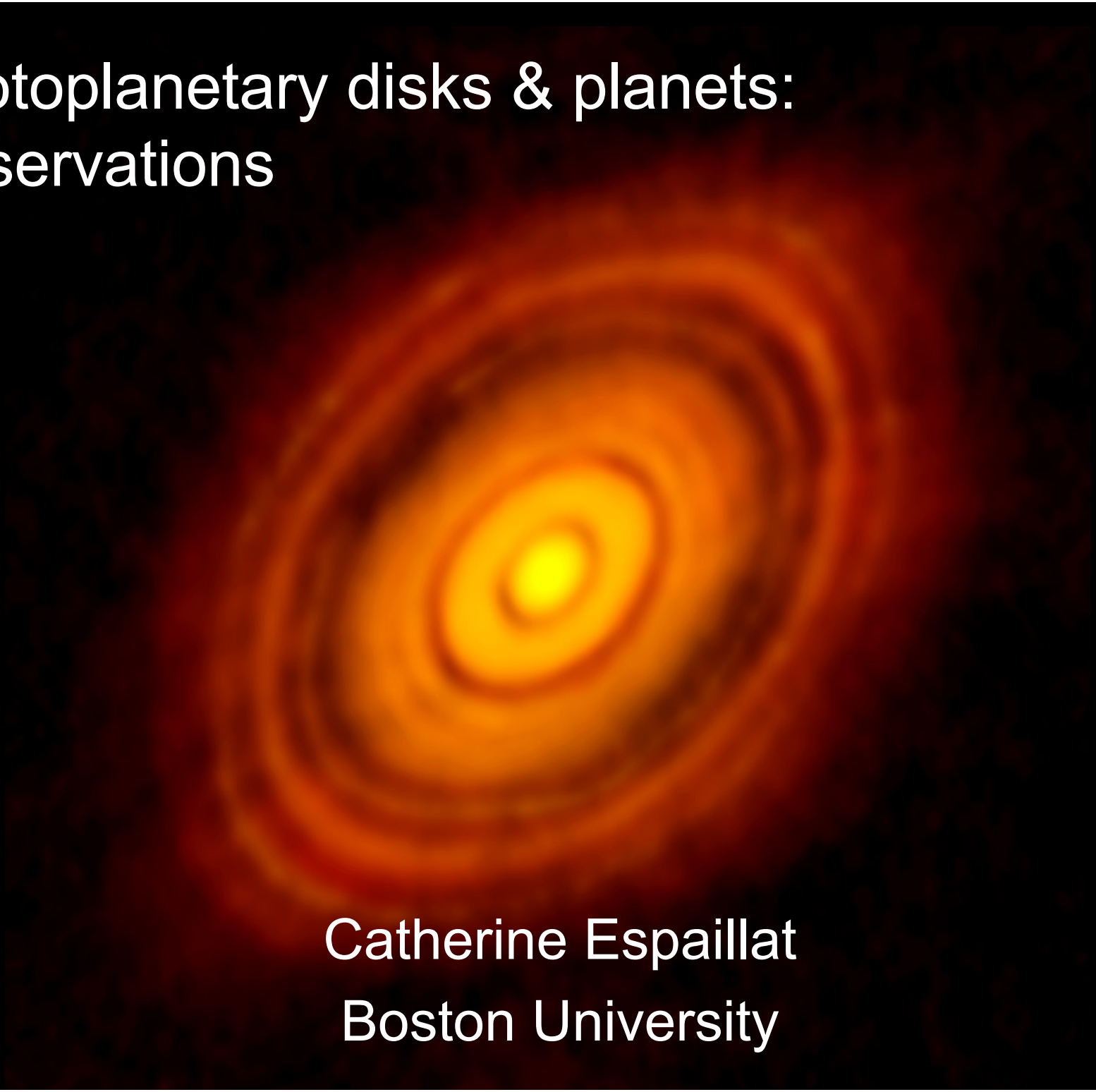
Protoplanetary disks & planets: observations



Catherine Espaillat

Boston University

Planets display diverse compositions and sizes

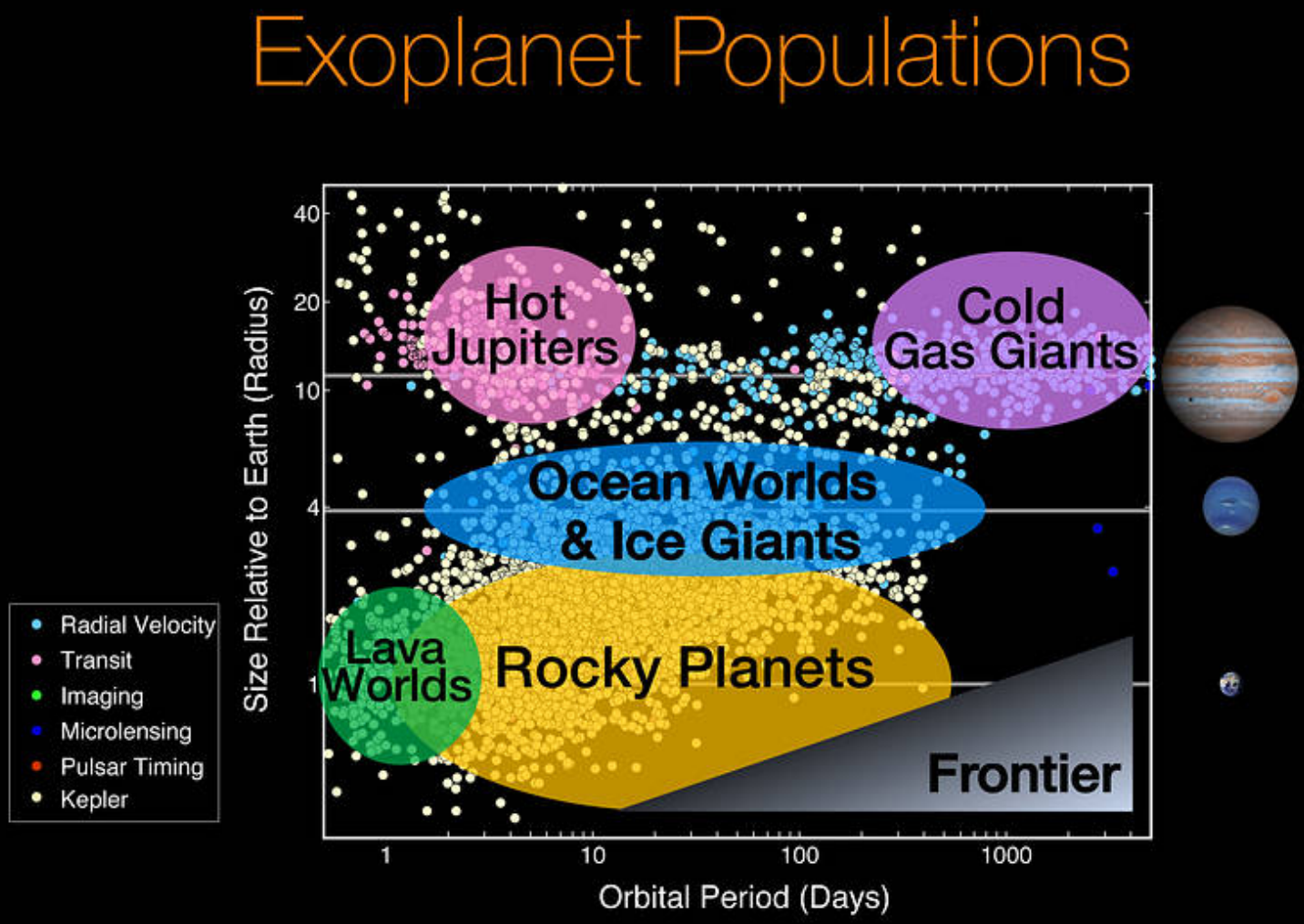


Image: NASA

Are there habitable exoplanets?

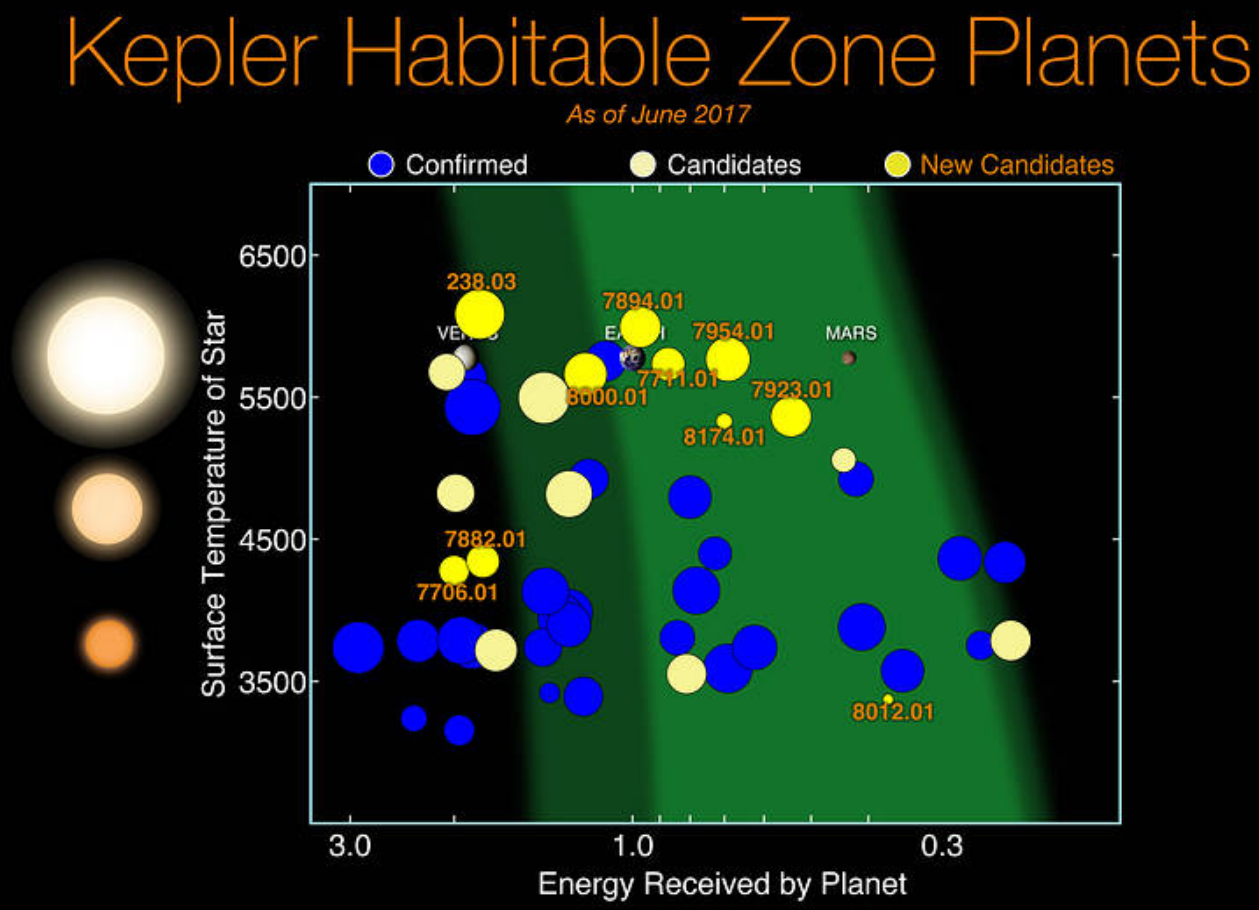
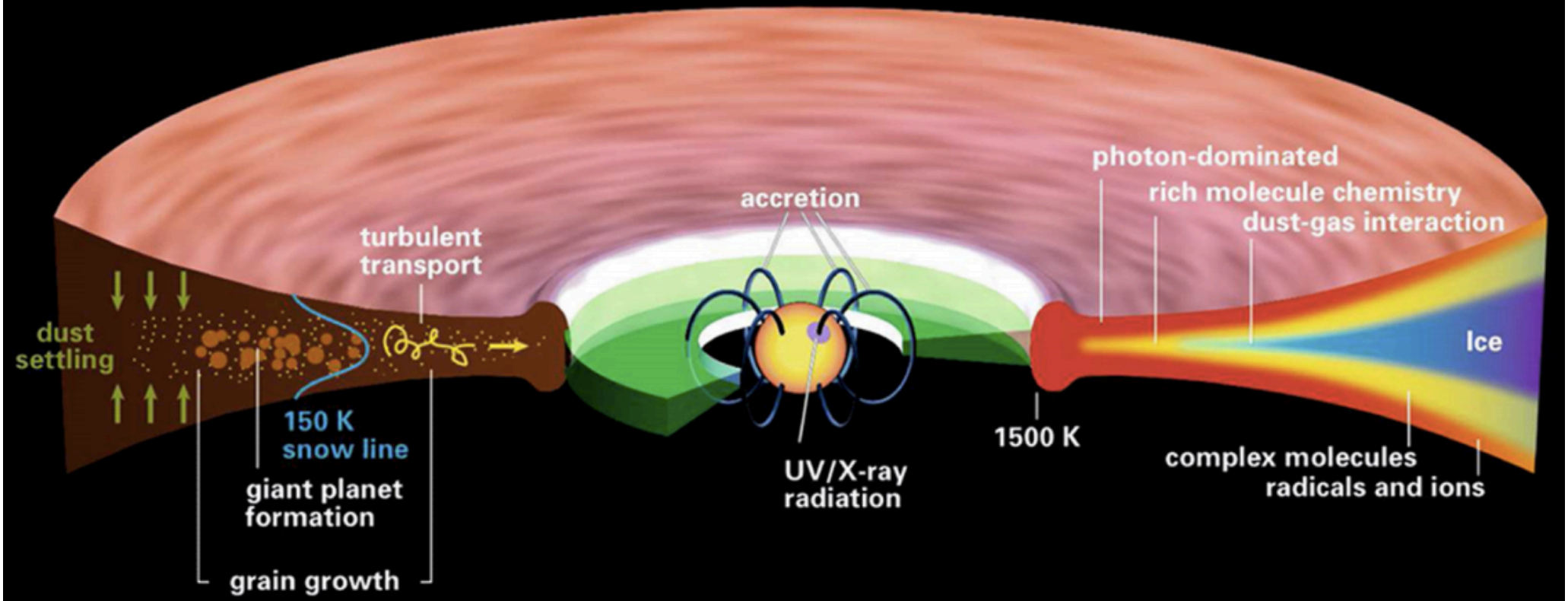


