Velocity fields of infrared selected galaxies at $z \sim 2^*$

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ABSTRACT

Context. The TFR at high redshift can best be studied using massive galaxies and using galaxies that resemble local disk galaxies. The rest frame K band TFR is locally tighter and less sensitive to extinction than the rest frame B band TFR, and rest frame K band magnitudes can now be obtained at high redshift using IRAC. The stellar mass TFR is a measure of the build-up of the stellar population within halo’s.

Aims. We target a sample of massive and a sample of morphologically and photometrically large disk galaxies at $z \sim 2$, most of which are selected at MIPS 24μm. As we showed in a separate paper, one of these large disks galaxies is very similar to local disk galaxies.

Methods. We used VLT-SINFONI to observe the Hα velocity fields and hence rotation curves of 9 $z \sim 2$ galaxies. IRAC and MIPS 24μm photometry are available for all targets.

Results. We detect velocity fields for four galaxies. The S/N of a fifth galaxy is too low to measure the VF. All are consistent with a rotating disk interpretation, although irregularities are observed in two cases and the extent of the Hα distribution limits the interpretation of two velocity fields. All galaxies are massive, with flat or maximum rotation curve velocities of $200 \sim 400$ km s$^{-1}$. Within the observed radii, there is no evidence for dark matter. The morphological and photometrically large disk selected galaxies have similar angular momentum and spin parameter as local spiral galaxies. The zero points of the rest frame B and K band TFR at $z \sim 2$ are (after correction for extinction) $\sim 2.4$ and $\sim 1.4$ mag brighter than in the local universe. All galaxies appear to be consistent with the local baryonic mass TFR. However, the interpretation of the TFR results is strongly limited by the small sample of galaxies which all have peculiarities.

Key words. Galaxies: high-redshift – Galaxies: kinematics and dynamics – Galaxies: evolution

1. Introduction

In the local universe, the best tracer of the velocity fields (VFs) of disk galaxies is H1. The H1 disk extends to a few times larger radius than the stellar and molecular gas disk. However, H1 can only be observed for nearby galaxies. The VFs of galaxies at cosmologically significant redshifts can only be observed using other tracers.

Alternative tracers for VFs are rest frame optical emission lines, such as Hα, [O iii]λ5007/4959 and [O ii]λ3727. Their extent is limited to the star forming disk. Also, these lines shift out of the range of optical spectrographs at $z \sim 0.3, 0.7$ and 1.3 respectively.

Until recently, the rotation curves (RCs) of galaxies at larger redshifts could only be observed using long slit near infrared spectrographs. Integral field spectra have significant advantages over long slit spectra with respect to identifying kinematic disturbances. Near-infrared integral field spectrographs, like VLT-SINFONI, are able to observe the VF of galaxies at $z \sim 2$ provided the rest-frame optical emission lines are sufficiently bright.

A number of Hα and [O iii]λ5007 velocity fields (VFs) of redshift $z \sim 1-3$ galaxies have now been observed (Forster-Schreiber et al. 2006, Genzel et al. 2006, Bouché et al. 2007, Law et al. 2007, van Starkenburg et al. 2008a (hereafter PaperI), Wright et al. 2007, Nesvadba et al. 2006, 2008, Bournaud et al. 2008). Some VFs are consistent with rotating disks, others appear to be mergers (see also Shapiro et al. 2008). Many show dynamical disturbances. A convincing case for a ordered rotating disk at $z \sim 2$ was presented in PaperI. Interestingly, this galaxy is one of the morphologically selected large disk galaxies of Labbé et al. (2003b). Most galaxies observed were UV or optically selected.

The Tully-Fisher relation (TFR) is a tight correlation between luminosity and rotation velocity. Its scatter decreases from optical to near-infrared wavelengths (e.g. Verheijen 2001). If luminosity is replaced by stellar mass, determined from SED modeling, the tight correlation remains. Finally, the baryonic mass...
TFR relates the total baryonic (stellar and gas mass) to the rotation velocity.

Predictions for evolution in the slope, zero-point and scatter TFR and stellar mass TFR have been made (e.g. Steinmetz & Navarro 1999, Buchalter, Jimenez & Kantiokowski 2001, Portinari & Sommer-Larsen 2007). However, theoretical models fail to simultaneously reproduce the zero-point, scatter and slope of the TFR in all photometric bands and the shape and zero-point of the luminosity function (e.g. Courteau et al. 2007).

We attempted to select galaxies suited for a TFR analysis. We therefore selected galaxies with photometry over a large wavelength range, so that we have rest-frame K band luminosities and can derive reliable stellar masses. We selected our galaxies from the two FIRES fields, HDF-S and MS1054 (Labbé et al. 2003a, Förster-Schreiber et al. 2006). The FIRES data cover optical and near infrared bands and are publicly available.1

For these fields, we also obtained IRAC imaging and MIPS 24 µm imaging (Labbé et al. 2005, Labbé private communication, Egan et al. 2006, Gordon et al. 2005).

Although some star formation (i.e. Hα, [O II] or [O III] emission line) is needed to measure the VFs, samples strongly biased towards extreme star formation rates are not suited for TFR studies (e.g. van Starkenburg et al. 2006). Also, massive galaxies are preferred because their log(L) are less affected by star formation than the log(L) of less massive galaxies (van Starkenburg et al. 2006). Franceschini et al. (2003) studied a sample of ISO 15µm selected galaxies at z ∼ 0.2 to 1.5 in the HDF-S and found that these are among the most massive galaxies in the field. We have obtained VFs of a subsample of these and will present the results in a forthcoming paper (van Starkenburg et al. 2008b). Here, we apply the same selection at a higher redshift and focus on MIPS 24µm selected targets at z ∼ 2. This strategy allows the selection of massive galaxies and simultaneously allows a comparison between similarly selected galaxies in two different redshift ranges.

We also attempted to select suitable galaxies by selecting galaxies that morphologically resemble large disk galaxies (Labbé et al. 2003b). These galaxies are characterized by an exponentially declining light profile extending over 2–3 effective radii. Their sizes are comparable to those of local L∗ galaxies. Their appearance in the rest frame optical is remarkably smooth and becomes irregular and more extended at shorter wavelengths (larger effective radii, r_e). Their SEDs show large rest frame optical breaks in their centers and bluer colors in the outer parts. This is reminiscent of local spiral galaxies with red bulges and blue disks. These large disks galaxies are bright in Ks band and are massive with stellar masses > 10^{11}M_☉. These galaxies, if true disks, are ideal targets for high redshift TFR studies. We have confirmed the disk nature of one these candidate disks and have shown that it has an ordered VF similar to well-developed disk galaxies in the local universe (PaperI).

The morphology of the large disk galaxies of Labbé et al. (2003b) shows some similarity with the double clump and clump-cluster galaxies of Elmegreen et al. (2005b). Both classes of galaxies show clumps at rest frame UV wavelengths. The large disk galaxies were selected by their exponentially declining light profiles and large scale lengths. Also, the clumps are symmetrically distributed around their K band centers. This is not generally the case of double clump and clump cluster galaxies (Elmegreen et al. 2005b), 2005a. These galaxies do appear to be spiral galaxy progenitors (Bournaud et al. 2007 and references therein) and recent SINFONI observations of one of these clump cluster galaxies at z = 1.6 revealed indeed a VF consistent with a rotating disk (Bournaud et al. 2008), albeit with significant kinematic disturbances related to the clumps.

