"THE GALACTIC BULGE AND BEYOND"

A conference in honour of Mike R. Rich

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List of Abstracts:

Andrew Bunker

JWST at the edge of the Universe - finding galaxies in the epoch of reionization with NIRSpec

Since launching on Christmas Day, 2021, JWST has produced spectacular views of the Universe, both near and far. I will describe observations of some of the most distant galaxies yet through near-infrared spectroscopy with NIRSpec. With my colleagues on the NIRSpec and NIRCam instrument science teams of JWST, we are undertaking large JADES survey to explore galaxy evolution into the epoch of reionization (the first billion years of history). We have recently spectroscopically confirmed galaxies at redshifts beyond 10 for the first time, including spectacular spectrum of a galaxy which unexpectedly has Lyman-alpha in emission, as well as a suggestion of non-standard elemental abundance ratios. I will discuss the implications of these recent discoveries for our understanding of galaxy evolution, and the potential role of star-forming galaxies at redshifts beyond 6 in reionizing the inter-galactic medium.

Will Clarkson

Hubble Space Telescope Proper Motions towards the Bulge: a retrospective and look forward

The Hubble Space Telescope (HST) can measure scientifically useful proper motions towards and in the Galactic bulge even with observations separated by only a few years. Kuijken & Rich (2002) started this subfield, using WFPC2 to demonstrate a clean bulge population kinematically cleaned of foreground and background interlopers, suggesting the majority of the inner bulge is probably old, and demonstrating proper motion-based rotation curves. Since then, HST proper motions have brought new dimension to observational studies of the bulge, including: detection of bulge vertex deviation; detection of the bulge white dwarf cooling sequence; isolation of a likely blue straggler population; the detailed star formation history of the bulge; and new correlation between kinematics and metallicity throughout the bulge. I will review the use of HST proper motions to better understand the bulge since the pioneering work of Kuijken & Rich, and will provide a brief look ahead to what we might expect next.

Francesco Calura

On the origin of the double [α/Fe] sequence in the Milky Way Disk

I briefly review the current knowledge on the double [α/Fe] sequence discovered in the Galactic stellar disk in the last decade. I start from a result that dates back a few years before its discovery, in which its existence was predicted but regarded as a shortcoming of the model. I discuss a few more theoretical studies that came afterwards and compare the results of cosmological galaxy formation and chemical evolution models.

Effects of Type Ia Supernovae in young globular clusters

The presence of multiple populations in globular clusters (GCs) is a well-established phenomenon,but the exact mechanisms responsible for their formation are still debated. In particular, the physical processes that determined the end of star formation in GCs are poorly understood,as the role of type Ia Supernovae (SNe) in their evolution. Using 3D hydrodynamic simulations, we investigate how the formation and the chemical properties of Second-generation (SG) stars in a massive proto-GC are affected by the explosions of type Ia SNe belonging to the first stellar generation (FG), one likely cause for the quenching of star formation in these systems. In our model, the formation of SG stars starts at ∼40 Myr after the birth of the cluster and results from the retention of fresh materials from FG asymptotic giant branch stars, combined with the accretion of cold, pristine gas. Simultaneously, SNe Ia start exploding, creating hot and rarefied bubbles in the surrounding interstellar medium. We focus on understanding how SNe Ia influence the abundances of iron and helium, as well as examining some of the main factors that regulate the effectiveness of

SN Ia feedback. We show that SNe explosions can halt star formation only if the accreted pristine gas is tenuous (i.e. with a density ∼ of 1cm-3), whereas they have minimal effects when the pristine gas density is a factor 10 denser. We also demonstrate that gas originating from SNe Ia may contribute to the iron variability observed in Type II GCs, an unusual subgroup of GCs.

Michelle Collins

The unusually low density dwarf galaxies of Andromeda – a challenge for cold dark matter?

In this contribution, I will discuss three unusual dwarf galaxies orbiting our nearest neighbour galaxy, Andromeda. These objects – Andromeda (And) XIX, XXI and XXV – have central dark matter densities that are far lower than predicted by cold dark matter. Low dark matter densities are typically explained by appealing to extended, bursty star formation, however by combining precision star formation histories from Hubble imaging with state-of-the-art mass modelling techniques, we have shown that this cannot explain the central densities of these galaxies. In this presentation, I will show whether we can understand these systems as objects residing in cold dark matter halos with unusually low concentrations, objects that have been heavily tidally stripped, or whether we need to appeal to other dark matter models. I will also discuss the constraints they can place on the mass of the warm dark matter particle.

