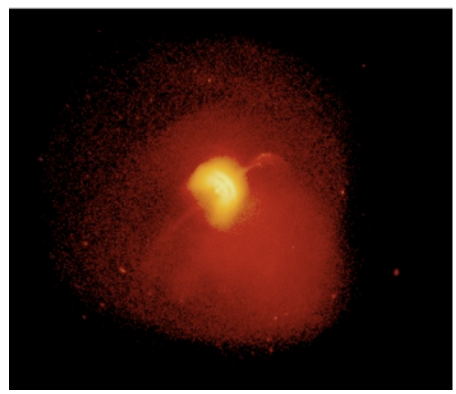
I have been working in the area of high-energy astrophysics of compact objects for the past ten years, focusing on studies of neutron stars (NSs) and related phenomena (such as pulsar wind nebulae; PWNe). NSs offer a unique opportunity to take a peek at the properties of matter under the most extreme conditions (nowhere else found) because they produce a variety of observational manifestations which can be used to verify theoretical models. On the other hand, the progress in theoretical physics studying matter under those extreme conditions is essential for creating correct models of NSs and for adequate interpretation of the observations. In my future research I plan to build upon my achievements as well as expand my research to new promising areas within the exciting subject of high-energy astrophysics of Galactic compact objects. I plan to have a balanced research program, which will include both observational and theoretical (modeling) components, and will focus on the following five synergetic research topics of the compact object astrophysics.

I. Observations of pulsar-wind nebulae and modeling of pulsar winds:

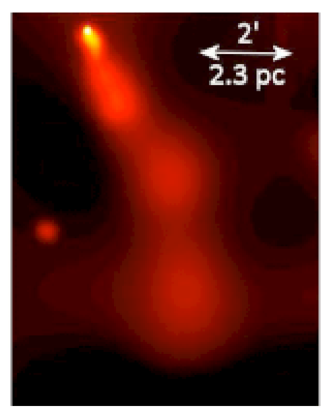
I am currently in charge of a number of successful observing programs (with the Chandra X-ray observatory and HST) as well as archival data studies devoted to this topic. My recent review articles on pulsar/PWN observations in X-rays and TeV (Kargaltsev & Pavlov 2008, 2010) have been cited on 91 occasions. Some highlights of my recent and current research in this area are:

- ***Jets and collimated outflows from pulsars:***

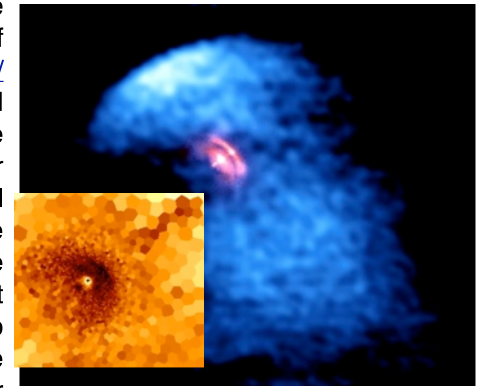
Jets are ubiquitous among many types of astrophysical sources (pulsars, binaries, protostars, active galactic nuclei). Therefore, it is important to understand the complex underlying physics of the processes that lead to formation and stability of the collimated magnetized outflows. An excellent opportunity to study these is offered by pulsar jets and pulsar tails, which have been resolved in detail by Chandra (Kargaltsev & Pavlov 2008). Particularly striking and rich in detail is the jet of the nearby Vela pulsar (see http://www.astro.ufl.edu/~oyk100/ChandraPWNe.html). We have just obtained a long (320 ks) Chandra observation that revealed an unexpected corkscrew-like motion of the jet which can hold the key to understanding the pulsar wind physics and jet physics in general. In total we have accumulated ~700 ks of Chandra data on the Vela PWN which represents the deepest study of a PWN yet. The analysis of this rich data set has just started, and it will undoubtedly result in new discoveries and high-impact publications in the next few years. I have also been granted 16 HST orbits to perform optical polarimetry of the Vela PWN. The data have recently arrived and are being analyzed, I am also a member of a team preparing XVP (~3Ms) proposal for Chandra Cycle 14 to observe several other PWNe that are known to have rich structures for ~500 ks each. To complement the X-ray and optical data, I plan to propose and carry out an extensive high-resolution imaging of the Vela PWN with EVLA (radio) and ALMA (mm-wavelength).



