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PHOTOGRAPHIC REGION ELEMENTAL ABUNDANCE ANALYSES OF DR. DAVID S. LECKRONE'S GTO HST STARS II.

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Final Report

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This is the final report for this grant. It covers the period May 1, 1993 - August 31, 1993 in specifics and indicates what remains to be done and continuing efforts.

I observed at the Dominion Astrophysical Observatory (DAO) at the end of June and the beginning of July for 9 nights. The DAO Reticon detector's performance is slowly getting worse. One can still obtain good exposures provided that one carefully monitors the time between filling the dewar. The first long CCD which is scheduled to replace this detector has a low quantum efficiency in the blue. If it can be thinned successfully, a gain of a factor of two in wavelength coverage and quantum efficiency relative to the Reticon may be achieved. These factors and optimum extraction techniques may considerably speed up future observing beginning next summer.

Of the Northern Hemisphere program stars, only 112 Her remains to be analyzed. Dr. Tanya Ryabchikova and I have a preliminary solution for the components of this binary system. The coaddition of photographic region spectrogram has proven to be useless for abundance studies as the lines of the secondary were stronger than originally thought. In some cases I have had to obtain a second Reticon exposure of the same spectral region to be able to separate the lines of the primary and secondary. The individual IIaO spectrograms are still useful to improve the orbital elements. The analyses have been published mainly in the MNRAS.

I was supposed to observe in Argentina at Casleo Observatory in July. But I was sick and had to postpone my trip. My collaborator Dr. Olga Pintado obtained some observations, but the weather was poor. We have additional time in September. A major project will be to compare the spectrograms with those of similar stars taken at the DAO. This requires measuring both the instrumental profiles and the amount of scattered light. We expect to be able to place the data from both observatories on the same scale. In addition to obtaining photographic region CCD spectra of this program's Southern stars, we plan to take visual and red spectra of these stars and those located in equatorial regions.

I have started to reevaluate the effective temperatures and surface gravities that I derived for all program stars using the new ATLAS9 models. As soon as all the low dispersion IUE SWP and LWP exposures have been reprocessed, I will complete this exercise. I am concerned that some of the Mercury-Manganese stars with the most extreme compositions will require one to use opacity sampling distribution techniques to obtain proper fits. I also want to make the analyses more self-consistent. I will incorporate new Reticon observations into many of the studies. Eventually I plan to apply spectrum synthesis techniques to the full data set.

A poster paper by Adelman, Gulliver, Hill, and Pintado presented at Joint Discussion 16 of the IAU General Assembly describes a plan to obtain the needed gf values as well as some first applications of our astrophysical gf values, the most important of which was to Vega. A copy of this paper has been attached to this report.

In June I used most of the remaining funds in this grant to purchase an upgrade to my VAX STATION 4000/model 60. The DEC 3000 model 300X running Open VMS is a factor of 7 times faster. Calculating model atmospheres hotter than 10,000 K now takes only a few minutes. But to calculate models at 7500 K still takes a few hours. Some of the suite of model atmospheres programs and the reduction codes are now running on the new workstation. Many still need to be converted. Austin Gulliver and I have been using our workstations to calculate extensive grids of model atmospheres. For this purpose, for additional work on Vega like stars, and for future spectrum synthesis calculations the gain in computer power will make a substantial difference.

Astrophysical gf Values from High S/N Data of A Type Stars

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Abstract. We developed observational techniques which resulted in observations of Vega, A0Va, with an unprecedented mean S/N of 3000 from 3650 Å to 6700 Å. The anomalously flat bottomed profiles of the weak lines cannot be explained by a latitude independent effective temperature and surface gravity. These complications led to the initiation of a lower S/N atlas of the ultrasharp-lined metal rich A1 IV star o Pegasi. We want to determine astrophysical gf values to study Vega and other stars, an approach with a long astrophysical history. Significant differences between the observed and calculated line strengths indicate problems in the best available atomic data. Since refining large numbers of astrophysical gf values is extremely arduous, we are developing appropriate software. We tested our preliminary astrophysical gf values from o Pegasi for 31 lines in 4519 Å to 4540 Å. A much improved fit for several other B and A stars resulted from adjusting the best NIST critically compiled gf values. These values were also used by us in modeling Vega as a rapid rotator seen pole-on. Further with higher quality gf values elemental abundance analyses with synthetic spectra should have greater accuracies and precisions than fine analyses especially for stars with some rotation.

1. Introduction

Astrophysicists who determine the elemental abundances of stellar photospheres want to minimize both random and systematic errors and be certain that their abundances are on the same scale as those of the Sun. This is critical if these values are to be used to study the chemical history of the Galaxy and to understand hydrodynamical processes in stellar envelopes. In the last two decades the quality of stellar spectroscopic data has been greatly improved by the use of electronic detectors, especially Reticons and CCDs, as well as understanding how to reduce this data to maximize the resultant signal-to-noise ratio. At the same time model atmospheres computer codes have produced more physically realistic models with the incorporation of atomic line data (see, e.g., Kurucz 1993). Analyses with synthetic spectrum programs promise greater accuracies and precisions than the current standard method of fine analyses based on the use of equivalent widths as they require one to include the contributions of blending lines, which depend on the stellar parameters, and to better model the scattered light in the spectrograph.

Main sequence band stars near spectral type A0 have atmospheres and envelopes in which the energy transfer is primarily by radiative processes. The opacities are dominated by that due to hydrogen. Non-Local Thermodynamic Equilibrium effects are usually insignificant for most lines, but often can be calculated if they are important. These are the stars that should be most easily modeled by current techniques.

Rather than using large spectral regions and as many lines as possible for elemental abundance analyses as was a common practice with high dispersion photographic spectroscopy, the relatively small sizes of modern electronic detectors and the higher quality spectra suggest that one could use a modest number of well-calibrated lines of each element instead. Experiments in this direction have been relatively successful (see, for example, Adelman & Philip 1992). Hill & Landstreet (1993) used about 260 Å of spectrum at a signal-to-noise ratio of 500 to study early A stars with a range of rotational velocities. But there are systematic and random errors in the gf values and one must account for weak blending lines. In principle these can be remedied via synthetic spectrum techniques as discussed below, provided one obtains high quality data.

The use of higher signal-to-noise spectra also meant that weaker lines became available for analysis. If the lines are on the linear part of the curve-of-growth, then the uncertainties in the atomic line broadening constants do not enter into the analysis. But the probability for a good laboratory gf value being known decreases with decreasing laboratory intensity. To properly analyze any line one has to identify and account for all possible significant blending lines. As one uses weaker lines, an increasing percentage lack good laboratory wavelengths and/or identifications. Besides using line widths and wavelengths as clues to blending, one can see the signatures of blended lines in the line profiles of stars with moderate and low apparent rotational velocities if the signal-to-noise ratio is sufficient at high dispersion.

