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14. Abstract/Notes

Results of a photometric and spectroscopic survey of Southern Irregular Variables (of types L, I and Is) are summarized. About 400 stars were observed and nearly 20% of them were found to be misclassified. Among stars with magnitude fainter than 14, there is an increasing fraction of interesting objects. A total of 12 new Cataclysmic Variables or related objects were identified and a few of them are discussed in some detail.

15. Remarks

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OBSERVATIONS OF SOUTHERN IRREGULAR VARIABLES [1]

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ABSTRACT

Results of a photometric and spectroscopic survey on Southern Irregular Variables (of types L, I and Is) are summarized. About 400 stars were observed and nearly 20% of them are misclassified. Among stars with magnitude fainter than 14, there is an increasing fraction of interesting objects. A total of 12 new Cataclysmic Variables or related objects were identified and a few of them are discussed in some detail.

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1. The data presented in this work were collected at the Laboratório Nacional de Astrofísica (CNPq/LNA) in Brazil and at the Cerro Tololo Interamerican Observatory (CTIO), Chile.

2. Visiting astronomer, Cerro Tololo Interamerican Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

1. INTRODUCTION

Irregular Variables (hereafter IVs) comprehend two groups of objects: slow irregular variables (type L) and fast irregular variables (type I). The slow IVs are usually red giants (Lb) or red supergiants (Lc). The fast IVs can be classified as Is or In depending on their association to nebulosity. Due to the way in which many IVs were historically characterized, i.e., as a by-product of proper motion surveys, photographic surveys and patrols, etc., and due to the lack of more detailed information, many variable stars that have no intrinsic similarities to the "normal" IVs were classified as such. In these cases, types L or I are usually assigned. In the past, some of these misclassified stars, when better studied, turned out to be quite interesting objects, like QSOs, BL Lac objects or Cataclysmic Variables (CVs).

We became interested in studying IVs in a more systematic way after we discovered (Steiner et al. 1981) that V1223 Sgr, previously classified as an IV of type L is actually a Cataclysmic Variable of the Intermediate Polar subclass. This star is the optical counterpart of the UHURU X-ray source 4U1849-31. CVs in general are described in Robinson (1976) and Intermediate Polars were reviewed by Warner (1983).

Also related to misclassified objects among IVs, there is another strong reason to do a survey on these objects: the possibility of discovering Low Mass X-ray Binaries (LMXBs) using optical techniques (see Bradt and McClintock 1983 for a review on LMXBs). In general, LMXBs do not show X-ray eclipses and this is interpreted as due to occultation caused by an optically and geometrically thick disk around an accreting neutron star. Because of a selection effect in X-rays, pole-on systems are more prone to detection. There must exist, however, a class of objects seen edge-on -- that are not strong X-ray sources -- but with optical photometric and spectroscopic properties similar to those of the pole-on LMXBs. Both short and long timescales for photometric variability in these objects are such that they could be easily confused with Irregular Variables.

The best place to search for this class of edge-on LMXBs is the galactic bulge. It is well known that the observed LMXBs and classical novae are highly concentrated in that region of the Galaxy. Here we have to recall, however, that even in the absence of interstellar absorption these objects would be relatively faint, $V \sim 17$-18.

A third, but not less important motivation to carry out this study, is the opportunity of collecting a homogeneous data set on "normal" (whatever they are) Irregular Variables.

2. OBSERVATIONS AND ANALYSIS

The general procedure was to select L, I or Is stars from the 3rd edition of the General Catalogue of Variable Stars (Kukarkin et al. 1969 and supplements) and from the New Catalogue of Suspected Variable Stars (Kukarkin et al. 1982) and obtain B-V photoelectric photometry for them with the 0.6m and 1.6m telescopes of the Laboratório Nacional de Astrofísica (CNPq/LNA) in Southeast Brazil. About 350 stars were observed photometrically.

A spectroscopic follow-up program on objects selected photometrically was carried out using the 2D-Frutti detector (Phillips, 1986) on the Yale 1m telescope at CTIO. For some objects with close optical companions or in crowded fields, we took spectra without previous photometry (about 50 stars).

Photoelectric photometry shows that about 80% of the objects are quite red (see Figure 1). Most red giant variables have colours in the range B-V = 1.6-1.8, and can easily be distinguished from QSO or CV candidates, whose colours are rather blue, B-V < 0.5. As reddening effects can play an important role, the selection of candidates for the spectroscopic follow-up was done by means of a (B-V) vs csc |b| diagram (see Figure 2). Objects below the dashed line meet our criterium for inclusion in the spectroscopic program. Spectra of 110 objects were taken.

The spectroscopic and photometric classification criteria reveal that the fraction of misclassified stars among IVs of type L depends strongly on their apparent brightness:

Magnitude range	Fraction of misclassification
V < 12	0%
12 < V < 14	10%
V > 14	50%
V > 17	∿ 100%

We expect that IVs fainter than V ∿ 17 are nearly all misclassified. The basic reason is that all non obscured red giants in our galaxy should be brighter than that limit. On the other hand, Figure 2 shows that most IVs are not affected by strong reddening. It is also interesting to note that CVs and LMXBs in the galactic bulge are fainter than this limit.

3. RESULTS

Many objects in the colour range 0.5 < B-V < 1.2 are probably intrinsic variables (Cepheids, RR Lyrae, etc.). Intermediate colours can also be associated to extrinsic variables like eclipsing binaries.

As an example of a pulsating system, we mention V529 CrA. We analysed this object in more detail and found that it has two kinds of variability, each one periodic along the time base over which both historical (Kooreman 1965) and our data were collected. The longest variability has a period of ∿ 760 days with a mean semiamplitude exceeding one magnitude. As Figure 3a shows, the duty cycle of the oscillations is less than 50% and during the bright phase, a 47.1 day, double peaked periodic variation shows up (Figure 3b). The spectroscopic characteristics as well as the ratio of photometric periods Plong/Pshort makes this object a typical member of the RV Tau class of variable stars (actually of RVb subtype).

Emission line objects were also found among red and intermediate colour IVs (see Figure 4). In our sample of slightly more than 100 stars studied spectroscopically, the following distribution of subtypes was found:

T Tau:	4 objects
Mira:	10 "
Symbiotic:	1 object
Planetary Nebulae:	1 "

We also found 6 late type stars (K,M) with Balmer lines in emission; the exact nature of them not being clear at this moment without a more detailed study.

