

# Report on IAU Symposium 355 “The Realm of the Low Surface Brightness Universe”

## 1. Motivation

This is a brief report on the **IAU 355 symposium on “The Realm of the Low Surface Brightness Universe”** that was held in San Cristobal de La Laguna, Tenerife, Spain, from 8 – 12 July 2019. The aim of the meeting was to bring together a large and varied community of experts in low surface brightness astrophysics covering fields as diverse as Zodiacal light in the Solar System all the way to cosmological backgrounds. The conference put particular emphasis on advertising the collaborative works between the amateur and professional communities.

The timing of this conference was also clear. Although various physical phenomena that produce very low surface brightness signals have been known for a long time, there has been a prolonged silence in this field for several decades. With the advent of new observational techniques as well as new instrumentation both on the ground and in space, the time was right to bring together a large community of experts to discuss this branch of astrophysics.



Conference photograph, courtesy of Prof. Stéphane Courteau.

In addition to the Scientific Programme, the conference also included a number of Social Events. Among them we highlight the excursions to the Teide Observatory (OT) located in the island of Tenerife, and to the Roque de los Muchachos Observatory (ORM) in the neighbouring island of La Palma.

## **2. Summary of the scientific highlights of the meeting**

During the meeting a general consensus emerged that in recent years there has been a renaissance in low surface brightness science due to advances in both specific techniques for deep image reduction and in dedicated technical equipment for this purpose. In the first session of the programme (see Sect 4 of this report), particular emphasis was placed on the role of amateur astronomy both historically and today in the discovery of very low surface brightness objects (potentially satellites) around nearby galaxies.

The conference continued with a detailed description of the large number of facilities and surveys that are currently, or will be in the near future, dedicated to deep imaging and the study of low surface brightness. Among these facilities, the future LSST survey as well as a network of refracting telescopes such as the Huntsman were highlighted. There was also a special mention for future space missions dedicated to the study of low surface brightness such as the MESSIER or AMUSS satellites, or stratospheric balloons such as FIREBall-2.

In addition to very deep imaging, dedicated telescopes and specific observing techniques, it is necessary to have specialized software to make the best possible use of observations for the study of low surface brightness. In recent years, important advances have been made in the development of software capable of detecting very low surface brightness structures, such as Gnuastro. In addition, strategies have been developed to remove the scattered light from astronomical sources. There have also been important advances in the analysis of the reproducibility of low surface brightness images. All these topics were discussed in Session 2 of the conference.

Session 3 aimed to discuss the properties and effects of both Solar System (Zodiacal light) and intergalactic dust grains on deep imaging. The concept of Zodiacal light variability was debated, as well as methods to identify and, if possible, remove the effect of Galactic cirrus from deep images. The study of astrospheres and the low surface brightness remnants of stellar evolution were considered in Session 4. In the coming years, it is expected that these fields will undergo important advances with the development of instruments and new techniques that allow the study of low surface brightness features near bright sources.

One of the most extensive blocks of the conference was devoted to recent advances in the analysis of low surface brightness structures around galaxies. Progress in both resolved stars and integrated photometry techniques was presented. A particularly hotly debated aspect was the question of whether or not there are enough stars in the stellar haloes of galaxies. New observational results were confronted with the predictions of state-of-the-art cosmological simulations. It is expected that the development of new observations and simulations will help to clarify a possible tension between the two fields. Another highlight of the discussion was on the size of galaxies. New imaging surveys routinely detect the edges of galaxies and new proposals for defining size based on the position of these edges were discussed. In particular, the need

to use new ways of measuring size (beyond the effective radius) to advance our understanding of galaxy evolution was proposed.

The other major block of discussion was on the nature of ultra-diffuse galaxies. To discern whether they are low surface brightness dwarf galaxies or a new class of objects, their stellar properties, abundances and structures were debated, as well as their dynamical properties, amount of dark matter and HI content. Two other types of very low surface brightness galaxies, dark galaxies and galaxies with very extended Malin I-type stellar discs, were also discussed. Ideas such as the collision of satellites in the gas clouds surrounding these objects as generators of star formation in the peripheral parts were presented. The origin of the dark galaxies was also speculated on, either as galaxies in their own right or as remnants of large hydrogen clouds fragmented after their gravitational interaction with other objects.

