MAPPING THE DISTRIBUTION OF THE PREBIOTIC MOLECULE METHANIMINE AND HCN IN ARP220

1 Scientific Justification

Starbursts in galaxies are often triggered by external dynamical disturbances such as galaxy mergers. The dust heating associated with these intense bursts of star formation within giant molecular clouds can produce hugely increased IR luminosity and conditions favorable for maser emission with luminosities that are orders of magnitude greater than their counterparts in our Galaxy [3]. Ultra Luminous Infrared Galaxies (ULIRGs) are thought to be systems where all of these processes are occurring simultaneously [10, 15, 24]. Obscured AGNs in these objects are also considered to be an alternative (or additional) energy source, fueled by molecular gas falling into the central regions of these merging systems [11, 18, 24, 26, 27, 29, 30]. Molecular gas is thus one of the most important constituents of the ISM, playing a critical role in the evolution of these galaxies.

Over 140 molecules have now been identified in space, mostly in the ISM of our Galaxy. Some of these are rather complex, containing as many as 8 to 13 atoms. Interstellar organic molecules are thought to form mostly on the surface of dust grains. Heating events, such as the formation of a protostar, release the icy grain mantles into the gas phase [5, 21]. Once released, these molecules may form amino acids by the combination of organic species known as pre-biotic molecules [4]. We note that non-gas phase reaction pathways for the formation of extraterrestrial amino acids have been described in [9]. Methanimine is one such molecule (CH2NH; [14]) which can form the simplest amino acid, glycine (NH2CH2COOH), either by (i) first combining with hydrogen cyanide (HCN) to form aminoacetonitrile (NH2CH2CN), with subsequent hydrolysis (Strecker Synthesis; 8], or (ii) directly combining with formic acid (HCOOH) [13]. Methanimine has been previously detected in the ISM of our own Galaxy [7, 13] and tentatively in the nearby galaxy, NGC 253 [19], but never beyond the neighborhood of our Galaxy (i.e. beyond ∼5 Mpc).

The majority of interstellar molecules (both galactic and extragalactic) have been discovered at millimetric wavelengths, as molecules with small moments of inertia are the most abundant cosmically, with their rotational lines occurring at mm or shorter wavelengths. However, although less abundant, many complex molecules have spectral lines in the radio regime for $\lambda > 3$ cm, where "line confusion" does not set a limit to their detectability. Many transitions of small polycyclic aromatic hydrocarbons (PAHs), pre-biotic molecules, and even a number of transitions of the simplest amino acid, glycine, fall within the relatively unexplored spectral range between 1 and 10 GHz. In addition, observations in this frequency range are complementary to mm spectral-line surveys.

Using Arecibo, we are well advanced toward the completion of a spectral-line survey of the prototypical megamaser/starburst galaxy, Arp 220, between 1.1 and 10 GHz. Analysis of the data taken so far reveals a rich molecular spectrum of various cm-wave lines, such as several excited-OH lines, numerous HCN lines, as well as methanol and methanimine [23].

At a distance of ∼77 Mpc (z=0.018126), Arp 220 is the nearest Ultra-Luminous Infra-Red Galaxy (ULIRG) and the prototypical OH megamaser galaxy [3, 6, 16]. Its IR luminosity arises from a powerful, dust-enshrouded starburst triggered by the merger of two counter-rotating gas-rich galaxies [20, 22, 24]. Evidence for this is provided by high resolution optical and radio images, revealing a double-nucleus structure with tidal tails and dust lanes. A huge supernova rate has been found from recent high-resolution VLBI studies [17]. Molecules such as the OH radical [3, 12], CO [25], formaldehyde [2], ammonia [28], and mm-transitions of HCN [1] have been detected in Arp 220. Detailed maps of those lines enable the determination of the velocity structure in this merger system.

The methanimine line ($\nu_0 = 5289.8$ MHz) detected in our Arecibo observations shows a broad emission feature covering all six transitions of the C-band $1_{10} - 1_{11}$ multiplets (rest frequency $\nu_0 \sim 5289.8$ MHz; Fig. 1). The velocity width (FWHM) of the discovered line is 270 km/s; similar to the large velocity widths observed for almost all molecular spectra in Arp 220 (e.g. [28]). Contrary to all the other transitions discovered in our Arecibo observations, which are seen in absorption, methanimine is seen in emission, and as for formaldehyde in Arp 220 [2], this molecule is likely to be showing weak maser emission for this transition. Therefore, it is important to image the methanimine emission at high angular resolution to delineate the physical conditions and the actual sites for the origin of this prebiotic molecule.

