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LOW-FREQUENCY RADIO RECOMBINATION LINES: OBSERVATIONS AND DATA PROCESSING

In this report, observations of radio recombination lines which are carried out with radio telescope UTR-2 using a 4096-channel autocorrelometer and 16-bit digital spectral analyzer are described. The correct processing and interpretation of observational results provide new information about the basic parameters of the interstellar medium – electron temperature, electron density, element abundances, distribution of ionized gas. Analysis of radio recombination lines' parameters provides new opportunities not only for astrophysics but also for physical science as a whole.

Keywords: *radio recombination lines, quantum transitions, radio telescope UTR-2, spectral analyzer.*

Highly excited atoms are formed in space as a result of recombination of electrons and ions. In the subsequent cascade transitions the trapped electron jumps down into the ground state and the photons are emitted. Consequently, the spectral lines arising in such transitions are called as radio recombination lines (RRLs) [2]. They can be observed from the Earth's surface in the almost all radio range from millimeter to decameter waves.

The possibility of observing RRLs was predicted by N. S. Kardashev in 1959. Then they were discovered in 1964 by Sorochenko & Borodzich (Pushchino, $H90\alpha$) and by Dravskikh & Dravskikh (Pulkovo, $H104\alpha$). The high-frequency RRLs were detected in the directions of classic hot HII-regions as well as in the directions of planetary nebulae, external galaxies and some circumstellar shells. RRLs at decameter wavelengths were discovered in 1980 using the world largest decameter waves radio telescope UTR-2, located near Kharkov [3].

OBSERVATIONS

At first, low frequency radio recombination lines were detected in the clouds lying on the line of sight towards supernova remnant Cassiopeia A using high sensitive spectral analyzer based on the digital sign autocorrelometer [1]. The carbon RRL $C631\alpha$ were detected [4]. This medium remains to be the most studied object using RRLs observations. Low frequency recombination lines from hydrogen (in the decameter and close meter ranges) are not detected still because hydrogen remains almost completely neutral in the cold low density interstellar plasma. Ionization potential of carbon (11.2 eV) is less then than that of the hydrogen

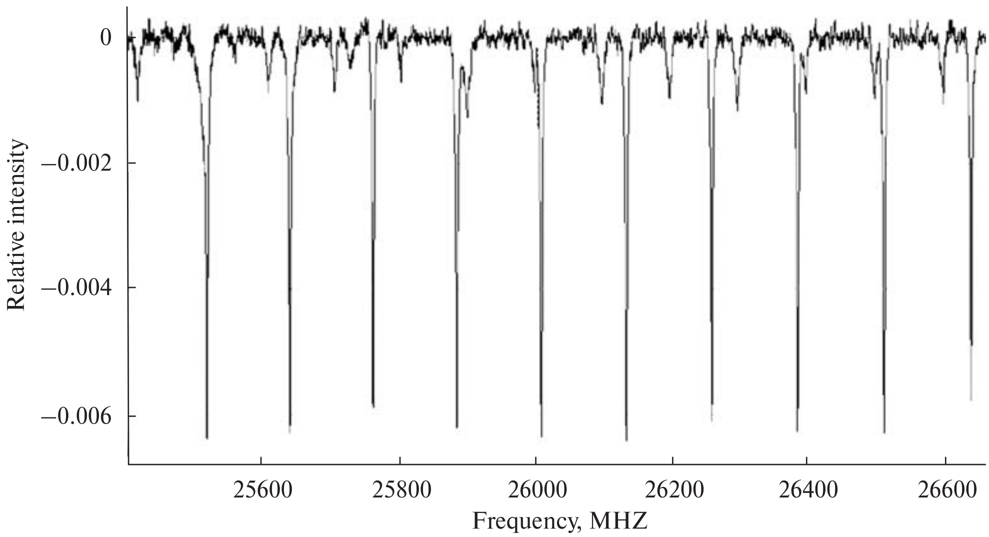

Fig. 1. Spectrum measured in the direction of Cas A with UTR-2. Relative intensity means ratio T_L/T_C, α, β , γ and lines are visible

(13.6 eV) and this leads to the absence of detection of the corresponding spectral features. However, the attempts to find hydrogen RRLs with $n > 600$ are been continuing.

