International Astronomical Union
Union Astronomique Internationale

POST MEETING REPORT FORM

1. **Meeting Identification Number:** Symposium 398

2. **Meeting Title: Compact Stars and Binaries in Dense Stellar Systems**

3. **Coordinating Division: G**

4. **Dedication of meeting (if any):**

5. **Location (city, country): Seoul, Seoul, Korea**

6. **Dates of meeting: June 16-20, 2025**

7. **Number of participants: 139**

8. **Total Amount of IAU Grant funds received (in euros):** 20,000

9. **Number of IAU Grant recipients: 25**

10. **List of represented countries:**
Australia, Azerbaijan, Bangladesh, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Israel, Italy, Japan, Kazakhstan, Korea (South), Nepal, Netherlands, New Zealand, Poland, Spain, Taiwan, Ukraine, United Kingdom, United States, Uzbekistan, Vietnam

11. **Anticipated number of separate papers in the proceedings:** 55

12. **Report submitted by:** Hyung Mok Lee, SOC Chair
Seoul National University
hmlee@snu.ac.kr

13. **Date and place:** September 15, 2025, Seoul, Korea

14. **Signature of SOC Chairperson:**

Summary of the IAU Symposium 398 Compact Stars and Binaries in Dense Stellar Systems

Date: 2025 June 16-20

Venue: Seoul National University, Seoul, Korea

Coordinating IAU Divisions: Division G "Stars and Stellar Physics"
Division D "High Energy Phenomena and Fundamental Physics"

Supporting IAU Divisions: Division H "Interstellar Matter and Local Universe"
Division J "Galaxies and Cosmology"

Scientific Organizing Committee (Female 2/Male 5):

Hyung Mok Lee	Seoul National University, Korea (co-chair)
Rainer Spurzem	University of Heidelberg, Germany(co-chair)
Sourav Chatterjee	Tata Institute for Fundamental Research (TIFR), India
Michiko Fujii	University of Tokyo, Japan
Di Li,	Tsinghua University, China
Antonio Milone	Padova University, Italy
Fred Rasio	Northwestern University, USA
Anna Lisa Varri	University of Edinburgh, United Kingdom

Local Organizing Committee (Female 3/Male 3):

Chunglee Kim	Ewha Womans University, Korea (chair)
Jongsuk Hong	Korea Astronomy and Space Science Institute, Korea
Elahe Khalouei	Seoul National University, Korea
Sungsoo Kim	Kyunghee University, Korea
Joohee Lee	Seoul National University, Korea

(i) Final scientific programme

Yellow Box: Invited talks
Blue Box: Contributed talks
Green box: Online presentation (all contributed)

Monday, June 16		
09:00 - 09:30	Welcome and Registration	
09:30 - 10:00	Opening	Hyung Mok Lee (SOC Chair), Jae-Jun Lee (Dean of the College of Natural Sciences, Soul National University)
Session 0: 10:00 - 10:30	Overview	
Invited	Myung Gyoon Lee	Globular Clusters in the Universe
Break 10:30 - 11:00		
Session 1: 11:00 - 12:30	Black Holes and Pulsars in dense clusters 1	Chair: Hyung Mok Lee
Invited	Michela Mapelli	Growing black holes via collisions
Invited	Holger Baumgardt	Massive black holes in star clusters
	Sara Rastello	Close encounters between stars and compact objects in young star clusters
	Abbas Askar	Formation and growth of intermediate-mass black holes in dense star clusters
Lunch 12:30 - 14:00		

Session 2: 14:00 - 15:30	Galactic and Extragalactic Star Clusters, Tidal Tails I	Chair: Rainer Spurzem
Invited	Anna Lisa Varri	The phase space of star clusters
	Cristiano Ugolini	The assembly of intermediate black holes with complementary approaches: Dragon II and Bpop
	Abylay Bissekenov	Evolution of star clusters with initial bulk rotation via N-body simulations
	Jayanand Mauriya (online)	The role of the stellar rotations and binaries in the origin of extended Main Sequence Turn-Off in open cluster
	Steffani Grondin	Unraveling Common Envelope Evolution: A New Window from Star Clusters
Break 15:30 - 16:00	Break	
Session 3: 16:00-17:30	Poster Sparkler 1/Poster	Chair: Hyung Mok Lee
	End of the Day	
	Tuesday, June 17	
Session 4: 9:00-10:30	Galactic and Extragalactic Star Clusters, Tidal Tails II	Chair: Anna Lisa Varri
Invited	Long Wang	Dynamic Relationship Between Star Cluster Evolution and Tidal Stream Formation
Invited	Zhen Yuan	The most metal poor stellar stream as a probe of globular cluster formation and evolution
	Alessandro Della Croce	Black holes in Globular Clusters: a structural and kinematic perspective
	Stefano Torniamenti	Black holes on the move: from globular clusters to galactic nuclei
10:30 - 11:00		
Session 5: 11:00-12:30	Galactic and Extragalactic Star Clusters, BH	Chair: Jongsuk Hong
Invited	Sourav Chatterjee	Formation and Evolution of Black Hole Binaries in Dense Star Clusters
Invited	Claire Ye	Black Hole and Neutron Star Dynamics in Dense Star Clusters
	Newlin weatherford	Black Holes Quench Observable Velocity Dispersion in Globular Cluster Stellar Streams
	Maximilian Häberle	The kinematics of Omega Centauri studied in 3D: velocity dispersion, kinematic distance, anisotropy, and energy equipartition
Lunch 12:30 - 14:00		
Session 6: 14:00-15:30	Populations in Star Clusters I	Chair: Myungshin Im

Invited	Zhanwen Han	Stability of Mass Transfer and Common Envelope Evolution of Binary Stars
	Stefano Souza	Tracing the ancient Omega Centauri dwarf galaxy
	Kristen Dage	Ultraluminous X-ray Sources in Extragalactic Star Clusters
	Giacomo Cordoni	Understanding Multiple Stellar populations through cluster internal dynamics
	Pavan Vynatheya	Comparing the collision and merger products of stars using magnetohydrodynamics
Break 15:30 - 16:00		
	Populations in Star Clusters II	Chair: Long Wang
__ Invited	Mirek Giersz	Simulations of the evolution of globular clusters with multiple stellar populations
	Peter Berczik	Dynamical co-evolution of the Multiple Stellar Populations in Globular Clusters.
	Arkadiusz Hypki	Formation of hierarchical systems in dense globular star clusters
	Tian Qiu	The Binary Fraction of Stars in the Dwarf Galaxy Ursa Minor via DESI
	Frazer Evans	High-velocity and hypervelocity stars ejected from compact object binaries in Milky Way globular clusters
	End of the Day	
	Wednesday, June 18	
Session 8: 09:00-10:30	Multi-Messenger Astronomy, GW Sources	Chair: Michiko Fujii
Invited	Myungshin Im	7-Dimensional Telescope for Multimessenger Astronomy
Invited	Debatri Chattopadhyay	Evolutionary Links: From Gaia Neutron-Star Binaries to Pulsar–White Dwarf Endpoints
	Nafisa Aftab	ECLIPSE DOES NOT HIDE, BUT REVEALS: Comprehensive X-ray Reprocessing Studies in High and Low Mass X-ray Binaries with XMM-Newton
	Andris Dorozsmai (Online)	The redshift-evolving eccentricity distribution of merging binary black holes observed by ground-based gravitational-wave detectors
10:30 - 11:00	Break	
Session 9: 11:00 - 12:30	Cluster Formation I: Black Holes	Chair: Carl Rodriguez
Invited	Natalia Lahen	Mergers all the way down: building massive star clusters in dwarf galaxy starbursts

