

## ALMOST COMPLEX STRUCTURES ON SPHERES

PANAGIOTIS KONSTANTIS AND MAURIZIO PARTON

**ABSTRACT.** In this paper we review the well-known fact that the only spheres admitting an almost complex structure are  $S^2$  and  $S^6$ . The proof described here uses characteristic classes and the Bott periodicity theorem in topological  $K$ -theory. This paper originates from the talk “Almost Complex Structures on Spheres” given by the second author at the MAMI workshop “(Non)-existence of complex structures on  $S^6$ ”, held in Marburg from March 27th to March 30th, 2017. It is a review paper, and as such no result is intended to be original. We tried to produce a clear, motivated and as much as possible self-contained exposition.

## 1. INTRODUCTION

A *complex manifold* is a differentiable manifold  $M$  whose transition functions are holomorphic. If  $x+iy$  denotes local coordinates around  $p \in M$ , the multiplication by  $i$  induces an endomorphism  $J_p$  of the tangent space  $T_p(M)$  given by

$$\begin{cases} \frac{\partial}{\partial x}|_p \longmapsto \frac{\partial}{\partial y}|_p \\ \frac{\partial}{\partial y}|_p \longmapsto -\frac{\partial}{\partial x}|_p \end{cases} \quad (1.1)$$

Writing the Cauchy-Riemann equations on the intersection of two overlapping charts, one obtains that  $J_p$  is globally defined. The endomorphism  $J : T(M) \rightarrow T(M)$ , locally defined by (1.1), is an example of almost complex structure. More generally, an *almost complex structure* on a real differentiable manifold  $M$  is a linear bundle morphism  $J$  of the tangent vector bundle  $T(M)$  satisfying  $J^2 = -\text{Id}$ . The pair  $(M, J)$  is called an *almost complex manifold*, and whenever  $J$  arises from (1.1) for certain holomorphic coordinates  $x+iy$ , one says that the almost complex structure  $J$  is *integrable*.

One often refers to the above discussion by the sentence: “on a complex manifold the multiplication by  $i$  gives a compatible integrable almost complex structure”.

The problem of deciding if a given almost complex structure  $J$  is integrable is nowadays an easy task, due to the celebrated Newlander-Nirenberg Theorem [NN57]. Much more challenging is the problem of deciding whether a differentiable manifold admits *any* integrable almost complex structure: in real dimension  $> 4$ , the only known general obstruction is the trivial one, that is, the existence of an almost complex structure.

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*Date:* July 14, 2017.

*2010 Mathematics Subject Classification.* Primary 53C15; Secondary 01-02, 55R40, 55R50, 57R20, 19L99.

*Key words and phrases.* Almost Complex Structures on Spheres, Classifying Space, Characteristic Classes.

The second author was supported by the GNSAGA group of INdAM and by the MIUR under the PRIN Project “Varietà reali e complesse: geometria, topologia e analisi armonica”.

# Almost Complex And Complex Structures

**Izu Vaisman**



## **Almost Complex And Complex Structures:**

Almost Complex Structures - Proceedings Of The International Workshop Kouei Sekigawa, Stancho Dimiev, 1994-12-16

The geometry of almost complex structures is fundamentally concerned with complex analysis and also mathematical physics In view of the increasing interest in almost complex structures this volume will be useful in future studies of geometry and complex analysis and related fields *Almost Complex And Complex Structures* Chuan-chih Hsiung, 1995-08-31 This book gives a self contained fundamental study of the subject Besides the following special features it contains the author's detailed solution to the long standing unsolved problem in the theory of complex manifolds Does there exist a complex structure on the six sphere The special features of the book are a classification of almost complex and similarly almost Hermitian structures together with inclusion relations discussions about various known almost Hermitian structures a necessary and sufficient condition for a general almost Hermitian manifold to have constant holomorphic sectional or bisectonal curvature and similar conditions for various special almost Hermitian manifolds some complex Laplacians together with some of their relationships with the real Laplacian the spectral geometry of Riemannian manifolds and some general almost Hermitian manifolds including Kählerian manifolds as a special case conditions for an almost complex structure to be a complex structure some vanishing theorems for Riemannian and almost Hermitian manifolds **Several Complex Variables and**

**Complex Manifolds** Mike Field, 1982 Annotation This self contained and relatively elementary introduction to functions of several complex variables and complex especially compact manifolds is intended to be a synthesis of those topics and a broad introduction to the field Part I is suitable for advanced undergraduates and beginning postgraduates whilst Part II is written more for the graduate student The work as a whole will be useful to professional mathematicians or mathematical physicists who wish to acquire a working knowledge of this area of mathematics Many exercises have been included and indeed they form an integral part of the text The prerequisites for understanding Part I would be met by any mathematics student with a first degree and together the two parts provide an introduction to the more advanced works in the subject **Symplectic**

