Quantum Electronics **37** (7) 685 – 690 (2007)

PACS numbers: 42.55.Lt; 42.68.Wt; 98.70.Lt
DOI: 10.1070/QE2007v037n07ABEH013534

The $^2P_{1/2} \rightarrow {}^2P_{3/2}$ laser transition in atomic iodine and the problem of search for signals from extraterrestrial intelligence

Yu.F. Kutaev, S.K. Mankevich, O.Yu. Nosach, E.P. Orlov

Abstract. **It is proposed to search for signals from extraterrestrial intelligence (ETI) at a wavelength of 1.315 μm of the laser $^2P_{1/2} \rightarrow {}^2P_{3/2}$ transition in the atomic iodine, which can be used for this purpose as the natural frequency reference. The search at this wavelength is promising because active quantum filters (AQFs) with the quantum sensitivity limit have been developed for this wavelength, which are capable of receiving laser signals, consisting of only a few photons, against the background of emission from a star under study. In addition, high-power iodine lasers emitting diffraction-limited radiation at 1.315 μm have been created, which highly developed ETI also can have. If a ETI sends in our direction a diffraction-limited 10-ns, 1-kJ laser pulse with the beam diameter of 10 m, a receiver with an AQF mounted on a ten-meter extra-atmospheric optical telescope can detect this signal at a distance of up to 300 light years, irrespective of the ETI position on the celestial sphere. The realisation of the projects for manufacturing optical telescopes of diameter 30 m will increase the research range up to 2700 light years. A weak absorption of the 1.315-μm radiation in the Earth atmosphere (the signal is attenuated by less than 20 %) allows the search for ETI signals by using ground telescopes equipped with adaptive optical systems.**

Keywords: *extraterrestrial intelligence, space communication, frequency reference, iodine lasers, active quantum filter, quantum sensitivity limit, diffraction-limited divergence, optical telescope, adaptive optical systems.*

1. Introduction

The principal possibility of the space communication with extraterrestrial intelligence (ETI) by using electromagnetic waves in the microwave range was demonstrated in pioneering papers of Cocconi, Morrison [1] and Drake [2]. Schwartz and Townes [3] showed that the space communication can be also performed in principle in the optical range by using lasers. The possibility of a search for ETI signals in the optical range was also discussed in [4 – 6]. The development of science and technology stimulated theoretical and experimental investigations devoted to a search for ETI signals [7 – 10]. However, no ETI signals have been reliably detected so far.

The problem of a search for ETI signals and communication with ETI involves a number of basic technological tasks, which should be solved to make this problem real. These tasks are:

(i) The choice of radiation wavelengths suitable for the search for ETI signals.

(ii) The development of methods for the signal separation against the background of the galactic noise and emission of a star around which a planet with the assumed ETI rotates.

(iii) The provision of the detection sensitivity sufficient for detecting the ETI signal with the probability no less than 0.9.

(iv) The provision of the required energy of the communicated signal.

In connection with the first problem, we mention that the authors of [1] substantiated the expediency of searching for the ETI signal at a wavelength of 21 cm of the radio line of hydrogen. As for the optical range, the authors of [3] pointed out that '...perhaps it would be appropriate to examine high-resolution stellar spectra for lines which are unusually narrow, at peculiar frequencies, or varying in intensity' and that '...the choice probably being dictated by the availability of suitable maser material to produce the desired frequency'.

The principal possibility of solving the last three problems by laser methods was analysed in [3 – 6]. It was assumed that high-power diffraction-limited lasers will be used in a transmitter, and the useful signal will be separated against the background of the star emission with the help of narrowband filters, which virtually do not absorb the useful signal, and detected by photon detectors with the 100 % quantum yield providing the maximum possible reception sensitivity. The attempts to create receivers and transmitters with such ideal parameters have been unsuccessful for a long time.

The aim of our paper is to consider the new possibilities for solving these problems, which appeared due to the development and improvement of laser methods. At present, a receiver with a narrowband iodine active quantum filter

---

Yu.F. Kutaev, S.K. Mankevich Astrofizika Research and Production Association, Volokolamskoe shosse 95, 123424 Moscow, Russia;
O.Yu. Nosach, E.P. Orlov P.N. Lebedev Physics Institute, Russian Academy of Sciences, Leninsky prosp. 53, 119991 Moscow, Russia;
e-mail: orlov@sci.lebedev.ru

Received 29 January 2007
Kvantovaya Elektronika **37** (7) 685 – 690 (2007)
Translated by M.N. Sapozhnikov

(AQF) operating at a wavelength of 1.315 μm and having virtually ideal parameters is developed [11 – 23] and high-power diffraction-limited iodine lasers are created [25 – 34].

