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Evolution of H_2O maser emission in the direction of the semiregular variable RT Virginis during 1985-1996

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Abstract. We present a catalog of the 22 GHz H_2O maser profiles of the semiregular variable RT Vir. The observations were made from 1985 to 1996 at the RT-22 radio telescope of the Radio Astronomical Station at Pushchino, Russia. Results obtained after the analysis of the integrated fluxes, the average spectra, the centroid velocity and the superposition of the spectra are reported.

Anticorrelation of the integrated fluxes of two spectral intervals ($V_{\rm LSR} < 15.5$ and $V_{\rm LSR} > 21$ km s^{-1}) was found. The characteristic time variation of the maser emission at each of these groups was about 5-6 years. This phenomenon may be explained by a variation of the outflow of the matter from the star. The outflow is weakly bipolar. We can suppose that in such a model the enhancement of the outflow occured alternately with a period of about 5-6 years. The anticorrelation of the integrated fluxes of two groups of maser features, located symmetrically relative to the star, may be a result of this alternation.

Key words: RT Vir — radio lines: masers — stars: variables: other

1. Introduction

Semiregular variables, like RT Vir, are thought to be surrounded by circumstellar gas-dust shells formed from the usual stellar mass loss. The H_2O maser emission originates in the inner side of the shell at a distance of a few radii from the upper photosphere (Lepine & Barros 1976). The maser emission has large time variations which may correlate with stellar luminosity variations.

The semiregular variable RT Vir is an M 8 spectral type star, according to the General Catalog of Variable Stars (Kholopov et al. 1985). The average period of luminosity is 155 days and the magnitude varies between $9^{\rm m}\!.0$ and $10^{\rm m}\!.3$. Spencer et al. (1981) determined a distance to RT Vir of 1.35 kpc while Bowers et al. (1993) gave a distance of 700 pc. From SiO (Spencer et al. 1981) and 1667 MHz OH (Le Squeren et al. 1970) line observations, a radial velocity of the star equal to $14 - 16$ km s^{-1} was deduced. Further observations gave a value of 18.2 km s^{-1} (Nyman et al. 1986). The rate of mass loss is 3 10^{-6} $M_\odot$ yr^{-1} (Bujarrabal et al. 1989).

The H_2O maser emission from the gas-dust shell of RT Vir was first observed by Dickinson (1976) in 1973 March. At that time, the profile had a single feature with velocity of 15.1 km s^{-1} and flux of 16 Jy. Further observations between 1975 and 1977 (Spencer et al. 1979; Cox & Parker 1979) showed the presence of a stronger component at 22 km s^{-1}, the flux of which was in the range $100 - 300$ Jy. The feature at 15 km s^{-1} did not exceed 30 Jy in those observations.

Berulis et al. (1983) observed another feature of $11 - 12.5$ km s^{-1} during 1980-1982. In this period the H_2O maser was not active. However, during 1984-1986 H_2O maser flares have taken place in a wide range of velocities (Berulis et al. 1987), probably caused by a shock wave. The amplitude of the strongest flare attained 2400 Jy. Some spectral features underwent a velocity drift, which was correlated with flux variations.

VLA observations of RT Vir have been reported for two epochs: 1985.05 (Bowers et al. 1993) and 1988.95 (Bowers & Johnston 1994). The spatial distribution of components with velocities between 12 and 24 km s^{-1} obtained by Bowers & Johnston (1994) was highly asymmetric relative to the star position and showed a loop structure, which differs from the distribution found earlier (Bowers et al. 1993).

Submillimetre maser emission from RT Vir at 321 GHz ($10_{29} - 9_{36}$ transition of ortho H_2O and 325 GHz ($5_{15} - 4_{22}$

