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Splinter Meeting F

Galaxy Evolution

Contributed Talks: F 01 . . . 09

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Related posters: P 40 . . . 49

Semi-analytic Modelling of Galaxy Formation in Different Environments

F 01
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We present results from our new semi-analytic galaxy formation code which is combined with dark matter halo merger trees from high resolution n-body simulations. In particular we investigated luminosity functions and color-magnitude relations in different environments as well as the clustering properties of the simulated galaxies.

The Evolution of Poor Groups of Galaxies

F 02
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We used a subsample of 20 poor groups of galaxies from the Mulchae et al. (2003) X-ray catalogue and a subsample of 20 groups of the RASSCALS (Mahdavi et al. 2000) to study intensively the physics, dynamics and the evolution of poor groups of galaxies. This sample consists of groups from spiral rich to early type dominated systems and systems with and without substructure. We find that early type dominated X-ray bright groups have more dominating galaxies and dwarf galaxies as well as higher velocity dispersions on average than spiral rich X-ray undetected groups. Using the fainter group members we investigated on the relationship of the velocity dispersion from N_{grp}, absolute magnitude, radial distances and substructure. We found that these variables depend on the type of the group (e.g. the behavior of spiral rich groups differ systematically from those who are dominated by ellipticals). At least for the more massive, early-type dominated groups we define the number of group members required to calculate a robust velocity dispersion. Finally we used the gained knowledge of this study on the entire Mulchaey-catalogue to make constraints on the X-ray scaling laws for a better understanding of the relationship between the kinematics of the hot gas and galaxies in these common environments.

Baryonic and Dark Halo Masses of Galaxies: A Relationship Born out of the Inefficiency of the Cosmological Star Formation

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We weigh the baryonic and the total mass density of galaxies by means of their internal motions and find that these systems have retained only less than $1/9$ of their primordial HI content by tranforming it in stars or by arranging it in gaseous disks. This value matches that obtained by integrating the star formation occurred over the whole Hubble time, and traced by the galaxies' IR and UV fluxes at different redshifts. We derive the Baryonic Mass Function of galactic structures and prove its Universal nature. From the BMF and the theorethical Halos Mass Function of of virialized objects we obtain the baryonic mass vs galaxy mass relationship, a crucial benchmark for theories of galaxy formation and, in turn, a route to relate the fundamantal properties of the dark and the ordinary matter. In detail:

• Almost 90% of the baryonic matter, once well mixed in protogalaxies with the non-baryonic matter, did not forme stars or a cold HI disk, but presently it lies outside the "luminous" regions of galaxies.
• The SFR measured in galaxies out to redshift 5 is approximately that needed to assemble the stellar content that Spirals and Ellipticals have at redshift 0.
• The primordial gas "expelled" out of galaxies or "not used", can account for the "missing baryons" intrigue: there is not need for other cosmological sites such as Galaxy Groups or failed galaxies storing the *majority* of the BBN baryonic matter.
• The theoretical halo mass fuction and the observed baryonic mass function are consistent: as a consequence $M_h \simeq 10^{13} M_\odot \,(M_b/(10^{12} M_\odot)^{2/3}$.

