes the radio observations extremely sensitive to clumping in the wind. Radio observations can be used to constrain clumping, and by comparing them with observations in other spectral regions, including near-IR, mm and Hα, we can determine the run of the clumping factor as a function of the geometrical region in the wind (e.g. [9, 10, 8]).

COBRaS will provide accurate flux-density measurements which will enable determination of the mass-loss rates and constrain the level of clumping over a large selection of stellar parameters. These will also be combined with other (already available) multi-wavelength datasets to study clumping as a function of stellar radii. Morford et al. (these proceedings) discuss the nature of clumping and the determination of massive star mass-loss rates with COBRaS in more detail.

3.2 Binary systems

Non-thermal radiation can be used as a highly efficient way to identify binary systems. Stellar non-thermal emission is associated with the interaction of two (or more) stellar winds and can therefore be used to directly detect and count binary systems within a cluster. The multi-frequency

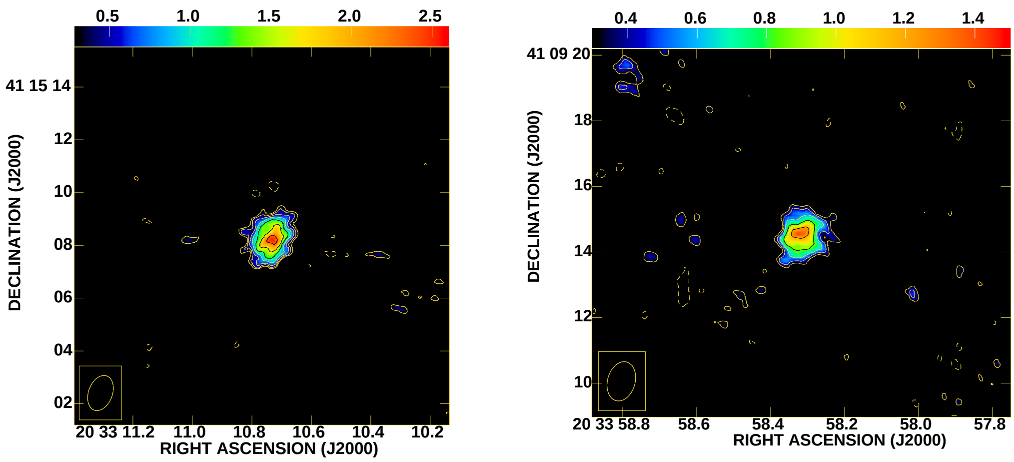
PoS(EVN 2014)058

and wide-bandwidth observations within the COBRaS project will provide single-epoch, direct detections of wind-collision regions, hence enabling detailed study of these regions as well as the associated individual binary systems and the binary population of Cyg OB2 as a whole. Though uncertain, the binary population of Cyg OB2 is currently estimated to be $\sim 55\%$ [11], suggesting that a significant portion of massive stars form in multiple-star systems. Evolutionary population synthesis codes are used to determine the formation and evolution of stellar populations, following a large number of simulated stars taking into account their evolution and dynamical interactions. These codes rely heavily on information about binary populations, requiring statistical information about binary fractions and the distribution of masses in a binary system [12, 13, 14].

4. Preliminary results from COBRaS

The majority of the L-band legacy observations were performed between January and June 2014 and are currently undergoing data reduction and calibration. Successful processing of earlier data taken in 2013 has provided some preliminary results including images with sensitivities of $\sim 65-80\mu$Jy/beam and detections of some of the brighter sources within the Cyg OB2 region.

Cyg #9 is a known binary system of spectral type O5-5.5I + O3-4III [15, 16] with an orbital period of 860 days and an eccentricity of $\sim$0.7. Cyg #9 has been detected in these observations with an integrated flux of 2.5 mJy and is shown in Fig. 2.



(a) Cyg #9 (b) SBHW 90

Figure 2: Preliminary images from early 2013 COBRaS data, (a) the well known binary system Cyg #9 with $S_{1.6\mathrm{GHz}}$ 2.5 mJy, (b) Identified as source SBHW 112 from the WSRT continuum survey from [2]. Observed in these observations with $S_{1.6GHz}$ 1.5 mJy.

Fig. 2 shows another source detected in these observations identified as SBHW 112 from the SBHW radio continuum survey of Cyg OB2 from [2]. This source was imaged within the Westerbork survey at 1.4 GHz with a flux density of 2.2$\pm$0.3 mJy. It was detected within the L-band observations with a central frequency of $\sim$1.6 GHz with a flux density of $\sim$1.5 mJy. The difference in observed flux density could be attributed to a steep spectral index, which would suggest the presence of non-thermal emission. It is also possible that this source is time variable. The non-thermal emission within the colliding wind region of a binary system for example, is likely to vary as a function of the orbital position. Therefore a combination of both steep spectrum and variable emission could also explain the difference in the two observed flux densities. Further information will be gathered about this source using the full COBRaS Legacy observations.

