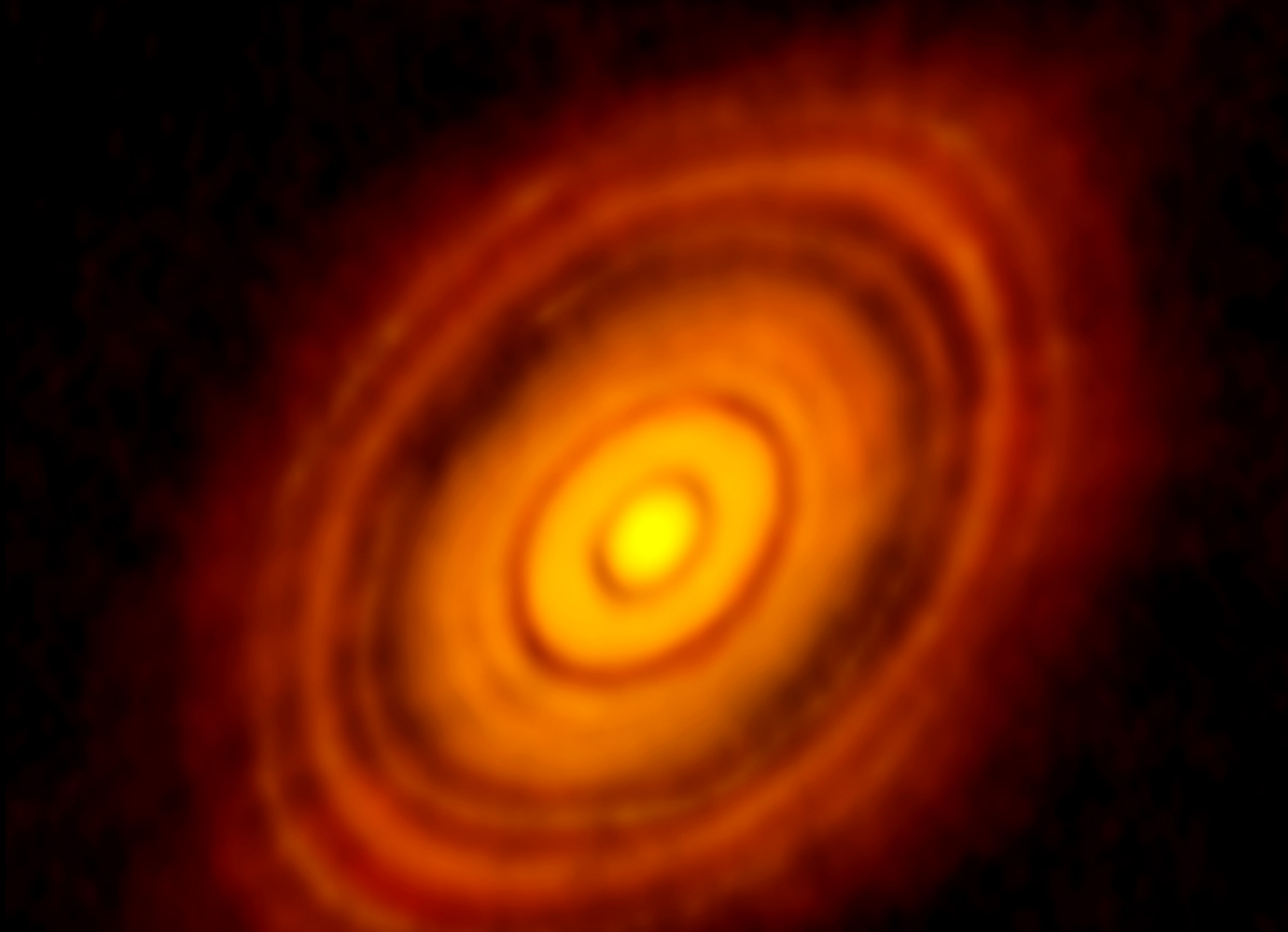
Tracking planet footprints in dusty disks



Catherine Espaillat

Boston University

Planets display diverse compositions and sizes

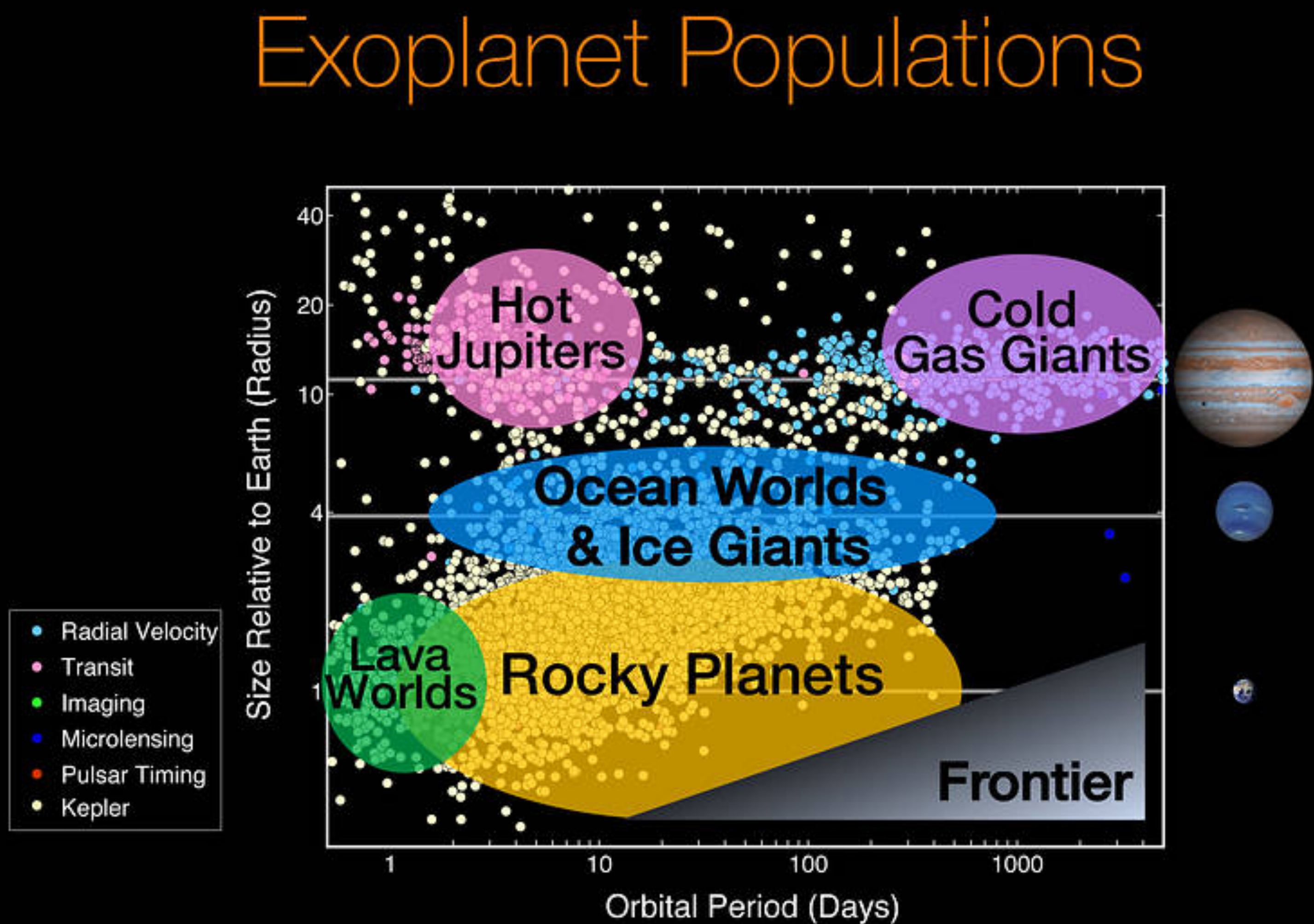
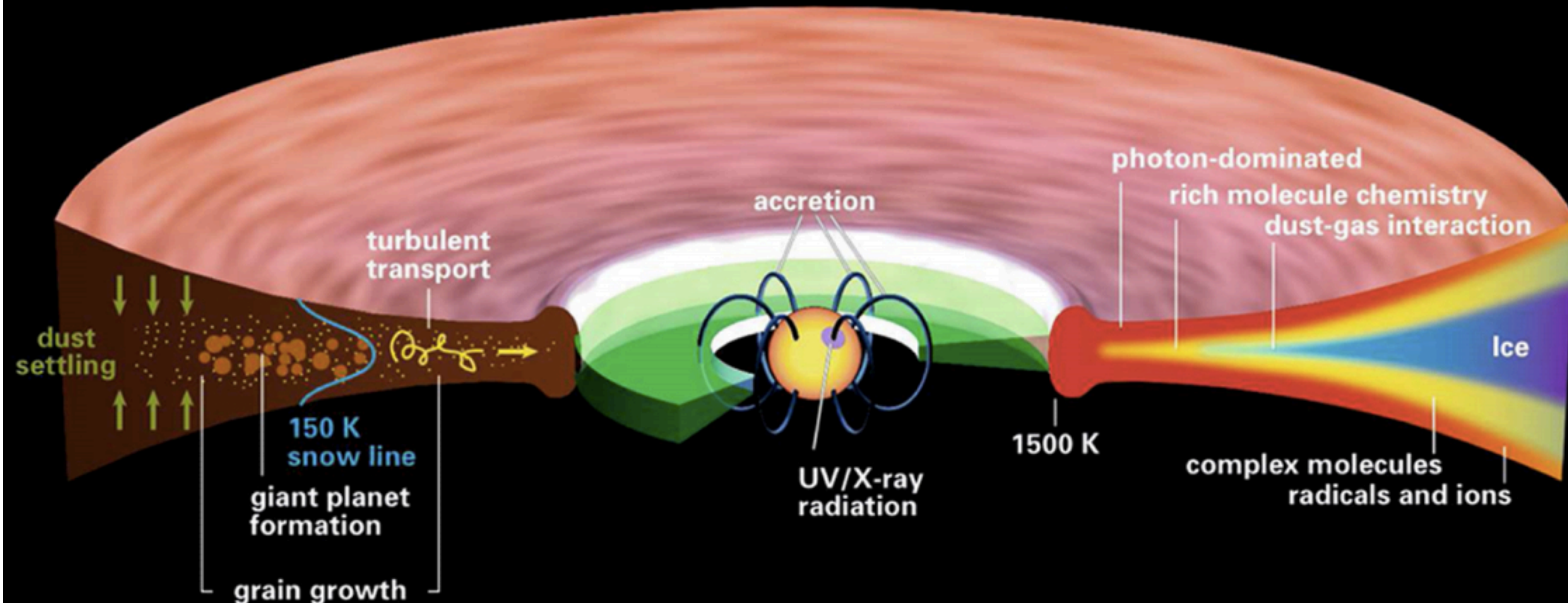