	Eun-jin Shin	The MandelZoom project I: modelling black hole accretion through an α-disc with a resolved interstellar medium in dwarf galaxies
	Arn Marklund	Simulations of the dynamical evolution of lower mass binary stars in the Milky Way Nuclear Stellar Cluster
	Philip Cho	"Modeling Tidal Disruption Events and Compact Object Plunges in Nuclear Star Clusters"
	Guimei Liu	Formation and Evolution of New Primordial Open Cluster Groups: Insights from Feedback-Driven Star Formation
Lunch 12:30 - 14:00		
Session 10: 14:00 - 15:30	Cluster Formation II, Black Holes	Chair: Mirek Giersz
Invited	Michiko Fujii	Formation of intermediate-mass black holes in forming star clusters
	Benedetta Mestichelli	Simulating intermediate-mass black holes in the first star clusters
	Lavinia Paiella	Seeds to Success: growing heavy black holes in star clusters
	Elena Gonzalez Prieto	Modeling Massive Black Holes in Globular Clusters with the Cluster Monte Carlo Code
	Maria Paola Vaccaro	Hierarchical Black Hole Mergers in AGN Disks
15:30 - 16:00	Break	
16:00 - 17:30	Poster Viewing/ Discussions	
Special Public Lecture (Ewha Womans Univ.)		Chair: Chunglee Kim
	Di Li	Dynamic Universe: fundamental cosmic rules beyond Galileo, Newton, and Einstein
	Thursday June 19	
Session 10: 9:00-10:30	Cluster Dynamics - Simulation Codes I + Populations	Chair: Jarrod Hurley
Invited	Carl Rodriguez	Monte Carlo N-body Methods for Star Cluster Dynamics
	Yongseok Jo (online)	Formation and evolution of star clusters in the early universe using self-consistent hybrid hydro/direct N-body simulations
	Nolan Dickson	Fast dynamical modelling of globular clusters; constraints on initial conditions and black hole physics.
	Erin Eastep	BPASS Predictions of Compact Remnant Binaries in the Milky Way
	Mark Dodici	Stellar binaries orbiting supermassive black holes should often shrink to near-contact separations
Break 10:30 - 11:00		
Session 11: 11:00-12:30	Cluster Dynamics - Simulation Codes II	Shuo Li

Invited	Paolo Bianchini	From direct N-body to deep-learning: modelling the internal dynamics of globular clusters
Invited	Antti Rantala	Exploring hierarchical star cluster and massive black hole seed formation using a hierarchical 4th order forward integrator
	Chunglee Kim	Evolution of Rotating Clusters and Formation of Binary Black Holes
	Thibaut FRANCOIS	Unveiling the dance of off-center black hole duets: Insights from Jacobi capture in dwarf galaxies
Lunch 12:30 - 14:00		
Session 12: 14:00-15:30	Populations in star clusters III	Chair : Woong-Tae Kim
Invited	Taeho Ryu	Stellar collisions - Blue straggler stars and electromagnetic transients
	Koushik Sen (online)	X-ray emission from helium star+black hole binaries as probes of tidally induced spin-up of second-born black holes
	Maria Rah (online)	Modeling Normal Pulsars in Globular Clusters via NBODY6++GPU
	Jordan Bruce	Dynamics of Binary Stars and Multiple Stellar Populations in Globular Clusters
	Ataru Tanikawa	Dynamical formation of compact binary systems detected by Gaia astrometry
Break 15:30 - 15:50		
Session 13: 16:00 - 17:30	Session for Sverre	Chair: Chunglee Kim
Invited	Jarrod Hurley	Kitchen Sink N-body Models (bug hunting with Sverre)
Invited	Rainer Spurzem	From NBODY1 to NBODY7: the growth of Sverre's industry
	Kai Wu	DRAGON-III simulation: modelling million-body globular and nuclear star clusters over cosmic time
	Seungjae Lee	Formation and Evolution of Compact Binaries Containing Intermediate Mass Black Holes in Dense Star Clusters
18:00 - 20:30		
	End of the day	
	Friday June 20	
Session 14: 9:00-10:30	Black Holes and Pulsars in dense clusters 2	Chair: Peter Belczik
Invited	Sambaran Banerjee	Gravitational-wave mergers from star clusters and isolated binaries
	Darsh Bellie	Expanding the Family Tree: Refined Population Inference of Hierarchical Mergers in Gravitational-Wave Data

	Daniel Marin Pina	The dynamical origin of Gaia BH3
	Yuzhe Song	Modelling Millisecond Pulsar Populations in Globular Clusters with NBODY6++GPU
	Veronica Vazquez-Aceves	The multimessenger life of intermediate mass-ratio inspirals in globular clusters: The tidal stripping of white dwarfs.
Break 10:30 - 11:00		
Session 15 11:00 - 12:00	Nuclear Star Clusters with SMBH	Chair: Taeho Ryu
Invited	Shuo Li	Tidal disruptions of supermassive black hole binaries in galaxy mergers
	Odelia Teboul	Strong Scatterings Invalidate Proposed Models of Enhanced TDE Rates in Post-Starburst Galaxies
	Evgeni Grishin	Gravitational-Wave Signatures of Highly Eccentric Stellar Binary Black-Holes in Galactic Nuclei
	Myank Singhal (online)	Investigating the Origins of Hypervelocity Stars in the Galactic Center
	Yoko Funato	Resonant Relaxation in the Galactic Center : Multi-Component Stellar System Cases
	closing	
	End of Conference	

Number of speakers invited talks: Female 6/Male 16
Number of speakers contributed talks: Female 19/Male 28
Number of session chairs: Female 4/Male 11

List of posters (Alphabetical order in last name)

