

**George Mason University**  
**Center for Earth Observing and Space Research**  
*Fairfax, Virginia 22030-4444*

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This report covers the astronomy-related activities of the Center for Earth Observing and Space Research (CEOSR), a component of the School of Computational Sciences (SCS) at George Mason University, for the period October 1, 2000 to September 30, 2001. Faculty and postdocs in the CEOSR program were J. Beall, P. Becker, R. Ellsworth, J. Guillory, P. Hertz, M. Kafatos, K. Olson, L. Ozernoy, R. Sambruna, S. Satyapal, M. Summers, L. Titarchuk, A. Vourlidas, J. Wallin, K. Wood, and R. Yang. S. Roy was a visiting faculty member. Further program information is available at <http://www.ceosr.gmu.edu>).

## 1. INTRODUCTION

The interdisciplinary doctoral program in Computational Sciences and Informatics offered by the School of Computational Sciences recognizes the importance of numerical computation as a unifying theme in modern research and education. The doctoral program, begun in the Fall of 1992, focuses on a number of specialty areas, including bioinformatics, computational chemistry, Earth systems and global change, computational mathematics, computational physics, space sciences, and computational statistics. The program emphasizes three intellectual elements: a common computational core; computationally intensive science courses; and doctoral research. SCS Space Sciences faculty are involved in many ongoing collaborations with scientists at the Naval Research Laboratory and NASA/Goddard Space Flight Center. SCS also maintains active relationships with a number of high-technology corporations in the Washington, D.C. area. Many members of CEOSR participate in the Washington Area Astronomers Association, a regional organization of professional astronomers stretching from Charlottesville to Baltimore.

## 2. OBSERVATIONAL ASTRONOMY AND MULTIFREQUENCY DATA ANALYSIS

Jie Zhang, working under the cooperative agreement between CEOSR and the Naval Research Laboratory (NRL), has been analyzing data from LASCO (Large Angle and Spectroscopic Coronagraph) and EIT (Extreme-Ultraviolet Imaging Telescope) to investigate the origin of solar activities such as coronal mass ejections and their impact on space weather. J. Zhang, K. P. Dere (NRL), R. A. Howard (NRL), M. R. Kundu (UMD) and S. M. White (UMD) have examined four well-observed CME events whose source regions are sufficiently close to the solar limb that they are able to directly measure the CME initial evolution in the low corona without any extrapolation; this height range was not available in previous space-based coronagraph observations. The velocity-time profiles show that the kinematic evolution of CMEs can be described in a three-phase scenario: the initiation phase, the impulsive acceleration phase, and the propagation phase. The initiation phase is characterized by a slow ascension with a speed less than 80 km/s for a period of tens

of minutes. The initiation phase always occurs before the onset of the associated flare. Following the initiation phase, the CMEs display an impulsive acceleration phase which coincides very well with the flare rise phase lasting for a few to tens of minutes. The acceleration of CMEs ceases near the peak time of the soft X-ray flares. The CMEs then undergo a propagation phase which is characterized by a constant speed or slowly decreasing speed. They suggest that CMEs and flares have a strongly coupled relationship, but not a causal connection.

J. Zhang, M. R. Kundu, S. M. White, K. P. Dere and J. S. Newmark (NRL) have carried out a quantitative comparison of coronal imaging observations made in EUV domain by the EIT and the radio domain by the Very Large Array. The two sets of images show very similar morphologies, indicating that the different wavelengths originate from common solar features. They predict radio fluxes using the temperature and emission measure of the corona calculated from EIT observations, adopting Meyer's table of coronal abundances for the calculations. In each of the nine observations investigated, there always exists a good linear correlation in the pixel-by-pixel correlation plot between the predicted and the observed radio flux for coronal features over a wide range of flux variation. Nevertheless, the predicted radio flux is systematically larger than that observed by a factor of 2.0 on average. They attribute the difference to the underestimation of the abundance of Fe relative to H in the abundances adopted by Meyer. On this basis, they place the absolute Fe abundance in the corona at  $7.8 \times 10^{-5}$ , which has an enrichment factor of 2.4 relative to the accepted photospheric Fe abundance.

