Mapping the Properties of SDSS Galaxies with the VIMOS IFU

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We present initial results from our VIMOS IFU study of galaxies selected from the Sloan Digital Sky Survey. Large fibre-based surveys like SDSS have made a major contribution to our understanding of processes that shape galaxies. The SDSS results, however, are derived from integrated properties over the area of the fibre. As the angular extent of galaxies is usually considerably larger than the fibre diameter, the SDSS results are biased toward the nuclear properties of galaxies. By contrast, data obtained with an Integral Field Unit (IFU) are free of aperture bias.

In the increasingly well-defined cosmological framework, the broad outline of galaxy formation is thought to be well understood. Briefly, galaxies form in the gravitational wells of dark matter halos from gas that got trapped there after losing kinetic energy through cooling or dissipative shocks. However, galaxy-formation models generally overpredict the fraction of gas that is locked up by a factor of about five compared to observations. To overcome this problem a feedback mechanism is needed to remove gas from galaxies. The detailed physical processes that govern this are not well known and are at present hard to constrain observationally (Wilman et al. 2005, Bower et al. 2006).

The vast database accumulated by the SDSS survey (York et al. 2000) is ideally suited to constrain many of the fundamental physical processes that drive galaxy evolution. For example, Tremonti et al. (2004) find evidence for stellar-wind feedback in the SDSS data from the observed mass – metallicity relations. Unfortunately, mass cannot be measured directly from the SDSS data and the derived metallicities could be affected by aperture bias.

Another essential ingredient of galaxy evolution, intimately connected to feedback, is the star-formation history. Quantifying the star-formation rate from the past to the present is therefore an active area of research. The largest study to date (Brinchmann et al. 2004) uses ~ 10^5 galaxies in the SDSS database. They conclude that the present-day star-formation rate is now at about a third of the average value over the lifetime of the Universe. As the SDSS apertures typically sample less than half of a galaxy's size, they need to correct their results for this missing information using resolved images and procedures based on nuclear correlations between SFR and colour.

Aperture bias

Large surveys such as the SDSS provide the statistically most complete samples of fundamental galaxy properties. However, the SDSS properties represent integrated quantities derived over the central three arcsec only. Consequently, the results suffer from highly significant aperture effects (Brinchmann et al. 2004, Wilman et al. 2005, Kewley et al. 2005) that bias the results toward the bulge and nuclear emission properties. Galaxies, however, can exhibit strong colour gradients. Correcting emission line strengths for aperture effects when gradients are present is uncertain at best, and compounded by unknown contributions from variations in metallicity and age. With IFU observations the bright emission lines are spatially resolved and can be traced over the whole galaxy. These data are therefore free of aperture effects.

This project

To quantify internal variations in the emission line properties of SDSS galaxies we have begun a project to map a number of them with the VIMOS IFU. In order to build up a sample of galaxies in a modest amount of observing time we selected galaxies from the SDSS database with moderately strong Hα emission (minimum equivalent widths of 2 nm). This could potentially bias us toward selecting objects with strong nuclear emission such as AGN. However, it ensures that each galaxy requires only 60 minutes of observing time to build a detailed map of spatially resolved star formation and metal abundance. We use the MR mode of VIMOS as its wavelength coverage (~ 450 to 900 nm) and spectral resolution closely match the SDSS fibre observations.

The sample was constructed to uniformly cover the redshift range up to 0.1. Above these redshifts aperture effects become less important. We visually inspected the SDSS images of candidates to assess their morphology and inclination and selected a total of 24 galaxies to guarantee that after binning the data in a variety of ways (in redshift, size, or luminosity) we still obtain statistically significant results for each bin.

The selected galaxies are all at intermediate inclination. While not the main goal of our project, this allows us to constrain the velocity fields and, hence, the enclosed mass profiles of the galaxies in our sample. The mass distribution as a function of radius is a key prediction of hierarchical galaxy formation scenarios. Observational constraints on velocity fields are scarce even in the local Universe. The SDSS database itself contains no kinematical information other than the recessional velocity of a system. The total masses of SDSS galaxies are normally estimated indirectly, usually from their total magnitude.

