# The First Fifty Years of Bacterial Growth and Antibiotic Effectiveness Research in Space

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## Abstract

From the USSR's launch of Korabl-Sputnik 2 in 1960 through 2010, numerous studies on bacterial proliferation and antibiotic effectiveness were conducted in space. A literature review of over 400 publications and international databases was conducted to identify which spaceflights carried bacterial experiments along with their respective testing details and findings. Experiments conducted in free-flying satellites, human spacecraft and space stations, and even onboard orbiting rocket stages, were considered. The ultimate objective of this investigation is to map how knowledge has evolved in this field. The compiled data include the bacterial species and strains that have been used as model organisms, protocols and data acquisition methods, results, conclusions, and new hypotheses formulated, as applicable. With few exceptions, the information was acquired directly from original source publications. This analysis also outlines how theories on spaceflight bacterial growth and antibiotic effectiveness have evolved during this half century of space research. These statistical data and discussions will help researchers plan better future experiments and to more readily find applicable references. During the first two decades, the majority of bacterial space research was conducted by Soviet scientists. US research also began in this timeframe and additional international cooperation later allowed other countries to enter this research field, namely France and Germany. Some of the highlights of this analysis show that forty-four different bacterial species have been flown to space during the 171 experiments conducted onboard ~100 missions. Although P. aeruginosa and B. subtilis have been heavily used, E. coli is the species utilized the most as a model organism, and has been flown in over 50 individual experiments.

## Rationale for this Investigation

When I started planning my Ph.D. work in gravitational microbiology, in spite of numerous thorough review papers available, no straightforward, concise answers to the following key questions were found:

## Driving Questions

1. What bacterial species and strains have been used as research models in space?
2. What antibiotics have been assessed in spaceflight and what were the results?

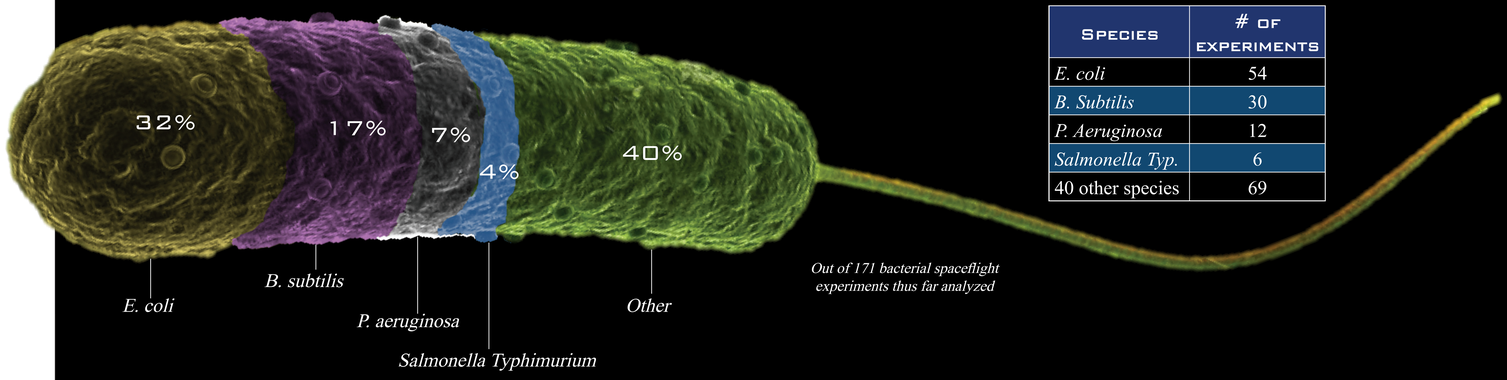
## Methodology

During the last four years, a literature review of over 400 (and counting) publications including journal papers, conference proceedings, book chapters, and space agencies reports, has been conducted. The investigation has also been based on space agencies online databases (e.g. NASA's Life Sciences Data Archive and ESA's Erasmus Experiment Archive) and face-to-face interviews around the U.S. and Germany (six months in DLR). Only published data was used to produce the data plots.

## Objective & Contribution to the Field

The ultimate objective is to map how has knowledge evolved during the first 50 years of gravitational microbiology. This may help future researchers and agencies prioritize goals and develop roadmaps.