Menas Kafatos, Ruixin Yang, X. Sean Wang (ISE, GMU) with Kirk Borne, Cynthia Cheung and Ed Shaya (ADC) collaborated on building a prototype search and navigational system for the National Virtual Observatory (NVO). The system will serve the multispectral data in the Astronomical Data Center. The joint work will combine the ADC XML metadata which identify parameters (XML tags) with GMU's federated "DIstributed METadata System" (DIMES) originally developed for Earth science data searches (Yang *et al.*, 2001). DIMES is being adopted for astronomical research to provide an efficient "semantic-based" search capability to support complex astronomical scientific queries.

Angelos Vourlidas worked under contract at the Large Angle and Spectroscopic Coronagraph (LASCO) project which is flown aboard the Solar Heliospheric Observatory (SOHO) satellite. LASCO is a Navy Research Laboratory (NRL) project and therefore he is stationed at NRL. His responsibilities at NRL include research and data analysis in support of LASCO. During the past year, he continued his work on the analysis of CMEs observed by LASCO. As one of the instrument managers, he was involved in the phase-B studies for the SECCHI/COR2 coronagraph to be flown aboard the NASA/STEREO spacecraft in 2005. As the

project scientist for the NRL VAULT sounding rocket payload, he supervised the refurbishing and preparation of the payload for its second flight in October 2002. He also continued to provide user/calibration/software support for the daily operations of the LASCO instrument.

Nickolai Shaposhnikov and Lev Titarchuk developed a useful technique for X-ray spectroscopy. They used the new technique to study the problem of Type I X-ray bursts, which are believed to occur in the bottom of accreting neutron star atmospheres in close binary systems due to thermonuclear runaway phenomena. Combining analytical and numerical approaches, they constructed a formulae for fitting observational spectra which can yield important information about the neutron star and its atmosphere. The paper is submitted to *Astrophysical Journal*. As a straightforward continuation of this research, fitting of observational spectral data using obtained shapes is planned by the authors in the near future.

Rita Sambruna's research focused on X-ray and multi-wavelength observations of extragalactic radio jets, using data collected with the Chandra X-ray Observatory, the Hubble Space Telescope, and various ground-based radio telescopes. Primary collaborators on this project are C. M. Urry (Yale) and L. Maraschi (Oss. Brera, Milan). In particular, Sambruna studied the emission from the jets of the distant quasar 3C273 (Sambruna *et al.* 2001, *ApJ*, 549, L161). She found that the X-ray emission can be attributed to Inverse Compton scattering of the Cosmic Microwave Background photons off the relativistic electrons in the jet, deriving the jet physical parameters (electron's energy, magnetic field, beaming) as a function of radial position along the jet. On the contrary, a similar study of the nearby jet of the radio source 3C371 (Pesce, Sambruna *et al.* 2001, *ApJ*, 556, L79) shows that the X-ray emission is due primarily to synchrotron.

Using high-resolution observations from Chandra, Sambruna studied the spatial and spectral properties of the nearby galaxy Circinus, known to host a starburst and a supermassive black hole. The X-ray data show that the distribution of the gas around the nucleus of Circinus is highly complex, with diffuse soft X-ray emission around the central black hole, an outflow in the N-W direction, and several bright X-ray point sources, possibly massive binaries (Sambruna *et al.* 2000, *ApJ*, 546, L9; Bauer *et al.* 2001, *AJ*, 122, 182). The high-resolution spectrum of the nucleus shows a plethora of emission lines at both soft and hard X-rays, indicating that gas components at different ionization levels coexist in the nucleus (Sambruna *et al.* 2000, *ApJ*, 546, L13).

In collaboration with N. Brandt (PSU) and others, Sambruna also studied the X-ray emission from nearby active galaxies using high-resolution data from Chandra. The high-resolution X-ray spectrum of the Seyfert galaxy NGC3783 shows several absorption lines indicating an origin in a highly ionized gas outflowing from the nucleus at velocities of 600 km/s (Kaspi *et al.* 2001, *ApJ*, 554, 216). This is similar to another studied galaxy, NGC4051 (Collinge *et al.* 2001, *ApJ*, 557, 2). In addition, in collaboration with Ho (Carnegie) and others, Sambruna performed an X-ray survey of a volume-limited sample of early-type galaxies with Chandra, aimed at determining the fraction of galaxies host-

ing a supermassive black hole at their centers. In 62% of the objects a compact, pointlike source astrometrically coincident with either the optical or radio position of the nucleus. The high detection rate strongly suggests that the majority of the objects do contain weakly active, AGN-like cores, presumably powered by central massive black holes (Ho *et al.* 2001, *ApJ*, 549, L51).

