THE DIFFICULTY OF ULTRAVIOLET EMISSION FROM SUPERNOVAE

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I would like to point out the conceptual difficulties of generating the ultraviolet radiation that has been presumed for the creation of both the optical fluorescence mechanism of supernova light emission as well as the ionization of a nebula as large as the Gum Nebula.

The efficiency of the helium optical fluorescence mechanism is roughly 10^{-3} so that at least 10^{52} erg must be emitted in the ultraviolet to create the observed 10^{49} erg of optical emission. Similarly, we have recognized here today that at least 10^{52} erg are needed in ultraviolet emission to create the Gum Nebula.

There are several obvious requirements concerning the energy distribution of the ultraviolet photons:

1. The energy of the greater fraction of the photons must be sufficient to cause both helium fluorescence as well as hydrogen ionization. The former implies $51 \leq h\nu \leq 54$ eV and the latter implies $h\nu \geq 15$ eV.

2. In addition, if the photons are emitted in an approximate black-body spectrum, the fraction of the energy emitted in the optical must be no more than what is already observed in the optical. The bolometric correction therefore, must be 10^3 or greater in order that the optical emission associated with the ultraviolet radiation not be greater than observed. Since the integral energy of the low energy part of the spectrum is proportional to $(h\nu_{max})^3$, this implies that $kT \simeq 17$ eV in both cases.

The question of ultraviolet black-body emission depends primarily upon the energy source. The supernova explosion as described by the author elsewhere in this volume, converts explosion energy to kinetic energy of expansion in a highly efficient fashion. Consequently, we expect by far the major fraction of the energy released in the explosion to appear as kinetic energy of ejecta. Since the upper limit of the explosion energy is of the order of 10^{52} erg, essentially all the kinetic energy of expansion must be reconverted into heat and then emitted as black-body radiation or go directly into photons by atom-atom impact. The latter direct atom-atom or transparent emission depends in detail upon the available atomic states. The probability that the wide mixture of elements present in the interstellar medium as well as supernova ejecta should result in an emission spectrum localized to the limited region of the spectrum for either ionization or fluorescence ultraviolet with less than 10^{-3} emission in the visible is remote indeed. We therefore exclude transparent emission as being highly unlikely and emphasize black-body or at least quasi-black-body emission.

Presumably 1/2 to 1 $M_\odot$ is ejected with 10^{52} erg. The ejection velocity therefore becomes

$$1/2\, U^2 M_\odot = 10^{52} \text{ erg}$$

or

$$U = 3 \text{ to } 4 \times 10^9 \text{ cm sec}^{-1}.$$

In order that at least half of this kinetic energy be converted into heat by collision, the stationary mass must be $\geq$ moving mass. In order that the radiation associated with the heat can escape, the integral opacity must be less than several mean free paths; otherwise, the re-expansion of the hot gas will again reconvert the heat to kinetic energy of motion rather than emitted radiation. The ultraviolet opacity of such a mixture of heavy elements is at least 1 $\text{cm}^2\ \text{gm}^{-1}$ so that the stationary matter can be no thicker than 1 gm cm^{-2}.

The energy source is kinetic and this energy must be delivered to a shell 1 gm cm^{-2} thick, 1 $M_\odot$, and at a rate so that this layer will radiate as a black-body at $kT \simeq 17$ eV. This places a similar density limit on both moving and stationary matter.

The energy conversion rate depends slightly on details of the shocks propagating in both the moving and stationary gases and is limited to

$$(1/4)\, \rho U^3 \geq (c/3)\, a T^4.$$

Then $\rho \geq 1.5 \times 10^{-11}$ gm cm^{-3}. Since the shell mass thickness must be no greater than 1 gm cm^{-2}, the linear thickness must be $\partial < 10^{11}$ cm. On the other hand the mass of these shells $\simeq M_\odot$, requires that

$$4\Pi r^2 \rho\, \partial = M_\odot$$

or

$$r = 1.4 \times 10^{16} \text{ cm.}$$

Therefore the moving and stationary matter must be distributed in shells with a ratio of thickness to radius of less than 10^{-5}. This seems highly unlikely (1) in view of the velocity distribution of supernova ejecta and (2) in view of the present theories of quasi-static mass loss leading to planetary nebulae. Both observations and theory lead to a nearly uniform distribution. From both standpoints then, intense ultraviolet emission seems unlikely from supernova explosions.