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The General Assembly of Galaxy Halos: Structure, Origin and Evolution

Edited by

Angela Bragaglia

Magda Arnaboldi

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THE GENERAL ASSEMBLY OF GALAXY HALOS:
STRUCTURE, ORIGIN AND EVOLUTION

IAU SYMPOSIUM 317

COVER ILLUSTRATION:

This is a montage of three images illustrating hot topics of our Symposium, clockwise from the bottom:

1) the Milky Way galaxy arching above the platform of ESO's Very Large Telescope (VLT) on Cerro Paranal, Chile. The extent of our galaxy's cloudy and dusty structure can be seen in remarkable detail as a dim glowing band across the observation deck. Our galaxy is surrounded by several smaller satellite galaxies. Prominent here, to the left, are the Small Magellanic Cloud and Large Magellanic Cloud dwarf galaxies which are members of our Local Group of galaxies. Credit: John Colosimo (colosimophotography.com)/ESO.

2) a contrasting pair of galaxies: NGC 1316, and its smaller companion NGC 1317 (right). Although NGC 1317 seems to have had a peaceful existence, its larger neighbour bears the scars of earlier mergers with other galaxies. Credit: ESO.

3) the surface brightness of a simulated halo (standard halo number 8 in Johnston et al. 2008, ApJ, 689, 936), as viewed from an external perspective. The panel is 300 kpc on a side. Adapted from Fig. 14 in Johnston et al. (2008).

IAU SYMPOSIUM PROCEEDINGS SERIES

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INTERNATIONAL ASTRONOMICAL UNION
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International Astronomical Union



THE GENERAL ASSEMBLY OF GALAXY HALOS: STRUCTURE, ORIGIN AND EVOLUTION

PROCEEDINGS OF THE 317th SYMPOSIUM
OF THE INTERNATIONAL ASTRONOMICAL
UNION HELD IN HONOLULU, USA
AUGUST 3–7, 2015

Edited by

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Preface

The IAU Symposium 317 titled “The General Assembly of Galaxy Halos: Structure, Origin and Evolution” was held during the IAU General Assembly XXIX in Honolulu, Hawaii, from August 3 to 7, 2015.

The IAU Symposium 317 aimed at bringing the studies of the Milky Way halo together with the perspective on external galaxies’ stellar halos and their evolution. The motivation for understanding the physics of galaxy halos begins with the statement from Eggen, Lynden-Bell and Sandage (1962, *ApJ* 136, 748): “The time required for stars in the (Milky Way) halo to exchange their energies and angular momenta is very long compared with the age of the Galaxy. Hence, knowledge of their present energy and angular momenta tells us something of the initial conditions under which they formed.” This statement, which is more than half a century old, illustrates the wealth of information contained in the dynamics and chemical composition of stars in the halos of galaxies and their implication for the models of galaxy formation. This quest starts right at our doorsteps with the study of the Milky Way galaxy. Because we live in it and its light dominates our skies, we can study its stars with state-of-the art instrumentation out to its farthest outskirts.

Measuring the physical parameters of the structural components of the MW thin and thick disk, bulge and halo with imaging and spectroscopic surveys from the ground tells us when these components formed and whether they were dominated by accretion or by dissipative collapse of the MW own gas. These surveys also tell us about the frequency and the generations of stars that emit the light that we see today in our sky, and about the stars progenitors that are responsible for their chemical content. And the future looks even brighter: astronomers are now preparing for a big revolution brought about by the Gaia satellite. They are assessing all the observational implications of the most accredited models for the formation of the Milky Way to be tested against the measurements provided by this space mission. The Gaia satellite will measure the parallaxes and proper motions for the MW stars with exquisite precision such that we shall obtain a tridimensional map distribution for nearly one billion stars around our Sun and a kinematical and chemical census of all Galactic components!

