BOLETÍN DE LOS OBSERVATORIOS DE TONANTZINTLA Y TACUBAYA, VOL. 4, N°26, 1965.

THE H-R DIAGRAMS OF YOUNG CLUSTERS AND THE FORMATION OF PLANETARY SYSTEMS

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Sumario

La existencia de estrellas del tipo T Tauri y ráfaga, debajo de la secuencia principal en algunos cúmulos jóvenes, presenta un problema difícil de interpretar dentro de la teoría convencional de estrellas en contracción gravitacional. Por otra parte, la existencia de la fase completamente convectiva en las primeras etapas de una estrella, plantea también serias dificultades desde el punto de vista geoquímico; ya que en la fase puramente convectiva de Hayashi el sol debió haber sido tan luminoso que toda el agua presente en los planetesimales debió haberse evaporado en épocas lejanas, lo cual está en contradicción con la evidencia terrestre y meteorítica.

En el presente trabajo se demuestra que en las primeras épocas del sistema planetario, cuando los planetas todavía estaban en forma de material circunestelar, la absorción producida por este material fue considerable, del orden de 50 mag/U. A. en el visual; en consecuencia, para un observador externo el sol debió parecer primero como una estrella muy infrarroja, y después como una estrella del tipo T Tauri pero debajo de la secuencia principal.

Estas consideraciones, resultado de nuestro conocimiento actual del sistema planetario, seguramente no son privativas del sol y bien podemos esperar que con frecuencia estados similares a los descritos se presenten en otras estrellas jóvenes. Por lo tanto en el presente artículo avanzamos las siguientes hipótesis:

a) Cuando una estrella (de tipo solar) recién se forma, parte de la materia nebular que le dio origen permanece en su vecindad en la forma de una pequeña y compacta nebulosa circunestelar.

b) Bajo ciertas condiciones favorables, las partículas de esta nebulosa se aglutinan con una velocidad tan grande como lo permiten sus mutuas colisiones.

Estas 2 hipótesis, que han sido inspiradas por la existencia de estrellas jóvenes debajo de la secuencia principal y por la paradoja de Faulkner Griffiths y Hoyle sobre la existencia de agua en la tierra y los meteoritos, permiten a su vez entender, al menos superficialmente, todo un grupo de fenómenos que resultan ahora articulados dentro de un solo modelo.

Los fenómenos que en esta forma resultan comprensibles son los siguientes:

1.—La coexistencia de la fase de Hayashi con la retención del agua en la tierra y los meteoritos.

2.—La existencia de estrellas en contracción gravitacional debajo de la secuencia principal.

3.—El esclarecimiento rápido de la nebulosa circunestelar, y el consiguiente aumento de brillo de la estrella central en escalas de tiempo del orden de 0.3 años o más.

4.—La aparición, en un intervalo de tiempo comparable al anterior, de 2 nuevos objetos Herbig-Haro en Orión.

5.—La naturaleza de las nebulosas variables; el porqué de su relación con las estrellas T Tauri y porqué las variaciones de brillo en la estrella y la nebulosa no están correlacionadas.

6.—La posibilidad de entender los fenómenos anteriores dentro de un mismo modelo fundamenta, en forma independiente, la conjetura sobre la abundancia de sistemas planetarios en las estrellas de tipo solar.

Finalmente estas ideas permiten predecir que en la vecindad de los objetos Herbig-Haro recién aparecidos, debe existir una o más estrellas fuertemente obscurecidas y que comienzan a esclarecerse. Esta (o éstas) estrella debe ser muy infrarroja (λ max $\approx$ 7 μ) pero en el futuro deberá hacerse visible, primero como una estrella debajo de la secuencia principal, posteriormente como una estrella arriba de ésta, para terminar finalmente en la secuencia principal rodeada de un sistema planetario.

I.—Introduction

Well known are the numerous attempts that have been made to describe the evolutionary tracks followed by young contracting stars before they become main sequence stars.(1, 2, 3) Of necessity, these pre-main sequence stages in the evolution of a star (in hydrostatic equilibrium) are characterized by large luminosities and low temperatures, placing the stars above the main sequence. The agreement of this general prediction with the observed H-R diagrams of young clusters, lent considerable support to the hypothesis of gravitational contraction but, at the same time, it biased somewhat the attitudes with which the empirical evidence was looked upon.

