Protoplanetary disks meet artificial neural networks: revisiting the viscous disk model and updated disk masses

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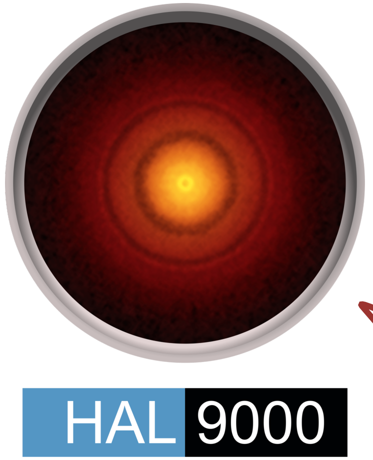


With the aid of artificial neural networks, we drastically sped up the physically-motivated DIAD models of protoplanetary disks. Thanks to this improvement, we were able to model the Spectral Energy Distribution (SED) of 23 disks in the Taurus-Auriga region using a Bayesian approach. Our results suggest that viscosity may not be enough to fully explain angular momentum transport in protoplanetary disks, and that disk winds may play an important role in that process. Our derived disk masses are higher than direct estimates from (sub)mm fluxes, which decreases pre-existing tensions between measured disk masses and those of exoplanetary systems.

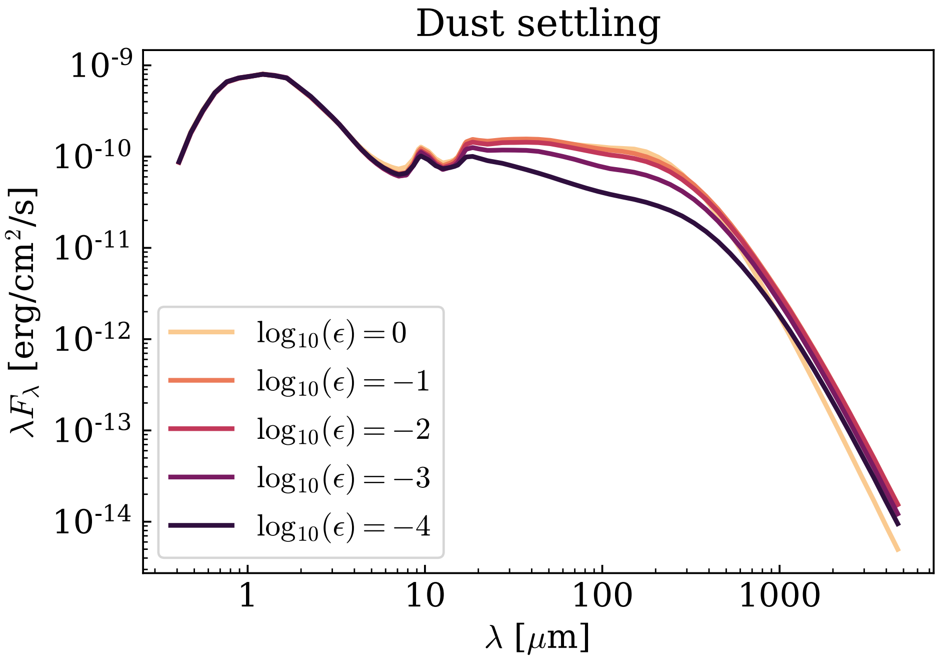
Ribas et al., submitted

Detailed disk models vs large-scale modeling

Models of protoplanetary disks involve many free parameters and are computationally expensive. Therefore, modeling large samples usually requires fixing several free parameters or using simplified models and/or statistical frameworks.

The D’Alessio Irradiated Accretion Disk models (**DIAD**, see Paola D’Alessio’s paper series) are protoplanetary disk models that compute the disk structure self-consistently using the viscous α-disk prescription. However, they require 1-2 hours to calculate the SED of a disk, making any large-scale modeling unfeasible.

Could we somehow combine the benefits of these models with large samples and a Bayesian approach?



SEDs of protoplanetary disks with different levels of dust settling computed with the DIAD models.

