arXiv:0809.2355v1 [astro-ph] 13 Sep 2008

Baltic Astronomy, vol. 17, 21–37, 2008

YOUNG STARS IN THE CAMELOPARDALIS DUST AND MOLECULAR CLOUDS. IV. SPECTRAL OBSERVATIONS OF THE SUSPECTED YSOs

C. J. Corbally[1] and V. Straižys[2]

[1] *Vatican Observatory Research Group, Steward Observatory, Tucson, Arizona 85721, U.S.A.; corbally@as.arizona.edu*

[2] *Institute of Theoretical Physics and Astronomy, Vilnius University, Goštauto 12, Vilnius LT-01108, Lithuania; straizys@itpa.lt*

Received 2008 March 15; accepted 2008 March 30

Abstract. In the first three papers of this series, about 200 objects in Camelopardalis and the nearby areas of Cassiopeia, Perseus and Auriga were suspected of being pre-main-sequence stars in different stages of evolution. To confirm the evolutionary status of the 15 brightest objects, their far-red range (600–950 nm) spectra were obtained. Almost all these objects are young stars with emissions in Hα, O I, Ca II and P9 lines. The equivalent widths of emission lines and approximate spectral classes of the objects are determined.

Key words: stars: pre-main-sequence – stars: emission-line

1. INTRODUCTION

In the previous papers of this series (Straižys & Laugalys 2007a,b, 2008, Papers I, II and III) about 250 young stellar objects were identified in the Camelopardalis segment of the Milky Way, including the nearby areas of Cassiopeia, Perseus and Auriga (ℓ, $b = 132$–$158°$, $\pm 12°$). The limits of the area were defined by the distribution of the Cam OB1 association members. Paper I listed 43 massive members of the association and 18 stars of lower masses which were known to exhibit emission in Hα or to belong to irregular variable stars of types IN and IS. In Paper II, 142 suspected young stellar objects (YSOs) were selected on the ground of infrared photometry taken from the 2MASS, IRAS and MSX databases. In Paper III, 50 suspected YSOs were selected in the same way in a $3° \times 3°$ area covering the densest part of the dust cloud T 942 (Dobashi et al. 2005), with the high-mass object GL 490 embedded. Although some of the suspected YSOs (especially those without IRAS and/or MSX measurements) can be stars with dense envelopes belonging to the asymptotic branch, or even heavily reddened spiral galaxies, there is a strong evidence of star-forming activity in the Camelopardalis dust and molecular clouds.

Naturally, the evolutionary status of each suspected YSO needs spectral confirmation. For the beginning, spectral observations were obtained for 15 objects from

Table 1. List of the investigated stars. F is the red photographic magnitude. In the last column, YSO means the known or suspected young stellar object, Hα means the star with Hα emission found in objective-prism spectra.

Name	RA (2000)	DEC (2000)	ℓ	b	F	Type
SL 21	2 23 18.4	+61 25 41	133.688	+0.490	15.14	YSO
SL 37	2 27 16.0	+62 00 50	133.919	+1.204	13.31	YSO
SL 78	2 51 47.0	+55 42 01	139.369	–3.283	13.10	YSO
KW 14-24	3 01 21.6	+60 28 56	138.280	+1.541	13.40	Hα
SL 75	3 03 25.8	+60 23 10	138.550	+1.580	14.18	YSO
SL 79	3 10 46.3	+59 30 04	139.788	+1.269	15.12	YSO
SL 82	3 17 26.1	+60 09 42	140.160	+2.268	9.31	Hα
GL 490	3 27 38.8	+58 47 00	142.000	+1.820	17.67	YSO
IRAS 03243+5819	3 28 14.6	+58 29 38	142.227	+1.624	15.75	YSO
SL 101	3 29 07.6	+57 01 34	143.152	+0.479	14.90	YSO
SL 158	3 30 05.5	+58 13 25	142.580	+1.539	14.63	YSO
Gahm 25	3 54 20.3	+53 05 34	148.399	–0.487	14.87	Hα
Gahm 23	3 57 55.0	+52 25 37	149.241	–0.650	14.26	Hα
Gahm 22	3 58 31.7	+52 02 42	149.560	–0.880	14.21	Hα
Gahm 21	3 59 53.4	+51 31 46	150.055	–1.135	13.76	Hα

the described lists, including seven stars for which the presence of the emission lines was known earlier, and some brightest stars from the Paper II and Paper III lists. The list of the observed stars is presented in Table 1, and their identification charts of the $1.8' \times 1.8'$ size are given in Figure 1.

2. SPECTRAL OBSERVATIONS

The spectra were taken with the Bollen & Chivens spectrograph on the Steward Observatory 2.3 m telescope at Kitt Peak, using the 400 g/mm red-blazed grating, giving a resolution of 5.7 Å and a range from 6075 to 9395 Å on the BCSpec 1200×800 CCD detector. The slit width was $1.5''$.

The spectra, shown in Figure 2 in a widened form, were reduced using IRAF software. The energy distributions, shown in Figure 3 (a–p), were obtained by calibrating the spectra with the spectrophotometric standard Hiltner 600 and removing an atmospheric extinction curve typical for Kitt Peak. For the classification of stars the criteria described by Danks & Dennefeld (1994) in the far-red and near-infrared spectral region were applied. The results of classification are only approximate since the spectral features at this resolution and S/N do not give the discrimination of luminosities and, in some cases, even of spectral subclasses. Some interference is also due to unexcluded H_2O and O_2 telluric bands and some spectral fringing which was not eliminated completely for the low-S/N spectra. The emission line intensities of the spectral classifications are scaled in relation to those given by Herbig (1962, Table I) for the T Tauri stars CW Tau, CY Tau, BP Tau and T Tau, whose spectra were observed in the same nights as the program stars.

