Tully Fisher Relation

TULLY-FISHER relationship

Total luminosity of a galaxy is correlated to its rotational velocity

$$L \propto V_c^{\alpha} \quad \text{with } \alpha \sim 4$$

Q Does this sound reasonable? Why or why not?

If it applies generally & ~~as~~ it has ~~have~~ a physical basis, it will be very useful as a distance indicator to galaxies.

Let's try to explain physics behind it

Newtonian gravity : $V^2 \propto \frac{GM}{R}$

so $M \propto R V^2$

Assume mass-to-light ratio for whole galaxy

$$M = L \times \frac{M}{L}$$

Surface brightness $= \frac{\text{flux}}{\text{area}} =$

$$I = \frac{L}{R^2}$$

so $R = \sqrt{\frac{L}{I}}$

L — total luminosity

I — surface brightness

$$\text{So } M \propto RV^2 \propto L \times \left(\frac{M}{L}\right)$$

$$\sqrt{\frac{L}{I}}\, V^2 \propto L \times \left(\frac{M}{L}\right)$$

$$\text{so } L \propto \frac{V^4}{I\left(\frac{M}{L}\right)^2}$$

So if surface brightness $\times \left(\frac{M}{L}\right)^2$ is constant, this works.

But we dont have any idea why ....

But this must be telling us something about how disk galaxies form

Tully-Fisher Relation
Tully & Fisher (1977)

A relation between the luminosity of rotating disk galaxies and their line-width.

Widely used as a distance indicator; also constrains galaxy formation physics.

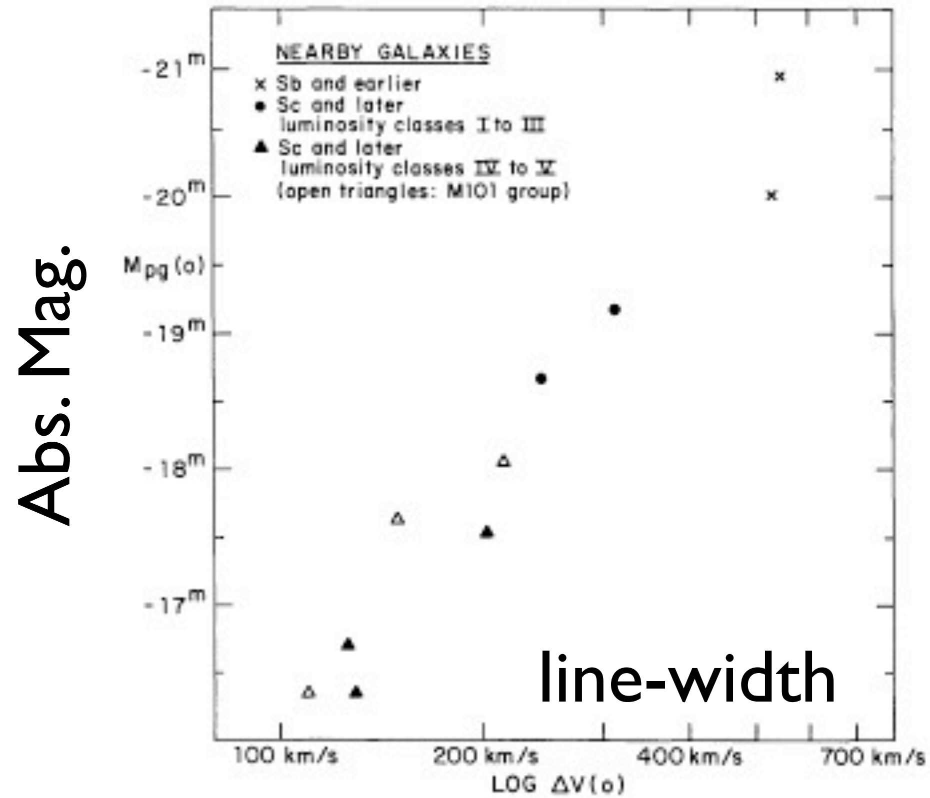
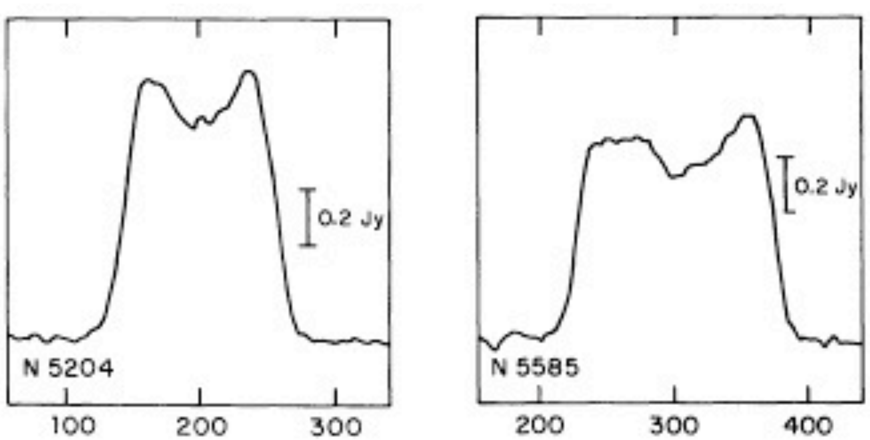


Fig. 1. Absolute magnitude – global profile width relation for nearby galaxies with previously well-determined distances. Crosses are M31 and M81, dots are M33 and NGC 2403, filled triangles are smaller systems in the M81 group and open triangles are smaller systems in the M101 group

others from ST I and ST III]; (4) photographic magnitudes (Holmberg, 1958); (5) magnitude corrections due to galactic extinction according to the precepts in ST I [based on Sandage (1973), except that the source for M31 and M33 is McClure and Racine (1969), and for NGC 2403 is Tammann and Sandage (1968)]; (6) magnitude corrections due to galactic absorption as a function of inclination according to the precepts used by Sandage and Tammann (1974d, hereafter ST IV)



Observables

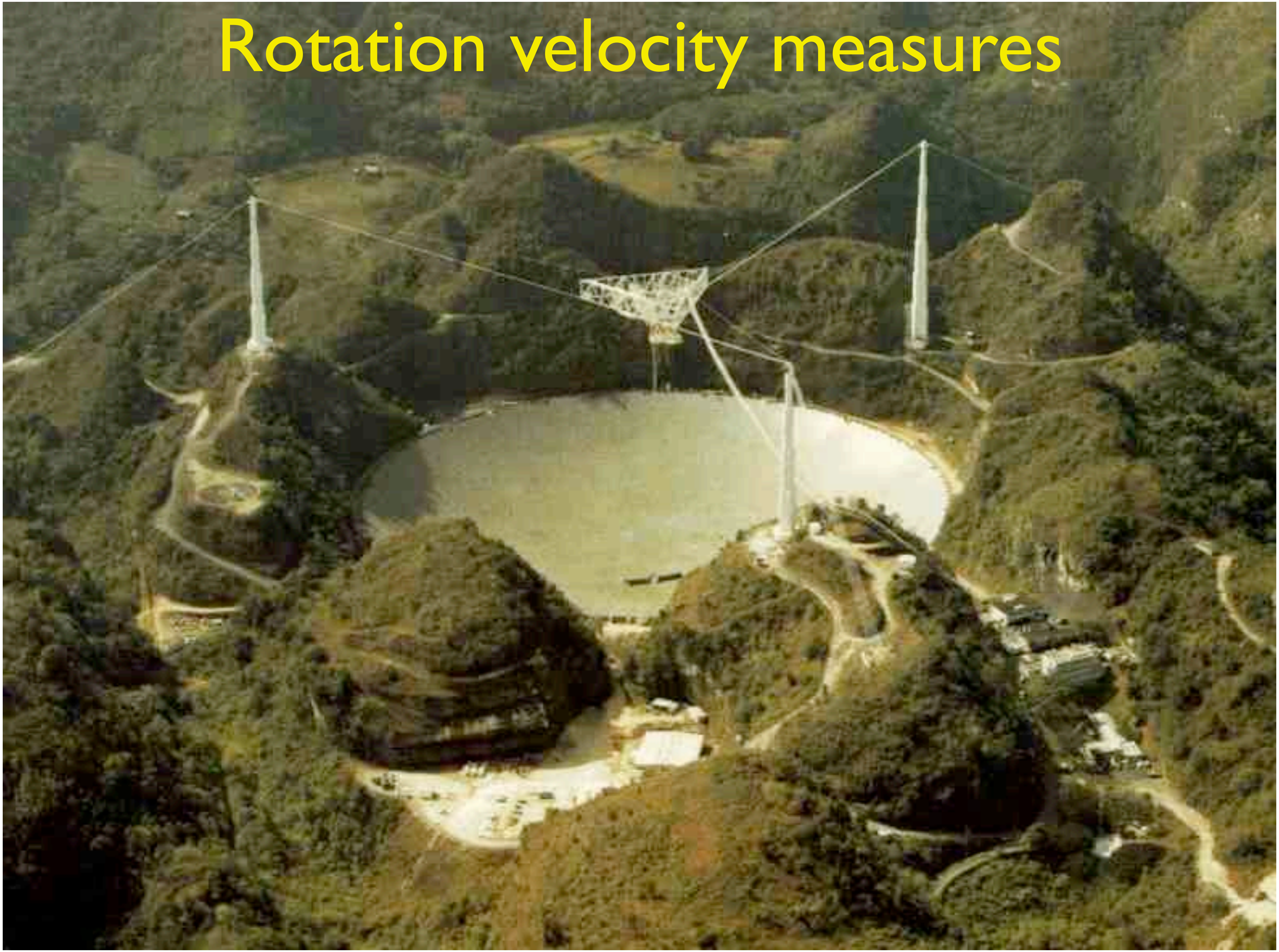
distance

- Luminosity (must calibrate with known D)
  - Band pass (*BVRIJHK*) [slope varies with band]
  - Mass - stars, gas, stars+gas
- Rotation Velocity
  - line-widths; rotation curves
    - $W_{20}, W_{50}; V_{flat}, V_{2.2}, V_{max}$
  - inclination corrections $1/\sin(i)$
  - turbulence/non-circular motions

