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The Massive Expanding Torus in the PN NGC6302

Nicolas Peretto, Gary Fuller, Albert Zijlstra (Manchester), Nimesh Patel (CfA)

Summary

Observations of CO towards the planetary nebula NGC 6302 reveal a massive concentration of molecular material centred on the exciting star. JCMT observations of both the J=2-1 and J=3-2 transitions of ^{12}CO and ^{13}CO show three velocity components with a total velocity extend of >40 km/s in all four transitions. SMA observations of the J=2-1 transitions of ^{12}CO and ^{13}CO with an angular resolution of 6"x3" show all three of these components are centred on the exciting star and have a complex velocity structure. Two of these components are identified as the front and rear sides of torus of material which is expanding away from the star. The CO emission arises from two temperature components which are interpreted as a warm inner edge of the torus and a cooler outer region. With a mass of ~2$M_\odot$ the gas traced by the CO dominates the mass of the source and implies a progenitor mass of 3-5 $M_\odot$. The size and expansion velocity of the torus indicate that the torus has an age of ~7000 yr and its inner edge was eject ~2700 years ago, suggesting that this coincided with the eruptive event which Meaburn et al. (2005) proposed formed the bipolar lobes. While the torus was forming the mass loss rate from the star was 2-5x10^{-4} $M_\odot$/y, somewhat too large to be consistent with current models of AGB evolution.

Background

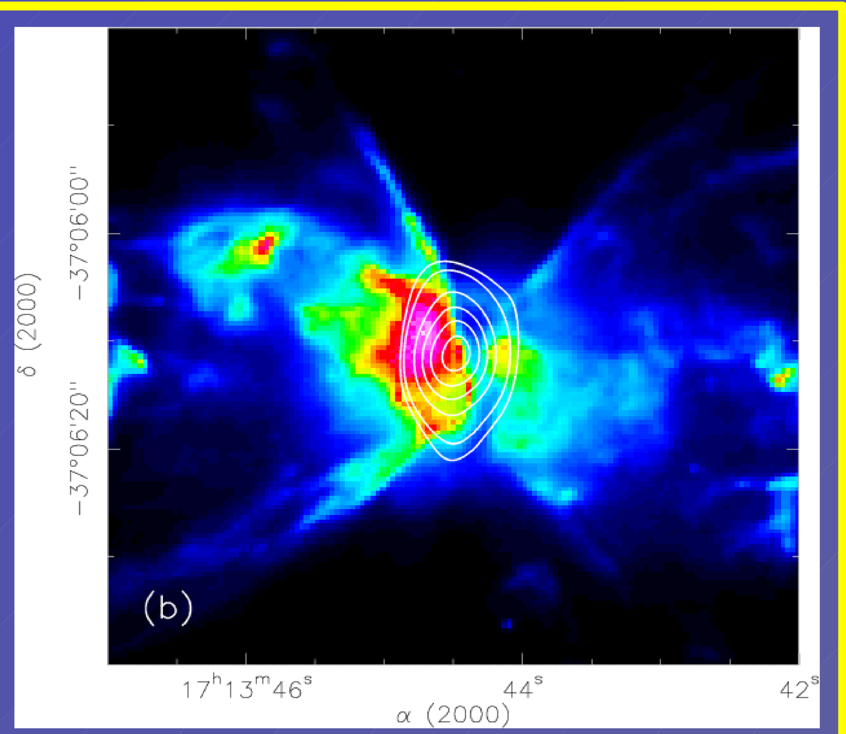
The material ionised to form a planetary nebula (PN) represents up to 80% of the initial mass of its low mass progenitor star. This material was ejected at mass loss rates of up to ~10^{-4} $M_\odot$/yr while the progenitor evolved along the asymptotic giant branch (AGB). Although elliptical and bipolar PNe are common (e.g. Manchado 1997), it is unclear how these morphologies are related to the structures seen in AGB stars and proto-planetary nebula (PPNe). Understanding the structure and dynamics of the densest material in the youngest PNe contain can provide important clues about the final death throes of low mass stars. However to date the molecular content of few young PNe has been well studied.

