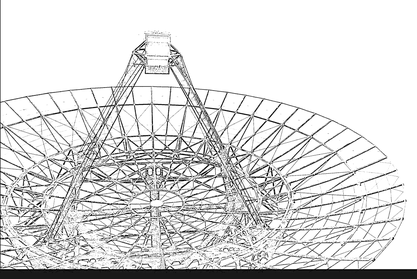


The WSRT HALOGAS Survey: HI Observations of NGC 5055

Maria T. Patterson (NMSU), Rene Walterbos (NMSU), George Heald (ASTRON), Gyula Jozsa (ASTRON), Laura Zschaechner (UNM), Richard Rand (UNM), David Thilker (JHU), and the HALOGAS team

Introduction

We present deep neutral hydrogen observations of the nearby spiral galaxy NGC 5055 as part of the Westerbork Hydrogen Accretion in LOcal GAlaxieS (HALOGAS) survey currently being performed with the Westerbork Synthesis Radio Telescope (WSRT). See **Heald et al. (2011)** for a comprehensive overview of the HALOGAS survey.

The galaxy NGC 5055 is a moderately-inclined SAbc galaxy with a large pronounced warp of the extended gaseous disk and a declining rotation curve outside of the optical radius. We present an analysis of new HI data for this galaxy based on modeling of the 3-D HI distribution and kinematics. We also discuss the relation between star formation in the faint outer disk by comparison of the HI with GALEX.

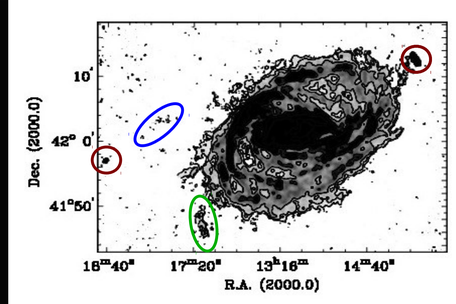


Figure 1. Moment-0 map of NGC 5055 for 30"-taper data cube with beam size 35.6"×33.0". The red circles show the positions of UGC 8365 (left) and UGC 8313 (right). The blue and green ellipses show HI clouds that cannot be explained by modeling and are possible signs of accretion.

Contours: 1.9x2ⁿ mJy/beam

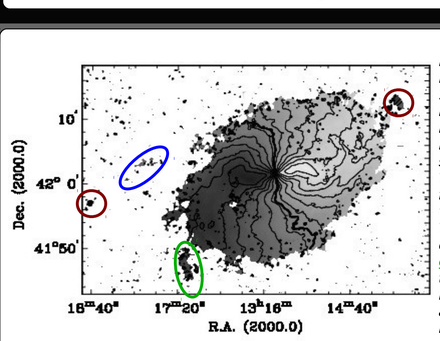


Figure 2. Moment-1 map of NGC 5055. The data cube has a velocity resolution of 4.12 km/s, and the west side is approaching. The thick line contour follows the systemic velocity at 498 km/s. The HI features enclosed in blue and green can be seen in the channel maps below near 562 km/s and 610-650 km/s, respectively.

