

FINAL REPORT
SUMMARY OF RESEARCH ACTIVITIES
SUPPORTED IN FULL OR IN PART BY
NASA GRANT NAG 5-2898
(Gamma Rays from Classical Novae)
AT THE UNIVERSITY OF CHICAGO, 1995-96

NASA grant NAG 5-2898, at the University of Chicago, provided support for a program of theoretical research into the nature of the thermonuclear outbursts of the classical novae and their implications for gamma ray astronomy. In particular, problems which have been addressed include the role of convection in the earliest stages of nova runaway, the influence of opacity on the characteristics of novae, and the nucleosynthesis expected to accompany nova outbursts on massive oxygen-neon-magnesium (ONeMg) white dwarfs. In the following report, I will identify several critical projects on which considerable progress has been achieved and provide brief summaries of the results obtained.

1. Two-dimensional simulations of nova runaways

A critical and yet unresolved aspect of the nova problem is that concerning the early evolution of the convective nuclear burning region in response to thermonuclear ignition and runaway. The detailed behavior during this phase substantially determines a number of critical observable features of novae that can be utilized to guide, to constrain, and/or to confirm our model simulations. The relevant, impacted behaviors with observational consequences include: (1) the early evolution of the light curves of fast novae (the "super-Eddington" phase (Truran 1982); (2) the mixing of white dwarf core material into the envelope (which mixing determines both the overall composition of the ejecta and the violence of the runaway); and (3) nucleosynthesis in novae (which includes questions concerning the elemental composition of the ejecta, the possibility of observing nuclear decay gamma rays from novae, and the contributions of novae to isotopic anomalies observed in 'stardust.' Notwithstanding the fact that the close binary nature of nova systems and the implied asymmetry of the accretion flows make clear that this is intrinsically a multi-dimensional problem, virtually all hydrodynamic studies of the nova problem to date have been carried out in one dimension. Recently, two independent studies of the early evolution of the runaway (Glasner, Livne, & Truran 1997; Kercek, Hillebrandt, & Truran 1997) have been undertaken, which provide interesting clues to the nature of the nova event and important implications for observations of novae in outburst.

2. Nucleosynthesis tests of nova modeling

The nova outburst is a consequence of the accretion of hydrogen rich material onto a white dwarf (WD) in a close binary system. The strong degeneracy of the massive WD prevents the expansion of the gas and drives the temperatures in the nuclear burning region to values exceeding 10^8K under all circumstances. As a result, a major fraction of the CNO nuclei in the envelope are transformed into β -decay nuclei. The energy released from the decay of these nuclei assists in the ejection of more than $10^{-5}M_{\odot}$ of gas at high velocities. Studies of this phenomenon have shown that the TNR produces large concentrations of the short lived positron unstable isotopes of the CNO nuclei: ^{13}N ($\tau_{1/2} = 9.97\text{ m}$), ^{14}O ($\tau_{1/2} = 7\text{ s}$), ^{15}O ($\tau_{1/2} = 122\text{ s}$), ^{17}F ($\tau_{1/2} = 64.5\text{ s}$), and ^{18}F ($\tau_{1/2} = 109.8\text{ m}$) which are transported to the surface by convection where we expect significant numbers of radioactive decays to occur. The resulting γ -ray emission may be detectable from nearby novae early in their outbursts. The TNR also is expected to produce substantial amounts of ^7Be ($\tau_{1/2} = 53\text{ d}$) and ^{22}Na ($\tau_{1/2} = 2.6\text{ y}$) which are ejected into space by the explosion. Their decays also

