Integral field spectroscopy on small aperture telescopes

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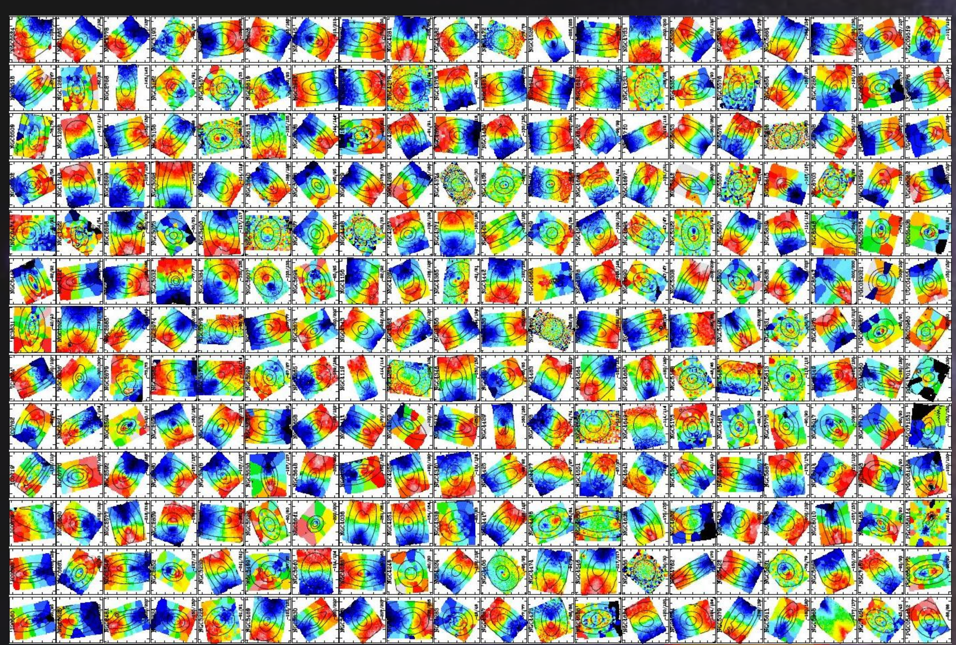
Abstract

The art of integral field spectroscopy is one that has come on in leaps and bounds over the last decade, and is really pushing our understanding of galaxy formation and evolution. Of the 30 such instruments around the world, all but one are on 2+metre class telescopes. It is now possible to exploit recent advancements in small aperture telescopes (<0.5m) to enable an integral field spectrograph with a performance that allows taxonomy via optical emission line analysis (Hβ to SII). An integral field spectrograph on this class of telescope has the ability to obtain data on 10^2–10^3 nearby galaxies (z~0.003) in 100 nights probing a new parameter space to aid our understanding of galaxies.

Scientific Rationale

Integral field spectroscopy is the ability to obtain spatially resolved spectral data of a source in a single exposure, in most cases the observation is of a galaxy. In doing so it can overcome the single aperture biases found in galaxy surveys such as 2dFGRS and SDSS (Lahav & Suto, 2004) & (Bland-Hawthorn et al., 2011). These biases mean the spectrum obtained is not a true representation of the galaxy. If the galaxy is larger than the aperture then only a section of the galaxy is being observed, and if the galaxy is smaller than the aperture the spectrum is a convolution of the light from all parts of that galaxy. Integral field spectroscopy greatly reduces these biases, resulting in more accurate data and its interpretation. This has lead to an increase in the use of integral field spectrographs over the last decade, with ~30 in operation around the world. The most notable is SAURON (Emsellem et al., 2007), which when used in the ATLAS 3D survey (Krajnović et al., 2011) has produced the largest sample of galaxies observed using the technique of integral field spectroscopy (see Figure 1a). It is a fact of all science that the larger your sample is the more accurate your data is. Given this, multi-object integral field spectrographs are now being implemented e.g. SAMI (Croom et al., 2011),which has the ability to observe up to 13 galaxies at once using Hexabundles (Bland-Hawthorn et al., 2011) (see Figure 1b). SAMI has the potential to observe 10,000 galaxies in 100nights.