Image: NASA

Planet traits are inherited from their birth disks



Henning & Semenov 2014

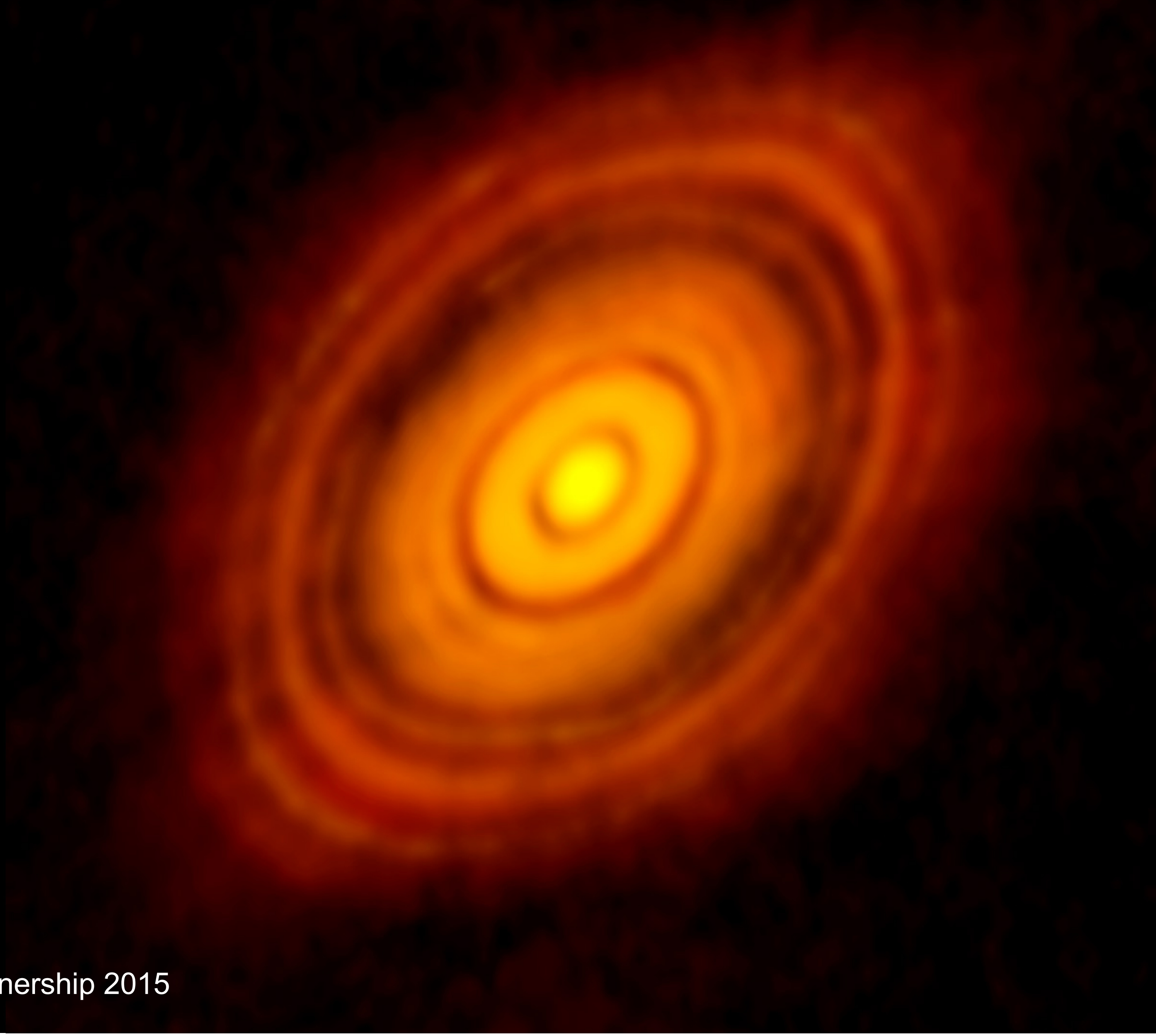
TMT & protoplanetary disk science

Characterizing dust structure in the inner disk

Measuring gas in the inner disk

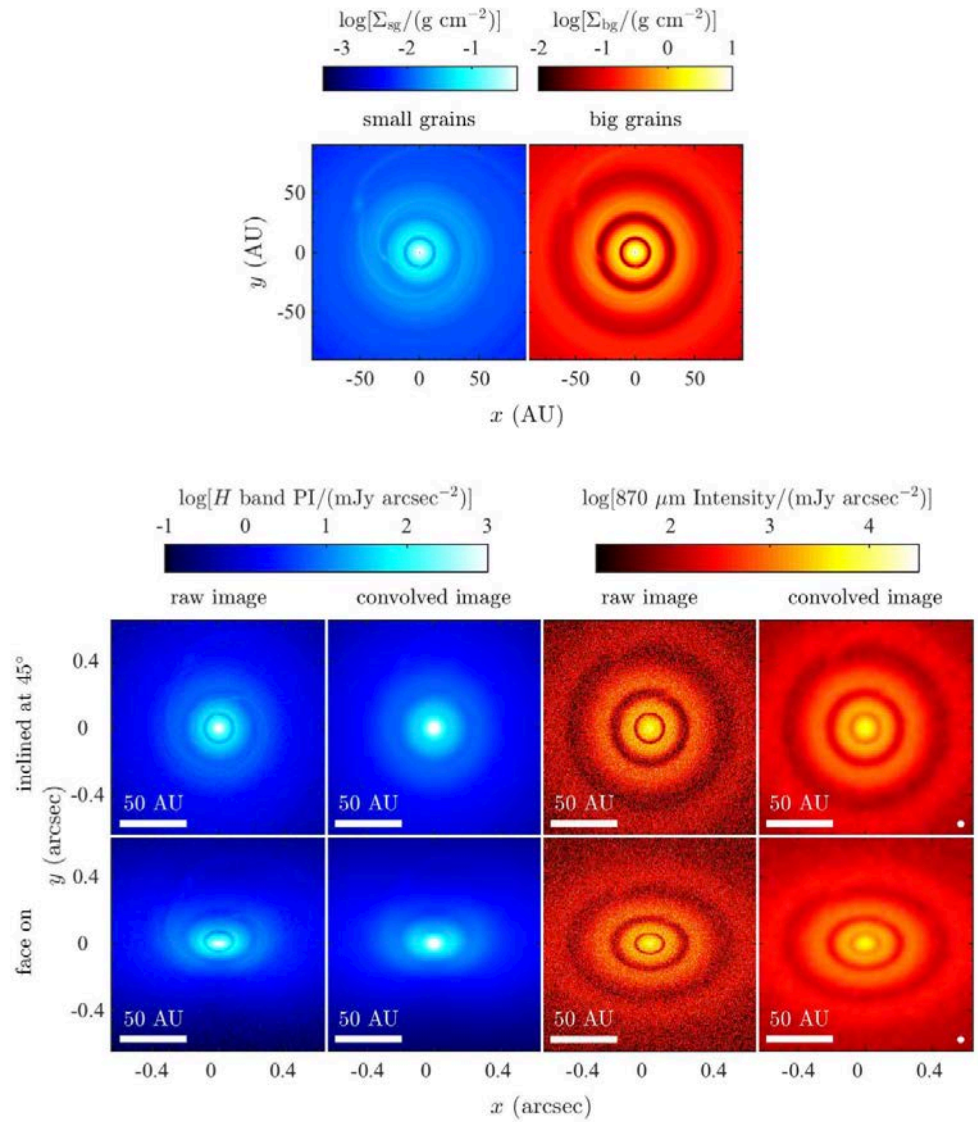
Identifying protoplanets & circumplanetary disks

Small ~1-2 AU disk gaps have been revealed



ALMA Partnership 2015

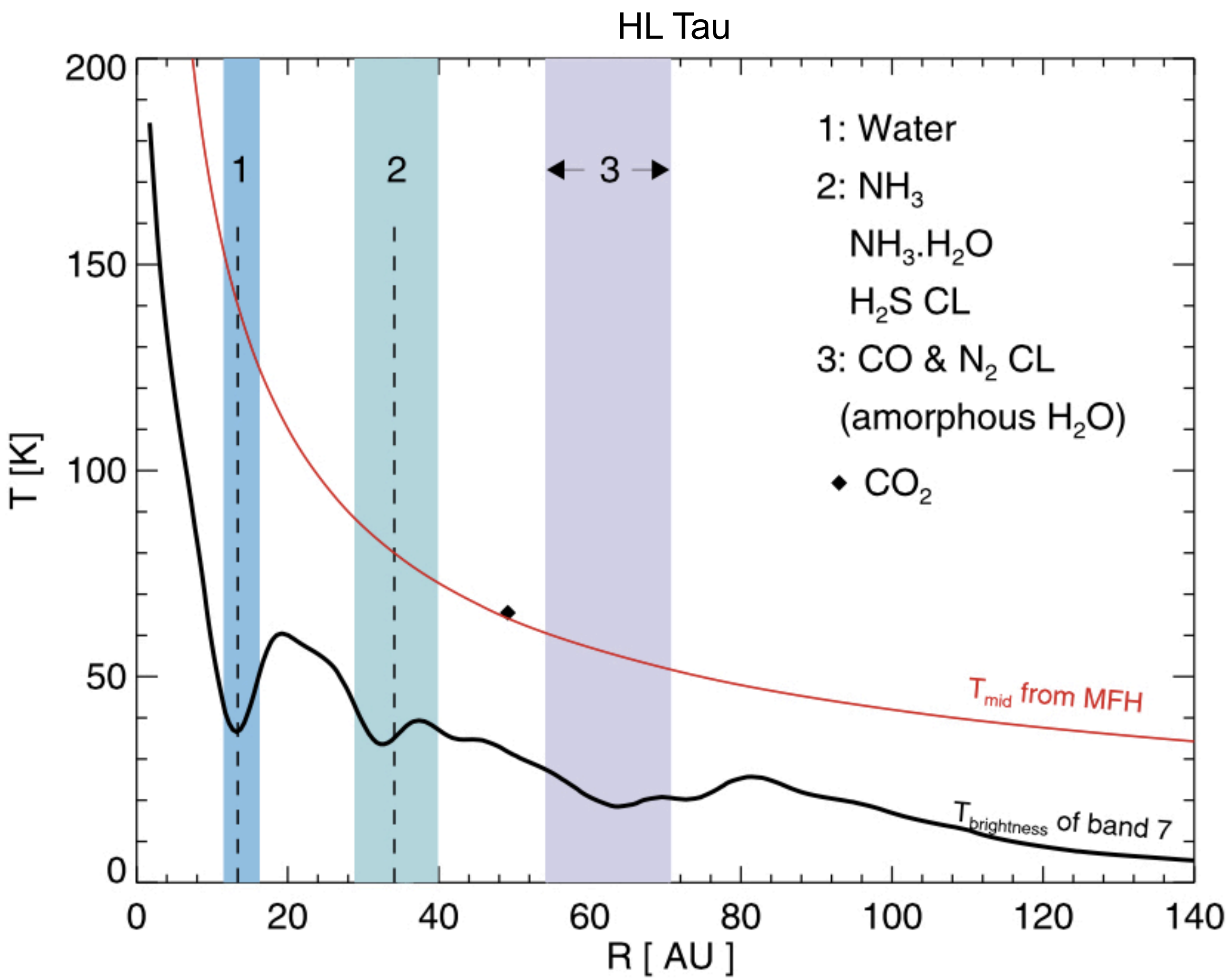
Multiple planets can form small gaps in disks



