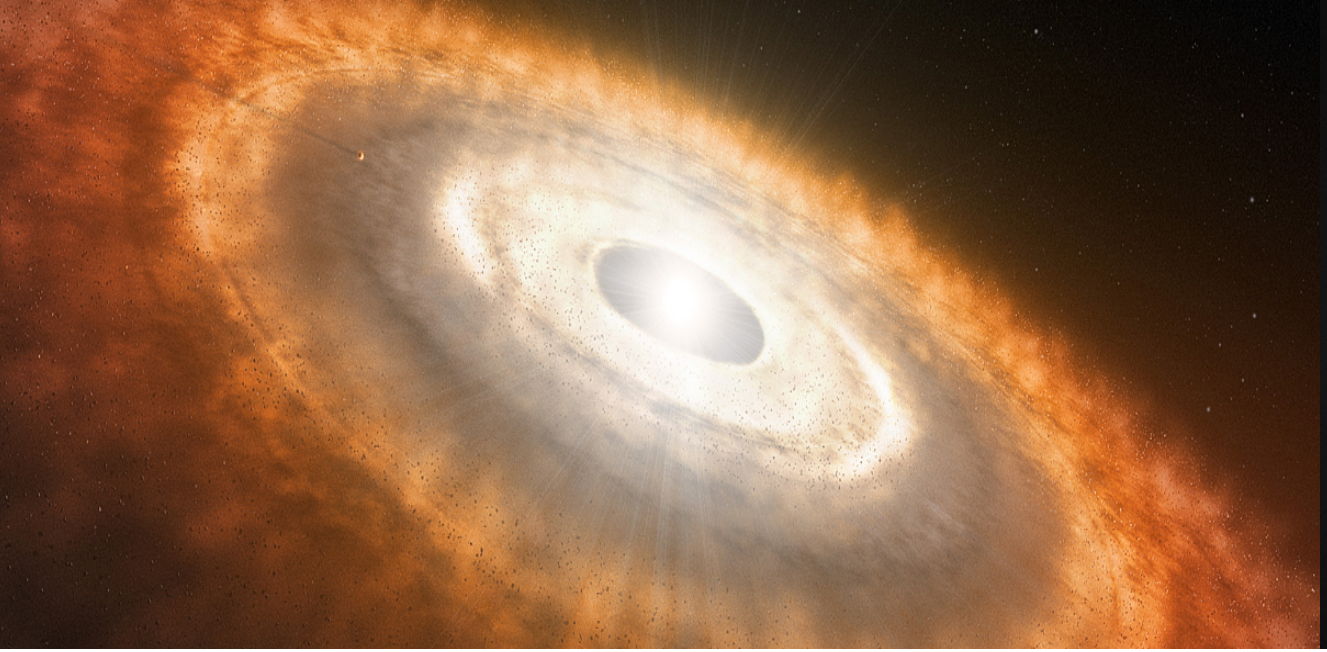
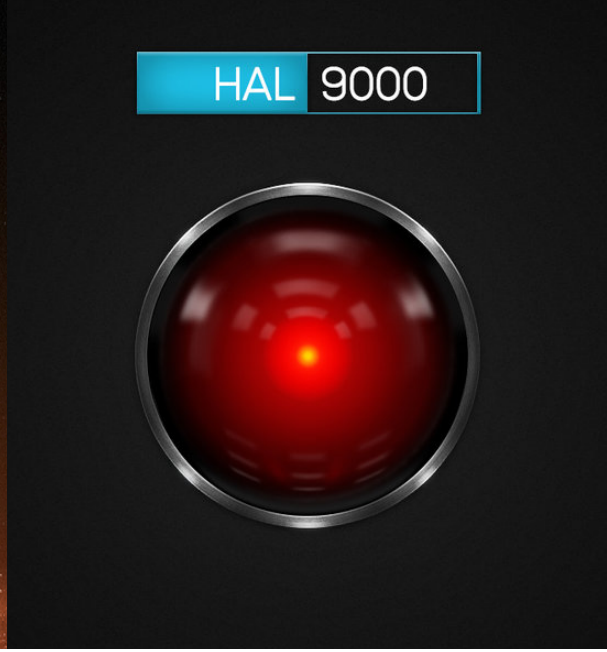