Contours: Δ30 km/s from 270 to 780 km/s

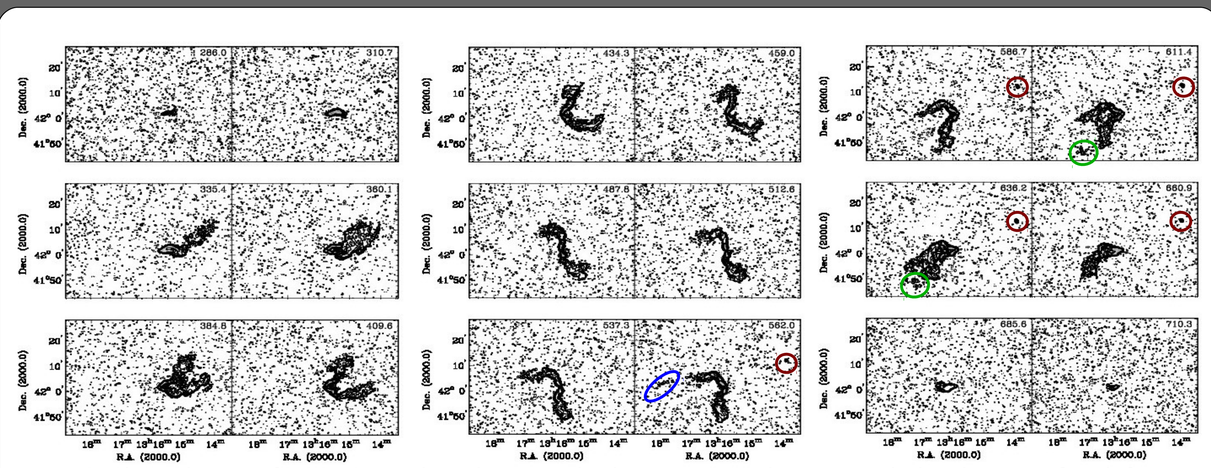


Figure 3. Channel maps of NGC 5055. The velocities in km/s are given in the upper right hand corner of each frame. The blue and green ellipses show the positions of the corresponding filaments in Figs 1 and 2. The red circles show UGC 8313.

Contours: 0.36x2ⁿ mJy/beam

Data and Observations

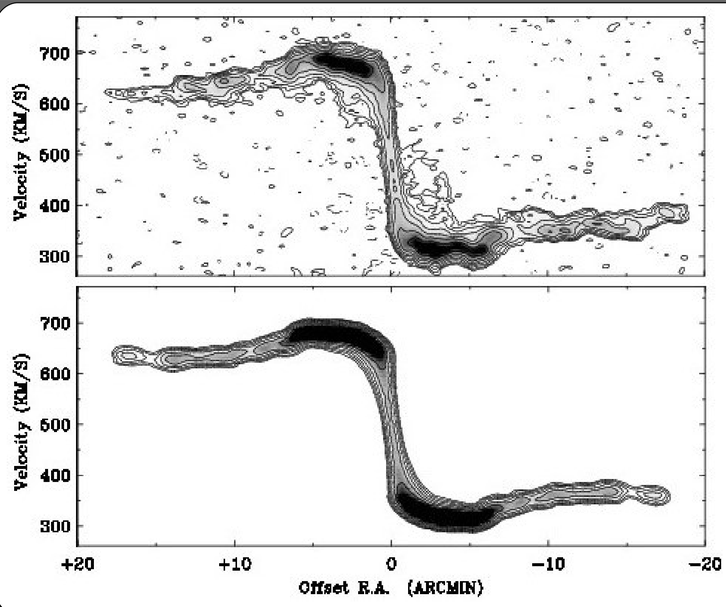
Figures 1 and 2 show moment maps for the HALOGAS 10×12 hrs observations of NGC 5055. The deepest contour for the moment-0 map corresponds to a column density of 7.8×10^{18} cm^{-2}. The rms noise for these data is 0.18 mJy beam^{-1}, meaning the data is sensitive to a column density of 2.1×10^{18} cm^{-2} at the 3σ level.

We estimate the total HI mass of NGC 5055 corrected for primary beam attenuation to be ~8.5×10^{9} $M_\odot$, assuming a distance of 8.5 Mpc. This is consistent with previous results of Battaglia et al. (2006) and Bosma (1978), corrected for distance.

Discussion

Previously undetected HI clouds providing possible evidence for accretion are encircled in Figures 1 and 2 and in individual channel maps in Figure 3. To the south is a large (~320" = 13 kpc) filament of mass ~2.7×10^{7} $M_\odot$. To the east are HI clouds suggesting a possible interaction with the galaxy UGC 8365, which was not seen in previous observations.

Below, 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).



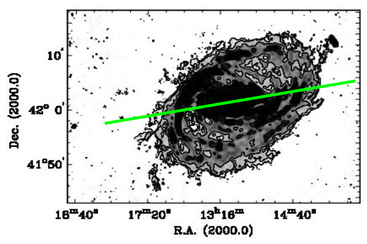


Figure 4. Position-velocity diagrams of NCG 5055 sliced along the optical major axis, as shown above. Top left shows the data. Bottom left is a slice through our preliminary model. At a distance of 8.5 Mpc, 1' = 2.5 kpc.

