HIGH TIME-RESOLUTION ASTROPHYSICS

High time-resolution astrophysics (HTRA) involves measuring and studying astronomical phenomena on timescales of seconds to milliseconds. Although many areas of astronomy, such as X-ray astronomy and pulsar observations, have traditionally required high time-resolution studies, HTRA techniques are now being applied to optical, infrared and gamma-ray wavelength regimes, due to the development of high-efficiency detectors and larger telescopes that can gather photons at a higher rate. With lectures from eminent scientists aimed at young researchers and postdocs in observational astronomy and astrophysics, this volume gives a practical overview of and introduction to the tools and techniques of HTRA. Just as multi-spectral observations of astrophysical phenomena are already yielding new scientific results, many astronomers are optimistic that exploring the time domain will open up an important new frontier in observational astronomy over the next decade.

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Canary Islands Winter School of Astrophysics

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Preface

High time-resolution astrophysics (HTRA) concerns itself with observations on short time-scales, normally defined as milliseconds to seconds. HTRA is, therefore, an important tool in understanding the fundamental physics of radiative processes from a diverse range of objects. Understanding the radiation processes allows one to extract information encoded in the observed radiation. It allows us to test fundamental theories by measuring important physical parameters, such as temperatures, velocities, magnetic field strengths, the energy of accelerated particles and their distribution. In addition, the interpretation of the observed high time-resolution variability often requires the development of physical models describing the complex dynamical processes occurring in these extreme environments. Due to their small physical size, variability on the fastest time-scales are associated with compact stellar remnants (black holes, neutron stars, and white dwarfs), which is tightly related to their relevant physical processes and emission mechanisms.

Current high time-resolution observations of compact objects are providing remarkable insights into fundamental questions, such as how black hole accretion takes place, how jets/outflows operate and the nature of the extreme gravity conditions around neutron stars and the stable orbits around stellar mass black holes. Indeed, it is becoming increasingly clear that multi-wavelength high time-resolution observation is the best way to disentangle the physical origin of the complex broadband spectral emission (e.g., accretion flow and jets) observed from compact binary systems. However, HTRA is not limited to only compact objects; for instance, transit observations involving fast timing also provide vital information on the basic parameters of exoplanets.

The astronomical community has put extreme environment astrophysics as one of their key ground- and space-based research areas, implying that HTRA is critical for the success of these projects. HTRA demands the use of very fast, highly efficient, large photon-counting detectors with intrinsic energy resolution across a wide spectral range. There have been significant advances towards such detectors, e.g., the superconducting tunnel junction and microwave kinetic inductance detectors, with a realistic chance that we will see such detectors in the next decade. Combined with high time-resolution, these have the potential for revolutionizing observational astronomy over a wide range of wavelengths.

Recognizing the importance of this field, the Instituto de Astrofísica de Canarias organised the XXVIIth Winter School on the topic of 'High Time-Resolution Astrophysics'. The aim of the School was to bring together a number of the leading scientists working in the field of HTRA with PhD students and recent postdocs. The School tackled many aspects of HTRA and was particularly designed to provide a wide-ranging and up-to-date overview of the instrumental and theoretical tools, and applications to observations at different wavelengths, necessary for carrying out front-line research in the study of HTRA.

The forty lectures present a comprehensive and up-to-date introduction to the major observational and theoretical topics associated with HTRA. With emphasis on the physical processes involved, this includes applications to compact stellar objects (black holes, neutron stars, and white dwarfs), jets/outflows, interaction between highly relativistic plasma and strong magnetic fields and the relevant physical processes and emission mechanisms operating on very short time-scales. Given that it is not possible to understand their associated phenomena without covering multi-wavelength HTRA, the School took a strong multi-wavelength approach, covering HTRA at radio, optical, X-ray and Gamma-ray wavelengths. Furthermore, the requirements of low-noise, fast-readout detectors,

time systems to correctly compare data from different telescopes on the ground and in space, and the use of non-conventional software tools specific for time-series analysis was addressed.

The lectures were given by seven experienced research scientists, who have played key roles in the advancements made in the field of HTRA.

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The success of the School was without doubt due to the hard work of our secretary Lourdes González, who ensured the smooth running of the School. We would also like to thank Gabriel Pérez Díaz, who prepared the School's poster, the IAC's Centro de Cálculo for their IT assistance and Annia Domènech for organising the press releases.

As always, the School provides a guided tour of Teide Observatory (Tenerife), Roque de los Muchachos (La Palma) and the IAC's headquarters in La Laguna. We thank the IAC's Research division for helping out with these visits. We are also grateful to the Cabildo de Tenerife and the Town Hall of San Cristóbal de La Laguna, who kindly organised visits to Teide National Park and the city, respectively.

Finally, we greatly acknowledge financial support from the Severo Ochoa Centre of Excellence.