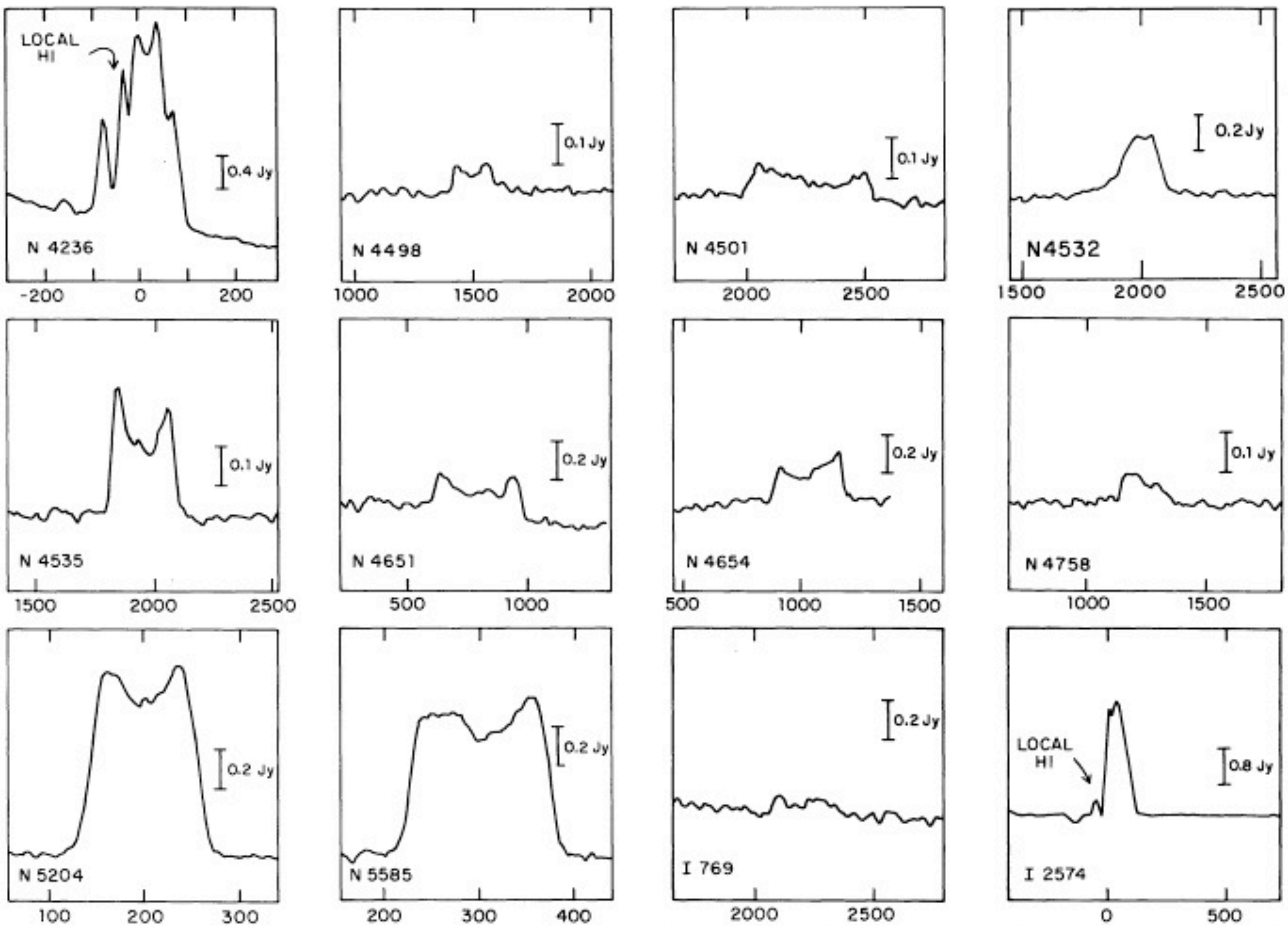
Luminosity measures

- Band pass
  - slope becomes steeper from bluer to redder bands (*B* *I* *H*)
  - Worry about internal extinction, especially for blue bands and highly inclined galaxies
- Mass
  - Can convert luminosity to stellar mass by estimating the stellar M/L via population modeling.
    - IMF biggest systematic uncertainty

