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Water MASER emission: a powerful diagnostic tool for the search of extra-terrestrial life

Cristiano Cosmovici

Institute for Space Astrophysics and Planetology (IAPS-INAF), Fosso del Cavaliere 100, 00133 Rome, Italy, e-mail: cosmo@iaps.inaf.it

Abstract. After the first discovery of a Jupiter-mass planet in 1995 (Mayer et al. 1995), (Butler, Marcy 1997), in the next 20 years more than 3000 exo-planets have been found to exist around main sequence stars. Most of the detection techniques are based on the radial velocity method (which involves the measurement of the stars wobbling induced by the gravitational field of the orbiting giant planets) and on telescopes (Hubble and Spitzer) outside the absorbing Earth atmosphere or dedicated spacecraft like Kepler and Corot measuring the transit of planets in front of hosting stars. From the ground, as infrared observations are strongly limited by atmospheric absorption, radio astronomy offers almost the only possible way to search for water presence and abundance in the planetary atmospheres of terrestrial-type planets where life may evolve. Following the discovery in 1994 (Cosmovici et al. 1996) of the first water maser emission in the atmosphere of Jupiter, induced by a cometary impact, our measurements have shown that the water MASER line at 22 GHz (1.35 cm) can be used as a powerful diagnostic tool for water search outside the solar system, as comets are able to deliver huge amounts of water to planets raising the fascinating possibility of extraterrestrial life evolution. Thus in 1999 we started, over a period of 13 years, the systematic search for water on 35 different targets up to 50 light years away from the Sun using the two twin 32m-radio telescopes of Medicina (Italy) and Noto (Sicily) equipped with new developed Fast Fourier Transform (FFT) spectrometers. Here we report the first detection of the water MASER emission from the exoplanetary systems Epsilon Eridani, Lalande 21185 and Gliese 581. We have shown the peculiar feasibility of water detection and its importance in the search for exoplanetary systems especially for the Bioastronomy (SETI) and Astrobiology programs, given the possibility of long period observations using powerful radio telescopes equipped with adequate spectrometers.

Key words. Exoplanets – Comets – Masers – Radio astronomy – Planetary Systems – Astrobiology

1. Introduction

The 1.35 cm (22 GHz) MASER line has been a well-known emission line in Astrophysics since its discovery in 1968 (Cheung et al. 1969); it has been detected in many galactic and extragalactic interstellar clouds and also in comets (Cosmovici et al. 2014) and in the Saturnian system (Pogrebenko et al. 2009).

The possibility of natural Lasers and Masers detection in our solar system has been investigated by (Mumma 2005) but the only experimental evidence was given during the impact of Comet Shoemaker/Levy 9 with

Jupiter in July 1994 (Cosmovici et al. 1996). In that particular case, the very narrow line width (40 KHz) and the high brightness temperature (20,000 K) of the water emission could not be explained in terms of the usual thermal emission when taking into account thermal and/or collisional broadening, and it was shown that only a MASER effect could explain the observed values. From this first detection in the Solar System, we deduced that, under particular physical conditions, MASER emission could be detected from exoplanetary atmospheres and that the water line could be used as a powerful diagnostic tool for planetary search outside the solar system where cometary bombardments may occur today as they occurred on our planet four billion years ago. Host stars of the spectral class K,M are preferable because of lower UV radiation. See for example the planetary system HD 189733 (star K1-K2), where water was detected in the infrared by (Tinetti et al. 2007) with the Spitzer space telescope, as a demonstration of its detection feasibility by orbiting telescopes and of the presence of water vapor in some exoplanetary atmospheres.

The calculations of the feasibility of the maser detection are reported by (Cosmovici 2000), (Minier et al. 2006), (Strelnitski 1997). The applied model predicts a mean flux density in the masing line of about 100 mJy, within 10 ly of the Sun. This value was obtained with the 32 m telescopes located in Italy given sufficient observation time and sensitivity of the radio-spectrometers.

