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Search for the 22 GHz water maser emission in selected comets

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ABSTRACT

Following the first evidence of planetary water maser emission induced by the collision of comet Shoemaker/Levy with Jupiter and the puzzling detection of the 22 GHz water emission line in Comet Hyakutake we started in the period 2002–2008 systematic observations of selected comets at 22 GHz (1.35 cm) with the aim of clarifying the unusual behavior of the maser line in the cometary "scenario". Using a fast multichannel spectrometer coupled to the 32 m dish of the Medicina (Bologna, Italy) Radio Telescope we investigated 6 bright or sungrazing comets down to a heliocentric distance of 0.11 AU: **96P/ Machholz, 153P/ Ikeya–Zhang, C/2002 V1 (NEAT), C/2002 X5 (Kudo–Fujikawa), C/2002 T7 (Linear), and 73P/Schwassmann–Wachmann 3**. All of them, similarly to Comet Hyakutake, demonstrate spectral features that, if real and due to the 1.35 cm water vapor transition, are strongly (up to tens of km/s) shifted relative to the radial velocity of the nucleus and, at least sometimes, seem to be present as two separate peaks. If our interpretation of these spectral peaks is correct, there must be some mechanism of acceleration of neutral water molecules up to the velocities of ions. We discuss here the results achieved and the possible explanation of the chemo-physical constraints.

1. Introduction

Water was detected already often in comets at infrared wavelengths starting with the detection in comet Halley (Mumma et al., 1986; Crovisier and Schloerb, 1991) and also jets of H_2O^+ could be visualized in the same comet by a special image processing technique (Cosmovici et al., 1995).

The detection of the 22 GHz emission line has been claimed in the past for comet Bradfield 1974 III (Jackson et al., 1976) and comet IRAS–Araki–Alcock 1983 VII (Altenhoff et al., 1983). Because of the low signal to noise ratio and because the 1.35 cm transition has been searched for but not confirmed in other bright comets like Hale–Bopp (Bird et al., 1997; Graham et al., 2000), these detections have been questioned.

The water maser detection during the comet Shoemaker–Levy 9/Jupiter event (Cosmovici et al., 1996) was induced by a catastrophic impact in a planetary atmosphere, thus it cannot be considered a cometary emission.

The detection in comet Hyakutake (Cosmovici et al., 1998) was the first reliable detection despite the puzzling velocity offset and line splitting but it occurred under very special conditions: at a distance of only 0.23 AU from the Sun and during a strong coronal activity observed by the LASCO coronograph C3 on the SOHO spacecraft.

The 22 GHz transition occurs between the rotational levels 6_{16}–5_{23} at 643 K above the zero point energy and may be inverted in some regions of the cometary coma under particular conditions. A very detailed investigation on the probabilities of detecting the 22 GHz line in comets was published by Graham et al. (2000). They concluded from their calculations that the line could be detected only if it were masing in a region observed along a jet against the radio continuum background of the nucleus.

As our detection in comet Hyakutake needed more investigation in sungrazing comets because of the anomalous splitting of the line and its Doppler shift by a variable amount and with a variable separation we decided to observe, starting in 2002, all possible sungrazing and very bright comets in order to check if the Sun distance and the solar activity could explain the puzzling behavior of the water maser line.

2. The observations

The observations were carried out with the 32 m Medicina (Bologna, Italy) VLBI antenna equipped with a 22 GHz receiver. The very high frequency and time resolution, direct Fourier transform spectrometer (MSPEC0) was used (Montebugnoli et al., 1996) after

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its successful performance during the Comet Shoemaker–Levy impact on Jupiter (Cosmovici et al., 1996). It uses an extremely powerful Digital Signal Processor (DSP optimized for the Fast Fourier Transform (FFT) computations and is able to perform transforms in a very short time: 1 k complex points need only about 90 μs and 256 k complex points FFT about 20 ms. This tremendous computation rate allows us to compute the FFT and the square magnitude "on fly" over an input bandwidth of 8 MHz, with a duty cycle efficiency of 30–37%.With this instrument the 8 MHz bandwidth was used with 8192 spectral channels which permitted observation of the high velocity shifted spectral lines reported in this work.

During the observations the telescope was pointed to the center of the comet and to the reference position (R.A. Comet + 1 deg × cos elevation), thus enabling us to obtain differential ON–OFF spectra. The spectra were calibrated using as a standard noise source generator. Secondary data reduction was done by using the ASTRA (Pluchino, 2008) software package.

The ASTRA post-processing software performs an accurate and rigorous analysis of spectral data. This software package, after a numeric validation of the raw nodding on–off–cal data, extracts each spectrum block and header in which are stored fundamental information about the related observing session (antenna and receivers setup, meteo, etc.). ASTRA automatizes the normalization and the calibration of a great number of spectra, performing on them an accurate time–frequency analysis and an accumulation over the time by means of a selectable addition (stacking) of individual spectra. The data processing 'core' of this software tool is the 'de-Doppler engine module', which takes into account the known Doppler shift of the target, i.e. the radial component of its velocity, makes the necessary correction and accumulates the final spectrum. In the case of cometary observations, the software performs a Doppler compensation taking the radial velocity as a function of time from the JPL Horizons system.

