General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

ULTRAVIOLET AND X-RAY DETECTION OF THE 56 Peg SYSTEM (K0 IIp + WD)

Mark Schindler, R. E. Stencel,[a] J. L. Linsky[b]
Joint Institute for Laboratory Astrophysics
University of Colorado and National Bureau of Standards
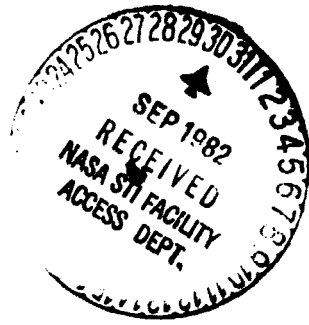Boulder, Colorado

G. Basri[a]
Department of Astronomy
University of California
Berkeley, California

and

D. Helfand
Columbia Astrophysical Laboratory
Columbia University
New York, New York

I. Introduction

We have heard much discussion concerning stars with evidence of hot coronae and transition regions such as the sun, stars with cool massive winds such as α Ori, and hybrid stars which show evidence of both high temperatures and cool winds. In this paper we will discuss 56 Peg, representing a class of evolved stars, the barium star binaries, in which the fundamental physical processes are completely different from the picture of cool evolved stars we have painted at this workshop. What is unique about this system? 56 Peg has the largest ratio of C IV flux to bolometric flux of all 38 stars in a recent survey of cool stars near the coronal-star noncoronal-star boundary (Simon, Linsky and Stencel 1981) (fig. 1). In addition, 56 Peg has an X-ray luminosity of 3×10^{31} ergs s^{-1}, comparable to the rapidly rotating RS CVn binary systems, yet lies in a region of the HR diagram where stellar X-rays are generally not observed (fig. 2). But 56 Peg is not a rapid rotator, as Smith and Dominy (1979) have observed. The key to understanding the emission from this
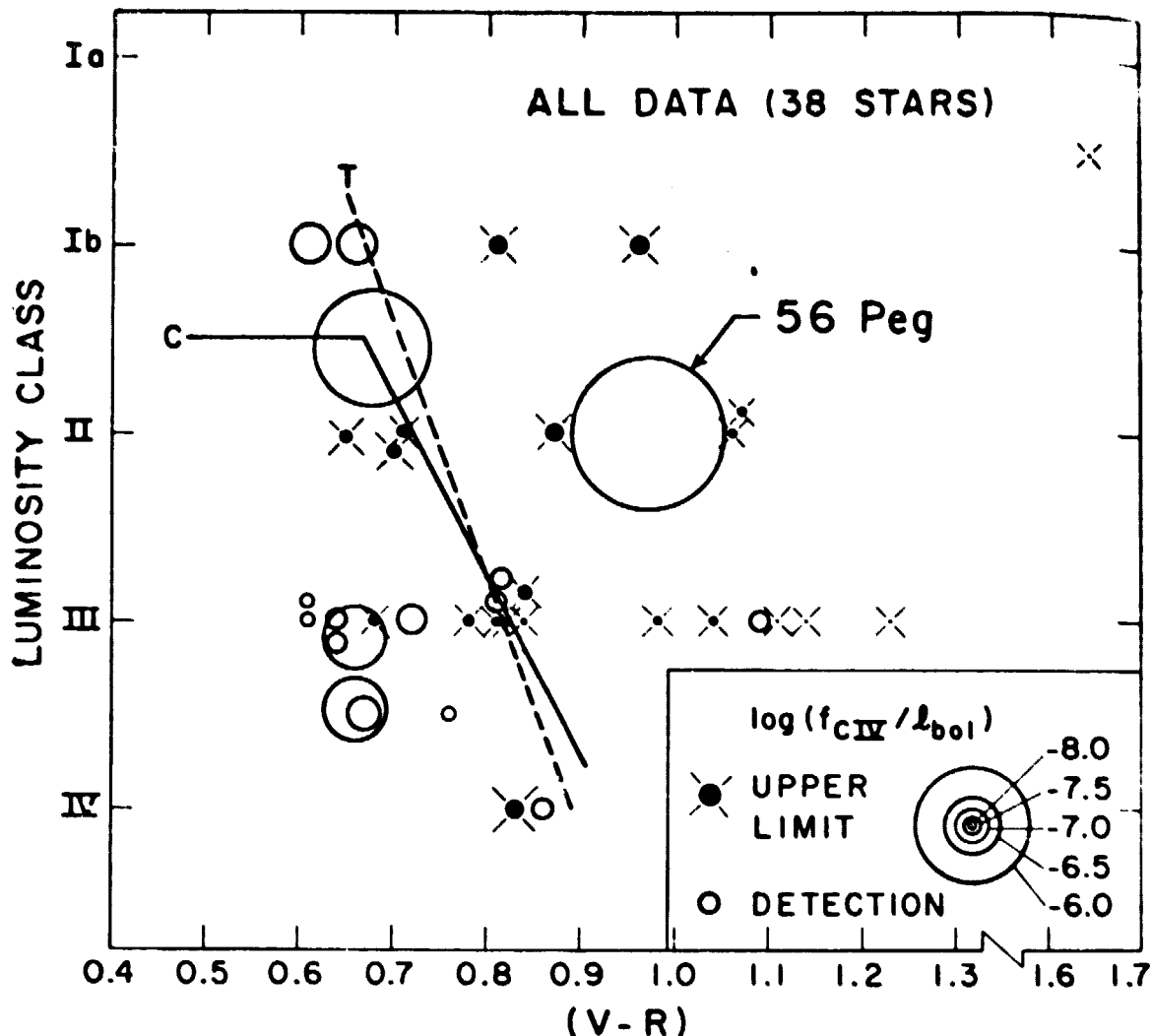