NGC6302

NGC 6302 is an extremely young PN with bipolar `butterfly' morphology with the central star obscured by an absorption lane (e.g. Matsuura et al. 2005). The nebula is excited by one of the high temperature central PN stars known (Casassus et al. 2000) , although due to the high extinction, the central star has not been directly detected. Recent submillimetre continuum observations at 850μm imply a mass of ~3$M_\odot$ associated with the absorption lane, which is considerably larger than the ~0.1$M_\odot$ inferred from earlier observations of CO (Huggins & Healy 1989; Gomez et al. 1989). Here we present recent JCMT and SMA observations of NGC6302 which were originally motivated by this large mass discrepancy.

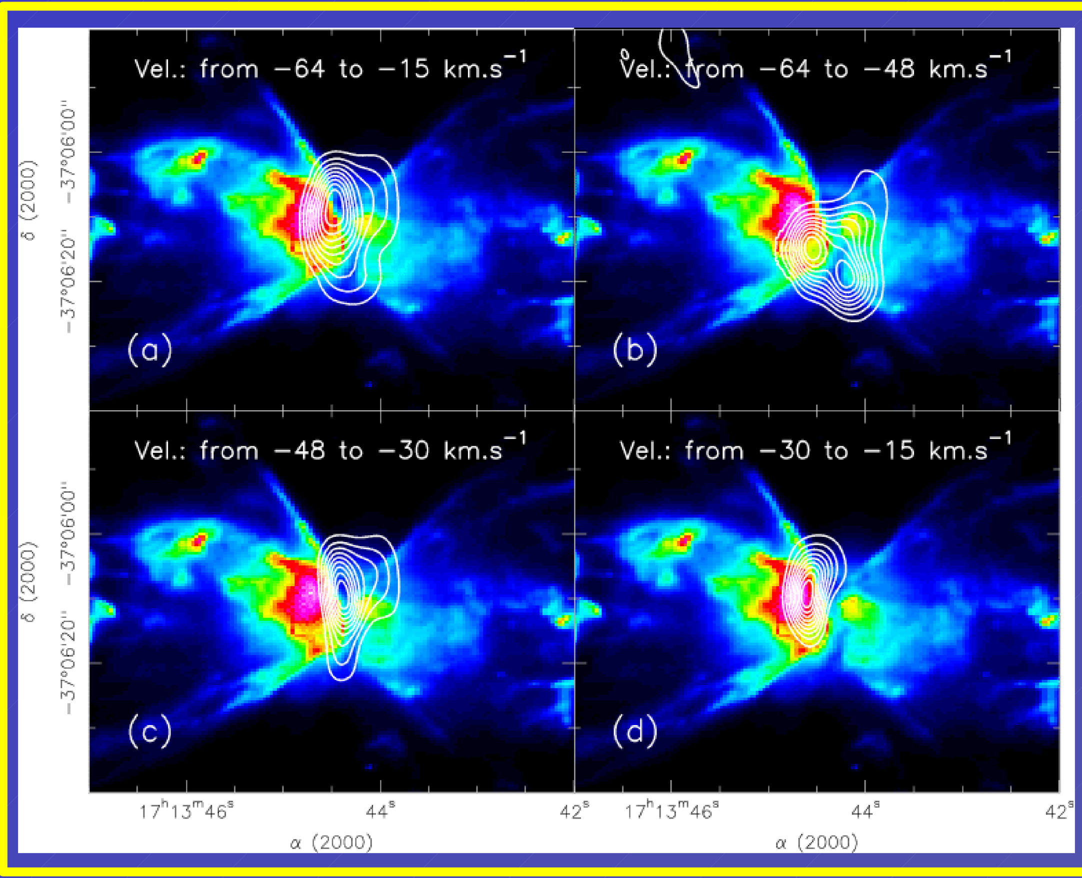
Dust Emission

- SMA 1.3mm continuum emission
- Integrated flux 1.3 Jy
- Peak offset from extinction in direction of 6cm radio continuum peak
- 50% free-free, 50% dust (Matsuura et al.
- 2005)
- Total dust mass = 0.015$M_\odot$ (T=70K, dust opacity 2 cm^2/g, similar protostellar disks)
- Assume 100:1 gas to dust. total mass of 1.5 $M_\odot$
  - Very similar mass from 850μm emssion in 14" beam on JCMT (Matsuura et al. 2005)
    - There is no extended emission.

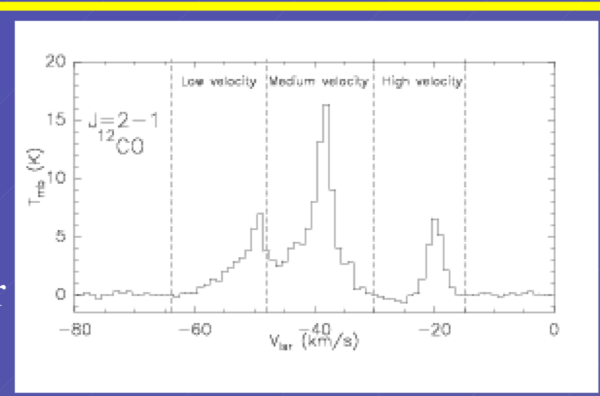


Contours of 1.3mm (white) overlaid on a colour scale of the H emission (Matsuura et al. 2005). The contours increase in steps of 10% from 10% to 90% of the 0.6 Jy peak flux.