2. Vega

Several years ago Gulliver and Adelman began to observe what we thought was the prime stellar candidate for obtaining astrophysical gf values, the canonical A0 main sequence star, Vega, the fifth brightest star in the sky. They developed new observational and reduction techniques with the Reticon at the Dominion Astrophysical Observatory (DAO) 1.22-m coudé spectrograph which resulted in a mean signal-to-noise (S/N) ratio of 3500 from 3650 Å to 6700 Å at 2.4 Å mm^{-1} in second order and 4.8 Å mm^{-1} in first order. Their unprecedented S/N for a stellar spectrum is rivaled only by a few atlases of the Sun. One changes orders near 5500 Å as the overcoated aluminum coudé mirror train's reflectivity rapidly decreases near this wavelength which is far from the grating's blaze (4060 Å in second order). Part of the improvement is due to using the low gain setting rather than the high gain setting to obtain more photons per observation, part to coadding exposures, part to illuminating the spectrograph for the flat (lamp) exposures in the identical way that the star does by placing a lamp in the light path and using a central stop to simulate the shadow of the secondary mirror, and part to taking flat exposures just before and/or after the stellar exposures so that the Reticon's behavior is nearly identical for the stellar and flat exposures. We will obtain a few additional spectra regions longward of 6700 Å which are minimally affected by telluric lines at the DAO.

We plan to synthesize the entire observed spectrum, to verify the identifications of the atomic lines, and to obtain the elemental abundances. We have a preliminary instrumental profile of the 96-inch camera of the coudé spectrograph of the DAO 1.22-m telescope (Gulliver & Hill 1990). Blackwell (Fletcher, private communication) found in the red that the scattered light was 4% of the continuum level. Still a more accurate and complete analysis of the scattered light is needed. Kurucz (private communication) suggests that one observe the twilight sky, the moon, or a Galilean satellite of Jupiter and then compare these observations with FTS solar data which should be free of scattered light. We are now analyzing observations for three blue spectral regions which was obtained recently at the DAO.

We have compared spectra of the same star with S/N ratios of 100+ taken with electronic detectors using high dispersion spectrographs of different observatories. Discrepancies of order 5% are common in both equivalent widths and residual intensities. This unacceptable situation indicates perhaps differing amounts of scattered light or reduction technique problems. In this regard Adelman & Philip (1990, 1994) found a wavelength dependent systematic difference between spectra taken with the Kitt Peak National and Dominion Astrophysical Observatory coudé spectrographs.

Gulliver et al. (1991) found that in all observed spectral regions the unblended weak lines of Vega had anomalously flat bottomed line profiles which cannot be explained by the canonical assumption that we are observing a stellar photosphere whose effective temperature and surface gravity are not a function of latitude. Thus they could not use Vega's spectrum to correct the systematics in the atomic parameters. Instead they discovered a critical property which can be used to better understand this important star and several others which we discovered. Now astronomers can identify rapidly rotating stars among the variety of moderately sharp-lined superficially normal main sequence band stars seen near A0. Including the effects of stellar rotation in the stellar atmospheric models should aid understanding the behavior of stars in this part of the HR diagram.

3. Stars for Astrophysical gf Values

The discovery of the anomalous weak line profiles in Vega led to the initiation of a second, but lower S/N atlas of the ultrasharp-lined metal rich A1 IV star o Pegasi (V = 4.79). This data can be used to assess line blending effects as the measured line broadening in Vega is 22 km s^{-1} compared with 6 km s^{-1} for o Pegasi. There are significant differences between the observed and calculated line strengths which indicate problems in the best available atomic data. By using a star which is slightly metal-rich, we can adjust the gf values of many blending lines which will be weaker in metal normal stars of similar effective temperatures and surface gravities.

Our approach is inspired by a long astrophysical history of using stellar spectra, especially those of the Sun (see e.g., Gurtovenko & Kostik 1981), to derive gf values. Stars are hotter than many of the usual laboratory sources of atomic lines. Further the physical conditions under which atomic lines are produced in stars with radiative envelopes are about as well understood as those of the typical laboratory source. Errors in the gf values propagate directly into those of the abundances. For many lines the errors are of order 50% or greater. The best gf values are known to have uncertainties of about 1%. Unfortunately, high and moderate accuracy gf values exist for only a small percentage of the lines observed in our stellar spectra. Leckrone et al. (1993) used many astrophysical gf values in matching the observed Hubble Space Telescope GHRS spectra of sharp-lined stars. We want to produce similar templates for optical region spectra. Despite the extensive work on solar type stars, an independent effort is required for the early A type stars as the line blending is entirely different. The use of Procyon, a mid-F star (see below), should link our work with that done using the Sun.

Atomic spectroscopists are quite interested in those lines whose origin we cannot identify and those with very discrepant intensities especially if we can find them in stars with different photospheric parameters. Unidentified lines can provide clues for extending the analyses of the energy levels of important atomic spectra such as Fe II as the intensities are configuration dependent. As additional energy levels of a given atomic species are identified, the wavelengths of transitions to and from these levels become known, theoretical calculations of the gf values and atomic damping constants can be made, and then both types of data can be used for synthetic spectrum calculations. Line identification studies with DAO spectrograms show that even in the normal stars there are a few weak unidentified line in each 100 Å of optical region spectrum. One can get an idea of candidate species by using stars with somewhat different compositions. Such an analysis of all the stars whose spectra Adelman has analyzed with DAO coadded plates is now in progress.

By comparing spectra of stars with some rotation with those with minimal rotation, one can empirically identify those lines of telluric origin. Due to DAO being close to sea level and the Pacific Ocean, these lines tend to be stronger than those in spectrograms taken at higher and dryer sites. Although the strengths of many telluric lines are somewhat time dependent, it is very useful to know where they occur. For example, we have detected the rarely mentioned telluric lines in $\lambda\lambda$4415-65.

Our o Pegasi atlas is now complete from 3995 Å to 4880 Å. In addition we have 67 Å regions centered at 3860 Å, 5015 Å, and 5070 Å. Our mean S/N is 800. Further observations are planned to complete its coverage from 3830 Å to at least 5400 Å. The same spectral coverage as for Vega would be highly desirable except for the regions rendered unusable by telluric lines. A new elemental abundance analysis of o Pegasi has been started. Previous studies by Adelman (1988) and by Hill & Landstreet (1993) will serve as guides. The former used S/N = 80 coadded photographic data from IIaO baked plates while the later used 260 Å of S/N = 500 spectrograms. The measurement of equivalent widths of our new material is nearly two-third complete. Many weak lines have not been previously seen. When finished more than 3000 lines will have been measured. The observed line density is about 2 per Å.