In this paper, we present our sample of infrared and morphologically selected galaxies at z ∼ 2. Sample selection is further discussed in Sect. 2 followed by a short overview of the observations and data reduction in Sect. 3 and 4. We discuss the properties of the 1D spectra in Sect. 5. The VFs and RCs are presented in Sect. 6. We then discuss the masses in Sect. 7 and angular momenta in Sect. 8. Finally, we present the rest frame B and K band TFR and the stellar and baryonic mass TFR in Sect. 9 followed by our conclusions in Sect. 10.

Throughout this paper, we use H_0 = 70 km s^{-1}Mpc^{-1}, Ω_M = 0.3, Ω_Λ = 0.7 and Vega magnitudes.

2. Sample selection

We observed our sample during four observing runs between April 2005 and August 2006. We selected both 24µm detected and morphologically large disks galaxies. We selected morphologically large disks galaxies in the MS1054 field using the same selection criteria as Labbé et al. (2003b) for the HDF-S field. Selection criteria, 24µm flux, redshifts and K magnitudes are summarized in Table 1. There is significant overlap between the two samples.

A special case is MS1054 1383 (Förster Schreiber et al. 2006). This galaxy is also detected with SCUBA at 850µm (Knudsen et al. 2005) and is also a distant red galaxy (Franx et al. 2003). A second special case is HDF-S -1, which falls outside the HDF-S FIRES area. It is the brightest MIPS 24µm source in the HDF-S area and it has a radio detection (REF. ** mailed Tracy ***).

Choosing targets from each sample, we preferred targets bright in Ks band and with known spectroscopic redshift. Hα should be observable with SINFONI (we choose Hα for consistency with other data sets and to get a reliable estimate of the SFR). Also, it had to be possible to keep the target inside SINFONI’s field of view (FOV) during the observations, so some targets in very crowded regions were excluded. In one case, it was possible to observe two targets (MS1054 1714 and 1719) at the same time. This increased their priority, especially of the fainter large disk galaxy.

3. Observations

We observed our targets with SINFONI (Eisenhauer et al. 2003, Bonnet et al. 2004), the near infrared integral field spectrograph of the VLT. We used the 8′′ x 8′′ FOV and the H, K or H+K grating depending on (photometric) redshift. The spectral resolution in these modes is respectively R ∼ 2900, R ∼ 4500 and R ∼ 1600.

Our targets were observed during 5 observing runs in 2005 and 2006. We used an ABA’B observing strategy, keeping the target in the FOV at all times for optimal efficiency. Offset positions and rotation angle were chosen so that nearby galaxies did not interfere with the observations of the target galaxy. As all our targets are too faint to acquire directly, we blind offset from a nearby bright star. Individual exposures were 600 or 900 s. Total integration times varied between 1 and 7 hours. For galaxies with photometric redshifts, we switched to the next target if we did not detect an emission line after integrating for 1-2 hours. The seeing (measured on the PSF star images) varied between 0′′3 and 0′′5.

For all but two, all galaxies in this paper were observed using the multiple PSF star strategy described in PaperI. Briefly,
this means that a star is observed at every position in the FOV where we observe the target, as closely in time as possible. The positions and FWHMs of these PSF stars are then used to combine the data. The details of SINFONI’s FOV reconstruction require a star for every position, as explained in PaperI. For the two galaxies from the 2005 runs, we used the ‘single PSF star strategy’ which means only one PSF star per OB was observed and the data is combined using the telescope offsets (see also van Starkenburg et al. 2008b).

We also observed one or more telluric standard stars for flux calibration for each target. We refer to PaperI for a detailed description of our observing strategy. Table 2 summarizes our observations.

### 4. Data reduction

When possible, we follow the data reduction scheme described in PaperI. Briefly, this includes removal of bad pixels and cosmic rays, removal of the odd-even effect, distortion correction, flat fielding, wavelength calibration and cube reconstruction. After first subtraction, an illumination correction is applied using a recipe from Juha Reunanen. The frames are combined using the positions of the so called "PSF stars" observed at the same positions in the FOV as the target while weighting with the FWHM of the PSF stars squared (in y direction and measured at the wavelength of Hα, see PaperI). We used a second weighting parameter to correct for the different airmass of each frame, using the correlation between PSF star flux and airmass.

Compared to the reduction scheme described in PaperI, the following changes were made for (some of) the targets presented here.

For MS1054 1383 and HDF-S -1, we observed only one PSF star in the center of the FOV per OB of four exposures. We combined the exposures according to this single PSF star and the telescope offsets, but note that the increased position uncertainty of the target in the x direction of SINFONI’s FOV and hence worse image quality (see also PaperI).

We determine the position and FWHM of the PSF stars at the wavelength of Hα (see for an explanation PaperI). In the case of MS1054 383, the PSF stars were too faint to reliably measure the FWHM. Therefore, we combined the cubes using the position measured at the relevant wavelength while weighting with the FWHM as measured on the median collapsed cube. In the final combined PSF cube, it is possible to measure the FWHM at the relevant wavelength, and this is the FWHM we use for seeing.

For HDF-S 257, we did a relative flux calibration using the correlation between PSF star flux and air mass. For the other targets, we did not apply this correction because either the number of PSF stars was too small, the conditions were not good enough (no or weak correlation between PSF star flux and airmass) or we did not detect any emission lines.

The SINFONI pipeline uses arc frames for wavelength calibration. However, the positions of the slitlets on the raw science frames is not entirely stable. Small shifts in the wavelength direction lead to strong OH line residuals in the final reconstructed cubes. For the J and H band data, the SINFONI pipeline can be easily modified to do the wavelength calibration on the OH sky lines, which enables us to measure the wavelength calibration for individual science frames and correct for small shifts accordingly.

In J and H band, a star like persistence effect with constant slope spectrum is sometimes observed at the beginning of an OB. We give a full description of this effect and how to remove it in van Starkenburg et al. (2008b). For the galaxies presented in this paper, we only removed this faint persistence effect for HDF-S 302.

During the two observing nights in April 2006, telluric standards without directly measured H and K magnitudes were used for some targets (MS1054 1459 first and second night, MS1054 1714 and 1719 second night, MS1054 383 second night). In these cases, we used the correlation between H or K and I magnitudes from all stars of the same spectral type from the same catalog (Hipparcos) to estimate the H or K magnitude. These correlations have ~ 0.1 mag spread with outliers up to 0.5 mag. The uncertainty in the final flux calibration according to ESO documentation is 5-20%.

### 5. Results

We detect Hα and at least one more emission line in 7 out of 9 galaxies. We can derive VFIs for four galaxies, three are presented in this paper. Our best case, HDF-S 257, was presented in PaperI.

We calculated the SFR for each galaxy using the Kennicutt (1998) relation for a Salpeter IMF assuming all Hα flux is due to star formation (see Table 3). All targets are forming stars at large rates. Two are in the ULIRG regime.

