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Observations of OH maser comets in 1.6GHz frequency band: adaptation of the Irbene RT32 radio telescope and development of the data processing methods

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Abstract

Institute of Astronomy (University of Latvia) with Ventspils International Radio Astronomy Centre (Ventspils University of Applied Sciences) participation is implementing the scientific project "Complex investigations of the small bodies in the Solar system" related to the research of the small bodies in the Solar system (mainly, focusing on asteroids and comets) using methods of radio astronomy and signal processing. One of the research activities is hydroxyl radical (OH) observation in the radio range - single antenna observations and VLBI (Very Long Baseline Interferometry) observation.

1. Introduction

There are four known (1612.231, 1665.402, 1667.359 and 1720.530 MHz) hyperfine transitions of OH at 18 cm wavelength which have been used for 40 years, historically to observe comets. In 1973, the molecule OH in comet Kahoutek [1] was observed fwith Nancay 30 meter telescope. The 18 cm line is the result of an excitation from resonance fluorescence, whereby molecules absorb solar radiation and then reradiate the energy. The OH molecule absorbs the UV solar photons and cascades back to the ground state Lambda doublet, where the relative populations of the upper and lower levels strongly depend upon the heliocentric radial velocity (the "Swings effect") [2].

The result of comets observations in 1.6GHz frequency band made by other astronomy groups [3],[4],[5],[6] and others - show that the typical peak source flux densities of the comet are in the range of 4 to 40 mJy. Weakness of the radio signal is the main challenging factor. Assuming that the detection threshold is 3*σ, at least 1.3 to 13 mJy noise floor is required.

2.Observations

Preparation of the Irbene RT32 radio telescope includes design and installation of the dedicated low-cost L-band (18 cm wavelength) receiver, capable to receive hyperfine transitions of the OH masers on comets. The developed custom receiver consists of compact feed horn with dual circular polarized channels and parabolic reflector, which together with existing Cassegrain antenna forms triple mirror system. Uncooled low noise amplifiers are used for both channels, which allows to achieve system noise temperatures of less than 60 K. Estimated aperture efficiency at 1.65 GHz is between 30 and 50 % which translates to RT32 radio telescope gains of at least 0.1 K/Jy. The overall estimated sensitivity SEFD = 650 - 900 Jy depending on the elevation of the antenna. Flux detection threshold levels were estimated - in the case of single dish mode, Irbene RT-32 (IR) sensitivity is assumed to be sensitivity SEFD = 650 Jy. In the case of a two element interferometer (IR+TR), the Irbene RT-32 (SEFD1 = 650 Jy) and Torun (operated by Torun Observatory, Poland) 32m telescope (SEFD2 = 300 Jy) is assumed. The calculated results of the *noise floor dS vs integration* show - the detection of the source with the flux density below 40 mJy is possible by a single antenna (integration time ~ 6 hours, spectral channel bandwidth BW=20 KHz) and the detection of the source with the flux density below 20 mJy by VLBI (integration time ~ 3 hours, spectral channel BW=20 KHz).

To verify the calculation of the model, multiple observations at L-band were performed in single and VLBI modes. Successful test observations in single dish mode were performed, which includes continuum calibration sources and OH spectral lines at 18 cm. To test the performance of the receiver and to verify the Solar System object tracking mode of the RT32 control software, continuum observations of Venus were carried out (28.12.2018, total power BW: 20 MHz, 2 channels, flux density at time of the observation: 0.65 Jy (angular size: 28”, surface temperature: ~600 K, f0 = 1670 MHz)). Observations of various maser sources with flux density in range of 0.8 Jy to 3 Jy were performed. The observed objects - W75 S, U_Aur, G133P715.

In collaborations with colleagues from Torun Observatory in Poland the two-baseline (stations: Irbene RT32 and Torun 32 m radio telescope) VLBI AGN and spectral line observations were successfully performed - 4.02.19, freq.1665 MHz, LCP and RCP, 16 channels, observed objects: W3OH, 3C123, 3C84, W49N and 20.03.2019, freq.1667 MHz, LCP and RCP, 2 channels, observed objects: W3OH, G133P715.

Observations’ planning and performance continues in both modes.

3.Data recording and processing methods

Single antenna mode - a spectrometer backend based on software defined radio USRP X300/310+TwinRX is used to record data using 16bit+16bit (real + imag part) per sample. For spectral data calibration, the frequency switching [8] method currently is used. Data processing is implemented to collect data using large integration time and to calculate as the result the spectrum of the object.

VLBI mode - the recording of VLBI data is carried out in accordance with the EVN guidelines. VLBI data processing is performed with large numbers of computations on the raw sampled signals from the pairs of VLBI stations. These computations yield signal interference functions, the so called “fringe function” and the basic delay parameters (delays). The spectral characteristics of the fringe functions with the corresponding delays are used in the next step of data processing, which ultimately leads to the measured physical parameters of observed object, such as angular positions and velocities. To achieve that, the existing methods for time and frequency delay compensations is reviewed and additional concepts of time-frequency analysis, such as extended short time Fourier transforms, specific data windows, wavelet analysis and Gabor frames are applied to the data for fractional step compensations in the correlation integral constructions. Previous experience with acquiring and processing data from the DA14 asteroid [7] on February 15, 2013, offered a good experience to develop methods for the comet’s OH maser location detection and its behavior approaching the Sun, in addition to developing new methods for measuring delay and frequency of interference using hyperfine transitions of OH molecules. Observations of small bodies are possible with the best available accuracy when optical (using the optical *Schmidt* telescope of Institute of Astronomy) and VLBI methods are combined. Data processing from two independent simultaneous measurements (using specific Kalman filters) allows one to reduce human errors in sporadic sources.

4.Summary and Conclusions

Observations of OH masers of comets can be a very challenging task. The upgrade of the L band receiver was performed to observe comets. Multiple data processing methods were developed to acquire a weak signal - from observations of single antenna and VLBI. We are waiting for a “*bright and close*” comet. One of the possibilities - comet 2P/Encke with its close perihelion at 0.3302 AU on 2020-06-17.

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