Towards Resolving Terrestrial-Scale Planet Formation

“The Scientific Quest for High Angular Resolution”

NRAO Special Session  
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Honolulu, HI  
January 7, 2020
Looking for reminders of home
Very massive protoplanets can be studied via direct imaging.
Planets too faint to be imaged can still create large disturbances in disks

Credit: P. Armitage
http://jila.colorado.edu/~pja/planet_migration.html

Disk is smooth initially

Perturbation by a planet triggers a spiral density wave

As the planet grows, the spiral density wave shocks and opens a gap

In low-viscosity disks, a single planet may open multiple gaps (e.g., Duffell & MacFayden 2013, Zhu+ 2014, Dong+ 2017, Bae+2017)
A gap at 1 au in the TW Hya disk
The Disk Substructures at High Angular Resolution Project (DSHARP)

Andrews, Huang+ 2018 (DSHARP I)
Most disk gaps detected so far with ALMA seem to be consistent with giant planet formation at tens of au

Zhang+ 2018 (DSHARP VII)
## Disk observations: ALMA vs. VLA

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<th>ALMA</th>
<th>VLA</th>
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<td>Access to frequencies where dust is optically thin</td>
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<td>High spatial resolution</td>
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<td>High signal-to-noise ratio</td>
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The case for a next-generation VLA

- Coverage of key frequencies where dust is optically thin but still the dominant source of emission (~30-100 GHz)
- Spatial resolution < 1 au to resolve substructures in the inner disk at distance of nearby star-forming regions (~160 pc)
- 10x improvement in sensitivity to detect substructures carved by planets smaller than Solar System ice giants
Tracing the formation of Super-Earths

Gaps induced by super-Earths are predicted to be detectable in low-viscosity disks ($\alpha=10^{-5}$) with 20 h on-source with the ngVLA

Ricci+ 2018
Gaps induced by Earths are predicted to be detectable in low-viscosity disks ($\alpha=10^{-5}$) with 100 h on-source with the ngVLA.
Summary

• ALMA is well-suited for characterizing the giant planet formation zone in disks
• The ngVLA is necessary to access the appropriate frequencies, spatial resolution, and sensitivity to study the terrestrial planet formation zone
• Selection of high-priority ngVLA targets will rely on present efforts to constrain dust grain sizes, disk turbulence, and pressure scale heights with facilities such as ALMA and the VLA