The rest frame EWs were calculated using the interpolated broad band fluxes for continuum. We find that EW correlates with SFR. The FWHMs of Hα integrated over the target are also listed in Table 3. All but one are < 500 km s\(^{-1}\).

We calculated the [N II]/Hα or [S II]/Hα ratios for all galaxies for which we detect emission lines. In three cases (MS1054 1383, 1459 and 1719), the [N II]/Hα ratio suggest the presence of

<table>
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<th>FIELD</th>
<th>ID</th>
<th>selection</th>
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<th>zspec</th>
<th>zphot</th>
<th>Ks mag</th>
</tr>
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<td>1383</td>
<td>SCUBA MIPS LD</td>
<td>202 ± 15</td>
<td>2.43</td>
<td>19.55</td>
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<td>MIPS</td>
<td>??</td>
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<td>21.21</td>
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<td>&lt; 12</td>
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<td>MIPS LD</td>
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<td>19.42</td>
<td></td>
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<td>19.46</td>
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<td>19.61</td>
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<td>LD MIPS</td>
<td>18 ± 3</td>
<td>1.82</td>
<td>19.98</td>
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a type II AGN or shocks (see also Table 3). In one case, MS1054 and SFRs. The results are presented in Table 4. The SFRs de-
cept HDF-S 257, for which we refer to Paper I). More informa-
First, we discuss the galaxies for which we can derive a VF (ex-

Table 2. Observations. See Table 1 for an explanation of the IDs. The seeing is the seeing in y direction of SINFONI’s FOV (see Paper I for a definition of x and y direction). The image quality is worse in the x direction, especially for targets observed with the single PSF star strategy.

<table>
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<th>ID</th>
<th>run date</th>
<th>$t_{ex}$</th>
<th>grating</th>
<th>PSF strategy</th>
<th>emission lines</th>
<th>seeing (H$_\alpha$)</th>
<th>notes</th>
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<td>MS1054</td>
<td>1383</td>
<td>April 2005</td>
<td>7h</td>
<td>K</td>
<td>single</td>
<td>H$_\alpha$, [N II]</td>
<td>0.4</td>
<td></td>
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<td>HDF-S</td>
<td>-1</td>
<td>August 2005</td>
<td>1h</td>
<td>H+K</td>
<td>single</td>
<td>—</td>
<td>—</td>
<td></td>
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<tr>
<td>HDF-S</td>
<td>302</td>
<td>April 2006</td>
<td>2h20min</td>
<td>H</td>
<td>multiple</td>
<td>H$_\alpha$, [N II]</td>
<td>—</td>
<td>lines fall on OH lines</td>
</tr>
<tr>
<td>MS1054</td>
<td>383</td>
<td>April 2006</td>
<td>2h40min</td>
<td>H+K</td>
<td>multiple</td>
<td>H$_\alpha$, [S II]</td>
<td>0.5:50 OH lines at [N II] wavelength</td>
<td></td>
</tr>
<tr>
<td>MS1054</td>
<td>1459</td>
<td>April 2006</td>
<td>3h</td>
<td>H+K</td>
<td>multiple</td>
<td>H$_\alpha$, [N II]</td>
<td>—</td>
<td></td>
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<tr>
<td>MS1054</td>
<td>1714</td>
<td>April 2006</td>
<td>2h</td>
<td>H+K</td>
<td>multiple</td>
<td>H$_\alpha$</td>
<td>—</td>
<td></td>
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<tr>
<td>MS1054</td>
<td>1719</td>
<td>April 2006</td>
<td>2h</td>
<td>H</td>
<td>multiple</td>
<td>H$_\alpha$, [N II]</td>
<td>0.5:54</td>
<td></td>
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<td>257</td>
<td>August 2006</td>
<td>6h</td>
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<td>H$_\alpha$, [N II]</td>
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<td>August 2006</td>
<td>2h</td>
<td>H</td>
<td>multiple</td>
<td>—</td>
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</table>

Table 3. $H\alpha$ flux (units $10^{-16}$ erg s$^{-1}$ cm$^{-2}$), SFR, SFR corrected for extinction using the best fit $A_V$ from Wyys et al. (2007), (rest frame) EW, [N II]/$H\alpha$ ratio and FWHM. The line ratio of MS1043 383 refers to a [S II]/$H\alpha$ ratio (marked with a '*').

<table>
<thead>
<tr>
<th>FIELD</th>
<th>ID</th>
<th>$F(H\alpha)$</th>
<th>SFR $(M_\odot$ yr$^{-1}$)</th>
<th>SFR$<em>{corr}$ $(M</em>\odot$ yr$^{-1}$)</th>
<th>EW($H\alpha$) (Å)</th>
<th>[N II]/$H\alpha$</th>
<th>FWHM (km s$^{-1}$)</th>
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<td>3</td>
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<td>380</td>
<td>0.7</td>
<td>—</td>
<td>422</td>
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<td>1</td>
<td>90</td>
<td>95</td>
<td>0.2</td>
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<td>43</td>
<td>170</td>
<td>0.48</td>
<td>574</td>
<td></td>
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<td>0.8</td>
<td>610</td>
<td>54</td>
<td>0.16*</td>
<td>372</td>
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<td>574</td>
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<td>116</td>
<td>260</td>
<td>0.22</td>
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Table 4. Results from SED fitting. The stellar masses are in units of $10^{10}M_\odot$, the ages in Myr and the SFRs in $M_\odot$ yr$^{-1}$. The SFR from $H\alpha$ is listed in the final column for comparison.

<table>
<thead>
<tr>
<th>FIELD</th>
<th>ID</th>
<th>$M_*$</th>
<th>age</th>
<th>$A_V$</th>
<th>SFR</th>
<th>SFR$_{corr}$</th>
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<td>352</td>
<td>380</td>
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<td>9.0$^{+0.0}_{-0.0}$</td>
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<td>MS1054</td>
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<td>43</td>
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<td>9.6$^{+0.0}_{-0.0}$</td>
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<td>89</td>
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<td>29.5$^{+0.0}_{-0.0}$</td>
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<td>1.2</td>
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<td>44</td>
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<td>180</td>
<td>1.2</td>
<td>143</td>
<td>116</td>
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<td>HDF-S</td>
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<td>4.9$^{+0.1}_{-0.1}$</td>
<td>360</td>
<td>1.4</td>
<td>87</td>
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</table>

MS1054 1383 was selected as MIPS 24μm source and as large disk galaxy. This galaxy has a small companion (see Fig. 2) as will be discussed further in Sect. 6.2. The K band (rest frame optical) profile is a smooth disk with inclination $i \sim 59^\circ$, the F814W (rest frame UV 2600Å) image shows an irregular distribution with two prominent clumps. The satellite is also bright in the F814W image.

After integrating 2hrs40mins, we detect $H\alpha$ and faint [S II] at $z = 2.43$. The derived SFR is $380M_\odot$ yr$^{-1}$ (uncorrected for extinction), consistent with the values found from the 850μm flux ($\sim 500M_\odot$ yr$^{-1}$, van Dokkum et al. 2004) and from SED fitting ($\sim 352M_\odot$ yr$^{-1}$).

