1. INTRODUCTION

Supermassive black holes are widely accepted to lie at the centers of all bulge-dominated galaxies, with the observed correlation between black hole mass and bulge velocity dispersion evident in both active and inactive galaxies confirming a causal link between previous phases of accretion-driven nuclear activity in the galactic life cycle (Gebhardt et al. 2000; Merritt & Link 2010). The dynamical instability to explain structural differences observed in both active and inactive galaxies is therefore vital.

The merging and fueling mechanisms remain unknown. Further, the transportation of fuel to the AGNs and any corresponding ejection or feedback are key components of cosmological models and are tuned to deliver observed properties of today’s galaxies (e.g., Springel et al. 2005). Merger-driven galaxy evolution and nuclear activity are central to these models but is unlikely to be a valid mechanism in the local universe where the merger rate has declined and the ~20% of galaxies currently exhibiting nuclear activity (Goulding et al. 2010) are commonly found in early-type spiral galaxies in non-cluster environments and do not show signatures of strong interactions (Westoby et al. 2007; Gabor et al. 2009). Identifying the triggering and fueling mechanism and the origin and transportation of fuel in AGNs therefore remain an important goal in astrophysics.

Optical/IR imaging studies have remained ambiguous in identifying a single fueling mechanism (Bushouse 1986; Fuentes-Williams & Stocke 1988; De Robertis et al. 1998; Hunt & Malkan 2004; Tang et al. 2008; Kuo et al. 2008). External perturbations, such as tidal interactions or minor mergers, and internal instabilities in non-axisymmetric potentials such as bars or $m = 1$ spirals have long been suggested as viable mechanisms for removing angular momentum from host galaxy gas to allow it to move closer to the AGN (Wada 2004; Maciejewski & Sparke 1997), and more recently hydrodynamic turbulence in the nuclear interstellar medium has been suggested to contribute to low-level accretion (Alig et al. 2011), but direct evidence of such physical mechanisms has been hard to obtain (e.g., Mundell & Shone 1999; Martini et al. 2001). The availability of large numbers of uniformly derived galaxy properties from the Sloan Digital Sky Survey (SDSS; York et al. 2000) has allowed statistical comparisons of active and inactive galaxies to be performed and evolutionary trends to be investigated in an attempt to explain the location of active and inactive galaxies across the so-called blue and red sequences in galaxy color–magnitude space (Baldry et al. 2004; Westoby et al. 2007; Schawinski et al. 2009). These studies build on earlier work on smaller samples, such as that by Hunt & Malkan (2004), who suggested an evolutionary sequence driven by an underlying, but unidentified, dynamical instability to explain structural differences observed in a sample of 250 active and inactive host galaxies imaged with NICMOS on the Hubble Space Telescope (HST). Direct determination of the dynamical properties of active and inactive host galaxies is therefore vital.

Radio interferometric spectroscopy provides valuable information on the large-scale gaseous environment and gaseous structure and kinematics of the host galaxy disks to large radii (e.g., Mundell et al. 2007; Haan et al. 2008, 2009) but surface brightness sensitivity constraints of current interferometers limit achievable angular resolutions to ~5″ at best (Mundell et al. 1999; Walter et al. 2008), but more typically ~18″. Millimetric observations can sample dense gas, such as CO, closer to the nucleus, but this gas may be clumpy and
discontinuous, limiting the ease with which the velocity fields can be interpreted (e.g., Dumas et al. 2010). Optical observations of galactic kinematics offer the capability of sampling the velocity field close to the center of a galaxy; in Seyferts, such kinematic observations were traditionally performed with a combination of narrowband imaging to identify line-emitting regions and long-slit spectroscopy in a preferred position angle (e.g., Ekers & Simkin 1983; Tadhunter et al. 1989; Wilson & Tsvetanov 1994), but disentangling the kinematics of the host galaxy from non-gravitational AGN-driven outflows is difficult and model-dependent.

With recent developments in integral-field unit (IFU) technology on large telescopes, which provide two-dimensional imaging spectroscopy, it is now feasible to study the distribution and kinematics of gas and stars on scales ever closer to the galactic nucleus (e.g., Fathi et al. 2006; Barbosa et al. 2006; Riffel et al. 2008). Spurious misinterpretation of one-dimensional velocity fields is less likely when full two-dimensional velocity fields are sampled; the comparison of stellar and gaseous velocity fields is vital to identify kinematics associated with the galactic gravitational potential rather than non-circular gaseous streaming motion that may be erroneously interpreted in long-slit data, e.g., mistakenly implying the presence of black holes offset from their galactic centers (Wilson & Baldwin 1985; Ferruit et al. 2004).

The two-dimensional approach was particularly effective in the comparison of stellar and gaseous kinematics in a small-matched sample of active and inactive galaxies by Dumas et al. (2007), who used the SAURON IFU (Bacon et al. 2001) on the 4.2 m William Herschel Telescope to tentatively identify a kinematic difference between Seyfert and inactive galaxy hosts, after removal of non-gravitational AGN dynamics. The SAURON IFU provides a large field of view (FOV, $33\arcmin \times 73\arcmin$) but at the cost of pixel sampling ($1\arcsec$) and the sample was selected before SDSS data were available. We, therefore, carefully selected a larger, distance-limited, and well-matched sample of active and inactive control galaxies from the SDSS (see Westoby et al. 2007) and observed them with the IMACS-IFU on the 6.5 m Magellan telescope (Bigelow et al. 1998; Schmoll et al. 2004). The IMACS-IFU is particularly well suited to the study of galactic nuclei as it has small pixels ($0\farcs2$) to sample its ($4\arcsec \times 5\arcsec$) FOV and an unusually large wavelength coverage ($\sim$4000–7000 Å), which provides access to all major emission lines from H$\alpha$ to H$\beta$ as well as the underlying stellar continuum and stellar absorption lines such as Mg $b$ and Fe $i$.

Table 1 shows a comparison of selected integral-field spectrographs.

IMACS is most commonly used as a multi-object spectrograph (MOS) and published documentation concentrates on this MOS mode. In this paper, we describe the full procedure for obtaining stellar and gaseous distribution and kinematic maps from Magellan IMACS-IFU data. In particular, we present, for the first time, the detailed procedure for reducing and calibrating IMACS in IFU “long mode.” We present the resultant gaseous and stellar maps in catalog form for our SDSS-selected IMACS-IFU sample of active and matched inactive galaxies. The detailed dynamical analysis, interpretation, and comparison will be presented in Paper II.

2. OBSERVATIONS AND ANALYSIS

2.1. Sample Selection

The purpose of this study was to compare active and inactive galaxies. To do this, it was important to carefully select a sample of Seyfert galaxies with a well-matched control sample of inactive galaxies. Our active galaxy sample was initially selected from the Hao et al. (2005) AGN catalog. The Hao catalog was compiled from the Second Data Release (DR2) of the SDSS, based on the emission-line properties of the galaxies and their locations in the various line-ratio diagnostic diagrams (Baldwin et al. 1981). The catalog therefore contains 1317 broad-line AGNs, 3074 narrow-line AGNs (assuming the Kewley et al. 2001 criteria), and a further 10,700 narrow-line AGNs that satisfy the Kauffmann et al. (2003) criteria.

A redshift cut of $z < 0.05$, an $r$-band fiber-magnitude cut of $r < 17.5$, and a declination cut of $\delta < 10^\circ$ were applied to the Hao catalog, along with a right ascension cut. The SDSS images and spectra for the remaining galaxies were then examined individually, and a selection was made based on the spectra—i.e., ensuring the presence of the forbidden lines typical of an AGN.

Once a Seyfert galaxy had been selected (which here can include LINER galaxies), we required a matched control galaxy. The matching process used here was similar to that used in a statistical study of the parent Hao catalog (Westoby et al. 2007). Potential control galaxies were obtained from the SDSS DR2 SkyServer, under the same conditions as above ($z < 0.05$, $r < 17.5$, $\delta < 10^\circ$), and $\text{specClass} = 2$ (i.e., galaxies).

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Table 1: Comparison with Other Selected IFU Instrumental Parameters

| Instrument         | Telescope    | Telescope Diameter (m) | FOV (arcsec) | Spaxel Size (arcsec) | Spaxel Number | Resolution ($\lambda/\Delta\lambda$) |
|--------------------|--------------|------------------------|--------------|----------------------|---------------|-------------------------------------|
| IMACS-IFU (f/4)    | Magellan+I   | 6.5                    | 4.15 $\times$ 5.0 | 0.2 hexagonal        | 600 + 600     | 10 000                              |
| FLAMES-ARGUS (1:1.67) | VLT         | 8.2                    | 6.6 $\times$ 4.2 | 0.3 circular         | 308 + 15      | 19 000                              |
| IMACS-IFU (f/2)    | Magellan+I   | 6.5                    | 6.92 $\times$ 5.0 | 0.2 hexagonal        | 1 000 + 1 000 | 1 800                               |
| GMOS               | Gemini       | 8.1                    | 7 $\times$ 5    | 0.2 hexagonal        | 1 000 + 500   | 1 700                               |
| FLAMES-ARGUS (1:1) | VLT          | 8.2                    | 11.5 $\times$ 7.3| 0.52 circular        | 308 + 15      | 19 000                              |
| INTEGRAL           | WHT          | 4.2                    | 34 $\times$ 29  | 2.70 circular        | 115 + 20      | 4 200                               |
| SAURON             | WHT          | 4.2                    | 41 $\times$ 33  | 0.94 $\times$ 0.94   | 1 577         | 1 250                               |
| DensePak           | WIYN         | 3.5                    | 45 $\times$ 30  | 2.81 circular        | 91 + 4        | 20 000                              |
| VIMOS              | VLT          | 8.2                    | 54 $\times$ 54  | 0.67 $\times$ 0.67   | 6 400         | 220                                 |
| SparsePak          | WIYN         | 3.5                    | 72 $\times$ 71  | 4.69 circular        | 75 + 7        | 12 000                              |
| PMAS PPak          | Calar Alto   | 3.5                    | 74 $\times$ 64  | 2.68 circular        | 331 + 36      | 8 000                                |

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6 Data publicly available at: [http://fsc.astro.cornell.edu/~haol/agn/agncatalogue.txt](http://fsc.astro.cornell.edu/~haol/agn/agncatalogue.txt).

