Birth Rings of Planetesimals in Nearby Debris Disks

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Abstract

Debris disks around young main-sequence stars result from the collisional grinding of planetesimals, relics of planet formation analogous to comets and asteroids. The millimeter emission from debris disks is dominated by large grains that uniquely trace the unseen population of dust-producing planetesimals. We review our SMA programs that provided the first well-resolved images of millimeter emission from the debris disks surrounding the nearby ~20 Myr-old stars β Pictoris (Wilner et al. 2011) and AU Microscopii (Wilner et al. 2012) For these systems, each of which is viewed nearly edge-on, the SMA reveals a belt of millimeter emission surrounding the star with the same geometry as the more extended disk imaged in optical scattered light. Simple modeling shows that the locations of these millimeter emission belts are consistent with reservoirs of planetesimals (``birth rings'') invoked to explain the detailed shape of the midplane scattered light surface brightness profiles. For both systems, the SMA programs have been followed-up by ALMA studies that reveal more detail in the emission structure (MacGregor et al. 2013, Dent et al. 2014)

1. The β Pic and AU Mic Debris Disks

The nearby A-type star β Pic (19.4 pc) and M-type star AU Mic (9.9 pc), located in the 20 Myr-old β Pic moving group, are both surrounded by tenuous dusty circumstellar disks seen nearly edge-on (Smith et al. 1984, Kalas et al. 2004). Detailed observations of these nearby systems have been important for advancing our understanding of the debris disk phenomenon. The scattered light disks around these stars extend to 100's of AU, and their detailed structure has been the subject of intense scrutiny (e.g. Heap et al. 2000, Graham et al. 2007). Remarkably, the midplane optical surface brightness profiles of these disks have a very similar shape (Liu 2004) described by a broken power-law that is shallow in the inner regions and much steeper in the outer regions. The break occurs at roughly 100 AU for β Pic and at 35 AU for AU Mic.

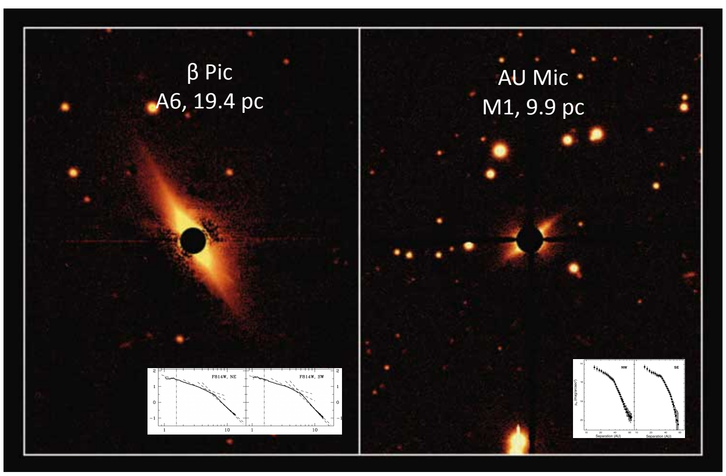

Figure 1. Scattered light images of the sister stars β Pic and AU Mic (courtesy Paul Kalas). Insets show the disk midplane optical surface brightness profiles with similar broken power-law shapes (Heap et al. 2000, Liu 2004) that inspired the development of debris disk birth ring theory (Augereau et al. 2006, Strubbe and Chiang 2006).

2. "Birth Rings" of Planetesimals?

The similar broken power-law scattered light shapes are naturally explained in ``birth ring'' theory, where a localized belt of planetesimals produces dust with a range of sizes in a collisional cascade (Augereau et al. 2006, Strubbe and Chiang 2006). The smallest grains are blown out to large radii, larger grains are launched into eccentric orbits with the same periastron as the belt, and the largest grains do not travel far before collisions grind them down. In this scenario, the abrupt change in slope of the scattered light profile marks the outer extent of the planetesimal belt.

