Observations of B-type protostars with the VLA and CARMA

Katharine Johnston, Debra Shepherd, Anthony Remijan & Kenneth Wood
(St Andrews University, UK and NRAO)

University of St Andrews

Project Outine

We have observed two early B-type protostars in outflow - AFGL2591 and Mol12. With multi-configurational VLA observations, we have begun to map the HII regions and ionized outflows associated with these protostars. With complementary CARMA observations of Mol12 we will map the molecular outflow in ^{12}CO; ^{13}CO; several lines to trace the core, disk and torus (Methanol, CH_3CN and Methyl Formate); and 3mm continuum. In addition, we have observed AFGL2591 in ^{13}CO , $C^{18}O$, Methanol and 3mm continuum.

Combining these datasets, we hope to link cause and effect: how do the more extreme conditions of massive star formation - a forming HII region, strong stellar winds, and a more massive and possibly more turbulent disk - affect the accretion and outflow properties of the protostar?

In this poster we present our current findings for AFGL2591.

AFGL2591
Source Background - Previous Studies

Fig 1. Combined JHK image of AFGL2591 (2'x2' field) Gemini North, N-IR imager commissioning image, 2001

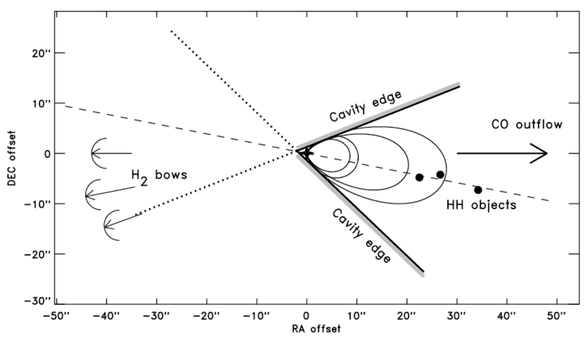


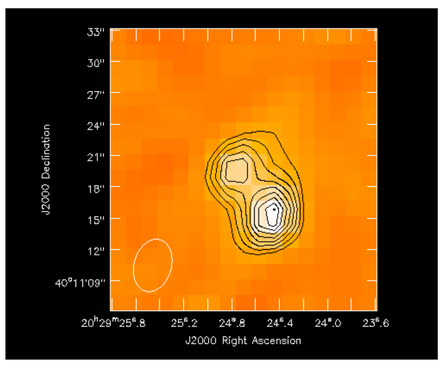
Fig 2. Schematic of AFGL2591 (Fig 5, Preibisch et al. 2003)

AFGL2591 is an **early B-type** protostar in **outflow**, at a distance of approx. 1kpc. The source is luminous (L~ 1-3x10^4 Lsun), with an SED peaking at ~100μm. Near-IR observations show a distinct **cone-shaped reflection nebula** (see Fig 1), with the IR source AFGL2591 at its apex.

Fig 2. shows a schematic of AFGL2591, which includes the cavity geometry, the positions of several **HH objects** observed in the region (Poetzel et al. 1992), and **shocked H_2 bows** which can be seen in Fig 1. The map of Tamura & Yamashita (1992) - not shown here - also uncovers H_2 emission along the axis of the cavity, coincident with the HH objects.

Millimeter molecular line observations (e.g. Hasegawa et al. 1995, CO(3-2)) have mapped an **E-W oriented bipolar outflow**. The blue shifted emission is to the West, implying that the **Near-IR reflection nebula represents a blue shifted outflow cavity**, which is slightly inclined toward the observer. The large flow extends 5'x5' (Lada et al. 1984), having outflow $\Delta v_{(100mK)}$=42kms^{-1} and a low degree of collimation. The existence of a **small scale, more collimated flow**, which is **aligned with both H_2 emission and HH objects** in the region has also been established by Hasegawa et al. (1992), with a size of 20"x90" and outflow speeds reaching ±40kms^{-1}.

