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ESO from an Italian perspective

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Abstract. Italy joined the European Southern Observatory (ESO) 30 years ago. This membership has allowed Italian scientists and engineers to exploit the superior facilities provided by ESO and to successfully participate to their development and construction. Some of the effects on Italian astrophysics of these thirty years of membership and collaboration are briefly summarized. A few examples of high impact results obtained by Italians with the ESO telescopes are given for the fields of resolved stellar populations and galaxy evolution.

Key words. Stars: abundances – Stars: evolution – Globular clusters: general – Galaxies: evolution – Large Scale Structure of the Universe – Telescopes

1. Introduction

In May 1982 Italy became officially a member of the European Southern Observatory, the intergovernmental organization created exactly fifty years ago to develop state of the art astrophysical facilities to be shared by the Member States and make European astronomy a worldwide leader. Italian astronomers have now the opportunity to celebrate simultaneously two anniversaries: ESO's 50th birthday and 30 years of membership. Giancarlo Setti is the astrophysicist who put the maximum effort in convincing the Italian Parliament and Governments to let us join ESO, and he lively recalls in this book (Setti 2012) some of the circumstances that led to Italy's ESO membership.

That year, 1982, was a special one for Italian astronomers, because only two months earlier another key event contributed to significantly improve the conditions for professional astrophysics: the Parliament approval in March of a law (DPR 163 1982) introducing a much more coordinated and efficient organization of the Observatories and of the astronomers. That law was conceived and strongly pushed forward by Franco Pacini, and we should all pay him a tribute for having envisaged the needs of a modern Italian astrophysics. It is too sad that he passed away last January and missed the celebrations for this year anniversaries.

The two almost simultaneous events of 1982 had a very positive impact on astrophysical research in our country. They led to a significant modernization of the organization and to a much higher international competitiveness. Italian astrophysicists at the time were appreciated abroad, but more as individuals than as part of a national community. And it was increasingly challenging, specially for observers, to be competitive at international levels, at a time when communities were becoming increasingly strong, and ground based surveys performed by large consortia at large facilities were becoming increasingly important.

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Had we not entered ESO, we would have been out of many big astrophysical enterprises.

In practice, our ESO membership has allowed real quantum leaps with respect to what we were able to afford as individual nation. In 1982, the largest Italian telescope was still the 1.8m in Asiago, affected not only by size limitations but also by bad weather and seeing conditions. Entering ESO finally allowed us to have access to (and build) 4m class telescopes in one of the best sites in the world and with state-of-the-art instrumentation. Seventeen years later, less than one year after Italy's 3.6m National Telescope Galileo started operations, ESO opened access to the first unit of its four 8m Very Large Telescopes (VLT). Now ALMA (the Atacama Large Millimeter Array) is already partially available for Early Science, and we are all looking forward to the final approval and the construction of the next new generation ESO facility, the 39m European Extremely Large Telescope, E-ELT. None of these facilities would have been achievable by Italy, had we not entered ESO.

INAF, the Italian National Institute for Astrophysics founded in 1999 from the unification of all the Observatories and, later, of all the other astrophysical research institutes, is very supportive of the E-ELT project and is making all its best efforts to favor its final approval and our Government support to its financial needs. As a result of these efforts, Italy has been one of the ten Member States that have voted in favor[1] of the project at the last ESO Council meeting in June 2012. Had we abstained, with only 9 States in favor out of 14, E-ELT would have not been approved.

Entering ESO implied a significant investment for Italy, in terms of both human and financial resources. Many Italian scientists emigrated to ESO since 1982, some for several years, others for ever. The annual fee is proportional to the Gross National Product of each Member State. Correspondingly, our current contribution is about 13% of the ESO budget, and it was fairly larger before the entrance of other big countries like the United Kingdom and Spain. These investments have been amply compensated by the corresponding scientific and technological returns.

Italian companies (such as ADS, Ansaldo, EIE, Medialario, Microgate, to mention just a few), engineers and scientists have often contributed to many of ESO's technological enterprises, from buildings and domes, to revolutionary mirrors and high-performance instruments, always with outstanding results and excellent financial return. As described in this book by Tarenghi (2012) and by Marchiori (2012), we built the New Technology Telescope, we participated to all the subsequent constructions, and we are now ready to contribute to the technological challenges set by the E-ELT. INAF will exploit all its financial, human and political resources to support successful Italian contributions to the development of the E-ELT constituents.

