The shape of dark matter halos of galaxies derived from HI observations

Cosmology in Miramar, SISSA, Trieste, August 28 – September 02, 2023

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The Gravitational Support of Disks and Dark Matter

- The rotational support of rotating disks is approximately given by : $GM(dyn)/r^2 = v^2/r$
- But the vertical support is due to the self gravity of the stellar disk. But what happens in regions where there is very little stellar disk mass?
- There are many examples of large extended HI gas disks that are associated with very little stellar mass. How can an HI disk support itself without the self gravity of stars?

The disk dark matter must be important for the vertical equilibrium. If it is, then what is the shape of the halo? Can we determine halo shapes using the vertical equilibrium? Also, what is the effect of disk dark matter on disk dynamics such as bar formation and star formation?

ABSTRACT

We present a study to measure the the shape of dark matter halos of gas rich galaxies that have extended HI disks. We have assumed that the halo axes ratios in the disk plane are approximately so that q=c/a measures the halo prolateness or oblatelness. We have applied our model to a sample of 20 nearby galaxies that are gas rich and close to face-on. We find that gas dominated galaxies (such as LSB dwarfs) have have oblate halos ($q < 0.55$), whereas stellar dominated galaxies have a range of q values from 0.2 to 1.3. We also find a significant positive correlation between q and stellar mass, which indicates that galaxies with massive stellar disks have a higher probability of having halos that are spherical or slightly prolate, whereas low mass galaxies preferably have oblate halos.

Sample of Face-on Galaxies

The sample galaxies were selected based on their inclination angles (nearly face-on). The HI velocity dispersion σ and Σ(HI) were obtained from THINGS survey data products (Walter et al. 2008) and the LITTLE THINGS (Hunter et al. 2012) survey. We have totally 20 galaxies, 12 have very low stellar masses, and 8 have higher stellar masses.

