TACKLING THE GREAT SCIENCE QUESTIONS OF OUR TIME

II

CHAMELEON SCHOOL

CHAMELEON ITN

CHAMELEON is a Marie Curie Innovative Training Network for European Joint Doctorates. The network is developing a virtual laboratory to research exoplanets and protoplanetary disks that will play a key role in simulating yet unexplored physico-chemical environments. CHAMELEON aims to retrieve and predict chemical compositions of planet-forming disks and exoplanet atmospheres, transfer knowledge, codes and models between planet and disk communities, and share state-of-the-art scientific concepts with the wider community.

CHAMELEON is made up of 15 early stage researchers (ESRs) and a supervisory board. There are both single discipline ESRs (astronomy) and interdisciplinary ESRS (astronomy + social sciences). The single-discipline ESRs are using models and simulations to learn more about exoplanets and protoplanetary disks. The interdisciplinary ESRs are exploring the intersections that scientific topics from the network have with both the arts and education.

WINTERSCHOOL II

The CHAMELEON network holds bi-annual network schools. The second CHAMELEON school was held in January of 2022 and focused on putting the research that the network is conducting into the context of the big science questions of our time. For this, discussions were had about the science questions that are driving instrument development and future observational facilities and the processes and difficulties that accompany these developments.

The final project of the school consisted of the development of proposals for future space missions that would answer some of the big science questions of our time. These proposed missions were pitched to a panel of supervisors who provided feedback and assessed the value, feasibility and innovativeness of the missions. To develop the missions the ESRs were divided into four teams, with the exception of the multidisciplinary ESRs who acted as consultants. The consultations included helping with presenting and pitching the ideas to a general audience and helping to determine what these missions could bring to both the scientific community and society as a whole.

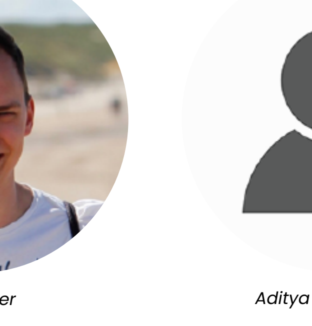
PROJECTS

PINEAPPLES | ALONE | PlaDiPro | SLOTH

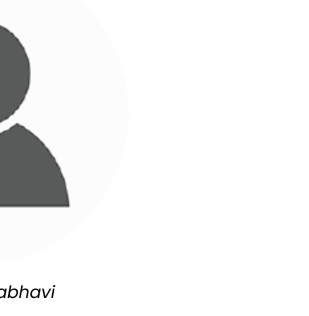
PlaDiPro: Circumplanetary Disk Probe

The first steps towards answering the open question of how planets form

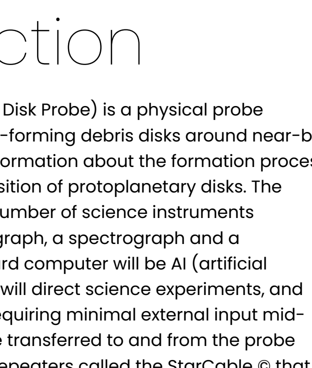
Areli Castrejon



Jayatee Kanwar



Thorsten Balduin



Till Käufer

Aditya M. Arabhavi

Introduction

PlaDiPro (Circumplanetary Disk Probe) is a physical probe designed to explore planet-forming debris disks around near-by stars in order to provide information about the formation process of planets, and the composition of protoplanetary disks. The probe itself will contain a number of science instruments including a gas chromatograph, a spectrograph and a magnetometer. The onboard computer will be AI (artificial intelligence) based. The AI will direct science experiments, and navigate the probe, thus requiring minimal external input mid-mission. Information will be transferred to and from the probe through a series of signal repeaters called the StarCable © that cover the distance from earth to the probe. The data that could be received from PlaDiPro will give a unique insight into the evolution process of planetary systems, and may help to answer questions about our own solar system.

