# The e-MERLIN Legacy L-band Cyg OB2 Radio Survey (COBRaS): Constraining mass-loss and other stories

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Jack Morford, Raman Prinja (P.I.) & collaborators

EVN Symposium

# COBRaS

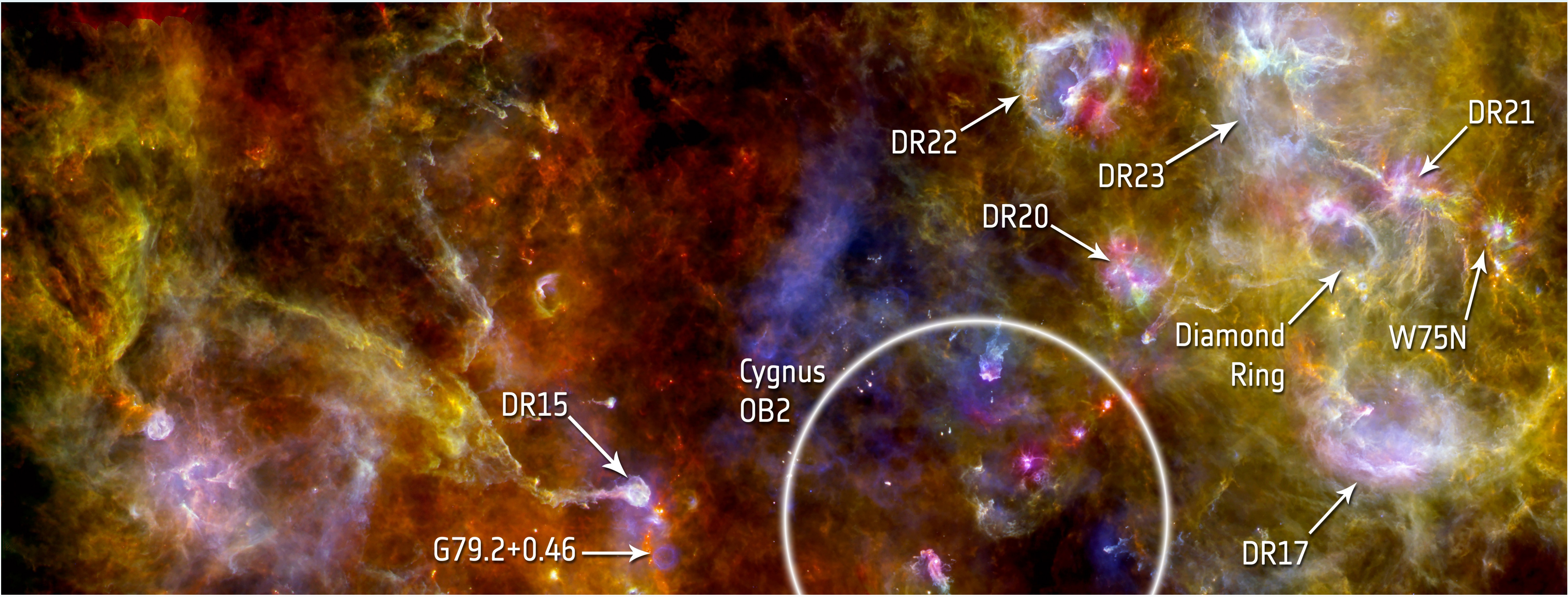



Image:ESA/Herschel/PACS/SPIRE/HOBYS Consortium

# COBRaS - Introduction

- COBRaS is an e-MERLIN legacy project (P.I. R. Prinja) awarded ~300 hrs of observing time over two bands (1.4 GHz, 5 GHz).
- Intensive radio survey of the core of the Cygnus OB2 association in our Galaxy.
- Cyg OB2:
  - Tremendously OB rich: 120 ± 20 O-stars, 2600 ± 400 OB-type stars.
  - 1.7 kpc away in the core of the Cygnus X region.
  - Large visual extinction – ideal for radio studies.
  - Cluster mass: 4-10 x $10^4$ $M_o$ , Estimated age: 2-3 Myr
- Offer direct comparison to not only massive clusters in general, but also young globular clusters and super star clusters.

# COBRaS Observations

- Mosaiced observations of central region of cluster
- 42 hours L-band 1.5 GHz
  - 6 hrs/pointing
  - rms ~ 24 μJy
  - Resolution ~ 170 mas
- L-band Legacy observations complete – three datasets 2014
  - 24th Jan
  - 11th Apr ~ 25%
  - 25th Apr ~ 75%
- 252 hrs C-band 5 GHz ~50 mas
  - 6 hrs/pointing
  - Expected rms ~3-4 μJy
  - 2 GHz instantaneous bandwidth