Haro has pointed out that, for a number of years, there has been some evidence that the H-R diagrams of young clusters are more complex than what it is expected from the simple contraction theory. Good examples of this are the color magnitude diagrams of the Orion Cluster,(4) NGC 2264(5) the Taurus Auriga Cluster(6) and the Pleiades,(7, 8) where many suspected members fall below the main sequence. The existence of these stars as well as their more or less abrupt appearence at spectral types F 5 or later, have no place in any of the conventional theories of young contracting stars.

The possibility of the young stars below the main sequence has been strengthened by recent work due to Haro and Chavira,(9) who have given a number of convincing arguments in its favour; in fact it does not appear possible to explain all the underluminous stars as background objects or as the result of color anomalies. Furthermore, these authors have found that a number of flare stars —for which there are good evidences of their youth— fall below the main sequence in Orion and in the Pleiades.

In the present paper we shall first make some comments in support of the existence of young stars below the main sequence; next we shall try to explain this peculiarity as the result of the formation of planetary systems around contracting stars. Finally it will be seen how this hypothesis can explain a number of phenomena related to T Tauri stars, Herbig-Haro objects and variable nebulae.

We are adopting here the point of view that the phenomena that took place in the early history of the Sun —and the planets— are not unique, but quite common for stars of solar type; also the phenomena characteristic of T Tauri stars and related objects are regarded as a clue to some of the events in the early history of our planetary system.

II.—Some remarks on the existence of young stars below the main sequence

T Tauri stars and flare stars (in young clusters) are now generally accepted as stars in the process of gravitational contraction. However a number of these objects fall below the main sequence, as noticed by Herbig(6, 8) for some T Tauri like stars in the Taurus clouds and in the Pleiades, and by Walker(5) for NGC 2264. More recently Haro and Chavira(9) found that of 121 flare stars in the Orion Nebula (in an area 5° × 5°) one half of those fainter than magnitude 16, i. e. 26, fall below the main sequence. Because of the surface distribution of these stars, it is safe to consider that most of the 26 flare stars that are below the main sequence in Orion are members of the cluster. Hence it is necessary to explain why some young stars should fall significantly below the main sequence. To solve this, one thinks immediately in the effects of interstellar absorption; but to be of any use, these would have to be of very unusual properties. It will be necessary that the interstellar absorption in Orion and in the Pleiades be strongly fluctuating; like strongly absorbing patches of small extent, because on the contrary the stars below the main sequence will show a clumpiness in their surface distribution, which is not observed. Now if the interstellar absorption is in the form of small patches, some of these should appear like dark globules and the stars "below" should show some correlation with them. Actually it is well known, that —for instance— in the Pleiades there are no dark globules, and so the underluminous flare stars and T Tauri like stars cannot be explained by dark interstellar patches. We think, therefore, that there are good basis for accepting the existence of young stars whose observed positions in the H-R diagrams cannot, at first sight, be explained by the tracks of contracting stars with interstellar absorption and color anomalies.

III.—The Hayashi phase and the Faulkner-Griffiths-Hoyle paradox

The more recent analysis by Hayashi and his colleagues, of the gravitationally contracting stars, shows the existence of a relevant period during which a contracting star is wholly convective; as a result, in most of this phase the star is very luminous, considerably more than at its termination point in the main sequence. If we now follow Parker's(10) theory of solar activity we should expect this period to be also characterized by an unusually strong flare activity.(11)

If we look now at the problem from the point of view of the planetary system, we see that the geochemical (and meteoritical) evidence on the abundance of H^2, Li^6, Li^7, Be^9, B^{10}, B^{11}, can best be interpreted(12) as the result of spallations due to a strong corpuscular bombardement of the planetesimals when they still contained substantial quantities of condensed water. This is needed because otherwise the relative abundances Li^6/Li^7 B^{10}/B^{11} would be about ten times the present values in the earth and in the meteorites. To lower these abundances to the observed values, Fowler Greenstein and Hoyle(12) proposed that Li^6 and B^{10} were destroyed by thermal neutrons which were produced in the spallations and subsequently slowed down by the condensed water present in the planetesimals. The fact that H^2, Li^6, and B^{10} were not completely destroyed also sets the average size (10 m) for the planetesimals at the time of the corpuscular bombardement.

