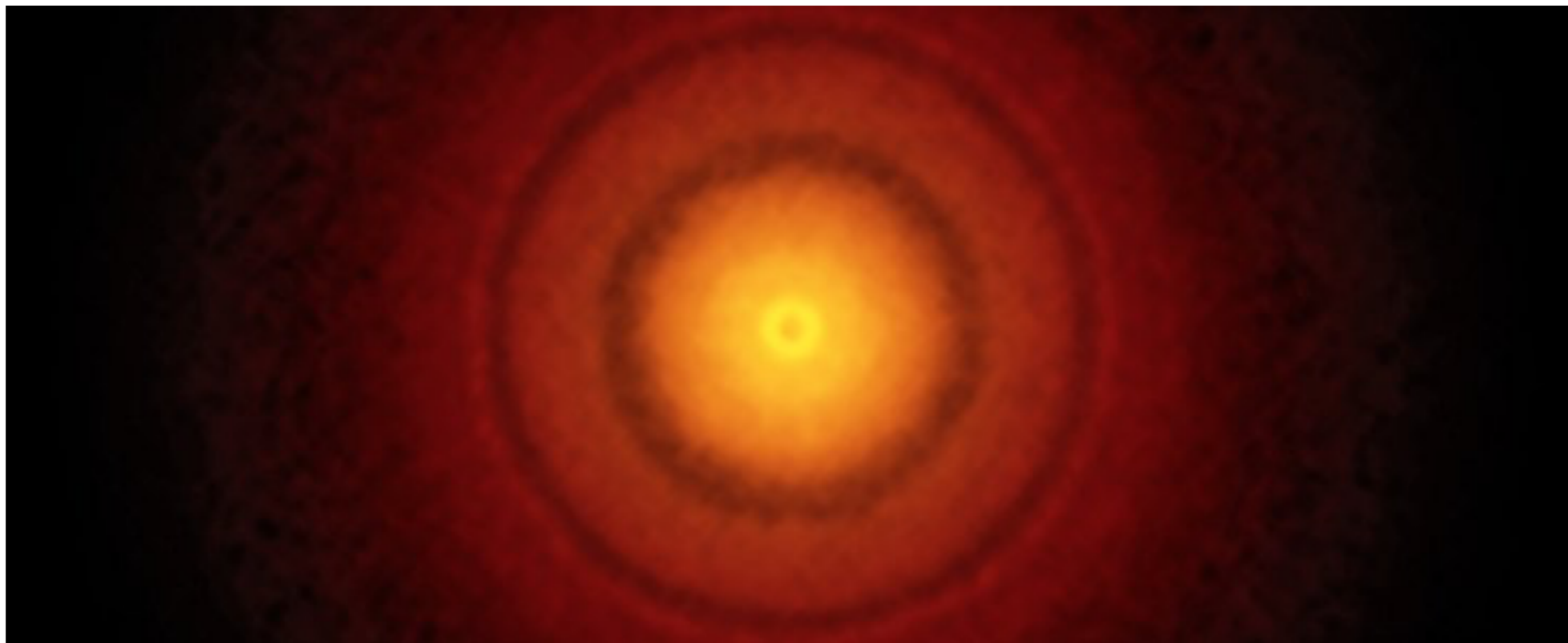


# Millimeter Continuum Observations of Disk Solids

Sean Andrews

*Harvard-Smithsonian CfA*



the *value* of mm continuum data

tension with evolutionary models

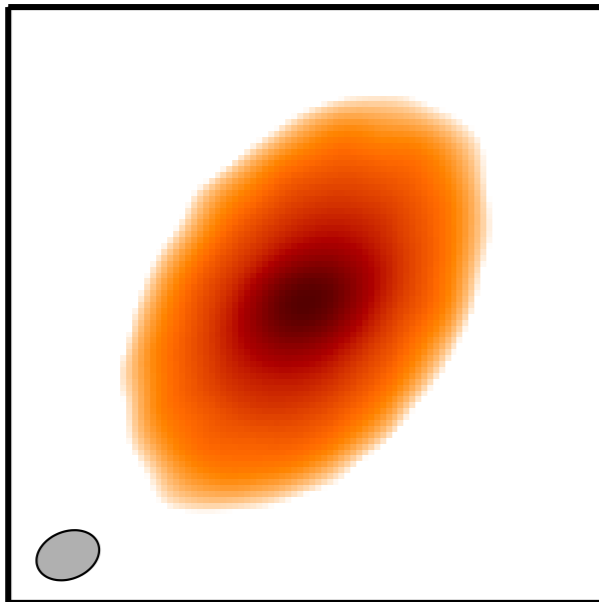
substructures and planet formation

bully pulpit: some things to consider

note: references are [hyperlinks](#) in pdf (and in reference page at end of presentation)

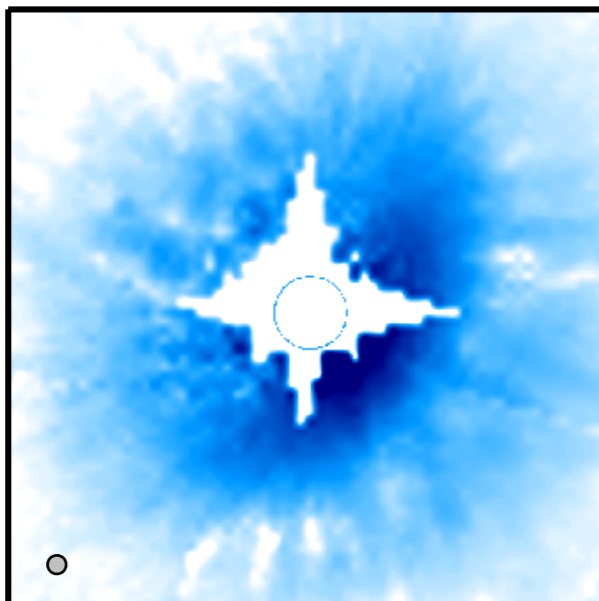
# the *value* of mm continuum data

IM Lup



ALMA: 1.3 mm

[1]



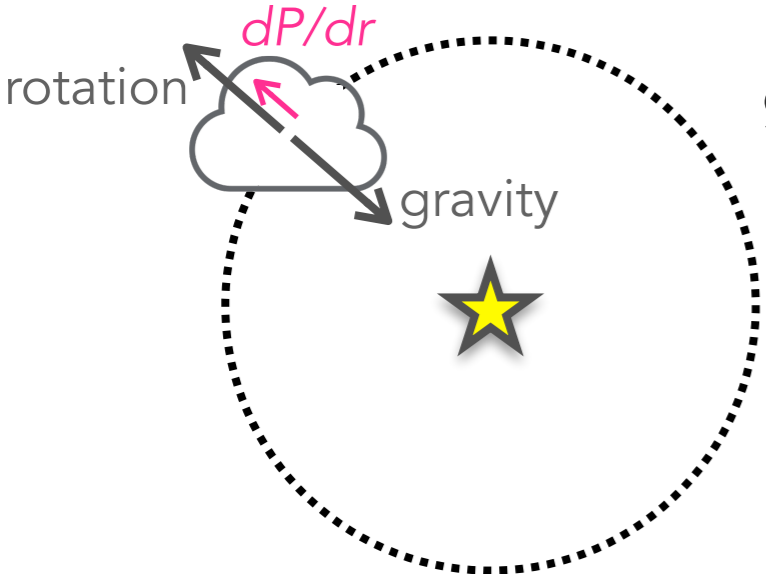
HST: 1.6  $\mu\text{m}$

[2]

- “tidier” data product
  - no stellar contrast issues  
(*IWA, post-processing, uncertainties*)
- access to interesting particle sizes
  - peak sensitivity to size  $\sim$  wavelength  
(*pebble growth, migration*)
- access to midplane conditions
  - low optical depths:  $I_{\nu} \propto \kappa_{\nu} B_{\nu} \Sigma$   
(*densities, temperatures, particle sizes*)

[some reviews: 3, 4, 5]

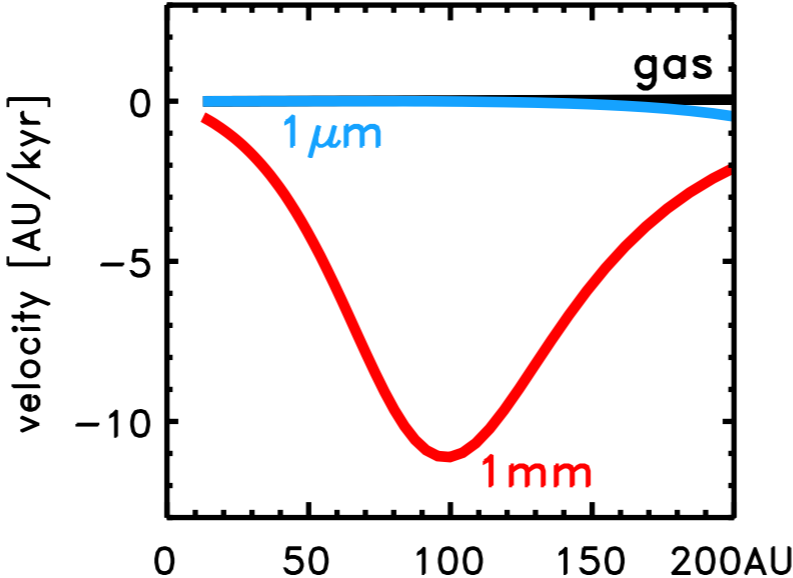
# tension with evolutionary models



gas pressure gradient drives migration

(radial drift of solids)