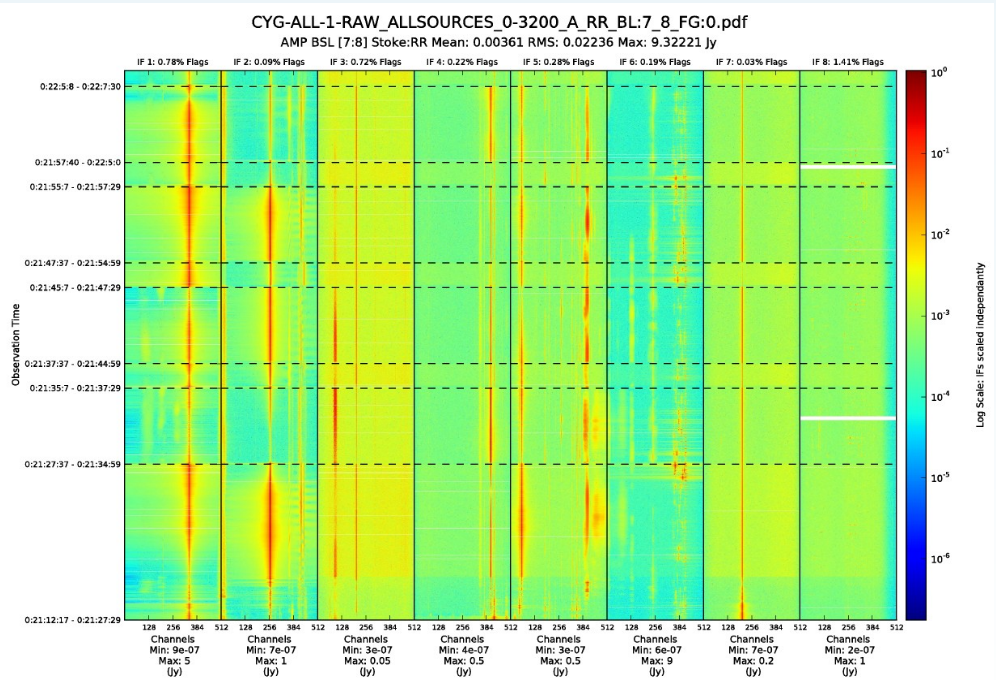
# e-MERLIN

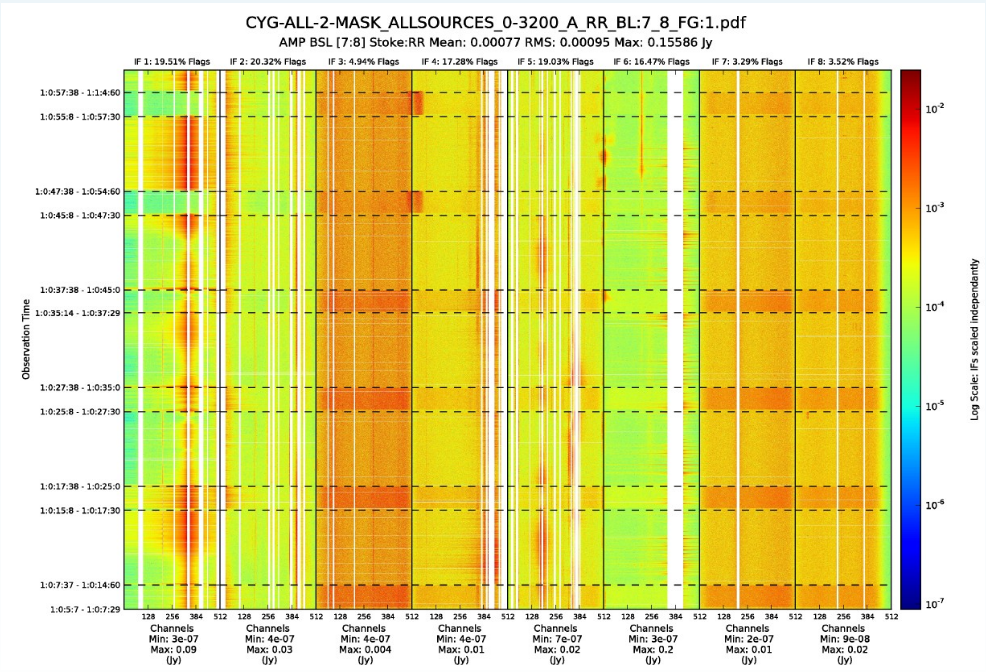
- Technical challenges
  - Data volume
  - Inhomogeneous array
  - Wide bandwidths
  - Radio Frequency Interference
  - Variability

# SERPent & SPPlot

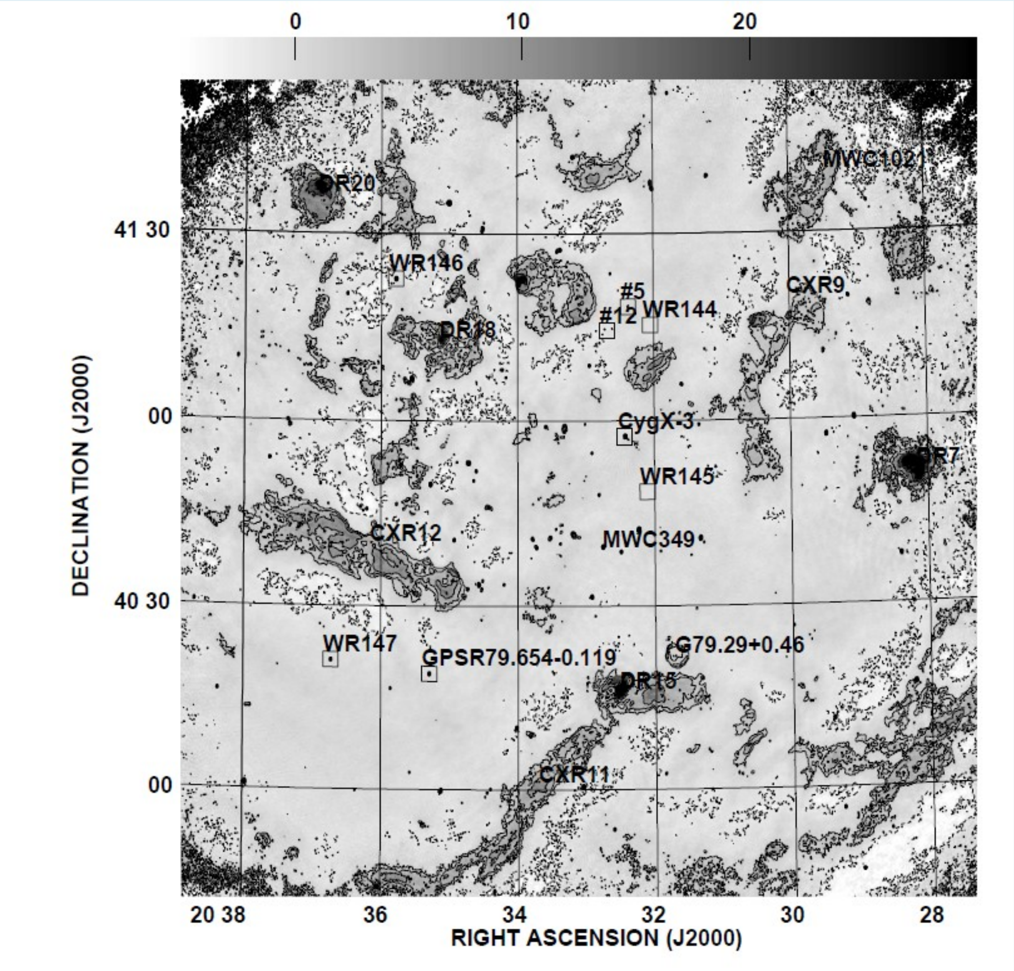
Luke Peck, Danielle Fenech, Jack Morford

