Have Starship, Will Travel

The Newsletter of the Interstellar Research Group

Issue 21
Oct 2020

Newsletter Contents

2020 TVIW (IRG) Scholarship Winners

TVIW (now IRG) is proud to announce the winners of the 2020 Scholarship Program.

Following a competitive process with many high-quality applicants, the Tennessee Valley Interstellar Workshop has chosen three students as the recipients of our 2020 scholarships. With the support of Baen Books (who sponsor the Tim Bolgeo Memorial Scholarship), Rob and Ruann Hampson, and Jay and Beth Roye, we are awarding these deserving students one graduate scholarship ($2500) and two undergraduate scholarships ($2500 each). These scholarships were created to encourage the next generation to study science, technology, engineering, and math (STEM) fields that support the research needed to get humanity to the stars.

Our winners are:

Hayden Morgan, our graduate-level winner, and winner of the Tim Bolgeo Memorial Scholarship, earned a BS in Aerospace Engineering from the University of Cincinnati in 2019. He participated in the Midwest Hyperloop group which competed in the 2019 SpaceX Hyperloop Pod Competition, as well as serving as a mentor to high school students in designing, fabricating, and testing robots capable of completing complex tasks. He is pursuing a MS in Aerospace Engineering at Texas A&M University.

Our first undergraduate winner, Isabel Collins, comes from New Orleans, LA, and will be attending The University of the South in the fall, majoring in Biochemistry. In high school, she was very involved several service organizations, as well as the National Honors Society, and she took first place in the Biology AP competition. Summer internships at Ochsner Medical Center and Tulane Medical School have led her to pursue a career in research.

Evelyn Johnson, our second undergraduate winner, is an undergraduate at Mercer University in Macon, Georgia. She took classes from West Georgia Technical College (dual enrollment program) and plans a double major in History and Biology with a minor in Chemistry. She plans to attend Mercer Medical School for her M.D., to serve the rural areas in her community, to dedicate her studies to the betterment of public health in this country.

A Dialogue on SETI between Keith Cooper and Paul Gilster

The editor of Astronomy Now and the author of both The Contact Paradox: Challenging Assumptions in the Search for Extraterrestrial Intelligence (Bloomsbury Sigma), and Origins of the Universe: The Cosmic Microwave Background and the Search for Quantum Gravity (Icon Books) to be published later this year, Keith Cooper is an excellent source of ideas that stretch the imagination. In the dialogue that follows, IRG's Paul Gilster talks to Cooper about SETI and its prospects. With the recent expansion of the search through Breakthrough Listen, where does SETI stand both in terms of its likelihood of success and its perception among the general public?

Paul Gilster

Keith, we're 60 years into SETI and no contact yet, though there are a few tantalizing things like the WOW! signal to hold our attention. Given that you have just given us an exhaustive study of the field and mined its philosophical implications, what's your take on how this lack of results is playing with the general public? Are we more or less ready today than we were in the days of Project Ozma to receive news of a true contact signal?

…continued on Page 2

TVIW reorganizing to Interstellar Research Group

TVIW started organizational life in 2011 as a social group of scientists and science enthusiasts who recognized a need to make serious, concerted steps toward interstellar travel. To that end, the *Tennessee Valley Interstellar Workshop* was formed, affirming our roots in the southeastern United States and our intention to hold regular meetings dealing with interstellar topics. Over the intervening time, we've succeeded in our efforts: we have grown both in our abilities and in our reach. We now are holding symposia outside our original region, we have a regularly-updated YouTube channel with the best minds in interstellar research, and are collaborating with sister organizations globally. For these reasons, our original name no longer accurately represents us. To that end, we are excited to announce that we are reorganizing as the

Interstellar Research Group

with the same mission and expertise we have developed through our ongoing efforts. We have a big vision, and now we have an identity to match that vision. You'll notice changes to our brand that reflect our more comprehensive Interstellar Mission. We are glad you're here for the (interstellar) ride!

Ad Astra!

A DIALOGUE ON SETI *(CONT'D)*
BETWEEN KEITH COOPER AND PAUL GILSTER

…continued from Page 1

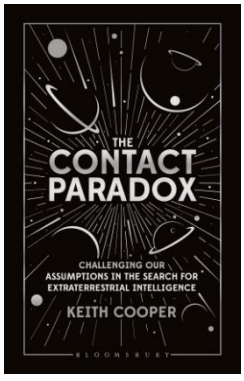
Paul Gilster (continued)

And despite what we saw in the film *Contact*, do you think the resultant clamor would be as widespread and insistent? Because to me, one of the great paradoxes about the whole idea of contact is that the public seems to get fired up for the idea in film and books, but relatively uninterested in the actual work that's going on. Or am I misjudging this?

Keith Cooper (pictured)

What a lot of people don't realize is just how big space is. Our Galaxy is home to somewhere between 100 billion and 200 billion stars. Yet, until Yuri Milner's $100 million Breakthrough Listen project, we had looked and listened, in detail, at about a thousand of those stars. And when I say listened closely, I mean we pointed a telescope at each of those stars for half an hour or so. Even Breakthrough Listen, which will survey a million stars in detail, finds the odds stacked against it. Let's imagine there are 10,000 technological species in our Galaxy. That sounds like a lot, but on average we'd have to search between 10 million and 20 million stars just to find one of those species.

And remember, we're only listening for a short time. If they're not transmitting during that time frame, then we won't detect them, at least not with a radio telescope. Coupled with the fact that incidental radio leakage will be much harder to detect than we thought, then it's little wonder that we've not found anyone out there yet. Of course, the public doesn't see these nuances – they just see that we've been searching for 60 years and all we've found is negative or null results. So I'm not surprised that the public are often uninspired by SETI.