By far the most interesting group of objects identified in our survey is that of the Cataclysmic Variables and related systems (see spectra in Figure 5). A total of 12 such stars were found. Table 1 summarizes their properties. Notice that the objects AN Gru, AY Oct and KQ Mon were already known or suspected to be CVs; the first one was cataloged by Vogt and Bateson (1982) as a probable Z Cam system; the second one was classified as a probable Z Cam system by Gessner (1981), based on its photometric behaviour; and the third one was identified as a UX UMa system by Bond (Sion and Guinan 1983).

4. PARTICULAR CASES

A few of the CV-like objects deserve special comments, and we do this for three systems.

4.1. ST Cha

This star has a spectrum similar to luminous CVs or to LMXBs, with broad and shallow absorption Hydrogen lines and HeII 4686 Å in emission. The UBV colours are also similar to those of CVs. Historical photographic photometry measurements (Mauder and Sosna 1975) analysed by us show that this object is an eclipsing binary system with an orbital period of 6.85 hrs. We cannot rule out the aliases of this period, namely the values P=1.9975/(2n+1) hrs, (n=0,1,2,...) as the true orbital period.

An orbital period of ∿ 7 hrs is quite typical for luminous CVs and is not out of question also for LMXBs. Indeed, judging from its spectrum, likely orbital period and mean light curve, ST Cha could be the first case of an optically selected LMXB. Of course, it could also be an UX Uma or a Nova-like CV. Fast photometry, carried out on 1987 March 23, shows that the star flickers and the power spectrum analysis shows an excess of power for periods near 20 min.

4.2. V617 Sgr

The colours of this star are typical of CVs. The star does not flicker as much as CVs normally do. The optical light curve displays a double wave shape with a period of 4^h41^m (Figure 6).

The spectrum of V617 Sgr is quite impressive (Figure 5i). HeII 4686 Å is the strongest line in the visible range of wavelengths, being ∿2.5 times stronger than Hβ. A closer inspection to the spectrum shows a large number of highly excited lines of CIII,IV,V, NIII,IV,V and OIII,IV,V,VI. Such lines are quite common in

Wolf-Rayet stars. The short time-scale variability indicates, however, that V617 Sgr is more likely related to Cataclysmic Variables. Magnetic CVs like AM Her or like Intermediate Polars usually display strong HeII emission. At least the latter case seems not to apply to this system, since no optical variation of brightness with period shorter than half the orbital period was found in the light curves so far. Polarimetric measurements could be decisive to clarify a possible magnetic nature for this system. In this context it is interesting to note the similarities between the light curve of the AM Her type system QQ Vul in September 1985 (Osborne et al. 1987) and V617 Sgr.

The closest resemblance to V617 Sgr is found in the spectrum, colours, and light curve of V Sge. This star also has unusually strong HeII 4686 Å emission, displaying other high excitation emission lines as well. The biggest difference between the two stars is in the orbital periods. While V617 Sgr shows a period typical of CVs, in V Sge that period is quite long, P $\sim$ 12.5 hrs (Herbig et al. 1965).

4.3. V1082 Sgr

This is perhaps the most fascinating object so far discovered in the survey. The system presents two photometric states: a "high" one, characterized by an increase in brightness of $\sim$ 1 magnitude, blue colours (B-V $\sim$ 0.30) and strong flickering; and a "low" state, where V $\sim$ 15, no flickering shows up, and the B-V colour becomes fairly red (B-V $\sim$ 1.0). Figure 7 shows fast photometry light curves at both states.

Spectroscopically the low state is characterized by a late type stellar absorption spectrum (Figure 5j) while the high state shows the same absorption spectrum plus narrow emission lines of Hydrogen and Helium and a blue continuum superimposed (Figure 5k). The HeII 4686 Å line is quite strong, making the high state spectrum similar to that of the polars (Stockman et al. 1977) and intermediate

Polars (Warner 1983) with the difference that the absorption spectrum is always present here. We classify the absorption spectrum as K3.

Even with extensive photoelectric photometry coverage made on 1987, both at the LNA/Brazil and at ESO/La Silla, it is not obvious at this moment what the orbital period is. The most probable value from our data is $\sim$ 7.9 hrs. This is certainly consistent with the expected one for an early K companion star.

It seems to be clear that the differences in behaviour in the high and low states of V1082 Sgr are due to the presence or absence of mass transfer between the components of the system. The emission lines were observed to appear from the low state absorption spectrum in a time scale of $\sim$ 2 hrs. It is not clear at this moment if the transitions to low/high/low states have any correlation with orbital phase. Many more observations are certainly needed in order to understand this rather intriguing object.

5. CONCLUSIONS AND PERSPECTIVES

The approach used in our work to search for new and interesting objects like those related to CVs or other accreting systems turned out to be quite successfull. However, such objects only begin to appear when we go to a magnitude limit fainter than V $\sim$ 14. The fraction of misclassified objects among irregular variables increases steeply with magnitude. We believe that for IVs fainter than V $\sim$ 17, nearly all objects are misclassified.

To have a reasonable chance of finding optically selected LMXBs, we really have to go fainter than V $\sim$ 17 and search in the bulge of the Galaxy. This is probably not feasible with the technique we have used up to now, since it would involve the use of larger telescopes and more crowded fields. In such a situation, the classical field-diaphragm technique is no longer apropriate. The use of direct

CCD imagery can make such an observational program feasible even with modest telescopes. We will be working in this direction in the near future.

The data presented in this work were collected at the Laboratorio Nacional de Astrofísica (CNPq/LNA) in Brazil and at the Cerro Tololo Inter-American Observatory (CTIO), Chile.

Table 1
Cataclysmic Variable Candidates

Name	V	B-V	U-B	Flicker	P (hrs)
ST Cha	14.5-16.3	+0.08,+0.11	-0.77,-0.46	Y	6.8:
V342 Cen	14.5-15.3	+0.05	-0.69	Y	-
V617 Sgr	14.8-15.6	-0.04	-0.87	little	4.7
V1082 Sgr	14.1-15.0	+0.3,+1.0	-0.90,+0.40	Y	Y
V729 Sgr	14.5-16.3	+0.09,+0.3	-1.15,-0.2	Y?	-
CZ Aql	14.5-14.8	+0.37,+0.44	-0.66,-0.44	Y	7.3:
V730 Sgr	14.7-14.8	-0.02,+0.11	-0.66	N?	-
UY Mic	14.1	+0.50	0.00	N	-
VZ Gru	14.8	+0.11	+0.18	N	Y
AN Gru	15.5	-0.08,+0.17	-0.24,+0.16	Y?	-
AY Oct	14.8-15.3	+0.25	+0.27	little	N
KQ Mon	12.9-13.1	0.00	-0.87	Y	N

FIGURE CAPTIONS

Figure 1 - Colour distribution of Irregular Variables of types I plus Is (top) and L (bottom).

