Pavan Hebbar

Curriculum Vitae

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Research Interests

- Using X-rays and gamma rays to study compact objects, especially neutron stars and black holes.
- Understanding the structure and evolution of GRBs and supernovae from high-energy observations.
- Investigate the growth of SMBHs in active galactic nuclei and their role in host galaxy evolution.
- Following-up gravitational wave detections of binary neutron star mergers in electromagnetic radiation.

Education

2017 – Present **Masters in Physics, Specialization: Astrophysics**,
University of Alberta, Current GPA - **4.0/4.0**,
Supervisor: Craig Heinke.

2013 – 2017 **B.Tech Aerospace Engineering**,
Indian Institute of Technology, *Grade* – ***9.48/10***.

- **Department Rank 1** among the class of 2017
- Awarded **AP** grade (for exceptional performance) in Spaceflight Mechanics
- Completed Honors, *Honors' Grade* – ***10.0/10***
- Minor: Computer Science, Physics

Publications

- P. R. Hebbar, C. O. Heinke, G. R. Sivakoff, A. Shaw (preprint)
  'X-ray spectroscopy of the candidate AGN in Henize 2-10 and NGC 4178: Likely supernova remnants', (Submitted to MNRAS)
- P. R. Hebbar, C. O. Heinke, D. Kandel, R. Romani
  'On the vanishing X-ray variability in the eclipsing binary millisecond pulsar 47 Tuc W', (in preparation)
- P. Hebbar, C. O. Heinke
  'X-ray spectroscopy reveals the nature of compact object in SNR 1E 0102.2-7219', (in preparation)

Conference talks and publications

- "X-ray spectra of proposed AGNs in bulgeless galaxies" (talk),
  Canadian Astronomical Society 2018, Victoria, Canada
- R. Mishra, S. Shahane, P. R. Hebbar, S. Jain, Manmohan
  "Designing and Analysis Using ANSYS for 'Pratham' Student Satellite IIT Bombay", 65^{th} International Astronautical Congress 2014, Toronto, Canada
- R. Mishra, S. Shahane, P. R. Hebbar, S. Jain, Manmohan
  "Structural Dynamics-Modeling and Simulation of IITB Student Satellite-Pratham",
  National Seminar on Aerospace Structures 2014

Relevant Skills

Languages C/C++, Python, Shell Scripting, Matlab, HTML, LaTeX

Softwares and Packages *Engineering*: ANSYS, NASTRAN, OpenFOAM, SolidWorks CAD, AutoCAD
Astronomy: CIAO (including ChiPS, Sherpa), HEASOFT (XSPEC, FTOOLS, XRONOS), ASTROSAT CZTI pipeline

Graduate Research Experience

September 2018 – Present

X-ray spectroscopy reveals the nature of compact object in SNR 1E 0102.2-7219,
Co-author: Craig O. Heinke, University of Alberta, In preparation.

Neutron stars (NSs) manifest themselves through various ways in X-rays. Identification and spectroscopic studies of NSs are crucial to discern the properties of the NS, which allows us to learn the behavior of matter at extremely high densities $(10^{14} - 10^{15})$g cm^{-3} and understand the different cooling mechanisms in NS. We re-analyzed the *Chandra* X-ray observations of bright supernova remnant (SNR) 1E 0102.2-7219 in SMC to validate the detection of a compact object in the SNR by Vogt et al. 2018. We find that scaling the background spectra using a different normalization constant cannot explain the spectra from this source without background subtraction. The residuals from fitting the background model to the source indicate an additional thermal emission with temperature, $T \sim 10^6$K from a ~ 10km region, thus confirming the presence of an NS in the SNR. Further spectral analysis shows that a (Black body + Power law) model and an NS carbon atmosphere model with $B = 10^{12}$G best fit the observed X-ray spectra, with the NS carbon atmosphere model giving a marginally better fit. Despite the poor quality of the NS H atmosphere fits, we cannot rule them out due to the high flux from the SNR itself. Our results point towards the need for instruments with small angular resolution and large effective area as ideal probes to study young NS in SNRs.

February 2018 – Present

X-ray spectroscopy of candidate AGN in Henize 2-10 and NGC 4178: Likely supernova remnants,
Co-authors: C. O. Heinke, G. R. Sivakoff, A. W. Shaw (University of Alberta)), Submitted.

Black holes in dwarf/bulgeless galaxies play a crucial role in studying the co-evolution of galaxies and their central black holes. 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 AGN 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 Observatory observations of candidate active galactic nuclei (AGN) in Henize 2-10 and NGC 4178, considering the potential signals of emission lines in the minimally-binned X-ray spectra. We find 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 AGN. We identify clear signals of X-ray lines in the faint X-ray source identified with the radio source in Henize 2-10 by Reines et al. 2016. Combining our work with the MUSE measurement of the ionization parameter in this region by Cresci et al. 2017 indicates that this radio and X-ray source is more likely a supernova remnant than an AGN. A similar analysis of the low-count X-ray spectrum of a candidate AGN in NGC 4178 shows that a hot plasma model is about seventeen times more probable than a simple power-law model. Our results indicate that the 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.