The emission lines are tilted and we discuss the VF and RC in Sect. 6.

MS1054 383 was selected as MIPS 24μm source and as large disk galaxy. This galaxy has a small companion (see Fig. 2) as will be discussed further in Sect. 6.2. The K band (rest frame optical) profile is a smooth disk with inclination $i \sim 59^\circ$, the F814W (rest frame UV 2600Å) image shows an irregular distribution with two prominent clumps. The satellite is also bright in the F814W image.

After integrating 2hrs40mins, we detect $H\alpha$ and faint [S II] at $z = 2.43$. The derived SFR is $380M_\odot$ yr$^{-1}$ (uncorrected for extinction), consistent with the values found from the 850μm flux ($\sim 500M_\odot$ yr$^{-1}$, van Dokkum et al. 2004) and from SED fitting ($\sim 352M_\odot$ yr$^{-1}$).

The emission lines are tilted and we discuss the VF and RC in Sect. 6.

We can derive a VF and discuss it in Sect. 6.

MS1054 414 was also in the FOV, see Fig. 2. We detect [OⅡ]λλ4959, 5007, [OⅢ]λλ13727 and [N Ⅱ]λ6583 at $z = 3.229$, consistent with the photometric redshift.

MS1054 1719 We selected MS1054 1719 for observations because it has a MIPS 24μm detection and it is bright in K. Its half light radius is 0.40 and its Sersic index is 2.10 (measured in Js...
Fig. 1. Js (FIRES) image, Ks (FIRES) image and Hα linemap of MS1054 1383 (MS1054 1383 is not detected in F814W, therefore we show the ISAAC Js image). Image sizes are 3′′ x 2′′. The Hα linemap has been smoothed by a 3 pixel width gaussian to increase S/N. The + point marks the Ks position from Labb´ e et al. (2003a), the X point marks the brightest pixel of the Js extension. The contrast was increased in all figures to show the extent of the emission.

Fig. 2. F814W (rebinned to FIRES) image, Ks (FIRES) image and Hα linemap of MS1054 383. Image sizes are 3′′ x 3′′. The + point marks the Ks position from Labb´ e et al. (2003a), the X points mark the centers of the F814 clumps and the diamond marks the location of the satellite. A Ks band contour is shown in the Hα linemap. Note that Hα only covers the western clump and the central part of the Ks band image. Also visible in the F814W and Ks images is a second, unrelated, galaxy, id 414 in the FIRES catalog. The seeing corrected inclination is 41° (Trujillo et al. 2006). The Ks band emission is much more extended than the F814W emission, see Fig. 3, in contrast to the large disk galaxies.

We detect Hα and [N II]λ6583/6548 at z = 1.716. The extent of the Hα emission is in between the Ks and F814W, see Fig. 3. The [N II]λ6583 line is on top of an OH line which makes it difficult to put constraints on the [N II]λ6583/Hα ratio. We estimate it is underestimated by a factor two from the [N II]λ6548 line flux. [S II]λ6717/6731 is in a region with many OH lines and not detected.

The Hα line (and the [N II] lines) is tilted. We discuss the VF and RC in Sect. 6.

5.2. Notes on individual targets without VF

For 5 galaxies, we could not derive a VF. In one case, the S/N is good but there is no velocity gradient. In another case, the we detect a velocity gradient, but the S/N is too low to extract a RC. In a third case, Hα is on a bright OH line and cannot be used for a velocity analysis. In two cases, we do not detect any emission lines. We discuss possible reasons for each galaxy below.

HDF-S -1 We selected this target because it is the brightest MIPS 24μm source in this field and has a radio detection. The photometric redshift is 2.16 and we used the H+K grating for maximal spectral coverage. We do not detect emission lines.

HDF-S 302 We detect Hα at the expected redshift, but the line is faint and on top of a bright OH line, as is [N II]λ6583. Even a synthetic long slit analysis failed.

MS1054 1459 This galaxy was selected because it is bright in K and had a known spectroscopic redshift (z = 2.08). We detect Hα and [N II]λ6548/6583. We do not detect [S II]λ6716/6731, [O III]λ4959/5007 and Hβ ([O III] and Hβ are in a region where to OH lines are blended at the resolution of the H+K grating).

We find no hints for rotation in the cube or synthetic long slit spectra. One explanation could be that the galaxy is viewed almost face-on. A second explanation is that the emission line flux is dominated by emission from an AGN: the FWHM of Hα is ~ 570 km s⁻¹ and [N II]/Hα = 0.48 ± 0.10.

MS1054 1714 We observed MS1054 1714, a large disk galaxy, as a bonus galaxy in the same FOV as (the MIPS 24μm selected...
Fig. 3. F814W (rebinned to FIRES) image, Ks (FIRES) image and Hα linemap of MS1054 1719. Image sizes are 3” x 3”. The right-most two columns in the Hα image are missing. The + point marks the Ks position from Labbé et al. (2003a). Two Ks band contours are shown. The bright contour corresponds approximately to the Hα distribution, while the fainter contour shows the total extent of the Ks band image. The F814W flux is even more concentrated than the Hα flux.

Fig. 4. Synthetic long slit spectrum along the K band major axis (position angle 87° counterclockwise from the north, slit width 1”25) of MS1054 1714. The horizontal axis is wavelength (or velocity), the vertical axis is position. The contrast and scales were chosen so that the lines are visible in print. Hα and [NII]λ6583/6548 are visible as tilted emission lines. Also visible as dark vertical stripes are OH line residuals.

galaxy) MS1054 1719. The Ks band profile is a very smooth edge-on disk (i ~ 70°), but at shorter wavelengths, a small clump at the west side of the disk is visible.

The photometric redshifts of MS1054 1714 and 1719 placed their Hα lines between H and K band and indicated they were possibly at the same redshift. To maximize the chance of detecting an emission line, we started our observations using the H+K grating. After we detected Hα in H band for MS1054 1719, we switched to H band for better spectral resolution. In the H grating data, we were able to identify Hα and possibly [NII] at a different redshift, z = 1.46, for MS1054 1714. Although close together on the sky, MS1054 1714 and 1719 are not a pair. We do not detect [SII]λ6717/6731.

The S/N is too poor to measure a VF. In a synthetic long slit spectrum, the Hα line is clearly tilted and extends over ~500 km s^{-1} in ~1.5” but we were not able to measure a RC, as the line lies on top of an OH line and the S/N remains poor. The synthetic long slit spectrum is shown in Fig. 4.

HDF-S 267 As third HDF-S large disk target, we choose HDF-S 267 because it was the brightest of the remaining targets (after HDF-S 302 and HDF-S 257) and had a (photometric) redshift that would put Hα at an observable wavelength with SINFONI. We detect no emission lines after 2 hrs integrating in H band (z_{phot} = 1.82). There a several possible reasons for this non-detection. HDF-S 267 has a photometric redshift which puts Hα between H and K band. We choose the H grating and not the H+K grating because the spectral resolution of the H+K grat-

ing is often not sufficient to resolve emission lines between the many OH lines in H band. But it is possible that Hα falls outside H band and other lines are too faint to detect.

