

COSMIC RAY SOURCES, ACCELERATION,  
AND PROPAGATION

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Review of selected papers on the theory of CR propagation and acceleration, presented in divisions OG, 2, 5, 6, 7, 8, and related problems.

I. CR propagation in the Galaxy

I.I. CR transfer in a turbulent medium.

The high isotropy and a comparatively large age of galactic CR are explained by the effective interaction of relativistic particles with random and regular electromagnetic fields in interstellar medium. The kinetic theory of CR propagation in the Galaxy is formulated similarly to the elaborate theory of CR propagation in heliosphere (see the review by Quenby, 1984). The substantial difference between these theories is explained by the necessity to take into account in some cases the collective effects due to a rather high density of relativistic particles. In particular, the kinetic CR stream instability and the hydrodynamic Parker instability is studied (see Cesarky, 1980).

The interaction of relativistic particles with an ensemble of given weak random magnetic fields is calculated by perturbation theory. The theory of CR transfer is considered to be basically completed for this case. (A new field of activities is suggested by Webb (8.3 - 8) in his paper on CR diffusion in relativistically moving plasma.) The main problem consists in poor information about the structure of the regular and the random galactic magnetic fields.

To calculate the diffusion coefficient of a particle with a gyroradius  $r_H$ , it is necessary to know the spectrum of a random field  $\delta B^2(k)$  in the resonant region of wave vectors  $k_{res} \sim 1/r_H$ . The CR diffusion coefficient along a magnetic field  $B_0$  is equal to

$$D_{||} \approx \frac{v r_H}{3} \frac{B_0^2}{\delta B^2(\geq k_{res})}, \quad (I.I)$$

Remember that the gyroradius is

$$r_H = \frac{pc}{ZeB} \approx 1.1 \cdot 10^{12} Z^{-1} (E/1 \text{ GeV}) \cdot (B/3 \cdot 10^{-6} \text{ G}) \text{ cm} \quad (v \approx c). \quad (1.2)$$

The diffusion of CR with energies  $10^9 - 10^{17}$  eV is therefore determined by random fields with a size of inhomogeneities from  $3 \cdot 10^{12} - 3 \cdot 10^{20}$  cm (for  $E > 3 \cdot 10^{17} Z$  eV, the gyroradius of particles exceeds the main turbulence scale in interstellar medium,  $L_t \sim 100$  pc, and the scattering becomes not very effective,  $D_{\perp} \propto E^2$ ).

The existence of the random magnetic field spectrum necessary for CR diffusion has not been reliably established although it is not excluded by the available observations (Armstrong et al., 1981). At the same time, the simplest version of realization of a unique spectrum as an ensemble of linear mhd waves seems rather doubtful because of the presence of a strong wave damping.

In their papers Highdon (7.2 - 13) and Bykov and Toptygin (7.2 - 14) give a thorough theoretical analysis of turbulence formation processes in interstellar medium. The first-mentioned paper deals with a small-scale turbulence due to evolution of isobaric entropy structures in interstellar plasma. Turbulence is shown to appear even on scales substantially smaller than the Coulomb mean free path. But the two-dimensional perturbations ( $\vec{k} \cdot \vec{E}_0 = 0$ ) arising in this case are inefficient for CR scattering. The second paper considers generation of secondary shocks appearing in the interaction of a primary shock, which is due to a supernova explosion, with interstellar clouds. The interstellar turbulence spectrum is determined. The corresponding value of the CR diffusion coefficient turned out to be equal to  $D_{\perp} \approx 5 \cdot 10^{28} \text{ cm}^2/\text{s}$ .

The problem of transverse diffusion of strongly magnetized particles in a stochastic large-scale magnetic field, which has not yet been strictly solved, is discussed in the paper by Ptuskin (7.2 - 16).

Ginzburg and Ptuskin (7.2 - 15) present a microscopic calculation of the force acting on the CR gas on the side of background plasma and discuss the applicability limits of standard hydrodynamic equations, including the CR action.

The relatively high CR pressure provides an important role played by relativistic particles in the formation of equilibrium distributions of gas and magnetic field in the galactic halo. This classical problem is considered anew by Dougherty et al. (7.2 - 18). The new element is an account of a finite pressure of mhd waves generated due to the stream instability of CR escaping from the Galaxy. The formation of an extended "tail" in the spatial distribution of gas over the galactic plane is confirmed.

I.2. Semiempirical galactic models ( $E < 10^{15}$  eV)

Kinetic theory gives serious ground for using the diffusion approximation in the description of propagation of CR with energies up to  $10^{15} - 10^{17}$  eV in the Galaxy. Using the "microscopic" theory only, one cannot however strictly prove the diffusion character of motion and unambiguously determine the diffusion tensor and the velocity of CR convective transfer. Semiempirical models are of particular importance in this situation. They make it possible to classify and correlate numerous observational data, to explain the specificities of the composition, energy spectra, and anisotropy of different CR components, to find the CR composition in the sources.

The diffusion galactic model is the most thoroughly developed and on the whole explains well the relative observations. Its first basic version was proposed by Ginzburg and Syrovatsky (1964) (for the modern version see, for instance, the review by Ginzburg and Ptuskin (1985)). To simplify calculations, this model can in some cases (but not always!) be replaced by the leaky-box model. Many important problems remain, however, insufficiently investigated.

At the Conference particular attention was given to the analysis of the role of particle acceleration in interstellar medium, to the study of stream instability of low-energy CR (Bretthorst and Margolis 7.2 - 9), to the clarification of consequences of strong interstellar gas density variations for CR transfer and fragmentation (Morfill et al. 7.2 - 4).

The interest in acceleration in interstellar medium is connected with a great popularity of the scheme of diffusive shock acceleration by extended SN remnants. The decisive argument against the substantial CR acceleration in the course of their propagation and fragmentation in interstellar gas is the observed decrease with energy of the amount of secondary nuclei in the CR composition.

The argument which was considered doubtless is objected in the papers by Lerche and Schlikeiser (8.3 - 2, 7.2 - 8, 8.3 - 1). According to formal calculations of these authors, in a continuous Fermi acceleration of CR in the entire Galaxy, the ratio of number densities of secondary to primary nuclei may decrease with energy. The crucial point of the model proposed by Lerche and Schlikeiser is the introduction of two different leakage times  $T_{Ls} = T_{Lp}$  in the equations for concentrations of secondary and primary nuclei on the basis that the spatial distributions of interstellar gas and CR sources do not coincide. This procedure does not seem to be correct. (Under some simplifying assumptions applied to this case the whole information on propagation of stable nuclei, both primary and secondary, is contained in the particle distribution function with respect to pathlength  $x$ ,  $G(x, \vec{r})$ , here  $\vec{r}$  is the point of observation, see Ginzburg and Syrovatsky (1964).

For the leaky-box model to be applicable, it is necessary and sufficient that the distribution function have the form  $G(x, \vec{r}) = \exp(-x/x_\ell(\vec{r}))$ . In this case at each observation point  $\vec{r}$  there exists only one value of  $x_\ell (= \bar{n}cT)$ , common for all nuclei, which should be used in transfer equations for CR concentration.)

