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A new class of rapidly pulsating star – I. EC 14026 – 2647, the class prototype

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ABSTRACT

We report the discovery of small-amplitude, very rapid light variations in the sdB binary, EC 14026 – 2647. The variations, probably due to pulsation of the sdB star, have an apparently stable main period near 144 s with a semi-amplitude of ~ 0.012 mag. There is good evidence for a period near 134 s with a semi-amplitude of ~ 0.004 mag; the latter might be variable. We regard this star as the prototype for a new class of variable which we refer to as EC 14026 stars.

Key words: binaries: general – stars: individual: EC 14026 – 2647 – stars: oscillations – stars: variables: other.

1 INTRODUCTION

The Edinburgh–Cape (EC) Blue Object Survey is a southern hemisphere search for blue stellar objects. A full description of the survey methods and procedures has been given by Stobie et al. (1997) and progress reports have been presented by Stobie et al. (1987, 1992) and Kilkenny et al. (1994), for example. As expected, the survey has detected many new hot subdwarfs, white dwarfs, cataclysmic variables, apparently normal B stars at high galactic latitudes, blue horizontal branch stars and bright quasi-stellar objects. Zone 1 of the survey, that part of the North Galactic Cap ($b > 30°$) which extends south of declination $\sim -12\overset{\circ}{.}3$ has been completed (Kilkenny et al. 1997). As a follow-up to the body of the survey, in which we usually obtain only a single *UBV* measurement and low-dispersion (100 Å mm^{-1}) spectrogram for each blue object, we are carrying out more detailed observations of potentially interesting stars. New ZZ Ceti stars have been reported by Stobie et al. (1993, 1995); a new member of the rare AM CVn class of hydrogen-deficient binaries by O'Donoghue et al. (1994); an evolved close binary by Chen et al. (1995); and studies of apparently normal B stars at high galactic latitudes have been reported by Kilkenny, O'Donoghue & Stobie (1991), Kilkenny et al. (1995) and Rolleston et al. (in preparation).

In a project such as the EC survey, an underlying hope, however fugitive, must be that completely new types of object will be discovered that could lead to new astrophysical insights. Perhaps the best recent example of such a survey discovery was the variability in some PG 1159 stars: a class of object discovered in the Palomar–Green survey (Green, Schmidt & Liebert 1986), found to be multiperiodically pulsating (e.g. McGraw et al. 1979) and, in the case of the class prototype PG 1159 – 035, extensively observed and impressively exploited by Winget et al. (1991). In this paper, we present the first results from a study of a completely new class of very rapidly pulsating hot stars. EC 14026 – 2647 appears to be an sdB star in a binary system which exhibits low-amplitude light variations, presumably as a result of stellar pulsation, with a main period of 144 s and a secondary period near 134 s, making it one of the shortest period stellar pulsations known (a few white dwarfs have shorter periods).

2 THE COMEDY OF ERRORS

Zone 1 of the EC survey contains 675 genuinely blue objects, over half (~ 53 per cent) of which are hot subdwarfs. Of these subdwarfs, more than 50 were noted to have the Ca II K line in absorption; surprising for such hot stars, which are unlikely to be significantly reddened at $b > 30°$. Closer inspection showed that some of these objects also have the *G* band and, occasionally, weak He I in absorption. The natural conclusion is that these are binaries with each of their two components having roughly equal brightness in the blue region of the spectrum. Initially, we referred to these as sdB + F binaries because the *K* line seemed to be the dominant feature from the cool component but, as we did not have quantitative measures of the cool companions, we finally classified these stars 'sdB+' in Zone 1 of the survey (Kilkenny et al. 1997).

