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Galactic Dynamics in the Era of Large Surveys

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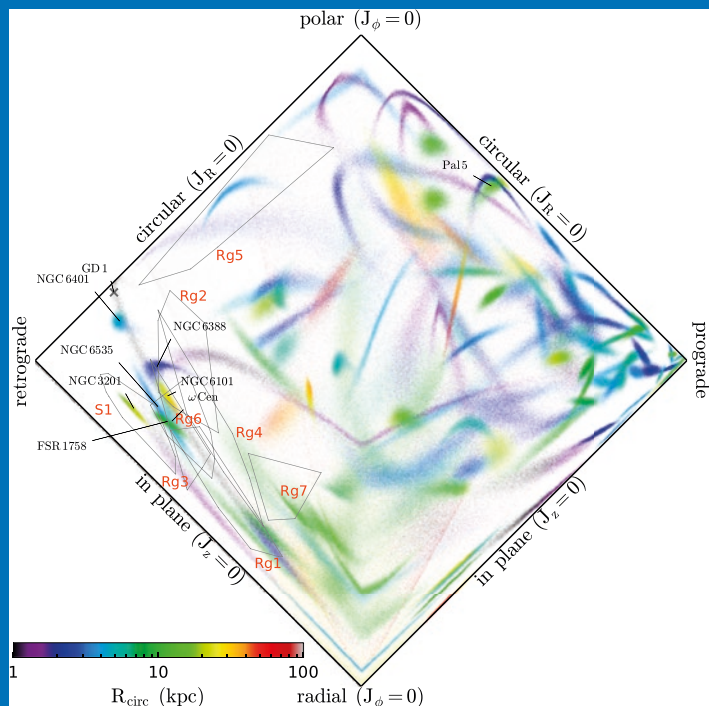
Monica Valluri
J. A. Sellwood

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COVER ILLUSTRATION:

Distribution of tidal debris and globular clusters within the stellar halo of the Milky Way, derived using data from ESA's Gaia satellite. The position of each coloured feature indicates the nature of the orbits of the stars that make up that feature and are colour coded by their current distance from the Galactic centre. See the article by Evans on p113 for more details.

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Chief Editor

MARIA TERESA LAGO, IAU General Secretariat

IAU-UAI Secretariat

98-bis Blvd Arago

F-75014 Paris

France

mtlago@astro.up.pt

Editor

JOSÉ MIGUEL RODRÍGUEZ ESPINOSA, IAU Assistant General Secretary

IAU-UAI Secretariat

98-bis Blvd Arago

F-75014 Paris

France

IAU_AGS@iap.fr

INTERNATIONAL ASTRONOMICAL UNION
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GALACTIC DYNAMICS IN THE ERA OF LARGE SURVEYS

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30 June–5 July, 2019

Edited by

MONICA VALLURI
University of Michigan, USA

and

J. A. SELLWOOD
*Steward Observatory,
University of Arizona, USA*



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Preface

Galactic dynamics is fundamental to understanding the formation of galaxies, their internal evolution and their current structure. It also governs interactions between galaxies in systems ranging in size from groups to large clusters of galaxies. While galactic dynamics has traditionally focused on the evolution of the stellar components of galaxies, studies over the past two decades have shown that all aspects of galaxy evolution: star formation, the nature and distribution of stellar populations and the chemical evolution of a galaxy as a whole are strongly influenced by the interplay between the dynamics of stars, gas, and dark matter.

IAU Symposium 353, “Galactic Dynamics in the Era of Large Surveys” was the first major symposium specifically focusing on galaxy dynamics since the St. Petersburg conference in 2007. In the interim there has been a divergence in the dynamical methods employed to understand the Milky Way where 3D kinematics of resolved stellar populations are becoming available, but observed from our heliocentric view point, and the dynamical methods employed in the study of external galaxies where wide field line-of-sight kinematics are available for large samples of galaxies. Two primary aims of the symposium were to bring these diverging communities together to ensure that (1) our detailed understanding of the Milky Way and other Local Group galaxies informs our understanding of distant galaxies, their formation and evolution, and (2) the comparison of the Local Group galaxies with external galaxies in turn informs our understanding of the formation and evolution of the Local Group in a cosmological context.

The Symposium attracted observers and theorists who presented their latest findings and discussed how their combined expertise could address important open questions in galaxy formation and evolution, which are some of the major topics and challenges of modern astronomy.

