Peculiar Velocity Dipoles of Field Galaxies Using the Tully-Fisher Relation

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Method

- Tully-Fisher relation
  - $I = a \log w + b$
  - $I$ – absolute magnitude $\rightarrow$ stellar mass
  - $w$ – line width of 21cm line or optical emission line
    $\rightarrow$ total gravitational mass
- Secondary standard candle
- Direct vs. Inverse TF
  - Direct relation is obtained from a least-squared fit of $\log w$
    as a function of $I$
- Malmquist bias (cluster of galaxies)

Tully & Fisher 1977
CMB radiation dipole moment

- Observed CMB radiation dipole moment

- Interpretation

\[ T' = T \frac{\sqrt{1-v^2/c^2}}{1-(v/c) \cos \theta'} \]

- \( V_{\text{CMB}} \) (LG wrt the CMB)
  - 611\pm22 \text{ km/s, } l=273^\circ\pm3^\circ, b=27^\circ\pm3^\circ

- Uncertainty: \( V_{\text{sun wrt LG}} \): 300 \text{ km/s, } l=90^\circ, b=0^\circ
Motivation

- Peculiar velocity induced on the LG by the inhomogeneities present within a sphere of radius $R$
  \[
  V_{\text{pec, LG}}(R) = \frac{H_0 \Omega_0^{0.6}}{4\pi} \int \delta_{\text{mass}}(r) \frac{r}{r^3} W(r, R) d^3r,
  \]

- $\delta_{\text{mass}}$ – mass overdensity
- $W$ – window function of width $R$
- average value of $\delta_{\text{mass}}$ within a shell of radius $R \rightarrow 0$
  \[
  V_{\text{pec, LG}} \rightarrow V_{\text{CMB}} \quad \text{when} \quad R \rightarrow \infty
  \]

In a universe homogeneous on large scales, the reflex motion of LG, wrt the contents of a shell of large enough radius $R$ will exhibit a dipole that closely matches that of the CMB radiation field.

- How large is large
  - within 5000-10,000 km/s vs. outside 10,000 km/s

(from Dale 1998)
SFI samples and peculiar velocity calculations

- **SFI** – a homogeneous all-sky sample of 1289 field objects extending to $cz \approx 6500$ km/s, bias minimized
- **SFI+** – SFI complemented by several hundred additional objects to $cz \approx 9500$ km/s

- **SCI** – sample of cluster galaxies

- **I band**: CTIO 0.9-m, Blanco, and KPNO 0.9-m
- **21cm line**: Arecibo, etc.

Obtain dipoles of peculiar velocity field

- Inverse TF used to estimate peculiar velocities
  - Select galaxies by observed redshift $cz$
- Direct TF with velocities corrected for the IMB
  - Window galaxies by TF distance ($cz_{TF} = cz - V_{pec}$)
Dipole moment calculations

Merit function

\[ \chi^2 = \sum_i w_i \left( \frac{V_i - V_d \cdot \hat{r}_i}{\epsilon_i} \right)^2 \]

\( V_d \) – vector of the dipole moment
\( r_i \) – unit vector in the direction of the \( i^{th} \) galaxy
\( w_i \) – weight (1 or \( r_n^3 \) for the fading selection function)
\( V_i \) – peculiar velocity of the \( i^{th} \) galaxy in the sample
\( \epsilon_i \) – uncertainty on \( V_i \) \((-0.325(\log W -2.5)+32)\)
Data Fitting

Chi-Squared Fit:

\[ \chi^2 = \sum \limits_i w_i \left( \frac{V_i - V_d \cdot \hat{r}_i}{\epsilon_i} \right)^2 \]

Weights:

- Equal: \( w = 1 \)
- Fading Selection: \( w = r_n^3 \)

Bootstrap Error Analysis:

- Data
- Many Data Subsamples
- Distribution of Statistics

\( x \)
Results - Numbers

- Velocity Groupings
  - Global Groups (b)
    - All $V \sim 400$ km/s
  - Shells (everything else)

- TF Groups
  - Inverse (1-13)
  - Direct (14-19)

- SFI and SFI+ Groups
  - SFI+ groups have +

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<td><strong>SFI Dipole Solutions</strong></td>
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<td>Inverse Tully-Fisher</td>
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<td>13b. 5500–9500 + ..........</td>
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<th>Direct Tully-Fisher, IMB Corrected</th>
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(From Giovanelli et. al. 1998)
Results – Velocity Magnitudes

- Convergence as maximum cz used increases
- Similarities among groups

(From Giovanelli et. al. 1998)

Dashed Line: CMB dipole
Open Points: SFI Sample
Closed Points: SFI+ Sample
Starred Points: Direct TF
Results – Velocity Directions

- 2000 km/s groups:
  - Local Supercluster?
  - M87 ($l = 284^\circ$, $b = +74^\circ$)

- The others:
  - Well centered wrt CMB
  - Convergence

(From Giovanelli et. al. 1998)

Crossed Circle: CMB dipole
(Crossed Box: Lauer & Postman 1994)

Open Points: SFI Sample
Closed Points: SFI+ Sample
Starred Points: Direct TF
Conclusions

- Tully-Fisher Relation can find Distances and Peculiar Velocities of Spiral Galaxies

- Local Supercluster likely candidate for cause of dipole within 2000 km/s

- Convergence depth is near about \( cz = 4000 \text{ km/s} \)
  - Low end (or below) the low camp

- Bulk flow wrt CMB of 6500 km/s sphere:
  - \( 200 \pm 65 \text{ km/s} \)
  - \((l = 295^\circ, b = +25^\circ) \pm 20^\circ\)
References