Contours: 0.38x2ⁿ mJy/beam

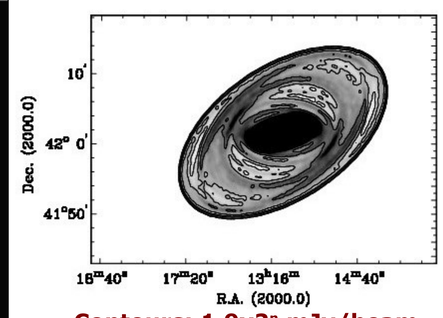


Figure 5. Moment-0 map of NGC 5055 model, with the same contours as Figure 1.

Contours: 1.9x2ⁿ mJy/beam

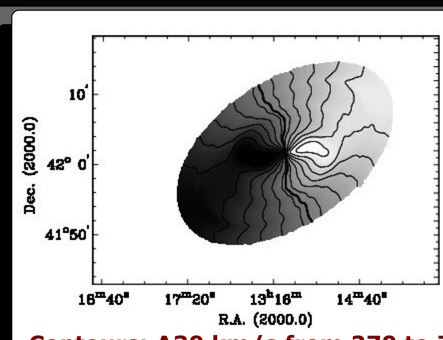


Figure 6. Moment-1 map of NGC 5055 model, with the same contours as Figure 2.

Contours: Δ30 km/s from 270 to 780 km/s

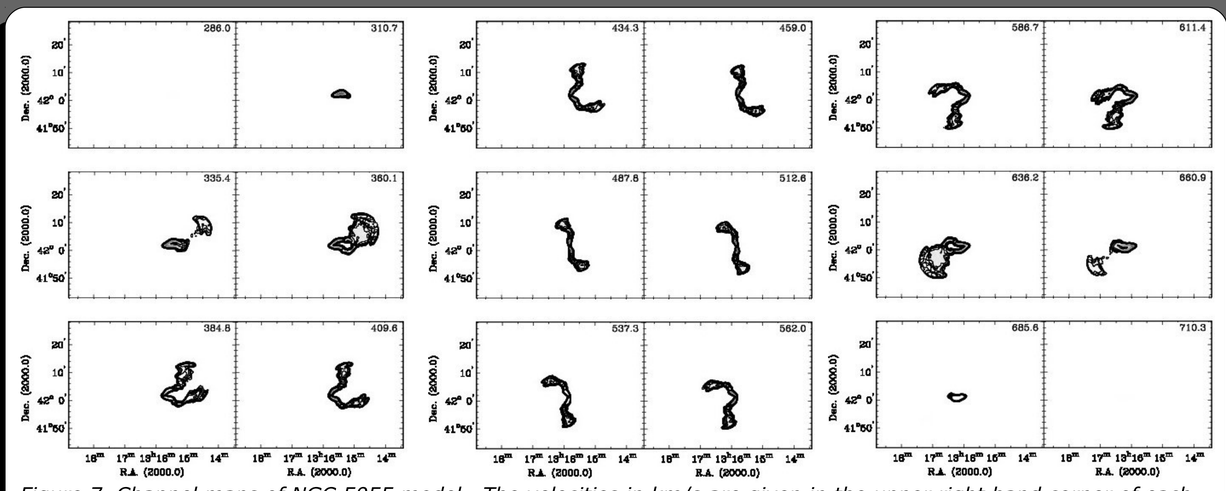


Figure 7. Channel maps of NGC 5055 model. The velocities in km/s are given in the upper right hand corner of each frame. The contours are the same as in Figure 3.

