Tully-Fisher Relation: A DIRECT IFS COMPARISON OF GALAXIES ACROSS ~8 Gyr
GALAXY EVOLUTION WITH REDSHIFT

HOPKINS & BEACOM (2006)
GALAXY EVOLUTION WITH REDSHIFT

HOPKINS & BEACOM (2006)

MUSE
K-CLASH
KGES
KMOS3D
KDS

IFU OBSERVATIONS

HOPKINS & BEACOM (2006)
“DIRECT” COMPARISON?

HOPKINS & BEACOM (2006)

IFU OBSERVATIONS

MATCH DATA QUALITY THEN DIRECTLY COMPARE
Durham: Richard Bower (co-PI), Mark Swinbank, Ian Smail, Ray Sharples, Helen Johnson
Oxford: Martin Bureau (co-PI), Andy Bunker, Matt Jarvis
ESO: Chris Harrison
Copenhagen: Georgios Magdis
Lancaster: John Stott, David Sobral
Others: Philip Best, Owen Turner
KROSS

K-band Multi-Object Spectrograph:

- 24 IFUs
- 2.″8 x 2.″8 FOV
- D=7.2’
- 0.8-2.5μm
- YJ R~4000
- Hα, [N II]
KROSS

Harrison+17

TILEY 2017

[Graphs and images related to stellar mass and Hα luminosity, with data points and labels indicating resolved and unresolved samples.]

[Legend for data points with annotations like "Resolved v_*(Q1/Q2) [70%]", "Unresolved v_*(Q3/Q4) [9%]", and "Hα undetected (Q5) [21%]".]
- 12 x 1.”6 “hexabundles” of 61 fibres
- 0.”5 spaxels
- D = 14.”7 FOV
- Red ~630-740nm

Collaborators: Luca Cortese + SAMI

Croom+12
H$\alpha$ and [N II] Kinematics from 824 z~0 SAMI galaxies in GAMA

Bryant+16
“DIRECT” COMPARISON?

Tully-Fisher Relation

IFU OBSERVATIONS

HOPKINS & BEACOM (2006)
$v^2 = GM/r$

$\Sigma \propto M/\pi r^2$

$M = L(M/L)$

$M \propto L(M/L) \propto v^2 r \propto (L/\Sigma)^{1/2} v^2$

$L \propto v^4 / [\Sigma (M/L)]$

The Tully-Fisher Relation

Tully+Fisher 1977
The Tully-Fisher Relation

\[ v^2 = \frac{GM}{r} \]

\[ \Sigma \propto \frac{M}{v^2 r^2} \]

\[ M \propto L(M/L) \propto v^2 r \propto \left( \frac{L}{\Sigma (M/L)} \right)^{1/2} v^2 \]

\[ L \propto v^4 / [\Sigma (M/L)] \]

Tully+Fisher 1977
“DIRECT” COMPARISON?

Change in $\Sigma(M/L)$?

IFU OBSERVATIONS

HOPKINS & BEACOM (2006)
<table>
<thead>
<tr>
<th>Evolution in TFR zero-point?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No</strong></td>
</tr>
<tr>
<td>Miller+11,12</td>
</tr>
<tr>
<td>Conseilice+05</td>
</tr>
<tr>
<td>Flores+06</td>
</tr>
<tr>
<td>Kassin+07a,b</td>
</tr>
<tr>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td>Chiu+07</td>
</tr>
<tr>
<td>Puech+08</td>
</tr>
<tr>
<td>Cresci+09</td>
</tr>
<tr>
<td>Gnerucci+11</td>
</tr>
<tr>
<td>Swinbank+12</td>
</tr>
<tr>
<td>Vergani+12</td>
</tr>
<tr>
<td>Sobral+13</td>
</tr>
<tr>
<td>Tiley+16</td>
</tr>
<tr>
<td>Übler+17</td>
</tr>
<tr>
<td>Straatman+17</td>
</tr>
</tbody>
</table>
Evolution in TFR zero-point?

No
- Miller+11, 12
- Conseilice+05
- Flores+06
- Kassin+07a, b

Yes
- Chiu+07
- Puech+08
- Cresci+09
- Gnerucci+11
- Swinbank+12
- Vergani+12
- Sobral+13
- Tiley+16
- Übler+17
- Straatman+17
Degraded SAMI data to match KROSS quality:
- spatial (kpc) res. & spectral resolving power and sampling
- median Hα S/N
Strongly correlated but measurements from matched data biased ~10-15% toward lower $v$ and higher $\sigma$ - despite beam smearing correction.
## KROSS-SAMI

### SAMI MATCHED

### SAMI ORIGINAL

#### Diagram

- **(a)**: $M_K$ vs. $\log (V_{2.2}/\text{km s}^{-1})$ for $v/\sigma > 1$
- **(b)**: $M_K$ vs. $\log (V_{2.2}/\text{km s}^{-1})$ for $v/\sigma > 3$
- **(c)**: $\log (M_*/M_\odot)$ vs. $\log (V_{2.2}/\text{km s}^{-1})$ for $v/\sigma > 1$
- **(d)**: $\log (M_*/M_\odot)$ vs. $\log (V_{2.2}/\text{km s}^{-1})$ for $v/\sigma > 3$