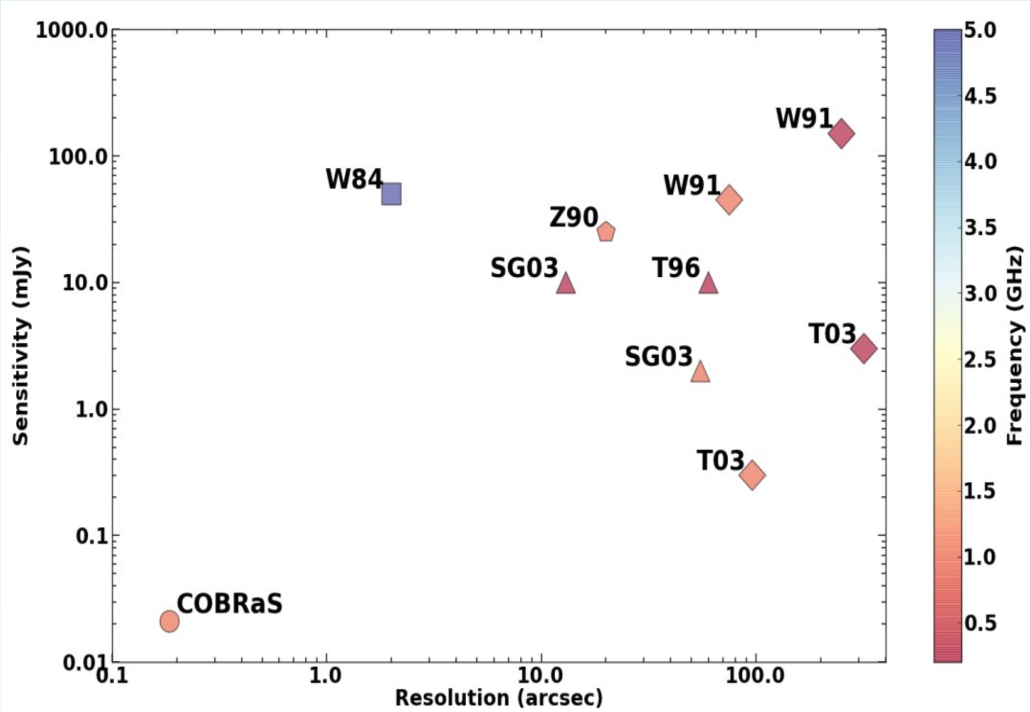
- **S**cripted **E**-merlin **R**fi-mitigation **P**ypelin**E** for i**NT**erferometry (SERPent)
- Algorithm developed primarily for LOFAR AOFlagger - Offringa et al. 2010, MNRAS, 405, 155, Offringa et al. 2012, A&A, Volume 539, A95
- Zero-level dropouts, Lovell off-source scans
- **SPPlot** – data visualisation tool frequency vs. time, phase and amplitude