Science returns are not easily quantifiable. However, it is worth considering that in the last 15 years (actually 31 observing Periods: from P59 to P89), of the 54 Large Programmes (LPs) submitted by Italian PIs, 22 were approved and scheduled, with a fairly satisfactory success rate of ~40%. These 22 LPs correspond to about 18% of all the LPs scheduled in the same time interval. This fraction, larger than the 13% of our annual fee share, already indicates that the scientific return is excellent. Much more important than this quantitative but not really meaningful comparison, is the worldwide impact of Italian studies based on observations at ESO telescopes. In the next section I will describe a few cases of such successful studies, without attempting to provide a complete or objective recollection of the most important results obtained by Italians at ESO. For reports on the scientific highlights, see Bono (2012) and Renzini (2012) in this volume.

2. Italian Astrophysics with the ESO telescopes

I shall give a few examples of major Italian achievements with the ESO facilities in the field of resolved stellar populations and of

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[1] to be precise: *ad referendum*, in view of further information

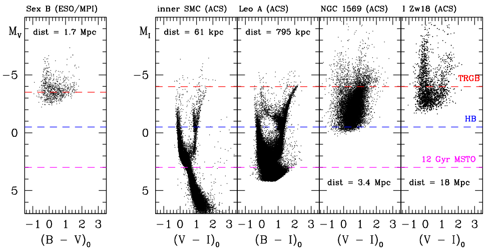

Fig. 1. The first CMDs exploited to infer the SFH of an external galaxy with the synthetic CMD method were derived from ESO photometry more than 2 decades ago. The left panel shows the CMD of the dwarf irregular galaxy Sextans B from photometry acquired at the ESO/MPI 2.2m telescope (Tosi et al. 1989). The other panels display the CMDs much more recently obtained from the HST/ACS for target galaxies at increasing distance (labelled in each box). The dashed horizontal lines correspond to key evolutionary features: from top to bottom, the Tip of the Red Giant Branch (TRGB, in red), the Horizontal Branch (HB, in blue), and the old Main Sequence Turn Off (MSTO, in magenta).

galaxy evolution, and I apologize for having possibly missed equally important results.

Let me start with my own research field this incomplete list of scientific results with significant impact. The idea of deriving the star formation histories (SFHs) of resolved galaxies by comparing the colour magnitude diagrams (CMDs) of their individual stars with synthetic CMDs derived from stellar evolution models came from ESO data and was developed and tested with them. The photometry of the first nearby galaxies for which the synthetic CMD method was devised was acquired in La Silla at the 1.5m Danish and 2.2m ESO-MPI telescopes from 1983 and 1990. One of the first galaxies analysed with this approach was the dwarf irregular Sextans B (Tosi et al. 1989, 1991), and its original CMD is shown in the left panel of Fig.1. This CMD that today looks rather poor and shallow opened the route to a very successful international enterprise. The worldwide burst of interest in the SFHs of resolved stellar populations actually exploded when the refurbished Hubble Space Telescope (HST) started to provide unprecedentedly deep and tight CMDs, thanks to the exquisite image quality and space resolution of its instruments. The latest, best CMDs obtained with the HST Advanced Camera for Surveys for galaxies at distances from 60 kpc to 18 Mpc are shown in the other panels of Fig.1, and it is striking to notice that the CMD of IZw18 is tighter and deeper than that of Sextans B, in spite of a distance more than 10 times larger: twenty years of technological improvement have not elapsed in vain. We expect the next quantum leap in the quality and depth of the photometry of resolved stellar populations to occur with the E-ELT, when even the inner, most crowded regions of elliptical galaxies as far as in the Virgo cluster will be measurable thanks to the resolving power of adaptive optics mounted on a 39m telescope.

In spite of HST's fantastic performances, ESO has had a fundamental role in the SFH research field. First, without the ESO data, people wouldn't have been ready to exploit all the advantages of Hubble's CMDs, and Europeans would have been unlikely the leaders in the field. Moreover, SFHs are a key but partial aspect of galaxy evolution, and to infer a more complete view of how a system has formed and evolved one needs to know also the chemistry and the dynamics of its main constituents. This implies that photometric studies need to be complemented with spectroscopic ones, and this is where ESO really provides the best instruments in the world. In particular, studies of resolved nearby galaxies have greatly benefited from the advent of the high-performance Flames+UVES spectrographs (see, e.g., Tolstoy, Hill & Tosi 2009, and references therein). The synergy between Hubble and ESO is the key ingredient for the success of several scientific challenges: the evolution of resolved galaxies is definitely one of these.

