

ASTROINFORMATICS

DOI:<http://dx.doi.org/10.18524/1810-4215.2020.33.216403>THE EMISSION-LINE DUSTY OBJECT IRAS 07080+0605,
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ABSTRACT. The all-sky survey conducted by the InfraRed Astronomical Satellite (IRAS) in the 1980's discovered many objects with infrared excesses whose nature has not been explored until recently. IRAS 07080+0605 is one of those identified in the visual spectral range with an early-type star, which shows the B[e] phenomenon. The object is puzzling, because it exhibits one of the strongest infrared excesses associated with a star of one of the lowest surface temperatures (~ 8500 K) among objects with the B[e] phenomenon, an apparent combination of spectral features of dwarfs and supergiants, and the absence of a surrounding optical nebula. Our photometric and spectroscopic study shows that the object's properties are similar to those of the famous Red Rectangle proto-planetary nebula. In this paper we describe our findings and hypotheses about the nature and evolutionary status of IRAS 07080+0605.

Keywords: Stars: emission-line, Be – Stars: evolution – (Stars:) circumstellar matter – (Stars:) binaries: general

АНОТАЦІЯ. Завдяки огляду всього неба, проведеному супутником IRAS у 80-ті роки, було виявлено багато об'єктів з інфрачервоними надлишками, чия природа не була досліджена до сьогодні. IRAS 07080+0605 – один з цих, що був ідентифікований, у візуальному діапазоні спектру, як зоря раннього спектрального класу, що показує B[e] феномен. Цей об'єкт є загадковим, тому що він демонструє один з найсильніших інфрачервоних надлишків, що асоціюється з зорею з однією з найменших ефективних температур (~ 8500 K) серед об'єктів з B[e] феноменом, очевидною комбінацією спектральних особливостей карликів та надгігантів, та відсутністю навколишньої оптичної туманності. Наші фотометричні та спектральні дослідження показують що властивості об'єкту є подібними до відомої протопланетної туманності "Червоний прямокутник". В цій роботі ми опишемо наші знахідки та гіпотези щодо природи та еволюційного статусу IRAS 07080+0605. IRAS 07080 + 0605 – це перший об'єкт групи FS CMA,

який може представляти ранню стадію подвійних зірок після стадії AGB. Здається, ця подвійна менш розвинена, ніж "Червоний прямокутник", але вона може йти тим самим еволюційним шляхом. Якщо припустити, що супутник типу А показує мало доказів дефіциту вогнетривких елементів, IRAS 07080 + 0605, ймовірно, також менш розвинений, ніж пилові подвійні після стадії AGB. Молодий вік об'єкта не підтверджується енергетичним балансом між спостережуваним болометричним потоком та інтегрованим ГЧ-надлишком, відсутністю сусідньої зореутворюючої області та швидким зменшенням ГЧ-потоків у напрямку довших хвиль, що виявляє відсутність холодного пилу, типового для зірок до стадії Головної Послідовності.

Ключові слова: Зірки: емісійна лінія, Be – Зірки: еволюція – Зірки: навколосоряна речовина – Зірки: подвійні файли: загальне

1. Introduction

Excess of infrared (IR) radiation in the spectral energy distribution (SED) of a star or stellar system typically manifests the presence of a circumstellar material in the form of gas and/or dust. Various distributions of this material produce different features in the object's spectrum, such as emission lines (both permitted and forbidden) that form in its gaseous part and emission or absorption bands that form in its dusty parts. Examples of these effects in the observational behavior of early-type stars are known as the Be phenomenon and B[e] phenomenon. In particular, the B[e] phenomenon discovered by Allen & Swings (1976) is defined as the presence of line emission (e.g., H I, Fe II, [O I]) and large IR excesses produced by circumstellar dust in the spectra of B-type stars. It has been detected in objects, which belong to five stellar groups: pre-main-sequence stars, symbiotic binaries, compact Proto-Planetary Nebulae, some supergiants, and FS CMa objects. The former four groups were identified by Lamers et al. (1998), while the latter one was proposed by Miroschnichenko (2007) to explain the properties of nearly half (~ 30) of the objects originally found by Allen & Swings (1976) and called unidentified by Lamers et al. (1998).