Name	Affiliation	PosterTitle
Sultan Abylkairov	Nazarbayev University	Constraining Nuclear Matter Properties with Gravitational Wave Signals from Core-Collapse Supernovae
Shabnam Aghayeva	Shamakhy Astrophysical Observatory	The influence of gravitational waves in massive compact binary systems
Mayte Alfaro Cuello	Universidad Central de Chile	Internal Kinematics of Outer Fields in Globular Clusters with HST: the case of M15
Jasmine Anderson-Baldwin	Swinburne University of Technology	M67 in NBODY6++GPU and Gaia DR3
Lucy Arditi	Institute of Astronomy, University of Edinburgh	Dynamics of Tidally Perturbed, Rotating Stellar Systems
Adilkhan Assilkhan	Almaty University of Power Engineering and Telecommunications	Centrally concentrated star formation
Paul Barnaud	Seoul National University	Formation of IMBH-SBH binaries within globular clusters and their properties
Abylay Bissekenov	Xi'an Jiaotong-Liverpool University	Evolution of star clusters with initial bulk rotation via N-body simulations
TOMASZ Bulik	University of Warsaw	StarTrack - the current status
Sang-Hyun Chun	Korea Astronomy and Space science Institute	Star Cluster or Chance Alignment? Red Supergiants in RSGC4 and the Complex Dynamics of the Scutum Complex
Eunwoo Chung	Seoul National University	Enzo-Abyss: Self-consistent hybrid hydro/direct N-body simulation for the formation and evolution of IMBHs in galaxies
Pierfrancesco Di Cintio	ISC-CNR, INAF OAA & INFN	Binary BHs inspirals in dark matter cusps. Dark matter dynamical friction and Post-Newtonian corrections
Pierfrancesco Di Cintio	ISC-CNR, INAF OAA & INFN	Binary BHs inspirals in dark matter cusps. Dark matter dynamical friction and Post-Newtonian corrections.
Le Duc Thong	Dong Nai Technology University	Exploring New Physics with White Dwarf Binaries in Dense Stellar Environments
Zack Freeman	University of Utah	Detecting Black Holes in Omega Centauri via Microlensing
Toshinori Hayashi	Yukawa Institute for Theoretical Physics, Kyoto University	Constraint on the binarity of the dark companion in Gaia BH1
Muhammad Akmal Husain	Institut Teknologi Bandung	Analysis of a Septuple Open Cluster System and Its Extended Family in Gaia DR3
Ryutaro Iwakura	Kobe University	New approach for predicting the stability of hierarchical triple systems
Sohee Jang	Yonsei University	New Insights into the Multiple Populations Phenomenon in Galactic Globular Clusters from a Wide-field Photometric Survey
Mukhagali Kalambay	Heriot-Watt University Aktobe Campus	Mock Observation of Simulated Star Clusters
Jungeun Kim	KAIST	High-frequency Power Spectrum of Active Galactic Nucleus NGC 4051 Revealed by NICER
Jae-Rim Koo	Kongju National University, Korea	Variation of the Stellar Initial Mass Functions in the Antennae Galaxies

Gourav Kumawat	University of Alberta	A Comprehensive Analysis of X-ray Sources in Terzan 5
Jae-Woo Lee	Department of Physics and Astronomy, Sejong University	Multiple Stellar Populations of Globular Clusters with a New Photometric System
Nathan Leigh	Universidad de Concepcion	The evolution of binary black holes due to dynamical interactions
Songting Li	Shanghai Jiaotong University	Binary fraction of equal-mass binary systems based on DESI Year-1 data
Dongwook Lim	Yonsei University	Near-Infrared Spectroscopy of Globular Clusters in the Milky Way Bulge and Their Stellar Populations
Chia-Ching Lin	National Central University, Taiwan	Deciphering Survival Old but Populous Galactic Open Clusters
Arn Marklund	Observatoire Astronomique de Strasbourg	Simulations of the dynamical evolution of lower mass binary stars in the Milky Way Nuclear Stellar Cluster
Benedetta Mestichelli	Gran Sasso Science Institute	Bring to light the unseen: learning from blue stragglers in globular clusters
Hubiao Niu	Xinjiang Astronomical Observatory, Chinese Academy of Sciences	Study of Pulsating Binary Stars at Xinjiang Astronomical Observatory
Kwangmin Oh	Michigan State University	Dynamical Status of Globular Clusters and Its Influences on Binary Populations
Taras Panamarev	Fesenkov Astrophysical Institute	Efficient Mergers of IMBH-SMBH binaries in galactic nuclei
Chan Park	Henan Academy of Sciences	Detection of Gravitational Waves using Electromagnetic Waves beyond Geometrical Optics
Ishika Paudel	Tri-Chandra Multiple Campus, TU.	Classification of Compact Object Binaries Using Random Forest: A gravitational wave approach.
Sanjaya Paudel	Yonsei University	Evidence of star cluster migration and merger in dwarf galaxies
Václav Pavlík	Astronomical Institute of the Czech Academy of Sciences	Insights into spatial mixing of multiple populations in dynamically-young globular clusters
Shafayet Rahman	National IAU Volunteer, NOC-Bangladesh Office, IAU Office for Astronomy Outreach	Hierarchical Black Hole Binaries in Dense Stellar Systems and Their Impact on Gravitational Wave Astronomy
Khushboo K Rao	Institute of Astronomy, National Central University, Taiwan	Investigating Extended Main-Sequence Turnoffs of Galactic Open Clusters
Arianna Rodríguez-Ortiz	University of Puerto Rico-Mayagüez	M17 & W51 CH Spectral Radio Analysis In the Interstellar Medium
Navonil Saha	Astronomisches Rechen-Institut (ARI), Universität Heidelberg	The Dynamics of Triple and Binary Super Massive Black Holes in a cosmological context
Soroush Shakeri	Isfahan University of Technology (IUT) and Iranian National Observatory (INO)	Observation and Modeling of the Massive Pulsar Binary J2215+5135 by INO340
Fazliddin Shamshiev	Uzbekistan	On the existence of a local integrals in the dynamics of stellar systems
Ira Sharma	Indian Institute of Astrophysics, Bangalore	Tidal Tidals and Their Dynamics in Open Clusters Using Gaia DR3
Megha sharma	Monash university	Binary star collisions around Hypermassive black holes: Statistics and possible signatures
Jiwon Shin	Chungnam National University	Second discovery of a GeV-TeV connection in the Globular Cluster UKS 1
Peter Smith	Max Planck Institute for Astronomy	Internal Dynamics of Omega Centauri: Towards Discrete Schwarzschild modelling

Margaryta Sobolenko	Main Astronomical Observatory National Academy of Sciences of Ukraine	Black hole binary formation and merging in a globular clusters central black hole subsystem
Donggeun Tak	SNU	Understanding the role of heavy elements in forming the kilonova spectrum and lightcurve
Fred Thompson	University of Oxford	Modelling the formation of star clusters with sink particle algorithms in cosmological simulations
Cristiano Ugolini	Gran Sasso Science Institute	Constraining the features of the BBH mass distribution through population synthesis simulation
Zumrud Vidadi	Shamakhy astrophysical Observatory	Observations of remnants of gravitational wave sources in the late stages of stellar evolution
Yifan Wang	Xi'an Jiaotong-Liverpool University	AI-Driven Diffusion Models as a Scalable Alternative to Traditional N-Body Simulations
Matthew Whitaker	University of Utah	Astrometric Binaries in Omega Centauri
Grzegorz Wiktorowicz	Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences	The Role of Dynamics and Environment in Forming Ultraluminous X-ray Sources in Globular Clusters
Jia-syuan Wu	National Central University	Diagnosis of substructures around the rare double cluster h and χ Persei

Total number of posters: 56

(ii) Summary of the scientific highlights of the meeting

During the IAUS 398, we discussed 7 major science topics dense star clysters.