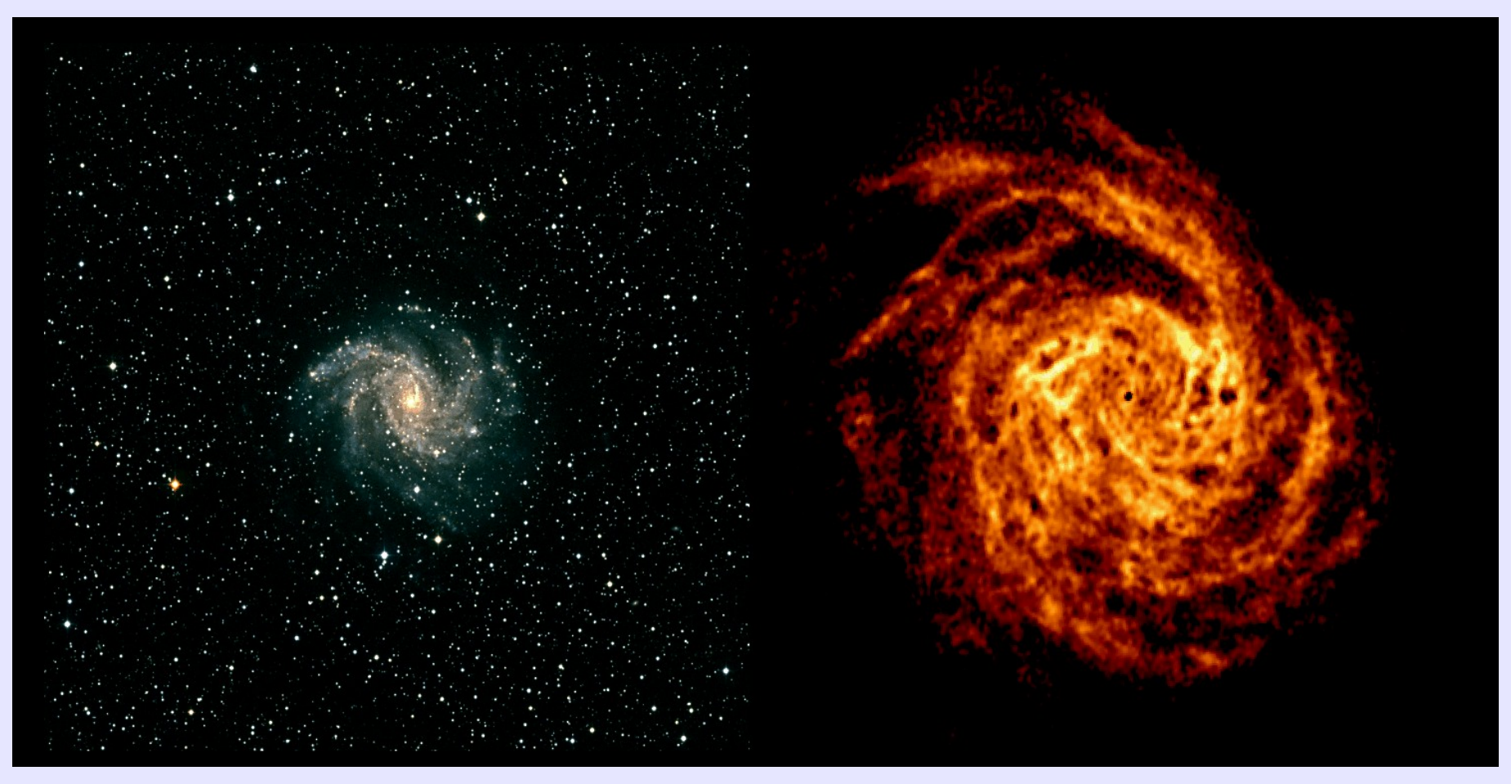


Image credit : van der Hulst, NGC6946 in optical and HI

Using HI velocity dispersion in face-on galaxies to determine disk vertical equilibrium

- The HI can be used to trace the potential of the disk using simple vertical equilibrium : $1/\rho_{HI}\, d/dz[\rho_{HI}\sigma_{HI}^2] = -d\Phi/dz$
- We can then determine an expression for the disk dynamical mass surface density which is given by $\Sigma_{dyn}=\sigma_{HI}^2/\pi G z_{g0}$ where z_{g0} is the disk vertical scale length.
- If $\Sigma_{dyn} > \Sigma(baryonic)$, it means that the disk dark matter is significant. In these regions the dark matter associated with the galaxy disk helps gravitationally bind the HI to the disk (Das et al. ApJ, 2020).
- We assume a logarithmic form for the halo potential and an exponential form for the vertical gas and stellar distributions.

$$\mathbf{1/\rho_{HI}\, d/dz[\rho_{HI}\sigma_{HI}^2] = -d\Phi/dz}$$

Where $\Phi_{halo} = ½\, v_o^2 \ln(R_c^2 + R^2 + z^2/q^2)$. For regions where there is no stellar disk and only HI gas we obtain

$$\mathbf{q^2 = v_o^2 z_{g0}^2 \times 1/R^2[\sigma^2 - \pi G z_{g0}\Sigma(HI)]}$$

- So if we have HI velocity dispersion and surface density in the outer parts of the disks we can determine the halo oblateness parameter q.

