ARE PERYTONS SIGNATURES OF BALL LIGHTING?

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ABSTRACT

The enigmatic downchirped signals, called "perytons", that are detected by radio telescopes in the GHz frequency range may be produced by an atmospheric phenomenon known as ball lightning. Although this is still a hypothesis, the parallels between perytons and ball lightning are striking.

Subject headings: radiation mechanisms: general, waves

1. INTRODUCTION

In the past several years, a number of unusual isolated signals were recorded with the 64-m Parkes Radio Telescope, Australia, in the frequency range $f \sim 1.2$-1.5 GHz (Burke-Spolaor et al. 2011; Bagchi et al. 2012; Kocz et al. 2012; Burke-Spolaor 2011; Kulkarni et al. 2014). These signals, dubbed "perytons", exhibit a negative chirp $\dot{f} \sim -1\,\text{GHz/s}$ and last for hundreds of ms.[1] Also notably, perytons are detected in all or most of the 13 telescope beams, which suggests a large angular size of their sources, and correlate with terrestrial settings such as time of day and weather. Hence perytons are commonly believed to have a terrestrial origin.

What could be the sources of these signals? It is not entirely impossible that perytons are due to a man-made radiofrequency (RF) emission. However, this seems unlikely, because perytons cross the band 1.4-1.427 GHz, where terrestrial transmitters are legally forbidden to operate (Cohen et al. 2005), and also exhibit amplitude modulation that, perhaps, excludes hardware failures as their origin (Burke-Spolaor et al. 2011). Thus perytons are more likely to be atmospheric phenomena. Yet, a specific mechanism through which the Earth's atmosphere produces such RF bursts remains elusive. Although perytons do correlate with weather, they are extremely rare compared to weather fluctuations and not necessarily accompanied by strong wind, rain, or thunderstorms (Bagchi et al. 2012). Perytons are therefore not likely to result from common atmospheric phenomena. Rather, they seem to be emitted by structures, perhaps of decimeter size, that can last for about a second and change their geometry on the same time scale (Katz 2014).

This paper will point out that, although exotic, such atmospheric structures are not unheard of; they are, in fact, widely known as the curious and equally puzzling phenomena called ball lightnings (BLs). We hence suggest that perytons are signatures of BLs. Although quantitative data on BLs is scarce, certain parallels between them and perytons are striking, with considerable circumstantial evidence linking these two types of effects.

2. PERYTONS VS BLS

2.1. *Observation patterns*

First, note that BLs are correlated with weather and time of day (Smirnov 1993) similarly to perytons. In particular, both BLs and perytons are observed primarily around midday. Perytons are also known to occur most likely during rainy weather. This is not exactly typical for BLs, which are more common during thunderstorms rather than *just* rain. But keep in mind that the observed perytons properties are subject to a selection bias. Specifically, peryton observations were performed with a radio telescope that needs to be stowed during local storms[2] and thus cannot perform measurements when the appearance of BLs is most probable. At the same time, BLs are known to be not entirely restricted to foul weather (Smirnov 1993), just like perytons (Bagchi et al. 2012).

Also note that the presence of large conducting surfaces (and, supposedly, powerful electric transformers) on a radio telescope should significantly increase the probability of the BL appearance in its immediate vicinity (Smirnov 1993). That may explain why perytons are observed in many of the telescope beams simultaneously: the RF signals may actually be produced on-site or nearby, so the angular size of the peryton source is large indeed. Moreover, both perytons and BLs have in common also that they remain rare events even under these favorable conditions.

2.2. *Frequency range*

BLs are commonly (although not unanimously (Smirnov 1993)) believed to be accompanied by RF activity in just the frequency range where perytons are observed. Indeed, it has been suggested that a BL can serve as a natural electromagnetic cavity (Kapitsa 1955; Watson 1960; Tonks 1960; Silberg 1961; Dawson & Jones 1969; Jennison 1973; Endean 1976; Muldrew 1990; Zheng 1990; Wessel-Berg 2003). The lowest eigenmode of such a cavity has frequency[3]

$$f_c \sim c/D, \qquad (1)$$

where D is the BL diameter, and c is the speed of light. Even if the radiation were well-trapped inside the cavity, one can still expect it to somewhat radiate at frequency

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[1] The duration of a whole signal must not be confused with the duration of its constituents in individual frequency channels of the telescope, which is typically tens of ms.

