Photometric and spectroscopic study of the burst-like brightening of two 
Gaia-altered young stellar objects

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ABSTRACT

Young stars show variability on different time-scales from hours to decades, with a range of amplitudes. We studied two young stars, which triggered the Gaia Science Alerts system due to brightenings on a time-scale of a year. Gaia20bwa brightened by about half a magnitude, whereas Gaia20fgx brightened by about two and half magnitudes. We analyzed the Gaia light curves, additional photometry, and spectra taken with the Telescopio Nazionale Galileo and the Gran Telescopio Canarias. Several emission lines were detected toward Gaia20bwa, including hydrogen lines from Hα to Hδ, Paβ, Brγ, and lines of Ca ii, O i, and Na i. The Hα and Brγ lines were detected toward Gaia20fgx in emission in its bright state, with additional CO lines in absorption, and the Paβ line with an inverse P Cygni profile during its fading. Based on the Brγ lines the accretion rate was (2.4 – 3.1) × 10⁻⁸ M⊙ yr⁻¹ for Gaia20bwa and (4.5 – 6.6) × 10⁻⁸ M⊙ yr⁻¹ for Gaia20fgx during their bright state. The accretion rate of Gaia20fgx dropped by almost a factor of 10 on a time-scale of half a year. The accretion parameters of both stars were found to be similar to those of classical T Tauri stars, lower than those of young eruptive stars. However, the amplitude and time-scale of these brightenings place these stars to a region of the parameter space, which is rarely populated by young stars. This suggests a new class of young stars, which produce outbursts on a time-scale similar to young eruptive stars, but with smaller amplitudes.

Key words: Stars: variables: T Tauri – stars: pre-main sequence

1 INTRODUCTION

About half of young stellar objects (YSOs) show photometric variations on daily-weekly timescales, with typical values of a few times 0.1 mag at optical and infrared wavelengths (e.g. Megeath et al. 2012). Some young stars show brightness variations on even longer time-scales: months, years, centuries. These variations are related to different physical processes (Hillenbrand & Findeisen 2015). Some of the light variations are periodic, and are related to photospheric inhomogeneities, such as starspots. Periodic or quasi-periodic dips in the light curves can be related to circumstellar dust passing through the line of sight toward the star. One example of this phenomenon is the class of AA Tau-type stars, where the occultations are caused by an inner disk warp (e.g. Bouvier et al. 1999, 2003, Cox et al. 2013, Nagy et al. 2021). Aperiodic events can also occur due to the unsteady mass transfer from the inner disk to the star (Blinova et al. 2016), including ”clumpy accretion” (Gullbring et al. 1996; Siwak et al. 2018). The eruptive class of young stars shows bright-
ness variations with an amplitude of a few magnitudes and remain bright on longer timescales. These events are typically called outbursts and are caused by a sudden increase of the mass accretion rate from $10^{-10} - 10^{-8} \, M_\odot$ yr$^{-1}$ during outburst. Eruptive young stars are commonly divided into two main classes: EX Lupi-type stars (EXors) and FU Orionis-type stars (FUors). The former show brightenings of 2-4 mag, last for less than a year and are recurrent (e.g. Herbig 2008); the latter brighten by up to 5 magnitudes and last for several decades (e.g. Audard et al. 2014). So far the number of confirmed FUors is limited to no more than a dozen while the number of known EXors is limited to less than 25, including candidates (Audard et al. 2014). Recent studies have shown, that not all the eruptive young stars belong to these two main classes (Hillenbrand et al. 2019, Hodapp et al. 2020).

ESA’s Gaia space telescope has been monitoring the whole sky, determining the parallax and proper motion of 1.8 billion stars. The sources which show significant brightness changes are reported as Gaia Photometric Science Alerts (Hodgkin et al. 2021), which are Gaia sources which show significant brightness changes are reported as Gaia Sciencealerts were also published for the two targets analyzed below.

2 OBSERVATIONS

2.1 Photometry

We obtained ground-based optical photometric observations of Gaia20bwa and Gaia20fgx with the 80 cm Ritchey-Chrétien telescope (RC80) at the Piskvárető6 Mountain Station of Konkoly Observatory (Hungary) and with the 60 cm Carl-Zeiss telescope at Mount Suhora Observatory of the Cracow Pedagogical University (Poland). The RC80 telescope was equipped with an FLI PL230 CCD camera, 0.55 pixel scale, 18.8’’ x 18.8’’ field of view, Johnson $BV$ and Sloan $r’/r’’$ filters. The telescope at Mount Suhora was equipped with an Apogee Aspen-47 camera, 1’’x1’’ pixel scale, 19.0’’ x 19.0’’ field of view, Sloan $g’/r’/i’$ filters. Figure 1 shows portions of the images taken of our targets. We typically obtained 3 to 13 images in each filter. We first applied CCD reduction including bias, flatfield, and dark current corrections. Then we calculated aperture photometry for the science target and several comparison stars in the field of view using an aperture radius of 2’’. We selected those comparison stars from the APASS9 catalog (Henden et al. 2015) that were within 6.5’’ of the target and which were mostly constant, i.e., the rms of their V-band observations from the ASAS-SN Photometry Database (Shappee et al. 2014; Jayasinghe et al. 2019) were below 0.1 mag. The APASS9 catalog provided Bessell $BV$ and Sloan $g’/r’/i’$ magnitudes for the comparison stars. We used the comparison stars for the photometric calibration by fitting a linear color term. Magnitudes taken with the same filter on the same night were averaged. The final uncertainties are the quadratic sum of the formal uncertainties of the aperture photometry, the photometric calibration, and the scatter of the individual magnitudes that were averaged per night. The results can be found in Tab. A1 in the Appendix. As seen in Fig. 1, Gaia20fgx is close to a very bright star, however, given the used aperture, and that the separation between Gaia20fgx and the bright star is ~7", the results from the photometry were not affected by this nearby source.