Fig. 1. HR diagram showing C IV (10^5 K emission) detections and upper limits of 38 late-type stars (Simon, Linsky, and Stencel 1981). Bubble size indicates the magnitude of the $f_{C IV}/f_{bol}$ ratio. The line marked C is the coronal boundary line proposed by Ayres et al. (1981), dividing the diagram into a region (to the left) which shows X-ray detections of stellar coronae, and a region (to the right) which shows only low upper limits to the X-ray flux. The line marked T is the temperature dividing line of Linsky and Haisch (1979), and is based on the detection of 10^5 K emission lines, generally associated with the transition regions of coronal type stars. Note that 56 Peg has the largest $f_{C IV}/f_{bol}$ ratio of all the stars, both coronal and non-coronal. Yet 56 Peg lies well into the region where no evidence of plasma hotter than 20,000 K is usually observed.
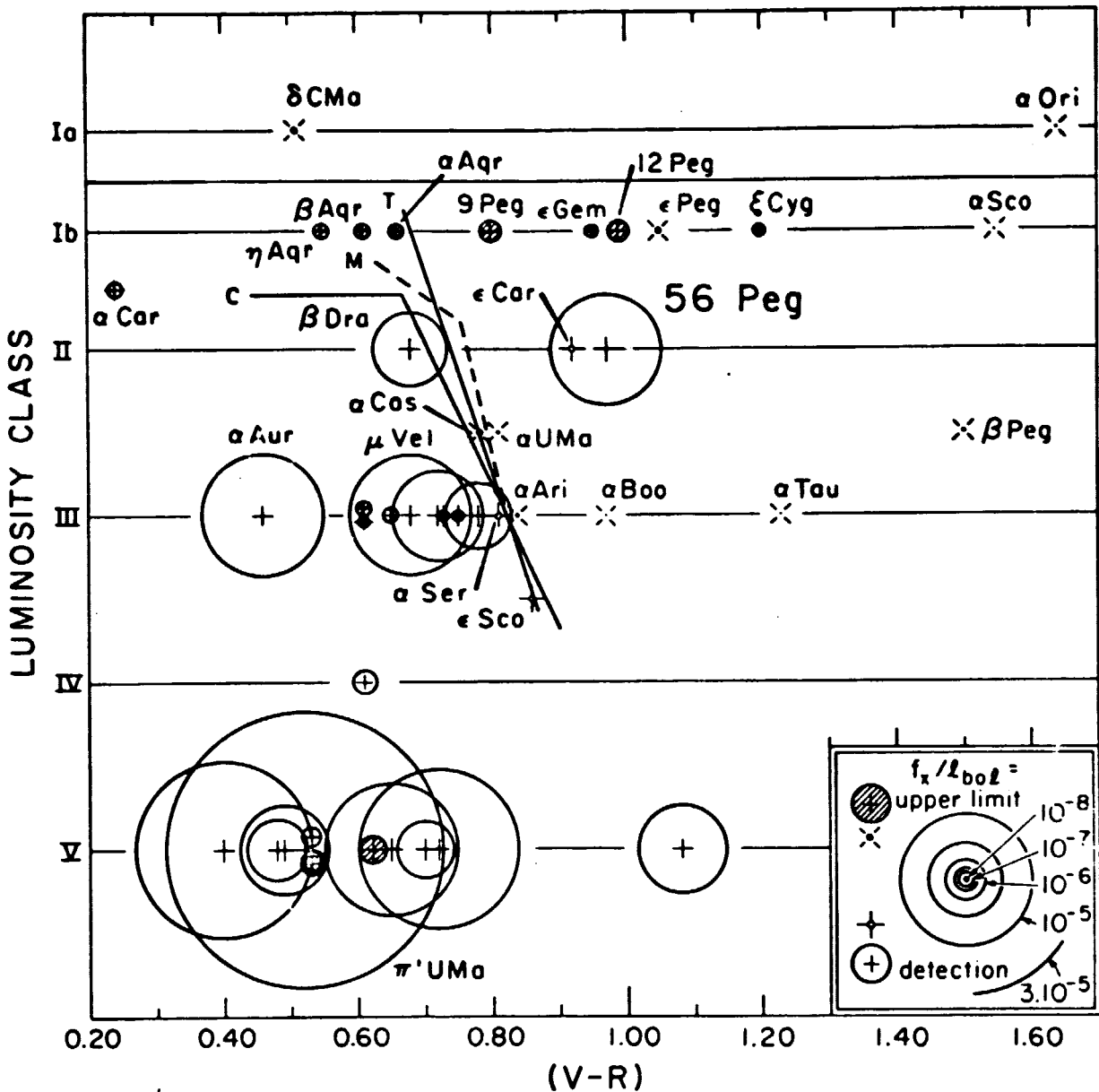
Fig. 2. HR diagram showing Einstein X-ray detections and upper limits of 42 late-type stars (Ayres et al. 1981), and our 56 Peg detection. Bubble size indicates the magnitude of the f_x/f_{bol} ratio. The lines marked C and T are identical to figure 1. The line marked M is the dividing line of Stencel and Mullan (1980a,b), based on the double peaked emission core of the Mg II k line, and separates stars showing outflow or massive stellar winds from solar type stars. Again, 56 Peg is clearly anomalous, and violates these statistical trends. The X-ray luminosity is 3×10^{31} ergs s^{-1}, as bright as the rapidly rotating RS CVn binaries.