Valeria Cerqui

The age - metallicity relation as Galactic archaeology tracer

The processes of formation and assembly of the components of the Milky Way leave strong signatures in the chemistry of stars. It is possible to use the chemical properties of different stellar populations and combine them with other signatures to reconstruct the formation and evolution of our Galaxy. The relationship between the age and metallicity of stars is particularly powerful for this purpose. Thanks to the high-quality data provided by recent spectroscopic surveys such as GALAH, it's now possible to obtain the local age-metallicity relation with unprecedented accuracy. However, to fully understand the global picture it is necessary to link the patterns in the solar neighbourhood and on larger scales. What is the relationship between these different patterns? Can we explain them as separate evolutions or are they connected? These are just some of the open questions that the combination of APOGEE and GALAH datasets can help to answer.

Gabriele Cescutti

Galactic Archaeology with neutron capture elements in the Bulge

In the last years, the search for the oldest stars have started to investigate the central region of our Galaxy. The Galactic bulge host extremely old stars, with ages compatible with the ages of the oldest halo stars. The data coming from these recent observations present new signatures in neutron capture elements. Our study, based on stochastic chemical evolution models, shows how this new fundamental informationcan improve dramatically the constraints on the nature of the first sources of neutroncapture elements: the first stellar generations, but also the r-process events.

Cristina Chiappini

Stellar populations in the Galactic bulge

In this talk I will describe the complex mix of stellar populations we observe in the innermost kpcs of our Galaxy. Open questions will be discussed also in view of recent extragalactic work. Finally we will describe how we intend to complement our current views with 4MIDABLE-LR and, in the future, Haydn and Gaia-NIR.

John Danziger

SN1987A with JWST

Massimo Della Valle

The role of Nova explosions in galactic nucleosynthesis

I will present a brief summary of the contribution of Nova explosions to the chemical evolution of the Milky Way, in particular their role as Lithium factories.

Patrick de Laverny

The Gaia/RVS chemical cartography of the Milky Way

I will explain how 5.6 millions stars have been physically and chemically parameterized thanks to the automatic analysis of the Gaia/RVS spectra by the DPAC/GSPspec module. I will then present several results related to Galactic Archaeology and Stellar Physics that are based on the scientific exploitation of this first all-sky and largest catalogue of stellar parameters.

Roberto de Propris

X-stars in the Galactic Bulge

We have used the AAOMEGA spectrograph to obtain R ~ 1500 spectra of 714 stars that are members of two red clumps in the Plaut Window Galactic bulge field (l, b) = (0°, - 8°). We discern no difference between the clump populations based on radial velocities or abundances measured from the Mgb index. The velocity dispersion has a strong trend with Mgb-index metallicity, in the sense of a declining velocity dispersion at higher metallicity. We also find a strong trend in mean radial velocity with abundance. Our red clump sample shows distinctly different kinematics for stars with [Fe/H] <-1, which may plausibly be attributable to a minority classical bulge or inner halo population. The transition between the two groups is smooth. The chemo-dynamical properties of our sample are reminiscent of those of the Milky Way globular cluster system. If correct, this argues for no bulge/halo dichotomy and a relatively rapid star formation history. Large surveys of the composition and kinematics of the bulge clump and red giant branch are needed to further define these trends.

Francesco R. Ferraro

Fossil fragments as tracers of the Galactic Bulge formation process

We have discovered that two objects commonly catalogued as bulge globular clusters (Terzan 5 and Liller 1) are actually complex stellar systems hosting stars with very different ages and iron content, and showing a striking chemical similarity to the field population. They probably are remnants of more massive structures that, in place of dissolving and contributing to the hierarchical assembling of the bulge, evolved in isolation and experienced a second burst of star formation from gas enriched by supernova ejecta. In this talk I summarize the main findings and discuss the possible link among these systems and the massive clumps observed at high redshift. Indeed, we likely discovered the crucial missing piece in the bulge formation puzzle: the connection between what we observe in the distant and in the local Universe

Mauro Giavalisco

Following the structural evolution of massive galaxies in time

The sensitivity, angular resolution and panchromatic wavelength coverage of HST and now JWST are allowing us to robustly reconstruct both the integrated and spatially resolved star-formation history (SFH) of massive galaxies at “Cosmic Noon”, 1.5<z<4, when they were transitioning from the star-forming phase into the quiescent one. I will discuss how information on the SFH can be used to derive the properties of the galaxies at the beginning of their evolution (progenitor bias) and, crucially, to follow their evolution in time in a completely empirical way, including the growth of size (the effective radius Re) during the star-forming phase, the formation of dense stellar cores and the shrinking of size of the central regions as the galaxies head toward quiescence. I will also discuss the evolution of metallicity gradients. Finally, I will briefly review relevant key results from current observations of galaxies up to redshift z~16 with JWST.

