SPIRAL/ELLIPTICAL GALAXY KINEMATICS

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DISTANCE LADDER

There is a mathematical relation between the velocity dispersion and the luminosity of a galaxy.

Using this, you can estimate the galaxy's luminosity. Then, compare with the apparent magnitude and determine the distance.

Does this make sense?

Let's do a sanity check.

Spiral/Elliptical Galaxy Kinematics

Credit: NASA, ESA & D. Carter

Credit: NASA, ESA & A. van der Hoeven

Surface Brightness

SANITY CHECK

Start with orbital velocity: $\sigma \propto v \propto \sqrt{\frac{M}{R}}$

Assuming $L \propto M$, we can relate R and σ:

$$R \propto \frac{L}{\sigma^2}$$

Assume a constant surface brightness $B = \frac{L}{4\pi R^2}$:

$$L = 4\pi B R^2$$

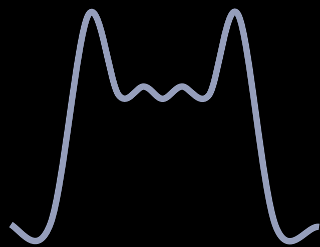
$$L \propto 4\pi B \left(\frac{L}{\sigma^2}\right)^4$$

$$L \propto 4\pi B L^2 \sigma^{-4}$$

$$L \propto \sigma^4$$

Credit: NASA, ESA & D. Carter

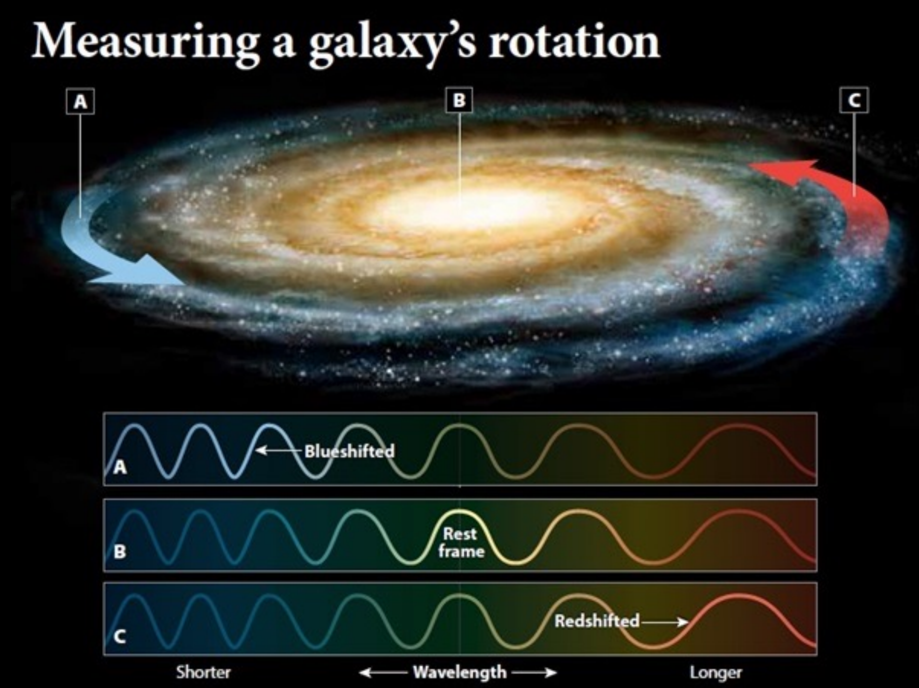
MEASURING DISPERSION



Measure emission lines of the galaxy (Usually 21cm hydrogen line)

Combination of blueshift and redshift widen emission lines

Emission line width measures line of sight component of random motion in the galaxy (subtracting peculiar velocity and rotation), which gives velocity dispersion