We are rederiving the stellar effective temperature and surface gravity with the new ATLAS9 model atmospheres (Kurucz 1993) using the known metallicity, microturbulence, Balmer line profiles, and optical region fluxes. Minor adjustment to previous values (see, Adelman 1988) have already been found. We will also use the ultraviolet fluxes as observed by IUE in finalizing the choice of the stellar model atmosphere. This study is part of a comprehensive reexamination for all the stars that Adelman has analyzed in the last few years. When Kurucz makes his ATLAS12 program available, we plan to calculate model atmospheres whose abundances are those of the stars being analyzed rather than using models for the final analyses whose input abundances are scaled solar.

We tested the determination of astrophysical gf values from the o Pegasi spectrum for 31 lines in a short wavelength interval from 4519 Å to 4540 Å (see Figure 1). Refining large numbers of astrophysical gf values is extremely arduous. We are developing a computer program to greatly speed the task. With Adelman (1988)'s stellar parameters and abundances, an ATLAS9 atmosphere (Kurucz 1993), and SYNTHE synthetic spectrum (Kurucz & Avrett 1981), a much improved fit to the observed spectrum was achieved after adjusting the best laboratory gf values of Fuhr, Martin & Wiese (1988) and Martin, Fuhr & Wiese (1988) (see Figure 1). A preliminary check with a γ Gem S/N = 500 spectrum of Dr. Grant Hill confirmed the improved fit as did experiments with several S/N=200 spectra of B and A stars.

Our experience suggests that we should not base the gf value corrections on one star alone. o Peg may have a weak magnetic field of order 2 kG with a complicated configuration (Mathys & Lanz 1990) which would affect mainly those relatively few lines at the top of the linear part of the curve-of-growth and those on the damping portion. Although most lines are too weak to be affected, we continue to acquire data on several other sharp-lined stars at a S/N of 1000. We have already obtained a nearly complete photographic region spectrum of Procyon (F5 IV-V) and about one-half of the spectrum of γ Gem (A0 V). For the photographic region, we also have complete or near complete spectra of several sharp-lined B, A, and F stars at a S/N of 200+ and many more at a S/N of 80.

Procyon is the canonical mid-F dwarf, an appropriate intermediate star between the B and A stars and the early G stars. Including it in this program will allow us to check blending components which appear in F and early G type stars and to compare with astrophysical gf values derived from solar spectra. The spectral data for Procyon will be carefully compared with those of Griffin & Griffin (1979) which has been used as the basis for many recent studies of this star.

Fekel & Tomkin (1993) revised the spectroscopic orbit of γ Gem and detected the spectrum of the secondary in the red. The mass of A is 2.8 M_0 and of B is 1.07 M_0. As the difference in V magnitudes is 6.0 mag., one can analyze the spectrum almost as if it were from a single star. Its abundances appear to be as close to solar as found among sharp-lined late B or early A stars analyzed with modern techniques (Adelman & Philip 1992, 1994).

In correcting the gf values, we will start with those lines on the linear part of the curve-of-growth which have the best laboratory gf values to define the stellar abundances. We will work first on those species with the most lines and then concentrate on lines of the trace species. An iterative procedure may be needed. We may not be able to finalize the values for any major species except as part of a global procedure. Lines which exhibit significant hyperfine structure and isotopic shifts will require especially careful analysis. By using several stars we should be able to identify the individual peculiarities of each and minimize any systematics.

Reducing the errors in the gf values has enormous consequences for elemental abundance analyses. This work should provide a reproducible standard for all investigators to use for a considerable effective temperature range. It will make it possible to use smaller regions of the spectrum to get high quality results for many elements. It should make it possible to analyze stars which are rotating faster than the moderately sharp-lined stars with much greater accuracies and precession than are now possible provided one obtains spectra with sufficient signal-to-noise and a known amount of scattered light. For faint stars, it should be possible to perform good analyses with a somewhat lower dispersion than we have been using.

As an application, we will perform synthetic spectrum analyses of all the stars (now of order 35) studied in Adelman's current series of analyses with DAO spectrograms. This should result in a set of consistently performed analyses of superficially early B through late F and non-magnetic CP stars with smaller errors than can be done with equivalent widths. We plan to add at least one HgMn star to the atlas program to obtain astrophysical gf values of those species which are extremely overabundant in this class of star such as Mn II.

4. Modeling Vega Stars

The preliminary sample of astrophysical gf values derived from o Peg was used in modeling Vega as a rapid rotator seen pole-on (Gulliver, Hill & Adelman 1994). We calculated a grid of ATLAS9 models for effective temperatures of 7500 to 11500 K in steps of 500 K and surface gravities (log g) from 3.00 to 4.50 dex in steps of 0.25 with scaled solar abundances of -0.5 dex and a microturbulence of 1 km s^{-1}. Then, using the improved log gf values, we calculated a synthetic intensity spectrum at 17 values of cos θ on the stellar surface for each model.

These synthetic spectra were used in the program, ROTATION, developed by Graham Hill (DAO) from his program LIGHT (Hill 1979, 1986). The physical model is based on Collins' (1963) formulation for the geometry of a single rapidly rotating star although the program solves for the radii at each point rather than using expansion formulae. The star is considered to be an oblate spheroid with many latitudinal zones at temperatures and surface gravities appropriate to the chosen polar temperature, the polar surface gravity, and the equatorial velocity. The mass distribution within the model is that of a Roche model. The star is assumed to rotate as a rigid body. The energy producing mechanism of the star and hence the total luminosity are assumed to be unaffected by rotation. A composite synthetic spectrum is produced by integrating over the photospheric surface after assuming an inclination of the axis of rotation to the line of sight. Rather than visually checking the fit of a model to the observations, the four variables, polar temperature, polar surface gravity, projected rotational velocity, and inclination are allowed to vary to produce the best fit to the observations. The fit has been performed both for the observed line spectrum from 4519 Å to 4540 Å (see Figure 2) with particular emphasis on two examples of flat bottomed lines, Fe I λ4528 and Ti II λ4529, and for the observed continuous flux from 1200 Å to 10500 Å with similar results. Figure 3 shows the results for these two lines in detail while Figure 4 shows those for Fe II λ4522, a considerably stronger line. The analysis of the fluxes will be repeated with recalibrated IUE fluxes and with Voyager UVS observations Only minor changes are anticipated. The Voyager UVS observations should produce a tighter constraint on the polar temperature.

