AU Mic is Not Alone: New M Dwarf Debris Disks

Peter Plavchan*, Geoff Bryden†, Karl Stapelfeldt†, Mike Werner†, George Rieke** and Patrick Lowrance*

*IPAC, Caltech, 770 S. Wilson Ave, M/C 100-22, Pasadena, CA 91125
†Jet Propulsion Laboratory, Caltech, MS 183-900, 4800 Oak Grove Drive, Pasadena, CA 91109
**University of Arizona

Abstract. M dwarfs constitute ~70% of the stars in our local neighborhood, yet we know little about the frequency and evolution of debris disks and planetary systems for this diverse spectral class. Among the numerous M dwarfs sampled by Spitzer in the nearest 25 pc, AU Mic remains a unique M dwarf with its debris disk, infrared excess, 12 Myr age, flaring, and X-ray activity. We have observed 22 X-ray saturated M dwarfs like AU Mic with the Spitzer Space Telescope. These late-type dwarfs are likely to both be young and lack significant radial winds. Compared to the relatively old population of nearby M dwarfs, circumstellar disks are more likely to both exist and persist around these stars. From this sample, we have discovered 3 new M dwarf debris disks. Combining our results with previous Spitzer observations, we will constrain the age evolution, frequency, and dynamics of M dwarf debris disks to place into context disks around solar type stars.

Keywords: circumstellar matter – stars: late-type – stars: winds, outflows
PACS: 97.82.Jw

INTRODUCTION

Due to smaller stellar sizes, larger reflex motions, and closer habitable zones, M dwarfs are ideal targets for detecting the first terrestrial mass planets in the habitable zone, and for obtaining the first spectra and bulk-density measurements of transiting earth-like planets (e.g., the detection of the super-Earth transiting M dwarf GJ 436, Gillon et al. 2007, NASA Exo-planet task force recommendations). Statistical studies of the planetary companion frequency for this large and diverse spectral class are lacking, with fewer than 10 M dwarfs with known radial velocity extra-solar planets.

To investigate M dwarf planetary systems, we are carrying out a program to characterize M dwarf debris disks, their frequency, age evolution, and dust dynamics. Relative to earlier-type stars, the frequency and properties of M dwarf debris disks are observationally poorly constrained. More than half of low-mass T Tauri stars as young as 1 Myr possess primordial disks (Meyer et al. 1997, Haisch et al. 2001), and primordial disks are known to persist for longer around M dwarfs than earlier-type stars (Hernandez et al. 2007, Carpenter et al. 2006). Detectable disks around mature M dwarfs, however, are rare; debris disks are more common around G- and A-type stars (Su et al., 2006, Meyer et al. 2006). Despite considerable searching, only four field M dwarfs older than 10 Myr – AU Mic, GJ 182, GJ 842.2, and HD 95650 – show any evidence for remaining disk material (Plavchan et al. 2005, Currie et al. 2008, Gautier et al. 2008, Lestrade et al. 2006, Smith et al. 2006, Kalas et al. 2005, and references therein). Selection effects, such as luminosity contrast and effective dust temperatures relative to earlier-type stars, do not fully explain the lack of >10 Myr M dwarfs with observable circumstellar material (Song et al. 2002, Liu et al. 2004, Plavchan et al. 2005). Forbrich et al. (2008) identified nine debris disk candidates in the ∼30–40 Myr open cluster NGC 2547, and suggest the frequency of M dwarfs with disks is higher than the frequency of disks surrounding G and K dwarfs.

OBSERVATIONS AND RESULTS

We identify a sample of X-ray saturated M dwarfs by cross-correlating 2MASS, USNO-A2.0 and ROSAT catalogs. We take into account infrared cirrus, and exclude contaminating giants, T Tauri stars, extragalactic sources, and optical/near-IR companions with our empirically and theoretically derived selection criteria. These M dwarfs can be inferred to both be young (∼10–300 Myr), and to lack strong radial stellar winds to remove circumstellar debris. Detectable disks are more likely to both exist and persist around these stars (Plavchan et al. 2005).