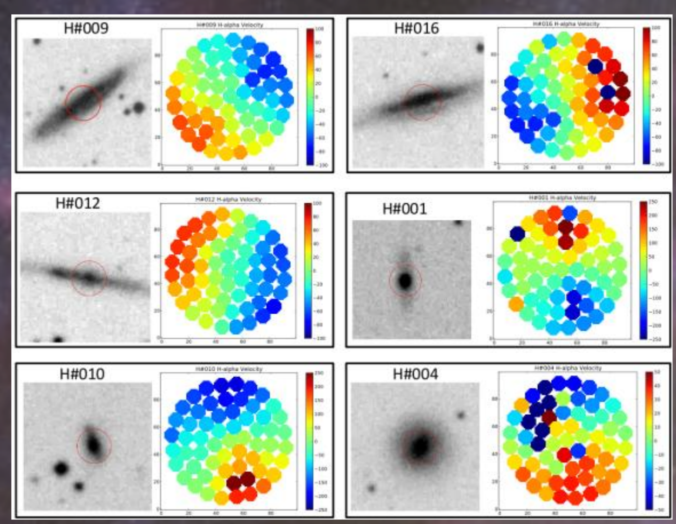


Figure 1a (left) & 1b (right) – (left)Velocity fields of 260 galaxies observed as part of the ATLAS 3D survey (Krajnović et al., 2011). (right) Velocity fields of 6 galaxies taken during the commissioning of SAMI (Croom et al., 2011).

Obtaining data cubes of galaxies (2 spatial axes and 1 wavelength axis) means that the spectrum from each spatial pixel (spaxel) can be analysed. One of the key methods is spectral emission line analysis using the BPT diagram (Baldwin, Phillips,& Terlevich, 1981) (see Figure 2). Depending on the ratio of different line strengths, the location of the spaxel on a BPT diagram reveals information about the ionisation mechanism responsible for the emission. The three main mechanisms are star forming regions, active galactic nuclei (AGN) and low ionisation nuclear emission regions (LINERs). Table 1 shows the criteria that needs to be met for the classification of ionisation mechanisms.

With the ability to place individual spaxels on a BPT diagram, the problems of single aperture biases are significantly reduced. This is displayed clearly in Figure 3 where the green points are the individual spaxels and the red triangle is the integration of all the green points. If a single aperture were used to observe this galaxy (H#009 from Figure 1b) then it is obvious that a bias towards star formation is present. In reality the spaxels that cover the disk of the galaxy are the green points clustered in the star formation region, and the points spreading up to the AGN region are the spaxels covering the central part of the galaxy, which is what is expected.

Integral field spectroscopy on telescopes with apertures greater than 2 metres have the ability to probe galaxies at redshifts z~0.001 to z~0.1 depending on the instrument parameters. The difficulty comes with obtaining time on the telescopes, in addition to the cost of such instruments. Effort is then directed towards finding a way to perform integral field spectroscopy using small aperture telescopes (<0.5m) to not only pursue similar science goals but also collect large samples of galaxies (10^2–10^3). When achieved, it will open up integral field spectroscopy to a wider community as there are thousands of small aperture telescopes world wide.

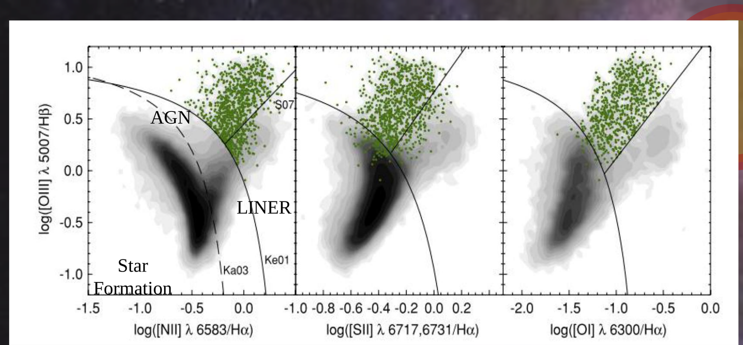


Figure 2 - (Schawinski et al., 2010) – BPT diagrams for different emission line ratios. If the spaxel is found in the lower left then emission is due to star formation, top then an AGN, right then a LINER.

