MUSICOS Observations of SU Aur

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Abstract:

We present first results of the high-resolution observations of SU Aur obtained through the MUSICOS network in 1996 Nov. The data set is unique in that it gives us complete phase coverage for almost two rotation periods of SU Aur. This is particularly valuable for T Tauri stars as they can vary dramatically on the time scale of one rotation period.

1. MUSICOS

The MUlti-SIte COntinuous Spectroscopy (MUSICOS) network was set up with the aim of investigating the time-dependent behaviour of stars with rotation periods that necessitate coordinated observations from several longitudes (Foing et al. 1994, Catala et al. 1993).

SU Aur was chosen as one of the targets for the MUSICOS 1996 campaign that took place in November of that year. 126 échelle spectra were taken over 10 nights at the Beijing Astronomical Observatory (Xinglong, China), the Observatoire de Haute Provence (France), the INT (La Palma, Spain), the McDonald observatory (Texas) and the CFHT (Hawaii). The observations at the CFHT were taken with a polarimeter, providing additional Stokes V information.

The weather was somewhat patchy, particularly at the CFHT, but for SU Aur good phase coverage was obtained between HJD 2450406.5 and HJD 2450410.0, and reasonable phase coverage for the subsequent days up to HJD 50414.0 (see Fig. 1). The wavelength range and resolution varies from spectrograph to spectrograph. For clarity, all the spectra shown here have been re-binned to a uniform resolution of about $\lambda/\Delta\lambda = 30,000$ corresponding to a velocity resolution of approximately 10 km s$^{-1}$.

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2. SU Aurigae

SU Aurigae is a relatively unusual classical T Tauri star (cTTS) that shows comparatively little veiling and only very few emission lines. Its parameters are listed in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Type</td>
<td>G2</td>
<td>Cohen &amp; Kuhi (1979)</td>
</tr>
<tr>
<td>Brightness (V)</td>
<td>9 mag</td>
<td>Cohen &amp; Kuhi (1979)</td>
</tr>
<tr>
<td>Mass</td>
<td>2.25 $M_\odot$</td>
<td>Cohen &amp; Kuhi (1979)</td>
</tr>
<tr>
<td>$v \sin i$</td>
<td>$\approx 66$ km s$^{-1}$</td>
<td>Hartmann et al. (1986)</td>
</tr>
<tr>
<td>Period (photom.)</td>
<td>1.55, 2.73 d</td>
<td>Herbst et al (1987)</td>
</tr>
<tr>
<td>Period (photom.)</td>
<td>$\leq 3.5$ d</td>
<td>Bouvier et al. (1993)</td>
</tr>
<tr>
<td>Period (Hα wing)</td>
<td>$\approx 3$ d</td>
<td>Johns &amp; Basri (1995b)</td>
</tr>
<tr>
<td>Period ($v_{rad}$)</td>
<td>3.03 ± 0.03 d</td>
<td>Petrov et al. (1996)</td>
</tr>
</tbody>
</table>

It has been the subject of several extensive spectroscopic studies (see e.g., Johns & Basri 1995b (hereafter, JB95), Giampapa et al. 1993 and Petrov et al. 1996 (hereafter, P+96)). Even though SU Aur has been monitored frequently, the photometric period determinations are very uncertain. This is because the light curve of SU Aur does not tend to show any clear periodic variations. To date, the most conclusive period determinations are not due to photometric variations, but to spectral variations in the emission lines (see JB95 and P+96). Despite the period uncertainties, SU Aur is, compared to most other cTTS, a promising surface-mapping candidate, mainly due to its small veiling and high rotation velocity.

3. The Hα Profiles

Fig. 1 clearly shows that SU Aur’s Hα profiles are very variable even on the relatively short time scale of several hours. The profile shapes vary relatively smoothly, but they do not show any obvious periodicities. We observe two redward moving features in the blue wing of the line, one centred around HJD 2450409, the other around HJD 2450413. The average and normalised variance profile (see e.g., Johns & Basri 1995a) are shown in Fig. 2. The normalised variance profile shows that most of the variability comes from a velocity region centred on $-80$ km s$^{-1}$. It is at this velocity shift that JB95 found a peak in their power spectrum corresponding to about 7.7 days, though the detection was only marginal. The strongest peak (corresponding to a period of about 3 days) in the power spectrum of JB95 was found between $-250$ and $-100$ km s$^{-1}$. With the existing data set, we could not confirm either period as the short-term variability dominates our power spectra.

The residual profiles from HJD 2450406.5 onwards are plotted in Fig. 3a). They are obtained after division by the mean profile. The plot also illustrates another interesting feature, namely the strong flux enhancement at about HJD 2450409. Simultaneous observations taken with the APT of the University of
Figure 1. A plot of the stacked H-alpha profiles. The offset between subsequent profiles reflects the difference in observing time. For clarity, the profiles have been binned. The black lines show profiles that are the sum of several profiles observed at different observatories. Otherwise, the different observatories are color and line-coded as follows. Dotted red: Xinglong (China), dashed blue: OHP (France), dot-dashed orange: INT (La Palma, Spain), triple-dot-dashed green: McDonald (Texas) and long-dashed purple: CFHT (Hawaii).
Figure 2. The mean (solid line) and the variance profile (filled area) of SU Aur during the MUSICOS campaign. The variance profile is calculated as $\frac{(\sum (f_i - \bar{f})^2/(n - 1))^{0.5}}{\bar{f}}$.

Vienna (Fig. 4) indicate that SU Aur was moving into a photometric minimum from about HJD 2450408 onwards. Unfortunately, the observations are too patchy to deduce whether this minimum was a short-lived event and whether the observed Hα flux enhancement is then due to a change in the continuum to line-flux contrast.