7 SDSS SkyServer currently at [http://cas.sdss.org/astro/en/](http://cas.sdss.org/astro/en/).
## Table 2
Selection Properties of the IMACS-IFU Sample

| Pairs | SDSS ID | Alternative Name | Hubble Type | Activity Class | $V_{\text{sys}}$ (km s$^{-1}$) | $M_r$ (mag) | Inclination (deg) | $R_{90}$ (arcsec) |
|-------|---------|------------------|-------------|---------------|----------------|------------|------------------|------------------|
| 1     | SDSS J023311.04–074800.8 | S0$^4$ | S1 | 9289 | −19.89 | 43 | 7.0 |
|       | SDSS J002029.40–033330.8 | S0$^4$ | S2 | 9163 | −20.08 | 40 | 8.0 |
| 2     | SDSS J024440.23–090742.4 | Sa$^4$ | H II | 7116 | −20.13 | 62 | 8.5 |
|       | SDSS J015536.83–032329.4 | H II | S0 | 6735 | −19.74 | 49 | 7.0 |
| 3     | SDSS J032535.35–060837.9 | Mrk 609 | Im pec? | 10339 | −22.16 | 55 | 8.0 |
|       | SDSS J031237.12–073422.2 | Mrk 1404 | S0 | 10798 | −21.98 | 73 | 9.5 |
| 4     | SDSS J033955.68–063237.5 | S0$^4$ | S2 | 9384 | −19.75 | 47 | 4.0 |
|       | SDSS J082323.42–042439.9 | S0$^4$ | S2 | 10850 | −20.50 | 64 | 7.0 |
| 5     | SDSS J034547.53–000047.3 | S0$^4$ | S2 | 10822 | −20.59 | 65 | 10.5 |
|       | SDSS J032519.40–003317.9 | S0$^4$ | S1 | 10581 | −20.96 | 35 | 5.0 |
| 6     | SDSS J085310.26+021436.7 | S0$^4$ | S2 | 10338 | −20.79 | 33 | 8.0 |
| 7     | SDSS J034547.53–000047.3 | S0$^4$ | S2 | 8564 | −20.99 | 41 | 11.5 |
|       | SDSS J085828.59+000124.4 | S0$^4$ | S1? | 8921 | −20.77 | 56 | 14.0 |
| 8     | SDSS J030040.66–020902.3 | S0$^4$ | S2 | 12146 | −20.95 | 22 | 9.5 |
|       | SDSS J002029.30–033330.8 | S0$^4$ | S2 | 11934 | −21.00 | 32 | 12.5 |
| 9     | SDSS J113085.11–004002.3 | ARK 402 | S0a$^4$ | 5338 | −21.18 | 40 | 26.5 |
|       | SDSS J094603.54+021436.7 | UGC 05226 | S2 | 5044 | −21.13 | 49 | 20.5 |
| 10    | SDSS J144424.44+014047.1 | NGC 5740 | SAB(rs)b | 1572 | −19.68 | 22 | 37.0 |
|       | SDSS J231904.77–082906.3 | NGC 7606 | SAb(s)b | 2231 | −20.98 | 11 | 58.5 |
| 11    | SDSS J144611.12–001322.6 | NGC 5750 | SB0/ab(r) | 1687 | −20.12 | 30 | 34.5 |
|       | SDSS J231904.77–082906.3 | NGC 5750 | SB0/ab(r) | 11934 | −21.00 | 32 | 12.5 |
| 12    | SDSS J150000.40–015328.7 | NGC 5806 | SAB(rs)b | 1359 | −19.77 | 23 | 43.5 |
|       | SDSS J231904.77–082906.3 | NGC 5806 | SAB(rs)b | 1359 | −19.77 | 23 | 43.5 |
| 13    | SDSS J150000.40–015328.7 | NGC 5806 | SAB(rs)b | 1359 | −19.77 | 23 | 43.5 |
|       | SDSS J150126.67+020405.8 | NGC 5740 | SAb(rs)b | 12721 | −20.68 | 44 | 6.5 |
|       | SDSS J153747.90+030209.7 | NGC 5750 | SAb(rs)b | 12609 | −20.61 | 41 | 6.0 |
| 14    | SDSS J150126.67+020405.8 | NGC 5750 | SAb(rs)b | 12721 | −20.68 | 44 | 6.5 |
|       | SDSS J153747.90+030209.7 | NGC 5750 | SAb(rs)b | 12609 | −20.61 | 41 | 6.0 |
| 15    | N/A | NGC 6500 | SAab | S3 | 3003 | ... | ... |
|       | SDSS J113411.67+123044.3 | NGC 3731 | E | 3124 | ... | ... |
| 16    | N/A | ESO 399-IG 020 | IC 1068 | S1 | 7480 | ... | ... |
|       | SDSS J145332.08+030456.5 | IC 1068 | S1 | 8437 | ... | ... |
| 17    | N/A | ESO 399-IG 020 | IC 1068 | S1 | 8437 | ... | ... |

**Notes.** Summary of the Magellan–IMACS-IFU observations.

- a Galaxy pair ID.
- b SDSS identification number.
- c Alternative galaxy name.
- d Galaxy morphological classification (NED).
- e Activity classification: S1–Seyfert 1 galaxy; S2–Seyfert 2 galaxy; S3–LINER; H II–star-forming galaxy.
- f Systemic velocity (NED).
- g Absolute $r$-band magnitude (SDSS).
- h Inclination (SDSS).
- i Radius containing 90% of the Petrosian flux, in arcseconds (SDSS).
- 1, 2, 3 Common controls.
- 4 Not all galaxies were classified on NED, so these galaxies have been classified by the authors.

Controls were closely matched to the active galaxies following the photometric properties:

1. Redshift, $z$.
2. Absolute $r$-band magnitude, $M_r$.
3. Aspect ratio, $b/a$ (isophotal minor/major axis ratio in the $r$ band): inclination, in principle.
4. Radius, $R_{90}$ (in arcsec), containing 90% of the Petrosian flux, averaged over $r$ and $i$ bands.

Potential matches were identified by calculating the differences, $\Delta z$, $\Delta [b/a]$, $\Delta M_r$, and $\Delta R_{90}$, between the AGN and each control. The differences were then weighted and summed as

$$\Delta C = \frac{|\Delta z|}{0.01} + \frac{|\Delta M_r|}{0.2} + \frac{|\Delta [b/a]|}{0.1} + \frac{|\Delta R_{90}|}{0.2}. \quad (1)$$

The SDSS images of the 10 controls with the lowest values of $\Delta C$ were then extracted and visually compared to that of...
the Seyfert galaxy, with the best visual, morphological match being retained. The SDSS spectrum of the matched control was also checked prior to observation, to ensure that its “inactive” classification was correct.

In our final observing run, in 2007 August, the MPIA complete galaxy catalog of SDSS DR4 had become available. We therefore did not restrict ourselves to selecting control galaxies from DR2, thus providing many more galaxies to match to the Seyferts, increasing the probability of obtaining a good match. To date, a total of 28 galaxies have been observed: 17 Seyferts and 11 control galaxies. Table 2 summarizes the basic properties of the IMACS sample. In addition, the parameter space probed by the IMACS sample is directly compared to that of the parent sample (Westoby et al. 2007) in Figures 1 and 2. In Figure 1, the distributions of the selection properties for the parent SDSS sample are plotted (histograms), with the range of values covered by the IMACS sample shown by the shaded area. The locations of the IMACS sample in the color–magnitude diagram are shown in Figure 2. The contours represent the parent sample and show the bimodal split of late- and early-type galaxies. The locations of the IMACS galaxies are overplotted and show that the majority of the IMACS sample is made up of low-luminosity, early-type galaxies. Despite color not being a matching criteria in selecting controls, Figure 2 also shows that the Seyferts and controls are still well matched. The SDSS images and spectra for the final sample are shown in Figure 3.

Observations were carried out over four observing runs for a total of nine nights. The first was in 2005 December, the second and third were in 2006 April, and the final run was in 2007 August. Table 3 summarizes the final sample and observations thereof. Some of the control galaxies fit the matching criteria for more than one Seyfert, so to maximize telescope usage, some Seyferts share a control galaxy. The total integration time is also given in Table 3. The original aim was to obtain four individual 30 minute exposures for each galaxy to achieve a minimum signal-to-noise ratio (S/N) of 60 Å⁻¹, but due to time constraints resulting from bad weather and technical problems, this was not always possible. For example, the control galaxy MCG +00-02-006 was excluded from any analysis due to the small integration time resulting in very weak signal-to-noise (S/N < 20 Å⁻¹).

2.2. IMACS-IFU

The IMACS-IFU is a fiber-fed IFU developed and built for the IMACS at the Magellan-I 6.5 m telescope at Las Campanas Observatory, Chile. The IMACS spectrograph itself, located on the Nasmyth platform and mechanically derotated, was
Figure 3. gri SDSS color images of the sample galaxies, along with their SDSS spectrum obtained through a 3′′ fiber. Each Seyfert galaxy is displayed on the left, with its associated control galaxy on the right. The orientation is such that north is up and east is left. The spatial scale displayed for each image is given in the top-left corner of the image. Note: NGC 6500 and ESO 399-IG 020 are located beyond the SDSS footprint, and as yet no control galaxy has been observed or selected. The images displayed for these galaxies are therefore R-band Digitized Sky Survey (DSS) images. The spectrum for NGC 6500 was derived from long-slit spectroscopic observations (Ho et al. 1995), available on NED. The spectrum for ESO 399-IG 020 was created by integrating over the central 3′′ of IMACS-IFU data, thus replicating an SDSS spectrum.

(A color version of this figure is available in the online journal.)

designed for imaging long-slit and multi-slit spectroscopy with an FOV of 27 arcmin (Schmoll et al. 2004). The spectrograph operates two different cameras, offering different imaging scales and dispersions. The “short” (f/2.5) camera works with grisms, while the “long” (f/4) camera utilizes reflective gratings. In addition to integral-field spectroscopy (IFS) observations, IMACS can be used for image-slicing multi-slit observations (GISMO), tunable narrowband imaging (MMTF), and multi-object Echelle observations (MOE).

Our observations were carried out in f/4 long mode, and thus used the IMACS Mosaic1 CCD camera, which consists of eight 2K × 4K × 15 μm SITe detectors, forming an 8192 × 8192 mosaic image.

The IFU is an optional part of IMACS and can be moved into the focal plane by the IMACS slit-mask server in the same manner as an ordinary slit mask. It consists of two identical fields—one object and one sky field—separated by 60″, allowing for classical background subtraction, and beam
Figure 3. (Continued)
switching. The basic specification of the IMACS-IFU in its two different modes is summarized in Table 4, along with a summary of our observing setup (in long mode). All observations were run in 1 × 1 binning.

2.3. Observational Strategy

Integral-field spectroscopy requires a similar observing strategy to that of optical imaging. In traditional fashion, at the start of the night bias frames, domeflat exposures, and skyflat exposures were taken in order to undertake basic CCD reduction. In addition, preliminary arc frames were taken to provide an initial wavelength calibration. Arc frames were also taken throughout the night, before and after each science observation. Typically two or three standard stars were also observed throughout the night (again, preceded and followed by arc exposures) to enable flux calibration, and/or to be velocity standards. Table 5 summarizes the typical observing process for IMACS-IFU.
### Table 3
Summary of IMACS-IFU Observations