Valeria Grisoni

Galactic archaeology with the lens of asteroseismology

I will discuss the chemical evolution of the Milky Way by focusing on the importance of asteroseismology to shed light on the history of our Galaxy. Indeed, we are in a golden era for Galactic archaeology thanks to the advent of large spectroscopic surveys, that can provide detailed stellar abundances of stars in the Milky Way; these surveys can then be combined with asteroseismic campaigns, that allow us to have also precise stellar ages.Then, by means of detailed chemical evolution models, it is possible to predict the chemical abundances expected in the stars of the different Galactic components. From the comparison between data and model predictions, it is possible to constrain the history of star formation occurred in each component, and thus the history of the entire Galaxy. In particular, I will present results based on new data from spectroscopic surveys combined with asteroseismic campaigns, such as Kepler, K2 and TESS.

Chiaki Kobayashi

Elemental abundances in the Galactic bulge, M31 disks, and in the early Universe

Elemental abundances can constrain physical processes during galaxy formation and evolution. This approach, Galactic Archaeology, has been popularly used for our Milky Way Galaxy. It can also be applied to external galaxies thanks to recent and future observations with integral field spectrographs. Including all chemical enrichment sources, i.e., core-collapse supernovae, asymptotic giant branch stars, Type Ia supernovae, and neutron-star mergers, I will show the prediction of the distributions of elemental abundances in the bulge from our chemodynamical zoom-in simulations of a Milky Wa-type galaxy. Then I will show the predictions from larger-scale cosmological simulations to discuss the first chemical enrichment in the Universe. Comparing with the observations, I will discuss the origin of our Milky Way bulge and bar, and the link to the very high-redshift galaxies observed with the James Webb Space Telescope.

Andrea Kunder

MWBest: Charachterizing tidal debris around inner Galaxy Globular Clusters

The origin of the metal-poor (Fe/H < -1.0 dex) stellar population in the bulge, which likely consists of some of the oldest stars in the inner Galaxy, is still not well understood. MWBest is a spectroscopic survey with the goal of identifying stripped globular cluster stars from inner Galaxy clusters. In this way, an indication on the fraction of bulge metal-poor stars that have originated from globular clusters can be determined. I will present the spectroscopic analysis of stars in and around understudied globular clusters in the bulge, particularly those with large mass to light ratios. Radial velocities and chemistry allow the identification of extra-tidal stars out to 3-5 times the tidal radius. RR Lyrae stars in the clusters allow a distance and orbit to be obtained. The observed tidal debris is spatially coincident with theoretical predictions of the tidal tails around the clusters.

Marco Limongi

Evolution and final fate of stars in the transition between AGB and Massive Stars

According to a standard initial mass function, stars in the range 7-12 $M_\odot$ constitute ~ 50% (by number) of the stars more massive than 7 $M_\odot$ but, in spite of this, their evolutionary properties, and in particular their final fate, are still scarcely studied. In this paper we present a detailed study of the evolutionary properties of solar metallicity, non rotating, stars in the range 7-15 $M_\odot$, from the pre main sequence up to the presupernova stage or up to an advanced stage of the thermally pulsing phase, depending on the initial mass. We find that (1) the 7.00 $M_\odot$ develops a degenerate CO core and evolves as a classical AGB star in the sense that it does not ignite the C burning reactions; (2) stars with initial mass $M \geq 9.22\ M_\odot$ end their life as core collapse supernovae; (3) stars in the range $7.50 < M/M_\odot < 9.20$ develop a degenerate ONe core and evolve through the thermally pulsing SAGB phase; 4) stars in the mass range $7.50 \leq M/M_\odot \leq 8.00$ end their life as hybrid CO/ONe- or ONe-WD; (5) stars with initial mass in the range $8.50 \leq M/M_\odot \leq 9.20$ most likely achieve the central densities in excess of the threshold value for the activation of the electron capture on ^{20}Ne before losing the entire H-rich envelope and therefore may potentially explode as electron capture supernovae.

