INAF (Italian National Institute for Astrophysics)

The Strategic Vision for Astronomy in Italy 2014-2023

Cover figure: The Prawn Nebula from the VST (ESO courtesy)

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Preface

Astronomy is the oldest science in the world. It started with the astronomical observations in China and Babylon thousands of years ago and continued through the centuries with Aristarcos and Tolomeus in Greece and Copernicus and Galileo in Europe. It was in Italy with Galileo Galilei in 1609 that the science we call Astronomy started. For the first time Galileo revealed that the white stripe in the sky called Milky Way was made of stars. Since then, Astronomy has developed enourmosly until the present time. In particular, in the last years our vision of the nearby and far Universe has incredibly improved. We know that our Universe was born 13,7 Gyr ago, starting with the *Big Bang*, that it is accelerating in its expansion and that will continue forever pushed by an obscure force called *dark energy*. We also know that the majority of matter in the Universe is *dark* and not made of baryons (proton and neutrons) which compose the ordinary matter. The Italian National Institute for Astrophysics was born to foster and coordinate the scientific research in Astronomy and Astrophysics in Italy. In particular, the strategic objectives of INAF can be summarized as follows:

- To promote and coordinate the italian scientific research in the field of Astrophysics by pursuing results of excellence at an international level.
- To provide researchers with the necessary observational infrastructures from remote(telescopes from the ground and space missions) operating at all wavelenghts and space monitors in situ as well as to facilitate access to international facilities. To ensure the necessary computing facilities, scientific documentation, national and international mobility that are vital to establish and maintain collaborations to national and international projects and to disseminate the scientific results.
- To concur, together with international organizations operating in the field of Astrophysics, to define the strategic objectives of modern Astrophysics and therefore the choice, the plan and the building of the large research infrastructures necessary to reach such objectives.
- To promote new technologies to power observational infrastructures and space instrumentation, involving national industries and working in strict relation with them, favoring the participation and competitiveness of the Italian industry.
- To collaborate to the formation of new researchers by participating to the university master courses in Astronomy and Astrophysics and the supervision of master and PhD theses.
- To support and fund the researches for the projects concerning innovative and fundamental Astrophysics where INAF teams have succeeded in gaining a worldwide leadership in several primary astronomical fields.

- To develop outreach programmes to communicate the knowledge and the astronomical discoveries, to contribute to the orientation of young people towards scientific and technological studies, thus promoting public scientific knowledge.

Chapter 2

Scientific challenges in the 21th century: science questions for the next decade

2.1 Our parent star: the Sun

The next 10 years will be important for the solution of some still open questions in the physics of the interior and atmosphere of the Sun:

- Which mechanisms drive the quasi-periodic 11-year cycle of solar activity?
- Why is the solar corona so hot (million degrees)?
- What accelerates the solar wind, coronal mass ejections and other phenomena influencing the interplanetary space and the Earth's environment?

The current space missions (Hinode, Stereo, SDO) and the main high-resolution ground-based telescopes (SST, DST, VTT, BBSO) devoted to observe the Sun collect data on the plasma-magnetic field interaction at different layers of the solar atmosphere to understand the physics of solar cycles and the transient phenomena occurring in the solar atmosphere. Particular attention is dedicated to solar eruptions (flares, jets and coronal mass ejections or CMEs), which are also powerful accelerators of particle beams, which can reach near-relativistic velocities, influence the Earth and other planets, endanger space crew and cause damage to space instruments. For these reasons, it has become apparent that understanding of the space environment must be given high priority (Space weather). In the next years, the scientific community will develop several projects in order to understand the physical processes at the base of the solar variability and, in particular, at the base of the reconfiguration of magnetic fields and release of free magnetic energy stored in the solar corona. In this context, it is scheduled in 2017 the launch of the Solar Orbiter, dedicated to the study of the structure of the Suns magnetic field especially by observing it from above the poles; other space missions like SOLAR-C and Solar Probe Plus are also scheduled, with launch in 2018. On the side of ground-based activities, the main european project under development is the European Solar Telescope (EST). The main science questions which EST will address with its high spatial resolution and accurate polarimetry are the formation and disappearance of kGauss flux concentrations in the photosphere, the characteristics of the quiet Sun internetwork fields, the magnetic topology of the photosphere and chromosphere and the energy dissipation in chromosphere.

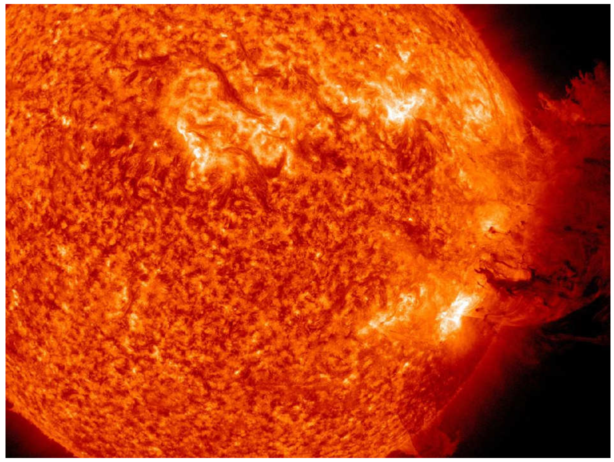

Figure 2.1: Solar eruption observed on June 7, 2013 by the Solar Dynamic Observatory Courtesy of NASA/SDO and the AIA,EVE, and HMI science teams.

2.2 The planetary systems of the Sun and other stars

Planets

Many questions are still open about the planets of our Solar System. How were the planetary systems formed? Did the planets formed in the position where they are now? Were they different in the past? If yes, how? What has been their evolution? There is some form of life on some of the planets or on some their moons? Even if some information about planets is provided by ground-based observations, a more complete knowledge comes from space missions, to provide full pictures of the phenomena as well as peculiarities of a single planet and its moons. Expectations are coming, for instance, from the newly planned missions to Mars (Exomars), to Mercury (BepiColombo), to Jupiter and its small system of moons (Juno and JUICE). What are the peculiarities of Mercury, the densest planet of the Solar System, and what are the gravitational effects induced by our star? What peculiarities will came out from in situ detailed investigations of the Martian surface? How does the huge Jupiters magnetosphere work? What electromagnetic links exist between the planet and its moons? What about the observed auroras? How much water is present in the Jupiters atmosphere? How is the interior of the planet? Does it have a core? Moreover, do conditions exist that may have led to the emergence of habitable environments among the Jovian icy satellites, the three ocean-bearing worlds, Ganymede, Europa, and Callisto? What diversity of processes in the Jupiter system may be required in order to provide a stable environments at Ganymede, Europa and Callisto on geologic time scales? Juno and JUICE are aimed to answer these questions focusing on observing both Jupiter and the activity on the Galileian satellites. The better is the knowledge of our Solar System, the better understanding we can have of the exoplanets that, recently, almost daily are discovered. The diversity in our solar system is enormous and the comprehension of those new exotic worlds necessary passes through what we know about our neighbour planets.

Small bodies

Huge developments are expected in the next years in the field of the studies of the small bodies of the Solar System (asteroids, comets, trans-Neptunian objects, etc.). This will be the effect of two space missions, like Rosetta and DAWN currently active, and ground-based activities. The rendez-vous of Rosetta with comet 67P/Churyumov-Gerasimenko is expected in mid-2014, and will mark the understanding of the origin and evolution of these objects. This will be followed, in 2015, by the arrival of DAWN to Ceres. The exploration of this dwarf planet will follow the previous DAWN exploration of Vesta, providing also information on the thermal evolution

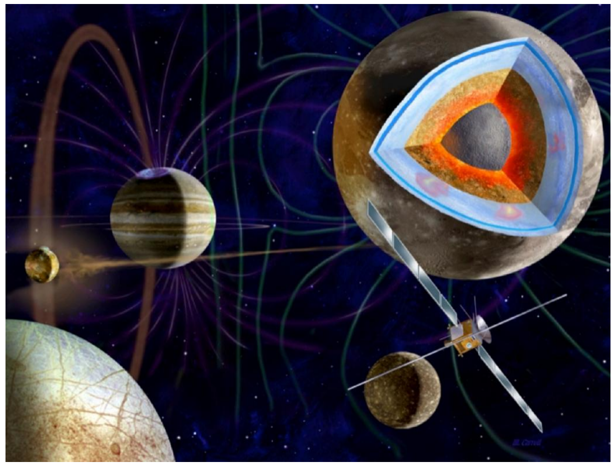

Figure 2.2: Artistic view of JUICE with Jupiter and its Galilean moons.@ESA

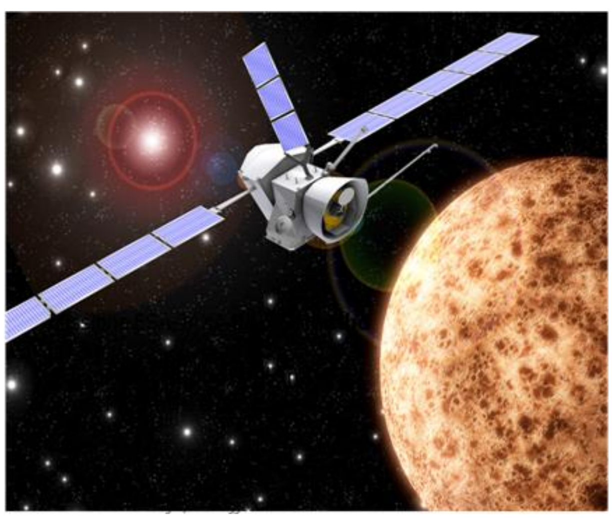

Figure 2.3: Mission ESA-JAXA BepiColombo to planet Mercury. To be launched in mid-2016.

of the asteroids. Gaia, launched in 2013, will produce for the first time accurate masses and bulk densities for about 100 main belt asteroids, and spin properties (rotation period, spin axis orientation), reflectance spectra from blue to red wavelengths, and taxonomic classifications for about 100,000 asteroids. Ground-based activities will bring new discoveries of so-called main belt comets, asteroids found to exhibit some transient cometary activity. Ground-based activities will accomplish the ESA Space Situational Awareness program, aimed at studying potentially dangerous near-Earth objects (NEOs). They include spectroscopic and polarimetric monitoring, as well as studies of links between NEOs and dynamical asteroid families in the main belt.

Sun-Solar System bodies interaction

The study of the interactions between a solid body and its environment is fundamental for determining realistic scenarios for the evolutionary history of the body itself and the bodies strongly linked to it. In the case of Solar System bodies, the Sun plays the major role for providing energy and material to them. The investigation of such interactions has been the subject of the last-decades planetary missions (e.g.: MEX, VEX, Cassini) and will be the major driver of the forthcoming ones (e.g.: Juno, BepiColombo, JUICE). In particular, the fundamental questions to be answered are: Which are the major active processes in the different scenarios like presence of external or internal magnetic field, thick gas envelope (atmosphere), different surface material, energy and mass balance? How has the effectiveness of these processes evolved from the time of Solar System formation? How has the body evolution been influenced by the action of the Sun? Which is the role of the Sun in the Mars atmospheric loss? Are solar wind and/or radiative energy responsible of water escape? How does the solar wind directly interact with the Venus dense atmosphere? Which is the role of the Sun in the surface/upper crust erosion at Mercury? Is the Moon a Mercury-like body, more distant from the Sun and protected by Earths magnetosphere? Which is the role of Sun radiation in the surface release processes at Jupiters moons? How much do the asteroids preserve their primordial characteristic in the continuous space weathering action due to solar wind and to Sun irradiation along their motion in the Solar System? Major role in the interaction with the solar wind is played by the planetary shielding where an internal magnetic field is present. Which are the diverse time scales, spatial scales, effectiveness of the processes characterizing the interaction of the solar wind plasma with the various planetary magnetospheres like Earth, Mercury, Jupiter and Saturn?

