PARTICLE ACCELERATION: FROM GALAXIES TO LARGE SCALE STRUCTURE

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Abstract. In this brief review we discuss current efforts to understand the origin of energetic particles, focussing here on the recent work on the physics of supernova explosions. Acceleration to the highest energy may come from jets and hot spots emanating from massive black holes. If the sky remains smooth in the arrival directions of ultrahigh energy cosmic rays to the highest energies, then we need new sources, and one extreme speculation would be to invoke Lorentz Invariance Violation, with proton decay, neutron survival, and no strong photomeson interaction to higher energy. For the Galactic cosmic rays explosions of red supergiant stars and Wolf Rayet stars may provide much of the cosmic rays. This is intimately connected with the physics of their explosion, and implies that the magneto-rotational mechanism is the main one chosen by Nature. This offers a consistent picture for the X-ray fans of Cas A, and gamma ray bursts. Each of these concepts leads to clear predictions. It will be quite an achievement to prove this or any other proposal - none is without difficulties. We do have potentially a full theory to account for cosmic rays at all energies; crucial tests will be performed with the current new instruments.

Keywords: Fundamental aspects of astrophysics: Elementary particle processes. Cosmic rays: Composition, energy spectra, and interactions, Extensive air showers, Neutrinos and muons. Late stages of stellar evolution (including black holes): Supernovae, Black holes. Interstellar medium (ISM) and nebulae in Milky Way: Physical properties. Unidentified sources of radiation outside the Solar System: Gamma-ray bursts, Cosmic rays
PACS: 95.30Cq, 96.40.De, 96.40.Pq, 96.40.Tv, 97.60.Bw, 97.60.Lf, 98.38.Am. 98.70Rz, 98.70.Sa

INTRODUCTION

Ever since their discovery 1912/1913 by V. Hess and W. Kohlhörster cosmic ray particles have fascinated the physics community. These particles offer the opportunity to explore physics at energies far beyond any accelerator on Earth. In recent years there have been many experimental advances, especially the start of the construction of the AUGER airshower array with the forthcoming publication of the first data in 2005, the first results from the very sensitive TeV gamma-ray telescopes HESS and MAGIC, many balloon flights in Antarctica, mostly recently the Antarctic triply circumpolar flight of CREAM, the first results and limits from the neutrino experiment AMANDA, soon to be followed by ICECUBE, and the ongoing analysis of the results from the airshower experiment KASKADE and KASKADE GRANDE, to name just some. Of special interest is the recognition, that the radio emission from airshowers might present a new path to a physical understanding, using instruments like the very high speed radio telescope array

LOFAR (H. Falcke *et al.*., from 2003). On the theoretical side the relatively flat gamma ray spectrum of the Galaxy measured by EGRET keeps challenging us, but we begin to see a possible connection between the explosions of massive stars, and gamma ray bursts, and the ensuing cosmic ray particles. This illustrates the importance of studying the massive star and its structure and evolution, as well as environment for understanding its explosion. Here in this review we emphasize some of these latter points, noting that the magneto-rotational mechanism for the explosions of massive stars is currently the only proven candidate as an explosion mechanism for massive stars; a common concept is developing, albeit still tentative, between arguments from stellar evolution, supernova physics, gamma ray burst physics, and cosmic ray arguments.

This review is divided in the following sections: 1) Large scale structure, 2) Large and small black holes, 3) Supernovae (SNe) from zero age main sequence (ZAMS) mass to 15 solar masses, 4) SNe from red/blue supergiants and from Wolf Rayet stars, 5) Gamma ray bursts (GRBs), as well as a summary. For lack of space we cannot approach to do justice to all the researchers in the field, and refer the interested reader to websites and reviews, mentioned in overviews and articles which we do quote (e.g., P. Biermann *et al.*., 2004, A. Olinto 2004, J. Niemiec & M. Ostrowski 2004, R. Protheroe 2004, J. Quenby & A. Meli 2004); explicitly we list only a few papers from 2003 here. Other lectures at this meeting cover some of the same topics, from different viewpoints.

