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Variation of spectral features in the ON2 water maser

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Abstract. Results are presented of the analysis of H_2O maser spectra in ON2, obtained with the RT-22 radio telescope at Pushchino during 1981–1996. The spectral features are analyzed and their time evolution examined. Anticorrelation between the fluxes of features with close radial velocities is found. A systematic displacement of the drifts sum of all features from 0.8 to -0.3 km s^{-1}year^{-1} during 1981–1988 and 1990–1996 is observed. In 1989 a fast jump of this parameter from -0.3 to 0.8 km s^{-1}year^{-1} took place. The quadratic sum of the drifts of the features always increased during a rise in maser activity. Possible causes of the observed phenomena are discussed.

Key words: ISM: ON2 — masers — radio lines: ISM

1. Introduction

Water vapour emission in ON2 is associated with interstellar masers in a region of active star formation in the dust–gas cloud complex Cygnus X (Johnston et al. 1973). The main H_2O maser source in ON2 (the northern one) is located near a compact HII region (Matthews et al. 1973; Harris 1976; Matthews & Spoelstra 1983) and consists of two spatially separated regions, which are located on the opposite sides of a shell (Walker et al. 1978) whose diameter is about 2.7 10^{15} cm.

According to recent VLBI observations, the main H_2O maser is composed of three groups of features, located in a volume with diameter about 4 10^{16} cm (Hofner & Churchwell 1996). The maser is situated about 0.04 pc in front of the "cometary" ultracompact HII region G75.7 – 0.34.

From regular observations of the maser emission at 22 GHz made since 1981 it is found that there is: 1) anticorrelation between the integrated fluxes of two groups of spectral features (Lekht et al. 1996) and 2) velocity drift of the centroid velocity of each group (Márquez & Lekht 1997). The observed velocity drift may be caused by luminosity variations of the central star. However, we cannot exclude the possibility that other factors, related with the process of star formation in the ON2 region (Márquez & Lekht 1997), may exert an influence on the maser.

In the present work we continue the study of the H_2O maser sources in ON2 made earlier by Lekht et al. (1996). In that work the H_2O spectra obtained with the Pushchino RT-22 radio telescope (Russia) during 1981–1995 were presented and a detailed analysis of the time variation of the integrated H_2O emission and velocity centroid were made. The aim of the present work is to study the variations of individual spectral features: their flux, radial velocity and line widths. The results of our latest observations during December 1995–July 1996 with the RT-22 radio telescope at Pushchino are also included.

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2. Presentation of the results

The ON2 water maser spectra are complex. During the active phase the spectrum extends from -10 to 15 km s^{-1}. However, in the spectra the features appear, as a rule, to form groups clustered in certain spectral ranges. Isolated features do not appear often. For this reason a method was employed to fit gaussian curves to the spectra, on the basis of the velocity of each feature.

First of all, each spectrum observed was considered as the superposition of gaussian curves. The aim of the analysis was to determine the flux and the radial velocity for the peak of each gaussian and the gaussian width at half power. In order to gain a clearer insight into the variation of these parameters (specially the flux and the radial velocity because the width was not always determined with enough precision) we searched in the spectra for an existing emission feature, i.e. a feature which belongs to the same maser condensation. To determine whether a spectral feature corresponded to a maser condensation we assumed that:

1) there is only a monotonous trend of velocity for each spectral feature;

2) there are no fast velocity jumps;

