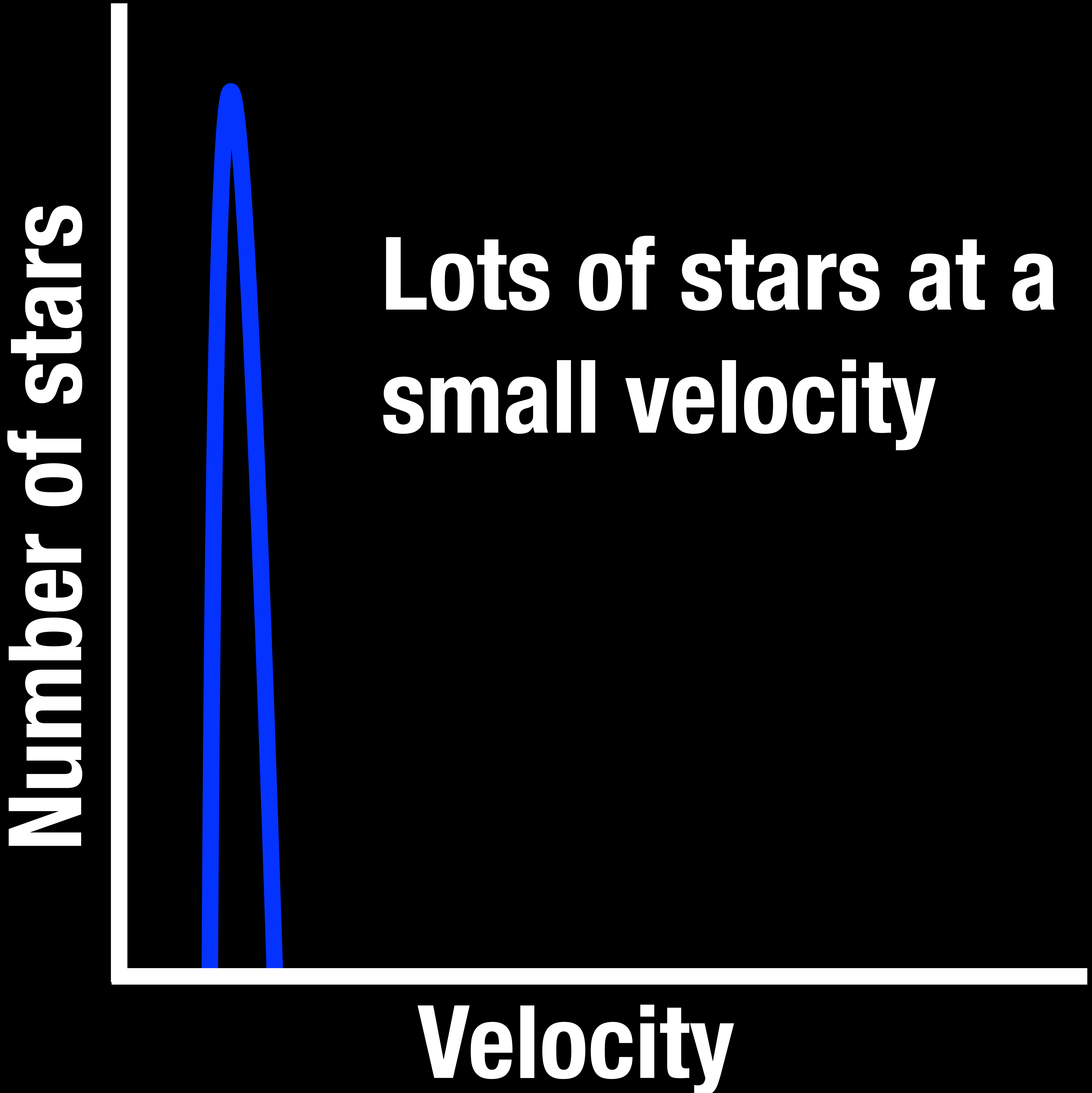
ASTR-3301: Extragalactic Astronomy

Lecture #12: Galaxy Kinematics

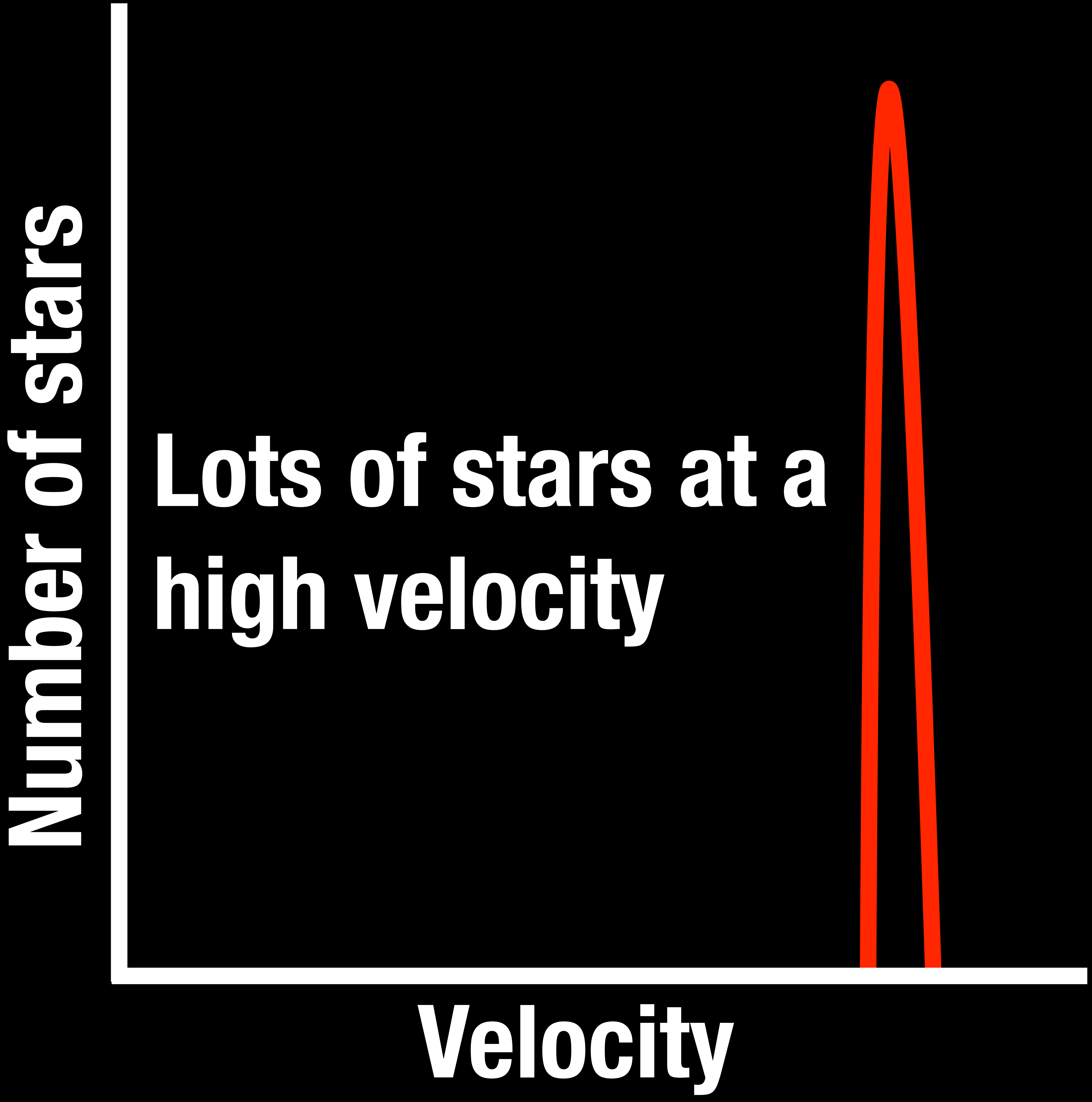
Results for Ellipticals: Kinematic Correlations

If all stars were blueshifted
(all moving towards us)



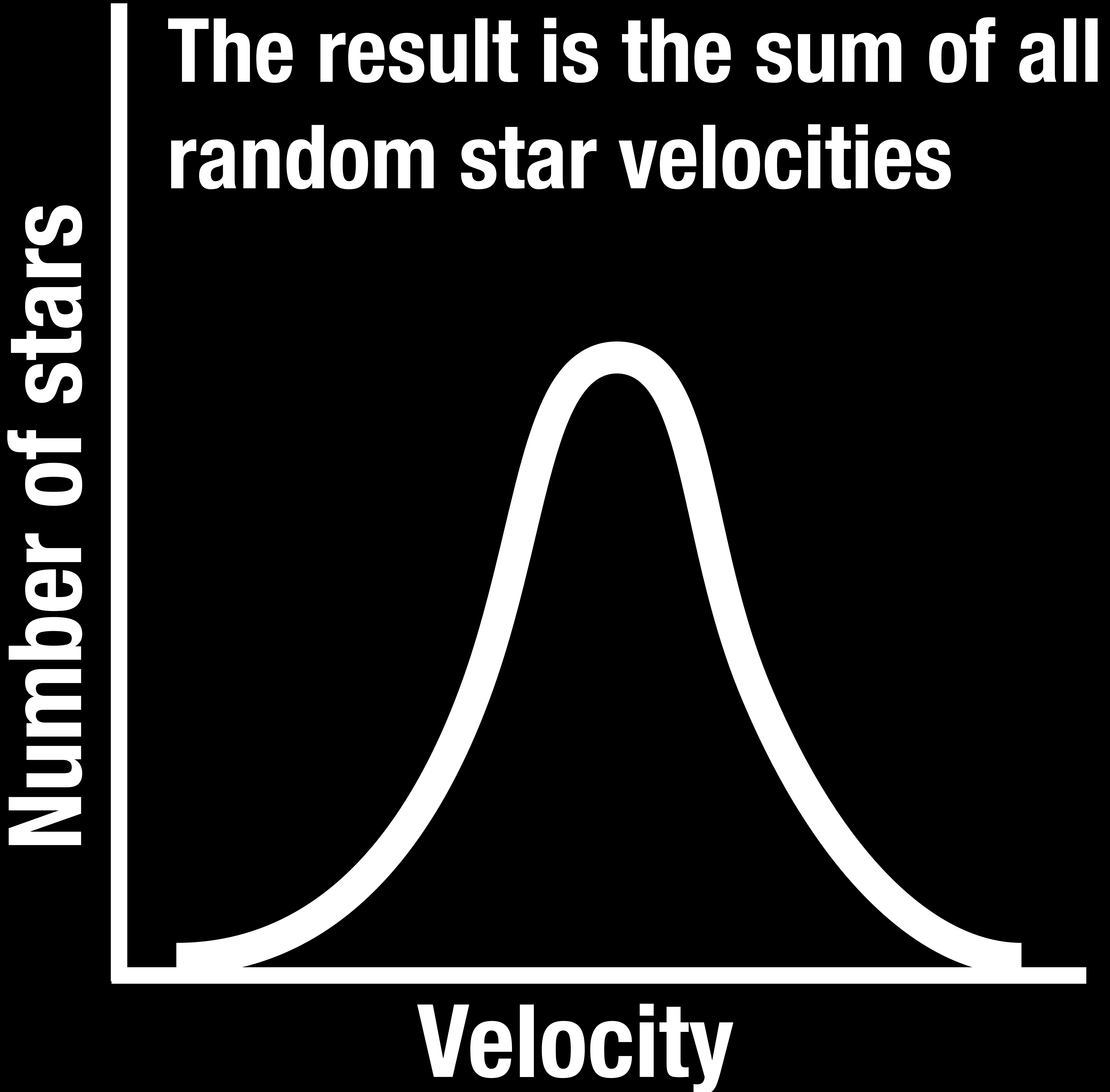
Results for Ellipticals: Kinematic Correlations

If all stars were redshifted
(all moving away from us)