The principal difference of the AQF from passive optical filters is that the signal is separated in it by amplifying a narrow spectral line containing the signal. As we will show below, the second and third problems mentioned above can be solved by using the receiver with the iodine AQF. The use of high-power diffraction-limited iodine lasers in the transmitter allows one to solve the fourth problem and, therefore, the first one – the choice of the radiation wavelength suitable for a search for ETI signals.

2. Parameters of an iodine active quantum filter

The experimental studies of the possibility of detecting weak laser signals by using optical quantum amplifiers were initiated in papers [35, 36]. The quantum limit of the sensitivity was achieved in the iodine AQF [11 – 23] based on a photodissociation quantum amplifier, which amplifiers the 1.315-μm radiation at the laser $^2P_{1/2} \rightarrow {}^2P_{3/2}$ transition of the atomic iodine [24]. The possibility of using the iodine optical quantum amplifier as an AQF for receiving extremely weak signals against a strong illumination background is caused by the following characteristic features of the active medium of photodissociation lasers:

(i) the gain-line frequency is strictly fixed and the line FWHM is $\Delta\nu \simeq 0.01$ cm^{-1} for the gain close to unity (the linewidth decreases with increasing gain);

(ii) the gain of the active medium of the laser (above 0.1 cm^{-1}) greatly exceeds its absorption coefficient (less than 10^{-4} cm^{-1});

(iii) the real lifetime of the excited iodine atoms is hundreds of microseconds;

(iv) the active medium has a high optical homogeneity;

(v) the lower level of the laser transition is not occupied by iodine atoms.

These features of the active medium, found in experimental studies, make the use of the iodine AQF expedient for a search for ETI signals. Consider in more detail the consequences following from these features and present the results of experimental studies confirming them.

The gain exceeding 0.1 cm^{-1} provides the signal gain $K > 10^6$ for active medium lengths of AQFs less than 1 m [14, 18], which is much more than the gain at which the quantum noise of the AQF exceeds the shot and thermal noise of photodiodes and elements of electrical circuits. In this case, only the quantum noise of the AQF is detected in the experiment.

Due to a rapid depletion of the lower energy level and almost a complete absence of iodine ions on it because of their rapid recombination, the AQF noise is minimal. Owing to the high optical homogeneity of the AQF active medium, the signal emitted by a point source can be focused after amplification in the AQF in a diffraction spot [15], i.e. the single-mode amplification can be realised. Because the gain of the AQF active medium greatly exceeds the absorption coefficient, the ultimately high sensitivity can be achieved, which is restricted by the quantum limit of one photon per mode for the time $1/c\Delta\nu$, which varies approximately from 9 to 12 ns with increasing the AQF gain from 10^3 to 10^6.

In [14, 18], for the signal-to-noise ratio equal to unity for signals with a FWHM of 40 ns, the experimental sensitivity equal approximately to three photons was achieved, which is three times worse than the quantum limit. This is caused by the fact that the signal duration was not matched with the AQF gain linewidth, the signal reception angle exceeded the diffraction AQF angle by a factor of three in [14], while in [18] the reception angle was equal to the diffraction angle but the pulse duration and the averaging time of a video amplifier were not matched with the AQF gain linewidth. The quantum limit (one photon per mode) will be achieved for the diffraction reception angle, if the signal pulse duration is matched with the AQF gain linewidth, i.e. the pulse duration is shortened approximately to 10 ns, and a sufficiently broadband video amplifier is used. The external view of the AQF is shown in Fig. 1.

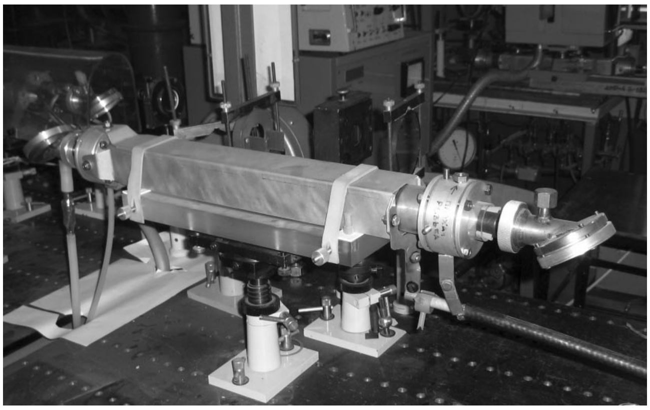

Figure 1. External view of the iodine AQF developed at the N.G. Basov Department of Quantum Radiophysics, P.N. Lebedev Physics Institute, RAS.

