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NASA AMA: We just sequenced DNA in space for the first time. Ask us anything!

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[1]Affiliation not available

April 17, 2023

the WINNOWER

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This is probably a stupid question, but why would you think that it wasnt possible to sequence DNA in space? I would think that it was possible without needing to perform experiments. What's different in the space station that you would think it may not be possible?

RANDOM_SHEEP

Some of the challenges of spaceflight include the way bubbles and fluids behave in microgravity. Another challenge is the launch vibrations a payload experiences when being launched to space. Despite these challenges, we were confident that sequencing in space would work, and happy to report that it was very successful. - KJ

This is probably a stupid question, but why would you think that it wasnt possible to sequence DNA in space? I would think that it was possible without needing to perform experiments. What's different in the space station that you would think it may not be possible?

RANDOM_SHEEP

Some of the challenges of spaceflight include the way bubbles and fluids behave in microgravity. Another challenge is the launch vibrations a payload experiences when being launched to space. Despite these challenges, we were confident that sequencing in space would work, and happy to report that it was very successful. - KJ

Hi NASA Scientists,

Are there any benefits to do sequencing in orbit compared to on earth, or rather, what's the practical challenges?

Edit; sentence composition.

fl0w_io

Right now we aren't able to identify contaminating microbes in the ISS environment or diagnose infectious disease in crew members. The ability to sequence DNA could address both areas and provide the identity of microbes. The sequencer could also be used in many ISS research investigations. Therefore, we think that there are many benefits to sequencing in-flight. SW

Were the results any different?

coolshifts

It is a bit different (loading the sequencer)! We had to make sure that it would be safe to conduct on the ISS and not take extreme amounts of crew time to complete. We ran the same samples on Earth with the same techniques, and found that the data was very similar (the sequences from space were even a bit better!). http://biorxiv.org/content/biorxiv/early/2015/12/10/032342.full.pdf SW

Were the results any different?

coolshifts

The results for sequencing in space and on the ground have been the same. This helps to confirm that sequencing in space was indeed successful! -KJ

What interesting, if any, unique properties show up when doing this in space compared to on Earth?

imtalkintou

We did observe that the base accuracy, throughput, and the technical parameters of the runs in space (skips/base, stays/base, read size, read speed) were just as good, or even better, in space. But, this is just 4/4 times, which given a 50/50 chance for Space to look better than Earth, means this is just a 1/16 chance, so not quite significant yet. -CM

What interesting, if any, unique properties show up when doing this in space compared to on Earth?

imtalkintou

what is perhaps most remarkable is how similar nanopore sequencing performance was between space and Earth -- a result that we did not necessarily predict given concerns regarding the behavior of the microfluidics of the instrument in microgravity. -CC

Hi. What are the main health issues that could effect humans travelling for long periods of time in space? Thanks

mistymountainz

Long term stays in space can potentially impact numerous aspects of human health. For example, we know that bone and muscle mass is lost, the astronauts are exposed to higher levels of radiation, the immune system is altered, and microbes can become more pathogenic. SW

Hi. What are the main health issues that could effect humans travelling for long periods of time in space? Thanks

mistymountainz

This is a good question. One thing that didn't get brought up below are muscle atrophy. If you spend 9 months in microgravity traveling to Mars, how well can you perform necessary tasks? Mars may only have ~40% the gravity of Earth, but that's a lot more than 0g. AB

Hi. What are the main health issues that could effect humans travelling for long periods of time in space? Thanks

mistymountainz

Check out this whole series we've recently done about it:http://www.nasa.gov/content/exploring-space-through-you-omics -CM

how big a step forward is this in long distance space travel? Is it a complete necessity or could it be done without?

Also a more personal question, what could a university student looking to get into the industry do in order to improve their chances of getting into this field?

Thanks for the AMA

JustTheAverageJoe

Studying what you are passionate about is key - this was a very interdisciplinary project. We have team members with backgrounds in molecular biology, microbiology, astrobiology, chemistry, engineering, and computer science DS

how big a step forward is this in long distance space travel? Is it a complete necessity or could it be done without?

Also a more personal question, what could a university student looking to get into the industry do in order to improve their chances of getting into this field?

Thanks for the AMA

JustTheAverageJoe

Missions to Mars are going to be fairly long duration (1 to 3 years). We need to develop methods for in flight diagnostics, and we think sequencing can be an important technology for this. AB

Is this an above average thing for us lay people to get excited about? Obviously its great for the astronauts, but im assuming so is everything cool you do. Is this huge?

AdseyV

There is so much to be excited about! As a microbiologist, I am so excited that we may finally be able to identify microbes (from the environment or humans) in-flight. Also, this technology may potentially be the early version of the device that one day is able to detect nucleic acid-based life beyond Earth! SO EXCITING to think about and definitely HUGE! :) SW

I imagine the ISS is a bit cramped. How much space does the equipment necessary for this require? Did something have to be removed from the ISS to let it fit?

kitikitish

The sequencer is tiny (3 ¾ x 1 ¼ x 5/8 inches) and lightweight (less than 120 grams). Nothing had to be removed. When we are operating, they attach us to the front of an Express Rack which is what the ISS uses to house experiments and equipment. All of our hardware for this experiment (excluding the Surface Pro 3) could fit into a shoe box. -KJ

I imagine the ISS is a bit cramped. How much space does the equipment necessary for this require? Did something have to be removed from the ISS to let it fit?

kitikitish

Nope, nothing had to be removed! The hardware is very small (smaller than your smartphone and only weighs about 90 grams). A Surface Pro3 tablet was the largest piece of hardware that we needed (to power the MinION sequencer), which is used for other purposes on the ISS. SW

Hello NASA, and thanks for doing this AMA. I have 2 questions.