The group of FS CMa objects exhibits the following observational features: a hot star continuum with emission lines of H I, Fe I, O I, [Fe II], [O I], Ca II; a large IR excess peaking at $\lambda = 10 - 30 \mu\text{m}$ and sharply decreasing at longer wavelengths; location outside of star-forming regions. A hot star in them has a spectral type between O9 and A2 and a luminosity range of $\log L/L_{\odot}$ between ~ 2.0 and ~ 4.5 . Spectra of some FS CMa objects contain absorption lines of neutral metals typical of cool stars (e.g., MWC 623, MWC 728), while several other group members show

evidence for the presence of a very evolved compact or even a degenerate secondary component (e.g., CI Cam, AS 386, 3 Pup). The main hypothesis about the nature of the FS CMa group implies that it comprises mostly intermediate-mass binary systems at an evolutionary stage after mass-transfer between the stellar components (e.g., Miroschnichenko 2007). Mergers of some binaries with remaining circumstellar medium cannot be ruled out as well (e.g., de la Fuente et al. 2015).

This paper is devoted to a study of the IR source IRAS 07080+0605 ($V \sim 12.0$ mag), which has one of the strongest IR excesses among the objects with the B[e] phenomenon. The star associated with IRAS 07080+0605 was detected by Kohoutek & Wehmeyer (1999) in a survey for stars with H α emission and designated as HBHA 717-01. Miroschnichenko et al. (2007) included it in the FS CMa group and suggested a binary nature. However, neither Miroschnichenko et al. (2007) nor a recent study by Condori et al. (2019) found a direct evidence of a companion in their limited observations. Additionally, the latter authors suggested that IRAS 07080+0605 is an A[e] star with an uncertain classification, such as either main-sequence or pre-main-sequence object.

2. Observations

Optical spectroscopic observations of IRAS 07080+0605 were obtained with échelle spectrographs at the following telescopes: 3.6 m Canada-France-Hawaii Telescope (CFHT, USA, spectral resolving power $R = \lambda/\Delta\lambda = 65000$), 2.7 m Harlan J. Smith telescope (McDonald Observatory, USA, $R = 60000$), 2.1 m telescope of the Observatorio Astronómico Nacional San Pedro Martir (OAN SPM, Mexico, $R = 18000$). One spectrum taken with the FEROS spectrograph ($R \sim 40,000$) was retrieved from the ESO archive. Photometric observations were obtained with a 1 m telescope of the Tien-Shan Astronomical Observatory (Kazakhstan) in *BVR* filters in 2014–2016. We have also used a *V*-band light curve from the ASAS SN all-sky survey (Kochanek et al. 2017).

3. The properties of IRAS 07080+0605

The absorption-line spectrum of IRAS 07080+0605 is represented by weak lines of He I, Fe II, Mg I as well as by strong hydrogen lines of the Balmer and Paschen series. Such a content is typical for early A-type stars. We found a good fit of the object's optical spectrum for $T_{\text{eff}} \sim 8500$ K, $\log g = 3-4$, and a projected rotational velocity of $v \sin i \sim 60 \text{ km s}^{-1}$ using the program *SPECTRUM* (Gray & Corbally 1994), which calculates synthetic spectra based on model atmospheres. At the