Galaxies in the Local Group have seen the largest increase in high quality resolved data resulting in a substantial revision to our understanding of both the structures of the individual galaxies and the dynamical interactions between them. Alongside these developments, there have been significant advances in theoretical understanding of the internal structure and evolution of spiral and elliptical galaxies. However, it is not yet clear what the relative roles of internal secular evolution and environmental effects are in the cosmological context. It has become clear that bars and spirals drive substantial secular evolution in disk galaxies, though there are still unsolved questions regarding the mechanisms. These structures also transport angular momentum from the inner to the outer disk, scatter stars away from circular orbits contributing to the well-established age-velocity dispersion relation, cause radial migration of stars, smooth rotation curves and disk density profiles, and influence the chemo-dynamical structure of stellar disks. Thus, the present-day properties of disk galaxies are not simply determined by their formation history. Likewise elliptical galaxies and the stellar halos of individual galaxies and those in clusters are not simply products collisionless mergers – the role of gas in determining their structure and evolution is much better understood with large surveys but many questions remain. Large surveys of the Milky Way and Local Group have also yielded exquisite kinematical data on stars in the Galaxy’s halo and in neighboring galaxies allowing us to derive much better constraints on the properties of dark matter halos. Increasingly deep optical surveys both in the Local Group and in external galaxies have revealed a plethora of satellite galaxies some small and faint others quite massive but extremely extended diffuse. How these systems form, evolve and interact with their hosts is a subject of great current interest and active research.

The Symposium provided an important and timely platform to discuss and share ideas on the applications of galactic dynamics to the Milky Way and external galaxies. The key topics included but were not limited to:

- The structure, dynamics, and assembly history of the Milky Way galaxy,
- Dynamical evolution of the Local Group and its members (including M31, the Magellanic clouds, dwarf spheroidal galaxies),
- Dynamical influence of internal secular evolution vs. mergers and tidal interactions on galaxy evolution
- Dynamics of disk galaxies: the influence of spiral structure, radial migration and bars,
- The role of gas in the dynamical evolution of galaxies,
- Dynamical modeling of galaxies to measure the mass profiles of baryons and dark matter halos and central supermassive black holes using large integral field spectroscopic surveys,
- Dynamics of galactic nuclei and nuclear star clusters.

IAU Symposium 353 was held at the historic Shanghai Jianjian Hotel in the very room where US President Richard Nixon signed the “China-US” Shanghai Communique. Symposium attendees were welcomed by Professor Zhiqiang Shen, Director of the Shanghai Astronomical Observatory of the Chinese Academy of Sciences, after which the SOC Co-Chairs, Juntao Shen and Monica Valluri, opened the conference.

The Scientific Organizing Committee (SOC) invited a total of 40 speakers to give major talks (29 male and 11 female) of which 35 were delivered at the Symposium. Four female invited speakers backed out at a late stage, otherwise the fraction of female speakers would have been even higher. All submitted abstracts were reviewed by the SOC, who selected a further 42 contributed oral presentations, with the aim of achieving broad scientific representation, gender diversity, geographical distribution and career stage. Each invited talk was allocated 25 minutes, and each contributed talk was allocated 12 minutes, including time for discussion. In addition there were three 30 minute sessions for open discussion. 108 poster presentations were also accepted. In total, nearly 200 individuals from 25 countries spanning all continents attended and 35% of the participants were female. Individual sessions were chaired by members of the SOC and other senior attendees whilst a variety of postdocs and PhD students supported the logistics throughout the sessions.

During the conference, Jo Bovy (University of Toronto) and Karen Masters (Haverford College) moderated an open discussion on the second day on the topic ‘What we have learned about disk galaxies (including the Milky Way) from large surveys’ where many important questions were raised and discussed. It became clear that bringing the communities (Milky Way and external galaxies; high and low redshift galaxies; dynamical theorists and observers, etc.) together is extremely important to reinvigorate the field.

On the fourth day, Ortwin Gerhard (Max-Planck-Institut fuer extraterrestrische Physik) moderated an open discussion on ‘Galactic nuclei, bars and bulges’. After a brief overview of the current understanding on the barred Milky Way, he summarized the upcoming challenges in this field, including the bulge/bar structure from RCG star count tomography, dynamical models from star counts and radial velocities, new 3D view from VIRAC/Gaia proper motions, and dynamical structure of stellar populations. The discussion reached a final conclusion, that further new data from Gaia and ground-based surveys, and further modelling is likely to lead to improved dynamical constraints and new understanding of the stellar population in the bulge.