Due to the high gain in combination with a small gain linewidth of the AQF, the sensitivity of the AQF receiver detecting signals spectrally matched with the gain line remains virtually invariable even upon observation of signals against the background of any high-power natural light source. Thus, if a signal is detected against the background of the Sun disc, which has the surface temperature 6000 K, the sensitivity will decrease only by 12 % [16, 17].

This statement was verified in model experiments by detecting a signal against the background of a plasma radiation source (ISI-1 Podmoshenskii source) with the brightness temperature 40000 K [18]. Figure 2 from [18] shows the oscillogram of the output voltage of an electron amplifier with the effective averaging time of 90 ns, which was obtained by applying a 40-ns optical pulse against the background of the radiation pulse from the ISI-1 source to a photodiode connected with the amplifier. For the signal-to-noise ratio equal to unity, the reception sensitivity achieved in [18] was three photons outside the pulse from the ISI-1 source and six photons within this pulse. Thus, if an ETI sends signals at 1.315 μm to us, the iodine AQF can be used to detect them efficiently against the star emission background. Therefore, the iodine AQF provides the solution of the second and third problems of the space communication in the IR spectral range.

The methods of detecting and processing weak pulsed laser signals in iodine AQF systems were verified and protected by patents [13, 19 – 23].

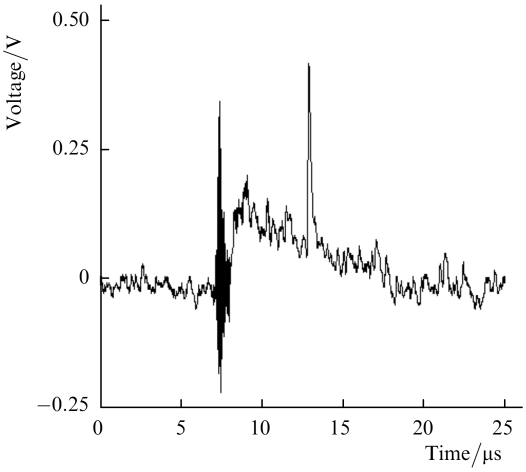

Figure 2. Oscillogram of the output voltage of an electron amplifier upon detection of an optical pulse and the ISI-1 radiation from the AQF by a photodiode (the effective averaging time is 90 ns). The ISI-1 radiation pulse starts within 8 microseconds after the time counting origin, immediately after the high-frequency electric interference from the ignition pulse; the useful signal pulse appear at the 13th microsecond.

3. Parameters of atomic iodine lasers and estimates of the range of communication with extraterrestrial civilisations

Let us now discuss the possibility of providing the energy of signals required for communications with ETI. The specific features of the active medium considered in section 2 and high-power pump sources elaborated at present resulted in the development of high-energy 1.315-μm iodine photodissociation lasers pumped by xenon flashlamps [25, 26], high-current open electric discharges [26–28], and by radiation of strong shock waves initiated by explosives [29–31]. High-power repetitively pulsed and cw oxygen–iodine lasers were also developed [32].

For example, lasers pumped by pulsed xenon flashlamps and high-current open electric discharges emit nanosecond and subnanosecond pulses with energy of up to a few kilojoules in one beam [33, 34], while lasers pumped by a strong shock wave initiated by explosives emit megajoule microsecond pulses [29, 31]. The output power of cw oxygen–iodine lasers approached the megawatt level [32]. The high optical homogeneity of the active gas medium of the iodine laser in combination with phase-conjugation methods allows the generation of diffraction-limited pulses. At present, such lasers are being further developed in many laboratories worldwide.

Thus, laser receivers with the ultimate sensitivity and high-power, high-energy diffraction-limited lasers operating at a wavelength of 1.315 μm have been developed. In other words, the efficient transmitter–receiver pair has been realised which has a vast dynamic range of output powers and pulse energies and the diffraction-limited divergence of radiation and the ultimate sensitivity. In addition, the receiver of this pair can separate efficiently the $\lambda =$ 1.315 μm signal against the background of the star emission only with a weak loss of the sensitivity.