1. What are some future experiments on the ISS that this team would like to see completed but cannot due to their complexities or lack of equipment capable of completing the experiment?

2. How does a student with less than perfect grades go about working for the awesomeness that is NASA? I will have a BS in mechanical engineering in may 2017.

Martles

1. Imaginations run wild, but experiments must be constrained by the realities of the available equipment, budgets, and crew time. It is more productive to focus on what you can accomplish with the resources available or find a way to create those resources.
2. Grades are only part of the equation. The rest is experience, creativity, and passion. Jobs are posted at https://www.usajobs.gov and at the equivalent job sites at NASA contractor organizations. Look at these opportunities and see if you need a BS, MS, or PhD for what you want to do. -JD

Hello NASA, and thanks for doing this AMA. I have 2 questions.

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2. How does a student with less than perfect grades go about working for the awesomeness that is NASA? I will have a BS in mechanical engineering in may 2017.

Martles

For this experiment we sent up DNA we prepped on the ground. Next steps will be have the astronauts do the entire process on the ISS. The key is to design processes that work without gravity, and that don't require specialized techniques or a lot of time for the crew members.

Hello NASA, and thanks for doing this AMA. I have 2 questions.

1. What are some future experiments on the ISS that this team would like to see completed but cannot due to their complexities or lack of equipment capable of completing the experiment?

2. How does a student with less than perfect grades go about working for the awesomeness that is NASA? I will have a BS in mechanical engineering in may 2017.

Martles

Since I joined NASA (in 2008) nobody has asked me about my grade in college calculus. Whew! Thankfully we are surrounded by other brilliant coworkers who we can call on for subject matter expertise when we need it! DS

What was the most challenging part about sequencing DNA in space?
Also, how much do you love your job?
Edit: Thank you so much for the replies!

flamebird3

The most challenging part was making sure that all of our methods and everything for operations in space were worked out ahead of time. Normally you can go in the laboratory and try a bunch of things, but it's not so easy to pop up to the ISS to test a few things. You've got to anticipate a lot of the things that could go wrong, even if you don't think that is going to happen.

And I consider myself very lucky that I get to wake up and work at NASA everyday. Working on space problems challenges a lot of your assumptions - gravity, air to breathe, boiling points and freezing

points of water. So many things change once you're not in the Earth paradigm.

EDIT: signature: AB

What was the most challenging part about sequencing DNA in space?
Also, how much do you love your job?
Edit: Thank you so much for the replies!

flamebird3

One of the most challenging parts about sequencing in space was certifying the hardware to be “space-approved”. We went through a series of safety reviews, interface meetings, and worked with several engineers to meet the requirements of flying an experiment in space and on ISS. -KJ

What was the most challenging part about sequencing DNA in space?
Also, how much do you love your job?
Edit: Thank you so much for the replies!

flamebird3

I really, really love my job! Working at NASA is awesome and a childhood dream come true! -KJ

What kind of amazing or exciting advances do you personally look forward to seeing this technology implemented towards?

For example I would imagine this would be great for future research for pregnancy in space and the affects.

Or put towards research to what causes the differences in the aging process between Earth and space.

FalloutTron

There are many potential exciting applications from deployment of this technology in space: (1) monitoring health of astronauts by real-time infectious disease testing with a "pan-pathogen" assay, (2) discovery of new life, if DNA, RNA or other polymer-based, (3) monitoring effects of radiation, aging, pregnancy on the human genome during prolonged stays in space (your examples are right on target), (4) environmental and quality monitoring of precious resources (food, water, drugs), and (5) analyzing gene expression to diagnose causes of illness -CC

What kind of amazing or exciting advances do you personally look forward to seeing this technology implemented towards?

For example I would imagine this would be great for future research for pregnancy in space and the affects.

Or put towards research to what causes the differences in the aging process between Earth and space.

FalloutTron

We expect that the measures of epigenetic aging to be different, and we will be looking for that also with the Twins Study. We think a continual monitoring of stations, hospitals, and areas of the world will soon be routine, and show us a shifting of alleles and genetic elements as they move around the world (or the ISS), just as you would have a measure of temperature and humidity; there will be a genetic measurement too. We'll know as soon as anything looks amiss long before anyone gets sick. -CM

What are the key challenges of DNA sequencing in the Space Station? And I was wondering what sequencing technique your using, basic Sanger, some NGS or a proprietary method? One last question, what's your opinion about DNA-based life forms beyond Earth? Do you think this DNA will share the same nucleotides and structure?

Thanks for the AMA and keep up the good work!