Some of this dissatisfaction might stem from the assumptions made in the early days of SETI, when it was assumed that ETI would be blasting out messages through powerful beacons that would be pretty obvious and easy to detect. Clearly, that doesn't seem to be the case. Maybe that's because they're not out there, or maybe it's because the pure, selfless altruism required to build such a huge, energy-hungry transmitter to beam messages to unknown species is not very common in nature. Certainly on Earth, in the animal kingdom, altruism usually operates either on the basis of protecting one's kin, or via quid pro quo, neither of which lend themselves to encouraging interstellar communication.

So I think we – that is, both the public and the SETI scientific community – need to readjust our expectations a little bit.

Are we ready to receive a contact signal? I suspect that we think we are, but that's different from truly being ready. Of course, it depends upon a number of variables, such as the nature of the contact, whether we can understand the message if one is sent, and whether the senders are located close in space to us or on the other side of the Galaxy. A signal detected from thousands of light years away and which we can't decode the message content of, will have much less impact than one from, say, 20 or 30 light years away, and which we can decode the message content and perhaps even start to communicate with on a regular basis.

Paul Gilster

I'll go further than that. To me, the optimum SETI signal to receive first would be one from an ancient civilization, maybe one way toward galactic center, which would make by virtue of its extreme distance a non-threatening experience. Or at least it would if we quickly went to work on expanding public understanding of the size of the Galaxy and the Universe itself, as you point out. An even more ancient signal from a different galaxy would be even better, as even the most rabid conspiracy theorist would have little sense of immediate threat.

I suppose the best scenario of all would be a detection that demonstrated other intelligent life somewhere far away in the cosmos, and then a century or so for humanity to digest the idea, working it not only into popular culture, but also into philosophy, art, so that it becomes a given in our school textbooks (or whatever we'll use in the future in place of school textbooks). Then, if we're going to receive a signal from a relatively nearby system, let it come after this period of acclimatization.

Great idea, right? As if we could script what happens when we're talking about something as unknowable as SETI contact. I don't even think we'd have to have a message we could decode at first, because the important thing would be the simple recognition of the fact that other civilizations are out there. On that score, maybe Dysonian SETI turns the trick with the demonstration of a technology at work around another star. The fact of its existence is what we have to get into our basic assumptions about the universe. I used to assume this would be easy and come soon, and while I do understand about all those stars out there, I'm still a bit puzzled that we haven't turned up something. I'd call that no more than a personal bias, but there it is.

Image: The Parkes 64m radio telescope in Parkes, New South Wales, Australia with the Milky Way overhead. Breakthrough Listen is now conducting a survey of the Milky Way galactic plane over 1.2 to 1.5 GHz and a targeted search of approximately 1000 nearby stars over the frequency range 0.7 to 4 GHz. Credit: Wikimedia Commons / Daniel John Reardon.

Keith Cooper

It's the greatest puzzle that there is. Radio SETI approaches things from the assumption that ET just sat at home belting out radio signals, and yet, as we know, the Universe is so old that ET has had ample time to reach us, or to build some kind of Dysonian artefact, or to do something to make their presence more obvious. And over the years we've all drawn our own conclusions as to why this does not seem to be the case – maybe they are here but hidden, watching us like we're in some kind of cosmic zoo. Or maybe interstellar travel and building megastructures are more difficult than we envision. Perhaps they are all dead, or technological intelligence is rare, or they were never out there in the first place. We just don't know. All we can do is look.

I think science fiction has also trained us to expect alien life to be out there – and I don't mean that as a criticism of the genre. Indeed, in *The Contact Paradox*, I often use science fiction as allegory, largely because that's where discussions about what form alien life may take and what might happen during contact have already taken place. So let me ask you this, Paul: From all the sf that you've read, are there any particular stories that stand out as a warning about the subtleties of contact?

Paul Gilster

I suppose my favorite of all the 'first contact through SETI' stories is James Gunn's *The Listeners* (1972). Here we have multiple narrators working a text that is laden with interesting quotations. Gunn's narrative methods go all the way back to Dos Passos and anticipate John Brunner (think *Stand on Zanzibar*, for example). It's fascinating methodology, but beyond that, the tumult that greets the decoding of an image from Capella transforms into acceptance as we learn more about a culture that seems to be dying and await what may be the reply to a message humanity had finally decided to send in response. So *The Listeners* isn't really a warning as much as an exploration of this tangled issue in all its complexity.

Of course, if we widen the topic to go beyond SETI and treat other forms of contact, I love what Stanislaw Lem did with *Solaris* (1961). A sentient ocean! I also have to say that I found David Brin's *Existence* (2012) compelling. Here competing messages are delivered by something akin to Bracewell probes, reactivated after long dormancy. Which one do you believe, and how do you resolve deeply contradictory information? Very interesting stuff! I mean, how do we respond if we get a message, and then a second one saying "Don't pay any attention to that first message?"

What are some of your choices? I could go on for a bit about favorite science fiction but I'd like to hear from you. I assume Sagan's *Contact* (1985) is on your list, but how about dazzling 'artifact' contact, as in the Strugatsky brothers' *Roadside Picnic* (1972)? And how do we fit in Cixin Liu's *The Three Body Problem* (2008)? At first glance, I thought we were talking about Alpha Centauri, but the novel shows no familiarity with the actual Centauri system, while still being evocative and exotic. Here the consequences of contact are deeply disturbing.

Keith Cooper

I wish I were as well read as you are, Paul! I did read *The Three Body Problem,* but it didn't strike a chord with me, which is a shame. For artefact contact, however, I have to mention the Arthur C. Clarke classic, *Rendezvous with Rama* (1973). One of the things I liked about that story is that it removed us from the purpose of Rama. We just happened to be bystanders, oblivious to Rama's true intent and destination (at least until the sequel novels).

Clarke's story feels relevant to SETI today, in which embracing the search for 'technosignatures' has allowed researchers to consider wider forms of detection than just radio signals. In particular, we've seen more speculation about finding alien spacecraft in our own Solar System – see Avi Loeb pondering whether 1I/'Oumuamua was a spacecraft (I don't think it was), or Jim Benford's paper about looking for lurkers.