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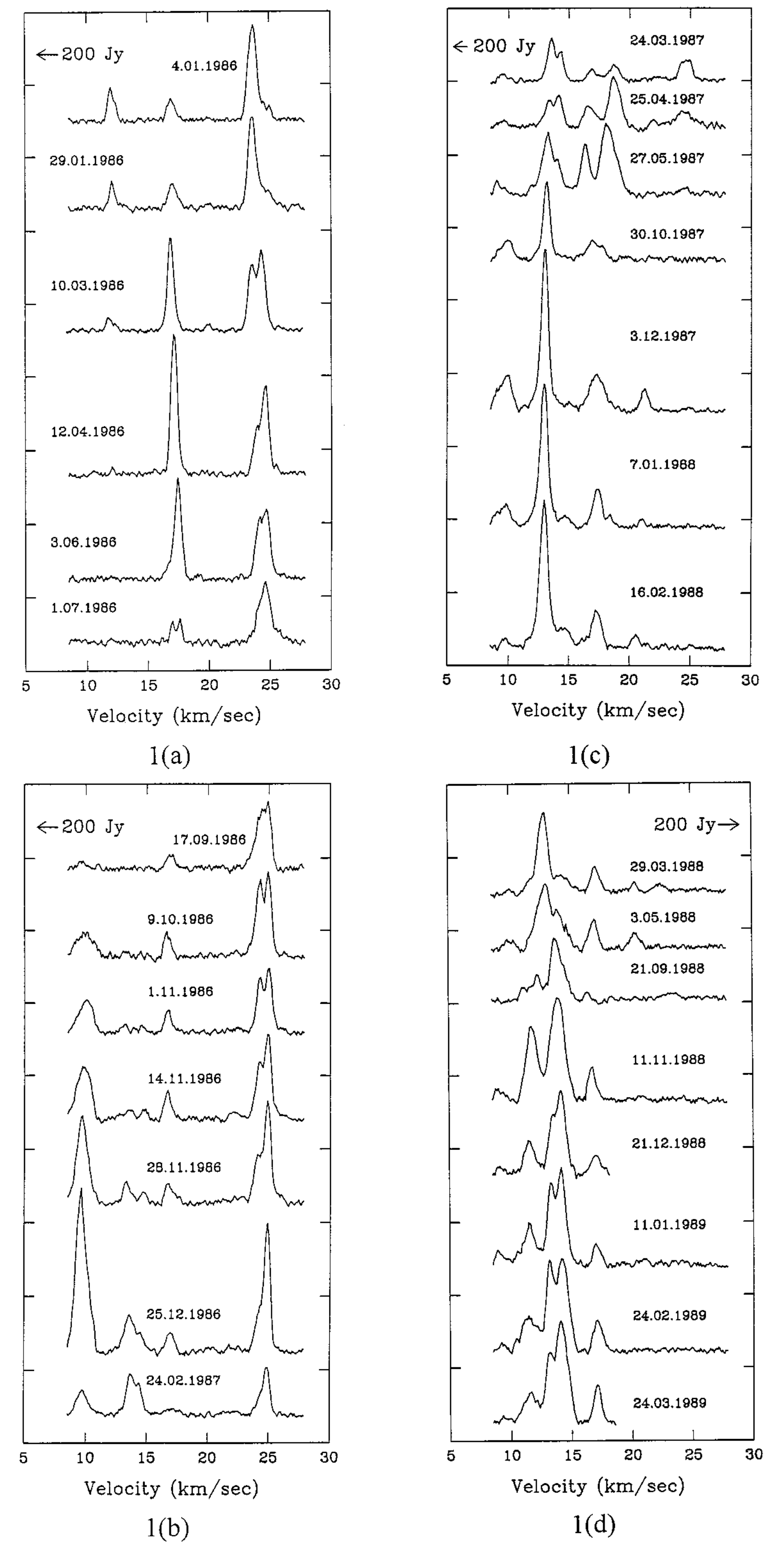
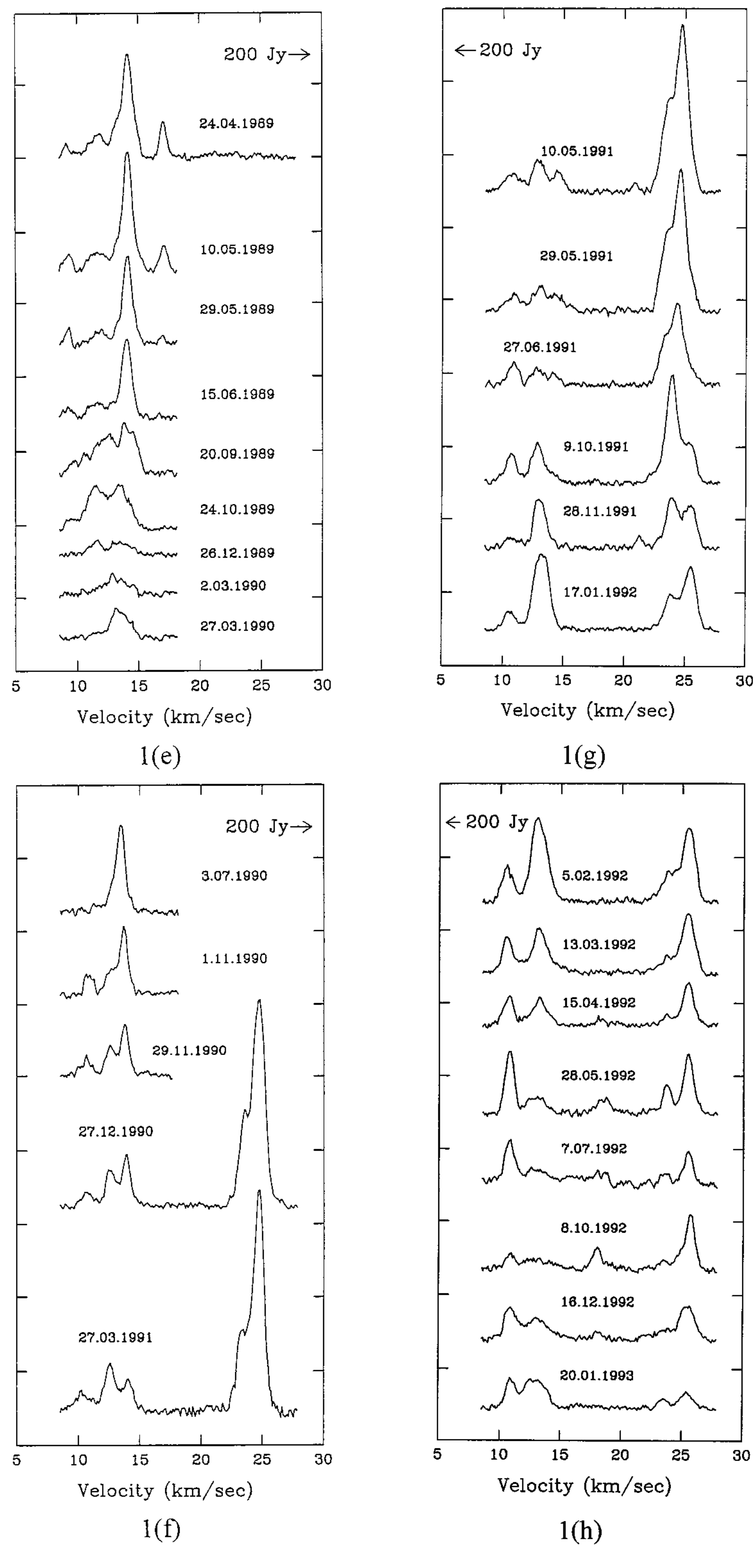


