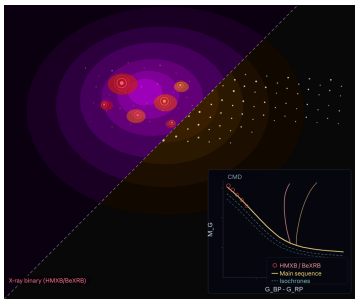
From Star Birth to X-ray Binaries: Mapping the Magellanic Clouds with Gaia DR4



SUMMARY.
The Small Magellanic Cloud (SMC) is a disrupted dwarf disk galaxy actively being tidally stripped by the Milky Way and the LMC, producing extended structures — the Magellanic Bridge, Wing, and Stream — that overlap with the SMC main body on the sky but are kinematically distinct. The forthcoming Gaia DR4 catalogue will provide precise photometry and proper motions for millions of SMC stars, enabling a detailed map of its three-dimensional structure and kinematic substructure. Depending on the student's interests, the project can be extended to investigate the connection between SMC, star-formation history, and the population of High-Mass X-ray Binaries — linking the disruption history of the galaxy to the formation of its most extreme stellar systems.

— OBJECTIVES

- **Knowledge:** galaxy structure and tidal interactions, stellar evolution, star formation history, proper motions, the Magellanic System; optionally: X-ray binary populations
- **Skills:** Python, color-magnitude diagram (CMD) analysis, proper motion measurements, machine-learning clustering, probabilistic population classification

— INSTITUTE

- Department of Physics, National and Kapodistrian University of Athens (NKUA)
- Dr. G. Vasilopoulos, Prof. D. Hatzidimitriou

— THEORY

by G. V. & D. H.

The SMC is a disrupted dwarf disk galaxy at ∼60 kpc with an exceptionally large line-of-sight depth of ∼20 kpc [1], so stars at very different distances are projected onto the same sky region. Combined with distinct kinematic components — the SMC disk, Bridge, and tidal Wing — this produces broadened and blurred features in the CMD [2] that cannot be decomposed from photometry alone. *Gaia* proper motions [3] are key to separating these populations, as structures overlapping on the sky remain kinematically distinguishable. A natural extension concerns the SMC population of HMXBs and BeXRBs, which trace recent star formation [4] and may preferentially associated with specific kinematic components, connecting the galaxy's disruption history to the formation of its most extreme stellar systems.

— APPLICATIONS

by G. V. & D. H.

***Gaia* structure and kinematics.** Using *Gaia* DR4 photometry and proper motions the student will: (a) map the SMC line-of-sight depth using CMD morphology across its full extent, accounting for reddening and population mixing; (b) identify kinematically distinct populations by combining proper motions with CMD position; (c) apply unsupervised machine-learning (e.g. GMM, HDBSCAN) in the 4D space of sky position and proper motion (μ_α, μ_δ) to assign probabilistic membership to the SMC disk or tidal structures.

HMXBs and star-formation history. Cross-matching kinematic maps with SMC HMXB/BeXRB catalogues [4,5] to test whether X-ray binary surface density correlates with recent star formation in specific kinematic components. All analysis in Python with reproducible, well-documented code.

— MAIN PROGRESSION STEPS

- `Tier 1`: Stellar evolution, galaxy structure & tidal interactions; introduction to *Gaia* data products and the Magellanic System; CMD, proper motion and clustering exercises; line-of-sight depth mapping and 4D kinematic analysis
- `Tier 2` *(optional)*: Cross-matching with HMXB/BeXRB catalogues; SFH comparison per kinematic component; statistical analysis of the HMXB–SFH association
- `Other`: We also offer the opportunity to participate in the *Gaia* Doctoral Network workshop (Athens, January 2027) for advanced training and networking with the European *Gaia* community

— EVALUATION

- `Theory grade [20%]`
  Exercises based on lectures (50%), journal club article presentation (50%)
- `Practice grade [40%]`
  Project: clarity of code, understanding of context, written report, presentation skills
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

— BIBLIOGRAPHY & RESOURCES

- [1] Ripepi, V. et al. 2017, MNRAS, 472, 808
- [2] Dhanush, S. R. et al. 2025 ApJ, 980, 73
- [3] Zivick, P. et al. 2018, ApJ, 864, 55
- [4] Antoniou, V., Zezas, A., Hatzidimitriou, D., & Kalogera, V. 2010, ApJL, 716, L140
- [5] Haberl, F. & Sturm, R. 2016, A&A, 586, A81
- [6] Gaia Collaboration, Prusti, T., et al. 2016, A&A, 595, A1

— CONTACT

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