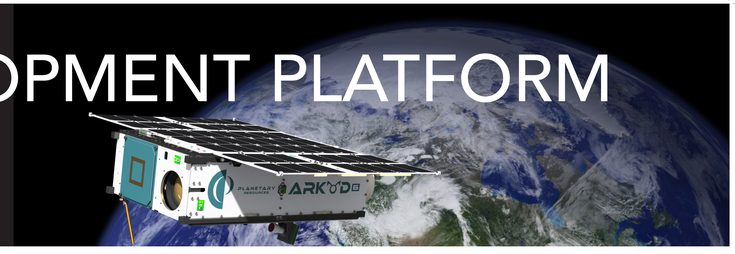
THE ARKYD SPACECRAFT DEVELOPMENT PLATFORM

Hannah Goldberg,
Planetary Resources
hannah@planetaryresources.com

Chris Voorhees,
Planetary Resources
voorhc@planetaryresources.com

Planetary Resources
6742 185th Ave NE,
Redmond, WA 98052



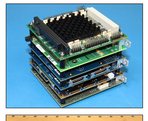
PLANETARY RESOURCES USES EARTH ORBIT AS A TESTBED FOR ITS DEVELOPMENT OF DEEP SPACE ROBOTIC PROSPECTORS

Planetary Resources, the asteroid mining company, is developing a series of deep space robotic explorers named "Arkyd". These spacecraft will explore the inner solar system, prospecting near-Earth asteroids to identify and characterize their potential for in-space resources. To enable the commercial viability of such missions, new low-cost, robust, and efficient systems are required.

Planetary Resources has designed such a spacecraft platform that can be rapidly iterated to accommodate science and technology platforms as payloads and instruments both for internal risk-reduction needs and utilization by external customers. A capable spacecraft bus architecture and subsystem components have been designed and developed utilizing a CubeSat form-factor to enable rapid demonstration of new technologies in Earth orbit.

The Arkyd series spacecraft began with a 3U demonstration, the Arkyd-3, in low-Earth orbit and has presently evolved to a 6U, Arkyd-6, scheduled for launch at the end of 2015. The Arkyd-100 and Arkyd-200 spacecraft, currently in design, continue the evolution of spacecraft development and maturation, building the platform to a full scientific remote sensing system capable of leaving orbit and exploring deep space.

CORE CAPABILITIES OF ARKYD SUBSYSTEMS

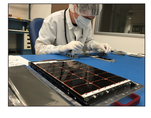


AVIONICS

- The Arkyd avionics is a multi-tiered computational structure to maximize efficiency of resources.
- The architecture was designed internally for reliable deep-space capability from the beginning of its development
- The avionics is core to the demonstration of Arkyd spacecraft and is designed to continually evolve and mature with each spacecraft
- Modular topologies allows for easy integration and testing on the ground as well as multi-mission rapid reconfiguration.

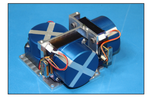
COMM

- UHF, S, and X band communications used for Earth orbit testing and operations
- Free space optical communications used for deep space data return



POWER

- Scalable and reliable power systems, designed for deep space operation
- In-house development of battery assemblies, solar arrays, and power management electronics

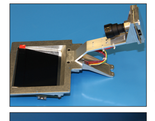


ATTITUDE DETERMINATION AND CONTROL (ADCS)

Two-tiered ADCS architecture uses:

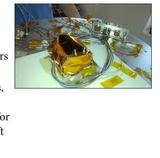
- Magnetorquers and sun sensors for coarse pointing
- Reaction wheels and dual star trackers for fine tracking

In house development of ADCS sensors, actuators, and algorithms enables a cost-effective and repeatable solution for the Arkyd platform across all spacecraft systems.