(1)) Black holes and pulsars in dense clusters
(2) Galactic Nuclei, dynamics and evolution
(3) Galactic and Extragalactic Star Clusters
(4) Stellar Population in Star Clusters
(5) Formation of black hole binaries in star clusters
(6) Simulations of realistic cluster dynamics with various codes
(7) Multi-messenger astronomy

In addition, we held a special session dedicated to the memory of the late **Sverre Aarseth**, who devoted his entire professional career to the development of N-body simulation codes. Many participants have benefited from Sverre's lifelong contributions, and numerous presentations at the symposium were indeed based on simulations performed with various versions of his N-body codes.

IAU Symposium 398 brought together an international community of researchers to explore the dynamic, multi-messenger universe of compact stars and binaries in dense stellar systems. These systems—globular clusters, nuclear star clusters, and young massive clusters—are natural laboratories where the interplay of stellar dynamics, binary evolution, and relativistic physics gives rise to the most energetic astrophysical phenomena observed today.

A central highlight of the meeting was the deepening connection between stellar dynamics and gravitational-wave (GW) astrophysics. Over the past decade, GW detections have revealed a population of black-hole binaries whose masses, spins, and eccentricities often differ from those expected in isolated binary evolution. Talks at IAUS 398 showed that dense stellar environments can naturally reproduce these features. Results from large-scale N-body and Monte Carlo simulations demonstrated that dynamical exchanges and hierarchical encounters efficiently assemble and harden compact binaries, leading to mergers observable by LIGO–Virgo–KAGRA. Many of the heaviest and most isotropically spinning mergers detected so far are consistent with a dynamical origin in globular clusters. These findings mark an emerging consensus that clusters are not merely incidental contributors but may account for a substantial fraction of observed mergers.

The symposium also highlighted progress in understanding hierarchical black-hole growth and the possible formation of intermediate-mass black holes (IMBHs). Several talks presented simulations in which successive mergers within massive clusters can produce remnants exceeding 100 $M_\odot$—potentially bridging the gap between stellar-mass and supermassive black holes. Although direct observational confirmation remains elusive, this scenario offers a plausible explanation for GW events like GW190521, whose component masses lie in the predicted pair-instability gap. Complementary observational studies of clusters such as ω Centauri, M15, and G1 in M31 presented increasingly stringent upper limits on central IMBHs from stellar kinematics, while new radio and X-ray campaigns continue to search for faint accretion signatures. The debate remains open, but the convergence of dynamical modeling, high-resolution spectroscopy, and GW detections is pushing the field toward a testable framework.

Another prominent highlight was the integration of electromagnetic and GW observations into a unified, multi-messenger perspective. Radio surveys from MeerKAT, FAST, and ASKAP are uncovering large samples of millisecond pulsars in clusters, providing precise probes of cluster potentials and compact-object populations. X-ray and optical studies using Chandra, HST, and JWST are resolving core structures and binary fractions with unprecedented precision. These observations, when combined with cluster simulations, are revealing strong correlations between encounter rate, pulsar abundance, and compact-binary formation efficiency. The ability to cross-compare multi-wavelength data with GW event statistics marks a key step toward quantitatively linking dynamical models with observations.

Methodologically, the symposium showcased a new era of computational astrophysics. GPU-accelerated direct N-body codes and hybrid Monte Carlo approaches now allow researchers to simulate clusters with up to a million stars over gigayear timescales, incorporating detailed stellar evolution and relativistic effects. Benchmark comparisons between codes (such as NBODY6++GPU, PeTar, CMC, and MOCCA) revealed encouraging consistency while highlighting areas for improvement, particularly in binary-interaction prescriptions. Discussions emphasized open data, reproducibility, and standardized test problems as priorities for the MODEST community.

The broader significance of these developments lies in their implications for the origin and evolution of compact objects throughout cosmic history. Dense stellar systems may have seeded both the first GW sources and the low-mass black holes that grew into supermassive ones. By tracing how stellar remnants interact, merge, and evolve within clusters, astronomers are beginning to link small-scale stellar dynamics with the large-scale assembly of galaxies and black holes.

In conclusion, the scientific highlight of IAUS 398 was the convergence of diverse lines of evidence—numerical, observational, and GW—toward a coherent picture in which dense stellar systems play a central role in producing the Universe's most compact and energetic objects. The meeting underscored that progress now depends on close collaboration across subfields: dynamicists refining models with realistic physics, observers pushing the limits of resolution and sensitivity, and GW providing direct tests of cluster-formation scenarios. Together, these efforts are transforming the study of dense stellar systems from a traditional branch of stellar dynamics into a cornerstone of modern, multi-messenger astrophysics.