What about the MW halo then? Our Galaxy halo turned out to be a livelier environment than was previously believed. Chemical tagging of globular clusters permitted to discover distinct multiple stellar generations. The accreted stars found in the halo are associated with several different substructures like for example the disrupted Sagittarius dwarf. This substructure provides 20% of all the debris of the stellar halo in the Milky Way, including multiple extended stellar streams. The modelling of these streams constrains the Galaxy potential and its associated mass to $\sim 5 - 8 \times 10^{11} M_{\odot}$ within 200 kpc, in agreement with the kinematics of halo stars and satellites in the Local Group. Similar complex network of structures is found in the halo of the Andromeda galaxy (M31), the giant spiral galaxy closest to us, as well. Numerous dwarf galaxies and globular clusters, but also streams without clear progenitors contribute to this network as shown by the map of the red giant stars in the M31 halo from the PAndAS survey.

Are halos and streams found around disk galaxies only? No, galaxy halos are ubiquitous in luminous galaxies and we now know that they also extend out to hundred kiloparsecs, that they have complex morphologies with a maze-like web of tails, plumes and spurs, and that they harbor multiple stellar components, with different chemical content and ages. Vivid testimony of these intricate luminous substructures are shown by the very deep images, reaching surface brightness levels to 1% of the night sky. Also the two

dimensional maps of discrete tracers like planetary nebulae and globular clusters allow to see substructures both in space and velocity. The recent beautiful example for the giant elliptical galaxy M87 shows the debris of a satellite disrupted in its halo forming a crown and provides evidence that the outer halo is still growing.

To understand how the galaxy assembly took place we need to combine observations with theoretical modelling. This is because we deal with a long sequence of events, where mass accretion, i.e. stars and gas brought in by smaller satellites, and dissipative collapse of the galaxies own gas play important roles, leading to the formation of different structural components that we see today in our own Milky Way and in external galaxies.

The IAU Symposium 317 provided a vibrant forum where experts discussed many different aspects of the global assembly, formation and evolution of galaxy halos and their constituents. Hundred and sixty-eight participants were officially registered, but many more attended the Symposium joining us from the parallel sessions and shared our enthusiasm for the research on stellar halos. By bringing together observers and theorists, we made progress toward a coherent picture of the formation and evolution of the halos in the MW, Andromeda and more distant galaxies.

The Scientific Organizing Committee (SOC) made a terrific job in putting together a stimulating scientific program, and supporting the participation of many young astronomers. The SOC members took an active role during the Symposium also, by chairing the sessions and fostering lively discussions with timely posed and insightful questions. We wish to thank all of them here: Wako Aoki, Kenneth Freeman, Doug Geisler, Ortwin E. Gerhard, Oleg Gnedin, Laura Greggio, Rodrigo Ibata, Alan McConnachie, Poul Erik Nissen, Eric Peng, Chis Sneden, Else Starkenburg and Enrico Vesperini.

The organisation for the Symposium was provided by the IAU personnel. Everything went smoothly and we wish to thank in particular Cathy Cox and Lisa Idem for their help.

The program listed 13 sessions that included 17 invited talks, 39 oral contributions, a summary talk and a plenary talk for the whole Assembly. There were many poster contributions and the scientific program had two poster sessions dedicated to 21 short contributions of 2 minutes each, where the scientific highlights of the poster contributions were presented. We wish to warmly thank all participants for their valuable contributions to the success of our Symposium, and in particular Raffaele Gratton for the summary talk and Ortwin Gerhard for the plenary talk.

During the conference, we received the sad news of the passing away of Dr Nigel Douglas, senior researcher at the Kapteyn Institute in Groningen, Netherlands. He was one of the builders of the Planetary Nebulae Spectrograph (PN.S) and the first Principal Investigator; his contribution to the study of stellar halos was acknowledged by the PN.S team members attending the Symposium and shared with the participants of the IAU Symposium 317.

We include in the following the scientific program of the Symposium, and are proud to share the proceedings of these exciting contributions with the entire IAU community.