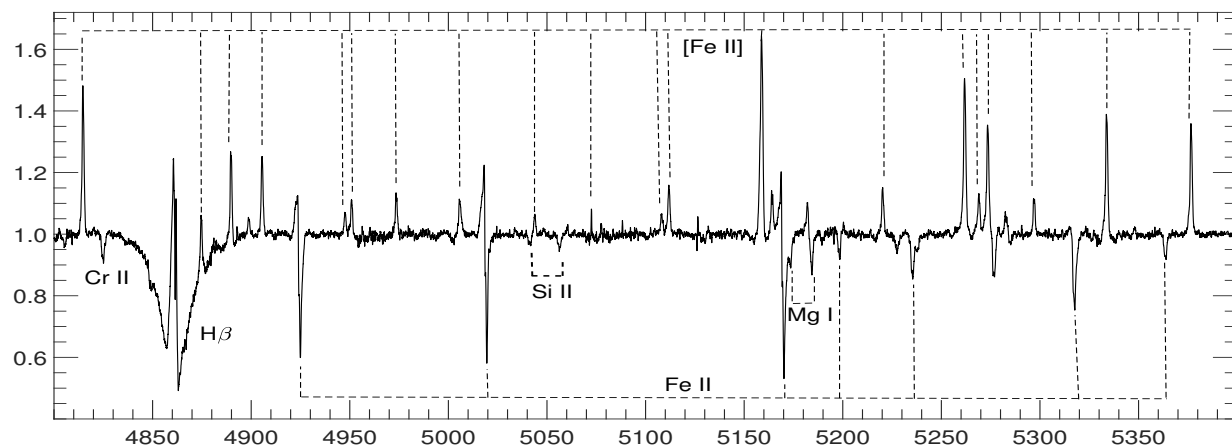


Figure 1: Part of the spectrum of IRAS 07080+0605 taken at CFHT on 2018/11/20. Most identified spectral lines are shown with dashed vertical lines. Intensity is normalized to the local continuum, heliocentric wavelengths are shown in Å.

same time, the O I 7772–7775 Å triplet (equivalent width ~ 3 Å) and Si II 6347 & 6371 Å lines (equivalent widths ~ 0.3 – 0.5 Å), which are weak in the spectra of dwarf stars, are unexpectedly strong and comparable to those of the highest luminosity supergiants. The emission-line spectrum of IRAS 07080+0605 includes emission components of the H α and H β lines and forbidden lines of [O I], [Fe II], [Ca II], and [N II]. A part of the CFHT spectrum taken on 2018 November 20 is shown in Fig. 1.

Most emission lines in the spectrum of IRAS 07080+0605 show variable profiles. In particular, the H α line profile varies from a single-peaked to a triple-peaked (Fig. 2, top panel). Profiles of the forbidden oxygen lines (6300 and 6364 Å) sometimes exhibit a strong central peak on top of a double-peaked structure typical of a circumstellar disk (Fig. 2, bottom panel).

The IR-excess of IRAS 07080+0605 is unusually strong compared to the observed flux in the visual spectral region. Assuming that the object’s brightness is affected by the interstellar extinction only, which is calculated from the color-excess $E(B - V) = 0.1$ mag, and using the effective temperature derived above, the bolometric flux from the star turns out to be ~ 10 times lower than the integrated IR-excess. The low interstellar extinction is supported by the absence of diffuse interstellar bands in the object’s spectrum. This result implies that the star may be attenuated by almost grey circumstellar extinction and/or has a compact companion, which supplies additional energy to the circumstellar dust. The emission features detected in the IR spectrum of IRAS 07080+0605 belong to carbonaceous molecules, which are typically observed in very evolved stars (e.g., planetary nebulae).

The parallax measured by the GAIA mission (GAIA Collaboration 2018) corresponds to a distance of

543 ± 15 pc, which is consistent with the interstellar extinction law in the object’s direction (Fig. 3) and the derived color-excess. Using the average optical brightness of IRAS 07080+0605 ($V \sim 12.0$ mag, see Fig. 4) corrected for the interstellar extinction ($A_V = 3.1 \times E(B - V) = 0.3$ mag) and the GAIA distance result in an absolute visual magnitude of $M_V = 3.1$ mag and a luminosity of $5 L_\odot$, below the main sequence. It is difficult to reconcile some of the object’s spectral features mentioned above (e.g., the oxygen triplet strength) and the strong IR excess with such a low luminosity. The absence of a nearby star forming region and a lack of the far-IR excess compared to that of pre-main-sequence stars contradicts the assumption of the object’s young age made by Condori et al. (2019).

