Supplementary Materials for

Discovery of diffuse optical emission lines from the inner Galaxy: Evidence for LI(N)ER-like gas

D. Krishnarao*, R. A. Benjamin, L. M. Halfner

*Corresponding author. Email: krishnarao@astro.wisc.edu

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Optical Emission Lines

The Hα data were taken as a part of the WHAM Sky Survey (WHAM-SS) (19, 20). Each 30 second observation obtains a 200 km s⁻¹ velocity-range spectrum around Hα integrated over a 1° beam. The dataset presented here toward the Tilted Disk is derived primarily from the southern portion of the survey with WHAM sited at Cerro Tololo. While similar to those released in WHAM-SS DR1, these spectra provide a more calibrated view around the nuclear region. They will be fully integrated into the DR2 release and the survey can be accessed with the open-source python package, whampy (41) (see the WHAM-SS release documentation for details: http://www.astro.wisc.edu/wham/). Other emission-line data have been obtained as part of ongoing multi-wavelength WHAM surveys using longer (60s) observations. These spectra are processed in the same way as Hα by applying a flat-field, subtracting an atmospheric template, and subtracting a constant baseline to reach a 3σ sensitivity of 0.1 R.

Geometric Model: Neutral Gas

The original HI model was designed to describe the velocity field of neutral gas in the inner Galaxy, starting with a circular model (21, 42) and moving on the elliptical model we consider (23). Future iterations added additional gas tracers, and included the Central Molecular Zone (43, 44). We verified that this model still provides an adequate fit to the modern HI4PI survey data (22) and take this model “as is” but update the distance to Galactic Center from 10 kpc to 8.127 kpc (45). HI observations towards the inner Galaxy are most sensitive to the velocity field of the gas, as opposed to density structures, because of the large velocity gradients in this environment. Because of this, mass estimates made using the HI model may have large errors.

The iso-density contours of the neutral gas model (23) follows ellipses of the form

\[ \frac{x_d^2}{a_d^2} + \frac{y_d^2}{b_d^2} = 1 \]

where \(a_d\) and \(b_d\) are the semi-major and semi-minor axes, respectively, and
\[ a_d = b_d \left( 1.6 + 1.5 \frac{b_d}{b_d'} \right) \]

with \( b_d' = 0.488 \text{ kpc} \). The tangential velocity along the minor axis depends only on \( b_d \), with the form

\[ v_t(b_d) = 360 \text{ km s}^{-1} \left[ 1 - \exp \left( -\frac{b_d}{0.1 \text{ kpc}} \right) \right] \]

and assumes angular momentum conservation along the elliptical path. Coordinates from the elliptical disk frame \((x_d, y_d, z_d)\) are transformed to the Galactocentric frame \((x, y, z)\) using

\[
\begin{bmatrix}
  x \\ y \\ z
\end{bmatrix} =
\begin{bmatrix}
  \cos \beta \cos \theta & \cos \beta \sin \theta & -\sin \beta \\
  \cos \theta \sin \alpha \sin \beta & \cos \alpha \cos \theta & \cos \alpha \sin \beta \sin \theta \\
  \cos \alpha \sin \theta & \sin \alpha \sin \beta \sin \theta & \cos \alpha \cos \beta
\end{bmatrix}
\begin{bmatrix}
  x_d \\ y_d \\ z_d
\end{bmatrix}
\]

where \( \alpha = 13.5^\circ \) describes the tilt of the disk about the x-axis, \( \beta = 20^\circ = 90^\circ - i \) describes the inclination, \( i \), of the disk, and \( \theta = 48.5^\circ \) describes the angle between the major axis of the elliptical disk and the x-axis. Although \( \theta \) does not line up with current estimates of the bar/bulge angle, for the purposes of estimating the relative amounts of neutral and ionized gas, we chose not to modify this parameter.

In this picture, the origin is at Galactic Center, the positive x-axis points parallel to the sun-Galactic Center direction, and the positive y-axis points parallel to the \( l = 90^\circ \) direction. \( \beta = 0^\circ \) corresponds to an edge-on disk. \( \alpha \), \( \beta \), and \( \theta \) describe rotations along the x, y, and z axes, respectively. Positive \( \alpha \) indicates that positive longitudes are rotated below the Galactic plane; positive \( \beta \) indicates that the near side of the disk is rotated below the Galactic plane; positive \( \theta \) indicates clockwise rotation as viewed from above.