Fig. 1. a-k) Catalog of the H_2O maser spectra of RT Vir obtained during 1986-1993. Flux interval shown on the vertical axis is 200 Jy



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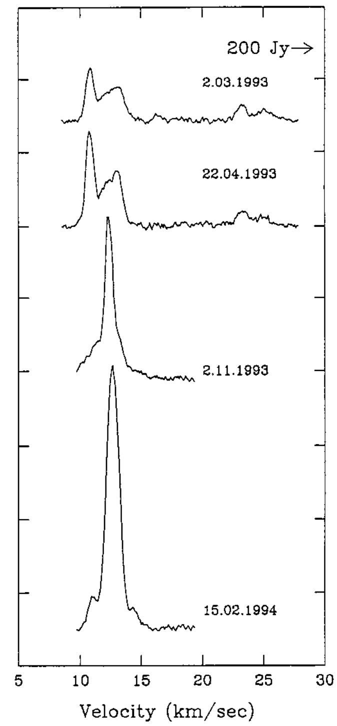
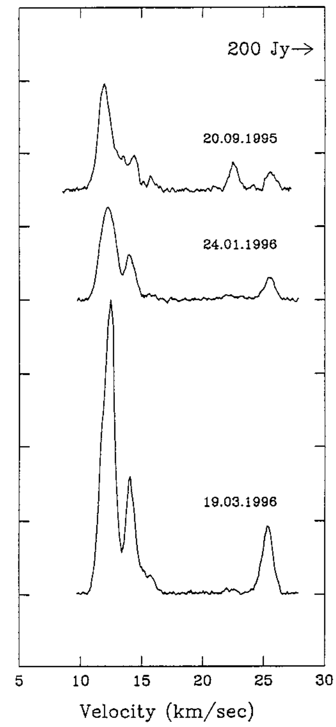


1(i)



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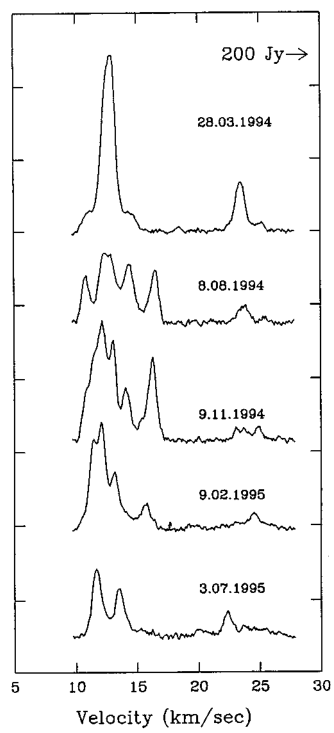

1(j)

Fig. 1. continued

transition of para H_2O) was also reported (Yates & Cohen 1996).

In this paper we present the observations of 22 GHz H_2O maser emission in the direction of the semiregular variable RT Vir made during 1985-1996.

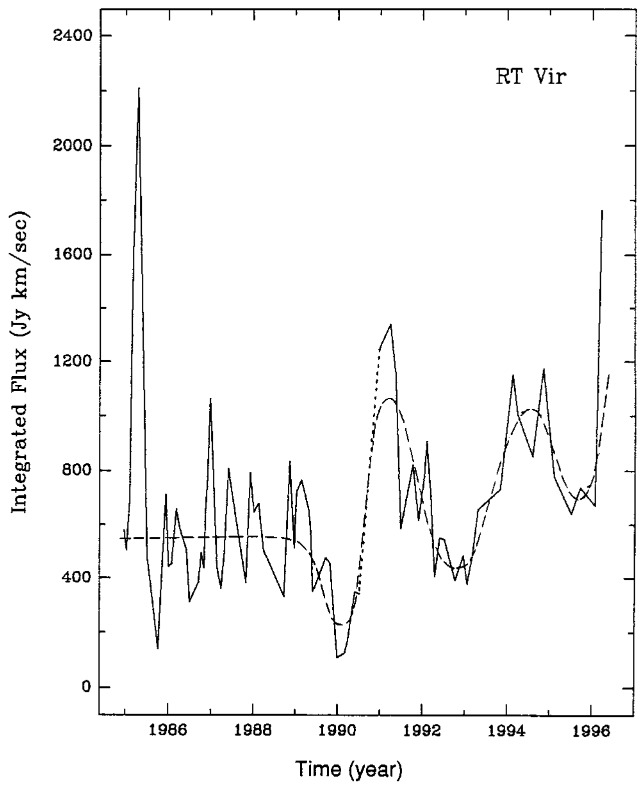

Fig. 2. Time variations of the flux integrated over all the H_2O spectrum. The dashed line shows the smoothed curve, which excludes the influence of fast variations