Image: NASA

Planet traits are inherited from their birth disks



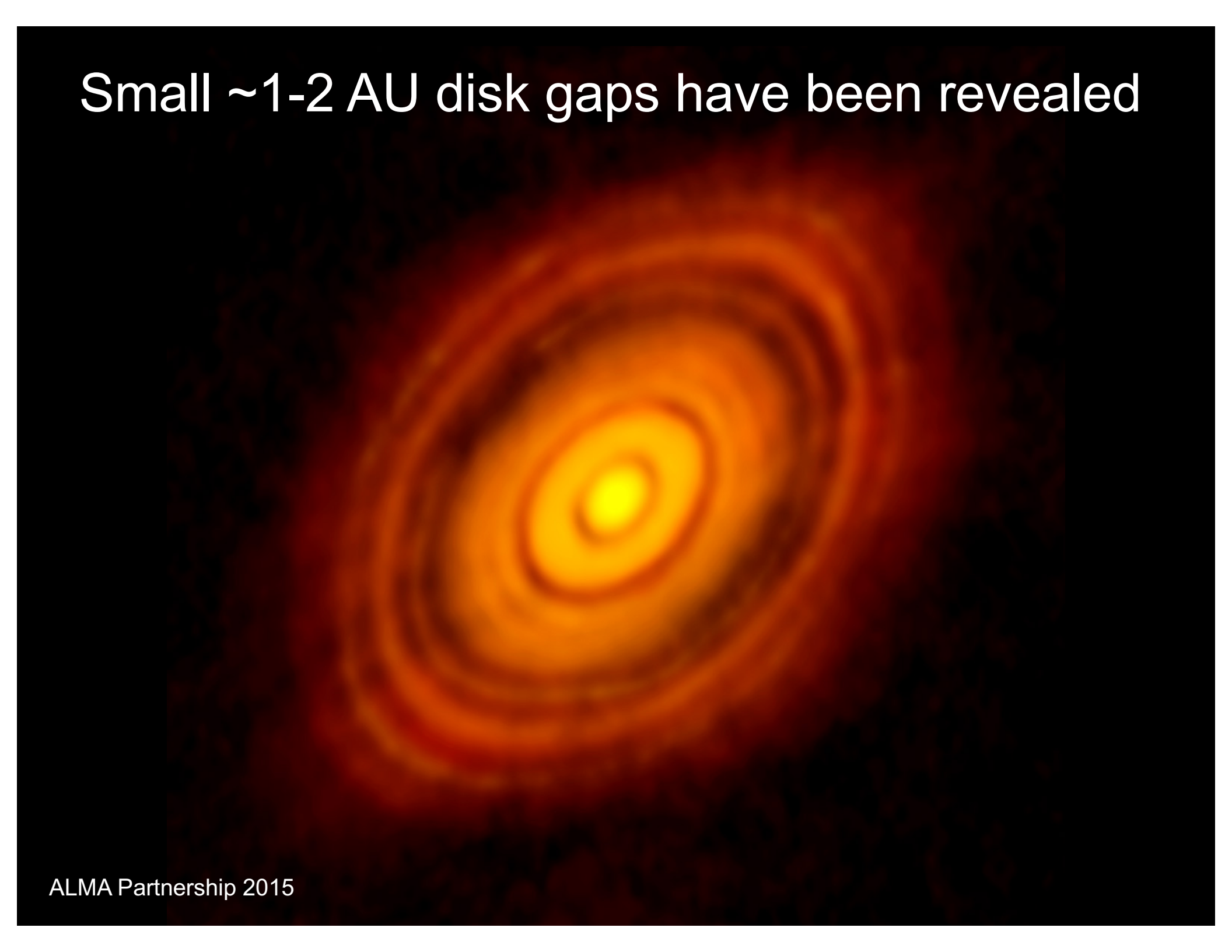
Henning & Semenov 2014

Protoplanetary disks & planets: observations

Do planets leave observable disk signatures?

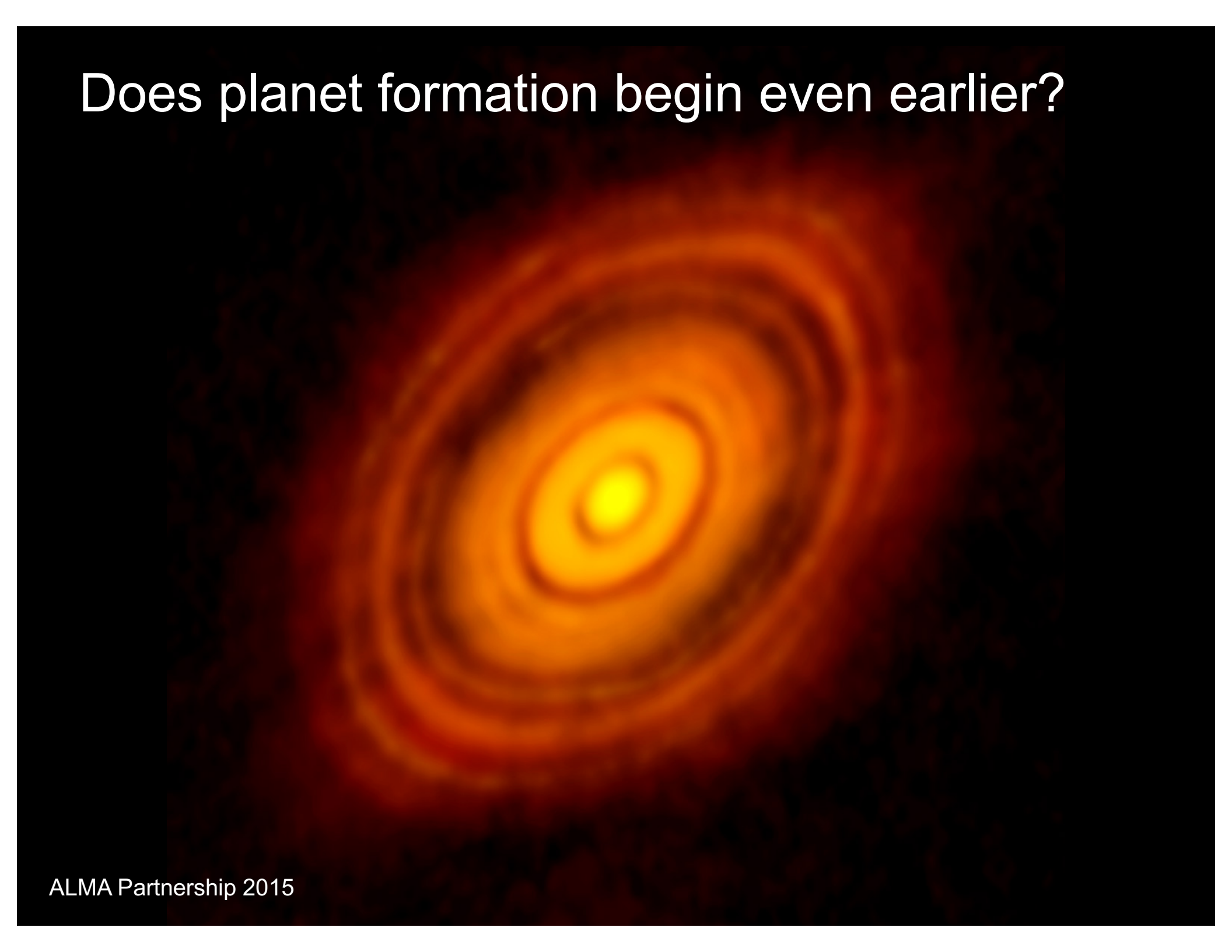
Where do planets form in disks?

Small ~1-2 AU disk gaps have been revealed



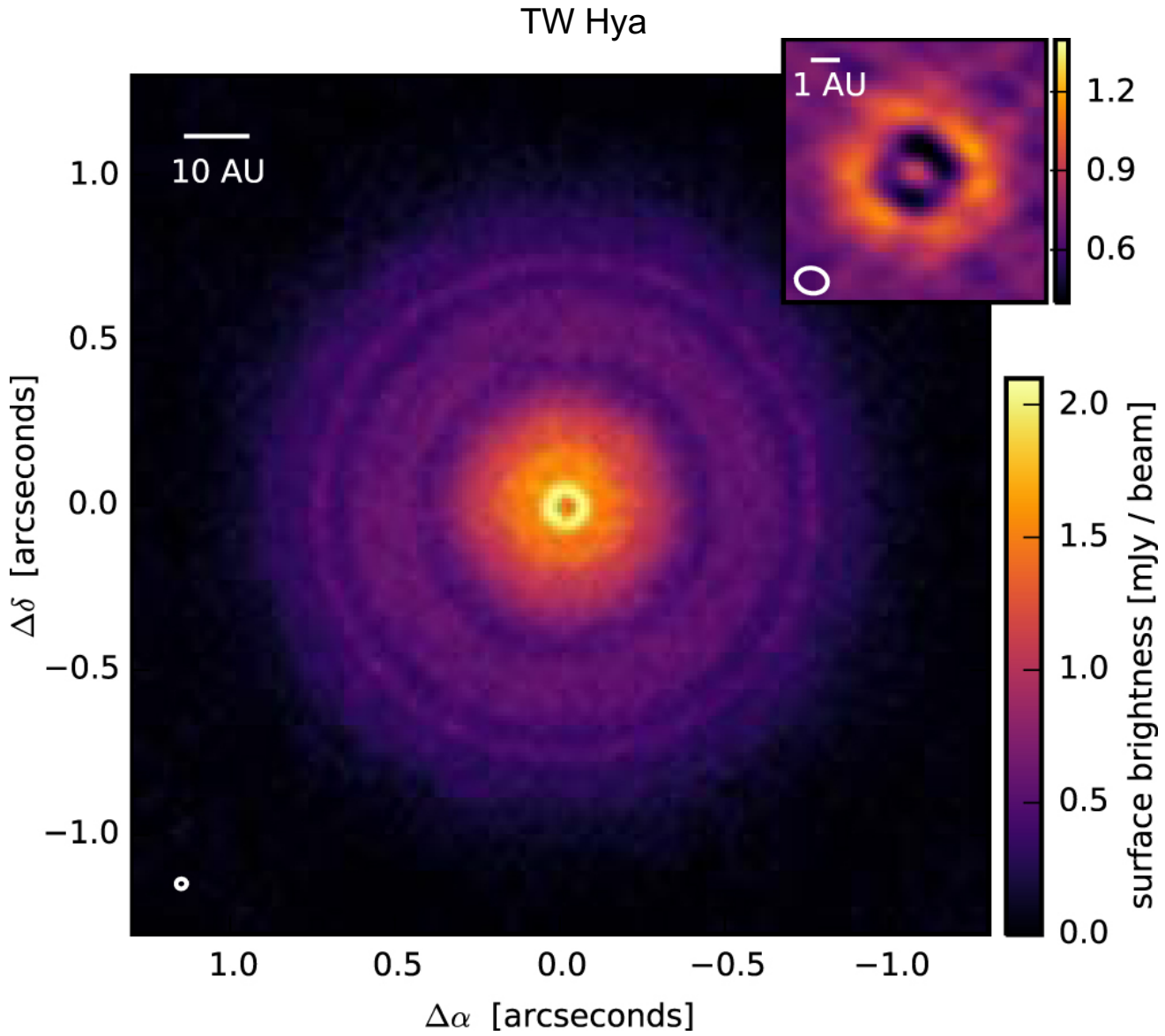
ALMA Partnership 2015

Does planet formation begin even earlier?



