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CURJ

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CALTECH UNDERGRADUATE RESEARCH JOURNAL vol. 14. no. 1

Welcome to the latest issue of the biannual Caltech Undergraduate Research Journal (CURJ)! We are proud to present to you some of the latest research at Caltech from a few of the best and brightest. Every summer, students from all across the world participate in research at Caltech and at the affiliated Jet Propulsion Laboratory. These students have shown great commitment to science and the advancement of knowledge.

CURJ is honored to partner with Caltech's Summer Undergraduate Research Fellowship program to highlight some of the cutting edge research done at Caltech by three young scientists: Bertrand Ottino-Löffler, David Miller, and Sangavi Pari. Their research topics include analyzing traffic flow in urban areas, detecting black hole and neutron star collisions, and understanding chemical hydrolysis in organic compounds.

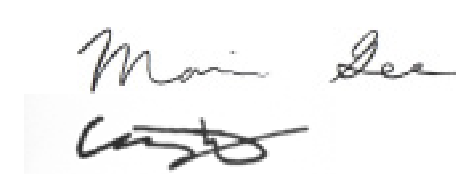
With all the exciting student research at Caltech, let us not forget the overwhelming support of dedicated faculty and mentors. CURJ would like to take this opportunity to thank all the faculty and mentors for their dedication and investment in future scientists. Moreover, CURJ is proud to feature interviews of Professors John Johnson and Sarkis Mazmanian to learn more about their history, accomplishments, and their outlook on research.

Professor Johnson joined Caltech's astronomy department in 2009, and after 4 short years, he won Caltech's Feynman teaching prize. His immersive and unique teaching style has won praise from students. Instead of following the traditional lecturing style of classrooms, he prefers working with students on problems in small groups. In this way, students get a more hands-on approach to learning. His research focuses on the detection and characterization of planets outside of our solar system. Another accomplished professor is Sarkis Mazmanian, the winner of the MacArther Fellowship. The MacArthur Fellowship is given to "individuals who have shown extraordinary orginiality and dedication in their creative pursuits and a marked capacity for self-direction." Sarkis joined Caltech's biology program in 2006; he focuses on the symbiotic relationship of beneficial microbiota in the gastrointestinal tract. Both of these young and distinguished professors have shown incredible promise and continue to be leaders in their fields.

We thank you for picking up this latest edition of CURJ and sincerely hope that you enjoy it. You can find more CURJ information as well as previous issues on our website (curj.caltech.edu). As always, feel free to let us know your thoughts.

Best regards,

Marvin Gee and Conway Xu



What are some examples of in class activities that you've tried?

So if I'm doing a lecture on star formation, I can stand in front of the group and write on the board in my own words and my own ways of understanding, I could do the derivation in a way that I am familiar with. But it's important to remember that I'm standing in front of a classroom of 30 students who each bring their own ways of understanding, knowledge and deficiencies in knowledge. Instead, I write a worksheet that guides the students through the thought process necessary to do the derivation. The students get into groups, go up to the whiteboard, and think their way through the problem. The worksheet is merely a guide that helps them do the derivation themselves. If they make a mistake, I can give them individualized assistance that's custom for their specific needs.

You've met many students, both at Caltech and at Berkeley. What do you think makes a successful student?

If I had a student that turned in a half completed homework because she noticed similarities between something she saw in statistical mechanics and quantum and got sidetracked following those tangents; that is the ideal student. That's the student who will have success over the student who did problem one, then problem two and so on just to finish the assignment and move on. You're in college to learn, not to just fill out answers on homework sets.

Many of our readers are aspiring scientists. What would you tell them are qualities that set good scientists apart?

The people who are not afraid of being wrong are the ones who are going to take risks. And when you take risks, you're going to discover things that that other people didn't. For example, when we used the Doppler technique, we're meaning the Doppler shift of the star as it is being tugged back by the planet. But the star is also tugging on the planet and because the planet is less massive, the planet is moving much faster that the star is. Why shouldn't we just detect what the planet is doing? The answer is that the planet is too faint: for every million photons coming from the star, only one is coming from the planet. But if you could measure the speed of both the star and the planet, you could get the masses of both bodies. Most people think that it's too challenging of a problem. Many people have already tried and failed. But I look at that and think that we should tackle this problem. We're doing that right now, and my student not

"Many people have already tried and failed. But I look at that and think that we should tackle this problem."

only succeeded, but also detected water in the atmosphere of that planet.

What does it take to tackle challenging problems like that?

Ingenuity, grit, not being afraid, attention to detail, and trying nonstandard solutions. You can do it. Just because other people haven't succeeded in answering a question doesn't mean that you can't succeed at it. As a matter of fact, that's what I teach at Caltech. Stop focusing on what can go wrong, and focus on what can go right.

Clearly, you would advise students to take risks. What other advice would you offer?

Well, I have to go back on my words a little. You have to balance the risk with bread and butter work. I got where I am where I am right now through a lot of luck. But like my football coach would say, luck favors the prepared. You can position yourself to be lucky. You can position yourself for good luck to stay optimistic and looking for opportunities around every corner.

Any last comments to Caltech students in particular?

Another way to think about passion is the ability of an individual to think about what their goals are and how to pursue those goals. Why would a student come to Caltech instead of a school with a much bigger, energetic campus? I think you come to Caltech because you can rub shoulders with the best scientists in the world and if your goal is to become one of them, then shouldn't you be knocking on doors? Instead, I see so many students who are so timid around here. You have to have the courage to step out and do that and have the foresight to try and set yourself up to be lucky. Professors always want to talk about their research. That's the best advice I can give students: position yourself to be lucky, take risks, go out and take advantage of being at Caltech!

Interview with Professor John Johnson

By Caroline Yu

Professor John Johnson received his Ph.D. and M.A. from the University of California, Berkeley in Astrophysics. He is currently an Assistant Professor of Astronomy and Astrophysics and has been honored with numerous awards, including the Richard P. Feynman Prize for Excellence in Teaching as well as the American Astronomical Society (AAS) Newton Lacy Pierce Prize. His current research focuses on exoplanet detection and characterization. In the following interview, he discusses exoplanet astronomy and offers some advice to current students.

"My whole teaching philosophy is to get students to actively think rather than passively listen."

In lay terms, can you explain what your lab is working on?

We do detection and characterization of planets. As recently as 1995, we knew of only one star that harbored planets, the Sun, but since then, there have been more than 700 planets discovered. We use Doppler technique, transit, direct imaging and microlensing to detect planets that are around other stars. Once we find that they're there, we also use various techniques to study the characteristics of the planets' physical properties, such as mass and radius. We also are interested in their orbital characteristics.

So what exactly are exoplanets and what is the significance of your findings?

Exoplanets are planets that are beyond our solar system. We have multiple goals in the study of exoplanets. For example, by studying the relationships between exoplanets and the physical properties of the stars they orbit, we discover important clues about how planets are formed. We're also interested in general how the solar system formed.

How many planets have you discovered so far?

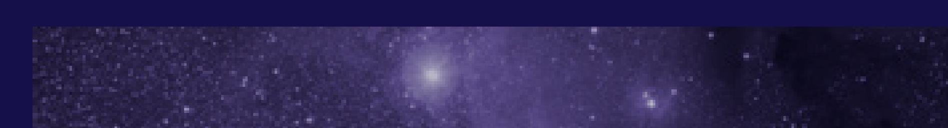
It's difficult to count how many, but I'm the first author on the discovery papers for around 43 planets and have been involved discovery of hundreds of others.

That's amazing. What are your thoughts on extraterrestrial life?