The fit of such a model to the observed line spectrum successfully explained the existence of both the normal Gaussian line profiles for strong lines and the anomalous, flat-bottomed line profiles for weak lines. Moreover, the $\chi 2$ of the fit to the observed continuous flux is 35% better than the best classical model of Castelli & Kurucz (1994). The best fit to the observations is found for an inclination of 5.1°, a polar temperature of 9695 K, polar gravity of log g = 3.75 and an apparent rotational velocity v sin i = 21.8 km s^{-1} . The equatorial rotational velocity is 245 km s^{-1}, slightly greater than that of a typical A0 main sequence star. This provides a partial explanation of Vega's circular disk or shell (Aumann 1984; Zuckerman & Becklin 1993).

The apparent abundance anomalies in Vega may partially be due to its rapid rotation. If so, it might be related to the λ Boo stars. This will be checked by using ATLAS9 models and SYNTHE synthetic spectra to fit the observed spectrum. A major forthcoming undertaking will be the analysis of the He I lines as their line broadening theories are far more complex than those of the normal metal lines. Software to make these calculations is available from Dr. Ivan Hubeny who will collaborate in their analysis. We also will analyze the Balmer lines as well as lines of other species whose strengths appreciably change for the range of temperatures and surface gravities seen for Vega. It is important to see how closely the results of the analyses of different weak lines agree. We also plan to analyze three other previously found stars with anomalous flat-bottomed profiles and are searching for other class members in collaboration with Dr. Charles Perry.

Acknowledgments

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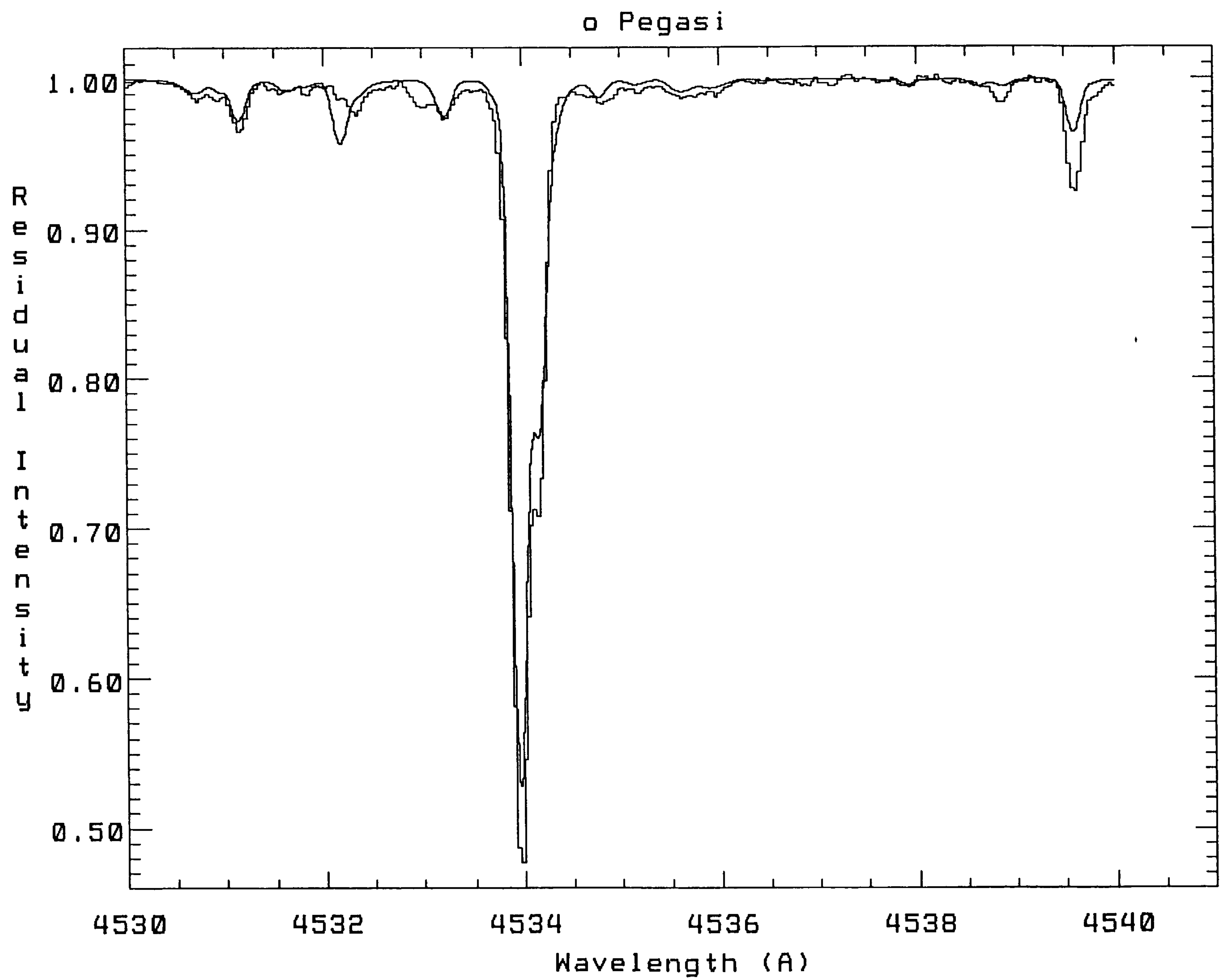
References

Adelman, S. J. 1988, MNRAS, 230, 671
Adelman, S. J., and Philip, A. G. D. 1990, PASP, 102, 842
Adelman, S. J., and Philip, A. G. D. 1992, PASP, 104, 316
Adelman, S. J., and Philip, A. G. D. 1994, PASP, submitted
Aumann, H. H. 1984, AJ, 96, 1415
Castelli, F., and Kurucz, R. L. 1994, A&A, 281, 817
Collins, G. W., III 1963, ApJ, 138, 1134
Fekel, F. F., and Tomkin, J. 1993, AJ, 106, 1156
Fuhr, J. R., Martin, G. A., and Wiese, W. 1988, J. Phys. Chem. Ref. Data, 17, Suppl. 4
Griffin, R., Griffin, R. 1979, A photometric atlas of the spectrum of Procyon, λλ 3140-7470 Å
Gulliver, A. F., Adelman, S. J., Cowley, C. R., and Fletcher, M. F. 1991, ApJ, 380, 223
Gulliver, A. F., and Hill, G. 1990, PASP, 102, 1200
Gulliver, A. F., Hill, G., and Adelman, S. J. 1994, ApJ, 429, L81

