WHAT PERYTONS ARE NOT, AND MIGHT BE

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ABSTRACT

Chirped radio pulses known as perytons are consistent with plasma propagation, but an astronomical origin has been excluded. This paper considers several physical processes as possible explanations. TE and TM waveguide modes have dispersion relations formally similar to those of plasmas, and emission at the plasma frequency of a plasma recombining by two-particle processes also produces a chirp \( \delta t \propto \omega^{-2} \), but these hypotheses fail quantitatively. The chirp might be approximately fitted to three-body recombination, cyclotron radiation in exponentially decaying fields, or to the resonance of a distributed LC circuit whose component conductors move. Constraints are placed on these possible processes, but no specific source has been identified.

Key words: instrumentation: miscellaneous – radio continuum: general

1. INTRODUCTION

Perytons (Burke-Spolaor et al. 2011; Kocz et al. 2012; Bagchi et al. 2012; Saint-Hilaire et al. 2014; Kulkarni et al. 2014) are short (tens of ms) chirped radio pulses first observed in the Parkes Multibeam Pulsar Survey. The most remarkable property of perytons is that their chirps have a very similar functional dependence of frequency on time to those of radio pulsars \( \delta t \propto \omega^{-2} \) and apparently extragalactic fast radio bursts (Lorimer et al. 2007; Thornton et al. 2013). The dispersion measures of perytons can be regarded as measures of their chirp (Lorimer et al. 2007; Thornton et al. 2013). The dispersion measures of perytons can be regarded as measures of their chirp rates independent of their cause, and are almost all between 350 and 400 pc cm\(^{-3} \). These values, but not their concentration in a narrow range, are characteristic of propagation from cosmological distances (Thornton et al. 2013). A simple calculation shows that they are inconsistent with emission from sources of stellar or lesser dimensions because of free–free absorption (Spitzer 1962) at the high densities that would be implied if the dispersion were produced along such short path lengths. A variety of arguments indicate that perytons are not astronomical events, but they remain of interest to astronomers as a source of interference and of possible misidentification as astronomical phenomena.

The purpose of this paper is to consider possible telluric (for example, in lightning or meteor trails) or anthropogenic origins of the chirped signals of perytons. Propagation in a waveguide (except for TEM modes) and emission by a plasma recombining by two-body processes produce chirps \( \delta t \propto \omega^{-2} \) mimicking that of plasma propagation. Three-body recombination or cyclotron radiation in the magnetic field of an impulsively excited LR circuit leads to different functional forms but may be fitted to plasma dispersion chirps over limited ranges of frequency. The resonant frequencies of LC circuits whose values of inductance \( L \) or capacitance \( C \) change with time are chirped, as are the resonant frequencies of conducting structures whose geometry changes, but special assumptions must be made to reproduce the observed chirps of perytons. In any of these models the instantaneous emission bandwidth (typically \( \Delta \nu / \nu \approx 0.03 \)) is a measure of the homogeneity of the emission region. In this paper I consider each of these physical processes as a possible source of perytons.

2. PROPAGATION

2.1. Cold Plasma

The dispersion relation for electromagnetic waves in cold plasma is

\[
\omega^2 = \omega_p^2 + c^2 k^2, \tag{1}
\]

where the plasma frequency

\[
\omega_p \equiv \sqrt{4\pi ne^2/m}, \tag{2}
\]

and \( n \) and \( m \) are the number density and mass of the species (usually electrons, but possibly other charged particles) dominating the plasma dispersion, \( \omega \) is the wave angular frequency, \( k \) is the wave vector, \( c \) the speed of light, and \( e \) the unit of charge. The propagation time is

\[
t = \int \frac{d\ell}{v_g}, \tag{3}
\]

where the group velocity of the wave \( v_g = d\omega / dk \) and the integral is over path elements \( d\ell \). Then

\[
t = \int \frac{d\ell}{c} \left( 1 + \frac{1}{2} \left( \frac{\omega_p}{\omega} \right)^2 + \frac{3}{8} \left( \frac{\omega_p}{\omega} \right)^4 + \cdots \right). \tag{4}
\]

It is usually (for example, in intergalactic and interstellar media, even in dense clouds) sufficient to take the first two terms. The third term may be significant in denser plasma, such as a stellar corona, but at such high density, inverse bremsstrahlung absorption (Spitzer 1962) precludes the observation of any emitted radiation. As is frequently the case in such expansions, when higher terms are significant the expansion is so slowly convergent that the exact expression must be used.