I've got mixed feelings about this. On the one hand, although it's speculative and I really don't expect us to find anything, I see no reason why we shouldn't look for probes in the Solar System, just in case, and it would be done in a scientific manner. On the other hand, it sets SETI on a collision course with ufology, and I'd be interested to see how that would play out in the media and with the public.

It could also change how we think about contact. Communication over many light years via radio waves or optical signals is one thing, but if the SETI community agrees that it's possible that there could be a probe in our Solar System, then that would bring things into the arena of direct contact. As a species, I don't think we're ready to produce a coherent response to a radio signal, and we are certainly not ready for direct contact.

Contact raises ethical dilemmas. There's the obvious stuff, such as who has the right to speak for Earth, and indeed whether we should respond at all, or stay silent. I think there are other issues though. There may be information content in the detected signal, for example a message containing details of new technology, or new science, or new cultural artefacts.

However, we live in a world in which resources are not shared equally. Would the information contained within the signal be shared to the whole world, or will governments covet that information? If the technological secrets learned from the signal could change the world, for good or ill, who should we trust to manage those secrets?

These issues become amplified if contact is direct, such as finding one of Benford's lurkers. Would we all agree that the probe should have its own sovereignty and keep our distance? Or would one or more nations or organizations seek to capture the probe for their own ends? How could we disseminate what we learn from the probe so that it benefits all humankind? And what if the probe doesn't want to be captured, and defends itself?

My frustration with SETI is that we devote our efforts to trying to make contact, but then shun any serious discussion of what could happen during contact. The search and the discussion should be happening in tandem, so that we are ready should SETI find success, and I'm frankly puzzled that we don't really do this. Paul, do you have any insight into why this might be?

Paul Gilster

You've got me. You and I are on a slightly different page when it comes to METI, for example (Messaging to Extraterrestrial Intelligence). But we both agree that while we search for possible evidence of ETI, we should be having this broad discussion about the implications of success. And if we're talking about actually sending a signal without any knowledge whatsoever of what

might be out there, then that discussion really should take priority, as far as I'm concerned. I'd be much more willing to accept the idea of sending signals if we came to an international consensus on the goal of METI and its possible consequences.

As to why we don't do this, I hear a lot of things. Most people from the METI side argue that the cat is already out of the bag anyway, with various private attempts to send signals proliferating, and the assumption that ever more sophisticated technology will allow everyone from university scientists to the kid in the basement to send signals whenever they want. I can't argue with that. But I don't think the fact that we have sent messages means we should give up on the idea of discussing why we're doing it and why it may or may not be a sound idea. I'm not convinced anyway that any signals yet sent have the likelihood of being received at interstellar distances.

But let's leave METI alone for a moment. On the general matter of SETI and implications of receiving a signal or finding ETI in astronomical data, I think we're a bit schizophrenic. When I talk about 'we,' I mean western societies, as I have no insights into how other traditions now view the implications of such knowledge. But in the post-Enlightenment tradition of places like my country and yours, contacting ETI is on one level accepted (I think this can be demonstrated in recent polling) while at the same time it is viewed as a mere plot device in movies.

This isn't skepticism, because that implies an effort to analyze the issue. This is just a holdover of old paradigms. Changing them might take a silver disc touching down and Michael Rennie strolling out. On the day that happens, the world really would stand still.

Let's add in the fact that we're short-sighted in terms of working for results beyond the next dividend check (or episode of a favorite show). With long-term thinking in such perilously short supply (and let's acknowledge the Long Now Foundation's heroic efforts at changing this), we have trouble thinking about how societies change over time with the influx of new knowledge.

Our own experience says that superior technologies arriving in places without warning can lead to calamity, whether intentional or not, which in and of itself should be a lesson as we ponder signals from the stars. A long view of civilization would recognize how fragile its assumptions can be when faced with sudden intervention, as any 500 year old Aztec might remind us.

Image: A 17th century CE oil painting depicting the Spanish Conquistadores led by Hernan Cortes besieging the Aztec capital of Tenochtitlan in 1519 CE. (Jay I. Kislak Collection).

Keith, what's your take on the 'cat out of the bag' argument with regard to METI? It seems to me to ignore the real prospect that we can change policy and shape behavior if we find it counterproductive, instead focusing on human powerlessness to control our impulses. Don't we on the species level have agency here? How naive do you think I am on this topic?

Keith Cooper

That is the 'contact paradox' in a nutshell, isn't it? This idea that we're actively reaching out to ETI, yet we can't agree on whether it's safe to do so or not. That's the purpose of my book, to try and put the discussion regarding contact in front of a wider audience.

In *The Contact Paradox*, I'm trying not to tell people what they should think about contact, although of course I give my own opinions on the matter. What I am asking is that people take the time to think more carefully about this issue, and about our assumptions, by embarking on having the broader debate.

Readers of *Centauri Dreams* might point out that they have that very debate in the comments section of this website on a frequent basis. And while that's true to an extent, I think the debate, whether on this site or among researchers at conferences or even in the pages of science fiction, has barely scratched the surface. There are so many nuances and details to examine, so many assumptions to challenge, and it's all too easy to slip back into the will they/won't they invade discussion, which to me is a total straw-man argument.

To compound this, while the few reviews that *The Contact Paradox* has received so far have been nice, I am seeing a misunderstanding arise in those reviews that once again brings the debate back down to the question of whether ETI will be hostile or not. Yet the point I am making in the book is that even if ETI is benign, contact could potentially still go badly, through misunderstandings, or through the introduction of disruptive technology or culture.