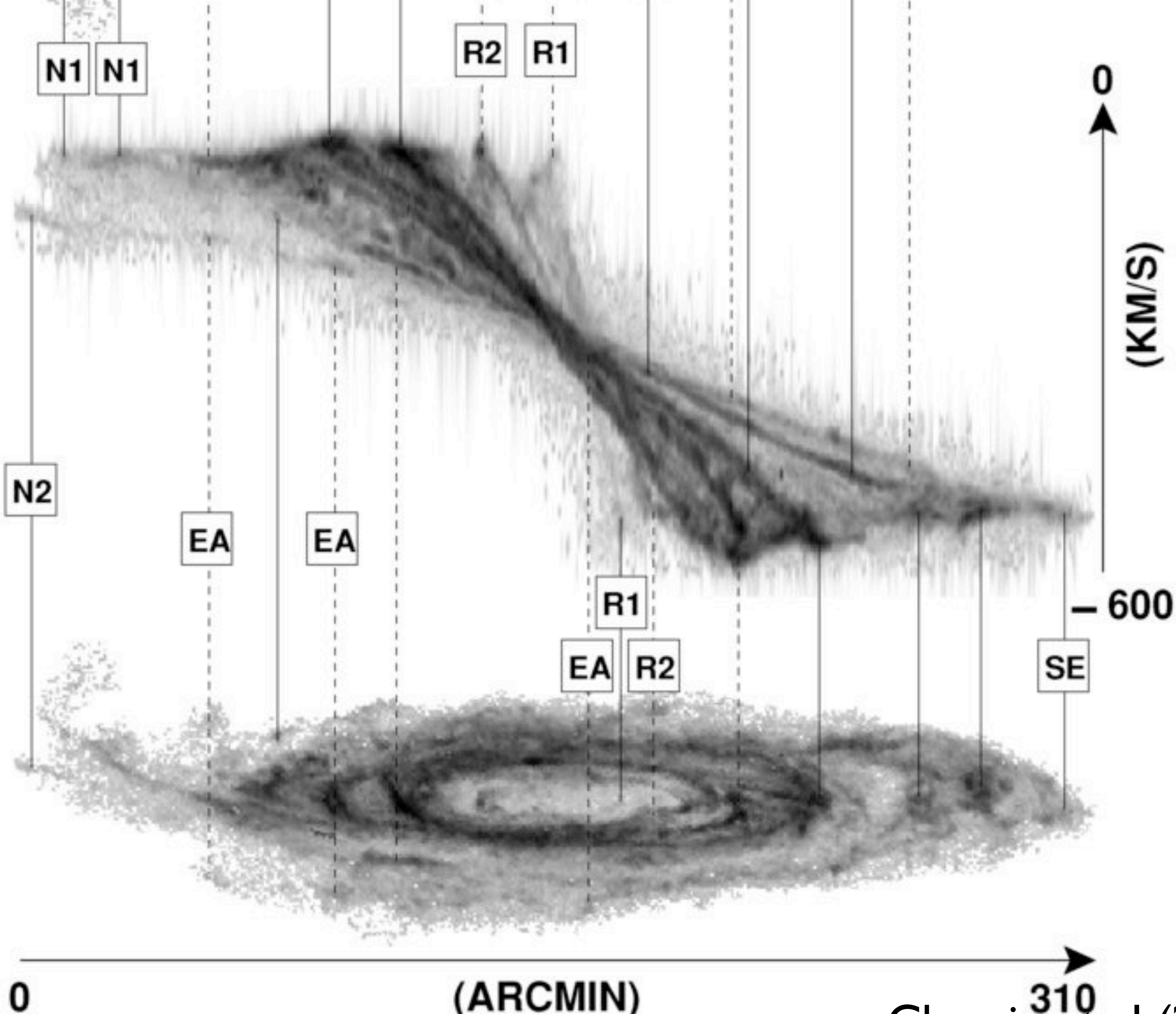
Rotation velocity measures



single dish HI observations - flux integral & line-width

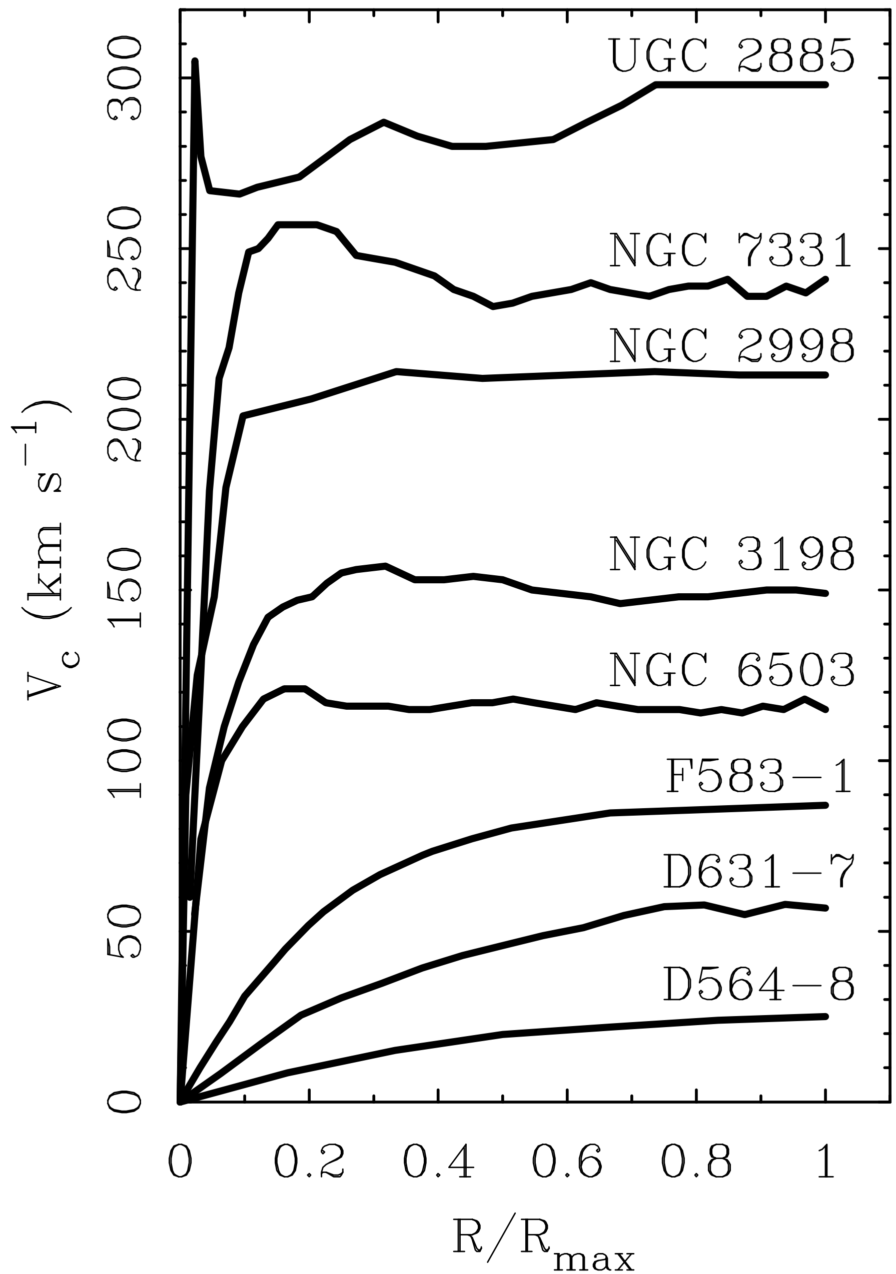


Radio synthesis observations - complete rotation curve

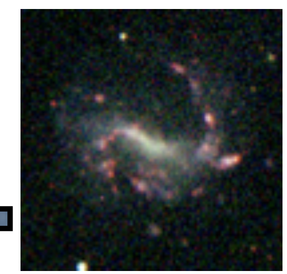


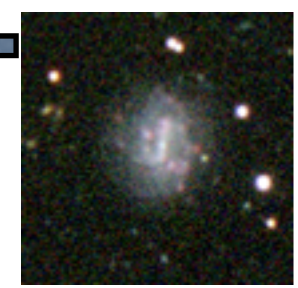
Chemin et al (2009)

Flat rotation curves



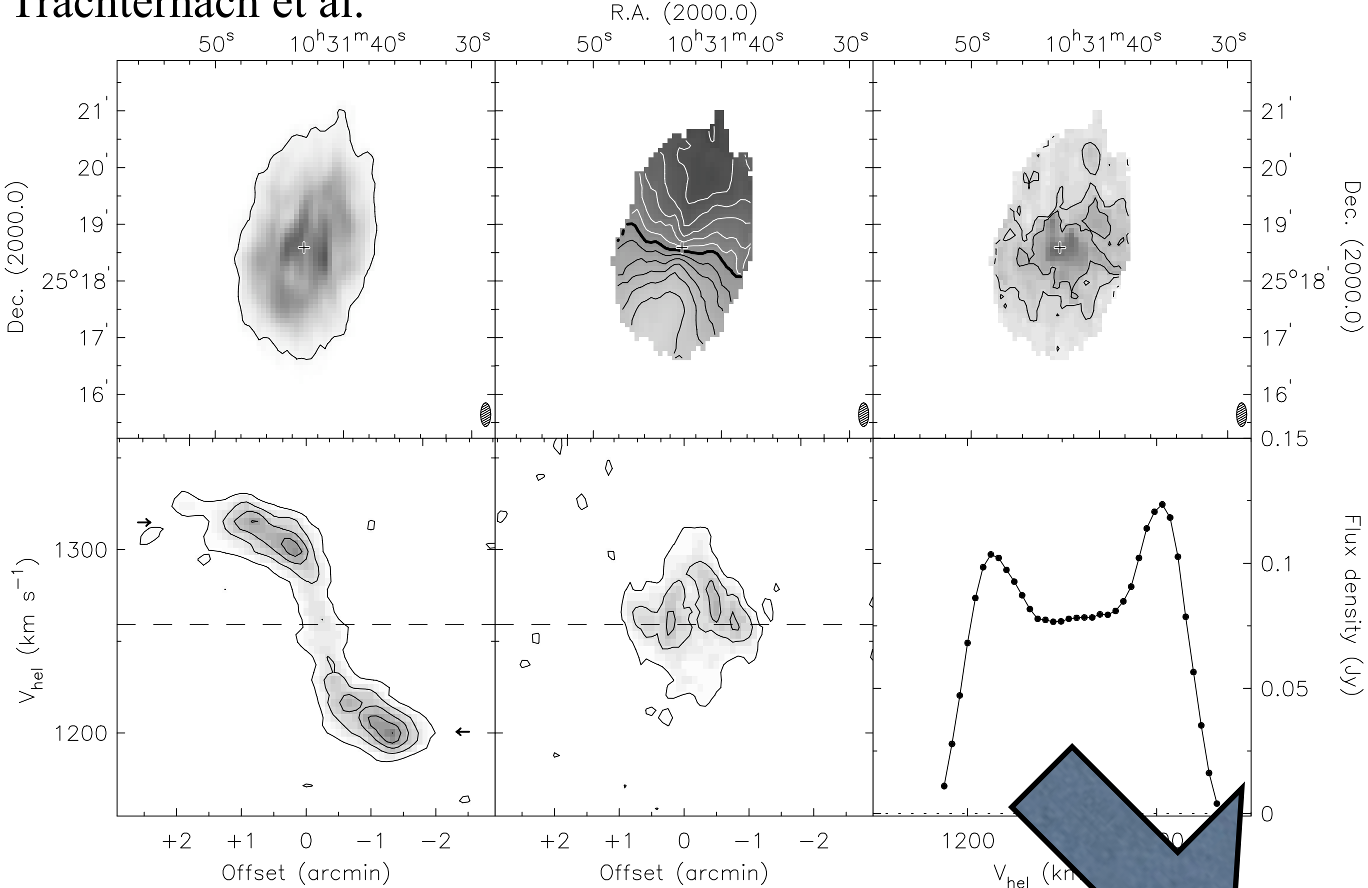
star dominated HSB



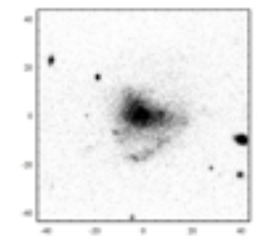


gas dominated LSBs

Trachternach et al.



HI



optical

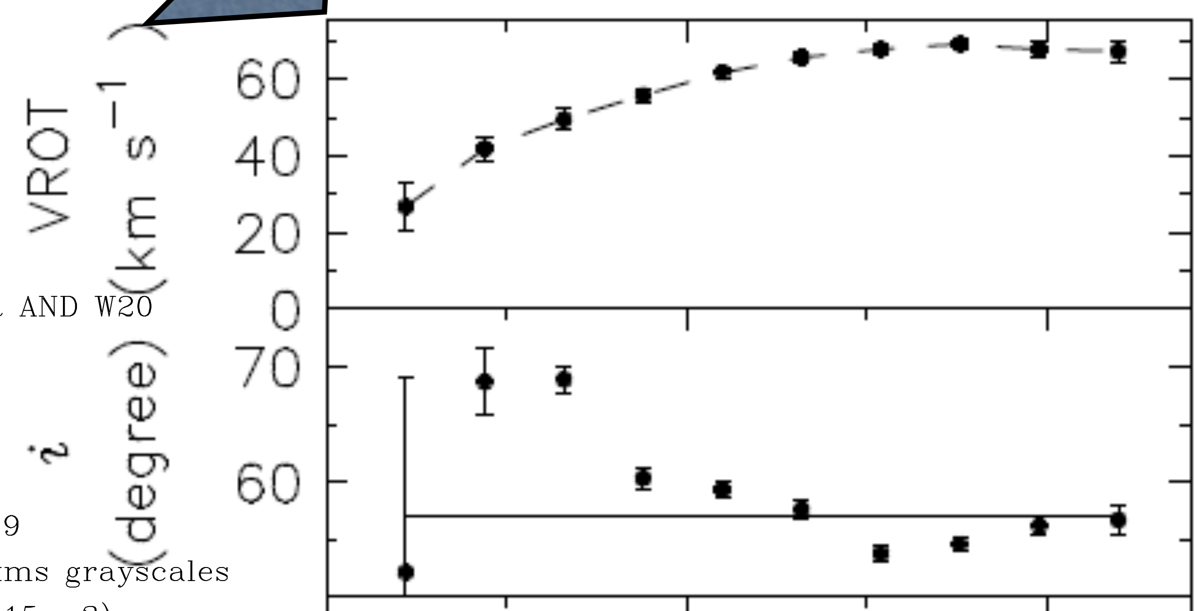
D500−2

"best−quality sample" Vrot AND Vflat AND W20
Vrot=67.7, vflat=68
I_{opt}=... I_{ell}=53 I_{kin}=57
box=−40 −40 40 40

