First results from the ALMA Large Program
Small Scale Substructure in Protoplanetary Disks

Wassily Kandinsky, 1913

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What do we learn about disks from radio continuum?

Rich set of information from sub-mm to cm wavelengths

Dust component
(thermal dust emission)

Contrast is not a problem!

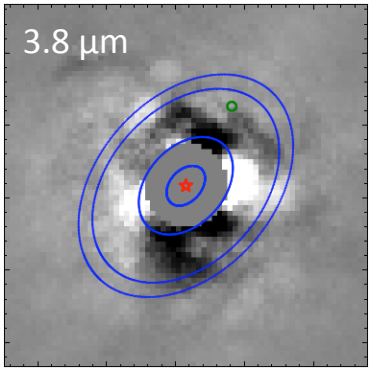
Generally optically thin at λ>mm

$$I_\nu \approx B_\nu(T_d)\tau_\nu \approx \kappa_\nu \Sigma_d T_d$$

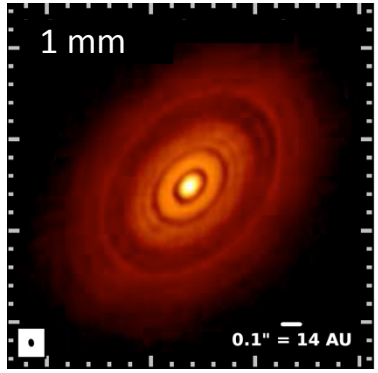
Dust properties

Mass available

Disk temperature

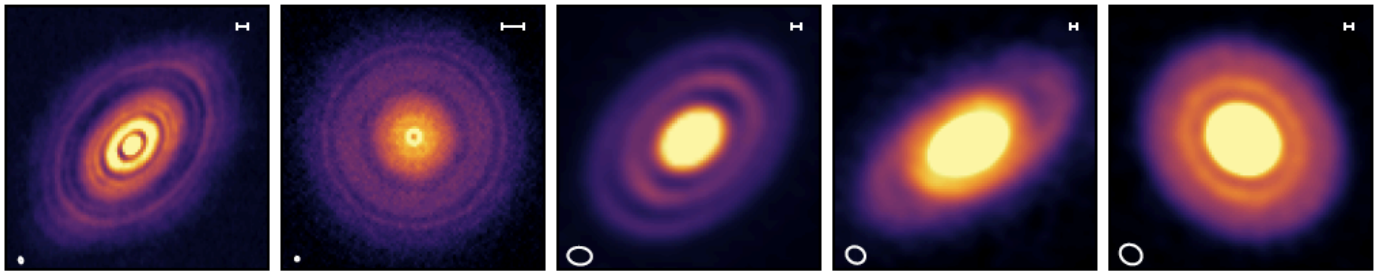


Testi et al. 2015



ALMA Partnership +LP et al. 2015

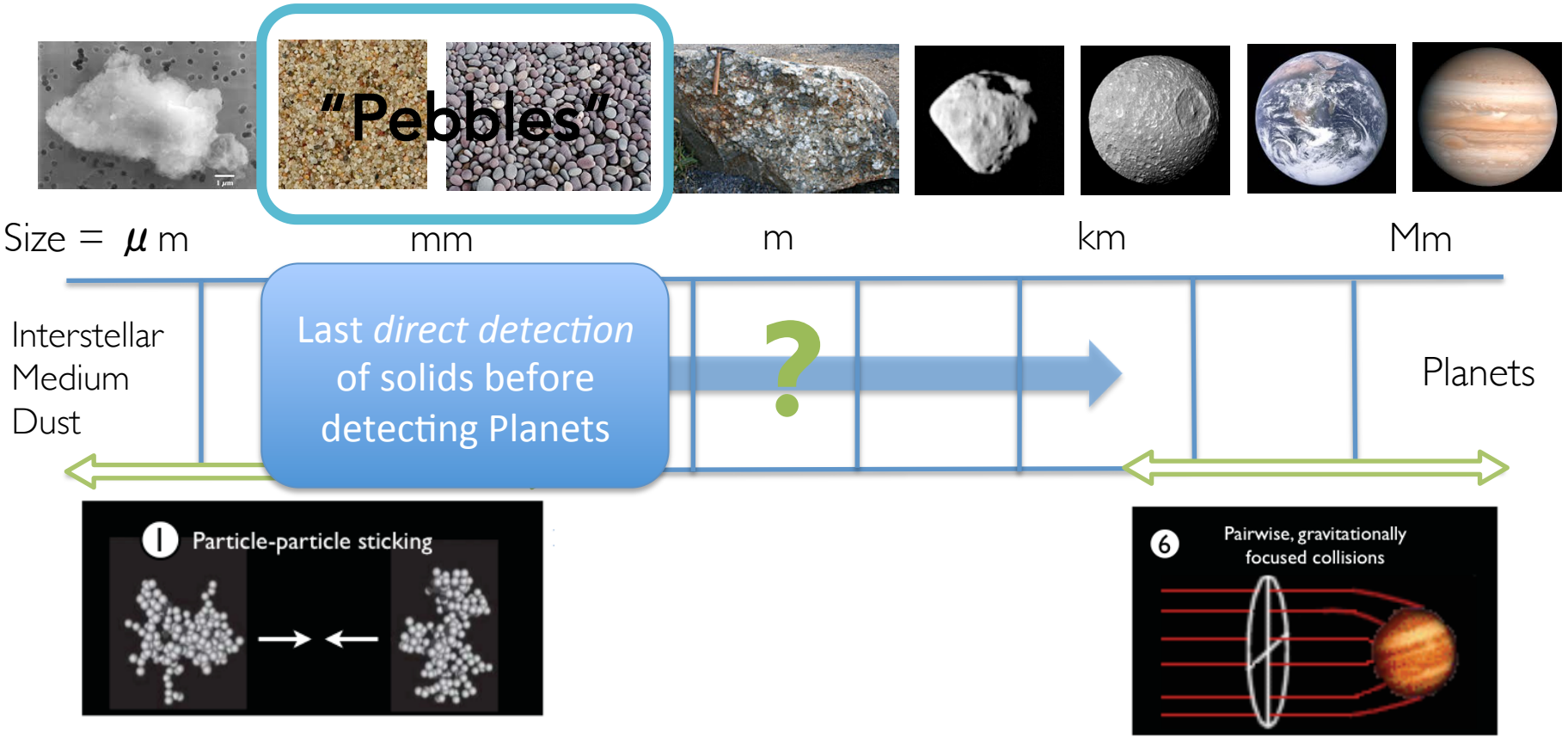
ALMA has been transformational to the field