# COBRaS Observations

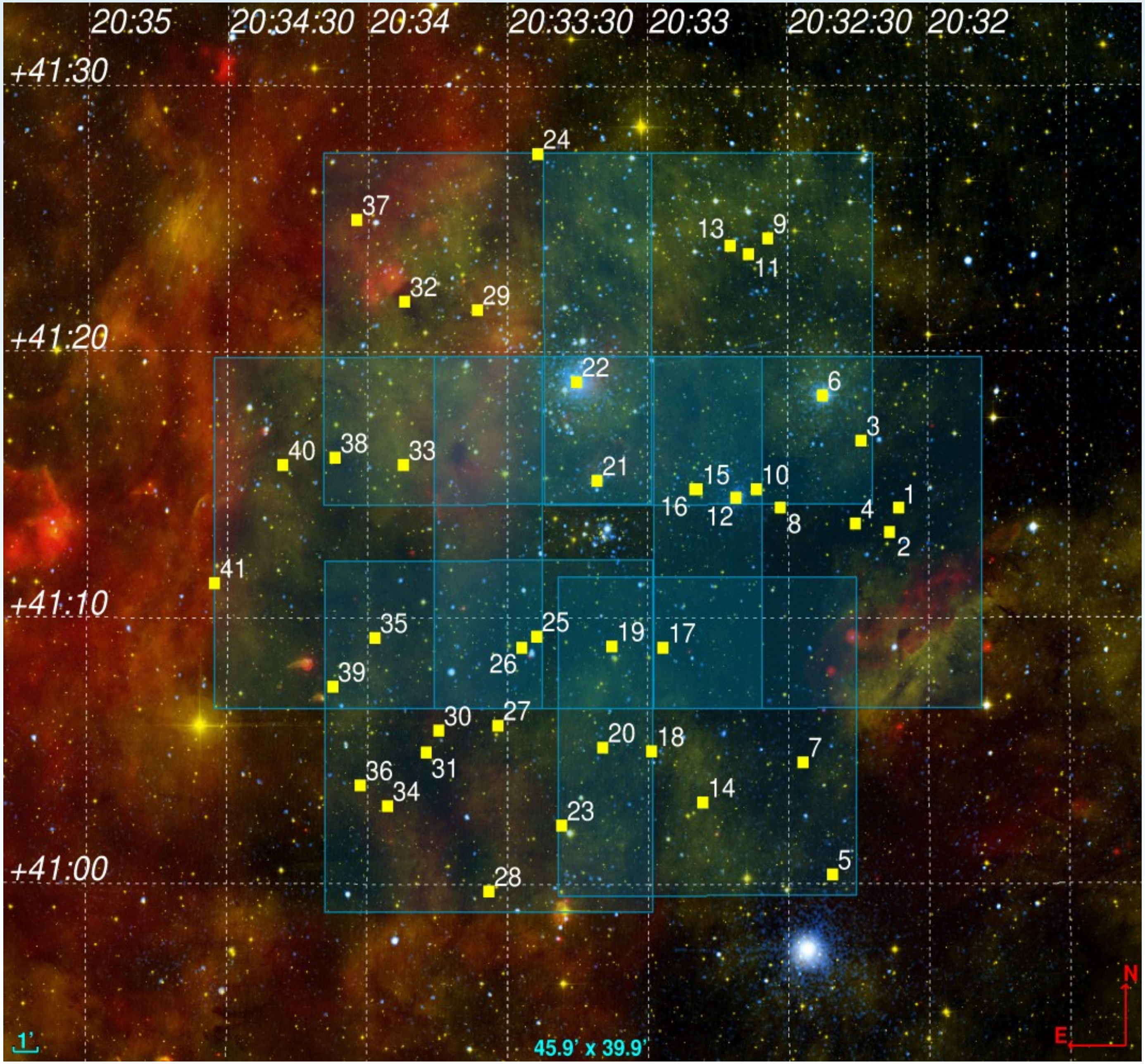



Setia-Gunawan et al. 2003 ApJSS, 149,123
350MHz/1.4GHz WSRT survey, 13”, 2 degs

# COBRaS Observations

- Multiple-pointing observations of central region of cluster
- 42 hours L-band 1.5 GHz
  - 6 hrs/pointing, rms ~ 24 μJy
  - Resolution ~ 170 mas
- Region 0.48°x0.48°
- Total 41 sources

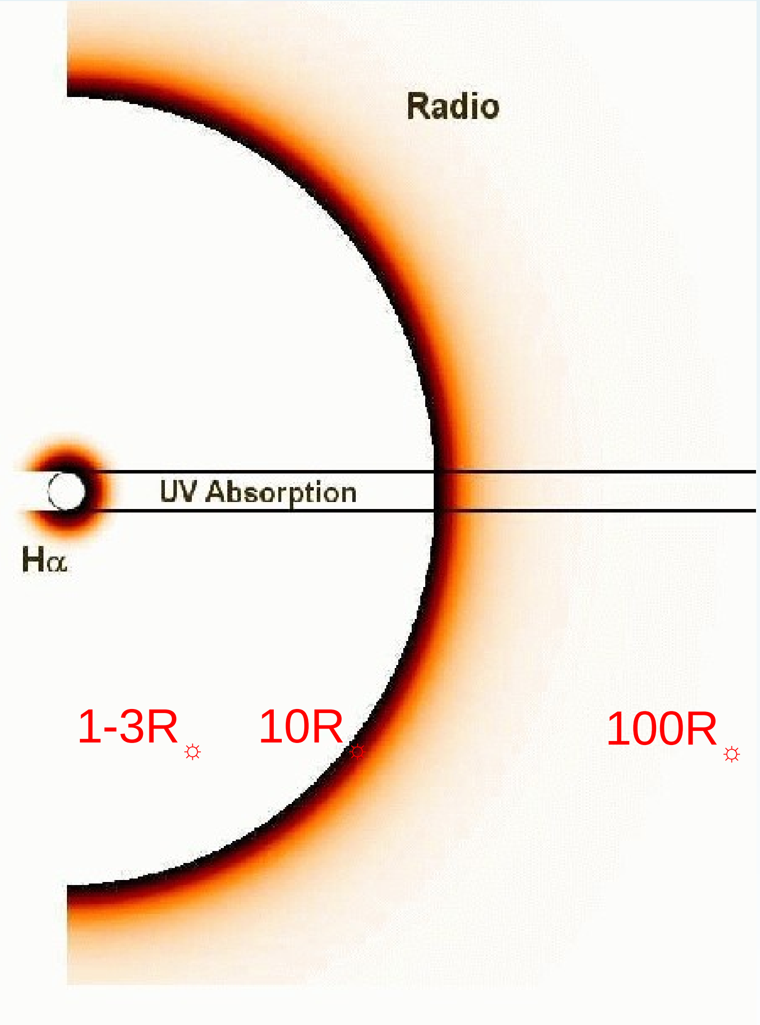


# Key Science Goals

- Accurate mass-loss determinations putting constraints on wind clumping and stellar evolution.
- Studying the incidence of non-thermal emission in colliding wind binaries leading to a better binary fraction estimate.

# Measuring mass-loss

- Three main diagnostics – free-free; Hα; UV P-Cygni
- Not dependant on – Vel. Field; Ionisation conditions; Photospheric profile
- But different mass-loss diagnostics disagree
- Clumping?



# COBRaS L-band – single stars

Morford et al. 2016 MNRAS 463, 763

- Known single massive stars – Wright et al. 2015 MNRAS, 449, 871
- Limited to OI-OIII or BI stars
- Definitely single or wide binary – no non-thermal emission

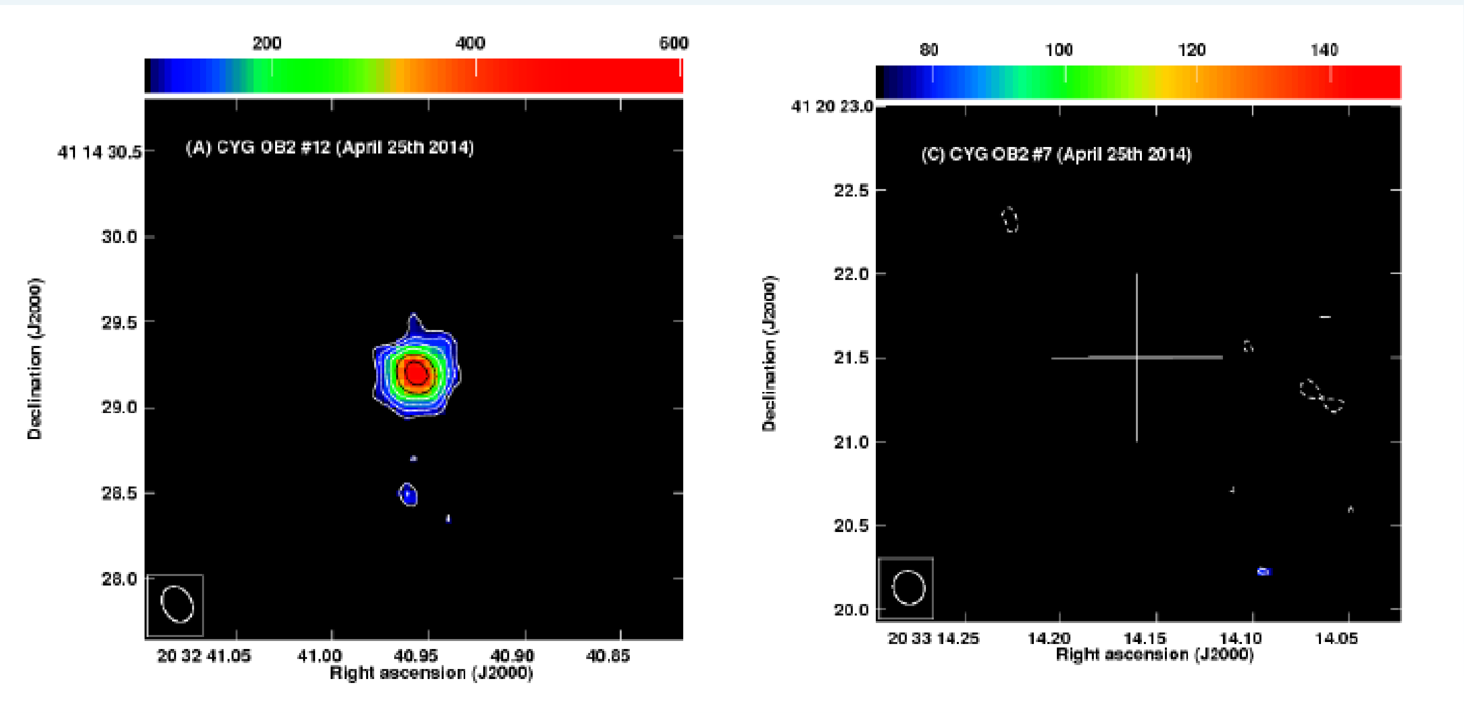
| RA (J2000) | DEC (J2000) | S58 | MT91 | Other | Spectral Type | $T_{eff}$ (K) | $v_\infty$ km $s^{-1}$ | log*g* | $M_{spec}$ $M_\odot$ | Flux Density (μJy) | $\dot{M}_{max}$ $10^{-6}$ $M_\odot yr^{-1}$ | Predicted $\dot{M}$ $10^{-6}$ $M_\odot yr^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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.