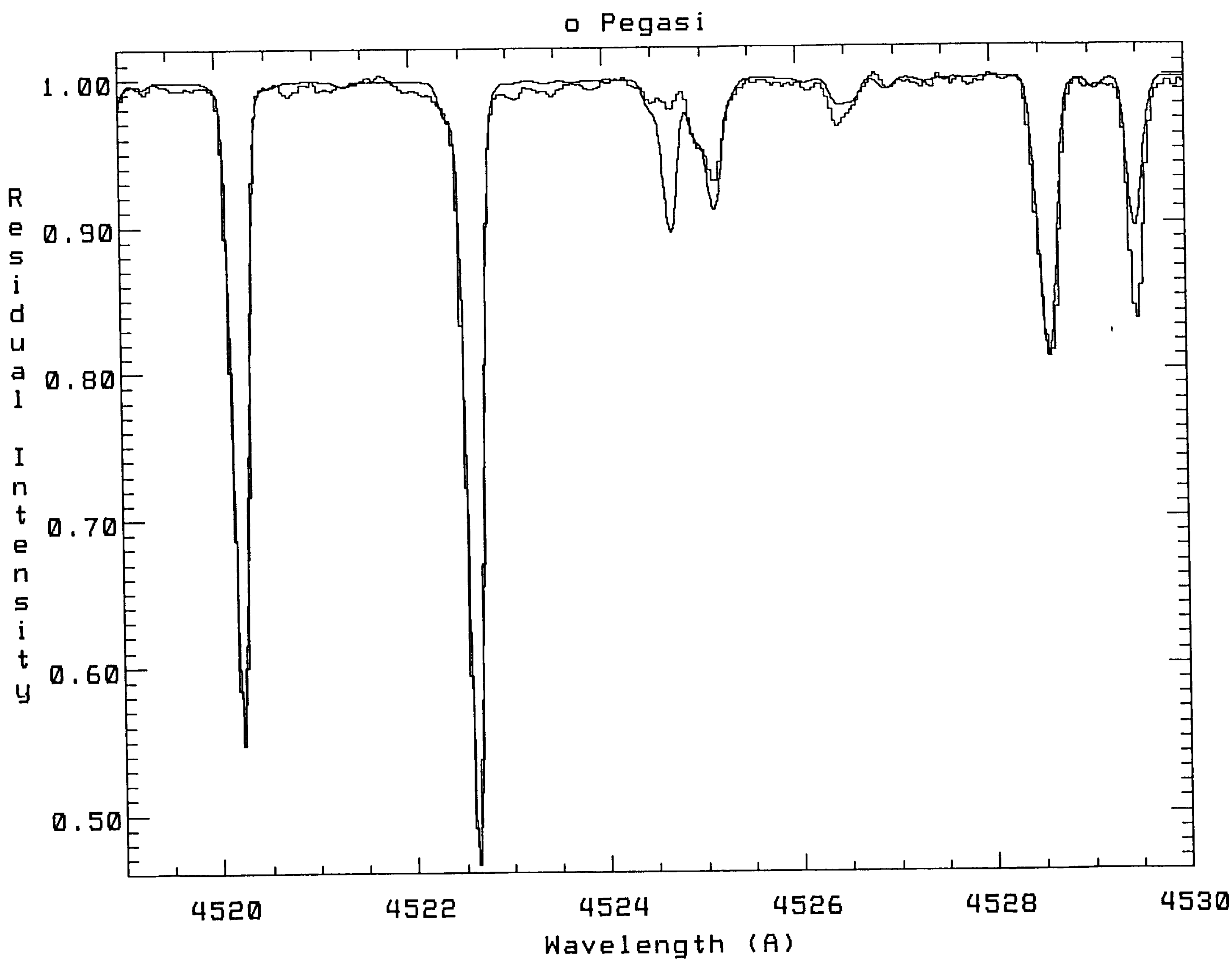
Gurtovenko, E. A., and Kostik, R. I. 1981, A&AS, 46, 239
Hill, G. 1979, Publ. Dom. Astrophys. Obs. Victoria, 15, 297
Hill, G. 1986, LIGHT2 User Manual, Dom. Astrophys. Obs. Victoria
Hill, G., and Landstreet, J. D. 1993, A&A, 276, 142
Kurucz, R. L. 1993, in M. M. Dworetsky, F. Castelli, R. Faraggiana, eds, ASP Conference Series, 44, 87
Kurucz, R. L., Avrett, E. H. 1981, Smithsonian Ap. Obser. Special Report, 391
Leckrone, D. S., Wahlgren, G. M., Johansson, S. G., and Adelman, S. J. 1993, in M. M. Dworetsky, F. Castelli, R. Faraggiana, eds, ASP Conference Series, 44, 42
Martin, G. A., Fuhr, J. R., and Wiese, W. 1988, J. Phys. Chem. Ref. Data, 17, Suppl. 3
Mayths, G., and Lanz, T. 1990, A&A, 230, L21
Zuckerman, B., and Becklin, E. E. 1993, ApJ, 414, 793

Fig. 1 - The fit to the spectrum of o Pegasi with the original and adjusted sets of gf values. The upper panels show the original fit while the lower the adjusted fit.