Spectroscopy for the EC stars is obtained with the Reticon photon-counting system on the South African Astronomical Observatory (SAAO) 1.9-m telescope. Usually, the observer makes a preliminary estimate of the spectral type at the telescope from the 'on-line' reductions; amongst other things, this enables sorting for quick follow-up observations where necessary. In the case of EC 14026 − 2647, an observer labelled the star 'F/G' on the basis of the Ca II line and a weak *G* band (Fig. 1). Normally, the star would not then have been observed further. Luckily, *UBV* photometry had been obtained [$V = 15.28$, $(B-V) = +0.15$, $(U-B) = -0.84$] and this showed that the classification was wrong; the star is far too blue in $(U-B)$ to be an F or a G star and, in fact, lies above the blackbody line in the $(U-B)/(B-V)$ diagram. A repeat spectrogram of better quality was obtained and the star tentatively classified DAZ: although the broad Balmer lines of EC 14026 − 2647 are much narrower than those of most DA white dwarfs, the Balmer lines of cool DA white dwarfs (< 10 000 K) are comparable to those of EC 14026 − 2647. Indeed, such a low temperature is consistent with the presence of the Ca II K line and the *G* band. This classification is not unreasonable in light of the confusion which can occur in separating cooler hydrogen-rich degenerate stars from classical subdwarfs (Hintzen & Strittmatter 1975), but remains problematic for an object with such a blue $(U-B)$ colour.

Nevertheless, the DAZ classification caused the star to be put on a list of EC survey degenerates. We are obtaining 'high-speed' or continuous photometric measurements of all DA stars with colours in or near the ZZ Ceti pulsation range [roughly $+0.15 < (B-V) < +0.25$, although $(B-V)$ is not a sensitive discriminant for these stars]. EC 14026 − 2647 is on the edge of this range but, as its spectrum is very different from that of a ZZ Ceti star, it should not have been included in the search for ZZ Ceti stars and thus should not have been observed. At the telescope it appeared non-variable but in the Fourier analysis of the first high-speed photometry run, an apparently significant peak near 144 s was noted. A repeat run on the star showed the same frequency and the variation was confirmed; this is described in the next section.

A co-added spectrogram (Fig. 1) shows Balmer series lines to at least $n = 12$ and probably $n = 14$, so that the object cannot be a single degenerate white dwarf or hot subdwarf. The lines are presumably a blend in some proportion of the sdB and an F- or a G-type star. This conclusion is established by higher dispersion spectroscopy, which will be discussed in a companion paper (O'Donoghue et al. 1997).

The coordinates of EC 14026 − 2647, accurate to ~1 arcsec, are: $\alpha(1950.0) = 14^h\,02^m\,41\overset{s}{.}8$ and $\delta = -26°\,47'\,15''$.

3 MEASURE FOR MEASURE

Fig. 2 shows the 'high-speed' discovery run on EC 14026 − 2647 made on the night of 1994 May 16/17. The data were obtained as 10-s integrations with no filter, using the St Andrews photometer on the SAAO 1-m telescope at the Sutherland site. One subsequent run was made with this equipment; all further data were obtained with the University of Cape Town (UCT) High-Speed Photometer on the

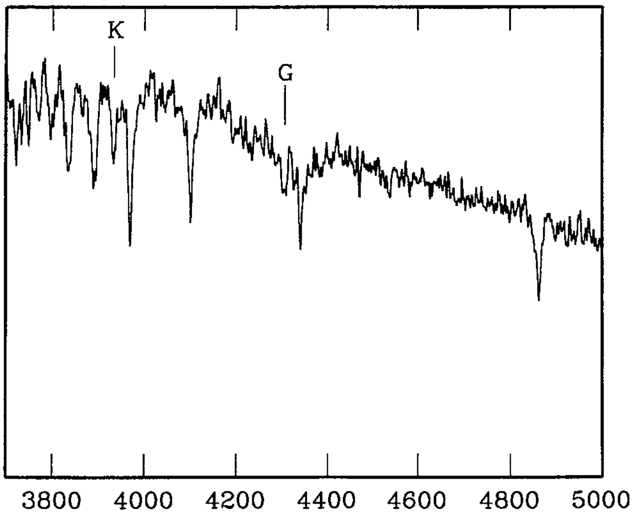

Figure 1. Flux-calibrated spectrogram at 100 Å mm^{-1} for EC 14026 − 2647 co-added from 1989 April 26 and 1995 March 3 and smoothed with a triangular blocking function. The strongest features are Balmer series hydrogen lines; the Ca II K line and the *G* band are indicated. Absolute flux calibration is not accurate, but the abscissa is the zero and full-scale is about 6×10^{-15} erg cm^{-2} s^{-1} Å^{-1}.

