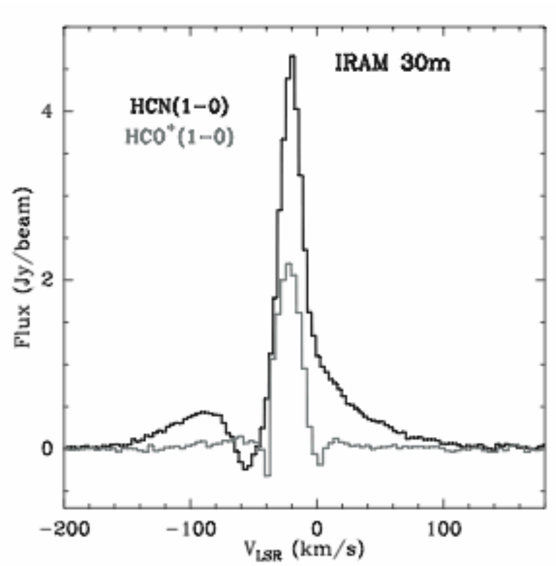
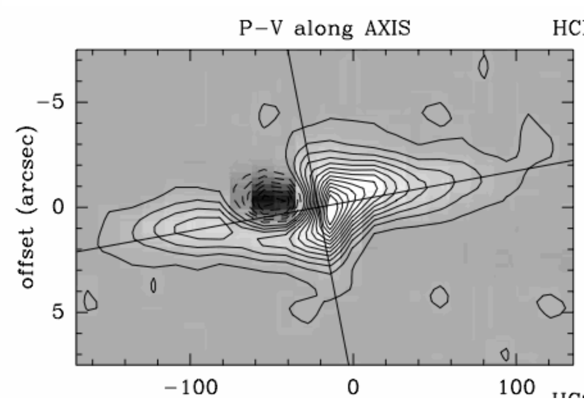
The Astrophysical Journal, 602:960–977, 2004 February 20

PHYSICAL STRUCTURE OF THE PROTOPLANETARY NEBULA CRL 618. II. INTERFEROMETRIC MAPPING OF MILLIMETER-WAVELENGTH HCN $J = 1\text{–}0$, HCO^+ $J = 1\text{–}0$, AND CONTINUUM EMISSION

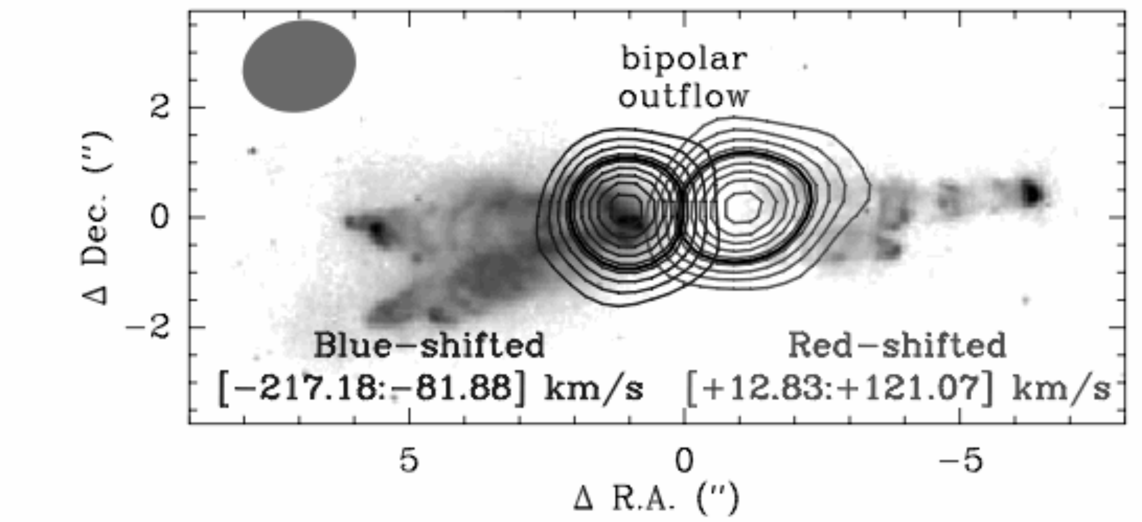
C. Sánchez Contreras
California Institute of Technology, Astronomy Department, MS 105-24, 1200 East California Boulevard, Pasadena, CA 91125; sanchez@astro.caltech.edu
and
R. Sahai
Jet Propulsion Laboratory, California Institute of Technology, MS 183-900, 4800 Oak Grove Drive, Pasadena, CA 91109; sahai@eclipse.jpl.nasa.gov
Received 2003 June 25; accepted 2003 October 31

2004ApJ...602..960S





This left figure shows the integrated HCN and HCO+ profiles of CRL618. The systemic velocity of CRL618 is -22 km/s. There's some self absorption that arises very close to the nucleus, but the radial velocity is fairly small. The high-velocity (HV) molecular gas is seen in two regions on opposite sides of the nucleus at the base of the optical lobes. Its (detected) spatial extent is limited to a radius of 2", as seen in the right figure. The HV gas peaks at about ±70 km/s from the systemic velocity . Faint higher-velocity wings extend to slightly larger radii, as you can see in the right panel. There's marginal evidence (not shown) that the speed increases with radius. Even so, there's no evidence of molecular gas at outflow Doppler shifts above ±120km/s.



