Radio Variability and Broad-Band Spectra of Infrared Galaxies with and without OH Megamaser Emission

Yu. V. Sotnikova,1* T. V. Mufakharov,1,2 A. G. Mikhailov,1 V. A. Stolyarov,1,2,3 Z. Z. Wu,4 M. G. Mingaliev,1,2 T. A. Semenova,1 A. K. Erkenov,1 N. N. Bursov,1 and R. Y. Udovitskiy1
1Special Astrophysical Observatory of RAS, Nizhny Arkhyz 369167, Russia
2Kazan Federal University, 18 Kremliyovskaya St, Kazan 420008, Russia
3Astrophysics group, Cavendish laboratory, University of Cambridge, J J Thomson Ave, Cambridge, CB3 0HE, UK
4College of Physics, Guizhou University, 550025 Guiyang, China

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ABSTRACT
We study the radio variability of galaxies with and without sources of hydroxyl (OH) megamaser radiation based on the continuum radio measurements conducted in 2019–2022 with the radio telescope RATAN-600 at frequencies of 2.3, 4.7, 8.2, and 11.2 GHz. Presumably, radio continuum emission significantly affects the megamaser radiation brightness, therefore, such a characteristic as the variability of radio emission is important for determining the OHM galaxies parameters. With additional data from the literature, the parameters of radio variability on a time scale up to 30 years were estimated. The median values of the variability index for 48 OHM galaxies are in the range $V_S = 0.08–0.17$, and for 30 galaxies without OH emission they are $V_S = 0.08–0.28$. For some individual galaxies in both samples, flux density variations reach 30–50%. These sources either are commonly associated with AGNs or reveal active star formation. Generally, the variability of luminous infrared galaxies with and without OH megamaser emission is moderate and of the same order of magnitude on long time scales. From estimating the spectral energy distribution parameters in a broad frequency range (from MHz to THz), we determined the spectral index below 50 GHz and the color temperatures of dust components for megamaser and control sample galaxies. At a level of $p < 0.05$, there are no statistically significant differences in the distribution of these parameters for the two samples, as well there are no statistically significant correlations between the dust color temperatures and the variability index or luminosity in the OH line.

Key words: galaxies: active – quasars: general – galaxies: starburst – galaxies: infrared – radio continuum: galaxies

1 INTRODUCTION
The galaxies hosting OH megamaser emission (OH megamaser galaxies – OHMs) are radio sources with the enhancement of spectral lines corresponding to the quantum transitions between the sub-levels of hydroxyl molecule (OH) hyperfine structure at frequencies of 1665 and 1667 MHz (Baan et al. 1992). Galaxies are classified as OHMs in the case of $L_{OH} > 10^{11}L_\odot$ (Zhang et al. 2014). Almost all known megamasers are located in luminous and ultra-luminous infrared galaxies (U/LIRGs) with luminosity in the far infrared range $L_{FIR}$ exceeding $10^{11}L_\odot$. It is believed that their emission is generated due to strong tidal interaction during the merging of rich molecular gas galaxies Clements et al. (1996). There is an opinion that the OH emission is characteristic of the evolutionary stage of formation of quasars and massive elliptical galaxies (Haan et al. 2011).

The dominant energy source in the central parts of OHMs can be extensive star formation or radiation from the accreting supermassive black hole in an AGN, or a combination of these two processes (Vardoulaki et al. 2015). One of the main conditions of megamaser radiation is the presence of seed radio emission. By measuring the radio spectra parameters and variability for as many OHM galaxies as possible, we can determine the statistical radio properties of this class of objects and their possible difference from the properties of infrared galaxies without OHM emission sources. To date there are few systematic OHM radio measurements due to their weak flux densities (units or tens of mJy) (Kandalyan 2005a,b).

In 2019–2021 with the radio telescope RATAN-600 we carried out one of the largest OHM radio continuum surveys. A sample of 74 OHM galaxies was observed at frequencies 1.2–22.3 GHz (Sotnikova et al. 2022). The aim of the study was to determine the parameters of the sample of OHM galaxies in the radio domain and compare them with the same parameters obtained for a control sample of 128 infrared galaxies without megamaser emission (Zhang et al. 2014). As a result, statistical differences of radio properties in the two samples were obtained. We found significant correlations between the OH line and radio continuum luminosities ($L_{OH}–P_{1.4}$), between the OH line luminosities and the radio spectral index ($L_{OH}–\alpha_{4.7}$), between the FIR and radio continuum luminosities ($L_{FIR}–P_{1.4}$). Despite the fact that both samples were dominated by objects with steep radio spectra (53% and 61%), it was found that the sample of OHM galaxies contains 2 times more objects with flat spectra (32%) than the control one (17%).

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The results may indicate a significant impact of radio continuum emission on the intensity of megamaser radiation. Obviously, a significant proportion of AGNs in both samples (47% and 30% for OHM and non-OHM respectively) influenced the obtained properties. The purpose of this work is to estimate the radio flux density variability of infrared galaxies in both samples. The variability of radio emission was estimated using both the multifrequency RATAN-600 measurements in 2019–2022 and the literature data. Light curves were analyzed for individual objects on time scales up to 34 years.

The objects with high frequency measurements (THz) were selected to assess the contribution of the synchrotron and dust components to the continuum radio spectra of galaxies. The spectral index of the low-frequency component was determined and estimates of dust color temperature were made. The estimates of the correlation of dust color temperature with some characteristic parameters of megamaser radiation were obtained.