# COBRaS L-band – single stars

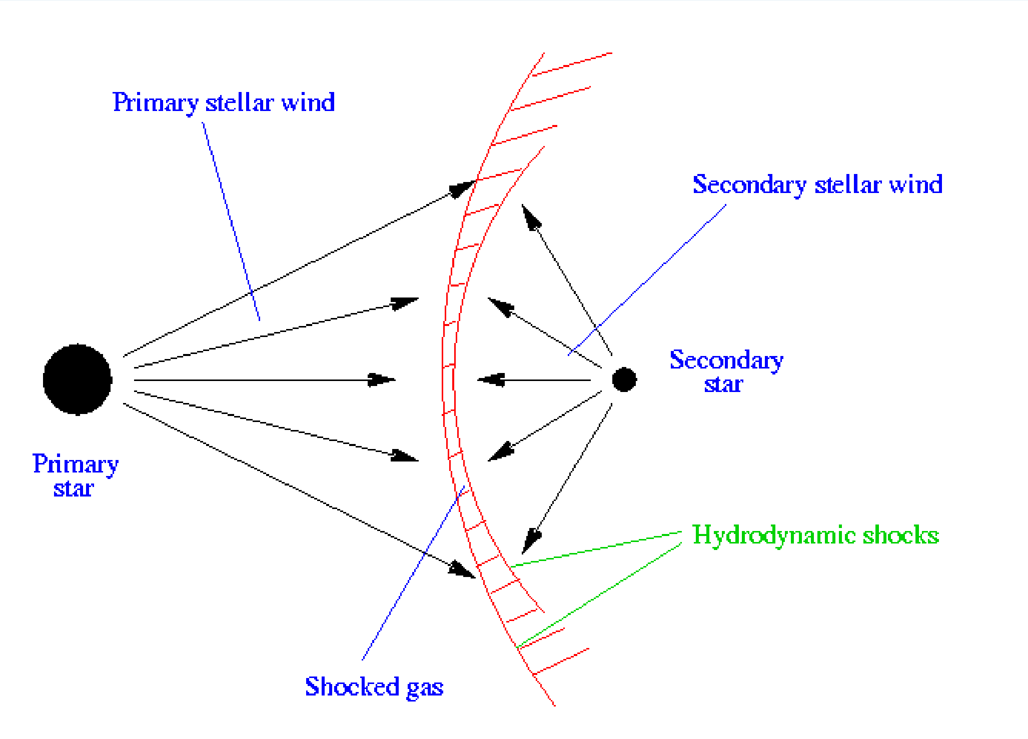
Morford et al. 2016 MNRAS 463, 763

- Cyg #12 – 1.01mJy
  - Ia+ Blue Hypergiant – high luminosity, high $\dot{M}$
  - Slow dense wind – inhomogeneities?
  - Binary Cabellero-Nieves et al. 2014, Maryeva et al. 2016
- Cyg #7
  - O3If star
  - Radio determined $\dot{M}$ ~ factor of two lower than previous studies



# Binary interactions- Colliding wind regions

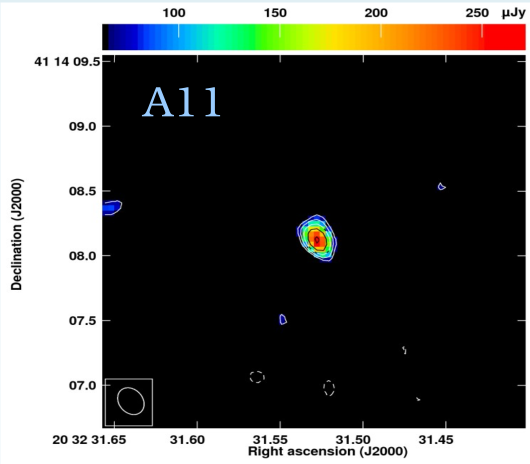
- Close binary system
- Stationary shocks created where two stellar winds collide
- Fermi acceleration
- Source of synchrotron (non-thermal) emission
- Also strong X-rays