Contours: 0.36x2ⁿ mJy/beam

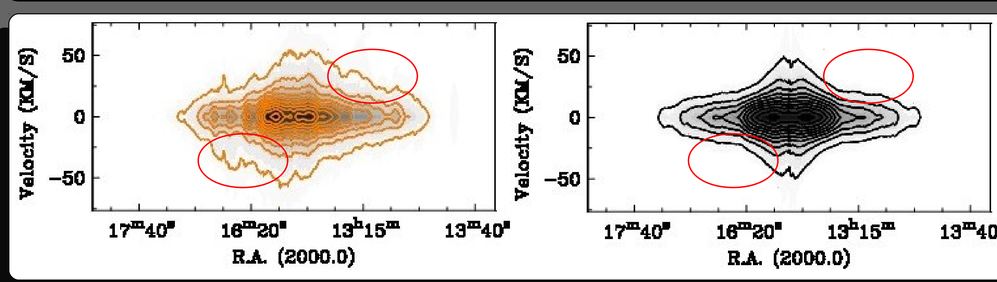


Figure 8. Integrated pv diagrams for the data (left) and model (right). In the data, the receding (left) half shows HI at lower velocities and the approaching (right) half shows HI at higher velocities. This may indicate a lagging halo. Adding a lag to the model may be an improvement.

GALEX

NGC 5055 has a prototypical Type-I XUV (extended UV) disk (Thilker et al. 2007), with concentrated UV-bright complexes beyond the radius of expected star formation. The UV emission follows the dense HI spiral arms in the disk, however we do not see UV emission in all regions of dense HI. We also do not see UV emission in the outermost HI filaments.

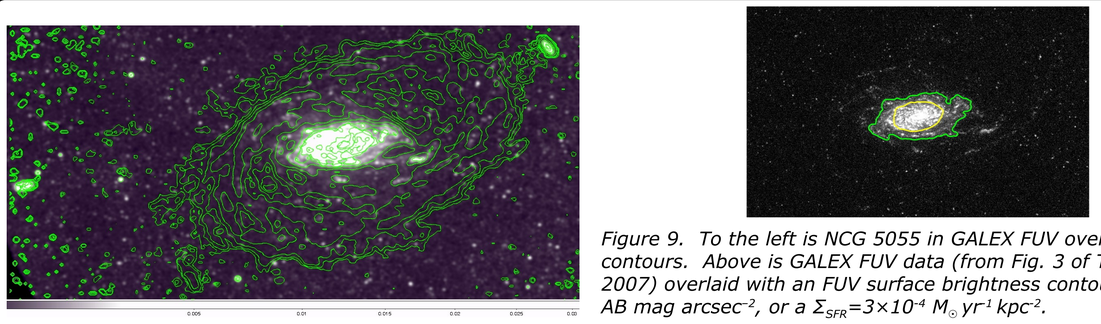


Figure 9. To the left is NCG 5055 in GALEX FUV overlaid with HI contours. Above is GALEX FUV data (from Fig. 3 of Thilker et al. 2007) overlaid with an FUV surface brightness contour at 27.25 AB mag arcsec^{-2}, or a $\Sigma_{SFR}=3\times10^{-4}$ $M_\odot$ yr^{-1} kpc^{-2}.

Conclusions

In our new data of the HI for NGC 5055, we find that the HI disk extends to ~48 kpc from the galaxy center, nearly 3.5 R_{25}. Our preliminary warped disk tilted-ring model nicely explains most features, but there are HI clouds and filaments that cannot be explained by the modeling pointing to a possible external origin. We also find a stream of clouds that may be evidence for an interaction with the galaxy UGC 8365.

Our future work includes a further exploration of the HI model, including the addition of a lagging halo and an in-depth look at the correlation between the HI and the outer disk star formation.

Modeling

We used a tilted-ring modeling software program based in the Groningen Image Processing System (GIPSY) to model the HI. We fit for initial input parameters such as position angle, inclination, rotational velocity, and column density in 40 concentric rings of width 29"≈1.2 kpc using the moment maps shown in Figures 1 and 2, and then made adjustments to the model by visual inspection. Figures 5 and 6 show the moment maps for a preliminary model with the same contours as for the data. At a distance of 8.5 Mpc, our model extends to a radius of ~48 kpc. Figure 7 shows channel maps of the model for comparison to the data. In both the moment maps and the channel maps can be seen HI clouds and filaments outside of the disk that cannot be explained by our model. Figure 8 shows integrated pv diagrams for the data and model, which may indicate a lag in the data.

