

INTERACTING BINARIES WITH ECCENTRIC ORBITS. III. ORBITAL EVOLUTION DUE TO DIRECT IMPACT AND SELF-ACCRETION

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ABSTRACT

The rapid circularization and synchronization of the stellar components in an eccentric binary system at the onset of Roche lobe overflow is a fundamental assumption common to all binary stellar evolution and population synthesis codes, even though the validity of this assumption is questionable both theoretically and observationally. Here we calculate the evolution of the orbital elements of an eccentric binary through the direct three-body integration of a massive particle ejected through the inner Lagrangian point of the donor star at periastron. The trajectory of this particle leads to three possible outcomes: direct accretion onto the companion star within a single orbit, self-accretion back onto the donor star within a single orbit, or a quasi-periodic orbit around the companion star, possibly leading to the formation of a disk. We calculate the secular evolution of the binary orbit in the first two cases and conclude that direct impact accretion can increase as well as decrease the orbital semi-major axis and eccentricity, while self-accretion always decreases the orbital semi-major axis and eccentricity. In cases where mass overflow contributes to circularizing the orbit, circularization can set in on timescales as short as a few per cent of the mass transfer timescale. In cases where mass overflow increases the eccentricity, the orbital evolution is governed by competition between mass overflow and tidal torques. In the absence of tidal torques, mass overflow results in direct impact can lead to substantially subsynchronously rotating donor stars. Contrary to assumptions common in the literature, direct impact accretion furthermore does not always provide a strong sink of orbital angular momentum in close mass-transferring binaries; in fact we instead find that a significant part can be returned to the orbit during the particle orbit. The formulation presented in this paper together with our previous work can be combined with stellar and binary evolution codes to generate a better picture of the evolution of eccentric, Roche lobe overflowing binary star systems.

Subject Headings: Celestial mechanics, Stars: Binaries: Close, Stars: Mass Loss, Accretion, Methods: Numerical

1. INTRODUCTION

In close binaries, the combined effects of stellar and orbital evolution can cause a star to fill its Roche lobe and transfer mass to its companion. If the orbit is eccentric this mass transfer is expected to commence at or near the periastron of the binary orbit where the effective Roche lobes of the component stars are smallest (Layton et al. 1998; Sepinsky et al. 2007a; Church et al. 2009; Begus et al. 2005). Until recently, studies of mass transfer in eccentric binaries mainly focused on smoothed particle hydrodynamics calculations of the mass transfer stream and much less on the effects of the mass transfer on secular binary evolution.

To the best of our knowledge, Sepinsky et al. (2007b, 2009) were the first to study in detail the secular evolution of the orbital semi-major axis and eccentricity of eccentric mass-transferring binaries. The authors adopted a perturbation method initially outlined by Hadjidemetriou (1969) and found that, depending on the binary properties at the onset of mass transfer, the orbital semi-major axis and eccentricity can either increase or decrease at a rate linearly proportional the mass transfer rate at periastron. Contrary to common assumptions, tides therefore do not always rapidly circularize binary orbits as a star evolves towards filling its Roche lobe.

Sepinsky et al. (2007b, 2009) calculated the orbital evolution due to mass transfer in eccentric binaries as-

suming mass transfer leads to the formation of an accretion disk. Tidal interactions between the disk and the donor star then allow at least some fraction of the angular momentum carried by the transferred matter to be returned to the orbit. However, if the size of the accretor is a considerable fraction of the size of the orbit, matter lost by the donor star through the inner Lagrangian point may impact the accretor's surface directly rather than form an accretion disk.

In this paper, we complement the work of Sepinsky et al. (2007b, hereafter Paper I) and Sepinsky et al. (2009) by investigating the orbital evolution due to mass overflow in eccentric binaries in which no disk forms around the accretor. For this purpose, we calculate the trajectories of mass elements escaping through the inner Lagrangian point of the donor star in the ballistic limit, and distinguish between three possible cases: (1) the ejected matter falls back onto the donor star, (2) the ejected matter impacts the surface of the accretor, and (3) the ejected matter orbits the accretor for at least one orbital revolution of the binary. In the first two cases, the evolution of the orbital elements is obtained directly from the ballistic trajectory calculations. In the third case, the evolution of the orbital elements depends on the interactions between mass elements ejected during successive periastron passages of the donor star. Since such interactions are