4. The Sodium Doublet

The residual profiles of the sodium doublet are shown in Fig. 3b. They are somewhat difficult to analyse due to the interstellar absorption lines and some light pollution. Furthermore, the Na D lines on SU Aur are also intrinsically less variable than the Balmer lines. However, it appears that the red-ward moving feature in the blue wing of the Hα line (See Fig. 1 at HJD 2450409) is mirrored in both Na D lines. A small emission bump begins to appear at a blue-shift of about 80 km s$^{-1}$ around 2450407.75 and moves slowly towards the line centre, and perhaps even beyond it. The second feature that was found in the blue wing of Hα does not show such a clear counterpart in the Na D profiles.

5. He I at 5876 Å

Rather unusually for a cTTS, SU Aur shows He D$_3$ in absorption. The profiles tend to be asymmetric and at times there is an indication that part of the profile is filled in by emission. Fig. 3c) shows the dynamic spectrum of the helium line.
Figure 3. The left-most image shows a colour representation of the residual Hα profiles. Red is at a level of about 1.0, blue and black indicate stronger absorption than the mean, orange and yellow show excess emission. There is a strong flux enhancement at HJD 2450409 and a moving absorption feature in the blue wing at about 2450413. The moving absorption feature at HJD 2450408 is less easily distinguishable in this representation. The middle plot shows the residual Na D profiles. The colour table is as for the image on the left. Note the coherent drift of the features between 2450408 and 2450410. The plot on the right shows the He 1 (5876 Å) line profiles. The equivalent width shows a strong enhancement about every 2.5 to 3 nights. On this plot, the continuum is shown in yellow.

The average line profile tends to be red-shifted by about 20 km s⁻¹. The strength of the absorption varies markedly and there seems to be periodically recurring strong absorption. This is shown again in Fig. 5 where the EW of the helium line is plotted as a function of time. The periodogram shows a significant peak corresponding to a period of 2.7 days. The peak is relatively broad, with a FWHM of about 0.8 days.

Petrov et al. 1996 observed periodic or quasi-periodic radial-velocity variations in the Balmer lines and in He D3. We find that there is a trend for the radial velocity to be further redshifted as the equivalent width of the He line increases. During our observations, the He 1 line is usually asymmetric, though without clear indication of a secondary absorption component. Because of this
asymmetry, the velocity shift of the line centre is not very well determined so that we can not confirm the periodic variation of the radial velocity.

6. The Magnetic Field on SU Aur

The observations at the CFHT were taken with the MuSiCoS spectropolarimeter (Donati et al. 1992, 1997a), allowing us to obtain unpolarised and circularly polarised data spanning the whole 410 to 810 nm range. Due to bad weather, no more than 35 unpolarised and 9 circularly polarised spectra could be recorded throughout the 9 d run, with S/N ratios of the order of 60 and 120 (per 3.8 km s⁻¹ spectral bin) for the Stokes I and V spectra respectively. Even though more than 3,000 spectral features could be used for Least-Squares Deconvolution (see Donati et al. 1997b for details on this technique), the moderate spectrum quality only allowed us to obtain one marginal detection (false alarm probability of 0.2%) on 1996 Nov. 19 (see Fig. 6), but nothing on the other four clear nights.

7. Conclusions

As in earlier studies we find that the Hα line is very variable on time scales of a few hours. We observe two very clear redward-moving emission bumps. The first bump (starting at about HJD 2450408) can be traced for about 1.5 days or so and seems to be mirrored in the Na D lines. The second emission feature
Figure 5. A plot of the He D$_3$ equivalent width as a function of time. The different colours indicate at which particular observatory a spectrum was taken. (See the caption to Fig. 1 for the colour codes). Note the apparent periodicity of about 2.5 to 3 days, and the non-sinusoidal variation of the EW.

(starting around HJD 2450412) is much clearer in H$_\alpha$, but can not be identified in the sodium doublet. The second feature also appears to persist longer, though we can not be sure to identify it unambiguously in the last 3 exposures due to a gap in our coverage between HJD 2450414 and HJD 2450415.

The He I triplet at 587.6 nm shows very strong (periodic) equivalent width variations with a period of about 2.7 days. This period is shorter than the periods measured from variations in the Balmer lines (J95, P+96). The different periods, however, need not be at odds; we can invoke a picture in which the Balmer-line variability arises in extended structures (that may not be strictly co-rotating), while the He I variations are due to changes closer to the stellar surface.

We could not detect any coherent equivalent width variations of SU Aur’s photospheric lines above the 5% level; and even then most of the discrepancy came from taking into account spectra from different observatories. There are, however, clear changes in the line-profile shape, suggesting the presence of starspots. This is illustrated in Fig. 5., where two deconvolved profiles are superimposed. Note that both profiles were obtained from data that were taken 6.14 days apart, which should correspond to two rotation cycles according to the period obtained by P+96. The large difference between the two profiles lends additional support to our conjecture that the rotation period of SU Aur is indeed shorter than 3 days.
LSD profiles of SU Aur, 1996 Nov. 19

Figure 6. A plot of the deconvolved Stokes V and I profiles on November 19 (HJD 2450407). The Stokes V profile has been offset and enhanced by a factor of 25.

LSD profiles of SU Aur, 1996 Nov 20 & 26

Figure 7. A plot of two deconvolved profiles that were taken 6.14 days apart at the CFHT. The solid line is the profile taken on Nov 19, the dashed line is from the data taken on Nov 25.
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References