4. Results and Discussion

Positions of both the absorption and emission lines in the optical spectrum of IRAS 07080+0605 are variable. In particular, the Si II absorption lines at 6347 and 6371 Å, which are nevertheless weak and noisy in some spectra, change their radial velocity determined by Gaussian fitting within ± 40 km s $^{-1}$. The strongest Fe II lines (e.g., at 4923, 5018, 5169 Å) exhibit both absorption and emission components at their short-wavelength edge (see Fig. 1). This type of profile (inverse P Cyg) may be interpreted as evidence of the matter infall onto the A-type star.

Even a visual inspection of the light curve of IRAS 07080+0605 composed from the data of the ASAS SN survey (Fig. 4) implies the presence of a cyclic component in the brightness variations. Nevertheless, no stable period has been found in these data. After deleting a long-term trend, the most prominent period in the Fourier power spectrum is found at 127

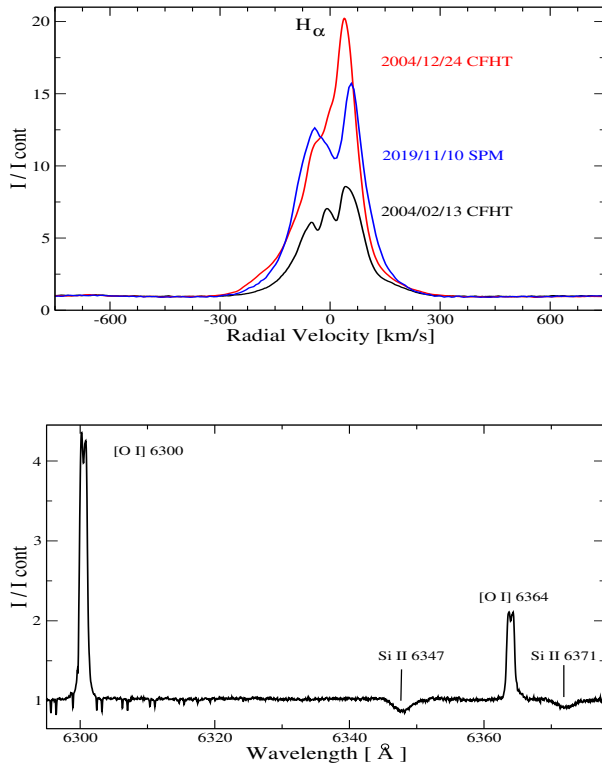


Figure 2: **Top panel.** Comparison of the $H\alpha$ line profiles in the spectrum of IRAS 07080+0605 taken at different times. **Bottom panel.** Part of the spectrum of IRAS 07080+0605 taken at CFHT on 2018/11/20 with [O I] and Si II lines. Intensity and wavelengths are in the same units as in Fig. 1.

days, while the last three observing seasons suggest a period of 190 days. Condori et al. (2019) reported a most probable period of 72 days, although they also found that the highest peak in the Fourier power spectrum corresponds to 248.2 days based on the ASAS-3 survey data (Pojmanski 1997). The ASAS SN data do not show regular variations with these two periods.

The *BVR* photometric data taken at TShAO shows no noticeable variations in the optical color-indices, although this data set is rather small (10 observations). Also, the high-resolution spectra taken near a local brightness maximum (ESO spectrum of 2015/12/06) and near a minimum (CFHT spectrum of 2018/11/20), time of whose taking is shown in Fig. 4) are nearly identical. Therefore, it is reasonable to assume that the cyclic variations are due to a variable circumstellar extinction rather than to eclipses in the system.