Teaching an artificial neural network about protoplanetary disks

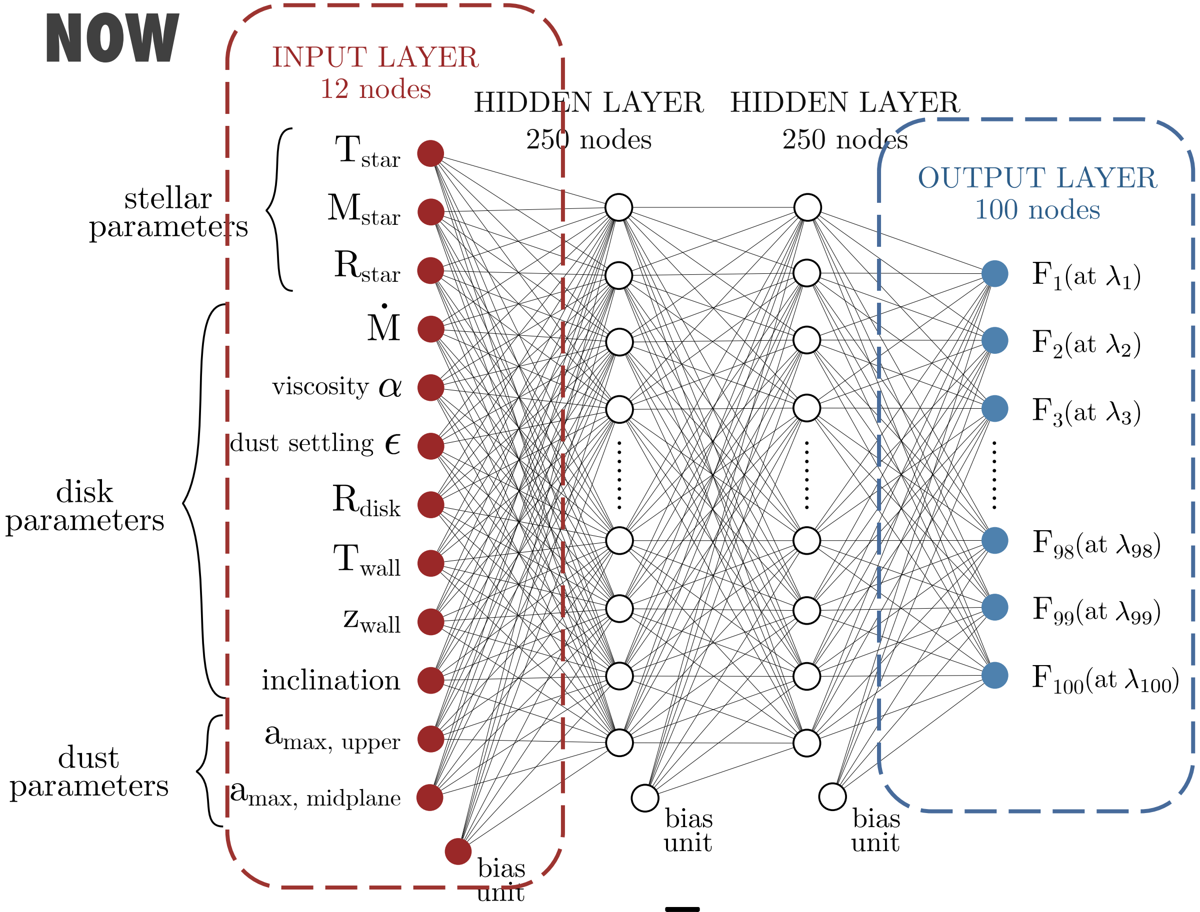
BEFORE

Input parameters → DIAD (detailed calculations) ⏳ 1-2 h → SED

We trained an artificial neural network using pre-computed DIAD disk models. The neural network takes the same input parameters and yields the same output as DIAD, but **within milliseconds**.

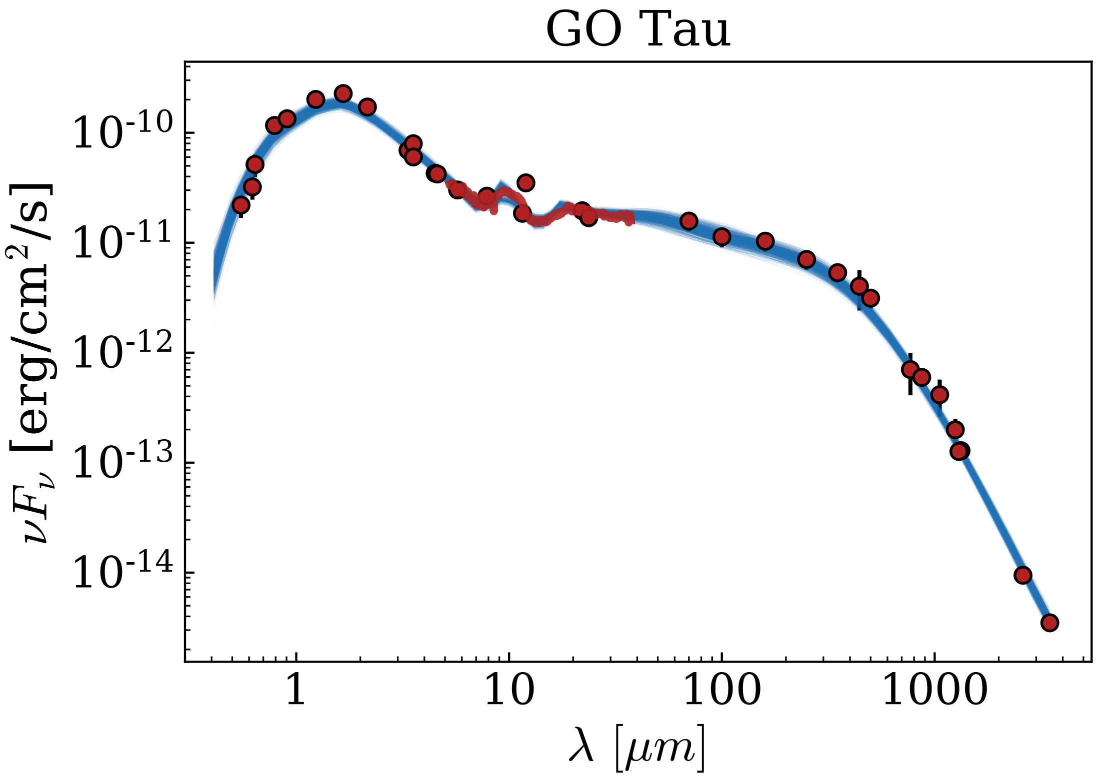
We can now run a full Markov Chain Monte Carlo analysis on sources in hour timescales.