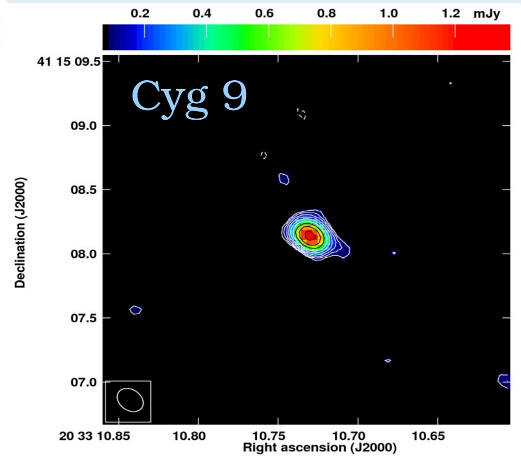


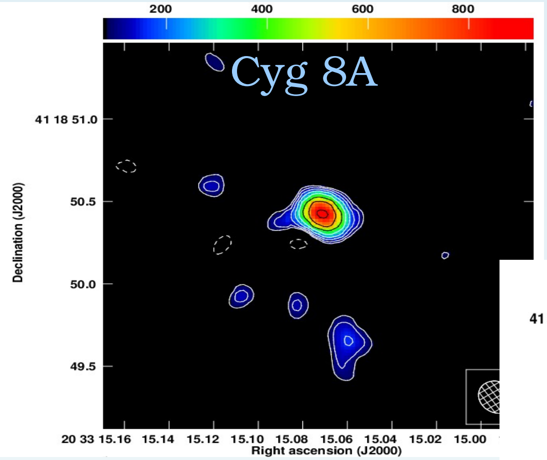

De Becker et al. 2007, MmSAI, 79, 242

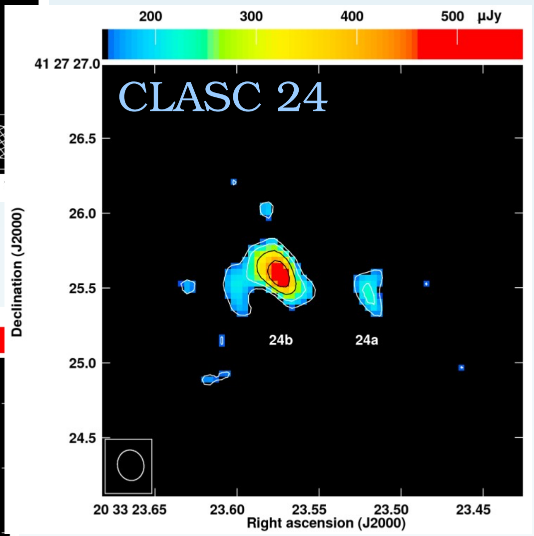
# Binaries

Known

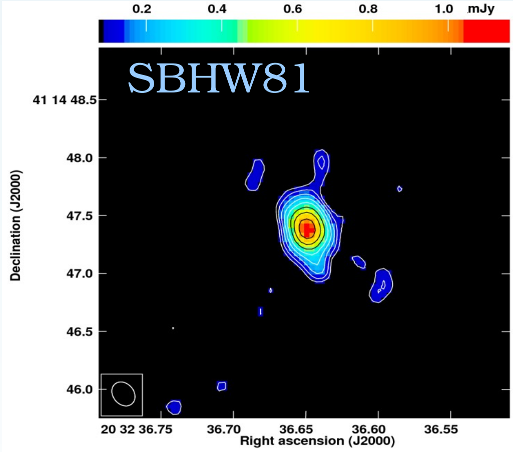


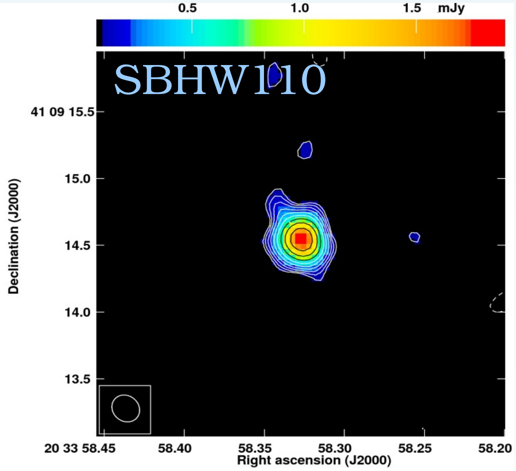



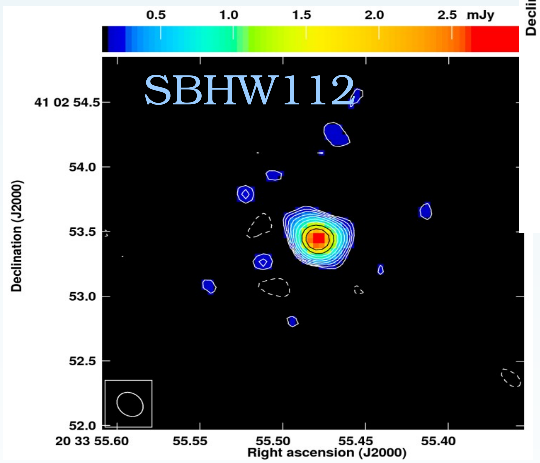



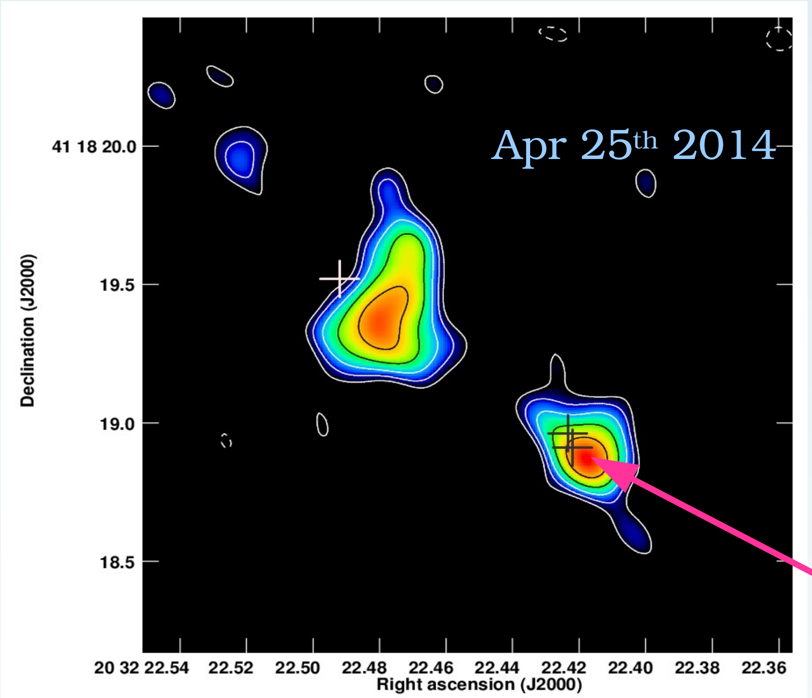

Potential

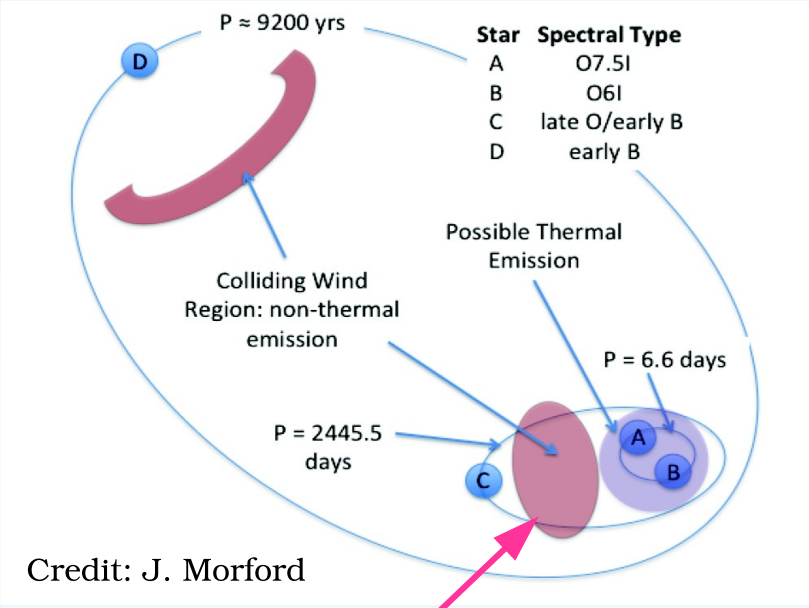


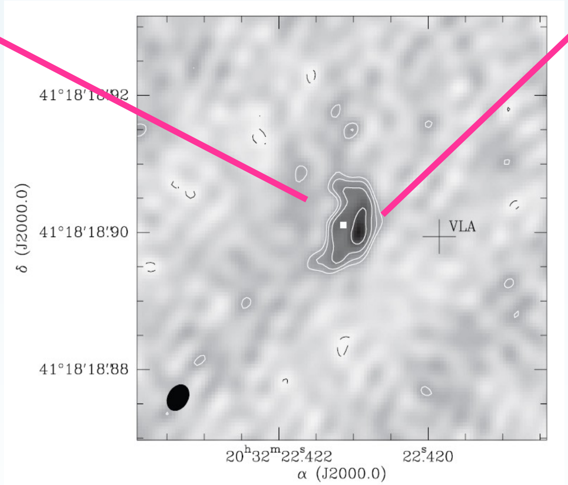



# Cyg OB2 #5 – when two stars isn't enough



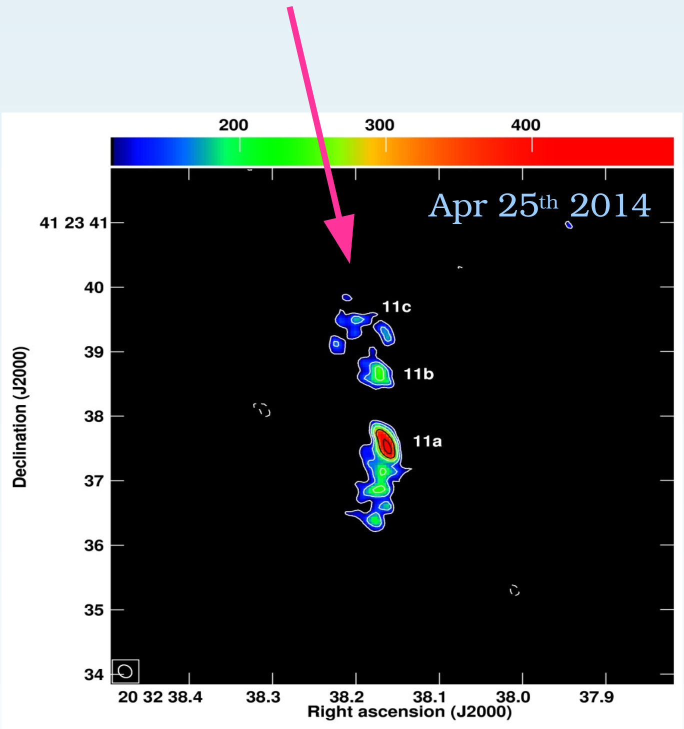




