A Sub-Milli-Arcsecond View of the Gas-Dust Transition Region in Herbig Ae Stars.

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Abstract

Contrary to the predictions of `standard' models, we have detected strong near-infrared (NIR) emission from hot gas in the prototype Herbig Ae stars MWC275 and AB Aur. Using the sub-milli-arcsecond resolution of the CHARA interferometer array, we place the gas emission to be interior to and on the same spatial scale as the dust sublimation radius. In the absence of shielding of starlight by gas, we demonstrate that the dust evaporation front in these young stellar objects (YSOs) will have to contain highly refractory dust sublimating at ~1850K. MWC275 and AB Aur have very similar structures in the thermal NIR, and yet their outer disks are substantially different. As opposed to MWC275, AB Aur has a substantial amount of small dust grains in the disk atmosphere even beyond 10 AU that produce significant 10-20 micron emission, indicating the presence of planetesimal collisions that maintain the small grain population.

Hot Gas and Dust in the Inner Disk

Herbig Ae stars show a significant excess of near-infrared flux over a Black-Body source (expected for a star at a given photospheric temperature). Current theories (Dullemond et al. 2001) explain this excess solely on the basis of a "puffed up inner dust-rim". In these theories, dust sublimation terminates the circumstellar dust-disk at a finite radius creating an optically-thin cavity around the star (Millan-Gabet et al 1999, Tuthill et al. 2001). The outer edge of the cavity forms a rim that traps stellar photons, re-radiating the energy mostly in the NIR. The geometry of the rim is tied to multiple dust properties such as grain evolution, sedimentation (Tannirkulam et al. 2007) and sublimation temperatures (Isella & Natta 2005). Here, we confront models with high-angular-resolution interferometry data.

The top panel in Fig 1. shows a K-band image of a curved inner-rim model (the ``standard" model) where the rim curvature (variation in cylindrical radius between the rim midplane and the atmosphere) is set by the density dependence of dust sublimation temperatures, taken from Pollack et al. (1994). In this model, silicate grains sublimate at a higher temperature compared to other grains and hence fix the rim location. The rim is assumed to be composed of 1.3micron grains, as larger grains do not affect the rim shape and location significantly (Isella and Natta 2005), at the same time making numerical convergence slower due to strong backwarming effects. In order to fit the data before the first visibility minimum (Fig 2), the sublimation temperature at the base of the rim had to be set at ~1800K (Tannirkulam et al. 2008b), much higher than the 1400K typically assumed in the literature.

As seen in Fig 2, rim models which are sharply truncated due to dust sublimation and produce all of the NIR excess fail to fit observations beyond the first visibility minimum. These models display bounces in visibility at long baselines (not seen in the data) because of the presence of sharp ring-like features with high spatial frequency components in the corresponding images. In Tannirkulam et al. 2008a, we showed that presence of a smooth emission component inside the dust destruction radius (Fig 1 bottom panel) providing 50-60% of the total K-band emission helps fit the data for MWC275 (Fig 2) and AB Aur. The most plausible physical mechanism for the smooth emission is hot gas with opacities likely dominated by free-free + bound-free transitions of H- (Tannirkulam et al. 2008b, Najita et al. 2008).