ALMA Partnership 2015

Small disk gaps may be common



Andrews et al. 2016

Large > 10 AU disk cavities also seen

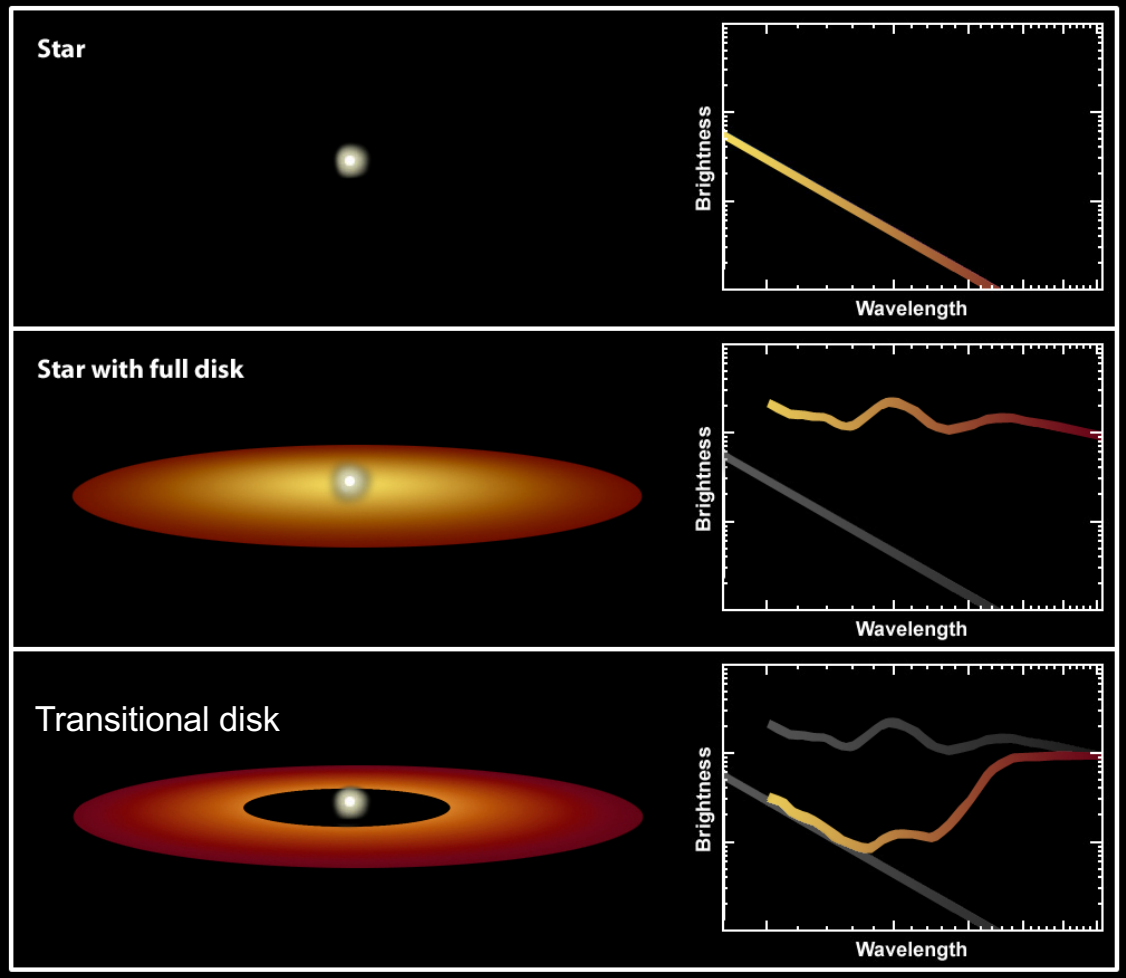
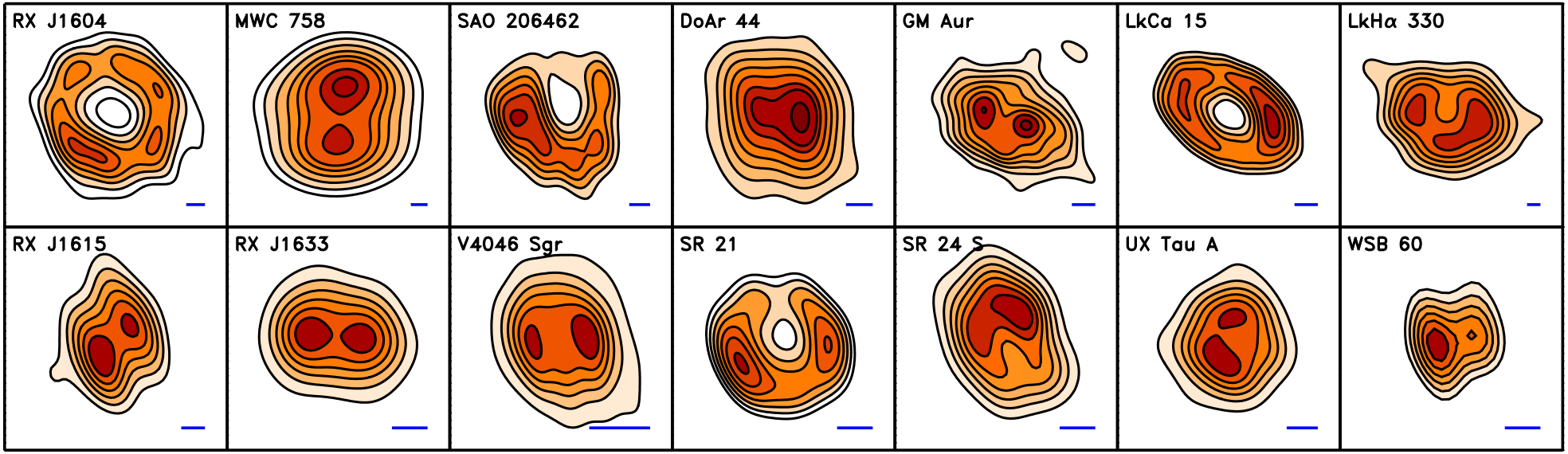


Image: NASA

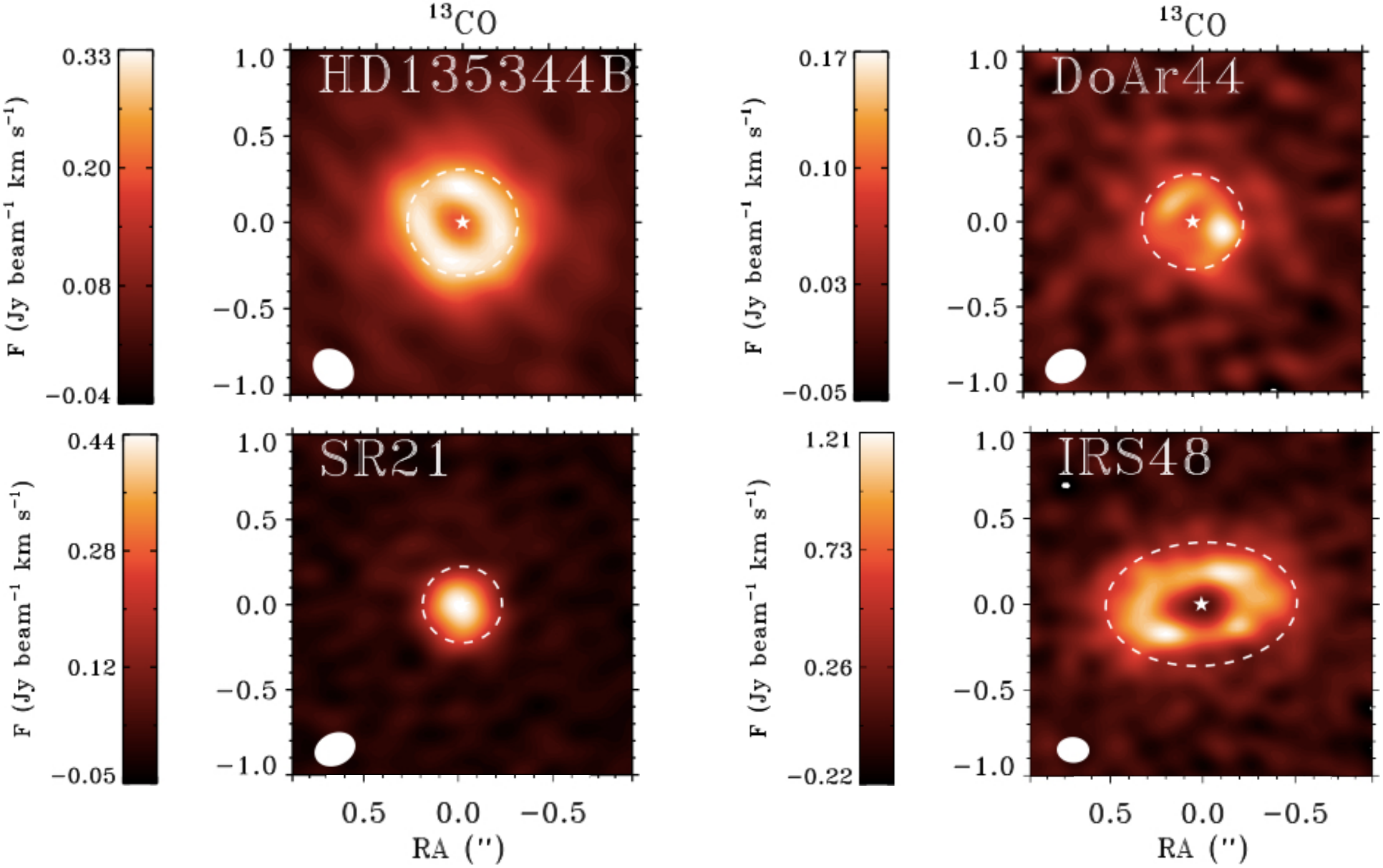
Several large disk cavities confirmed via (sub-)mm interferometric imaging



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*)