The HV molecular gas distribution is overplotted on the fingers. The detection threshold for low-brightness gas is limited. So the surface brightness of molecules <u>might</u> extend to larger radii.

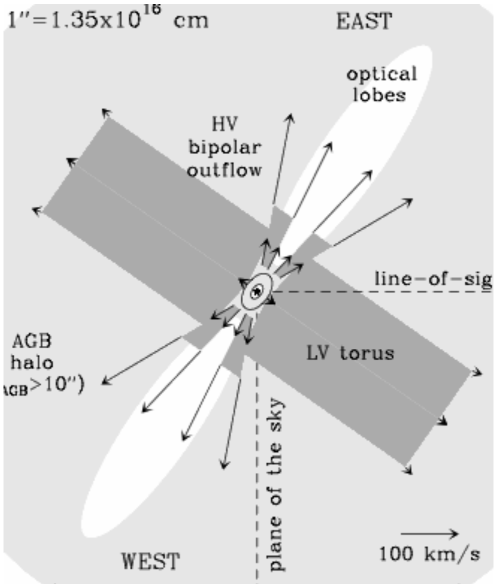
The authors fitted a geometric model of density and temperature to the data. The results are shown below. Those that bear on the hydro model are highlighted in red/

TABLE 1
SPATIO-KINEMATICAL MODEL FOR CRL 618

	LV component	HV component
Shape	Cylinder	Truncated bicone
R_{in} (arcsec)	0.5	0.3 (0.0)
R_{out} (arcsec)	$R_{out} \geq 5.5$	0.9
H_{in} (arcsec)	0.0	0.6
H_{out} (arcsec)	1.45	2.0
Inclination, i (deg)	35(45)	32
Radial Expansion Velocity V_{exp} (km s^{-1})	17.5	$\boxed{70\ (r/1'')}$
Temperature T_{ex} (K)	120	120
HCO^+ Abundance X_{HCO^+}	$>7 \times 10^{-8}$	5×10^{-7}
HCN Abundance X_{HCN}	$>2 \times 10^{-7}$	4×10^{-6}
Density (cm^{-3})	$7 \times 10^6\ (0''.5/r)^2$	$7.0 \times 10^6 (0''.5/r)^2$; if $R_{in} = 0''.3$
	...	$5.8 \times 10^6 (0''.5/r)^2$; if $R_{in} = 0''.0$
Total mass M_T ($M_\odot$)	0.25	$\boxed{0.01}$

The authors actually fitted several models. Two of these are called “Filled” and “Hollow” HV lobes. Both models fit the data equally well, suggesting that there’s a lot of wiggle room in the geometric fit to the HV gas near the nucleus. That’s no surprise: the spatial resolution of their study is about 1.5” E-W and about 1” N-S.

The hollow HV lobe model is shown schematically below. In the filled model the opening along the symmetry axis is filled in by HV gas.



Here's how the authors describe their model for HV gas. The "aperture" is the opening angle of the cone at its apex.

4. The HV bipolar outflow can be approximated by a bicone, with a total axial length of 2.7×10^{16} cm and an aperture $\sim 24°$. The HV outflow, with an adopted total mass of 0.01 $M_{\odot}$ (§ 5), is most likely AGB material accelerated, compressed, and shaped by the hydrodynamical interaction with tenuous, post-AGB jetlike ejections.

5. The inclination of the symmetry axis of the HV outflow (with respect to the plane of the sky) derived from the model is 32°. The inclination of the LV torus is more uncertain, $i \sim 35° - 45°$.

The Astronomical Journal, 134:2035–2045, 2007 November

SUBMILLIMETER ARRAY OBSERVATION OF THE PROTO–PLANETARY NEBULA CRL 618 IN THE CO $J = 6–5$ LINE

Jun-ichi Nakashima,[1] David Fong,[2] Tatsuhiko Hasegawa,[1] Naomi Hirano,[1] Nico Koning,[3] Sun Kwok,[1,4] Jeremy Lim,[1] Dinh-Van-Trung,[1] and Ken Young[5]
Received 2007 June 20; accepted 2007 July 26

[2007AJ....134.2035N]

This is them most recent paper on the observed structure of CRL618 that I can find. The paper reports an interferometer mapping of CO in CRL618. Just to remind you, interferometers can have difficulty detecting extended, low-surface brightness emission. However, the authors claim that fully 80% of the flux of the ^{12}CO(2-1) (230GHz) HV flux is captured in their images (the remaining 20% -- the part of central interest to us right now! -- is too extended to be observed). At that wavelength their spatial resolution is poor. The ^{12}CO 6-5 line frequency is 3x higher than the 2-1 line (690GHz), so the spatial resolution is 3 better (about 1”). However, they capture only 17 of the total line flux but almost all of the flux of the compact HV components.