LARGE SCALE STRUCTURE

In the large scale structure of the galaxy distribution there are accretion shocks (T. Enßlin *et al.*., from 1998), both around clusters of galaxies, as well as on both sides of the sheets and filaments. These accretion shocks accelerate particles to high energy (H. Kang *et al.*., 1997), but not quite the maximum energy observed. These shocks also on the one hand squeeze clouds of low energy suprathermal particles, and on the other influence the expansion of radio galaxies.

The structure formation itself can be modified slighty by ubiquitous energetic particles, with some smearing of small scale structure (D. Ryu *et al.*., 2003). This effect lowers the power in the cosmological small scale density perturbations.

LARGE BLACK HOLES

Connecting the relativistic jets to the rotating black holes, and the surrounding accretion disks leads to a spatial limit for the maximum energy of particles, first derived via scaling arguments by R. Lovelace, and then confirmed quantitatively by H. Falcke *et al.*. (from 1995) in detailed modelling:

$$E_{max} \simeq 5\,10^{20}\,L_{disk,46}^{1/2}\,\mathrm{eV} \tag{1}$$

Losses are a stronger constraint at high luminosity:

$$E_{max} \simeq 10^{21}\,L_{disk,46}^{-1/4}\,\mathrm{eV} \tag{2}$$

In these estimates of the maximum particle energies we have used the fit to the cutoff frequency observed in the optical (P. Biermann & P. Strittmatter 1987; P. Biermann 2001); fitting this observed cutoff due to the loss of the electrons allows to fix the key free parameters for the proton acceleration. One has to note that in these models the acceleration itself has been treated in a frame in which the shock is non-relativistic.

Modelling then the scattering in a putative magnetic Galactic wind model (work by A. Curutiu, 2003, www at Bonn) demonstrates that we can attain a smooth sky distribution of arriving particles, even if we had only one nearby source, around $3\,10^{19}$ eV, but certainly not at $2\,10^{20}$ eV. At the higher energies the sky distribution should get progressively patchy, we predict.

If this is confirmed, then the two nearby sources, the radio galaxies M87 and Cen A, might account for all the high energy particles, M87 at the highest energies, and Cen A up to a few 10^{19} eV (work by O. Tascau, 2003, www at Bonn). Both are easily within the radial distance allowed for cosmic ray interaction with the microwave background, of about 50 Mpc, commonly referred to as the Greisen-Zatsepin-Kuzmin (GZK)-distance, after the discoverers of this interaction.

On the other hand, if the sky remains smooth to the highest energies, even for a subset of the events, then we just might require very different physics, in one extreme speculation Lorentz Invariance Violation (S. Coleman, S.L. Glashow, 1999): This is an effect predicted in quantum gravity, and could allow the decay of protons, the stability of neutrons, and a shift of photomeson production to higher energy, so that all the highest energy particles could be neutrons, going straight through the universe. Another option would be neutrinos, including the Z-resonance (e.g. G. Gelmini, A. Kusenko, T. Weiler, *et al.*.).

SMALL BLACK HOLES AND NEUTRON STARS

Work by H. Falcke *et al.*., S. Markoff *et al.*., and F. Yuan *et al.*. (www at Bonn) has demonstrated, that with the jet-disk symbiosis picture we do get satisfactory fits to the electromagnetic spectra of microquasars, low luminosity active galactic nuclei (AGN), and normal AGN. This entails that active black holes, even on the stellar mass scale, accelerate particles in shocks in their relativistic jets. However, the maximum particle energy expected from such sources is around 10^{17} eV; so contributions beyond the cosmic ray knee, at about $3\,10^{15}$ eV, are possible (see also work by S. Heinz & R. Sunyaev 2002). In extreme cases the ankle around $3\,10^{18}$ eV might be reachable, so the AUGER threshold of $3\,10^{17}$ eV might well be attained. As work by W. Bednarek & M. Bartosik (2004) has shown, pulsars are a possible contributor as well, although probably not even all the way to the knee energy. The only exception to such limits are GRBs, that almost certainly accelerate particles to close to 10^{20} eV, maybe even beyond, in a full analogy to radio galaxy jets and hot spots.

