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The Extended $CO(3-2)$ Emission in the Protogalaxy IRAS F10214+4724

Robert L. Brown[1]

National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903-2475

Abstract. Preliminary observations of the $z = 2.286$ protogalaxy in the redshifted $J = 3-2$ transition of CO made with the Owens Valley Radio Observatory array suggest that the CO emission is spatially extended. This is particularly evident in the narrow band spectral channels. There are indications of CO emission regions in the field of IRAS F10214+4724 that are not related to the IRAS galaxy.

1. Introduction

The single dish observations of redshifted $CO(3-2)$ in the $z = 2.286$ protogalaxy IRAS F10214+4724 discovered by Rowan-Robinson et al. (1991) are sufficient to provide good evidence for an enormous accumulation of molecular material early in the history of the universe, and they even provide a reasonable estimate of the total molecular mass involved (Brown and Vanden Bout 1992, 1992a). But with limited angular resolution they cannot establish the relationship of the CO emission uniquely with the IRAS galaxy, or any other object in the field, and neither do they provide an estimate of the size of the CO emission region or of its kinematics. Aperture synthesis observations are needed for these purposes.

Interferometric observations of the $CO(3-2)$ emission from IRAS F10214 +4724 have been reported from the Nobeyama Array (Kawabe et al., 1992; Sakamoto et al., 1992) and from the IRAM interferometer (Radford et al., 1993). Those observations provide convincing evidence for the association of the CO "cloud" with the position of the IRAS galaxy. Hence they constitute the proof needed for the conclusion that IRAS F10214 +4724 is indeed a galaxy whose mass is dominated by its gaseous component, not (yet) by stars. In this sense it is a true protogalaxy.

The previous aperture synthesis observations were made with large spectral resolution, 140-185 km s^{-1}, so only a limited amount of information is available on the kinematics of the CO distribution. Partially to address this latter question, we observed the source with the Owens Valley Radio Observatory array with 22 km s^{-1} velocity resolution.

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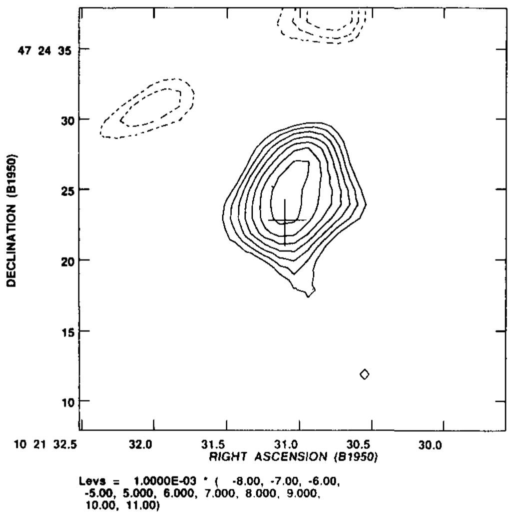

Figure 1. The $CO(3-2)$ emission in a spectral channel centered at a systemic velocity of -70 km s^{-1} (relative to $z = 2.2867$) and with a velocity width of 140 km s^{-1}.

2. Observation and Discussion

Over the winter of 1991-92 the $CO(3-2)$ emission of IRAS F10214+4724 was observed with nine configurations of the 3-element OVRO array and baselines as long as 300 m. The details are discussed elsewhere (Brown et al., 1993). The correlation spectrometer provided 128 spectral channels of 11 km s^{-1} velocity resolution. The data cube was averaged over two channels providing a final cube of 64, 22 km s^{-1} spectral channels.

Figure 1 shows an average of seven spectral channels centered on a systemic velocity of -70 km s^{-1}. This map has a velocity coverage identical to that of the IRAM map (Radford et al., 1993) and similar to the -24 km s^{-1} channel map of Sakamoto et al. (1992). It shows a single CO emission component centered near, but slightly offset from, the VLA radio source position of IRAS F10214+4724. Both the OVRO observations (Kawabe et al., 1992 and Sakamoto et al., 1992) and the IRAM observations (Radford et al., 1993) produce this same result.