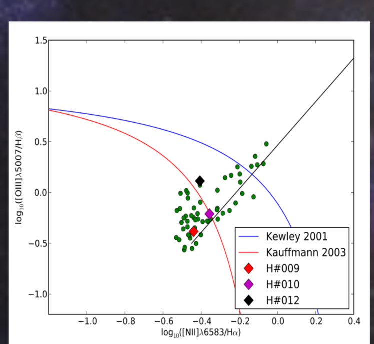


Figure 3 – (Croom et al., 2011) – BPT diagram with placement of individual spaxels from H#009 (Figure 1b), shown by the green points. The red triangle is the integration of all spaxels.

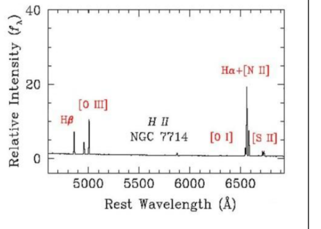
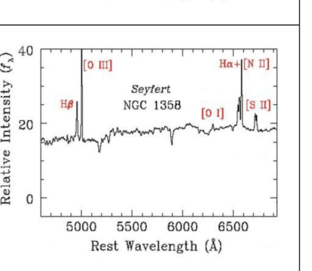
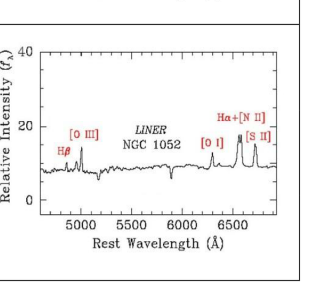
Primary source of ionisation	Standard line ratio formula for classification (Kewley et al., 2006)	Example spectra for each classification (Ho et al., 1993)
Star Formation	$\log\left(\frac{[OIII]}{H\beta}\right) < \frac{0.61}{\left(\log\left(\frac{[NII]}{H\alpha}\right) - 0.05\right)} + 1.30$	
	$\log\left(\frac{[OIII]}{H\beta}\right) < \frac{0.72}{\left(\log\left(\frac{[SII]}{H\alpha}\right) - 0.32\right)} + 1.30$	
	$\log\left(\frac{[OIII]}{H\beta}\right) < \frac{0.73}{\left(\log\left(\frac{[OI]}{H\alpha}\right) + 0.59\right)} + 1.33$	
AGN	$\log\left(\frac{[OIII]}{H\beta}\right) > \frac{0.61}{\left(\log\left(\frac{[NII]}{H\alpha}\right) - 0.47\right)} + 1.19$	
	$\log\left(\frac{[OIII]}{H\beta}\right) > \frac{0.72}{\left(\log\left(\frac{[SII]}{H\alpha}\right) - 0.32\right)} + 1.30$	
	$\log\left(\frac{[OIII]}{H\beta}\right) > \frac{0.73}{\left(\log\left(\frac{[OI]}{H\alpha}\right) + 0.59\right)} + 1.33$	
LINERs	$\log\left(\frac{[OIII]}{H\beta}\right) > \frac{0.61}{\left(\log\left(\frac{[NII]}{H\alpha}\right) - 0.47\right)} + 1.19$	
	$\log\left(\frac{[OIII]}{H\beta}\right) > \frac{0.72}{\left(\log\left(\frac{[SII]}{H\alpha}\right) - 0.32\right)} + 1.30$	
	$\log\left(\frac{[OIII]}{H\beta}\right) < \frac{0.73}{\left(\log\left(\frac{[OI]}{H\alpha}\right) + 0.59\right)} + 1.33$	

Table 1 – Criteria for ionisation mechanism classification. It is accepted that only two of the criteria need to be met for classification, but for first order purposes the OIII/Hβ v NII/Hα ratio can stand alone.

Instrument

To be able to perform integral field spectroscopy on small aperture telescopes, there are a few of parameters that are required: (Figure 4, 5 and 6 display these constraints)

1. A spectral resolution of less than 10Å to be able to accurately resolve the Hα6563Å emission line from the NII6584Å line, and acquire accurate positions of the lines to measuring Doppler shifts for velocity fields.
2. A spectral bandwidth of ~2000Å to capture the primary emission lines from Hβ4861Å to SII6731Å so the emission line ratios OIII5007Å/Hβ4861Å, NII6584Å/Hα6563Å and SII6717,6731Å/Hα6563Å can be used for placement on the BPT diagram.
3. A signal-to-noise ratio (SNR) of greater or equal to 10 such that the line strengths can be accurately measured.