Vsys= 1259, deltaV=10km/s

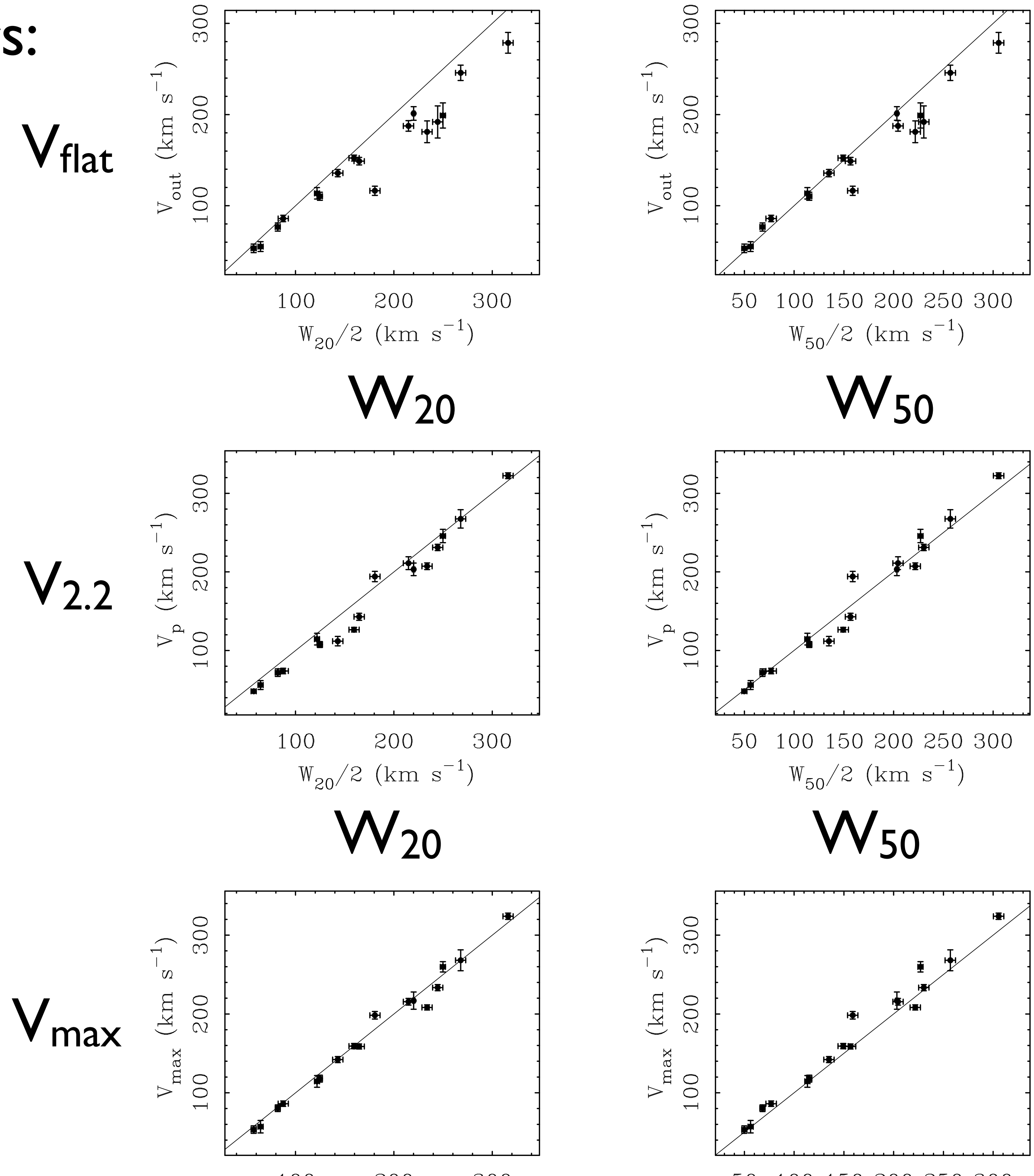
3sigma=5,09mJy == nhi von 8.8 E+19

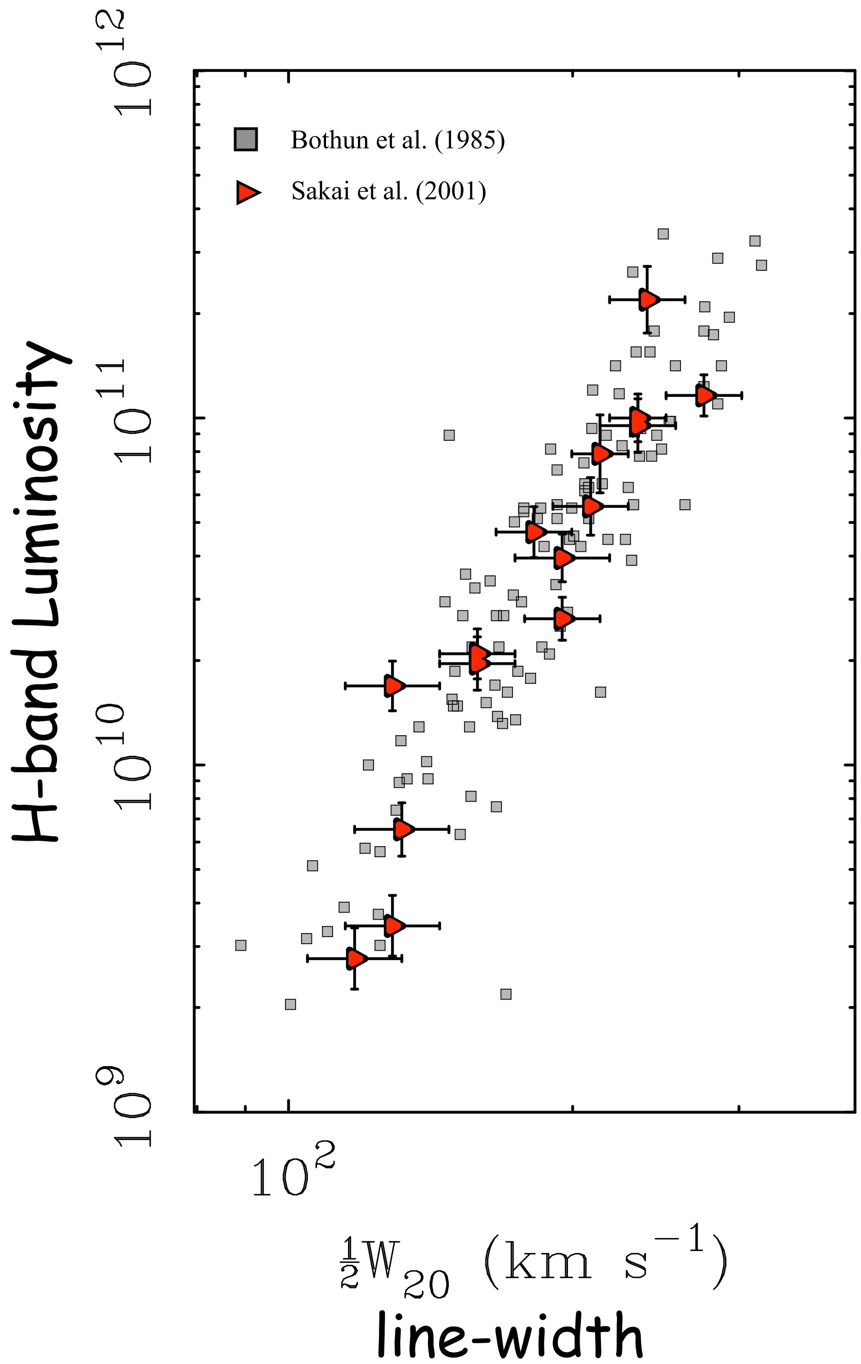
MOM2: 5,10,15 km/s contours, 2−40kms grayscales



Velocity estimators:

Line-widths are often corrected for instrumental resolution and some guess at turbulent gas motions. Care must be taken to treat everything in a uniform manner.





Tully-Fisher is a relation between luminosity and line-width.

Very useful as a distance indicator.

Application: Tully & Courtois arXiv:1202.3191

Clusters containing spirals compared to calibrated TF relation (solid line).

