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PhD Program: Astronomy and Space Physics

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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.

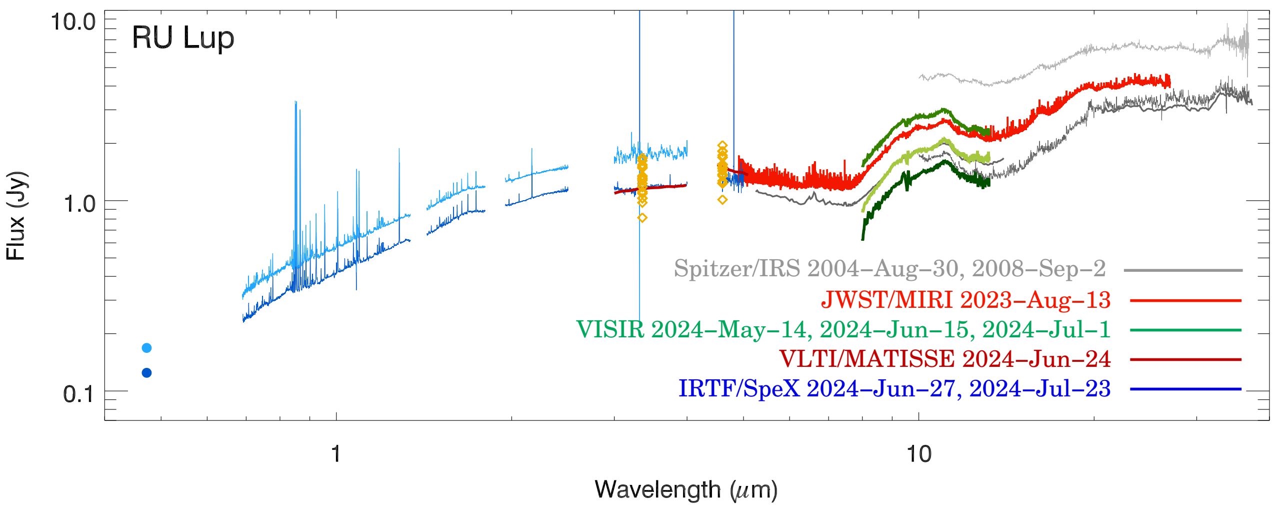

Figure 1: Spitzer, JWST, VISIR, MATISSE and IRTF spectra of RU Lup in 0.5-30 μm range, Ábrahám et al. (in prep.)

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).

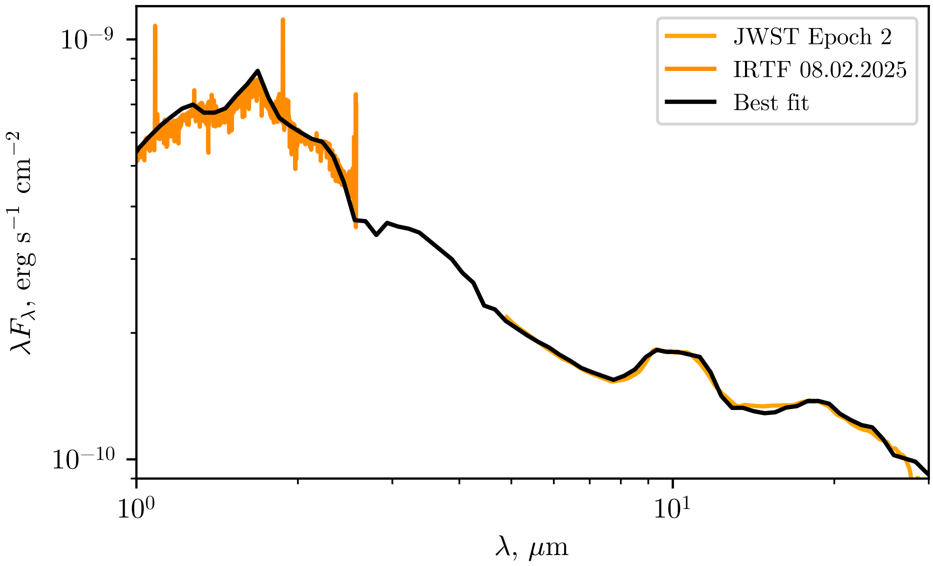

Figure 2: The best fit SED for DQ Tau Epoch 2 together with JWST and IRTF observations