**4-Manifolds and Algebraic Surfaces** Denis Auroux, Fabrizio Catanese, Marco Manetti, Gang Tian, Paul Seidel, Bernd Siebert, Ivan Smith, 2008-04-17 Modern approaches to the study of symplectic 4 manifolds and algebraic surfaces combine a wide range of techniques and sources of inspiration Gauge theory symplectic geometry pseudoholomorphic curves singularity theory moduli spaces braid groups monodromy in addition to classical topology and algebraic geometry combine to make this one of the most vibrant and active areas of research in mathematics It is our hope that the five lectures of the present volume given at the C I M E Summer School held in Cetraro Italy September 2 10 2003 will be useful to people working in related areas of mathematics and will become standard references on these topics The volume is a coherent exposition of an active field of current research focusing on the introduction of new methods for the study of moduli spaces of complex structures on algebraic surfaces and for the investigation of symplectic topology in dimension 4 and higher **The Wild World of**

**4-Manifolds** Alexandru Scorpan, 2022-01-26 What a wonderful book I strongly recommend this book to anyone especially graduate students interested in getting a sense of 4 manifolds MAA Reviews The book gives an excellent overview of 4 manifolds with many figures and historical notes Graduate students nonexperts and experts alike will enjoy browsing through it Robion C Kirby University of California Berkeley This book offers a panorama of the topology of simply connected smooth manifolds of dimension four Dimension four is unlike any other dimension it is large enough to have room for wild things to happen but small enough so that there is no room to undo the wildness For example only manifolds of dimension four can exhibit infinitely many distinct smooth structures Indeed their topology remains the least understood today To put things in context the book starts with a survey of higher dimensions and of topological 4 manifolds In the second part the main invariant of a 4 manifold the intersection form and its interaction with the topology of the manifold are investigated In the third part as an important source of examples complex surfaces are reviewed In the final fourth part of the book gauge theory is presented this differential geometric method has brought to light how unwieldy smooth 4 manifolds truly are and while bringing new insights has raised more questions than answers The structure of the book is modular organized into a main track of about two hundred pages augmented by extensive notes at the end of each chapter where many extra details proofs and developments are presented To help the reader the text is peppered with over 250 illustrations and has an extensive index

Contemporary Geometry Hung-Hsi Wu, 2013-06-29 Early one morning in April of 1987 the Chinese mathematician J Q Zhong died unexpectedly of a heart attack in New York He was then near the end of a one year visit in the United States When news of his death reached his Chinese American friends it was immediately decided by one and all that something should be done to preserve his memory The present volume is an outgrowth of this sentiment His friends in China have also established a Zhong Jia Qing Memorial Fund which has since twice awarded the Zhong Jia Qing prizes for Chinese mathematics graduate students It is hoped that at least part of the reasons for the esteem and affection in which he was held by all who knew him would come through in the succeeding pages of this volume The three survey chapters by Li and Treibergs Lu and Siu Chapters 1 3 all center around the areas of mathematics in which Zhong made noteworthy contributions In addition to putting Zhong's mathematical contributions in perspective these articles should be useful also to a large segment of the mathematical community together they give a coherent picture of a sizable portion of contemporary geometry The survey of Lu differs from the other two in that it gives a firsthand account of the work done in the People's Republic of China in several complex variables in the last four decades

**Geometric, Algebraic And Topological Methods For Quantum Field Theory - Proceedings Of The 2011 Villa De Leyva Summer School** Sylvie

Paycha, Alexander Cardona, Hernan Ocampo, Andres F Reyes-lega, Carolina Neira-jimenez, 2013-11-15 Based on lectures held at the 7th Villa de Leyva summer school this book presents an introduction to topics of current interest in the interface of geometry topology and physics It is aimed at graduate students in physics or mathematics with interests in geometric

algebraic as well as topological methods and their applications to quantum field theory This volume contains the written notes corresponding to lectures given by experts in the field They cover current topics of research in a way that is suitable for graduate students of mathematics or physics interested in the recent developments and interactions between geometry topology and physics The book also contains contributions by younger participants displaying the ample range of topics treated in the school A key feature of the present volume is the provision of a pedagogical presentation of rather advanced topics in a way which is suitable for both mathematicians and physicists Mathematical Structures Joachim