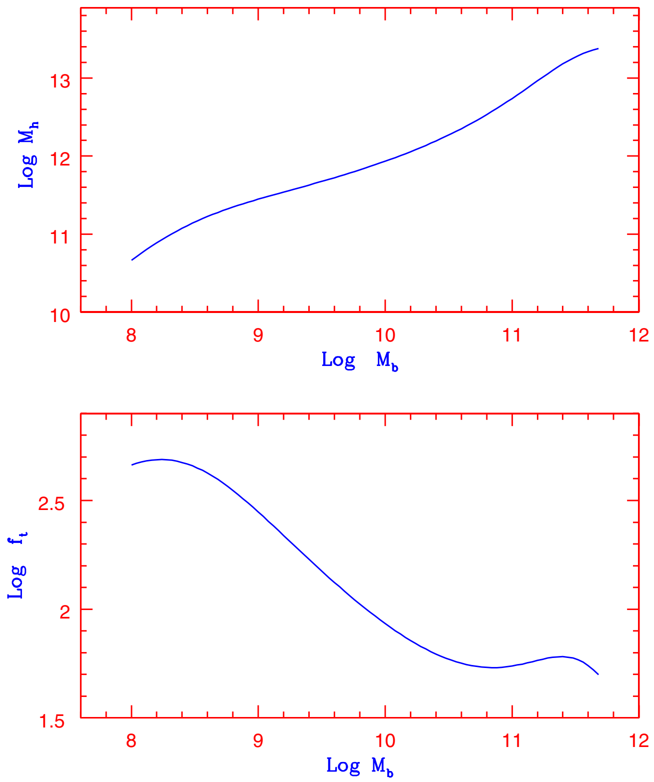

Fig. F 03. Top: The halo mass versus baryonic mass; Bottom: The dark to baryonic mass fraction as a function of baryonic mass.

Lyα Emission Galaxies in the Young Universe

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The Lyα emission line is the most conspicuous spectral feature in high-redshifted galaxies. It allows to detect and identify galaxies even at redshifts of z = 10 (Pelló et al., 2004, Astron. Astrophys., 416, L35). Despite the fact that the Lyα emission line is widely used to derive star formation rates and luminosity functions of these galaxies, the nature of the strong Lyα emission is not well understood. It is assumed that in all star forming galaxies Lyα photons are produced by recombination in HII regions ionized by massive stars. In the local universe star forming galaxies tend to show no or a much weaker Lyα emission than expected from the star formation rate derived from, e.g., Hα. This is explained by the fact that even a small amount of dust absorbs Lyα photons. The Lyα photons are resonance scattered and thus have a large optical path and, thus, they can be absorbed by dust grains. A systematic investigation of a complete sample of high-redshifted galaxies shows that the fraction of galaxies with strong Lyα emission increases with redshift (Noll et al. 2004, Astron. Astrophys., 418, 885). Lyα emission galaxies (LAE) at a redshift of z=5.7 show Lyα with much higher equivalent widths than observed in the local universe (Hu et al. 2004, AJ, 127, 563). Kudritzki et al. (2000, ApJ, 536, 19) have argued that LAE must have a very low dust content, while Kunth et al. (1998, Astron. Astrophys., 334, 11) noted that a suitable velocity field (e.g. a superwind) may cause a high escape probability of Lyα photons.

The FORS Deep Field spectroscopic survey (Noll et al. 2004, Astron. Astrophys., 418, 885) containing about 100 low-resolution spectra (R $\approx$ 200) of high-redshifted galaxies forms a good base for investigating LAEs. About 20 FDF objects show strong Lyα emission. However the low-resolution spectra are not suitable for investigating the profiles of the Lyα emission line. Therefore we obtained additional medium-resolution spectra (R $\approx$ 2000) of 10 LAE with FORS2 and the VLT.

The z = 3.148 galaxy FDF-5215 was found to have a strong Lyα emission (rest-frame EW = 30 Å). Comparison of the UV-restframe spectra with Starburst99 (Leitherer et al. 1999, ApJSuppl. Ser., 123, 3) shows that FDF-5215 is a young starburst galaxy ($>$ 20 Myr) with a SMC/LMC metallicity and a rather low dust attenuation (E(B-V) = 0.1 mag). The star formation rate derived from the Lyα emission is significantly lower than that derived from the continuum flux, showing that Lyα is attenuated relative to the continuum. Radiative transfer model computations to reproduce the double peaked Lyα profile show that the profile can be explained by a turbulent emission region and an expanding shell. An additional absorption component with a column density of about $N_H = 10^{19}$ cm^{-2} is observed blue wards of the Lyα line.

The z = 3.304 galaxy FDF-4691 has an even stronger Lyα emission (rest-frame EW = 100 Å). This galaxy has been analyzed in Tapken et al. (2004, Astron. Astrophys., 416, L1). This starburst galaxy has a SMC/LMC metallicity and a low attenuation too, but is younger than FDF-5215 (5-10 Myr). Lyα is not significantly attenuated relative to the continuum. The profile is again been modeled with a turbulent emission region and a neutral shell. But here the neutral shell was found to be almost static. The strong Lyα emission is explained by a low HI column density and a broad intrinsic Lyα emission and a essentially normal dust/gas ratio in the neutral shell.