| Name                  | α(J2000) | δ(J2000) | Date       | $T_{\text{Exp}}$ | Seeing (″) |
|-----------------------|----------|----------|------------|------------------|------------|
| SDSS J023311.04–074800.8 | 02:33:11.04 | −07:48:00.8 | 2005 Dec 10 | 3 × 1800 | 0.6–1.2 |
| SDSS J023233.42+042349.9 | 08:23:23.42 | +04:23:49.9 | 2005 Dec 9  | 4 × 1800 | 0.7–0.8 |
| SDSS J024440.23–090742.4 | 02:44:40.64 | −09:07:35.6 | 2005 Dec 8  | 4 × 1800 | 0.8–0.9 |
| SDSS J015536.83–002329.4 | 01:55:35.89 | −00:23:28.2 | 2005 Dec 7  | 4 × 1800 | 0.6–0.7 |
| Mrk 609                | 03:25:25.35 | −06:08:37.9 | 2005 Dec 7  | 4 × 1800 | 0.7–1.0 |
| Mrk 1404               | 03:12:37.12 | −07:34:22.2 | 2005 Dec 8  | 3 × 1800 | 0.6–0.8 |
| SDSS J023955.68–063237.5 | 03:39:55.97 | −06:32:28.9 | 2005 Dec 10 | 4 × 1800 | 1.0–1.1 |
| SDSS J082323.42+042349.9 | 08:53:10.26 | +02:14:36.7 | 2006 Apr 4  | 4 × 1800 | 0.6–0.9 |
| SDSS J015536.83–002329.4 | 12:10:32.18 | −01:18:51.4 | 2006 Apr 4  | 4 × 1800 | 0.6–0.7 |
| CGCG 005-043           | 08:58:28.59 | +00:01:24.5 | 2006 Apr 5  | 4 × 1800 | 0.6   |
| SDSS J104409.99+062220.9 | 10:44:09.99 | +06:22:20.9 | 2006 Apr 5  | 1 × 1800 | 0.5   |
| SDSS J090040.66–002902.3 | 09:00:40.66 | −00:29:02.3 | 2005 Dec 7  | 2 × 1800 | 0.7–1.4 |
| MCG +00-02-0062        | 00:20:29.30 | −00:33:18.0 | 2007 Aug 21 | 1 × 1000 | 1.1   |
| ARK 402                | 13:08:50.11 | −00:49:02.4 | 2006 Apr 5  | 4 × 1800 | 0.5   |
| UGC 05226              | 09:46:03.54 | +04:24:12.4 | 2006 Apr 30 | 3 × 1800 | 0.5   |
| NGC 5740               | 14:44:24.45 | +01:40:47.2 | 2006 Apr 30 | 3 × 1800 | 0.5–0.6 |
| NGC 7606               | 23:19:04.78 | −08:29:06.3 | 2006 Aug 20 | 1 × 1800 | 1.1   |
| NGC 7606               | 23:19:04.78 | −08:29:06.3 | 2006 Aug 20 | 1 × 1800 | 1.1   |
| NGC 5750               | 14:46:11.12 | −00:13:22.6 | 2006 Apr 4  | 4 × 1800 | 0.6–0.7 |
| NGC 5806               | 15:00:00.40 | +01:53:28.7 | 2006 Apr 4  | 3 × 1800 | 0.7   |
| NGC 6500               | 17:55:59.78 | +18:20:17.7 | 2007 Aug 20 | 1 × 1500 | 1.0   |
| NGC 7371               | 11:34:11.67 | +12:30:44.3 | ...         | ...     | ...   |
| ESO 399-IG 020         | 20:06:57.70 | −34:32:58.0 | 2007 Aug 20 | 3 × 1800 | 1.0   |
| IC 1068                | 14:53:32.92 | +03:04:38.3 | ...         | ...     | ...   |
| SDSS J122224.50+004235.6 | 12:22:24.50 | +00:42:35.6 | 2006 Apr 30 | 4 × 1800 | 0.5–0.6 |
| CGCG 050-048           | 15:37:47.90 | +03:02:10.0 | 2006 Aug 20 | 2 × 1800 | 0.6   |
| MCG +00-02-0062        | 15:00:00.40 | +01:53:28.7 | 2006 Apr 4  | 3 × 1800 | 0.7   |
| SDSS J150126.67+020405.8 | 15:01:26.67 | +02:04:05.8 | 2006 Apr 5  | 3 × 1800 | 0.5   |
| SDSS J023233.42+042349.9 | 12:22:24.50 | +00:42:35.6 | 2006 Apr 30 | 4 × 1800 | 0.5–0.6 |
| ESO 399-IG 020         | 20:06:57.70 | −34:32:58.0 | 2007 Aug 20 | 3 × 1800 | 1.0   |
| IC 1068                | 14:53:32.92 | +03:04:38.3 | ...         | ...     | ...   |
| SDSS J215259.07–000903.4 | 21:52:59.08 | −00:09:03.5 | 2007 Aug 20 | 2 × 1800 | 1.0   |
| SDSS J023939.41–062533.4 | 20:39:39.41 | −06:25:33.4 | 2006 Apr 30 | 2 × 1800 | 0.8   |
| ...                   | ...       | ...       | ...         | ...     | ...   |
| Notes.                  | Summary of the Magellan–IMACS-IFU observations. Listed are the dates of observations, the total integration time of each observation, and the range of seeing conditions at the times of observation (in arcseconds). NGC 3731 and IC 1068 are yet to be observed. |

In fiber-fed IFS, domeflats are required to trace the fibers across the CCD. As such, several domeflat exposures were taken with various exposure times. These domeflats were taken with the grating in place, and Quartz lamps turned on, allowing for all fibers to be illuminated at all wavelengths, and hence traceable across the CCD.

Skyflats, or twilight flats, can be used to correct for variations in fiber throughput. These are again taken with the grating in place and quartz lamps on, and with the vents of the telescope dome also open, allowing twilight radiation onto the detector. If no skyflats are observed, domeflats can also be used to correct for variations in fiber throughput.

Prior to starting the science observations, an acquisition frame was acquired. A reconstructed image of the acquisition frame could be viewed immediately to ensure that the galaxy was located centrally in the FOV. Science observations were then done in exposures of 1800 s, with the telescope dithered between exposures. Arc frames of 60 s were sufficient for wavelength calibration.

### 2.4. Data Reduction

Prior to our observations, no reduction pipeline had been developed for IMACS in IFU mode (note: since then a pipeline, kungifu, has been developed for IMACS-IFU “short mode”;

8
Bolton & Burles 2007). We have therefore produced a full reduction and calibration procedure to ensure reliable science products.

Reduction of IFU data utilizes standard CCD imaging reduction techniques, but also requires additional processes. In particular, careful extraction of the multiple spectra is required. For this we used an adaptation of the p3d package developed for the Potsdam Multi-Aperture Spectrograph (PMAS; Roth et al. 2005), called imacs_online. This extraction process is described in Section 2.4.4.

Figure 4 shows a schematic of the reduction steps needed to produce a final datacube. The routines used to do each step are also shown. All processing was done using specific scripts written in the Interactive Data Language by the authors.

### 2.4.1. Raw IMACS-IFU Data

As in the majority of fiber-fed spectrographs, IMACS-IFU raw data consists of a number of spectra distributed along one axis of a two-dimensional frame. Figure 5 shows an example of a raw IMACS-IFU data frame. This is a small section of a raw, 60 s arc exposure with He–Ne–Ar calibration lamps turned on. Each spectrum is distributed across the image in the dispersion axis. At each wavelength the spectra are also spread perpendicular to the dispersion axis, in the “cross-dispersion” axis. Spectra are separated by approximately 5 pixels along the cross-dispersion axis, limiting the cross-contamination (or cross-talk) between neighboring fibers. The spectra are not perfectly aligned along the dispersion or cross-dispersion axes due to the instrument itself, the instrument setup, and telescope flexure effects. The transmission of individual fibers also varies due to tensions, misalignments, and intrinsic physical differences (Sánchez 2006), which cause the light from each fiber to enter the spectrograph with slight relative offsets.

A cross-dispersion cut through a raw domeflat exposure can illustrate the variations in fiber response. Figure 6 shows such a cut through a single CCD chip at approximately 6500 Å. The plot shows all 12 blocks of 50 fibers of which 6 blocks are object fibers and 6 blocks are sky fibers. Each block is separated by approximately 20 pixels that are not directly illuminated. Assuming each peak to be approximately Gaussian, this plot highlights the effect of cross-talk between adjacent spectra.

8 The latest version of p3d (Sandin et al. 2010) can be found at: http://p3d.sourceforge.net/.

### Table 4

| Basic Specification and Instrument Setup | f/2.5 Short Mode | f/4 Long Mode |
|-----------------------------------------|-----------------|--------------|
| Spatial coverage                        | 6′92 × 5′00     | 4′15 × 5′00  |
| Total apertures                         | 1 000 per field | 600 per field|
| Format                                  | 25 × 40 elements| 25 × 24 elements|
| Shape                                   | Rectangular pattern |
| Fiber size                              | 0′2            |
| Wavelength range                        | 400–900 nm      |
| Spectral resolution                     | ...            | 1.6 Å at 5000 Å |
| Grating                                 | ...            | 600 lines mm\(^{-1}\) |
| Grating order                           | ...            | First        |
| Blaze angle                             | ...            | 10:33        |
| Central wavelength                      | ...            | 5520 Å       |
| Wavelength range                        | ...            | 3975–7097 Å |
| Dispersion                              | ...            | 0.388 Å pixel\(^{-1}\) |

### Table 5

| Typical Observing Procedure | \(N_{\text{exp}}\) | \(T_{\text{exp}}\) (s) |
|-----------------------------|-------------------|-------------------------|
| Bias                        | 8                 | 0                       |
| Domeflat (image)            | 2                 | 3                       |
| Domeflats (spectra)         | 4                 | 600                     |
| Skyflats (screen)           | 3                 | 120                     |
| Skyflats (sky)              | 3                 | 120                     |
| Arcs                        | 2                 | 600                     |
| Acquisition                 | 1                 | 10                      |
| Arc                         | 1                 | 60                      |
| Science observations        | 4                 | 1800                    |
| Arc                         | 1                 | 60                      |
| Standard star observations  | 2                 | 10                      |
| Arc                         | 1                 | 60                      |

**Notes.** Overview of the observing strategy. The table lists the number of exposures of each type of frame (\(N_{\text{exp}}\)) and the desired exposure time (\(T_{\text{exp}}\)).

which has to be accounted for along with scattered light, when extracting the spectra.

The IMACS-IFU consists of two fields. One field is centered on the target object, while the other field is located 1 arcmin away from the object field, to collect uncontaminated sky emission only.

All fibers are arranged in blocks of 50. The blocks along the pseudo-slit then come alternately from the object fibers and sky fibers to avoid large changes in spectrograph behavior when the background is to be subtracted. The distribution of the two fields on the detector also follows this pattern, allowing for straightforward sky subtraction via the “mean-sky” method or interpolated sky values.

### 2.4.2. Basic Imaging Reduction

As a starting point, all raw frames were subjected to standard CCD reduction processes. All images were debiased using the bias strips at the top and side of the frame. In the cross-dispersion direction the bias level was approximately constant in each case. In the dispersion direction, however, some structure was observed, but successfully removed. The overscan regions were then removed from the bias-subtracted images.

Next, a number of flat-field direct-image frames were studied to identify bad pixels and columns on the CCD. These bad pixels were then replaced with the average value of the six neighboring pixels in the dispersion direction. A further correction was also required for CCD chip number 8, which suffers from a large number of saturated pixels in one area of the CCD. These were also replaced with the average value of the neighboring pixels in the wavelength direction.

### 2.4.3. CCD Mosaicking

Once the individual CCD frames were corrected for bad pixels, they were mosaicked together to form a single image displaying all fibers over the full wavelength range. The configuration of the CCD chip setup is displayed in Figure 7. Of importance here is that the “top” row of CCD chips need to be flipped in both the “\(x\)”- and “\(y\)”-directions (or alternatively rotated 180°) to result in wavelength increasing from left to right. Doing this on a flat-field frame first, however, showed that this
process alone does not provide an accurate mosaic, since the illuminated fibers were not aligned at the chip boundaries. To overcome this problem, a cross-correlation of the last column of one CCD chip with the first column of the next CCD chip was performed to derive offsets (in the cross-dispersion direction) between neighboring CCD chips. The CCD frames were then shifted accordingly to align the fibers over the full wavelength range. These offsets could be applied to correctly align the CCD chips in all subsequent observations for that night.

2.4.4. Spatial Calibration

In order to perform an accurate spectral extraction, the location of each spectrum on the CCD needs to be determined. This requires all fibers to be illuminated with a continuum
Figure 5. Gray-scale image of a section of IMACS-IFU raw data. The dispersion axis is the $x$-axis in this case, while the cross-dispersion (“spatial”) axis is along the $y$-axis.

Figure 6. Cross-dispersion cut through a domeflat image illustrating the typical fiber-to-fiber throughput variation.

source, so that they can be traced across the whole wavelength range.

As implied by Section 2.4.3 and Figure 6, the optical fibers are resolved from each other in a domeflat. The location of the spectra can therefore be found for each column on the CCD by comparing the intensity at each row along the column with that of neighboring pixels in the same column. Each peak in the cross-dispersion direction marks the center of each fiber. Doing this for each column then traces the fibers across the CCD.
Creating the “trace masks” is done within the imacs_onl ine package. The algorithm used to do the trace is described in detail in Section 4.1 of Sánchez (2006), and basically searches pixels along a column, locating the pixels that satisfy a maximum criterion relative to adjacent pixels. The user can specify certain input parameters, such as the distance (in pixels) between adjacent maxima and the number of adjacent pixels to include in the search for maxima. The algorithm also makes it possible to use more than one column to look for the peaks. This is beneficial to avoid cosmic rays and to increase $S/N$. The number of columns to be used can also be specified by the user.

The tracing of the peak intensity along the dispersion axis is done by searching for more maxima around the original location within a certain window specified by the user. This is an iterative process, starting in the original column and continuing across the CCD. The result is a trace mask containing the central locations of each fiber, at each pixel in the dispersion direction. The user specifies the distance between adjacent maxima, and they must also account for the large gaps between the blocks of 50 fibers. A visual inspection of the trace mask superimposed on the domeflat is therefore often required to check that the input parameters are satisfactory and that the gaps are being dealt with accordingly, as this can be difficult to implement automatically.