Also at UTR-2 spectral observations in the direction to various radio sources including Galactic plane have been carried out. After construction of new autocorrelometer [7] and modernization of preamplification system at the end of the 1990s, the lowest frequency spectral lines (n ~812) were detected near the frequency of 12 MHz. The atoms with even higher principal quantum numbers of about 860 and of 1009 were detected by observations of β -lines near 20 MHz, and by observations of δ -line, near 26 MHz correspondingly [7]. The size of a corresponding carbon Rydberg atom is about 0.1 mm.

Detection of the extremely low frequency carbon RRLs opens new opportunities for studying low-density partially ionized interstellar medium (ISM). It helps to determine the parameters of the ISM from the line characteristics (intensity, line width, radial velocity etc.).

Currently radio spectroscopic studies at UTR-2 are held using 4096-channel digital autocorrelometer and new generation digital spectral analyzers DSPZ (Digital Spectro-Polariemeter of Z-type) which performs real time Fourier transform providing frequency resolution of 4 kHz. In order to improve sensitivity and reliability of the low frequency spectral studies, the observation range will be increased up to 80 MHz using the new generation radio telescope GURT and the newest digital spectral analyzers ADR (Advanced Digital Receiver) [5].

DATA PROCESSING AND THEIR INTERPRETATION

Figure 1 shows spectrum where the series of carbon RRLs *C627*α–*C636*α and *C790*β–*C802*β are clearly seen. It is measured in the direction of Cassiopeia A at frequencies near 26 MHz with UTR-2 and 4096-channels autocorrelometer. The integration time is more than 500 hours.

In our case of very high atom quantum states the condition $n \gg \Delta n$ is valid and the adjacent lines could be considered as equivalent. So we could fold individual transitions and dramatically improve measurement sensitivity. Figure 2 shows the folded *C631*α... *C636*α RRLs measured towards Cassiopeia A.

The heaviest problem with the low frequency radio spectroscopy of the interstellar medium is connected with low intensities of the studied features and with the influence of terrestrial interferences and ionosphere. In order to overcome these difficulties we must improve dynamic range of our radio astronomical equipment. Also the simultaneous

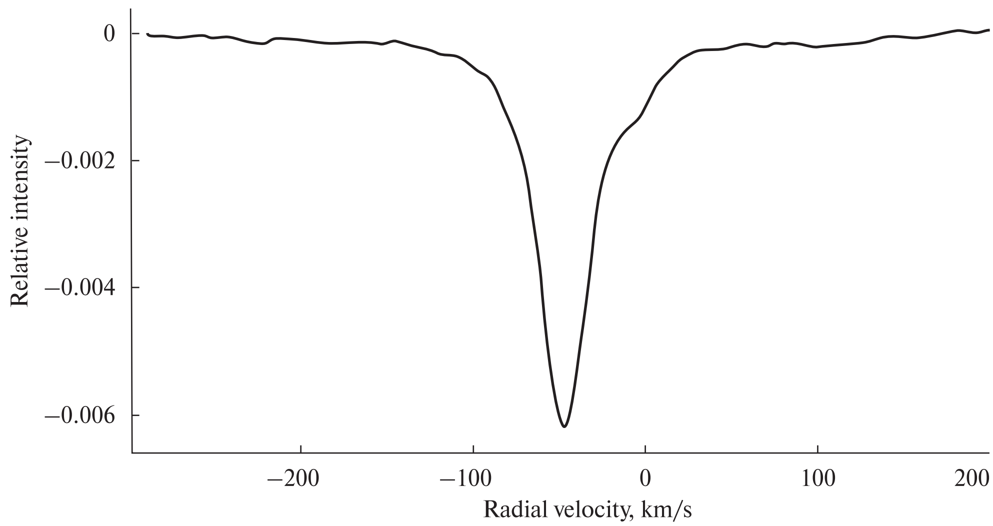

Fig. 2. Folded *C627*α...*C636*α RRLs measured towards Cas A

observations using different instruments situated at big distances between them very helps.