ALMA Partnership et al. 2015 | Andrews et al. 2016 | Isella et al. 2016 | Pérez et al. 2016 | Dipierro et al. 2018

From ISM dust to Planetary Systems

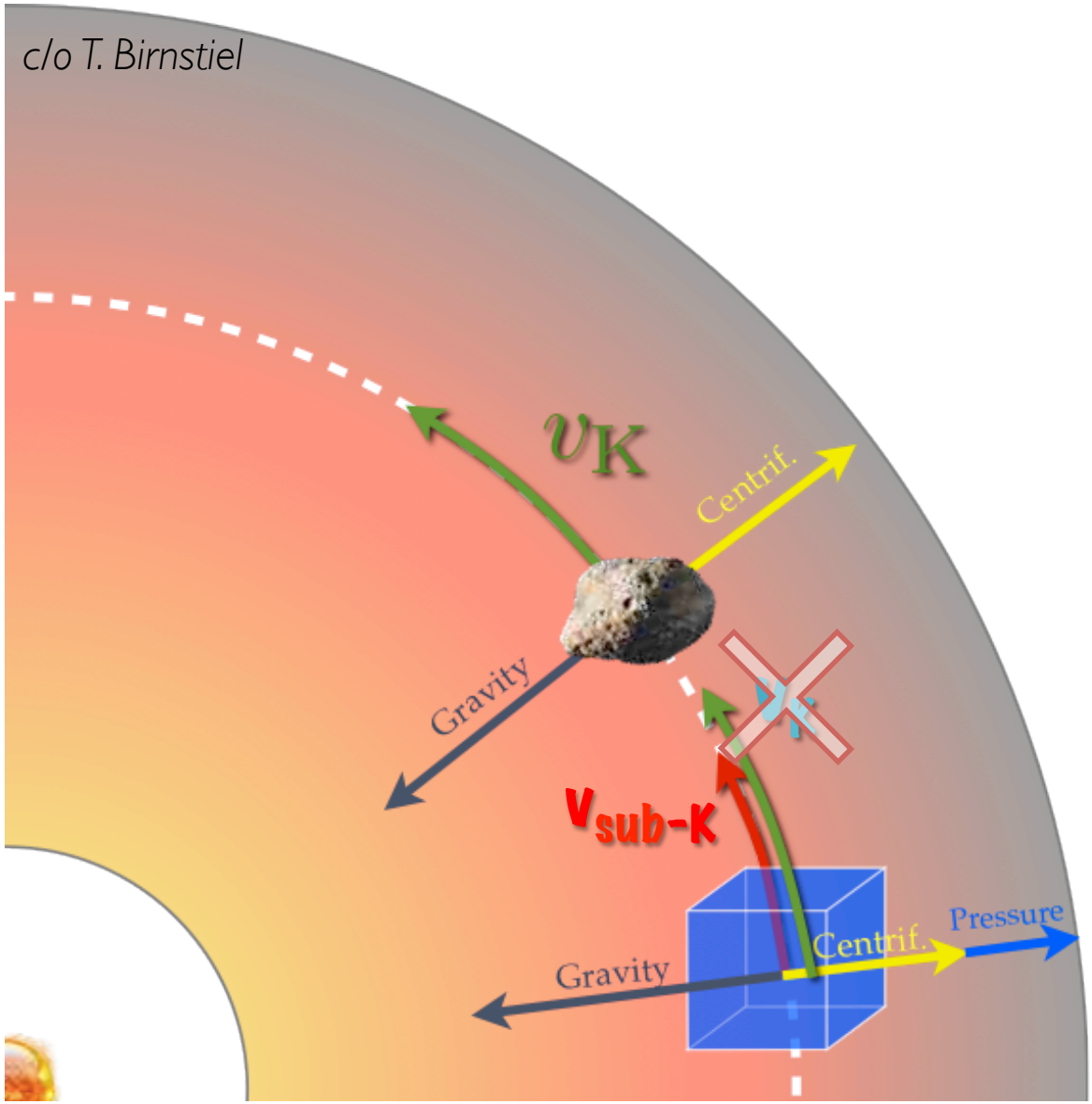
… as seen in Blum's and Najita's talk before …



Adapted from Chiang & Youdin (2009)

Solids Growth: Modulated by the Gas

Dust transport impacts its growth



The radial drift of solids

Whipple (1972)

Weidenschilling (1977)

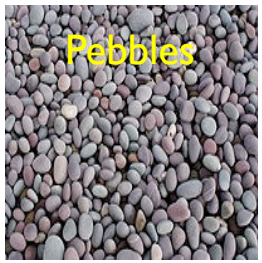
Drift velocity of the dust:

