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FIRST DETECTION OF AN H_2CO 6 cm MASER FLARE: A BURST IN IRAS 18566+0408

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ABSTRACT

We report the discovery of a short-duration (less than 3 months) outburst of the H_2CO 6 cm maser in IRAS 18566+0408 (G37.55+0.20). During the flare, the peak flux density of the maser increased by a factor of 4; after less than a month, it decayed to the preflare value. This is the first detection of a short, burstlike variability of an H_2CO 6 cm maser. The maser shows an asymmetric line profile that is consistent with the superposition of two Gaussian components. We did not detect a change in the velocity or the line width of the Gaussian components during the flare. If the two Gaussian components trace two separate maser regions, then very likely an event outside the maser gas triggered simultaneous flares at two different locations.

Subject headings: H II regions — ISM: individual (IRAS 18566+0408) — ISM: molecules — masers — radio lines: ISM — stars: formation

1. INTRODUCTION

IRAS 18566+0408 (G37.55+0.20; Mol 83; Molinari et al. 1996) is a massive star-forming region located at a distance of 6.7 kpc (Araya et al. 2004). Active star formation in the region is evident from detection of 22 GHz H_2O and 6.7 GHz CH_3OH masers and multiple molecular outflows (Beuther et al. 2002a, 2002b). Compact ($<6''$) and weak centimeter radio continuum detected toward IRAS 18566+0408 (Carral et al. 1999; Araya et al. 2005) likely marks the position of a young massive stellar object that has not yet developed a bright ultracompact H II region. IRAS 18566+0408 has been classified as a massive disk candidate (Zhang 2005). This region is a promising source to study the process of massive star formation because of the absence of more evolved, nearby radio continuum sources that often compromise the interpretation of single-dish observations at centimeter and millimeter wavelengths.

IRAS 18566+0408 harbors one of the few H_2CO 6 cm masers known (Araya et al. 2005). Despite the ubiquity of the H_2CO molecule in molecular clouds (e.g., Araya et al. 2002; Watson et al. 2003; see also Evans 1999), H_2CO 6 cm emission has only been detected toward five regions in the Galaxy as maser emission (Araya et al. 2006a) and only toward Orion BN/KL as thermal emission (see discussion in Araya et al. 2006b). Variability of H_2CO masers has been reported toward two sources (Sgr B2 and NGC 7538; Mehringer et al. 1994 and Forster et al. 1985, respectively); however, only long-term (more than a year) variability has been found. Here we report the first detection of the rapid (less than 3 months) flarelike variability of an H_2CO 6 cm maser.

2. OBSERVATIONS AND DATA REDUCTION

We report observations conducted with the NRAO Green Bank Telescope[9] (GBT) toward the massive star-forming region IRAS 18566+0408 (R.A. = $18^h59^m09.9^s$, decl. = $04°12'15''$, J2000). The observations were carried out on 2002 November 09 and 15; 2004 October 15 and 16; and 2005 July 17. The GBT autocorrelator was used to observe the H_2CO 6 cm transition ($\Delta J_{\rm KaKc} = 1_{10}$–$1_{11}$, $\nu_0 = 4829.6594$ MHz) in two linear polarizations, with a bandwidth of 12.5 MHz ($\sim$770 km s^{-1}), and 4096 channels per polarization (0.19 km s^{-1} channel width). The system temperatures were approximately 26, 24, and 28 K on 2002 November, 2004 October, and 2005 July, respectively. The observing mode was position switching. After inspection of the ON- and OFF-source spectra separately, the data were calibrated to antenna temperature units using AIPS++. The spectra were subsequently exported to CLASS[10] for further calibration and analysis. To calibrate the antenna temperature spectra to flux density units, we divided the spectra by the telescope gain values 1.83, 1.90, and 1.95 K Jy^{-1} for the 2002 November, 2004 October, and 2005 July observations, respectively. The gain values were obtained from observations of NGC 7027, 3C 48, 3C 147, and 3C 286 (the assumed flux densities for the four sources were 5.37, 5.47, 7.94, and 7.52 Jy, respectively).[11] Based on the dispersion of the telescope gain values, the flux density calibration is better than 22%. Further details of the flux density calibration and telescope characterization are given in Sewiło et al. (2004) and E. Araya et al. (2007, in preparation). After checking the consistency of both orthogonal polarization spectra, we averaged the spectra and subtracted a linear baseline.