Due to the weight of the IFU itself, IMACS-IFU suffers from flexure throughout a night of observing. As a result, a unique trace mask is required for an accurate extraction of each observation. Domeflats were only taken at the start of each night, so fresh trace masks at different stages of the night could not be created. However, by overplotting the trace mask created for a domeflat at the start of the night on a calibration arc frame, it was found that the general pattern of the fibers across the CCD was approximately constant and that there was only a shift in the cross-dispersion direction, so one set of trace masks could be created for each night and just shifted (in the “y”-direction) accordingly.

Shifting a trace mask for use on a set of arc frames was straightforward, as there are many bright emission lines to see whether the trace mask is passing through the peak emission. In the science frames, however, this is more difficult, as the $S/N$ is much lower, and the locations of the fibers cannot be seen directly. To overcome this problem, the arc frames taken before and after the science frames were used to limit the amount of signal lost in the extraction process.

Our galaxy observations were typically four exposures of 1800 s each. In the majority of cases, the trace mask is stable over the observing time. In the remaining cases, the post-observation arc required shifting only a few pixels.

2.4.5. Extraction of Spectra

After tracing the location of the spectra on the detector, it is then possible to extract the spectra—i.e., extract the flux corresponding to the 1200 spectra at each pixel along the dispersion axis. This is again done in imacs_onl ine, involves co-adding the flux within a certain aperture around the location of the spectral peaks defined by the trace mask, and storing the resulting spectra in a two-dimensional image. The $x$-axis of the resulting image remains as the original dispersion axis, while the $y$-axis translates to the ordering of the spectra along the pseudo-slit—i.e., each row contains a spectrum corresponding to a particular point in the FOV. The extraction works to minimize the effects of cross-talk, while maximizing the recovered flux. This utilizes a technique developed for P3d, known as Gaussian-suppression, as described in Section 4.3 of Sánchez (2006).

Figure 8 shows a twilight flat before extraction, while Figure 9 shows the same exposure after spectral extraction. In these frames, emission features are brighter sources and absorption features appear darker. The separation of the fiber blocks can
be seen in the skyflat before extraction, but not in the extracted image.

2.4.6. Flat Fielding

As with CCD imaging, flat fielding is required to correct for pixel-to-pixel variations. In the dispersion direction, this corresponds to the detector response as a function of wavelength (the quantum efficiency, QE), while in the cross-dispersion direction this translates to fiber-throughput variations. This variation of fiber-to-fiber response, as seen in Figure 6, can also be seen in the extracted skyflat image of Figure 9. Due to the effects of flexure it is not possible to flat field the raw science frames, as the locations of the fibers vary with each telescope pointing. Instead, flat fielding is done on extracted data, using an extracted domeflat exposure. The extracted domeflat is first normalized to unity and then divided out of all science frames. This procedure not only corrects for QE and fiber-throughput variations, but also any relative CCD scalings not corrected during bias subtraction.

2.4.7. Wavelength Calibration

Grating spectrographs cause distortions in the entrance slit, leading to the spectral image being curved on the CCD (Meaburn et al. 1984). Fiber-fed IFUs suffer from additional distortions due to the placing of the fibers at the slit. The upper panel of Figure 10 shows both of these effects. The overall curvature can be seen in the cross-dispersion direction, and there are also varying shifts in the dispersion direction. As a result, these distortions must be corrected fiber-to-fiber before deriving a common wavelength solution.

He–Ne–Ar arc calibration frames were therefore first used to correct for these distortions, and then used to determine the wavelength solution. The relative fiber-to-fiber offsets in the dispersion direction were found by tracing the location of the peak of one arc emission line along the cross-dispersion axis. The fiber-to-fiber offsets are then applied in order to shift the lines to a common reference.

The wavelength solution is determined by the identification of a number of known arc emission lines. The corrected arc spectra
are then transformed to a linear wavelength coordinate system, by assuming a polynomial transformation. This transformation is then stored in an ASCII file to be applied to the science frames. The accuracy of the dispersion solution depends on the selected order of the polynomial transformation (typically chosen to be three or four), the number of identified arc lines, and the coverage of these lines across the wavelength range.

The lower panel of Figure 10 shows the wavelength-calibrated arc frame: wavelength increases from left to right. These images have also been flat fielded, so the bright line approximately a third of the way up this image is a broken fiber. In the dispersion direction, as many as 50 pixels per CCD chip were lost in wavelength calibration as a result of the image being curved on the CCD.

### 2.4.8. Cosmic-ray Rejection

Cosmic-ray rejection was of critical importance for our data set. Science exposures were of the order of 1800 s resulting in a large number of cosmic rays. In IFS, care needs to be taken in removing cosmic rays, as emission lines can easily be mistaken for cosmic rays. The most effective method of cosmic-ray rejection was found to be after the spectra were extracted, by comparing adjacent spectra (Swinbank et al. 2003).

Figure 11 shows an example of a science frame before and after cosmic-ray rejection. This example is one CCD frame of the Seyfert 2 galaxy NGC 5740, in the wavelength range 6375–7100 Å. This frame also demonstrates the ordering of the fibers on the detector—i.e., in a sequence of 50 object spectra followed by 50 sky spectra followed by 50 object spectra, and so forth. The peaks in the object spectra correspond to emission lines in the galaxy. The lines that can be seen are [N II] (doublet), Hα, and [S II] (doublet). Sky lines can also be seen as the emission that appears in both the object fibers and sky fibers, illustrating the importance of sky subtraction.

### 2.4.9. Sky Subtraction

On the IMACS CCD, object and sky fibers are distributed in blocks of 50 in the cross-dispersion direction with the intention of allowing simple sky subtraction via the mean-sky method (i.e., for each wavelength slice (column), subtract the average of the 50 pixels in one block of sky fibers from the adjacent block of object fibers).

When using this method, however, the sky was found to be systematically over- then under-subtracted in each neighboring block, resulting in a “striping” effect in the reconstructed two-dimensional images. This is in part due to the fact that the sky background in the sky fibers is not guaranteed to be exactly representative of the background in the object fibers. In addition, scattered light in the optics, estimated to be of the order of 1%–2% by Dressler et al. (2011), contributes to a more varying background.

A number of different ways to estimate the sky background at the location of the object fibers were tried, but the most robust method was to interpolate across all sky fibers, as the sky was found to be brighter in the fibers toward the center.
of the CCD compared to the outermost fibers. A model of the sky in the cross-dispersion direction was therefore derived for each wavelength slice to produce a modeled sky field over all wavelengths. The sky was then smoothed over a few pixels in the wavelength direction and subtracted from the science frame. An example of a sky-subtracted frame is also shown in Figure 11.

2.4.10. Image Stacking

As our science observations were multiple exposures of 1800 s, they need to be stacked to form one, combined image. A number of our observations also made use of dithering, and as a result multiple exposures could not be simply added together, as the target would fall on different fibers in each different exposure. Typically we dithered by 0.4", which is twice the spatial resolution of the IFU. The spatial offsets can be seen when viewing the reconstructed two-dimensional images. We therefore transformed the two-dimensional frames into datacubes using the mapping information given in Schmoll et al. (2004).

The result is a 25 × 24 pixel image for each wavelength slice. Given the shape of the lenslets (hexagonal), and the number of pixels in a two-dimensional image, there was a significant error in terms of finding the galaxy centers. We therefore oversampled in both the “x”- and “y”-directions to transform to a 50 × 48 square grid of 0.1 × 0.1 pixels, for each wavelength slice.

The effects of dithering can easily be seen by viewing different exposures at a common wavelength, or sum of wavelengths (Figure 12). Summing pixel to pixel over the full wavelength range can provide a high-S/N image in which a “photometric” center can be found through profile fitting. The multiple images were then shifted so that the photometric peaks were aligned in all frames. The exposures were normalized to one second, and a median datacube created. At this point, our pipeline also allowed for a weighting term to be applied to each data set, to account for seeing conditions, for example. In this paper, however, seeing conditions remained approximately constant through a set of galaxy exposures, so all weights were set equal to one.

2.4.11. Flux Calibration

The final element of the reduction pipeline is spectroscopic flux calibration. A number of standard stars were observed during each observing run and reduced as described above. An integrated spectrum of a standard star was then created by summing all spectra in an aperture covering the whole...
star—typically greater than 3′′. An absolute flux calibration was then found using the spectrophotometric flux calibration tables of Hamuy et al. (1992). The integrated IMACS spectrum is divided by the standard spectrum to provide a table of conversions as a function of wavelength. Absorption features were masked out, and a third-order polynomial fitted to the conversion data, to provide an absolute calibration curve, such as that shown in Figure 13, which can be applied directly to the science observations to convert to an $F_{\lambda}$ flux scale.

2.4.12. Spatial Binning

It is very common for IFU data to be locally averaged to maximize the S/N, at the expense of spatial resolution. Averaging is generally done by either smoothing or binning. The Voronoi two-dimensional binning method of Cappellari & Copin (2003) performs adaptive spatial binning of two-dimensional data to reach a constant S/N per bin. To maximize the possibility of extracting the stellar kinematics from our
Figure 15. IMACS-IFU maps for active galaxy SDSS J023311.04−074800.8. Cosmology-corrected scale: 581 pc arcsec$^{-1}$. Top row (from left to right): reconstructed continuum image; mean stellar velocity, $V_{\text{stars}}$; and stellar velocity dispersion, $\sigma_{\text{stars}}$. Second row: Hα distribution, Hα velocity, and Hα velocity dispersion. Third row: [O iii] distribution, [O iii] velocity, and [O iii] velocity dispersion. Bottom row: [N ii]/Hα ratio map, [O iii]/Hβ ratio, and [S ii] $\lambda$6716/[S ii] $\lambda$6731 ratio. Fluxes are in units of $F_\lambda (10^{-17}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$) and velocities are given in km s$^{-1}$.

(A color version of this figure is available in the online journal.)

data, all datacubes were rebinned using the Voronoi method. This method required a noise datacube, for which we used the non-sky-subtracted datacube. A reconstructed two-dimensional continuum image and a reconstructed two-dimensional noise image were then created using the full wavelength range and excluding emission lines, and two-dimensional binning was performed on the resulting image to achieve a constant S/N of 60 Å$^{-1}$ pixel$^{-1}$. Each wavelength slice in the datacube was then binned according to these results to maximize the probability of deriving reliable stellar kinematics.
Figure 16. IMACS-IFU maps for active galaxy SDSS J033955.68–063237.5. Cosmology-corrected scale: 592 pc arcsec$^{-1}$. See Figure 15 for description of maps plotted.

2.5. Derivation of Stellar and Gaseous Distributions and Kinematics

To derive the stellar kinematics, we used the maximum penalized likelihood formalism developed by Cappellari & Emsellem (2004). The penalized pixel-fitting method (pPXF) treats the line-of-sight velocity distribution (LOSVD) as a Gauss–Hermite series and fits the kinematic parameters ($V_\star, \sigma_\star, h_3, ..., h_n$) simultaneously, while adding an adjustable penalty term to the $\chi^2$. An advantage of this method is that emission lines and bad pixels can be excluded from the fit—a property that is of particular importance when fitting to Seyfert spectra.

The pPXF algorithm finds the best fit to all galaxy spectra by convolving a template stellar spectrum with the corresponding LOSVD. The success of pPXF is therefore sensitive to the input stellar templates. An optimal template is produced for each spectrum in the datacube, thus the input stellar spectra must cover a range of metallicities and ages to account for any potential variation in the properties across the FOV. Libraries of observed or synthetic stellar spectra are therefore often used as the input stellar templates. Previous studies have shown, however, that reliable stellar kinematics can be successfully derived over the spectral range 4800–5400 Å using the Mg $b$ doublet and Fe $\text{II}$ absorption features. Although IMACS-IFU has a much broader wavelength coverage, the continuum fit is very sensitive to slight inaccuracies in CCD relative normalization. As a result, we restricted pPXF to the range 4800–5400 Å.
An initial pPXF fit was performed on a median galaxy spectrum to select a subset of the input stellar spectra, which was then used to derive the kinematics for the whole datacube.