Acknowledgments

This material is based in part upon work supported by the National Science Foundation under Grant No. AST 0908106 to RJR and AST 0908126 to RAMW. RAMW also acknowledges support from Research Corporation for this project.

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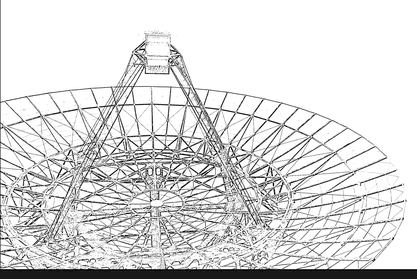


The WSRT HALOGAS Survey: HI Observations of NGC 4258

Maria T. Patterson (NMSU), Rene Walterbos (NMSU), George Heald (ASTRON), Laura Zschaechner (UNM), and the HALOGAS team

Introduction

In this slide we present an initial model for the neutral hydrogen disk of NGC 4258 based on preliminary HALOGAS survey 4x12 hr data. We follow the same method as described in the previous slide.

The galaxy NGC 4258 (also M106) is a moderately inclined SABbc galaxy with a star formation rate of 1.7 $M_\odot$ yr^{-1}. We adopt a distance of 7.6 Mpc. NGC 4258 has the unique characteristic of having anomalous spiral arms seen in both x-ray and radio continuum (blue and purple in the image below).

Image Credit:
X-ray (blue): Yuxuan Yang (UMCP) et al., NASA, CXC
Optical (gold): DSS
IR (red): NASA, JPL-Caltech
Radio (purple): NRAO, AUI, NSF.

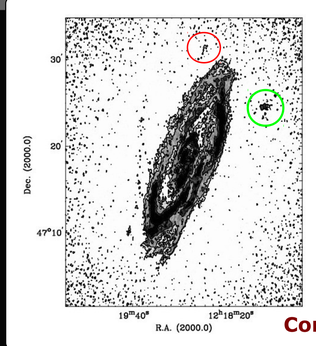


Figure 1. Moment-0 map of NGC 4258 for 4x12 hr data cube with beam size 18.4"×13.5". To the north and to the east are HI filaments extending from the galaxy. Encircled in green is the galaxy NGC 4248. In red is an HI cloud.

Contours: 16 x2^n mJy/beam

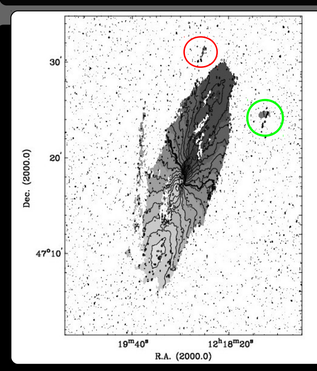


Figure 2. Moment-1 map of NGC 4258. The data cube has a velocity resolution of 4.12 km/s, and the southeast side is approaching. The thick line contour follows the systemic velocity at 468 km/s. The data shows asymmetry across the major axis in the velocities, particularly near the systemic velocity.

Contours: Δ30 km/s from 220 to 730 km/s

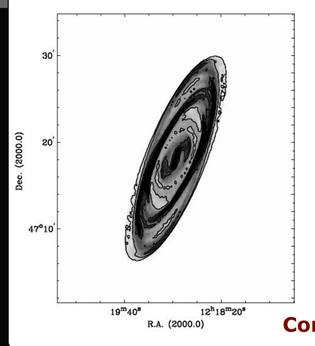


Figure 5. Moment-0 map of our first model for the preliminary data for NGC 4258, with the same contours as Figure 1.

Contours: 16 x2^n mJy/beam

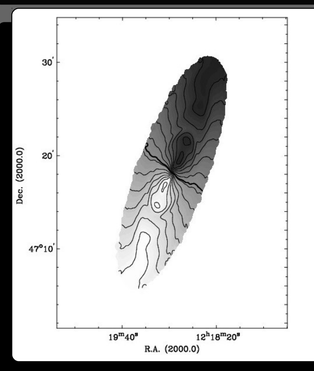


Figure 6. Moment-1 map of the initial model for NGC 4258, with the same contours as Figure 2.