The first term is independent of frequency and does not contribute to dispersion. Then

\[
\delta t(\omega) \equiv t(\omega) - t(\infty) \approx \frac{1}{2} m_e \omega^2 c DM, \tag{5}
\]

where the dispersion measure \( DM \equiv \int d\ell / n \) and the subscript \( e \) refers to electrons. The chirp of most perytons is well, but not exactly, fitted by Equation (5) with \( DM \) in the narrow range 350–400 pc cm\(^{-3} \), corresponding to a delay at wave frequency \( \nu \equiv \omega / 2\pi = 1400 \text{ MHz} \) of \( \delta t_{1400} = 0.75–0.86 \text{ s} \).
where $\omega_0$ is the cutoff angular frequency of the mode of propagation considered. Equation (6) leads to a relation of the same form as Equation (5), with indistinguishable consequences:

$$\delta t(\omega) \approx \frac{1}{2} \frac{\ell}{c} \frac{\omega_0^2}{\omega^2}. \quad (7)$$

The equivalence between $\omega_0$, the waveguide length $\ell$, and the dispersion measure is

$$\ell \omega_0^2 \iff 4 \frac{\pi e^2}{m_e} DM = 3.2 \times 10^9 \text{cm}^3 \text{s}^{-2} \text{DM}. \quad (8)$$

Unfortunately, propagation in a waveguide cannot explain chirped perytons because the required length would be

$$\ell \approx 2c \delta t_{1,400} \frac{\omega_0^2}{\omega_0^2} \gtrsim 10^{11} \text{cm}. \quad (9)$$

There are no such waveguides, and if they did exist, they would be orders of magnitude longer than their attenuation lengths that are typically $O(10^8 c/\omega)$ $\approx 3 \times 10^4$ cm (Jackson 1999).

### 3. Plasma Recombination

An alternative explanation for chirped perytons may be sought in plasma recombination in a spark (natural lightning or anthropogenic, perhaps in electrical equipment) or discharge, a meteor entry trail, or some other natural or artificial phenomenon. A variety of processes, including beam-plasma instability, excite electrostatic plasma waves with frequencies close to $\omega_p$. At density gradients these waves couple to propagating electromagnetic waves. These processes are familiar in laboratory plasmas. If the plasma density declines with time, or if the excitation moves from regions of greater to lesser plasma density (Burke-Spolaor et al. 2011), so will $\omega_p$, producing a chirp that could under the right conditions be indistinguishable from plasma dispersion. The narrow instantaneous frequency width of the emission would require remarkable homogeneity (about 5%) in the density of emitting plasma.

#### 3.1. Two-body Recombination

Recombination reduces the charged particle density of a plasma. If recombination is the result of two-body reactions between positively and negatively charged species (for example, electrons and positive atomic or molecular ions),

$$\frac{dn}{dt} = -\alpha_2 n^2, \quad (10)$$

where $\alpha_2$ is the recombination coefficient and we have assumed there are two singly charged species, each with the number density $n$ but opposite charges, as required by electrostatic neutrality, and that there is no further ionization. The trivial solution to Equation (10) is

$$n(t) = \frac{1}{\alpha_2 t}, \quad (11)$$

where $t$ (corresponding to $\delta t$ in Equations (5) and (7)) is the time elapsed since the nominal creation of the plasma at infinite density. Equating the observed radiation frequency $\omega$ to $\omega_p$, using Equations (2) and (11), we find

$$\delta t = \frac{4 \pi e^2}{m_e \omega_0^2}. \quad (12)$$

This has the same form as the dispersion delays Equations (5) and (7) with the equivalence

$$\alpha_2 \iff 2 \frac{m_e}{m} \frac{c}{DM}. \quad (13)$$

and appears to be an alternative explanation of the chirp. It even offers a plausible explanation of deviations observed in perytons from the exact $\delta t \propto \omega^{-3}$ because $\alpha_2$ depends on temperature, which is likely to vary in atmospheric or electronic systems, and the kinetics may be complicated by the presence of other species; many other possible explanations (or excuses) exist.

Unfortunately, the numbers do not work out. We distinguish two cases.

1. For an electron–ion plasma $m = m_e$ and the required $\alpha_2 \approx 5 \times 10^{-11} \text{cm}^3 \text{s}^{-1}$. Because the electrons are unbound to the ions that may capture them, two-body recombination requires the emission of a photon and is slow. At temperatures $O(1 \text{ eV})$, as found in sparks and lightning, the radiative recombination rate $\alpha_2 \approx 3 \times 10^{-13} T_e^{-1/2}$, where the electron temperature $T_e$ is in units of eV (NRL 2007).