At the conference held in Graz 2002 we announced the first ”possible” detection of the 22 GHz water maser emission originating in the stellar systems Eps Eri, Ups And, 47 UMa. Looking for confirmation in the following months, the following groups searched for the water maser line for very short periods reporting no detection: (Butler et al. 2003), (Greenhill et al. 2002), (Minier et al. 2006) (only one possible weak water maser detection on HD 47536). An observational campaign was also done by us with the 100m dish in Bonn but unfortunately, due to very poor weather conditions, it was only possible to detect a faint emission toward EQ Peg (C.Henkel, private communication). We also made a 4 hours negative trial on Lalande 21185 using the GBT antenna. In the following years no further attempts were made by other observers, thus we had no opportunity for data comparison. Our experience on observations carried out in Italy during a non-continuous period of 13 years helps to explain the non-detections obtained elsewhere with short trials. Six factors could affect the observability of the MASER emission: pumping conditions, beaming geometry, rotation and orbital motion of the planet around the star, non-continuous cometary bombardment or localized MASER spots in the atmosphere of the exoplanet.

2. Observations and results

We observed with the 32 meter dishes of the Medicina and Noto radio telescopes (Italy), up to 50 light years from the Sun, main sequence stars (dwarfs) where either cometary clouds have been discovered, or planetary systems have been detected. For this purpose, and considering also the limited observing time available, very sophisticated instrumentation and software had to be developed taking into account the unknown Doppler shifts of possible planets due to both rotation and orbital velocities. In the period 1999-2006 we used the Fast Fourier Spectrometer named MSPEC0 developed for the observations of the impact of comet SL/9 with Jupiter, (Montebugnoli et al. 2002). The very high frequency and time resolution Fourier Transform Spectrometer uses an extremely powerful DSP (Digital Signal Processor) engine optimized for the FFT (Fast Fourier Transform) computations and it is able to perform transforms in a very short time.

Starting in 2005 a completely new and challenging fast spectrometer named SPECTRA-2 was developed. It is based on FPGA (Field Programmable Gate Arrays) technology and allows real-time elaboration of two simultaneous analog inputs, performing fine channelization by using polyphase filter-banks to isolate with high rejection of the different sub-bands. A new post processing software named ASTRA (Pluchino 2002) was also developed which performs an accurate