A number of libraries were available, such as the simple stellar population (SSP) models of Vazdekis (1999), hereafter V99, the Indo-U.S. Coudé Feed Spectral Library (Valdes et al. 2004), MILES (Sánchez-Blázquez et al. 2006), and an IMACS-IFU library of observed velocity standards. For comparison with previous work (e.g., SAURON; Sarzi et al. 2006; Dumas et al. 2007), the stellar kinematics presented in this paper are those derived from the V99 synthetic stellar library. The V99 library covers the spectral range 4800–5400 Å with a resolution of 1.8 Å which is well matched to the IMACS-IFU spectra (FWHM_{IMACS} ∼ 1.6 Å at 5000 Å). The observed Indo-U.S. Library, which is of higher spectral resolution (FWHM 1.0 Å), was also tested and found to be in good agreement with the kinematics derived using the V99 stellar models.

To estimate the errors in recovering the LOSVD from the optimal template, Monte Carlo simulations were performed to create synthetic spectra by adding Poisson noise to the template spectra, and fitting for \((V, \sigma)\). The resulting rms scatter was found to be of the order of a few percent. The scatter in the recovered parameters, however, puts only a lower limit on the uncertainty in deriving the kinematics from a given template, as it does not include the more dominant uncertainty due to template mismatch. Errors are therefore considered to be in the range 5%–10%.

The GANZALF algorithm of Sarzi et al. (2006) extended pPXF to also derive the gas kinematics from the emission lines. Assuming the emission lines to be Gaussian, the line strength, mean position (velocity), and width (velocity dispersion) can be calculated. GANZALF was performed simultaneously with pPXF, so it was also restricted to the wavelength range of approximately 4800–5400 Å, thus constraining only the Hβ, [O iii], and [N ii] emission-line kinematics. Beyond the operating range of GANZALF, however, there is still a wealth of data. In particular, in the range 6000–7000 Å, lie [N ii], Hα, and [S ii] emission lines. Kinematics from Hα, [N ii], and [S ii] emission were therefore subsequently derived independent of GANZALF through single-Gaussian fitting.

In the range where the stellar kinematics were extracted, the optimal stellar template derived from pPXF was subtracted from the observed spectrum, removing contamination from any underlying stellar absorption—this is of particular importance for removing the true Hβ kinematics, as this line is expected to be a blend of emission and absorption that cannot be assumed to have the same kinematic profiles. The spectrum in the range 6000–7000 Å lacks stellar absorption features—analogous to Mg b or Fe ii—to allow an independent estimate of any Hα stellar absorption, so the line intensity relative to the local continuum was used, as is standard in narrowband imaging. The total Hα flux density may therefore be an underestimate (e.g., Charlot et al. 2002).

The best amplitude, mean velocity, and velocity dispersion were therefore extracted for all the emission lines in each spectrum. The velocity dispersions were corrected for the instrumental resolution, which were estimated to be 35 km s\(^{-1}\) at ∼6500 Å and 42 km s\(^{-1}\) at ∼5000 Å.

3. OBSERVED IMACS-IFU KINEMATICS

This section is dedicated to the presentation of the IMACS-IFU moment maps. A variety of structures are revealed in the IMACS kinematic maps, examples of which are shown in Figure 14. Features include elongated stellar continuum light profiles suggestive of photometric nuclear bars (top left in Figure 14), complex star formation regions (center left), stellar and gas rotation (top right, middle right, and bottom left), highly ionized gas with significantly blue-shifted velocities with respect to systemic indicative of outflow (bottom right), and other distorted velocity structures.

Figures 15–41 display the stellar and ionized gas distributions and kinematics of the 17 Seyferts and 10 control galaxies analyzed. The maps are presented in the order in which they are described in Section 4. For each Seyfert galaxy and two of the control galaxies, we show the stellar continuum distribution, the [O iii] \(\lambda5007\) and Hα emission-line distributions, the velocity and velocity-dispersion fields of the stars and ionized gas (Hα and [O iii]), the [O iii]/Hβ and [N ii]/Hα line-ratio maps, and finally the [S ii] doublet-ratio map. For the remaining control galaxies, which contain no ionized gas, we only show the stellar continuum distribution and the velocity and velocity-dispersion fields of the stars. All maps are oriented so that north is up and east is left. Fluxes are in units of\(F_\lambda (10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1})\) and velocities are given in km s\(^{-1}\). A signal-to-noise cut of a minimum of three was applied to all flux and velocity maps.

The range of values plotted in each map is given above the map. \(V_{\text{stars}}\), \(V_{\text{Halpha}}\) and \(V_{\text{OIII}}\) are given relative to the systemic velocity derived from the stellar velocity fields, and is given in km s\(^{-1}\). The map is plotted on the same scale, where the (0,0) coordinates mark the peak of the stellar continuum flux.
Figure 18. IMACS-IFU maps for active galaxy SDSS J024440.23–090742.4. Cosmology-corrected scale: 446 pc arcsec$^{-1}$. See Figure 15 for description of maps plotted.

(A color version of this figure is available in the online journal.)

The cosmology-corrected scale for each galaxy is given in the caption for each figure.9

A brief description of the observed structures and kinematics including references to any previous work on these objects are presented in Section 4.

9 These values were taken from the NASA/IPAC Extragalactic Database, http://nedwww.ipac.caltech.edu/, and are based on the following cosmology: $H_0 = 73$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_{\text{matter}} = 0.27$, and $\Omega_{\text{vacuum}} = 0.73$.

4. NOTES ON INDIVIDUAL GALAXIES

This section describes the properties of the individual galaxies in the sample with reference to their derived intensity, velocity, dispersion, and line-ratio maps presented in Figures 15–41. The galaxies are grouped into pairs of active and control, following Table 2. Seyferts that share a control galaxy are grouped together with the control following afterward so as to avoid repetition.
4.1. Pairs One and Four

4.1.1. Active Galaxy: SDSS J023311.04–074800.8

SDSS J023311.04–074800.8 is an S0 galaxy classified as a broad-line AGN in the Hao AGN catalog. The IMACS continuum map (top left in Figure 15) shows a central peak with a slight extension to the southeast. The stellar velocity field shows no obvious rotation.

The OIII and Hα emission-line distributions roughly coincide, although the Hα emission is much weaker. There is no noticeable rotation in the ionized gas, but the gas dispersion velocity reaches around 100 km s\(^{-1}\). The OIII/Hβ line ratio increases toward the center, consistent with an increase in ionizing potential.

4.1.2. Active Galaxy: SDSS J033955.68–063237.5

SDSS J033955.68–063237.5 is an S0 galaxy at a redshift of 0.031. The IMACS continuum map (Figure 16) reveals a weak but concentrated stellar nucleus. The Hα emission is extended NW of the photometric center. The stellar velocity field shows signs of rotation, with the stellar...
velocity dispersion showing a possible increase toward the center.

The Hα velocity field shows clear signs of rotation, with a kinematic position angle (P.A.) along the direction of elongation of the Hα emission. The Hα velocity dispersion peaks at approximately 150 km s\(^{-1}\) in the galactic center. The distribution of [O\textsc{iii}] emission is also complex, with a double-peaked nucleus in the N–S direction. The [O\textsc{iii}] velocity field reveals no rotation, but instead is blue shifted by \(\sim 150\) km s\(^{-1}\) with respect to the systemic velocity, suggesting an outflow from the nuclear region. Interestingly, the fact that the Hα velocity field is symmetric about the minor axis suggests that the outflowing [O\textsc{iii}] component has had little effect on the rotating disk and so must be directed perpendicular to the disk. The [O\textsc{iii}] velocity dispersion is much higher than that of the stars and Hα, but also increases toward the center. The [O\textsc{iii}]/Hβ and [N\textsc{ii}]/Hα ratios also rise toward the center, typical of Seyfert galaxies.

Figure 20. IMACS-IFU maps for active galaxy Mrk 609. Cosmology-corrected scale: 650 pc arcsec\(^{-1}\). See Figure 15 for description of maps plotted.
(A color version of this figure is available in the online journal.)
4.1. Control Galaxy: SDSS J082323.42+042349.9

SDSS J082323.42+042349.9 is the control galaxy for both SDSS J023311.04–074800.8 and SDSS J033955.68–063237.5. The stellar nuclear region is uniformly concentrated (Figure 17). The stellar velocity field shows no evidence of rotation. The velocity dispersion shows a general increase toward the center. In contrast to the active galaxies, this control contains no ionized gas to a 3σ limiting flux density, so the corresponding emission-line maps are not shown.

4.2. Pair Two

4.2.1. Active Galaxy: SDSS J024440.23–090742.4

SDSS J024440.23–090742.4 is an Sa galaxy classified as a type 2 Seyfert. The continuum distribution is regular, while the stellar velocity map (Figure 18) shows a hint of low-level rotation ($V_{\text{rot}} < 100$ km s$^{-1}$). The stellar velocity dispersion is high and increases to around 200 km s$^{-1}$ in the center.

The Hα emission is faint and concentrated in the inner 500 pc. The [O III] emission is slightly brighter than the Hα emission.
and similarly concentrated, although a marginal elongation in the NE–SW direction can be seen. There is a hint of rotation in all maps, but the P.A. of the line of nodes for Hα and stellar velocity fields are misaligned by 180°. The Hα velocity dispersion shows an increase toward the center, similar to that of the stars, but the [O III] velocity dispersion remains approximately constant at ∼110 km s⁻¹. The [O III]/Hβ ratio is high, while the [N II]/Hα ratio remains relatively low across the nucleus.

4.2.2. Control Galaxy: SDSS J015536.83–002329.4

The starburst galaxy SDSS J015536.83–002329.4 is the control galaxy for SDSS J024440.23–090742.4. The stellar continuum distribution is centrally concentrated, although a marginal elongation in the SW direction can be seen (Figure 19). Since the continuum is weak, there is no obvious rotation in the stellar velocity field and the stellar velocity dispersion is irregular.
The gas distribution is extended northeast in both $H\alpha$ and $[O\,\text{iii}]$. The $H\alpha$ line strength is significantly larger than the $[O\,\text{iii}]$ strength, resulting in a low, but approximately uniform $[O\,\text{iii}]/H\beta$ ratio across the field. Unlike the stellar velocity field, both of the gas velocity fields show evidence for rotation, resulting in velocities of up to $130$ km $s^{-1}$ within $1$ kpc. The $H\alpha$ dispersion velocity also increases toward the center. The $[N\,\text{ii}]/H\alpha$ shows a slight gradient across the kinematic major axis, although the difference is only $\sim 0.2$. The $[S\,\text{ii}]$ doublet ratio also shows an increase along the kinematic major axis, with the SW region seemingly of higher density than the NE region.

4.3. Pair Three

4.3.1. Active Galaxy: Mrk 609

Mrk 609 is a starburst/Seyfert composite galaxy. There is a strong Seyfert 1-like nucleus that appears somewhat extended, and weak, broad H-recombination lines are seen in the optical spectrum, resulting in an intermediate Seyfert classification, 1.5–1.8 (Osterbrock 1981; Goodrich 1990). UV/optical ratios and X-ray spectra (Pappa et al. 2002) show slight extinction toward the nucleus. On larger scales, observations show no signs of a bar (Crenshaw et al. 2003; Deo et al. 2006), although a more complex morphology emerges in the nuclear region, where two spiral arms connect to an elongated stellar structure. VLT-SINFONI observations reveal clumpy hydrogen recombination emission that peaks where the nuclear bar meets the spiral arms, and also along the minor axis (Zuther et al. 2007).

The stellar continuum map (Figure 20) shows a slight elongation in the SE–NW direction. There is no overall rotation observed in the stellar velocity field ($V_{\text{stars}}$), while the stellar velocity dispersion ($\sigma_{\text{stars}}$) rises slightly toward the center.

