The Occurrence of Warm Dust around Cool Stars

Christopher A. Theissen
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Committee Members: Dan Clemens (Chair), Catherine Espaillat, Andrew West, and Paul Withers
Some Interesting Background

- Low-mass stars (cool stars; M dwarfs → dM)
  - Most populous type of star in the Galaxy (>70%; West et al. 2008)
  - Extremely faint (can’t see any with the naked eye from Earth)
  - Penchant for building terrestrial planets (Dressing & Charbonneau 2013)
Formation and Evolution of Stars and Disks

<table>
<thead>
<tr>
<th>Timescale</th>
<th>Observable (SED)</th>
<th>Model</th>
</tr>
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<tbody>
<tr>
<td>$t &lt; 0.03$ Myr</td>
<td>IR, Nir, Visible</td>
<td>Black body, Infrared excess</td>
</tr>
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<td>Disk</td>
</tr>
<tr>
<td>$t \approx 1$ Myr</td>
<td>IR, Nir, Visible</td>
<td>stellar black body, Disk</td>
</tr>
<tr>
<td>$t \approx 10$ Myr</td>
<td>IR, Nir, Visible</td>
<td>debris + planets</td>
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Adapted from Lada (1987)
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Adapted from Lada (1987)
Disk Removal Mechanisms
(Radiative Examples)

Photoevaporation
(Radiation Pressure)

Particle will decelerate and spiral inwards

Poynting-Robertson

Adapted from Williams & Cieza (2011)

Credit: Michael Schmid
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(Radiative Examples)

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Disk Removal Mechanisms
(Grain Growth/Planets)
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Motivating Questions

What is the timescale for disk dispersal around low-mass stars?

Multiple mechanisms play an important role in removing disks around stars. What are the dominant dispersal mechanisms for low-mass stars, and how does that affect their disk evolution?
WHERE ARE THE M DWARF DISKS OLDER THAN 10 MILLION YEARS?

Peter Plavchan, M. Jura, and S. J. Lipsky
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Received 2004 October 18; accepted 2005 June 6

ABSTRACT

We present 11.7 μm observations of nine late-type dwarfs obtained at the Keck I 10 m telescope in 2002 December and 2003 April. Our targets were selected for their youth or apparent IRAS 12 μm excess. For all nine sources, excess infrared emission is not detected. We find that stellar wind drag can dominate the circumstellar grain removal and plausibly explain the dearth of M dwarf systems older than 10 Myr with currently detected infrared excesses. We predict that M dwarfs possess fractional infrared excesses on the order of $L_{IR}/L_\ast \sim 10^{-6}$ and that this may be detectable with future efforts.
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WARM DUST AROUND COOL STARS: FIELD M DWARFS WITH WISE 12 OR 22 \( \mu m \) EXCESS EMISSION

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Received 2014 April 23; accepted 2014 August 27; published 2014 October 2

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Using the Sloan Digital Sky Survey Data Release 7 (SDSS DR7) spectroscopic catalog, we searched the WISE AllWISE catalog to investigate the occurrence of warm dust, as inferred from IR excesses, around field M dwarfs (dMs). We developed SDSS/WISE color selection criteria to identify 175 dMs (from 70,841) that show IR flux greater than the typical dM photosphere levels at 12 and/or 22 \( \mu m \), including seven new stars within the Orion OB1 footprint. We characterize the dust populations inferred from each IR excess and investigate the possibility that these excesses could arise from ultracool binary companions by modeling combined spectral energy distributions.
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Strength in Numbers

SDSS spectroscopic sample of many low-mass stars (70,841; West et al. 2011).
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**WISE** color-magnitude criteria to select stars with excess IR flux.
Other Explanations for IR Excess - Ultra-cool Binaries

![Graph showing M Dwarf Teff (K) vs. FW1/FW3 with lines for different temperatures and log(g) values.](image)

Adapted from Theissen & West (2014)
Other Explanations for IR Excess - chance alignment with a Galaxy

![Graph showing probability distribution vs. distance (arcsec)].

- Approximate Confusion Limit
- $\frac{1}{2} \times \text{FWHM}_w^3$

11
Other Explanations for IR Excess - chance alignment with a Galaxy

\[ \text{Probability (\%)} \]

\[ \text{Distance (arcsec)} \]

\[ \frac{1}{2} \times \text{FWHM}_{W3} \]

Approximate Confusion Limit

Theissen & West (2014)
The Final Sample

(a) Number of stars as a function of spectral type.

(b) Number of stars as a function of distance (pc).

Theissen & West (2014)
Where did we find them?

Galactic Coordinates

Theissen & West (2014)
Where did we find them?

![Galactic Coordinates](image)

Distance (pc)

Theissen & West (2014)
Combining Surveys for SEDs
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Adapted from Theissen & West (2014)
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Adapted from Theissen & West (2014)

100"

SDSS ~Visible

W1, W2, W3, W4

gri, JHKs, W1

\( \lambda (\mu m) \)
Combining Surveys for SEDs

Adapted from Theissen & West (2014)
Combining Surveys for SEDs

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Aging a Star:
Part 1: Surface Gravity aka \( \log(g) \)
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Aging a Star:
Part 1: Surface Gravity aka log(g)

Mann et al. (2012)
Aging a Star:
Part 1: Surface Gravity aka log(g)

Mann et al. (2012)
Aging a Star: 
Part 1: Surface Gravity aka log(g)

![Normalized Flux](image)

Adapted from Theissen & West (2014)
Aging a Star:
Part 2: Hydrogen Balmer emission

Morgan et al. (2012)
Aging a Star:
Part 2: Hydrogen Balmer emission

West et al. (2008)
Aging a Star:
Part 2: Hydrogen Balmer emission

Adapted from Theissen & West (2014)
Motivating Questions

- What is the timescale for disk dispersal around low-mass stars?
  - Multiple mechanisms play an important role in removing disks around stars. What are the dominant dispersal mechanisms for low-mass stars, and how does that affect their disk evolution?