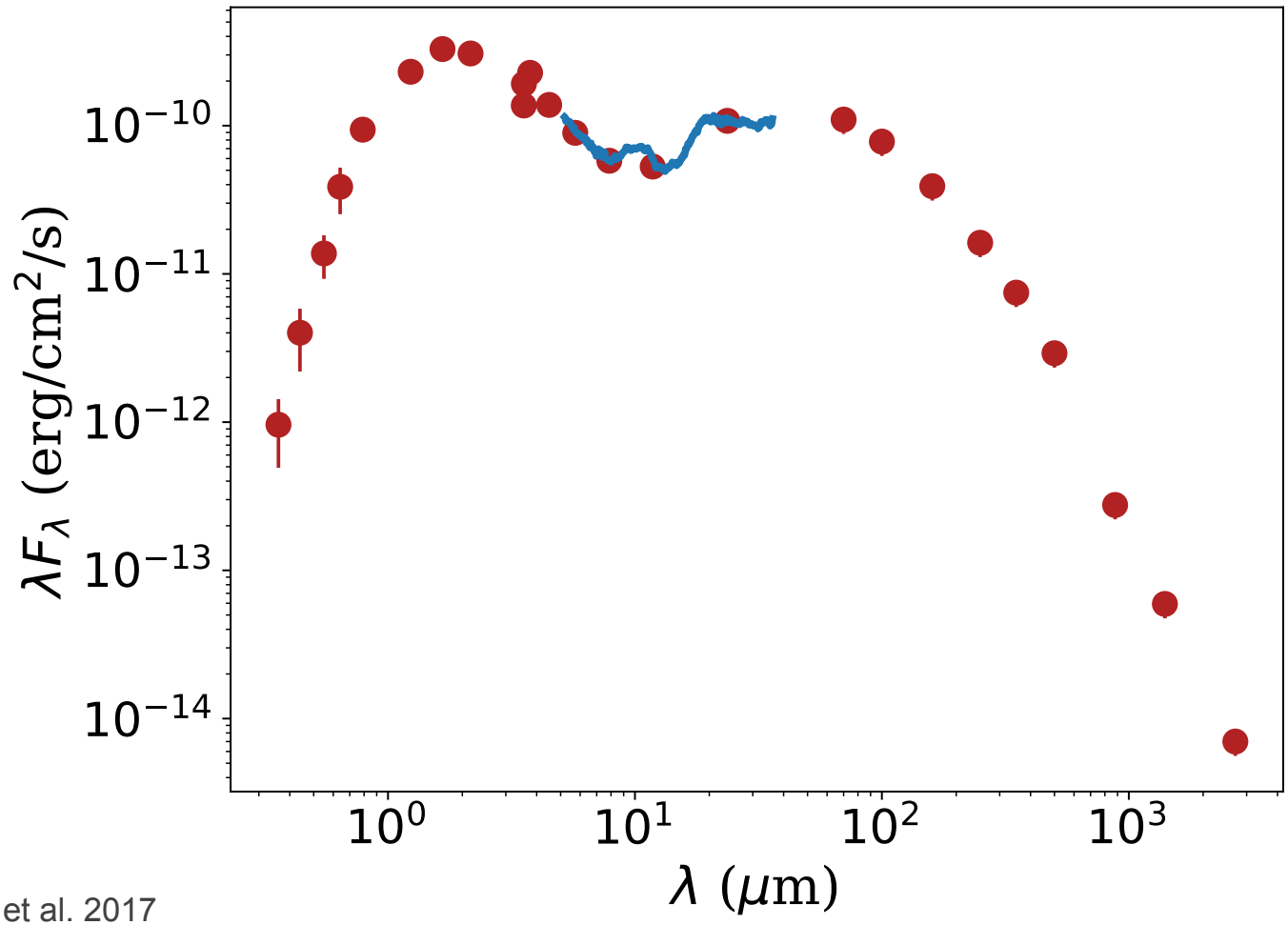
PROTOPLANETARY DISKS MEET ARTIFICIAL NEURAL NETWORKS: EVIDENCE AGAINST THE ALPHA-DISK?

Álvaro Ribas (ESO fellow at ALMA)

Catherine Espaillat, Enrique Macías,
Luis Sarro, Connor Robinson

Great Barriers in Planet Formation 2019

There is a large number of disks with complete SEDs



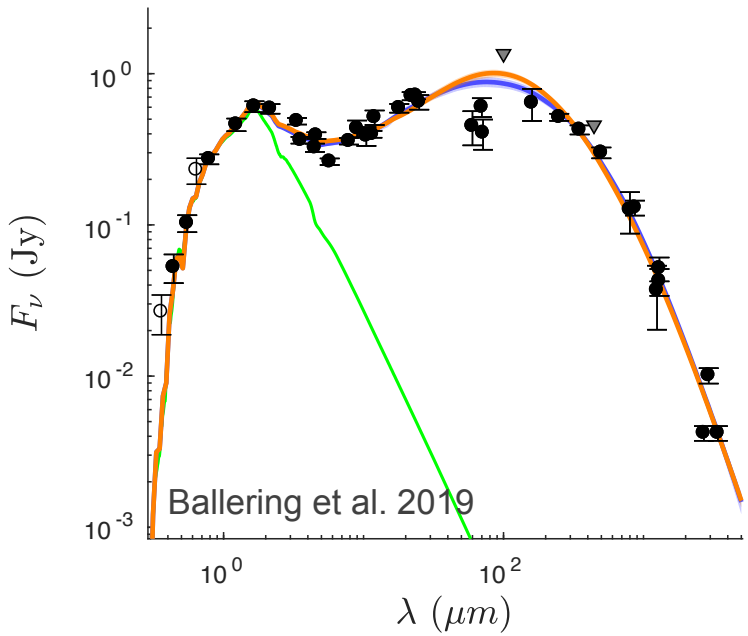
Ribas et al. 2017

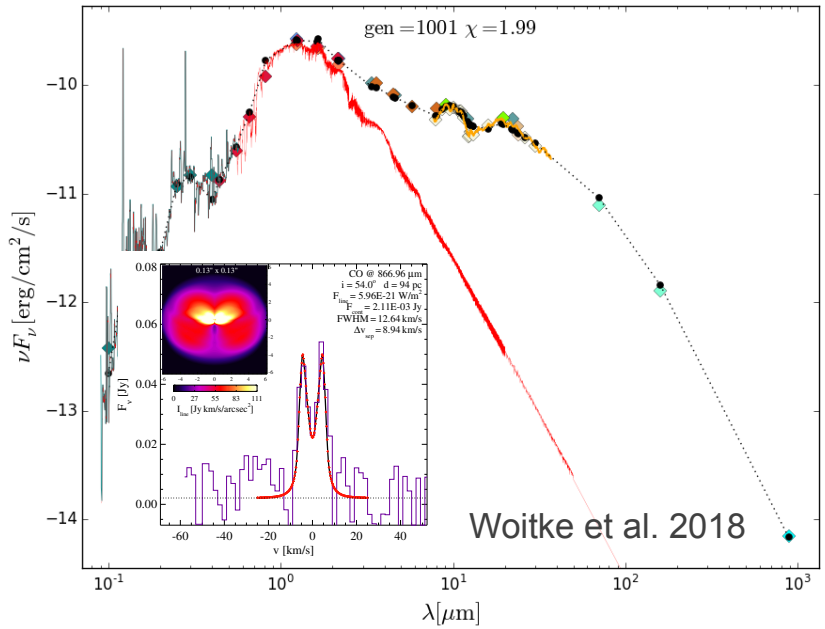
So far...