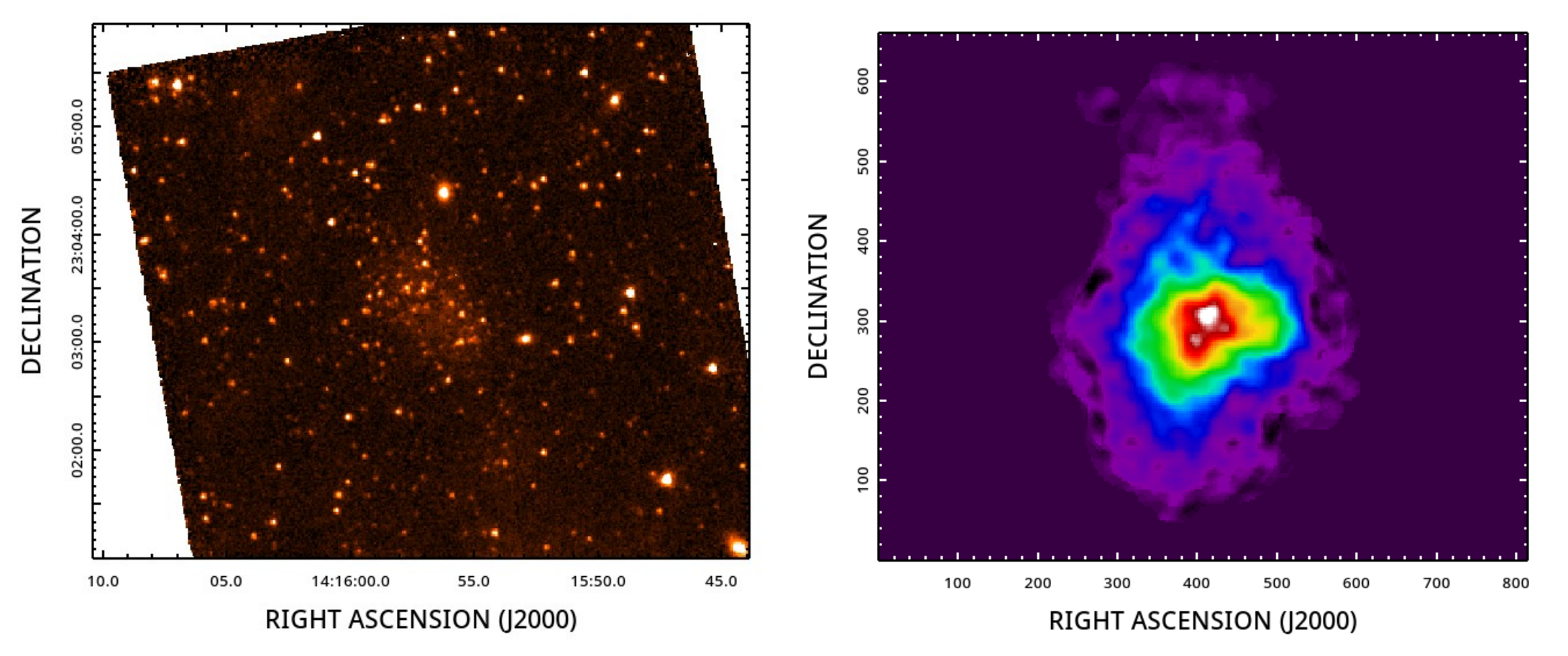
