The 2020 University of Chicago Undergraduate Research Symposium Proceedings: Abstract

The Size to X-ray Luminosity Relationship of Galactic Supernova Remnants

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Mentor(s): Professor Vikram Dwarkadas, Astronomy and Astrophysics

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This poster presents an X-ray study of the Galactic supernova remnant (SNR) population. We focus on the relationship between the X-ray luminosity and remnant size, limiting our sample size to remnants for which the total X-ray luminosity, and size measurements, exist. In our analysis we also take into account estimated age and interstellar medium densities from the literature. Results are compared to the size-luminosity relationship in other wavelengths to study how the total emission from galactic remnants evolves. We also compare Galactic remnants to those in the Large and Small Magellanic clouds, for which a larger and arguably more accurate data set exists, due to better distance measurements. The Galactic SNR properties have larger error bars due to uncertainties in distances. Results of this study will help to further constrain SNR evolution models.

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Fast Inference for Gravitational Lensing Classification with LSST

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Mentor(s): Professor Brian Nord, Astronomy and Astrophysics, Fermi National Accelerator Laboratory

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Our goal is to utilize neural networks to classify simulated gravitational lensing data for the Large Synoptic Survey Telescope (LSST) and perform fast inference on LSST data when it is fully operational. We train our networks on 20,000 images with binary classifications (labeled as either a "lens" or a "no-lens") and is then fed into numerous neural network architectures such as a Convolutional Neural Network (CNN) called ResNet50. We perform inference on 100k images on various hardware (e.g. CPUs, GPUs, TPUs, and FPGAs) and examine the overall accuracy and efficiency of each model architecture/hardware combination. The model architecture/hardware pipeline with the best accuracy and efficiency will be used to perform fast inference at or near LSST when the telescope begins collecting data. Our automatic classification pipeline will be efficient enough (likely on the order of milliseconds/image) that follow-up observations can be performed on images our program denotes as containing strong gravitational lensing. Model efficiency is key for allowing the scientific community to capture more strong lensing data and develop a deeper understanding of this rare phenomenon while potentially help solve problems like the Hubble Constant discrepancy.

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Searching for Infrared Galaxies in the MUSE Sky Survey's Optical Data

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Infrared galaxies are 100 to 1,000 times brighter than typical galaxies and radiate over 90% of their light in infrared. Unlike many previous surveys, spectroscopic surveys with integral field unit (IFU) instruments, which simultaneously take imaging and spectroscopic data do not require scientists to pre-select targets and instead take spectra for an entire field-of-view. This means that the state-of-the-art optical IFU instrument, the Multi Unit Spectroscopic Explorer (MUSE), is able to collect optical data for infrared galaxies that were not bright enough in the optical range to be selected in previous surveys. The first goal of this project was to match the galaxies in an infrared catalog to the optical sources in the MUSE catalog. I ran an automated approach that matched galaxies to any optical source within a 3-arcsecond radius. Some galaxies had multiple possible matches. For these sources, I displayed images of the galaxies and marked locations of the possible matches and then manually identified which match was correct. Out of the 129 galaxies in the catalog, 30 did not have a match, 21 had too many matches to determine the correct one, and 78 had a single match. I then analyzed the redshifts of these galaxies. There are two ways the optical catalog calculates redshift: spectroscopic redshift and photometric redshift. For fainter galaxies, these two calculations often have a notable discrepancy. Since infrared galaxies are a faint subset of the optical catalog, I created a graph that plots the discrepancy between the two values. I found no significant discrepancy in the redshifts. I then classified the infrared galaxies into two types: those powered by a supermassive black hole and those powered by extraordinarily high rates of star formation. Since black holes are a more powerful source, they have emission lines with higher ionization potential. Thus, I was able to use 3 classification diagrams that compared the flux ratios of different emission lines to classify the galaxies.

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Density Under Invertible Hölder Continuous Mappings in R^m

Srihari **Narayanan**, 2nd-Year, Mathematics, Astrophysics
Mentor(s): Professor Jon Peter May, Mathematics; Professor Marianna Csörnyei, Mathematics; Nixia Chen, Mathematics

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Measure theory, the study of generalizations of n-dimensional volume, n ě 1, called mea-sures, forms the backbone of areas of analysis such as functional analysis, geometric measure theory, and probability theory. Central to measure theory (and this paper) is the pointwise notion of the density of a Lebesgue measurable set (that is, a set to which we can assign a measure without contradictions), which is defined at a particular point x by comparing the measure of an *n*- dimensional ball (that is, a solid sphere) of arbitrarily small radius centered at x with the measure of the set restricted to the ball. In 1992, it was proved that, if f: $A \to B$ is bi-Lipschitz (a stricter version of continuity for invertible functions) for A, B Lebesgue measurable subsets of Rm, then all density points of A are mapped by f to density points of B, and all density points of the complement of A Ac (termed 'dispersion points') are mapped by f to dispersion points of B (Buczolich, 1992). This paper explores this property and proves a small but nontrivial extension to the slightly more general class of α1-H¨older continuous functions with α2-H¨older continuous inverse, where H¨older continuity holds @α1, α2 ă 1 (and is exactly the definition of bi-Lipschitz functions for α1 " α2 " 1). We then use this result to derive a theorem analogous to the result that bi-Lipschitz images of Caccioppoli sets, a formalization of the notion of a set with sufficiently nice boundary integral to geometric measure theory, are Caccioppoli, in a much less involved manner than in most of the research literature. Possible future steps include attempting to find and prove or conjecture some form of converse to the above results.

