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978-1-107-02944-6 - Asteroseismology: XXII Canary Islands Winter School of Astrophysics

Edited by Pere L. Pallé and César Esteban

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ASTEROSEISMOLOGY

Our understanding of stars has grown significantly due to recent advances in asteroseismology, the stellar analog of helioseismology, the study of the Sun's acoustic wave oscillations. Using ground-based and satellite observatories to measure the frequency spectra of starlight, researchers are able to probe beneath a star's surface and map its interior structure. This volume provides a wide-ranging and up-to-date overview of the theoretical, experimental, and analytical tools for carrying out front-line research in stellar physics using asteroseismological observations, tools, and inferences. Chapters from seven eminent scientists in residence at the twenty-second Canary Islands Winter School of Astrophysics examine the interior of our Sun relative to data collected from distant stars, how to measure the fundamental parameters of single field stars, diffusion processes, and the effects of rotation on stellar structures. The volume also provides detailed treatments of modeling and computing programs, providing astronomers and graduate students with a practical, methods-based guide.

Pere L. Pallé is a pioneering astrophysicist in the field of helioseismology and head of the Instituto de Astrofísica de Canarias's Research Group for Helioseismology and Asteroseismology. He completed his undergraduate studies and PhD at the University of La Laguna, Spain, and is deeply involved in the deployment, operation, and scientific exploitation of the first Earth-based international helioseismology networks (BiSON, IRIS, GONG), space missions (such as GOLF/SoHO), and asteroseismology networks (SONG). His research is focused on the instrumentation, analysis, and interpretation of solar and stellar internal structures and dynamics by means of seismology tools.

César Esteban is a lecturer in the Astrophysics Department of the University of La Laguna and researcher at the Instituto de Astrofísica de Canarias in Spain. He completed his undergraduate studies and PhD at the University of La Laguna, where he was head of the Astrophysics Department from 2010 to 2011. He researches the physical structure and chemical composition of ionized nebulae, the chemical evolution of galaxies, and the astronomy of ancient cultures. He coordinates different research projects and is a member of various scientific societies and governing boards.

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Canary Islands Winter School of Astrophysics

Volume XXII

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Participants of the XXII Canary Islands Winter School of Astrophysics, in front of the “Casino” (Spanish meaning equivalent to Cultural Club) of La Laguna, located in the historical centre of the town.



Lecturers and scientific organizer of the Winter School in the balcony of the Conference Room at Hotel Nivaria in La Laguna. From left to right: Donald Kurtz, Steven Kawaler, Sarbani Basu, Pere L. Pallé, William Chaplin, Thierry Appourchaux, and Tim Bedding. Not present: Jørgen Christensen-Dalsgaard and Mario J. Monteiro.

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Edited by

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Preface

Background

The XXII Canary Islands Winter School of Astrophysics, organized by the Instituto de Astrofísica de Canarias (IAC), focuses on the new advances and challenges that asteroseismology provides in the domains of stellar structure, dynamics, and evolution. Every year the Winter School welcomes around 60 Ph.D. students and young postdocs and provides a unique opportunity for them to broaden their knowledge in a key field of astronomy.

Scientific rationale

When oscillations of the Sun were first discovered, a new era of science began. The observed frequencies could be used to probe deep into the stellar interior, the only measurements that could possibly pierce the stellar surface. Today, “helioseismology” has been responsible for some of our deepest understanding of the Sun: we know the radial and longitudinal rotation profile of the interior, we have measured the depth of the outer convection zone, and it has helped solve the so-called neutrino problem when the observations and theory predicted a much hotter central temperature than the observed neutrinos predicted. Today, these seismic observations are not only available in much higher quality, but they are also available for hundreds of other stars. In the last few years, many space missions (CoRoT and Kepler) have produced these data of exquisite quality, and for the first time we are in a position to study the Sun in the context of other stars, measure the fundamental parameters of single field stars to within 2 percent, learn about diffusion processes and the effects of rotation on the stellar structure, and test opacities and equations of state in extreme conditions.

The key objectives of this Winter School are to provide young scientists with knowledge and understanding of observation, instrumentation, theory, modeling, and computing for asteroseismology.