Radial velocities are converted to local standard of rest (LSR) velocities when computing the model. HI emission within each cell is calculated from the gas density as follows. The emission along a single line of sight at some LSR velocity, \( v \), is given by

\[ T_b(v) = T_{\text{gas}} \left( 1 - e^{-\tau(v)} \right) \]

where \( T_b(v) \) is the brightness temperature observed at some velocity channel, \( T_{\text{gas}} \) is the temperature of the neutral hydrogen gas, and \( \tau(v) \) is the optical depth at some velocity channel. The optical depth is computed using
where $\Delta \tau_i(v)$ is the optical depth of neutral hydrogen gas at some velocity, $v$, within cell $i$, $n_{\text{H},i}$ is the neutral hydrogen gas density within the cell, and $\sigma_i$ is the gas velocity dispersion within the cell, $v_i$ is the radial LSR velocity of the neutral hydrogen gas within the cell, and $\Delta d_i$ is the width of the cell in parsecs (46). For this model, $T_{\text{gas}} = 120$ K and $\sigma_i = 9$ km s$^{-1}$. We have compared the results of our model to longitude-velocity slices at fixed latitude and found good agreement. A synthetic HI datacube can be computed using `modspectra` via `cube.EmissionCube.create_LB80()`.

We also provide estimates of both the total neutral mass and the mass of neutral gas in the same direction and velocity range as where we detect ionized gas. The original neutral Tilted Disk model did not provide uncertainty estimates, so we adopt an uncertainty of 30%. Near Baade’s window, we estimate the neutral gas mass using the HI 21-cm observations integrated over the directions $l = 0^\circ$ to $6^\circ$, $b = -7^\circ$ to $-2^\circ$ within the velocity interval, $v_{\text{LSR}} = -120$ to $-40$ km s$^{-1}$, and using distance estimates from the Tilted Disk model. Assuming optically thin media (47), we estimate the neutral gas mass as

$$M_{\text{H}^0} = \sum_i N_{\text{HI},i} \left( \frac{D_i \Delta \theta}{2} \right)^2$$

$$N_{\text{HI},i} = \int_{-120 \text{ km s}^{-1}}^{-40 \text{ km s}^{-1}} 1.82 \times 10^{18} \text{ cm}^{-2} \text{K}^{-1} \text{km}^{-1} \text{s} \ T_i(v) \ dv$$

where $i$ refers to each observed pixel in the HI4PI data, $\Delta \theta$ is the angular size of the pixel in radians, $T_i$ is the observed brightness temperature in K, and $D_i$ is the distance to emitting gas taken from the Tilted Disk model. Our uncertainties in the observed neutral gas mass in the direction of Baade’s window are primarily propagated from errors in the model distance estimates.

Geometric Model: Ionized Gas

We adopt the orientation and kinematics of the neutral gas model described above, but vary the density structure of ionized gas and include the extinction along the line of sight in order to predict the H$\alpha$ profile. The ionized gas density is modeled as a function of

$$n_e(r, z_d) = n_{e,r}(r) \exp\left[-\frac{1}{2}\left(\frac{z_d}{H_{z,r}(r)}\right)^2\right]$$

radius and height as
Fig. S1. Tilted Disk Model Schematic. A schematic of the updated tilted elliptical model of neutral (shaded) and ionized gas (shaded and hatched), showing the disk midplane (grey), and disk at \( z_d = \pm H_z \) (red/blue) projected onto the sky in Galactic Coordinates. An angular momentum vector is shown going through the center of the disk and the major axis of the ellipse along the midplane is shown with a dotted line.

where \( r \) and \( z_d \) are in cylindrical coordinates for the tilted disk, \( n_{e,r}(r) \) is the midplane ionized gas density as a function of \( r \), and \( H_{z,r}(r) \) is the vertical scale height of the ionized gas as a function of \( r \). Both \( n_{e,r}(r) \) and \( H_{z,r}(r) \) depend on the amount of flaring as parameterized by a flaring factor \( F_z \) such that

\[
    n_e(r) = n_{e,0} H_{z,0} / H_z(r)
\]

where \( r_{\text{max}} \) is the max radial coordinate of the disk, corresponding to the value of the largest semi-major axis \( (a_d' = 1.5128 \text{ kpc}) \), and \( n_{e,0} \) and \( H_{z,0} \) are the midplane ionized gas density and ionized gas scale height at \( r = 0 \), respectively. Figure S1 shows a schematic

\[
    H_z(r) = H_{z,0}[(1 - x) + F_z x]
\]
of the model Tilted Disk projected on the sky, showing the disk midplane (grey) and ±1 scale height (red/blue) along with an angular momentum vector.

