Astronomical X-Ray Sources

Dewey B. Larson, December 1974

Recent advances in techniques and equipment for x-ray observation of astronomical objects have resulted in the accumulation of enough information to enable checking the general nature of the observational results against the theoretical picture derived from development of the consequences of the postulates of the *Reciprocal System of physical theory*, the *RS theory*, we will call it for convenience. X-rays can, of course, be produced in relatively small quantities by a number of different processes, but the RS theoretical development indicates that the source of the very strong radiation in this frequency range that is generated in astronomical objects is radioactivity from matter which has reverted to speeds below unity (the speed of light) after having remained at a higher speed long enough to attain isotopic stability at the ultra-high speed.

This is the inverse of the process that theoretically gives rise to radiation at radio frequencies from the matter in objects such as quasars and pulsars that has just recently crossed the boundary in the other direction, from low speeds to ultra-high speeds, and is in the process of attaining isotopic stability at the ultra-high speeds. According to the theoretical findings, as explained briefly in *Quasars and Pulsars*, and in more detail in a supplement to that book entitled *Quasars—Three Years Later*, the factors which govern atomic stability are, like all other properties related to the speed, inverted at the unit level. Under low speed conditions, the zone of isotopic stability in the normal galactic environment is above the basic level at which the atomic weight is twice the atomic number. In an earth-like environment, the deviation of the theoretical center of the zone of stability from this basic level is $Z^2/156.45$ atomic weight units, where Z is the atomic number. At ultra-high speeds, the direction of the mass increment is reversed, and in a corresponding environment, the zone of stability is centered at $Z^2/156.45$ atomic weight units *below* the basic level.

This means that any matter which moves from low speed to ultra-high speed, or vice versa, is outside the zone of stability at the new speed, and must undergo a radioactive process to move into the stable zone. For example, the center of the zone of stability for the element silver, $Z = 47$, is 14.12 above the basic level, $2Z = 94$ amu, at low speeds, and 14.12 amu below this basic level at ultra-high speeds. A silver atom crossing the unit boundary therefore has to undergo a radioactive change of isotopic weight from 108 to 80, or the reverse. At the low speeds of our ordinary experience, this radioactivity involves the emission of high frequency radiation: x-rays and gamma rays. At ultra-high speeds, the emitted radiation is in an equivalent frequency range on the other side of the unit level, which puts it in the radio range.

The discrete astronomical sources of strong radiation of these two types are objects in which such radioactive transitions are taking place on a vast scale; where extremely large quantities of matter have been transferred from one speed range to the other in a relatively short period of time. The radio emitters are explosion products—quasars, radio galaxies, pulsars, etc.—composed wholly or in part of particles that have been accelerated from low speeds to speeds greater than unity by stellar or galactic explosions. Inasmuch as there are no *aggregates* of ultra-high speed matter in the material (low speed) sector of the universe, other than these explosion products, the x-ray and gamma ray emission originates from those of the explosion products which return to the low speed range after spending a substantial period of time at the ultra-high speeds.

In the chaotic conditions that exist in the turbulent products of the explosion of a star or galaxy, some of the atoms or particles that have acquired ultra-high speeds drop back into the low speed range temporarily by reason of loss of energy in encounters with other particles, and emit high frequency radiation at the low speed. All of these explosion products are therefore x-ray sources as well as radio emitters, but the high frequency radiation is relatively minor in the quasars, and also in the pulsars (except under some special conditions that will be discussed later), because the speed of these objects is great enough to enable escape from the material sector, and the aggregate as a whole never returns. The high frequency emission from the low speed products of galactic explosions, the radio galaxies, is likewise relatively weak because only a small percentage of the mass of these objects is moving at ultra-high speed, and while this matter was accelerated to the high speed suddenly, its reversion to the low speed range is spread out over a long period of time.

The strong x-ray emitters are explosion products of intermediate energy, those in which the entire aggregate initially acquires speeds that are greater than unity, but are not high enough to permit escape from the material sector. These ultra-high speed aggregates that remain in the low speed environment gradually lose energy to that environment, and ultimately drop back below the unit speed level. The speeds of the component particles follow the same course, and these aggregates therefore become x-ray emitters in the stage of their existence immediately following their return to the low speed range. The intermediate-energy explosion products are of two kinds. The Type I supernova is not energetic enough to raise its high speed explosion product, the white dwarf star, to the escape speed, and the entire white dwarf aggregate eventually returns to the low speed status after spending some time at the ultra-high speed. The speeds of the products of the more powerful Type II supernovae are distributed throughout the entire range below the maximum value, and, although the fastest particles are able to escape in the form of pulsars, there are some portions of the explosion products that acquire speeds greater than unity, but below the escape limit. Like the white dwarfs, this material, which forms part of the objects that are observed as supernova remnants, reverts to the low speed status in time. Both kinds of products emit x-rays while the isotopic changes required by the inversion at the unit level are taking place. The relatively strong discrete x-ray sources are therefore mainly white dwarf stars and supernova remnants (or extra-galactic aggregates containing these or similar objects).

In what we may call *Stage 1*, the immediate post-ejection period following the Type I supernova explosion in which the white dwarf star is formed, this star is expanding in time, which means that from a spatial standpoint it is contracting. In this stage, the constituent particles, newly raised to ultra-high speeds, are emitting radiation at radio frequencies as they move toward isotopic stability at these speeds. Such a star is observable only as an otherwise unidentifiable source of radio emission. A great many such sources—"blank fields", as they are often called by the optical astronomers—have been located, and presumably some of these are Stage 1 white dwarfs.

