FUORS

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The characteristic trait of FU Orion (fuors) is that they suddenly increase their luminosity in the spectral region observed by over a hundredfold within a short time span, after which they retain the enhanced luminosity for extended years. An explanation is offered for this phenomenon, based on the assumption that, prior to the rise in the light-curve in the region directly surrounding the star, there exist energy sources the bulk of whose output is in the form of energy of corpuscular radiation. An envelope encompassing those external sources forms, as indicated by observations, at the time of the rise in brightness. For that reason, almost all of the energy from those sources is emitted, following the rise in brightness, in the form of thermal radiation flux. A parallel is drawn between the differences in the emission of a prefuor and a postfuor, on one hand, and the differences between the emission of fast and slow flares (of flare stars), on the other hand. If this is a valid picture of the reality, slow flares resulting from liberation of energy beneath the photosphere must be radiated in photographic light at a rate 100 times as great as the equivalent (explosive) energy emitted released by fast flares.

It is generally acknowledged that an enormous number of papers, principally of a theoretical nature, have been devoted to problems of stellar evolution. The authors of those papers usually proceed from the existing theory of internal stellar structure as their point of departure. They view stellar evolution as a sequential transition from some equilibrium models to others. It is assumed that stellar evolution is due to the behavior of thermonuclear reactions and to a gradual expenditure of the nuclei becoming involved in those reactions.

We will therefore not try to criticize such a theoretical and somewhat schematic approach. We need only point out that, in our view, the approach has not been sufficiently fruitful. It would be better to turn the brunt of our attention to another way of studying stellar evolution based on analysis of observational data. As we are well aware, that alternate approach has made it possible in due time to secure significant information on the early stages of development of stars of different masses, on group star formation, etc.

The study of such phenomena that appear so infrequent, that get lost so easily among a welter of superficially similar facts, and that appear to be unsubstantial in a superficial examination, should not be neglected in an analysis of the observational data. Furthermore, their great infrequency may be responsible for an erroneous tendency to consider those objects in which the phenomena are observed to be exceptional objects, some sort of freaks of nature, and as such incapable of affecting general regularities in stellar evolution. Meanwhile, if some rapidly unfolding phenomenon occurs, say, only once during the lifetime of a star, that phenomenon will be observed extremely infrequently among the stars surrounding us, despite the fact that it may constitute a regular and even major stage in the evolution of all stars or, say, of stars having masses within a certain specified range.

Here we wish to draw attention to a group of phenomena which is observed with extreme rarity and which can apparently be brought, by dint of careful study, to shed some light on the problems of stellar evolution.

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1. FU Orionis Stars. At the close of the past year, we received from the Swedish astronomer Gunnar Wellin a preprint of his short report on a star Lk H_α 190 located in the North America nebula (NGC 7000) among a group of stars featuring bright lines (type T Tauri, etc.), with the magnitude $m_{pg} = 16.0$ indicated by Herbig in 1957, and varying its brightness only slowly over the ensuing years, with $m_{pg} = 10.0$ reported in 1970 [1]. Comparison of various negatives indicates that an abrupt increase in brightness occurred in late 1969. Since that time the brightness of the star varied slightly. According to photoelectric measurements taken by Grigoryan in mid-July 1970 (at Byurakan), its brightness $m_V = 10.8$. There is no doubt that we are dealing in this case with such an abrupt rise in brightness as witnessed in 1936 in the case of FU Ori. Prior to the increase in brightness, the magnitude of the star FU Ori was 16, but it became brighter than a 10th magnitude star in 1936 following the flare; later on, after attenuating slowly, it eventually arrived at the magnitude $m_{pg} = 10.5$; since then the brightness has hardly varied at all. Consequently, in both instances the star in question shifted from one state, in which its brightness fluctuated slightly about some low level to another state where it was approximately a hundredfold greater.

