Jane Huang

Insights into Disk Structures from High Resolution ALMA Observations

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

The Disk Substructures at High Angular Resolution Project (DSHARP)

ALMA Cycle 4 Large Program

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Calibrated visibilities, images, and reduction scripts available at
https://almascience.org/almadata/lp/DSHARP

DSHARP paper series

I. Motivation, Sample, Calibration, and Overview
Andrews et al. 2018, ApJL, 869, 41

II. Characteristics of Annular Substructures
Huang et al. 2018b, ApJL, 869, 42

III. Spiral Structures in the Millimeter Continuum of the Elias 27, IM Lup, and WaOph 6 Disks
Huang et al. 2018c, ApJL, 869, 43

IV. Characterizing Substructures and Interactions in Disks around Multiple Star Systems
Kurtovic et al. 2018, ApJL, 869, 44

V. Interpreting ALMA Maps of Protoplanetary Disks in Terms of a Dust Model
Birnstiel et al. 2018, ApJL, 869, 45

VI. Dust Trapping in Thin-Ringed Protoplanetary Disks
Dullemond et al. 2018, ApJL, 869, 46

VII. The Planet-Disk Interactions Interpretation
Zhang et al. 2018, ApJL, 869, 47

VIII. The Rich Ringed Substructures in the AS 209 Disk
Guzmán et al. 2018, ApJL, 869, 48

IX. A High Definition Study of the HD 163296 Planet Forming Disk
Isella et al. 2018, ApJL, 869, 49

X. Multiple Rings, a Misaligned Inner Disk, and a Bright Arc in the Disk around the T Tauri Star HD 143006
Pérez et al. 2018, ApJL, 869, 50

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THIS TALK

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Guzmán et al. 20

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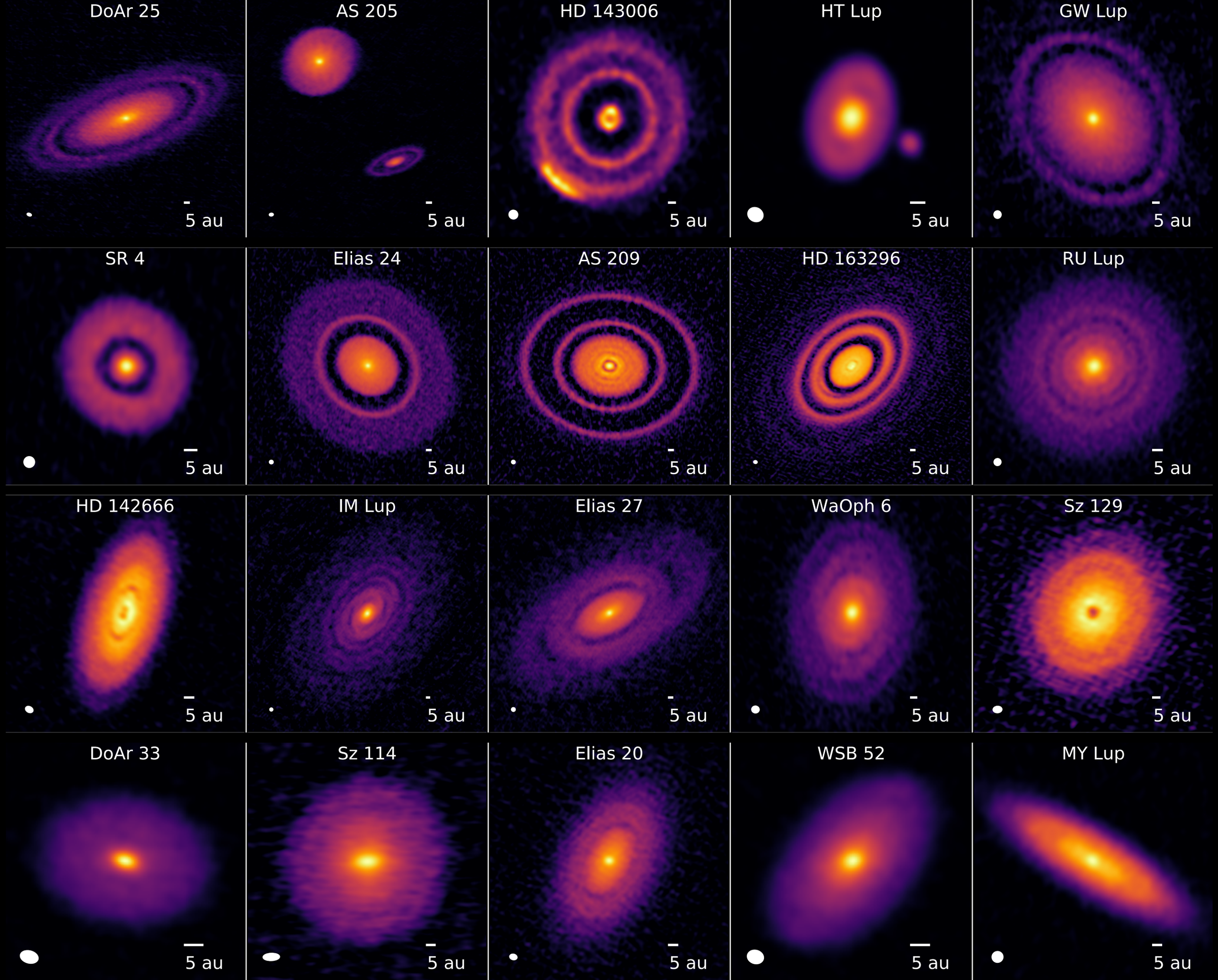
Pérez et al. 2018, ApJL, 869, 50

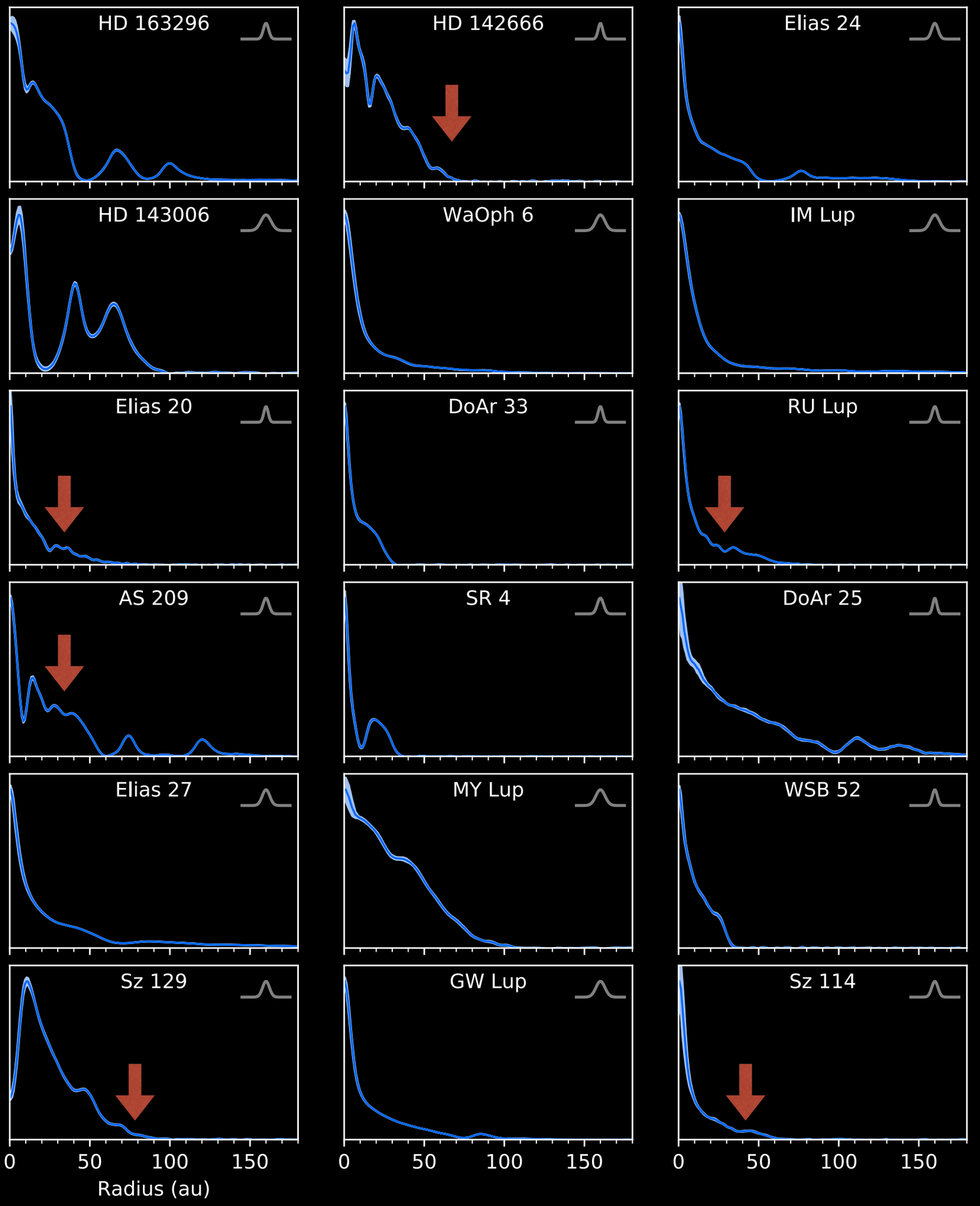
Also see talks by L. M. Pérez and Z. Zhu