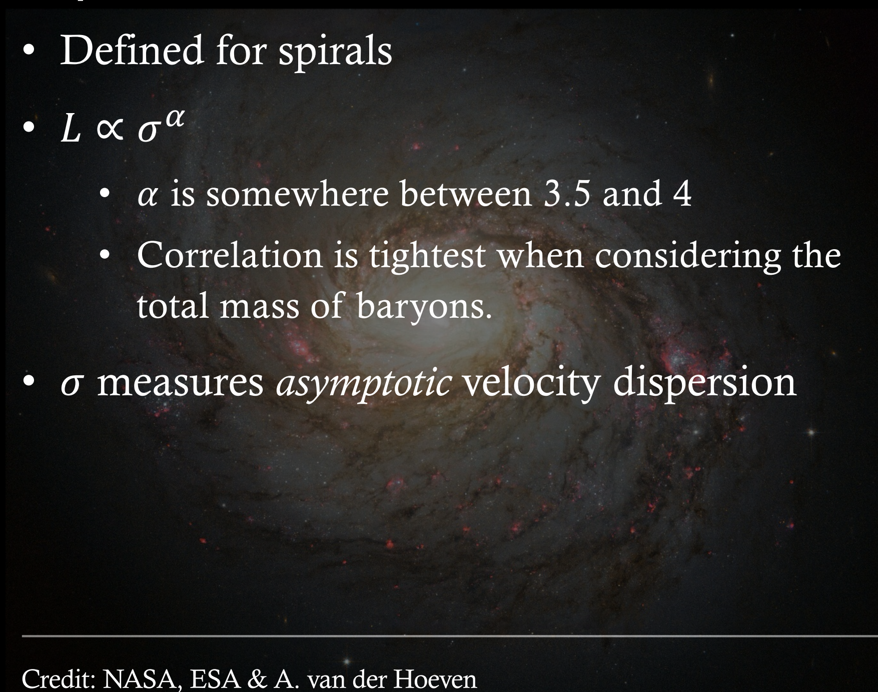


Credit: Astronomy Magazine (2018)

RELATIONS

Tully-Fisher Relation

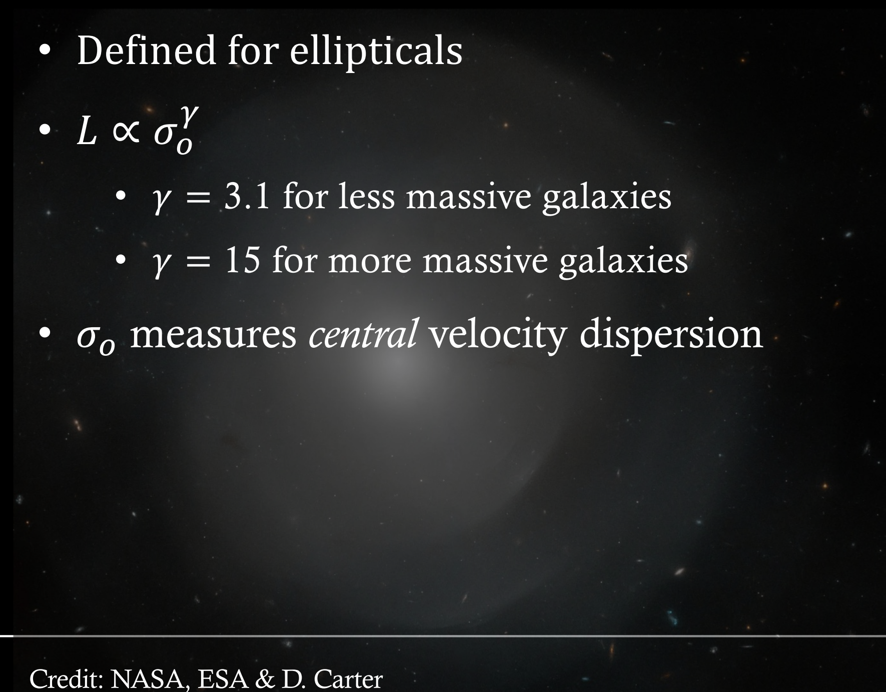
- Defined for spirals
- $L \propto \sigma^{\alpha}$
  - α is somewhere between 3.5 and 4
  - Correlation is tightest when considering the total mass of baryons.
- σ measures *asymptotic* velocity dispersion



Credit: NASA, ESA & A. van der Hoeven

Faber-Jackson Relation

- Defined for ellipticals
- $L \propto \sigma_o^{\gamma}$
  - $\gamma = 3.1$ for less massive galaxies
  - $\gamma = 15$ for more massive galaxies
- σ_o measures *central* velocity dispersion