One of the hottest topics of today's stellar astrophysics is another result of an optimal exploitation of the HST-ESO synergy and an outstanding scientific return of the Italian ESO membership: the revolutionary discovery that globular clusters contain stellar populations born in multiple generations. The first direct evidence that, contrary to common belief, globular clusters are not simple stellar popu-

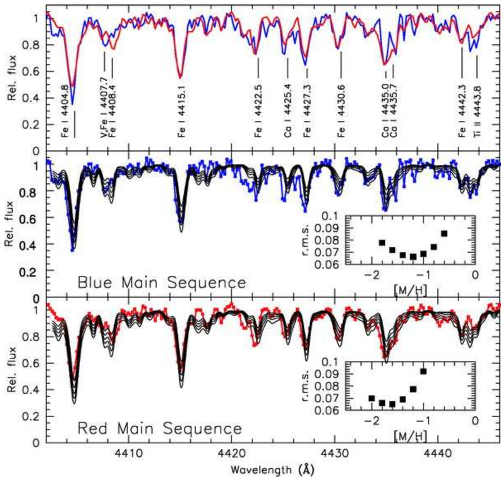

Fig. 2. Flames spectra of stars on the different MSs of ω Cen. Stars on the red MS have radial velocities 235±11 km/s and [Fe/H]=-1.56; stars on the blue MS have radial velocity 232±6 km/s and [Fe/H]=-1.27. The blue MS is more metal rich than the red one (from Piotto et al. 2005).

lations came from the exquisite resolution of HST photometry, when it allowed to distinguish two or more separate main sequences (MS) in the CMDs of a number of globulars (e.g. Bedin et al. 2004). However, it was through Flames spectroscopy acquired thanks to Director Discretionary Time that this evidence was demonstrated to correspond to an intrinsic real property and not to distance or observational effects (Piotto et al. 2005). Those spectra are displayed in Fig.2 and show that the stars on the different MSs of ω Centauri have the same radial velocity, velocity dispersion and reddening, but quite different chemical abundances. The blue MS is more metal rich and more concentrated in the inner cluster regions (Bellini et al. 2009).

The suggestion that globular clusters host at least two generations of stars had already been proposed to explain the anticorrelation between the sodium and oxygen abundances measured with the ESO spectrographs in the stars of several clusters (Carretta, Bragaglia, & Cacciari 2004). The circumstance that the Na-O anticorrelation is found not only in giant stars but also in non evolved ones rules out the possibility that it results from stellar nucleosynthesis. Gratton et al. (2001) and D'Antona et al. (2002) were the first to suggest that the stars with more O and less Na should be those formed in the first stellar generation, while the stars with less O and more Na should be those formed in the second generation.

Why and how do globulars manage to have a second generation of stars formed from the processed gas ejected by the stars of the first generation is still unclear and a matter of hot debate. Recent spectroscopic surveys with UVES, Flames and X-Shooter of thousands of red giants hosted in tens of globulars demonstrate that all the target clusters show the Na-O anticorrelation (displayed in Figure 3), and therefore likely host multiple populations (Gratton et al. 2012, and references therein). It is then compelling to find a solution applicable to the whole class of objects.

Another intriguing aspect of cluster's multiple populations is their helium content. From Flames spectra (Fig.2) of stars on the splitted main sequences of ω Centauri, Piotto et al. (2005) found that the bluest stars are more metal rich than redder ones. The only way to make the photometric and spectroscopic data consistent with each other is to conclude that the bluer, metal richer stars are also much more helium rich, with a helium mass fraction of Y= 0.39 ± 0.02: an astonishingly high value for the oldest systems in the Galaxy. ω Centauri is a very peculiar system, now considered more likely the relic nucleus of a dwarf galaxy cannibalized by the Milky Way than a real cluster, but other globulars also seem to show enhanced helium abundances, even if not so extreme. The quest for direct spectroscopic measures of the helium abundance in stars of a number of globulars is the current challenge. The first results suggest that stars with enhanced Na/O also have higher He, thus supporting the connection of the He overabundance to the second stellar generation (Villanova et al. 2009; Pasquini et al. 2011; Villanova et al 2012).