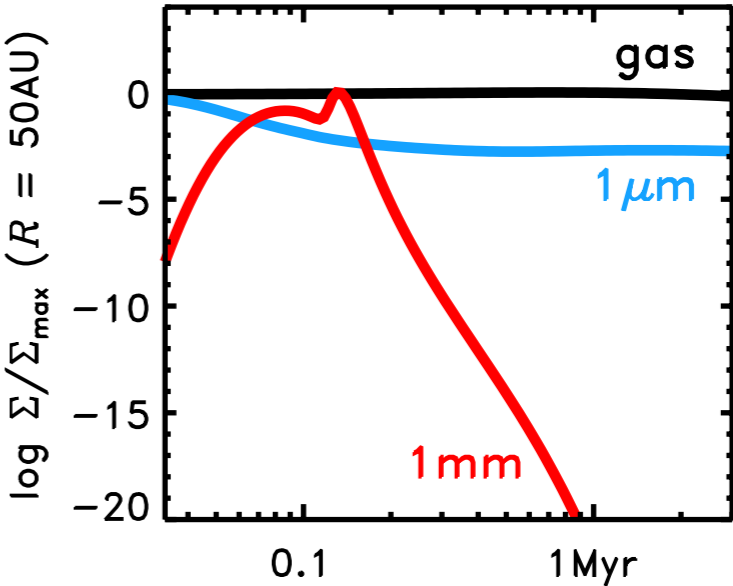
[6, 7, 8, 9, 10]



mm/cm solids deplete quickly

[11, 12, 13, 14]

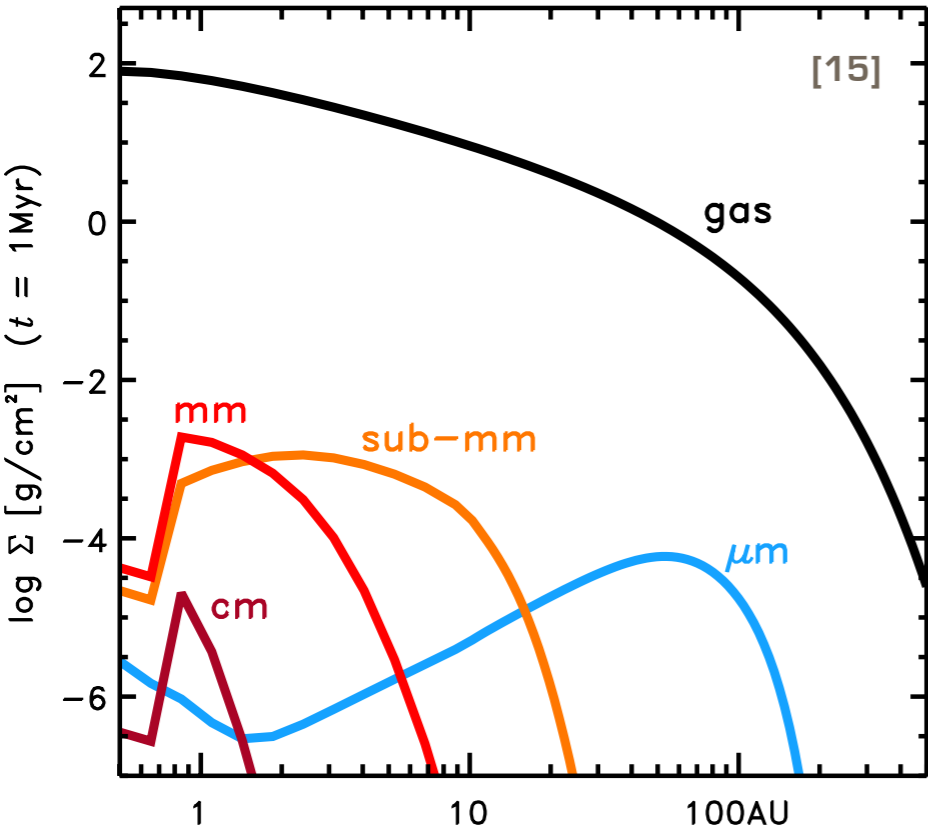
is this really happening?  
*(we shouldn't see extended mm continuum)*



[reviews: 16, 17, 18]

[simulations: 15]

# tension with evolutionary models



predictions:

radial size segregation, d/g gradient

[e.g., 19, 20, 21, 22]

[e.g., 15, 23, 24, 25]

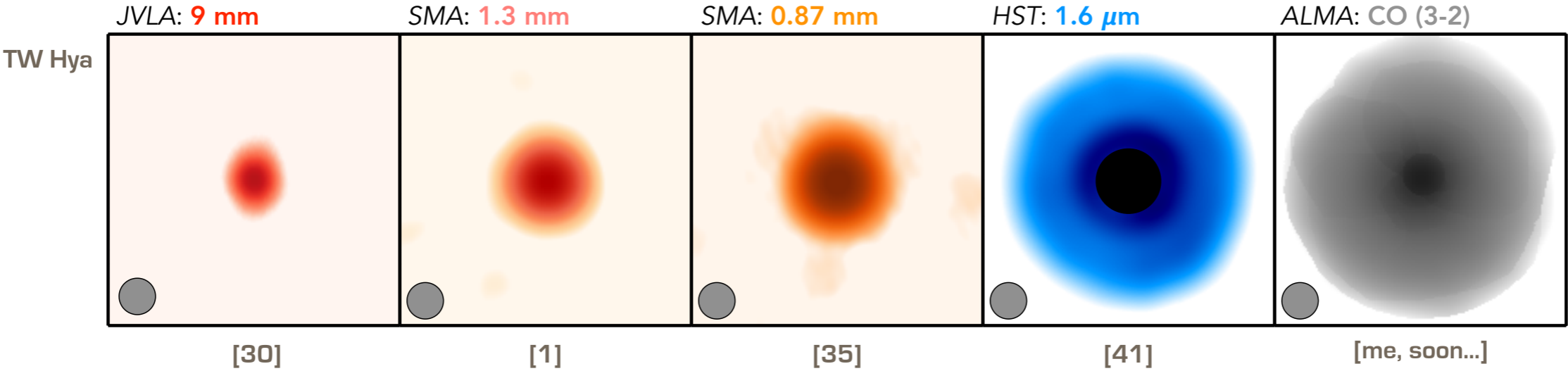
data:

color gradient (size ~ frequency)

[26, 27, 28, 29, 30, 31, 32, 33]

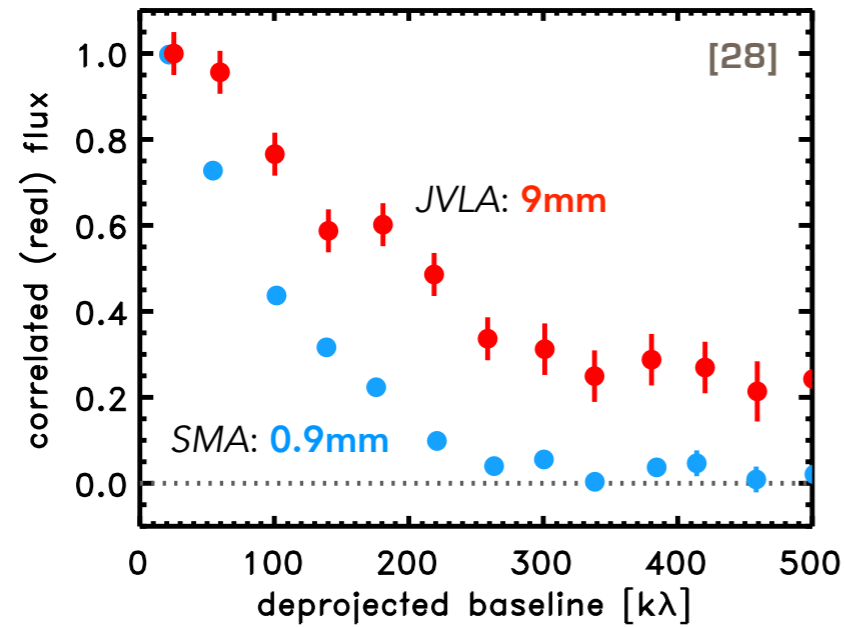
size (line) >> size (continuum)

[34, 35, 36, 37, 38, 39, 40]