Magda Arnaboldi, Angela Bragaglia, Marina Rejuba, Donatella Romano, Editors

Table 1. Program of IAUS 317

1. GLOBAL PROPERTIES OF STELLAR HALOS FROM THE MILKY WAY TO EXTERNAL GALAXIES		
I - Monday, 3 August 2015 10:30-12:30 am		
SOC Chairs	Welcome address	
Kathryn Johnston	Origins of Stellar Halos	invited
Marina Rejkuba	Tracing the stellar halo of an early type galaxy out to 25 effective radii	contributed
Alan McConnachie	Stellar halos around Local Group galaxies	invited
Matthias Steinmetz	Investigating the earliest epochs of the Milky Way halo	contributed
Denija Crnojevic	Resolving the extended stellar haloes of nearby galaxies: the wide-field PISCeS survey	contributed
Chair: Else Starkenburg		
II - Monday, 3 August 02:00-03:30 pm		
Chris Mihos	Intragroup and Intracluster Light	invited
Justin Read	Stellar halos: a rosetta stone for galaxy formation and cosmology	invited
Paul Schechter	New axes for the stellar mass fundamental plane	contributed
Johan Knapen	Direct imaging of haloes and truncations in face-on nearby galaxies	contributed
Chair: Oleg Gnedin		
III - Tuesday, 4 August 08:30-10:30 am		
Ortwin Gerhard	The Milky Way, the Galactic halo, and the halos of galaxies	plenary
IV - Tuesday, 4 August 10:30-12:30 pm		
2. HALO STARS AND CHEMICAL EVOLUTION		
Anna Frebel	Chemical abundances of the most metal-poor stars in the Milky Way	invited
Kevin Schlaufman	The Most Ancient Stars in the Milky Way's Halo	invited
Wako Aoki	Very Low Mass Stars with Extremely Low Metallicity in the Milky Way's Halo	contributed
David Yong	Neutron-capture element and Sc abundances in low- and high-alpha Galactic halo stars	contributed
Haining Li	Searching for chemical relics of first stars with LAMOST and Subaru	contributed
Chiaki Kobayashi	Inhomogeneous chemical enrichment in the Galactic Halo	contributed
Chair: Chris Sneden		
V - Tuesday, 4 August 02:00-03:30 pm		
3. DISCRETE CONSTITUENTS OF STELLAR HALOS IN THE MILKY WAY AND IN EXTERNAL GALAXIES : PLANETARY NEBULAE and GLOBULAR CLUSTERS		
Terese Hansen	Exploring the Early Universe with Extremely Metal-Poor Stars	contributed
Magda Arnaboldi	Planetary Nebulae and their parent stellar populations: tracing the mass assembly of the giant elliptical galaxy M87 and the intracluster light in the Virgo cluster core	contributed
Giuliana Fiorentino	RR Lyrae to build up the Galactic Halo	contributed
Warren Reid	PN populations in the Local Group and distant stellar populations	invited
Judith Cohen	Outward Bound with RR Lyrae Stars: Studies of the Outer Halo of the Milky Way	contributed
Chair: Angela Bragaglia		