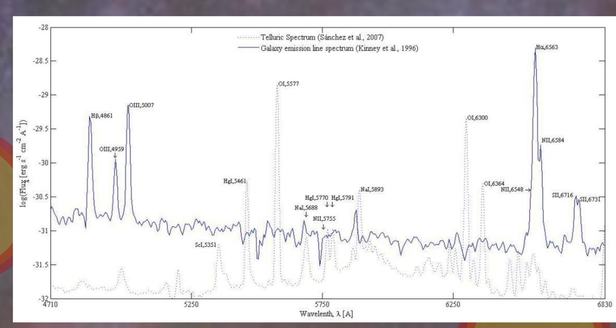


Figure 4 – Template galaxy spectrum (solid blue line) with the telluric spectrum overlaid for reference (dotted blue line). Both have a resolution of ~10Å. Note the bandwidth to capture Hβ to SII.

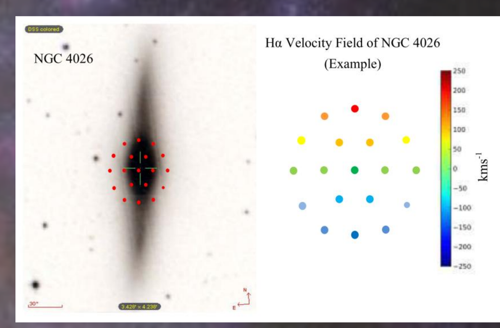


Figure 5 – Example Hα velocity field with maximum resolution of ~75kms^{-1}.

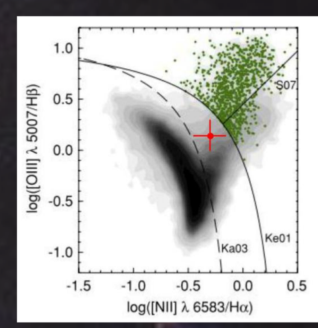


Figure 6 – BPT diagram with one spaxel placed (red) showing the error bars for a SNR ~10.

Taking into account these constraints, recent advancements in small aperture telescopes and their respective instruments make this possible. The Meade LX200 16-inch telescope (Figure 7) and the SBIG Self-Guiding Spectrograph (SGS) (Figure 8) are both widely used around the world, so they will be the instruments looked at here. The LX200 has an f/10 beam giving a focal plane of ~40mm with a plate scale of ~52arcsec/mm. The SBIG SGS, when using the 150 l/mm grating and a slit width of 50μm, has a bandwidth of ~2120Å and a resolution of ~7Å. The CCD that the SBIG SGS uses is the ST-7E with an average QE of ~65%. The best way to combine the LX200 with the SBIG SGS for the use as in integral field spectrograph is via an optical fibre integral field unit. As the slit of the SBIG SGS is ~5mm in length, a maximum of 40 fibres can be used that each have a 50μm core and 125μm. Focal ratio degradation and attenuation in the fibre optics is not an issue as the length is less than 5m, meaning that communication grade fibre can be used. The theoretical efficiency of this setup is ~20%, but a working efficiency of 5% shall be used as it is more realistic.

The best way to make an integral field unit with less than 40 optical fibres is a fibre bundle. The Hexabundle (Bland-Hawthorn et al., 2011) is a good example of this, as used in SAMI (Croom et al., 2011). The decision to remove the fibre buffer before making the fibre bundle is one of fill factor and overall aperture size. To make this as easy as possible, the buffer is left on as the fibres can break easily when it is removed. Concentric fibre bundles come in sizes of 7 fibres, 19 fibres and 37 fibres. As 37 fibres is near the limit of the SBIG SGS, 19 will be used, allowing 4 sky fibres. In the end, the working efficiency of 5% means a 20min exposure of a 13mag/arcsec^2 source will give a SNR ~10, with a ~1arcmin field of view.

A first-order reduction of the Third Reference Catalogue of Bright Galaxies (RC3) (de Vaucouleurs et al., 1991) produces a suitable target list of ~650 galaxies, where the best from each class of galaxy is given in Figure 9. Further reduction of other catalogues can add more targets to this list.

There is only one integral field spectrograph for use on a small aperture telescope currently in development, BASIS, summarised in the following section.