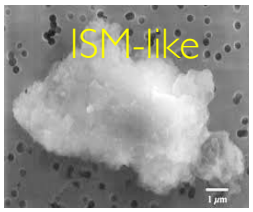
$$v_{r,\,dust} \propto \frac{dP}{dr}$$

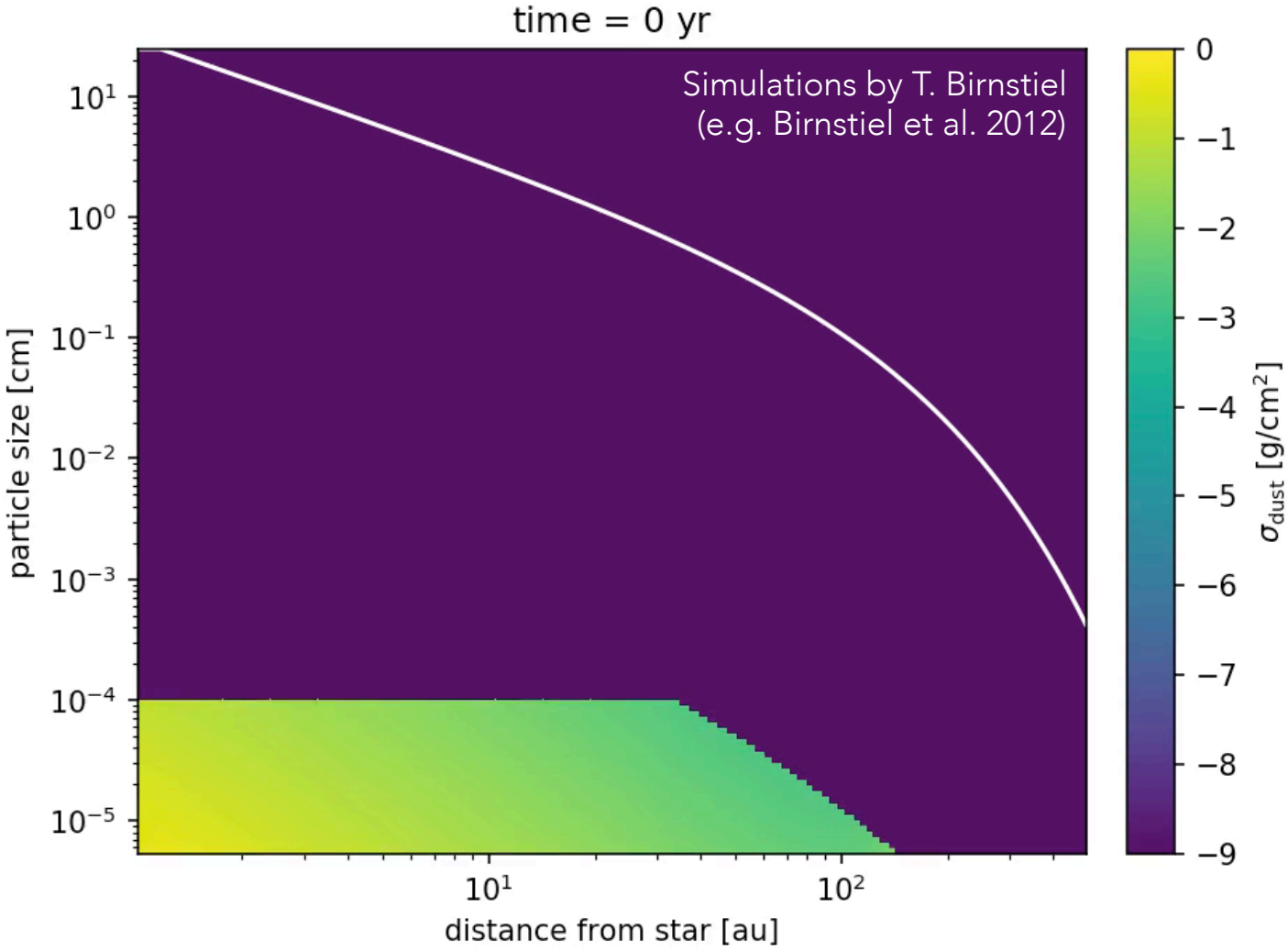
→ Dust drifts toward P_{max}

Solids Growth: Modulated by the Gas

A disk *without substructure* will lose solids needed for planetesimal formation



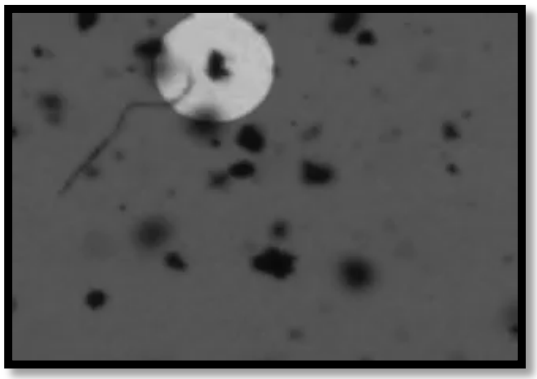




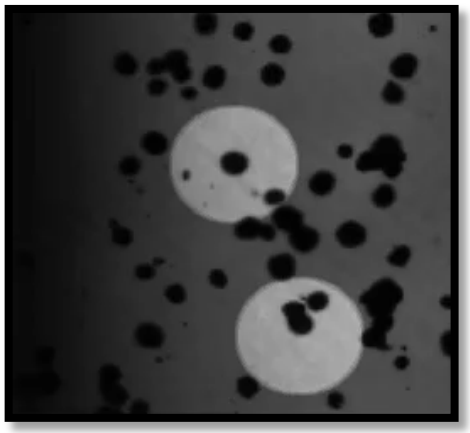
Solids Growth: Contingent on its Properties

