PROCEEDINGS OF SCIENCE

A method for Identifying the Effects of Nonstationarity in the Radio Emission from Nearby Stellar Systems in Spaced Observations

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We describe a method for processing the records produced on two (as well as a larger number) RT32 radio telescopes at the Badary and Zelenchukskaya observatories of the Institute of Applied Astronomy of RAS (IAA RAS) with broadband continuous spectrum receivers at wavelengths of 6.2 and 3.5 cm in the circular polarization receiving mode. The method is based on the calculation of the cross-correlation matrix for the Pearson correlation coefficients, where the horizontal elements are the coefficients of the simultaneous groups of samples in a sliding time window, and the vertical variable is its width. Our software implementation of the method in Python, PICASO (Pearson Image Correlation Array Stars Observing), allows the result of the calculations to be displayed in the form of a triangular image of correlation levels in grayscale or in pseudocolor. The examples of processed observations for the star TRAPPIST-1 with a planetary system and the quasar 3C147 are presented.

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1. Introduction

The search for non-stationary radio emission from both the parent star and its planetary environment is certainly interesting both for detecting possible transmissions [1] of extraterrestrial civilizations and the studies of host star activity in the context of its influence on the emergence and persistence of life on suitable planets. Unfortunately, long-term radio observations of even the closest ordinary stars are greatly complicated by powerful terrestrial radio interference and strong noise. The most unpleasant are the noises from radiometers and the atmosphere with a $1/f$ spectrum that makes an increase of the signal-to-noise ratio for long exposures impossible. Partially, the problem of isolation of the terrestrial radio interference is solved by the known methods based on the frequency dispersion of broadband radio sources in the interstellar medium [1, 2], which are nevertheless difficult to use when studying objects close to the Sun (especially red dwarfs).

Much more reliable are the simultaneous observations with geographically separated radio telescopes, when a mutually correlated increase in the dispersion of the received noise is recorded.

2. Method and implementation

The method is based on the calculation of the cross-correlation matrix $r_{kj}(w)$ of the Pearson correlation coefficients [3–5] for the X and Y records, where the horizontal elements are the coefficients of the simultaneous groups of samples in a sliding time window, and the vertical elements represent its width w:

$$r_{kj}(w) = \frac{\sum_{j-\frac{w_k+1}{2}}^{j+\frac{w_k+1}{2}} (X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{j-\frac{w_k+1}{2}}^{j+\frac{w_k+1}{2}} (X_i - \overline{X})^2 (Y_i - \overline{Y})^2}}, \text{ where } i \in w_k$$

Our software implementation of the method in Python, PICASO (Pearson Image Correlation Array Stars Observing), allows the result of the calculations to be displayed in the form of a triangular image of correlation levels in grayscale or in pseudocolor. This allows the further use of known classification methods to select the most informative observations, especially if there are a lot of them.

3. The first demonstrations of the processing

An example of the application of the processing method, an observation (11/13/2021) of the star TRAPPIST-1[6] with a planetary system, is shown in Fig. 1. The star had been followed for 3200 s with a 0.1-s cadence. Respectively, the size of the window for calculating the cross-correlation varies from 1 s to 3200 s.

The colors from blue to red-brown corresponding to the positive values of the coefficient in percentage from 0% to 100% highlight the time areas with a high degree of correlation. At the same time, with a probability $< 5\%$ of a false rejection of the hypothesis about the absence of mutual

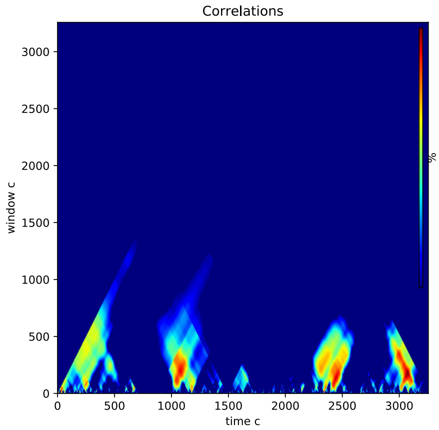

Figure 1: Cross-correlations in the observations of TRAPPIST-1 on 11/13/2021.

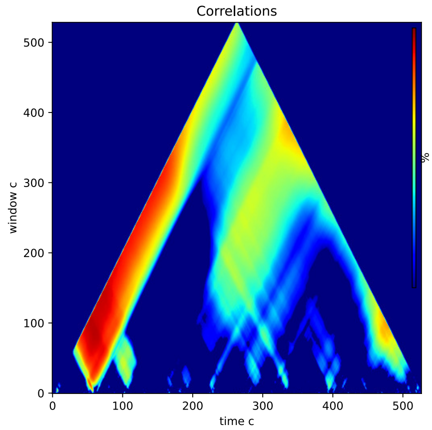

Figure 2: Cross-correlations in the observations of 3C147.

dependencies, we see synchronous manifestations of radio emission nonstationarity, falling into the beam pattern of the radio telescopes.

For comparison, Fig. 2 shows a similar correlogram of a 10-min record (Fig.4) of the quasar 3C147 [7], where the region of high correlation at the beginning is due to the simultaneous retraction of the antennas from the source.

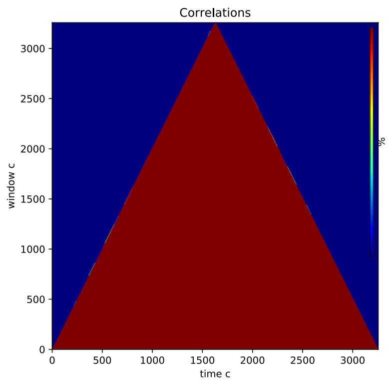

Figure 3: Autocorrelations in hourly observations.

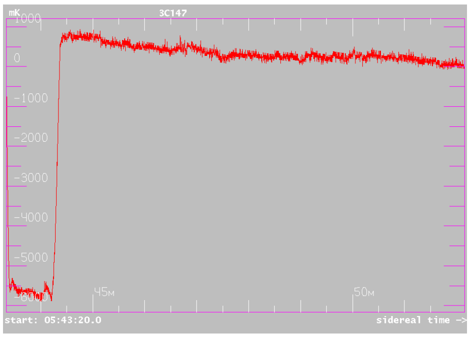

Figure 4: A fragment of the recording of the quasar 3C147. At the beginning of the recording, the antenna is retracted from the source.

Figure 3 shows, as a standard, the processing of a hourly recording by this method, but in the autocorrelation mode for one telescope (in Badary).

Thanks to this, we can conclude that the nature of the detected nonstationarity in the radio emission of TRAPPIST-1 is possibly of a noninterference nature.

4. Acknowledgements

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