I'd like to know where it is! It's definitely possible. At least, it's not impossible.

Outside of research, you have also been recognized with several teaching awards. What is your teaching philosophy?

My teaching philosophy is based on the notion that lectures are a very outdated, outmoded way of teaching effectively. Lectures stem from medieval times when there were only a few books. The knowledgeable few read the books and would disseminate the knowledge to the masses. These days, information is everywhere. There's no longer a need for one learned individual to stand in front of the masses and lecture. Furthermore, people don't learn by hearing, they learn by doing. My whole teaching philosophy is to get students to actively think rather than passively listen.



CURJ Interview with Professor Sarkis Mazmanian

By Mahati Mokkarala

Professor Sarkis Mazmanian received his Ph.D. from the University of California, Los Angeles. He is currently a Professor of Biology at Caltech and was recently awarded the prestigious MacArthur Fellowship. His current research focuses on the interactions between the immune system and the microbiome, which is the collective genomes of human intestinal bacterial species. Specifically, his current work aims to gain a better understanding of the molecular processes evolved by symbiotic bacteria that mediate protection from inflammatory and autoimmune diseases.

First, CURJ congratulates you on being named a MacArthur Fellow earlier this year. How did you first find out that you won the award and how did you feel afterwards?

I was initially shocked as I recognize how arbitrary the selection process actually is. While I feel we are doing good work, I don't feel like our work was that much more exceptional than the work of other people, but I am obviously grateful for it. I believed that I got the award obviously when I got the call from the Foundation; I didn't appreciate the full magnitude until a couple of days later.

Why a career in science research? Did any undergraduate or graduate experiences made you recognize the benefits of pursuing a career in science research?

I actually started college as an English major and I never liked science in high school! When I went to college I started as an English major because I always like writing, my teachers always told me that I had a talent for writing. But unfortunately I never enjoyed English as a career as I enjoyed writing on my own. I really didn't appreciate the idea of being graded on my thoughts and feelings. I realized that a career in English was not what I wanted to do; the English career paths never really appealed to me. So I was taking some biology classes in order to full an undergraduate requirement and I really started to enjoy them. I think it was a convergence of being mature and actively looking for something to do with my life. I really liked biology so I began to take more and more biology classes and never looked back after that. Not to say that I wanted a career in research but I wanted to do something biology related. It was not until third year that I found out about the microbiology major. I hadn't taken a microbiology class but took the class because I had began doing research by my second year, I really liked research and was thinking of pursing a path that combines biology and research at the same time. Microbiology at UCLA was the most research oriented of the other majors; most of the other majors were geared towards medical school. I actually graduated with a degree in microbiology and since then I've been a microbiologist by training. I feel it is better to have diverse interests rather than being prescribed at a younger age when we are not clearly sure what a career in science, business really means. Having an understanding on what you want to do with your life and being able to decide on your path should be connected with each other. I remember very distinctly that the point of life is not to make money but be happy. You do academic science/research because you have a passion for it. I tell people all the time I have the past life in the world; I get to create things. With science I'm now writing about nature rather than about me; it allows me to fulfill both of my interests: the ability to write and also be creative.

Can you describe to us; what kind of research you are working on in the lab and what is the next exciting discovery you and your lab are pursuing right now?

Historically our lab worked on the interactions between microbes and the immune system. The perspective that we've taken that is really unique in the field is to look at the beneficial effects of microbes. All of us have grown up thinking that microbes are these little creatures that want to make us sick and that they are all bad. In fact if you look at the entire field of microbiology, most of the total microbiota is not infectious. Many microbes that interact with humans are beneficial yet up until a decade ago very few people were studying these microbes. Our research program was to not study pathogens but rather look at organisms that we can harness for beneficial effects. We focused on interactions between microbes and the immune system. We picked various immunological disorders that had a likelihood of having a microbial component but have been never been shown to do so. For instance we are studying autoimmune disorders. Classically autoimmune diseases are known to be genetic disorders. However with autoimmune disorders the concordance rate with monozygotic twins is less than 50%. People have known for decades that environment has a huge effect on autoimmune diseases but hadn't figured out what those environmental conditions were. People thought that factors like pollution or diet clearly had an effect but the research was not rigorous enough to validate any of these environmental factors. We've shown that microbes are one of these environmental factors that influence autoimmunity. The hypothesis we propose is that if microbes have beneficial functions then the absence of bacteria may be the risk factor of disease. We argue that there are certain microbes that if you lose you can become sick. We identified microbes with beneficial functions. Identify mechanisms by which they interact and enhance the activity of immune system to prevent immunological disease such as Multiple Sclerosis. The long-term goal is to develop new drugs from natural sources that can treat autoimmune diseases.

Your research has been known to focus on commensal microbiota and the innate microbiology relationships within a host. What about the commensal bacteria in the gut that makes it so interesting? Also why focus on one possible application linking commensal gut microbiota to appropriate immune system function?

So there's both strong human and mouse evidence to suggests that there is a strong contribution of gut microbes in IBD, colitis, psoriaris, asthma, food allergies, hay fever, and probably several others that I'm thinking of. All of these diseases fall under the same category; immunologically all of these diseases are similar. With all of these diseases, the immune system has become overactive, functioning like there is an infection when there isn't any infection. MS has no infection in the brain are with arthritis no infection in the joints. The immune system perceives that there is an infection. The reason for this is because there is a breakdown in certain checkpoints. The main differences I see with these diseases is the location of these inflammatory regions rather than the reasons behind the inflammatory response. We hypothesize that the microbes that we've identified as protective against MS might be protective for the other diseases as well. These microbes work by suppressing uncontrolled immune system hyperactivity. For instance, we work with PSA, a microbial compound that activates a protective immune subset linked towards a reduction of immune system activation. We believe that activating protective immune subset using these molecules can treat many autoimmune, hyperactive immune system diseases. That's where we are right now in terms of research. And so you ask what's the next frontier- I have a very new, an idea that came into being in my mind because I am at Caltech. The idea is that immune system function is very similar to the way the nervous system works from the way cells synapse with each other all the way to the specific molecules used by the immune and nervous systems. If I were in a traditional immunology department I would not have been exposed to neuroscientists; since I am at Caltech I can interact with neuroscientists. I asked myself you know what, perhaps microbes interact with the nervous system? We have in collaboration with Paul Patterson a project on how gut microbes affect autism. We then started to think about whether nervous system development and function depended on gut microbes. Using the maternal infection model (MIA) for autism, we showed that microbes in the autistic mice gut are different from their normal counterparts. When we published these differences we noticed that humans with autism have different microbes than humans without autism. Ultimately what we've shown is that not only do mice with autism have disrupted microbiota but specific gut organisms can restore autistic mice behavioral deficits. We have strong evidence that gut microbes have a role in nervous system disorders.