2 Work carried out during the semester

2.1 Mid-IR variability

This semester's efforts continued to be predominantly directed towards fitting JWST observations of DQ Tau (see previous report). After many trials and errors and consultations with experts in the field, such as Prof. Thomas Henning (MPIA) and Prof. Cornelis Dullemond (University of Heidelberg), I successfully fitted the second, quiescent, epoch of DQ Tau observations where the stars are in apoastron. The fitted SED is presented in Fig. 2. Epoch 2 was chosen first as it is representative of the most common state for the system and there is contemporaneous optical spectral data from IRTF/SpeX. Fitting this epoch was important to establish the baseline global structure of the disk that remains unchanged on the observational timescales. The result of the fitting allowed us to reveal that the inner disk of DQ Tau is heavily flared while the outer disk remains in the shadow. Now, my task is to fit the other epochs where the stars are in the periastron and have recently produced or about to produce a luminosity burst. As changes can only be where dynamical timescales are shorter than two weeks, I am trying to fit the data by adding a variable amount of dust in the region between periastron and apoastron radii of the stars. At the moment of writing the report, the fitting routines for two epochs are still running. Meanwhile, I made a good progress on writing the paper draft and it is finished up to the available results. The results obtained so far were presented on a Graz-Vienna Exoplanet Scientist Meeting VII in Vienna Observatory.

Regarding fitting with hydrostatic equilibrium, I presented my struggles with it at a joint meeting of our group and group of Dr. Mario Flock (MPIA) organised at Vienna Observatory. I was given advice to try pressure-dependent sublimation temperature for dust. Trying that did not lead to a better fit and I have concluded that my model uses too simple assumptions for this problem. A proper solution would require including the radiative transfer for gas and a correct treatment for heat redistribution between dust and gas components. I decided to postpone the solution of this problem for now. Additionally, I am abandoning the project with hydrodynamical model HURAKAN as I found the code to be yet in the testing stage and too slow for my problem (it takes months to compute just one model). Instead, I will pursue a project proposed by Prof. Thomas Henning (MPIA) with modelling different inner disk geometries (misaligned disk, warped disk, inner rim wall) to investigate the impact of these geometries on SED and how variabilities in this geometries also impact the SED. So far I have written the code for a misaligned disk and I am yet to test it with radiative transfer.

2.2 Other projects

Regarding the rest of the projects, Dr. Tamara Molyarova (University of Leeds) and I made very good progress on the project about FUor line diversity. We run several test models to identify the parameters that affect the line emission the most and we found them. They turned out to be: mass of the surrounding the disk envelope, initial chemical composition of the disk, disk size and dust maximum size. We agreed upon a grid of models to run for a systematic investigation and I have received computing resources at HUN-REN cloud to carry it out (titled "Molecular line diversity of FU Ori-type stars", approved until May 2026). As of now, the models are running and preliminary estimates show that they will finish in a month. As they run I have started to prepare a paper draft on our first results.

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, Volume 699, id.A377, 17 pp., July 2025
3. Kóspál et al., Time-resolved protoplanetary disk physics in DQ Tau, A&A, Volume 703, id.A20, 21 pp., October 2025
4. Zwicky et al., Variable inner disk structure of DQ Tau revealed by JWST (preliminary title), in prep.
5. Zwicky et al., FUor molecular line diversity (preliminary title), in prep.
6. 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.
7. 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.
8. Molyarova et al., Modelling optical images of cometary nebulae around FUor-like objects, MNRAS, in prep.

4 Studies

ELTE courses:

1. Accretion processes in star formation (FIZ/5/033, by Ábrahám Péter)
2. Radio Astronomy I (FIZ/5/009, by Szentirmayné Gabányi Krisztina Éva & Frey Sándor)

Other:

1. Accepted to Les Houches School of Physics Session CXXVII "From the Interstellar Medium to the Formation of Stars: Physics, Tools and Methods.", to be held on 6th — 31st July in Les Houches, France

5 Conferences

1. Graz-Vienna Exoplanet Scientist Meeting VII, Vienna, Austria, 26 September 2025; oral presentation, title "Mid-infrared variability monitoring and modelling of DQ Tau disk"