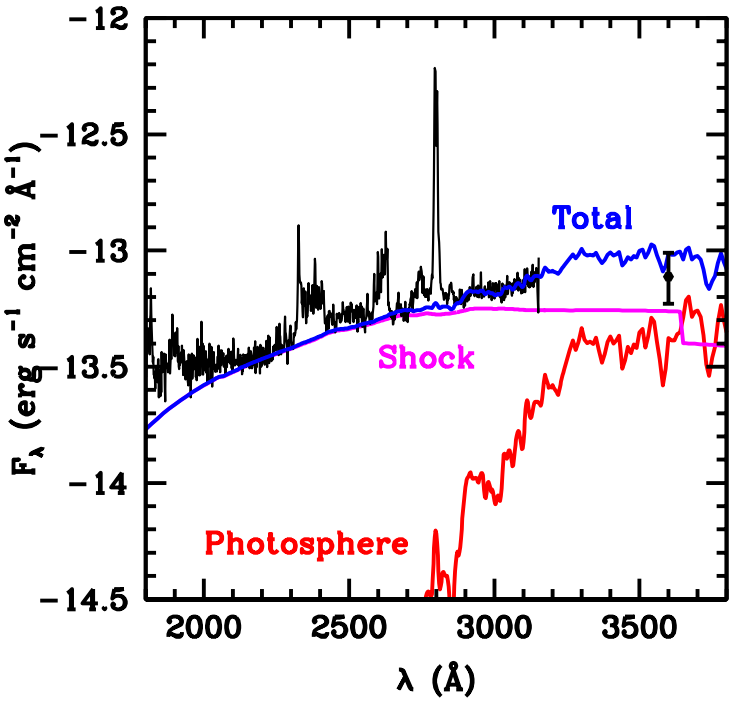
Figure from Espaillat et al. 2014, PPVI; Data from Mathews et al. 2012 Isella, et al. 2010, Brown et al. 2009, Andrews et al. 2009, Hughes et al. 2009, Andrews et al. 2011b, Brown, et al. 2008, Cieza et al. 2012, Rosenfeld et al. 2013, Andrews et al. 2010

Cavities also seen in the disk gas distribution

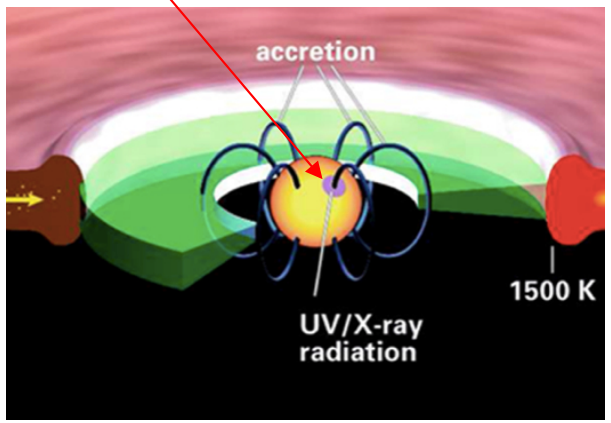


van der Marel et al. 2015

Gas still accretes onto stars with disk cavities



UV excess originates from accretion shock on stellar surface

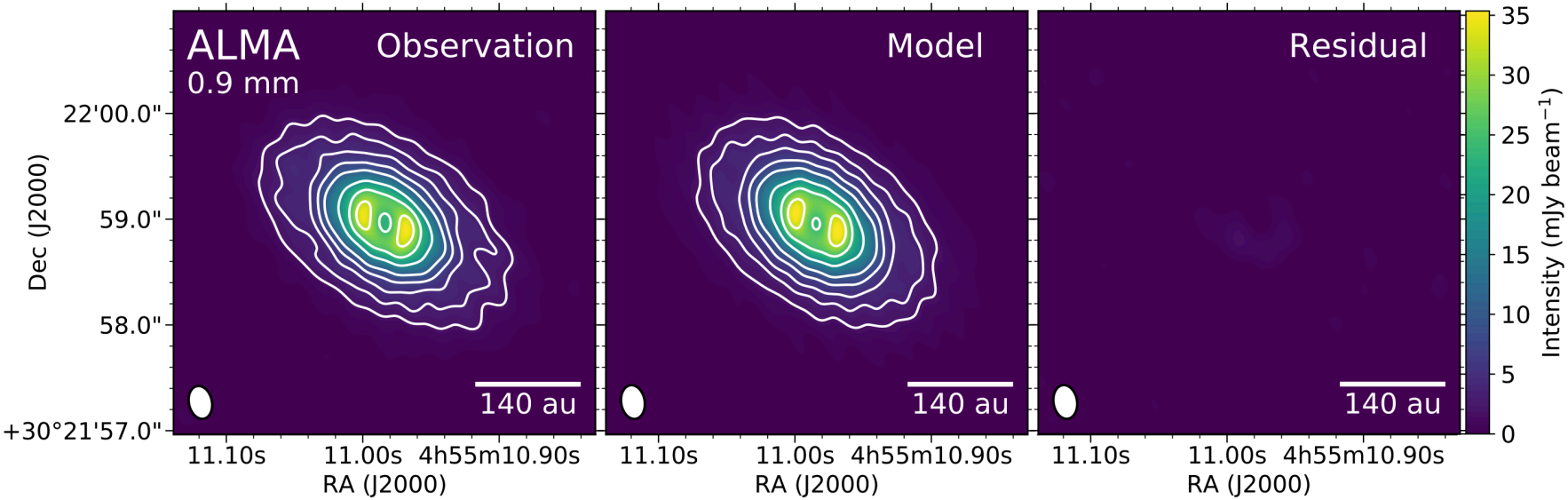


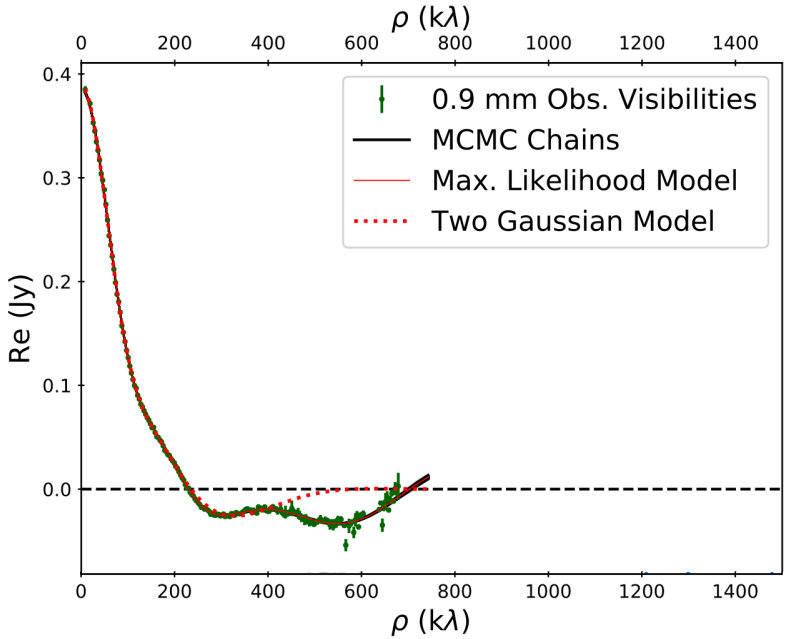
GM Aur $\dot{M}$ ~ 10^{-8} $M_\odot$ yr $^{-1}$

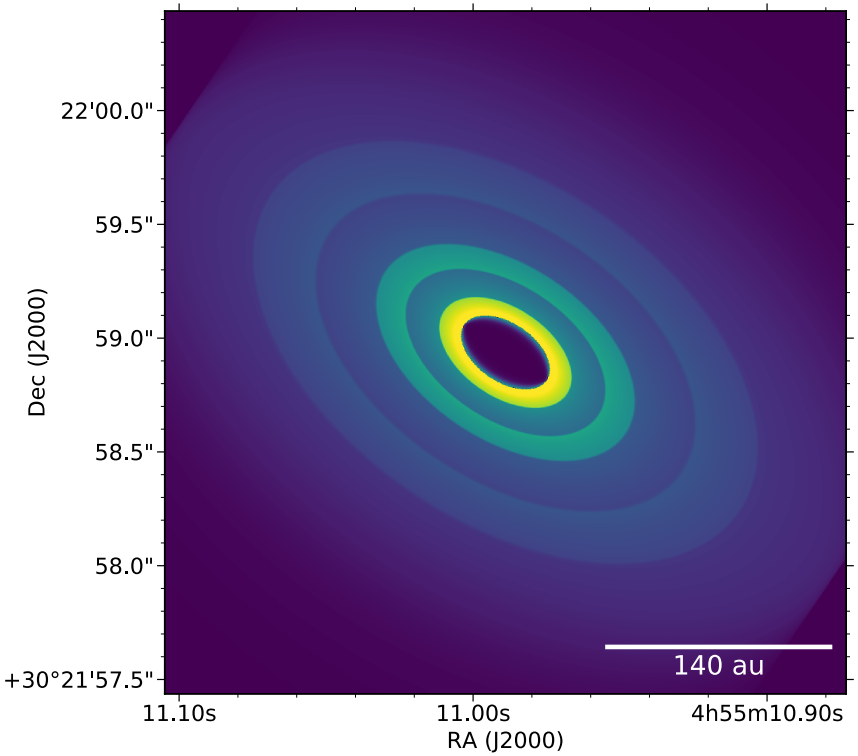
T Tauri star average $\dot{M}$
~ 10^{-8} $M_\odot$ yr $^{-1}$

