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Pavan Hebbar

Curriculum Vitae

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 compact objects (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, Thesis: *High Energy Emission from "Dead" stars*.
Supervisor: Craig Heinke

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

Refereed publications

[1] **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.

[2] **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.

[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] Y. Sharma, A. Marathe, V. Bhalerao, V. Shenoy, G. Waratkar, D. Nadella, P. Page, **P. Hebbar**, A. Vibhute, D. Bhattacharya, A. R. Rao, and S. Vadawale. The Search for Fast Transients with CZTI. *Accepted in the "AstroSat - 5 years" special issue of the Journal of Astrophysics and Astronomy*, November 2020.

Conference presentations

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

2020 **Changing X-ray light curve of binary millisecond pulsar 47 Tuc W (iPoster)**, *Canadian Astronomical Society General meeting*.

2019 **X-ray Spectroscopy of the Candidate AGN in Dwarf Galaxy Henize 2-10: A Likely Supernova Remnant (Poster)**, *20 Years of Chandra Science Symposium*, Boston, USA.

2019 **The neutron star in supernova remnant 1E 0102.2-7219 (Poster)**, *Canadian Astronomical Society General meeting*, Montreal, Canada.

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

2014 **Designing and analysis using ANSYS for 'Pratham' — student satellite of IITB (poster)**, *65$^{\text{th}}$ International Astronautical Congress*, Toronto, Canada.

Awards

Graduate Awards

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

2019 **Valerie Jagoldas Graduate Scholarship in Science**.

2019 **University of Alberta Doctoral Recruitment Scholarship**.

2019 **Top oral presentation**.
Graduate Physics Student Association colloquium 2019

2019 **Top poster presentation**.
Graduate Physics Student Association colloquium 2019

Undergraduate awards

2017 **Institute Silver medal**.
For being ranked first in the aerospace department at IITB.

2017 **Institute Technical Organization Special Mention**.
For exceptional performance as the manager of Krittika - Astronomy Club of IITB.

International Representations

2013 **Prof. Harry Messel International Science School**,
University of Sydney, Australia.
One of the 5 students to represent India and awarded a medal.

2012 **IGNOU UNESCO Science Olympiads for SAARC countries**.
Awarded medal for being among the top 40 participants.

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

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

Other Achievements

2011 **Kishore Vaigyanik Protsahan Yojana Scholarship**, *Indian Institute of Science*, Govt. of India, (Ranked 24 at national level)..

2009 **National Talent Search Examinations**, *NCERT*, Govt. of India.
Ranked 2$^{\text{nd}}$ at the National level and 1$^{\text{st}}$ at state level

Event Organization

2017 – Present **Volunteer**, University of Alberta Observatory.

2015 – 2016 **Manager**, Krittika — Astronomy Club of IITB.
I planned a budget of ₹ 225,000 for club activities which included lectures from senior students and professors, field-trips to telescope sites — Giant Metre-wave Radio Telescope, Udaipur Solar Observatory and Mount Abu Infrared Observatory, night-sky observations and telescope handling workshops, competitions like astronomy trivia and astrophotography contests. I was also a part of the Student Technical Activities Body and conducted Institute Technical Summer Projects 2015 with a budget of ₹ 800,000. I was awarded Institute Technical organization colour for my exceptional work.

December 2016 **Academic Committee Member**, International Olympiad on Astronomy & Astrophysics 2016.

July 2015 **Academic Committee Member**, International Physics Olympiad 2015.

Scientific Service

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

Mentoring Experience

2016 – 2017 **Institute Student Mentor**, IITB.
I was selected into a team of 81 mentors from 368 applicants for guiding first-year undergraduate students to get accustomed to the academic and social environment at IITB. For the training, I attended a workshop by Tata Institute of Social Service to gain the essential skills for identifying and approaching students with mental health issues, advising people against substance abuse, etc.

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, 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. The final team of five students that was selected and further trained received three gold medals and two silver medals in the International Olympiad on Astronomy and Astrophysics.

Teaching Experience

August 2018 **Graduate Teaching and Learning Program — Level 1**, University of Alberta.
Received certificate for attending a series of 21 lectures on principles of pedagogy, communication and leadership in classroom, teaching ethics and active learning.

Graduate Teaching Assistant

Winter 2018, 2019 **ASTRO 322: Galactic and Extragalactic Astrophysics**, University of Alberta.

Fall 2018 **ASTRO 320: Stellar Astrophysics I**, University of Alberta.

Winter 2018 **ASTRO 122: Astronomy of Stars and Galaxies**, University of Alberta.

Fall 2018, 2019 **ASTRO 120: Astronomy of the Solar System**, University of Alberta.

Winter 2019 **PHYS 381: Electromagnetic Theory I**, University of Alberta.

Fall 2017, Spring 2018 **PHYS 124: Particles and Waves (Lab TA)**, University of Alberta.
Instructor: Prof. Erik Rosolowsky

Undergraduate Teaching Assistant

Fall 2014, 2015, 2016 **PH 107: Quantum Mechanics**, IITB.

Winter 2016, 2017 **MA 214: Introduction to Numerical Analysis**, IITB.

Winter 2015 **BB 101: Introduction to Biology**, IITB.

Private Tutoring

Winter 2019 **PHYS 271: Introduction to Modern Physics**, University of Alberta.

Graduate Research Projects

2019 – Present **Data driven methods to classify X-ray sources**, *Supervisor: Craig O. Heinke.*
Modern X-ray telescopes have detected hundreds of thousands of X-ray sources which could be white dwarfs, neutron stars, black holes, supernova remnants or normal stars with hot atmospheres. Current methods to classify the X-ray sources are inefficient for large surveys — detailed modelling of how X-ray flux changes with energy is tedious and using standard ratios of X-ray flux in different energy bands alone to estimate the properties of X-ray source can be inaccurate. We plan to devise machine learning algorithms to identify emission-line dominated X-ray sources from continuum ones and thus classify the X-ray source. Our preliminary results show that such methods can differentiate active black holes at centre of galaxies from hot stars in a young cluster with an accuracy of ~90%.

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 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

June 2017 **MOTIVE: Monitoring of Transients Integrating Venus and Earth**,
Supervisor: Varun Bhalerao, IITB.

I was involved in writing a proposal for a high energy X-ray all-sky monitor as a payload to India's Venusian Orbiter mission. We argued that such a tool could help up detect and localize the position of GRBs within 1 arcmin^2. Additionally, such an instrument could also be used to observe solar flares in much detail and also study Venusian Gamma-ray Flashes that could enable us to understand the atmosphere of Venus. In particular, I developed tools to localize the GRBs using Earth-Venus-Mars triangulation or just using IPN and Venus. Using this program, and the ephemeris data from astropy, I estimated the average area of localization that could be achieved. When the proposal got rejected, I generalized the code to also include triangulation from satellites orbiting the earth using the sgp4 algorithm to determine the position of each satellite a the time of detection. Such a code could be used for future missions like LISA.

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.

December 2015 **B-Mode spectrum of CMBR and inflation models**,
Supervisors: N. Malsawmtluangi; P. K. Suresh, University of Hyderabad.

This project was a 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.

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 in 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.

Technical projects

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

I analyzed the structural response of the satellite by simulating the satellite under static, transient and periodic loads and suggested design changes to ensure the rigidity of satellite and its equipment during launch. I also performed thermal analysis of the satellite to keep the electrical equipment in their optimal range of temperatures as the satellite orbits the earth. I designed optimized satellite models to reduce the time for analysis without sacrificing the accuracy of the results. I was also involved in selection of payload and discussions to use tether as a de-orbiting mechanism for the next student satellite Advitiy.