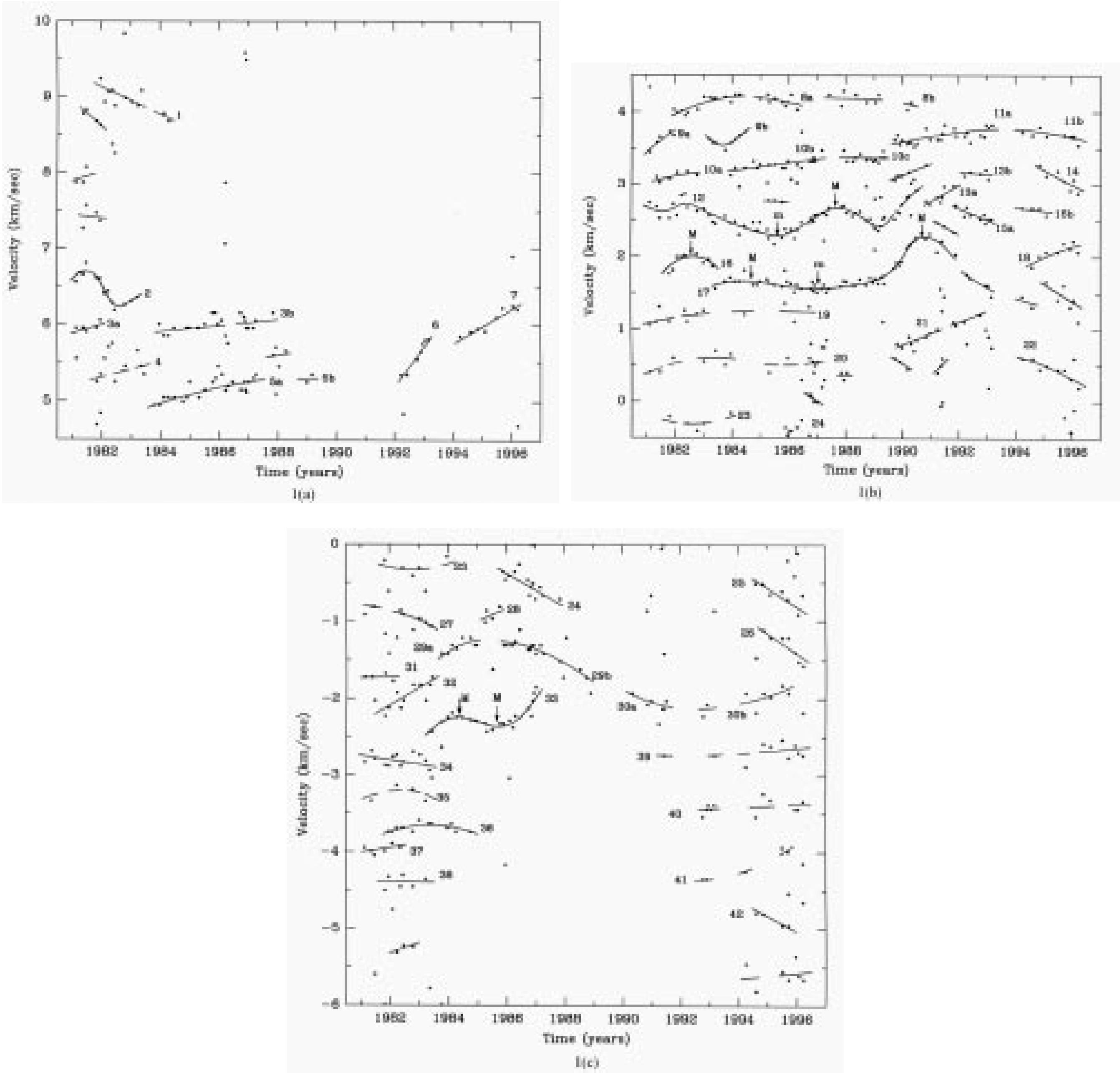

Fig. 1. Time variation in the velocity of H_2O maser features (dots). The solid lines delineate those features which belong to the same maser condensation. Dashed lines show the segment of the curves where no emission was detected in a given time

3) the similarity in shape in a given spectrum (and in spectral fragments) between adjacent components suggested that we were dealing with the same feature;

4) a feature should have more or less continuous flux variations.

On the basis of the above criteria we distinguished more than 60 features and 35 of them were in an active phase for more than two years. The emission of more than 10 features was observed for a considerable time, between 4–8 years. However, these condensations were not in the active phase for all of this time. For some periods, of up to 2 years, there was no emission from them. We denoted with numbers the most interesting features.

All the features that we identified in the interval from -6 to $10\ \mathrm{km\,s^{-1}}$ are shown in Figs. 1a–c. As may be seen from Fig. 1 the dots are not chaotically distributed and it is possible to fit most of them with more or less smooth curves. So, the curves of Figs. 1a–c, according to the above criteria, belong to separate maser condensations. In some cases (particularly, when the maser emission of the condensations was weak), the corresponding features appeared episodically in the spectra for brief intervals. In such situations there are only isolated dots or short curve segments. Some of these segments may belong to the same spectral feature. As a result, for these features we will have a disrupted curve.

Most of the dots are well fitted by smooth curves. This supports the idea that there are preferred velocities at which the H_2O features appear. We indicate with arrows and the letters "M" and "m" in Figs. 1a–c the times of the flux maxima and minima respectively. Only for three features (12, 16 and 17) do the flux maxima coincide with radial velocity maxima.

