II. Semester Report

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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:

This semester, I have started to write a paper on the Gaia20dsk source, which I began analysing last semester. One of the part of my work involved performing synthetic photometry on the source using its X-Shooter spectra taken on 2022-06-12. On the other hand I compiled the spectral energy distribution (SED) of the source. These findings are visible in Figure 1, where fainter markers represent the SED photometry data, while brighter markers indicate specific observations.

To obtain the SED data, I utilized the VO SED Analyzer (VOSA)[1] websites. For the calculation of synthetic photometry, I relied on the PYPHOT[2] Python tool. The inputs for this tool are response functions (filter) that describe how photons are detected and measured by the different

1 http://svo2.cab.inta-csic.es/theory/vosa/
2 https://mfouesneau.github.io/pyphot/

photometric bands in stellar spectrum. Using the appropriate filter from the tool and specifying the spectral range, I computed the synthetic flux for the following six bands: Gaia's Bp, G and Rp, and 2MASS' J, H and Ks.

In Figure 1, I show how that the measured photometry from the 2MASS survey and the synthetic photometry computed from the X-Shooter spectrum, exhibit significant differences, particularly in the J and H passbands. It is worth noting that the 2MASS survey was conducted on 1998-08-10, whereas the spectrum was obtained in 2022-06-12. These time gap may suggest the occurrence of past outbursts or some real physical events (Kóspál et al. 2011[a]). Thus, we constructed a color-color diagram to search for valuable insights in understanding the cause of this changes.

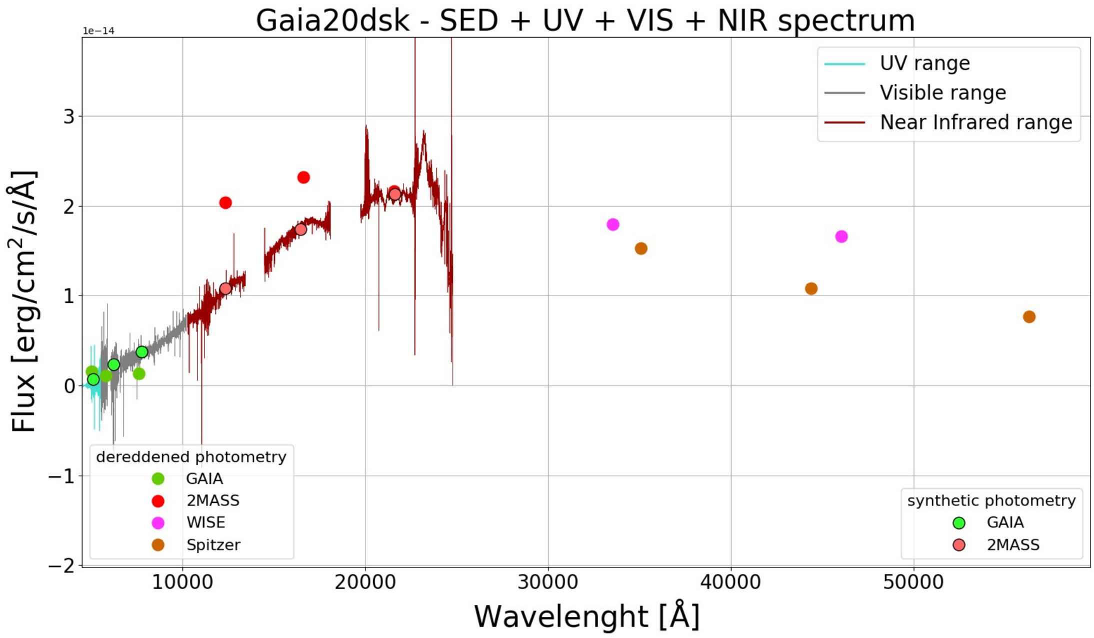

Figure 1: Gaia20dsK SED and synthetic photometry. The spectral and SED photometry is corrected to the extinction. Different spectral range are denoted with different color. The measured photometry signified by light colors, while the synthetic photometry denoted by dark colors.