In view of the latter considerations it appears necessary to accept, following Huang(13), that the time when terrestrial H^2, Li, B, was formed coincided with the period when the sun was a flare star which, as we have shown(11), was also in its wholly convective phase of high luminosity. Now, as Faulkner Griffiths and Hoyle(14) have pointed out, if the sun had a convective phase, its luminosity would have been so large that the planetesimals could not have retained any water as required for the thermalization of the neutrons. This contradiction between the astrophysical theory and the theory of the terrestrial abundances was indeed a serious one. Fortunately Huang has just shown(13) that the above considerations can be made beautifully consistent, and the paradox resolved(15), if we assume that in the wholly convective phase there was enough absorbing material near the sun to lower its luminosity by a few magnitudes.*

The existence of substantial absorbing material in the immediate vicinity of the sun is not at all strange, because it is precisely in this convective phase when the solar nebula is flattening into a

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* Faulkner Griffiths and Hoyle first considered, and abandoned, the possibility of the planetesimals shielding one another.

disk and the planetesimals collecting into larger blocks. In fact, since the planets must have been formed by concentration of the interstellar medium, one can estimate the absorption in the early solar nebula. Let us assume its radius was comparable to the present radius of pluto's orbit, and its mass ten times the present mass of the planetary system, hence the density of the solar nebula at that stage was 2.5×10^{-14} gm/cm^3. As the dust follows the motion of the gas, its concentration in the solar nebula was increased accordingly in relation to its interstellar value. In a typical region of the interstellar medium the density is $\approx 2 \times 10^{-24}$ gm/cm^3 and the absorption 1^m/kpc; thus in the solar nebula which was 10^{10} times more dense, the visual absorption should have been $1^m/3 \times 10^{11}$ cm, or 50^m/A. U.! This argument shows that there was a strong circumstellar absorption in the early stages of the planetary system which coexisted with the beginning of the wholly convective phase in the sun.

The circumstellar absorption we have been considering need not be of the same nature as the interstellar extinction; the higher density should produce particles of larger radius which absorb and scatter optical wave lengths with equal efficiencies, i. e. in the optical range the absorption must have been neutral. Clearly, even though the sun was a giant, to an observer outside the nebula it would have looked, if visible at all, very faint and below the main sequence. Furthermore the nebula did not last very long as an spherical cloud, the magnetic activity inherent in the convective phase (with the larger solar rotation) should have transferred angular momentum from the sun to the nebula which, consequently, began to rotate and to flatten; at the end the solar nebula was a flattened torus with a large amount of angular momentum.

Nothing in the events described above appears to be unique to the sun; in fact, one would expect that all the stars when condensed should be surrounded by a compact "left over" nebula which could develop into a planetary system. Thus it is almost inevitable that stars of solar type (and less massive as well) in their early development appear very underluminous. This property, which is a function of time, depends also in the orientation of the principal plane relative to the observer. A star which appears below the main sequence for an observer in the principal plane, may appear well above for another observer which looks at the star from its axis of rotation.

From what has been said it should be clear that the observed position of a cluster star in the H-R diagram has not, in general, an immediate relation to its actual degree of contraction (i. e. to its true position on the Hayashi tracks). To know its true degree of contraction one has to learn how to substract the shielding effects in addition to the corrections due to extinction and color anomalies.

IV.—The nature of the shielding process

We will discuss now some of the properties of the shielding material; unfortunately we can not go very far because of the uncertainties in our knowledge of the early history of the planetary system, and especially because the rate of growth of the planetesimals is poorly known.

From very general considerations regarding the early phases of the planetary systems, we concluded —in the previous section— that solar type stars, at the onset of the Hayashi phase, should be surrounded by a very opaque absorbing nebula. At first, when this nebula is most opaque and spherical, the photons emitted by the star cannot cross the nebula without beeing scattered —many times— by the dust grains.

The result of this multiple scattering will be to degrade the "color of the photons" to the point where, (when they finally leave the circumstellar nebula), their energy distribution will be that of a black body corresponding to the radius of the circumstellar nebula. For the sake of a rough estimate, we may assume that at one time the solar nebula had a radius of 10 A. U. and the sun a luminosity 100 times the present solar output. In this case the radiation of the parent star will leak through the nebulae as that of a black body with an effective temperature of about 400° K; the maximum intensity in its continuum will be at $\lambda = 7.2\mu$. The conclusion seems inescapable that in places where extremely young stars *have just achieved* hydrostatic equilibrium, it should be possible to find bright "infrared" stars with effective temperatures around 400° K.

