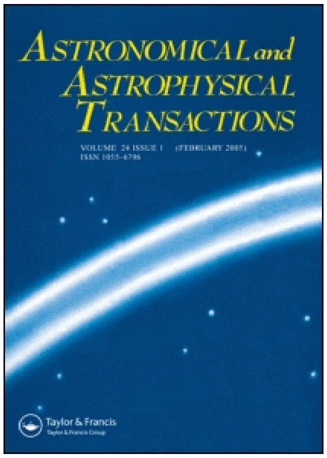

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NEW RESULTS OF THE STUDY OF H_2O MASERS IN STAR FORMATION REGIONS

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New results of the study of H_2O masers in the regions of star formation are presented. They reflect the global character of separated H_2O maser variations – the anticorrelation of the fluxes of individual H_2O groups of the features; the simultaneous velocity drift of the H_2O main spectral features; the non-chaotic character of the variations of the velocity centroid, and certain others.

KEY WORDS Water masers, time variability

1 INTRODUCTION

Regular observations of maser sources in the water vapour line at 1.35 cm wavelength allowed us to find a series of important results concerning time variations of maser sources associated with star formation regions. The time variations of H_2O maser emission are the result of non-stationary physical processes in the early stages of star formation. In this period the star luminosity is to a large extent due to non-stationary accretion into the star.

As shown by Yorke and Krugel (1977), Garlick (1978) and Tutukov and Shustov (1978) the relation between the matter accretion rate on to a star, the luminosity variations and the emission field may lead to fluctuating processes with periods of some years (and possibly more than 10 years).

The long-term regular observations of H_2O maser emission showed that the total flux varies between maximum and minimum values. The time interval between the maximum or minimum is of the order of 4–10 years (Lekht *et al.*, 1983; Liljeström *et al.*, 1989; Lekht *et al.*, 1995). Thus more or less periodic variations of the maser activity, which are the result of luminosity fluctuations of the central star, may take place (Figure 1). Also, a burst component seems to appear more or less periodically but it has a shorter period (2–4.5 years).

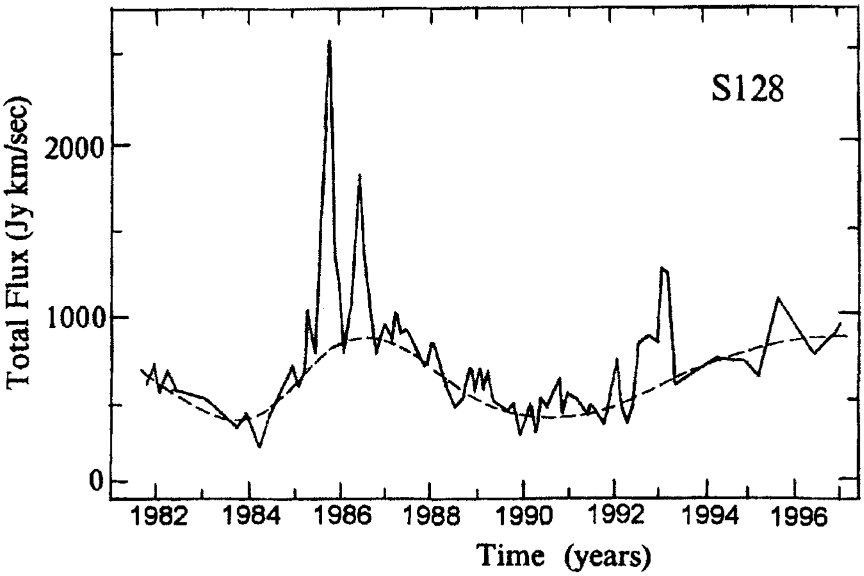

Figure 1 Time variations of the total flux of the H_2O maser emission in S128. The dashed line shows the long-term component.

