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The Dense Gas Structure and Kinetic Temperature in the Serpens Molecular Cloud

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We present measurements of the CS and H_2CO emission toward the Serpens molecular cloud. Using the recently–developed on–the–fly (OTF) observing technique at the NRAO 12m telescope, we have mapped the region containing the Serpens SMM1 through SMM6 and S68N dust continuum sources. These measurements have allowed us to derive the spatial structure and kinetic temperature toward the dense molecular cores associated with the Serpens dust continuum sources.

Introduction

Infrared and submillimeter continuum measurements of the stellar population in the Serpens molecular cloud have uncovered an extensive ($\sim 10'$) region of active stellar formation. Low-resolution ($\theta_B \gtrsim 2'$) molecular spectral line studies of this region detect a large area of warm, dense material coextensive with the stellar distribution derived from the infrared measurements. The smaller-scale structure of the dense gas in Serpens and its relationship to the ambient young and pre-main sequence stellar population is relatively unknown. To derive the detailed physical conditions within the molecular material and study its interaction with the young and forming stars in Serpens, we have made maps of the CS (carbon monosulfide) and H_2CO (formaldehyde) emission toward this region.

Star Formation in the Serpens Molecular Cloud

At a distance of $\sim$ 310 pc (Chavarria *et al.* 1988), the Serpens molecular cloud is one of the more nearby sites of active star formation. Low-resolution measurements of the CO (Bally & Lada 1983), H_2CO (Loren, Evans, & Knapp 1979), and NH_3 (Ungerechts & Güsten 1984) emission toward this region found a warm ($T_K \simeq$ 20–30 K), dense ($n(H_2) \gtrsim 10^4 cm^{-3}$) core $\sim 5'$ in extent containing a high-velocity outflow. Far-infrared measurements of the region (*c.f.* Zhang *et al.* 1988; Nordh *et al.* 1982) found a number of embedded pre–main sequence (PMS) stars buried within a larger-scale distribution morphologically similar to that derived from the molecular measurements. Near-infrared imaging of the region (Eiroa & Casali 1992) has identified 163 sources of which at least 51 are embedded PMS stars or young stellar objects

(YSO's). One of these objects, designated FIRS1, is an embedded YSO with a triple radio continuum source. The morphology of this radio continuum emission suggests an interaction between FIRS1 and the placental environment from which it formed (Torrelles *et al.* 1992).

Recent high spatial resolution ($\theta_B \simeq 20''$) measurements of the 800 and 1100 μm continuum emission toward the Serpens molecular cloud (Casali, Eiroa, & Duncan 1993) have uncovered six dust continuum cores, four of which have no near-infrared counterparts. With $L_{bol} \lesssim 30 L_{\odot}$, Casali *et al.* suggest that these four newly-discovered submillimeter continuum sources are part of a second, younger phase of star formation in Serpens.

To investigate the dense gas properties within the Serpens molecular cloud, we have used the newly-developed on-the-fly (OTF) observing technique at the NRAO 12m telescope to map the H_2CO $3_{03} \rightarrow 2_{02}$ and CS $3 \rightarrow 2$ emission toward this region. Our results are the following:

- With the exception of SMM2, the 800 and 1100μm continnum sources mapped by Casali *et al.* (1993) have CS and H_2CO emission counterparts (see Figures 1 and 2).
- Mangum & Wootten (1993) have shown that the relative intensities of several H_2CO transition pairs are very good monitors of the kinetic temperature in dense molecular clouds. The $3_{03} \rightarrow 2_{02}$ and $3_{22} \rightarrow 2_{21}$ transitions are such a pair. Mangum & Wootten have shown that, *independent* of the spatial density, the $\frac{T_R(3_{03}\rightarrow 2_{02})}{T_R(3_{22}\rightarrow 2_{21})}$ ratio can be used to measure $T_K \lesssim 50$ K. Comparison with measurements of the H_2CO $3_{22} \rightarrow 2_{21}$ emission toward the SMM1 through SMM6 sources leads to the derived kinetic temperatures shown in Table 1.
- An analysis of the velocity structure in our CS map indicates that the S68N and SMM4 sources possess dense-gas kinematic motion. This kinematic motion could be due to infall, outflow, or rotation. Given the added properties of high gas density, ($n(H_2) > 1.0 \times 10^5$ cm^{-3}), moderate gas kinetic temperature, and lack of near– or far–infrared emission, we suggest that S68N and SMM4 are Class 0 objects.