Figure 2 - The distribution of the observed stars in the B-V vs. csc $|b|$ diagram. The stars below the dashed line were selected for spectroscopic follow-up.

Figure 3 - a) The historical data on V529 CrA folded against the 763 d period. The times of maximum are well described by the ephemeris T_{max} = JD 2,438,169.53 + 763 E. b) The data corresponding to the bright portion of the 763 d cycle folded against the 47.1 d period. A sinusoidal fit to these data gives the following elements to predict the times of maximum light: T_{max} = JD 2,438,159.41 + 47.144 E.

Figure 4 - Spectra of some emission line objects not related to Cataclysmic Variables. NSV11776 is a planetary nebula and V417 Cen is probably a symbiotic star.

Figure 5 - Spectra of the CV candidates. UY Mic, VZ Gru, AY Oct, and AN Gru have quite similar spectra. V730 Sgr has broad absorption lines of Hydrogen similar to those of UX UMa systems. CZ Aql, V729 Sgr and V342 Cen display emission lines characteristic of Dwarf Novae at minimum light. Our data show that V729 Sgr has eruptions of roughly 2.5 mag amplitude. The spectrum of V1082 Sgr is shown at both the "low" and "high" spectroscopic states. These spectra as well as the spectra of V617 Sgr and ST Cha are discussed in the text.

Figure 6 - (top) The light curve of V617 Sgr through the U, B, and V filters, showing the double wave 4^h41^m orbital modulation. The ordinates are presented in normalized intensity units, with each light curve displaced arbitrarily for clarity. Tick marks

represent a 20% variation in flux. (bottom) The ratio of U/B and B/V fluxes, in arbitrary units.

Figure 7 - Integral light fast photometry light curves of V1082 Sgr at the "high" state (upper curve) and at the "low" state (lower curve).

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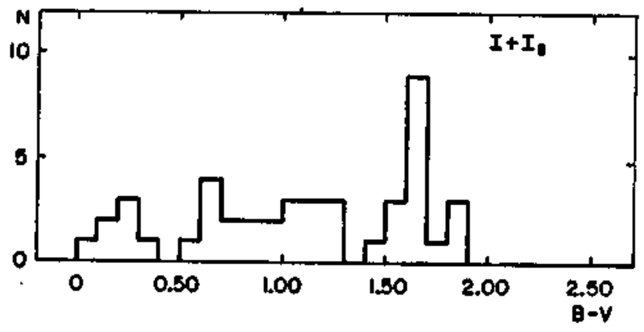
DISCUSSION AFTER THE TALK

A. COWLEY: In searching for LMXB, (since on average they have brighter absolute magnitudes than CVs) one is able to detect systems at greater distances and therefore with greater reddening. Therefore it might be worth while to search your redder stars sample too, even though they will contain a high percentage of irregular variables.

J. STEINER: In fact, we took this into account by selecting the objects from a colour versus galactic latitude diagram.

N. VOGT: You have selected your stars from the Kukarkin catalogue, so you will mainly find variables with large amplitudes. Why do you find several UX UMa stars which normally are characterized by low amplitude variations? Also, did you find dwarf novae in your survey?

J. STEINER: On long timescales, UX UMa may have larger amplitude variations. Eclipses also are frequently large in amplitude. This seems to be the case of ST Cha. In regard to judging from the spectra, I would say that four objects could be dwarf novae: V342 Cen, CZ Aql, V729 Sgr, and V730 Sgr.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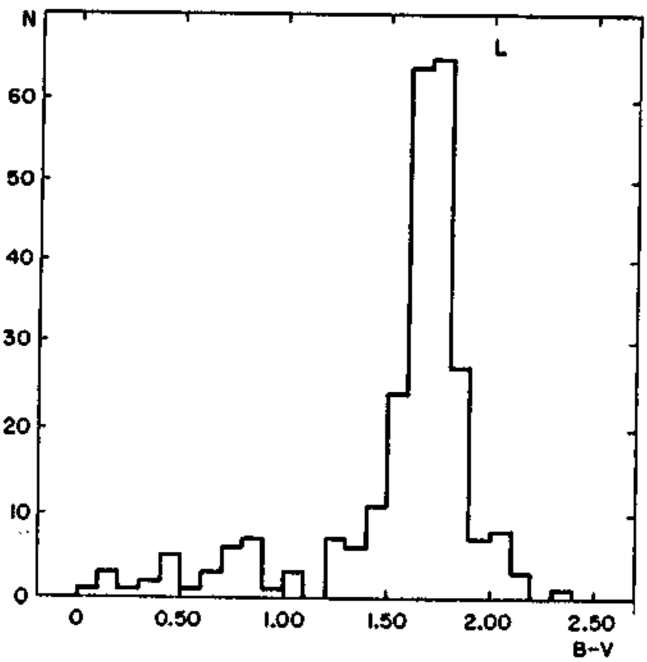
2.00
2.50
B-V