2 SAMPLE AND OBSERVATIONS

Our target and control samples, containing 74 OHM galaxies and 128 galaxies without megamaser emission greater than 5 mJy at the 1.4 GHz frequency, are borrowed from Zhang et al. (2014). This list of OHM galaxies had been the most complete at the time of their study, also the authors collected a control sample that included all Arendibo survey galaxies without detected megamaser emission (Darling & Giovanelli 2002). The observations were conducted in 2019–2022 with the radio telescope RATAN-600 at 1.2, 2.3, 4.7, 8.2, 11.2, and 22.3 GHz. Flux densities measured in 2019–2021 and the radio properties of the target and control samples are published in Sotnikova et al. (2022). In total, with RATAN-600 we managed to detect 63 OHMs and 35 galaxies of the control sample, noticing the low detection level (4–75% at different frequencies).

3 VARIABILITY

To estimate variability, we used both the RATAN-600 measurements obtained in 2019–2022 and the literature data from CATS1 (Verkhodanov et al. 1997, 2005), NED2 and VizieR3. For 61 OHMs and 56 galaxies of the control sample, there are radio continuum measurements in the literature for at least one observing epoch and at frequencies within ±20% of the RATAN-600 frequencies.

As a quantitative estimate of variability, we used the variability index $V_S$ from Aller et al. (1992):

$$V_S = \frac{(S_{\text{max}} - \sigma_{S_{\text{max}}}) - (S_{\text{min}} + \sigma_{S_{\text{min}}})}{(S_{\text{max}} - \sigma_{S_{\text{max}}}) + (S_{\text{min}} + \sigma_{S_{\text{min}}})},$$

(1)

where $S_{\text{max}}$ and $S_{\text{min}}$ are the maximum and minimum values of flux density for all epochs of observations; $\sigma_{S_{\text{max}}}$ and $\sigma_{S_{\text{min}}}$ are their errors. Thus we can partially exclude the influence of flux density measurement uncertainties that could cause overestimation of the variability index. The negative value of $V_S$ corresponds to the case when the errors of measured flux density are greater than their scatter, which makes impossible to detect object’s variability.

Uncertainties of variability indices were estimated as:

$$\Delta V_S = \frac{2S_{\text{min}}(\sigma_{S_{\text{max}}} + \sigma_{S_{\text{min}}})}{(S_{\text{min}} + S_{\text{max}})^2}.$$  

(2)

The modulation index, defined as the standard deviation of flux density divided by the mean flux density, was calculated as in Kraus et al. (2003):

$$M = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(1 - \frac{N}{\sum_{i=1}^{N}} S_i \right)^2},$$

(3)

where $S_i$ is the $i$-th flux density, $N$ is the number of observations.

The calculated variability indices at frequencies of 2.3, 4.7, and 8.2 GHz for the OHM and control sample galaxies are presented in Table A1 and Table A2.

For 48 OHM galaxies and 30 control sample galaxies, there are at least two measurements at least at one frequency. The statistics of variability indices for them are presented in Table 1. Only positive values of $V_S$ were used to calculate the mean and median values of the variability indices. On average, at a frequency of 4.7 GHz, which represents the largest number of sources with available measurements, variability of 15–20% for the sample of megamasers and 10–15% for the control sample is obtained. When considering galaxies identified as having AGNs in both samples, it is obvious that their variability is higher, but it also lies within 15–20% for the OHM galaxies, and for a few galaxies in the control sample the spread is slightly wider: 12–22% (Table 1).

The most variable source in the control sample, J0854+2006, is identified with a blazar in Abdo et al. (2010) ($V_{S_{\text{1.4}}} = 0.86$ (0.02), $V_{S_{\text{5.0}}} = 0.81$ (0.03), $V_{S_{\text{8.2}}} = 0.82$ (0.02)), it also has the biggest number of measurements ($N = 776–2830$). The most variable galaxies among OHMs are: the AGN (Ackermann et al. 2011) NGC 253 (J0047–2517 with $V_{S_{\text{2.3}}} = 0.34$ (0.04), $V_{S_{\text{8.2}}} = 0.35$ (0.05)) and the Seyfert 2 galaxy (Véron-Cetty & Véron 2006) IRAS 15065–1107 ($V_{S_{\text{1.4}}} = 0.49$ (0.06)).

The distributions of variability and modulation indices at 4.7 GHz for megamaser and control sample galaxies are shown in Fig.1 and Fig.2.

We have not found any statistically significant (with p-value < 0.05) correlations between the modulation and variability indices at frequencies of 4.7 and 8.2 GHz and other parameters such as the luminosity in the $L_{\text{OH}}$ hydroxyl line, luminosity in the far infrared region $L_{\text{FIR}}$, spectral index in the FIR, radio loudness, $q$ parameter, and radio luminosity at 1.4 GHz for both the OHM and control samples.

The distribution of variability and modulation indices at 4.7 and 8.2 GHz in both samples does not differ statistically according to the Kolmogorov–Smirnov and Mann–Whitney tests ($p < 0.05$). Also we found that variability and modulation indices belong to the same distribution according to the Kruskal–Wallis test ($p < 0.05$).

It is obvious that to assess the relationship between the activity of the host galaxy nucleus and the megamaser emission (or its variability), simultaneous measurements are essential. In this work we analyze individual measurements of integrated radio flux density, which does not allow us to estimate the possible correlation of such events.

3.1 Light curves

For 14 OHM galaxies we estimated radio variability near a frequency of 5 GHz on a time scale of 2–34 yrs, and near a frequency of 11.2 GHz on a scale of 1–9 yrs. We used available literature data provided by the GB6 (Gregory et al. 1996), 87GB (Gregory & Condon 1991),
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Figure 1. The distribution of variability indices at 4.7 GHz for the (a) OHM and (b) control samples. AGNs are shown with the dark grey color.

