Towards Resolving Terrestrial-Scale Planet Formation

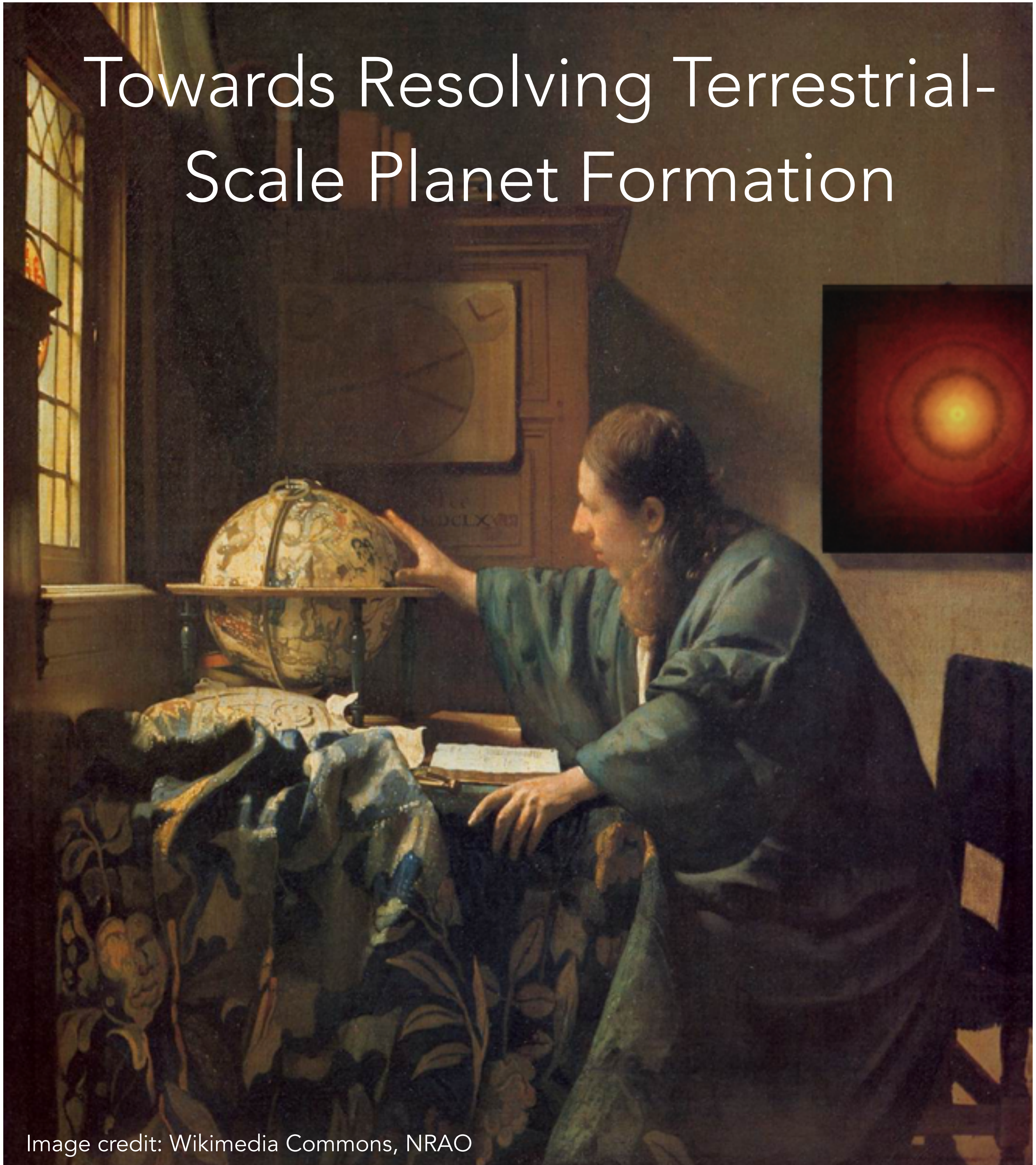


Image credit: Wikimedia Commons, NRAO

Jane Huang

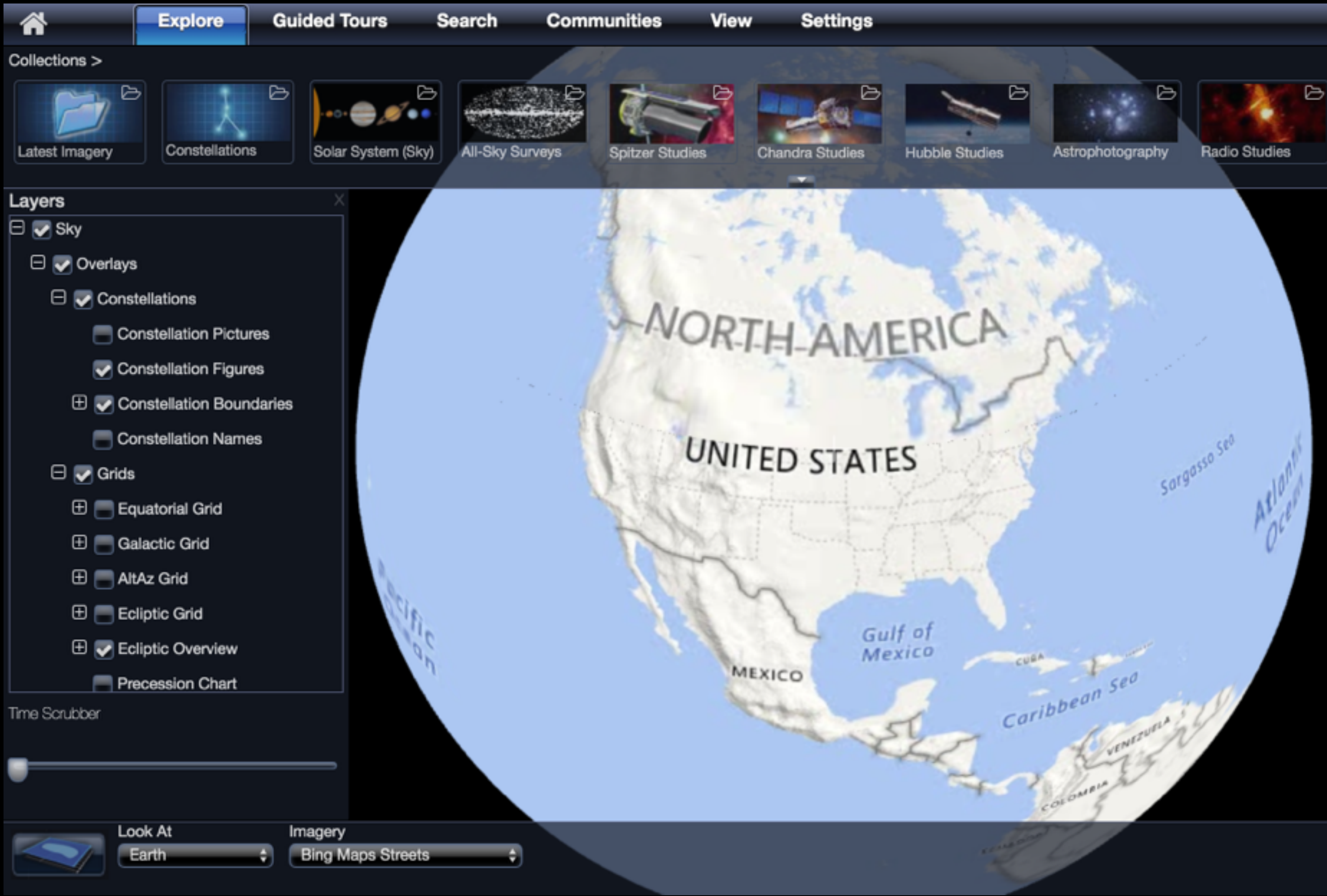
CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