On the fifth day, Monica Valluri (University of Michigan) moderated an open discussion on ‘the halos of the Milky Way and other galaxies’. She raised several important questions and challenges regarding to the current status of the halo study. Possible improvements on cosmological simulation to better model the Milky Way halo were also discussed.

In addition to the scientific sessions, the attendees enjoyed a welcome reception on Sunday June 30. The conference dinner was held on the third day, during which the attendees also celebrated the 70th birthday of influential dynamicist, Jerry Sellwood, who thanked the organizers for their outstanding efforts that largely contributed to the success of the meeting.

Before the Symposium, a free summer school for graduate students and junior researchers was held from June 24 to 28 at Shanghai Jiao Tong University. It aimed to foster and train a new generation of galactic dynamicists in the Far East and other developing countries. The seventy participants of the summer school represented eleven countries spanning all continents. The lectures were delivered by Jerry Sellwood, John Kormendy, Robyn Sanderson (University of Pennsylvania), Monica Valluri, Eugene Vasiliev (University of Cambridge), and Ling Zhu (Shanghai Astronomical Observatory), all of whom are international experts in galactic dynamics. In addition to 3-4 daily lectures there were several hands-on sessions to enable students to learn the use of dynamics software and the analysis of real and simulated data.

Two public outreach talks were held in the Shanghai Science & Technology Museum to celebrate the 100th year of the IAU. Professor Jerry Sellwood (University of Arizona) and Professor John Kormendy (University of Texas at Austin) gave public talks to an audience of about 200, half of whom were teenagers in middle school or high school. Sellwood talked about ‘Spirals in Galaxies’, and Kormendy talked about ‘Black Holes: Death Stars in the Hearts of Galaxies and Monsters’. Both talks are warmly appreciated, with over 40 questions from the audience.

Juntai Shen, and Monica Valluri as Co-Chairs of the Science Organizing Committee (SOC), were greatly aided in their duties by the other members of the SOC: Gurtina Besla (Univ. of Arizona), Joss Bland-Hawthorn (Univ. of Sydney), Jo Bovy (Univ. of Toronto), Michele Cappellari (Oxford Univ.), Françoise Combes (Obs. de Paris), Dmitri Gadotti (ESO), Ortwin Gerhard (MPE), Amina Helmi (Univ. of Groningen), Woong-Tae Kim (Seoul National Univ.), John Kormendy (Univ. of Texas at Austin).

The Local Organizing Committee (LOC) was chaired by Juntai Shen of Shanghai Astronomical Observatory (SHAO), and Shanghai Jiao Tong University (SJTU) both in Shanghai, China and included Zhao-Yu Li (SHAO, SJTU), Yang Yang (SHAO), Zhong Liu (SHAO), Sarah Bird (SHAO) and Behzad Tahmasebzadeh (SHAO).

The organizers gratefully acknowledge major financial support from the Shanghai Astronomical Observatory, the International Astronomical Union, National Natural Science Foundation of China and Chinese Academy of Sciences as well as Shanghai Jiao Tong University which hosted the summer school.

The editors would especially like to thank Juntai Shen, co-chair of the SOC and chair of the LOC for doing an outstanding job of organizing both the conference and summer school.

These proceedings provide a partial record of the material presented at the conference. A full record of the slides presented and video recordings of the presentations is available on the website: <https://pan.cstcloud.cn/s/OaHRZGsQTgs>. A full record of the slides and video recordings of summer school talks is available at <https://pan.cstcloud.cn/web/share.html?hash=hqjYx4SuQdw>.

Monica Valluri and Jerry Sellwood
October 2019

Editors

Monica Valluri
University of Michigan, USA

J. A. Sellwood
Steward Observatory, University of Arizona, USA

Organizing Committees

Scientific Organizing Committee

| | |
|---------------------|--|
| Juntai Shen | (Shanghai Jiao Tong University, China; co-chair) |
| Monica Valluri | (University of Michigan, USA; co-chair) |
| Gurtina Besla | (University of Arizona, USA) |
| Joss Bland-Hawthorn | (University of Sydney, Australia) |
| Jo Bovy | (University of Toronto, Canada) |
| Michele Cappellari | (Oxford University, UK) |
| Francoise Combes | (Observatoire de Paris, France) |
| Dimitri Gadotti | (ESO, Germany) |
| Ortwin Gerhard | (MPE, Germany) |
| Amina Helmi | (University of Groningen, Netherlands) |
| Woong-Tae Kim | (Seoul National University, Korea) |
| John Kormendy | (University of Texas at Austin, USA) |

