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N. E. White and F. E. Marshall

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Goddard Space Flight Center
Greenbelt, Maryland 20771

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N.E. White[1] and F.E. Marshall
Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

ABSTRACT

The observed X-ray luminosities seen from an Einstein survey of nine Algol-like systems are similar to those found by Pallavicini et al. (1981) for single or widely separated rapidly rotating late stars, but fall an order of magnitude below those seen from RS CVn stars with similar orbital periods and spectral types. We conclude that the X-ray emission is most probably associated with a hot coronae surrounding the secondary. Possible explanations for the lower luminosity of the Algol systems relative to the RS CVn systems are considered.

[1]Also Dept. of Physics and Astronomy, Univ. of Maryland

I. INTRODUCTION

The correlation between coronal X-ray luminosity and rapid stellar rotation in stars later than F5 is now well established, although the exact form of the relationship remains controversial. Without any detailed physical model for guidance, there is no obvious form to use in relating the X-ray luminosity L_x to observable stellar parameters. Walter and Bowyer (1981) in a study of the rapidly rotating stars in RS CVn systems suggest that the ratio of the X-ray luminosity to the bolometeric luminosity (L_x/L_*) is inversely proportional to the stellar rotation period, with the constant of proportionality increasing for later spectral types (independent of luminosity class). Walter (1981) and Walter (1982) extended this relation to other stars and found evidence for a break in it at an orbital period of ~ 12 days. Alternatively Pallavicini et al. (1981) examined mostly single late type stars and found that for all luminosity classes and spectral types L_x is proportional to the square of the projected equatorial velocity of the star, v sini. The two models show the same general trends although they in general make different quantitative predictions.

Algols are a class of binaries that contain a rapidly rotating late star and represent an independent sample of rapid rotation in late stars. They are semi-detached binaries where a G or K subgiant fills its Roche lobe and spills material onto a B or A main sequence companion. In fact Algol was one of the first stellar X-ray sources to be discovered (Schnopper et al. 1975). Observations by the Einstein Solid State Spectrometer (SSS) eliminated models for the X-ray emission involving either the collision of the gas stream with the primary (or a corona surrounding the primary) and by analogy with the RS CVn systems it was proposed that the lobe filling normally unseen subgiant has an active corona (White et al. 1980; Paper 1). Gibson (1980, priv. comm.)

independently reached the same conclusion based on the similarity of the radio outburst properties of RS CVn stars and Algol. The presence of the bright early star in Algol systems masks the normal coronal activity diagnostics such as Ca II K emission that are so distinctive in the RS CVn stars.

This suggests that Algols as a class could, like the RS CVn stars, be among the most active coronal X-ray sources. In §II we present an Einstein Imaging Proportional Counter (IPC) survey of some optically well studied Algols and in §III we compare the observed X-ray luminosities and rotational parameters with those of previous studies. We find that the Algols are typically an order of a magnitude less luminous than RS CVn stars with the same rotation period, but that they are consistent with an extrapolation of the relation found for single or widely separated stars by Pallavicini et al (1981). In §IV we discuss possible explanations for this unexpected result.

II. RESULTS

The Einstein IPC made a series of four or five ~ 2000s observations of each of the Algol-like systems listed in Table 1, except for Algol itself which was observed with the Einstein SSS (Paper 1). Six of the nine IPC targets were detected. In the case of RY GEM the source was only seen once out of four observations. This is illustrated in Figure 1 where the average count rate for each observation is shown with a light curve of U CEP for comparison. RY GEM is barely detected, if at all, on three occasions, but on 1980 day 107 a factor of ~ 20 flare occurred such that the IPC rate was twice that from U CEP. There was no variability seen within the 2000s interval when the source was bright. We note that in Paper 1 a factor of 3 flare that lasted at least 12 hours was reported from Algol. No other flares or variability was seen from the other five sources. We have also examined 2 to 60 keV HEAO-1 A2 scanning data of the same IPC targets for any significant detections or flares. None of the sources were detected at a level greater than ~ 2×10^{-11} erg s^{-1} cm^{-2} (2-10 keV).