The evolution of the stellar nebula changes its geometry as well as the mean radius of its dust grains. In fact the growth of the solid particles has to proceed all the way up to planetary dimensions, going through the decameter planetesimals of Fowler, Greenstein and Hoyle. As the solid particles grow in size, the parent star remains practically invisible (at least in the visual) for an observer in the principal plane. This situation will last until the planetesimals have grown so much that their collective shielding power vanishes. This can be evaluated as follows:

Let L_0 be the visual luminosity radiated by the parent star and L the flux measured by an outside observer on the principal plane, then:

$$L = \frac{L_0}{4 \pi R^2} e^{-k \rho s} \qquad (1)$$

where R is the distance to the star, k is the mass absorption coefficient, ϱ the mean density of matter in the form of planetesimals and s the extent of the circumstellar nebula in its principal plane. Since the particles we are considering are already larger than the optical wave lengths, and assuming their density to be one, it follows easily that $k = 3/4\ r$ where r is the radius of the planetesimals assumed to be spherical.

We may consider only the region of the terrestrial planets, here we are fairly certain that the mass Mp of the planetesimals was at least of the order of the present mass of the terrestrial planets. Let us suppose that indeed their mass was twice the present one, i. e. $Mp \approx 2.4 \times 10^{28}$ gms and that this mass was spread uniformly in a cylinder, with a radius of one astronomical unit and a height of 0.1 A. U.; then the mean density of the nebula *at this stage* was $\approx 2.4 \times 10^{-11}$ gm/cm^3 so we have

$$L = \frac{L_0}{4\pi R^2}\, exp \left(-\frac{3}{4\,r} \times 2.4 \times 10^{-11} \times 1.5 \times 10^{13} \right) = \frac{L_0}{4\pi R^2}\, exp \left(-\frac{270}{r} \right) \qquad (2)$$

Thus, when the planetesimals grow to the size of a few meters, the whole inner shielding will vanish. This calculation takes into account only the heavier elements but a similar result is obtained if one considers also the rest of the planetary system.

For an observer outside the stellar nebula there is a second mode of clearing. In fact, as a result of the transfer of angular momentum from the star to the stellar nebula(13), the latter will recede from the star and at the same time it will become flattened; evidently, in the direction of the axis of rotation the optical depth will decrease considerably; actually this is also true for a finite solid angle centered at the axis of the star. In the first mode of clearing the star will become visible at its full brightness even for an observer on its principal plane.

The time scale for the two clearings is very hard to estimate. When conditions are favorable they can go very fast. Huang has suggested(13) that the contraction into a disk can go on a time scale comparable with the orbital period of its particles around the parent star. If —as in our planetary system— most of the mass is inside of 5 A. U., this time of flattening can be as short as 11 years!

The first mode of clearing depends on the growth of the planetesimals. To the best of our knowledge, no theory exists that can explain how —and at what moment— the small dust particles grow to become planets, although one is fairly sure that they must grow from microns all the way to planetary dimensions. So even if we do not understand how and when the particles aggregate to become the decameter planetesimals, we must accept as a sound hypothesis the increase with time of the mean radius of the particles. The rate of growth is unknown, but clearly depends on the interplay of two mechanisms:

a) The ability of the particles to stick together when they collide in random encounters; and

b) The destruction of the particles because the collisions are too violet for their mechanical strength.

In the limiting case in which the sticking efficiency is one and the shattering efficiency zero, one can find, following Kuiper(16), that the decameter condensation can be obtained in times of the order of 4-10 years (for a density of $\approx 10^{-9}$ gm/cm^3. At the very beginning it is unlikely that large condensations could develop in such a short time scale, because hydrogen and helium, which were the dominant constituents, cannot make very resistent planetesimals, i. e., the shattering was close to one. However, after most of the H and He have moved away of the zone of the terrestrial planets, leaving the heavier elements, the resulting planetesimals will be more resistant and capable of enduring their mutual collisions. From this time on their growth may be very fast indeed, as every collision may result in an agglutination.

It seems logical to conclude that, under certain favorable circumstances, important clearing effects may occur in the very early stages of solar type stars, in time scales of the order of a few years. As will be seen in the next section, this interesting possibility may help in the understanding of some puzzling aspects of variable nebula, F U Orionis and the sudden appearence of Herbig-Haro objects.