"The Scientific Quest for High Angular Resolution"

NRAO Special Session

235th AAS Meeting
Honolulu, HI
January 7, 2020

Looking for reminders of home



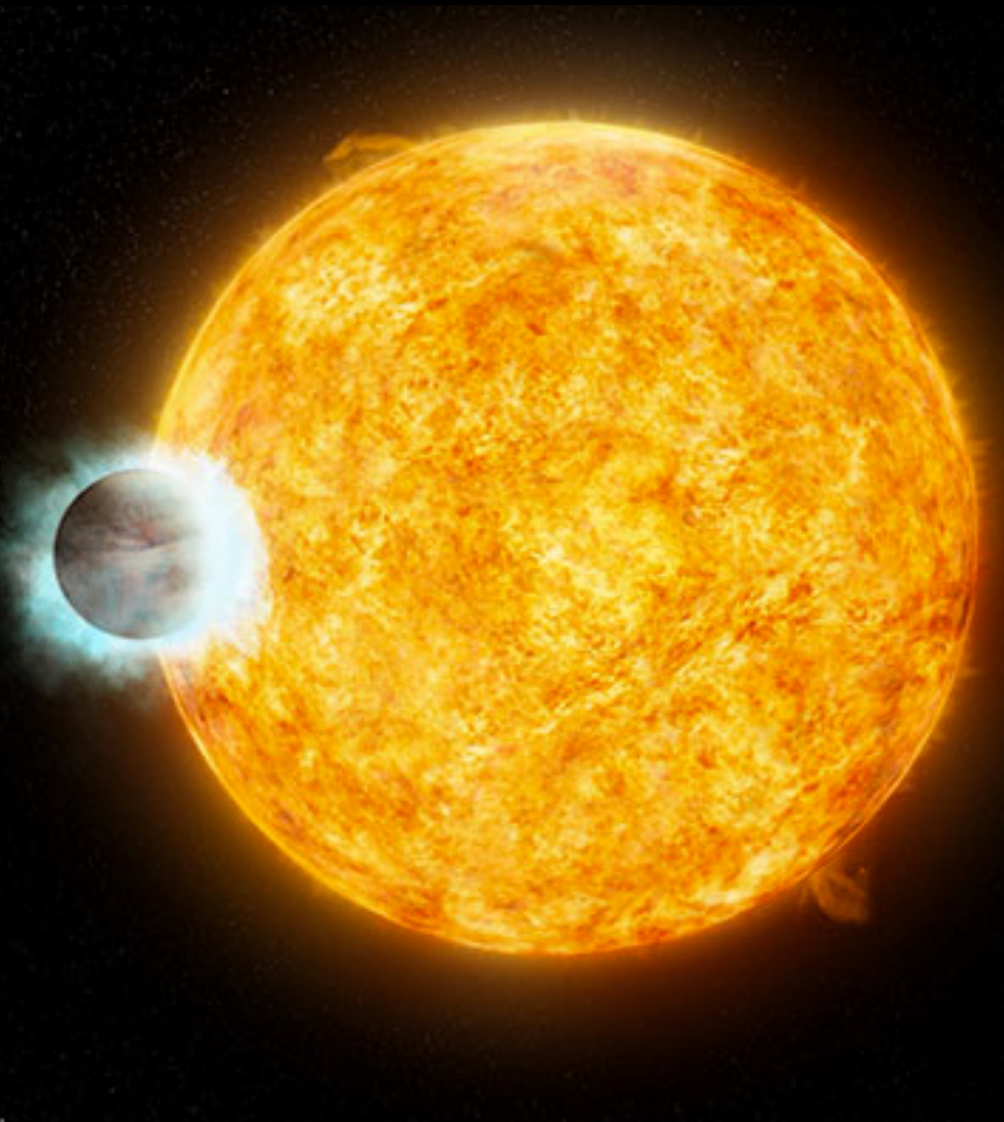
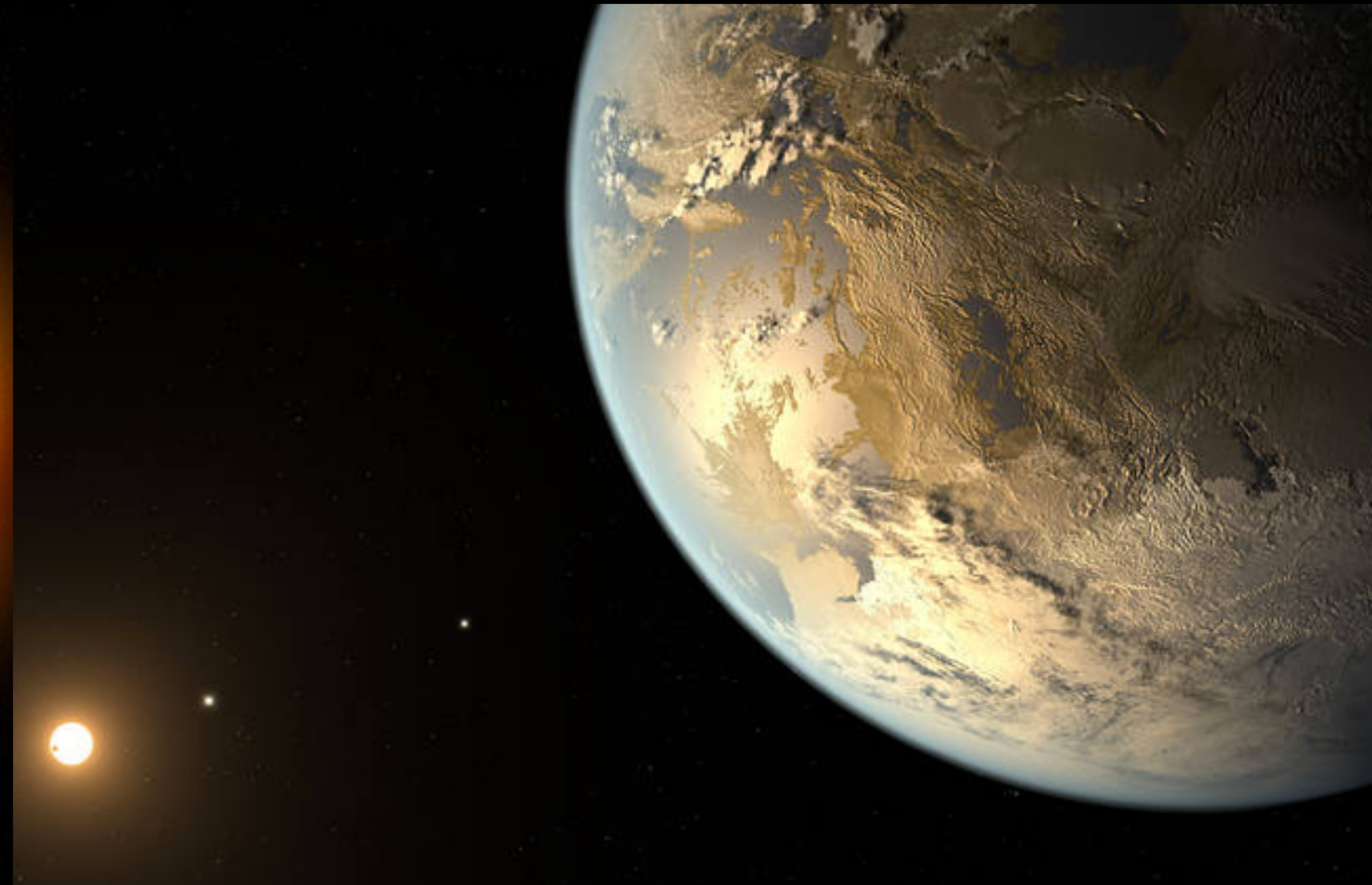
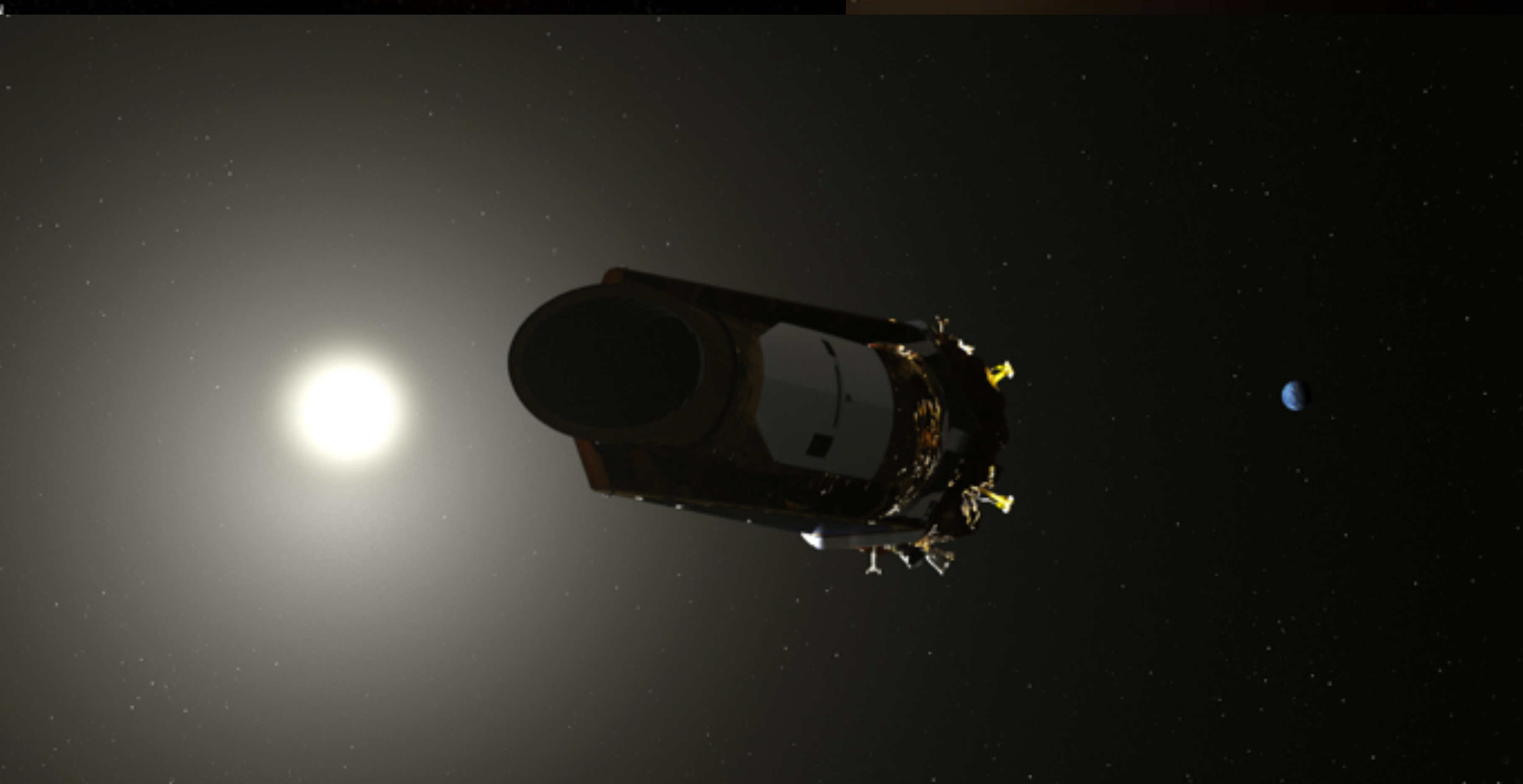