3. RESULTS AND DISCUSSION

We detected H_2CO maser emission and absorption in all our GBT observing runs. In the top portion of Table 1, we list the maser line parameters of our GBT observations, and we also include the line parameters of all other observations of the H_2CO maser in IRAS 18566+0408 reported in the literature. The line profiles of the two 2002 November observations were consistent with the superposition of two Gaussian profiles (see the top portion of Table 1 for line parameters). A discussion of the double-line profile is given in § 3.1.

In both of our 2002 November observations obtained within 6 days (see the top portion of Table 1), the peak flux density

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[10] CLASS is part of the GILDAS software package developed by the Institut de Radioastronomie Millimétrique (IRAM).

[11] 3C 48 was also used as flux density calibrator of the observations reported by Araya et al. (2005) that are listed in the top portion Table 1. The 3C 48 flux density assumed in this work is the same as the one used in Araya et al. (2005).

TABLE 1

Multiepoch Observations of the Maser in IRAS 18566+0408

Date	rms (mJy)	S_ν (mJy)	V_{LSR} (km s^{-1})	Width (km s^{-1})	Telescope	Reference
Individual Observations						
2002 Jul 27[a]	1.3	28.5	79.70 (0.05)	1.52 (0.09)	Arecibo	Araya et al. 2004
2002 Sep 18[b]	3.5	38.3	79.43 (0.05)	1.6 (0.1)	VLA-CnB	Araya et al. 2005
2002 Nov 09[c,d]	10.0	72.0	79.33 (0.11)	1.2 (0.2)	GBT	This work
	10.0	89.1	80.04 (0.03)	0.66 (0.05)	GBT	This work
2002 Nov 15[c,e]	8.2	77.5	79.27 (0.05)	1.34 (0.09)	GBT	This work
	8.2	123.4	80.05 (0.01)	0.58 (0.03)	GBT	This work
2002 Dec 16[a]	1.2	28.3	79.75 (0.04)	1.8 (0.1)	Arecibo	Araya et al. 2004
2003 Sep 05[b,f]	4.3	38.4	79.50 (0.07)	1.6 (0.2)	VLA-A	Araya et al. 2005
2003 Oct 12[a,f]	2.2	22.1	79.72 (0.06)	1.4 (0.1)	Arecibo	Araya et al. 2004
2004 Oct 15, 16[a,f]	3.6	23.9	79.8 (0.1)	1.0 (0.2)	GBT	This work
2005 Jul 17[a]	7.7	36.9	79.1 (0.1)	1.2 (0.3)	GBT	This work
Combined GBT 2002 Observations and Arecibo Observations						
GBT 2002[c,g]	6.5	75.2	79.31 (0.06)	1.28 (0.09)	GBT	This work
	6.5	106.2	80.05 (0.01)	0.63 (0.04)	GBT	This work
Arecibo 2002, 2003[c,h]	1.7	21.1	79.3 (0.1)	1.2 (0.2)	Arecibo	Araya et al. 2004
	1.7	24.3	80.12 (0.03)	0.61 (0.08)	Arecibo	Araya et al. 2004

[a] Line parameters obtained with a Gaussian fit. The uncertainties are 1 σ statistical errors from the fit.

[b] The line parameters and errors are as in note a, except for the flux density, which corresponds to the brightest channel in the spectrum.

[c] The line profile is consistent with two superposed Gaussian lines. We report the line parameters of both Gaussian components. The uncertainties are 1 σ statistical errors from the fit.

[d] The flux density and velocity of the brightest channel in the spectrum are 118.2 mJy and 79.95 km s^{-1}, respectively. The full width at half-maximum of the combined Gaussian profile is 1.4 (0.1) km s^{-1}.

[e] The flux density and velocity of the brightest channel in the spectrum are 146.2 mJy and 79.94 km s^{-1}, respectively. The full width at half-maximum of the combined Gaussian profile is 1.4 (0.1) km s^{-1}.

[f] This data point is not shown in Fig. 1.

[g] Average of the 2002 November 9 and 15 data.

[h] Average of all observations obtained with Arecibo by Araya et al. (2004).

of the maser was ~4 times greater than the peak flux density of the maser measured at all other epochs. The increase in the flux density of the maser detected in 2002 November is due to real variability of the maser and not a calibration error, because the flux density value of the *absorption* feature redward from the maser line was consistent in all our GBT observations.

The variability of the maser detected with the GBT is exemplified in Figure 1, where we show the combined spectrum of the 2002 November observations and four other H_2CO spectra of the region obtained at different epochs. The figure shows that all three telescopes measured approximately the same peak flux density of the maser in its quiescent state. It also shows that the H_2CO 6 cm absorption is extended, since the peak of the absorption feature is greater in the GBT spectrum than in the Arecibo spectrum, while the absorption was heavily resolved/filtered out by the Very Large Array (VLA; see Westpfahl 1999 for a brief introduction about interferometers as spatial filters).

