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A NEW SOURCE OF MASER RADIO EMISSION IN THE 1720-MHz OH LINE

Новый источник мазерного радиоизлучения в линии ОН 1720 МГц

Abstract. Observations of the source of OH maser radio emission G188.946+0.886 on the Nançay Radio Telescope (France) are reported. We have detected for the first time an emission feature in the 1720-MHz satellite line in the OH molecule ground state. The radial velocity of the feature, $V_{\rm LSR} = 3.6$ km s^{-1}, is blueshifted with respect to the velocity interval of the emission in the main OH lines 1665 and 1667 MHz, 7–11 km s^{-1}. This suggests an association of the observed 1720-MHz feature with the blue wing of the bipolar outflow observed in this region in the CO line. No emission and(or) absorption in the other OH satellite line 1612 MHz was detected. We have also observed on the 22-meter Pushchino radio telescope the H_2O $\lambda = 1.35$ cm maser in G188.946+0.886, which has demonstrated a fast variability, especially in the features blueshifted with respect to the main-line OH emission.

Резюме. Сообщается о результатах наблюдений источника мазерного радиоизлучения в линиях молекулы гидроксила ОН G188.946+0.886 на радиотелескопе Обсерватории Нансэ (Франция). Впервые обнаружена эмиссионная деталь в сателлитной линии 1720 МГц основного состояния молекулы ОН. Лучевая скорость детали, $V_{\rm LSR} = 3.6$ км с$^{-1}$, имеет «синее» смещение относительно интервала скоростей излучения в главных линиях ОН 1665 и 1667 МГц, 8–11 км с$^{-1}$. Это указывает на вероятную связь наблюдаемой детали в линии 1720 МГц с «синим» крылом биполярного истечения, наблюдаемого в этой области в линии СО. Не обнаружено излучения и(или) поглощения в другой сателлитной линии ОН 1612 МГц. На 22-м радиотелескопе в Пущино наблюдался также мазер H_2O $\lambda = 1.35$ см, который продемонстрировал быструю переменность, особенно в эмиссионных деталях, имеющих«синее» смещение относительно эмиссии в главных линиях ОН.

In 2007–2013 we have surveyed on the Nançay Radio Telescope (France) a sample of OH maser sources in star-forming regions (SFRs) at wavelength $\lambda = 18$ cm. The observations were carried out in the four Λ-doubling radio lines in the ground rotational state $^2\Pi_{3/2}$, $J = 3/2$ of OH molecule 1612, 1665, 1667, and 1720 MHz. At declination $\delta = 0°$, the telescope beamwidth at 18 cm is $3\rlap{.}'5 \times 19'$ in right ascension and declination, respectively. The receiving system of the telescope allows us to obtain simultaneously four Stokes parameters of the emission polarization. The telescope sensitivity is 1.4 K/Jy, the detection threshold with a 10-min integration time is about 0.2 Jy. The 8192-channel autocorrelation spectrometer can measure simultaneously the profiles in two spectral lines, in two linear and two circular polarization modes in each of the lines. In our observations the velocity resolution was 0.07 km s^{-1}. Details of the observational technique can be found in our previous papers

(M.I. Pashchenko et al., Astron. Rep. **53**, 541, 2009; G.M. Rudnitskij et al., Astron. Rep. **54**, 400, 2010; V.I. Slysh et al., Astron. Rep. **54**, 599, 2010; E.E. Lekht et al., Astron. Rep. **56**, 45, 2012; P. Colom et al., Astron. Rep. **56**, 731, 2012).

The observed source G188.946+0.886 (named in some papers as G188.94+0.89 or G188.95+0.89) is located near the emission nebula Sh2-247 in the Gem OB1 association at a distance of about 2 kpc. This region hosts several dense clumps of molecular gas observed in CO molecule lines and a cluster of infrared sources (T. Shimoikura et al., ApJ **768**, 72, 2013). The source is probably associated with the infrared object IRAS 06058+2138, or AFGL 5180 (S.K. Ghosh et al., Bull. Astron. Soc. India **28**, 515, 2000). It is separated by 95″ from the compact radio continuum source G188.949+0.915, a compact HII region.

The source G188.946+0.886 was first observed as an H_2O maser at wavelength $\lambda =$ 1.35 cm by R.A. Batchelor et al. (Austral. J. Phys. **33**, 139, 1980). The same authors mentioned that OH emission in the 1665-MHz line had been detected in Parkes observations. However, these data seem to have remained unpublished. Later the source was extensively studied in the H_2O $\lambda = 1.35$ cm line (e.g., C.S. Oh et al., PASJ **62**, 101, 2010; and references therein). It is also a class II methanol maser typical of regions of formation of massive stars (e.g., F. Fontani et al., A&Ap **517**, A56, 2010; D.J. van der Walt, AJ, **141**, 152, 2011; and references therein). In this region a bipolar outflow is observed in the ^{12}CO $J = 1$–0 line at $\lambda = 2.6$ mm (R. Snell et al. ApJ **325**, 853, 1988).