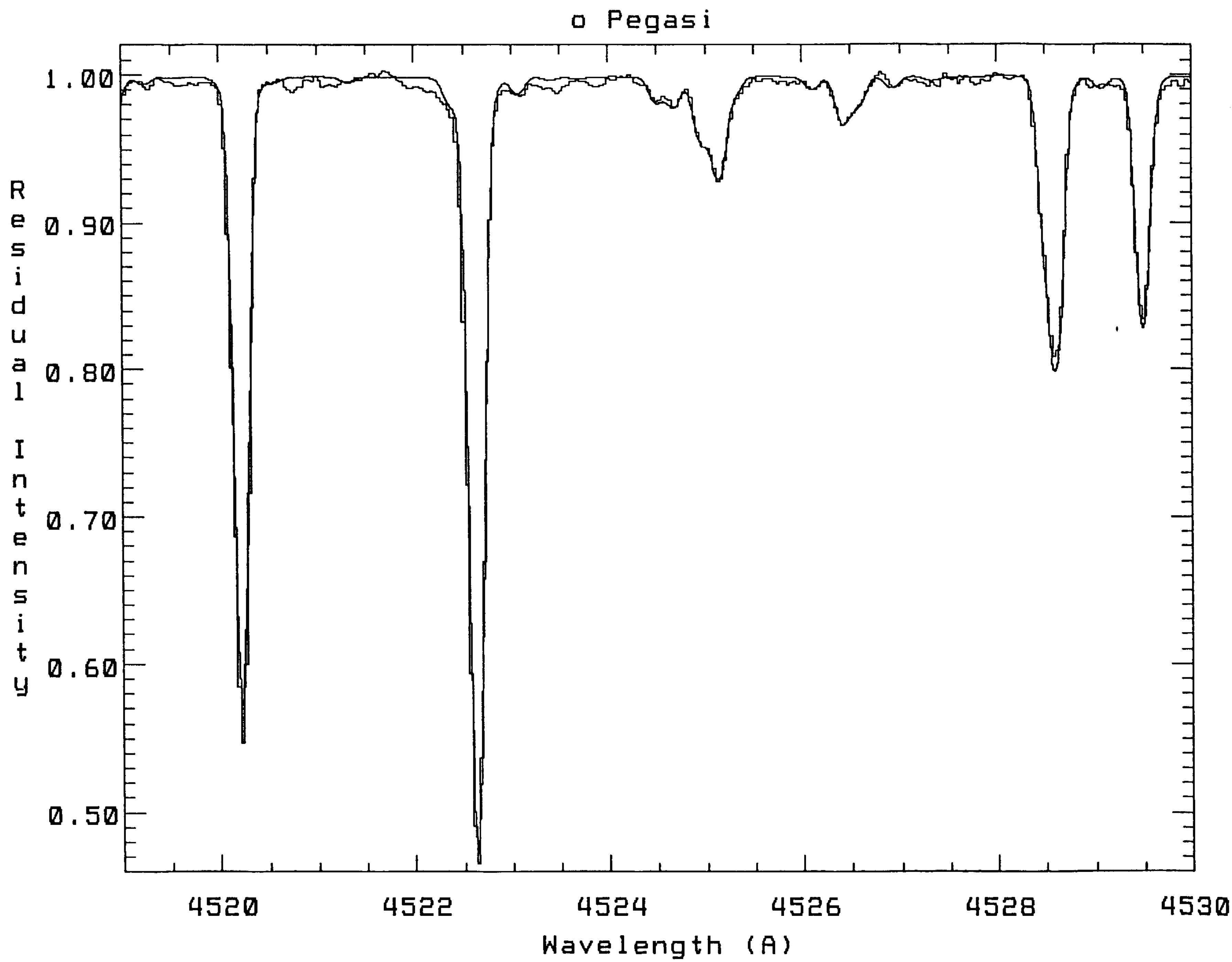
IUE_IDL>


o Pegasi
Residual Intensity
1.00
0.90
0.80
0.70
0.60
0.50
4530
4532
4534
4536
4538
4540
Wavelength (A)

IUE_IDL>


o Pegasi
Residual Intensity
1.00
0.90
0.80
0.70
0.60
0.50
4520
4522
4524
4526
4528
4530
Wavelength (A)

IUE_IDL>


o Pegasi
Residual Intensity
1.00
0.90
0.80
0.70
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0.50
4520
4522
4524
4526
4528
4530
Wavelength (A)