e.g. outcomes of collissions depend on composition/structure of grains

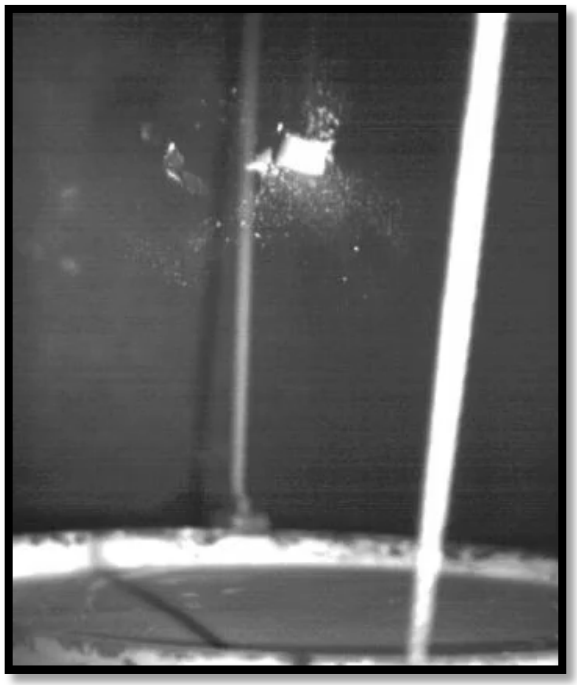
Sticking



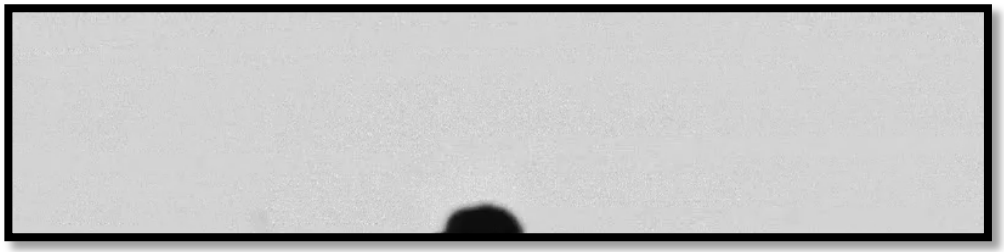
Bouncing



Fragmentation



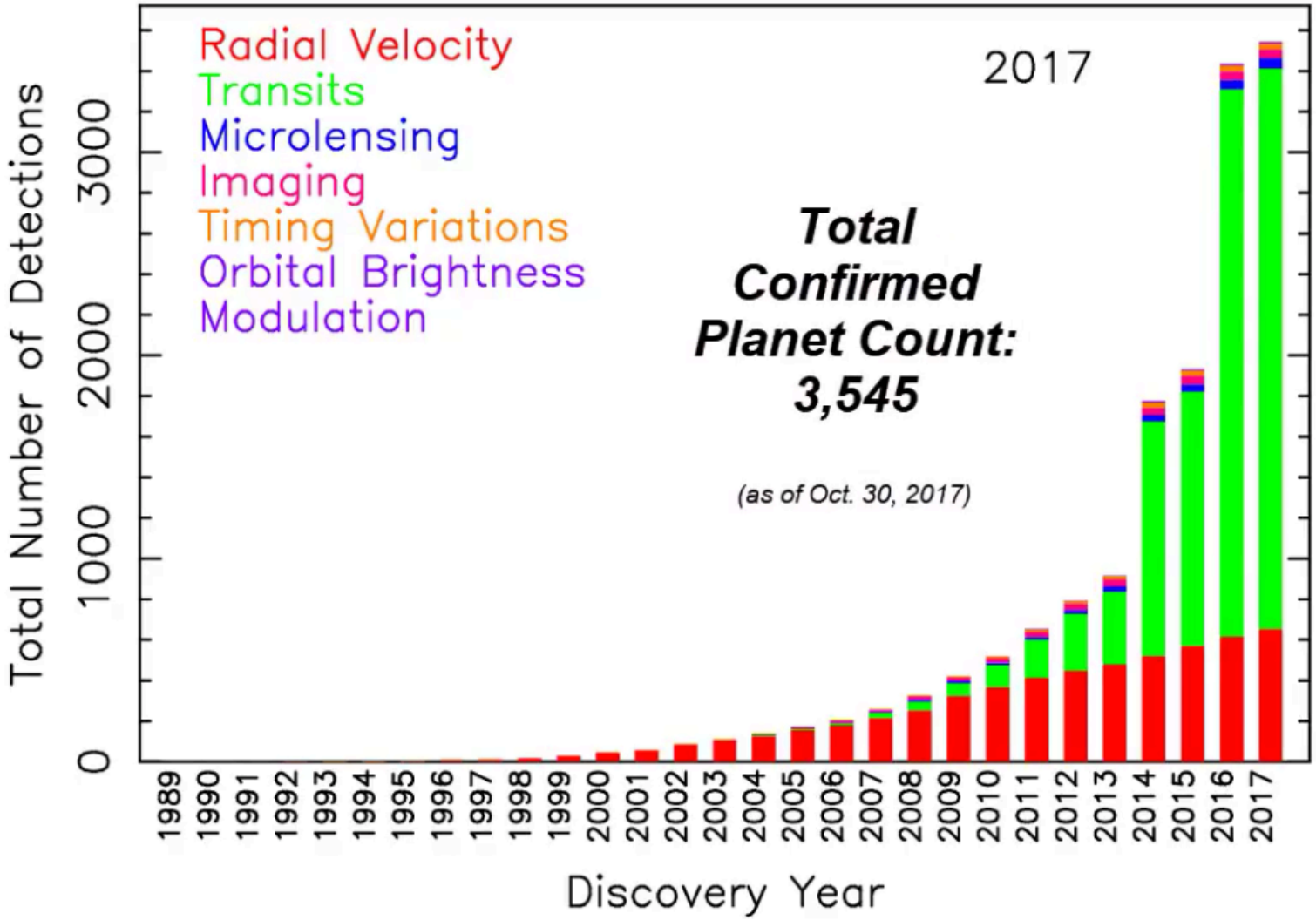
Mass Transfer



Experiments from J. Blum's Lab
Movies courtesy of J. Blum and collaborators,
see e.g. Blum & Wurm 2008, Güttler et al. 2010

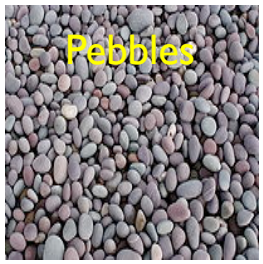
Nature somehow overcomes these barriers

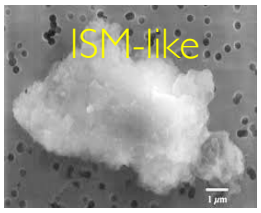
… after all, planets exist!