statistical treatment, but with simple disk models

or

detailed modeling, but with several fixed parameters and/or little statistical treatment





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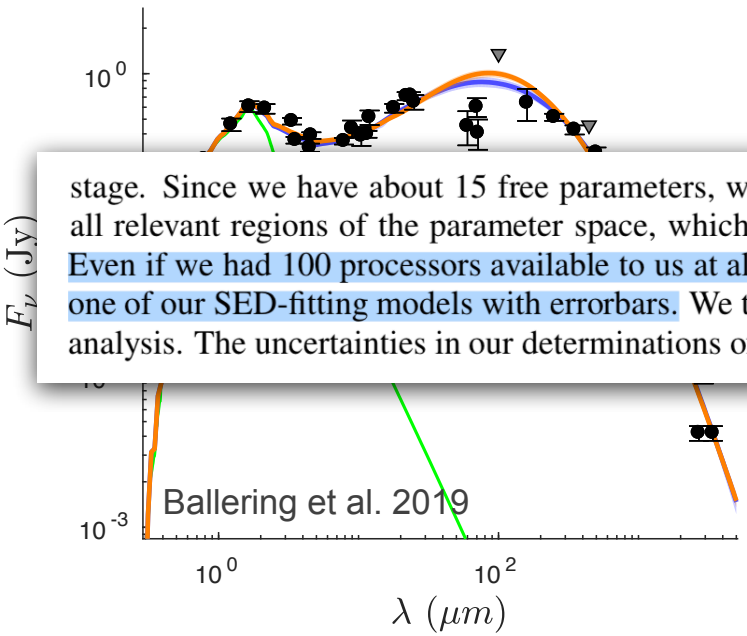

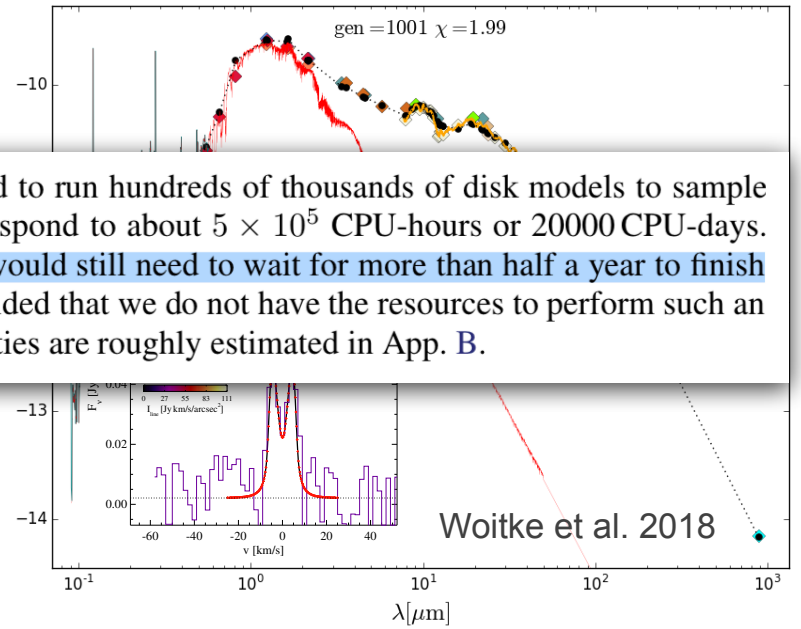

stage. Since we have about 15 free parameters, we would need to run hundreds of thousands of disk models to sample all relevant regions of the parameter space, which would correspond to about 5×10^5 CPU-hours or 20000 CPU-days. Even if we had 100 processors available to us at all times, we would still need to wait for more than half a year to finish one of our SED-fitting models with errorbars. We therefore decided that we do not have the resources to perform such an analysis. The uncertainties in our determinations of disk properties are roughly estimated in App. B.

The D'Alessio Irradiated Accretion Disk models (DIAD)

Self-consistent disk models:

- Alpha-disk prescription (Skakura and Sunyaev 1973)
- Alpha and accretion rate determine surf. density profile
- Vertical hydrostatic equilibrium
- Active disk, includes viscous heating
- Two layers of dust grains, settling included by transferring dust mass from upper layer to mid plane

D'Alessio 1998, 1999, 2001, 2005, 2006

Each model requires 1-2 hours to run:
with 100 processors, ~10 years PER OBJECT
(not parallelizable!)

