Ionized Gas Velocities for Edge-on HALOGAS Galaxies

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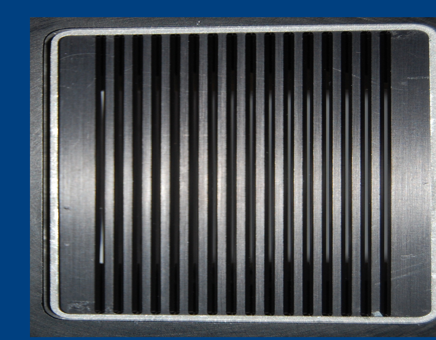
Introduction

Several galaxies show decreasing rotational velocities of neutral and ionized hydrogen gas with increasing height above the disk (e.g. Rand 1992, Heald et al. 2007). This is likely due to a combination of outflow from galactic fountains (Shapiro & Field 1976) and infall from the IGM or satellite accretion. The degree to which each component contributes affects the rotational velocity gradient of the gas and has implications for halo formation and evolution.

We have optical observations for several edge-on HALOGAS (Hydrogen Accretion in LOcal GAlaxieS) targets from a multi-slit spectroscopic setup on the ARC 3.5m telescope at APO. HALOGAS is a WSRT deep HI survey studying cold gas accretion in the local universe. Our multi-slit setup allows us to measure velocities of Hα-emitting gas as a function of height above the midplane in 11 radial distance bins in a single exposure. We present results from Hα observations and modeling of the ionized extra-planar gas in NGC 891, NGC 4565, and UGC 4278, three edge-on HALOGAS galaxies. The goal of our project is to characterize the kinematics of extra-planar ionized gas and see if we can detect a lagging component in any of our targets.

Multi-slit Spectroscopy



Slitmask with 11 1.5' slits

- series of uniform, parallel slits
- 11 slits, 1.5” wide, spaced 22.5” apart
- narrowband filter prevents neighboring spectra from overlapping
- 0.58 A/pix dispersion → 65 km/s resolution
- field of view: 3.75' wide, 4' tall
- used with Dual Imaging Spectrograph on the ARC 3.5m telescope at APO, NM