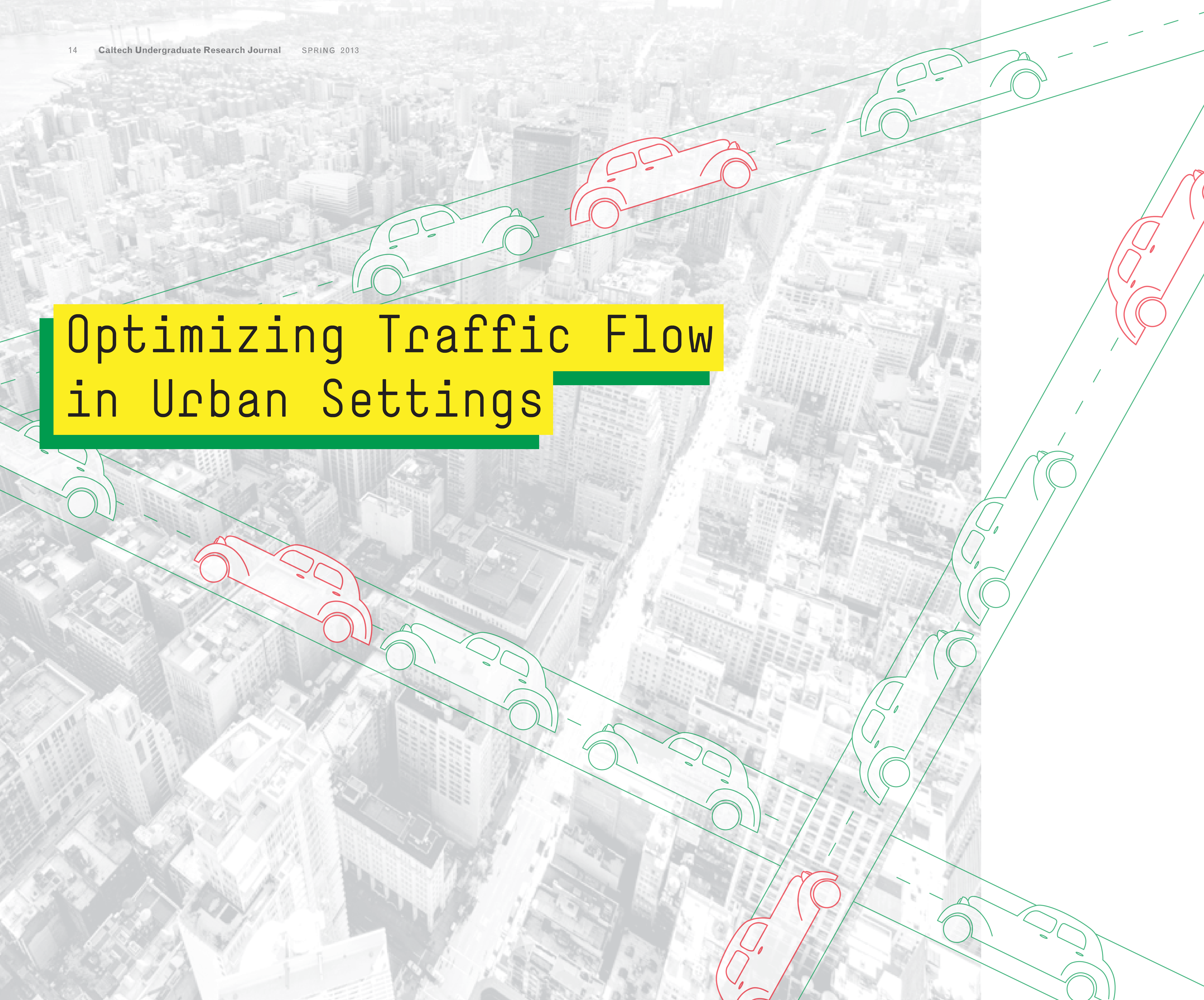
Did you always focus on this interesting relationship between commensal gut bacteria and overall human health or did your research interests shift from the time you were a graduate student to now? If your research interests did shift, what subject did your earlier research projects focus on? Was the shift difficult to handle at first?

The research shifted because at the late 90s, like every other microbiologist, I was actually studying infectious pathogens like S. aureus. The work went quite well but I wanted to focus on something different. So I stopped the research as a graduate research and became the research I am doing now as a postdoctoral scholar. I wouldn't classify the research shift as difficult; I had to obviously learn a lot of things I didn't know but that is how a career in science works. The new research topic was very rewarding as there were very few people working on this kind of science. And so the commonality of my research is microbes, but the difference between my past and current work is studying microbes that make us sick versus microbes that make us healthy.

The Caltech Undergraduate Research Journal (CURJ) focuses on publishing undergraduate research done during the school year. What advice would you give to current Caltech undergraduates thinking about a possible career in science?

I think that the advice is to not take your research seriously but try to expose yourself to as many different lines of research as possible. Caltech is very in that the undergrads can be exposed to not only many different facets of biology but also many different facets of science. I guess the most rewarding approach to optimizing this environment is to do several different things and see what you like. Eventually after undergrad those interested in science will have to pick a discipline- as a graduate student you become very specialized. Exploring as much as possible as an undergrad will give you tools on what you want to do in the future.

Optimizing Traffic Flow in Urban Settings



Author: Bertrand Ottino-Löffler
Hometown: Winnetka, Illinois
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(but with strong interest in physics)
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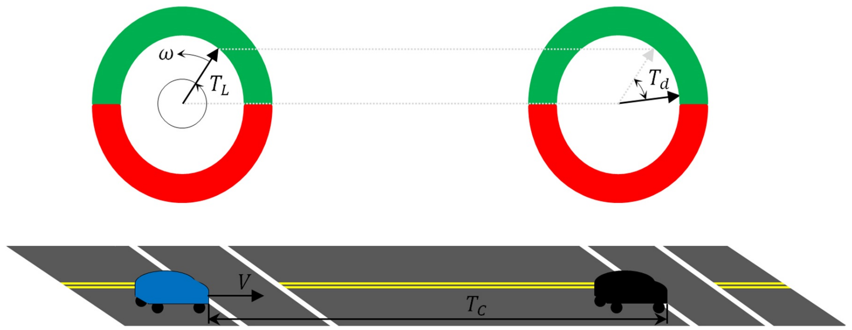
Hobbies: Bertrand's interests include yoga, reading comics, and playing video games, because he doesn't believe in being serious all the time. His plans for the future most likely involve teaching, mathematical physics, and plenty of research.
Mentors: Daniel Abrams, Mark Panaggio

Introduction

Nearly everyone is unhappy with the rage-inducing congestion that plagues their city roads. Improving the traffic situation on a city-wide scale is a difficult task, due to public policy factors and many conflicting interests. Here, we address only one aspect of the problem: optimizing the timing of traffic lights. The challenge appears simple, but it turns out to be a rich problem that presents an opportunity for substantial theoretical analysis.

We start by modeling a two-way street. Assume that all cars exist on a ring with evenly-spaced traffic lights, and an equal number of cars are present on both sides of the street. The cars are granted instantaneous acceleration from zero to velocity V, which is constant across all cars. Next, imagine each traffic light as an arrow rotating continuously around a circle (Fig. 1). The light is red when the arrow is in the red half of the circle, and green when it is in the green half. The angle of the arrow is its phase, and we let 0 to π

Figure 1.



Visual representation of a two-way street. A car moves at velocity V between two traffic lights in time T_C. Traffic lights are depicted as rotating arrows with angular velocity ω, and complete one full cycle in time T_L. The phase of each traffic light is delayed from the previous one by a time T_d.

Table 1.

Key variables used in the theoretical model and simulation.

Variable	Definition
V	Speed of a car in motion
V_{avg}	Average car speed, or $V \times$ (Time Moving)/(Total Time)
N_{LT}	The number of lights a car has passed
ω	Angular frequency of each traffic light
T_L	Time for a traffic light to complete one full cycle
T_C	Time for a car to travel between two lights
T_d	Delay time between lights
r	T_L/T_C
r_d	T_d/T_c
M	$r/(1-r_d)$

At first, it appears that the overall system is best served by giving one direction a perfect green wave and forgetting about the other side. But […] we actually do better by sacrificing some of the efficiency in one direction for improved conditions in the reverse direction.

radians denote green and π to 2π radians denote red. The time it takes for each arrow to complete full cycle is the period, T_L, which implies an angular frequency ω (Table 1).