Strong $H\alpha$ emission is consistent with VLT-SINFONI observations, with multiple peaks occurring in the SE–NW direction. In contrast, the $[O\,\text{iii}]$ emission is more concentrated, centered on the continuum peak and elongated in the NE–SW direction. The $H\alpha$ velocity field shows signs of low-level rotation, with a slight velocity gradient north–south. In contrast to the low velocities observed in the $H\alpha$ field, the $[O\,\text{iii}]$ velocity map is dominated by blueshifted emission up to $300$ km $s^{-1}$ across the central kiloparsec. These observed velocities are the result of prominent blue wings seen in the $[O\,\text{iii}]$ emission lines, which could be attributed to an outflow component, in addition to a narrower, low-level rotation component, similar to that seen in the $H\alpha$ velocity map.

The gas velocity dispersion is also high, but drops by around $50$ km $s^{-1}$ in the very center. The $[O\,\text{iii}]/H\beta$ line ratio rises toward the center where the AGN dominates.

4.3.2. Control Galaxy: Mrk 1404

The S0 galaxy Mrk 1404 is the control galaxy for Mrk 609. The optical spectrum exhibits strong $H\alpha$ and $[N\,\text{ii}]$ emission lines, but weaker $H\beta$ and $[S\,\text{ii}]$ lines.

The stellar velocity field (Figure 21) shows no significant rotation. The $H\alpha$ distribution reveals an asymmetric star formation pattern, with the peak offset NE of the continuum peak. The $H\alpha$ velocity reveals a regularly rotating disk with peak velocity $\sim 100$ km $s^{-1}$ at a 1.3 kpc radius. The $H\alpha$ velocity dispersion field is low ($\sigma < 50$ km $s^{-1}$) but also shows an increase toward the center. The weak $[O\,\text{iii}]$ emission confirms the lack of highly ionized gas in the central region of Mrk 1404. No net rotation is obvious in the $[O\,\text{iii}]$ velocity field, but the gas velocity dispersion shows a slight increase toward the center. Due to the lack of strong emission, the $[O\,\text{iii}]/H\beta$ and $[N\,\text{ii}]/H\alpha$ line ratio maps both show generally low ratios, consistent with its classification as an inactive star-forming galaxy. The $[S\,\text{ii}]$ doublet ratio map reveals a slight decrease toward the center, indicating an increase in (electron) density.

4.4. Pair Five

4.4.1. Active Galaxy: SDSS J034547.53–000047.3

SDSS J034547.53–000047.3 is an isolated S0/a galaxy (Allam et al. 2005), classified as a narrow-line Seyfert (see Figure 22). The stellar continuum map shows a centrally concentrated, but weak continuum. As a result of the weak continuum, the stellar kinematics were not well constrained, so the velocity field does not reveal any signs of rotation or obvious pattern in the velocity dispersion map.

The $H\alpha$ distribution appears to be elongated (NE–SW) in the inner few arcseconds. There is a clear rotation component in the $H\alpha$ velocity field, while the velocity dispersion also shows an increase toward the center. The $[O\,\text{iii}]$ distribution, of comparable strength to $H\alpha$, is also slightly elongated in the NE–SW direction, but not entirely coincident with the $H\alpha$ distribution. The $[O\,\text{iii}]$ velocity field, however, shows no rotation. Instead, there is again evidence for a strong outflow component, with blueshifted velocities up to $200$ km $s^{-1}$. The high velocity dispersions here ($\sim 275$ km $s^{-1}$) also support this scenario. The $[O\,\text{iii}]/H\beta$ map peaks at the photometric center and decreases with increasing radius. The $[S\,\text{ii}]$ ratio distribution reveals little structure.

4.4.2. Control Galaxy: SDSS J032519.40–003739.4

SDSS J032519.40–003739.4 is the control galaxy for SDSS J034547.53–000047.3. It is an early-type, almost
face-on galaxy. The IMACS maps (Figure 23) show a regular nuclear stellar structure. Due to the weak continuum of SDSS J032519.40–003739.4, the stellar kinematics were once again not well constrained. As a result, no hint of a gradient can be seen in the stellar velocity field, and the stellar velocity dispersion is also dominated by noise. The ionized gas maps confirmed the absence of ionized gas, and have thus been omitted from the figure.

4.5. Pair Six

4.5.1. Active Galaxy: SDSS J085310.26+021436.7

SDSS J085310.26+021436.7 is an S0a, broad-line Seyfert galaxy. The SDSS spectrum for SDSS J085310.26+021436.7 reveals a strong continuum, which the reconstructed IMACS continuum map (Figure 24) shows to be distributed symmetrically across the inner kiloparsec.
The stellar velocity field reveals a regular rotation field with a kinematic P.A. of roughly 180°, which is consistent with the photometric P.A. of the outer disk. The stellar velocity dispersion increases in the galaxy center, reaching a maximum of ∼250 km s\(^{-1}\).

The H\(_{\alpha}\) emission is weak so the underlying velocity field is not well traced in the H\(_{\alpha}\) velocity and dispersion maps. In contrast, the [O\(_{\text{III}}\)] emission is strong and centrally concentrated, with marginal evidence for an N–S elongation in the central 300 pc. The [O\(_{\text{III}}\)] velocity map shows possible evidence for rotation, with an E–W gradient, which is offset by approximately 90° to that of the stellar velocity field. The [O\(_{\text{III}}\)] dispersion velocity is high at 200–300 km s\(^{-1}\) in the central 300 pc.

**4.5.2. Control Galaxy: Mrk 1311**

Mrk 1311 (classification 50a) is the control galaxy for SDSS J085310.26+021436.7. The IMACS maps (Figure 25) show a centrally peaked continuum emission with a hint of elongation in P.A. ∼ 80° and evidence for rotation with a kinematic major axis along the same P.A. The stellar dispersion is high, at ∼250 km s\(^{-1}\), and rises toward the nucleus.

Ionized gas emission was not detected to a 3σ limiting flux density, so the corresponding emission-line maps are not shown.

**4.6. Pair Seven**

**4.6.1. Active Galaxy: CGCG 005-043**

CGCG 005-043 is an S0–a, broad-line Seyfert galaxy. The IMACS continuum map (Figure 26, top-left panel) shows a roughly circular distribution in the stellar core, with a possible east–west elongation. The stellar velocity field shows weak evidence of rotation, with the eastern side of the galaxy significantly more blueshifted. The photometric major axis P.A. is known to be 151.5° (Paturel et al. 2005), so this would suggest a photometric–kinematic misalignment of around 60°.

The ionized gas distribution is similar in both H\(_{\alpha}\) and [O\(_{\text{III}}\)], with both extended roughly east–west. The H\(_{\alpha}\) velocity field shows an S-shaped zero-velocity line, but the kinematic center is offset to the west compared to the stars and the H\(_{\alpha}\) field, with strong blueshifted [O\(_{\text{III}}\)] emission lines observed in the very center. This could be due to outflow from the nucleus. The gas velocity dispersion is consequently high and increases peaks in the inner few hundred parsecs. The [S\(_{\text{II}}\)] ratio distribution shows a slight drop in the center.

**4.6.2. Control Galaxy: SDSS J104409.99+062220.9**

SDSS J104409.99+062220.9 is the control galaxy for CGCG 005-043. The continuum distribution for SDSS J104409.99+062220.9 (see Figure 27) is weak but shows a slight extension approximately north–south. No trends or gradients are identified in the stellar velocity or dispersion maps. Again, no detection of emission from ionized gas is made and the noise-dominated maps are omitted.

**4.7. Pairs Eight and Fourteen**

**4.7.1. Active Galaxy: SDSS J090040.66–002902.3**

SDSS J090040.66–002902.3 is an Sab, narrow-line Seyfert galaxy. The IMACS maps (Figure 28), show weak stellar continuum emission that is slightly elongated in the NE direction. Since the continuum is weak the stellar kinematics are not well constrained, but there is possibly stellar rotation with a kinematic P.A. of ∼30°.

The H\(_{\alpha}\) distribution is relatively strong in the outer regions of the FOV, but shows a clear void in the central 2″, suggesting the presence of a circumnuclear star-forming ring. The [O\(_{\text{III}}\)] distribution is weak but highly concentrated in the central region where the H\(_{\alpha}\) flux drops. The H\(_{\alpha}\) velocity map reveals clear evidence of rotation over the entire IMACS-IFU FOV, with a P.A. similar to that implied by the stellar velocity field. The ionized gas dispersion velocity again shows a small increase toward the center. The [O\(_{\text{III}}\)] kinematics reveal no clear patterns. The [N\(_{\text{II}}\)]/H\(_{\alpha}\) and [O\(_{\text{III}}\)]/H\(_{\beta}\) line ratios are comparable, with both highest in the center, where the AGN dominates.

**4.7.2. Active Galaxy: CGCG 050-048**

CGCG 050-048 is a radio-loud narrow-line Seyfert galaxy. The NVSS image for CGCG 050-048 shows circular contours for the galaxy, but with a resolution of 45′. The IMACS maps, which are of much finer spatial resolution, reveal significant structure in the inner 2″ (see Figure 29). The continuum map reveals an elongated distribution extended along P.A. ∼ 30°.

The stellar velocity field of CGCG 050-048 shows signs of rotation, with the kinematic major axis roughly oriented in the N–S direction. The stellar velocity dispersion map again increases toward the center.

The H\(_{\alpha}\) emission-line map reveals an elongated distribution running north to south, but with the northern half being almost twice as bright as the southern half. The H\(_{\alpha}\) velocity field shows clear evidence of rotation, with a P.A. of −13° that is consistent with the stellar velocity field. The [O\(_{\text{III}}\)] flux map shows a more
compact distribution. Rotation is again visible in the \([\text{O} \text{iii}]\) velocity field, although the zero-velocity line is significantly offset from the center of the galaxy, suggesting again that there may be an outflow component. The gas dispersion velocity shows a sharp increase to 280 km s\(^{-1}\) at the location of the peak \([\text{O} \text{iii}]\) emission, further suggesting outflow from the nucleus. The \([\text{O} \text{iii}] / \text{H} \beta\) ratio shows an increase toward the center, where the AGN dominates, and a strong decrease in the northwest corner, where star formation dominates. The \([\text{S} \text{ii}]\) doublet ratio is generally high across the whole field, indicating a low density.

4.7.3. Control Galaxy: MCG +00-02-006

MCG +00-02-006 is the control for SDSS J090040.66–002902.3 and CGCG 050-048. MCG +00-02-006 is an Sab
galaxy with a P.A. of 58°2 (Paturel et al. 2005). The SDSS spectrum shows that the continuum is quite weak ($<40 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$). This, coupled with the fact that only a single exposure of 20 minutes was achieved for this galaxy due to telescope time lost to bad weather, resulted in a very low signal-to-noise level for MCG +00-02-006. As a result, IMACS-IFU maps are not presented here.

4.8. Pair Nine

4.8.1. Active Galaxy: ARK 402

The compact red object ARK 402 is a narrow-line Seyfert galaxy of morphological type S0a. The IMACS continuum distribution (Figure 30) is regular in the central 2′, with a possible elongation in the direction of the photometric axis of the outer disk (98°). The stellar velocity field hints at rotation with a kinematic P.A. consistent with the P.A. of the outer disk. The stellar velocity dispersion is generally high ($\sigma_{\text{stars}} > 200$ km s$^{-1}$) in the inner 4′.

The ionized gas content is low, but reveals some structure. The H$\alpha$ distribution is slightly elongated E–W, with a velocity field showing clear, fast rotation along that axis. The [O$\text{iii}$] flux distribution is more concentrated in the center than H$\alpha$, but not uniform. The [O$\text{iii}$] velocity field also shows signs of rotation along the photometric major axis. The [O$\text{iii}$] velocity dispersion shows a strong increase toward the center.

4.8.2. Control Galaxy: UGC 05226

UGC 05226 (classification S0) is the control for ARK 402. It has strong continuum emission (see Figure 31), but shows no clear sign of rotation and the velocity dispersion remains high at 200 km s$^{-1}$ across the central ∼350 pc. There is no clear sign of rotation in the stellar velocity field, but the stellar velocity dispersion remains above 200 km s$^{-1}$ in the inner few arcseconds. No line emission is detected in the circumnuclear region so the maps are not presented.

