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The **H**eidelberg **I**nfra**R**ed / **O**ptical **C**luster **S**urvey (HIROCS)

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Abstract

We present an outline of a survey for distant clusters of galaxies to be conducted at the Max-Planck-Institut für Astronomie in Heidelberg. The survey will use multi-colour optical and near-infrared wide-field cameras to isolate clusters up to redshifts of about 1.5 using the clustering of galaxies in 3D-space, *i.e.* RA, DEC and redshift.

1.1 Introduction

Clusters of galaxies are ideal laboratories to study the evolution of galaxies and the formation of structures in the universe. In this respect, distant clusters at various redshifts are of special importance, allowing a look back in time. However, with the advent of very large telescopes, which would allow detailed studies of these clusters, systematic surveys for high redshift clusters were still lacking. This gave the primary motivation for the ESO Imaging Survey EIS (Scodeggio *et al.* 1999), the Palomar Deep Cluster Survey PDCS (Postman *et al.* 1996), the Toronto Red-Sequence Cluster Survey TRCS (Gladders and Yee 2000) and others. None of these has, so far, published a sizeable sample of distant galaxy clusters. The main reason is, that no survey over a larger area has used near-infrared data.

Our long term aim is to acquire a sample of distant clusters of galaxies ($z \lessapprox 1.5$) for a study of their galaxy populations with the VLT and LBT. We wish to understand the evolution of the cluster population and the evolution of cluster galaxies themselves. For these follow-up studies we plan to employ Fabry-Perot-imaging to isolate emission line galaxies (Thimm et al. 1994) and photometric redshifts from multi-colour imaging to identify cluster members (Belloni et al. 1995, methods further refined in CADIS and COMBO-17, see Wolf et al. 2001, Hippelein et al. 2003).

1.2 Signatures of Elliptical Galaxies

As rich clusters are to a good fraction populated by early type galaxies, which were already in place at redshifts of 1.5 (Stanford *et al.* 1998), we use the spectral signatures of these to identify regions, where these objects cluster. The most prominent feature in the spectra of elliptical galaxies is the 4000 Å break. Bracketing this break by two filters object colours derived from such data indicate elliptical galaxies. The *B*- and *R*-band are suitable to detect galaxies at redshifts around 0.5. The optical limit is increased to a redshift of about one, when the *R*- and the Gunn-*z*-filters bracket the 4000 Å break. However, for red-shifts above unity infrared data are mandatory to find rich clusters (Fig. 1.1). The signature of the 4000 Å break can be strengthened considerably by using multi-colour imaging data and

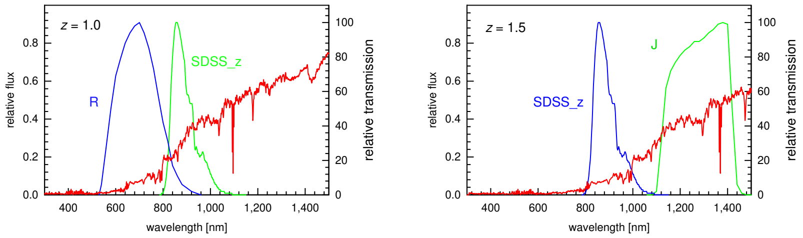

Fig. 1.1. The spectrum of an elliptical galaxy redshifted to $z = 1.0$ (left) and to $z = 1.5$ (right). Transmission curves of filters bracketing the 4000 Åbreak are indicated. At redshifts above unity an infrared band becomes mandatory.

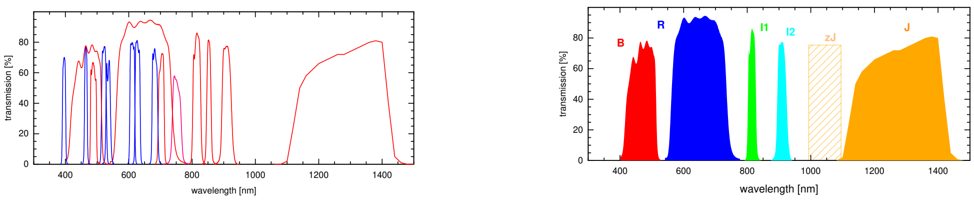

Fig. 1.2. The transmission curves of the full CADIS filter set (left). For HIROCS the number of filters as to be reduced (right) to a suitable subset.

photometric redshifts derived from these. However, the number of filters used in a cluster survey is certainly limited to only a few to avoid excessive observing time.