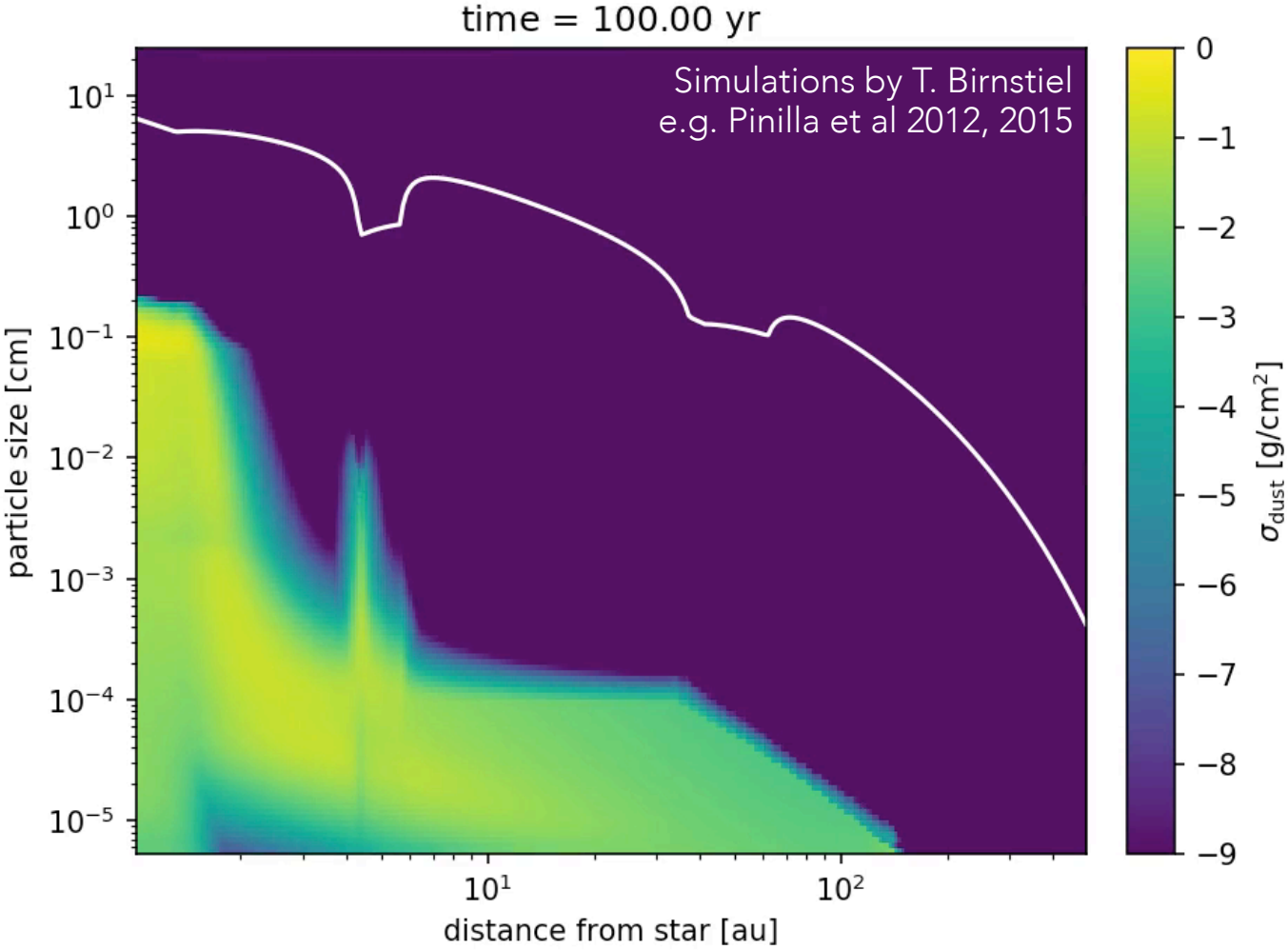


What promotes solid concentration?

A disk *with substructure* will concentrate solids needed for planetesimal formation



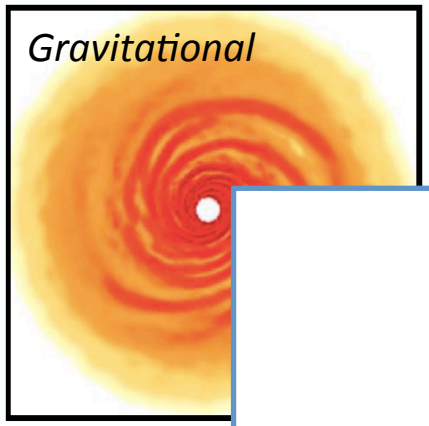




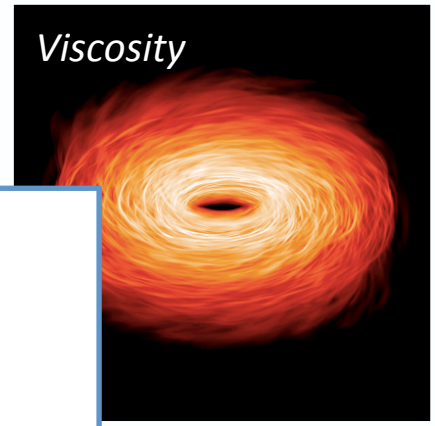
How is substructure created?

There are plenty of ways!