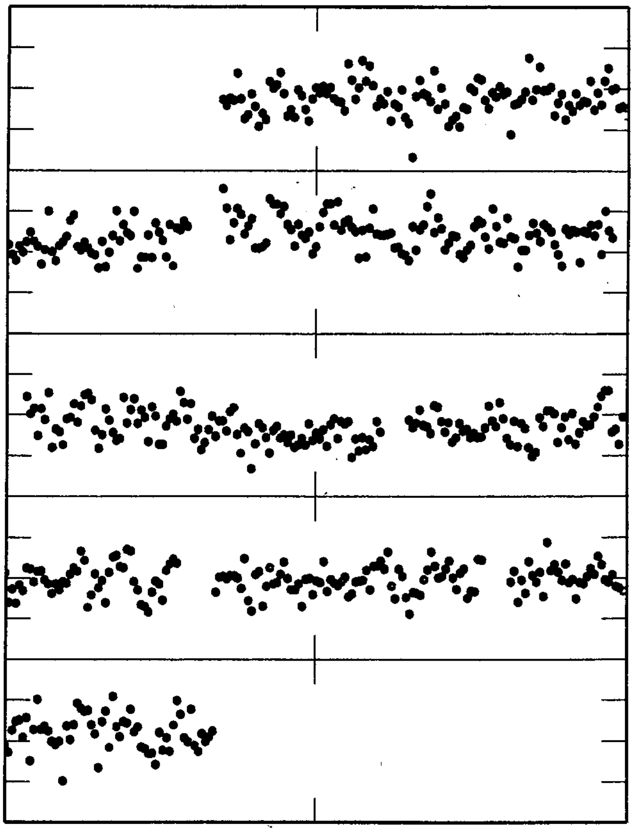

Figure 2. Continuous 10-s integrations in 'white light' for EC 14026 − 2647 for the night of 1994 May 16/17 – the discovery observations. The ordinate carets are separated by 0.05 mag and the abscissae by 0.01 d, so that the data read continuously from left to right and top to bottom, from fractional Julian date 0.307 to 0.387.

Table 1. Data log and frequency/semi-amplitude results for EC 14026 – 2647.

Date	Tel (m)	Phot	Run (sec)	Run (hr)	f_1 (mHz)	s.amp. (mag)	f_2 (mHz)	s.amp. (mag)
1994 May 16/17	1.0	StAP	7110	1.98	6.916	0.0113	7.56	0.0048
Jul 13/14	1.0	StAP	7300	2.03	6.928	0.0092	7.27	0.0052
1995 Mar 02/03	0.75	UCTP	15100	4.19	6.932	0.0125	7.452	0.0013
03/04	0.75	UCTP	14500	4.30	6.932	0.0125	7.498	0.0025
05/06	0.75	UCTP	10280	2.86	6.922	0.0123	7.382	0.0043
May 23/24	0.75	UCTP	28100	7.81	6.930	0.0122	7.482	0.0045
24/25	0.75	UCTP	24150	6.71	6.930	0.0107	7.488	0.0045
25/26	0.75	UCTP	26100	7.25	6.930	0.0106	7.476	0.0035
28/29	0.75	UCTP	25400	7.06	6.930	0.0102	7.490	0.0041

SAAO 0.75-m telescope at the same site, using the same integration time and no filter, but typically with a much longer total 'run' time. Both instruments were equipped with blue-sensitive, S11 photomultipliers, so the effective wavelength is similar to that of Johnson *B*, but the bandpass is much broader. A log of all the data acquired at the time of writing is given in Table 1.

EC 14026 – 2647 is fairly faint, the amplitude of the variation is quite small, the telescopes available to us are modest in size and we have used photomultiplier photometers, so the variation is often quite difficult to see and might be considered unconvincing in simple plots against time. What *is* convincing is the comparison of the periodograms from each run. A sample of these is shown in Fig. 3, where the 144-s variation is clearly evident in each night (results from the excluded nights are similar: the full data are not shown only so that a reasonable vertical scale can be used in a single figure). In the lower three runs, which were all ~7 h in duration, it is easy to see a second peak at about 7.5 mHz (~133 s) which may be present in the other runs. It is also possible to see power near 8.3 mHz which is the 120-s worm error in the drive of the 0.75-m telescope. We have searched for higher frequencies in all our data sets, in the range 12–50 mHz, but have found nothing significant. Examination of the four longest runs (see, for example, the bottom three amplitude spectra in Fig. 3) shows no peak above 0.0025 mag, the average noise level being about 0.0008 mag. These periodograms also show very little power in the range 0–12 mHz above about 0.0015 mag (apart from the frequencies already noted above and the low-frequency variations attributed to sky changes). The few peaks around this semi-amplitude do not repeat from night to night.

