GRASP-AirPhoton Multi-Angle Polarimeters (GAPMAP): Calibrated high information content measurements for atmospheric and surface products from a commercial constellation of cubesats.

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1 ABSTRACT

This work presents a project to launch a commercial constellation of GRASP-AirPhoton Multi-Angle Polarimeter (GAPMAP) instruments. The instruments are inspired by the HyperAngle Rainbow Polarimeter (HARP) that has been orbiting Earth in a 3U cubesat making calibrated measurements of sufficient quality for the true scientific usage. The GAPMAP instruments will measure atmospheric radiation at multiple wavelengths, multiple angles and in multiple polarization states at each pixel all over the Earth. This wealth of data allows for detailed characterization of aerosol, cloud and surface properties. The first instrument, GAPMAP-0, will be the vanguard of a proposed constellation of small satellites with payloads designed to provide commercial products of high quality. This in-orbit demonstration sensor will fly aboard the Spire Adler-2 6U cubesat to be launched at the end of 2022 and is funded by Findus Venture. The commercial venture will offer a range of data products, going well beyond simple imagery, to include retrieved Level 2 aerosol and surface characterization using the Generalized Retrieval of Aerosol and Surface Properties (GRASP) retrieval algorithm. In addition, GRASP SAS aims for retrieval of sources of emissions and atmospheric dynamics using chemical transport inverse modeling at global, regional and local scales. Targeted customers will include air quality, agricultural communities and other customers needing surface products and atmospheric characterization that can be obtained economically from a constellation of small satellites.

2 INTRODUCTION

Recent improvements in technology have facilitated the development of relatively inexpensive cubesats and led to a rapid expansion of space exploration. Many companies are emerging in the sector called "NewSpace" to bring new solutions to society. This paper introduces the new space missions from the partnership between GRASP SAS and Airphoton LLC: GAPMAP that will be the first commercial constellation of Multi-Angle Polarimeters devoted to advanced atmospheric and surface characterization.

Polarimetry is one of the most promising types of remote sensing observations for improved characterization of atmospheric aerosol [1]. Due to the temporal and spatial variability of aerosols and the difficulty in properly describing atmospheric particle composition, quantifying their effects on climate and the environment is very challenging. Aerosol effects are still considered to be among the most uncertain factors in understanding global climate change [2]. In this regard, observations that measure both the angular distribution of the scattered atmospheric radiation as well as its polarization state at multiple wavelengths covering the UV–SWIR spectral range carry substantial implicit information on the atmospheric composition. Reference [1] is a good review of polarimetric missions past and already planned for the next few years.

3 MISSION DESCRIPTION

3.1 The payload: GAPMAP

GAPMAP is a commercial multi-angle polarimeter designed specifically to be on board a cubesat spacecraft. The instrument inherits the experience of the HARP mission [3]. The Hyper-Angular Rainbow Polarimeter (HARP) is a wide field-of-view imaging polarimeter instrument of 1.5U optimized for a 3U CubeSat spacecraft. The HARP CubeSat mission is a NASA/ESTO InVest project designed for accurate and comprehensive measurements of aerosol and cloud properties from space. It has demonstrated the capabilities of the cubesat technology to deliver science-quality multi angle imaging data [4]. HARP was named the best cubesat mission of the year (2020) by American Institute of Aeronautics and Astronautics. The more advanced HARP2 will be delivered to NASA's Plankton, Aerosols, Clouds, ocean Ecosystem (PACE) mission later this year. Finally, the HARP CubeSat was replicated into AirHARP, an airborne demonstration of HARP technology, for use on NASA aircraft campaigns.

The GRASP Airphoton MultiAngle Polarimeter (GAPMAP) payload is a wide Field of View (FOV) imaging polarimeter that measures each Earth scene at multiple along track angles spanning ±55º and in four wavelengths in the 440 nm to 870 nm range. GAPMAP is a simplified commercialized descendant of the HARP family of multi-angle imaging polarimeters. GAPMAP has been designed to provide scientifically-valid calibrated polarized reflectances with on-ground processing to transform the measured reflectances into marketable products for *climate research and service*, air quality and environmental monitoring. The final GAPMAP program goal is a constellation of commercial MAP payloads in LEO coupled seamlessly with state-of-the-art data processing and retrieval algorithms to produce commercial products for different agencies and public and private organizations.

