III. Semester Report

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Astronomy and Space Physics PhD program

Supervisor: Fernando Cruz-Sáenz de Miera

Title of the thesis: Near-infrared spectroscopy of eruptive young stars: new discoveries and long term follow-up observations

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Introduction:

Protostars form in the densest molecular cloud cores. Due to the non-zero angular momentum of the initial cloud, matter forms a disk around it. In this orbiting disk, the material slowly spirals inwards and accretes onto the surface of the star. Accretion hits up the disc, causing it to be bright, and thus it causes the disc to be significant contributor to the bolometric luminosity of the young stellar objects (YSO). Therefore, it is expected any changes in these mass accretion rates are reflected as changes in the brightness of the young stars. One group of YSOs are young eruptive stars. These objects show large outbursts in visible and near-infrared light (Δmag > 1). The luminosities suggest an increase in the mass accretion rate.

My project will be to identify new eruptive young stars. To do this, I use measurements from the Gaia space telescope or the Zwicky Transient Facility, which have an alerts program that reports if there are sudden changes in the photometry of a star. Afterwards, I will examine whether they are in a star forming region by analyzing their coordinates and distances and, finally, will compile their spectral energy distribution to verify that they a young stellar object. After these steps, I will be confident that these sources are good eruptive young star candidates, and prepare follow-up optical and near-infrared observations to obtain their spectra. For these spectroscopic observations, some of the facilities that I will request time for are the Very Large Telescope and the Nordic Optical Telescope. I will identify the spectral lines which are typical indicators of mass accretion rate (e.g. Hα, Paβ, Brγ), search for indications of a P-Cygni line profile, which is common in eruptive young star, and estimate the mass accretion rate from the accretion luminosity. I will follow up by analyzing the CO band heads (>2.29 μm), and of other lines (e.g. Fe I, Na I and Ca I) to estimate the geometry of the circumstellar disk. Finally, I will search for jets, using different forbidden metallic and H_2 lines.

Description of research work carried out in current semester:

During this semester, I have re-evaluated most of the calculations I previously conducted for the Gaia20dsk Young Stellar Object (YSO). This re-evaluation was prompted by the realization that the extinction value had been inadequately estimated. In addition to addressing this issue, I explored a new approach aimed at revealing more spectral lines in a given spectrum or extracting additional information from already detected lines. The results of evaluating this new method are expected in the next month. Apart from these tasks, I have initiated discussions with my supervisor regarding the drafting of a paper based on the findings from this source. The goal is to prepare the draft for submission in the near future.

Since the previous semester, the Gaia space observatory has conducted additional measurements. In Figure 1., the light curve of Gaia20sdk illustrates the new measurements represented by red open circles. The new peak is around at 17.4 mag in the Gaia G band, which is similar to the previous peak. This observed re-brightening effect over a few years suggests that the event may be attributed to a real physical phenomenon, rather than being solely a result of changes in extinction. If it were another periodic non-physical effect, we would have observed another brightening in the 3-4 years preceding the Gaia alerts date.

