Honoring Charlotte Moore Sitterly: Astronomical Spectroscopy in the 21st Century
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Laboratory Astrophysics Activities IAU Commission B5 2022 GA

P. S. Barklem[1], B. Barbuy[2], M.L. Dubernet[3], D. Ryu[4], F. Salama[5], P.K. Tan[6] and N. Watanabe[7]

[1]Theoretical Astrophysics, Department of Physics and Astronomy, Uppsala University, Box 516, S 75120 Uppsala, Sweden
email: paul.barklem@physics.uu.se

[2]Universidade de São Paulo, Rua do Matão 1226, São Paulo 05508-090, Brazil
email: b.barbuy@iag.usp.br

[3]LERMA, Observatoire de Paris, PSL Research University, CNRS, Sorbonne University, 5 Place Janssen, 92190 Meudon, France
email: marie-lise.dubernet@observatoiredeparis.psl.eu

[4]Department of Physics, UNIST, Ulsan, 44919. Korea
email: dsryu@unist.ac.kr

[5]Space Science and Astrobiology Division, NASA Ames Research Center, Moffett Field, California 94035, USA
email: farid.salama@nasa.gov

[6]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, S117543, Singapore
email: cqttpk@nus.edu.sg

[7]Institute of Low Temperature Science, Hokkaido University, Sapporo, Hokkaido 060-0819, Japan
email: watanabe@lowtem.hokudai.ac.jp

Abstract. This paper gives an overview of the IAU B5 commission session on "Laboratory Astrophysics Activities" at the 2022 IAU General Assembly (GA). It provides a brief overview of the talks that were given in that session. The IAU 2022 GA B5 commission meeting was organised to present Laboratory Astrophysics activities in various parts of the world in an attempt to provide a first step towards a "Global Network of Laboratory Astrophysics Network of Activities and Data". The program (10.5281/zenodo.7051332) and the presentations can be found in the ZENODO "cb5-labastro" community (https://zenodo.org/communities/cb5-labastro).

Keywords. Laboratory astrophysics, laboratory astrochemistry, experiment, theory, interdisciplinary studies, data network, astronomy, planetary.

1. The Laboratory Astrophysics commission B5 Activities

The purpose of the Laboratory Astrophysics commission† is to address the multidisciplinary needs and requirements of modern astronomy and planetary science. As a result, the Commission encompasses the four fundamental research areas that generate astrophysical data needs: atomic and molecular astrophysics, physics and chemistry of solid materials and condensed matter (dust and ices), plasma astrophysics, and nuclear and particle astrophysics. The Commission embraces interdisciplinary studies crossing

† https://www.iau.org/science/scientific_bodies/commissions/B5

physical, chemical, biological, geological sciences of relevance to astronomy, including experiment, theory, and modeling, from the nuclear and atomic/molecular level to application on astronomical scales.

Presently the commission has 163 members, of which 4 (2%) are junior members, and 37 (23%) are female; this can be compared with the percentages in the IAU of 9% and 22%, respectively. The members are distributed geographically as follows: Europe 53%, North America 28%, Asia 14%, South America 2%, with Africa and Oceania having only one member each (<1%).

The main activities of the commission are to run working groups and organise meetings. The most recent meeting organised by the commission was IAUS 350 "Laboratory Astrophysics: from Observations to Interpretation" in Cambridge, UK, in April 2019 [1]. The commission has been involved in IAU Symposium 371 "Honoring Charlotte Moore Sitterly: Astronomical Spectroscopy in the 21st Century" in Busan, Korea, August 2022 (this GA), and is supporting IAU Symposium 383 "Astrochemistry VIII: From the First Galaxies to the Formation of Habitable Worlds", Traverse City, Michigan, USA to be held in 2023 coordinated by commission H2. An IAU symposium in laboratory astrophysics coordinated by the commission is tentatively planned for 2025. The commission presently has two working groups: "Spectroscopic and Radiative Data for Molecules"† and "Laboratory Astrophysics Data Compilation, Validation and Standardisation: from the Laboratory to FAIR Usage in the Astronomical Community"‡, the later being an inter-commission working group with commission B2 (Data and documentation).

In addition, the commission advises the IAU on laboratory astrophysics, promotes laboratory astrophysics, coordinates the flow of information in the community, including annual and triennial reports, runs elections, and evaluates IAU symposium proposals and prizes. Slides are here§.