For both, FDF-4691 and FDF-5215 the observed line widths indicate the presence of highly turbulent Lyα regions. In the case of FDF-4691 the absorbing HI shell appears be essentially static, while the HI shell of FDF-5215 is expanding. A model, which incorporates the formation and evolution of a supershell as proposed by Mas-Hesse et al. (2003, ApJ, 598, 858) might allow to explain the spectra of the observed LAEs. In this model, FDF-4691 is just starting to form a supershell, while FDF-5215 has already formed an expanding supershell.

Environmental Dependence of the Evolution of Ellipticals and S0s at $z \sim 0.2$

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The central regions of nearby rich galaxy clusters are dominated by early-type galaxies, which encompasses both elliptical (E) and lenticular (S0) galaxies. Detailed studies of the properties of these galaxies in clusters provide strong constraints on their formation and evolution.
Numerous works based on the local Universe discovered that E+S0s form a very homogeneous galaxy population (e.g., Bender et al. 1993, ApJ, 411, 153). These galaxies exhibit a small scatter in their relations of colours (e.g., Mg–$(B-V)$), M/L ratios and absorption line indices with velocity dispersion (e.g., Mg–σ). In addition, their kinematics (velocity dispersion σ) and structural parameters (effective surface brightness $\langle\mu\rangle_e$ and the effective radius R_e) form a tight correlation with small dispersion, the Fundamental Plane (FP). Most previous studies using the FP at $0.2 < z \leq 1.3$ revealed that the mass-to-light ratio of luminous galaxies evolves only mild in accordance with passive evolution models (e.g., Ziegler et al. 2001, MNRAS, 325, 1571). Further support is accumulated by the modest increase of the L_B luminosity derived from the Faber–Jackson relation (L *vs.* σ) and the weak evolution seen in the tight correlation of the Mg–σ relation at $z \approx 0.4$. These observational results are all evidence for a high redshift formation ($z_f \geq 2$) for the majority of the stars in cluster ellipticals. However, as these findings are restricted to the special environment of rich galaxy clusters the question arises, whether E+S0s are indeed one single family or rather a diverse group following different formation and evolutionary processes.
In general, semi-analytic CDM models predict a hierarchical mass assembly of galaxies through merging of subclumps and replenishment of gas from their halos. Only in the richest clusters galaxies experienced their last major merger already at $z > 2$. Thus, the population of E+S0s should be more diverse in lower density regions. For this reason, one aim of this work is to look into different environments to explore the evolution of E+S0s. Futhermore, possible differences between the properties of elliptical and S0 galaxies are investigated. In order to accomplish these studies, three large spectroscopic projects dealing with different galaxy densities have been carried out: (1) Two rich clusters, (2) Six poor clusters and (3) a field galaxy sample. All studies analyse the population of E+S0s at $z \approx 0.2$, thus assuring a reliable comparison of the properties at similar cosmic epochs.
Combining the two rich clusters Abell 2218 and Abell 2390, we investigate a total number of 98 objects, spanning a wide range in luminosity (e.g., for A 2390: $21.0 \leq B \leq 23.5$) and a wide field-of-view of $\sim 10' \times 10'$.
The second project analysis the evolutionary status of E+S0 galaxies in 6 poor clusters at intermediate redshifts of $0.2 < z < 0.3$ selected to have very low X-ray luminosities ($L_X < 5 \times 10^{43}$ erg/s) and poor optical richness class. Here, the Mg–σ relation will reveal whether there is more spread in the age/metallicity distribution than in rich clusters at similar redshift. The third program focuses on a sample of 13 field galaxies within the FORS Deep Field (FDF) using detailed *HST/ACS* morphological and structual information.
As a summary, all three projects are perfectly suited to explore the evolution of elliptical and lenticular galaxies and the combination of these studies allows to look for differences between sub-populations and/or differences in the properties of these galaxies depending on their environments. The authors acknowledge their collaborators R.G. Bower, M.L. Balogh, I. Smail and R.L. Davies and thank the VW Foundation (I/76 520) for financial support.