Fishermanz12

We've got Mars meteorites on Earth, and presumably Earth meteorites could have ended up on Mars. So it's possible that life could have been transferred between the planets. This would make it theoretically possible that life on Mars (if it existed) could share a common ancestry . I think alternative nucleic acids like threose or glycerol nucleic acids, or other different nucleobases could all be possible.

What are the key challenges of DNA sequencing in the Space Station? And I was wondering what sequencing technique your using, basic Sanger, some NGS or a proprietary method? One last question, what's your opinion about DNA-based life forms beyond Earth? Do you think this DNA will share the same nucleotides and structure?

Thanks for the AMA and keep up the good work!

Fishermanz12

One key challenge is dealing with bubbles and fluids in microgravity. Another challenge is surviving the launch vibrations when you launch to space. The method of nanopore sequencing in space, as opposed to other methods, was very conducive to spaceflight in the sense that is was small and we did not have laser or optics. Despite those challenges, we are happy to report sequencing in space was successful. -KJ

I'm probably too late to the game here, but I was wondering if you were considering doing a similar experiment to the long term evolution of E. coli run by Richard Lenski , to see if microbial evolution is more or less rapid in space.

Also what would you theorize would be the outcome of the experiment?

IAmKindOfCreative

This would be an awesome experiment! I'm sure it would be different, not sure if it would be faster or slower. A microbe is definitely going to face different selection pressures in microgravity and the confined environment of the ISS compared with on the Earth.

AB

Have you thought about doing a control by performing sequencing OUTSIDE of the space station? Just for funsies?

hypermarv123

Yes, kinda sorta – and not just for funsies! This has come up in some conversations as a way to start getting smarter about how to do this in a less controlled environment – for example, some day on the surface of Mars. However, sample prep outside the station is not something anticipated anytime soon. But getting a sample from the outside of station (e.g. outside a vent) and then bringing it in for prep and sequencing is something we've considered. ML

My father was involved in developing the processes and technologies used to sequence DNA (starting

with sequencing Amino Acids and Proteins). How do your instruments in space differ from instruments that would be used on Earth?

MlleGateaux

Cool! In this case we were able to use a nanopore Earth instrument without modification due to the applicability of the technology to the harsh launch environment and microgravity environment. See: http://biorxiv.org/content/biorxiv/early/2015/12/10/032342.full.pdf -JD

You've probably gotten this a million times, and I apologies if it's off topic.

I'm a freshman at Arizona State University; my major is currently microbiology along with Biotechnology. My dream/goal is to do exactly what you all are doing. Astrobiology along the lines of DNA sequencing and analyzing. What advice do you have for young blood like me? What classes would you say are essential? What are some good electives? How much schooling would you recommend? What steps should I take after leaving school? I apologize for a flurry of questions, but this has been a passion of mine since I was a kid. Any advice is fantastic, thank you very much!

Imgonnaroll

check this out: https://www.nasa.gov/ames/research/space-life-sciences-training-program I would recommend studying a wide variety of topics in college. You can specialize later in grad school! Study what you love; a topic you would want to investigate in your free time. DS

Hi NASA! Thanks for doing this AMA! What effects on DNA, if any, are you noticing in space vs on Earth? I'm interested in seeing if your findings shed any more light on the effects of organisms being born/created in space.

Thanks!

MikeHauk

Overall it looks great (even slightly better) in space. We did observe that the base accuracy, throughput, and the technical parameters of the runs in space (skips/base, stays/base, read size, read speed) were just as good, or even better, in space. But, this is just 4/4 times, which given a 50/50 chance for Space to look better than Earth, means this is just a 1/16 chance, so not quite significant yet. And we don't yet know if this would impact organisms born in space, but we can use these data to look at both genetic and epigenetic information. -CM

Thanks for doing this AMA, you guys are great.

What are the effects of solar radiation on DNA in space? Are they significant enough to pose a problem to astronauts in the ISS? What about during deep space travel or on Mars? And even further that, what about in interstellar space?

Thanks again!

Froguy1126

Radiation is certainly a concern when in space, although less so on the ISS. When we go to destinations like Mars and beyond, radiation is a major concern. Radiation comes from particles from the sun and from other sources in our galaxy and universe so this is something we will deal with in interstellar space. The damage radiation has on DNA can make it difficult for cell reproduction. Great questions! -KJ

Congrats! What was the first DNA specimen you sequenced? Wouldnt using MALDI-TOF and PCR be

more useful currently for bacterial and viral identification?

Krakenhelm

The sample contained a mix lambda bacteriophage, e. coli bacterium and mouse DNA. PCR has been done on the ISS, and is good for amplifying DNA. You can ID organisms with RT PCR, but you need a primer set for each organism you're trying to ID. Maldi-ToF would be cool but large, and hard to automate for crew members. For bacterial and fungal ID with the MinION, you can PCR and sequence entire 16S and 18S ribosomes, and then identify all of bacteria and fungi with two sets of primers. AB

What happens if someone is sick inside the space station? Do they recover more slowly?

hypermarv123

Personal health questions are between crew members and their flight surgeons. It has been observed that microbial virulence can increase during spaceflight, and that astronaut immune system response gets downregulated.