2. Observations and presentation of the results

2.1. Observations

Observations of the 22 GHz maser emission in the direction of RT Vir were made with the RT-22 radio telescope of the Radio Astronomical Station of the Lebedev Physical Institute in Pushchino, Russia. A receiver with low noise amplifiers at the feed and a 96-channel spectrometer of filter-bank type were used. The spectral resolution in radial velocity was 0.101 km s^{-1}. An antenna temperature of 1 K from a point source with unpolarized emission corresponds to a flux of 25 Jy. A detailed description of the instruments and the observational method can be found in Sorochenko et al. (1985) and Lekht et al. (1995).

The obtained data were reduced and analyzed at the National Institute of Astrophysics, Optics and Electronics, Tonantzintla, Puebla, Mexico.

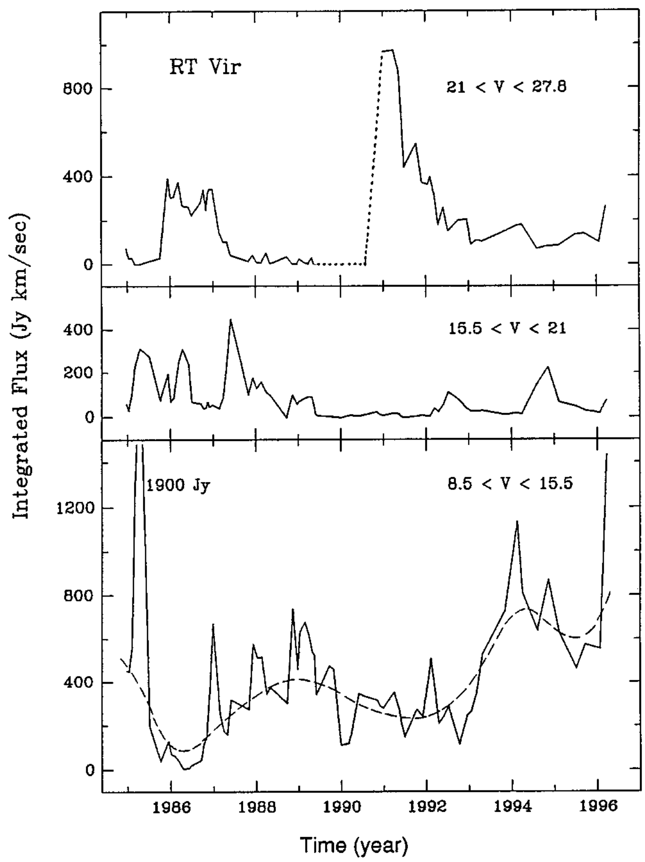

Fig. 3. Time variations of the flux integrated over different spectral intervals. The dashed line shows the presence of long-term variations of the H_2O emission (the characteristic time of the variability is about 5-7 years)

2.2. H_2O *profiles and the variation of the integrated flux*

In Fig. 1 we show the H_2O maser profiles for RT Vir observed from 1986 to 1996. Some of the profiles obtained during the first half of 1986 were published earlier by Berulis et al. (1987), but we included them in our paper to have the total catalog of the H_2O profiles for 1986.

The H_2O maser emission of RT Vir is concentrated in three velocity ranges of the spectrum: at velocities < 15.5 km s^{-1}, between 15.5 and 21 km s^{-1}, and at velocities > 21 km s^{-1}. In the central interval, near the radial velocity of the star, H_2O emission has not frequently been detected. The time variation of the integrated flux of the overall spectrum is shown in Fig. 2. Figure 3 shows the integrated flux for the three above-mentioned ranges of the spectrum. The integrated fluxes for the epoch 1984 December to 1985 December were deduced from Berulis et al. (1987). The dashed lines denote the smoothed curves of the long-term variations of the integrated flux. Since the maximum of the flare of 1985 is very high (1900 Jy km s^{-1} for the integrated flux at velocities < 15.5 km s^{-1}), its corresponding value is given in Fig. 3 for convenience.