Table 1 contains the relevant parameters for each system. Minimum and maximum X-ray luminosities are given for the variable sources Algol and RY GEM. The stellar parameters come from Popper (1980), Cester et al. (1978), Cester et al. (1977) and Allen (1973). We were unable to find any orbital solution for QS AQL and will not include it in any of the following discussion. The distances assume that the primaries are main sequence.

III. A COMPARISON WITH OTHER SURVEYS

The non-flare X-ray luminosities vary from $< 1 \times 10^{30}$ erg s^{-1} up to 7×10^{30} erg s^{-1}, with a peak luminosity during the RY GEM flare of 2×10^{31} erg s^{-1} (Table 1). These seem rather low when compared to the range of luminosity from the RS CVn stars of ~ 1×10^{30} to 3×10^{31} erg s^{-1} (Walter and Bowyer 1981). In Figure 2 we show L_x/L_* versus P_{orb} for all the Algols in our sample. The dashed lines indicate the range of variation seen during the flares from RY GEM and Algol. Also given is the region of scatter occupied by the RS CVn stars studied by Walter and Bowyer (1981). Two of the Algol secondaries have earlier spectral types than is typical of the subgiant in RS CVn stars and are given a different symbol in Figure 2 (because L_x/L_* depends on spectral type). The spectral types of the secondaries in the remaining seven are similar to the subgiants in the RS CVn systems. All the Algol-like systems lie about one order of magnitude below the values of L_x/L_* seen from the RS CVn stars.

In Figure 3 we show L_x versus v_{rot} for both our sample of Algols and also for the RS CVn and related systems with $P_{orb} < 12$ days studied by Walter and Bowyer (1981) and Walter (1981). In both cases the relation of $L_x = 10^{27} v_{rot}^2$ found by Pallavicini et al. (1981) is indicated, where v_{rot} is equatorial velocity assuming synchronized rotation. The quiescent Algol X-ray luminosities are in excellent agreement with the Pallavicini relation; the RS CVn stars lie systematically above it. Pallavicini et al. (1981) include in their survey stars of all spectral types and find for stars earlier than A that the X-ray luminosities do not show any rotational dependence, but that there is a good correlation of L_X with $L_\star$. This predicts for the early primaries of the Algol systems coronal X-ray luminosities of $\sim 10^{29}$ erg s^{-1}, far below that observed from many in our sample.

IV. DISCUSSION

By analogy with the solar corona, current models of late type stars picture the X-ray emitting plasma confined in magnetic loops, with the coronal activity increasing with stellar rotation through the action of an internal dynamo. This model was initially applied to explain the early X-ray detections of the RS CVn systems (e.g. Walter et al. 1980), but has since provided a plausible qualitative description of the coronae of late type stars in general. In Paper 1 we argued that this model is also appropriate for the late type secondary of Algol. The results presented here show that this model can be extended to Algols as a class. In particular the observed X-ray luminosities are comparable to that seen from other late type stars.

The $L_X \propto v^2$ relation proposed by Pallavicini et al. (1981) for mainly single or widely seperated late stars gives a good estimate of the observed X-ray luminosities of Algol systems. The $L_X/L_\star \propto P_{orb}^{-1}$ relation found by Walter (1981) for RS CVn stars overestimates the observed flux, in particular at the longer orbital periods. This latter result is at first sight surprising given that the late component in both the RS CVn and Algol systems have roughly the same spectral type and class (~ K0IV) and are also rotating at similar periods. However, during its evolution the subgiant in an Algol system has filled its Roche lobe while evolving off the main sequence and spilled a large part of its original mass onto its companion. This mass loss process is still procedding and may be disrupting the magnetic loops in the vicinity of the inner Lagrangian point. Kondo, McCluskey and Harvel (1981) have found that in U CEP material leaves from a significant fraction of the surface of the secondary and this could significantly reduce the number of closed loops. But the disruption should, for co-rotation, preferentially occur on the side facing the primary. The lack of strong orbital modulation (e.g. Fig. 1) tends to argue either that the mass flow does not disrupt the corona or that the loop sizes are larger than a stellar radius. A similar argument tends to discount any disruption of the loops by the stellar wind of the primary.

