Resolving Structure in the Debris Disk around HD 206893 with ALMA

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Debris Disks and Brown Dwarfs

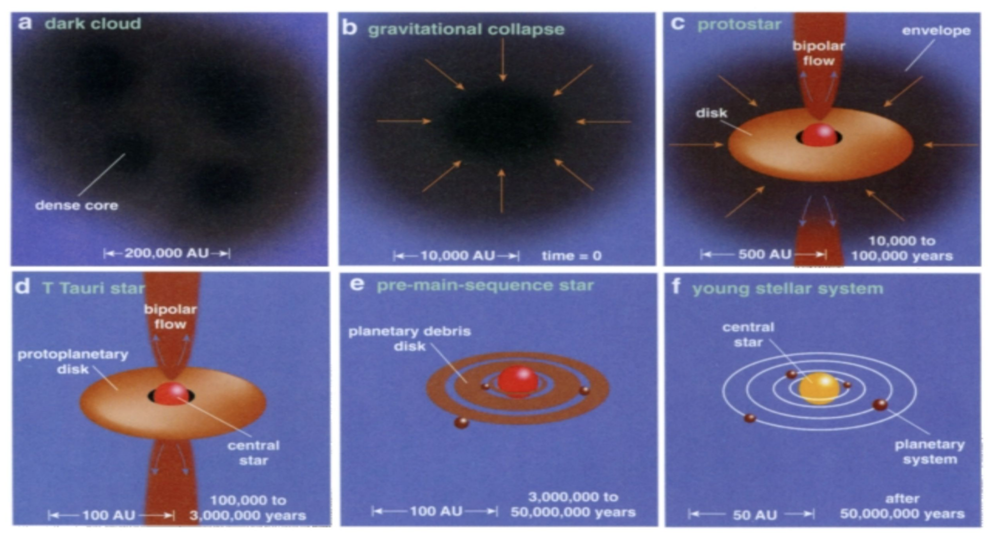

Figure 1 - Overview of the formation of a star and accompanying circumstellar disk. (Greene, 2001)

- Debris disks are thin belts of dust surrounding main sequence stars at ages of more than about 10 mega-years (Myr). They are the result of collisional cascades, which produce dust grains of many different sizes when planetesimals, solid objects that are about 1km across, collide.
- A brown dwarf is an object between 15 and 75 times the mass of Jupiter.

HD206893: A Brown Dwarf Orbiting Inside a Debris Ring

- HD 206893 is only one of two known systems to host a brown dwarf within its debris disk. When a brown dwarf interacts with a debris ring, we can use the dynamical concept of a chaotic zone to measure the mass of the brown dwarf.
- Since most brown dwarf masses are estimated based on uncalibrated models, a dynamical mass measurement provides an important test of our understanding of brown dwarfs.

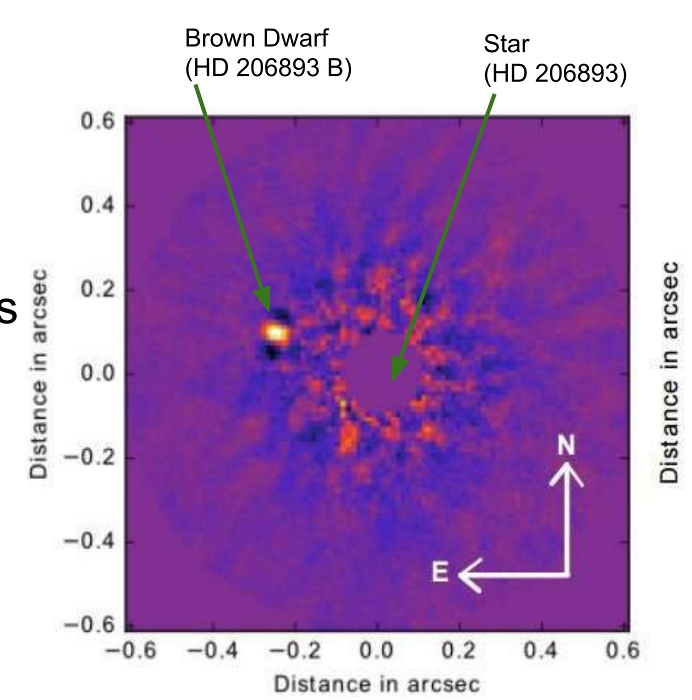

Figure 2 - SPHERE H-band coronagraphic image reduced with ADI + PCA, showing the detection of the companion HD 206893 B at 270 mas with a S/N of 14. The debris disk is not detected. (Milli et al. 2016)