When the energy loss to the environment has been sufficient to terminate the contraction, a process of re-expansion begins, the first portion of which may be called *Stage 2* of the white dwarf existence. In this stage an increasing number of the constituent particles of the star lose enough energy to drop below unit speed. The atoms of which these particles are composed then make the radioactive transition to the upper zone of stability, emitting x-rays and gamma rays in the process. In the early part of this stage, the radiation at optical frequencies is minimal, and the white dwarf is still not optically visible, manifesting itself only as a source of high frequency radiation, and in its gravitational effect on its companion star. As the re-expansion proceeds, the white dwarf star continues accreting portions of the diffuse material ejected in the original supernova explosion, together with other matter from the environment, and gradually builds up an outer shell of low speed matter. This shell, increasing in thickness, absorbs more and more of the radiation from the interior, and ultimately the x-ray emission ceases. The star is then in *Stage 3*, the stage in which it is readily observable optically, and has the recognized white dwarf characteristics.

From theoretical considerations it has been deduced (See *The Structure of the Physical Universe*) that the equivalent of a pressure builds up in the interior of the white dwarf as the expansion toward gravitational equilibrium continues, and in *Stage 4* this pressure breaks through the overlying material periodically, exposing the radioactive material from the interior. During these outbursts (novae and related phenomena) x-ray and gamma ray emissions are again observable; that is, the high frequency radiation of Stage 2 is resumed on a *periodic* basis.

Summarizing, we find from theory that the relatively strong discrete sources of x-ray emission are

(1) white dwarf stars, not optically visible, in the early part of Stage 2 of their existence,

(2) novae and nova-like variable stars (Stage 4 white dwarfs),

(3) local concentrations of matter, or diffuse clouds of matter, in remnants of supernovae, and

(4) extra-galactic aggregates containing these or similar sources.

Here, then, is the general theoretical account of the principal sources of radiation in the x-ray range now being observed from astronomical sources, as derived from the basic postulates of the RS theory. As can be seen from the foregoing explanation, all of the information required to put this description together was already available in previous publications dealing with this system of theory. It had already been determined that the explosion products—quasars, pulsars, white dwarfs, etc.—theoretically undergo inverse radioactivity on crossing from the low speed to the ultra-high speed range, and thereby produce radiation at radio frequencies. It had also been found, from theoretical considerations (See *Quasars and Pulsars*), that certain of these explosion products (quasars, for example) acquire sufficient speed to escape from the material (low speed) sector, whereas others (white dwarfs, for example) do not attain the escape speed, and eventually return to the normal, relatively low, speeds of that sector. All that was needed to complete the theoretical picture was a recognition of the rather obvious fact that the process previously deduced as the source of the radiation at radio frequencies from the products of stellar and galactic explosions also works in reverse to produce x-rays and gamma rays from those of the explosion products that return to the low speed range.

We thus have a theoretical definition of the origin and properties of the x-ray emitters that has not been constructed to fit the observations, in the manner in which most scientific theories are devised, but was already in existence *prior to the discovery* of the astronomical x-ray emission. The close agreement between this pre-existing theory and the observational information thus far obtained is therefore highly significant.

In undertaking a correlation between theory and observation, we will reserve the emission in the supernova remnants for later consideration, and will begin with the observations of the other strong galactic sources, which, the RS theory tells us, are early (Stage 2) white dwarfs, or nova-like late (Stage 4) stars of this class. According to the previously published theoretical account of the origin and nature of the white dwarfs, they are components of binary (or multiple) systems in which they are associated with stars that originate, coincidentally with the white dwarfs, as infrared stars, and pass through a supergiant or giant stage as they move toward gravitational equilibrium on the main sequence.

Inasmuch as the observable white dwarfs appear to be distributed rather uniformly among the stars in the disk of the galaxy (as the theory requires), it can be expected that both the continuous and the periodic x-ray emitters will share this uniform distribution, and the x-ray sources of this class should therefore be concentrated toward the galactic center and the galactic equator in the same manner as the general run of disk stars. The observed distribution of the sources is in full agreement with this theoretical expectation.

Thus far, only about 20 percent of the x-ray emitters that have been identified as stars are definitely known to be members of binary systems, and the theoretical conclusion that they are all members of binary or multiple systems has been confirmed only to that extent, but there is no evidence to indicate that the remainder are not components of binaries. Indeed, it was suggested by R. Giacconi at a symposium reported in *Earth and Extraterrestrial Sciences*, February, 1973, that the evidence from observation warrants adopting "a working hypothesis that all galactic x-ray sources are either members of a binary system or supernova remnants."

As stated in a review article in the *New Scientist*, February 7, 1974, the observations indicate that the x-rays "must originate from relatively small, compact objects". The theoretical identification of these objects with the white dwarfs is in complete agreement with this and the previously stated conclusions from observation. The stars currently recognized as white dwarfs are "relatively small, compact objects"; they are members of binary systems in which they are associated with stars on or above the main sequence; and they are distributed in roughly the same manner as disk stars in general. These same statements are likewise applicable to the stars not currently included in the white dwarf class, but theoretically identified as Stage 4 white dwarfs, the novae and nova-like variables. The RS theory and observation are thus in complete harmony. But the predominant astronomical opinion rejects this straightforward interpretation, and invokes some products of the imagination to explain the x-ray emission. As reported in *Science News*, February 23, 1974:

> The main candidates (as x-ray emitters) are black holes and neutron stars—though a few observers may hold out for white dwarfs.