Clearly the new generation TeV-Cerenkov-telescopes, HESS, MAGIC, and VERITAS, will provide decisive progress on our knowledge of the sites of cosmic ray acceleration (e.g., F. Aharonian *et al.*., 2004). Also, the final analysis of the airshower observations across the knee by KASKADE and KASKADE-GRANDE in Karlsruhe should provide additional constraints; here it is important for any model to also match the higher energy data.

SUPERNOVAE FROM ZAMS MASS UP TO 15 SOLAR MASSES

A. Heger *et al.*. (2003) have given an overview on single star explosions of massive stars. In these descriptions, rotation was included, but otherwise stars were assumed to be single, and to have no magnetic field; a large fraction of all stars are in binary systems, and at least initially, and many, maybe all, are magnetic: Therefore one question is then where magnetic fields in stars come from.

As was shown some time ago, a weak magnetic seed field in stars can be produced by a non-coincidence of surfaces of constant pressure and constant density in rotating stars (work by L. Biermann 1950). This weak seed field can be enhanced by the rise-twist-fold mechanism, usually called dynamo mechanism, invented independently at about the same time by M. Steenbeck & F. Krause in the former East Germany, and by E. Parker in the US. The mechanism requires many rotations, since at each rotational period the weak field is enhanced only a small amount. However, as most stars have about 10^{10} rotations in their lifetime, this appears to be sufficient. The Sun is the testbed for all such plasma physics arguments. Stars are thus one key to understand cosmic magnetic fields.

These magnetic fields are probably important for the explosion physics at all masses (for SN Ia see G. Lugones *et al.*. 2002, and C. Ghezzi *et al.*. 2004). Stars of a ZAMS mass below about 15 solar masses explode into the interstellar medium (ISM), and then through a snow-plow effect the shock gets slower with time (see, e.g., D.P. Cox 1972a, b, c).

These stellar explosions cause a shock wave to travel through the interstellar medium; this shock wave is thought to inject and accelerate ions to cosmic ray energies. However, in this concept, the abundances of cosmic rays, which are very different from normal interstellar matter, need explanation: there are two main suggestions for this: One idea is that low mass stars in their chromospheric activity inject selectively many ions into a suprathermal energy level (e.g., work by M.M. Shapiro), which then provides the seed population in the ISM. Another idea is that charged dust grains reflect in their motion another selective path as the injection step for energetic particles (work by J.P. Meyer, L. Drury). However, this latter notion predicts broad gamma lines, which have not yet been observed to date. And the first concept may require more power of these low mass stars than is available.

Both ideas fail considering the abundances in the young Galaxy, when spallation products are abundant at the same time the heavy element abundance is still very low. For this R. Ramaty *et al.*. probably have found the explanation, in that they convincingly argue that the injection and acceleration happen in a very enriched environment.

One other aspect that is usually ignored in modelling these explosions, is that we in fact observe extreme unsteadiness with time, e.g. in Cas A, for which radio movies exist today. The amplitude of the random velocity component is equal to the overall expansion velocity (work by R. Braun, R. Tuffs). Therefore, we should not be surprised, if also the cosmic ray emission spectra of young supernova remnants (SNR) vary in space and time; cosmic rays as observed are the result of accumulation of all accelerated particles, including adiabatic losses. In one acceleration model (P. Biermann from 1993) this unsteadiness is a key aspect of the physical argument on particle scattering and acceleration.

Incorporating the slow deceleration of the expanding shock, C. Cesarsky *et al.*. showed that the final maximum particle energy is of order 10^{14} eV, still below even the knee near $3\,10^{15}$ eV.

This last limitation is seen by many as the key problem of the notion, that supernova explosions into the ISM can account for all observed cosmic rays.

SNE FROM RED/BLUE SUPERGIANTS AND WOLF RAYET STARS

Radio observations have shown (work by J. Bieging and E. Churchwell), that very massive stars have magnetic fields, despite the fact, that their outer layers are radiative, in contrast to stars such as the Sun, which are convective in the surface layers. Very massive stars are convective at their center.