Image credits: NASA

Very massive protoplanets can be studied via direct imaging

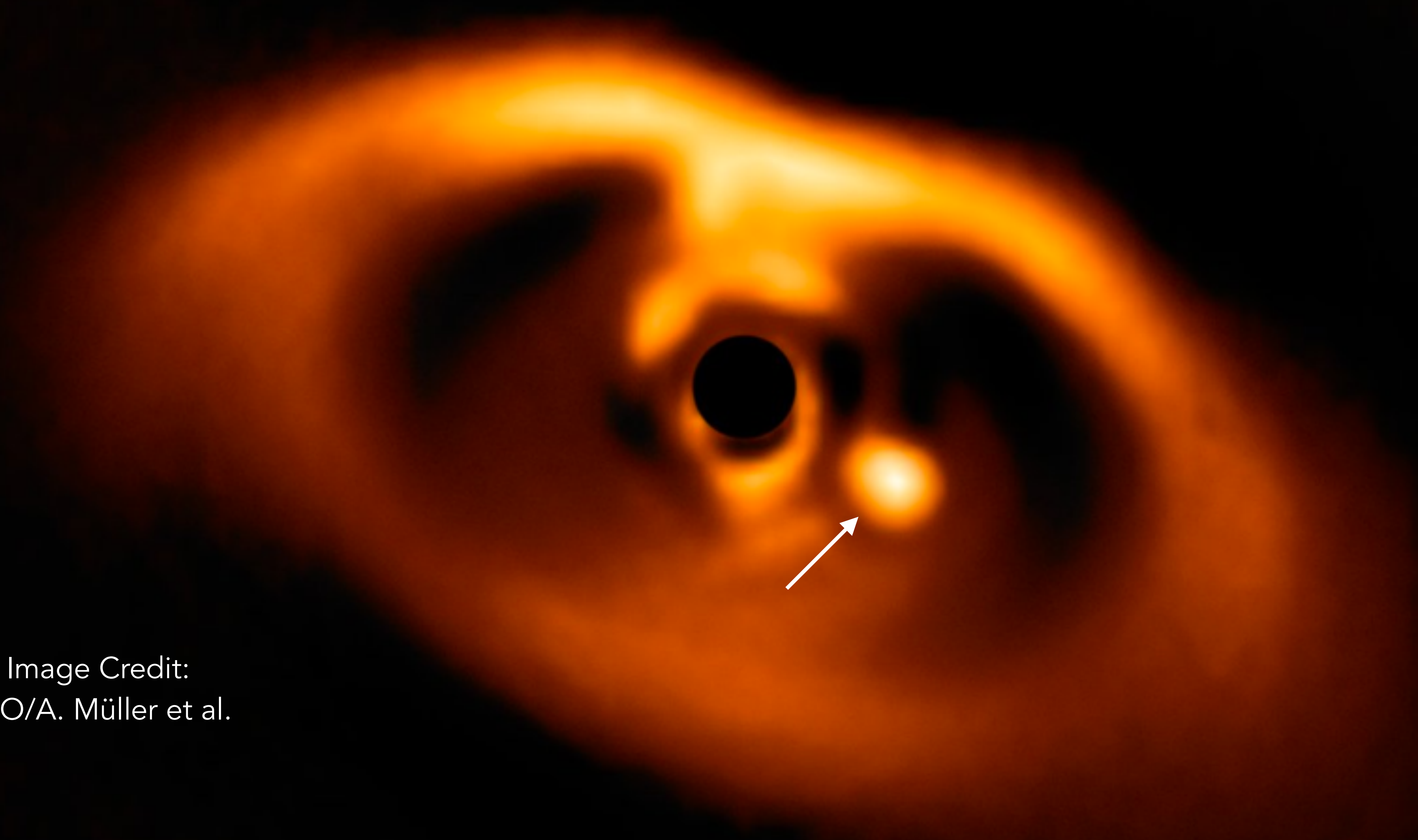
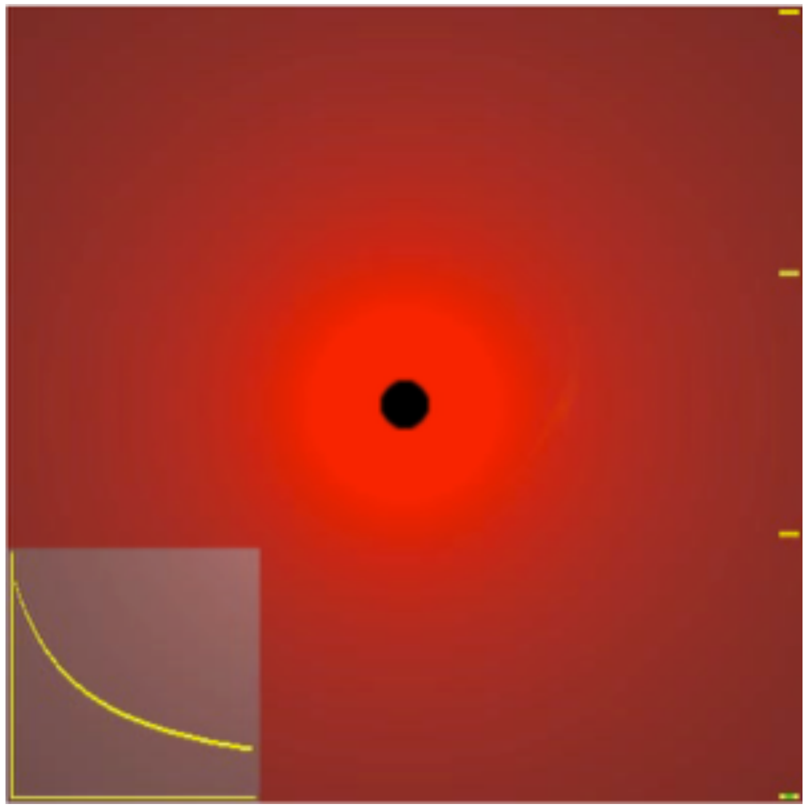


Image Credit:
ESO/A. Müller et al.