We deliberately refrain from using the term "flare" and refer instead to an abrupt rise in brightness, since we are concerned with the establishment of a new, approximately a hundredfold higher, level for a protracted period, measured in terms of centuries at the least. In order to avoid the use of the term "flare stars" in this context, we shall refer to these objects as fuors.

Note that P Cyg furnishes an example of such a phenomenon. The difference, from the standpoint of the state of our knowledge of these objects, is the following.

In the case of P Cyg, the only information we have available on the state of the star prior to the brightness rise is that it was not visible to the unaided eye. Its magnitude is now $m_{pg} = 4.8$.

In the case of FU Ori, we are also acquainted with the brightness prior to the rise in luminosity ($m = 16.0$). But only in the case of LkH_α 190 are we also acquainted with the spectrum prior to the rise in brightness: the spectrum corresponded to a T Tauri type late dwarf [2]. Unfortunately, owing to the small dispersion, Herbig was unable to give a determination of spectral type based on the absorption lines. There are also other objects, in which an appreciable enhancement of brightness was observed to occur within a short period of time, resulting in a more or less stationary state. That means that we cannot exclude the possibility of assigning these objects also to the group of fuor-stars, after analysis of the observations in question.

It is an essential point that both FU Ori, and especially Lk H_α 190, demonstrate, after the rise in brightness, spectral features typical of stars of relatively high luminosity. In particular, in the star Lk H_α 190 the observed H_α emission line has an absorption component on the shortwave side which is displaced 420 km/sec. In other words, that star now features a continuous outflow of matter similar to that established in the case of P Cyg. Such an outflow of matter must result in an extended shell around the star. In addition, the atmospheres of Lk H_α 190 and FU Ori are rich in lithium, which is typical of young stars. Finally, all three of the stars mentioned belong to stellar associations.

If we adhere to the usual concepts regarding stellar emission, the shift of the star from one level of more or less stationary luminosity to another level many times higher must be accounted for in terms of the total output of the energy sources present in the star. But it would be difficult to imagine that the internal structure of the star could vary to such an extent within a mere few months that the total output of the energy sources would increase more than a hundredfold. We therefore have to find some other explanation.

The gist of the explanation which we propose to account for the facts is that there exist high-intensity and constantly active energy sources in the space above the photosphere in some or all of the T Tauri type stars, somewhere in the region of the corona or even higher. A portion of this energy is released in the form of nonthermal continuous emission in blue, violet, and ultraviolet light. In some T Tauri type stars, this emission is so intense that it is observed directly in the form of an "ultraviolet excess" in the spectrum of the corresponding star (e.g., XX Ori, NS Ori, NX Monocerotis). The maximum of this nonthermal emission is found in the far ultraviolet, however, and is not observable from the surface of the earth. In many cases, the "tail" of that excess extending out from the near ultraviolet observable from the earth is so faint that it is not perceptible against the background of the star's thermal emission in the same wavelengths. Nevertheless, the existence of the excess in the far ultraviolet can be ascertained with reasonable confidence from the existence of the emission lines in the spectra of those stars. We need not dwell here on which portion of the energy released by the nonthermal sources is converted to electromagnetic radiation and which portion is released in the form of the kinetic energy of corpuscular matter ejected into the surrounding space. However, if we assume that the energy released is the result of primary processes of a nuclear decay type which are as yet unknown to us, then the conversion factor of that energy into photographic light observable from the earth's surface must be very small in those cases where the energy is released in the rarefied interstellar space. It is probably less than 0.01. All of the remaining energy in the supposed decay process must be released either in the form of the kinetic energy of the particles emitted in the process or drifting into cosmic space, or else in the form of short-wavelength electromagnetic radiation which is filtered out by our atmosphere.

On the other hand, should a shell which is opaque not only to shortwave radiation but also to high-energy particles form about the star for any reasons whatever (say, because of a process by which matter is ejected from the star), then all of the energy released by sources located within the shell will be released in the form of thermal radiation of the shell, and when shell temperatures are on the order of 10,000° the conversion factor for photographic light will be close to unity.

