Pavan Hebbar

Curriculum Vitae

Department of Physics
4-181 CCIS, University of Alberta
Edmonton, AB, T6G 281, Canada
+1 (780) 935-2798
hebbar@ualberta.ca
sites.ualberta.ca/~hebbar
pavanhebbar

Research Interests

- Applications of machine learning in identifying and studying X-ray sources.
- Multi-wavelength observations to understand the physics of neutron stars and accretion processes around white dwarfs, neutron stars and black holes.

Educational Background

2019 – Present **Ph.D. Physics; Sub-group: Astrophysics**, *University of Alberta*, CGPA 4.0/4.0
Supervisor: Craig Heinke

2017 – 2019 **MSc Physics; Sub-group: Astrophysics**, *University of Alberta*, CGPA: 4.0/4.0
Supervisor: Craig Heinke

2013 – 2017 **B.Tech Aerospace with Honours**, (Minor in Physics and Computer Science), *Indian Institute of Technology Bombay IITB*, CGPA: 9.48/10.0,
Department Rank 1 in the class of 2017

Awards

Graduate Awards

2024, 2020, 2019 **Alberta Graduate Excellence Scholarship**

2023 **Pansy and George Strange Graduate Scholarship**

2022 **Ivy A Thomson, and William A Thomson Graduate Scholarship**

2021 **Dr. Isaac Yakoub Isaac graduate Scholarship in Physics**

2019 **Valerie Jagoldas Graduate Scholarship in Science**

2019 **University of Alberta Doctoral Recruitment Scholarship**

Undergraduate awards

2017 **Institute Silver medal**, (For ranking first in the aerospace department at IITB)

Representing India at International competitions

2012 **Bronze Medal, International Olympiad on Astronomy and Astrophysics**,
Rio De Janeiro, Brazil

2011 **Silver Medal, International Astronomy Olympiad**,
Almaty, Kazakhstan

Thesis Projects

PhD Thesis **Data-driven classification of X-ray sources through automated emission line detection**, *Supervisor: Craig Heinke*, University of Alberta
Modern X-ray telescopes have detected hundreds of thousands of X-ray sources across the universe. However, current methods to analyze the X-ray spectra on large catalogs supper problems – detailed X-ray spectroscopy of individual sources is time-consuming, and hardness ratios might be inaccurate for faint/moderately bright sources [5]. Therefore, we are developing machine learning methods to identify emission lines in the CCD spectra of X-ray sources and use the position and strength of these lines to classify X-ray sources.

Masters Thesis **High Energy Emission from "Dead" stars**, *Supervisor: Craig Heinke*, University of Alberta

We studied faint and moderately bright sources where the Poisson noise from low photon counts, high background and changing detector response caused confusion in the source properties, and provided more conclusive results — showed that the proposed AGN in Henize 2–10 and NGC 4178 are more likely to be SNR [5]; argued for the presence of a luminous NS in SNR 1E 0102.2-7219 [4]; and concluded that the vanishing orbital X-ray variability of binary MSP 47 Tuc W is due to the weaker sensitivity of *Chandra* HRC to hard X-rays from the intra-binary shock [3].

Honors Project **Numerical simulation of collisionless shocks**, *Supervisors: Bhooshan Paradkar, University of Mumbai, Kowsik Bodi, IIT Bombay*

Simulated collisionless shocks from unmagnetized relativistic plasma using a particle-based approach. We showed the development of turbulent magnetic fields in the transient region through Wiebel-like instabilities that could accelerate electrons to high energies.

Skills

Programming Python, C/C++, AstroSQL, Shell Scripting, HTML, LaTeX

Tools CIAO, HEASOFT (XSPEC, FTOOLS, XRONOS) *Astronomy packages*

Technical projects

2013 – 2017 **Mechanical Subsystem, Pratham — Student Satellite of IITB**

I analyzed the structural response of the satellite by simulating it under static, transient and periodic loads to ensure the rigidity of satellite equipments. I also performed the thermal analysis to keep the electrical components in their optimal temperature range. I optimized satellite models to reduce the analysis time. I was also involved in selection of payload and discussions to use tether as a de-orbiting mechanism for the next student satellite Advitiy.

Mentoring Experience

2016 – 2017 **Institute Student Mentor**, IITB

I was selected into a team of 81 mentors from 368 applicants to guide first-year undergraduate students to get accustomed to the academic and hostel environment at IITB. For the training, I attended a workshop by the Tata Institute of Social Service to gain the essential skills for identifying and approaching students with mental health issues.

