



# The Gamma-Ray Pulsar Phenomenology in View of 3D Kinetic Global Magnetosphere Models

Constantinos Kalapotharakos<sup>1,2</sup>, Zorawar Wadiasingh<sup>1,2</sup>, Alice K. Harding<sup>2</sup>, and Demosthenes Kazanas<sup>2</sup>

<sup>1</sup> University of Maryland, College Park (UMCP/CRESST II) College Park, MD 20742, USA;

[constantinos.kalapotharakos@nasa.gov](mailto:constantinos.kalapotharakos@nasa.gov), [ckalapotharakos@gmail.com](mailto:ckalapotharakos@gmail.com)

<sup>2</sup> Astrophysics Science Division, NASA/Goddard Space Flight Center Greenbelt, MD 20771, USA

Theoretical Division, Los Alamos National Laboratory Los Alamos, NM 87545, USA

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## Abstract

We develop kinetic plasma models of pulsar magnetospheres with magnetic-field-line-dependent plasma injection that reveal the importance of various magnetosphere regions in regulating the  $\gamma$ -ray emission. We set different particle injection rates for the so-called open, closed, and separatrix zones. Moderate particle injection rates in open and closed zones ensure a global field structure close to the force-free structure, while the dissipation occurs mainly in and around the equatorial current sheet. The particles that are injected into the separatrix zone affect the particle populations that enter the equatorial current sheet region, and therefore the corresponding accelerating electric fields, particle energies, the spectral cutoff energy, and  $\gamma$ -ray efficiency. The separatrix zone models reproduce the recently discovered fundamental plane of  $\gamma$ -ray pulsars consistent with curvature radiation emission, the  $\gamma$ -ray light-curve shapes, and the radio-lag versus peak-separation correlation reported in the Fermi second pulsar catalog. The model beaming factors indicate that the pulsar total  $\gamma$ -ray luminosities listed in the Fermi catalogs are overestimations of the actual ones. We find that the radiation reaction limited regime starts ceasing to govern the high-energy emission for  $\dot{E} \lesssim 10^{34} \text{ erg s}^{-1}$ . Our results also indicate that toward high magnetic inclination angles, the  $V$  point around the rotational equator migrates well inside the light cylinder, sparking additional peaks in the  $\gamma$ -ray pulse profiles. We find that an equivalent enhanced particle injection beyond the  $V$  point strengthens these features, making the model  $\gamma$ -ray light curves inconsistent with those observed.

Unified Astronomy Thesaurus concepts: Pulsars (1306); Gamma-rays (637); Gamma-ray telescopes (634);

Computational methods (1965); Neutron stars (1108)

## 1. Introduction

Over the past decade, the Fermi Large Area Telescope (LAT) has greatly increased the number of  $\gamma$ -ray rotation-powered pulsars detected between 30 MeV and 300 GeV. The LAT has detected over 270 new  $\gamma$ -ray pulsars to date, 117 of which were compiled in the Second Fermi Pulsar Catalog (2PC; Abdo et al. 2013) and more are expected later this year in the forthcoming Third Pulsar Catalog (3PC).

The Fermi data largely ruled out the possibility that the observed  $\gamma$ -rays originate from near the stellar surface, implicating the outer magnetosphere as the region of the pulsar  $\gamma$ -ray emission in most pulsars. Moreover, the patterns of the  $\gamma$ -ray light curves show clear dependence of the  $\gamma$ -ray pulse peak separation  $\Delta$  on the phase-lag between radio and  $\gamma$ -ray emission  $\delta$ . This important multi-wavelength correlation sets strict constraints on the pulsar emission physics and geometry (Bai & Spitkovsky 2010; Contopoulos & Kalapotharakos 2010; Kalapotharakos et al. 2014). These studies indicated that the equatorial current sheet (ECS), a characteristic feature of the force-free (FF) global magnetosphere solutions (Contopoulos et al. 1999; Spitkovsky 2006; Timokhin 2006) emerging at and beyond the light cylinder (LC), was a prime candidate region for the observed  $\gamma$ -ray pulsar emission.

Kalapotharakos et al. (2017), assuming curvature radiation in the radiation reaction limited (RRL) regime that occurs at the ECS region near the LC, demonstrated that the LAT data imply

the corresponding accelerating electric-field components,  $E_{\text{acc}}$ , and their dependence on the spin-down power  $\dot{E}$ , uncovering the corresponding operational regime, i.e., the dissipation degree of the emitting region.