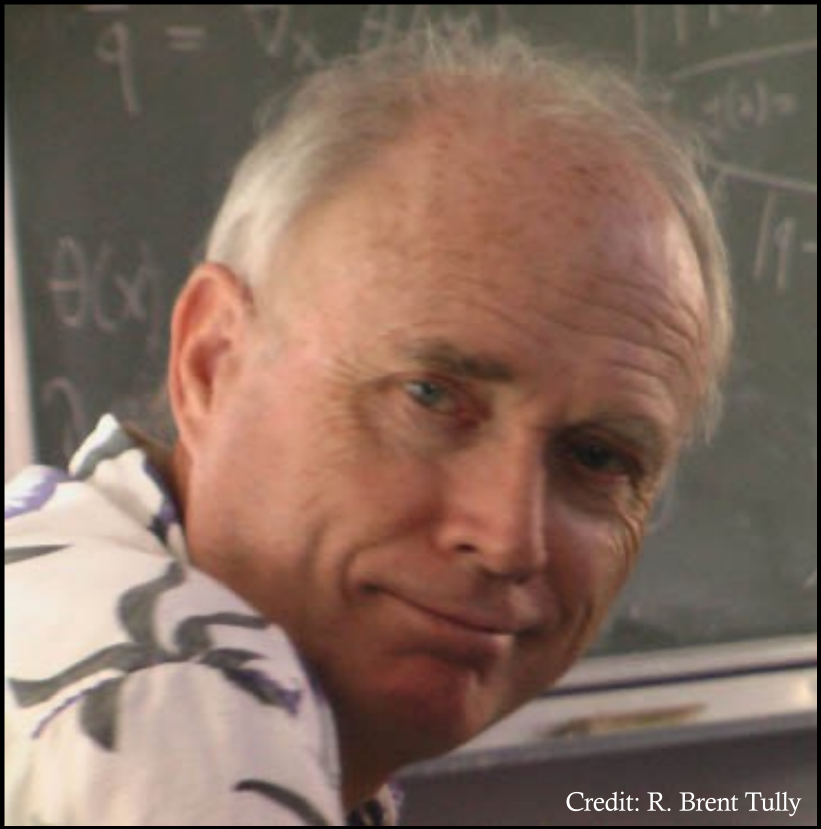


Credit: NASA, ESA & D. Carter

TULLY-FISHER RELATION

Richard Brent Tully

- Received his PhD in 1972 for observing the 2D velocity field of M51
- Published the *Nearby Galaxies Catalog/Atlas* in 1988
- Helped identify and name the Laniakea Supercluster
- Won the Gruber Prize in Cosmology in 2014