Ortiz-Leon et al. 2011 ApJ 737,30

- SW component variable on 6.7 yrs timescale
- Non-thermal and only detected through radio observations
- NE component also non-thermal, but constant on timescales of ~20 yrs (kennedy et al. 2010)

# ...others

Extragalactic

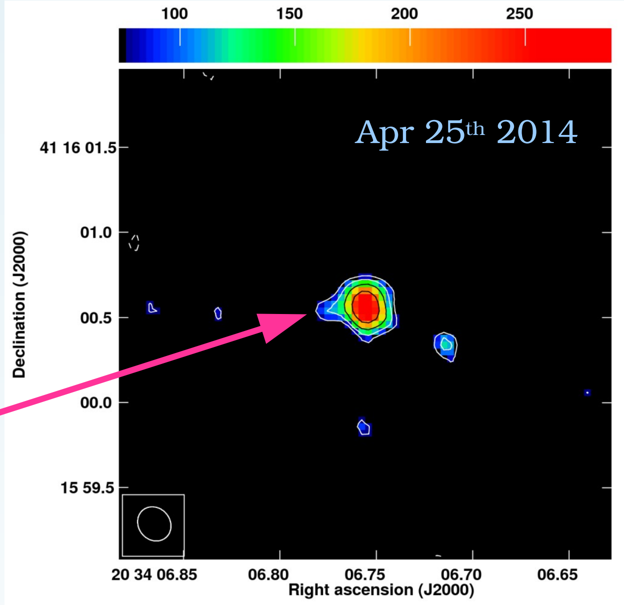



Extragalactic

- Estimate expected from previous radio surveys, but most at lower resolution
- Muxlow et al. 2005, Chi et al. 2013
- Expect ~23 background sources