The interesting part of the problem comes from modifying the initial phases of the lights. Let T_C be the time it takes for a car to travel between two lights, and T_d be the time delay between the phases of two adjacent lights. If the T_d for every pair of lights is equal to T_C, then we achieve a "green wave": a driver never sees more than one red light, and his takeout food is still warm when he gets home. This is optimal. However, suppose T_d were larger than T_C by the constant value $T_L / 2$. Now, our driver hits every red light on the road and has to wait the entire half-cycle before moving again. This suboptimal "red wave" leaves him nothing but frustration and cold, mushy takeout.

Therefore, holding T_d constant between all the lights allows us to span the best and worst case scenarios. If we take $r = T_L / T_C$ and rd = T_d / T_C, then the entire system is described with two parameters. Since $T_d < T_L$ by definition, it follows that $0 < r_d < r$. Also, we tend to assume $r > 1$. Note that for cars going the reverse direction, the phase difference between consecutive lights is the opposite of what the forward direction experiences. Thus, their effective rd becomes $r - r_d$. This means that it is generally impossible to set up a green wave in both directions, so maximizing efficiency for the whole street is a messy affair.

Producing a chimera state in a ring of traffic lights is tricky, but could potentially lead to significant improvements in efficiency for cars travelling in both directions.

Figure 2.

Travel efficiency versus r_d at two fixed values of r. 1001 values of r_d were sampled on each plot. The red and green curves show the efficiency of cars moving to the right and left, respectively. The black curve is the average of the green and red curves.

Figure 2. a

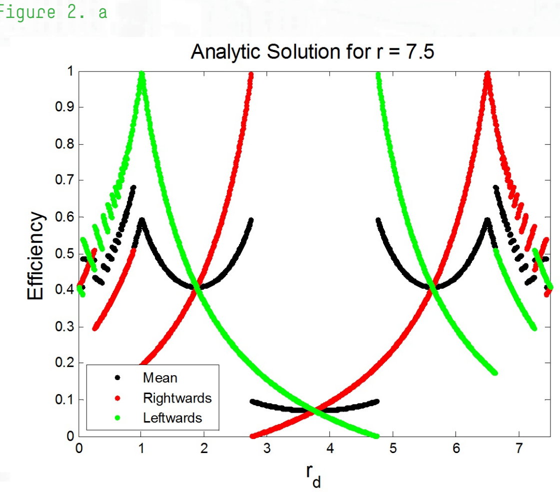
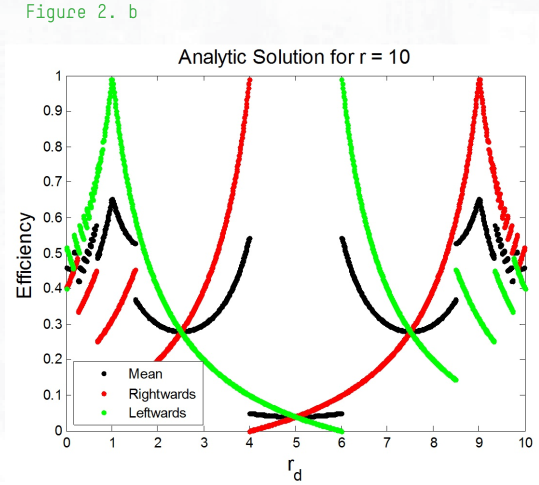


Figure 2. b



Mathematical Modeling

We start by trying to predict how the average speed of a car varies with r_d, for a fixed r. Constraining the value of r lets us limit the range of rd, as noted before. Let us begin by considering just one car. The average speed of the car is defined as the distance traveled over time, or in other words,

$$V_{avg} = \frac{V \times (\text{Time Moving})}{(\text{Total Time})} \quad \text{(Eq. 1)}$$

We want to rewrite Eq. 1 in terms of the parameters of our model. It is clear that the Time Moving is simply equal to the travel time between lights (T_C) times the number of lights passed, henceforth known as N_{LT}. Now, let us find the Total Time – the sum of the time moving and the time spent at a red light. When the car reaches the N_{LT} th light, it's journey will end if the light is red; that is, if the phase of this light mod 2π is between π and 2π radians. If we take Z to be some integer, and ΔΦ to be the phase difference between consecutive lights, then the inequality

$$(2Z-1)\pi \;<\; \Delta\phi \times N_{LT} + \omega \times (\text{Time Moving}) \;<\; 2\pi Z \quad \text{(Eq. 2)}$$

must be satisfied for the car to stop. Because we are looking for the furthest that the car can travel under our constraints, we must find the most restrictive (i.e. smallest) integer value for N_{LT}. By letting $M = r / (1 - r_d)$, we have that

$$Z = \text{ceiling}\left(\frac{N_{LT}}{M}\right) = \text{floor}\left(\frac{N_{LT}}{M} + \frac{1}{2}\right) \quad \text{(Eq. 3)}$$

must hold as well.

It is possible to solve Eq. 3 for N_{LT} in terms of M. After doing so, we find that the Total Time is equal to $Z \times T_L + N_{LT} \times T_d$. This allows us to rewrite the average velocity function in terms of r and r_d, giving us

$$V_{avg} = \frac{V \times N_{LT}}{r \times \text{ceiling}\left(\frac{N_{LT}}{M}\right) + r_d \times N_{LT}} \quad \text{(Eq. 4)}$$

We can normalize this expression into an efficiency value, because we know the maximum and minimum possible speeds. V_{avg} cannot be greater than V, the average speed during a green wave. Likewise, it cannot be less than the red-wave speed, which is given by $(V \times T_C) / (T_C + T_{Lt} / 2)$.

Figs. 2a and 2b plot efficiency versus r_d for forward and reverse traffic, as predicted by this model, for two different values of r. The curve for cars going in the forward direction is the horizontal mirror of the curve for the reverse direction. Let us recall the discussion of red and green waves. We would predict that the velocity of the leftwards car is maximized at $r_d = 1$ and minimized at $r_d = r/2 + 1$, and that the velocity of the rightwards car is maximized at $r_d = r - 1$ and minimized at $r_d = r/2 - 1$. Both plots reflect this prediction. An unexpected feature is the second maximum, which occurs just beyond the red wave minimum. Here, each light turns red just after the car travels through it – a careful distinction that is, as one might imagine, highly sensitive to perturbations. Examining the average curve, we realize something curious. At first, it appears that the overall system is best served by giving one direction a perfect green wave and forgetting about the other side. But in 2a, we actually do better by sacrificing some of the efficiency in one direction for improved conditions in the reverse direction. This compromising behavior is worth noting, and should be investigated upon future work.

Creating a Simulation

To confirm these theoretical results with simulations, adaptive time steps are needed to accurately record the time spent waiting at a red light or travelling between lights. We begin by simulating the "bosonic" case, where the cars do not interact with one another. With some slight modifications, we can extend this simulation to the more realistic "fermionic" situation, in which the cars cannot pass through one another.

Bosonic

Since the cars in the bosonic model have no interaction with one another, it suffices to simulate just one car on a ring of 500 lights for 5000 arbitrary time units. A plot of the simulation efficiency versus the model-predicted efficiency is shown in Fig. 3. The bosonic simulation aligns almost perfectly with the model.

Fermionic

As it turns out, two cars in the real world usually cannot occupy the same place at the same time. How can we tell if our predictions are still valid for cars with non-zero densities? Addressing this question requires a proper simulation of the situation, in which cars cannot pass one other. We expect that as more cars are added to the system, the average velocity will monotonically decrease. Moreover, we expect that cars will start piling up behind red lights, resulting in an additional time delay in reaching the next light. If the first car in the line barely makes it through a green light, all of the following cars will not. This should result in a smoothing of discontinuities in the efficiency graph, especially in the peak right before the red wave.

