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Surface compositional changes observed during last stages of stellar evolution

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1. Introduction

The time scales of stellar evolutionary phases are generally quite large. Only in the case of massive stars the evolution takes place in shorter time span. A massive star exploding as a supernova would show spectacular changes in the brightness and spectrum over short time scale, like days.

Another case, when the evolutionary changes are expected to occur on a relatively short time scale so that it may be possible to observe them over a reasonable length of time, is during post-AGB evolution. At AGB stage, the star has an electron degenerate C-O core and He and H burning in the outer shells alternately. The star loses considerable amount of mass possibly caused by pulsation coupled dust-driven winds. When the mass of envelope drops below a critical value the envelope is ejected. To keep up the energy output, the inner part contracts and heats up. The increased temperature will cause the star to move towards left in the H-R diagram. When the temperature is high enough to ionise the surrounding gas it will be seen as Planetary Nebula (PN). The stellar remnant continues to lose mass via a stellar wind now driven by radiation pressure on the ionised hydrogen and metals. Eventually, when the envelope mass decrease below a critical value the hydrogen burning drops abruptly and the remnant cools as white dwarf.

2. Final helium shell flash objects

Instead of continuing its path towards cooling track, a fast final helium flash in the central star of a planetary nebula (CSPN) might cause this compact object to enlarge and reach giant or supergiant dimensions. Theoretical calculations of the final helium flash models are made by Iben et al. (1983), Renzini (1990) and Iben and MacDonald (1995) though this stage was predicted earlier by Fujimoto (1977). Some 10% of post-AGB stars are predicted to undergo helium shell flash. In this model as the helium-rich and helium-carbon layers are heated to sufficiently high temperature, a final helium shell flash is initiated. The convective shell that is now created because of the high fluxes generated by helium burning grows until its outer edge reaches the hydrogen-helium discontinuity and it also extends further into the hydrogen

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- rich envelope. It will be able to ingest the residual hydrogen left at the surface of the post-AGB star. The captured H is brought deeper to high temperature and the energy generated by the rapid burning of hydrogen causes the desired expansion to red giant dimensions. The hydrogen will be burnt via reaction $^{12}C(p,n)^{13}$ C which subsequently β decays to ^{13}C causing a small $^{12}C/^{13}C$ ratio. In the course of the flash about 20% of the carbon initially in the second convective zone is converted into nitrogen. The chemical composition profile of the model shows that following the formation of these two convective regions the model star has become hydrogen-deficient, carbon-rich and nitrogen-rich ($X_H \approx 0.03$, $X_{HE} \approx 0.76$, $X_C \approx 0.15$, $X_N \approx 0.05$ and $X_O \approx 0.01$). This abundance pattern is most commonly found in R CrB and other H-deficient stars. Renzini (1990) argued that final flash scenario can also explain the enhanced Li and overabundance of s-process elements. Renzini suggested that along with hydrogen some ^{3}He will also be ingested in the convective shell as this isotope is present in the outer envelope. The reaction $^3He(\alpha,\gamma)^7$ Be $(e^+,\upsilon)^7$ Li known as Cameran-Fowler process will cause the production of Li. It is shown by Caloi (1990) that the ingestion of H into helium burning convective shell causes the shell itself to split into two separate convective shells. At the base of upper shell H burns rapidly whereas He continues to burn at the base of lower convective shell. Once the H burning in upper shell is complete the ^{13}C and ^{14}N produced will move to hotter still He burning base of the lower shell. As a temperature of $\approx 1.5 \times 10^8$ K is reached, reaction $^{13}C(\alpha,n)^{16}$ O becomes active releasing neutrons while He is still burning at the base of lower shell. Since the temperature at which ^{13}C burning is taking place is much lower for α-capture reaction on ^{14}N to take place. Hence the ^{13}C burning leaves ^{14}N unaffected. A fraction of neutron produced by ^{13}C burning might be captured by ^{14}N causing the production of ^{15}N. The rest will produce s-process elements.

The observational evidence of this evolutionary stage (born-again star) have been rather scanty. Only known final helium shell flash objects are FG Sge discovered in 1894, V 605 Aql in 1919 and now Sakurai's object (V 4334 Sgr) discovered in Feb 1996. The PNs in our galaxy A30, A78, WC 11 objects and PG 1159 objects are also known to be hydrogen deficient and are considered older examples of Final Flash objects.

3. FG Sge

Herbig and Boyarchuck (1968) first suggested this star to be a central star of an old planetary nebula. The brightness of this star, over the years has been increasing slowly and the spectral type becoming later. From 1992 several instances of the star going into deep decline are reported. Gonzalez et al. (1998) did spectroscopic monitoring of this object between 1992-1996 and that enabled them to study the star when it underwent deep light declines in May 1994 and 1996 June. Before the light minimum the spectrum contains large number of absorption lines of moderate strength. During the deep decline C_2 band strength increases and it is also seen in emission at times. Na D lines also show emission components and a strong, violet-shifted absorption component appears possibly from the material leaving the star. Enhanced IR flux during the light minimum indicates the formation of a newly formed dust shell. The light fading due to the formation of a dust shell is typical of RCrB behaviour. The star displayed near solar chemical composition till 1960, then the enhancement of rare-earth elements was found after a decade, the abundance derived by Kipper and Kipper (1993) and later by Gonzalez et al. (1998) also shows the abundance of rare-earth elements have kept increasing. In addition, the abundance of C also has increased considerably. The H_α profile of this star appears to be much weaker with narrower wings suggesting the star is becoming a H-deficient star. The light variations of this object, spectral variations during light minima and abundance pattern strongly support the view that it is now a R CrB star.