star has been the recent discovery of the white dwarf companion to this cool
bright giant (Schindler et al. 1981). Accretion onto the white dwarf of ~0.1%
of the stellar wind of the primary is sufficient to power an X-ray source of
the observed luminosity. Reprocessing of the X-rays in the cool dense stellar
wind explains the origin of the UV emission line spectrum, and may explain
the time-varying asymmetry of the Mg II k line profile that is observed.

II. The Barium Star Binaries

56 Peg A is a mild barium star, and exhibits anomalously strong lines of
CN, barium, strontium, and other "s-process" elements resulting from the slow
neutron capture process (Roman 1952, Yoss 1961, Warren and Williams 1970).
Most schemes proposed to explain both the red-giant stage and the anomalous
surface abundances of the barium stars invoke unspecified special mixing
mechanisms that operate mysteriously in only a small fraction of the red gi-
ants (Sneden et al. 1981, and references therein). Recently, McClure et al.
(1980) have discovered that 10 out of a sample of 11 barium stars they studied
are long-period binaries (P ~ 1000 d), several with 1-2 M_Θ companions. It has
been proposed that the enhanced abundance of carbon and s-process elements in
the primary is the result of the transfer of nuclear processed layers from the
companion, during its evolution to its present white dwarf stage (McClure et
al. 1980, Smith et al. 1980). Further evidence for this scenario is found in
the work of Böhm-Vitense (1980) who published IUE short wavelength spectra of
the cool barium star ζ Cap which showed the hot continuum of the white dwarf
companion.

III. The Observations

In figure 3 we show both the IUE short wavelength and long wavelength
exposures of the 56 Peg system. In addition to the numerous emission lines