Using different methods, Giler et al. (8.3 - 4) and Cow-sik (8.3 - 7) have shown that a simultaneous CR acceleration and propagation in interstellar medium lead to sec/prim ratio increasing with energy (in some cases  $s/p \rightarrow \text{const}$  for  $E \rightarrow \infty$ ).

Thus, acceleration in interstellar gas, which is accompanied by nuclear fragmentation, is excluded as the main process of CR acceleration. This does not mean, of course, that particles accelerated in compact sources cannot undergo any additional reacceleration. Such a scheme seems fairly probable (Silberberg et al. 1983, 8.3 - 5).

Simon et al. (8.3 - 3) have studied a leaky-box model in which CR accelerated in their sources are then moderately re-accelerated during propagation. A model with reacceleration time approximately equal to leakage time from the Galaxy has been revealed to agree well with the data on the amount of secondary boron nuclei in the interval of  $I \sim 100$  GeV/n. In this case  $x_\ell = 4 \text{ g/cm}^2$  ( $R < 6$  GV) and  $x_\ell \propto R^{-0.3}$  ( $R > 6$  GV), whereas in the standard model without reacceleration  $x_\ell = 8 \text{ g/cm}^2$  and  $x_\ell \propto R^{-0.5}$  ( $R > 6$  GV). Thus, the real energy dependence of CR leakage time may be substantially weaker than in the standard leaky-box model (see Fig. I). This makes easier the interpretation of observations of CR anisotropy which point to a weak energy dependence of the leakage time for  $E < 10^{14}$  eV.

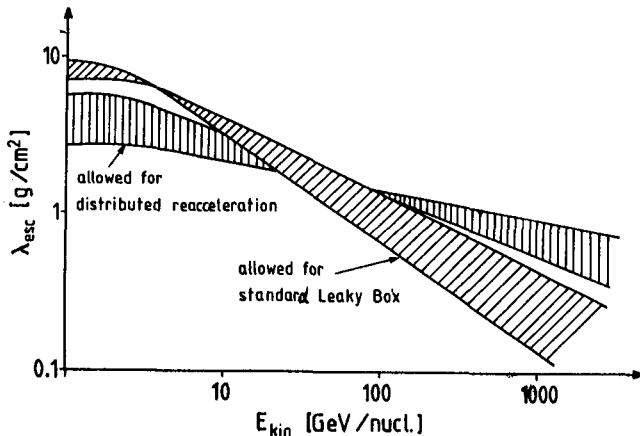


Fig. I. Schematic drawing of the energy dependence of  $x_\ell(E)$  as predicted by the standard Leaky Box and the distributed reacceleration model. OG 8.3 - 3.

Note that reacceleration should not necessarily be associated with diffusive shock acceleration. If CR diffusion in interstellar medium is due to particle scattering by an isotropic mhd turbulence, the same scattering inevitably leads to statistical particle acceleration. It can be easily shown that the ratio of the particle leakage time from the Galaxy to the characteristic time of their acceleration is

$$T_e / T_a \sim \left( \frac{v_a}{c} \frac{x_e}{\int dz \rho(z)} \right)^2 \quad (I.3)$$

Here  $v_a$  is the Alfvén velocity,  $\int dz \rho(z)$  is the gas thickness across the galactic disk. With a standard choice of parameters, we obtain  $T_e \sim T_a$  for GeV-energy particles. As the energy increases,  $\chi_e(E)$  decreases, and acceleration becomes inessential.

### I.3. Radioastronomical evidence

Radioastronomical observations make it possible, in principle, to establish the dimension of the CR confinement region in a Galaxy (the halo dimension) and also to find the diffusion coefficient and the speed of convective CR outflow (the galactic wind speed). It is difficult to interpret the radio-maps of our Galaxy since we are inside the radiating volume. When observing other normal galaxies "from outside", it is often easier to distinguish the region of their halo. Examples are on-edge galaxies NGC 4631 and NGC 891 in which clearly pronounced radio halos were revealed.

Lerche and Schlickeiser (6.2 - I) and Cowsik and Sukumar (6.2 - 3) have constructed CR propagation models for NGC 4631 on the basis of radio continuum observations for frequencies from 327 MHz to 10.7 GHz. In the former paper it is stated that the observed dependences of the effective radio halo dimension on the frequency and of the spectral radiation index on the height over the galactic plane are an unambiguous evidence of the existence of a large-scale galactic wind and a convective CR transfer in the galaxy NGC 4631. The latter paper shows, on the contrary, that a simple diffusion model without convection explains well the available radio data.

### I.4. Ultra high-energy CR

As has already been mentioned, for particles with energies  $E > 3 \cdot 10^{17} \text{Z} \text{ eV}$ , scattering on inhomogeneities of the galactic magnetic field becomes inefficient and the diffusion coefficient increases rapidly with energy ( $D_{\mu} \sim r_H^2 B_0^2 / L_t (\sigma B)^2$  for  $r_H > L_t$ ). Diffusion gives turn to particle drift in an inhomogeneous regular magnetic field. At still higher energies, when the Larmor radius is comparable with the dimension of the region occupied by the regular field, the

particle motion becomes simpler, and as the energy increases, it differs smaller and smaller from the free motion. For the field strength  $B = 2 \cdot 10^{-6}$  G and for the dimension of the halo with an ordered field  $h = 5$  Kpc, the condition  $r_H \leq h$  holds for the energies  $E \leq 10^{19}$  eV.

An informative concise presentation of the origin of ultra high-energy CR is given by Hillas (1984).

Most of the authors believe at present that particles with energies  $10^{17} - 10^{19}$  eV are of galactic origin, and for  $E > 10^{19}$  eV there dominates the extragalactic component. The arguments in favour of this assertion are given in the paper by Efimov and Mikhailov (5.4 - 15) (this paper is a continuation of the paper by Berezhinsky and Mikhailov, 1983). The main attention is given to the weakest point of the galactic model - to the explanation of high CR isotropy. It is assumed that CR sources are distributed in the galactic disk, the regular azimuthal magnetic field in the disk  $B_\varphi = 2 - 3 \cdot 10^{-6}$  G, in the halo  $B_\varphi \leq 10^{-6}$  G. The corresponding trajectory calculations yield a good agreement with the observed values for the amplitude and phase of the 1-st harmonic of CR anisotropy and for the southern excess of particles in the energy range from  $10^{17}$  to  $10^{19}$  eV. The apparent S/N asymmetry is probably connected in this case with the enhancement of particles from the general direction of the galactic plane (like in the model of galactic plane excess proposed by Wdowczyk and Wolfendale, 1984, 5.4 - II).

For the energies  $E > 3 \cdot 10^{19}$  eV the observed picture changes drastically and there appears a particle flux from high northern galactic latitudes - roughly speaking, from the direction to the supercluster Virgo. This can be explained only by the action of extragalactic sources.