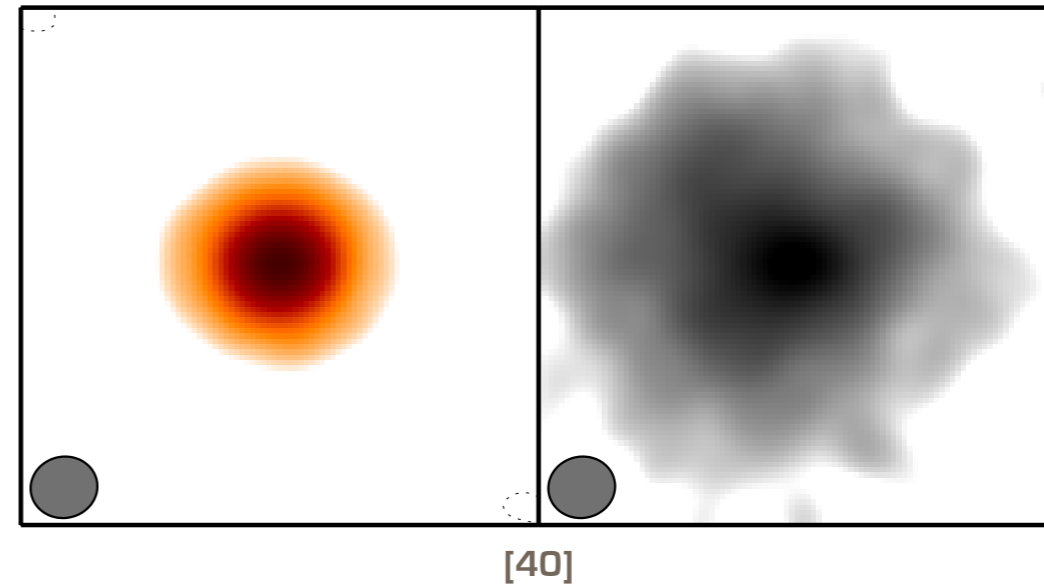
# tension with evolutionary models

AS 209

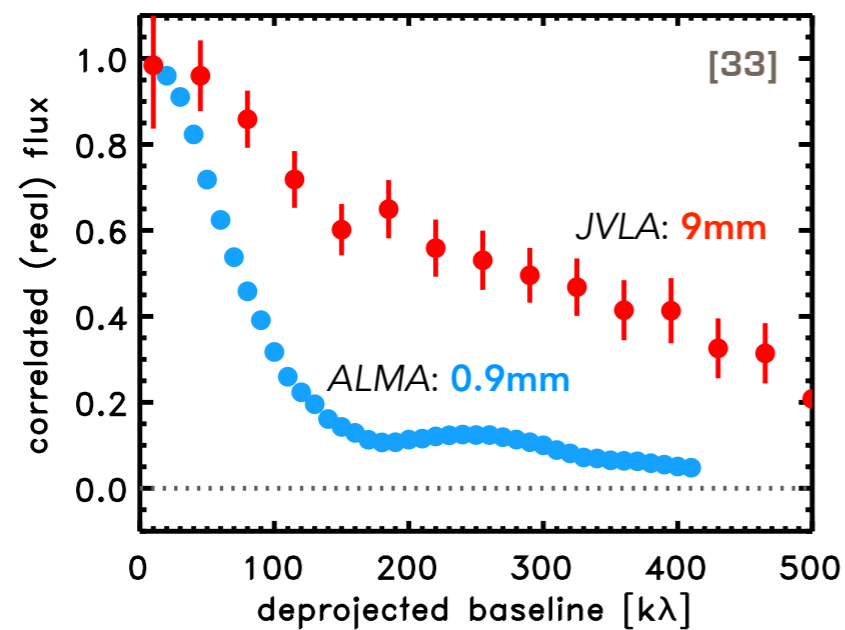


ALMA: 1.3mm

ALMA: CO (2-1)

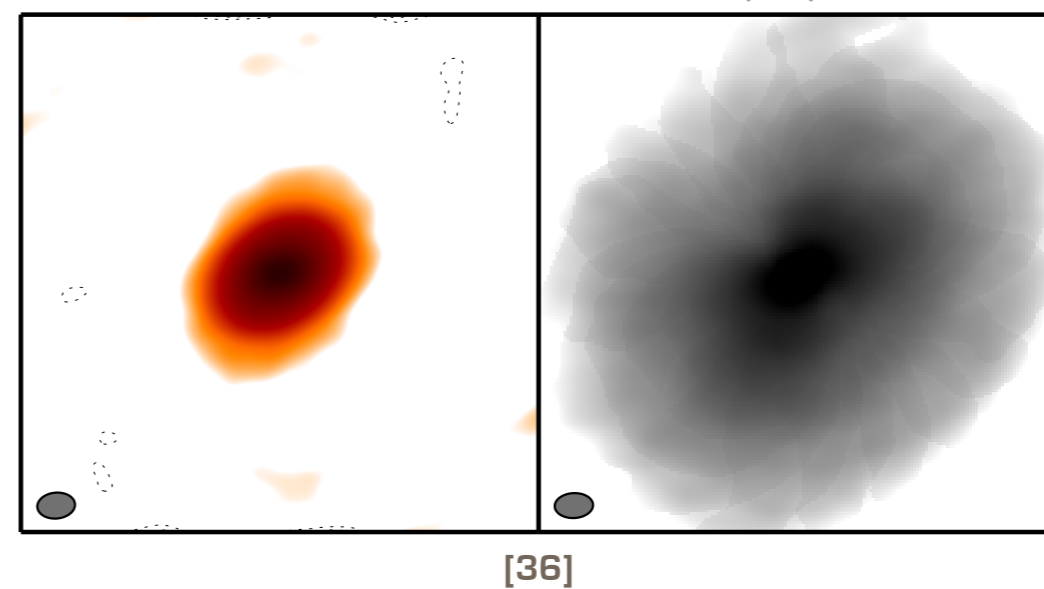


HD 163296



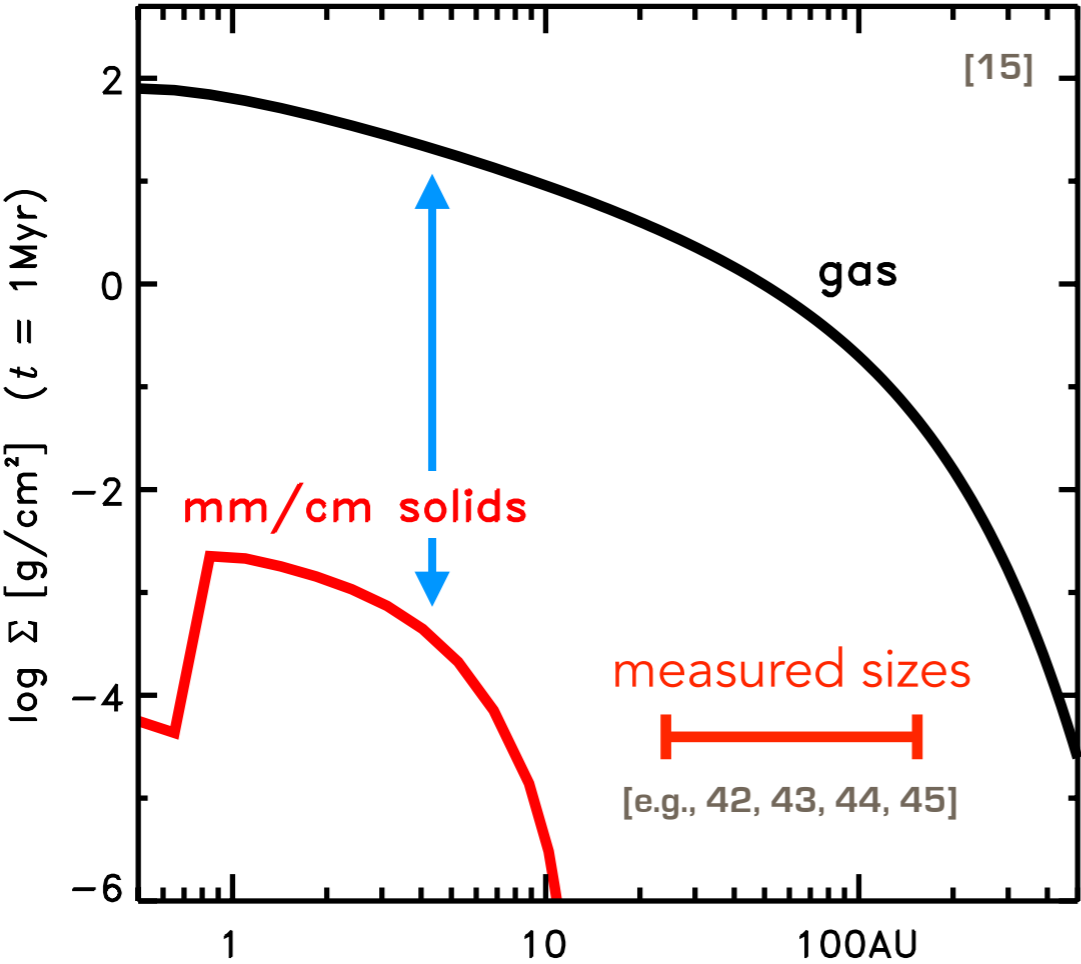
ALMA: 0.87mm

ALMA: CO (3-2)