DoAr 25
AS 205
HD 143006
HT Lup
GW Lup
SR 4
Elias 24
AS 209
HD 163296
RU Lup
HD 142666
IM Lup
Elias 27
WaOph 6
Sz 129
DoAr 33
Sz 114
Elias 20
WSB 52
MY Lup
5 au

Ring formation is not a specialized process

- Structures occur at a range of radii in the disk
- Observed in disks around stellar hosts with spectral types ranging from M to A
- Most targets are ~1 Myr old, but rings are also observed in disks up to 10 Myr old
- Caveat: observed disks generally have radii 30 au or larger - significant fraction of population excluded

Many features in the radial intensity profiles are very narrow (~5 au in width or less)



Huang+ 2018b (DSHARP II)

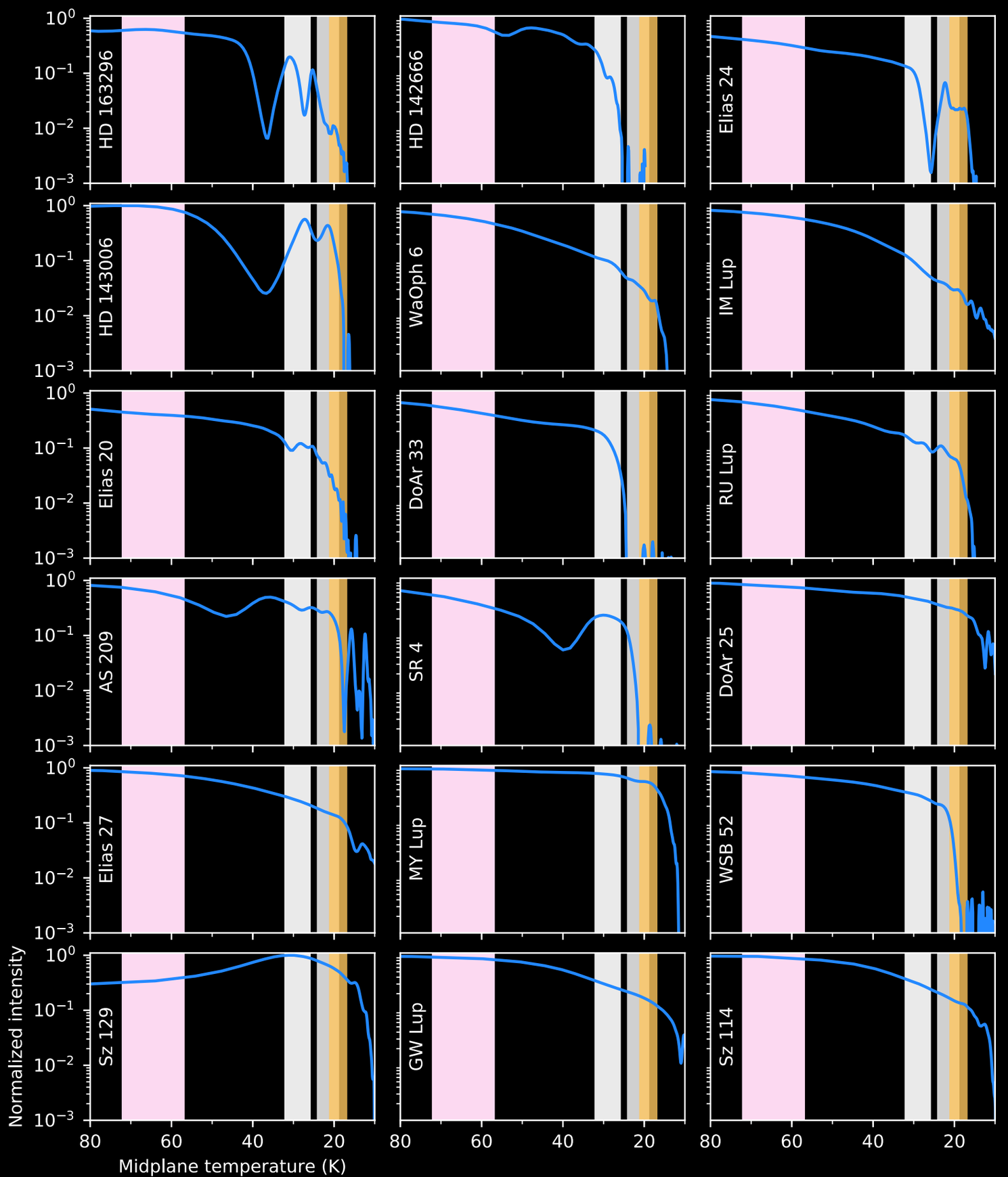
What mechanisms might generate rings?

- Planet-disk interactions
- Modification of dust properties due to volatile freezeout
- Hydrodynamic instabilities such as the vertical shear instability, dust-driven viscous ring instability, secular gravitational instability…
- Magnetohydrodynamic instabilities related to, e.g., winds, dead zones, MRI turbulence…

See, e.g., talks by **S. Inutsuka, S. Suriano, S. Perez, Z. Zhu, N. van der Marel, R. Dong, A. Vericel, J. Simon, W. Lyra**

Are the structures associated with snowlines?

