ADVANCING ASTROBIOLOGY THROUGH PUBLIC/PRIVATE PARTNERSHIPS: THE FDL MODEL.

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Overview: Addressing fundamental knowledge gaps in astrobiology demands the synergistic analysis of vast amounts of data from diverse scientific domains and sources, including planetary and space missions, ground-based telescopes, field and lab experiments, and theoretical modeling. It also requires to envision countless probabilistic occurrences. Meanwhile as Artificial Intelligence (AI) and Machine Learning (ML) develop exponentially and become mainstream practice across many applied technology and social sciences domains, private companies are eagerly searching for large datasets to develop and test novel data analytics and machine-learning algorithms. This combination of high dataset demand by the public sector, and the complex and multidisciplinary data analysis needs of astrobiology, generates an outstanding potential for the development of powerful public/private partnerships. NASA has already engaged in such a partnership in astronomy and planetary science through the *Frontier Development Lab* (FDL) **[1].** FDL is an AI applied research accelerator, and a public/private partnership between NASA Ames Research Center, the SETI Institute and leading edge technology companies. Initiated two years ago, this highly successful program is an intense 8-week workshop that tackles knowledge gaps in science and technology by pairing machine learning experts from diverse backgrounds, with early career scientists. This interdisciplinary construct has proven highly successful in fostering novel and unique approaches to addressing complex research questions, leveraging advanced AI tools and vast datasets.

1. The Challenge: The questions, goals, and objectives of astrobiology **[2-3],** related instrument development, technology and mission design, require a synergistic view of countless datasets and modeling. As we explore the possibility of life beyond Earth, we paradoxically do not yet have a consensus definition for what life is, or a clear understanding of how it started on our own planet (e.g., abiogenesis, planetary exchange, panspermia) – or where (e.g., land, ocean, minerals) – and how prebiotic chemistry transitioned to biology. We are still struggling to ascertain whether the evidence in some early samples on Earth are of biological or abiotic origin, and we are barely starting to envision concepts for life as we do not know it. Meanwhile, the Kepler data show how potentially diverse coevolutions of life and environments could be on exoplanets.

Bridging knowledge gaps and crossing uncertainly thresholds require simultaneous advancement on multiple scientific fronts **[2-3]** to enable a holistic view on how a planetary environment may shape biological architecture, and conversely how biological processes influence environments **[4-5]**, including for life as we do not know it. Critically, the field of astrobiology extends to all scales, from the elemental bricks of life to the intricate evidence resulting from loops and feedbacks, and external forces that characterize the coevolution of life and its physical environment. Vast amounts of data encompassing, *e.g.,* biology, astronomy, planetary, space, and environmental sciences, need to be brought together, thus creating an obvious opportunity for AI to help us improve understanding and accelerate new discoveries **[6]**, and where a FDL-model based approach to astrobiology can help the field make unprecedented advances.

2. FDL – A New Public/Private Partnership Approach for Astrobiology: Recent advances in unsupervised machine learning and artificial intelligence may help to enable this required "open minded" analysis with minimal assumptions and lower bias.

2.1 The Frontier Development Lab: The FDL program brings together emerging talents in planetary science and machine learning **[1]**. In the past two years, early career scientists have focused their expertise on tightly defined questions. Using new approaches in computer science, such as deep learning and machine vision, interdisciplinary teams were able to analyze large amounts of data with great accuracy and speed. As a result, they were able to rapidly advance their research and investigate different approaches, models, and alternate solutions.