Time variations of the fluxes and differences between the radial velocities of close spectral features are presented in Figs. 2–6. In each figure the flux of two–three features is shown. This allows comparison of the evolution of those maser condensation which, most probably, are located in the vicinity of the shell and whose H_2O flux variations probably have a common cause.

As may be seen from Fig. 2 the fluxes of two spectral components, whose radial velocities are close, clearly anticorrelate. The anticorrelation was continuously observed during 1981–1986, having more or less periodic character with a period of about 1.5 years.

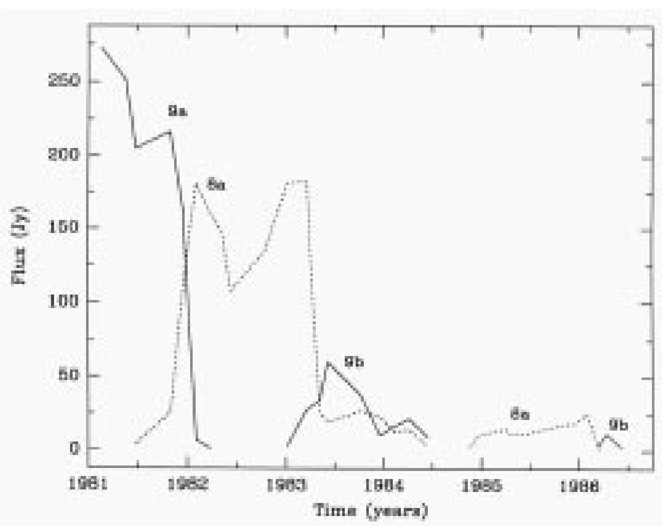

Fig. 2. Flux variations of spectral features 8 and 9 which are anticorrelated

Flux variation of the strong features at negative velocities during 1981–1986 is shown in Fig. 3. In this period a slow change of the maser to a minimum activity took place.

Time evolution of the most long lived features is given in Fig. 4. For convenience in the analysis of flux and velocity variations we considered (on the basis of the arguments below) that features 16 and 17 are identical. They have similar radial velocities and one feature merges into the other. After plotting smoothed curves (Fig. 4b, dashed

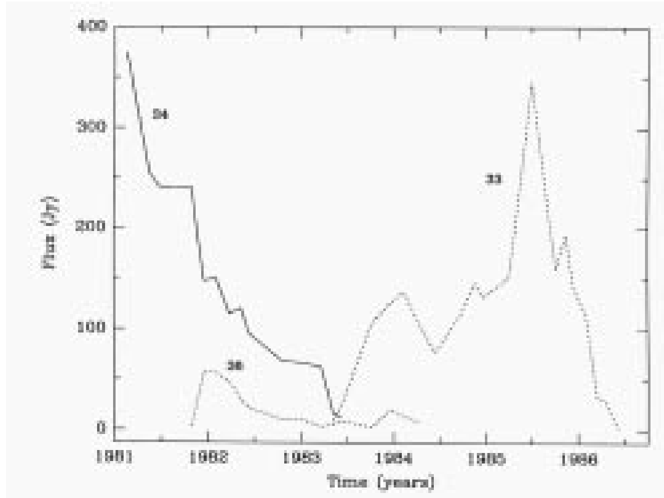

Fig. 3. Flux variations of the two main spectral features at negative velocities

line) the anticorrelation of the fluxes of the two main spectral features (12 and 16/17) becomes clear. Moreover, there is correlation between the flux variation of component 12 and the difference of radial velocities. The maximum velocity separation between features in the H_2O spectra are observed at times when one of the features (either of them) has a flux maximum.

The flux variations of the most intense features in 1988–1996 are shown in Fig. 5. In Fig. 6 time variations of the radial velocities of features 10c and 11a relative to feature 17 are given. At first the variation has an almost sinusoidal character with amplitude about 0.05 km s^{-1}. Later, the two components approach each other, the velocity difference reducing linearly from 1.8 to 1.3 km s^{-1}.

According to Fig. 1 many features show radial velocity drifts. To analyze the character of the drift for the many H_2O features in ON2 we introduced the parameters Σ_1 and Σ_2. They are the sum of the drifts at a given time for all distinct features. The sum of the drifts squares was also computed. Parameters Σ_1 and Σ_2 characterize of the state of the system (maser condensations). The values of the drifts in a given time were determined from the smoothed curves of Fig. 1, using a sampling interval of 1/3 year. The results are shown in Figs. 7a–c, where also the averaged values are given. In plotting Fig. 7 we did not take into account the features at velocities $V < -7$ km s^{-1}, since they were rather weak and belong to the S component.