- Gap/ring structures have been hypothesized to trace molecular snowlines (e.g., Zhang+ 2015, Pinilla+ 2017)
- Stellar luminosity can be used to estimate disk temperature
- DSHARP substructure locations do not appear to line up with snowlines (similar conclusions in Long+ 2018 and van der Marel+ 2019)



CO_2 snowline

CO snowline (on water ice)

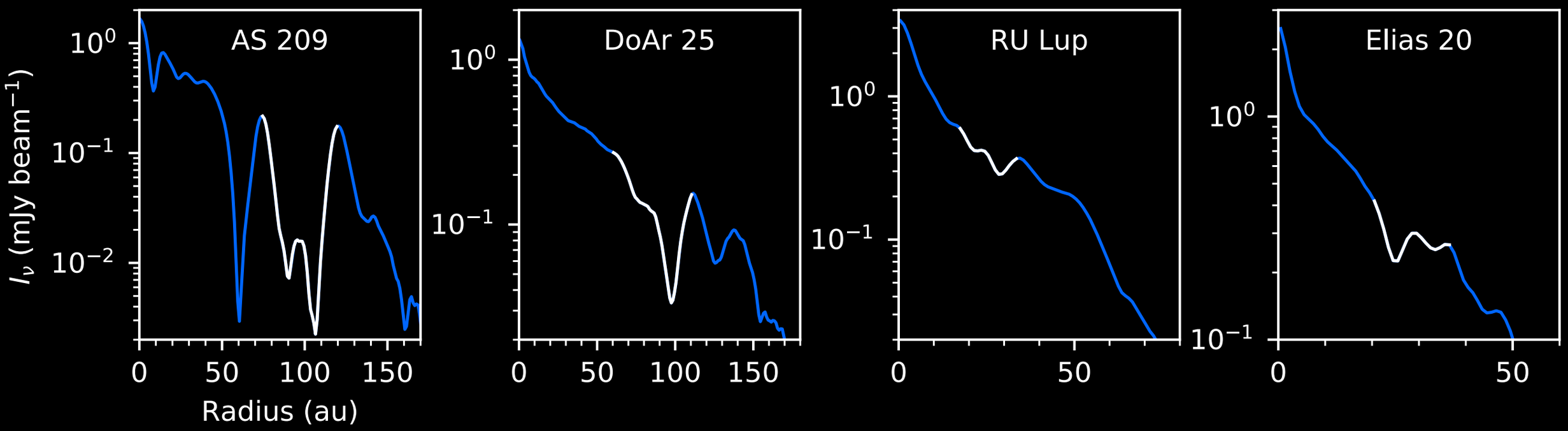
CO snowline (on pure ice)

N_2 snowline

Huang+ 2018b (DSHARP II)

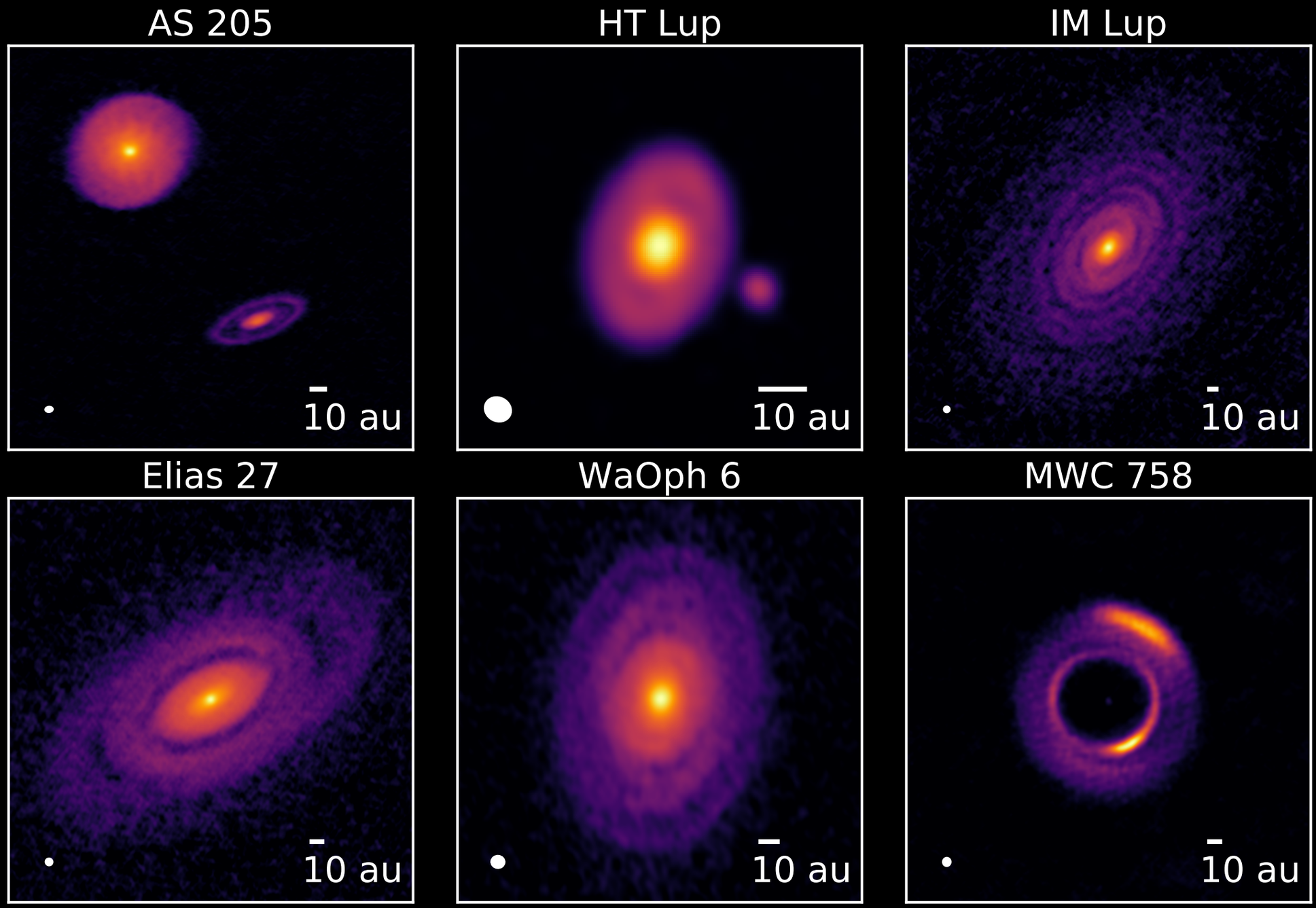
“W-features” (“Double gaps”)

Huang+ 2018b (DSHARP II)



See, e.g., Duffell & MacFayden 2013, Zhu+ 2014, Dong+ 2017, Bae+ 2017, Zhang+ 2018