A second source from the SBHW radio continuum survey has been detected within these early COBRaS data that displays a significantly resolved structure in the L-band images (see Fig. 3). This source has been identified as SBHW 90 [2]. The previous survey imaged the region at 1.4 and 0.35 GHz finding an integrated source flux of 14.7 ± 0.8 and 54 ± 4 mJy respectively. This source was observed in the COBRaS observations with an integrated flux at 1.6 GHz of 6.3 mJy, thus in comparison to the 2003 observations this suggests a steep spectral index. Combined with the resolved structure similar to those observed in other binary systems e.g. WR147, it is possible that this may well be an as yet unidentified binary system. The full L-band and C-band COBRaS legacy observations will be able to determine if this is in fact the case.

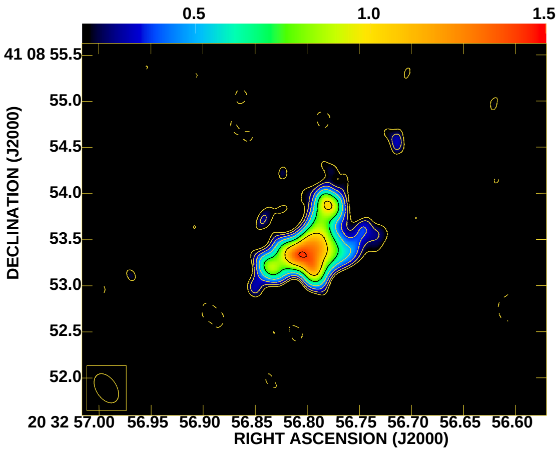


Figure 3: Preliminary image from early 2013 COBRaS data. Source identified as SBHW 90 from the WSRT continuum survey from [2]. Observed with a flux density in these COBRaS observations of $S_{1.6\,\mathrm{GHz}}$ 6.3 mJy.

References

[1] J. Knödlseder, *Cygnus OB2 - a young globular cluster in the Milky Way*, A&A, **2000**, 360, 539

[2] D. Setia Gunawan et al., *A Westerbork Synthesis Radio Telescope 1400 and 350 MHz Continuum Survey of the Cygnus OB2 Association, in Search of Hot Massive Stars*, The Ast. J. S. S., **2003**, 149, 1, 123

[3] M. Hanson, *A Study of Cygnus OB2: Pointing the Way toward Finding Our Galaxy's Super-Star Clusters*, ApJ, **2003**, 597, 957

[4] J.F. Albacete Colombo et al., *X-ray flaring from the young stars in Cygnus OB2*, A&A, **2007**, 474, 495

[5] P. Fischer et al., *Dynamics of the young LMC cluster NGC 1866*, AJ, **1992**, 103, 857

[6] V. Reddish, L. Lawrence & N. Pratt, Publs. R. Obs. Edinburgh, **1996**, 5, 111

[7] A. Fullerton, D. Massa & R. Prinja, *The Discordance of Mass-Loss Estimates for Galactic O-Type Stars*, ApJ, **2006**, 637, 1025

[8] J. Puls, N. Markova & S. Scuderi, *Stellar winds from massive stars - What are the REAL mass-loss rates?*, ArXiv Astrophysics e-prints, astro-ph/0607290, **2006**

[9] R. Blomme et al., *Radio and submillimetre observations of epsilon Ori*, A&A, **2002**, 382, 921

[10] R. Blomme et al., *Radio and submillimetre observations of wind structure in zeta Puppis*, A&A, **2003**, 408, 715

[11] H. Kobulnicky et al., *Toward Complete Statistics of Massive Binary Stars: Penultimate Results from the Cygnus OB2 Radial Velocity Survey*, ApJS, **2014**, 213, 34

[12] H. Zinnecker & H. Yorke, *Toward Understanding Massive Star Formation*, ARAA, **2007**, 45, 481

[13] S. Portegies Zwart, S. McMillan & J. Makino, *Star cluster ecology - VII. The evolution of young dense star clusters containing primordial binaries*, MNRAS, **2007**, 374, 95

[14] D. Kiminiki et al., *A Radial Velocity Survey of the Cyg OB2 Association*, ApJ, **2007**, 664, 1102

[15] Y. Nazé et al., *The 2.35 year itch of Cygnus OB2 #9. I. Optical and X-ray monitoring*, A&A, **2012**, 546, A37

[16] R. Blomme et al., *The 2.35 year itch of Cygnus OB2 #9. II. Radio monitoring*, A&A, **2013**, 550, A90

PoS(EVN 2014)058