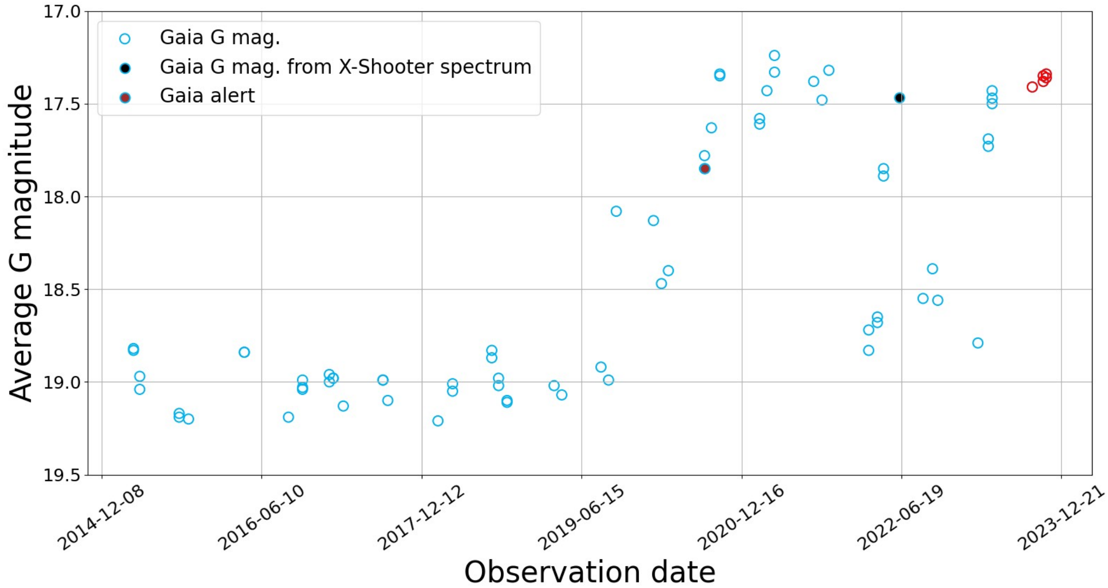

Figure 1: Gaia20dsk light curve. The unfilled circles represent the Gaia magnitude measurements of the stars taken since the end of 2014. The filled blue circle indicate the time when the spectrum of the Gaia20dsk source was captured using X-Shooter while the red filled circle indicate the time of Gaia alerts . The red circles represent recent measurements taken during this semester, indicating that the source found a new peak.

Regarding the extinction calculation, I employed the Stilism[1] web tool. Given the substantial distance of my source (approximately 2.5 kpc), calculations at such distances involve around 40% uncertainties, significantly impacting the extinction of the spectrum and consequently the calculated mass accretion rates (Macc). Fortunately, the method used for computing the mass accretion rate inherently addresses this challenge. I utilized the approach outlined by Alcala et al, 2017[a]. (additional details can be found in the previous semester reports), which employs an empirical model to compute Macc from emission lines. Theoretically, these emission lines probe the accretion process, indicating that they should exhibit similar Macc values. Hence, I adjusted the extinction value until I minimized the differences between the Macc values calculated from the identified emission lines associated with the magnetic accretion process. To achieve this, I applied linear regression to the calculated data points to obtain the minimal slope. The obtained extinction is about 6.55 in V band with R_V=3.1 extinction factor. Figure 2. illustrates the new Macc values, with an average of approximately $6*10^{-8}$ $M_{\odot}$/year. The considerable error bars primarily stem from the coefficients provided by Alcalá in his equations. Conversely, the Hα line deviates from the trend. This deviation is attributed to the fact that this line probes other effects surrounding the star, not just the accretion process.

