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This report covers astronomical and astrophysical research done in the Physics Department at North Carolina State University from November 1995 through October 1997.

1. PERSONNEL

During the report period, faculty performing research in astrophysics and relativity included Drs. John M. Blondin, Kazimierz J. Borkowski, J. David Brown, Donald C. Ellison, and Stephen P. Reynolds. Dr. Borkowski joined the department as a Research Assistant Professor in September 1995. Dr. Todd Story held a position as a Post-Doctoral Associate during 1996-97.

During the report period, undergraduate and graduate students carried out research on various projects. C. L. Bennett completed his Ph. D. degree on hybrid simulations of particle acceleration in shocks, and assumed a post-doctoral appointment at UCLA in January 1996. D. Dinge, a student at UNC-Chapel Hill, completed a doctoral thesis under the co-direction of Dr. Blondin, and has taken a job at the University of Minnesota Supercomputing Institute. Graduate students G. Double, K. Dyer, S. Hendrick, C. Kuster, M. Owen, and E. Wright have been working in the group as well. W.J. Lyerly performed substantial astrophysical research at NC State as an undergraduate, and continues to work in the group as a graduate student. Other undergraduates making significant contributions included M. DeMasi, J. Puryear, V. Rekovic, S. Starin, and the entire membership of the undergraduate class PY 228, Introduction to Astrophysics. J. Koerwer, a local high-school student, also performed significant research. Their work is described below.

2. NOTABLE ACTIVITIES

Dr. John Blondin chaired the Local Organizing Committee for the 190th American Astronomical Society meeting (June 1997) in Winston-Salem, NC – the first AAS meeting ever to be held in North Carolina. Blondin also opened the meeting with the leadoff invited talk. Borkowski and Reynolds organized a special-topics session, New Light on Supernova Remnants, at that meeting as well. Reynolds organized a session of the Minnesota workshop on supernova remnants (Minneapolis, March 1997).

Dr. John Blondin was designated a Cotrell Scholar by Research Corporation, and also received an NSF CAREER award. NASA's Space Physics Theory Program grant to NCSU (D.C. Ellison, PI) was renewed. Other funding sources have included NASA's Astrophysics Theory Program (separate grants to Reynolds and Blondin), the NSF's Research Experiences for Undergraduates program, various other NASA programs, and Sigma Xi.

3. INDIVIDUAL RESEARCH

Astrophysical research at NCSU is carried out in the areas of relativity (Brown); supernova hydrodynamics (Blondin, Brown); supernova remnants and the interstellar medium (Blondin, Borkowski, Ellison, Reynolds); shock waves, particle acceleration, and cosmic rays (Ellison, Reynolds); X-ray binaries (Blondin); planetary nebulae (Borkowski); and general computational hydrodynamics (Blondin).

3.1 Relativity

Brown has studied the statistical mechanical and quantum mechanical properties of black holes using Hamiltonian/path integral techniques. Several key results were obtained. The first was a derivation of the entropy for an arbitrary (stationary) black hole in any diffeomorphism invariant theory of gravitational and matter fields. The second key result was a demonstration that the pair creation rate for electrically charged black holes in an electric field must equal the pair creation rate for magnetically charged black holes in a magnetic field. Finally, an interpretation was given of black hole entropy as a sum over boundary states of the gravitational field.

Work on relativistic fluids and elastic media was conducted by Brown in collaboration with V. Husain (Penn State) and D. Marolf (Syracuse). Their results revealed the relationship between different classes of variational principles for material systems, and showed that any fluid or elastic medium can be used as a reference coordinate system for classical and quantum gravity. In addition, anisotropic materials were used to construct theoretical black holes that are not classified solely by their mass and angular momentum – these serve as counterexamples to the ''no short hair'' conjecture.

