P2 8 Only a Sith deals in Magnetohydrodynamics

J. Fuller, P. Clevely, N. Sowter

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 4, 2025

Abstract

In this paper, we investigate the iconic humming noise produced by the *lightsaber* from the *Star Wars* movie franchise. We apply a magnetohydrodynamic model to investigate the formation of standing Alfvén waves within the *lightsaber* plasma and find that for the fundamental frequency of these waves to be within the range of human hearing, a *lightsaber* of magnetic field 1 T would require a plasma density of $10^{26}\,\mathrm{m}^{-3}$.

Introduction

One of the most iconic weapons in cinema, the *lightsaber*, while often referred to as a laser sword, is a beam of plasma spatially confined to form a blade [1]. *Lightsabers* emit a characteristic hum. In this paper, we apply a magnetohydrodynamic (MHD) model to the *lightsaber* plasma in an attempt to explain the formation of this famous sound.

Theory

In his seminal 1942 work, Hannes Alfvén [2] described how the application of a magnetic field to a plasma can give rise to perturbations perpendicular to the field, resulting in transverse motion that is analogous to that of a wave on a string.

We propose that the characteristic hum of a *lightsaber* may be explained by the formation of these Alfvén waves within the confined plasma blade. First, we assume that the blade of a *lightsaber* may be modelled as a perfect cylinder of length L and radius a with a constant magnetic field $\vec{B} = B\hat{z}$ that points parallel to the length and exists only within the plasma-filled cylinder.

Following from Alfvén, a mechanical disturbance in this plasma perpendicular to the field direction leads to the magnetic tension acting as a restoring force [3] which results in a transverse wave propagating along the magnetic field line. This motion is governed by the equation:

$$\frac{\partial^2 B_\perp}{\partial t^2} = \frac{B^2}{\mu_0 \rho}\frac{\partial^2 B_\perp}{\partial z^2} \tag{1}$$

where all the terms have their usual meanings, $B_\perp$ denotes the component of the field that has been perturbed perpendicular to the rest field. We have made slight modifications to the results of Alfvén [2] to write our wave equation in terms of the more familiar B rather than the magnetic intensity H.

Using Equation 1, it is easy to verify that the simplest valid waveform is a plane wave given by:

$$B_\perp = B_0 e^{i(kz - \omega t)} \tag{2}$$

where k and ω are the wavenumber and (angular) frequency, respectively, and that the ratio:

$$\frac{\omega}{k} = v_A = \sqrt{\frac{B^2}{\mu_0 n m_i}} \tag{3}$$

where v_A is the wave or Alfvén speed and the mass density $\rho = n m_i$ where n is the plasma density and m_i is the mass of the plasma particles. We assume that the *lightsaber* plasma is largely protons and electrons, and so to a good approximation the plasma mass is simply the proton mass.

As this wave propagates in the *lightsaber* cylinder, it may reflect at either endpoint, resulting in two opposing waves which will superpose to form a standing wave [4]. This standing wave will have a series of resonant frequencies, f_p, which can be expressed in terms of the Alfvén speed via the standing wave condition [4]:

$$f_p = p\frac{v_A}{2L} = \frac{p}{2L}\sqrt{\frac{B^2}{\mu_0 n m_i}} \tag{4}$$

where p is simply an integer denoting the harmonic frequency number. By assuming the motion of the plasma-magnetic field system in the *lightsaber* forms a standing wave resonating at the fundamental frequency f_1, we can estimate the scale of magnetic field and plasma density required to generate the characteristic hum.
We make two key assumptions, first that the *lightsaber* has a blade length $L = 1$ m and radius $a = 2.5$ cm. And we've implicitly assumed that the plasma behaves as an ideal MHD system [2] [3]. We can safely make this assumption if the length scale along the direction of gyration, that is to say the cylindrical radius a, is much larger than the particle gyro radius r_g [3]:

$$r_g = \frac{m v_\perp}{qB} \tag{5}$$

where $v_\perp$ is the speed of gyration, which we can approximate as the thermal speed [5]:

$$v_\perp = \sqrt{\frac{2kT}{m}} \tag{6}$$

and so by combining Equations 5 and 6 and assuming a reasonable temperature inside the lightsaber of $1\,\text{MK}$, we find the proton gyro radius for our $1\,\text{T}$ magnetic field to be $r_g = 1.3\,\text{mm}$. This is much smaller than our estimate of the blade radius, and therefore, the assumption of ideal MHD can be considered valid.
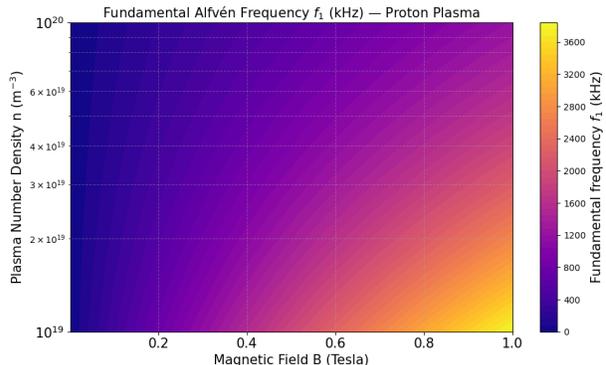

Figure 1: Contour plot showing how the fundamental frequency varies with magnetic field B and plasma density n. Note that the y-axis has a log scale and the x-axis has a linear scale.

Discussion & Conclusion

In Figure 1, we display the fundamental frequency as a function of the magnetic field strength B and plasma density n for our assumed length L.
From Figure 1, we can see that for common plasma densities and magnetic field strengths [6], the fundamental frequency is in the kHz to MHz range. Taking an upper estimate for the range of human hearing as $20\,\text{kHz}$ [7], we find that for a reasonable magnetic field strength of $B = 1\,\text{T}$, the *lightsaber* must have a plasma density of $n \approx 10^{23}\,\text{m}^{-3}$. This is comparable to the density of plasmas produced by modern-day high-powered lasers [6] and so would be well within the technological capabilities of the *Jedi*.
This result is for a high $20\,\text{kHz}$ hum, in the movies the *lightsaber* hum is a much lower pitch and so we would likely require a density of $10^{26}-10^{28}\,\text{m}^{-3}$, assuming that the magnetic field of *lightsaber* lies in the $1-100\,\text{T}$ range.

References

[1] Wookieepedia. *Lightsaber* `https://starwars.fandom.com/wiki/Lightsaber` [Accessed 11 November 2025]

[2] Alfvén, H. *Existence of Electromagnetic-Hydrodynamic Waves.* Nature 150, 405–406 (1942). https://doi.org/10.1038/150405d0

[3] W. Baumjohann & R. A. Treumann, *Basic Space Plasma Physics*, Imperial College Press, London. (2012)

[4] P. A. Tipler and G. Mosca, *Physics for Scientists and Engineers*, Freeman, New York (2007)

[5] S. J, Blundell and K. M. Blundell, *Concepts in Thermal Physics* Oxford University Press, Oxford. (2010)

[6] P. Gibbon, *Introduction to Plasma Physics* arXiv preprint arXiv:2007.04783 (2020).`https://arxiv.org/abs/1705.10529` [Accessed 11 November 2025]

[7] Purves D, Augustine GJ, Fitzpatrick D, et al., editors. Neuroscience. 2nd edition. Sunderland (MA): Sinauer Associates; 2001. The Audible Spectrum. Available from: `https://www.ncbi.nlm.nih.gov/books/NBK10924/` [Accessed 11 November 2025]