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Searching for MASER spectral features in extrasolar planets: the ITASEL project

E. Salerno[1], L. Zoni[2], and S. Righini[1]

[1] INAF – Istituto di Fisisca dello Spazio Interplanetario, via del Fosso del Cavaliere 100, I-00133 Roma (RM), Italy
e-mail: `esalerno@ira.inaf.it`

[2] INAF – Stazione Radioastronomica di Medicina, Via Fiorentina 3508/B, I-40059 Medicina (BO), Italy

Abstract. An accurate spectroscopical analysis of the atmospheres of extrasolar planets is of primary importance for the knowledge of the planetary chemical composition and, more speculatively, for the study of a possible development of life on these sites. The ITASEL project has the aim to detect the maser spectral features coming from the planets' atmosphere by using radioastronomical tools. In order to detect even faint maser lines with more accuracy and reliability, the development of innovative hardware technologies is ongoing. The new hardware system SPECTRA1 is a modular instrument for radioastronomical antennas that provides several analysis capabilities. Final target is the production of a programmable, general-purpose device, able to meet the requirements of different kinds of applications (spectrometry, polarimetry, radar detection, etc.)

Key words. Bioastronomy – Masers – Stars: planetary systems – Radio lines: extrasolar systems – Instrumentation: polarimeters – Instrumentation: spectrographs – Techniques: spectroscopic

1. Introduction

In the past decades more than 200 extrasolar planets have been discovered using indirect detection methodologies (see the Extrasolar Planets Encyclopaedia for an updated catalog: http://exoplanet.eu/). Due to the currently achievable detection techniques all the planets discovered so far are characterized by Jupiter-like masses. Together with the development of innovative methodologies for the detection of new gas giants (e.g. the CoRoT mission), new space missions have been planned to probe nearby stars for Earth-sized planets (e.g. the NASA SIM Planet Quest and the Terrestrial Planet Finder −TPF). At the same time considerable effort has been spent by astronomers for the study of both the morphology and chemical composition of the detected objects. Radioastronomical observations are one of the most direct way to perform spectral studies by means of ground based instruments. The observation of a particular kind of radiation emitted by the planet atmosphere at high radio frequencies − the radiation amplified by maser effect − provides a direct way to analyse the planetary chemical composition. In the frame of the ITASEL project we are monitor-

Send offprint requests to: E. Salerno

ing a selection of exoplanetary systems and other potential scenarios where methanol and water maser lines may be found. The sample includes nearby stars – when considered interesting from an astrobiological point of view – and peculiar bright comets with short perihelion distances.

2. Maser emission from extrasolar planets and comets

Astronomical masers (Microvawe Amplification by Stimulated Emission of Radiation) are molecular clouds that are able to produce coherent, monochromatic electromagnetic radiation at a characteristic frequency. All masers share a few general features: a "population inversion" – that is, a larger population in the higher of two energy levels of an ensemble of particles – is created in the medium. Through stimulated emission the population inversion amplifies the electromagnetic fields that are resonant with the transition frequency between the two levels. As a result a highly intense radiation characterized by that frequency is emitted. Maser emission has been detected from many different molecules (water H_2O, hydroxyl radicals OH, methanol CH_3OH, formaldehyde CH_2O and silicon monoxide SiO) in a variety of astronomical sources, from nearby comets to interstellar space, star forming regions and faraway galaxies.

Strelnitski (1997) and (2005) first discussed the application of astronomical masers to the study of extrasolar planets demonstrating that maser in molecular lines from the atmospheres of planets on close orbits around their parent star can be detected with ground-based radioastronomical facilities.

In 1994 the impact of Comet Shoemaker/Levy 9 on the Jupiter's atmosphere allowed radioastronomers to detect the water maser line for the first time in the Solar System (Cosmovici et al. 1996). Successively the 22 GHz neutral water line was also observed during the transit of the Comet Hyakutake C/1996 B2 (Cosmovici et al. 1998).