Outline of the school

The primary aim of the XXII Winter School is to provide a wide-ranging and up-to-date overview of the theoretical, experimental, and analytical tools necessary for carrying out front-line research in stellar physics by means of asteroseismological observations, tools, and inferences. The school is particularly designed to offer young researchers tips and guidelines to help them direct their future research toward these themes, which are among the most important in modern astrophysics. To achieve these goals, the Winter School lectures are given by eight eminent and experienced scientists who are actively working on a variety of forefront research projects, and who have played a key role in major advances over the recent years. The list of invited researchers includes leading theoreticians and pioneering observers in each area of the subject. The format of the school also encourages direct interaction between the participating students and lecturers.

The school is primarily intended for doctoral students and recent postdocs in any field of research in Astronomy. Participants of the school will have the opportunity to display their current work by presenting a poster contribution and later to discuss them within a dedicated session.

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Acknowledgments

The organizers of the XXII Canary Islands Winter School of Astrophysics would like to express their sincere gratitude, first and foremost, to the lecturers, for making it a great scientific and educational event. The careful preparation of the lectures, the attendance and intense interaction with students, and the subsequent writing up of the manuscripts for this book have been a major – but we hope rewarding – commitment in their very busy agendas. The students played a major role in the success of the Winter School: their enormous enthusiasm – maintained throughout the entire two weeks – and outstanding human quality resulted in a really pleasant and fruitful event. Ismael Martínez-Delgado played a major part in the creation of this book, revising in minute detail and with enormous patience and technical editorial skill all the submitted manuscripts.

The Secretary of the Winter School, Mrs. Lourdes González, has been involved in the administration of every school since their inception in 1989. She is therefore the soul and memory of the event. Her great knowledge and diligence before, during, and after each Winter School is a key component in its success. The Web page of the Winter School is a vital tool in the preparation and development of the event, and we thank Jorge Andrés Pérez (SIE/IAC) for its care and maintenance. The press room of the Winter School was the responsibility of Annia Domenech, who did a wonderful job interviewing the lecturers and students. Inés Bonet (Gabinete de Dirección/IAC) complemented the press room coverage with fine and high-quality videos. Ramón Castro and Gabriel Pérez (SMM/IAC) designed the posters and additional multimedia support material for the Winter School, and Diego Sierra and Francisco López (SIC/IAC) set up for us a wonderful wireless system and computer network in the conference room. The visits to the observatories (on Tenerife and La Palma) were possible thanks to the support of their respective managers (Miquel Serra and Juan Carlos Pérez Arencibia) and volunteer guides Antonio-Eff Darwich, Rafael Barrena, and Katrien Uytterhoeven. One of the sessions of the Winter School took place in the Computing Laboratory of the Department of Astrophysics of the Faculty of Physics at the University of La Laguna and we thank Professor Teodoro Roca (Dean of the Faculty) and Dr. Fernando Pérez for their support and invaluable help.

Each year, the Canary Islands Winter School of Astrophysics is a major institutional event at the IAC, whose various departments and support services always actively and enthusiastically contribute to it. We thank all concerned for their support and efficiency.

We are greatly indebted to Spain's Ministerio de Ciencia e Innovación, the Cabildo de Tenerife, and the Ayuntamiento de San Cristóbal de La Laguna for vital financial assistance. The Director of the Museo de Historia y Antropología de Tenerife kindly offered us the use of the Casa Lercaro historical monument to hold the welcoming cocktail party and registration of participants. The Winter School took place in the main conference room of Hotel Nivaria, a sixteenth-century mansion situated in the heart of the city of La Laguna, where all the lecturers and students were lodged. We would like to thank the hotel for its superb facilities and the friendliness of its entire staff.