More recently, Kalapotharakos et al. (2019), using 88  $\gamma$ -ray pulsars from the 2PC, showed that the entire  $\gamma$ -ray pulsar population, i.e., millisecond pulsars (MPs) and young pulsars (YPs), lie on a fundamental plane (FP)

$$L_{\gamma} \propto \epsilon_{\text{cut}}^{1.38 \pm 0.24} B_{\text{LC}}^{0.17 \pm 0.05} \dot{E}^{0.41 \pm 0.08} \quad (1)$$

that relates their total  $\gamma$ -ray luminosity,  $L_{\gamma}$ , spectral cutoff energy,  $\epsilon_{\text{cut}}$ , stellar surface magnetic field,  $B_{\text{LC}}$ , and spin-down power,  $\dot{E}$ . Remarkably, the observed FP is consistent with the theoretically expected behavior

$$L_{\gamma} \propto A_{\text{cut}}^{1/3} B_{\text{LC}}^{1/6} \dot{E}^{5/12} \quad (2)$$

that attributes the pulsar  $\gamma$ -ray emission to curvature radiation in the RRL<sup>1</sup> by particles accelerated in the ECS just outside the LC.

Kalapotharakos et al. (2022)<sup>2</sup> expanded the pulsar sample by more than two-fold to 190, which they used to update the FP

<sup>1</sup> Kalapotharakos et al. (2022) showed that the RRL regime is a sufficient but not necessary condition for the derivation of the FP theoretical scaling, i.e., Equation (2).

<sup>2</sup> They adopted the spectral analysis data from the 12 yr incremental version of the fourth Fermi-LAT catalog of point  $\gamma$ -ray sources (4FGL, Abdollahi et al. 2020; 4FGL-DR1, for Data Release 1, Fermi-LAT collaboration et al. 2022) combined with data from the Australia Telescope National Facility (ATNF) Pulsar Catalog (Manchester et al. 2005).



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## **Models Of Phenomenology Conven:**

**Beyond Standard Model Phenomenology at the LHC** Priscila de Aquino, 2013-09-16 This thesis provides an introduction to the physics of the Standard Model and beyond and to the methods used to analyse Large Hadron Collider LHC data The hierarchy problem astrophysical data and experiments on neutrinos indicate that new physics can be expected at the now accessible TeV scale This work investigates extensions of the Standard Model with gravitons and gravitinos in the context of supergravity The production of these particles in association with jets is studied as one of the most promising avenues for researching new physics at the LHC Advanced simulation techniques and tools such as algorithms allowing the computation of Feynman graphs and helicity amplitudes are first developed and then employed **Standard Model**

**Phenomenology** Shaaban Khalil, Stefano Moretti, 2022-06-20 This new book is fully up to date with all the latest developments on both theoretical and experimental investigations of the Standard Model SM of particle physics with a particular emphasis on its historical development on both sides It further stresses the cross fertilisation between the two sub disciplines of theoretical and experimental particle physics which has been instrumental in establishing the SM In other words the book develops a truly phenomenological attitude to the subject In addition to emphasising the successes of the SM this book also critically assesses its limitations and raises key unanswered questions for the purpose of presenting a new perspective of how to further our knowledge above and beyond it It also contains both historical information from past experiments and latest results from the Large Hadron Collider at CERN This book will be an invaluable reference to advanced undergraduate and postgraduate students in addition to early stage researchers in the field Key Features Provides a unique approach not found in current literature in developing and verifying the SM Presents the theory pedagogically but rigorously from basic knowledge of quantum field theory Brings together experimental and theoretical practice in one cohesive text Particle Theory and Phenomenology

International Kazimierz Meeting on Particle Physics 1995, Iowa State University, Kenneth E. Lassila, 1996 In this book leading researchers in theoretical and experimental particle physics summarize the recent developments in their areas of expertise There are also concentrated presentations on top quark discoveries and new theory consequences of top data **The Phenomenological Theory of Linear Viscoelastic**

**Behavior** Nicholas W. Tschoegl, 2012-12-06 One of the principal objects of theoretical research in any department of knowledge is to find the point of view from which the subject appears in its greatest simplicity J Willard Gibbs This book is an outgrowth of lectures I have given on and off over some sixteen years in graduate courses at the California Institute of Technology and in abbreviated form elsewhere It is nevertheless not meant to be a textbook I have aimed at a full exposition of the phenomenological theory of linear viscoelastic behavior for the use of the practicing scientist or engineer as well as the academic teacher or student The book is thus primarily a reference work In accord with the motto above I have chosen to describe the theory of linear viscoelastic behavior through the use of the Laplace transformation The treatment of linear time

dependent systems in terms of the Laplace transforms of the relations between the excitation and response variables has by now become commonplace in other fields. With some notable exceptions it has not been widely used in viscoelasticity. I hope that the reader will find this approach useful.