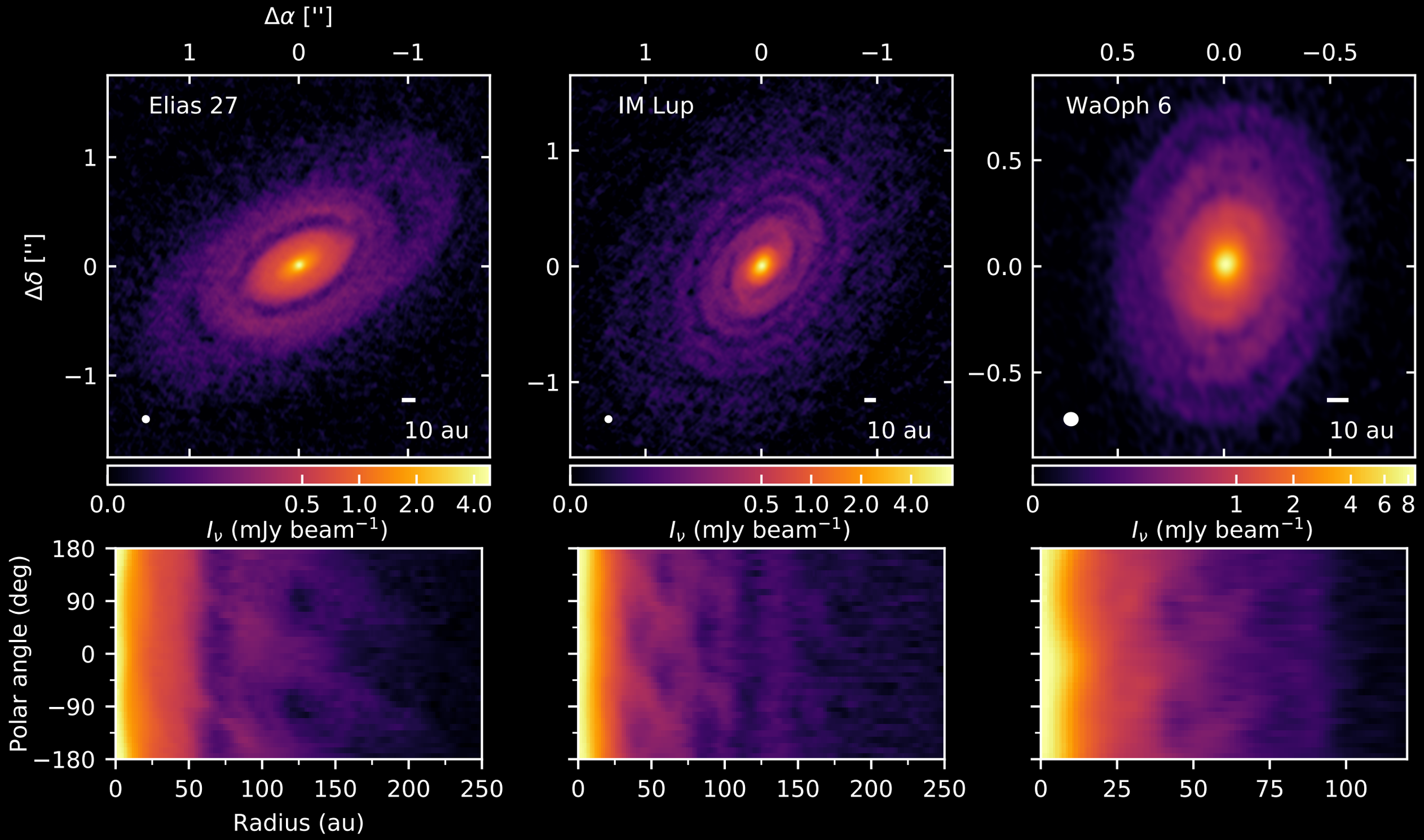
Spiral detections in millimeter continuum are comparatively rare



Andrews+ 2018 (DSHARP I), Kurtovic+ 2018 (DSHARP IV), Huang+ 2018c (DSHARP III), Dong+2018

Spiral arms in DSHARP disks without known companions

Huang+ 2018c (DSHARP III)



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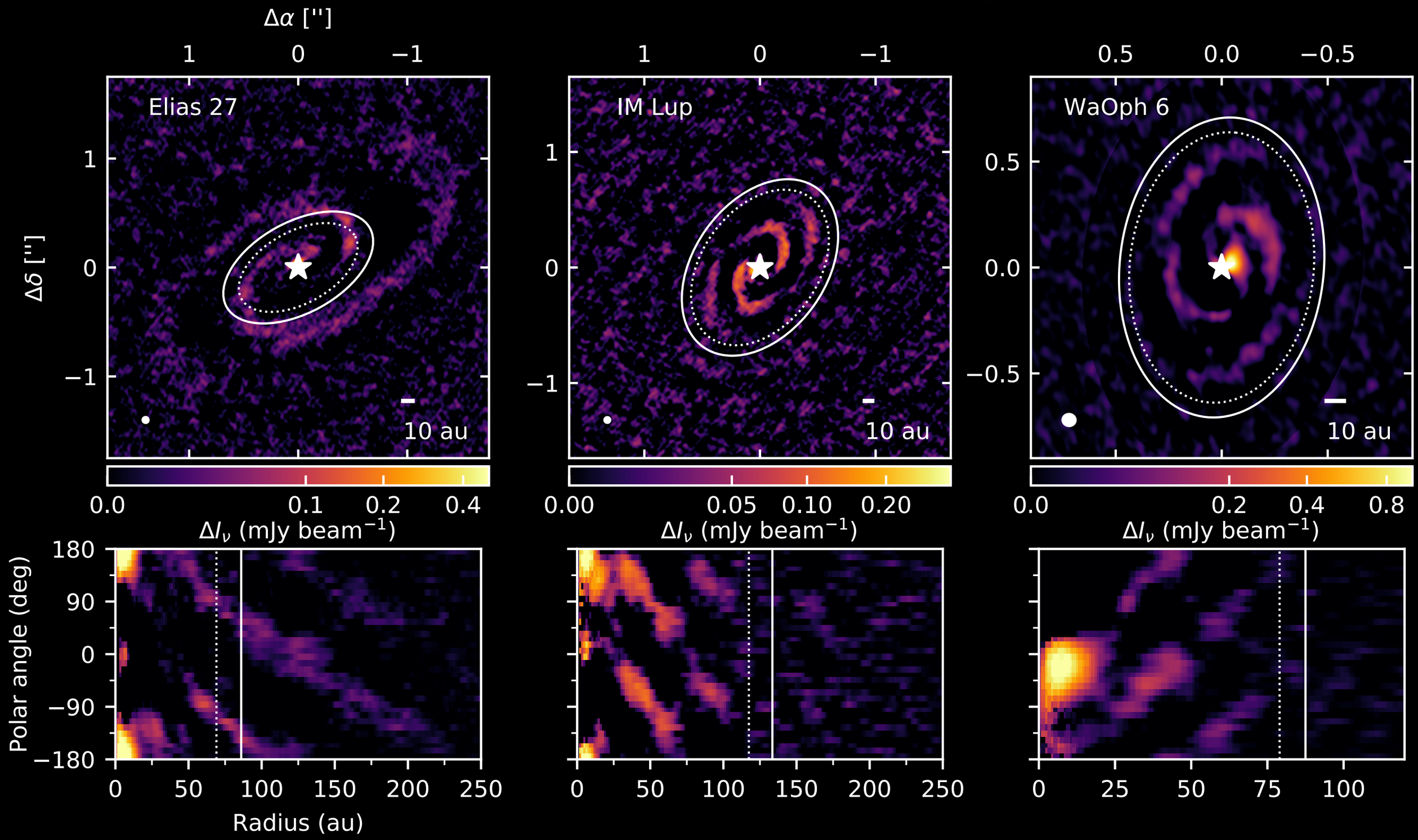
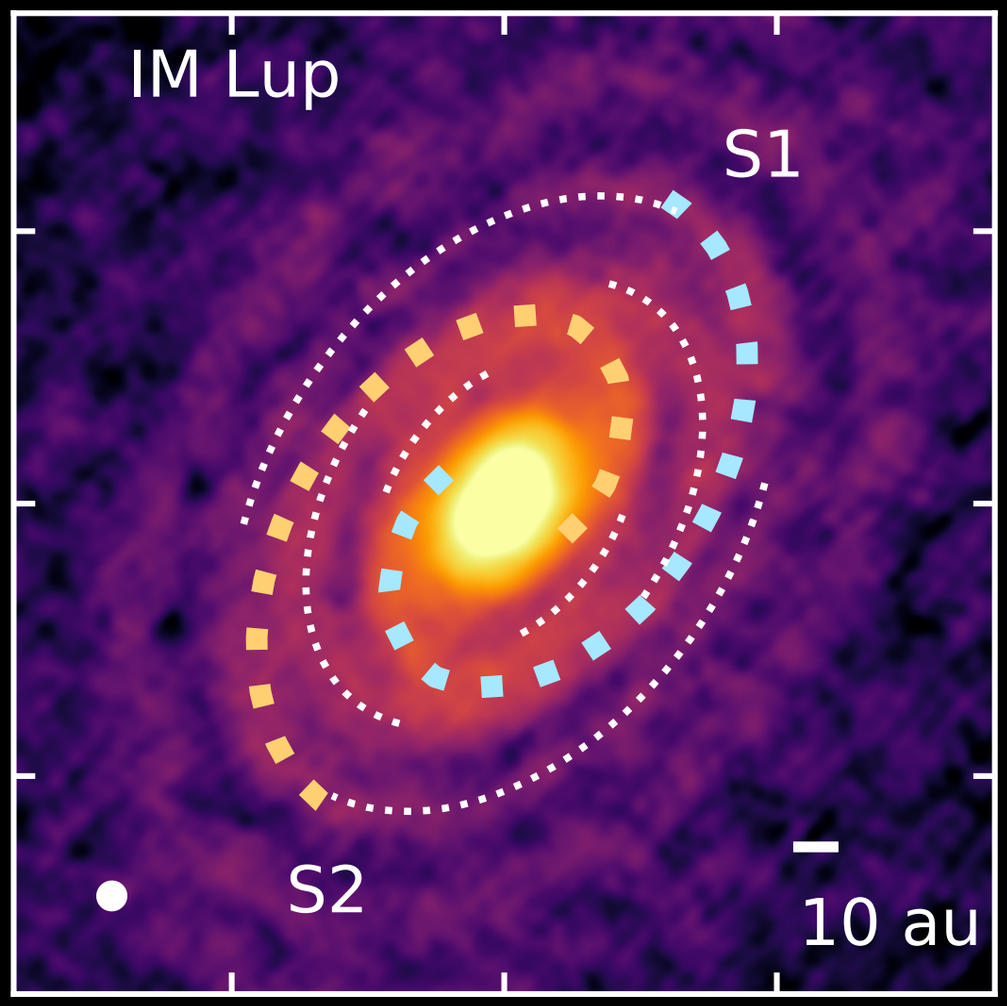
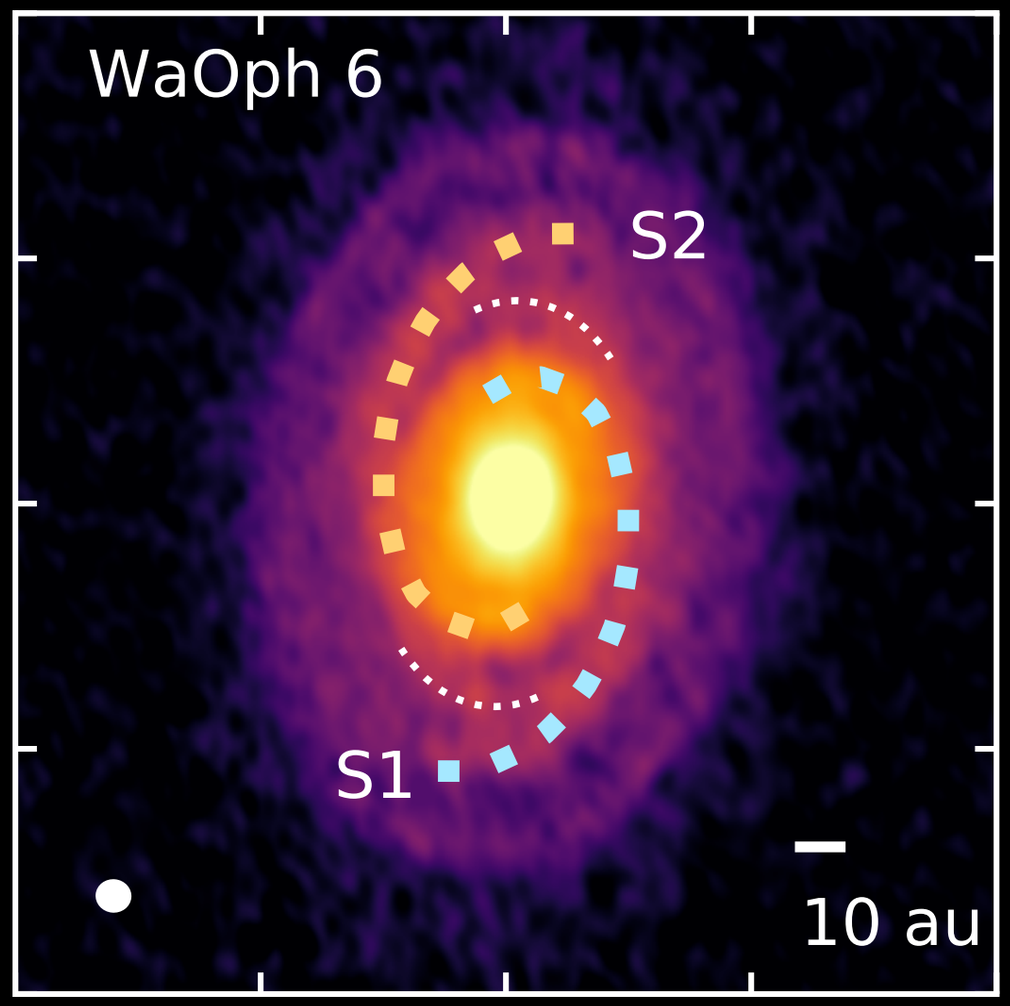