Italians have often participated to the development at ESO of new technology instruments and telescopes. They have also exploited them. One recent experiment, to bet-

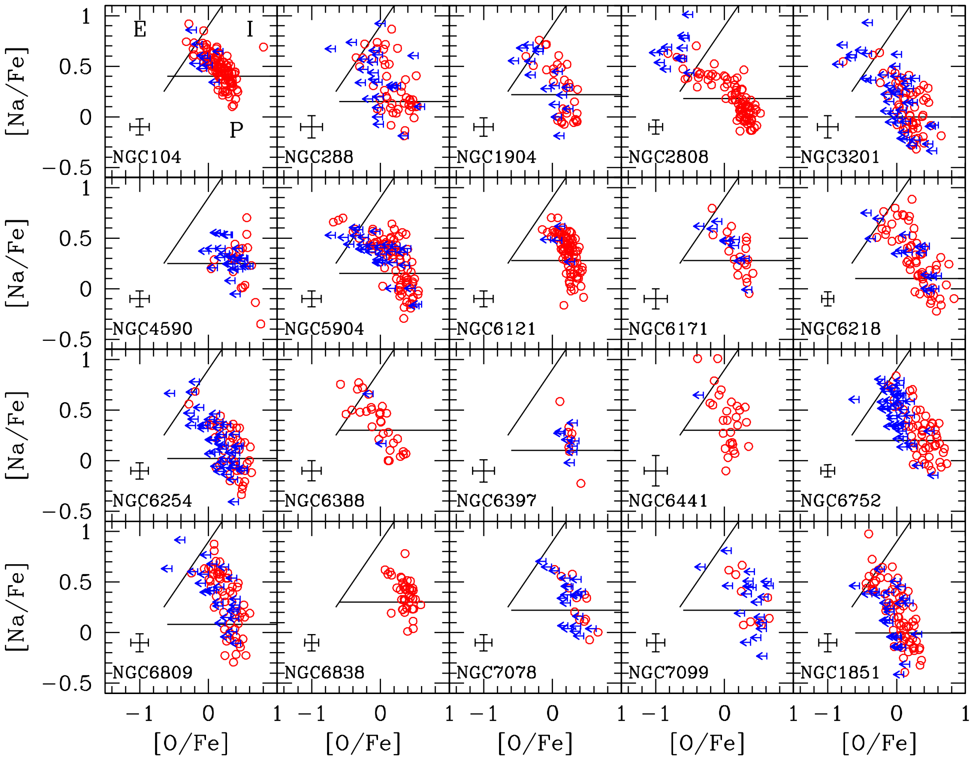

Fig. 3. The Flames survey of ~100 RGB stars in each of 25 Galactic globular clusters confirms and quantify the universality of multiple populations in these systems (from Gratton et al. 2012).

ter characterize adaptive optics effects in view of the E-ELT project, has been MAD (Multi-Conjugate Adaptive Optics Demonstrator), developed by ESO in collaboration with the INAF Observatories of Arcetri and Padova and installed at one VLT unit. Thanks to the incredibly sharp K-band images of the Bulge cluster Terzan 5 acquired with MAD, Ferraro et al. (2009) were able to find in its CMD two distinct red clumps (top panel in Fig.4), corresponding to two populations with slightly different ages. Follow-up high-resolution spectroscopy of the clump stars has shown that the two clumps are populated by stars with different [Fe/H] and different [α/Fe], but all consistent with being Bulge objects (see bottom panel of Fig.4). Ferraro et al. (2009) suggestion is that Terzan 5 is the remnant of one of the pristine fragments that contributed to the Bulge build-up.

Let me conclude this *excursus* on resolved stellar population studies mentioning the great