present, one observes an enhanced continuum shortward of 1800 Å, rising to
the shorter wavelengths. The continuum is fit well by a 30,000 K blackbody
curve. Combining the integrated continuum flux (3.0×10^{-11} erg cm^{-2} s^{-1}),
the distance (215 pc) and the temperature give a radius of about 10,000 km for
the companion. Further, we can compare the broad hydrogen Lyman α absorption
feature with a grid of white dwarf model atmosphere calculations of Wesemael
et al. (1980). Both the T_{eff} = 30,000 K, log g = 9 and T_{eff} = 25,000, log g =
8 models fit the observational profile equally well, with M ~ 1 M_Θ.

The X-ray luminosity is 3×10^{31} ergs s^{-1}, as bright as the rapidly ro-
tating RS CVn binaries (Walter and Bowyer 1981). Figure 2 shows our X-ray de-
tection plotted on an X-ray survey of late-type stars by Ayres et al. (1981).
It is not surprising that Zirin (1976) reports a large equivalent width for
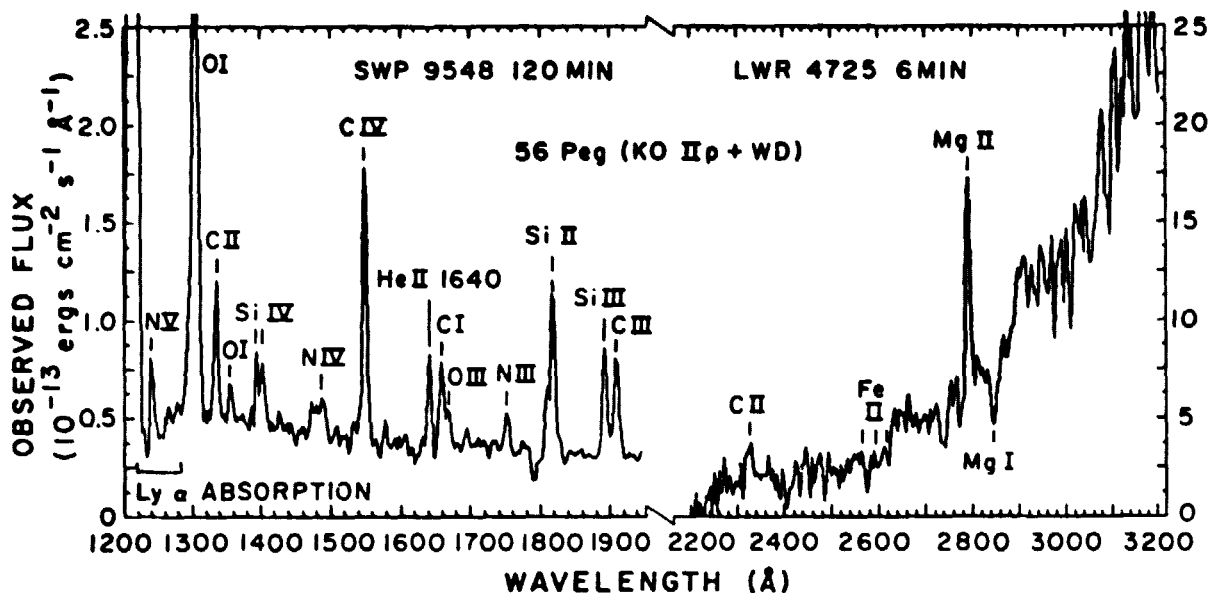
Fig. 3. Combined IUE SWP and LWR exposures of 56 Peg A and B (KO IIp+WD). The data consist of a 150 minute short wavelength exposure (SWP 9548) obtained on 1980 July 20, and a 6 minute long wavelength exposure (LWR 4725) obtained on 1979 June 8. Note that the observed flux scales differ by a factor of 10. In the long wavelength region of the spectrum we see the continuum of the cool star (T_{eff} = 4400 K), and in the short wavelength region of the spectrum we see a hot continuum rising to the shorter wavelengths. We see also the broad hydrogen Lyman α absorption feature of the white dwarf extending to ~1280 Å. The emission lines are indicated, and are likely the result of stellar wind reprocessed X-rays from the white dwarf. The emission line fluxes are tabulated by Schindler et al. (1981).

