Molecular & Ionized Outflows - Synergy between EVLA, CARMA, Spitzer & ALMA

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Introduction

Magnetically collimated outflows launched from accretion disks around young stellar objects (YSOs) can be detected and studied in several ways. When the flow entrains material from the ambient cloud, we can trace the molecular flow using CO, SiO, HCO+ and other outflow tracers with CARMA and soon, ALMA. Using the VLA, an ionized outflow can often be detected very close to the source, especially for more luminous YSOs. Yet, the high luminosity YSOs can turn onto the main sequence and begin burning hydrogen and generating an HII region even while they are still accreting. Exactly how the engulfing HII region affects the outflow collimation and dynamics and how the material is entrained is unclear at this time.

Here we show three early B stars at different ages to evaluate how the HII region might affect the outflow morphology:

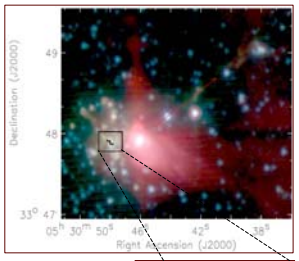
- AFGL 5142 few x 10^4 years old
- W75 N ~10^5 years old
- G192.16 few x 10^5 years old

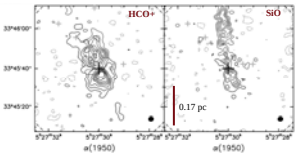
Conclusions

- The ionized flows observed with the VLA in cm continuum emission are all relatively poorly collimated within 1000 AU of the protostar.
- In one (G192.16), possibly 2 (W75 N) sources the interaction between the UCHII region and the ionized outflow is seen.
- In G192.16, the collimation of the outflow inside the HII region appears to widen considerably once it punches through the HII region boundary. Perhaps the molecular gas beyond the HII region acts as a nozzle?

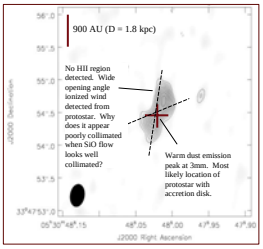
AFGL 5142

Early B protostar cluster - No obvious UC HII region (not on ZAMS yet). Still accreting & producing outflow.
Age ~ few x 10^4 years





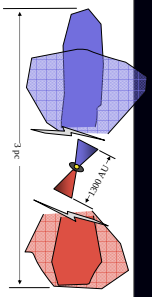
Hunter et al. (1999) discovered an HCO^+, SiO, young outflow. Spectral types unknown but mass of molecular cores suggests the formation of early B stars.



New VLA observations: 3.6 cm continuum: A+B+C configurations with multi-scale clean deconvolution.

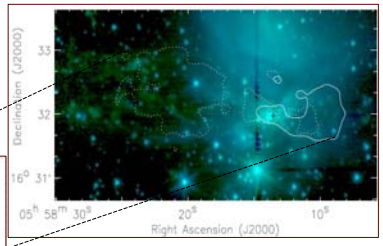
Resolution= 0.25"x0.3"
RMS = 25 microJy/bm,
Peak = 0.26 mJy/bm
Contours = -3,3,4,5,6,7,8,9 σ
Grey scale = 1σ to peak

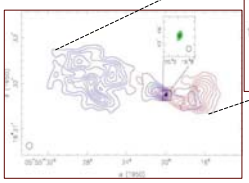
New Spitzer observations above (Qiu et al. 2007) show shocked gas (green) beyond CO flow suggestive of collimated jets.
cm continuum emission: wide-opening angle ionized outflow - No detectable emission from HII region associated with central protostar => not on the ZAMS yet. SiO suggests collimated flow, HCO+ suggests wider opening angle - precession? But ionized flow has relatively wide opening angle.



G192.16

B2 (proto)star - ZAMS (with HII region) but still accreting and producing outflow.
Age ~ few x 10^5 years

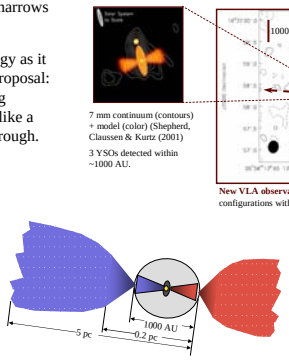




7 mm cont. (~100 AU res.): outflow opening angle = 40°±10°. ^{12}CO & ^{13}CO obs: flow opening angle = 90° 0.2 pc from protostar, then narrows to ~50°.

Ionized gas: flow morphology as it breaks out of HII region. Proposal: HII region expands, creating molecular shell. Shell acts like a nozzle as outflow breaks through.

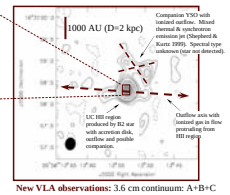
Flow expands as a wind-blow bubble. Evidence for possible pre-HII region collimated jet obliterated by wide-angle wind over time?



Shepherd et al (1998, left) discovered 100 $M_\odot$ molecular outflow with mm cont peak (~15 $M_\odot$). Outflow morphology & kinematics => wind-blown bubble. **New Spitzer observations** above (Qiu et al. 2007) show shocked gas (green) - *still* no sign of a jet (consistent with Davis et al. 1999)

7 mm continuum (contours) + model (color) (Shepherd, Claussen & Kurtz (2001)

3 YSOs detected within ~1000 AU.

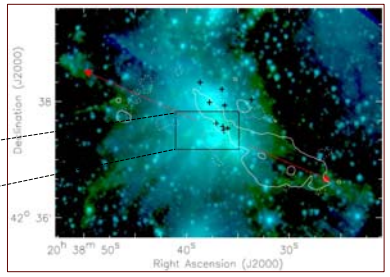


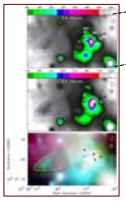
New VLA observations: 3.6 cm continuum: A+B+C configurations with multi-scale clean deconvolution.

Resolution= 0.29"x 0.26"
RMS = 15 microJy/bm
Peak = 0.82 mJy/bm
Contours = -3,3,4,5,6,8,16,32,45 σ
Grey scale = 1σ to peak

W75 N

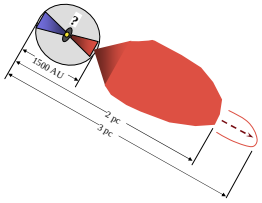
Early B (proto)star cluster - ZAMS (with HII region) but still accreting & producing outflow.
Age ~ 10^5 years

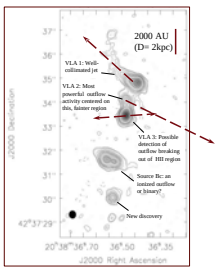




Shepherd, Testi & Stark (2003) discovered outflow cluster with >100 $M_\odot$ high velocity material (contours above). VLA1 = collimated jet; unknown sp. type. VLA2 (B2) outflow morphology & kinematics => wind-blown bubble.

New Spitzer observations above & left (Qiu et al. 2007) show shocked gas (green) beyond CO flow suggestive of remnant, collimated jet.





New VLA observations: 3.6 cm continuum: A+B+C configurations with multi-scale clean deconvolution.

Resolution= 0.3", Grey scale = 1σ to peak
RMS = 26 microJy/bm, Peak = 2.9 mJy/bm
Contours = -3,2,3,6,9,12,15,20,40,60,80,100 σ