We obtained near-infrared photometric observations in the $J$, $H$ and $K_s$ bands of Gaia20bwa on 2021 February 11 and Gaia20fgx on 2021 January 27. We used the Near Infrared Camera Spectrometer (NICs) instrument on the Telescopio Nazionale Galileo (TNG) located in the Island of San Miguel de La Palma (Canary Islands, Spain), proposal ID: AOT42, PI: Eleonora Fiorellino. In each filter a 5-point dithering was performed, with 3 s of exposure time at each position. The data reduction, performed with our own IDL routines, included the construction and subtraction of a sky image, and flat-fielding. On 2021 September 18, we obtained additional $JHK_s$ photometry of Gaia20fgx from the Gran Telescopio Canaria (GTC) using the Espectrógrafo Multiobjetivo Infra-Rojo (EMIR) instrument (Balcells et al. 2000), proposal ID: GTC01-21BDDT, PI: David García. The images were obtained in four dither positions with 10” offsets with 5 s exposure per dither point. These data were processed using the PyEMIR (Pascual et al. 2010) pipeline version 0.163. For photometric calibration of the TNG and GTC photometry, the 2MASS catalog was adopted. We extracted the instrumental magnitudes for the target as well as for all good-quality 2MASS stars (i.e. with a 2MASS photometric quality flag of AAA) in the field in an aperture with a radius of ~1.5". The final step was the determination of an average constant calibration factor between the instrumental and the 2MASS magnitudes of typically 30 – 50 stars, and this offset was applied on the target observations. The formal photometric uncertainties are 0.01 – 0.02 mag for the TNG data and 0.07 – 0.14 for the GTC data. The results can be found in Tab. A1 in the Appendix.

We also used mid-infrared photometry from the Wide-field Infrared Survey Explorer (WISE) and NEOWISE surveys from the...
NASA/IPAC Infrared Science Archive. NEOWISE observes the full sky on average twice per year with multiple exposure per epoch. For a comparison with the photometry from other instruments, we computed the average and standard deviation of multiple exposures of a single epoch. The error bars are a quadratic sum of the average magnitude uncertainty per exposure. We downloaded G band photometry from the Gaia Science Alerts Index website. We also used r and g band photometry from the Data Release 11 of the Zwicky Transient Facility (ZTF; Masci et al. 2019).

2.2 Optical spectroscopy

We used the TNG equipped with the Device Optimized for the LOw RESolution (Dolores) to obtain low-resolution optical spectra of Gaia20bwa on 2021 February 11/12, and Gaia20fgx on 2021 January 27/28. The UV-NIR coverage was achieved using the LRB and LRR gratings, which operate in ~3500–7980 Å and ~4980–10370 Å spectral ranges, respectively. The spectra were reduced in a standard way on bias, flatfield and then wavelength-calibrated within IRAF. The strong fringing pattern (apparent above 7800 Å) was successfully removed by normalized flatfield division. This worked only for the Gaia20bwa spectrum, the same procedure failed for the second star. This appears to be have been caused by the low elevation at which the telescope was pointing during the observation of Gaia20fgx, at an airmass range 2.5 – 2.7, resulting in increased instrumental flexures distorting the nominal optical path. We averaged the overlapping part of LRB and LRR ranges assuming weights appropriate to the obtained signal. In addition, we observed Gaia20bwa on 2021 February 17/18 using the 2-m Liverpool Telescope (LT) equipped with the SPectrograph for the Rapid Acquisition of Transients (SPRAT, Piascik et al. 2014) \(^1\). SPRAT provides low-resolution (R=350) spectra in the range of 4020 – 7994 Å. The spectrum was reduced and approximately calibrated to absolute flux units by means of the dedicated SPRAT pipeline. The spectral resolutions and total integration times corresponding to the optical spectra are listed in Table 1.

2.3 NIR spectroscopy

Low resolution (R=500-1250) NIR spectra were obtained with the Near Infrared Camera Spectrometer (NICS, Baffa et al. 2001) installed on the TNG on 2021 February 11 for Gaia20bwa and on 2021 January 27 for Gaia20fgx. For Gaia20bwa the J, HK, and K\(_{\text{b}}\) bands were used with exposure times of 1000 s, 120 s, and 520 s, respectively. For Gaia20fgx, the J, H, and K\(_{\text{b}}\) bands were used with exposure times of 2000 s, 400 s, and 1400 s, respectively. The sources were observed through the 1” wide slit. The data were reduced using IRAF. For each image, sky subtraction, flat-fielding, bad pixel removal, aperture tracing, and wavelength calibration (using argon lamp) were performed. Then, the telluric correction was performed: the hydrogen absorption lines in the telluric stellar spectrum were removed by Gaussian fitting, and the telluric spectrum was normalized. Subsequently we divided the target spectrum by the normalized telluric spectrum. The barycentric velocity was calculated by barycorpy (Kanodia & Wright 2018) as −23.22 and −15.14 km s\(^{-1}\) for Gaia20bwa and Gaia20fgx, respectively, and then subtracted from the target spectra. Finally, after normalizing the telluric corrected target spectrum, flux calibration was performed by using our photometry from Mt. Suhora and the TNG during the bright state, and the WISE W1 and W2 photometry close to the bright state for Gaia20bwa. For Gaia20fgx, faint states of WISE data are used in addition to bright states of optical to NIR.

We obtained medium-resolution (R=4000–5000) spectra for Gaia20fgx in JHK\(_{\text{b}}\) bands on 2021 September 19, using the GTC equipped with EMIR configured in the long-slit mode (PI: D. García). The star was observed through the 0.7” wide slit. The total exposure times were 7174 s in the J, 2795 s in the H, and 3235 s in the K\(_{\text{b}}\) band. HgAr lamp provided wavelength calibration. The spectra were obtained in ABA/B nodding pattern along the slit and were processed by means of the dedicated PyEMIR package. The final spectrum extraction was performed under IRAF. The telluric correction was done using the telluric standard HD 212495. We calibrated these spectra to absolute flux using the JHK\(_{\text{b}}\) band photometry obtained on the same night. The spectral resolutions and total integration times corresponding to the NIR spectra are listed in Table 1.

3 RESULTS

3.1 The distance of Gaia20fgx

While the distance of Gaia20bwa is accurately known, the distance of Gaia20fgx (1.01\(+1.88\)-\(0.32\) kpc, Bailer-Jones et al. 2021) has a large uncertainty. Based on its position, proper motion, and its distance, Gaia20fgx belongs to the Cep OB3 association. To derive its more accurate distance, we collected the list of sources, which also belong to the Cep OB3 association (Jordi et al. 1996, Getman et al. 2009), and downloaded their Gaia EDR3 distances from Bailer-Jones et al. (2021). We considered only those sources, that had a Renormalised Unit Weight Error (RUWE) below 1.4. We removed the sources with a negative parallax from our sample, and those, where the parallax was less than five times its error. After applying these selection criteria, the number of sources used for the analysis is 235. The number or sources per photogeometric distance in 10 pc bins is shown in Fig. 2. Based on a Gaussian fit, the distribution of distances peaks at ~816 pc. The FWHM of the Gaussian fit is ~124 pc. We use the Gaussian sigma of \(\sigma = \text{FWHM}/2.355 = 52.7\) pc as the error of the distance. Based on this analysis, the distance of Cep OB3 is ~816±53 pc. We will use this value when calculating physical parameters for Gaia20fgx in the next sections.