However, there are but few papers devoted to the study of G188.946+0.886 in OH lines. C. Kömpe et al. (A&Ap **221**, 295, 1989) observed the source in Nançay and detected it in the 1665 and 1667 MHz lines; no 1720-MHz emission was found. Searches in G188.946+0.886 for Λ-doubling lines in higher lying rotational states of OH were undertaken: $^2\Pi_{1/2}$, $J = 1/2$ at 4.7 GHz (R.J. Cohen et al., MNRAS **250**, 611, 1991; M. Szymczak et al., MNRAS **312**, 211, 2000) and $^2\Pi_{3/2}$, $J = 5/2$ at 6 GHz (A. Baudry et al., A&Ap **325**, 255, 1997). In all cases the results were negative.

In August 1991 A.L. Argon et al. (ApJSS **129**, 159, 2000) mapped G188.946+0.886 on VLA in the 1665 MHz OH line with an angular resolution $2\farcs17 \times 1\farcs36$. The map demonstrates four unresolved, 100 per cent right and left circularly polarized emission components in a velocity interval of $V_{\rm LSR} = 8.54$–9.97 km s^{-1} within a region of $\approx 0\farcs1$, i.e., in a projected area of 200 AU for a distance of 2 kpc. According to Argon et al., the OH main-line 1665-MHz position of G188.946+0.886 (J2000) is RA = $06^{\rm h}08^{\rm m}53\fs33$, Dec = $+21°38'29\farcs0$. No other ground-state OH lines were observed.

We observed G188.946+0.886 on three occasions: on December 5, 2011 (in the 1665 and 1667 MHz lines), on May 2 and June 2, 2013 (in all four ground-state OH lines). Figure 1 presents the profiles of the Stokes parameters measured on May 2, 2013. In the 1665 MHz profile a group of elliptically polarized emission features with peak flux densities of 0.5–2.6 Jy is visible in a velocity interval $V_{\rm LSR} \approx 7$–11 km s^{-1} in agreement with Argon et al.'s profile of 1991. In the 1667 MHz line an isolated 90 per cent right-hand polarized feature with a peak flux density of 2 Jy and FWHM ≈ 0.35 km s^{-1} is present at $V_{\rm LSR} \approx 9.16$ km s^{-1}. No signal, either in emission or absorption, was detected in the 1612 MHz line.

A new result is a narrow emission feature in the 1720 MHz satellite line (Fig. 1, right column). Its peak flux density is 1.6 Jy at $V_{\rm LSR} \approx 3.6$ km s^{-1}, it is elliptically polarized. Observed for the first time on May 2, 2013, the feature was confirmed on June 2. Its radial velocity is blueshifted by $\approx$5.6 km s^{-1} with respect to the 1667 MHz peak.

