HI Streams and Spurs in HALOGAS Observations of NGC 5055

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Introduction

We present the results of a tilted-ring analysis of the HI in the nearby galaxy NGC 5055 (M 63) from deep observations of the Westerbork Hydrogen Accretion in LOcal GAlaxieS (HALOGAS) survey. See **P346.24 (Heald et al.)** for a comprehensive overview of the HALOGAS survey. NGC 5055 is a moderately-inclined SAbc galaxy with a large pronounced warp of the extended gaseous disk. The HALOGAS observations reveal extended emission in the form of faint HI spurs and streams in the galaxy outskirts, which were undetected in previous data. We compare these features with stellar streams seen in recent deep optical imaging and with extended UV emission from GALEX. We also discuss anomalous velocity gas in the inner region of the galaxy.

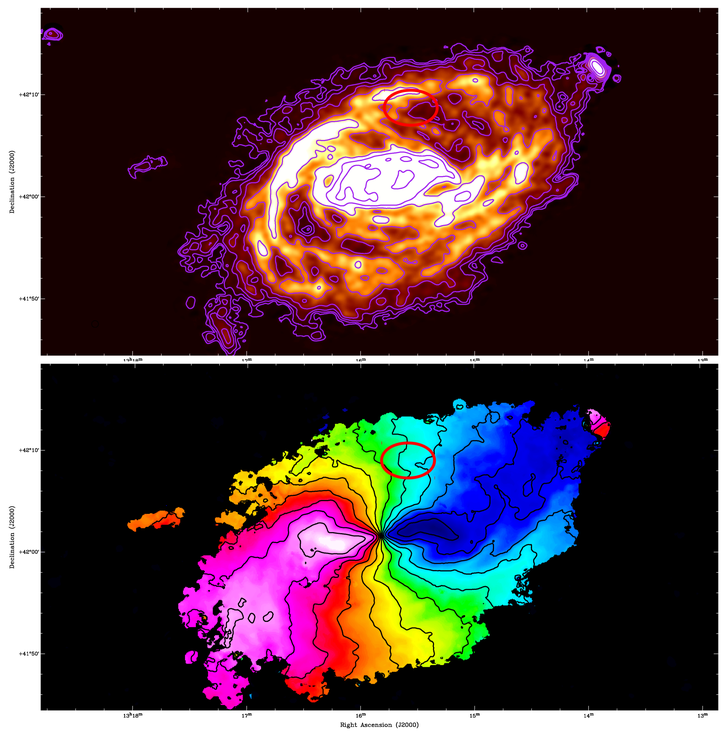

Figure 1. *Moment-0 column density map (top) and moment-1 velocity map (bottom) for NGC 5055.*

The data shown here have a total integration time of 10x12 hours, a beam size of 35.63" x 33.03" and a velocity resolution of 4.12 km/s.

The deepest contour for the moment-0 map corresponds to a column density of 1.1×10^{19} cm^{-2}.

With the red circle, we mark the same location as highlighted at the end of the stellar stream in Fig. 2 for comparison.

Details concerning the HALOGAS observations can be found on the HALOGAS website at **www.astron.nl/halogas** *or in the recent pilot paper by Heald et. al. (2011).*

