Stellar motion (and gas motion) in galaxies 2

Block Course Introduction to Astronomy and Astrophysics

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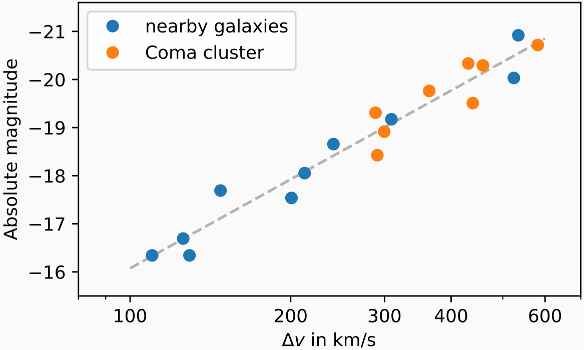
Spiral and S0 galaxies

- dynamics: orderly motion in disk, dynamically cold
- random motion only accounts for 5% of total kinetic energy, but dispersion-supported bulges
- with arms (spiral) or without (S0)
- gas concentrated in disk (viscosity!)
- often (faint, few % of total luminosity) metal-poor halos
- Sa and S0 prominent inner bulges (10^5 higher stellar number density)
- not usually found in high-density regions — field galaxies or groups instead

ESO

Tully-Fisher relation 1

Empirical find by Tully & Fisher 1977:
correlation between global HI profile width and absolute magnitude $\Rightarrow$ $L \sim \Delta v^{\alpha}$,
originally $\alpha \approx 2.5$, but filter-dependent



Data from Tully & Fisher 1977

ESO/O. Maliy

Tully-Fisher relation 2

Simplest estimate gives $L \sim {v_{rot}}^4$ as follows:

Assumptions:

- flat rotation curves, $v_{rot}(R) \sim const.$
- constant surface brightness $L/R^2 = const.$
- constant mass-to-luminosity ratio $M/L = const.$

Circular orbit around central mass (point mass or in disk plane):

$$\frac{v_{rot}^2}{R} = \frac{GM}{R^2} \quad \Rightarrow \quad M = \frac{v_{rot}^2 R}{G}$$

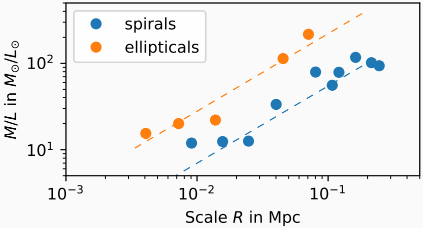
so with the additional assumptions

$$L = \frac{L}{M} M \sim v_{rot}^2 R \quad \Rightarrow \quad L \sim v_{rot}^2 \sqrt{L} \quad \Rightarrow \quad \sqrt{L} \sim v_{rot}^2 \quad \Rightarrow \quad L \sim v_{rot}^4$$

Tully-Fisher relation 3

Slightly less simple assumptions:

- flat rotation curves, $v_{rot}(R) \sim const.$
- constant surface brightness $L/R^2 = const.$
- mass-to-luminosity ratio $M/L \sim R^{0.8}$ from obs



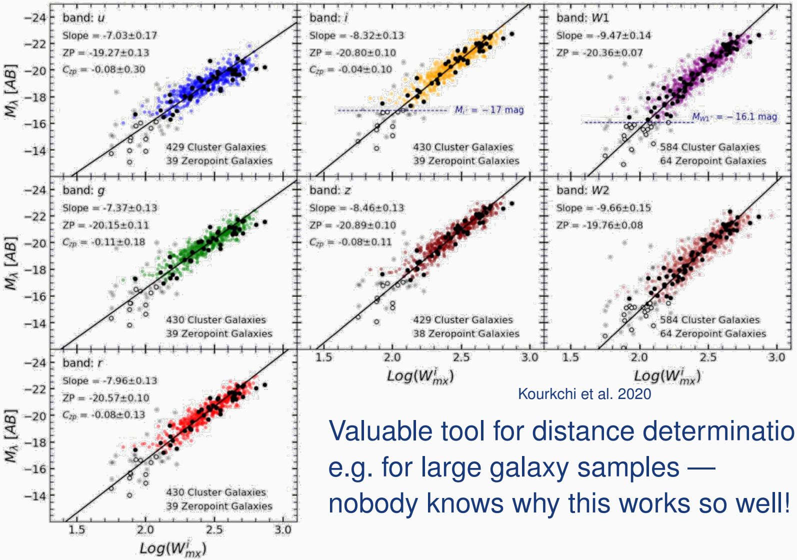
Data from Bahcall and Fan 1998

Starting point again:

$$\frac{v_{rot}^2}{R} = \frac{GM}{R^2} \quad \Rightarrow \quad M = \frac{v_{rot}^2 R}{G}$$

Same general reasoning:

$$L = \frac{L}{M} M \sim v_{rot}^2 R^{0.2} \quad \Rightarrow \quad L \sim v_{rot}^2 L^{0.1} \quad \Rightarrow \quad L^{0.9} \sim v_{rot}^2 \quad \Rightarrow \quad L \sim v_{rot}^{2.2}$$