References

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Serpens Source Kinetic Temperatures

Source	$\frac{T_R(3_{03}\rightarrow 2_{02})}{T_R(3_{22}\rightarrow 2_{21})}$	T_K	$L_{bol}{}^a(L_\odot)$	IR counterpart?
SMM1	5±1	55^{+40}_{-15}	79	FIRS1
SMM2	>7	<40	0.8–30	none
SMM3	11±4	25^{+15}_{-5}	2–30	none
SMM4	6±0.7	45±10	3–30	none
SMM5	>7	<40	0.8–40	IRS53
SMM6	>8	<35	0.6–30	SVS20

[a] From Casali *et al.* (1993)

CS 3–2 Image:

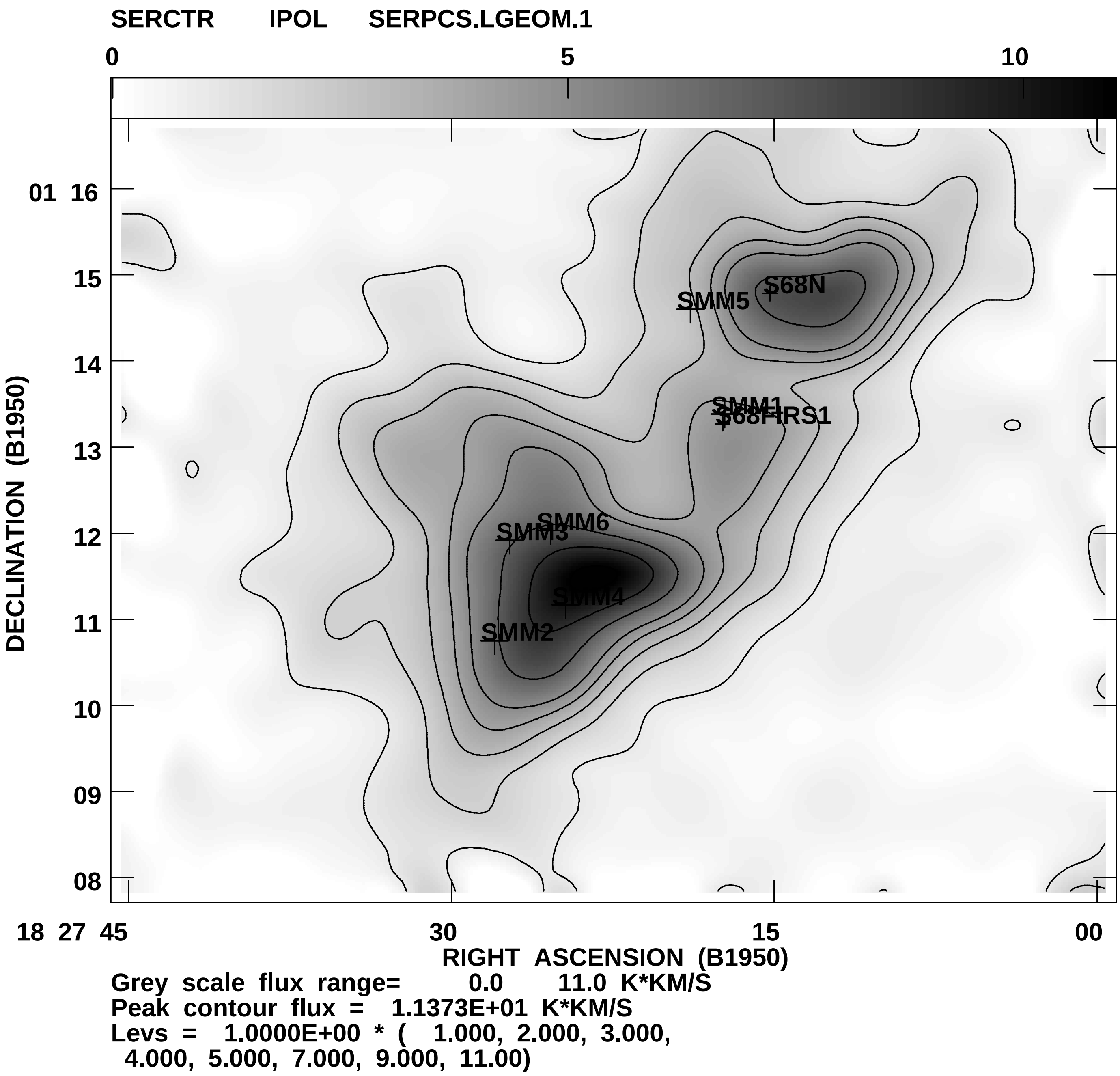

Figure 1. Image of the CS 3 → 2 (146.969049 GHz) transition toward the Serpens star formation region. This map was acquired by combining 16 maps of a field 9′ × 9′ in extent. In total, over 700,000 individual raw spectra compose this data set. The row spacing used for each map was 16″, while the spectrometer used for the image shown consisted of two banks of 128 100 kHz filters sampling signals of orthogonal polarization. A total of approximately 13.3 hours of telescope time were used for these measurements (approximately 50 minutes per map). The single-channel rms for this data is approximately 0.13 K.

