COBRaS: The e-MERLIN Legacy L-band Cygnus OB2 Radio Survey

D. Fenech, J. Morford, R. Prinja, R. Blomme, J. Yates, J. Drake, S. Eyres, A. Richards, I. Stevens, N. Wright,
J. Clark, S. Dougherty, J. Pittard, H. Smith and J. Vink
Department of Physics and Astronomy, University College London, U.K.

COBRaS

COBRaS (**Cyg OB2 Radio Survey**) is an e-MERLIN legacy project (P.I. R. Prinja) awarded ~300 hrs of observing time over two bands to perform an intensive radio survey of the core of the Cygnus OB2 association in our Galaxy. We will conduct a uniquely probing, targeted deep-field mapping of this young massive cluster.

Positions of the e-MERLIN radio telescopes across the U. K.

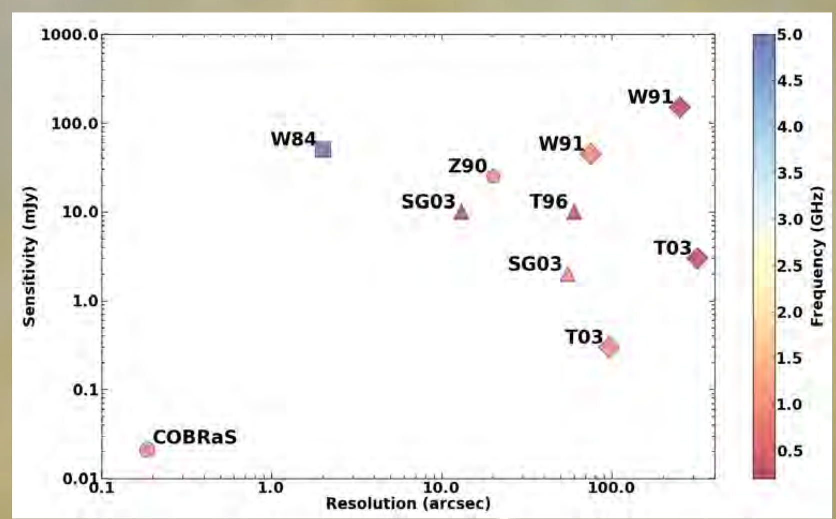
e-MERLIN

e-MERLIN is a UK radio astronomy National Facility operated by The University of Manchester on behalf of the Science and Technology Facilities Council (STFC). It is an upgrade to the MERLIN (Multi-Element Radio Linked Interferometer Network) array, consisting of seven radio telescopes, spanning 217 km. It offers high-resolution micro Jy sensitivity radio observations with up to 2 GHz instantaneous bandwidth. There are three available observing bands: L-band (1.3 -1.8GHz), C-band (4-8 GHz) and K-band (22-24 GHz) providing resolutions of ~150, 40 and 12 milliarcseconds respectively.

COBRaS survey observations

The COBRaS observations consist of mosaiced observations covering approximately 20 square arcmins of the core of the Cyg OB2 cluster over two bands:

- 42 hrs at L-band (1.5 GHz) split over 7 pointings with an rms noise level of ~21μJy. These observations were split over two main observing sessions 11th Apr. and 26th Apr. 2014 and are presented here.
- 252 hrs at C-band (5 GHz) over 27 pointings with an expected rms noise level of ~3-4 μJy, due to commence observing in 2018.