Figure 2. The distribution of modulation indices at 4.7 GHz for the (a) OHM and (b) control samples. AGNs are shown with the dark grey color.

PMN (Griffith & Wright 1993), RGB (Laurent-Muehleisen et al. 1997), VLBIT (Taylor et al. 1996), VLAC (Taylor Very Large Array Calibration Source List), JVAS (Wilkinson et al. 1998), AT20G (Murphy et al. 2010), and MGV (Identifications of Radio Sources in the MG-VLA Survey) catalogs. The light curves are presented in Fig. 3. The classification of the galaxies, number of observing epochs $N$, time scale $t$, radio morphology, and references are presented in Table 2. For eight galaxies the variability index reaches values of 0.20–0.49 at 5 GHz. Seven of them are identified as AGNs according to Véron-Cetty & Véron (2006). Information about angular structure is available for a few objects.

For four galaxies, J0159−2924, J0512−2421, J0622−3647, and J1642−0943, the variability of integrated flux density was estimated based only on the RATAN measurements at 5 GHz in 2019–2022 with $V_{S_{4.7}}$ equal to 0.12, 0.35, 0.33, and 0.14 respectively. For the galaxies J0817+3128, J1153+3905, J1534+2330, and J1723−001, the variability was calculated on a long time scale with a rare number of observations, and $V_{S_{4.7}}$ does not exceed 0.04–0.09. And one galaxy, J1513+0713, with the “core” type morphology turned out to be low-variable, $V_{S_{4.7}} = 0.13$ (15 measurements over 34 years).

One of the brightest objects, J0047-2517 (Table 2), according to the VLA (Lenc & Tingay 2006) has a complex radio morphology with several dozen compact components which can be identified with supernovae, supernova remnants, or HII regions (Ulvestad & Antonucci 1991). In one of the components a flux density variability of 6.5%±2.5% was found at 4.7 GHz over a time interval of 18 months in 1989–1990. According to the VLBI measurements at 2.3 GHz, the central region of the galaxy has a core+jet type morphology (astrogeo⁴, an angular resolution of about 5 mas). We estimated (Fig. 3) the variability $V_{S_{4.7}} = 0.25 ± 0.02$ on a time scale of 28 years (12 observing epochs) and an insignificant variability $V_{S_{1.4}} = 0.03 ± 0.004$ over 2 years (10 epochs).

The galaxy Arp 299 (J1128+5833) with an active nucleus is one of the most variable in our sample, $V_{S_{4.7}} = 0.42 (0.02)$ on a 34-year

⁴ https://http://astrogeo.org/vlbi_images/
scale (Fig. 3) and $V_{S11.2} = 0.18 (0.03)$ on a 2-year scale. The VLA measurements (Romero-Cañizales et al. 2011) revealed variable radio emission from one of the compact components at 8.4 GHz with a variability index of about 0.22 in 1990–2006 on a time scale of more than 10 years.

The galaxy J0144+1706 (III Zw35) has a similar angular structure with many compact components. The radio continuum VLA and MERLIN measurements (Chapman et al. 1990; Pihlström et al. 2001) at 18 cm in 1986–1998 revealed no change in spectral flux density. We found variations in radio emission $V_{S1.4} = 0.49 \pm 0.06$ in the period of 1987–2022. The most variable galaxy with $V_{S4.7} = 0.31 \pm 0.06$ is J1256+5652 with a resolved core and a 2.3 GHz two-side jet.

We estimated the variability of individual galaxies using low-cadence measurements. Due to this reason the obtained results most likely correspond to the lower bound of variability. The integral flux density variability of OHM galaxies results from the contributions of an active nucleus and the variability of compact regions (supernova remnants or regions of ionized hydrogen HII), which are potential megamaser emission sources (Pihlström et al. 2001). VLBI measurements of compact components show that radio emission variations in them can reach a few dozen per cent on scales of several years. Spectral flux density in such regions can be an order of magnitude less than the integral flux density of the host galaxy. Obviously, in the case of RATAN-600 measurements we observe the dominant contribution of a variable radio nucleus.

### 4 Modeling the Spectral Energy Distribution of OHM Galaxies

#### 4.1 Problem formulation—an overview

Continuum radiation from galaxies containing hydroxyl megamasers is formed due to several mechanisms that dominate in certain frequency ranges. At low frequencies (up to 30–50 GHz), the main
**Table 1.** The median and mean values of the variability indices at different frequencies for the OHM and control samples. The left part of the table is for the full sample, and the right part is for the AGN subsample.

|          | OHM          |          | OHM-AGN        |          |
|----------|--------------|----------|----------------|----------|
| $M_{8.3}$ | 9            | 0.08     | 12 (0.08)      | 8        |
| $V_{8.3}$ | 6            | 0.17     | 19 (0.11)      | 6        |
| $M_{4.7}$ | 47           | 0.13     | 16 (0.12)      | 23       |
| $V_{4.7}$ | 27           | 0.17     | 20 (0.14)      | 18       |
| $M_{3.2}$ | 29           | 0.15     | 17 (0.13)      | 18       |
| $V_{3.2}$ | 13           | 0.08     | 13 (0.13)      | 9        |

|          | Control      |          | Control-AGN    |          |
|----------|--------------|----------|----------------|----------|
| $M_{8.3}$ | 5            | 0.08     | 11 (0.12)      | 2        |
| $V_{8.3}$ | 5            | 0.22     | 24 (0.26)      | 2        |
| $M_{4.7}$ | 30           | 0.11     | 15 (0.11)      | 11       |
| $V_{4.7}$ | 16           | 0.08     | 17 (0.21)      | 6        |
| $M_{3.2}$ | 11           | 0.14     | 18 (0.13)      | 6        |
| $V_{3.2}$ | 5            | 0.28     | 38 (0.32)      | 2        |

The emission of dust at frequencies of 100 GHz–10 THz was approximated by a power law

$$S_\nu = A \cdot \nu^\beta,$$

where $S_\nu$ is the flux density, $\nu$ is the frequency, $\beta$ is the power law index, which is mainly determined by the synchrotron component emission, and $A$ is a scale coefficient.