6. Velocity fields and rotation curves of individual targets

We followed the method described in Paper I to measure and model the VF and RC. Here, we summarize our methods and refer to Paper I for a more detailed description.

Because the S/N of individual spectra is low, automatic fitting routines confuse Hα with OH line residuals. We therefore manually fit gaussians to Hα using IRAF’s ‘splot’. We sum over 4 or 9 pixels to increase S/N if necessary.

For HDF-S 257, we also measured the velocity dispersion field (see Paper I). For the galaxies presented in this paper, we were not able to measure a dispersion field. The spectral resolution was insufficient (H+K grating) and/or the S/N of the individual spectra was too small.

The VFs reveal generally monotonic velocity gradients. In order to test whether these represent order rotation, we fit tilted ring models using GIPSY (van der Hulst 1992, Vogelaar & Terlouw 2001) to model our VFs. We start with fixed values for all parameters except the rotation velocity (i.e. position angle of the major axis, inclination and center fixed to the Ks band values, systemic velocity fixed to the velocity measured in the center, and expansion velocity fixed to zero). We then redo the fit with a second free parameter. If we get consistent results between the rings, we replace the original value by the average of the free parameters. We continue with the next parameter until our best fit values do not change anymore. We found that the S/N of the VF is insufficient to constrain most parameters from the VF alone. For these parameters, we keep the default values mentioned above.

We make a model VF from our best fit model and compare this to the observations. In particular, we look for systematic differences between the observations and models.

We compare the RC of our best fit VF with the RCs of fits with slightly different parameters to get an idea of the uncertainties of the best fit velocities, and in particular those of V_{max} or V_{flat}.

For HDF-S 257, we also modeled the effect of the PSF on the best fit RC (see Paper I). Here, we did not attempt to model the
The resulting RC is shown in Fig. 7a. The receding half is flat at $\sim 85 \text{ km s}^{-1}$. The approaching half steeply rises to $\sim 400 \text{ km s}^{-1}$ and then the $S/N$ is insufficient to decide between a shallower rise or a flatting.

The strong residuals from the fit led us to investigate the VF further. We noted that the photometric center is not the point with the largest velocity gradient as determined in a spider diagram. This point lies $0''.375$ (3 pixels) to the left in Fig. 5 and we will refer to it as the 'spider center’. When we made a new tilted ring model taking this point as the center of rotation, we were able to reproduce the systemic velocity from the VF, the quality of the fit increases (see Fig. 5d-f, residuals from the fit are smaller and there are less systematic differences) and the RC becomes almost symmetric: the receding and approaching half flatten at $\sim 240 \text{ km s}^{-1}$ and $\sim 190 \text{ km s}^{-1}$, see Fig. 7b. We use the average of these two velocities, $215 \pm 40 \text{ km s}^{-1}$ in the analysis below.

The photometric center was determined in the K band image. At this redshift, observed K band corresponds to rest frame R band. In local ULIRGS, offsets between the optical nucleus (or nuclei) and the near-IR center are not uncommon due to heavy extinction. Also, the resolution of the K band image ($0''.46$ which corresponds to 3.7 kpc at this redshift) does not rule out the possibility of double nuclei.

We did not attempt to model the effect of the PSF on the RC on the observed. As MS1054 1383 is not detected in F814W, we do not have a high resolution model for the intrinsic H\alpha distribution.

The velocity gradient in the center is very steep. This implies a large concentration of mass in the centre. For $r < 0''.25$, the inferred mass is $1.4 \times 10^{10} M_{\odot}$ (smearing by the seeing was not taken into account) or $\Sigma_{\text{dyn}} = 1.1 \times 10^{3} M_{\odot} \text{ pc}^{-2}$.

We conclude that the VF of 1383 shows some irregularities from a simple rotating disk. There is some evidence for a different photometric and dynamical center. The $S/N$ of the VF and the lack of (detected emission in) high resolution imaging data prohibit definitive conclusions about the interpretation of the irregularities.

### 6.1.1. Double peaked emission line region

We will now investigate the nature of the double peaked emission line region.

We checked whether the two peaks are real by splitting the data set in half. The double peak is visible in both data sets. The velocity difference between the two peaks is similar for H\alpha and [N\text{II}] ($\sim 210 \text{ km s}^{-1}$) and there are no bright OH lines that could cause the observed splitting. We therefore conclude that the lines are truly double peaked.

The double peaked area is centered slightly eastward of the photometric center. It does not coincide with the spider center.

The fluxes in the receding and approaching lines are approximately the same for H\alpha and [N\text{II}] ($\sim 210 \text{ km s}^{-1}$), see Fig. 6. The [N\text{II}]/H\alpha ratio is slightly different: 0.54 and 0.38 for approaching and receding sides respectively.

The area over which the lines are double peaked is comparable to the seeing disk. In principle, a point source could be responsible for the line splitting. On the other hand, the double peak region almost coincides with the peak in the H\alpha flux. It may be possible that the $S/N$ is too poor over most of the galaxy to detect line splitting.

We searched for velocity structure (velocity or velocity difference gradients) but could not find it. The small area and low $S/N$ may prohibit the detection of small gradients.

The measured VF in Fig. 5 shows the velocity measured after smoothing the spectra until a single gaussian can be fit to both...
Fig. 5. From left to right: observed VF, model VF (for \( r \leq 1''25 \)) and the residuals from the model of MS1054 1383. The upper panels show the model using the photometric center, the lower panels show the model with the spider center. Image size and orientation are the same as in Fig. 1, except that two pixels on the left hand side have been added to show the velocity scale. The + point is again the photometric center. The best fit kinematic center is marked by the square. The best fit systemic velocity is marked with the circle. In the left most panels, the best fit systemic velocity of the photometric center and the spider center are marked. In the most right panels, the diamond indicates where the velocity difference is zero. The X points marks the location of the J band extension. In the upper left panel, the model fit of the dynamical major and minor axis are fit with properties described above.

peaks together. We checked whether this velocity best matches with the overall VF by replacing the measured values with the velocities from either the approaching or receding line and refitting the VF. This has very little effect on the overall best fit VF. The single fit leaves indeed the smallest residuals.

There are several possible explanations for this double peaked line region. A good explanation should be consistent with properties described above.

First, a very strong velocity gradient near the center smeared by seeing might result in observing both the receding and approaching half in the same pixel. This could result in a double peaked line if there is for example a bright ring around the center which increases the fluxes of the velocities of the ring. The velocity gradient \( \Delta V \sin(i) \) as observed in the RC (with photometric center) is \( \sim 200 \text{km s}^{-1} \) over 0.4 (the seeing disk). This value is very similar to the velocity difference found between the receding and approaching side of the double peaked emission line. This is encouraging, but without knowledge of the flux distribution at smaller scales, no evidence. The velocity gradient of the RC with the spider center is slightly larger over the same distance: \( \sim 240 \text{km s}^{-1} \), but we do not observe a line splitting in that area. This could be due to the lower line fluxes in that area. An argument against this ring hypothesis is that the location of the double peaked area does not coincide with the photometric (or spider) center.