yield potentially detectable levels of γ -ray emission for relatively nearby novae. Nevertheless, no detections of these γ -ray sources have occurred for any of the novae discovered in outburst during the lifetime of Compton GRO. Since we are also interested in the role played by novae in the production of the $\sim 3M_{\odot}$ of ^{26}Al ($\tau_{1/2} = 7.4 \times 10^5$ y) found in the galaxy, we have performed new calculations of TNR's on white dwarfs with an updated nuclear reaction network and opacities. Our results show that a smaller amount of ^{26}Al is produced and the abundances of ^{31}P and ^{32}S increase by factors of more than two. A major fraction of novae in outburst are observed to form dust in the ejected matter. We review the infrared (IR) observations which reveal the onset and evolution of this dust formation phase. We discuss the characteristics of nova dust and show that it may be the most interesting dust produced by any astrophysical object. IR observations show, in addition, that novae appear capable of condensing dust of virtually every known chemical and mineral composition. We argue that the class of ONeMg Novae may form dust grains that carry the Ne-E and ^{26}Mg anomalies. We also report on the results of new calculations of thermonuclear runaways on both carbon-oxygen and oxygen-neon-magnesium white dwarfs using our one-dimensional, fully implicit, hydrodynamic stellar evolution code that includes a large nuclear reaction network. We have updated both the nuclear reaction network and the nuclear reaction rates. Our results show that the changes in the reaction rates and opacities produce quantitative changes with respect to our earlier studies. The causes are (1) that the new opacities are larger than those we previously used, which results in less mass being accreted onto the white dwarf, and (2) that the proton-capture reaction rates for some of the intermediate mass nuclei near ^{26}Al have increased so that the evolution to higher mass nuclei is enhanced.

3. A quasi-analytic study of nucleosynthesis in ONeMg novae

Wanajo, Nomoto, Hashimoto, & Truran (1997) have undertaken a detailed investigation into the nucleosynthesis consequences of nova explosions occurring on ONeMg white dwarfs. A quasi-analytic study on ONeMg novae is performed to examine nucleosynthesis over wide ranges of white dwarf and envelope masses. The comparison of our results with recent observations enables us to constrain those two parameters. About half of all observed ONeMg novae may have attained considerably higher envelope masses such as $\sim 10^{-4} M_{\odot}$, then obtained high burning temperatures $\sim 3\text{--}4 \times 10^8$ K. Such novae may have produced significant amount of ^{22}Na . Recent observations show that ~ 25 % of well-studied novae are classified to *ONeMg novae*, occurrences of outbursts with underlying ONeMg white dwarfs. Such nova events are characterized by highly enhanced neon and $\text{CNO/Ne-Fe} \sim 1$, which comes from the outward mixing (dredge-up) of ONeMg-rich core material. Novae occurring on massive ONeMg white dwarfs may be expected to achieve considerably high temperatures during outburst, leading under some circumstances to the production of nuclei as massive as sulfur. This behavior is strongly suggested, as well, by observations of the compositions of nova ejecta. Our studies in progress will enable us to distinguish readily an ONeMg from a CO white dwarf, and to estimate as well the mass of the underlying dwarf. ONeMg novae may be important targets for the γ -ray detection of ^{22}Na by *CGRO* and *INTEGRAL*, as well as the sites of origin of anomalies such as *Ne-E*, in certain primitive meteorites. The production of ^{22}Na is found, however, to be highly dependent on the burning temperature, the operation of convection in the envelope, and the white dwarf and envelope masses.

BIBLIOGRAPHY

PUBLICATIONS RESULTING FROM NASA AWARD

PUBLICATIONS OF THE PRINCIPAL INVESTIGATOR SUPPORTED IN FULL OR IN PART BY NASA Grant NAG 5-2898 (Gamma Rays from Classical Novae) AT THE UNIVERSITY OF CHICAGO, 1995-96