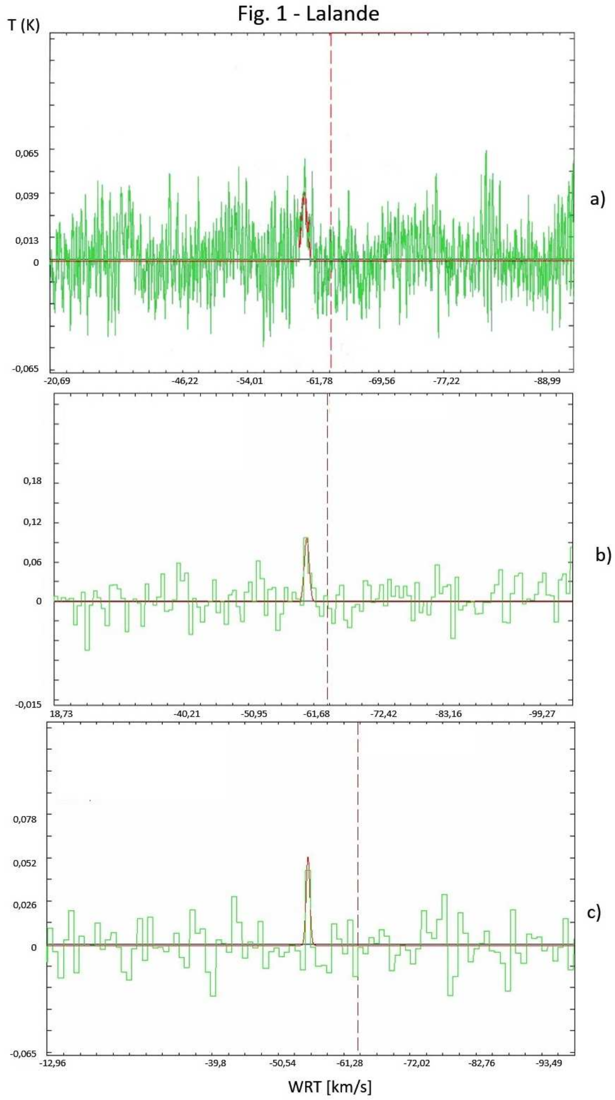

Fig. 1. Spectra of Lalande 21185: Lalande 21185 is one of the closest stars at 8.3 ly from the Sun. It is a small red dwarf (M2V) about 10 billion years old and it is believed to be surrounded by 3 giant planets. One at a distance of 2.2 AU from the star was tentatively astrometrically detected in 1996 (Gatewood 1996) but this possible discovery needs to be confirmed. *Panel a)*: spectrum of Lalande 21185 obtained November 24 , 2009 with the Medicina 32 m radio telescope; 200 minutes integration time (ON) and Gaussian smoothing. The observational data are summarized in Table 3.The background subtraction (ON-OFF) was done moving the telescope by 1 degree in a region not contaminated by interstellar MASER lines. The line shows a Doppler shift WRT (With Respect to the Target) by 3.2 km/s. *Panel b)*: the same spectrum obtained with box-car smoothing in order to emphasize the line. The box-car may affect the values of SNR, FWHM, flux peak, but will not affect the velocity shift position. *Panel c)*: the spectrum of Lalande one day later , November 25, 2009. The line is shifted by 8.1 km /s, i.e. 4.9 km/s with respect to the previous day showing a motion in the same direction.

