Periodic Spectral Modulations Arise from Nonrandom Spacing of Spectral Absorption Lines

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Abstract
In recent papers, Borra in 2013 and 2017, and Borra & Trottier in 2016, those authors claimed that the discovery of ultrashort (10⁻¹² s) optical pulses originating from stars and galaxies may be sent by extraterrestrial intelligence. I show that these signals are not astrophysical or instrumental in nature, but that they originate due to the nonrandom spacings of spectral absorption lines. They can be shown to arise in their clearest form in synthetic solar spectra, as these do not suffer from noise.

Key words: extraterrestrial intelligence – instrumentation: spectrographs – methods: data analysis

Online material: color figure

1. Introduction
Over the last years, Borra (2010a, 2010b, 2012) developed and publicized a novel method, dubbed Spectral Fourier Transform (SFT), to detect and characterize ultrashort pulses from spectra. It appears that the method has gradually evolved from work by Delisle & St-Arnaud (1970), Mandel & Wolf (1976), and Chin et al. (1992). It is important to appreciate the efforts to build such a new technique, a tool which may prove valuable in the future.

As a first application, SFTs were used to examine astronomical spectra from the SDSS survey of galaxies (Borra 2013), stars (Borra & Trottier 2016), and exotic objects (Borra 2017). Astrophysical pulse detections were claimed with repetition times ρ = 1.64 × 10⁻¹² s (Borra & Trottier 2016, stars) and ρ = 1.09 × 10⁻¹³ s (Borra 2013, galaxies). The authors speculate that the factor of ~15 between these repetition times is caused by different originators: extraterrestrial intelligence (Section 7.2 in Borra & Trottier 2016) versus black holes. Recent reobservations of three candidate stars with different equipment have failed to reproduce the signals (Isaacson et al. 2019).

The Berkeley SETI Research Center team (2016) speculated that the signals may be artifacts from instrumental optics, fringing, movement of the telescope, variations in observing conditions, the process of wavelength calibration, or “inconsistencies in the manufacture of detectors (…) of high-resolution spectrographs”. This is a valid concern, as a myriad of CCD artifacts exist (Desai et al. 2016) and more have been discovered regularly (e.g., Boone et al. 2018).

In this paper, I show that the signals are caused by the nonrandom spacing of spectral absorption lines (Fowler 1924). They can be shown to occur in their clearest form in synthetic spectra, as these do not suffer from noise. They can also be shown to arise in high signal-to-noise ratio (S/N) spectra of our Sun and many other sources.

2. Method: Spectral Fourier Transforms
Most commonly, Fourier transforms are applied to timeseries data to identify periodic signals. Equally, spectra can be Fourier transformed to yield periodic signals (Chin et al. 1992). A seminal summary of the method is given by Borra (2012).

A unique feature of SFTs is their sensitivity to ultrashort periods, ρ_min = λ_min/c ≈ 10⁻¹⁵ s for λ_min = 300 nm optical pulses, which is six orders of magnitude shorter than time-resolved (10⁻⁹ s) photometry using photomultipliers (Abassi et al. 2010). The period of the longest detectable pulses depends on λ_min and the spectral resolution R. For SDSS spectra (R = 4000 at a wavelength 380 < λ < 920 nm, Yanny et al. 2009; Eisenstein et al. 2011), we get ρ_max = R ρ_min ~ 4 × 10⁻¹² s.

SFTs are not sensitive to the actual pulse length, Δt_min, but to the duration between pulses (ρ), so that 1/ρ is the pulse repetition rate. As the pulse lengths are unresolved in time, it may well be that Δt_min ≪ ρ, exacerbating the atmospheric effects of group delay dispersion. Atmospheric models indicate that turbulence smears picosecond pulses, so that it may well be impossible to use SFT-based methods on the ground. Then, the pulses could not be of astrophysical origin. Without picosecond photon counters, however, this is impossible to verify in practice (Hippke 2018).

Astronomical spectra are typically sampled at equal wavelength intervals, λ = c/λ with Δλ = const. For a search of signals with constant temporal periods, these spectra need to be converted to equal frequency intervals f = c/λ, where Δf = const. Afterward,
the overlaying blackbody-like flux shape needs to be subtracted out to perform a period search. It is adequate to use a sliding median with a boxcar-window-size of a few percent. Typically, sizes of 1%–5% give very similar results, with only a slight variation in the relative amplitudes of the peaks in the resulting Spectral Fourier transform. The SFT then produces a spectrum with power for signals with a constant temporal period, e.g., repeating laser pulses.

As the SFT method is not intuitive and requires careful implementation, I provide an open-source Python code\(^1\) that reads spectra, performs the transformation, and creates Figure 1.