The subgiant in an RS CVn system is probably also post-main sequence (Popper and Ulrich 1977) but in this case there is no evidence that any substantial mass transfer has yet occurred between the two components. It is usually assumed that both components (the other is typically a G dwarf) are evolving as single stars. In contrast the progenitor to an Algol subgiant must originally have been much more massive and of an earlier spectral type. As a consequence of loosing mass it is now substantially over luminous compared to a "normal" subgiant in, for example, an RS CVn system (e.g. Paczynski 1971). The reduced L_x/L_* of an Algol subgiant may be caused by this difference in the mass to bolometric luminosity ratio.

That the Algols X-ray luminosities are in such good agreement with the relation proposed by Pallavicini et al. (1981) for mainly single stars may suggest that the coronal activity of the RS CVn systems is abnormal. There has been the suggestion that a significant fraction of the coronal loops have dimensions comparable to the binary orbit (e.g. Swank et al. 1981) and that in

RS CVn systems there may be "interactions" between the loops on the two stars (Simon, Linsky and Schiffer 1981). This could lead to an overall enhancement in the coronal activity either by superposition of many small flares, or more likely, by making available an increased magnetic volume to contain the X-ray emitting plasma. Such interstar or magnetic loop interactions may not be possible due to the earlier spectral type of the primary in Algol systems, where the origin of the corona may not involve magnetic loops (cf. Lucy and White 1980). However we would then expect that the longer orbital period RS CVn systems where the binary separation is larger than the loop lengths would show a marked decrease in X-ray flux; no such cutoff is seen (Walter and Bowyer 1981).

We conclude therefore that the reduced coronal activity of the Algol secondaries relative to the RS CVn systems is somehow caused by the different evolutionary histories of the two populations. The similarly low values of $L_x/L_\star$ vs. P_{orb} found by Cruddace and Dupree (1983) for the W UMa contact binaries may also reflect such effects. Without a better understanding of the underlying physical processes that are responsible for the coronal activity it is premature to speculate as to the cause of these effects. Nonetheless this result does show that it is unrealistic to expect a single rotational relation to be applicable to all stars irrespective of their history.

ACKNOWLEDGMENTS

We thank Fred Walter for some helpful comments on an earlier manuscript.

TABLE 1. RESULTS

Source	P_{orb} (days)	Sp. Type	Radii ($R_\odot$)	$\log(L_*/L_\odot)$	distance (pc)	$\log(L_x)$[b] (erg s^{-1})	$\log(L_x/L_*)$	V_{rot} (km s^{-1})
RY AQR	2.0	A5	1.5	0.9	230	30.3	-3.44	43
		K1	1.7	0.2				
U CEP	2.5	B7	2.9	2.1	220	30.9	-3.80	95
		G8	1.4	1.0				
QS AQL	2.5	B4	3.9	2.9	417	<30.4	?	?
		?	?	?				
AS ERI	2.7	A3	1.8	1.2	200	30.1	-3.89	41
		K0	2.2	0.4				
TW DRA	2.8	A3	2.4	1.4	190	30.8	-3.64	62
		K0	3.4	0.8				
ALGOL	2.9	B8	3.1	2.2	27	30.6	-3.43	55
		G8	3.2	0.8		31.0	-3.82	
U SGE[a]	3.4	B8	4.1	2.6	180	30.7	-4.15	80
		G5	5.3	1.3				
RS VUL	4.5	B5	4.1	2.9	380	30.3	-4.80	63
		G0	5.6	1.5				
RY GEM	9.3	A2	3.3	1.8	263	31.3	-4.38	33
		K2	6	1.1		<30.0	-4.68	
S CNC	9.5	A0	2.1	1.5	340	<30.2	-4.36	27
		K2	5	1.0				

[a] Source was at the edge of the FOV

[b] Assumes 1 IPC ct s^{-1} = 2×10^{-11} erg $cm^{-2}s^{-1}$

REFERENCES

Allen, C.W. 1973, Astrophysical quantities, 3rd ed: London:Athlone.

Cester, B., Fedel, B., Giuricin, G., Mardirossan, F., Pucillo, M. 1977, Astr. Ap. 61, 469.