He I λ10830 of 1.1 Å, since λ10830 formation is closely linked to the presence of stellar X-rays.

Figure 4 shows the enigmatic Mg II k line profile data. The double peaked emission core has undergone extreme asymmetry variations. Our first observation of 1979 June shows a Mg II emission core dominated by the redward emission peak, usually ascribed to radial outflow of Mg^+ material (such as found in a strong stellar wind) which absorbs photons from the short wavelength peak due to the line-of-sight velocity. The 1980 profiles show a complete reversal of the emission core, resembling that seen in the sun and other stars without massive stellar winds. This observation implies a lack of absorbing Mg^+ material along the line-of-sight in the stellar wind. Recent 1981 October profiles show a symmetric emission core, indicating a trend back towards the profile observed in 1979 June.

IV. Discussion

Current understanding of late-type stars (Linsky 1981, Pallavicini et al. 1981, Rosner 1980) relates chromospheric and coronal emission to the presence of magnetic fields, which are maintained by dynamo action, which is in turn dependent upon stellar rotation and subphotospheric convection. Attempts to explain the bright X-rays and UV emission lines in terms of the rotation-activity connection meet with failure. Smith and Dominy (1979) observed v sin i < 3 km s^{-1}. We can place 56 Peg on a figure from Pallavicini et al. (1981), which plots log L_x against log v sin i (fig. 5). We are struck by its anomalous nature once again; it lies 3 1/2 orders of magnitude brighter in L_x than the other slowly rotating luminosity class I and II stars of this survey.

Detection of the white dwarf companion has made accretion of wind material from the primary onto the degenerate secondary an important process to consider. The luminosity in X-rays produced by accretion is a function of the mass loss rate and wind speed of the primary, the separation of the binary, and the mass and radius of the secondary. This mechanism provides a self-consistent explanation for the 56 Peg system. (See Schindler et al. 1981 for details of the calculation.) L_x implies a mass loss rate of 10^{-9} to 10^{-8} $M_\odot$ yr^{-1} for the primary, a reasonable value for this spectral type and luminosity class.