3. Results: The Origin of the Signals

3.1. Synthetic Spectrum

To determine whether the signals are inherent to the data reduction method, I check the synthetic solar spectrum by Kurucz (2005a, 2005b) where the telluric lines have been removed. It has the advantage that it is essentially noise-free and without instrumental issues. I downsample and crop the resolution from \(R \approx 10^6\) between 300–1000 nm to match the \(R = 4000\) coverage between 380–920 nm of the SDSS survey, where the signals have originally been found. Following the recipe described in the previous section, I perform the spectral Fourier transform and show the result in Figure 1.

The highest spectral peak in the SFT corresponds exactly to one of the two claimed pulse spacings \(\rho = 1.09 \times 10^{-13}\) s. The chance for this to happen by coincidence is 0.05%. As there are no artificial laser pulses in a synthetic solar spectrum, it appears

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\(^1\) [http://github.com/hippke/pulses](http://github.com/hippke/pulses). In the case of evenly spaced data without gaps, as is the case here, the Fourier transformation is equivalent to the Lomb–Scargle periodogram (Lomb 1976; Scargle 1981; VanderPlas 2018). The code uses the periodogram provided by Astropy (Astropy Collaboration et al. 2013; Price-Whelan et al. 2018), but delivers identical results when swapped for SciPy’s (Jones et al. 2001) FFT implementation.

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**Figure 1.** (a): SFT of the synthetic solar spectrum by Kurucz (2005a, 2005b). A sliding median with a boxcar width of 3% (red line) is fitted to the spectral flux (black line). (b): After subtracting the median from the flux, a Fourier transformation is calculated (black). The highest peak coincides with one of the claimed pulse spacings (dashed red lines). (c): The median-subtracted flux (black) is shown together with the best-fit sine derived from the FFT. (d): A zoom-in to show the fit of the sine to the data.

(A color version of this figure is available in the online journal.)
highly likely that such signals commonly arise as part of the processing method.

The plot of the best-fitting sine found in the period search shows that its mean is slightly below the mean of the normalized spectrum, so that the peaks of the sine fit out the flux near its nominal values, and the bottoms of the sine fit out (more or less) the absorption lines.

3.2. Stellar Spectra

Additionally, it can be shown that the signals arise in many high S/N spectra of luminous bodies with absorption lines, and quite often with the highest, or one of the highest peaks, at exactly the same $\rho = 1.09 \times 10^{-13}$ s. Figure 2 (a) shows an SFT made from a high signal-to-noise solar spectrum. Here, the $\rho = 1.09 \times 10^{-13}$ s signal corresponds to the second highest peak when performing the same reduction as for the synthetic spectrum. The other claimed pulse spacing with $\rho = 1.64 \times 10^{-12}$ s coincides with a peak in the periodogram which is also significantly above the noise floor.

As a crosscheck, I have also re-reduced the SDSS spectrum of one of the stars for which Borra & Trottier (2016) found a signal (SDSS J160133.35+273355.2; Figure 2(b)). This star was also reobserved using the optical Levy Spectrometer at the Automated Planet Finder (APF) without a detection of the signal (Isaacson et al. 2019). The APF spectrum with $R = 100,000$ was not downsampled to the $R = 4000$ of the SDSS survey. Processing variations and different noise levels plausibly explain a nondetection of the signal.

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Figure 2. (a) SFT of a solar spectrum and (b) a FVW star (TYC 2041-872-1) from SDSS found by Borra & Trottier (2016) to exhibit the signals. In both cases, a prominent peak is visible in the spectrum near one of the claimed periods. (A color version of this figure is available in the online journal.)

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Stars of different stellar type and metallicity exhibit different absorption lines. The power of the corresponding pulse spacings $\rho$ in the periodogram will show similar variations. Further exploration would likely not yield additional insights and may be taken as an exercise in numerology.

3.3. Galaxy Spectra

Borra (2013) reports a correlation of signals with redshift and argues that this excludes instrumental and data processing effects as a source. This is incorrect: the integrated flux of galaxies originates from starlight, and thus comprises the same spectral line spacings, although stacked and redshifted.

As an independent validation, I have randomly selected 12,000 Galactic spectra (~10%) from the 6df survey (Jones et al. 2004) and DR3 (Jones et al. 2009). Data were taken with the Anglo-Australian Observatory’s UK Schmidt Telescope at a wavelength range $400 < \lambda < 750$ nm at $R \sim 1,000$, similar to SDSS, but with completely independent hardware, and placed in a different location.

Each Galactic spectrum was converted to SFT using the method described in Section 2 and in Borra (2012). Redshifts were taken from Jones et al. (2010) obtained through cross-correlation with template absorption-line spectra. Spectra were summed in redshift bins $\Delta z = 10^{-4}$, typically 10–100 spectra per bin.