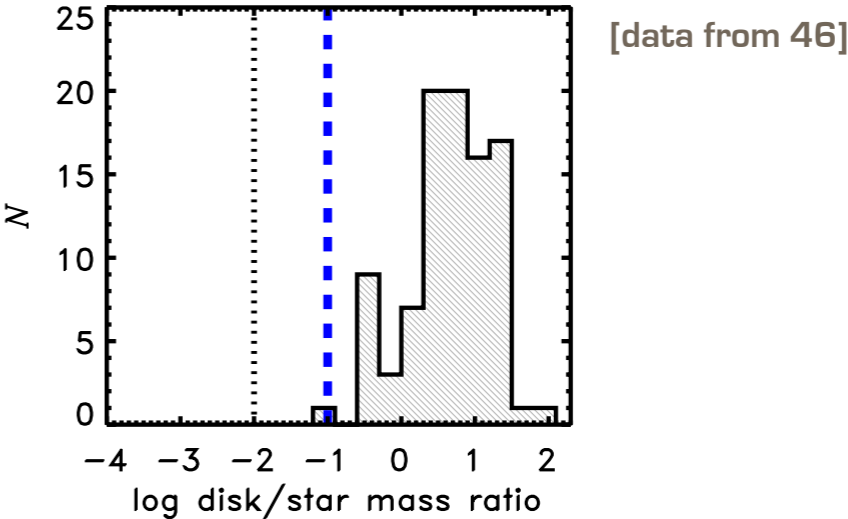
# tension with evolutionary models

multi-faceted, but *qualitative*, agreement between theory + data



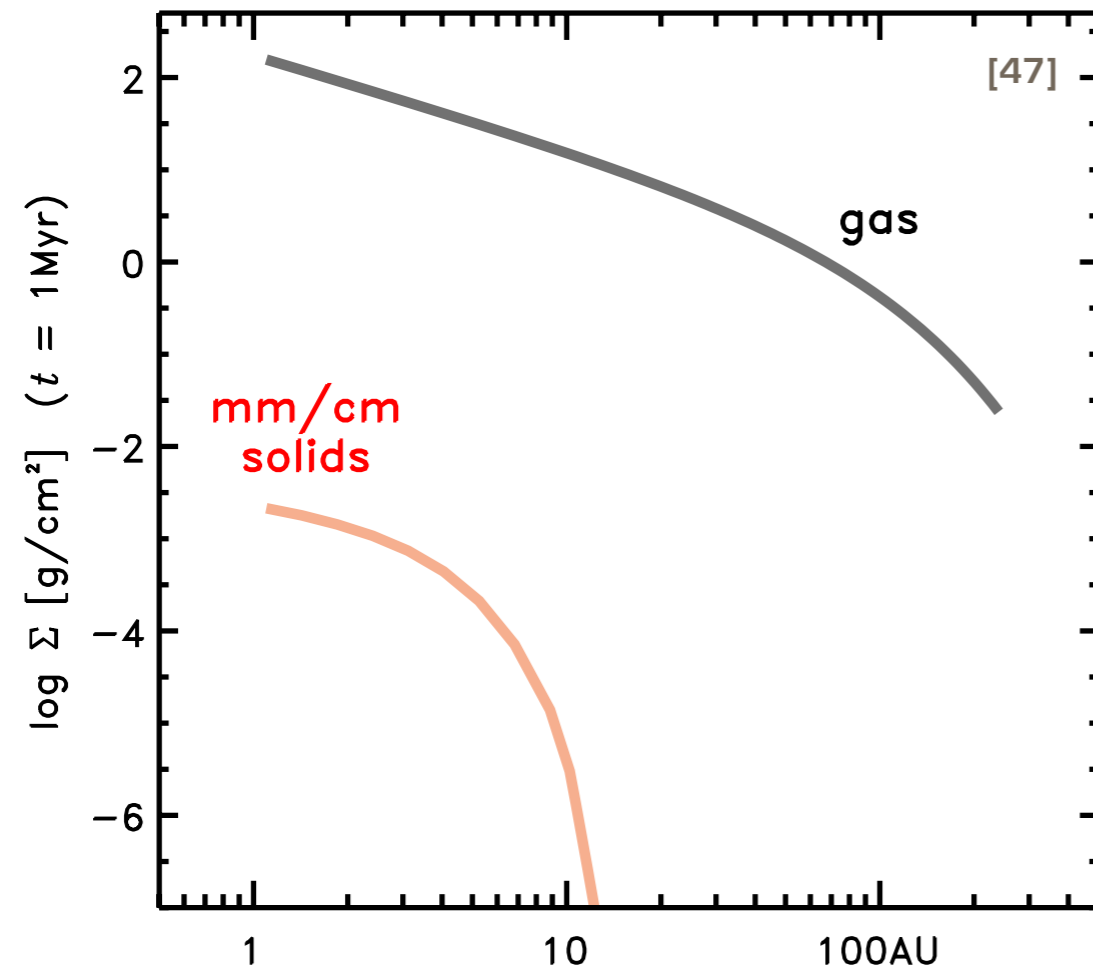
continuum **sizes** >> predicted

implied **masses** >> stable



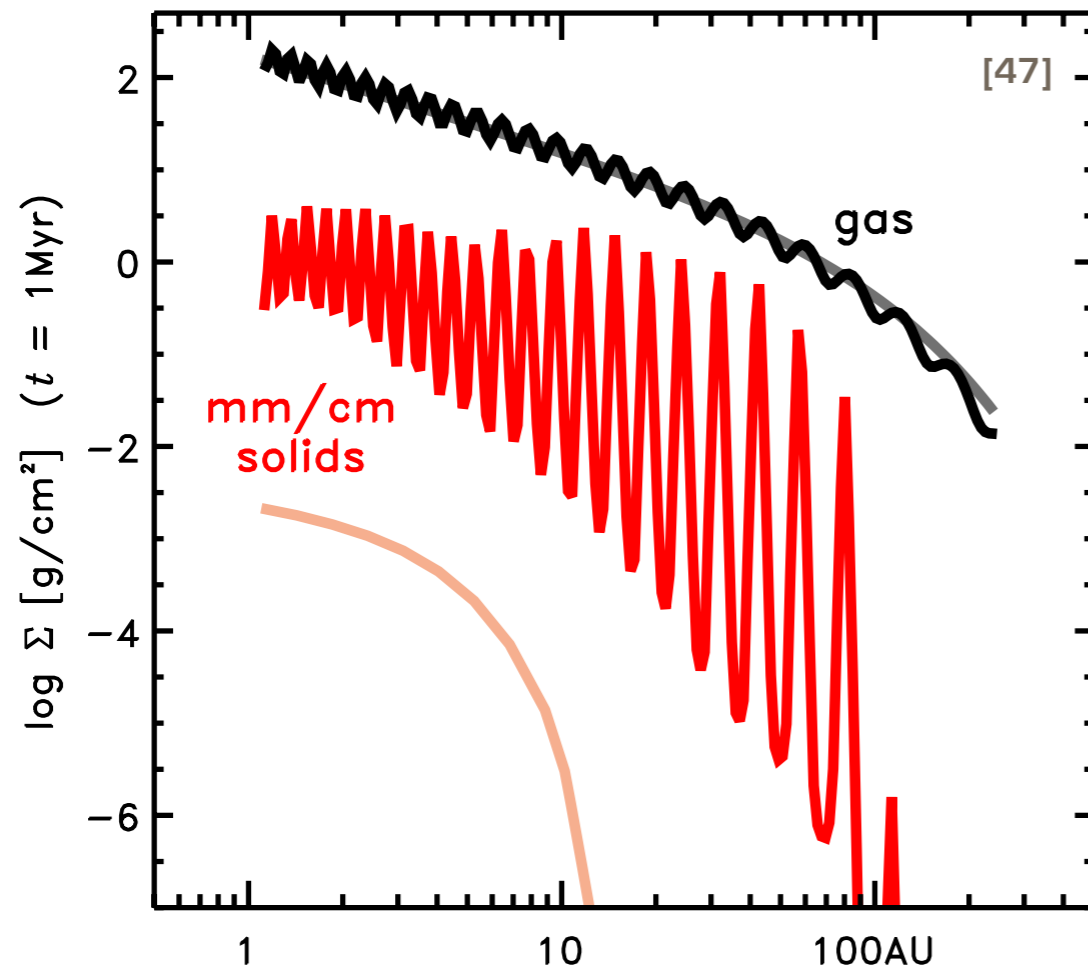
radial drift *happens*, but it must be stopped! (or slowed)