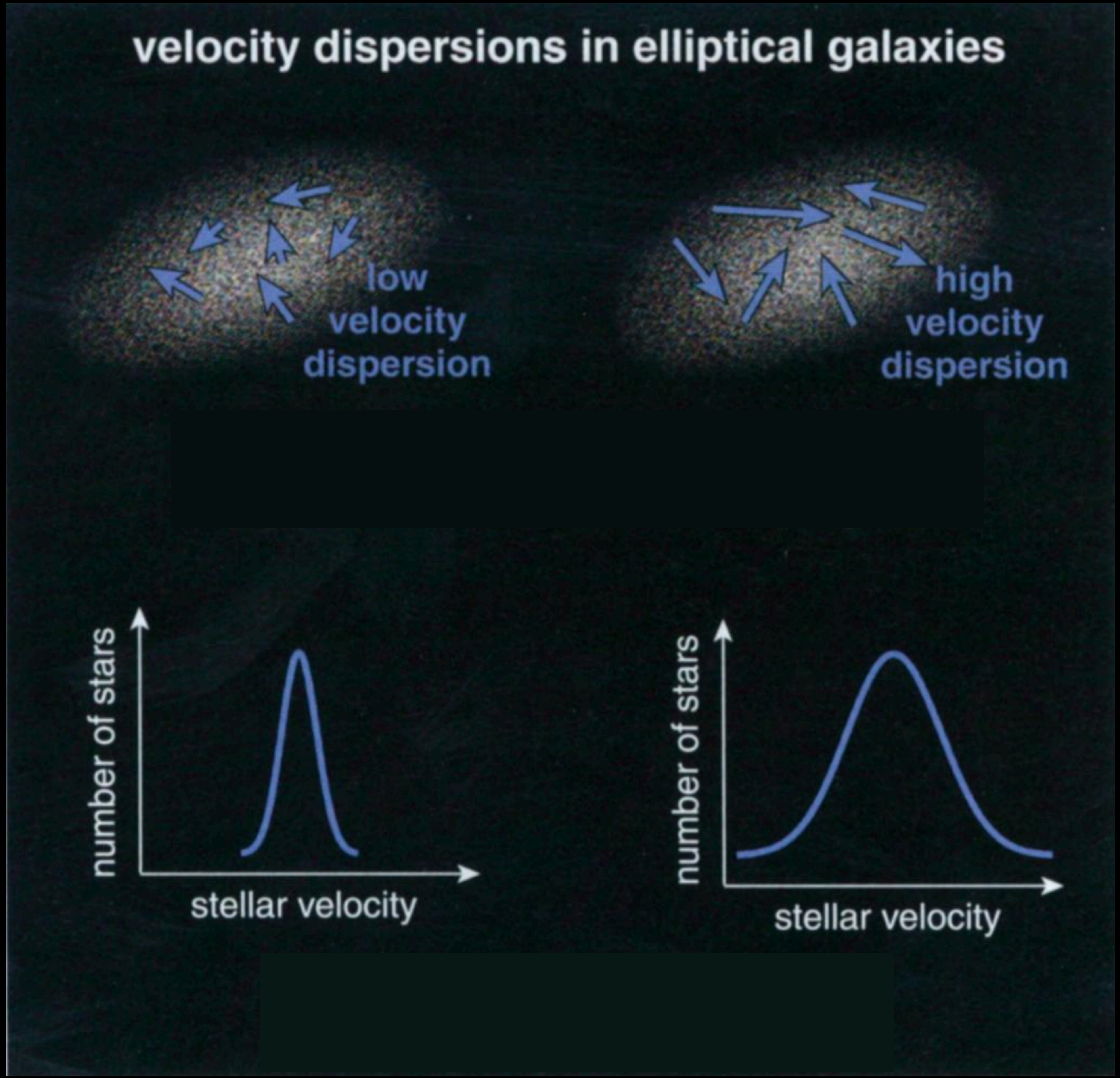


Results for Ellipticals: Kinematic Correlations

But stars are moving on ellipses in billions of orientations



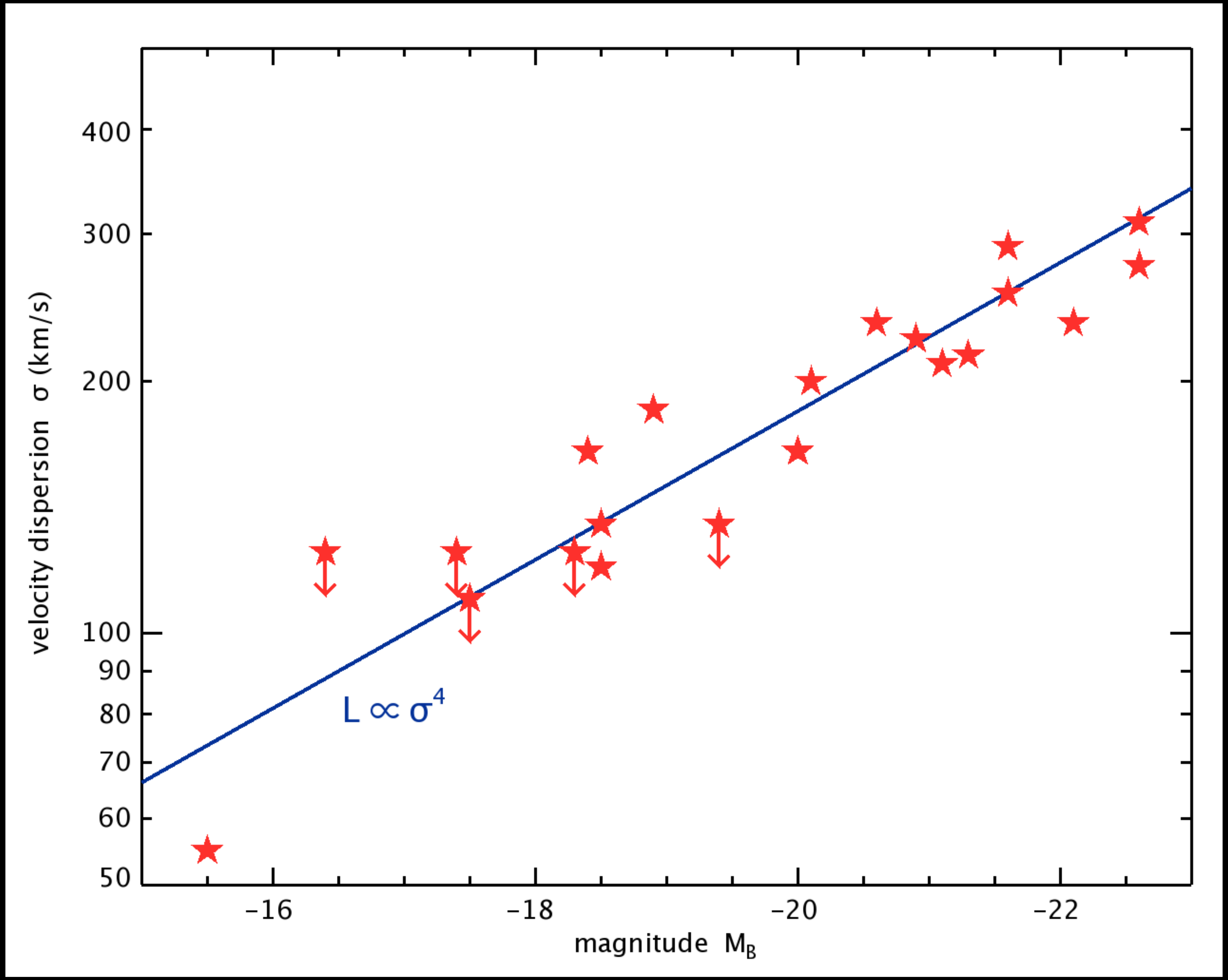
Results for Ellipticals: Kinematic Correlations



Low velocity dispersion: skinny distribution

High velocity dispersion: fat distribution

The Faber-Jackson Relation



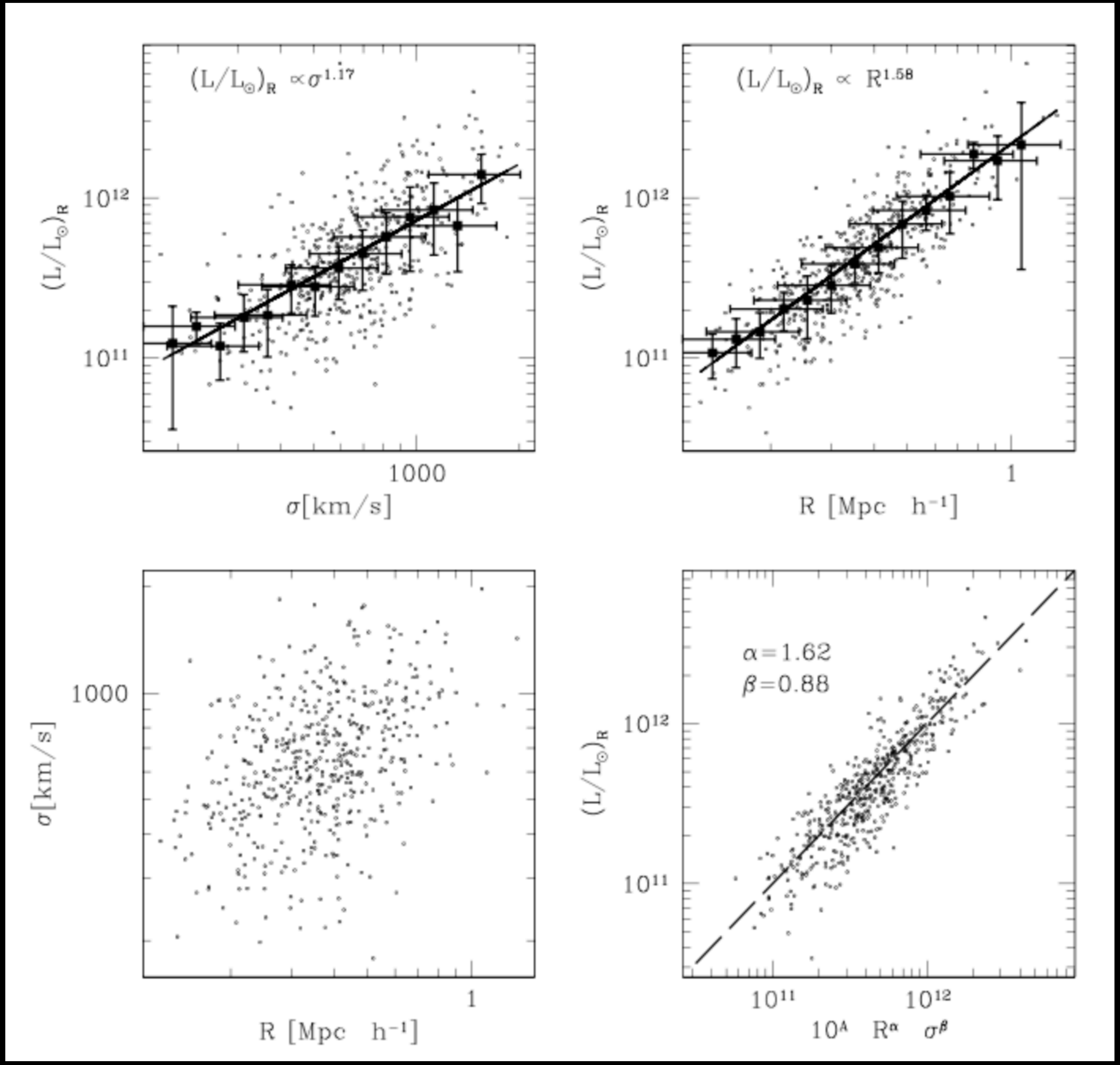
(Faber & Jackson 1976, ApJ, 204, 668)

By measuring σ in elliptical galaxies with known distances, Faber and Jackson discovered the correlation between σ and M for Es

Faber-Jackson relation: $L \sim \sigma^4$ (σ: central velocity disp.)

$$\frac{L_V}{2\text{x}10^{10} L_\odot} = \left(\frac{\sigma}{200 \text{ km s}^{-1}} \right)^4$$

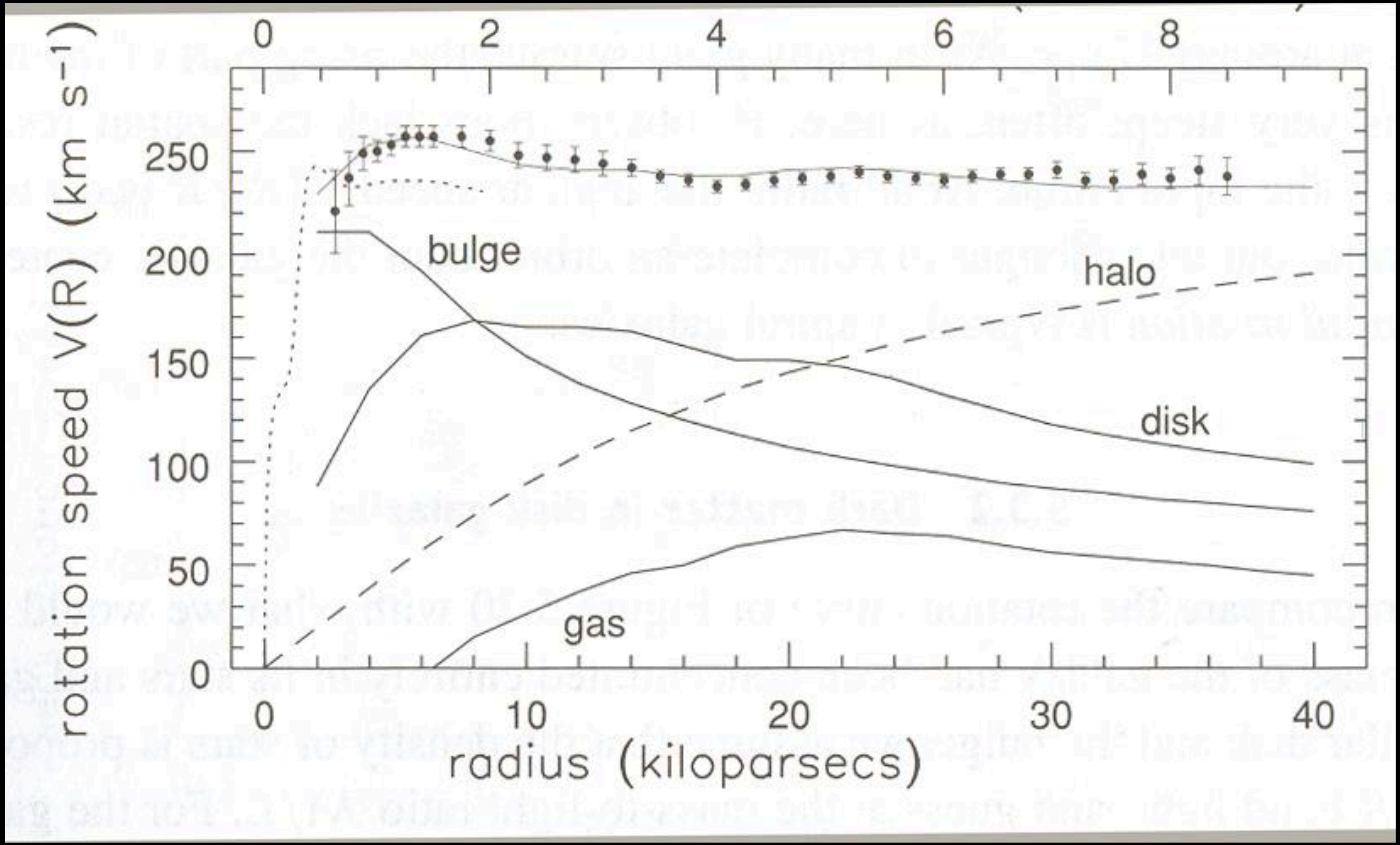
The Fundamental Plane Relation



(Diaz & Muriel, MNRAS, 364, 1299)

- Reexaminations over the years yielded an abundance of scatter about the FJ relation (top left panel)
- Tighter correlation found for L vs galaxy radius (R) and σ -> renamed "Fundamental Plane" (3 variables instead of 2)

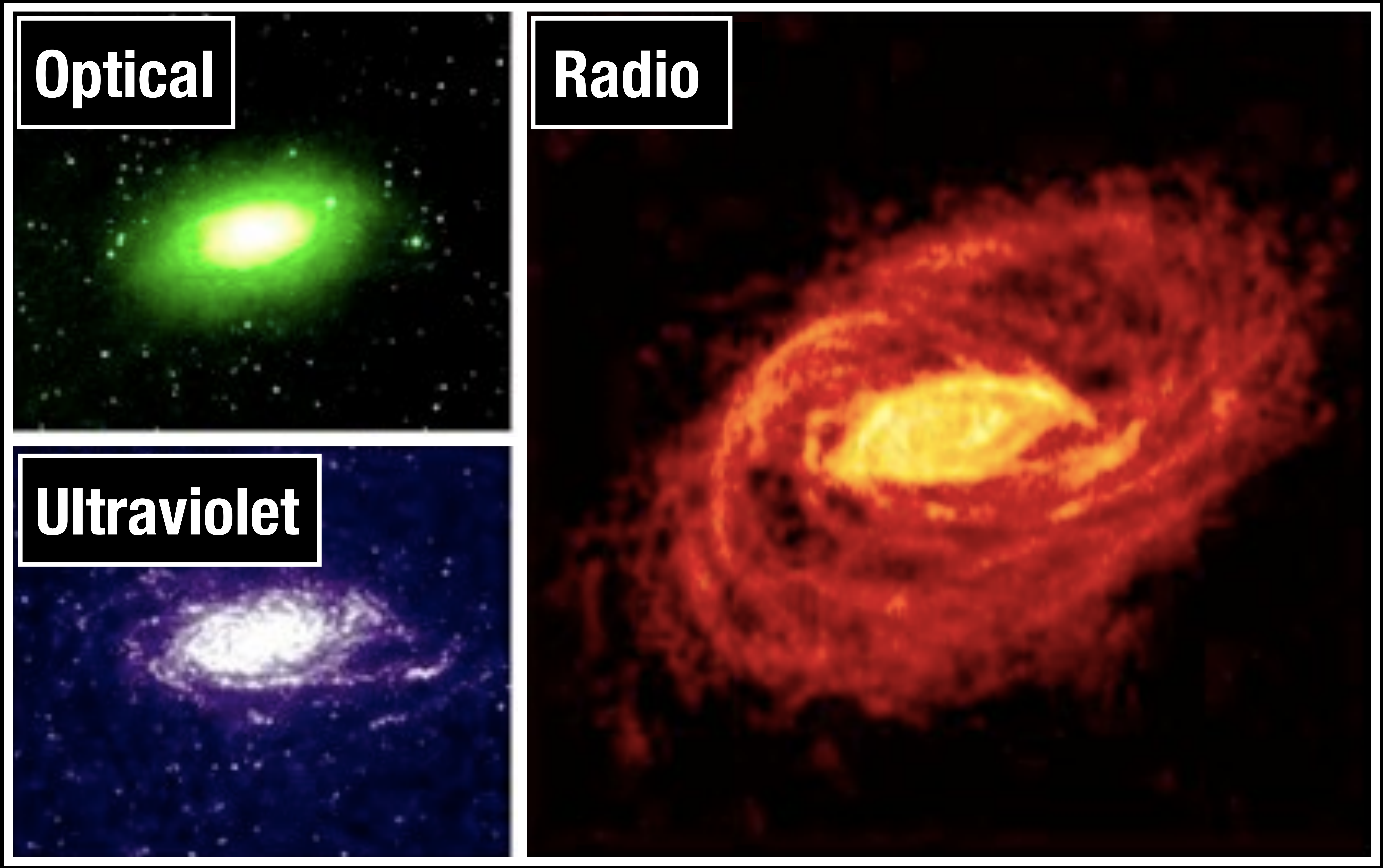
Spiral Galaxy Rotation Curves



(Sparke & Gallagher, p 197)