Instabilities



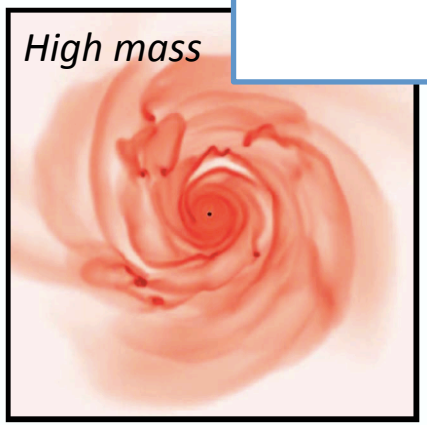
Dipie



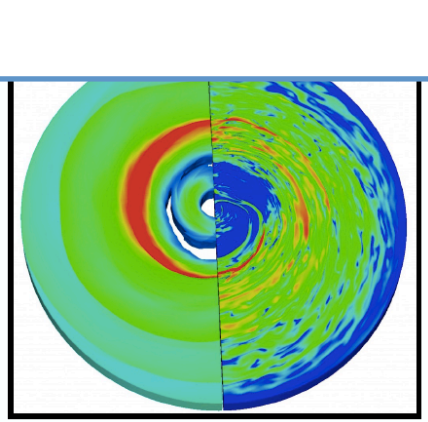
M. Flock

Talks by:
M. Montesinos
G. Bertrang
N. Cuello
M. Gárate

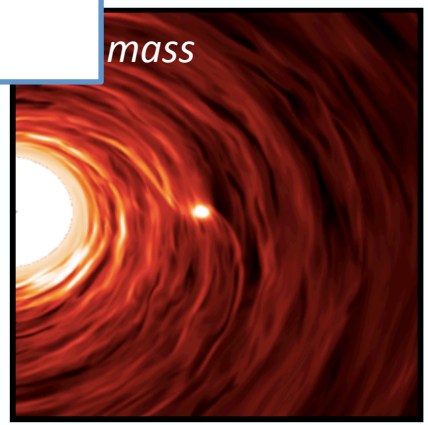
Companions



Lichtenberg & Schleicher 2015

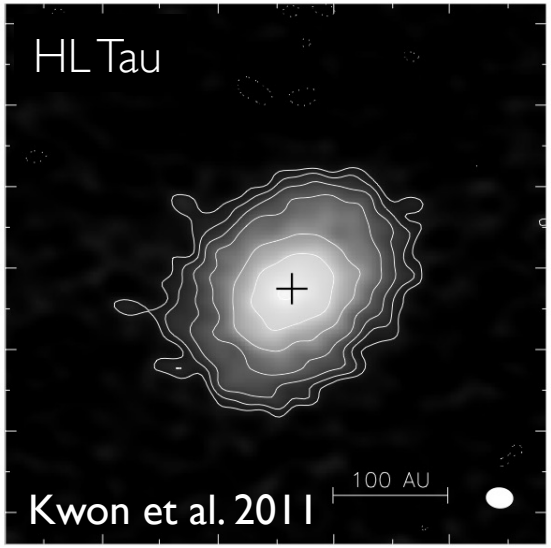


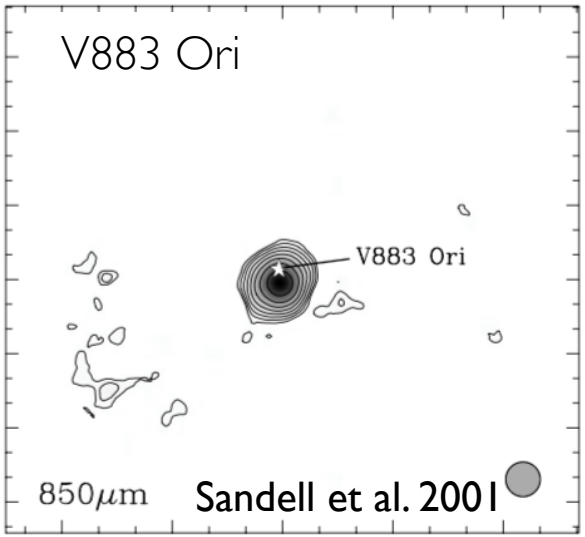
Z. Zhu

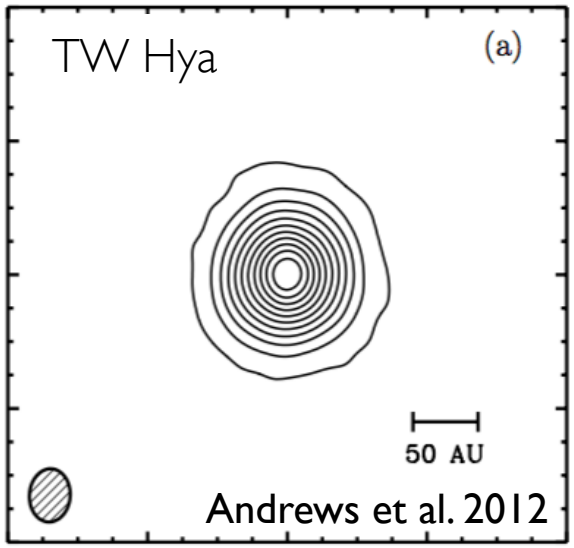


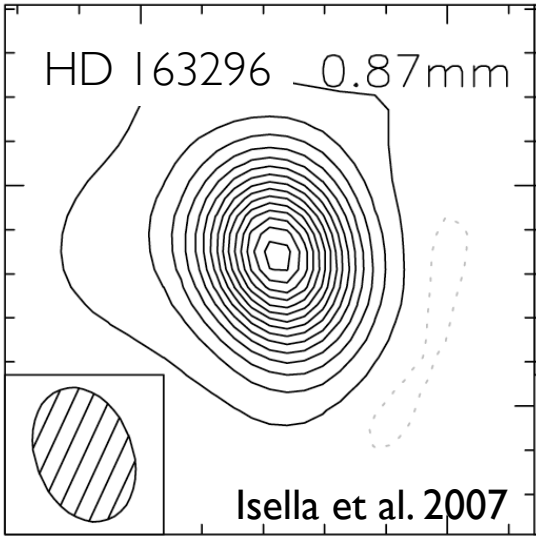
C. Baruteau

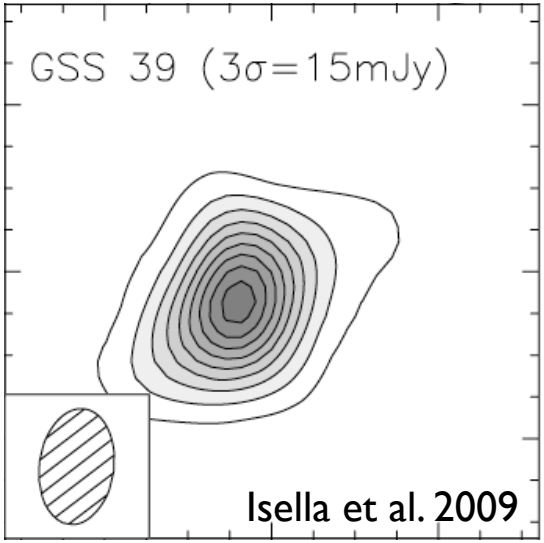
A mm-wave gallery of protostellar disks pre-ALMA