INSTRUMENT

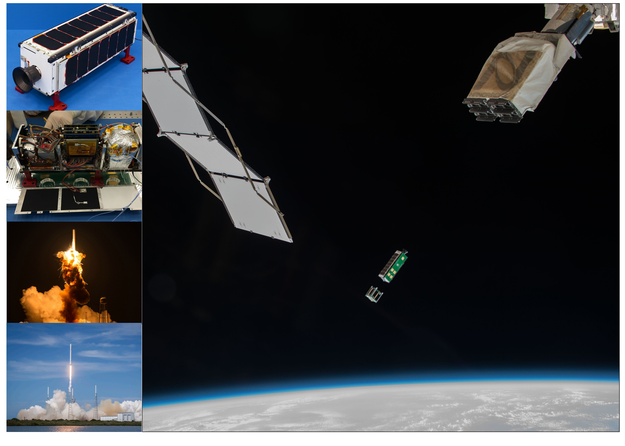
- The Arkyd platform is designed to provide a simple, generic interface to a variety of hosted payload instruments
- Planetary Resources is using this capability to develop, demonstrate, and utilize its MWIR and VNIR instruments in Earth orbit



THERMAL

Modular nature of avionics allows for scalable thermal control of the spacecraft. Thermal design, simulation, and test are all completed in-house. Thermal coatings and blanket implementations are also done internally.

DEMONSTRATIONS IN SPACE



DESIGN AND SPECIFICATIONS

PRECURSOR – TECHNOLOGY DEMONSTRATOR ARKYD-3

The CubeSat form-factor is an ideal platform for technology demonstration. The standardization of access to space helps provide a somewhat regular cadence, especially for orbit-agnostic mission needs. The Arkyd-3 spacecraft was developed as Planetary Resources' first flight mission of the largely in-house developed Arkyd series spacecraft technologies. The major focus of demonstration was on core spacecraft functions:

- Distributed avionics
- Robust flight and ground software
- Power systems
- Attitude determination and control hardware and software

More than 85% of the spacecraft was created in-house in Planetary Resources' facility in Redmond, WA.

The Arkyd-3 Cubesat was delivered and integrated into the Nanoracks NRCSD to be deployed into low-Earth orbit from the International Space Station. Unfortunately, the Arkyd-3 spacecraft was lost during the Orbital Antares launch failure on October 28, 2014.

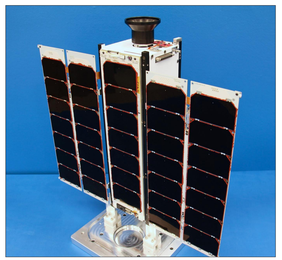
ARKYD-3 REFLIGHT

One month after the loss of the Arkyd-3 spacecraft due to a launch failure, Planetary Resources was given a second opportunity to fly the lost hardware. In less than three months, a second build-to-print spacecraft was manufactured, integrated, and tested, and once again integrated into the Nanoracks NRCSD deployer. The Arkyd-3 Reflight ("A3R") spacecraft was successfully delivered to the International Space Station via the SpaceX CRS-6 cargo mission on April 14, 2015.

On July 16, 2015, the Arkyd-3 Reflight spacecraft was deployed from the ISS, starting the first on-orbit operations of an Arkyd Spacecraft.

ARKYD OPERATIONS

Planetary Resources operates the Arkyd spacecraft from a ground station located at its facility in Redmond, WA.



ARKYD-3 SPECIFICATIONS

Spacecraft Mass	<5 kg
Volume	3U CubeSat form factor
Power	~30W
Comm	115 kbps S-band communications

ADDING CAPABILITY, ITERATION AND DEVELOPMENT OF CORE TECHNOLOGY DEMONSTRATIONS ARKYD-6

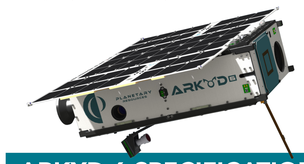
The Arkyd-6 provides the next evolutionary step in the development of the Arkyd platform. It iterates on the initial Arkyd-3 pathfinder and enables state-of-the-art spacecraft vehicle performance while enabling the accommodation of hosted experimental payloads and instruments.

The Arkyd-6 builds on the capabilities of the Arkyd-3 by taking advantage of the added mass and volume for additional payload and instrument accommodation. The Arkyd-6 spacecraft demonstrates core internal system elements developed in-house, including avionics, flight software, restraint and deployment devices, star trackers, reaction wheels, power generation, power management, and energy storage elements.

The first demonstration of the Arkyd-6 also includes the first flight of the company's MWIR imaging instrument. Representing the core functionality necessary for critical remote sensing measurements at a near-Earth asteroid, its flight accommodation on Arkyd-6 will help retire risk of the instrument performance in the harsh space environment as well as resolve system issues related to instrument accommodation and operation.