In other words, the formation of a shell must lead, under those conditions, to intensified conversion of the energy released by the presumed sources into photographic light, by a factor of more than a hundred.

Hence, we assume that we are not dealing here with an increase in the intensity of the sources of energy, but rather with an increase brought about by the appearance of the sheel in the factor of conversion to photographic light of the energy released by the presumed sources.

The ultraviolet excess observed in some T Tauri type stars has approximately the same energy distribution as the radiation emitted in flares of UV Cet type stars. Some investigators therefore advanced the suggestion that we are dealing essentially with one and the same physical process in those two cases, except that the process has a rigorously discrete character in the case of flare stars.

It is all the more intersting that, in the case of flare stars, we are actually dealing with the same differences in the conversion factor that we were constrained to admit in the case of fuors both prior to and after the process of the rise in brightness. The reasons behind those differences are discussed in the third section.

2. .The Concept of Calorimetric Stellar Magnitudes. It is generally known that the concept of visible and absolute bolometric magnitudes and bolometric corrections to the visual or photographic magnitudes have proved quite useful in discussions of stellar luminosity. In relation to bodies which emit into the surrounding space appreciable corpuscular radiation in terms of the amount of kinetic energy carried off, it would be desirable to introduce, in addition to the bolometric quantities characterizing the total intensity of the electromagnetic radiation, a system of stellar magnitudes characterizing all of the energy emitted in a unit time, including both the total energy associated with the electromagnetic radiation and the kinetic energy of all of the corpuscles emitted. It is convenient to term this system the calorimetric system of stellar magnitudes. A natural definition of such stellar magnitudes is provided by the formula

$$m_{\text{kal}} = m_{\text{bol}} - 2.5 \lg \frac{L_k + L}{L}, \tag{1}$$

where L is the luminosity at electromagnetic wavelengths, and L_k is the total kinetic energy carried off in unit time by the particles emitted. A corresponding definition of calorimetric corrections could be devised.

Let us now attempt a definition of the "calorimetric correction"

$$\delta' = m_{\text{kal}} - m'_{\text{pg}} \tag{2}$$

for a fuor prior to the rise in brightness. Subsequently, all of the stellar magnitudes referring to the stage preceding the rise in brightness will be designated by a single prime, while those referring to the stage following the rise in brightness and the quiescence of the star will be designated by double primes. In that case the gist of our hypothesis can be expressed in terms of the equation

$$m_{\text{kal}} = m''_{\text{bol}}. \tag{3}$$

Upon comparing Eqs. (3) and (2), we can state

$$\delta' = (m''_{\mathrm{bol}} - m''_{\mathrm{pg}}) + (m''_{\mathrm{pg}} - m'_{\mathrm{pg}}). \tag{4}$$

The first term in the right-hand member of Eq. (4) is the bolometric correction to the photographic magnitude (and not the bolometric correction to the visual magnitude, as the bolometric correction is customarily defined) after the flare. Since it is assumed that the fuor gives forth normal thermal radiation after the rise in brightness, this correction can be calculated on the basis of the effective temperature. For T = 10,000°, we have the value −0.4. That correction is probably right for both FU Ori and for Lk H_α 190. As for the second term in Eq. (4), it directly comprises the observed rise in brightness, which is 5 in both of these instances. Hence, we have

$$\delta' = -5.4.$$

But the resulting calorimetric correction for a fuor which has yet to undergo a rise in brightness (hence, a prefuor) does not have a simple physical meaning, since the electromagnetic radiation emitted by a prefuor consists of two parts: the thermal emission (t) of the star and the nonthermal emission (nt) emanating from the source(s) located above the photosphere. Evidently, the factor of conversion of the energy released by those sources to radiation in the photographic part of the spectrum is determined preponderantly by the second part. We therefore have to look for the calorimetric correction to the nonthermal radiation of a prefuor taken separately. We denote this correction as δ. We now have

$$\delta = m_{\mathrm{kal}}^{\prime\,\mathrm{nt}} - m_{\mathrm{pg}}^{\prime\,\mathrm{nt}}. \tag{5}$$