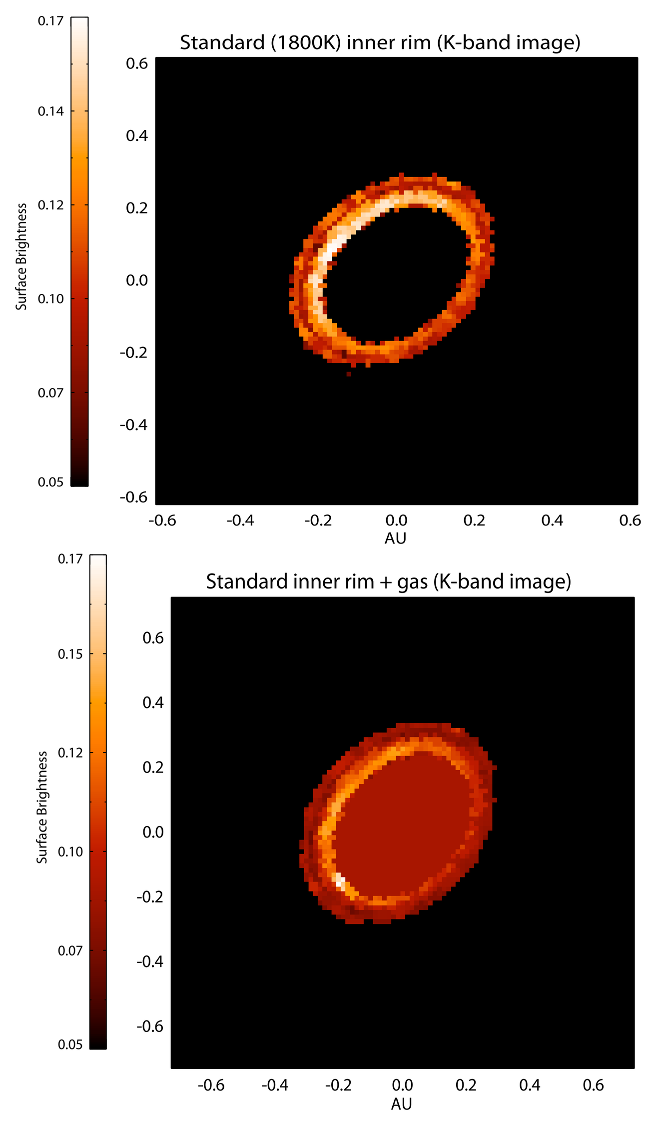

Fig. 1 - Inclined-disk models for NIR emission in MWC275. Top: Standard curved dust-rim-only model with rim-base temperature of ~1800K. Bottom: Curved dust-rim model with gas emission (modeled as a uniform disk centered on the star) inside the dust rim to smooth out the emission profile.