All these properties of the active medium of atomic-iodine lasers, which can be used for communication with ETI, make the 1.315-μm line of the $^2P_{1/2} \rightarrow {}^2P_{3/2}$ transition in atomic iodine a candidate for the natural frequency reference. This solves the first problem of optical communication with ETI formulated in Introduction, because it is reasonable to assume that the above considerations and approach to the solution of space-communication problems are also accessible to the representatives of the assumed ETI, which can be even at a higher development level than the Earth civilisation. In this case, they also should conclude that the $^2P_{1/2} \rightarrow {}^2P_{3/2}$ transition of the atomic iodine is promising for generating signals directed to other civilisations.

Let us now estimate the ultimate range at which signals from an ETI can be detected by using the AQF receiver and the transmission range of signals emitted by an iodine laser. Let us assume that the ETI of a planet rotating around a star over the elliptic orbit with the major semiaxis a emits 1.315-μm laser pulses of energy E to the direction of our solar system and the extra-atmospheric iodine AQF receiver is located in our solar system.

Figure 3 presents the principal scheme of the AQF receiver. An optical pulsed signal sent by the ETI is incident on primary mirror (*1*) of a receiving telescope directed to the star under study and is focused to AQF (*2*). The signal behind the AQF is focused by optical system (*3*) on photodetector (*4*) whose output electric signal is fed to electron video amplifier (*5*). The output signal of the video amplifier is fed to processing unit (*6*).

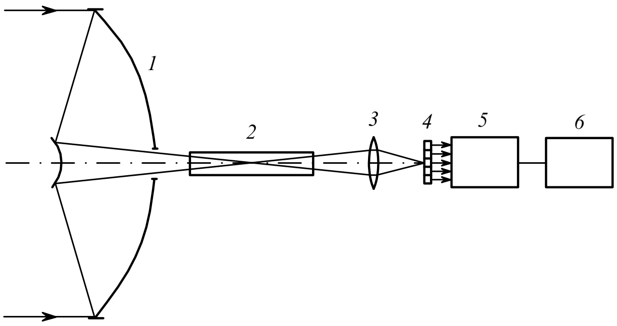

Figure 3. Principal scheme of the AQF receiver: (*1*) primary mirror of the receiving telescope; (*2*) AQF; (*3*) focusing lens; (*4*) photodetector; (*5*) video amplifier; (*6*) signal processing unit.

The distance R between the star under study and the receiver is, as minimum, a few tens of parsec (1 pc = 3.08×10^{16} m, 1 light year = 9.46×10^{15} m). For a distance more than 25 pc (above 80 light years) and a equal approximately to the astronomic unit (1 a.u. = 1.5×10^{11} m), the observed maximum angle ϑ between a radiation source located near the planet with the assumed ETI and the star is a/R and is less than 0.04 arc seconds, which virtually excludes the possibility of the optical resolution of the radiation source and star even by using the receiving telescope with the primary mirror of a ten-meter diameter. Therefore, all the radiation both from the ETI radiation source and the star falling into the aperture of the receiving telescope is incident on the photodetector. Therefore, to separate the useful signal against the radiation background from the star, the spectral filtration is required, which is performed with the AQF.

We can assume that the probability of life origination is highest for the single stars of the initial main sequence, which belong to spectral classes located between classes F5 and K5 [37]. The surface temperature of these stars does not differ strongly from the Sun surface temperature [38] and the brightness of their radiation is close to that of the Sun. Therefore, the sensitivity of the iodine AQF receiver almost will not change when signals are received against the background of radiation from such stars, as mentioned above.

The main elements of a laser transmitter are a laser and an astronomical telescope playing the role of a transmitting antenna. Let us assume that the ETI transmitter contains the same elements and is located outside the atmosphere of the ETI planet. If the total energy E of a pulse emitted by the transmitter is distributed uniformly over the aperture, then it is known [39] that the angular energy density in the direction to the centre of the diffraction pattern is

$$I_0 = \frac{ES_t}{\lambda^2}, \tag{1}$$

where S_t is the transmitter-aperture area equal to $\pi D_t^2/4$ for a circular aperture of diameter D_t. If the receiver is also located outside the Earth atmosphere at the centre of the diffraction pattern, the energy received by the detector is

$$E_r = \frac{I_0 S_r}{R^2} = \frac{S_t S_r}{\lambda^2 R^2} E, \tag{2}$$

where S_r is the receiver-aperture area (if its is circular, then $S_r = \pi D_r^2/4$); D_r is the diameter of the primary mirror of the receiving telescope; and R is the distance between the transmitter and receiver.

