The Bipolar Outflow NGC2264G

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Detailed observations in CO(2-1) have been obtained of the highly collimated bipolar outflow NGC2264G. A complete map with 20 arcsec resolution shows rich structural detail in both the spatial morphology and the velocity field of the outflow. Figure 1 shows position-position maps of $^{12}CO(2 \rightarrow 1)$ obtained with the JCMT.

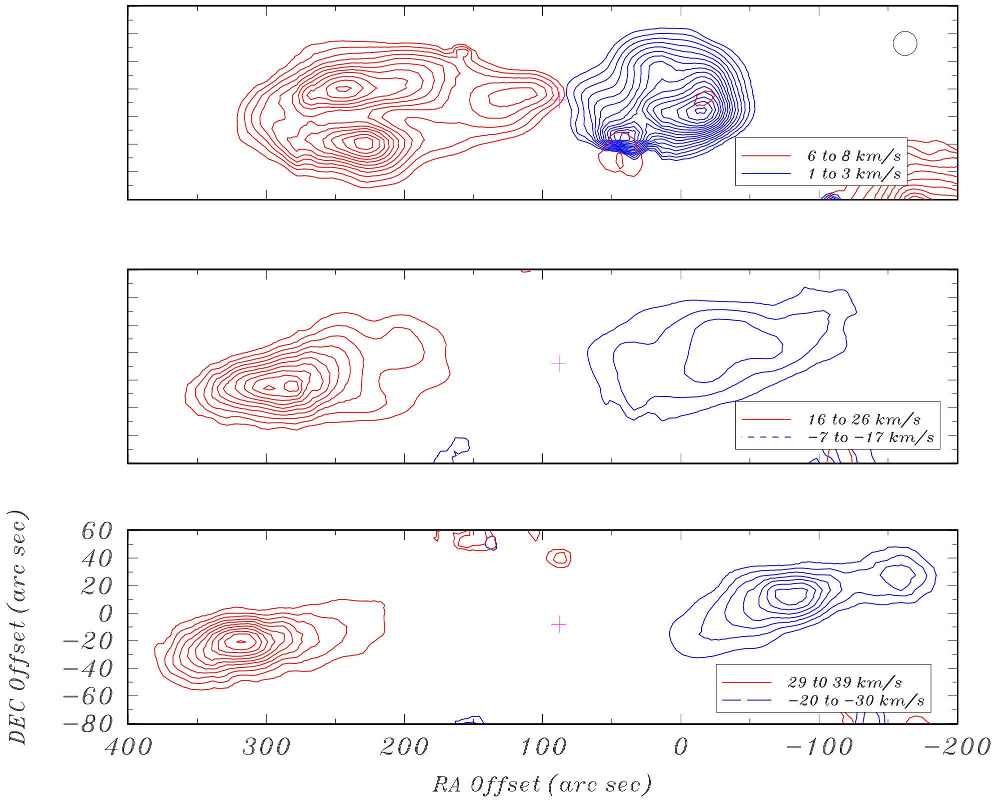

Figure 1: Contour plots of the outflow at increasing pairs of velocity intervals.

In each panel the blue-shifted lobe is on the right in solid contours and the red lobe is on the left in dotted contours. Note the faint cross in the center of each plot marking the position of the recently discovered central source (Gomez et al, 1994) that is seen in NH_3 and radio continuum with the VLA. The ammonia is centered at 4.6 km/s, which we take to be the central velocity of the outflow, perfectly consistent with observations of the large surrounding ambient cloud. This central source has recently been detected at submillimeter wavelengths (Ward-Thompson, Eiroa, and Casali 1995) and found to have a luminosity of approximately 12 $L_\odot$.

The two lobes exhibit nearly identical extents in space and velocity although there are significant differences in their structure. In particular at low velocities the red lobe shows a bow-shock like appearance far from the central object. No such structure is apparent anywhere in the blue lobe. It is clear that there is a systematic increase in flow velocity and collimation with distance from the central source.

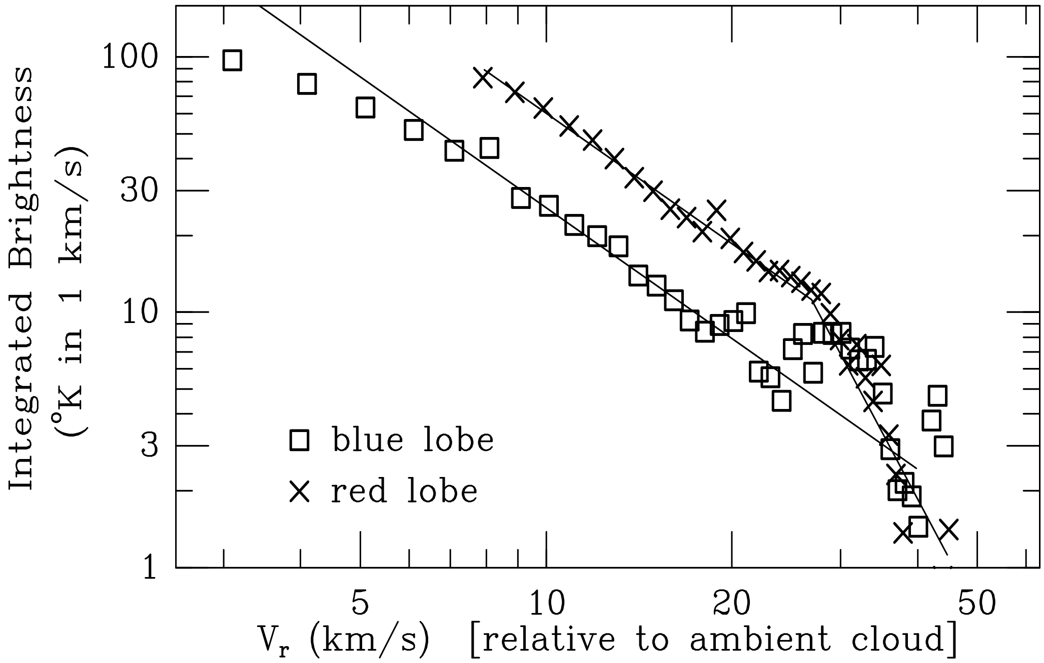

Figure 2: Velocity profiles of each wing. A break in the power law slopes occurs at 28 km/s in both wings.