2015 – 2017 **Department Academic Mentor**, Aerospace Engineering, IITB

I was a part of the 25-member team to guide sophomores and students under the academic rehabilitation program, to perform better academically.

May 2015 **Resource person and Student facilitator**, *Orientation-cum-selection camp in Astronomy*, Homi Bhabha Centre for Science Education

I was selected as a resource person for the Indian Astronomy Olympiad Orientation-Cum-Selection-Camp to mentor students, handle academic arrangements and aid in evaluations.

Teaching and Outreach Experience

2018, 2022 **Graduate Teaching and Learning Program — Level1: Foundations & Level 2: Practicum**, University of Alberta

The courses aimed at establishing foundations of knowledge and teaching the creation of learning objects & outcomes, lesson plans, teaching goals, and teaching philosophy and deepening classroom management skills through practice.

2017–2023 **Graduate Teaching Assistant**, University of Alberta

Tutored and graded courses — Stellar Astrophysics (I and II) and introductory courses on astronomy of solar system, stars and galaxies; electromagnetism; and modern physics.

2017–2023 **Volunteer at the University of Alberta observatory**

2015–2016 **Manager, Krittika — Astronomy club of IIT Bombay**

Organized bi-weekly lectures, field trips to observatories and 1st year summer projects. Awarded the Institute Technical Organization Special Mention for exceptional performance

Refereed publications

[1] **Hebbar, Pavan R.** and Craig O. Heinke. Machine Learning Applied to X-Ray Spectra: Separating Stars in Orion Nebula Cluster from Active Galactic Nuclei in CDFS. *ApJ*, 949(1):12, May 2023.

[2] Y. Sharma, A. Marathe, V. Bhalerao, V. Shenoy, G. Waratkar, D. Nadella, P. Page, **Hebbar, P.**, A. Vibhute, D. Bhattacharya, A. R. Rao, and S. Vadawale. The search for fast transients with CZTI. *Journal of Astrophysics and Astronomy*, 42(2):73, October 2021.

[3] **P. R. Hebbar**, C. O. Heinke, D. Kandel, R. W. Romani, and P. C. C. Freire. On the vanishing orbital X-ray variability of the eclipsing binary millisecond pulsar 47 Tuc W. *MNRAS*, 500(1):1139–1150, January 2021.

[4] **Pavan R. Hebbar**, Craig O. Heinke, and Wynn C. G. Ho. X-ray spectral analysis of the neutron star in SNR 1E 0102.2-7219. *MNRAS*, 491(2):1585–1599, January 2020.

[5] **Pavan R. Hebbar**, Craig O. Heinke, Gregory R. Sivakoff, and Aarran W. Shaw. X-ray spectroscopy of the candidate AGNs in Henize 2–10 and NGC 4178: likely supernova remnants. *MNRAS*, 485(4):5604–5615, Jun 2019.

Significant Conference presentations

2024 **Automated identification of emission lines to classify X-ray sources (invited talk)**, *21st meeting of the High Energy Astrophysics Division, AAS*, Chandra Source Catalog splinter session, Horseshoe Bay, TX, US

2024 **Identifying neutron stars in Galactic Bulge with X-ray data (Poster)**, *21st meeting of the High Energy Astrophysics Division, AAS*, Horseshoe Bay, TX, US

2022 **Machine learning applied to X-ray spectra: separating stars from active galactic nuclei (Poster)**, *International Conference on Machine Learning for Astrophysics*, Catania, Italy

2021 **Data Driven Methods to Classify X-ray sources (iPoster)**, *Canadian Astronomical Society General Meeting*

2019 **The neutron star in supernova remnant 1E 0102.2-7219 (Talk)**, *Annual symposium by Graduate Physics Student Association, University of Alberta*, Edmonton, AB
(Awarded top oral presentation)

2018 **X-ray spectra of proposed AGN in bulgeless galaxies (talk)**, *Canadian Astronomical Society General meeting*, Victoria, Canada

Scientific Service

2023 **Co-authored Safi-Harab et al. 2023**, *White Paper as part of the AXIS Probe Concept Mission,*, arXiv:2311.07673

2020 **Refereed for Banovetz et al. 2021**, *The Astrophysical Journal, 912, 1*, and suggested improvements