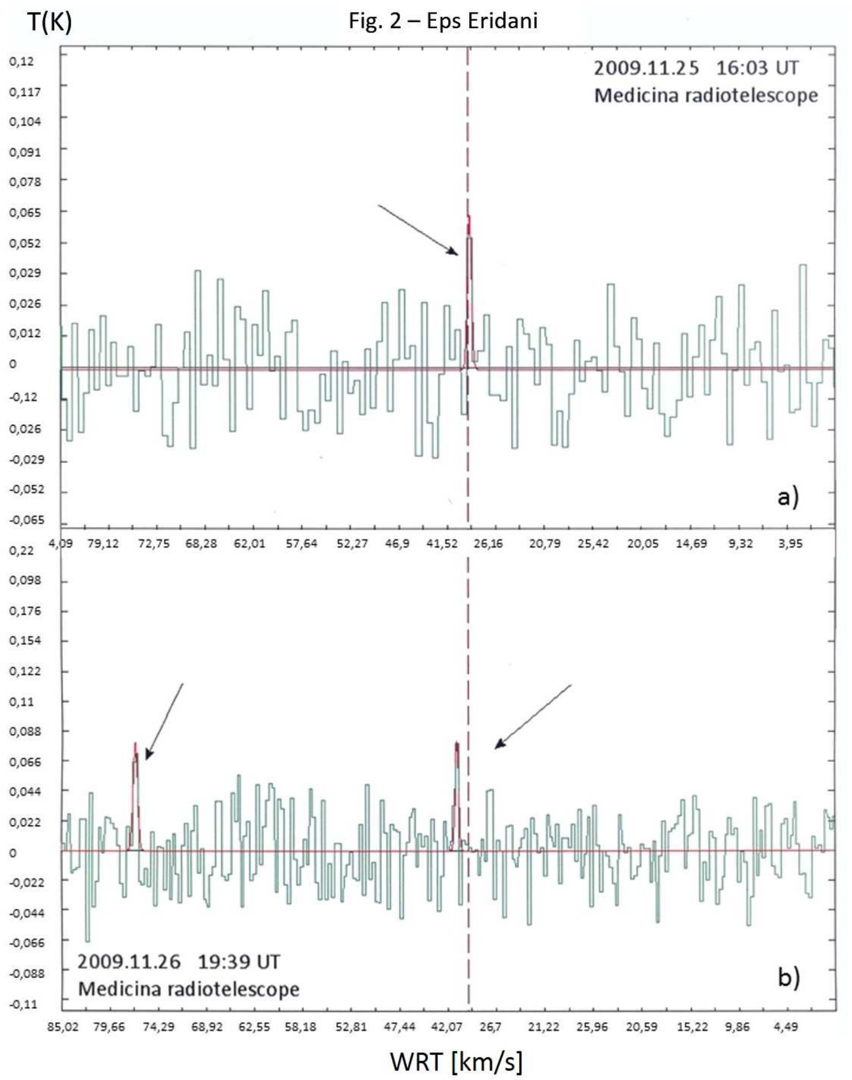

Fig. 2. Spectra of Epsilon Eridani a K2V star, only 10.8 ly away and among the 10 star systems closest to Earth, seemed to be the most interesting candidate in our target list. It is also of historical relevance as one of Drakes two candidates during his first SETI search in 1960 (Cocconi, Morrison 1959). Recently a ring of dust or cometary belt has been detected around it in the sub-millimeter region by the James Clerk Maxwell Telescope (Greaves et al. 1998). Planetary formation around the star is probably complete since the stellar age is around 0.5-1.0 Gyr, and Earth-like planets are believed to form within 0.1 Gyr (Hatzes et al. 2000). This target is extremely interesting for Bioastronomy as it represents the terrestrial condition about 4 Gyr ago when cometary bombardment is supposed to have ended and life started. *Panel a)*: spectrum of Eps Eri obtained 25 nov.2009 with the Medicina 32 m antenna ; 200 min integration (ON), box-car smoothing, observational data summarized in Table 3. The line shows a weak shift of 0.21 km/s WRT. *Panel b)*: spectrum of Eps Eri one day later, Nov. 26, 2009, same integration time, box-car smoothing. The shift of the line increased to 1.23 km/s. We note here (excluding experimental errors) the presence of a new second line shifted by 37 km/s WRT. As it is not present the day before and the day after, it could be a transient phenomenon due to cometary impacts from the ring belt.

Table 1. Selected targets observed 1999-2012. Red = water maser detected , blue = possible maser detection

Stellar system	Star characteristics	Distance [parsec]
Lal 21185	M2V	2.54
Eps Eri	K2V	3.2
Tau Cet	G8.5V	3.65
Gliese 876	M3.5V	4.72
EQ Peg	M3.5V/M4.5V	6.25
Gliese 581	M3V	6.26
Beta Cvn	G0V	8.39
55 Cnc	G8V/M3.5V	13.4
Ups And	F8V/M4.5V	13.47
47 Uma	G1V	13.9
51 Peg	G2.5V	14.7
Tau Boo	F7V/M2V	15
Rho Crb	G0V	17.43
HD 195019	G3V	20
70 Vir	G2.5V	22
HD 52265	G0V	28
HD 209458	G0V	47

Table 2. Observed Star characteristics

Star #	Distance (parsec)	Type	v LSR (km/s)	RA	DEC
Eps Eri	3.20	K2V	15.5	03h:3m:2.5s	-09 : 2 :7.3
Lalande	2.54	M2V	-85.0	01:10:3.2	+35:58:11
Gliese (GJ) 581	6.26	M3V	-9.5	15:19:26.0	-07:43:20

and rigorous analysis of spectral data. 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: the radial component of its velocity makes the necessary correction and accumulates the final spectrum.

Here we report only on three objects with a signal to noise (SNR) level > 4, as other possible candidates (see Table 1, 2) with weaker signals need a longer dedicated investigation for validation. We selected the most significant results from among those with a distance from the Sun < 20 ly where planets or cometary belts have been discovered around main sequence stars.

The results are summarized in Table 1, 2, 3 and Fig. 1, 2, 3, 4.