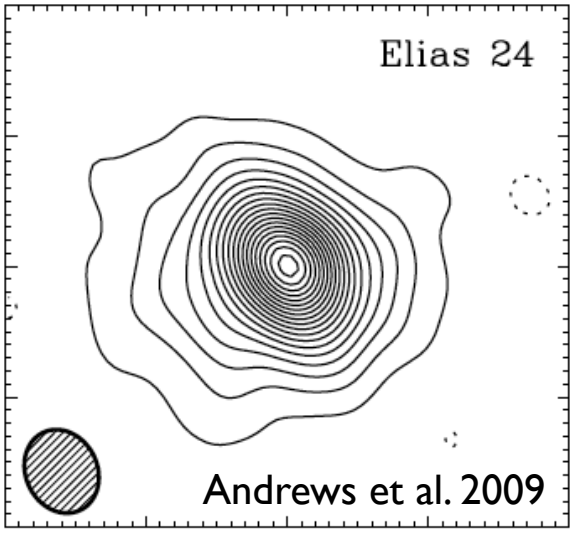




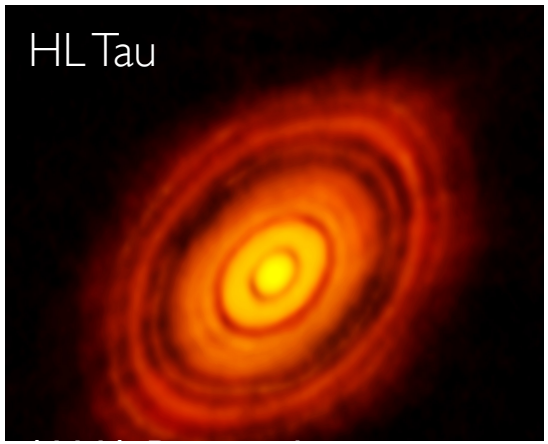


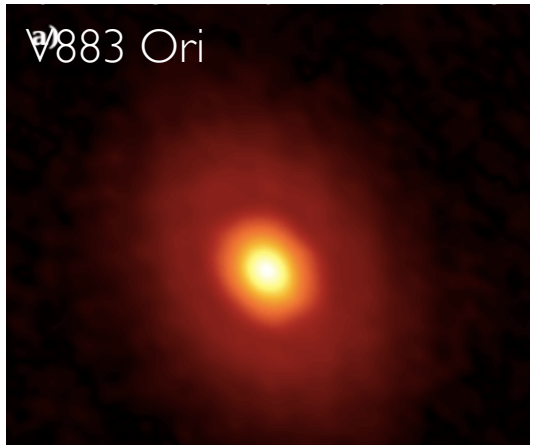


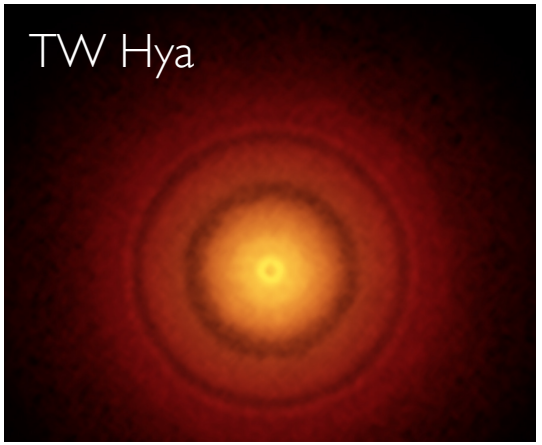




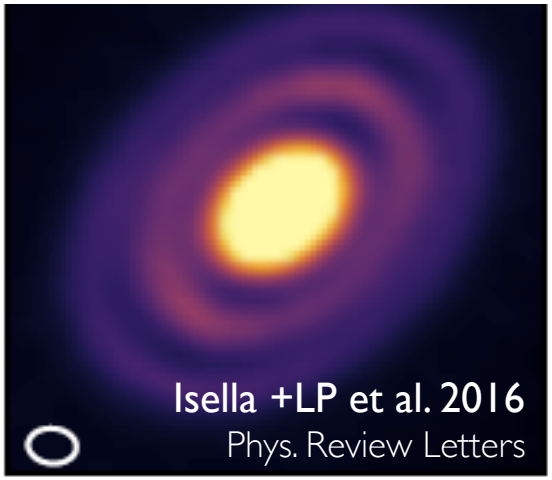
A mm-wave gallery of protostellar disks post-ALMA

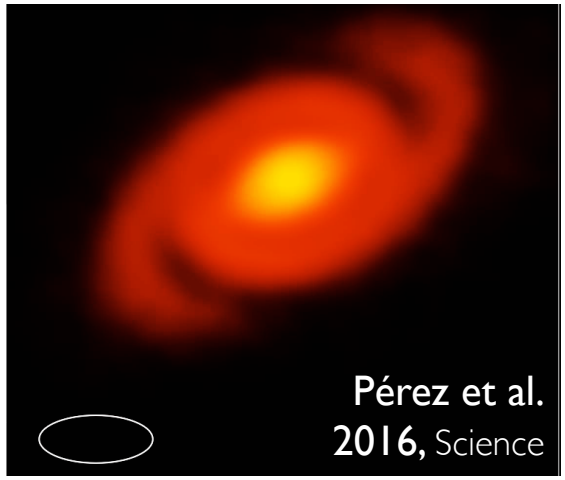


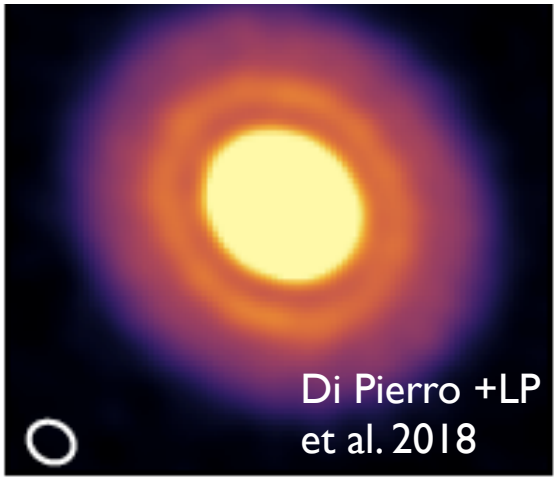




Motivate the need for an homogeneous sample!







ALMA Large Program in Protoplanetary Disks

"Small-scale substructures in Protoplanetary Disks"

Plan:
- 240 GHz (Band 6) observations of 20 classical disks
- Angular resolution ~ 5 AU
- Sensitivity ~ 17 microJy/beam

Goals:
Understand prevalence, forms, scales, spacings, symmetry, amplitudes, etc. of substructures in a representative sample of classical disks

Observational Status:
43.5/46 EBs completed; very preliminary images on the next slide!

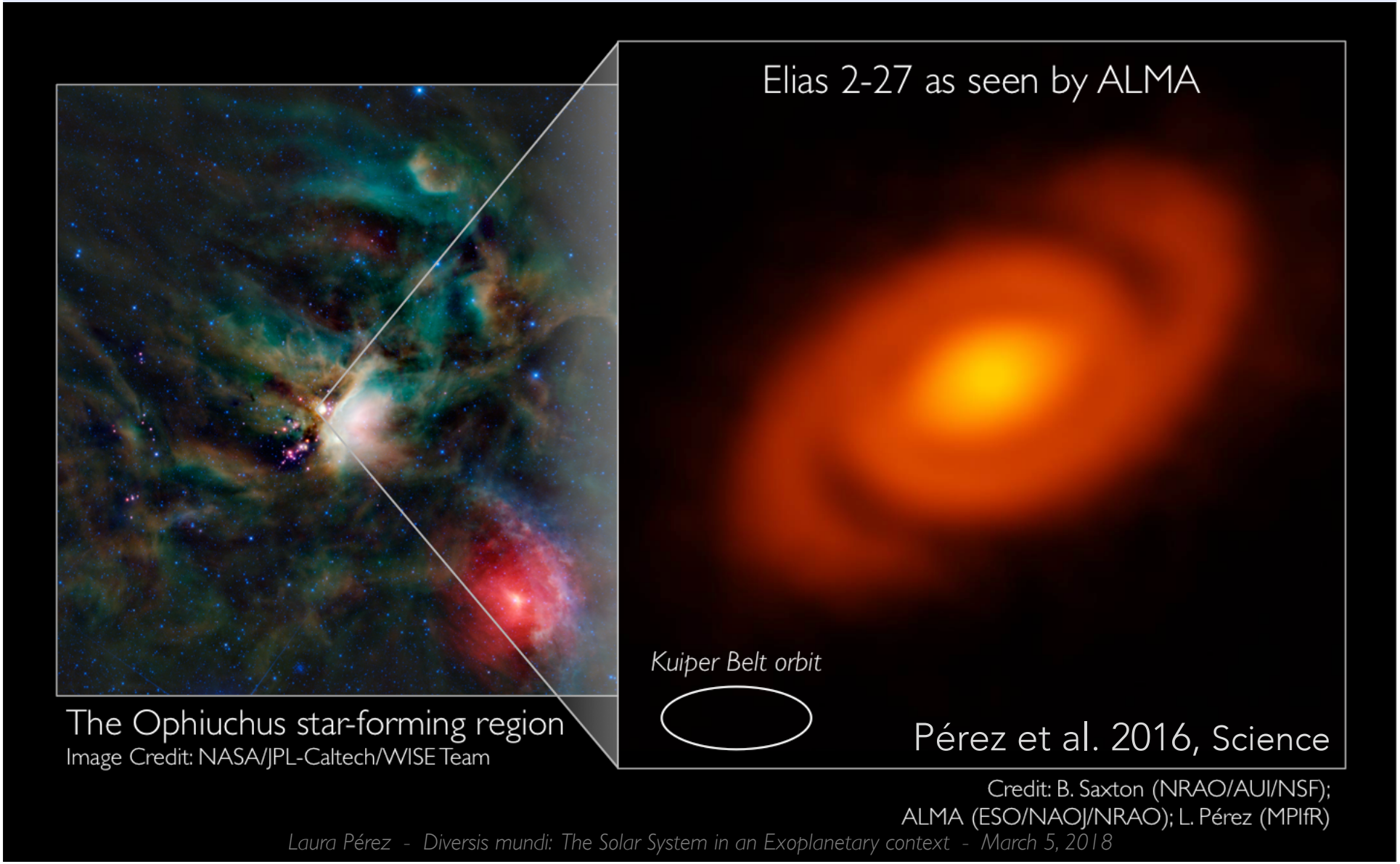
Analysis ongoing:
Look for first papers (with data product release) in the fall