Exoplanets

The study of exo-planets (planets around stars other than our Sun) is a fast-growing and extremely hot field of astrophysics, since it deals with the ultimate question of the existence of life outside our Solar System. The answer comes from the study of the formation of planetary systems, the search for Earth analogues and ultimately for planets able to host life. Drawing from solar system planetary studies, exo-planetary science covers three broad themes: 1) Detections: understanding the census and architecture of planetary systems. 2) Characterization of the internal structure: mass and radius and comparing them to structure models. 3) Characterization of the exo-planet atmospheres: effective temperature, composition, and presence of possible bio-signatures in their atmospheres. An exo-planet can be discovered because of the attenuation of its host star's light during transit; by measuring the Döppler effect from the perturbation of the radial velocity of its host star, by micro-lensing gravitational effect, by timing, by direct imaging and many others. Thanks to those several different investigation techniques the discovery rate is now approaching the number of one exo-planet per day.

In the next decade the exoplanet community will fully exploit the new generation of instruments of TNG (HARPS-N, GIANO) and VLT (SPHERE, ESPRESSO) from the ground, as well as the approved GAIA, CHEOPS and TESS missions from space.

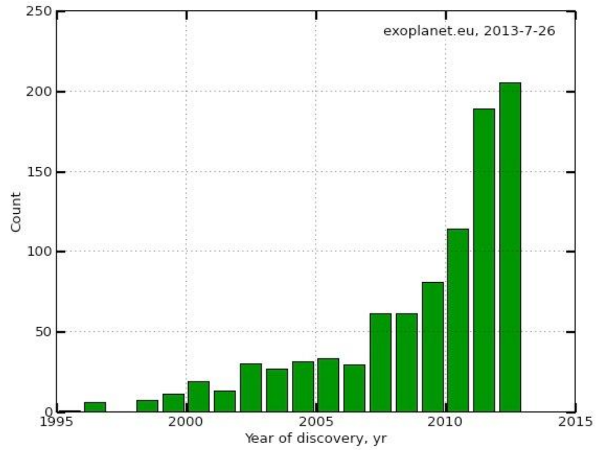

Figure 2.4: Number of discovered exo-planets per year.

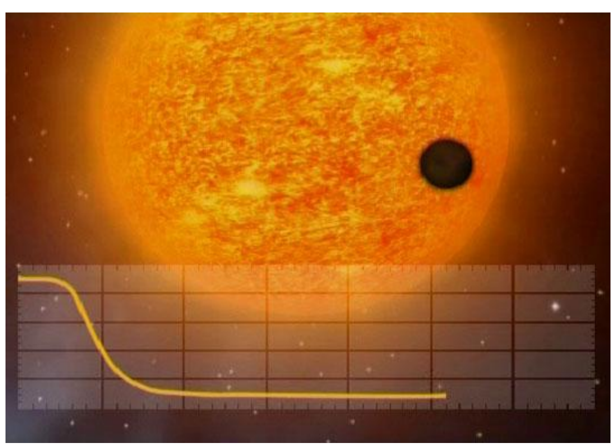

Figure 2.5: Detection of a transiting world (artist's rendition).

2.3 The building blocks of the Universe: the stars

Stars mainly drive the evolution of the baryons across the history of the Universe and represent our probes to unveil the history of the matter from cosmological distances, where the formation of early stellar structures took place, to the Sun neighbourhoods, where a number of extrasolar planetary systems have been discovered. Therefore, a solid framework explaining how stars form and evolve is mandatory. In this context the stellar evolution and pulsation models provide a number of detailed tracks in a full range of masses and chemical compositions. Nevertheless, several processes capable of changing the evolution and the final fate of the stars are not yet fully included in standard models; for example, rotations, shear-mixing, presence of dust in the external layers of the atmospheres, internal gravity waves, and magnetic fields are still open issues that will take advantage of the upcoming hydrodynamical models. On top of it, the overall vision of this matter needs to consider that the traditional scenario, where solar, stellar and extragalactic Astronomy are treated as separated issues, is fading swiftly. As a consequence, interdisciplinarity will rule the research in stellar Astronomy in the next decade.

On the other hand, in the next years the results of the Gaia mission will deeply change our view of the Galaxy and will represent a leap forward in our understanding on the formation, evolution and dynamics of stars in the Milky Way. These findings will represent the base for any theory of galaxy formation and the cornerstone to lead the cosmic distance scale to calibration uncertainties much lower than a few percent. Furthermore, the incoming decade will have the goal of preparing the astronomical community for the next generation of ground and space observational facilities, like E-ELT, JWST, SKA, LSST at the maximum level of their extreme technical performances.

The scientific challenge involving stars will tackle fundamental questions that should be included in the most relevant lines of research of the next years. What are the physical mechanisms driving the formation of stars of different mass? What are the effects of the environment? Is the Initial Mass Function universal? Is the star formation rate (SFR) following the same law in galaxies at different ages and redshift? How precisely do we know the size of nearby and remote objects in the Universe? What is the number of uncertainties of Cepheids and other stellar distance indicators in measuring distances through the extragalactic distance scale? How does the expected light curve of supernovae type Ia depend on their progenitors? What do we really know about the stellar progenitors exploding as supernovae Ia? How accurately do we interpret the increasing zoo of supernovae explosions? How precise are our predictions on the nucleosynthesis of the elements in supernovaeand in Asymptotic Giant Branch (AGB) stars?

It is also extremely compelling that multiple populations have been found in most galactic globular clusters (GGC), an issue which fully revolutionized the idea that stars harboring in these simple stellar systems were formed by one single episode of star formation. How and when were these multiple populations formed? Who and how (AGB, fast rotating massive, binaries?) produced the gas needed to form second generation stars? What are the consequences of this completely new view on our understanding of the stellar systems outside the Galaxy?

Moreover, we still need a clear view of the first stars (if any) shining in the epoch of reionisation and thus on the population III stars. How did the first stars and galaxies form and evolve? What is the interaction between stars, radiation, gas and dust in a normally evolving galaxy? Stars associated in faint and ultra-faint dwarf galaxies have been discovered in the Local Group. Are these structures a relic of a hierarchical formation process of more massive galaxies like the Milky Way? What do we know about the dark matter content of these galaxies having high M/L ratios? Could such dark matter be proved by the new generation of Cerenkov telescopes? Can we understand more on the earliest phases of formation of the Galaxy by studying the stellar population in these galaxies?

A further element of investigation on stellar Astronomy, expected to be extremely fruitful in

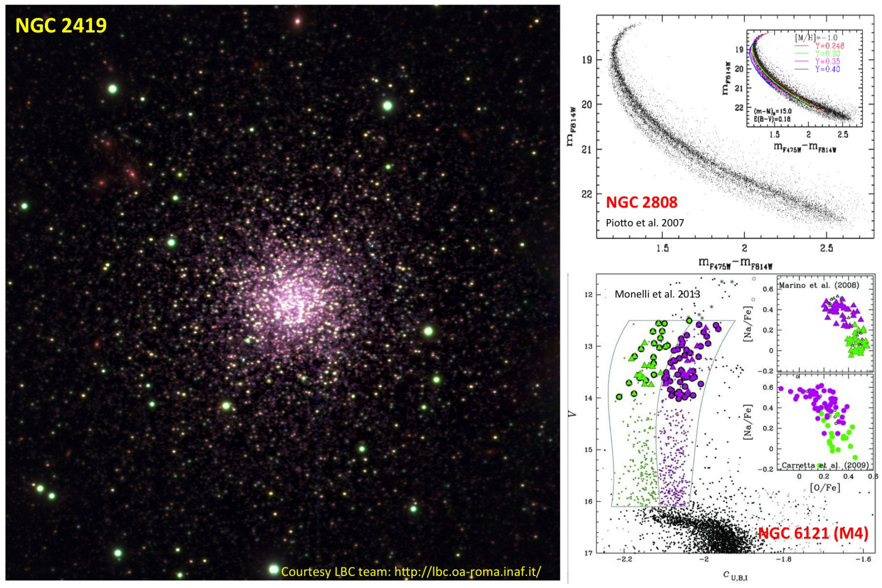

Figure 2.6: Photometric and spectroscopic observations, mainly obtained by italian astronomers (Piotto et al. 2007 ApJ 661,L53; Monelli et al. 2013, MNRAS 43, 2126;Carretta et al. 2009 A&A 508, 695; Marino et al. 2008 A&A 490, 625) demonstrate the presence of multiple stellar populations in some galactic globular clusters.

the next decade, is the huge mapping of the sky by large Surveys (e.g. SDSS, VST, PanSTARRS, LSST) and space missions (e.g. Euclid) following the Gaia mission. New fundamental hints on the real structure of the Galaxy and on the substructures deployed in the halo will be possibly observed thanks to the overwhelming statistics foreseen by such large surveys.

2.4 History of the formation and evolution of the Milky Way and nearby galaxies

Tracing the history of the formation and evolution of galaxies is a fundamental step to understand the evolution of the Universe. The chemical and dynamical evolution of galaxies is traced by the chemical abundances and kinematics in resolved stellar populations. The best laboratory where to start this kind of analysis is our own Galaxy and Local Group galaxies. In the near future, new and important results concerning distances, radial velocities, chemical abundances for millions of stars are expected from ongoing and planned large surveys (RAVE, OGLE, APOGEE, HERMES, GES, LAMOST) from present and future telescopes (VISTA, VST, ALMA, Gaia, JWST and E-ELT). The study of local galaxies allows us to perform an astroarchaeological approach leading to the first evolutionary phases of galaxies and Universe, and therefore to impose important constraints on the whole evolutionary history of galaxies, and therefore also on the first stars, early galaxy formation and reionization. The most important goals are:

- to understand the Milky Way and its stellar components: halo, bulge, thick-disk, thin-disk. This can be done by means of high resolution abundances compared to detailed chemical and dynamical evolutionary models. From this comparison one will be able to answer the following questions: i) how did the stellar halo of the Milky Way form? Were its stars accreted or formed in situ? ii) which is the origin of globular clusters? How can

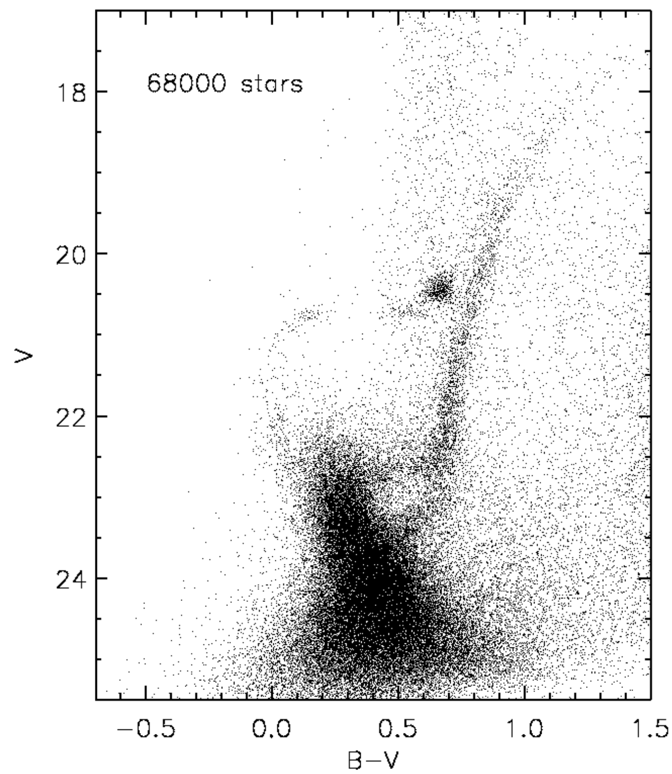

Figure 2.7: Example of Colour-Magnitude diagram of a Local Group dwarf spheroidal, Carina. Figure and data from Monelli et al. (2003, Astron. J. 126).

we explain the multiple stellar populations found in some of them? iii) how was the initial mass function of the first stars? Have they survived up to now? iv) how did the bulge form? Did a galactic wind develop in the bulge thanks to supernova and AGN feedback? v) how did the thick disk form? vi) did the thin-disk form by accretion of cold gas and inside-out? vii) how did the abundance gradients in the thin-disk form and evolve in time? viii) which is the role of gas flows, galactic fountains and stellar migration in the evolution of the thin-disk? ix) which is the dark matter distribution within a few kpc from the Galactic disk?

