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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 was 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, Kospal 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.

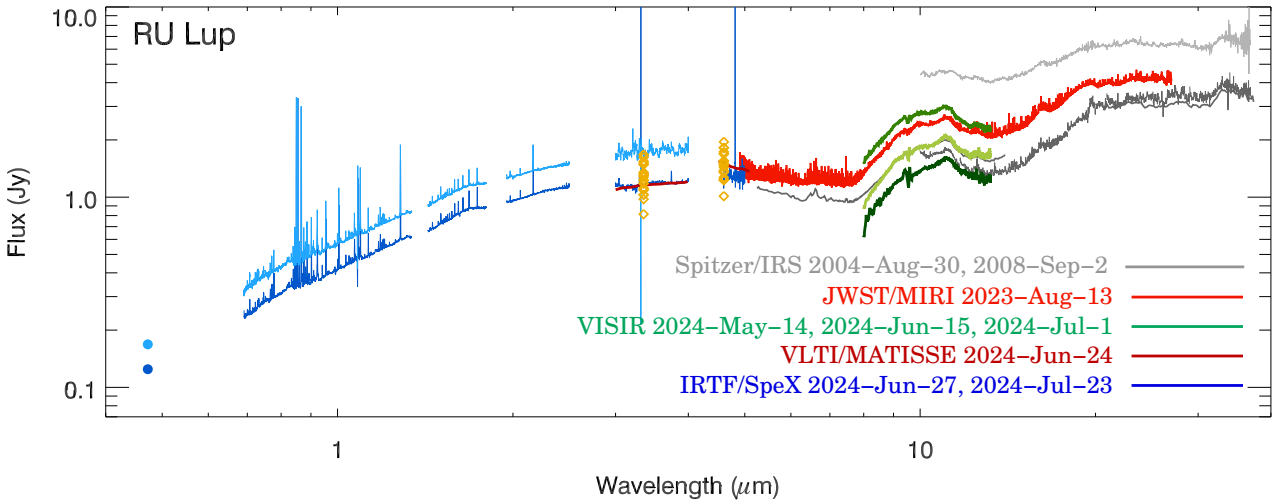

Figure 1: Spitzer, JWST, VISIR, MATISSE and IRTF spectra of RU Lup in 0.5-30 μm range, Ábrahám el al. (in prep.)

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 T.A. et al. 2006), 2) the research on origins of the molecular line enhancement in certain FUors (e.g., Lee J.E. et al. 2019) and 3) the development of a new hydrodynamic 2D model of a protoplanetary disk with a careful treatment of dynamic heating.

2 Work carried out during the semester

2.1 Mid-IR variability

Majority of this semester was dedicated to picking the right model for the job. My first instinct was to utilise astrochemical model ANDES (Akimkin et al. 2013) that I was most familiar with. The chemical part of it is irrelevant for the project at the moment but it does provide a ready tool for setting up disk physical structure. Together with radiative transfer code RADMC-3D I produced first SEDs to test the applicability of the model. They revealed that disk temperature profiles produced by ANDES are too high in the relevant inner regions. To resolve the problem I upgraded ANDES to have an option of temperature calculation via RADMC-3D's mctherm (based on Monte Carlo method of Bjorkman & Wood 2001). It led to a different problem: inner regions of interest turned out to be so optically thick that for a computationally reasonable amount of photon packets, too few of them reached the disk midplane. This led to a noisy low temperature distribution and temperature-density distributions could not converge to an equilibrium solution (thermal and hydrostatic).

During my trip to Heidelberg, Prof. Cornelis Dullemond (creator of RADMC-3D) proposed a solution from a previous iteration of RADMC, RADMC-2D. It included a module that allowed to find temperatures using diffusion approximation in cells with low photon statistics. RADMC-2D is hard to use and implement at the moment due to its reliance on IDL scripts to set up input files. So I took it upon myself to write a diffusion module for RADMC-3D based on RADMC-2D. I was successful and also expanded it to include new features of RADMC-3D and now I am in discussion with Prof. Dullemond to make it a permanent part of RADMC-3D.

What we plan to do with this new version of ANDES (I call it radANDES) is to use it to fit SEDs of objects in our sample at different epochs and see which model parameters change between the epochs. I am currently conducting a literature study and preliminary analysis for the sample to identify what values and ranges of values of model parameters we should use.

At the same time I am exploring a more physical approach to the problem with a different model, HURAKAN, written by Dr. Yaroslav Pavlyuchenkov and Dr. Vitaly Akimkin that I helped test and benchmark (additional project 3 from Introduction). HURAKAN is a hydrodynamic model with its own dynamic radiative transfer using flux limited diffusion method so it is perfect for inner regions of interest. As a dynamic model, it naturally takes into account the required timescales as opposed to radANDES that provides an equilibrium solution for physical structure (though I have developed subroutines for it that allow for limited dynamics, i.e. an equilibrium solution will be only where it can be reached on a given timescale and everywhere else is kept fixed as in the initial time moment). However it takes a very long time (several hours for one time moment) to run so I am still at the testing stage for it.

2.2 Other projects

In November we made a decision to unearth a project I did with Dr. Tamara Molyarova during July 2023 and turn these results into a paper. Initially results were presented and reported in Russian so I translated the report, polished the text, found some mistakes which prompted me to rerun the whole model set and in a few weeks the paper was ready. It is now submitted to A&A and is under peer-review.

Regarding other projects, little progress was made since they are not a priority to the first authors and I am there only on co-author rights. I did some plots and added some text to the manuscripts when asked but not more. At some point, however, FUor line variability project leadership was transferred to me and after analysing what was done I decided that we need actual observational data to proceed. I am in contact with Zsófia Szabó from MPIfR (Bonn,

Germany), who has the observational data I need and waiting for her to send them to me in a format and units I requested.

3 Publications

1. Varga et al., T CrA has a companion. First direct detection of T CrA B with VLTI/MATISSE, A&A, under review
2. Zwicky et al., A guide to CO isotopologue flux variations with protoplanetary disk parameters, A&A, under review
3. 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.
4. 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.
5. Molyarova et al., Modelling optical images of cometary nebulae around FUor-like objects, MNRAS, in prep.

4 Studies

ELTE courses:

1. (Exo)planetary atmospheres seminar I
2. Astrostatistics I

Other:

1. Accepted to Spring school "The Birth of Solar Planets", to be held on 25th February — 6th March in Bertinoro, Italy

5 Conferences

1. Born in Fire: Eruptive Stars and Planet Formation, September 24-27, 2024, Santiago, Chile; online participation with a poster, title "Searching for the past FU Ori Outbursts with Submillimeter Molecular Lines"

6 Awards

1. STSM grant of COST Action PLANETS, 1247 EUR (for a short work trip that is going to be in Feb 2nd-7th 2025)