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Chemical evolution in NGC 6302

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Observations of the butterfly planetary nebula (PN) NGC 6302 reveal a complex bi-polar structure with a massive low-velocity torus coupled with high-velocity knots. This massive expanding torus has a high mass-loss rate ($\sim 1.5 \times 10^{-4}$ $M_\odot$ yr^{-1}) (Trung et al. 2008) and is believed to contain the highest mass of circumstellar material of any known PN (between $\sim$1–3$M_\odot$)(Peretto et al. 2007). Its striking morphology also conceals a peculiar chemistry whereby both OH maser and PAH emission have been detected.

Shocks, X-rays and an encroaching hard radiation field permeating NGC 6302 are similar properties to those found in AGN and accordingly provide an extreme environment in which to test models of the interaction of UV photons and X-rays with molecular gas.

We report here on the first detection of CN, HCN, HCO+ and a tentative detection of SiC_2 towards NGC 6302 made using the James Clerk Maxwell Telescope (JCMT). These molecular species, along with CO, are modelled with the Meudon PDR code to constrain conditions in the source. The effects of $^{12}C/^{13}C$ chemistry on molecular abundances are also modelled to ascertain their affects on the rich chemistry in NGC 6302.

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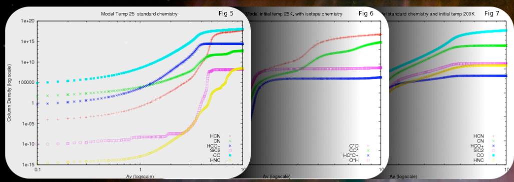
Observations of the butterfly planetary nebula (PN) NGC 6302 reveal a complex bi-polar structure with a massive low-velocity torus coupled with high-velocity knots. The recently discovered central star for this PN [1] has a high mass loss rate (~1.5 x 10-4 M$_\odot$ yr-1) and is believed to contain the highest mass of circumstellar material of any known PN (between ~1 to 3 M$_\odot$) [2]. Its striking morphology also conceals a perculiar chemistry whereby both OH maser and PAH emssion have been detected [3].

Shocks, x-rays and an encroaching hard radiation field permeating NGC 6302 are similar properties to those found in AGN and as such provide an extreme environment in which to test models of the interaction of UV photons and x-rays with molecular gas.

Emission lines from a number of high-ionisation species have been detected via infrared spectroscopy of NGC 6302, in particular that of [Si IX], [Mg VIII] and [Al VI] [4]; accordingly, large fluxes of energetic photons are required in order to produce such strong emission lines (> 300 eV) [1]. Whilst X-ray emission has yet to be observed in NGC 6302's central region, NGC 7027 a PN at a similar evolutionary stage, has been established as a diffuse X-ray source [5]. It is thus likely that NGC 6302 will follow suit in the future.

We report here on the first detection of CN, HCN, HCO+ and a tentative detection of SiC2 towards NGC 6302 made using the James Clerk Maxwell Telescope (JCMT). These molecular species, along with CO, are modelled with the Meudon PDR code [6] to constrain conditions in the source. The effects of 12C/13C chemistry on molecular abundances are also modelled to ascertain their affects on the rich chemistry in NGC 6302.

Fig 5-10: The graphs below show varying parameters of the Meudon PDR code to constrain conditions and mimic XDR regions. Figures 5 & 7 show standard chemistry, whilst Fig 6 is isotope chemistry. Temperature increases from left to right. Figures 8-10 are the same layout with cosmic ray ionisation rate increased instead. X and Y axis are the same throughout