- to understand the formation and evolution of Local Group galaxies. In connection to the formation of the Milky Way, great attention will be devoted to the formation and evolution of the Local Group galaxies including spirals, dwarf spheroidals and dwarf irregulars. According to the cosmological paradigm, giant galaxies were assembled in a hierarchical process involving dwarf objects. Then the main question is: were the dwarf spheroidals or other dwarfs (e.g. ultra faint dwarfs or dwarf irregulars) the building blocks of the Milky Way?

From an observational point of view, Color- Magnitude diagrams of Local Group galaxies will be acquired and analysed with the aim of deriving their histories of star formation. Deep photometry and high resolution spectroscopy from HST, LBT and VLT, including the largest spectroscopic survey ever approved by ESO (the Gaia-ESO Spectroscopic Survey) will serve to study the stars in the Milky Way disk and open clusters, in Galactic globular clusters and in the Local Group galaxies.

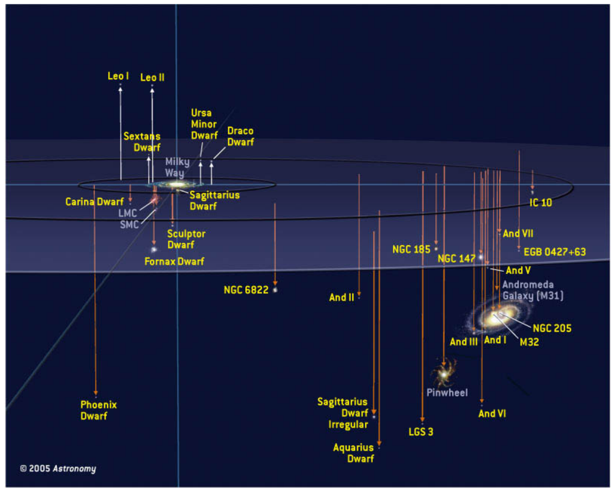

Figure 2.8: The Milky Way and the galaxies of the Local Group.Time Travel Research Center 2005 Cetin BAL - GSM:+90 05366063183 - Turkey/Denizli

For the future it is very important to study the chemical evolution of the Milky Way and Local Group galaxies by means of data analysis as well as detailed models including stellar nucleosynthesis and dynamics, and the derivation of the histories of star formation from the Color-Magnitude diagrams of local galaxies and coupled with the abundance analysis of their stars.

2.5 Formation and evolution of galaxies and cosmic structures

The study of the formation and evolution of galaxies and the way these are assembled in cosmic structures is one of the most active and rapidly evolving fields in astrophysics. The matter in the Universe is not homogeneously distributed in space, but is organized into a cosmic web of filaments that intersect to form groups and clusters of galaxies. Galaxies are the first self-gravitating structures formed in the Universe where gas falling into the dark matter potential wells started to condense into stars. The physical mechanisms that have driven the evolution of these complex systems are yet to be fully understood. Soon after the Big Bang, matter and energy were largely, but not fully uniformly distributed in space. According to the current cosmological paradigm, the tiny density fluctuations in the primordial Universe have amplified due to gravity to form the highly structured Universe we observe today.

This field of research has a pivotal role in modern cosmology and requires a concerted effort of observations, theory and simulations. The study of galaxies and cosmic structures, from the earliest phases of the Universe till today, is one of the main scientific drivers of major ground and space observational facilities that will become available in the next decade, such as E-ELT, JWST, SKA and Euclid.

Galaxies are the location where stars form and evolve, and are the beacons that allow us to explore the Universe over cosmological times. When and how did the first stars form? When and how was the Universe reionized? How do stars form and evolve in different galaxies? Planet Earth and the many life forms that we know are mostly composed of heavy atomic elements that were formed through nuclear reactions by stars in galaxies. What is the chemical enrichment history of the Universe? How does it depend on galaxy type and mass?

Galaxies are extremely complex systems and gravity is just one of the many physical processes that determine the diversity of galaxy properties. Understanding the origin of the diversity of galaxy shapes, masses and stellar histories is one of the great challenges of the coming years.

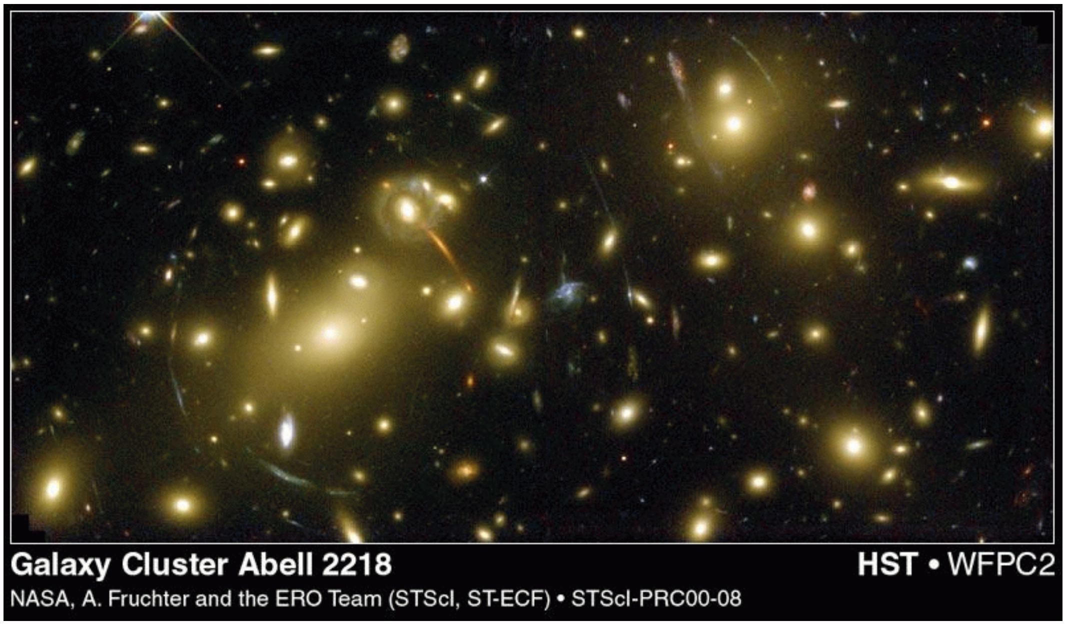

Figure 2.9: Hubble Space Telescope image of the cluster of galaxies A2218.

What is the origin of the Hubble sequence? What mechanisms lead to the formation of elliptical galaxies, and spheroids in general, and how do they differ from galaxies with a dominant disk component, dominating in earlier cosmic times? How important and effective is the environment on the galaxy formation mechanisms? Many of these questions require large sky surveys to be addressed, as we have learned from the SDSS, to compare to more sophisticated cosmological simulations possibly including the physics of the gas assembly, chemistry and feedback mechanisms.

One of the most daunting questions in astrophysics, and one which we may expect to have more insight in the next decade, is the relation between the dark and luminous components of galaxies. Dark matter around galaxies can be investigated using the gravitational lensing or other mass probes (planetary nebulae, globular clusters, X-rays). The nature of dark matter and its role in shaping cosmic structures will be one of the greatest challenges of the coming years. Is the dark matter really Cold? Or is it Warm? In case the Dark Matter particle remains elusive, is Dark Matter really the only viable explanation of the equilibrium of the cosmic structures?

The great technological advances of the last years have allowed to observe galaxies at early epochs, at high redshifts. The upcoming astronomical facilities of the next decade will allow to push the frontier of the exploration of the Universe even further in space and time, to unprecedented distances and young ages, and directly observe the very first phases of galaxy infancy. Answers to fundamental question will thus be within reach: how were the first building blocks of galaxies assembled? How did star formation and mass assembly proceed at very early epochs? What physical laws governed the beginning of structure formation?

Higher resolution mapping of galaxies with the new generation of instruments will be crucial to study galaxies on all scales, in particular their central regions. Great advances are to be expected in the next decade to clarify the characteristics of active galactic nuclei and their influence on galaxy evolution. Why is the mass of the central supermassive black hole tightly related to the spheroidal component of galaxies? What are the effects of an active galactic nucleus on the evolution of its host galaxy? For what galaxies and when were they relevant?

Going to the largest gravitationally bound structures in the Universe, galaxy clusters, they can be a powerful tool to test the cosmological model and the theories of structure formation.

Galaxy properties vary with their location, but how and why exactly a galaxy environment affects its evolution is still largely unknown. As clusters and groups of galaxies will be found and better characterized in the coming years in larger numbers and at larger distances, we will be able to use them to underpin both the galaxy dependence on environment and, in conjunction with other cosmological probes, to measure with great accuracy the parameters and the laws governing our Universe and the formation of structures within it.

2.6 Geometry of the Universe

Modern cosmology can be summarized in a set of wide key topics: understanding the early stages of the Universe, its global geometry and evolution; addressing the nature and properties of its constituents, of both discovered and fully unknown particles; linking cosmology to fundamental physics, including theories of gravity. Astronomers aim to both mapping and understanding the late stages of the Universe evolution, with its rich astrophysical phenomenology, and the early stages of structure formation including cosmological reionization and the first stars. Key in this quest is a precise determination of all cosmological parameters in standard and non-standard scenarios.

The comprehension of the nature of dark matter (DM) and dark energy (DE) represent two of the most profound topics that the scientific community is going to address in the coming decade. Their nature will be investigated by quantifying the impact they have on the large scale structure on the cosmic microwave background (CMB) and on the cross-correlation signal with the Large Scale Structure (LSS), by measuring their physical properties over cosmic time. These topics can shed light on the following questions: what is DM and what is DE? are they interacting? do we understand gravity at the largest scales? can we probe fundamental physics with cosmological observations (neutrino masses, violation of fundamental laws of physics etc.) All these topics have a strong multi-disciplinary character since direct searches for DM and other particles are also currently performed by physics experiments. Moreover, they require multi-wavelength approaches in order to detect the signatures of such particles with higher statistical significance and without systematic biases.

