Time-monitoring of “Extreme” Debris Disks

Thematic Areas (Check all that apply):

☐ (Theme A) Key science themes that should be prioritized for future JWST and HST observations
☐ (Theme B) Advice on optimal timing for substantive follow-up observations and mechanisms for enabling exoplanet science with HST and/or JWST
☐ (Theme C) The appropriate scale of resources likely required to support exoplanet science with HST and/or JWST
☒ (Theme D) A specific concept for a large-scale (∼500 hours) Director’s Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: Exceptionally dusty debris disk systems are thought to result from collisional activity during terrestrial planet formation or from dynamical instabilities triggered after gas dispersal. Of the few dozen detected, many show near-IR variability (as much as a factor of two) over a period of days to months, consistent with violent impacts involving large asteroid-size bodies. Some also show strong mineralogical features in their mid-infrared spectra indicative of fine silica grains thought to originate from the condensation of silica gas produced in violent collisions (like the Moon-forming event). Here we propose a JWST Director Discretionary program to understand how violent impacts affect the subsequent evolution of planetary systems. It consists in the time-monitoring over five years of six ”extreme” debris disks found to be variable by Spitzer, using NIRCam/Grism and MIRI/MRS. The goals are to study the composition of the debris, the rate of large collisions and the timescale for debris clearing, parameters that can be used to test planetary system formation and evolution models. This program will allow to identify periods of increased collisional activity for higher-cadence, follow-up observations.

Anticipated Science Objectives: We propose time-monitoring of six targets: ID 8, P1121, and TYC 4209, showing periodic, high frequency time-variability in Spitzer IRAC light curves (Su et al. 2019, Moor et al. 2022) and v488 Per, RZ Psc, and HD 166191, exhibiting larger, longer-timescale, stochastic behavior (Rieke et al. 2021 and Su et al. 2022). We will use NIRCam/Grism (2.4-5 um) + MIRI/MRS (5-13 um) to monitor the hot dust and 10 um features (crystalline silicates vs. silica), and MIRI/MRS to study dust mineralogical features in the 20 um region and to constrain the dust temperature. We propose two epochs per year per target over a period of five years. Assuming two hours for MIRI/MRS and one for NIRCam-Grism, this will amount to a total of 180 hours over five years. These observations will allow to study the composition of debris (altered by the energetics of the collisions), the rate of large collisions and the timescale for debris clearing, major unknowns in circumstellar disk studies that can be used as benchmarks to test models of terrestrial planet formation and planetary system evolution. The continued monitoring of these six targets by JWST builds upon Spitzer's monitoring and will allow the community to request higher-cadence, follow-up observations when periods of increased collisional activity are identified.

Urgency: The results of this program can help plan and interpret future observations of debris disks with JWST and Roman (the latter allowing to study dust in the terrestrial planet region of nearby debris disks at distances $<$10 pc).

Risk/Feasibility: Because of the uncertainty of when the time-variable, extreme debris disks will be active, we suggest a cost-effective spectroscopic, time-monitoring approach using NIRCam Grism Time Series with the 2048x64 subarray in the near-IR, as the best compromise between bright source limits, wavelength coverage and spectral resolution (R$\sim$ 1,600), and MIRI MRS in the mid-IR.

Timeliness: As identified by Astro2020, the study of debris disks is key to understand the diversity of architectures and dynamical histories of exoplanetary systems, helping address one of Astro2020 key questions: ”what is the range of planetary systems and is the configuration of the solar system common”. Understanding the production and evolution of dust in the inner regions of planetary systems will inform the design of the habitable planet search by HWO.

Cannot be accomplished in the normal GO cycle: Long-term monitoring over five years is outside the scope of GO opportunities.

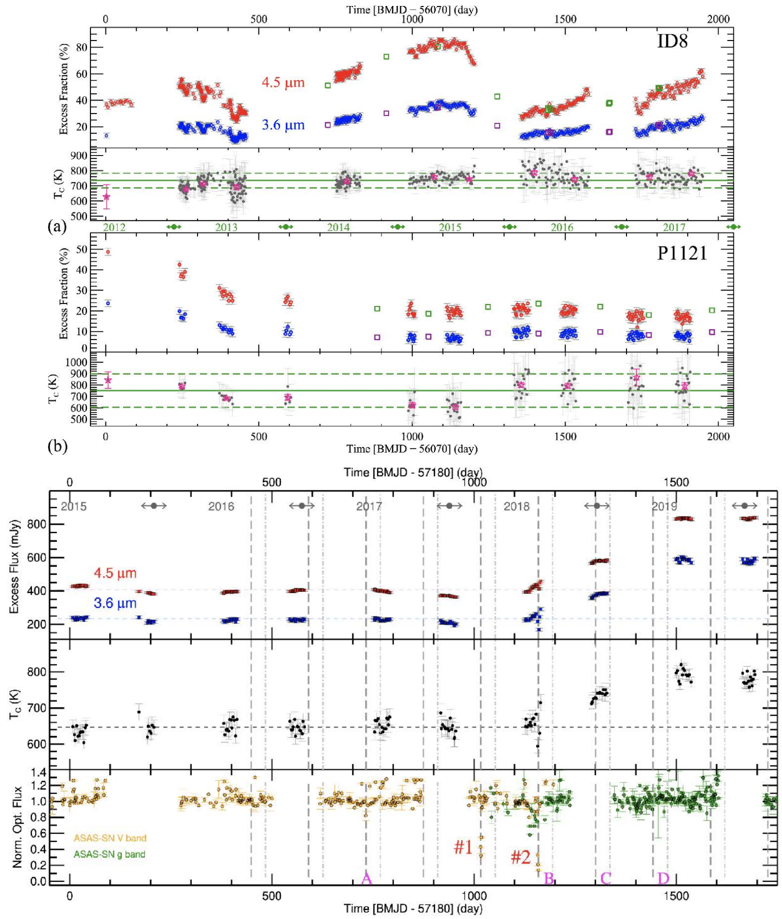

Figure 1: Top: Time-series observations of ID 8 and P11121 from Su et al. (2019) showing excesses emission and color temperatures relative to the stellar photosphere (open circles correspond to Spitzer and squares to WISE; the green line is the 5-year average color temperature). Bottom: Same for HD 166191 from Su et al. (2022) with data from the warm Spitzer mission, with the horizontal dashed lines corresponding to median values of the disk fluxes and temperatures.

References

[1] Kate Y. L. Su et al. "Extreme Debris Disk Variability: Exploring the Diverse Outcomes of Large Asteroid Impacts During the Era of Terrestrial Planet Formation". In: 157.5, 202 (May 2019), p. 202.

[2] Attila Moór et al. "Mid-infrared time-domain study of recent dust production events in the extreme debris disc of TYC 4209-1322-1". In: 516.4 (Nov. 2022), pp. 5684–5701.

[3] G. H. Rieke et al. "Extreme Variability of the V488 Persei Debris Disk". In: 918.2, 71 (Sept. 2021), p. 71.

[4] Kate Y. L. Su et al. "A Star-sized Impact-produced Dust Clump in the Terrestrial Zone of the HD 166191 System". In: 927.2, 135 (Mar. 2022), p. 135.