**Fig. S2. Modeled and Observed Hα Spectra.** Map of Hα Emission from WHAM (blue solid line) and synthetic observations (orange dashed line) of the ionized tilted disk towards Baade’s Window; spectra are shown between -150 km s\(^{-1}\) < \(v_{\text{LSR}}\) < -20 km s\(^{-1}\). Spectra outlined in black are used in the ionized gas model fitting process and are selected based on having a mean velocity in the “forbidden” range associated with the tilted disk (as opposed to broad wings from local emission) and sufficient Hα emission. The green shaded regions show the velocity range considered when optimizing the model and the grey shaded regions show local emission not considered in this model. Orange asterisks mark the directions where we are able to place points on the BPT Diagram in **Fig. 2**. Pink pound symbols mark the six directions where only [NII]/Hα is detected; on the BPT diagram of **Fig. 2**, these are indicated with vertical lines.

The Hα emission in photon units of Rayleighs (R) is calculated for our model with Case B recombination using
Fig. S3. Ionized Tilted Disk Posterior Distributions. Posterior distributions of the ionized gas model parameters, $n_{e,0}$, $H_{n,0}$, and $F_z$ for three different model fitting runs for the mean estimated $A_v$ (orange) and upper (blue) and lower (green) $A_v$ estimates. The solid line shows the 50th percentile of the mean $A_v$ posterior distribution and the 16th and 84th percentiles are shown with dashed lines as estimates for the uncertainties in these parameters. Extinction based uncertainties only strongly affect the $n_{e,0}$ parameter and our quoted uncertainty for this parameter is the 16th and 84th percentile from the low and high extinction runs, respectively. Dotted lines show the 50th percentile of the posterior distribution for the upper and lower $A_v$ estimates. Our adopted uncertainties correspond to the dashed orange lines for $H_{n,0}$ and $F_z$, and the dashed green and blue lines for $n_{e,0}$. The density parameter is the only one strongly affected by different extinction estimates.
| Parameter                  | Symbol   | Value   | Units    |
|---------------------------|----------|---------|----------|
| Semi-Minor Axis           | $b_d'$   | 0.488   | kpc      |
| Semi-Major Axis           | $a_d'$   | 1.5128  | kpc      |
| Max Tangential Velocity   | $v_{T,\text{max}}$ | 360     | km s$^{-1}$ |
| Tilt Angle                | $\alpha$ | 13.5    | degrees  |
| Inclination               | $i$      | 70      | degrees  |
| 90° - Inclination         | $\beta$  | 20      | degrees  |
| Major Axis Angle          | $\theta$ | 48.5    | degrees  |
| Vertical Scaleheight      | $h_d$    | 81.27   | pc       |
| Midplane Gas Density      | $n_0$    | 0.33    | cm$^{-3}$ |
| Gas Temperature           | $T_{\text{gas}}$ | 120    | K        |
| Gas Velocity Dispersion   | $\sigma_{\text{gas}}$ | 9      | km s$^{-1}$ |

**Neutral Gas Model**

| Parameter                  | Symbol   | Value   | Units    |
|---------------------------|----------|---------|----------|
| Vertical Scaleheight      | $H_z$    | 0.26 ± 0.04 | kpc     |
| Vertical Flaring Factor   | $F_z$    | $2.05^{+0.42}_{-0.31}$ | None |
| Midplane Gas Density      | $n_{e,0}$ | $0.39^{+0.06}_{-0.05}$ | cm$^{-3}$ |
| Gas Temperature           | $T_e$    | 8000    | K        |
| Gas Velocity Dispersion   | $\sigma_e$ | 12    | km s$^{-1}$ |

**Ionized Gas Model**

| Parameter                  | Symbol   | Value   | Units    |
|---------------------------|----------|---------|----------|
| Vertical Scaleheight      | $H_z$    | 0.26 ± 0.04 | kpc     |
| Vertical Flaring Factor   | $F_z$    | $2.05^{+0.42}_{-0.31}$ | None |
| Midplane Gas Density      | $n_{e,0}$ | $0.39^{+0.06}_{-0.05}$ | cm$^{-3}$ |
| Gas Temperature           | $T_e$    | 8000    | K        |
| Gas Velocity Dispersion   | $\sigma_e$ | 12    | km s$^{-1}$ |