Observations

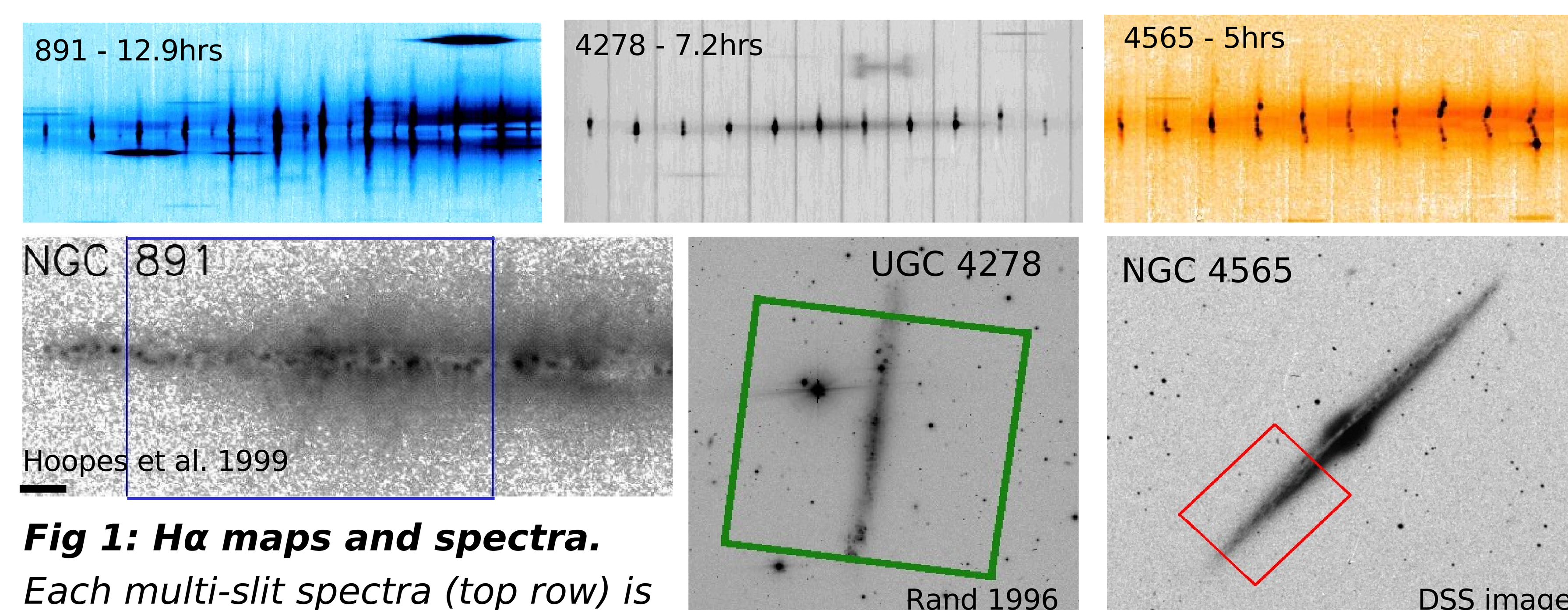


Fig 1: Hα maps and spectra. *Each multi-slit spectra (top row) is essentially 11 spectra side by side (with vertical slits). Wavelength is along the x-axis, and the wavelength range repeats for each slit. Spectra are binned spatially (vertically). Bright splotches along each slit are Hα emission, vertical stripes are skylines (most of which were subtracted), and horizontal blobs are stars. The gray-scale Hα maps (bottom row) show the observed fields overlaid with a box. The slits are oriented perpendicular to the midplane of each galaxy.*

Modeling

We measure velocities by fitting Gaussians to the emission profiles and measuring the centroids. However, because we observe edge-on targets, our line of sight (LOS) crosses through a range of observed velocities (Fig. 2), producing a non-symmetric profile with a tail (eg, Kregel & van der Kruit 2004). Centroids are biased by this tail and are not an accurate depiction of the true tangential velocity of the gas.

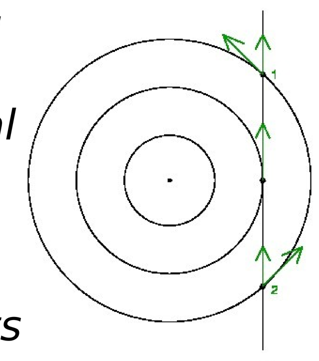


Fig 2: Viewing an edge-on disk. *Tangential and LOS velocities are shown by green arrows. At points 1 and 2, velocities smaller than v_{tan} are observed, resulting in a low-velocity tail.*

Model Inputs:
- HI rotation curve
- density scale height and length measured from our data
- vertical velocity gradient (lag)
- inclination

To correct for centroid-fitting, we model each galaxy specifically for the multi-slit setup and at the same resolution. The models are only meant to correct for centroids, so we do not include dust. For each slit position and height, we calculate density (from SH and SL) and observed velocity (from rotation curve, height, and inclination) along our LOS. This produces an emission profile which re-creates the observed Hα emission. We do this for all slits and a range of heights. We run models with different lags, measure centroids in the same way as our data, and determine which model best fits the data.

NGC 891

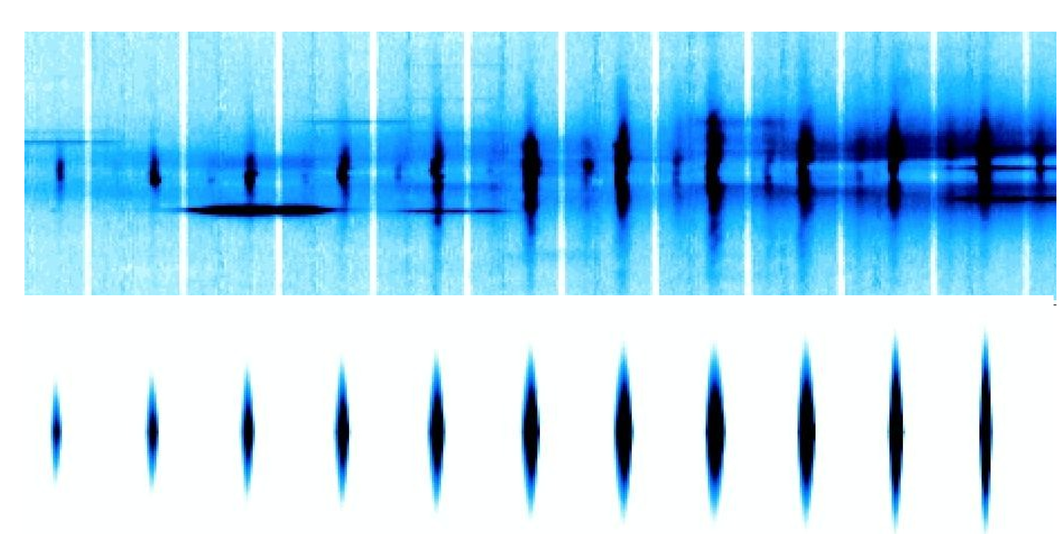


Fig 3: *Observations (top) of the approaching side of NGC 891 show extended Hα emission as vertical blobs along most slits. Dust is prominent near the midplane. The white stripes are over-subtracted sky lines. A model with a lag of 14 km/s/kpc (bottom) reproduces the observed Hα emission.*