2. Laboratory Astrophysics in Korea

While laboratory astrophysics is still in its early stage in Korea, a number of facilities that have potential for laboratory astrophysics have been constructed or are under construction. A partial list includes high-intensity lasers at CoReLS (Center for Relativistic Laser Science), XFEL (X-Ray Free-Electron Laser) at PAL (Pohang Accelerator Lab), RAON (Rare isotope Accelerator complex for ON-line exp) at IBS (Institute of Basic Sciences), 4th Generation Synchrotron Radiation Sources (under construction), and Next Generation High Intensity Laser (proposed). Laboratory astrophysics projects, either in progress or proposed, include X-ray spectroscopy of highly charged ions with PAL-XFEL, wave-particle interaction using the lasers at CoReLS, and nuclear astrophysics at IBS RAON. Slides are here¶.

3. Laboratory Astrophysics in South America

There are many laboratories in Physics, with some relation to astronomy, such as ultracold atoms, atomic and molecular collisions, laser spectroscopy and optics, photonics, nano-optics,high energies, etc. The main universities having these activities are in Brazil: Universidade de São Paulo (USP) (mainly campus at São Carlos), Universidade Estadual de campinas (Unicamp), Universidade Federal de São Carlos (UFSCar), Universidade Federal do Rio de Janeiro (UFRJ), Universidade Federal de Minas Gerais (UFMG), Universidade Federal do Rio Grande do Sul (UFRGS), Universidade Federal de Pernambuco (UFPe), and the national facility Laboratorio Nacional de Luz Sincrotron

† https://www.iau.org/science/scientific_bodies/working_groups/309/
‡ https://www.iau.org/science/scientific_bodies/working_groups/335/
§ https://doi.org/10.5281/zenodo.7002737
¶ https://doi.org/10.5281/zenodo.7002820

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(LNLS,SIRIUS); in Argentina: Centro de Investigaciones Optics (CIOp), Universidad de Buenos Aires (UBA), Universidad Nacional del Centro; in Colombia: Universidad del Atlantico.

The group most related to astronomy is the one initiated at Centro de Investigaciones Optics (CIOp), La Plata, Argentina, and that is continued presently at Universidade Estadual de Campinas (UNICAMP), with studies of emission spectra of noble gases. Slides are here†.

4. Quantum Sensing for Astronomy : Singapore

Singapore's geography being situated at the equator with tropical climate may not make it a natural location for astronomy, but it has deep investment into quantum research, spearheaded by the Centre for Quantum Technologies (CQT) hosted at the National University of Singapore (NUS), and the Quantum Engineering Programme (QEP) by the National Research Foundation (NRF), Prime Minister's Office (PMO).

The diversity of Singapore's quantum ecosystem has led to the development of laboratory based astronomy research exploiting quantum sensing techniques and instrumentation [2)]. Investigative highlights include intensity interferometry and super-resolution imaging, with application in the temporal and spatial domains respectively.

Intensity interferometry is based on the Hanbury-Brown Twiss (HBT) effect, also known as photon bunching, which is the characteristic behaviour of thermal photons to propagate closer together than described by random Poissonian statistics. The spatial component of this property has been observed by HBT in the 1950s, and while we have achieved direct measurements of Solar temporal photon bunching [3], the stellar temporal photon bunching remains unresolved presently. Successful stellar measurements may allow to probe the coherence of starlight and hence the possible presence of phase dispersion in vacuum, or the detection of coherent radiation such as laser light from astrophysical sources e.g. Eta Carinae, Wolf-Rayet stars, or techno-signatures.

Super-resolution imaging is being explored via Mach-Zehnder interferometry with radial image inversion. When placed in the context of luminosity transits, this experimental scheme may allow for sub-shot-noise measurements by separating the incident starlight into radially symmetric and asymmetric modes, corresponding to signals from the star and a transiting exoplanet respectively. By separating the bulk of the shot noise contribution from the star into a detection channel different from the exoplanet signal, this should therefore increase the signal-to-noise ratio of the transit signal. Experimental proof-of-concept tests with laboratory light sources have been successfully measured. Slides are here‡.

5. Activities of laboratory astrophysics in Japan

The relevant society in Japan is gradually spreading in the last decade. Thank to recent big projects, astrophysics and astrochemistry have been recognized as interesting interdisciplinary science among pure physicists and chemists. At the same time, technical developments enable us to investigate various elementary processes in both gas and solid phases, which used to be hardly performed. Interaction among researchers in laboratory astrophysics, astronomy, planetary science, physics, and chemistry is getting stronger.

For the research on the gas phase spectroscopy of interstellar molecules, there are three active groups in Toyama university, Toho university and RIKEN. The number of groups and researchers in this field is gradually decreasing which is one of serious problems for the society in Japan. The research of reaction dynamics of interstellar molecules in the

† https://doi.org/10.5281/zenodo.7002776
‡ https://doi.org/10.5281/zenodo.7002788

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gas phase has been often studied in the society of atomic collision. Now, active groups exist in Sophia University, Rikkyo University, Tokyo Metropolitan University and so on.