Massive stars inject through their powerful winds already appreciable energy into the ISM, before they blow up in explosions. Considering magnetic wind models (e.g. D. Breidtschwerdt *et al.*., H. Seemann & P. Biermann) it is conceivable that their injection of magnetic energy is of order 10 percent of their kinetic energy injection. This means that we may not need a Galactic dynamo to strengthen the magnetic field, we need it - or an equivalent process - to order the field, to provide large scale coherence (see G.S. Bisnovatyi-Kogan, A.A. Ruzmaikin, R.A. Sunyanev 1973).

When these stars blow up, they explode into the heavily enriched winds (work by H. Völk, P. Biermann *et al.*.), so quasi automatically providing the sites of injection and acceleration, that R. Ramaty *et al.*. require. We note that there we have one mechanism for the explosion (A. Heger *et al.*., 2003), and in addition Ni decay as a strong contributor for the lightcurve. The explosion mechanism is discussed below.

One important aspect in the acceleration of cosmic ray particles in shock waves that run through a magnetic wind, is that the magnetic field is normally almost exactly perpendicular to the shock normal; this requires a rethinking of the scattering of the energetic particles during acceleration, à la R. Jokipii (1987). He showed that the scattering coefficient in that case can approach a value smaller then the canonical value by c/V_{sh}, so providing much faster acceleration. Given this faster acceleration, the maximum particle energy is given by the time or the space available; A. Meli has performed Monte-Carlo simulations (2005) of Jokipii's approach, and finds consistency: The detailed understanding of the physical properties of red and blue supergiants, as well as Wolf Rayet stars is key to understand the cosmic ray acceleration by supernova shocks running through these winds.

What is then in this picture the origin of the knee? There are several arguments: Historically, the bend in the cosmic fray spectrum at around $3\,10^{15}$ eV, was believed to be due to a change in the transport of cosmic rays through the Galaxy. There is in fact a scale in the disk which just might relate to the scattering mean free path at the knee, and that is the thickness of the cold disk embedded in the much thicker hot disk of the ISM. It remains to be seen, whether such an argument can also explain the almost perfect isotropy in the sky distribution; we barely observe the gradient due to radial cosmic ray diffusion out of the Galaxy (AGASA). A second choice to interpret this is a modification in acceleration, from scatterings across a shock back and forth, to a scattering between different shocks, all running around in a hot star bubble environment, such as the Orion region. Here the question is whether the knee would not be expected to be quite smooth since many Orion like regions, all different, would contribute to what we observe. Third, the possibility exists, that the acceleration efficiency of a shock is modified, when the drift component changes at a scale given by the shocked layer's thickness in the wind: drift energy gain derives from the electric field in the frame of the shock, moving through the wind, and is proprotional to the curvature; the curvature in turn is given by the supersonic turbulence, until we reach the thickness of the shocked layer; an additional effect is the acceleration efficiency as a function of latitude in the wind, since the toroidal magnetic field scales as $\sin\theta/r$, with poloidal angle θ and radius r. However, such a concept requires that the cores of all massive stars are essentially the same in the rotation, magnetic field, and explosion properties at the time of explosion; one main difference among the very different appearances of supernovae type II could be due to aspect angle just as for AGN, for whom this is one key parameter, and a second parameter could be the residual envelope mass in a binary system for instance, irrelevant for the explosion, but leading to different lightcurves. If that were true, then almost certainly this points to the magneto-rotational mechanism as the physical mechanism to explode massive stars (N. Kardashev 1964, G. Bisnovatyi-Kogan 1970, P. Biermann 1993). It also means that the maximum energy is given by $Z\,10^{17}$ eV, and so the "second knee" is then explained by the ultimate cutoff in the Galactic cosmic ray spectrum.