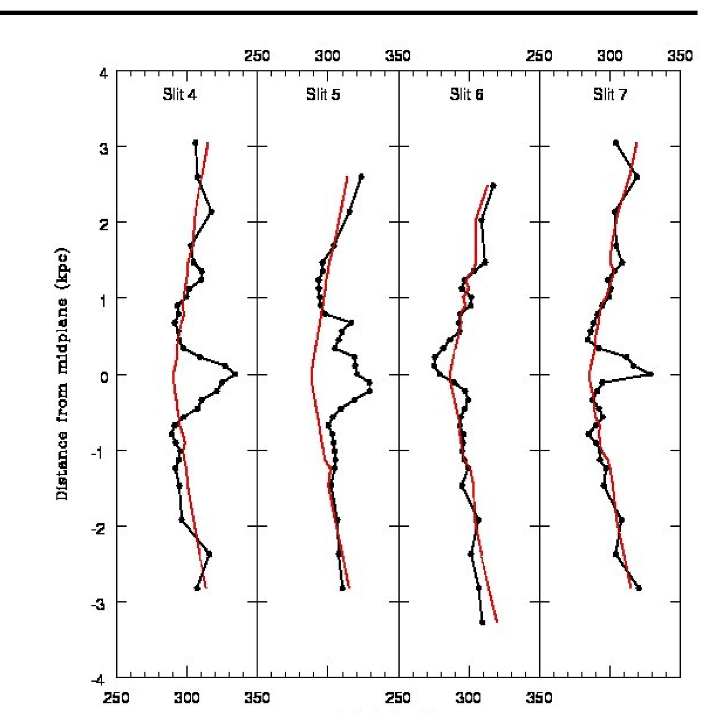
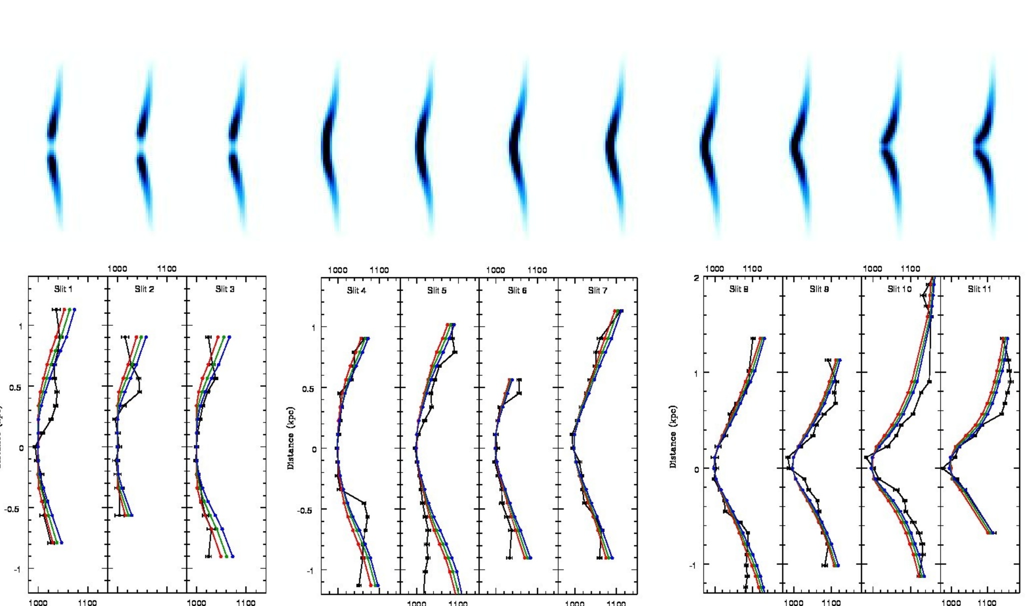