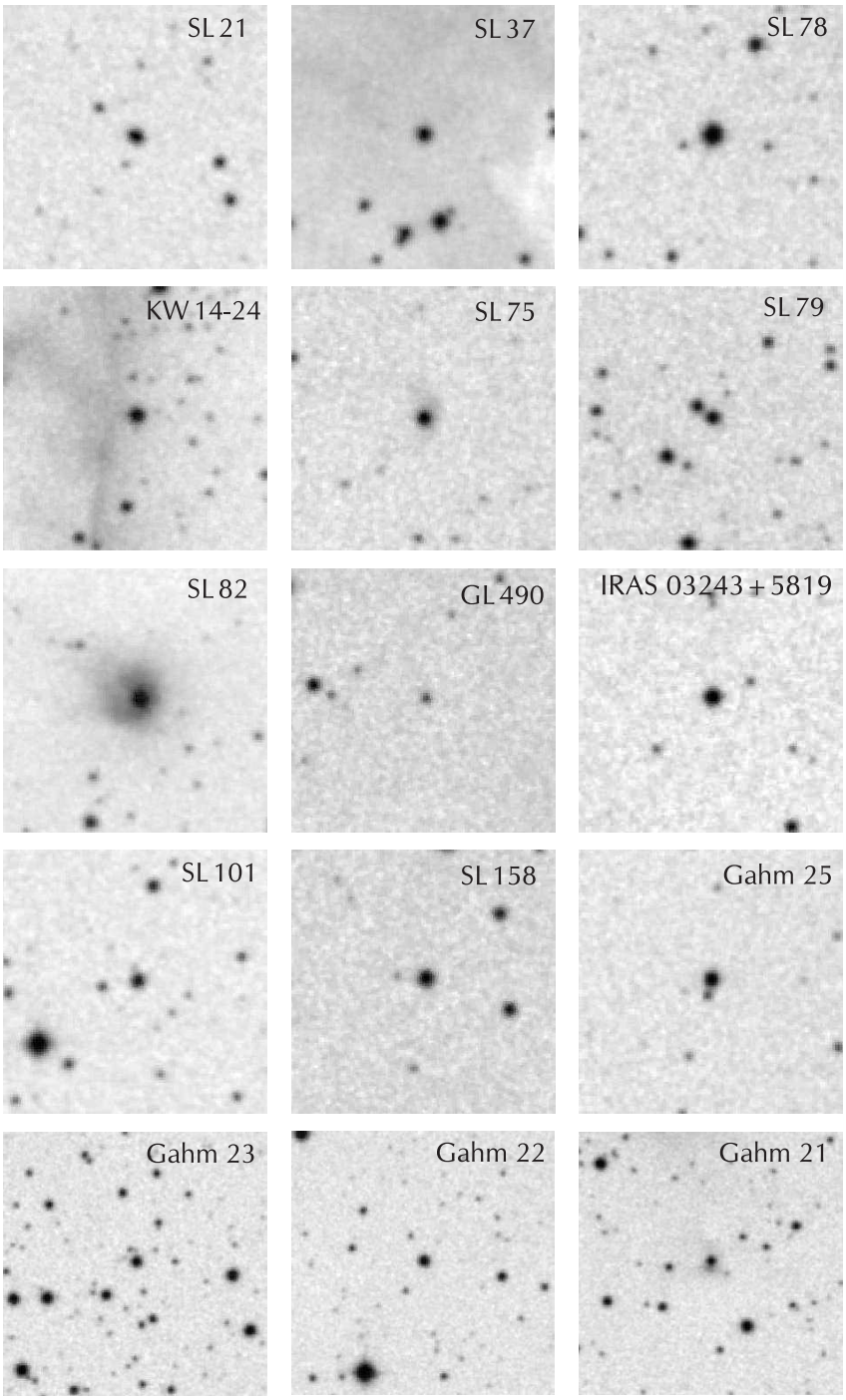


Fig. 1. Identification charts. The fields of $1.8' \times 1.8'$ sizes are DSS2 red copies taken from the Internet's Virtual Telescope SkyView.

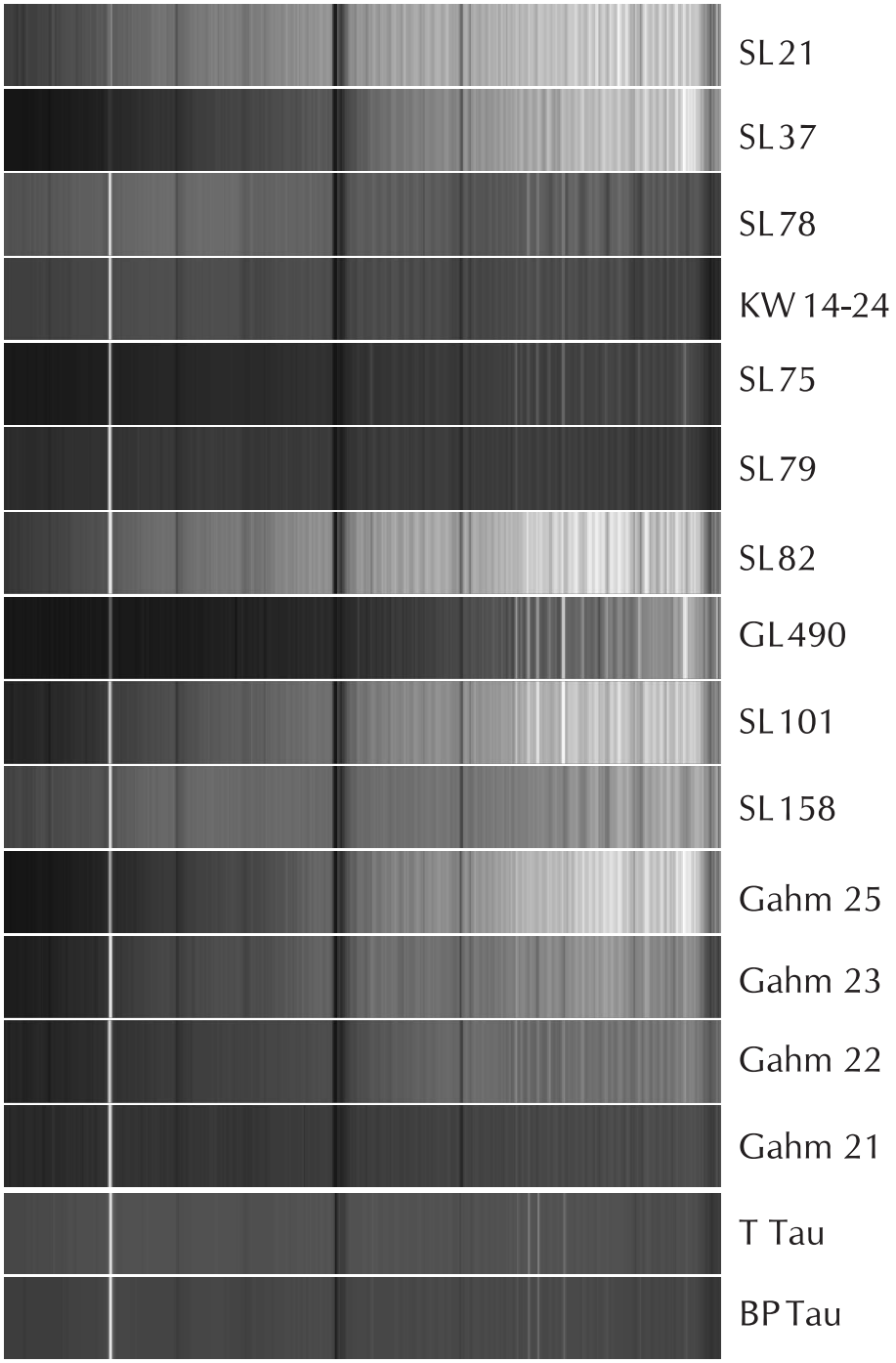


Fig. 2. The widened spectra of the investigated stars. For comparison, the spectra of two T Tauri type stars are given at the end. The telluric H_2O and O_2 bands are not excluded.