4. Sakurai's object

This object was discovered by Y. Sakurai on Feb 20, 1996 though the process of brightening had begun nearly an year ago. The multicolour light monitoring by Duerbeck et al. (1997) showed light curve to contain several low-amplitude quasiperiodic variations with time scales of 50-70 days. The overall light curve indicates a slowly expanding photosphere surrounding an object of only slightly increasing luminosity. A surrounding planetary nebula has been identified that further supports the final-flash view. This star was monitored using high resolution spectra for several months by Asplund et al. (1997). For the two epochs separated by 5 months the derived abundances showed very interesting changes. The abundance of H declined but Li and light s-process elements have increased in abundance by a factor of 4. Also the elements Sc, Ti, Cr and Zn appear enhanced. We are witnessing quite a rapid chemical evolution!! The spectrum taken in October 1996 also showed $^{13}C^{12}C$ component in C_2 (1-0) Swan band. The production of ^{13}C is expected in final flash scenario. The chemical composition of Sakurai's object shows the evidence of severe contamination by the material exposed to hydrogen and helium burning and the related nuclear reactions.

Another important fact is that the chemical composition of Sakurai's object with few exceptions resembles that of a R CrB star V854 Cen. V854 Cen belongs to a smaller subgroup of R CrB star showing relatively smaller hydrogen deficiency. It appears that both these objects have the same evolutionary background and V854 Cen is also final flash object. The detection of nebular emission lines of [OI], [NII], S[II] during the light decline for V854 Cen further strengthens the view that it is a final shell object.

5. V605 Aql

It was discovered in 1919 and thought to be a slow nova when it brightened from m_{pg} of about 15 to m_{pg} = 10.2 in August 1919. Lundmark (1921) reported that the spectrum of this object closely resembled that of HD 182040 which is a well-known HdC star. Hydrogen deficiency of V 605 Aql is obvious from the weakness of G-band and the spectrum contains strong C_2, CN bands normally seen in R CrB stars. Between 1919-1923, it went through three events of light fading and recovering as reported by Seitter (1985) and Harrison (1996). After 1923 it was too faint for the observations. It was reported by van den Bergh (1971), Biedelman (1971) and Ford (1971) that its position coincided with the centre of PN Abell 58. The inner part of nebula has developed a small knot at its centre. Pollaco et al. (1992) did spectroscopy of the central knot and found it to be H-poor and has a much larger expansion velocity of 100km s^{-1} whereas the parent nebula shows smaller expansion velocity of 31km s^{-1}. Guerrero and Manchado (1996) derived the physical properties and abundances of inner knot and outer nebula and found normal PN composition for outer nebula and confirmed H-deficiency for the inner knot. The spectrum of inner knot exhibits CIV feature at 5800 Å. Clayton and Marco (1997) confirm the presence of CIV feature from their HST spectrum. They also indentify the lines of He II, [NeII], [OII] etc. They suggest that presently V605 Aql is a Wolf-Royet star with $T_{eff} \geq 50{,}000$ K. It appears that for a short time before 80 years the spectrum of V605 Aql was very similar to R CrB spectra.

6. Conclusions

The existence of these three objects supports final flash scenario to explain R CrB phenomenon. The FF model of Iben & MacDonald predicts relatively short lifetime as R CrB star, hence it is difficult to account for the large number of R CrB observed. However, if the FF occurs when the star is further down the cooling track, as suggested by Iben et al. (1996) and Renzini (1990) then the star can remain as R CrB star for longer time. Detection of these objects also points to the possible evolutionary connection between PNs and R CrB stars. More comprehensive models of final flash evolution are needed to explain observed abundance anomalies and the abundance changes with time. Spatially resolved spectroscopy of PN and other objects with large circumstellar shells may lead to the discovery of interesting objects undergoing rapid evolutionary changes.

References

Asplund M., Gustafsson B., Lambert D. L., Kameswara Rao N., 1997, A&A, 321, L17.

Caloi V., 1990, A&A, 232, 67.

Clayton G. C., Marco O. D., 1997, 114, 2679.

Duerbeck H. W., Benetti S., Gautschy A., Van Genderen A. M., Kemper C., Liller W., Thomas T., 1997, AJ, 114, 1657.

Fujimoto M. Y., 1997, Publ. Astr. Soc. Japan, 29, 331.

Ford H. C., 1971, ApJ, bf 170, 547.

Gonzalez G., Lambert D. L., Wallerstein G., Kameswara Rao N., Smith V. V., McCarthy J. K., 1998, ApJS, 114, 133.

Harrison T. E., 1996, PASP, 108, 112.

Herbig G. H., Boyarchuck A. A., 1968, ApJ, 153, 397.

Iben I. Jr., Kaler J. B., Truran J. W., Renzini A., 1983, ApJ, 264, 605.

Iben Icko Jr., MacDonald H., 1995 in white dwarfs, Koester D., Werner K. (eds), Springer, Berlin, 48.

Iben K. Jr., Tutkov A. V., Yungelson L R., 1986, ApJ, 456, 750.

Kipper T., Kipper M. 1993, A&A, 276, 389.

Lundmark K., 1921, PASP, 33, 314.

Pollaco D. L., Lawson W. A., Clegg R. E. S., Hill P. W., 1992, MNRAS, 257, 33.

Renzini A., 1990, In Confrontation between stellar pulsation and evolution, Cacciari C., Clementini G. (eds), ASP conf. series vol. 11, 549.

Seitter W. C., 1985, Mit A. G., 63, 181.

Van den Bergh S., 1971, PASP, 83, 819.