In considering the conflict between the RS theory and current astronomical thought, it should be realized that there is no independent evidence of the existence of such things as neutron stars or black holes; they are *purely* hypothetical, and they are brought into the x-ray situation only because the accepted theory of the nature of the white dwarfs imposes limits on the range of sizes and densities of these objects: limits which are wholly theoretical and without factual support of any kind. From an *observational* standpoint, all of the ultra-high density non-pulsating stars are alike. There is no physical evidence to indicate the existence of any division by sizes such as that which is required by current theory. The truth is that the inability of the conventional white dwarf theory to account for the full range of this group of observationally similar objects is a serious defect in the theory: one which, in most fields of science, would be enough to prevent its acceptance. But in this case, the *weakness* in the white dwarf theory is used as an argument *in favor* of the black hole theory, or at least, as conceded by the proponents of the theory, it is a "key link" in that argument.

When the hypothesis of black holes and neutron stars was first proposed as an explanation of x-ray emission, it was recognized in its true character as an extreme case of speculation. As seen by P. Murdin (*Nature*, January 26, 1973), black holes are a "solution looking for a problem". Only a "counsel of desperation," he said, would suggest calling upon such a hypothesis. Of course, even far-fetched speculations are scientifically legitimate, and sometimes serve a useful purpose, but unfortunately, there is a tendency to forget that they have no tangible basis. As they are repeated over and over again, they gradually acquire a standing merely by virtue of the repetition, and soon the observations which they were invented to fit begin to be accepted as evidence in their support. Anticipating this sort of a development, O. R. Burbidge sounded this note of warning only two years ago (*Comments on*

Astrophysics and Space Physics, July, 1972).

> Will it be firmly announced that black holes and/or neutron stars have been discovered... and shall we then build on this shaky foundation to explain even more about the universe?

Burbidge's apprehensions have been fully justified. The *observational* status of the black hole hypothesis is no firmer now than it was when his comments were made. It has been *enlarged* by the addition of subsidiary hypotheses, but aside from the things that hare been deliberately built into the theory by means of these additional hypotheses (for example, a reason why the emitters are members of binary systems), none of the new items of information that have been derived from observation, such as those discussed in these pages, can be explained by means of the black hole theory. Since every additional unexplained or contradictory item weakens the theory, its status has deteriorated to that extent. Notwithstanding the reluctance of those who are working in this area to concede the point, black holes and neutron stars are still pure speculations, just as they were when first proposed. "Black holes", say Fabian and Pringle (*New Scientist*, February 7, 1974), "are still in the realm of science fiction".

This black hole hypothesis—"Of all the conceptions of the human mind... perhaps the most fantastic", says K. S. Thorne, *Scientific American*, December, 1974 (not, as one might assume from his words, a caustic critic of the black hole theory, but one of its enthusiastic protagonists)—is another example of the results of the general unwillingness to reevaluate existing ideas or theories when new information becomes available. When the existence of matter at ultra-high densities was first brought to light by the discovery of the white dwarf stars, it was found possible to devise a theory which appeared plausible in the light of the facts that were known at that time. But later, when the *same* phenomenon—ultra-high density matter—was encountered in the form of quasars, where the existing white dwarf theory was obviously inapplicable, instead of taking the hint and reexamining the white dwarf situation, the theorists have devoted their efforts (so far unsuccessfully) to finding some different explanation to fit the quasars.

Then, when the same ultra-high density showed up in the pulsars, still another explanation was required, and this time the neutron star hypothesis was invented. Now we again meet the same ultra-high density in the constituents of the x-ray emitters, and since none of the previous explanations fits this case, we must again have a new theory. Here the resourceful theorists bring out the black hole. So in order to explain the different astronomical manifestations of *one* physical phenomenon—ultra-high density matter—we have an ever-growing multitude of separate theories, one for the white dwarfs, one for the pulsars, at least two for the x-ray emitters, several for the dense cores of certain types of galaxies, and no one knows how many for the quasars.

The application of the RS theory to the problem merely accomplishes something that was long overdue in any event: a reevaluation and reconstruction of the entire theoretical structure—particularly the white dwarf theory—in the light of the vastly greater amount of information now available. This theoretical investigation shows that the ultra-high density results, in all cases, from the same cause, and all of the ultra-high *density* stars, regardless of whether we observe them as white dwarfs, pulsars, x-ray emitters, or unidentified sources of radio emission, are identically the same kind of objects, differing only in their speeds and in the current stage of their radioactivity. The existing multiplicity of theories is not only confusing, but definitely misleading, and wholly unnecessary.

The next significant item of observational evidence that should be noted is that the "normal stars in x-ray binary systems are O and B supergiants" (*Sky and Telescope*, November, 1974). Theoretically, the companions of the white dwarfs in the *largest* binary systems should be supergiants, when these companions first reach the stage where they are optically visible. Since these large systems are the strongest emitters, they are the easiest to identify, and the fact that the first few systems to be located have supergiant components is therefore in accord with the theoretical expectation. However, the range of white dwarf companions in the optically observed binary systems extends all the way to the main sequence. It can be expected, on the same basis, that as observational techniques and facilities are improved, some infra-red stars (earlier than supergiants), some giants (smaller than supergiants), and some main sequence stars (later than supergiants), will also be found associated with x-ray emitting white dwarfs. Indeed, the observations already reported include an infra-red component of Cygnus X-3.