Fig. 1a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B-V

Fig. 1b

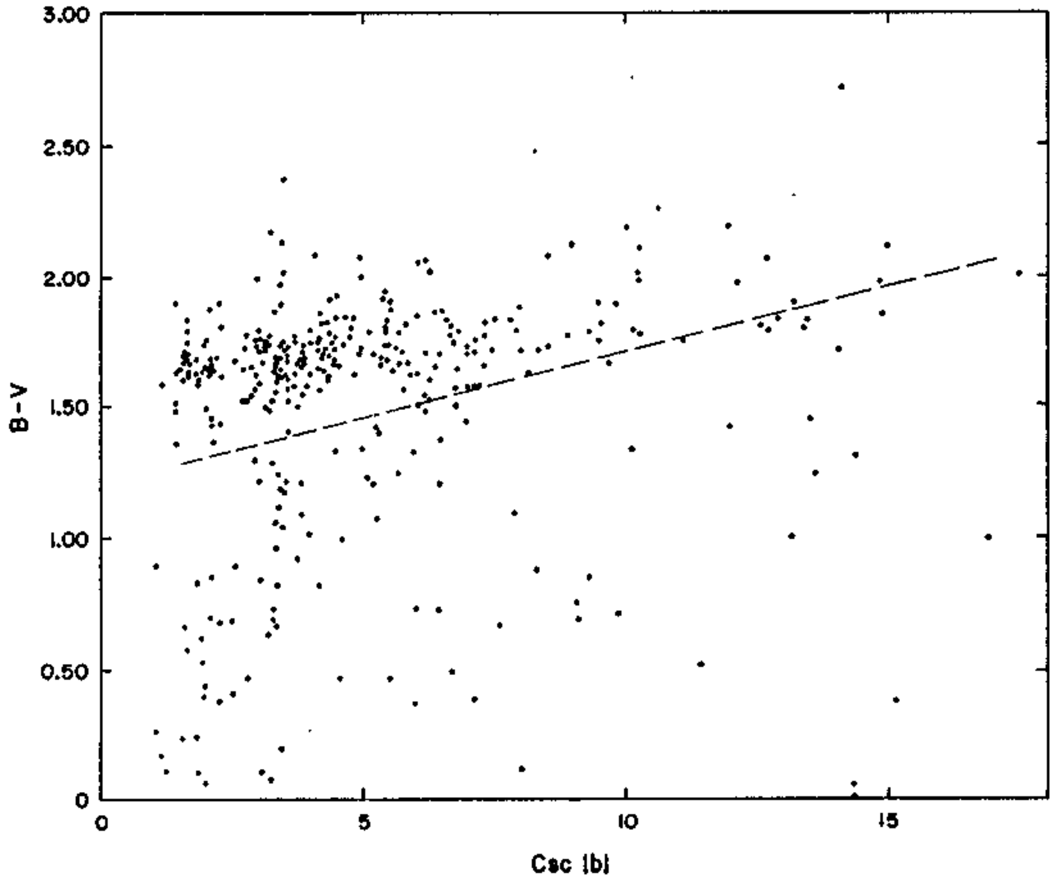
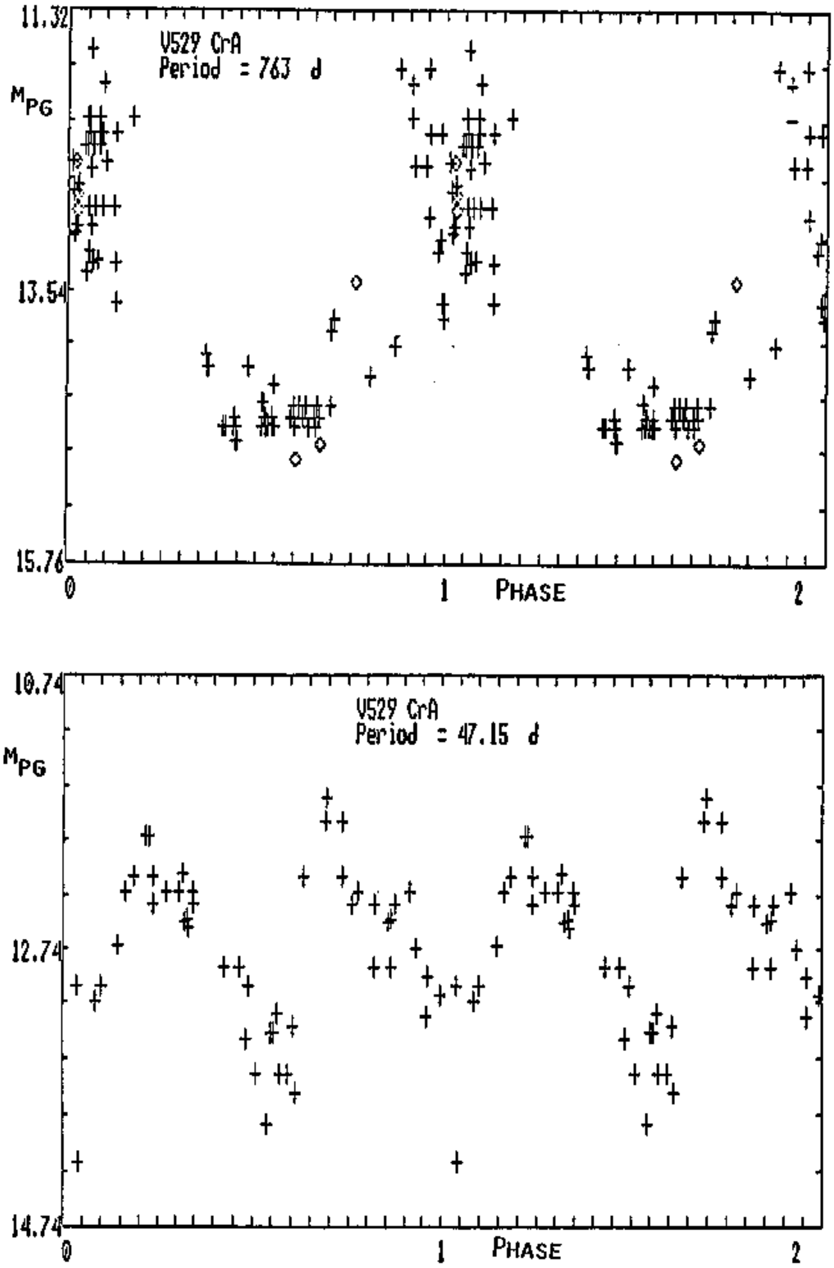


Fig. 2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11.32
13.54
15.76
0
1
PHASE
2
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10.74
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14.74
0
1
PHASE
2