Cester, B., Fedel, B., Giuricin, G., Mardirossan, F., Mezzetti, M. 1978, Astr. Ap. 62, 291.

Cruddace, R., and Dupree, A. 1983, preprint.

Kondo, Y., McCluskey, Jr., G.E., and Harvel, C.A. 1981, Ap. J. 247, 202.

Lucy, L.B., and White, R.L. 1980, Ap. J. 241, 300.

Paczynski, B. 1971, Ann. Rev. Ast. Ap. 9, 183.

Pallavicini, R., Golub, L., Rosner, R., Vaiana, G.S., Ayres, T., and Linsky, J.L. 1981, Ap. J. 248, 279.

Popper, D.M. 1980, Ann. Rev. Astr. Ap. 18, 115.

Popper, D.M., and Ulrich, R.K. 1977, Ap. J. 212, L131.

Schnopper, H.W. et al. 1976, Ap. J. 210, L75.

Simon, T., Linsky, J.L., and Schiffer, F.M. 1980, 239, 911.

Swank, J.H., White, N.E., Holt, S.S., and Becker, R.M. 1981, Ap. J. 246, 208.

Vaughan, A., and Preston, G. 1980, Pub. A.S.P. 92, 385.

Walter, F.M., Cash, W., Charles, P.A., and Bowyer, C.S. 1980, Ap. J. 236, 212.

Walter, F.M. 1981, Ap. J. 245, 677.

Walter, F.M. 1982, Ap. J. 253, 745.

Walter, F.M. and Bowyer, S. 1981, Ap. J. 245, 671.

White, N.E., Holt, S.S., Becker, R.H., Boldt, E.A., and Serlemitsos, P.J. 1980, Ap. J. 239, L69.

FIGURE CAPTIONS

Figure 1 - The background subtracted X-ray light curves as a function of time for U CEP and RY GEM. Each 2500s observation has been summed.

Figure 2 - L_x/L_* versus P_{orb} for the Algols given in Table 1. The hatched region shows the range of values seen from the RS CVn stars by Walter and Bowyer (1981).

Figure 3 - L_x vs V_{rot} for both the RS CVn and the Algol systems. The dashed lines indicate the range of variability seen from those sources where multiple observations have been made. Systems with $P_{orb} \lesssim 10$ days taken from Walter and Bowyer (1981) are shown. For the RS CVn stars we assumed for simplicity an average radius of 3 R_0 and that both stars contribute equally, which either overestimates V_{rot} or underestimates L_x.

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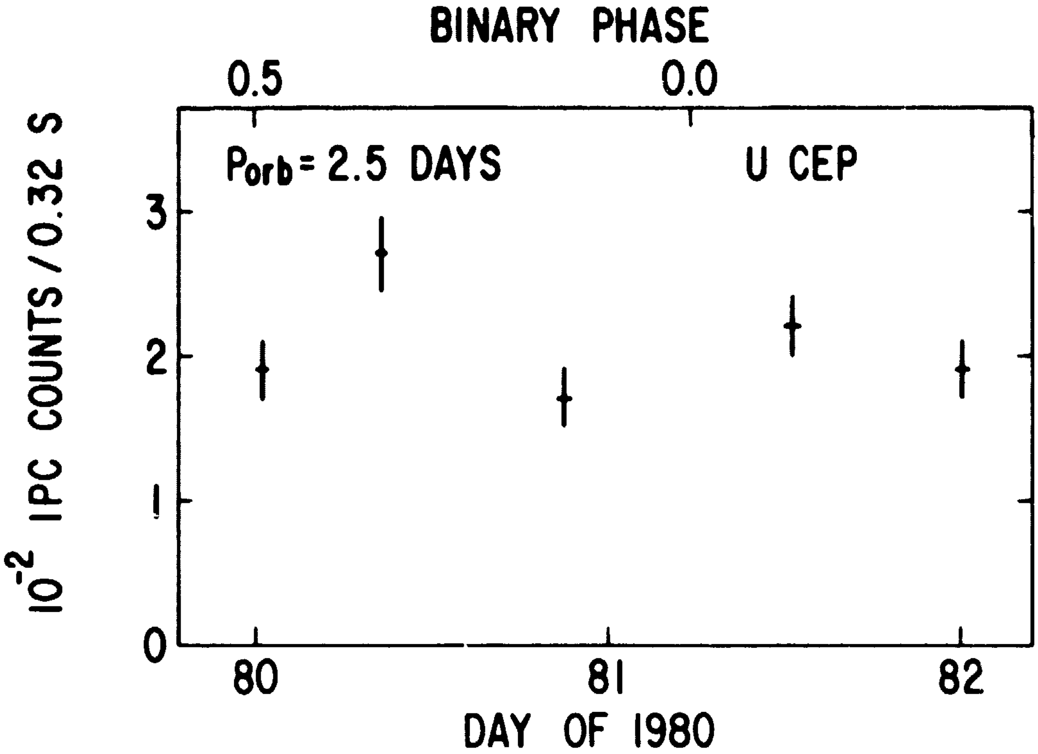