Local Organizing Committee

| | |
|----------------------|---|
| Juntai Shen | (Shanghai Jiao Tong University, China; chair) |
| Zhao-Yu Li | (Shanghai Jiao Tong University, China) |
| Yang Yang | (Shanghai Astronomical Observatory, China) |
| Zhong Liu | (Shanghai Astronomical Observatory, China) |
| Sarah Bird | (National Astronomical Observatories of China, China) |
| Behzad Tahmasebzadeh | (Shanghai Astronomical Observatory, China) |

CONFERENCE PHOTOGRAPH



Participants

| Last Name | First Name | Affiliations |
|-----------------|------------|---|
| Agertz | Oscar | University of Lund |
| Amarante | João A. S. | Shanghai Astronomical Observatory, China |
| An | Sung-Ho | Korea Astronomy and Space Science Institute |
| Arnaboldi | Magda | ESO |
| Belokurov | Vasily | University of Cambridge |
| Beraldo e Silva | Leandro | University of Central Lancashire |
| Besla | Gurtina | University of Arizona |
| Bezanson | Rachel | University of Pittsburgh |
| Binney | James | University of Oxford |
| Bird | Sarah | National Astronomical Observatories of China |
| Bisht | Devendra | University of Science and Technology of China |
| Bittner | Adrian | ESO |
| Blana | Matias | MPE, Garching |
| Bonaca | Ana | Harvard University |
| Bovy | Jo | University of Toronto |
| Brauer | Kaley | MIT, USA |
| Bureau | Martin | University of Oxford |
| Cappellari | Michele | University of Oxford |
| Carignan | Claude | University of Cape Town, South Africa |
| Carlberg | Raymond | Univ of Toronto |
| Chen | Xiaodian | National Astronomical Observatories of China |
| Chen | Zhu | Shanghai Normal University, China |
| Chiba | Masashi | Tohoku University |
| Clarke | Jonathan | MPE, Garching, Germany |
| Combes | Francoise | Observatory of Paris |
| Cuomo | Virginia | University of Padova |
| Danieli | Shany | Yale University |
| Debattista | Victor | University of Central Lancashire |
| Deepak | | Indian Institute of Astrophysics |
| Deg | Nathan | University of Cape Town, South Africa |
| Dehnen | Walter | University of Leicester |
| Dieu | Nguyen | National Astronomical Observatory of Japan |
| Ding | Yuchen | Shanghai Astronomical Observatory, China |
| Du | Min | KIAA, Peking University, China |
| Du | Hangci | Tsinghua University China |
| Evans | Wyn | University of Cambridge |
| Famaey | Benoit | CNRS/University of Strasbourg |
| Feng | Shuai | Shanghai Astronomical Observatory, China |
| Feng | Zixuan | Shanghai Astronomical Observatory, China |
| Foster | Caroline | University of Sydney |
| Fragkoudi | Francesca | MPA, Garching |
| Fraser-McKelvie | Amelia | University of Nottingham |
| Fu | Xiaoting | Università di Bologna |
| Fuentes-Carrera | Isaura | Instituto Politécnico Nacional, Mexico |
| Gadotti | Dimitri | ESO |
| Gajda | Grzegorz | MPE, Garching |
| Garma | Luis | UNAM, Mexico |
| Gerhard | Ortwin | MPE, Garching |
| Ghafourian | Neda | University of Mashhad, Iran |
| Gillessen | Stefan | MPE, Garching |
| Gouda | Naoteru | National Astronomical Observatory of Japan |
| Grady | James | University of Cambridge |
| Grillmair | Carl | IPAC, Caltech |
| Gao | Sufen | Xinjiang University, China |
| Guo | Helong | SWIFAR, Yunnan University, China |
| Guo | Kaizheng | Shanghai Astronomical Observatory, China |