1. Shrader, C.R., Starrfield, S.G., Truran, J.W., Leising, M.D., & Shore, S.N., "CGRO Observations of Nova Herculis 1991 and Nova Cygni 1992," Bulletin American Astronomical Society, January, 1995.
2. Truran, J.W. & Glasner, S.A., "On the Nature of the Soft x-Ray Emission from Nova GQ Muscae 1983," in Cataclysmic Variables, Bianchini, A., Della Valle, M., & Orio, M. (Eds.), Kluwer Academic Publishers, Dordrecht, pp. 453-461, 1995.
3. Politano, M., Starrfield, S., Truran, J.W., Weiss, A., & Sparks, W.M., "Hydrodynamic Studies of Accretion onto Massive White Dwarfs: Dependence on White Dwarf Mass," Astrophysical Journal, Vol. 448, pp. 807-821, 1995.
4. Hayes, J. and Truran, J.W., "Powering of the Early Light Curves of the Classical Novae," 1996.
5. Starrfield, S., Hauschildt, P., Truran, J.W., Sparks, W.M., & Wiescher, M., "A New Generation of Evolutionary Sequences for Novae," Bulletin American Astronomical Society, January, 1996.
6. Starrfield, S., Truran, J.W., Wiescher, M., & Sparks, W.M., "Nucleosynthesis and the Nova Outburst," in Cosmic Abundances, Holt, S., & Sonneborn, G. (Eds.), PASP Press, San Francisco, pp. 242-252, 1996.
7. Yungelson, L., Livio, M., Truran, J.W., Tutukov, A. & Fedorova, A., "A Model for the Galactic Population of Binary Supersoft X-Ray Sources," Astrophysical Journal, Vol. 466, pp. 890-910, 1996.
8. Glasner, S.A., Livne, E., & Truran, J.W., "2D Simulations of Thermonuclear Runaways on Accreting White Dwarfs," in Cataclysmic Variables and Related Objects, Evans, A. & Wood, J.H. (Eds.), Kluwer Academic Publishers, Dordrecht, pp. 299-308, 1997.
9. Yungelson, L., Tutukov, A., Fedorova, A., Livio, M., & Truran, J.W., "A Model for the Galactic Population of Supersoft Sources," in Cataclysmic Variables and Related Objects, Evans, A. & Wood, J.H. (Eds.), Kluwer Academic Publishers, Dordrecht, pp. 309 -318, 1997.
10. Starrfield, S., Truran, J.W., Wiescher, M., & Sparks, W.M., "Nova Nucleosynthesis," in Nuclei in the Cosmos IV, in press, 1997.
11. Wanajo, S., Nomoto, K., Hashimoto, M., & Truran, J.W., "A Quasi-analytic Study of Nucleosynthesis in ONeMg Novae," in Nuclei in the Cosmos IV, in press, 1997.
12. Wanajo, S., Nomoto, K., Hashimoto, M., & Truran, J.W., "A Study of Nucleosynthesis in ONeMg Novae," Nuclear Physics A, submitted, 1997.
13. Glasner, S.A., Livne, E., & Truran, J.W., "Reactive Flow in Nova Outbursts," Astrophysical Journal, Vol. 475, pp. 754-762, 1997.

14. Gehrz, R., Truran, J.W., Williams, R.E., & Starrfield, S., "Novae: Contributions to the Interstellar Medium," PASP, in press, 1997.
15. Starrfield, S., Truran, J.W., Wiescher, M.C., & Sparks, W.M., "New Evolutionary Sequences for ONeMg Novae," Monthly Notices Royal Astronomical Society, in press, 1997.
16. Starrfield, S., Gehrz, R., & Truran, J.W., "Dust Formation and Nucleosynthesis in the Nova Outburst," in *Astrophysical Implications of the Laboratory Study of Presolar Materials*, AIP Conference Proceedings, Bernatowicz, T. & Zinner, E. (Eds.), New York, 1997.
17. Tuchman, Y. & Truran, J.W., "The Influence of Composition on the Core Mass-Luminosity Relation for Degenerate Cores and its Relevance to the Extinction Timescales of the Classical Novae," Astrophysical Journal, in press, 1997.
18. Kercek, A., Hillebrandt, W., & Truran, J.W., "2D Simulations of Thermonuclear Runaways on White Dwarfs," Preprint, 1997.
19. Glasner, S.A., Truran, J.W., & Yungelson, L., "Supersoft X-Ray Outbursts on White Dwarfs," Preprint, 1997.
20. Wanajoh, S., Nomoto, K., & Truran, J.W., "Constraining the Properties of ONeMg Novae," Preprint, 1997.