(iii) List of participants

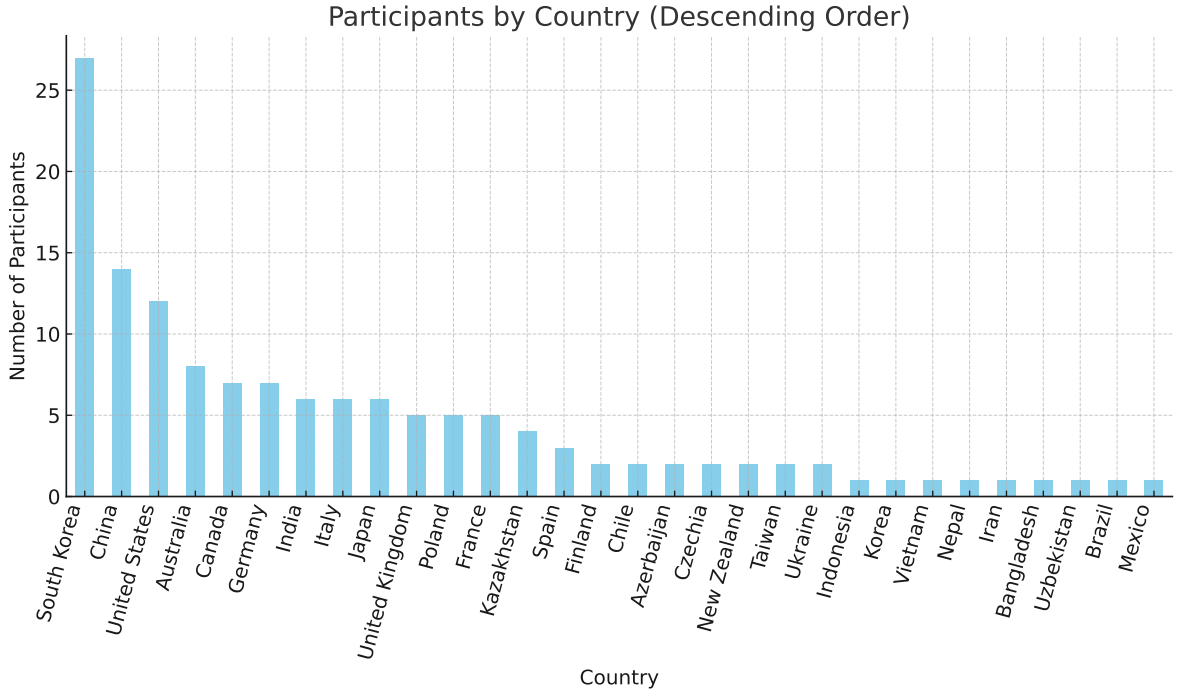
Given Name	Last Name	Country	Affiliation	
Sultan	Abylkairov	Kazakhstan	Nazarbayev University	
Nafisa	Aftab	India	Raman Research Institute, Bengaluru, India	
Shabnam	Aghayeva	Azerbaijan	Shamakhy Astrophysical Observatory	
Mayte	Alfaro Cuello	Chile	Universidad Central de Chile	
Jasmine	Anderson-Baldwin	New Zealand	Swinburne University of Technology	
Lucy	Arditi	United Kingdom	Institute of Astronomy, University of Edinburgh	
Abbas	Askar	Poland	Nicolaus Copernicus Astronomical Center, PAS	
Adilkhan	Assilkhan	Kazakhstan	Almaty University of Power Engineering and Telecommunications	
Sambaran	Banerjee	Germany	University of Bonn	
Paul	Barnaud	France	Seoul National University	
Holger	Baumgardt	Australia	The University of Queensland	
Darsh	Bellie	United States	CIERA, Northwestern University	
Peter	Berczik	Ukraine	Main Astronomical Observatory, National Academy of Sciences of Ukraine	
Paolo	Bianchini	France	Observatoire Astronomique de Strasbourg	
Abylay	Bissekenov	China	Xi'an Jiaotong-Liverpool University	
Abylay	Bissekenov	China	Xi'an Jiaotong-Liverpool University	
Jordan	Bruce	India	Indiana University Bloomington	
TOMASZ	Bulik	Poland	University of Warsaw	
Sourav	Chatterjee	India	Tata Institute of Fundamental Research	
Debatri	Chattopadhyay	United States	CIERA, Northwestern University	
Philip	Cho	South Korea	Astronomisches Rechen-Institut, Heidelberg University	
Sang-Hyun	Chun	South Korea	Korea Astronomy and Space science Institute	
Eunwoo	Chung	South Korea	Seoul National University	
Giacomo	Cordoni	Australia	Australian National University	
Kristen	Dage	Australia	Curtin Institute of Radio Astronomy	
Alessandro	Della Croce	Italy	INAF - OAS Bologna	
Scot	Devlin	Australia	University of Queensland	
Pierfrancesco	Di Cintio	Italy	ISC-CNR, INAF OAA & INFN	
Nolan	Dickson	Canada	Saint Mary's University	
Mark	Dodici	United States	University of Toronto	
Andris	Dorozsmai	Japan	National Astronomical Observatory of Japan	Online
Le	Duc Thong	Vietnam	Dong Nai Technology University	
Erin	Eastep	New Zealand	University of Auckland	
Fraser	Evans	Canada	University of Toronto	
Thibaut	FRANCOIS	United Kingdom	University of Surrey	
Zack	Freeman	United States	University of Utah	

Michiko	Fujii	Japan	The University of Tokyo	
Yoko	Funato	Japan	University of Tokyo	
Mirek	Giersz	Poland	Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences	
Elena	Gonzalez Prieto	United States	Northwestern University	
Evgeni	Grishin	Australia	Monash University	
Steffani	Grondin	Canada	University of Toronto	
Maximilian	Häberle	Germany	Max Planck Insitute for Astronomy	
Zhanwen	Han	China	Yunnan Observatories, Chinese Academy of Sciences	
Toshinori	Hayashi	Japan	Yukawa Institute for Theoretical Physics, Kyoto University	
Jongsuk	Hong	South Korea	KASI	
Jarrod	Hurley	Australia	Swinburne University of Technology	
Muhammad Akmal	Husain	Indonesia	Institut Teknologi Bandung	
Narae	Hwang	South Korea	Korea Astronomy and Space Science Institute	
Arkadiusz	Hypki	Poland	Faculty of Mathematics and Computer Science of Adam Mickiewicz University in Poznan	
Myungshin	Im	South Korea	Seoul National University	
Giuliano	Iorio	Spain	ICCUB, University of Barcelona	
Ryutaro	Iwakura	Japan	Kobe University	
Sohee	Jang	South Korea	Yonsei University	
Yongseok	Jo	South Korea	Columbia University	Online
Minyong	Jung	South Korea	Seoul National University	
Mukhagali	Kalambay	Kazakhstan	Heriot-Watt Aktobe Campus, Zhubanov University	
Elahe	Khalouei	South Korea	Seoul National University	
Bokyoung	Kim	Germany	Nature Astronomy, Springer Nature	
Chunglee	Kim	South Korea	Ewha Womans U.	
Jungeun	Kim	South Korea	KAIST	
Sungsoo	Kim	Korea	Kyunghee Univ.	
Woong-Tae	Kim	South Korea	Seoul National University	
Jae-Rim	Koo	South Korea	Kongju National University, Korea	
Gourav	Kumawat	Canada	University of Alberta	
Natalia	Lahén	Finland	Max Planck Institute for Astrophysics, Garching bei München, Germany	
Hyung Mok	Lee	South Korea	Seoul National University	
Jae-Woo	Lee	South Korea	Department of Physics and Astronomy, Sejong University	
Myung Gyoon	Lee	South Korea	Seoul National University	
Seungjae	Lee	South Korea	Seoul National University	
Sumi	Lee	South Korea	Ewha Womans University	
Nathan	Leigh	Chile	Universidad de Concepcion	
Shuo	Li	China	National Astronomical Observatories, CAS	
Songting	Li	China	Shanghai Jiaotong University	