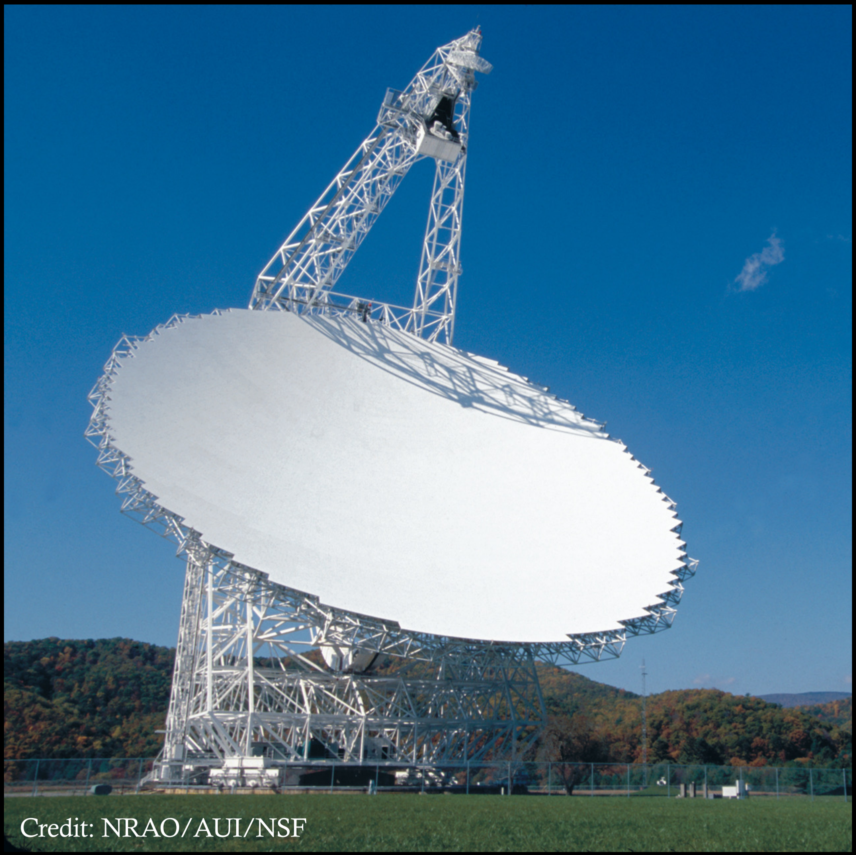


Credit: R. Brent Tully

TULLY-FISHER RELATION

James Richard Fisher

- Most of his career revolved around radio instrumentation.
- Received his PhD in 1972 for testing the design of an array at Clark Lake Radio Observatory.
- Joined NRAO in 1972, helped design the Green Bank Telescope (the world's largest steerable radio telescope).
- Retired in 2012, but still active in instrumentation projects.



Credit: NRAO/AUI/NSF

FABER-JACKSON RELATION

Sandra Moore Faber

- First woman on staff at the Lick Observatory.
- Principal Investigator on the "Seven Samurai", which discovered irregularities in the Universe's expansion.
- Discovered the Great Attractor.
- Principal Investigator on the Nuker Team, which discovered that every galaxy has a supermassive black hole in its center.
- Received the National Medal of Science in 2013.
- Currently the University Professor of Astronomy & Astrophysics at the University of California, Santa Cruz

Credit: US White House (Public Domain)

FABER-JACKSON RELATION

Robert Earl Jackson Jr.

- Studied under Faber when they discovered the Faber-Jackson relation.
- Earned his PhD in 1982 on the anisotropy of the Hubble Expansion.
- Has since worked to create numerous online catalogs for astronomers.
- Partially the reason we have so many catalogs readily available today.
- Has the shortest Wikipedia page I have ever seen.

Robert Jackson (astronomer)

5 languages

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From Wikipedia, the free encyclopedia

(Redirected from Robert Jackson (scientist))

> This biography of a living person **needs additional citations for verification**. Please help by adding reliable sources. Contentious material about living persons that is unsourced or poorly sourced **must be removed immediately** from the article and its talk page, especially if potentially libelous.
>
> *Find sources:* "Robert Jackson" astronomer – news · newspapers · books · scholar · JSTOR *(May 2011) (Learn how and when to remove this message)*

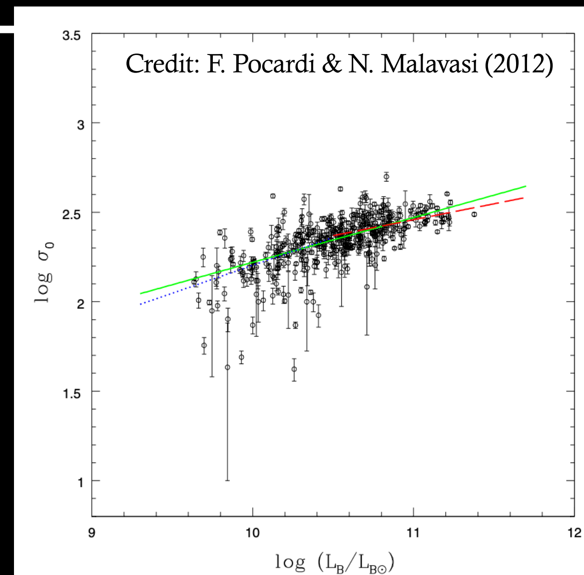
Robert Earl Jackson (born 1949) is a scientist, who, with Sandra Faber, in 1976 discovered the Faber–Jackson relation between the luminosity of an elliptical galaxy and the velocity dispersion in its center.[1][2]