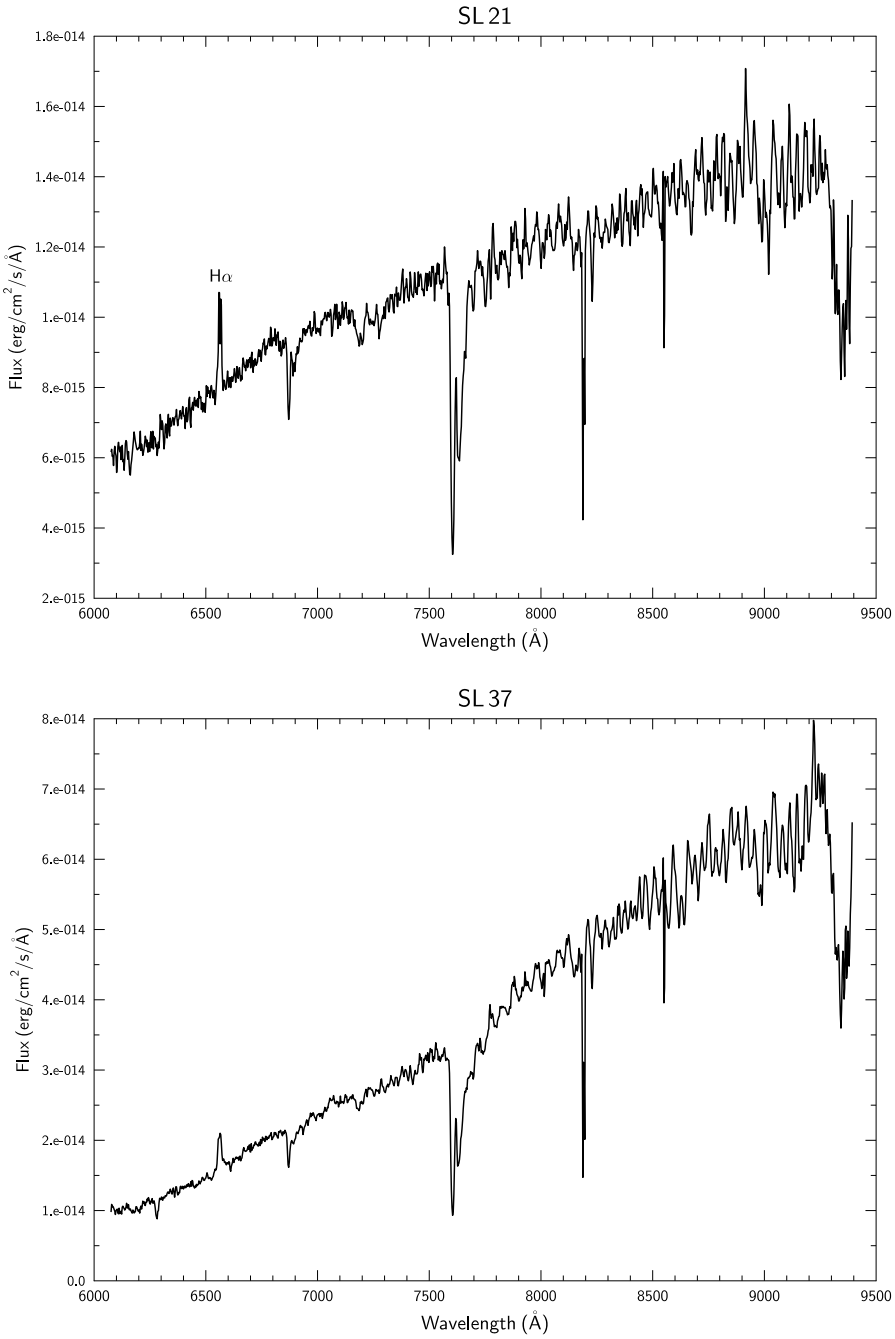


Fig. 3a and 3b. Spectral energy distributions for the stars SL 21 and SL 37.

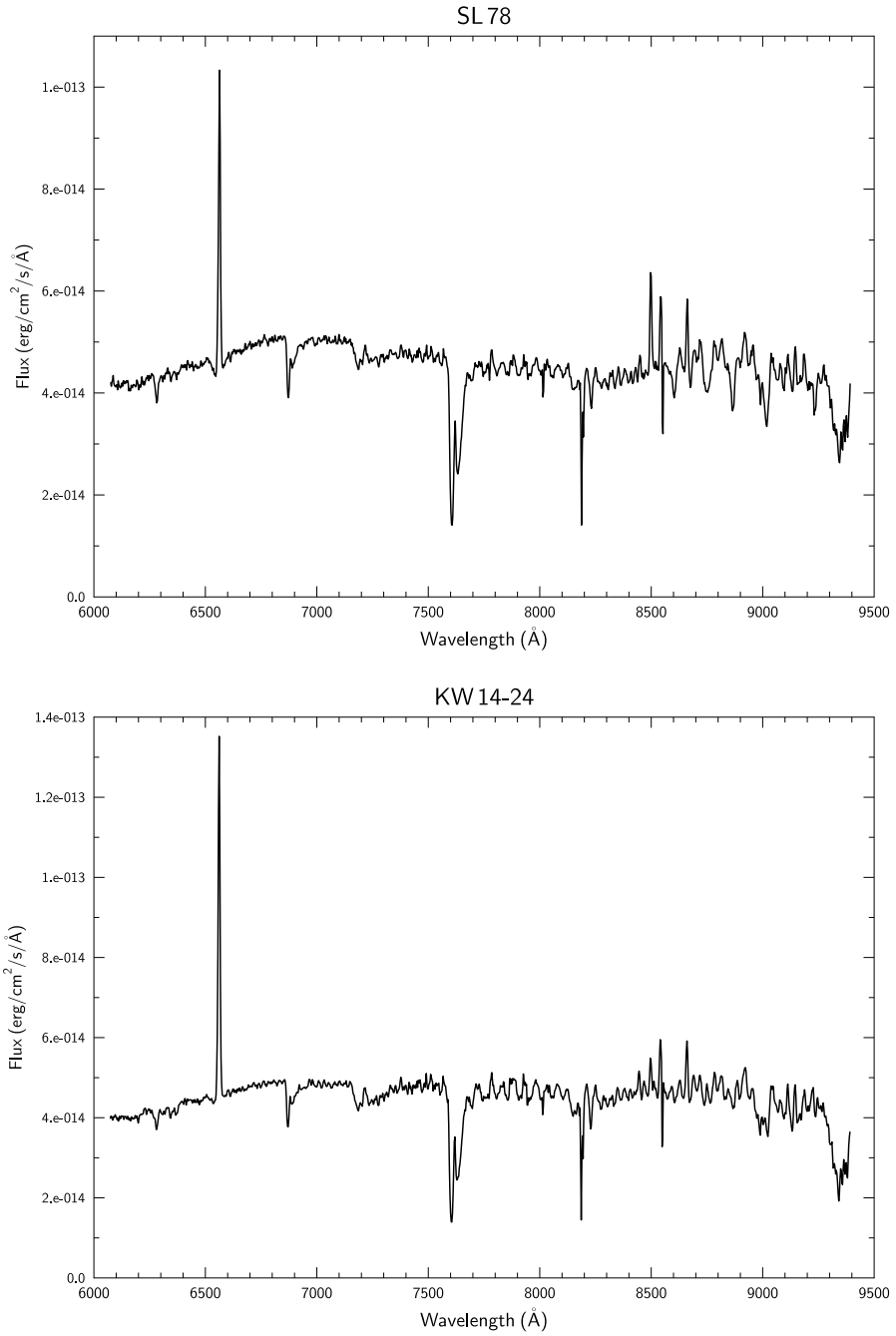


Fig. 3c and 3d. Spectral energy distributions for the stars SL 78 and KW 14-24.