3. Discussion and conclusions

The aim of our work was to demonstrate that the water MASER line may be detected in exoplanetary systems given appropriately powerful radio telescopes and spectrometers as FFT devices, able to follow fast-moving objects for long periods. The significance of the maser search is due to the fact that exoplanetary water is detectable from the ground only in the radio region, just as the thermal emission in the infrared is observable only from space. As our FOV (Field Of View) (2 arcmin) covers a typical exoplanetary system, we were not able

Table 3. Observations. *Total integration time in the period 1999 - 2012. Average integration time for a single observation: 200 min, FWHM = Full Width Half Maximum - SNR = Signal to Noise Ratio - Jy = Jansky - LSR = Local Standard of Rest, WRT = With Respect to Target , Conversion factor 0.11K/Jy 37% antenna efficiency , 8192 frequency channels in a 8 MHz bandwidth, calibrators (flux and frequency): dr21, w3oh, w51, 3c286, 3c123, 3c353,s231,hh7, T (K) = Antenna temperature

Star #	Fig.	Date (y:m:d)	UT (start)	Int.time ON (hrs)*	FWHM (kHz)	SNR	Flux peak (Jy)
Lalande	1a, 1b	2009/11/24	10:28	120*	53.6	4.8	0.37
Lalande	1c	2009/11/25	08:32	-	43.5	5.4	0.42
Eps Eri	2a	2009/11/25	23:33	205*	40.5	5.4	0.58
Eps Eri	2b	2009/11/26	19:39	-	39.3	5.0	0.73
Second peak	2b	2009/11/26	19:39	-	44.2	5.9	0.73
Eps Eri	3	2011/4/2	12:00	-	41.5	4.3	0.63
Gliese 581	4	2012/8/30	14:20	25*	43.3	5.3	0.67

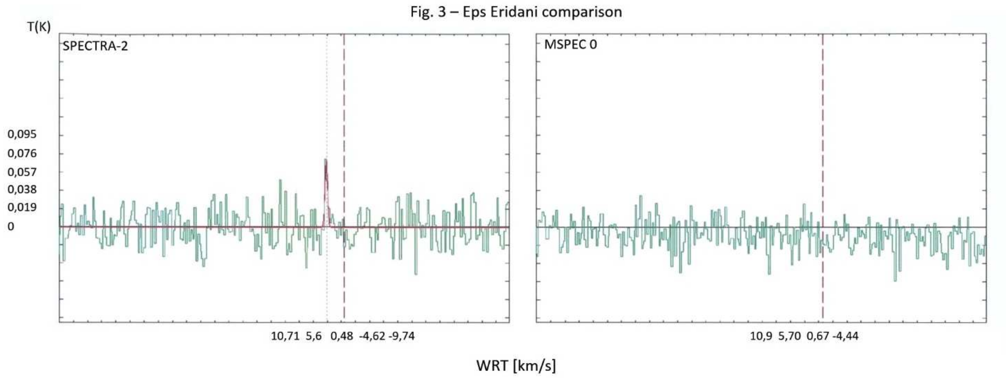

Fig. 3. Comparative spectra of Eps Eri: April 2 , 2011 we made the following test on Eps Eri to prove the real detection of the maser line and the performance of the new spectrometer SPECTRA-2: on the left hand the spectrum acquired with SPECTRA-2 shows a clear detection with SNR 4.3 and shift WRT of 3.2 km/s; on the right hand the same target was simultaneously acquired with the old FFT spectrometer MSPEC0 used in the period 1994-2007. Both spectra were obtained by means of a similar instrumental and antenna setup. It should be remarked that MSPEC0 was not able to detect any visible feature.

to quantify the distance of the emitting planet from the star and its orbit. The use of a FOV of few sec of arc is suitable only if one knows the position of the planet with respect to the star. It is evident from our spectra that the detected velocity shifts are clearly of a different nature from all other objects that emit water MASER radiation and therefore it is highly likely that we have detected water masers associated with planets or planetary formation. The line-band width (see Table 3) and intensity are similar to those observed during the Jupiter/Comet collision (Cosmovici et al 1996). In the case of a young star like Epsilon Eridani we suppose that the water emission is probably a consequence of a shower of cometary impacts as the star is surrounded by a cometary belt (Greaves et al.1998). For the older stars, where planetary