**Phenomenology of Gauge Theories** J. Thanh Van Tran, 1984

**Theory And Phenomenology Of Sparticles: An Account Of Four-dimensional  $N=1$  Supersymmetry In High Energy Physics** Manuel Drees, Rohini Godbole, Probir Roy, 2005-01-18

Supersymmetry or SUSY, one of the most beautiful recent ideas of physics, predicts sparticles existing as superpartners of particles. This book gives a theoretical and phenomenological account of sparticles. Starting from a basic level, it provides a comprehensive pedagogical and user-friendly treatment of the subject of four-dimensional  $N=1$  supersymmetry as well as its observational aspects in high energy physics and cosmology. Part One of the book introduces the requisite formal theory preceded by a discussion of the naturalness problem. Part Two describes the supersymmetrization of the Standard Model of particle interactions as well as the origin of soft supersymmetry breaking and how it can be mediated from higher energies. Search strategies for sparticles, supersymmetric Higgs bosons, nonminimal scenarios, and cosmological implications are some of the other topics covered. Novel features of the book include a dictionary between two-component and four-component spinor notation, a step-by-step derivation of the nonrenormalization theorem, an extended discussion of supersymmetric renormalization group evolution, detailed analyses of minimal and nonminimal models with gravity, including anomaly-mediated and gauge-mediated supersymmetry breaking, as well as elaborate self-contained presentations of collider signals of sparticles, plus supersymmetric Higgs bosons and of supersymmetric cosmology. Appendices list all Feynman rules for the vertices of the Minimal Supersymmetric Standard Model.

*Mathematical, Theoretical And Phenomenological Challenges Beyond The Standard Model: Perspectives Of The Balkan Collaborations* Goran Djordjevic, Ljubisa Nesic, Julius Wess, 2005-03-28

This book contains invited lectures and shorter contributions to the workshop Mathematical Theoretical and Phenomenological Challenges Beyond the Standard Model Perspectives of the Balkan Collaborations BW2003, which was held in Vrnjacka Banja, Serbia, 29 August–3 September. It was one of the first high-level HEP workshops in the South East European region after many years, and the papers give a clear perspective on the scientific potential of this area. The contributions cover topics and problems under research in high energy particle physics and quantum field theory, in particular string theory and M-theory, grand unification, quantum gravity, and cosmology, standard and noncommutative quantum field theory. Some papers concern more mathematical topics, such as the integrability, topology of gauge groups, and operator matrices. The contributors are leading international scientists, such as G. Arutyunov, K. Behrnt, G. Cardoso, M. Chaichian, G. Lazarides, D. Lust, N. Kaloper, G. Senjanovic, and J. Wess, with an emphasis on researchers from South East Europe, including B. Bajc, A. Mikovic, and B. Sazdovitch. The proceedings have been selected for coverage in Index to Scientific Technical Proceedings, ISTP, ISI Proceedings, Index to Scientific Technical Proceedings, ISTP, CDROM version, ISI Proceedings, CC Proceedings, Engineering Physical Sciences.

*Phenomenology and Media* Paul Majkut, Alberto J. L. Carrillo

Canán,2010 During the first decade of its existence from 1999 to 2008 the Society for Phenomenology and Media held annual international conferences in San Diego California Puebla Mexico Krakow Poland Helsinki Finland Buenos Aires Argentina Provo Utah and Monmouth Oregon Papers delivered at these conferences were published in the Society s journal Glimpse The current volume is an anthology of essays drawn from the first ten years of Glimpse From its birth the Society sought to bridge the gap between contemporary media theory and practice and phenomenological insight Essays in this anthology include work on digital representation film mobile communication cyberspace medieval manuscripts print radio the stage TV virtual reality and other media as well as theoretical papers dealing with media aesthetics epistemology ethics politics and ontology **An Introduction to the Phenomenological Theory of Ferroelectricity** J. Grindlay,2017-08-26 An