Brown, with S.R. Lau (U. Vienna) and J.W. York (UNC), studied the properties of the Brown–York definition of quasilocal energy in general relativity. They showed that the quasilocal energy contained within a bounded region of a spacelike hypersurface gives the accepted result, namely, the Bondi mass, in the limit as the boundary approaches future null infinity.

3.2 Supernova Hydrodynamics

Blondin has continued to participate in a large-scale collaboration led by Tony Mezzacappa (ORNL) and Steve Bruenn (FAU) to study the explosion mechanism in Type II supernovae, and in particular, the role of convection in reviving the stalled blastwave.

They have coupled two-dimensional hydrodynamics to detailed one-dimensional multigroup flux-limited diffusion neutrino transport to investigate prompt convection in core collapse supernovae. The development and evolution of prompt convection and its ramifications for the shock dynamics were investigated for both 15 and 25 $M_{\odot}$ models, representative of the two classes of stars with compact and extended iron cores, respectively. In the absence of neutrino transport, prompt convection develops and dissipates on a time scale ~15 ms for both models. Prompt convection seeds convection behind the shock, which causes distortions in the shock's sphericity, but on the average, the shock radius is not boosted significantly. In the presence of neutrino transport, prompt convection velocities are too small relative to bulk inflow velocities to result in any significant convective transport of entropy and leptons.

The development and evolution of neutrino-driven convection and its ramifications for the shock dynamics were investigated for a 15 $M_\odot$ model, which is representative of the class of stars with compact iron cores, and therefore, an ''optimistic'' model. Our run began at 106 ms after bounce and proceeded for ~400 ms. At ~225 ms after bounce, we saw large-scale convection behind the shock characterized by high-entropy mushroom-like expanding upflows and denser infalling low-entropy finger-like downflows. The upflows reach the shock and distort it. However, in time the shock recedes, and by ~500 ms after bounce there is no evidence in our simulation of an explosion or of a developing explosion. We conclude that neutrino-driven convection does not lead to an explosion in our 15 $M_\odot$ Newtonian model, and it is unlikely that it will lead to explosions for more massive stars with fatter iron cores or in cases in which general relativity is included.

Jeff Knerr (UNC-Greensboro), Blondin, and collaborators used a purely hydrodynamics code to study the dependence of simulated convection on both numerical (grid) resolution and the number of physical dimensions employed in the simulation. For the resolution study, the initial postbounce data (from a one-dimensional supernova simulation that implements multigroup flux-limited diffusion) was mapped onto two-dimensional grids at resolutions of $N_r \times N_\theta = 128^2$, 256^2, and 512^2 computational zones. These data were then evolved forward by the hydrodynamics code for over 300 ms. For the dimensionality study, these same initial data are used for simulations in one, two, and three spatial dimensions. Fourier power spectra and the position of the shock wave versus time were used to monitor both the fine-scale and the gross features of the flow, respectively. The results of the simulations show that the models are fairly insensitive to numerical resolution, but clearly dependent on the number of spatial dimensions used. In 3D there is significantly less power on the largest scales, resulting in less variation in shock radius with both position and time.

With undergraduate student J. Puryear, Blondin and **Brown** are building a numerical code that will be used to simulate Type II supernovae and the gravitational waves they produce. The motivation for this work is the new generation of interferometer gravitational wave detectors, such as LIGO and VIRGO, which will be operational in three or four years. These detectors will allow researchers to observe directly the changes in mass distribution that occur during violent cosmological events such as supernova explosions. There are several potential sources of gravitational waves from supernovae, but currently little is known about the frequency spectrum and amplitude of these waves. However, accurate predictions of these wave forms will be crucial for the success of LIGO and VIRGO, since they are needed as templates to help separate signal from noise. Blondin *et al.* have written a multigrid Poisson solver to couple to the 3D supernova hydrodynamics code in order to study the production of gravitational waves from asymmetries in the core-collapse process. Initial work is limited to purely hydrodynamic models, but follows the dynamical collapse of the core through bounce.