Together with H. Krawczynski (Yale), Sambruna studied the correlated X-ray and TeV variability of the blazar Mrk421, using proprietary RXTE and HEGRA observations collected during 2000 March (Krawczynski *et al.* 2001). In both X-ray and TeV energy bands several flares with very rapid flux variability were observed. In the X-ray band, the flux increased and decreased with e-folding times as short as about 5 hr, with significant spectral variability. They present the results obtained by modeling the data with a time-dependent homogeneous synchrotron self-Compton model. The X-ray and TeV gamma-ray emission strengths and energy spectra together with the rapid flux variability strongly suggest that the emission volume is approaching the observer with a Doppler factor of 50 or higher. The different flux variability timescales observed at X-rays and TeV gamma rays indicate that a more detailed analysis will require inhomogeneous models with several emission zones.

With H. Marshall (MIT), Sambruna studied the EUV flux and spectral variability of the blazar PKS 2155–304 using data collected with the EUVE satellite (Marshall *et al.* 2001). Light curves showed variations of a factor of 2 over 1 month in 1993 and up to 25% variations on timescales of hours on several occasions. The spectra do not show significant spectral features and are fitted acceptably with simple power-law spectra with an energy index  $\alpha = 3.0$ .

Lev Titarchuk and Charles Bradshaw have analyzed RXTE X-ray timing data of Scorpius X-1 to develop an understanding of the close dynamics of the neutron star and its accretion disk. The dynamics are based on a theoretical model of X-ray quasi-periodic oscillations from which they inferred a magnetic field strength for the binary's neutron star. To date, this Transition Layer Model of X-ray oscillations has enabled them to explain all observed X-ray oscillations.

Jessica K. Reitz, graduate student of Dr. Rita M. Sambruna, is researching the X-ray emission of Radio-Loud quasi-stellar objects (QSO's), a variety of luminous Active Galactic Nuclei (AGN). The research is based on observations made by the *Chandra X-Ray Observatory* and discerns the spectral, spatial and variability properties of the emission from the quasar cores and jets. Chandra shows exciting results: two prominent Fe-K $\alpha$  lines, evidence of some thermal excess at soft energies and indication of a strong correlation of the X-ray and radio components of quasars. The X-ray observations are being combined with archival radio flux data and *Hubble Space Telescope* (HST) optical observations to form a strategic multiwavelength study of black hole accretion processes and relativistic jet emission.

### 3. BLACK HOLE AND NEUTRON STAR ACCRETION

Lev Titarchuk has recently formulated the two-oscillator (TO) model to interpret the lowest of the kilohertz frequen-

cies of the twin-peak quasi-periodic oscillations in X-ray binaries as the Keplerian frequency  $\nu_K$ . The high twin frequency  $\nu_h$  in this model holds the upper hybrid frequency relation to the rotational frequency of the neutron star's magnetosphere  $\Omega$ :  $\nu_h^2 = \nu_K^2 + 4(\Omega/2\pi)^2$ . The vector  $\Omega$  is assumed to have an angle  $\delta$  with the normal to the disk. The first oscillator in the TO model allows one to interpret the horizontal branch observed below 100 Hz as the lower mode of the Keplerian oscillator under the influence of the Coriolis force, with frequency  $\nu_L$  being dependent on  $\nu_h, \nu_K$ , and  $\delta$ . For some stars such as In the sources 4U 0614+09, Scorpius X-1, and 4U 1702-42,  $\nu_h, \nu_K$ , and  $\nu_L$  have been observed simultaneously, thus providing the opportunity to check the central prediction of the TO model, i.e., the constancy of  $\delta$  for a particular source. Given the considerable variation of each of these three frequencies, the existence of an observational invariant with a clear physical interpretation as a global parameter of the neutron star magnetosphere is an important test of the TO model.