Let us now use the equation

$$10^{-0.4\, m_{\mathrm{kal}}^{\prime\,\mathrm{nt}}} = 10^{-0.4\, m_{\mathrm{kal}}} - 10^{-0.4\, m_{\mathrm{bol}}^{\prime\,\mathrm{t}}},$$

where m_{bol} denotes the bolometric thermal radiation of the prefuor. The equation means that the calorimetric luminosity of the prefuor is on the whole the sum of the intensity of thermal radiation by the star and the calorimetric luminosity of the nonthermal sources (producing both corpuscular radiation and electromagnetic radiation). While also taking Eqs. (3) and (5) into account, we readily find

$$\delta = m_{\mathrm{kal}}^{\prime\,\mathrm{nt}} - m_{\mathrm{pg}}^{\prime\,\mathrm{nt}} = (m''_{\mathrm{bol}} - m''_{\mathrm{pg}}) + (m''_{\mathrm{pg}} - m_{\mathrm{pg}}^{\prime\,\mathrm{nt}}) - 2.5 \lg\left[1 - 10^{-0.4\,(m_{\mathrm{bol}}^{\prime\,\mathrm{t}} - m''_{\mathrm{bol}})}\right]. \tag{6}$$

In essence, however, the last term is very small (on the order of several hundred), so that we can resort to the formula

$$m_{\mathrm{kal}}^{\prime\,\mathrm{nt}} - m_{\mathrm{pg}}^{\prime\,\mathrm{nt}} = (m''_{\mathrm{bol}} - m''_{\mathrm{pg}}) + (m''_{\mathrm{pg}} - m_{\mathrm{pg}}^{\prime\,\mathrm{nt}}). \tag{7}$$

Unfortunately, we cannot determine the magnitude of the nonthermal component in photographic light from the spectral observations of the prefuor Lk H_α 190 by Herbig. But since this component is not a prominent one, we are free to surmise that it accounts for no more than 15% in photographic light. That would mean $m_{\mathrm{pg}}^{\mathrm{nt}} \geq 18.0$. On the other hand, the great intensity of the emission lines of the Balmer series in a prefuor spectrum argues in favor of a rather large excess in the far ultraviolet. That supports the assumption that the excess cannot be much less than the indicated 15% in the near ultraviolet. We can therefore settle for a rough assignment $m_{\mathrm{pg}}^{\mathrm{nt}} \simeq 18.0$. Consequently, Eq. (7) yields, for Lk H_α 190:

$$\delta = m_{\mathrm{kal}}^{\prime\,\mathrm{nt}} - m_{\mathrm{pg}}^{\mathrm{nt}} \simeq -7.4.$$

From this we can infer the effectiveness of the transformation of the nonthermal energy released above the photospheres of prefuors to photographic light.

As we readily see from the tabulated bolometric corrections and color indices of Planck radiation, the highest value of the differences $m_{bol} - m_{pg}$ is attained at T = 8000° and is −0.2 [3]. Consequently, the value we obtained indicates that, in a prefuor, the factor for conversion of the energy released to photographic light is at least 700 times less than in normal thermal radiation by F type stars, where it is at a maximum. All of that signifies that the rise in brightness experienced by a fuor is due to an increase of several hundredfold, at least in the conversion factor. That difference δ is of course determined only very roughly, below, for the energy released in fast flares occurring in young stars with membership in stellar aggregates.

3. Slow Flares and Fast Flares in Flare Stars. In the present section, it is our intention to go into somewhat further detail than was done in 1954 [8], on flares occurring in several late UV Cet type dwarfs in the vicinity of the sun, and in broader groups of dwarfs present in associations (Orion, NGC 2264, NGC 7023) and in young clusters (Pleiades).