It is worth noting that the frequencies seen in Fig. 3 are *not* instrumental; the drive errors for the various telescopes are well known from years of observation of small-amplitude variables (120 s for the 0.75-m telescope and 80 s for the 1.0-m telescope). Moreover, the same oscillation frequencies appear in light curves of EC 14026 – 2647 obtained with different photometer/telescope combinations, and we have also acquired high-speed photometric observations using a CCD photometer (but not of EC 14026 – 2647), which give the same results as photomultiplier data. Finally, we have observed a large number of stars that show no variation at all above the millimag level on the same nights that we detect the variations of the type shown in Figs 2 and 3 (material in preparation).

Taking the last four nights (by far the longest runs) we obtain $f_1 = 6.930$ mHz and $f_2 = 7.485$ mHz, or periods of 144.3 and 133.6 s respectively. The 133.6-s period is very clear in the data of the last four nights (1995 May) but is less so in the three runs from 1995 March where the semi-amplitude is comparable with the noise level. In the 1994 data, both runs of which were quite short (~2 h), the secondary period is not at all clear, but the noise levels are much higher. The data on individual nights in Table 1 show that, to within the errors, the amplitude of the f_1 term is

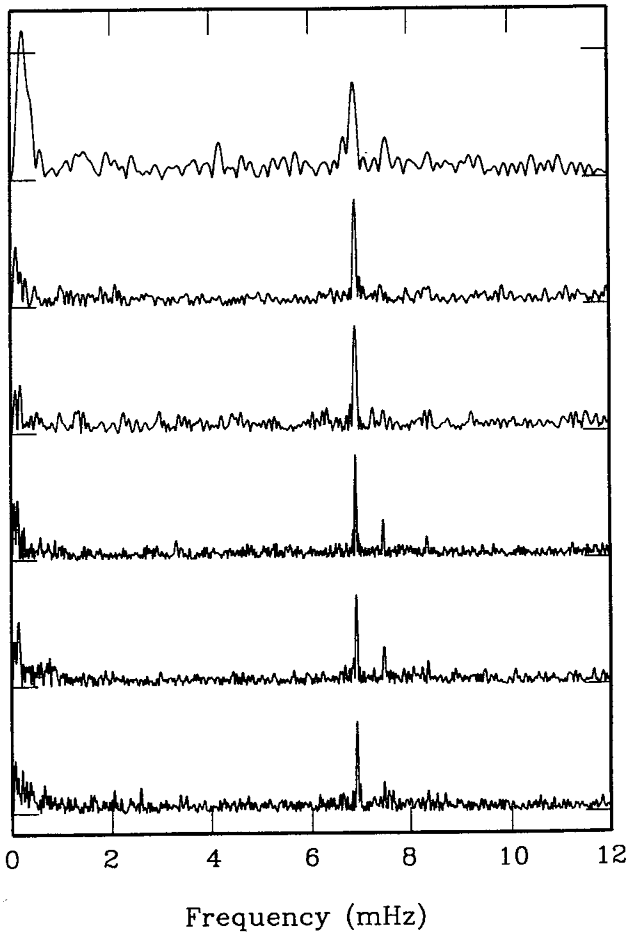

Figure 3. Amplitude spectra for EC 14026 – 2647 for (top to bottom) 1994 May 16/17 (data in Fig. 2), 1995 March 2/3 and 3/4, May 23/24, 24/25 and 25/26. Ordinate carets are separated by 0.015 mag. Note the secondary frequency near 7.5 mHz and the worm error frequency near 8.33 mHz. Conspicuous features at very low frequency are due to sky transparency variations.

constant. On the other hand, the f_2 term shows some evidence of a variable amplitude. There is no indication of signal at $2f_1$, so that the variation must be close to sinusoidal. There is also no evidence for significant signal at f_1+f_2 (which would be a good indicator for pulsation) and f_2-f_1, if present, would be at ~ 0.55 mHz and probably lost in the low-frequency sky variations. [The referee has pointed out that the amplitude of variation in this star is similar to that of the known pulsating DOV star, PG 1159 – 035 (Winget et al. 1991), which does not show the sum and difference frequencies at detectable levels. The absence of f_1+f_2 and f_2-f_1 could therefore simply be a result of the very small amplitudes involved.]