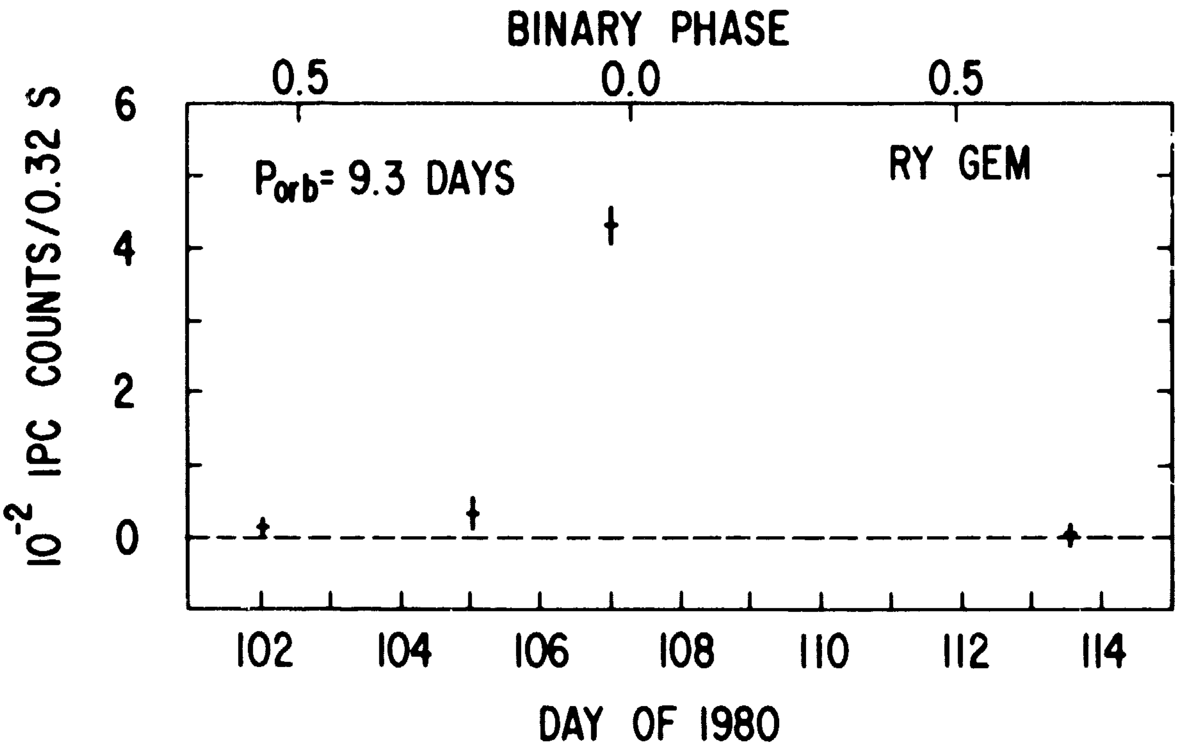