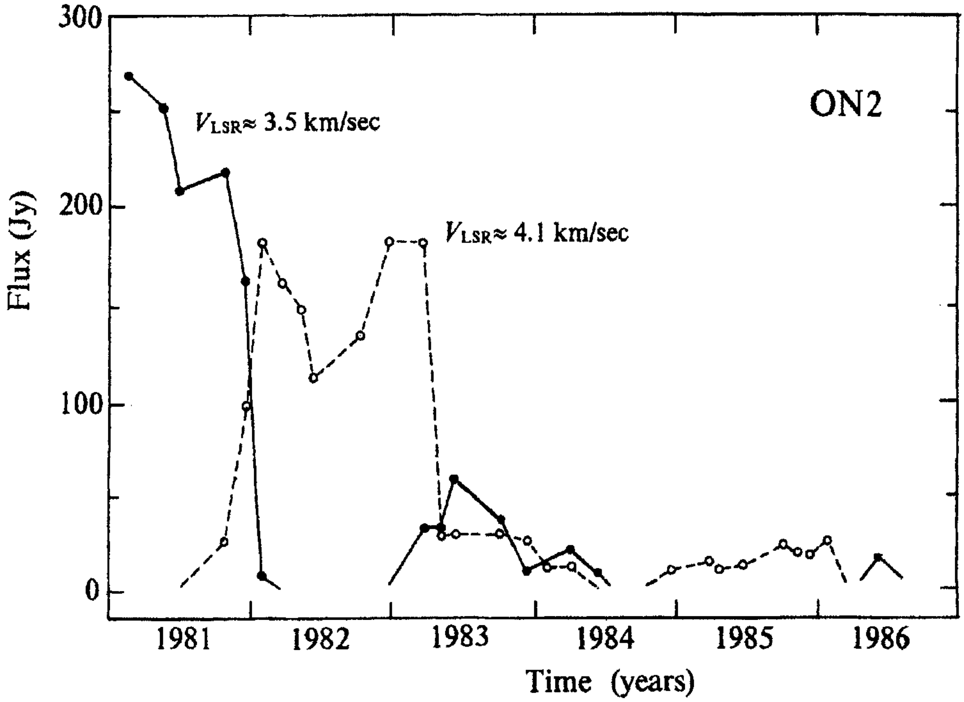

Figure 2 Anticorrelation of the flux variations of two spectral features in ON2.