The observed southern excess of particles with energies below  $10^{19}$  eV can be explained, in principle, by a non-symmetric CR outflow across the galactic plane. In this case, the particle concentration in the region P in Fig. 2 must be lower than in the external region Q. The Hillas interpretation

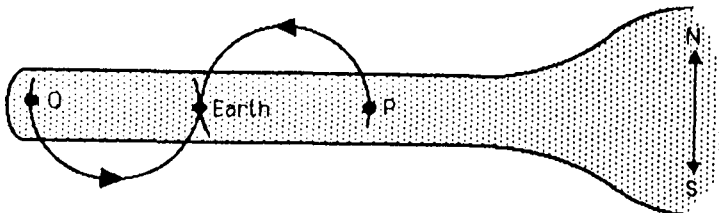


Fig. 2. Trajectories of positively charged particles in azimuthal galactic magnetic field. OG 5.4 - 9.

(1984) suggests the presence of a local CR gradient in this energy range ( $\sim 15\%$  Kpc) increasing toward the Orion region. Sommers and Elbert (5.4 - 9) believe that in the region P, at a distance of several Kpc from the solar system there oc-

curs a reverse of the azimuthal field which is accompanied by a rapid evacuation of CR and a local decrease of their intensity.

Karakula and Tkaczyk (5.4 - 8) have calculated the trajectories of ultra high-energy particles and determined transparency of the Galaxy for extragalactic protons. The regular galactic magnetic field is assumed to be contained in the disk  $|z| \leq 0.4$  Kpc. In constructing a concrete model of CR origin, the authors assume the isotropic flux from galactic sources to be summed up with the directed flux from the source to Virgo Cluster (these fluxes are equal to each other for  $10^{18}$  eV).

## 2. Antiprotons

An understanding of the large flux of antiprotons found in CR remains an intriguing problem. The available observations (unfortunately, they have been little enriched during this Conference) can be briefly resumed as follows. The observed integrated antiproton flux was found to exceed significantly the flux of secondary antiprotons calculated from the standard model of CR propagation in interstellar medium. (See, for example, Stephens 1981). For energies 0.1 - 10 GeV, the observed total flux of antiprotons 4-10 times exceeds the flux expected in the leaky-box model for  $X_L = 5$  g/cm. The observed energy spectrum of antiprotons is also unexpectedly different from the production spectrum of secondary antiprotons generated in p-p collisions. It is greatly enriched with low-energy particles and on the whole is similar to the CR proton component spectrum (in contrast with the production spectrum of secondary antiprotons which falls sharply for the energies  $E < 2$  GeV).

The explanations proposed may conditionally be divided into "exotic" and "non-exotic".

Here is the list of "exotic" explanations exploiting the new physical principles: quantum evaporation of mini black holes Kiraly et al. (1984),  $n-\bar{n}$  oscillations Sawada et al. (1981), Sivaram and Krishnan (1982), primary extragalactic origin Stecker et al. (1981), Stecker and Wolfendale (6.I - 8), photino annihilation in the galactic halo Silk and Srednicki (1984), Stecker et al. (6.I - 9).

The photino hypothesis is based on the assumption that in the Nature there exist stable massive photinos. These particles originate in the early Big-Bang. Photino is assumed to make up the missing mass in the galactic halo and to provide the matter density in the Universe which is close to the critical one  $\Omega = 1$ . In the paper submitted to the Conference Stecker et al. investigate photino annihilation in the galactic halo and calculate the spectrum of antiprotons appearing in this process. An intriguing fit is obtained to all the existing data on antiprotons for a photino mass  $m_{\tilde{\gamma}} \approx 15$  GeV. The cut-off of the spectrum for  $E \geq m_{\tilde{\gamma}}$  is predicted. (One should remember that it is still unknown in what concrete

form, if at all, the very supersymmetry principle is realized in the real world).

Non-exotic hypotheses do not require new physical mechanisms for explanation of a high  $\bar{p}$  flux. However, they require reconsideration or specification of the old habitual galactic models of CR propagation (see the Discussion in the papers by Ginzburg and Ptuskin, 1984; Lagage and Cesarsky, 1985).

It is possible, in particular, that part of CR sources (or all the sources at a certain stage of their evolution) are surrounded by a thick layer of matter in which secondary  $\bar{p}$  are produced. Heavy nuclei either do not escape from such objects due to a strong fragmentation or are not accelerated in them at all. One of the possible realizations of such a model has been considered by Mauger and Stephens (1983). Primary CR are assumed to accelerate in SN explosions in dense clouds and to be confined there for several thousand years, traversing the thickness of about  $50 \text{ g/cm}^2$ . If  $\sim 30\%$  of nucleons observed in CR come from such sources, one can satisfactorily explain the observations of  $\bar{p}$ . Now Stephens shows (6.1 - 7, 6.2 - 9, 2.5 - 3) that the fluxes of secondary positrons and gamma-quanta expected in this model do not contradict the observational data. More favourable here is the version in which the time of CR leakage from the Galaxy is almost independent of the energy. If the dependence is strong ( $T_L \propto E^{-0.6}$ ), the flat CR spectrum in the sources leads to a too rigid spectrum of gamma-rays and to a too large flux of secondary positrons.

Dermer and Ramaty (6.1 - 4) have presented a model in which low-energy antiprotons appear as secondary in  $p-p$  interaction in a relativistic plasma with a temperature  $kT \sim 0,2 m_p c^2$ . It is assumed that the appropriate conditions may exist in the vicinity of a neutron star or a black hole.

Various versions of secondary antiproton generation in dense gas clouds in models with a nonuniform CR propagation are developed by Tan (5.4 - 13, 6.1 - 6, 6.2 - 7), Dogiel et al. (8.2 - 17), Morfill et al. (7.2 - 4).

The model which would explain the high antiproton flux in the CR composition has not yet been finally chosen.

The correctness of calculations of the expected fluxes of secondary  $\bar{p}$  has been verified by Bowen and Moats (6.1 - 3). The parameters  $\lambda = 0.333$  - the probability of  $np$  charge exchange, and  $\mathcal{E}/2 = 0.45$  - the average elasticity, have been determined by measuring the proton spectrum at mountain altitude. The calculated spectrum of secondary  $\bar{p}$  in the atmosphere satisfactorily agrees with the measurements by Bowen et al. (1983). The contribution of atmospheric  $\bar{p}$  in balloon measurements by Golden et al. (1979) and Buffington et al. (1981) has been shown not to exceed about 10 %.

### 3. Shock acceleration: theory and application to the CR origin problem

The diffusive shock acceleration mechanism remains the most popular with theoreticians engaged in the problem of



CR acceleration (see the reviews by Axford, 1981, Drury, 1983, Volk, 1984).