The D'Alessio Irradiated Accretion Disk models (DIAD)

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with 100 processors, ~10 years PER OBJECT

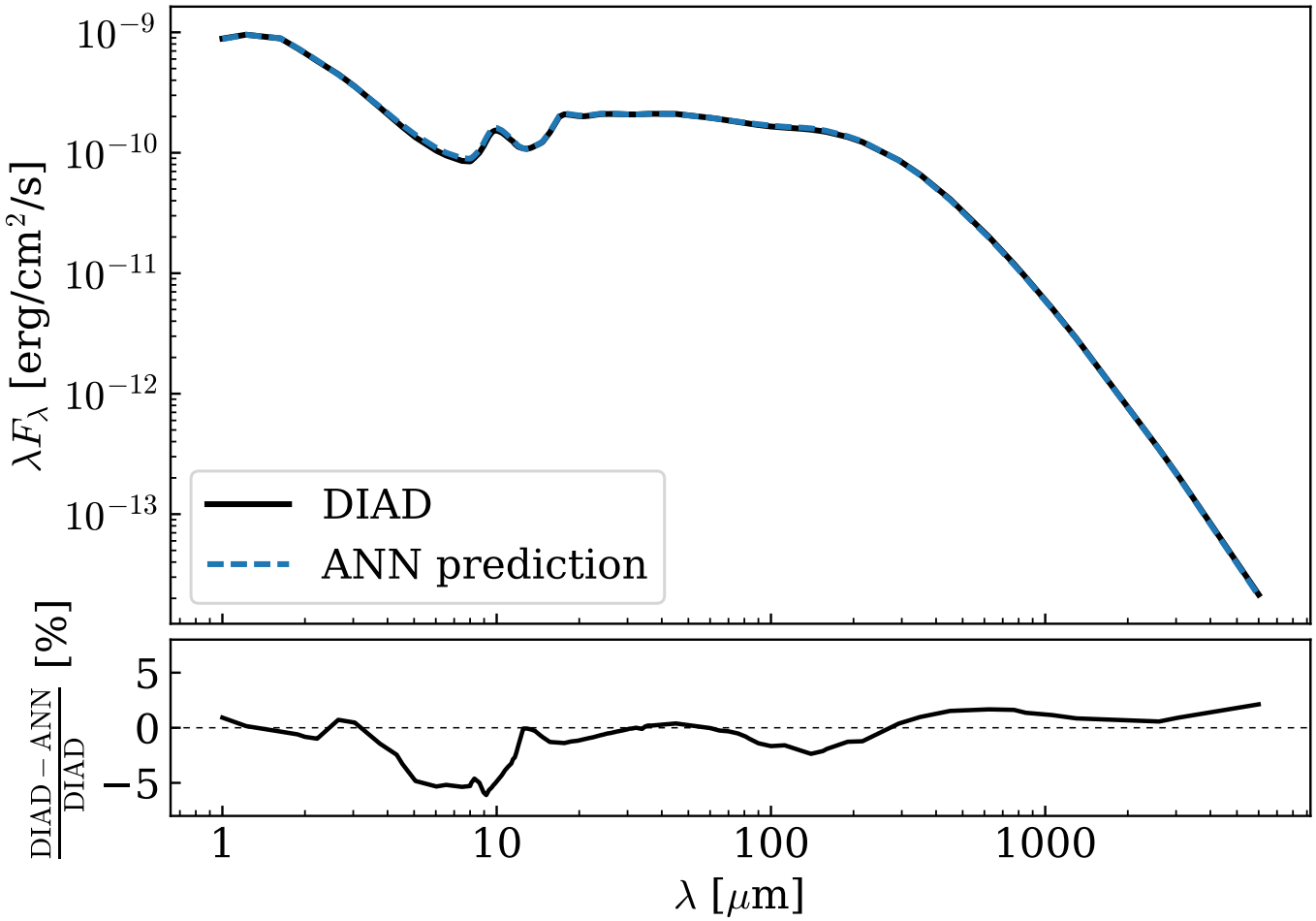
(not parallelizable!)

Input parameters → Function → Output (SED)

Input parameters → Neural Network → Output (SED)

The prediction from the neural network is within 5-10% of the DIAD true model across all wavelengths.

Takes a few ms!



The sample

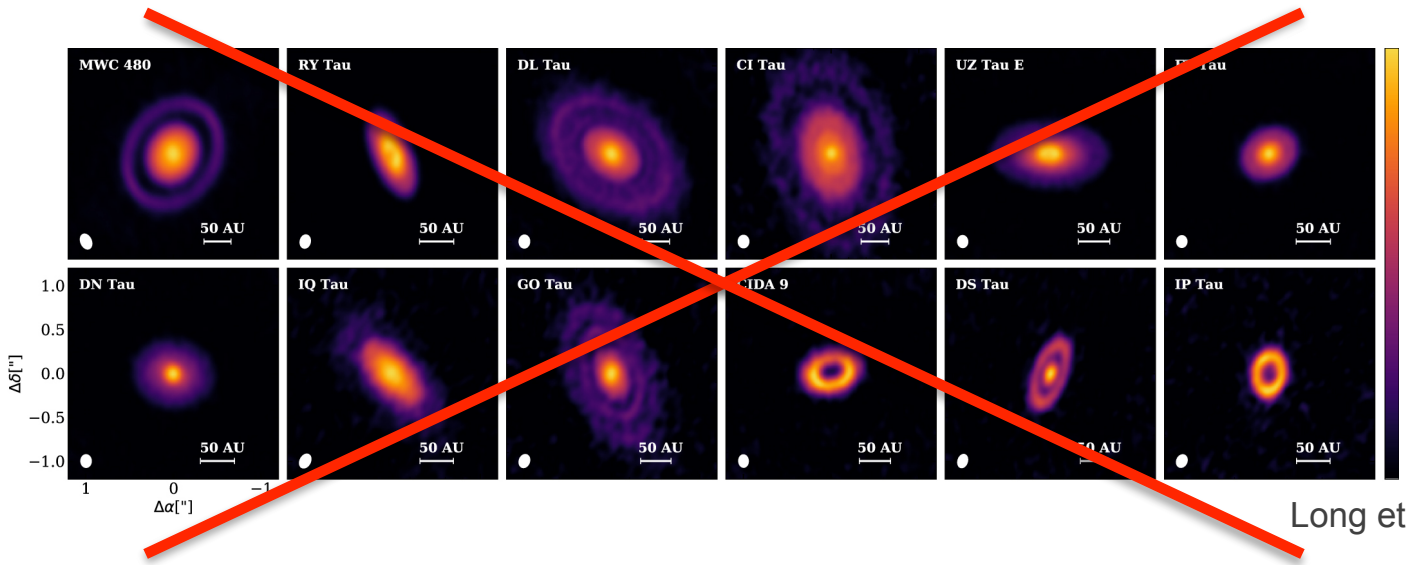
~160 objects in Taurus with well-sampled SEDs (Andrews et al. 2013)