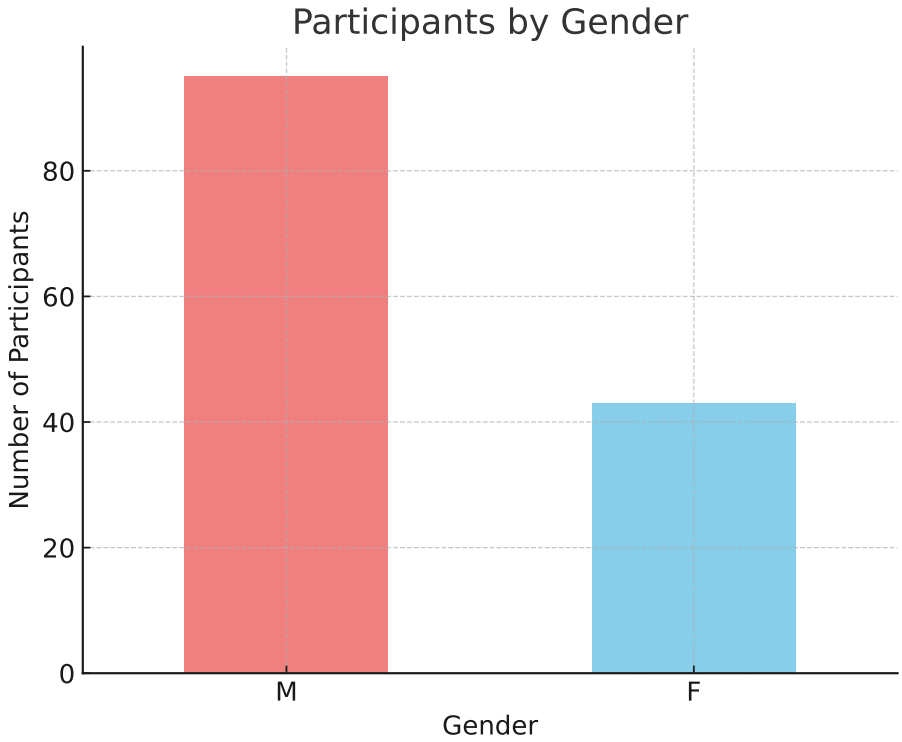
Beomdu	Lim	South Korea	Kongju National University	
Dongwook	Lim	South Korea	Yonsei University	
Chia-Ching	Lin	Taiwan	National Central University, Taiwan	
Guimei	Liu	China	Xinjiang Astronomical Observatory, Chinese Academy of Sciences	
Michela	Mapelli	Germany	Heidelberg University	
Daniel	Marín Pina	Spain	Universitat de Barcelona - ICCUB	
Arn	Marklund	France	Observatoire Astronomique de Strasbourg	
Jayanand	Maurya	China	Xinjiang Astronomical Observatory, Chinese Academy of Sciences, China	Online
Benedetta	Mestichelli	Italy	Gran Sasso Science Institute	
Benedetta	Mestichelli	Italy	Gran Sasso Science Institute	
Hubiao	Niu	China	Xinjiang Astronomical Observatory, Chinese Academy of Sciences	
Kwangmin	Oh	United States	Michigan State University	
Lavinia	Paiella	Italy	Gran Sasso Science Institute	
Taras	Panamarev	Kazakhstan	Fesenkov Astrophysical Institute	
Chan	Park	South Korea	Henan Academy of Sciences	
Jihwan	Park	South Korea	Ewha Womans university	
Ishika	Paudel	Nepal	Tri-Chandra Multiple Campus, TU.	
Sanjaya	Paudel	South Korea	Yonsei University	
Václav	Pavlík	Czechia	Astronomical Institute of the Czech Academy of Sciences	
Tian	Qiu	China	Shanghai Jiao Tong University	
Maria	Rah	Iran	Byurakan Astronomical Observatory, Armenia; PhD student	Online
Shafayet	Rahman	Bangladesh	National IAU Volunteer, NOC-Bangladesh Office, IAU Office for Astronomy Outreach	
Antti	Rantala	Finland	Max Planck Institute for Astrophysics (MPA), Garching, Germany	
Khushboo K	Rao	India	Institute of Astronomy, National Central University, Taiwan	
Sara	Rastello	Spain	University of Barcelona	
Florent	Renaud	France	Strasbourg Observatory	
Carl	Rodriguez	United States	University of North Carolina	
Arianna	Rodríguez-Ortiz	United States	University of Puerto Rico-Mayagüez	
Luke	Rosier	Australia	University of Queensland	
Taeho	Ryu	United States	The University of Colorado, Boulder (JILA)	
Navonil	Saha	Germany	Astronomisches Rechen-Institut (ARI), Universität Heidelberg	
Koushik	Sen	United States	Steward Observatory, University of Arizona	Online
Gwang Eon	Seong	South Korea	Ewha Womans University	
Fazliddin	Shamshiev	Uzbekistan	National University of Uzbekistan	
Ira	Sharma	India	Indian Institute of Astrophysics, Bangalore	
Megha	Sharma	India	Monash university	
Eun-jin	Shin	United Kingdom	IOA, Cambridge	
Jiwon	Shin	South Korea	Chungnam National University	

Myank	Singhal	Czechia	Astronomical Institute, Charles University	Online
Peter	Smith	Canada	Max Planck Institute for Astronomy	
Margaryta	Sobolenko	Ukraine	Main Astronomical Observatory National Academy of Sciences of Ukraine	
Yuzhe	Song	Australia	Swinburne University of Technology	
Stefano	Souza	Brazil	Max-Planck Institute for Astronomy (MPIA)	
Rainer	Spurzem	China	NAOC/CAS and Uni Heidelberg	
Donggeun	Tak	South Korea	SNU	
Ataru	Tanikawa	Japan	Fukui Prefectural University	
Odelia	Teboul	France	Weizmann Institute	
Fred	Thompson	United Kingdom	University of Oxford	
Stefano	Torniamenti	Italy	Max Planck Institute for Astronomy	
Cristiano	Ugolini	Italy	Gran Sasso Science Institute	
Maria Paola	Vaccaro	Germany	ITA-ZAH, Universität Heidelberg	
Anna Lisa	Varri	United Kingdom	University of Edinburgh	
Veronica	Vazquez-Aceves	Mexico	The Kavli Institute for Astronomy and Astrophysics, Peking University	
Zumrud	Vidadi	Azerbaijan	Shamakhy astrophysical Observatory	
Pavan	Vynatheya	Canada	Canadian Institute for Theoretical Astrophysics, University of Toronto	
Long	Wang	China	Sun Yat-sen University	
Yifan	Wang	China	Xi'an Jiaotong-Liverpool University	
Newlin	Weatherford	United States	Carnegie Science Observatories	
Matthew	Whitaker	United States	University of Utah	
Grzegorz	Wiktorowicz	Poland	Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences	
Jia-syuan	Wu	Taiwan	National central university	
Kai	Wu	Germany	ARI/ZAH, Heidelberg University	
Claire	Ye	Canada	Canadian Institute for Theoretical Astrophysics	
Zhen	Yuan	China	Nanjing University	
Yu	Zhang	China	XinJiang Astronomical Observatory	