Let me give you a hypothetical example based on a science-fiction technology. Imagine we made contact with ETI, and they saw the problems we face on Earth currently, such as poverty, disease and climate change. So they give us some of their technology – a replicator, like that in *Star Trek*, capable of making anything from the raw materials of atoms. Let's also assume that the quandaries that I mentioned earlier, about who takes possession of that technology and whether they horde it, don't apply. Instead, for the purpose of this argument, let's assume that soon enough the technology is patented by a company on Earth and rolled out into society to the point that replicators became as common a sight in people's homes as microwave ovens.

Just imagine what that could do! There would be no need for people to starve or suffer from drought – the replicators could make all the food and water we'd ever need. Medicine could be created on the spot, helping people in less wealthy countries who can't ordinarily get access to life-saving drugs. And by taking away the need for industry and farming, we'd cut down our carbon emissions drastically. So all good, right?

But let's flip the coin and look at the other side. All those people all across the world who work in manufacturing and farming would

suddenly be out of a job, and with people wanting for nothing, the economy would crash completely, and international trade would become non-existent – after all, why import cocoa beans when you can just make them in your replicator at home? We'd have a sudden obesity crisis, because when faced with an abundance of resources, history tells us that it is often human nature to take too much. We'd see a drugs epidemic like never before, and people with malicious intent would be able to replicate weapons out of thin air. Readers could probably imagine other disruptive consequences of such a technology.

It's only a thought experiment, but it's a useful allegory showing that there are pros and cons to the consequences of contact. What we as a society have to do is decide whether the pros outweigh the cons, and to be prepared for the disruptive consequences. We can get some idea of what to expect by looking at contact between different societies on Earth throughout history. Instead of the replicator, consider historical contact events where gunpowder, or fast food, or religion, or the combustion engine have been given to societies that lacked them. What were the consequences in those situations?

This is the discussion that we're not currently having when we do METI. There's no risk assessment, just a bunch of ill-thought-out assumptions masquerading as a rationale for attempting contact before we're ready.

There's still time though. ETI would really have to be scrutinizing us closely to detect our leakage or deliberate signals so far, and if they're doing that then they would surely already know we are here. So I don't think the 'cat is out of the bag' just yet, which means there is still time to have this discussion, and more importantly to prepare. Because long-term I don't think we should stay silent, although I do think we need to be cautious, and learn what is out there first, and get ready for it, before we raise our voice. And if it turns out that no one is out there, then we've not wasted our time, because I think this discussion can teach us much about ourselves too.

Paul Gilster

We're on the same wavelength there, Keith. I'm not against the idea of communicating with ETI if we receive a signal, but only within the context you suggest, which means thinking long and hard about what we want to do, making a decision based on international consultation, and realizing that any such contact would have ramifications that have to be carefully considered. On balance, we might just decide to stay silent until we gathered further information.

I do think many people have simply not considered this realistically. I was talking to a friend the other day whose reaction was typical. He had been asking me about SETI from a layman's perspective, and I was telling him a bit about current efforts like Breakthrough Listen. But when I added that we needed to be cautious about how we responded, if we responded, to any reception, he was incredulous, then thoughtful. "I've just never thought about that," he said. "I guess it just seems like science fiction. But of course I realize it isn't."

So we're right back to paradox. If we have knowledge of the size of the galaxy — indeed, of the visible cosmos — why do we not see more public understanding of the implications? I think people could absorb the idea of a SETI reception without huge disruption, but it will force a cultural shift that turns what had been fiction into the realm of possibility.

But maybe we should now identify the broad context within which this shift can occur. In the beginning of your book, Keith, you say this: "Understanding altruism may ultimately be the single most significant factor in our quest to make contact with other intelligent life in the Universe."

I think this is exactly right, and I hope we can talk again, digging into why this statement is true, and its ramifications for how we deal with not only extraterrestrial contact but our own civilization. Along with this, let's get into that thorny question of 'deep time' and how our species sees itself in the cosmos.

FROM HERE TO THE STARS VLOG

From Here to the Stars has increased its production schedule to bring insightful new interviews from the professionals who are working to advance interstellar science and exploration. Host Stephen Euin Cobb most recently sat down with TVIW founder Les Johnson, watch here:

https://www.youtube.com/watch?v=eEP0nZyT_Lg

Recent interviews also included Prof. Angelle Tanner and Dr. Tracie Prater - you could be next!

In an effort to continue to bring in the best guests to answer burning questions about space travel and life among the stars, the team is interested in your efforts throughout the scientific community, even beyond the focus of interstellar travel. You are doing important work for the improvement of humankind and your unique voice would be a highly desired addition.

If you have any recommendations for guests, let the team know those as well!

In more exciting news, From Here to the Stars is expanding beyond the YouTube video series into a podcast which will be available for streaming across many platforms, like iHeartRadio, Spotify, and Stitcher.

The team is excited to have you along on the journey!

Check out all past and future videos at https://irg.space/from-here-to-the-stars/.

USE AMAZONSMILE TO BENEFIT TVIW / IRG

An exciting opportunity to support the great work that TVIW is doing is to use the AmazonSmile program. Every dollar counts for non-profit groups. TVIW can benefit from each purchase you make at no additional charge to you. Amazon donates 0.5% of each purchase to the non-profit organizations of your choice and the TVIW is one of those organizations. This is a painless way to support us.

