3D SPECTROSCOPY IN ASTRONOMY

Simultaneously storing both spectral and spatial information, 3D spectroscopy offers a new way to tackle astrophysical problems, and opens up new lines of research. Since its inception in the eighties and early nineties, research in this field has grown enormously. Large telescopes all around the world are now equipped with integral field units, and two instruments of the James Webb Space Telescope will have integral field spectroscopic capabilities. Nowadays, more effort is dedicated to refining techniques for reducing, analysing and interpreting the data obtained with 3D spectrographs.

Containing lectures from the seventeenth Winter School of the Canary Islands Astrophysics Institute, this book explores new 3D spectroscopy techniques and data. A broad and balanced presentation of research in this field, it introduces astronomers to a new generation of instruments, widening the appeal of integral field spectroscopy and helping it become a powerful tool in tackling astrophysical problems.

Canary Islands Winter School of Astrophysics

Volume XVII

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F. Sánchez, *Instituto de Astrofísica de Canarias*

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Edited by

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Preface

3D spectroscopy has a relatively short history. Most of the present instrument concepts were developed in the 1980s and early 1990s. During those pioneering years a great deal of work was done in optical labs in an attempt to understand how the optical fibres, micro-lenses and image slicers behave. Only a few groups (often formed by one or two people) worked on this topic. Communications were not very good, which explains why virtually all the groups decided to refer to this technique by a different name. So we ended up with 'spectral imaging', 'bidimensional spectroscopy', 'integral field spectroscopy', 'two-dimensional spectroscopy', '3D spectroscopy', etc.

During those years it was more than doubtful whether this technique was going to be useful at all. In fact, it looked like a kind of curiosity of limited practical interest to astronomy. However, in the 1990s the first scientific results were obtained and they inmediately produced a change of perception.

In the last few years investment in this type of instrumentation has been enormous. Large telescopes all around the world are now equipped with integral field units. Two instruments of the future James Webb Space Telescope will also have integral field spectroscopic capabilities, etc. Instead of being based in the optical lab trying to characterize optical fibres or micro-lenses, more effort is dedicated nowadays to refining techniques for reducing, analysing and interpreting the data obtained with a new generation of 3D spectrographs. Clearly, we are in a wholly different phase; by attending the lectures and viewing the posters of our Winter School, it is clear that 3D spectroscopy has truly arrived on the scene.

This Winter School is particularly timely. It is aimed at instructing a new generation of astronomers in a new generation of instruments. This will probably be the first and last school on this topic. In a few years' time, organizing a similar school would seem like organizing a school today on 'imaging'. However, the string of recent scientific conferences on 3D spectroscopy and the over-subscription to this school would seem to indicate that this is the right topic at this time.

The Instituto de Astrofísica de Canarias (IAC) is specially pleased to be organizing a Winter School on the topic of 3D spectroscopy because it has contributed to this field since its inception. More than 15 years ago a small group of researchers at the IAC started working in this field. They set up from scratch an optical fibre lab at the institute and developed the first experimental integral field systems for the telescopes on La Palma. That was just the beginning of the IAC's contribution to the development and diffusion of this technique, a contribution that continues today to extend on several fronts, including the organization of this workshop in collaboration with the European Euro3D network.

The aim of this Winter School is to widen the appeal of integral field spectroscopy beyond the limited community of experts and to help it become a powerful tool in the hands of a new generation of astronomers for tackling new (and old) astrophysical problems. We thank all the participants, lecturers and students for their valuable contributions to this objective.

The Editors

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Abbreviations

2dF	The Two Degree Field system
2D-FIS	2-Dimensional Fiber ISIS System
AAT	Anglo-Australian Telescope
ACS	The Advance Camera for Surveys
AOB	Adaptive Optics Bonnette
APO	Apache Point Observatory
APOGEE	Apache Point Observatory Galactic Evolution Experiment
ARGUS	
ARIES	Arizona infrared imager and echelle spectrograph
CAHA	Centro Astronómico Hispano Alemán
CCD	charge coupled device
CFHT	Canada–France–Hawaii Telescope
CIGALE	Scanning Perot–Fabry Interferometer, comparable with the UK TAURUS system, developed by Marseille Observatory to work at the Cassegrain focus of the 3.6 m CFH Telescope
CIRPASS	Cambridge Infrared Panoramic Survey Spectrograph
COHSI	Cambridge OH Suppression Instrument
EFOSC	ESO Faint Object Spectrograph and Camera
ESI	Echellette Spectrograph and Imager
ESO	European Southern Observatory
F2T2	Flamingos-2 Tandem Tunable Filter
FaNTOmM	Fabry–Perot of New Technology for the Observatoire du mont Megantic
FGS-TF	Tunable Filter
FISICA	The Florida Image Slicer for Infrared Cosmology and Astrophysics
FITS	Flexible Image Transport System
FLAMES	Fibre Large Array Multi Element Spectrograph
FLAMES/GIRAFFE	FLAMES Intermediate Resolution Spectrometer
FLAMINGOS	The Facility Near-Infrared Wide-field Imager and Multi-Object Spectrograph for Gemini
FORS	Focal Reducer and low dispersion Spectrograph
FWHM	full-width-at-half-maximum
GMOS	Gemini Multi-Object Spectrograph
GNIRS	Gemini Near Infrared Spectrograph
GriF	Grating Infrared Fabry–Perot
GTC	Gran Telescopio CANARIAS
HARPS	High Accuracy Radial Velocity Planet Searcher
HET	Hobby–Eberly Telescope
HEXAFLEX	Hexagonal Lattice Fiber Linked Experimental
HEXAFLEX-II	Hexagonal Lattice Fiber Linked Experimental II
HIFI	Hawaii Imaging Fabry–Perot Interferometer
HIRES	High Resolution Echelle Spectrometer
HST	Hubble Space Telescope

