PhD project in ASTROPHYSICS

Title of the Project:

A combined optical-HI study of nearby dwarf galaxies in the LCDM hierarchical merging framework with ELT and SKA precursors

INAF-OAS Supervisor: Francesca Annibali

Co-Supervisors: C. Gruppioni, M. Meneghetti, E. Vanzella

Scientific Case:

Although **dwarf galaxies** are pivotal systems in the history of the Universe, many questions related to their evolution and mass assembling in a Lambda CDM hierarchical merging paradigm remain still poorly understood. Indeed, while studies of merging/accretion phenomena onto dwarf hosts have received little attention observationally so far (mostly because of the difficulty in detecting very faint satellites or merger signatures around them), such processes cannot be ignored, as interactions and accretions can strongly affect dwarf galaxies' morphology and kinematics, triggering the inflow of gas and the possible onset of starbursts.

In order to provide new insights on this problem, we propose a Ph.D. project based on a unique sample of ~50 nearby (D<10 Mpc) dwarf galaxies for which a highly valuable dataset in optical and HI is available: i) Proprietary deep, wide-field **Large Binocular Telescope** (LBT) **imaging** from the "SSH" Strategic Program (45 hrs, PI Annibali); ii) Proprietary **Hubble Space Telescope data** for a subsample of the SSH dwarfs with merging signatures (HST Cycle 30, 38 orbits, PI Annibali); iii) Both proprietary (PI Cannon) and archival **HI data** from different facilities (Very Large Array, Giant Metrewave Radio Telescope, Westerbork Synthesis Radio Telescope).

While the deep, wide-field LBT data and HI data will permit to unveil signatures of accretion or merging events around the dwarfs (e.g. through peculiar gas/stellar features or streams, and/or morphological/kinematical distortions), the superb depth and spatial resolution of HST will allow to infer the galaxies' star formation history (SFH) through modeling of their resolved-star color magnitude diagrams. In the end, the galaxies' optical and HI morphologies, the stellar and gas masses, the HI kinematics, and the spatially-resolved SFH will provide all the ingredients necessary to run tailored hydrodynamical N-body simulations of merging gas-rich dwarfs.
This project will pave the way for future, deeper studies of more distant merging dwarfs with **JWST, ELT and SKA.** In particular, while JWST will permit to resolve individual stars at much fainter magnitudes than HST, thus reaching larger distances for SFH studies, the extreme resolving power of **MORFEO/MICADO@ELT** will permit to study individual stars in the most central and crowded galaxy regions well beyond 20 Mpc, an achievement out of reach of HST and JWST. As well, future SKA observations will enable to map gas accretion features down to much fainter surface brightness limits that possible with the current instrumentation.

During the Ph.D project, it is expected that candidate will apply for new observations of dwarf galaxies with JWST and with existing AO instrumentation, such as SOUL-LUCI@LBT or ERIS@VLT. Furthermore, part of the project will be devoted to the development and analysis of simulations of resolved stellar populations in dense regions of dwarf galaxies with MORFEO/MICADO@ELT, within the activities that the MORFEO Science Team is currently performing in preparation for the ELT science exploitation under the coordination of the proposed PhD supervisor, who is the MORFEO Science Team Project Scientist.

Outline of the Project:

YEAR 1: analysis of the LBT and HST data, with particular focus on resolved star color-magnitude diagrams (CMDs). Lead of proposals (JWST, HST, LBT, VLT) for new observations. Participation to at least 2 refereed papers. Participation to the activities of the MORFEO@ELT science team and involvement into preparatory work for future resolved stellar population studies.

YEAR 2: analysis of the LBT/HST CMDs for the SSH dwarf galaxies (plus new data from successful proposals), derivation of their star formation histories, derivation of associated streams/satellites' properties. Publication of at least 1 paper as first author. Participation to MORFEO@ELT science team activities, simulations of resolved-star science cases.

YEAR 3: finalization of the results in the context of galaxy formation, evolution, and hierarchical merging buildup, also taking into account new results from the collaboration on HI data and N-body hydrodynamical simulations. Publication of at least 1 paper as first author. Participation to MORFEO@ELT science team activities, contribution to updated MORFEO white paper.

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PhD project in ASTROPHYSICS

Title of the Project | High-resolution radio and optical synergy: a jump in Fundamental Physics with millisecond pulsars in globular clusters

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Main Collaborators: Livia Origlia (INAF-OAS), Alessandro Della Croce (INAF-OAS), Francesco R. Ferraro (UNIBO), Cristina Pallanca (UNIBO), Mario Cadelano (UNIBO), Paulo Freire (Max Planck Institute – Germany), Scott Ransom (NRAO – USA)

Scientific Case | Globular clusters (GCs) are compact and dense aggregates of up to a million of stars held together by their mutual gravitational attraction in a nearly spherical configuration. They are collisional systems where the frequent two- and three-body interactions can promote the formation of peculiar stellar populations, as millisecond pulsars (MSPs), i.e., binary systems where a neutron star is spun up by mass accretion from its companion star. GCs are remarkably efficient factories of MSPs. In fact, the number of MSPs per unit mass in the Galactic GC population is some 10^3 times larger than in the Galactic field. In addition, GCs host other exciting binary systems that cannot be found in the Galactic field, as binaries made of two MSPs, or a pulsar bound to a black hole, the holy grails of compact object astrophysics.

Outline of the Project | The unprecedented power of the MeerKAT radio telescope for the identification of new MSPs is now setting a new era in GC pulsar science. In fact, with 66 new pulsars already cataloged, MeerKAT is the leading contributor to the surge in the GC pulsar population, which increased by >60% in the last 3 years and promises to triple its number in the near future.
In this framework, the main goal of the proposed project is to fully capitalize the radio-band scientific outcome by providing a systematic characterization at optical/NIR wavelengths of the MSPs recently discovered by MeerKAT (and of those expected from upcoming observations), by exploiting the high-spatial resolution and accurate photometry enabled by proprietary and archival JWST and HST observations of dense GC cores (where MSPs are concentrated due to dynamical friction).

In the first place, the optical identification of the companion stars to MSPs will bring key information on the nature, the physical parameters, the evolutionary processes and the recycling mechanisms occurring in these systems.
Secondly, the full characterization of binary MSPs will enable a wealth of groundbreaking scientific applications, such as testing general relativity and alternative theories of gravity, studying stellar and binary evolution, modeling the expected detection rate of low-frequency gravitational waves, and constraining the equation of state of matter at the nuclear equilibrium density, thus eventually opening a new window in the domain of Fundamental Physics research.
Finally, the use of radio and optical/NIR observations, together with state-of-the-art simulations, will link the current properties of the MSP population to the internal dynamical status of the host cluster, thus clarifying the role that the most massive objects/binaries play in the evolution of GCs, and, vice versa, the role that internal dynamical processes play in the evolutionary path of these objects.

Such a project will definitely set the stage of our understanding of the population of MSPs currently reachable with the available radio and high-resolution facilities. In turn, this will allow the selection of the most urgent and promising targets for the next generation of telescopes (like, ELT and SKA).