Figure 2 depicts the J-H vs. H-Ks color-color diagram, where the blue filled dots represent synthetic photometry, and the red dots indicate the measured photometry from the 2MASS survey. The red arrow represents the direction and magnitude of the extinction in the V band, with a value of 1 magnitude. Generally, if the data points align parallel to the extinction vector, it suggests that the observed objects are primarily affected by extinction rather than intrinsic variations. However, in the case of Gaia20dsk, the data points and the extinction vector in Figure 2 are not parallel to each other. This indicates the presence of additional factors influencing the observed properties. It suggests that real physical effects, such as possible outbursts (Hodapp et al. 2020[b]), may have occurred in the Gaia20dsk system.

There are several method to classify a YSO object. For example one can use the 2MASS and WISE color-color diagram. In the case of Gaia20dsk source, I used this color-color diagram method, based on the Fig. 6. of Koenig and Leisawitz 2014[c] paper. I used the 2MASS J and H photometry, and I used the WISE W1 and W2 photometry as well as. From these values, I get the following color indices: J-H: 1.241 | W1-W2: 1.266. After that, we put these values on the forementioned figure. These colors indicate that the star could be a Class I object i.e. a still embedded protostar.

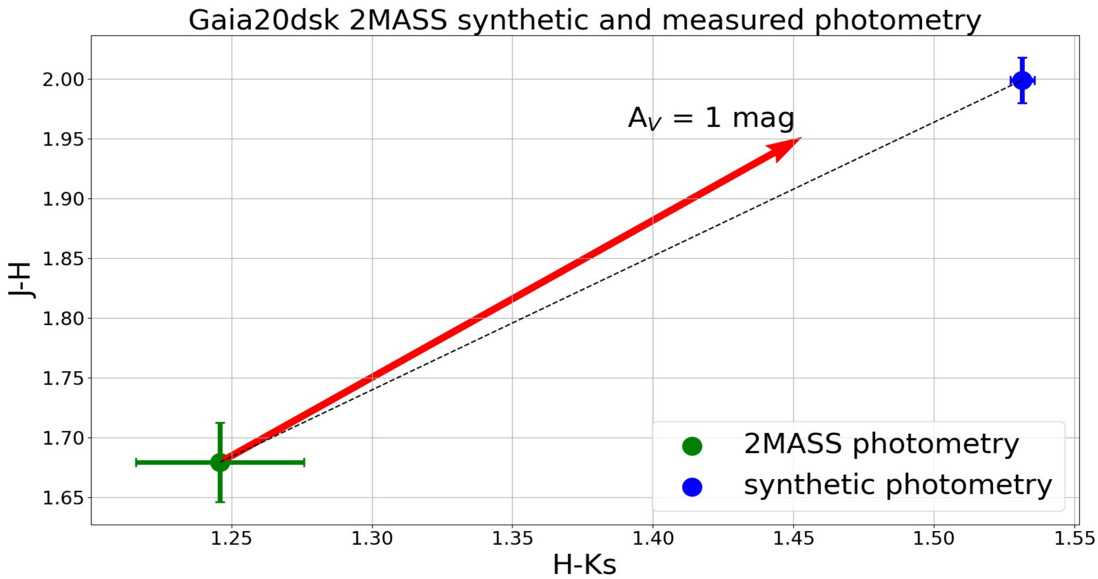

Figure 2: J-H vs. H-Ks color-color diagram. The green dots represent the measured 2MASS photometry data from 1998, which can be accessed from the VOSA webpage (details in the text). The blue dots indicate the synthetic photometry calculated from the X-Shooter spectrum. The red arrow represents the direction of the extinction. The difference in the slope between the two points (2MASS and synthetic photometry) and the extinction vector suggests that the differences observed may be attributed to other real physical effects beyond just extinction.