In Period 76 we obtained data for 12 of the galaxies in our sample. A further 12 systems are scheduled for observation in Period 78. The VIMOS IFU provides data sets of the form (RA, DEC, λ). Four examples of our data are shown in Figure 1. For each galaxy we show an image slice (i.e. a cut in λ through a data set) in the light of Hα and a composite broadband image.

Preliminary results

The emission line properties are derived by fitting Gaussian profiles simultaneously to the Balmer lines (Hα, Hβ) and strong

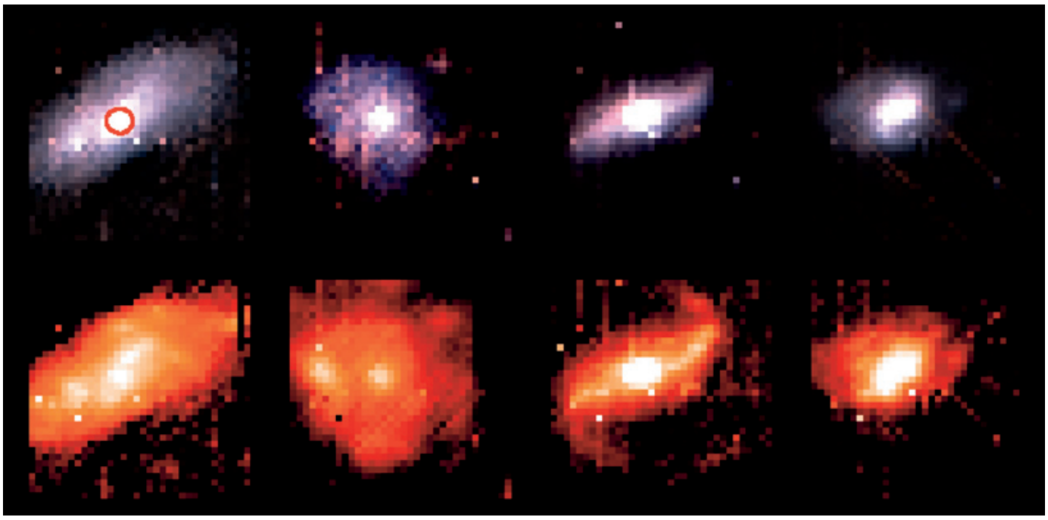

Figure 1: Examples from our sample of SDSS galaxies observed with the VIMOS IFU. Shown from left to right in ascending redshift order are sdss6, sdss13, sdss22 and sdss9 (the names simply reflect the RA ordering in our selected sample) at redshifts of 0.028, 0.034, 0.074 and 0.106 respectively. In the top panels composite colour images derived from the VIMOS IFU data extracted over the SDSS *r* and *i* bands are shown. The corresponding Hα images are shown in the bottom panels. Panels measure 27 by 27 arcsec and each pixel is 0.67 arcsec. For comparison the SDSS fibre size is indicated by the red circle in the top left panel.

forbidden transition lines ([O III], [N II]) after removing the continuum using a sliding median. In our full analysis we will follow Tremonti et al. (2004) and fit the continuum with an optimal stellar template model. Subtracting this model will correctly take any underlying absorption into account that may otherwise significantly affect our results (in this article we assume an average correction for absorption of EW = 0.2 nm). This model also provides a handle on the stellar kinematics.

To quantify aperture effects we examine the cumulative line flux and line strength of the Hα lines in the four galaxies used in this article (Figure 2) as a function of aperture size. Not surprisingly, the cumulative flux grows systematically beyond the radius of the SDSS aperture. When extrapolating to larger radii it is frequently assumed that the line flux and continuum properties follow the same trend. But as the bottom panel illustrates the line-flux to continuum-flux ratio (that is, equivalent width or line strength) is not always constant. Extrapolating quantities derived from the SDSS database to larger radii is therefore fraught with difficulties.