Consider first the process of signal receiving from a radiation source, which is used by the assumed ETI to communicate with our solar system. Let us discuss the reception of single pulses in which each of the pulses should be found and received; in this case, the pulse repetition rate is not important for detecting. If the development level of the ETI is such that the ETI knows the parameters of the laser transition in atomic iodine, the optimal duration of the pulse received by the AQF is also known. Therefore, we will assume that the ETI transmitter sends diffraction-limited $\sim$ 10-ns laser pulses. As mentioned above, pulses of such duration are well spectrally matched with the gain line of the iodine AQF for the gain $K \approx 10^6$.

For the signal-detection probability to exceed 0.9, the energy of the detected signal should exceed the quantum noise of the AQF by a factor of three, i.e. the signal-to-noise ratio should be equal to three. By expressing this energy, which represents the sensitivity of the receiver for the given signal-to-noise ratio, in the number of photons N_3, we obtain from the condition $E_r \geqslant \varepsilon N_3$, where $\varepsilon = hc/\lambda = 1.5 \times 10^{-19}$ J is the 1.315-μm photon energy, and from expression (2) we obtain the condition to which the distance R should satisfy for the signal sent by the transmitter to be detected by the receiver:

$$R \leqslant \frac{\pi}{4} \left(\frac{E}{\varepsilon N_3} \right)^{1/2} \frac{D_t D_r}{\lambda}. \tag{3}$$

As pointed out above, in the iodine AQF the single-mode amplification can be realised in which the quantum noise of the AQF is one photon per mode per $\sim$10-ns pulse [15]. Therefore, $N_3 = 3$.

Let us assume that $E = 1$ kJ, as for nanosecond single-beam iodine lasers [33]. The diameter of the primary mirror of the receiving telescope is set equal to 10 m, as for modern ground telescopes, such as KETIK I and KETIK II in Mauna Kea (Hawaii, USA) and GTC in La Palma (Canaries, Spain) [40, 41].

Let us assume that the diameter D_t of the primary mirror of the ETI transmitting telescope is also 10 m. By substituting the above values of N_3, E, E_r, and D_t into expression (3) and taking into account that this expression can be used both in the case when we receive signals sent by the ETI and when we send signals, which are received by the ETI, we conclude that we can send and receive signals for distances between civilisations up to 300 light years ($\sim$90 pc).

Note that a sphere of such radius contains approximately 10^5 stars [10, p. 49].

4. Discussion of results

One can see from (3) that the distance R increases proportionally to the product of diameters of the transmitting and receiving telescopes and the square root of the pulse energy. Note that if the sensitivity of the iodine AQF receiver and the divergence of radiation of iodine lasers are close to their physical limit, the energy of emitted pulses and the telescope aperture can be considerably increased. For example, projects exist for constructing the 30-m and 100-m telescopes [42–44]. If both civilisations used telescopes with diameters $D_t = D_r = D = 30$ m, the communication range achieved for 1-kJ pulses would increase up to 2700 light years ($\sim$850 pc). A sphere of such radius contains already about 10^8 stars [10, p. 49] and more than 200 planets discovered at present [45].

These estimates concerns civilisations of type I according to Kardashev [46]. Signals from ETI much more highly developed than our civilisation can be, probably, received from considerably greater distances.

Let us now compare the pulse energies required for communication with a ETI at the 1.315-μm laser transition in atomic iodine and the 21-cm radio line of hydrogen. We assume that the spectra of pulses in both cases are matched with the frequency characteristics of receivers, the distance from to the ETI is the same and the diameters of the transmitting and receiving telescopes (radio telescopes) are the same. Let us assume that in the first case the diameters of primary mirrors of the telescopes are $D = 10$ m and in the second case the diameters of the antennas of radio telescopes are $D_A = 305$ m. The antenna of the world largest Aresibo radio telescope has such a diameter [10]. By using expression (3) and taking into account that the sensitivity in the radio-frequency range is determined by the background at temperature $T = 10$ K [10] and in the IR range – by the quantum noise, we obtain the ratio of the compared energies

$$\frac{E}{E_H} = \frac{\varepsilon}{kT} \left(\frac{\lambda}{\lambda_H} \right)^2 \left(\frac{D_A}{D} \right)^4 \approx \frac{1}{27} \tag{4}$$

for the same signal-to-noise ratio.