3.3 Supernova Remnants and the Interstellar Medium

Borkowski, **Blondin**, and R. McCray (JILA) continue their studies of the interaction between the supernova ejecta and the circumstellar matter seen around SN1987A, including its famous circumstellar ring. The soft X-ray emission and the apparent deceleration of the radio source expansion suggest that the supernova blast wave has encountered a moderately dense H II region interior to the ring. They simulated the hydrodynamics of this interaction and calculated the resulting X-ray and ultraviolet emission-line spectrum and light curves. They predicted that broad Lyα and N V λ 1240 lines should brighten steadily and should be observable with the Hubble Space Telescope (HST). In 1997 May, the broad Lyα emission was indeed detected with the HST. Borkowski, with Michael, McCray (JILA/CU), Pun and Sonneborn (NASA/GSFC), modeled this emission as coming from hydrogen atoms in ejecta crossing a reverse shock in the shape of a slightly prolate ellipsoid with equatorial radius equal to 80% of the distance to the ring. Further hydrodynamical modeling of the interaction of the supernova ejecta with the H II region is in progress. This modeling should be useful in interpretation of present and future observations of SN 1987A with the HST and other space- and ground-based instruments. The climax will come in a few years when the blast wave hits the ring. The most recent observations with the HST show that the blast wave is already colliding with the dense material at the inner edge of the ring. According to our hydrodynamical simulations of the blast wave impact with the ring, this impact will generate a copious amount of X-ray emission.

Studies of X-ray emission from supernova remnants other than SNR 1987A are also at the center of attention. Borkowski and A. Szymkowiak (NASA/GSFC) showed that the fluorescent Fe Kα emission from dust should be present in X-ray spectra of SNRs, in addition to Kα emission from highly ionized Fe ions. This opens an entirely new avenue of research involving dust grains in SNRs. Graduate student J. Lyerly, with Borkowski and Reynolds, are completing their investigation of X-ray spectral models in the context of Sedov SNR dynamics. These new calculations allow for partial electron heating at the shock front, finally providing a complete set of models for analyzing X-ray spectra of SNRs. For Sedov models with fast shock velocities, X-ray spectra can be approximated by a combination of several simple nonequilibrium ionization models.

The late stages of SNR evolution play a key role in the ecology of the ISM, as radiative cooling leads to a two-phase medium of dense clouds immersed in hot gas, and turbulent kinetic energy is imparted to the ISM. These processes are mediated by dynamical instabilities, the action of which may be responsible for the irregular morphologies of older SNRs. Graduate student E. Wright, with Blondin, Borkowski and

Reynolds, found a violent, nonlinear instability in simulations of SNRs evolving from the adiabatic phase to the pressure driven thin shell phase. This instability becomes important as the ambient ISM density increases, and should disrupt the blast wave propagating in dense environments such as molecular clouds. Because the magnetic field pressure is expected to play a major role in the dynamics of the radiative blast wave, Wright is continuing his work on this problem with the help of a magneto-hydrodynamical code.

Supernova remnants are widely believed to be the principal source of galactic cosmic rays, produced by diffusive shock (first-order Fermi) acceleration in the environs of the remnant's expanding blast wave. Such energetic particles can produce gamma-rays and lower energy photons by various interactions with the ambient plasma. **Ellison** and Reynolds (in collaboration with M. Baring at NASA/GSFC and P. Goret and I. Grenier at C.E. Saclay) have studied particle acceleration and photon emission in SNRs using a nonlinear calculation which includes the dynamical influence of the accelerated cosmic rays on the shocked plasma and result in distributions of cosmic rays which deviate from pure power-laws. Such deviations are crucial to efficiency considerations and impact photon intensities and spectral shapes at all energies and, in particular, produce GeV/TeV intensity ratios that are quite different from test particle predictions. A new model for electron injection in shock acceleration is presented and predictions for ion and electron distributions that spawn neutral pion decay, bremsstrahlung, inverse-Compton, and synchrotron photon emission are calculated. The complete photon spectra that result are fully consistent with Whipple's TeV upper limits on those EGRET unidentified sources that have SNR associations. Supernova remnants in low density regions may produce higher energy cosmic rays capable of producing emission observable at TeV energies and consistent with the recent SN 1006 detection. It is found that, in general, sources in low density regions will be gamma-ray dim at GeV energies.