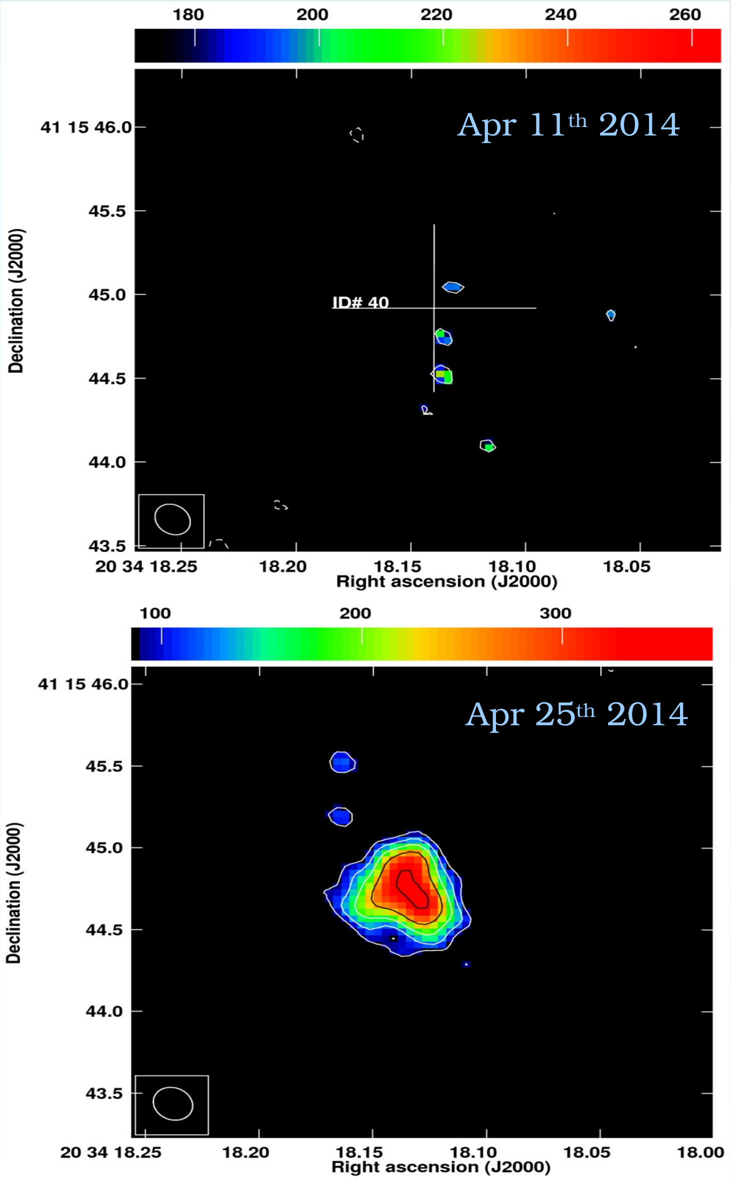
# ...others

YSO - G13 318006
(Guarcello et al. 2013)



# ...others

- Transients
  - 4 sources, resolved and highly variable
  - Not detected Apr. 11th, appeared Apr 26th
  - Apr 11th rms ~ 57μJy/beam
  - Flux Apr 25th -1.3+-0.16 mJy
  - All 4 similar fluxes/morphologies
  - Potential YSOs e.g. Forbrich et al. (2008)



# Future COBRaS

- L-band
  - Morford et al. 2016 MNRAS 463, 763 – massive stars
  - Morford et al. 2018 A&A, subm. - full project paper
  - But further analysis underway….
- C-band (5 GHz) observations due to commence…

  ~252 hrs (L-band 42 hrs)
- Increased sensitivity – 3-4 μJy/bm
- Expected flux density of stars higher at C-band – $\nu^{0.6}$

# Consortia and further information

*Astronomy & Astrophysics* manuscript no. morford_2017
June 15, 2017


## COBRaS: The e-MERLIN 21cm Legacy Survey of Cygnus OB2

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Received September 15, 1996; accepted March 16, 1997

**ABSTRACT**

*Context.* The role of massive stars is central to an understanding of galactic ecology. It is important to establish the details of how massive stars provide radiative, chemical and mechanical feedback in galaxies. Central to these issues is an understanding of the evolution of massive stars, and the critical role of mass-loss via strongly structured winds and stellar binarity. Ultimately, and acting collectively, massive stellar clusters shape the structure and energetics of galaxies.
*Aims.* To conduct high resolution, deep field mapping at 21 cm of the core of massive Cygnus OB2 association, and to characterise the properties at this waveband of the massive stars and colliding winds.
*Methods.* We utilise 7 stations of the e-MERLIN radio facility, with its upgraded bandwidth and enhanced sensitivity to conduct a 21 cm census of Cygnus OB2. Based on 42 hours of observations, seven overlapping pointings are employed over multiple epochs during 2014 resulting in $1\sigma$ sensitivities down to $\sim 21\ \mu$Jy and a resolution of $\sim 180$ mas.
*Results.* A total of 41 sources are detected at 21cm over a $\sim 0.48^\circ \times 0.48^\circ$ region centred on the heart of the Cyg OB2 association. 19 of these sources have been detected for the first time. We have detected four previously known massive stellar binary systems, the LBV candidate (possible binary system) and blue hypergiant (BHG) star of Cyg OB2 #12, one previously identified class ı YSO and a number of previously identified X-ray and radio sources.
*Conclusions.* The 21 cm observations secured in the COBRaS Legacy project provide data to constrain conditions in the outer wind regions of massive stars; determine the non-thermal properties of massive interacting binaries; examine evidence for transient sources, including those associated with young stellar objects; and provide unidentified sources that deserve follow-up observations. The 21cm data are of lasting value and will serve in combination with other key surveys of Cyg OB2, including Chandra and Spitzer.

**Key words.** (Galaxy:) open clusters and associations: individual: Cygnus OB2 – Radio continuum: stars – Techniques: interferometric – Stars: massive – Stars: winds, outflows

**www.ucl.ac.uk/star/research/stars_galaxies/cobras**