Our Arecibo observations detected the HCN molecule in absorption at various frequencies corresponding to J= 2, 3, 4, 5, 6 vibrational levels of the $v_2 = 1$ direct l-type transitions [23]. None of these low level vibrational transitions have been previously detected in any celestial source. They all represent a high excitation energy above the HCN ground state (e.g. 1067 K for J=4 level). Two of these lines that are seen at C-band correspond to J=4 and J=5 vibrational levels, and have velocity widths (FWHM) of 363 and 330 km/s, respectively [23]. The linear correlation between $L_{\rm IR}$ and $L_{\rm HCN}$, as seen in mm-wave HCN observations, marks out HCN as the best tracer of dense molecular gas mass in galaxies, and hence of active star-formation. Our recent Arecibo discovery of these HCN lines, and follow-up interferometric observations, provide a unique window to study this well known indicator of high-density gas in starburst environments at cm-wavelengths.

Here we propose to carry out simultaneous C-band HCN and methanimine observations using all available EVLA antennas in A-configuration to image and study these lines in the ULIRG Arp 220 with a velocity resolution of $\sim$ 40 km/s. The requested array configuration will provide sub-arcsecond resolution at this frequency band, which is essential to spatially separate the two nuclei of the target source that are separated by $1''$, and measure their contribution to the total intensity of the lines seen with Arecibo. Furthermore, the requested velocity resolution will be adequate to obtain a view of the velocity field traced by these two molecules in each of the two nuclei. In this project, and of the two HCN lines seen at C-band, namely the J=4 level at $\nu_0 = 4488.5$ MHz and J=5 level at $\nu_0 = 6731.9$ MHz, we plan to image the J=5 absorption line ($\tau_{\rm peak} = 0.0205 \pm 0.001$; Fig. 2), because it has a higher optical depth compared to the J=4 line ($\tau_{\rm peak} = 0.016 \pm 0.001$). Moreover, the velocity and spatial resolution of the proposed observations for the J=5 HCN line will make it possible to study the three distinct absorption peaks seen in its spectrum (Fig. 2). These peaks appear more blended, and harder to distinguish, in the J=4 HCN spectrum [23].

2 Observational Requirements

We request to use the EVLA to carry out simultaneous spectral-line observations targeting two recently discovered cm-wave molecular lines in the ULIRG Arp 220, methanimine ($\nu = 5195$ MHz) in emission, and HCN ($\nu = 6612$ MHz) in absorption. Considering that Arp 220 has two nuclei separated by $1''$, the observations require the use of the array in A-configuration to be able to spatially separate them.

Benefiting from the wider frequency coverage of the EVLA antennas, as well as their flexible tuning ranges, we will utilize all four IFs of the current VLA correlator, with each IF pair tuned to the frequency of one of the targeted lines to observe both of them simultaneously. Using 12.5 MHz bandwidth with 16 spectral channels will deliver a spectral resolution of 0.78 MHz, i.e. 36 km/s for HCN and 46 km/s for methanimine, adequate to image these two spectral lines. The resulting velocity resolutions are comparable to those in the Arecibo spectra (Figs. 1, 2), and would be suitable to image these very wide (270–330 km/s) spectral lines. The requested bandwidth will also provide a few MHz of line-free channels for proper continuum imaging and subtraction.

Considering the higher SEFD values of the current C-band receivers at the proposed frequencies, we will achieve an rms noise level of ~ 0.23 mJy/beam/channel after 8 hours of on-source integration time. Including overhead for calibration, the total requested time is 10 hours.

The proposed observations will not only lead to the study of the spatial and the velocity distribution of these two molecules in Arp 220, and hence their physical conditions, but we hope it will serve as a demonstrator and a prelude for the unique capabilities of the EVLA in molecular-line studies at cm-wavelength, specially when the array becomes fully equipped with the sensitive, wide-band, receivers and the WIDAR correlator.