- Dotted line: CO observations (traces colder molecular gas)
- Points and solid line: H I 21-cm measurements
- Bulge, disk, and gas: deduced from surface-brightness profiles
- Inferred dark halo mass: 2 to 4 times visible mass (in general)

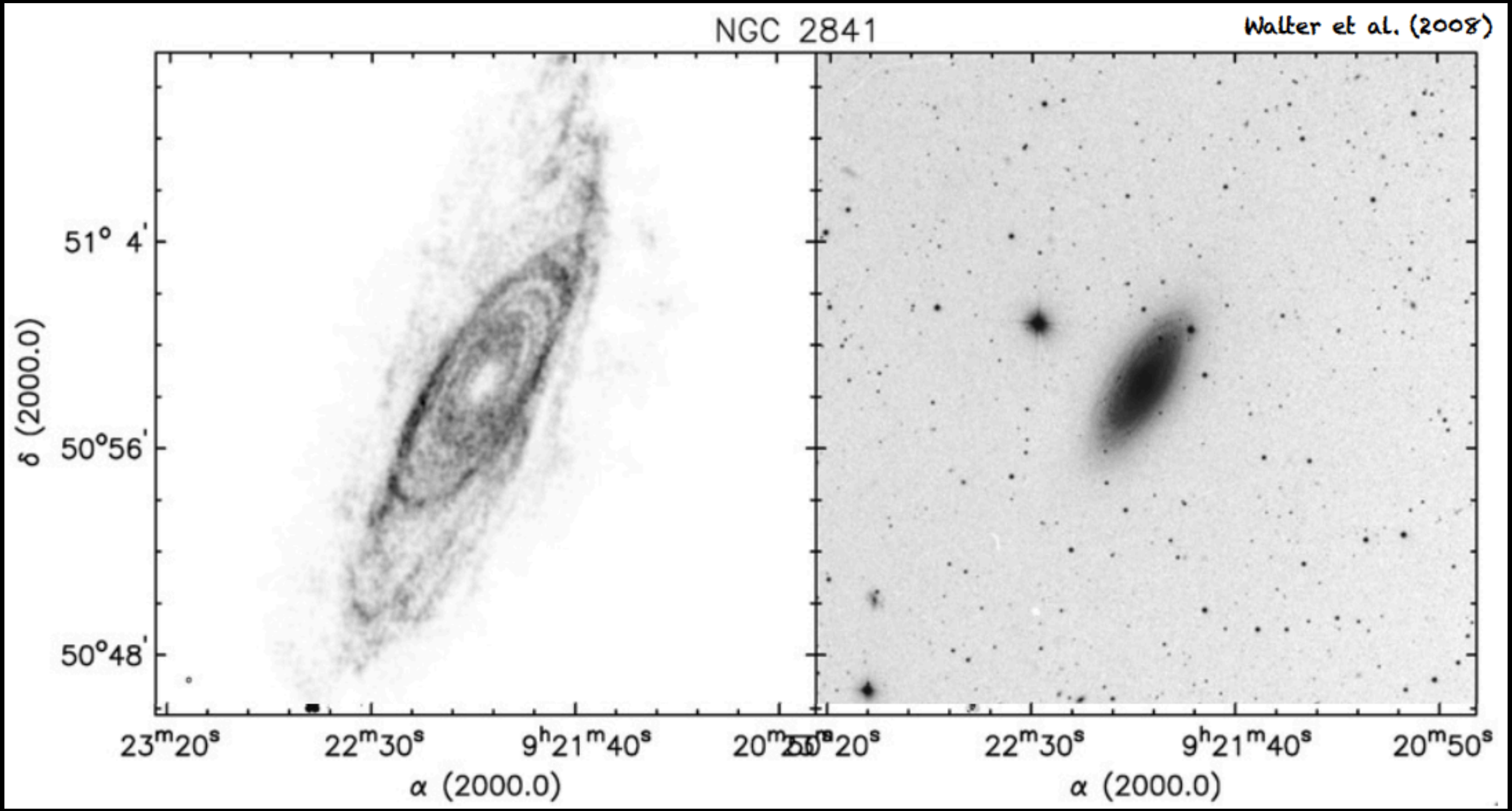
HI 21cm Emission Line



Sancisi et al. 2008, A&A Rv, 15, 189

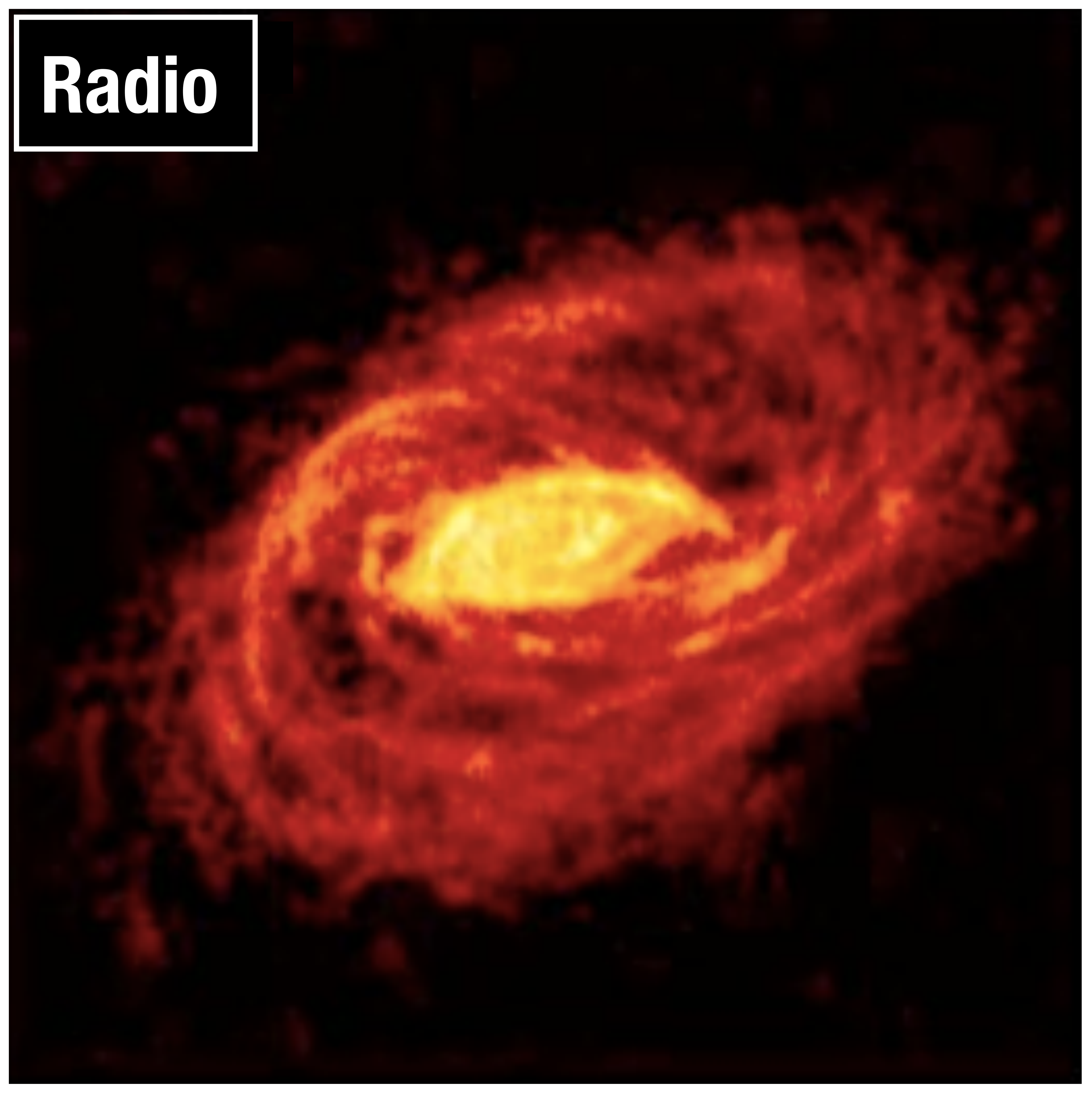
Because HI is so prevalent in gas-dominated galaxies (spirals, mostly), the extent of the 21cm radiation extends much further past the stellar radius (cold gas more abundant than stars)

HI 21cm Emission Line

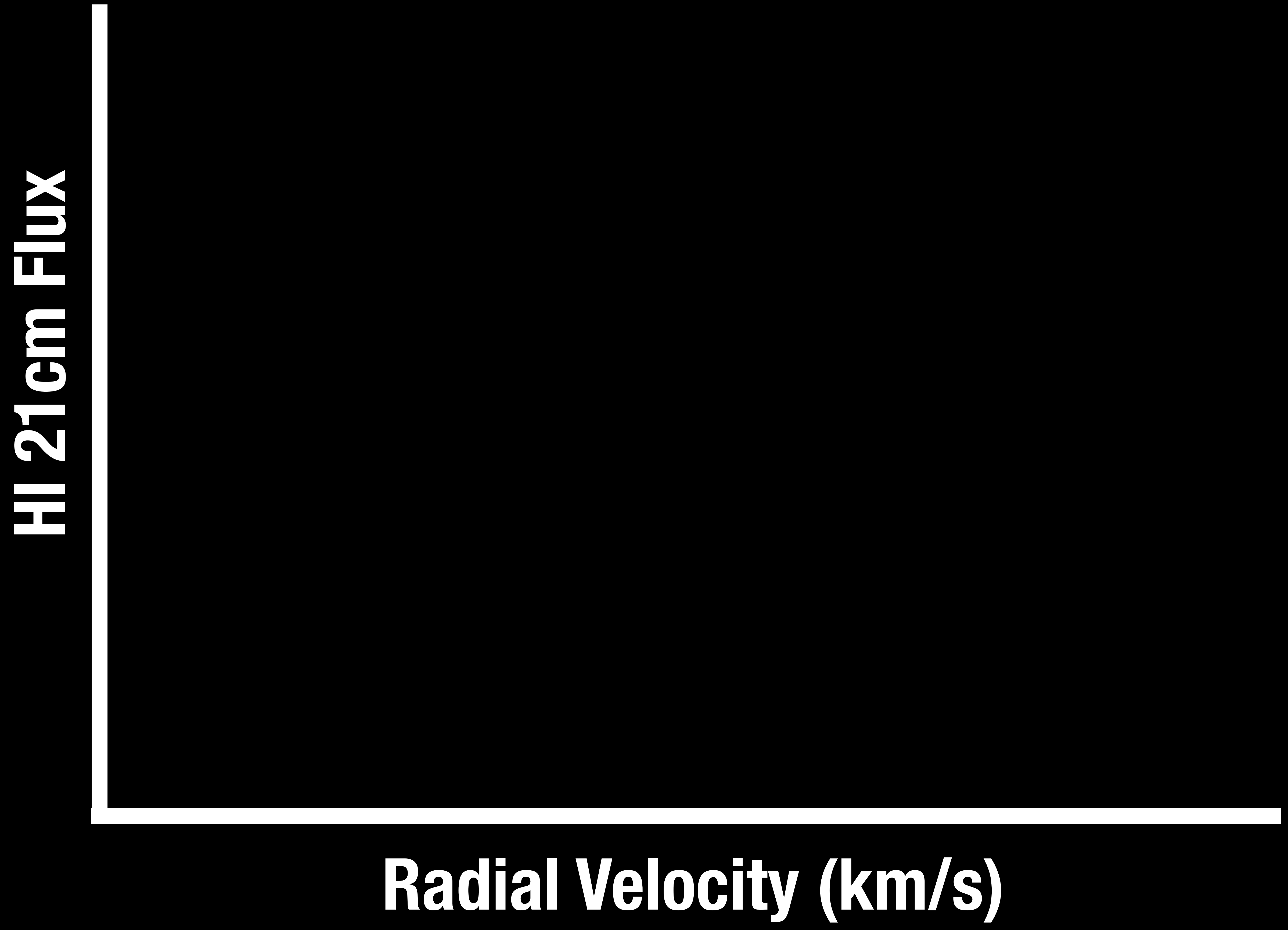


Optical image (right) and HI 21cm emission map (left) of NGC 2841

HI 21cm Emission Line



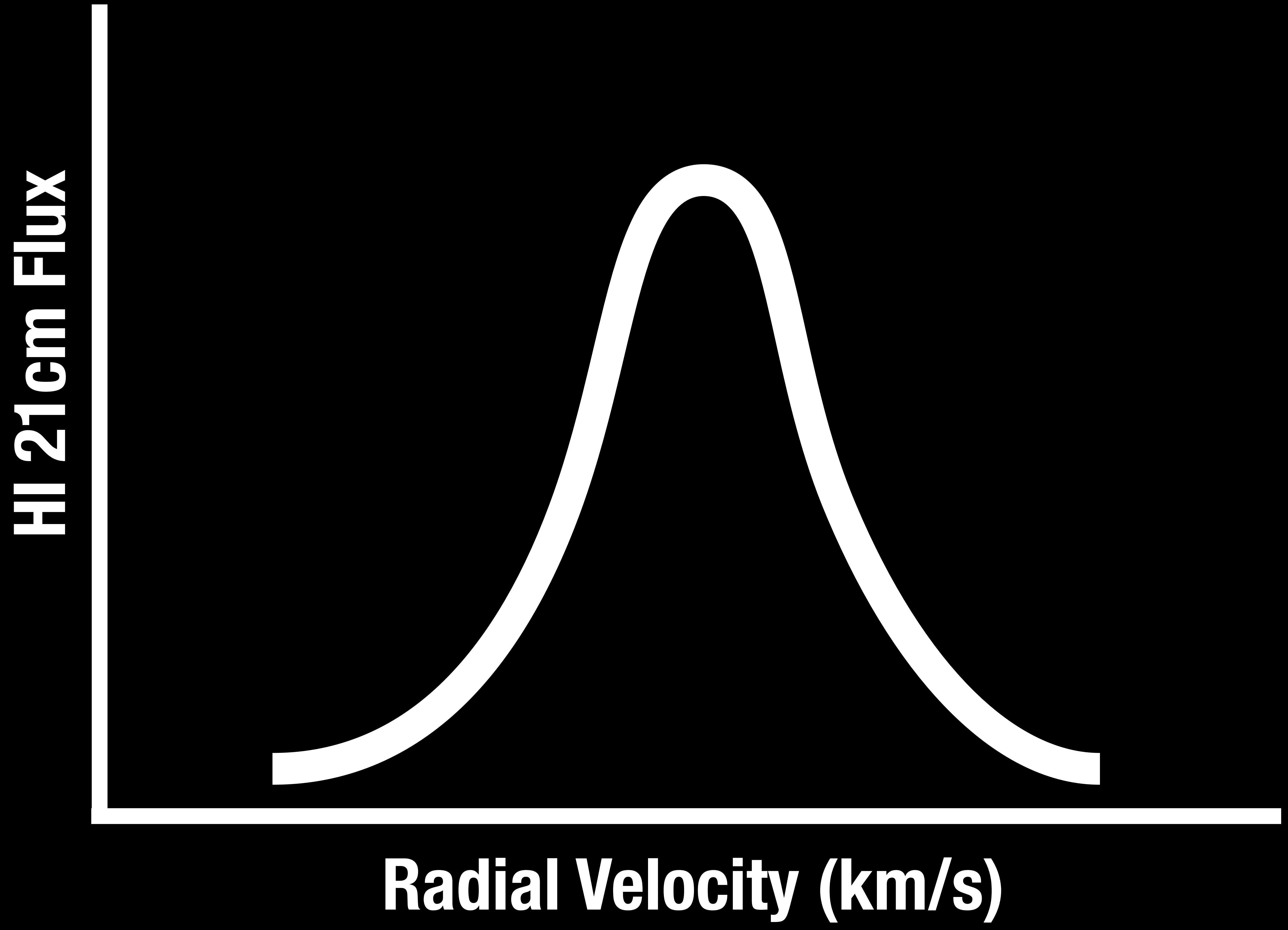
Sancisi et al. 2008, A&A Rv, 15, 189



Integrate 21cm emission over the whole galaxy and plot as a function of radial velocity (or λ)