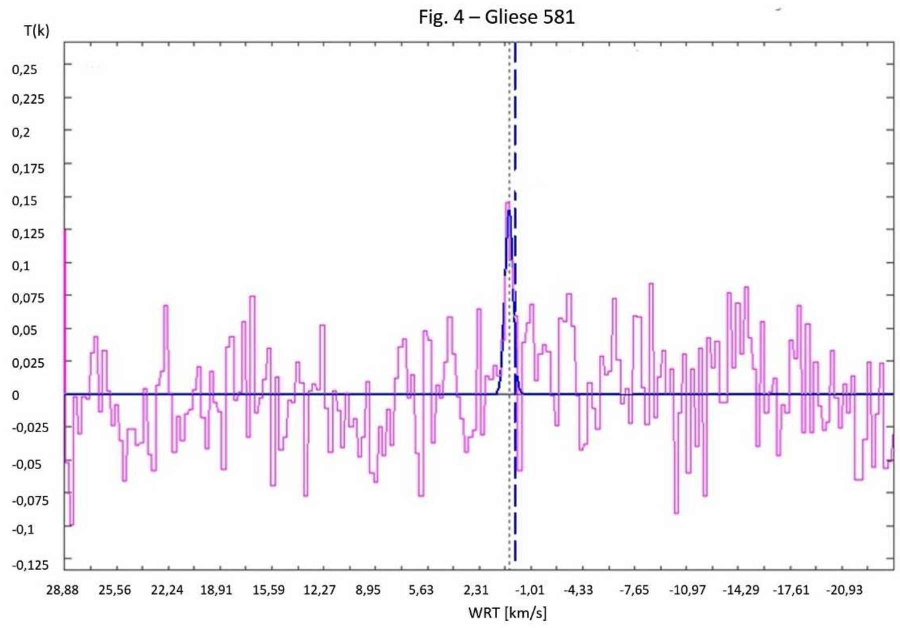

Fig. 4. Spectrum of Gliese 581, 20.4 ly from the Sun, a red dwarf M3V. From recent observations it seems that the star has a planetary system consisting of 3 or 5 planets, GJ 581 b,c,d (the newly discovered e and g are yet to be confirmed). The system GJ 581 is one of the most attractive from the point of view of possible habitability. In 2012 the space telescope Herschel observed a comet belt extending from 25 to 60 AU around the star. The calculations show that the belt should have at least 10 times as many comets as does our Solar System. This seems to rule out Saturn-mass planets beyond 0.75 AU, (Lestrade et al. 2012). Spectrum of Gliese 581, obtained August 30, 2012 with the Noto 32 m dish in Sicily. The shift of 0.4 km/s shows a moving object inside the FOV of the exoplanetary system. This detection is particularly interesting as obtained on a target surrounded by 3-5 planets and suitable for habitability. This object should be studied in detail in the future also with higher spatial resolution in order to state the origin of the maser emission.

systems may be more stable, the most promising hypothesis is that the masers are emitted from water-rich atmospheres where the necessary maser pump is provided by photodeposited energy which can affect the level populations. MASER emission from the chromosphere of solar-type stars is not expected. As we observed over a period of 13 years that the MASER emission is a transient phenomenon due to rotation and orbital motion of the planet(s) or to localized cometary impacts, future search for exoplanetary masers should be organized with dedicated powerful radiotelescopes for a survey up to 100 ly from the Sun to check for other candidates and to confirm and state the origin of the lines, the position and orbits of the emitting planets and the amount of water present in the planetary atmospheres. This was a pioneering work as the observations of exoplanetary systems are at the very early stages of exploring our Galaxy. We plan to continue our observations of water as the main candidate for life evolution, and also of important masing prebiotic molecules like CH3OH (methanol), taking advantage of contemporary research and the new Sardinia (SRT) 64 m dish in Italy. Moreover this work could be very helpful for the SETI program in the radio search for habitable exoplanets as MASER emission represents the only way to detect water from the ground and to communicate at 22 GHz with possible extraterrestrial intelligence.

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