Ingleby et al. 2013

Some disks have large cavities and small gaps



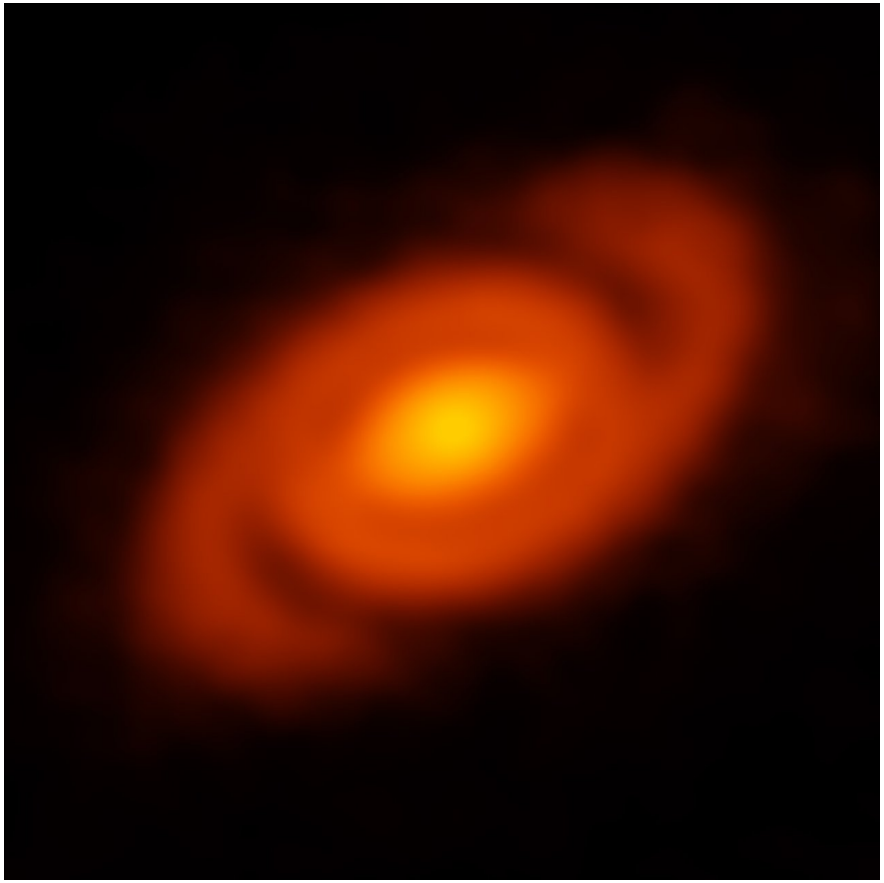




Macias, Espaillat, et al. submitted to ApJ

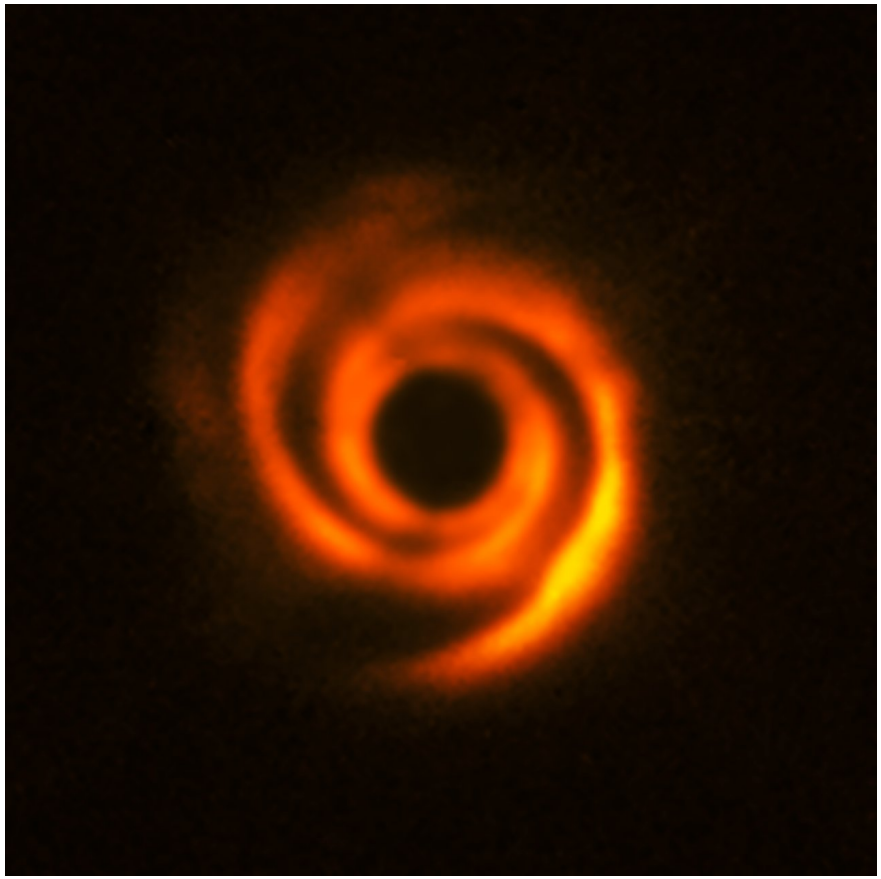
Spiral structures detected in disks

Elias 2 – 27 with ALMA



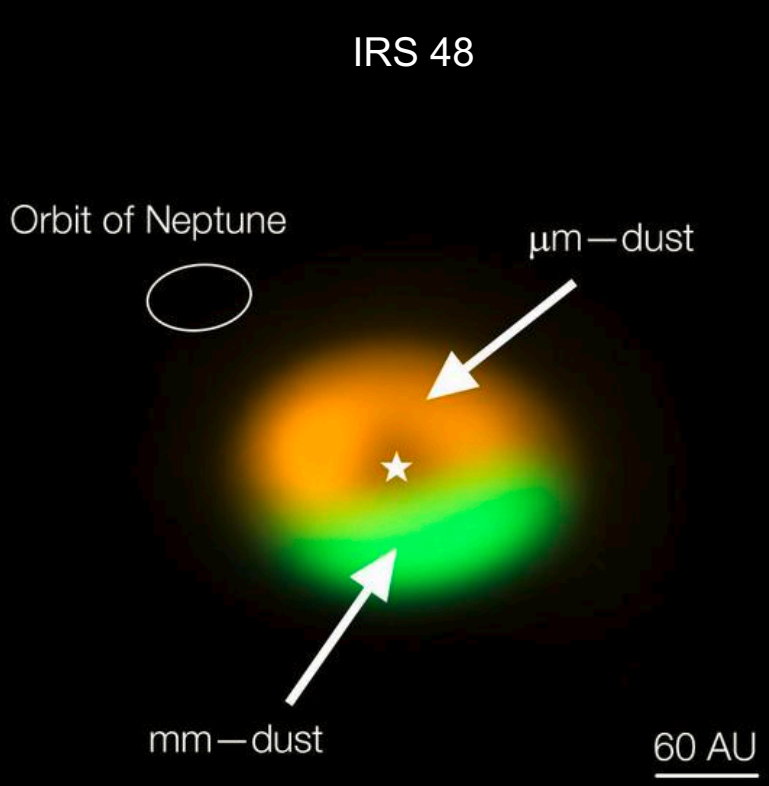
Perez et al. 2016

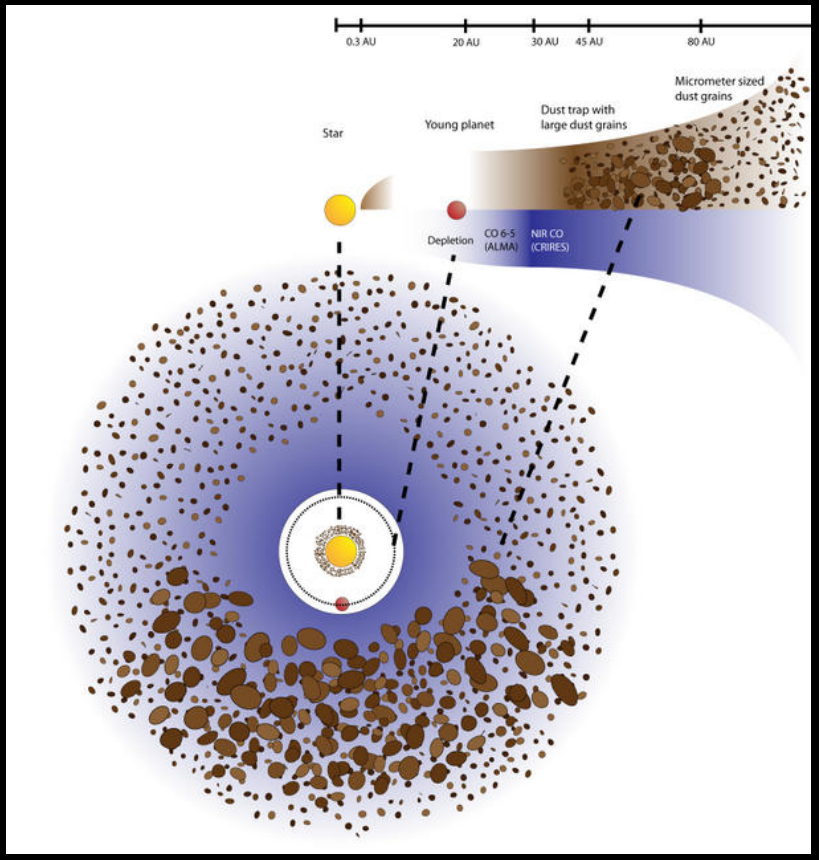
HD 135344B with SPHERE



Stolker et al. 2017

ALMA has revealed dust asymmetries in disks



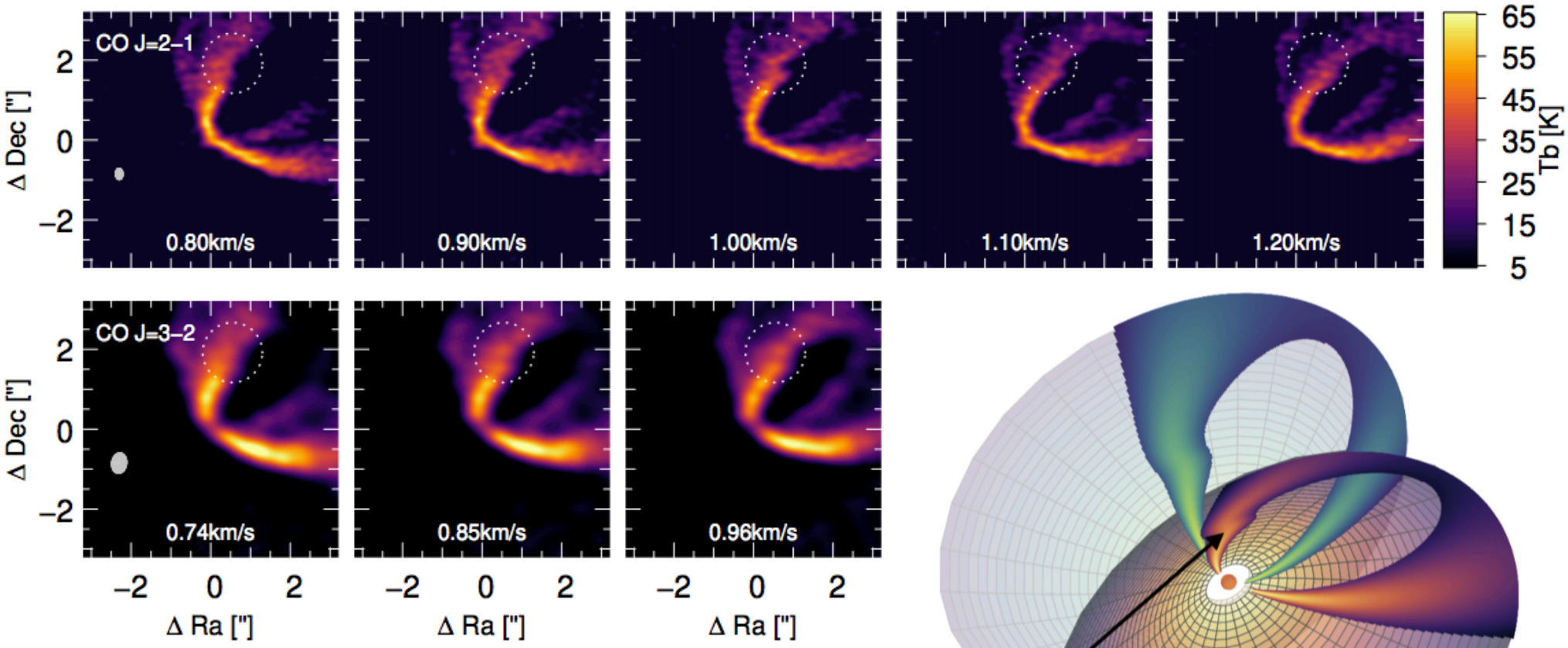


van der Marel et al. 2013

also Casassus et al. 2013; Fukagawa et al. 2013; Isella et al. 2013; Perez et al. 2014; Pineda et al. 2014

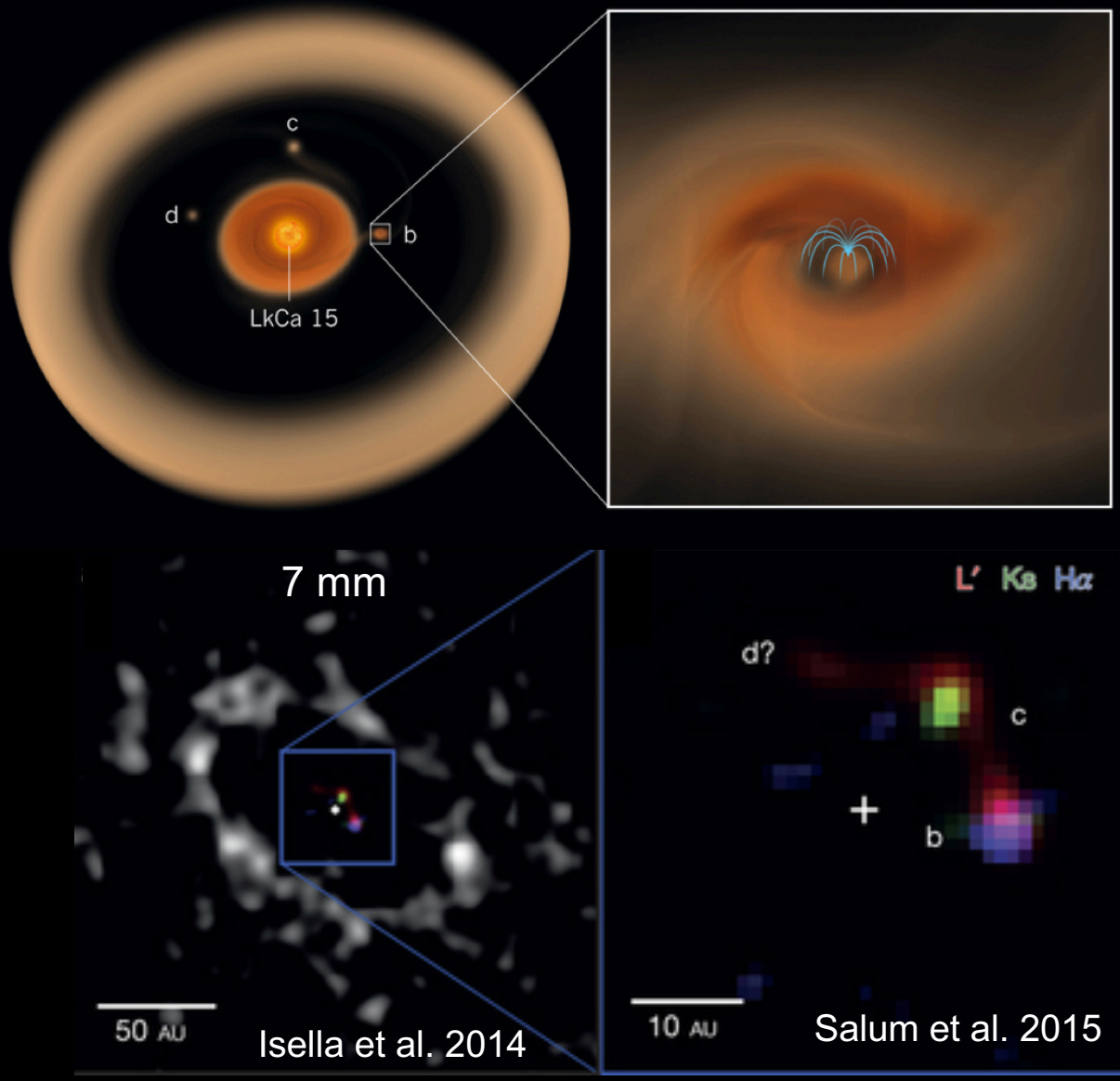
Protoplanet candidate via gas kinematics