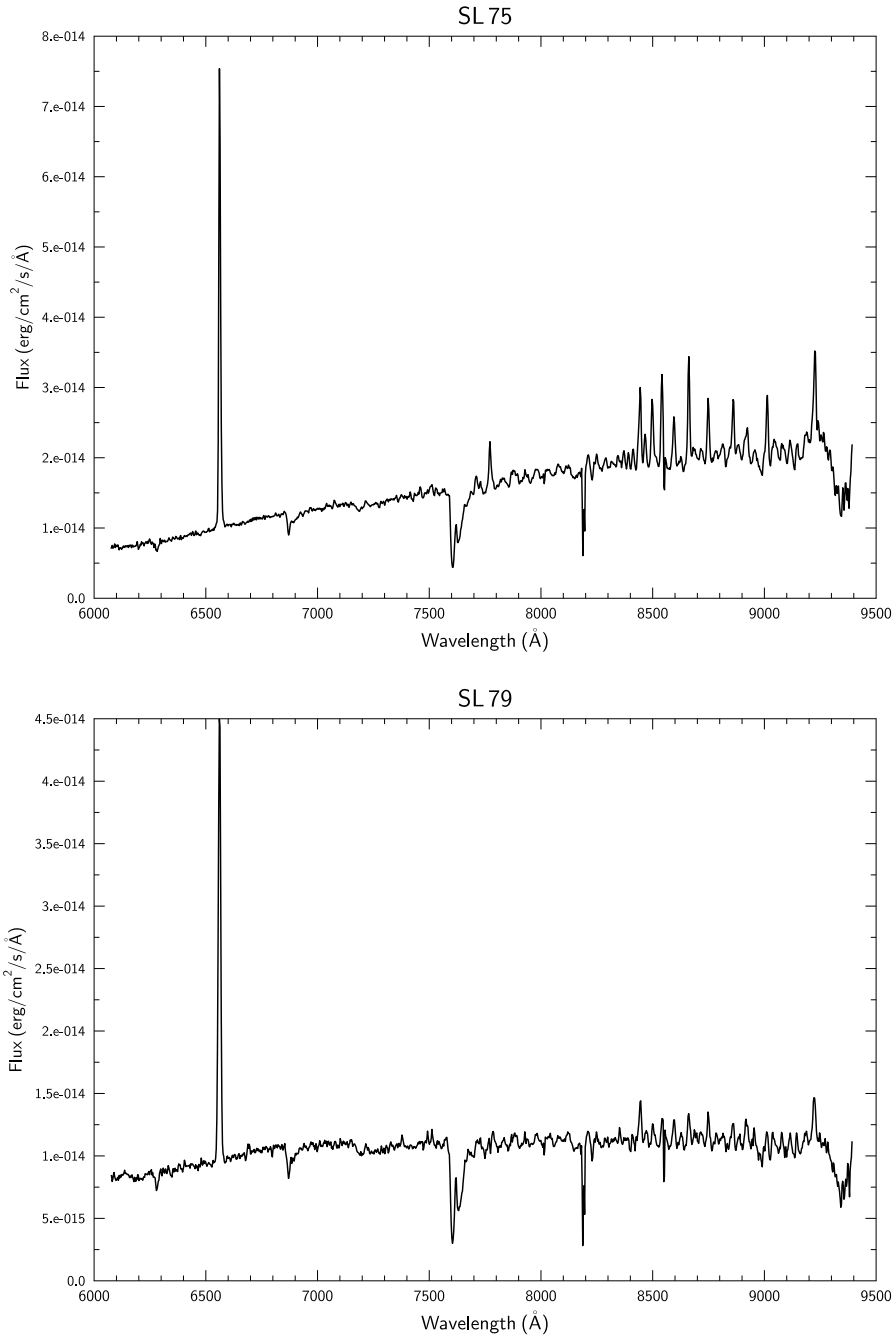
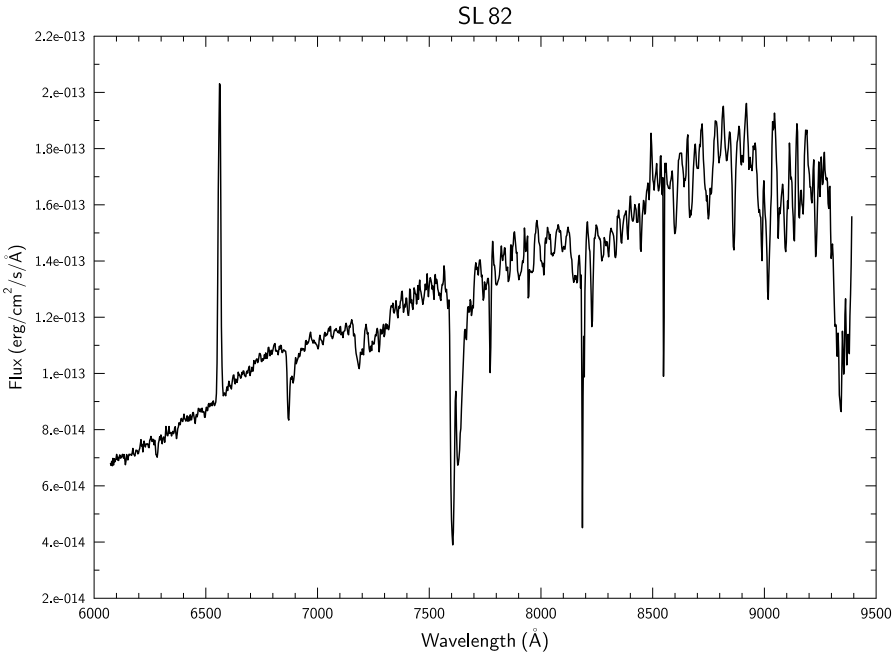


Fig. 3e and 3f. Spectral energy distributions for the stars SL 75 and SL 79.



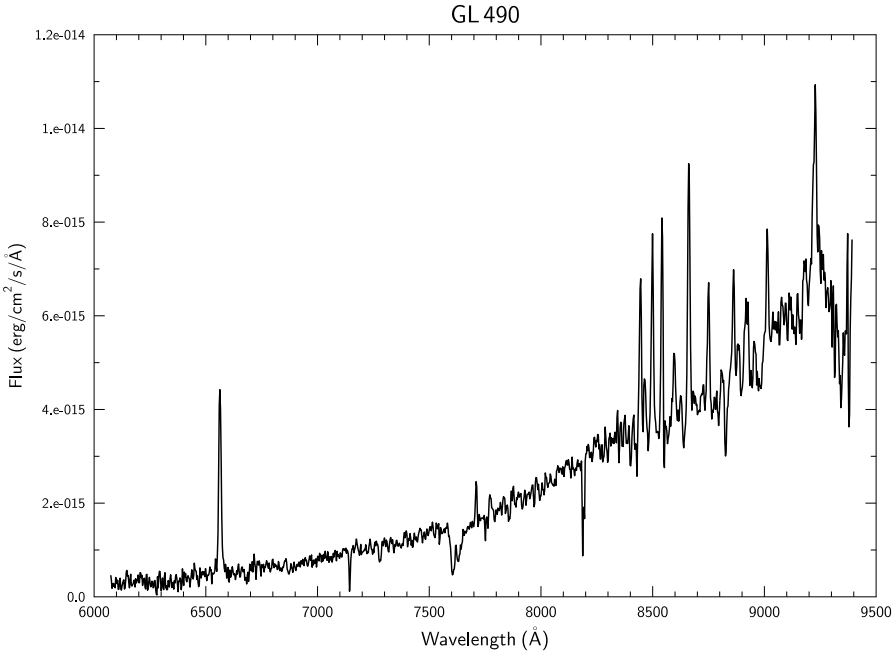
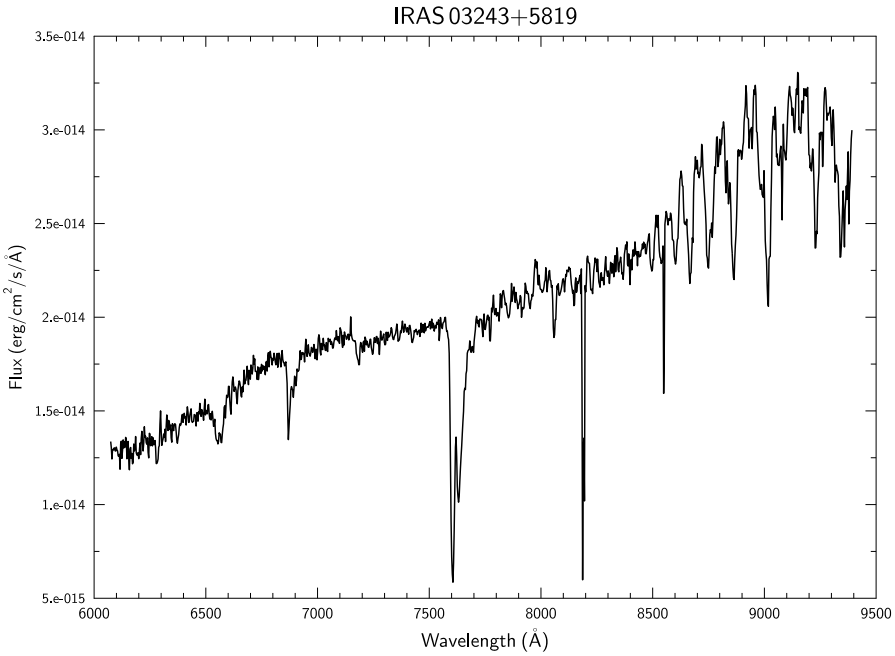


Fig. 3g and 3h. Spectral energy distributions for the stars SL 82 and GL 490.



