The Tully-Fisher relation for early-type galaxies

Bluedisk: HI-rich spiral galaxies

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Overview

- **Tully-Fisher (TFR) for early-type galaxies (ETGs):**
  - Project within the ATLAS3D project (Cappellari, 2011).
  - Multi-wavelength survey of 260 nearby (D ≲ 40 Mpc) ETGs + semi-analytical modeling.
  - Goal: study formation & evolution of ETGs.

- **Bluedisk (G. Kauffmann):**
  - Multi-wavelength survey of 50 nearby (D ≳ 100 Mpc) HI-rich spiral galaxies.
  - Goal: study accretion of gas by galaxies.
Tully-Fisher for ETGs

- TFR: correlation between HI line width and K-band magnitude → proxies for **dynamical mass** and **stellar mass** (DM halo, stellar component).

- Baryonic TFR: HI line width vs. **baryonic (stellar+gas) mass**. Important constraint galaxy formation models + test for modified gravity.

http://pluslucis.univie.ac.at
Tully-Fisher for ETGs: Sample

- D < 42 Mpc, MK < -21.5 mag

- From the detected 53 ETGs in HI (S0 and E, Serra et al. 2012), we selected 16 in which rotation dominates over random motions and which have a resolved HI-disk. Use deep WSRT HI data to model the kinematics.

- Stellar mass is derived using M/L from stellar kinematics (JAM, Cappellari et al. 2008) and star formation histories (SFH, Cappellari et al. 2013).

- Crucial: rotation velocity inclination correction...
Tully-Fisher for ETGs - Methods

- Analysis of HI velocity fields (rotation curves instead of W): tilted-rings, study residual patterns with harmonic decomposition.

- $a(3)$-amplitude ~ inclination error, $b(1)$ & $b(3)$: radial motions.

\[ v(x,y) = a(0) + \sum_{k=1}^{fitdeg} a(k) \cdot \cos(k \cdot \theta) + b(k) \cdot \sin(k \cdot \theta) \]

Warner, 1973
Tully-Fisher for ETGs - Results

K-band (NIR) TFR

Baryonic TFR (JAM, R-band)
Tully-Fisher for ETGs - Results

- Shows that M/L in K-band is smaller than 0.8 (max. disk) for the spirals, confirms Martinsson et al. (2013).

- Possible explanation: Tonini (2010), improved stellar population models show increased TP AGB-star contribution to K-band luminosity.
Using M/L from stellar kinematics yields tightest BTFR, offset from spiral relation suggesting structural M/L variations amongst ETGs.

BTFR is better defined than K-band TFR.

Possible alternative explanation for offset from spirals: smaller size of ETGs.

Comparison with ATLAS3D CO TFR ⇒ the rotation curves stay flat.

Baryonic-/K-band TFR shallower than established relations for spirals. Elliptical orbits?
Bluedisk - Introduction

- Neutral gas **accretion rate** MW/M31 type galaxies:
  
  \[ \sim 0.7 \, M_\odot \, /\text{yr} \text{ (Richter, 2012)} \].

- **Star formation rate** (SFR): factor 3-5 higher.

- Cooling of hot X-ray coronae not enough to explain SFR.

- Indirect evidence for gas accretion:
  
  - Warps, lopsided HI-disks,
  
  - extra-planar gas in local spirals (NGC 891).
**Bluedisk - Introduction**

- Catinella et al. (2010): atomic gas content correlates with UV-r colours and stellar surface mass densities, however:
  - >10% of the galaxies have an excess HI content,
  - have metal-poor ionised gas in their disks,
  - and are bluer/younger (Wang 2011).

⇒ Indirect evidence of gas accretion.
Bluedisk - Introduction

- WSRT HI observations of 25 gas-rich galaxies and 25 control galaxies matched in stellar mass, size, inclination, z.

- Paper I (Wang et al., 2013): morphology. Results:
  - HI-rich galaxies lie on the same HI mass vs. HI size relation,
  - they have larger HI size/optical sizes,
  - appear clumpy than normal spirals, but...
  - they are not more asymmetric and are not more disturbed.

- Points at a scenario where hot gas in the hot corona shock-heated gas cools and condenses onto the disk rather than the accretion of cold gas.
Do the HI-rich galaxies have kinematics different from the normal spirals?

Do they have larger radial motions?

Are they more kinematically lopsided?