What happens if someone is sick inside the space station? Do they recover more slowly?

hypermarv123

It's hard for us scientists to say, as that information is kept confidential between the astronaut and their flight surgeon. It would definitely be an interesting study! SW

Does this mean that there is potential for the asteroid gathering missions to return the samples to the space station rather then risk re-entry?

SirTwill

Theoretically this might be possible depending on where the sample is coming from (e.g. an asteroid in orbit around the moon), but it would be very challenging in terms of the astrodynamics. Also, the sample prep and analytical capabilities on earth far exceed what is presently on ISS. ML

In what way can we use genetic manipulation to make space travel easier on the human body?

0wlington

We can alter many things about humans to better prepare for long-term space travel, including both the human genome and the microbiome. This could be modifying the genome to have greater DNA repair capacity, improved immune surveillance, faster vasculature adaptation, and cognitive improvements. We can switch the types and proportions of bacteria, fungi, and viruses in and on the astronauts. Also some of this is discussed here: http://www.tedmed.com/speakers/show?id=526461 (shameless link to my own TEDMED video). -CM

In what way can we use genetic manipulation to make space travel easier on the human body?

0wlington

Alteration of the microbiome (the population of microbes -- bacteria, fungi, and viruses -- living in niches in the human body, such as the gastrointestinal tract) would probably be the most practical kind of genetic manipulation in the near term. We already treat diseases such as Clostridium difficile diarrhea by alternating the microbiome with a fecal stool transplant. Direct modification of the human genome to improved adaptation to space will also likely be possible, albeit in the more distant future. -CC

If I am reading this correctly you used a nanopore to sequence the DNA, which is an interesting test of the technology. What where the differences between the ground read and the ones you did in space? I am curious what you can take away from it because my university is one of the few who have been been given nanopore readers to test, and statistically speaking, it has a terrible read accuracy because it is a low output, long read technology. What would have been different if you had used one of the desktop ion-torrent units? Also would it have been possible to create those samples in space? Does PCR work properly in a space environment?

Ngoscope

Nanopore performance with respect to base accuracy, throughput, and technical parameters (sequencing rates) was comparable between ground and space. The experiments in space used the R7 flow cells which had error rates of 15-25%. The current (and now only available) R9 flow cells have lower error rates of 5-15%, and the manufacturer (Oxford Nanopore Technologies, UK) has stated that their goal is to get the error rates under 3%. Certainly, the error rates would have been significantly better had we used an Ion Torrent, Illumina, or PacBio instrument but it is not cost-effective or practical to bring these bulky instruments aboard the ISS. We believe that sample library preparation in space is feasible given success with conducting molecular biology assays up there. -CC

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Ngoscope

Based on our experiments, the results for sequencing in space and on the ground have been the same (actually the space runs were a little better!) This helps to confirm that sequencing in space was indeed successful! Using nanopore sequencing, as opposed to another method, made sequencing in space possible because of its size and the technology. Some of the other methods involve sophisticated optics that aren't conducive to spaceflight. The Genes in Space project http://www.genesinspace.org/ showed that PCR does work properly in a space! -KJ

If I am reading this correctly you used a nanopore to sequence the DNA, which is an interesting test of the technology. What where the differences between the ground read and the ones you did in space? I am curious what you can take away from it because my university is one of the few who have been been given nanopore readers to test, and statistically speaking, it has a terrible read accuracy because it is a low output, long read technology. What would have been different if you had used one of the desktop ion-torrent units? Also would it have been possible to create those samples in space? Does PCR work properly in a space environment?

Ngoscope

NASA has a new facility called Wetlab-2 (https://www.nasa.gov/ames/research/space-biosciences/wetlab-2) which recently showed PCR in space is possible. The system can also be used to prepare samples for downstream molecular biology assays. In addition, a mini-PCR (http://www.minipcr.com/) was recently tested on ISS. Our team also showed a combined sample prep and sequencing workflow inside the NEEMO habitat (https://www.nasa.gov/mission_pages/NEEMO/index.html) DS

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the technology. What where the differences between the ground read and the ones you did in space? I am curious what you can take away from it because my university is one of the few who have been been given nanopore readers to test, and statistically speaking, it has a terrible read accuracy because it is a low output, long read technology. What would have been different if you had used one of the desktop ion-torrent units? Also would it have been possible to create those samples in space? Does PCR work properly in a space environment?

Ngoscope

We do see that the reads are about 85-92% accurate, which is from the v7 flowcells; more recent runs will show around 90-95% accuracy, so it is getting better. And the length of the reads overcomes their per-base error rates, which helps with taxonomic classification. we will now try to do the whole thing in space next! PCR should work OK. -CM

Hello, and congratulations. Have you considered sequencing RNA, for the purpose of identifying viruses, and have you ever seen evidence of viruses infecting astronauts, plants, fungi, or bacterium in space?

rabbitburger

Yeah that's the hope. We're definitely interested in looking at RNA for gene expression purposes as well as viral identification. AB

This is kind of a dumb one, but have you guys ever heard of Kerbal Space Program?

temporalExile

Yes. Jason Dworkin from our team is heavily involved (project scientist) with OSIRIS-REx, which had a Kerbal Space Program challenge:

http://www.space.com/33262-recreate-osiris-rex-mission-kerbal-game.html

Hi NASA, What sort of other biological experiments in space are you planning to do in the future?