Reynolds calculated the synchrotron X-ray emission expected from young SNR shock waves, for a large range of SNR parameters. Electrons accelerated in those shocks should reach energies limited only by the remnant age, electron radiative losses, or absence of suitable upstream scattering turbulence. For the remnants of supernovae less than about 5000 years old, the maximum allowed energies can be above 100 TeV (10^{14} eV), allowing the production of synchrotron X-rays to 10 keV and beyond. The spectral shape is gently curving downward, made up of the sum of many exponentials of different cutoff energies broadened by convolution through the single-electron synchrotron emissivity. A major summary of this work is in press. Recently, Reynolds has been calculating X-ray images and spectra from remnants expanding into stellar-wind bubbles.

Reynolds and J. Keohane (GSFC) used a very simple subset of Reynolds's SNR synchrotron X-ray models to obtain upper limits to relativistic-electron energies in W49 B, Cas A, 3C 397, and Kepler's SNR. In all these cases, electron spectra must begin significantly steepening well below 100 TeV. Since radiative losses are not thought to be the limiting factor for the electrons, these results suggest that ion energies are also similarly restricted, with significant implications for the acceleration of Galactic cosmic rays up to the ''knee'' at 1000 TeV.

Reynolds, in collaboration with D. Moffett (New Mexico Tech), G. Dubner, E. Giacani, and E. Reynoso (IAFE, Argentina), J. Dickel (Illinois), F.P. Winkler (Middlebury College), and W.M. Goss (NRAO), has completed second-epoch VLA study at 21 cm of Tycho's supernova remnant. The mean expansion parameter (m, where $r \propto t^m$) was found to be 0.47, consistent with earlier studies, but with substantial azimuthal variations, from 0.3 to 0.6. For the first time, the expansion of interior features was measured, with a similar expansion rate to the average. Little change was seen in radio flux or polarization properties.

Graduate student K. Dyer, with Reynolds, has studied the radio-bright supernova remnant 3C397 at radio (VLA) and X-ray (ROSAT) wavelengths. The remnant shows relatively weak polarization at 6 cm and none at 20, consistent with bandwidth depolarization due to a RM of order 500 rad m^{-2}. There is little variation in spectral index between 6 and 20 cm. The ROSAT HRI image resembles the radio images, but with one striking difference: a small, perhaps unresolved, central emission peak. Insufficient counts were available in this peak for useful pulsation limits.

Reynolds, with Moffett and D. Wilner (CfA), obtained data from the NRAO 12-m telescope on the SNR 3C 391 in CO. Ambient emission was seen up to the edge of the bright radio-continuum shell, where it disappeared abruptly. The image represents very strong morphological evidence for the association of 3C 391 with molecular gas, as Reynolds and Moffett conjectured earlier, and shows that SNR shock waves moving into mostly neutral gas can still accelerate relativistic particles. Follow-up studies are planned.

Reynolds, with Moffett and N. Kassim (NRL), continued a project to map four bright, compact SNRs (3C 391, 3C 396, 3C 397, and W49 B) with high sensitivity at 90 cm, to compare with images in hand at 20 and 6 cm, to search for spectral-index variations and curvature in the local spectrum of these objects, as predicted by nonlinear theories of shock acceleration. Preliminary images of W49 B, using new high-fidelity imaging software, have attained a factor of 10 better sensitivity than earlier efforts.