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3. SMA Reveals Planetesimal Belts

Millimeter emission, which is dominated by large grains minimally affected by stellar radiation and winds, should trace the reservoir of dust-producing planetesimals that extends to the break in the scattered light profile. We set out to test this key prediction of size dependent dust dynamics in the β Pic and AU Mic debris disks using the SMA to resolve emission at 1.3 millimeters wavelength (Wilner et al. 2011, Wilner et al. 2012). These observations obtained about 3'' resolution, corresponding to 60 AU and 30 AU for β Pic and AU Mic, respectively (Figure 2). For each system, the emission shows two peaks offset approximately symmetrically from the central star, indicative of a highly inclined and limb brightened belt.

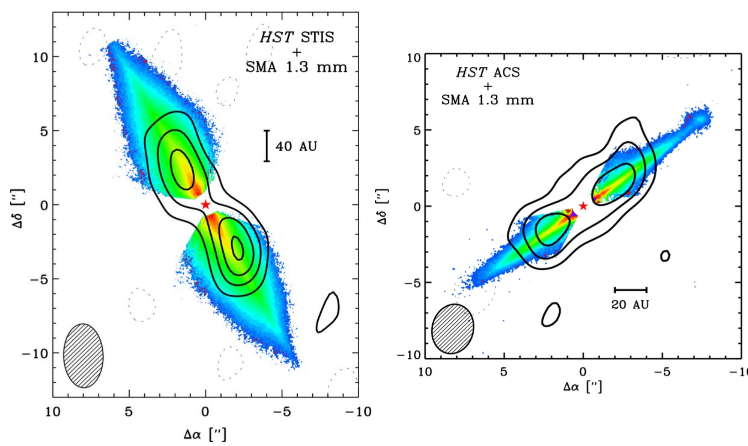

Figure 2. SMA images of the 1.3 millimeter continuum emission overlayed on images of optical scattered light from the *Hubble Space Telescope* for the debris disks surrounding (left) β Pic and (right) AU Mic. The contour levels are -2,2,4,6,…x the rms noise levels of 0.6 mJy and 0.4 mJy, respectively. Negative contours are dotted. The ellipses in the lower left corners represent the SMA synthesized beams. The star symbols indicate the location of the central stars.

We used simple parametric models of a thin, axisymmetric annulus to constrain the belt center radius and width, assuming the disk geometry inferred from scattered light. This very simple model reproduces the millimeter observations very well (Figure 3). The best fit center radius for the belt is R=94±8 AU for β Pic, and R = 36 +7,-16 AU for AU Mic. For each system, the location of the millimeter emission belt coincides closely with the radial region where the scattered light surface brightness profile steepens. These results provide strong support for the presence of a ``birth ring'' of planetesimals within the extended debris disk.

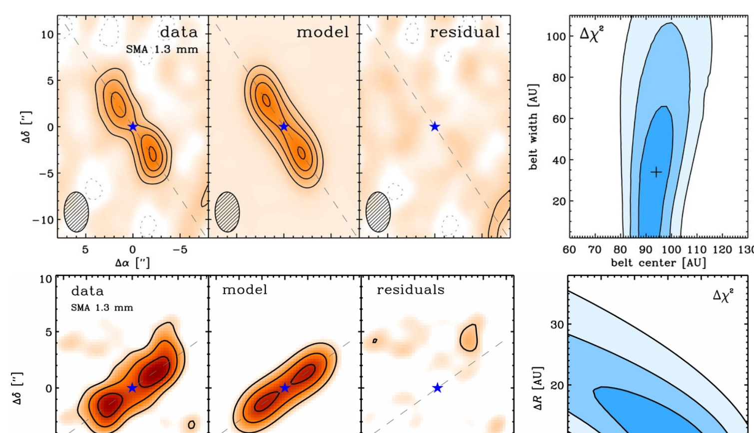

Figure 3. Modeling the SMA data for β Pic (upper row) and for AU Mic (lower row) with axisymmetric emission belts. The panels show an SMA image at 1.3 millimeters, an image of the best-fit belt model, and the residual image, all with the same contours and symbols as Figure 1, together with χ^2 surfaces for the model belt center and width parameters, with contours at 1,2,3σ. The best-fit model parameters are marked by a cross.

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