Hilgert,2024-08-06 This textbook is intended to be accessible to any second year undergraduate in mathematics who has attended courses on basic real analysis and linear algebra It is meant to help students to appreciate the diverse specialized mathematics courses offered at their universities Special emphasis is on similarities between mathematical fields and ways to compare them The organizing principle is the concept of a mathematical structure which plays an important role in all areas of mathematics The mathematical content used to explain the structural ideas covers in particular material that is typically taught in algebra and geometry courses The discussion of ways to compare mathematical fields also provides introductions to categories and sheaves whose ever increasing role in modern mathematics suggests a more prominent role in teaching The book is the English translation of the second edition of *Mathematische Strukturen* Springer 2024 written in German The translation was done with the help of artificial intelligence A subsequent human revision was done primarily in terms of content **Analysis, Manifolds and Physics Revised Edition** Yvonne Choquet-Bruhat,Cécile DeWitt-Morette,Margaret

Dillard-Bleick,1982 This reference book which has found wide use as a text provides an answer to the needs of graduate physical mathematics students and their teachers The present edition is a thorough revision of the first including a new chapter entitled Connections on Principle Fibre Bundles which includes sections on holonomy characteristic classes invariant curvature integrals and problems on the geometry of gauge fields monopoles instantons spin structure and spin connections Many paragraphs have been rewritten and examples and exercises added to ease the study of several chapters The index includes over 130 entries **Fifth International Congress of Chinese Mathematicians** Lizhen Ji,2012 This two part

volume represents the proceedings of the Fifth International Congress of Chinese Mathematicians held at Tsinghua University Beijing in December 2010 The Congress brought together eminent Chinese and overseas mathematicians to discuss the latest developments in pure and applied mathematics Included are 60 papers based on lectures given at the conference Concrete Operators, Spectral Theory, Operators in Harmonic Analysis and Approximation Manuel Cepedello

Boiso,Håkan Hedenmalm,Marinus A. Kaashoek,Alfonso Montes Rodríguez,Sergei Treil,2013-11-04 This book contains a collection of research articles and surveys on recent developments on operator theory as well as its applications covered in the IWOTA 2011 conference held at Sevilla University in the summer of 2011 The topics include spectral theory differential operators integral operators composition operators Toeplitz operators and more The book also presents a large number of

techniques in operator theory      **Differential Geometry of Lightlike Submanifolds** Krishan L. Duggal, Bayram Sahin, 2011-02-02 This book presents research on the latest developments in differential geometry of lightlike degenerate subspaces The main focus is on hypersurfaces and a variety of submanifolds of indefinite Kählerian Sasakian and quaternion Kähler manifolds      **Direct and Projective Limits of Geometric Banach Structures.** Patrick Cabau, Fernand

Pelletier, 2023-10-06 This book describes in detail the basic context of the Banach setting and the most important Lie structures found in finite dimension The authors expose these concepts in the convenient framework which is a common context for projective and direct limits of Banach structures The book presents sufficient conditions under which these structures exist by passing to such limits In fact such limits appear naturally in many mathematical and physical domains Many examples in various fields illustrate the different concepts introduced Many geometric structures existing in the Banach setting are stable by passing to projective and direct limits with adequate conditions The convenient framework is used as a common context for such types of limits The contents of this book can be considered as an introduction to differential geometry in infinite dimension but also a way for new research topics This book allows the intended audience to understand the extension to the Banach framework of various topics in finite dimensional differential geometry and moreover the properties preserved by passing to projective and direct limits of such structures as a tool in different fields of research

The Ricci Flow: Techniques and Applications , 2007-04-11 This book gives a presentation of topics in Hamilton's Ricci flow for graduate students and mathematicians interested in working in the subject The authors have aimed at presenting technical material in a clear and detailed manner In this volume geometric aspects of the theory have been emphasized The book presents the theory of Ricci solitons Kähler Ricci flow compactness theorems Perelman's entropy monotonicity and no local collapsing Perelman's reduced distance function and applications to ancient solutions and a primer of 3 manifold topology Various technical aspects of Ricci flow have been explained in a clear and detailed manner The authors have tried to make some advanced material accessible to graduate students and nonexperts The book gives a rigorous introduction to Perelman's work and explains technical aspects of Ricci flow useful for singularity analysis Throughout there are appropriate references so that the reader may further pursue the statements and proofs of the various results      *Tensor Analysis*