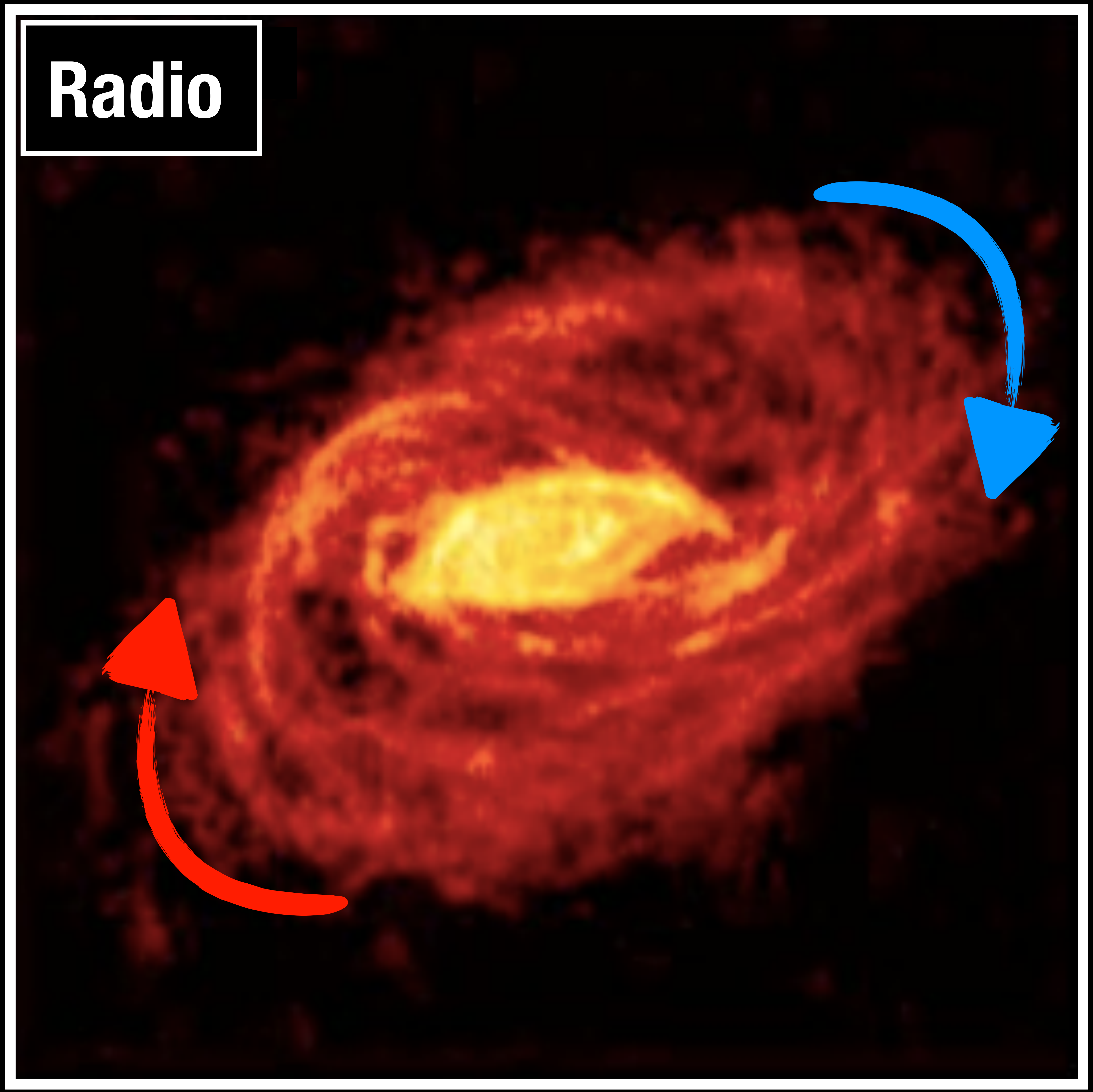
HI 21cm Emission Line

Sancisi et al. 2008, A&A Rv, 15, 189

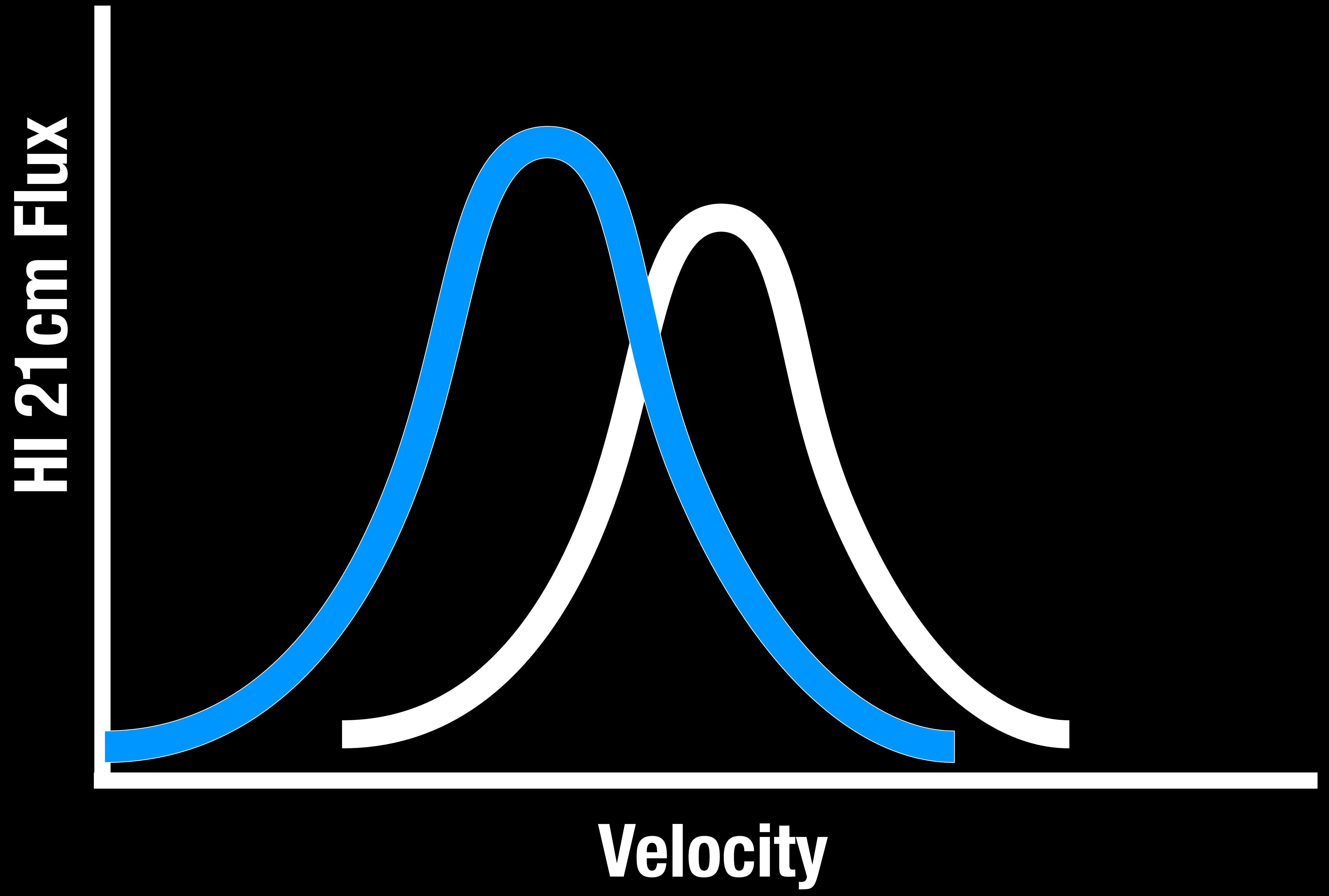


A uniform, non-rotating distribution of gas would yield a Gaussian distribution of flux

HI 21cm Emission Line

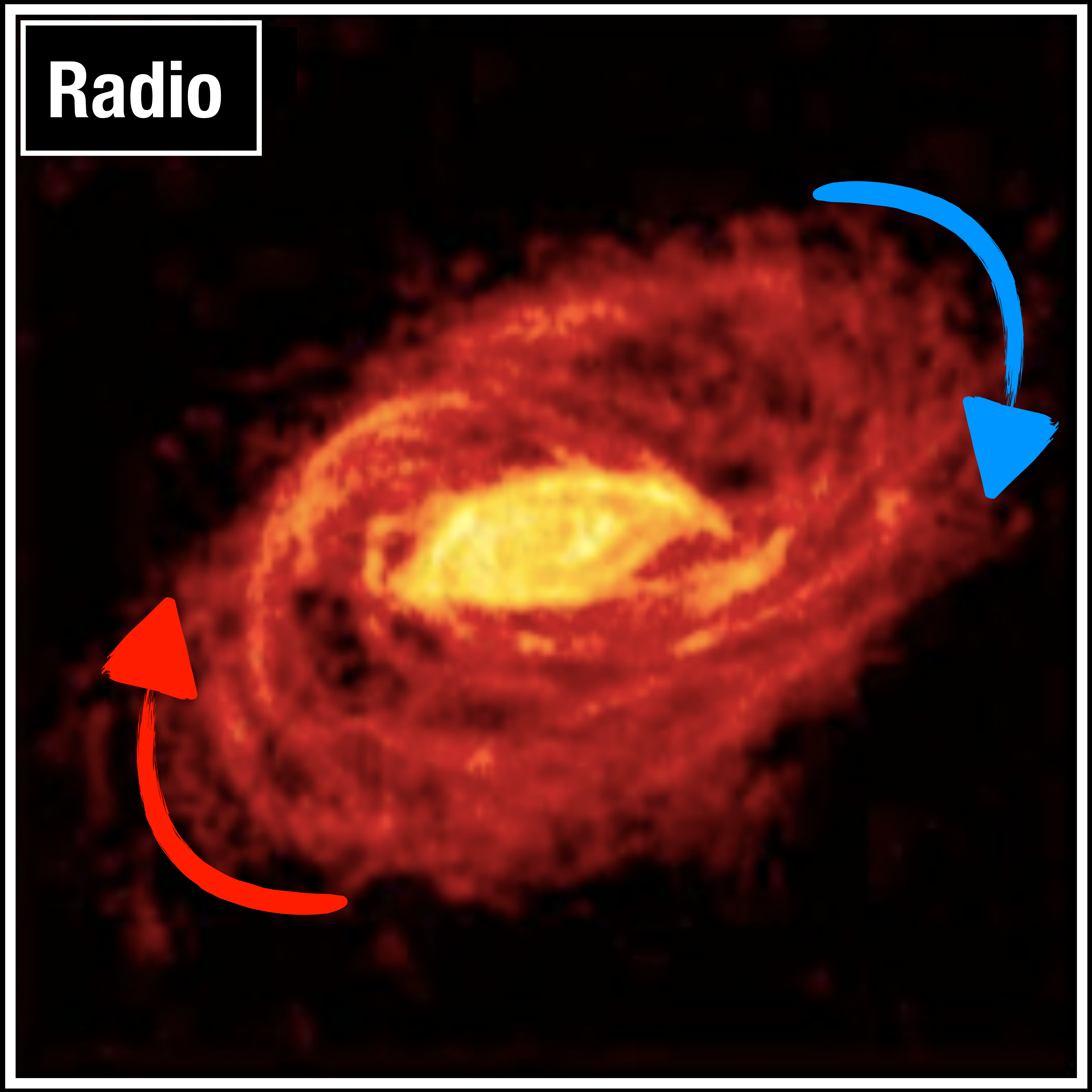


Sancisi et al. 2008, A&A Rv, 15, 189

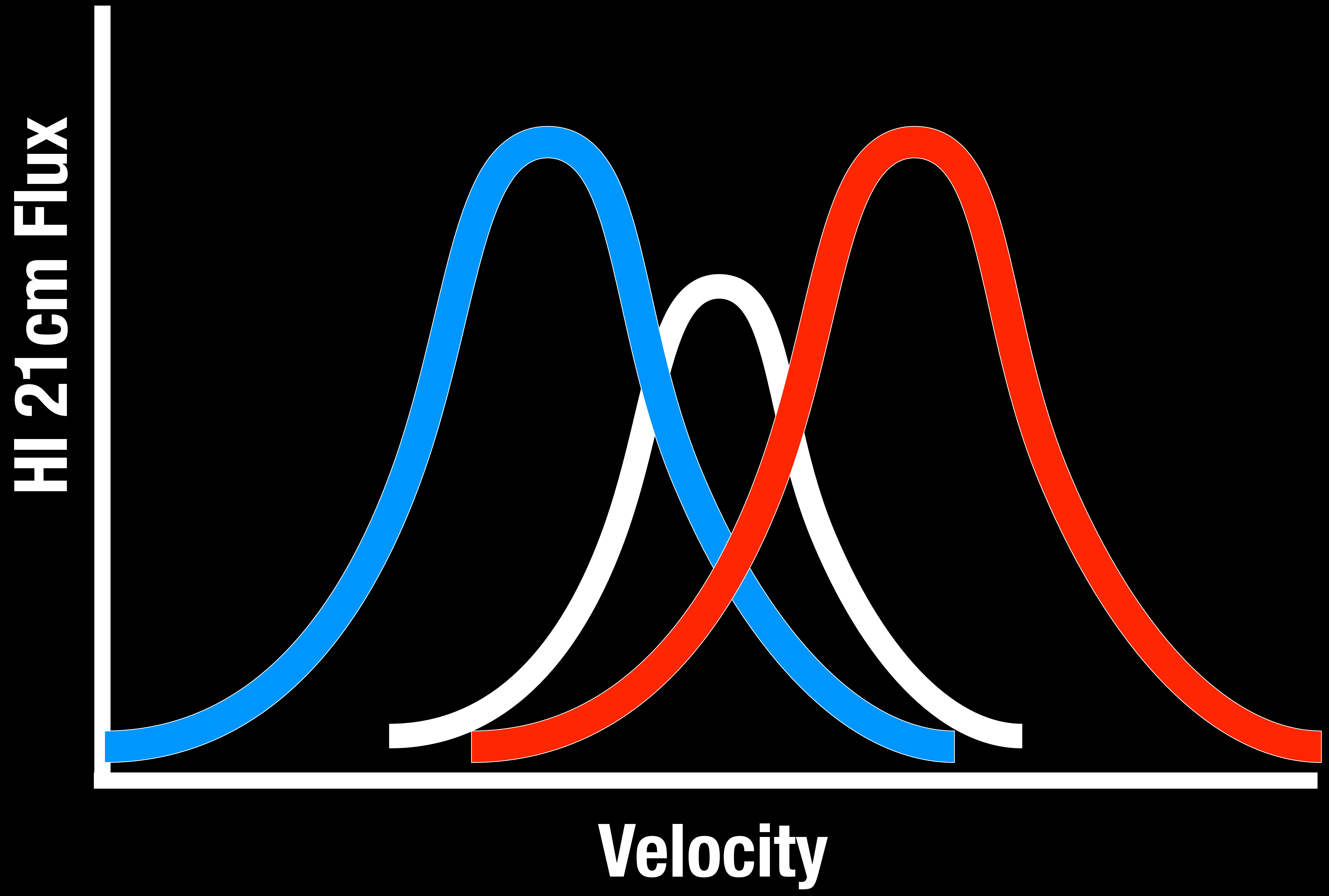


However: every galaxy rotates, so one side is blueshifted (some fraction of flux is shifted to slower velocities)

