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Transient Classification and Novae Ejecta

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Abstract. A third parameter, in addition to luminosity and rate of brightness decline, derived from the spectra of transients is suggested as a means of more accurately classifying objects in outburst. Principal component analysis of the spectra of transients is suggested as the best way to determine the third parameter. A model is suggested for novae ejecta that is based on the ballistic ejection of an ensemble of clouds having a wide range of sizes. Short term brightness fluctuations of novae, the formation of dust, and the production of X-ray emission follow naturally from such a picture of the evolving clouds.

1. Introduction

Although the basics of the nova outburst have been understood for some time there is still uncertainty about some aspects of the phenomenon. Outbursts are the result of steady accretion but there may be other triggers. What causes some novae to vary 1-2 magnitudes in brightness over a few weeks time? What are the key parameters that determine how and when some novae develop copious dust? In recent years new luminous transients have been discovered that do not fit into either the normal nova or supernova paradigm, including some that are observed only in the infrared. It is important to determine what observations may be most useful in understanding the physical mechanism driving these outbursts.

2. Classifying Transients

The standard plot used to describe transients is one of luminosity vs. brightness decline time. The significance of this plot derives from Arp's (1956) classic study of the novae in M31, which he undertook immediately after completing his doctoral thesis at Caltech with the support of W. Baade, A. Sandage, and E. Hubble shortly before the latter's death. Observing 290 clear nights on Mt. Wilson over a 1.5 yr interval in a Herculean effort Arp found that rapidly declining novae were more luminous than slow decliners. The resulting Maximum Magnitude vs. Rate of Decline (MMRD) relation, calibrated independently from the Cepheid, RR Lyrae, H II region distances for M31, was useful to Sandage as a more refined primary extragalactic distance indicator compared to the less accurate average absolute magnitude of the few novae determined by Curtis (1917) in his famous debate with Shapley over the size of the Milky Way and distance to M31.

The MMRD relation has an intrinsic dispersion that has steadily increased over time with the larger sample of novae that have been observed within nearby galaxies since Arp's original survey. Until the past two decades a plot of visible luminosity vs. time of decline for transients was dominated primarily by novae and SNe that occupied a relatively small region of space in the plot. However, as seen in Figure 1 whose data come primarily from the Palomar Transient Factory survey (Rau et al. 2009; Kasliwal 2011), the MMRD relation is at best a 'tendency', with many variant outlier novae. And transients of all types now occupy virtually every part of the luminosity-decay time diagram, as can be seen in Figure 2.

Historically, the position of a transient on a plot of maximum magnitude vs. light decay time has been a standard way of expressing the nature or type of the transient. However, it is clear from Fig. 2 that there is so much overlap of different transient types in the diagram that little information on the nature of a transient results from its position in this diagram. Since many transients have a broad distribution of decay times following outburst the decline time is not a good defining characteristic of a transient. Rather, some other parameter would be much more useful in distinguishing between different transient phenomena.

A similar situation confronted stellar population studies after studies of galaxies showed that three parameters were important for defining the stellar population of a galaxy: age, metal abundance, and star formation history. This led to the concept of the 3-dimensional population box (Hodge 1989). The same situation appears to apply to transients, where the identification of a third parameter, in addition to the luminosity and decline time, would be useful in distinguishing between different classes of transients.

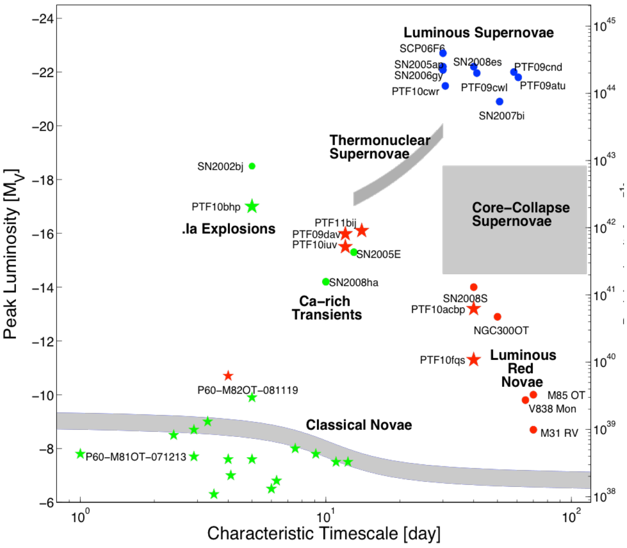

Figure 1. MMRD relationship with transients (from Kasliwal 2011)