Formaldehyde 3(03)–2(02) Image:

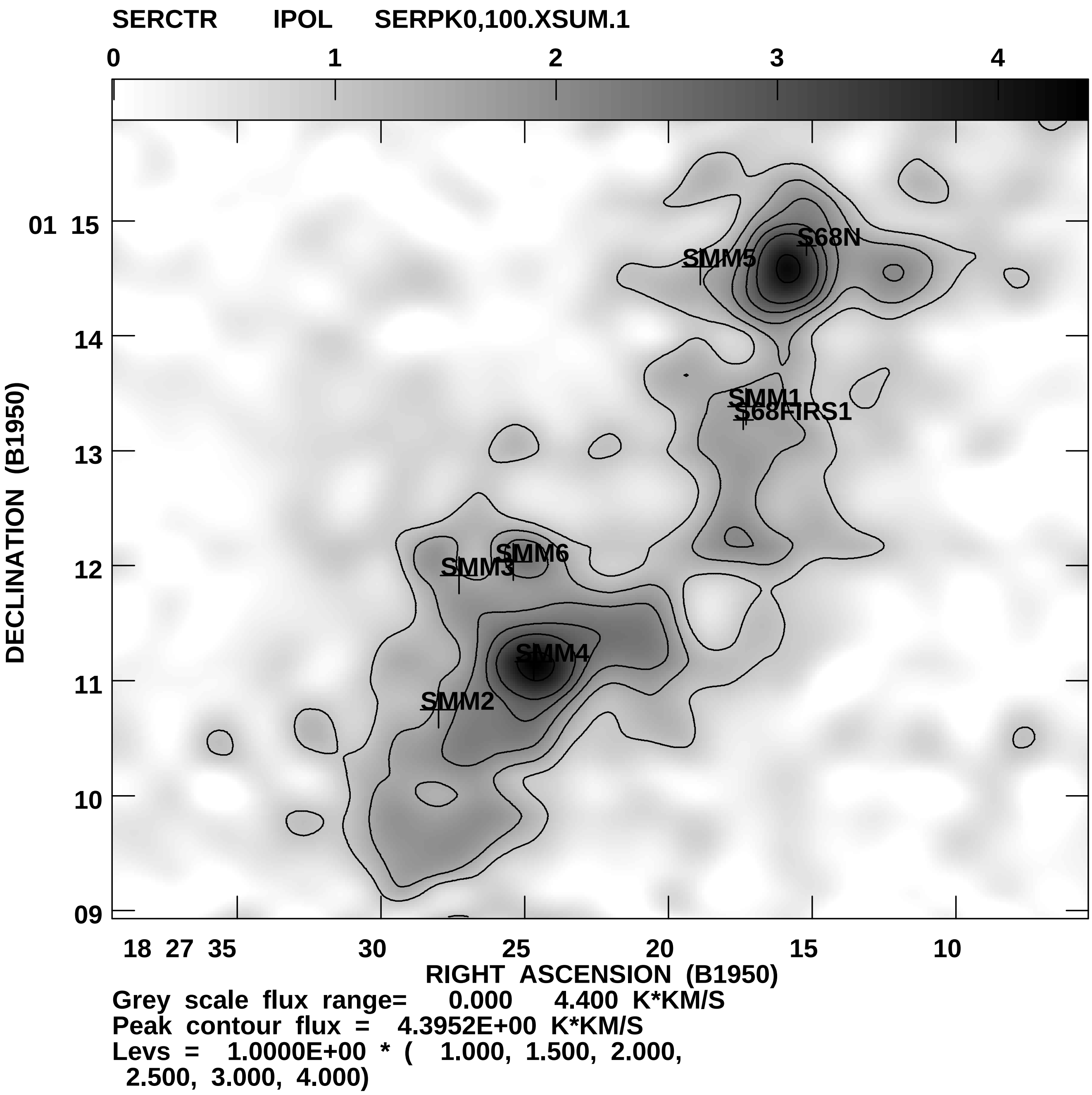

Figure 2. Image of the H_2CO $3_{03} \rightarrow 2_{02}$ (218.222192 GHz) transition toward the Serpens star formation region. This map was acquired by combining 16 maps of a field $7.5' \times 7.5'$ in extent. In total, over 1,100,000 individual raw spectra compose this data set. The row spacing used for each map was $12''$, while the spectrometer used for the image shown consisted of two banks of 128 100 kHz filters sampling signals of orthogonal polarization. A total of approximately 18 hours of telescope time were used for these measurements (approximately 70 minutes per map). The single-channel rms for this data is approximately 0.25 K.