# role of substructures





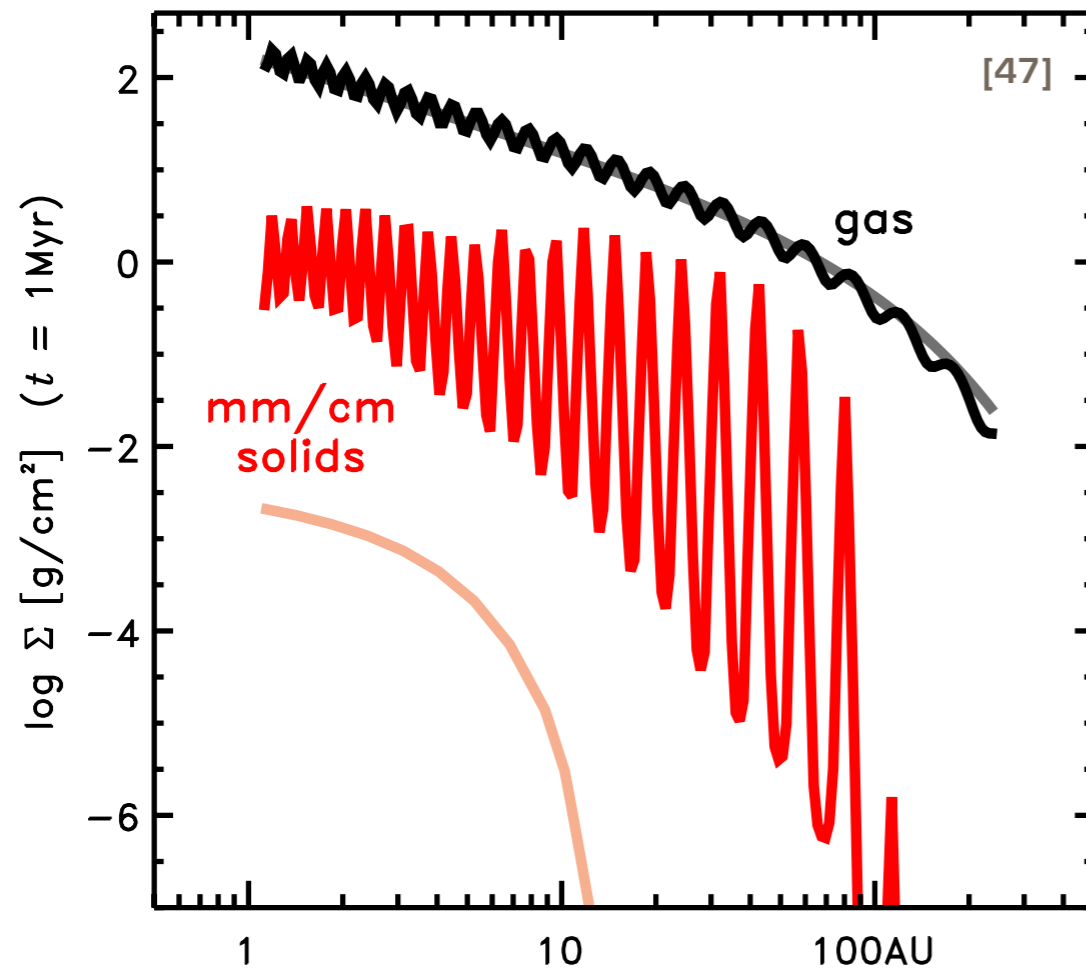
# role of substructures



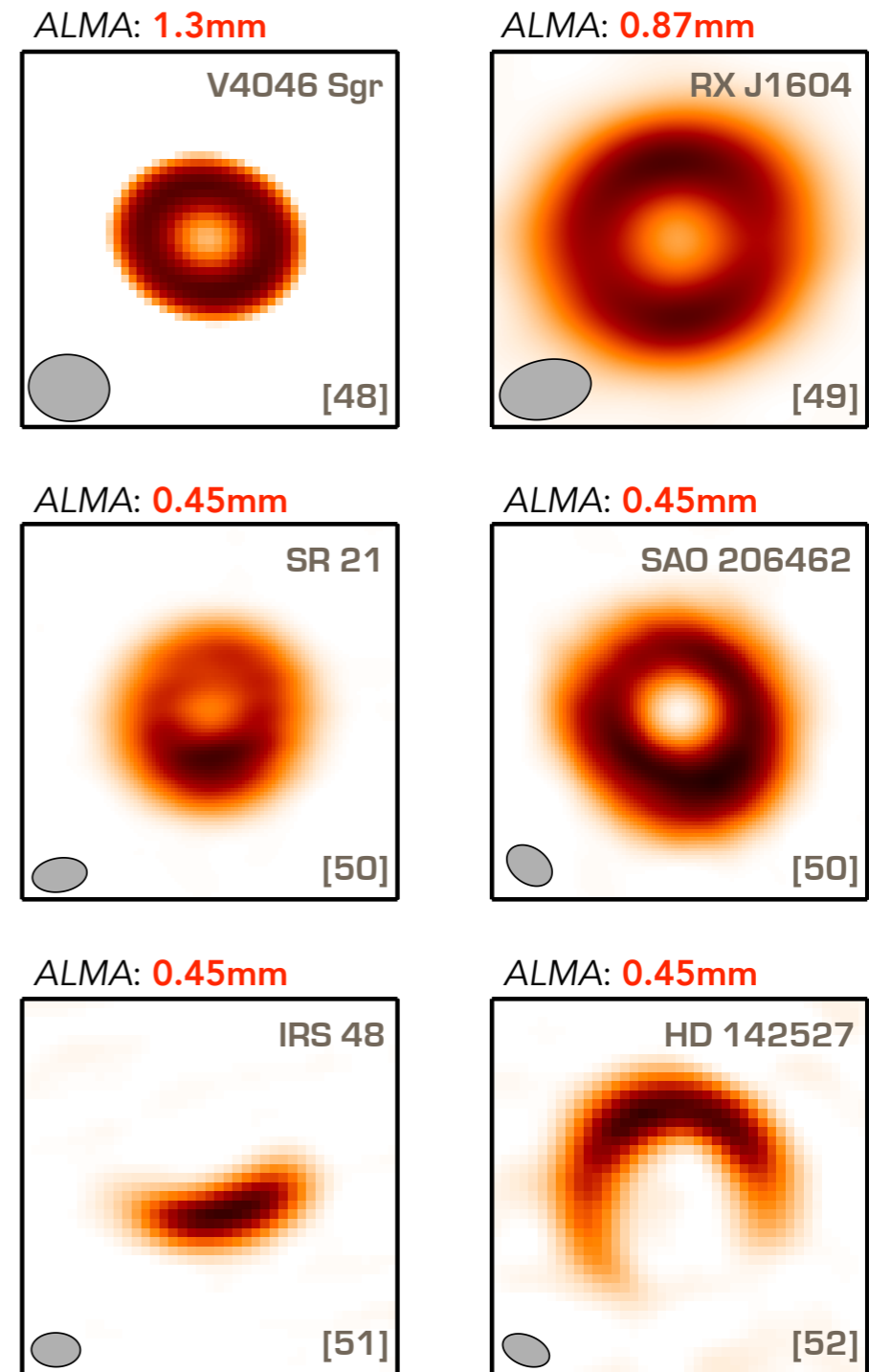
local pressure maxima: solution to the radial drift "problem"