While the first Arkyd-6 spacecraft tests its own MWIR instrument, the system incorporates a generic instrument interface definition, such that any potential customer or payload/instrument provider can take advantage of the Arkyd-6 spacecraft bus as a capable space platform for operations.

The first on-orbit demonstration of the Arkyd-6 spacecraft is current planned for the end of 2015, with additional flight demonstrations following at a regular cadence.



ARKYD-6 SPECIFICATIONS

Spacecraft Mass	10 kg
Volume	6U CubeSat form factor
Power	35W deployable array
Comm	UHF TT&C @ 40 kbps S-band uplink @ 500 kbps X-band downlink @ 6 Mbps
Instrument	Generic instrument interface for easy accommodation MWIR, 3-5um, 26m GSD

LOOKING AHEAD

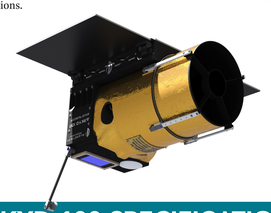
ARKYD-100 – CAPABLE EARTH-ORBIT SCIENCECRAFT / DEEP SPACE PATHFINDER

The Arkyd 100 utilizes a larger optical aperture to facilitate the suite of scientific instruments necessary for asteroid identification, remote sensing, and classification. The system services two different sensor elements on its shared aperture:

- MWIR imager: based on heritage from the Arkyd-6 configuration, operating across 3-5um
- Visible-NIR Hyperspectral imager: 40 spectral channels across 400-900 nm

Built to be compatible with the 12U form-factor, the Arkyd-100 is both a deep-space pathfinder vehicle and a capable scientific Earth observing platform.

Additionally, the Arkyd 100 spacecraft bus will include small propulsion technology demonstrations, but will remain in Earth orbit for operations.



ARKYD-100 SPECIFICATIONS

Spacecraft Mass	20 kg
Volume	12U Cubesat compliant
Power	90W articulated array
Comm	UHF TT&C @ 40 kbps S-band uplink @ up to 2 Mbps X-band downlink @ up to 40 Mbps
Instrument	VNIR Hyperspectral, 400-900nm, 40 spectral channels, 10m GSD MWIR, 3-5um, 20m GSD

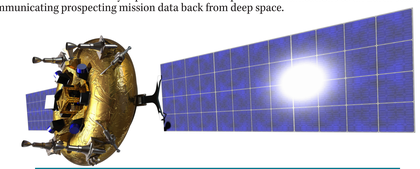
ARKYD-200 – ARKYD INTERPLANETARY SPACECRAFT, THE PROSPECTORS

The Arkyd 200 will be the first Arkyd spacecraft to escape the confines of Earth-orbit. The bus is designed to be capable of exploring the Moon, Mars, Asteroids, and other targets of interest within Earth orbit and the inner solar system. The spacecraft is ESPA-class in size as to take advantage of commercial rideshare launch opportunities. The Arkyd 200 mission design begins in LEO as to not require any custom maneuvers from the launch vehicle, using its own propulsion and guidance to navigate to the mission target.

The spacecraft can be deployed in pairs or swarms, using redundancy to increase the chances of mission success, while also providing coordinated operations.

The Arkyd 200 is the first spacecraft in the Arkyd series to demonstrate high delta-V propulsion. The propulsion functionality is integrated directly into the spacecraft, combining the propulsion module geometries and spacecraft primary structure into a single element. This technology is enabled by revolutions in additive manufacturing, reducing assembly and test complexity while enabling innovate new design solutions.

The Arkyd 200 will also be the first Arkyd spacecraft to utilize optical communications to an Earth station, the system's primary means of communicating prospecting mission data back from deep space.



ARKYD-200 SPECIFICATIONS

Spacecraft Mass	250 kg wet
Payload Mass	10 kg
Volume	95 x 80 cm (ESPA compatible)
Power	>100W (1 AU)
Comm	Optical: up to 2 Mbps from Mars
Instrument	VNIR Hyperspectral, MWIR
Propulsion	5 km/s delta-V w/green prop