Thus, the energy of the 1.315-μm pulses required for communication with the ETI is lower by a factor of 27 than that of the 21-cm pulses. Taking into account the projects of optical telescopes with $D = 30$ m, this ratio becomes equal to $\sim$1/2000. Note that the area of the Aresibo radio telescope (0.73×10^5 m^2) is close to the constructive limit for ground-based radio telescopes. The area of space radio telescopes rotating in orbits around the Earth achieves

10^5 m^2 [10], and in this case the ratio E/E_H is equal to 1/1000. In any case, we see that the energy of the 1.315-μm pulses required for communication with ETI is lower than that of the 21-cm pulses. In addition, the noise level at 1.315 μm is independent of the orientation of the axis of the receiving telescope with respect to direction to the Galactic centre.

Note that the 1.315-μm radiation is virtually not absorbed in the Earth atmosphere. As shown in [47], the absorption coefficient in the near-ground layer is $\sim 2 \times 10^{-7}$ cm^{-1}. Absorption is mainly caused by water vapour, whose concentration decreases with height. The signal is attenuated after its propagation through the entire Earth atmosphere by less than 20 %, especially when a detector is located high over the sea level.

A weak absorption of the 1.315-μm radiation in the Earth atmosphere allows a search for and transmission of the ETI signals almost without a decrease in the communication range by using ground-based optical telescopes equipped with adaptive optical systems, which are capable of real-time compensation for the atmospheric spread of images. For example, the size of the corrected images of stars at a wavelength of 1.2 μm on a 8.2-m VLT telescope of the south observatory at the Paranal mount (Chile) was 0.04 arc second, coinciding virtually with the theoretical limit for a telescope of this diameter [42]. A similar resolution was achieved in 10-m KETIK I and KETIK II telescopes [48].

Thus, by using the proposed receiver mounted on a 10-m ground-based astronomical telescope equipped with adaptive optics, the search for signals from ETI at distances up to 240 light years ($\sim$75 pc) can be performed already at present. The communication with these ETI can be performed with the help of a transmitter based on an atomic iodine laser.

If ground-based telescopes with adaptive optical systems and the diameter of the primary mirror equal to 30 m will be constructed, the communication range, taking into account absorption in the atmosphere, will be 2200 light years ($\sim$700 pc).

5. Conclusions

We have proposed to perform a search for signals from extraterrestrial intelligence at a wavelength of 1.315 μm of the laser $^2P_{1/2} \rightarrow {}^2P_{3/2}$ transition in atomic iodine. This wavelength is promising for this purpose because at present the efficient transmitter–receiver pair operating at this wavelength is realised. It consists of a high-power diffraction-limited iodine laser and an active quantum filter (with the bandwidth less than 0.01 cm^{-1} and the gain $\sim 10^6$) with the quantum sensitivity limit based on the iodine photodissociation amplifier.

The AQF receiver is in fact a new technical device for astronomical observations of the outer space for searching for ETI signals. Such a receiver provides the selection and detection of weak signals consisting of only a few photons against the emission background of the star under study.

The range of communication with ETI similar in their development to our civilisation is estimated. Thus, this range for 10-ns, 1-kJ pulses and the 10-m space telescopes of the transmitter and receiver is 300 light years ($\sim$90 pc). The realisation of 30-m optical telescopes will increase the communication range up to 2700 light years ($\sim$850 pc).

A weak absorption of the 1.315-μm radiation in the Earth atmosphere (2×10^{-7} cm^{-1}) mainly caused by water vapour allows the search for ETI by using ground-based optical telescopes equipped with adaptive optical systems, the communication range decreasing only by less than 20 %. Thus, by using the 10-m telescopes such as KETIK I and KETIK II at Mauna Kea (Hawaii, USA) or GTC at La Palma (Canaries, Spain), the communication range can be up to 240 light years ($\sim$75 pc). With the use of 30-m ground-based telescopes equipped with adaptive optical systems, the communication range will be increase up to 2200 light years ($\sim$700 pc).