CARMA 3mm continuum



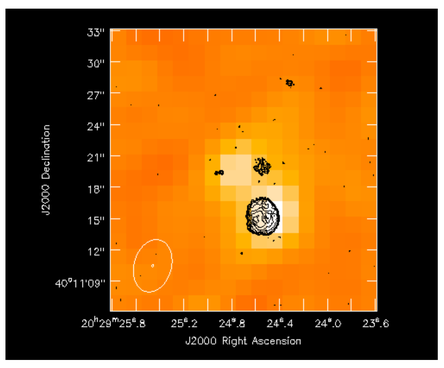
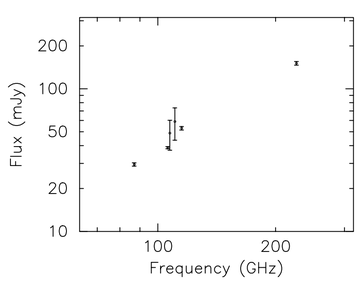


Fig7a. CARMA 107.3GHz map.
Contours at -3,3,4,5,6,7,8,9,10 & 11x σ=4.7mJy.
Beam: 4.93 x 3.44", PA=-15.6°.
Fig7b. 107.3GHz map overlaid with 8.46GHz contours from in Fig 5.

- CARMA D array 3mm continuum observations (at 107.3, shown in Fig. 7a, and 110.5GHz), show the same morphology as that observed at nearby frequencies by van der Tak et al. 1999.
- Fig 7b shows that the SW source is coincident with VLA1, and the NE source with VLA3 within the 5" pointing accuracy of CARMA
- Our 3mm fluxes of the SW source/VLA1 are consistent with its current calculated spectral index, which gives a roughly flat SED, indicating free-free emission from an optically thin HII region
- Our 3mm fluxes of the NE source/VLA3 are consistent with its current calculated spectral index (~2 at millimetre wavelengths) which supports the hypothesis that the emission is due to warm dust (see Fig 8.)

Fig 8. Millimetre SED of the NE source/VLA3. Our preliminary fluxes for this source are measured assuming it is a point source, in accordance with the findings of van der Tak et al. 1999.
Our fluxes are in agreement with previous data which has a spectral index of ~ 2.
The offset of these fluxes from the other four may be due to small flux calibration differences.



VLA A array images, 8.46 GHz continuum

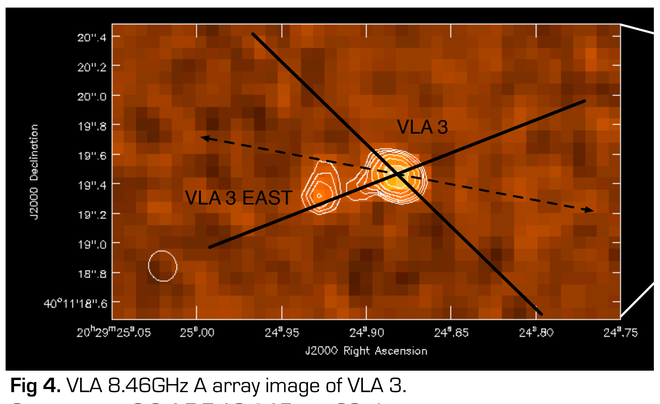


Fig 4. VLA 8.46GHz A array image of VLA 3.
Contours at -3,3,4,5,7,10 &15x σ=30μJy.
Beam: 0.21 x 0.19", PA=16.6°.

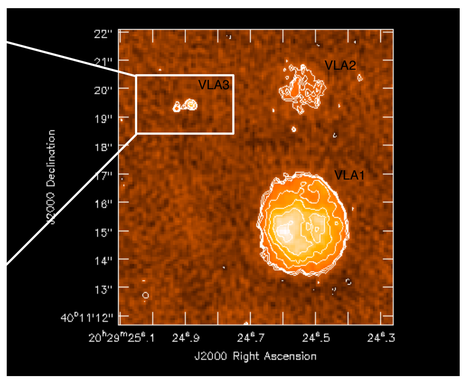


Fig 5. VLA 8.46GHz A array image of AFGL2591
Contours at -3,3,4,5,7,10,15,20 & 25x σ=30μJy.
Beam: 0.21 x 0.19", PA=16.6°.

Fig 5. presents our recent continuum observations at 8.46GHz of AFGL2591.