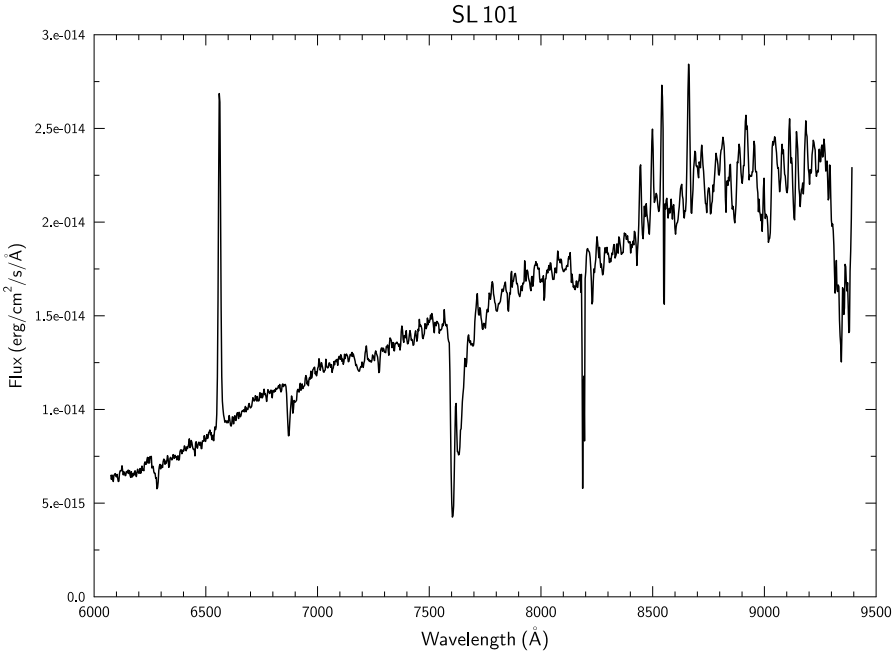


Fig. 3i and 3j. Spectral energy distributions for the stars IRAS 03243+5819 and SL 101.

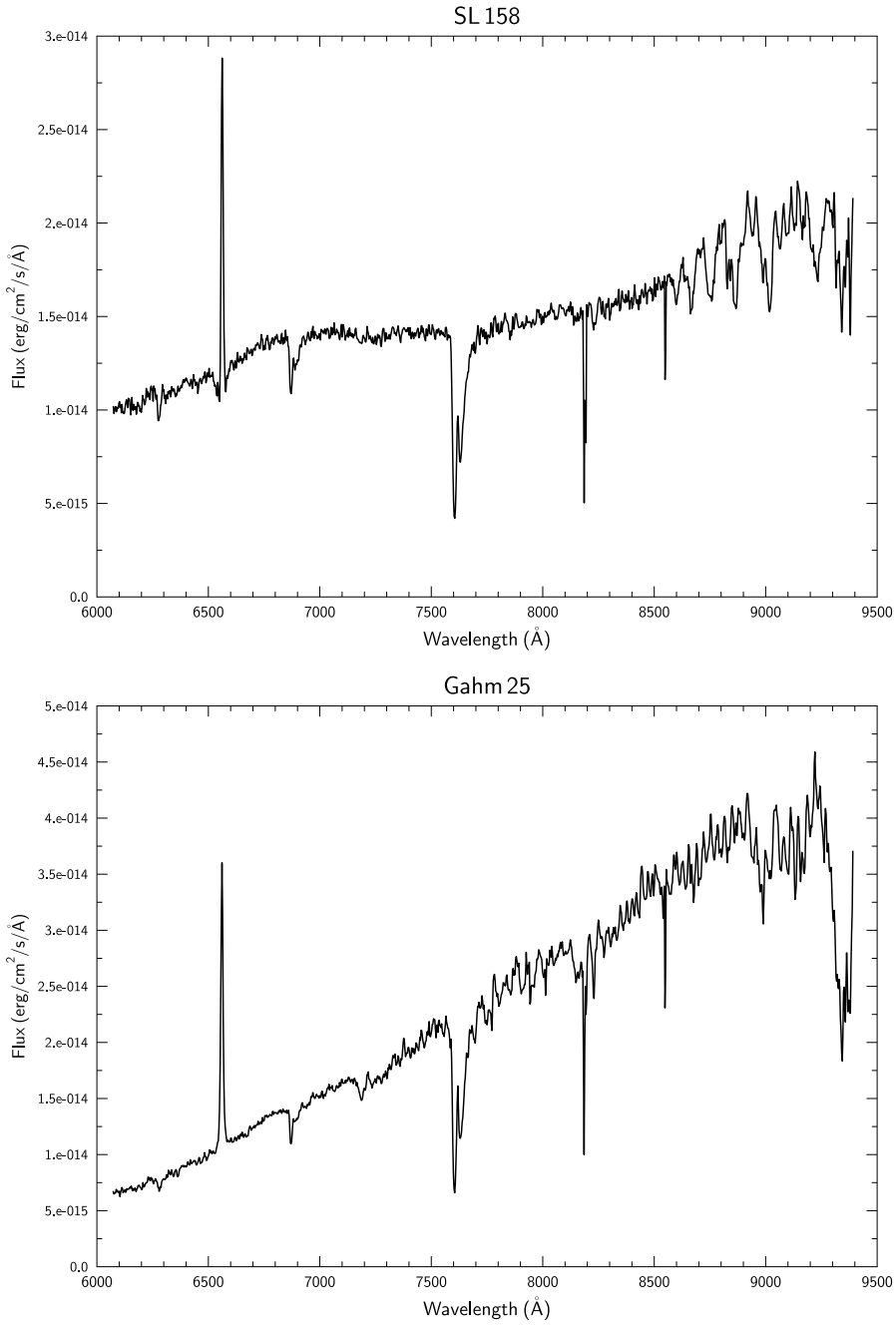
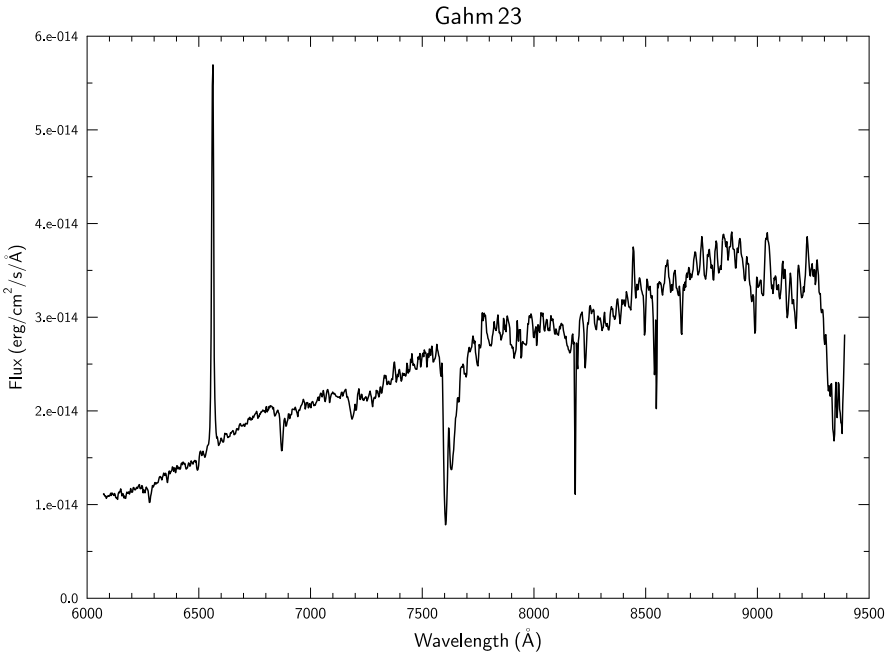


Fig. 3k and 3l. Spectral energy distributions for the stars SL 158 and Gahm 25.