HI 21cm Emission Line

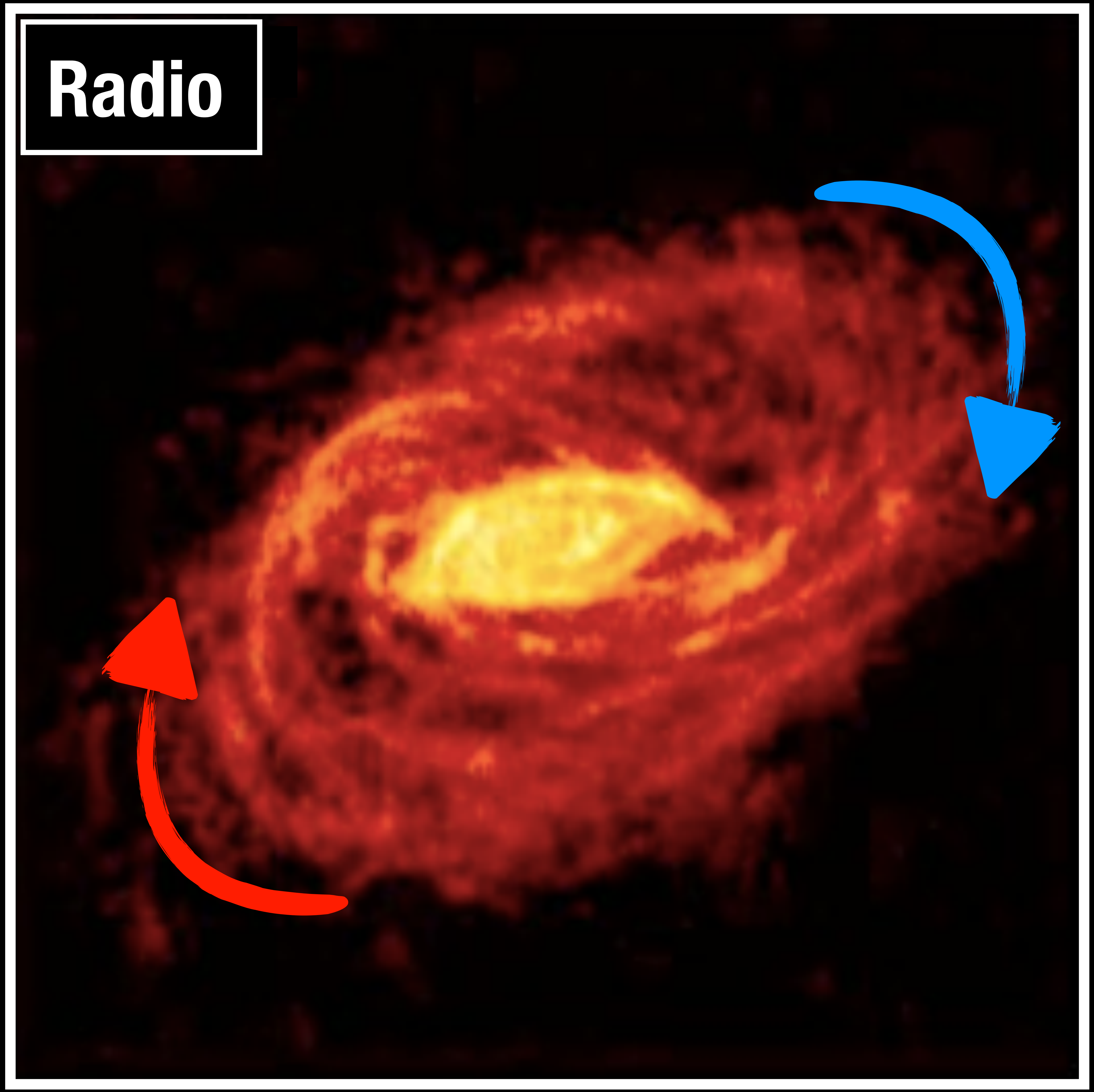


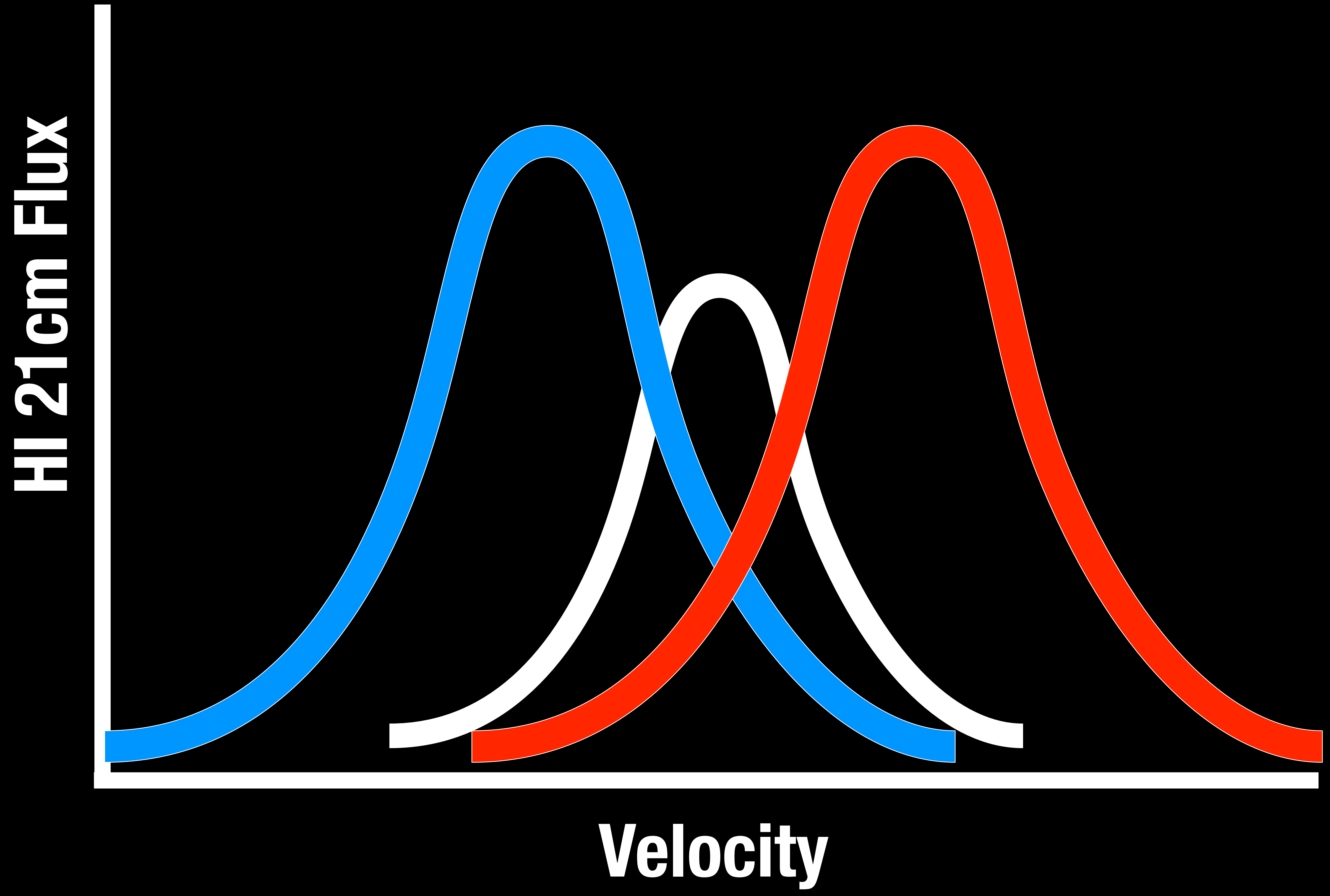
Sancisi et al. 2008, A&A Rv, 15, 189



And one side is redshifted (some fraction of flux is shifted to faster velocities)

HI 21cm Emission Line

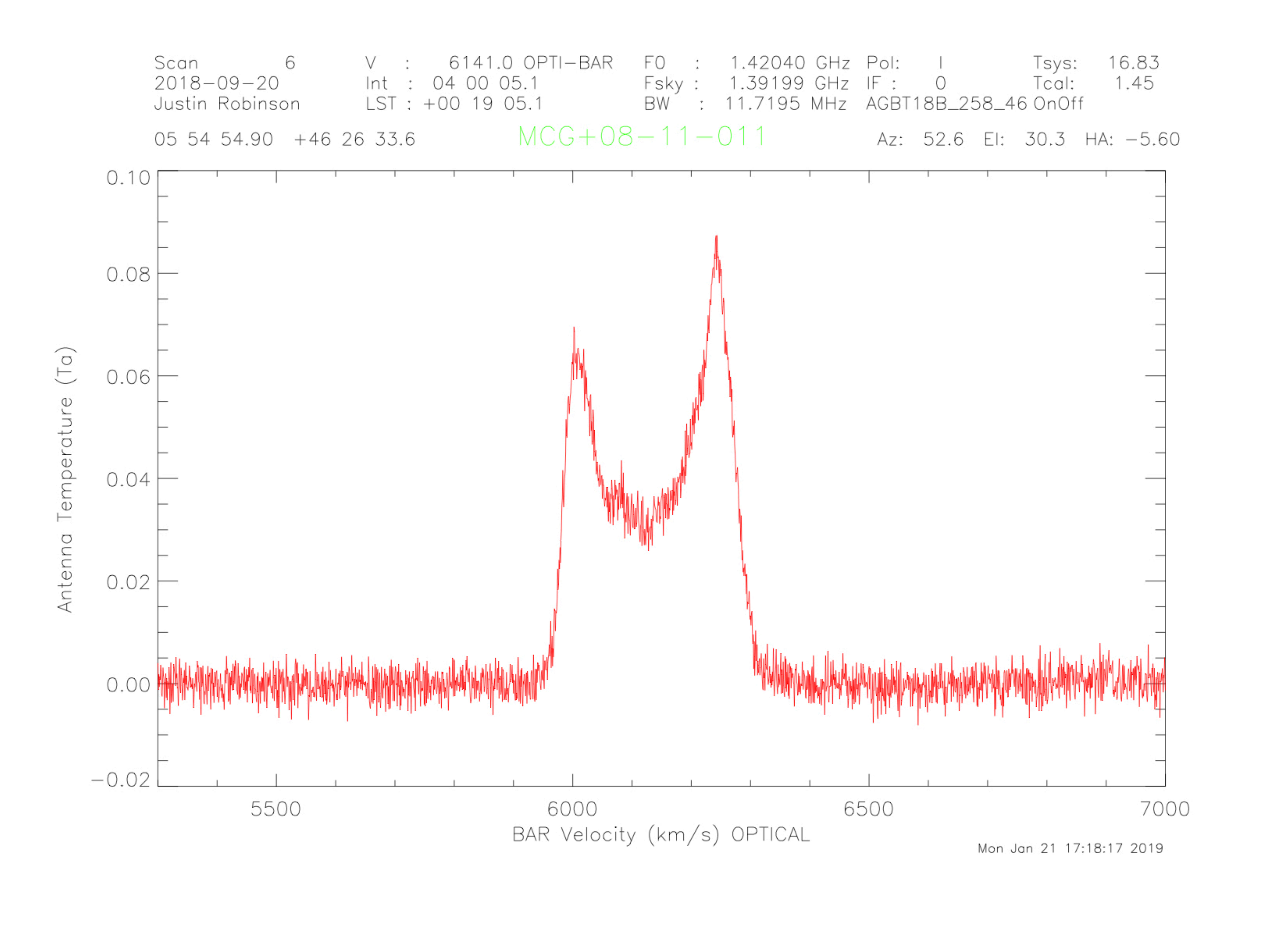




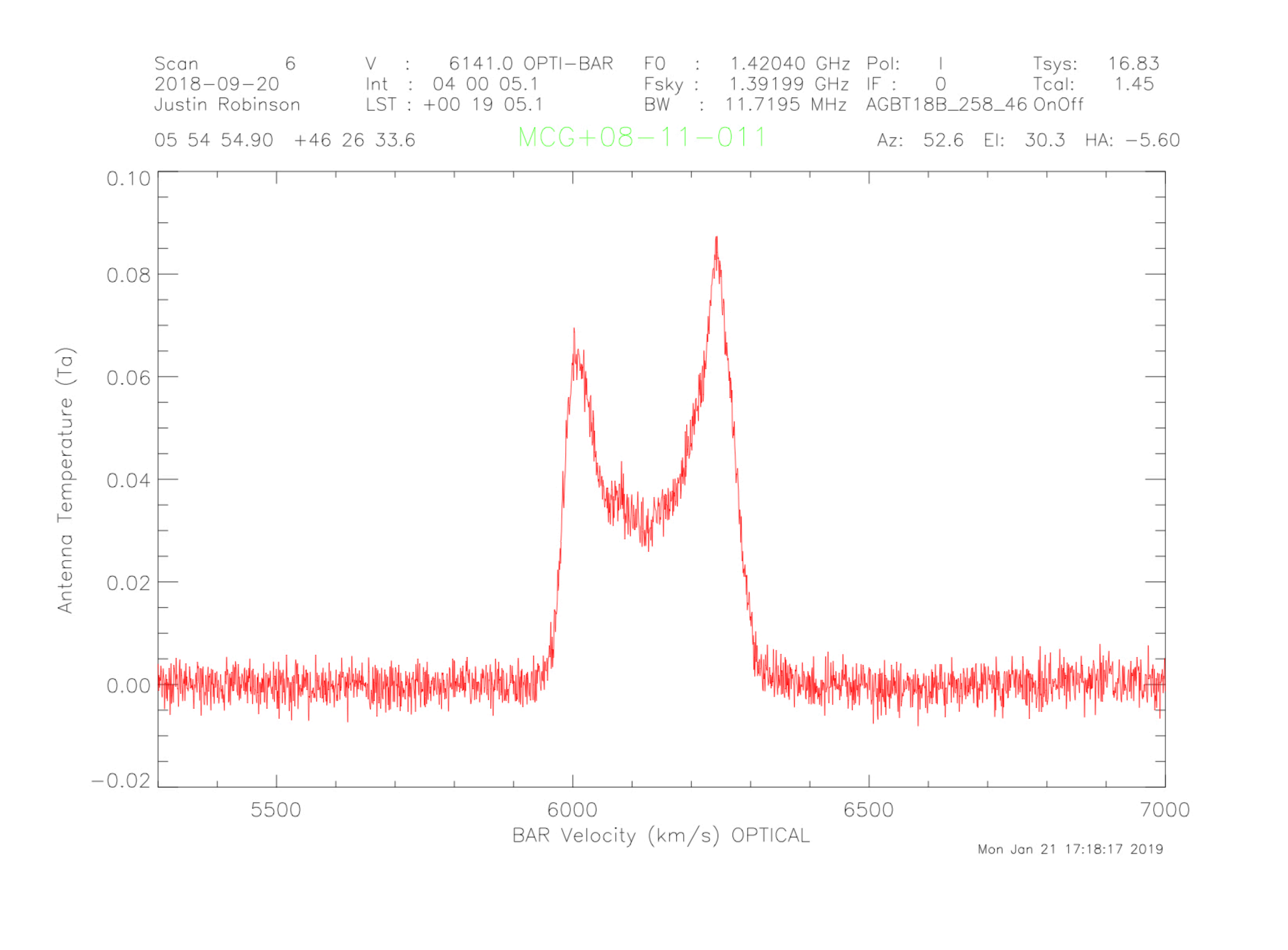
The faster the rotation, the broader the width of the emission line becomes