May 2016 – Present

47 Tuc W: X-ray Variable star,
Co-authors: C. O. Heinke (University of Alberta); D. Kandel, R. W. Romani (Stanford University), In preparation.

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 occultation of the shock by the companion. Some redbacks ("transitional" millisecond pulsars) have shown dramatic changes in their multiwavelength properties, which may indicate a transition from a radio pulsar state to an accretion-powered state. The redback millisecond pulsar 47 Tuc W showed clear X-ray eclipses in Chandra observations in 2002, which were not detectable in longer Chandra observations in 2004-2005 with a different instrument. This could be a signal that 47 Tuc W is a transitional pulsar that changes between accretion-powered and radio pulsar states. We analyze Chandra observations of 47 Tuc in 2014-15 to test if 47 Tuc W has dramatically changed its X-ray behavior but observe eclipses in 2014-15 at the same orbital phase as before. We explain the different X-ray light curves from the three Chandra observations 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 modeling software, including calculations of heating by an IBS, to model the X-ray, optical, and UV light curves of 47 Tuc W and interpret the geometry of the system.

Undergraduate Research Experience

June 2017 – August 2017 **MOTIVE: Monitoring Of Transients Integrating Venus and Earth**,
Supervisor: Prof. Varun Bhalerao, Indian Institute of Technology Mumbai.

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 2017 – July 2017 **Automated GRB detection from AstroSAT CZTI data**,
Supervisor: Prof. Varun Bhalerao, Indian Institute of Technology Mumbai.

I worked with Prof. Varun Bhalerao to develop 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 and Inflation Models**,
National Initiative of Undergraduate Research - Astronomy,
N. Malsawmtluangi and Prof. P. K. Suresh, School of Physics, 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.

May 2015 – April 2016 **Numerical Simulation of Collisionless Shocks**,
Guide: Prof. Bhooshan Paradkar, Centre for Excellence in Basic Sciences, University of Mumbai
Co-guide: Prof. Kowsik Bodi, Aerospace Department, Indian Institute of Technology Bombay.

Collisionless shocks are shocks where the transition region is much smaller than the mean free path of the plasma species. When plasma streams traveling 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.

Jan 2016 – April 2016 **Solving Brio - Wu Shock Tube Problem**,
Prof. Avijit Chatterjee, Aerospace Department, Indian Institute of Technology Bombay.

The extreme conditions required to create plasma and analyze their interaction can only be achieved through theoretical simulations. In this project, I developed a code to analyze the propagation of waves in plasma using the conservative first order Godunov scheme to solve the magnetohydrodynamic equations numerically. I tested my algorithm using the standard Brio-Wu shock tube problem and showed that despite slight differences, the first order scheme was a good approximation to the results.

December 2013 **Gamma Ray Detection Through Čerenkov Radiation**,
National Initiative for Undergraduate Science – Astronomy,
Dr. K K Yadav, Bhabha Atomic Research Center, Mumbai.

Very high energy (TeV) gamma rays are observed through Čerenkov emission. As a part of the fifteen-day NIUS program, I designed programs to differentiate between the Čerenkov shower of gamma rays and cosmic rays. I analyzed the data from the TACTIC (TeV Atmospheric Cherenkov Telescope with Imaging Camera) telescope using this code to study the properties of MRK 421 and Crab nebula.

Technical Experience

2013 – Present **Mechanical Subsystem, Pratham – Student Satellite Team of IIT Bombay**.

- Performed vibrational, harmonic, modal analysis and developed the response spectrum of the satellite.
- Performed steady-state and transient thermal analysis to determine the temperature distribution.
- Proposed SNAP model to switch the satellite on with minimum power, after launch.
- Optimized satellite models for structural analysis to minimize the simulation time with required accuracy.
- Implemented ways to access the server remotely and perform parallel processing on ANSYS.
- Analyzed the feasibility of tethers as a deorbiting mechanism in the next satellite Advitiy.

Mentoring and Work Experience

Sptember 2017 – Present **Teaching Assistant at University of Alberta**.

- Held lab sessions and graded reports for the course PHYS 124 - Particles and Waves in Autumn 2017.
- Graded homework assignments for the courses ASTRO 122 - Astronomy of Stars and Galaxies and ASTRO 322 - Galactic and Extragalactic Astrophysics in Spring 2018.
- Demonstrating the use of telescopes to ASTRO 120 (Astronomy of solar system) students and grading their assignments.

March 2016 – Present **Institute Student Mentor**.