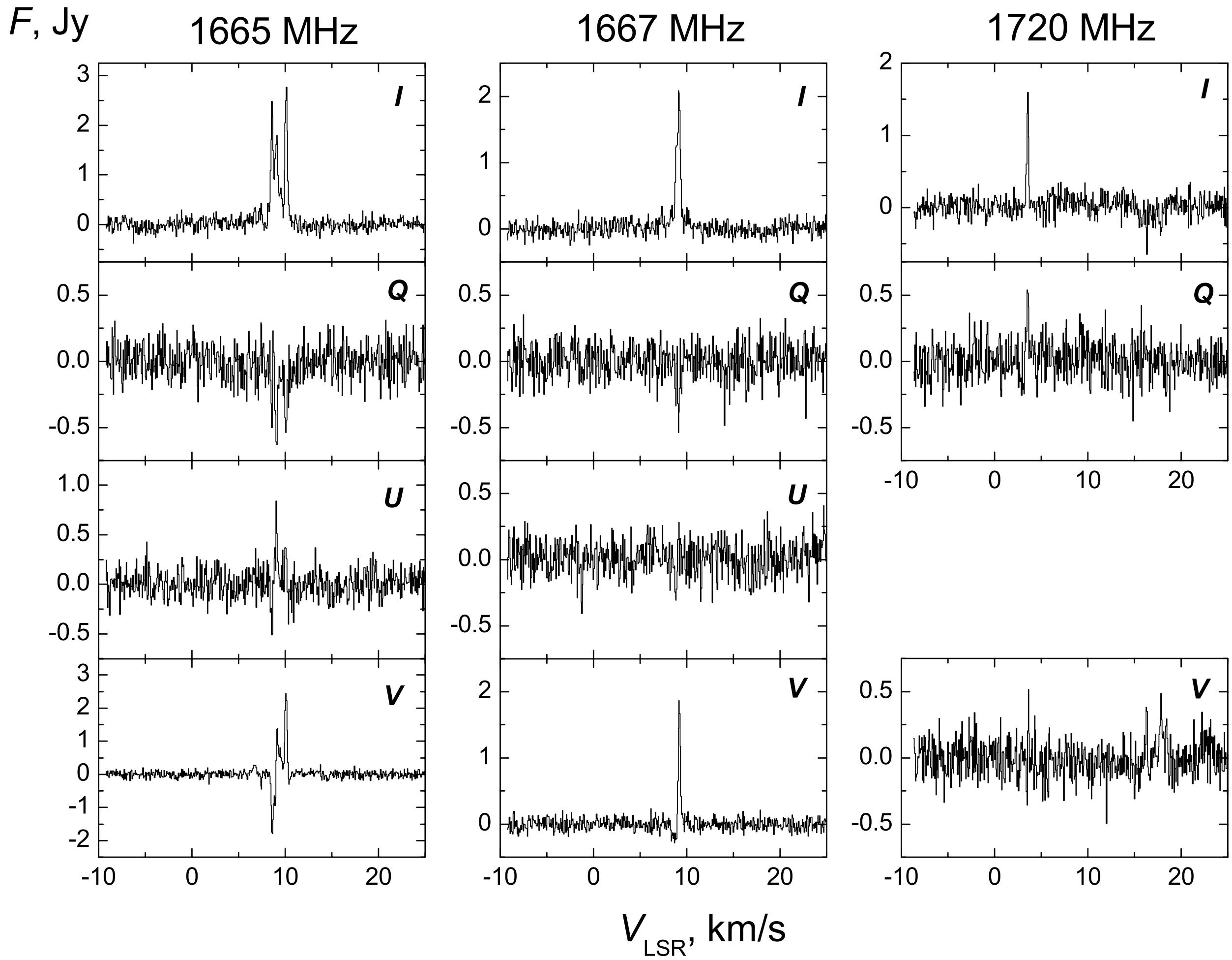

Figure 1: Stokes parameters of the maser emission in the OH lines in the source G188.946+0.886 observed on May 2, 2013. I is the total flux density, Q is the difference of the vertical and horizontal linear polarizations, U is the difference of the $+45°$ and $-45°$ position angle linear polarizations, V is the difference of the right- and left-hand circular polarizations.

According to OH pumping considerations, 1720 MHz OH masers are excited collisionally by shock waves. For the first time this was suggested by S.A. Pustil'nik (Astrofiz. Issled. Izv. Spets. Astrofiz. Observ. **6**, 16, 1974) in application to 1720 MHz OH masers in the vicinity of supernova remnants (SNRs). Pumping of 1720 MHz masers in SNRs was further analyzed by M. Elitzur (ApJ **203**, 124, 1976) for the case of interaction of an SNR shock with the surrounding interstellar molecular cloud. Since then, OH 1720 MHz masers have been detected in many SNRs (A.J. Green et al., AJ **114**, 2058, 1997).

In addition to main-line masers in star-forming regions (where the 1665 MHz line is usually the strongest one among the ground-state OH transitions), 1720 MHz OH masers turned out to be also widespread in SFRs (J.L. Caswell, MNRAS **308**, 683, 1999). They are, too, believed to be excited by shocks, though they require somewhat different physical conditions, namely higher gas densities than near SNRs. Dedicated surveys (e.g., J.L. Caswell, MNRAS **349**, 99, 2004; I.D. Litovchenko et al., Astron. Rep. **56**, 536, 2012) have yielded