GAMMA RAY SPECTRUM OF THE GALAXY

The gamma ray spectrum of the Galaxy, found by the EGRET data (St. Hunter *et al.*., 1997) to be too flat to be compatible simply with the pion decay from the average cosmic ray interaction, is another test for any cosmic ray origin theory and interaction model. Here we note that interactions near the source can be important, and are in fact demanded by the arguments of R. Ramaty *et al.*.. The shockwave races through the wind of a highly developed star, and so picks up the chemical abundances of that wind. The shock loaded up in energetic particles then smashes into the shell of gas around the stellar wind, and excites a wave spectrum, scatters in those waves, and spallates locally. This then gives the required spectral behaviour of the B/C ratio in low energy cosmic rays, and also contributes to the gamma ray emission. However, here we have to distinguish the large extended winds of the Wolf Rayet stars from the moderate size winds of red supergiants; in the latter winds there is not enough time to reach the maximum article energy, and also the wind shell is much less massive. Therefore we have proposed that in the encounter of the supernova shock with those winds the wave excitation is not relevant, the destruction of the shell is fast, so happens convectively, and then the resulting pion decay spectrum corresponds to the cosmic rays as accelerated, so fairly flat. A competing model has been developed by I. Strong *et al.*., which, however, requires an unknown additional emission component, which could be connected to quite different physics, like the decay product of some new particle.

Further cosmic ray interaction may happen close to the stars, that explode. This results then in a combination of several spectral contributions (see S. Casanova *et al.*., 2004): i) The interaction of the particles from the Wolf Rayet stars in the wind shell and the immediate environment, a diffusive process; ii) The interaction of the particles from the Red Supergiant stars in the wind shell and the immediate environment, a convective process. iii) The interaction of all particles in the average interstellar medium, from all three sites of origin, during the diffusive escape from the Galaxy.

This model has passed the tests of the multi-GeV spectrum of the Galaxy, the inner Galaxy, the outer Galaxy, and the latitude distribution. It predicted a sec/prim ratio of spallation products of $E^{-5/9}$, confirmed by V. Ptuskin. Also, the slight flattening of the sub-Fe and Fe-spectra of the primary cosmic ray has been interpreted as differential spallation. The chemical abundances have been checked in this model by A. Popescu (2003).

Further tests are the anti-proton and positron spectrum, and of course, the higher energy gamma-spectrum of the Galaxy; these tests remain to be performed.

MAGNETO-ROTATIONAL MECHANISM - SUPERNOVA EXPLOSIONS OF MASSIVE STARS

This idea was originally proposed by G. Bisnovatyi-Kogan (1970), based on an earlier suggestion by N. Kardashev (1964), and has recently been successfully worked out in numerical simulations (N. Ardeljan *et al.*., 2004, 2005, and S. Moiseenko, *et al.*., 2004). Magnetic fields may also be relevant for SN Ia (C. Ghezzi et al., 2004, G. Lugones *et al.*., 2002).

The idea is basically, that when pressure in the core of the star can no longer be maintained, it collapses, and due to angular momentum conservation, winds up; in winding up it enhances the magnetic field. When the angular momentum barrier is reached, then it stops collapsing in the equatorial plane, but keeps winding up the magnetic field. This ultimately very strong magnetic field acts as a conveyor belt to transport the energy out, and explodes the star. The subsequent lightcurve is then dominated by the explosion, and the energy input from Ni decay.

After several decades of toiling, and the development a new numerical scheme, using a triangular grid, it has now been possible to perform numerical simulations. These simulations demonstrate that the explosion energy does not depend on the initial magnetic field; varying the initial energy of the magnetic field by ten powers of ten does not change the final explosion. In Fig. 1 we show a typical result of the current simulations.

Interestingly, there is a dependence on the initial magnetic field topology: The energy of the explosion is almost the same $(0.5 - 0.6) \cdot 10^{51}$ erg, but the topology of the explosion is different. In the quadrupole case we have obtained the maximal ejection in the region around the equatorial plane, while for the dipole topology we have obtained in the calculations mildly collimated jets along the rotational axis.