Fig. 4 shows the data analysed by week with the frequency scale expanded. The first two 'weeks' from 1994 consist of only single relatively short runs (the top periodogram in Figs 3 and 4 is the discovery run), but the third and fourth weeks from 1995 consist of three $\sim$3–4 h runs and four $\sim$7-h runs respectively. Fig. 4 also suggests that the period near 134 s is variable in amplitude, since there is only a very weak peak at the right frequency in the 1995 March data, whereas it is very clear in the 1995 May data. A frequency spectrum for all the data is very similar in appearance to the spectrum for 1995 May (which data, of course, heavily weight the total).

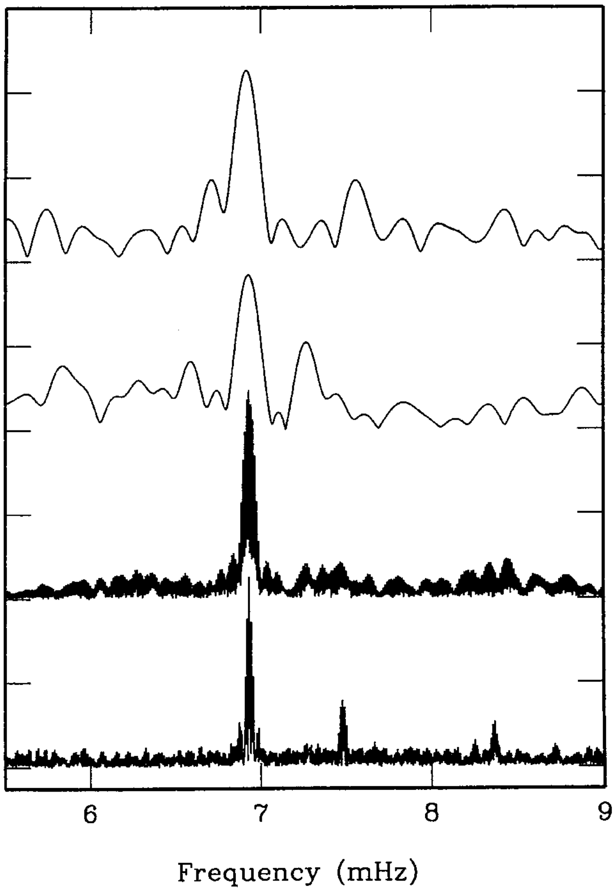

Figure 4. Amplitude spectra for EC 14026 – 2647 for (top to bottom) 1994 May (one night), 1994 July (one night), 1995 March (three nights) and 1995 May (four nights). Ordinate carets are separated by 0.005 mag.

4 EC14026...OR WHAT YOU WILL

Observationally, we are now enthusiastically obtaining high-speed photometry for all the sdB+ stars in the EC survey as well as other known sdB+ stars (i.e. sdB stars with the Ca II K line and/or *G* band). We are also doing the same for the apparently single, relatively bright sdB stars accessible to us. The first results of this survey will be discussed elsewhere, but it appears that the phenomenon announced in this paper is confined to those objects showing evidence (the K line and/or *G* band) of a companion.

In this fashion, we have so far detected very similar variability in four other EC sdB+ stars and four non-survey sdB+ or sdB stars (and found many objects to be non-variable). It is therefore not too presumptuous to refer to these stars as a new class of object, nor to suggest a designation. We cannot simply refer to them as sdB+ stars since our results so far indicate that only a small minority, probably less than 5 per cent, actually show variations above our detection level – say ~ 0.002 mag. By analogy with the PG 1159 stars, we refer to the new variables as EC 14026 stars (although the PG 1159 designation refers to spectroscopic appearance – not all PG 1159 stars are known to vary). The referee has suggested that, by analogy with the white dwarf pulsators, sdBV might be a better term, but would be inappropriate if the cool companion is in any way involved in the variations. Undoubtedly, usage will determine the final outcome.

5 FOR WHOM THE BELL TOLLS

A number of lines of evidence strongly suggest that the cause of the oscillation is stellar pulsation.

