

Direct Detection CO J=7→6 Spectroscopy: First Light with SPIFI

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1. Introduction, Scientific Motivation

Spectroscopy in the submillimeter bands represents a unique opportunity to study the excited atomic and molecular ISM. The submillimeter spectral lines probe interstellar gas which is heated by star formation UV and shocks in cloud-cloud collisions. Our primary tracers are the 370 μm [CI] and 372 μm CO (7→6) lines. Both are upper-level transitions, and thus not subject to foreground absorption or contamination from cold material. Because of their high excitation requirements, the mid-J CO lines typically arise in warm, dense molecular material of PDRs and shocked molecular flows. The 370 μm [CI] line is more easily excited, and is optically thin, making it an excellent tracer of mass. When combined with the 609 μm [CI] line, the 370 μm line also provides a reliable temperature probe for the C⁰-bearing regions. To the limited extent that these lines have been observed, heterodyne techniques have been used. However, a direct detection system can be made more sensitive, with greater bandwidth, and is naturally suited to spatial multiplexing. We present the first direct-detection imaging submillimeter spectrometer, SPIFI.

2. SPIFI Design

SPIFI employs two cryogenic scanning Fabry Perot Interferometers with metal-mesh mirrors to provide a spectral resolution variable from 300 to 30 km s^{-1} . The detectors are a 5×5 array of Goddard Si bolometers cooled to 60 mK which provide near background limited performance. The optical system is designed to fit the 1.7 m AST/RO telescope at the South Pole and the 15 m JCMT telescope on Mauna Kea. More information can be found in Bradford *et al.*, (2000, in prep), and at astrosun.tn.cornell.edu/research/projects/spifi.html.

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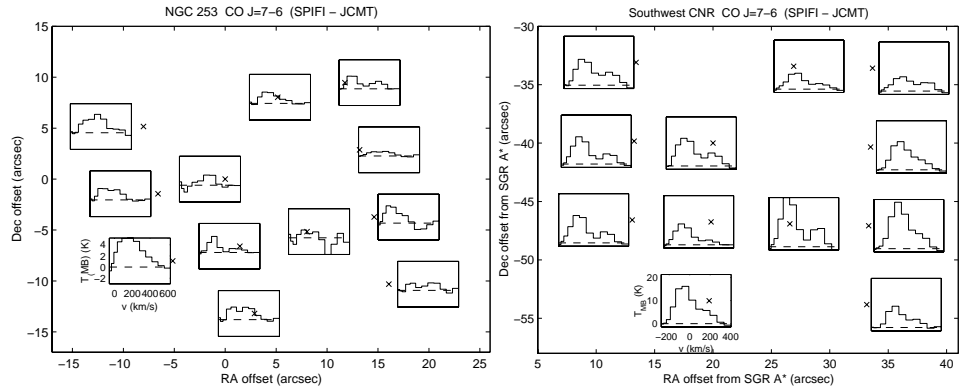


Figure 1. SPIFI Array footprints of CO 7→6 toward the nucleus of NGC 253 (left) and the SW region of the Galactic Center CNR (right).

3. First Light Results

In April 1999, SPIFI had first light at the James Clerk Maxwell Telescope on Mauna Kea, HI. On this run, 12 of our 15 installed detectors were functional, and the sensitivity at the telescope was very close to predicted. We measured system temperatures of 10000 - 12000 K with an atmospheric transmission of 0.08, which corresponds to $T_{rec} = 30$ K (DSB) (see JCMT web page). Our primary source was the Galactic Center Circumnuclear Ring, in which we observed CO 7→6 in 13 array pointings (each with 12 positions), mapping a $1.5' \times 1'$ region with $7''$ resolution. A preliminary reduction of one of the pointings toward the SW portion of the region is shown in Figure 1 (right). In this portion, there is prominent emission of the CNR at -100 km s^{-1} as well as emission at $+100$ km s^{-1} , likely associated with the $+70$ km s^{-1} streamer observed in HCN (see Jackson et al, 1993 ApJ **402**, 173). We also observed the nuclei of starburst galaxies NGC 253 (see Fig. 1, left) and M82, and found CO 7-6 lines of 3 - 5 K and 1 - 1.5 K, respectively. These are the first detections of this transition in extragalactic sources, and the intensities are in good agreement with the lower J CO observations (see Wild et al, 1992, A&A 265, **447** and Israel, White, and Baas, 1997 A&A **317**, 299).

4. Future Plans

In the near future, we will upgrade the SPIFI array to 5×5 pixels, and intend to continue observing at the JCMT and AST/RO. Our initial projects include the mapping of the Galactic Center Region and the nearby starburst galaxies in both [CI] and CO lines. We also plan to observe these lines in distant ultraluminous systems such as Arp 220. The [CI] and CO observations can address the low [CII] intensity recently observed in these systems (see Luhman et al, 1994, ApJ 504, L11) by probing the UV field strength and hardness, and the column density of excited gas. At even greater distance, SPIFI has the sensitivity to observe bright far-IR fine structure lines such as [CII] from high-redshift objects, providing our first unobscured spectroscopic probe of early-epoch star formation.