Dong, Zhu, & Whitney 2015

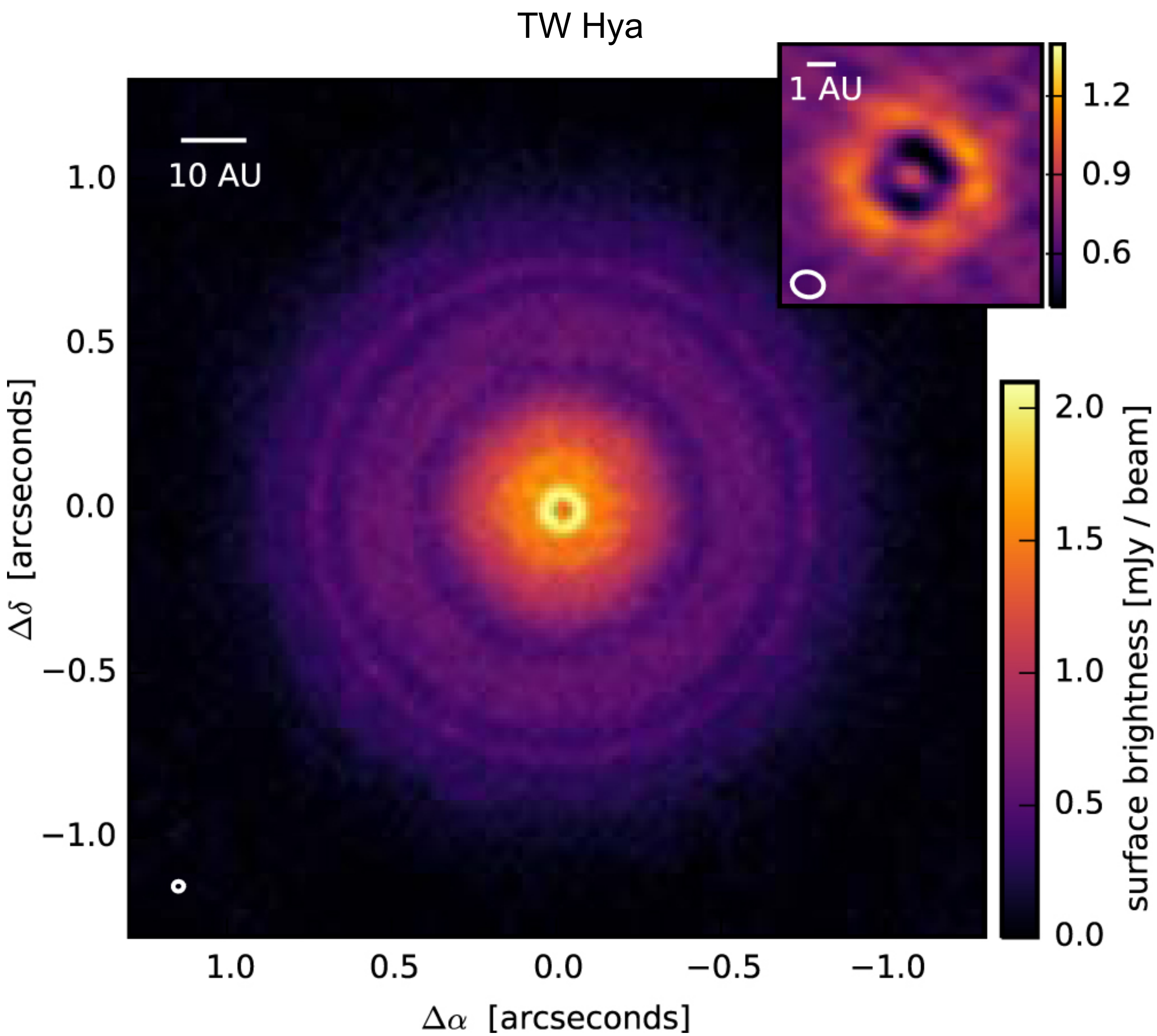
also Meru et al. 2015, Tamayo et al. 2015, Dipierro et al. 2015, Gonzalez et al. 2015, Bae et al. 2017

Condensation fronts can lead to dust growth and "gaps" in the disk



Zhang et al. 2015

Small disk gaps may be common



Andrews et al. 2016

Large > 10 AU disk cavities also seen

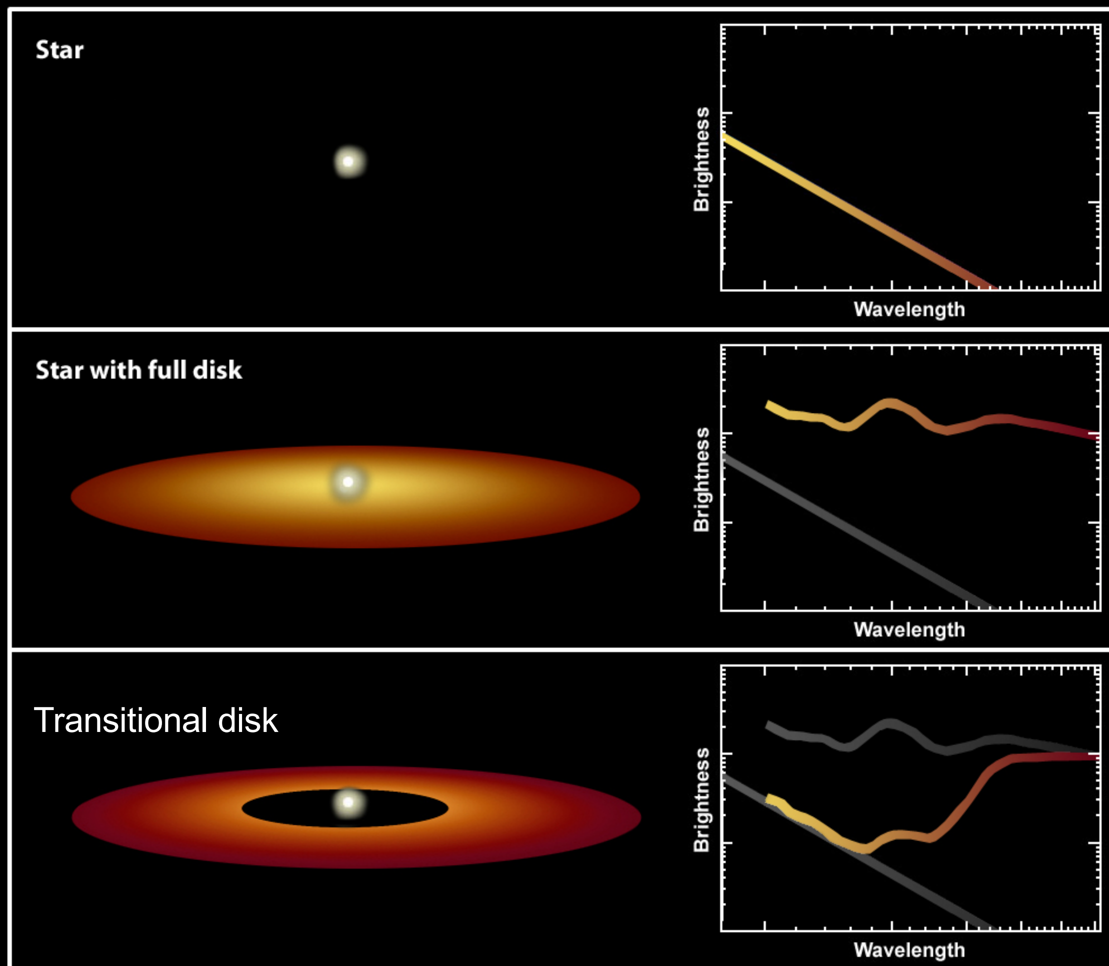
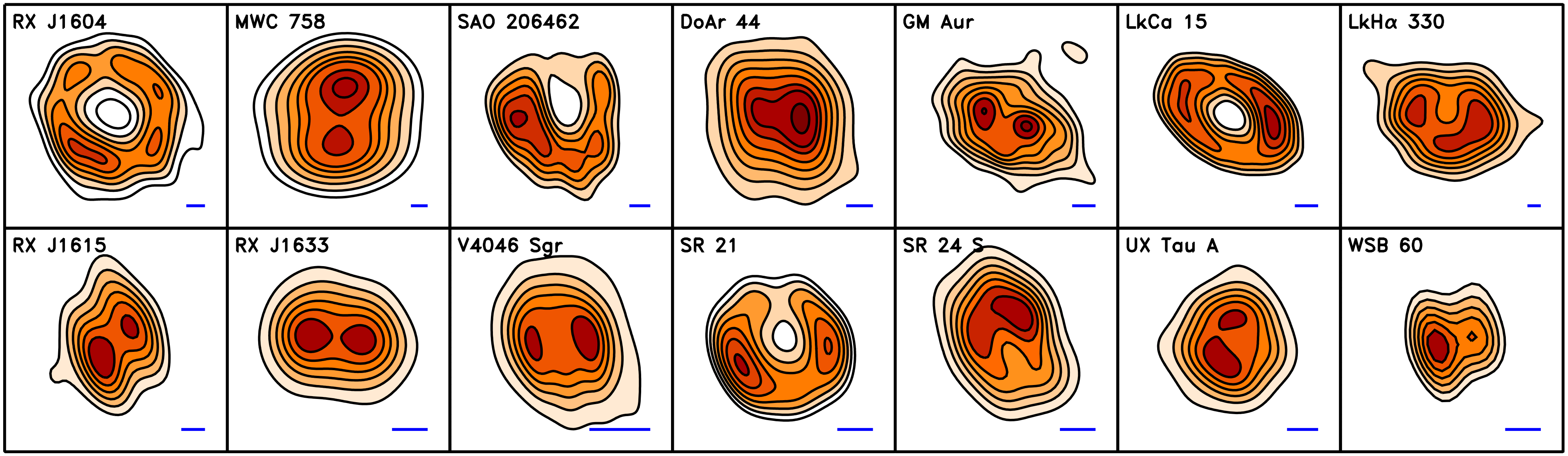


Image: NASA

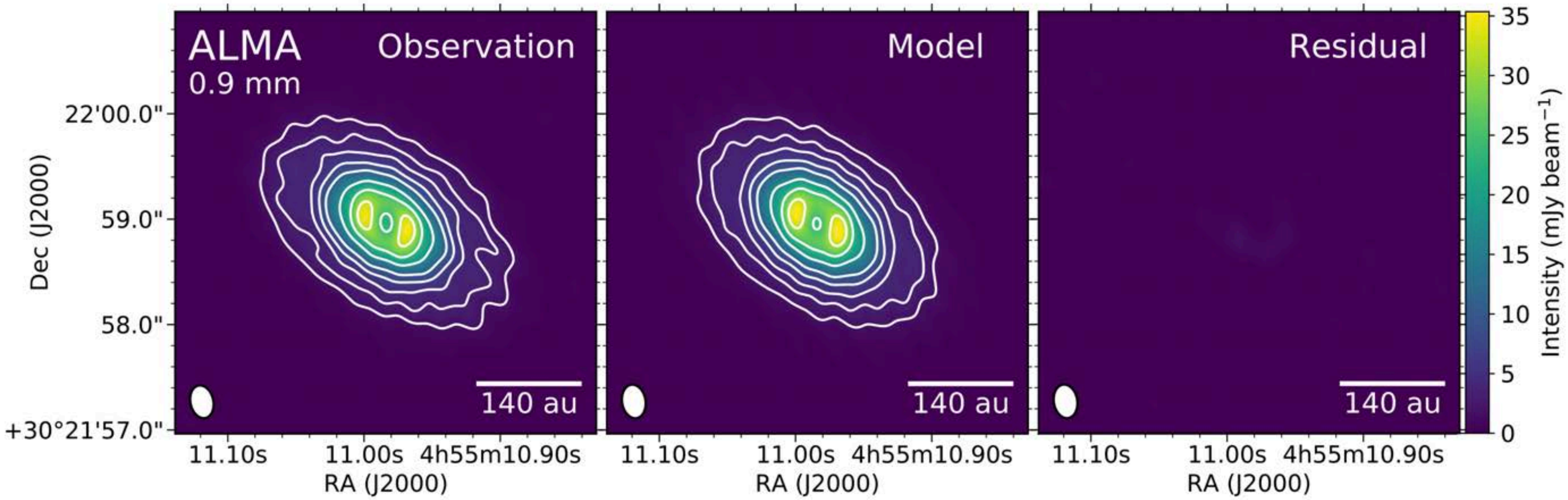
Several large disk cavities confirmed via (sub-)mm interferometric imaging