Contours: Δ30 km/s from 220 to 730 km/s

Modeling

We fit for initial input parameters such as position angle, inclination, rotational velocity, and column density in ? concentric rings of width 27"≈1 kpc using the moment maps shown in Figures 1 and 2, and then made adjustments to the model by visual inspection. Figures 5 and 6 show the moment maps for a preliminary model with the same contours as for the data. At a distance of 7.6 Mpc, our model extends to a radius of ~30 kpc.

Figure 7 shows channel maps of the model for comparison to the data. In Figure 8, we overlay the moment maps for both the data and the model with radio continuum contours.

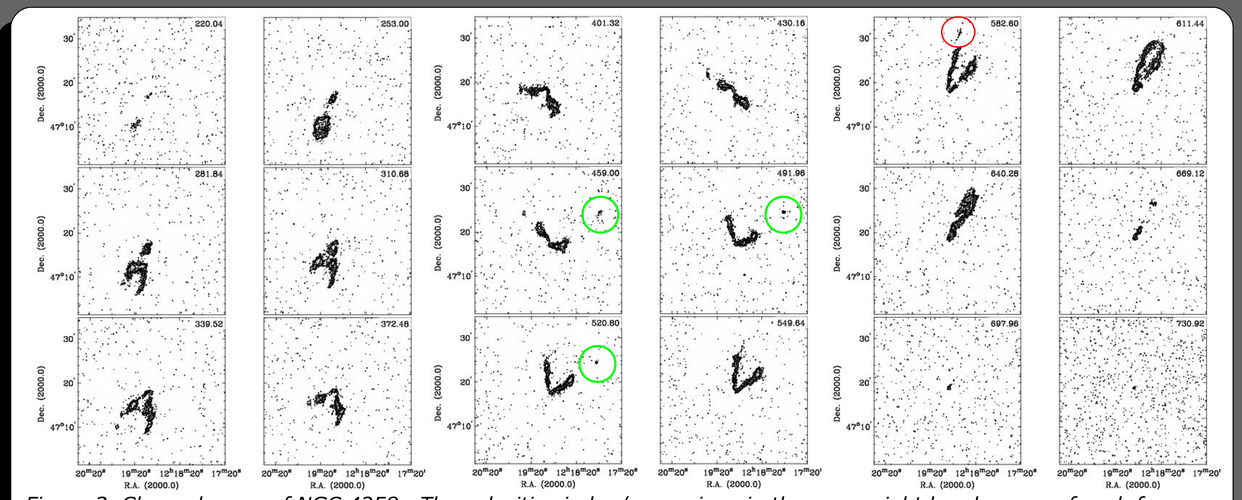


Figure 3. Channel maps of NGC 4258. The velocities in km/s are given in the upper right hand corner of each frame. Encircled in green is the galaxy NGC 4248, and in red the cloud corresponding to the encircled cloud in Figs 1 and 2.

