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Polarization of Synchrotron Radiation in Galactic Jets

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The analysis of electromagnetic radiation serves as a primary method for studying the Universe that surrounds us. The main mechanisms for the generation of electromagnetic waves by charged particles can be conditionally divided into bound-bound transitions (atomic and molecular), bound-free transitions (recombination of ions), and free-free transitions (bremsstrahlung radio emission of electrons flying near ions), see, for example, [1]. Additionally, both coherent and incoherent mechanisms of emission exist in the radio range, occurring in dense plasma (e.g., sporadic solar radiation) as well as in a vacuum (e.g., synchrotron radiation). The latter plays an enormous role in radio astronomy, and will be the focus of this discussion.

Without delving into what synchrotron radiation is, for the task at hand it is essential to remember two key aspects: first, the source of this radiation are relativistic electrons, and second, this radiation is polarized, see for example [2]. Such polarized radiation, propagating in a medium with an embedded magnetic field, experiences the Faraday effect—the rotation of the plane of polarization, proportional to the longitudinal component of the magnetic field along the line of sight and the length of the path traveled. Massive astrophysical scales, such as, for example, the thicknesses of galaxies and nebulae, compensate for relatively small magnetic fields and even where the minuteness of the fields does not allow for the detection of effects such as Zeeman splitting or Doppler broadening—the Faraday effect enables humanity's astrophysical "magnetometer" to probe deep into distant galaxies and nebulae. Of course, measuring cosmic Faraday rotation is a very complex and laborious procedure and, in particular, requires measuring the rotation of the plane of polarization not at a single wavelength, but at multiple wavelengths. However, astrophysicists, with the aid of modern radio telescopes, have learned to cope with many technical issues in observations of such nonthermal radio emissions [3].

The talk will focus on Burn's well-known formula [4], derived in 1966, for the polarization of synchrotron radiation from a flat galaxy as a function of wavelength. In this case, both the radiation sources and the magnetic field are located within the same region, making the computation of the plane rotation of polarization due to Faraday rotation slightly more complicated than for the classical Faraday screen through which light from a distant source passes. Nevertheless, the simplicity of the resulting formulas, a detailed mathematical derivation of which can be found in [5], has ensured the wide applicability of Burn's results for assessing astrophysical magnetic fields to this day. There are numerous works in this area, and it would be remiss not to mention significant contributions from distinguished scientists such as Richard Veilbinsky, Elli Berkhauzen, Rainer Beck, and Marita Krause. Using Burn's formula, these researchers have greatly contributed to our modern understanding of the Universe's magnetic field formation [6]. However, there is a serious issue with the universal applicability of Burn's formula. The problem is that not all magnetic structures in the Universe resemble a thin flat disk of constant thickness, making its default application to all objects for synchrotron radiation analysis a rather contentious decision.

Main Objective

The primary goal of this presentation is to show the extent to which Burn's formula is applicable (or rather, inapplicable) to objects significantly different from flat disks, particularly to galactic jets. Such jets are cylindrical structures protruding perpendicularly or at an angle from flat, disk-like, or spiral galaxies. According to modern theories, these areas are also saturated with magnetic fields, much like galactic disks, and contain relativistic electrons, consequently undergoing Faraday rotation of the polarization plane of synchrotron radiation as well. However, the geometry of jet regions, their azimuthal symmetry, and the complexity of the field lead to doubts about the applicability of Burn's formula even as a zeroth-order approximation. In the presentation, following the ideas of Burn and other authors, we will demonstrate the derivation of the dependencies of the degrees of polarization on the wavelength for synchrotron radiation in such cylindrical areas. We hope that this study will be of interest both from theoretical and practical viewpoints for applications not only to galactic jets but also to other objects of similar structure. The work has been supported by the BASIS Foundation Grant No. 21-1-3-63-1.

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