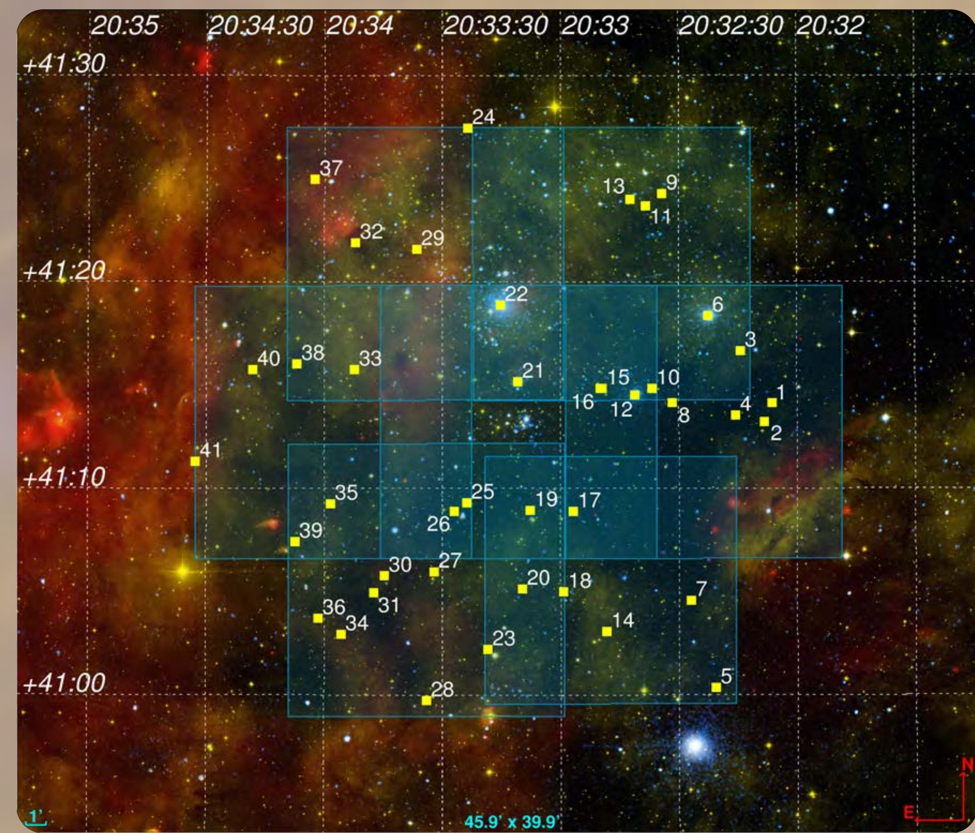
A comparison of resultion and sensitivity of COBRaS and previous radio surveys of Cygnus OB2. For full details see Morford et al. 2017, A&A, subm.

COBRaS L-band all-source catalogue

The COBRaS L-band All-Source Catalogue (CLASC) consists of the 41 objects detected in the seven pointings of the L-band observations (see Fig.) in the Apr. 26th observations. 26 of these were also detected in the lower sensitivity Apr. 11th observations. The detections were cross-correlated with a number of published catalogues of the region including from 2MASS, Spitzer and Chandra (for full details see Morford et al. 2017, A&A, subm.).

Of the 41 CLASC objects, 23 were identified in other observations and 6 of these have only been previously observed at radio wavelengths. These 23 sources include known binary systems, young stellar objects and a suspected background galaxy. However, though observed in mulitple wavelengths, the nature of around alf of these sources is still unknown.

A further 18 of the 41 CLASC sources are detected for the first time in these observations. These are potentially newly detected binary sytems, flares from young stellar objects or faint background galaxies, amongst others.



Positions of the 41 CLASC sources overlaid onto the 7 pointing positions. Background shows a composite of images from Chandra X-ray (NASA/CXC/SAO/J.Drake et al), INT (Optical: UoH/INT/IPHAS) and Spitzer IR (NASA/JPL-Caltech) observations.

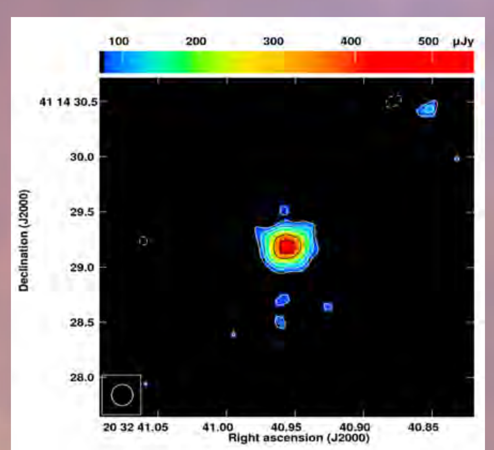
Cygnus OB2

The Cygnus OB2 association is located at the core of the Galactic Cygnus X region at a distance of 1.45 kpc (Hanson 2003, ApJ, 597, 957) making it one of the closest young massive stellar clusters.