Reynolds, with F. Seward (CfA), has analyzed ROSAT PSPC data on the high-latitude SNR DA 530. The remnant is extremely faint in X-rays, possessing an X-ray to radio luminosity ratio lower than that of the relatively faint SN 1006 remnant by a factor of 50. In collaboration with T. Landecker (DRAO) and D. Routledge (Calgary), they find evidence for an H I shell outside DA 530, with a very low density in the interior into which DA 530 is expanding.

Graduate student C. Kuster, with Reynolds, is calculating the ionization expected due to cosmic rays escaping from SNRs in molecular clouds. They find that significant elevations in ionization above the mean level in the cloud may occur over substantial volumes.

3.4 Planetary Nebulae

Borkowski, with K. Arnaud (NASA/GSFC) and J.P. Harrington (UMD), using *Advanced Satellite for Cosmology and*

Astrophysics, obtained an X-ray spectrum of a wind-blown bubble in the planetary nebula BD+30°3639. This is the first good-quality X-ray spectrum of a wind-blown bubble, showing the presence of hot, neon-rich gas. The chemical composition of the X-ray emitting gas differs from that of the stellar wind and of the nebular gas itself. Borkowski, with Harrington, N.J. Lame and S. White (UMD), observed BD +30°3639 with the HST and the VLA. They found many small, dusty clumps projected against an axisymmetric, nearly square nebular shell, most likely associated with the neutral and molecular envelope surrounding the wind-blown bubble and the wind-swept shell. The extinction properties of dust in these clumps appear close to the normal ISM dust. HST images revealed a substantial halo due to light scattered by dust in the neutral envelope surrounding the ionized shell. Monte Carlo models indicate that such scattering could result from a dust halo with an optical depth of unity. HST images also provided evidence for the presence of shocks in regions associated with molecular hydrogen emission.

With the HST, Borkowski and Harrington are carrying out a snapshot survey for jets in planetary nebulae, following their discovery of precessing jets in the Cat's Eye nebula. Observations of the first target, He 3-1475, revealed what appear to be large-scale flows being collimated into narrow bipolar jets. This is a unique object: we may be observing the actual collimation process of an astrophysical jet. Analytical models and hydrodynamical simulations by **Blondin** suggest that the jet in He 3-1475 may be produced by purely hydrodynamical means, through focusing of a weakly collimated bipolar outflow into jets by oblique radiative shocks. This hypothesis will be tested by planned HST observations of He 3-1475 in 1998 and by further hydrodynamical simulations. The expectation is that we will at last understand the collimation process of an astrophysical jet.

3.5 Stellar Winds

Motivated by speculation about the stability of isothermal bowshocks, high-school student J. Koerwer and **Blondin** studied the bowshock formed around a star moving supersonically through the interstellar medium. The papers in question suggested that if the conditions were such that both shockwaves (the forward shock moving into the ISM and the reverse shock decelerating the stellar wind) were rapidly cooling, the bowshock would be unstable to something they called the ''transverse acceleration instability,'' or TAI. Independent of this conclusion, the bowshock should be wildly unstable to the nonlinear thin-shell instability, or NTSI. A series of 2D simulations dramatically confirmed these suspicions. Two other high-school students used Joel's code to show that the most relevant parameter was the Mach number of the star through the ISM: the Mach number of the wind had little effect on the stability. A subsequent 3D simulation showed that the NTSI was even more effective in 3D than in 2D.

3.6 Binary Stars

Blondin and undergraduate student J. Wilson have used a 2D hydrodynamic model to study the enigmatic system AX-Mon. A recent observational analysis of this object by Elias and collaborators has found evidence for the presence of a large gas cloud that remains at a more or less fixed location in the binary system. The spectral type of the mass gaining star is early enough that it may posses a strong stellar wind, suggesting that the unusual gas cloud may be the result of a dynamical interaction between the tidal stream and the stellar wind. Hydrodynamic simulations have provided a remarkable confirmation of this conjecture, showing that the stream will be broken up into small cloudlets that are then driven out of the binary system by the ram pressure of the stellar wind.