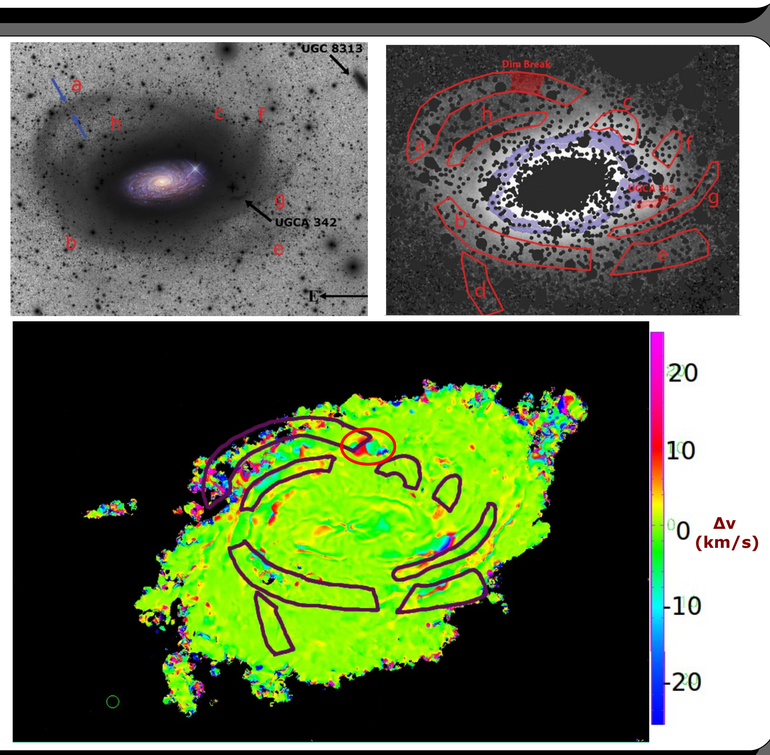

Figure 2. *The two top images show low surface brightness optical features identified by Chonis et. al. (2011). The authors characterize the arc-loop feature labeled "a" as a stellar stream resulting from the disruption of a dwarf companion.*

In the bottom image, we show the difference between an intensity-weighted mean velocity map and a velocity map constructed with the peak of a Gaussian-Hermite fit to the HI profile. The resultant map essentially highlights regions with asymmetric profiles and multiple velocity components along the line of sight.

Of particular interest is the anomalous velocity HI cloud encircled in red, between the "a" and "c" loops.

Modeling

We used the software programs GIPSY (Groningen Image Processing SYstem) and TiRiFiC (Tilted Ring Fitting Code) to model the HI disk. We made a tilted-ring model with 45 rings of width 29"≈1.2 kpc based on the moment maps of Fig. 1 and then made adjustments based on visual inspection.

The current model has a large warp and is best fit with rings that are not concentric but have centers and systemic velocities that vary with radius.

Future work for the model includes exploring the addition of a lagging component as well as spiral arm-like features.

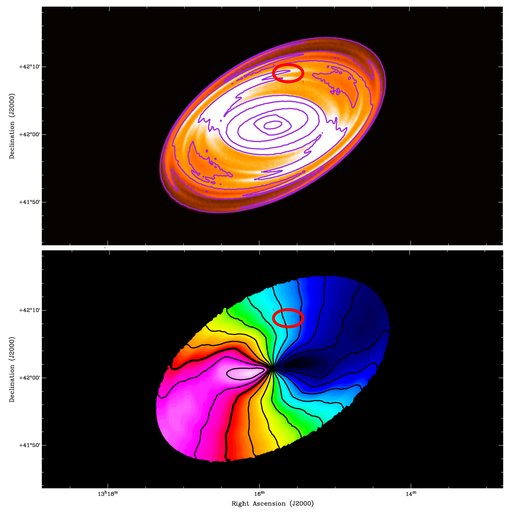

Figure 3. *Moment maps for our current tilted-ring model of NGC 5055, using the same contours as Fig. 1 for comparison.*

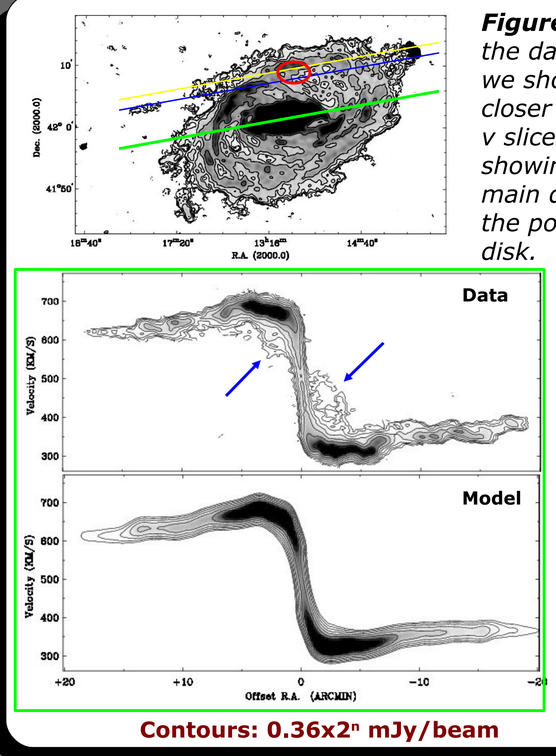

Figure 4. *Position-velocity diagrams across various slices of the data and model for NGC 5055. In green to the bottom left, we show a slice along the major axis. Notice gas "lagging" closer to systemic velocity. To the bottom right, we show 5 p-v slices through the anomalous velocity cloud encircled in red, showing a probable stream of gas outside the velocities of the main disk. Notice, here, gas in the "forbidden" quadrants of the position-velocity diagrams and gas rotating faster than the disk.*