Fig. 3

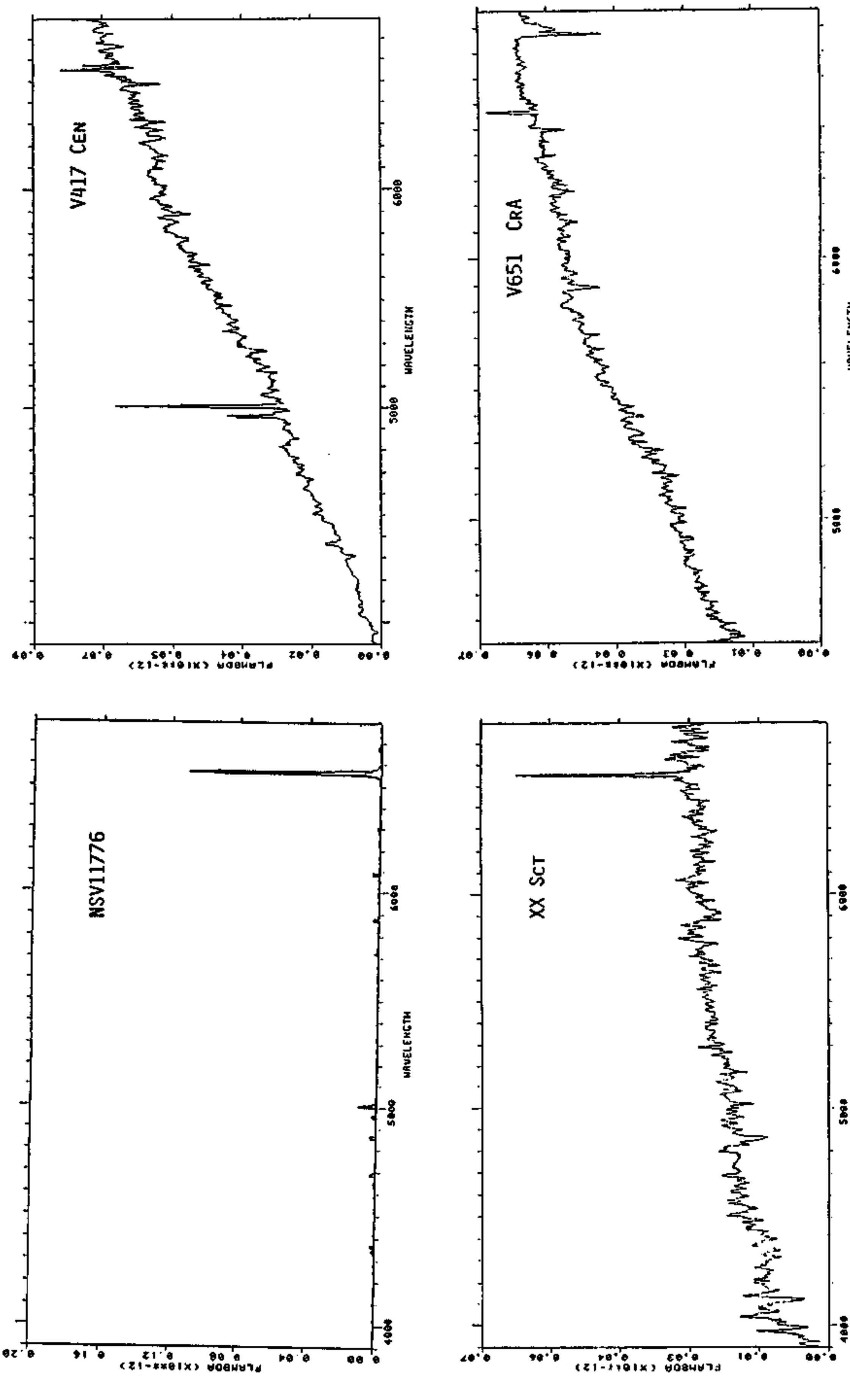
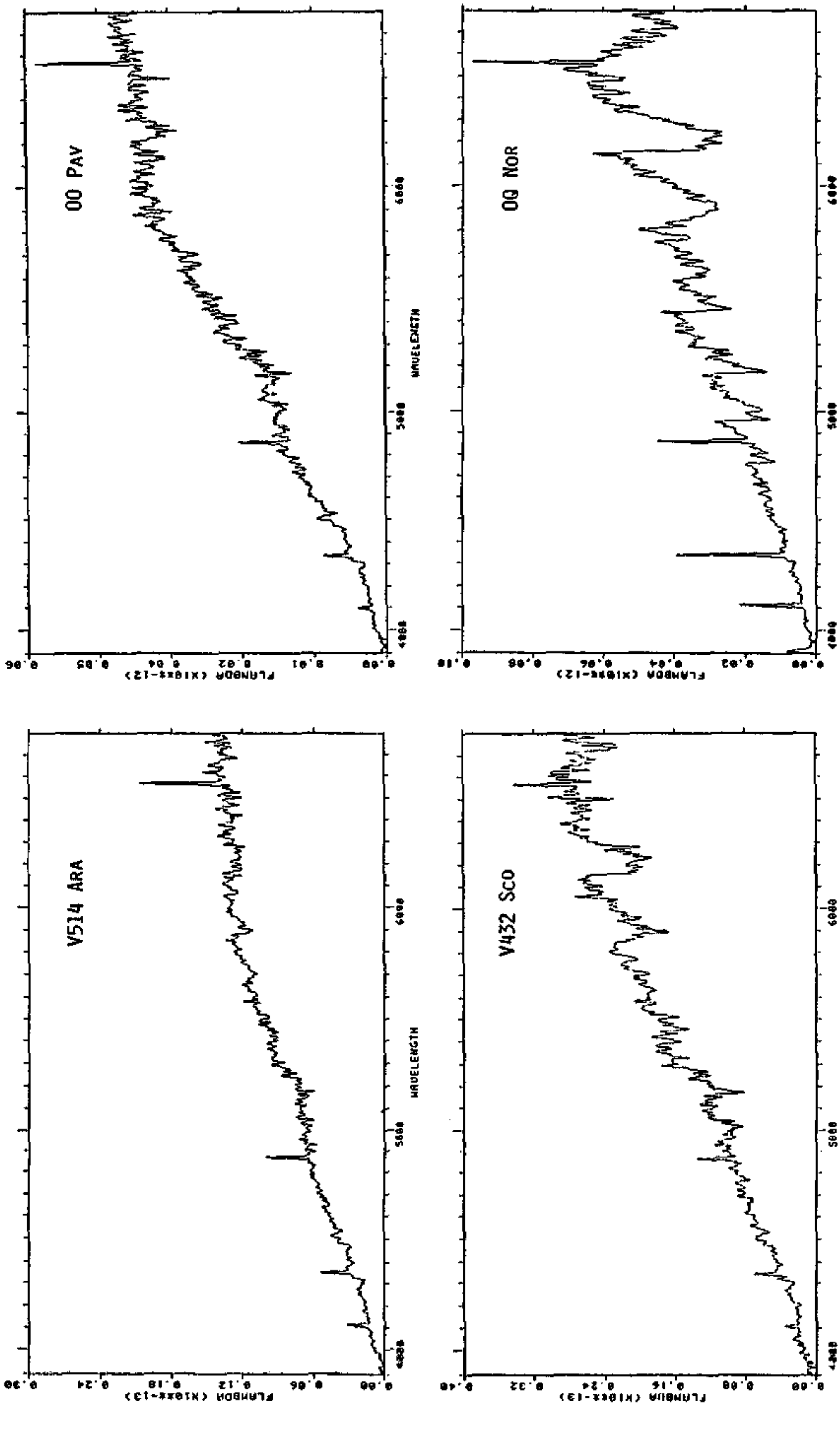


Fig. 4a


OO Pav
OQ Nor
V514 Ara
V432 Sco
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FLAMBDA (X10**-13)
4000
5000
6000