The CMB shedding light on ther dark side of the Universe

We are approaching the almost definitive legacy in the mapping of CMB anisotropy and the next decade will be dedicated to precisely extract all the cosmological information they contain. In contrast, the mapping of the CMB polarization anisotropy is still in an early stage and the discovery of CMB spectrum distortions at its infancy. If the detection of primordial B-mode polarization is the smoking gun of inflation, allowing to precisely fix its energy scale, a wide set of inflationary and early Universe models can be constrained or discarded by studies in both CMB polarization and non-Gaussianity. The CMB spectrum will open a new window on inflation through its sensitivity to power spectrum at extremely small scales, dissipated by photon diffusion and then masked in anisotropies, on particle decays/annihilation and atomic properties at recombination and post-recombination epochs. The precise mapping of foregrounds, i.e. all the astrophysical emissions, of Galactic and extragalactic origin, in front of CMB signal and the continuous improvement of data analysis methods for their accurate separation are crucial, unavoidable steps of this research.

The large scale structure of the Universe

Our Universe at large scales is rich in cosmic structures as galaxies, clusters of galaxies, intergalactic medium filaments of the cosmic web: these are all tracers of the underlying gravitational field and probe a variety of environments and epochs. Investigation of the LSS is done by comparing simulations of cosmological volumes performed with super computers to multi-wavelength data of different observables like weak and strong gravitational lensing, statistical distribution analysis of the objects (clustering and high order moments), observations of spectra of quasars to

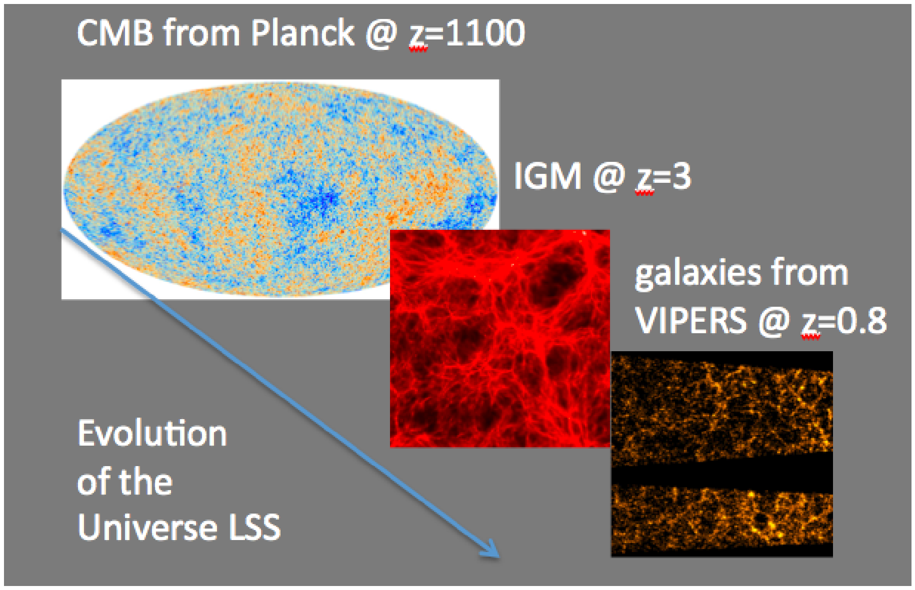

Figure 2.10: The evolution of large scale structure in the Universe.

probe intervening matter along the line-of-sight. Progress can be expected in: i) a comprehensive characterization of the physical and chemical properties of the most massive virialized structures of the Universe, clusters of galaxies, with particular emphasis on their redshift evolution and on the implications for galaxy formation and cosmology, by using multi-wavelength data sets; ii) the investigation of the formation of the first structures in the high redshift Universe (in particular physical and chemical properties of first stars and their impact on cosmic backgrounds); iii) hydrogen reionization and the modelling of neutral hydrogen inside and outside virialized objects in order to forecast its detectability with future instruments; iv) formation and evolution of super-massive black holes at high redshift Universe and characterization of their environment.

The cosmic cycle of baryons

The interplay between luminous and dark matter will be investigated also in terms of its astrophysical implications for galaxy formation models. While the census of baryons amounts to the total cosmic (CMB probed) value at high redshift, at more recent epochs it appears that there is a deficit of baryons: these can be in the elusive so-called Warm-Hot Intergalactic Medium. The gas in such phase can be observed in the X-ray (absorption and emission) but the observations made are not definitive. This gas also retains imprints of the interplay with galaxies in the form of feedback (thermal and mechanic) that affects its chemical and physical properties. In the coming years progress can be expected in investigating the galaxy/intergalactic medium (IGM) interplay and the Intracluster Medium (ICM) in clusters of galaxies. The main questions that the community is trying to answer are: where are the baryons in the low redshift Universe? To what extent are the properties of the ICM, IGM and Circum Galactic Medium influenced by feedback? Can we trace the physical and chemical properties of baryons from high to low-redshift?

2.7 High energy Astrophysics

The high-energy astrophysics is the kingdom of extreme behaviours in many different environments. From the Sun to the most massive black-holes these environments allow astronomers to probe extreme physical conditions where typically X-ray, gamma-rays and high-energy particles are copiously emitted. The fundamental physics diagnostics offered by these processes is impressive and still to be fully explored. Black-holes from the stellar size to billion of solar masses objects lying at the center of massive galaxies are typical objects of study. Several fundamental questions are expected to be solved in a decade or so. How do black-holes form and grow? Compact objects are fundamental ingredients of some of the most spectacular astrophysical sources as X-ray binaries, Gamma-Ray Bursts and Active Galactic Nuclei. How is energy extracted from these objects to power their radiation output? This is still a topic of intense debate. Matter accretion still lacks a detailed understanding. Can the same laws simply be scaled up from star binaries to galaxy scale black-holes?

Jets are ubiquitous phenomena related to matter accretion on compact objects of any size. How are jets collimated and powered? How do they interact with the surrounding environment? Compact object internal structure is still largely unknown. What is the correct equation of state of neutron stars? Pulsars and magnetars are different aspects of magnetized rotating neutron stars. What is powering their emission? In the next decade observational techniques related to very high energies will reach a maturity and also polarization studies will become routinely possible. Many classes of high-energy sources are known to emit high-energy photons and particles. What emission processes are responsible for these emissions? Can the origin of ultra high-energy cosmic rays be finally clarified? The standard model is tested at the highest energies reachable by the most advanced ground-based laboratories. Will cosmic-rays allow the astronomers to push these tests at energies virtually never accessible by Earth laboratories?

The high-energy range is where non-classical effects are expected to become important. Families of alternatives to standard general relativity will be tested and constrained. Is the speed of light affected by space time structure at high energy? Future observational facilities will allow the study of regions very close to compact objects opening unprecedented possibilities to explore strong-gravity regimes. Are quantum effects present and at which scale do they become important? Will we directly observe the space-time distortion near the event horizon of black-holes? Event horizon existence will finally be unequivocally proved?

An entire new research scenario is provided by the so-called transient Universe. Many still unknown transient objects, often at high-energies, are expected to be discovered and classified in the next decade. For those already known many open questions will be addressed. How and which stars will end their evolution as Gamma-ray Bursts and Supernovae? Which is the connection between these two phenomena? Large scale surveys will also characterize the next decade allowing astronomers to develop a less biased census of the various classes of astrophysical sources. What is the true population of compact objects in a typical Galactic environment? Finally, substantial advancements are expected by the availability of high-power super-computers together with improved numerical analysis techniques. In this context fundamental questions about the structure and energetic composition of relativistic flows will be addressed. How does particle acceleration in (ultra-)relativistic flows occur? Numerical relativity is a promising tool. Do we really understand the neighborhood of rotating black holes?

2.8 New Physics and multi-messenger Astronomy

A revolution in science is expected for the next decade, when innovative facilities in the context of the new or advanced physics will be fully operational. Neutrino detectors will become efficient enough to be able to perform observations of astrophysical sources routinely, and gravitational wave (GW) detectors are expected to observe for the first time gravitational waves, confirming a fundamental pillar of modern physics, the theory of general relativity. Technological advancements of the detectors are bringing this so-called non-electromagnetic Astronomy to maturity, and make it possible to start a multi-messenger Astronomy, in which progress in research is obtained using all vehicles of physical information (electromagnetic waves, neutrinos

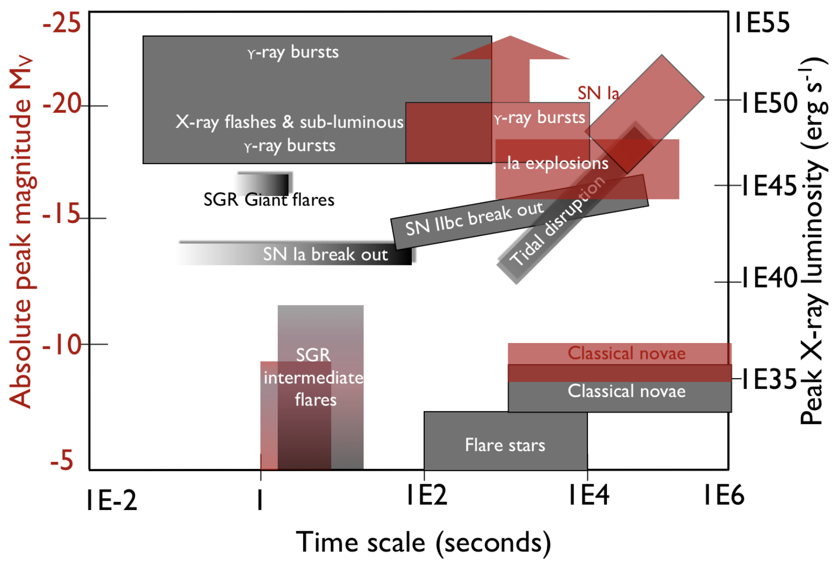

Figure 2.11: The discovery space for the transient Universe (Jonker et al., 2013,arXiv:1306.2336).

and gravitational waves) and can potentially open an entirely new window into the Universe. "Multi-messenger studies will require to develop stimulating synergies between different scientific communities: astrophysicists, GW and particle physicists. The upcoming opportunity of a complete knowledge of astrophysical phenomena through the different messengers is one of the most striking and promising achievements of modern Astronomy. The most fundamental questions to answer through the different messengers will be: are we able to detect gravitational waves? Are we ready to set up multi-messenger observations and to perform joint analyses and interpretations? Are gravitational waves and neutrinos emitted as expected from theory and from indirect observations? Gravitational waves and high-energy neutrinos (HEN) are messengers that are able to escape very dense media and travel unaffected over cosmological distances, opening the possibility to study the very inner parts of astrophysical sources that are essentially unreachable by electromagnetic observations. One of the most promising astrophysical sources of gravitational waves are binary coalescing systems of compact objects (neutron stars, NS, and/or black holes, BH), the core collapse of massive stars and single rotating asymmetric NSs. Electromagnetically, the first two are believed to power the most energetic explosions in the Universe: the short Gamma Ray Bursts and the supernovae. The latter are the inner engines of pulsars, among the most extreme objects in the Galaxy. Joint multi-messenger studies of NS and BH offer a unique opportunity to infer for example the connection between short GRB and NS-NS and NS-BH mergers, to study the birth and evolution of the BHs, and to test the validity of physical laws under extreme conditions of gravity and electromagnetic fields. Furthermore, anytime a new observational window is open, unexpected discoveries have always been the rule. Fundamental questions are: Which astrophysical systems are the more effective GW sources? Are there exotic sources? What is the fraction of energy emitted in gravitational wave, electromagnetic and neutrino? For all classes of GW and HEN sources, the gravitational wave and neutrino detections will allow us to derive accurate population rates to be compared with those based on electromagnetic messengers and theoretical studies. What is the true rate of short GRBs, SN or any GW source? And how can it be compared to the rates based on electromagnetic observations and population synthesis models? In particular, to organize the search and detection of the electromagnetic counterparts of multi-messenger observations represents an enormous challenge for INAF and for all the international astronomical community. The large sky positional uncertainties of the GW and HEN signals, the short timescales of the phenomena and the low apparent brightness of the gravitational GW and HEN sources in some electromagnetic bands require large field of view facilities with an extremely short reaction time and deep sensitivity. Furthermore, the identification of a unique electromagnetic counterpart requires a deep knowledge of the transient background (astrophysical transients in the space-time search region not directly associated with the gravitational signal). Thus, further key questions are: Do we have the technological capabilities to catch the elusive electromagnetic counterpart of transient gravitational signals? What is the current knowledge of the transient sky and how can we improve this knowledge? Are there telescopes and satellites with the capabilities to continuously monitor radio, X-ray, gamma pulsars and ensure precision timing?