Many of the pulsars are known to move supersonically through the interstellar medium (ISM). However, only recently it has been discovered that such pulsars are accompanied by very long, well-collimated tails filled with ultrarelativistic plasma that must be confined by the ram-pressure and internal magnetic field (the latter makes the tails akin to jets). The longest X-ray tail (l >7 pc at d = 4 kpc) was observed behind PSR J1509–5058 (image on the right). The large extent of the tail indicates that it is not just a trail of electrons (or positrons) "dumped" behind the moving pulsar because such an assumption would imply an improbably high pulsar speed >10,000 km/s. Therefore, the tails represent ram-pressure confined streams of relativistic electrons with a large bulk flow velocity. The tail flow starts as mildly relativistic, and the tail's properties could be similar to those of a jet. Thus, X-ray and radio observations of pulsar tails are essential for studying the properties of collimated MHD flows (Kargaltsev et al. 2008). I plan to carry out deep X-ray, TeV, and radio observations of the most prominent pulsar tails and perform detailed modeling looking for signatures of relativistic wind hadrons, entrained ISM, and particle re-acceleration



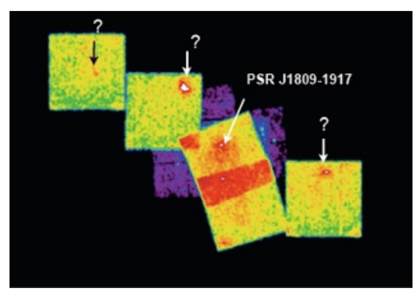
• ***Dynamics and evolution of pulsar winds:*** Thanks to the unprecedented angular resolution of the Chandra X-ray Observatory, we now have a unique opportunity to see the pulsar wind dynamics (a spectacular demonstration is our recent series of Vela PWN observations; see http://www.astro.ufl.edu/~oyk100/ChandraPWNe.html) as well as map the changes (via spatially-resolved spectroscopy) in the particle spectral energy distribution (SED) as the injected wind particles propagate (via advection and diffusion) further away from the pulsar. Having measured the flow speed, the spectral changes, and the multiwavelengths surface brightness distribution, we are finally in position to perform an accurate theoretical modeling of the pulsar wind flow (Kargaltsev 2012, in preparation) which will tell us about the wind energetics, composition, and magnetization. A spectral map (Kargaltsev & Pavlov 2008; the inset on the right) demonstrates that the inner PWN elements have extremely hard spectra (significantly harder than those of the Crab inner PWN), incompatible with the predictions of the conventional shock acceleration models. I am completing an archival study of nine PWNe observed with long Chandra exposures (to be published in ApJ later this year).



X-ray (red) and radio (blue) images of the Vela PWN. The inset shows the spectral map of the inner PWN obtained from Chandra data.

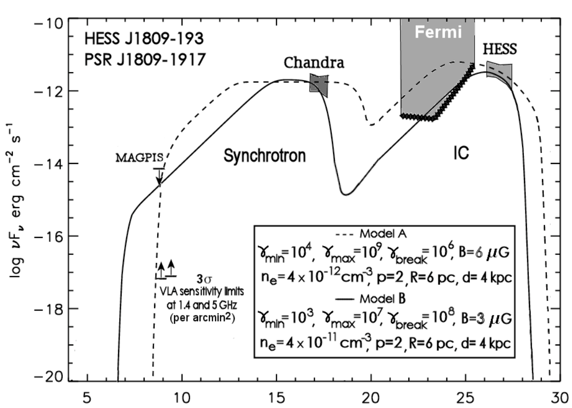
II. **Origin of the extended Galactic VHE sources found by ground based Cherenkov imaging arrays and the Fermi Gamma-Ray Observatory.** Among ~60 extended sources resolved by the HESS and VERITAS TeV observatories in the Galactic plane, about 30% are thought to be powered by pulsars, 10%-15% are shell-type SNRs, and the remaining 50%-55% are currently unidentified, many without obvious counterparts at lower frequencies. My working hypothesis is that many of these unidentified sources are *relic* pulsar-wind nebulae whose electrons have cooled so much that they do not emit synchrotron emission in X-rays anymore. This study is ongoing, and I find cases that are difficult to explain even within this scenario, which may imply that a new kind of particle accelerator is at work. Here are the recent and ongoing research highlights:

• ***Chandra reveals PWNe in HESS J1809-193, HESS J1804-216:*** In both cases the asymmetric morphologies of X-ray PWNe (extending toward the center of the TeV source) clearly suggest a physical connection between the PWNe and the unidentified TeV sources. Such convincing identifications are important because they reveal the nature of the Galactic Cosmic ray accelerators. In particular, it becomes more and more apparent that PWNe constitute the largest fraction of extended Galactic TeV sources (Kargaltsev et al. 2007, 2008). I currently have an ongoing multicycle (10-13) Chandra program (as a part of GTO program by G. Garmire) to survey the unidentified GeV (Fermi) and TeV sources and determine their nature.