Distribution by country



Distribution by gender



(iv) List of recipients of IAU grants

First Name	Family Name	Gender	Institute of work	Country of work	Amount (€)
Nafisa	Aftab	Female	Raman Research Institute, Bengaluru, India	India	800
Shabnam	Aghayeva	Female	Shamakhy Astrophysical Observatory	Azerbaijan	1,000
Peter	Berczik	Male	Main Astronomical Observatory, National Academy of Sciences of Ukraine	Ukraine	1,000
Abylay	Bissekenov	Male	Xi'an Jiaotong-Liverpool University	China	700
Jordan	Bruce	Male	Indiana University Bloomington	United States	700
Debatri	Chattopadhyay	Female	CIERA, Northwestern University	United States	1,000
Giacomo	Cordoni	Male	Australian National University	Australia	500
Erin	Eastep	non-binary	University of Auckland	New Zealand	500
Thibaut	FRANCOIS	Male	University of Surrey	United kingdom	1,000
Elena	Gonzalez Prieto	Female	Northwestern University	United States	1,000
Arn	Marklund	Male	Observatoire Astronomique de Strasbourg	France	1,000
Lavinia	Paiella	Female	Gran Sasso Science Institute	Italy	600
Ishika	Paudel	Female	Tri-Chandra Multiple Campus, TU.	Nepal	900
Shafayet	Rahman	Male	NOC-Bangladesh Office, IAU Office for Astronomy Outreach	Bangladesh	500
Sara	Rastello	Female	University of Barcelona	Spain	1,000
Navonil	Saha	Male	Astronomisches Rechen-Institut (ARI), Universität Heidelberg	Germany	500
Fazliddin	Shamshiev	Male	National University of Uzbekistan	Uzbekistan	1,000
Ira	Sharma	Female	Indian Institute of Astrophysics, Bangalore	India	1,000
Yuzhe	Song	Male	Swinburne University of Technology	Australia	700
Maria Paola	Vaccaro	Female	ITA-ZAH, Universität Heidelberg	Germany	700
Zumrud	Vidadi	Female	Shamakhy astrophysical Observatory	Azerbaijan	1,000
Yifan	Wang	Male	Xi'an Jiaotong-Liverpool University	China	600
Long	Wang	Male	Sun Yat-sen University	China	300
Clair	Ye	Female	Canadian Institute for Theoretical Astrophysics	Canada	1,000
Le	Duc Thong	Male	Dong Nai Technology University	Vietnam	1,000

Number of IAU Travel Grant Recipients by Gender: Female 11/Male 13/ None Binary 1
Total Amount: 20,000 EURO

(v) An Executive Summary of the Meeting

The IAU Symposium 398, jointly organized with the MODEST (Modeling Dense Stellar Systems) collaboration, convened more than 130 participants at Seoul National University to discuss one of the most rapidly advancing frontiers in modern astrophysics: the formation, evolution, and observational signatures of compact stars and binaries within dense stellar systems. These systems—globular clusters, nuclear star clusters, and young massive clusters—represent extreme environments where the interplay of stellar dynamics and evolution gives rise to a rich population of exotic objects.

In such dense environments, close encounters between stars are frequent, and gravitational interactions often dominate over isolated stellar evolution. Binary formation through three-body processes, mass segregation toward the core, and repeated dynamical exchanges lead to the creation of massive stellar remnants and compact binaries. These binaries are important not only as progenitors of high-energy transients and X-ray sources, but also as the dominant dynamical channel for the formation of gravitational-wave (GW) sources detectable by the LIGO–Virgo–KAGRA network. The symposium aimed to synthesize results across theoretical modeling, numerical simulation, and multi-wavelength observation, while connecting traditional stellar dynamics with the new field of gravitational-wave astrophysics.

The timing of the meeting was especially appropriate: the fourth observing run (O4) of LIGO–Virgo–KAGRA is ongoing, producing unprecedented data on compact binary mergers. Simultaneously, new high-resolution imaging and radio surveys—carried out by facilities such as MeerKAT, FAST, ASKAP, Chandra, and HST/JWST—are transforming our understanding of globular clusters and nuclear environments. The symposium thus served as a timely forum to confront theoretical predictions with rapidly expanding observational evidence.

Dynamics of Dense Stellar Systems

One major focus of IAUS 398 was the dynamical evolution of dense clusters. Talks presented results from advanced N-body and Monte Carlo simulations that trace the long-term structural evolution of clusters, emphasizing the role of core collapse, mass segregation, and tidal interactions with the host galaxy. Several presentations showed how dynamical friction and repeated gravitational encounters drive the most massive remnants—black holes and neutron stars—toward the cluster core, where they can form tightly bound subsystems and undergo mergers.

A recurrent topic was the retention of compact remnants after supernovae. New population-synthesis models incorporating fallback-dependent natal kicks suggest that black-hole retention fractions may be significantly higher than previously assumed, particularly in metal-poor environments. This has direct implications for the size and stability of black-hole subclusters and for predicting merger rates. Simulations demonstrated that even a small population of retained black holes can delay or reverse core collapse, influencing the entire cluster's observable properties.

Speakers also addressed the importance of primordial binaries. Their fraction and orbital-parameter distribution strongly affect the cluster's dynamical heating, core radius, and long-term evolution. Updated models now include realistic binary stellar evolution (mass transfer, wind mass loss, supernova kicks) coupled with few-body integrators to follow exchange interactions and mergers. The consensus emerging from the meeting was that no accurate model of cluster evolution can neglect the complex feedback between binaries and global dynamics.

Formation of Compact Binaries and Gravitational-Wave Sources

The symposium devoted extensive discussion to the formation channels of compact binaries within clusters and their connection to the growing catalog of gravitational-wave detections. Direct N-body and Monte Carlo simulations presented by several groups show that hierarchical interactions efficiently assemble black-hole binaries and harden them through repeated encounters. These dynamical binaries typically exhibit isotropic spin distributions**,** mass ratios close to unity**,** and occasionally detectable eccentricities, distinguishing them from isolated field binaries.

Comparison with LIGO/Virgo catalogs (O1–O3 and preliminary O4 results) suggests that cluster formation channels may account for the most massive events—those with total masses above 60 $M_\odot$—and possibly for systems with effective spin parameters near zero or negative. Several talks explored how these predictions depend on metallicity, cluster age, and initial conditions. The combined evidence favors a mixed population, in which a substantial but uncertain fraction of mergers originates dynamically.

Particularly interesting were results concerning multiple merger generations. In massive clusters, the merger remnants can remain bound and undergo subsequent mergers, producing **second-generation black holes** with masses in the intermediate-mass regime (100–300 $M_\odot$). This pathway provides a natural explanation for events such as **GW190521**, whose component masses fall in the pair-instability mass gap. Yet, the efficiency of such hierarchical growth depends critically on cluster escape velocities and black-hole spin magnitudes, parameters that remain poorly constrained observationally.