Fig. 4b

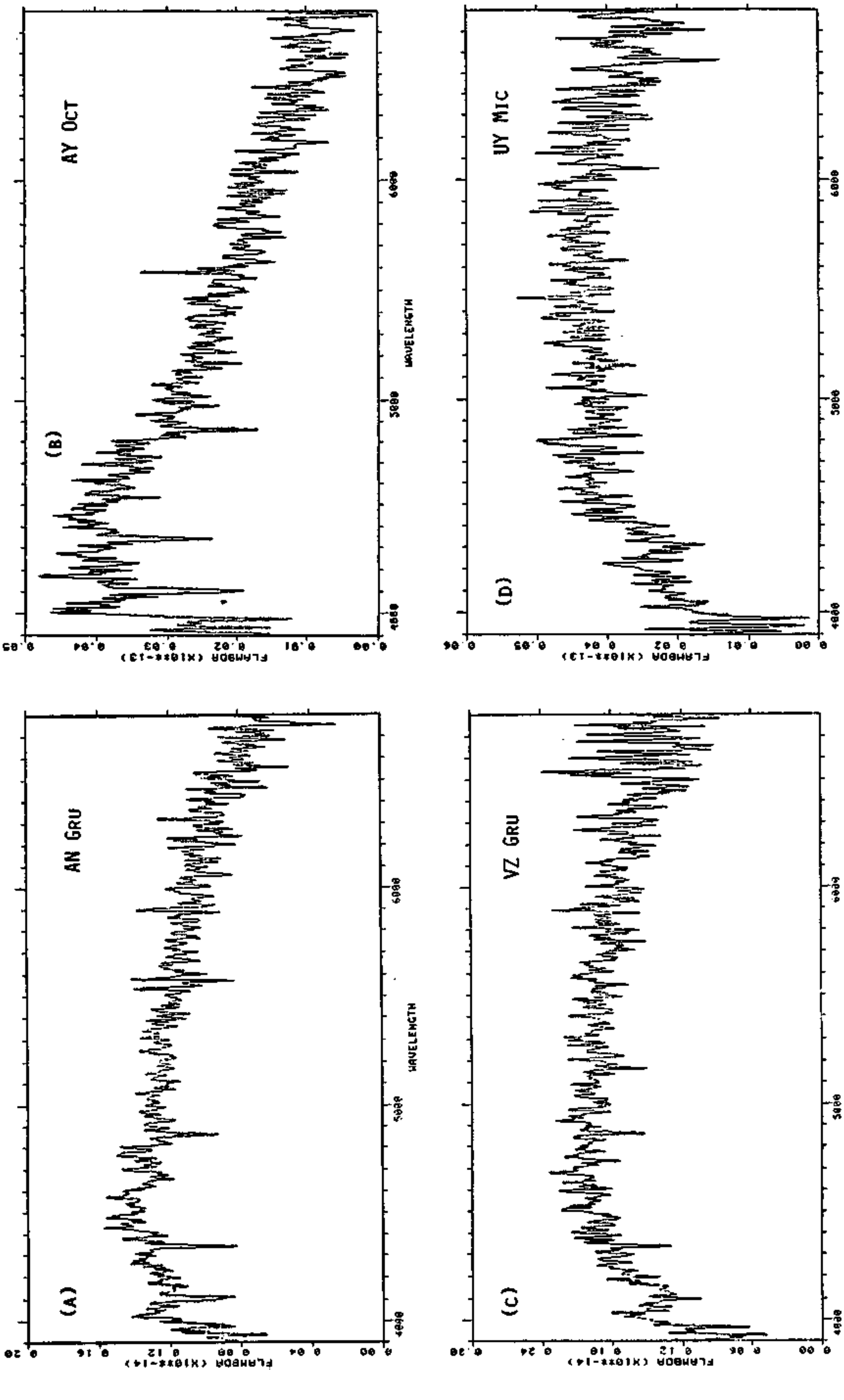
(A)
AN GRU
(B)
AY OCT
(C)
VZ GRU
(D)
UY MIC
WAVELENGTH
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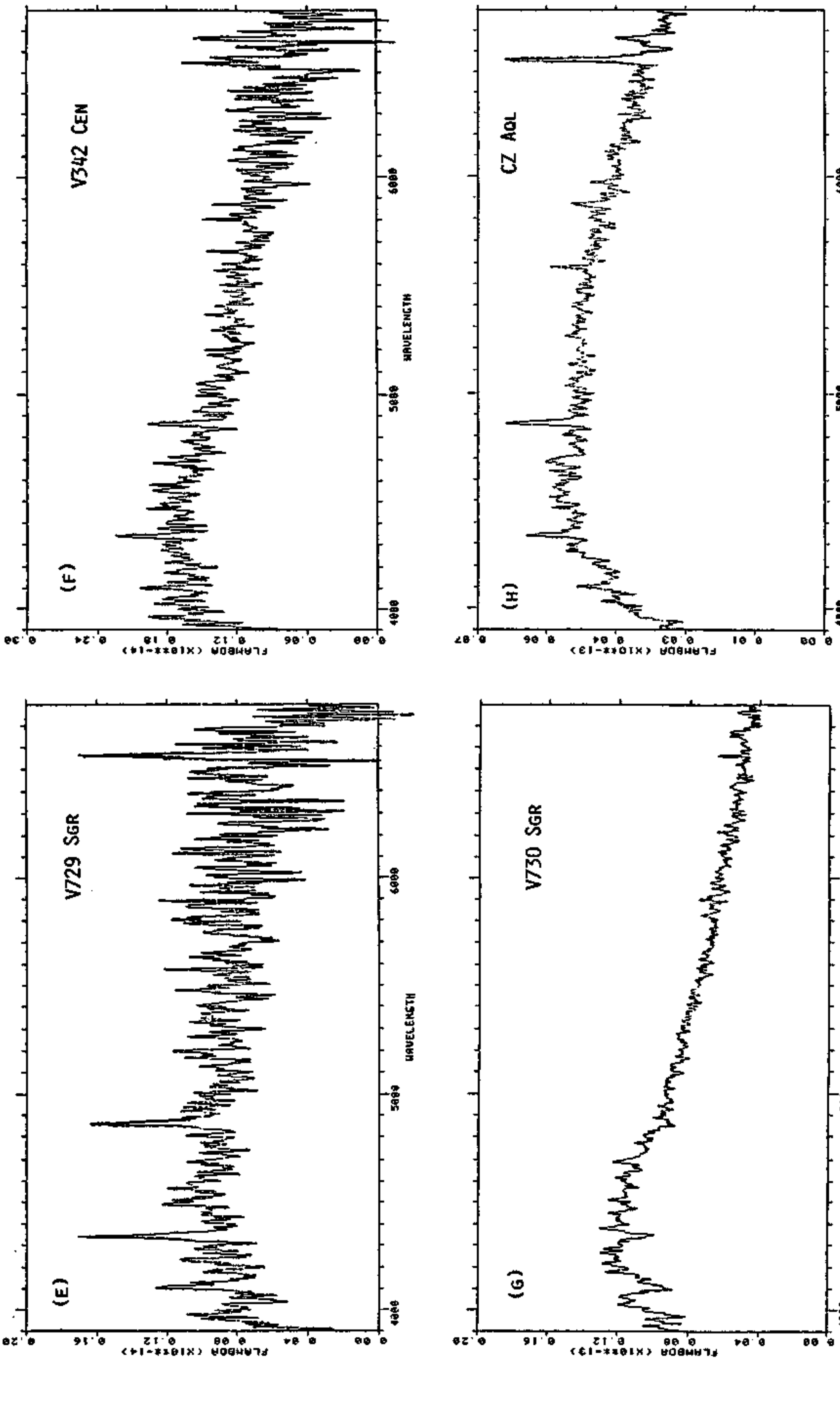
Fig. 5 (a-d)


