X-RAY CHEMISTRY IN THE ENVELOPES AROUND YOUNG STELLAR OBJECTS

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ABSTRACT

We have studied the influence of X-rays from a massive young stellar object (YSO) on the chemistry of its own envelope by extending the models of Doty et al. (2002) and Stübler et al. (2004a). The models are applied to the massive star-forming region AFGL 2591 for different X-ray luminosities and plasma temperatures. Enhanced column densities for several species are predicted. In addition we present first detections of CO⁺ and SO⁺ toward AFGL 2591. These molecular ions are believed to be high-energy tracers. Herschel-HIFI will be able to observe other tracers like CH and CH⁺ whereas ALMA is well suited to measure the size and geometry of the emitting region.

2. CHEMICAL X-RAY MODEL

The chemical model is based on the detailed thermal and gas-phase chemistry models of Doty et al. (2002), including UV radiation from the in- or outside (Stübler et al. 2004a). The model assumes a given temperature and density distribution and calculates the time-dependent chemistry at a certain distance from the central source. For the chemical X-ray network we follow Maloney et al. (1996) and Yan (1997). It contains direct X-ray ionization and dissociation of atomic and molecular species and X-ray induced reactions caused by electron impact. The main reactions of the electrons are the ionization and dissociation of H₂ and the excitation of H, He and H₂. The electronically excited states of H, He and H₂ decay back to the ground states by emitting UV photons. The internally generated ultraviolet photons can photoionize and photodissociate other species in the gas. These secondary processes are far more important for the chemical network than the primary interaction of the X-rays with the gas, making it more difficult to distinguish X-ray and UV-induced processes.

We have applied our model to the massive star-forming region AFGL 2591 and adopt the temperature and power-law density distribution proposed by van der Tak et al. (1999) and Doty et al. (2002). The most important parameter in the chemistry and physics of XDRs is $H_X/n$, the local X-ray energy deposition rate per particle (Maloney et al. 1996). Since the heating rate is ~ proportional to this ratio, we can estimate its importance for the gas temperature. Our first radial point of interest is at ~ 200 AU from the central source where the density is already fairly high (n ~ 10⁷) but $H_X$ is low due to absorption and geometric dilution. We can therefore neglect additional heating of the gas through X-rays and assume $T_{dust} \approx T_{gas}$. For the X-ray spectrum we have fitted a thermal spectrum $\propto \exp(-E/kT_X)$ which is normally used to fit observed spectra toward star-forming regions.

Fig. 1 shows some model results for AFGL 2591 with
3. OBSERVATIONS

In addition to our theoretical models we are also searching for observational X-ray and FUV tracers near deeply embedded objects. We have carried out a survey of the rotational 3–2 transitions of CN, NO, CO$^+$ and SO$^+$ toward a sample of 11 sources – both high- and low-mass – with the James Clerk Maxwell Telescope on Mauna Kea, Hawaii. These high-J transitions probe uniquely the dense gas close to the protostar and filter out the lower density material. CN and NO are detected in all observed sources, but CO$^+$ and SO$^+$ only toward the high-mass YSOs (see also Stäuber et al. 2004b). CO$^+$ is tentatively seen toward one low-mass source, IRAS 16293. Fig. 2 shows the first detections of CO$^+$ and SO$^+$ toward AFGL 2591.

4. FUTURE OBSERVATIONS

Our models have shown that hydrides like CH or CH$^+$ are enhanced due to either inner FUV fields (Stäuber et al. 2004a) or due to X-ray emission from the central source (Stäuber et al., in prep.). However, these lines are not observable with ground based telescopes and are therefore candidates for Herschel-HIFI observations. In order to constrain the size and geometry of the emitting region of ions like CO$^+$ or SO$^+$ the high angular resolution and sensitivity of ALMA are needed. It will then be possible to make precise estimates of the X-ray and FUV flux and maps will reveal whether the emission is really concentrated in the surrounding envelope or whether it is in the outflow cones or even in the protostellar disk. For example, the 0.1 arcsec beam of ALMA represents a resolution of ~ 200 AU toward AFGL 2591 which should be sufficient to resolve the different regions. Such observations will provide new and important information about the evolution of the surroundings of young stellar objects.

REFERENCES