In Figure 2 we show the complete light curve of the H_2CO maser in IRAS 18566+0408. The flux density values used for the 2002 November observations are those given in the notes d and e to Table 1. The peak flux densities of the two 2002 November observations (see notes d and e to Table 1) agree with each other within 4 σ (and within 3 σ in the other line parameters); however, at an ~3 σ level, the maser flux density might have been increasing between 2002 November 9 and 15. All other epochs agree with no variability within conservative limits of 6 σ error bars (Fig. 2).

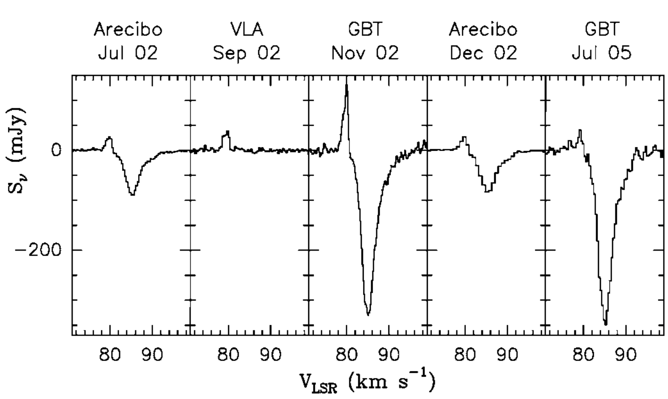

Fig. 1.—H_2CO 6 cm maser flare in IRAS 18566+0408. The flare was detected with the GBT in 2002 November (the 2002 November spectrum is the average of both 2002 November observations reported in Table 1). The flare is a real variability and not a calibration artifact because the H_2CO absorption is consistent in all our GBT observations (compare the 2002 November and 2005 July spectra).

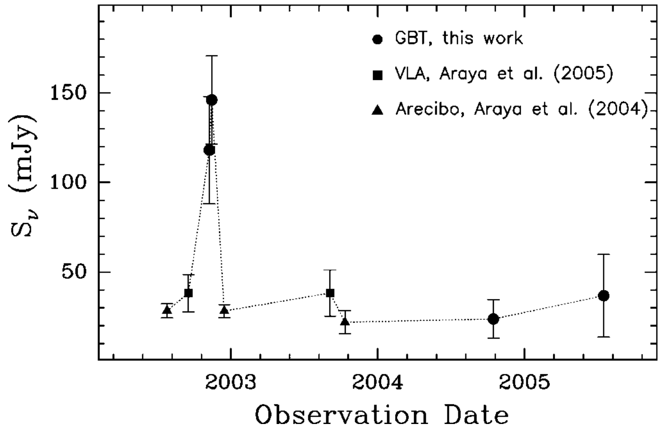

Fig. 2.—Light curve of the H_2CO 6 cm maser in IRAS 18566+0408. The maser flare is clearly seen in the figure. The H_2CO maser decayed to the preflare flux density in less than a month. The length of the error bars is 6 times the rms noise of the respective spectrum as reported in the top portion of Table 1.

The differences between the flux density measurements during the quiescent state of the maser probably result from small differences in the flux density calibration (e.g., a systematic flux density calibration error between the Arecibo and VLA data may explain why the flux densities measured with the VLA are greater than the flux densities measured with Arecibo; see Fig. 2). However, we cannot rule out lower amplitude variation of the maser during the quiescent phase.

3.1. H_2CO 6 cm *Maser Line Profile*

The line profiles of the H_2CO spectra during the maser flare are clearly asymmetric and are consistent with the superposition of two Gaussian profiles. In the upper panel of Figure 3 we show the combined spectrum of the 2002 November observations, and the two Gaussian profiles used to fit the H_2CO maser line. The line parameters of the fit are given in the bottom portion of Table 1. To check if the double-peaked profile detected during the flare is also present during the quiescent state of the maser, we combined all three (2002 July, 2002 December, and 2003 October) Arecibo observations reported by Araya et al. (2004) without applying any smoothing to the spectra (channel width $= 0.19$ km s^{-1}). The combined Arecibo spectrum (see Fig. 3, *lower panel*) is also consistent with the superposition of two Gaussian components (line parameters given in the bottom portion of Table 1). Excluding the obvious difference in peak flux densities, the other line parameters of the two Gaussian profiles during the flare and the quiescent phase are consistent within 3 σ errors from the fit.