MoralisticCommunist

Next up we'd like to do sample prep, then design experiments for in-flight microbial identification, characterizing the ISS microbiome, and doing gene expression by sequencing RNA. AB

What types of techniques would be used for nucleotide isolation in space? I would expect conventional column based and phenol-chloroform based extractions might be tough without being able to control liquid movement outside of a centrifuge (Washes and phases floating all over the place).

Is it harder to control for DNase/foreign DNA contamination in an environment like micro-g? Have you done RNA work in space? Do you have to use a RNA tent/hood due to all the aerosolized contaminants?

what_are_you_saying

Yes, traditional column-based extractions might be difficult. Magnetic bead-based extractions are a possibility, or controlled vacuum-based extractions. We also do not know as yet what levels of contamination will be in a microgravity environment, which is certainly a concern with metagenomic sequencing. -CC

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column based and phenol-chloroform based extractions might be tough without being able to control liquid movement outside of a centrifuge (Washes and phases floating all over the place).

Is it harder to control for DNase/foreign DNA contamination in an environment like micro-g? Have you done RNA work in space? Do you have to use a RNA tent/hood due to all the aerosolized contaminants?

what_are_you_saying

I'd hate to be the person trying to get phenol and chloroform through the safety screening process! AB

Is the procedure for DNA Sequencing in space any different than on earth? If so, why? And could the results of sequencing the same molecule on earth be different in space? Thanks

mistymountainz

It is a bit different! We had to make sure that it would be safe to conduct on the ISS and not take extreme amounts of crew time to complete. We ran the same samples on Earth with the same techniques, and found that the data was very similar (the sequences from space were even a bit better!). http://biorxiv.org/content/biorxiv/early/2015/12/10/032342.full.pdf SW

Is there any knowledge about witch micro-organisms thrive inside and outside of the iss?

gusti75

Here is a recent summary of an inside survey:
http://www.nasa.gov/mission_pages/station/research/news/MT1

DS

I work for EarthKAM! A NASA educational outreach program for middle school students. We have a payload on the ISS and ever couple of months we have a mission in which one of the crew members have to set up our camera in the worf. I hope we never got in your way! Are there any special precautions one has to take while conducting this experiment as opposed to being on Earth?

Steve_Thunderstorm

Hi EarthKAM! We are familiar with your awesome program! Keep up the good work! -KJ

Hello NASA scientists! What type of sequencing method did you use and what machine? Is RNA and/or protein sequencing going to be the next step? Do you need to send your sequences back to Earth to be compared or do you have genetic data stored on the ISS (for faster, though less up-to-date data)? Less important questions: if you are able to do RNA sequencing in the future, will you look at the different expression levels of astronauts before during and after orbit? Thanks!

mylittlecarrot

We used nanopore sequencing on the MinION (Oxford Nanopore Tehcnologies). The next steps would be to enable library preparation and data analysis of DNA sequence data while in space, so that we don't have to lose time sending sequences back to Earth for analysis. RNA and protein sequencing are also on the horizon -- RNA sequencing ("RNA-Seq") in particular will be helpful in monitoring gene expression levels in astronauts by transcriptome profiling -CC

What are some of your (the whole crew's) biggest non-space related accomplishments?

Cool_McStellar

Being able to juggle the extracurricular activities of two 8 and 10 year boys while sequencing everything in sight (I sequenced a nasal swab from my younger kid and it was positive for rhinovirus type 16). -CC

What are some of your (the whole crew's) biggest non-space related accomplishments?

Cool_McStellar

being married for 7+ years, helping raise a 5 and 7 year-old. AB

What are some of your (the whole crew's) biggest non-space related accomplishments?

Cool_McStellar

Raising an 11 year old girl (or "young lady"!) ML

What are some of your (the whole crew's) biggest non-space related accomplishments?

Cool_McStellar

Raising an amazing dog @mapiemcmapleson DS

What are some of your (the whole crew's) biggest non-space related accomplishments?

Cool_McStellar

I just had a baby! :) -KJ

Thank you for this AmA.

It is my understanding that the MinIon technology relies on nanopores embedded on a lipid membrane that is "pre-fabricated" in the flow cell.

1. Do the vibrations involved in the launch process pose a mechanical threat to the membrane?
2. Do you think impulsive shocks (such as required for orbit transfer maneuvres, e.g., for potential future missions to other planets) could pose different risks?
3. Can you sense the structural integrity of the membrane to assess potential damage before sequencing?

Thanks and great job!

stratanis

--> 1. We thought launch might have an effect. We did vibration testing on the ground, which seemed to indicate that we would lose about 30% of the pores (McIntyre et al NPJ Microgravity coming out soon). The actual launch vibration seems to have had no significant effect.

--> 2. It's hard to imagine those processes being any harsher than the initial launch conditions. This didn't seem to have much effect on the 4 flow cells we've tested so far.

--> 3. Within the software you can do a platform QC which tests the integrity of the membranes and pores. AB

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3. Can you sense the structural integrity of the membrane to assess potential damage before sequencing?