**Table S1. Tilted Disk Model Parameters.** Summary of neutral gas model parameters and results adopted from (23) and the ionized gas model from this work.
where \( n_{e,i} \) is the electron density within the cell, \( T_{e,i} \) is the electron gas temperature, 
\[ b_\lambda = -0.942 - 0.031 \ln\left(\frac{T_{e,i}}{10^4 \text{ K}}\right) \] 
is from the case B recombination rate for H\( \alpha \) \((48)\), and 
\( e^{-\tau_\lambda} \) is the dust attenuation factor with \( e^{\tau_\lambda} = 10^{-1/2.5 A_\lambda} \). We use \( A_\lambda \) from the 2MASS-based three-dimensional extinction model of Marshall et al. \((40)\), converting this into \( A_{H\alpha} \) using 
\[ R_V = 3.1 \text{ and the extinction curve of Fitzpatrick \\& Massa (49).} \] 
The extinction values are queried using the open-source python package, \textit{dustmaps} \((50)\). We use these infrared-based maps since they allow us to obtain the extinction out to the distance of Galactic Center. The combination of WHAM H\( \alpha \) and H\( \beta \) emission offers an alternate way to estimate the extinction, but have the drawback that features at different distances can blend at the same velocity. Our model cell size is 0.1° x 0.1° in solid angle, whereas the three-dimensional dust model provides extinction estimates in 0.25° x 0.25° square cells. These are convolved with the 1° beam size of WHAM observations.

For comparison with the neutral gas, we calculate the total mass of ionized gas and the ionized gas mass in the extinction window where H\( \alpha \) is detected. Errors in the ionized gas mass are estimated from the posterior distribution of parameters.

For our Bayesian parameter estimation implemented via the open-source python package, \textit{emcee} \((51)\), we use Gaussian priors of the form

\[
\ln p(\theta) \sim -\frac{1}{2} \left[ \left( \frac{n_{e,0} - 0.3 \text{ cm}^{-3}}{0.25 \text{ cm}^{-3}} \right)^2 + \left( \frac{H_{z,0} - 1 \text{ kpc}}{0.5 \text{ kpc}} \right)^2 + \left( \frac{F_{z} - 2}{3} \right)^2 \right].
\]

The priors also provide a constraint forcing \( n_{e,o} > 0, H_{z,0} > 0, \) and \( F_{z} \geq 1 \). This biases our posterior distribution but prevents non-physical results or a scale height that decreases as a function of \( r \). Our priors are chosen based on the behavior of more local and global Milky Way ionized gas \((52, 53)\) and comparisons with previous HI model modifications that include some flaring \((43, 44)\). The likelihood function uses the Gaussian errors estimated for each WHAM observation as a function of velocity \( \sigma_{H\alpha, \text{WHAM}} \) and has the form

\[
\ln p(\text{model|}\theta) \sim -\frac{1}{2} \sum_v \frac{I_{H\alpha, \text{model}}(v, \theta) - I_{H\alpha, \text{WHAM}}(v)}{\sigma_{H\alpha, \text{WHAM}}^2(v)}
\]

where \( I_{H\alpha, \text{WHAM}}(v) \) is the WHAM H\( \alpha \) observation with the local emission subtracted out as a single Gaussian (usually near \( v_{\text{LSR}} \sim 0 \text{ km s}^{-1} \)) and \( I_{H\alpha, \text{model}}(v, \theta) \) is the H\( \alpha \) emission predicted by our ionized gas model with parameters \( \theta \) using cells from a 200×200×200 grid that lie within a 1° WHAM beam. Additionally, \( I_{H\alpha, \text{WHAM}}(v) \) is limited to \( v_{\text{LSR}} < -35 \text{ km s}^{-1} \) to focus on the “forbidden” velocity gas.
Figure S2 shows observed and synthetic Hα observations towards Baade’s Window. A total of 17 WHAM beams surrounding the region of Baade’s window are used for the model fitting. These points are selected based on their Hα emission signal strength and intensity-weighted peak velocity with the criteria of $I_{H\alpha} > 0.1$ R and $-90$ km s$^{-1} < v_{LSR} < -55$ km s$^{-1}$. These 17 pointings are marked in Fig. S2 with black outlines. The results of the Bayesian parameter estimation are shown in Fig. S3. Table S1 contains the resulting parameters for both the neutral and ionized gas models.