L. Titarchuk has also suggested that persistent low-frequency quasi-periodic oscillations (QPOs) detected in the black hole (BH) sources XTE J1118+480, GRO J1655-40, and LMC X-1 at 0.1 Hz, in HZ Her/Her X-1 at 0.05 Hz, and in neutron star (NS) binaries 4U 1323-62, 4U 1746-31, and EXO 0748-76 at 1 Hz are caused by the global disk oscillations in the direction normal to the disk (normal mode). He argues that these disk oscillations are a result of the gravitational interaction between the central compact object and the disk. A small displacement of the disk from the equatorial plane results in a linear gravitational restoring force opposite to this displacement. His analysis shows that the frequency of this mode is a function of the mass of the central object and that it also depends on the inner and outer radii of the disk, which in turn are related to the orbital period of the binary system. He derives an analytical formula for the frequency of the normal disk mode and show that these frequencies can be related to the persistent lower QPO frequencies observed in the NS and BH sources. The results offer a new independent approach to the BH mass determination by interpreting this low QPO frequency as the global disk oscillation frequency. The implementation of this method combined with the independent method recently developed by Shrader & Titarchuk that uses the X-ray energy spectra results in stringent constraints for the BH masses.

Peter Becker, Prasad Subramanian (IUCAA, India), and Demos Kazanas (NASA/GSFC) have continued to study the physical processes operative in viscous accretion disks surrounding rotating and non-rotating black holes. Their most recent work (Becker, Subramanian, & Kazanas 2001) has focused on generalization of the ADIOS model of Blandford & Begelman to include the effect of general relativity. This is done by replacing the Newtonian potential used in ADIOS with a pseudo-Newtonian potential, resulting in the Relativistic Advection-Dominated Inflow Outflow Solution (RADIOS). The resulting model displays a relativistic outflow emanating from just outside the radius of marginal stability around a Schwarzschild black hole. They speculate that the outflow may be powered by the shear-induced Fermi acceleration of relativistic protons, due to collisions with the mag-

netic scattering centers (kinks) embedded in the Keplerian flow. The relativistic protons accelerated in the flow are postulated to feed a magnetically collimated jet, leading to the production of a strong gamma-ray flux when the jet collides with a distant cloud, possibly in the broad line region within one parsec of the central source.

For neutron star sources, L. Titarchuk has worked recently on completing the classification of the QPOs based on the recently developed Two-Oscillator (TO) model. The new model covers the range of frequencies from 1 Hz to 1200 Hz. It suggests the coexistence of viscous radial oscillations of the innermost part of the rotating disk with the diffusive process which involves also interaction with the normal disk mode (global mode of oscillations of the entire disk). In the outer (Keplerian) part of the disk the Two-Oscillator model interprets the twin peaks kHz QPOs as the Keplerian frequency and the upper hybrid frequency of the Keplerian oscillator under the influence of the Coriolis force in the differentially rotating NS magnetosphere. The developed TO model predicts that a certain combination of the observed kHz QPO frequencies and Horizontal Branch frequencies (HBO) is constant for a particular source. The existence of the constant which is an inclination angle between the magnetic and rotational axes of the star is a central prediction of the TO model. There is no free parameters involved in the determination of this invariant. Furthermore, the TO model allows the determination of the position of the outer radii of the Keplerian disk, the size of the transition layer between the inner edge of the disk and the Keplerian part of the dish, and find constraints for the NS mass-radius relation and the NS spin. This model allows global classification of QPO phenomena in NS systems.

L. Titarchuk has developed the mass black hole determination technique and applied this technique to nearby Galaxy spectra obtained by Colbert and Mushotsky and found BH masses of about 120, 600, and  $\sim 10^4$  in spiral galaxies M33, NGC 1313 and NGC 5408 respectively. These results thus provide compelling evidence for the existence of "middle-weight" black holes near the center of three spiral galaxies, owing largely to the reliability of the mass determinations.