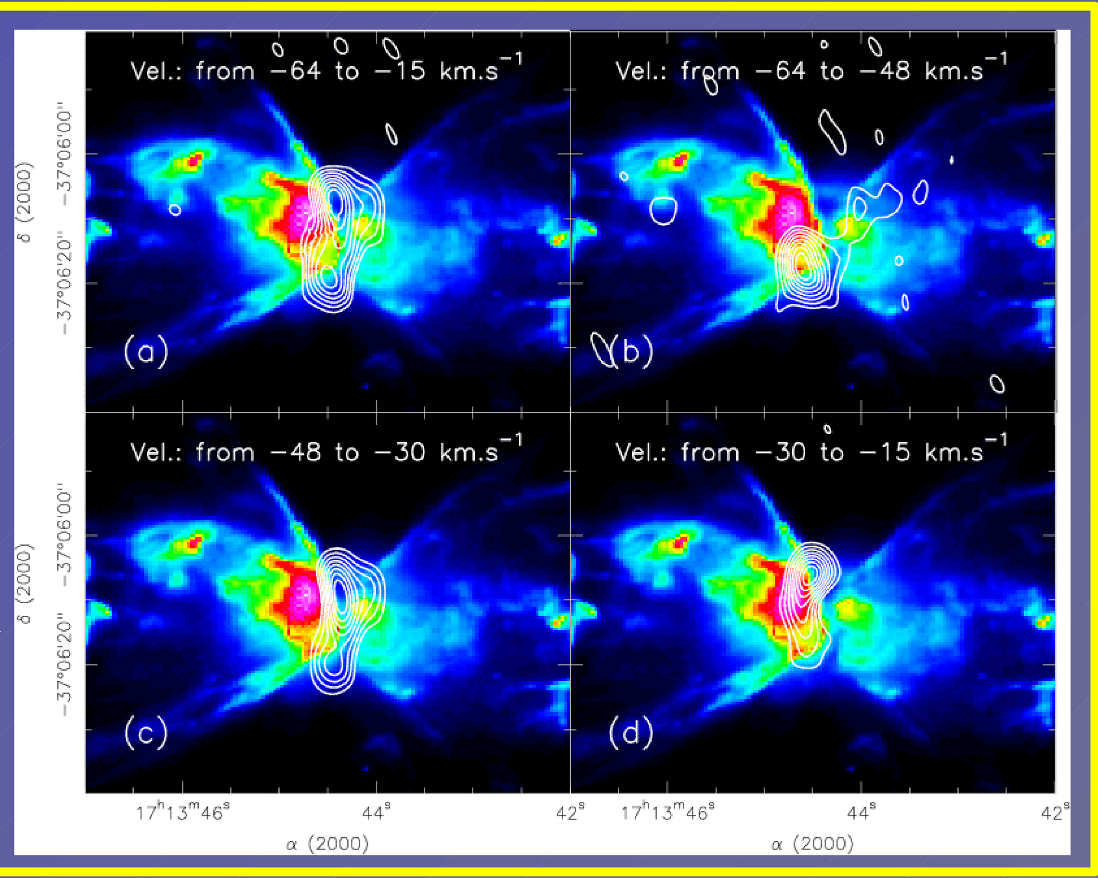
CO Emission



- Integrated CO spectrum (right) shows three velocity components
- Medium velocity component matches absorption lane (SMA images left and far right)
- OH absorption covers same velocity range (Payne et al. 1988)
  - This component is in front of central source
- High velocity component curved and offset east of the extinction
  - Behind central source