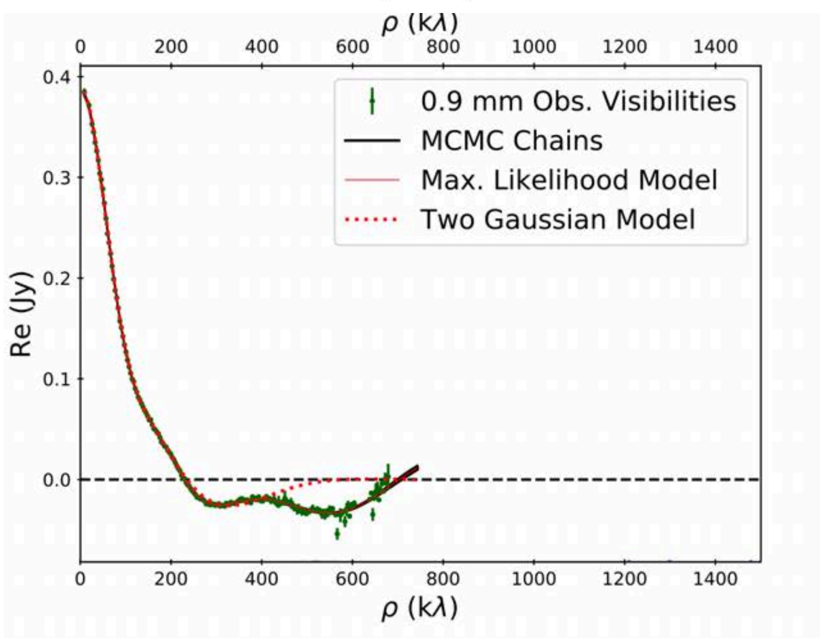


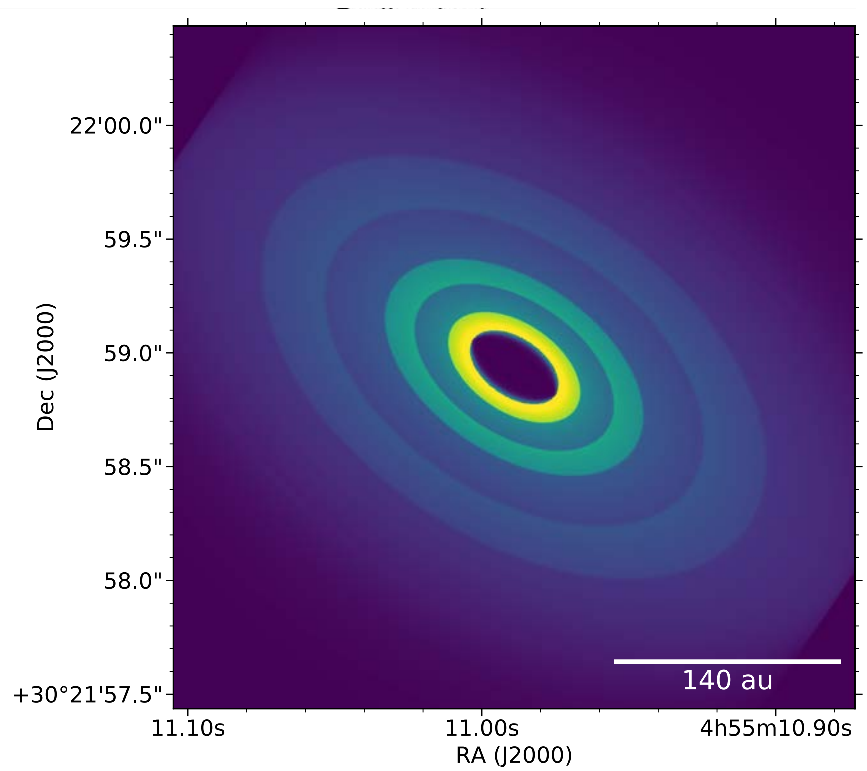
also AB Aur (*Pietu et al. 2005*), TW Hya (*Hughes et al. 2007*), SAO 206462 (*Brown et al. 2009*), RY Tau (*Isella et al. 2010a*), DM Tau (*Andrews et al. 2011*), IRS 48 (*Brown et al. 2012*), HD 142527 (*Casassus et al. 2013*), Sz 91 (*Tsukagoshi et al. 2014*)

Figure from Espaillat et al. 2014, PPVI; Data from Mathews et al. 2012 Isella, et al. 2010, Brown et al. 2009, Andrews et al. 2009, Hughes et al. 2009, Andrews et al. 2011b, Brown, et al. 2008, Cieza et al. 2012, Rosenfeld et al. 2013, Andrews et al. 2010

Some disks have large cavities and small gaps



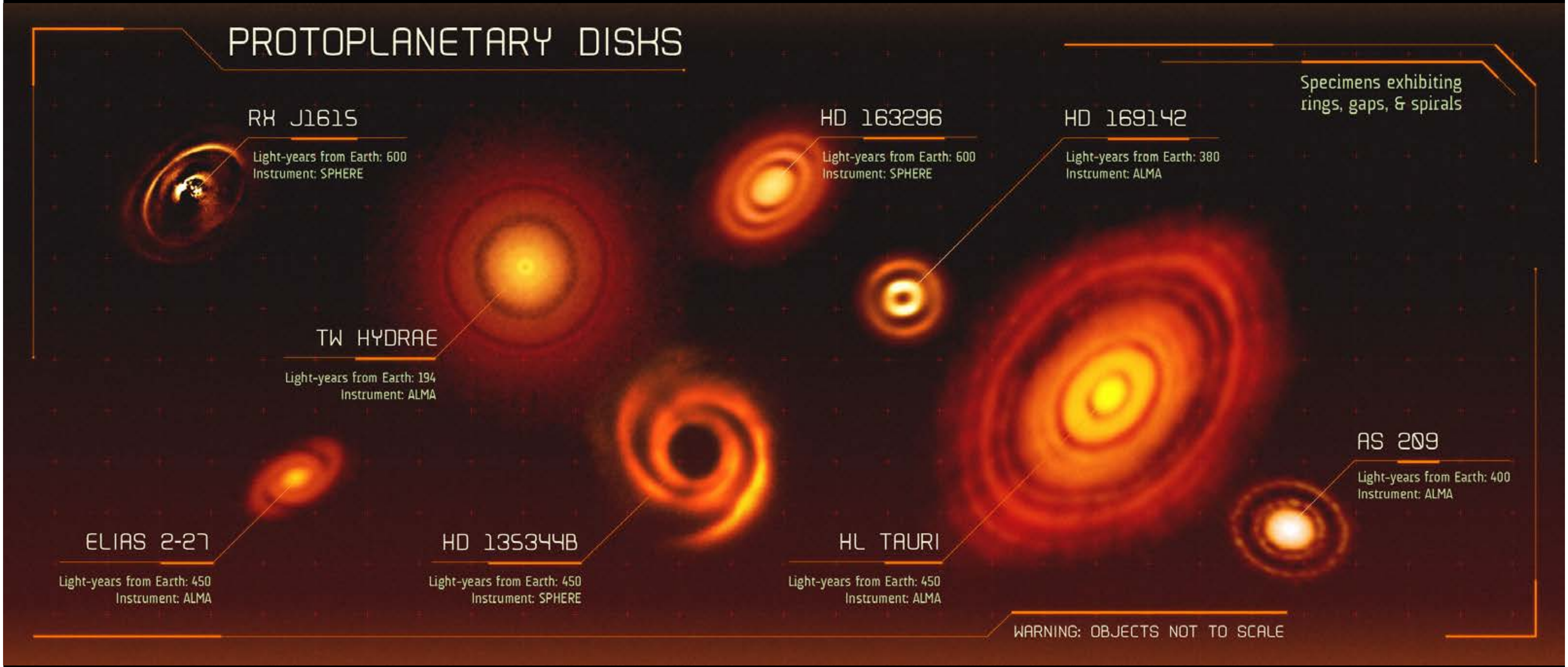




Macias, Espaillat, et al. 2018; also Long et al. 2018

Greg Herczeg's talk Wed. morning

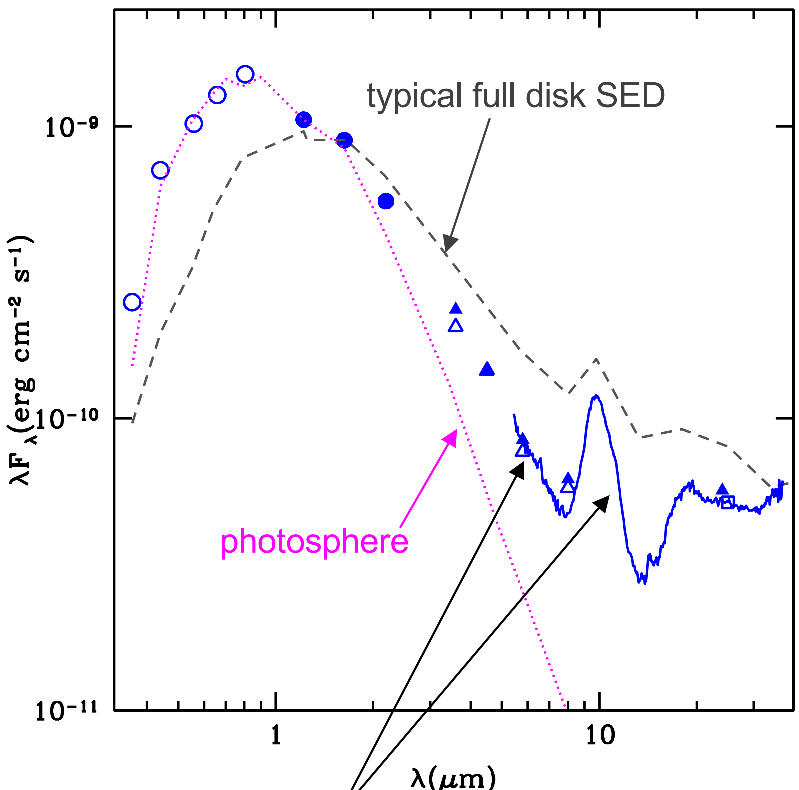
What will TMT reveal about the inner disk?



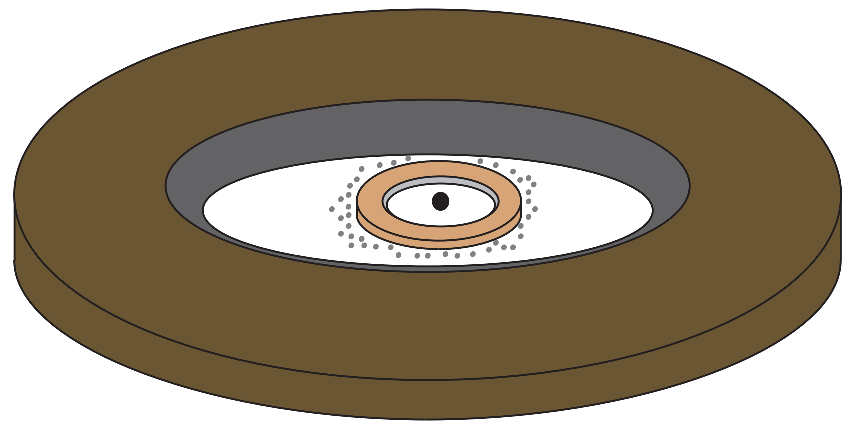
Disk images by ALMA and ESO, Adapted by Olena Shmahalo/Quanta Magazine