L. Titarchuk has presented RXTE observations of the eclipsing X-ray binary Hercules X-1 during an anomalous low state. Data reduction reveals a light curve over 2.7 orbital cycles remarkably similar to optical and UV light curves dominated by the companion star. Count rates are modulated close to the orbital period, attaining a maximum when the inner face of the companion star, irradiated by X-rays from the compact source, is most visible. Cold reflection provides an acceptable fit to the energy spectrum. Employing binary geometry to scale the model and assuming companion-star reflection, he is able to reconstruct the incident X-rays that are removed from our direct line of sight (presumably by the accretion disk). He finds the flux of the hidden source to be identical to the observed flux of Her X-1 at the peak of its main high state. Consequently, Her X-1 is emitting a reflected spectrum, largely uncontaminated by direct X-rays in the anomalous low state. The spectral energy distribution, period, amplitude, and phasing of the modulation are all consistent with a companion-star origin. Since

this source occurs in a well-understood binary environment, it provides an excellent case study for more sensitive experiments in the future.

L. Titarchuk presented a theoretical analysis of Rossi X-Ray Timing Explorer data of Z source GX 340+0 obtained by Jonker *et al.* In the frameworks of the recently formulated transition layer model, the delta -angle is an angle between the neutron star (NS) magnetospheric axis and the disk (presumably NS rotational) axis. He determines the angle,  $\delta=6^\circ+/-0^\circ.3$  which is a combination of the simultaneously observed kilohertz quasi-periodic and horizontal-branch oscillation frequencies. While these three frequencies change by a factor of 3 or more, their delta-combination stays almost constant. GX 340+0 is the fourth source (in addition to 4U 0614+09, Scorpius X-1, and 4U 1702-42) for which delta has been determined. With one (constrained) parameter, at most, he makes a complete classification of six observed power spectral features, including the two kilohertz frequencies, the first and second harmonics of the horizontal-branch oscillation frequency, the low-frequency noise component, and the break frequencies. He demonstrates that a new component discovered by Jonker *et al.* in the GX 340+0 power spectrum is related to the viscous-frequency branch that has in fact been reported earlier in 4U 1728-34 by Ford & van der Klis. Finally, he reclassifies several previously misidentified features in the power spectrum.

L. Titarchuk developed a method for determining the B-field around neutron stars based on observed kHz and viscous QPO frequencies used in combination with the best-fit optical depth and temperature of a Comptonization model. In the framework of the transition layer QPO model, he analyzes magnetoacoustic wave formation in the layer between a neutron star surface and the inner edge of a Keplerian disk. He derives formulas for the magnetoacoustic wave frequencies for different regimes of radial transition layer oscillations. He also demonstrates that the model can use the QPO as a new kind of probe to determine the magnetic field strengths for 4U 1728-42, GX 340+0, and Sco X-1 in the zone where the QPOs occur. Observations indicate that the dependence of the viscous frequency on the Keplerian frequency is closely related to the inferred dependence of the magnetoacoustic wave frequency on the Keplerian frequency for a dipole magnetic field. The magnetoacoustic wave dependence is based on a single parameter, the magnetic moment of the star as estimated from the field strength in the transition layer. The best-fit magnetic moment parameter is about  $(0.5-1)\times 10^{25}$  G cm<sup>3</sup> for all studied sources. From observational data, the magnetic fields within distances less than 20 km from neutron star for all three sources are strongly constrained to be dipole fields with the strengths  $10^{7-8}$  G on the neutron star surface.

L. Titarchuk demonstrated that a X-ray spectrum of a converging inflow (CI) onto a black hole is the sum of a thermal (disk) component and the convolution of some fraction of this component with the Comptonization spread (Green's) function. The latter component is seen as an extended power law at energies much higher than the characteristic energy of the soft photons. He shows that the high energy photon production (source function) in the CI atmosphere is distributed

with the characteristic maximum at about the photon bending radius,  $1.5 r_S$ , independently of the seed (soft) photon distribution. He shows that high frequency oscillations of the soft photon source in this region lead to the oscillations of the high energy part of the spectrum but not of the thermal component. The high frequency oscillations of the inner region are not significant in the thermal component of the spectrum. He further demonstrates that Doppler and recoil effects (which are responsible for the formation of the CI spectrum) are related to the hard (positive) and soft (negative) time lags between the soft and hard photon energy channels respectively.