According to the RS theory, this diversity in the type of the companions of the white dwarfs is a result of differences in the relative rates of evolution of the two components. The binary systems containing observable white dwarfs (Stage 3, no x-ray emission) evolve toward the main sequence, the giant star contracting and the white dwarf expanding, both moving toward gravitational equilibrium. As mentioned earlier. Stage 4, the latter portion of the expansion period, is characterized by periodic outbursts of an explosive nature, and the normal white dwarf is therefore followed by a succession of novae and nova-like variables. The general nature of these "cataclysmic variables" (a term used to apply to "novae, recurrent novae, dwarf novae, and nova-like variables" in an article in *Sky and Telescope*, November, 1973) is clearly in agreement with the conclusions of the RS theory. As the foregoing article says, such a star "is a close binary system in which the primary component is a white dwarf. The secondary is a normal star".

The astronomical community is currently unwilling to accept the theoretical conclusion that the cataclysmic variables are *successors of* the normal white dwarf stars, because the observations do not define the direction of the evolution of these systems, and conventional thinking *assumes* that the normal white dwarf is in the last evolutionary stage of optically visible stars, the last stage before they descend into the hypothetical realm of black dwarfs, neutron stars, and black holes. But the conclusions of the RS theory with respect to the direction of evolution of the white dwarfs are now given powerful support by the x-ray observations, which reveal that there are, in fact, "x-ray novae", as asserted by the theory. Elliott and Liller (*Astrophysical Journal*, July 15, 1972) report that there is "some compelling observational evidence that relates the nova phenomenon...with at least some galactic x-ray sources". These authors concede that the x-ray emission comes only from *some* of the novae, or only at *some* times. "Certainly not all old novae are galactic x-ray sources", they say. The observations thus agree with the theoretical finding that only the interior material of the Stage 4 star is emitting high frequency radiation, and that, as a consequence, the x-rays are observable only when the explosive outbursts bring the interior material to the surface.

As noted earlier, there are some special conditions under which it is theoretically possible to have x-ray emission from pulsars, radiation which, like the radio emission from these objects is received in regular pulses. It was pointed out in *Quasars and Pulsars* that the two components of a binary system do not necessarily undergo supernova explosions at the same time, even though both are of the same age, and it is therefore quite possible that a second such explosion may take place in the remnants of the first. In such a case, relatively rapid accretion of matter by the second pulsar can be expected. This accreted low-speed matter will interact with the adjacent portions of the pulsar, and will reduce the speeds of some of its constituent particles below the unit level, causing the emission of x-rays. If the accretion proceeds far enough while the pulsar is still within observable range, the optical radiation from the accreted matter will also be visible. Inasmuch as all of the three types of radiation, radio, x-ray, and optical, originate in the rapidly moving pulsar, the pulsation rates will be the same for all.

The observed characteristics of the pulsar 0531+21 in the Crab Nebula are in full agreement with this theoretical pattern. Optical, x-ray, and radio emissions have been observed, and all have the same pulsation period. The x-ray emission, produced in the outer regions of the pulsar, is stronger than the radio emission from the interior, as would be expected. This pulsar is located approximately in the center of a mass of diffuse material, the characteristics of which are such as to lead to the conclusion that it is made up of two dissimilar components, suggesting that it originated in two separate events. Furthermore, a second pulsar, 0525+21, has been located in a position which is generally believed to indicate association with this nebula.

The recently reported discovery of a pulsar, 1913+16, which appears to be a member of a binary system and *not* an x-ray emitter, is of interest in this same connection, inasmuch as these characteristics suggest that this is a case where the pulsar has originated from the *first* explosion in a binary system, rather than the second. Like the Crab Nebula pulsar, 1913+16 is the only member of its class thus far discovered. Indeed, it was stated in *Nature* only a few months before this discovery that “no known pulsar is a member of a binary system”. The scarcity of such objects indicates either that our galaxy is not old enough to have many Type II supernova explosions of binary systems (second generation stars), or else that the interval between the two explosions is ordinarily considerably greater than in the two known cases.

Another situation in which x-ray emission from a pulsar could theoretically occur is that which would exist if, for any reason (perhaps a continuation of heavy accretion), the pulsar loses so much energy that it drops below the escape speed. In that event, it will follow the same course as the white dwarf, eventually returning to the low speed range, and emitting high frequency radiation in the process. Ultimately, it will be indistinguishable from the ordinary white dwarf. Unlike that star, however, the retarded pulsar will be returning from an unobservable condition at a (temporal) distance outside the observable range, and in reentering the observable region it will pass through the same pulsation zone that it crossed on the way out. While in this zone, the x-ray radiation will be pulsed in essentially the same manner, and within the same range of pulsation periods, as the radio emission from the outgoing pulsars.