Add Spitzer spectra + Herschel photometry/spectra (Ribas et al. 2017)

Remove:

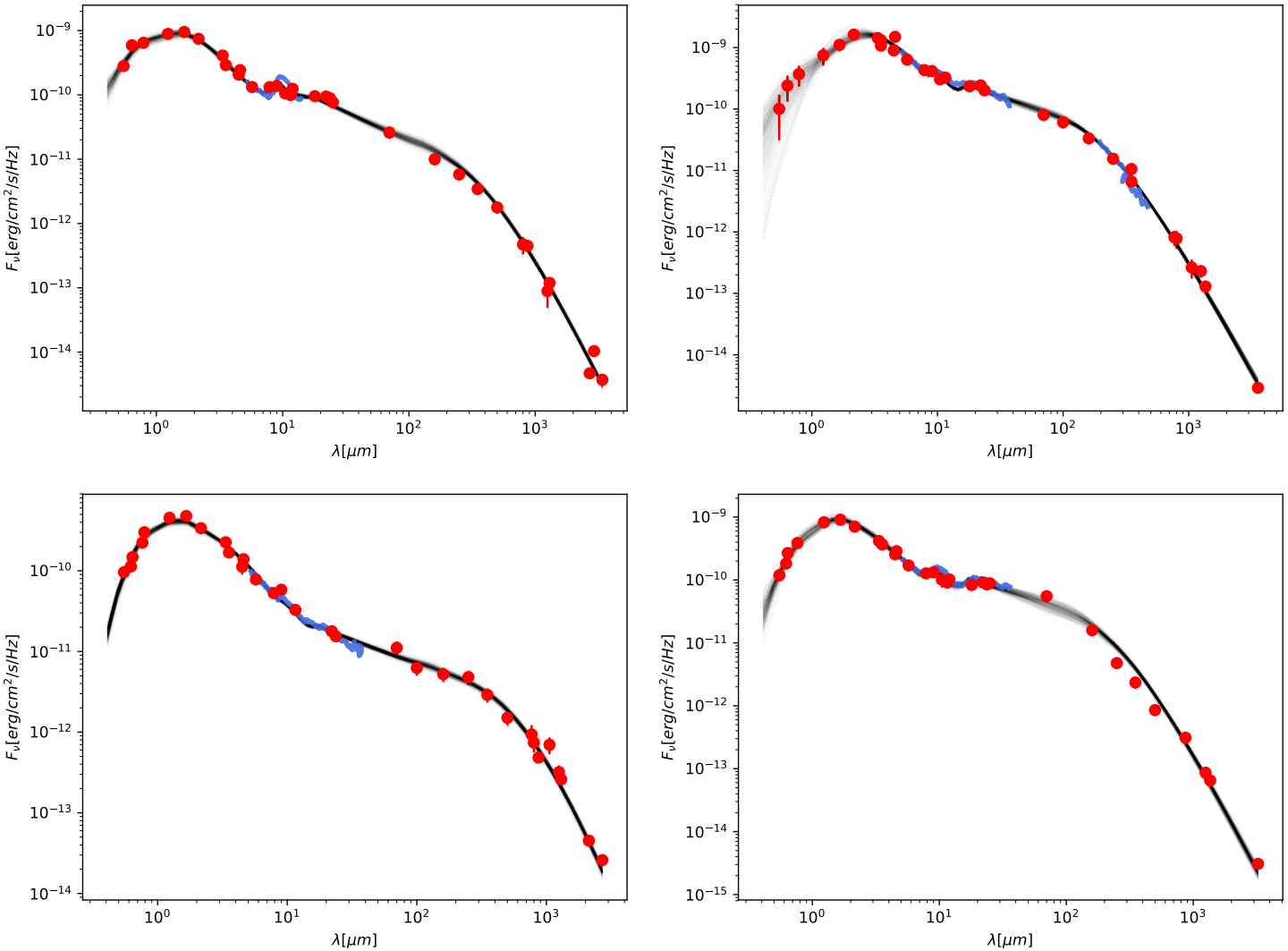
- binaries (<300 au)
- edge-on disks
- crazy SEDs
- disks with substructures (down to ~15 au)