3 References

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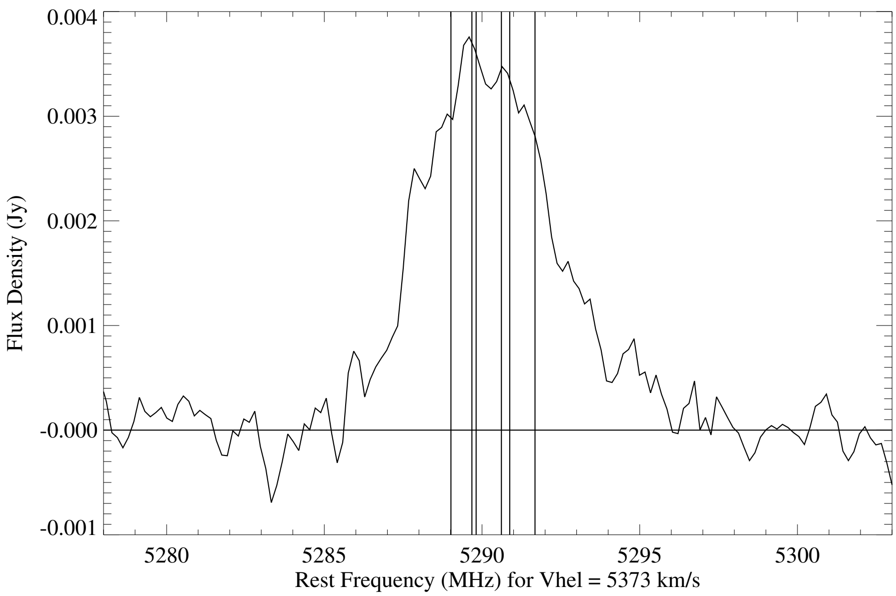

Figure 1: Newly discovered C-band spectrum of the blended emission line from the six $1_{10} - 1_{11}$ multiplet transitions of methanimine (ch$_2$nh) in Arp 220. the frequencies of the six transitions are indicated by vertical lines. The velocity resolution is $\sim$ 30 km/s [23].

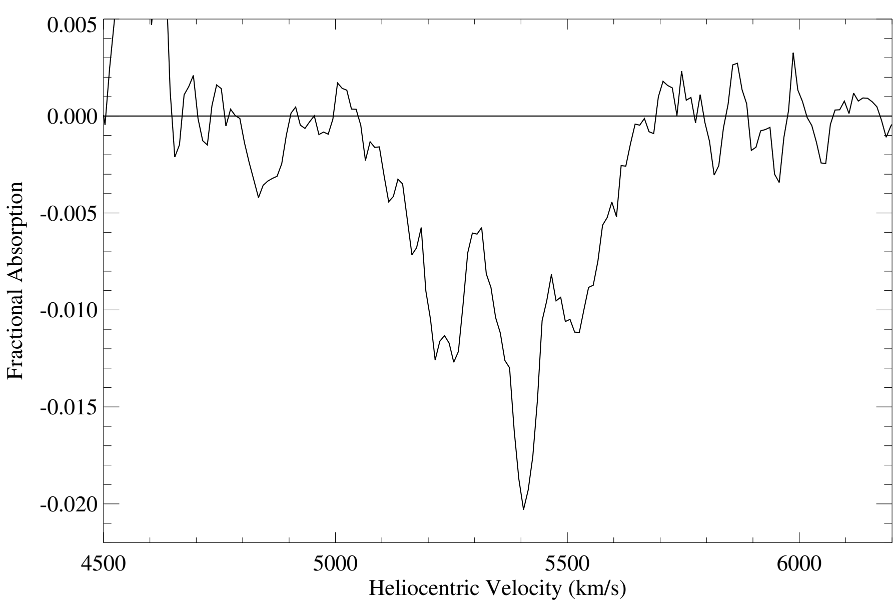

Figure 2: Newly discovered C-band absorption spectrum of the HCN $v_2 = 1$ direct l-type transition in the J=5 vibrational level at 6732 MHz in Arp 220. The velocity resolution is $\sim$ 30 km/s [23]. The depth of the peak absorption feature in this spectrum is 3.5 mJy.