4.9. Pairs Ten, Eleven, and Twelve

4.9.1. Active Galaxy: NGC 5740

NGC 5740 is a nearby, SAB(rs)b-type, narrow-line Seyfert galaxy. The IMACS continuum map (Figure 32) and the H$\alpha$ emission-line map, which shows two strong peaks, confirm the presence of a circumnuclear bar running approximately south–north. The stellar velocity map shows overall rotation, with a kinematic P.A. similar to the photometric P.A. of the outer disk (∼160°), derived from SDSS data. The stellar velocity dispersion shows a general increase toward the very center. The H$\alpha$ velocity map also shows an axisymmetric rotation field with a kinematic P.A. similar to the photometric P.A.

The [O$\text{iii}$] maps exhibit more complexity. The [O$\text{iii}$] emission-line distribution does not show the same bar-like feature that is observed in H$\alpha$ and starlight. First, the [O$\text{iii}$] emission is less extended in the south of the nucleus, and in the northern half, the distribution tends to the east. The [O$\text{iii}$] velocity field shows that the [O$\text{iii}$] emission is rotating at velocities comparable to the stellar field. The kinematic P.A. of the [O$\text{iii}$] velocity field, however, differs from the stellar kinematic P.A. by approximately 30°, suggesting the gas is more disturbed in the nucleus. The kinematic minor axis is also warped in the northeast corner, which could be due to either an outflow in the northeast corner or gas streaming into the nucleus. The [O$\text{iii}$] dispersion velocity is low, but does increase to ∼50 km s$^{-1}$ in the center. The [O$\text{iii}$]/H$\beta$ line ratio shows a gradient from east to west, with [O$\text{iii}$] dominating in the center and east, suggestive of an outflow in this direction.

4.9.2. Active Galaxy: NGC 5750

NGC 5750 is a nearby spiral galaxy classified as SB(r)0/a. The SDSS spectrum shows that it is a low-luminosity narrow-line Seyfert. The stellar continuum (Figure 33) shows a possible extension E–W, confirming the presence of a nuclear bar.

The IMACS stellar velocity field shows tentative signs of low-level rotation. The kinematic major axis of the stellar velocity field is oriented at a P.A. of around 75°, which roughly coincides with the photometric major axis of 65° (Erwin 2005).

The H$\alpha$ gas emission coincides with the peak in the stellar distribution, although it is quite weak. General rotation is clear in the H$\alpha$ velocity field, although the velocity field is blueshifted, with the kinematic minor axis offset eastward from the photometric center. The [O$\text{iii}$] emission line distribution shows a more complex, clumpy structure within the central 2′. The [O$\text{iii}$] velocity field shows similar rotation to that in H$\alpha$, albeit without the apparent shift in kinematic center. The [O$\text{iii}$] and H$\alpha$ velocity dispersion maps show an increase in the nucleus, reaching over 100 km s$^{-1}$. Line ratio maps show no particular trend across the field.

4.9.3. Active Galaxy: NGC 5806

NGC 5806 is a late-type, SAB(s)b galaxy, originally classified as a narrow-line Seyfert galaxy based on its SDSS classification. HST/NICMOS2 observations, however, re-classified it as a galaxy with concentrated nuclear star formation mixed with...
Figure 28. IMACS-IFU maps for active galaxy SDSS J090040.66–002902.3. Cosmology-corrected scale: 788 pc arcsec$^{-1}$. See Figure 15 for description of maps plotted.
(A color version of this figure is available in the online journal.)

dust, based on its nuclear NIR- and optical/NIR-color morphology (Carollo et al. 2002).

Very Large Array observations from the VHIKINGS survey (Mundell et al. 2007) revealed that the H$\alpha$ distribution traced the optical disk well, while the H$\alpha$ kinematics were consistent with global rotation aligned with the outer disk major axis. SAURON kinematics (Dumas et al. 2007) showed that the gas and stellar velocity fields ($33'' \times 40''$) also revealed regular rotation patterns aligned with the photometric major axis, with a velocity dispersion that rises in the nucleus.

Elongated features in the nucleus were seen in the HST/NICMOS2 and SAURON observations. This is also evident from the IMACS stellar continuum map (Figure 34), which shows elongation at a P.A. of roughly zero. The stellar velocity field in the inner arcsec shows global rotation at a P.A. of approximately $-160^\circ$—a $50^\circ$ misalignment.
from the outer disk major axis. The stellar velocity dispersion shows a small increase in the nucleus.

The [O\textsc{iii}] emission-line distribution is somewhat weak, and irregular throughout the IMACS FOV. The [O\textsc{iii}] velocity field, however, still shows tentative signs of rotation, but with a kinematic major axis even further offset from previous results (i.e., the outer disk major axis). The H\textalpha{} distribution, however, shows almost no emission in the inner few arcseconds, but strong emission in the outskirts of the field. This emission is likely to be the inner edge of the nuclear star-forming ring at a radius $\sim 3''$ found in Dumas et al. (2007). In addition, the H\textalpha{} velocity field shows a departure from axisymmetry, with an S-shaped zero-velocity line. The H\textalpha{} velocity dispersion remains low ($<60$ km s$^{-1}$) across the IMACS-IFU FOV. Finally, the

Figure 29. IMACS-IFU maps for active galaxy CGCG 050-048. Cosmology-corrected scale: 745 pc arcsec$^{-1}$. See Figure 15 for description of maps plotted. (A color version of this figure is available in the online journal.)
[N\textsc{ii}]/H\textalpha line ratio map shows a small increase toward the center. The [O\textsc{iii}]/H\beta line ratio map generally remains quite low, again suggesting that the SDSS classification as a narrow-line Seyfert may be incorrect, and that NGC 5608 is at most a composite galaxy (Westoby et al. 2007).

4.9.4. Control Galaxy: NGC 7606

The SA(s)b star-forming galaxy NGC 7606 is the control for NGC 5806, NGC 5750, and NGC 5740. It is thought to have a nuclear bar, based on infrared ellipticity measurements (Menéndez-Delmestre et al. 2007). However, the IMACS continuum map (Figure 35) reveals an almost circular distribution in the nucleus, suggesting that a stellar bar may not be present. The stellar velocity field reveals a low-level ($V_{rot} < 80$ km s$^{-1}$) rotation field, with a kinematic P.A. of approximately 75°. A $\sigma$-drop of $\sim 60$ km s$^{-1}$ is observed in the inner 2′ of the stellar velocity dispersion map.

H\alpha rotation curves derived from long-slit spectroscopy along the galactic major axis (Mathewson et al. 1992) show that the outer galaxy disk ($R > 100^\circ$) is rotating. The IMACS H\alpha and
Figure 31. IMACS-IFU maps for control galaxy UGC 05226. Cosmology-corrected scale: 346 pc arcsec$^{-1}$. See Figure 17 for description of maps plotted.

(A color version of this figure is available in the online journal.)

Figure 32. IMACS-IFU maps for active galaxy NGC 5740. Cosmology-corrected scale: 118 pc arcsec$^{-1}$. See Figure 15 for description of maps plotted.

(A color version of this figure is available in the online journal.)
[O iii] emission-line maps, however, show an absence of ionized gas in the central few hundred parsecs, and have therefore been omitted from Figure 35.

4.10. Pair Thirteen

4.10.1. Active Galaxy: SDSS J150126.67+020405.8

SDSS J150126.67+020405.8 is a broad-line Seyfert galaxy. SDSS data suggest that the galaxy is a morphological type S0, with a P.A. of 125°. The IMACS continuum distribution (Figure 36) shows a symmetric central peak, with no signs of a nuclear bar. There is a slight gradient across the stellar velocity field (E-W direction) suggesting it may be rotating at a kinematic P.A. of approximately 100°, but this is inconclusive. The stellar dispersion velocity increases to around 150 km s\(^{-1}\) in the center.

The [O iii] emission-line distribution shows a slight elongation north–south, and possibly some structure. The H\(\alpha\) emission...
is also extended N–S, but is weaker than the [O Ⅲ]. The Hα velocity field shows a more obvious gradient, confirming that the galaxy disk is rotating at a P.A. similar to the global photometric P.A. The [O Ⅲ] velocity field also shows signs of rotation at a similar P.A. to the other components. The [O Ⅲ] velocity dispersion shows an increase toward the center, reaching up to ∼175 km s⁻¹. The [O Ⅲ]/Hβ line ratio is high and increases toward the center of the galaxy, as expected for AGNs.

4.10.2. Control Galaxy: SDSS J122224.50+004235.6

The control galaxy for SDSS J150126.67+020405.8 is the S0 galaxy SDSS J122224.50+004235.6. The IMACS continuum map (Figure 37) shows a uniform distribution of stars. There is evidence of rotation in the stellar velocity field, with a kinematic P.A. approximately aligned E–W. The velocity dispersion shows an increase toward the center. No ionized gas is detected in the 2.5 kpc FOV, so the corresponding maps are omitted from Figure 37.

4.11. Pair Fifteen

4.11.1. Active Galaxy: NGC 6500

The SAab galaxy NGC 6500 contains a LINER nucleus. Twenty-centimeter radio studies have revealed extended emission to the southeast, perpendicular to the galactic major axis (Hummel et al. 1983), and on smaller scales (central arcsecond) the nuclear emission is extended along the major axis.
(P.A. \( \sim 55^\circ \); Unger et al. 1989). This complex radio structure has been interpreted as an outflow component along the galactic minor axis.

No evidence for significant elongation is seen in the IMACS-IFU stellar continuum, H\( \alpha \), and [O III] intensity maps (Figure 38), although a marginal elongation in P.A. 80° may be present. The velocity fields of the stars and gas all reveal rotation along the galactic major axis. The H\( \alpha \) and [O III] gas velocities at the photometric center are redshifted with respect to that of the stars, suggesting a receding outflow component in addition to any galactic rotation. The increased ionized gas velocity dispersion in this region is consistent with this interpretation. The velocity dispersion maps of the gas and stars are also in agreement with each other, with an increase toward the center.

The [N II]/H\( \alpha \) and [O III]/H\( \beta \) ratio maps reveal little structure, while the [S II] ratio map shows a strong increase toward the center, indicating a lower gas density in the nucleus.

4.11.2. Control Galaxy: NGC 3731

NGC 3731 has been selected as the control galaxy for NGC 6500, but it has yet to be observed.

4.12. Pair Sixteen

4.12.1. Active Galaxy: ESO 399-IG 020

As can be seen from the Digitized Sky Survey (DSS) image in Figure 3, ESO 399-IG 020 is the largest galaxy of an interacting system consisting of up to three galaxies. The presence of broad Hydrogen-Balmer emission lines in the spectra of ESO 399-IG 020 confirms its classification as a Seyfert 1 nucleus, but has so far prevented the extraction of the kinematics. As can be seen in the integrated IMACS spectrum shown in Figure 39, the width of the H\( \alpha \) emission line is unresolved from the [N II] doublet. In addition, the H\( \beta \) emission line is not consistent with a single Gaussian model, suggesting the presence of a narrow component in addition to the broad component.

As a result, in the operating range of GANDALF, masking the broad emission lines leaves little continuum spectra with which to fit the stellar kinematics. Higher angular resolution spectral imaging is required to determine the two-dimensional gas kinematics robustly. The detailed study of this object therefore lies beyond the scope of this paper.

4.12.2. Control Galaxy: IC 1068

The matched control galaxy for ESO 399-IG020, IC 1068, has yet to be observed.

4.13. Pair Seventeen

4.13.1. Active Galaxy: SDSS J215259.07–000903.4

SDSS J215259.07–000903.4 is a Seyfert 2 galaxy. The stellar continuum is relatively weak, but strong emission lines can be seen in the SDSS spectrum. The IMACS maps (Figure 40) show a regular structure in the continuum image. The continuum is, however, quite weak, so there is only marginal evidence for rotation in the stellar velocity field and little systematic structure in the velocity dispersion map.