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AAT	Anglo-Australian Telescope
ACRIM	Active Cavity Radiometer Irradiance Monitor
ADIPLS	Aarhus aDIabatic PuLSation code
AMU	Atomic Mass Unit
ASTECC	Aarhus STellar Evolution Code
AT&T	American Telephone and Telegraph
BCE	Before the Common Era
BiSON	Birmingham Solar Oscillations Network
BJD	Barycentric Julian Date
BJED	Barycentric Julian Ephemeris Date
CCD	Charge Coupled Device
C-D	Christensen-Dalsgaard diagram
CEFF	Coulomb corrections Eggleton-Faulkner-Flannery equation
CNES	Centre National d'Etudes Spatiales
CNO	Carbon-Nitrogen-Oxygen cycle
CORALIE	Echelle Spectrograph on the 1.2-metre Leonard Euler Swiss telescope
COROT	COncvection ROtation et Transits planétaires
CP	Chemically Peculiar
CTIO	Cerro Tololo Inter-American Observatory
CZ	Convective Zone
DFT	Discrete Fourier Transform
DSP	Digital Signal Processing
EFF	Eggleton-Faulkner-Flannery equation
ESA	European Space Agency
ET	Ephemeris Time
EVRIS	Etude de la Variabilité et de la Rotation des Intérieurs Stellaire
FFT	Fast Fourier Transform
FWHM	Full Width at Height Maximum
GK	Gough and Kosovichev set
GMST	Greenwich Mean Sidereal Time
GOLF	Global Oscillations at Low Frequency
GONG	Global Oscillations Network Group
GPS	Global Positioning System
HARPS	High Accuracy Radial Velocity Planet Searcher
HJD	Heliocentric Julian Date
HR	Hertzsprung Russell diagram
HST	Hubble Space Telescope
IAC	Instituto de Astrofísica de Canarias
IAU	International Astronomical Union
IPHIR	InterPlanetary Helioseismology by IRadiance measurements
JD	Julian Date
KIC	Kepler Input Catalogue
KOI	Kepler Object of Interest
LBV	Luminous Blue Variable
LHS	Left Hand Side
LOWL	Low- l
LS	Lomb-Scargle periodogram
MAP	Maximum A Posteriori
MDI	Michelson Doppler Imager

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Abbreviations

MH	Metropolis-Hastings algorithm
MHD	Mihalas, Hummer and Däppen equation
MIX	Core Mixing Model
MJD	Modified Julian Date
MLE	Maximum Likelihood Estimation
MOLA	Multiplicative Optimally Localised Averages
MONS	Measuring Oscillations in Nearby Stars
MOST	Microvariability and Oscillations of STars
NACRE	Nuclear Astrophysics Compilation of REaction rates
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NODIF	No Diffusion
OGLE	Optical GRavitational Lensing Experiment
OLA	Optimally Localised Averages
OPAL	Opacity Project Los ALamos
PLATO	PLANetary Transits and Oscillations of stars
PSD	Power Spectral Density
PRISMA	Probing Rotation and Interior of Stars: Microvariability and Activity
PVSG	Periodically Variable Super Giant star
RHS	Right Hand Side
RJD	Reduced Julian Date
RLS	Regularized List Squares
SARG	Spettrografo Alta Risoluzione Galileo
sdB	subdwarf B
SDSS	Sloan Digital Sky Survey
SMEI	Solar Mass Ejection Experiment
SMM	Solar Maximum Mission
SOHO	SOLar and Heliospheric Observatory
SOI	Solar Oscillations Investigations
SOLA	Subtractive Optimally Localised Averages
SONG	Stellar Observations Network Group
SPB	Slowly Pulsating B stars
STD	Standard Model
SVD	Singular Value Decomposition
TAI	Temps Atomique International (International Atomic Time)
TCB	Temps Coordonnée Barycentrique (Barycentric Coordinate Time)
TCG	Temps Coordonnée Géocentrique (Geocentric Coordinate Time)
TDB	Temps Dynamique Barycentrique (Barycentric Dynamical Time)
TDT	Terrestrial Dynamical Time
TJD	Truncated Julian Date
TT	Terrestrial Time
UCLES	University College London Echelle Spectrograph
UK	United Kingdom
US	United States
USA	United States of America
UT	Universal Time
UTC	Coordinated Universal Time
UVES	Ultraviolet and Visual Echelle Spectrograph
VIRGO	Variability of solar IRadiance and Gravity Oscillations
VLBI	Very Long Baseline radio Interferometry
WIRE	Wide-field Infra Red Explorer
YREC	Yale Rotating Stellar Evolution Code