VI - Wednesday, 5 August 10:30-12:30 pm		
Eugenio Carretta	Globular clusters and their contribution to the formation of the Galactic halo	invited
Giampaolo Piotto	Single & Multiple Stellar Populations in Globular Clusters: Chemical Tagging, Photometric Sequences, and Dynamics	invited
Corinne Charbonnel	Did globular clusters contribute to the stellar population of the Galactic halo?	contributed
Gary Da Costa	Are the globular clusters with significant internal [Fe/H] spreads all former dwarf galaxy nuclei?	contributed
Douglas Geisler	CaTaclism in the SMC - star clusters vs. field stars	contributed
Pawel Pietrukowicz	RR Lyrae stars as probes of the Milky Way structure and formation	contributed
Chair: Magda Arnaboldi		
VII - Wednesday, 5 August 02:00-03:30 pm		
Soeren Larsen	Globular clusters in M31, LG and external galaxies	invited
Michael Hilker	Globular clusters as tracers of the halo assembly of nearby central cluster galaxies	contributed
Karoline Gilbert	Recent Results from the SPLASH Survey: Chemical Abundances and Kinematics of Andromeda's Stellar Halo	contributed
Andreas Kupper	Globular Cluster Streams as Galactic High-Precision Scales	contributed
Poster presentation		
Chair: Else Starkenburg		
VIII - Wednesday, 5 August 04:00-06:00 pm		
4. DWARF GALAXIES		
Josh Simon	Satellite systems and halos in the Local Group and beyond	invited
Giuseppina Battaglia	Stellar kinematics and dark matter in dwarf galaxies	invited
Sergey Koposov	Discovery of a large number of Ultra Faint satellites in the vicinity of the Magellanic Clouds	contributed
Eric Peng	Globular Clusters, Ultra-Compact Dwarfs, and the Formation of Galaxy Halos	contributed
Michelle Collins	The Andromeda dwarf galaxies as probes of cosmology and galaxy evolution	contributed
Kim Venn	Chemical abundances in metal-poor stars in Dwarf Galaxies	contributed
Chair: Wako Aoki		
IX - Thursday, 6 August 08:30-10:00 am		
Vanessa Hill	Dwarf galaxies around the Milky Way: linking ages, kinematics and chemistry	invited
Donatella Romano	Chemical enrichment in Ultra-Faint Dwarf galaxies	contributed
Antonino Milone	Multi-wavelength photometry of the M54+Sagittarius stellar system, of NGC1851, M22, M2, and other building blocks of the Galactic Halo	contributed
Else Starkenburg	Investigating the earliest epochs of the Milky Way halo	contributed
Poster presentation		
Chair: Doug Geisler		

X - Thursday, 6 August 10:30-12:30 pm		
5. PROBING THE DYNAMICS OF GALAXIES WITH SMOOTH HALOS STELLAR SUBSTRUCTURES		
Jenny Greene	Metallicity gradient in the halos of external galaxies	invited
Jean Brodie	Constraints from discrete tracers on the assembly histories of ETG halos	invited
Benjamin Cook	Stellar populations of stellar halos: Results from the Illustris Simulation	contributed
Nicola Napolitano	Mass and stellar orbit distribution of Early-Type galaxy haloes	contributed
Bruce Elmegreen	Gas accretion from halos to disks: observations, curiosities, and problems	contributed
Laura Greggio	Studying Stellar Halos with Future Facilities	contributed
Chair: Alan McConnachie		
XI - Thursday, 6 August 02:00-03:30 pm		
Annette Ferguson	Dissecting Galactic Accretion Events within the Local Group and Beyond	invited
Jorge Penarrubia	The formation of the smooth halo component	invited
Oleg Gnedin	Tracing the assembly of stellar halos with globular clusters	contributed
Antonela Monachesi	Resolving the stellar halos of six massive disk galaxies beyond the Local Group	contributed
Chair: Laura Greggio		
XII - Thursday, 6 August 04:00-06:00 pm		
6. ORIGIN OF STELLAR HALOS		
Amina Helmi	The connection between galaxy formation and the assembly of stellar halos in the LG	invited
Gerhard Hensler	The early gaseous and stellar mass assembly of Milky Way-type galaxy haloes	contributed
Allyson Sheffield	Contributions to the Galactic Halo from In-Situ, Kicked-Out, and Accreted Stars	contributed
Roelof de Jong	GHOSTS: the age and structure of stellar halos around nearby disk galaxies	contributed
Michaela Hirschmann	The stellar accretion origin of stellar population gradients at large radii in massive, early-type galaxies	contributed
Carl Grillmair	Stellar Debris Streams in the Galactic Halo	contributed
Myung Gyoong Lee	Dual Stellar Halos in the Standard Elliptical Galaxy M105 and Formation of Massive Galaxies	contributed
Chair: Eric Peng		
XIII - Friday, 7 August 08:30-10:30 pm		
7. SUMMARY and DISCUSSION		
Raffaele Gratton	Summary talk and Discussion	
Chair: Ortwin Gerhard		