To participate, go to smile.amazon.com. Sign into your account and a "pop up" page will appear. On the right side of the page, at

the bottom is a "search" window. Type in: Tennessee Valley Interstellar Workshop and click the search button. Click on the top one and you are done. Your donations will be automatic for any purchase within the Amazon Smile program (which is most merchandise). You can also use the following link.

https://smile.amazon.com/ch/46-4572727

WINNING SCHOLARSHIP ESSAY: INTERSTELLAR MISSIONS RESEARCH ESSAY BY HAYDEN MORGAN

Problem Statement

Humans have always been fascinated by the stars in the sky and significant study has gone to develop telescopes to see far beyond our planet into these distant stars. We put satellites into orbit to better understand our planet, our close neighbors in the solar system, and distant star systems. The study of all this eventually manifests as a crewed mission like we did with the Moon in 1969 and what we will do on Mars. In preparation for these missions, science spacecrafts were sent to study the area planned for the crew. For interstellar travel, this process and the ultimate end goal will not be different. We have been studying beyond our star for a long time, now we are arriving at the era where sending scientific spacecrafts to near star systems becomes feasible. It is important for us to explore beyond our star system because these understandings help us learn more about ourselves, provide technology benefits that can be used on Earth, but also they provide a great sense of collective pride in what it means to be a human. Every time we push beyond the boundary, we previously thought impossible, we create a milestone in human scientific development. However, a large challenge that comes with interstellar missions is the time to see results. It is difficult to get the public excited about a scientific mission that they or their children may not see benefits from. For this reason and many others, trying to reach the nearest star system within a human lifetime is increasingly valuable and is one of the highlights of initiatives like Breakthrough Starshot [1].

Current space propulsion methods do not have high enough specific impulse to accomplish these missions in a reasonable timeline. For this reason, different forms of beamed propulsion and solar sailing technology are being studied. The benefits of these methods are removing the requirement of housing propellant onboard the science spacecraft and having an increased thrust duration that can propel the spacecraft to very high speeds. Traditional projects evaluating beamed energy propulsion suffer from the divergence of light or particles used to transfer momentum to the science spacecraft. Reducing this effect has caused many designs to involve kilometer sized sails and transmitters which is a monumental task on top of another very difficult challenge. A propulsion method proposed by Limbach and Hara [2] uses a combined laser and particle beam to produce a self-guiding effect that nearly eliminates beam divergence over millions of kilometers. With this method, the sail and transmitter can remain on the order of meters in size, which reduces the challenge. A breakdown of this technology will be discussed in the following section.

Background

The fundamentals of the self-guiding beam propulsion method [2] is a high flux particle source, a laser cooling module that reduces the natural thermal divergence of the particles from the source, then an overlapped laser beam that will propagate with the particles and form the self-guiding, and finally the transmitter will need a way to ionize and accelerate the particles to very high speeds (10% the speed of light). The scientific spacecraft will need a way to accept the momentum transfer without the particles barraging the sail, and while this is a research challenge, it is left for future developments. The principles of the light and particle guiding are well understood. Like a step-index fiber optic cable, the laser light is confined to the higher index of refraction core or particle jet. The particle guiding has also been studied by experiments such as those by Grimm et al. [3] and Bjorkholm et al. [4].

The operating principles of the particle trapping comes from starting with a low temperature source of atoms and overlapping them with a high intensity laser. When the laser is tuned near the resonance of an energy level transition of the atom, it has different effects. Tuning the overlapped laser slightly to the red of resonance will produce a focusing effect and create a potential "well" that these low temperature particles cannot escape. Shifting the overlapped laser to slightly blue of the transition pushes the particles out of the center of the beam. The figure of the effects of tuning on this overlapped beam can be seen in Bjorkholm [4].

The area of study currently being researched at Texas A&M is the focusing effect of the particle guiding on the laser. The study of particle traps mentioned previously [3,4], focus primarily on the effect on the particles but not the output of the overlapped laser. In the self-guiding beam, it is crucial to understand the behavior of both the particles and the laser during the propagation.

Current Research

The current experimental research, led by Dr. Christopher Limbach, involves breaking apart the fundamental requirements of the propulsion method outlined in the Background section. The original goal of this initial study was to develop a custom, scalable rubidium particle jet source to study the light-matter coupling. This particle source is shown in Figure 1. The primary elements included a heated rubidium reservoir, a converging-diverging nozzle to accelerate the particles to supersonic speeds, a beam skimmer that extracted the low divergence center of the plume, and a surrounding chilled condensation chamber that will condense rubidium on contact with the walls such that reflections do not interfere with the central plume. This configuration was evaluated in an experiment in the Spring of 2020. The results of this experiment along with design improvements are the planned subject of a conference paper for the 2020 AIAA Propulsion and Energy Conference. Additionally, this experiment requires the use of a vacuum facility that is equipped with enough space to house the experimental setup, allow the beam significant propagation distance, and provide the capability for laser diagnostics of the jet. The vacuum facility design has, and continues to be, a sizeable portion of the effort. The initial vacuum configuration from the Spring 2020 experiment is shown in *Figure 2*. During this experiment, the absorption spectroscopy diagnostics, which will be discussed in detail in a following section, showed that there was a substantial ambient pressure of rubidium in the chamber. The conclusion from this experiment was the condensation chamber did not remain at the low temperature required and caused significant back pressure against the converging-diverging nozzle, causing the rubidium vapor to be subsonic upon leaving the skimmer. Several improvements to this experiment have been designed and constructed and awaits laboratory evaluation.

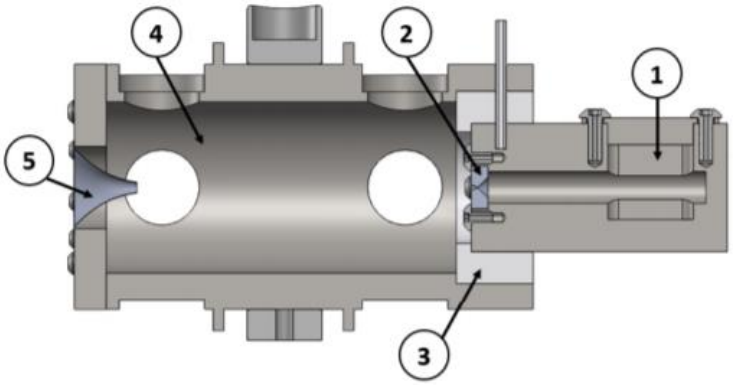


Figure 1. Rubidium particle jet source. 1. Heated rubidium reservoir, 2. Converging-diverging nozzle, 3. Ceramic insulator insert, 4. Chilled condensation chamber, 5. Beam skimmer