- Low velocity component: torus material swept up by stellar wind?



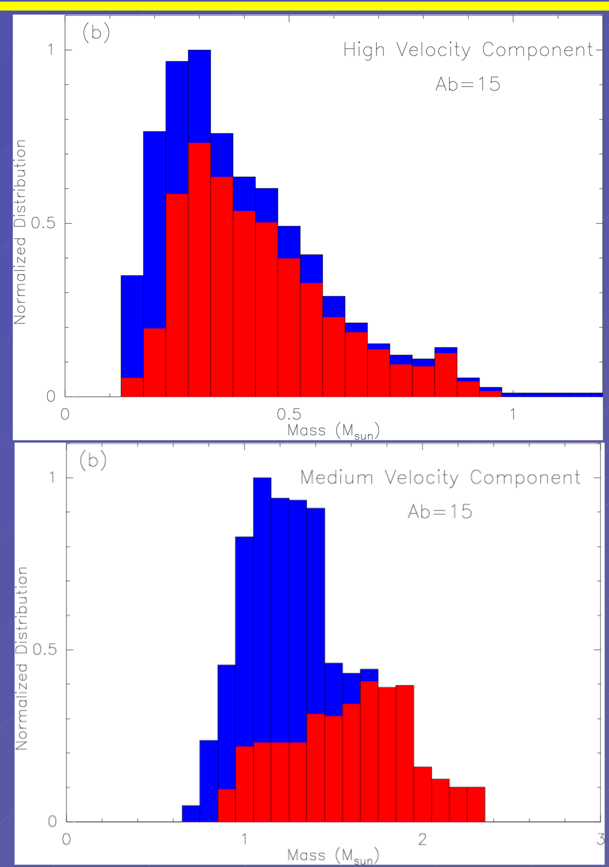
Above: Integrated CO 2-1 spectrum from SMA data.
Left: SMA ^{12}CO 2-1 maps of the integrated intensity (top left), low velocity component (top right), medium velocity component (bottom left), high velocity component (bottom right).
Right: SMA ^{13}CO 2-1 maps in the same order as the ^{12}CO images.