[2] Parkes Radio Telescope Users Guide, `http://www.parkes.atnf.csiro.au/observing/documentation/user_guide/pks_ug.pdf`

[3] A geometric factor of order one (Kapitsa 1955) is omitted because D itself varies within almost two orders of magnitude (Smirnov 1993), and perytons too may exist also beyond the frequency range within which they are being presently studied.

f_c. Typically, $D \sim 20\,\text{cm}$ (Smirnov 1993), so $f_c \sim 1.5\,\text{GHz}$, which is close to peryton frequencies.

What also supports the theory that BLs represent cavity phenomena are measurements of the RF emission generated naturally at thunderstorms. As shown in (Kosarev et al. 1968, 1970), the spectral density of this emission (measured at discrete frequencies) increases with frequency at $f \gtrsim 1.0\text{-}1.3\,\text{GHz}$, in striking contrast with the spectral density in the sub-GHz range, which decreases with f. It was suggested that this GHz radiation may be associated with BLs (Kosarev et al. 1968, 1970). Note also that the signals in individual frequency channels recorded in those studies are similar to the corresponding signals recorded for perytons.

2.3. *Frequency chirping*

The only quantitative observation of a natural BL available today (Cen et al. 2014) shows that the BL size can evolve significantly on a fraction of a second. During the quasistationary phase of the BL, this size, in fact, increased at the rate $\dot{D}/D \sim 0.5\,\text{s}^{-1}$. The value of D itself cannot be inferred directly from the observations in (Cen et al. 2014), which were performed from a large distance (0.9 km) and, as the authors pointed out, gave only the "apparent" diameter (in the several-meter range) rather than the actual diameter of the BL. But if one estimates D to be $20\,\text{cm}$, as usual, this leads to $\dot{f}_{\text{BL}} \sim -0.75\,\text{GHz/s}$. Again, this value is consistent with what is seen for perytons.

But can the expanding-BL model explain the characteristic *shape* of $f(t)$ observed for perytons? To answer this, a brief excursion into the history of peryton studies is needed. Originally, perytons were discovered during an archival data survey (Burke-Spolaor et al. 2011) inspired by the discovery of the so-called Lorimer burst (LB), a similarly-shaped chirped GHz signal reported in (Lorimer et al. 2007). As opposed to perytons, the LB was observed in only three beams of the Parkes telescope and thus was identified as a signature of a distant, extraterrestrial event associated with a few-ms RF emission. Such an RF signal undergoes dispersive spreading when propagating in space plasma. Specifically, its instantaneous frequency, as detected after time t at a given distance ℓ from the source, satisfies (Katz 2014)

$$\frac{d}{dt}\left[f^{-2}(t)\right] = C(\ell), \qquad (2)$$

where the time-independent $C(\ell)$ is determined by the plasma density integrated along the signal trajectory (also known as the "dispersion measure"). Choosing the value of $C(\ell)$ to fit the observations places the LB origin outside our galaxy. This motivated the search for other signals that would be similar to the LB, and, through that, perytons were discovered accidentally.

But do we know for sure that all perytons, whatever they are, satisfy Eq. (2)? Certainly not. First of all, the very procedure of automatically searching for perytons in archival data introduced a selection bias; e.g., signals corresponding to vanishingly small C and others that were not similar enough to the LB were simply ignored. (One

may find this ironic, considering that the similarity between perytons and the LB was later hypothesized to be accidental.) Therefore, Eq. (2) may, in fact, reflect properties of the selection algorithm rather than an objective pattern determined by a specific physical effect. Second, even among those perytons that *were* identified as such, there are some that do not quite satisfy Eq. (2). That includes, for example, Peryton 06 in (Burke-Spolaor et al. 2011) and also some of the more recent observations of peryton-like signals at Bleien Observatory, Switzerland (Saint-Hilaire et al. 2014). This is particularly notable considering that surveys of GHz bursts cover only a narrow frequency band ($\Delta f/f \lesssim 0.25$), thus leaving a lot of freedom for fitting.