For the surface or solid phase experiments relevant to dust grains, Hokkaido University is one of the world's leading institutes. Recent years, groups in University of Tokyo and RIKEN have started new type of experiments with microscopic methods like STM and AFM which will open the new phase of research.

As specific examples of recent activities, the following projects are now on going. For the gas phase, experiments of reactions between molecular ion and neutral atom like carbon, reactions between ion with polar molecules like water, ion-molecule reactions with analyzing structural isomers in products For the surface, the analysis of electronic and vibrational structures of adsorbates and Raman, photoluminescence, absorption spectroscopy of a single molecular adsorbate on the dust relevant surfaces with STM, direct observation of adsorbates such as COMs with AFM, monitoring the radical behaviors on ice with newly-developed PSD-REMPI and ion-pickup methods. Slides are here†.

6. Laboratory Astrophysics in the United States of America

Laboratory astrophysics is a strong and vibrant field in the Unites States with its primary national representation as a full Division of the American Astronomical Society (AAS, https://lad.aas.org) whose object is "to advance our understanding of the Universe through the promotion of fundamental theoretical and experimental research into the underlying processes that drive the Cosmos". Laboratory Astrophysics is also represented in other major scientific societies such as the Astrochemistry subdivision of the American Chemical Society (ACS, http://astro.phys-acs.org) whose object is to promote astronomy among chemists [...] and study the abundance and reactions of molecules in the Universe, and their interaction with radiation, the High Energy Density Laboratory Astrophysics (HEDLA) and the Division of Astrophysics (DAP) of the American Physical Society (APS, https://engage.aps.org/dap/home) to cite a few.

Laboratory Astrophysics and Astrochemistry is also well represented in federal agencies such as the National Aeronautics and Space Administration (NASA ‡) and the National Science Foundation (NSF) where research programs are fully dedicated to the support of laboratory astrophysics research in support of astrophysics and planetary science missions§.

Laboratory Astrophysics is also well represented in the Academic arena where Physics, Astronomy and/or Chemistry Departments in many universities host a Laboratory Astrophysics or Astrochemistry curriculum.

The increasing recognition of the field of laboratory astrophysics as an essential tool for the progress and the development of astrophysics and astronomy has been recently strongly reinforced by its inclusion into the recommendations of the two most recent Decadal Surveys of the National Academy of Sciences (NAS), the Pathways to Discovery in Astronomy and Astrophysics for the 2020s [4] and the Planetary Science and Astrobiology Decadal Survey 2023-2032 [5]. Slides are here ¶.

7. Laboratory Activities in Europe

The European Task force for Laboratory Astrophysics, arising out of the ASTRONET initiative, in 2013 identified at least 250 groups working in diverse fields, both theoretically and experimentally, including gas-phase astrochemistry, spectroscopy of the ISM, spectroscopy of hot-bodies, solid state and molecular complexity, stellar and planetary

† https://doi.org/10.5281/zenodo.7002770
‡ NASA : https://science.nasa.gov/astrophysics/programs/astrophysics-research
§ https://science.nasa.gov/solar-system
¶ https://doi.org/10.5281/zenodo.7002764

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formation, primitive and planetary material, high-energy processes and space plasmas, stellar evolution and nuclear astrophysics, astrophysical conditions for the emergence of life, and databases for laboratory astrophysics data.

The activities encompass large and medium-sized research infrastructures (e.g. synchrotron Soleil†, FELIX laboratory‡, Heidelberg CSR§ and DESIREE¶), large EU projects such as Training Networks with post-docs and PhD students, COST actions with exchange between many groups, summer schools, EU and nationally funded individual projects and infrastructures, and infrastructure platforms (e.g. VAMDC (vamdc.org) for atomic and molecular databases, SSHADE (sshade.eu) for solid spectroscopy databases). Further there is a European Conference on Laboratory Astrophysics (ECLA), that has been held in 2011 in Paris, 2016 in Madrid, and 2021 in Anacapri. Attempts to improve information flow and coordination include the website (`https://astrochemistry.eu`), an email list (email: labastro@jiscmail.ac.uk), the AstroPaH newsletter (https://astropah-news.strw.leidenuniv.nl/), and the AstroChemical newsletter (https://acn.astrochem-tools.org/). Slides are here : (https://doi.org/10.5281/zenodo.7002754).

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† www.synchrotron-soleil.fr
‡ https://www.ru.nl/felix/
§ https://www.mpi-hd.mpg.de/blaum/storage-rings/csr/index.en.html
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