BRIEF COMMUNICATIONS ARISING

The Great Eruption of η Carinae

ARISING FROM A. Rest *et al. Nature* **482,** 375–378 (2012).

During the years 1838–1858, the very massive star η Carinae became the prototype supernova impostor: it released nearly as much light as a supernova explosion and shed an impressive amount of mass, but survived as a star[1]. In the standard interpretation, mass was driven outward by excess radiation pressure, persisting for several years. From a light-echo spectrum of that event, Rest *et al.*[2] conclude that "other physical mechanisms" are required to explain it, because the gas outflow appears cooler than theoretical expectations. Here we note that (1) theory predicted a substantially lower temperature than they quoted, and (2) their inferred observational value is quite uncertain. Therefore, analyses so far do not reveal any significant contradiction between the observed spectrum and most previous discussions of the Great Eruption and its physics.

Rest *et al.* state that a temperature of 7,000 K was expected, and that 5,000 K is observed. These refer to outflow zones that produced most of the emergent radiation. For the 7,000 K value those authors cite a 1987 analysis by one of us[3], but they quote only a remark in the text, not the actual calculated values. According to figure 1 in ref. 3, η Carinae's Great Eruption should have had a characteristic radiation temperature in the range 5,400–6,500 K, not 7,000 K. (Here we assume mass loss exceeding one solar mass per year and luminosity exceeding 10^7 solar luminosities[1].) The mention of 7,000 K in ref. 3 concerned less extravagant outbursts, and η Carinae was explicitly stated to differ from them. Moreover, to establish a conflict between observations and expectations, new calculations with modernized opacities would be needed.

The approximately 5,000 K temperature 'observed' by Rest *et al.* is based on a derived classification for the light-echo spectrum, using automated cross-correlations with a set of normal supergiant stars. This technique may be suitable for mass-production normal spectra, but any non-routine object requires specific feature-by-feature comparisons instead. One of the first principles of stellar classification is to separate luminosity from temperature criteria, but all the reference stars in this case were far less luminous than η Carinae's eruption. (Luminosity correlates with surface gravity, which affects gas density and thereby the spectrum.) Furthermore, emission lines appear to be present and may contaminate an automated analysis; but without access to the spectrum we cannot verify this. Rest *et al.* used a temperature calibration from a 1984 reference[4] taken from an even older publication in 1977[5]. Considerable work has been done since then, and for the highest luminosities, each spectral type has a substantial range of possible temperatures—for example, 5,100–6,200 K for the G2–G5 spectral types favoured in their paper[6–8]. The temperature range indicated by stellar classification thus overlaps the theoretical expectations.

Moreover, η Carinae's eruption was a large-scale mass outflow, not a static atmosphere with definable surface gravity. This distinction quantitatively alters the relation between absorption lines and the underlying continuum. The characteristic radiation temperature T_0 in the 1987 theoretical description[3] is therefore defined differently from a normal star's 'effective temperature'. If spectral types are assigned to outflows, there is no reason to expect their temperatures to coincide with the stellar-atmosphere calibration adopted by Rest *et al.*[1]. This is not a question of stellar wind versus explosion; dense winds, stellar eruptions, and opaque explosions are basically alike in their emergent radiation physics[1,3], and their density dependences $\rho(r)$ differ in character from normal stellar atmospheres. In conclusion, as far as existing models allow anyone to say, the observed spectrum appears to be consistent with what one expects for a giant eruption with η Carinae's parameters.

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Rest *et al.* reply

REPLYING TO K. Davidson & R. M. Humphreys *Nature* **486,** http://dx.doi.org/10.1038/nature11166 (2012).

In our Letter[1] reporting the light echoes of η Carinae we analysed the spectral characteristics of η Carinae during the Great Eruption of the mid-1800s, and found the line content to be similar to that of G supergiant stars. This we interpret as evidence that η Carinae's Great Eruption was not a typical luminous blue variable (LBV) outburst, because spectra similar to those of F and A supergiant stars, earlier and hotter than G-type stars, are observed in LBV eruptions of all kinds, in agreement with theoretical predictions. Davidson & Humphreys[2] object that our spectral type and temperature estimate are not sufficiently robust, and that the spectral features are in agreement with their theoretical predictions.

The issues raised by Davidson and Humphreys[2] involve elementary considerations of stellar atmospheres and LBV spectra, as well as deeper ones of epistemology. We are well aware of these issues, but they are outside the scope of a *Nature* Letter. As they say, other things (such as chemical abundances) being equal, a spectrum is determined by the temperature and pressure. In stellar atmospheres, the latter is in turn determined by the gravity, or more fundamentally the mass and radius. In a LBV outburst, the physical situation is entirely different and at present unknown; in the accompanying News & Views[3] Soker and Kashi describe their favoured hypothesis of a role for episodic binary mass transfer in the Great Eruption, but they also say that an instability in the primary itself is an equally viable hypothesis. Basically, we do not know whether Great Eruptions are late evolutionary events in all hypermassive stars, or whether they occur only in binary systems. There is no definitive model for these events, whether primitive or modern, and hence any derived physical parameters are highly uncertain. The comparison with stellar spectral types provides only a description of the line content of the LBV spectrum. By the same token, the comment that the Great Eruption of η Carinae was more luminous than the comparison supergiant stars is irrelevant.

The absolute temperature derived for an LBV outburst spectrum, whether observationally or theoretically, is virtually meaningless, because there are no reliable models for the physical structure that produced it. However, the relative spectral types and temperatures at different stages of these events, or among different LBV stars at similar stages, may be more meaningful and indeed are traditionally used by all LBV specialists for descriptive purposes. For example, during LBV outbursts the spectral type becomes later and the apparent temperature lower towards the visual-light maximum. The G spectral type at the Great Eruption peak, which we derived from detailed comparison of several spectral features with those of the supergiants, both visually and by cross-correlation, is unusually late and unprecedented for an LBV outburst. It may be related to the huge amplitude of this event or additional physical mechanisms in η Carinae's Great Eruption. Our suggestion of an explosion and blast wave is motivated by the large ratio of kinetic to radiative energy in the event[4], and by the direct observation of velocities up to several thousand kilometres per second in some of the ejecta[5].

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