1.3 Optimizing the Filter Set

We have used the CADIS multi-colour imaging survey (Wolf *et al.* 2001b) for optimising the filter set to be used in HIROCS. CADIS uses four broad bands (B, R, J and K') and 13 mediumband filters. A method was developed to classify objects based on these colours and also estimate redshifts for quasars and galaxies (Wolf *et al.* 2001a). For our tests we here also introduced an intermediate filter zJ between the z and J band (sometimes called Y), which is not contained in the CADIS data set. To obtain object fluxes in this filter we had to take the best-fitted object spectrum from the CADIS classification procedure and use the spectral library. Together with the spectral response of the instrument we calculated the flux expected in zJ for each object.

Restricting the filter set for the classification to various subsets of the CADIS set (Fig. 1.2) we have classified again all objects up to $I = 23^{\mathrm{mag}}$ and compared the results, mainly the redshifts, with the genuine CADIS classification (Fig. 1.3). Without the I- or the J-band data the scatter above redshifts of one becomes excessively large. Including the zJ-band data, however, does not significantly improve the redshift classification. The final HIROCS filter set will thus comprise the filters B, R, SDSS_i, SDSS_z and J. As i and z are not optimised in terms of low night sky emission, we currently consider the use of the CADIS filters $I1$ and $I2$, which are located in the gaps of night sky emission at 820 and 915 nm. Tests with data of the CADIS 16h-field, for which SDSS_i, SDSS_z as well as CADIS $I1$ and $I2$ are available, are currently under way.

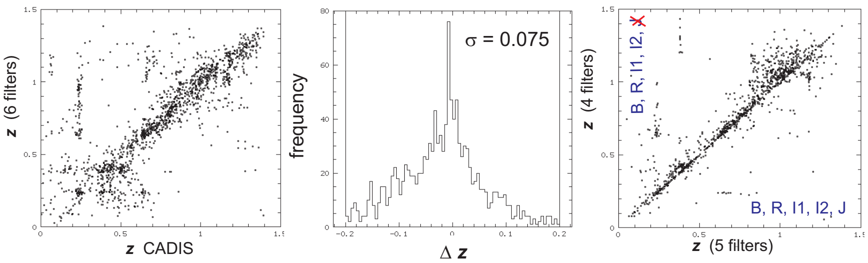

Fig. 1.3. Comparison of classification results from a reduced filter set as it will be used in HIROCS with the results from the full CADIS data set. In the panel at left the zJ-filter is included. The central panel shows the resulting uncertainty in photometric redshift if six filters are used (B, R, CADIS $I1$, CADIS $I2$, zJ and J). As could be shown, the information provided by the zJ filter is redundant and it can be omitted. However, if the J-band is also dropped, the redshifts above unity become very uncertain (right).

1.4 Finding the Clusters

For each object classified by the multi-colour analysis one can calculate the projected Abell radius (or a fraction thereof) according to its redshift z_0 and count the number of objects $N_{\rm obj}$ within this radius having a relative velocity with respect to the object picked less than a given threshold:

$$\frac{v}{c} = \frac{(1+z_1)^2-(1+z_0)^2}{(1+z_1)^2+(1+z_0)^2} \leq \left(\frac{v}{c}\right)_{\rm limit}.$$

Any excess in $N_{\rm obj}$ over the values expected for a random distribution of objects points to a potential cluster of galaxies.

Evidently the procedure established in the Toronto survey (Gladders and Yee 2000) using the red sequence can also be employed with the HIROCS data set as can be other methods. We plan to use these too and compare the final results.

1.5 Area to be Covered by the Survey

Bartelmann and White (2002) have calculated how many clusters could be detected in the SDSS by means of their surface brightness enhancement. From their work we expect more than 5 clusters per square degree with redshifts above unity. This is certainly a lower limit for our survey. Therefore we are aiming at a survey area of >10 square degrees to establish a statistically significant sample of distant clusters.

1.6 Fields

The MUNICS S2-, the COMBO-17 S11, and the CADIS 16h-field all provide extensive calibration data and many galaxies and quasars with slit spectra. To make use of these we decided to place our survey stripes across these fields. The location of a fourth field is still open.