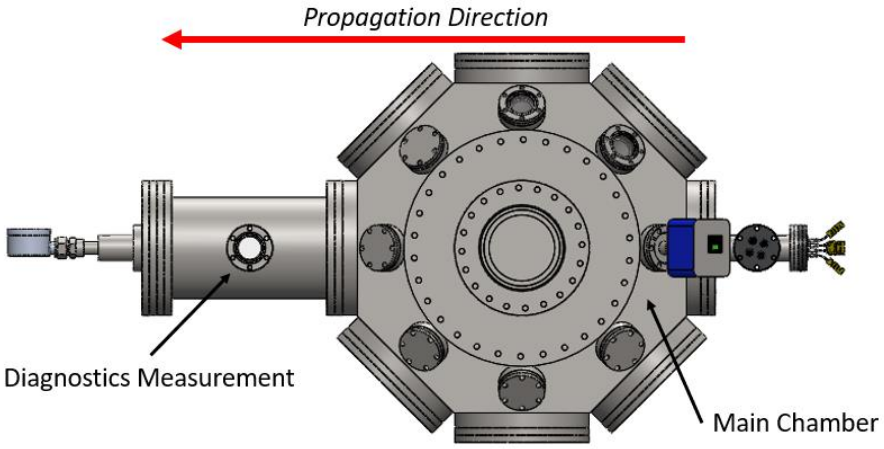


Figure 2. Initial vacuum facility configuration

Measurement Diagnostics

Understanding the behavior of the particles in the experiment is crucial to evaluating and modeling the behavior of the propulsion method. The primary particle jet parameters of interest are the density of the jet and the bulk velocity and temperature of the atoms. A tunable diode laser absorption spectroscopy (TDLAS) diagnostic method was employed in the Spring 2020 experiment, shown in *Figure 3*.

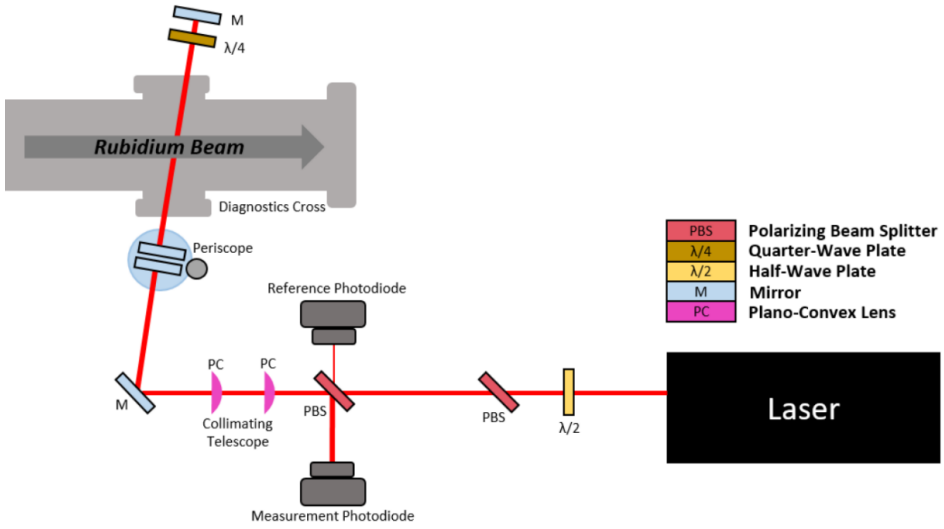


Figure 3. Tunable diode laser absorption spectroscopy experimental setup

The experimental setup for this diagnostic method involves a saturated absorption spectroscopy (SAS) reference, an adjustable periscope to scan across the particle beam, and a series of optics to perform a double pass through the particle beam at an angle and isolate the return signal. The slight angle introduced to the diagnostic beam allows the bulk velocity of the particle jet to manifest as a combination of a red and blue shift in the double pass measurement. The temperature of the atoms is evaluated through traditional thermal Doppler broadening effects, while the jet density is seen as the intensity of the absorption feature. The saturated absorption spectroscopy reference measurement acts as a source of comparison for the bulk velocity Doppler shifting. An example of the results from this TDLAS experiment is provided in Figure 4

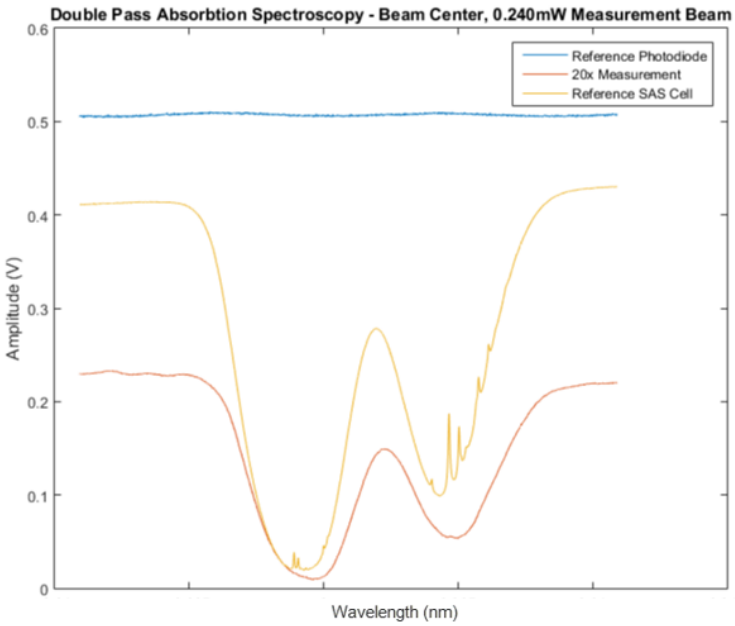


Figure 4. TDLAS measurement data compared with SAS reference cell

Another diagnostic planned to be implemented in future iterations of the experiment is laser induced fluorescence (LIF). With LIF, a laser sheet, generated by the same tunable diode laser in the TDLAS measurement, will be scanned across the beam to gather density and temperature. Additionally, an angle relative to the jet propagation direction can be introduced to also see a bulk velocity Doppler shift. The goal of this addition of LIF is to add another point of comparison as well as study locations in the beam that might not be possible or practical with absorption spectroscopy. In the previous jet source configuration, Figure 1, a series of four sapphire windows was installed onto the condensation chamber which served as an access point for the LIF beam and the collection optics to gather the fluorescence. With the experimental configuration, a TDLAS measurement in this location would be increasingly difficult. In the future experimental facility, it is possible to conduct a TDLAS measurement and then also collect the fluorescence in the same location. This dual measurement capability will aid in providing accurate results.