| Last Name | First Name | Affiliations |
|--------------|----------------|--|
| Han | Jiaxin | Shanghai Jiao Tong University, China |
| Hao | Lei | Shanghai Astronomical Observatory, China |
| Hattori | Kohei | University of Michigan |
| Hou | Shutong | Shanghai Jiao Tong University, China |
| Huang | Yang | SWIFAR, Yunnan University, China |
| Hughes | Meghan | ESO |
| Jonathan | Clarke | MPE, Garching |
| Kam | Sié Zacharie | University of Ouagadougou, Burkina Faso |
| Kamdar | Harshil | Harvard University |
| Kassin | Susan | Space Telescope Science Institute |
| Kataria | Sandeep Kumar | Indian Institute of Astrophysics |
| Kaur | Karamveer | Raman Research Institute, India |
| Khoperskov | Sergey | MPE, Garching |
| Kim | Ji Hoon | National Astronomical Observatory of Japan |
| Kipper | Rain | Tartu Observatory |
| Kormendy | John | University of Texas, Austin |
| Korsaga | Marie | Laboratoire d'Astrophysique de Marseille |
| Koulidiati | Jean | University of Ouagadougou, Burkina Faso |
| Kowalczyk | Klaudia | Nicolaus Copernicus Astronomical Center |
| Kumar | Ankit | Indian Institute of Science, India |
| Lai | Dong | Cornell University |
| Laporte | Chervin | University of Victoria, Canada |
| Lelli | Federico | ESO |
| Lewis | Megan | University of New Mexico, USA |
| Li | Pengfei | Case Western Reserve University |
| Li | Haochuan | Queens University, Canada |
| Li | Xinyi | Shanghai Jiao Tong University, China |
| Li | Zhaozhou | Shanghai Jiao Tong University, China |
| Li | Zhi | Shanghai Jiao Tong University, China |
| Li | Ting | Fermi National Accelerator Laboratory, USA |
| Li | Zhao-Yu | Shanghai Jiao Tong University, China |
| Lilleengen | Sophia | University of Heidelberg |
| Lin | Douglas | UC Santa Cruz, USA |
| Liu | Chao | National Astronomical Observatories of China |
| Liu | Qing | University of Toronto |
| Liu | Zhong | Shanghai Astronomical Observatory, China |
| Liu | Jie | Shanghai Astronomical Observatory, China |
| Lokas | Ewa | Nicolaus Copernicus Astronomical Center |
| Loubser | Ilani | North West University, South Africa |
| Lu | Xinyu | Johns Hopkins University |
| Lucero | Danielle | Virginia Tech |
| Mao | Shude | National Astronomical Observatories of China |
| Martin | Nicolas | University of Strasbourg |
| Masters | Karen | Haverford College |
| McDermid | Richard | Macquarie University |
| McGaugh | Stacy | Case Western Reserve University |
| Mckay | Myles | University of Washington |
| Mendez-Abreu | Jairo | Instituto de Astrofísica de Canarias |
| Minniti | Javier | Instituto Milenio Astrofísica |
| Minniti | Dante | Universidad Andres Bello |
| Moffett | Amanda | Vanderbilt University |
| Mogotsi | Moses | South African Astronomical Observatory |
| Namumba | Brenda | University of Cape Town, South Africa |
| Navarro | Maria Gabriela | Andrés Bello University |
| Neumann | Justus | ESO |
| Newberg | Heidi | Rochester Polytechnic Institute |