### 3.1. Test particle approximation

An acceleration of a fast test particle diffusing near a shock front is a version of a first-order Fermi acceleration. It is due to a repeated crossing of the shock front in a random particle walk and to an energy gain in front collisions with scattering centres embedded to the background plasma. A formal solution of the problem can be obtained using the equations for the test particle distribution function which describes spatial diffusion, convective transfer, and a regular alteration of particle energy in a nonuniform flux:

$$\frac{\partial f}{\partial t} + \vec{u} \nabla f - \nabla \hat{D} \nabla f - \nabla \vec{u} \frac{p}{3} \frac{\partial f}{\partial p} = 0. \quad (3.1)$$

The particle density is equal to  $N(p) dp = 4\pi p^2 f(p) dp$ .

For a plane front the velocity profile  $u(x)$  is approximated by a step function (see Fig. 3). If particle distribution in a nonperturbed medium in an upstream region has the form  $f_1 \propto \delta(p - p_0)$ , the stationary spectrum of accelerated particles in a downstream region has a power-law form:

$$f_2(p) \propto \Theta(p - p_0) \cdot p^{-\frac{3r}{r-1}}, \quad (3.2)$$

where  $r = u_1/u_2$  is a compression ratio in a shock.

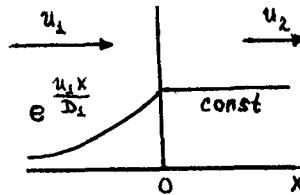


Fig. 3. Spatial distribution of accelerated test particles in the shock frame

For an extremely strong shock wave without radiation, which propagates in a gas with the adiabatic index  $\gamma_g = 5/3$ , the quantity  $r = 4$  and, therefore, the spectrum of accelerated particles is  $N(p) \propto p^{-2}$ . This is close to the expected CR spectrum in the sources.

The characteristic time of particle acceleration (i.e. the time of its energy variation by a factor of  $e$ ) under shock acceleration is equal to

$$t_a(p) = \frac{3}{u_1 - u_2} \cdot \left( \frac{D_1}{u_1} + \frac{D_2}{u_2} \right) \quad (3.3)$$

Note that the estimate of the characteristic acceleration time  $t_a \sim D/u^2$  is valid both for the diffusive shock acce-

leration and for the statistical Fermi acceleration. In the latter case  $u$  has the meaning of the turbulent motion velocity.

If a particle bears additional energy losses in a medium (with a characteristic time  $t_\ell$ ), then for acceleration it is necessary that the condition  $t_a \ll t_\ell$  should be fulfilled. In particular, for a spherical shock wave with a radius  $R$ , the role of losses, is played by a diffusion particle escape for the time  $t_d \sim R^2/D$ , and therefore particles are accelerated only under the condition (the numerical factor is omitted here and it is assumed that  $D_1 \geq D_2$ )

$$R u_1 / D_1 > 1. \quad (3.4)$$

These assumptions are confirmed, in particular, by the numerical calculations made by Ko and Jokipii (8.2 - 2).

By the terminology accepted in the theory of particle propagation in a solar wind, the inequality (3.4) implies a strong CR modulation.

Since the diffusion coefficient usually increases with energy, the condition (3.4) imposes limitation on the maximum possible accelerated particle energy  $E_{max}$ . Under scattering in a magnetic field  $D_{||} > r_H v$ , accordingly,

$$E_{max} \sim \frac{ZeB}{c} R u_1 \quad (D_1 \sim r_H v, v \sim c). \quad (3.5)$$

An impressive example of a possible realization of the mechanism of CR shock acceleration in the Galaxy is given by Jokipii and Morfill (8.1 - 8). They suggest that CR particles with energies  $E \gtrsim 10^{15}$  eV are accelerated at a termination shock of galactic wind. If the wind in the Galaxy does actually exist (which can be strongly doubted, see, for instance, Habe, Ikeuchi, 1980) and if the large-scale magnetic galactic field has a structure similar to the Parker spiral in interplanetary space, then  $B \sim B_0 (R_0/R)$  for  $R > R_0$ , where  $B_0 = 3 \cdot 10^{-6}$  G is a field at a distance  $R_0 = 10$  Kpc. It is assumed that the distance to the shock is  $R \sim 100 - 200$  Kpc, the wind velocity  $u_w = 300 - 500$  km/s.

Formula (3.5) does not work in this case since in an ordered, strongly twisted spiral magnetic field, the diffusion coefficient in the radial direction is smaller

$$D_{eff} = d^2 D_{||} + (1 - d^2) D_\perp \quad (3.6)$$

where  $d = R_0 u_w \cdot (R u_{gal})^{-1} \ll 1$  ( $u_{gal} = 250$  km/s is the speed of Galaxy rotation),  $D_\perp \approx r_H^2 c^2 / D_{||}$  is the diffusion coefficient across a regular magnetic field.

The minimum value of  $D_{eff}$  is reached for  $D \sim r_H c / d \sim 20 r_H c$ . In this case, instead of (3.5) we have

$$E_{max} \sim \frac{Ze}{c} B_0 R u_{gal} = 5 \cdot 10^{17} Z \left( \frac{B_0}{3 \cdot 10^{-6} \text{ G}} \right) \left( \frac{R}{100 \text{ Kpc}} \right) eV \quad (3.7)$$

The maximum energy density of accelerated particles can be estimated by assuming that the whole power of the galactic wind ( $Q \sim 5 \cdot 10^{40}$  erg/s, according to Jokipii and Morfill) goes to accelerated particles

$$w_{cr \max} \sim \frac{3QT_e}{4\pi R^3} \sim 10^{-15} \cdot \left(\frac{100 \text{ kpc}}{R}\right)^2 \text{ erg/cm}^3 \quad (3.8)$$

Here the time of CR escape from the galactic wind region is  $T_e = R/u_w \sim 3 \cdot 10^8 \cdot (R/100 \text{ kpc})$  years.

The CR intensity modulation effects lead, in fact, to a substantial lowering of the  $w_{cr}$  value. In this case, particles with  $E \lesssim 10^{15}$  eV do not reach the observer at all. We should recall that the values observed near the Earth are  $w_{cr} (> 10^9 \text{ eV}) \approx 10^{-12}$  erg/cm<sup>3</sup> and  $w_{cr} (> 10^{15} \text{ eV}) \approx 5 \cdot 10^{-16}$  erg/cm<sup>3</sup>.

Thus, CR acceleration on the galactic wind boundaries could, in principle, be a noticeable source of particles with energies  $E > 10^{15}$  eV. It remains unclear how the main energy output can be provided just in the region  $E > 10^{15}$  eV (with the particle spectrum  $N(E)dE \propto E^{-3.1} dE$ ) and how for  $E < 10^{15}$  eV a smooth conjugation with the CR spectrum ( $N(E) \propto E^{-2.7}$ ) generated, according to Jokipii and Morfill, in galactic SN remnants can be obtained. Note that reacceleration of CR supplied by SN is inessential in this case because due to the geometrical factor it gives not more than  $(R_0/R)^2 \lesssim 10^{-2}$  of the CR concentration in the galactic disk. It is necessary to consider particle acceleration directly from the thermal plasma on the galactic wind boundaries.

SN remnants are regarded as "classical" astronomical objects, in which the action of diffusive shock acceleration is possible. A direct interpretation of radio data from SN remnants with an age exceeding 100 years is ambiguous. The hypothesis concerning diffusive shock acceleration is consistent with observations, but is not rigorously proved (Beck et al. 8.1 - 10, Bogdan et al. 8.1 - II, Lawson et al. 6.2 - 4).