1.7 Instrumentation

As survey instruments we will use the wide-field imager LAICA for the optical and OMEGA2000 for the near-IR. Both are prime focus instruments at the 3.5m-telescope on

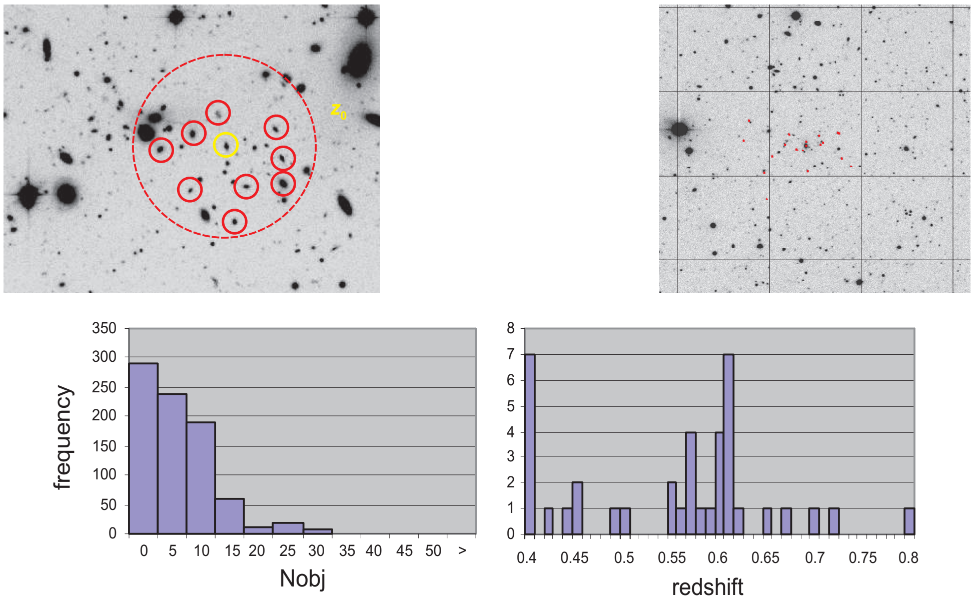

Fig. 1.4. Tests with the data for the CADIS 1h-field. The diagram at above left illustrates the procedure to establish the counter $N_{\rm obj}$: For each object classified as a galaxy (redshift z_0) the number of galaxies within a given fraction of the projected Abell radius (dashed) at that redshift z_0 and within the relative velocity limits (circled in red) are counted. The histogram at lower left shows the distribution of $N_{\rm obj}$ in the CADIS 1h-field ($I \leqq 23^{\rm mag}$). An excess above $N_{\rm obj} \gtrapprox 20$ is evident. The redshift distribution of objects with $N_{\rm obj} \geqq 20$ is shown at lower right. A clumping around $0.55 < z < 0.63$ is conspicuous. These are mostly galaxies (red dots) centered around a bright galaxy with photometric redshift $z = 0.603 \pm 0.004$, the central galaxy of a likely galaxy cluster (upper right).

Calar Alto (Spain, see Fig. 1.5). For the equatorial fields in the B- and R-bands we also use the WFI at the ESO/MPG 2.2m-telescope on La Silla.

LAICA uses four 4k × 4k CCDs with pixels $0\farcs225$ wide. Four exposures are required to cover a contiguous one square degree. OMEGA2000 uses a single 2k × 2k Rockwell HgCdTe detector with $0\farcs45$/pixel. The camera was commissioned in January 2003 and will be offered to the community in summer 2003.

1.8 Required Observing Time

Integration times (Tab. 1.1) were calculated to detect on a 5σ level an elliptical galaxy at redshift 1.5 which is $1^{\rm mag}$ fainter than L^*. Seeing was assumed to be $1\farcs5$. Evolutionary corrections are taken from Poggianti (1997). In Tab. 1.1 the z-filter is representative for the two long-wavelengths CCD bands, which still have to be decided upon. The zJ will not be used and the time freed will be available for the CADIS-$I1$ / SDSS_i observations.

1.9 Current Status

First LAICA observations were taken in July 2002, WFI observations started in December 2002. OMEGA2000 observations will commence in summer 2003.

Fig. 1.5. LAICA (left) and OMEGA2000 (right) on the 3.5m-telescope.

Table 1.1. *Estimate of required observing time.*

	m^*_{k-corr}	E-corr [mag]	m_{lim}	$f_{\lambda lim}$ [W/m^2/nm]	sky [R/Å]	Δt [sec]	S/N	Δt/sqa. degree [ksec]
B	29.0	-6.0	24.1	1.51E-20	0.5	1500	19.0	6
R	27.3	-2.9	25.4	1.32E-21	1.1	4000	5.3	16
z	25.0	-2.5	23.5	3.57E-21	2.0	6000	5.2	24
zJ	23.7	-2.0	22.7	4.27E-21	1.7	1600	5.0	26
J	22.3	-1.6	21.8	5.58E-21	53.0	3000	5.1	48
				nights/squ. degree (with overhead)				5.0

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