Scientific Background

How are planets formed?

How planets are formed is currently one of the big open questions in planetary science. There are two leading scenarios that scientists believe may be how planets form: the accretion model and the gas-collapse model. In the accretion model, there is a large disk made of dust and gas that orbits a central star. The dust grains collide and form together to make up small lumps called planetesimals. These planetesimals grow over time as they collide and more dust accretes onto them, until they are large enough to become planets. The gas-collapse model also begins with a disk around a star made of gas and dust, however in this model the planets form when there are gravitational instabilities in a clump of gas and it collapses in and becomes a self-gravitating planet. As this planet orbits the central star, it sweeps out a path as it continues to feed on gas from the disk.

Artist impression of the probe in a stellar disk

The PlaDiPro probe is positioned within a stellar disk. The signal is transmitted from the probe and then sustained by the chain of repeaters that make up the Star Cable

Why study debris disks?

Regardless of which planet forming scenario is correct, it is widely agreed that planets form in disks of gas and dust around stars, therefore the composition and dynamics of the disk will dictate what kinds of planets will form around that star and how they will evolve. Once we learn more about disks, it could help us to understand more general rules about how planets form and evolve, and may help to give insight as to how our solar system came to be the way it is today.

The features within debris disks can act as indicators that there are planets within the disk, for example Jupiter determines the location of the Asteroid belt, and Neptune dictates the inner edge of the Kuiper belt, by looking for similar features within debris disks around other stars it could be possible to find 'signposts' for planets within those disks.

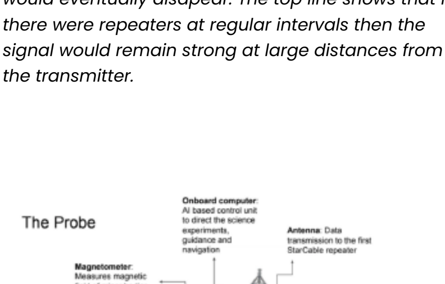
PlaDiPro

Goals

Currently, our data on circumplanetary disks is limited as we can only view them from very far away and we can only observe them from the angle at which we see them from earth. PlaDiPro (the Circumplanetary Disk Probe) plans to negate both of these issues by sending a physical probe into a nearby debris disk in order to get a 'hands-on' analysis of the composition and dynamics within the disks.

The structures within debris disks can be examined in order to determine the composition of both small and large bodies that are not observable by telescopes, and by observing both the disk and planets within it comparisons can be made between atmospheric composition and dust composition.

PlaDiPro will focus on nearby disks as the distance dictates the time before we get the first data. The time to get the first data will take at least the flight time for the probe plus the transmission time of the data. With optimistic calculations, it will take approximately 60 years between launch of the probe and receiving the first data.



Signal as a function of distance from the transmitter

This figure represents the drop off of signal as a function of distance from the transmitter. The lower line shows that without any amplification the signal would eventually disapear. The top line shows that if there were repeaters at regular intervals then the signal would remain strong at large distances from the transmitter.

Technical Details

The probe will be propelled by Ion thrust engines. These will be used to power the probe, navigate it and also slow the probe down once it reaches its target. The ion thrust engines will be powered by RTG (Radioisotope Thermoelectric Generators), and the development of these engines will have a significant benefit to technological advances in humanity.

The navigation, acceleration and deceleration of the probe will be monitored and adjusted as needed by the onboard AI. The probe will be propelled by Ion thrust engines, these will be used to power the probe, steer it and slow the probe down once it reaches its target. The ion thrust engines will be powered by RTG (Radioisotope Thermoelectric Generators).