Old remnants of the SN Loop I and III are studied in the paper by Lawson et al. Diffusive shock acceleration of electrons up to energies  $E \sim 10$  GeV has been revealed. The CR diffusion coefficient in the galactic disk has been determined to be  $D \sim 10^{27}$  cm<sup>2</sup>/s.

Of importance is finding the fraction of SN explosion energy which can be transferred to CR. This problem has been solved numerically in the test particle approximation in the paper by Dorfi and Drury (8.1 - 9). With the explosion energy of  $10^{51}$  erg and with the diffusion coefficient equal to  $10^{27}$  cm<sup>2</sup>/s, the effective acceleration of background relativistic particles starts at the moment  $t = 6 \cdot 10^{11}$  sec after the explosion, and by the moment  $t = 2 \cdot 10^{14}$  sec about 12 % of the initial SN energy is transferred to high-energy particles. Such an efficiency is, in principle, sufficient to replenish the observed CR energy density.

## 3.2. Nonlinear CR shocks

The high efficiency of shock acceleration and a comparatively large energy density of relativistic particles in cosmic plasma lead to the necessity to study the back reaction of accelerated particles to thermal plasma. (In this case the quantities  $\bar{u}$  and  $\bar{D}$  in equation (3.1) cannot be regarded as externally given parameters). This nonlinear problem turns out to be very complicated.

If CR are assumed to be a separate relativistic gas component with a pressure  $P_{cr}$ , an internal energy density  $w_{cr}$ , and an effective average diffusion coefficient  $\bar{D}$

$$P_{cr} = \frac{4\pi}{3} \int_0^{\infty} dp p^3 v f(p), \quad w_{cr} = 4\pi \int_0^{\infty} dp p^2 E_k f(p), \quad (3.9)$$

$$P_{cr} = (\gamma_{cr} - 1) w_{cr}, \quad \bar{D}(x) = \left( \int_0^{\infty} dp p^2 D E_k \frac{\partial f}{\partial x} \right) \cdot \left( \int_0^{\infty} dp p^2 E_k \frac{\partial f}{\partial x} \right)^{-1}$$

then in the double-fluid hydrodynamic approximation the equations of one-dimensional motion of a medium, with an account of CR action, have the form

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x} (\rho u) = 0, \quad \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} = - \frac{1}{\rho} \frac{\partial}{\partial x} (P_g + P_{cr}), \quad (3.10)$$

$$\frac{\partial P_g}{\partial t} + u \frac{\partial P_g}{\partial x} + \gamma_g P_g \frac{\partial u}{\partial x} = 0, \quad \frac{\partial P_{cr}}{\partial t} + u \frac{\partial P_{cr}}{\partial x} + \gamma_{cr} P_{cr} \frac{\partial u}{\partial x} = \frac{\partial}{\partial x} \bar{D} \frac{\partial}{\partial x} P_{cr}.$$

In the study of self-consistent shock structure, one seeks for steady solutions which would describe the transition from the state given for  $x = -\infty$  (upstream) to the state uniform for  $x = +\infty$  (downstream), see the reviews cited at the beginning of Sec. 3.

A more complicated problem, which takes into account the finite energy of CR-scattering mhd waves, has been considered in the papers by Volk and Mc Kenzie (1982), Volk et al. (1984). These waves are assumed to be generated due to stream instability of relativistic particles before the shock front. The set of equations (3.10) must then be modified in the respective way.

An account of CR pressure changes the profile of a hydrodynamic flow near the shock front, see Fig. 4. There appears a region of smooth variation of upstream velocity (precursor), and in the general case there remains a step-like jump of velocity (subshock) determined by gas viscosity. This situation is similar to isothermal jumps for strong shocks in media with a thermal conductivity coefficient substantially exceeding the viscosity coefficient in the usual hydrodynamics (Landau and Lifshitz, 1959).

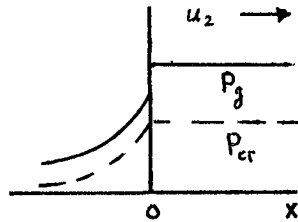


Fig. 4. A stationary modified shock

Unfortunately, one had not yet succeeded in obtaining a single-valued steady-state solution to the problem (more precisely, in obtaining generalized Rankine-Hugoniot conditions for arbitrary values of  $N = P_{cr}(-\infty)/(P_{cr}(-\infty) + P_g(-\infty))$  and the Mach number of the incoming flow  $M_*^2 = \rho u_1^2 \cdot (\gamma_g P_g + \gamma_{cr} P_{cr})^{-1}$ . It is shown, in particular, that for  $\gamma_g = 5/3$ ,  $\gamma_{cr} = 4/3$  in the general case there may exist three solutions in the downstream region for certain upstream conditions. Such an unambiguity is caused by divergency of the quantity  $P_{cr}$  with the momentum  $p$  for flat spectra  $f(p) \sim p^{-4+\epsilon}$  ( $\epsilon \geq 0$ ), see (3.9). Then the definition (3.9) also loses sense for  $D$  (if  $D(p)$  increases with  $p$ ). Indeed, let the diffusion coefficient increase with energy and the transition region from  $u(-\infty)$  to  $u(+\infty)$  have the finite dimension  $\Delta x$ . For particles with momenta  $p \gg p_*$ , where the value  $p_*$  is determined from the condition  $u_1 \cdot \Delta x / D(p_*) = 1$ , acceleration proceeds in the same way as on a step-like profile of the velocity  $u(x) = u_1 \Theta(-x) + u_2 \Theta(x)$ , and the spectrum of high-energy particles has the form (3.2). The degree of compression for a strong shock exceeds here  $r = 4$  since the presence of relativistic particles in the downstream region softens the equation of state ( $\gamma_{cr} < \gamma_g$ ). In this case the spectrum  $f(p) \sim p^{-4+\epsilon}$  and  $P_{cr} = \infty$ . This implies that a steady-state solution with a limited total width of the transition region is impossible. Additional difficulties are caused by the functional dependence  $\gamma_{cr}(f(p))$ .

It has become clear that in general either the maximum particle energy must be restricted by introducing additional loss processes into the problem or the acceleration must be treated as a time-dependent problem (Drury, 1984),

The time-dependent structure of a nonlinear CR shock is numerically investigated in the paper by Dorfi (8.1 - 3). For not too large a value  $M_* = 4.4$  and for  $N = 0.5$ , the transition from a gas dominated shock to a shock modified by CR takes up the time of  $(30 - 40) D/u^2$ . For a high Mach number  $M_* = 10$  and for a small value  $N = 0.05$ , there appears no back effect of the CR pressure on the motion of background plasma up to a time  $t \sim 10^3 D/u^2$ .

Beck and Drury (8.1 - 4) analytically investigate the time-dependent problem. They construct a selfsimilar solution which depends on the similarity variable  $\zeta = x/t$ . Selfsimilar shock structures are shown to contain always a subshock. The solution to the problem for shocks with a large Mach number has not been obtained.

