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PhD thesis title:
Multi-wavelength modelling of multi-epoch variability in protoplanetary disks

1 Introduction

The main project of this semester is the investigation of mid-infrared variability of T Tauri stars. They have been long known to be variable in the optical and near-infrared and with Spitzer observations it became apparent that the same holds true for mid-infrared as well (e.g., Espaillat et al. 2011, Kóspál el al. 2012). Now, with new observations performed on JWST the problem is becoming again the center of attention due to discrepancies between JWST and Spitzer observations (e.g. Gasman et al. 2023). An example from Ábrahám el al. (in prep.) is presented in Fig. 1.

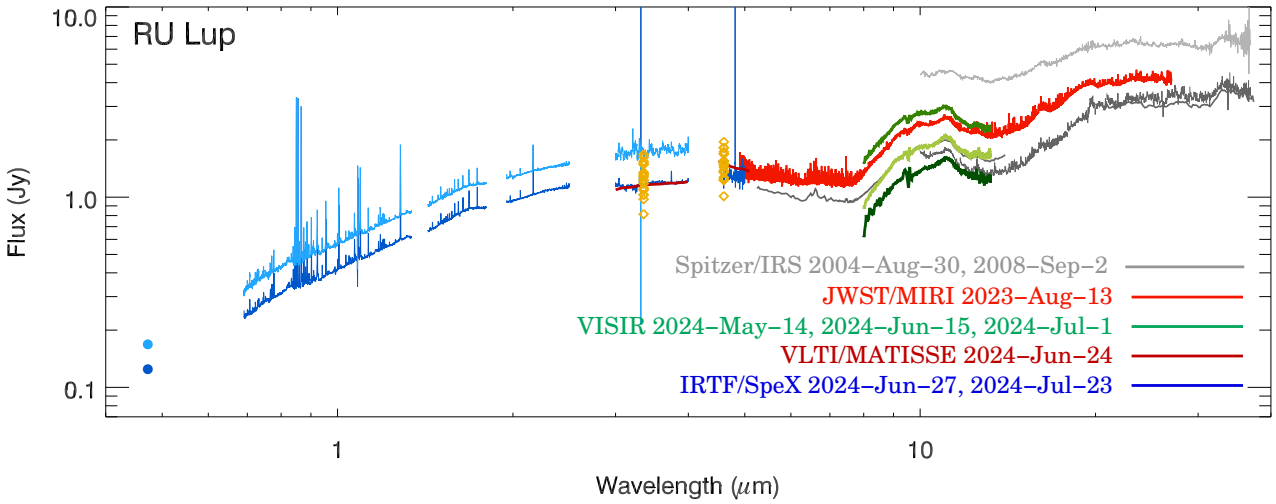

Figure 1: Spitzer, JWST, VISIR, MATISSE and IRTF spectra of RU Lup in 0.5-30 μm range, Ábrahám et al. (in prep.)

Observations on VLT/VISIR and IRTF/SpeX conducted by one of my supervisors, Péter Ábrahám, in June-July of 2024 revealed that this variability occurs on at least week-month timescale (Fig. 1). My task is to model processes responsible for this behaviour and identify the causes.

In addition I have several projects with my previous supervisor, Dr. Tamara Molyarova, that were started towards the end of my MSc degree. They are: 1) an investigation of the formation of cometary nebular structures around FUors (e.g., Movsessian et al. 2006), 2) the research on origins of the molecular line enhancement in certain FUors (e.g., Lee et al. 2019) and 3) the development of a new hydrodynamic 2D model of a protoplanetary disk with a careful treatment of dynamic heating (HURAKAN).

