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Intracluster Planetary Nebulae in the Virgo cluster: tracers of diffuse light

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Abstract. Intracluster light is of potentially great interest to studies of galaxy and galaxy cluster evolution. Recently much progress has been made in the study of intracluster star light on several fronts. Individual intracluster stars, planetary nebulae detected from the ground and red giants detected using HST, have been discovered in the Virgo cluster. These intracluster stars give the promise of studying in detail the kinematics, metallicity and age of the intracluster stellar population in nearby galaxy clusters and thereby learning about the origin of this diffuse stellar component, and the details of the cluster origin

Key words. Cluster evolution – Planetary Nebulae – harrassment

1. Introduction

Stars are usually observed to form in galaxies, that is, in disks, dwarfs and starburst. In nearby galaxy cluster, a diffuse intracluster star component has been inferred from surface brightness measurements and detection of individual stars (e.g. Arnaboldi et al. 1996; Ferguson et al. 1998; Feldmeier et al. 1998).

Intracluster light (ICL) is of potentially great interest to studies of galaxy and galaxy cluster evolution. The dynamical evolution of cluster galaxies is complex, involving poorly understood processes such as galactic encounters, cluster accretion, and tidal stripping. Various studies have suggested that anywhere between 10% and 50% of a cluster's total luminosity may be contained in the ICL, with a strong dependence on the dynamical state of the cluster. The properties of the ICL may also be sensitive to the distribution of dark matter in cluster galaxies, as simulations have shown that the structure of DM halos in galaxies plays a central role in the formation and evolution of tidal debris.

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this diffuse stellar component, and the details of the cluster origin.

1.1. Direct observations of stars in Virgo field

Ferguson et al. (1998) were the first to look for individual RGB stars in intracluster space. By using the WFPC2 on the HST to take deep F814W (I-band) images of a "blank" field located 45′ east of the central Virgo Cluster galaxy M87, they were able to detect the statistical excess of point sources over that seen in the HDF-north caused by the presence of IC red giants. Follow-up studies on a different IC field 41′ northwest of M87 confirmed an excess of objects (with respect to background HDF-N and HDF-S fields) with $I \geq 27$.

Are these stars tidally stripped from galaxies during the early phases of cluster collapse (Merritt 1984), or are they removed gradually over time via "galaxy harassment" (Moore et al. 1996)? Do all of these stars have parent galaxies or do they form *in situ*? Recent observations of an isolated compact HII region in the Virgo cluster (Gerhard et al. 2002) have shown that some star-formation activity can indeed take place in the outskirts of galaxy halos if not already in Virgo IC space. The spectrum of this isolated compact HII region is shown in Figure 1. This HII region is powered by a small star cluster of $\simeq 400 M_{\odot}$, with 1-2 O stars involved, and an estimated metallicity of Z= 0.4. The age of this HII region is ~ 3 Myr and it will dissolve by internal process in 10^8 yr: stars and metals will then be added to the diffuse stellar population nearby.

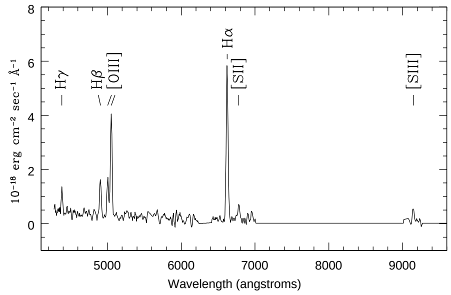

Fig. 1. Emission spectrum of the compact HII region obtained with UT4 and FORS2 in MOS mode.

2. Intracluster Planetary Nebulae as tracers of cluster evolution

Intracluster planetary nebulae (ICPNe) have several unique features that make them ideal for probing intracluster starlight. The diffuse envelope of a PN is very efficient in re-emitting 15% of the central star UV light in one bright optical emission line, the green [OIII]λ5007 Å line: PNe can therefore be detected in external galaxies out to distances of 25 Mpc and their velocities can be determined via moderate ($\lambda/\Delta\lambda \sim 5000$) resolution spectroscopy, making kinematical studies of the IC stellar population possible. PNe also trace stellar luminosity and therefore provide an estimate of the total IC light. In addition through the [OIII] λ5007 Å planetary nebulae luminosity function (PNLF), PNe are good distance indicators, therefore the shape of the PNLF provides information on the line of sight distribution of the IC starlight.

ICPNe become useful traces to study the properties (spatial distribution, kinematics, metallicity) of the diffuse stellar population in nearby clusters. Different cluster formation mechanisms predict different spatial distributions and velocity distribution functions for the IC stars. If most of the IC light originates in the initial cluster collapse, its distribution should follow closely that of galaxies in the cluster and be relaxed. On the other hands, if the IC light builds slowly with time because of galaxy harassment and tidal stirring, then a fraction of IC light may still be located in long streams, and un-relaxed structures should become easily visible in phase space.