It is known to contain a rich population of massive stars (Setia-Gunawan et al. 2003, ApJS, 149, 123) including 120 ± 20 O-type stars and 2600 ± 400 OB-type stars (knodlseder 2000, A&A, 360, 539) and is tremendously rich in both its stellar density and diversity.

As one of the most massive clusters in the Milky Way it offers direct comparison to not only massive clusters in general, but also young globular clusters and super star clusters found in high star-forming galaxies. Located behind the great Cygnus rift Cyg OB2 is heavily obscured making this ideal for radio studies.

Massive stars and mass-loss



Cyg OB2 #12 Apr. 26th, flux density 1.05±0.12 mJy

Radio observations can be used to determine the mass-loss rates of single massive stars, whilst offering constraints on the degree of structure or clumping within their powerful stellar winds. Of the 23 previously identified objects deected in COBRaS, the only 'single' massive star detected is the hypergiant Cyg OB2 #12. However, recent observations have now discovered secondary and tertiary components associated with Cyg OB2 #12 (Caballero-Nieves et al 2014, AJ, 147,40; Maryeva et al. 2016,MNRAS,458,491). The COBRaS observations provide the first resolved detections of this source at 21cm.

Based on these COBRaS L-band observations, Morford et al. (2016, MNRAS, 463, 763) presented constraints on the 21cm flux densities of O3-O6 supergiant and giant stars within Cyg OB2 to less than ~70 μJy. Using the relation derived in Wright & Barlow (1975, MNRAS, 170,41), these flux densities were used to calculate 'smooth' wind mass-loss upper limits of ~4.4-4.8x10^{-6} M$_\odot$yr^{-1} for O3 I stars; i.e. the hottest and most luminous stars in the sample. The mass-loss ratesof early B supergiants (B0-B1) are constrained to less than ~1.8–2.9 × 10^{-6} M$_\odot$yr^{-1}.

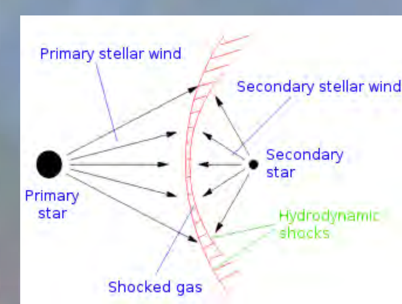
RA (J2000)	DEC (J2000)	S58	MT91	Other	Spectral Type	T_{eff} (K)	v_∞ km s^{-1}	log$g$	M_{spec} $M_\odot$	Flux Density (μJy)	$\dot{M}_{max}$ 10^{-6} $M_\odot yr^{-1}$	Predicted $\dot{M}$ 10^{-6} $M_\odot yr^{-1}$
20 32 40.88	41 14 29.3	12	304	-	B3.5Ia+	13700[1]	400[1]	1.70[1]	110[1]	1013±55	5.4±1.4	24.5
20 33 14.16	41 20 21.5	7	457	-	O3If	45800[2]	3080[3]	3.94[2]	65[2]	<72	<4.8	3.5
20 33 18.02	41 18 31.0	8C	483	-	O5III	41800[2]	2650[3]	3.74[2]	49[2]	<71	<4.1	1.9
20 33 08.78	41 13 18.1	22	417	-	O3If	42551[4]	3150[6]	3.73[4]	67[4]	<61	<4.4	4.3
20 33 14.84	41 18 41.4	8B	462	-	O6.5III	35644[4]	2545[6]	3.63[4]	34[4]	<78	<4.3	0.7
20 32 39.06	41 00 07.8	-	-	E47	B0Ia	28100[5]	1535[6]	2.99[5]	25[5]	<87	<2.9	0.8
20 33 39.14	41 19 26.1	19	601	-	B0Iab	28900[5]	1535[6]	3.13[5]	31[5]	<63	<2.2	1.1
20 33 30.81	41 15 22.7	18	556	-	B1Ib	21700[5]	1065[6]	2.67[5]	22[5]	<73	<1.8	1.6
20 33 33.97	41 19 38.4	-	573	-	B3I	16400[5]	590[6]	2.16[5]	19[5]	<58	<0.8	1.4