Several groups highlighted progress in predicting electromagnetic counterparts of GW sources. Although most dynamical mergers are expected to be "dark," mergers occurring within gas-rich clusters or near galactic centers could generate observable transients. The possibility of detecting such signatures through coordinated gravitational-wave and optical/radio follow-ups was an active topic of debate.

Intermediate-Mass Black Holes and Cluster Cores

A recurring theme throughout the symposium was the search for intermediate-mass black holes (IMBHs)—objects bridging the gap between stellar-mass and supermassive black holes. Both theoretical arguments and numerical experiments suggest that IMBHs can form through runaway stellar collisions in young massive clusters or through successive black-hole mergers. Yet, after decades of searches, no IMBH has been conclusively confirmed.

Observational presentations summarized the current state of the field. In several Galactic and extragalactic clusters (e.g., ω Centauri, 47 Tuc, M15, and G1 in M31), high-precision stellar-kinematic studies have placed stringent upper limits on central black-hole masses. Complementary radio and X-ray observations have also constrained accretion luminosities, yielding limits of a few thousand solar masses. Some new results from the FAST and MeerKAT radio surveys suggest that compact radio sources at cluster centers could still hide low-luminosity IMBHs, though alternative interpretations—such as unresolved millisecond-pulsar populations—remain viable.

Numerical studies presented at IAUS 398 demonstrated how even a modest IMBH (10^3–10^4 $M_\odot$) profoundly alters cluster structure, suppressing core collapse and producing characteristic surface-brightness and velocity-dispersion profiles. Several talks proposed using these dynamical signatures, together with pulsar timing and future astrometric monitoring by JWST or Gaia NIR, to detect or rule out IMBHs in nearby clusters. Another promising route is through low-frequency gravitational waves: mergers involving IMBHs could be detected by upcoming space-based observatories such as LISA, providing the most direct evidence yet for their existence.

Observational Synergies and Multi-Messenger Approaches

A strong unifying thread of the symposium was the emphasis on multi-messenger astrophysics. Observers presented new catalogs of millisecond pulsars and X-ray binaries in globular clusters, revealing correlations between pulsar abundance, cluster encounter rate, and central density. High-precision timing of cluster pulsars is increasingly being used to infer the gravitational potential and constrain the presence of central dark mass components. Also, some new facilities dedicated for the rapid detection of the electromagnetic counterparts, including 7-dimensional telescope, are presented.

Simultaneously, optical and near-infrared surveys with JWST, HST, and ground-based telescopes are resolving cluster cores with unprecedented detail, enabling the measurement of stellar mass functions, binary fractions, and structural parameters. These data are essential for anchoring theoretical models and for constraining initial cluster conditions, which remain one of the largest sources of uncertainty in population synthesis.

The gravitational-wave community contributed by demonstrating how merger population studies can be used to infer the fraction of events arising in clusters versus the field. Bayesian hierarchical inference combining LIGO/Virgo data with dynamical models is beginning to yield quantitative constraints, though degeneracies persist. Several talks showcased machine-learning and surrogate-model approaches for rapidly mapping parameter space and linking observable GW properties to cluster physics.

Advances in Numerical and Computational Methods

The symposium also served as a platform to present major methodological advances. Direct N-body codes such as NBODY6++GPU and PeTar now exploit GPU clusters and hybrid parallelization to simulate clusters with millions of particles, incorporating stellar evolution and relativistic corrections. Monte Carlo codes (e.g., MOCCA, CMC, and RAPID) have achieved similar realism with far greater computational efficiency, allowing ensemble studies of thousands of clusters. Recent efforts of integrating direct N-body and magnetohydrodynamics (e.g., Enzo) in the context of cosmological simulations begin to produce useful insights on the formation of nuclear star clusters and central black holes.

Several benchmarking efforts were reported, comparing results between different codes under controlled initial conditions. These comparisons revealed broad consistency in global evolutionary trends, but highlighted discrepancies in binary interaction rates and merger outcomes—emphasizing the need for standardized test cases and open data sharing. Participants also discussed integrating stellar-evolution modules (e.g., MESA, SEVN) directly into dynamical frameworks to ensure self-consistency between internal stellar physics and external dynamical interactions.

Looking ahead, the community is moving toward reproducible, data-driven simulations that can be validated against real cluster observations and gravitational-wave catalogs. Many groups stressed the importance of open-source development and common interfaces for simulation outputs to facilitate collaboration across the diverse computational landscape.

Challenges and Future Directions

Despite rapid progress, several challenges remain.

- **Initial conditions:** The primordial structure, binary fraction, and metallicity distribution of globular clusters are still poorly constrained, making it difficult to connect present-day clusters to their formation environments.
- **Retention efficiencies:** Uncertainties in supernova kicks and fallback physics translate directly into large variations in predicted black-hole and neutron-star populations.
- **Statistical linkage to observations:** Current gravitational-wave catalogs contain only dozens of well-measured events; distinguishing cluster and field contributions will require larger samples and refined selection models.
- **IMBH confirmation:** Robust detection demands simultaneous dynamical, accretion, and possibly gravitational-wave evidence, which may only come with next-generation facilities such as LISA and the ngVLA.

Nevertheless, the tone of the meeting was optimistic. The combined power of precise observations, improved simulations, and data-intensive methods is gradually transforming dense-cluster studies from descriptive to predictive science. Several participants proposed continued collaborative projects under the MODEST framework, emphasizing benchmarking, open data, and multi-messenger coordination.

Conclusion

IAU Symposium 398 demonstrated that dense stellar systems remain fundamental to our understanding of stellar evolution, compact-object physics, and gravitational-wave astrophysics. These clusters serve as both fossils of early star formation **and** ongoing factories of compact binaries**.** The meeting underscored the importance of sustained interaction between observers and theorists, and between electromagnetic and gravitational-wave communities.

As the field moves into the era of routine multi-messenger detections and petascale simulations, the questions raised at IAUS 398—How do clusters retain black holes? Do IMBHs exist? What fraction of mergers arise dynamically?—will shape the next decade of research. The discussions in Seoul established a roadmap for answering these questions through coordinated global effort, ensuring that dense stellar systems continue to illuminate the origins of compact objects and the evolution of the gravitational-wave universe.

The SOC and LOC gratefully acknowledge the National Science Challenge Support & Network (NSCN), the Astronomy Research Center of Seoul National University, and the Korean Astronomical Society for their generous financial and logistical support of IAU Symposium 398. For this symposium, the IAU Division G (Stars and Stellar Physics) and Division D (High Energy Phenomena and Fundamental Physics) served as the coordinating divisions, with additional kind support from Division H (Interstellar Matter and Local Universe) and Division J (Galaxies and Cosmology). Finally, we express our sincere appreciation to the International Astronomical Union (IAU) for approving the symposium and providing travel support for participants.