# role of substructures

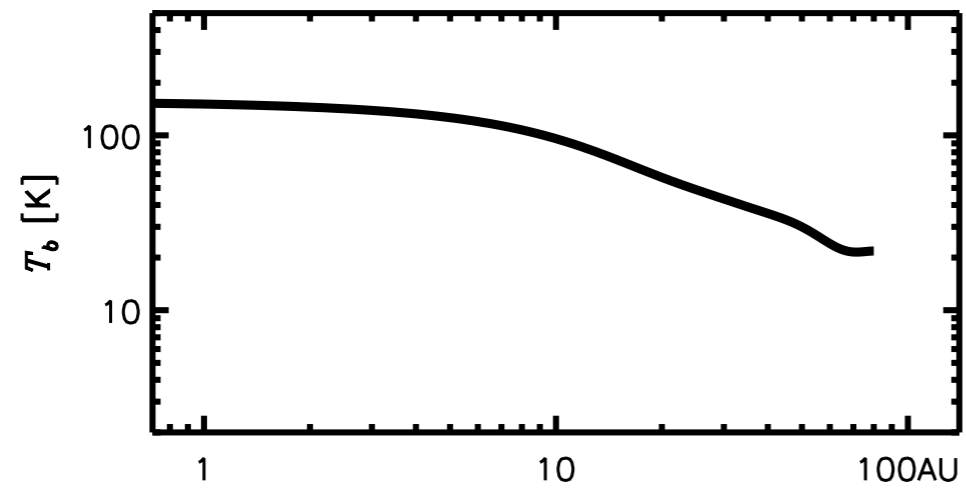
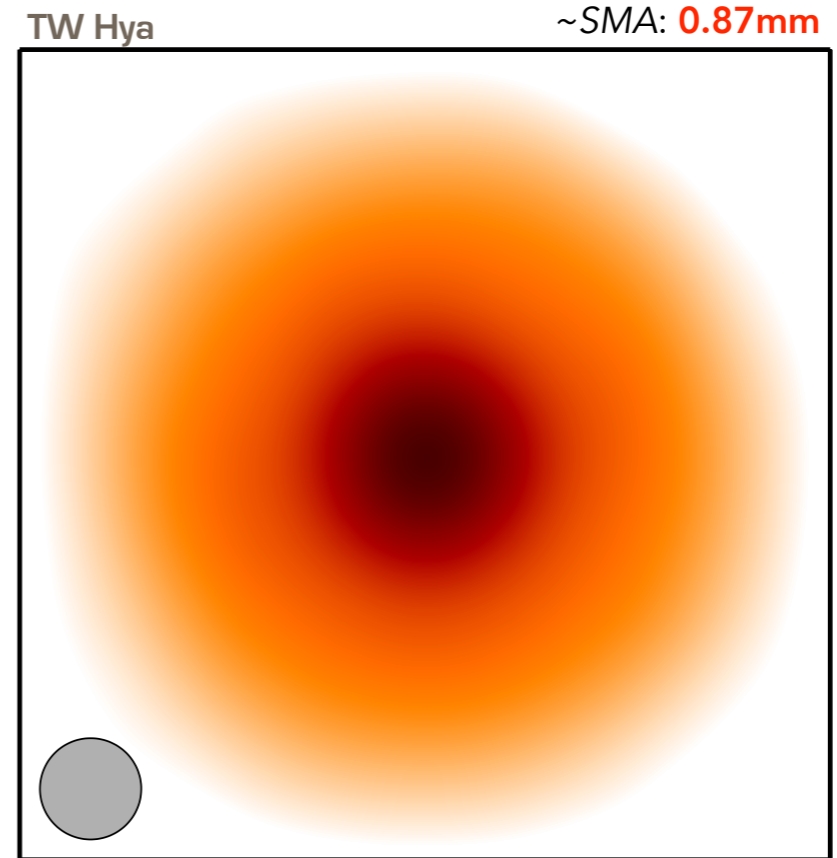
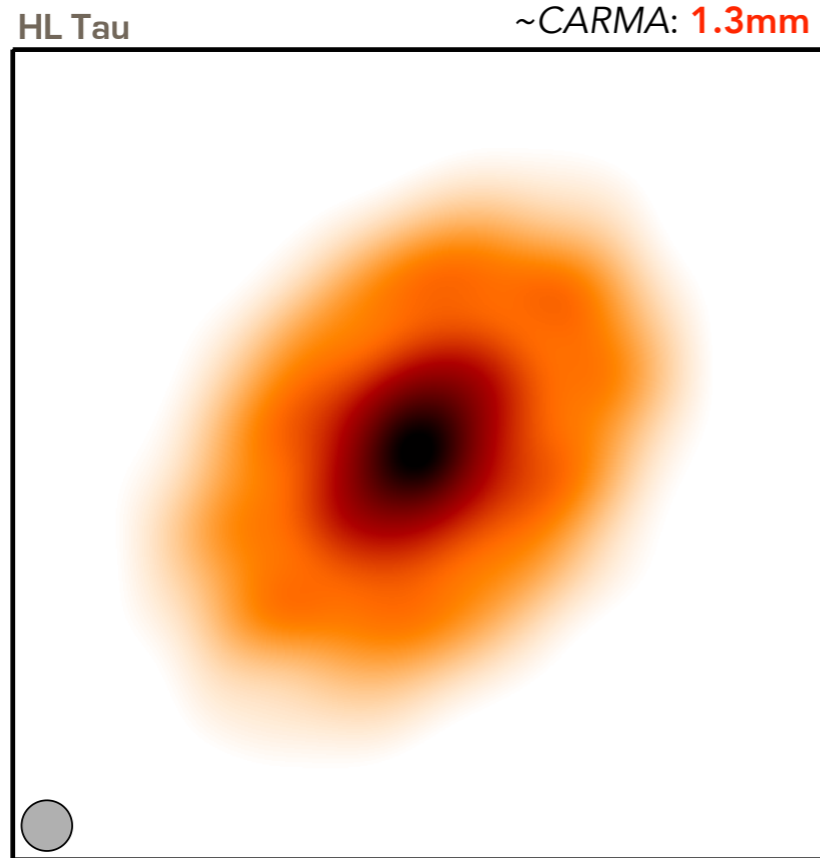
e.g., transition disks



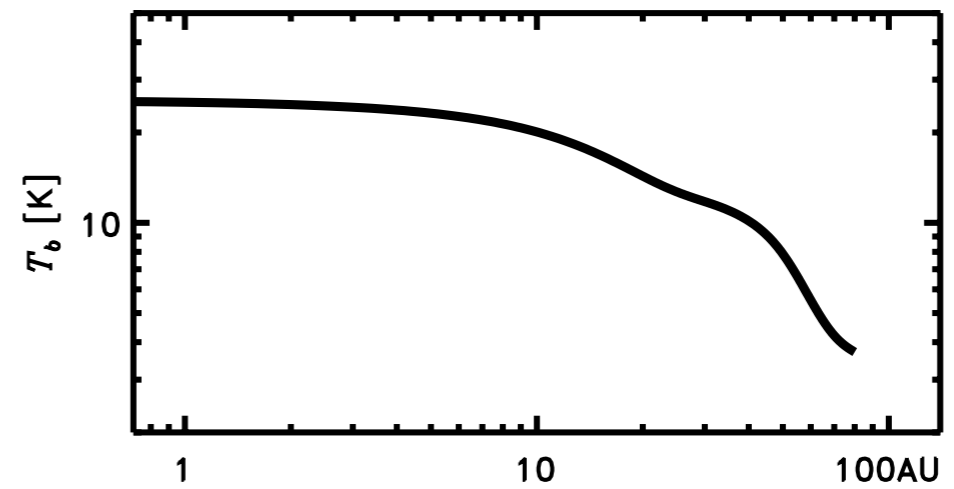
local pressure maxima: solution to the radial drift "problem"



# role of substructures

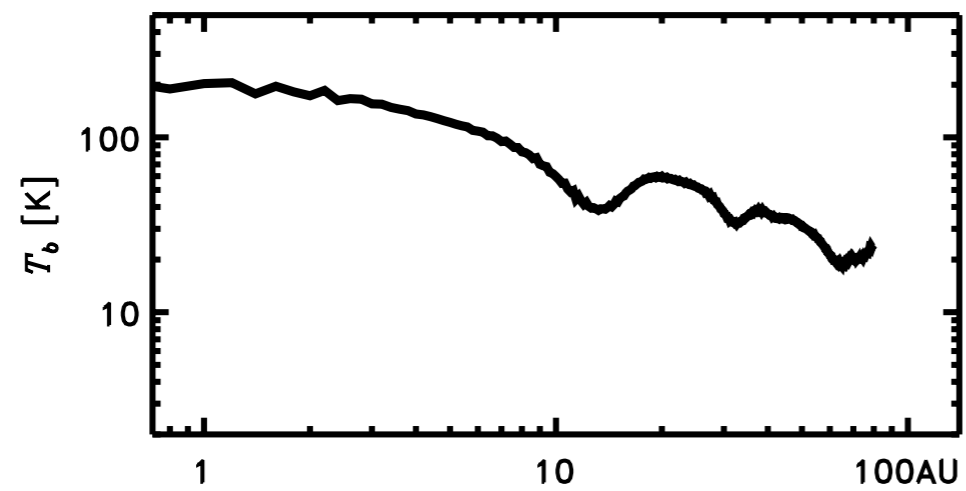
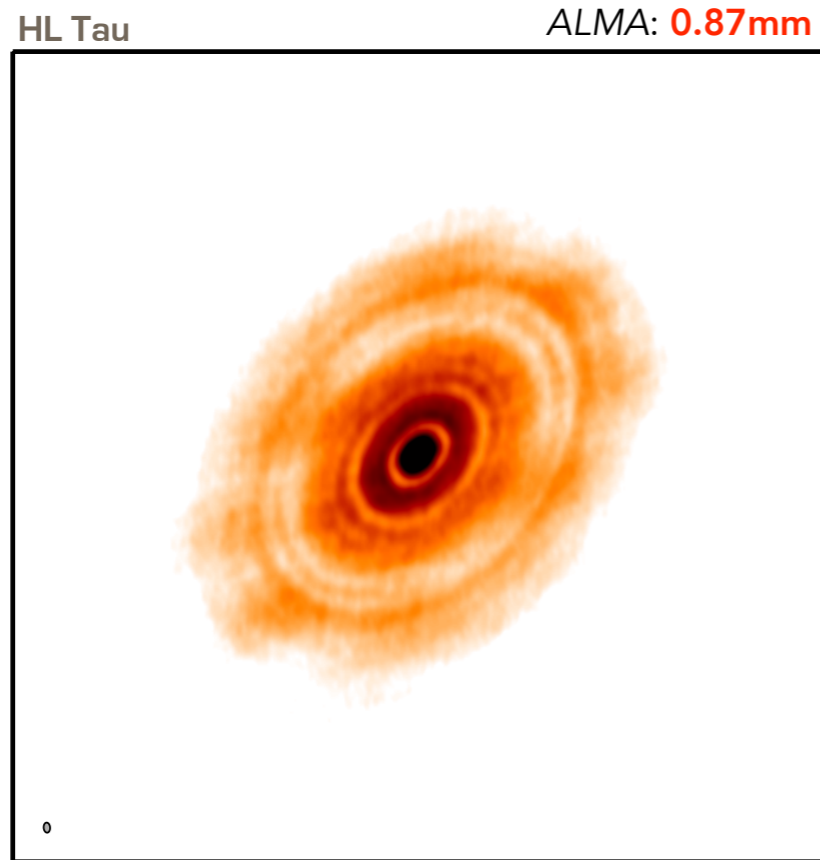


[53]