Complexity within spiral structures





Huang+ 2018c (DSHARP III)

There is little consensus on the origins of spiral arms

- Flybys and binary interactions likely explain at least a few but not all spirals (e.g., Wagner+ 2015, Meru+2017, Kurtovic+ 2018)

- Perturbations from a planetary-mass companion? (e.g., Goldreich & Tremaine 1979, Tanaka+ 2002, Zhu+ 2015)

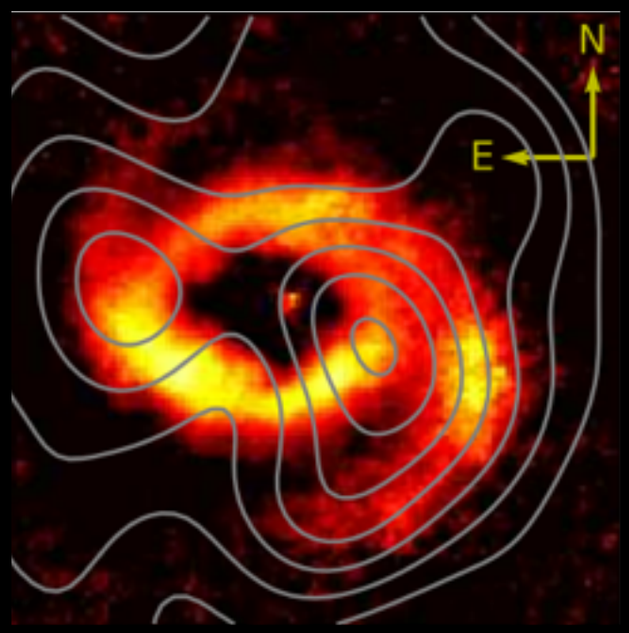
- Gravitational instabilities? (e.g., Boss 1998, Mayer+ 2004, Tomida+ 2017)

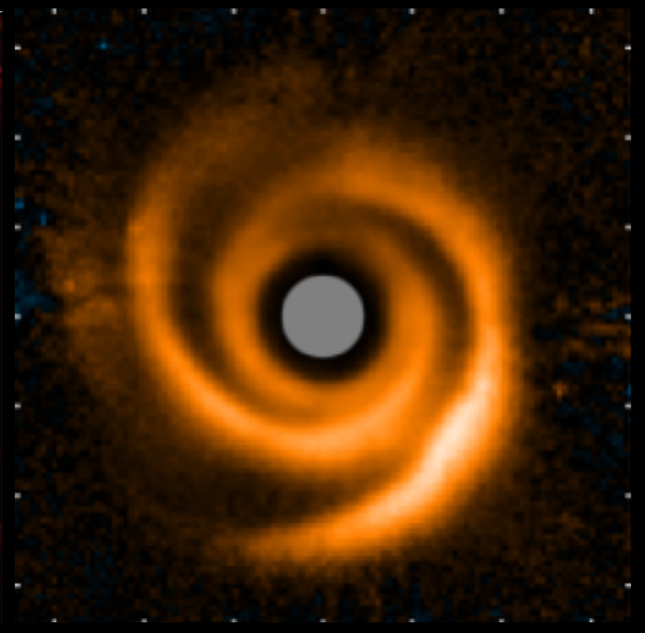
- Infall from circumstellar envelopes? (e.g., Lesur+ 2015)