Future Research and Thesis Development

The goal of future research is to focus on the light-matter coupling and its effect on the focusing of both the rubidium atoms and the overlapped laser as a function of the laser tuning. To complete this, a transition from a high flux source to using an off-the-shelf rubidium vacuum getter cartridge was made. The rubidium getter releases a relatively low mass flux of rubidium out into the vacuum chamber when heated via an electrical current. An improved condensation shroud is then used to surround the getter source such that only the central region expands into the chamber, similar to the principal operation of the beam skimmer but now the particles are strictly in the free molecular flow regime, not continuum as before. This new source configuration is shown in Figure 5. The shroud has significant improvements from the previous version, starting from the change in material from the original stainless steel with low conductivity to high thermal conductivity copper. Additionally, the cooling system for this condensation shroud has changed from being an immersion probe chiller in a coolant reservoir to an actively pumped cooling coil brazed to the outside of the shroud.

From this new source development, an initial experiment with roughly the same vacuum facility as the Spring 2020 experiment will be conducted to get a baseline estimated for the behavior of this source. The key objective of this experiment is to see a significant reduction in the ambient rubidium pressure in the vacuum system, this will indicate that the condensation shroud is operating nominally and condensing the particles well enough to cryopump out the unwanted region of the flow. Since the source will now originate the rubidium atoms in a free molecular flow regime, the trajectory of the atoms is purely the ballistic angles they have upon leaving the source. Using the equations provided by Cai and Boyd [5], the plots shown in Figure 6 were produced. The benefits of using a free molecular source to study the interaction is that the initial beam parameters are much easier to model and simulate. From the density and velocity flow fields, the effective absorption signals can be hypothesized and compared to future experimental results to calculate the efficiency of the experimental source in relation to the theoretical maximum.

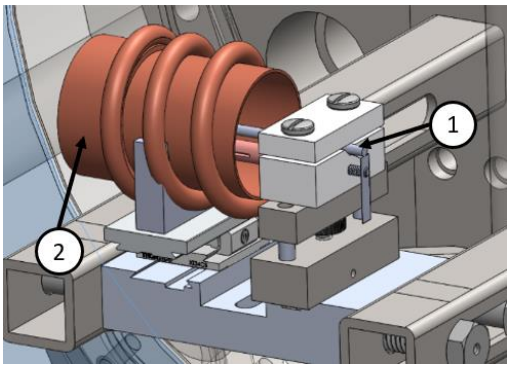


Figure 5. Revised jet source. 1. Rubidium getter cartridge in ceramic mounting block, 2. Chilled copper condensation shroud mounted to an

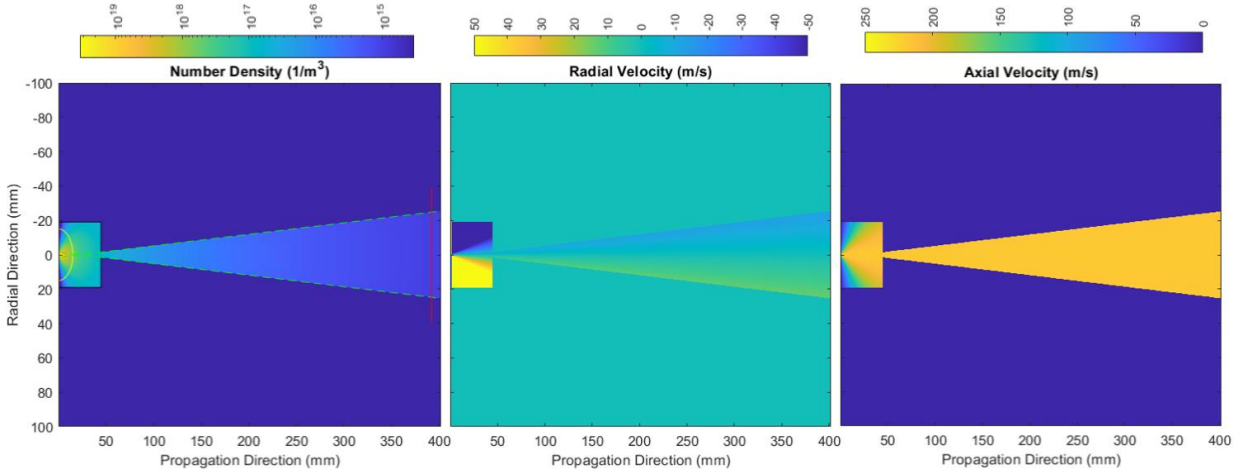


Figure 6. Free molecular flow regime number density, radial velocity, and axial velocity flow field profiles

In addition to the new source, a new vacuum facility has been constructed and will be implemented, this is shown in *Figure 7*. The new vacuum facility includes significantly more diagnostics access, as well as the ability to have an extended propagation section. This extended propagation section will allow the effects of divergence to be quite clear near the end of the run. The main highlight of transferring to this new vacuum chamber is the ability to introduce laser cooling.