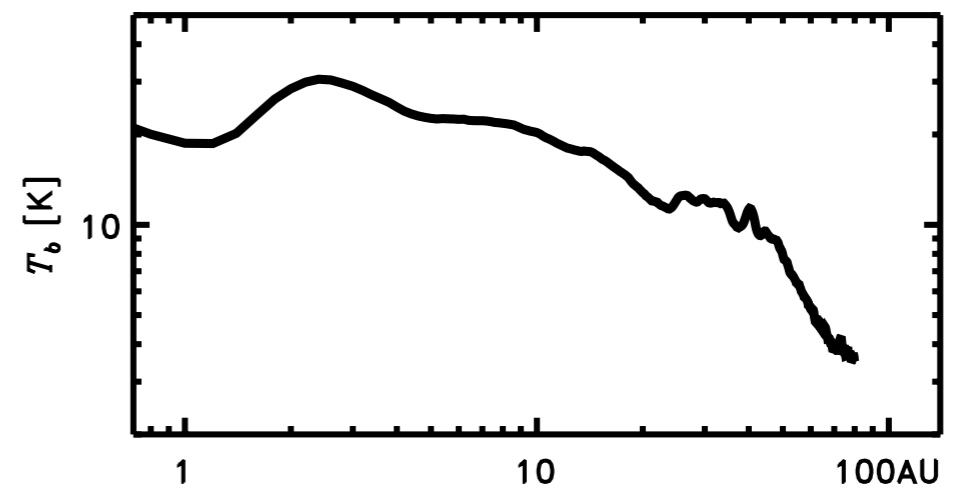
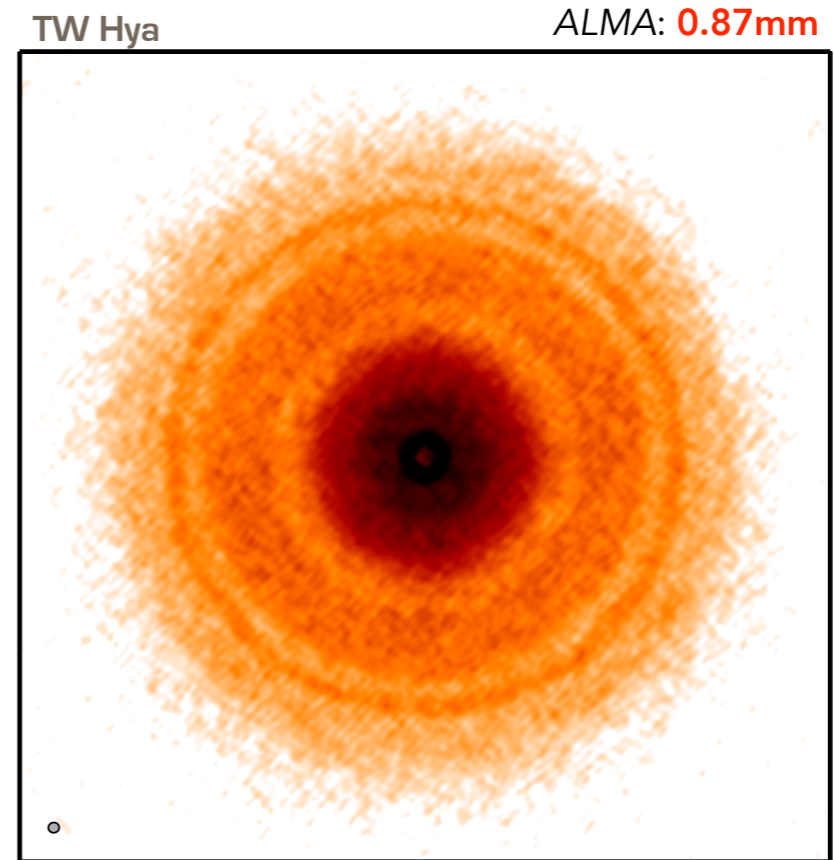


[35; see also 54, 55]

# role of substructures

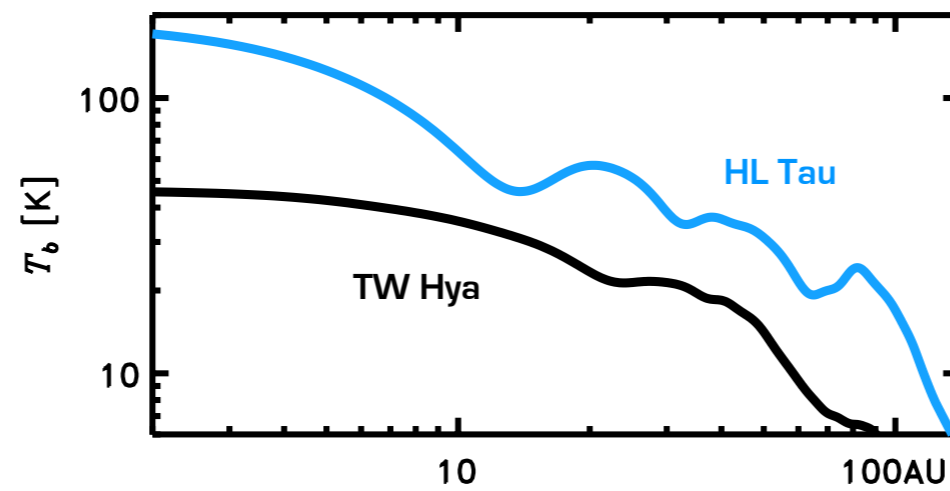
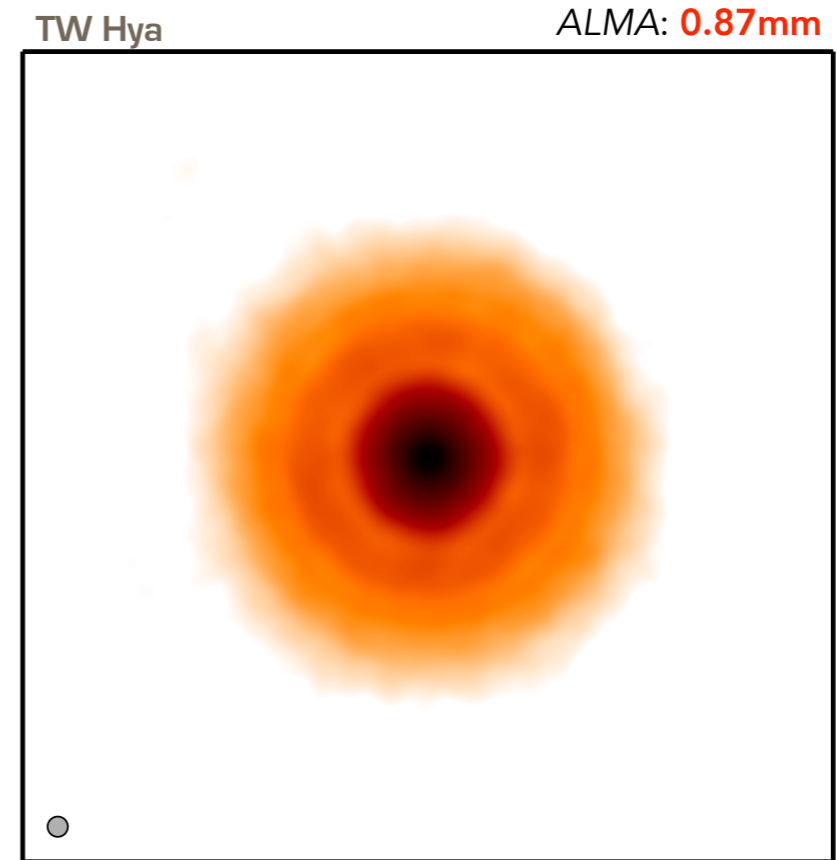
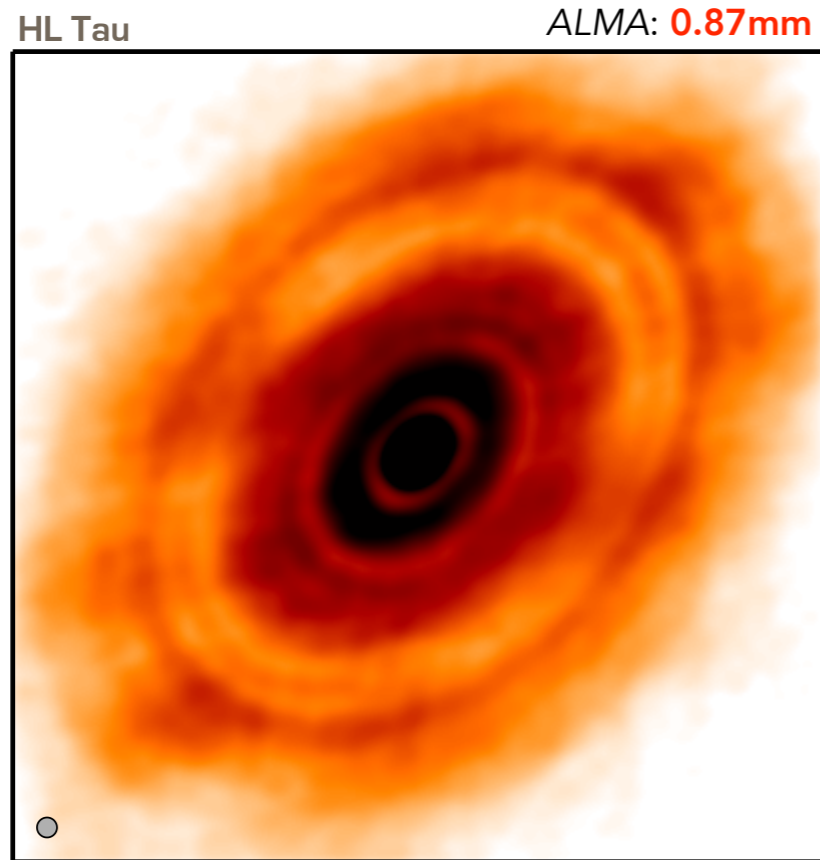