However, the narrow OVRO spectral channels which went into the average shown in Figure 1 reveal substantial velocity and spatial structure in the line. Figure 2 is one velocity channel, that at a systemic velocity of -29 km s^{-1}. In this map we see that the CO emission region near the IRAS galaxy bifurcates into two clumps, one north and one south of the IRAS galaxy. The separation between the two clumps is approximately 6" ($\sim$ 25 kpc). In addition, there are two other CO emission regions present in this velocity channel that are spatially unrelated to the IRAS galaxy, one to the northeast and the other to the southeast. Preliminary indications from the OVRO observations are that these field emission regions are localized both spatially as well as in velocity. If they are real they indicate that IRAS F10214+4724 is forming together with

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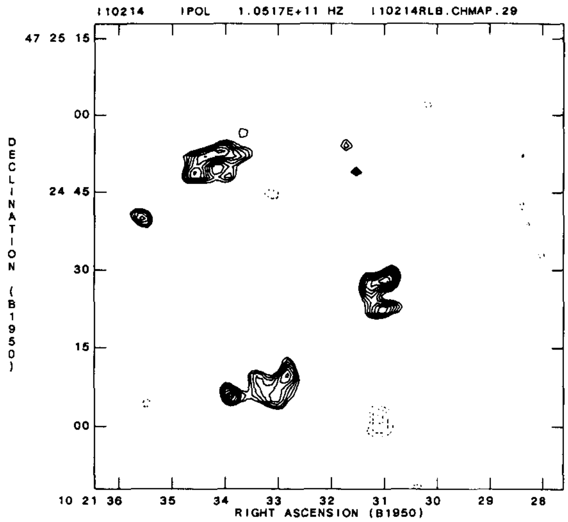

Figure 2. The $CO(3-2)$ emission in a spectral channel centered at a systemic velocity of -30 km s^{-1} (relative to $z = 2.2867$) and with a velocity width of only 22 km s^{-1}. Contour levels begin at $\pm$ 12 mJy/beam and increment at 2 mJy/beam.

a cluster of like objects, perhaps a protocluster of galaxies. They would also, of course, begin to explain the discrepancy between the large and small beam, single dish $CO(3-2)$ observations of IRAS F10214+4724 noted by Kawabe (these proceedings).

Analysis of these data is continuing.

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DISCUSSION

L. Avery You show several sources in your OVRO map including object F associated with IRAS 10214. Were any of these other sources seen in the VLA radio map?

R. Brown The present VLA map is a 10 minute "snapshot " observation. It does not show any other source in the field. I understand efforts are underway to observe for many hours and produce a very sensitive VLA image but there are no results yet.

S. Ishizuki How many sigmas at the peak? Is the rms is calculated from system noise temperature, or measured in the map statistically?

R. Brown At the map peak, in this one velocity channel, the signal appears to be 5-6 sigma.

J. Kenney How would you characterize the velocity field of the CO as seen in the OVRO map?

R. Brown We haven't completed our analysis of the data cube and can't yet address this question which is, of course, our primary motivation for doing observations.

P.T.P. HO
1) The extended stuff at the edge of the primary beam seems hard to believe. If corrected for primary beam attenuation, the signal would be huge in a single dish map.
2) Contouring at these linear steps with a high cut off in the lowest contour makes t difficult to judge statistical significance.
3) If this is really a proto-cluster or proto-galaxies, I am surprised that the emission could be that close in velocities. Perhaps that could be checked in a comparison of observed velocities and model of expected velocities in a cluster environment.

R. Brown The present OVRO maps are data that we are still working with, not final images. The single dish observations suggest that there exists a significant flux off the central position; The outlying sources seen here could be the sources of that flux. The image seen here is a single velocity channel and we haven't completed the analysis of the cube.

R. Genzel If these is an extended "protocluster" the obvious question is whether multi-object optical spectroscopy has tuned up any additional high-z sources?

R. Brown The optical observations are being done in Hawaii. I know of no results yet.