Thanks and great job!

stratanis

Launch vibration is certainly a challenge we were aware of. We performed launch vibration testing of the flow cell before we flew for this very reason. Based on our launch vibration tests, and our experiments now performed on the ISS after a successful launch to space, it seems that launch vibes did not pose a threat to the flow cell. -KJ

Thank you for this AmA.

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3. Can you sense the structural integrity of the membrane to assess potential damage before sequencing?

Thanks and great job!

stratanis

We did some testing of vibrations and we think most of the pores should work fine even with space launch conditions: http://biorxiv.org/content/biorxiv/early/2015/12/10/032342.full.pdf

Thanks for doing this AMA.

This question is for Dr. Mason, as well as those with a background in studying radiation induced DNA damage.

I have been involved on a project recently with computational biologists at Weill Cornell who are using whole genome sequencing and deep sequencing technologies to screen for somatic mutation, be they indels, low frequency recombinant events, or SNP variation.

It is clear that simple sequencing technology has many purely scientific applications relevant to space travel - especially as it applies to locus specific sequencing of earthly organisms, or traditional shotgun sequencing of ...alternative... life forms.

Assuming that the cost and size efficiency continues to fall (with technologies such as 10x's GemCode), how do you envision whole genome, single cell, or deep sequencing being applied to human health over the course of a prolonged mission? Especially in the context of somatic mutation induced by radiation exposure.

Is it reasonable to expect (within the short to medium term) to screen travelers and prospectively treat, for example, an enriching fraction of circulating cells with potentially pathological genomic changes? Would you even want to screen astronauts for DNA damage, given the potential intractable nature of the damage, and the potential compromise of the mission given human psychology?

Thanks again for doing this AMA - Y'all are my personal heroes.

sinigang93

This could be routinely done for monitoring not only cancer but cell-free DNA which (with its epigenetic signature) also reveal the tissue of origin when there is tissue damage. We would try and find the epigenetic changes (chromatin) that also occur to track the dys-regulation of cells before it becomes too severe. In a dreamy world, we would detect the mutations incurred by space travel and then send a specific CRISPR-Cas9 construct to fix the specific genetic insult. And if you're here, come on by my office!

This is only nominally related to your announcement (which is awesome, by the way), but is there much anticipated future need for molecular biologists in NASA? Also, what sort of benefit could a biology lab in space have over a ground-based lab?

Sawses

As the technology is becoming more suited for spaceflight, as seen with miniPCR (http://www.minipcr.com/) and now with MinION, we will need more people with molecular biology backgrounds and folks who can support the bioinformatics assessments. There are still many unknowns when it comes to the impacts of long duration spaceflight on human systems. Having the capability to do molecular investigations on the ISS would substantially decrease the need to return samples to Earth and increase the science from those samples (without having to worry about if they were fixed properly). Also, we currently still rely on culture-based methods to monitor the ISS for microbial contamination and don't have a way to diagnose infectious disease. All of these areas could be benefited by molecular biology on the ISS. Thanks for your questions! SW

If we have contaminated other planets with microbes that hitched a ride on our spacecraft, will we be able to analyse the DNA of those microbes in such a way that we can tell for sure where they came from? Or will we face a mystery as to whether the microbes came from Earth or not? Mars being the example everyone is talking about at the moment, let's say microbes attached to Viking have survived on the face of Mars somehow - might they have adapted to the new home environment to such an extent that they are now unrecognisable? How unlikely is this type of scenario?

ohdon

That's a very good question. Here's a NYT interview with NASA's planetary protection officer: http://www.nytimes.com/2015/10/06/science/mars-catharine-conley-nasa-planetary-protection-officer.html?_r=0

Sequencing DNA we found on Mars would be a good way to determine if it's something we brought with us. And if you found DNA that looked distinctly different from Earth organisms, well that would be really cool! AB

What's that little box everyone is holding in the photos?

chain83

That's the sequencer! It's the Oxford Nanopore Technology MinION sequencer. -KJ

Hi NASA, Thanks for doing this AMA. I am not a science student so this may be a off topic but How

much of this can help with cryosleep?

surkur

That's a good question. I suppose you could maybe develop some sort of automated metabolism monitor while you're out? That's pretty much just wild speculation on my part. AB

In the long run, do you see genetic engineering being used to help humans survive space? Things such as making it so bones don't deteriorate, better resistance to radiation, and maybe being able to hibernate for long journeys such as animals do in the winter. I know the technology is in its infancy, but would be a much better solution than trying to make a completely Earth like in space. Instead we could make humans more at home in space.

Congratulations btw, and thanks for doing this AMA!

WileyCyboaty

Yes, I think we might actually have a moral obligation to improve the human genome to enable long-term missions, or we send many humans off and let evolution do its work. There are some things we could modify, like Myostatin (MSTN) homozygous nulls (-/-) give lean and large muscles, and Low density lipoprotein receptor 5 (LRP5) heterozygotes (+/-) can have very strong bones, or increased expression of TP53 to protect against DNA damage. -CM

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Congratulations btw, and thanks for doing this AMA!

