

## COMMISSION H4

## STELLAR CLUSTERS THROUGHOUT COSMIC SPACE AND TIME

*AMAS STELLAIRES À TRAVERS*

*L'ESPACE ET LE TEMPS COSMIQUES*

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## TRIENNIAL REPORT 2018–2021

### 1. Introduction

The research of Commission H4 concerns star clusters, of any size, at any distance, and of any age. It includes the observation and theory of stellar groupings as they form and evolve, cluster disruption, stellar interactions inside clusters, and star formation in dense environments.

The Commission H4 has an official newsletter: “The Stellar Clusters Young and Old Newsletter” (SCYON), edited by G. Carraro, M. Netopil and E. Paunzen, a link to the scientific activity in the field.

From the beginning of modern astrophysics, the field of research on star clusters has always been important, since it grants astronomers the unique opportunity to study systems of coeval stars. Studies of clusters allow us to easily determine ages of galactic structures using HR diagrams and from the location of the main sequence turnoff location; to determine distances within the Milky Way Galaxy; along with the study and understanding of variable star. Star clusters also provide critical tests of stellar evolution models, and provide important constraints for stellar nucleosynthesis and Galactic chemical evolution. In the new century, thanks to improvements in observational techniques and new theoretical tools, this research field has witnessed a great transformation.

In this report, we highlight the main research fields, the review papers that have appeared, and provide a list of the international meetings devoted to or related to star clusters.

### 2. Research topics and new tools

- (a) The formation and dynamics of multiple stellar populations in massive clusters.
- (b) The astrometric Gaia revolution: identification of new clusters, discovery of halos and structures extending many tens of parsec and of expansion in many young clusters, the study of clustered formation in star forming regions etc.
- (c) The study of the internal kinematics of globular clusters.
- (d) The results based on new data provided by HST and ESO/VLT instruments.

(e) The interplay between dynamics and the formation of exotic stellar populations including possible sources of gravitational waves.

(f) The discovery of stellar streams, tidal tails, extra-tidal features around Galactic globular clusters.

### 3. Reviews

We list the main reviews on the subject of Star Clusters published in the period September 2018 – February 2021:

- S. Cassisi & M. Salaris 2020: “Multiple populations in massive star clusters under the magnifying glass of photometry: theory and tools”, *The Astronomy and Astrophysics Review*, Volume 28, Issue 1, article id.5
- M.R. Krumholz, C.F. McKee, J. Bland-Hawthorn 2020 ‘Star Clusters Across Cosmic Time’, *Annual Review of Astronomy and Astrophysics*, vol. 57, p.227-303
- R. Gratton, A. Bragaglia, E. Carretta, V. D’Orazi, S. Lucatello & A. Sollima 2019 “What is a globular cluster? An observational perspective”, *The Astronomy and Astrophysics Review*, Volume 27, Issue 1, article id. 8
- N. Bastian, C. Lardo 2018: “Multiple Stellar Populations in Globular Clusters”, *Annual Review of Astronomy and Astrophysics*, vol. 56, p.83-136

Concerning the GAIA revolution, we select two sample papers to highlight from the huge recent literature on this topic:

- Cantat-Gaudin, T. and 12 colleagues, 2020 ‘Painting a portrait of the Galactic disc with its stellar clusters’, *Astronomy and Astrophysics* 640, A1
- S. Meingast, J. Alves, A. Rottensteiner, 2021 ‘Extended stellar systems in the solar neighborhood. V. Discovery of coronae of nearby star clusters.’ *Astronomy and Astrophysics* 645, A84

In addition, the Proceedings of the IAU Symposium 351, ”Star Clusters: from the Milky Way to the Early Universe”, edited by Angela Bragaglia, Melvyn Davis, Alison Sills and Enrico Vesperini (2020), is a very useful tool for exploring the multifaceted issues of Star Cluster research.

### 4. Past meetings (June 2018 – February 2021)

Many meetings have been cancelled or postponed in 2020 and 2021, while some meetings have been held virtually.

- Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun (Cool Stars 20.5), (virtual meeting), March 2-4 2021
- Globular Clusters at the Nexus of Star and Galaxy Formation (virtual meeting), March 30th-June 12th, 2020, KITP, Santa Barbara, USA
- Star clusters and their role in the build-up of galaxies, March 9th-11th, 2020, La Serena, Chile
- MODEST-20, February 2nd-7th, 2020, Tata Institute of Fundamental Research in Mumbai, India
- From Gas to Stars: The Links between Massive Star and Star Cluster Formation, September 16th-20th, 2019, York, the United Kingdom
- A Synoptic View of the Magellanic Clouds: VMC, Gaia and Beyond, ESO Workshop, ESO-HQ, 9-3 Sept. 2019
- Special Session 23 at EWASS 2019: The dynamics of stellar clusters: simulations and observations at low/high redshifts, Lyon, France, June

- IAU Symposium 351, "Star Clusters: from the Milky Way to the Early Universe" and MODEST-19, May 27th-31st 2019, Bologna, Italy
- ISSI workshop on Star Formation, May 20th-24th, 2019, Bern, Switzerland
- Formation of stars and massive clusters in dwarf galaxies across cosmic time, February 18th-22nd, 2019, Lorentz Center, Leiden, the Netherlands
- The Survival of Dense Star Clusters in the Milky Way System, November 19th-23rd, 2018; Heidelberg, Germany
- The formation of globular clusters at high and low redshift; tracing star and cluster formation across cosmic times, July 16–20, 2018; Sexten Centre for Astrophysics, Sexten (Sesto), Italy
- Multiple Populations in Stellar Clusters: Recent Progress and Future Directions, July 9–13, 2018; Sexten Centre for Astrophysics, Sexten (Sesto), Italy
- MODEST-18: Dense Stellar Systems in the Era of GAIA, LIGO & LISA, June 25–29, 2018; Santorini, Greece

## 5. Publications

The topic of star clusters and associations continues to be one of the most widely followed fields in all of astronomy. It spans the range of interest from stellar properties, to stellar clusters, to star formation and evolution, the stellar initial mass function, stellar nucleosynthesis and Galactic chemical evolution, exotic stellar objects etc.

Peer-reviewed publications in the period from August 2018 to March 2021 as follows (from NASA's Astrophysics Data Service):

- Globular clusters:  $\sim 1030$  papers;
- Young massive clusters:  $\sim 346$  papers;
- Open clusters:  $\sim 816$  papers;
- Stellar associations:  $\sim 67$  papers.
- Star clusters and gravitational waves:  $\sim 173$  papers.

Some of the issues addressed in these publications include the formation and dynamical evolution of star clusters; stellar evolution and ages; star clusters as tracers of stellar populations; not-so-simple stellar populations in star clusters; studies of specific types of objects within clusters; nuclear clusters; the link between gravitational waves and star clusters, extragalactic cluster systems; and the structure of star clusters.

The authors use observations covering a significant portion of the electromagnetic spectrum, ranging from studies in X-rays to the far-infrared, as well as advanced theoretical  $N$ -body simulations.

## 6. Databases of note

- Data on Open Clusters in the Milky Way and the Magellanic Clouds can be found in the WEBDA site (<http://www.univie.ac.at/webda/>), which was originally developed by Jean-Claude Mermilliod from the Laboratory of Astrophysics of the EPFL (Switzerland) and is now maintained and updated by Ernst Paunzen, Christian Stütz, and Jan Janik from the Department of Theoretical Physics and Astrophysics of the Masaryk University, Brno (Czech Republic).

- General Data on Galactic Globular Clusters can be found in the "Catalog of Milky-Way Globular Cluster Parameters" by W. E. Harris (<http://physwww.mcmaster.ca/~harris/Databases.html>), as well as in "The Galactic Globular Clusters Database" at the Astronomical Observatory of Rome INAF-OAR: (<http://gclusters.altervista.org/>).

- More specific research data on Globular Clusters can be found in:
  - “The HST large legacy treasure program” led by G. Piotto (<http://groups.dfa.unipd.it/ESPG/treasury.php>).
  - COSMIC-LAB “Star Clusters as Cosmic Laboratories for Astrophysics, Dynamics and Fundamental Physics”, led by Francesco Ferraro (<http://www.cosmic-lab.eu/Cosmic-Lab/Home.html>)
  - “Fundamental parameters of Galactic globular clusters” maintained by H. Baumgardt (<https://people.smp.uq.edu.au/HolgerBaumgardt/globular/>);
  - GALFOR “Galactic Archaeology with Stellar Clusters”, led by Antonino Milone <http://progetti.dfa.unipd.it/GALFOR/index.html>
- A catalog of “Open Clusters and Galactic Structure,” by W. S. Dias, et al. (2002, A&A, 389, 871), which also contains references to other catalogs, is available at: <https://wilton.unifei.edu.br/ocdb/>.
- A Catalogue of Variable Stars in Globular Clusters is maintained by Christine Clement at <http://www.astro.utoronto.ca/~cclement/read.html>.
- There are several databases suitable for a variety of studies on star clusters, namely: VISTA VVVX, VISTA VMC, STEP, YMCA, OGLE IV, GAIA EDR3, GALEV, SAGE, GAMA, WISE, APOGEE SDSS DR16, SMASH, DESI, Pan-STARRS1, among others.

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