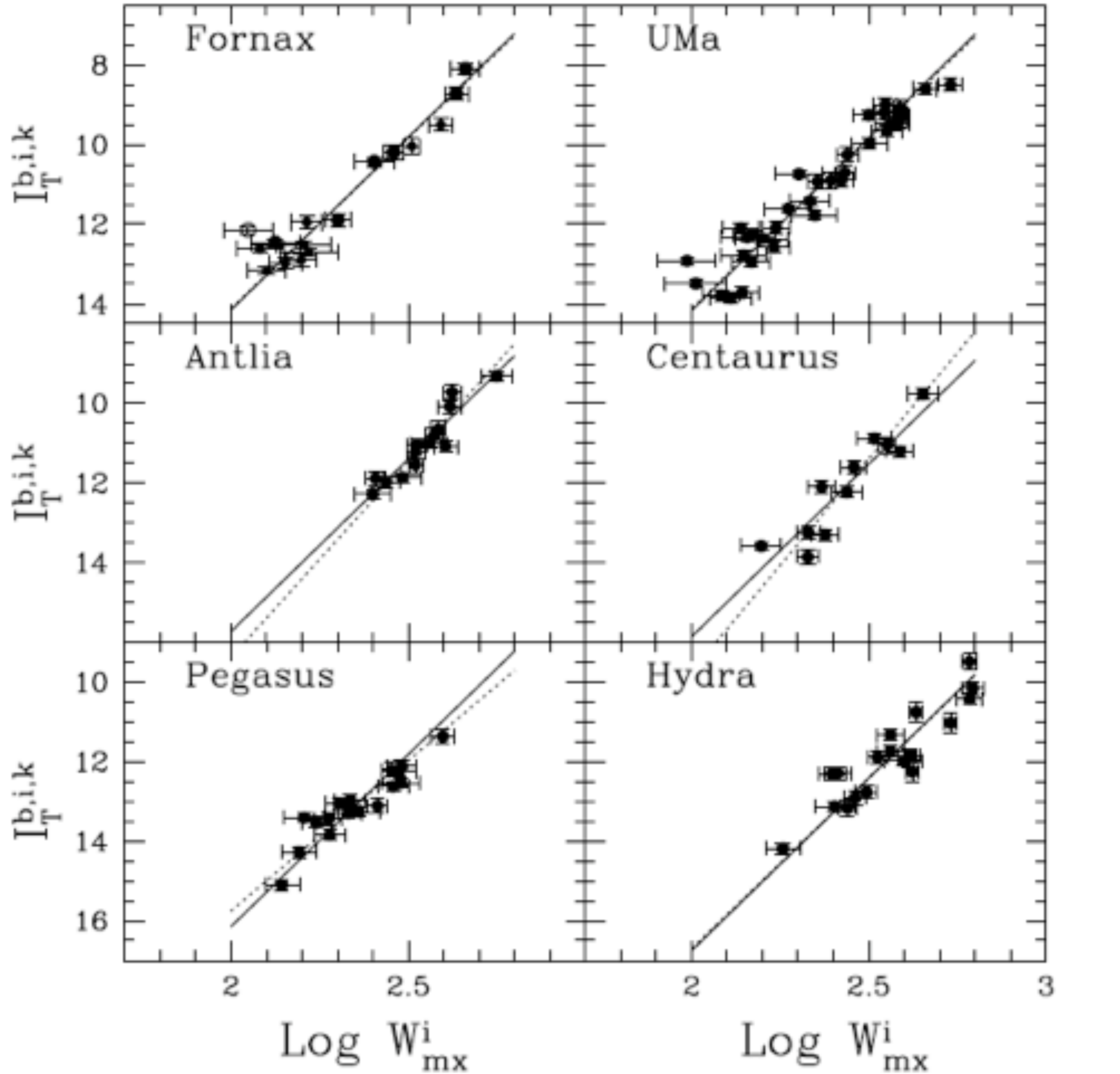
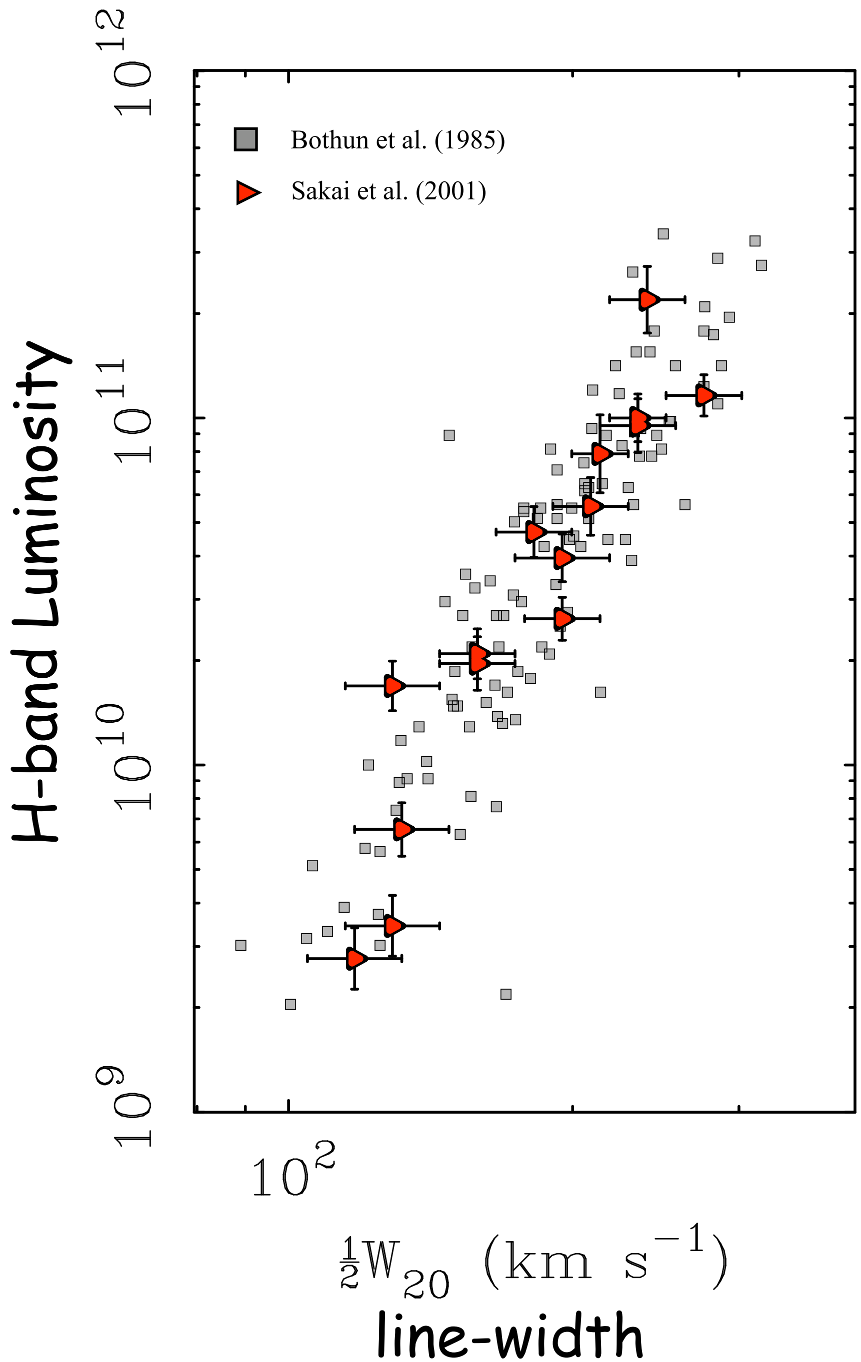


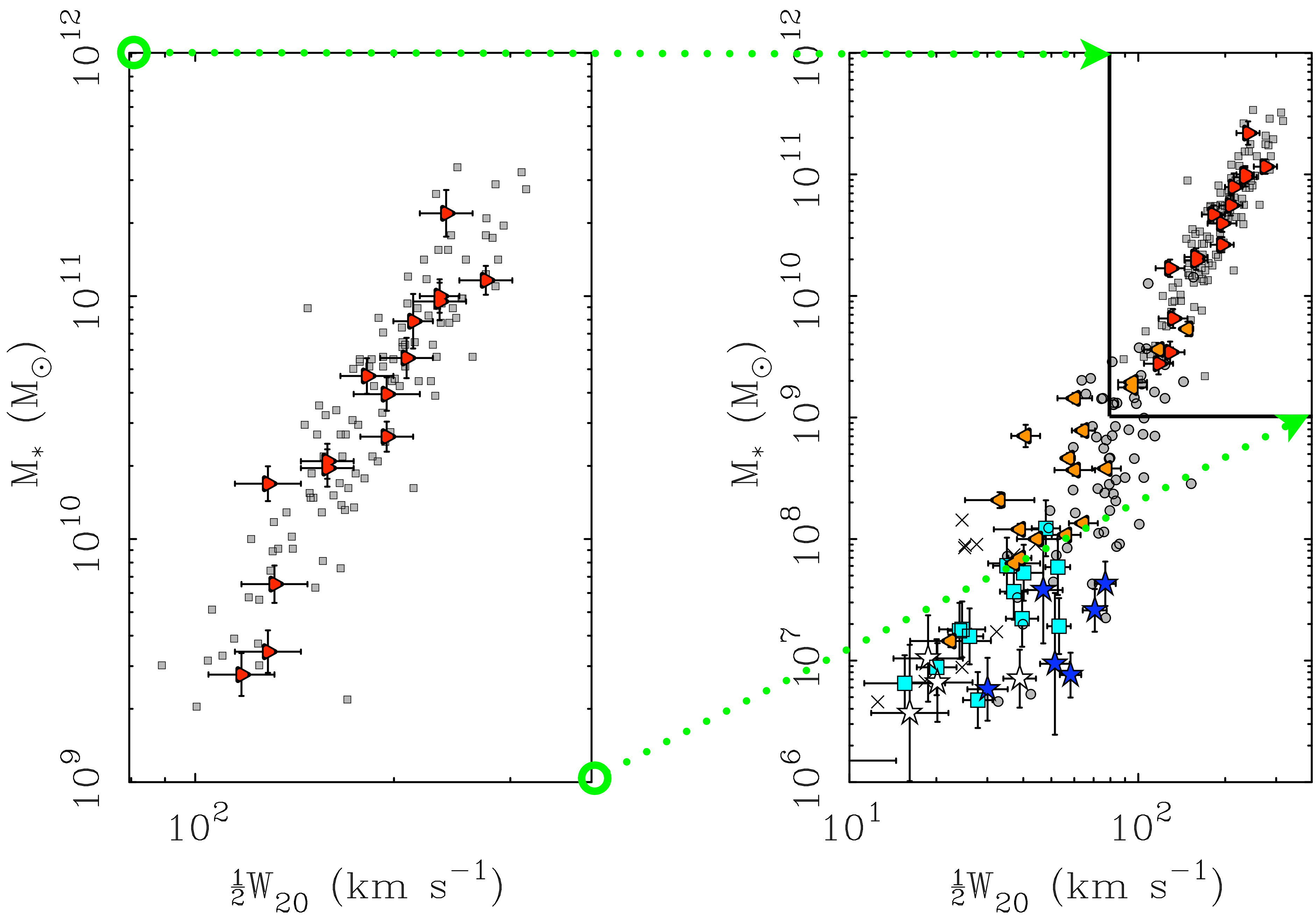
Fig. 6a.— I band luminosity–linewidth correlations for 15 galaxies in Fornax, 34 galaxies in Ursa Major, 14 galaxies in Antlia, 11 galaxies in Centaurus, 17 galaxies in Pegasus, and 19 galaxies in Hydra. Solid lines are the universal template fits and dotted lines are fits to the individual clusters. In the case of the Fornax Cluster, galaxies superimposed on the central core are identified with larger symbols, galaxies in the periphery are identified by smaller symbols, and one rejected galaxy is identified by an open symbol. See Appendix for discussions of individual clusters.