References: **1** Clark et al. 2012, **2** Mokiem et al. 2005, **3** Herrero et al. 2001, **4** Martins et al. 2005, **5** Searle et al. 2008, **6** Prinja et al. 1990.

Table of L-band mass-loss rates for single massive stars in the COBRaS field. See Morford et al. (2016, MNRAS, 463, 763) for full details.

Colliding winds in binaries

In a binary consisting of two early-type stars (e.g. O+O), the stellar winds collide and electrons are accelerated to relativistic velocities around the stationary shocks in the colliding-wind region (CWR). These CWR produce non-thermal synchrotron emission detectable at radio wavelengths with a steep spectral index which can be distinguished from the thermal emission expected from the stellar wind itself.

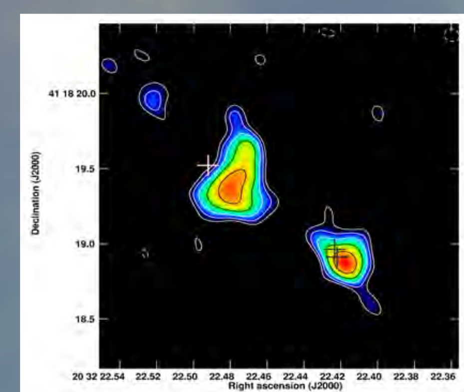


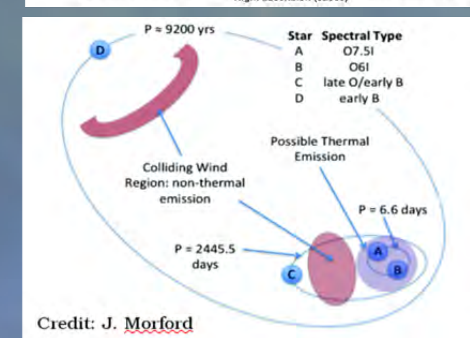
Shocks in a colliding wind. De Becker et al. 2007 MmSAI, 79,242

Binaries in Cyg OB2

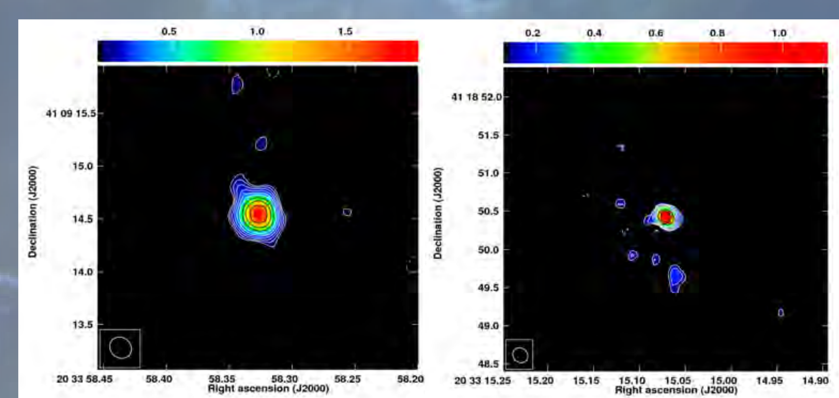
There are several well-studied binary systems in Cyg OB2 whose radio emission appears as a single resolved source at ~150 mas resolution, that are detected with COBRaS. These include the 21.908±0.040 day, O6If + O5.5III binary Cyg OB2 #8A, which shows orbital phase-locked radio flux density variation (Blomme et al. 2010, A&A, 519, 111). The resolution of e-MERLIN also allows a more detailed study of systems such as #5, a quadruple star system in which there appear to be two detectable wind-wind collision regions as can be seen in the COBRaS L-band image and the diagram of the system.

