Debris Disk Studies with the ngVLA

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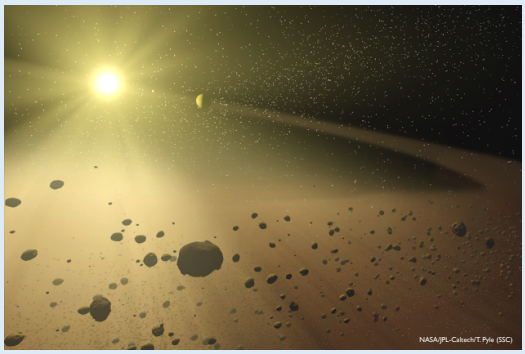
Summary

- Debris disks around main-sequence stars represent the end stage of circumstellar disk evolution and are sustained by the collisional erosion of planetesimals (comets and asteroids); they serve as signposts for planetary mass bodies that sculpt and stir the planetesimals.
- Observations with the ngVLA at 3 to 10 mm can play a key role to advance understanding because the large grains that dominate emission at these long wavelengths faithfully trace the dust-producing planetesimals, unlike small grains seen in the optical and infrared that are rapidly redistributed by stellar radiation and winds.
- The ngVLA can reveal disk structures resulting from planets on wide orbits and enable precise measurements of spectral indices in the mm/cm regime that encode the sizes, relative velocities and tensile strengths of the colliding bodies.

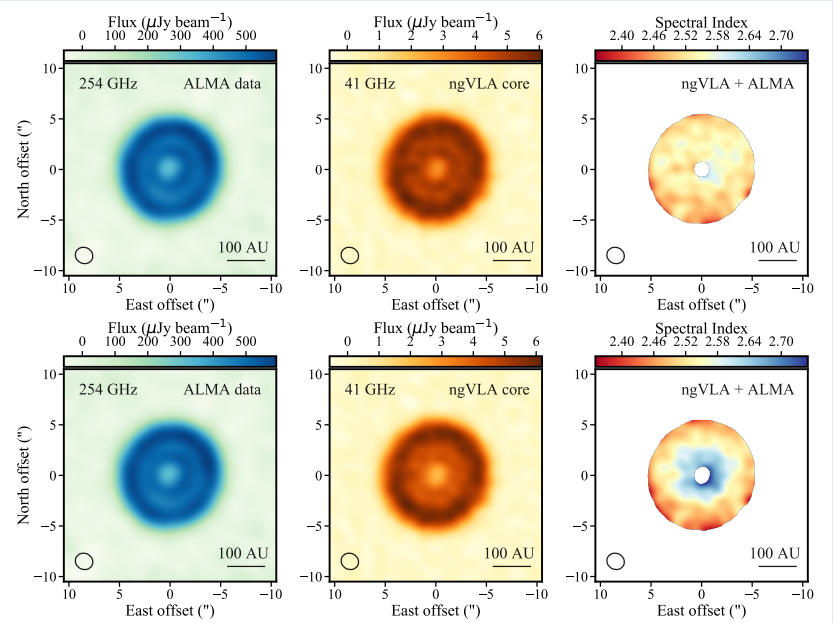


ngVLA complements ALMA

- The spectral index of debris disk emission provides the clearest window into the properties of collisionally generated dust. However, the low masses of debris disks (a lunar mass or lower) coupled with the steep drop in dust opacities to long wavelengths results in weak emission that makes debris disk detection difficult at wavelengths beyond 1.3 mm, even with ALMA (e.g. Ricci et al. 2012, Greaves et al. 2012, Ricci et al. 2015, MacGregor et al. 2016).
- The ngVLA will make possible detailed investigation of 3 to 10 mm emission from essentially all debris disks that can be detected and imaged by ALMA at shorter wavelengths. The ngVLA will *uniquely* probe cm-sized grains ("pebbles"), which likely hold significantly more mass than mm-sized grains.
- The sample of probable ngVLA targets consists of about 50 systems located within 100 pc, with typical fluxes 1 to 10 mJy at 1.3 mm, which correspond to about 1 to 10 μJy at 10 mm.

Imaging Structure and Spatially Resolved Spectral Indices

- Resolved imaging with ngVLA can reveal spectral index variations in the mm/cm regime that arise if the debris is fed by planetesimals with different physical properties (e.g. compact vs. rubble piles) or different collisional processes (e.g. steady state cascade vs. stochastic giant impact).
- The index of a power-law grain size distribution, $n(a) \sim a^{-q}$, can be directly related to observables: $q = [(\alpha_{mm} - \alpha_{PI}) / \beta_s] + 3$, where α_{mm} is the mm/cm spectral index, α_{PI} is the Planck function spectral index (≈ 2 for planetesimal belt dust temperatures), and β_s is the dust opacity spectral index in the small particle limit, 1.8 ± 0.2 for a wide range of interstellar grain compositions (Draine 2006).
- The reference self-similar shattering model gives q=3.5 (Dohanyi 1969), while models that incorporate more realistic material physics and dynamics range from about 3.0 to 4.0 (Pan and Schilchting 2012).



ALMA 1.2 mm observations (Marino et al. 2018, in prep) and ngVLA 7 mm imaging simulations of the debris disk around HD 107146, a 100 Myr-old Solar analog (spectral type G2V) at 27.5 pc. The gap in the disk at a radius of 80 AU may be caused by the dynamical influence of an unseen planet.

- The two rows illustrate two scenarios, one where the spectral index is invariant with position (upper row), and one where the spectral index changes with radius between 20 to 170 AU by an amount that corresponds to a decrease of 0.15 in q, the power-law index of the grain size distribution (lower row).
- For each of the two scenarios: (*Left*) ALMA band 6 image smoothed to match the 1.67 arcsec (46 AU) resolution of the ngVLA imaging simulation. (*Center*) Simulated ngVLA band 5 image using the 114 core antennas, at 41 GHz, with 10 h integration time, where the disk total flux density was extrapolated from mm/submm data using the observed spectral index of 2.6). (*Right*) Resolved spectral index map of the emission obtained using ALMA and the ngVLA (masked where signal-to-noise ratio falls below 20).
- The simulated ngVLA observations clearly recover the radial dependence of the spectral index (lower row), easily distinguishable from the simulation with no radial dependence (upper row).

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