The essence of the concept which we put forth at that time was that each flare is the result of liberation of some amount of energy which is heavily concentrated prior to the flare and is included in some portion of the "prestellar material." We deliberately eschewed constructing hypotheses on the nature of that prestellar material, only stressing the point that we were not referring to rarefied material, but rather to superdense matter. Consequently, certain masses of that matter capable of existing in a stable state for a protracted period were in question, masses capable of being carried out into the space surrounding the star (possibly into the coronal layers, or even further, out to distances in excess of several stellar radii), and susceptible to almost instantaneous decay at those distances.

The fact that the phenomenon observed takes place above the star's photosphere, as a rule, derives from the particular energy distribution in the continuous spectrum of the flare (large ultraviolet excess). Here there are no significant quantities of absorbing matter, or by the same token conditions for thermalization of the emission spectrum. The fact that we are dealing here with an explosion, rather than a quiet expansion of the mass of hot gas ejected from the star, as proposed by several authors, is confirmed by photoelectric observations with a high time resolution, according to which the increase in brightness is often measured literally in seconds.

We have pointed out that in addition to the cases where the energy is released above the photosphere layers we can conceive of cases where the energy is liberated underneath the photosphere layers. The latter cases can be separated in turn into two groups:

1) Release of energy occurring deep down in the inner layers of the star, with the energy working its way up to the surface over the course of many months or years. In that case, the very process of energy release will become protracted by only slightly shorter time spans, i.e., extended at least by a matter of weeks or months. That means that we shall not be observing any separate and distinct flares, but only their overall averaged result, which reduces to some increase in the brightness of the star.

2) The release of energy takes place directly beneath the photosphere layers, at a depth from which the energy makes its way (via diffusion of the radiation or an ionization wave) to the surface in the course of several hours. The observed flare process must last several hours in that region. The process of the rise in brightness of the star must proceed at a much slower pace than in those cases where the liberated energy advances above the star's surface, and the color of the additional radiation must be a function of the amplitude of the brightness. The lower that amplitude, the lower must be the color temperature of the additional radiation.

Professor Haro, in his first observations of "slow flares," which differ radically in their nature from "fast flares," fully confirmed the existence of two classes of flares in flare stars in the constellation Orion, and the recent discovery by Parsamyan [7] of a slow flare in the Pleiades showed that slow flares are also encountered in members of older aggregates than the Orion association.

We would now like to focus attention on some quantitative data derived from observations which proved to be in close agreement with our hypothesis on the nature of fast and slow flares.

The problem is that, if the flares are the result of disintegration of superdense matter, i.e., of some body of nuclear density, into an assemblage of particles, then conversion of the decay energy into the optical radiation at the frequencies we observed will be very small in the vacuum. Most of the decay energy will become converted either into the kinetic energy of the particles formed (as occurs, for example, in β decay) or into electromagnetic radiation such as γ photons, x-ray photons, or radiation in the far ultraviolet.

An entirely different state of affairs prevails when decay takes place underneath the photosphere layers. In that case, all of the decay energy, except perhaps for neutrino energy, will become converted into the thermal energy of the star's radiation. In other words, the flare energy in the form of optical light must be many times greater in those cases than in the case of fast flares. This relationship is difficult to define, as it comprises only a concrete mechanism acting in the flare process. One of the possible concretizations to consider is the mechanism proposed by Gurzadyan, wherein anti-Compton scattering of quanta of the star's thermal radiation takes place on the electrons (or positrons) released in the decay process. When that mechanism is at work, the conversion factor must be below 0.01. Then the energy at optical wavelengths must be a hundred times greater, in slow flares, than the energy at optical wavelengths released in fast flares.

Observations show that: 1) slow flares are observed many times less frequently than fast flares; 2) the amplitudes observed in slow flares are not smaller than those observed in fast flares; while the largest amplitudes of fast flares in photographic light attain a magnitude of 5 in the Orion stellar association, one of the slow flares observed in Orion (at the star VZO 177) by Haro had an amplitude of 8.4 in that range of light; 3) the color of the emission of slow flares is redder than that of fast flares.