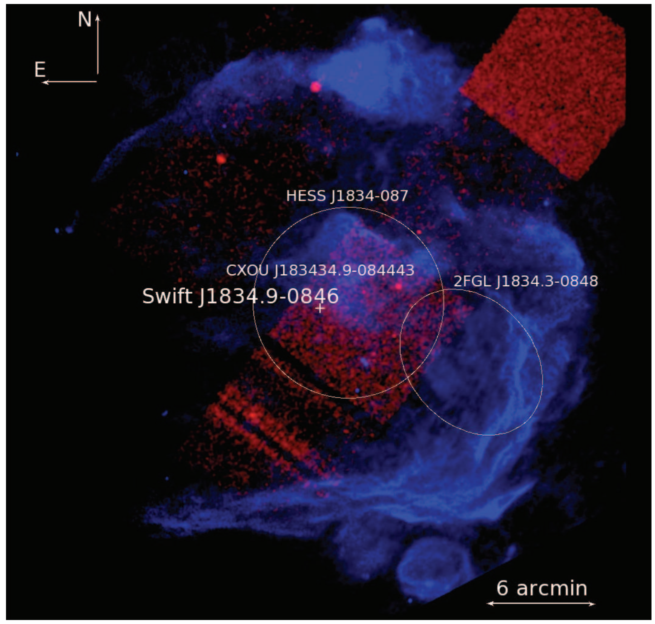


The field of HESS J1809-193. Suzaku and Chandra combined.

• ***A detailed population study of >60 extended TeV/GeV sources is being carried out*** via the analysis of the archival multiwavelength data (research is funded by NASA and NSF). First results of this work have been published in our recent review (Kargaltsev & Pavlov 2010). Multiwavelength data are needed to develop and test theoretical models, such as the model of leptonic emission from relic pulsar-wind nebula (Kargaltsev, et al. 2012, in preparation). In this model, freshly accelerated electrons, injected in the vicinity of a pulsar, are responsible for the synchrotron emission in X-rays, while the cooled, aged electrons that have propagated further away are emitting in the radio (synchrotron) and TeV/GeV (via inverse Compton). In this model I take into account both advection and diffusion of the wind particles. Calculating the resulting spectra will allow me to disentangle the magnetic field from the other wind parameters and thus obtain accurate measurements of the pulsar wind properties (see an example on



the right). As a byproduct of this large research project, I am developing a comprehensive database of pulsars with PWNe detected either in X-rays or GeV/TeV (or both). Preliminary version can be found at http://www.astro.ufl.edu/~oyk100/prototype/VHE_Cat.html (the work is ongoing). I have active observing programs with VERITAS as an associate member of the VERITAS collaboration.



- ***HESS J1834-087 - a first evidence for hadrons in pulsar wind?***

Our recent Chandra observation (Misanovic, Kargaltsev et al. 2011) revealed a compact pulsar-wind nebula within the extent of the HESS J1834-087 located inside SNR W41. In the Fermi all sky survey data we also found a GeV source, which is positioned between the X-ray PWN and the SNR shell (see image on the right). It is possible the GeV emission is produced via the hadronic mechanism when the relativistic wind hadrons interact with the dense material in the SNR shell, which, in turn, interacts with very dense, cold molecular cloud. We plan to carry out a detailed modeling of this scenario in our subsequent paper.