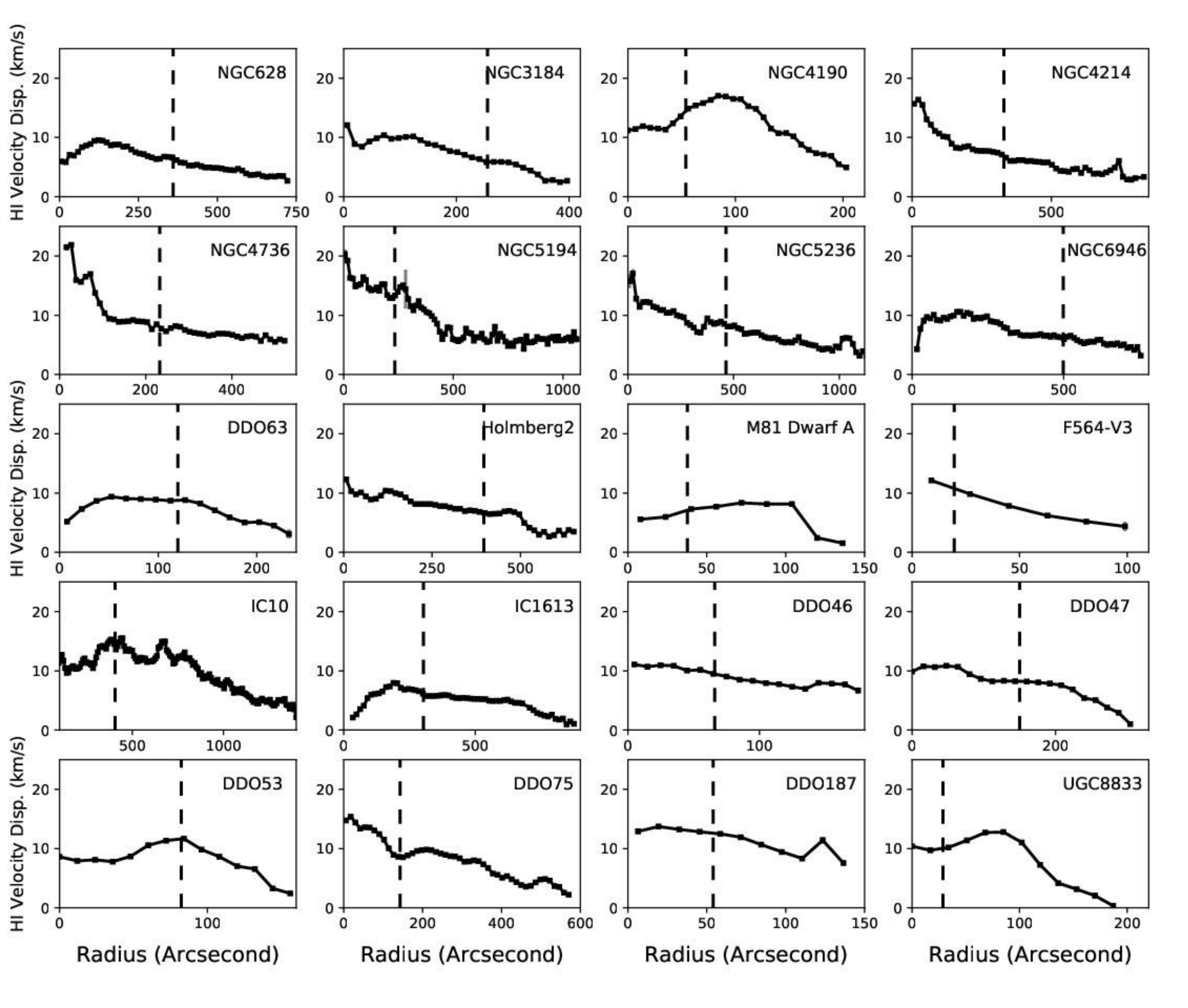