The first of the circumstances enumerated here seems to be due to the fact that the energy must be released in a layer of relatively small linear thickness (possibly of the order of a hundred kilometers) beneath the photosphere (case 2) in order for a slow flare of some appreciable amplitude to be observed. For instance, if we assume that the decay of prestellar masses ejected outwards takes place more or less spontaneously, then the decay probability in any layer must be proportional to the residence time in that layer, i.e., must be proportional to the thickness of that layer. In that light, the infrequency of slow flares presents no difficulty to understanding.

The second of these circumstances is a direct indication that the observed total energy of the optical radiation emitted in slow flares is several tens of times greater than the total energy observed in the optical range in fast flares, since the duration of the slow flare is tens of times longer when the radiation intensity is of that order of magnitude. Consequently, the observed relationship between slow and fast optical flares is in complete accord with the concept of different values of the conversion factor in those two instances which we developed above.

Finally, the third of these circumstances corresponds fully to our concept of the nature of slow flares.

In sum, the available data on differences between slow flares and fast flares confirm the hypothesis to the effect that flares are associated with high-energy decay processes.

4. Factor of Conversion of Decay Energy during Stellar Flares. Proceeding on the basis that prefuors and flare stars are members of the same stellar associations, we can surmise that the processes of decay and energy release are of the same physical nature in the two instances. We could then expect that the factor of conversion of the liberated energy into photographic light in those processes, in the vacuum, must be of the same order of magnitude. We saw above that, during slow flares, we measure the stellar magnitude which corresponds, when certain corrections are applied, to the total energy associated with the explosion, whereas only a small portion of the energy liberated in a fast flare is released in the form of photographic light. But in contrast to fuors, in this case it is difficult to determine the value of the calorimetric correction δ, since we can never be certain, when comparing data on any slow flare and data on any fast flare, that the two respective explosions were identical in scale. Consequently, the results of such comparisons must be approached with caution and relied on to give only qualitative findings.

However, the problem is solvable when we have rich statistical material at our disposal. For example, we could take for comparison a fast flare such that exactly 10% of all fast flares would have greater energy in photographic light than the one in question. In exactly the same manner, we could select from among the slow flares one such that only 10% of all slow flares would possess energies greater than the energy of the selected slow flare. These two flares could be treated as the result of an explosion of identical scale, with the difference that one took place above the photosphere, the other beneath the photosphere.

In addition to the absence of sufficient material for tests of that sort, we must state that the results can become severely distorted by the effect of differences in the probability that flares of different types will actually be detected. We therefore would have to devise more subtle statistical tests requiring, first of all, a still greater amount of observational data. Moreover, as mentioned earlier, such data are extremely hard to come by to date. We are therefore thrown back on cruder comparisons than even the statistical test referred to.

We can state that the overwhelming majority of fast flares observed in Orion have an ultraviolet amplitude ΔU less than six stellar magnitudes, even though that amplitude has been attained and even surpassed in rare instances. The Dec. 27, 1965 slow flare of the star VZO 177 was the most powerful [4] of all those observed in the Orion association. We can therefore assume that if we rely on an equivalent fast flare of amplitude $\Delta U = 6.0$, we will not admit any large error into the calculations. But the amplitude of the VZO 177 slow flare in question here was $\Delta U = 8.4$ in the ultraviolet region. Accordingly, the difference in the stellar magnitudes at the maximum of two such flares is 2.4. But we must recall the fact that the residence time at the maximum in the case of the slow flare was of the order of 3 h, whereas it does not last longer than 15 min in the case of fast flares. Actually, the residence time near the maximum is much shorter than 15 min in the case of a fast flare. However, we must not forget that what we are interested in is the energy of the flare. The subsequent two errors encountered when the method of photographic observations of flares is employed almost cancel each other out for that reason. First, the residence time near the maximum was several times overestimated, and second, the estimated brightness of the star near the maximum becomes diminished roughly several times because of the averaging effect. On the basis of the foregoing, we can state that, in our case of a flare star, approximately 200 times more energy is liberated in the ultraviolet than in the case of an equivalent fast star. Assuming that the bolometric magnitude in the case of a slow flare corresponds to the calorimetric magnitude in the case of a fast flare, we can write