The curve giving the sum of the velocity drifts of the components (Fig. 7b) has a sharp jump, which divides it into two equal parts. In each of them there is a clear tendency to drift changing from $\sim$ 0.8 to ~ -0.3 km s^{-1} year^{-1}. The drift jump took place during 1989, i.e., two years before the beginning of the maser activity enhancement in ON2. The analysis of the

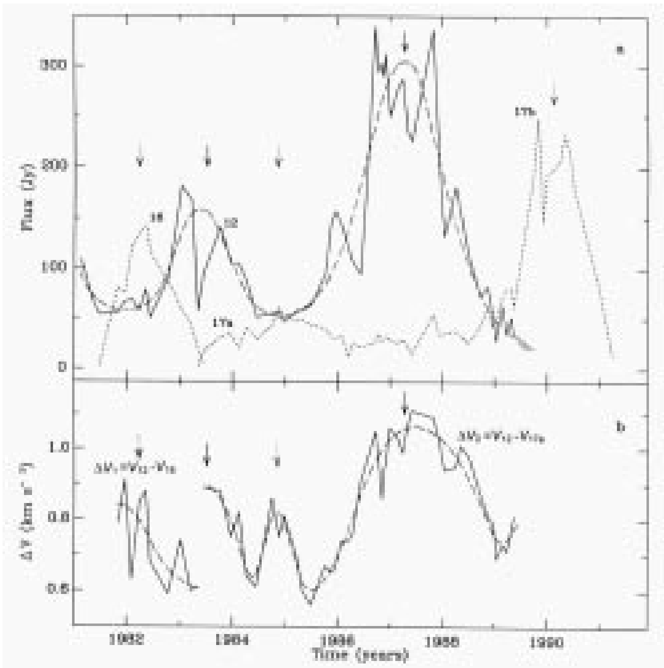

Fig. 4. a) Flux variations of the most long lived spectral features and **b)** difference of their radial velocities. Dashed lines shown the fitted smoothed curves. Solid and dotted arrows indicate the position of flux maxima

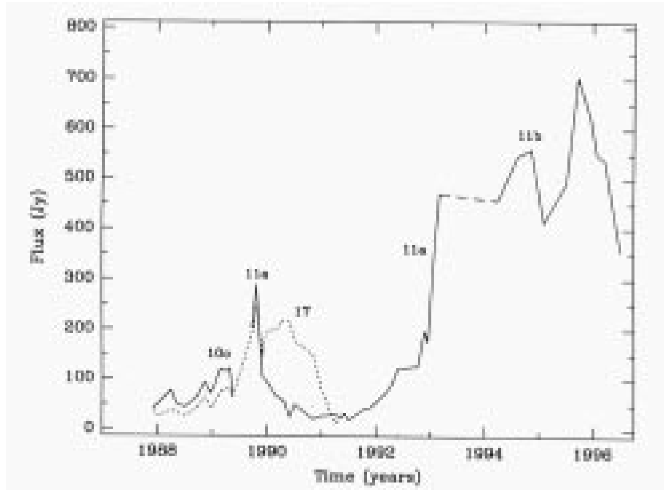

Fig. 5. Flux variations of the strongest H_2O components during the transition of the maser to the active phase

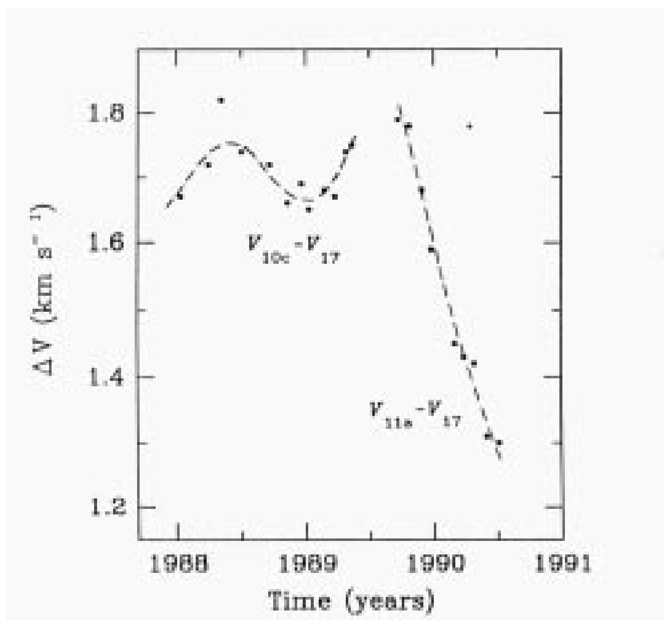

Fig. 6. Variations in the radial velocity of features 10c and 11 relative to feature 17

component widths did not give interesting results, so we do not show these data here.