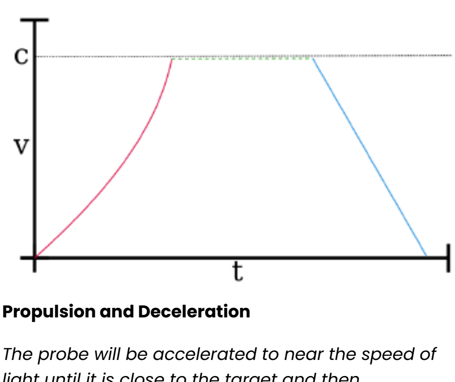


Diagram of the probe

Once the probe is in position, information will be passed to and from the probe using a series of signal repeaters making up the StarCable ©. There will be enough repeaters in this chain that there is redundancy in case any are damaged, and while data is not being sent along the StarCable © test signals will be sent back and forward to monitor the connection.

Propulsion and Deceleration

The probe will be accelerated to near the speed of light until it is close to the target and then decelerated towards the target.

The probe will have a number of scientific instruments on board in order to learn as much as possible about the disks and planets that the probe travels to. The science experiments will be directed by the onboard AI computer that will learn more as the experiments are conducted, so as to improve upon further experiments.

The science instruments onboard will be:

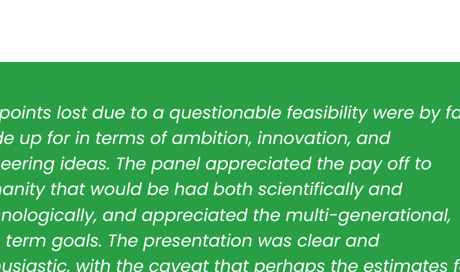
1. A magnetometer to measure the magnetic field of the star, the planets and any other orbiting bodies. This will help to determine how the dust in the disk interacts with the magnetic field, and can give insight into the interior of any planets as planets must have a liquid rotating core to have a magnetic field.
2. A dust analyser to collect high resolution data of the dust. Dust is a key building block in any planetary system, so learning more about their composition and dynamics will help us to understand the evolution of the system
3. A spectrograph to find out the chemical compositions of the dust, gas and planetary atmospheres
4. A gas chromatograph to help us understand the properties and physical processes of the gas in the system. This may also help us to understand the delivery of ingredients for life (such as water and prebiotic molecules) to planets.

Scientific & Societal Output

PlaDiPro is expected to have a significant impact on scientific advances in the field of planet formation. A detailed, up-close study of multiple stellar systems and their debris disks will help to provide a robust understanding of how planetary systems evolve. The instruments onboard will allow for scientific experiments that will give us a better understanding of how protoplanetary disks evolve and how planets form within them. This mission may also help to give an indication of what properties are needed in a stellar system for there to be the possibility for life.

Predicted PlaDiPro timeline

In addition to this, the technology that will be resultant from this mission will help to advance both earth based technology and in the space industry. This will come in the form of propulsion technology, AI advancements, energy efficiency and signal transmission.



Estimated Costs

In addition to the technological and scientific outcomes of the mission, there will also be an impact on society. PlaDiPro will be a proof of concept that will enable further space missions. Protoplanetary disks are younger than debris disks and will be an exciting target for further research. However, these objects are further away from earth which makes multigenerational missions necessary. These missions will provide fascinating information for decades and beyond. By helping us better understand how planets form, and how the chemistry and dynamics of a disk impact the planets that form within it, it may help us to better understand the history of our own solar system.

"Inspiration to dream big"

"Crazy, multi-generational mission that was fun to hear about. I loved it!"

"Technology payoff to society"

The points lost due to a questionable feasibility were by far made up for in terms of ambition, innovation, and pioneering ideas. The panel appreciated the pay off to humanity that would be had both scientifically and technologically, and appreciated the multi-generational, long term goals. The presentation was clear and enthusiastic, with the caveat that perhaps the estimates for time frame and finance estimates were also perhaps too optimistic.

This project is funded by the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant No 860470.

Multidisciplinary ESRS:
Oriel Marshall & Pieter Steyaert

Main organizer of the Chameleon Winter School (Chameleon School II):
Michiel Min