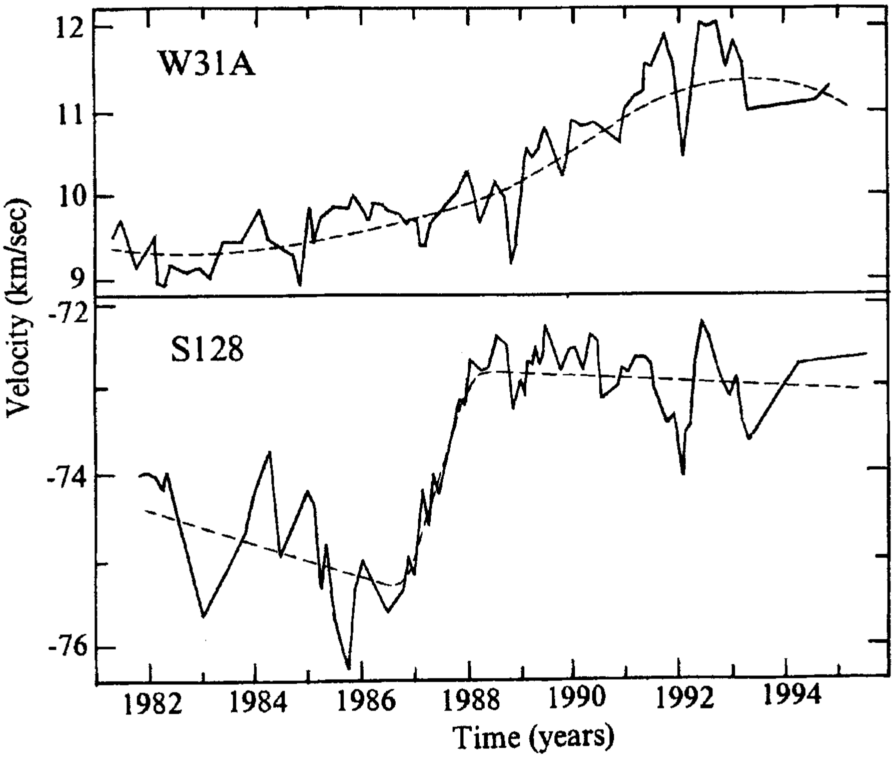

Figure 3 Time variations of the weighted mean radial velocity of the spectra of the H_2O sources S252A and S128.

It was found that the variations of the emission of separate features or groups of features of many sources happen in counterphase (Figure 2). This anticorrelation (like the case of Keplerian disks and structures with considerably more inhomogeneous material) is stimulated by the anisotropy of maser pumping under the action of the forming star or by density and temperature inhomogeneities or by the abundance of active molecules. Under such conditions, the competition of maser modes for pumping in a partially saturated maser may take place (Cezaroni, 1990; Lekht *et al.*, 1993). For maser regions located in star shells, the anticorrelation of the fluxes of two features appears under the fulfilment of stricter conditions than for a Keplerian disk.

An important parameter of the maser emission is the centroid velocity. Provided there exists a regular drift of this velocity, the model, in which a processing jet acts over different parts of a disk hosting the maser region, seems to be the more adequate. Examples of the centroid velocity drift are shown in Figure 3.

During strong bursts of maser emission of some features a relation between intensity and line width has been observed. When this relation exists, enhancement is most frequently accompanied by a narrowing of lines $\Delta V \propto (\ln F_\nu)^{-1/2}$. This