We don’t have the ability to probe ages < 100 Myr, but the majority of our stars appear to have ages > 1 Gyr.
Motivating Questions

❖ What is the timescale for disk dispersal around low-mass stars?

❖ Multiple mechanisms play an important role in removing disks around stars. What are the dominant dispersal mechanisms for low-mass stars, and how does that affect their disk evolution?

❖ What are the possible causes of warm dust around (older) field stars?

❖ Formation theories suggest that field stars should have already dispersed their primordial disks.
Simple Disk Modeling

Adapted from Theissen & West (2014)
Simple Disk Modeling

Adapted from Theissen & West (2014)
Motivating Questions

- What are the possible causes of warm dust around (older) field stars?
  - Formation theories suggest that field stars should have already dispersed their primordial disks.

1) Primordial disks. Stars appear to be too old.
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1) Primordial disks.
2) Tidal disruption of planetary bodies.

Stars appear to be too old.
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Would expect excess to orbit at Roche limit.
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1) Primordial disks. Stars appear to be too old.
2) Tidal disruption of planetary bodies. Would expect excess to orbit at Roche limit.
3) Collisions between terrestrial planets.
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1) Primordial disks.
2) Tidal disruption of planetary bodies.
3) Collisions between terrestrial planets.

Stars appear to be too old. Would expect excess to orbit at Roche limit.
Possible Clues Leading to Collisions - The Grand Tack Scenario

Adapted from Walsh et al. (2013)
Possible Clues Leading to Collisions - The *Kepler* Dichotomy

*Kepler* has found lots of multi-transiting and single-transiting planetary systems.

- Both populations cannot be explained by the same planetary architecture (Ballard & Johnson 2014).
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**Possible Clues Leading to Collisions - The *Kepler* Dichotomy**

**Singles**

- Slower stellar rotation rates
- Farther from the Galactic plane

**Multis**

- Faster stellar rotation rates
- Closer to the Galactic plane

Ballard & Johnson (2014)
**Possible Clues Leading to Collisions - The *Kepler* Dichotomy**

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**Possible Clues Leading to Collisions**

- Older?
  - Slower stellar rotation rates
  - Farther from the Galactic plane

- Younger?
  - Faster stellar rotation rates
  - Closer to the Galactic plane

---

*Kepler* Dichotomy:

<table>
<thead>
<tr>
<th>Slow Rotating</th>
<th>Fast Rotating</th>
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<tbody>
<tr>
<td>Farther</td>
<td>Closer</td>
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**Eccentricity = 0**

**Number of Planets Per Star**

**Scatter in Mutual Inclination**

Ballard & Johnson (2014)
Motivating Questions

- What is the timescale for disk dispersal around low-mass stars?
  - Multiple mechanisms play an important role in removing disks around stars. What are the dominant dispersal mechanisms for low-mass stars, and how does that affect their disk evolution?

- What are the possible causes of warm dust around field stars?
  - Formation theories suggest that field stars should have already dispersed their primordial disks.

- How frequently do we see warm dust around low-mass field stars?
  - Potential effects on the formation of (exo-)planetary systems and habitability of said systems.
Number of collisional events per star (over the lifetime of stars surveyed), $N_g$
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$N_g \sim 100$
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$$N_g \sim 100$$

For solar-type stars, $N_g \sim 0.2$
Motivating Questions

- How frequently do we see warm dust around low-mass field stars?
- Potential effects on the formation of (exo-)planetary systems and habitability of said systems.

Far more frequently than around Solar-type stars. This is possibly due to a higher-number of terrestrial planets formed around low-mass stars, all with close in orbits.
Current & Future Work

SDSS Data Release 10: Over 50 million photometric M dwarfs!
Current & Future Work

SDSS Data Release 10: Over 50 million photometric M dwarfs!
Final Thought

If terrestrial planets around M dwarfs are prone to collisions, this is just one more complication in finding a “habitable” Earth analog around a low-mass star.
Other Explanations for IR Excess
Possible Clues Leading to Collisions - The *Kepler* Dichotomy (Part 2)

**Figures:**
- Scatter plot showing the number of systems (KOI Sample) vs. number of planets per star.
- Graph illustrating the scatter in mutual inclination with limits from Fabrycky et al. (2014).
- Diagram depicting the magnitude ratio with inclination.

*Ballard & Johnson (2014)*
Fraction of stars observed with dust, $f$

Lifetime of collisional products, $L$

Age of stars surveyed, $A$

Number of collisional events per star, $N_g$

$$N_g = \frac{f \times A}{L}$$

- $f \sim 4 \times 10^{-3}$
- $L \sim 10^5$ years
- $A \sim 2.6 \times 10^9$ years

$N_g \sim 100$

For solar-type stars, $N_g \sim 0.2$
Is There an Age Effect?

Adapted from West et al. (2011)
Is There an Age Effect?

\[
\frac{\text{# stars w/ IR excess}}{\text{Total # stars}} = \text{Disk Fraction}
\]

Theissen & West (2014)