Thus, the 1.315-μm line can be used as the natural frequency reference for a search for ETI signals and sending signals to stars with planetary systems where the life can be assumed. At this wavelength, the sharp aiming at the chosen star can be performed and the search for ETI signals can be carried out over the entire celestial sphere irrespective of the direction to the Galactic centre.

Because no ETI signals have been detected at other wavelength so far, the authors believe that it is necessary already now to develop and realise the program for studying radiation from nearest stars with planetary systems suitable for life and then from remote stars with the aim of searching for ETI signals at a wavelength of 1.315 μm. We can assume that, if a signal with the spectral brightness greatly exceeding the natural brightness of a star will be detected in a narrow spectral range at the wavelength of the laser transition in atomic iodine, this will mean the detection of a signal of the artificial origin.

Acknowledgements. The authors thank V.V. Ragul'skii for his interest in this work, fruitful discussions, and useful information on the SETI problem.

References

1. Cocconi G., Morrison P., in *Interstellar Communication*. Ed. by A. Cameron (Moscow: Mir, 1965) pp 177–182; Cocconi G., Morrison P. *Nature*, **184**, 844 (1959).
2. Drake F.D., in *Interstellar Communication*. Ed. by A. Cameron (Moscow: Mir, 1965) pp 183–192;
Drake F.D. *Sky and Telescopes*, **9**, 140 (1959).
3. Schwartz R.N., Townes C.N., in *Interstellar Communication*. Ed. by A. Cameron (Moscow: Mir, 1965) pp 247-256;
Schwartz R.N., Townes C.N. *Nature*, **190**, 205 (1961).
4. Oliver B., in *Interstellar Communication*. Ed. by A. Cameron (Moscow: Mir, 1965) pp 229–246.
5. Oliver B., in *Interstellar Communication*. Ed. by A. Cameron (Moscow: Mir, 1965) pp 296–310.
6. Kaplan S.A. (Ed.) *Vnezemnye tsivilizatsii* (Extraterrestrial Civilisations) (Moscow: Nauka, 1969).
7. *Trudy soveshchaniya 'Vnezemnye tsivilizatsii'* (Proceeding of Conference on Extraterrestrial Civilisations) (Byurakan, 1964) (Erevan: Izd. Akad. Nauk Arm SSR, 1965).
8. Shwartsman V.F., in *Problema vnezemykh tsivilizatsii* (Problem of Extraterrestrial Civilisations) (Moscow: Nauka, 1981).
9. Tarter J., in *Problema poiska zhizni vo Vselennoi. Trudy Tallinskogo simpoziuma* (Problem of a Search for Life in the Universe. Proceeding of Tallinn Symposium) (Moscow: Nauka, 1986).
10. Gindilis L.M. *Poisk vnezemnogo razuma* (Search for Extraterrestrial Intelligence) (Moscow: Fizmatlit, 2004).
11. Nartov S.S., Nosach O.Yu. Preprint FIAN, No. 21 (Moscow, 1994).
12. Nosach O.Yu., Orlov E.P. Preprint FIAN, No. 20 (Moscow, 1994).