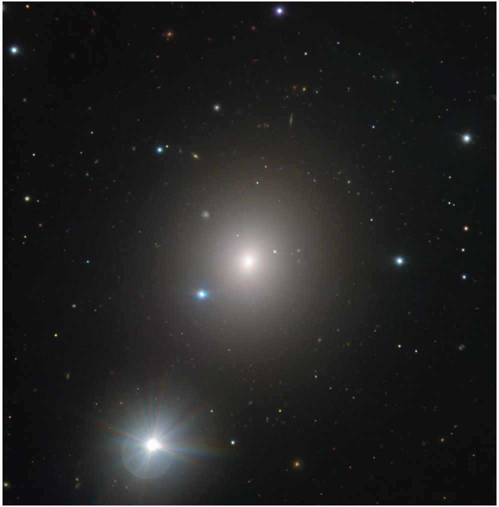


Kourkchi et al. 2020

Valuable tool for distance determination
e.g. for large galaxy samples —
nobody knows why this works so well!

Elliptical galaxies

- little if any cool gas, but hot X-ray gas
- variety of rotation states
- most at least mildly triaxial
- sometimes, complex dynamics, e.g. decoupled core regions
- lots of kinetic energy in random motion $\Rightarrow$ hot system, pressure-supported
- mostly old stars, all > 1 Gyr, often ~ 10 Gyr



NGC1404, image: ESO

Faber-Jackson relation: L (and thus the distance) from velocity dispersion

Luminosity vs. velocity dispersion: $L \sim \sigma^4$

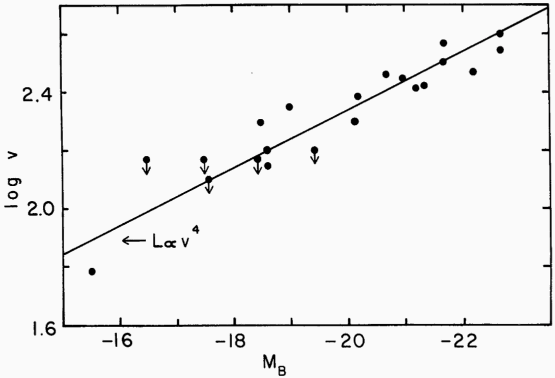
Derivation similar to Tully-Fisher argument, but with virial theorem:

$$\sigma^2 \sim \frac{GM}{R}$$

Assumptions:

- constant surface brightness
  $L/R^2 = I_e = const.$
- constant mass-to-luminosity ratio
  $M/L = const.$

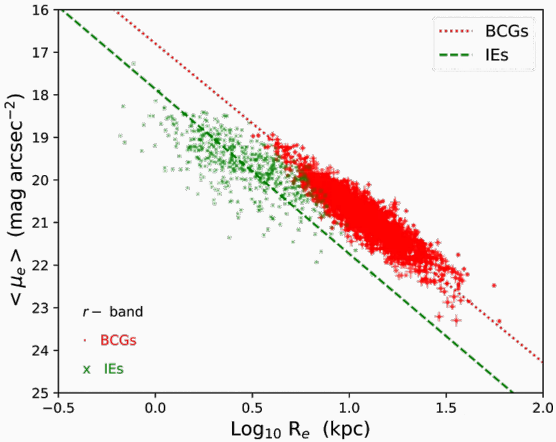
$$\sigma^2 \sim \frac{M}{R} \sim \frac{L}{R} \sim \frac{L}{\sqrt{L}} \sim \sqrt{L}$$



Faber & Jackson 1976

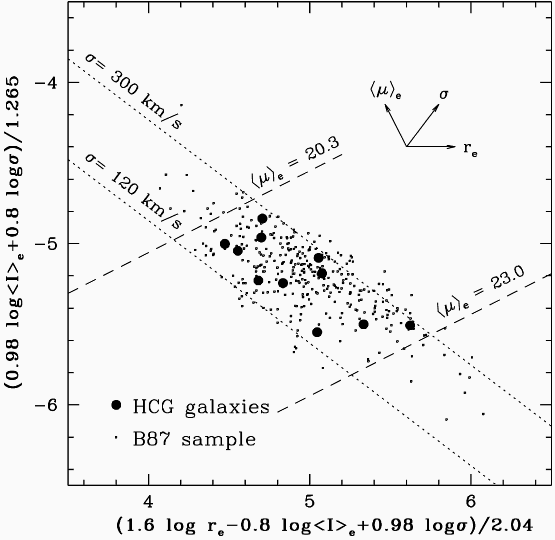
Kormendy relation: effective radius vs. surface brightness

- Originally found by Kormendy 1976
- greater effective radius r_e
  $\Rightarrow$ lower surface brightness
- brighter ellipticals are apparently less dense!



Samir et al. 2020

- Originally: Djorgovski & Davis 1987
- Plane in three-dimensional parameter space: effective radius r_e, mean surface brightness μ_e (alternatively written as: $\langle I \rangle$), velocity dispersion σ
- $r_e \sim \sigma^{1.2} \langle I_e \rangle^{-0.8}$
- Projections lead to (scattered) 2D scaling relations, e.g. Kormendy relation, Faber-Jackson



de Carvalho et al. 2003