| Last Name | First Name | Affiliations |
|------------------|----------------------|---|
| Patsis | Panagiotis | Academy of Athens |
| Peng | Eric | KIAA, Peking University, China |
| Peper | Marius | Institute of Astronomy - Nicolaus Copernicus University |
| Peschken | Nicolas | Institute of Astronomy - Nicolaus Copernicus University |
| Peterken | Thomas | University of Nottingham |
| Pietrukowicz | Pawel | Astronomical Observatory, University of Warsaw |
| Quinn | Peter | University of Western Australia |
| Rajohnson | Sambatriniaina H. A. | University of Cape Town, South Africa |
| Randriamampandry | Toky | KIAA, Peking University, China |
| Robles | Victor | University of California, Irvine |
| Rozier | Simon | Institute of Astronomy Paris, France |
| Rubino | Michela | University of Padova |
| Salomon | Jean-Baptiste | Institut UTINAM |
| Sanders | Jason | University of Cambridge |
| Sanderson | Robyn | University of Pennsylvania |
| Sarkar | Suchira | Indian Institute of Science, India |
| Schmidt | Thomas | Leibniz-Institut für Astrophysik Potsdam |
| Sellwood | Jerry | Steward Observatory, University of Arizona, USA |
| Seo | Woo-Young | Seoul National University |
| Shan | Xingmei | Shanghai Astronomical Observatory, China |
| Shen | Juntai | Shanghai Jiao Tong University, China |
| Shi | Jingjing | KIAA, Peking University, China |
| Shu | Shuanghao | National Astronomical Observatories of China |
| Simion | Iulia | Shanghai Astronomical Observatory, China |
| Singh | Arun Kumar | Guru Ghasidas Vishwavidyalaya Bilaspur, India |
| Sjouwerman | Lorant | National Radio Astronomy Observatory, Socorro, USA |
| Sorgho | Amidou | University of Cape Town, South Africa |
| Spekkens | Kristine | Royal Military College of Canada |
| Stroh | Michael | University of New Mexico, USA |
| Sui | Yuan | Shanghai Astronomical Observatory, China |
| Sun | Weixiang | SWIFAR, Yunnan University, China |
| Tahmasebzadeh | Behzad | Shanghai Astronomical Observatory, China |
| Tanaka | Takahiro | University of Tsukuba, Japan |
| Tempel | Elmo | University of Tartu |
| Terrazas | Bryan | University of Michigan |
| Thakkalapally | Swetha | Osmania University, India |
| Thakuri | Janak Ratna Malla | Tribhuvan University, Khatmandu, Nepal |
| Thater | Sabine | Leibniz-Institut für Astrophysik Potsdam |
| Tian | Haijun | China Three Gorges University |
| Tian | Hao | National Astronomical Observatories of China |
| Tremaine | Scott | Institute for Advanced Studies, Princeton USA |
| Tsujimoto | Takuji | National Astronomical Observatory of Japan |
| Tsukui | Takafumi | National Astronomical Observatory of Japan |
| Valluri | Monica | University of Michigan |
| van de Sande | Jesse | University of Sydney |
| van Dokkum | Pieter | Yale University |
| van Houdt | Joshua | MPIA, Heidelberg Germany |
| Varidel | Mathew | University of Sydney |
| Vasiliev | Eugene | University of Cambridge |
| Vickers | John | Shanghai Astronomical Observatory, China |
| Wang | Weichen | Johns Hopkins University |
| Wang | Fei | KIAA, Peking University, China |
| Wang | Shu | KIAA, Peking University, China |
| Wang | Yougang | National Astronomical Observatories of China |
| Wang | Yunchong | Tsinghua University |
| Wang | Haifeng | SWIFAR, Yunnan University, China |
| Wegg | Christopher | Observatoire de la Côte d'Azur |

| Last Name | First Name | Affiliations |
|-----------|------------|--|
| Weiner | Benjamin | University of Arizona |
| Wheeler | Adam | Columbia University, New York USA |
| Widrow | Lawrence | Queens University, Canada |
| Williams | Theodore | SALT, South Africa |
| Wuyts | Stijn | University of Bath |
| Wylie | Shola | MPE, Garching |
| Xu | Dandan | Tsinghua University |
| Yang | Meng | University of St. Andrews, UK |
| Yu | Si-Yue | KIAA, Peking University, China |
| Yu | Sijie | University of California, Irvine |
| Yuan | Zhen | Shanghai Astronomical Observatory, China |
| Yuan | Sunshun | Shanghai Astronomical Observatory, China |
| Zhang | Meng | KIAA, Peking University, China |
| Zhang | Shen | University of Chinese Academy of Sciences, China |
| Zhang | Yanqiong | Shanghai Astronomical Observatory, China |
| Zhang | Junkai | Shanghai Astronomical Observatory, China |
| Zhao | Hongsheng | University of St. Andrews, UK |
| Zhou | Yingying | Shanghai Astronomical Observatory, China |
| Zhou | Yipeng | Shanghai Astronomical Observatory, China |
| Zhu | Kai | National Astronomical Observatories of China |
| Zhu | Ling | Shanghai Astronomical Observatory, China |
| Zou | Yanfei | Polar Research Institute, China |

Conference Program

(I)=Invited talk

Monday July 1 2019

Welcome Address: Zhiqiang Shen (Director of Shanghai Astronomical Observatory (SHAO))

Welcome and opening remarks (Juntai Shen & Monica Valluri)

Session 1: Chair Monica Valluri

Gaia and the Galactic disk (I): Jo Bovy (University of Toronto)

A GLamARous view of the Milky Way - Robust ages for millions of stars in the extended solar neighbourhood: Martin Smith (SHAO)

Dissecting the Phase Space Snail: Zhao-Yu Li (SJTU & SHAO)

Connecting the topography of phase-space in Gaia DR2 to the underlying orbital structure: Francesca Fragkoudi (MPIA)

The echo of the bar buckling: Phase-space spirals in Gaia DR 2: Sergey Khoperskov (MPE)