In summary then, we may not actually have enough evidence to conclude whether the frequency of perytons, whatever those are, follows a power scaling like Eq. (2) or, for that matter, any other universal scaling.[4] In this sense, the model of a BL as a nonstationary electromagnetic cavity seems to be generally consistent with the peryton frequency chirps that are observed.

2.4. *RF emission mechanism*

But can this model explain also how the RF energy is produced or confined long enough within the BL cavity? The existing RF models of BL (Kapitsa 1955; Watson 1960; Tonks 1960; Silberg 1961; Dawson & Jones 1969; Jennison 1973; Endean 1976; Muldrew 1990; Zheng 1990; Wessel-Berg 2003) are too sketchy to answer this question, so it may be premature to speculate on specifics. On the other hand, there is a growing experimental and theoretical evidence that most of the BL energy may be accumulated in a non-RF form, namely, in the form of internal molecular excitations or chemical energy (Paiva et al. 2007; Dikhtyar & Jerby 2006; Alexeff et al. 2004; Bychkov 2002; Abrahamson & Dinniss 2000; Brandenburg & Kline 1998; Zhil'tsov et al. 1995; Golka 1994; Ohtsuki & Ofuruton 1991). Thus, a hybrid mechanism may be in effect, such that the RF power does not produce a BL but is generated as a byproduct through a "plasma maser" mechanism akin to that in (Handel & Leitner 1994). Specifically, this could work as follows.

With the expected temperature of several thousand Kelvin (Cen et al. 2014), the body of a BL acts as a cold plasma for RF oscillations. This means that its dielectric susceptibility exhibits temporal (but not spatial) dispersion determined by the nonzero electron density n_e. For waves with a given angular frequency $\omega = 2\pi f$, the corresponding dielectric susceptibility is $\chi \approx -\omega_p^2/[\omega(\omega + i\nu)]$ (Stix 1992), where $\omega_p = (4\pi n_e e^2/m_e)^{1/2}$ is the plasma frequency, e and m_e are the electron charge and mass, and ν is the electron scattering rate. The scattering is mostly due to collisions with neutrals, so ν can be taken roughly as a constant, say, $\nu \sim 10^{12}\,\text{s}^{-1}$ (Dawson & Jones 1969). Since $\nu \gg \omega$ in the frequency range of our interest, we can approximate

$$|\chi| \sim 5 n_{13} f_{\text{GHz}}^{-1} \sim n_{13}. \qquad (3)$$

Here f_{GHz} is the frequency in GHz, and n_{13} is the electron density measured in units $10^{13}\,\text{cm}^{-3}$.

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[4] This is also consistent with the study (Katz 2014) that indicates: if perytons were produced by terrestrial basic plasma effects leading to Eq. (2), then the values of C would have been very different from those seen in practice.