Abbreviations

ACD	anti-coincidence detector
ADAF	accretion-dominated accretion flow
ADIOS	advection-dominated inflow-outflow solution
AGN	active galactic nuclei
APD	avalanche photodiode
ALICE	a large ion collider experiment
ARCONS	Array Camera for Optical and Near-IR Spectrophotometer
ATHENA	Advanced Telescope for High Energy Astronomy
AXMP	accreting X-ray millisecond pulsar
AXTAR	advanced X-ray timing array
BB	Blackbody
BH	black hole
BHB	black hole binary
BHXRB	black hole X-ray binary
BIPM	Bureau International des Poids et Mesures
BL	boundary layer
CCD	charge-coupled device
CCDM	colour-colour diagram
CCF	cross-correlation function
CCO	central compact objects
CDAF	convection dominated accretion flow
CERN	European Organization for Nuclear Research
CGRO	Compton Gamma-ray Observatory
CMOS	complementary metal-oxide-semiconductor
CV	cataclysmic variable
DBB	disk-blackbody
DEPFET	DEpleted P-Channel Field Effect Transistor
DM	dispersion measure
DNS	double neutron star
EDISP	energy dispersion
EM	electron multiplication
e-ELT	European Extremely Large Telescope
EMCCDS	electron multiplying charge-coupled device
EoS	equation of state
EPIC	European photon imaging camera
ESA	European Space Agency
FBO	flaring branch oscillation
FOV	field of view
FSSC	fermi science support center
FWHM	full width at half maximum
GASP	the Galway Astronomical Stokes Polarimeter
GBM	gamma-ray burst monitor
GPS	Global Positioning System
GR	general relativity
GUI	graphical user interface
GW	gravitational wave
HS	Hot Spot
HBO	horizontal branch oscillation

HESS	High Energy Stereoscopic System
HFQPOs	High-Frequency quasi-periodic oscillation
HID	hardness–intensity diagram
HIMS	hard-intermediate state
HiPER-CAM	High PERformance CAMera
HMBP	high-mass binary pulsar
HMXB	high-mass X-ray binary
HRD	Hardness-RMS diagram
HSS	high-soft State
HST	Hubble Space Telescope
HTRA	high time-resolution astrophysics
IBIS	imager on board the INTEGRAL satellite
IMBP	intermediate-mass binary pulsar
IMXB	intermediate-mass X-ray binary
INTEGRAL	INTErnational Gamma-ray Astrophysics Laboratory
IPC	imaging proportional counter
IR	infrared
IRF	instrument response function
ISCO	innermost stable circular orbit
ISS	International Space Station
JEM-X	Joint European X-ray Monitor
KIDspec	Kinetic Inductance Detector Spectrograph
L3	low light level
LAPC	large area proportional counters
LAT	large area telescope
LFQPO	low-frequency quasi-periodic oscillation
LHC	Large Hadron Collider
LHS	low-hard state
LLE	large area telescope low-energy
LMBP	low-mass binary pulsar
LMXB	low-mass X-ray binary
LOFT	large observatory for X-ray timing
LT	Lense–Thirring precession
MAGIC	Major Atmospheric Gamma Imaging Cherenkov
MAMA	multi-anode microchannel array
MHD	magnetohydrodynamic
MIC	MCP-Intensified CCD
MJD	Modified Julian Day
MKID	microwave kinetic inductance detector
MSP	millisecond pulsar
NBO	normal branch oscillation
NGC	New General detector Controller
NICER	Neutron star Interior Composition ExploreR
NIR	near-infrared
NS	neutron star
NS-LMXB	neutron star low-mass X-ray binary
OIR	optical/infrared
OM	optical monitor
OPTIMA	Optical Pulsar TIMing Analyzer

PC	proportional counter
PCA	proportional counter array
PDS	power density spectra
PK	post-keplerian
PMT	photomultiplier tube
PSU	power supply unit
PSF	point spread function
PTA	pulsar timing array
PWN	pulsar wind Nebula
QE	quantum efficiency
QPO	quasi-periodic oscillation
RB	gamma-ray burst
RID	RMS-intensity diagram
RMS	root mean square
ROI	region of interest
RPM	relativistic precession model
RRATs	rotating radio transients
RXTE	Rossi X-ray Timing Explorer
S/N	signal-to-noise
SAS	small astronomy satellite
SDD	silicon drift detector
SDSS	Sloan Digital Sky Survey
SED	spectral energy distribution
SEP	strong equivalence principle
SIMS	soft-intermediate state
SNR	supernova remnant
SNR	signal-to-noise ratio
SPAD	Single-Photon avalanche photo-diode
SPI	SPectrometer on INTEGRAL
SSB	solar system barycenter
SSS	solid-state spectrometer
STIS	Space Telescope Imaging Spectrograph
STJ	superconducting tunnel junction
TAI	Temps Atomique International
TCB	Barycentric Coordinate Time
TDB	Barycentric Dynamical Time
TES	transition edge sensor
TMT	Thirty Meter Telescope
ToA	Time of Arrival
TOV	Tolman–Oppenheimer–Volkoff
TS	test statistic
UCT	University of Cape Town
ULMBP	ultra low mass binary pulsar
UV	ultraviolet
VERITAS	Very Energetic Radiation Imaging Telescope Array System
VLMBP	very low mass binary pulsar
WD	white dwarf
WISE	Wide-field Infrared Survey Explorer
XDINS	X-ray dim isolated neutron star
XMM-Newton	X-ray Multi-Mirror Mission