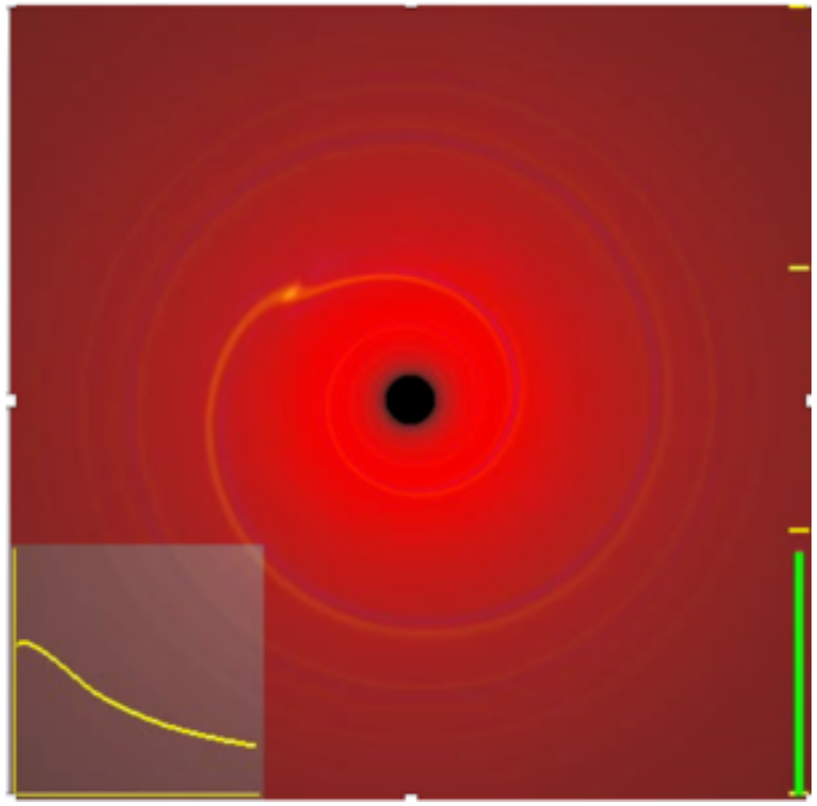
Keppler+ 2018

Planets too faint to be imaged can still create large disturbances in disks

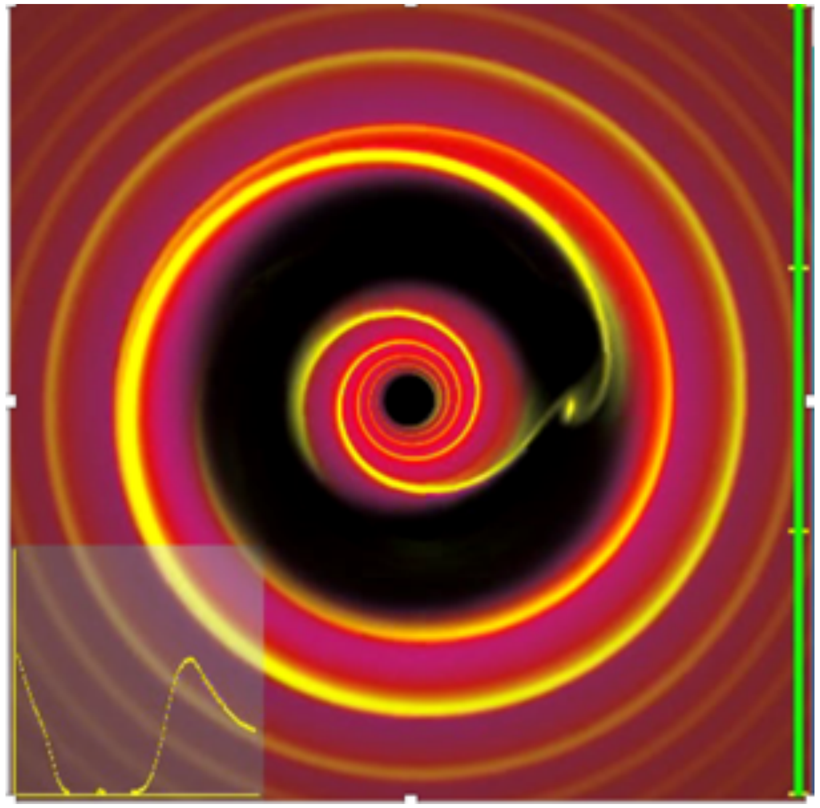
Credit: P. Armitage
http://jila.colorado.edu/~pja/planet_migration.html



Disk is smooth initially



Perturbation by a planet triggers a spiral density wave



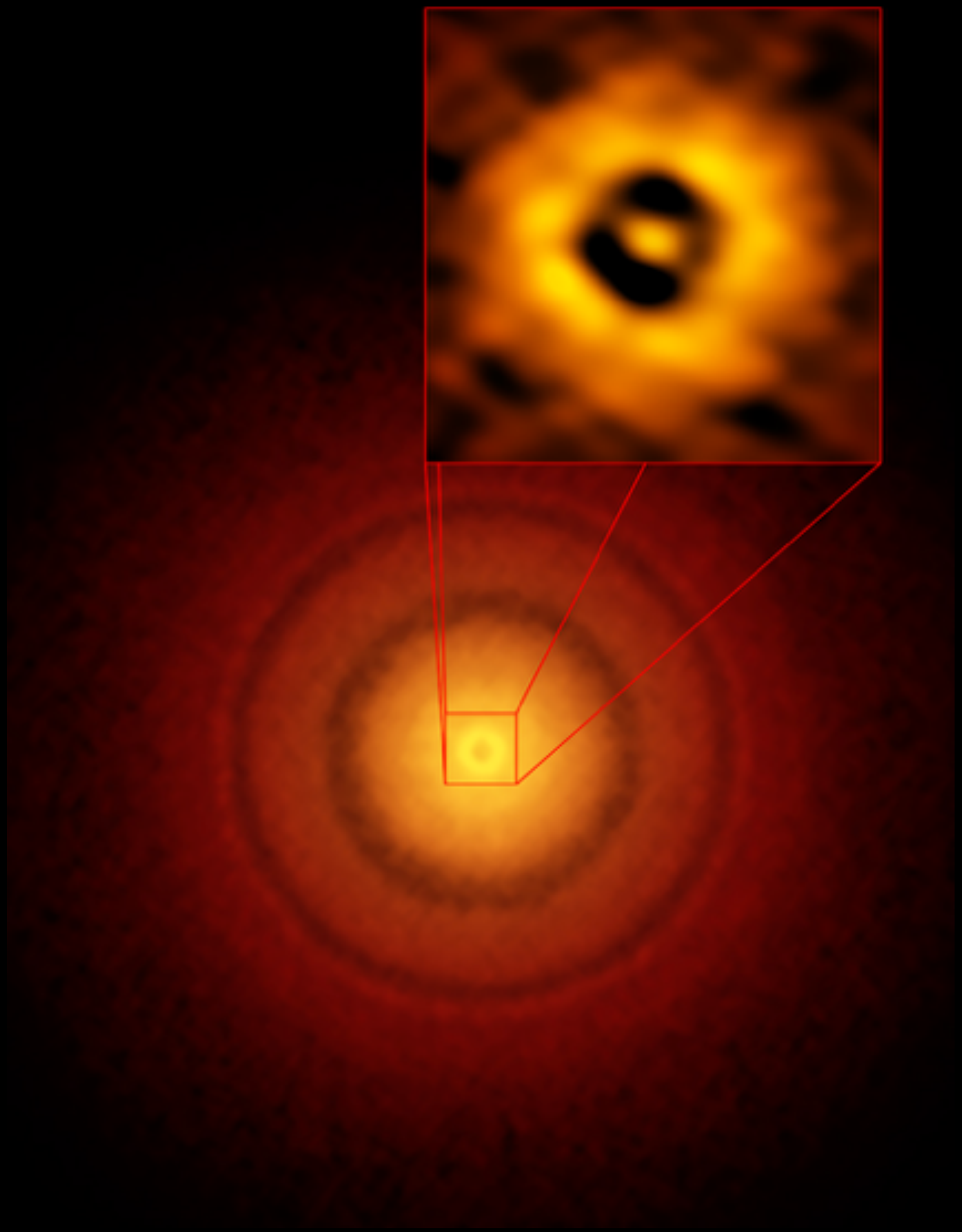
As the planet grows, the spiral density wave shocks and opens a gap

In low-viscosity disks, a single planet may open multiple gaps (e.g., Duffell & MacFayden 2013, Zhu+ 2014, Dong+ 2017, Bae+2017)

Illustration credit: Melissa Hoffman (NRAO)