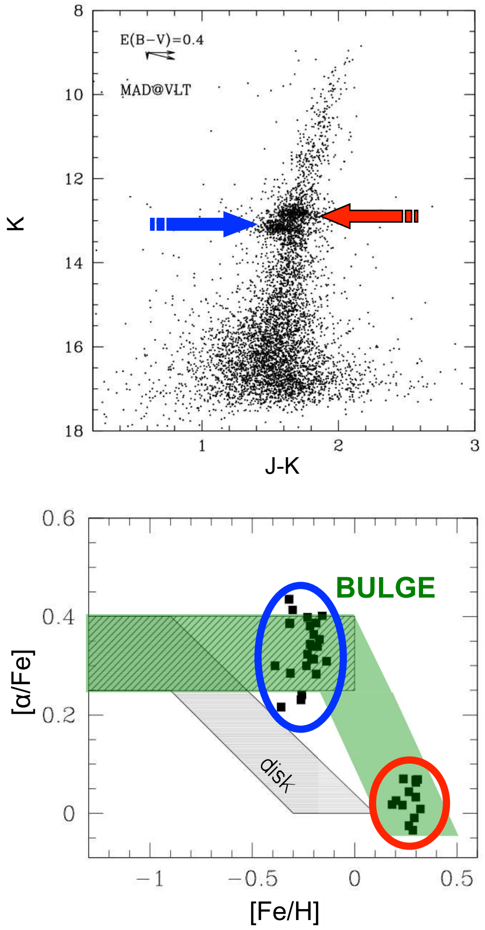

Fig. 4. Top panel: CMD of the Bulge cluster Terzan 5 derived from MAD photometry. Bottom panel: α/Fe ratio vs iron abundance of the stars in the two distinct clumps, superimposed on the average trend of Bulge and disk objects (Ferraro et al. 2009).

expectation we have on the outcome of the Gaia-ESO spectroscopic survey (GES), one of whose PIs is Italian (S. Randich). GES will provide chemical abundances, radial velocities and physical parameters of stars of all Galactic components: Halo, Bulge, Thick and Thin disks, as well as of open clusters in all evolutionary phases. When combined with Gaia's information on their position, it will lead to the first complete 3D picture of the Galaxy and its immediate surroundings.

On the cosmology side, ESO observations have allowed Italians to achieve many important results (see, e.g., Renzini 2012). Here I only mention those resulting from the exploitation of an instrument (Vimos), to whose design and construction they have also significantly contributed. This multi-object spectrograph mounted at the VLT has been used by international consortia for several large and deep surveys of galaxies at increasing redshifts, most of which connected to other surveys, such as GOODS, COSMOS, HDF, etc., performed with other telescopes in imaging or at different wavelengths, from X-rays to radio. Combining LPs with normal general observer programs, these consortia have achieved an unprecedented view of the large scale structure of the Universe and of galaxy evolution with redshift, getting new insight on the nature and nurture of galaxy evolution through cosmic time.

In chronological sequence, first the VVDS (Vimos-VLT Deep Survey, PI O. Le Fèvre) and then the zCOSMOS redshift survey (PI S. Lilly) have led to measuring with Vimos more than 80 thousand spectra of galaxies over more than 10 deg^2, with most of the resulting redshifts at $z{\sim}1$, but with a significant tail at higher redshifts ($z{>}3$). With these data it has been possible to reconstruct the galaxy cosmic web and follow the evolution of different galaxy types. With the VVDS Zucca et al. (2006) were able to investigate the evolution of the galaxy luminosity function for different morphological types over $\sim$ 70% of the age of the Universe. They derived the faint end slope of the luminosity function with unprecedented accuracy and found that early-type galaxies are much more numerous at low redshifts than at high z, while the opposite holds for late-type galaxies (top panel in Fig.5).

From the combination of the COSMOS multi-band photometry with the zCOSMOS spectra, Pozzetti et al. (2010) found that less massive blue galaxies transform into the massive red sequence systems after quenching their star formation. The transformation from blue, active, spiral galaxies of intermediate mass to blue quiescent and subsequently (1-2 Gyr after) red, passive types of low specific star formation is driven mainly by the