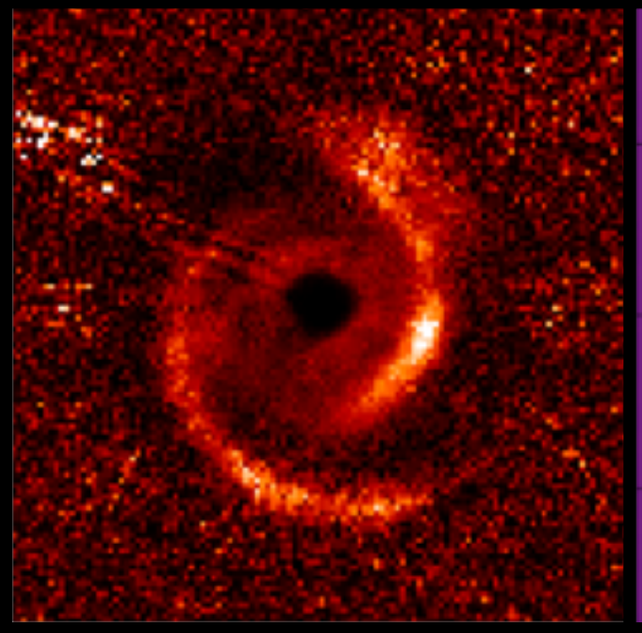
- Thermal perturbations from misaligned inner disk? (e.g., Montesinos+ 2016)

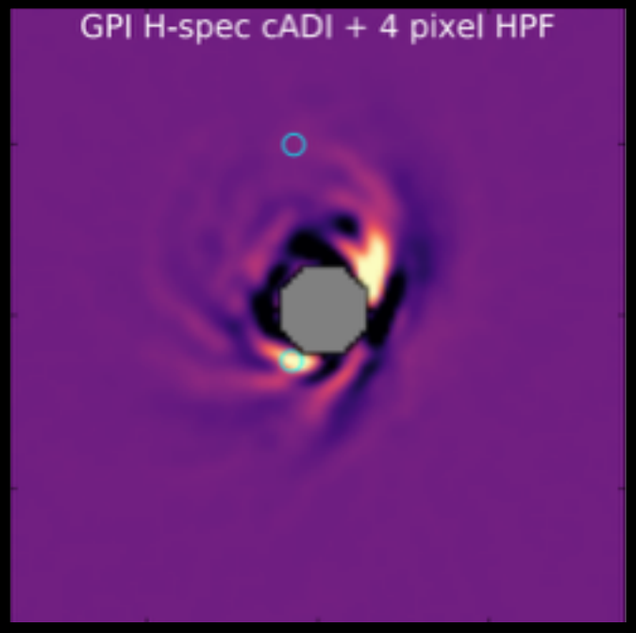
See also talks by **T. Paneque, G. van der Plas, R. Dong, N. Cuello**

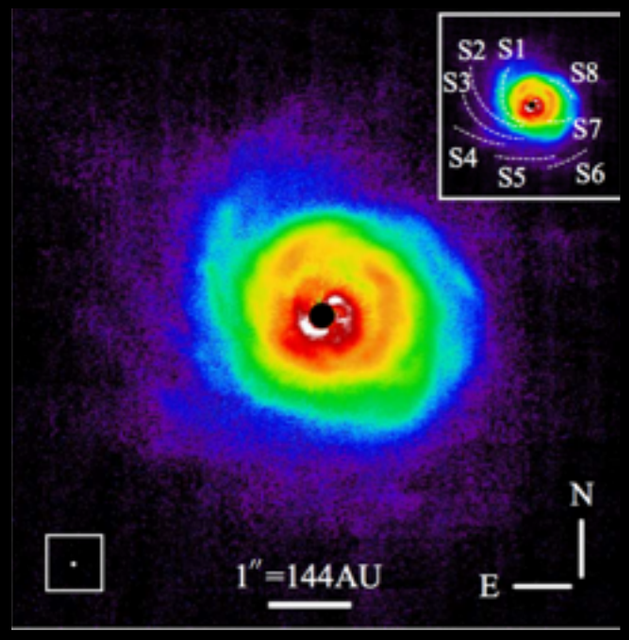
Disks with spiral arms in scattered light