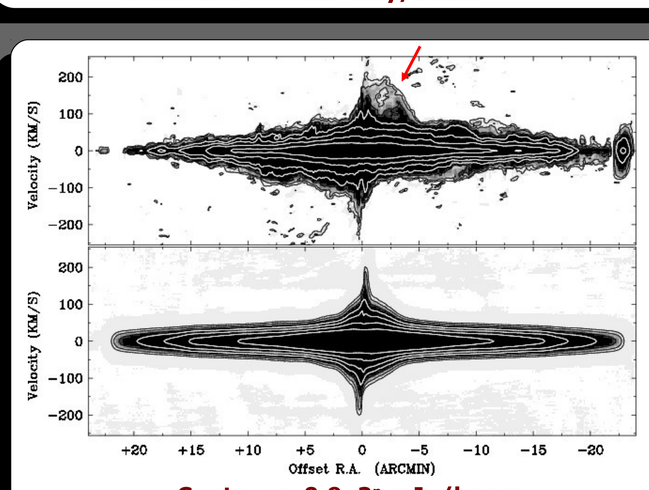

Figure 5. *Total HI position-velocity diagrams for NGC 5055 data (top) and model (bottom) parallel to the major axis after integrating the derotated HI emission along the minor axis. Emission from the disk is centered about 0 km/s, while gas that is "lagging" will shift to positive velocities on the approaching side (right) and negative velocities on the receding side (left). The bubble protruding on right side is likely the large anomalous velocity cloud in Fig. 2.*

Clouds, streams, and anomalous velocity gas

The HI data for NGC 5055 shows previously undetected HI clouds providing possible evidence for accretion both outside and within the HI disk of the galaxy.

To the southeast is a large (~320" = 13 kpc) filament of mass $\sim2.7\times10^7$ $M_\odot$. To the far east is a stream outside of the disk of length about 14.5 kpc and mass $\sim9.4\times10^6$ $M_\odot$. The large anomalous velocity cloud within the disk has a mass of $\sim1.5\times10^7$ $M_\odot$. Given its mass and an expansion velocity of ~50 km/s estimated from the total HI p-v diagram of Figure 5, this object would have required an energy input of roughly 4×10^{53} ergs, or 400 supernovae to be created. This is suggestive of an external origin.

Figure 4 shows some anomalous velocity HI in the inner parts of the galaxy, lagging closer to the systemic velocity. This "beard" may signify gas above or below the disk that is rotating more slowly than the disk, as seen in the PV diagrams of, for example, NGC 2403 (Fraternali et al. 2002). Additionally, in p-v diagrams sliced through the anomalous velocity cloud highlighted in Figure 2, we see gas rotating faster than the disk and gas in the "forbidden" quadrant, also suggesting an external origin for this feature.

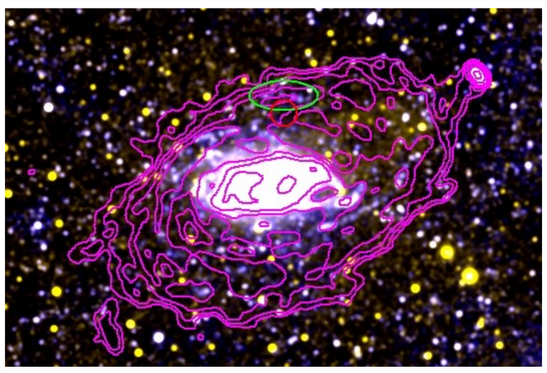

Figure 6. *GALEX image overlaid with HI contours. With the red circle, we highlight the location of the anomalous velocity cloud at the end of the optical stellar stream. While this cloud has no GALEX counterpart, directly north is a region of faint UV emission in the extended UV (XUV) disk. The optical features marked as "h" and "g" arcs in Fig. 2 have both GALEX and HI spiral arm- like counterparts.*

Conclusions

NGC 5055 shows HI clouds and streams outside of the main disk and at velocities consistent with an external origin. We are in the process of compiling these types of features into an "accretion catalog" for all the HALOGAS galaxies.

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Acknowledgments

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