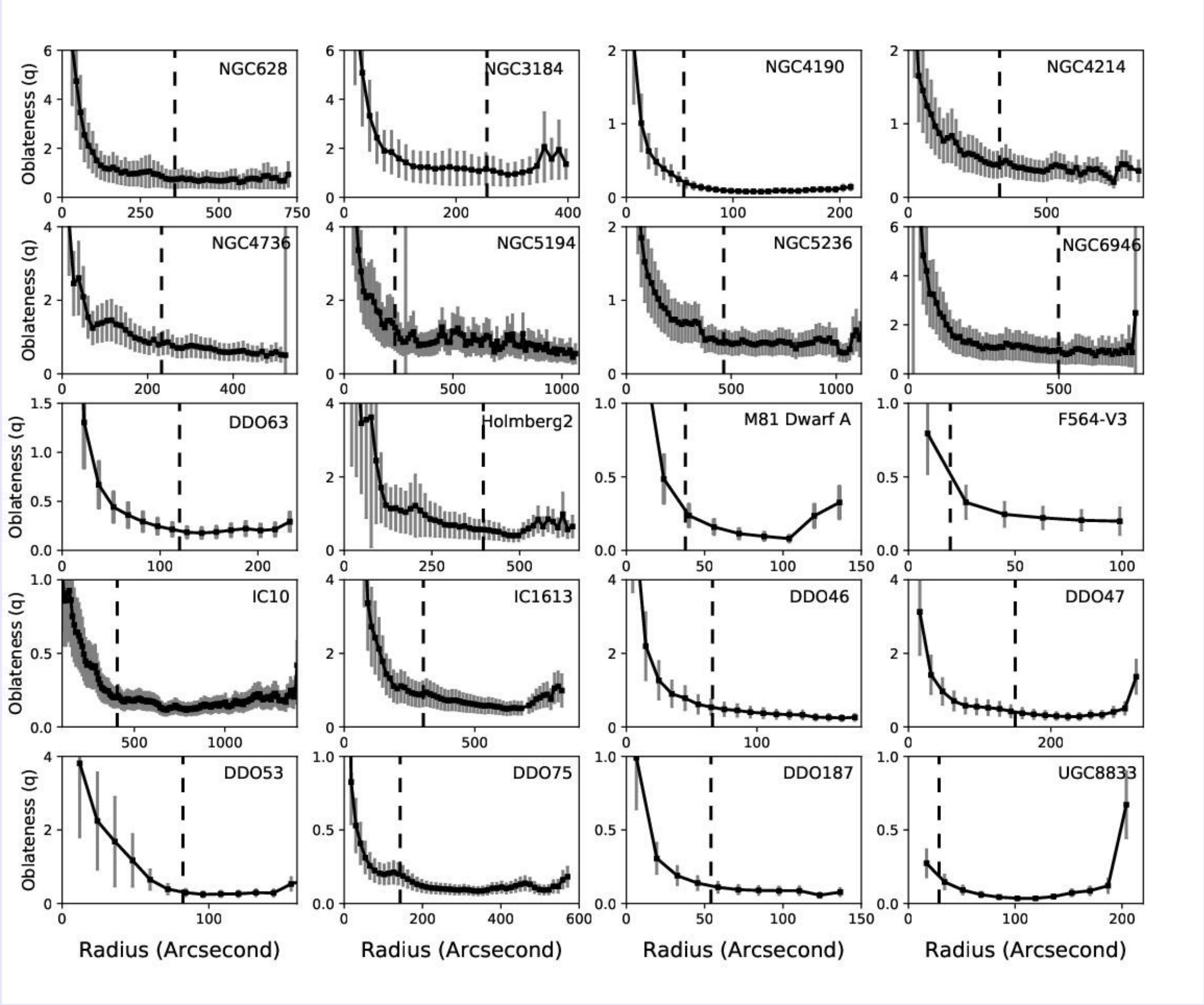