HD 163296 12CO with ALMA

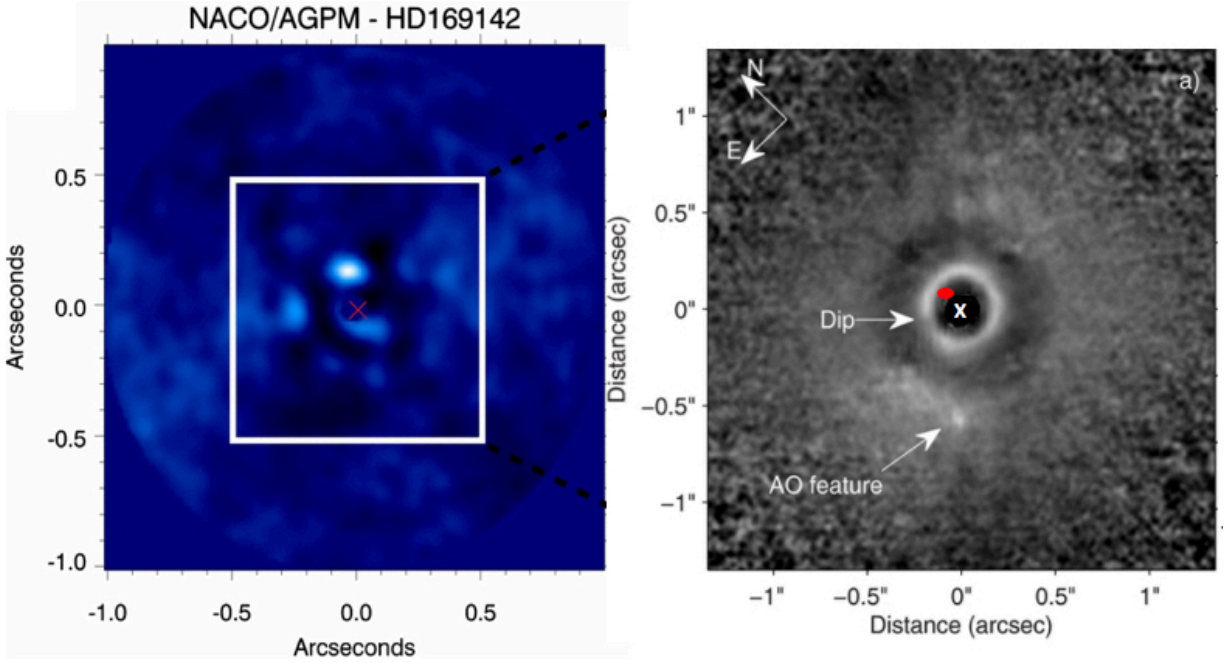


Pinte et al. 2018, see also Teague et al. 2018

Protoplanet candidate via Halpha imaging



Protoplanet candidate via NIR imaging



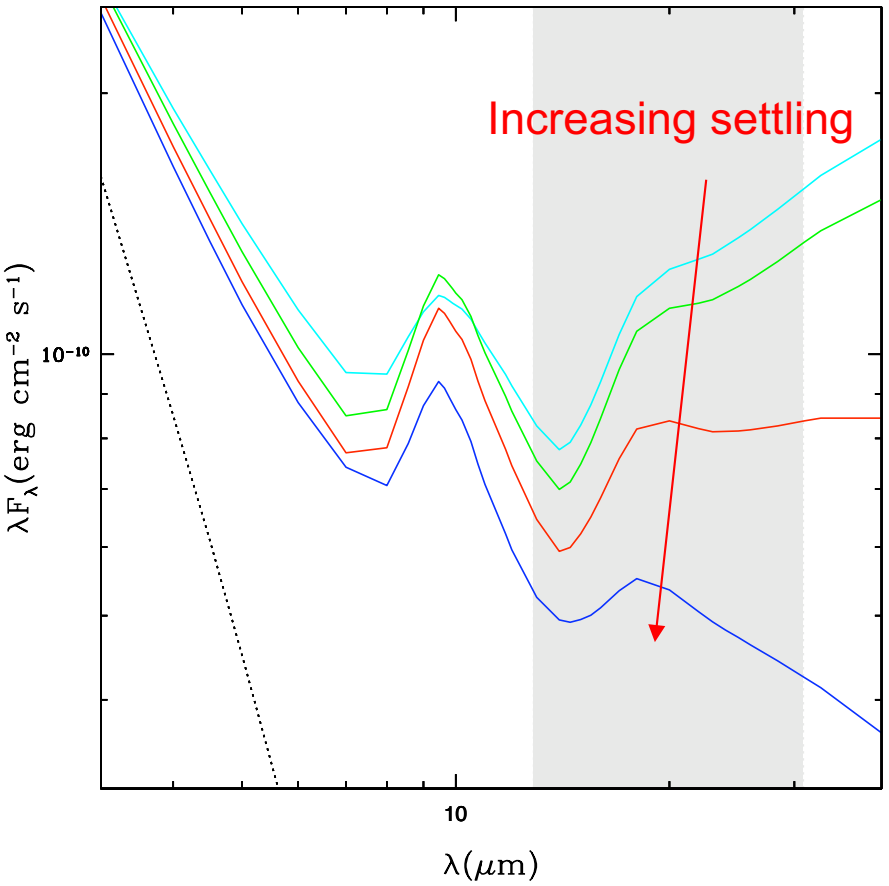
Quanz et al. 2013, Reggiani et al. 2014

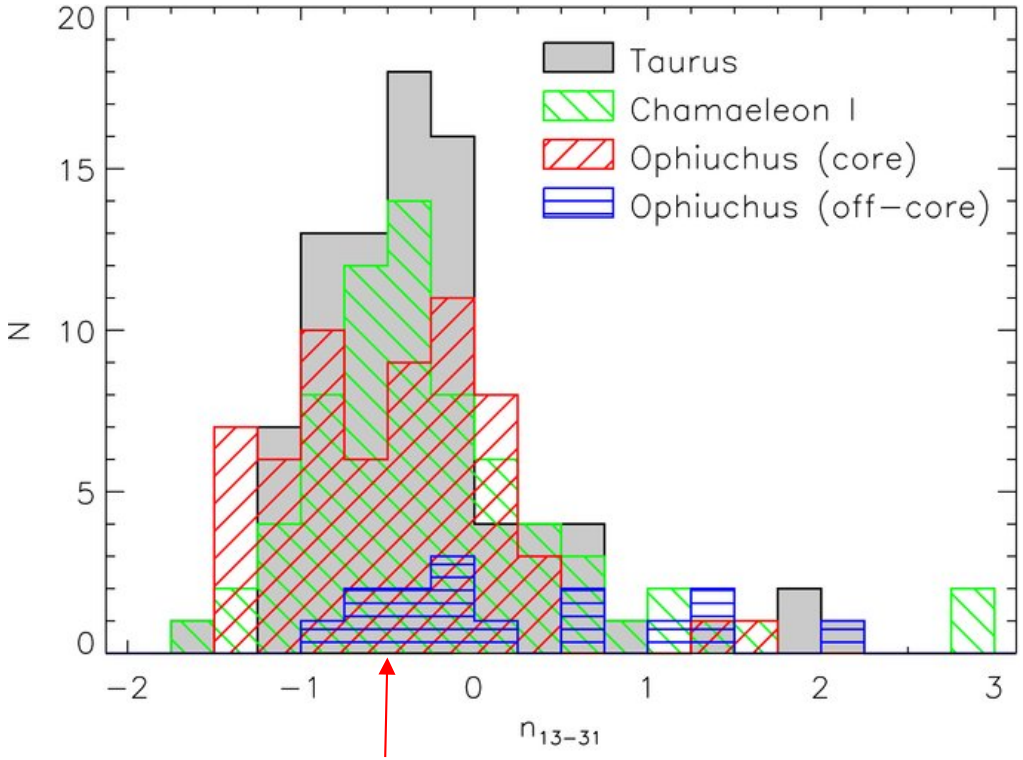
Protoplanetary disks & planets: observations

Do planets leave observable disk signatures?

Where do planets form in disks?

Even ~1 Myr old disks have experienced significant dust settling to midplane



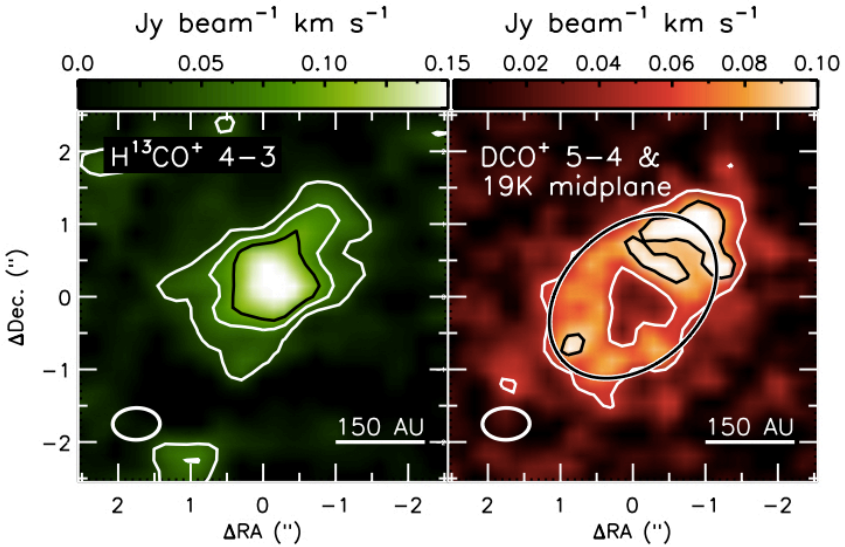


Corresponds to a depletion of dust relative to gas by a factor of 1000 in the upper disk layers