Figure 3 demonstrates that the double-peak line profile of the H_2CO 6 cm maser in IRAS 18566+0408 was maintained during the maser burst and that both components showed approximately the same relative increase in flux density during the flare, i.e., a flux density increase by a factor of approximately 3.6 and 4.4 for the weak and strong components, respectively. The relative intensity and LSR velocity of the components are inconsistent with the superposition of the hyperfine structure of the H_2CO line (e.g., Tucker et al. 1970); thus, the line profile most likely is a consequence of the superposition of (at least) two different H_2CO maser regions separated by less than 0″.5 (i.e., the highest angular resolution of the observations reported by Araya et al. 2005). The difference in velocity and the quasi-simultaneous variability of the two Gaussian components suggest that the trigger mechanism for the burst must be external to the two maser clumps and that the distance between the trigger source and each maser region must be the same within a few light-weeks.

Asymmetric and double line profiles have been detected before toward other H_2CO maser regions (e.g., NGC 7538 IRS1, Downes & Wilson 1974; G29.96−0.02, Pratap et al. 1994). In the case of NGC 7538 IRS1, the H_2CO spectrum shows two maser peaks with a velocity separation of ~2 km s^{-1}. MERLIN observations by Hoffman et al. (2003) show that the two maser components are separated by approximately 80 mas, with a relative orientation of approximately northeast-southwest (P.A. ≈ 17°). VLBA+VLA observations of NGC 7538 IRS1 also by Hoffman et al. (2003) showed that one of the maser components has a northeast-southwest (P.A. ≈ 30°) velocity gradient that is consistent with maser emission from a rotating disk. This northeast-southwest velocity and spatial distribution of the H_2CO masers in NGC 7538 IRS1 are particularly interesting because De Buizer & Minier (2005) report a possible circumstellar disk oriented in a northeast-southwest direction; i.e., the H_2CO 6 cm masers in the region may be tracing the kinematics of a circumstellar disk in NGC 7538 IRS1. As mentioned in § 1, IRAS 18566+0408 is thought to harbor a massive circumstellar disk (Zhang 2005), and recent NH_3 VLA observations show that the H_2CO 6 cm maser is coincident with the putative disk (Q. Zhang 2006, private communication). Although further higher angular resolution (VLBI) observations are required, it is possible that the two maser components shown in Figure 3 are tracing gas associated with a circumstellar disk in IRAS 18566+0408.

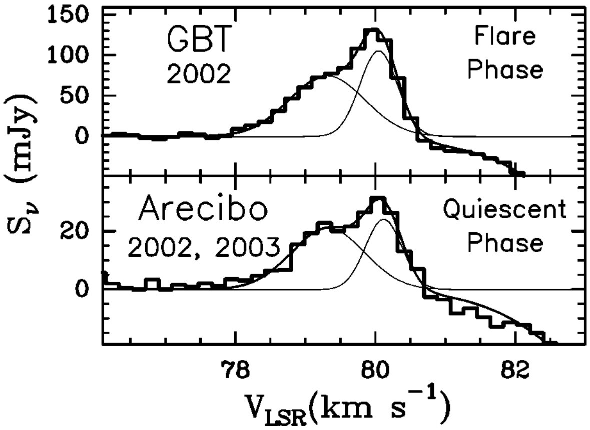

FIG. 3.—H_2CO 6 cm maser profile during the flare (*upper panel*) and the quiescent phase (*lower panel*). Each spectrum is a combination of several observations made during each phase. Both line profiles are well fit by two Gaussian components; the fitted line parameters are given in the bottom portion of Table 1. The red falloff is due to H_2CO absorption (see Fig. 1).

3.2. *On the Possible Nature of the* H_2CO *Flare*

In this section we qualitatively explore possible causes of the H_2CO 6 cm flare in IRAS 18566+0408. One possibility is that the flare and quiescent maser originate from different gas. An unrelated molecular clump might undergo population inversion and/or have its maser emission momentarily beamed in our direction. Alternatively, a molecular clump passing in front of the maser region might further amplify the radiation. Although possible scenarios, all of these mechanisms would probably produce some change in the line profile. Because no such change was seen, we consider these possibilities to be unlikely. Variability due to a scintillation event is another possibility; however, we also find it unlikely because of the large amplitude variation (see, e.g., Dennison et al. 1987 and Qian et al. 1995) and the isolated character of the variation (e.g., see discussion in Macquart & Bower 2006). It seems more likely that the flare could have been a consequence of (1) a change in the maser gain τ or (2) a change in the background 6 cm continuum radiation. Below we discuss both possibilities for the cases of saturated and unsaturated maser emission.