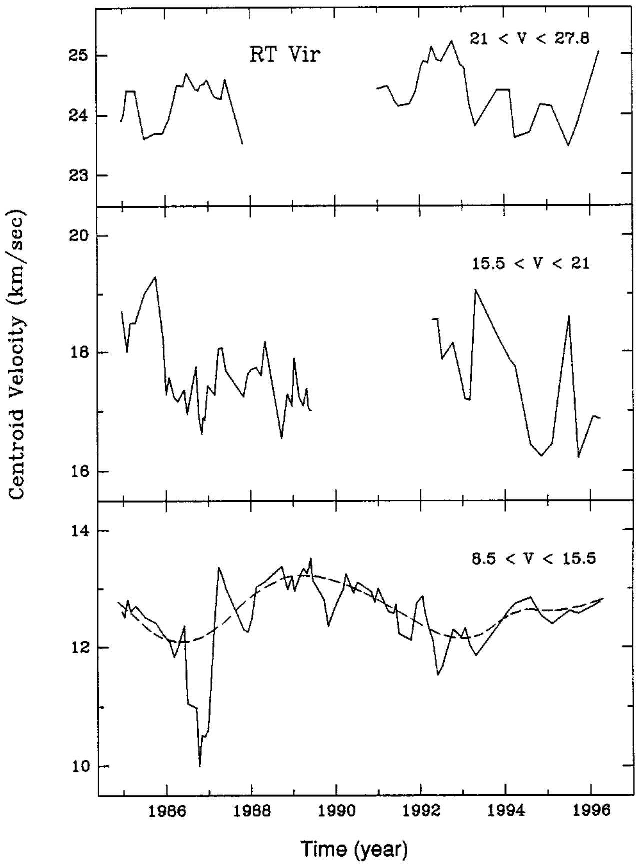

Fig. 4. Time dependence of the centroid velocity of different spectral intervals

Beginning from 1988 the emission at $V > 21$ km s^{-1} was very weak and appeared only occasionally. For this reason, the observations at these velocities were not carried out from 1989 May to 1990 November. However, at the end of 1990 December intense emission at ~ 25 km s^{-1} was observed.

A rough estimate of the time of this flare can be deduced from the following facts: 1) from 1988 the emission at $V > 21$ km s^{-1} was very weak and appeared only from time to time; 2) the maximum flux of this feature was observed in 1990 March; 3) in previous years the increase of the flux was faster than the decrease; 4) according to the smoothed curve (Fig. 3) the maxima and the minima of the integrated flux of the principal H_2O spectral groups ($V < 15.5$ km s^{-1} and $V > 21$ km s^{-1}) are in opposite phase.

On the basis of the above facts, we may assume that the rapid enhancement of the emission at velocities > 20 km s^{-1} began no earlier than the middle of 1990. The probable increase of the integrated flux for the time interval from 1989 May up to 1990 November are presented by dotted lines in Figs. 2 and 3.

The dashed line in Fig. 2 for which fast variations of the integrated flux are excluded has a complex form. At

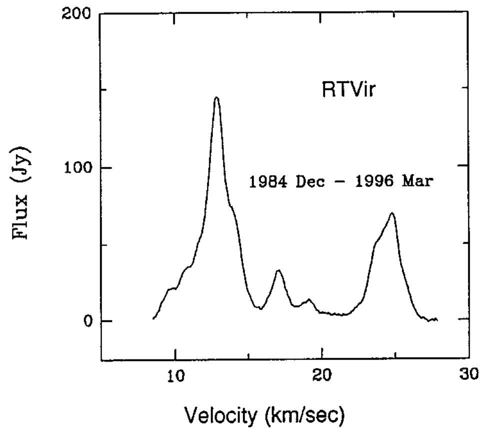

Fig. 5. Average H_2O spectra for all the period of our observations (1984 December - 1996 March)

the beginning, in the time interval 1985-1988, the curve is approximated by a horizontal line at the level of about 550 Jy km s^{-1}.

The intense flare and the deep minimum relative to this level are remarkable. Afterwards, the behaviour of the curve may be presented by a waveform curve with a characteristic time variation of about three years.

Such behaviour of the integrated flux of the total spectra does not necessarily reflect the physical processes that took place in the H_2O maser of RT Vir, since it is a superposition of three curves, each of which reflects the variations of the integrated flux in one of three ranges of the spectrum (Fig. 3). At the side intervals of the spectra ($V < 15.5$ km s^{-1} and $V > 21$ km s^{-1}) where emission appears more frequently, quasi-periodic variations are observed. The time interval between two consecutive maxima or minima in both cases is about 6 years. For the mentioned spectral intervals the variations of the integrated flux are in opposite phase, i.e. there is anticorrelation of the fluxes (this has been observed in 1986, 1992 and 1993-1995).

Thus, the superposition of the curves with more or less the same period, but in different phase may lead to a curve with twice shorter period (1989-1995) or slow variations will be smoothed and only fast components will be left (1985-1988).

2.3. The centroid velocity

The time variations of the centroid velocity for the three specified spectral intervals are shown in Fig. 4.

Since the emission was very weak and appeared only from time to time in the second spectral interval from 1989 July to 1992 March and in the third one from 1988 January to 1990 July, the computation of the centroid velocity for these periods was not possible. This is the reason for the discontinuities in the curves in Fig. 4.