Edward Nelson, 2015-12-08 These notes are based on a course of lectures given by Professor Nelson at Princeton during the spring term of 1966 The subject of Brownian motion has long been of interest in mathematical probability In these lectures Professor Nelson traces the history of earlier work in Brownian motion both the mathematical theory and the natural phenomenon with its physical interpretations He continues through recent dynamical theories of Brownian motion and concludes with a discussion of the relevance of these theories to quantum field theory and quantum statistical mechanics Originally published in 1967 The Princeton Legacy Library uses the latest print on demand technology to again make available previously out of print books from the distinguished backlist of Princeton University Press These editions preserve

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### **The Geometry of Jordan and Lie Structures**

Wolfgang Bertram, 2003-07-01 The geometry of Jordan and Lie structures tries to answer the following question what is the integrated or geometric version of real Jordan algebras triple systems and pairs Lie theory shows the way one has to go Lie groups and symmetric spaces are the geometric version of Lie algebras and Lie triple systems It turns out that both geometries are closely related via a functor between them called the Jordan Lie functor which is constructed in this book The reader is not assumed to have any knowledge of Jordan theory the text can serve as a self contained introduction to real finite dimensional Jordan theory

### **Modern Geometric Structures and Fields** Сергей Петрович Новиков, Искандер Асанович Тайманов, 2006

Presents the basics of Riemannian geometry in its modern form as geometry of differentiable manifolds and the important structures on them This book shows that Riemannian geometry has a great influence to several fundamental areas of modern mathematics and its applications

*Moment Maps, Cobordisms, and Hamiltonian Group Actions* Victor Guillemin, Viktor L. Ginzburg, Yael Karshon, 2002 During the last 20 years localization has been one of the dominant themes in the area of equivariant differential geometry Typical results are the Duistermaat Heckman theory the Berline Vergne Atiyah Bott localization theorem in equivariant de Rham theory and the quantization commutes with reduction theorem and its various corollaries To formulate the idea that these theorems are all consequences of a single result involving equivariant cobordisms the authors have developed a cobordism theory that allows the objects to be non compact manifolds A key ingredient in this non compact cobordism is an equivariant geometrical object which they call an abstract moment map This is a natural and important generalization of the notion of a moment map occurring in the theory of Hamiltonian dynamics The book contains a number of appendices that include introductions to proper group actions on manifolds equivariant cohomology Spin  $c$  structures and stable complex structures It is geared toward graduate students and research mathematicians interested in differential geometry It is also suitable for topologists Lie theorists combinatorists and theoretical physicists Prerequisite is some expertise in calculus on manifolds and basic graduate level differential geometry

### **4-Manifolds and Kirby Calculus**

Robert E. Gompf, András I. Stipsicz, 2023-08-10 Since the early 1980s there has been an explosive growth in 4 manifold theory particularly due to the influx of interest and ideas from gauge theory and algebraic geometry This book offers an exposition of the subject from the topological point of view It bridges the gap to other disciplines and presents classical but important topological techniques that have not previously appeared in the literature Part I of the text presents the basics of the theory at the second year graduate level and offers an overview of current research Part II is devoted to an exposition of Kirby calculus or handlebody theory on 4 manifolds It is both elementary and comprehensive Part III offers in depth treatments of a broad range of topics from current 4 manifold research Topics include

branched coverings and the geography of complex surfaces elliptic and Lefschetz fibrations h cobordisms symplectic 4 manifolds and Stein surfaces The authors present many important applications The text is supplemented with over 300 illustrations and numerous exercises with solutions given in the book I greatly recommend this wonderful book to any researcher in 4 manifold topology for the novel ideas techniques constructions and computations on the topic presented in a very fascinating way I think really that every student mathematician and researcher interested in 4 manifold topology should own a copy of this beautiful book Zentralblatt MATH This book gives an excellent introduction into the theory of 4 manifolds and can be strongly recommended to beginners in this field carefully and clearly written the authors have evidently paid great attention to the presentation of the material contains many really pretty and interesting examples and a great number of exercises the final chapter is then devoted to solutions of some of these this type of presentation makes the subject more attractive and its study easier European Mathematical Society Newsletter *Cohomology and Differential Forms* Izu Vaisman, 2016-08-17 This monograph explores the cohomological theory of manifolds with various sheaves and its application to differential geometry Based on lectures given by author Izu Vaisman at Romania's University of Iasi the treatment is suitable for advanced undergraduates and graduate students of mathematics as well as mathematical researchers in differential geometry global analysis and topology A self contained development of cohomological theory constitutes the central part of the book Topics include categories and functors the de Rham cohomology with coefficients in sheaves the theory of fiber bundles and differentiable foliated and complex analytic manifolds The final chapter covers the theorems of de Rham and Dolbeault Serre and examines the theorem of Allendoerfer and Eells with applications of these theorems to characteristic classes and the general theory of harmonic forms



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