1 https://stilism.obspm.fr/

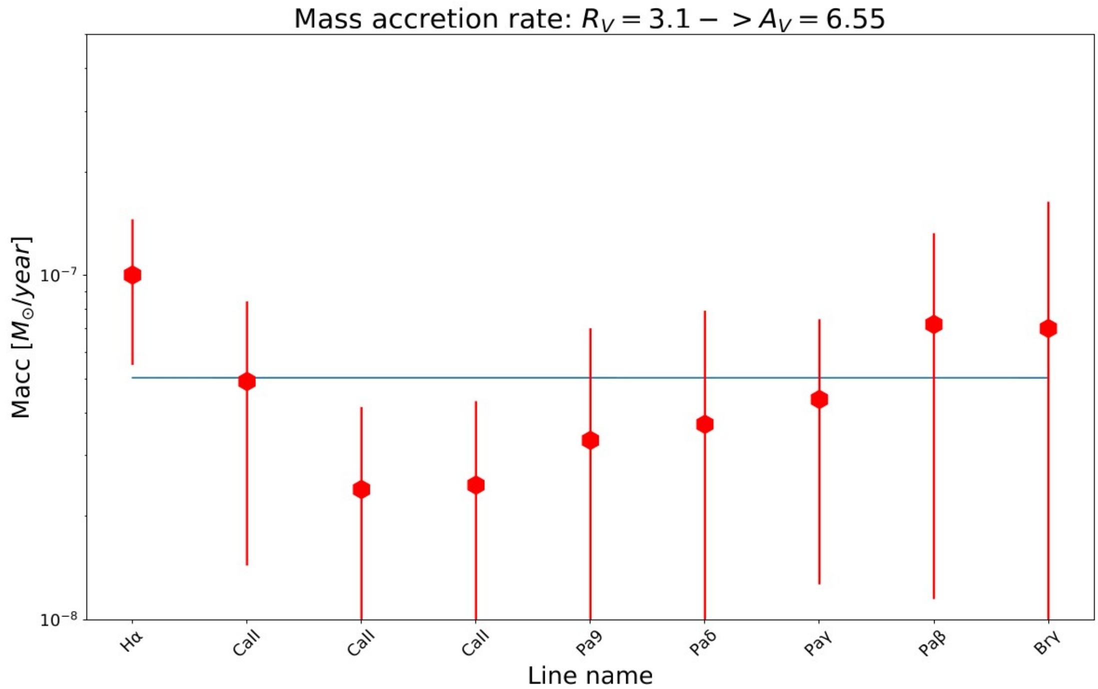

Figure 2: Gaia20sdk mass accretion rate. The red hexagons represent the mass accretion rates from each identified line. On the x-axis the lines name are the follows: Hα line is part of the Balmer series, Paγ lines are part of the Paschen series (where γ = 9, δ, γ, β), and the Brγ is part of the Bracket series. The numbers after the letters associated to the upper energy level of the transmission in the series. The three CaII are the CalciumII triplets. The blue line is a linear fit for the datapoint (see text).

The changes in extinction will naturally affect other processes detailed in the previous semester reports. While the fundamentals of these processes remain the same; their outcomes, as for quantity have been changed, but they still reinforce the conclusions drawn in the last semester.

In addition to the recalculation, I accomplished a new method suggested by my supervisor to reveal new lines in the spectrum or extract new information from already detected spectral lines. To do this, I used the XSL DR3 (X-shooter Spectral Library) database, comprising about 830 stellar spectra. The original idea involved comparing absorption lines from a short range of the Gaia20dsk spectrum to specimens within the same wavelength range in the database. Initially, I narrowed the sample to stars with properties similar to TTauri stars. For the comparison, I selected a few ten Angstrom range in the Gaia20dsk spectrum where absorption lines are present and where the veiling effect more or less negligible or at least has weaker effect. Subsequently, I developed a Python code to accomplish the required process to compare this region with the same corresponding range in the restricted specimen stars. Finally, I chose the result where the Xi^2 test showed the least differences. Figure 3. illustrates the best fit, allowing me to identify a star exhibiting a similar photosphere to Gaia20dsk. This star can then be used to subtract from my spectrum. The benefits of this method are not yet clear and will be further assessed in the next month.