Systems harbouring an AGN such as sdss22 display the strongest variation in cumulative line strength. A useful way to classify the activity level of a galaxy is by determining its location in a diagnostic BPT diagram (Baldwin, Phillips and Terlevich 1981). In Figure 3 we reproduce the BPT diagram derived by Brinchmann et al. (2004) using ~ 10^5 SDSS galaxies. This diagram of emission line ratios has a

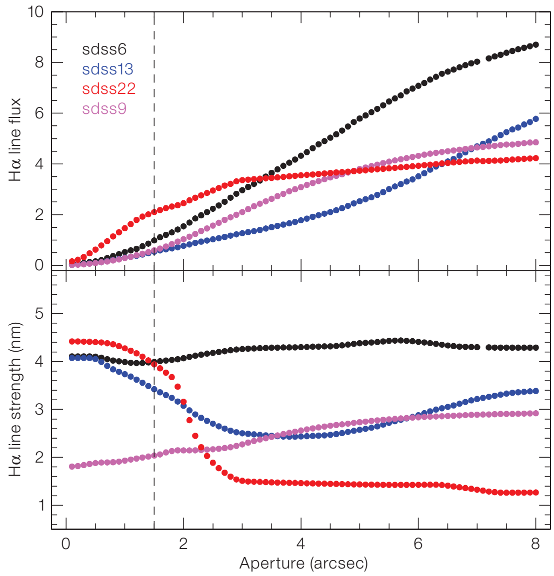

Figure 2: Cumulative quantities derived using a software aperture with increasing radius and centred on the nucleus of each galaxy. The cumulative Hα line flux (arbitrarily normalised) shown in the top panel grows monotonically as the galaxies in our sample are larger than the radius of the SDSS fibre (dashed line). The continuum flux does not necessarily follow the same trend. This is illustrated in the bottom panels where the cumulative line strength of the Hα emission line is shown. This can lead to strong aperture bias when extrapolating the SDSS results to larger radii.

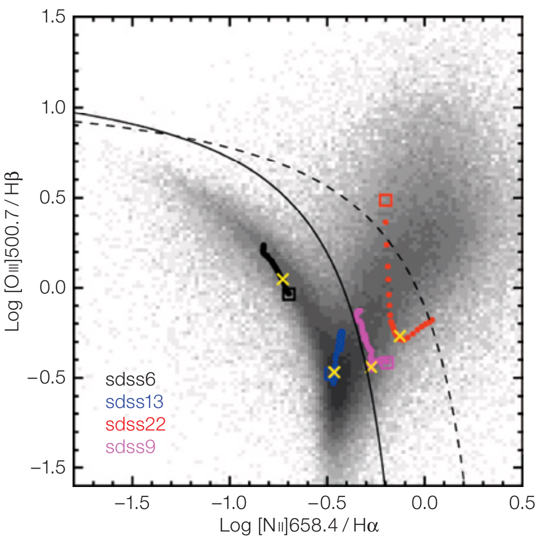

Figure 3: To quantify the effect of varying aperture size on the derived metallicities we plot the VIMOS IFU results as 'tracks' in a BPT diagram. The starting point (i.e. smallest radius) of each track is highlighted by the open squares. The crosses mark where the radius is equal to the SDSS fibre radius. The underlying grayscale image shows the 'raw' emission line measurements by Brinchmann et al. (2004, see also *http://www.mpa-garching.mpg.de/SDSS/#dataprod*) of some 500 000 SDSS galaxies. The lines divide the sample into star forming (left), hybrid (centre) and AGN (right).

characteristic 'double-wing' shape. Normal galaxies are found on the left branch while active systems occupy the top right part. Overplotted on this diagram are the results of our cumulative emission line analysis. Varying the size of the aperture can have an impact on the location of a galaxy within this diagram. But, as the four examples used here show, it would not necessarily change the classification of a system.