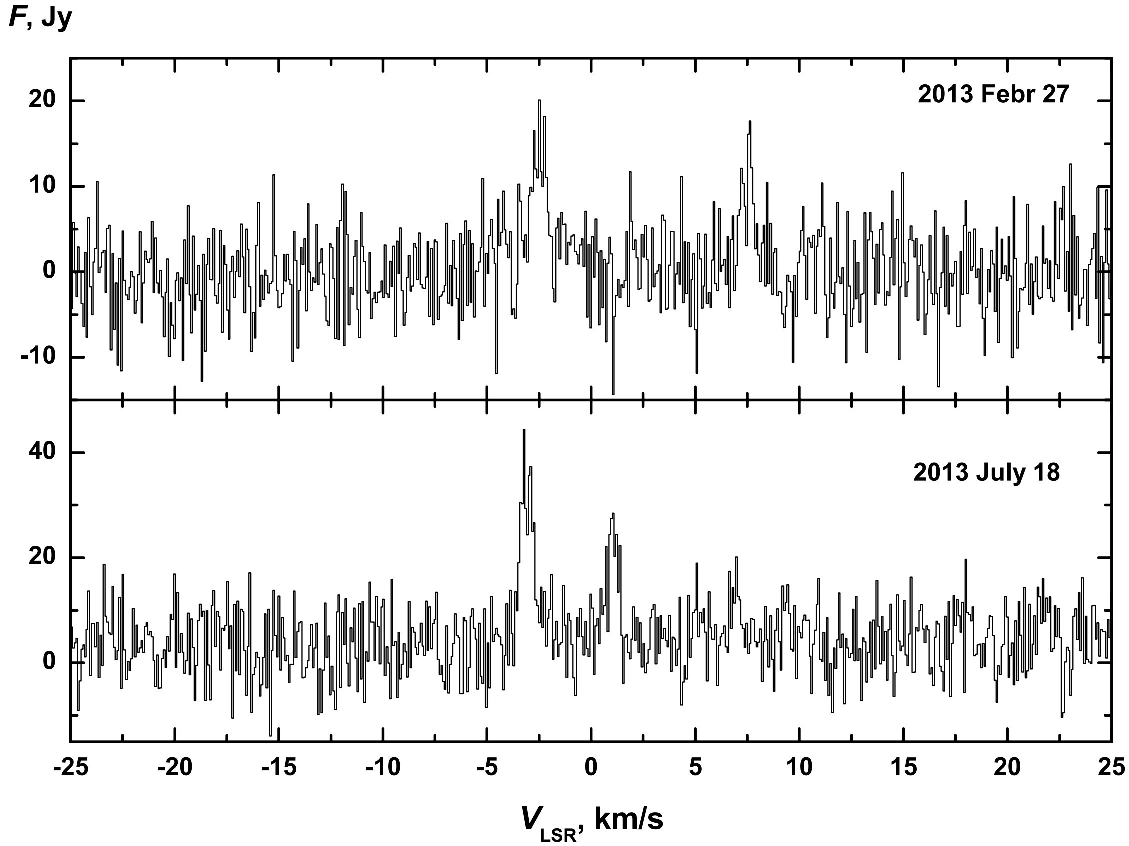

Figure 2: Profiles of the H_2O maser emission at $\lambda = 1.35$ cm in the source G188.946+0.886 observed in 2013 on the 22-meter radio telescope of the Pushchino Radio Astronomy Observatory, Russia. The telescope HPBW is $2\overset{\prime}{.}6$, the velocity resolution is 0.082 km s^{-1}.

several tens of detected 1720 MHz masers in SFRs. In particular, Litovchenko et al. suggest an association of 1720 MHz OH masers with bipolar outflows in the vicinity of methanol masers. Indeed, as noted above, R. Snell et al. (ApJ **325**, 853, 1988) found a bipolar outflow in the Sh2-247 region in the vicinity of G188.946+0.886. The examination of Snell et al.'s Figure 11 shows a two-peaked structure of the CO line, with the blueshifted peak at $V_{\rm LSR} \approx 4.2$ km s^{-1}, close enough to the velocity of the 1720 NHz emission detected by us. Thus, we concluded that the "blueshifted" 1720-MHz feature may be produced by the "blue" wing of the bipolar molecular outflow from the young stellar object IRAS 06058+2138.

We have also been monitoring G188.946+0.886 since 2000 in the $\lambda = 1.35$ cm 6_{16}–5_{23} H_2O maser line on the 22-meter telescope in Pushchino (Lekht et al., 2012). Figure 2 presents two sample spectra obtained in February and July 2013. The H_2O maser turned out to be rather variable. In February there were two emission features at $V_{\rm LSR} \approx -2.6$ and 7.1 km s^{-1} with peak flux densities 17 and 12 Jy respectively. The July spectrum demonstrates peaks at $V_{\rm LSR} \approx -3.2$, 1.0, and 7.0 km s^{-1} (33, 22, and 17 Jy, respectively, the 7-km s^{-1} feature is barely visible). In their first H_2O detection Batchelor et al. (1980) saw a 40 Jy feature at $V_{\rm LSR} \approx -5$ km s^{-1} and a fainter one, 10 Jy, at $V_{\rm LSR} \approx 8$ km s^{-1}. The latter, together with ours at 7 km s^{-1}, match into the velocity interval of the OH main-line emission and are close to that of the methanol masers (e.g., M. Szymczak et al., A&ApSS **143**, 269, 2000). On the other hand, the "blueshifted" H_2O features, like the newly detected 1720 MHz OH emission feature, may be related to the "blue" wing of the bipolar outflow.

To check the association between the bipolar outflow, OH and H_2O masers, of interest would be multiwavelength VLBI observations of G188.946+0.886.

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