- Selected among a team of 81 mentors out of 368 participants to mentor first-year students.
- Guided twelve mentees allotted to me to get adjusted to the social and academic life as an undergraduate.
- Volunteered in the organization of welcome programs for freshmen.
- Attended a one day workshop organized by Tata Institute of Social Service (TISS) to learn different skills required for mentoring.

2015 – 16 & 2016 – Present **Department Academic Mentor**.

- Selected twice into a team of 25 mentors to help sophomores of aerospace department academically
- Involved in guiding and solving academic problems of four mentees in 2015 – 16, and three mentees in 2016 – 17, one of whom secured the department rank one of their batch for that year.

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

- Selected as a student grader for the theory round of the Olympiad.
- Involved in the critical discussion of theory questions.
- Evaluated the answer scripts of students from 89 different countries.

June 2015 **Resource Person and Student Facilitator**.

- Selected as a resource person for the Indian Astronomy Olympiad OCSC (Orientation-Cum-Selection Camp) for mentoring students, handling academic arrangements and aiding in evaluations.
- Involved in the selection and training of Indian team which won 3 gold medals and 2 silver medals at International Olympiad for Astronomy and Astrophysics 2015.

2014 – 2016 **Teaching Assistants for IITB courses** .

PH 107: Quantum Physics and Application	Autumn 2014, Summer 2015, Autumn 2015
BB 101: Biology	Spring 2015
MA 214: Introduction to Numerical Analysis	Spring 2016

- Held tutorials where doubts of students were addressed and applications and problems related to the concepts learnt in lectures were discussed.
- Evaluated the answer scripts of students in various exams.

March 2015 – March 2016 **Manager, Krittika – Astronomy Club of IIT Bombay**.

- Planned a budget of 225,000 rupees for club activities including lectures, documentary screenings, night-sky observations and workshops, field trips and competitions.
- Organized Institute Technical Summer Project 2015 which had a budget of 800,000 rupees.
- Planned and organized the Inter IIT Messier Marathon 2014-15.
- Selected college level teams to participate in intercollegiate events.
- Awarded the Institute Technical Organization Color for exceptional performance.

2014 – 2015 **Coordinator, Abhyudhay – Social Festival of IIT Bombay**.

- Worked under the Events Division and managed the logistics of various events including lectures, competitions, and Interactive sessions.
- Planned and implemented urban farming in the hostels of the institute.

Awards

International Representations

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

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

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.

Other Achievements

2010 – 2012 **Olympiad Orientation Cum Selection Camps**.
- Astronomy Camps (2010, 2011 & 2012) for top 30 students in India.
- Awarded **Best Theory** Solution in 2012 and **Best Observer** in 2011 Astronomy Camps.
- Awarded Certificates of Merit in the National Standard Examinations in Physics(2013) and Junior Science (2011) for being in top 1% of the participants.

2011 **Kishore Vaigyanik Protsahan Yojana Scholarship**, *Indian Institute of Science*, Banglore.
- Awarded by Government of India for students interested in research.
- Ranked 24 at national level.

2009 **National Talent Search Examinations**, *NCERT*, Delhi.
- Awarded by Government of India for students interested in research.
- Ranked 2nd at national level and 1st at state level.

2016 **Online Physics Brawl**.
Secured first position among 245 teams from all over the world in the online physics brawl conducted by FYKOS - students from Dept. of Maths and Physics at Charles University.

2014 **Inter IIT Messier Marathon**.
Secured IIT Bombay the second position by putting on board 72 Messier objects including the entire Virgo cluster of galaxies.

Relevant Courses Undertaken[1]

Physics Stellar astrophysics II*, Theoretical Astrophysics*, Extragalactic astrophysics*, Classical electromagnetism*, Advanced Simulation Techniques in Physics*, General Theory of Relativity*, Quantum Mechanics I*, Condensed Matter Physics*, Statistical physics, Classical Mechanics, Introduction to Nuclear and Particle Physics, Nonlinear Dynamics

Aerospace Engineering Introduction to Plasma*, Computational Fluid Mechanics*, Particle methods to simulate fluid flows, Compressible and Incompressible Fluid Mechanics, Thermodynamics and Propulsion

Computer Sciences Computer Graphics, Image Processing, Data Structures and Analysis, Logic for Computer Programming, Introduction to Computer Science

Other relevant experiences

December 2018 **GROWTH Winter School**
Selected for a three day workshop on multi-wavelength follow-up of transients organized at Indian Institute of Technology Bombay by the GROWTH collaboration, led by Caltech.

July 2018 **Dunlap Summer School on Astronomical Instrumentation**
Attended a one week workshop on instrumentation across different wavebands for observational astronomy organized by Dunlap Institute, University of Toronto.

[1] starred courses are taken at a graduate level