Graduate Research Projects

2023 – 2024 **Identifying neutron stars in Galactic Bulge with X-ray data**, *Co-authors: Jiaqi Zhao, Craig O. Heinke*

Fermi observations of the inner degree of the Milky Way Galaxy show an excess of gamma-rays in addition to the expected emission from cosmic ray interactions. This gamma-ray excess (GCE) could be from dark-matter annihilation or an underlying population of millisecond pulsars (MSPs). X-ray observations from XMM-Newton and Chandra, which have higher angular resolution than Fermi, can detect the X-ray emission from bright MSPs and constrain the fraction of GCE that could be explained from MSPs. However, the Galactic Bulge also contains a population of bright intermediate polars and X-ray binaries that emit X-rays. We use deep (> 100 ks) XMM-Newton observations of the Galactic Bulge to study 838 sources with $N_{H,Gal} > 5 \times 10^{22}$ cm^{-2}. We compare the (6.2–7.2) keV emission with the surrounding (5.8–6.2) keV and (7.2–7.6) keV emission to distinguish continuum sources from sources that show significant 6.4 keV fluorescence Fe emission (such as X-ray binaries and active galactic nuclei) or Fe-K emission at 6.7 and 7.0 keV (such as cataclysmic variables). The high diffuse background emission allows us to use this methodology only on sources with more than 100 counts. Using this approach, we select 32 sources that show emission consistent with a continuum source. One source, 4XMM J174501.0-291045, has an extended radio counterpart and could be a possible young neutron star with a pulsar wind nebula. Follow-up observations, especially in high-frequency radio wavelengths, will allow us to reveal the nature of these sources.

2019 – 2022 **Machine Learning Applied to X-Ray Spectra: Separating Stars in Orion Nebula Cluster from Active Galactic Nuclei in CDFS**, *Supervisor: Craig O. Heinke*

Modern X-ray telescopes have detected hundreds of thousands of X-ray sources in the universe. However, current methods to classify these sources using the X-ray data themselves suffer problems-detailed X-ray spectroscopy of individual sources is too time consuming, while hardness ratios often lack accuracy, and can be difficult to use effectively. These methods fail to use the power of X-ray CCD detectors to identify X-ray emission lines and distinguish line-dominated spectra (from chromospherically active stars, supernova remnants, etc.) from continuum-dominated ones (e.g., compact objects or active galactic nuclei, AGN). In this paper, we probe the use of artificial neural networks (ANN) in differentiating Chandra spectra of young stars in the Chandra Orion Ultradeep Project (COUP) survey from AGN in the Chandra Deep Field South (CDFS) survey. We use these surveys to generate 100,000 artificial spectra of stars and AGN, and train our ANN models to separate the two kinds of spectra. We find that our methods reach an accuracy of $\sim$92% in classifying simulated spectra of moderate-brightness objects in typical exposures, but their performance decreases on the observed COUP and CDFS spectra ($\sim$91%), due in large part to the relatively high background of these long-exposure data sets. We also investigate the performance of our methods with changing properties of the spectra such as the net source counts, the relative contribution of background, the absorption column of the sources, etc. We conclude that these methods have substantial promise for application to large X-ray surveys.

2018 – 2019 **X-ray spectral analysis of the neutron star in SNR 1E 0102.2-7219**, *Co-authors: C. O. Heinke; W. C. G. Ho*

We re-analyzed numerous archival *Chandra* X-ray observations of the bright supernova remnant (SNR) 1E 0102.2-7219 in the Small Magellanic Cloud, to validate the detection of a neutron star (NS) in the SNR by Vogt et al. (2018). We find that a blackbody + power-law model is a decent fit, suggestive of a relatively strong B field and synchrotron radiation, as in a normal young pulsar, though the thermal luminosity would be unusually high for young pulsars. Among realistic NS atmosphere models, a carbon atmosphere with $B = 10^{12}$G best fits the observed X-ray spectra. Comparing its unusually high thermal luminosity ($L_{bol} = 1.1^{+1.6}_{-0.5} \times 10^{34}$ ergs s^{-1}) to other NSs, we find that its luminosity can be explained by the decay of an initially strong magnetic field (as in magnetars or high B-field pulsars) or by slower cooling after the supernova. The nature of the NS in this SNR (and of others in the Magellanic Clouds) could be confirmed by an X-ray telescope with high angular resolution, and superior spectral resolution and effective area, such as the *Lynx*.