The problem of seeking for an unambiguous solution, which has not yet been finally solved, is in a sense only of academic interest. Volk et al. (1984) have shown that in the framework of three-fluid hydrodynamics in the strong wave damping approximation the solution is unique in a wide range of reasonable astrophysical parameters.

The study of the dynamics of SN remnants with an account of the action of accelerated CR, which is of great importance for astrophysics, has been started in the paper by Volk et al. (8.I - 12). First results have been obtained on the time evolution of the kinetic remnant energy, the thermal energy of a heated gas, and the total CR energy. It has been shown that 10 - 50% of the initial energy of an explosion can be transferred into the CR energy.

Another, not hydrodynamic approach to nonlinear CR shocks is developed in the papers by Eichler and Ellison (8.I - 6) and Berezhko et al. (8.I - 13) (see also Eichler (1979, 1984), Krymsky (1981), (1983), Ellison and Eichler (1984)). This approach consists in a unified description of thermal and accelerated particles, i.e. along with acceleration one considers thermal particle injection. Particle acceleration is an inherent part of the very process of shock formation in plasma. It is assumed that there exists a maximum particle energy  $E_{max}$  above which they cannot be confined near the shock. Therefore, there exists a continuous energy flux from a system

$$q(x) = - \frac{j}{3} \int_{-\infty}^x \frac{du}{dx'} E_{kmax}^2 N(E_{kmax}) dx' \quad (3.9)$$

( $j = 2$  for nonrelativistic particles and  $j = 1$  for ultra relativistic particles). The diffusion coefficient  $D(p)$  is assumed to increase with momentum.

For fast particles the distribution function obeys equation (3.1). Using the mass and momentum flux conservation conditions for given upstream values, one finds a stationary solution of equation (3.1). The final solution is obtained by matching the low-energy spectrum region to the thermal background distribution.

An alternative procedure consists in the numerical solution of the kinetic equation with a simplified collision integral in the entire particle momentum region and in the definition in this way of the complete distribution function.

In the paper by Eichler and Ellison (8.I - 6) in the described scheme, the final velocity of waves generated by an accelerated particle stream is taken into account for the first time. Figures 5,6 present the obtained spectrum of accelerated particles for the case of acceleration by SN remnants in interstellar medium. The values  $E_{max} = 10^{15}$  eV,  $B = 3 \cdot 10^{-6}$  G,  $n = 10^{-2}$  cm $^{-3}$ ,  $u_1 = 10^3$  km/s were used.

It is remarkable that for a wide range of reasonable astrophysical parameters the spectrum turned out to be close to  $N(E_k) \propto E_k^{-2}$ . Typical is also the presence of two maxima in the function  $E_k^2 N(E_k)$  - for thermal energies and for  $E_{max}$ .

For the spectra shown in Fig 5 the kinetic energy flux going into relativistic particles makes up 72 - 26 %.

Such a calculation is in a good agreement with observations for shocks in interplanetary medium (Ellison and Eichler, 1984), but the problem as a whole cannot yet evidently be considered as finally solved. Suffice it to say that the indicated scheme must include, in particular, the theory of collisionless shocks in a usual plasma. This theory has been intensively developed for already about 30 years.

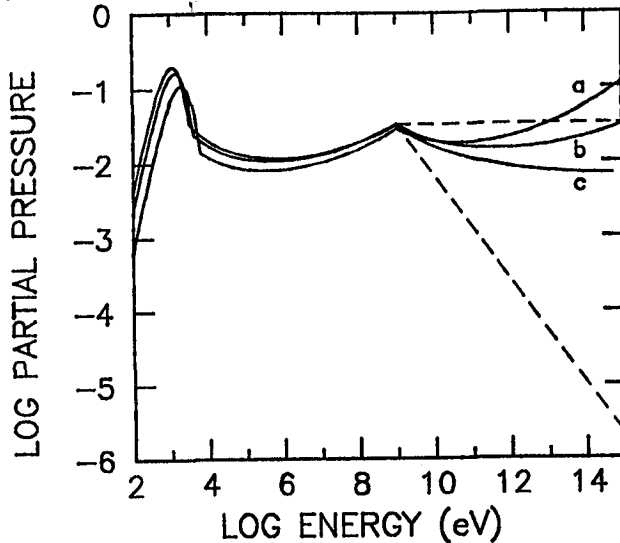


Fig. 5 Postshock partial pressure vs. energy. An energy cutoff =  $10^{15}$  eV has been used. Each label represents a family of curves with a particular  $u_1/u_2$  (GeV). 068.1-6.

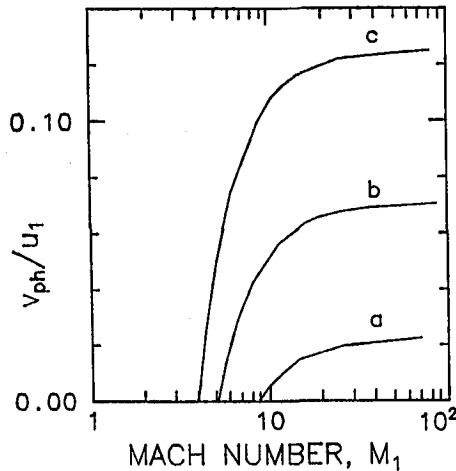


Fig. 6 Labels same as Fig. 5

It is of importance to note, however, that the difficulties in the theory of nonlinear CR shocks are due to the high efficiency of the diffusive shock acceleration and, in fact, we try to understand what it is limited to. In any case, the efficiency of the conversion of the energy of an ordered hydrodynamic stream into the energy of relativistic particles typical for the galactic model of CR origin ( $\sim 10\%$ ) does not seem to be excessive.

There are no essential difficulties with explanation of the observed power-law energy CR spectrum. The problem consists in obtaining a sufficiently large  $E_{\max} \sim 10^{17} - 10^{19}$  for galactic CR sources. So, for instance, the value  $E_{\max} \sim 10^{15}$  eV presented in Fig. 5 has been not calculated, but postulated. For the values  $B = 3 \cdot 10^{-6}$  G,  $n = 10^{-2}$  cm $^{-3}$  used by the authors, an SN explosion with a total energy  $W = 10^{51}$  erg may, in accordance with (3.5), actually give  $E_{\max} = 3 \cdot 10^{14}$  eV. In the standard model of CR propagation in interstellar medium, the value of  $D_{\parallel} \sim r_H v$  entering (3.5) seems to be strongly underestimated. The value of  $E_{\max}$  should rather be lowered by several orders of magnitude (for more details see Volk, 1981).

The effect somewhat increasing  $E_{\max}$  is generation of a strong random magnetic field near the remnant due to the stream instability of accelerated particles. This process cannot be investigated within the theory of weak turbulence, and its analysis remains a challenge for theoreticians (see Drury 1983, Volk 1984). The possibility of hightening  $E_{\max}$  (may be up to  $10^{16}$  eV) under CR acceleration in the reverse shock inside an SNR is pointed out by Volk et al. (8.I - 12).

