Molecular Line Surveys with Arecibo

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1 Introduction

Recent Arecibo observations of Arp 220 have demonstrated the power of using the 305-m dish as a 'photon bucket' to detect molecular species at extragalactic distances. So far, the Arp 220 Spectral Survey has made the first detection of the pre-biotic molecule Methanamine (CH_2NH) outside of the Local Group, has seen three cm-wavelength transitions of HCN that had not previously been observed, has detected three transitions of excited OH that were not previously known in Arp 220, has detected an absorption feature of either ^{18}OH or Formic Acid (HCOOH), and has seen a possible absorption feature from Methanol (CH_3OH) which, if confirmed, would again be the first detection beyond the Local Group, and the first extra-galactic detection in absorption.

The current observations are taking data for 1 hour on-source. However, the total time required for the project is considerably longer due to the need to switch between different receivers and the need to take multiple observations within each receiver due to the current limits on the instantaneously available bandpass. Future developments in instrumentation, in particular a 1-10 GHz receiver, and a wide-band backend, could reduce the time taken for such a project by more than an order of magnitude if the whole frequency range were observable in a single shot.

This would allow much deeper spectral surveys of nearby sources, such as Arp 220, with the possiblity of discovering more molecular species in these galaxies, and/or similar sensitivy spectral surveys of more distant galaxies, reaching galaxies over a much larger volume than is currently possible in a given amount of telescope time.

2 The Arp 220 Spectral Survey

The Arp 220 Spectral Survey will, when completed, cover the spectrum of the galaxy almost contiguously over the frequency range 1-10 GHz. Using the dual-board mode of the WAPPs, 680 MHz of instantaneous bandwidth is available with a frequency resolution of 25 kHz. The project uses the L-band, S-low, S-high, C-band, C-high and X-band receivers to cover the full frequency range, with multiple observations being necessary to cover the complete range of most of the individual receivers. In total, twelve frequency bands are observed to build up the spectral coverage, with the eventual target of reaching one hour on-source in each band, or twelve hours on-source in total.

Two of the major discoveries of the Arp 220 Spectral Survey are shown in Figures 1 and 2. Figure 1 shows the methanamine (CH_2NH) emission seen in