Milky Way structure based on thousands of Cepheids and RR Lyrae stars from OGLE: Pawel Pietrukowicz (Warsaw University Observatory)

Footprints of the Sgr Dwarf Galaxy on the Milky Way disk: Chervin Laporte (UVic/ CITA)

3D map of the Galactic warp's precession from classical Cepheids MW warp: X. Chen (NAOC)

Spirals and secular evolution in disks (I): Jerry Sellwood (University of Arizona)

Session 2: Chair Walter Dehnen (University of Leicester)

Radial migration (I): Victor Debattista (U. Central Lancashire)

Constraining the Milky Way non-axisymmetries with Gaia: Benoit Famaey (Obs. Astro. De Starabourg)

Kinematical Signatures of Disc Instabilities and Secular Evolution in the MUSE TIMER Survey: D Gadotti (ESO)

How do spiral arm contrasts relate to bars, disc breaks and other fundamental galaxy properties?: Adrian Bittner (ESO)

Warps and tides (I): Larry Widrow (Queen's University)

Key dynamical results from MaNGA (I): Shude Mao (Tsinghua University)

Galaxy systematics (I): Stacy McGaugh (Case Western Reserve University)

Cosmological simulations of the Milky Way, comparison with observations and open issues in cosmological simulations of disks (I): Oscar Agertz (Lund University)

Tuesday July 2, 2019

Session 3: Chair, Claude Carignan (Univ of Cape Town)

Gas in disk galaxies and the cusp/core controversy (I): Kristine Spekkens (RMC & Queen's University)

Distribution of baryonic and dark matter in spiral and irregular nearby galaxies: M. Korsaga (University of Cape Town)

Key dynamical results from SAMI (I): Jesse van de Sande (University of Sydney)

Key dynamical results from CALIFA (I): Ling Zhu (Shanghai Astronomical Observatory)

The measurement of Dark Matter profile of NGC1380 with ALMA and VLT/MUSE: Takafumi Tsukui (National Astronomical Observatory)

Key results from Galaxy Zoo (I): Karen Masters (Haverford College)

Structure, kinematics and metallicity of observed and simulated stellar halos (I): Robyn Sanderson (University of Pennsylvania)

Open discussion "What have we learned about disks (including the Milky Way) from large surveys?": Karen Masters (Haverford College) & Jo Bovy (University of Toronto)

Session 4: Chair, Zhao-Yu Lu (SJTU)

The Magellanic Clouds (I): Gurtina Besla (University of Arizona)

Revisiting the innermost Kinematics of the M31 Galaxy with the OMM Fabry-Perot interferometer: Sie Zacharie Kam (Univ. Ouaga I, Burkina Faso)

Gas rich dwarf Leo-T: First infall or back-splash?: M. Blana (MPE)

The Milky Way bar/bulge (I): Ortwin Gerhard (MPE)

The VVV survey (I): Dante Minniti (University Andres Bello)

Constraining halo mass distribution with satellite galaxies in phase space: ZhaoZhou Li (SJTU)

Transverse bar/bulge kinematics with Gaia and VVV: J. Sanders (University of Cambridge)

Secular evolution and pseudo-bulges (I): Françoise Combes (Paris Observatory)

Wednesday July 3, 2019**Session 5: Chair, Dong Lai (Cornell University & T. D. Lee Institute)**

Dynamics of galactic nuclei (I): Scott Tremaine (Institute for Advanced Study)

Stellar motion near the supermassive black hole of the Milky Way (I): Stefan Gillessen (MPE)

Origin and evolution of disk and S stars in the Galactic Center: D. Lin (University of California Santa Cruz)

Gas flow patterns in the Milky Way: Zhi Li (Tsung-Dao Lee Inst.)

WISDOM: Weighing Supermassive Black Holes with ALMA: M. Bureau (University of Oxford)

Testing the robustness of dynamical black hole mass measurements with ALMA and MUSE: S. Thater (Leibniz-Institute für Astro. Potsdam)

Schwarzschild modeling of bars from IFU kinematics (I): Eugene Vasiliev (University of Cambridge)

Measuring the Bar Pattern Speed of MaNGA Galaxies from Stellar and H α Kinematic: Yanfei Zou (Shanghai Astronomical Observatory)

The face-on views of X-shaped bulges: Panagotis Patsis (Academy of Athens)

The intricate relationship between galaxy dynamics and intrinsic shape (and why so-called “prolate-rotation” is a misnomer): Caroline Foster (University of Sydney)