The profile of a radio recombination line is determined by several broadening effects. Thermal particles motion and turbulence in the ISM leads to a Doppler broadening. Other reasons of line profile broadening are collisions in the gas (leading to Stark effect) and influence of background radiation. The resulting line shape is described by the Voigt function which has Gaussian and Lorentzian component.

In order to determine the maximum excitation level at which atom can exist as a bound system we have to analyze the dependence of the line broadening values against principal quantum number and physical parameters of the interstellar medium. For the directions towards Cassiopeia A the principal influence on the line width are made by collision and radiative effects. Correspondingly, we have to analyze the Lorentzian line width firstly. It is determined by:

$$\Delta V_L = \Delta V_P + \Delta V_R, \qquad (1)$$

where ΔV_P and ΔV_R are the pressure and the radiation broadening correspondingly.

The theoretical behaviors of these phenomena have already been studied [6]. The radiation broadening is determined by

$$\Delta V_R \approx 2c/\pi\nu \sum_{m=1}^{n-1} I_\nu B_{n\,m}, \qquad (2)$$

where I_ν is intensity of background radiation and $B_{n,m}$ is Einstein coefficient of induced emission, c is light velocity in km/s and ν is the observation frequency in Hz [7].

The pressure broadening can be calculated using

$$\Delta V_P = 2\times10^{-8} e^{-26/T_e^{1/3}} n_e\, n^{5.2} / T_e^{1.5}\, c/\nu. \qquad (3)$$

When we take into account the typical conditions of the ISM in the Galaxy, the fundamental limit of the highest bound state of a Rydberg atom is near $n \sim 1500$ [5].

Evaluation of the line width dependence against principal quantum number helped to determine the parameters of the medium where these spectral lines arise. Electron temperature T_e and electron density N_e were found to be 75 K and 0.002 cm^{-3} correspondingly. Also it was proven that the intensities of the low frequency RRLs in the directions toward Cassiopeia A are increased by the effect of dielectronic-like recombination. It is connected with the fine-structure transition in the ground state of a carbon atom between $^2P_{3/2} - {}^2P_{1/2}$ with energy of 92 K. This process significantly influences the level populations in carbon atoms in the low-density interstellar medium when electron temperature is not less than 50 K.

CONCLUSIONS

Low-frequency RRLs investigations are one of the most promising areas of radio astronomy. The results of the observations on the UTR-2 made a great contribution to modern space science. At present time, investigations of low-frequency RRLs with UTR-2 and GURT are carried out for many Galactic objects. We are confident that these investigations will be continued.

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НИЗЬКОЧАСТОТНІ РЕКОМБІНАЦІЙНІ РАДІОЛІНІЇ: СПОСТЕРЕЖЕННЯ ТА ОБРОБКА ДАНИХ

Описуються спостереження, які проводяться за допомогою радіотелескопа УТР-2 з використанням 4096-канального цифрового автокорелометра та 16-бітного цифрового спектроаналізатора. Коректні обробка та інтерпретація результатів спостережень дають нові відомості про основні параметри міжзоряного середовища — електронну температуру, електронну щільність, кількість та поширеність елементів, розподіл іонізованого газу. Аналіз параметрів рекомбінаційних ліній дає нові можливості не тільки для астрофізики, але й для фізичної науки в цілому.

Ключові слова: рекомбінаційні радіолінії, квантові переходи, радіотелескоп УТР-2, спектроаналізатор.

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НИЗКОЧАСТОТНЫЕ РЕКОМБИНАЦИОННЫЕ РАДИОЛИНИИ: НАБЛЮДЕНИЯ И ОБРАБОТКА ДАННЫХ

Описываются наблюдения, которые проводятся на радиотелескопе УТР-2 с использованием 4096-канального цифрового автокоррелометра и 16-битного цифрового спектроанализатора. Правильная обработка и интерпретация результатов наблюдений дают новые сведения об основных параметрах межзвездной среды — электронной температуре, электронной плотности, обилии элементов, распределении ионизованного газа. Анализ параметров рекомбинационных радиолинии дает новые возможности не только для астрофизики, но и для физической науки в целом.

Ключевые слова: рекомбинационные радиолинии, квантовые переходы, радиотелескоп УТР-2, спектроанализатор.