Moving on to cosmology, Sessions 7 and 9 dealt with how to identify the cosmic web through the emission lines of the gas that passes through it. The emission of this circumgalactic medium is extremely weak, and it is currently a huge technological challenge to detect the emission of this medium, through the Lyman alpha line. Different observations of objects at high redshift were presented, as well as the development of specific surveys using narrow-band filters centred on the Lyman alpha line emission.

A further highlight of the conference was the revival of the study of the very weak intra-cluster light. Although this faint light has been known for several decades, it is only now that we can study it both in nearby clusters and in galaxy clusters at high redshifts. Several speakers discussed the use of intra-cluster light both to gain insight into the evolutionary state of galaxy clusters and as an indicator of the distribution of dark matter in these gigantic structures. This is one of the fields of low surface brightness science where major developments are expected in the coming years.

The conference ended with examples of the most recent progress in the study of extragalactic background light. This emission, which makes an important contribution to the background brightness of the deepest astronomical images, has been analysed over almost the entire electromagnetic spectrum. With the advent of very deep and increasingly high spatial resolution images there is hope that the individual emitters of this light (potentially very faint galaxies at high redshifts) will finally be identified.

### **3. List of Invited Speakers and Reviewers**

#### *Invited Reviewers:*

François Boulanger (France)  
Sebastiano Cantalupo (Switzerland)  
Denija Crnojevic (USA)  
Michael Disney (UK; historical review)  
Jose Fonseca (South Africa)  
Eva Grebel (Germany)  
Anny-Chantal Levasseur-Regourd (France)

David Malin (Australia; historical review)  
David Martínez Delgado (Germany)  
Chris Mihos (USA)  
Mireia Montes (Australia)  
Jayant Murthy (India)  
Raghvendra Sahai (USA)  
Eva Villaver (Spain)  
Dennis Zaritsky (USA)

*Invited Speakers:*

Mohammad Akhlaghi (Spain)  
Dominik Bomans (Germany)  
Chris Brook (Spain)  
Sarah Brough (Australia)  
Emanuele Contini (China)  
Alberto Domínguez (Spain)  
Simon Driver (Australia)  
Pierre Alain Duc (France)  
Florence Durreet (France)  
Matthew Hayes (Sweden)  
Yolanda Jiménez Teja (Brasil)  
Sugata Kaviraj (UK)  
Johan Knapen (Spain)  
Jeremie Lasue (France)  
Allison Merritt (Germany)  
Ewald Puchwein (UK)  
Nicolas Tejos (Chile)  
Sebastien Viaene (Belgium)  
Freeke van de Voort (Germany)

**4. Scientific programme**

IR : invited review. IT : invited talk.

***Monday July 8<sup>th</sup>, 2019***

9:00-9:15 Casiana Muñoz-Tuñón (Deputy Director, IAC, Spain). Welcome.

9:15-9:30 David Valls-Gabaud (Obs. Paris, France). Introduction and overview.

*Chairperson: Pierre-Alain Duc*

9:30-10:00 Michael Disney (Cardiff Univ., UK). Hidden galaxies: but not for long (IR).

10:00-10:30 Eva Grebel (ARI, Germany). The renaissance of LSB galaxies (IR).

*Session 1A State-of-the-art in current and future ground-based instrumentation*

11:00-11:30 Christopher Mihos (CWRU, USA). Deep imaging of galaxies and clusters: successes and challenges (IR).

11:30-11:45 Matthew Lehnert (IAP, France). Low surface brightness molecular and atomic line emission in distant galaxies.

11:45-12:15 David Martínez Delgado (ARI, Germany). Ultra-deep imaging with amateur telescopes (IR).

12:15-12:30 Raúl Infante Sáinz & Alex Roig (IAC; Astroprades, Spain). A 100h imaging of M101 with a small telescope: reaching the limits of amateur telescopes for low surface brightness science.

*Session 1B State-of-the-art in current and future ground-based instrumentation*

*Chairperson: Noah Brosch*

14:30-14:55 Sarah Brough (UNSW, Australia). LSST and the LSB universe (IT).

14:55-15:20 Johan Knapen (IAC, Spain). Going towards wide-area ultra-deep imaging surveys (IT).

15:20-15:35 Lee Spitler (Macquarie Univ., Australia). The Huntsman Telescope.

15:35-15:50 Jean-Charles Cuillandre (CEA, France). The Canada-France imaging survey as a Euclid precursor: blind all-sky low surface brightness survey of the northern sky.

15:50-16:15 Armando Gil de Paz (UCM, Spain). Darkness revealed: The MESSIER surveyor (IT).