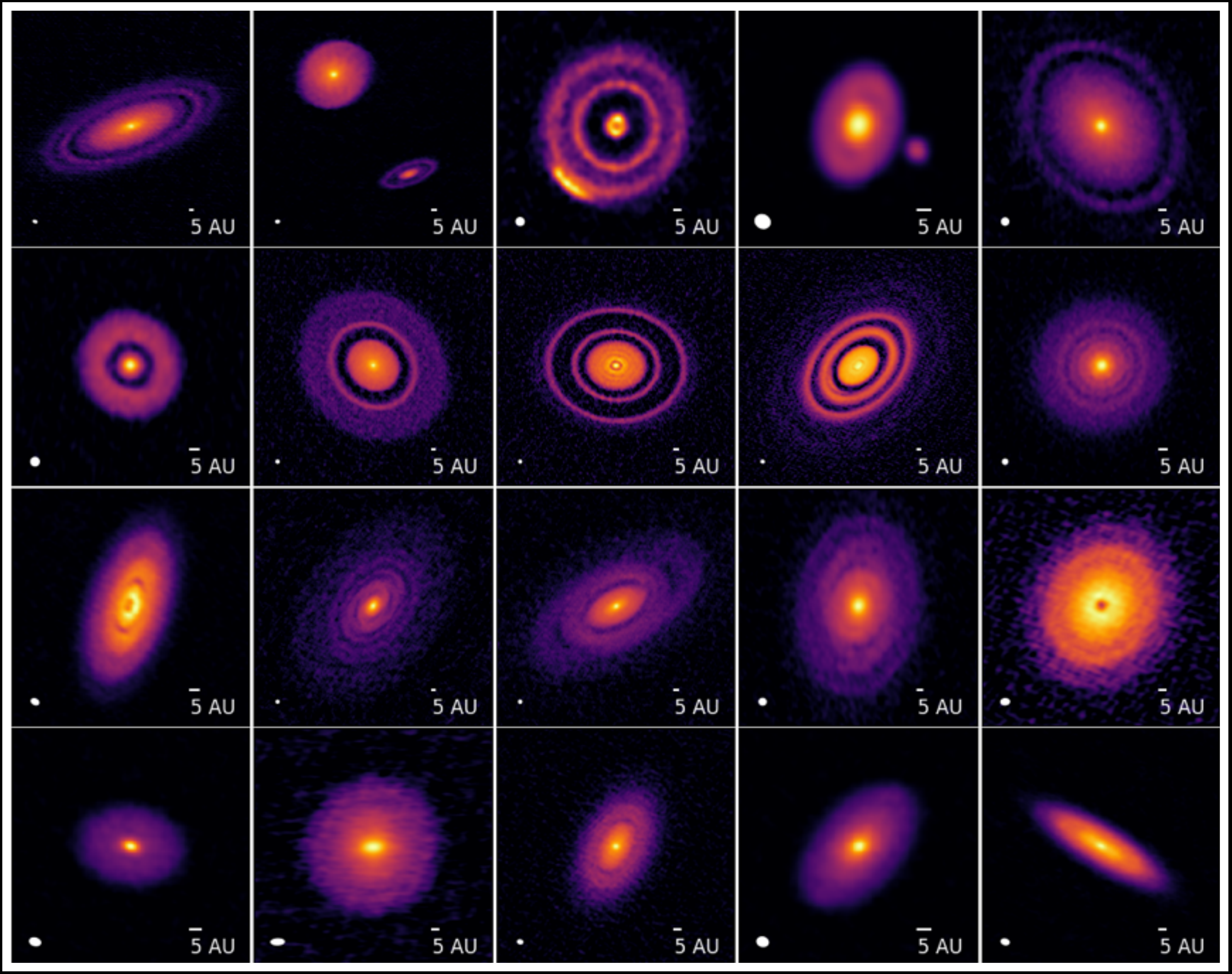
ALMA Partnership 2015

A gap at 1 au in the TW Hya disk



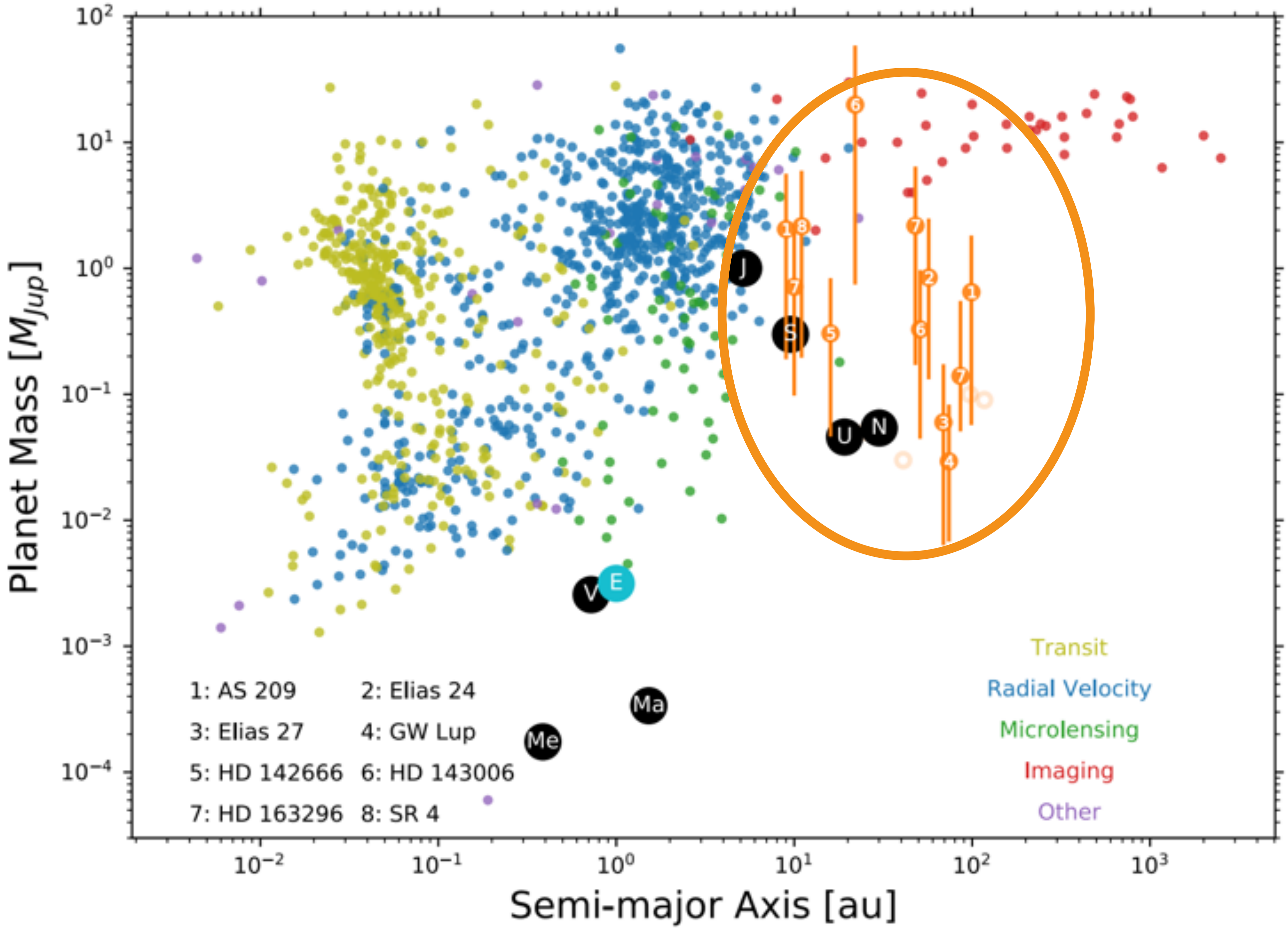
Andrews+ 2016

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

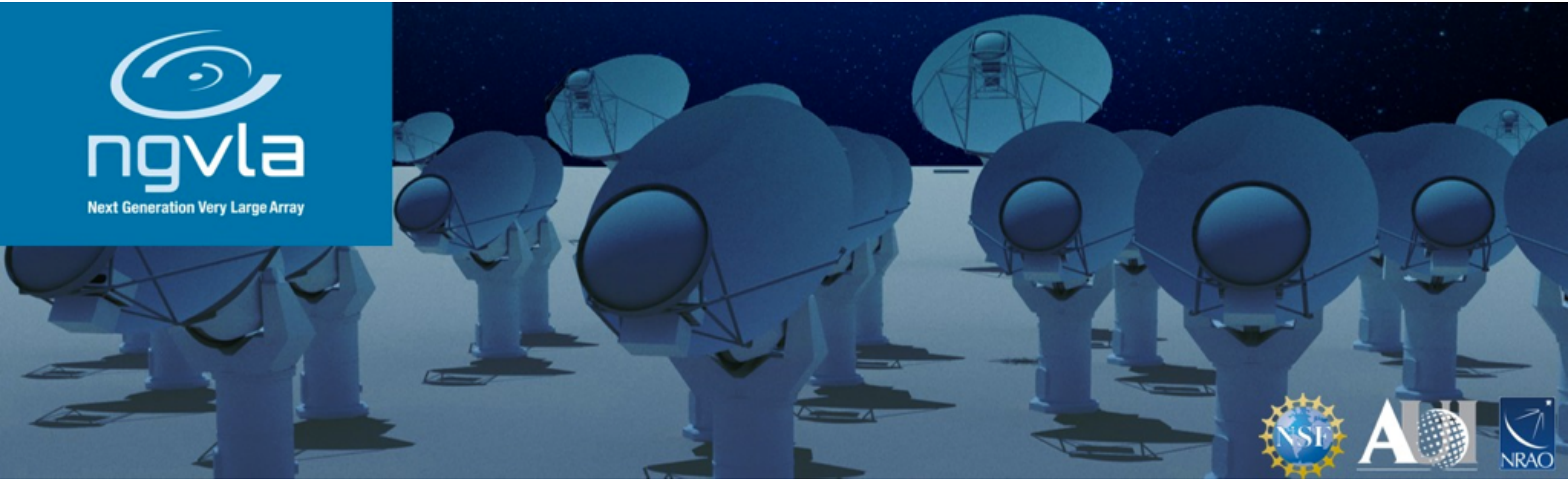