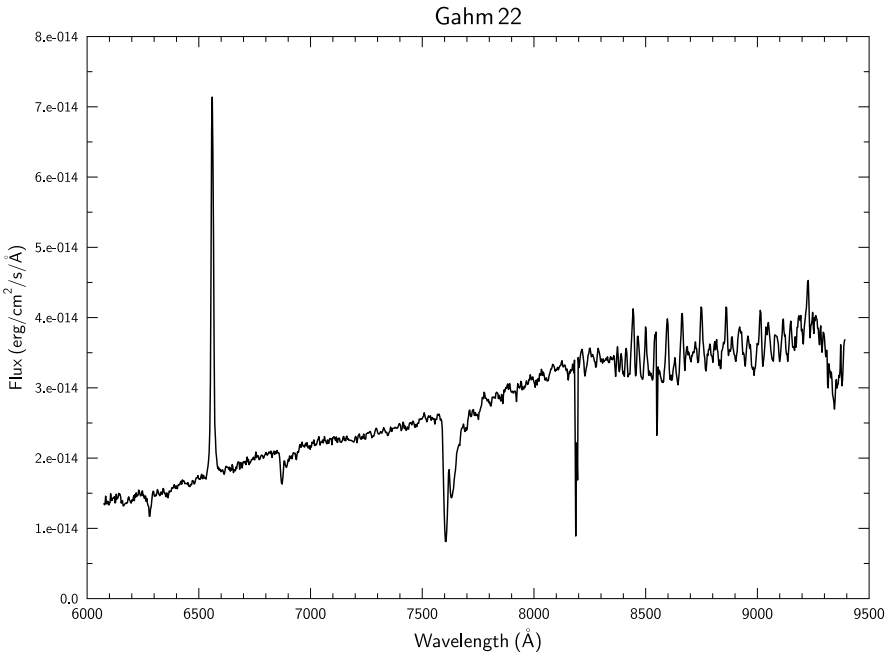


Fig. 3m and 3n. Spectral energy distributions for the stars Gahm 23 and Gahm 22.

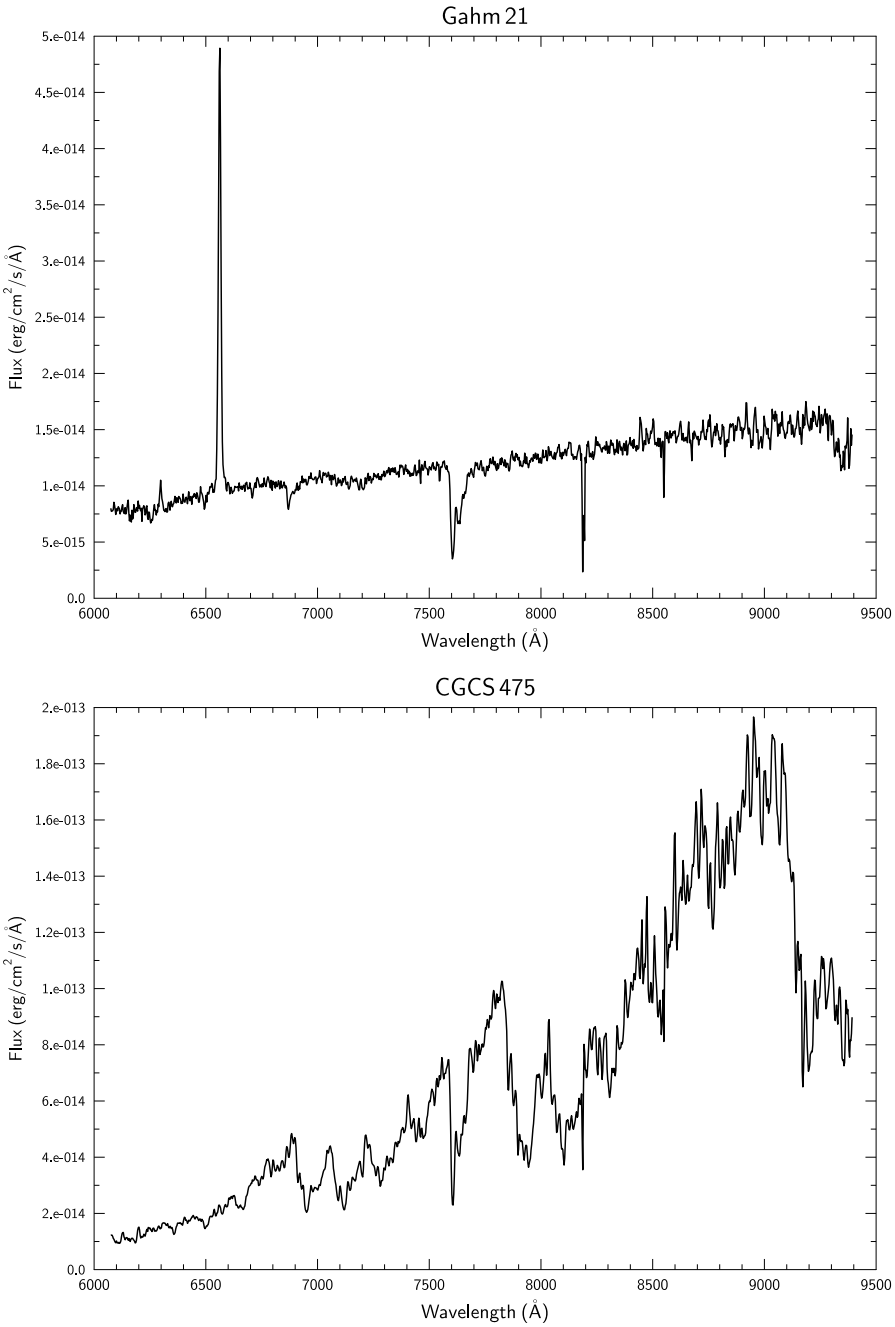


Fig. 3o and 3p. Spectral energy distributions for the stars Gahm 21 and CGCS 475 (carbon star).

Table 2. Equivalent widths of emission lines and spectral classification.

Star	Obs. date	EW 6563 Hα	EW 8446 O I	EW 8498 Ca II	EW 8542 Ca II	EW 8662 Ca II	EW 9226 P9	Spectral class
SL 21	2007-10-23	−4.6						G0e (0.2)
SL 37	2007-10-23	−6.5					−1.6	A5e (0.2)
SL 78	2007-10-23	−10.2	−1.7	−3.4	−1.8	−2.2		F5e (0.5)
KW 14-24	2007-10-21	−20.6	−0.8	−1.4	−2.2	−2.1		G5e (1)
SL 75	2007-10-23	−64.8	−4.8	−4.1	−4.5	−6.7	−12.2	G0e (1.5)
SL 79	2007-10-23	−50.6	−3.0	−1.1	−0.4	−2.2	−3.9	G0e (1)
SL 82	2007-10-21	−17.2		−0.8				G5e (0.5)
GL 490	2007-10-22	−86.2	−8.2	−10.6	−11.1	−14.7	−9.6	Ae (2)
IRAS *	2007-10-22							Ae *
SL 101	2007-10-23	−26.0	−1.5	−2.0	−2.0	−4.0		G0e (0.5)
SL 158	2007-10-22	−11.8						Ae (0.5)
Gahm 25	2007-10-21	−29.5					−0.5	K2e (0.5)
Gahm 23	2007-10-21	−28.4	−1.3				−0.8	Ge (1)
Gahm 22	2007-10-22	−42.2	−1.6	−1.4	−1.8	−0.8	−1.6	Ae (1.5)
Gahm 21	2007-10-22	−59.0	−1.1	−1.0				Ke (1.5)
T Tau	2007-10-21	−91.8	−4.0	−13.9	−10.8	−14.0	−1.9	K1e
BP Tau	2007-10-21	−149.1	−3.1	−9.3	−9.0	−11.7	−3.9	K7e
CY Tau	2007-10-21	−36.0						M1e
DI Tau	2007-10-22	0.4						M0e

* IRAS 03243+5819, emission core in the center of Hα absorption line.