$$\begin{aligned} \delta = m^{r}_{\mathrm{kal}} - m^{r}_{\mathrm{pg}} &= (m^{s}_{\mathrm{bol}} - m^{s}_{\mathrm{pg}}) + (m^{s}_{\mathrm{pg}} - m^{r}_{\mathrm{pg}}) = \\ &= (m^{s}_{\mathrm{bol}} - m^{s}_{\mathrm{pg}}) + (U^{s} - U^{r}) + (m^{s}_{\mathrm{pg}} - U^{s}) - (m^{r}_{\mathrm{pg}} - U^{r}). \end{aligned} \tag{8}$$

The superscripts r and s here denote the respective magnitudes for fast flares and slow flares, but it must be kept in mind that, in contrast to Sec. 2 of this article, the stellar magnitudes introduced here do not characterize the intensity of the radiations, but rather the integrals of the intensity, taken over the duration of the respective flare. In other words, here we are dealing with a comparison of the energies radiated. In that case, according to the estimate put forth, the second term in the right-hand member of the equation is equal to magnitude -5.7. The sum of the last two terms of Eq. (8) constitutes the color difference $\Delta(U - m_{pg})$ for a fast flare and a slow flare. We do not know the true color of a slow flare. Assuming the difference to be in the range from -0.5 to -1.0, we put it at -0.7. As for the first term in the right-hand member of Eq. (8), it constitutes the bolometric correction for a slow flare, and it would be entirely reasonable to assign it a small value. If we assign it the value -0.3, we obtain $\delta = -6.7$ for the calorimetric correction for a fast flare. Comparison of that number and the value of δ for nonthermal radiation emitted by a prefuor shows that the factor of conversion to photographic light must be of the same order of magnitude in the two cases.

5. Duration of the Postfuor Stage. In sum, we can safely infer from the available data on fuors that the process by which the brightness rise takes place is associated with the following transition:

T Tauri type stars		Fuor phenomenon		A type stars with
with UV excess	———	brightness rise	———	P Cygni characteristic
(prefuor)		(shell formation)		(postfuor)

Even though postfuors probably represent a group of objects which is fairly homogeneous in many physical properties, it should still be pointed out that the absolute magnitudes are close to zero in the two cases in question (FU Ori and Lk H 190), whereas the absolute photographic magnitudes are of the order of -7.0 in P Cygni itself, and also in other P Cygni type objects found in O-type associations. It should be acknowledged that we are not yet in a position to state from which objects P Cyg type supergiants originate, but their frequent presence in O-associations suggests that here too the initial phase was a T Tauri type star with energy sources of enormous intensity.

Once the frequency of occurrence of fuors is known, as well as the number of objects with a P Cyg spectral characteristic, we would be able to estimate the duration of the postfuor stage, or more precisely that portion of it within which a continuous outflow of matter continues to occur.

Only two typical fuors have been observed in the last 50 years (i.e., since 1920), and these remained stars brighter than $11^{m}.0$ after their brightness had stabilized. Of course, there may have been cases where the fuor phenomenon escaped notice. But it must be assumed that if two plates taken at protracted times apart (on the order of a score of years or more) were ever compared for a given region of the sky, fuor becoming brighter than $11^{m}.0$ and flaring over the time period elapsed between the two plates taken in that portion of the sky would have to be detected with a probability close to unity. Even though such comparisons have been carried out so frequently at observatories that they undoubtedly encompass most of the northern hemisphere, the time intervals between two plates are still not very long. Even if we assume that the value of the maximum time interval Δt, averaged over the entire sky, for which the comparison was carried out, was 20 years (assuming $\Delta t = 0$ with the averaging, if no such comparisons were carried out at all), it would be found that we could detect only 40% of the fuorized stars becoming brighter than $11^{m}.0$ in the last 50 years, in the best case. Then the total number of stars fuorized during this half-century in the northern hemisphere will be of the order of 5; in other words, a single star fuorized in one decade on the average. On the other hand, if T is the average duration of that postfuor phase when the P Cygni characteristic in the spectrum is still detectable and, moreover, the brightness shows no appreciable decrease, then we must have