Further, X-ray illumination of the cool stellar wind of the primary can account for the UV emission lines. We note that the observed X-ray and ultraviolet emission line fluxes are comparable, so that absorption by the wind of half the initial X-ray flux can explain the energy in all of these ultraviolet emission lines. This scenario could also explain the curious Mg II k line
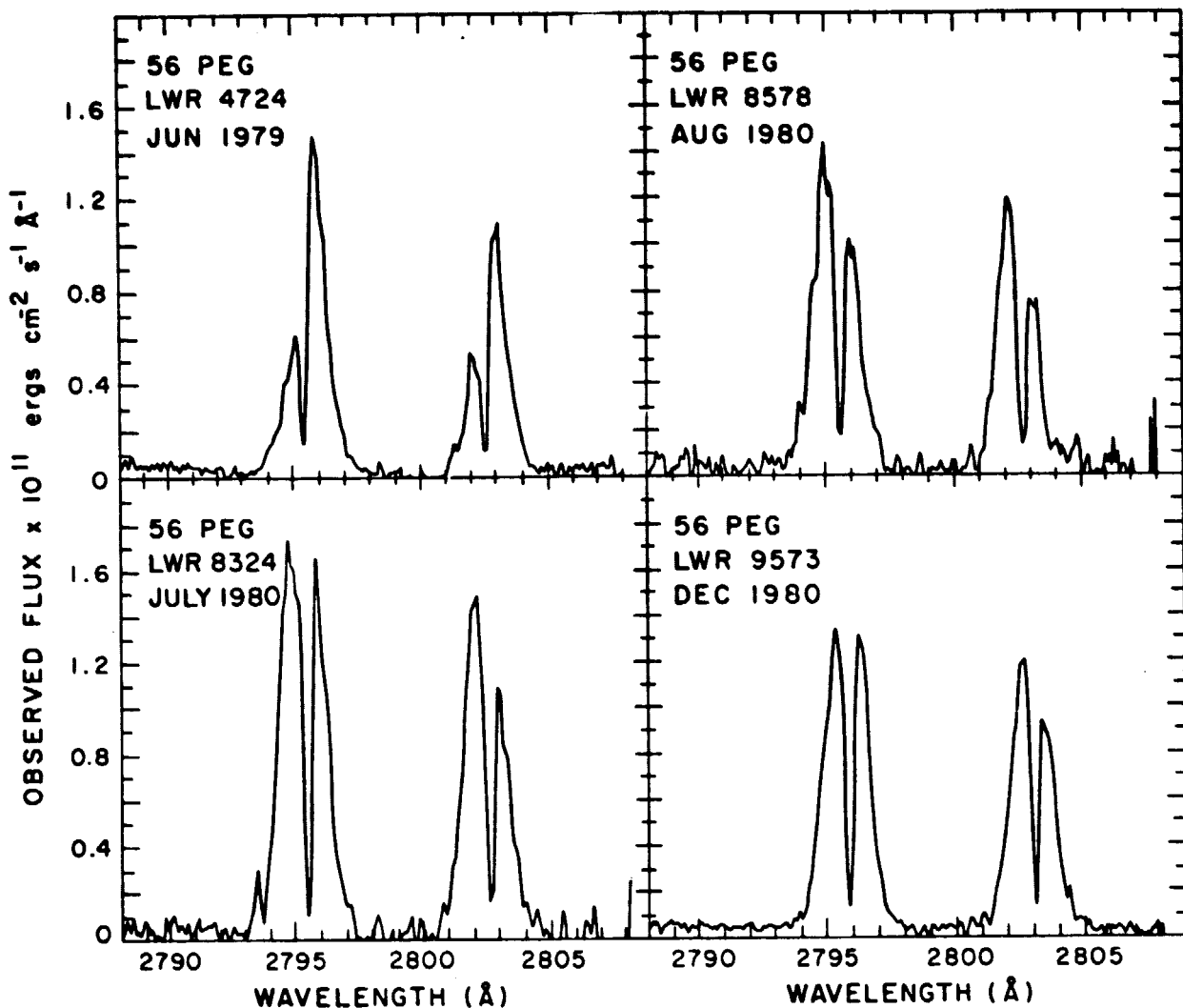
Fig. 4. The Mg II k line profiles show a dramatic change in the double peaked
emission core between our first observation of 1979 June, and subse-
quent observations during 1980. The emission core in 1979 is domi-
nated by the redward emission peak, usually ascribed to radial outflow