3. Discussion

3.1. Radial velocity drift of the complex of features

Let us see first the time variations in the magnitude of Σ_1, which is related to the evolution of all the H_2O maser sources in ON2 and not only to independent features. Comparison with variations of the total flux (Lekht et al. 1996) shows that the drift jump took place long before (about two years) the main increase of maser activity. The jump coincided in time with an increase in activity at positive velocities.

Comparison of Σ_1 with the centroid time variations in ON2 (Lekht et al. 1996), as in the case of the total flux, did not give a clear result. Good correlation was found between the variations of Σ_1 and the drift of the group of features at positive velocities (Márquez & Lekht 1997). This correlation occurred during 1981–1988. The second drift cycle (1990–1996) showed no correlation between parameters. At the present time we can not try to explain the observed phenomena and their possible causes. It will be appropriate to observe the H_2O maser in ON2 in the decreasing part of its activity curve which began in the middle of 1996.

The variations of Σ_2 may be interpreted as the superposition of the slowly varying and flare components. The first of these correlates with the long-term component of variations of the total flux and the second with faster variations with period of about 3 years (Lekht et al. 1996). The position of the local maximum, expected at the end of 1992 — beginning of 1993 was not well determined due to the fast increase of the main maximum.

It was found that during any increase of the maser activity in ON2 the Σ_2 parameter always increased, i.e. the acceleration of the maser condensations occurred.

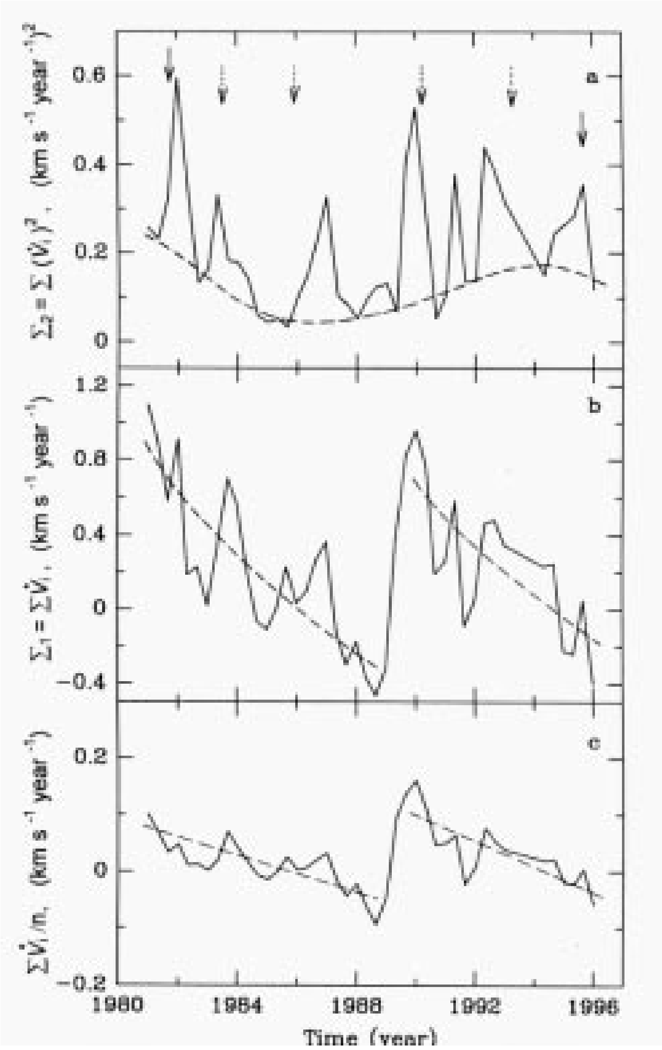

Fig. 7. a) Variation of the quadratic sum of the drifts of the spectral H_2O features in radial velocity, **b)** the sum of the drifts values and **c)** the mean value of the drifts. The solid arrows indicate the positions of the main maxima of total flux and (dotted) of the local maxima. Dashed lines are fitted smoothed curves. The position of the local maximum in 1992–1993 was not determined due to the growth of the main maximum

3.2. Anticorrelation of the fluxes

Analysis of the H_2O masers in ON2 showed that anticorrelation between the fluxes of components with close radial velocities was not a rare phenomenon. Below we analyze three more important cases. It should be noted that the character of the flux variations are somewhat different in these cases compared with that described earlier.