(E)
V729 SGR
(F)
V342 CEN
(G)
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5000
6000

Fig. 5 (e-h)

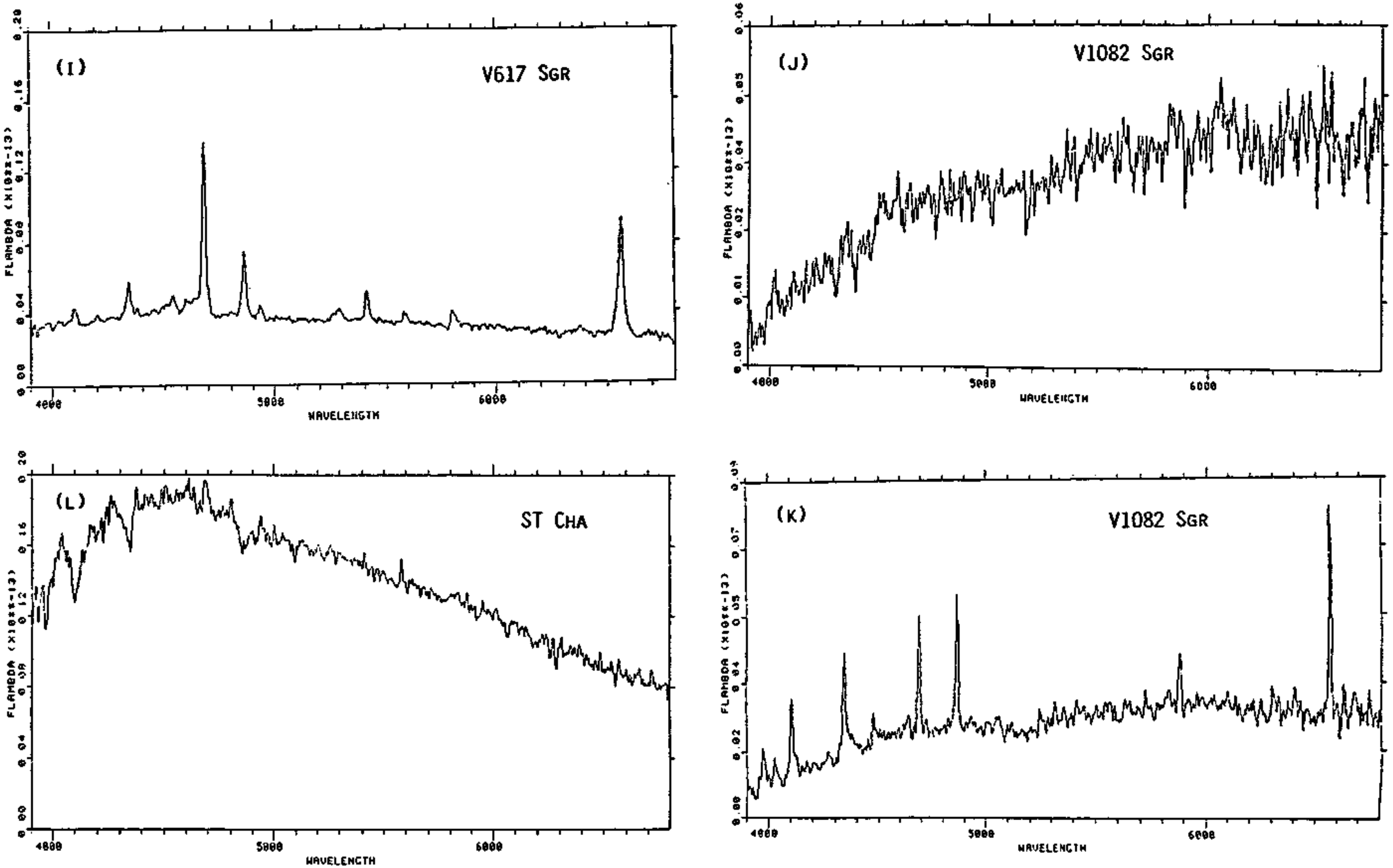
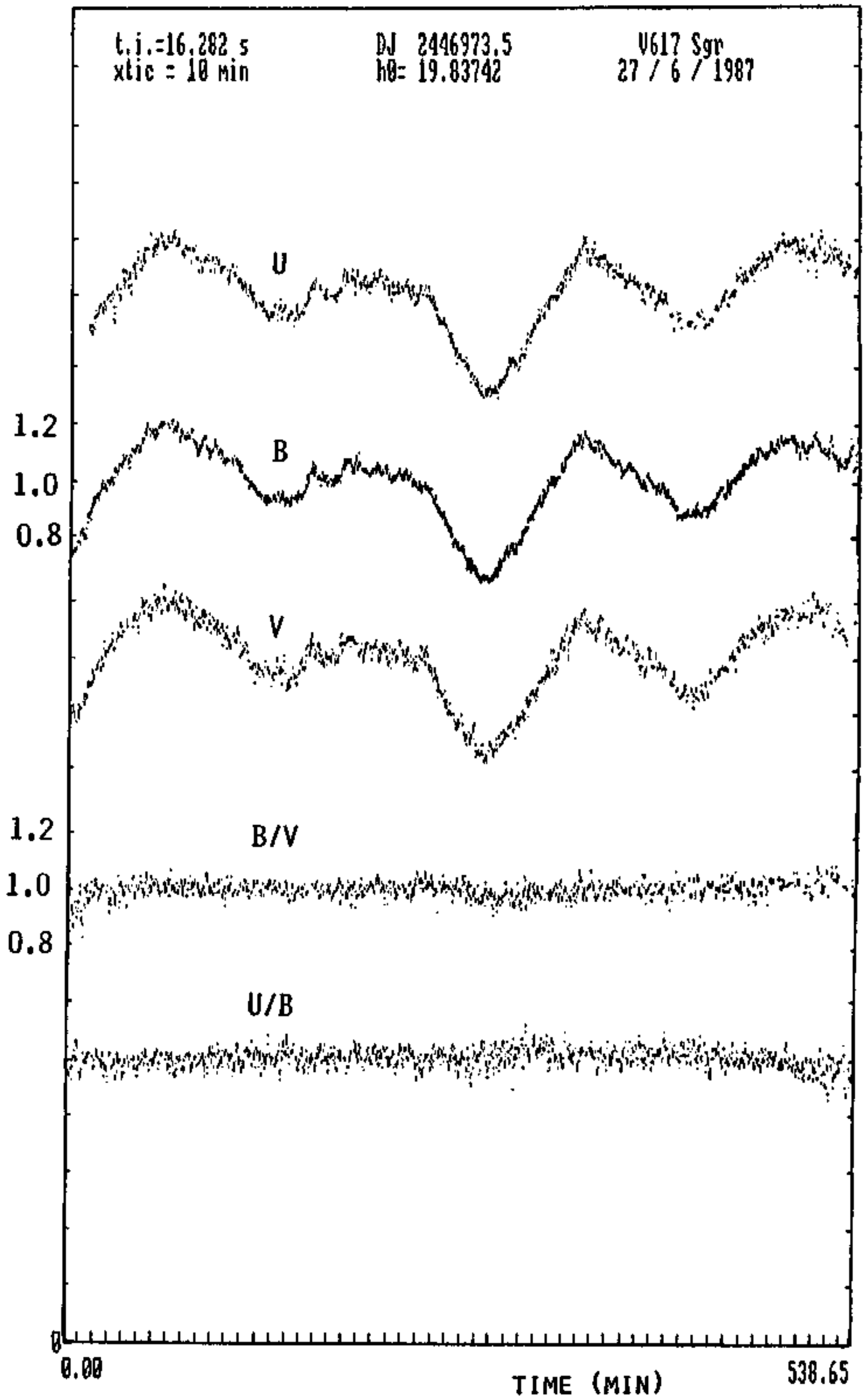