13. Zemskov E.M., Kazanskii V.M., Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Russian Federation Patent No. 2133533, 30.09.1997; *Izobret*., (20), 480 (1999).
14. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. *Kvantovaya Elektron*., **30**, 833 (2000) [*Quantum Electron*., **30**, 833 (2000)].
15. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. *Kvantovaya Elektron*., **31**, 419 (2001) [*Quantum Electron*., **31**, 419 (2001)].
16. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. Prepring FIAN, No. 27 (Moscow, 2001).
17. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. *J. Rus. Laser Research*, **23** (3), 235 (2002).
18. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. *Kvantovaya Elektron*., **32**, 349 (2002) [*Quantum Electron*., **32**, 349 (2002)].
19. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. Russian Federation Patent No. 2152056, 23.06.1999; *Izobret*., (18), 434 (2000).
20. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. Russian Federation Patent No. 2183841, 24.01.2001; *Izobret*., (17), 327 (2002).
21. Akhmeneev A.D., Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P., Khishev A.A. Russian Federation Patent No. 2191406, 19.06.2001; *Izobret*., (29), 400 (2002).
22. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. Russian Federation Patent No. 2249234, 08.08.2003; *Izobret*., (9), 1106 (2005).
23. Kutaev Yu.F., Mankevich S.K., Nosach O.Yu., Orlov E.P. Russian Federation Patent No. 2248555, 20.10.2003; *Izobret*., (8), 490 (2005).
24. Zuev V.S., Katulin V.A., Nosach V.Yu., Nosach O.Yu. *Zh. Eksp. Teor. Fiz*., **62**, 1673 (1972).
25. Brederlov G., Fill E., Vitte K. *Moshchnyi iodnyi lazer* (High-Power Iodine Laser) (Moscow: Energoatomizdat, 1985).
26. Borovich B.L., Zuev V.S., Katulin V.A., Mikheev L.D., Nikolaev F.A., Nosach V.Yu., Nosach O.Yu., Rozanov V.B. *Sil'notochnye izluchayushchie razryady i gazovye lazery s opticheskoi nakachkoi* (High-Current Emitting Discharges and Optically Pumped Gas Lasers) (Itogi Nauki i Tekhnki, Ser. Radfiotekh.: Moscow: VINITI, 1978) Vol. 15.
27. Borovich B.L., Zuev V.S., Katulin V.A., Nosach V.Yu., Nosach O.Yu., Startsev A.V., Stoilov Yu.Yu. *Kvantovaya Elektron*., **2**, 1282 (1975) [*Sov. J. Quantum Electron*., **5**, 695 (1975)].
28. Annenkov V.I. et al. *Kvantovaya Elektron*., **36**, 508 (2006) [*Quantum Electron*., **36**, 508 (2006)].
29. Zuev V.S. Preprint FIAN, No. 161 (Moscow: 1990).
30. Arzhanov V.P. et al. *Kvantovaya Elektron*., **19**, 135 (1992) [*Quantum Electron*., **22**, 118 (1992)].
31. Zarubin P.V. *Kvantovaya Elektron*., **32**, 1048 (2002) [*Quantum Electron*., **32**, 1048 (2002)].
32. Yuryshev N.I. *Kvantovaya Elektron*., **23**, 583 (1996) [*Quantum Electron*., **26**, 567 (1996)].
33. Baumhacker H., Brederlow G., Fill E., Volk R., Witkowski S., Witte K.J. *Czechoslovak J. Phys*., **41** (3), 272 (1991), http://www.springerlink.com/content/p31j5kq39747jkq7/; *Appl. Phys. B*, **61** (4), 325 (1995), http://adsabs.harvard.edu/abs/1995ApPhB..61..325B; Jungwirth K., Ullschmied J., Rohlena K., Rus B. www.pals.cas.cz/pals/doc/pb077[3].doc
34. Kirillov G.A., Kochemasov G.G., et al. htpp://www.vniitf.ru/rig/konfer/5zst/sectsiya4/4-01.pdf; Parafonova V. htpp://nauka.relis.ru/05/0302/05302002.htm
35. Basov N.G., Grasyuk A.Z., Zubarev I.G. *Zh. Prikl. Spektr*., **3**, 26 (1965).
36. Basov N.G., Grasyuk A.Z., et al. *Trudy FIAN*, **31**, 74 (1965).
37. Su-Shu Huang, in *Interstellar Communication*. Ed. by A. Cameron (Moscow: Mir, 1965) pp 96–99.
38. Grigor'ev I.S., Meilikhov E.Z. (Eds) *Fizicheskie velichiny. Spravochnik* (Handbook of Physical Quantities) (Moscow: Energoatomizdat, 1991) p. 1208.
39. Born M., Wolf E. *Principles of Optics* (Oxford: Pergamon Press, 1969; Moscow: Nauka, 1970) p. 432.
40. http://astrotelecope.narod.ru/tele3links.html
41. htpp://galspace.spb.ru/index62-2.html
42. Terebizh V.Yu. *Sovremennye opticheskie teleskopy* (Modern Optical Telescopes) (Moscow: Fizmatlit, 2005).
43. http://tmt.ucolic.org/
44. http://www.aura-nio.noao.edu/book/index.html
45. htpp://exoplanet.eu/catalog.php
46. Kardashev N.S. *Astronom. Zh*., **41**, 282 (1964).
47. Zuev V.S., Korol'kov K.S., Krylov A.Yu., Nosach O.Yu., Poskacheev A.Yu. *Kvantovaya Elektron*., **15**, 1959 (1988) [*Sov. J. Quantum Electron*., **18**, 1224 (1988)].
48. htpp://wO.sao.ru/hg/komarov/tel/01/index.html