Sancisi et al. 2008, A&A Rv, 15, 189

HI 21cm Emission Line



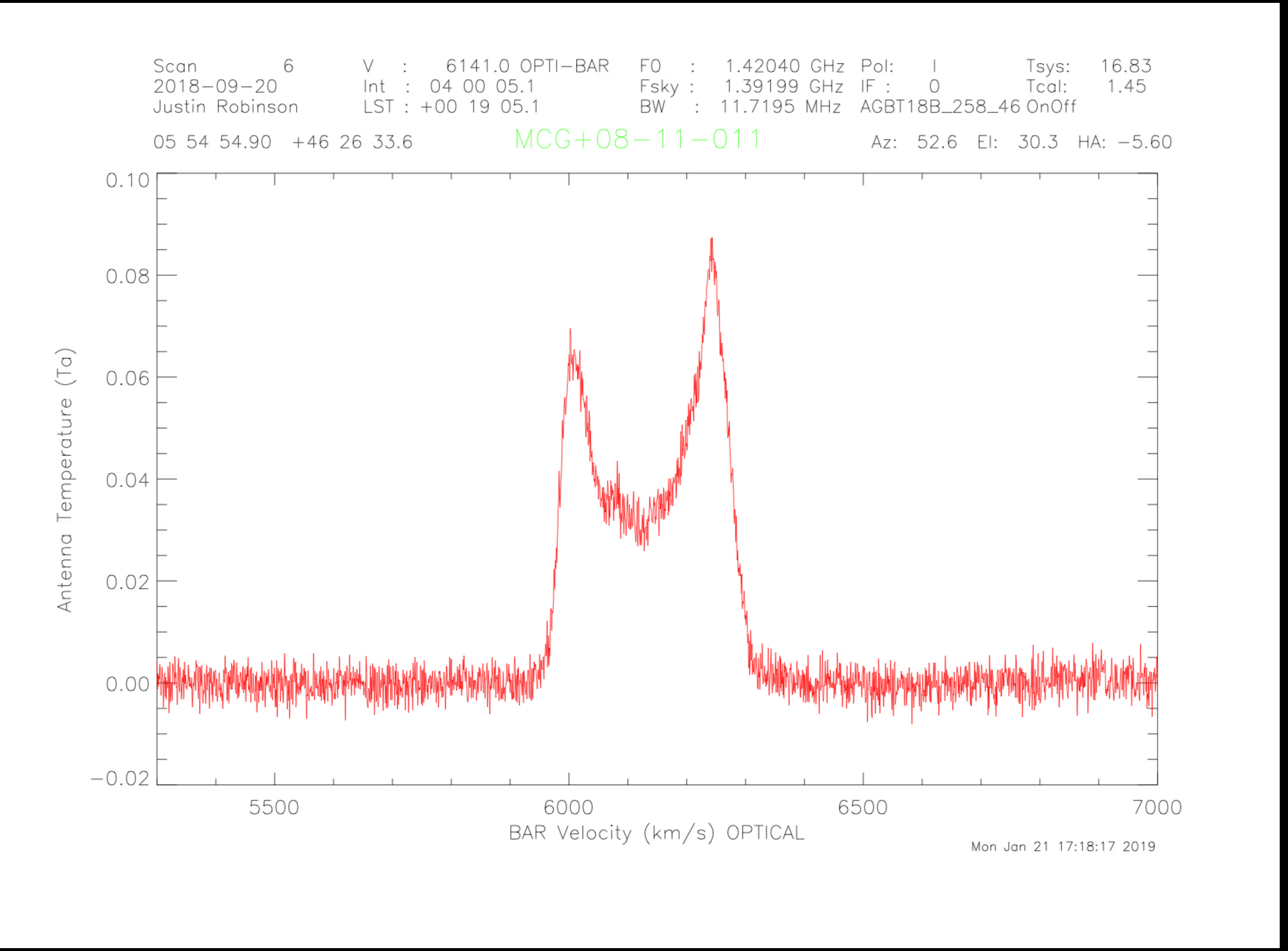
HI 21cm Emission Line



One of the most important uses of the 21cm line is redshift measurement

Theoretically, any emission line from another galaxy can be used to measure redshift. Why would the 21cm line provide a more accurate measurement?

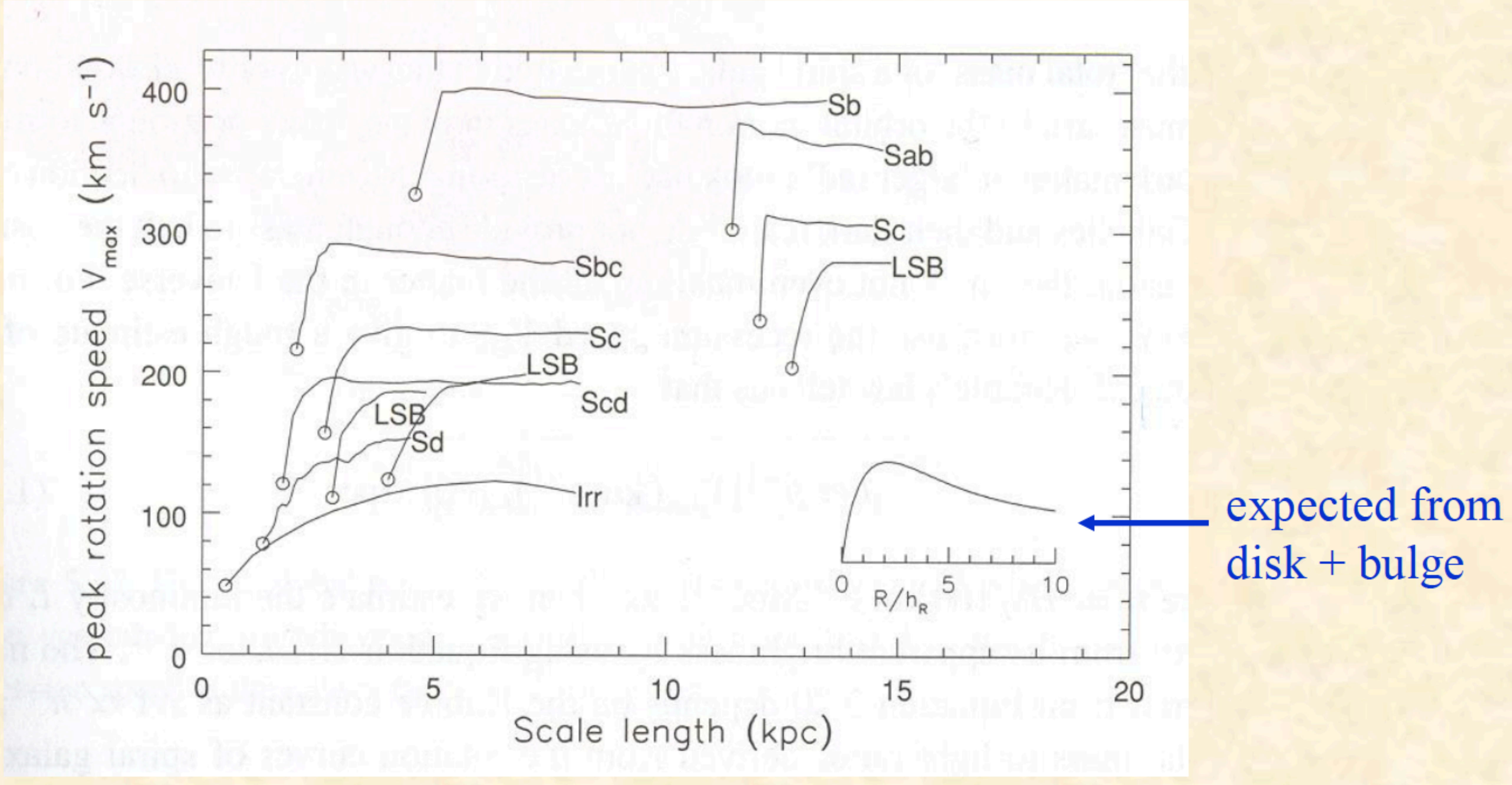
HI 21cm Emission Line



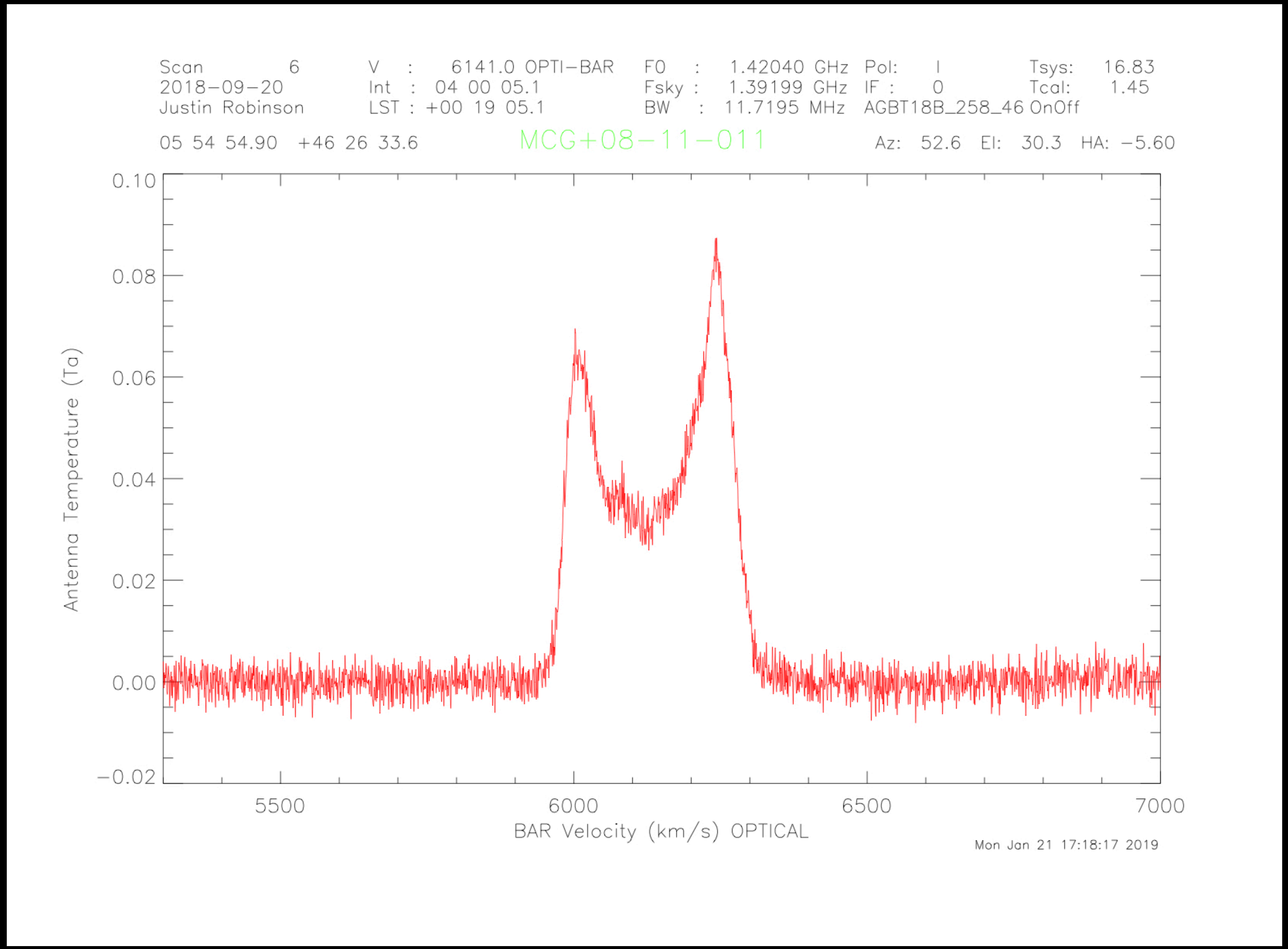
-> HI is cold, thus only moved by galaxy rotation. Other lines (like the H Balmer series, [O III]) are in significantly warmer environments

Warm environments (like star-forming regions) can induce internal motions of gas, which directly effects redshift (something is making the gas move other than the motion of the galaxy)

Spiral Galaxy Rotation Curves

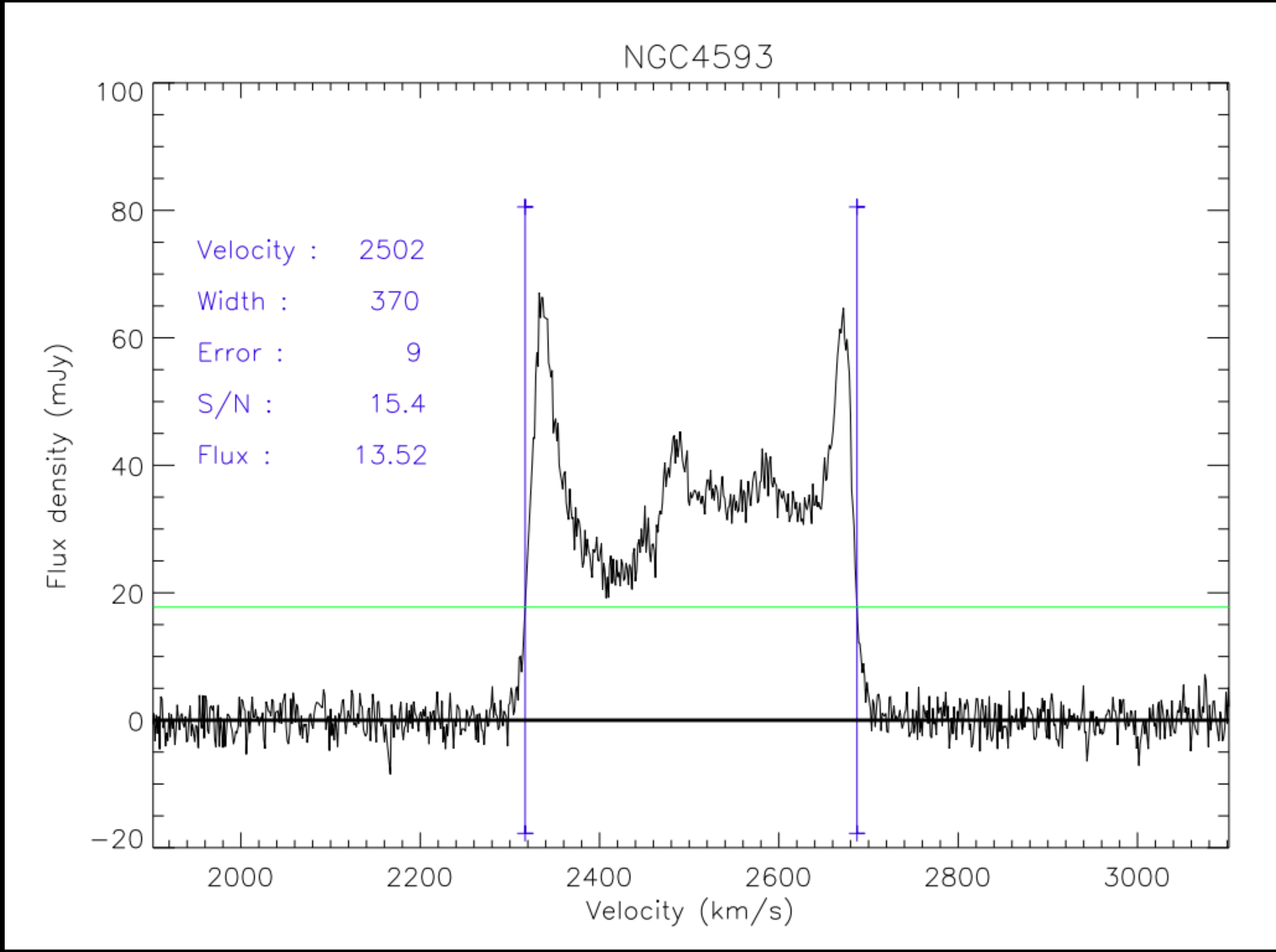


(Sparke & Gallagher, p. 218)