(i) As the oscillations in EC 14026 – 2647 (as well as the other stars) are quite stable clocks, the most obvious mechanisms are pulsation, rotational modulation or orbital motion. In two of the other oscillators, at least three periods have been seen, eliminating simple stellar rotation – as seen in the Ap stars, for example.

(ii) Orbital motion can be eliminated, as the periods are far too short to accommodate the kind of stars suggested by the spectra (e.g. a G dwarf fills its Roche lobe only if the orbital period is longer than ~ 0.5 d).

(iii) Multiple periods are seen in the intermediate polar subclass of cataclysmic variables due to a combination of orbital motion and the rotation of one stellar component (see reviews by Warner 1995 and Patterson 1994). Such an explanation cannot be applied to the EC 14026 stars with three periods because equal frequency spacing is expected, and is observed in the intermediate polars but not in the EC 14026 stars. Furthermore, there is no clear evidence of mass transfer, accretion discs or any other signature of such a configuration.

(iv) Very recent photoelectric measurements in the *V* and *U* bands of another oscillator (Koen et al. 1997) show that the variations are more obvious at *U* than at *V*, which is a strong indicator that the variation originates in the hot sdB star rather than in the cooler companion (although we have not, as yet, carried out the same test for EC 14026 – 2647).

(v) Finally, stellar pulsation is consistent with the evidence: the period–mean density relation for stellar pulsation (Cox 1980) predicts that for an sdB star of 0.5 $M_\odot$ and $\log g = 5.8$ (Saffer et al. 1994), the period of the fundamental radial mode is

$$P \sim 2860(\bar{\rho}_\odot/\bar{\rho})^{1/2}\ \mathrm{s} = 227\ \mathrm{s},$$

agreeing with the periods seen in the EC 14026 stars to within a factor of 2. Better agreement can be achieved if the observed pulsations are higher overtone, or the gravity of the pulsator is larger than 5.8. Higher dispersion spectrograms (30 Å mm^{-1}) are being used to try to separate the two components of the binary so that the temperature and gravity of the sdB star can be used to constrain pulsation models (O'Donoghue et al. 1997).

We conclude that stellar pulsation is consistent with the observations and can devise no other plausible alternative scheme.

6 ALL'S WELL THAT ENDS WELL

By a series of small errors and a fair amount of careful observing and systematic frequency analysis, we have discovered and confirmed very rapid, small-amplitude variations in EC 14026 − 2647, an sdB+ star from the Edinburgh–Cape (EC) Blue Object Survey. The variations, which are probably pulsational and almost certain to originate in the sdB component, are sinusoidal and have an apparently stable main period of 144 s (semi-amplitude ~0.012 mag) with a secondary period of 134 s (~0.004 mag) which may vary in amplitude.

It is interesting to note that the discovery of the EC 14026 stars as a class has depended critically on the power of periodogram analysis to reveal coherent frequencies hidden in the noise. This is in marked contrast to the discovery of pulsating white dwarfs (ZZ Ceti stars) as a class, where the variations are usually obvious in the light curve (see comments by Robinson & McGraw 1976) and where the power spectrum confirms the variation and separates the frequencies. White dwarfs can have light variations in excess of 0.2 mag (e.g. McGraw & Robinson 1975) whereas the EC 14026 stars discovered so far typically have semi-amplitudes of less than 0.01 mag [in at least one relatively bright star (Koen et al. 1996) the variation is clearly visible in the 'on-line' light curve, although the semi-amplitude of the main frequency is still ~0.01 mag].

The importance of these stars lies in the possibility of using the pulsations as probes of their interiors: this is being successfully exploited for the white dwarf stars. As white dwarf periods are quite short (100–1200 s) and many cycles can be observed in a short space of time, it is hoped that pulsations can be used to measure the evolutionary timescale of the white dwarfs; a similar hope can be entertained for the EC 14026 stars. An important step in the study of these stars would be to look for multiplet fine structure in the frequencies; we plan multisite campaigns to do this. It might also be possible to determine at least the binary periods of the systems if phase shifts in the variations due to light travel time were detectable; efforts are being made to do this for some of the systems.

Despite a programme of careful observation, serendipity appears to have a major role to play in research and we are forcibly reminded that if we only look for what we expect to find, we might well miss exciting new discoveries.

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