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Interacting Binaries Luciano Burderi, 2005-11-02 This conference examines the progress in the field of interacting binaries discussing a number of relevant astrophysical problems regarding the interaction between stars in binary systems such as the physics of neutron stars and black holes that accrete matter from their companion stars and the study of the end points of stellar evolution like supernovae and gamma ray bursts This proceedings provides an updated overview of both observations and theory Topics include compact binaries in globular clusters millisecond binary pulsars supernovae from massive binary systems and GRBs accretion on black holes and microquasars accretion on white dwarfs and novae rapid variability and secular evolution of LMX Ray binaries supernovae type Ia as well as secular evolution of high mass x ray binaries

Evolutionary Processes in Interacting Binary Stars Y. Kondo, R.F. Sisteró, R.S. Polidan, 1992-06-30 This book contains the proceedings of IAU Symposium No 151 Evolutionary Processes in Interacting Binary Stars which was held from 5 to 9 August 1991 in Cordoba Argentina The primary aim of this conference was to review and evaluate our current understanding of the evolutionary processes in wide variety of interacting binary stars from their births to their deaths Subjects included the formation of binaries mass flow and transfer accretion processes and binaries with collapsed components such as novae X ray binaries and binary pulsars As the field covered is both broad and diverse there were in all thirty seven invited talks sixty two contributed papers were also presented In addition these proceedings contain comments from a panel discussion of the major unsolved problems of interacting binary stars

Reports on Astronomy 2006-2009 (IAU XXVIIA) Karel A. van der Hucht, 2009-03-23 The Transactions XXVIIA Reports on Astronomy 2006 2009 provides a comprehensive and authoritative review of what has been achieved in astronomy during the years 2006 to 2009 These insightful and up to date reviews have been written by the presidents and chairpersons of the IAU scientific bodies the Divisions the Commissions and the Working Groups Topics covered in this wide ranging volume include fundamental astronomy the Sun and heliosphere planetary sciences stars variable stars interstellar matter the Galactic system galaxies and the Universe optical and infrared techniques radio astronomy space and high energy astrophysics and other IAU activities The reviews have been written at a level suitable for colleagues in the same fields but will also be useful for students and researchers wishing to gain an overview of astronomical fields beyond their own research area

The Impact of Binary Stars on Stellar Evolution Giacomo Beccari, Henri M. J. Boffin, 2019-04-18 An advanced review of how binary stars affect stellar evolution presenting results from state of the art models and recent observations

[The Magellanic System \(IAU S256\)](#) International Astronomical Union. Symposium, 2009-04-16 Provides the most complete and up to date account of our understanding of the Magellanic Clouds and the astrophysical processes within them

Proceedings of the Third Workshop on Science with the New Generation of High Energy Gamma-ray Experiments Alessandro De

Angelis, Oriana Mansutti, 2006 Introduction I Detectors for high energy gamma rays First results from the MAGIC experiment

D Bastieri for the MAGIC collaboration H E S S P Vincent for the H E S S collaboration CANGAROO M Mori for the CANGAROO II III Team The status of VERITAS M K Daniel on behalf of the VERITAS collaboration Gamma ray bursts recent results obtained by the SWIFT mission G Chinearini on behalf of the SWIFT team Functional tests and performance characterization during the assembly phase of the modules of the AGILE silicon tracker M Basset und weitere Status of GLAST the gamma ray large area space telescope L Rochester on behalf of the GLAST team Status of the ARGO YBJ experiment P Camarri for the ARGO YBJ collaboration Gamma Air Watch GAW an imaging atmospheric Cherenkov telescope large with large field of view T Mineo und weitere II Topics in fundamental physics Frontiers of high energy cosmic rays M Pimenta Measurement of cosmological parameters A Balbi The present and the future of cosmology with gamma ray bursts G Ghirlanda G Ghisellini Supersymmetry breaking extra dimensions and neutralino dark matter A M Lionetto Dark matter at symbol rays L Pieri Populations of subhalos in cold dark matter halos E Bisesi III Multiwavelength observations WEBT multifrequency support to space observations C M Raiteri and M Villata for the WEBT collaboration REM The Remote Observatory for GRB et al E Molinari on behalf of the REM ROSS team Planck LFI operation of the scientific ground segment F Pasian und weitere INTEGRAL three years later L Foschini G Di Cocco G Malaguti XMM observations of Geminga PSR B1055 52 and PSR B0656 14 phase resolved spectroscopy as a tool to investigate the X symbol connection P A Caraveo und weitere IV Poster session Software time calibration of the ARGO YBJ detector A K Calabrese Melcarne for the ARGO YBJ collaboration Gamma ray burst physics with GLAST N Omodei Observations of blazars and EGRET sources with INTEGRAL V Vitale und weitere A third level trigger programmable on FPGA for the gamma hadron separation in a Cherenkov telescope using Pseudo Zernike moments and the SVM classifier M Frailis und weitere PulsarSpectrum simulating gamma ray pulsars for the GLAST mission M Razzano und weitere