Date/Time	Beam Major Axis ($''$)	Beam Minor Axis ($''$)	BeamPA (°)	rms noise (μJy/beam)
27Jun/06:52	1.61829	1.2594	-79.0109	2.31104e-05
27Jun/07:49	1.61525	1.24769	-68.8193	2.12221e-05
30Aug/02:23	0.733162	0.572043	76.757	1.38017e-05
30Aug/03:34	0.753207	0.584745	80.7047	1.40707e-05
10Sep/01:22	0.561489	0.430729	53.4742	1.33853e-05
17Sep/01:22	0.48584	0.34161	54.7331	1.03497e-05
combined	0.700482	0.568317	66.5652	7.28887e-06

Table 1 - ALMA Observations of HD 206893

Fitting Models of Debris Disk Structure Affine-Invariant MCMC

Using CASA (the Common Astronomy Software Applications package), we read in interferometric data from ALMA to clean and image the data. We use a ray-tracing code described in Flaherty et al. (2015) to generate sky-projected model images of debris disks, which we then convert into synthetic interferometric visibilities using MIRIAD. We then compare the data and model in the visibility domain to calculate a χ^2 metric as a goodness-of-fit test. We fit models to data using an affine-invariant MCMC sampler called emcee.

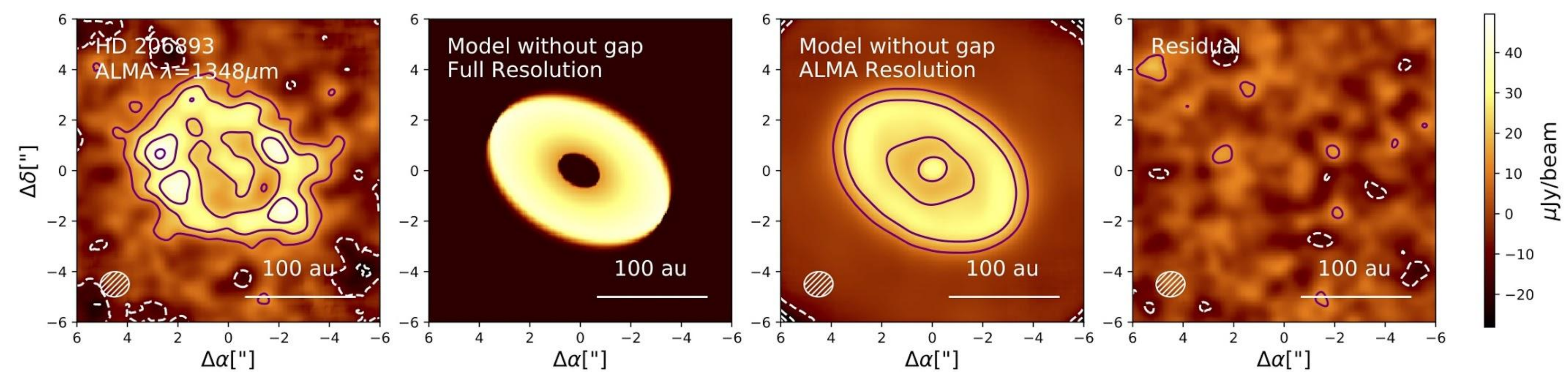

Figure 3. (Left) Naturally weighted ALMA image of the 1.3mm continuum emission from the HD 206893 system, with a taper of 200kλ applied to bring out the large-scale structure of the source. (Center) Model image sampled at the same baseline lengths and orientations as the ALMA data, showing the best-t model without a gap in the middle of the dust disk. (Right) Residual image after subtracting the model from the data in the visibility domain. The contour levels are [-2,2,4,6] x σ, where σ is the rms noise in the image: 6.0μJy beam^{-1} for the image with the taper. The hatched ellipse in the lower left corner represents the size and orientation of the synthesized beam: 0."9x1."0 for the tapered image.