3. The observed comets

We investigated 6 comets: two of them, Comet NEAT (S/N: 7.20) and comet Kudo–Fujikawa(S/N: 7.13) present the most reliable detection values. Four of them gave possible positive results with S/N values > 3–4 under acceptable weather and instrumental conditions.The results of the observations are given in the following subheadings (I–VI), in Figs. 1–7 and in Table 1 where the ordering is by distance from the Sun. It should be mentioned that the negative detection of water in the following 6 comets at distances 0.13–2.0 AU from the Sun is here not analyzed as the data were not usable because of very strong RFI, bad weather conditions or malfunctions in the K-receiver during the short time of observations.

The comets were M4 Swan; P1 McNaught; WM1 Linear; Q4 Neat; 9P Tempel 1; and 17P Holmes. Period of observations: 2004–2007.

I) **C/2002 V1 NEAT**. It was the most interesting comet we could study as we could carry out the Sun closest observation of a comet from the ground. Observations were made on February 17,18 and 19, 2003 when the distance from the Sun was $\boldsymbol{R}$ = **0.101–0.121 AU** during the strong Coronal Mass Ejection (CME) detected by the SOHO spacecraft (Cosmovici et al., 2003) (see Fig. 1). The beam size was 2′, corresponding to an observed region at the comet of d = 80,000 km. As in the case of comet Hyakutake the line is shifted toward positive velocities and it shows a puzzling double peaked feature separated by a velocity difference of 4 km/s (see Fig. 2).

II) **Comet 96P/Machholz.** Also a sungrazing comet observed on January 12, 2002 at $\boldsymbol{R}$ = **0.21 AU.** The observed region around the nucleus was d = 79,000 km (FOV = 2′). The SOHO spacecraft had a unique opportunity to observe the extended coma and dust tail structure at the extremely close perihelion transit (R = 0.1 AU). The water maser line appears shifted toward positive velocities by 47.9 km/s. It has been calculated that the emitting source would cross the entire antenna beam in about 27 min if the velocity in the plane of the sky is similar to the observed radial velocity. This value would indicate that jets and not the surrounding coma are the source of the water emission. (The second peak at 30.8 km/s is not reliable as S/N < 3 (see Fig. 3A).)

III) **C/2002 X5 Kudo–Fujikawa**. Sungrazing comet observed January 20, 2003 at $\boldsymbol{R}$ = **0.37 AU** over a region around the nucleus d = 90,000 km (FOV = 2′). The comet passed within 0.2 AU from the Sun on January 29 and the UVCS images of the SOHO spacecraft could show a brightening of the comet at perihelion reflecting a fivefold increase in the comet's water production rate (from Lyman alpha). In our observations the water maser line is split in two components both shifted toward positive velocities, the first by 20.2 km/s and the second by 3.8 km/s. Velocity difference: 16.4 km/s (see Fig. 4).

IV) **153P/Ikeya–Zhang**. Observations were made on March, 16, 2002 at $\boldsymbol{R}$ = **0.51 AU** over a region around nucleus d = 71,000 km. Despite the fact that it was not a sungrazing comet we could detect the maser line, even if with lower SNR (3.3) with a positive velocity shift of 8 km/s. No split observed. (see Fig. 5).

V) **C/2002 T7 (LINEAR).** Observations on May 18 and 24, 2004 at $\boldsymbol{R}$ = **0.82 AU** over a region around nucleus d = 22,000 km. (distance from observer 0.27 AU). The possible detection of the water line shows two components with a positive velocity shift of 17.8 and 15.7 km/s. Velocity difference: 2.1 km/s (see Fig. 6).

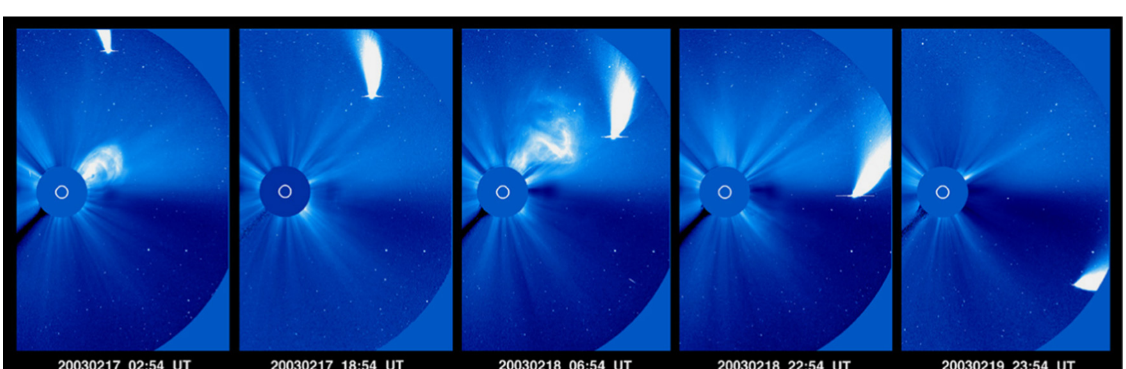

Fig. 1. Comet NEAT as seen by the LASCO Coronograph C3 on SOHO, February 17–18, 2003. Credit: NASA/ESA.