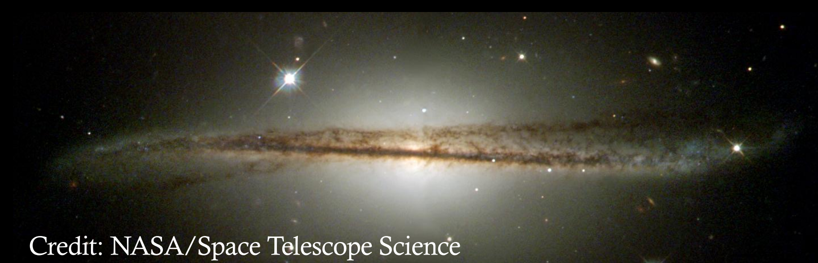
Jackson was a graduate student at the University of California at Santa Cruz. As a research assistant for Faber, he contributed to the data analysis on the project that led to the Faber–Jackson relation (1976). Jackson received his PhD in 1982 with the thesis titled "The Anisotropy of the Hubble Constant".

From 1984 to 1999, he worked for Computer Sciences Corporation at the Space Telescope Science Institute in Baltimore, Maryland.

LIMITATIONS

- Both methods have very high scatter
  - Can be improved when measuring total baryonic mass for spirals (difficult)
  - Some evidence of environmental variation for ellipticals
- TFR is highly affected by inclination and assumes constant M/L ratio
- FJR is actually a projection of the fundamental plane
- Easiest to measure dispersion for nearby (resolvable) galaxies



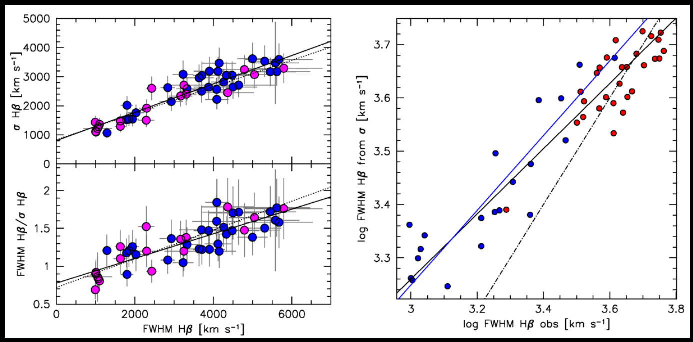

Credit: NASA/Space Telescope Science

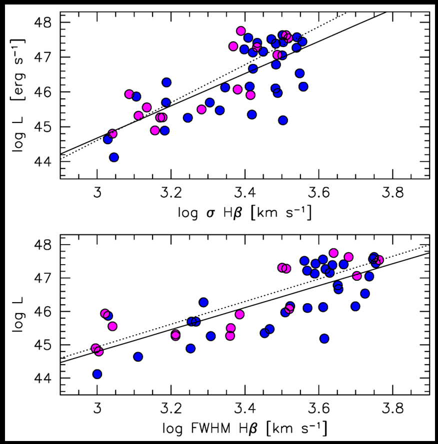
$$R_e \propto \sigma_o^{1.4} \langle I \rangle_e^{-0.9}$$

CURRENT RESEARCH

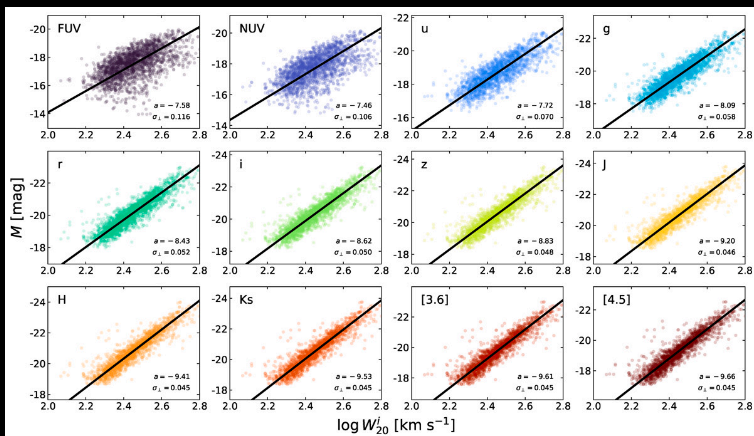
- D'Onofrio et al. (2024) formulate a variant of the FJR for Type 1 AGNs.
    - Aimed to account for the Virial Theorem, and the effects of galaxy mergers
    - Observed a correlation between the Hβ line in the BLR and the velocity dispersion
- Determined Type 1 AGNs follow a similar power law to the FJR:

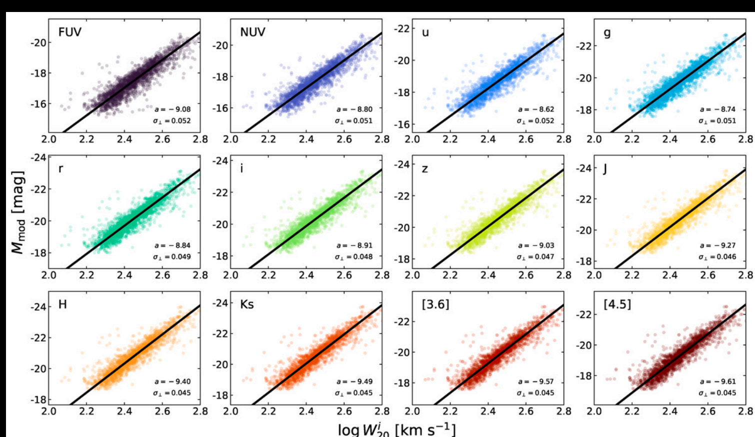
$$L \propto \sigma^n, \quad n \approx 4$$





Credit: D'Onofrio et al.





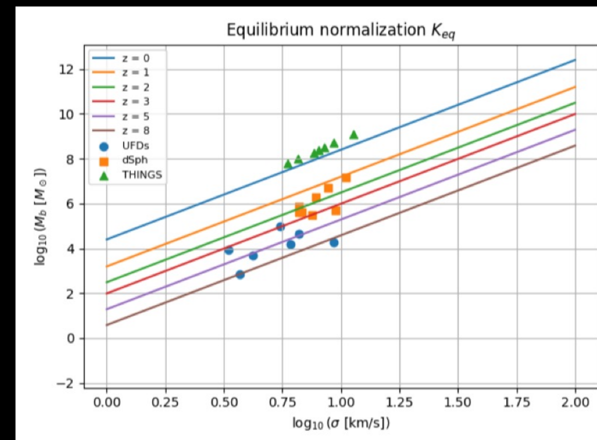
Credit: Baes et al.

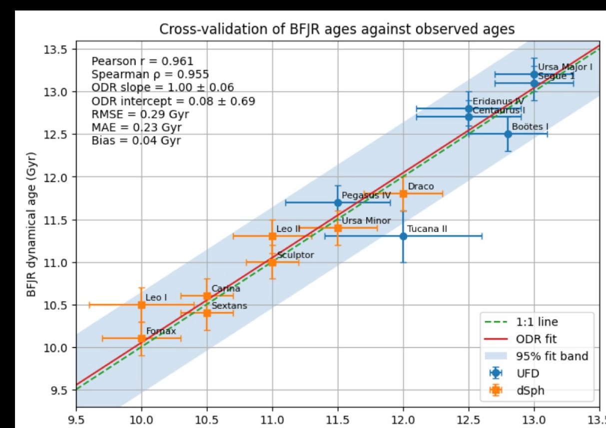
CURRENT RESEARCH

- Baes et al. (2025) simulate late-type galaxies and use them to estimate a TFR in different wavelength bands
- Noticed the TFR becomes steeper and tighter in longer wavelengths
  - Simulated slopes match well with observations.
  - With $u - r$ color as a third parameter, this TFR had roughly constant tightness over the full UV to mid IR range.

CURRENT RESEARCH

- Marongwe & Kauffman (2026) create a variant of the TFR and FJR that changes over time
  - Intended to correct for the scale factor of the Universe
  - Can be applied to many types of galaxies
- Used it to determine ages of galaxies
  - Compared it to metallicity-determined ages





Credit: Marongwe & Kauffman


ANY QUESTIONS?