The plots of fermionic simulation efficiency versus model-predicted efficiency in Figs. 4a and 4b confirm these predictions. 1250 and 6500 cars were simulated on a ring of 500 lights that could support a maximum of 12500 cars. The large number of cars means that multiple parts of the system are being sampled at once; thus, the simulation only needed to be run for 450 arbitrary time units (as opposed to 5000 previously) for convergent behavior to be observed.

Because making a full efficiency versus r_d graph can be taxing at high densities, it is more efficient to hold r_d constant and vary the number of cars in the system. Fig. 5 shows the effects of increasing the number of cars for a fixed r and r_d on the average car speed. Even for a frustratingly high traffic density, Fig. 5a shows that there is little lost in the way of speed until a critical transition point. The critical point arises when so many cars have backed up behind a red light that it takes multiple cycles of the light before a car can pass. This is called a "jamming transition". No complete theory currently exists for the locations of the critical point given a value of r_d. Part of the problem is that, as mentioned before, certain r_d values produce ideal results that are highly sensitive to perturbations. So even though velocity graphs made with these values do contain a transition, the curve is rounded off as seen in Fig. 5b. This makes it difficult to determine the true critical point. Sometimes, as in Fig. 5c, this decay causes a secondary transition that makes critical point detection even harder. All the transitions that are clean enough to estimate a critical point are plotted in Fig. 6.

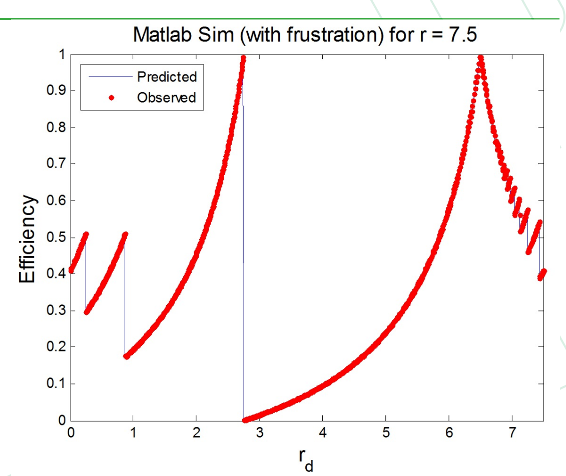


Figure 3.

Simulated efficiency data (red) superimposed on the analytic efficiency curve (blue) for Bosonic traffic in one direction. Cars were simulated on a loop of 500 lights for 5000 arbitrary time units. 1001 equally spaced values of r_d were taken at r = 7.5, T_c = 1. Frustration refers to a boundary effect which has little effect on the overall performance.

Figure 4. a

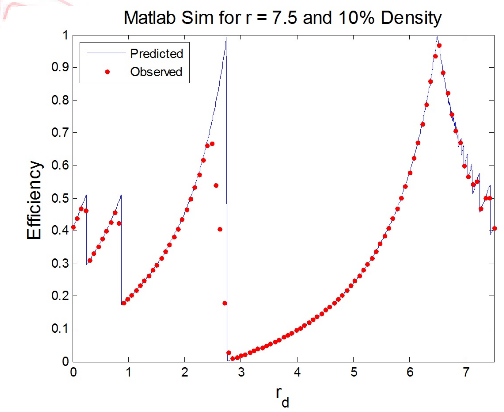


Figure 4. b

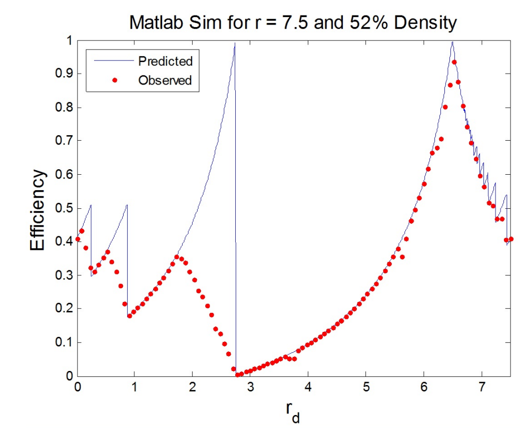


Figure 4.

Simulated efficiency data (red) superimposed on the analytic efficiency curve (blue) for fermionic traffic in one direction. The simulated road was a ring of 500 lights with room for 12500 cars. 1250 cars were simulated in 4a, and 6500 cars were simulated in 4b. In both simulations, 101 values of r_d are simulated at r = 7.5 and T_c = 2 for 450 time units.

Figure 5.

Figure 5 a, b, c. The value of r_d is held constant at three different values. Plots show the average car velocity versus number of cars. Simulations were run in a system with a maximum capacity of 12500 cars, with r = 7.5 and T_c = 2. 76 simulations were each run for 500 arbitrary time units.

Figure 5. a

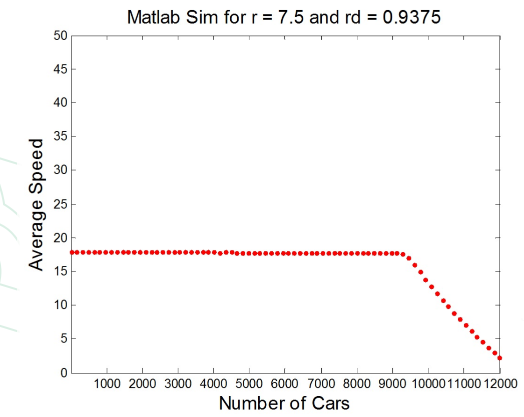


Figure 5. b

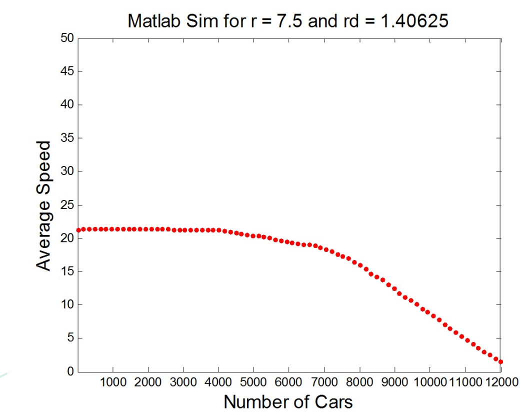
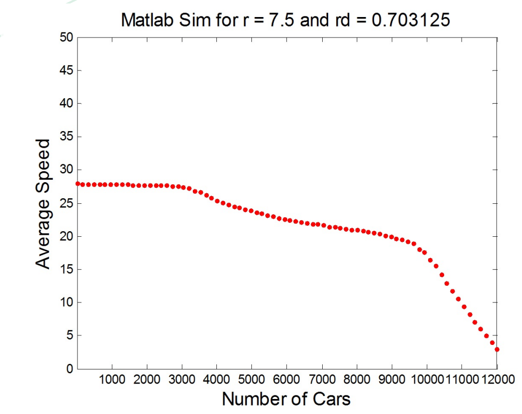


Figure 5. c



Future work

The results presented cover only a fraction of possible questions. But the model is fully set up to address many different optimization problems.

In the real world, cars travel at different speeds. How does randomness affect the efficiency of the cars? Since the simulated traffic is moving around a ring, all the cars would likely bunch up behind the slowest moving car. These results would be uninteresting and uninformative. More meaningful results can be obtained if the cars re-randomize their velocities periodically throughout the simulation. However, we predict that this randomization will not drastically alter the shape of the efficiency graph.