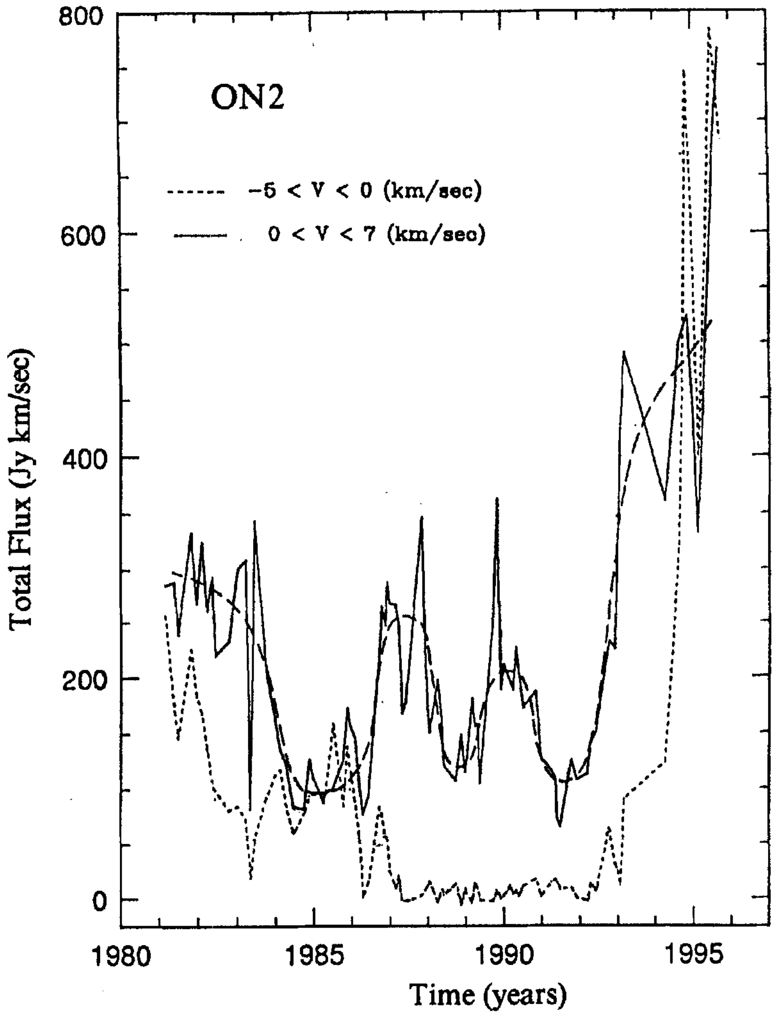

Figure 4 Time variations of the integrated flux of two main groups of spectral features in ON2. The dashed line denotes the smoothed curve which reflects flux oscillations of the second group.

behaviour is associated with the unsaturated state of the maser. In a saturated maser we have $\Delta V \propto F_\nu^{-1/2}$, i.e. the dependence between the variation of the flux and line width is most strong. However, as shown by Ishankuliev (1990), if one takes into account the statistical property of the radiation during strong bursts, then reinforcement of relation between ΔV and F_ν is possible. More than 12 years of regular observations of a feature at a velocity of 42.2 km s^{-1} in G43.8–0.1 allowed us to observe the state of the cosmic maser during different levels of saturation and to see the transition from unsaturated to saturated states and vice versa (Lekht, 1994). The results of these investigations will permit us to establish some limits for theoretical models of cosmic masers.

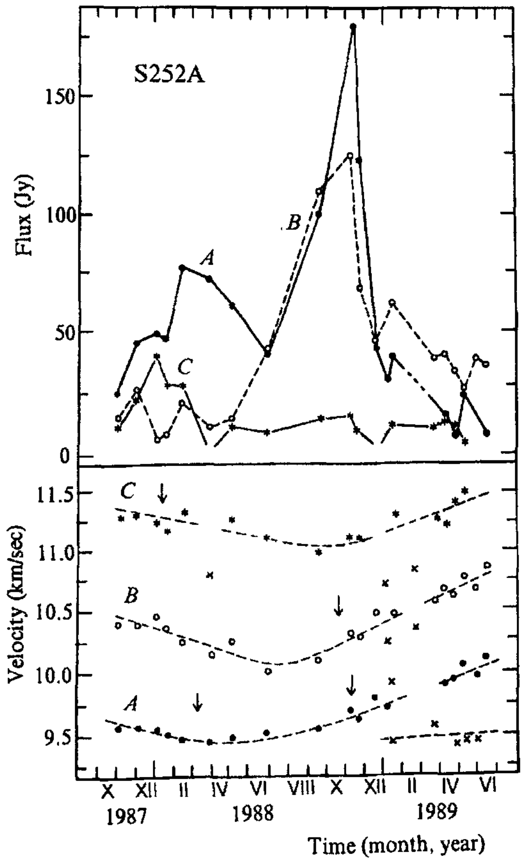

Figure 5 Evolution of the flux and radial velocity of spectral features during the burst of 1988–1989 in S252A. Velocity drift of the main features with the inversion of the drift direction is observed.

2 THE MAIN RESULTS

In this work new, observational results obtained recently are presented. Some of the results have been submitted for publication (Lekht *et al.*, 1996; Lekht *et al.*, 1997) and others are in preparation. Below the most important ones are shown.

(1) In the maser source ON2, a global character of the anticorrelation of the fluxes was found (Figure 4). In this source, the maser condensations are located in two regions which have a common central star. The distance between the regions is about 10^{16} cm. The integrated fluxes of these groups of features changed mainly in antiphase during 1981–1995.

(2) The burst of 1988–1989 in S252A was accompanied by the velocity drift of the main features with the inversion of the direction drift (Figure 5).