We observed 22 of these M dwarfs at 24 and 70 μm with MIPS and the *Spitzer* Space Telescope. We reduce these observations with the DAT pipeline v.3.1 (Gordon et al. 2007) and MOPEX/APEX. One late-K/early-M dwarf shows a strong excess at 24 μm (Figure 1a), and two M dwarfs show evidence for strong excesses at 70 μm (Figure 1b). **The new debris disks we have identified join AU Mic and HD 95650 as the only field M dwarfs older than 10 Myr with infrared excesses.** The ∼15% excess fraction within our sample confirms that young M dwarfs go through an observable debris phase similar to earlier-type stars, in contradiction to previous studies of older field M dwarfs.

DISCUSSION

The Role of Stellar Winds

Plavchan et al.(2005) proposed that corpuscular stellar winds can dominate the dust removal time-scales in M dwarf debris disks, relative to Poynting-Robertson drag and grain-grain collisions. Plavchan et al.(2005) constructed a simple model to predict the observable fractional infrared excess:

$$\frac{L_{IR}}{L_*} \propto \frac{\dot{M}_d c^2}{(L_* + \dot{M}_{sw} c^2)} \tag{1}$$

where L_{IR} is the dust luminosity, L_* is the stellar luminosity, $\dot{M}_d$ is the production rate of dust from colliding parent bodies, and $\dot{M}_{sw}$ is the radial stellar wind mass-loss rate. For the Sun, $L_*/(\dot{M}_{sw}c^2) > 3$, implying that stellar winds are not currently relevant. However, for M dwarfs, $L_*/(\dot{M}_{sw}c^2)$ can be $<< 1$ due to lower stellar luminosities and stellar winds can play an important role in M dwarf disk evolution. Stellar winds can also be important for younger K and G type stars when mass-loss rates are up to 100 times larger than the current solar mass-loss rate (Minato et al. 2006, Plavchan et al. 2005, Wood et al. 2005). With Equation (1), an empirically derived time-dependence for the evolution of stellar winds from Wood et al. (2005), and time dependence for dust production rates inferred from Spitzer observations and Spangler et al. (2001), Plavchan et al.(2005) derives that for M dwarfs older than ∼300 Myr, $L_{IR}/L_* \sim 10^{-6}$. This fractional infrared excess is below the detection threshold of Spitzer, and recent results confirm that nearby older M dwarfs do not have detectable infrared excesses (Gautier et al. 2008).

The Role of Youth and X-Ray Activity

Equation (1) is approximately time-independent for stars older than ∼300 Myr, with typical dust production rates, X-ray activity and radial stellar winds decreasing with time in tandem. While the typical $\dot{M}_d$ from circumstellar disks can be substantially larger for stars younger than ∼300 Myr relative to older stars, the stellar radial wind mass-loss rates break from this trend. This is observationally manifested by the break-down in the correlation between energetic X-ray activity and radial stellar winds at young ages (Wood et al. 2005; Figure 3). Wood et al. (2005) posed the hypothesis that stars undergo a transition at around 0.3–0.7 Gyr from poloidal to toroidal magnetic field configurations, leaving "coronal holes" at equatorial latitudes to explain the observational break for saturated X-ray activity and wind mass-loss at young ages. Recent spectropolarimetry investigating low-mass star magnetic fields supports this transition hypothesis (Donati et al., 2007).

To summarize, saturated X-ray activity ($F_X > 8 \times 10^5$ ergs cm^{-2} s^{-1}) implies both youth and the lack of a strong radial wind. AU Mic, for example, possesses a saturated X-ray flux of $\sim 10^7$ ergs/s/cm^2 ($L_X/L_* \sim 10^{-3}$), and consequently does not have a significant radial wind (Wood et al. 2005, Strubbe & Chiang 2006). As a result, stellar wind drag does not contribute to dust removal. This in turn allows for longer circumstellar dust lifetimes limited by the grain-grain collision time-scale, and yields a larger fractional infrared excess (Plavchan et al. 2005). For AU Mic, the 70 μm flux excess due to circumstellar material is ∼9 times the photospheric emission (Chen et al. 2006).