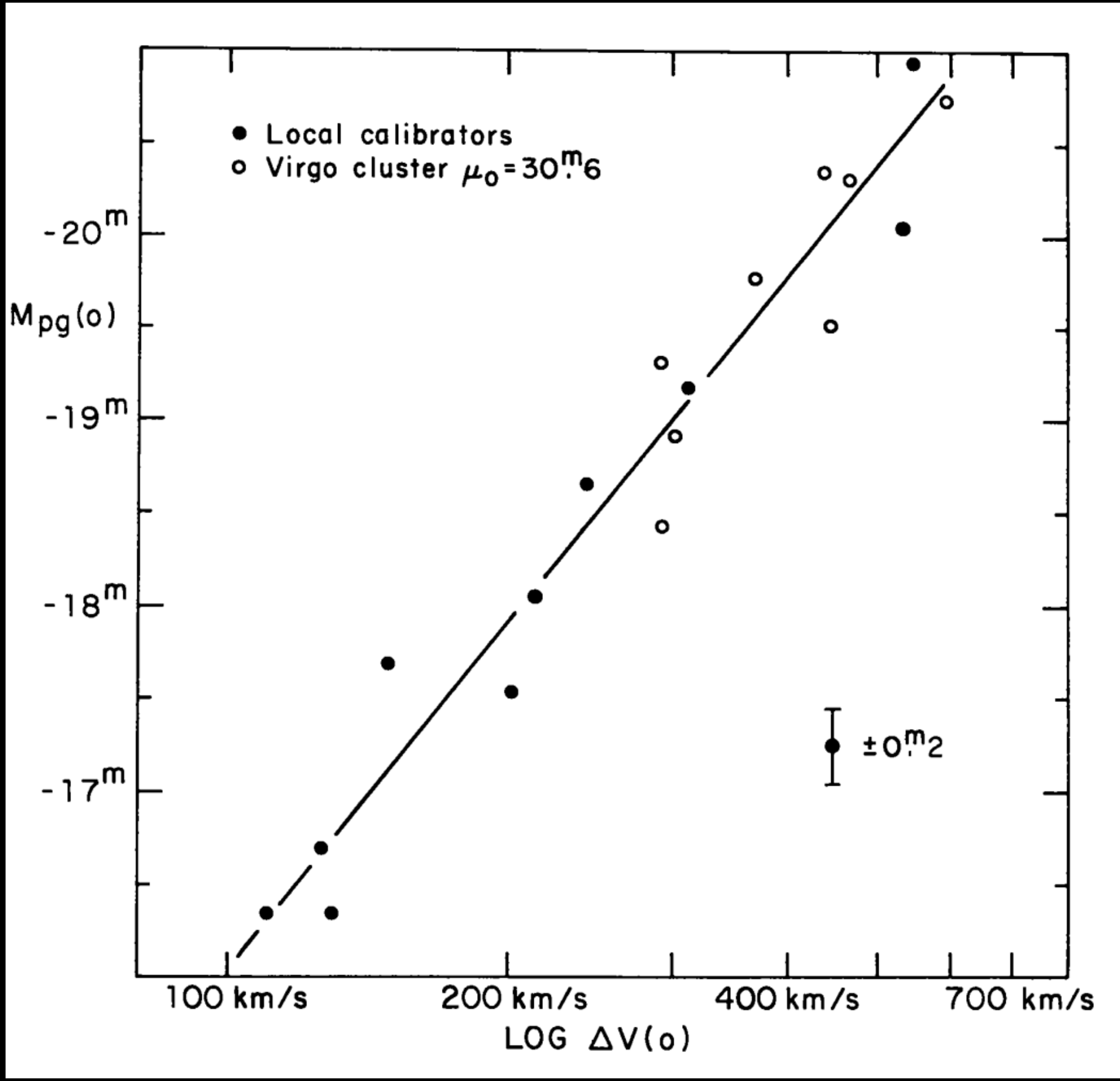
- Larger disk galaxies rotate faster
- Early types tend to rise more steeply
- Flat rotation curves: evidence for dark halos in disk galaxies
- Rotation curves not possible for more distant spirals, have to use unresolved HI 21cm emission line to trace rotational velocity (from width of emission line and inclination)

Spiral Galaxy Rotation Curves



- Green horizontal line between blue vertical lines: W
- V_{max} = 1/2 W/sin(i)

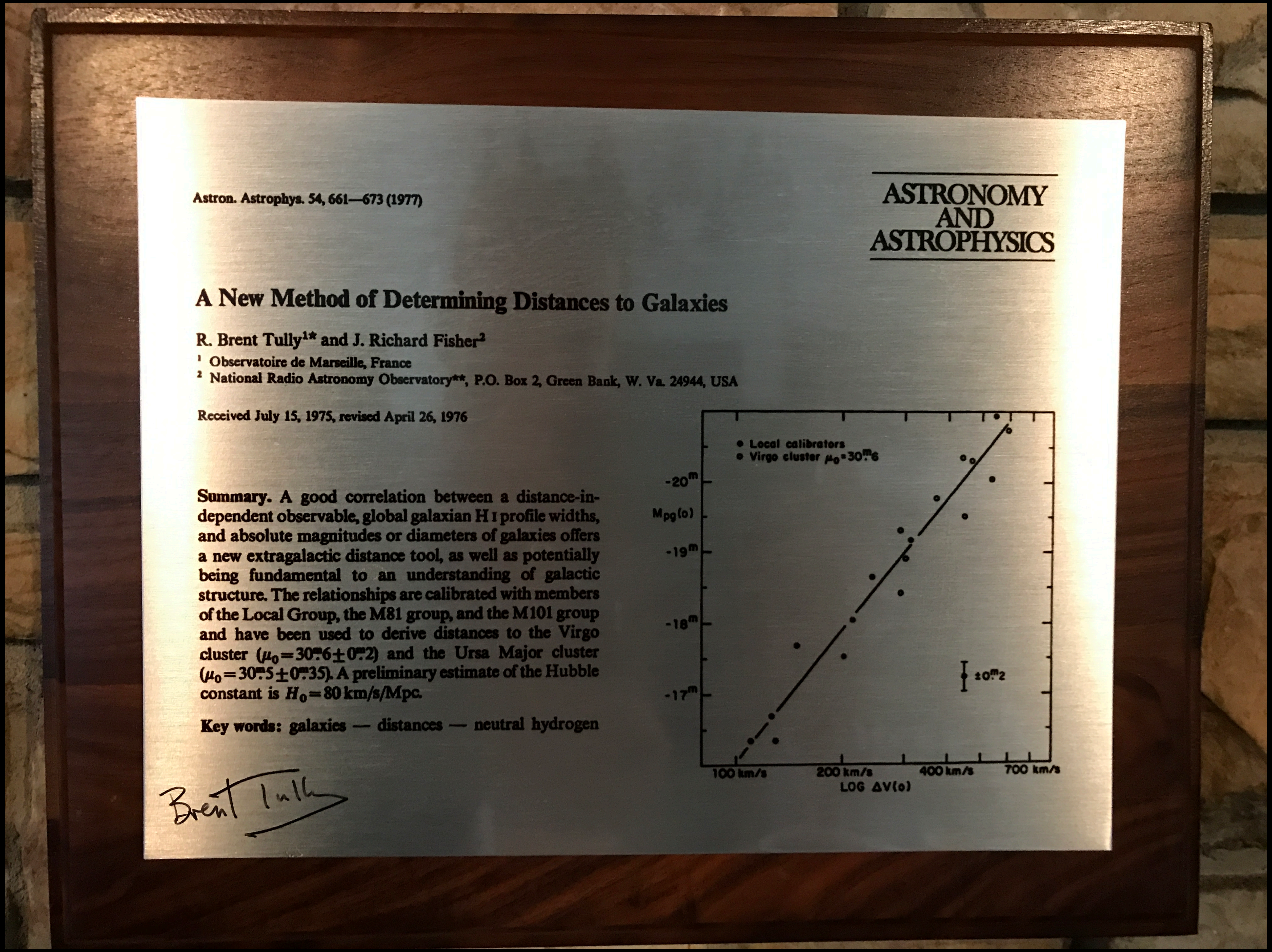
The Tully-Fisher Relation



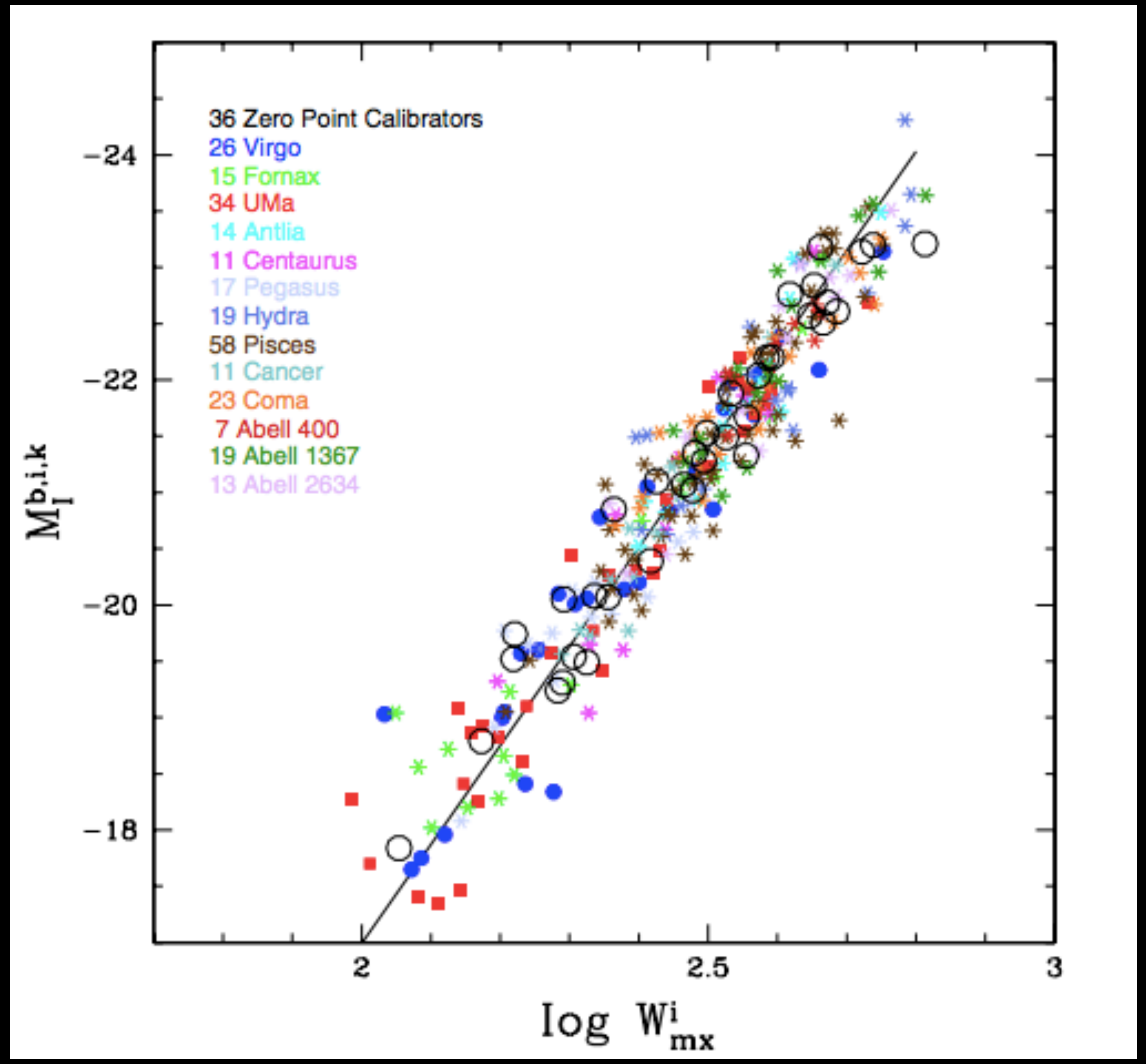
(Tully & Fisher 1977, A&A, 54, 661)

By measuring rotation of spiral galaxies with known distances (from Cepheids), Tully & Fisher discovered that rotation rate (here ΔV) and M were related

The Tully-Fisher Relation

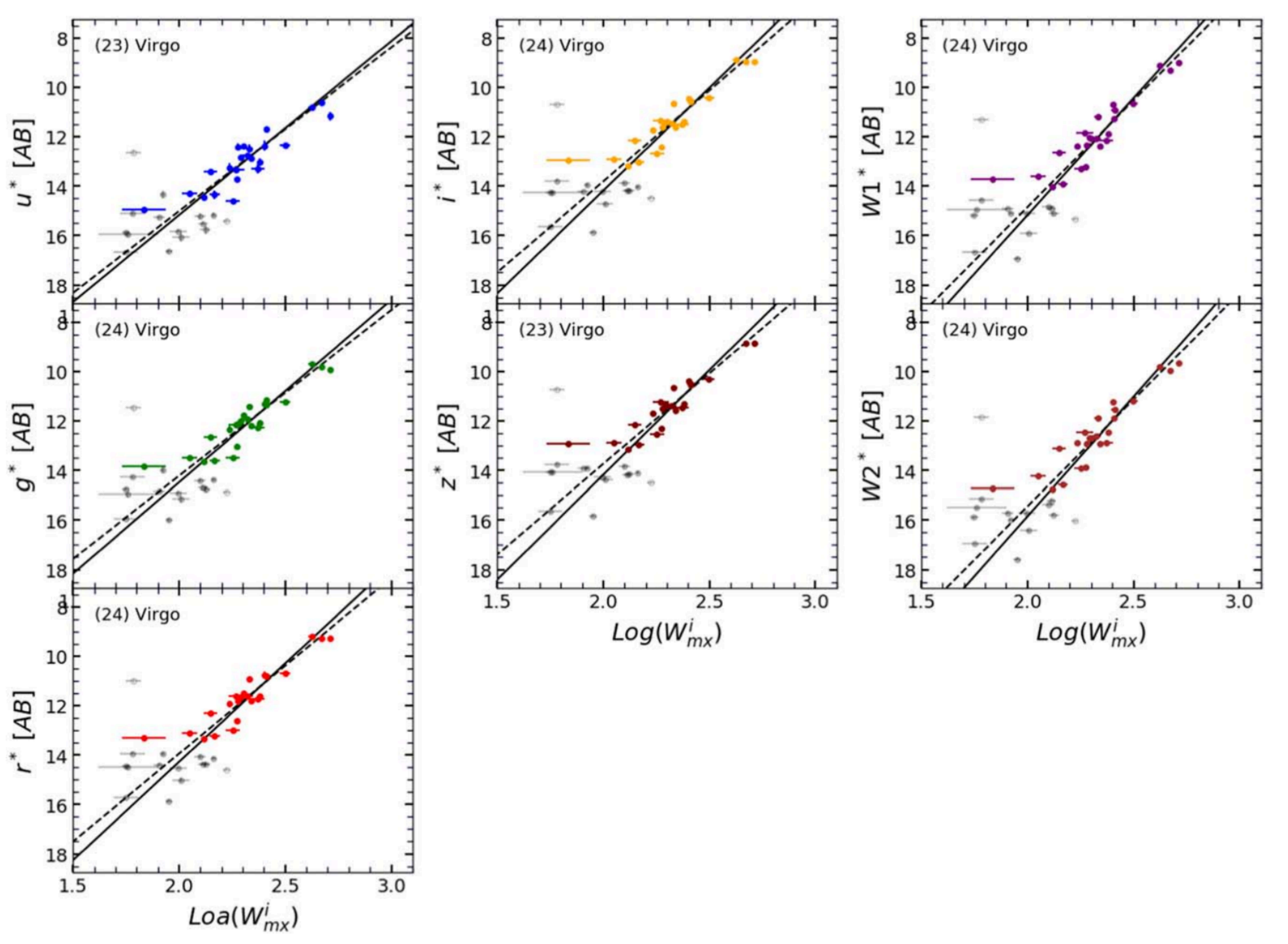


The Tully-Fisher Relation



(Tully & Courtois 2012, ApJ, 749, 78)