See also SEEDS images in poster by Carol Grady

Unresolved evidence for dust in the inner disk

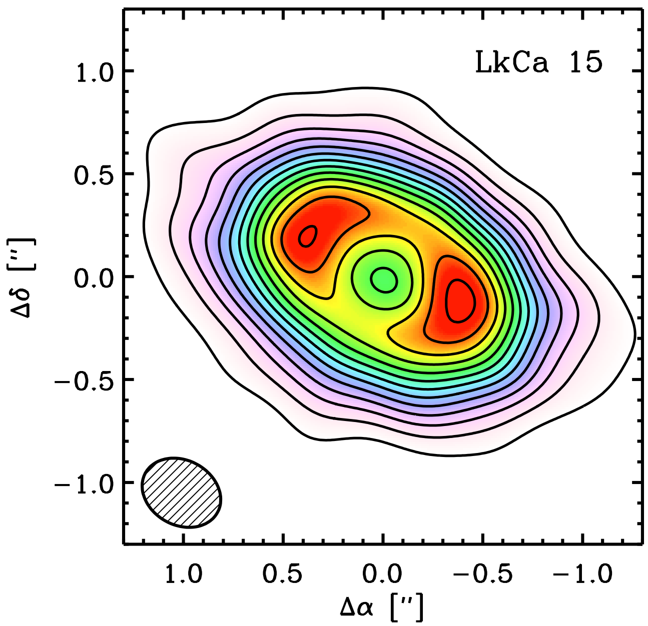


strong near-IR excess &
prominent silicate
emission feature



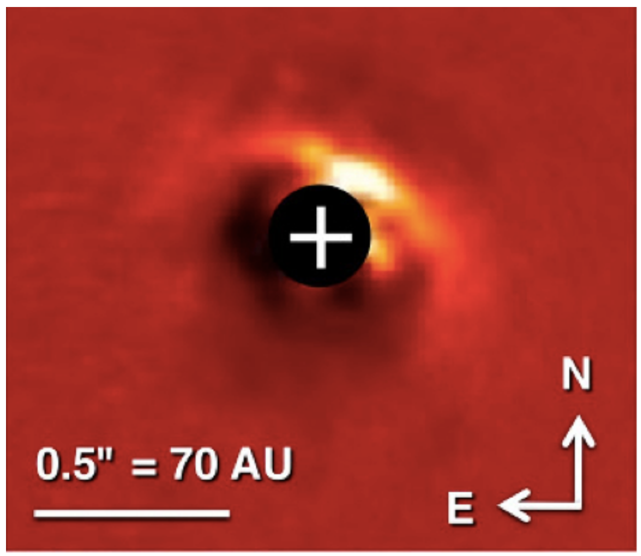
Espaillat et al. 2011, 2014

Resolving structure in the inner disk

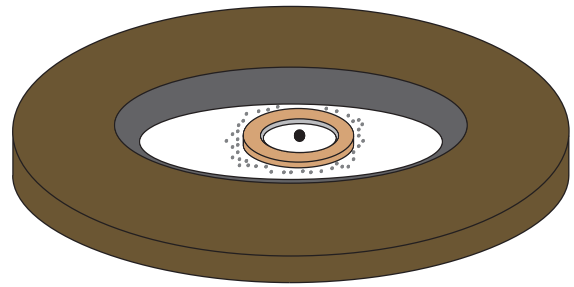


Andrews et al. 2011

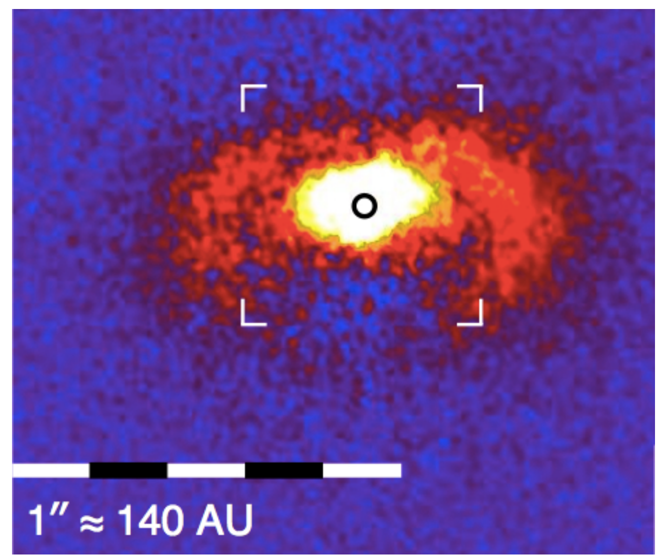
(also Pietu et al. 2006)



Thalmann et al. 2014



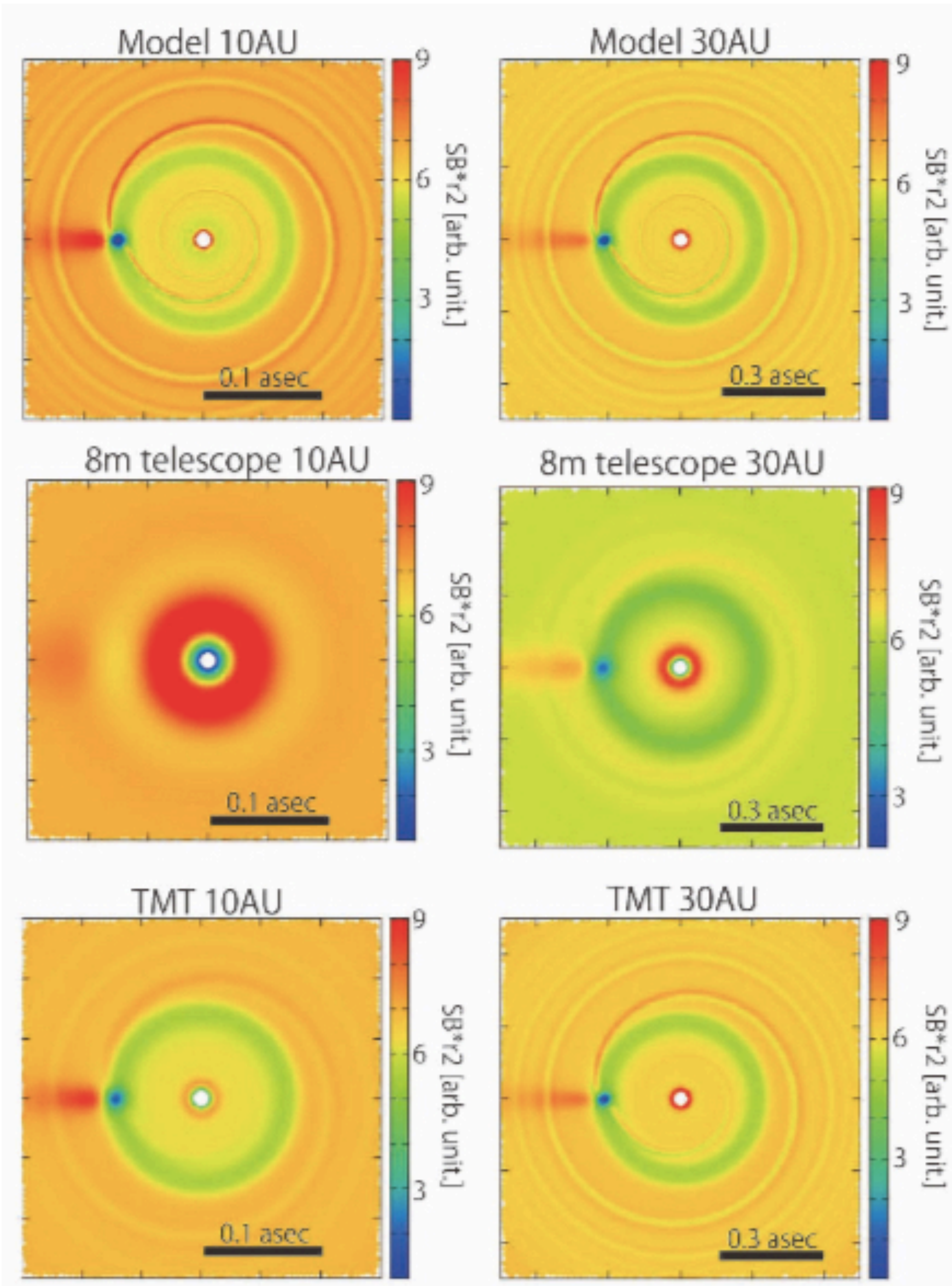
Espaillat et al. 2014



Thalmann et al. 2015

See also poster by Carol Grady

TMT will resolve the innermost disk structure



TMT will provide a resolution of
~ 1 AU at ~ 1 micron and
~ 3 AU at ~ 10 microns for disks at 140 pc

Taken from TMT Science Case (2015) based on Jang-Condell (2009)