Furlan et al. 2009; Ribas, Espaillat, et al. 2017; Grant, Espaillat, et al. 2018

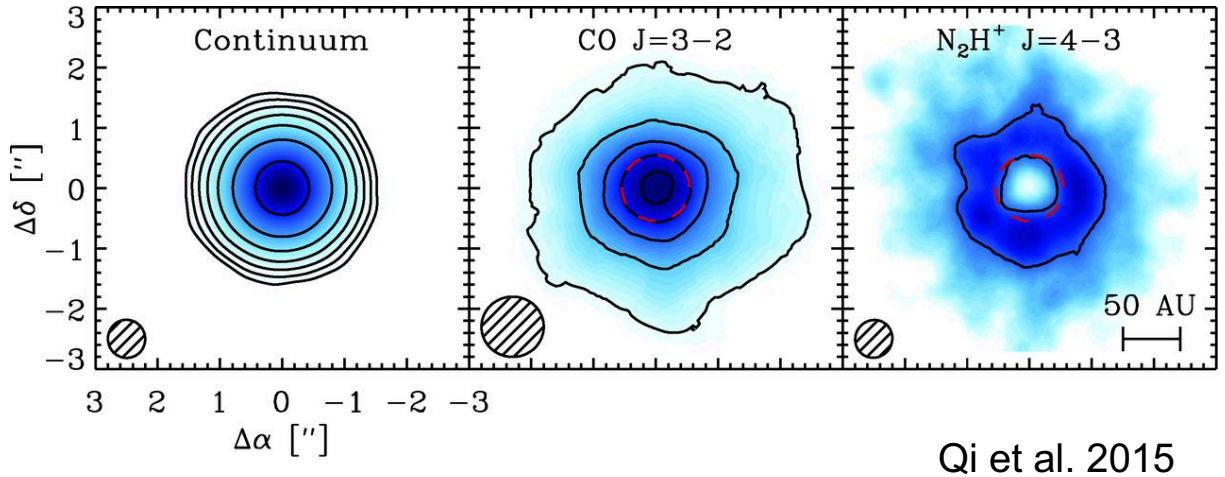
Snowlines may increase grain growth

HD 163296



Matthews et al. 2013

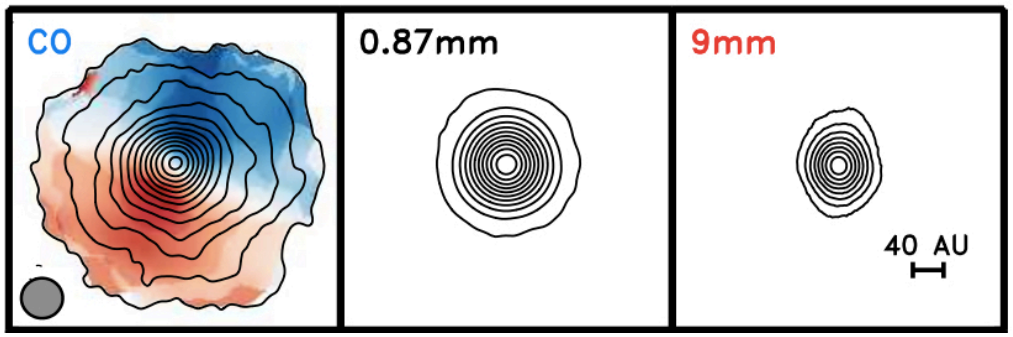
TW Hya



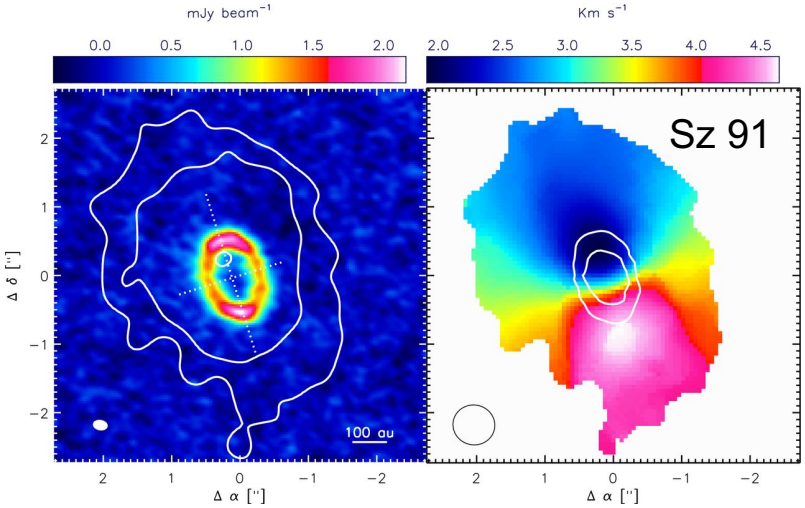
Qi et al. 2015

Dust radial drift observed towards inner disk

TW Hya

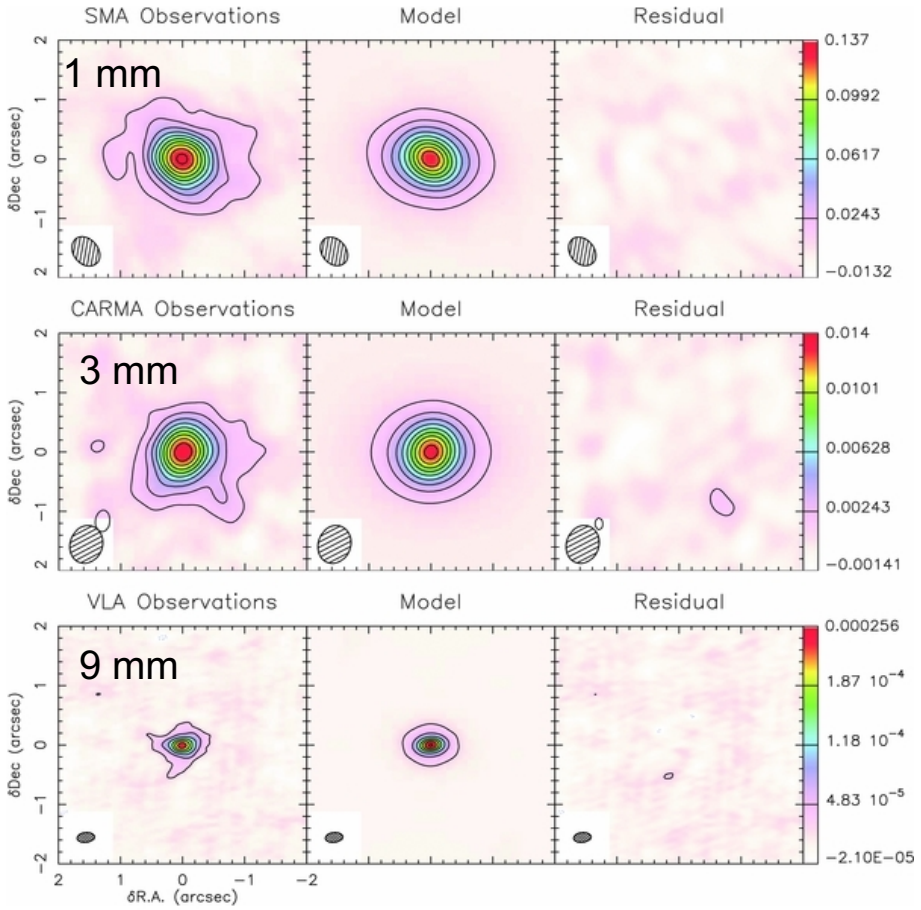


Andrews et al. 2012, 2015; Menu et al. 2014



Canovas et al. 2016

AS 209

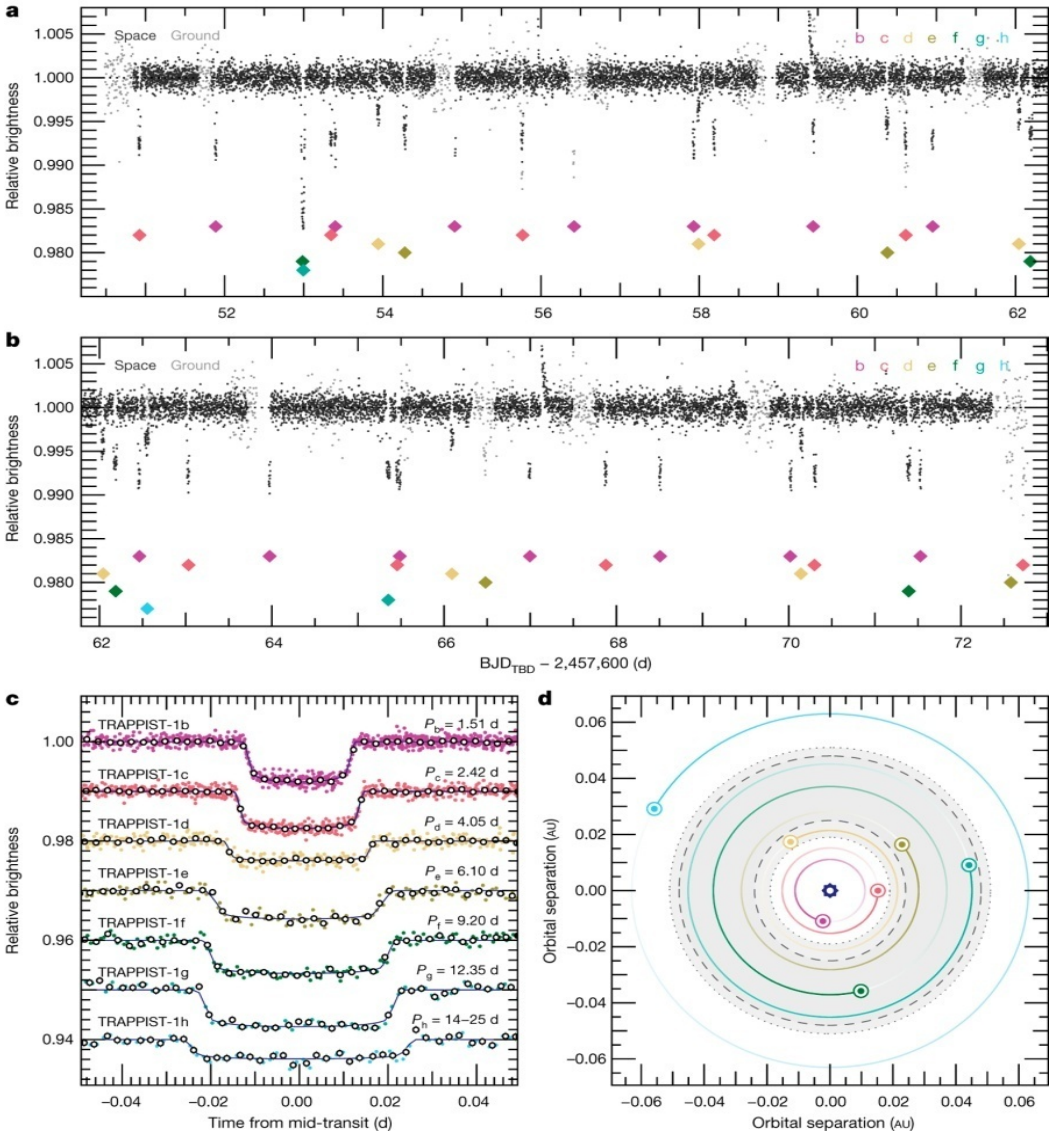


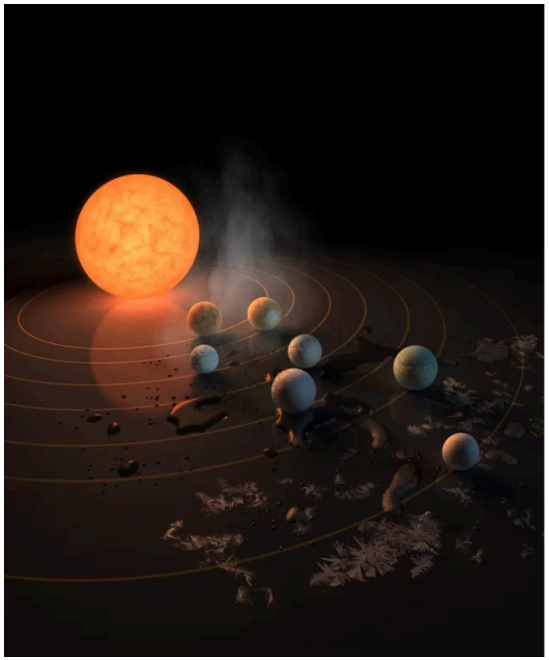
Perez et al. 2012

also Banzatti et al. 2011, Guilloteau et al. 2011, Andrews et al. 2012, Rosenfeld et al. 2013, Trotta et al. 2013, Pineda et al. 2014, Zhang et al. 2014, Espaillat et al. 2015, Guidi et al. 2016

Migration or in situ formation in inner disk?