3.2 Light curves

Gaia and WISE light curves of Gaia20bwa and Gaia20fgx are shown in Fig. 3. For Gaia20fgx we also show data from the Zwicky Transient Facility (ZTF; Masci et al. 2019).
Table 1. Log of spectroscopic observations.

| Target     | Date       | Telescope | Instrument | Wavelength (µm) | Resolution | Total int. time (s) |
|------------|------------|-----------|------------|----------------|------------|--------------------|
| Gaia20fgx  | 2021 Jan 27| TNG       | DOLORES    | 0.59–1.00      | 585–714    | 1700               |
| Gaia20fgx  | 2021 Jan 27| TNG       | NICS       | 0.90–1.45      | 500        | 1600               |
| Gaia20fgx  | 2021 Jan 27| TNG       | NICS       | 1.40–2.50      | 500        | 1600               |
| Gaia20fgx  | 2021 Jan 27| TNG       | NICS       | 1.95–2.34      | 1250       | 5600               |
| Gaia20fgx  | 2021 Sep 19| GTC       | EMIR       | 1.17–1.33      | 4000–5000  | 7174               |
| Gaia20fgx  | 2021 Sep 19| GTC       | EMIR       | 1.53–1.78      | 4000–5000  | 2795               |
| Gaia20fgx  | 2021 Sep 19| GTC       | EMIR       | 2.03–2.38      | 4000–5000  | 3235               |
| Gaia20bwa  | 2021 Feb 17| LT        | SPRAT      | 0.40–0.80      | 350        | 200                |
| Gaia20bwa  | 2021 Feb 11| TNG       | DOLORES    | 0.59–1.00      | 585–714    | 630                |
| Gaia20bwa  | 2021 Feb 11| TNG       | NICS       | 1.12–1.40      | 1200       | 4000               |
| Gaia20bwa  | 2021 Feb 11| TNG       | NICS       | 1.40–2.50      | 500        | 480                |
| Gaia20bwa  | 2021 Feb 11| TNG       | NICS       | 1.95–2.34      | 1250       | 2008               |

Figure 2. Histogram of Gaia EDR3 distances of the members of the Cep OB3 region in 10 pc bins. The fitted Gaussian peaks at a value of ~816 pc.

Facility (ZTF) archive. For Gaia20bwa, we did not consider the ZTF data, due to the quality of the photometry in the ZTF Data Release 11: most of the data points are defined as bad-quality.

Gaia20bwa had a Gaia alert on 2020 April 17, when its brightness increased by about 0.3 mag in the Gaia G-band. It continued brightening by about 0.2 mag to reach its maximum brightness in 2020 October. The last WISE data point also follows the brightening seen in the Gaia light curve. Based on the Gaia light curve as well as our follow-up photometry with the RC80, Gaia20bwa faded back to its long-term brightness by the end of 2021 August, therefore, the brightening episode lasted for approximately 17 months.

Gaia20fgx had a Gaia alert on 2020 November 11, due to its brightening by ~2.5 mag over about 10 months. It reached its maximum brightness by 2021 February, and returned to quiescence by 2022 May, based on the G-band data. The Gaia light curve also shows an earlier brightening from early 2018 until early 2019, with a lower amplitude compared to the second brightening that corresponds to the Gaia alert. In addition to the two long-term brightening events, shorter brightenings with an amplitude of ~1 mag are apparent on the Gaia light curve between 2015 and 2018.

3.3 Color variations

Figure 4 shows the (J − H) versus (H − Ks) color–color diagram of the sources. Gaia20bwa is close to the locus of unreddened CTTS based on each three data points, and in both the bright and faint states. This suggests that the visual extinction for Gaia20bwa is low, however, we will use the SEDs in Sect. 3.5 to constrain the AV for Gaia20bwa. For Gaia20fgx, there is evidence for a change in the visual extinction between the faint state represented by the 2MASS data point and the bright state represented by the TNG data point, while the GTC photometry corresponds to the fading of the source, between the bright and faint states. Gaia20fgx was redder at the 2MASS epoch, than at the later epochs observed with the TNG and the GTC. For Gaia20fgx, we used the expression from Cardelli et al. (1989) to measure the visual extinction of the source at each epoch by projecting its location in Fig. 4 to the line representing the locus of unreddened CTTS (Meyer et al. 1997) along the extinction path. This method results in an AV = 3.6 ± 0.2 mag for the bright state and 5.7 ± 0.6 mag for the faint state, when assuming an RV of 3.1. An AV = 4.1 ± 0.2 mag was found for the GTC data point.

Color–magnitude diagrams based on the WISE data are shown in Fig. 5. There is no significant color change in the case of Gaia20fgx. For Gaia20bwa, the W2 versus W1–W2 color–magnitude diagram suggests reddening during the brightening, which is likely due to the disk component.

Figure 5 also shows a g vs. [g − r] color–magnitude diagram for Gaia20fgx based on archival data from the ZTF survey and our follow-up observations with the RC80 and Mt. Suhora telescopes. Some of the data points indicate color-variations related to changing extinction. Both brightening events seen in Fig. 5 based on the g vs. [g − r] color–magnitude diagram show a linear color variation over time: the red-orange data points correspond to the first brightening event, while the blue data points to the brightness related to the Gaia alert. The data points corresponding to the second brightening event seem to follow the extinction path. The r versus [r − i] color–magnitude diagram shown in Fig. 5 for Gaia20bwa based on data points during the bright state and the fading shows a linear trend, however, it is not consistent with the extinction path. It suggests that the fading was caused by a mechanism other than variable extinction.

3.4 Results from spectroscopy

Due to the low spectral resolution of the TNG and LT spectra, the velocities of the lines cannot be accurately determined. However, the
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Figure 3. Light curves of Gaia20bwa and Gaia20fgx. The Gaia G data are shown with black dots, the ZTF g, r, and i data with light blue, orange, and red asterisks, the WISE W1 and W2 band data with blue and grey dots. The red, orange, and green dots are i, r, and V data measured with the RC80 or the Mt. Suhora telescope, as shown in Appendix A. The vertical lines show the epochs of the TNG and GTC spectra. The arrows show the epochs of the Gaia alerts.