Introduction to the Phenomenological Theory of Ferroelectricity covers topics about the basis and derivation of the macroscopic or phenomenological theory of the elastic dielectric and thermal properties of crystals as applied in the field of ferroelectricity The monograph discusses the elastic dielectric and thermal properties of ferroelectric crystals the standard linear time dependent electroelastic theory the non linear static properties of an elastic dielectric on a variational principle and the phenomenological theory of the static thermal elastic and dielectric properties of a homogeneous material The book also describes the theory of the static non linear behavior of an elastic dielectric as well as the phenomenological models for ferroelectricity Students taking physics courses and practicing physicists will find the book invaluable Science and Convention Jerzy Giedymin,2014-05-20 Science and Convention Essays on Henri Poincare s Philosophy of Science and The Conventionalist Tradition contains essays concerned with Henri Poincare s philosophy of science physics in particular and with the conventionalist tradition in philosophy that he revived and reshaped simultaneously with but independently of Pierre Duhem Separating five essays as chapters the book discusses the main ideas of the philosophy Essays 1 and 5 traces at least some of its historical background Essays 1 2 and 3 and provides some of its developments Essays 2 and 4

**Phenomenological Aspects Of Superstring Theories, Past '97** Goran Senjanovic,Alexei Smirnov,1999-01-25

**Beyond Mimesis and Convention** Roman Frigg,Matthew Hunter,2010-04-28 Representation is a concern crucial to the sciences and the arts alike Scientists devote substantial time to devising and exploring representations of all kinds From photographs and computer generated images to diagrams charts and graphs from scale models to abstract theories representations are ubiquitous in and central to science Likewise after spending much of the twentieth century in proverbial exile as abstraction and Formalist aesthetics reigned supreme representation has returned with a vengeance to contemporary visual art Representational photography video and ever evolving forms of new media now figure prominently in the globalized art world while this return of the real has re energized problems of representation in the traditional media of painting and sculpture If it ever really left representation in the arts is certainly back Central as they are to science and art these representational concerns have been perceived as different in kind and as objects of separate intellectual traditions

Scientific modeling and theorizing have been topics of heated debate in twentieth century philosophy of science in the analytic tradition while representation of the real and ideal has never moved far from the core humanist concerns of historians of Western art Yet both of these traditions have recently arrived at a similar impasse Thinking about representation has polarized into oppositions between mimesis and convention Advocates of mimesis understand some notion of mimicry or similarity resemblance or imitation as the core of representation something represents something else if and only if the former mimics the latter in some relevant way Such mimetic views stand in stark contrast to conventionalist accounts of representation which see voluntary and arbitrary stipulation as the core of representation Occasional exceptions only serve to prove the rule that mimesis and convention govern current thinking about representation in both analytic philosophy of science and studies of visual art This conjunction can hardly be dismissed as a matter of mere coincidence In fact researchers in philosophy of science and the history of art have increasingly found themselves trespassing into the domain of the other community pilfering ideas and approaches to representation Cognizant of the limitations of the accounts of representation available within the field philosophers of science have begun to look outward toward the rich traditions of thinking about representation in the visual and literary arts Simultaneously scholars in art history and affiliated fields like visual studies have come to see images generated in scientific contexts as not merely interesting illustrations derived from high art but as sophisticated visualization techniques that dynamically challenge our received conceptions of representation and aesthetics Beyond Mimesis and Convention Representation in Art and Science is motivated by the conviction that we students of the sciences and arts are best served by confronting our mutual impasse and by recognizing the shared concerns that have necessitated our covert acts of kleptomania Drawing leading contributors from the philosophy of science the philosophy of literature art history and visual studies our volume takes its brief from our title That is these essays aim to put the evidence of science and of art to work in thinking about representation by offering third or fourth or fifth ways beyond mimesis and convention In so doing our contributors explore a range of topics fictionalism exemplification neuroaesthetics approximate truth that build upon and depart from ongoing conversations in philosophy of science and studies of visual art in ways that will be of interest to both interpretive communities To put these contributions into context the remainder of this introduction aims to survey how our communities have discretely arrived at a place wherein the perhaps surprising collaboration between philosophy of science and art history has become not only salubrious but a matter of necessity