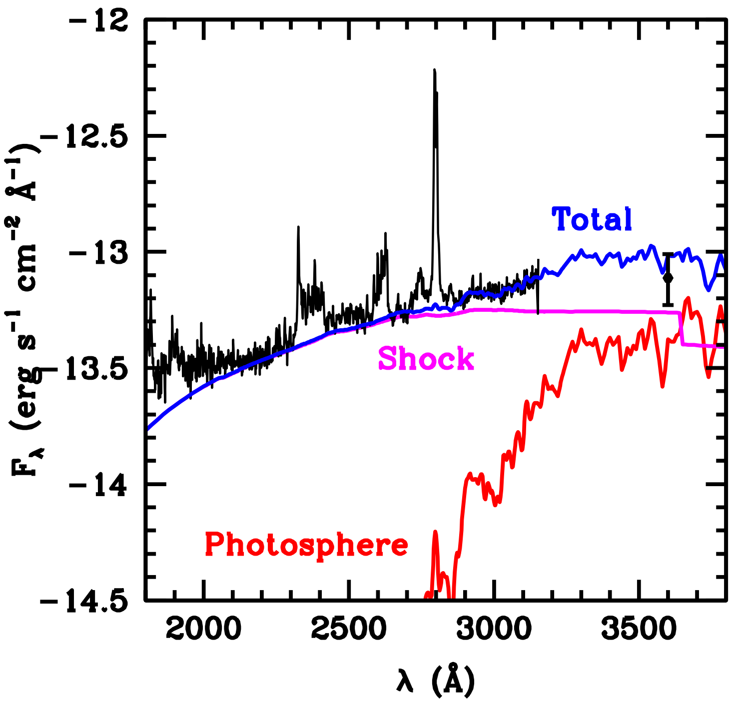
TMT & protoplanetary disk science

Characterizing dust structure in the inner disk

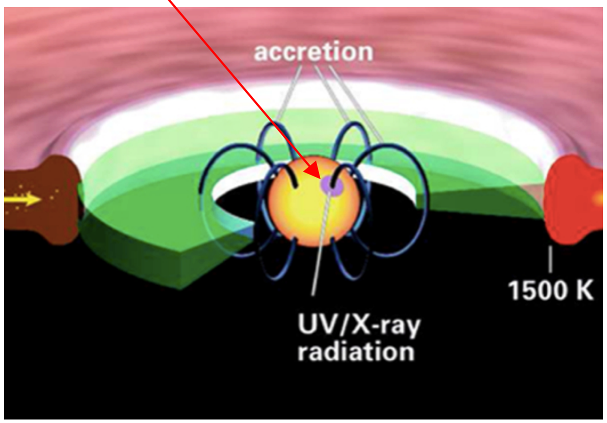
Measuring gas in the inner disk

Identifying protoplanets & circumplanetary disks

Gas still accretes onto stars with disk cavities



UV excess originates from accretion shock on stellar surface

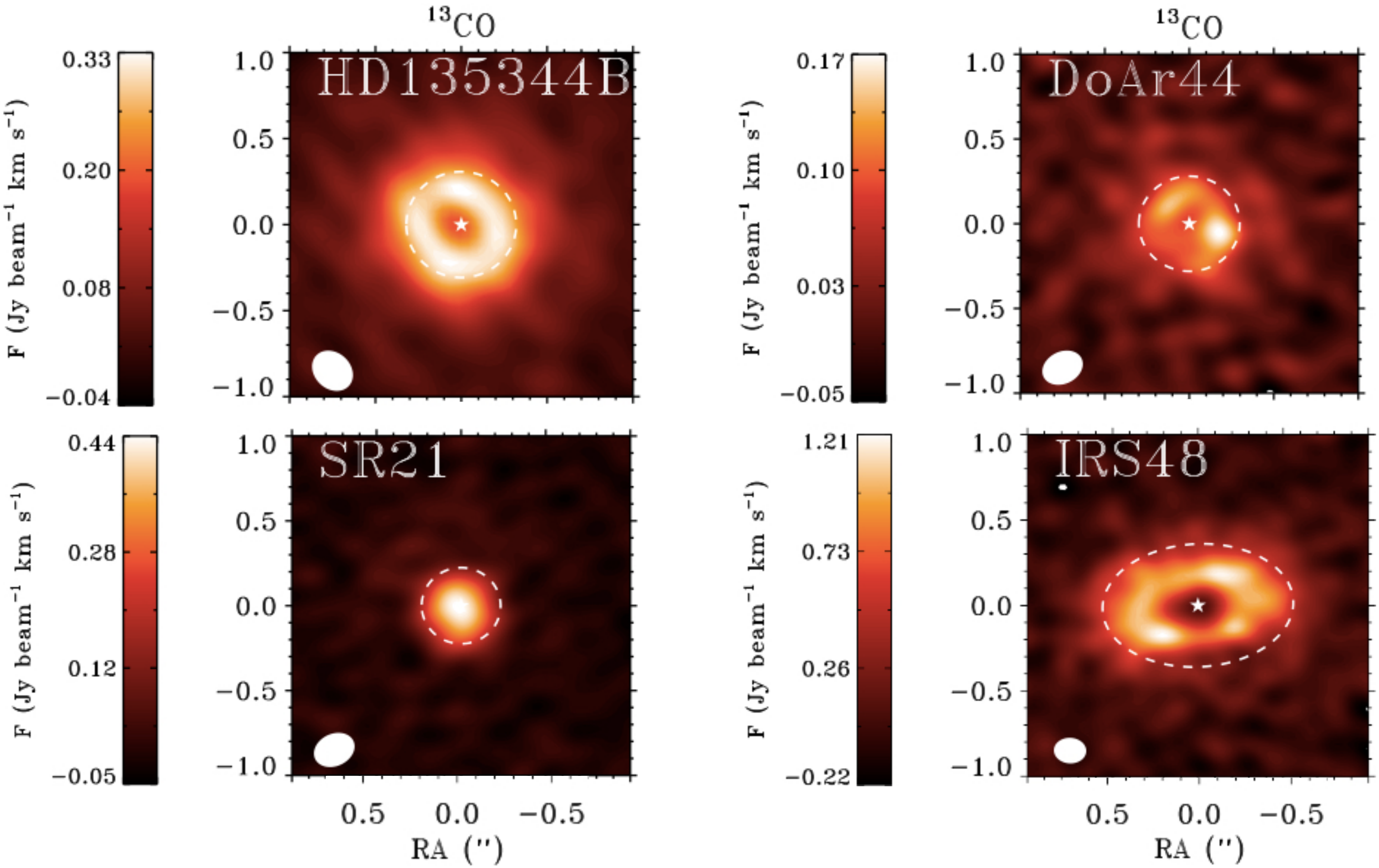


GM Aur $\dot{M} \sim 10^{-8} M_\odot\ yr^{-1}$

T Tauri star average $\dot{M}$
$\sim 10^{-8} M_\odot\ yr^{-1}$

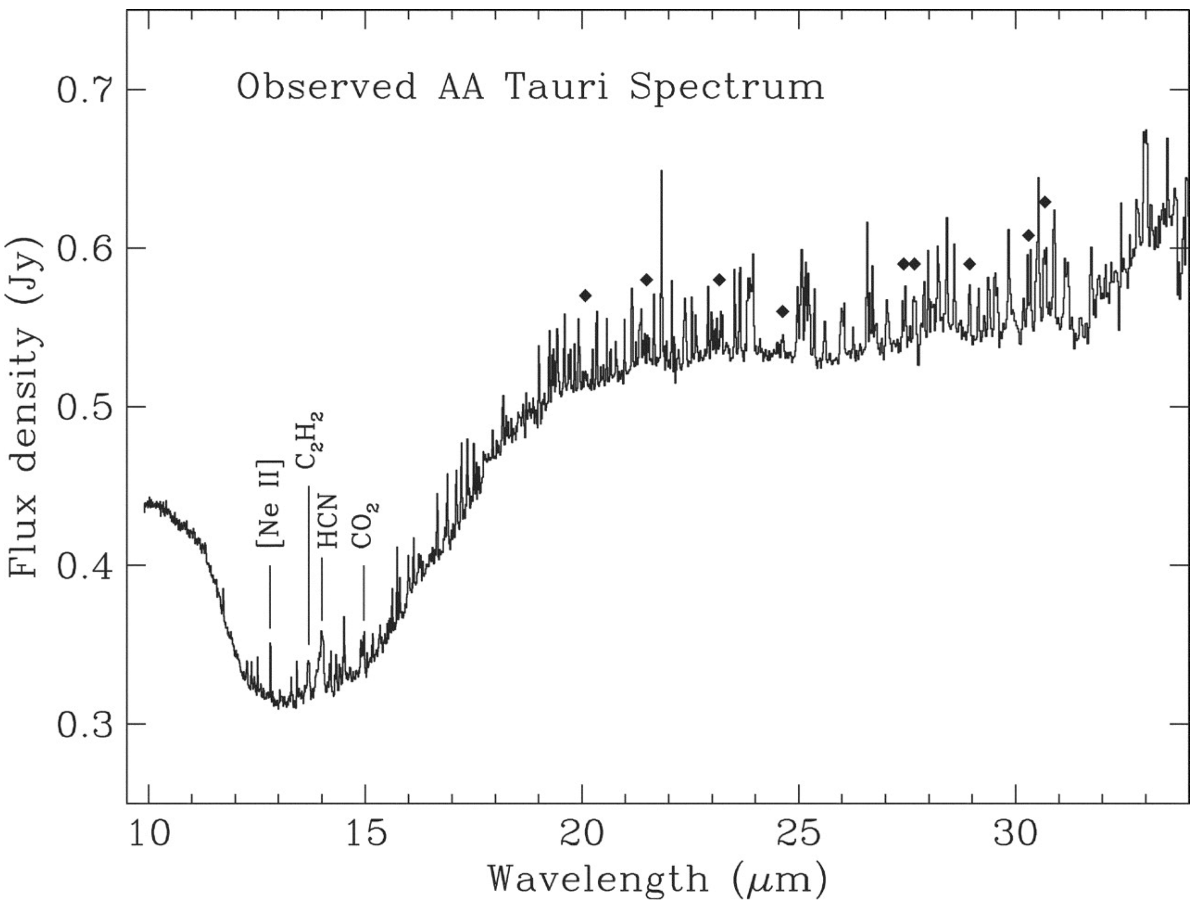
Ingleby, Espaillat et al. 2015, Robinson & Espaillat, submitted

Gas seen within dust cavities with ALMA



van der Marel et al. 2015

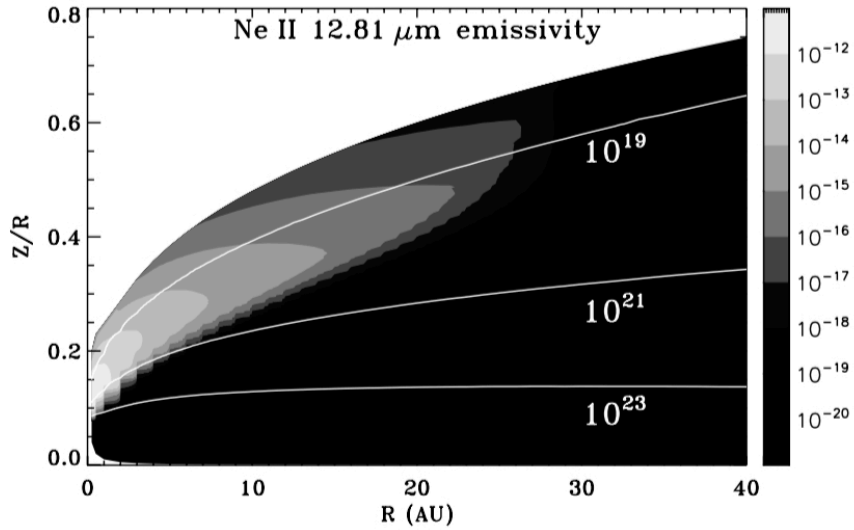
TMT will resolve gas emission lines in the innermost disk

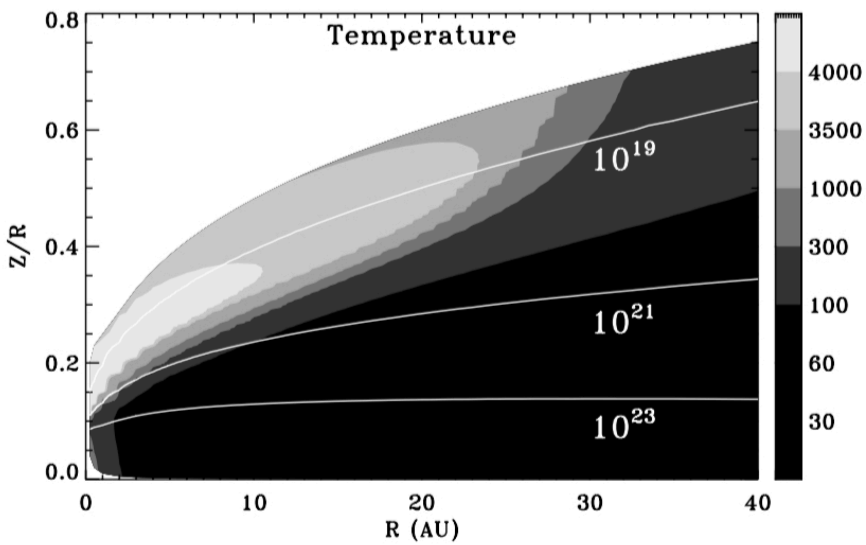


TMT will be able to spectroscopically resolve water, ro-vibrational CO, CO_2, HCN, C_2H_2, CH_4, NH_3

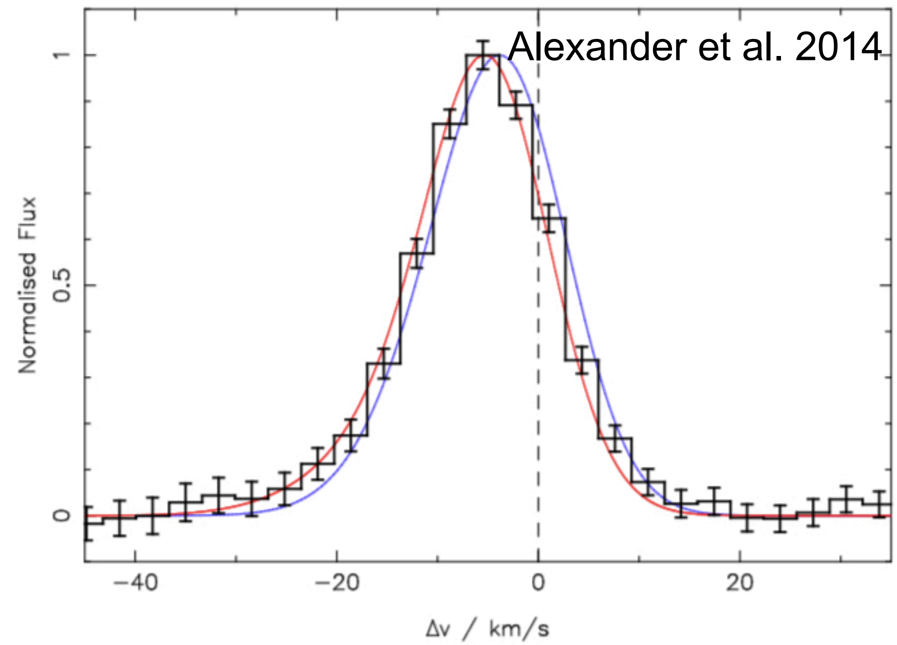
Carr & Najita 2008; see also Peregrine McGehee's talk Wed. morning

TMT & disk photoevaporation





Meijerink et al. 2008



[Ne II] 12.81 um in of TW Hya fit with EUV-driven and X-ray driven photoevaporation models (Pascucci et al. 2011, Alexander et al. 2008, Ercolano & Owen 2010)

Several disks with [Ne II] identified to date (e.g., Pascucci et al. 2007, Espaillat et al. 2007, Herczeg et al. 2007, Gudel et al. 2010, Szulagyi et al. 2012, Espaillat et al. 2013, 2017)

