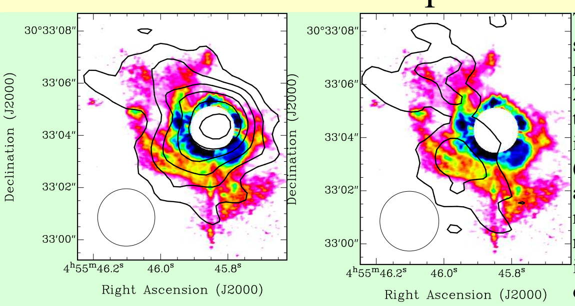
AB Aurigae Resolved: Evidence for Spiral Structure

Stuartt Corder, Josh Eisner, & Anneila Sargent

Abstract

We present high angular resolution (~2") Owens Valley Radio Observatory (OVRO) millimeter array images of the circumstellar gas and dust surrounding the Herbig Ae star AB Aurigae. Observations of the ^{13}CO emission coupled with a Keplerian disk model reveal a disk of radius 615 AU, inclination 21.5^{o}, and position angle 58.6^{o} and a dynamical mass of 2.8 M_{sun} for the central source. These values agree reasonably well with those determined from lower spatial resolution observations of ^{12}CO and $C^{18}O$. Continuum observations of the optically thin circumstellar dust emission at 2.7 mm shows that the material is distributed asymmetrically, and the locations of these asymmetries are consistent with the spiral structure suggested by near-IR scattered light images, indicating that the spiral structure represents a density contrast in the disk.

1. Evidence of Spiral Structure

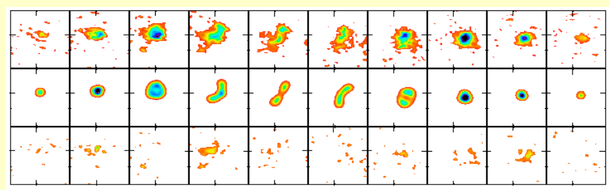


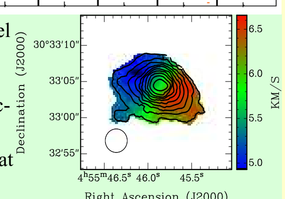
The image to the far left shows our 2.7 mm continuum map of AB Aur (resolution 2.2") as contours overlaid on the near-IR scattered light image of Fukagawa et al. (2004). Contours begin at 3σ and increase as 2σ (1σ~0.36 mJy). Given the optical thinness of the 2.7 mm emission, image asymmetries represent differences in density at a given radius. The southeastern spiral feature seen in scattered light is clearly visible in our continuum map at the 7σ level. The northeastern feature is seen at 5-7σ as well. The other image displays the same scattered light image but with a best-fit central continuum source subtracted. Given the uncertainties in the central source fit, the residual emission features contribute 5-11% (northeastern) and 7-14% (southeastern) of the 11.5 mJy integrated source emission. The presence of such spiral structure is important to planet formation. While the ability of spiral structure to experience local collapse (Boss 2002) has recently been criticized (Rafikov 2005), the presence of such structures may point to the possibility of existing planets or may aid the core accretion process by enhancing the cross section for collisions of planetesimals (Bate et al. 2003; Rice et al. 2004).

2. Model Description

We measure disk properties in three ways: fitting visibilities, measuring the angular separation of the emission in extreme velocity channels, and fitting Keplerian disks. Inclination (i) and position angle (PA) were measured for all three methods, radius was determined from visibilities, and radius and dynamical mass were determined for Keplerian fits. The Keplerian model consisted of a flat disk undergoing rotation. A power law emission profile was convolved with the beam and fit empirically to the data.

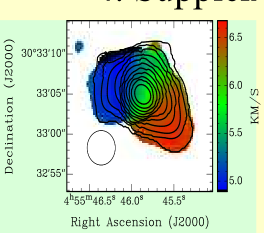
3. Model & Data



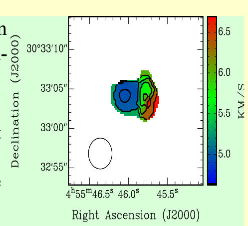


Above, the ~2" resolution ^{13}CO channel maps are shown. The top, middle and bottom rows are the AB Aur data, the best-fit model, and the residuals, respectively. Right, the ^{13}CO velocity (color) and integrated emission (contour) map at 3.25" resolution is displayed. From the velocity map we see that there is a strong, systematic velocity progression with gradient in the direction of the PA, indicating rotation. The visibilities from the integrated map show a 33^{o} inclination with a PA of 85^{o}. The separation of extreme velocity channels gives i~24^{o} and PA~69^{o}. Inclusion of all channel information via comparison to the Keplerian model results in i~21.5^{o}, PA~58.6^{o}, and a dynamical mass of 2.8 M_{sun}. The measured outer radius, 615 AU, is consistent with the 390 AU FWHM radius determined from the visibilities. The results are summarized in the table below.

4. Supplemental Data



The ^{12}CO emission from AB Aur is shown to the right, with color representing velocity and contours providing integrated intensity information. The beam (4.25") is shown for scale. The visibilities indicate that the FWHM of the emission is 1000 AU and Keplerian models find an outer radius of over 1000 AU. This extent and the shape of the emission suggest that there may be substantial contamination from the envelope (Semenov et al. 2004). Therefore, the i, PA, and dynamical mass fit to the ^{12}CO image are not likely to represent well either the disk geometry or the mass of the central source.



The $C^{18}O$ emission from AB Aur, similar to the ^{12}CO image, is displayed to the right (beam~3.9"). Using the extreme velocity channels, we find the disk inclined by 17^{o} to the line of sight at a PA of 73^{o}. Keplerian model fits provide a mass and i consistent with that determined from ^{13}CO, although the systematic uncertainties may be larger due to the poorer resolution. The deviation of the PA from the ^{13}CO value may arise from local density enhancements, as the $C^{18}O$ line is more sensitive to such localized differences.

5. Table of Results

Line	Mass	Radius	Inclin	PA	Method
	M_{sun}	AU	Degrees	Degrees	
^{13}CO	2.8+/- 0.1	615+8-3	21.5+0.4-0.3	58.8+/- 0.5	Model
$C^{18}O$	2.8+0.1-0.15	497+10-3	21.4+0.7-0.3	75+/-2	Model
^{12}CO	3.25+/-0.13	1060+/-10	32.5+0.4-0.5	61+/-3	Model
^{13}CO	N/A	N/A	24+/-4	69+/-8	Ex Velo
$C^{18}O$	N/A	N/A	17+/-6	73+/-21	Ex Velo
^{12}CO	N/A	N/A	26+/-9	66+/-25	Ex Velo
^{13}CO	N/A	390+/-15	33+/-5	85+/-10	UV Plane
^{12}CO	N/A	500+/-13	41+/-3	26+/-4	UV Plane

References

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