IUE_IDL>

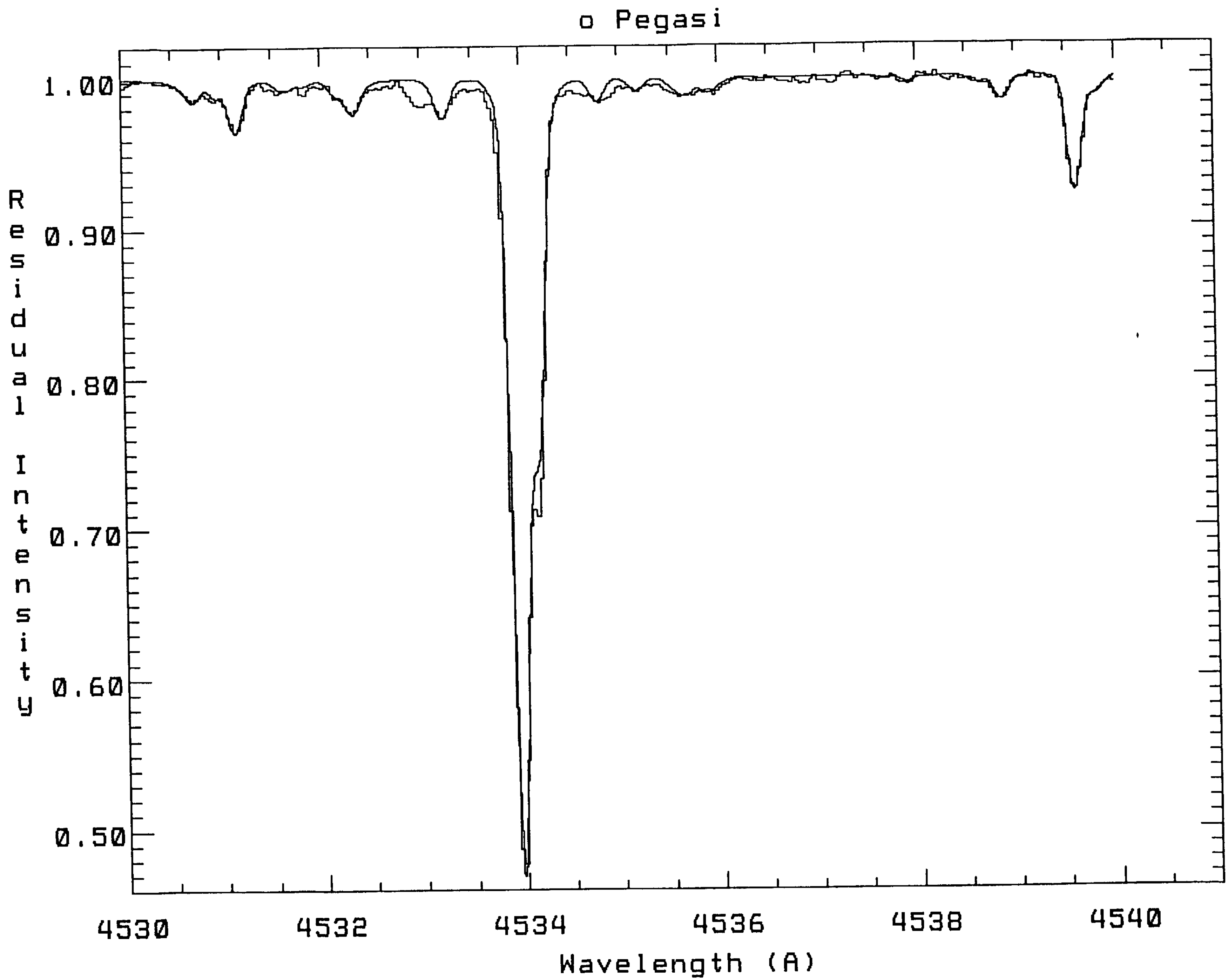
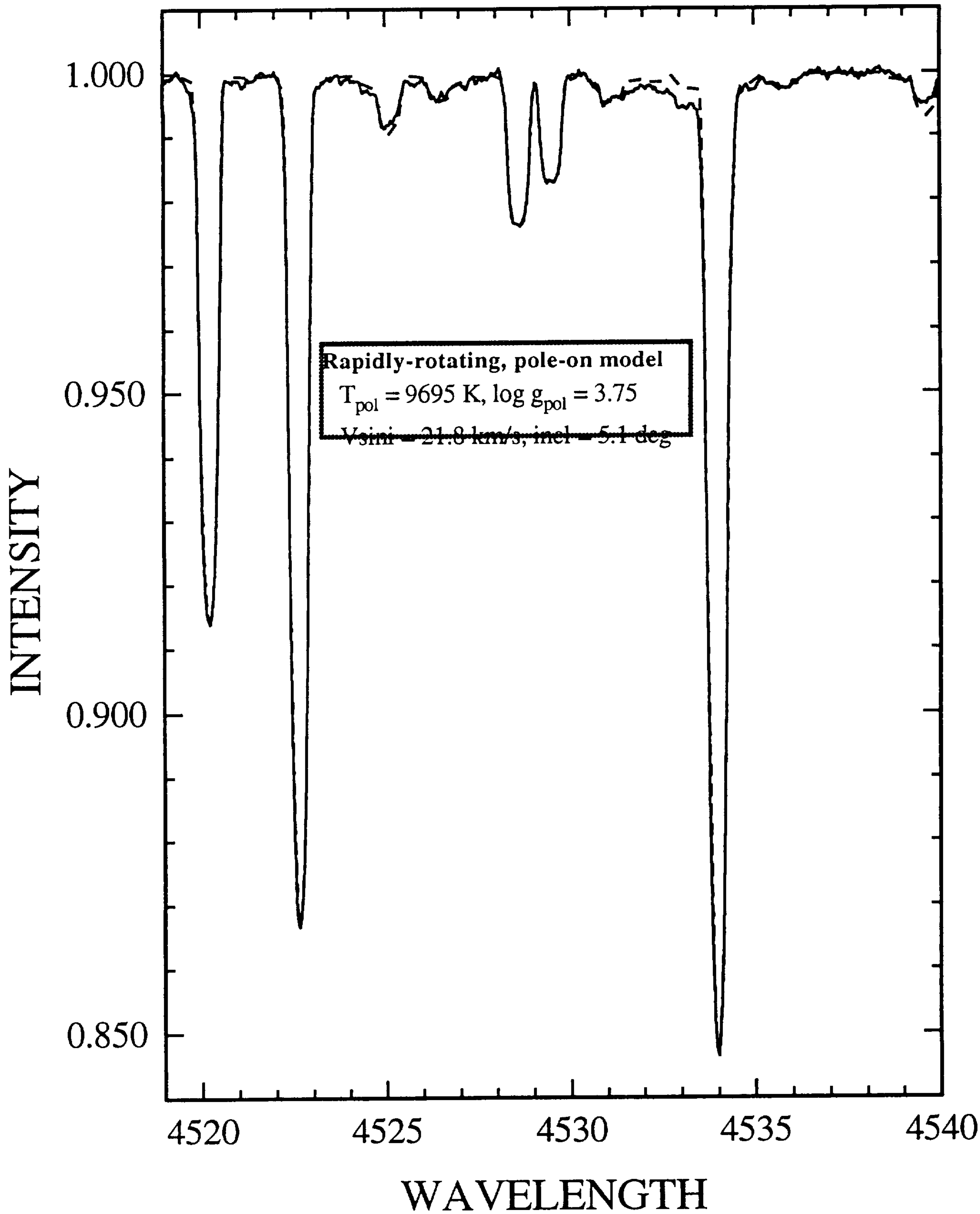
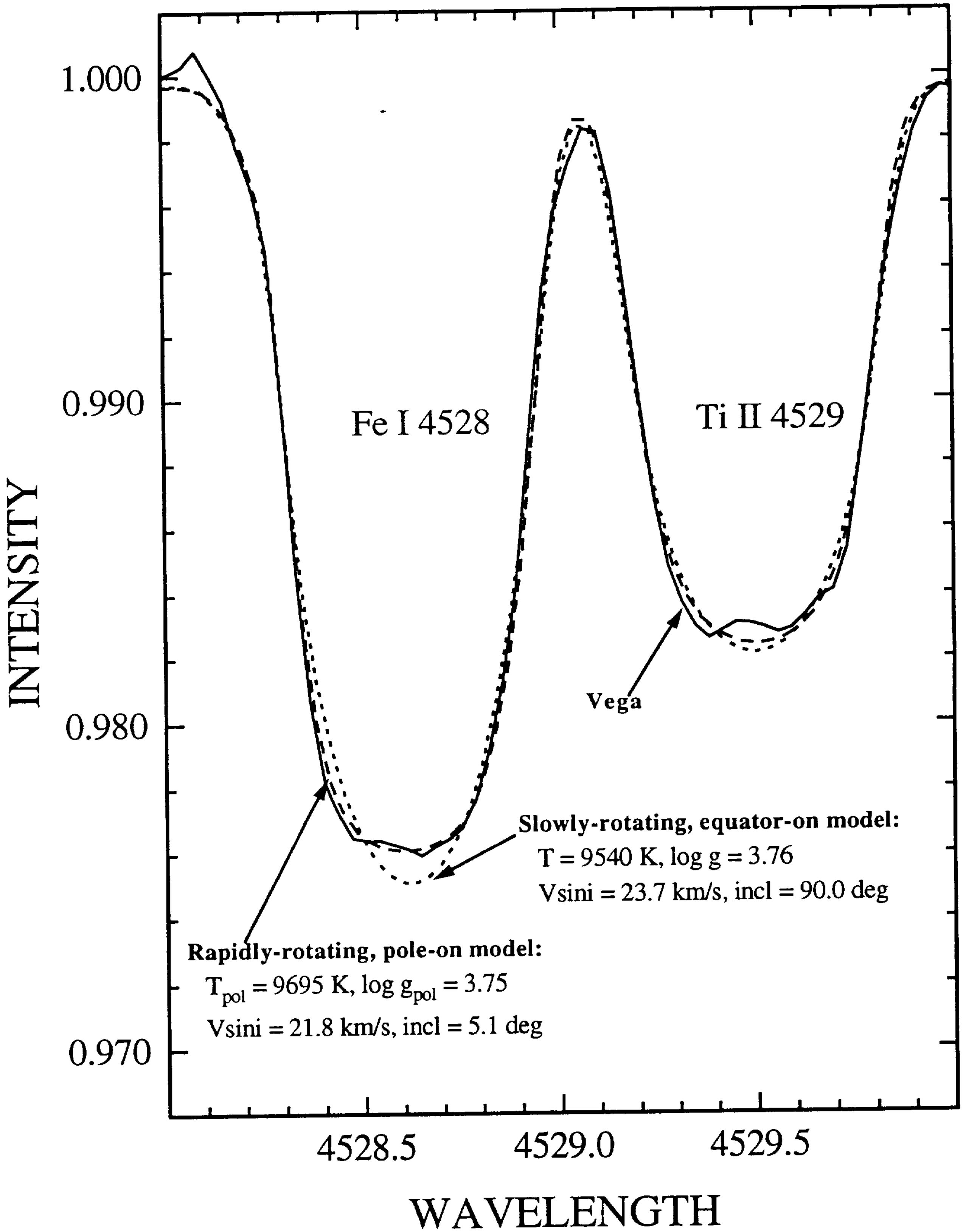

o Pegasi
Residual Intensity
1.00
0.90
0.80
0.70
0.60
0.50
4530
4532
4534
4536
4538
4540
Wavelength (A)