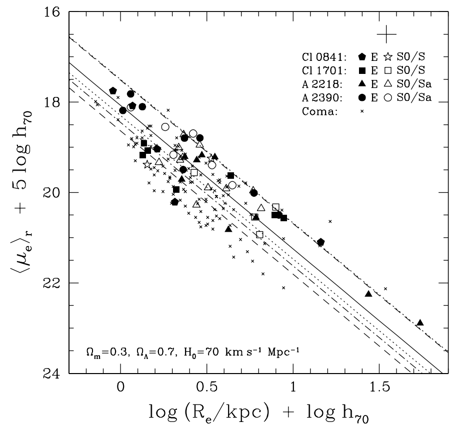

Fig. F 05. Kormendy relation for the poor clusters Cl 0841 (z=0.24) and Cl 1701 (z=0.25), compared to the rich clusters A 2218 (z=0.18), A 2390 (z=0.23) and to the local Coma sample of JFK95. On average, the poor clusters show an evolution of $\overline{m}_r$∼0.37 compared to Coma. The 34 rich cluster galaxies are brighter by ∼0.47 mag.

Chemical Properties and Kinematics of Blue Compact Dwarf Galaxies

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In this project deep long-slit spectra of a sample of Blue Compact Dwarf Galaxies (BCDs) was used to determine the physical and chemical properties of the gaseous component as well as the stellar component. The spectra revealed not only nebular emission lines but also the continuum and several absorption lines.
A set of line-strength indices sensible to galaxy metallicity and recent star formation were used (Trager et al. 1998, Longhetti et al. 1998). The comparison to theoretical indices of Single Stellar Population (SSP) models by Vazdekis et al. (1996) gives ages of 10 – 14 Gyr and [Fe/H] $\leq$ -1.68 for the stellar population.

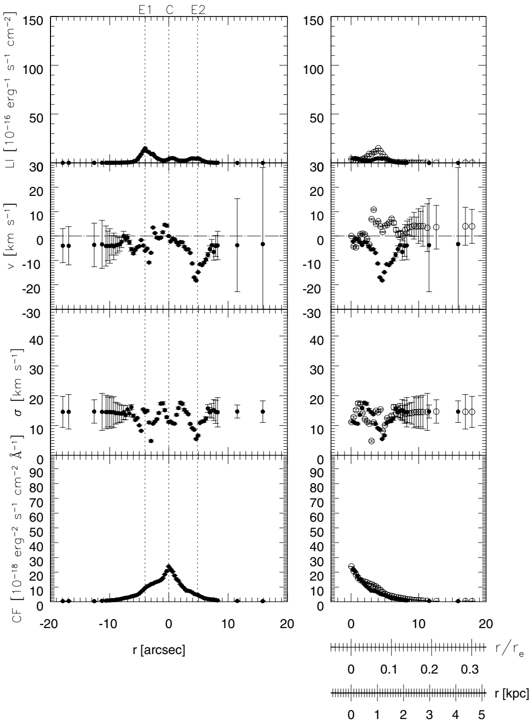

Fig. F 06. Radial profiles of line intensity, radial velocity, velocity dispersion, and continuum flux of the Hα emission line in Mrk 1090. E1 and E2 denote individual H II regions, C is the center of the galaxy.

The velocity profiles of the emission lines (see figure F 06) show peculiar motions of the ionised gas around individual spots of star formation, but low or absent ordered rotation. The velocity profiles of absorption lines also fail to show ordered rotation ($v_{\mathbf{rot}} < \mathbf{20}$ km s^{-1}). This suggests that BCDs are pressure-supported systems ($v/\sigma^* < \mathbf{0.7}$). Velocity dispersion of the stellar component are with the range of 48 – 64 km s^{-1}. By using NIR half-light radii and a simplified model, the virial masses of the sample BCDs are calculated.
Physical parameters and chemical abundance ratios of the starburst regions were obtained from dereddened line intensity ratios. [O III] electron temperatures range from 10,200 – 23,300 K, [S II] electron densities are generally low, between 100 – 189 cm^{-3}, indicating high-temperature low-density H II regions of the BCD galaxy sample. The H II regions have ages between 4.4 and 11.5 Myr and star formation rates between almost 0 and 5.3 $M_\odot$ yr^{-1}. Heavy-element abundances or O, N, Ne, S, Ar and Fe were derived and compared with results in the literature. The ^{4}He abundance of BCDs follows a stringent linear relation with O/H and N/H and can be used to determine the primordial helium abundance.
By using the results of both near-infrared surface photometry and long-slit spectroscopy, the location of the stellar component of BCD galaxies in the fundamental plane and in the Mg$_2$ – σ relation has been determined, both relate them morphologically close to dynamically hot dwarf galaxies, i.e. dwarf ellipticals.