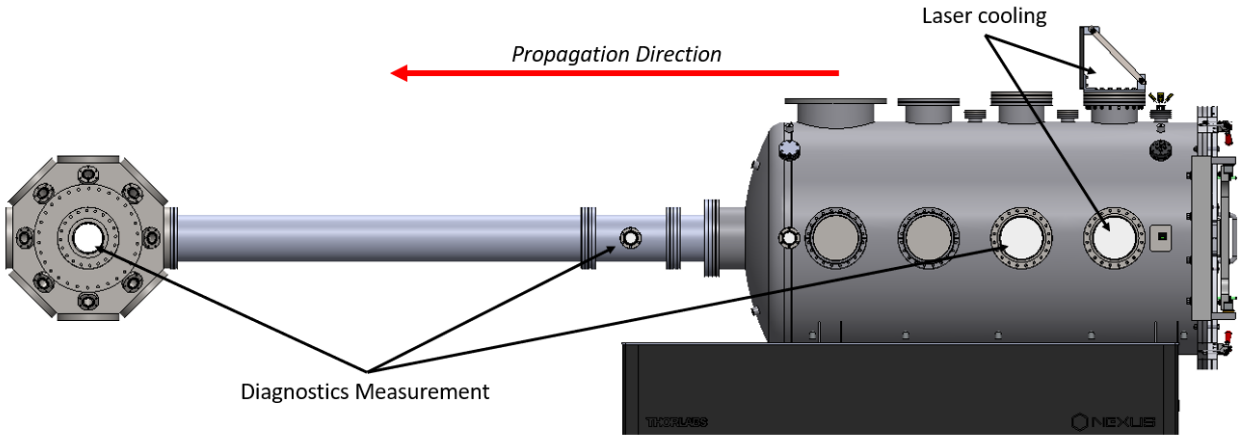


Figure 7. Future experimental setup with measurement locations and laser cooling location

The laser cooling works by creating an intersection of four orthogonal lasers, tuned slightly red of the atom's energy level transition of interest. The laser cooling intersection is referred to as an "optical molasses". From this, if the atom has a velocity that is traveling towards one of the laser beams, it experiences a Doppler blue shift of the laser frequency which, paired with the laser tuning, will possibly cause it to fall right at the frequency of the transition. The atom then absorbs the photon, which imparts some momentum on the atom. Later, the excited atom emits this same photon and repeats the process until the atoms leave the optical molasses. The rate at which the atom

releases the absorbed photon is equal to the inverse of the Einstein A coefficient for the transition. For this reason, rubidium and other alkali metals are ideal candidates for laser cooling as the A coefficients are orders of magnitudes higher than other species, meaning they can have momentum imparted on them significantly more times while in the laser cooling optical molasses. The ultimate result of this laser cooling is to lower the divergence of the jet significantly. However, there will still be some jet divergence after laser cooling. Diagnostics methods at discrete locations along the jet propagation will be able to identify the jet size, which can be used to calculate the divergence. An area of study of this research will involve fine tuning the laser cooling frequency to optimize the red shift such that the divergence of the resultant jet is minimized.

Now the overlapped laser beam can be introduced. This is the area that will be the primary focus of the thesis work. Using a pinhole mirror for the particles to pass through [4], the laser can be overlapped with the particle jet. The point at where in the jet the laser comes to a focus to maximize trapping potential is also an area of study for this research. With the laser overlapped, the same diagnostics along the propagation direction will be used the parameterize the jet and determine if the jet divergence has been significantly reduced relative to the laser cooling. Additionally, another measurement will be conducted at the end of the propagation axis: a heated window will be used to reflect the particles out of the beam axis where they will go to a condensing beam dump, but the laser will be allowed to pass through. From here, the laser beam will propagate out of the vacuum and go to a beam profiler. This addition to the experiment introduces a novel aspect that will provide significant insight into how the particles will then focus the light. This interaction can then be compared to theory and simulations. Various experiments will be conducted to see the effects of overlapped laser detuning on the shape of the particle jet as well as the end profile of the laser beam. These experiments will also show trends toward the optimal laser cooling frequency and overlapped beam frequency to produce a tight, low divergence combined beam.

Conclusion

The development of a ground-breaking propulsion method for interstellar travel is about overcoming hurdle after hurdle, not simply one giant leap. The goal of my Master of Science thesis is to study the fundamental physics behind light-matter focusing and coupling that could lead to a form of beamed energy propulsion capable of pushing a scientific spacecraft to speeds of a significant portion of the speed of light [2]. After this study has been conducted, the various other elements of the propulsion method can be evaluated. Understanding the fundamental physics and being able to simulate the propulsion method's behavior is important for future funding of the project as well as knowing the capability and mission profiles. This work has the potential to provide greater understanding of a fundamental physics interaction that could be the key to helping develop a space propulsion system that could be used to orchestrate a planetary flyby of Proxima Centauri B within a human lifetime.

References

[1] Breakthrough Initiatives - Starshot,", 2016. URLhttps://breakthroughinitiatives.org/initiative/3

[2] Limbach, Christopher, and Kentaro Hara. PROCSIMA: Diffractionless Beamed Propulsion for Breakthrough Interstellar Missions. 2019, NIAC Phase I Report, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190014041.pdf

[3] Grimm, Rudolf, and Matthias Weidemuller. "Optical Dipole Traps for Neutral Atoms." Advances in Atomic, Molecular and Optical Physics, vol. 42, 2000, arxiv.org/abs/physics/9902072v1.

[4] Bjorkholm, J. E, Freeman, R. R, Ashkin, A, Pearson, D. B. "Observations of Focusing of Neutral Atoms by the Dipole Forces of Resonance-Radiation Pressure." The American Physical Society, vol. 41, ser. 20, 13 Nov. 1978, pp. 1361–1364. 20.

[5] Cai, Chunpei, and Boyd, Iain D. *Collisionless Gas Expanding into Vacuum.* Journal of Spacecraft and Rockets. Vol 44. 2007