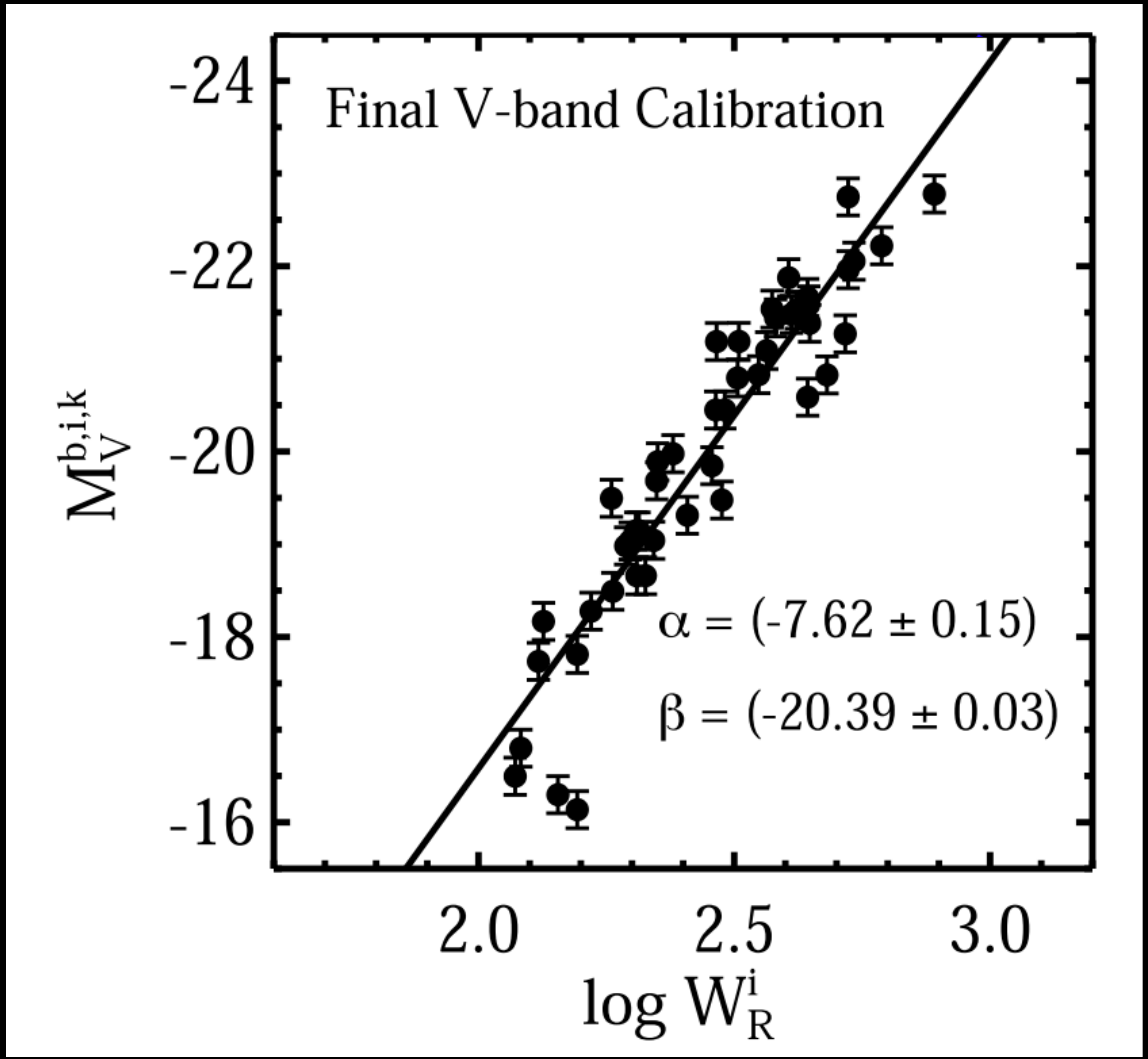
(Kourkchi et al. 2020, ApJ, 896, 3)



The Tully-Fisher Relation has been calibrated for most filters, including B, R, I (top image), and lots of infrared filters (bottom image)

For a while, the V filter (middle of the optical) calibration was missing…

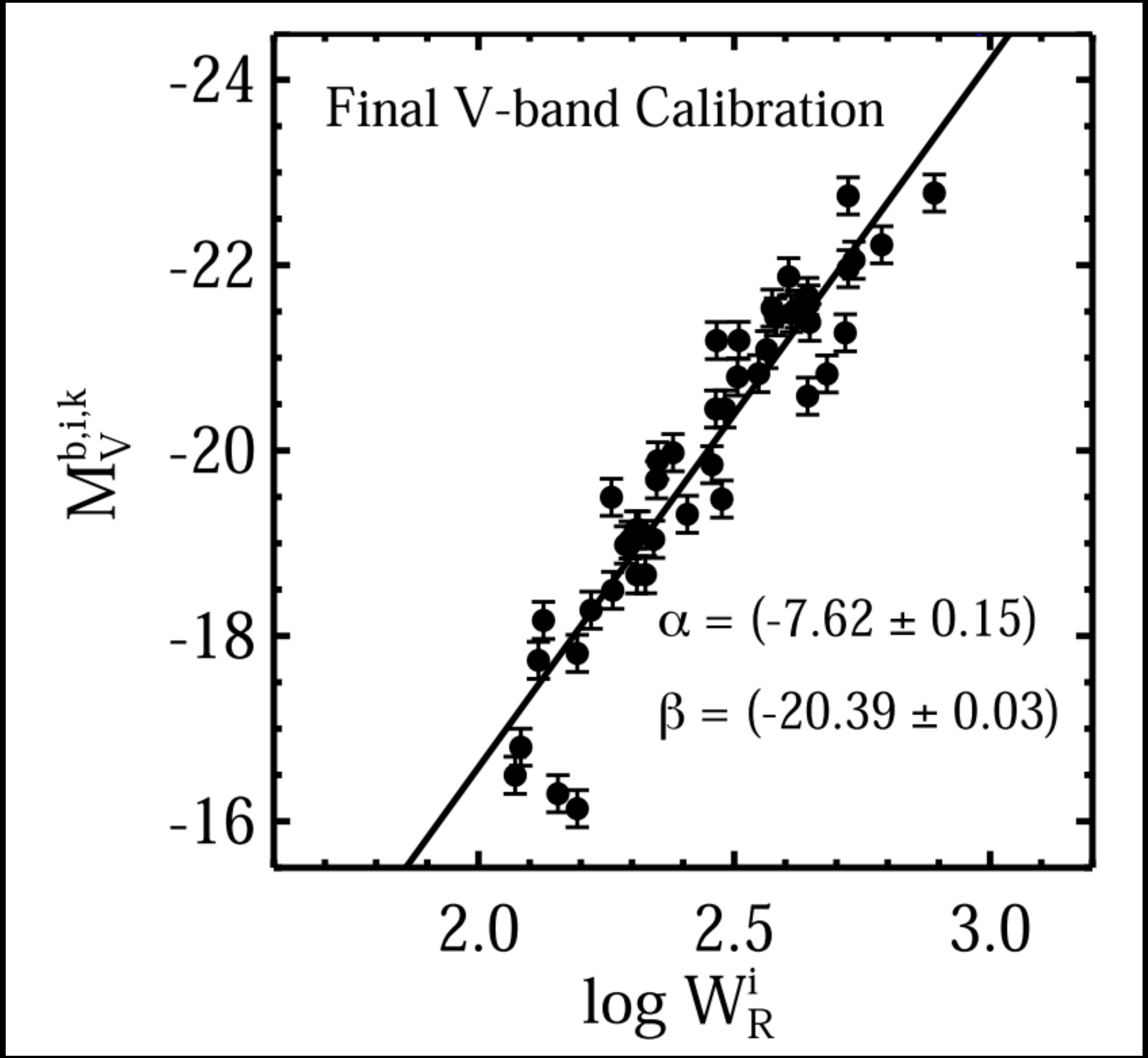
The Tully-Fisher Relation



(Robinson et al. 2021, ApJ, 912, 160)

So I calibrated the relationship for the V filter :)

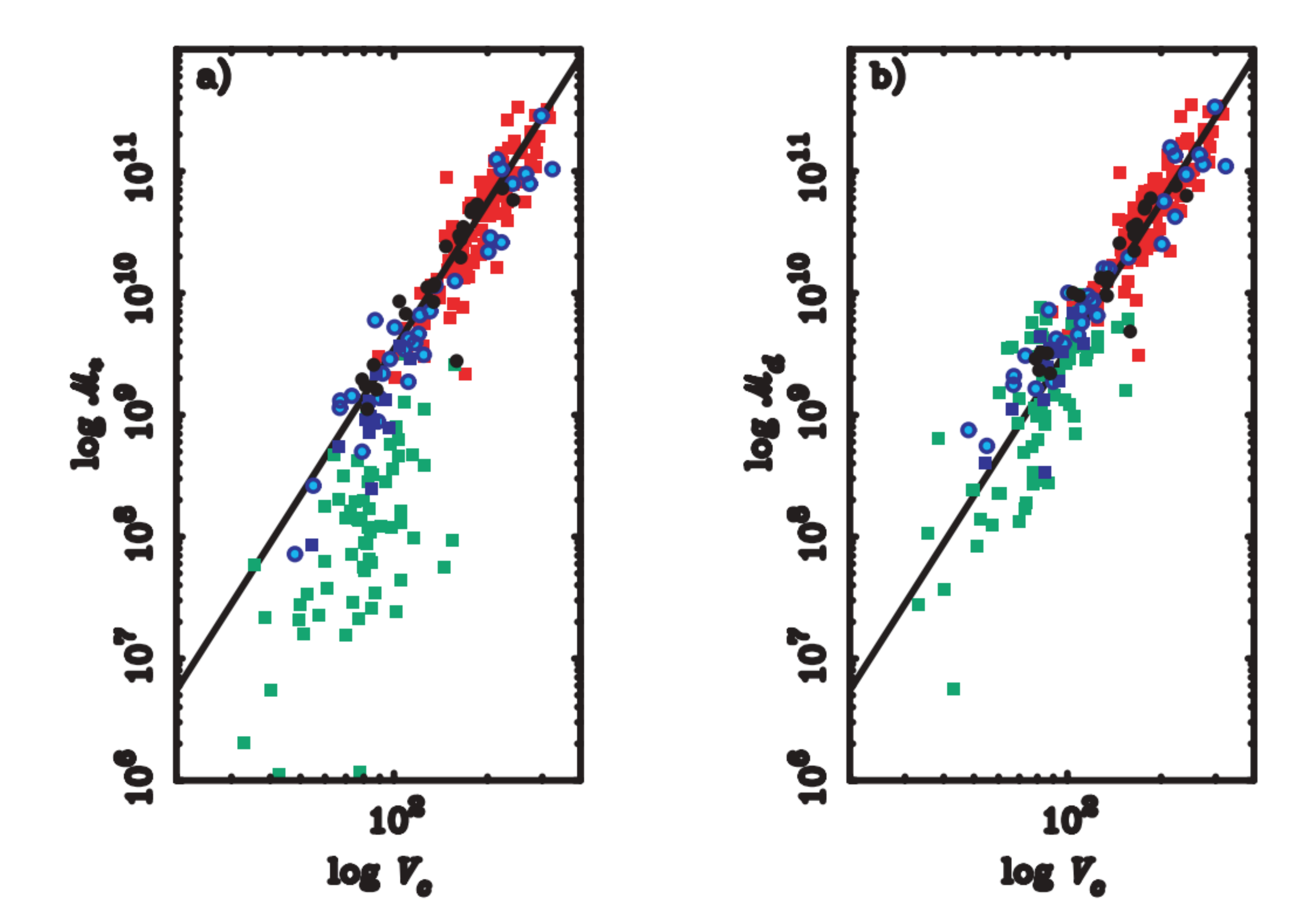
The Tully-Fisher Relation



(Robinson et al. 2021, ApJ, 912, 160)

- The TF relation effectively uses stellar light (absolute magnitude) as a mass tracer (more massive galaxies rotate faster)
- Earlier observations used the brightest galaxies -> much higher stellar mass than gas mass

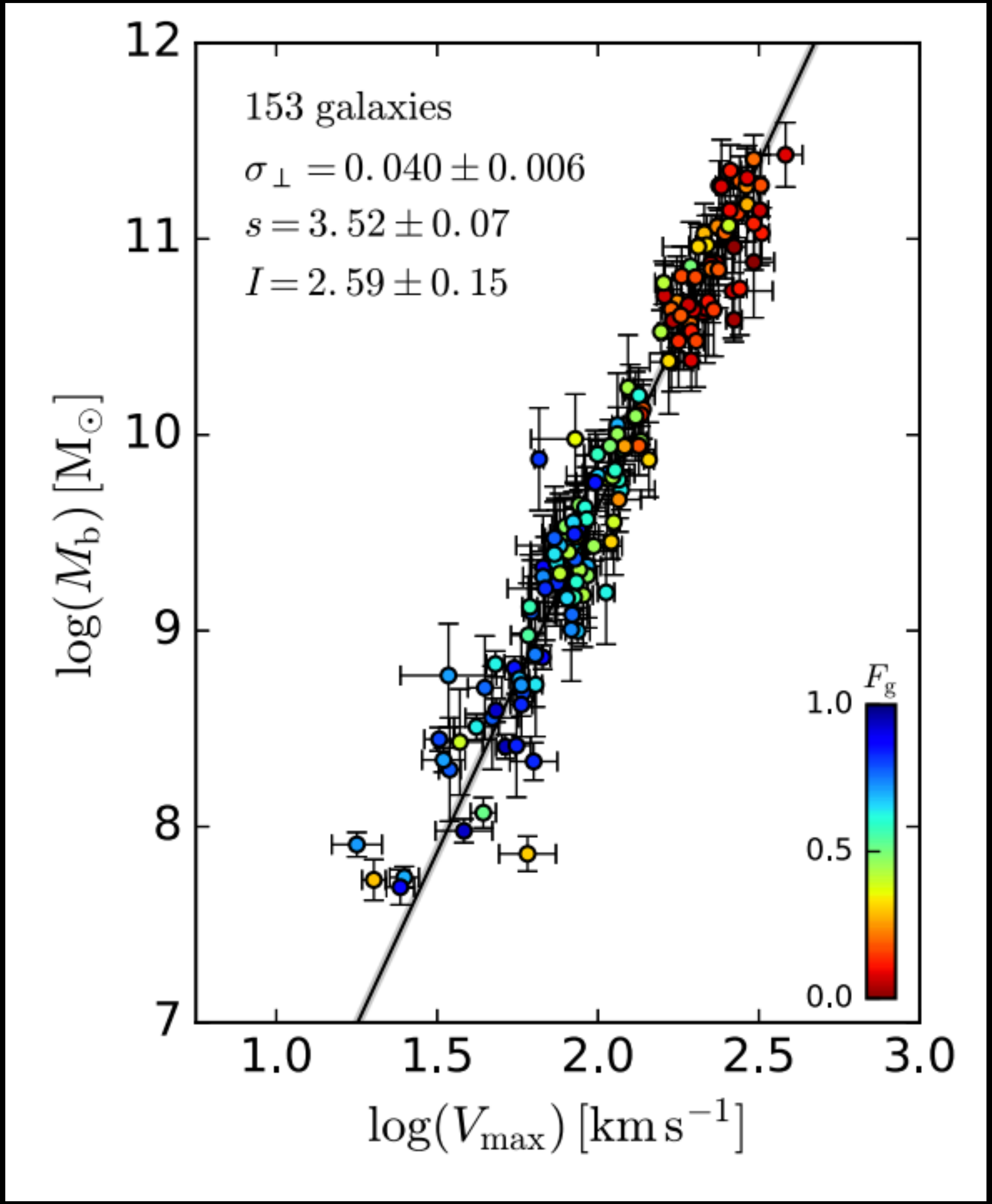
The Baryonic Tully-Fisher Relation



Left: stellar mass ; Right: baryonic mass
(McGaugh et al. 2000, ApJ, 533, L99)

- For systems of lower stellar mass, gas mass begins to dominate (later-type spirals)
- More fundamental form of TF: the Baryonic Tully-Fisher (BTF) Relation
- Gas + Stars (baryonic matter) as a function of maximum rotational velocity

The Baryonic Tully-Fisher Relation



- Considered the "true" form of the TF relation, one of the most tightly-correlated relations in astrophysics

(Lelli et al. 2019, MNRAS, 484, 3267)