16:15-16:30 Vincent Picouet (LAM, France). FIREBall-2: The first stratospheric balloon coupled to a multi object spectrograph to reveal the CGM at  $z \sim 0.7$ .

16:30-16:45 Sona Hosseini (JPL, USA). AMUSS – Astrophysics Miniaturized UV Spatial Spectrometer for spectroscopic studies of diffuse astrophysical objects.

*Session 2 Data analysis in LSB imaging*

*Chairperson: Lee Spitler*

17:15-17:40 Sugata Kaviraj (Univ. Hertfordshire, UK). The low-surface-brightness universe: the new frontier in the study of galaxy evolution (IT).

17:40-18:05 Mohammad Akhlaghi (IAC, Spain). Digging out the low-surface-brightness universe: understanding and constraining the limits of methods used (IT).

18:05-18:20 Ignacio Trujillo (IAC, Spain). Reproducibility in ultra-deep imaging.

18:20-18:35 Cristina Martínez Lombilla (UNSW, Australia). Brightness overestimation due to PSF in very faint galaxy structures: the thick discs case.

18:35-18:50 Alejandro S. Borlaff (ESA, Spain). New limits to low surface brightness details: the Hubble ultra deep field even deeper.

18:50 POSTER SESSION (#15 Kotulla, #18 Lee, #27 Mehrabani, #34 Sharbaf, #40 Weimann)

## *Tuesday July 9th*

### *Session 3 Dust particles and grains: from the Zodiacal light to the ISM cirri*

*Chairperson: Eva Villaver*

9:00-9:30 Anny-Chantal Levasseur-Regourd (LATMOS/IPSL, France). Progress in Zodiacal light understanding (IR).

9:30-9:55 Jérémie Lasue (IRAP, France). Interpreting the Zodiacal light observations from the properties of interplanetary and cometary dust particles (IT).

9:55-10:25 François Boulanger (ENS, France). Diffuse light from interstellar cirrus clouds across the electromagnetic spectrum (IR).

10:25-10:50 Sébastien Viaene (Ghent Univ., Belgium). Deriving diffuse dust properties from UV and optical observations (IT).

10:50-11:05 Javier Román (IAA, Spain). Galactic cirri in deep optical imaging.

### *Session 4 The LSB circumstellar medium and orphan stars*

*Chairperson: Sarah Brough*

11:35-12:05 Raghvendra Sahai (JPL, USA). Faint but not forgotten: astrospheres around dying stars (IR).

12:05-12:35 Eva Villaver (UAM, Spain). The tale of the lost mass (IR).

12:35-13:00 Dominik Bomans (Bochum, Germany). Multi-wavelength observations of Orphan SN and other transients as signposts for very low surface brightness structures (IT).

13:00-13:15 Thomas Sedgwick (LJMU, UK). Low surface brightness galaxies & the galaxy stellar mass function from core-collapse supernovae.

### *Session 5A Low surface brightness features around and within galaxies*

*Chairperson: Gaspar Galaz*

15:00-15:30 Denija Crnojević (Univ. Tampa, USA). Near-field cosmology with low surface brightness features (IR).

15:30-15:55 Allison Merritt (MPIA, Germany). A survey of observed and simulated stellar halos around Milky Way-like galaxies in the nearby universe (IT).

15:55-16:20 Chris Brook (IAC, Spain). Forming low surface brightness objects in simulations (IT).

16:20-16:35 Bärbel Koribalski (CSIRO, Australia). Hydrogen tails, plumes, and filaments.

17:05-17:30 Pierre-Alain Duc (Obs. Strasbourg, France). MATLAS: An investigation of the mass assembly of galaxies with their fine structures, satellite and globular cluster populations (IT).

17:30-17:45 Sarah Pearson (FICCA, USA). Detecting thin stellar streams in external galaxies: resolved stars and integrated light.

17:45-18:00 Nushkia Chamba (IAC, Spain). The size of the galaxies in the era of ultra-deep imaging.

18:00-18:15 Sakurako Okamoto (Subaru, Japan). Signatures of on-going interactions at M81 group centre in the low-surface-brightness features.

18:15-18:30 Oliver Müller (Obs. Strasbourg, France). Hunting for low-surface-brightness features in nearby galaxy groups.

18:30-18:45 Noah Brosch (Tel Aviv, Israel). Low-surface-brightness features in Hickson compact groups.