Apart from the large variation in the single AGN system, all systems show at least 0.2 dex change in their line ratios as a function of radius. This translates roughly into 0.1 dex in metallicity, a value that is not inconsistent with the 0.13 dex average difference of Kewley et al. (2005) for large galaxies and which they claim is substantial. At this preliminary stage it should be kept in mind that different methods to estimate metallicities from strong emission lines can yield values that differ considerably.

Our project aims to quantify the internal variations of emission line properties in a self-consistent manner. A by-product of these observations are emission line velocity fields. The data analysis yields mean line positions for every spatial location in our data sets. An example is shown in Figure 4 where the velocities are derived from the mean positions of the Hα and [N II] lines.

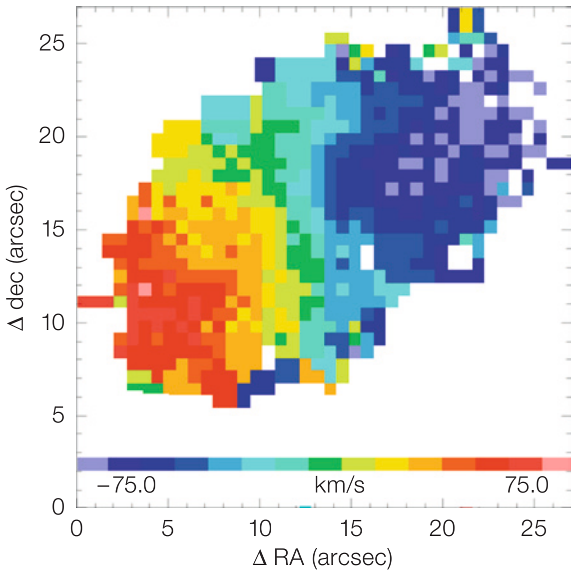

Figure 4: Together with metallicity, mass is another key observable used to quantify galaxy evolution. However, it can only be estimated indirectly from the SDSS database using magnitude as a proxy. Our VIMOS IFU data analysis yields emission line velocity maps with which the circular velocity, and hence the enclosed mass, can be constrained accurately. In the preliminary example shown here the velocity field is derived from a three-component Gaussian fit to the Hα + [N II] lines.

Flores et al. (2006) recently demonstrated the power of IFU observations to constrain internal kinematics at intermediate redshifts. They used the Flames IFU buttons to reach the striking conclusion that only one in three galaxies is dynamically unperturbed at redshifts of ~ 0.5 and thus presumably undergoing rapid evolution. It will be very interesting to compare this to the kinematical properties derived from our lower redshift galaxies.

Aperture effects are important. To investigate the accuracy of the various correction methods we are observing a small sample of SDSS galaxies. To fully probe the data-space covered by SDSS requires a much larger sample. As our results show, such a sample can be obtained efficiently with the VIMOS IFU even in relatively poor atmospheric conditions.

References

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The barred spiral galaxy NGC 613 was imaged with the FORS1 and FORS2 multi-mode instruments (at VLT MELIPAL and YEPUN, respectively) in December 2001. The images were taken by Mark Neeser (Universitäts-Sternwarte München, Germany) and Peter Barthel (Kapteyn Astronomical Institute, the Netherlands) during twilight. The galaxy was observed in three different wavebands for up to 300 seconds per waveband, and the image obtained in each waveband was associated to a colour: *B* (blue), *V* (green) and *R* (red). The full-resolution version of this photo retains the original pixels. Note the many arms and the pronounced dust bands. North is up and East is left. Neeser and Barthel also performed the first stage of the image processing; further processing and colour-encoding was made by Hans Hermann Heyer and Henri Boffin (ESO).

(From ESO Press Photo 33a/03)