Using cosmic ray statistics to estimate the required explosion energy for very massive stars implies, that we require a factor of ten more again, so 10^{52} erg (work by G. Pavalas, 2002). This is remarkably close to the hypernova concept proposed by B. Paczynski. It exceeds the energy obtained in the simulations, but variation of initial mass and stellar

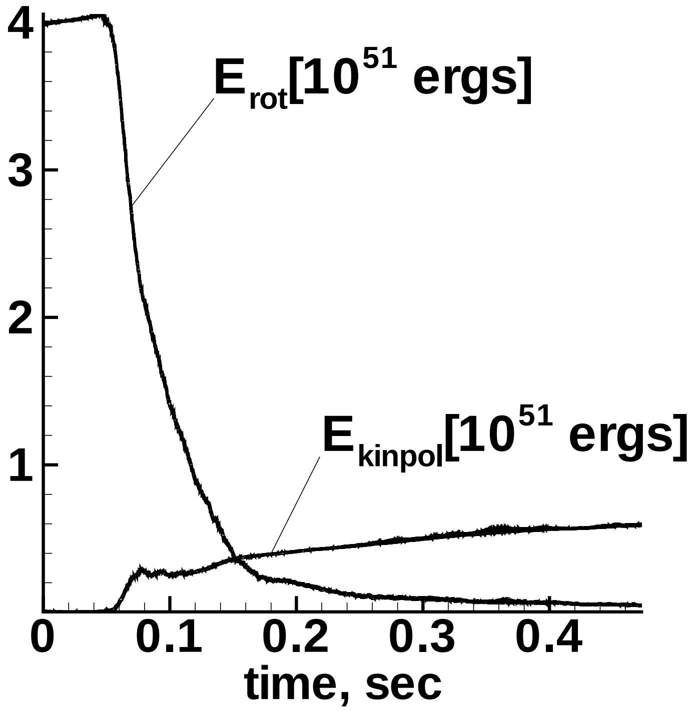

FIGURE 1. The time dependence of the rotational energy and the poloidal kinetic energy of the star during the magneto-rotational explosion; from N. Ardeljan *et al.*. (2004, 2005)

angular momentum distribution could make it larger.

The key point is that these explosions are rotationally symmetric, with a large dependence of appearance on poloidal angle, and so in their statistics begin to resemble active galactic nuclei. Such explosions can almost certainly explain the fans seen in X-rays, such as for Cas A (U. Hwang *et al.*., 2004). Also, for one supernova suspected to be a gamma ray burst as well, 1998bw a.k.a. GRB980425, the optical fits to the observations also suggest an asymmetric explosion.

This is then one of the oldest proposals to explain the explosions of massive stars, and the only one to date that has been shown to work.

If we accept the reasoning of the corresponding proposal for the knee feature in the cosmic ray spectrum, then the cores of all very massive stars are rather similar late in life, in fact nearly identical in their explosion. If we could determine a correction for the asphericity, these supernovae may even turn out to be standard candles, but much more energetic that supernova type Ia. This may require infrared polarization observations.

GAMMA RAY BURSTS

In a close binary system of massive stars the star exploding could lose much of its envelope through mass transfer or mass loss from the system prior to the explosion;

when the remaining core then explodes, the small mass of the envelope would still make the star appear as a giant, but the explosion could then become relativistic. This might explain naturally many if not all gamma ray bursts. Since the star explodes into its former wind, which integrates the past wind activity, it may even solve the problem with the magnetic field, pointed out by T. Piran. SN 87A has demonstrated how complicated the prior wind history may become. So a relativistic jet may be an inevitable result.

Petrovic *et al.*. (2005) hav recently discussed the boundary conditions for GRB models in terms of stellar evolution, including mass loss, binary character, rotation and magnetic fields.

If the analogy to radio galaxies and their relativistic jets holds, then acceleration of protons, and conversion of protons to neutrons in p-γ interactions could produce neutron beams (J. Rachen & P. Meszaros, P. Biermann *et al.*. 2004), with particles energies approaching 10^{20} eV (see also the large body of work by M. Milgrom, T. Piran, E. Waxman, *et al.*.).

CONCLUSIONS

Acceleration to the highest energy may come from jets and hot spots emanating from massive black holes. The prediction here is that at $3\,10^{19}$ eV the sky appears smooth in arrival directions, but at near 10^{20} eV the sky distribution of arrival directions should become patchy. This does require that our Galaxy has a magnetic halo wind. Within the GZK sphere this may imply that Cen A contributes up to a few 10^{19} eV, and at the highest energies only M87.