- Previously known sources VLA1, VLA2 and VLA3 are detected
- Additional source to the East of VLA3 is detected for the first time: VLA3 EAST.
- Does VLA3 EAST represent another source, an ionized clump close to VLA3, or part of an outflow?
- Table 1 lists several calculated properties of the sources, assuming they are simple HII regions. As mentioned, this may not be the case for VLA3 EAST.
- Values in Table 1 suggest sources VLA1 to 3 are powered by early B stars (in agreement with other authors e.g. Trinidad et al. 2003).

Fig 4. provides a closer look at the source VLA3 with the position of the cavity edge and outflow axis. (this image is on a much smaller scale than Figs 1 & 2!)

- Morphology of VLA3 is extended along the outflow axis, in agreement with previous observations.
- There are also two previously unobserved extensions of the source to the North East and South East
- These protrusions align with the edges of a proposed redshifted cavity with a mirrored geometry to the blueshifted one observed.
- Another possibility is that these represent ionized jets emanating from VLA3, one of which is the base of the jet associated with the larger scale outflow. However, neither are aligned with the position angle of the outflow cavity (260±10°).

Table 1: Calculated properties for the three previously known compact HII regions in the field: VLA1, VLA2 and VLA3, assuming a simple, optically thin, HII region. Properties are also included for VLA 3 EAST, a new source detected with these observations. Luminosities and spectral types are taken from Panagia 1973.

Source Name	EM (cm^{-6} pc)	n_e (cm^{-3})	L ($10^3 L_\odot$)	Spectral type
VLA1	1.55×10^7	3.03×10^4	$5.25 - 11.0$	B1-B0.5
VLA2	3.37×10^6	1.99×10^4	$1.05 - 2.88$	B3-B2
VLA3	1.10×10^7	7.18×10^4	$1.05 - 2.88$	B3-B2
VLA3 EAST	3.83×10^6	5.74×10^4	< 1.05	later than B3

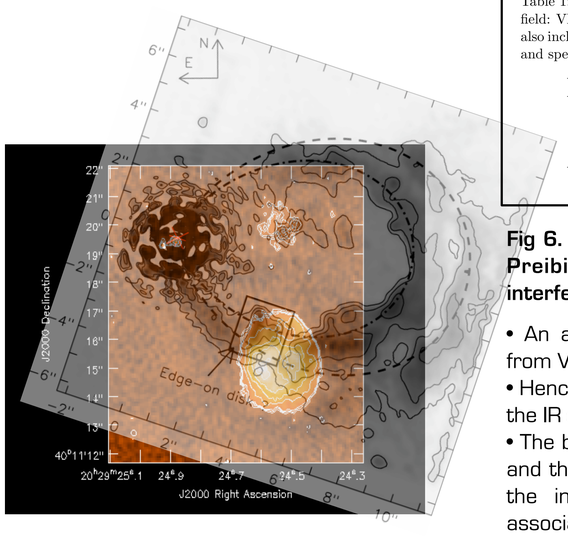


Fig 6. 8.46GHz map from above (Fig 5.) overlaid with Figure 3 from Preibisch et al. 2003.

Fig 6. shows our 8.46GHz map overlaid with Figure 3 from Preibisch et al. 2003 (Near-IR bispectrum speckle interferometry).

- An anti-correlation between the radio continuum emission from VLA1 and the Near-IR image can be seen.
- Hence the HII region VLA1 appears to have created a dent in the IR outflow lobe.
- The bright rim of IR emission at the boundary between VLA1 and the cavity may be material which is being compressed by the interaction of the outflow with the expanding shell associated with the HII region, and not an edge on disk as suggested by Preibisch et al. 2003.
- VLA2 also appears to be coincident with two IR bright sources, referred to as the 0.5" separation binary in Preibisch et al. 2003.

Summary of current results

New VLA 8.46GHz continuum observations of the B type protostar AFGL2591 have revealed:

- A new source, VLA3 EAST, near the radio source responsible for the outflow
- Two extensions (NE and SE) in the morphology of ionised gas associated with AFGL2591

Comparison of VLA 8.46GHz continuum observations with Near-IR observations show:

- A bright rim of emission previously thought to be an edge on disk is more likely an interaction region between the outflow lobe and the HII region VLA1

3mm continuum CARMA observations of AFGL2591 show:

- Measurements of the flux of the 3mm counterpart of VLA3 support the emission at these wavelengths is due to warm dust