INAF is operating telescopes and instruments (VST, LBT, SRT, TNG, REM etc) capable of playing a key role and it is a top level institute in the development and realization of focused technological projects. Moreover, INAF and italian researchers have both the observational know-how to optimize the identification of the candidate counterparts and their characterization and the deep expertise in theoretical models needed to optimize the observational and interpretative strategies. Thus, INAF enjoy a prominent position in taking up this amazing challenge and building up a new bridge between the time domain Astronomy and the new physics carried by multi-messenger.

Chapter 3

Research in technology

Modern Astronomy can be done only with powerful instruments demanding for a high technology. Moreover, the development of technologies for astronomy in Italy is a science by itself, with researchers active in many interdisciplinary fields having applications in Astronomy, sometimes not even related to the development of a specific instrument, as it is the case for computer science applications (e.g. the Virtual Observatory effort), for atmospheric turbulence characterization studies and so on.

In addition, the development of new technologies with applications to instruments need parallel Research and Development (R&D) efforts and time. The major achievements are impossible in instrument projects with tight schedules where only mature technologies will be adopted, but need budget and time for preparatory R&D work. Specific activities should be funded, in order to sustain applied technology research besides the limits imposed by the technology readiness level required by most of the infrastructural projects, where even small performance degradations or delays are not an option. In this way, the astronomical technology work will continue to be a mix of applied research with development of more and more advanced instruments.

The technological innovation potential of INAF should be maintained and possibly improved working in close cooperation with national industry, also through public-private initiatives favoured by the European Community and the Italian government, like the participation to large technological districts (e.g. INAF is already partner in several regional aerospace and micro-technologies districts, in collaboration with universities, research organizations, small-medium and large enterprises).

3.1 Cutting edge technology

A good example of close cooperation between INAF researchers and industry is the adaptive optics field, where Italy has reached a leading role. Nowadays, Italian industries are worldwide leaders in the production of large adaptive optics mirrors for most of the large and extremely large telescopes of today and tomorrow. Furthermore, the multi-conjugate adaptive optics module MAORY, designed for the most advanced telescope of the future E-ELT, has an Italian leadership. Last but not least, the pyramid wavefront sensor has been invented in Italy. These results have been obtained after a long period of applied research in technology. The full scientific exploitation of these long time research activities is still to come, with the construction or completion of facilities adopting this technology, nevertheless it has already produced a significant return for the Italian industry. Adopting the Horizon 2020 terminology, the adaptive optics is a typical show-case of how the research in INAF, although of course it is knowledge driven (i.e. devoted to the progress of knowledge), it is indeed also technology driven (i.e. close to technological aspects with social and economic impacts).

Also, there are many other cutting-edge fields where Italian researchers are at the forefront: the active optics, with complete systems already delivered by INAF researchers in close cooperation with precision opto-mechanical Italian industries; the production of mirrors with innovative technologies, proposed for the future CTA (ASTRI project); the control systems and control engineering for telescopes and instruments, already implemented and delivered in many international projects; the development of payloads for space environment, with bidirectional transfer of know-how with Italian industry; the developments of detectors and associated electronics for different wavelengths and applications; the development of advanced cryogenic systems, both for use on earth, and in space; the development of dust particle impact sensors, born in space environment but with possible applications on Earth.

3.2 Interdisciplinary technology

The forefront technological research in INAF is cross-correlated with other research disciplines. Here are a few significant examples.

- The gamma-ray detectors developed for CTA inherit the experience of gamma-ray detectors for HESS, Magic, Veritas (mainly from INFN).

-The techniques developed for TES (Transition Edge Superconductors) for X-ray spectroscopy microcalorimeters (Athena space mission) and for bolometers for CMB research (Planck, OLIMPO, PRISM etc.) present significant synergies and offer opportunities of important cross-disciplinary collaborations.

In the same way, detectors technologies developed for particle physics can be used for high energy astrophysics: see the LOFT space mission proposal where the large area Silicon drift detectors (SDDs) are derived from the detectors developed for particle tracking in the Inner Tracking System of the ALICE experiment at the Large Hadron Collider at CERN.

- Interdisciplinary use of accelerometers in Bepi Colombo and gratings developed in collaboration with INFN is another example of how INAF is well using the most advanced technological developments.

- The development of novel sensors to detect neutral particle escape (thanks to the cooperation with CNR -ISC and -IFN) allows INAF to promote new technologies for interdisciplinary use in the frame of the interaction of particle radiation with various materials.

- Techniques developed to cool detectors at cryogenic temperatures are useful for radio-receivers, mm-wave detectors, IR detectors, X-ray microcalorimeters. The need to operate these systems remotely has produced control techniques useful for applications on remote sites on the Earth (Antarctica), on stratospheric balloons, and on satellites.

As the research in technology is intrinsically very interdisciplinary, the technical cooperation with other key players in national and international research should be favoured and strengthened.

3.3 Technology transfer

INAF cooperates with Italian industries in technological programmes, both for the realization of infrastructures and for the development of cutting-edge technologies. Italian industries have reached leadership positions in several fields applied to ground-based Astronomy, for example. adaptive optics, telescope enclosures, precision opto-mechanics for telescopes and instruments.

Furthermore, INAF is regularly partner in industrial projects financed by the Italian government, transferring to the industry technologies that are successfully adopted in environments even rather different from the astronomical research, helping to create new occupation (e.g. one program was about the monitoring of fissile material smuggling in marine ports).

This is an increasing trend in the relationship between governments and research world, which INAF has the potential to exploit through its technological component.

Chapter 4

Infrastructures

The astronomical research infrastructures are the large facilities used by the scientific community to conduct top-level research. Today, the Italian astronomers can access major ground-based infrastructures that will remain into operations also in the next decade, in many cases with updates coming from second or third generation instruments. This will be the case, for example, of the European Souther Observatory (ESO) observatories hosting the VLT, the most advanced optical telescope in the world, recently complemented with the two survey telescopes VISTA for the infrared and VST for the visible bands (Fig. 4.1), and for the ALMA radiotelescopes array, the largest in existence. These ESO infrastructures have been built with significant INAF contributions in international consortia for instrumentation development, or in particular cases (e.g. VST) they have been totally realized in Italy.

Other remarkable ground-based facilities for Italian astronomers in the next decade will continue to be the LBT and TNG with their new instruments, and the recently completed Sardinia Radio Telescope (SRT) which will join the existing Italian radiotelescopes. From space, the missions producing data in the next decade will be the ones that have already been launched or are already at a very advanced development stage. Talking about the future major infrastructures, unavoidably a plan of a single country must take into account the European and world strategies. The high level of competition pushes towards large investments that are affordable only through international collaborations and/or the collaboration of intergovernmental organizations like the ESO and the European Space Agency (ESA). This strategy overcomes the limits of national policies, providing Europe with research infrastructures competitive worldwide. In fact, the next largest astronomical facilities will be unique in Europe or even in the world, because of their cost for construction and operations. Therefore, the choice of these facilities needs to be accurate and based on the scientific goals and on the synergies between them, and the overall plan shall be agreed between many European (or global) partners. A coordination effort not limited to Astronomy was implemented through the creation of ESFRI (European Strategy Forum on Research Infrastructures), whose mission is to support a strategic approach to research infrastructures in Europe. The ESFRI roadmap was issued in 2008 and afterwards has been periodically updated.

4.1 Ground-based large projects

In the ground-based domain, among the large projects identified as the highest priorities for the future of European research by the Astronet Infrastructure Roadmap, INAF has identified four projects, supporting them so far in their preliminary study phases. The European Extremely Large Telescope (E-ELT) is a planned ground-based extremely large telescope for the optical/near-infrared range, to be built by the European Southern Observatory on a mountain top in Cerro Armazones, Chile (Fig. 4.2). The design comprises a reflecting telescope with a

Figure 4.1: Paranal observatory, today the most productive astronomical observatory worldwide.

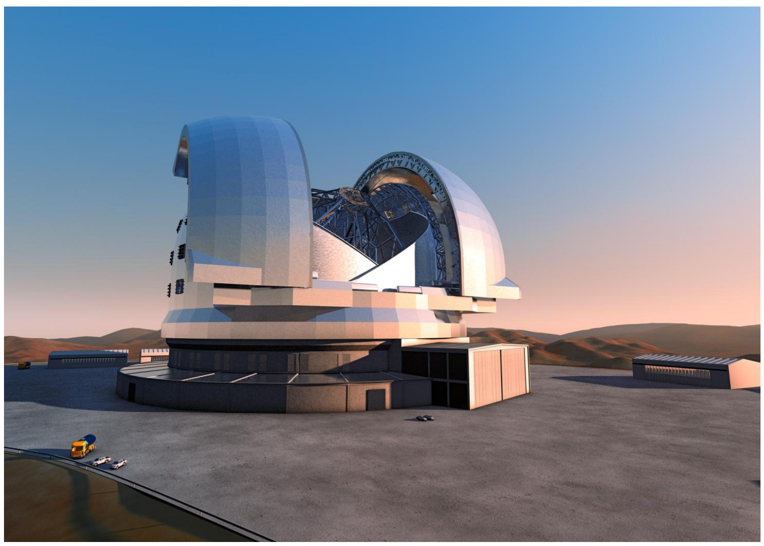

Figure 4.2: The European Extremely Large Telescope (artist's view)

Figure 4.3: The Square Kilometre Array (artist's view)

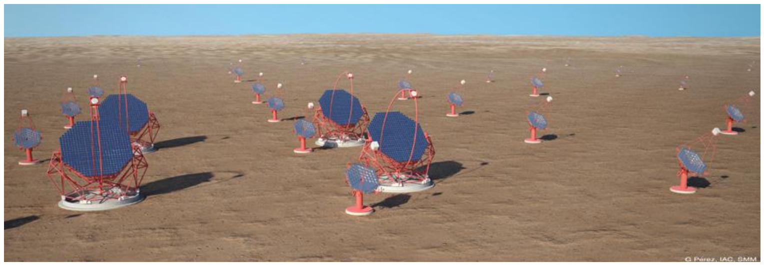

Figure 4.4: The Cherenkov Telescope Array (artist's view)