If, however, the sky remains smooth in the arrival directions of ultrahigh energy cosmic rays to the highest energies, then we need new sources, and one extreme speculation would be Lorentz Invariance Violation (S. Coleman, S.L. Glashow, 1999), with proton decay, neutron survival, and no strong photomeson interaction to higher energy. In that case one prediction would be that we should identify active galactic nuclei for all arriving cosmic rays, and these sources should be capable of producing very energetic (originally) protons. I. Maris has done some of such tests successfully (2003, www at Bonn; see especially the large body of earlier work by V. Ginzburg, P. Tinyakov, I. Tkachev, G. Farrar, St. Westerhoff, *et al.*.). Another solution might be to invoke neutrinos with Z-resonance.

For the Galactic cosmic rays explosions of red supergiant stars as well as Wolf Rayet stars may provide much of the cosmic rays. This is intimately connected with the physics of their explosion, and requires that the magneto-rotational mechanism is the main one chosen by Nature. This offers a consistent picture for the X-ray fans of Cas A, and gamma ray bursts. However, it implies that all of these massive stars are nearly identical at the point of explosion; the main difference could be due to aspect angle just as for AGN this is one key parameter, and the other one could be the residual envelope mass. It predicts that the relatively flat gamma-ray spectrum of the Galaxy should persist to much higher energies, and that the sky distribution of TeV emission should be very patchy.

It will be quite an achievement to prove this or any other concept - none is without difficulties. We do have potentially a full theory to account for cosmic rays at all energies; crucial tests will be performed with the current new instruments.

ACKNOWLEDGMENTS

P.L. Biermann would like to acknowledge E.-J. Ahn, F. Aharonian, I. Axford, W. Bednarek, D. Bosanac, S.-X. Chen, J. Cronin, W. Cui, A. Curutiu, A. Donea, L. Drury, D. Durisen, R. Engel, T. Enßlin, H. Falcke, L. Gergely, T.W. Jones, A. Kandus, H. Kang, G. Krishna, P.P. Kronberg, N. Langer, H. Lee, K. Mannheim, I. Maris, S. Markoff, G. Medina Tanco, A. Meli, B. Nath, A. Olinto, M. Ostrowski, G. Pavalas, C. Pilachowski, A. Popescu, R. Protheroe, D. Ryu, E.-S. Seo, A. Shukurov, R. Sina, T. Stanev, O. Tascau, S. Ter-Antonyan, R. Ulrich, A. Vasile, T. Weiler, F. Yuan, and J. Ziolkowski for many comments and discussions of these questions; several of them helped to improve this manuscript with detailed comments, and additional references. Special support comes from the European Sokrates / Erasmus grants in collaboration with East-European Universities, with partners W. Bednarek, L. Gergely, M. Ostrowski, K. Petrovay, A. Petrusel, M.V. Rusu, and S. Vidrih, and VIHKOS through the FZ Karlsruhe. Support came from NATO for a collaboration between P.L. Biermann (Bonn), S. Moiseenko and G. Bisnovatyi-Kogan (Moscow). Work with PLB was also supported through the AUGER theory and membership grant 05 CU1ERA/3 via DESY/BMBF (Germany).