The x-ray radiation from accelerating pulsars should always be accompanied by strong radio emission, and pulsed x-rays without any more than a weak radio accompaniment can theoretically be regarded as originating in decelerating pulsars. Another distinguishing characteristic is the direction of change of the period. The periods of the accelerating pulsars are, of course, increasing. Those of the decelerating objects are decreasing, but the rate of change is relatively slow, and within the current accuracy of measurement, the period may appear to be constant. Aside from that of the Crab Nebula pulsar, 0531+21, no increasing x-ray pulsation periods have been found. The other observed sources of pulsed x-rays therefore appear to be decelerating pulsars. In the case of one of them, Centaurus X-3 (4U 1118-60), it has been specifically reported that the pulse rate is *not* slowing down.

The near absence of observable x-ray pulsars in the accelerating stage tends to support the theoretical conclusion that the observable portion of this stage, the period of time during which a pulsar is observable after the supernova explosion, is very short. The theoretical basis of this conclusion appears to be firm, inasmuch as the age of the oldest pulsar thus far located, calculated from its pulsation period as 9100 years, is consistent with the maximum observable life, calculated from gravitational fundamentals as 13,000 years (where the gravitational restraint is exerted by one solar mass). However, the only definite observational evidence that was available to support such a short life at the time the foregoing values were published in *Quasars and Pulsars* was the observed ratio of pulsars to white dwarfs. As pointed out in the book, this ratio would lead to an improbably long life for the white dwarfs if the pulsar life exceeded the calculated figure by any substantial amount. In the meantime, further observational support has accumulated, including this confirmation of the theoretical deduction as to the rarity of observable x-ray pulsars.

Additional confirmation of a more direct nature has come from the supernova remnants. These remnants have been more carefully examined for evidence of association with the pulsars, and it is now conceded that this evidence is conclusive in only two cases—the Crab Nebula (900 years) and the Vela remnant (currently estimated at 11,000 years, calculated at 1500 years). Eric M. Jones (*Astrophysical Journal*, July 1, 1974) summarizes the situation as follows:

> Although the numbers of identified supernova remnants and known pulsars both approach 100, only two well-established pulsar-SNR pairs are known.

The fact that associations of greater ages are not *observed* is strong support for the theoretical conclusion that they are not *observable* for longer periods of time. The possibility that the pulsars and the remnants may have moved apart since the explosions, so that association is no longer evident, has been investigated, but it is difficult to obtain any specific evidence that such a separation has actually occurred. On the other hand, there *is* evidence that separation of the two objects does not *always* occur, since the pulsars in the observed associations are centrally located, as most, if not all, of them theoretically should be. This available evidence is conclusive, as the conclusion with respect to a limiting age in the neighborhood of the calculated figure is essentially the same regardless of whether *all* of the pulsars remain within the remnants, or only *some* of them remain. In either case, if the very low age limit did not exist, pulsars should be found associated with at least *some* of the remnants of greater age.

Current views as to the pulsar life, which differ radically from the conclusions of the RS theory, are based on the *assumption* that the increase in the period of pulsation is linear with respect to time. On this basis, ages in the range from 103 to 108 years are obtained by dividing the period by the rate of increase, expressed on an annual basis. But the finding of the RS theory that the age is proportional to the square root of the pulsation period means that, instead of being a simple quotient as assumed, the age is inversely proportional to the effective rate of change of the period. It is necessary to specify that this relationship applies to the *effective* rate of change because the theory indicates that the measured quantity, the continuous change, is the third power of the effective rate, the difference being taken up in time adjustments (sudden changes in the period similar to the observed phenomena known as "glitches") resulting from the pulsar motion in time. Theoretically, therefore, the age of the pulsar is inversely proportional to the 1/3 power of the measured rate of change of the period.

Application of this relation to the two youngest pulsars for which complete data are available arrives at an age ratio of 1.5. On the basis of 900 years for the Crab pulsar, this gives us 1350 years as the age of Vela X (4U 0833-45). The age of this pulsar calculated directly from the period is 1480 years. The agreement is within ten percent, which is probably as close as we can expect at the present stage of observational and theoretical development. Because of the many factors that affect the "fine structure" of the pulsation periods, and the greater proportionate effect of these factors at the lower rates of change, the individual deviations of the ages similarly calculated for the pulsars of longer periods exceed ten percent in many cases, but the *average* deviation is even less, except at the very low rates of change. For example, a compilation of pulsar data by Y. Terzian (August, 1972) includes 20 pulsars with periods lengthening more than 0.100 n sec per day, and the average deviation between the ages of these 20 pulsars calculated from the rate of change of the period and the ages calculated directly from the period is only four percent. This is clearly a confirmation of the theoretical deductions.

The finding of G. R. Huguenin, *et al* (*Astrophysical Journal*, October 1, 1971) that the evolutionary properties of the pulsars—from simple to complex—are related to the period is further evidence in support of the theoretical conclusion that the period is a function of the age. These observers classify the pulsars into three groups, those in which the pulse shape is simple, those in which it is complex, and an intermediate group. All of the pulsars of the simple type have periods less than one second; all of the complex type have periods longer than one second. Complex pulsation periods will theoretically develop as the pulsar overcomes the gravitational retardation and gets up to full speed, for the same reasons that apply to the development of complex radio structure in the quasars. The double-peaked pulse (double temporal structure) that is typical of pulsars with periods greater than one second is analogous to the double spatial structure of the quasar radio emission (See *Quasars—Three Years Later*).

It will be appropriate to close the discussion of the compact x-ray sources by checking the theoretical findings outlined in the foregoing pages against G. R. Burbidge's itemization of "What we need to explain" (*Comments on Astrophysics and Space Physics*, July, 1972). His list is as follows:

1. The great power of the sources.
2. Rapid and complex variability.
3. Binary character.
4. Rarity of powerful x-ray sources compared with the number of close binaries.
5. Non-thermal radio emission from two x-ray sources and non x-ray binaries.