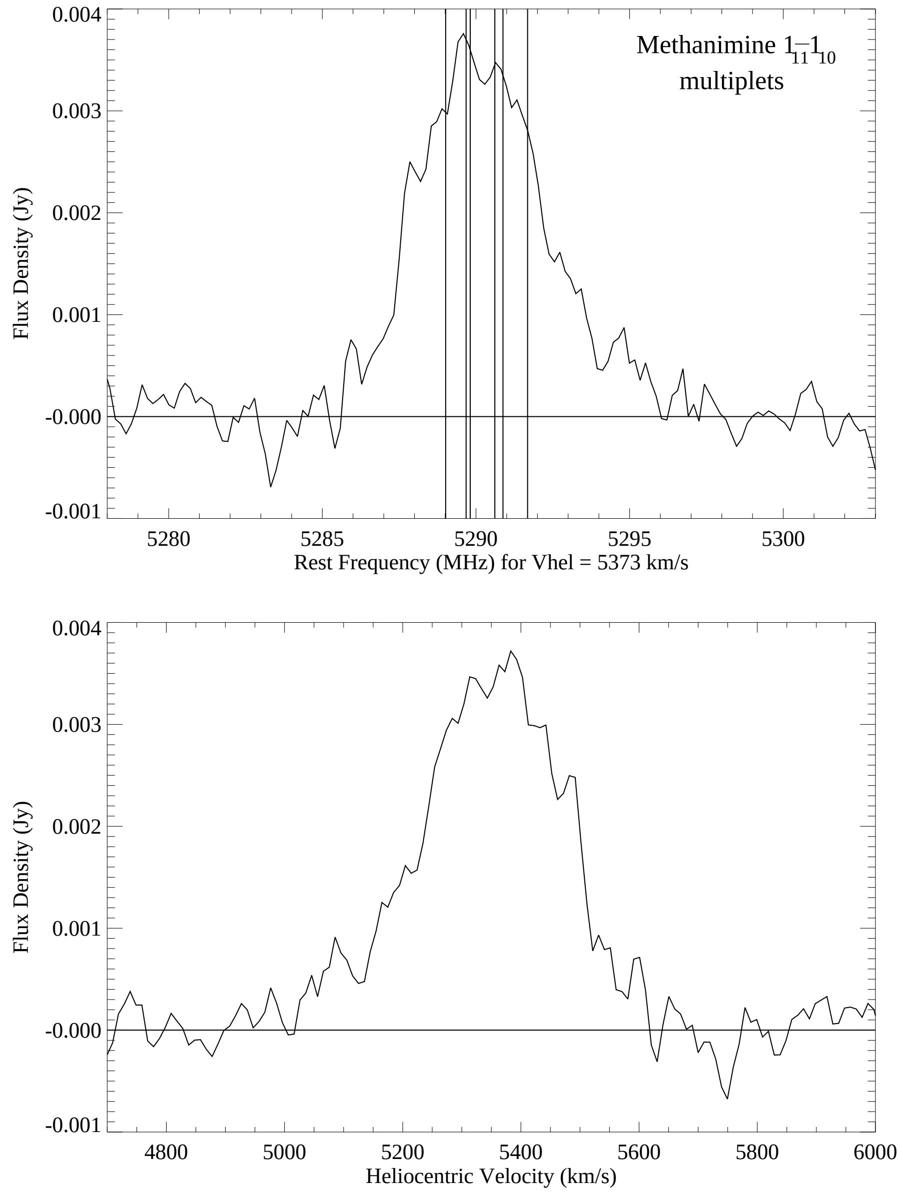

Figure 1: These two plots show the blended line from the six $1_{10} - 1_{11}$ multiplet transitions of methanimine which is seen in emission. The upper diagram shows the absorption feature in the rest frequency after having been corrected for an assumed heliocentric velocity of 5373 km/s. The six transitions are indicated by vertical lines. The lower diagram shows the feature as a function of heliocentric velocity using the expected strongest line in the multiplet.

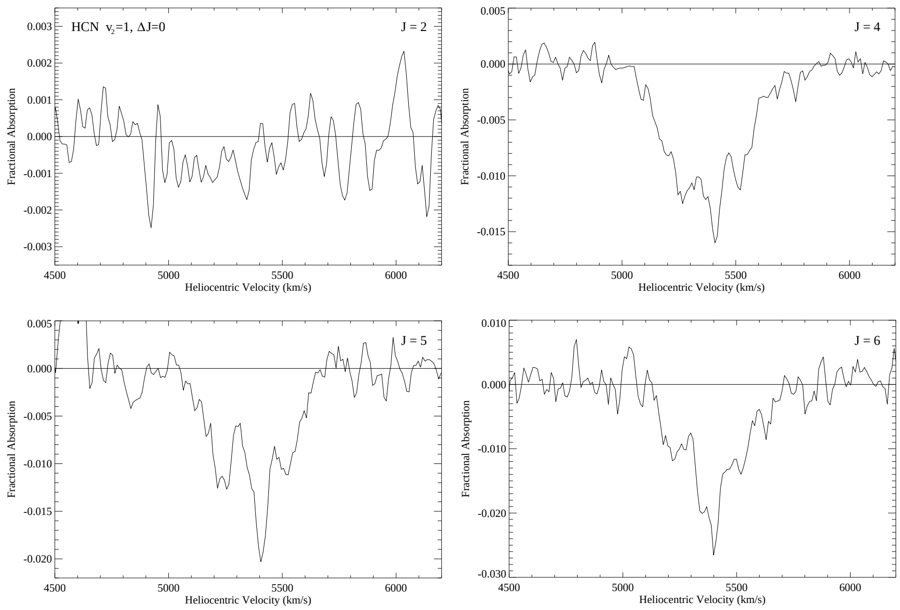

Figure 2: These plots show the first astronomical detection of the the $v_2 = 1$ direct l-type absorption lines of HCN with vibrational levels J=4, 5 and 6. The non-detection of the J=2 vibrational level is also included in the figure.