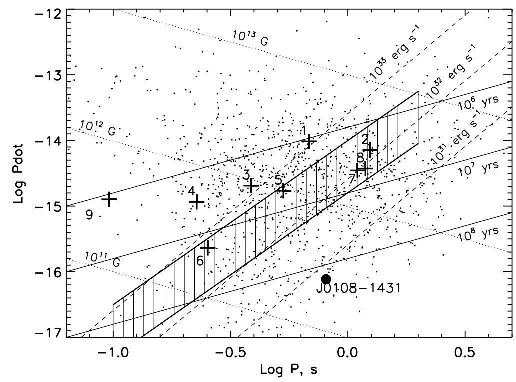
- ***Searching for radio emission from extended TeV sources.*** For a detailed modeling of extended VHE sources, one needs multiwavelengths spectra. I have recently obtained VLA images of HESS J1809-193 and HESS J1804-216, which are currently being analyzed. We have also imaged the X-ray-dark TeV source HESS J1616-508 with the Australia Telescope Compact Array. I believe that deep radio observations of X-ray dark sources holds the key to understanding the nature of these elusive sources, and therefore, I plan to pursue this direction in my future research.

- ***VERITAS search for new TeV counterparts of the Galactic compact objects.*** Being an associate member of the VERITAS collaboration, I actively work with other members of the VERITAS Galactic Science working group to select the most interesting sources for future TeV observations. I have also submitted several observing proposals for consideration by the VERITAS TAC this year. After recent upgrades, VERITAS is expected to become one of the top TeV observatories in the world, providing exciting discoveries and fueling the need for multiwavelength observations. In the next few years I hope to actively contribute to the success of the VERITAS program via my own projects as well as through the work I will be doing in collaboration with the other VERITAS collaboration members. The field of TeV astronomy is a rapidly developing one and compact objects are expected to dominate the TeV sky in the Galactic plane. Therefore, I plan to devote a significant fraction of my research to this field within the next five years.

III. Emission from surface and magnetosphere of isolated neutron stars and pulsars:

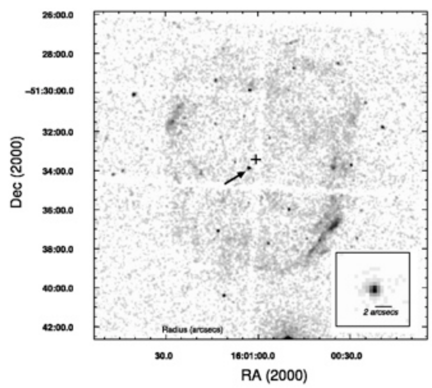
Observations of isolated (non-accreeting) neutron stars offer an opportunity to study the emission originating close to (or at the surface of) the neutron star (NS), which would otherwise be outshined by the accretion disk. The observed optical, UV, and X-ray emission can be of thermal or non-thermal nature. This emission tells us about the properties of the extreme NS magnetospheres (nonthermal emission) and about the NS surface temperature and composition (thermal emission). Measuring the nonthermal spectra and pulsations allows us to understand the pair production, particle acceleration, and radiation mechanisms, as well as the magnetic topology of the magnetosphere. Measuring the temperature of the NS surface constraints the equation of state of the superdense matter in the NS interior. To separate and study these two emission components, I am conducting X-ray and optical observations of isolated NSs of different ages and surface magnetic fields. The highlights of the recent and ongoing research are:

- ***A 170-Myr old pulsar turns out to be very efficient X-ray emitter (NASA/CXC Press Release, 02/26/09):***

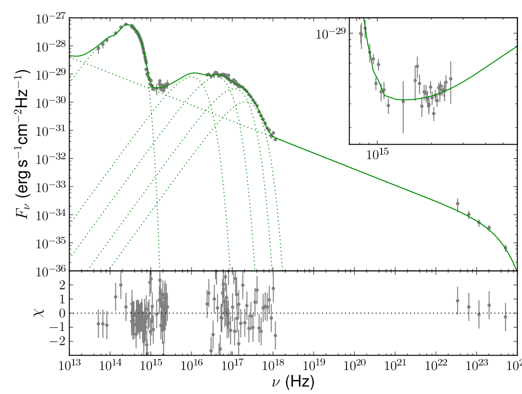


PSR J0108-1431 is a nearby, 170-Myr-old, faint pulsar at the very edge of the radio pulsar population in the P-Pdot diagram (P and Pdot are the pulsar period and its derivative; see figure). The pulsar is also way below the "death valley" (hatched area), that represents plausible locations of the death line for the curvature radiation (CR) induced pair cascade. Other old pulsars detected in X-rays (shown by crosses) are in the region where CR cascade still could operate. Yet, the J0108-1431's X-ray efficiency exceeds that of any other old pulsar detected in X-rays (Pavlov, Kargatsev et al. 2009; Kargaltsev et al. 2006).