2. In an ion plasma (such as may result in weakly ionized air if electrons are captured by neutral molecules to make negative molecular ions), recombination may occur in non-radiative collisions because the excess energy is taken up by the reaction products’ kinetic energy. Then $m$ is properly the reduced mass of the two ions ($\approx 14 \text{ a.m.u.}$) and the required $\alpha_2 \approx 2 \times 10^{-15} \text{cm}^3 \text{s}^{-1}$. A plasma of such massive ions must be very dense to have the inferred plasma frequency, and hence $\alpha_2$ must be small to keep the recombination rate in the range inferred from the observed chirp. Ionic collisional neutralization charge exchange rates are not small because the cross-sections are $O(5 \times 10^{-15} \text{cm}^2)$ (Flannery 1996); $\alpha_2 \approx 10^{-9} T^{1/2} \text{cm}^3 \text{s}^{-1}$, with $T$ in eV. Similar results apply to atomic ions.

In neither case is it possible to obtain a recombination coefficient consistent with observed peryton chirps.

#### 3.2. Three-body Recombination

At higher electron densities, radiative recombination is insignificant compared to three-body recombination. Equation (10) is replaced by

$$\frac{dn}{dt} = -\alpha_3 n^3, \quad (14)$$

where $\alpha_3$ is the three-body recombination coefficient, if the third body is a second electron and the recombining ion density equals the electron density (there are no other charged particles). Then $\delta t \propto n^{-2} \propto \omega^{-4}$ rather than $\delta t \propto n^{-1} \propto \omega^{-2}$ (Equation (5)).

1 An equation analogous to Equation (10), with $\alpha_2$ replaced by $\alpha_3 n_B$, is obtained if the third body is a bystander, such as the dominant neutral species, whose density $n_B$ is nearly constant. This may apply to weakly ionized gases.
Over a limited frequency range, a fit to $\delta t = C_2 \omega^{-2}$ may not be distinguishable from a fit to $\delta t = C_4 \omega^{-4}$ with $C_4 = C_2 \omega^2/2$, equating the chirp rates at $\tilde{\omega}$, the midpoint of the range. The required three-body recombination coefficient

$$\alpha_3 = \frac{32\pi e^2 c}{m_e \omega^2 \Delta \nu} \approx 8 \times 10^{-21} \text{ cm}^6\text{s}^{-1}. \quad (15)$$

This may be compared to the estimated $\alpha_3 \approx 9 \times 10^{-27} T^{4.5}$, where $T_e$ is in eV (NRL 2007). These rates might be reconciled for $T_e \approx 0.05$ eV (500 K, a plausible value for a weakly ionized gas), but assumption-dependent simulations of complex reaction networks would be required for quantitative conclusions, as well as a quantitative test of how well peryton chirps may be fit by $\delta t \propto \omega^{-4}$ rather than $\delta t \propto \omega^{-2}$. In addition, the strong temperature dependence implies that unavoidable temperature changes in the course of recombination will make the actual $\delta t(\omega)$ deviate from a simple power law.

4. CYCLOTRON RADIATION

The frequency of cyclotron radiation by an electron in a magnetic induction $B$ is

$$\nu = \frac{eB}{2\pi m_ec}. \quad (16)$$

Observed peryton frequencies $\nu \approx 1400$ MHz correspond to $B \approx 500$ gauss, a field readily achievable with permanent magnets or electromagnets. The observed chirp $\delta t \propto \omega^{-2}$ requires $B \propto (\delta t)^{-1/2}$. If the field is produced by a linear ferromagnetic material, the current magnetizing it must also vary $\propto (\delta t)^{-1/2}$. This does not have an obvious origin. Currents in simple LR circuits decay exponentially with a time constant $\tau = L/R$, where $L$ is the inductance and $R$ the resistance. Inclusion of ferromagnetic material such as an electromagnet in a circuit implies a large $L$ and a slow decay of field and current. Ferromagnetic materials are generally very nonlinear, and a simple functional form for the decay of the magnetic field would not be expected.

Just as for three-body recombination, any smooth decay over a limited frequency range can be fitted to a $\delta t \propto \omega^{-2}$ form. Fitting an exponential decay to a slope $dt/d\omega$ described by the dispersion measure $DM$ implies

$$\tau = \frac{4\pi e^2}{m_e \omega^2 c} \Delta \nu \approx 1.6 \text{ s}. \quad (17)$$

This is consistent with plausible values of $L$ and $R$, but there is no reason to expect such circuits to have this particular value of $\tau$.