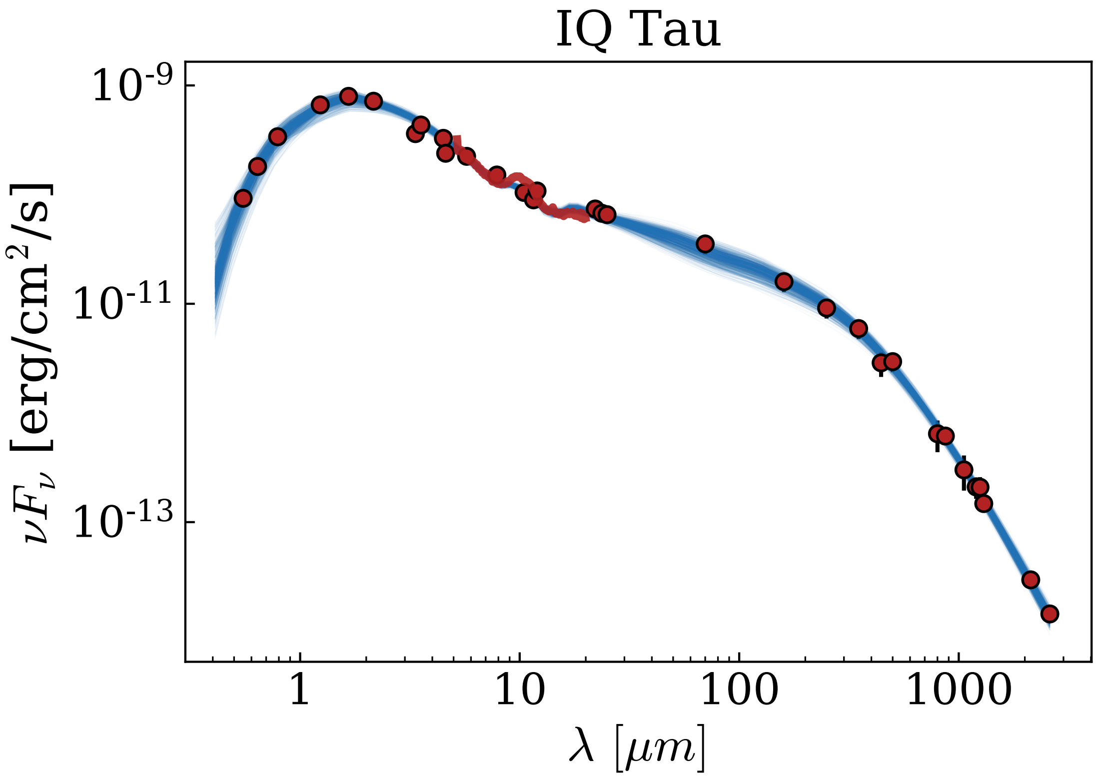
NOW



Input parameters ⏳ ~ ms → SED

We fitted 23 protoplanetary disks in Taurus-Auriga with the artificial neural network using a fully Bayesian approach





Two examples of fitted SEDs. Red dots and lines are observational data. Blue lines show 1000 models randomly drawn from the obtained posterior distributions (Ribas et al., submitted).

Implications for the viscous disk model and disk masses

- Our modeling yields high viscosity values in many cases, in contrast with recent observational results. We also find no correlation between the derived high viscosities and dust settling towards the disk midplane. These findings suggest that **viscosity alone may not completely account for angular momentum transport in protoplanetary disks, and that disk winds may be relevant for this process**.

- **Disk masses derived using full models are systematically higher than direct estimates from (sub)mm fluxes**, possibly because emission at these wavelengths is still (partially) optically thick. This **decreases previous tensions between measured disk masses and those of exoplanetary systems.**

A similar approach could be used to speed up other models!
Feel free to contact me if you are interested: aribas@eso.org