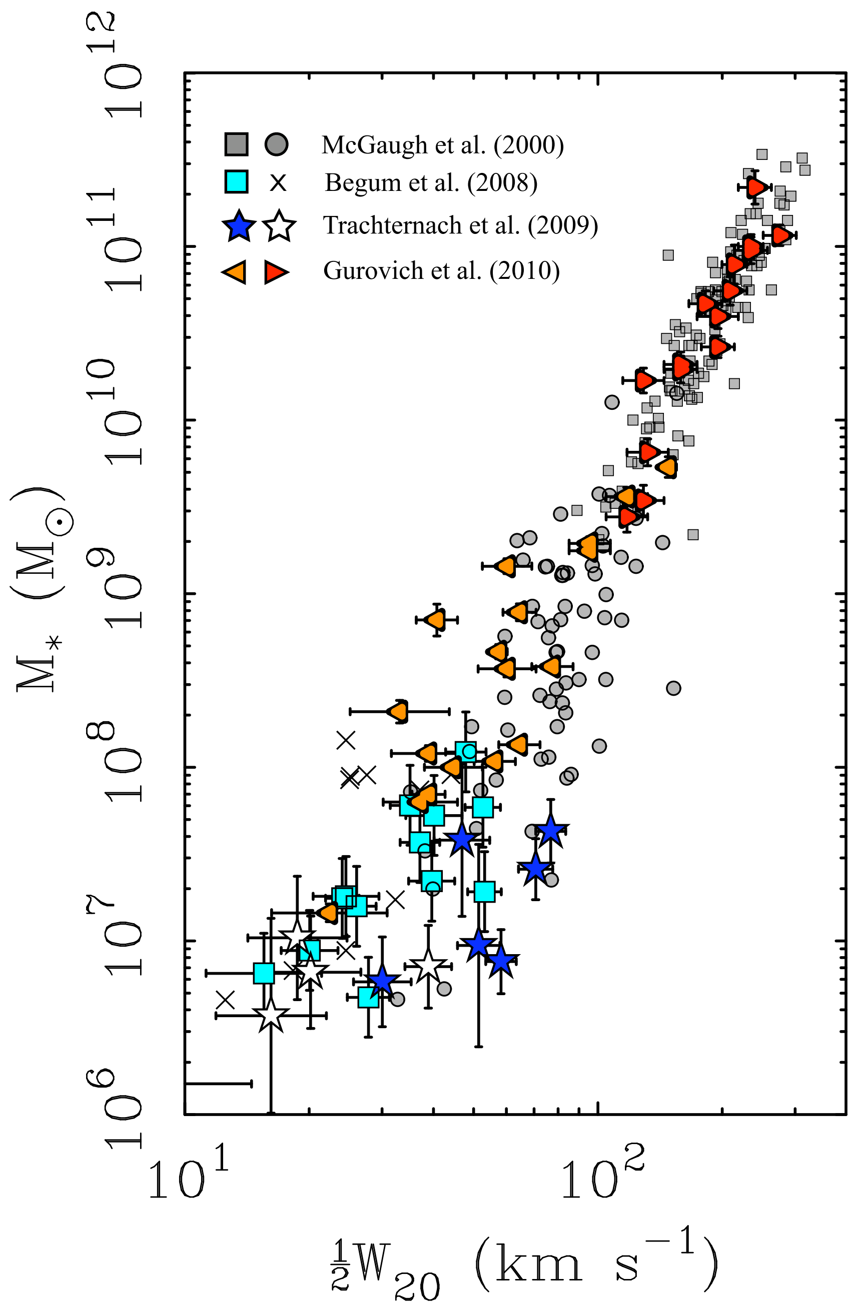
Luminosity and line-width are proxies for stellar mass and rotation velocity.

The traditional Tully-Fisher relation covers the range illustrated at right.
Can expand this range by considering lower rotation velocities...