The main task of the continuum SED modeling was to obtain the key model parameters ($\beta$, $T_1$, and $T_2$) for the objects, evaluate their statistical properties, and compare them in the megamaser and control samples. It is worth noting that the studied samples are quite small, and these estimates may be biased.

### 4.2 Data used for the SED modelling

In addition to the proprietary flux density data obtained at the radio telescope RATAN-600, the catalogs and databases listed in Table 3 were used to construct spectra in a broad range from low frequencies to the mid-IR wavelengths.

Although there are some flux data in the near and middle IR range (mainly from the WISE catalog (Wright et al. 2010)) for all 74 megamasers from the list under study, in the sub-millimeter and far infrared range the data were found for only 28 objects (38% of the list). In the control sample, the contribution of the sub-mm and IR components turned out to be even smaller, and the spectral energy distribution in this range was approximated only for 10 objects out of 128 (8%).

### 4.3 Main results and parameter statistics

Modeling of the SED was carried out for 28 megamasers and 10 objects from the control sample where maser radiation was not detected. With a few exceptions, the low-frequency spectral indices $\beta$ are in the range from $-1.0$ to $-0.2$, which illustrates the variants of the superposition of the synchrotron and free-free components for different cases. The color temperatures for the dust component lie in the intervals $T_1 = 5–33$ K and $T_2 = 40–160$ K. Notice that the contribution of “warm” dust, despite an insignificant weight $w$, has a significant effect on the shape of the spectrum. The parameters for all the sources for which the simulation was performed are given in Table 4. The weighted average color temperature $T_{\text{aver}} = w_1 T_1 + w_2 T_2$, where $w_1 + w_2 = 1$, is also included in this table.
Table 2. The variability index $V_3$ of the OHM galaxies calculated using the RATAN-600 and literature data.

| NVSS name | $t_s$, years | $N_{4.7}$, epochs | $V_{4.7}$ | $t_{11.2}$, years | $N_{11.2}$, epochs | $V_{11.2}$ | type | morph | reference |
|-----------|--------------|-------------------|----------|-------------------|-------------------|----------|------|-------|-----------|
| 004733–251717 | 28 | 12 | 0.25 (0.02) | 2 | 10 | 0.03 (0.004) | AGN | core+jet | Ulvestad & Antonucci (1991) |
| 014439+170608 | 29 | 12 | 0.31 (0.06) | – | – | – | AGN | diffused | Pihlström et al. (2001) |
| 015913–292435 | 3 | 12 | 0.12 (0.02) | – | – | – | AGN | – | Imanishi et al. (2019) |
| 051209–242156 | 2 | 11 | 0.35 (0.08) | – | – | – | AGN | – | Kandalian (1996) |
| 062222–364742 | 2 | 11 | 0.33 (0.07) | – | – | – | AGN | – | Kandalian (1996) |
| 081755+312827 | 34 | 14 | 0.08 (0.01) | 2 | 9 | 0.34 (0.07) | AGN | – | Tarchi et al. (2011) |
| 093551+612112 | 34 | 13 | 0.20 (0.05) | – | – | – | AGN | core | Pérez-Torres et al. (2010) |
| 112832+583346 | 34 | 13 | 0.42 (0.02) | 1 | 7 | 0.18 (0.03) | AGN | core+jet | Tarchi et al. (2011) |
| 115311+390748 | 28 | 10 | 0.07 (0.01) | 1 | 9 | 0.02 (0.002) | AGN | core+double jet | astrog eo |
| 125614+565223 | 34 | 18 | 0.49 (0.06) | 1 | 9 | 0.10 (0.01) | AGN | multi-components | Bondi et al. (2005) |
| 134442+555313 | 34 | 14 | 0.39 (0.05) | – | – | – | AGN | core | astrog eo |
| 151313+071331 | 34 | 15 | 0.13 (0.04) | 2 | 5 | 0.20 (0.05) | AGN | core | astrog eo |
| 153457+233011 | 34 | 18 | 0.04 (0.003) | 9 | 30 | -0.04 | AGN | core | astrog eo |
| 164240–094315 | 2 | 12 | 0.14 (0.03) | – | – | – | AGN | resolved | EVN archive |
| 172321–001702 | 32 | 12 | 0.09 (0.01) | 2 | 4 | 0.31 (0.07) | AGN | diffused | Momjian et al. (2006) |

Table 3. A list of the databases and catalogs with flux density data used to construct the OHM spectra in a broad frequency range from megahertz to IR. The procedure from Cutri et al. (2012) was used to convert the photometric stellar magnitudes of the ALLWISE catalog into the flux units (Jy).