With competition between radiative modes for pumping in a partly saturated maser, a rapid decrease in the emission of one feature accompanies a rapid increase in the emission of arother. An example of such a situation with a repetition time of about 1.5 years may be seen in Fig. 2. This anticorrelation was consistent throughout the entire period of the existence of these features.

The flux anticorrelation between the two longest-lived features also lasted during all the time they were in the active phase (Fig. 4). The maximum emission of one of these features always coincided with the minimum of the other and vice versa. The time delay between the two consecutive maxima lay between 2 to 3 years. The maser condensations responsible for this emission may belong to different groups, located in the front of the cometary arc (Hofner & Churchwell 1996).

The third type of anticorrelated emission appeared for the more intense features at negative velocities (Fig. 3). Flaring in features 34 and 33 took place consecutively. Feature 33 appeared in the H_2O spectrum just as feature 34 disappeared. Feature 34 showed an exponential decline and the flux of 33 after this had two different maxima. The flux decrease of this feature was fast and almost linear over about one year.

This time dependent behaviour of the maser emission did not seem to be related to competition between modes in the two features, since it lasted throughout different maser activity phases in ON2. However, this may be a result of the reported anticorrelation between two groups of spectral features (Lekht et al. 1996).

3.3. Velocity variation of separated features

Velocity variations of many features followed either a wave-like or an arc-like curve. Only for three features did the flux maxima and minima coincide with the velocity maxima and minima. This correlation may be interpreted in terms of the velocity increase of the condensations under the action of an external agent, such as shock waves or strong stellar winds. Following this action or its decline the deceleration of the condensations in the medium seems quite possible, with a simultaneous decrease in the emission level.

The fitting of smoothed curves may lose some small effects in the radial velocity variations. For this reason we analyzed the differences between the velocities of given features $\Delta V_1 = V_{12} - V_{16}$ and $\Delta V_2 = V_{12} - V_{17}$. This also eliminated any errors there may have been in the determination of absolute velocities. We found that during flux increase of any of the features, the difference between their radial velocities also increases.

The relatively small member of features with correlation between flux and velocity variations suggests the existence of another cause. In some cases, it appears that superposition of the emission from neighbouring condensations took place. Their consecutive flaring up and dying down leads to a systematic drift in the maximum emission in the H_2O spectrum. If the lifetime of the features does not significantly exceed the time between the observations, either a dispersion of the dots relative the solid curve or jumps in the velocity may appear. Such effects were observed approximately in 15 cases.

For seven features velocity variations with a period of $1.5 - 2$ years and amplitude about 0.1 km s^{-1} are superposed in the smoothed curve. No correlation between these velocity variations and flux variations was found.

4. Conclusions

We have presented the results of the analysis of H_2O maser spectral features in ON2. We do not exclude the possibility that in some cases close features in radial velocity are superimposed. They may flare consecutively, leading to a drift in radial velocity. However, we do not exclude the existence of real velocity variation of the features under the action of a strong stellar wind or other influence coming for example from the ultracompact HII region $G75.78 - 0.34$.

Anticorrelation in the flux of two features with similar radial velocity in the ON2 H_2O maser is not a rare phenomenon. The anticorrelation was consistent for some pairs of features, excluding only the period of maximum activity in 1995. The different character of the anticorrelation for other features may be due to the complex nature of this phenomenon.

The complicated character of the flux and radial velocity variations of maser features, the dependence between them (anticorrelation) and the radial velocity drift of an ensemble of features all show that these phenomena are interrelated in ON2. The cause may be that the maser is located near (0.04 pc) to the ultracompact cometary HII region $G75.78 - 0.34$ (Hofner & Churchwell 1996) and follows its action.

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References

Johnston K.J., Sloanaker R.M., Bologna J.M., 1973, ApJ 182, 67
Harris S., 1976, MNRAS 174, 1
Hofner P., Churchwell E., 1996, A&AS 120, 283
Lekht E.E., Márquez A., Mendoza-Torres J.E., 1996, A&AS 120, 415
Márquez A., Lekht E.E., 1997, AZh 74, 80
Matthews H.E., Goss W.M., Winnberg A., Habing H.J., 1973, A&A 29, 309
Matthews H.E., Spoelstra T.A.T., 1983, A&A 126, 433
Walker R.C., Burke B.F., Haschick A.D., et al., 1978, ApJ 226, 95