Several lines were detected in the optical spectrum of Gaia20bwa measured with the TNG, including lines from the H i Balmer series from Hα to Hδ, the Na i D line, the O i triplet at 7771/9/5 Å, the O i line at 8446 Å, and three lines of Ca ii (Fig. 6). The H i Balmer series from Hα to Hγ were also detected in the spectrum taken with the LT. The Brγ and Paβ lines were detected in the NIR spectrum obtained with the TNG.

Due to the lower S/N of the fainter Gaia20fgx, only the Hα line of the H i Balmer series was detected in the optical spectra measured with both the TNG and LT. The Brγ line was detected in the NIR spectrum observed with the TNG. A few additional lines were also detected in the medium resolution spectrum obtained with the GTC during the fading of the source: the CO 2-0 and 3-1 bandhead features in absorption, and the Paβ line detected as an inverse P Cygni profile (Fig. 7). The line parameters obtained from Gaussian fitting are shown in Table 2.
Detecting several lines of the Balmer series for Gaia20bwa allows us to determine the excitation temperature of the gas that emits these lines. In Fig. 8 we plotted the line fluxes divided by the statistical weights of the energy levels in logarithmic scale as a function of the energy of the levels and applied a linear fit to the data points. The inverse of the slope of the line gave an excitation temperature of \( \sim 7600 \) K for both the TNG and LT data. This value is higher than the photospheric temperature of CTTS, as well as the 3142.5 \( \text{K} \) derived above and the extinction corrected \( H \)-band data measured close to the TNG and Mt. Suhora observations, and on the last published WISE W1 and W2 fluxes. The data points for the faint state are based on archival data from Pan-STARRS, \( Gaia \), WISE, 2MASS and Spitzer. We computed black body functions for a range of temperatures and visual extinctions and compared them to the SEDs by visual inspection. We used the temperature and \( A_V \) values estimated from the SEDs to derive stellar parameters for the sources. We explain the results for each source below.

### 3.5 SEDs and stellar parameters

The SEDs of Gaia20bwa and Gaia20fgx are shown in Fig. 9. The data points for the bright state (red symbols) are based on our follow-up observations with the TNG and Mt. Suhora telescopes, the \( Gaia \) G-band data measured close to the TNG and Mt. Suhora observations, and on the last published WISE W1 and W2 fluxes. The data points for the faint state are based on archival data from Pan-STARRS, \( Gaia \), WISE, 2MASS and Spitzer. We computed black body functions for a range of temperatures and visual extinctions and compared them to the SEDs by visual inspection. We used the temperature and \( A_V \) values estimated from the SEDs to derive stellar parameters for the sources. We explain the results for each source below.

#### 3.5.1 Gaia20fgx

The SED of Gaia20fgx in the faint state is consistent with a temperature of \( 3700 \pm 300 \) K and a visual extinction of \( A_V = 7.0 \pm 0.7 \) mag, which is slightly above the value that was derived for the faint state based on the \( J-H \) versus \( H-K_s \) plot, and is consistent with the \( \sim 7.3 \) mag value derived by Chen et al. (2020). Similarly, the SED in the bright state is more consistent with a higher \( A_V \) compared to the value derived from the \( J-H \) versus \( H-K_s \) plot, with an \( A_V \) of \( 5 \pm 0.5 \) mag. The 3700 K temperature is between the M0 and M1 spectral types (Pecaut & Mamajek 2013). The luminosity of Gaia20fgx can be derived from the observed magnitudes corrected for extinction and assuming a bolometric correction (BC). We used the bolometric correction value corresponding to the average of the values for the M0 and M1 spectral types in the \( J \) band (BC\( J \)) of 5-30 Myr stars from Table 6 of Pecaut & Mamajek (2013). The luminosity of Gaia20fgx is then

\[
\log \left( \frac{L_*}{L_\odot} \right) = 0.4(M_{\text{bol,}\odot} - M_{\text{bol}}),
\]

where \( M_{\text{bol,}\odot} = -5.2 \) is the bolometric magnitude of the Sun (Mamajek et al. 2015), and the bolometric magnitude of the source is \( M_{\text{bol}} = m_J - 5 \log(d/[10 \text{pc}]) + BC_J \) where \( m_J \) is the extinction corrected \( J \) magnitude of 12.57\( \pm 0.03 \) mag (assuming an \( A_V = 7 \) mag). This results in \( L_* = 1.02 \pm 0.20 L_\odot \) for Gaia20fgx. Based on the \( L_* \) and \( T_{\text{eff}} \) derived above and the evolutionary tracks by Siess et al. (2000), we determined a stellar mass of \( M_* = 0.53 \pm 0.10 M_\odot \). Assuming that the central object emits as a black-body, the stellar radius can be derived as

\[
R_* = \frac{1}{2 \sigma \pi} \sqrt{\frac{L_*}{\pi \sigma}}
\]

where \( \sigma \) is the Stefan-Boltzmann constant. The \( R_* \) for Gaia20fgx is 2.46\( \pm 0.52 R_\odot \) using this method. The stellar parameters derived for Gaia20fgx in the faint and bright states are summarized in Table 3.

#### 3.5.2 Gaia20bwa

The SED of Gaia20bwa in the faint state is consistent with a temperature of \( 3300 \pm 200 \) K and a visual extinction of \( A_V = 3.0 \pm 0.5 \) mag. This temperature is consistent with the 3142.5\( \pm 16.0 \) K derived by Da Rio et al. (2016), but the derived \( A_V \) value is above the 0.9\( \pm 0.35 \) mag suggested by Da Rio et al. (2016). These parameters (3300 K temperature and 3.0 mag visual extinction) are also consistent with SED in the bright state. Temperature of 3300 K is close to the M3 spectral type (Pecaut & Mamajek 2013). We used the bolometric correction value corresponding to the M3 spectral type in the \( J \) band (BC\( J \)) of 5-30 Myr stars from Table 6 of Pecaut & Mamajek (2013). The extinction corrected \( J \) magnitude is 12.03\( \pm 0.03 \) mag (assuming an \( A_V = 3.0 \) mag). Using Eqn. 1, we derived a luminosity of \( 0.38 \pm 0.06 L_\odot \). Based on the \( L_* \) and \( T_{\text{eff}} \) derived above and the evolutionary tracks by Siess et al. (2000), we determined a stellar
mass of $M_*=0.28 \pm 0.06 \, M_\odot$. Using Eqn. 2, we derived a radius of $1.89 \pm 0.32 \, R_\odot$. The stellar parameters derived for Gaia20bwa are summarized in Table 3. The temperature, $A_V$, $L_*$, and $M_*$ derived for Gaia20bwa by Da Rio et al. (2016) are also listed in Table 3. The $R_*$ corresponding to these parameters was derived using Eqn. 2 based on the temperature and luminosity from Da Rio et al. (2016). Although the temperature derived here for Gaia20bwa is consistent with the value derived by Da Rio et al. (2016) within the uncertainties, the stellar luminosity, mass, and radius derived here are about factors of 2, 1.4, and 1.3 larger, respectively. The difference between the stellar parameters derived here and by Da Rio et al. (2016) is mostly due to the higher visual extinction we found from the SED fit.