A second explanation could be a small disk in the center with different inclination and position angle. However, the double-peak area is slightly off the photometric center, and certainly off from the dynamical centre.

A third explanation is inflowing and/or outflowing material. The receding component is most offset from the general VF, which would imply infalling material. The similar fluxes would be a coincidence in this case. Given the SFR of this galaxy, a superwind would be expected (Heckman 2003). The velocity offsets are consistent with the superwind interpretation (Rupke et al. 2005), but the approaching component being the less offset from the overall VF than the receding component contradicts this interpretation. Evidence for a superwind has been found for a lensed submillimeter galaxy at \( z \approx 2.6 \) by Nesvadba et al. (2007). Their H\( \alpha \) and [N\( ii \)].6583 lines show a blue wing with a relative offset of \( \sim 340 \text{km s}^{-1} \). Also, their [N\( ii \)]/H\( \alpha \) ratio, 0.83, indicates the presence of shocks in the outflowing gas. We searched for wings in the line profiles of MS1054 1383 but found none, which is however consistent with the poorer \( S/N \) of our data.

Another explanation is a merger or two nuclei that are not resolved in the K band image, because they are close and/or because one is more luminous (or much more extincted) than the other. The distance (less than one seeing element) between the photometric and spider center is consistent with this interpretation. The double peaked lines coming from one of the two nuclei can then be explained by a strong velocity gradient in the center and/or a small rotating disk in around the center of that nucleus.

We conclude that the last explanation has the least problems, but supporting evidence is unfortunately not available.

6.1.2. Comparison to other submillimeter sources

MS1054 1383 is the ninth SCUBA submillimeter (SMM) source for with there is integral field spectroscopy of H\( \alpha \) (Nesvadba et al. 2007, Swinbank et al. 2005, 2006). Of the other 8 SMM galaxies, five show two or more components separated by 1-2''or 8-16 kpc. Two are compact sources, and the last morphology is unknown due to a not fully understood foreground lens (Swinbank et al. 2006). The average velocity offset observed between dynamical subcomponents is \( \sim 180 \text{km s}^{-1} \). MS1054 1383 is morphologically and dynamically different from these other SMM galaxies. It has an extended morphology without these galactic scale clumps (although there is the J band extension/background galaxy). Its VF is consistent with a single large disk, but shows kinematic distortions in the center that may be evidence for multiple components in the center. In some cases,
Fig. 7. RCs of MS1054 1383 (upper two panels, for two different choices of dynamic center, receding and approaching sides fitted separately), MS1045 383 (lower left panel) and MS1054 1719 (lower right panel).

(part of) the dynamical differences may be attributed to seeing differences during the observations.

Bouché et al. (2007) compared their UV and optical selected samples with 13 bright submillimeter galaxies \((F(850\mu m) > 5mJy)\) at \(z \sim 2.5\) observed with the IRAM Plateau de Bure Interferometer. All but one are compact galaxies with \(R_d < 3\) kpc and their maximum rotation velocities as calculated from their line profiles vary between 150 and 550 km s\(^{-1}\). Based on millimeter interferometry, they find that submillimeter galaxies are more compact and more dense that rest frame UV and rest frame optical selected galaxies at similar redshift. In contrast, we find that our submillimeter detected galaxy, MS1054 1383, that was observed in rest frame optical traces, has a similar scale length and density as the UV and optical selected galaxies.

6.2. MS1054 383

The VF, shown in Fig. 8, was measured after rebinning to \(0''25\) scale to increase \(S/N\) in individual spectra. Still, the \(S/N\) at the outer edges of the \(H\alpha\) distribution is poor and these points should be interpreted with caution. The companion is shown in this figure as a single pixel, but its velocity was measured integrated over the whole clump (approximated with a \(r = 0''375\) (3 pixels) radius circle centered on the K band center of the clump). Its velocity relative to the K band center is \(-281\) km s\(^{-1}\). One
notices that the VF is not as regular as that of HDF-S 257 (see Paper I). Moreover, the position angle of the major axis seems to be different from the position angle of the K band major axis.

We fitted tilted ring models to the VF following the methods described above. The position angle of the major axis was found to be slightly different (∼20°) from the position angle of the major axis of the Ks image. We were unable to constrain other parameters from the VF. The fact that we detect only the receding part of the VF leaves in particular the center of the galaxy poorly constrained. The best fit VF and its residuals are shown in Fig. 8. The systematic residuals illustrate the complex kinematics of this galaxy.

The RC of the best fit model is shown in Fig. 7c. We find $V_{\text{flat}} \sim 180 \pm 20 \pm 50 \text{ km s}^{-1}$, where the first error bar reflects the scatter that occurs when different parameters are chosen for the tilted ring model and the second error bar reflects the choice of slightly different centers from the RC gradient. The RC appears to flatten at $r > 6 \text{ kpc}$, but this flattening is uncertain due to the poor $S/N$ in the outer parts.

We did not attempt to model the effect of the PSF on the RC observed because the expected effect on $V_{\text{flat}}$ of the PSF is much smaller than the uncertainties due to the fact that the approaching side of the VF is hardly covered and the complex kinematics of this galaxy.

6.3. MS1054 1719

MS1054 1719 is the only target that was not selected as a large disk galaxy for which we can derive a VF. It is a smooth VF extending over nearly 2′′ along the major axis which is significantly smaller than the Ks image, see Fig. 9.

We fit tilted ring models to the VF following the method described above. We were able to determine the position angle of the major axis and the dynamical center from the VF alone. The best fit position angle is ∼5−10° offset from the PA found on the K image, but within the errorbars. We were also able to reproduce the center from the VF alone. The center found is 1 pixel west of the expected center from H band, but as this new center is consistent with the center of the Hα linemap, we suspect that there is a slight offset between the H band and SINFONI data and that the photometric and dynamical center are the same. The best fit model and its residuals are also shown in Fig. 9.

The RC of the best fit model is shown in Fig. 7d. There is a tentative flattening at the largest radii, but this flattening is sensitive to the parameters of the fit and not significant. The maximum velocity (corrected for inclination) is very large: $V_{\text{max}} = 389 \pm 45 \text{ km s}^{-1}$, where the error bars were determined from tilted ring models with slightly different parameters and taking into account 5° uncertainty in the inclination. As the Ks image extends to larger radii, both the already very large maximum velocity and the derived dynamical mass should be interpreted as lower limits. Similar maximum velocities are rarely observed for local galaxies.

We did not attempt to model the effects of the PSF on the VF observed because the RC does not flatten and the total extent of the RC is relatively small.

6.4. Summary

We detect VFs in 4 out of 7 galaxies with emission lines. A fifth galaxy shows a relatively steep gradient in a synthetic long slit spectrum, but with insufficient $S/N$ to measure a RC. In one case, we were unable to detect tilts because of poor $S/N$ and OH line contamination. In only one case, there was no evidence for velocity gradients at all.

The extent of the Hα emission was a limiting factor in our analysis of two targets, MS1054 383 and 1719. In the first case, a longer integration time is likely to reveal Hα emission at the approaching side, as it is detected in F814W (rest frame UV). For MS1054 1719, increasing the integration time might not result in detecting Hα over a larger area, as the F814W flux is concentrated in the center.