of Mg^+ material which absorbs photons from the shorter wavelength
peak, due to its line-of-sight velocity. The profiles in 1980 show a
complete reversal of the emission core, resembling that seen in the
sun and stars without massive stellar winds. Recent 1981 profiles
indicate the emission core is now symmetric, tending towards the
asymmetry observed in 1979. This curious phenomenon can be explained
by an overionization of the Mg^+ material by X-ray emission from the
white dwarf. We expect the photoionized region of the cool stellar
wind to corotate with the binary period of the system, giving rise to
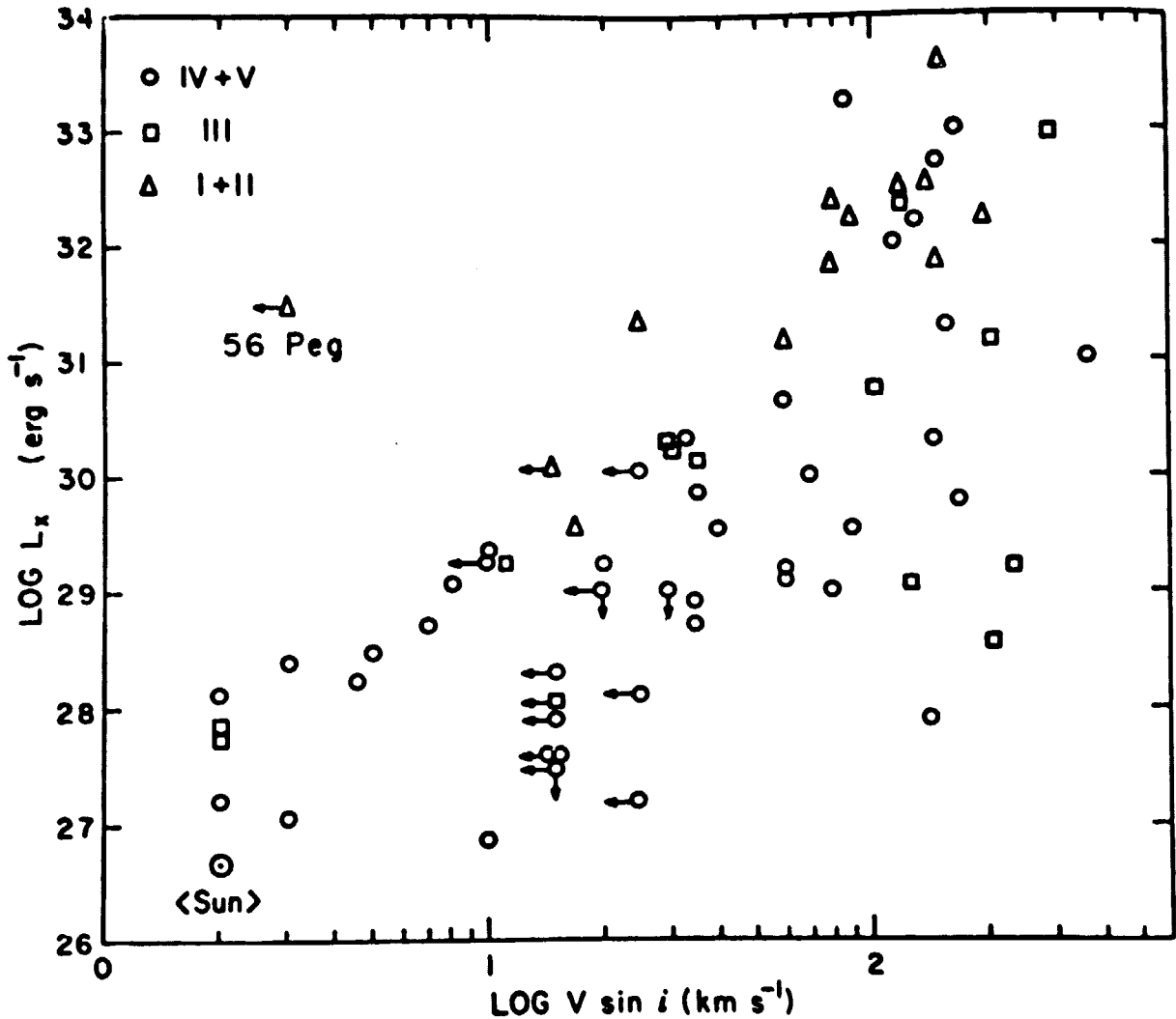the time-varying Mg II k line profile.