Mass Estimate

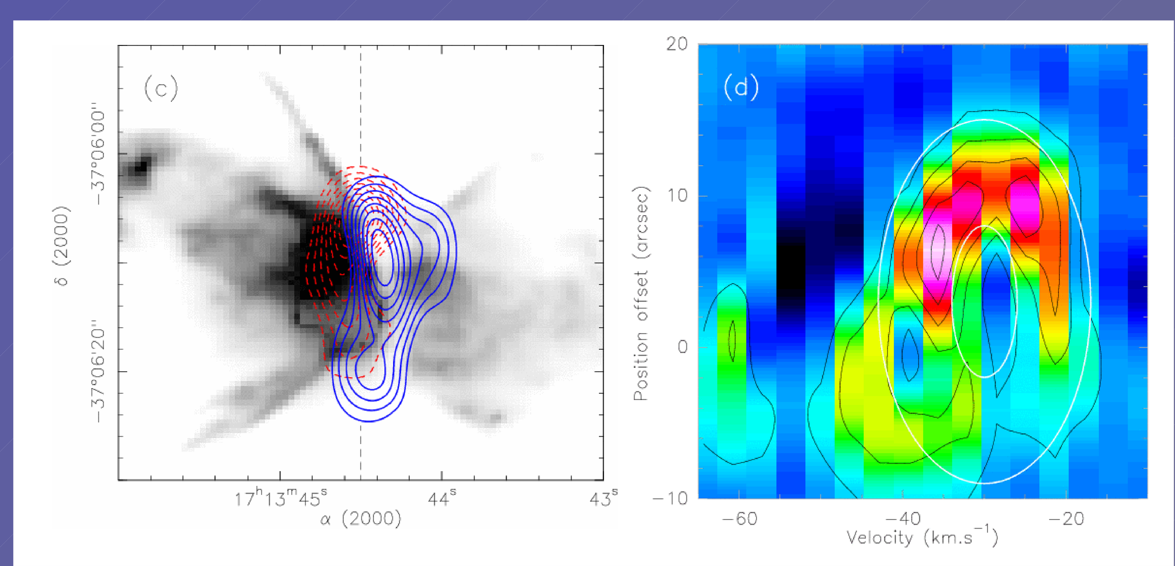
- The ratios of the four transitions observed with JCMT are not consistent with material at a single temperature.
- Assume a mixture of two temperature components
- Used RADEX to model a mixture of hot and cold gas with mass fractions between 0.1 and 0.9 for the hot component.
- Adopted $^{12}C/^{13}C$=15 (and also used 30).
- The distribution of best fit masses for the high and medium velocity components are shown to the right
- Best fit properties:

Component	$N(H_2)$	Mass ($M_\odot$)
	(10^{21} cm^{-2})	
High	4.4	0.3
Medium	16.1	1.1
Low	0.5	0.06



Distributions of best fit mass for two component models. Red: Hot, T>80K component. Blue: Cold component. High (top) and medium (bottom) velocity components

Kinematics: An Expanding Torus



Torus in ^{13}CO J=2-1 (left). Blue and red contours show the medium and high velocity components respectively. The PV diagram (right) is a slice in declination through the central star.

- The PV diagram is well fitted by an elliptical ring (above right)
  - ➔ Torus of emission
- The torus is expanding with a velocity of 9 km/s with no evidence for rotation which would appear as a tilt in the axis of the ellipse
- Age of torus: 7000 yr (from size)
- Duration of formation event: 4300 yr (from thickness), ending 2700 yr ago (from inner radius)
  - ➔ End of torus formation/torus ejection coincides with formation of bipolar lobes (Meaburn et al 2005)
  - ➔ Did this decouple the CO and the star and so terminate the CO outflow typically seen for AGB sources?

Implications And Future Prospects

- Implied mass loss rate at end of AGB: 2-5x10^{-4} $M_\odot$/yr
  - ➔ Larger than models can match (e.g. Bloecker 1995)
- Progenitor mass 3-5 $M_\odot$
  - ➔ Bulk of mass still within 2x10^{17} cm of star
  - ➔ High mass progenitor required to form bipolar PN ?
- Eruptive event ejected torus, decoupled molecular material from star
  - ➔ Termination of massive CO outflow seen in AGB objects

Future Observations with ALMA:

Image higher transitions of CO to map temperature in the torus to understand it origins and fate

Image larger sample of young PNe:

➔ Are mass loss rates this high common? Is the distribution consistent with models?

➔ Are morphology and progenitor mass connected?

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Email: Nicolas.Peretto@manchester.ac.uk