### 3.3. New problems

In their paper (8.I - 5) Dorfi and Drury have revealed a new interesting effect which accompanies CR diffusive shock acceleration. It has been shown that in the region of precursors there develops an instability of compressional disturbances of the medium, due to the CR gradient, for the wavelengths  $1 \ll \lambda \ll L$  ( $l = 3D/v$  is the mean free path of a particle,  $L = D/u$  is the dimension of the precursor). The instability arises for  $L < |I + \frac{\delta(\ln D)}{\delta(\ln \rho)}| \cdot D/v_{s2}$  and develops during the time  $\tau \sim L/v_{s2} \cdot M_1^2$ . For  $M_1 \gg 1$ , the time  $\tau$  is small as compared with the time of convectional outflow of disturbances from the precursor region  $L/v_{s2} \cdot M_1$ . Slight density disturbances in the upstream medium must be substantially amplified in the precursor region.

Zank and Mc Kenzie (8.I - 2) confirm the existence of such an instability. They also investigate instability of a CR shock with respect to long-wave disturbances ( $\lambda \gg L$ ). In the presence of a relativistic CR gas, strong shocks always prove to be unstable.

The effect of these instabilities on the shock structure has not yet been investigated. One may expect a strong stochasticization of the motion of the medium before a shock, the appearance of secondary shocks, an additional widening of the



front and even destruction of its plane structure.

Webb (8.I - 1) was the first to study the structure of relativistic CR shocks. He points out that the effective CR acceleration proceeds for  $u_1 < c \sqrt{\gamma_{cr} - 1} \approx 0.58c$ . In high-velocity streams ( $u_1 > c \sqrt{\gamma_{cr} - 1}$ ) CR cool down.

#### 4. High-energy particles in various astronomical objects

##### 4.1. Active galactic nuclei

AGN and quasars are possibly the most powerful CR sources. It is believed now that the particles of ultra high energies  $E > 10^{19}$  eV observed near the Earth have been accelerated just in AGN. To the presence of relativistic particles there testifies nonthermal AGN radiation (see Rees 1984), but concrete mechanisms of particle acceleration remain unclear.

Kazanas and Ellison (8.I - 7) consider diffusive shock acceleration of protons in accreting matter near a black hole of mass  $M_g = M/(10^3 M_\odot)$ . Accelerated relativistic protons provide the pressure to support the standing shock. They undergo inelastic nuclear collisions and generate secondary  $e^\pm$ ,  $\gamma$ ,  $\gamma$ , which are responsible for the observed radiation. For a nearly 100% conversion of the hydrodynamic motion energy into relativistic particles, Kazanas and Ellison have calculated the expected nonthermal luminosity  $L = 1.5 \cdot 10^{47} M_g x_1^{-1}$  erg/s =  $1.2 L_E x_1^{-1}$ , where  $L_E = 1.3 \cdot 10^{47} M_g$  erg/s is the Eddington luminosity,  $x_1 = R/R_g$  is the radius of a spherical shock in Schwarzschild radii. The model provides a natural explanation of the observed  $L \propto M$  correlation for quasars and galactic nuclei. In this case  $10 \lesssim x_1 \lesssim 200$ . For the case NGC 4151 ( $M = 3 \cdot 10^7 M_\odot$ ,  $L = 10^{43}$  erg/s)  $L = 2.5 \cdot 10^{-3} L_E$ ,  $x_1 = 140$ .

##### 4.2. Neutron stars in close binary systems

Ultra high-energy ( $> 10^{15}$  eV)  $\gamma$  - rays (or/and unidentified neutral particles) have been observed from Cyg X - 3 and possibly from the X-ray binary sources LMC X-4, Vela X-I. Taking the measurements at face value, we have indication of a striking efficiency of CR acceleration in the compact binary systems containing n-stars. It is sufficient to have CygX-3 alone to maintain the present flux of the galactic CR above  $10^{16}$  eV. The extragalactic source LMC X-4 ( $E_\gamma > 10^{16}$  eV) has (?) a luminosity more than 20 times the one of Cyg X-3.

Taking the Haverah Park flux for Cyg X-3  $F_\gamma (> 2 \cdot 10^{15} \text{ eV}) = 1.1 \cdot 10^{-10}$  erg/cm<sup>2</sup>s, Hillas (5.4 - 7) obtains the following estimate for proton luminosity of the source

$$L_p(10^{16} - 10^{17} \text{ eV}) = \frac{\Omega}{4\pi} \times 6 \times 3 \times 50 \times 4\pi r^2 \times 1.1 \cdot 10^{-10} = \frac{\Omega}{4\pi} 1.7 \cdot 10^{39} \text{ erg/s} \quad (4.1)$$

Here we have the factors taking into account the appearance of particles in a solid angle  $\Omega$ , the efficiency of energy

conversion  $p \rightarrow \gamma$ , absorption in rout due to  $e^-e^+$  pair creation on relic radiation, pulse duty ratio of the 4.8 h period of the system. The distance to Cyg X-3 is taken to be equal to  $r = 12$  Kpc.

The proton luminosity being so high, Cyg X-3 must also be a source of secondary neutrinos (see Beresinsky 2.I - 7, Brecher and Chamugam 2.2 - 5, Gaisser and Stanev 1985).

The hypothesis on propagation of neutral radiation from Cyg X-3 in the form of photino (V.J.Stenger) requires an im-probably high proton luminosity  $L_p = 2 \cdot 10^{44} (\Omega / 10^{-2})$  erg/s (Beresinsky 2.I - 7).

As the energy source of accelerated particles in a bi-nary system consisting of a normal star and a magnetized neu-tron star, one considers two main possibilities: 1) accre-tion from a normal star onto an n-star; 2) pulsar action of the n-star itself.

In any case, proton acceleration proceeds in the vicini-ty of an n-star. The primary proton spectrum has a power-law form or is a monoenergetic beam with an energy  $E \sim 10^{17}$  eV. In the latter case, the power-law spectrum of radiation and of secondary particles is caused by a cascade in the target re-gion (Hillas 1984, 5.4 - 7).

Secondary UHE  $\gamma$ -rays appear as a result of pp collisions in an accreting gas outside the acceleration region or in the atmosphere of the companion star. (Aharanian et al. (2.6 - 13) notice that at a rather high density of background low-fre-quency radiation in the source, a substantial contribution is made also by photomeson  $\gamma$ -ray generation).

In the source Cyg X-3 in different periods of observa-tions in the UHE range,  $\gamma$ -pulses had two different values for the phase of the 4.8-hour binary orbit:  $\psi = 0.25$  and

$\psi = 0.63$ . According to Hillas (5.4 - 7), in the periods of  $\psi \sim 0.6$  the target for the production of secondary  $\gamma$ -photons is a wake which occurs if accretion appears from a stellar wind, see Fig.7 (a similar scheme is discussed by Protheroe and Clay (1985) for LMC X-4).