Figure 3 illustrates the light curve of Gaia20dsk. The data for the light curve are accessible on the Gaia alerts[3] web page. Notably, since the previous semester, Gaia has provided new data points, represented by red circles. It appears that the source has begun to brighten up again. Considering that the previous brightening event lasted only three years, this re-brightening could be indicative of real physical events occurring within the system. To gain further confidence and understanding, acquiring new spectral data and additional data points for the light curve would be necessary. These additional measurements would provide valuable insights into the nature of the re brightening and help shed light on the underlying physical mechanisms at work within the Gaia20dsk system.

Figure 4 illustrates the mass accretion rate of the star. Since the previous semester, it was necessary to recalculate these values using the method described in the paper by Alcala et al. (2017[d]) (More details in last semester report). The average mass accretion rate is approximately 10^{-8} solar masses per year. This calculated mass accretion values are an order of magnitude lower than those typically observed in Exors (Stock et al., 2020[e]). However, the 2MASS measurements and synthetic photometry from the X-Shooter spectra suggest that a real physical event could occurred in the Gaia20dsk system at the end of the last century, which cannot be solely explained by extinction effects (Kóspál et al. 2011[a]). As the classification based on the 2MASS J-H and WISE W1-W2 colors suggest this source could be a Class I type YSO (Koenig and Leisawitz 2014[c]).

The light curve of this source in the Gaia G band reveals two recent brightening events in the last 3-4 year. The spectrum was taken at the end of one of these events exhibits various emission spectral lines, including transitions of hydrogen (Balmer, Paschen, and Bracket series) and helium, as well as strong accretion tracer lines such as Hydrogen α, Paschen β, Bracket γ, and the Calcium II triplets. There may also be possible presence of forbidden iron emission lines, indicative of bipolar jets or outflows (Davis et al. 2011[f]).   It is not conclusive that this source is an eruptive YSO, there are compelling indications suggesting that it could be a ClassI type YSO with an accreting disk system.