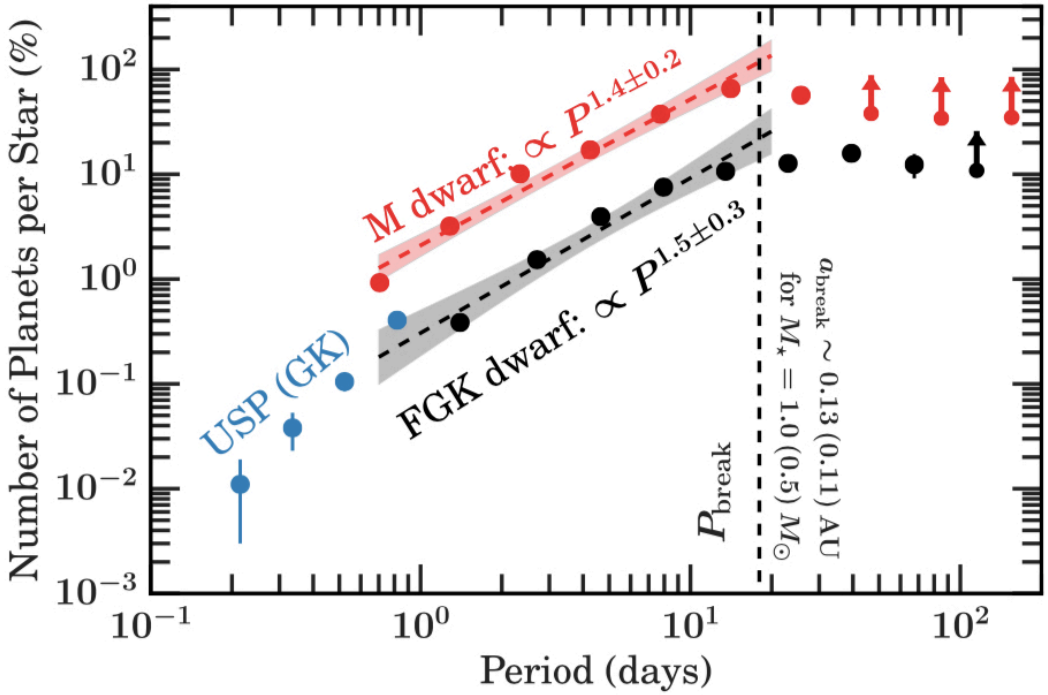
Trappist 1

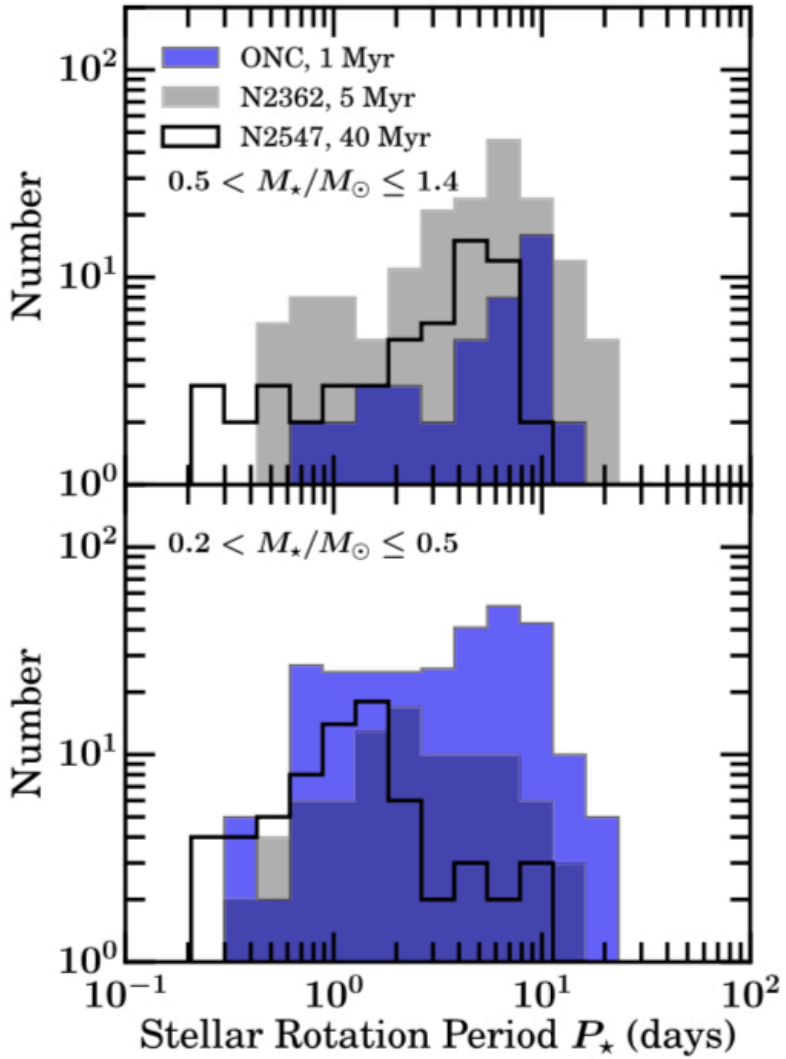




Gillon et al. 2017

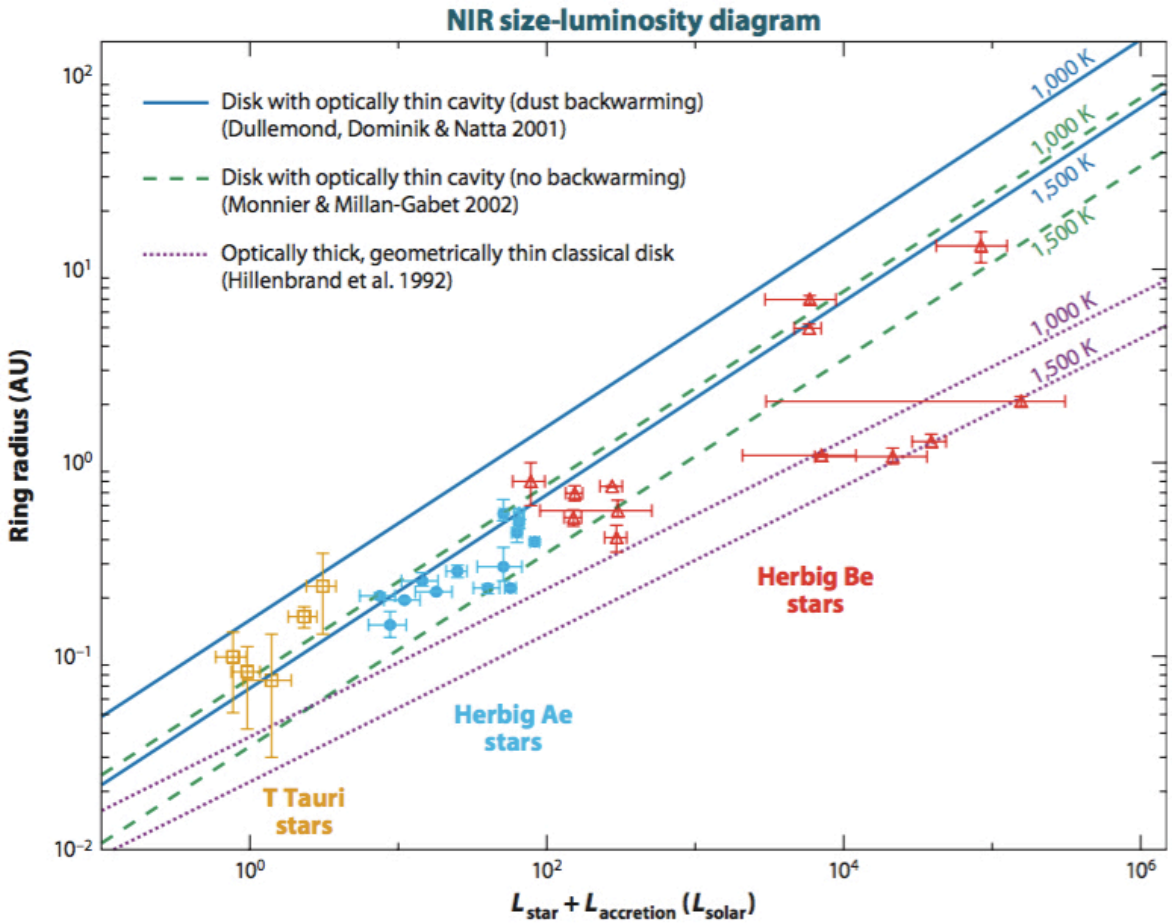
Short period sub-Neptune planets



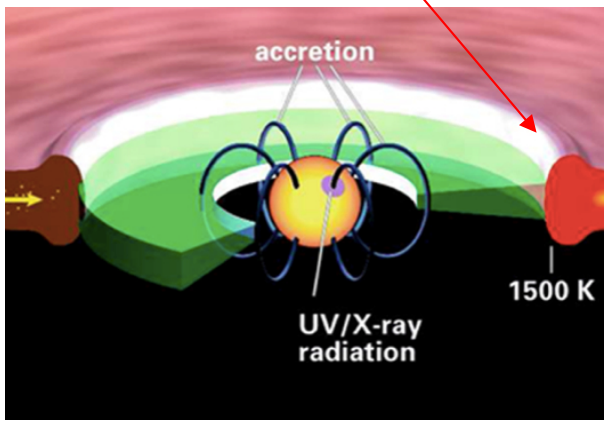


Lee & Chiang 2017

Locating the inner disk rim radius

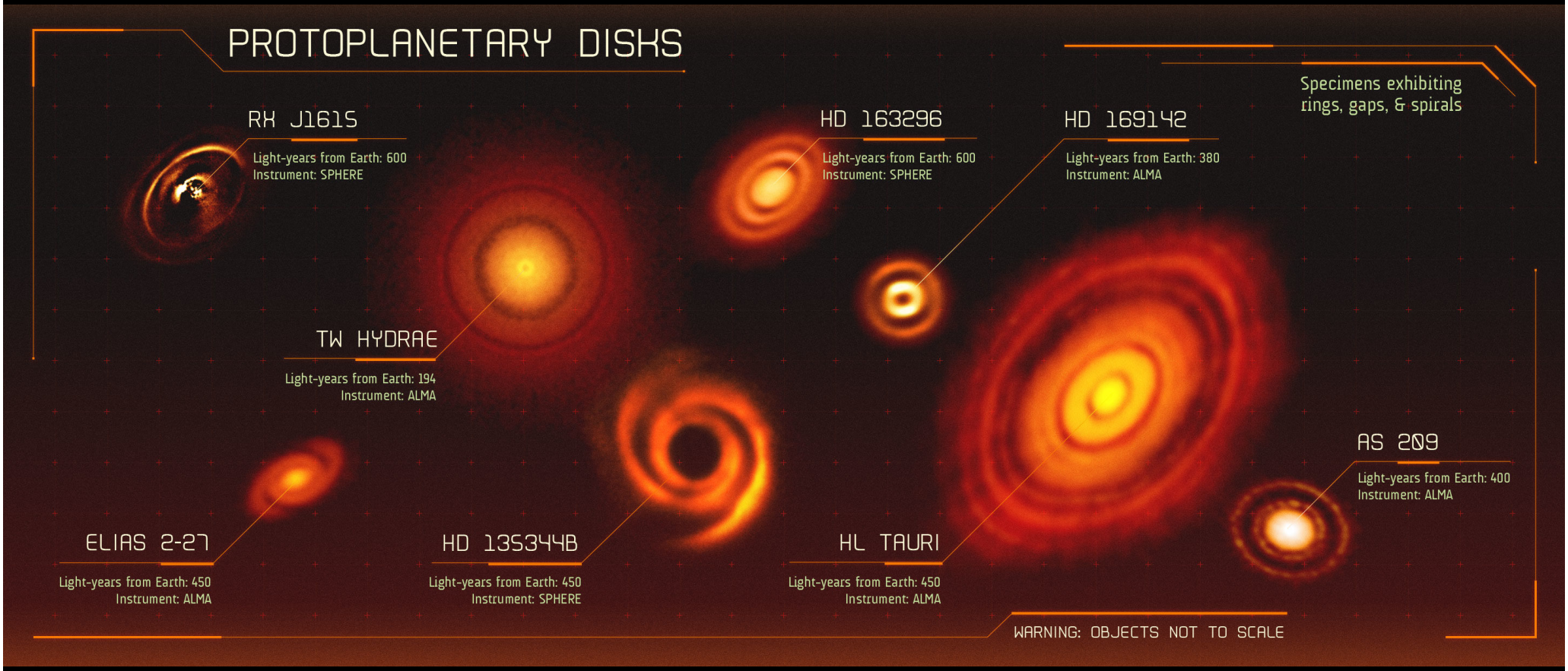


Inner disk rim



Dullemond & Monnier 2010

Evolutionary sequence or diverse architectures?



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