A more exotic possibility is to change the fundamental behavior of the lights, which is the long-term goal of this research. Under the new schema, each light would be coupled to every other light in the following manner. For a system with N lights, we define a coupling strength K and a phase delay α.

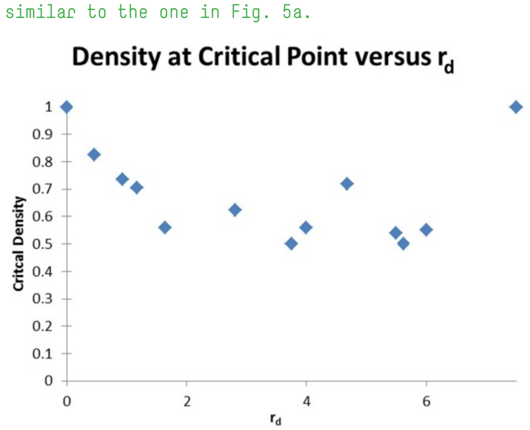
If light **i** has phase **Φ i** and natural frequency ***ω*** **i**, then its behavior is described by

$$\frac{d\phi_i}{dx} = \omega_i + \frac{K}{N}\sum_{j=1}^{N}\sin(\phi_j - \phi_i + \alpha). \qquad \text{(Eq. 5)}$$

If the lights all have the same ***ω*** and start at random phases, a Kuramoto model predicts that the lights will eventually attain identical phases for any nonzero K – a drab result.[1] If the coupling decays with distance, however, the results are intriguing. With the right initial conditions, then we may arrive at a "chimera state", in which the lights are divided into two categories: coherent oscillators (which move together) and incoherent oscillators (which move in a randomized fashion).[2] Producing a chimera state in a ring of traffic lights is tricky, but could potentially lead to significant improvements in efficiency for cars travelling in both directions.

Figure 6.

Figure 6. Estimated critical densities at various values of r_d. These values were inferred from plots similar to the one in Fig. 5a.



Acknowledgements

I would like to thank Daniel Abrams, Mark Panaggio, the Student Faculty Programs office of Caltech, and Northwestern University. I would also like to thank the Mellon Mays Fellowship for their continued support.

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DETECTING GRB COUNTERPARTS TO NEUTRON STAR MERGERS WITH ALIGO/VIRGO AND SWIFT

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Introduction

When a mass accelerates, it creates a ripple through the fabric of space-time. These ripples are known as gravitational waves (GWs). **Detecting GWs is the ultimate test for Einstein's theory of general relativity and will allow for observations of the universe in an entirely new spectrum.** The most promising source for detecting GWs is coalescing neutron-star (NS) and black-hole (BH) binary systems. As the system coalesces, the objects emit GWs causing their orbits to shrink. Eventually, the objects will merge, emitting GW transients detectable by the ground-based Advanced LIGO/Virgo network (hereafter ALIGO/Virgo).

Short Gamma-ray Bursts

NS-NS and NS-BH binary systems are expected progenitors of short gamma-ray bursts (SGRBs). Seconds after the merger, an accretion disk (blue in Figure 1) forms around the newly formed object (typically a black hole) creating collimated relativistic jets. The jets propagate outward into the surrounding medium (pink in Figure 1) producing a prompt SGRB lasting less than two seconds that is detectable by high-energy telescopes such as Swift. As the jets interact with the surrounding medium, they engender electromagnetic (EM) radiation across numerous energy bands, called an afterglow. This paper focuses on the X-ray afterglow, which is observable seconds after the prompt SGRB and can last for hours. **Detecting the presence of a SGRB and its X-ray afterglow in coincidence with a GW increases parameter estimation of the merger event, maximizing the scientific return of detecting a GW.**

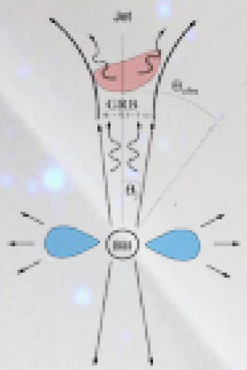

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Figure 1
Illustration of the formation of a prompt SGRB. The accretion disks (blue) around the newly formed compact object (BH) cause collimated relativistic jets to form, producing a SGRB. The interaction of the jets with the surrounding medium (pink) engenders an afterglow across EM bands ranging from X-ray to radio. Note: Image adopted from Metzger et al. (2012)

SGRBs are characterized by two angles: the jet half-opening angle θ_j, which is the angle between the center and edge of the collimated jet, and the observer angle θ_o, which is the angle between the observer and the center of the collimated jet. Typically, SGRBs are detected only if the observer angle is within the half-opening angle of the jet, for which an observer will detect the GW signal seconds before the EM signal. Other parameters include the total energy released in both jets, *E*, and the circumburst particle density, *n*, as illustrated in Figure 2.

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Figure 2
Depiction of the parameters of a SGRB. o is the observer angle, j is the jet half-opening angle, E is the total energy released in both jets, and n is the circumburst particle density.

There are two approaches to detect SGRBs in coincidence with GW signals. One approach is to detect a SGRB with high-energy telescopes and then check GW data for a signal. However, no SGRB with an identified redshift has ever been observed within the ALIGO/Virgo sensitivity range for NS-NS binary systems and only two within the NS-BH sensitivity range (Metzger et al. 2012). **Thus, I will focus on the second approach: detect a GW signal and then search for EM counterparts with high-energy telescopes.** The beneficial aspect of this approach is that GW detectors are all-sky instruments, while telescopes are limited to detecting sources within their field of views. Localizing GW signals detected by ALIGO/Virgo in real time makes it possible to direct high-energy telescopes at GW signal localization error regions within minutes after the initial GW signal, allowing for the detection of the X-ray afterglow of a SGRB. After upgrades are completed as early as 2015, ALIGO/Virgo expect to detect 40 NS-NS and 10 NS-BH merger events per year; however, due to the beaming of the collimated jets, only 0.3 and 3 SGRBs are expected to be detected per year in coincidence with NS-NS and NS-BH mergers, respectively (Metzger et al. 2012; Nakar et al. 2006).

"When a mass accelerates, it creates a ripple through the fabric of space-time. These ripples are known as gravitational waves (GWs). Detecting GWs is the ultimate test for Einstein's theory of general relativity and will allow for observations of the universe in an entirely new spectrum."

Simulating Black Holes and Neutron Stars

For my project, **I wanted to determine if the X-ray Telescope (XRT) on-board Swift could detect X-ray afterglows of prompt SGRBs in coincidence with GW signals from NS-NS and NS-BH binary systems, and if so, the expected light curve.** The light curve provides a wealth of knowledge about the parameters of the astrophysical event; in particular, the jet break is used to determine the jet half-opening angle. To investigate, I simulated a typical SGRB and its X-ray afterglow, and modeled the detection of the X-ray afterglow by XRT. I defined the parameters of a typical SGRB to be approximately the average of the minimum and maximum range as seen in Table 1.

