MOLECULE FORMATION IN THE SEYFERT GALAXY NGC 1068

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ABSTRACT

We have constructed models of relatively high-density radiation-bounded filaments near the nucleus of a Seyfert 2 galaxy. The amount of molecular hydrogen predicted by the models for reasonable values of the physical parameters is consistent with observations of the infrared continuum and the quadrupole rotation-vibration lines of H_2 in NGC 1068.

The first detection of extragalactic molecular emission lines was made by Thompson, Lebofsky, and Rieke (1978) with their observation of the $v = 1 \rightarrow 0$, S(1) and S(2) lines of H_2 in NGC 1068, a Seyfert 2 galaxy. The emission, if it is attributed to shocked gas at 2000 K, must come from approximately 6000 $M_\odot$ of shocked molecular hydrogen which is a fairly small fraction of the approximately 10^8 $M_\odot$ of cold material postulated by Jones et al. (1977) to account for the infrared luminosity. As noted in the report of the molecular emission observations, the hydrogen can be expected to lie in cold, relatively dense clouds or filaments.

Detailed models of the line emitting regions of NGC 1068 by Shields and Oke (1975) make use of two regions to explain the spectrum. One has a density of $\sim$800 cm^{-3} and a fairly uniform distribution, and the second, more filamentary in structure, has a density of 3×10^5 cm^{-3} (for T=12000 K). If the filaments of the second type of region are radiation bounded, then an even higher-density cold region can be expected to exist beyond the HII-HI transition. This region, in which we expect molecules to exist, is taken to be a thin slab illuminated on one of its faces by a continuum source with either a power law or blackbody distribution as given by Shields and Oke. We assume that no radiation below the Lyman limit is transmitted through the transition region.

Calculations of the photoionization equilibrium for the metals with ionization potentials below 13.6 eV yield an electron density and radiation field as a function of depth into the slab. The molecular

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equilibrium for hydrogen was calculated using gas-phase reactions. The effect of dust on the calculations was evaluated by computing models which either included or excluded the attenuation of radiation by dust and the formation of molecular hydrogen on grain surfaces (Hollenbach and Salpeter, 1971).

Models were computed at three different densities: $2\text{x}10^6$, $2\text{x}10^7$, and $2\text{x}10^8$ cm^{-3}. The slab is at a distance of 50 pc from the continuum source and a kinetic temperature of 100 K is assumed throughout.

At a sufficient depth into the cloud that the H_2 can be effectively shielded from photodissociation (via predissociation as described by Stecher and Williams, 1967), the hydrogen is all molecular in the cases including dust, and one-third to all molecular even if the grain surface reactions and dust attenuation are not included. The times to reach equilibrium, like the reaction rates, depend directly on the density. These times range from 3 to 300 years for the models including dust, and from 40,000 to 500,000 excluding dust. The shorter times correspond to the higher densities, but the frequency dependence of the radiation does not affect the times significantly.

The absorption of radiation by H_2 was not included in the calculations, so its shielding is due to the continuous absorption of neutral carbon. The formation of carbon monoxide, which eventually dominates the carbon chemistry, would allow into the slab more radiation capable of causing the predissociation of H_2. We considered a more detailed chemistry including CO and found that there is sufficient optical depth in neutral carbon to shield H_2 even in this case.

The column density of H_2 up to the point where the species with the second lowest ionization potential (Mg) became neutral ranges from $2\text{x}10^{23}$ to $1\text{x}10^{24}$ cm^{-2}. For a fraction 1/10 of the sky covered by the filaments, as seen from the source, the total mass of H_2 predicted is $2.5\text{x}10^7$ $M_\odot$. This is very close to the amount given by Jones et al.; excitation of only a small fraction of it can produce the observed emission.

A more detailed description is to be published in the Astrophysical Journal, vol. 233.

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