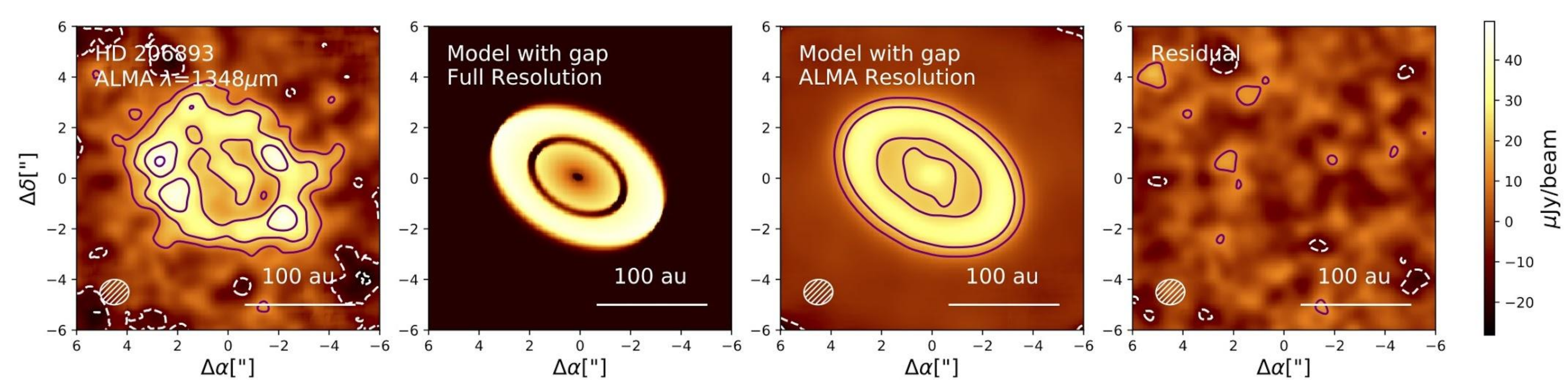

Figure 4. Same as Fig 3, but for a model of the disk that includes a gap in the radial dust distribution.

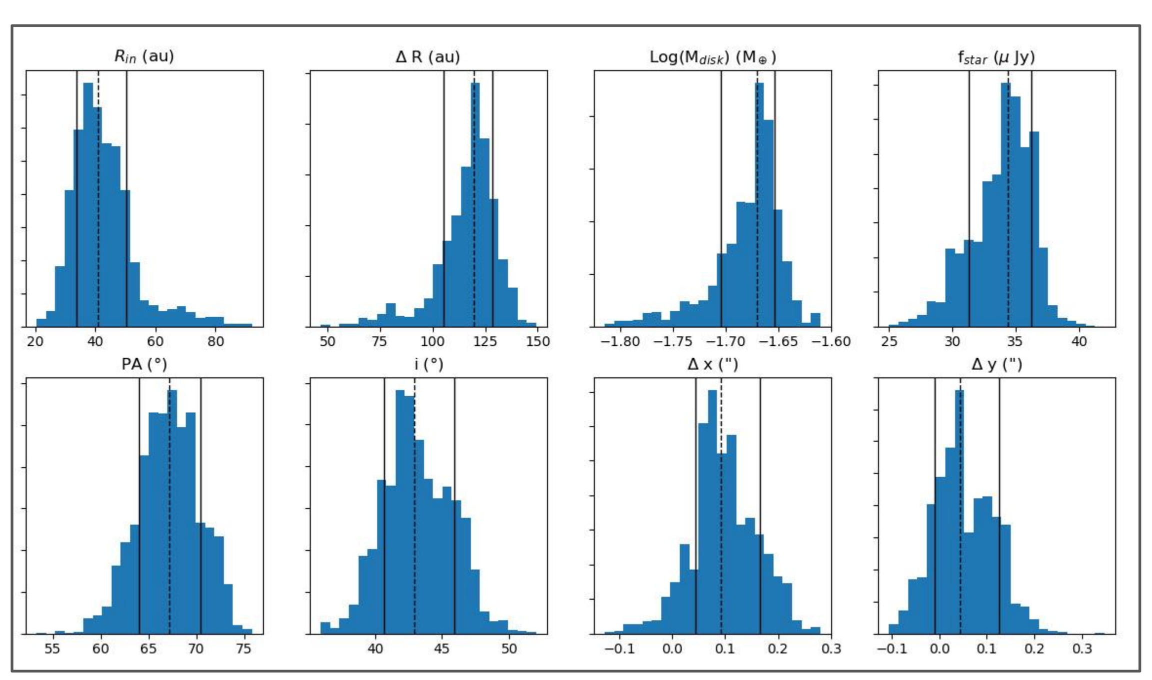

Figure 5. Histograms of the marginalized posterior probability distributions for the MCMC run without a gap. The central dashed line designates the median of each distribution while the outer lines mark the 16th and 84th percentiles.