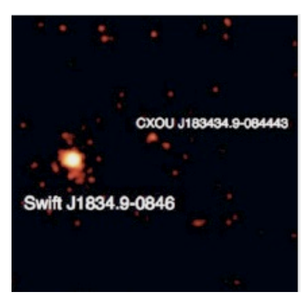
- ***X-ray properties and nature of enigmatic Central Compact Objects (CCOs) in Supernova Remnants (SNRs):*** Central Compact Objects are point-like, radio and gamma-ray quiet, soft X-ray sources inside young shell-type SNRs. The CCOs are thought to be young neutron stars born with a low surface magnetic fields. The X-ray spectra of CCOs usually fit thermal models (e.g., NS atmosphere models) with surprisingly small sizes of emitting regions (Kargaltsev et al. 2002). Thanks to the lack of the non-thermal emission from the magnetosphere, this type of NSs is particularly well suited for measuring the NS temperature and constraining the NS cooling and equation of state. The Chandra ACIS image on the right shows CCO G330.2+1.0 (Park, Kargaltsev, et al. 2006, 2009).



- ***HST observations of the 5 Gyr old PSR J0437-4715 suggests a thermal spectrum corresponding to the NS surface temperature of 100,000 K - much hotter than one could expect from a passively cooling neutron star.*** The figure shows the multiwavelength spectrum (FUV - HST; X-rays - Chandra, XMM-Newton and ROSAT; gamma-rays - Fermi) of PSR J0437-4715. Three dotted lines show formally acceptable blackbody models that fit the FUV and X-ray data. The large radius of the coldest component suggests that the FUV emission comes from a large portion of the NS surface while the X-ray emission comes from hotter polar regions (Kargaltsev et al. 2004; Durant, Kargaltsev, et al. 2012).

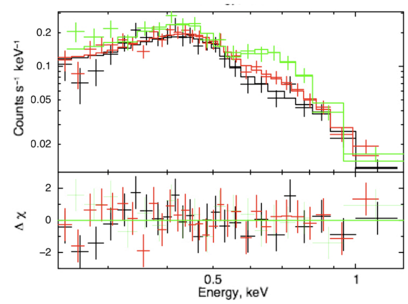


I will continue to actively carry out research in this direction. As X-ray observations are only sensitive to emission from the hottest regions of the NS surface, one cannot rely on X-ray observations to measure the temperature of the surface in older NSs, where only hot polar caps can be seen in X-rays. Therefore, I plan to exploit the unique capabilities offered by the latest instruments (e.g., Cosmic Origins Spectrograph) onboard HST to observe a number of NSs in the ultraviolet where one can see the Rayleigh-Jeans tail of the thermal spectrum originating from the NS surface or atmosphere. This ambitious program includes a large number of nearby pulsars, which span several decades in age. The results will constrain thermal evolution of neutron stars and tell us about their internal composition.



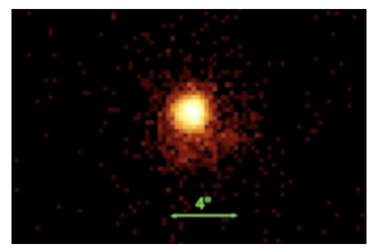
- ***Understanding properties of magnetars.*** Magnetars are the most extreme representatives of the NS population with surface magnetic fields reaching 10^{15} Gauss. A flare (peak luminosity reaching 10^{47} erg/s) on the surface of a magnetar located 50 kpc away is still capable of disrupting satellite communications and perturbing the Earth ionosphere. Although only a decade ago magnetars were thought to be rare, their population has grown rapidly in recent years, reaching 24 as of January 2012. Particularly interesting are recent discoveries of the transient magnetars, which imply that even a nearby magnetar can be invisible until its activation. We have just identified one of such transient magnetars (SWIFT J1834.9-0846) in X-rays via a coordinated campaign of Swift/RXTE/Chandra/XMM-Newton observations (Kargaltsev et al. 2012). A more detailed study is ongoing. We have also observed one of the nearest (d~2 kpc) transient magnetars, SGR 0418+5729, with HST and placed a restrictive limit on the NS surface temperature (Durant, Kargaltsev et al. 2012). I plan to continue further transient magnetar studies with the goal to characterize and understand their quiescent state.