Handbook of X-ray and Gamma-ray Astrophysics Cosimo Bambi, Andrea Santangelo, 2024-02-29 This book highlights a comprehensive coverage of X ray and Gamma ray astrophysics The first and the second parts discuss respectively X ray and Gamma ray experimental techniques and observatories The third part is devoted to science including galactic and extragalactic sources The fourth and last parts are dedicated to analysis techniques in X ray and Gamma ray astronomy spectral analysis imaging analysis timing analysis and polarimetric analysis Presenting the state of the art in X ray and gamma ray astronomy this is both a valuable book for students and an important reference resource for researchers in the field

Dark Matter In Astroparticle And Particle Physics - Proceedings Of The 6th International Heidelberg Conference Hans Volker Klapdor-kleingrothaus, Geraint F Lewis, 2008-05-09 Dark matter remains one of the central mysteries in modern physics although modern astronomical observations and particle physics experiments are providing vital clues in uncovering its true nature The Dark2007 Conference brought together world leading researchers in both astrophysics and particle physics providing them with an opportunity to present their latest results and engage in discussion on their meaning and future direction This book is

important in its field as it provides a vital snapshot of the seemingly disparate areas of dark matter research and provides an overview of current ideas and future directions

Compact Objects in Astrophysics Max Camenzind, 2007-02-24 Modern comprehensive introduction and overview of the physics of White Dwarfs Neutron Stars and Black Holes including all relevant observations Contains a basic introduction to General Relativity including the modern 3+1 split of spacetime and of Einstein's equations The split is used for the first time to derive the structure equations for rapidly rotating neutron stars and Black Holes Detailed discussions and derivations of current theoretical results In particular also the most recent equations of state for neutron star matter are explained Topics such as colour superconductivity are discussed and used for modelling A book for graduate students and researchers Contains exercises and some solutions

[Physics of Binary Star Evolution](#) Thomas M. Tauris, Edward P.J. van den Heuvel, 2023-03-28 A graduate level textbook on the astrophysics of binary star systems and their evolution Physics of Binary Star Evolution is an up to date textbook on the astrophysics and evolution of binary star systems Theoretical astrophysicists Thomas Tauris and Edward van den Heuvel cover a wide range of phenomena and processes including mass transfer and ejection common envelopes novae and supernovae X ray binaries millisecond radio pulsars and gravitational wave GW sources and their links to stellar evolution The authors walk through the observed properties and evolution of different types of binaries with special emphasis on those containing compact objects neutron stars black holes and white dwarfs Attention is given to the formation mechanisms of GW sources merging double neutron stars and black holes as well as ultra compact GW binaries hosting white dwarfs and to the progenitors of these sources and how they are observed with radio telescopes X ray satellites and GW detectors LIGO Virgo KAGRA Einstein Telescope Cosmic Explorer and LISA Supported by illustrations equations and exercises Physics of Binary Star Evolution combines theory and observations to guide readers through the wonders of a field that will play a central role in modern astrophysics for decades to come 465 equations 47 tables and 350 figures More than 80 exercises analytical numerical and computational Over 2 500 extensive up to date references

Gamma-Ray Bursts Gilbert Vedrenne, Jean-Luc Atteia, 2009-03-20 Since their discovery was first announced in 1973 gamma ray bursts GRBs have been among the most fascination objects in the universe While the initial mystery has gone the fascination continues sustained by the close connection linking GRBs with some of the most fundamental topics in modern astrophysics and cosmology Both authors have been active in GRB observations for over two decades and have produced an outstanding account on both the history and the perspectives of GRB research