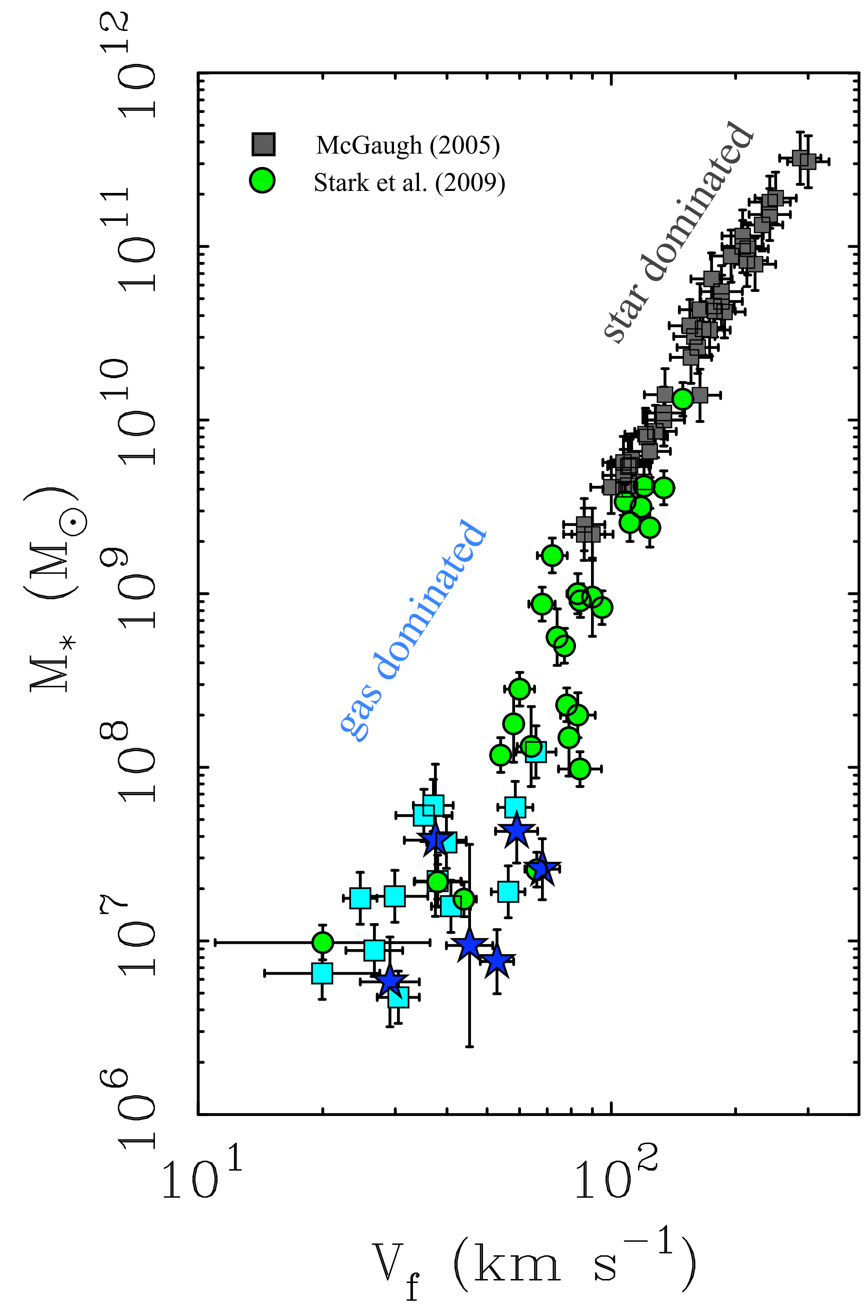
$$M_* = \left(\frac{M_*}{L}\right) L$$



Stellar Mass Tully-Fisher relation

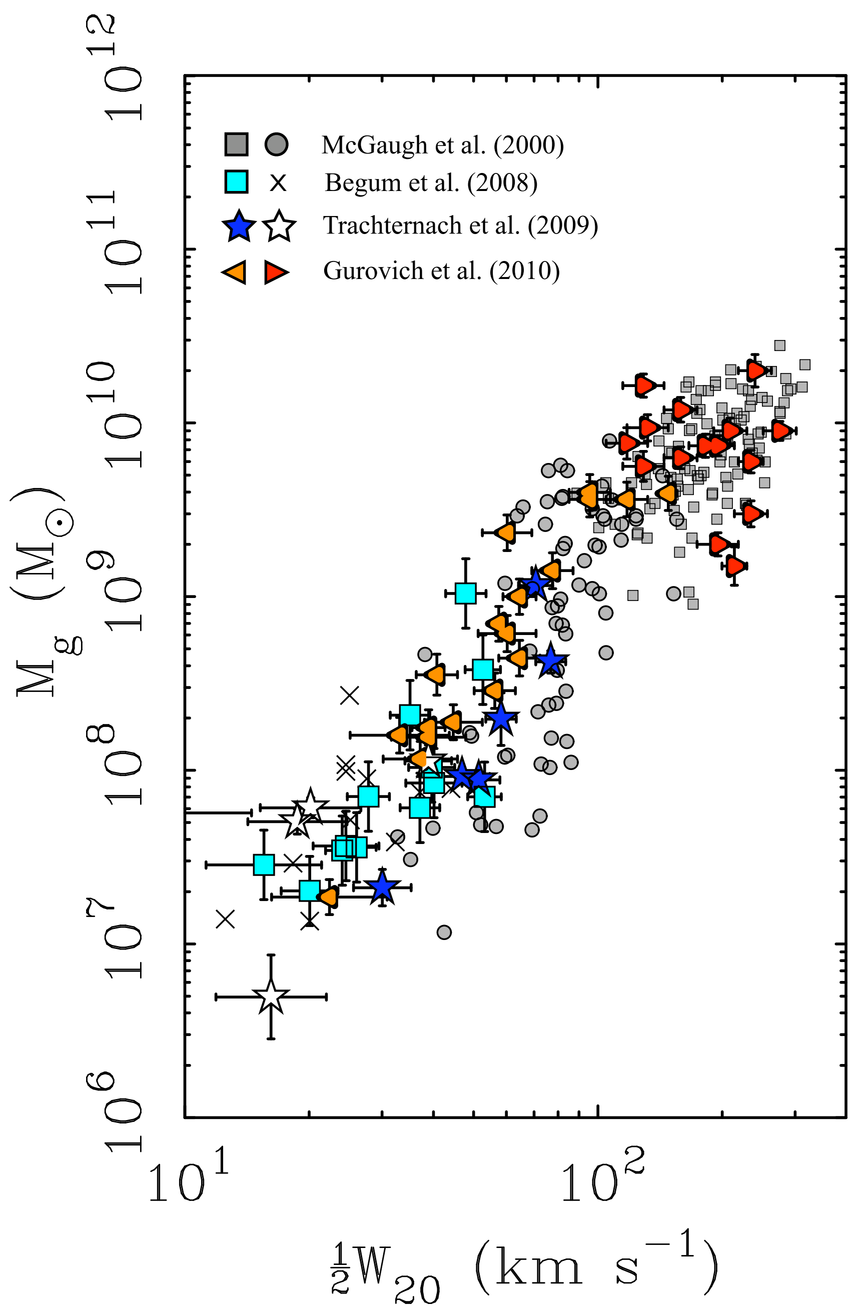


line-width

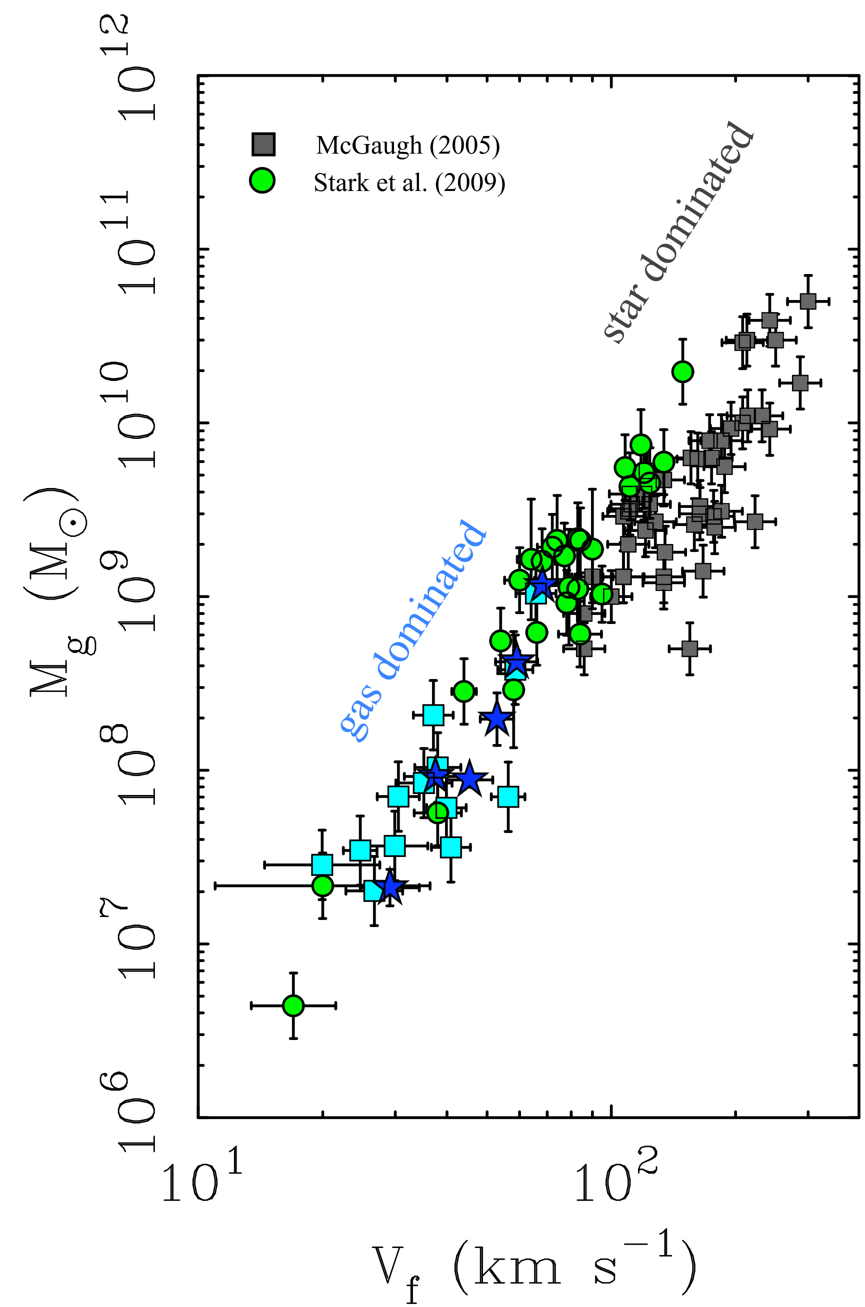


outer (flat) velocity

HI Tully-Fisher relation

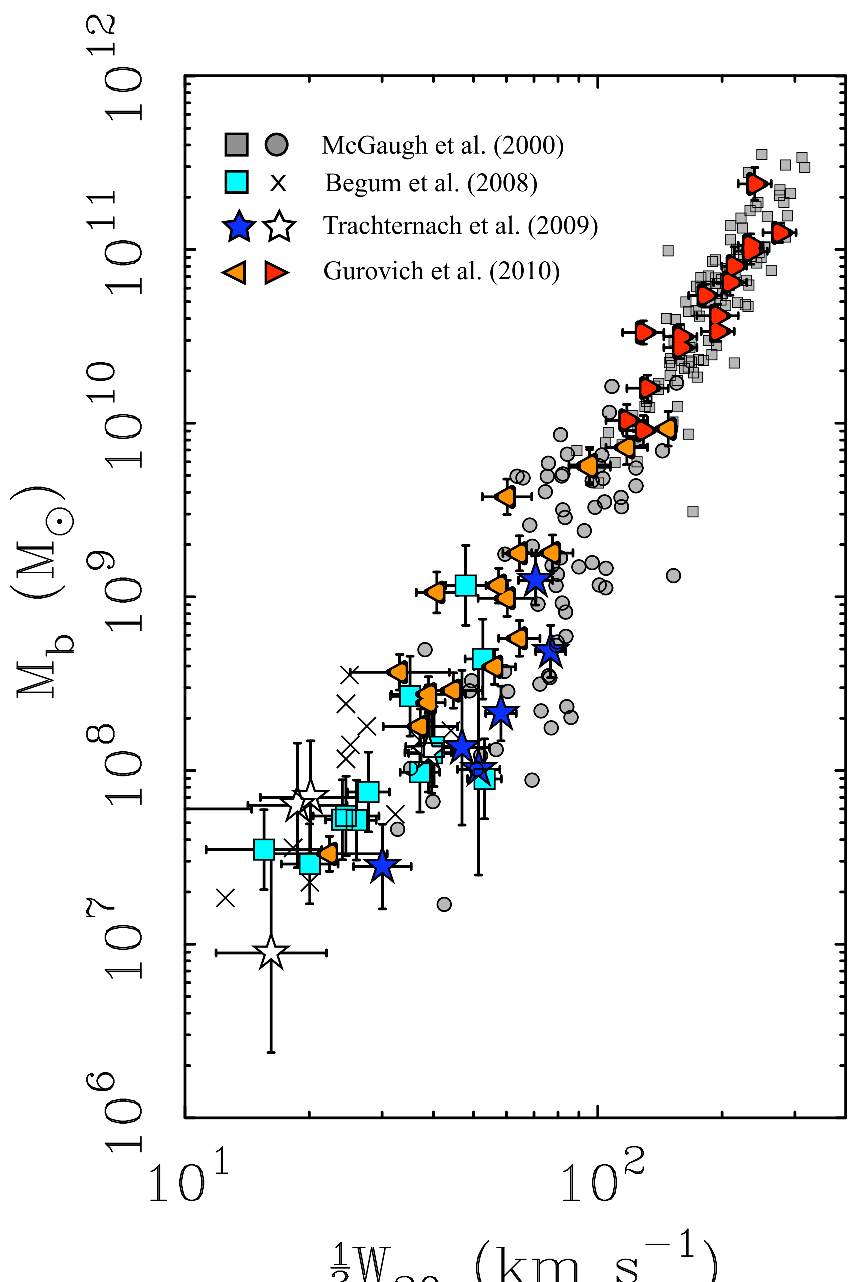


line-width



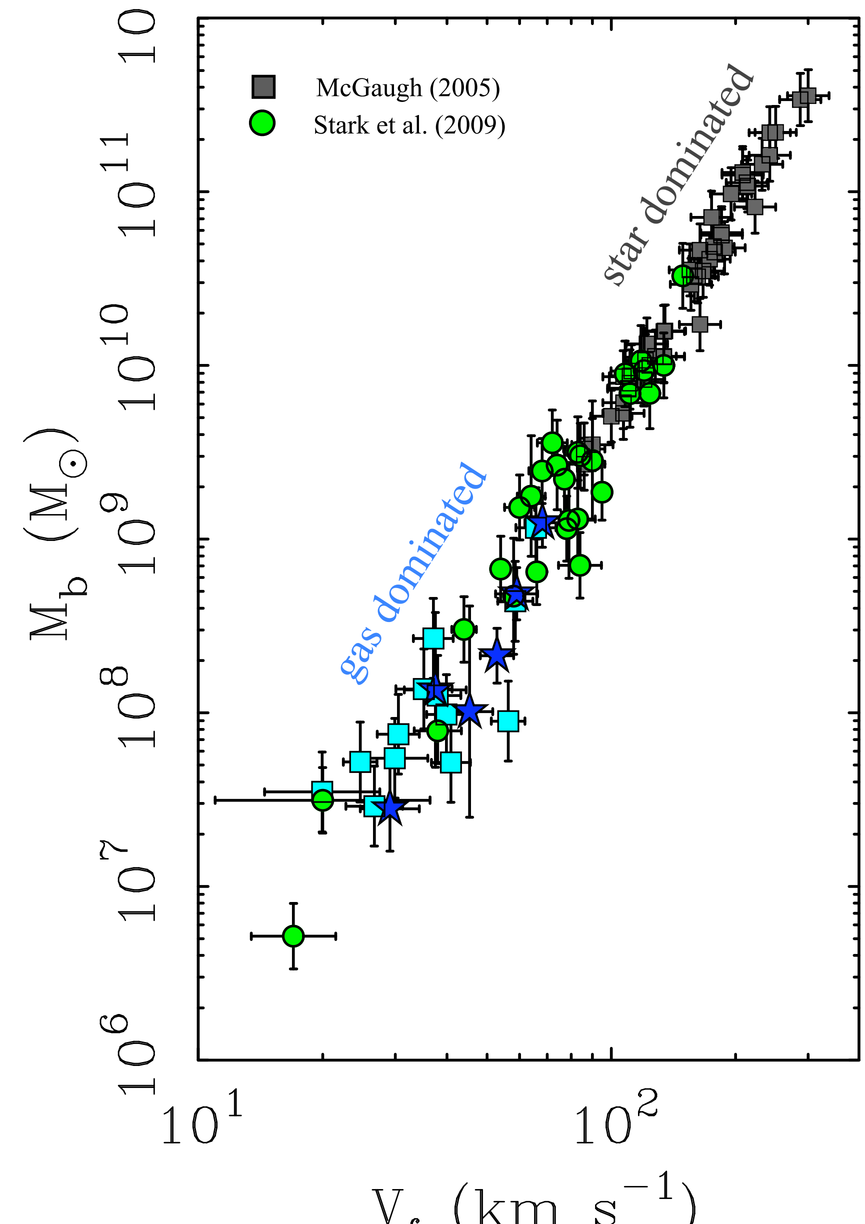
outer (flat) velocity

Baryonic Tully-Fisher relation: $M_b = A\ V_f^4$

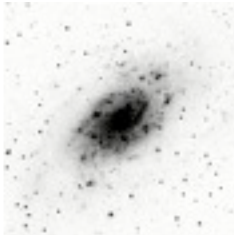


line-width

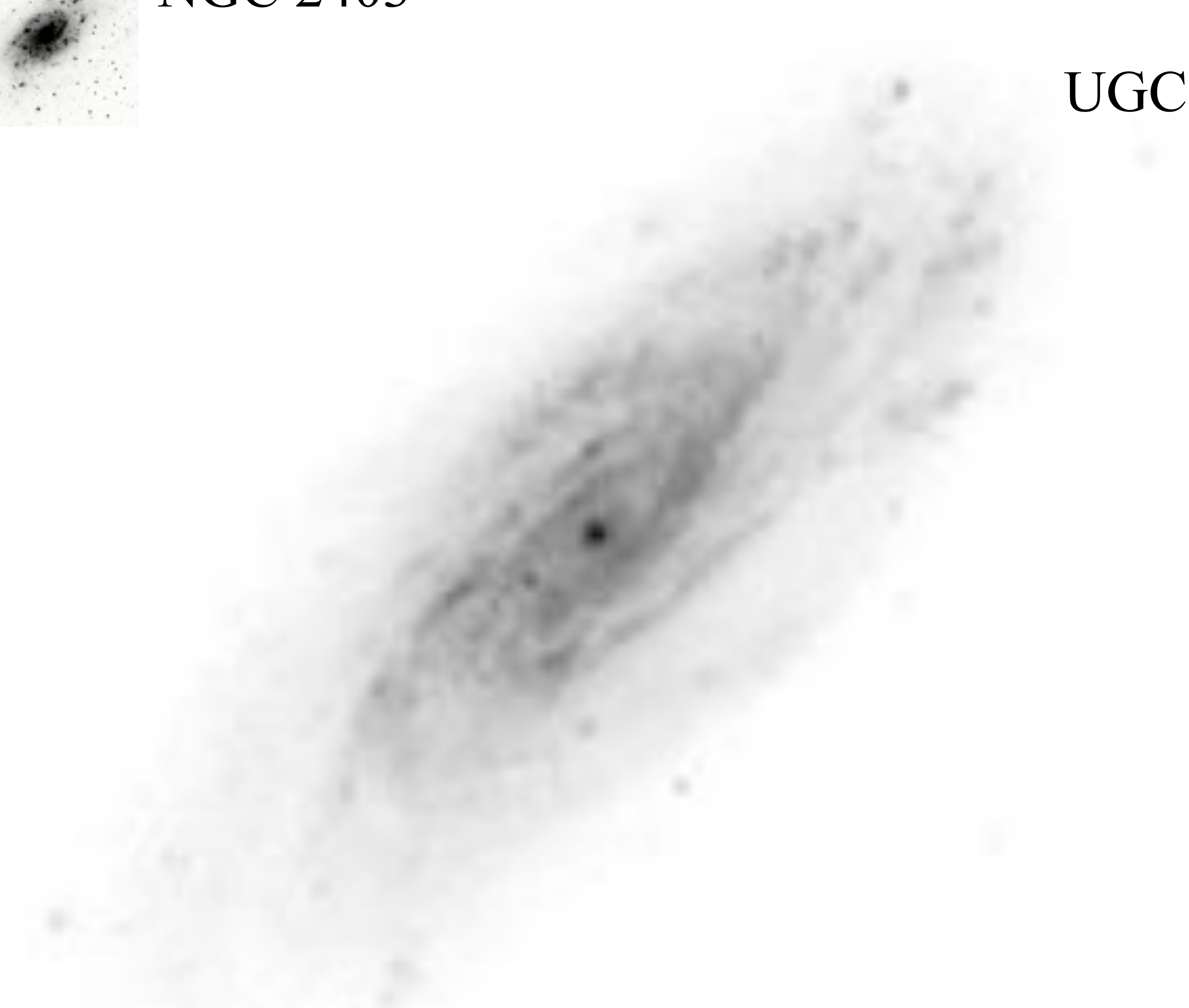
$A = 45{-}50\ M_\odot\ \mathrm{km^{-4}\ s^4}$