TABLE 1: Parameters of SGRBs

Parameter	Minimum	Maximum	*Typical*
E	10^{48} ergs	10^{50} ergs	10^{49} ergs
n	10^{-3} cm^{-3}	1 cm^{-3}	10^{-3} cm^{-3}
θ_{jet}	6°	22°	11°
θ_{obs}	0°	$\sim\theta_{jet}$	5.5°

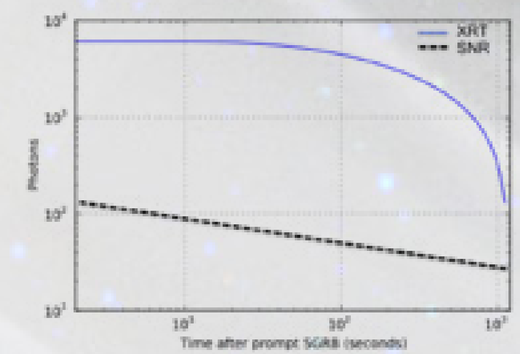
To simulate a SGRB and its X-ray afterglow, I used the program Boxfit developed by van Eerten et al. (2012), which uses relativistic hydrodynamics to compute the evolution of the collimated jets that produce the SGRB and its X-ray afterglow. I performed the simulation for a 20 minute period following the prompt SGRB. The number of photons XRT detects for a starting observation time after the prompt SGRB, tobs, and an ending observation time of 20 minutes after the initial prompt SGRB can be determined by relating the total number of photons detected, N, to energy flux density, S(t, Ephot):

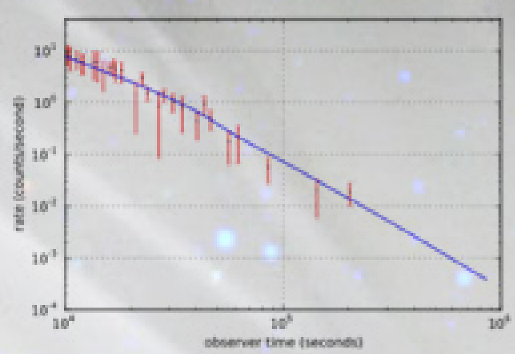
$$P = \int_{t_{obs}}^{42t_{obs}} \int_{\Omega}^{\Omega} \frac{U_k G_{j\varphi} + C_{\varphi}^{*} G_{j\varphi} +}{G_{j\varphi}} \cdot f G_{j\varphi} \cdot f v$$

where E2 and E1 are the maximum and minimum energy range of XRT respectively, Aeff is the effective area of XRT, Ephot is the photon energy, and t is time. I assumed a detection occurred when the telescope's SNR (signal to noise ratio) equaled 5 or greater. Following Poisson statistics, I defined the SNR, , as:

$$\sigma = \frac{P}{\sqrt{P + P_{B}^{4}}}$$

where N is the number of detected photons and NBG is the diffuse background noise. The numerator is thus the number of photons detected by the telescope from the signal, and the denominator is the number of photons detected by the telescope as noise.





Swift Telescope

The Swift telescope, launched in 2004, uses the Burst Alert Telescope (BAT) to detect prompt SGRBs and initially localize the source, and then slews the X-ray Telescope (XRT) to search for X-ray afterglows. BAT has a sensitive energy range primarily between 15-150 keV that can extend up to 500 keV. BAT's primary objective is detecting prompt SGRBs by performing an all-sky hard X-ray survey and monitoring for hard X-ray transients to search for bursts. XRT is sensitive in the energy range of 0.2-10 keV with a ~0.16 square degree field of view and effective area of 110 cm2 at 1.5 keV.

To create a synthetic XRT light curve, we must satisfy the conditions:

1. Constant 47 minutes on/off view time due to Swift's 94 minute orbit of Earth.

2. Observed count rate scaled to 0.1 after 1.0 day.

3. Fractional exposure drops from 1.0 to 0.1 after 1 day since Swift is no longer fully dedicated to observing X-ray afterglow of SGRB.

4. No observations below a rate of 5 x 10-4 counts per second.

Results and Discussion

Figure 3 shows the number of photons XRT would detect from a typical SGRB for a 20 minute observation time after the prompt SGRB and a source distance of d=200 megaparsecs (Mpc), the range of ALIGO/Virgo for NS-NS binary systems. XRT will make a detection for d=200 Mpc if it begins its observation within ~19 minutes after the prompt SGRB because XRT detects more photons than the SNR threshold for almost the entire 20 minutes, depicted by the dotted black line. XRT typically slews to the source within a few minutes after the initial prompt SGRB, thus XRT should detect the X-ray afterglow of a typical SGRB for a source distance of d=200 Mpc. Swift has twice been slewed to follow up GW candidates.

Figure 4 shows synthesized XRT data points for the X-ray afterglow from a typical SGRB. The simulated light curve from which the synthetic data is constructed from is also shown. The simulated light curve reveals a jet break around 3 x 104 seconds, however, the jet break is not as apparent in the synthetic XRT data. This is consistent with the difficulty in discerning jet breaks in SGRBs as only a handful of unambiguous jet breaks have been identified (Fong et al. 2012). For the closest SGRB with a known redshift, GRB 050709 at z=0.16 which equates to a luminosity distance of 757 Mpc (assuming a standard Lambda-CDM cosmology), the jet break would certainly not be discernible with XRT.

Figure 3
Photons detected by XRT for d=200 Mpc with an ending observation time of 20 minutes after the initial prompt SGRB. The black dotted line is the approximate SNR threshold.

Figure 4
Synthesized XRT data for an X-ray afterglow of a typical SGRB. The XRT data is overlaid the simulated light curve.

> "X-ray telescopes are crucial to maximize the scientific return of detecting a GW signal."

What Have We Learned?

X-ray telescopes are crucial to maximize the scientific return of detecting a GW signal, as ALIGO/Virgo expects to do in the coming years. For the closest NS-NS mergers detected by ALIGO/Virgo, it is conceivable that the Swift XRT telescope might identify an X-ray afterglow in coincidence with gravitational waves. However, caution must be taken when evaluating the light curve of XRT because the presence of a jet break may be hidden in the data.

Further Reading

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Sample Processing Through Subcritical Hydrolysis of Organics.

Sangavi Pari
Mentor: Valerie J. Scott

Introduction: The Search for Extraterrestrial Life

Around 10:31 PM on August 5, 2012, the Mars Science Laboratory mission survived its major hurdle as the Curiosity Rover successfully landed in Mars[1]. The goal of this mission is to determine whether Mars contains or once contained the elements necessary to harbor life[2]. This is part of NASA's investigation to study evidence for life on planetary bodies[3]. Thus, development of sample-processing technology is necessary to facilitate chemical analysis of samples, such as planetary sediment, to find evidence for life.

One instrument currently in development is the Micro-scale Ion Analyzer (MIA). Designed by the same principles used in making the Sub-critical Water Extractor[4], this instrument utilizes water under high temperatures and pressure to extract organics. The objective is to determine if MIA is able to hydrolyze different bonds found in larger molecules or found between targets and regolith under varying experimental conditions.

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Experimental: Lysozyme Hydrolysis

Figure 1, shown below, portrays the instrument MIA. MIA is connected to a pressure pump andheater to vary conditions placed on the samples injected into MIA. To test the goals of this experiment, different sample solutions were chosen to be injected under MIA. These include lysozyme in 6mM HCl, lysozyme in H2O, dipeptide (Glu-Asp) in H2O, cholesterol in 6mM HCl, cholesterol in H2O, and 50 mg/ml of 53 micron soil sample.

The lysozyme solutions were chosen to test MIA's ability to hydrolyze large molecules. The resulting sample solutions were analyzed with High-Performance Liquid Chromatography (HPLC).

The data retrieved from the HPLC portrays that pressure does not make a significant effect on hydrolysis.

The data pertaining to the lysozyme samples also portray a loss in signal strength in resulting sample solutions kept in 150oC or higher. This loss in signal strength is hypothesized as due to gelling, which causes residue to build up in the instrument and the resulting sample solution does not collect much of the original lysozyme.