TMT & protoplanetary disk science

Characterizing dust structure in the inner disk

Measuring gas in the inner disk

Identifying protoplanets & circumplanetary disks

Imaging protoplanets in disk cavities

M. Keppler et al.: Discovery of a planetary-mass companion around PDS 70

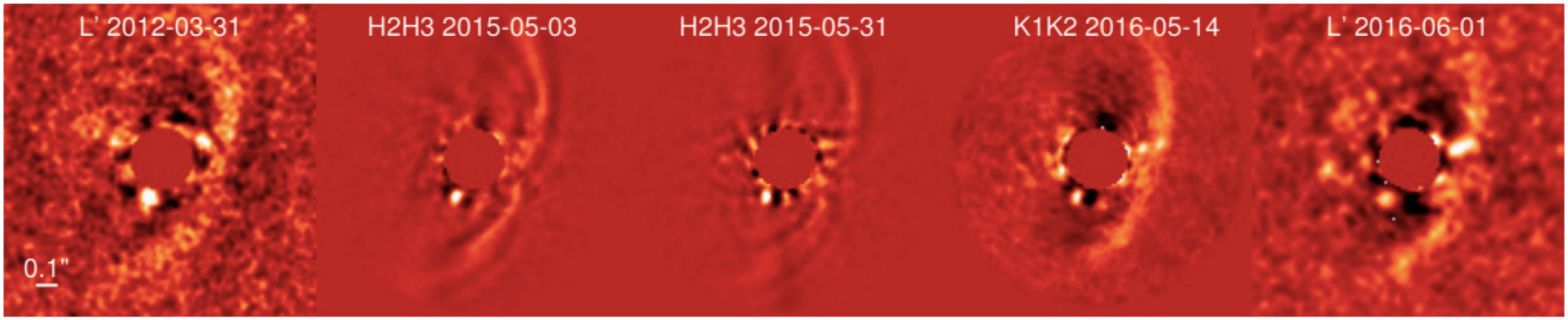
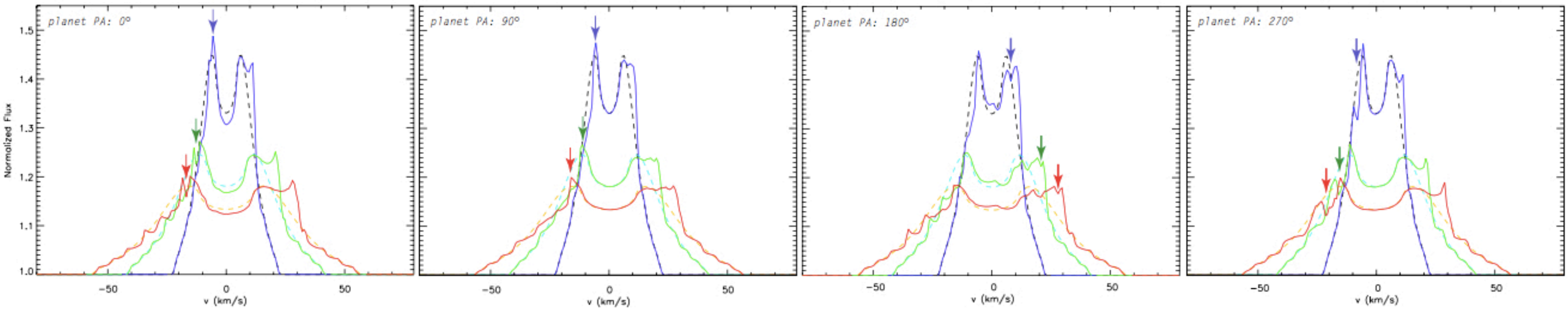


Fig. 9. Images of the point source detection as retrieved with the sPCA reduction (*from left to right*): NICI L'-band (2012-03-31), IRDIS H2H3-band (2015-05-03), IRDIS H2H3-band (2015-05-31), IRDIS K1K2-band (2016-05-14), NaCo L'-band (2016-06-01). North is up and east is to the left. The images were smoothed with a Gaussian kernel of size $0.5 \times FWHM$.

Protoplanets expected to distort gas lines, leading to variability

8 M_J planet orbiting 1 Msun star at 1 AU

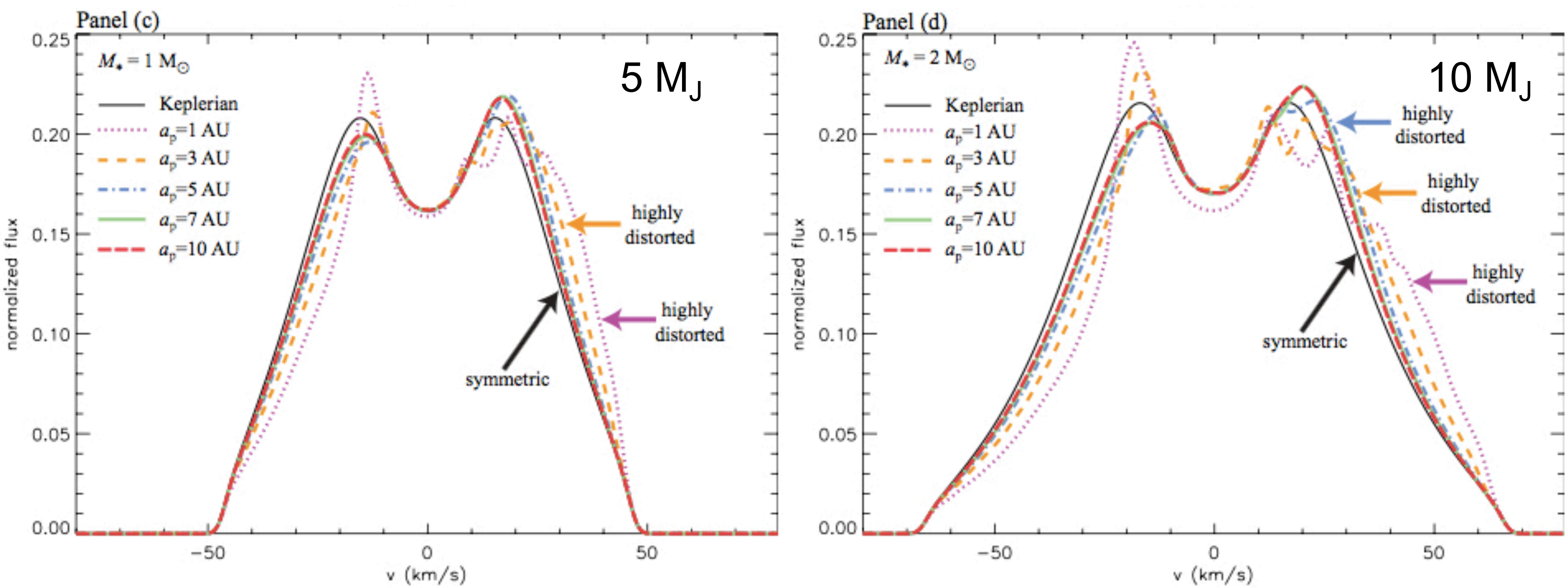


Disk inclinations are 20 degrees, 40 degrees, 60 degrees

Dashed lines: planet-free disk

Regaly et al. 2010

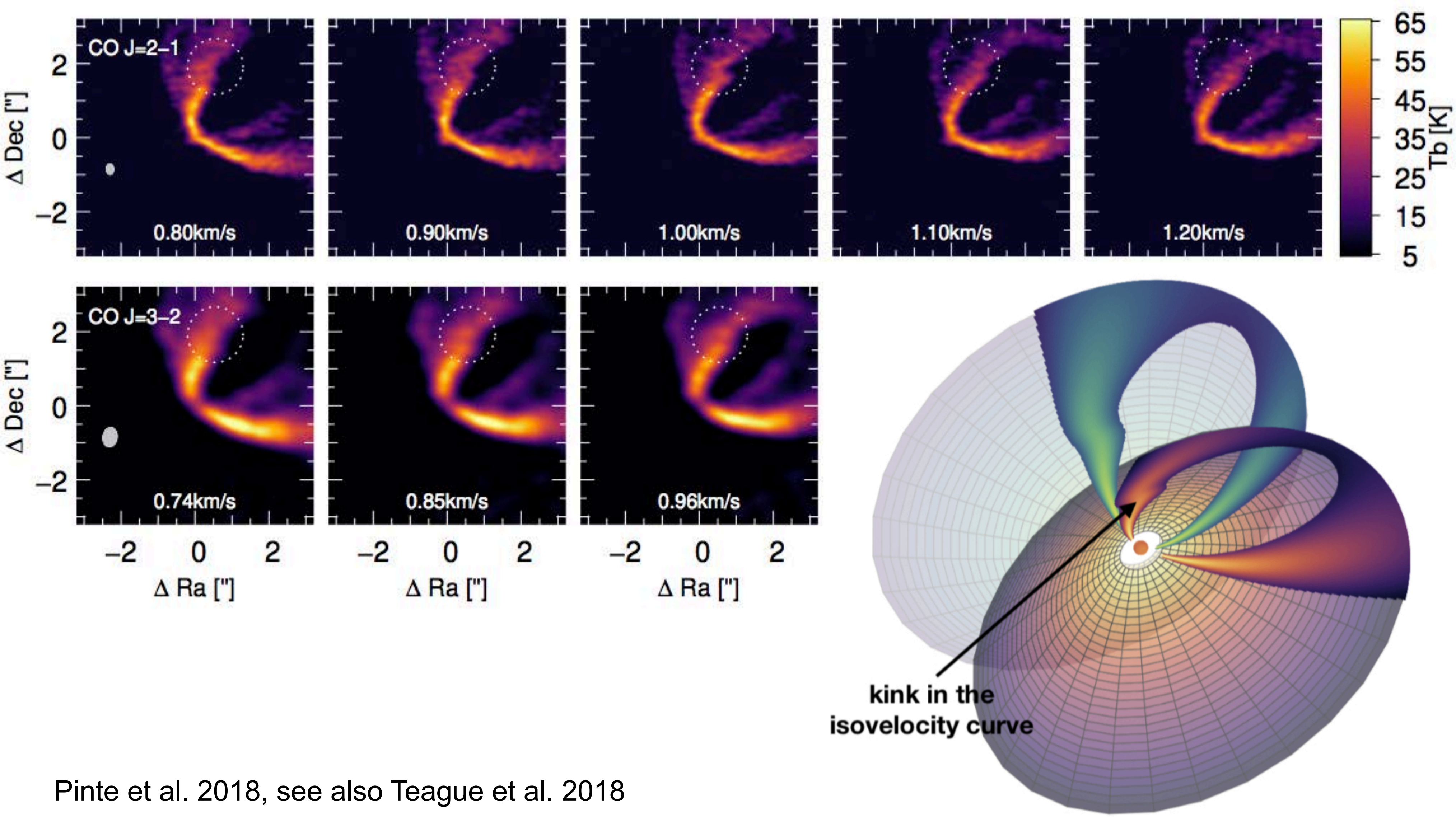
Giant protoplanets can excite global disk eccentricity within orbit



Regaly et al. 2014

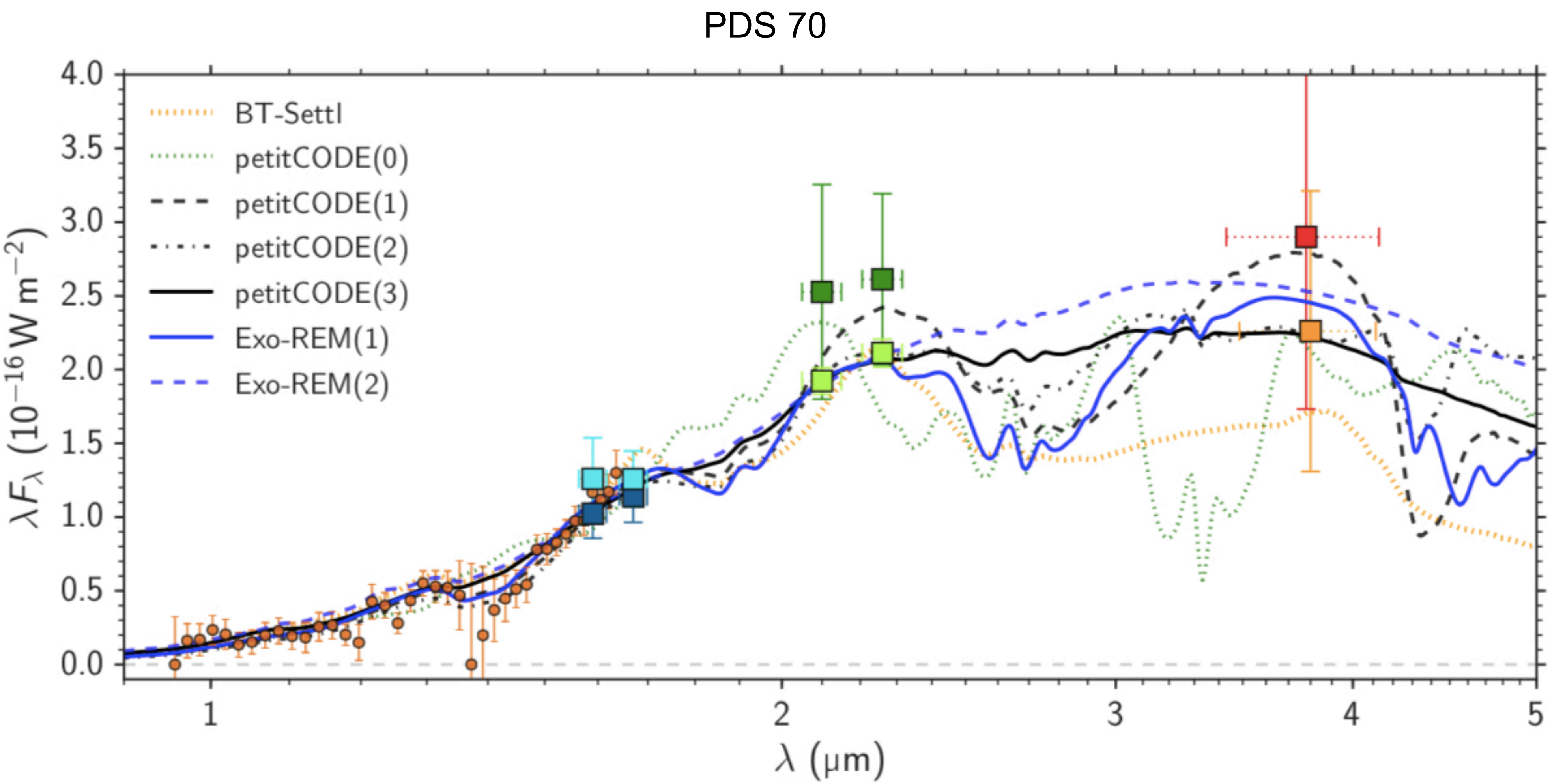
Protoplanet candidate via gas kinematics