In contrast, the H\( \alpha \) velocity field provides evidence for galactic rotation, with a kinematic major axis in P.A. of 70°. The H\( \alpha \) dispersion velocity increases toward the center, but remains below 100 km s\(^{-1}\). The [O III] emission is very strong, and concentrated in the nucleus. The resulting [O III] velocity field shows less-obvious signs of rotation, but with a kinematic P.A. comparable to that of the H\( \alpha \) velocity field. The distribution of H\( \alpha \) and [O III] emission is well matched and the [O III]/H\( \beta \) ratio increases toward the nucleus as the AGN dominates.

4.13.2. Control Galaxy: SDSS J203939.41–062533.4

SDSS J203939.41–062533.4 is the control galaxy for SDSS J215259.07–000903.4. The stellar continuum distribution (Figure 41) is regular, with a bright central peak. The stellar velocity field suggests rotation, with the kinematic major axis roughly consistent with the photometric P.A. from SDSS observations. No significant ionized gas, H\( \alpha \) or [O III], is detected in the IMACS-IFU maps, so they are omitted from the figure.

5. SUMMARY OF OBSERVED FEATURES

5.1. Stellar Continuum Distributions

Nineteen of the 27 galaxies show an axisymmetric, roughly circular distribution in the central 2″. Six galaxies show more flattened isophotes, while CGCG 050-048 and NGC 5740 show strong elongations, reflecting the presence of a nuclear bar.

5.2. Ionized Gas Distributions

The ionized gas was mapped in both [O III] and H\( \alpha \), via direct Gaussian fitting to the emission lines. H\( \alpha \) emission is detected to some level in all 15 Seyfert galaxies, but in only 2 of the 9 controls analyzed. [O III] emission, associated with active accretion, is also found in all of the Seyferts and in one of the controls. A number of different properties were seen in either H\( \alpha \) or [O III], or both. These can be summarized as follows:
Figure 36. IMACS-IFU maps for active galaxy SDSS J150126.67+020405.8. Cosmology-corrected scale: 816 pc arcsec$^{-1}$. See Figure 15 for description of maps plotted.

1. Eight Seyfert galaxies (e.g., SDSS J024440.23–090742.4; Figure 18) show regular, centrally concentrated distributions in both H$\alpha$ and [O iii].

2. Mrk 609 and SDSS J090040.66–002902.3 show round distributions in [O iii], but more complex H$\alpha$ distributions. In Mrk 609 (Figure 20) spiral features emerge, with the distribution extending to an excess of emission in the north of the FOV. SDSS J090040.66–002902.3 (Figure 28) shows a ring-like star-forming structure, with a radius of $\sim 2''$.

3. Spiral-like features can be seen in the nuclear H$\alpha$ emission of the Seyfert galaxy NGC 5806 and the control galaxy Mrk 1404 (Figures 34 and 21 respectively). In these cases the [O iii] emission is also complex, with the distribution confined to the nuclei, but broken up. ARK 402 appears to show ring-like structures in both emission lines, with the H$\alpha$ ring more broken up.

4. Four Seyferts and one control galaxy show extended or bimodal distributions. SDSS J033955.68–063237.5
Figure 37. IMACS-IFU maps for control galaxy SDSS J122224.50+004235.6. Cosmology-corrected scale: 818 pc arcsec$^{-1}$. See Figure 17 for description of maps plotted.

(A color version of this figure is available in the online journal.)

Figure 38. IMACS-IFU maps for active galaxy NGC 6500. Cosmology-corrected scale: 192 pc arcsec$^{-1}$. See Figure 15 for description of maps plotted.

(A color version of this figure is available in the online journal.)
An increase in \([\text{O} \text{iii}]\) galaxies show a general increase in \([\text{O} \text{iii}]\) controls. Over the IMACS-IFU FOV, the majority of Seyfert 14, compared to a maximum of approximately 2 seen in the Seyfert galaxies: the maximum seen in the Seyferts is around 3900–7100 Å. As a result, we can investigate both the dynamical impact of AGNs through the high-ionization \([\text{O} \text{iii}]\) emission line and the kinematics of the host galaxy disk through the star-formation-related \(\text{H}\alpha\) emission line.

5.4. Stellar and Ionized Gas Kinematics

The velocity maps discussed here present the line-of-sight velocity components, while the velocity dispersion maps represent the more random motions of the system.

5.4.1. Stellar Kinematics

Only 7 of the 26 galaxies analyzed show a gradient in their stellar velocity field consistent with rotation, with 4 more showing marginal gradients that require deeper observations for confirmation. These are SDSS J024440.23–090742.4, CGCG 005-043, SDSS J090040.66–002902.3, and NGC 5750.

In the majority of galaxies (Seyferts and controls), the stellar velocity dispersion shows a general increase toward the center. The remainder of the galaxies show more random dispersion distributions, as a result of the kinematics not being well constrained.

5.4.2. Ionized Gas Kinematics

An advantage of IMACS-IFU is the broad wavelength coverage—approximately 3900–7100 Å. As a result, we can investigate both the dynamical impact of AGNs through the high-ionization \([\text{O} \text{iii}]\) emission line and the kinematics of the host galaxy disk through the star-formation-related \(\text{H}\alpha\) emission line.

The \(\text{H}\alpha\) velocity maps are dominated by rotation for 13 Seyferts and two control galaxies. Departures from axisymmetry can be seen in many of these galaxies, such as S-shaped zero-velocity lines (e.g., Mrk 1404, CGCG 005-043, and NGC 5806), and distortions in the very center. Only SDSS J033955.68–063237.5, SDSS J015536.83–002329.4, CGCG 005-043, and NGC 5740 show regularly rotating \(\text{H}\alpha\) velocity fields.

Nine of the 11 Seyfert galaxies showing rotation in the low-ionization gas also show rotation in the high-ionization gas \([\text{O} \text{iii}]\). The \([\text{O} \text{iii}]\) velocity fields are more distorted, and the range of observed velocities with respect to the systemic velocity is generally lower than those of the \(\text{H}\alpha\) velocity fields. In seven Seyfert galaxies, however, there is evidence of an ionized outflow component, inferred by purely blueshifted \([\text{O} \text{iii}]\) velocities compared to a rotating \(\text{H}\alpha\) velocity component (SDSS J033955.68–063237.5, Mrk 609, and SDSS J034547.53–000047.3), by a spatial offset of the zero-velocity line with respect to the photometric center (CGCG 005–043, CGCG 050–048, NGC 6500, and SDSS J215259.07–000903.4), or by a strong warping of the zero-velocity line (NGC 5740).

(Figure 16) reveals an elongated \(\text{H}\alpha\) distribution and a misaligned, bimodal \([\text{O} \text{ii}]\) distribution suggesting a significant dust presence. The \(\text{H}\alpha\) emission in SDSS J034547.53–000047.3 (Figure 22) reveals extended star formation (NE–SW) while the \([\text{O} \text{iii}]\) emission extends to the NE only. CGCG 050-048 (Figure 29) shows compact \([\text{O} \text{iii}]\) emission in the nucleus, while the \(\text{H}\alpha\) emission is extended N–S, with the northern half significantly brighter. NGC 5740 (Figure 32) shows extended star formation in a nuclear bar, with two bright peaks north and south of the continuum center. In between lies the location of the \([\text{O} \text{iii}]\) emission, which also extends north. The control galaxy SDSS J015536.83–002329.4 (Figure 19) shows extended emission in the SW–NE direction, with \(\text{H}\alpha\), in particular, showing a strong excess in the NE.

5.3. Ionized Gas Line Ratios

As implied by our selection criteria, emission-line ratios trace the ionization mechanism. Low \([\text{O} \text{ii}]\)/\(\text{H}\beta\) and \([\text{N} \text{ii}]\)/\(\text{H}\alpha\) ratios are characteristic of star formation, while high \([\text{O} \text{iii}]\)/\(\text{H}\beta\) and \([\text{N} \text{ii}]\)/\(\text{H}\alpha\) ratios are due to the presence of a harder ionizing continuum, characteristic of AGN activity. In addition, the \([\text{S} \text{ii}]\) doublet ratio is a good density indicator.

As expected, the \([\text{O} \text{iii}]\)/\(\text{H}\beta\) ratios are generally higher for the Seyfert galaxies: the maximum seen in the Seyferts is around 14, compared to a maximum of approximately 2 seen in the controls. Over the IMACS-IFU FOV, the majority of Seyfert galaxies show a general increase in \([\text{O} \text{iii}]\)/\(\text{H}\beta\) toward the center. An increase in \([\text{O} \text{iii}]\)/\(\text{H}\beta\) is often accompanied by an increase in \([\text{N} \text{ii}]\)/\(\text{H}\alpha\) ratio.

The majority of the control galaxies contain little ionized gas; only two controls—Mrk 1404 and SDSS J015536.83–002329.4—contained sufficient ionized gas to make meaningful maps from which to derive line ratios. The \([\text{S} \text{ii}]\) doublet ratio maps show very little structure for nine of the Seyferts and eight of the controls. A number of Seyferts (e.g., Mrk 609; Figure 20) show a slight drop toward the center, indicating an increase in (electron) density, while NGC 6500 (Figure 38) shows very low \([\text{S} \text{ii}]\) ratio values in the central few arcseconds. The control galaxy SDSS J015536.83–002329.4 (Figure 19) shows a gradient across the \([\text{S} \text{ii}]\) field, with a decrease in electron density observed at the location of increased star formation in the northeast section.
In the cases of the strongly blueshifted [O III] velocity fields, the outflows show approaching velocities of over 200 km s$^{-1}$, extending over 2" ($>1.5$ kpc). In one of these cases, SDSS J033955.68–063237.5, the H$\alpha$ velocity field is remarkably undisturbed suggesting that the ionized-gas outflow must be almost perpendicular to the plane of the rotating disk.

All galaxies tend to show a maximum gas velocity dispersion (H$\alpha$ and [O III]) in the center, with the exception of Mrk 609, which shows a slight drop in [O III] dispersion in the center—possibly reflecting the effect of the outflow component.

6. CONCLUDING REMARKS

We have presented the first two-dimensional maps of ionized gas and stars in an SDSS-selected sample of active and inactive galaxies obtained using the IMACS-IFU on the Magellan-I 6.5 m telescope. This study required the development of a full reduction pipeline for IMACS-IFU, which was previously unavailable. In this paper, we have provided a detailed description of the reduction process and analysis of IMACS-IFU data, from observing strategy to final extracted maps, with particular
emphasis on aspects that affect IMACS-IFU such as telescope flexure. Following extensive testing of the IMACS-IFU pipeline, two-dimensional stellar and gas kinematics were derived for 26 of the 28 galaxies in the sample thus far.

In contrast to other IFUs, the unusually large wavelength coverage (∼4000–7000 Å) provided by the IMACS-IFU, coupled with the fine pixel sampling across the 4′15 × 5′00 FOV has allowed the extraction of gaseous and stellar kinematics that probe both the AGN-related regions and the host galaxy. In particular, simultaneous observation of [O iii] and Hα emission lines provide independent probes of galaxy rotation and AGN-driven outflow.

Evidence of rotation was found in the stellar velocity fields of 11 out of the 26 galaxies analyzed, while the S/N of the remaining galaxies was deemed insufficient to make any conclusions. Fifteen of 26 galaxies showed clear evidence of rotation in the Hα velocity fields. Seven Seyfert galaxies show possible evidence of an [O iii] outflow component, the most extreme of which exceeds a blueshifted line-of-sight velocity of 200 km s\(^{-1}\) and extends over 2″ (∼1.5 kpc).

We have demonstrated the value of large simultaneous wavelength coverage, which allows for the derivation of the underlying host-galaxy dynamics from Hα kinematics, regardless of the perturbations revealed in [O iii] kinematics. Full kinematics, modeling, and its interpretation will be presented in Paper II (P. B. Westoby et al., in preparation).

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Figure 41. IMACS-IFU maps for control galaxy SDSS J203939.41–062533.4. Cosmology-corrected scale: 531 pc arcsec\(^{-1}\). See Figure 17 for description of maps plotted.

(A color version of this figure is available in the online journal.)