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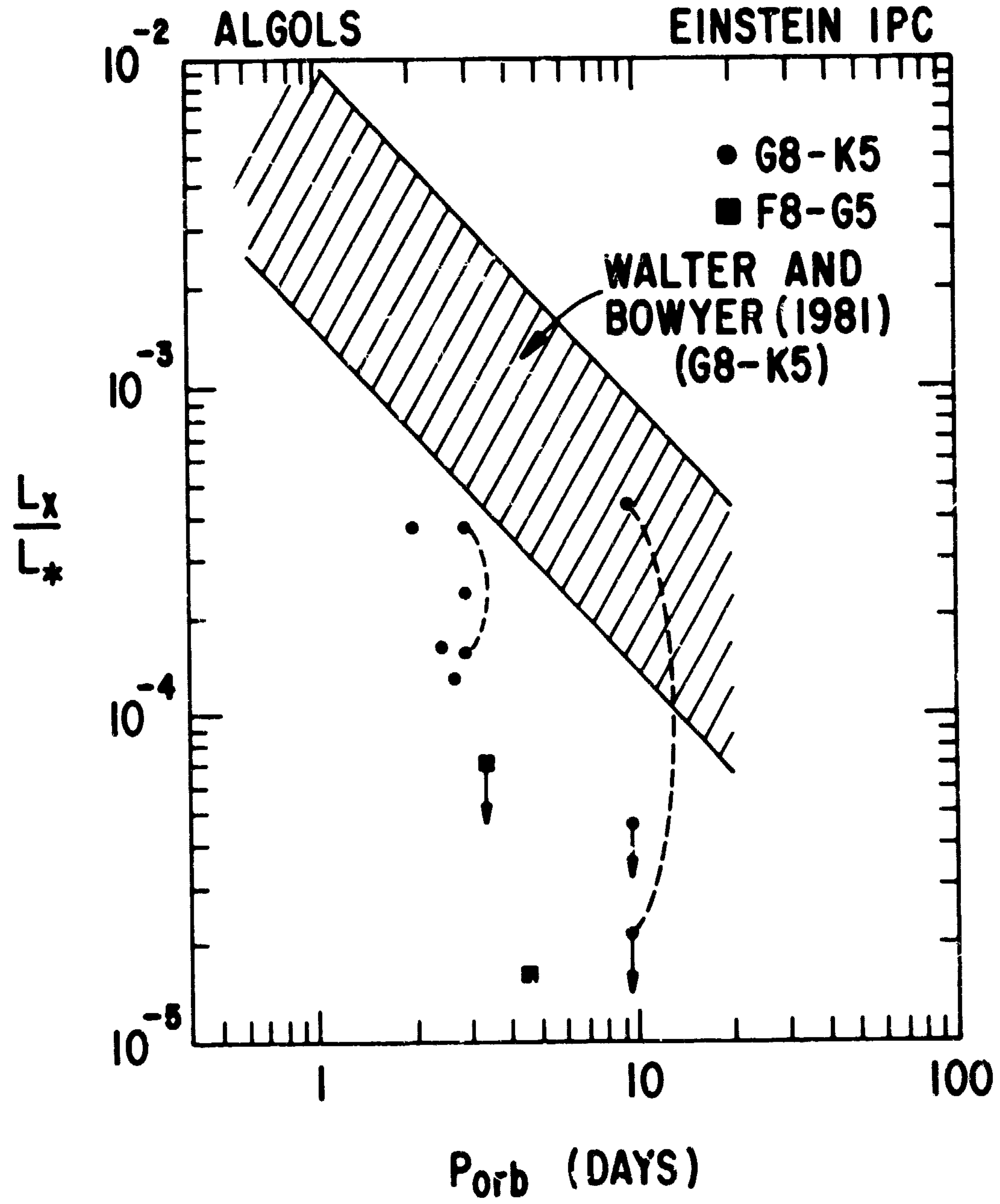