All of these features are explained by the RS theory. The following comments may be made with respect to the individual items:

1. Strong radioactive emission from masses of stellar magnitude is obviously sufficient to explain both the x-ray and the radio power.
2. Emission from constantly changing groups of isotopes with half-lives all the way from seconds to years accounts for both the rapidity and the complexity of the variation. Where a single event (a "burst") can be identified, the decay follows the normal exponential pattern of radioactivity, a pattern which, as noted in the *New Scientist*, April 18, 1974, is "incompatible with the usual models."
3. According to the theory, all of the compact galactic x-ray sources are white dwarfs or pulsars. These are the high speed products of Type I and Type II supernova explosions, respectively. The low speed products of these explosions ultimately consolidate into stars, and form binary systems with the white dwarfs and those of the pulsars that return to the low speed region. The theory thus requires *all* of the compact x-ray emitters to be members of binary systems.
4. This is simply a matter of the comparative amount of time spent in the respective stages. The x-ray emitting period in the life of a white dwarf is very short.
5. All x-ray emitters are radio emitters earlier, and produce x-rays in a later stage when they lose the ultra-high speed that was the cause of the radio emission. But the speeds of the individual atoms in the aggregates are distributed over a wide range, and there is some x-ray emission from the radio aggregates, and some radio emission from the x-ray aggregates. When the speed of the aggregate is near the boundary line, the amount of the deviant radiation may be substantial. As noted in the discussion of the Crab pulsar, it is also possible for the outer portion

> of a compact aggregate to revert to low speed and begin emitting x-rays, while the material in the interior is still radiating strongly at radio frequencies.

The RS theory meets all of Burbidge's specifications fully and easily, not by a series of ad hoc constructions tailored to fit the observations, but by a purely deductive, and wholly inflexible, process of development of the consequences of the postulates as to the properties of *space and time* upon which the Reciprocal System of theory is based. If space and time do, in fact, have the postulated properties, then x-ray emission *must* take place from certain specific types of astronomical objects (the existence of which is required by the theory) in a particular stage of their existence, and the emission *must* have the particular characteristics that have been described.

Turning now to a consideration of the emission from the supernova remnants, we find that very little in the way of detailed information is available as yet. One point of interest is that much of the high frequency radiation from these objects appears to be coming from localized areas within the remnants, such as an x-ray "hot spot" that has been reported in the center of the Cygnus Loop. Concentrations of this kind are natural results of the theoretical process that produces the emission, as some of the material in the intermediate range of speed—above unity, but below the escape speed—can be expected to form local aggregates: miniature white dwarfs, we may say. If this kind of material is more widely dispersed in the form of diffuse clouds of matter, it will be subject to the same processes, but will then manifest itself in the form of extended sources of x-ray emission, many of which have been reported by the observers.

The remnants provide an opportunity for observing the older x-ray emissions, which differ significantly from those of more recent origin. As is evident on examination of the properties of the common isotopes of the elements, the more distant the isotope is from the center of the zone of stability, the more energetic the radiation, and the shorter the half-life, on the average. Consequently, the original "hard", or energetic, x-rays from matter dropping back into the low speed range becomes softer as time goes on and the short-lived isotopes are eliminated. As indicated in the discussion in the preceding pages, the x-ray emission from the compact sources is cut off at a rather early stage by accretion of an outer shell of low speed matter, and according to the theory, the remnants are the only sources that are old enough to have eliminated most of the hard component. This theoretical conclusion is in full agreement with the observations. As reported by R. Giacconi (*Physics Today*, May, 1973), there is no evidence of the existence of any source, aside from the older remnants, that emits only x-rays below 1 keV energy.

Giacconi also points out that the compact x-ray sources are either "exceedingly rare or represent short-lived x-ray emitting phases in stellar evolution". The theoretical identification of the soft x-rays with age, and the evidence from the remnants that ages of 25,000 to 50,000 years are sufficient to reduce the emission to the soft status, show that the second alternative is the correct one. The production of x-rays in the interiors of the white dwarfs continues until all of the ultra-high speed matter has reverted to low speeds—a process that requires a billion years or more—but this radiation escapes from the surface of such a star only under special circumstances of short duration.

The correlation of x-ray energy with age enables differentiating between the emission from remnants and that originating in compact sources associated with, or contiguous to, the remnants. For example, where a pulsar originates in a remnant, or returns to a remnant after reversing its direction of motion, the observed x-ray emission will consist of two dissimilar components. That from the pulsar, initiated relatively recently in either of the two situations mentioned, will be more energetic (harder) than the emission from the remnants, which dates back almost to the original supernova explosion. The two components can therefore be distinguished on this basis. Such an identification has already been made in the case of Hercules X-l, and the ability to differentiate between the emissions from different sources will no doubt be helpful in overcoming some of the difficulty that has been experienced in determining the nature of other x-ray sources.

