SMA spectral survey at 279-355 GHz of the AGB star IK Tau

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Abstract

Broadband spectral surveys of stars are powerful tools to study the **chemical complexity** of their atmospheres and circumstellar envelopes (CSEs). Oxygen-rich asymptotic giant branch (AGB) stars have a rich molecular chemistry, but up to now there have been too few observations to provide comprehensive information on the ongoing chemical processes. We **expand the molecular inventory** for these stars by targeting one object in particular, the **high-mass-loss-rate star IK Tau**. With the Submillimeter Array we carried out a **spectral-line imaging survey** of its CSE in the frequency range 279 – 355 GHz.

Survey

The data were obtained during 10 nights in January and February 2010 using the SMA in its extended configuration. The characteristic angular resolution of the survey is 0.7″ at 345 GHz, and smooth structures larger than ∼5″ are missed. Every track – one per night – covered an instantaneous bandwidth of 8 GHz and lasted for 2 hours. **Fig. 1** shows the spectrum extracted for a square 1″ × 1″ aperture centred on the star. Typical noise values throughout the spectrum range between 0.06 Jy and 0.17 Jy at a 0.8125 MHz frequency resolution. The spectral ranges close to the 325 GHz water vapour line suffer from high noise owing to interfering atmospheric signal.

Molecular inventory

We detect 12 species at high signal-to-noise, CO, HCN, CS, SiO, SiS, H_2O, H_2S, SO, SO_2, NaCl, PN, and PO – 28 when counting all isotopologues – in ∼200 lines. Some of these molecules are seen for the first time towards an oxygen-rich AGB star. Several species, such as SiO, H_2O, and NaCl show emission in vibrationally excited states. We detect emission from molecules containing the low-abundance isotopes ^{13}C, ^{17}O, ^{18}O, ^{29}Si, ^{30}Si, ^{33}S, ^{34}S.