| Name of the catalog or database | Frequency bands, GHz | URL | References |
|-------------------------------|----------------------|-----|-------------|
| CATS                          | < 30                 | [http://cats.sao.ru](http://cats.sao.ru) | Verkhodanov et al. (1997), Verkhodanov et al. (2005) |
| IRSA                          | > 30                 | [https://irs.aipac.caltech.edu/frontpage/](https://irs.aipac.caltech.edu/frontpage/) | Berriman (2008) |
| Planck PCCS2 LFI              | 30, 44, 70           | [http://pla.esac.esa.int/pla/#catalogues](http://pla.esac.esa.int/pla/#catalogues) | Planck Collaboration et al. (2016) |
| Planck PCCS2 HFI              | 100, 143, 217, 545, 857 | [http://pla.esac.esa.int/pla/#catalogues](http://pla.esac.esa.int/pla/#catalogues) | Planck Collaboration et al. (2016) |
| Herschel HPPSC                | 1874, 2998, 4283     | [https://www.cosmos.esa.int/web/herschel/pacs-point-source-catalogue](https://www.cosmos.esa.int/web/herschel/pacs-point-source-catalogue) | Marton et al. (2017) |
| Herschel SPSC                 | 600, 857, 1199       | [https://www.cosmos.esa.int/web/herschel/spire-point-source-catalogue](https://www.cosmos.esa.int/web/herschel/spire-point-source-catalogue) | Schulz et al. (2017) |
| Akari                        | 16655, 33310         | [https://iris.ipac.caltech.edu/Missions/akari.html](https://iris.ipac.caltech.edu/Missions/akari.html) | Ishihara et al. (2010) |
| AllWISE                      | 13636, 25000, 65217, 88235 | [https://iris.ipac.caltech.edu/data/download/wise-allwise/](https://iris.ipac.caltech.edu/data/download/wise-allwise/) | Wright et al. (2010), Cutri et al. (2012) |

The distribution of the “cold” dust color temperature $T_1$ for the OHM and control samples is shown in Fig. 4. The average values for the two dust components are $(T_1) = 23.2 \pm 5.9 \text{K}$, $(T_2) = 60.9 \pm 24.6 \text{K}$ for megamasers and $(T_1) = 23.1 \pm 6.2 \text{K}$, $(T_2) = 73.1 \pm 45.6 \text{K}$ for the control sample.

The calculations performed do not show significant correlation between the dust color temperature $T_1$ in the sample of megamasers and such parameters as the variability index $V_{4.7}$, or the luminosity in the OH line $L_{\text{OH}}$. Also, no significant correlation was found between the synchrotron spectral index $\beta$ and $T_1$ (the Pearson correlation coefficient $r = 0.22$, p-value $= 0.27$).

The Pearson correlation coefficient for the sample of megamasers between the parameters $T_1$ and $T_2$ themselves is 0.4 (p-value = 0.03), which is not surprising, since with an increase in the average temperature of the ensemble of dust particles the color temperature should increase for all components of the model.

The Kolmogorov–Smirnov test for the two samples of $T_1$, megamasers and control, gives a value of $k_s = 0.23$ (p-value = 0.75), which makes it impossible to talk about statistical differences between these two distributions.

The results of the SED approximation for megamasers are shown in Figs. 5–8, and for the control sample in Figs. 9–10. It should be noted that the fluxes in the middle and near-IR region with frequencies greater than 10 THz are formed due to the radiation of the PAH molecules and were not modeled in this work.

5 CONCLUSION
We have studied the integral flux density variability of infrared-bright galaxies with megamaser (OHM) sources and a control sample of galaxies without OH radiation. For most OHM galaxies the variability level in the radio continuum does not exceed 0.20, and the median values of the variability index for the entire OHM sample vary within...
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0.08–0.17 at the considered frequencies. A comparison with the control sample of non-OHM infrared galaxies has shown that for this sample the variability level is 0.10–0.15, which does not differ much in order of magnitude from the obtained variability of OHM galaxies. Individual bright representatives of OHM galaxies demonstrate the variability level is 0.10–0.15, which does not differ much from the obtained variability of OHM galaxies. A comparison with the control sample of non-OHM infrared galaxies has shown that for this sample the variability level is 0.10–0.15, which does not differ much in order of magnitude from the obtained variability of OHM galaxies. Individual bright representatives of OHM galaxies demonstrate variability of the order of 0.30–0.50 near the 5 GHz frequency on a time scale of 2–30 yrs. Such galaxies are usually associated with AGNs, for example J0047–2517, or active star formation is observed in them, like in J1509–1119.

The parameters of the spectral energy distribution for the galaxies with available literature measurements in the frequency range from MHz to THz have been determined. The low-frequency spectral indices in the range < 50 GHz have been obtained, and the model parameters for thermal dust emission from 50 GHz to 10 THz have been estimated. A comparison of the dust component color temperature distributions for the two samples revealed no difference in their statistical properties. Also no significant correlations were found between the dust color temperature in the OHM galaxies and such parameters as the variability index or luminosity in the OH line.

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Table 4. Model parameters for the objects under study. The upper part of the table includes megamasers, the lower part includes objects from the control sample.