Claudia Maraston

Stellar population models based on 60,000 Milky Way empirical spectra

Evolutionary population synthesis models describing the energetic emission and stellar mass distribution of galaxies and star clusters are the essential interpretative tool in astrophysics and cosmology. They are used to infer key properties of stellar systems (age, chemical composition, stellar mass, dark matter fraction) from data, to predict the spectral energy distribution of simulated galaxies, to trace galaxy ages as a function of cosmic time for constraining cosmology, to predict the number, mass and location of stellar remnants rooting gravitational waves. Given their widespread use, the accuracy of population synthesis models directly affect our understanding of galaxy formation and evolution in a cosmological context. I shall review progress in

Francesca Matteucci

The history of the Bulge chemical evolution

I will start from Mike's PhD when he worked on the metallicity distribution function of Galactic bulge stars. That was, I think, the first paper on that subject. Two years later, I published a paper on the chemical evolution of the bulge, aimed at reproducing Mike's distribution. In that paper, I made predictions on the [alpha/Fe] ratios expected in bulge stars and in 1994 McWilliam & Rich provided the first measures of these ratios. The main conclusion from a comparison between model results and data was that the bulk of bulge stars should have formed very quickly in a burst. After then, a long series of papers appeared on the chemical evolution of the Galactic bulge and I will review the results of these papers until the present time.

Andrew McWilliam

TBD

Ivan Minchev

Bar parameter fluctuations lead to overestimated lengths and "ultrafast" bars

I will show that in numerical simulations bar length, Rb, measurements fluctuate on a dynamical time-scale by up to 100 per cent, depending on the spiral structure strength and measurement threshold. The bar amplitude oscillates by about 15 percent, correlating with Rb. The Tremaine– Weinberg method estimates of the bars' instantaneous pattern speeds show variations around the mean of up to ~20 per cent, typically anticorrelating with the bar length and strength. Through power spectrum analyses, we establish that these bar pulsations, with a period in the range ~60–200 Myr, result from its interaction with multiple spiral modes, which are coupled with the bar. Because of the presence of odd spiral modes, the two bar halves typically do not connect at exactly the same time to a spiral arm, and their individual lengths can be significantly offset. We estimated that in about 50 per cent of bar measurements in MW-mass external galaxies, bar lengths are overestimated by ~15 to ~55 per cent. Consequently, bars longer than their corotation radius reported in the literature, dubbed "ultrafast bars", may simply correspond to the largest biases. Given that the Scutum-Centaurus arm is likely connected to the near half of the MW bar, recent direct measurements may be overestimating its length by 1-1.5 kpc, while its present pattern speed may be 5-10 km/s/kpc smaller than its time-averaged value.

Marta Molero

Origin of neutron capture elements with the Gaia-ESO survey: the evolution of s- and r-process elements across the Milky Way

The majority of elements beyond the Fe peak are produced by neutron capture processes which can be rapid (r-process) or slow (s-process) with respect to the -decay in nuclei. Understanding which are the astrophysical formation sites of these two processes has become one of the major challenges in chemical evolution. The s-process mainly takes place in low-intermediate mass stars during the asymptotic giant branch phase and in rotating massive stars, with the latter being particularly relevant at low metallicities. On the other hand, the r-process sites are still under debate, with possible main producers candidates being peculiar supernovae (magneto-rotational supernovae, MR-SNe) or merging of compact objects (neutron stars or neutron star-black hole). Although observations point towards merging neutron stars (MNS) as the major astrophysical r-process site, chemical evolution simulations still struggle to reproduce the abundance pattern of the [Eu/Fe] vs. [Fe/H] (with Eu being a typical r-process element) if MNS are the only producers of r-process material and realistic timescales for merging are assumed. A large number of works point toward a scenario in which both a quick and a delayed source produce r-process material (e.g., Matteucci+14, Simonetti+19, Molero+21a). The delayed source is represented by MNS whose merging timescales depend on a delay time distribution, while the quick source is usually represented by MR-SNe. However, this scenario may have difficulties in reproducing other s-/r-process elements' abundance patterns, due to the too dominant contribution of the MR-SNe (Molero+21b). In this talk, I will first present the main steps done in chemical evolution simulations in order to understand the origin of neutron capture elements and then I will show results from our latest work. We studied both the abundance patterns and the radial gradients of five s-process elements (Y, Zr, Ba, La, Ce) and four mixed/r-process elements (Eu, Mo, Nd, Pr) in the Galactic thin disc by means of a detailed two-infall chemical evolution model with state-of-the-art nucleosynthesis prescriptions. Predictions of our model are compared with data from the sixth data release of the Gaia-ESO survey, which consists of 62 open clusters located at different Galactocentric distances and with ages ranging from 0.1 to 7 Gyr, and 1300 disc field stars. Our results show that MNS are not the dominant source of r-process material and there is no need for a delayed source, at least in order to reproduce observations in the thin disc. Rotating massive stars improve the production of s-process material, especially at low metallicities and for elements belonging to the first s-process peak, but

the contribution from MR-SNe and MNS is still needed in order to reproduce observations. The radial gradients of the neutron capture elements are well reproduced by our model. We show also some cases in which our simulations struggle to reproduce the observations and discuss some possible explanations including stellar migration and different Galaxy formation scenarios.