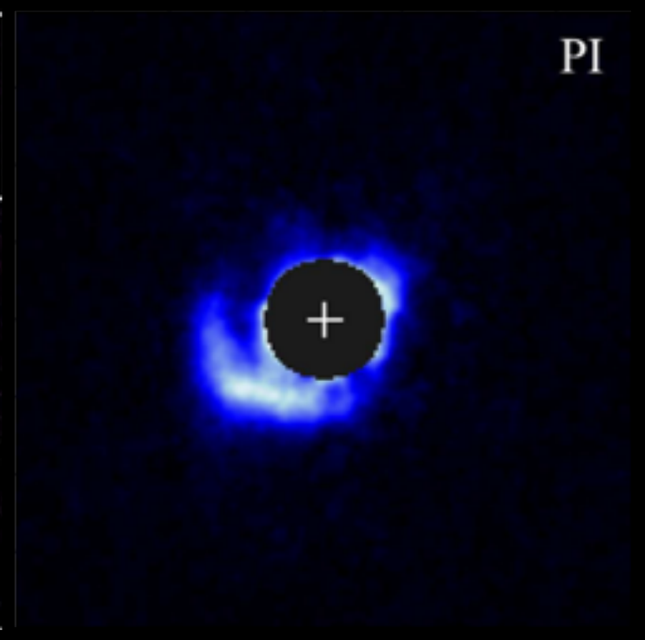


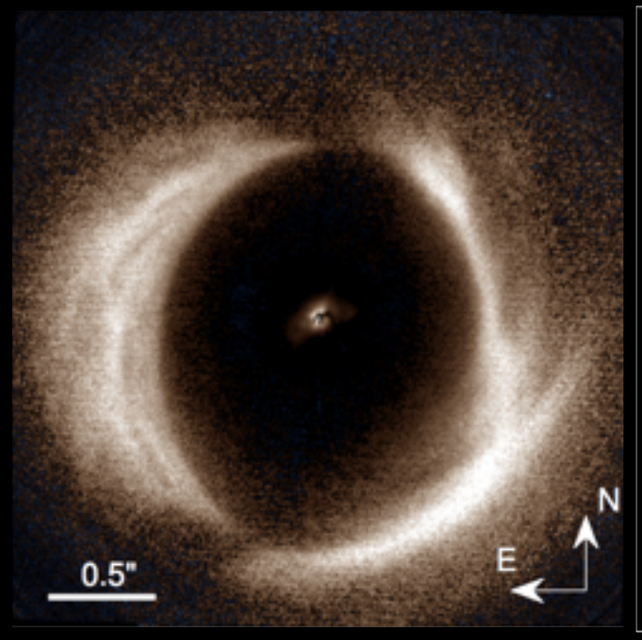


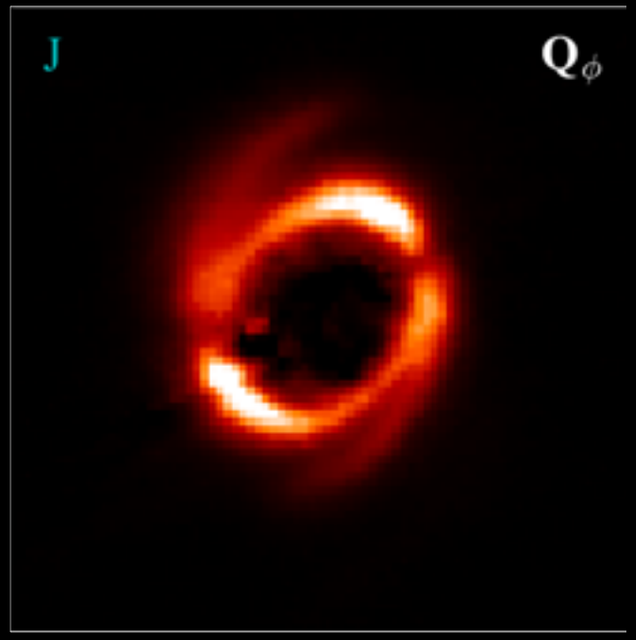






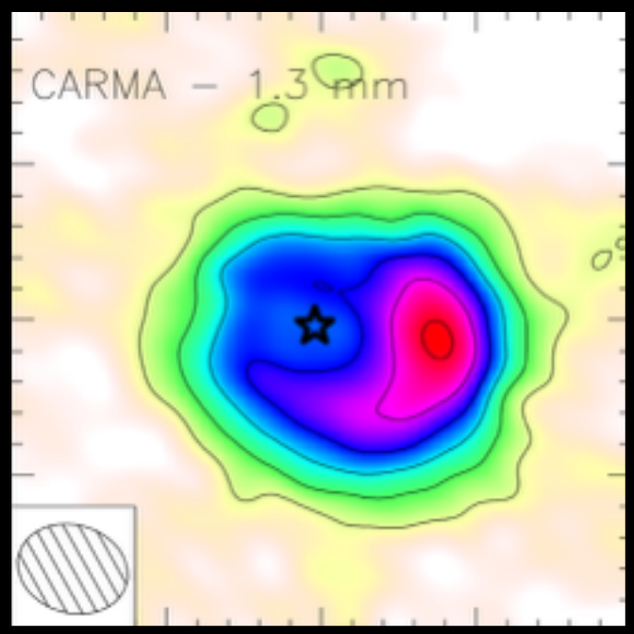


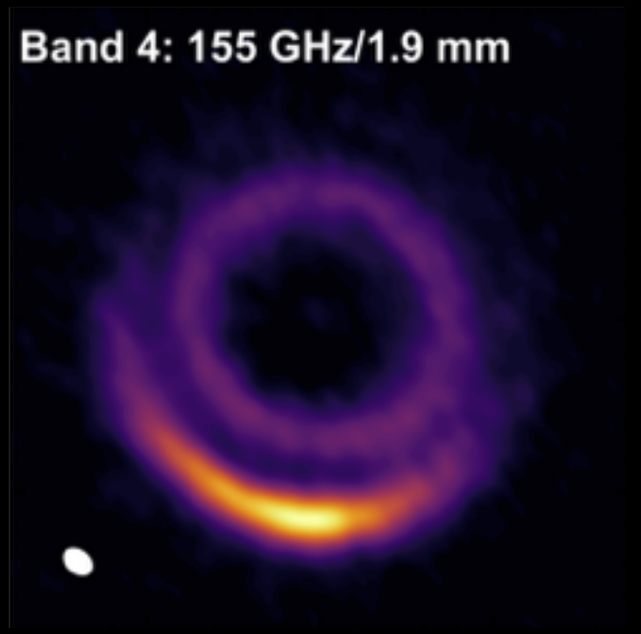


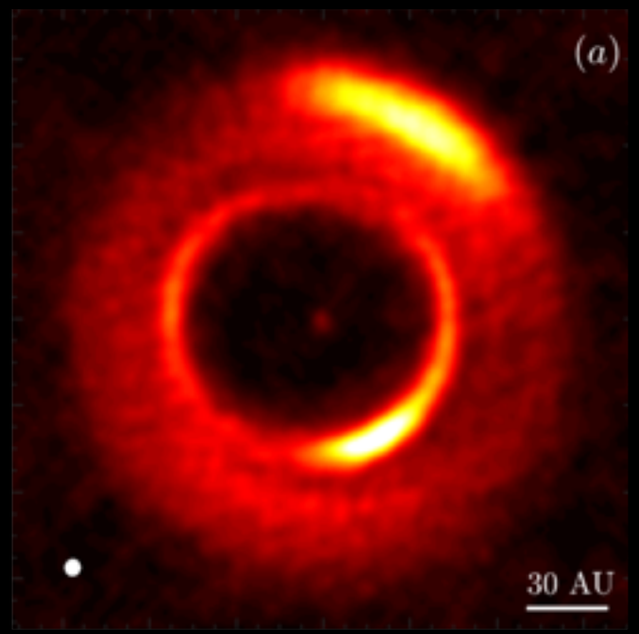


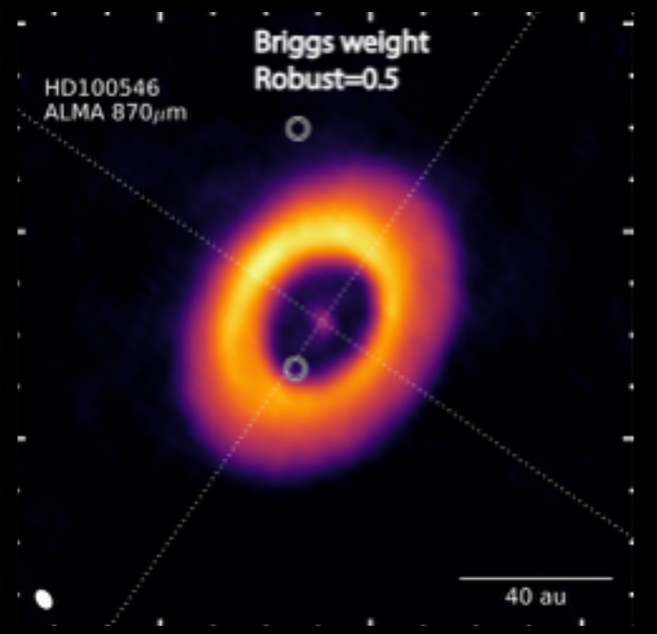
Clockwise from top left: LkHα 330 (Uyama+ 2018), SAO 206462 (Stolker+ 2017), MWC 758 (Benisty+ 2015), HD 100546 (Follette+ 2015), HD 100453 (Benisty+2017), HD 142527 (Avenhaus+ 2017), V1247 Ori (Ohta+ 2016), AB Aur (Hashimoto+ 2017)

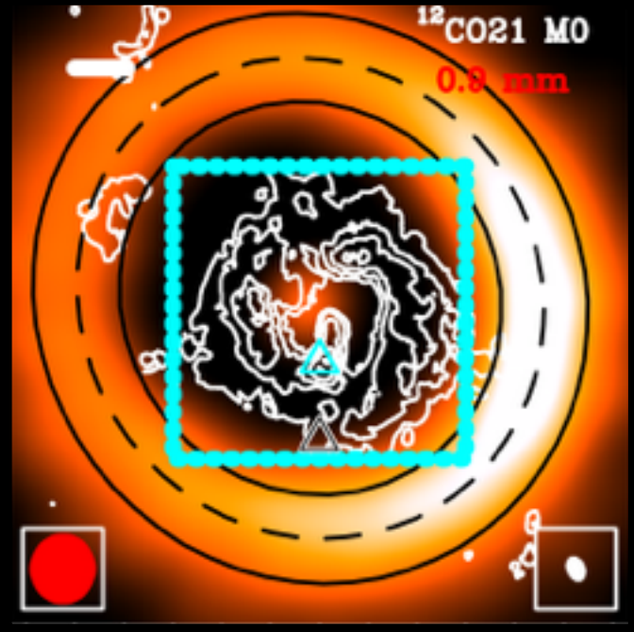
Millimeter continuum observations of disks with scattered light spiral arms