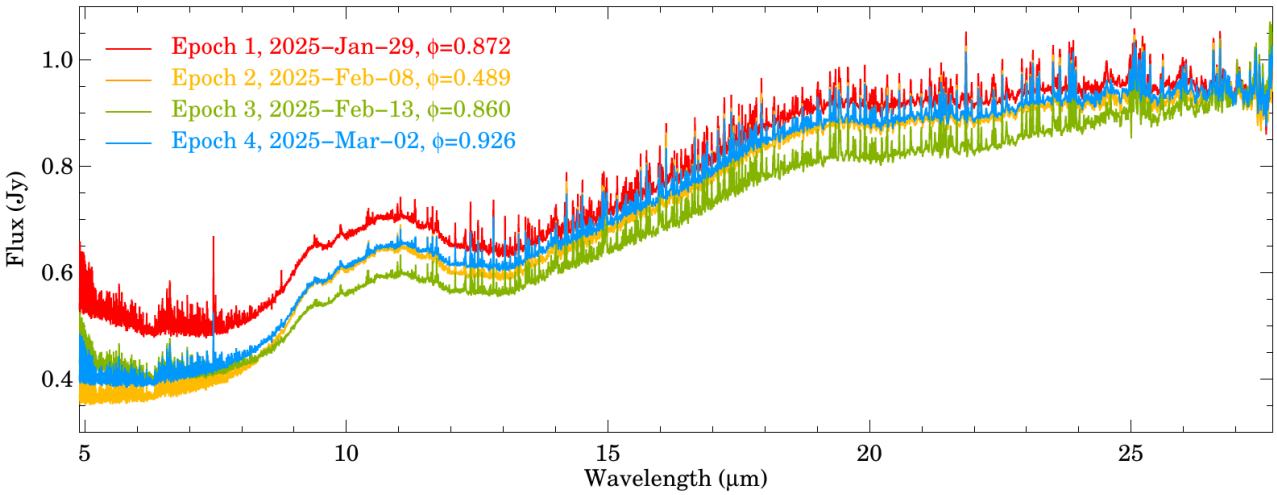

Figure 2: JWST spectra of DQ Tau in 0.5-30 μm range, Kóspál et al. (in prep.)

2 Work carried out during the semester

2.1 Mid-IR variability

This semester's efforts were mostly directed towards fitting newly obtained (in January-March) JWST observations of DQ Tau, a young binary with known accretion variability periodicity (e.g. Czekala et al. 2016, Kóspál et al. 2018). According to these observations, this binary also shows mid-IR variability as can be seen in Fig. 2 (Kóspál et al., in prep.). My task is to fit first the SED of the quiescent epoch of these observations and later see if variations in accretion luminosity and stellar locations as the binary components orbit each other can reproduce the observed variability. As fitting the shape of 10 μm feature required multiple dust species of different size and composition, and binary star positions were found to significantly impact the SED, I developed my own 3D and 2D disk models that can support these features as a part of DiskCheF python package (`https://gitlab.com/SmirnGreg/diskchef`). ANDES model that I used previously would require a complete rewrite to support this. My model sets up the gas and dust density structure (separate for each species) and uses RADMC-3D to compute dust temperatures and SED. I first tried fitting simply with a parametric vertical structure but the best fit had deviations from the fitted epoch on the level of variability between the epochs. So I have added to the 3D model an option of an azimuthally asymmetric puffed up inner rim because the binary is always closer to one part of the disk. At the moment of writing the review, the fitting routine is still running.

I also investigated an option of fitting the disk assuming hydrostatic equilibrium which turned out to be unfeasible without additional assumptions. I explored the role of dust settling, dust size, and dust to gas ratio distributions as well as gaps. Dust settling did in the end lead to the correct shape of the SED but not absolute flux values. Preliminary results from fitting also show a much larger scale height than what hydrostatic equilibrium gives. Currently I do not have a solution for a more physical approach to modelling of vertical structure but I will seek out help from experts on dust and gas dynamics in the disk this summer (from Dr. Mario Flock, for example). Additionally, I set up a reference HURAKAN model following Woitke el al. (2016) parameters to run for until a time moment of 30 yr (should be enough to find a stable solution for an area $\lesssim$10 au that mid-IR emission comes from). This initial solution can be later used to investigate mid-IR variability with hydrothermodynamics.

2.2 Other projects

A good portion of the semester was also dedicated to answering to a review to our paper that I submitted to A&A last semester. The review was positive but required a major revision that resulted in doubling the length of the paper. We also received a second review to the revised version and it was mostly concerning typos and small structural changes for the paper. This review was also now answered and the paper was resubmitted.

Regarding the rest of the projects, on the week of 9-13 June, Dr. Tamara Molyarova, my MSc supervisor and now close collaborator, came to Budapest as a part of short-term scientific mission funded by COST Action PLANETS to collaborate on FUor line variability and their cometary nebulae. We had many fruitful discussions and we will run more models this summer exploring the discussed ideas.

3 Publications

1. Varga et al., T CrA has a companion. First direct detection of T CrA B with VLTI/MATISSE, A&A, Volume 695, id.L21, 9 pp., March 2025
2. Zwicky et al., Dancing on the Grain: Variety of CO and its isotopologue fluxes as a result of surface chemistry and T Tauri disk properties, accepted to A&A
3. Kóspál et al., Time-resolved protoplanetary disk physics in DQ Tau, A&A, soon to be submitted
4. Ábrahám et al., A systematic investigation of the unsteady inner disks in a sample of young stars using VLT, VLTI, and JWST, A&A, in prep.
5. Pavlyuchenkov et al., Response of a protoplanetary disk to a luminosity flare: the case of EX Lupi type outburst. I. EXors, A&A, in prep.
6. Molyarova et al., Modelling optical images of cometary nebulae around FUor-like objects, MNRAS, in prep.

4 Studies

ELTE courses:

1. Exoplanetary research (FIZ/5/040, by László Molnár & Róbert Szabó)
2. The formation of planets and planetary systems (FIZ/5/045, by Zsolt Sándor & Ramon Brasser)

Other:

1. Spring school “The Birth of Solar Planets”, 25th February — 6th March in Bertinoro, Italy

5 Conferences

1. EAS Annual Meeting 2025, Cork, Ireland, 23-27 June 2025; online participation with a ePoster, title “Disk Parameters from CO isotopologues: Its COmplicated”