Among many objects with IR-excesses, there is one with a number of properties similar to those of IRAS 07080+0605. This is HD 44179, a binary system with a brighter A/F-type post-AGB star and a much fainter hot companion. The system is surrounded by a prominent visual nebula known as Red Rectangle. Both the absorption-line optical spectrum and the IR

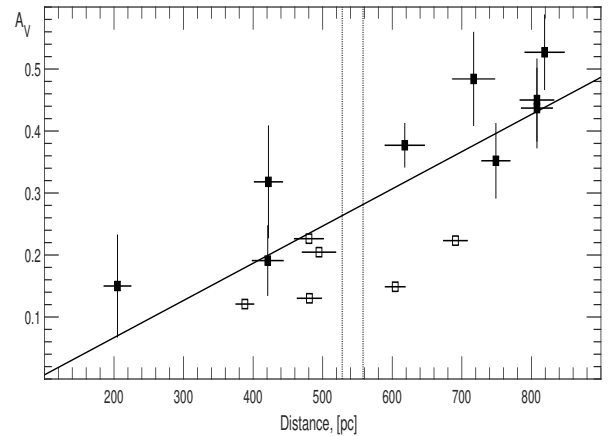


Figure 3: Interstellar extinction law in the direction of IRAS 07080+0605. The thick line shows a linear fit to the star data, while the thin lines show the object's distance uncertainty. Filled and open symbols show data for stars from a 15-arcminute and a 1-degree area around the object, respectively.

spectrum resemble those of IRAS 07080+0605 (Fig. 5).

The integrated flux in the IR excess of Red Rectangle is ~ 18 times larger than the bolometric flux of the bright stellar companion (Oomen et al. 2019). Men'shchikov et al. (2002) modeled the SED of Red Rectangle and found that large carbonaceous grains in the circumstellar disk/torus attenuate the visible system component by a factor of ~ 30 . A similar solution is probably applicable to IRAS 07080+0605.

The largest difference between the two objects is that IRAS 07080+0605 shows no detectable nebula around it, although both are located at about the same distance from the Sun (0.5 kpc for IRAS 07080+0605 and 0.7 kpc for Red Rectangle). Furthermore, IRAS 07080+0605 shows somewhat wider absorption profiles of the Balmer lines (see Fig. 5, top panel), which may imply a higher surface gravity than that of Red Rectangle ($\log g = 1.5$, Men'shchikov et al. 2002). If this is the case, IRAS 07080+0605 is less evolved than Red Rectangle.

Visible components of most of the post-AGB binaries with dusty envelopes are cooler (FGK spectral type) than IRAS 07080+0605 and demonstrate weaker absorption lines compared to those in the spectra of same spectral types with solar abundances. The latter effect has been explained by depletion of refractory elements from the star's atmosphere (Oomen et al. 2019). Although the absorption-line spectrum of IRAS 07080+0605 resembles those of A-type dwarfs, it also contains some lines highly sensitive to the luminosity, such as the Si II 6347 and 6371 Å lines and the O I triplet at 7772–7775 Å mentioned above, whose strengths are closer to those of giants and supergiants. This fact can be due to at least partial

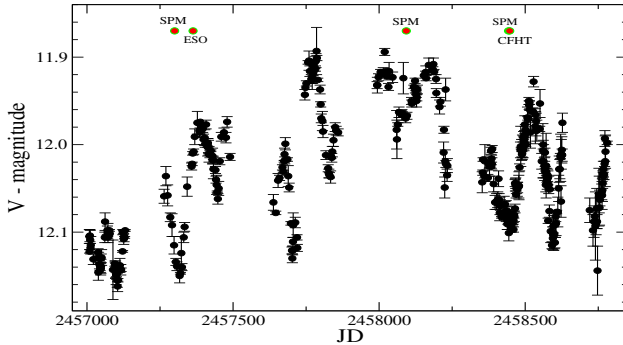


Figure 4: V -band light curve of IRAS 07080+0605 from the ASAS SN survey in 2013–2019 (Kochanek et al. 2017). Dates when some spectra of IRAS 07080+0605 were taken at various observatories are shown above the light curve.

formation of these lines in the circumstellar area.