Fig. 2 - The fit to the spectrum of Vega $\lambda\lambda$4519-4540 with the adjusted set of gf values and the rapidly-rotating pole on model.



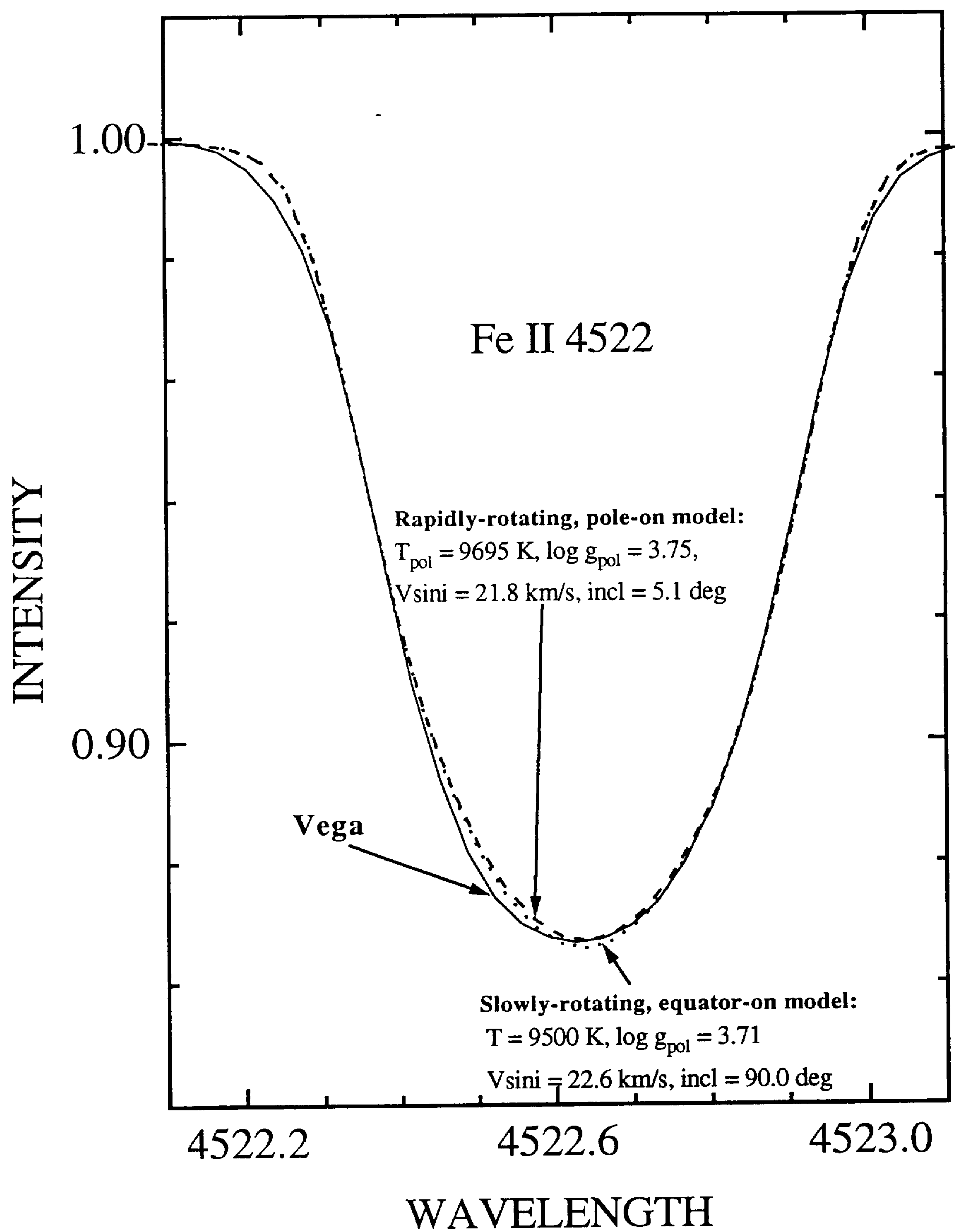
Rapidly-rotating, pole-on model
T_{pol} = 9695 K, log g_{pol} = 3.75
Vsini = 21.8 km/s, incl = 5.1 deg
1.000
0.950
0.900
0.850
INTENSITY
4520
4525
4530
4535
4540
WAVELENGTH

Fig. 3 - The observed line profiles (solid line) for the 4528-4530 Å features due to Fe I λ4528 and Ti II λ4529. Also shown is the best fit for the rapidly rotating pole-on model (dashed line) and the best fit for a slowly rotating,equator-on model (dotted line).



1.000
0.990
0.980
0.970
INTENSITY
Fe I 4528
Ti II 4529
Vega
Slowly-rotating, equator-on model:
T = 9540 K, log g = 3.76
Vsini = 23.7 km/s, incl = 90.0 deg
Rapidly-rotating, pole-on model:
T_{pol} = 9695 K, log g_{pol} = 3.75
Vsini = 21.8 km/s, incl = 5.1 deg
4528.5
4529.0
4529.5
WAVELENGTH

Fig. 4 - The observed line profiles (solid line) for the Fe II $\lambda 4522$ line with the best fit for the rapidly rotating pole-on model (dashed line) and the best fit for a slowly rotating,equator-on model (dotted line).



Fe II 4522
Rapidly-rotating, pole-on model:
T_{pol} = 9695 K, log g_{pol} = 3.75,
Vsini = 21.8 km/s, incl = 5.1 deg
Vega
Slowly-rotating, equator-on model:
T = 9500 K, log g_{pol} = 3.71
Vsini = 22.6 km/s, incl = 90.0 deg
1.00
0.90
INTENSITY
4522.2
4522.6
4523.0
WAVELENGTH

2