The equivalent widths of the prominent emission features (Hα, Ca II triplet, O I at 8498 Å and P9 at 9226 Å) were measured with the IRAF 'splot' utility. They are taken across the whole line, including any absorption wings, so positive EWs will result when there is emission in just the line cores. The mean values of three measures are given in Table 2. EWs were measured also in the spectra of four T Tauri stars, T Tau, BP Tau, CY Tau and DI Tau, having very different emission-line intensities. During our observations the star DI Tau did not show any emission, even in Hα.

3. DISCUSSION ON INDIVIDUAL OBJECTS

In this section we give more information about the investigated objects and discuss the results of spectral classification and emission line intensities.

SL 21 = 2MASS J02231856+6125416

The object is located in the dark cloud T 879 to W from the H II region W3/4. In Paper II, according to the LSR radial velocities of the surrounding CO clouds, the cloud is attributed to the Perseus spiral arm. However, in this direction the lower velocity components of some clouds are also prominent, so we do not exclude that SL 21 is an object of the Local arm. The inspection of its images in SkyView shows that the object is double. The components of similar brightness are separated by $\sim 1.5''$ and are located along the NE–SW direction. In the B passband the NE object is slightly fainter, in R and I both objects are of equal brightness, and in J, H and K the NE object dominates. This means that this object is the cooler component of the system. If the object is in the Local arm at a distance

of 1 kpc (the distance of the Cam OB2 association), then both components are separated by 1500 AU. An infrared object IRAS 02198+6111 (Kerton & Brunt 2003), located within about 3′, has no relation to SL 21, it corresponds to another 2MASS object. In our spectrum both components are not separated. It exhibits a noticeable Hα emission, the lines of O I and Ca II are not seen. Probably, one or both components are T Tauri or post T Tauri stars of early G class.

SL 37 = 2MASS J02271602+6200506

The object is located within the same cloud T 879, in the outskirts of the H II region W3. First recognized as an Hα emission object in the objective-prism spectra by Dolidze (1975, her number 02-075). The star was included in the emission-star catalog of Kohoutek & Wehmeyer (1997, star number 11-56). Faint X-ray source (Rosat). Our classification gives A5e(0.2) spectral type. Probably, it is a Herbig Ae/Be star related to clustering of stars in the H II region IC 1795, belonging to the Perseus arm.

SL 78 = 2MASS J02514696+5542014

The object is located within a dark cloud T 931 belonging to the Cam OB1 association dust layer of the Local arm. No object is present in the Simbad database within 2′ of its position. According to our spectra, the object exhibits quite strong emissions in Hα, O I and Ca II. Other criteria prove it to be of spectral class F5, consequently this is a star of intermediate temperature between classical T Tauri stars and Herbig Ae/Be stars. The star is present in the MSX catalog (G139.3681-03.2822) with a flux at 8.3 μm of 0.192 Jy (quality 3). The energy distribution curve of the star is similar to YSOs of Class III (see Paper II).

KW 14-24 = 2MASS J03012159+6028566

An entry in the emission-star catalog of Kohoutek & Wehmeyer (1997). First discovered by Dolidze (1975, her number 02-155). Recently the Hα emission was confirmed by the IPHAS photometric survey (Witham et al. 2008). Faint X-ray source (Rosat). The star is located at a bright rim of the ionized gas at the left edge of the H II region W5 belonging to the Perseus arm (Ogura et al. 2002; Karr & Martin 2003b). It may be one of the objects formed by a triggered star formation mechanism due to compression of gas and dust by ionization fronts. In our spectrum the emission line Hα is very strong, and the O I and Ca II emissions are much fainter, spectral class G5.

SL 75 = 2MASS J03032586+6023095

No object is present in the Simbad database within 2′ of its position. Thus, this is a new YSO in one of the clumps of the dust cloud T 912 at the left edge of the H II region W5. A broad 15″ long protrusion or jet is seen north of the object. Probably this is a classical T Tauri star of spectral class at G0 with strong emissions in Hα, O I, Ca II and P9 lines, similar in strengths to the emissions in the prototype star T Tau.

SL 79 = 2MASS J03104626+5930035

This object is located in a faint emission nebula LBN 140.07+1.64 (Lynds 1965), near the southern edge of Sh 2-202 belonging to the Local arm. However, this LBN nebula shows the velocity of the Perseus arm. The counterpart of the object is IRAS 03068+5918 (Karr & Martin 2003a; Kerton & Brunt 2003). Nearby, at an angular distance of about 8″ in the NE direction another very similar object, 2MASS J03104707+5930082, is located. This object in the V passband is fainter

by 1.3 mag, but with increasing λ the difference diminishes, and in J and H both sources are of equal intensity. In the K_s passband the NE object is again fainter by 0.8 mag. Our spectra correspond to the right, brighter object. The star seems to be a typical T Tauri star of G-type with very strong Hα emission line and fainter emissions in O I, Ca II and P9.

SL 82 = 2MASS J03172590+6009417

The star is also known as IRAS 03134+5958 and CPM 7 (Campbell et al. 1989). It was first described as an emission-line object and included in the catalog of emission-line stars of the Orion population by Herbig & Bell (1988). It is located at the center of the Sh 2-202 nebula, near the questionable open cluster Stock 23. In the Palomar atlas blue and red images it looks like a comet-like object surrounded by a nebulous coma with a diameter of $\sim 0.5'$, with a broad short tail directed to NE. Our spectra confirm its emission-line status with a moderately strong emission in Hα and faint emission in Ca II, spectral class is $\sim$ G5.

GL 490 = 2MASS J03273876+5847000

A heavily reddened ($A_V \approx 35$ mag, Alonso-Costa & Kwan 1989) high-mass young stellar object (IRAS 03236 +5836), embedded in the densest part of the dust cloud T 942. GL 490 was discovered in the US Air Force Geophysics Laboratory (AFGL) Infrared Sky Survey using 16.5 cm telescopes flown above the atmosphere on rocket probes. The Price & Walker (1976) catalog presents fluxes of GL 490 in the 11 and 20 μm passbands. The star belongs to the Cam OB1 association layer of the Local arm. It is a YSO of Class I: surrouded by circumstellar gas and dust shell which gives a strong far-infrared excess, see its spectral energy distribution in Paper II. The spectrum in the interval 600–1000 nm was observed by McGregor et al. (1984): Hα, Paschen series, O I, Ca II triplet and [S III] lines are in emission. The lines Brα, Brγ and Pfγ are also in emission (see Simon et al. 1983; Bunn et al. 1995 and references therein). Our spectrum shows strong emissions in Hα, O I, Ca II and P9.