Contours: 1.2 x2^n mJy/beam

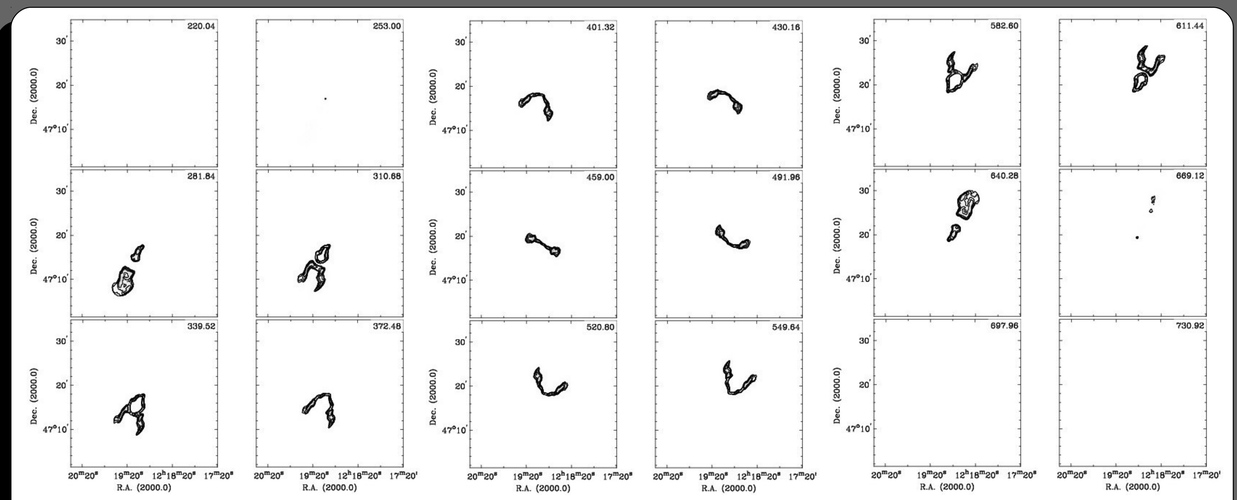


Figure 7. Channel maps of NGC 4258 model. The velocities in km/s are given in the upper right hand corner of each frame. The contours are the same as in Figure 3.

Contours: 1.2 x2^n mJy/beam

Data and Observation

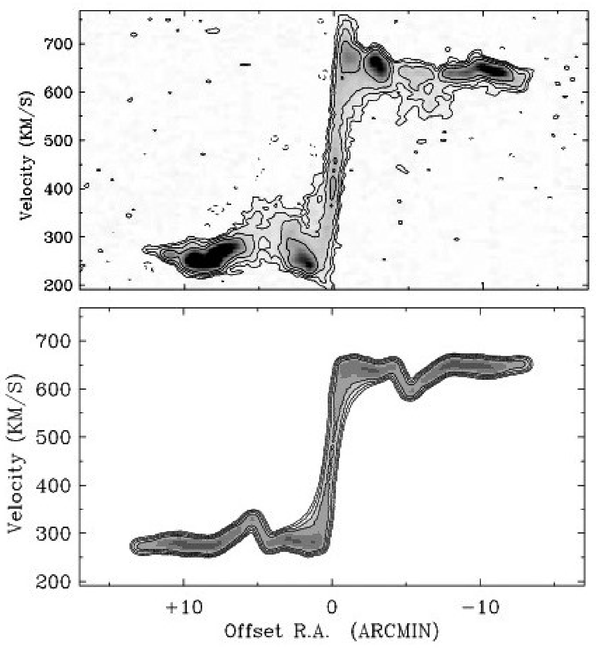
Figures 1 and 2 show moment maps for the HALOGAS 4×12 hrs observations of NGC 4258. The deepest contour for the moment-0 map corresponds to a column density of 3×10^{20} cm^{-2}. The full data set should be sensitive down to $\sim10^{18}$ cm^{-2}.

We estimate the total HI mass of NGC 4258 corrected for primary beam attenuation to be 6.5×10^9 $M_\odot$, assuming a distance of 7.6 Mpc. This is consistent with previous results of van Albada (1980), corrected for distance.

Discussion

These observations show an HI cloud to the north of the galaxy, encircled in the moment maps and shown in the corresponding channel maps of Figure 3 at ~580 km/s. Also interesting is the large HI filament extending from the southeastern end of the galaxy to the north.

Below, Figure 4 shows some anomalous velocity HI, lagging closer to the systemic velocity, a beard similar to that of NGC 5055 shown in the previous slide. The beard gas is prevalent enough to have caused an offset in our derived rotation velocity input for the preliminary model. It is likely that this model would be improved with a simpler rotation curve and the possible addition of a vertical decrease in velocity.



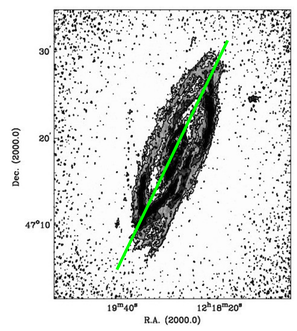


Figure 4. Position-velocity diagrams of NCG 4258 sliced along the optical major axis, as shown above. Top left shows the data. Bottom left is a slice through our preliminary model. At a distance of 7.6 Mpc, 1' = 2.21 kpc.