The signal at $1.09 \times 10^{-13}$ s is clearly visible in the resulting Figure 3 (as $109 \times 10^{-15}$ s for $z \rightarrow 0$). Additional features, undetected by Borra (2013), are also visible in the stack. While the vast majority of individual spectra show no significant ($S/N > 6$) peaks, it is apparent that all (or a large fraction of) galaxies contribute to these patterns. It appears that,
very commonly, signals are overwhelmed by noise, but can be recovered by stacking many spectra. By comparing Figures 2 and 3, it is clear that a whole set of frequencies is detected in many stars and galaxies. This comb-like structure corresponds to a set of correlated distances of absorption lines (in units of wavelength) in the stellar and galactic spectra.

The statistical correlation of the stacked signals with redshift has been tested using linear regressions to the features for 0 < z < 0.2 with a t-test. These yield positive slopes at >6σ confidence in each case, for a total significance (over noise) in excess of 30σ confidence. This is a clear verification that the features in question are not instrumental in nature.

4. Discussion and Conclusion

The discovery of artificial signals from outside our solar system may well require the discovery of new techniques, such as SFTs or yet unknown tools. For this and other goals, the development of new methods will prove invaluable. My refutation of this first SFT application does not mean that the method should be abandoned; instead, it should be refined. Peaks caused by the nonrandom spacing of absorption lines can be flagged in the future.

A natural application for the SFT method could be the template-free estimation of Galactic redshift from spectra. A follow-up work could analyze the feasibility of this approach. False-positives may arise; I have found several such cases. One is SDSS J130155.84 + 083631.6 with a S/N > 6 signal near 1.09 \times 10^{-13} \text{s}, which was classified as a galaxy with redshift z = 0.9703971 by Jones et al. (2010) through cross-correlation with template absorption-line spectra, but is really a carbon star (Green 2013). The outstanding advantage of SFTs is that they do not require dedicated SETI observations, but that they can be performed automatically to the many existing spectroscopic data originally acquired for other purposes.

The signals in question can be found in Galactic spectra from the 6df survey, as well as the SDSS survey, and show a correlation with redshift. Therefore, they can not be instrumental artifacts. However, their origin is not astrophysical. They can be found in SFTs of synthetic spectra, making them a processing effect from the nonrandom spacings of spectral absorption lines.

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**References**

Abassi, R., Abdou, Y., Abu-Zayyad, T., et al. 2010, NIMPA, 618, 139
Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, A&A, 558, A33
Berkeley SETI Research Center team, 2016, Breakthrough Listen at UC Berkeley to Conduct Follow up Observations of Reported Anomalous Spectral Features in Solar Type Stars, [https://seti.berkeley.edu/bl_sdss_seti_2016.pdf](https://seti.berkeley.edu/bl_sdss_seti_2016.pdf)
Boone, K., Aldering, G., Copin, Y., et al. 2018, PASP, 130, 064504
Borra, E. F. 2010a, ApJ, 715, 589
Borra, E. F. 2010b, A&A, 511, L6
Borra, E. F. 2012, AJ, 144, 181
Borra, E. F. 2013, ApJ, 774, 142
Borra, E. F. 2017, JApA, 38, 23
Borra, E. F., & Trottier, E. 2016, PASP, 128, 114201
Chin, S. L., François, V., Watson, J. M., & Delisle, C. 1992, ApOpt, 31, 1214
Delisle, C., & St-Arnaud, J.-M. 1970, CaJPh, 48, 1214
Desai, S., Mohr, J. J., Bertin, E., Kümmler, M., & Weitzstein, M. 2016, A&C, 16, 67
Eisenstein, D. J., Weinberg, D. H., Agol, E., et al. 2011, AJ, 142, 72
Fowler, A. 1924, JRASC, 18, 373
Green, P. 2013, ApJ, 765, 12
Hippke, M. 2018, JApA, 39, 74
Isaacson, H., Siemion, A. P. V., Marcy, G. W., et al. 2019, PASP, 131, 995
Jones, D. H., Saunders, W., Colless, M., et al. 2004, MNRAS, 355, 747
Jones, D. H., Read, M. A., Saunders, W., et al. 2009, MNRAS, 399, 683
Jones, D. H., Read, M. A., Saunders, W., et al. 2010, yCat, 73906683J
Jones, E., Oliphant, T., Peterson, P., et al. 2001, SciPy: Open Source Scientific Tools for Python, [http://www.scipy.org/](http://www.scipy.org/)
Kurucz, R. L. 2005a, MSAIS, 8, 189
Kurucz, R. L. 2005b, MSAIS, 8, 73
Lomb, N. R. 1976, Ap&SS, 39, 447
Mandel, L., & Wolf, E. 1976, JOSA, 66, 529
Price-Whelan, A. M., Sipócz, B. M., Günther, H. M., et al. 2018, AJ, 156, 123
Scargle, J. D. 1981, ApJS, 45, 1
VanderPlas, J. T. 2018, ApJS, 236, 16
Yanny, B., Rockosi, C., Newberg, H. J., et al. 2009, AJ, 137, 4377