Unlike the very regular VF of HDF-S 257, two of the VFs presented here show kinematic distortions. Two RCs (including that of HDF-S 257 described in Paper I) show convincing evidence for a flat RC. The others show hints for a turnover velocity. All galaxies are massive with $V_{\text{max}}$ ranging from 200 − 400 km s$^{-1}$.

7. Masses

We calculated dynamical masses for our galaxies using

$$M_{\text{dyn}} = \frac{v^2 r}{G}$$

where we used the flat or maximum rotation curve velocity for $v$ and the maximum radius of the RC for $r$. The dynamical masses are given in Table 5. The reader should bear in mind that some masses have large uncertainties due to the poor sampling of the VF (MS1054 383) or are lower limits due to the limited extent of the RC (MS1054 1719).

We determined the stellar masses from SED fitting using the method described in Wuyts et al. (2007). They used a Salpeter IMF which overpredicts the number of low mass stars. A ‘diet Salpeter’ IMF decreases the stellar masses by 30% (Bell & de Jong 2001). For comparison, we also list the stellar mass of the galaxies for which we could not detect a VF in Table 5.

Gas masses can be estimated using the global Schmidt law which relates the SFR and the surface density of the gas (Kennicutt 1998). This relation has significant scatter (±0.3 dex) but is independent of IMF if one uses the Hα luminosity to SFR conversion factor from the same paper. There is some evidence that the global Schmidt law also holds at high redshift (Bouché et al. 2007). We used the area over which we detect Hα to calculate the gas mass (which is significantly smaller than the total extent of the galaxy for MS1054 383 and 1719). The gas masses are also in Table 5.

We note that stellar mass correlates with 24µm flux (see also Table 5). Also, the stellar mass found in these galaxies is comparable to or larger than the dynamical mass out to the last measured point on the RC. HDF-S 257 has an exceptionally large gas-to-stellar mass ratio compared to the other galaxies of the sample, consistent with it being the youngest galaxy of the sample (according to the SED fitting, see Table 4). The baryonic mass of HDF-S 257 is comparable to the dynamical mass, so for none of the galaxies there is evidence for dark matter within the observed radii.

The stellar mass of MS1054 1383 is ∼ 3.4 times larger than the dynamical mass, which is of course unphysical. Adding the gas mass makes the situation even worse: $M_{\text{baryon}}/M_{\text{dyn}} \sim 4.5$. To bring the stellar and dynamical mass in agreement, the stellar mass must be decreased and/or the dynamical mass increased.

The stellar mass could be overestimated for two reasons: the SED fitting parameters (e.g. an IMF that overpredicts the number of low mass stars (other choices for IMF result in 30% to 50% lower stellar masses)) or a significant fraction of the light mass must be decreased and/or the dynamical mass increased.
emitted does not have a stellar origin. However, Toft et al. (2007) do not find evidence for an AGN (from X-ray flux, shape MIR continuum, SED, absence of blue point source).

To bring the stellar and baryonic mass in agreement, the rotation velocity should double. This is about the velocity of the approaching side of the galaxy when the VF is fitted with the photometric center (\( \sim 400 \text{ km s}^{-1} \)). If the inclination is overestimated, the rotation velocity is underestimated. To double the inclination corrected velocity, the inclination should be \( \sim 25^\circ \) which is unlikely. Also, a rotation velocity of 400 km s\(^{-1}\) is very rare among local galaxies which makes it unlikely that an underestimate of the rotation velocity is the only reason for the discrepancy between the stellar and dynamical mass.

More plausibly, the VF as measured by H\( \alpha \) does not well trace the gravitational potential. Colina et al. (2005) find for a small sample of 5 low redshift ULIRGS that the velocity amplitudes of the cold molecular gas are on average twice as large as the velocity amplitudes of ionized gas. In only one case the velocity amplitudes agree and this is the only galaxy in their sample with a VF consistent with an inclined rotating disk.

The stellar mass of MS1054 1719 is the stellar mass of the entire galaxy, while the gas and dynamical mass were calculated on the inner part where we detect H\( \alpha \). We checked the Ks band isophotes and calculated that \( \sim 15\% \) of the Ks flux comes from the outer parts where we do not detect H\( \alpha \). Decreasing the stellar mass by 15\% changes the stellar-to-dynamical mass ratio to 0.96 and the baryonic-to-dynamical mass ratio to 1.05.

The baryonic-to-dynamical mass ratio of MS1054 383 is also larger than 1. In this case, the dynamical mass estimate has large uncertainty because we have no information about the VF of the approaching side of the galaxy.

### 8. Specific angular momentum and spin parameter

We calculated the specific angular momentum for the galaxies in our sample with VFs using the same method as we did for HDF-S 257 (PaperI). We used the (rest frame V band) effective radii determined by Trujillo et al. (2006), noting that Trujillo et al. used a photometric redshift for MS1054 1719 that results in a rest frame B band effective radius given the spectroscopic redshift). We find that MS1054 383 and 1383 are consistent with the local relation between specific angular momentum and maximum rotation velocity (see Puech et al. 2007, Navarro & Steinmetz 2000), as was HDF-S 257 (PaperI). MS1054 1719 rotates about twice as fast as expected for its specific angular momentum.
We also calculated the spin parameter $\lambda$ following our approach in Paper I. We find that the spin parameters of MS1054 383 and 1383 are again consistent with those of local galaxies (as was HDF-S 257), but the spin parameter of MS1054 1719 is an order of magnitude smaller than the most probable value found by Tomini et al. (2006).

Contrary to the other three galaxies in our VF sample, MS1054 1719 is not a morphologically selected large disk. Its Sersic index is consistent with a disk galaxy (2.10, Trujillo et al. 2006), but its effective radius is smaller than those of the large disk galaxies and the center of the galaxy is bluer than the outer parts. Our results regarding the angular momentum of MS1054 1719 confirm that MS1054 1719 is morphologically and dynamically different from local disk galaxies.

9. Tully-Fisher relations

We will now investigate the TFR properties of our sample.

9.1. The rest frame B and K band TFR

The local B and K band TFR of Verheijen (2001) are shown in Fig. 10. We labeled our data points with their IDs for easy identification of individual sources and we also added HDF-S 257 for easy comparison. For the B band TFR, we also show the $A_V$ corrections using the best fit $A_V$ from SED fitting (Wuyts et al. 2007).

MS1054 1719 is fainter than expected for both the rest frame B and K band TFR. After correcting for extinction, it is in agreement with the B band TFR. The other three galaxies are consistent with or brighter than the local B and K band TFR, with average offsets of 0.5 and 1.4 magnitudes respectively. After correcting for extinction, the average offset from the B band TFR is large: 2.3 mag.

9.2. The stellar and baryonic mass TFR

The relation between the stellar mass and rotation velocity, known as the stellar mass TFR, is shown in Fig. 11a. MS1043 1383 shows a large offset from the local relation, which is due to the unphysical stellar-to-dynamical mass ratio. MS1054 383 and 1719 are consistent with the local relation, while HDF-S 257 is lies significantly below the stellar mass TFR, consistent with its large gas content.