Saturated H_2CO *maser emission.*—In a saturated maser, the output radiation in the line is dominated by the characteristics of the maser gas and not by the number of background seed photons. Thus, if the H_2CO maser is saturated, then the flare must have been a consequence of a change in the maser gain and not of a change in the background 6 cm continuum flux. If H_2CO 6 cm masers are collisionally pumped, as suggested by Hoffman et al. (2003), then the change in the maser gain must have been caused by a local disturbance of the gas (e.g., by a shock wave). However, a disturbance in the physical conditions of the gas due to a shock wave is expected to modify the maser's line velocity and width, which was not observed (see also the timescales for a crossing sound or shock wave mentioned below). On the other hand, the maser could be saturated and still show a flare if the inversion is due to a radiative mechanism, as in the case of OH masers toward OH/IR stars (e.g., Elitzur 1992; ter Haar & Pelling 1974 and references therein). Thus, if the H_2CO maser in IRAS 18566+0408 is saturated, then we find it most likely that the maser is radiatively pumped. For example, if H_2CO masers are pumped by IR radiation (as mentioned by Araya et al. 2006a) and the maser gas in IRAS 18566+0408 is coplanar with a clumpy circumstellar disk, then a change in the pumping photon flux, perhaps caused when an inner clump partially uncovered the central region, could have triggered the maser flare.

Unsaturated H_2CO *maser emission*.—In the case of an unsaturated maser, the flare could have been caused by (1) a change in the maser gain or (2) a change in the 6 cm continuum flux density:

1. In an unsaturated maser, a linear change in the gain produces an exponential variation in amplification. In order to explain the flux density variation of the maser, the gain must have changed by a factor between ~12% and ~24% (assuming that $-6 \geq \tau \geq -12$ as in the case of the H_2CO 6 cm masers in NGC 7538 and G29.96−0.02; Hoffman et al. 2003); i.e., a change as small as 12% in the relative population inversion might explain the flare.

If the maser in IRAS 18566+0408 is unsaturated and if the flare is caused by a change in the maser gain, then we find it unlikely that the pumping mechanism is due to a collisional process. We disregard this possibility because a change in the gain would have been caused by a modification of the physical conditions of the maser region via some kind of disturbance. But, assuming that the projected size of the H_2CO maser in IRAS 18566+0408 is similar to those measured toward G29.96−0.02 and NGC 7538 (i.e., $\gtrsim 30$ AU; Hoffman et al. 2003), then both a sound wave disturbance (~1 km s^{-1} sound speed) and a shock front ($\lesssim 100$ km s^{-1} propagation velocity; e.g., Goddi et al. 2005) would have timescales for a change of physical conditions in the maser gas (i.e., $\gtrsim 140$ and $\gtrsim 1.4$ yr, respectively) considerably greater than the observed timescale of the maser flare.

2. A variation of the background 6 cm continuum would have linearly changed the flux density of the unsaturated maser. A variation in the 6 cm continuum could have been caused by an outflow or accretion event, and assuming that a background 6 cm continuum flare was located approximately symmetric (within a distance difference of a few light-weeks) with respect to the two maser regions and our line of sight, then this possibility would explain the characteristics of the flare. A change in the 6 cm continuum flux density could be possible if the background ionized gas has an electron density $n_e \gtrsim 10^6$ cm^{-3}, because the recombination and radiative cooling timescales would be $\lesssim 2$ months for an electron temperature $T_e \sim 10^4$ K gas (Spitzer 1978).

Summarizing this section, if the flare was caused by a change in maser gain, then radiative pumping seems to be a more likely inversion mechanism for the H_2CO 6 cm maser in IRAS 18566+0408. This conclusion is independent of the saturation state of the maser. On the other hand, if the maser is unsaturated, the flare could have been caused by a change in the background 6 cm flux density, independent of the pumping mechanism of the maser.

4. SUMMARY

Using the Green Bank Telescope we have detected a H_2CO 6 cm maser flare toward IRAS 18566+0408, a massive star-forming region with a possible massive circumstellar disk (Zhang 2005). The H_2CO flare lasted for less than 3 months and fully decayed to the preflare flux density level in less than 1 month. The line profile during the burst was asymmetric and consistent with the superposition of two Gaussian components, strongly suggesting the existence of two different H_2CO 6 cm maser clumps.

The line profiles during the flare and the quiescent phases are remarkably similar: the line ratio between the two components remained relatively constant, and the line velocities and widths did not change within the 3 σ uncertainty errors. Based on our observations, and assuming that the two Gaussian components trace two different maser regions, we conclude that the burst was caused by some mechanism outside the two maser regions that triggered a quasi-simultaneous flare in both maser components.

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