~30 boring sources left



Long et al. 2018

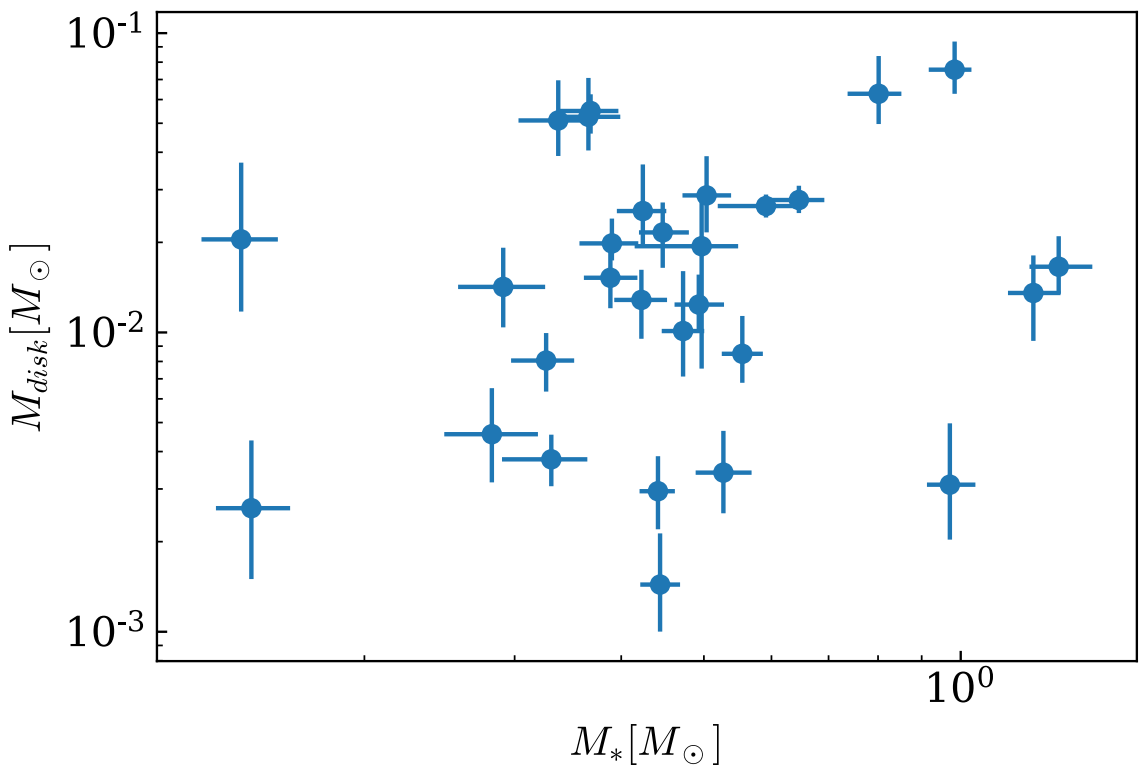
It works! 1-2 hours full MCMC per target



Disk dust masses

Improved dust mass estimates: this process considers thermal structure of the disk, includes opacity effects (yes, scattering too!), and derived uncertainties include the effect of all the other parameters in the model.

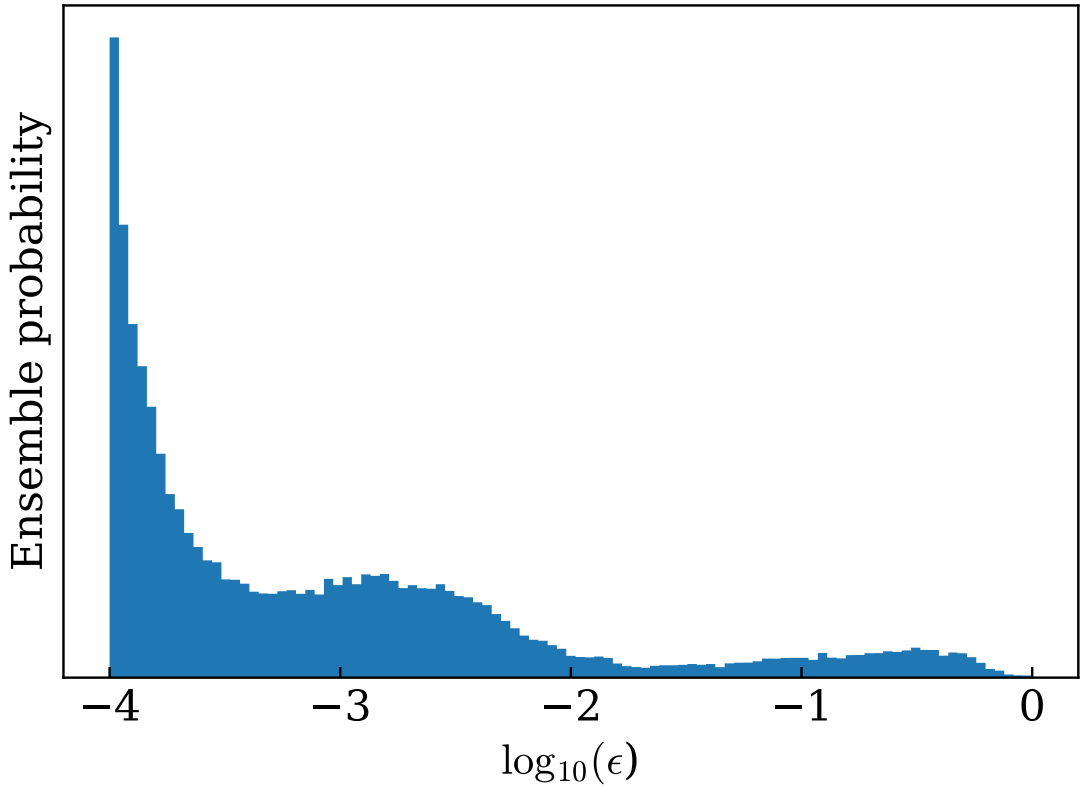
Large potential for disk demographics studies.