WileyCyboaty

Genetic engineering is certainly an area of active research, and has the potential to change the way humans survive on Earth and in space. You have some great ideas on the matter!-KJ

That is fantastic and I read about this a few days ago! My question regards how this will impact space exploration and the search for life outside our planet. So with the sequencer used, would it be able to sequence potential microbial life found on places such as Enceladus? How would it differentiate between life on Earth and foreign life? If there was a different type of life not based on Carbon, such as say Silicone, would it be able to sequence that? I'm an aspiring microbiologist with one year left on my BS and have always been fascinated by the possibility of life in space for potential microbes. Thanks so much! Great experiment!

GregMcD94

In theory, yes, this sequencer could detect something other than the traditional nucleotide bases. While most other sequencers detect fluorescently labeled nucleotides, the MinION detects a change in current. As any biomolecule could block the nanopore altering the current, we believe that this device could be an early version of what might one day detect life elsewhere in the universe. Good luck finishing up your microbiology degree! Wherever humans travel, microbes are sure to accompany them! :) SW

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GregMcD94

Thanks! There's a lot of groups working on solid state nanopores that could be robust enough to send to a hostile environment like Europa. In principle, nanopore-based detectors can analyze any polyelectrolyte (you can use electric potentials to drive the molecules through the membranes). AB

Hey, congrats! Couple of questions here, How long did it take you to reach this point? Like, how long was this in the works before it could be implemented in space? Also, who does writing the lab report fall under? Thanks!

MadameHootsALot

Several scientists at NASA and other institutions started the effort a couple years ago. However, we were officially given the go-ahead in February 2015 and delivered the hardware in December 2015 – so we were able to certify and deliver the hardware in just ten months. The entire science team helps in writing the science papers. In fact, we just released a pre-print of our paper yesterday, just one month after we sequenced in space for the first time.
http://biorxiv.org/content/early/2016/09/27/077651.full.pdf+html -KJ

Will the next step be to figure out how to make DNA libraries in space? Since this time the libraries were made on earth, correct? What do you think will be the challenges of doing this in space? What about the actual DNA isolation part?

sabbyfish

Yes, this time the libraries were made in our lab. However, we tested the whole process (DNA extraction, amplification with miniPCR [http://www.minipcr.com/] which is already on the ISS, library prep, and finally sequencing) during the NEEMO 21 mission this past July!
https://www.nasa.gov/mission_pages/NEEMO/index.html That paper is in works. Our next goal is to fly the sample prep and enable the sequencing of ISS samples. SW

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sabbyfish

Yes, this would be the next step. For these initial experiments, the libraries were made on Earth and sent to the ISS for sequencing. Molecular biology experiments such as PCR are now being routinely done on the ISS, (http://www.nasa.gov/mission_pages/station/research/experiments/1199.html) so we think that the the sample preparation challenges in space for sequencing should be manageable. -CC

I think i read somewhere that when a spacecraft lands in a planet (e.g Mars) we have to be careful not to "contaminate" the planet with possible micro-organisms from earth , is that true ? And if yes, how can we achieve it ?

pet98765

Yes. There's an international law on planetary protection that all space-fairing nations have agreed to:
https://en.wikipedia.org/wiki/Planetary_protection

And here's an interview with NASA's planetary protection officer: http://www.nytimes.com/2015/10/06/science/mars-catharine-conley-nasa-planetary-protection-officer.html?_r=0

AB

Are there any plans for an in-situ DNA extraction (extract DNA from live microbes/cells/etc) and library prep (DNA preparation for sequencing) aboard the ISS?

europajuice

YES! We actually tested the whole process (DNA extraction, amplification with miniPCR which is already on the ISS, library prep, and finally sequencing) during the NEEMO 21 mission this past July! https://www.nasa.gov/mission_pages/NEEMO/index.html That paper is in works. Our next goal is to fly the sample prep and enable the sequencing of ISS samples. SW

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europajuice

Also, DNA extraction was been successfully performed, along with quantitative PCR, on the ISS earlier this year: http://www.nasa.gov/ames/research/space-biosciences/wetlab-2

AB

Has there been any success in prepping DNA for sequencing in space? I'm curious because most of the spinning down could be done via centrifuge, which creates its own force, but anything aside from that, here on earth relies on gravity. Or am I about 40 years behind the times and asking questions that are pointless?

DrPineappleButts

There's 10-15 minute sample preps you can do on the ground, and we tested flight-compatible methods earlier this year. Shouldn't be too hard!

AB

Hi NASA Scientists, Well here's my question. If we would travel to mars and one of the astronauts has a disease or there are some bacteria in the landing module, would/could those bacteria survive on mars? If this is possible, we could "create" Aliens, assuming they evolve on mars.

Akkarin-32

Yes, this is something folks are trying to address. A sequencing capability on Mars would allow us to closely monitor and understand this kind of possibility. ML

Thanks for this AMA!

As a bioinformatician.. I'd like to know which sequencing technology you used.

Edit: And did you already verify the correctness of the results? Are there significant differences in the quality/NG50 or something?

ratherstayback

Also, we're going to be posting .fasta files of the reads on NASA's GeneLab site in the near future:

http://genelab.nasa.gov/

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ratherstayback

The quality of the assemblies from in-space and ground nanopore reads were comparable, which we were happy to see! -CC

Whose DNA did you sequence?

luigi2yoshi

Not a human, but DNA from a mouse, a virus (lambda phage), and a bacterium (E. coli). SW

Whose DNA did you sequence?

luigi2yoshi

1:1:1 of mouse:E. coli:lambda phage -CM

This is a stupid question but, What technology did you guys use to sequence it in space ? And how much did it cost ?

