Il Colle di Galileo

# A broadband excursus through stellar afterlife

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**Abstract.** The workshop drew experts from the Supernova Remnants, Pulsars and Pulsar Wind Nebulae communities, both from a multi-wavelengths observational point of view and a theoretical perspective. Recent developments in these fields were discussed, with broader coverage of the related physical processes (such as acceleration and propagation of particles, relevance of the sources for Galactic Cosmic Rays). Particular attention was also devoted to statistical methods in astrophysics. The workshop also provided an opportunity to celebrate the career of Rino Bandiera who successfully dedicated most of his career to the aforementioned matters and retired this year.

**Keywords:** neutron stars, pulsars, supernova remnants, statistical methods, non-thermal emission, acceleration of particles.

## Summary of the workshop

To mark Rino Bandiera's retirement, the high energy group of the Arcetri Observatory organized a short workshop that recalled some of the leading experts in the field of supernova remnants and pulsars, both in the theoretical and observational multi-frequency fields, topics to which Rino Bandiera successfully devoted much of his scientific career. The workshop took place at "Villa Il Gioiello", Galileo's last residence, kindly made available by Florence University, and hosted 25 participants. This event was funded by INAF through the "Contributo per l'organizzazione di scuole e congressi" and the RSN4 mini grant HYPNOTIC87A (PI B. Olmi).

After graduating in Physics from Scuola Normale Superiore, under the supervision of Prof. Claudio Chiuderi, and spending a few years abroad, Rino Bandiera joined the staff at the Arcetri Observatory, which was under the direction of Franco Pacini at the time. Rino has since been a part of the High Energy Astrophysical Group. He has worked on several different subjects over the years, from theory to observations, from Supernova Remnants and Pulsar Wind Nebulae to Galactic Dynamics, with a penchant for analytical and statistical approaches, mostly devoted to the properties of non-thermal emission.


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Figure 1. Group photo in the Villa's garden.

The congress did not have an exclusively celebratory purpose however, but provided an opportunity to discuss recent developments in the field and refresh long-standing collaborations, both at national level, within the INAF community, and at international level.

The main topics discussed in the workshop were all connected to the remnants of very massive stars which also happen to be among the most energetic sources observed in our Galaxy: supernova remnants and pulsar wind nebulae. The discussion focused on both theoretical and observational aspects: these celestial objects are among the most powerful accelerators in our Galaxy and are able to accelerate particles up to an impressive energy of $10^{15}$ electronvolts (=PeV). However, the acceleration processes at work are not completely understood yet and researchers are struggling to find the best way to understand them. Several steps forward have been made recently in identifying the regions where the acceleration is taking place and new insights are coming from gamma-ray observations about the way particles escape from the sources. A key ingredient that drives the acceleration is provided by the magnetic field, the structure of which can be now more precisely constrained using new polarimetric data from the IXPE satellite, a NASA mission that has a strong INAF participation, and numerical MHD simulations: the combination of these two different pieces of information continues to be a big challenge.

Several works on Supernovas and their remnants were presented, starting from the GalRSG project, an INAF-VST program recently approved to detect transients and variability related to the very late evolutionary stage of massive stars that could be the progenitors of the SN explosion. A detailed discussion focused on the multiwavelength analysis of SNRs, a powerful tool that uses the entire electromagnetic spectrum, including Balmer emission, and allows the constraint of the different non-thermal components of these objects, providing information on the acceleration efficiency of SNR shocks.


Figure 2. The Arcetri high energy group

Compact objects like pulsars are connected to some of the most significant discoveries in modern astronomy. An impressive result concerns gravitational waves: pulsars represent the most precise clocks in the Universe and can now be used to detect the small time delays produced by faint gravitational waves emitted by supermassive black holes: very promising preliminary results of this research have been presented. A further exciting idea is linked to Fast Radio Bursts (FRB), an obscure phenomenon that produces short and powerful bursts in the radio waveband; they seem to be connected to the pulsar and PWN activity.

In addition to the sources, much attention was devoted to the propagation of particles accelerated in those objects that escape and spread through the Galaxy, so-called cosmic rays. The process that allows them to escape is not yet clear but it seems to be closely connected to the kinetic instabilities that these particles are able to excite in the plasma around the sources, slowing down the speed of their escape. The existence of such a process is strongly suggested by peculiar features around PWNe observed either in gamma or X-rays. Finally, a special session was dedicated to statistical methods in astrophysics.