Molecules in Planetary Nebulae

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ABSTRACT

In the last decades, many molecules have been detected in planetary nebulae (PNe; see Kimura et al. 2012, A&A, 541, 112 and references therein). In this work, we study the molecular content of PNe using the code CLOUDY (Ferland et al. 2013, RMxAA, 49, 137). We explore different input parameters that describe different characteristics of the PN and study their impact on the amount and emission of simple molecules.

METODOLOGY

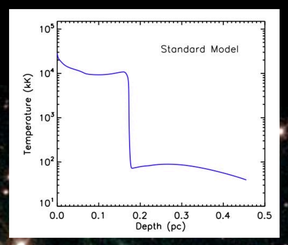
We use a developer version of CLOUDY v15 (May 2015) to run the models. We run models with various different parameters. We assume a standard model with the following parameters: $T_* = 80$ kK, log Hden = 3, $L_* = 3000$ Lsun. To study the impact of some important parameters on the molecular density and emission, we then vary each parameter at one time, within the following ranges, which are typical for PNe:

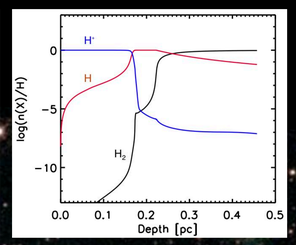
Central Star Luminosity (Lsun) : 100 – 30000
Log H density (cm^{-3}) : 2 - 6
Central Star Temperature (kK): 20 - 200

Where we do not specify, the parameters are those from the standard model.

The stopping criterion is T = 40 K, so the models run deep into the cloudy, where the temperature is low and the gas is mostly molecular (H_2)

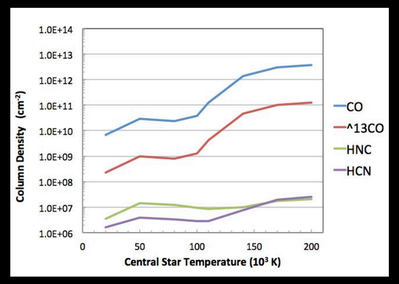
GAS TEMPERATURE AND IONIZATION STRUCTURE