#### Table

<table>
<thead>
<tr>
<th>Sub-sample</th>
<th>Criterion</th>
<th>SAMI original</th>
<th>SAMI matched</th>
<th>KROSS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>parent</strong></td>
<td>Detected in Hα</td>
<td>824</td>
<td>824</td>
<td>719</td>
</tr>
<tr>
<td></td>
<td>Resolved in Hα</td>
<td>752</td>
<td>575</td>
<td>552</td>
</tr>
<tr>
<td></td>
<td>$M_K$ and $M_*$ from SED fitting</td>
<td>751</td>
<td>574</td>
<td>535</td>
</tr>
<tr>
<td></td>
<td>$v_{2.2}$</td>
<td>668</td>
<td>479</td>
<td>528</td>
</tr>
<tr>
<td><strong>all</strong></td>
<td>$\frac{\Delta v_{2.2}}{v_{2.2}} \leq 0.3$</td>
<td>614</td>
<td>404</td>
<td>464</td>
</tr>
<tr>
<td></td>
<td>$\frac{\tau_{\text{Hα, max}}}{r_e} \geq 1.31$</td>
<td>516</td>
<td>361</td>
<td>454</td>
</tr>
<tr>
<td></td>
<td>$45^\circ &lt; i &lt; 85^\circ$</td>
<td>355</td>
<td>248</td>
<td>355</td>
</tr>
<tr>
<td></td>
<td>$\frac{v_{2.2}}{\sigma} + \frac{\Delta v_{2.2}}{\sigma} &gt; 1$</td>
<td>306</td>
<td>186</td>
<td>297</td>
</tr>
<tr>
<td><strong>rot-dom</strong></td>
<td>$\frac{v_{2.2}}{\sigma} + \frac{\Delta v_{2.2}}{\sigma} &gt; 3$</td>
<td>164</td>
<td>78</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>$R^2 &gt; 80%$</td>
<td>142</td>
<td>71</td>
<td>138</td>
</tr>
</tbody>
</table>
KROSS-SAMI

SAMI MATCHED
KROSS

<table>
<thead>
<tr>
<th>TFR</th>
<th>Sample</th>
<th>matched-original</th>
<th>KROSS-matched</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_K$</td>
<td>all</td>
<td>$-0.53 \pm 0.09$ mag</td>
<td>$-0.5 \pm 0.1$ mag</td>
</tr>
<tr>
<td></td>
<td>rot-dom</td>
<td>$-0.23 \pm 0.08$ mag</td>
<td>$-0.13 \pm 0.09$ mag</td>
</tr>
<tr>
<td>$M_*$</td>
<td>all</td>
<td>$0.24 \pm 0.05$ dex</td>
<td>$0.05 \pm 0.05$ dex</td>
</tr>
<tr>
<td></td>
<td>rot-dom</td>
<td>$0.07 \pm 0.05$ dex</td>
<td>$-0.08 \pm 0.05$ dex</td>
</tr>
</tbody>
</table>

Tiley+

TFR zero-point matched-original
SAMI \( \geq \) KROSS-matched in every case!
Assuming constant surface mass density, for SF galaxies with $v/\sigma > 3$:
- $M^*/M_{\text{TOTAL}} \uparrow \times 1.2 +/- 0.1$ over last $\sim 8$ Gyr
- $M^*/L_K \uparrow \times 1.3 +0.4/-0.2$ over last $\sim 8$ Gyr

<table>
<thead>
<tr>
<th>TFR</th>
<th>Sample</th>
<th>matched-original</th>
<th>KROSS-matched</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_K$</td>
<td>all</td>
<td>$-0.53 \pm 0.09$ mag</td>
<td>$-0.5 \pm 0.1$ mag</td>
</tr>
<tr>
<td></td>
<td>rot-dom</td>
<td>$-0.23 \pm 0.08$ mag</td>
<td>$-0.13 \pm 0.09$ mag</td>
</tr>
<tr>
<td>$M_*$</td>
<td>all</td>
<td>$0.24 \pm 0.05$ dex</td>
<td>$0.05 \pm 0.05$ dex</td>
</tr>
<tr>
<td></td>
<td>rot-dom</td>
<td>$0.07 \pm 0.05$ dex</td>
<td>$-0.08 \pm 0.05$ dex</td>
</tr>
</tbody>
</table>
Assume constant surface mass density?

Tiley+
But...

- 35% gas to baryonic mass fraction for KROSS (Stott+16)
- potential 0.24 dex offset
- short depletion timescales
- further accretion since z~1 (e.g. Elbaz+07, Salim+07, Dutton+10)
- *must* be significant M* growth since z~1
But...

*must* be significant $M^*$ growth since $z \sim 1$

Baryonic + dark accretion & growth intimately linked over last ~8Gyr
TFR zero-point evolution a function of $z$+selection

Tiley+
TFR zero-point evolution a function of z+selection

$v/\sigma > 1$

$v/\sigma > 3$

0.13 dex

KROSS-SAMI

Tiley+
- different sub-samples + TFRs for different data quality: same applies to all IFS comparisons between high and low-z

- Effect larger than zero-point evolution with $z$

- Literature zero-point evolution with $z$ but this depends on data quality and sample selection

- Matched comparison gives small offset between zero-point for $v/\sigma > 3$ star forming galaxies at $z \sim 0.9$ and $z \sim 0$

- Despite ongoing mass assembly, $M^*/M_{\text{TOTAL}}$ and $M^*/L_K \sim$constant

- dark + baryonic mass growth and accretion intimately linked
Harrison+17

~0.2-0.3 dex more specific ang. mom. In z~0 spirals than z~0.9 SF galaxies at fixed M*

On average, galaxies with higher n have lower specific ang. mom. at both z~0 and z~0.9
Highest specific ang. mom: disc-like
Lowest specific ang. mom: more bulge-dominated