PRELIMINARY!

PRELIMINARY!

Our old friend … Elias 2-27

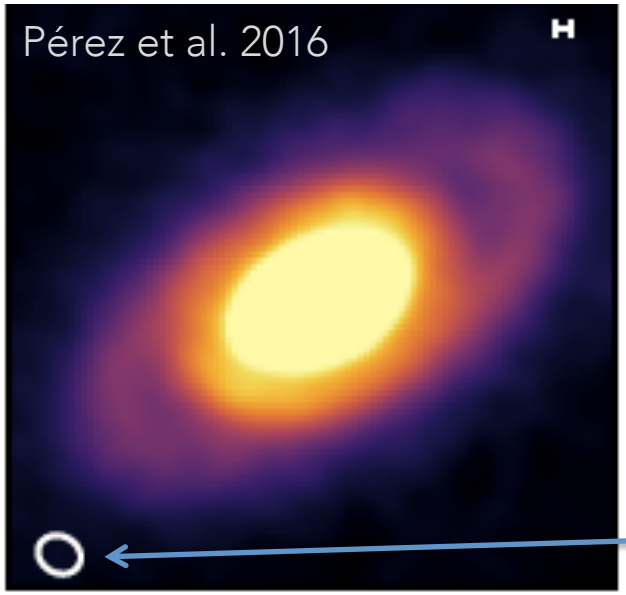
Spiral arms observed in the radio continuum for the first time



Our old friend … Elias 2-27

Spiral arms observed in the radio continuum for the first time

Elias 2-27 star ~ 0.5 M_{sun}
Class II ~1-3Myr old



ALMA Large Program

PRELIMINARY IMAGE!

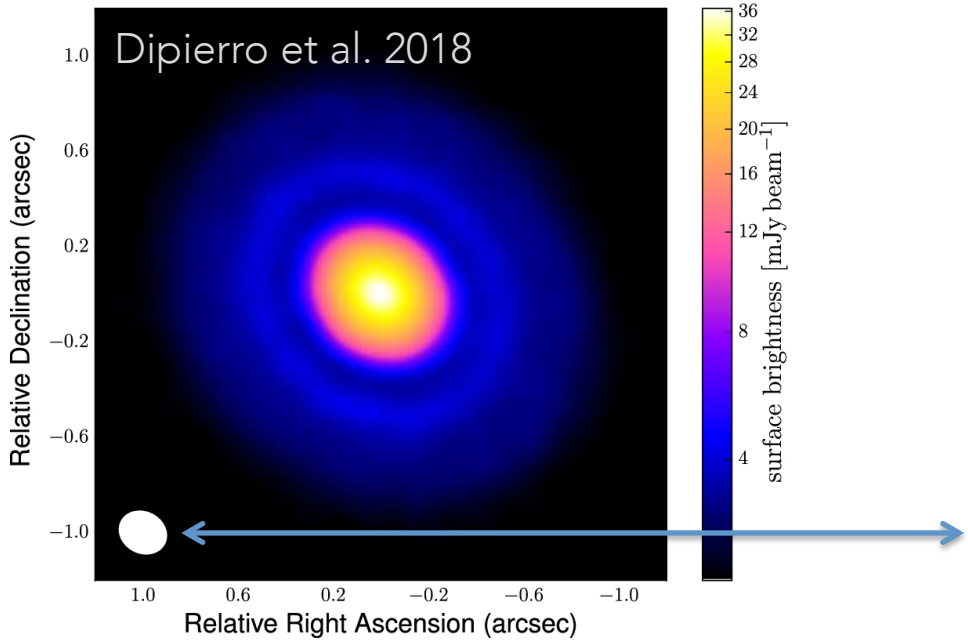
Spirals are not unique to this object!

PRELIMINARY!

Our newer friend … Elias 24

Rings and gaps in the disk revealed by ALMA

Elias 24 disk ~ 0.1 Msun
Class II ~1 Myr old



ALMA Large Program

PRELIMINARY IMAGE!

See also:
Cox et al. 2017
Cieza et al. 2017

Rings are not unique to this object!

Ongoing Follow-up of ALMA Large Program

Pilot programs approved, looking to complete the sample over next cycles

Cycle 5 ALMA observations at 3 mm to check for dust trapping in substructure
(PI: L. Pérez)

P101 NACO L' observations to check for companions creating substructure
(PI: L. Pérez)

ALMA Large Program will provide new insights into processes that transform the disk reservoir into a planetary system

Structure?

Substructure is needed to prevent solids from drifting and to form planets

A multitude of structures: new detections pave the way to understand star & planet formation

Evolution?

We are getting to understand basic disk evolution from mm-wave disk observations

We can now test if features predicted in disk evolution are present in most disks