These COBRaS observations allow us to study both the individual binary systems in detail and study statistically the colliding-wind phenomenon and better understand its dependence on stellar and binary parameters. In particular this survey will detect the intermediate period binaries that are difficult to detect with optical studies. Several potential binary systems have been identified from the unidentified objects that display similar properties to the known binary systems. For example SBHW112 (CLASC #35) was detected with a Apr. 26th flux density of 2.95±0.30 mJy increasing from 1.42±0.19 mJy on Apr. 11th. This source has only been observed once before in a previous radio study at 1.4 GHz (Setia Gunawan et al. 2003, ApJS, 149, 123). However, its appearance is also very similar to that of Cyg OB2 #8A.





COBRaS L-band observations Apr 26th. Top:Cyg OB2 #5. Bottom: Schematic of the quadruple star system.



COBRaS L-band observations Apr 26th. Left: Cyg OB2 #8A. Right: SBHW112

Transient sources

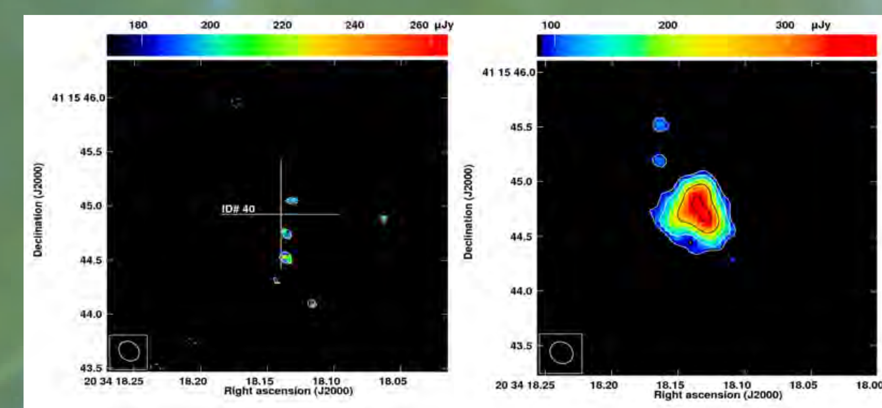
Four of the sources detected with COBRaS show significant flux density variability between the two observing runs separated by ~15 days (CLASC #24, #28, #40 and #41). In all cases their flux density has increased from Apr. 11th to Apr. 25th by a factor of > 5 and is in fact below the detection threshold in the Apr. 11th observations.

Interestingly all of these objects are heavily resolved (see example of CLASC #40 in the figure below).

Previous observations at different wavelengths detected three of these sources. CLASC #24 and #40 have been observed in the IR with Spitzer and CLASC #41 has been identified as an x-ray source (Wright et al. 2014). CLASC #28 is observed for the first time with COBRaS.

Short period CWB systems could give rise to radio variability on these timesales, but are usually seen to be compact objects e.g. Cyg OB2 #8A. If these objects are CWBs, the rapid variability would imply either a highly elliptical orbit or that the orbital spearation is within the radio photosphere and subject to significant free-free absorption. Young steallr objects (YSOs) are also known to be transient radio sources with Forbrich et al. 2008 showing variations of over 40 mJy in flaring YSOs over timescales of approximately 4 hrs.

The similarity in the extended morphology and rapid flux density variation suggests these four sources are potentially of a similar nature. However, follow-up observations will be necessary to fully understand their transient behaviour.



CLASC #40 left: Apr. 11th 3σ upper limit 57 μJy, right: flux density 1.3±0.16 mJy

Background Image: Cygnus X region. ESA/Herschel/PACS/SPIRE/HOBYS Consortium.

For further details about COBRaS please see: http://www.ucl.ac.uk/star/research/stars_galaxies/cobras