| NVSS name   | \( \beta \) | \( T_1 \), K | \( T_2 \), K | \( w_2 \) | \( T_{\text{aver}} \), K |
|-------------|-------------|-------------|-------------|---------|-----------------|
| 004733–251717 | -0.45 | 21.48 | 58.23 | 0.010 | 21.84 |
| 005334+124133 | -0.89 | 24.46 | 78.97 | 0.004 | 24.70 |
| 014430+170607 | -0.20 | 26.91 | 54.36 | 0.044 | 28.13 |
| 024240–000047 | -0.57 | 23.00 | 159.70 | 2 \times 10^{-3} | 23.01 |
| 033336–360826 | -0.59 | 17.94 | 62.90 | 0.001 | 18.01 |
| 052101–252145 | -0.60 | 29.66 | 69.02 | 0.024 | 30.61 |
| 054548+584203 | -0.62 | 16.52 | 31.18 | 0.054 | 17.31 |
| 093551+612112 | -0.44 | 24.60 | 56.94 | 0.010 | 24.92 |
| 100605–335317 | -0.63 | 8.33 | 39.72 | 0.001 | 8.36 |
| 102000+081335 | -0.30 | 26.44 | 52.23 | 0.058 | 27.94 |
| 110335+405059 | -0.48 | 24.72 | 52.76 | 0.016 | 25.17 |
| 112832+583343 | -0.66 | 21.71 | 61.12 | 0.013 | 22.24 |
| 115311–390748 | -0.52 | 24.35 | 53.33 | 0.018 | 24.86 |
| 121345+024840 | -0.21 | 27.05 | 54.78 | 0.036 | 28.04 |
| 122654–005238 | -0.40 | 25.93 | 61.34 | 0.034 | 27.12 |
| 125614+565222 | -0.31 | 29.32 | 68.79 | 0.022 | 30.18 |
| 131226–154751 | -0.48 | 21.28 | 57.19 | 0.004 | 21.43 |
| 131503+243707 | -0.26 | 24.99 | 51.53 | 0.044 | 26.18 |
| 134442+555313 | -0.43 | 27.83 | 58.10 | 0.035 | 28.89 |
| 134733+121724 | -0.52 | 32.90 | 117.39 | 4 \times 10^{-4} | 32.93 |
| 151313+071331 | -0.48 | 24.15 | 51.12 | 0.013 | 22.24 |
| 152659+355839 | -0.24 | 27.43 | 67.53 | 0.029 | 28.59 |
| 153457+233011 | -0.18 | 24.78 | 51.88 | 0.034 | 25.71 |
| 164240–094315 | -0.48 | 15.32 | 37.04 | 0.026 | 15.88 |
| 172321–001702 | -0.33 | 20.06 | 39.58 | 0.124 | 22.47 |
| 225149–175225 | -0.40 | 5.39 | 39.56 | 0.020 | 12.22 |
| 231600+253324 | -0.52 | 24.79 | 62.75 | 0.011 | 25.21 |
| 233901+362109 | -0.62 | 27.19 | 59.91 | 0.022 | 27.91 |
| 015950+002238 | -0.70 | 29.75 | 75.13 | 0.0178 | 30.56 |
| 090734+012502 | -0.27 | 24.37 | 46.29 | 0.0175 | 24.75 |
| 131653+234047 | -0.50 | 11.39 | 47.27 | 0.035 | 14.23 |
| 133718+242302 | -0.31 | 19.23 | 200.71 | 1 \times 10^{-3} | 19.23 |
| 134015+332437 | -0.96 | 17.89 | 56.34 | 0.124 | 22.68 |
| 140638+010255 | -0.74 | 21.28 | 57.19 | 0.004 | 21.43 |
| 140819+290446 | -0.76 | 23.00 | 72.26 | 0.048 | 31.18 |
| 142231+260203 | -0.86 | 25.89 | 34.76 | 1 \times 10^{-6} | 25.89 |
| 161644+031419 | -1.48 | 22.53 | 79.38 | 0.003 | 22.71 |
| 232427+293541 | 0.01 | 18.49 | 37.20 | 0.148 | 21.28 |

Figure 4. Distribution of dust temperature values \( T_2 \): a) the sample of megamasers; b) the control sample.
Figure 5. SED approximation for the OHMs having flux data in the sub-mm and IR regions. The fluxes in the mid-IR region at frequencies greater 10 THz are formed by the PAH molecules radiation and have not been modelled in this paper.
Figure 6. SED approximation for the OHMs having flux data in the sub-mm and IR regions (continued).
Figure 7. SED approximation for the OHMs having flux data in the sub-mm and IR regions (continued).
Figure 8. SED approximation for the OHMs having flux data in the sub-mm and IR regions (continued).

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Figure 9. SED approximation for the control sample sources having flux data in the sub-mm and IR regions.
Figure 10. SED approximation for the control sample sources having flux data in the sub-mm and IR regions (continued).
### APPENDIX A: VARIABILITY PARAMETERS

Table A1: Variability ($V_S$) and modulation indices ($M$) for OHM sample. N is the number of observations.

