A New Millimeter Look at the HD 15115 Debris Disk
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Abstract
We have used the Submillimeter Array (SMA) to make 1.3 millimeter observations of the debris disk surrounding HD 15115, an F-type star located in the 12 Myr-old β Pic moving group. This nearly edge-on debris disk (the “Blue Needle”) has been previously well-resolved in optical scattered light and displays an extreme asymmetry. Unlike scattered light that reflects tiny grains that are blown out by stellar radiation and swept by the interstellar medium, the thermal emission from large grains that dominate at millimeter wavelengths closely traces the locations of the dust-producing parent planetesimals. These SMA observations reveal a circumstellar belt of thermal dust emission that extends to a radius ~113 AU, coincident with the outer edge of the “birth ring” of planetesimals hypothesized to explain the midplane scattered light profiles. The detection of this cold belt strengthens the kinship between the debris disks around its moving group sister stars, AU Mic and β Pic. Additionally, the continuum emission shows a ~3σ feature coincident with the western extension previously seen in scattered light observations. This feature is plausibly explained by secular perturbations to grain orbits introduced by neutral gas drag. However, future multi-wavelength observations are needed to reveal the true origin and structure of this potential disk asymmetry.

An Introduction to HD 15115
HD 15115 is an F2V star at 45 ± 1 pc (van Leeuwen 2007) whose space motions suggest membership in the ~12 Myr-old β Pic moving group (Moor et al. 2011), which includes the well-studied β Pic and AU Mic debris disks systems. Scattered light imaging from HST, Keck, and LBT have revealed a remarkable edge-on circumstellar disk (e.g. Debes et al. 2008; Rodigas et al. 2012). In optical scattered light, the HD 15115 debris disk shows an extreme asymmetry (Kalas et al. 2007): the east side of the disk extends to ~7’ (315 AU), while the west side reaches 12.38’ (~550 AU).

Disk Modeling
In order to characterize the millimeter emission, we used the method described by MacGregor et al. (2011) that employs Markov Chain Monte Carlo (MCMC) methods to fit a simple parametric disk model to the observed visibilities and estimate the parameter uncertainties. We assume that the millimeter emission arises from a geometrically thin, axisymmetric belt. By fitting the visibility data directly, we are not sensitive to the non-linear effects of deconvolution, and take full advantage of the complete range of spatial frequencies sampled by the observations. Figure 2 shows the output of ~10⁵ MCMC trials and the table to the right lists the best-fit model parameter values and their 68% uncertainties. Figure 3 shows a comparison between the data and best-fit model in the image plane, including the imaged residuals in the rightmost panel. Overall, this simple, symmetric disk model reproduces the bulk of the millimeter emission well. However, the residual image shows a ~3σ feature coincident with the western extension of the scattered light along the disk axis.

Evidence for a “Birth Ring”
Submillimeter Array Observations
We observed HD 15115 in the fall of 2013 with the Submillimeter Array (Ho et al. 2004) on Mauna Kea, Hawaii at a wavelength of 1.3 mm using both the compact and extended configurations of the array (baseline lengths ranging from 6 to 182 m). Typically six (or fewer) of the eight array antennas were available during the five tracks, though the weather conditions were generally very good for the wavelength band. The phase center was located at ~0°06’14.30”, R = 00°07’13.19’” (~300 m, the position of the star uncorrected for its proper motion of 08.31...99.71 mas yr⁻¹). The remaining panels show contour plots of the 1σ and 2σ model fits.

What Causes Disk Asymmetries?
Dust scattered light debris disk morphologies have been observed previously, notably in HD 32297 (Currie et al. 2012; Delos et al. 2009; Boccaletti et al. 2012) and HD 61005 (Hines et al. 2007; Mannes et al. 2009). While all of these disks demonstrate unique features, similar physical mechanisms should apply to shaping the dust belt in all three cases. Using these data, we are exploring several potential mechanisms for creating asymmetric disk structures like what is seen in HD 15115 and consider whether or not they can plausibly explain these unique morphologies.

1. Ram Pressure Stripping of Disk Grains
   Ram pressure from interstellar gas can remove bound and unbound grains from a disk.

2. Ram Pressure Stripping of Disk Gas
   Disk grains are swept away when they become entrained in outflowing gas.

3. Neutral Gas Drag
   Neutral gas drag introduces secular perturbations to the orbits of bound grains.

4. Planetary Induced Resonance
   Planets within the system produce dust-trapping resonances that create clumpy, wavelength-dependent grain distributions.

5. Stellar Flyby
   Interaction with a second moving group member (possibly HIP 12545) truncates one side of the disk.