Do the rotation curves look different? → $V_{\text{asymp}}$ from HI, inner part from long-slit spectroscopy and CO.
Bluedisk kinematics - Methods

- Tools: velocity fields.
- However, distances >100 Mpc, beam-smearing is an issue → 1st moment velocity fields do not represent galactic dynamics.
- Improvement: Gauss-Hermite velocity fields.
- SKA pathfinder, Apertif etc. → Soon, many galaxies will be observed at comparable distance; how to quickly analyse kinematics?
**Bluedisk kinematics - Results**

- Systematical inspection of data cubes: gas-rich galaxies have more symmetric warps, but are not more lopsided or asymmetrically warped.

- Quantitative analysis: Tilted-ring fitting, asymmetry measures.

*Figure 2.* Left: difference between the kinematical and the morphological H\textsc{i} PA. Right: difference between the kinematical H\textsc{i} PA and the optical PA.
Bluedisk kinematics - Results

For our sample it is interesting to compare the K-band TFR with Block (2001). Since for our galaxies, due to the limited resolution (see e.g. Verheijen 2001; Davis et al. 2011; McGaugh, Rubin & de Blok 2001), it is preferable to use asymptotic circular mass (Walker 1999; McGaugh et al. 2000). More recent studies of the (B)TFR show that a tight correlation between circular velocity and baryonic mass (Tully & Fisher 1977; Tully & Pierce 2000) is an established relation between the width of the H\(\alpha\) scaling relation for disk galaxies. It is a tight correlation between luminosity and baryonic mass.

This significant difference between the kinematical and the morphological H\(\alpha\) can be a cause of the larger asymmetry. However, the control sample with large residuals (galaxies 26 and 50), the KS-test rejects the null hypothesis that the samples are drawn from the distribution. We perform a fit to the data points keeping the slope fixed to 0.55 mag and therefore comparable to the K-band TFR scatter. Our data seems to follow the McGaugh (2012) data very well, at a smaller mass-to-light ratio for H\(\alpha\)-rich galaxies suggesting asymmetry that does not involve fitting a model to the data nor computing the scatter of our points with respect to this relation and luminosity does not significantly reduce scatter in the TFR, even if the total baryonic mass rather than stellar mass is taken to be a measure of galaxy lopsidedness or asymmetric.

We define the baryonic mass from Paper I and compute the baryonic mass amplitudes are not very large, most are under 30 kms\(^{-1}\). Our data seems to follow the McGaugh (2012) data very well, at a smaller mass-to-light ratio for H\(\alpha\)-rich sample galaxies. This can be an indication that the galaxies could be on a smaller scatter of 0.34 mag corresponding to their asymptotic rotation velocities from resolved rotation curves. We use the optical centres (see Paper I). We derive the statistical reference points to the control sample galaxies.
Bluedisk kinematics - Results

Figure 5. Left: K-band TFR. The black diamonds are the NV07 galaxies and the black solid line their best-fitting TFR corresponding to their $V_{asymp}$ relation. The blue circles are the $\text{H}_i$-rich galaxies and the red triangles the control galaxies. The red dotted line is the line describing the fit to our data points with a slope fixed to the NV07 slope. Right: BTFR. The black diamonds are the McGaugh (2012) galaxies. The black solid line is their best-fitting line corresponding to the rotation velocity based BTFR and includes star-dominated galaxies.
Bluedisk kinematics - Results

* Quantitative asymmetry analysis:

  * Beam-smearing makes tilted-ring fits to velocity fields difficult. Future work: fit to data cube.

  * gas-rich galaxies are not more asymmetric.

  * It appears that the gas-rich galaxies are not more disturbed → smooth accretion from the ambient medium rather than episodic accretion.
Thank you!
Bluedisk kinematics - Methods

* Problem: beam-smearing effect due to limited WSRT resolution: ~13″ → semi-minor axes are stretched.

→ No inclination can be recovered from the HI kinematics.
Tu lly-Fisher for ETG s - R esults

• Comparison with the spiral BTFR (fixed M/L) from Noordermeer & Verheijen (2007).
ATLAS3D & Tully-Fisher for ETGs

* ATLAS3D-comb: alternative galaxy classification, based on bulge-to-disk stellar kinematics.

* Selected 16 galaxies where rotation dominates over random motions and which have a resolved HI-disk (mostly S0 and late type E). Use deep WSRT HI data to study their TFR.