5. Conclusions

Our spectroscopic and photometric study of the FSCMa object candidate IRAS 07080+0605 shows that in order to explain its observed properties one needs to assume that it is a binary system, in which:

1. the A-type companion's brightness is attenuated by the circumstellar disk-like envelope by a factor of 10 or more in order to explain the large amount of energy in the IR excess as Men'shchikov et al. (2002) did for Red Rectangle;
2. the secondary component is a hot star, which supplies UV photons to ionize the circumstellar gas;
3. some absorption lines, such as the Si II 6347 & 6371 Å and the near-IR oxygen triplet at 7772–7775 Å, partially form in the circumstellar disk.

IRAS 07080+0605 is the first object from the FSCMa group that may represent an early stage of binary post-AGB stars, which has been always studied separately (e.g., Van Winckel et al. 2009). The binary seems to be less evolved than Red Rectangle, but it may follow the same evolutionary path. Assuming that the A-type companion shows little evidence for the refractory element depletion, IRAS 07080+0605 is probably also less evolved than the dusty post-AGB binaries. The young age of the object suggested by Condori et al. (2019) is not supported by the energy balance between the observed bolometric flux and the integrated IR excess, the absence of a nearby star-forming region, and a fast decrease of the mid-IR flux toward longer wavelengths which manifests a lack of the coldest dust typical for pre-main-sequence stars.

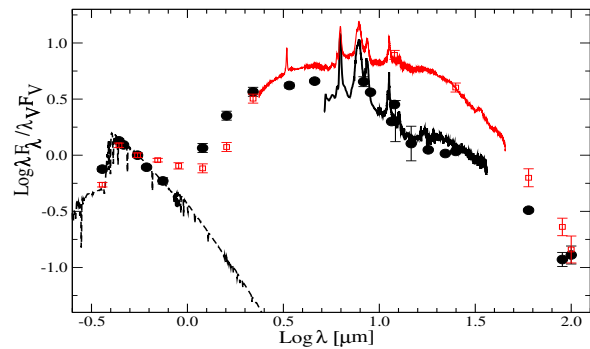
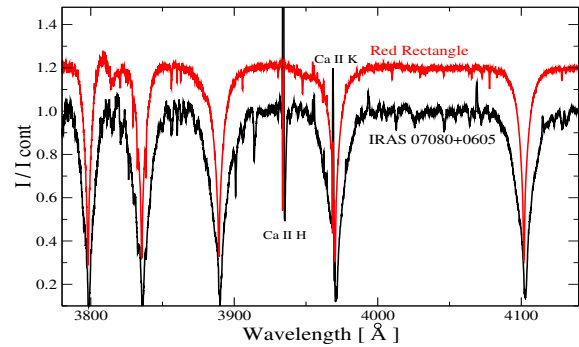


Figure 5: **Top panel.** Comparison of the blue part of the spectra of IRAS 07080+0605 (black line) and Red Rectangle (red line) taken with the ESPaDoNS spectropolarimeter at CFHT. **Bottom panel.** Spectral Energy Distributions of IRAS 07080+0605 (black filled circles – photometric data, black solid line – IR spectrum taken at the Spitzer Space Observatory) and Red Rectangle (red open squares – photometric data, red solid line – IR spectrum taken at the Infrared Space Observatory) corrected for the interstellar reddening. The dashed line shows a theoretical SED for the model atmosphere for $T_{\text{eff}} = 8500$ K, $\log g = 3.0$. The same model atmosphere was chosen to show the IR excess, although the optically brighter component of Red Rectangle was found to be ~ 800 K cooler (Waelkens et al. 1992).

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