IAU	International Astronomical Union
ICA	Instituto de Astrofísica de Canarias
IDL	Interactive Data Language
IFS	Integral Field Spectroscopy
IFU	Integral Field Unit
IMACS-IFU	Inamori Magellan Cassegrain Spectrograph–Integral Field Unit
IRAF	Image Reduction and Analysis Facility
ISIS	Intermediate-Dispersion Spectroscopic and Imaging System
JWST	James Webb Space Telescope
KMOS	K-Band Multi-Object Spectrometer
KPNO	Kitt Peak National Observatory
MACAO	Multi-Application Curvature Adaptive Optics
MCAO	Multi-Conjugate Adaptive Optics
MIDAS	Mid-Infrared Asteroid Spectroscopy
MIRI	Mid-InfraRed Instrument
MOS	Multi-Object Imaging Spectrograph
MPE 3D	Max Planck Institut für Extraterrestrische Physik 3D
MPFS	Multi-Pupil Field Spectrograph
MUSE	Multi-Unit Spectroscopic Explorer
NaCo	short for NAOS-CONICA (Nasmyth Adaptive Optics System – Near-Infrared Imager and Spectrograph)
NIC-FPS	Near-Infrared Camera and Fabry–Perot Spectrometer
NICMOS	Near Infrared Camera and Multi-Object Spectrometer
NIFS	Near-Infrared Integral Field Spectrograph
NIRSpec	Near-Infrared Spectrograph
NOAO	National Optical Astronomy Observatory
NOT	Nordic Optical Telescope
OAN-SPM	National Astronomical Observatory at San Pedro Martir
OASIS	Optically Adaptive System for Imaging Spectroscopy
OHP	Observatoire de Haute-Provence
OMM	Observatoire du mont Megantic
ORM	Observatorio del Roque de los Muchachos
OSIRIS	Optical System for Imaging and low/intermediate-Resolution Integrated Spectroscopy
PACS	Photoconductor Array Camera and Spectrograph
PMAS	Potsdam Multiaperture Spectrophotometer
PPAK	PMAS fiber pack
PSF	Point Spread Function
PUMA	UNAM (Universidad Nacional Autónoma de Mexico) Scanning Fabry–Perot Interferometer
PUMILA	Near-infrared Spectrograph for the Kinematic Study of the Interstellar Medium
PYTHEAS	Prisme Interferomètre Trames de lentilles pour l'Holometrie, et l'Endoscopie des Astres et des Sources
QSO	quasi-stellar object

RFP	Rutgers Fabry–Perot
RSS	Robert Stobie Spectograph
RSS	Row Stacked Spectra
RTN	Research Training Network
SALT	Southern African Large Telescope
SAO	Smithsonian Astronomical Observatory
SAURON	Spectrographic Areal Unit for Research on Optical Nebulae
SHM	shared memory server
SILFID	Spectrographe Integral Linarisation par Fibres de l'Image Directe
SINFONI	Spectrograph for Integral Field Observations in the Near Infrared
SIS	Stabilized Imager and Spectrometer
SMM	Submillimetre galaxy
SNIFS	SuperNovae Integral Field Spectrograph
SPIFFI	Spectrometer for Infrared Faint Field Imaging
SWIFT	Short Wavelength Integral Field Spectrograph
TF	Tully–Fisher
TIGER	Traitement Intégral des Galaxies par l'Etude de leurs Raies
TTF	TAURUS Tunable Filter
UFTI	UKIRT Fast-Track Imager
UIST	UKIRT Imager-Spectrometer
UKIRT	United Kingdom Infrared Telescope
VIMOS	Visible Imaging Multi-Object Spectrograph
VIRUS	Visible Integral-Field Replicable Unit Spectrograph
VLT	Very Large Telescope
VPH	Volume Phase Holographic
WFPC	Wide-Field Planetary Camera
WHAM	Wisconsin H-alpha Mapper
WHT	William Herschel Telescope
WiFeS	Wide-Field Spectrograph
WIYN	Wisconsin–Indiana–Yale
WYFOS	Wide-Field Optic Spectrograph