It has been reported that there is no remnant at the Hercules location, but, of course, this merely means that no optical evidence of a remnant has been detected. As noted in *Quasars and Pulsars*, a large proportion of the total mass of the star that explodes in a Type II supernova goes into the high speed product, and since this material is not optically visible, there are many relatively young remnants that cannot be identified optically until some later date when they have lost enough energy to bring a substantial part of the ultra-high speed matter back into the low speed (visible) range. The existence of so much invisible matter in the remnants, and its slow reversion to the lower speeds, with the accompanying radioactivity, also explains the variability, the long duration, and the large total amount of the energy release in the Type II remnants, an amount which, as some observers have commented, appears, in many cases, to be inconsistent with the visible state of the remnants.

Somewhat similar "remnants", as well as compact sources of radiation, will also be formed as a result of explosive events in the galaxies, not only the violent explosions that eject the quasars, but also the emission of jets of material from galaxies such as M 87, and the more widely dispersed ejections from the Seyfert and other intermediate type galaxies. The galactic explosions differ from the supernovae not only in size, but also in some other respects, particularly in that they hurl their products outward, giving them a spatial motion, whereas the high speed product of a supernova—a white dwarf or a pulsar—remains at the spatial site of the explosion unless that explosion is, for some reason, asymmetrical. Also, the products of the galactic explosions are subject to powerful gravitational forces, whereas the gravitational retardation of the supernova products is relatively minor. Because of these differences in the controlling factors, the extra-galactic x-ray sources do not follow a systematic pattern, in the manner of their galactic counterparts. Their distribution is essentially random, except that emission from diffuse matter (extended sources) is concentrated enough to be observable only while this matter is still in the general vicinity of the galaxy or galaxies from which it was expelled.

Unquestionably, the most important fact thus far disclosed by x-ray observations of the supernova remnants is simply the *existence* of the strong emission from these sources. There is no obvious or *a priori* reason why such remnants should necessarily emit x-rays, or, for that matter, why *any* astronomical object should emit x-rays. "The discovery of cosmic x-rays was totally unexpected", says R. J. Gould (*American Journal of Physics*, May, 1967). Current astronomical thought is still groping for an explanation of the conditions under which the emission takes place, and the mechanism by which the x-rays are produced. As expressed by G. R. Burbidge in the reference previously cited, "We don't really know... how the basic radiation mechanisms operate and are maintained". The symposium report mentioned earlier includes this statement:

> Most of the known, realistic mechanisms for the generation of x-rays lead to somewhat complicated theoretical statements, and the number of adjustable parameters is often too great for comfort.

The special significance of the emission from the supernova remnants is that, unless we make the rather far-fetched assumption that there are *two* processes by which astronomical objects produce x-rays in immense, totally unprecedented, quantities, the emission mechanism must be one that is applicable to *both* of the observed types of galactic sources: highly condensed stars and supernova remnants. This not only rules out the currently popular speculations that invoke the hypothetical properties of hypothetical entities such as neutron stars and black holes, but also imposes some severe constraints on the kind of a process that can be given serious consideration.

Furthermore, when the observed emission of x-rays from the *remnants* of the supernovae is considered in conjunction with the results of the observations that have sought, but failed to detect, high frequency radiation in significant amounts from the supernovae, a still more rigid requirement is imposed on astronomical x-ray theory. The fact that emission occurs both from concentrations of matter (hot spots) and from diffuse clouds (extended sources) in the remnants means that the emission must result from the condition of the matter itself, not from the nature of the aggregate. But the absence of high frequency radiation during the observable stage of the supernova explosion, when the particle energies are at a maximum, shows that temperature alone is not the answer, and that thermal processes are not, in themselves, adequate to account for the strong x-ray emission.

In the remnants (and in the other sources as well, if those sources are products of supernovae, as generally believed) the emission comes from matter which has been losing energy—for 50,000 years or more in some cases—and is now at an energy level far below the peak reached in the explosion. The observations thus require the existence of a process in which matter that *loses* a portion of its energy *after* having reached explosive energy levels undergoes some change that involves emission of x-rays. Conventional theory knows of no such process, but according to the RS theory, this is just exactly what takes place in the explosion products of intermediate energy.

When it is realized that a satisfactory theory not only has to meet these rigid requirements of a general nature, but also has to provide an explanation of the existence of "x-ray novae", a reason why the compact x-ray sources occur (so far as we can tell) only in binary systems, why some emissions are pulsed and some are not, and other such details, it is clear that this presents a formidable challenge to any theory of the phenomena that is proposed. It should not be surprising, therefore, that conventional astronomical theory is unable to cope with the situation. The discoveries of the past quarter of a century, including the x-ray phenomena, have taken astronomy into a totally new field, one in which it is evident, from the kind of difficulties that are being encountered, that some of the assumptions upon which conventional theory is based are not valid. Identification of the required modifications from within the system—that is, by reasoning from astronomical premises—encounters almost insuperable obstacles, and at many points progress toward understanding is at a standstill. Current literature is full of expressions such as "ever-deepening mystery", "baffling problem", "strange and inexplicable", and so on.

By deriving the basic astronomical relationships from general physical premises, totally independent of astronomical observations or theories, the Reciprocal System of theory now provides what is needed: identification of the features of existing thought that must be replaced or modified. This new development is a *general* physical theory, based entirely on some far-reaching assumptions as to the nature of *space and time*, and originally derived from a critical study of the physical and chemical properties of matter. It applies to astronomical phenomena, as well as to the more general physical relations, because all astronomical objects are also physical objects, subject to the general physical laws.