REFERENCES

1. High-energy particle acceleration in the shell of a supernova remnant, Aharonian, F. *et al.*., the HESS collaboration, *Nature* **432**, 75-77 (2004).
2. Magnetorotational Supernovae, Ardeljan, N.V., Bisnovatyi-Kogan, G.S., Moiseenko, S.G. , *Month. Not. Roy. Astr. Soc.* (in press) (2005), astro-ph/0410234
3. Two-dimensional simulation of the dynamics of the collapse of a rotating core with formation of a neuton star on an adaptive triangular grid in Lagrangian coordinates, Ardeljan, N.V., Bisnovatyi-Kogan, G.S., Kosmachevskii, K.V., Moiseenko, S.G., *Astrofizika* **47**, 47 - 64 (2004), in English *Astrophysics*, **47**, 37-51 (2004)
4. Contribution of pulsars to the cosmic rays in the Galaxy, Bednarek, W., Bartosik, M., *Nuclear Physics B* **136**, 185-190 (2004)
5. Cosmic Rays from PeV to ZeV, Stellar Evolution, Supernova Physics and Gamma Ray Bursts, Biermann, P.L., Moiseenko, S.G., Ter-Antonyan, S., Vasile, A., review at the 9th course of the Chalonge School on Astrofundamental Physics: "The Early Universe and The Cosmic Microwave Background: Theory and Observations"; Proceedings, Ed. Norma Sanchez, Kluwer, p. 489 - 516 (2003), astro-ph/0302201
6. The last Gamma Ray Burst in our Galaxy? On the observed cosmic ray excess at particle energy 10^{18} eV, Biermann, P.L., Medina Tanco, G., Engel, R., Pugliese, G., *Astrophys. J. Letters* **604**, L29-L32 (2004), astro-ph/0401150
7. Cosmic rays, stellar evolutions and supernova physics, Biermann, P.L., review at the Seeon meeting May 2003, Eds. R. Diehl et al., Elsevier, *New Astron. Rev.* **48**, 41-46 (2004), astro-ph/0309810
8. Sources of Cosmic Rays and Galactic Diffuse Gamma Radiation, Casanova, S., Biermann, P.L., Engel, R., Meli, A., Ulrich, R., in Proc. INTEGRAL workshop 2004 in Munich, (in press), (2004) astro-ph/0403661
9. Detecting radio emission from cosmic ray air showers and neutrinos with a digital radio telescope, Falcke, H., Gorham, P., *Astropart. Phys.* **19**, 477-494 (2003)
10. Asymmetric explosions of thermonuclear supernovae, Ghezzi, C.R., de Gouveia Dal Pino, E.M., Horvath, J.E., *Month. Not. Roy. Astr. Soc.* **348**, 451 - 457 (2004)
11. How massive single stars end their life, Heger, A., *et al.*., *Astrophys. J.* **591**, 288 - 300 (2003)
12. Radio emission from cosmic ray air showers: simulation results and parametrization, Huege, T., Falcke, H., submitted to *Astropart. Phys.* (2005), astro-ph/0501580

13. A million-second Chandra view of Cassiopeia A, Hwang, U., *et al.*., *Astrophys. J. Letters* **615**, L117-L120 (2004), astro-ph/0409760
14. Magnetorotational Supernova simulations, Moiseenko, S.G., Bisnovatyi-Kogan, G.S., Ardeljan, N.V., in Proc. “ 1604-2004 Supernovae as cosmological lighthouses, June 2004 Padua, Italy (in press, 2004), astro-ph/0410330
15. Cosmic-Ray Acceleration at Relativistic Shock Waves with a “Realistic” Magnetic Field Structure, Niemiec, J., Ostrowski, M., *Astrophys. J.* **610**, 851-867 (2004)
16. Highest Energy Cosmic Rays, Olinto, A. V., in the proceedings of the Gamma 2004 Symposium on High-Energy Gamma-Ray Astronomy, Heidelberg, July, 2004 (AIP Proceedings Series), (in press) (2004), astro-ph/0410685
17. Which massive stars are Gamma-Ray Burst Progenitors?, Petrovic, J., Langer, N., Yoon, S.-C., Heger, A., *Astron. & Astroph.* (in press) (2005)
18. Studies of relativistic shock acceleration, Quenby, J.J. and Meli, A., Overview Paper, in Proc. *Huntsville Workshop 2002: ’Astrophysical Particle Acceleration in Geospace and Beyond’, Chattanooga, Tennessee, USA (to be accepted for ’The AGU Particle Acceleration Monograph’), p. 2345* (2004)
19. Effect of energy losses and interactions during diffusive shock acceleration: applications to SNR, AGN and UHE cosmic rays, Protheroe, R. J., *Astropart. Phys.* **21**, 415 - 431 (2004)
20. www at Bonn: www.mpifr-bonn.mpg.de/div/theory; the research report 2001-2004, the reviews, and the additional literature listed therein