### 3.6 Accretion rates

The line fluxes shown in Table 2 can be converted to line luminosities as $L_{\text{line}} = 4\pi d^2 f_{\text{line}}$, where $d$ is the distance of the sources, and $f_{\text{line}}$ is the extinction-corrected flux of the lines. For the accretion parameters derived in this Section, we use the visual extinctions estimated from the SEDs when available, rather than the values derived from the $J-H$ versus $K_s$ plot. The SEDs allow to better constrain the visual extinctions than three data points (the $J$, $H$, and $K_s$ magnitudes). The accretion parameters derived from the different lines also confirm this, as they are more consistent when derived using the visual extinctions estimated from the SED, rather than from the $J-H$ versus $K_s$ plot. The visual extinctions derived from the SEDs in the bright state are 3 mag for Gaia20bwa and 5 mag for Gaia20fgx, while in the faint state they are 3 mag and 7 mag, respectively. For
the estimate based on the Brγ line observed with the GTC, we used the extinction of \(~4.1\) mag derived from the \(J - H\) versus \(H - K_s\) plot. However, we found, that the SEDs suggest 20-30% higher visual extinctions compared to the \(J - H\) versus \(H - K_s\) plot. Therefore, to be consistent with the \(A_V\) values derived from the SEDs, we used a value of \(5.5\) mag for the GTC data, a 25% higher value than derived from the \(J - H\) versus \(H - K_s\) plot. For the extinction correction, we assumed an \(R_V\) of \(5.5\) for Gaia20bwa, as suggested by Da Rio et al. (2016) as an average value for the Orion A cloud, while we assumed an \(R_V\) of \(3.1\) for Gaia20fgx. However, this does not make a significant difference in the derived accretion parameters, and affects the accretion parameters by \(~10\)% or less. For the distance of Gaia20bwa we adopted \(410^{+12}_{-11}\) pc (Bailer-Jones et al. 2021), while for the distance of Gaia20fgx we assumed the \(~816\pm53\) pc derived in Sec. 3.1 for the distance of Cep OB3. We derived the accretion luminosities from the line luminosities based on the relations pro-

![Figure 7. Lines detected toward Gaia20fgx (using TNG/DOLORES and NICS and GTC/EMIR).](image-url)

| Table 2. Parameters of the lines detected toward Gaia20bwa and Gaia20fgx. |
|------------------|------------------|------------------|------------------|------------------|
| Line | Telescope | Center (Å) | EW (Å) | FWHM (Å) | \(\bar{f}_{\text{line}}\) (W/m²) |
| Hα | TNG | 6567.3±0.3 | -153.6±10 | 12.3±0.4 | \((8.8\pm1.3)\times10^{-17}\) |
| Hα | LT | 6567.8±0.1 | -152±6 | 13.8±0.1 | \((9.4\pm1.4)\times10^{-17}\) |
| Hβ | TNG | 4863.3±1.5 | -58±5 | 12.6±1.0 | \((2.4\pm0.6)\times10^{-17}\) |
| Hβ | LT | 4866.1±0.1 | -108±7 | 14.5±0.1 | \((1.9\pm0.4)\times10^{-17}\) |
| Hγ | TNG | 4342.4±2.4 | -46.4±9.5 | 16.0±2.0 | \((1.3\pm0.7)\times10^{-17}\) |
| Hγ | LT | 4341.1±0.3 | -31.8±2 | 15.2±0.1 | \((8.4\pm2.5)\times10^{-18}\) |
| Hδ | TNG | 4163.4±0.8 | -19.2±5 | 6.5±1.9 | \((5.0\pm2.5)\times10^{-18}\) |
| Ca II | TNG | 8502.3±0.1 | -31.3±2.9 | 10.9±1.3 | \((4.4\pm0.9)\times10^{-17}\) |
| Ca II | TNG | 8546.6±0.3 | -30.8±2 | 11.4±1.0 | \((4.3\pm0.9)\times10^{-17}\) |
| Na I | TNG | 8666.2±0.6 | -29.2±1.3 | 11.7±0.8 | \((4.4\pm0.9)\times10^{-17}\) |
| O I | TNG | 7775.3±0.3 | -0.9±0.1 | 6.2±0.5 | \((1.0\pm0.5)\times10^{-18}\) |
| O I | TNG | 8449.0±0.7 | -2.7±0.8 | 7.6±1.6 | \((3.5\pm1.4)\times10^{-18}\) |
| Na I D | TNG | 5893.3±0.4 | -5.7±0.6 | 6.2±0.5 | \((3.8\pm1.9)\times10^{-18}\) |
| Na I D | TNG | 5900.5±0.1 | -4.9±0.3 | 4.3±0.1 | \((4.1\pm2.1)\times10^{-18}\) |
| Pa β | TNG | 12812±1 | -8.5±0.5 | 13.5±0.5 | \((1.4\pm0.5)\times10^{-17}\) |
| Br γ | TNG | 21647±2 | -13.7±2.3 | 23±1 | \((8.8\pm3.1)\times10^{-18}\) |

Gaia20fgx

| Line | Telescope | Center (Å) | EW (Å) | FWHM (Å) | \(\bar{f}_{\text{line}}\) (W/m²) |
| Hα | TNG | 6564.8±2 | -12.3±1 | 10±2 | \((4.0\pm0.8)\times10^{-18}\) |
| Br γ | TNG | 21683±4 | -10±1 | 48±6 | \((4.0±2.0)\times10^{-18}\) |
| Br γ | GTC | 21652±1 | -1.4±0.2 | 20±3 | \((7.0±2.1)\times10^{-19}\) |
Table 3. Summary of the stellar parameters of Gaia20bwa and Gaia20fgx.