The spatial resolution is ≈1”

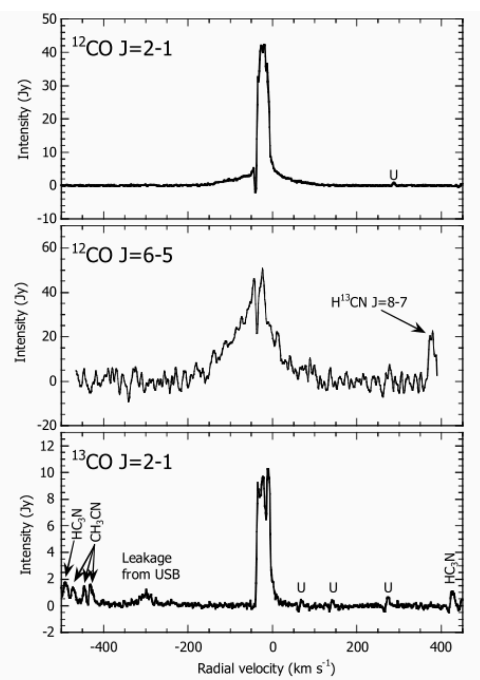


FIG. 2.—Spatially integrated spectra of the ^{12}CO $J = 2–1$, ^{12}CO $J = 6–5$, and ^{13}CO $J = 2–1$ lines. The integrated area is a circle with an angular diameter of 15″. For the ^{12}CO $J = 6–5$ line, the spectrum is smoothed over every 5 km s^{-1}.

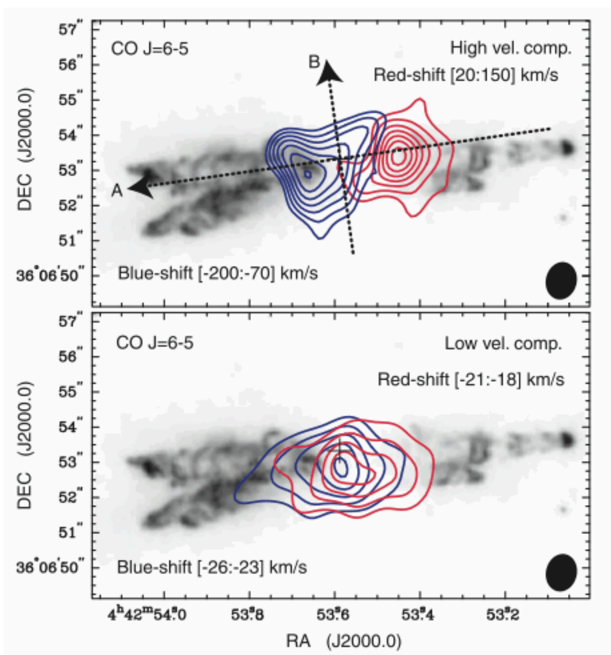


FIG. 4.—Velocity-integrated intensity maps of the CO $J = 6–5$ line superimposed on the *HST* WFPC2 Hα + continuum image (Trammell & Goodrich 2002). The red and blue contours represent the redshifted and blueshifted parts

The panel on the left shows the nebula-integrated molecular signal. If you look carefully at the top left panel (^{12}CO 2-1) you’ll see the presence of high-velocity (HV) outflows extending ±120 km/s or more. Note the blue absorption feature arising in colder, low-velocity foreground gas in the general direction of the nucleus. The images on the right show the HV (top) and LV CO superimposed on the HST image of the fingers. These results agree very well with those of HCN described earlier.

The better S/N of the HV image suggests that the emitting CO cuts off fairly abruptly beyond 2.5” of the nucleus (1” corresponds to about 1.2E11 km). This abrupt edge tot eh CO disagrees with the model density fits of Contreras et al. Since CO is the most robust of the radio molecules, the result also suggests that the gas becomes atomic as it propagates beyond ≈3E11 km. Also, unlike the previous paper, there’s no evidence that the Doppler speed of the HV outflows increase with distance in the ^{12}CO6-5 line. (Nakashima’s measurements in ^{12}CO 2-1 **DO** show the velocity increase on the west side from the nucleus.) Finally, they find no evidence that the density structure of the HV outflow is hollow.