Combining stellar populations and dynamical modelling: R. McDermid (Macquarie University)

Temporal Insights into the Secular Evolution of Bars from the MaNGA Galaxy survey: A. Fraser-McKelvie (University of Nottingham)

Free afternoon**Thursday July 4, 2019:****Session 6: Chair, Françoise Combes (Paris Observatory)**

Inner bars also buckle. The case of NGC1291: J. Mendez-Abreu (Institute de. Astro. De Canarias)

Evidence of a fast bar in the early-interacting galaxy NGC 4264 with MUSE: Virginia Cuomo (University of Padova)

The puzzle of unbarred galaxies (I): Juntai Shen (SHAO & SJTU)

Open discussion “Galactic nuclei, bars and bulges” moderator Ortwin Gerhard (MPE)

Origin of the $M_{\text{BH}}-\sigma$ relation (I): John Kormendy (University of Texas)

Black hole-galaxy scaling relations: clues to the physics behind quiescence (I): Bryan Terrazas (University of Michigan)

Resolved kinematics of early type galaxies (I): Michele Cappellari (University of Oxford)

Elliptical galaxies/stellar halos connection (I): Magda Arnaboldi (ESO)

Session 7: *Chair: Peter Quinn (ICRAR, Australia)*

Dwarf spheroidal galaxies/dynamics, dark matter distribution (I): Ewa Lokas (Nicolaus Copernicus Astro. Center)

Ultra Diffuse Galaxies (UDGs) (I): Pieter van Dokkum (Yale University)

Galaxies missing dark matter: Shany Danieli (Yale University)

Accreted Globular Clusters in External Galaxies: Why Adaptive Dynamics is not the Solution: Sophia Lilleengen (ESO)

Hyper-supreme Cam and the LF of galaxy satellites (I): Masashi Chiba (Tohoku University)

Gaia and the Galactic Stellar halo (I): Vasily Belokurov (University of Cambridge)

The Galactic Acceleration Field Measured from RR Lyrae in Gaia: Christopher Wegg (Observatoire de la Côte d'Azur,)

New ultra faint dwarfs from DES survey (I): Ting Li (Fermi National Accelerator Laboratory)

Friday July 5, 2019

Session 8: *Chair: Lei Hao (SHAO)*

The Stellar Halo of the Milky Way as Seen by Large Surveys (I): Wyn Evans (University of Cambridge)

Dynamical evidence for a dark substructure in the Milky Way halo: Ana Bonaca (Harvard University)

Dynamics of most metal-poor stars in the MW: Nicholas Martin (Strasbourg Astro. Observatory)

Kinematics of Highly r-Process-Enhanced Halo Stars: Evidence for Origins in Now-Destroyed Ultra-Faint Dwarf Galaxies: Kaley Brauer (MIT)

The SAGA Survey for Satellites around Analogs of the Milky Way Galaxy: Satellite Properties and Kinematics: Benjamin Weiner (MMT/Steward Observatory)

Streams and the MW dark matter halo (I): Heidi Newberg (Rensselaer Polytechnic Institute)

Halo substructure and tidal streams (I): Ray Carlberg (University of Toronto)

Stars formed in outflows may populate galactic stellar halos: Sijie Yu (UC Irvine)

Modeling the Milky Way (I): James Binney (University of Oxford)

Open discussion on “The halos of the Milky Way and other galaxies”, moderator Monica Valluri (University of Michigan)

Session 9: *Chair: Martin Bureau (Univ. of Oxford)*

The optimal tracer of the Milky Way halo mass: Jiaxin Han (SJTU)

Galactic Mass and Anisotropy Profile with Halo K-Giant and Blue Horizontal Branch Stars from LAMOST/SDSS and Gaia: Sarah Bird (NAOC)

The shape of the dark matter halo revealed from hypervelocity stars: Kohei Hattori (University of Michigan)

Galaxy Dynamics at $z=4.8$: Federico Lelli (ESO)

Dynamical properties of high redshift galaxies (I): Stijn Wuyts (University of Bath)

Stellar Kinematics at High Redshift from the LEGA-C Survey and Beyond: Rachel Bezanson (University of Pittsburgh)

The Kinematic Assembly of Galaxy Disks: Susan Kassin (Space Telescope Science Institute)

Stellar kinematics and metallicities from LAMOST (I): Yang Huang (SWIFAR & YNU)

A Dynamical Model for Clustered Star Formation in the Galactic Disk: Harshil Kamdar (Harvard University)