Dust settling

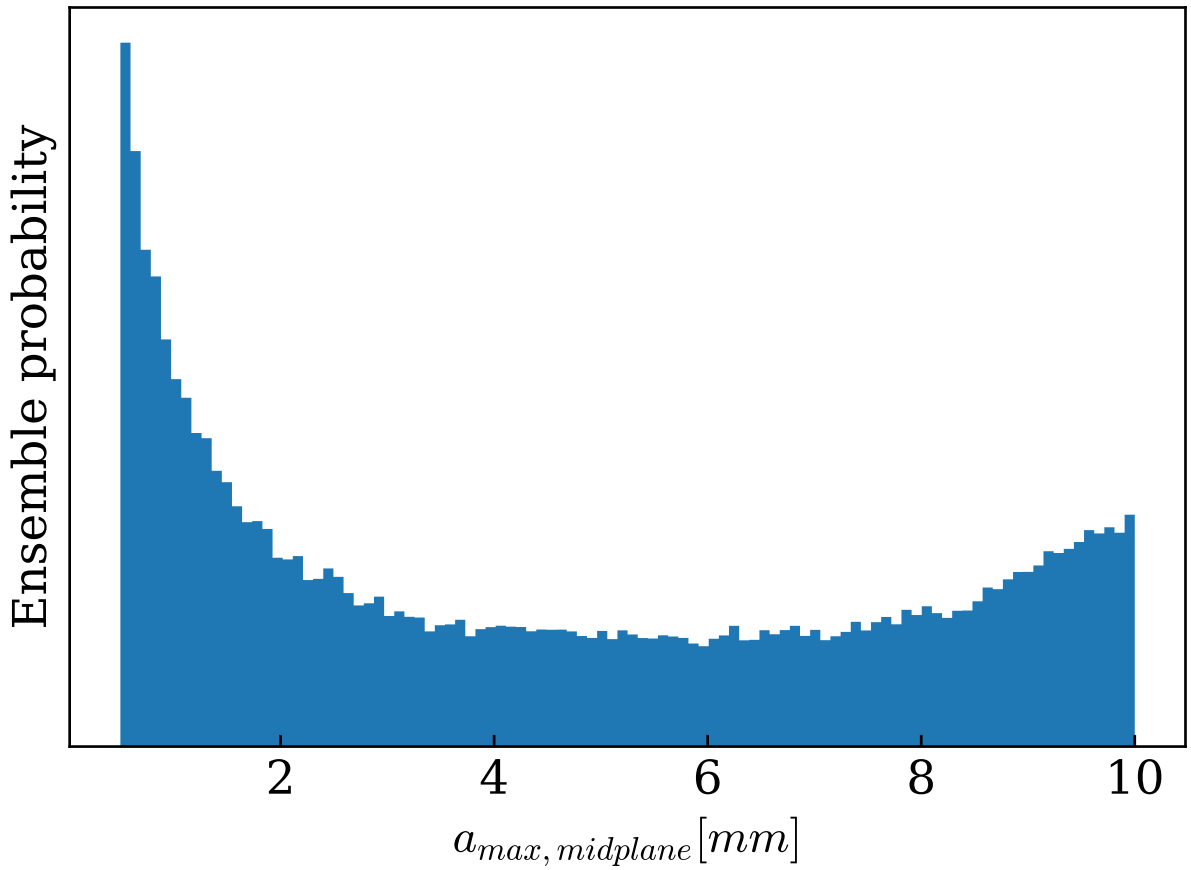
Most disks in our sample show significant signatures of dust settling.

$$\epsilon = \frac{\text{Dust-to-gas ratio upper layer}}{\text{Standard dust-to-gas ratio}}$$