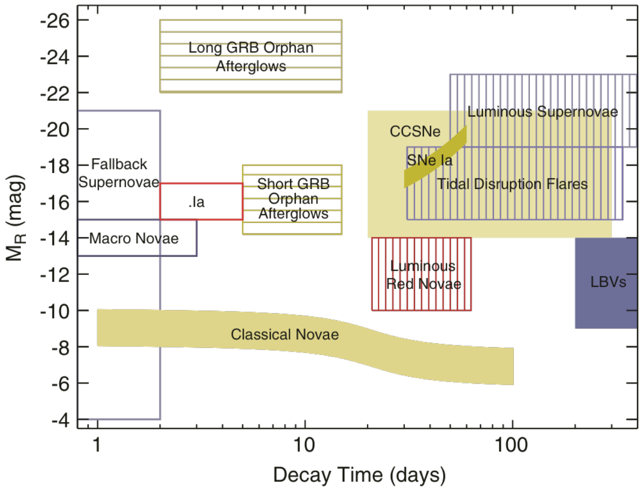

Figure 2. Luminosity vs. decay time plot for transients (from Rau et al. 2009)

Spectroscopy of transients offers easily obtained information that allows kindred objects to be identified and differentiated among the different types of objects. Thus, the spectroscopic characteristics of a transient are arguably the best way to determine what the object is and how it may be similar to or different from other transients. This same problem has been addressed by the quasar community, who have applied principal component analysis (PCA) to quasar spectra (Boroson & Green 1992; Francis & Wills 1999) to define those properties most useful in discriminating between different quasar properties and types.

Our understanding of transients would be greatly improved by subjecting the spectra of all such objects, i.e., novae, supernovae, stellar mergers, LBVs, [Ca II] transients, etc., to PCA. The breakdown of the main spectral features into principal components, or eigenvectors, could then be used to identify the largest PC (pc1, or 'eigenvector1' to use the nomenclature of the quasar community) that could be used as the third parameter to create a 3-dimensional 'transient cube', as shown in Figure 3. Pc1 might or might not correspond to some clear spectroscopic property such as the continuum slope or intensity of H-alpha or strength of narrow absorption lines, etc., however it almost certainly would better enable transients that are similar to be defined and differentiated from other types of transients. Classifying transients by plotting them on a diagram of luminosity vs. a principal component, such as pc1, would be much more instructive than the current practice of showing their position in a plot of luminosity vs. rate of brightness decline.

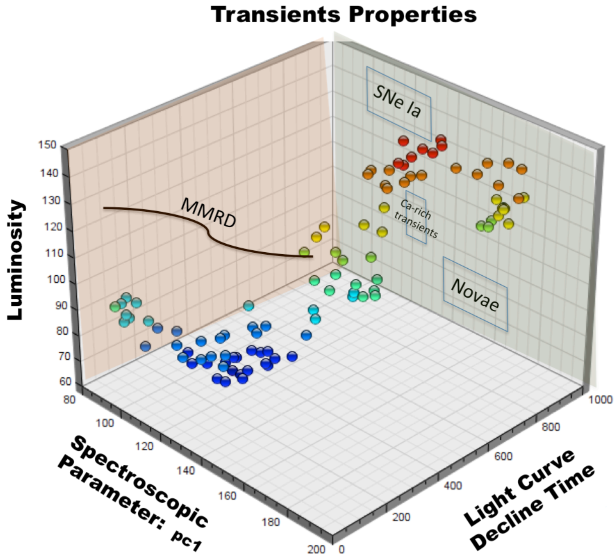

Figure 3. Consideration of a third parameter that characterizes the spectrum of a transient would provide important information that better allows identification of the class of the transient.

3. Novae Ejecta Geometry

Many novae, especially those having slower declines in brightness from maximum, show variation in visible brightness of several magnitudes over timescales of weeks. Multiple secondary maxima sometimes occur in addition to short-lived up-and-down fluctuations in brightness, i.e., jitter, that last a few days. These are no doubt due to changing conditions in the ejecta, but no systematic explanation for this behaviour has emerged.

Many novae form dust which produces an infrared continuum that is typically weaker than the optical continuum, although in the case of substantial dust formation can almost completely absorb the visible continuum, transferring most of the visible luminosity into the IR. High density regions in the ejecta that are protected to some extent from high UV radiation so that molecular species are plentiful are believed to define the locale of the dust formation.

Repeated observations of postoutburst novae by the *Swift* satellite have detected X-ray emission in most novae (Schwarz et al. 2011). Initially, the X-rays have hard 2-10 keV energies which progressively weaken until eventually soft X-rays emerge as the expanding ejecta reveal the hot post-TNR WD surface.