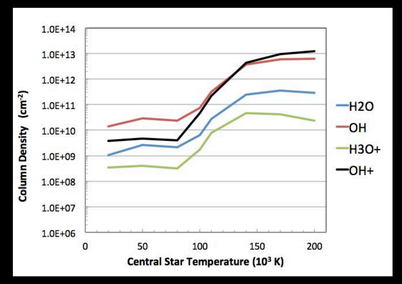


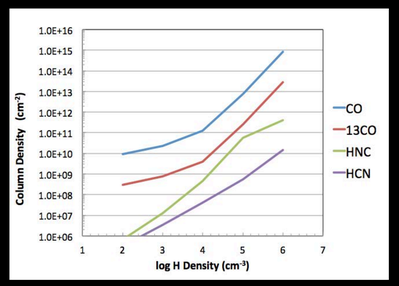
RESULTS

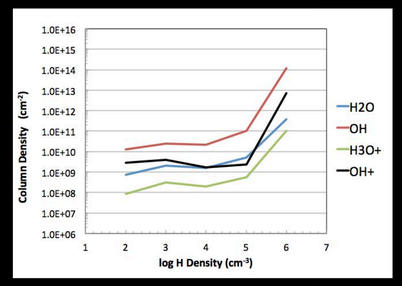
CARBON BEARING MOLECULES

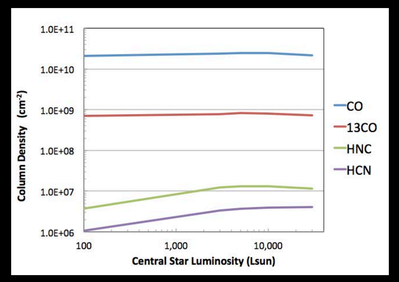


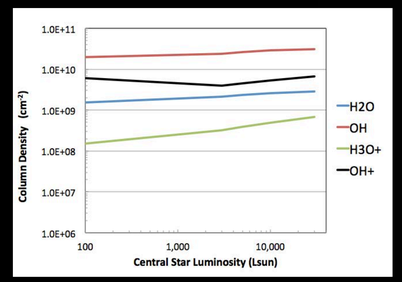
OXYGEN BEARING MOLECULES



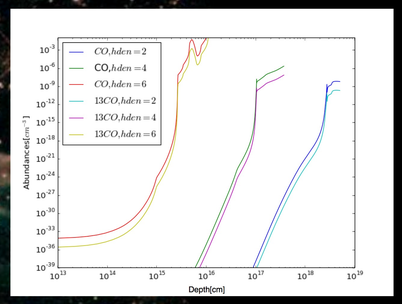








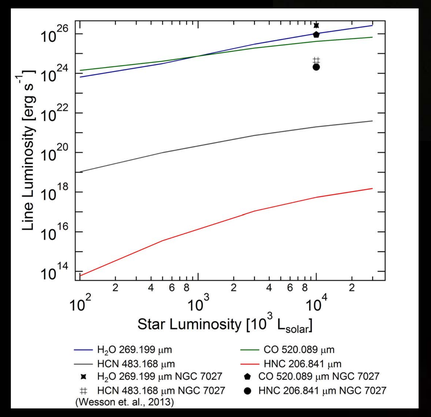
For the molecules above, their column densities changes significantly within the range of typical central star temperatures and gas densities, but this is not the case for central star luminosities.

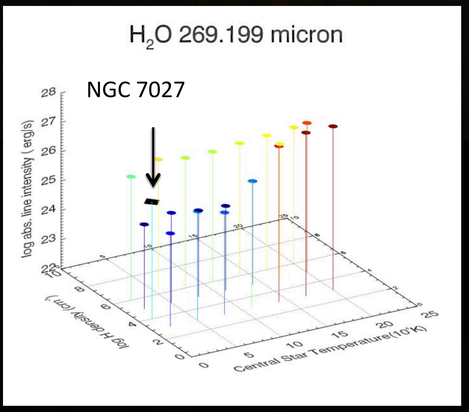


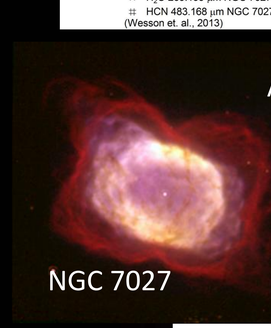
^{12}CO and ^{13}CO density as a function of the depth into the cloud for models of different gas density.

The ^{12}CO and ^{13}CO ratio is assumed constant as solar (standard value in CLOUDY).

LINE INTENSITIES







A SIMPLE TOY MODEL FOR NGC 7027

We study the impact of the stellar luminosity in the emission of some molecular lines, including H_2O lam 269.19 um, CO 520.089 um, HCN 483.168 um, and HNC 206.841 um. Within the typical range for PNe, these lines change by 2 to 4 orders of magnitude.
A toy model with L* = 10000 Lsun and T* = 170 kK, values appropriate for PN NGC 7027 (Wesson et. al., 2013) provides a good match for the H_2O and CO lines, but not for HCN and HNC. Present models in the literature do not reproduce the emission of these molecules well (Kimura et al. 2014).

Line	Cloudy_Mod	NGC 7027
H_2O λ269.19μm	1.03E+26	2.62E+26
CO λ520.089μm	4.13E+25	8.94E+25
HCN λ483.168μm	1.98E+21	4.40E+24
HNC λ206.841μm	5.41E+17	2.10E+24

OH^+: MODELS AND THE HERSCHEL OBSERVATIONS

Observations from: Aleman et al. (2014)
Herschel Space Observatory