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Multidimensional Database Reconstruction from Range Query Access Patterns

Adam **Rivkin**, 3rd-Year, Computer Science
Mentor(S): Professor David Cash, Computer Science

Because many large organizations like hospitals and businesses need to store computationally cumbersome amounts of data, there is a growing need to outsource databases to cloud computing platforms like Amazon Web Services or Dropbox for remote storage. These databases may contain sensitive information, so the data need to be stored in a secure manner and yet still allow the client organization to search for specific entries. This relies on a cryptographic primitive called searchable encryption, where a client can query a remote server and get back specific entries without even the server being able to figure out what query was issued or what entries were returned. While searchable encryption schemes exist in practice, the encryption is not perfect. If someone captures these encrypted data, they can infer some information about the database, but prior work has not been able to say exactly how damaging this information is. Our work considers the security of searchable encrypted database systems that process multi-dimensional range queries with only access pattern leakage, where an adversary learns which encrypted records are returned by a query. Recent cryptographic work showed that in one dimension, an adversary could use the access patterns of several uniformly random range queries to reconstruct a plaintext column of numbers up to its reflection. We extend this attack to two dimensions and find that the situation is much more complicated: Information theoretically it is complex to describe even what is possible to recover for the adversary in general. We provide a classification of these limits under realistic technical conditions and a heuristic approach to determine the actual distribution of the underlying data. We also give a faster algorithm that works for "dense" databases that contain at least one record for each possible value. Finally, we explore the implications for our classification on real data sets, using hospital and crime data. We find many cases where multidimensional reconstruction attacks are a feasible threat.

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Control over Intracellular Signalling using Bioelectronic Devices

Matthew **Seebald**, 3rd-Year, Chemistry
Mentor(s): Professor Bozhi Tian, Chemistry

The growing field of bioelectronic devices provides novel methods of cellular sensing and stimulation at the nanoscale. Stimulation of cells involves the alteration of a cell's equilibrium state by transducing basic forms of energy such as light or heat into perturbative cellular signals for multiple possible ends, including spatio-temporal control over apoptosis, contraction, or other pathways involving cellular signaling. Such control would provide alternate routes of treatment for diseases such as cancer. In this research, the control over apoptosis afforded by an extracellular (ECM) mimic, poly(3-hexylthione) (P3HT), was studied in multiple cell types and modelled using response time distributions. The fiber like matrix formed by P3HT allows cells to couple to it as they would the ECM. However, P3HT, being more porous than the ECM, forces cells to adopt a topographically altered, proapoptotic state. Furthermore, P3HT is capable of photothermal transduction, that is, the conversion of light into a thermal stimulus recognizable by target cells. These thermal pulses lead to membrane depolarization and a subsequent influx of calcium, pushing the cells from a proapoptotic state to an apoptotic one. Using a dye sensitive to proteins within the Type 1 apoptosis signaling pathway, response time distributions were created using a large ensemble of cells for different intensities of light. These were deconvoluted into simulated distributions generated using rate laws for different signaling motifs, specifically cascade, irreversible chain, and crosstalk signaling. Their contributions at different intensities of light elucidated that the combination of mechano- and photothermal transduction afforded by P3HT had the unique ability to modulate apoptotic signaling in cells adjacent to the matrix. For example, an uptick of crosstalk signaling, which only occurs at high degrees of stress to quicken cell death, was seen at higher intensities of light, implying that increasing the extent of photothermal signal transduction forces cells to accelerate apoptotic signaling. In this way, P3HT can be used in conjunction with or as an alternative to available cancer treatments by locally killing target cell types using a specific dose of light.

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Diffuse Interstellar Bands

Isaac **Sierra**, 2nd-Year, Astrophysics
Mentor(s): Professor Donald York, Astronomy and Astrophysics

Diffuse Interstellar Bands (DIBs) are absorption features in the interstellar medium seen in the spectra of stars in the visible to near infrared wavelengths. Since their initial discovery in 1919 by Mary Lea Heger, the number of known DIBs grew from the initial two to the more than 500 DIBs we see today. However, despite being discovered over a hundred years ago, no DIB has been positively matched with its corresponding source carrier, and though there are many potential candidates (such as C60+), none have yet to be identified. Thus, our goal is to identify source carriers for the DIBs. In the attempt to achieve this goal, we have been analyzing plots comparing the equivalent widths of particularly notable DIBs such as 4727, 5780, and 5797 (all measured in angstroms). In analyzing these plots, I would look for particular trends such as stars that appeared as outliers in EB-V (extinction) level, and write up and present reports to Dr. York. One trend of particular significance that we explored and are currently investigating in further detail is the clustering of a particular group of stars in all plots involving the 4727 DIB (due to the higher equivalent width of the 4727 DIB in each of the stars in the group). By further exploring the individual details such as EB-V levels, hydrogen frequencies, and carbon frequencies, we are attempting to find discrepancies between this particular group of stars and the rest of the stars in the plot, which will ultimately lead us closer to understanding the 4727 DIB and eventually even possibly discovering its corresponding source carrier. In the coming months, we will continue to find notable trends in the 4727 DIB as well as other DIBs in our attempt to discover more about aspects of interstellar gas in general. Ultimately, we aim to shed more light on the DIB phenomenon, as currently, only empirical evidence comprises our knowledge of these peculiar absorption features, and in this ever continuing journey, we work toward our overarching attempt to discover these elusive source carriers that have remained a mystery for over a century now.