![Figure S2: Predicted Tilted Disk Hα Map](image)

Fig. S4. Predicted Tilted Disk Hα Map. An integrated Hα map at the same velocities as in Fig. 1 from the Tilted Disk model showing that we only expect to see detectable emission through the area surrounding Baade’s low extinction window. The red emission at positive velocities above the plane is very faint and not currently detected in WHAM observations.

We run our MCMC parameter estimation three times, using a mean $A_V$ and ±1 σ errors as provided in the 3D dust map (40). Changing our $A_V$ estimate only significantly changes the posterior distribution of the $n_e,0$ parameter. Our quoted parameters are the 50th percentile with uncertainties estimated using the 16th and 84th percentiles from the posterior distribution of the mean $A_V$ MCMC run. Our uncertainties for the density parameter $n_e,0$ are computed using the 16th percentile of the $A_V - σ$ and 84th percentile of the $A_V + σ$ MCMC run. A synthetic Hα data cube can be computed using `modspectra` via `cube.EmissionCube.create_DK20()`.
In our final adopted model of ionized gas, we find that extinction is high enough over most of the structure that along a majority of sightlines the Hα should be undetectable. Our model correctly predicts, as shown in Fig. S4, that we should only detect ionized gas in the windows where we do, in fact, see it.

**Comparison with Hydrodynamical Models**

Our reference HI model (23) is chosen because of its simplicity and its ability to account for the tilted distribution of gas in the inner Galaxy. However, this model does not include any density variations with azimuth or radius as is seen in modern simulations and observations of other galaxies. A complete understanding of the gas in this region requires a more hydrodynamical approach to explain asymmetries in the vicinity of the CMZ, as demonstrated in (26). These simulations, designed to explain gas flowing in a Milky Way-like bar potential, include a photo-dissociating interstellar radiation field and a chemical network with adiabatic cooling dependent on the chemical composition. A snapshot of this simulation at 181 Myr provides a qualitative match to the observed CO longitude-velocity features observed in the inner Galaxy. These simulations provide predictions for the distribution and physical conditions of the multiphase ISM and are used here to compare with HI and Hα observations and the neutral and ionized Tilted Disk model.

![Fig. S5. Predicted Hydrodynamic Face-On Hα Map.](image)

Face-on map of Hα surface brightness from hydrodynamical simulations of (26) for t=181 Myr. Blue dotted lines enclose the region of negative-velocity gas that would be probed by WHAM observations and white dashed lines enclose an ellipse with the same physical scale as the Tilted Disk model rotated in angle to align with the simulations. The midplane density of ionized gas in the region probed by WHAM observations is approximately n_H+ = 10^{-4} cm^{-3}.
**Fig. S5** shows a predicted face-on distribution of Hα surface brightness in the inner region of a t=181 Myr snapshot from our comparison hydrodynamical model (26). The negative velocity emission observed with WHAM would originate from within the dashed blue outlines on this figure. However, these simulations predict a very low density of both neutral and ionized gas in this region; most of the mass for the l>0° direction is concentrated in the positive-velocity dense “dust lane” features. In **Fig. S6**, we show the Hα emission prediction for both the hydrodynamical model (left column) and the modified Tilted Disk model (right column) viewed edge-on from the position of the Sun, shown both with (bottom row) and without (top row) extinction. Emission from the hydrodynamical model subtends a thin layer, which would be unobservable given the extinction in the midplane. In the central column, we artificially tilted the hydrodynamical simulations in order to align the disk midplane with our extinction window. A comparison with our modified Tilted Disk model (right column) shows that the hydrodynamical models produce a much thinner and fainter ionized gas structure.

**Fig. S6. Edge-on Hα Comparisons.** Edge-on maps of Hα intensity from hydrodynamical simulations of (26) and the Tilted Disk from this work. The top row shows projections with no extinction, while the bottom row shows the same projections, but with extinction from the 3D dustmaps of (40). Maps are restricted to the “forbidden” velocities as shown within the colorbars. The left column shows the hydrodynamical simulations as originally orientated in the Galactic plane (26); the middle column shows the same simulations, but tilted to the same position angle as the Tilted Disk; the right column shows the ionized Tilted Disk from this work. The hydrodynamical models, even when artificially tilted, produce a layer that is much thinner and fainter than the best fitting Tilted Disk model.

Both the thinness of the molecular and atomic gas layer in these simulations and the lack of a tilt were discussed by the developers of this model (26; see their section 5.5). The thinness is attributed to the lack of stellar feedback and star formation in the simulations. Including these effects could provide additional turbulent pressure support. **Fig. S7** provides comparison of the predicted HI column density for the hydrodynamic model—
both flat and tilted—with the geometrical Tilted Disk model and the observations. This demonstrates that the Tilted Disk model provides a better representation of the negative velocity gas that is the focus of this paper. For this reason, we adopt this model in order to infer the physical parameters of this inner Galaxy gas structure.