The program and its methodological approach to addressing questions leveraging vast datasets and machine learning tools, is highly successful and increasingly popular in the scientific, tech., and exploration communities. This is reflected in an increased demand for participation. FDL 1.0 ran for 6 weeks in 2016. Three teams of young planetary and data scientists made up of US and international participants worked together to conceive news tools, and new approaches around the Asteroid Grand Challenge. The groups focused on specific projects while interacting with guest speakers and consultants who contributed their expertise. This program provided participants with a meaningful research opportunity, and a chance to support the work of the planetary defense community. Additionally, they matured as scientists, as they developed new research networks, learned news skills, and advanced their appreciation for problem solving using a multidisciplinary approach. FDL 2.0 ran for 8 weeks in the summer of 2017, and included five project teams, each composed of 4-5 interdisciplinary PhD researchers from the planetary and data sciences, and supported by 8 core mentors and 12 part-time subject specialists. Five projects applied AI to unresolved scientific questions in the domains of long-period comets, radar 3D shape modeling, solar-terrestrial interactions, solar storm prediction, and lunar water and volatiles. FDL provides participants with access to end users who might benefit from the research, to help guide the problem statements. This, in turn, offers the prospect of making the research immediately applicable and beneficial to real-world needs.

2.2. Public/Private Partnership: As a public/private partnership between NASA Ames Research Center and the SETI Institute, FDL greatly benefits from the involvement of core project partners, who in 2017, provided an array of support services, from funding to technology and expertise. For instance, IBM and Intel provided dedicated sandboxed hosting of relevant datasets and massive cloud-based compute resources. These included state-of-the-art kits to enable quick turnaround of experiments (*e.g.,* < 1 hour for the Imagenet Benchmark – 10 million images). The teams also had the ability to run small experiments using Nvidia's latest TX2 embedded GPU. IBM and Intel provided proprietary software libraries, accounts, and analytical resources – in addition to Nvidia's free libraries. Miso Technologies gave access to their AI driven reports and papers scanning services, and Space Resources LU (Grand Duchy of Luxembourg) provided capital to fully support one team. Our partners also provided training and machine learning "101s" including guidance on use of their respective software/hardware/cloud resources, and expert guests from both AI research problem domains. Prior to start of the research phase at the SETI Institute, FDL teams spent their first week at Nvidia for an intensive AI boot camp. Teams had access to the Autodesk *Techshop* for prototyping and making +Entire Software Suite, to the Autodesk *Gallery* for the Big Think event, and to NASA Ames special events and presentations.

2.3. Approaches for Astrobiology: The current FDL model is centered around the specific interests of NASA programs on science, technology, and system priorities and needs in astronomy and planetary sciences. Interdisciplinary teams are selected following a two-step application and review process [7]. FDL is currently organized as a summer workshop, but is highly flexible in its structure and can be applied to astrobiology in ways that are best adapted to various programs, including:

- *A summer workshop* supported by the NASA Astrobiology program that would keep its existing structure and would add to the breadth of NASA disciplines already contributing to FDL, providing a unique training ground to early career scientists.
- *A training program for early career or career-interruption scientists* or Postdoctoral researchers, as part of the NASA Astrobiology Institute mandate.
- *A new core program* in the NASA Astrobiology portfolio, along with Exobiology, PSTARR, MATISSE, and PICASSO.
- *Astrobiology/AI Hackathons* to engage high school and college students in competitive research programs, leveraging AI to advance astrobiology research
- *A relevant approach* to solving science, technology, and system questions in relevant NASA Astrobiology calls for proposals, including the NASA Astrobiology Institute.

3. Benefits of the FDL Model for Astrobiology: The benefits of such a model for astrobiology will be multifold and immediate, as shown by the success of FDL. It will help:

(a) ***Fulfill astrobiology basic principles*** [2-3]. We also expect that growing public awareness and interest in astrobiology and AI can give rise to strong popular support for this type of public/private partnership;

(b) ***Take quantum leaps*** in our understanding of life in the universe by augmenting funding through private partnerships and allowing rapid progress in the various domains of astrobiology. The FDL model is results-driven. One of its great strengths– as proven by results over the 2-year history of the program – is to engage teams of AI specialists and scientists on highly focused science/technology/system questions for short periods of time, and within weeks, to produce meaningful results and deliverables, including the development of new exploration methods, instruments, and systems.

(c) ***Identify, through the application of AI, new fields of enquiry*** by analyzing data in ways and at speeds that cannot be achieved by conventional computational means, and ***speed up new discoveries*** [8].

References:

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