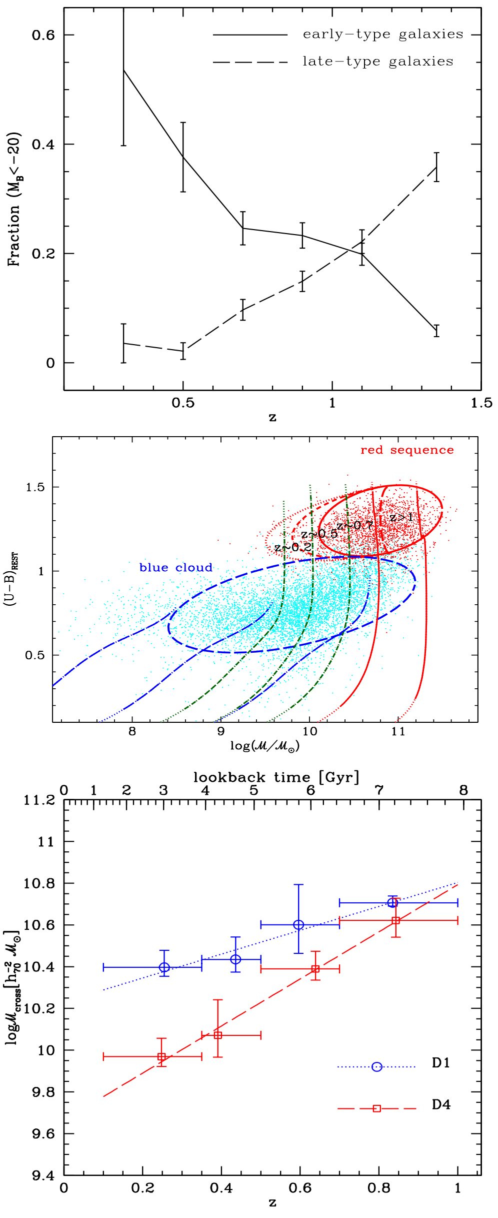

Fig. 5. Results from the VVDS and zCOSMOS surveys. From top to bottom: luminosity function for different morphological types (Zucca et al. 2006), evolution of galaxies of different mass and colors (Pozzetti et al. 2010), dependence on environment of the galaxy type transformation (Bolzonella et al. 2010).

SFH (see central panel in Fig.5). Pozzetti et al. (2010) suggested that the complete morphological transformation into red spheroidal galaxies, probably driven by dynamical processes, occurs on longer timescales. A continuous replacement of blue galaxies is expected to be accomplished by low-mass active spirals increasing their stellar mass through star formation. They concluded that the build-up of galaxies and in particular of early types occurs earlier for high-mass galaxies. From further analysis of the zCOSMOS sample of 8500 galaxies in the redshift range $0.1 \leq z \leq 1.0$, Bolzonella et al. (2010) found that the rate and the epoch of the transformation strongly depends on the environment. At redshift z∼1, the galaxy stellar mass function appears to be only slightly dependent on environment, but at lower redshifts the mass functions in high- and low-density environments become extremely different (bottom panel of Fig.5).

The current large survey of this series performed with Vimos is VIPERS, a LP led by L. Guzzo to cover 24 deg^2, with a mosaic of 288 Vimos pointings, and measure 100 thousand redshifts up to z∼0.8. This survey will allow to reconstruct the large scale structure of the Universe back to 7 Gyr ago. As of May 2012 about 60% of the total area has been covered and half of the planned redshifts have been measured. At this pace, the survey completion is expected by the end of 2014 (Guzzo, private communication). The preliminary redshift distribution of the first 10000 measured galaxies is shown in Fig.6.

3. Conclusions

It is apparent from this incomplete summary that the Italian community has had both scientific and technological rewards in participating to ESO's enterprises. The return of the investment is exceptionally high in terms of international competitiveness and leadership, scientific impact and technological achievements. We are grateful to those who understood on time the importance of joining ESO and made it possible. We are confident that we will con-

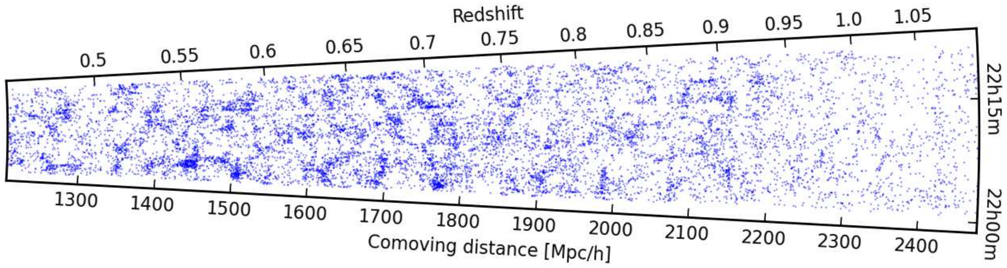

Fig. 6. The large-scale galaxy distribution at $0.45<z<1.1$ in the VIPERS preliminary data collected up to 2010 in the smaller of the two survey fields (~10,000 redshifts). Currently, the survey has reached beyond 65,000 measured redshifts over the W1 and W4 fields of CFHTLS, and aims at a total of $\sim 10^5$ redshifts over 24 square degrees by 2014 (Courtesy of the VIPERS Collaboration, http://vipers.inaf.it).

tinue to contribute with equal success and mutual advantage in the future.

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