Francisco Nogueras Lara

The nuclear stellar disc of the Milky Way as a tracer of the Galactic bar

The nuclear stellar disc is a flat dense stellar structure at the heart of the Milky Way. Recent work shows that analogous structures are common in the nuclei of external spiral galaxies, where there is evidence of an age gradient indicating that they form inside-out from gas funnelled to the centre by the galactic bar. Analysing the stellar population of the nuclear disc at different radii, we find an age gradient along the line of sight. We detect the presence of a significant mass (~40% of the total stellar mass) of intermediate-age stars (2-7 Gyr) in the outer regions of the nuclear stellar disc that is not present in its innermost regions, in which ~90% of the stellar mass is older than 7 Gyr. Our results are consistent with an inside-out formation of the nuclear stellar disc, and suggest that the age distribution of the nuclear stellar disc is similar to the one found in external galaxies. This implies that bar-driven processes observed in external galaxies are also at play in the Milky Way. Hence, the nuclear stellar disc is related to the Galactic bar and its properties can give us insight into its age and formation history.

Chi Thanh Nguyen

Stellar Evolution with Rotation in PARSEC v2.0

The new collection of stellar evolutionary tracks and isochrones for rotating low- and intermediate-mass stars is recently presented with the updated version of PARSEC V2.0 code. I will discuss about this new database where rotation is the most important improvement. Briefly, the considered evolutionary phases begin from the pre-main-sequence to the first few thermal pulses on the asymptotic giant branch in case of low-mass stars or central C-burning in case of intermediate-mass stars. The computed metallicity ranges from 0.002 to 0.03, and the masses are from 0.09 Msun up to 14 Msun. Furthermore, the corresponding theoretical isochrones are derived with TRILEGAL code and are converted into several photometric systems, taking into account different inclination angles due to rotation. Finally, I will discuss a bit about the possibility for studying the variation of chemical abundances under the impact of rotation with this new database.

Livia Origlia

My short story of BigMike

Sergio Ortolani

The metal rich globular clusters in the galactic bulge. A confirmation of early Mike analysis

We present our early studies of metal rich, and intermediate, globular clusters in the galactic bulge, showing that their high metal content, coupled with an old age, confirmed previous Mike Rich claims based on the stellar fields, of an early formation of a metal rich bulge. Recent studies indicate that most of the massive clusters, located in the bulge volume,are generated in situ, while at least some of the low mass clusters are possibly the result of later mergers.

Giulia Pagnini

On the dearth of C-enhanced metal-poor stars in the Galactic bulge.

According to the Stellar Archaeology, the chemical fingerprints of the first stars could be retained within the photospheres of old, low-mass, metal-poor second-generation stars observed in the Local Group. A significant fraction of these stellar fossils is represented by stars known as Carbon-Enhanced Metal-Poor (CEMP), characterised by an overabundance of carbon with respect to iron [C/Fe] > 0.7, and which are likely imprinted by primordial faint supernovae. These have been observed in large quantities in the Galactic halo and in the Ultra-Faint Dwarf galaxies (UFDs) with [C/Fe] reaching values up to +4.5. Interestingly, although the Milky Way bulge is predicted to host the oldest stars, it shows a striking dearth of CEMP stars with [C/Fe] $\gtrsim$ +2.0. In this talk, we explore the possible reasons for this anomaly by performing a statistical analysis of the observations of metal-poor stars in combination with the predictions of ΛCDM models. Our analysis shows that the scarcity of CEMP stars with high [C/Fe] is not due to the low statistics of observed metal-poor stars, but is the result of a different formation process of the Galactic bulge. N-body simulations show that the first star-forming haloes which end up in the bulge are characterised by the highest star formation rates. These rates enable the formation of rare massive first stars exploding as pair-instability supernovae (PISNe), which wash out the high carbon signature of primordial faint supernovae. We conclude that the dearth of CEMP stars in the Galactic bulge indirectly probes the existence of elusive PISNe, and propose a novel method which exploits this lack to constrain the mass distribution of the first stars.