outer (flat) velocity



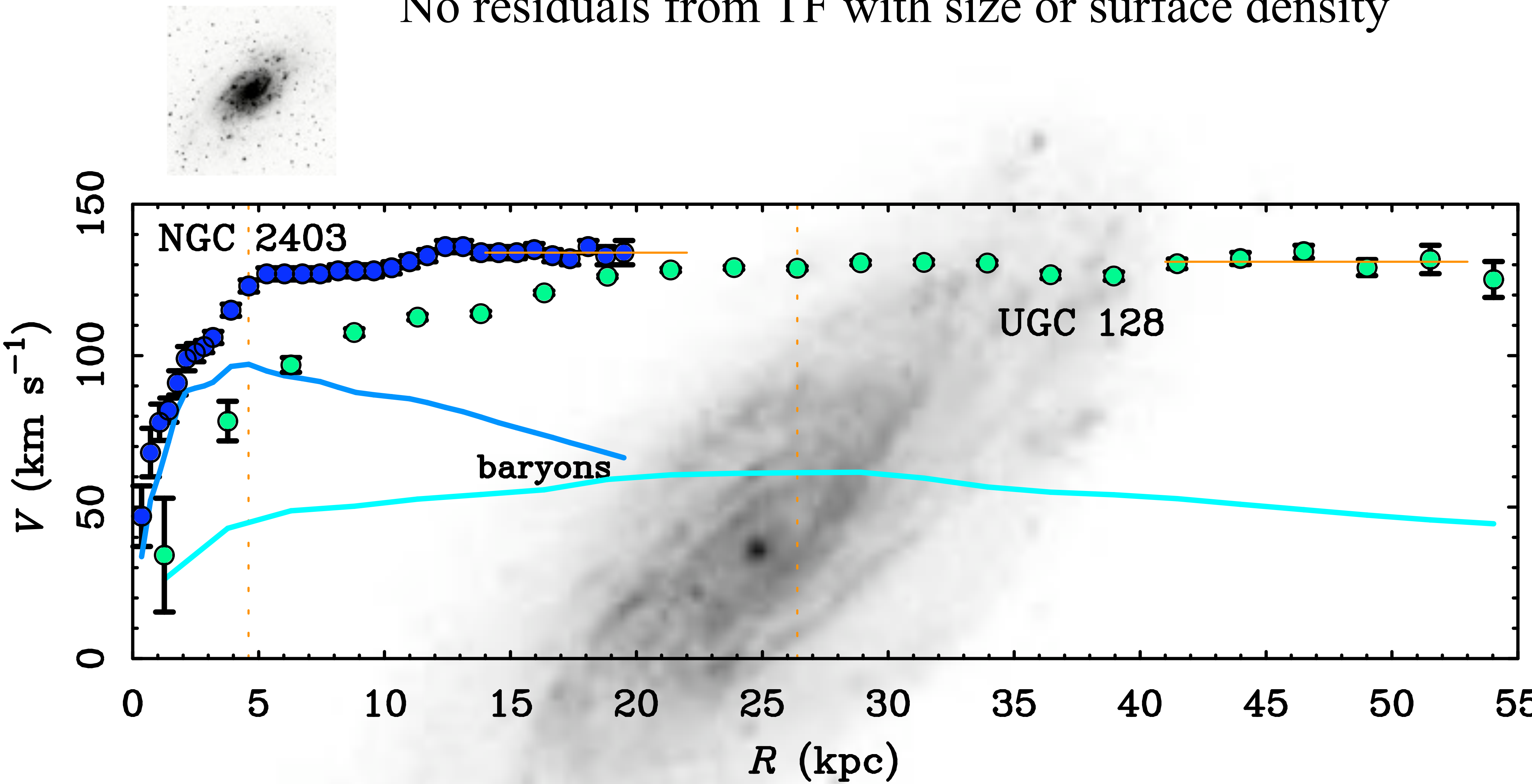
NGC 2403



UGC 128

The Tully-Fisher relation is the optimal projection of the disk galaxy fundamental plane (no R dependence).

No residuals from TF with size or surface density



Same (M,V) but very different size and surface density

which is strange, since $V^2 = \frac{GM}{R}$

TF relations

- Optical/IR luminosity correlates with line-width/rotation velocity
- Bedrock relation of extragalactic distance scale
- Physical basis of this relation unclear
    - tantamount to Natural Law?