Blondin and undergraduate student J. Layton investigated the dynamics of tidal stripping in elliptical orbit X-ray binaries with particular applications aimed at GX 301-2 and A 0538-66. Two-dimensional hydrodynamic simulations confirmed that mass accretion can occur only if the mass-losing star is rotating nearly synchronously at periastron, otherwise there is insufficient angular momentum in the stripped gas for it to catch up to the accreting star. However, this gas is accreted only well after the time of periastron passage, in contradiction to the per-periastron flares observed from GX 301-2.

A major thrust of the work by Blondin and his students has been the extension of their binary star models to three dimensions. In the case of wind accretion high-mass X-ray binaries like Vela X-1, this has allowed an accurate determination of the mass accretion rate, and hence the ability to investigate possible feedback between the accretion driven X-rays and the accreting stellar wind. Two distinct accretion solutions were found; a low L_x wind accretion solution with a relatively unmodified stellar wind, and a high L_x solution with a photo-ionized wind stalled out at small radii. Because of the low wind velocity in this latter solution, the wind is strongly focussed by the gravity of the accreting object, and the accretion flow resembles Roche lobe overflow more than wind accretion.

Graduate student M. Owen and Blondin have constructed a 3D model of LMC X-4, a high-mass system undergoing Roche lobe overflow. This preliminary model exhibited several fascinating characteristics. The dynamics of mass transfer were accurately modeled, from atmospheric Roche lobe overflow, through a ballistic tidal stream, to the formation of a Keplerian accretion disk. The stream was significantly larger than the thickness of the disk, and most of the stream mass flowed over(under) the disk, impacting it near the point of closest approach in its ballistic trajectory. The disk was truncated on the inner edge by photo-ablation driven by the intense accretion driven X-ray flux. This disk heating drove a strong wind off the inner edge of the disk, filling the binary system with a bipolar outflow carrying away 10^{18} g/s.

Blondin also constructed a 3D model of a low-mass X-ray binary, using two different hydrodynamic simulations. The first simulation was centered on the mass-losing star, and computed the dynamics of the Roche lobe overflow. The second simulation used the properties of the tidal stream computed in the first as boundary conditions to study the stream/disk interaction. One of the most important features found was that the stream impact efficiently drove mass accretion at least down to radii as small as the point of closest approach for a ballistic stream. For our model, this represents a radius roughly ten times smaller than the outer (tidally-truncated) disk radius. The effective α of this global hydrodynamic process is roughly unity! Granted there will be other internal processes transporting angular momentum (i.e., the Balbus-Hawley instability), but they are not necessary, and indeed will be overwhelmed by the effect of the stream impact.

3.7 Shock Waves and Particle Acceleration

One of the longstanding problems of astrophysics concerns particle injection and acceleration at collisionless shocks. **Ellison**, along with M. Baring and F. Jones (NASA/GSFC), has developed a Monte Carlo simulation of diffusive shock acceleration at oblique collisionless shocks. The simulation includes cross-field diffusion and nonlinear shock smoothing, and determines the absolute injection efficiencies of various ion species. The rate at which particles are accelerated is also determined; this depends on the obliquity angle that the upstream magnetic field makes with the shock normal. The greater the obliquity the greater the rate, and in quasi-perpendicular shocks rates can be hundreds of times higher than those seen in parallel shocks. In many circumstances pertaining to evolving shocks (e.g., supernova blast waves and interplanetary traveling shocks) or where acceleration competes with losses (e.g., through synchrotron cooling), high acceleration rates imply high maximum particle energies and obliquity effects may have important astrophysical consequences.

However, the efficiency with which thermal particles are injected into the acceleration mechanism also depends strongly on obliquity and, in general, more oblique shocks are less capable of injecting thermal particles into the acceleration process. In addition, the degree of turbulence and the resulting cross-field diffusion strongly influence both injection efficiency and acceleration rates. It has been found that turbulence must be quite strong for high Mach-number, highly oblique shocks to inject significant numbers of thermal particles and that only modest gains in acceleration rates can be expected for strong oblique shocks over parallel ones if the only source of seed particles is the thermal background.