Giampaolo Piotto

Stellar parameters of planet hosting stars from PLATO mission

The ESA PLAnetary Transit and stellar Oscillation (PLATO) mission is in advance phase of preparation, with a launch scheduled for end 2026. Aim of the mission is the discovery of Earth analogous planets, with the identification of thousands of planetary systems forseen. Goal of the mission is to also measure stellar parameters of hosting stars, including mass, radius and age using the same light curves for planet transits identification for asteroseismological studies. I will present the observing field, the PLATO input catalog (PIC) and potentialities of the mission for stellar studies.

Zdenek Prudil

7D mapping and timing of the Milky Way bar

The Milky Way Galactic bulge is a remarkable setting for studying stellar evolution and galaxy formation, representing one of the Milky Way's oldest and most metal-rich components, featuring a diverse metallicity distribution function. Within galaxies like the Milky Way, two distinct types of galactic bulges have been identified: the classical and pseudo-bulges, which differ in their formation mechanisms. Our research focuses on differentiating between stars belonging to the classical and pseudo-bulge populations through comprehensive chemodynamical analysis. To achieve this, we utilized old standard candles (older than 10 billion years) identified within the Galactic bulge. Our project leverages spectroscopic data obtained from the Bulge Radial Velocity Assay for RR Lyrae stars (BRAVA-RR survey) and the Apache Point Observatory Galactic Evolution Experiment (APOGEE), thus spanning the visual and near-infrared spectral ranges. We have devised specialized procedures tailored to the data available for the Galactic bulge, enabling the derivation of distances, reddening values, and systemic velocities for individual RR Lyrae stars. Consequently, we have obtained distance and systemic velocity information for over 7,000 RR Lyrae stars, both above and below the Galactic plane. Combining Gaia astrometry with our data products successfully distinguishes between halo interlopers and the bulge RR Lyrae population, subsequently examining their associations with classical or pseudo-bulge morphologies. Lastly, our work presents re-calibrated photometric metallicity estimates for the entire Galactic bulge RR Lyrae population, along with initial estimates of spectroscopic [Fe/H] and [alpha/Fe] ratios for a subset of the analyzed RR Lyrae stars.

Alvio Renzini

Globular clusters and high-redshift Universe

Michael Rich

The Bulge from Vulcano to Elba: 40 years of surveys and challenges

My scientific career began focused on stellar populations in large part thanks to the inspiration of Alvio Renzini and Francesca Matteucci. I will discuss my major surveys and their results, and the connection of the science to galaxy formation and evolution, with the emphasis being on new results from the Blanc DECam Bulge Survey (BDBS). BDBS has uncovered a striking tendency of the most metal rich stars in the bar to be concentrated toward the Galactic plane. Using photometric metallicities for 2.6 M stars precise to 0.2 dex, the survey has revealed a striking less metal rich component of the bulge with an abundance distribution that cannot be fit by a one zone model, requiring some application of chemical evolution theory to explain it. There are also new results on bulge kinematics (from Gaia) as a function of metallicity, with the fastest rotating population at [Fe/H] ~0. BDBS also offers new constraints on the age of the bulge, as well as insights into the globular clusters of the bulge and trends in their population complexity. These results offer potential challenges for the next generation of large spectroscopic surveys, and I will suggest some goals.

Federico Rizzuti

Nucleosynthesis and stellar evolution in 3D stellar models

Our knowledge of nucleosynthesis and stellar evolution is limited by uncertainties coming from complex multi-dimensional processes in stellar interiors, such as convection and nuclear burning. 3D hydrodynamic models can improve this knowledge by studying realistic multi-D processes, usually for a short timerange (minutes or hours). Recent advances in computing resources are starting to enable 3D models to run for longer time and include nuclear reactions, making the simulations more realistic and allowing to study nucleosynthesis firsthand. In this talk, I will present results coming from hydrodynamic simulations including explicit nuclear burning for different phases of advanced massive stars. In particular, I will focus on studying the space and time evolution of the chemical composition within the star. Finally, I will discuss the implications for stellar evolution, nucleosynthesis, and convection theory.