#### 4. RADIATION HYDRODYNAMICS

L. Titarchuk presented a comprehensive classification of all observed quasi-periodic oscillations (QPOs) within the framework of the transition layer model using a large set of Rossi X-Ray Timing Explorer data for Scorpius X-1. The model assumes an optically thin material along the observer's line of sight in the horizontal branch and an increasingly optically thick material while in the other two branches that is consistent with X-ray and radio observations and the disk transition layer model of QPOs. He identifies 6 Hz frequencies in the normal branch as acoustic oscillations of a spherical shell around the neutron star (NS) that is formed after radiation pressure near the Eddington accretion rate destroys the disk. The size of the shell is on the order of one NS radius from the NS. He also estimates the upper limit of Sco X-1's magnetic field to be  $0.7\times 10^6$  Gauss at about one NS radius above the NS surface while in the horizontal X-ray branch.

L. Titarchuk developed an analytical theory of thermonuclear X-ray burst atmosphere structure. Newtonian gravity and diffusion approximation are assumed. Hydrodynamic and thermodynamic profiles are obtained as a numerical solution of the Cauchy problem for the first-order ordinary differential equation. He elaborates a combined approach to the radiative transfer problem which yields the spectrum of the expansion stage of X-ray burst in the analytical form with Comptonization and free-free absorption-emission processes are accounted for and  $\tau\sim r^{-2}$  opacity dependence is assumed. Relaxation method on opacity-energy Euler grid is used to simulate radiative diffusion process in order to match analytical form of spectrum, which contains free parameter, to energy axis. Numerical and analytical results show high similarity. All spectra consist of power-law soft component and diluted black-body hard tail. He derived simple approximation formulae usable for mass-radius determination by observational spectra fitting.

L. Titarchuk presented a linear diffusion model for the evolution of the double-peaked outburst in the transient source XTEJ1118+480. The model treats the two outbursts as episodic mass deposition at the outer radius of the disk followed by evolution of disk structure according to a diffusion process. He demonstrated that light curves with fast-rise, exponential decay profile are a general consequence of the diffusion process. Deconvolution of the light curve proves to be feasible and gives an input function specifying mass deposition at the outer disk edge as well as the total

mass of the disk, both as functions of time. The derived evolution of total disk mass can be correlated with the observed evolution of the 0.1 Hz QPO in the source reported in Wood *et al.* (2000).

## 5. COSMIC RAY ACCELERATION

Peter Becker and Demos Kazanas (NASA/GSFC) have studied the acceleration of cosmic rays due to repeated scattering across a supernova-powered shock wave, using the “two-fluid” model of diffusive shock acceleration. This scenario remains an attractive model for the production of very energetic cosmic rays. When the acceleration process is efficient, a large fraction of the incident gas momentum flux is converted into cosmic ray pressure. In this case, the dynamical structure of the shock must be treated self-consistently, including the modifications due to the cosmic ray pressure. The upstream boundary conditions are stated in terms of the incident total Mach number and the incident ratio of the cosmic-ray pressure divided by the total pressure. It is well known that for certain combinations of these two parameters, 1, 2, or 3 distinct solutions are can be found for the shock structure. However, the precise nature of the constraint curves in the parameter space describing the number of possible solutions for given upstream conditions has remained unclear. Becker & Kazanas (2001) have derived new, exact critical constraints by reformulating the upstream conditions in terms of the two individual Mach numbers defined with respect to the cosmic-ray and gas sound speeds. Their results allow for the first time a systematic understanding of the parameter space and the implications for the resulting shock structure.

Peter Becker, Demos Kazanas, and student Truong Le have extended the analysis of the two-fluid model to explore the conditions under which multiple solutions are possible. They propose a new entropy-based method as a discriminant between the various steady-state solutions, when multiple solutions are possible. In the new method, the entropy of the combined gas/cosmic-ray system is computed. Application of the second law of thermodynamics then allows the identification of the most stable solution as that possessing the highest total entropy. This work is currently being prepared for publication.