Image credit : Comparison of the stellar and gas distribution in the dwarf galaxy DDO187. The image on the left is the Spitzer 3.6μm image and that on the right is the THINGS VLA HI 21cm emission map. Both the images are matched in WCS. Note that the HI is more extended than the stellar disk as traced by the 3.6μm emission.

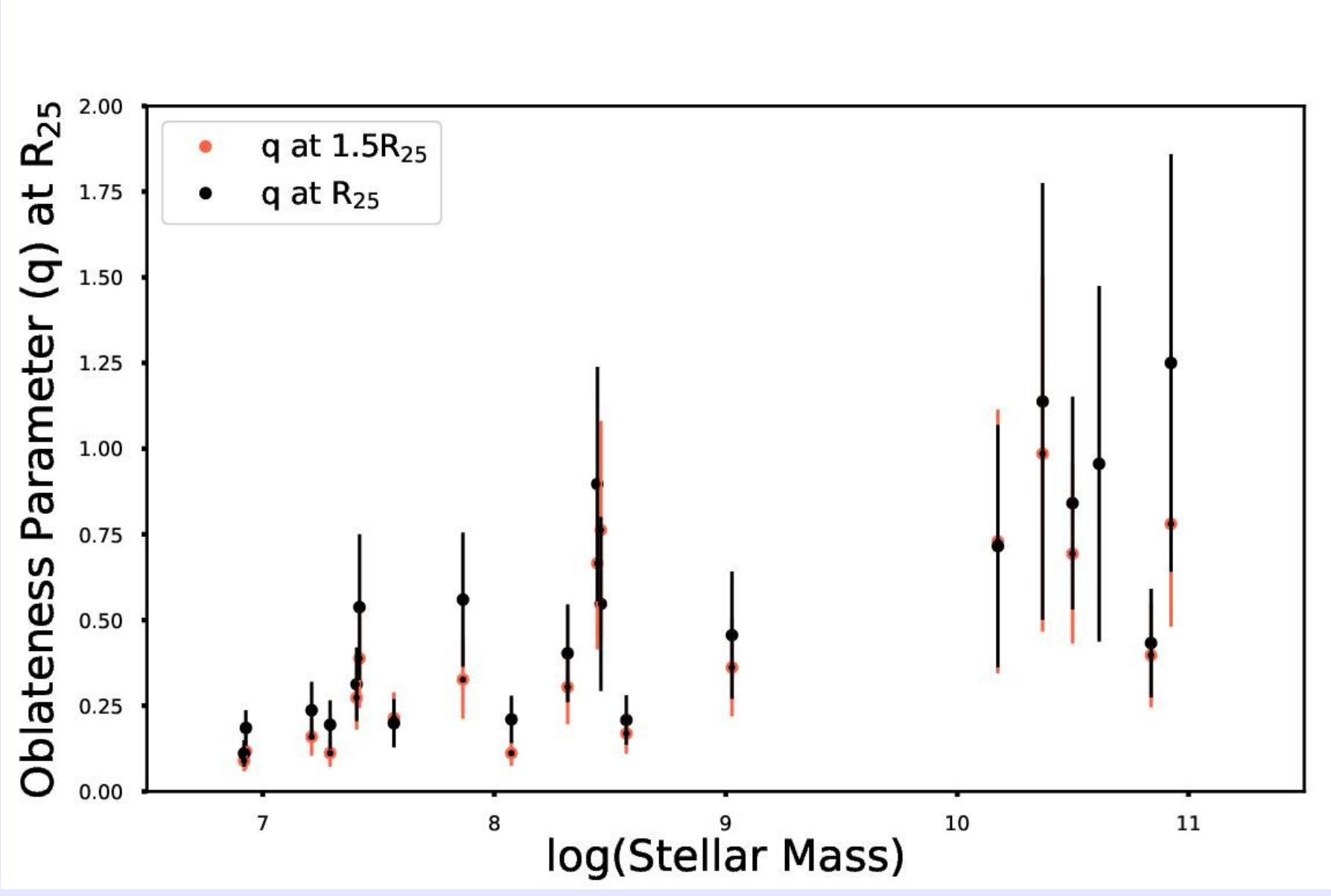
The Data : Neutral hydrogen (HI) velocity dispersion of face-on galaxies