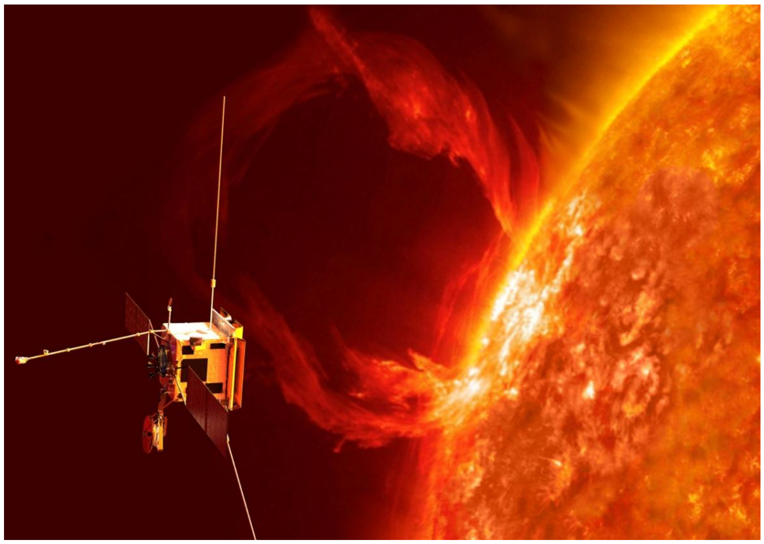

Figure 4.5: The Solar Orbiter mission (artist's view)

39.3 metre diameter primary mirror, a 4.2 m diameter secondary mirror, and will be supported by adaptive optics and multiple instruments, whose development plan has already been prepared and prioritized by ESO. The E-ELT will allow Europe to maintain in the next decades the current world leadership in ground-based optical telescopes. Italy is an ESO member state and has already guaranteed its financial support to the project through INAF. The Square Kilometre Array (SKA) will be the largest and world's most sensitive radio telescope . Thousands of linked radio wave receptors will be located in Australia and in Southern Africa (see Fig. 4.3). Combining the signals from the antennas in each region will create a telescope with a collecting area equivalent to a dish with an area of about one square kilometre. The Square Kilometre Array is a global science and engineering project led by the SKA Organisation, a not-for-profit company with the Italian participation through INAF. An array of dish receptors will extend into eight African countries from a central core region in the Karoo desert of South Africa. A further array of mid frequency aperture arrays will also be built in the Karoo. A smaller array of dish receptors and an array of low frequency aperture arrays will be located in the Murchison Radio-Astronomy Observatory in Western Australia. On a smaller scale with respect to E-ELT and SKA, the Cherenkov Telescope Array (CTA) will be an array of many tens of telescopes, designed in order to allow the detection of gamma-ray induced cascades over a large area on the ground. In a possible design scenario, the CTA (Fig. 4.4) will consist of three types of telescopes with different mirror sizes in order to cover the full energy range: 24 metre-class telescopes for the low energy range; telescopes of the 10-12 metre class for the medium energy range, and a large number of small (4-6 metre diameter) telescopes for high energy instruments. INAF is active in the CTA pathfinders development through the Italian ASTRI project and will be

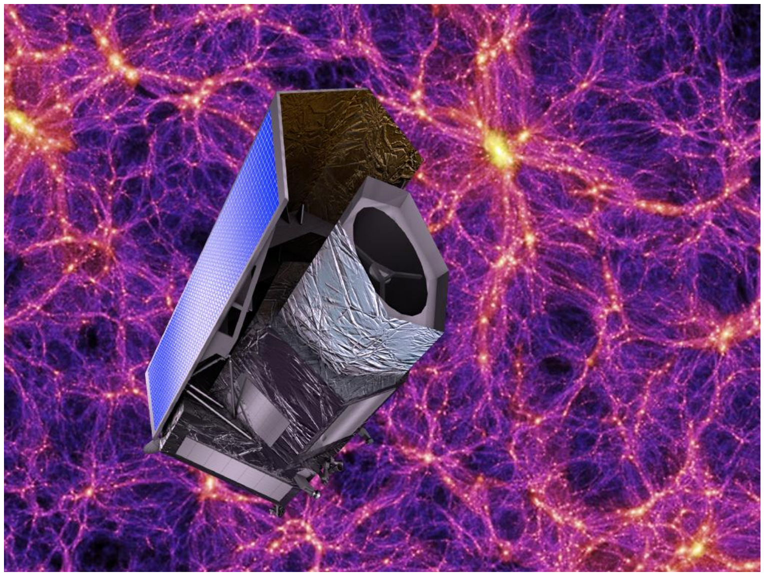

Figure 4.6: The Euclid mission (artist's view)

partner of the legal entity which is going to be created to manage this program.

The European Solar Telescope (EST) is a 4-m class telescope to be installed at the Canary Islands, four times larger than any existing solar telescope; Italian universities and INAF have participated to the international consortium that provided the preliminary study of the instrument.

4.2 Space missions

The development of scientific space missions in Europe is summarized in the ESA strategic plan, i.e. the Cosmic Vision 2015-2025 consisting of a number of Science Questions to be addressed in the next decade by the future space missions. Other space missions belonging to previous programmes are almost ready and will be launched in the very next years. INAF researchers have an active role in all the ESA scientific missions approved so far, both in the technological developments of payloads and in the scientific groups for the exploitation of data. Within the large missions, the JUICE planetary mission to Jupiter and its icy moons has been selected for the first L-Class launch slot in 2022. The mission concept is based on multiple flybys of Galilean Moons prior to entering into orbit around Ganymede; a payload suite of 11 instruments (including cameras, spectrometers, radars, etc.) will provide new insight into the Jovian system. Within the medium missions, Solar Orbiter (Fig. 4.5) has been chosen as the M1 mission for launch in 2017 and Euclid (Fig. 4.6) as the M2 mission for launch in 2020. Solar Orbiter is a mission going close to the Sun, that will perform near sun in-situ measurements, using instruments to measure the solar wind, energetic particles, magnetic fields and radio and plasma waves, producing also high-resolution images and spectra of the Sun and its environment. Euclid aims at studying the geometry and the nature of the dark Universe with unprecedented accuracy. The Euclid payload consists of a single 1.2 m diameter telescope and two focal plane instruments, i.e. a visible imager (VIS) and a near-IR photo-spectrometer (NISP). An additional development has been the release of the first Announcement of Opportunity for small missions; the mission CHEOPS (CHaracterising ExOPlanets Satellite) was selected for a launch in 2017, and is being studied as an ESA/Swiss-led S1 mission (Fig. 4.7). Besides the Cosmic Vision missions, other key space facilities with INAF contributions are going to be launched in the next years. Among them, BepiColombo is the planetary cornerstone of the ESA Horizon 2020

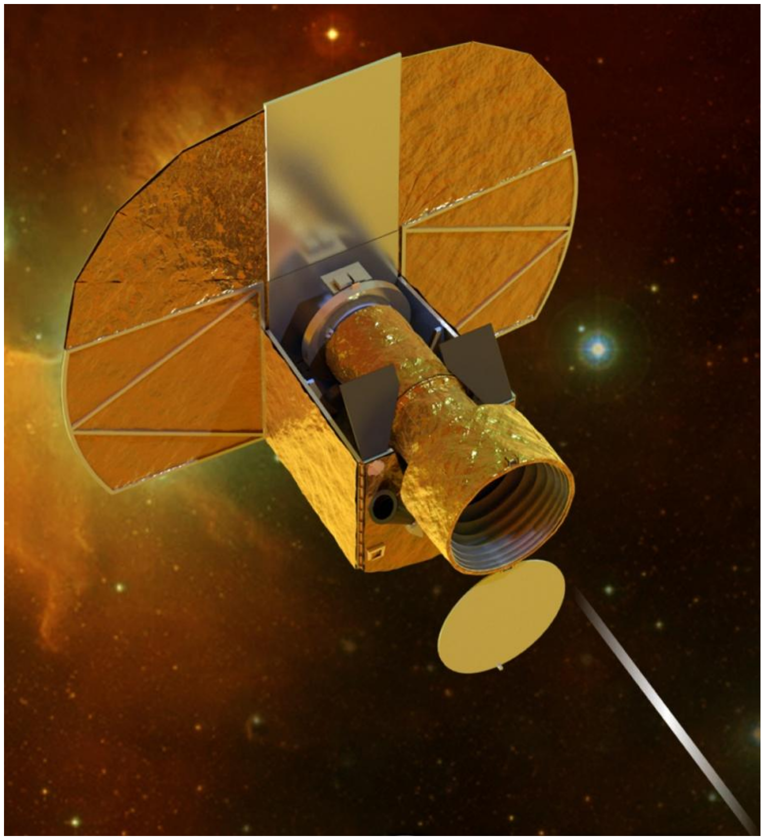

Figure 4.7: The CHEOPS satellite (artist's view)

programme, a mission that will provide the best understanding of the planet Mercury to date; its launch is scheduled for 2016. This mission is a cooperation between ESA and JAXA. and includes two satellites. Over the 11 instruments on board the ESA satellite (MPO - Mercury Planetary Orbiter), 4 of them are leaded by INAF and INAF-associated scientists. The ExoMars programme is going to investigate the Martian environment, articulated in two missions: one consisting of an Orbiter plus an Entry, Descent and Landing Demonstrator Module, to be launched in 2016, and the other, featuring a rover, with a launch date of 2018.

Chapter 5

Human resources

In the next decade INAF will be involved in most of the major worldwide astronomical projects. Unavoidably, the future success of the INAF research in these ambitious programs will highly depend on the excellence, motivation and numerical consistency of its personnel. It is obviously essential to make sure that a career in INAF can be both accessible and attractive for brilliant researchers, offering at the same time recruitment opportunities and possibilities for career advancements. With this in mind, an illuminating perspective is obtained by retrospectively looking at the trends of the research personnel opportunities for new recruitments and career advancements in the last 10 years. Applying the same rates of the last 10 years and considering retirements, Fig. 5.1 shows the numerical evolution of INAF permanent staff involved in research and technology, in total and for the three different career levels.

The current situation is characterized by permanent positions allocated almost exclusively at the lowest entry level, plus a high number of non-staff members. In this respect, INAF personnel is by far in the worse situation in Italy, compared to all other Astronomy and Physics research organizations and academic departments, as shown in Fig. 5.2.

Even more alarming is the predicted evolution of the situation. The scarce recruitment level of the last ten years, if maintained in the future, will lead to a drastic reduction of the overall number of research staff members, as well as to the almost total disappearance of the already modest career developments.

Nowadays, the newly recruited permanent staff researchers are at least 35 year old, or older. This means a brilliant young graduate person must overcome more than 10 years of precarious work before becoming a staff member. This might seem acceptable in some other countries, where short term jobs in research organizations have a better salary and the overall labor market is much more flexible. In Italy, however, such a perspective is not attractive at all for the best young students, who in addition would have the depressing prospect of remaining forever at the lowest career level (Fig. 5.1). As a logical consequence, if INAF will not offer realistic possibilities for a sufficient number of new job positions as well as opportunities for career development, the potentially best researchers will migrate towards better job alternatives, or other countries.