| NVSS name            | $N_{2.3}$ | $M_{2.3}$ | $V_{S_{2.3}}$ | $N_{4.7}$ | $M_{4.7}$ | $V_{S_{4.7}}$ | $N_{8.2}$ | $M_{8.2}$ | $V_{S_{8.2}}$ |
|----------------------|-----------|-----------|---------------|-----------|-----------|---------------|-----------|-----------|---------------|
| 000820+403755        | 0         | -         | -             | 2         | 0.08      | -0.17 (0.25)  | 0         | -         | -             |
| 004733−251171        | 15        | 0.20      | 0.34 (0.02)   | 27        | 0.24      | 0.29 (0.03)   | 10        | 0.29      | 0.35 (0.05)   |
| 005334+124133        | 1         | -         | -             | 2         | 0.21      | -0.13 (0.43)  | 0         | -         | -             |
| 014430+170607        | 0         | -         | -             | 14        | 0.28      | 0.31 (0.07)   | 5         | 0.19      | 0.03 (0.17)   |
| 015913−292435        | 0         | -         | -             | 12        | 0.14      | 0.12 (0.07)   | 4         | 0.05      | -0.13 (0.18)  |
| 024240−000047        | 27        | 0.05      | 0.06 (0.05)   | 30        | 0.08      | 0.15 (0.03)   | 16        | 0.23      | 0.29 (0.07)   |
| 025134+431514        | 16        | 0.16      | 0.16 (0.11)   | 53        | 0.21      | 0.45 (0.02)   | 22        | 0.17      | 0.33 (0.02)   |
| 030830+204620        | 0         | -         | -             | 2         | 0.14      | -0.05 (0.19)  | 0         | -         | -             |
| 032828+141207        | 0         | -         | -             | 2         | 0         | 0             | 0         | -         | -             |
| 033336−360826        | 7         | 0.24      | 0.31 (0.31)   | 4         | 0.17      | 0.19 (0.03)   | 2         | 0.38      | 0.18 (0.27)   |
| 035441+003704        | 0         | -         | -             | 2         | 0.20      | 0             | 1         | -         | -             |
| 051209−242156        | 0         | -         | -             | 11        | 0.35      | 0.35 (0.08)   | 1         | -         | -             |
| 052101−252145        | 0         | -         | -             | 3         | 0.46      | 0.33 (0.27)   | 2         | 0.47      | -0.33 (0.55)  |
| 054548+584203        | 0         | -         | -             | 5         | 0.13      | 0.11 (0.06)   | 0         | -         | -             |
| 062222−364743        | 0         | -         | -             | 11        | 0.37      | 0.33 (0.08)   | 1         | -         | -             |
| 065145+220427        | 0         | -         | -             | 4         | 0.24      | 0.05 (0.21)   | 1         | -         | -             |
| 080947+050108        | 0         | -         | -             | 5         | 0.23      | 0.20 (0.07)   | 1         | -         | -             |
| 090634+045125        | 0         | -         | -             | 2         | 0.11      | -0.11 (0.22)  | 0         | -         | -             |
| 093551+612112        | 0         | -         | -             | 17        | 0.18      | 0.20 (0.12)   | 4         | 0.10      | -             |
| 106065−335317        | 0         | -         | -             | 4         | 0.18      | -0.05 (0.26)  | 2         | 0         | 0             |
| 110353+405059        | 0         | -         | -             | 3         | 0.22      | 0.17 (0.06)   | 3         | 0.18      | 0.08 (0.13)   |
| 112832+583343        | 1         | -         | -             | 21        | 0.29      | 0.42 (0.02)   | 4         | 0.46      | -             |
| 115311−390748        | 0         | -         | -             | 12        | 0.10      | 0.06 (0.09)   | 2         | 0.09      | -0.20 (0.25)  |
| 121345+024840        | 0         | -         | -             | 3         | 0.08      | -0.13 (0.22)  | 4         | 0.26      | 0.18 (0.17)   |
| 122654−005238        | 1         | -         | -             | 5         | 0.06      | -0.07 (0.16)  | 4         | 0.09      | -0.06 (0.18)  |
| 125614+565222        | 0         | -         | -             | 23        | 0.32      | 0.16 (0.06)   | 6         | 0.15      | -             |
| 131126−154751        | 0         | -         | -             | 2         | 0.02      | -0.13 (0.15)  | 1         | -         | -             |
| 131503+243707        | 1         | -         | -             | 2         | 0.02      | -0.14 (0.16)  | 3         | 0.10      | -0.09 (0.20)  |
| 134442+555313        | 0         | -         | -             | 18        | 0.26      | 0.39 (0.04)   | 3         | 0.08      | -             |
| 134733+121724        | 35        | 0.08      | 0.17 (0.02)   | 65        | 0.09      | 0.19 (0.01)   | 32        | 0.08      | 0.14 (0.04)   |
| 140649+061035        | 0         | -         | -             | 3         | 0.20      | -0.08 (0.31)  | 0         | -         | -             |
| 150102+142001        | 0         | -         | -             | 3         | 0.09      | -0.11 (0.22)  | 0         | -         | -             |
| 150916−111925        | 0         | -         | -             | 3         | 0.58      | 0.49 (0.06)   | 0         | -         | -             |
| 151313+071331        | 4         | 0.08      | -0.15 (0.22)  | 17        | 0.14      | 0.13 (0.12)   | 6         | 0.08      | -0.10 (0.19)  |
| 152659+355839        | 0         | -         | -             | 4         | 0.09      | -0.08 (0.21)  | 4         | 0.18      | 0             |
| 153457+233011        | 8         | 0.19      | 0.10 (0.06)   | 19        | 0.06      | 0.06 (0.04)   | 12        | 0.04      | -0.04 (0.07)  |
| 161140−014707        | 0         | -         | -             | 3         | 0.12      | -0.05 (0.19)  | 2         | 0.08      | -0.17 (0.25)  |
| 163221+155146        | 0         | -         | -             | 2         | 0.09      | -0.09 (0.18)  | 0         | -         | -             |
Table A1: continued.