3. The observations

The observational sessions relative to stellar and exoplanetary systems are performed with the 32 meters parabolic antenna of the Medicina Radiotelescope Station – Istituto di Radioastronomia – nearby Bologna (Italy). They take place almost monthly, but are more intense during winter, when the low atmospheric humidity allows the antenna to achieve lower system temperatures (Tsys) and thus better signal-to-noise ratios. Files acquired observing the same source in different periods, after a first individual processing phase, are then averaged and manually de-dopplered – by means of an iterative process – in search for a possible faint MASER line with an unknown Doppler-shift. The development of a dedicated post-processing software is underway – along with the production of a new back-end – to guarantee an effective, faster and more reliable elaboration of the huge amount of collected data. The observation of comets is simpler from an operative point of view, as the dynamics of these Solar System objects is very well known. The nuclei orbits can be easily computed in advance, allowing a detailed dedopplering of the acquired spectra. No recent targets – included the fragments of the spectacular Comet 73P/Schwassmann-Wachmann3 – have shown potential lines yet.

4. The hardware

The technological component of the ITASEL project provides the development of an innovative hardware named SPECTRA1 (SPECTRum Analizer 1) that should allow the detection of faint maser lines with more accuracy and reliability. One of the main results would be the installation on modern radiotelescopes of a unique modular fast and programmable back end instead of several ones, each dedicated to single acquisition task (spectrometry, polarimetry, radar detection etc.). This approach would lower the costs and make available more compact and flexible back ends. SPECTRA1 offers relevant advantages such as reconfigurability, low dimensions and low costs. These features are

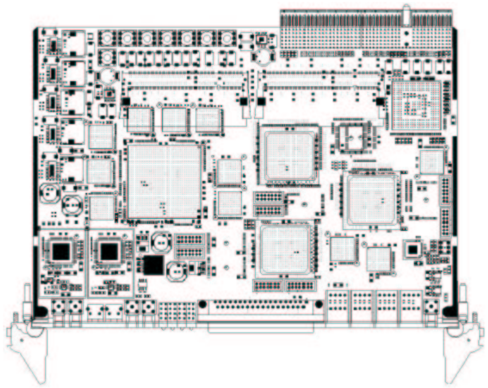

Fig. 1. SPECTRA-1 main board

due to the use of an innovative electronic devices – the Field Programmable Gate Array (FPGA) – which can provide large amounts of digital hardware resources on the same chip. SPECTRA1 (in Fig. 1) has a compact design and runs at very high speeds. For the ITASEL project high time and frequency resolutions are required on frequency bands below 400 MHz. The observations also include spectroscopy with the possibility to compensate a large range of Doppler shifts. The back end, together with new low-noise front ends installed at the 22 GHz receiver mounted on the 32 m parabolic antenna of Medicinal, will allow more efficient observations than it was possible with previous equipment. The system is modular, as up to 4 data-acquisition boards can be added as required: the parallel use of more boards allows the increase of both the input bandwidth and the number of channels. One particular system-feature is the parallel real-time FFT (bandwidth < 400MHz) and KL transforms (not in real time) use. This characteristic could play a fundamental role, either for basic line observations or for future applications, where an even higher processing speed and computing power is required to enable a leapfrog in quality of real-time radiotelescope signals analyses. SPECTRA 1 is extremely compact and it just requires power supply and clock source. This characteristic will allow radioastronomers to easily transport the spectrometer in different radiotelescope sites and to perform observations with several front ends.

5. The software

Together with the development of the hardware setup the production of a dedicated post-processing data software is underway. During data acquisition a very long integration time is necessary to also detect the fainter lines. This task can be implemented by using a particular observation technique – the "frequency switching" – or by using "multi-beam" receivers. Once data are acquired it is necessary to apply special elaboration procedures in order to identify the signals whose frequency continuously varies along the spectral sequence due to the Doppler effect generated by the planet rotation.

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