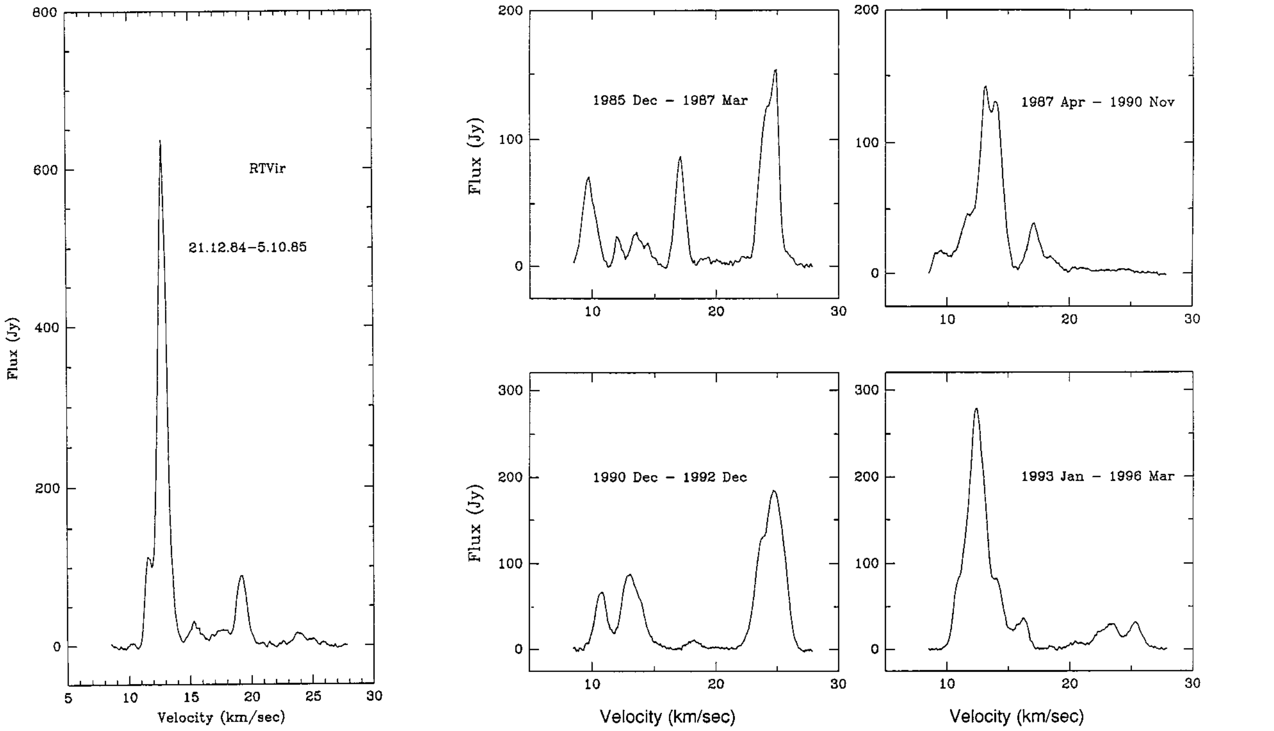

Fig. 6. a and b) Average H_2O spectra deduced for five time periods of the evolution of RT Vir H_2O maser emission: **a)** 1984 December – 1985 October, **b)** 1985 December – 1987 March, 1987 April – 1990 November, 1990 December – 1992 December and 1993 January – 1996 March

At velocities $V < 15.5$ km s^{-1} H_2O emission was seen all the time, and so the curve is smoothed with no sudden jumps during the period of our observations. The smoothed curve of Fig. 4 (dashed lines) is correlated with the analogous curve of the integrated flux (Fig. 3); i.e. the extreme values of these two curves coincide in time.

2.4. The average profiles

In order to determine the velocity where the H_2O maser in RT Vir is more active, we deduced the average profile for the period 1984 December - 1996 March (Fig. 5). It justifies the division of each profile into three parts at velocities 15.5 and 21 km s^{-1}. Average profiles were also deduced for five different time intervals (Fig. 6) and for each year. The latter are not presented here, but are used below.

The amplitude and the velocity of the more prominent features of the annual average profile were measured (Fig. 7). The circle size in Fig. 7 is proportional to the feature intensity. As may be seen in Fig. 7, the circles are not randomly distributed, and are located along four tracks. This means that the maser activity in RT Vir is manifested in four spectral ranges with average velocities of 10.7, 12.5, 23.5 and 24.5 km s^{-1} respectively. A minimal velocity drift of 0.2 km s^{-1} was observed at about

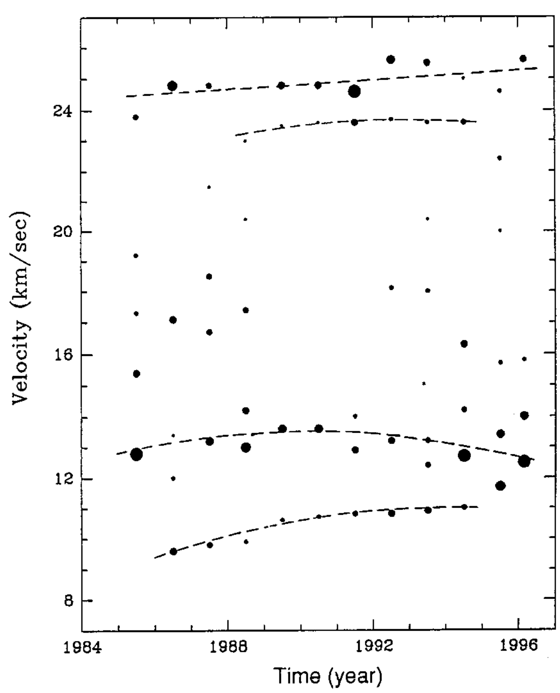

Fig. 7. Velocity drift of the principal spectral features of higher H_2O maser activity in RT Vir, obtained from the annual average spectra. The size of the circle depends on the intensity of the features