Donatella Romano

The chemical enrichment history of the peculiar cluster Terzan 5

Terzan 5 is a heavily obscured stellar system located in the inner Galaxy. It has been postulated to be a stellar relic - a Bulge Fossil Fragment - witnessing the complex history of the assembly of the Milky Way Bulge. We are able to reproduce the metallicity distribution function and the runs of different element-to-iron abundance ratios as functions of [Fe/H] in Terzan 5, by means of a chemical evolution model that assumes two major star formation bursts separated by a long quiescent period. The most metal-rich stars are predicted to be moderately He-enhanced ($Y \simeq 0.335$), starting from a primordial value YP = 0.248. Current observations fit within a formation scenario in which Terzan 5 originated from a gaseous clump about one order of magnitude more massive than the present-day mass of the cluster. Losses of gas and stars must have played a major role in shaping Terzan 5 the way we see it now. We conclude that the environment in which Terzan 5 was born has played a fundamental role in determining the observed properties of this cluster.

Nils Ryde

Abundances in the Nuclear Star Cluster

Mike Rich was very early in chemically characterising the stellar populations in the bulge, pushing all the way into the inner regions. An UCLA-Lund-Nice group, including Mike, have been following up on this work for some years in targeting the Galactic Center region, i.e. the Nuclear Stellar Disk and the Nuclear Star Cluster with high-resolution spectroscopy of M giants. I will present a status report on what we have found until now. The project would not be possible without the scientific insights and intuition of Mike.
We would like to congratulate him here.

Ivo Saviane

My works with Mike

I will present the main results of my collaboration with Mike, over the years.

Ralph Schoenrich

What we learn from chemical evolution in the nuclear disc

Nuclear discs are likely the most understudied component in galaxies, in particular compared to their great importance for several fields. To just name a couple of these points: the whole business of constraining the dark matter halo via the bar's slowing/angular momentum balance depends crucially on us being able to constrain the flow of gas driven by the bar onto the nuclear disc, and thus the angular momentum freed in this process. With this mass flow, nuclear discs are unique laboratories that offer us a chance to break the many degeneracies in chemical evolution parameters. They offer extremely high star formation densities, a unique enrichment setup, where almost all gas is delivered via the Galactic bar from the inner disc - and not from general galactic accretion processes, and most likely different loss rates and less retention of the hot ISM (e.g. lost in Galactic fountains). By contrast, very few papers have studied these objects. I will present new models for the chemical evolution of the nuclear disc, with particular focus on work by J. Friske and J. Fraser, their link to year-long proposal activity with Mike Rich, and discuss their implications for understanding chemical evolution in general.

Mattia Sormani

The nuclear stellar disc: the hearth of the Galactic bulge

Embedded at the centre of the Galactic bulge lies the Nuclear Stellar Disc, a highly flattened and dense stellar structure that dominates the gravitational field at Galactocentric radius $30<R<300$ pc. Only very recently we have started to characterise the structure, formation and evolution of this poorly understood component of our Galaxy, thanks to new high angular resolution astrometric and spectroscopic infrared datasets that can pierce through the extreme extinction that characterises the innermost 2 degrees of the Milky Way. These measurements indicate that the Nuclear Stellar Disc is chemically and kinematically distinct with respect to the inner bulge, indicating different formation scenario. In this talk I will give an introduction to the NSD, and I will present the first fully self-consistent 6D (position+velocity) dynamical models of the NSD.

Stefano O. Souza

Identifying the fundamental bricks of the Milky Way bulge

The chemodynamical information of globular clusters provides valuable hints on the formation and evolution of the Milky Way, making them important probes for understanding the Galactic assembly time. However, distinguishing between the in-situ (genuine) and ex-situ (accreted) material is challenging when studying the innermost part of the Galaxy, which is the most obscured, complex, and mixed region of the Milky Way. To investigate the early evolution of the Galactic bulge, we performed a chrono-chemo-dynamical analysis of two globular clusters: NGC 6355 and Palomar 6, both located in the inner part of the Galaxy. The analysis involved gathering information from high-resolution spectroscopy with FLAMES-UVES, photometry with the Hubble Space Telescope, and Galactic dynamical calculations applied to both clusters. Our results show that Palomar 6 has a mean metallicity of [Fe/H]$=-1.10\pm0.09$, an α-enhancement of 0.35 ± 0.05, and an age of 12.4 ± 0.9 Gyr. Palomar 6 appears to be a typical member of the moderately metal-poor population of the bulge ([Fe/H]~-1.0), confirmed by the age-metallicity relation and individual chemical abundances compatible with other well-known bulge members. For NGC 6355, we found an age of 13.2 ± 1.1 Gyr, a metallicity of [Fe/H]$=-1.39\pm0.08$, and an α-enhancement of [α/Fe]$=+0.37\pm0.11$, with an abundance pattern compatible with the metal-poor tail of the bulge composed by the field RR Lyrae stars. The metallicity found for NGC6355 suggests a lower metallicity floor for bulge GCs. Palomar 6 and NGC 6355, along with other globular clusters, belong to the group of genuine Galactic bulge members, composed of globular clusters formed from the same material as the bulge and still reside there today.