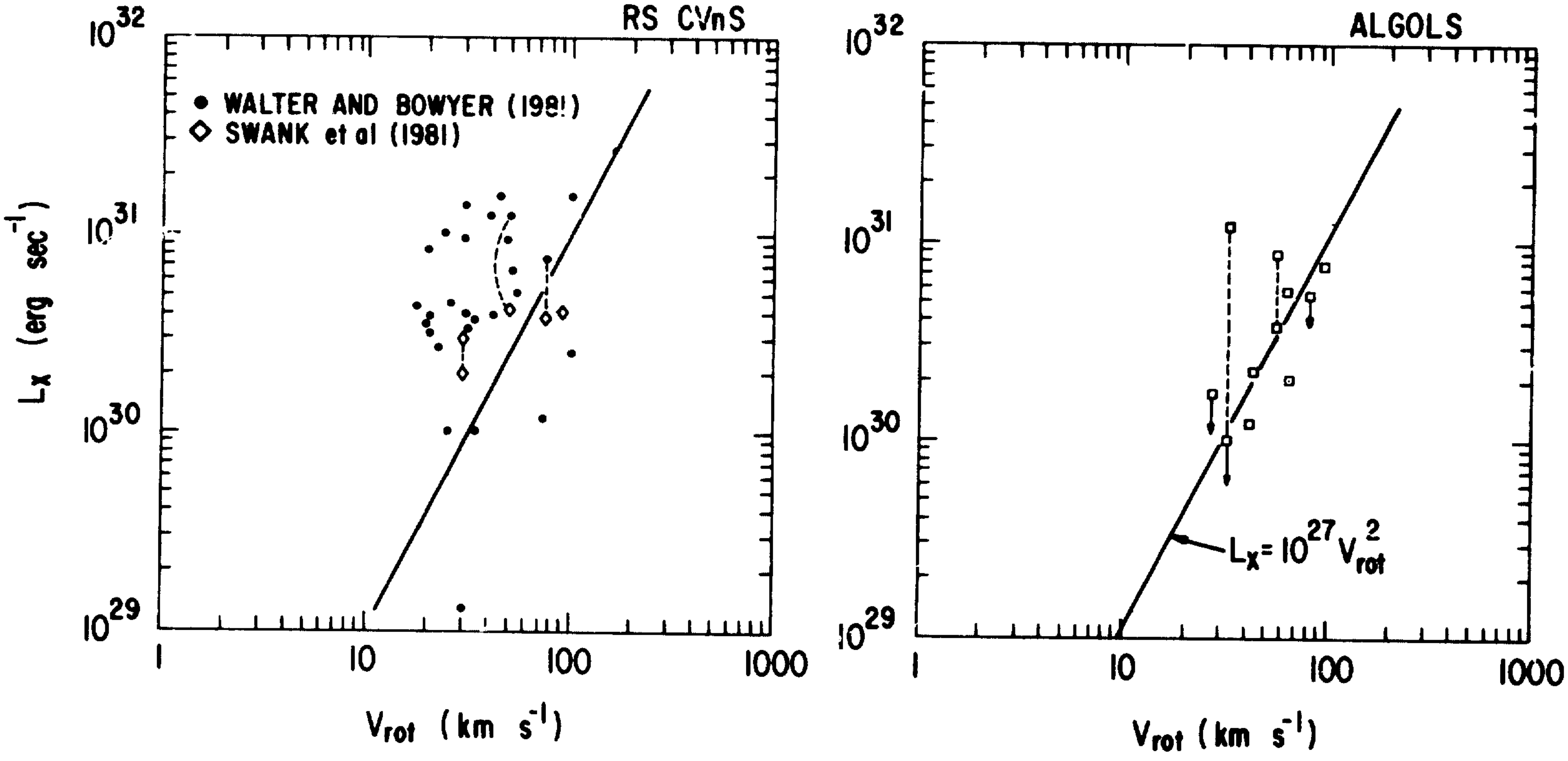

RS CVnS
WALTER AND BOWYER (1981)
SWANK et al (1981)
ALGOLS
$L_x = 10^{27} V_{rot}^2$
L_x (erg sec^{-1})
V_{rot} (km s^{-1})
10^{32}
10^{31}
10^{30}
10^{29}
1
10
100
1000

ADDRESS OF AUTHORS

F.E. MARSHALL, Code 661, Laboratory for High Energy Astrophysics, NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771

N.E. WHITE, Division SB, ESTEC, Postbus 299, 2200 AG Noordwijk Zh, THE NETHERLANDS