High Time Resolution Astrophysics Don Phelan, Oliver Ryan, Andrew Shearer, 2007-10-23 This is quite simply the first volume of its kind dedicated to the area of high time resolution astrophysics High time resolution astrophysics HTRA is an important new window on the universe and a vital tool in understanding a range of phenomena from diverse objects and radiative processes Underlining this science foundation technological developments in both instrumentation and detectors are described

[Extraterrestrial Seismology](#) Vincent C. H. Tong, Rafael A. García, 2015-06-25 Seismology is a highly effective tool for

investigating the internal structure of the Earth Similar techniques have also successfully been used to study other planetary bodies planetary seismology the Sun helioseismology and other stars asteroseismology Despite obvious differences between stars and planetary bodies these disciplines share many similarities and together form a coherent field of scientific research This unique book takes a transdisciplinary approach to seismology and seismic imaging reviewing the most recent developments in these extraterrestrial contexts With contributions from leading scientists this timely volume systematically outlines the techniques used in observation data processing and modelling for asteroseismology helioseismology and planetary seismology drawing comparisons with seismic methods used in geophysics Important recent discoveries in each discipline are presented With an emphasis on transcending the traditional boundaries of astronomy solar planetary and Earth sciences this novel book is an invaluable resource and reference for undergraduates postgraduates and academics

Timing Neutron Stars: Pulsations, Oscillations and Explosions Tomaso M. Belloni, Mariano Méndez, Chengmin Zhang, 2020-10-23 Neutron stars whether isolated or in a binary system display a varied and complex phenomenology often accompanied by extreme variability of many time scales which takes the form of pulsations due to the object rotation quasi periodicities associated to accretion of matter and explosions due to matter accreted on the surface or to starquakes of highly magnetized objects This book gives an overview of the current observational and theoretical standpoint in the research on the physics under the extreme conditions that neutron stars naturally provide The six chapters explore three physical regions of a neutron star the space around it where accretion and pulsar companions allow testing of general relativity its surface where millisecond pulsation and X ray burts provide clues about general relativistic effects and the equation of state of neutron matter its interior of course inaccessible to direct observations can nevertheless be probed with all observational parameters related to neutron star variability

Observational Imprints of Binary Evolution on B- and Be-star Populations Julia Bodensteiner, 2022-11-30 This book presents novel observational evidence toward detecting and characterizing the products of massive interacting binary stars As a majority of massive stars are born in close binary systems a large number of so called massive binary interaction products are predicted to exist however few have been identified so far Based on observations with the largest telescopes around the world equipped with state of the art instrumentation this book helps to remedy this situation In her outstanding PhD thesis Julia Bodensteiner identifies a new class of post interaction binaries in a short lived phase just briefly after the initially more massive star has been stripped of part of its envelope She further provides new evidence for the Be phenomenon to largely result from binary interactions These results represented a new and testable prediction for the evolution of these stars and opened up a new way forward for identifying hundreds of post interaction products Finally using the MUSE integral field spectrograph at the Very Large Telescope in Chile the author presents a novel spectroscopic campaign focusing on the 40 Myr old star cluster NGC 330 in the Small Magellanic Clouds Combined with photometric observations from the Hubble Space Telescope the MUSE data