Fig 4: *Velocities from centroid-fitting to the data from 4 slits on the approaching side of NGC 891 are shown in black. Near the midplane, dust prevents a proper measure of the rotational velocity. Away from the midplane, an extra-planar lagging component would show a C-shaped curve for the approaching side of a galaxy and the opposite for the receding side. We determine a lag of 14-17 km/s/kpc best fits the data. Centroid velocities from a model with a lag of 14 km/s/kpc are overplotted in red. Our results are in agreement with previous studies of ionized EP gas in NGC 891 (Heald et al. 2006). We used this galaxy as a test target to check the validity of our methods.*

NGC 4565

Fig 5: *This galaxy is likely slightly inclined with a small scale height, which mimics a large lag in the inner galaxy and a smaller lag in the outer part. Models with inclinations of ~79 deg and no lag match observations of the outer part. Velocities are shown for models with inclinations of 78 deg (red), 79 deg (green), and 80 deg (blue). Data are in black.*



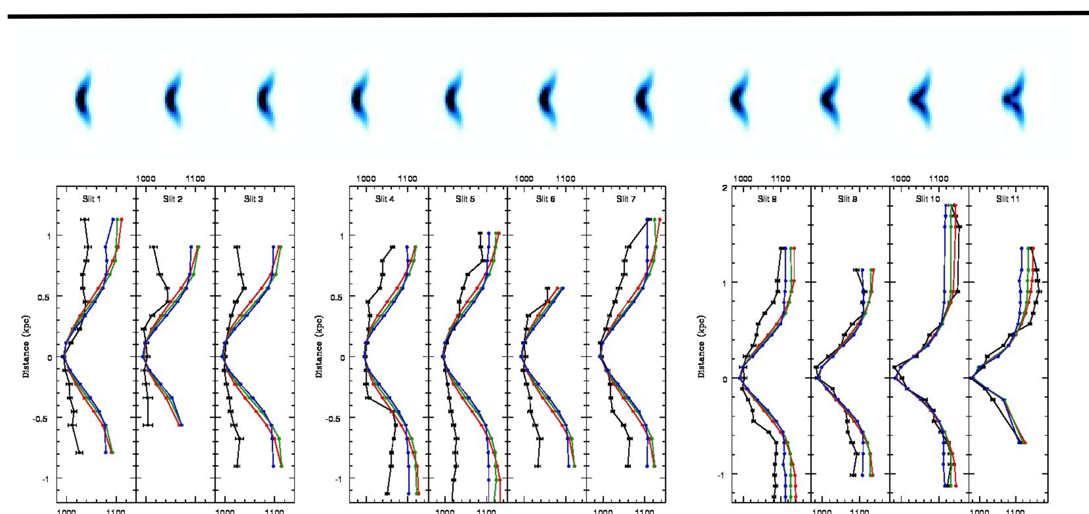
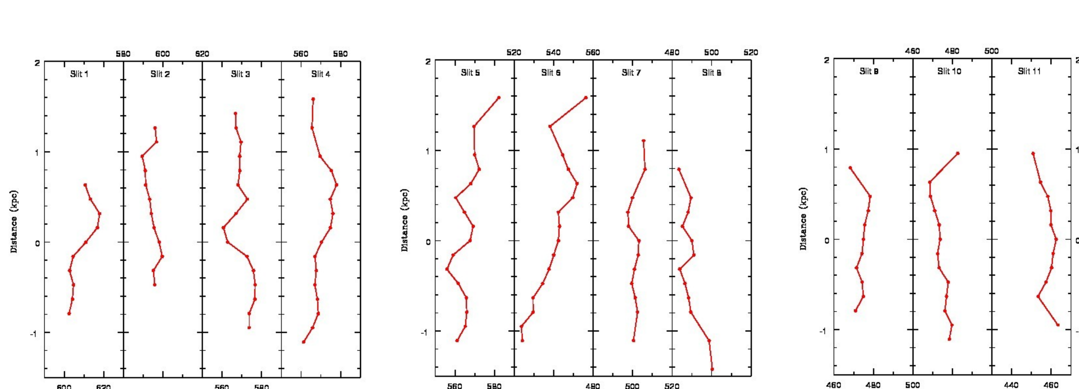


Fig 6: *Models inclined at ~86 deg and with no lag reproduce observed velocity patterns in the inner galaxy. Velocity plots are shown for models with inclinations of 85 deg (red), 86 deg (green), and 87 deg (blue). Data are plotted in black.*

UGC 4278

Fig 7: *This is a small galaxy with a low star formation rate and little Hα emission. Observations do not show a lagging component. Preliminary HI modeling (Serra et al., in prep) also shows no lag.*



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