The dynamics of the interaction between an accelerated particle beam and the atmosphere of a companion star is con-sidered by Beresinsky (2.I - 7). He proposes a heating model in which radiation in the phase  $\psi \sim 0.2$  is not accompanied by the appearance of a symmetric pulse  $\psi = 0.8$ .

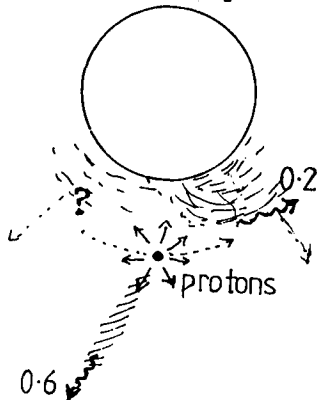


Figure 7. Supposed geometry for Cygnus X-3. 06 5.4 - 7.

To choose a concrete model of CR acceleration in binary systems, it is important to establish whether or not Cyg X-3 is a unique UHE  $\gamma$ -ray source.

So, for a pulsar model (Eichler and Vestrand 1984, Berezhinsky 1979, 2.1 - 7) a very young pulsar with a rotation speed of  $10^2 - 10^3$  times per sec. is needed. Such a version is excluded for the sources LMC X-4 ( $P = 13.5$  s), Her X-I ( $P = 1.24$  s), 4U 0115 + 63 ( $P = 3.61$  s), but is not excluded for Cyg X-3 (the value of  $P$  is unknown).

In accretion models of CR acceleration two schemes are considered - the dynamo model in an accretion disk and shock acceleration in an accretion flow.

Brecher and Channugam (1985; 2.2 - 5) proposed a unipolar induction model for CR acceleration in accretion binary systems, such as Cyg X-3, Her X-I, Vela X-I, LMC X-4.

Details of the electrodynamics of such systems are not yet clear. Particle acceleration is assumed to be caused in the end by a very high potential drop across the accretion disk between the Alfvén radius and the external edge of the disk. The scaling law  $E_{\max} \propto B^{-3/7} L^{5/7}$  ( $L = GM\dot{M}/R$  is the total accretion luminosity of an  $n$ -star of mass  $M$  and radius  $R$ ,  $B$  is a magnetic field on its surface) is obtained for the maximum possible energy of an accelerated particle. The maximum luminosity in relativistic particles is estimated to be  $L_{p \max} \sim 2cE_{\max}^2/e^2$  ( $e$  is the particle charge). Thus, for a given magnetic field strength the higher the accretion rate, the larger the maximum CR particle energy and the higher the total particle luminosity. For  $B = 10^{13}$  G the energy  $E_{\max} \sim 10^{17}$  eV is reached for a very high accretion rate  $\dot{M} = 10^{-6 \max} - 10^{-5} M_{\odot} \text{ yr}^{-1}$ , i.e.  $L \sim 10^{40} - 10^{41}$  erg/s. In this case for relativistic particles there goes  $L_{p \max} \sim 10^{39}$  erg/s. Most of the energy must be released in the form of a jet. In the unipolar induction model comparatively weak fields  $B \sim 5 \cdot 10^9$  G are preferable. In this case  $E_{\max} = 10^{17}$  eV,  $L_{p \max} = 10^{39}$  erg/s  $\sim L$ . The value  $B = 5 \cdot 10^9$  G is not excluded for Cyg X-3 (the field is unknown), but is excluded for Her X-I ( $B = 4 \cdot 10^{12}$  G) and 4U 0115 + 63 ( $B = 10^{12}$  G).

The model of shock acceleration of particles in application to the source Her X-I is considered by Eichler and Vestrand (2.2 - 8). For an explanation of  $\gamma$ -radiation outbursts observed for energies  $E > 10^{12}$  eV and  $E > 10^{14}$  eV, they suggest a diffusive shock acceleration in an accretion column at a distance  $R \sim 30$  radii of the  $n$ -star (at smaller distances acceleration is hampered by synchrotron losses). In this case  $E_{\max} \sim 10^7 mc^2 (R/10^6 \text{ cm})^{-1/6}$ . The observed  $\gamma$ -rays are formed in the interaction between protons and the surrounding accretion disk. The model predicts  $\gamma$ -ray outbursts at the onset and decline of the high-intensity X-ray state. At this time our line of sight is grazing the accretion disk. Radiation of  $\gamma$ -rays with an energy  $E > 10^{16}$  eV is impossible in this model (see, however, Kazanas and Ellison, 1985).

The existence of such UHE  $\gamma$ -ray sources as Cyg X-3, possibly leads to the formation of a galactic X-ray halo (Rana et al. 2.2 - 6). Under  $\gamma\gamma$  collisions with relic photons,

UHF  $\gamma$  -rays produce  $e^- e^+$  pairs, and these will in turn generate hard X-rays by synchrotron radiation in the galactic magnetic field.

#### 4.3. Stars

Normal stars may be injectors of fast particles which are further accelerated up to high energies. Bogdan and Schlickeiser (8.3 - 9) consider resonant statistical acceleration of electrons in flaring stars. The maximum particle momentum is limited in this case to the energy losses due to synchrotron radiation and in this model makes up  $p \sim 1.5 \cdot 10^8$  eV/c for the magnetic field of a star  $B = 100$  G.

#### 4.4. SN remnants

Most of the papers on CR acceleration in SNR have already been discussed in Sec. 3.

In some SNR (Crab), relativistic particles are supplied by a central source - a pulsar. The remnant G 29.7 - 0.3 (the distance - 19 Kpc, the dimension - 1.8 pc) may also appear to be an object of this type. High resolution maps obtained with the VLA show two spectrally distinct components - a flat-spectrum core surrounded by a shell. Koch-Miramond et al. (6.2 - 10) have presented the data of Exosat observations of X-ray radiation of the remnant in the 2-10 KeV range. The search for pulsations with a period between 32 ms and 10 s in the radiation of the object has not yielded a positive result. Assuming radio and X-ray radiation to be synchrotron, they obtained the values of the field  $B = 2 \cdot 10^{-4}$  G and of the total electron energy  $W = 1.6 \cdot 10^{47}$  erg. A continuous energy injection from the central source follows from the small synchrotron electron lifetime as compared with the SNR age.

#### 4.5. Molecular clouds.

In the paper by Dogiel et al. (8.2 - 17) giant molecular clouds are interpreted not as passive targets for relativistic particles, but as active objects which accelerate CR up to  $\sim 10$  GeV. The energy sources are hydrodynamic motions of a neutral gas which generate a chaotic magnetic field. The galactic CR that penetrate from without undergo a statistical acceleration, as a result of which the CR energy density increases by about an order of magnitude. This explains a heightened  $\gamma$  -luminosity of some molecular clouds (the expected  $\gamma$  -ray spectrum  $F_\gamma(E) \propto E^{-1}$  for  $E > 100$  MeV). An intensified production of secondary particles in clouds could explain also an anomalous amount of  $\bar{p}$ ,  $d$ ,  $^3\text{He}$ ,  $e^+$  in CR.

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