18:45-19:00 Sébastien Comerón (U. Oulu, Finland). The reports of thick discs' death are greatly exaggerated: thick discs are not artefacts caused by diffuse scattered light.

### **Wednesday July 10th**

#### *Session 5B Low-surface-brightness features around and within galaxies*

*Chairperson: Stéphane Courteau*

9:00-9:30 David F. Malin (AAO, Australia). Early photographic detection of LSB features (IR).

9:30-9:45 Raja Guhathakurta (UCSC, USA). Dark matter and chemical enrichment in the low-surface-brightness outskirts of galaxies.

9:45-10:00 In Sung Jang (Postdam, Germany). Tracing the extended stellar outskirts of low-mass disk galaxies.

10:00-10:15 Michal Bilek (Obs. Strasbourg, France). Census of tidal features in nearby early-type galaxies.

10:15-10:30 Fernando Buitrago (IASS, Portugal). Why finding an extended galaxy in a high redshift survey is not an annoyance but a potential treasure trove.

10:30-10:45 Yutaka Komiyama (NAOJ, Japan). Low-surface-brightness features in the Local Universe viewed from the Subaru Prime Focus.

*Session 6A The nature of ultra-diffuse galaxies and other LSB galaxies*

*Chairperson: Fernando Buitrago*

11:15-11:30 Anna Ferré-Mateu (ICCUB, Spain). On the nature of the ghostly ultra diffuse galaxies in the Coma cluster.

11:30-11:45 Tomás Ruiz-Lara (IAC, Spain). The stellar content in ultra diffuse galaxies: contrasting the galaxy “lacking dark matter” with other Coma cluster UDGs.

11:45-12:00 Daniel J. Prole (Cardiff Univ., UK). The formation of ultra diffuse galaxies: observational evidence.

12:00-12:15 Luis E. Pérez Montaña (UNAM Morelia, Mexico). Halo Structural parameters of low surface brightness galaxies.

12:15-13:00 POSTER SESSION (#26 Martínez-Vázquez, #33 Saremi, #09 Grishin, #11 Javadi, #13 Kemp, #28 Park, #32 Ribbeck, #36 Walker, #24 Mancillas, #05 Brosch, #14 Kemp, #35 Stein, #39 Zemaitis)

*Session 6B The nature of ultra-diffuse galaxies and other LSB galaxies*

*Chairperson: Mireia Montes*

15:00-15:30 Dennis Zaritsky (U. Arizona, USA). Searching for SMUDGes (IR).

15:30-15:45 Samuel Boissier (Marseille, France). Ultra-diffuse and low-surface-brightness galaxies in the Virgo cluster: constraints from the VESTIGE and GUViCS surveys, and simple models.

15:45-16:00 Gaspar Galaz (PUC, Chile). Unavoidable questions about giant low-surface-brightness galaxies.

16:00-16:15 Anna Saburova (SAI, Russia). Unveiling the origin of giant low surface brightness discs: results of the long-slit spectral observations.

16:15-16:30 Jeong Hwan Lee (U. Seoul, South Korea). Hunting distant UDGs in very massive clusters with HST.

17:00-17:15 Stéphane Courteau (Queen’s U., Canada). Structural and dynamical properties of LSB galaxies.

17:15-17:30 Igor Chilingarian (SAO, USA). Internal dynamics and stellar content of ultra-diffuse galaxies in the Coma cluster prove their evolutionary link with dwarf early-type galaxies.

17:30-17:45 Rhys Taylor (Prague, Czech Republic). Optically dark hydrogen clouds from the Arecibo Galaxy Environment Survey: dark galaxies or debris?



17:45-18:00 Pavel Mancera-Piña (Kapteyn, The Netherlands). The startling dynamics of HI-Rich ultra-diffuse galaxies.

18:00-18:15 Salvador Cardona Barrero (IAC, Spain). Dispersion vs rotation support in ultra-diffuse and low surface brightness galaxies.

18:15-18:30 Anton Afanasiev (SAI, Russia). Internal dynamics of the extended dwarf spheroidal galaxy KDG64: bridging the gap between ultra-diffuse galaxies and dwarf spheroidals.

18:30-19:00 POSTER SESSION (#02 Bennet, #04 Bouquin, #19 Li, #06 Díaz-García, #21 Malayi, #31 Rey, #37 Watkins, #12 Junais, #16 Laine, #17 Lee, #10 Gomes)

### *Thursday July 11th*

#### *Session 7 The circumgalactic medium of low- and high-redshift galaxies*

*Chairperson: Matthew Lehnert*

9:00-9:30 Sebastiano Cantalupo (ETH, Switzerland). Illuminating the cosmic web and the circumgalactic medium with fluorescent Lyman-alpha emission (IR).