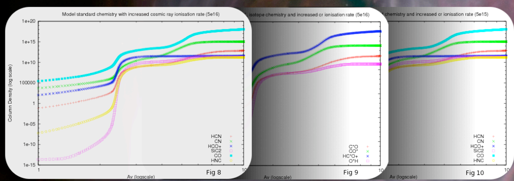


TABLE 1 : Model Variables Defined or Calculated in the Meudon PDR Code

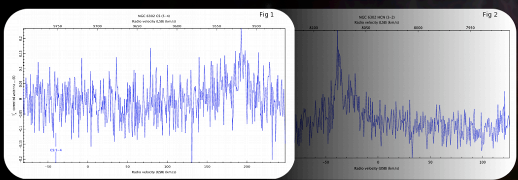
Variables	Unit	Name	Comment
Tk	K	Kinetic temperature	Varied in 25K steps. Lowest and highest graphs shown
nH	cm-3	Density (hydrogen)	Set at 8.34 x 10(4)
cr	10(-17) s-1	Cosmic-ray ionisation rate	Varied from 5 x 10(-17) to 5 x 10(-15)
Av	mag	Extinction	Set at 10

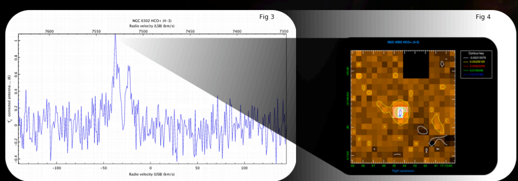
TABLE 2: Column densities calculated with RADEX for comparison against the Meudon PDR code.

Species	RMS (K)	Column Density (cm-2)	Integrated Intensities (K km s-1)
HCN (3-2)	0.08	1 x 10(15)	21.51
CN (2-1)	0.06	..	7.73
HCO+(3-2)	0.03	1 x 10(15)	20.55
SiC2	0.06	..	4.60

Integrated intensities corrected for a beam filling factor of 0.43 (taken from Peretto et al [2]). Line widths, kinetic temperature and H2 density were fixed at 10kms-1, 30K and 8x10(4) cm-3 respectively. The dotted line (for CN and SiC2) denote none calculation with RADEX

Figures 1-4: Below are the spectra obtained from the recent JCMT observations. Spectra were obtained for two transitions of each species in order to provide contraints on excitation parameters within the nebula. However only one spectra of each species is displayed here.





The two component lines of the spectra (seen easily in HCO+ for example) are very similar to the CO spectra (taken by Peretto et al (2007)[2]) which is a strong indication that the emission is also associated with the torus. This is re-iterated in the HCO+ contour map which shows emission arising from the central region (x marks the spot of the source)

To mimic the conditions of an X-ray dominated region (XDR), and hence establish if X-rays have made an impact on current chemical data, column densities for the recently obtained spectra were modelled with varying parameters of the Meudon PDR code in comparison with calculated column densities using RADEX, a 1D radiative code [7] (see Table 2). This is achieved by enhancing the cosmic ray ionisation rate within the PDR code.

The results show that column densities for HCO+ and HCN correlate closely with low temperature PDR models. In addition, HCN is significantly greater than HNC (which does not vary substantially between models) and ranges up to a few orders of magnitude greater than CN. It is only when the cosmic ray ionisation rate is increased does the column density for CN become enhanced. Studies on chemical complexity in PN [8] have highlighted the role of certain species which can aid in identifying the evolution of PPN/PN; namely CN and HCO+ whose abundances increase substantially, whilst species such as SiO, SiC2 and CS decrease dramatically towards evolved PN status.

Isotopes: Simple isotope chemistry was also modelled with the Meudon PDR code in order to provide preliminary data for future observations and to help ascertain constraints on stellar evolution; the production of 12C and 13C for example highlights differing nucleosynthetic processes. Column densities for C13O are only a factor of two less than C12O in low temperature models whilst those which mimic XDR regions do not notably vary.

Conclusions: Low abundances of CN and the presence of SiC2 do fit with suggested evolution trends implying that NGC 6302 is indeed a young PN. From the calculated column densities it would also appear that the chemistry has yet to be influenced by an increased X-ray flux. XDR modelling in PN environments is still in its infancy, accordingly additional modelling with different molecular species will be completed to help ascertain the evolution of NGC 6302.

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Background image: http://www.nasa.gov/mission_pages/hubble/multimedia/ero/ero_ngc6302.html