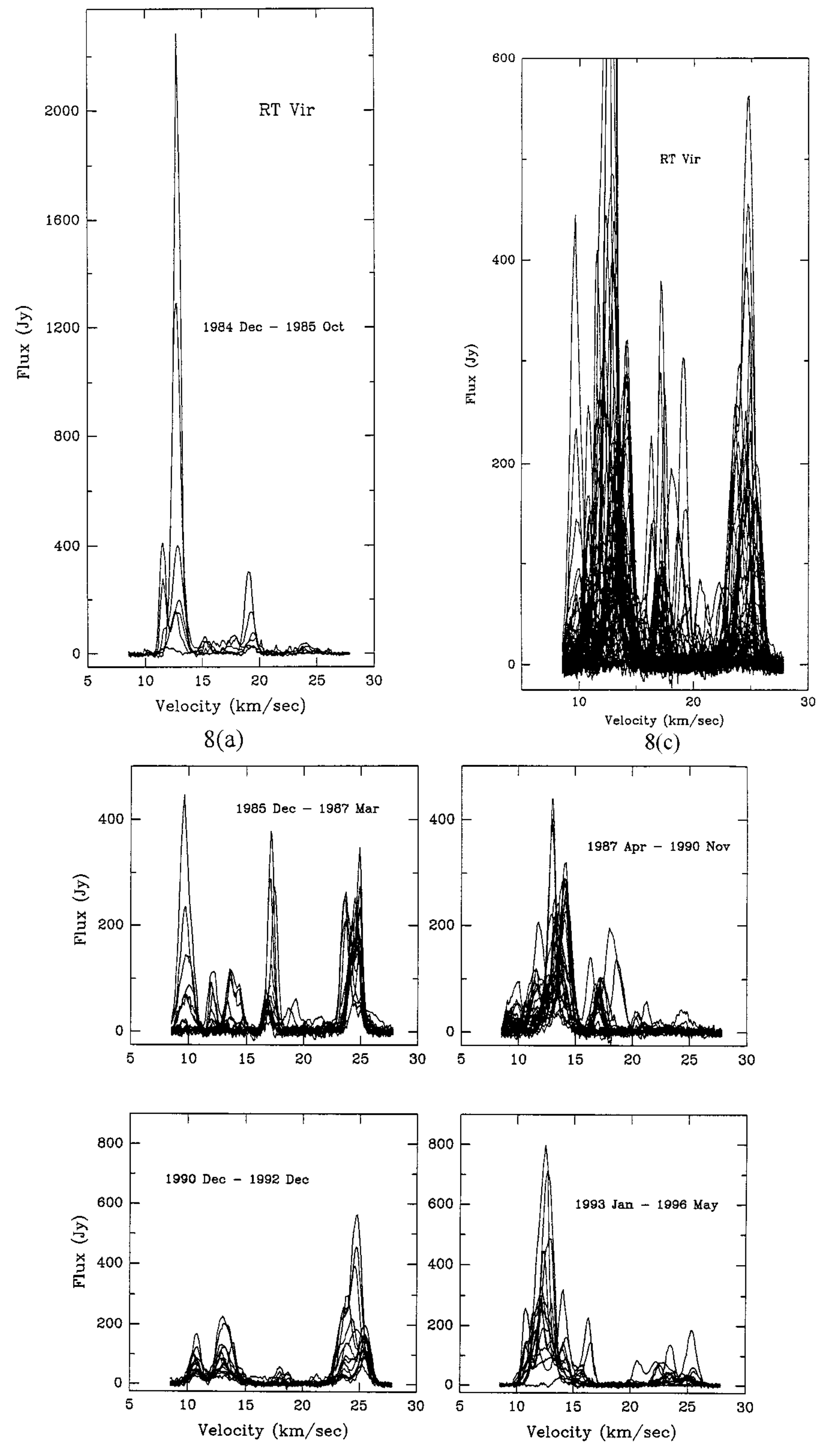

Fig. 8. a-c) Superpositon of the H_2O profiles for RT Vir at different periods: **a)** 1984 December – 1985 October, **b)** 1985 December – 1987 March, 1987 April – 1990 November, 1990 December – 1992 December and 1993 January – 1996 March, **c)** all the period

23.5 km s^{-1}, and a maximal drift of 1.4 km s^{-1} was observed at about 12.5 km s^{-1}.

The strongest H_2O maser emission flares have taken place in the second and fourth spectral ranges (12.5 and 24.5 km s^{-1}).