Zhang+ 2018 (DSHARP VII)

Disk observations: ALMA vs. VLA

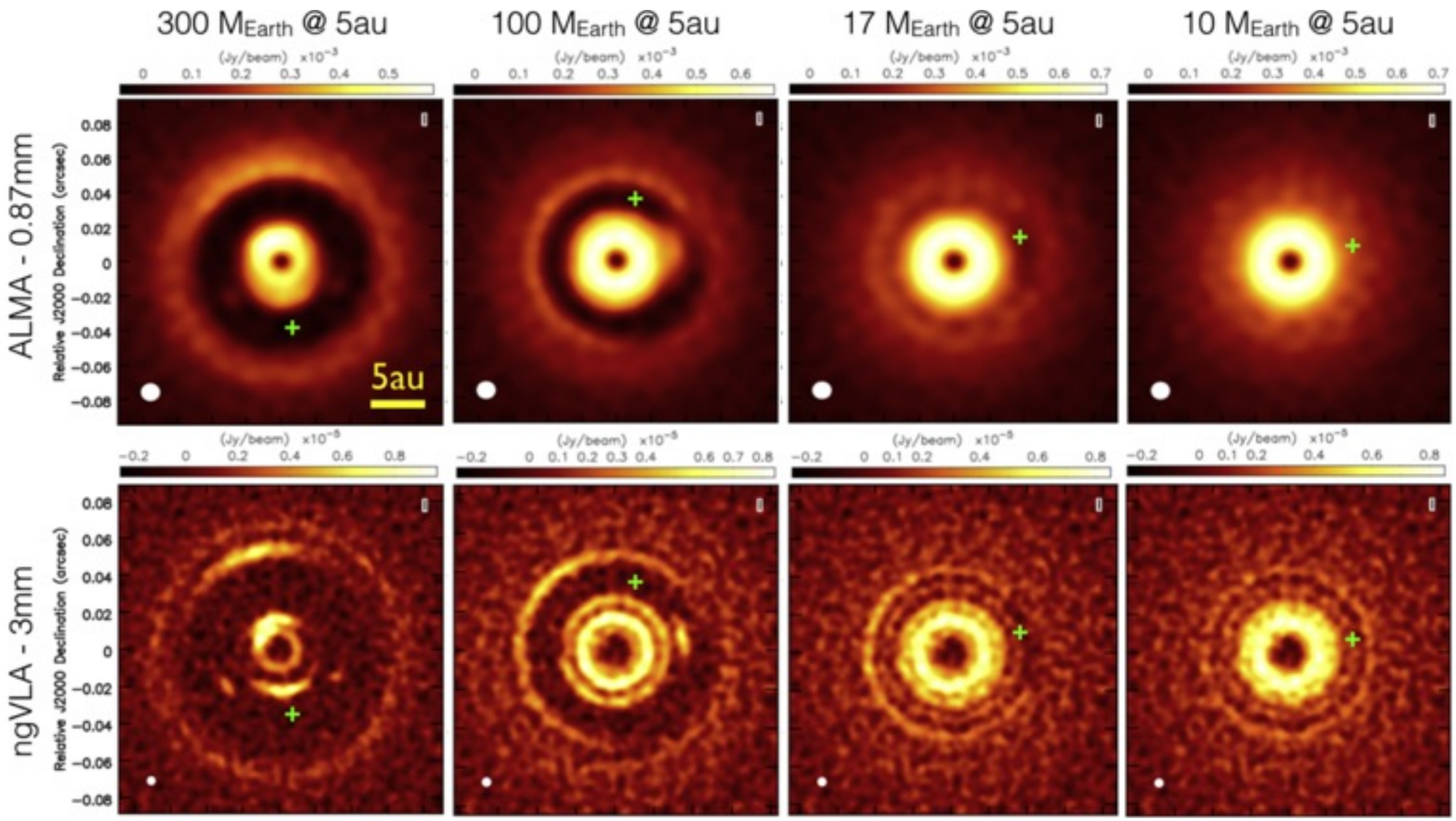
	ALMA	VLA
Access to frequencies where dust is optically thin	🤔	🤓
High spatial resolution	🤓	🙂
High signal-to-noise ratio	🤓	😐