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Trager S. C., Worthey G., Faber S. M., Burstein D., González J. J. 1998, ApJS 116, 1
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The Metallicity and Age Distribution of the Carina Dwarf Shperoidal Galaxy

F 07

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Numerous photometric analyses of the faint Carina dwarf spheroidal have revealed that it contains an intriguing variety of distinct stellar populations (e.g., Monelli et al., 2003, AJ, 126, 218), showing both a prominent old and an intermediate population as well as a younger population not older than ∼3 Gyr. This implies that Carina must have undergone several star forming (SF) episodes with at least three significant maxima. The galaxy's colour magnitude diagram exhibits a narrow red giant branch, although it is known to host populations of different ages. Yet this wide age range is counteracted by a wide spread in metallicities: presumably young and metal rich stars tend to have colours comparable to the older, more metal poor stars. This important though undesired manifestation of a pronounced age-metallicity degeneracy can be disentangled if accurate [Fe/H] measurements are obtained so that ages of individual stars can be determined from the appropriate isochrones.

In the framework of a VLT Large Programme we obtained spectra for a sample of 500 red giants in Carina. We used the multifiber spectrograph FLAMES at the VLT in low resolution mode centered at the Ca II triplet (CaT) at ~ 8550Å. Exploiting the instrument's large field of view and high multiplexing capability, this programme was designed to extend our chemical and kinematical analyses into several fields, each with diameter of 25′, well beyond the tidal radius out to 0.°8 from the galaxy's center. In these outer regions the membership probability is low, even with thorough photometric preselection, but the large number of targets ensures results for a substantial dataset of member stars, which are approved by means of precise radial velocity measurements. Combined with accurate photometry of these stars we were able to derive metallicities from the CaT equivalent widths. These were calibrated against our observations of globular clusters of known [Fe/H], based on the metallicity scale from Rutledge et al. (1997, PASP, 109, 883). With this large sample of metallicities and the large area coverage at hand we can for the first time spatially, kinematically and chemically separate subpopulations and derive ages of individual stars, from which we investigate Carina's age-metallicity relation. By comparing our data with evolutionary models constraints on the SF can be placed, thus contributing to the understanding of Carina's intricate star formation history.

We find an average metallicity of [Fe/H] $= -1.45 \pm 0.03$ (cf. Fig. F 07), which is about 0.5 dex more metal rich than the value found by Smecker-Hane et al. (1999, ASP Conf. Ser., 192, 159). The intrinsic dispersion of metallicities is found to be 0.44 dex. Also, we could detect a metallicity gradient, where the more metal rich giants tend to be concentrated towards the center.

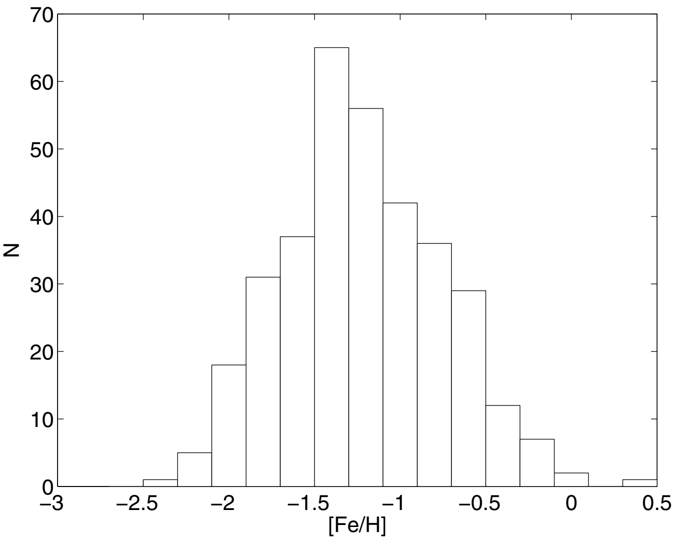

Fig. F 07. Distribution of metallicities in Carina.