Emanuele Spitoni

Chemical evolution models with Gaia DR3

The recent Gaia Data Release 3 (DR3) represents an unparalleled revolution in Galactic Archaeology, providing us with numerous radial velocities chemical abundances for millions of stars with all-sky coverage. We present a new chemical evolution model for the Galactic disc components (high- and low- α sequence stars) designed to reproduce the new abundance ratios provided by the GSP-spec module for the Gaia DR3 and also constrained by the detailed star formation (SF) histories for both the thick and thin disc stars inferred from previous Gaia releases. We extended previous chemical evolution models designed to reproduce APOGEE and APOKASC data to predict new Gaia DR3 chemical abundances in order to trace better both i) the young population in Gaia DR3 with evidence of chemical impoverishment and ii) the star formation history from previous Gaia releases. In the second part of my talk I will discuss effects of the spiral arms on the azimuthal variations of the chemical abundances for oxygen, iron and for the first time for neutron-capture elements (europium and barium) in the Galactic disc. We assume a model based on multiple spiral arm modes with different pattern speeds. Our model predictions are in good agreement with the azimuthal variations that emerged from the analysis of Gaia DR3 GSP-Spec [M/H] abundance ratios, if at most recent times the pattern speeds match the Galactic rotational curve at all radii.

Brian Throsbro

Detailed NLTE abundance analysis of 20 Nuclear Stellar Cluster/Disk stars

We present a detailed NLTE abundance analysis of 20 stars in the Nuclear Star Cluster and the Nuclear Stellar Disk using recently calculated NLTE departure coefficients. We compare the to results with an equivalent analysis of stars located in the disk further out in the Galaxy. Similar to previously analysed and published silicon abundances for the same set of stars, we show that even for elements such as calcium and titanium there is a significant difference between stars located in the Nuclear Stellar Cluster/Disk and stars located further out in the Milky Way disk.

Takuji Tsujimoto

Chemistry, the IMF, and migration of the Galactic bulge

Solar twin stars in the solar vicinity show ages widely distributed from 0 to 10 Gyr. From their detailed chemical abundances, we identify the Galactic bulge as the birthplace of the oldest solar twins. It means that we can look closely at bulge stars. We also argue that chemistry of the Galactic bulge must be built by a non-Salpteter IMF, based on recent findings that the upper mass bound for core-collapse supernova progenitor stars could be as small as 18 Msun.

Marica Valentini

A glimpse in the inner Galaxy using asteroseismology

In the recent years asteroseismology demonstrated its value for Galactic archaeology investigations, providing precise ages for red giant stars, reaching a precision in age better than 30%. Thanks to CoRoT, Kepler, K2, and TESS missions we obtained seismic data for a wealth of red giant stars located in different components of the Milky Way. Seismic targets in the inner part of our Galaxy have been observed by CoRoT and K2 satellites. Those targets reach ~5 kpc from the Galactic center. In this talk I will explore the CoRoT-GES, CoRoT-APOGEE, and K2-APOGEE Campaign 11 samples, characterizing the age-elements abundances distributions the inner regions of the Galactic discs. Although the reddened, faint red giants in the Bulge are still out of reach, we can have a first "seismic" insight into the Galactic inner regions.

Arianna Vasini

Galactic Archaeology with the [Mg/Mn] vs. [Al/Fe] diagram: uncertainties and caveats

In the recent literature the diagram [Mg/Mn] versus [AL/Fe] has been largely discussed, but not enough space is given to its limitations and uncertainties, in particular those related to the nucleosynthesis of these chemical species. The choice of these four elements is based on their nuclear properties and on their astrophysical production sites. Since they are all produced by different progenitors, on different time scales and with different metallicity dependencies, their behaviour in the plane [Mg/Mn] vs [Al/Fe] can unveil some information on the star formation history of the host galaxies. Our work is aimed at analyzing the uncertainties behind this diagram by adopting chemical evolution models of the Milky Way and the Large Magellanic Cloud that had already been tested.
I will discuss how, by changing the initial prescriptions such as the yields, the wind contribution and the IMF within their typical uncertainties, the trends on the [Mg/Mn] vs. [Al/Fe] can change dramatically. Therefore one can draw different conclusions from the [Mg/Mn] vs. [Al/Fe] diagram, as this combination of elements is strongly dependent on the model adopted