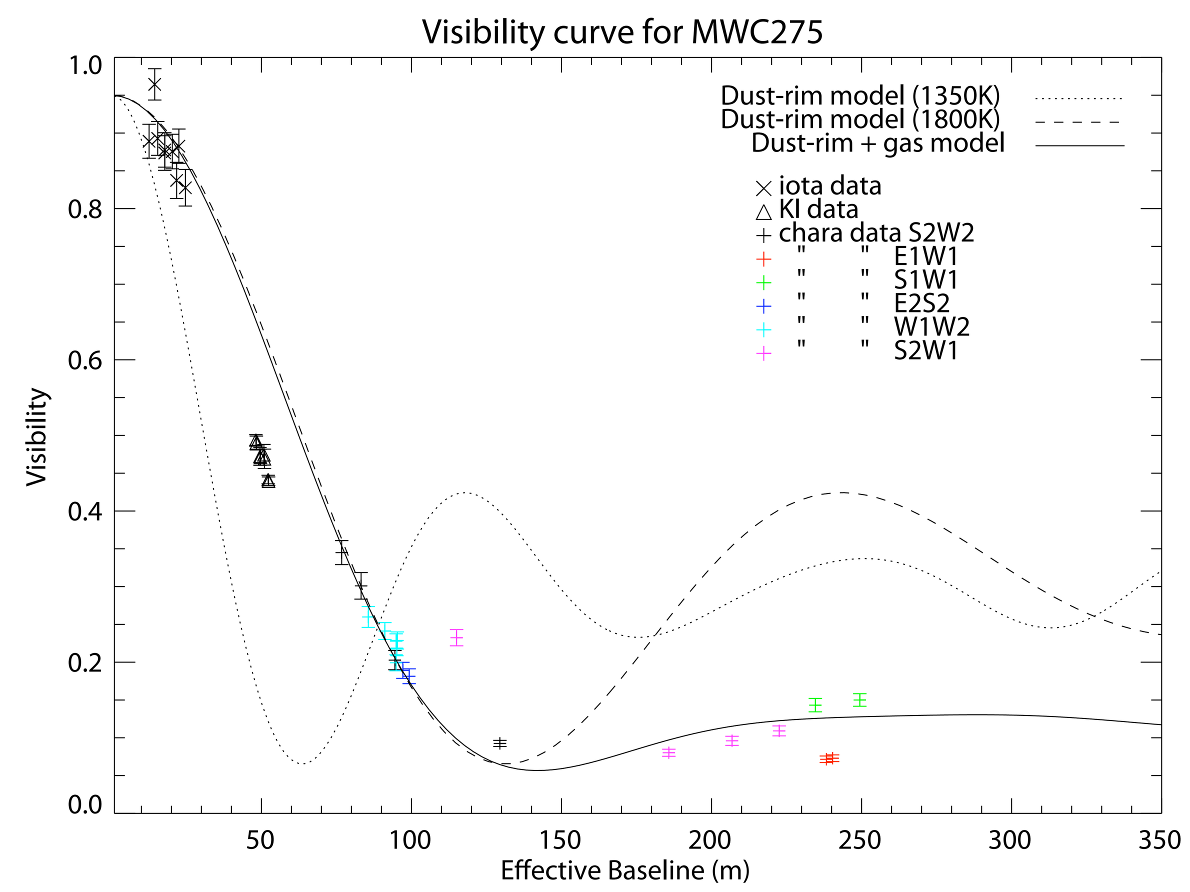

Fig. 2 - MWC275 visibility vs. ``effective baseline". The dotted and dashed lines are visibility curves for dust-only models. The solid curve includes gas emission which smooths the emission morphology and suppresses long-baseline visibility bounces seen in dust-only models.

Planetesimal Collisions in the Outer Disk

MWC275 and AB Aur have nearly identical structures in the thermal NIR, but models for MIR interferometry and spectral energy distribution (SED) suggest that the outer disks of these systems are at different evolutionary stages. MWC275 10 micron size and SED can only be reproduced if the disk is depleted in micron and sub-micron sized grains beyond ~ 7 AU. This meshes well with the fact that the observed 10.7micron size of MWC275 is ~3 times smaller than AB Aur (Figs 3 & 4). The depletion of small grains beyond 7 AU in the disk atmosphere indicates that the dust particles have undergone significant settling. We suggest that dynamical processes (such as planetesimal collisions) that maintain the population of micron-sized grains producing the 10micron feature in the spectrum are operational only in the inner 7AU of MWC275. However, in AB Aur the small dust producing mechanisms exist at least out to 20 AU and maybe even beyond (Tannirkulam et al. 2008b).

The initial step in both giant (Pollack et al. 1996) and terrestrial (Wetherill 1990) planet formation is coagulation of dust to form planetesimals. The high likelihood of planetesimal collisions in the inner 20AU of the AB Aur disk, makes it an excellent laboratory for studying the first stages of planet formation. The dynamic nature of the AB Aur disk is further supported by the detection of arcs and rings (Grady et al. 1999, Fukagawa et al. 2004, Oppenheimer et al. 2008) and a possible hot spot (Millan-Gabet et al. 2006).