*Critical Theory and Disability* Teodor Mladenov, 2016-06-30 *Critical Theory and Disability* explores social and ontological issues encountered by present day disabled people applying ideas from disability studies and phenomenology It focuses on disabling contexts in order to highlight and criticize the ontological assumptions of contemporary society particularly those related to the meaning of human being In empirical terms the book explores critically social practices that undermine disabled people's well being drawing on cases from contemporary Bulgaria It includes in depth examination of key

mechanisms such as disability assessment personal assistance direct payments and disability based discrimination On this basis wider sociological and ontological claims are made concerning the body identity otherness and exclusion Extended Objects And Bound Systems: From Relativistic Description To Phenomenological Application - Proceedings Of The International Symposium S Naka,O Hara,S Ishida,1993-02-08 Counterfeiting which has emerged as a recent global phenomenon has arisen due to economic liberalisation the changing nature of society and new competitive structures Branding has become an increasingly important area of research in marketing as well as a crucial decision making area in strategic marketing management Counterfeit related activities challenge the existing theoretical and methodological framework in many ways particularly consumer behavior and branding This book brings together the three areas counterfeiting branding and consumer behaviour within a very robust methodological and statistical modelling framework

In the Shadow of Phenomenology Stephen H. Watson,2009-04-07 A new monograph exploring the theoretical status of Merleau Ponty s contributions to epistemology and rationality in his account of phenomenology **Phenomenological Neuropsychiatry** Aaron L. Mishara,Marcin Moskalewicz,Michael A. Schwartz,Alexander Kranjec,2024-06-30 This innovative book offers a multidimensional exploration of the epistemological foundations of psychiatry and its major disorders By emphasizing the importance of phenomenology in unravelling the intricate interplay between basic categories of human experience and neurobiological processes it advocates for a shift in both psychiatric research and clinical practice Phenomenological Neuropsychiatry presents psychiatry as a hybrid discipline that synthesizes subjective mental experiences with objective neuroscientific findings and forms an integrative and interdisciplinary structure that provides a dialectical bridge between understanding compassion and explanation The first section of the book presents the lived experience of psychosis and argues for a more inclusive approach to mental health issues The second section examines the ways in which psychiatric knowledge is constructed and the unique challenges posed by combining understanding and explanation of mental disorders Section three sheds light on how disruptions in bodily experiences memory processes and self perception can contribute to the development and manifestation of psychiatric issues The following section discusses disorders of mood and anxiety including the phenomena of depression obsessions and depersonalization The fifth and final section provides an in depth examination of psychotic disorders It covers a range of topics such as timing intentionality self monitoring of action in schizophrenia and the neurobiology of prodromal psychosis As a singular work dedicated to revitalizing and advancing cross fertilization between psychiatry and phenomenology this groundbreaking book clears the foggy operationalized clusters of mental symptoms that may obscure diagnosis and treatment and argues for systematic integration of patient subjectivity and collaboration in clinical research It features an authorship of the leading clinicians and thinkers from throughout the world in psychiatry psychology neuroscience social sciences and philosophy Phenomenological Neuropsychiatry How Patient Experience Bridges the Clinic with Clinical Neuroscience is a major contribution to the clinical literature and a must read for

psychiatrists neurologists psychologists and professionals and students from other disciplines concerned with absorbing a deeper understanding of psychiatric disorders      The Higgs Hunter's Guide John F. Gunion,2018-03-05 The Higgs Hunter s Guide is a definitive and comprehensive guide to the physics of Higgs bosons In particular it discusses the extended Higgs sectors required by those recent theoretical approaches that go beyond the Standard Model including supersymmetry and superstring inspired models      **Mathematical Modeling and Simulation** Mr. Rohit Manglik,2024-07-08 EduGorilla Publication is a trusted name in the education sector committed to empowering learners with high quality study materials and resources Specializing in competitive exams and academic support EduGorilla provides comprehensive and well structured content tailored to meet the needs of students across various streams and levels      Nuclear Science Abstracts ,1976      Proto-Phenomenology and the Nature of Language Lawrence J. Hatab,2017-05-05 How is it that sounds from the mouth or marks on a page which by themselves are nothing like things or events in the world can be world disclosive in an automatic manner In this fascinating and important book Lawrence J Hatab presents a new vocabulary for Heidegger s early phenomenology of being in the world and applies it to the question of language He takes language to be a mode of dwelling in which there is an immediate direct disclosure of meanings and sketches an extensive picture of proto phenomenology how it revises the posture of philosophy and how this posture applies to the nature of language Representational theories are not rejected but subordinated to a presentational account of immediate disclosure in concrete embodied life The book critically addresses standard theories of language such that typical questions in the philosophy of language are revised in a manner that avoids binary separations of language and world speech and cognition theory and practise realism and idealism internalism and externalism



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