Circumstellar Disks in Young and Old Main-Sequence Stars

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Circumstellar Disks at All Stages of Stellar Evolution

• Pre-Main Sequence: protoplanetary disks  
  (see review by Andrews+2015)
  
• Main Sequence: debris disks  
  (see review by Matthews+2014)
  
• Post-Main Sequence: dusty disks around white dwarfs  
  (see review by Farihi2016)
  
Also see “Circumstellar Disks: What will be next?” by Kral, Clarke & Wyatt, astrophy/1703.08560

star forming region around HL Tau (red square )

~0.035” with ALMA in 2014
New Capabilities Enable New Discoveries

- Wavelength Coverage
- Sensitivity $\leftarrow$ telescope size + mirror temperature
- Resolution in both spectral and spatial
- Time Domain
Tremendous Strides in the Last Three Decades

The Fomalhaut debris disks: a wealth of observations at a wide range of wavelengths and spatial scales from photometry, imaging to interferometry reveal the complex disk structures.

IRAS 1984

Spitzer 24 μm
Stapelfeldt+ 2004
Su+ 2013

Herschel 70 μm
Acke+2012
Su+ 2013

ALMA 1.3 mm
MacGregor+ 2017

Infrared excess

Terrestrial Planets?

~1500 K very hot dust
~0.1 AU nanograin
under B trapping

~500 K hot dust
~a few AU grains under P-R drag.

Asteroid Belt
~170 K warm dust
~8-15 AU in-situ P. B.

Giant Planets?

~110 AU
Kalas+2008, 2013
not the shepherding planet

Kuiper Belt
~50 K cold dust
~130-150 AU in-situ P. B.

more than ~250 AU grains under radiation pressure.

Su et al. 2016

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The Need for Spatial Resolution

Planets determine the planetesimals distribution in a planetary system. Dust debris, generated by planetesimals, also influences by non-gravitational forces, and their resultant emission is temperature dependent.

- **Particle Distribution for Solar System**

- **Mid-Infrared Emission Distribution**

The dilemma in ε Eri using Spitzer observations: multiple belts? or one belt?

do not hallucinate.

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The dilemma in ε Eri using Spitzer observations: multiple belts? or one belt?
The Inner Debris Structure in ε Eri?

MIPS 24 μm

FORCAST 35 μm

PACS 160 μm

unresolved

Backman+ 2009

Su+ 2017

Greaves+ 2014

two narrow inner belts?

1.5-2 AU inner asteroid belt

8-20 AU outer asteroid belt

55-80 AU

Kuiper belt

one broad puff-up disk?

3-21 AU broad, puff-up disk

55-80 AU

Backman+ 2009

Su+ 2017

Greaves+ 2014

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The sub-arcsec resolution enabled by JWST observations will resolve the inner debris structure in ε Eri, and settle the long debate between two inner belts or one broad disk.

**two narrow inner belts?**
- Backman+ 2009
- Su+ 2017

**one broad puff-up disk?**
- Greaves+ 2014
- 3-21 AU broad, puff-up disk

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High Spatial & Spectral Resolutions of JWST

6.5 m infrared telescope to be launched in mid 2019

A suite of instruments (NIRCam, NIRSpec, MIRI, FGS/NIRISS) capable of performing high-resolution imaging and spectroscopy from 0.6 to 28 μm.

Mid-infrared spectra from thermodynamically altered minerals (various forms of crystalline silicates) can probe the physical conditions of violent events in the disks.

In addition to new discoveries, JWST will provide a great opportunity to extend and follow-up the legacy started by Spitzer with much more powerful capabilities.
Extreme Debris Disks: Tracers for Large Impacts

Systems around young stars (~10 Myr to 200 Myr) with large amounts of dust in the terrestrial zone and prominent silicate features. ~50% of them show disk variability at 3.6/4.5 μm (Meng, Su+ 2015; Su+ 2018, in prep.).

Mid-infrared spectra from Spitzer and JWST will enable time-series study in extreme debris disks, providing much needed constraints on terrestrial planet formation theories.
**Technical Specifications**

**Actively-Cooled Large Aperture**

- Attain sensitivities 100-1000x greater than any previous far-IR telescope.
- Diffraction limited at \( \sim 30 \, \mu m \)

**Timeline**

- **Spitzer** 0.85 m
- **WFIRST** Hubble 2.4 m
- **Herschel** 3.5 m
- **Webb** 6.5 m

**Wavelength Coverage**

Visit our websites:
- origins.ipac.caltech.edu
- asd.gsfc.nasa.gov/firs

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Models are the dust density distributions from Deller & Maddison (2005) with various planet masses and eccentricities, which are observed with 1” (OST, concept 1) and 5.6” (Herschel) resolutions.
A large, cryogenic cold telescope (like OST) can discover many more disks, and provide a census of true Kuiper-belt analogs, putting our Solar System into context.