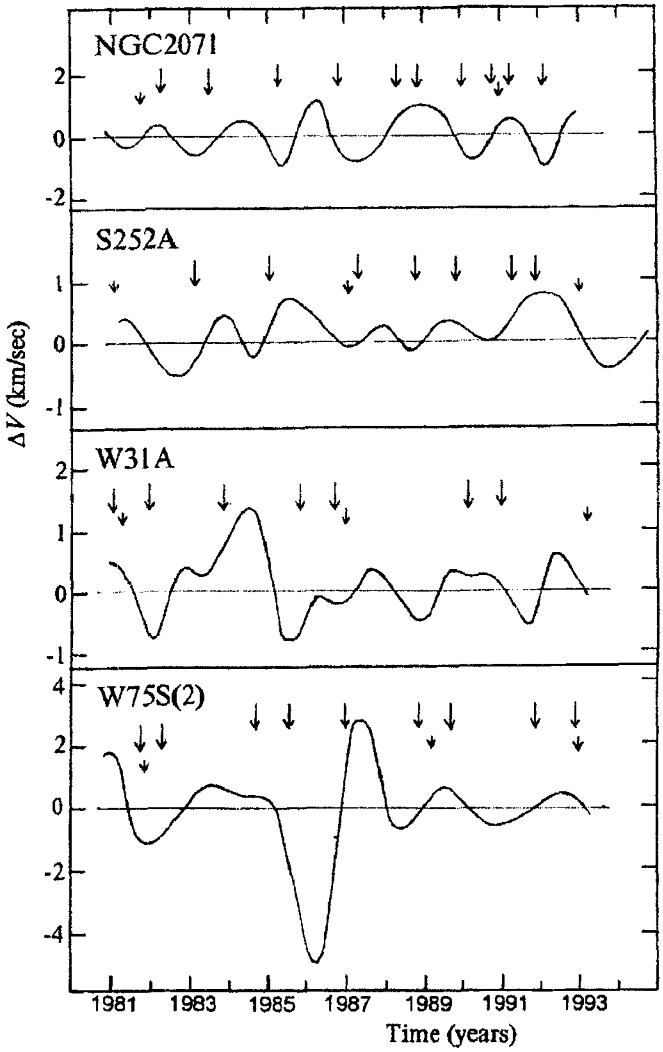

Figure 6 Non-chaotic component of the velocity centroid variations. Long arrows mark the positions of flaring components, while short arrows mark the maxima of the long-term component total flux variations.

(3) The variations of the centroid velocity of some sources have a more or less periodic character (Figure 6). We have found that the amplitude of these fluctuations is 5–10 times larger than the analogous fluctuations of velocity drift observed for separate features. The characteristic time scale variation is about 1.5–3 years.

(4) In the H_2O spectrum of S252A the approach of two main features with close by radial velocities was found. This event took place during the more in-