allow to characterize the entire massive star population of NGC 330 revealing their multiplicity properties and rotational velocities and providing unique observational constraints on their binary evolution history This is made possible by the developments of novel numerical methods allowing to extract star spectra from the MUSE integral field spectroscopic data and to characterize their properties by the simultaneous comparison of MUSE spectroscopy and Hubble photometry with atmospheric models This book is a partly re written version of the author s thesis offering a highly readable coherent text presenting not only new insights into the properties of binary interaction products but also giving students an excellent introduction into the field Science With The New Generation Of High Energy Gamma-ray Experiments - Proceedings Of The Third Workshop Oriana Mansutti,Alessandro De Angelis,2006-05-30 The contributions in this volume provide a snapshot of the latest research and future plans for space borne and ground based experiments dedicated to the observation of the gamma ray sky The articles are authored by both seasoned veterans of the first dedicated gamma ray missions and young scientists entering the fascinating field of gamma ray astrophysics With the advent of gamma ray instrumentation on spacecraft and large and sensitive ground based detectors new and unexpected phenomena have been discovered such as gamma ray bursts and gamma ray emission from blazars The immense vitality of the field in the current post EGRET era is witnessed by the numerous ongoing and forthcoming gamma ray experiments documented here complementary to various cosmic ray neutrino astroparticle and X ray projects Literature 1991, Part 2 Astronomisches Rechen-Institut,2013-06-29 Astronomy and Astrophysics Abstracts appearing twice a year has become one of the fundamental publications in the fields of astronomy astrophysics and neighbouring sciences It is the most important English language abstracting journal in the mentioned branches The abstracts are classified under more than a hundred subject categories thus permitting a quick survey of the whole extended material The AAA is a valuable and important publication for all students and scientists working in the fields of astronomy and related sciences As such it represents a necessary ingredient of any astronomical library all over the world *Populations of High-Energy Sources in Galaxies (IAU S230)* International Astronomical Union. Symposium,2006-06-15 For the last 40 years astronomers have observed sources of intense X ray radiation from beyond our Solar System These have been associated with remarkable objects such as neutron stars and black holes Current satellite observatories have enabled us to extend the studies of these objects from the Milky Way and Magellanic Clouds to individual X ray sources in other galaxies At the same time imaging facilities at gamma rays and TeV energies have improved enormously leading to many further discoveries within our own galaxy This Symposium presents an overview of these new developments covering detailed studies of individual sources within the Milky Way global descriptions of X ray source populations in other galaxies and less resolved relatives at high redshift Galaxy nuclei and diffuse emission components are included as are new discoveries at gamma rays and TeV energies IAU S230 is a valuable resource for astronomers and graduates working in high energy astrophysics Interacting Binaries P.P. Eggleton,J.E. Pringle,2012-12-06 Peter P

Eggleton and James E Pringle Institute of Astronomy Madingley Road Cambridge England The 1970 s can be described in retrospect as the Decade of the Close Binary Exciting observations with new technology combined with classical work both observational and theoretical convinced the astronomical world that binary interaction of various kinds is not only interesting but common Indeed by 1975 almost anything unusual had a good chance of being interpreted as due to binary interaction But astronomers are seldom overwhelmed by speculation even their own and solid observational work has confirmed or refuted such speculation without regard to its plausibility For instance binarity has been found where it was perhaps least expected in Barium stars and refuted where it could most reasonably be expected in Wolf Rayets Unfortunately many other classes of potential binaries remain without the clearest evidence of binarity for instance Be stars symbiotics and blue stragglers This Advanced Study Institute was held to commemorate John Whelan 1945 1981 whose scientific career sadly cut short in its prime did much to further the careful study theoretical and observational of close binaries as well as to encourage the spirit of international friendship and collaboration His own interests covered a greater field but Interacting Binaries seemed a reasonable restriction We publish here 15 review talks which still do not cover the whole topic although they range widely

Evolution of Massive Stars D. Vanbeveren, W. van Rensbergen, C. de Loore, 2012-12-06 Massive stars occupy an exceptional place in general astrophysics They trigger many if not all of the important processes in galactic evolution whereas due to their intrinsic brightness they offer the only until now possibility to study the stellar content and stellar behaviour in distant galaxies The last say 25 years massive stars have been the subject of numerous meetings discussing the influence of massive stars on population synthesis the number distribution of different types of massive stars the LBV phenomenon WR stars X ray binaries stellar winds in massive stars chemical peculiarities in massive stars supernova explosions of massive stars and the important SN1987A event the influence of massive stars and chemical evolution of galaxies It is clear that without a theory of stellar evolution the study of these topics loses a lot of its significance Massive star evolution therefore got a chance in these meetings but rarely as a prime subject The state of the art the physical processes and the uncertainties in stellar evolution were barely touched Even more the influence of close binaries in all these massive star meetings slowly disappeared the last say 13 years without any scientific justification although a significant fraction of stars occurs in close binaries with periods small enough so that both components will interact during their evolution Denying the binaries or not discussing their influence on results and conclusions makes the latter very uncertain or even completely unreliable

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