The Columbia Undergraduate Science Journal takes great pride in having the honor of hosting the annual Columbia Spring Research Symposium. This year, the 2021 Symposium was held virtually for the first time, and we are happy to have celebrated undergraduate research and retained the lively spirit of the event despite the unprecedented circumstances. Below are the winning presentations selected by our esteemed faculty judges!

First Place: "Can we use next-generation gravitational wave detectors for terrestrial precision measurements of Shapiro time delay?" by Andrew Sullivan

Abstract: Shapiro time delay is an effect predicted by Einstein's theory of general relativity whereby the travel time of light is delayed as light passes by massive objects. Shapiro time delay is related to the parameterized post-Newtonian formalism parameter $\gamma$, which quantifies spacetime curvature produced by a unit mass. Consequently, the measurement of Shapiro time delay can be used as a method of measuring the accuracy of the theory of general relativity. To date, all measurements of Shapiro time delay have been conducted in space over astronomical scales. We propose an experiment that will allow Shapiro time delay measurements to be conducted on Earth, in which we use a rotating mass unit and a next-generation gravitational wave detector. With this scheme, we find that Shapiro time delay and $\gamma$ may be measured with sub-percent precision. This is the most precise scheme proposed for measuring Shapiro time delay on Earth to date.

About the Author: "Andrew is a junior physics major at Columbia University from Yonkers, New York. Andrew has performed research with Columbia’s Experimental Gravity group for the last two years and his research interests lie in the field of gravitational physics and gravitational wave astronomy. Andrew hopes to obtain a PhD in physics and become a professional researcher. For fun, Andrew enjoys watching baseball and running."

Second Place: "Neural oscillations as predictors of second language learning" by Victoria Ogunniyi

The full body of this work can be found on page 39 of this issue of the Columbia Undergraduate Science Journal.

About the Author: "Victoria Ogunniyi is a third-year undergraduate student majoring in Neuroscience with a minor in Professional Writing at the University of Illinois at Chicago. After college, she plans to apply to medical school and pursue a residency in psychiatry. In her free time, she enjoys improving her fictional writing skills and hopes to one day become a published novelist."
Third Place: "Probing the Statistical Relationship Between Binary Black Hole Mergers and Active Galactic Nuclei Hosts" by Amanda Beck

Abstract: Since 2015, LIGO/Virgo has detected many Binary Black Hole merger Gravitational Wave signals. Identifying the origins of these is key to discover more about these mergers. Rare host galaxies, like AGN, present a favorable environment for these events due to the possible dynamical interactions in their accretion disks. In this project we will probe the statistical relationship between BBH mergers and AGN hosts by analyzing the overlap in localization, as outlined in Bartos et. al. 2017. To do that, we developed a python-based framework that can get the volume overlap between AGN catalogs and LIGO/Virgo 90% probability density volume of BBH mergers. It can be used to establish the fraction of BBH GW detections that come from AGN and to inform real-time EM follow-up.

About the Author: "My name is Amanda Beck, and I am a Brazilian Junior at Columbia University, Columbia College, majoring in Astrophysics. I am mainly interested in high energy astrophysics, and anything that deals with relativity and statistical analysis, as well as STEM education, but am open to any field of research. I plan on obtaining a PhD in Astronomy or Astrophysics, and engage in research and teaching. My favorite pastime is reading, specially fantasy or sci-fi!"

Fourth Place: "The Diagnosis of Median Arcuate Ligament Syndrome and Postural Orthostatic Tachycardia Syndrome and the effect upon the Presentation of Clinical Depression" by Jessica Eddy

Abstract: Median Arcuate Ligament Syndrome is a rare, congenital condition where the diaphragm sits too low and the median arcuate ligament crushes the celiac artery. Postural Orthostatic Tachycardia Syndrome often presents as a co-occurring condition. The presentation of these conditions impacts the solar plexus, celiac ganglion, autonomic nervous system dysregulation, and neuropathy. My research was conducted in order to see if patients with median arcuate ligament syndrome and orthostatic intolerance as a comorbidity present with higher levels of clinical depression. Furthermore, if the severity of the chronic condition increased, would clinical depression increase, as well? This research utilized methods such as peak systolic velocities from color duplex ultrasound technology, tilt table results to test for orthostatic intolerance, and the Beck Depression Inventory-II to seek to understand the connection between median arcuate ligament syndrome and orthostatic intolerance caused by dysregulation of the autonomic nervous system, which works in some level of conjugation with the solar plexus, sympathetic nervous system, dopamine and serotonin pathways, and dopamine receptor agonists and antagonists.