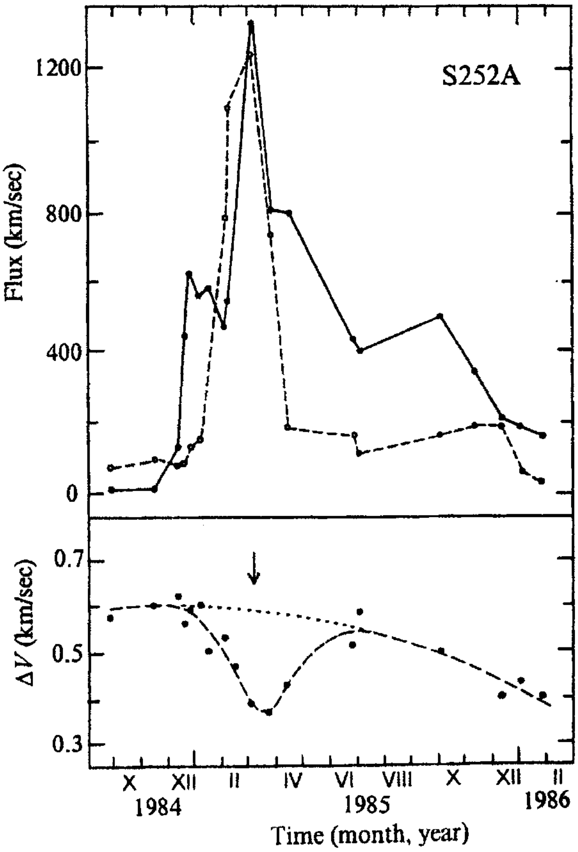

Figure 7 Flux variations of the two mean spectral features in S252A during the more intense burst of 1985 and the difference of their radial velocity. The arrow marks the position of the emission maximum of the burst.

tense burst of 1985 in S252A (Figure 7). During the increase of the burst intensity the difference between the velocity of the main features decreased to 0.3 km s^{-1}. After that, in the period of decreasing of the burst intensity the distance between the features in the H_2O spectrum again increased. This process lasted about six months.

3 INTERPRETATION

3.1 Anticorrelation of the Fluxes

We found anticorrelation of the fluxes of two spectral and spatially separated H_2O groups of features for almost all of the time of our observations (excepting two periods of maximum maser activity). During the emission maxima, the pumping was enough to maintain unsaturated the maser condensations of both ON2 nests. It seems that in such a case there is no competition of the emission modes (string modes) for pumping.

In other periods the pumping was not enough to maintain the maser in the unsaturated state. The maser turned to a partially saturated state, in which the competition of the modes for pumping is possible. This led to anticorrelation of the fluxes of the two groups of features (Lekht *et al.*, 1996).

We cannot exclude the appearance of anticorrelation as a consequence of a bipolar outflow from the central star. In this case in order to attain the observed anticorrelation, the intensity of the flows must change in antiphase.

3.2 Velocity Drift of a Group of Features

This phenomenon was observed for the main H_2O spectral features of S252A during almost two years (October, 1987 – June, 1989). In this period an H_2O maser burst in S252A took place. The reversal of the drift velocity of the spectral features occurred, not at the same time but sequentially, as the radial velocities of the features were increasing and did not correlate with the flux maxima. Unfortunately, later it was not possible to follow the evolution of these features, as since then, during almost all of 1990, the H_2O maser in S252A was in a deep minimum.

From the end of 1991 to the middle of 1993, a wave-like character of the radial velocity variations of each feature in the range 0.4–0.6 km s^{-1} was observed during about 1.5 years. We cannot exclude that these are the same features about which we spoke above. The correlation between the velocity variations of different features was not observed.

3.3 The Centroid of the Velocity

The time variations of the centroid velocity of the H_2O spectra of the sources NGC2071, S252A, W31A and W75S(2) have a complex shape. After the subtraction of the systematic trend, we obtain a more or less periodic character of the centroid velocity variations (Figure 6). The fluctuations of the velocity do not correlate with either the burst component or the long-term variations.

3.4 The Rapproachement of Spectrally Nearby Features

As a rule, the drift of radial velocity of the spectral features may be due to the strong stellar wind from the central star, which accelerates the maser condensations. However, during the strong burst in 1985, the approach of two spectral features close in radial velocities occurred. It is possible that maser condensations responsible for this emission are located close to each other or along the same line of sight. In the case of partial saturation of spatial modes, competition for pumping may take place. In such a situation, the amplification of the emission near the central velocity is possible at the expense of suppression of the emission at neighbouring velocities. In the decline phase of the burst evolution, this mechanism turns on.

The approach of spectral features from the middle of 1985 may be explained in terms of real velocity variations (dotted line in Figure 7).

Not all the results presented above have found an explanation in the framework of the existing maser models. First of all, this may be said regarding time variations of the radial velocity. For the corroboration of fast fluctuations of the velocity, it is necessary to carry out regular observations with time intervals not longer than one month over two or three years.

Acknowledgements

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