It is mandatory to reverse these negative trends, or Italy will run the serious risk of investing in the forthcoming world-class astronomical technological projects without having the capability to benefit of such facilities in terms of scientific return. In order to maintain the top level position Italy has achieved and maintained for many years in Astronomy, a prompt change of direction is imperative. INAF priority shall be to invert the trend of the last years, implementing a dedicated plan for the valorization of human resources employed in research and technology, for the whole career development of brilliant people. INAF is expected to plan and implement a development strategy for its personnel. The Italian Ministry of University and Research (MIUR) is expected to support this strategy, ensuring an adequate funding level and lifting turn-over budgets and number restrictions.

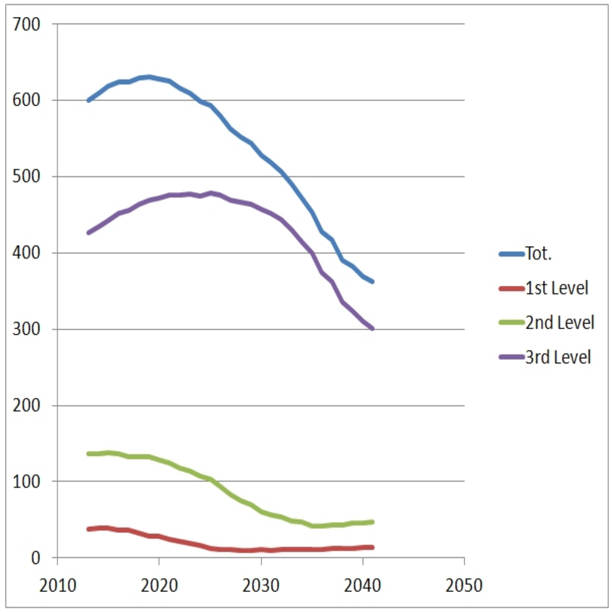

Figure 5.1: Numerical evolution of the research and technology INAF personnel, considering retirements and applying the average rate of recruitments and career developments of the last 10 years (2004-2013). The analysis for the three individual career levels (1st level is the highest) is included.

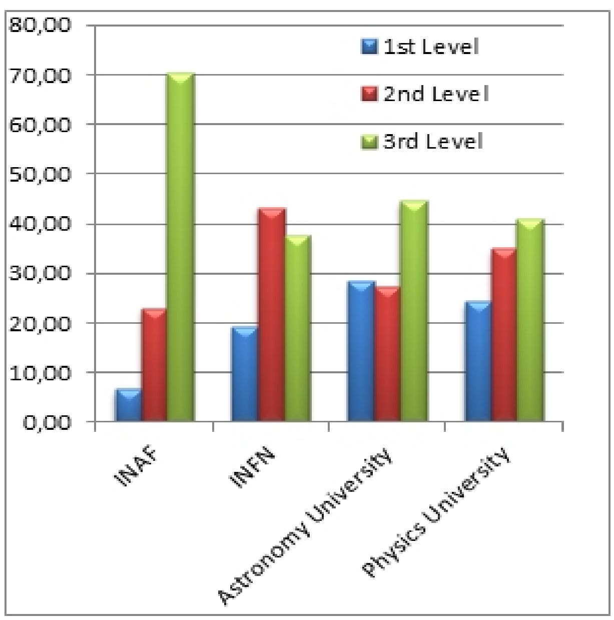

Figure 5.2: Personnel distribution from the highest (1st) to the lowest (3rd) level in Italian Astronomy and Physics main research organizations and University departments.

Chapter 6

Education and outreach

6.1 Education

Concerning education, INAF is strictly linked to Italian Universities with which it has established a long and fruitful collaboration. This occurs by means of a remarkable involvement of INAF scientific staff in teaching astronomical courses for the master degree in Astronomy and Physics at the universities and by tutoring undergraduate, graduate and PhD students. INAF scientific staff is present in the PhDs committees of several universities both for Physics and Astronomy, though only in few cases they have the right to vote, in particular only when there is a specific convention between INAF and the university. The sinergy between INAF and universities should still improve but this will require a better recognition of the equivalence of similar roles in the university and INAF, with the possibility of exchanging these positions (for example an INAF astronomer at the 1st level should be interchangeable with a full professor at the university). This would require a change in the present legislation. It is proven that the scientific production of INAF sections improves when they are physically close to university departments of Physics and Astronomy. This is because the presence of students in research institutes is fundamental for the development of scientific research, and also the contact of students with the national astronomical projects of the future is fundamental for the development of the projects themselves. In conclusion, it is advisable to continue promoting a free and frequent exchange of personnel between universities and research institutes, developing and defining a juridical scenario not only allowing but strongly encouraging this exchange of skills and experience with academic institutions with teaching duties.

6.2 Outreach

There are many cultural drives that make Astronomy an almost perfect outreach subject. It allows an effective scientific communication at any level, from children attracted by the beauty and immensity of the sky to highly cultured people interested in the hot open questions involving frontier physics. Not to mention the historical importance in developing the present world-wide cultural heritage. One of INAF primary duties is to communicate and popularize astrophysical knowledge at any level. In the last decade we have witnessed the progressive development of INAF outreach efforts both in local institutes and in INAF as a whole. These activities involve schools with students of any age, conferences for general and selected public, visits to the still operational observatories, and several other effective outreach activities. At a national level, INAF provides a useful communication service to the community through its MEDIA-INAF, INAF-TV and multi-media services that offer access to the most recent astrophysical discoveries and solid astrionomical documentation to millions of people.

Many INAF institutes have individuals or groups of researchers highly qualified to propose outreach initiatives attractive for the general public at several locations spread throughout the national territory. The relationships with local amateur societies is also of paramount importance for their capabilities to drive scientific messages in the society. Outreach activities should be indeed planned and financed within any scientific project competing for domestic or international financial support.

A specific attention to popular science institutions, as science museums and planetariums, has to be applied and will be further developed in the next decade, with the goal to build an effective network of astrophysical resources for the general public making a profitable use of all the numerous available facilities on the Italian territory.

Within the outreach activities, didactic for primary and secondary school pupils plays a fundamental role at many INAF institutes. Moreover, the Italian Astronomical Society (SaIt), a society formed by professional astronomers and also by school teachers, has a long and valuable tradition of close connections with primary and mainly secondary schools organizing courses, didactic experiments, and specifically targeted publications. Maintaining a strict connections with these institutions is a valuable goal for the next decade. In particular, for the future it is advisable to pursue and also implement the outreach activities of INAF by encouraging the various INAF sections to develop a plan for outreach involving guided visits and regular seminars open to the public.

Chapter 7

Italian contributions to Astronomy: the present and the future

The scientific challenges of the coming decade can find an italian astronomical community fully ready to tackle them. Italian astronomers and astrophysicists are key players in the international scenario. Using any of the most indicative scientific excellence parameters, Italy results among the top countries in the world. Italian Astronomy is fifth in the world (Fig. 7.1) when the scientific impact is measured from the total number of paper citations, and is fourth when considering the elite of the world astronomical production, i.e. the 200 most cited papers in recent years lead by an Italian scientist (see the Document on Evaluation of Italian astronomical productionP: 2010-2012 at http://www.inaf.it/it/sedi/sede-centrale-nuova/consiglio-scientifico /Evaluation%20of%20Italian%20astronomy%20production%20-%20v4.pdf). The trends with time in the last years, however, are negative, mainly for the reasons discussed in Chapter 5.

Finally, another interesting parameter to be considered is the distribution of the global h index h (J.E. Hirsch 2005), which indicates the number of papers and their citations (for example an h index of 20 means that the researcher under consideration has 20 papers quoted more than 20 times) and it is meaningful mainly on a statistical ground. We have analyzed the global h index for astronomers that are members of the INAF scientific staff, by gathering data for a total of 506 investigators from ADS, excluding people mainly involved in Instrumentation who cannot be evaluated by this type of analysis. The distribution of the h index is given in Fig. 7.2. The median value is 25. There are 43 investigators with an h-factor above 50 that is considered excellence according to topitalianscientists.org. We may also compare the average h index of Italian astronomers with the statistics given by Abt (2012)(in Organizations, People

Rank	Country	2001-2003	2004-2006	2007-2009	2010-12	Average	trend
1	United States	0.354	0.342	0.346	0.346	0.346	-0.004
2	Germany	0.110	0.118	0.114	0.114	0.114	+0.002
3	United Kingdom	0.093	0.092	0.088	0.080	0.090	-0.086
4	France	0.065	0.068	0.067	0.068	0.067	+0.012
5	***Italy***	***0.065***	***0.062***	***0.061***	***0.059***	***0.062***	***-0.060***
6	Canada	0.039	0.033	0.046	0.050	0.041	+0.329
7	Japan	0.037	0.036	0.033	0.030	0.035	-0.121
8	Spain	0.030	0.033	0.035	0.045	0.034	+0.284
9	Netherland	0.035	0.030	0.024	0.028	0.029	-0.203
10	Australia	0.027	0.022	0.021	0.021	0.023	-0.136

Figure 7.1: Table 1-Trends of the impact of different countries on world astronomy over the last 12 years. Impact is defined as number of citations (country of first author) over world total.

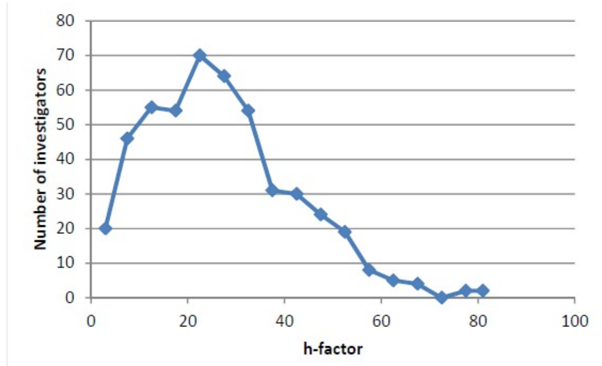

Figure 7.2: Distribution of the global h index for scientists members of INAF.

and Strategies in Astronomy (OPSA), 245-252 Ed.A.Heck @ 2012 Venngeist), who gives the following mean h indeces of IAU members: France=21.1; Germany=24.2; UK=23.5; USA=24.5. The values obtained for INAF astronomers are slightly higher, although this difference could be due to the time lapse between the two studies.

The priorities of italian Astronomy are linked to the fields where italians have been and are more competitive and to the future technologies and instrumentations. They can be summarized as follows:

- **Cosmology: probing early Universe and fundamental physics**

  Many of the open questions in cosmology are connected to fundamental and early Universe physics. Inflation scenarios, including Higgs inflation, compatible with available data, link large scale properties to fundamental and particle physics. The cosmic microwave background is the most powerful tool to address these topics, setting constraints on the inflation energy scale and dynamics, through limits to the polarization B-mode and non-Gaussianity and, at damped scales, through spectral distortions, and being sensitive to the crucial, subsequent stages of Universe evolution. Planck satellite final data will set the scene up to the advent of future CMB missions (like COrE and/or PRISM), representing the most exciting challenge in CMB cosmology, with a deep involvement of the Italian community.

  Accurate measurements of the dark matter content in galaxies and the distribution in the Universe through, e.g., gravitational lensing, as well as the equation of state of the dark energy by studying the distance-redshift relation and the clustering of hundreds of million of galaxies at different epochs, are within reach of the newly designed ground based observational programs and space missions from optical/NIR (ATLAS, KiDS, DES, Euclid), to radio frequencies (SKA). This is one the most exciting challenges of the next decade with a large involvement of the Italian community.