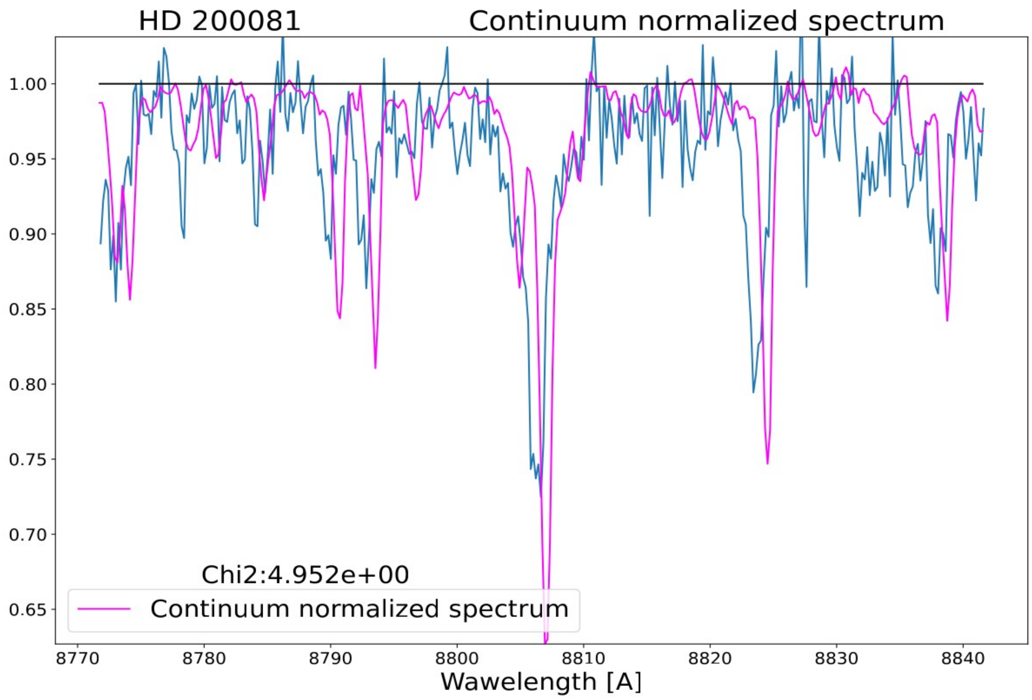

Figure 3: Photosphere comparison. The blue line is a spectrum range from Gaia20dsk, while the purple is a compared star with name HD200081.

To summarize our current understanding, Gaia20dsk is identified as a Class I/Class II young stellar object, exhibiting recurrent brightening events. These events are attributed to real physical effects rather than changes in extinction along the line of sight, a conclusion supported by the 2MASS color-color diagram. The brightening occurs by approximately 1.5-2 magnitudes in the Gaia G band, with a time separation of around 2.5 years between the two peaks. This short recurrence period, and short lived outbursts aligns with the properties observed in EXor-type stars (Marc A. et al 2014[b]). The distance to the source is crucial, as the flux of the star follows a $1/r^2$ dependency, introducing significant errors in mass accretion calculations. However, the calculated data suggests a rate of about $6*10^{-8}$ $M_{\odot}$/year, close to the 10^{-7} $M_{\odot}$/year lower limit for classifying a source as an EXor (Stock et al., 2020[c]). Notably, EXors stars exhibit numerous emission lines in their spectra, including specific lines characteristic of the magnetic accretion process. In the spectra of Gaia20dsk, lines from the Balmer, Paschen, and Brackett series associated with magnetic accretion, along with other emission lines related to the same process, have been identified.

Concluding this semester, I have completed the first draft of my paper on this source. In the upcoming month, my supervisor and I will scrutinize it in detail and prepare it for submission.

Studies in current semester:

FIZ/5/055 Solar System plasma physic
FIZ/5/031 The physics of interstellar matter I.

Teaching activity in current semester:

ELTE cseszlgyk2g17ga – Csillagászati észlelési gyakorlatok 2.; 2 lessons per week

Activities in scientific associations:

I became a member of the ‘Gaia alerts’ groups at Konkoly observatory, and I attended their meetings

I have been offered an opportunity to contribute to the ongoing research on sources detected in the Gaia Photometric Science Alerts system under the guidance of Dr. Zsófia Nagy.

References:

[a] Alcalá, J. M., Manara, C. F., Natta, A., et al. 2017, A&A, 600, A20

[b] Marc A., Péter Á., Michael M. D., et al. 2014, arXiv:1401.3368
[c] Stock, C., Caratti o Garatti, A., McGinnis, P., et al. 2020, A&A, 643, A181