2.5. Superposition of profiles

Besides the average profiles we plotted the superposed profiles for the same periods (Figs. 8a and b). The most frequent superposition of lines represents the most probable profile. Such spectra obtained for each of the five time intervals well illustrate the existence of anticorrelation of the integrated fluxes of two spectral groups (Fig. 9). The full superposition of all profiles obtained from 1984 December to 1996 March is given in Fig. 8c.

3. Discussion

The H_2O profiles of the semiregular variable RT Vir exhibit fast and large variations. In contrast with H_2O sources associated with star formation regions, flares of the features in RT Vir lasting more than three months were not observed. Series of flares with time delays between flares of different features from one to eight months were observed (Berulis et al. 1987). This is in agreement with the results of Engels et al. (1988), who also found that for semiregular variables the individual spectral features may be stable over a timescale of a few months. Hence the lifetime of the maser condensations at an active stage may have certain time limits.

Nevertheless, the analysis of our spectra showed that some features may be observed during periods of up to 1.5 years. Large velocity drifts of these features, attaining 0.7 km s^{-1}, were observed. The results of a more detailed analysis of the individual H_2O components of RT Vir will be published later.

On the basis of the whole data one may suggest that variations with timescales of up to 1.5 years depend not only on variations of the temperature structure and conditions of pumping (Lewis & Engels 1991), but also on other factors. The region of maser generation located in the shell may be displaced in radial direction (Berulis et al. 1983), and in case of the existence of a velocity gradient of the gas in the shell a drift of the spectral features will be observed.

The existence of some stable regions of maser activity in RT Vir (Fig. 7) shows that individual spectral features may be stable during a few years (Engels et al. 1988) not only in Mira variables but also in semiregular variables in the form of filaments or clumps distributed in the radial direction.

The long-term variation components of the integrated flux of two spectral parts (blue- and redshifted relative the star velocity) have a characteristic timescale of 5-6 years (Fig. 3). The maxima of these curves are in opposite phase, i.e. there is anticorrealation of the fluxes. This anticorrelation may have a nature other than that of a Keplerian disc in S255 (Cesaroni 1990) and S140 (Lekht et al. 1993) or that of a circumstellar toroidal structure, where the matter is sufficiently fragmented, as in W31A and W75S (Lekht et al. 1995). In such structures, there is a competition of radiative spatial modes for the pumping. (The possibility of a mere coincidence may not be excluded, since for characteristic variation timescales of 5-6 years a time interval of 11 years is not enough for revealing more clearly the anticorrelation of the fluxes).

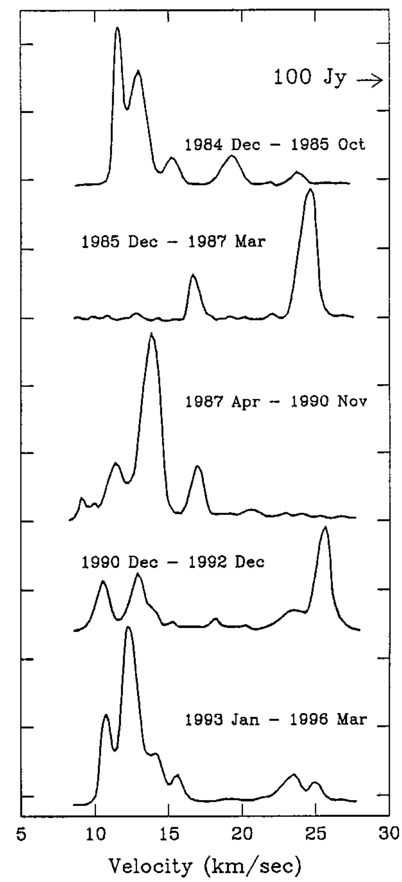

Fig. 9. The more probable H_2O profiles

A common factor with a Keplerian disc and toroid is that the maser condensations, responsible for emission at the right and left parts of the spectra are in opposite sides of the RT Vir shell. For stars of late spectral types the material outflow may be weakly bipolar (Bowers & Johnston 1994). In this case the parts of the shell, which are most strongly influenced by the bipolar outflow, have the most appropriate conditions for the H_2O maser emission. If we assume that the intensities of the bipolar outflow change in opposite phase, then the intensity of the maser emission of two groups of features, located on opposite sides of the shell, will change, i.e. anticorrelation of the integrated fluxes will be observed.

The more or less periodic character of the integrated flux variation with period of about 5-6 years considerably exceeds the period of optical variability of the star.

4. Conclusions

Long-term regular observations for more than 10 years of 22 GHz H_2O maser emission of the semiregular variable RT Vir have been carried out. The main results are as follows:

1. A catalogue of 68 H_2O spectra of RT Vir is compiled.

2. The division of the H_2O spectrum of RT Vir into three parts is argued and is related to the morphology of the source of the maser emission.

3. The integrated fluxes of the two parts of the spectrum ($V_{\rm LSR} < 15.5$ km s^{-1} and $V_{\rm LSR} > 21$ km s^{-1}) vary with the same timescale of about 5-6 years.

4. Anticorrelation of the integrated fluxes of these parts of the spectrum, which may be due to alternating increasing of the intensity of the bipolar outflow, is observed.

5. The period of the H_2O maser activity in the RT Vir direction is much longer than the average period of star variation.

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