- **High Redshift Universe**

  After a possible quiescent phase, following the electrons-ions recombination 380.000 years after the Big Bang, the formation of early stars and cosmic structures let the Universe emerge from its dark age, causing the reionization and heating of the intergalactic medium. Cosmic structure formation could generate (and/or amplify pre-existing cosmic) magnetic fields whose role in astrophysics and cosmology is of increasing interest. Among the others, the radio domain is particularly sensitive to these topics, allowing to observe cosmic objects and map their distribution up to very early stages. LOFAR, SKA and its precursors represent a new phase in radioastronomy facilities, in which a strong Italian involvement is recommended.

Population III stars and star formation rate evolution up to z$\sim$ 10 will be obtained by studying gamma-ray bursts (GRBs), a field where many italians are successfully involved. The evolution of the baryonic component up to z $\sim$ 10 and missing baryon problems will be also a subject of intense investigation. A support to X-ray missions as ATHENA+ would be fundamental in this respect.

- **Galaxy formation and evolution: from high to low redshift**

  Large photometric and spectroscopic surveys have opened new windows on the knowledge of the formation mechanisms of galaxies. Considerable progress has been made in understanding how galaxies evolved from z $\sim$ 1 to the present. In preparation to the era of the extremely large telescopes (e.g., ESO E-ELT), in the next decade the role of highly detailed imaging from optical to submillimiter wavelenght and large spectroscopic surveys (e.g. the SDSS IV) , especially in the infrared, will become increasingly more important to characterize the star formation processes and the mass assembly out to the epochs when first forming galaxies emerge from the dark ages. ESO facilities, like VST, VISTA, ALMA, next generation synoptic telescope like LSST, space missions like Euclid, and the next generation spectrographs like KMOS and MUSE, are expected to play a pivotal role in the field and to be of primary interest for the wide and strong Italian community working in this field. Galactic astroarchaeology by means of chemical abundances in galaxies, another field where the Italian community is deeply involved and recognized at international level, will be applied to the Milky Way by exploiting the 9D space of Gaia and the data from large Galactic surveys ((Gaia, Gaia-ESO, RAVE, HERMES-GALAH, SDSS, 4MOST, LAMOST, PANSTARRS, WEAVE) and to the galaxies of the Local Group.

- **Formation, evolution and death of stars**

  The study of star formation will be performed by means of theoretical and numerical models of interstellar medium evolution and star formation (heavy numerical simulations, big hardware equivalent to a large instrument project). A new view of the relation between interstellar filaments, protostellar cores and protostars will arise from sub-millimiter and far infrared wavelenghts (ALMA, CCAT, SPICA, MILLIMETRON, IRAM/PdB, ATCHA, HERSCHEL). The study of jets in low and high mass stars and kinematics of star formation will be performed through XSHOOTER@VLT, JVLA, SKA, JWST, E-ELT. Formation and evolution of protostellar/protoplanetary disks and accretion phenomena will be studied by means of ALMA, JVLA, SKA, XSHOOTER+@VLT, LBT, JWST and E-ELT. The feedback in star formation, the roles of clusters and chemical enrichment of the pre-planetary systems will take advantage of ALMA, SKA, HIRES@E-ELT, METIS@E-ELT, JWST. The evolution of stars and their interactions with the environment will be analysed by looking inside the stars from post Main Sequence to advanced evolutionary phases (Asteroseismology with 2-Wheel Kepler and TESS). Late stages of massive stars evolution will be revealed by studying mass-loss, stellar explosions and their impact on star formation and Galaxy evolution (JVLA, ALMA, SKA, EUCLID, VLT). The study of late stages of low- and intermediate-mass stars evolution will take advantage of ASymptotic Giant Branch (AGB) stars and their impact on the hosting system (FLAMES@VLT, Gaia). Italians are well known internationally for their work on stellar evolution and pulsations: new models will be developed, together with numerical models of the evolution of the galactic eco-system (phase transitions, star formation, feedback, chemical enrichment cycle) that will be tested on the data coming from the wide area Galactic surveys (Gaia, Gaia-ESO, VST, Herschel, SKA precursors, JVLA, APEX, CCAT). The large field surveys will provide the opportunity to derive key calibrations of primary distance indicators opening a new era on the accuracy and precision of the Cosmic Distance Ladder and thus on our knowledge of the spatial dimensions of the Universe. The deep experience of the Italian astronomical community on the stellar clusters will play a crucial role in understanding the formation and evolution of stellar populations along the cosmic ages. The origin and nature of multiple stellar populations in Galactic globular clusters and in Local Group stellar systems will be one of the more intriguing issues to be understood in the next years. Present and future of ground based and space observational facilities will allow to unveil fundamental quantities, such as the star formation rate, initial mass function, age, chemical composition, and M/L ratio of stellar aggregates with different size, from young star clusters and old globulars, through faint dwarf galaxies and up to distant spiral and elliptical galaxies. Theoretical and observational studies will also take the challenging issue of understanding if and how globular cluster systems in galaxies of different morphological type have different physical features and formation histories, and if they are comparable to the Galactic globular clusters. Supernovae (SNe) are the final phases of either massive stars (Type II, Ib,c) or low and intermediate mass stars (Type Ia). The Italian community is deeply involved in the study of supernovae. In the future the focus will be on how do the SNe occur and what do they produce in terms of chemical elements and energy feedback. Properties, progenitors, and rates of Type Ia SNe will be studied by means of VLT, LBT and VST. Also different classes of core collapse SNe will be observed with VLT, LBT and VST. All of these studies will have important consequences on cosmology and chemical evolution of the Universe.

The study of the Sun will include global solar dynamo, emergence of magnetic flux in the solar atmosphere, coronal heating problem, total and spectral solar irradiance, interactions between ionized plasmas and electro-magnetic fields. Other fundamental topics will be: the solar wind and its interactions with the solar system magnetospheres, acceleration and transport of the solar particles, Space Weather and Space Climate (forecasting and nowcasting), modulation of the Galactic Cosmic Rays, Space Situational Awareness.

- **The planetary system of the Sun and other stars. Exoplanets**

  Concerning the Sun, fundamental interest resides in the studies on the global solar dynamo, the emergence of magnetic flux in the solar atmosphere,the problem of energy transfer to the Photosphere to the Corona, the total and spectral solar irradiance, and the interactions between ionized plasmas and electromagnetic fields. Another cardinal interest is the solar wind and its interactions with the solar system magnetospheres, acceleration and transport of the solar particles,and the related effects on Earth environment: from Space Weather and Space Climate (forecasting and nowcasting) to the modulation of the Galactic Cosmic Rays,all needed to develop the Space Situational Awareness program. The space missions SOLAR ORBITER, SOLAR-C and SOLAR PROBE+, and, in the general frame of the SOLARNET program, the ground-based EST observatory are the key-programs for the future studies on the Sun and heliosphere. Mother star interaction with exospheres, atmospheres, surfaces and implications for solar system evolution will be studied in situ, by means of particle instrumentation on board the space missions for in situ and remote exploration of the Solar System bodies. These missions will be focused to discover terrestrial planets, like Mercury (BEPICOLOMBO), Mars (EXOMARS), Venus; giant planets like Jupiter (JUNO, JUICE), Saturn, Uranus, Neptune; rocky and icy natural satellites like the Moon, Ganymede-Europa-Callisto (JUICE), Titan; giant asteroids like Cerere-Vesta (DAWN); main belt asteroids and cometary nuclei (ROSETTA). The Solar System study will be taken as a paradigm for extrasolar systems. Discovery and observation of the exoplanets will be a hot topic for the Italian astronomical community, exploiting the capabilities of HARPS-N@TNG.Understanding the formation, history and evolution of planets and planetary systems will take great advantage from remote sensing telescopes, like HARPS-N@TNG, LBT, GAIA, GIANO@TNG, SPHERE@VLT, ESPRESSO@VLT, CHEOPS, TESS, ECHO, PLATO, JWST and HIRES@E-ELT, while delivery of solids, volatiles and processed chemical material on planets will be studied by means of ALMA and upgrades, CCAT, CRIRES+@VLT, VISIR@VLT, HIRES@E-ELT, METIS@E-ELT. Another important topic will be characterizing the atmospheres and interior structures of planets (HARPS-N@TNG, LBT, GAIA, GIANO@TNG, SPHERE@VLT, ESPRESSO@VLT, CHEOPS, TESS, ECHO, Plato, JWST, HIRES@E-ELT) and the star-planet interactions (HARPS-N@TNG, SKA and its pathfinders).

- **High energy astrophysics**

  The priorities in this field can be summarised as : 1) TeV astrophysics: in the last decade a new observational window in the high energy ($>$ 100 GeV) band has become fundamental for the physical understanding of many classes of astrophysical sources. In this picture, INAF in collaboration with the IFN (Istituto di Fotonica e Nanotecnologie), is playing a key role and is likely to be a central parent for the future CTA consortium. 2) Electromagnetic counterparts to gravitational waves: a new generation of gravitational wave detectors will be operational around 2015 (e.g. advanced VIRGO and advanced LIGO) and on a longer time scale the space mission LISA will possibly be launched. These advancements should likely open the gravitational wave Astronomy era. The main classes of sources expected to emit gravitational waves will likely have electromagnetic counterparts and it is fundamental that INAF will devote any effort in identifying and characterize these sources (e.g. by all-sky monitoring facilities, etc.). 3) Astrophysics in the MeV range: the 0.5-10 MeV band is important for a better understanding of the several classes of sources identified by hard X-ray surveys, and it gives information about the explosive stellar nucleosynthesis. 4) Acceleration and propagation of cosmic rays: acceleration and production of cosmic rays is still one of the most intriguing research fields. Cherenkov facilities will give important observational constraints, together with information from space missions as PAMELA and future facilities.

Chapter 8

Concluding remarks

According to Horizon 2020 guidelines, "Horizon 2020 will raise the level of excellence in Europe's science base and ensure a steady stream of world class research to secure Europe's long term competitivness. It will support ideas, develop talent within Europe, provide researchers with access to priority research infrastructure, and make Europe an attractive location for the world's best researchers". The strategic Vision of INAF has direct connections with two of the aims of Horizon 2020, and specifically with "Excellent Science" and "Competitive Industries". The first aim "Excellent Science" is "to support the most talented and creative individuals to carry out frontiers research". The research themes and the main objectives of the INAF strategic Vision for astronomical research include hot topics with great impact on the field of the evolution of the Universe, the formation and evolution of galaxies, the formation and evolution of stars and planets, the search of life in the cosmos and high energy phenomena. Our strategic Vision is well inserted in the European research and our successes will be shared with other international institutes, strenghtening the scientific bonds between Italy and other European countries. The strategic Vision of INAF is especially focused on the large projects of the future both european and international such as E-ELT and SKA as well as the large projects for the space Astronomy. The INAF astronomical community is deeply involved in pursuing those scientific projects which will take the best advantages from these telescopes. A very important aspect is the active partecipation to the development of the technologies necessary to build these instruments, thus favouring a feedback to the industries of Italy and pursuing the aim "Competitive Industries" of the Horizon 2020 programme for research and innovation. Finally, it is important to stress that we are facing a world economical crisis and in particular an economical crisis in Italy. Large cuts have been operated to state funds in many developed countries. However, some countries, such as USA, Germany and France, while suffering cuts to state funds, have *increased* the budgets for education and scientific research, a necessary step in the logic of investing more in the future in order to overcome the crisis of the present time. We hope that Italy also will move on this lines. In this way INAF will be able to support the most talented and creative individuals by creating more research positions and funding challenging scientific projects.