IRAS 03243+5819 = 2MASS J03281460+5829374

This star is located in the dust cloud T 942, only $\sim 20'$ from GL 490. In Papers II and III it was not included in the lists of suspected YSOs since in the J–H vs. H–K_s diagram the star was found to be located below the intrinsic line of T Tauri stars. Our spectrum shows the star is of spectral class A with emission in the core of the Hα absorption line (Figure 3i). Spectral energy distribution has its maximum between 2 and 12 μm. Probably this is a heavily reddened ($A_V \approx 10$ mag) Herbig Ae star with a thin disk or envelope.

SL 101 = 2MASS J03290756+5701336

The object is also identified as MSX G143.1521+00.4784. It is located in the cloud T 942, 1.1° from GL 490. The image has a north-directed 8″ long jet-like structure. In Paper II it was classified as a YSO of Class III on the grounds of a MSX point at 8.3 μm. In our spectrum a strong emission in Hα and fainter emissions in O I and Ca II lines are seen; its spectral type is about G0. According to the strength of emissions the star should be a T Tauri star or YSO of Class II.

SL 158 = 2MASS J03300545+5813253

The object is also known as IRAS 03261+5803 and MSX G142.5800+01.5382. Located in the same clump of the dust cloud T 942 as GL 490, 0.6° from it. In Paper III it is classified as a YSO of Class II. In our spectrum a strong emission in the core of absorption Hα line is present, spectral type Ae.

The four Gahm stars

As was described in Paper I, these stars have been discovered as containing Hα emission by Gahm (1990) in low-dispersion objective-prism spectra, obtained with the Stockholm Observatory Schmidt telescope. In Paper I these four stars were selected from 12 Hα-line emission objects discovered in this area: they lie above or near the intrinsic line of T Tauri stars in the J–H vs. H–K_s diagram. The Hα emission for three of them (Gahm 21, 22 and 23) was recently confirmed by the IPHAS photometric survey (Witham et al. 2008). The stars are located at the eastern part of the Cam OB1 association, near the Sh 2-205 nebula.

The blue, red and infrared SkyView images of Gahm 21 show a broad 'tail' which in the red image extends southward up to 10″. At about 14″ to SW, a faint star or a knot of the 'tail' is seen. In the blue image the 'tail' has an extended form running 22″ along the W–E direction and includes the mentioned knot. The star Gahm 25 at $\sim 6'$ southward has a much fainter neighbor seen in all colors from B to K_s.

In our spectra all four Gahm stars exhibit strong Hα emissions. The emissions of O I, Ca II and P9 lines are much fainter. Only three of them (Gahm 21, 23 and 25) seem to be T Tauri-type stars of spectral classes G and K. The star Gahm 22 is a heavily reddened Herbig Ae/Be star with $E_{H-K} \approx 0.5$ mag; this corresponds to $A_V \approx 7$ mag.

CGCS 475 = 2MASS J03191389+5841586

This star located at a distance of $\sim 1°$ from GL 490 was included into the observing program by chance. Later it was found that the star is a carbon star CGCS 475 (Alksnis et al. 2001), its magnitude V seems to be close to 15.0 and variable. Probably the star may be identified with IRAS 03154+5831, but their positions differ by 62.6″. The spectrum shown in Figure 3p is typical for N-type carbon stars, with strong CN bands. Another similar carbon star, IRAS 03156+5828, discovered from the IRAS low-resolution spectra (Chen & Chen 2003) is located just 6′ left of CGCS 475. It is much fainter in optical but brighter in K_s than CGCS 475.

4. CONCLUSIONS

The far-red slit spectra of 15 known and suspected YSOs embedded in dust/molecular clouds of Camelopardalis and the nearby region of Cassiopeia are obtained. Among them is the well-investigated infrared object GL 490, a pre-Herbig Ae/Be star in a dense gas and dust shell. All these objects exhibit strong Hα emission lines and fainter emission lines of O I, Ca II and P9. The spectral classes of these objects range from A to K. Since equivalent widths of Hα emissions for most of the objects (except one) are larger than 10 Å, these stars should be either in the T Tauri stage (7 objects) or in the Herbig Ae/Be stage (6 objects). One object is a star of intermediate temperature and one seems to be in a post T Tauri stage. The conclusion is in agreement with the form of spectral energy distributions of some of these stars in the medium and far infrared (Papers II and III). Some of the objects exhibit jets or outflows. In the future, the light, line intensity and spectral energy distribution variations are to be verified.

Consequently, we confirm that the brightest objects, which in Papers II and III have been suspected to be YSOs, indeed are in the pre-main-sequence stage of evolution. This fact gives a credence that the fainter objects, selected by the

same method in the mentioned papers, should be also in the same evolutionary stage. Recently, 13 more YSOs from Papers II and III were confirmed to be Hα emission stars by the IPHAS photometric survey (Witham et al. 2008; González-Solares et al. 2008). If the majority of the suspected YSOs will be confirmed by photometric and spectroscopic observations, the Camelopardalis dark cloud area can be recognized as a region of active star formation, similar to the Taurus SFR on the opposite side of the Galactic equator.

ACKNOWLEDGMENTS. We are thankful to the Steward Observatory for the observing time and to Edmundas Meištas for his help preparing the paper. The use of the 2MASS, IRAS, MSX, IPHAS, SkyView, Gator and Simbad databases and the IRAF program package is acknowledged.

REFERENCES

Alksnis A., Balklavs A., Dzervitis U., Eglitis I., Paupers O., Pundure I. 2001, *General Catalog of Galactic Carbon Stars by C. B. Stephenson*, 3rd Edition, Baltic Astronomy, 10, 1

Alonso-Costa J. E., Kwan J. 1989, ApJ, 338, 403

Bunn J. C., Hoare M. G., Drew J. E. 1995, MNRAS, 272, 346

Chen P.-S., Chen W.-P. 2003, AJ, 125, 2215

Danks A. C., Dennefeld M. 1994, PASP, 106, 382

Dobashi K., Uehara H., Kandori R., Sakurai T., Kaiden M., Umemoto T., Sato F. 2005, PASJ, 57, S1

Dolidze M. V. 1975, Bull. Abastumani Obs., 47, 3

González-Solares E. A., Walton N. A., Greimel R., Drew J. E. et al. 2008, MNRAS (in press) = arXiv 0712.0384

Herbig G. H. 1962, Advances in Astron. & Astrophys., 1, 47

Herbig G. H., Bell K. R. 1988, *Third Catalog of Emission-Line Stars of the Orion Population*, Lick Obs. Bull., No. 1111

Karr J. L., Martin P. G. 2003a, ApJ, 595, 880

Karr J. L., Martin P. G. 2003b, ApJ, 595, 900

Kerton C. R., Brunt C. M. 2003, A&A, 399, 1083

Kohoutek L., Wehmeyer R. 1997, *H-alpha Stars in Northern Milky Way*, Abh. Hamburger Sternw., 11, Teil 1+2 = CDS catalog III/205

McGregor P. J., Persson S. E., Cohen J. G. 1984, ApJ, 286, 609

Ogura K., Sugitani K., Pickles A. 2002, AJ, 123, 2597

Price S. D., Walker R. G. 1976, *The AFGL Four Color Infrared Sky Survey: Catalog of Observations at 4.2, 11.0, 19.8, and 27.4 μm*, Report AFGL-TR-76-0208

Simon M., Felli M., Cassar L., Fischer J., Massi M. 1983, ApJ, 266, 623

Straižys V., Laugalys V. 2007a, Baltic Astronomy, 16, 167 (Paper I)

Straižys V., Laugalys V. 2007b, Baltic Astronomy, 16, 327 (Paper II)

Straižys V., Laugalys V. 2008, Baltic Astronomy, 17, 1 (Paper III, this issue)

Witham A. R., Knigge C., Drew J. E., Greimal R. et al. 2008, MNRAS, 384, 1277