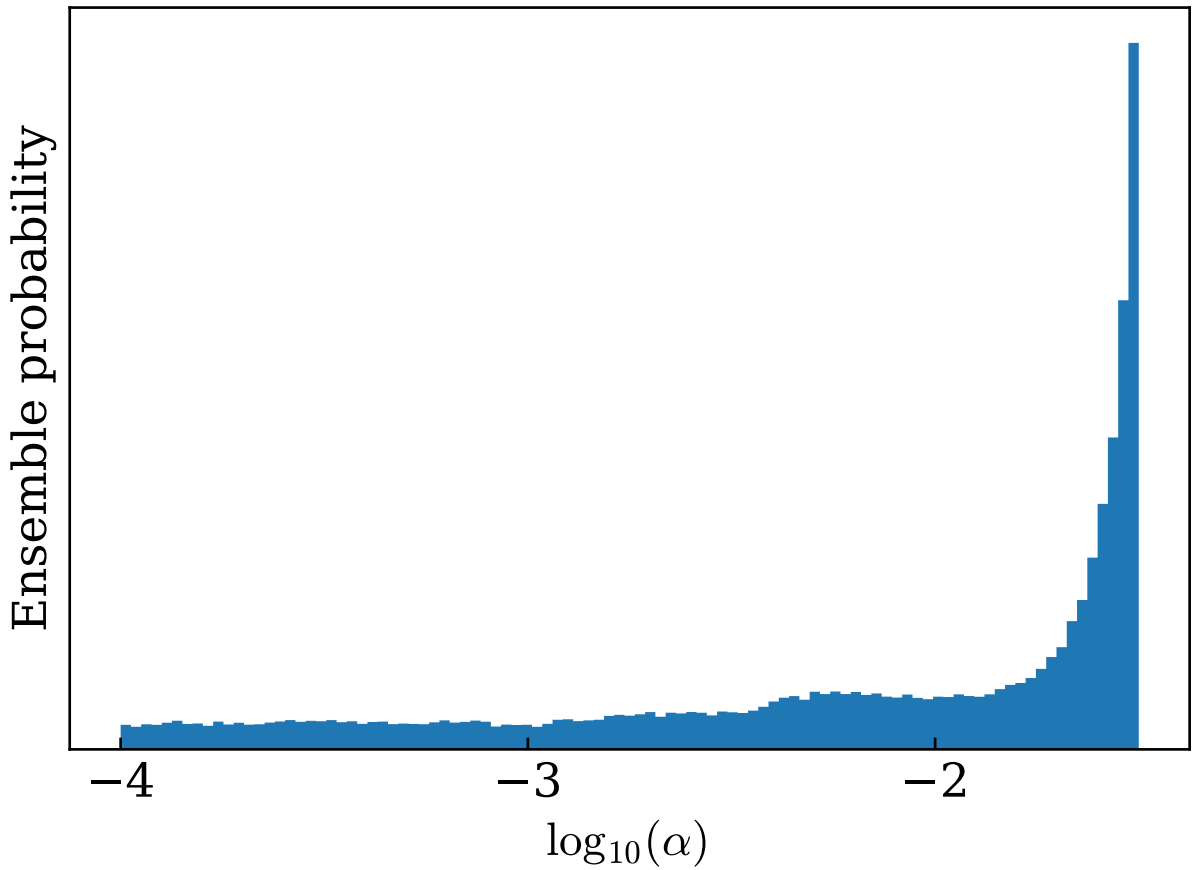
Maximum grain sizes

We may have been too optimistic when deriving grain sizes from spectral indices…



"Surprising" result: very high alphas

Clear preference for very high alpha values in most cases.

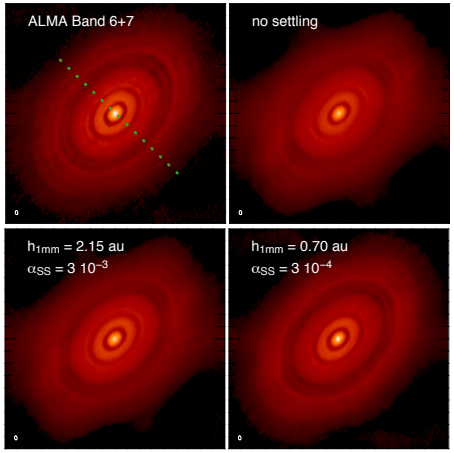


Evidence against standard alpha-disk model?

Increasing observational evidence for low viscosity:

- low turbulence
- settled disks
- multiple rings explained by planets

(Teage et al. 2016, 2018, Flaherty et al. 2018, Pinte et al. 2016, DSHARP results, …)



Pinte et al. 2016

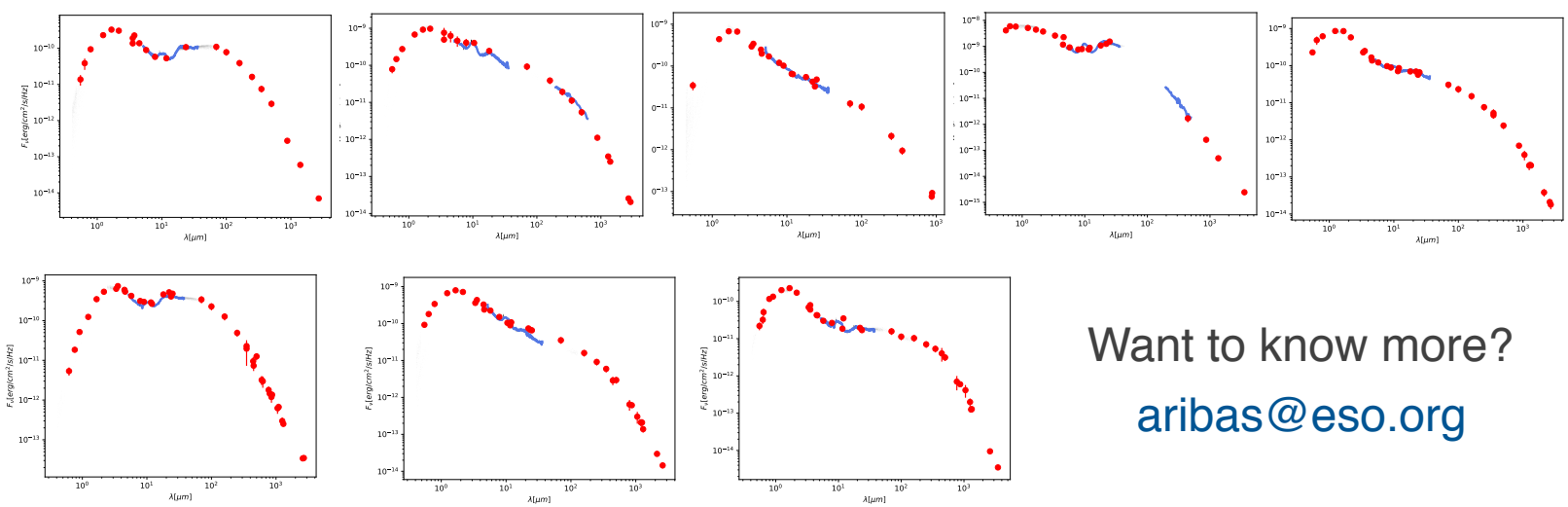
Explanations?

- Are boring disks not boring? Are there hidden substructures?
- DIAD assumes constant alpha and accretion rate across the disk.
- The alpha-disk model assumes viscous transport of angular momentum, which is being increasingly questioned.

(The rest of the parameter estimates should be fine)

Take-away messages

- Physically-motivated disk model + SEDs + MCMC fitting is now feasible
- When fitting ~30 boring disks in Taurus, we find:
  - Significant dust settling
  - No real constraint on grain sizes from SEDs
  - Very high alpha values —> possible evidence against the alpha disk model (or some of its assumptions)?
- Updated disk masses soon, large potential for disk demographic studies



Want to know more?

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