Results of Long-Term Monitoring of Maser Emission in the Star-forming Region G 10.623–0.383

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Abstract—The results of a study of the maser source G 10.623–0.383 in the $\lambda = 1.35$ cm H$_2$O line using the 22-m radio telescope of the Pushchino Radio Astronomy Observatory (Russia) and in the main hydroxyl lines ($\lambda = 18$ cm) using the Nançay Radio Telescope (France) are presented. Uncorrelated long-term variations of the integrated intensities and the velocity centroids with characteristic times of 11 yrs (mean value) and 32 yrs, respectively, are studied. The drift of the velocity centroid may be associated with maser condensations whose material is collapsing onto the OB cluster. It is shown that the H$_2$O maser source contains maser condensation configurations on various scales over a long time, which evolve with time. OH maser emission was only detected in the main lines at 1665 and 1667 MHz. The flux densities of the strongest emission components were variable, but their radial velocities did not change. A Zeeman pair was found at 1667 MHz with a splitting of about 1.44 km/s, corresponding to a line-of-sight magnetic field of 4.1 mG, which was preserved over at least 25 years. The characteristics of the H$_2$O and OH maser variability suggests that the masers are located in different parts of G 10.623–0.383.

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1. INTRODUCTION

The molecular complex W31 is an active star-forming region, which hosts several clumps of dense molecular gas. The 5-GHz observations of Goss and Shaver [1] indicated three isolated radio continuum sources in W31: G 10.2–0.3, G 10.3–0.1, and G 10.6–0.4. Reifenstein et al. [2] detected the hydrogen radio recombination line H109$\alpha$ at 13.9, 9.7, and 0.3 km/s, respectively, toward each of these regions, and Wright et al. [3] detected IR emission at 69 $\mu$m.

In turn, G 10.6–0.4 has a complex structure (see [4, 5]). Further we will refer to this region as G 10.623–0.383.

The distance to the region has been determined using various methods. A method based on mm and IR spectroscopic observations yielded a distance of 4.5±0.6 kpc [6]. The distance obtained using trigonometric parallax is probably the most accurate: 4.95$^{+0.51}_{-0.43}$ kpc from the Sun, according to Sanna et al. [7].

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G 10.623–0.383 harbors eight components (probably ultracompact H II regions), with sizes of less than 0.15 pc and gas masses from 0.3 to 1.08 $M_\odot$. This multiple structure of G 10.623–0.383 is explained by the existence of a cluster of young OB protostars. The IR object IRS7 is located at the center of the region [3].

The radial velocities of the radio recombination line H66$\alpha$ show the motion of ionized gas in the region [8]. A comparison with molecular lines arising in the neutral gas demonstrates that the molecular flow passes through the ionization front of the H II region in the direction toward the star cluster; i.e., there is a flow of accreting gas.

The accepted source model is a collapsing hot molecular core. NH$_3$ observations show that the molecular material is rotating and falling along spiral paths onto a ∼0.05-pc region that is rapidly rotating [9, 10]. The plane of the rotation passes through the center of the H II region and is oriented approximately 20° to the north-west.

According to Ho et al. [5] the core hosts a cluster of forming massive OB stars. The core is embedded in a slowly rotating envelope with a velocity gradient of
1 km/(s pc). Fragments of the core that are redshifted by 5 km/s with respect to its centroid may be regions collapsing onto the OB stars.


Fish and Reid [15] showed that the OH emission arises in three regions inside G 10.623–0.383, but none of the maser spots is located in the rotation plane. Some water maser features may be associated with core fragments [16]. This association may strongly affect the parameters of the H$_2$O maser emission and its variability (e.g., velocity centroid drift).

2. OBSERVATIONS AND DATA

We observed G 10.623–0.383 in the water line at 1.35 cm with the 22-m radio telescope of the Pushchino Radio Astronomy Observatory. A 2048-channel autocorrelation receiver was used to analyze the signal. The spectral resolution was 0.0822 km/s, and the telescope gain was 25 Jy/K. Monitoring was carried out between February 1981 and January 2017. Observations were not conducted from mid-2006 to the end of 2007 due to technical reasons. Results for 1981–2003 are presented in [16, 17].

OH maser emission in G 10.623–0.383 was observed with the Nan$\text{ç}$ay Radio Telescope in the main lines of the $\Delta$-doubling of the $^{2}\Pi_{3/2}, J = 3/2$ ground state of the OH molecule at wavelength $\lambda = 18$ cm (1665 and 1667 MHz). The full widths at half power of the antenna beam at 18 cm are 3.5' in RA and 19' in Dec. The telescope receivers enable measurement of the four Stokes parameters of polarized emission simultaneously. The telescope gain was 1.4 Jy/K, and the detection threshold at the $3\sigma$ level was 0.2 Jy for an integration time of 10 min. The radial velocity resolution was 0.137 km/s.

Figures 1–5 show the water maser spectra at 1.35 cm obtained as a result of the monitoring in 2004–2016. The horizontal axes plot the LSR velocities in km/s and the vertical axes the flux densities in Janskys. The observing epochs are indicated. The double-headed vertical arrows show the vertical scales. All the H$_2$O spectra were corrected for absorption in the Earth’s atmosphere, which is important at low elevations ($10^\circ$–$15^\circ$ for G 10.623–0.383).

Figure 6 shows the OH maser spectra in the main lines at 1665 and 1667 MHz. The notation is the same as in Fig. 1. Observations were performed in both circular and linear polarizations on September 16, 2008 and November 19, 2015. Spectra for right and left circular polarizations, $R_C$ and $L_C$, are presented, as well as the Stokes parameter $V$, equal to the difference between the two circular polarizations.

3. DISCUSSION

According to Forster and Caswell [13], the main H$_2$O maser features in G 10.623–0.383 fall in the radial-velocity range from $-4$ to $+4$ km/s; in December 1984, the spots formed a sort of belt 0.37'' long and 0.1'' wide. The insufficient angular (1.2'' $\times$ 1.1'') and spectral (1.32 km/s) resolutions precluded derivation of a detailed picture of the configurations formed by the maser spots, identification of the main emission features detected in our monitoring, or construction of a complete model for the H$_2$O maser source in G 10.623–0.383. We can only suppose that the main maser spots form a compact group, have a common source of pumping, and are associated with the flow accreting onto the cluster of OB stars.

In addition, according to Forster and Caswell [13] the OH maser spots are located within a region 1.5'' $\times$ 0.9'' in size. The H$_2$O and OH maser regions do not spatially coincide.

3.1. H$_2$O Maser Emission

3.1.1. Integrated flux and velocity centroid.

The integrated flux and velocity centroid are important parameters of the maser emission. The evolution of these parameters is shown in Fig. 7. We also included data obtained in other studies before our monitoring began (points 1–4) [18–21]. The complex curve fit to the integrated flux minima (thin solid line in Fig. 7a) probably describes long-term maser variability with a mean characteristic time scale of about 11 yrs. However, this variability is not very pronounced, distinguishing G 10.623–0.383 from all other sources observed in our monitoring program.

Shorter-term periods of increased maser activity are superposed on this curve. Lekht et al. [17] demonstrated the existence of a “corridor” 600 Jy km/s wide within which rapid variations of maser emission with characteristic time scales of 0.5–2 yrs occurred in 1983–2003. The observations presented in this paper (from 2004 to the beginning of 2017) confirm this result.

Including the data from other studies, we can trace the drift of the velocity centroid over almost 49 years, at radial velocities from $-3$ to $+1$ km/s (Fig. 7b). This drift can be described by a fourth-order polynomial.