Fig. 5. 56 Peg deviates from the rotation-activity correlation, L_x vs. v sin i, (Pallavicini et al. 1981) by 3 1/2 orders of magnitude in its X-ray luminosity compared to other, slowly rotating luminosity class I and II stars surveyed. This suggests a completely different mechanism at work in the case of 56 Peg, such as the proposed X-ray illumination of the cool stellar wind, as opposed to coronal heating due to magnetic field regeneration in rapidly rotating convective stars.

profile. Overionization of magnesium in the wind near the X-ray source re-
sults in too little Mg^+ in the line-of-sight to produce the blue-shifted ab-
sorption when the white dwarf is in front of the primary. This would give
rise to a phase dependent Mg II k line profile, which would appear to vary
with the long period of the binary system. Detailed calculations of X-ray
illuminated cool stellar winds are an untouched area of research, and are sure
to provide very interesting and exciting results, as the work on X-ray illumi-
nated stellar atmospheres (London, McCray and Auer 1981) and X-ray illuminated
hot stellar winds (Friend and Castor 1981) have proved to be.

References

Ayres, T. R., Linsky, J. L., Vaiana, G. S., Golub, L., and Rosner, R. 1981,
    Ap. J. (in press).
Böhm-Vitense, E. 1980, Ap. J. (Letters), 239, L79.
Friend, D. B. and Castor, J. I. 1981, in preparation.
Linsky, J. L. 1981, in Solar Phenomena in Stars and Stellar Systems, ed.
    R. M. Bonnet and A. K. Dupree (Dordrecht: Reidel), p. 99.
Linsky, J. L. and Haisch, B. M. 1979, Ap. J. (Letters), 229, L27.
London, R., McCray, R., and Auer, L. H. 1981, Ap. J., 243, 970.
McClure, R. D., Fletcher, J. M., and Nemec, J. M. 1980, Ap. J. (Letters),
    238, L35.
Pallavicini, R., Golub, L., Rosner, R., Vaiana, G. S., Ayres, T. R., and
    Linsky, J. L. 1981, Ap. J., 248, 279.
Roman, N. G. 1952, Ap. J., 116, 122.
Rosner, R. 1980, in Cool Stars, Stellar Systems, and the Sun, ed. A. K.
    Dupree, SAO Special Report No. 389, p. 79.
Schindler, M., Stencel, R. E., Linsky, J. L., Basri, G. S., and Helfand, D.
    1981, Ap. J. (Letters), submitted.
Simon, T., Linsky, J. L., and Stencel, R. E. 1981, Ap. J. (in press).
Smith, M. A. and Dominy, J. F. 1979, Ap. J., 231, 477.
Smith, V. V., Sneden, C., and Pilachowski, C. A. 1980, P.A.S.P., 92, 809.
Sneden, C., Lambert, D. L., and Pilachowski, C. A. 1981, Ap. J., 247, 1052.
Stencel, R. E. and Mullan, D. 1980a, Ap. J., 238, 221.
_____. 1930b, Ap. J., 240, 718.
Walter, F. and Bowyer, S. 1981, Ap. J. (in press).
Warren, P. R. and Williams, P. M. 1970, Observatory, 90, 115.
Wesemael, F., Auer, L. H., Van Horn, H. M., and Savedoff, M. P. 1980, Ap. J.
    Suppl., 43, 159.
Yoss, K. M. 1961, Ap. J., 134, 809.
Zirin, H. 1976, Ap. J., 208, 414.