Figure 7 – (Galactica, 2012) – A Meade LX200 16-inch telescope.

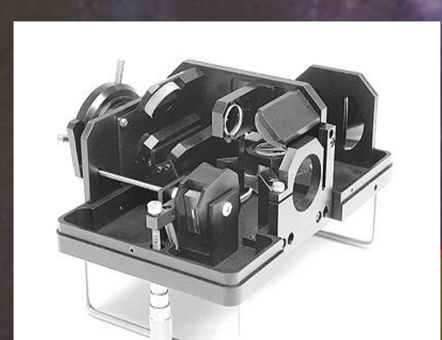


Figure 8 – (Holmes, 2001) – An SBIG Self-Guiding Spectrograph (SGS).

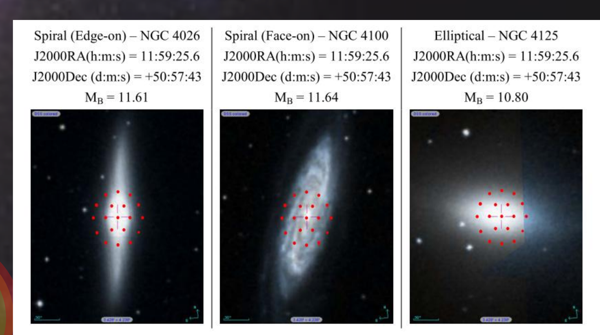


Figure 9 – A spiral (edge-on), spiral (face-on) and an elliptical galaxy found from the 650 suitable targets (de Vaucouleurs et al., 1991).

Bayfordbury Single-object Integral field Spectrograph (BASIS)

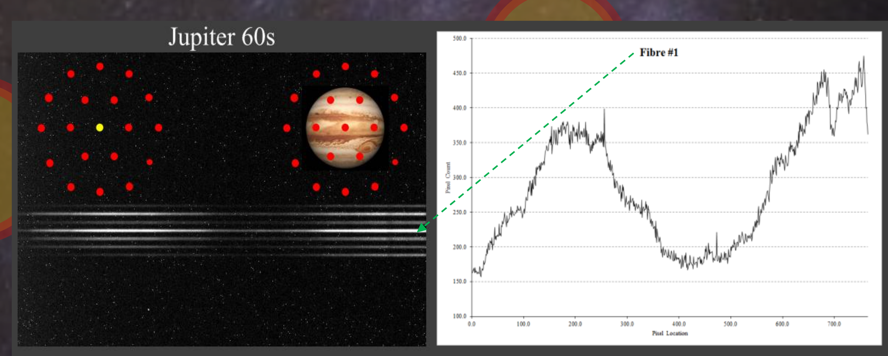


Figure 10 – A 60s exposure of Jupiter and spectrum from central fibre in the bundle (central spectrum on the exposure).

BASIS (Richards et al., 2012) is an integral field spectrograph still in development for use at the University of Hertfordshire's Bayfordbury Observatory, UK It follows the parameters above, utilising the existing Meade LX200 16-inch telescope and an SBIG SGS. Its integral field unit is a 19-fibre bundle with 4 sky fibres. A recent exposure of Jupiter is given in Figure 10, taken during the first commissioning run. The spectrum from the central fibre is also given. Only 7 spectra are visible because the angular size of Jupiter (~25") only covers the inner most 7 fibres in the fibre bundle. In both cases, the wavelength range is from ~4700Å to ~6800Å going from left to right. Note the O_2 telluric absorption feature. BASIS cost is <$500.

Conclusions

Integral field spectroscopy on small aperture telescopes is a viable venture to pursue, and it opens the way for a new large sample of galaxies, in addition to making it more accessible to the wider community. With a realistic instrument efficiency of 5%, it is possible to achieve a SNR ~10 for a 20min exposure of a 13mag/arcsec^2 source with an integral field of view of ~1arcmin. The preliminary target list of ~640 suitable galaxies can then be observed over a period of ~100 clear nights, time which can be spent on small aperture telescopes. BASIS is paving the way and will endeavour to bridge the divide between amateur astronomy and research science.

Poster

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Note: The background image is M81 and is displayed for aesthetic purposes only. A model 19-fibre bundle is overlaid for reference.

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Report