|                  | $T$ (K) | $A_V$ (mag) | $L_*$ ($L_\odot$) | $M_*$ ($M_\odot$) | $R_*$ ($R_\odot$) |
|------------------|---------|-------------|-------------------|-------------------|-------------------|
| Gaia20bwa faint & bright states | 3300±200 | 3.0±0.5 | 0.38±0.06 | 0.28±0.06 | 1.89±0.32 |
| Gaia20bwa based on Da Rio et al. (2016) | 3142.5±16.04 | 0.9±0.35 | 0.20±0.02 | 0.206±0.008 | 1.51±0.15 |
| Gaia20fgx faint state | 3700±300 | 7.0±0.7 | 1.02±0.20 | 0.53±0.10 | 2.46±0.52 |
| Gaia20fgx bright state | 3700±300 | 5.0±0.5 | 0.61±0.12 | 0.47±0.10 | 1.90±0.40 |

Figure 8. Excitation diagram for the hydrogen Balmer lines of Gaia20bwa based on data from the TNG (red dots) and the Liverpool Telescope (blue dots). Some of the error bars are smaller than the symbol sizes. The solid line is the linear fit to the TNG data, while the dashed line is the fit to the LT data. Both lines result in a temperature of ~7600 K.

The accretion luminosities can then be converted to accretion rates using the formula

$$M_{\text{acc}} = 1.25 \frac{L_{\text{acc}} R_*}{GM_*}$$

for which an inner-disk radius of 5 $R_*$ was assumed (Hartmann et al. 1998). For Gaia20bwa, we used the radius of 1.89±0.32 $R_\odot$ and stellar mass of 0.28±0.06 $M_\odot$ derived above to provide one estimate of the accretion rates, and the radius of 1.51±0.15 $R_\odot$ and stellar mass of 0.206±0.008 $M_\odot$ for another estimate (Da Rio et al. 2016). For Gaia20fgx, we adopt the $R_*=2.46±0.52 R_\odot$ and $M_*=0.53±0.1 M_\odot$ values derived above for the faint state, and $R_*=1.90±0.40 R_\odot$ and $M_*=0.47±0.1 M_\odot$ values derived above for the bright state.

The accretion luminosities and rates are shown in Table 2 for both sets of stellar parameters from Table 3 for both sources. For the stellar parameters derived above for Gaia20bwa, the accretion luminosities are in the range between $(6.1±2.4) \times 10^{-2} L_\odot$ and $5.78±3.11 \times 10^{-1} L_\odot$, and the accretion rates are in the range between $(1.65±0.79) \times 10^{-8} M_\odot$ yr$^{-1}$ and $(1.60±0.9) \times 10^{-7} M_\odot$ yr$^{-1}$. Based on the stellar parameters from Da Rio et al. (2016), the accretion luminosities are in the range between $(1.64±0.85) \times 10^{-2} L_\odot$ and $(1.67±4.35) \times 10^{-1} L_\odot$, and the accretion rates are in the range between $(4.82±2.55) \times 10^{-9} M_\odot$ yr$^{-1}$ and $(4.89±13.78) \times 10^{-8} M_\odot$ yr$^{-1}$.

The accretion luminosities for Gaia20fgx during its bright state based on the TNG data are $(0.95±5.21) \times 10^{-1} L_\odot$ and $(2.77±3.58) \times 10^{-1} L_\odot$ based on the H$\alpha$ and the Br$\gamma$ lines, respectively. The accretion luminosity and rate derived for Gaia20fgx based on the Br$\gamma$ line measured with the GTC about half a year after the TNG measurements are almost a factor of 10 below those derived from the TNG data during the bright state. Since the Pa$\beta$ line detected with the GTC also has an absorption component, we did not use it to derive the accretion luminosity and rate.

4 DISCUSSION
4.1 The origin of the brightening events
Both targets show a brightening on a time-scale, which is typical of EXors (Herbig 1989, 2008). However, the amplitude of the bright-
Table 4. Accretion luminosities and rates for Gaia20bwa and Gaia20fgx. The accretion luminosities calculated from the fluxes based on Alcalá et al. (2017). For Gaia20bwa, $L_{\text{acc,1}}$ and $M_{\text{acc,1}}$ correspond to the $M_\star$ and $R_\star$ values derived for the faint and bright states, while $L_{\text{acc,2}}$ and $M_{\text{acc,2}}$ correspond to the $M_\star$ and $R_\star$ values derived by Da Rio et al. (2016). For Gaia20fgx, $L_{\text{acc,1}}$ and $M_{\text{acc,1}}$ correspond to the $M_\star$ and $R_\star$ values derived for the faint state, and $L_{\text{acc,2}}$ and $M_{\text{acc,2}}$ correspond to the $M_\star$ and $R_\star$ values derived for the bright state.

| Line | Telescope | $L_{\text{acc,1}}$ (10$^3 L_\odot$) | $M_{\text{acc,1}}$ (10$^8 M_\odot$ yr$^{-1}$) | $L_{\text{acc,2}}$ (10$^2 L_\odot$) | $M_{\text{acc,2}}$ (10$^9 M_\odot$ yr$^{-1}$) |
|------|-----------|-------------------------------|---------------------------------|----------------|-------------------------------|
| Gaia20bwa | | | | | |
| Hα | TNG | 1.36±0.30 | 3.68±1.29 | 2.09±0.46 | 6.14±1.50 |
| Hα | LT | 1.47±0.32 | 3.97±1.39 | 2.25±0.49 | 6.61±1.60 |
| Hβ | TNG | 4.46±1.26 | 12.04±4.73 | 3.95±1.11 | 11.58±3.48 |
| Hβ | LT | 3.41±0.84 | 9.23±3.40 | 3.02±0.75 | 8.87±2.40 |
| Hγ | TNG | 4.54±2.51 | 12.26±7.56 | 3.50±1.94 | 10.26±5.79 |
| Hγ | LT | 2.79±0.90 | 7.55±3.19 | 2.15±0.70 | 6.32±2.17 |
| Hδ | TNG | 2.13±1.10 | 5.74±3.35 | 1.64±0.85 | 4.82±2.55 |
| CaII | TNG | 5.46±1.43 | 14.76±5.59 | 16.66±4.35 | 48.87±13.78 |
| CaII | TNG | 4.07±1.10 | 11.00±4.23 | 12.84±3.48 | 37.66±10.97 |
| NaI D | TNG | 3.90±1.07 | 10.53±4.08 | 13.19±3.62 | 38.71±11.40 |
| O1 | TNG | 1.07±0.57 | 2.90±1.74 | 1.90±1.00 | 5.56±2.99 |
| O1 | TNG | 1.44±0.67 | 3.88±2.09 | 3.89±1.81 | 11.40±5.44 |
| NaI D | TNG | 3.46±1.83 | 9.35±5.57 | 5.46±2.88 | 16.02±6.82 |
| NaI D | TNG | 5.78±3.11 | 15.60±9.41 | 9.13±4.92 | 26.78±14.71 |
| Paα | TNG | 0.61±0.24 | 1.65±0.79 | 3.17±1.26 | 9.31±3.83 |
| Brγ | TNG | 1.14±0.46 | 3.09±1.51 | 8.33±3.32 | 24.44±10.08 |

| Gaia20fgx | | | | | |
| Hα | TNG | 5.21±1.40 | 9.68±3.78 | 9.50±2.55 | 15.37±6.18 |
| Brγ | TNG | 3.58±1.93 | 6.64±4.04 | 27.70±14.96 | 44.83±27.68 |
| Brγ | GTC | 0.37±0.13 | 0.70±0.32 | 3.71±1.35 | 6.01±2.83 |