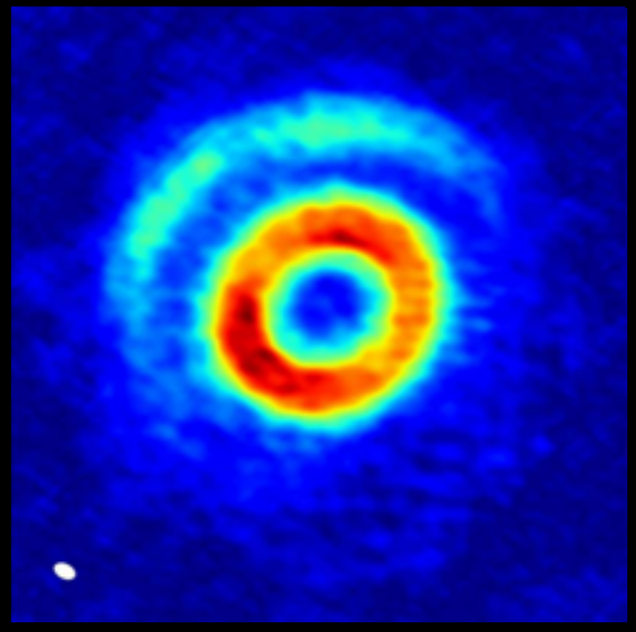


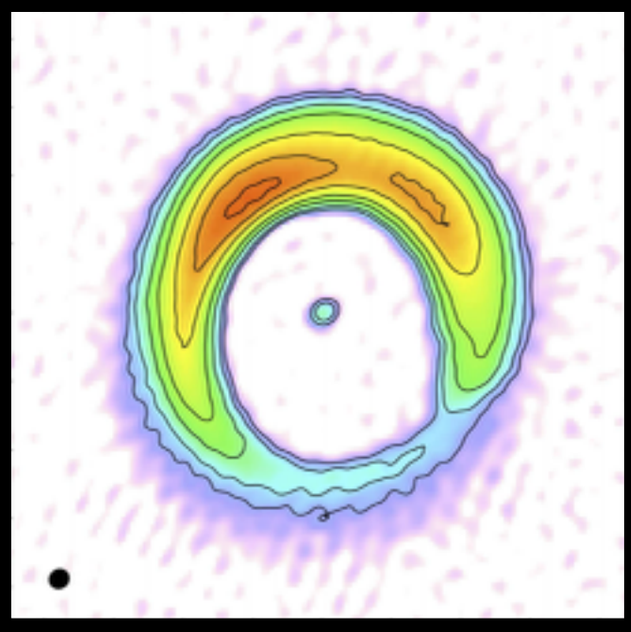


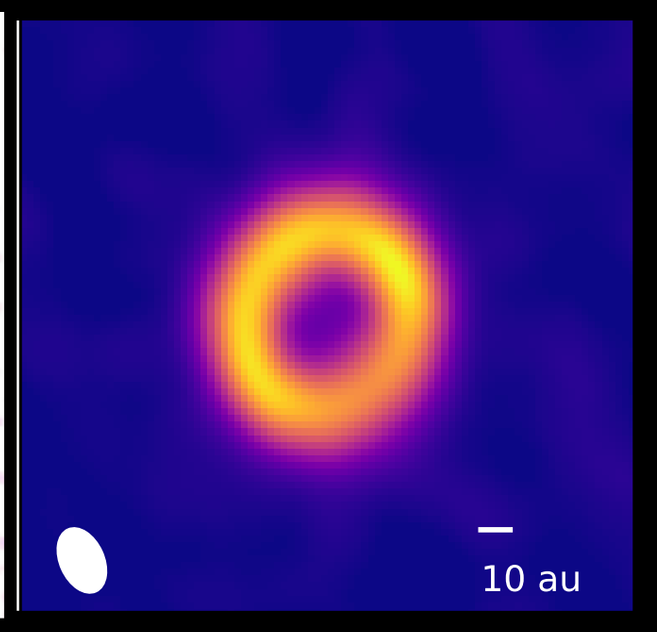












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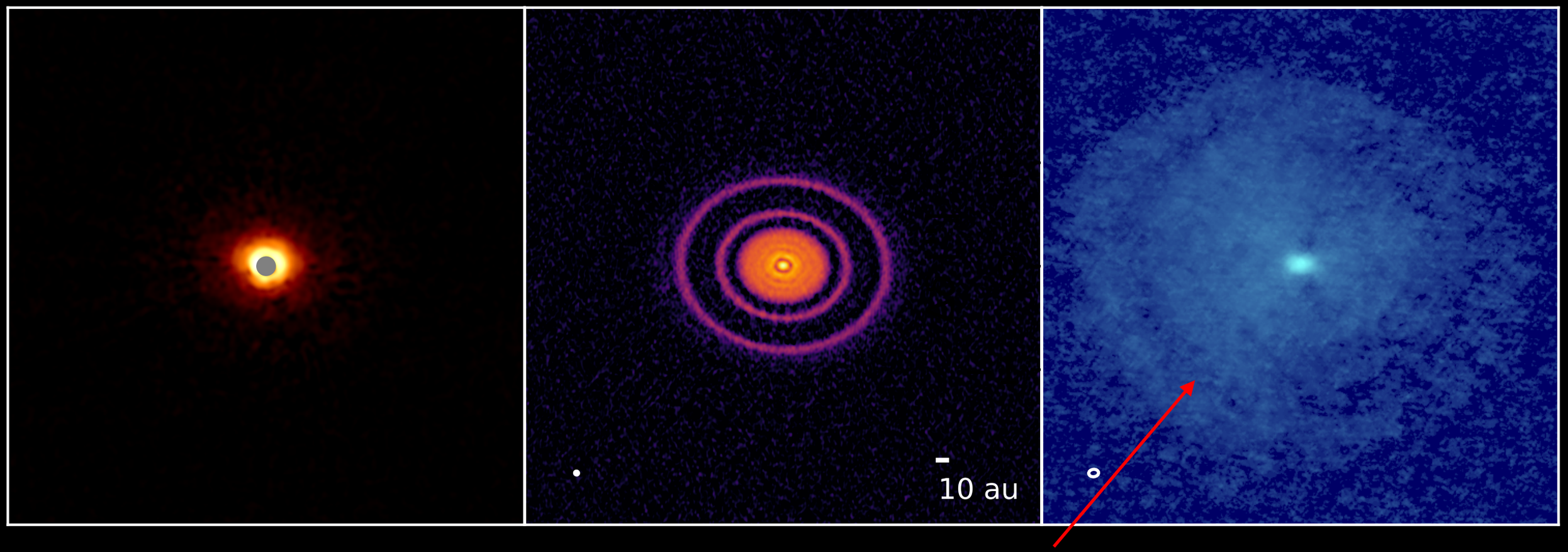
Dust observations don't tell the whole story…

AS 209 SPHERE *H* band
Avenhaus+ 2018

AS 209 1.25 mm continuum
Andrews+ 2018 (DSHARP I)

AS 209 CO 2-1
Guzmán+ 2018 (DSHARP VIII)



Deep, high-resolution observations of CO isotopologues are needed to characterize gas surface density profiles

Summary

- Complex dust structures in protoplanetary disks are common
- Rings appear to be the most common type of substructure and appear in disks hosted by stars with a wide range of properties
- Spiral arms have been detected less frequently, but show surprising complexity
- Multiwavelength dust observations + molecular line observations are crucial for fully characterizing disk structures