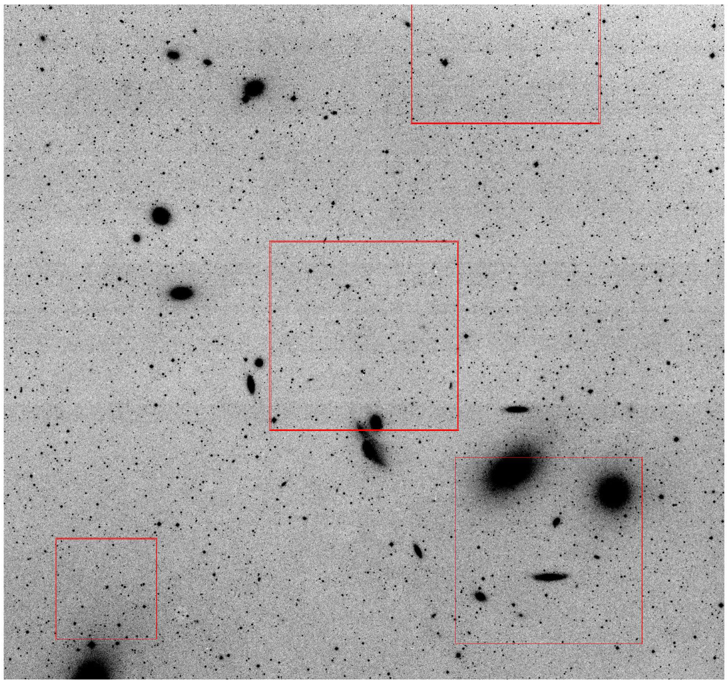

Fig. 2. Layout of our surveyed fields in the Virgo cluster. The two upper field were obtained at the ESO MPI 2.2m telescope; the lower-right field with the Suprime Cam at the 8.2m Subaru telescope. The lower-left field is from Feldmeier et al. (1998).

2.1. Narrow band field surveys

With the aim of studying the properties of the diffuse stellar light in the Virgo cluster, we have embarqued on a narrow band imaging survey with the aim of determining its radial density profile, and gaining information on the distribution function via subsequent spectroscopic follow-up of the obtained samples. Given the use of the PNLF as distance indicators, we obtain valuable information on the 3D shape of the Virgo cluster from these ICPN samples too. Large field mosaic cameras, such as the WFI on the ESO MPI 2.2m telescope and the Suprime Cam on the Subaru 8.2m, allow us the identification of the ICPNe associated with the ICSL (Arnaboldi et al. 2002, 2003; Okamura et al. 2002). These surveys require the use of data reduction techniques suited for mosaic frames, then the development and tests of selection criteria on color-magnitude diagrams (CMD), based on photometric catalogs produced with SExtractor. The spectroscopic follow-up carried out by our group at the AAT 4 m. telescope of the Feldmeier et al. (1998) Virgo sample showed that most of the emission line sources in this sample are ICPNe, because the combined spectrum of all the "sharp line" emitters showed the [OIII] 4959/5007 Å doublet. In 2002, a high S/N spectrum for a single ICPN in the Virgo cluster has been obtained for the first time at the Very Large Telescope-UT4 with FORS2 by Arnaboldi et al. (2003) and it is shown in Figure 3.

3. Properties of the diffuse light in Virgo cluster

Our goal is to estimate the fraction of light from intracluster stars in the surveyed region of the Virgo cluster. In our surveyed

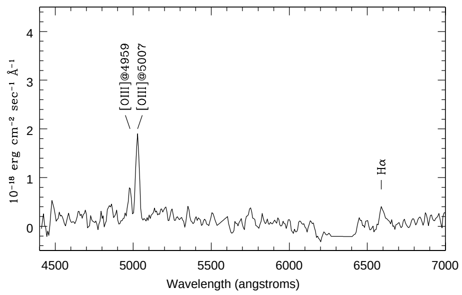

Fig. 3. One dimensional spectrum of the confirmed intracluster PN in the Virgo cluster. The [OIII] doublet and the Hα emission are visible in this large S/N spectrum.

field of 0.25 deg^2 at a distance of 1° from the cluster center, the ICPNe sample provide evidence for a total associated luminosity of $5.8 - 7.5 \times 10^9$ $L_{B,\odot}$, which translates in a surface luminosity of $0.33 - 0.57$ $L_{B,\odot}$ pc^{-2} or a surface brightness of $\mu_{B,*} = 28 - 27.7$ mag arcsec^{-2}. As discussed by Arnaboldi et al. (2002), over the range of radii probed by the survey fields, the luminosity surface density of galaxies in Virgo decreases by a factor of ~ 3, while that for the ICPNe is nearly constant. Therefore the ICPNe in Virgo are not centrally condensed as it results from the data available so far, but we need to investigate fields at larger radii to constraint the total amount of light. One needs to compare the values surveyed for the diffuse population with the luminous contribution from Virgo galaxies. If ICPNe are produced by phenomena acting locally, as the structure in the ICPNe distribution shown in Okamura et al. (2002) seems to support, then the fraction of diffuse light with respect to the computed light in galaxies in the field is 10%. On the other hand, the upper limit to this fraction is given by the comparison with the smoothed out surface brightness of galaxies from Bingelli et al. (1987), which gives 40%. Is the diffuse light in the Virgo cluster distributed uniformly? Recent discoveries of low surface brightness arcs in other nearby clusters, significant field-to-field variations in the number density of Virgo ICPNe, and remarkably inhomogeneous distribution of ICPN in single fields like the one surveyed by Okamura et al. (2002) have demonstrated that intracluster stars are not distributed uniformly.

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