It is feasible that the initial electron density is in the range $n_{13} \sim 1$ and is larger at the periphery, as would occur, e.g., in the case of a blast wave. Then an RF cavity is formed, to which excited molecules can emit a fraction of their energy much like in the well-known hydrogen maser (Major 2007). (We suppose that the emission is not particularly sensitive to the cavity size, assuming that many quantum transitions can contribute; e.g., rotational energy of polymer molecules (Bychkov 2002) can be involved, which naturally have a broad distribution of resonant frequencies.) Initially, the RF energy is only poorly confined in such a cavity and will dissipate rapidly, but there is a feedback mechanism that can improve the confinement. Note that a BL is expected to consist of *dusty* plasma (Meir et al. 2013), so n_e can vary significantly through absorption and release of electrons from the the dust particle surfaces. RF power is one of the determining factors here. As shown experimentally in (Berndt et al. 2006), application of RF field can decrease n_e in dusty plasma. The specific nature of this effect, which is being debated (Schweigert & Alexandrov 2012), is not important for our discussion. What is important, however, is that the effect is local and much stronger than that caused by ponderomotive expulsion (Zheng 1990). Already weak RF oscillations may then be able to substantially steepen the n_e profile within the plasmoid. Hence a well-defined electromagnetic mode can form and serve as a narrow-band transmitter of RF radiation at frequency f_c [Eq. (1)]. On the other hand, as the RF energy confinement improves, n_e continues to decrease in the BL core, leading to the increase of D and decrease of f_c; hence the transmission will be chirped until the maser is exhausted. Future details are beyond the sketch that we present here, which is intended only to show how one mechanism might possibly be common to perytons and BLs. What matters is only that the expansion is seen in some measurements indeed (Cen et al. 2014), so, in one way or another, chirping can be expected.

3. DISCUSSION

Our conjecture that two types of curious observations, perytons and BLs, actually result from one and the same phenomenon leads to two predictions. One, we predict that atmospheric BLs emit chirped GHz radiation. Two, if perytons are indeed signatures of BL, then they should also emit optical radiation. Facilities that observe perytons do not monitor these optical emissions, but maybe they should. Also note that, should the prediction of either of these emissions be confirmed, it would not only support strongly our theory that perytons and BL are coincidentally the same phenomenon, but it would also lead to the following consequences.

First, if perytons are indeed signatures of BLs, then they should have a common physical mechanism. Our proposal of such a mechanism here is only a preliminary sketch and describes one of many possibilities. However, what definitely would follow from the coincidence of perytons and BLs is that mechanisms not common to both types of observations could then be ruled out.

Second, a confirmation of the coincidence of perytons and BL would suggest that other unidentified curious RF signals be reconsidered in light of this coincidence. For instance, the LB may not be an extraterrestrial signal after all, as has been already suggested (Kulkarni et al. 2014). This also applies to the similar "fast radio bursts" (FRBs) reported more recently (Thornton et al. 2013). The FRBs, including the LB, may be peryton-like signatures of BLs. Then their smaller angular size is explained by the fact that the FRBs are observed from a larger distance; it also becomes clear then why FRBs are observed less frequently than perytons. We might also understand the so-called "Wow!" signal, a famous yet still-enigmatic 1.42 GHz burst that was received in 1977 by the Big Ear radio telescope, Ohio, and lasted for 72 s (Gray 2012). It is not unfeasible that, although not chirped, this signal is explainable as RF emission from a BL too, as large enough BLs are known indeed to last over a minute (Smirnov 1993). Thus, what we suggest here is a connection not only between BLs and perytons, but also, possibly, between these curious observations and other known GHz signals that remain unidentified.

In summary, the hypothesis is advanced here that two types of curious observations, perytons and BLs, actually result from one and the same phenomenon. Although this connection remains speculative, the circumstantial evidence is significant and leads to testable predictions, as summarized in Table 1.

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	BLs	perytons
explanation	unclear	unclear
observed patterns	midday; usually at thunderstorms, but not only	midday; usually on rainy days, but not only (detectors off during local storms)
frequency range	predicted in the GHz range	observations limited to $\sim 1.4\,\mathrm{GHz}$
negative frequency chirp	consistent with cavity expansion	observed
chirp rate $\sim -1\,\mathrm{GHz/s}$	predicted (based on a single observation (Cen et al. 2014))	observed
chirping consistent with Eq. (2)	possible	assumed, but not really demonstrated
duration	from a fraction of a second to a minute	fraction of a second
origin	terrestrial	assumed terrestrial (observed in multiple channels)
optical emission	observed	predicted
other curious observations ("Wow!" signal)	consistent with larger BL in terms of duration	similar frequency

TABLE 1

SUMMARY OF THE PARALLELS BETWEEN BLs AND PERYTONS.

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