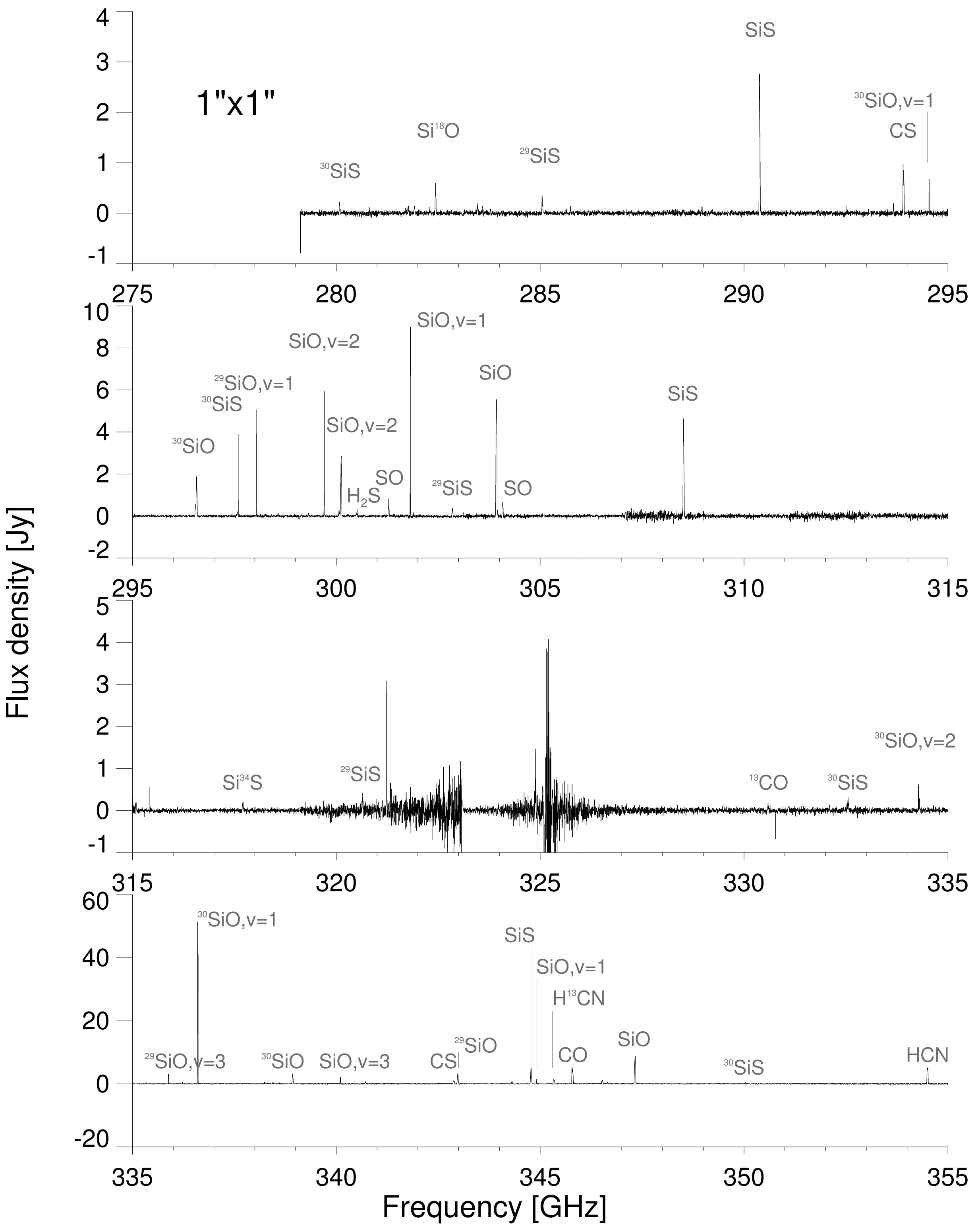

Figure 1: Spectrum extracted for $1'' \times 1''$ square aperture.

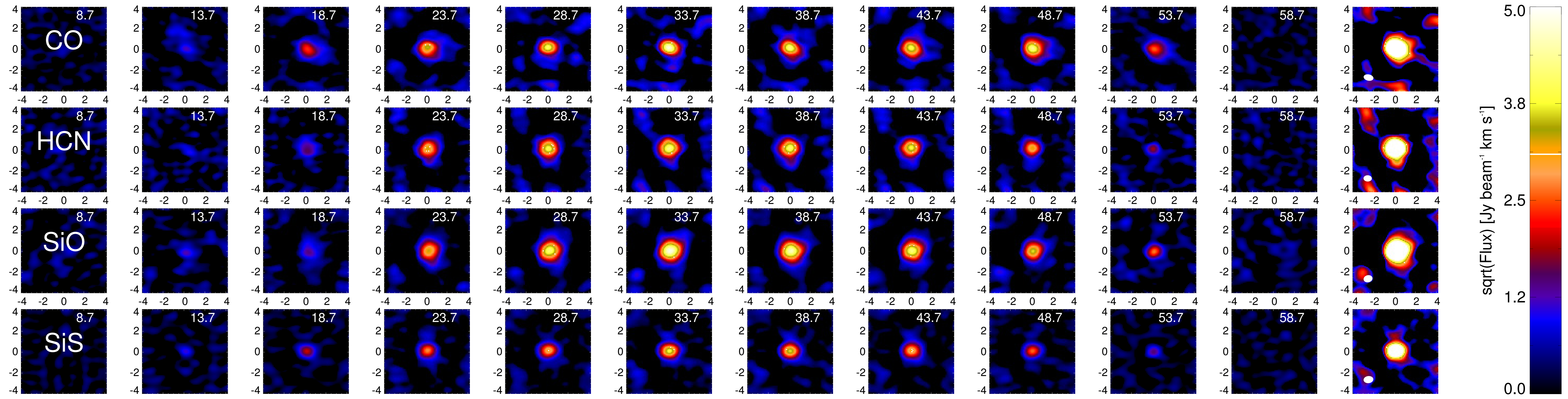

Figure 2: Channel maps at 5 km s^{-1} velocity resolution. Vertical and horizontal axes indicate the offset in arcseconds from the central star. *From top to bottom:* CO($J = 3-2$), HCN($J = 4-3$), SiO($J = 7-6$), SiS($J = 16-15$). The central LSR velocity of each channel is listed at the top of every panel in units of km s^{-1}. The rightmost panels show the integrated-intensity maps, cut off at 25 Jy beam^{-1} km s^{-1}, and the FWHM beam ellipse in the bottom left corner. All maps show the square root of the flux, for visualisation purposes.

Envelope structure

Channel maps of several emission lines, e.g. CO($J = 3-2$) and HCN($J = 4-3$), see **Fig. 2**, indicate possible **deviations from spherical symmetry** in the gaseous component of IK Tau's CSE. We find extra emission predominantly extending in the south-west direction, in agreement with previously reported results based on Keck, ISI, and PdBI interferometric observations, though on different spatial scales (Weiner et al. 2006, ApJ 636,1067-1077; Castro-Carrizo et al. 2010, A&A 523, A59). This could further support the hypothesis that IK Tau's CSE is elongated along a NE-SW oriented axis.