An impressive feature of the results of the application of this RS theory (one that is to be expected, but is no less impressive for that reason) is the way in which the simplification of the basic premises—deriving *all* conclusions from the *same* set of assumptions—accomplishes a drastic simplification of the processes that take place in the astronomical phenomena that are involved in the present discussion. In the context of the RS theory, *all* of the compact, high density astronomical objects—quasars, pulsars, observable white dwarfs, x-ray sources, etc.—originate in the *same* manner (as the result of explosions). The extremely high density of *all* of these objects is due to the *same* cause (ultra-high speeds imparted by the explosions). The strong radiation—radio and x-ray—observed from these sources in certain periods of their existence results in *all* cases from the *same* process (isotopic adjustment necessitated when matter goes from low speed to ultra-high speed, or vice versa). As shown in the description of the theoretical development in this and previous publications, the differences between the various explosion products, and their behavior, can be accounted for, in full detail, by the conditions under which they are produced, and under which they currently exist: the character and power of the explosions, the nature of the environment, etc.

Of course, a few cherished ideas of long standing must be sacrificed in order to enable accepting the premises of the new theory, but on careful consideration it will be found that there is no *real* sacrifice involved; that what has to be given up is only the *form* in which these ideas are currently expressed. Where there is real merit, the RS theory preserves the substance in a different form.

From the new theoretical development we find that the "mysterious" and "baffling" objects and events which the astronomers have recently discovered, and are now trying to understand, are ultra-high speed phenomena, in which the familiar physical relationships are inverted because the objects to which they apply are moving with speeds in excess of unity, the speed of light. The most important modification of conventional thought that is required by the Reciprocal System is therefore the elimination of the limitation on speed imposed by Einstein's theory of motion at high velocities. The immediate reaction of most scientists is that this is unthinkable; that the validity of Einstein's relationships has been demonstrated in countless experiments and applications, and that tinkering with them would lead to chaos in the high velocity field. But this is just another illustration of the way in which unsupported assertions acquire the standing of incontrovertible facts simply by virtue of long-continued repetition. The truth is that all of the achievements of Einstein's theory—the agreement with experiment, the successful use of the theory in the design and operation of particle accelerators, etc.—are *mathematical*. What these results demonstrate is that the theory is mathematically correct. But the limitation on speed does not come from the mathematics; it comes from Einstein's *explanation* of the mathematics.

Contrary to popular belief, this explanation, the *conceptual* aspect of Einstein's theory of motion at high velocities, has never been verified in any manner. Furthermore, it has the weakest possible kind of a foundation; it rests entirely on a pure *assumption*. The *fact* disclosed by experiment, and verified in practical application, is that when a presumably constant force of electromagnetic origin is applied to the acceleration of a presumably constant mass, the acceleration does not remain constant, as required by the definition of force, F=ma, but decreases at high speeds and approaches zero at the speed of light. This means that one of the presumably constant quantities is not a constant, but a variable. As most elementary physics textbooks point out, the mathematics are exactly the same whether the variable quantity is the mass or the force, and there is no physical evidence to indicate where the variation takes place. In the absence of such evidence, Einstein had to make an assumption, and he chose to build his theory—his *explanation* of the mathematical relations—on the basis of a variable mass. Development of the RS theory now indicates that he made the wrong choice, and that the variable quantity is actually the force; that is, instead of the mass approaching infinity as the speed approaches unity (the speed of light), the effective force approaches zero.

The significance of this difference in the interpretation of the mathematical relations is that if the *mass* were the variable quantity, as Einstein assumed, the limitation would apply to the speed. It would then be impossible to exceed the speed of light. But if the *force* is the variable quantity, in accordance with the conclusions of the RS theory, then the limitation is on the capabilities of the process; that is, the physical evidence then shows that it is impossible to produce a speed in excess of that of light by electromagnetic means. Such a limitation on the capability of one process does not preclude acceleration of a mass to a higher speed by some other process—by an explosion, for example. Replacement of Einstein's arbitrary selection from among the two possible interpretations of the mathematical pattern with the interpretation *derived theoretically* from the postulates of the Reciprocal System thus opens up the entire range of speeds beyond the speed of light *without altering any of the mathematics now being used in application to motion at speeds less than that of light*.

This is a good example of the way in which the Reciprocal System of theory accomplishes the objective of eliminating the errors and misconceptions of conventional theory without disturbing its valid and useful features. Of course, this is just what a correct general physical theory *must* do. The essential elements of existing theories are empirical. These theories agree with observations, and particularly with the observed mathematical relations, because they were designed specifically for this purpose. A valid general theory must also agree with the observations and measurements, and it must therefore arrive at these same results. But if a theory is to be anything more than a description of the observations, it must provide an *interpretation* of the observed facts, and this is where so many theories go wrong, as there is usually very little of a solid nature on which the theorist can rely for guidance. As expressed by Sir James Jeans:

> The history of theoretical physics is a record of the clothing of mathematical formulae which were right, or very nearly right, with physical interpretations which were often very badly wrong.

There is a tendency on the part of each new generation of scientists to assume that "things are different now", and that the surmises and conjectures involved in the current interpretations of observations and measurements are somehow free from errors of the kind that have been so prevalent in the past. But it should not require any great perspicacity to enable realizing that as long as any kind of guesswork enters into the construction of theories, mistakes will be made. The question that now confronts us is not *whether* there are errors in current astronomical thought, but *where* the errors are. This is the question that the Reciprocal System of theory is now ready to answer.