HD 163296 12CO with ALMA



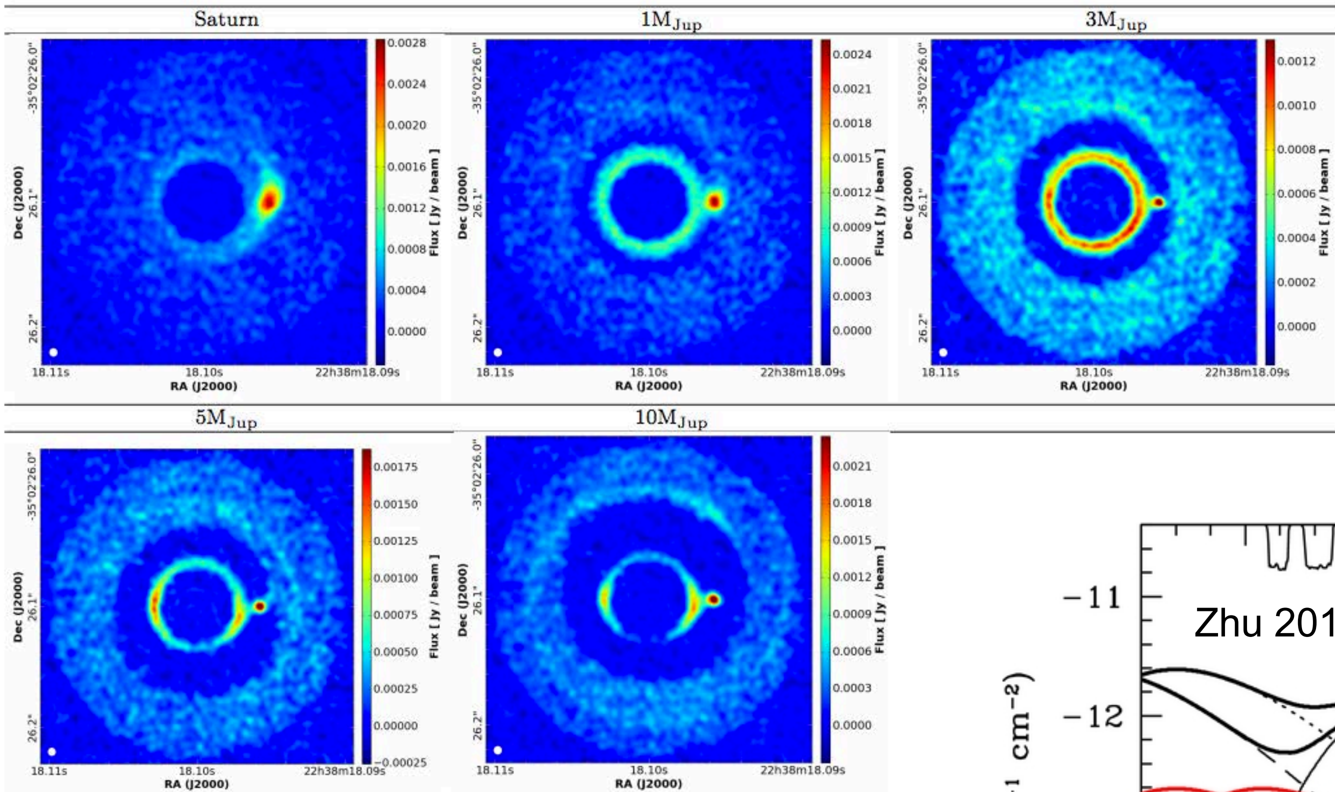
Pinte et al. 2018, see also Teague et al. 2018

TMT & the atmospheres of young planets

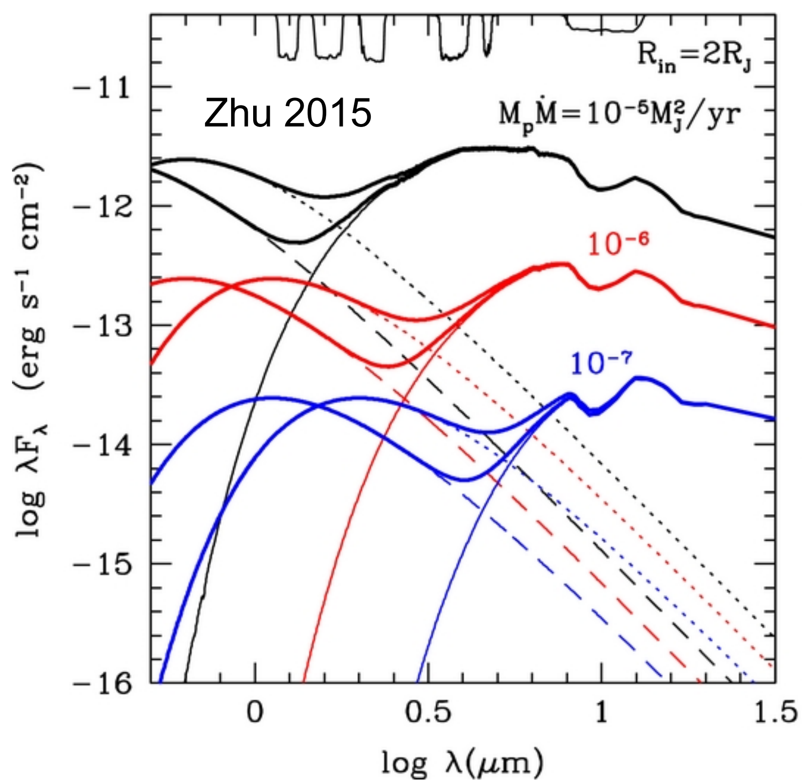


Muller et al. 2018

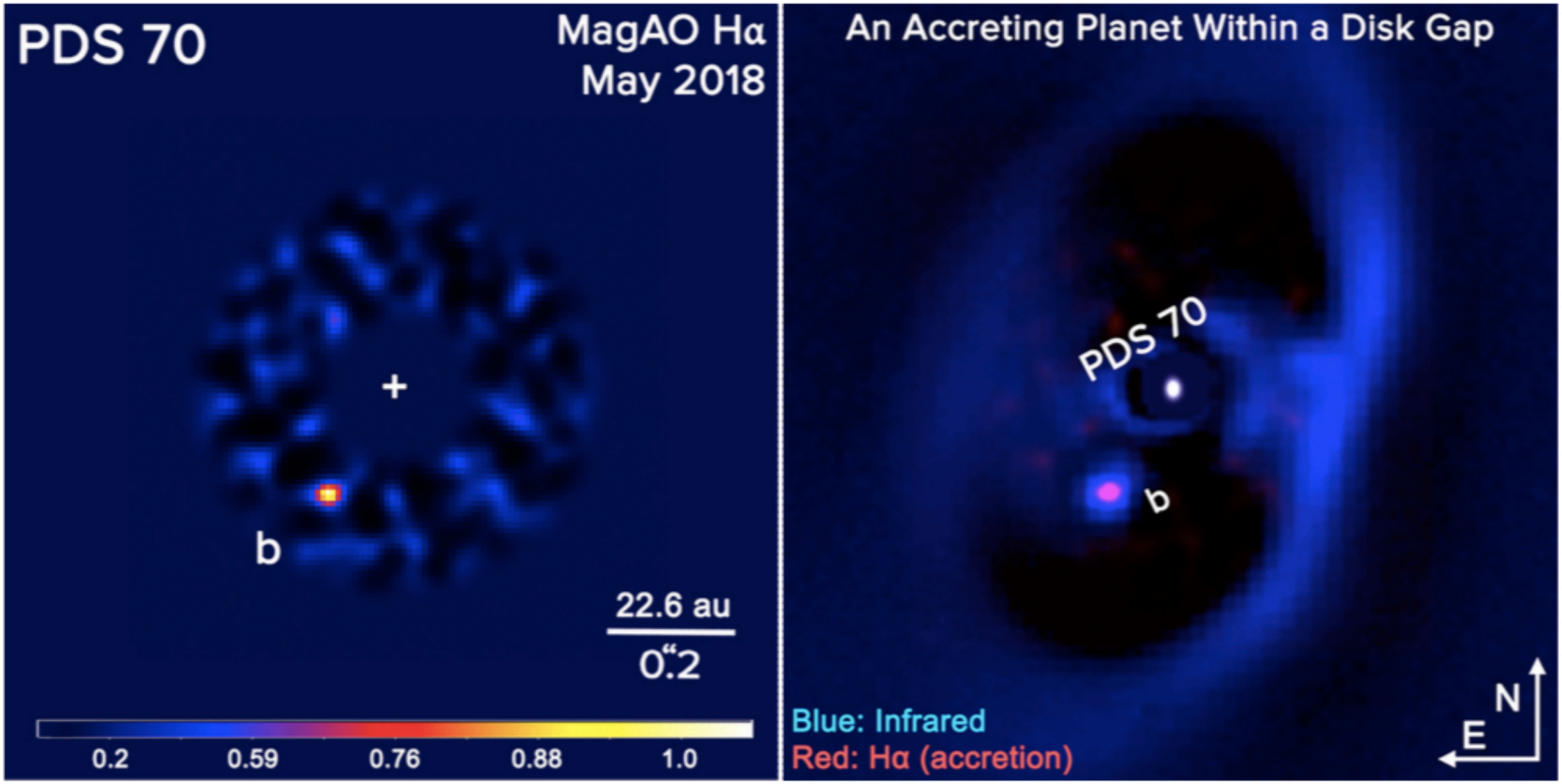
Imaging circumplanetary disks



Szulagyi et al. 2017



TMT & accretion onto young planets



Wagner et al. 2018

What will TMT reveal about the inner disk?

Characterizing dust structure in the inner disk

- spatial distribution of dust (gaps, spirals)
- *variability in structure*
- *shadows on disk*

Locating gas in the inner disk

- spatial distribution of gas
- photoevaporation
- *detecting & locating organics*
- *water snowline*

Identifying protoplanets & circumplanetary disks

- imaging & kinematic signatures
- protoplanet atmospheres
- *accretion variability onto protoplanets*

Breakout session on Planetary Formation (Chairs: Herczeg, Currie, Metchev)