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Phosphorus

Using the SMA and the IRAM 30 m telescope, we observed four rotational transitions of PN ($J = 2-1, 3-2, 6-5, 7-6$) and four of PO ($J = 5/2-3/2, 7/2-5/2, 13/2-11/2, 15/2-13/2$). These are the first detections of PN and PO in an O-rich AGB star. See **Fig. 3** for an overview of the observed PN transitions. We estimate abundances $X(\mathrm{PN/H_2}) \approx 3 \times 10^{-7}$ and $X(\mathrm{PO/H_2})$ in the range $0.5 - 6.0 \times 10^{-7}$. We detect no emission from PH_3 or PS, previously thought to be the major sinks of phosphorus in an AGB CSE. We suggest that PN and PO are the main carriers of phosphorus in the gas phase, with abundances possibly up to several 10^{-7}. The current chemical models cannot account for this, underlining the strong need for updated chemical models that include phosphorous compounds.

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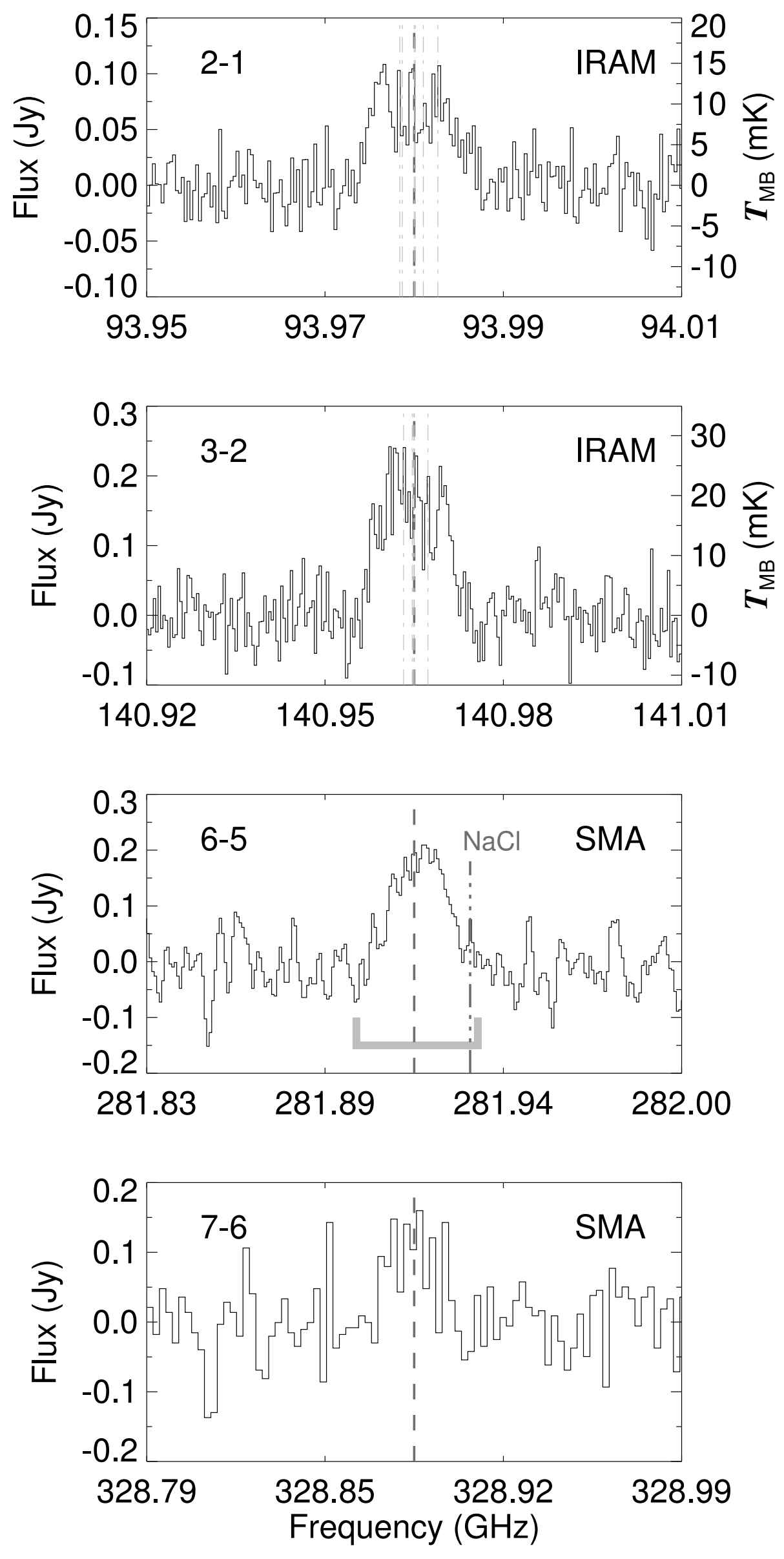

Figure 3: Observed PN lines.