- ***Properties of neutron star interiors, surface layers and magnetospheres*** can be tested through the observations of spectral features which so far have been seen only in a several exotic neutron stars. However, in our XMM-Newton observation of PSR J1740+1000 we have just discovered *first* features in spectrum of an ordinary pulsar. The depth of the absorption features varies with the pulsar rotation phase (see the plot). Since the energy of one feature is approximately twice the energy of the other one (see figure), the features must be caused by cyclotron absorption by magnetospheric electron/positron plasma or, alternatively, by absorption in the NS atmosphere via transitions in hydrogen-like ions. A large XMM-Newton program will be proposed next Cycle.



VI. Physics of intrabinary interaction and outflows in X-ray binaries. I am interested in studying the mechanisms that lead to the formation of large-scale outflows in accreting binaries with a compact object (NS or BH). Recent and current research highlights are:

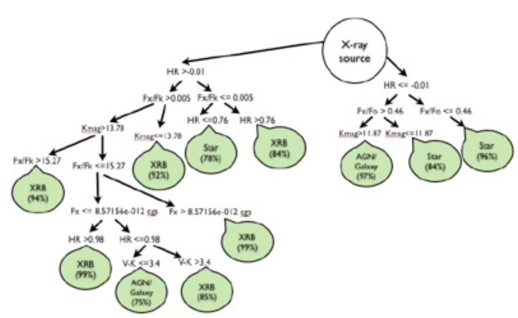
- ***Extended emission around microquasar LS 5039 and HMXB with PSR B1259-63 resolved with Chandra:*** It is possible that a PWN-like extended emission could be produced by relativistic particles accelerated at the intrabinary termination shock and then expelled outwards. To test this hypothesis, we have recently carried out Chandra observations of the two binaries. Our preliminary analysis suggests extended emission around the microquasar LS 5039 (Durant, Kargaltsev et al. 2011) and pulsar-Be-star binary B1259-63 (see a preliminary Chandra image on the right).



- ***X-ray emission from relativistic double neutron star binaries*** can be produced via interaction between the magnetized relativistic wind(s) and magnetosphere(s). A conclusive evidence of such interaction is a deficit of X-ray emission around apastron found with Chandra in the double NS binary J1537+1155 (Kargaltsev et al. 2006; Durant & Kargaltsev et al. 2011).

- ***Looking for HMXBs/LMXBs in Fermi LAT data:*** Through the multicycle campaign carried out as a part of the Chandra GTO program, I perform observations of unidentified Fermi/LAT sources in the Galactic plane. Although the Galactic gamma-ray sky is dominated by pulsars and their nebulae the new binaries are also occasionally discovered (for instance, we have just discovered X-ray emission from 1FGL J1018.6-5856; Pavlov et al. 2011).

V. Automated classification of galactic sources in Chandra and XMM-Newton source catalogs. The nature of over 99% of ~300,000 cataloged Galactic X-ray sources is unknown. The synergy between the Galactic surveys and existing multiwavelength catalogs will allow one to measure a large number of different multiwavelength attributes for ~ 50,000 well-localized, cataloged X-ray sources. To perform the classifications, I use the Learning Decision Tree (LDT) algorithms that are proven to be efficient in performing similar classification tasks and shown to work in our pilot study. As a natural extension of these classifications, I plan to investigate the parameters of various compact object classes and pick some of the most interesting objects for detailed spectroscopic follow-up and modeling. A corresponding NSF proposal has been submitted. NASA ADP and Chandra XVP proposals are in the works.



Further plans: In addition to the research directions I currently pursue, I plan to initiate (or to become involved in) the following research within the next few years:

- ✦ Automated cross-identification of extended sources in X-ray and radio images;
- ✦ Modeling properties of emission coming from the vicinity of the BH event horizon
- ✦ Analysis and development of deep imaging surveys of the Galactic plane in X-rays/radio;
- ✦ Modeling observational signatures from pulsars with shut-off pair cascades;
- ✦ Search and analysis of extended emission in the accumulating Fermi survey data;
- ✦ Near-infrared observations of soft gamma-ray repeaters and anomalous X-ray pulsars;
- ✦ Radial-velocity searches for non-accreting black holes in binary systems.

My research program is diverse and yet it is well focused. All the projects listed above fall within the grand theme of high-energy astrophysics of compact objects while targeting different key aspects (e.g., particle acceleration mechanisms, MHD of relativistic plasmas, radiative processes in strong magnetic and gravitational fields) directly reflecting the complex physical processes involved.