About the Author: "My name is Jessica Eddy. I am from Grand Rapids, Michigan and am currently studying at the University of Oxford. My current research includes the impact of rare vascular/gastrointestinal diseases and the role of endothelial cells in HIV latency. I plan to attend medical school for a joint MD/PhD and hope to research genetic biomarkers in rare vascular conditions. For fun, I love dancing and own my own dance studio, running with my puppy, and traveling the world!"
Can we use next-generation gravitational wave detectors for time precision measurements of Shapiro delay?*

Andrew G. Sullivan, Doğa Veske, Zsuzsa Márka, Imre Bartos, Stefan Ballmer, Peter Shawhan, Szabolcs Márka

Abstract
We propose a method for measuring Shapiro time delay using a rotating mass unit and the next-generation gravitational wave detectors Cosmic Explorer and Einstein Telescope. We find that we can measure $\gamma$ in the parameterized post-Newtonian formalism of gravity with sub-percent precision in half a decade.

Introduction
Shapiro time delay $\delta t$ in the travel time of light caused by a nearby massive object as predicted by general relativity (GR).

Parameterized post-Newtonian formalism (PPN)→ characterization of post-Newtonian gravity theories through a family of parameters including $\gamma$ which relates mass to spacetime curvature. In GR, $\gamma = 1$.

Shapiro delay of light $\delta t$ over path $s$ in the PPN formalism is:

$$\delta t = (1 + \gamma) \int ds$$

Where:
$\gamma$: Newtonian gravitational potential

We revisit an analysis to determine the prospects of measuring Shapiro delay and consequently $\gamma$ on Earth using next-generation gravitational wave (GW) detectors Cosmic Explorer (CE) and Einstein Telescope (ET) and a rotating mass unit (RMU).

Next-generation detectors CE and ET are gravitational wave interferometers currently being planned. They are expected to be operational in the 2030s with strain sensitivity 10 times lower than that of the current Advanced LIGO detectors.

Next-Generation Detectors and the Rotating Mass setup
Interferometric GW detectors measure periodic differences in length. An RMU provides a way to modulate the Shapiro delay such that it is periodic.

We suggest three possible RMU models: A, B, and C.

<table>
<thead>
<tr>
<th>RMU Model</th>
<th>Mass (kg)</th>
<th>Rotational Frequency (Hz)</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>$2.5 \times 10^5$</td>
<td>25</td>
</tr>
<tr>
<td>B</td>
<td>$1.5 \times 10^5$</td>
<td>25</td>
</tr>
<tr>
<td>C</td>
<td>$6.0 \times 10^4$</td>
<td>15</td>
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</tbody>
</table>

Table 1: The steel end mass and rotational frequencies of the three suggested RMU models.

Analysis
Using equation (1), we calculate the Shapiro time delay from each RMU model and compare with the the sensitivity curves of CE2 and ET-D-HF to calculate the SNR of each signal.

Figure 1: Diagram of a Michelson interferometer and a sketch of the RMU

Figure 2: Periodic Shapiro time delay produced by each of the three RMU models: A, B, and C, over the period oscillation of model C.

Figure 3: Fourier components of the Shapiro time delay signal converted to equivalent light path displacement plotted alongside the CE and ET sensitivity curves for 1 year of integration time.

In one year of integration time, we find that model A generates an SNR of of 29 in CE and 43 in ET. This corresponds to an expected measurement of $\gamma = 1$ with standard errors of $\pm 6.9\%$ and $\pm 4.6\%$, respectively.

We can measure both Shapiro delay and $\gamma$ with standard errors <1% in just 5 years of observation time with 3 synchronized model A RMUs and CE and 2 synchronized model A RMUs and ET.

This represents the most precise proposed Earth based Shapiro delay measurement to date.

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*Andrew G. Sullivan et al 2020 Class. Quantum Grav. 37 195018 https://doi.org/10.1088/1361-6382/ab9900
Stefan Ballmer et al 2010 Class. Quantum Grav. 27 065018 https://doi.org/10.1088/0264-9381/27/6/065018
Figure: Second place poster from Victoria Ogunniyi
Figure: Third place poster from Amanda Beck
The Correlation of Median Arcuate Ligament Syndrome and Orthostatic Intolerance and the Presentation of Clinical Depression

Abstract

MALS is a common diagnosis, but its correlation with clinical depression is not well understood. This study aimed to investigate the relationship between MALS and clinical depression in patients presenting with orthostatic intolerance.

Methods & Procedure

Participants were divided into two groups: those with MALS and those without. The Beck Depression Inventory (BDI) and Orthostatic Intolerance Questionnaire (OIQ) were administered to assess depression severity and orthostatic intolerance, respectively.

Results

A significant correlation was found between MALS and clinical depression, with patients with MALS having higher BDI scores.

Conclusions/Future Work

Further studies are needed to explore the mechanisms behind this correlation and to develop effective treatment strategies.

Figure: Fourth place poster from Jessica Eddy