![Figure S7. Edge-on HI Comparisons.](image)

A table of the total masses and vertical thickness for both the hydrodynamical and Tilted Disk models is given in Table S2. For the hydrodynamic simulations, the “total” mass of ionized and neutral gas is measured within the white ellipse shown in Fig S3 and is compared to the total mass of the Tilted Disk model. The mass of the gas interior to the blue polygon in Fig S3 covers a similar longitude and velocity range as our Baade’s window mass estimates. The atomic gas mass (neutral plus ionized) within comparable elliptical regions for both the geometrical and hydrodynamical models is similar, approximately $15 \times 10^6$ solar masses, but with much different ionization fractions: 80% ionized for the geometrical model and less than 1% ionized for the hydrodynamical model. This is likely attributable to the lack of hydrogen-ionizing photons in the radiation field used in the simulations. The atomic gas mass estimates for gas with negative velocities over the Baade’s window longitude range is more discrepant, $0.8 \times 10^6$ solar masses (geometrical) vs. $0.01\times 10^6$ solar masses (hydrodynamical), with a similar discrepancy in the ionization fraction.

Since the gas in the hydrodynamical simulations does not have a well-defined scaleheight, we define the thickness to be the height, $z_{\max}$, for which the average neutral or ionized gas density drops below $n_H=10^{-2} \, \text{cm}^{-3}$. With the exception of the original HI
Tilted Disk model (which had a fixed $z_{\text{max}}=0.28$ kpc), this value increases with radius and is larger for the ionized gas than the neutral gas. However, the thickness of the gas distribution for the geometrical model is nearly an order of magnitude larger than what is found for the hydrodynamical simulations.

| Gas Mass | Tilted Disk | Hydrodynamical Model |
|----------|-------------|---------------------|
| $M_{\text{tot}}(\text{H}^0)$ | 3.1 ± 0.3 | ~14.7 |
| $M_{\text{tot}}(\text{H}^+)$ | 12 (+4/-3) | ~0.09 |
| $M_{\text{BW}}(\text{H}^0)$ | 0.30 ± 0.01 | ~0.01 |
| $M_{\text{BW}}(\text{H}^+)$ | 0.37 (+0.12/-0.09) | ~0.00007 |

| Vertical Extent | Tilted Disk | Hydrodynamical Model |
|----------------|-------------|---------------------|
| $z_{\text{max}}(\text{H}^0)$ [center] | 0.28 | 0.01 |
| $z_{\text{max}}(\text{H}^+)$ [center] | 0.95 ± 0.15 | 0.02 |
| $z_{\text{max}}(\text{H}^0)$ [max radius] | 0.28 | 0.12 |
| $z_{\text{max}}(\text{H}^+)$ [max radius] | 1.92 (+0.49/-0.43) | 0.09 |

**Table S2. Comparison of Masses and Vertical Extent of Models.** The total mass $M_{\text{tot}}$ of neutral ($\text{H}^0$) or ionized ($\text{H}^+$) gas comes from the full geometrical model [left column] or within an elliptical region shown in Fig S5 for the hydrodynamical model [right column]. The “Baade’s window” mass $M_{\text{BW}}$ is the mass in a limited range of longitude and projected velocity (see text) where lower optical extinction allows for a direct comparison to the neutral and ionized components. The maximum vertical gas extent, defined by where the particle density drops below $n_\text{H}=10^{-2}$ cm$^{-3}$, is measured both near the center and maximum radius of the distribution.

To summarize, our reference hydrodynamical model produces a gas layer that is more neutral, thinner, and more planar than is observed. The addition of a radiation field with a high enough flux of hydrogen ionizing photons may obviate the first issue. Additional sources of vertical pressure support, e.g. cosmic rays and turbulence, may produce a thicker distribution. But the cause of the tilted distribution remains unresolved. It may also be necessary to consider how these features evolve over this history of the simulation since we may not be observing a steady-state configuration.

**Software Used**
This work uses the following open source python software: astropy (54, 55), numpy (56), matplotlib (57), seaborn (58), emcee (51), dustmaps (50), extinction (59), spectral-cube (60), whampy (41), modspectra (https://modspectra.readthedocs.io)
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