Contours: 2.4 x2^n mJy/beam

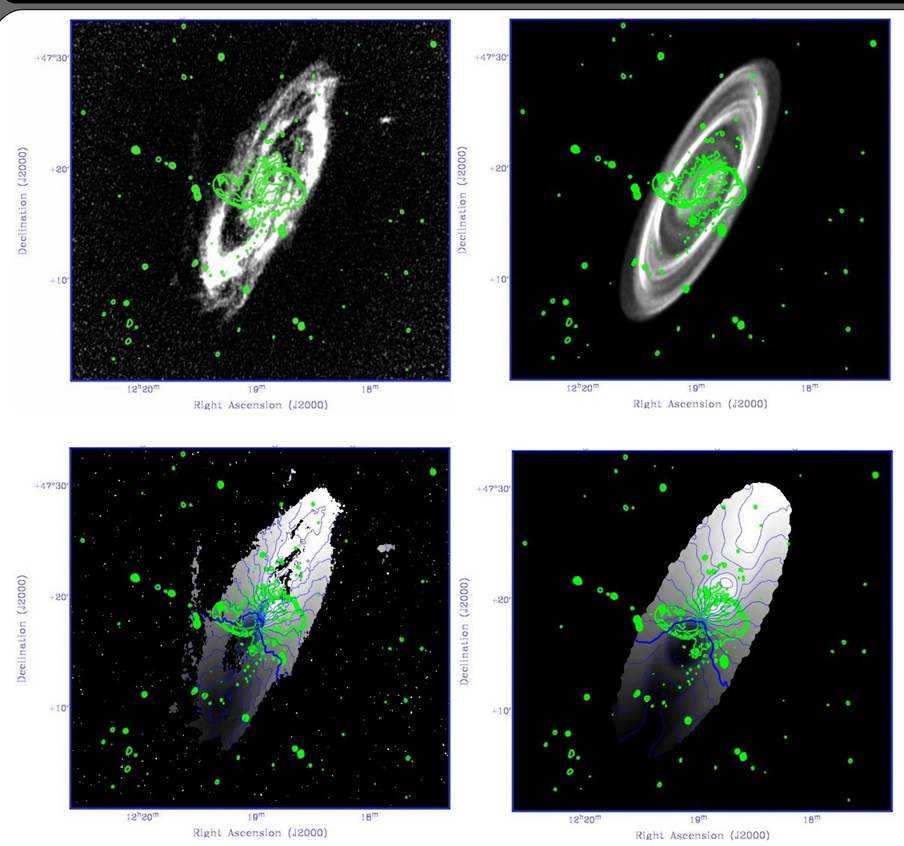


Figure 8.

Top: *HI moment-0 column density maps for the 4x12 hour data (left) and our preliminary model (right) overlaid with radio continuum contours (green).*

Bottom: *HI moment-1 velocity maps for the data (left) compared to the preliminary model (right) overlaid with radio continuum contours (green).*

The data are asymmetric in a way that cannot me explained by this initial model. It may be that the asymmetry is due to spiral arm signatures in the HI. Alternatively, it is possible that the radio continuum arms and the asymmetry in the HI moment maps may share a common cause. We do not, however, know whether the anomalous radio continuum arms are in the same plane as the HI.

Conclusions

This first model, though not without obvious problems, is a good representation of the main features of NGC 4258. The full observations (10x12 hrs) will push the sensitivity down two orders of magnitude in column density. It will be interesting to see whether more HI clouds and filaments will become obvious.

Our main goal in improving the model will be to address the asymmetries in the data and see whether or not this can be recreated in an improved model.

Acknowledgments

This material is based in part upon work supported by the National Science Foundation under Grant No. AST 0908106 to RJR and AST 0908126 to RAMW. RAMW also acknowledges support from Research Corporation for this project.

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