In work with K. Ogilvie (NASA/GSFC), spectra produced by this Monte Carlo simulation, of both protons and heavier ions, have been shown to be in good agreement with observations made by the Ulysses spacecraft at interplanetary shocks. The parameters required to fit the observations imply that substantial wave-particle interactions are taking place producing strong collisionless scattering.

The same oblique shock model is being applied to the modeling of anomalous cosmic rays believed produced by pickup ions accelerated at the solar wind termination shock. Pickup ions are interstellar neutral atoms which freely enter the heliosphere and are then ionized by either radiation or collisional processes. In collaboration with F. Jones and M. Baring at NASA/GSFC, Ellison has shown that the highly oblique termination shock can readily inject and accelerate pickup ions without prior pre-acceleration. Using completely standard assumptions for shock parameters, including assuming that fairly strong cross-field scattering occurs, acceleration efficiencies consistent with pickup ion and anomalous cosmic ray observations are easily obtained.

In collaboration with J. Giacalone (U. of Arizona), Ellison has been using plasma simulations to investigate particle injection and acceleration at 3-D shocks. These simulations self-consistently determine the electric and magnetic fields from the motions of individual particles and are able to determine the complex plasma physics occurring in collisionless shocks. Thus far most work with hybrid simulations (i.e., where protons are treated kinetically as particles, but the electrons are approximated as a massless, charge neutralizing fluid) has been restricted to one or two spatial dimensions. Recent work by R. Jokipii and collaborators (U. of Arizona) has shown that if the dimensionality is restricted, as in a one- or two-dimensional simulation, cross-field diffusion is artificially limited. This may have important consequences for particle injection in oblique shocks and 3-D simulations need to be performed to resolve the issue. Eventually, results from 3-D hybrid simulations will be compared directly with the simpler Monte Carlo model mentioned above.

Ellison, along with J.P. Meyer (Service d'Astrophysique, Saclay, France) and L. Drury (Dublin Institute for Advanced Studies, Ireland), is investigating the composition of galactic cosmic rays and changes in source composition occurring during shock acceleration in supernova remnants. The latest observational evidence points toward elements with low volatility being overabundant in cosmic rays compared to solar system abundances. This implies that ISM material which is locked in grains is preferentially accelerated to cosmic ray energies. A quantitative model of galactic cosmic ray (GCR) origin and acceleration, wherein a mixture of interstellar and/or circumstellar gas and dust is accelerated by a supernova remnant (SNR) blast wave, has been developed. The gas and dust are accelerated simultaneously, but differences in how each component is treated by the shock leaves a distinctive signature which we believe exists in the cosmic ray composition data. A re-examination of the detailed GCR elemental composition has led us to abandon the long held assumption that GCR abundances are somehow determined by first ionization potential. Instead, volatility and mass (presumably mass-to-charge ratio) seem to better organize the data: among the volatile elements, the abundance enhancements relative to solar increase with mass (except for the slightly high H/He ratio); the more refractory elements seem systematically overabundant relative to the more volatile ones in a quasi-mass-independent fashion. Our nonlinear shock model, which includes (i) the direct acceleration of interstellar gas-phase ions, (ii) a simplified model for the direct acceleration of weakly charged grains to $\sim$ 100 keV/amu energies, simultaneously with the acceleration of the gas ions, (iii) the energy losses of grains colliding with the ambient gas, (iv) the sputtering of grains, and (v) the simultaneous acceleration of the sputtered ions to GeV and TeV energies, produces GCR source abundance enhancements of the volatile, gas-phase elements, which are an increasing function of mass, as well as a net, mass independent, enhancement of the refractory, grain elements over protons, consistent with cosmic ray observations. We also show that cosmic ray source spectra, at least below $\sim 10^{14}$ eV are well matched by the model.

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