## 6. EXTRAGALACTIC ASTRONOMY AND COSMOLOGY

Sisir Roy, Menas Kafatos, and H. C. Kandpal (National Physical Laboratory, New Delhi, India) have been studying alternate theories of redshift formation. They found the redshift as well as the broadening of the spectral lines of two Hg lines from laboratory experiments at National Physical Laboratory, New Delhi. This shift mimics Doppler shift though the observer and the source are at rest. These results confirm the results of Roy *et al.* on the shift of the spectral lines and dynamic multiple scattering theory. The volume density found in this experiment is compatible with that found in quasar environment. This result will shed new light not only for quasar spectra but also for the long drawn debate on the age of the universe as well as for the big bang hypothesis. S.

Roy also made an extensive analysis of the astrophysical data for the evidence of frequency dependent speed of light.

Peter Becker, in collaboration with Gopal-Krishna (National Center for Radio Astrophysics/TIFR, India), Prasad Subramanian (IUCAA, India), and Paul Wiita (Georgia State University), has examined the basic question of whether the detection of optical synchrotron radiation in powerful extragalactic double radio sources mandates *in-situ* acceleration of relativistic electrons within the hotspots/lobes (Gopal-Krishna, *et al.*, 2001). They find that the observed optical/near-IR synchrotron emission of the hotspots can be explained even if the radiating relativistic electrons are accelerated exclusively within the nuclear region, provided the energy losses incurred by the electrons during their transport along the jet are dominated by inverse-Compton upscatterings of the cosmic microwave background photons. Under this circumstance, *in-situ* acceleration of relativistic electrons inside the hotspots or lobes is not found to be mandated by their reported optical/near-IR infrared detections.

Leonid Ozernoy proposed testing bipolar relativistic ejecta as his explanation for pairs of X-ray sources across disturbed and Seyfert galaxies. A number of such pairs have been found lying closely and symmetrically across to the nearby galaxy. The galaxies include NGC 4258 (a disturbed spiral), 1068 (SyG), 2639 (SyG), 3516 (SyG), 5985 (SyG), and IC 4553≡ Arp 220 (ULIRG). The optical counterparts to those X-ray pairs turn out to be always redshifted, with  $z > z_G$ , where  $z_G$  is the galaxian redshift. M. Burbidge proposed ejection of blobs from the nearby galaxy, assuming a substantial gravitational component of the redshift. Arp 220 supports an ejection model assuming the averaged redshifts of X-ray blobs be close to the quantized redshift peaks of quasars at  $z = .06, .30, .60, .96, 1.41, 1.96, \dots$  so that the ejection speed of the blobs is close to a fixed value  $\sim 0.1c$ . The above assumptions are not necessary if, as Ozernoy (2000 and Refs. therein) has shown, the blobs are ejected from the galactic nuclei with equal *relativistic* velocities in the opposite directions. In this case, the relativistic Doppler effect explains as to why the *redshifts* are only observed for the optical counterparts to X-ray blobs. The validity of the relativistic ejection could be verified by measuring, with Hubble Space Telescope, substantial proper motions of the optical counterparts, which are expected to be different for the approaching ( $\mu_a$ ) and receding ( $\mu_r$ ) blobs. For instance, for Arp 220 blobs #9 and #2, one expects  $\mu_a = 0.79(D/72\text{Mpc})^{-1}$  mas/yr and  $\mu_r = 0.78(D/72\text{Mpc})^{-1}$  mas/yr, which corresponds to a superluminal apparent relative velocity  $1.78c$ . The kinematics of the model can be further tested by measuring another feature of a purely relativistic origin, *viz.*, the projected distances to the approaching and receding blobs from the origin should be different due to the difference in the apparent velocities (arm length asymmetry).

## 7. THE SOLAR SYSTEM, MINOR BODIES, AND THE INTERPLANETARY DUST

L. Ozernoy and S. Ipatov (Inst. of Appl. Math., Russia) have shown that the gravitational interactions of EKBOs can also play a certain role in their orbital evolution. For in-

stance, during the last 4 Gyr as many as several percents of EKBOs could change their semimajor axes by more than 1 AU due to close encounters with other EKBOs. Even small variations in orbital elements of EKBOs caused by their mutual collisions coupled with the mutual gravitational influence can cause large variations in the orbital elements due to the gravitational influence of planets. About 6% of Neptune-crossers can reach the orbit of the Earth, with the average time in Earth-crossing orbits of about  $5 \times 10^3$  yr. The portion of former EKBOs now moving in Earth-crossing orbits can exceed 20% of all Earth-crossers. Evaporation of the volatile material from the EKBOs surfaces, due to mutual EKBO collisions, along with the Solar wind and the heating by the Sun, could produce the dust in the outer Solar system.