The Properties of Ultra-compact Dwarf Galaxies

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Ultra-compact dwarf galaxies (UCDs) have recently been proposed as a new galaxy type (Drinkwater et al. 2003). First discovered in the Fornax cluster (Hilker at al. 1999, Drinkwater et al. 2000), UCDs seem to constitute a galaxy population that is preferentially found in the dense central region of galaxy clusters. UCDs resemble globular clusters, but are up to 100 times more massive (1-5$\times 10^7 M_\odot$) and slightly more extended. Their luminosities are comparable to those of nuclei of dwarf ellipticals ($-13.5 < M_V < -11.0$). From high resolution spectroscopy of four UCDs in the Fornax cluster, the internal velocity dispersion of their stars has been derived (see figure). These range from 24 to 37 km s^{-1}. The mass-to-light (M/L_B) ratios of the UCDs are of the order 2-4 in solar units. This is slightly higher than the M/L ratio of globular clusters, but much lower than that of dwarf spheroidal galaxies of similar mass. The photometric colours of UCDs are comparable to those of metal-rich bulge globular clusters of giant ellipticals.
Bright UCDs ($M_V < -12.0$) do not seem to exist in large numbers in galaxy clusters. The fainter ones can easily be confused with the bright globular clusters of the extraordinary rich globular cluster systems of the brightest cluster galaxies, and therefore their exact abundances are unclear (see Mieske et al. 2002, 2004). With respect to the nature of UCDs it is heavily discussed what divides them from "ordinary" star clusters. Various formation scenarios have been brought forward to explain the origin and evolution of UCDs. Two of them seem to be most promising: first, UCDs might be the remnant nuclei of dwarf galaxies that have been disrupted in the cluster environment (Bekki et al. 2003). Second, UCDs might have formed from the agglomeration of many young, massive star clusters that were created during an ancient merger event (Fellhauer & Kroupa 2002).
In order to get further insights into the nature of UCDs more observations are needed. On the one hand, high signal-to-noise spectra would be useful to derive chemical abundances and age estimates from appropriate line indices. Also their spectral energy distribution could be fit by population synthesis models. This should clarify whether there exist stellar sub-populations of different matallicities and ages within the UCDs. On the other hand, UCDs should be searched for in very different environments, from galaxy groups to very rich clusters. The existence or non-existence in certain environments can help to decide on the validity of different formation scenarios. Up-to-date, UCD candidates have been proposed in several other clusters except Fornax: Virgo, Centaurus, Hydra I, Abell 1689. Whereas in Virgo the existence of UCDs has been confirmed, their occurence in other clusters has to be proven.