## Frequency of Bacterial Model Species used in space experiments




*Out of 171 bacterial spaceflight experiments thus far analyzed*

| Species | # of experiments |
|---|---|
| *E. coli* | 54 |
| *B. Subtilis* | 30 |
| *P. Aeruginosa* | 12 |
| *Salmonella Typ.* | 6 |
| 40 other species | 69 |

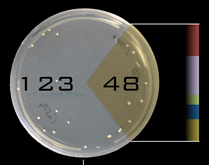
### *E. coli* Strains

| Strain | # of experiments |
|---|---|
| Not reported | 17 |
| K-12 | 10 |
| ATCC® 4157 | 7 |
| 16 others | 20 |

### *B. subt.* Strains

| Strain | # of experiments |
|---|---|
| ATCC® 6051 | 6 |
| 168 | 3 |
| HA101 | 3 |
| 2 others | 2 |
| Not reported | 16 |

## Growth Medium



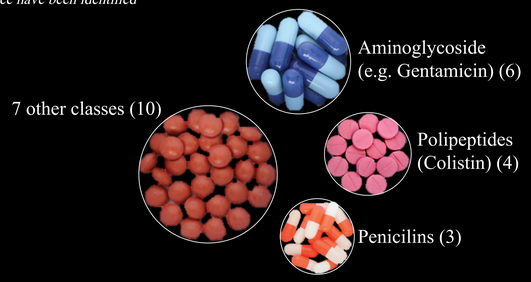

Not reported (13)
9 other media (16)
LB Broth (4)
Medium E (6)
Agar (9)

123 experiments yet to be analyzed

*Value in parenthesis indicates number of experiments*

## Antibiotics Assessed in Space

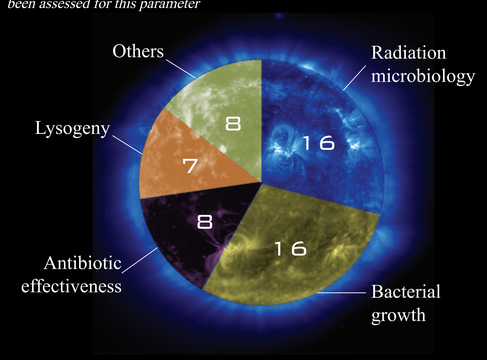
*Thus far 23 antibiotic assessments in space have been identified*



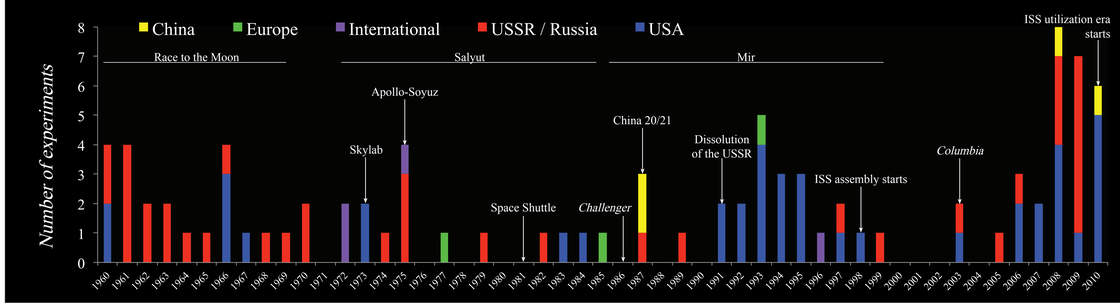

## Investigation Focus

*Thus far only 55 experiments have been assessed for this parameter*

*Value indicates number of experiments*




## Involvement per Country through time




## Other Parameters Currently being Assessed

1. Motility (currently ~50% reported/identified as motile)
2. Experiment duration, temperature, solution volume, etc.
3. Data acquisition methodology
4. Independent and dependent variables
5. Knowledge produced (lessons learned, results, conclusions)
6. Others

## Identified Knowledge Gaps

After years of investigative work, a series of knowledge gaps have been identified:

1. Chinese research besides that of the China 20 and 21 flights (e.g. Shenzou flights, etc.)
2. Experiments that took place in the Salyut and Mir Space Stations
3. Non-US experiments conducted in ISS
4. Microbiological spaceflight experiments conducted by countries other than the U.S., Russia, European states and China (e.g. Japan, India, South Korea, Brazil, etc.)

If you know anything about these knowledge gaps and would be interested in collaborating with this research, please let Luis Zea know at luiszea@gmail.com

## Conclusions

1. The most commonly used bacterial models are E. coli (K-12 and ATCC® 4157) and B. subtilis (ATCC® 6051)
2. At least ten antibiotic classes have been assessed in space. The most commonly used is Colistin
3. During the 1960's most of the spaceflight bacterial research was focused on macrophages and lysogeny
4. Since 2005 there has been a boom in spaceflight bacterial research thanks to the ISS

## Acknowledgements

Thank you to Dr. Gerda Horneck and Dr. Ralf Möller at the German Aerospace Center for the insightful conversations.

## References

From the 400+ publications reviewed, over 100 have been used as references for this investigation. Proper referencing is impractical in this poster and therefore only certain key review papers are cited.

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