3 http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia20dsk/

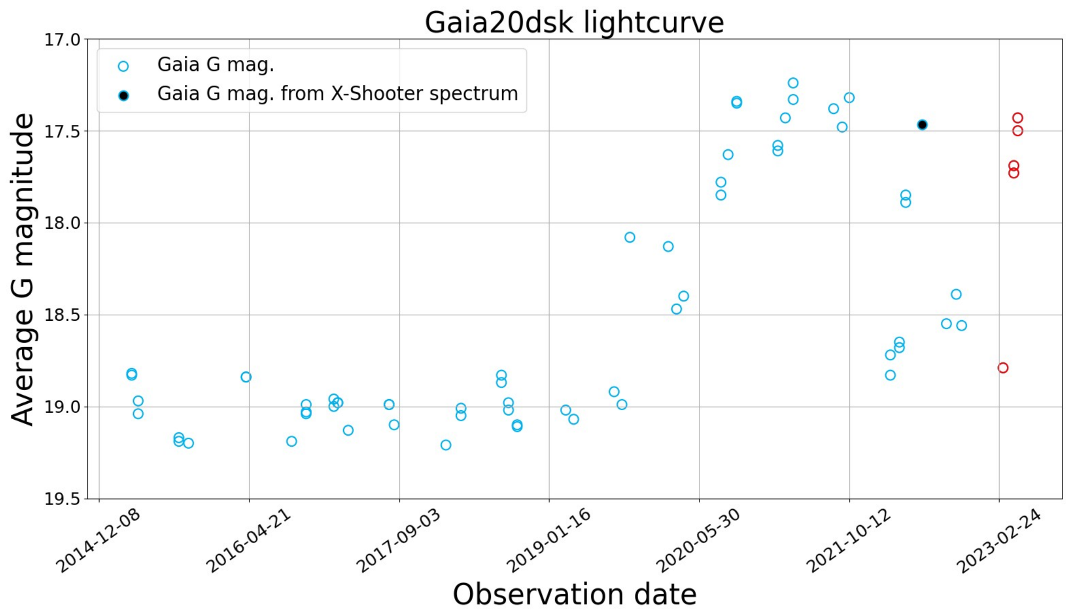

Figure 3: Gaia20dsk light curve. The data is sourced from the Gaia alerts webpage (see text). The unfilled circles represent the Gaia magnitude measurements of the stars taken since the end of 2014. The filled circles indicate the time when the spectrum of the Gaia20dsk source was captured using X-Shooter. The red circles represent recent measurements taken during this semester, indicating that the source has started to brighten up again.

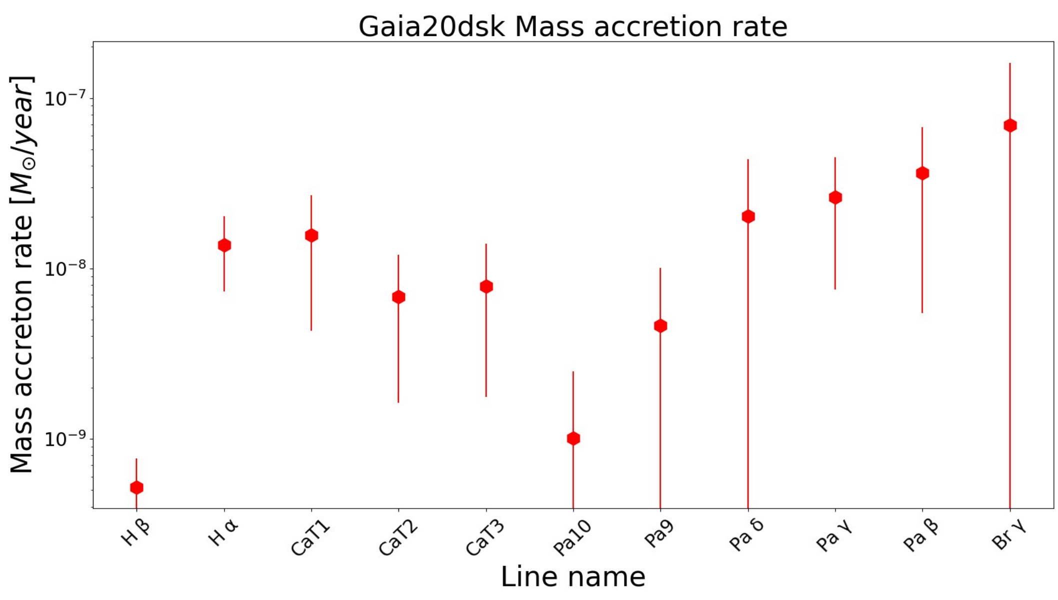

Figure 4: Gaia20sdk mass accretion rate. The red hexagons represent the mass accretion rates from each identified line. On the x-axis the lines name are the follows: H_x lines are part of the Balmer series (where x = β, α), Pa_y lines are part of the Paschen series (where y = 10, 9, δ, γ, β), and the Brγ is part of the Bracket series. The numbers after the letters associated to the upper energy level of the transmission in the series. CaT1, CaT2, CaT3 are the CalciumII triplets.

Studies in current semester:

The formation of planets and planetary systems (FIZ/5/045)
Data mining in astronomy (FIZ/5/006)

References:

[a] Kóspál, Á., Ábrahám, P., Acosta-Pulido, J. A., et al. 2011, A&A, 527, A133

[b] Hodapp, K. W., Denneau, L., Tucker, M., et al. 2020, AJ, 160, 164

[c] Koenig, X. P. & Leisawitz, D. T. 2014, ApJ, 791, 131

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

[e] Stock, C., Caratti o Garatti, A., McGinnis, P., et al. 2020, A&A, 643, A181

[f] Davis, C. J., Cervantes, B., Nisini, B., et al. 2011, A&A, 528, A3