$$N_P = 0.1 \cdot \mathrm{T}$$

for the total number N_p of stars brighter than 11.0 with a P-characteristic. Unfortunately, the available data are not sufficient to estimate the N_p number. However, not more than 10 or so stars with a P-characteristic are known [5] among the stars in the HD catalog of the northern sky. Herbig [6] has made a detailed investigation of the spectra of stars associated with cometary nebulae, but could detect only 4 stars with a P-characteristic, and one of those was, however, of magnitude $13^{m}.0$. Nevertheless, it can be safely assumed that a more detailed study of the spectra of most of the HD stars, particularly in the region of the H_α line, will result in doubling or even tripling the number of objects discerned with a P-characteristic. In addition, the HD catalog contains only a small portion (about a third) of the stars brighter than $11^{m}.0$. Consequently, a crude assumption would be $N_p \simeq 60$ in the northern sky. That would mean that the duration of the postfuor stage we are interested in here must be of the order of 600 years. By the way, we have to be careful in reaching our conclusions, since we do not know the true frequency of occurrence of fuors becoming transformed into P Cyg type supergiants, not even roughly. The lifetime of these supergiants can be much greater than in postfuors of lower luminosity.

There is no doubt, however, that the phase of the P Cyg type spectrum in postfuors of low luminosity is not very protracted. Our calculations were very rough, but we can still state with some assurance that the postfuor stage will not last longer than a time on the order of a thousand years, in those instances. But we then are confronted with the question of what happens after that stage has gone to completion; i.e., we have to deal with what we might call the postpostfuors, and whether the star resumes its initial brightness, i.e., reverts to the brightness of a prefuor or, on the contrary, retains its enhanced brightness. It would be difficult to venture an answer to that question at the present time. The only point that is certain is cases of an abrupt fall-off in brightness (the antifuor case) have not yet been discovered to date. We are then left with two possibilities: retention of the level of brightness retained, or a gradual elimination of the shell with a fall-off in brightness for decades or centuries. But if the first possibility held, then as many as tens of millions of postfuors exhibiting visible brightness greater than the 11th magnitude would have had to become accumulated over the course of, say, hundreds of millions of years. But there is in reality no such quantity of stars brighter than 11th magnitude. We therefore have to conclude that the brightness of the star must decline again within a short time.

6. The Nature of the Source of Nonthermal and Corpuscular Radiation in a Prefuor. At the present time, it is difficult to state anything definite about the nature of the source of nonthermal and corpuscular radiation in a prefuor. We consciously avoided dealing with the topic up to this point, since a knowledge of the nature of the source could be essential only when a more detailed investigation of fuors is in question. We need only point out that we cannot summarily exclude the supposition that a superdense satellite of the star (red dwarf) yielding the thermal radiation of the prefuor might constitute such a source. Nor can we exclude the possibility that the shell could be ejected by the superdense component. In that case, it would not be necessary for the red dwarf to be inside the shell in the postfuor stage. Its radiation will be simply imperceptible in the presence of the shell's radiation. In that case the distance separating the components can be large. Even if it were equal to tens of astronomical units, that would not be at variance with observations.

On the contrary, if the shell is ejected by a red dwarf, then the superdense satellite must end up inside the shell, and that would mean that the distance separating the components cannot be greater than several million kilometers, which would probably entail some serious difficulties in the explanation of detailed features of the phenomena.

Other assumptions as to the nature of the source are also warranted. At the present stage, we prefer to hold back from a detailed discussion of those options.

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