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Extragalactic Ammonia

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Abstract. Multi-line data of ammonia (NH_3) are presented for Maffei 2, IC 342, and the starburst galaxies NGC 253 and M 82. While in M 82 the NH_3 emitting gas is cool, presumably arising from well shielded dense cores deeply embedded in an environment dominated by Photon Dominated Regions, the other galaxies show 'warm' and 'hot' components that may be heated by shocks, ion-slip or cosmic rays. Interferometric observations show the detailed large scale distribution of NH_3 in galaxies for the first time. The first multi-line studies of ammonia at significant redshifts ($z = 0.65$ and 0.89) are also reported and rotational temperatures, measures of the kinetic temperature of the emitting gas, are derived for all sources.

Ammonia (NH_3) is one of the most important species to trace physical parameters of molecular clouds. While in the Galaxy inversion lines up to (J,K)=(18,18), 3130 K above the ground state, have been detected, previous studies of extragalactic NH_3 were mainly confined to low excitation transitions in IC 342 (e.g. Martin & Ho 1986), a nearby face-on spiral similar to the Milky Way.

While H_2 number densities can be derived from a variety of molecular species, ammonia can also be used to estimate kinetic temperatures by calculating relative populations in meta-stable (J=K) inversion doublets. The procedure is straightforward in galactic sources, where hyperfine splitting permits the direct determination of optical depths and column densities. Extragalactic lines, however, cover such a large velocity range that it is impossible to resolve the HF structure, so optically thin line emission has to be assumed. If we adopt this (unproven) assumption, the determined rotation temperatures ($T_{\rm rot}$) are lower limits to the true kinetic temperature.

New spectra were taken with the Effelsberg telescope toward the central regions of nearby galaxies. Towards IC 342, the detected (J,K)=(1,1) ... (6,6) and the tentatively detected (9,9) line, 848 K above the ground state, reveal a

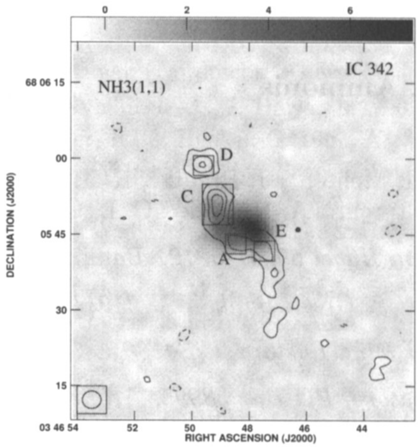

Figure 1. NH_3 (J,K)=(1,1) (contours) and 1.3 cm continuum (grayscale) emission towards IC 342.

'warm' ($T_{\rm rot}$~50 K) and a 'hot' ($T_{\rm rot}$>100 K) component, similar to the other 'normal' spiral we observed, Maffei 2. Towards the starburst galaxy NGC 253, a 'hot' component dominates the emission up to the (J,K)=(6,6) transition. Towards the other observed starburst galaxy, M 82, weak lines reveal a surprisingly 'cold' component with $T_{\rm rot}$~30 K, inferring $T_{\rm kin}$~50 K (Weiß et al. 2001; Mauersberger et al. 2003). 60μm/100μm dust temperatures are of order 50 K in all sources, consistent with the cold NH_3 component in M 82, but lower than $T_{\rm kin}$ in the 'warm' and 'hot' NH_3 components.

What can heat the gas to temperatures of 100 K or more? Shocks, perhaps caused by bar-like potentials or the dissipation of tidal motions, cosmic rays and ion-slip in the presumably strong magnetic fields of the nuclear regions can all heat significant volumes of gas to high temperatures. The warm ($T_{\rm kin}$~150 K) gas fraction as determined from H_2 emission lines (Rigopoulou et al. 2002) appears to be highest in M 82, where no hot ammonia component was detected and where the fractional NH_3 abundance was $<10^{-9}$ in comparison to normal abundances (by galactic standards), i.e. $10^{-7\ldots-8}$, in the other sources. Apparently, NH_3 traces a different molecular gas component in M 82 than in NGC 253, Maffei 2 and IC 342. For M 82, the presence of an intense dissociative radiation field and the predominance of warm molecular filaments with low H_2 column density explains not only the low abundance of NH_3 and other molecules like CH_3OH, SiO and CH_3CN, but also the excitation of CO. The low abundance of ammonia with its low photodissociation energy of ~4 eV, the properties of the CO emission (Mao et al. 2000) and the detection of abundant HCO (García-Burillo et al. 2002) indicate that PDRs are the main heating source in M 82, in contrast to NGC 253, Maffei 2 and IC 342.

The first high resolution images of NH_3 in galaxies have been obtained with the VLA. D-array images of Maffei 2 and IC 342 taken in the (1,1) and (2,2) lines reveal all the single-dish flux from the inner 40″ (see Fig. 1). In IC 342, the nuclear region, 'cloud B' (see Downes et al. 1992), is devoid of ammonia, while in Maffei 2 NH_3 is observed along the nuclear bar. Individual extended regions can be identified in both lines. In NGC 253, the (3,3) line was observed with the

CnD array, revealing an overall distribution compatible with that of CS (Peng et al. 1996).

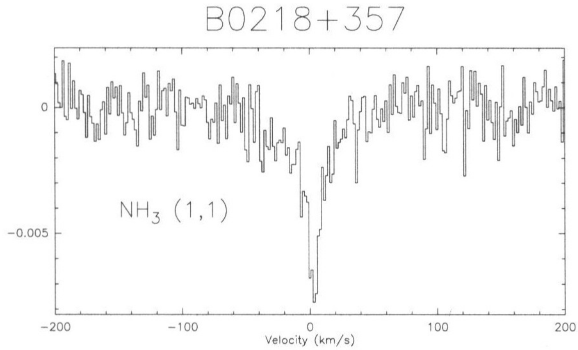

Figure 2. NH_3 spectrum towards B0218+357.

While until recently the most distant source detected in NH_3 was M 51 ($D\sim10$ Mpc; Takano, priv. comm.), new measurements with the 100-m telescopes at Effelsberg and Green Bank (GBT) reveal for the first time significantly red shifted line absorption, towards the gravitational lenses B0218+357 (z=0.68466) and PKS 1830–211 (z=0.88582). In the former source, detected lines up to (J, K) = (3,3) indicate $T_{\rm rot}\sim30$ K (for a spectrum, see Fig. 2). Towards PKS 1830–211, detected lines up to the (7,7) transition, 535 K above the ground state, demonstrate the presence of a 'hot' component. In view of the fact that high temperatures reduce fractionation effects, it is not surprising that searches for DCN or DCO^+ did not yield positive results.

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