The accretion luminosities versus the stellar luminosities as well as the accretion rates versus the stellar masses are plotted in Fig. 10. Samples of CTTS are also plotted for comparison toward the Lupus (black symbols, Alcalá et al. 2019), the Chamaeleon I (grey symbols, Manara et al. 2019), and the NGC 1333 (light blue symbols, Fiorellino et al. 2021) regions. The stellar luminosity of Gaia20bwa is close to the median value of the three samples, while its stellar mass is slightly below the median value of CTTS. Gaia20fgx is close to the most luminous end of the plotted CTTS, and its mass is above the median value of the plotted CTTS. While the accretion luminosities and rates for both Gaia20bwa and Gaia20fgx in their bright state are toward the upper end among CTTS with similar luminosities and masses, they still follow the trend seen in the accretion luminosity versus stellar luminosity and the accretion rate versus stellar mass in the CTTS samples. This is not the case for the few examples of EXors (triangles in Fig. 10), which are clearly above the general trends seen in the CTTS samples. One of the EXors plotted is the newly confirmed EXor corresponding to the Gaia alerted Gaia20aeae (Cruz-Sáenz de Miera et al. 2022). The accretion luminosities and rates of the other EXors are from Lorenzetti et al. (2009). For UZ Tau E we used a stellar luminosity of $\sim 0.6 L_\odot$ and a mass of $\sim 1.0 M_\odot$ (Prato et al. 2002). For DR Tau we adopted a stellar luminosity of $0.87 L_\odot$ (Muzerolle et al. 2003), which, together with its K7 spectral type, corresponds to a stellar mass of $\sim 0.67 M_\odot$ (Siess et al. 2000). For V1118 Ori we adopted a stellar luminosity of 0.18 $L_\odot$ and a stellar mass of 0.29 $M_\odot$ (Giannini et al. 2017). For a better comparison, Gaia20bwa, Gaia20fgx, and Gaia20aeae (Cruz-Sáenz de Miera et al. 2022), and the EXors from Lorenzetti et al. (2009) we used the accretion luminosities and rates calculated from the Brγ line. Based on this comparison of the accretion versus stellar parameters, not only Gaia20bwa, but also Gaia20fgx is closer to CTTS than to EXors.

Brightness variations for young stars also occur due to a change of the circumstellar extinction, not only due to a change of the accretion rate. As seen in Fig. 5 in the g versus [g − r] color–magnitude diagram of Gaia20fgx, the brightening event corresponding to the Gaia alert suggests a change in the visual extinction, such as suggested by the $J − H$ versus $H − K_\alpha$ plot and the SEDs. To investigate how the accretion rate changes, we observed the NIR spectra of Gaia20fgx over two epochs, the brightening event of Gaia20fgx corresponding to the Gaia alert was indeed due to an increase of the accretion rate, even if the increased accretion rate remained below the values expected for eruptive young stars. For Gaia20bwa, while there is only one estimate of its accretion rate, the color–color diagram in Fig. 4 indicates, that the visual extinction did not change significantly during the faint and the bright state. In addition to this, the brightening event was also seen in the WISE W1 and W2 bands. Therefore, the brightening event...
with lower amplitudes (Hillenbrand & Findeisen 2015). Though the brightening events with $0.5 - 2$ mag amplitudes on a time-scale of a year or above are not typical of non-eruptive YSOs, a number of sources with variability on a similar time-scale were identified at NIR wavelengths (Contreras Peña et al. 2017). The sample of Contreras Peña et al. (2017) includes targets with $\Delta K_S > 1$ mag, out of which, several sources show long-term brightening, on a similar time-scale to Gaia20bwa and Gaia20fgx. However, given that the survey of Contreras Peña et al. (2017) was in the NIR, it cannot be directly compared to the Gaia light curves of Gaia20bwa and Gaia20fgx. The long-term variability of a sample of 72 CTTS based on optical photometry was analysed by Grankin et al. (2007), and though most of the sources in the sample showed a variability with an amplitude of $\Delta V \leq 0.4$ mag, there are a few sources with variability amplitudes up to $\Delta V \sim 2$ mag. Based on the long-term optical light curves of 218 CTTS, Briceño et al. (2019) found mean variability amplitudes of $\sim 0.7$ mag in the $V$-band and $\sim 0.6$ mag in the $R$-band, which are close to the $\sim 1$ mag variability, that is seen for Gaia20fgx between 2015 and 2018. The information on long-term brightness variations of YSOs is limited. Databases from photometric surveys, such as the Gaia Science Alerts, are expected to provide more information on brightenings of young stars on a time-scale of months-years.

4.3 Spectral properties of the sources

The lines identified in the spectra of both sources are also typical of EXors (Cruz-Sáenz de Miera et al. 2022 and references therein). However, the number of lines detected in the spectra is below what is typical of EXors, even when observed at low spectral resolution (Lorenzetti et al. 2009). For Gaia20fgx, the low number of detected lines in the spectra, in addition to the low spectral resolution, may also be related to its low brightness even during its bright state, when the TNG spectra were observed, and during its fading, when the GTC spectra were observed. As a comparison with a known EXor, the prototype EX Lupi, we plotted in Fig. 11 the TNG spectra of Gaia20bwa and Gaia20fgx together with those of EX Lupi. We used the spectra obtained during its latest, 2022 outburst (Kóspál et al. 2022), as its amplitude was $\lesssim 2$ mag in the $g$ band (Ábrahám et al., in prep.), and as a less luminous outburst compared to the extreme eruption of EX Lupi in 2008 (Ábrahám et al. 2009), it provides a good comparison with our targets. Since these spectra were taken using VLT/XSHOOTER (Ábrahám et al., in prep.), we smoothed them to match their resolution to our low-resolution spectra. Several spectral lines are detected in the spectra of both Gaia20bwa and EX Lupi, e.g. the Balmer lines, Pa, Br, and Pa, are not seen in the spectra of Gaia20bwa and Gaia20fgx. The visual extinctions and spectral types of the sources derived from the SEDs are similar to those of CTTS (e.g., Fiorellino et al. 2021) including EXors (Lorenzetti et al. 2009). We conclude, that the spectral properties of Gaia20bwa and Gaia20fgx, together with their accretion parameters, are more consistent with active CTTS, than with typical EXors.