CONCLUSIONS

The physical mechanisms contributing to the dissipation of disks around M dwarfs are poorly constrained. We have observed 22 M dwarfs with ROSAT detections indicative of saturated X-ray activity like AU Mic that are likely to be young. Compared to the relatively old population of nearby M dwarfs, circumstellar disks are more likely to both exist and persist around these stars. We will construct a comprehensive statistical picture of disks around M dwarfs to constrain their evolution and dynamics.

ACKNOWLEDGMENTS

We would like to thank Thayne Currie for his comments and suggestions.

REFERENCES

Chen, C., et al., 2006, 166, 351
Carpenter, J., et al., 2006, ApJL, 651, 49
Currie et al., 2008, ApJ 688, 597
Donati, J.F., et al., 2007, eprint arXiv-0702159
Endl, M., et al., 2006, AJ, 132, 2755
Forbrich et al., 2008, ApJ, 687, 1107
Gautier, N., et al., 2008, ApJ, 667, 527
Gillon, M., et al., 2007, A&A, 471, L51
Gordon, K., et al., 2007, PASP, 119, 1019
Haisch, K., et al., 2001, ApJL, 553, 153
Hernandez et al., 2007, ApJ, 671, 1784
Kalas, P., et al., 2005, Science, 303, 1990
Lestrade, J.F., et al., 2006, A&A, 460, 733
Liu, M., et al., 2004, ApJ, 608, 526
Mathioudakis, M., & Doyle, J., 1993, A&A 280, 181
Meyer, M., et al., 2006, PASP, 118, 1690
Meyer, M., et al., 1997, AJ, 114, 288
Minato, T., et al., 2006, A&A, 452, 701
Plavchan, P., et al., 2008, ApJ, submitted
Plavchan, P., et al., 2008, ApJS, 175, 191
Plavchan, P., et al., 2005, ApJ, 631, 1161
Smith, P., et al., 2006, ApJL, 644, 125
Song, I., et al., 2002, 2002, AJ 124, 514
Spangler, C., et al., 2001, ApJ, 555, 932
Strubbe, L. & Chiang, E., 2006, ApJ, 648, 652
Su, K., et al., 2006, ApJ, 653, 675
Wood, B., et al., 2005, ApJ, 628, 143

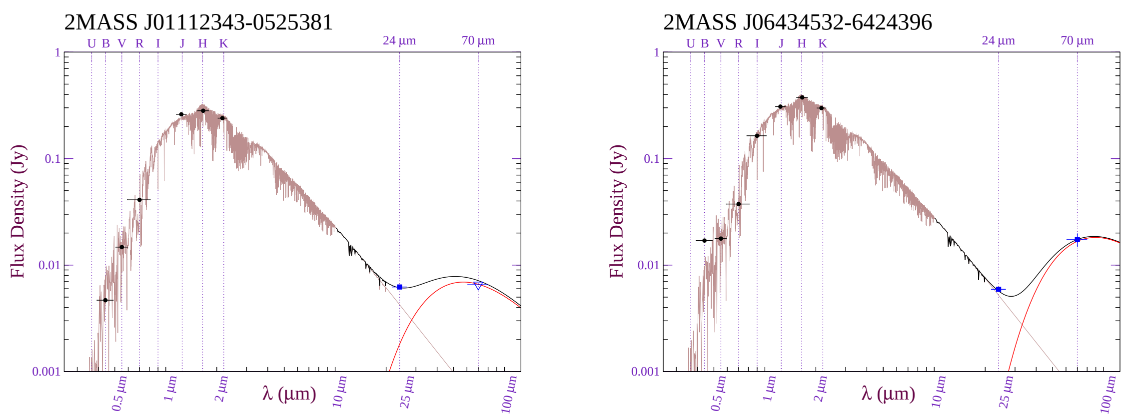

FIGURE 1. Debris disk candidate SEDs from our Spitzer program. Optical and near-IR photometry are shown as black circles, with PHOENIX NextGen model photospheres in brown fit with a least-χ^2 technique to the optical and near-IR photometry. Color-corrected Spitzer MIPS observations are shown in blue. The 70 μm flux for 2MASS J01112343-0525381 is a 3-σ upper limit. Single-temperature blackbodies (red) are fit to the MIPS photometry, and the total stellar+disk flux is shown as the black curve.