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

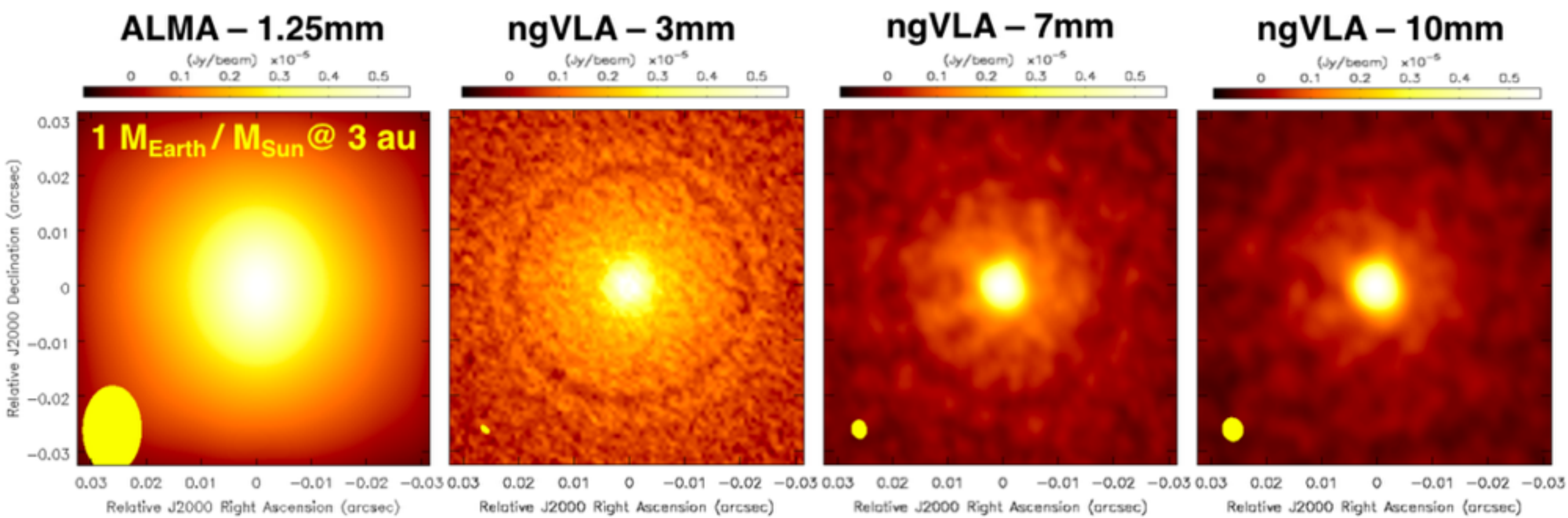
Tracing the formation of Super-Earths



Ricci+ 2018

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

Tracing the formation of Earths?



Harter+ 2019

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

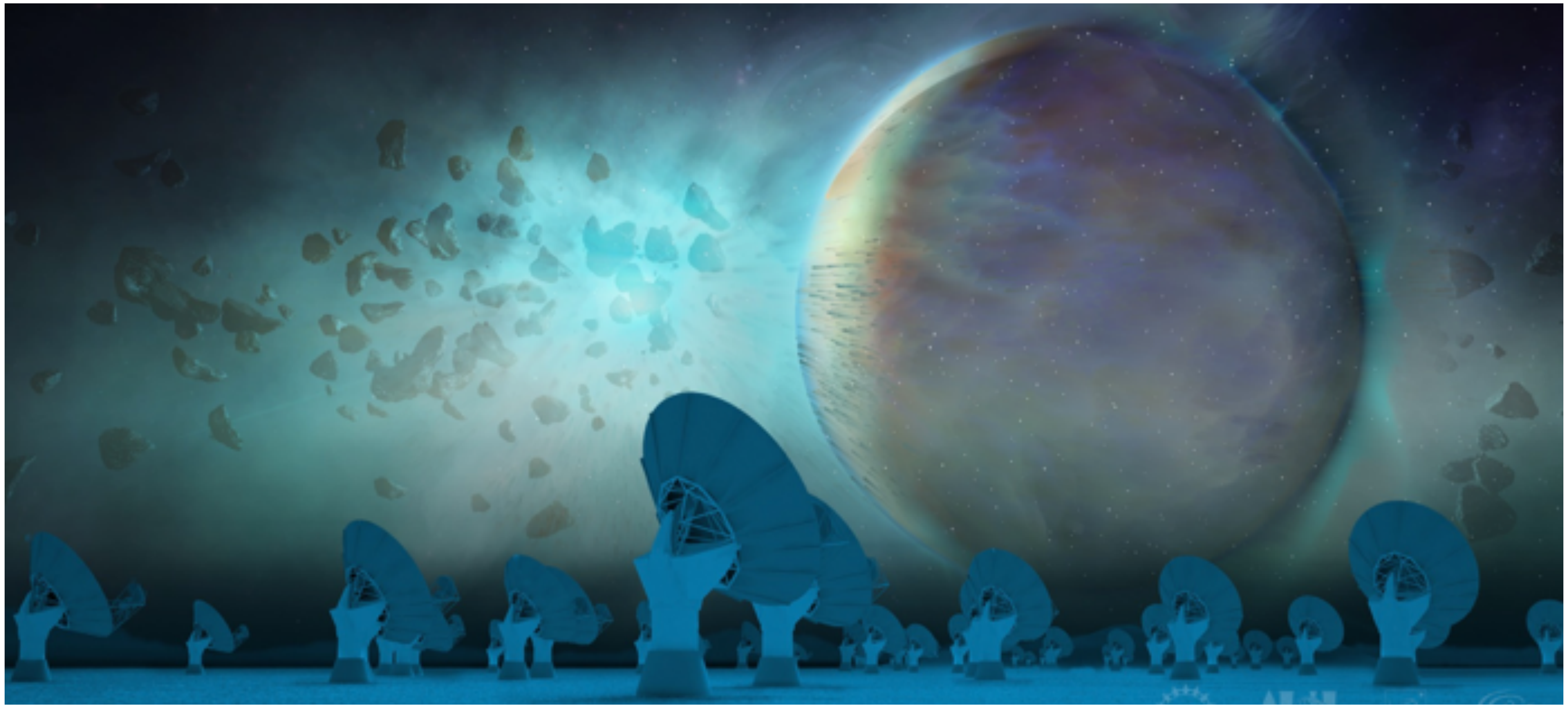


Image credit: NRAO