(I)
V617 SGR
FLAMBDA (X10**-13)
WAVELENGTH
(J)
V1082 SGR
FLAMBDA (X10**-13)
WAVELENGTH
(L)
ST CHA
FLAMBDA (X10**-13)
WAVELENGTH
(K)
V1082 SGR
FLAMBDA (X10**-13)
WAVELENGTH

Fig. 5 (i-k)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V617 Sgr
27 / 6 / 1987
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Fig. 6

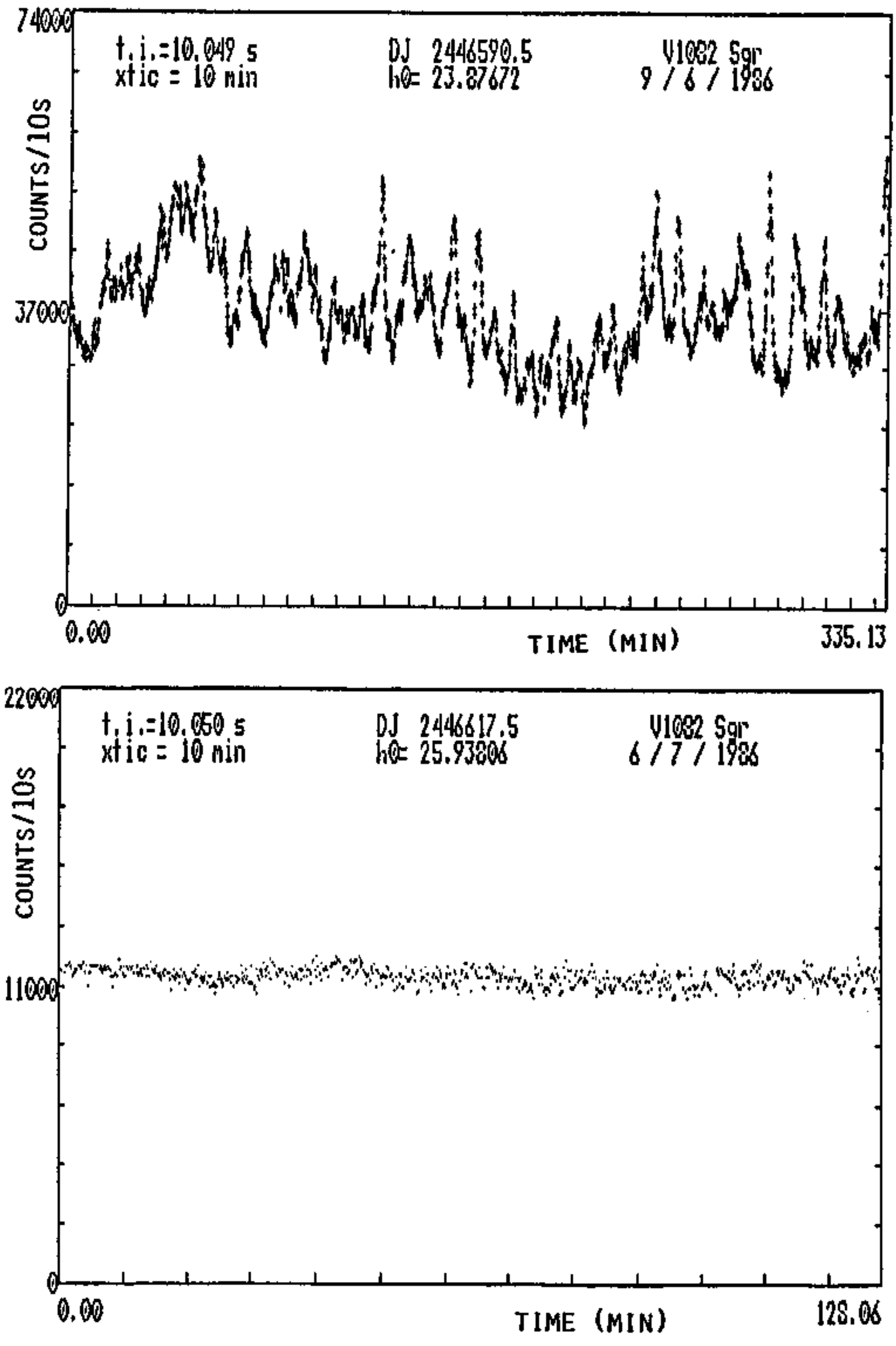

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Fig. 7