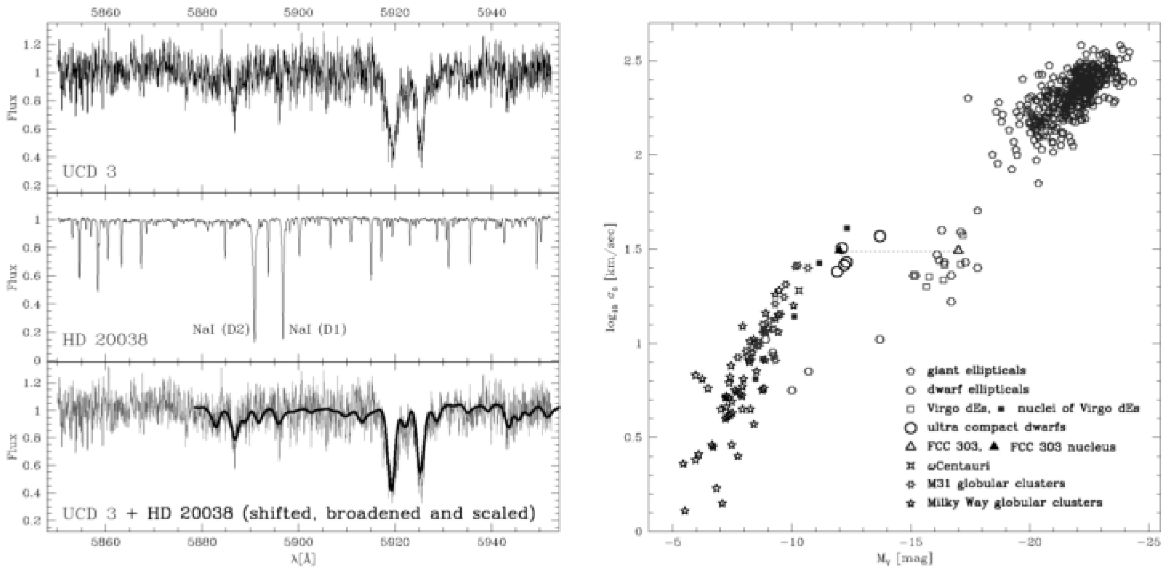

Fig. F 08. In the left panel, the high resolution spectra of an ultra compact dwarf and a standard star are shown. The lowermost panel demonstrates how the internal velocity dispersion of the UCDs was derived (in this case 37 km s^{-1}). The right panel shows a comparison of the internal dynamics (central velocity dispersion) of the UCDs with elliptical galaxies and globular clusters.

Spectroscopy of Extragalactic Planetary Nebulae as Tracers of Intermediate Age and Old Stellar Populations

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Among the classical tests for the validity of theoretical predictions concerning the formation and evolution of galaxies, integrated-light measurements of broad-band colors and of absorption line indices have played an important role. The observations can be compared with integrated light stellar population models in order to distinguish between different star formation histories and chemical enrichment. However, the presence of dust and ionized gas in the interstellar medium of elliptical galaxies has raised the question, whether or to which extent the observed gradients are real. Moreover, observational uncertainties present additional complications.

As an alternative approach, the quantitative spectroscopy of individual luminous stars in nearby galaxies is opening an independent path for the study of stellar populations. For example, using the ESO-VLT + FORS, high signal-to-noise spectra have been obtained for supergiants of spectral types B, A, and F with $V \approx 20.5$ out to NGC3621 at a distance of 6.7 Mpc. When compared to integrated light studies, the analysis of single objects has the advantage that the abundance determinations are based on detailed physical models, and that an assessment of individual errors is possible. The study of resolved stellar populations in galaxies out to the distance of the Virgo cluster has become a major science case for the proposed new generation of Extremely Large Telescopes.

Yet another method to study resolved stellar populations in nearby galaxies is through the emission line spectra of extragalactic planetary nebulae (XPN). In fact, currently the only way to measure individual abundances from old or intermediate age stars in galaxies more distant than the Magellanic Clouds is given by these objects, which are found abundantly in galaxies of all Hubble types, and on all scales of galactocentric distances. The approach has some similarities with the standard method of measuring abundance gradients from individual H II regions in the disk of spiral galaxies. However, as opposed to H II regions, XPN metallicities can be equally derived in late and early type galaxies. Abundance gradients out to large radii, where the surface-brightness is too low to measure reliable colors or absorption line indices, can be addressed with XPN, providing important constraints for galactic evolution models. Moreover, since radial velocities of XPN are measurable out to several effective radii, they are potentially useful for probing the gravitational potential of galaxies and for tracing merger events. Recently, XPN and an H II region have been detected in the intracluster space of the Virgo cluster, providing an excellent opportunity to study the properties of this unique stellar population and, potentially, their star formation history and metallicity.

Because of the good contrast provided by the bright [O III] λ5007 emission line, the detection of XPN in galaxies out to Virgo is, in principle, easy, if one uses well-established narrow-band imaging techniques. This is not so for spectroscopy, where it is necessary to measure diagnostic emission lines which are more than 2 orders of magnitude fainter than the bright [O III] line. Because of source confusion and background contamination, first attempts in the bulge of M31, in M33, or in NGC5128 have been, to a large extent, disappointing.

Based on the relatively new method of integral field spectroscopy, we have developed the technique of *crowded field 3D spectroscopy*, which has unique advantages over conventional slit spectroscopy for the observation of resolved stellar populations as summarized above. We will present results of our recent pilot study of XPN in the bulge of M31, using PMAS at the Calar Alto 3.5m Telescope. We will outline the use of AndroPASS, which is a continuing spectroscopic XPN survey in M31, and more observations in local group galaxies, for a systematic investigation of in how far XPN abundances can be used as reliable tracers of stellar populations. Future observational work will be combined with a critical theoretical comparison of conventional static ionization model predictions (“CLOUDY”) with the influence of hydrodynamical effects and nebular evolution.