4.2 The time-scale and amplitude of the brightening events

As discussed above from the comparison of the accretion rates, the sources studied here are most likely CTTS, rather than EXors. However, the brightness variations of CTTS typically occur on shorter time-scales than the brightenings of Gaia20bwa and Gaia20fgx, and

5 SUMMARY

We have analyzed the light curves and optical and NIR spectra of two young stars which had Gaia alerts due to brightening episodes on a time-scale which is typical of the EXor class of young eruptive stars. The main results can be summarized as follows.
The brightening episode of Gaia20bwa occurred on a time-scale of a year and few months with an amplitude of ~0.5 mag. Gaia20fgx showed two brightening episodes on a similar time-scale. Its second brightening episode which triggered the Gaia alerts system had an amplitude of ~2.5 mag.

We have taken optical and NIR spectra of the sources using the TNG during their bright state, and NIR spectra for Gaia20fgx to those of EX Lupi, the prototype EXor during its latest outburst (Ábrahám et al., in prep.). The spectra of EX Lupi were smoothed to match their spectral resolution similar to that of the TNG spectra. For a better comparison, the optical fluxes of Gaia20bwa were multiplied by 0.6, and the NIR spectra of EX Lupi were multiplied by 2.

- The brightening episode of Gaia20bwa occurred on a time-scale of a year and few months with an amplitude of ~0.5 mag. Gaia20fgx showed two brightening episodes on a similar time-scale. Its second brightening episode which triggered the Gaia alerts system had an amplitude of ~2.5 mag.

- We have taken optical and NIR spectra of the sources using the TNG during their bright state, and NIR spectra for Gaia20fgx using the GTC during its fading. The hydrogen Balmer lines from Hα to H6, Paβ, Brγ, and lines of Ca ii, O i, and Na i were detected in emission in the spectra of Gaia20bwa. The Hα and Br lines were detected toward Gaia20fgx in emission in its bright state, with additional 2-0 and 3-1 bandhead features of CO in absorption and the Paβ line showing an inverse P Cygni profile during its fading.

- Based on the Brγ lines the accretion rate was found to be \( (2.4 - 3.1) \times 10^{-8} \ M_\odot \ \text{yr}^{-1} \) for Gaia20bwa and \( (4.5 - 6.6) \times 10^{-8} \ M_\odot \ \text{yr}^{-1} \) for Gaia20fgx during their bright state. The accretion rate of Gaia20fgx dropped by about a factor of 10, to \( (6.01 - 7.0) \times 10^{-9} \ M_\odot \ \text{yr}^{-1} \) on a time-scale of half a year.

- The accretion luminosities and rates measured for both sources are closer to those found for CTTS for similar stellar luminosities and masses than to those measured for young eruptive stars. However, the amplitude and time-scale of these brightening events place these two stars to a region of the parameter space, which is rarely populated by accreting young stellar objects. This suggests a new class of young stellar objects, which produce outbursts on a time-scale similar to young eruptive stars, but with smaller amplitudes, possibly representing an intermediate case between variable CTTS and young eruptive stars.

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DATA AVAILABILITY

The data underlying this article will be shared on reasonable request to the corresponding author.

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APPENDIX A: PHOTOMETRY
Optical and near-infrared photometry of Gaia20bwa and Gaia20fgx. Uncertainties are typically 0.1 mag in the $B$ filter, 0.05 mag in the $gVri$ filters and 0.01 mag in the $JHK_s$ filters.

| Date          | JD – 2450000 | $B$  | $g$  | $V$  | $r$  | $i$  | $J$  | $H$  | $K_s$ | Telescope       |
|---------------|--------------|------|------|------|------|------|------|------|------|-----------------|
| 2021-01-03    | 9218.36      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | Mt. Subora      |
| 2021-01-22    | 9237.35      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | Mt. Subora      |
| 2021-02-11    | 9257.41      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | Mt. Subora      |
| 2021-03-01    | 9293.31      | 18.147 | 17.315 | 16.712 | 16.057 | 15.507 | 15.045 | 14.584 | 14.071 | RC80            |
| 2021-03-10    | 9295.29      | 18.004 | 17.073 | 16.596 | 16.054 | 15.504 | 15.045 | 14.584 | 14.071 | RC80            |
| 2021-03-05    | 9296.30      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-03-10    | 9460.60      | 19.291 | 18.218 | 17.496 | 17.085 | 16.674 | 16.284 | 15.894 | 15.484 | RC80            |
| 2021-03-08    | 9465.58      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-03-09    | 9466.57      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-03-10    | 9467.58      | 19.249 | 18.069 | 17.376 | 17.104 | 16.714 | 16.324 | 15.934 | 15.524 | RC80            |
| 2021-03-16    | 9473.63      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-03-26    | 9483.53      | 19.068 | 18.052 | 17.406 | 17.104 | 16.714 | 16.324 | 15.934 | 15.524 | RC80            |
| 2021-03-27    | 9484.57      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-04-04    | 9491.53      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-04-15    | 9502.63      | 19.298 | 18.199 | 17.471 | 17.104 | 16.714 | 16.324 | 15.934 | 15.524 | RC80            |
| 2021-04-20    | 9507.59      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-04-24    | 9512.49      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-07-06    | 9530.59      | 19.498 | 18.182 | 17.504 | 17.104 | 16.714 | 16.324 | 15.934 | 15.524 | RC80            |
| 2021-07-16    | 9542.56      | 19.371 | 18.219 | 17.499 | 17.104 | 16.714 | 16.324 | 15.934 | 15.524 | RC80            |
| 2021-07-12    | 9592.39      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-07-15    | 9595.33      | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | RC80            |
| 2021-07-22    | 9634.26      | 19.397 | 18.263 | 17.517 | 17.104 | 16.714 | 16.324 | 15.934 | 15.524 | RC80            |