9:30-9:55 Matthew Hayes (Stockholm Univ., Sweden). The circumgalactic medium of low- redshift galaxies, probed by emission lines at low surface brightness (IT).

9:55-10:10 Deborah Lokhorst (Univ. Toronto, Canada). Direct detection of the circumgalactic medium using Dragonfly.

10:10-10:25 Jorge Sánchez Almeida (IAC, Spain). GTC-based search for diffuse gas around local gas-accreting galaxies.

10:25-11:00 POSTER SESSION (#29 Pérez-Fournon, #30 Pérez Hernández)

11:30-11:55 Freeke van de Voort (MPA, Germany). Cosmological simulations of the CGM at sub- kpc resolution (IT).

11:55-12:10 Genoveva Micheva (AIP, Germany). Deep surface photometry of the Lyman Alpha Reference Sample (LARS).

12:10-12:25 Helmut Dannerbauer (IAC, Spain). Surprising existence of circumgalactic molecular medium in a galaxy protocluster at  $z=2.2$ .

12:25-12:40 Andrea Afruni (Kapteyn, The Netherlands). Understanding the cool circumgalactic medium of passive galaxies.

12:40-13:00 POSTER SESSION (#38 Wright, #23 Mancillas, #25 Mancillas, #03 Bilek, #01 Amiri, #20 De Oliveira)

#### *Session 8 The intracluster light and its role in galaxy evolution in clusters*

*Chairperson: Matthew Hayes*

15:00-15:30 Mireia Montes (UNSW, Australia). The intracluster light and its role in galaxy evolution in clusters (IR).

15:30-15:55 Emmanuele Contini (Nanjing Univ., China). Intracluster light: its formation and main properties (IT).

15:55-16:10 Marilena Spavone (Obs. Naples, Italy). Stellar haloes from deep VST surveys: comparing observations and theory.

16:10-16:25 Brandon Kelly (LJMU, UK). Intracluster light as a proxy for host cluster properties.

17:00-17:25 Florence Durret (IAP, France). Intracluster light and its influence on galaxy evolution in clusters (IT).

17:25-17:50 Yolanda Jiménez-Teja (Obs. Rio de Janeiro, Brazil). Unveiling the dynamical stage of massive clusters through the study of the intracluster light (IT).

17:50-18:05 Enrichetta Iodice (Obs. Capodimonte, Italy). The deep (photometric and spectroscopic) surveys of the Fornax cluster: exploring the faintest regions of the bright ETGs inside the virial radius.

18:05-18:20 Isaac Alonso Asensio (IAC, Spain). Similarity between stellar and total dark matter density distributions in the intra-cluster volume: a view from simulations.

18:20-18:35 Jongwan Ko (KASI, South Korea). Evidence for the existence of intracluster light  $\sim 5$  billion years after the Big Bang.

18:35-18:50 Michael Wilkinson (U. Groningen, The Netherlands). Sourcerer\*: a robust, multi-scale source extraction tool suitable for faint and diffuse objects.

18:50-19:00 POSTER SESSION (#07 Ebrova, #22 Mancillas, #08 Ellien)

### *Friday July 12th*

#### *Session 9 The cosmic web of large-scale filaments*

*Chairperson: Simon Driver*

9:00-9:30 José Fonseca (U. Padova, Italy). Line intensity mapping: a “novel” window to the cosmic web (IR).

9:30-9:55 Ewald Puchwein (AIP, Germany). Lyman-alpha emission and absorption by the cosmic web(IT).

9:55-10:20 Nicolas Tejos (Pontificia Universidad Católica de Valparaiso, Chile). Looking for a WHIM in the large-scale filaments of the cosmic web.

#### *Session 10 The UV / optical / IR cosmological background radiation*

*Chairperson: Florence Durret*

10:50-11:20 Jayant Murthy (IIA, India). The UV and optical sky background (IR).

11:20-11:45 Alberto Dominguez (UCM, Spain). The extragalactic background light in the Fermi- LAT era (IT).

11:45-12:10 Simon Driver (UWA, Australia). Measuring energy production in the Universe over all wavelengths and all time (IT).

12:10-12:40 Christopher Mihos (CWRU, USA). Summary of the conference.