The narrowness ($\Delta \nu/\nu \approx 0.03$) of the instantaneous spectrum constrains the field homogeneity in an emission region. Homogeneity may not be as serious an issue as for plasma recombination models because devices may be engineered to have homogeneous magnetic fields in the plasma region, while within a spark the plasma frequency varies continuously from zero outside to its maximum.

We conclude that although the magnetic fields necessary for cyclotron radiation at the observed peryton frequencies exist in terrestrial magnets, the observed chirp is not a natural product of electromagnet circuits.

5. LC CIRCUITS

The oscillation frequency of an LC circuit

$$\omega = \frac{1}{\sqrt{LC}}. \quad (18)$$

If the product $LC \propto \delta t$, then $\omega$ decreases from a nominal infinite value at $\delta t = 0$ according to a relation

$$\delta t = \left(\omega^2 \frac{d(LC)}{dt}\right)^{-1} \quad (19)$$

analogous to Equation (5) with

$$\frac{d(LC)}{dt} \Leftrightarrow \frac{m_e c}{2\pi e^2 DM} = 19 \text{ s}^{-1} \frac{1}{\text{DM}} \approx 1.6 \times 10^{-20} \text{ s}. \quad (20)$$

A circuit with the required resonant $\omega = \Omega(10^{10}/\text{s})$ has dimensions $\lesssim c/\omega = 3 \text{ cm}$, no lumped impedances, and distributed $L \approx 10 \text{nH}$ and $C \approx 1 \text{ pF}$. If its geometry changes, so will $LC$. Although the functional form $\delta t \propto \omega^{-2}$ requires a constant $d(LC)/dt$, just as in Sections 3.2 and 4, it may be possible to fit the observed peryton $d\omega/dt$ over a limited frequency range even if $d(LC)/dt$ varies, provided it approximates Equation (20) during the limited period of observation.

The required circuit must change its geometry, and therefore its resonant frequency, substantially in a few tenths of a second. In addition, some mechanism, such as a spark, must excite its resonant electromagnetic oscillations. For example, we might consider a bimetallic strip in a thermostat that changes its shape as the temperature relaxes, or a mechanical relay, and a spark that is struck as the gap opens. Varying electromagnetic resonance is consistent with perytons, provided circuits with the required resonant frequency and chirp exist, but none are yet known.

6. DISCUSSION

We have considered several processes that might explain the most remarkable property of perytons, their chirp that resembles that of plasma dispersion at extragalactic distances. Each of these proposals encounters difficulty, qualitative (difficulty in explaining the functional form of the chirp) or quantitative (difficulty in explaining the magnitude of the chirp). The LC circuit may be the most promising, if a suitable mechanically relaxing configuration exists.

No sources of perytons have been identified. Their narrow range of dispersion measures and observed timing patterns (including preferred times of day and intervals between events Burke-Spolaor et al. 2011; Kocz et al. 2012) and the absence of an association with any known natural telluric phenomenon point to an anthropogenic origin in a single class of electronic equipment, perhaps in an unexpected or abnormal state. Although perytons are local to the observers, they have been observed in both Australia and Switzerland, indicating that their sources are widely distributed. However, no perytons were observed at the Allen Telescope Array in California when $\sim 10$ would have been expected based on their event rate observed at Parkes (Siemion et al. 2012), indicating that their sources are not ubiquitous.

The perytons observed at Parkes were detected in all 13 beams of the multibeam receiver. Possible explanations include the following: (1) it was so close ($\lesssim 10$ km) to the telescope that it
was out of focus (Kulkarni et al. 2014); (2) the emission was distributed over a two-dimensional region on the sky at least a few degrees wide and long; (3) it was observed in the far sidelobes of all the beams (Burke-Spolaor et al. 2011); and (4) the signal entered by “back door” direct coupling to the circuits rather than by amplification of electromagnetic energy collected and focused by the telescope.

Speculative possibilities include devices, such as cathode ray tubes, amplifiers, and power supplies associated with radio telescopes; components of the power grid, such as circuit breakers and voltage regulators; and consumer devices, such as microwave ovens and fluorescent and vapor lamps. The timescale described by their chirp may be related to that of electromechanical switches. It may be fruitful to search for anthropogenic peryton-like events with simple dipole antennas and receivers in a variety of cultural environments, not limited to radio telescopes. If they are the result of “back door” coupling, the giant focusing dishes of radio telescopes would not be necessary for their detection.

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