The goal of this mission is to determine whether Mars contains or once contained the elements necessary to harbor life.

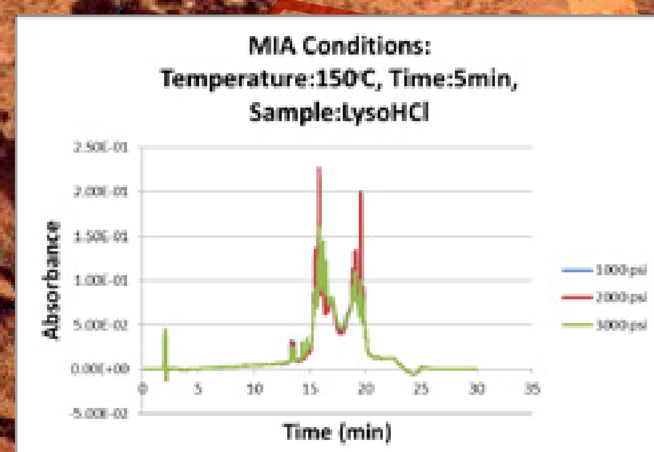

Figure 1: This spectrum gives a comparison of how different pressure affects the lysozyme in HCl solution by keeping the temperature constant and varying the pressure.

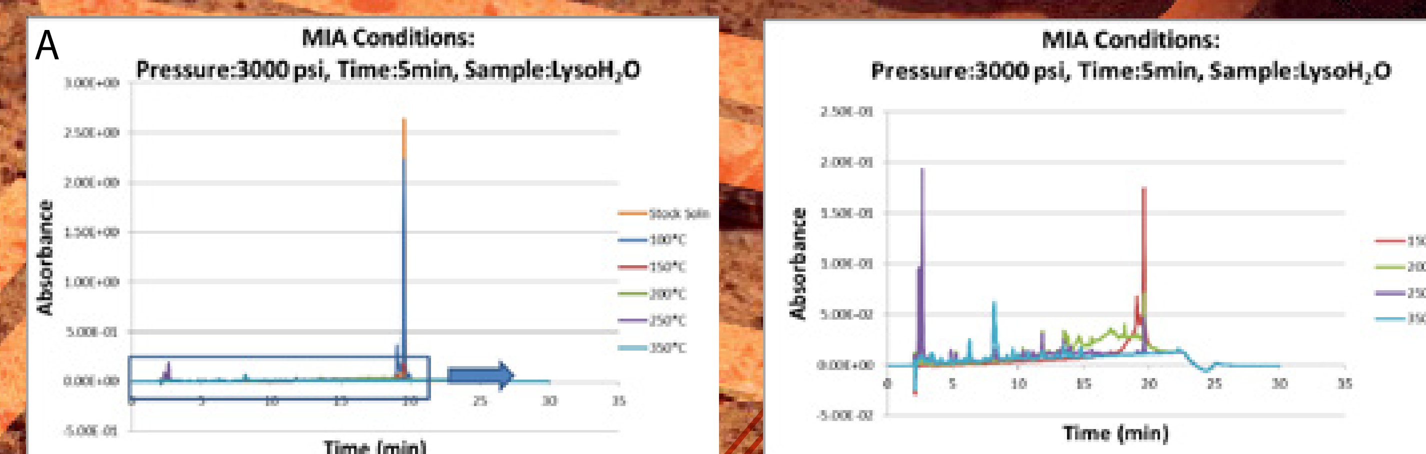

Figure 2: a.) This spectrum portrays the differences in signal strength from varying temperatures for the resulting sample solutions stemming from lysozyme in H2O. The signal drops significantly starting from 150oC. b.) This spectrum portrays only the signal strengths of the same resulting sample solutions starting from 150oC. This is to better portray the signals.

Experimental: Dipeptide Hydrolysis

To eliminate gelling, dipeptide (glycine and aspartic acid) in water was chosen to be tested under MIA. AccQ-tag, a fluorescent tag that allows for easier detection of amino acids or peptides analyzed by the HPLC, was added to the resulting dipeptide solution so that one can determine if the peptide bond was hydrolyzed to give two amino acids. Thus, one can test if MIA is able to break this peptide bond under the same conditions while eliminating the possibility of gelling, since dipeptide is a much smaller molecule than lysozyme.

From the spectrum shown to the right, there is no clear evidence that the original dipeptide hydrolyzed into glycine and aspartic acid. The subsequent peaks after the stock peak correspond to retention times that do not match with the usual retention times of either glycine or aspartic acid. One possible explanation for these subsequent peaks could be contamination. However, that is unlikely because the main amino acid that should be present from contamination is serine and there is no presence of serine in this spectrum. Thus, it could be hypothesized that the peaks that don't correspond to either glycine or aspartic acid came from polymerization of the dipeptide. Polymerization is the phenomena where the dipeptide binds together in new conformations to form possibly tripeptides or various other polypeptides.

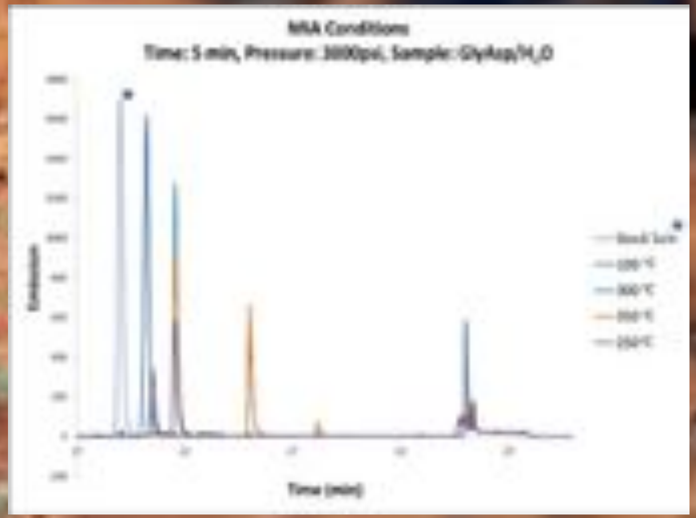

Figure 3: The spectrum shown portrays the different amino acids/peptides seen in solutions that were subject to experimental conditions. The stock solution is identified by the star.

After the dipeptide solutions were tested in MIA, cholesterol solutions in H2O and 6 ml HCl were chosen to test if presence of oxygen in the instrument affects any of the hydrolysis that is seen. This can be tested because if cholesterol is oxidized in the instrument under the various experimental conditions then there is a possibility that oxygen is affecting hydrolysis. The resulting cholesterol solutions after the experiments in MIA were tested under Flame Ionization Detection (FID). On analyzing data gathered, there is evidence for presence of cholesterol, which is expected if there is no oxidation of cholesterol. However, further experiments need to be done to determine if there is no presence of oxidized cholesterol.

The last stock solution that was run under MIA was the 50 mg/ml of 53 micron soil sample. This was run to test MIA's ability to detect pollutants in soil, such as polycyclic aromatic hydrocarbons and polychlorinated biphenyls. The resulting sample solutions were also run in the FID like the previous cholesterol samples. From the data collected regarding this sample there is no detection of the pollutants. Further experiments need to be run to test if MIA can help detect pollutants.

Conclusion: MIA Phoning Home

Development of sample processing technology is important to enable chemical analysis to search for signatures of life. MIA is one new prototype of sample processing technology. By running the different sample solutions aforementioned, MIA can be characterized. This leads to better designing and understanding of sample processing technology, which facilitates the search for any evidence of extraterrestrial life.

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Development of sample processing technology is important to enable chemical analysis to search for signatures of life.