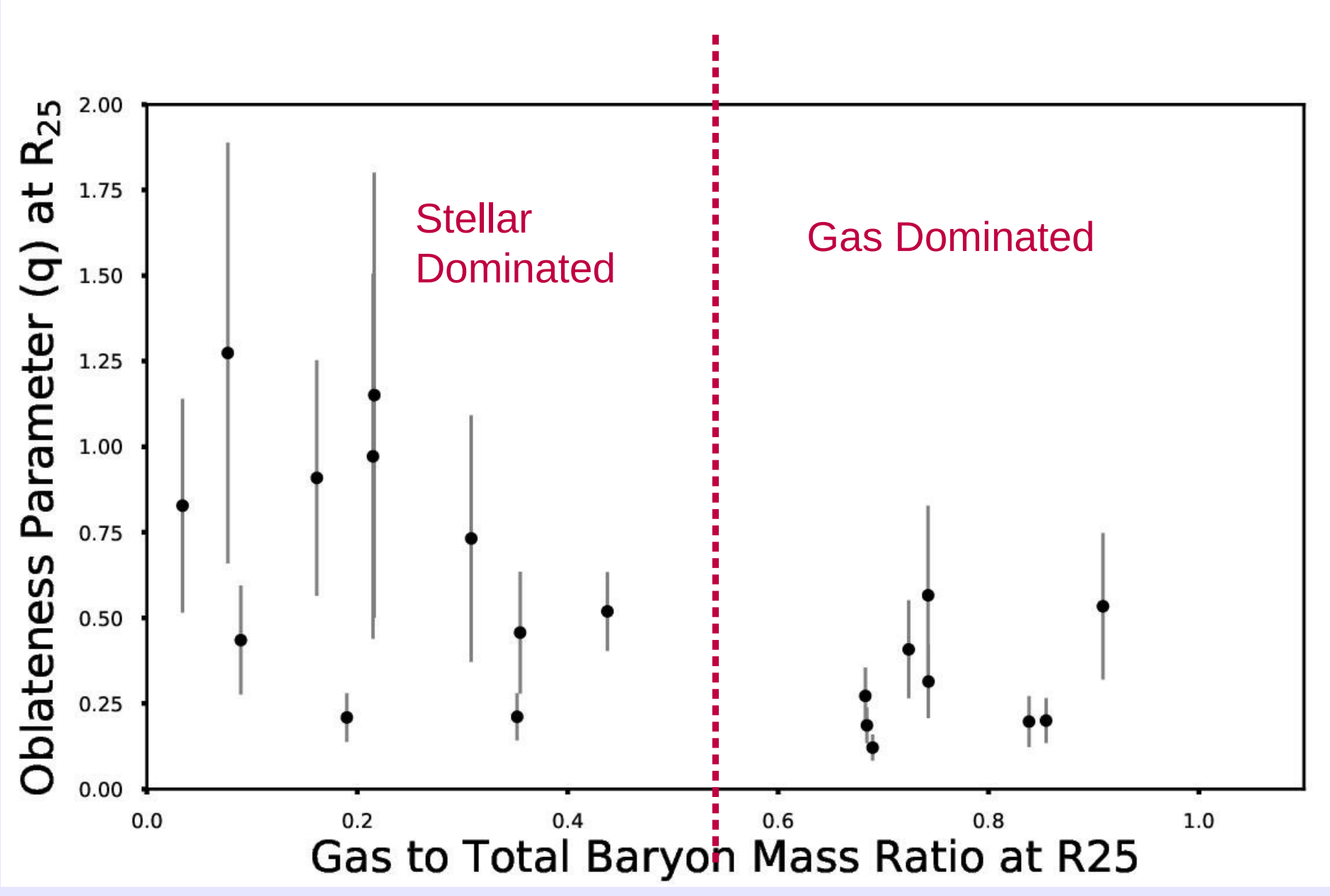
The Results : Halo Oblateness



Correlation of Oblateness with Stellar Mass



Correlation of Oblateness with Gas Mass Fraction



MAIN RESULTS

- The HI dispersion in face-on galaxies can be used to determine the oblateness q or c/a of dark matter halos. The method can be applied to the outer HI disks of face-on galaxies where there is no star formation and the stellar disk is not detected.
- We find that the galaxies with massive stellar disks have larger q, generally between q = 0.5 to 1.0, whereas the gas rich dwarfs have very oblate halos q~0.2. So disk galaxies with large stellar masses have rounder halos.
- The q shows an increasing trend with stellar mass. **The results clearly show that gas rich galaxies that are dwarfs have oblate halos with q<0.55, whereas the stellar dominated galaxies can have a variety of halo shapes.**

Acknowledgments:

M.D. acknowledges the support of the Science and Engineering Research Board (SERB) MATRICS grant MTR/2020/000266 for this research. RI acknowledges financial support from the grant CEX2021-001131-S funded by MCIN/AEI/ 10.13039/501100011033, from the grant IAA4SKA (Ref. R18-RT-3082) from the Economic Transformation, Industry, Knowledge and Universities Council of the Regional Government of Andalusia and the European Regional Development Fund from the European Union and financial support from the grant PID2021- 123930OB-C21 funded by MCIN/AEI/10.13039/501100011033, by ”ERDF A way of making Europe” and by the ”European Union” and the Spanish Prototype of an SRC (SPSRC) service and support funded by the Spanish Ministry of Science and Innovation (MCIN), by the Regional Government of Andalusia and by the European Regional Development Fund (ERDF).

References :

- Das, M., Ianjamasimanana, R., McGaugh, S. S., et al. 2023, ApJL, 946, L8.
- Das, M., McGaugh, S. S., Ianjamasimanana, R., et al. 2020, ApJ, 889, 10.