V.—Some observable consequences of the shielding phase

Clearly the introduction of the shielding phase has been inspired by the F G H paradox as well as by the existence of the young stars below the main sequence. Hence we may ask now: are there some unexplained observational properties of young stars whose understanding may be improved (if only superficially) by the hypothesis on the shielding phase? We think the answer is in the affirmative, as we shall proceed to show.

a) For the set of parameters which might have represented the solar nebula in the terrestrial neighborhood ($\varrho = 2.4 \times 10^{-11}$ gm/cm^3) we find from equation (2) that the sun looked —to an outside observer— 11 magnitudes fainter than its true value at the time when the planetesimals mean radius was 27 cm. In the conventional H-R diagram the sun appeared located at that time about 4 magnitudes below the main sequence. But by the time the planetesimals had grown to a mean radius of 60 cm, the star would look only 5 magnitudes fainter. How long would it take to achieve this brightening of 6 magnitudes? We cannot give a precise answer, and most likely there are many posibilities, but in some favorable cases, as described in the previous section, this time can be 4 years (with $\varrho = 2.4 \times 10^{-11}$ gm).

If instead of assuming a mass of terrestrial planetesimals equal to 2.4×10^{28} gms ($= 4\ M\oplus$), we take a mass 30 times smaller, and a volume also 30 times smaller, from formula (2) we see that the 6 magnitude clearing will be reached when the planetesimals have grown to be 32 cm, and this can be done, in the case of maximum sticking efficiency, in 3.2 years.

If besides we consider that the planetesimals orbiting around 0.5 A. U. from the parent star, may collide with relative velocities of 10 km/sec, instead of 1 km/sec. (as was assumed before), then the time of clearing can be reduced to 0.32 years!

These surprising short times scales for the clearing could well be the explanation for the strange case of the star F U Orionis, which in a time scale of a year (1936-1937) brightened from about $M_r = 8$ to $M_r = 2$(17) and has since remained at aproximately ($\pm\ 0.5^{m}$) the same magnitude.*

b) The clearing that we have been discussing applies also to the flux of corpuscular radiation which should be extremely intense at this stage. However, because the presence of magnetic fields and the different penetration of cosmic ray particles, the times of optical clearing will not necessarily coincide with those for corpuscular clearing.

It is known that in the case of the Herbig-Haro nebulae the source of excitation is not well understood, although Osterbrock(18) has given good reasons to reject the possibility of radiative excitation**. Also, since no high turbulent velocities seem to be present in these nebulae, one can probably rule out shock waves as the source of energy. Hence we have to consider corpuscular radiation as the acceptable source of excitation in the Herbig-Haro nebulae.

The fact that T Tauri has an H-H nebula (Burnham's nebula) very closely connected, strongly suggests that the corpuscular radiation of some stars when acting on an appropiate dense nebula can produce the peculiar emission observed in the H-H objects. Also from the extent of Burnham's nebula it appears that this excitation can extend *at least* 1500 astronomical units from the exciting star.

It is also known that the number of Herbig-Haro objects in Orion is not very large, which means that the likelihood of finding a new one in 8 years is very small (assuming a steady state this probability is $\approx 2 \times 10^{-4}$). Now, the probability that 2 of these nebulae will appear *independently* in the same period of 8 years is so extremely small, that in order to understand Herbig's dicovery of 2 new H-H objects in Orion we should link their appearence with one single event(19). This event may well be the corpuscular clearing of a young star which is located somewhere between the two new objects; In other words, during the clearing phase of a solar type star there is a moment when corpuscular radiation begins to leak about the axis of rotation (because of the dicoidal shape of the nebula); hence the shower of cosmic rays leaves the circumstellar system along two opposite cones centered on the axis of the system. If within these cones there happen to lie appropiate dense globule, they will begin to shine, in a time scale similar to that necessary for the operation of the clearing process which, as we have seen, can be as short as 0.3 years.

It is proposed that the appearence of the two new H-H nebulae in Orion was due to the existence of one such globule in each cone of a clearing star, which we can not yet see in visual light because we happen to be on or near the plane of its protoplanets. Notice that if the exciting star is halfway between the globules, their distance to the exciting star is comparable to the maximum extent of Burnham's nebula. If this explanation is correct one should be able to find somewhere between the two new nebulae a very infrared star somewhat hotter than the type described before ($L = 100\ L_{\odot}$; $T \approx 400°$K).

Such a star, as well as some of the T Tauri like stars below the main sequence are cases where we would be actually witnessing the formation of a planetary system. If the existence of these *infrared* stars is confirmed, one would have also proved the high frecuency of planetary systems in solar type stars.

c) Obviously, as the planetesimals grow to form a few large blocks (planets), they also cease

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* At present it is not easy to know whether still a third mode of clearing, related to the above, is responsible for the F U Orionis phenomenon. In fact, the onset of the Hayashi phase should produce a strong stellar wind whose flow is temporarily arrested by the circumstellar nebula; eventually the pressure built up by stellar wind will blow the gas and the smaller planetesimals, and obviously this effect can produce a clearing in an even shorter time scale.