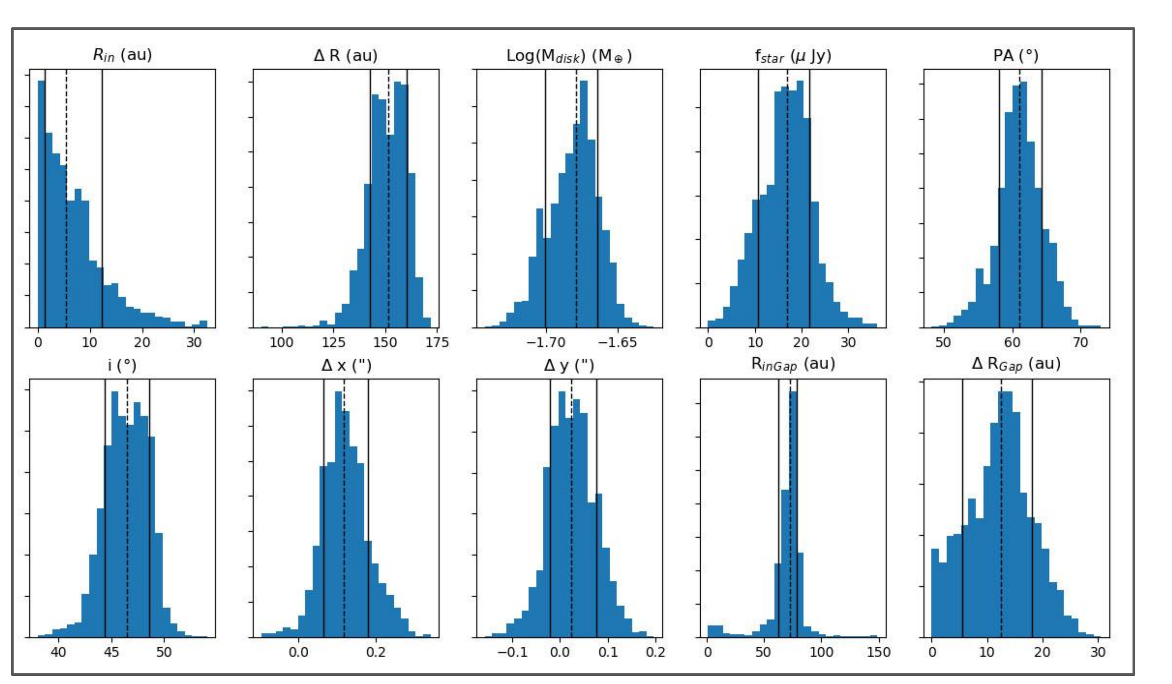

Figure 6. Histograms of the marginalized posterior probability distributions for the MCMC run with a gap. The central dashed line designates the median of each distribution while the outer lines mark the 16th and 84th percentiles.

MCMC Fitting Results

Parameter	Gap		No Gap	
	Best Fit	Median	Best Fit	Median
R_{in} (au)	8^a	$< 34^a$	38	40^{+9}_{-7}
ΔR(au)	150	150^{+9}_{-9}	128	120^{+9}_{-13}
Log(M_{disk}) ($M_\oplus$)	-1.678	$-1.679^{+0.015}_{-0.022}$	-1.662	$-1.671^{+0.017}_{-0.031}$
F_* (μJy)	15	17^{+5}_{-6}	29	35^{+2}_{-2}
PA (°)	62	61^{+3}_{-3}	62	68^{+3}_{-3}
i (°)	47	46^{+2}_{-2}	46	43^{+3}_{-2}
Δx ($''$)	0.12	$0.12^{+0.06}_{-0.05}$	0.07	$0.09^{+0.07}_{-0.05}$
Δy ($''$)	0.04	$0.02^{+0.05}_{-0.05}$	-0.01	$0.04^{+0.08}_{-0.05}$
$R_{in,Gap}$ (au)	78	73^{+5}_{-9}		
ΔR_{Gap} (au)	13	13^{+5}_{-7}		
Ln prob	-10733006.4		-10733015.1	

NOTE—^{a} The inner radius is unresolved in the models without a gap, so the best-fit value of 8 au is not meaningful. The upper limit of 34 au represents the 99.7th percentile of the posterior distribution.

Table 2 - Best Fit Parameters that were gained from the MCMC algorithm based upon the best calculated ln-prob

Conclusion

- The ALMA observations at a wavelength of 1.3mm presented here spatially resolve the radial structure of the disk for the first time, revealing a broad distribution of planetesimals extending from radii of < 34 au to 1586 au, with statistically significant evidence for a gap in the dust disk with inner radius 73 au and width 13 au.
- The origin of gapped structure is either inherited from the protoplanetary disk phase or carved by one or more additional, unseen companions at larger separation in the system, where the chaotic zone theory predicts that the mass to be 27$M_\oplus$ and semimajor axis to be 74 au.
- The inner radius of the disk is not resolved by the current ALMA observation of the system, allowing only an upper limit on the mass of the companion of < 1170M_{Jup}.
- Future ALMA observations at higher angular resolution have the potential for valuable dynamical constraints on the mass of the brown dwarf companion and constraints on the properties of the putative planet by measuring the gap width and depth.

Acknowledgements

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