| NVSS name         | N2,3  | M2,3  | V_S2,3  | N4,7  | M4,7  | V_S4,7  | N8,2  | M8,2  | V_S8,2 |
|-------------------|-------|-------|---------|-------|-------|---------|-------|-------|--------|
| 164240−094315     | 0     | -     | -       | 12    | 0.19  | 0.14 (0.11) | 3     | 0.13  | -0.11 (0.20) |
| 172321−001702     | 2     | 0.02  | -0.12 (0.13) | 13    | 0.12  | 0.09 (0.08)  | 5     | 0.41  | -0.05 (0.11)  |
| 175429+325312     | 1     | -     | -       | 13    | 0.23  | 0.15 (0.23)  | 2     | 0.18  | -0.05 (0.24)  |
| 205125+185804     | 0     | -     | -       | 3     | 0.10  | -0.13 (0.25) | 1     | -     | -       |
| 220436+421940     | 0     | -     | -       | 2     | 0.07  | -0.13 (0.20) | 2     | 0.07  | -0.14 (0.21) |
| 225149−175225     | 0     | -     | -       | 0     | -     | -        | 2     | 0.03  | 0.03 (0.01)  |
| 230735+041559     | 0     | -     | -       | 2     | 0.05  | -0.16 (0.21) | 0     | -     | -       |
| 231600+253324     | 1     | -     | -       | 5     | 0.08  | -0.10 (0.21) | 5     | 0.15  | 0.06 (0.20)  |
| 233511+293000     | 0     | -     | -       | 2     | 0.11  | -0.11 (0.22) | 0     | -     | -       |
| 233901+362109     | 2     | 0.04  | -0.23 (0.27) | 4     | 0.11  | -0.05 (0.19) | 4     | 0.15  | 0       |
Table A2: Variability ($V_S$) and modulation indices ($M$) for control sample. N is the number of observations.

| NVSS name     | N$_{2,3}$ | M$_{2,3}$ | V$_{S_{2,3}}$ | N$_{4,7}$ | M$_{4,7}$ | V$_{S_{4,7}}$ | N$_{8,2}$ | M$_{8,2}$ | V$_{S_{8,2}}$ |
|---------------|-----------|-----------|---------------|-----------|-----------|---------------|-----------|-----------|---------------|
| 002651+340122 | 0         | -         | -             | 3         | 0.07      | -0.17 (0.25)  | 1         | -         | -             |
| 013741+330935 | 710       | 0.09      | 0.24 (0.01)   | 126       | 0.04      | 0.18 (0.01)   | 552       | 0.07      | 0.28 (0.05)   |
| 015328+260939 | 0         | -         | -             | 4         | 0.08      | -0.10 (0.21)  | 1         | -         | -             |
| 015950+002338 | 0         | -         | -             | 4         | 0.05      | -0.18 (0.24)  | 1         | -         | -             |
| 021008+235049 | 0         | -         | -             | 2         | 0.08      | -0.23 (0.31)  | 0         | -         | -             |
| 041634+122457 | 0         | -         | -             | 3         | 0.31      | 0.08 (0.31)   | 1         | -         | -             |
| 063956+280956 | 0         | -         | -             | 2         | 0.29      | 0.08 (0.23)   | 1         | -         | -             |
| 072128+040146 | 0         | -         | -             | 3         | 0.04      | -0.18 (0.23)  | 0         | -         | -             |
| 081755+312827 | 0         | -         | -             | 18        | 0.13      | 0.07 (0.10)   | 6         | 0.37      | 0.23 (0.09)   |
| 085448+200630 | 1573      | 0.32      | 0.68 (0.02)   | 776       | 0.37      | 0.81 (0.03)   | 2830      | 0.44      | 0.82 (0.02)   |
| 094521+173753 | 0         | -         | -             | 2         | 0.04      | -0.19 (0.22)  | 1         | -         | -             |
| 111438+324133 | 2         | 0         | 0             | 8         | 0.06      | -0.09 (0.17)  | 2         | 0.09      | -0.12 (0.21)  |
| 115314+131427 | 0         | -         | -             | 3         | 0.44      | 0.25 (0.25)   | 1         | -         | -             |
| 121320+314053 | 0         | -         | -             | 5         | 0.26      | 0.24 (0.12)   | 3         | 0.09      | -0.15 (0.27)  |
| 122906+020308 | 109       | 0.08      | 0.22 (0.02)   | 739       | 0.12      | 0.48 (0.07)   | 1424      | 0.19      | 0.57 (0.01)   |
| 131653+234047 | 0         | -         | -             | 2         | 0.22      | 0          | 2         | 0.29      | 0             |
| 133718+242302 | 0         | -         | -             | 3         | 0.09      | -0.11 (0.22)  | 0         | -         | -             |
| 135646+102609 | 0         | -         | -             | 5         | 0.30      | 0.17 (0.22)   | 2         | 0.08      | -0.17 (0.25)  |
| 142056−000429 | 0         | -         | -             | 2         | 0.22      | 0          | 1         | -         | -             |
| 161413+260415 | 0         | -         | -             | 5         | 0.19      | 0          | 1         | -         | -             |
| 175105+265903 | 1         | -         | -             | 8         | 0.10      | 0.07 (0.06)   | 3         | 0.20      | -0.03 (0.26)  |
| 181700+155449 | 1         | -         | -             | 2         | 0.07      | -0.14 (0.21)  | 1         | -         | -             |
| 183336+225201 | 0         | -         | -             | 3         | 0.14      | -0.09 (0.27)  | 0         | -         | -             |
| 204817+193655 | 1         | -         | -             | 3         | 0.17      | 0          | 1         | -         | -             |
| 214633+354835 | 0         | -         | -             | 2         | 0.27      | 0.09 (0.18)   | 1         | -         | -             |
| 224509+323128 | 0         | -         | -             | 2         | 0.09      | -0.09 (0.18)  | 1         | -         | -             |
| 231354+033055 | 0         | -         | -             | 2         | 0.10      | -0.10 (0.19)  | 1         | -         | -             |
| 231635+040518 | 23        | 0.06      | 0.08 (0.07)   | 46        | 0.09      | 0.23 (0.01)   | 4         | 0.05      | -0.02 (0.09)  |
| 232549+283421 | 1         | -         | -             | 4         | 0.08      | -0.13 (0.22)  | 4         | 0.14      | -0.05 (0.26)  |
| 235630+238349 | 0         | -         | -             | 2         | 0.13      | -0.13 (0.25)  | 1         | -         | -             |