** Furthermore, no hot star has been found which might be responsible for their excitation.

to be uniformly distributed along the path of the future planet. They will tend to concentrate in a few centers. If, as we had assumed before, the width of the disc is 0.1 A. U., an agglomeration of planetesimals revolving —say— at 0.5 A U. of the central star will make the system behave as a sort of an eclipsing star, where the light will be eclipsed in a cone of about 13° in width. Surely enough there must be several centers of condensation, revolving at different distances, so the later stages of the clearing phenomena will be characterized by irregular fluctuations in light for an observer located near the plane of the protoplanets. It is possible that *some* of the irregular fluctuations in brightness in T Tauri stars are due to this complex sequence of eclipses produced by the dense clouds of planetesimals which are about to become planets.

If in the proximity of such a star and near its principal plane there happens to lie a dark cloud, this will glow as a reflexion nebula but with varying intensity; these variations in the illumination appear irregular because of the superposition of the different periods of the protoplanets. Certainly these periods could be disentangled by means of a proper harmonic analysis, but then it would be necessary to have fairly complete and extensive light curves. This property of the shielding process permits to explain in a natural way the variable nebulae and why they are associated with some T Tauri stars. Also it is easy to see that the light variations of the star and the nebula will not, in general, be correlated for the simple reason that the eclipsing effects of the proto-planets are not isotropic. These cases correspond to the more advanced stages of planetary formation. That variable nebulae might be explained as due to variable obscuration, has been suggested long before by Lampland(20) and Herbig(21), but now its meaning becomes clear: it is an inevitable consequence of the later stages of planetary formation in conjunction with a close nebula properly located.

d) Finally, we want to point out a simple relation that seems to exist between the F U Orionis phenomenon and the variable nebulae. The case of Hind's nebula illustrates well our point. As it is well known, the latter is a reflexion nebula of the variable type connected with T Tauri. In the period from 1920 to 1940 this nebula increased considerably in brightnees from being a difficult photographic object to an easy visual one(21). This increase in brightness in some areas of the nebula clearly corresponds to an increase in the radiation received from T Tauri. Obviously an observer along a line joining T Tauri and that part of the nebula that brightened the most, would have seen T Tauri increase in brightness by a factor of more than 10 when observing behind Hind's nebula. The time scale of the phenomenon is much slower than that in F U Orionis, but the qualitative nature of the two phenomena seems alike. Furthermore, there are other variable nebulae, like Hubble's, where the brightening is more intense and in a shorter time scale.

V.—Conclusions

In the present article we have introduced —and justified— two very plausible hypothesis, related to current ideas on the formation of young stars and planetary systems. These hypothesis were:

a) When solar type protostars first achieve hydrostatic equilibrium, they are surrounded by a close spherical cloud of small mass ($\approx 10^{-2} - 10^{-3}\ M_{\odot}$).

b) This cloud can evolve to form decameter planetesimals which, under certain favorable circumstances, can grow as fast as their collisional rates will allow (sticking efficiency one, shattering efficiency zero).

These hypothesis permited us to understand and to relate, within a simple theory, the following phenomena:

i.—The F G H paradox.

ii.—The existence of T Tauri like stars below the main sequence.

iii.—The increase in brighteness of young stars in short time scales. For example F U Orionis.

iv.—The appearence of two new Herbig-Haro objects in a period of a few years without seeing yet any new star.

v.—The nature of the variable illumination in variable nebulae, its lack of correlation with the variations of the illuminating star, and why the latter are T Tauri stars.

vi.—We obtained an independent foundation to support the conjecture that solar type stars are attended by planetary systems.

The above hypothesis permitted to predict the existence of one or more apparently cold stars in the vicinity of the new Herbig-Haro objects in Orion; these stars will eventually "clear up" and appear, first as T Tauri like stars below the main sequence, later as T Tauri like stars above the main sequence, to settle finally as a main sequence stars with a planetary system.

In view of the previous considerations, we think that the theory of gravitationally contracting stars, supplemented with the above hypothesis, is still the most fruitful and satisfactory theoretical scheme to understand the early stages of stellar evolution.

Acknowledgments.—I want to express my gratitude to Drs. G. Haro and S. S. Huang for letting me read their manuscripts before publication; these papers inspired me to write the present one.

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