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AMMONIA AS A TEMPERATURE TRACER IN THE ULTRALUMINOUS GALAXY MERGER Arp 220

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Abstract

We present Australia Telescope Compact Array (ATCA) and Robert C. Byrd Green Bank Telescope (GBT) observations of ammonia (NH_3) and the 1.2 cm radio continuum toward the ultraluminous infrared galaxy merger Arp 220. We detect the NH_3(1,1), (2,2), (3,3), (4,4), (5,5), and (6,6) inversion lines in absorption against the unresolved, (62 ± 9) mJy continuum source at 1.2 cm. The peak apparent optical depths of the ammonia lines range from ~0.05 to 0.18. The absorption lines are well described by single-component Gaussians with central velocities in between the velocities of the eastern and western cores of Arp 220. Therefore, the ammonia likely traces gas that encompasses both cores. The absorption depth of the NH_3(1,1) line is significantly shallower than expected based on the depths of the other transitions. The shallow (1,1) profile may be caused by contamination from emission by a hypothetical, cold (≲ 20 K) gas layer with an estimated column density of ≲ 2 × 10^{14} cm^{-2}. This layer would have to be located behind or away from the radio continuum sources to produce the contaminating emission. The widths of the ammonia absorption lines are ~120-430 km s^{-1}, in agreement with those of other molecular tracers. We cannot confirm the extremely large line widths of up to ~1800 km s^{-1} previously reported for this galaxy. Using all of the ATCA detections except for the shallow (1,1) line, we determine a rotational temperature of (124 ± 19) K, corresponding to a kinetic temperature of T_{kin} = (186 ± 55) K. Ammonia column densities depend on the excitation temperature. For excitation temperatures of 10 K and 50 K, we estimate $N(NH_3)$ = (1.7 ± 0.1) × 10^{16} cm^{-2} and (8.4 ± 0.5) × 10^{16} cm^{-2}, respectively. The relation scales linearly for possible higher excitation temperatures. Our observations are consistent with an ortho-to-para-ammonia ratio of unity, implying that the ammonia formation temperature exceeds ~30 K. In the context of a model with a molecular ring that connects the two nuclei in Arp 220, we estimate the H_2 gas density to be ~$f_V^{-0.5}$ × (1-4) × 10^3, where f_V is the volume filling factor of the molecular gas. In addition to ammonia, our ATCA data show an absorption feature adjacent in frequency to the NH_3(3,3) line. The line does not appear in the GBT spectrum. If we interpret the line to be from the OH $^2\Pi_{3/2}$ J = 9/2 F = 4-4 transition, it would have a line width, systemic velocity, and apparent optical depth similar to what we detect in the ammonia lines. Comparing the new line to the previously detected 6 GHz OH $^2\Pi_{3/2}$ J = 5/2 F = 2-2 transition, we determine a rotational OH temperature of ~245 K, about two times the rotational temperature of ammonia. If this association with OH is correct, it marks the first detection of the highly excited (~511 K above ground state) $^2\Pi_{3/2}$ J = 9/2 F = 4-4 OH line in an extragalactic object.

Keywords
ISM: molecules; galaxies: individual (Arp 220); galaxies: ISM; galaxies: nuclei; galaxies: starburst; radio lines: galaxies

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