2018 – 2019 **X-ray spectroscopy of candidate AGNs in Henize 2–10 and NGC 4178: likely supernova remnants**, *Co-authors: C. O. Heinke, G. R. Sivakoff, A. W. Shaw*

Identifying massive black holes in dwarf galaxies suggests that the growth of black holes could precede that of galaxies. However, some of the most intriguing candidate active galactic nuclei (AGNs) in small galaxies have such low luminosities that the sample is vulnerable to contamination by other sources, such as supernova remnants. We re-analyzed *Chandra* X-ray observations of candidate AGNs in Henize 2-10 and NGC 4178, and showed that hot plasma models, which are typical of supernova remnants, explain the observed spectra much better than simple power-law models, which are appropriate for AGNs. Our results indicate that investigation of X-ray spectra, even in a low-count regime, can be a crucial tool to identify thermally dominated supernova remnants among AGN candidates.

2016 – 2020 **On the vanishing orbital X-ray variability of the eclipsing binary millisecond pulsar 47 Tuc W**, *Co-authors: C. O. Heinke; D. Kandel, R. W. Romani*

Redback millisecond radio pulsars typically show pronounced orbital variability in their X-ray emission. This X-ray emission is thought to be produced by an intrabinary shock (IBS) between the pulsar wind and stellar wind from the companion, with the orbital variation induced by our changing view of the IBS. Some redbacks ("transitional" millisecond pulsars) have shown dramatic changes in their multiwavelength properties, which suggest a transition from a radio pulsar state to an accretion-powered state. The redback millisecond pulsar 47 Tuc W showed clear X-ray orbital variability in *Chandra* ACIS-S observations in 2002, which were not detectable in longer *Chandra* HRC-S observations in 2004-2005, suggesting that it might have undergone a state transition. However, *Chandra* observations of 47 Tuc in 2014-15 show similar X-ray orbital variability as in 2002. We explain the different X-ray light curves from the three *Chandra* epochs in terms of two components of the X-ray spectrum (soft X-rays from the neutron star, vs. harder X-rays from the IBS), and different sensitivities of the X-ray instruments observing in each epoch. We also use the ICARUS stellar modelling software, including calculations of heating by an IBS, to model the X-ray, optical, and UV light curves of 47 Tuc W and find that 47 Tuc W is a highly inclined system ($i = 63 \pm 7$ degrees) with the IBS dominated by the companion wind.

Undergraduate Research Projects

May–August 2017 **Automated GRB detection from AstroSAT CZTI data**, *Supervisor: Varun Bhalerao, IITB*

I worked on developing an algorithm to detect GRBs in the AstroSAT CZTI data. The crux of such a tool was to look for coincident peaks and two or more independent quadrants onboard CZTI. We wrote a python program that processed the raw data using the AstroSAT CZTI pipeline, constructed light curves with different bin sizes, used a median filter to subtract the background, and searched such peaks. We allowed for a flexible false-alarm rate to detect GRBs across varying brightness.

2015 – 2016 **Numerical simulation of Collisionless Shocks**,
Supervisors: Bhoosan Paradkar, University of Mumbai; Kowsik Bodi, IITB
Collisionless shocks are shocks where the transition region is much smaller than the mean free path of the plasma species. When plasma streams travelling at relativistic speeds interact, they can form collisionless shocks even in the absence of an external magnetic field. Such collisionless shocks can accelerate electrons and ions to much higher energies, equal to that of cosmic rays. As a part of my B. Tech project, I analyzed the structure of these unmagnetized collisionless shocks through particle-in-cell type numerical simulations to learn the mechanism through which these particles are accelerated. Through our simulations, we observed the development of turbulent magnetic fields within the transient regions through Wiebel-like instabilities. We conclude that these fields are responsible for the acceleration of plasma particles to higher energies.

December 2015 **B-Mode spectrum of CMBR and inflation models**,
Supervisors: N. Malsawmtluangi; P. K. Suresh, University of Hyderabad
This project was part of a fifteen-day winter school to provide a flavor of research in astrophysics to interested undergraduate students conducted by Homi Bhabha Center for Science Education in collaboration with the University of Hyderabad. Under the guidance of Dr. N Malsawmtluangi, we studied how different theories of inflation correlate to distinct covariance spectra of the anisotropies in cosmic microwave background (CMB). In particular, we looked into the B-mode polarization anisotropies in the CMB. We calculated the covariance spectrum for different test inflation models and compared them to the Planck observations to test the validity of these inflation models.