OutLiving

We used Oxford Nanopore Technology's MinION sequencer. It's commercially available from ONT. -KJ

Does gravity affect PFGEs?

PHealthy

We have not yet tried it, but if the gel was pre-case, the current should run the same. If you tried to pour a gel in space though, it would certainly be different. -CM

I thought this was about sequencing DNA FROM space :(My hopes for extraterrestrial organisms will have to wait another day

Doctor_Oceanblue

Sadly. It would be really cool, though!

AB

Wonderful work; I had a great time reading your preprint paper. I have a couple of additional questions:

1. What was the nature of the errors in the mouse mitochondrial assembly (i.e. mostly insertions,

deletions, SNPs)?

2. When/where will we be able to see the FAST5 reads from the runs that you did?

gringer

The errors were mostly substitutions and a few deletions. Insertions were relatively fewer. We are in the process of making the FAST5 reads from the all of the ISS and ground runs publicly available on NASA GeneLab (http://genelab.nasa.gov) -CC

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gringer

Indel rates will be posted soon, and the FASTQ /FASTQ5 files are going to be posted in GeneLab. https://genelab-data.ndc.nasa.gov Should be very soon. -CM

I just have to ask, but what part of DNA sequencing requires gravity? even old 404 sequencing didn't really need gravity if you modified some of the liquid containers. None of the cellular machinery requires gravity, it's done in suspension anyways. I see that you used the MinION device, but that still doesn't make any sense, unless there is a space-ban on centrifuges, which there could be, I don't know about space law.

tetramitus

Our primary concern was air bubbles interfering with the flow cells. This ended up not being an issue. AB

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tetramitus

Space law: http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html

Can you now miniaturize the sequencer into a probe for future missions like possibly one to europa? (the jupiter satellite) how much does it currently weigh?

4ananas

The sequencer is already very small (~100g+computer). Next is to miniaturize the sample handling fluidics and the ability to ingest material from rocks, ice, or plumes. The demonstration of performance after the launch environment and the ISS microgravity environment is an important step on the path to Europa, Mars, or Enceladus. -JD

Can you now miniaturize the sequencer into a probe for future missions like possibly one to europa? (the jupiter satellite) how much does it currently weigh?

4ananas

The sequencer is already quite small (3 ¾ x 1 ¼ x 5/8 inches) and less than 120 grams. Its small size is certainly an advantage for putting it on future missions and we hope that sequencers are used on missions to future destinations. - KJ

How will you address the viability of the membrane biyaler in extended space missions? Will you create the membrane in situ? Is it possible to freeze?

europajuice

This is an important next step. Solid state nanopores are one possible solution, particularly for robotic missions. Crewed missions in principle will have conditions that are more favorable for the membrane-based nanopores. AB

Which sequencing platform did you bring to space?

starmapleleaf

Oxford Nanopore Technologies MinION -CM

And thus, man created the xenomorph, and became the architect of his own demise.

Pegasus_Epsilon

Aaaaaahhhhhhhhhhh! What have we done!?!?

AB

Thanks for the AMA and reporting this! This has brought mind a few questions I have, as all of our chemical/bio analysis we've ever used have been designed for Earth.

What other instruments had to be modified in order to be used in space? Aside from needing to strap it down and reduce its weight.

Are there any plans to send an HPLC or LCMS? I imagine traveling near the asteroid belt, capturing samples outside the craft, and attempting to ID proteins floating about on dust expelled from within. (I just got my hands on a mini-MS and already foresee my grandchildren running around Mars, air sampling!)

Asco_mo

There are technology development programs for HPLC and LCMS type technologies in for robotic missions. There is an extensive program to demonstrate that the technology works under orbital conditions (gravity, vibration, shock, safety for other hardware—or crew) and more for planetary exploration (temperature, radiation, pressure). Plus the power and mass must be very low for planetary missions (10s of watts and kg). Like with BSeq, performance must be proved before it can be used as a centerpiece of a mission.

For example here are some instruments under development:
http://www.laboratoryequipment.com/news/2012/11/lcms-flies-space-hunt-amino-acids and
https://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=462829/solicitationId=%7B2665EF4A-83ED-D793-9203-2D1E5FC03740%7D/viewSolicitationDocument=1/PICASSO14%20Abstracts.pdf -
JD

1) The novel environment in which this DNA has been sequenced in is pretty cool, but, what is the biggest difference you are looking to study with DNA sequenced in micro gravity? More specifically, what unique differences do you expect to find in base pairs, or possibly the frequency with which the sample had damage from the radiation from the harsh space environment?

2) I am wildly interested in CRISPR developments and technology. Can any of your data provide insights to further this technologies progress? Any chance there will be furture research done on board the ISS itself?

Thanks!

GrimGrape

We view this project as providing the ability to sequence stuff in space. This will reduce the amount of samples you need to bring down for research, allow you to identify microbes in real-time, and potentially diagnose infectious diseases, look at the ISS microbiome and how it changes, look at gene expression changes...

AB