S. Ipatov and L. Ozernoy have considered the formation and evolution of the Trans-Neptunian belt. Trans-Neptunian objects (TNOs) with diameter exceeding 100 km currently moving in not too eccentric orbits could be formed directly by the contraction of large rarefied condensations. Along with the gravitational influence of planets, gravitational interactions of TNOs played a certain role in their orbital evolution as well. More than 20% of Earth-crossing objects could have come from the trans-Neptunian belt. TNOs and Centaurs (invisible comets mainly beyond Jupiter) could produce an important contribution to the dust content of the interplanetary dust cloud.

In a review paper, L. Ozernoy summarized an extensive work done in collaboration with N. Gorkavyyi, J. Mather, and T. Taidakova, which aimed at the physical modelling of the interplanetary dust (IPD) cloud in the Solar system, *i.e.*, establishing a link between the observable characteristics of the zodiacal cloud and the dynamical and physical properties of the parent minor bodies. Their computational approach permits with modest computer resources to integrate the trajectories of hundreds of particles and to effectively store up to  $10^{10-11}$  positions, which provides a high fidelity 3D distribution of the dust. Their numerical codes account for the major dynamical effects that govern the motion of IPD particles: the Poynting-Robertson (P-R) drag and solar wind drag; the solar radiation pressure; particle evaporation; gravitational scattering by the planets; and the influence of mean-motion resonances. The incorporation of secular resonances and collisions of dust particles (both mutual and with interstellar dust) is underway.

L. Ozernoy and S. Ipatov have studied the origins of water on Mars, Earth, and Venus by evaluating the supply from the outer Solar system. The goal of this project is to determine which particular kinds of ice sources in the outer Solar system could have provided the largest contribution of water onto the planets of the Earth group. As is known, the contemporary influx of comets and asteroids is just a tiny fraction of impact delivery occurring at the epoch of the planet formation. The approach has demonstrated that the amount of water delivered to the Earth during the formation of the giant planets has been substantially underestimated.

S. Ipatov and L. Ozernoy have proposed a new approach to evaluate more accurately the characteristic times for collisions of minor bodies with the terrestrial planets. Numerical integrations require a lot of computer time thus far have not

allowed to consider a large number of collisions. Previous analytical calculations of characteristic times  $T$  of collisions of Earth-crossing objects (ECOs) and comets with the Earth were mainly based on Öpik's formulas. However, this approach becomes very inaccurate whenever the periods of a minor body and the planet are close to each other. While taking into account this situation, S. Ipatov and L. Ozernoy also abandon the limitations of other approaches, which consider bodies moving in their orbits with an invariable velocity.

## 8. COMPUTATIONAL ASTROPHYSICS AND DYNAMICAL ASTRONOMY

John Wallin continued working on particle methods in hydrodynamics and their applications in galaxy simulations. Specifically, he created a highly optimized SPH code for use with GMU's Beowulf cluster and finished developing the Local Polynomial Regression Hydrodynamics Method (LPRH). LPRH is a Lagrangian, meshless method similar to SPH. LPRH eliminates the need to use artificial viscosity, and has a higher order consistency than SPH.

## 9. RELATIVISTIC JET INTERACTIONS

John Guillory and Jim Beall, together with former student David Rose (MRC Albuquerque) submitted to Physics of Plasmas a paper "Comparison of Particle-In-Cell Simulations and a Wave-Population Model of Electron-Beam-Plasma Interactions," in which they describe a new dissipative nonlinear quasi-equilibrium permitted by the nonlinear production of nonthermal high-energy tails on the energy distribution of ambient plasma electrons. The quasi-steady state allows the spatial coexistence of a hot 'beam' with a denser cool plasma having a warm nonthermal electron component. The paper has been accepted.

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Peter A. Becker