Both lobes show an elongated structure at the highest velocities, extending beyond the lower velocity gas and unresolved in the direction perpendicular to the flow direction. These structures may be the molecular component of the jet driving this outflow. Spatially integrated velocity profiles of the the outflow gas in each lobe are shown in Figure 2. These profiles, which trace mass of the flow if the gas is optically thin, appear to be well described by a power-law. A line with slope 1.7, similar to what is seen in several other similar outflows, is shown on each lobe's profile. However the highest velocity gas, that looks like a jet in the position-position plots, requires a steeper power law slope ($\gamma \approx 4$) with the identical index in both lobes.

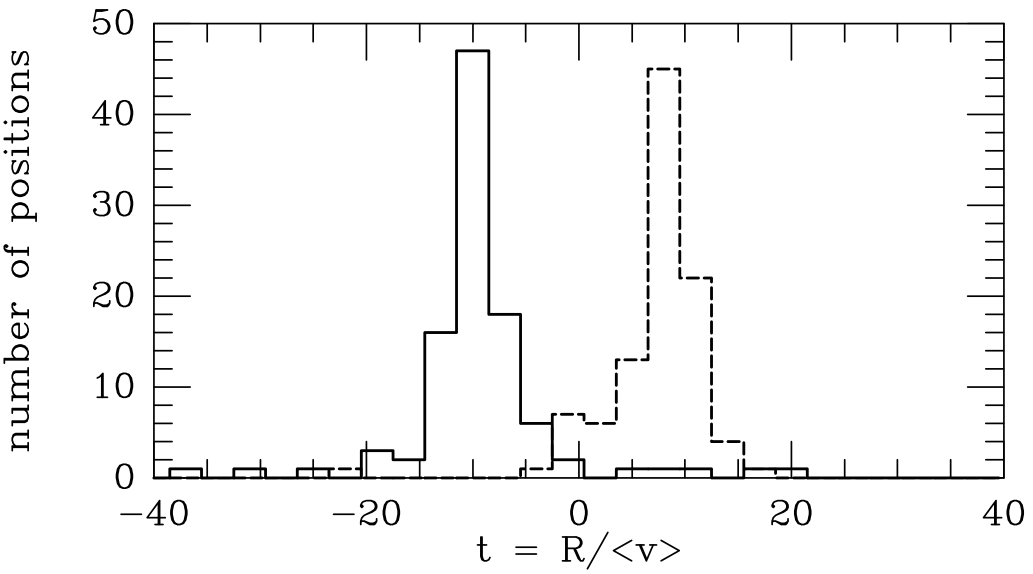

Figure 3: Flow dynamical timescales for the flow determined from each observed position in the outflow and binned in a histogram.

The systematic increase of velocity with distance shown in Figure 1 can be used to estimate a time scale. This can be done for every point in the outflow by estimating the mass-weighted mean velocity at each point $< v >$ and the projected distance from the central source R. The time scale is then simply $R/ < v >$. The frequency distribution of this timescale is shown in Figure 3. The positions in each lobe are shown separately in solid lines for

Table 1: Mass and Energetics of the Outflow

Lobe	Mass $M_\odot$	Momentum $M_\odot$ km s^{-1}	Mass Flux $(10^{-5})M_\odot$ yr^{-1}	Thrust $(10^{-4})M_\odot$ km s^{-1} yr^{-1}	Lumin. ($L_\odot$)
Red	0.4 (0.5)[a]	6.0 (2)[a]	0.84 (1.2)[a]	1.5 (0.5)[a]	0.52
Blue	0.4	4.2	0.73	1.2	0.44
Total	0.8 (1.3)[a]	10.2 (12.2)[a]	1.67 (2.87)[a]	2.7 (3.2)[a]	0.96

[a] Estimated mass and energetic parameters for the lowest velocity (6-12 km s^{-1}) red-shifted gas in the outflow and the totals in these flow quantities including this component.The contribution of this lowest velocity red-shifted gas to the outflow mechanical luminosity is negligible and not included in the Table.

blue, dashed lines for the red lobe. Both distribution functions are sharply peaked at a timescale corresponding to 3×10^4 years!

The mass, momentum, and luminosity of each lobe has been estimated and is shown in Table 1. The mass and momentum estimates are probably the most robust and accurate quantities we have determined. The momentum estimates indicate that that the driving engine of the flow is extremely efficient. In particular, the energy required to drive the molecular outflow is found to be an appreciable fraction of the gravitational accretion energy liberated in the process of forming the central protostellar object. The amount of momentum injection required to account for our observations probably cannot be supplied by a typical optical jet, unless it contains a substantial neutral component.

REFERENCES

Gómez, J. F., Curiel, S., Torrelles, J. M., Rodríguez, L. F., Anglada, G., & Girart, J. M. 1994, ApJ, 436, 749

Ward-Thompson, D., Eiroa, C., & Casali, M. 1995, MNRAS, 273, L25.