this galaxy. This is the first definite detection of methanamine outside of the our Galaxy (there is a tentative detection of a mm-line in NGC 254 by Martín et al. 2006). Methanamine is a pre-biotic molecule which can play a part in forming glycine, the simplest amino acid, either indirectly through combining with hydrogen cyanide (HCN) and then reacting with water molecules, or directly through combining with formic acid (HCOOH). The methanamine in Arp 220 appears to be a kilo-maser or a mega-maser, similar to the Formaldehyde (H_2CO) mega-maser already known in this galaxy. This raises the prospect that it could be seen in other galaxies, even in the absence of a strong continuum source which would be necessary to see absorption lines.

Figure 2 shows three detections and one non-detection of the four l-direct transitions of hydrogen cyanide (HCN) that were observed. A fifth transition falls within a band that was not available during the observations as the receiver was offline, but which will be observed when Arp 220 is next a night-time object. These cm-wavelength transitions of HCN have not been previously detected in any celestial source. In addition to the possibility of combining with methanamine to form glycine (above), HCN is also a tracer of dense molecular gas in galaxies, and hence of active star-forming regions.

3 Future spectral surveys

3.1 Extragalactic surveys

From the IRAS-NVSS catalogue (Yun et al. 2001), 25 galaxies can been identified within the Arecibo sky[1] with 60-μm luminosities $L_{60} > 10^{10} L_{\odot}$ and L-band fluxes $S_L > 80$ mJy. By scaling from their continuum fluxes, it is possible to work out how long an integration time would be needed to reach the same relative sensitivity as in Arp 220 – which is what is vital for detection of absorption lines. A project to carry out a spectral survey of all 25 galaxies to the same relative sensitivity to absorption as Arp 220 would require around 600 hours of telescope time, allowing for observations on-source, off-source and of a nearby continuum source. This compares very favourably with the 6,600 hours needed with the current system. The continuum flux is also known to be proportional to the star formation rate, so if this is there is a proportionality between this as maser emission then we would also expect to detect masers in these galaxies.

This would extend the science that has been done on an individual basis in Arp 220 to a large sample of galaxies that could then be interpreted statistically. For instance, it would be possible to see if the strength of the methanamine maser is related to the star-formation rate, or whether its presence in Arp 220 is simply a one-off. In addition, one could determine whether or not extragalactic methanol is common.

A second future survey could be to go an order of magnitude deeper on Arp 220 and other nearby ULIRGs. Rather than taking 100 times as much time as the current survey, the increase in speed would mean this would need around eight times longer. Thus Arp 220 could be observed with an order of magnitude greater sensitivity in 100 hours on-source (around 300 hours total telescope time). Such a survey would undoubtably uncover new lines, possibly even amino acids such as glycine, and would facilitate studies not only of the molecular transitions but also of radio recombination lines. Covering Arp 220, along with a couple of other ULIRGs with strong continuum, such as NGC 660 and NGC 6240, to an order of magnitude greater sensitivity than the large sample would take around 900 hours.

3.2 Galactic surveys

The same principles as noted above for the extra-galactic surveys apply equally to galactic sources. A 1-10 GHz wide-band system would allow unprecendented sensitivity levels to be reached on many interesting molecular clouds within the Arecibo sky, which would certainly to discover previously undetected molecules and transitions. Surveys of large numbers of sources could be carried out, or even more sensitive surveys of a few identified clouds. This would allow the chemical make-up of these clouds to be analysed with unprecedented levels of sensitivity and knowledge of their cm-wavelength transitions.

[1]The Arecibo sky is taken here to be the declination range $0° – 37°$, where sources can be tracked for at least 1 hour