If we add the gas mass to the stellar mass, we get the baryonic mass TFR, shown in Fig. 11b. We assumed a factor 2 uncertainty in the gas mass. HDF-S 257 is consistent with the baryonic mass TFR due to its relatively large gas mass.

9.3. Comparison to other high-$z$ samples

The most obvious comparison sample for our MIPS 24$\mu$m selected targets is our ISO selected sample at $z \sim 0.8$, as these samples were both selected using the same selection criterion (in their rest frames), observed with the same instrument, targeting the same emission line and analysed following the same method. WAITING FOR ISO PAPER/CHAPTER 4...

Puech et al. (2008) present the rest frame K band for a sample of [OII] emitting galaxies at $z \sim 0.6$. They observed their sample with the multi-object integral field spectrograph of the VLT (FLAMES-GIRAFFE) which makes this a good comparison sample for our data. When they restrict their sample to rotating disks (see Flores et al. 2006 for their definition of a rotating disk), they find that the rest frame K band TFR has not evolved in scatter and possibly in slope, while the zero point has brightened by $0.66 \pm 0.14$ mag from $z \sim 0.6$ to the present (note: this is opposite to the trend we find). They interpret this shift as mostly luminosity evolution. Perturbed rotators and especially galaxies with complex kinematics can have large offsets from the TFR. We find for our large disk selected galaxies, including our best case HDF-S 257, the opposite trend.

Puech et al. (2008) also determine the offset from the local stellar mass TFR for their sample and find 0.36 dex smaller stellar masses, with similar scatter and slope as the local relation. This is consistent with our findings for our best case HDF-S 257.

Swinbank et al. (2006) show the rest frame B and I band TFR of their sample of six lensed $z \sim 1$ galaxies. They find $0.41 \pm 0.34$ mag of brightening in the rest frame B band and $<0.10$ mag in rest frame I band.

Bournaud et al. (2008) note that the derived rotation velocity of their $z = 1.6$ clump-cluster galaxy is smaller than expected from the stellar mass and the stellar mass TFR. Their hypothesis is that the clumps will evolve into the thick disk of a spiral galaxy, which does not rotate as fast as the thin disk. This is in agreement with other observations (Elmegreen & Elmegreen 2006, Bournaud et al. 2008 and references therein). However, we find for HDF-S 257 that it rotates much faster than expected from its stellar mass and the stellar mass TFR. Another difference is the fact that the VF of HDF-S 257 does not show disturbances related to the clumps. The number of galaxies with known VFs in both samples is currently too small to allow a more systematic comparison.

9.4. Discussion

Did we select suitable targets for TFR analysis? The general properties of the sample are good. Morphologically, three of the four galaxies are large disk galaxies according to the criteria of Labbé et al. (2003b). The VFs of all four galaxies are consistent with rotating disks. There is strong evidence for a flattening RC

### Table 5. Masses and mass ratio’s. Masses are in units of $10^{10}M_\odot$. The $24\mu$m fluxes are in mJy and the upper limits are 3$\sigma$. The numbers in parentheses are the values after extinction correction.

<table>
<thead>
<tr>
<th>FIELD</th>
<th>ID</th>
<th>F(24$\mu$m)</th>
<th>$M_{dyn}$</th>
<th>$M_*$</th>
<th>$M_{gas}$</th>
<th>$M_{gas}/M_*$</th>
<th>$M_*/M_{dyn}$</th>
<th>$M_{bar}/M_{dyn}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS1054</td>
<td>1383</td>
<td>202</td>
<td>11</td>
<td>37.7$^{+0.3}_{-0.3}$</td>
<td>12 (35)</td>
<td>0.3 (0.9)</td>
<td>3.4</td>
<td>4.5 (6.6)</td>
</tr>
<tr>
<td>MS1054</td>
<td>1714</td>
<td>64</td>
<td>—</td>
<td>9.0$^{+0.2}_{-0.1}$</td>
<td>2.4 (5.2)</td>
<td>0.3 (0.6)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>MS1054</td>
<td>1719</td>
<td>289</td>
<td>30</td>
<td>33.9$^{+0.8}_{-0.5}$</td>
<td>2.6 (6.9)</td>
<td>0.1 (0.2)</td>
<td>1.1</td>
<td>1.2 (1.4)</td>
</tr>
<tr>
<td>MS1054</td>
<td>383</td>
<td>54</td>
<td>8</td>
<td>9.6$^{+0.4}_{-0.5}$</td>
<td>3.2 (4.6)</td>
<td>0.3 (0.5)</td>
<td>1.2</td>
<td>1.6 (1.8)</td>
</tr>
<tr>
<td>HDF-S</td>
<td>302</td>
<td>&lt; 12</td>
<td>—</td>
<td>3.4$^{+0.1}_{-0.1}$</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>MS1054</td>
<td>1459</td>
<td>107</td>
<td>—</td>
<td>29.5$^{+0.7}_{-0.7}$</td>
<td>3.1 (5.6)</td>
<td>0.1 (0.2)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>HDF-S</td>
<td>257</td>
<td>&lt; 15</td>
<td>14</td>
<td>3.6$^{+0.6}_{-0.6}$</td>
<td>5.3 (9.4)</td>
<td>1.8 (2.9)</td>
<td>0.2</td>
<td>0.6 (0.9)</td>
</tr>
<tr>
<td>HDF-S</td>
<td>267</td>
<td>18</td>
<td>—</td>
<td>4.9$^{+0.9}_{-0.9}$</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
in two cases, and weak evidence in two cases. The specific angular momentum and spin parameter of three galaxies is consistent with those of local galaxies. Broad line AGNs were found in none of the galaxies. There is evidence for type II AGN or shocks from the [N II]/Hα ratio in one case, while for two galaxies only lower limits to the [N II]/Hα ratios could be measured.

However, looking at the individual properties of each galaxy, we find peculiarities for all of them. The VF of MS1054
10. Conclusions

1. Selecting on 24µm flux selects galaxies with large stellar and dynamical mass. Flat or maximum rotation curve velocities range between 200 and 400 km s⁻¹.

2. The morphologically selected large disk galaxies are dynamically also large disk galaxies.

3. Although the [N II]/Hα ratio indicates the presence of shocks or a type II AGN in ~ 50% of our targets, there is no evidence for broad line AGNs.

4. Within the observed radii, all galaxies are dominated by baryonic matter.

5. The extent of the Hα emission is a limiting factor of the VF analysis.

6. The specific angular momentum and spin parameter of morphologically selected large disks galaxies are similar to those of local spiral galaxies.

7. The z ~ 2 rest frame B and K band TFR are brighter than the local TFR by ~ 2.4 and 1.4 mag (after correcting for extinction).

8. Our z ~ 2 galaxies are consistent with the baryonic mass TFR.

9. The interpretation of these TFR results are limited by the small sample of galaxies that each are peculiar in some way.

10. Our best case for a rotating disk has a unusually high gas-to-stellar mass ratio compared to local galaxies and to other z ~ 2 large disk and 24µm selected galaxies.