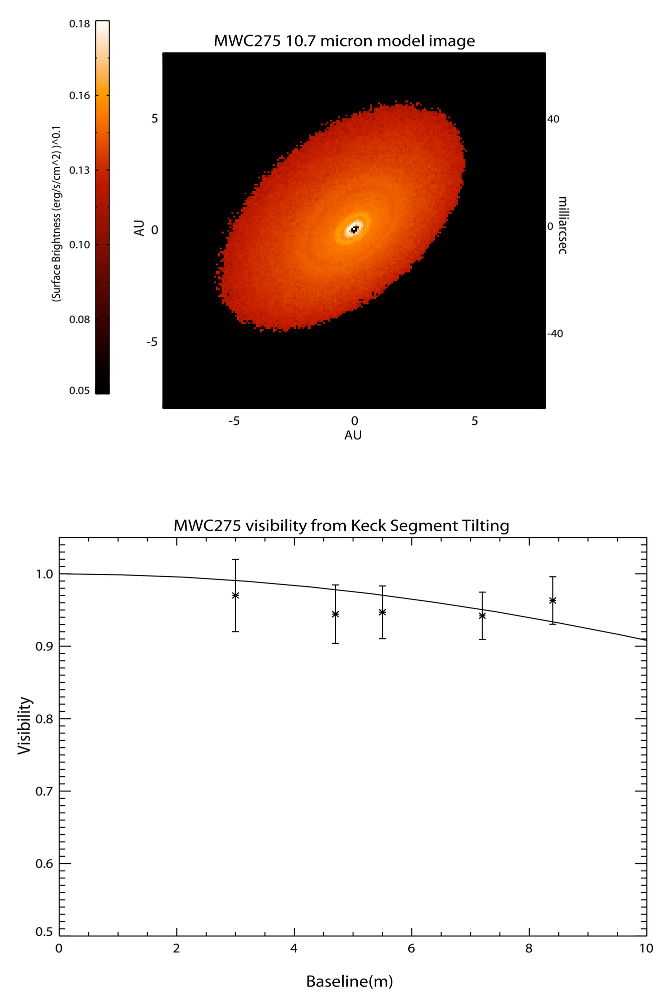

Fig. 3- MIR image and visibilities for MWC275. Top: Synthetic 10.7micron image. Bottom: Azimuthally averaged 10.7micron visibilities from the Keck Segment Tilting Experiment (Monnier et al. 2004).

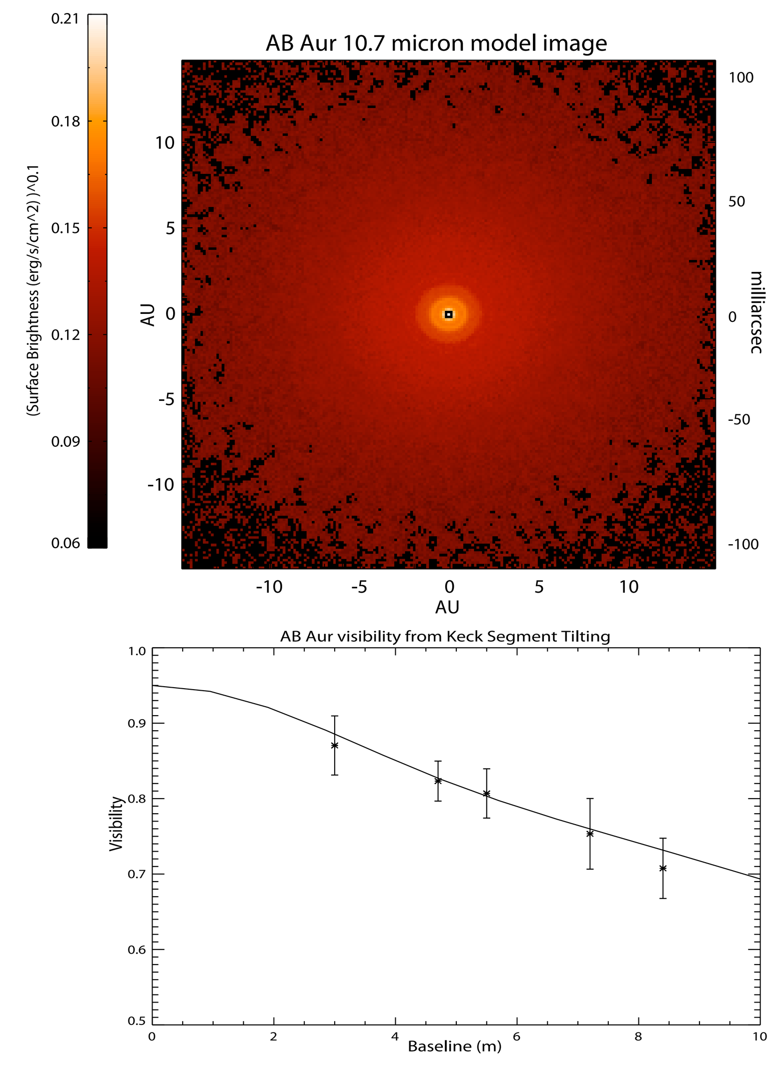

Fig. 4- 10.7 micron image and visibilities for AB Aur. Top: Synthetic model image. Bottom: Model visibilities compared with azimuthally averaged Keck Segment Tilting data. The large MIR size of AB Aur (FWHM ~10AU) compared to MWC275 (FWHM ~ 3AU) indicates the presence of micron-sized dust generating mechanisms in the outer disk of AB Aur.