[56]



[57]

# role of substructures



# role of substructures

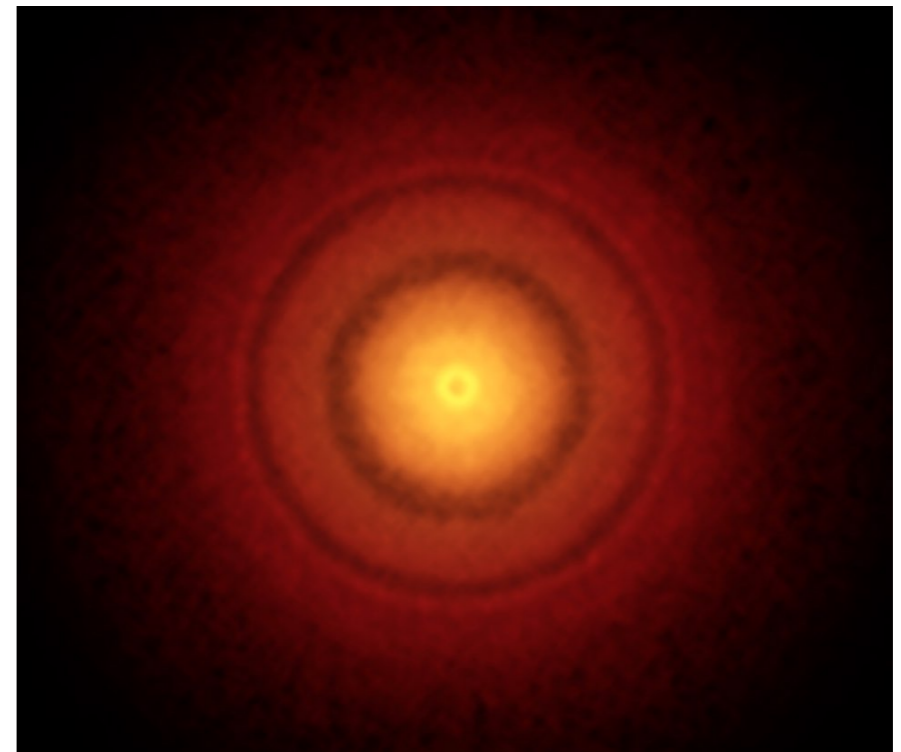
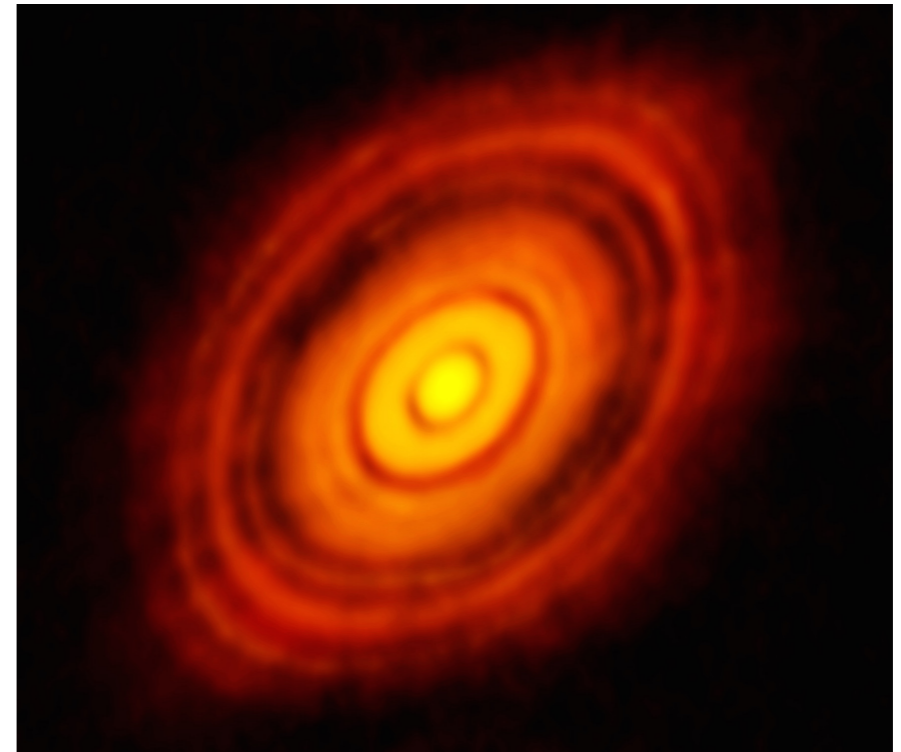
how common are substructures?

what forms do they take?

scales, amplitudes, locations, contents?

depend on host or bulk properties?

manifested in gas, small solids?



# bully pulpit: some things to consider

substructures as "savior"



solution to drift problem of long-lived extended disks

potentially a fundamental aspect of planet formation

# bully pulpit: some things to consider

substructures as "savior"



solution to drift problem of long-lived extended disks  
potentially a fundamental aspect of planet formation

substructures as "tormentor"

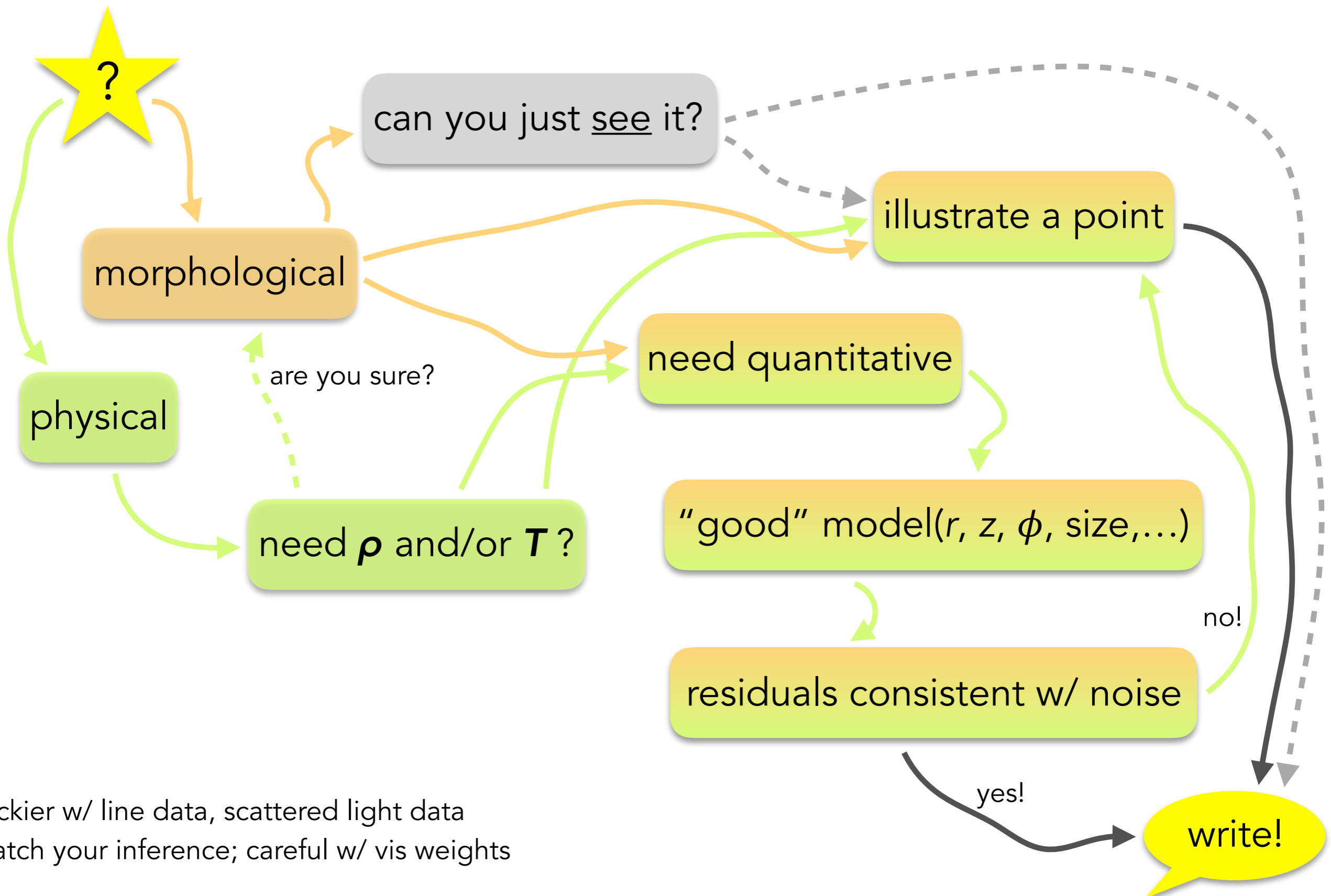


if caused by planets: chicken, meet egg...

if dense: trouble for dust masses, midplane gas tracers, etc.



# bully pulpit: some things to consider



trickier w/ line data, scattered light data  
watch your inference; careful w/ vis weights

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