All three features relating to the brightness variations, dust formation, and the evolution of the X-ray emission may be explained by constraining various ejecta parameters which do evolve over time due to their expansion. However, there has not been a coherent explanation of all of these phenomena that relates them to each other and explains how they differ so much between different novae.

We propose here that fluctuations in brightness, the formation of dust, and observed X-ray emission from novae in postoutburst decline all follow naturally from ejecta that are formed from an ensemble of dense clouds of different sizes that are ballistically ejected by the TNR. The small clouds collide with each other, emitting hard X-rays as they rapidly dissipate to form a low density ambient medium. Less common large clouds have hot, dense cores surrounded by a photosphere that provides protection for the outer dense regions where dust can form. And when a large cloud emerges from the photosphere of the lower density ambient region of ejecta its radiation will produce a variation in brightness of the ensemble. The large variation in characteristics of different novae can then be understood in terms of a differing size distribution of the ejected clouds from object to object.

Ejecta consisting of a predominance of small clouds will lack the more dense, longer lived large clouds that should be more favorable for dust formation and production of brightness fluctuations, but they are more amenable to the production of hard X-rays. Those novae whose ejecta have a predominance of large clouds are likely to experience a slower light decline with more brightness fluctuations, produce more dust, and result in a more clumpy resolved shell. Since dust may also form in the larger, ambient medium produced by the merging of small clouds if it is sufficiently dense, ejecta having a predominance of small clouds do not preclude dust formation in such objects. An example of the geometrical model for novae ejecta proposed here is shown in Figure 4.

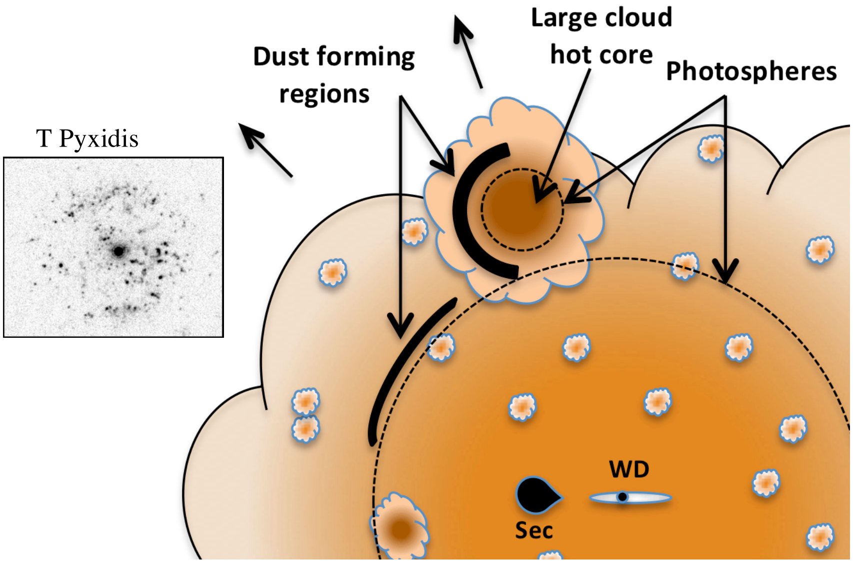

Figure 4. An expanding large cloud emerges from the ejecta and causes a brightness variation as it dissipates. Its dense, cooler layers form dust. X-rays are produced by collisions among the numerous small clouds. The inset shows an HST image of the resolved shell of the recurrent nova T Pyxidis (from Shara et al. 1997), whose ejecta may have been dominated by large clouds.

Acknowledgment

We pay tribute to our colleague Dr. Sun Kwok, who having done such a fine job of organizing this conference is now stepping back from his administrative responsibilities as HKU Dean for the past decade to return to full time research. Sun is a fine example of scientist who has succeeded in combining a career of significant research results with effective international leadership. At the same time he has authored a number of highly regarded books on a variety of subjects that have served to educate the professional community. A model worth emulating, we wish Sun continued success and longevity within our ranks.

References

Arp, H.C. 1956, *AJ*, **61**, 15
Boroson, T. & Green, R. 1992, *ApJS*, **80**, 109
Curtis, H.D. 1917, *PASP*, **29**, 206
Francis, P.J. & Wills, B.J. 1999, *ASPC*, **162**, 363
Hodge, P. 1989, *ARAA*, **27**, 139
Kasliwal, M. 2011, *BASI*, **39**, 375
Rau, A., Kulkarni, S.R., Law, N.M. et al. 2009, *PASP*, **121**, 1334
Schwarz, G.J., Ness, J.-U., Osborne J.P., et al. 2011, *ApJS*, **197**, 31
Shara, M.M, Zurek, D.R., Williams, R.E., et al. 1997, *AJ*, **114**, 258