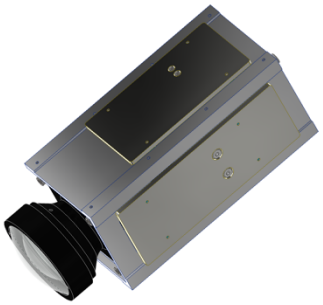

Figure 1. Illustration of GAPMAP instrument

Table 1 shows a detailed description of the characteristics of GAPMAP and HARP. One of the challenges for this kind of missions is the data downloading capabilities of the smallsats compared with its ability to get information. The GAPMAP constellation is intended to provide global data which is a challenge for these small satellites with limited power consumption and data transferring capabilities. There are several mitigation plans to achieve this goal, for example, using advanced on-board preprocessing or different configurations over different areas (e.g. global coverage at 8km while overall targets could be measured at 2km, ground targets at different number of angles, etc).

	HARP payload	GAPMAP payload (HIP)
Wavelengths	450, 550, 670, 870nm	450, 550, 670, 870nm
Calibration	Vicarious calibration with ground targets, satellite comparisons, and moon	Internal calibration diffuser; Vicarious calibration with ground targets, satellite comparisons, and moon
Nadir pixel resolution	400m @400km orbit	0.58 km @650km orbit
Nadir Binned resolution	16to 3.2 km	232km
Crosstrack Swath	94deg (892km@400km orbit)	77 deg (1070km @650km orbit)
Along track swath	114 deg	105.2 deg
Angular sampling	Hyperangular (10 to 60 angles along track)	Hyperangular (10 to 100 angles along track)
Wavelength selection	Stripe filters	Stripe filters
Polarization separation	Division of Aperture with Philips Prism	Division of focal plane with patterned focal plane array
Focal plane	3CCD sensors	1 CMOS sensor
Communication	UHF	X-band
Data volume goal	<1Gbit/day	1to 33 Gbytes/day
Payload Volume	1.5to 2U depending on configuration	15 to 2U depending on configuration

Table 1. Detailed GAPMAP characteristics compared to HARP

3.2 First demonstration in ADLER-2 mission

The ADLER mission [5] is a private initiative of Findus Ventures GmbH with the goal of boosting commercial spatial activities. ADLER-1 is devoted to space debris monitoring activity carrying a combination of the two complementary micro debris detection systems in orbit: radar-based detection of debris particles that pass in the proximity of the spacecraft and determine their relative velocity and measure the impact energy of the particles with a deployable piezoelectric array. ADLER-1 is operated by SPIRE and it was launched on 13 Jan 2022 by Virgin Orbit.

ADLER-2 mission will be the follow up mission. Planned to be launched in Q4 of 2022, it adds on top of the instruments already flying on ADLER-1 the GAPMAP-0 as an in-orbit demonstrator instrument [6]. GAPMAP-0 will have the characteristics described in section 3.1 except the on-board calibration which will be added to the rest of the instruments.

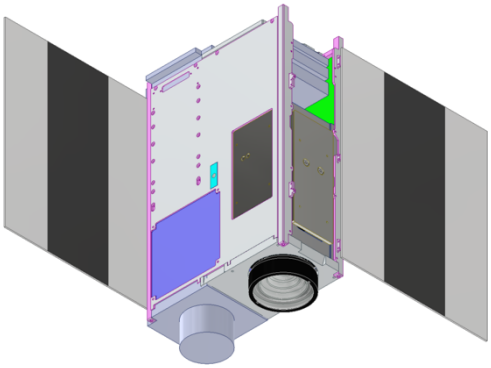

Figure 2: Illustration of GAPMAP carried by the ADLER-2 spacecraft.

3.2 Data processing using GRASP

Generalized Retrieval of Aerosol and Surface Properties (GRASP) is one of recent state-of-the-art algorithms developed with the objective of achieving complete and accurate characterization of aerosol and surface properties. It is a new-generation algorithm developed for deriving extensive aerosol properties from MAP observations. The overall concept of the algorithm is described by Dubovik et al. [7], while specific aspects are detailed in [8]. An open-source GRASP-OPEN software version and documentation are available from https://www.grasp-open.com.

The algorithm is based on highly advanced statistically optimized fitting implemented as multi-term least square minimization [9] that had earlier been successfully implemented (e.g., see Refs. [10], [11], [12]) for aerosol retrievals from ground-based AERONET radiometers. Satellite GRASP retrieval shares its methodology with AERONET retrievals while the concept is now more flexible, includes several original features, and enables the implementation of advanced retrieval scenarios like the combined retrieval of atmosphere and surface properties or the multipixel approach [13].

GRASP is being adapted to process the observations provided by various satellite instruments, ground-based networks, single instruments and for various synergetic data sets that combine coordinated passive and active remote sensing observations. As it can be seen in the figure 3, the code has been already tested for many different applications and it has been selected as an operational algorithm for Level 2 products in several major future missions including Sentinel-4, 3MI/EPS-SG and MAP/CO2M.

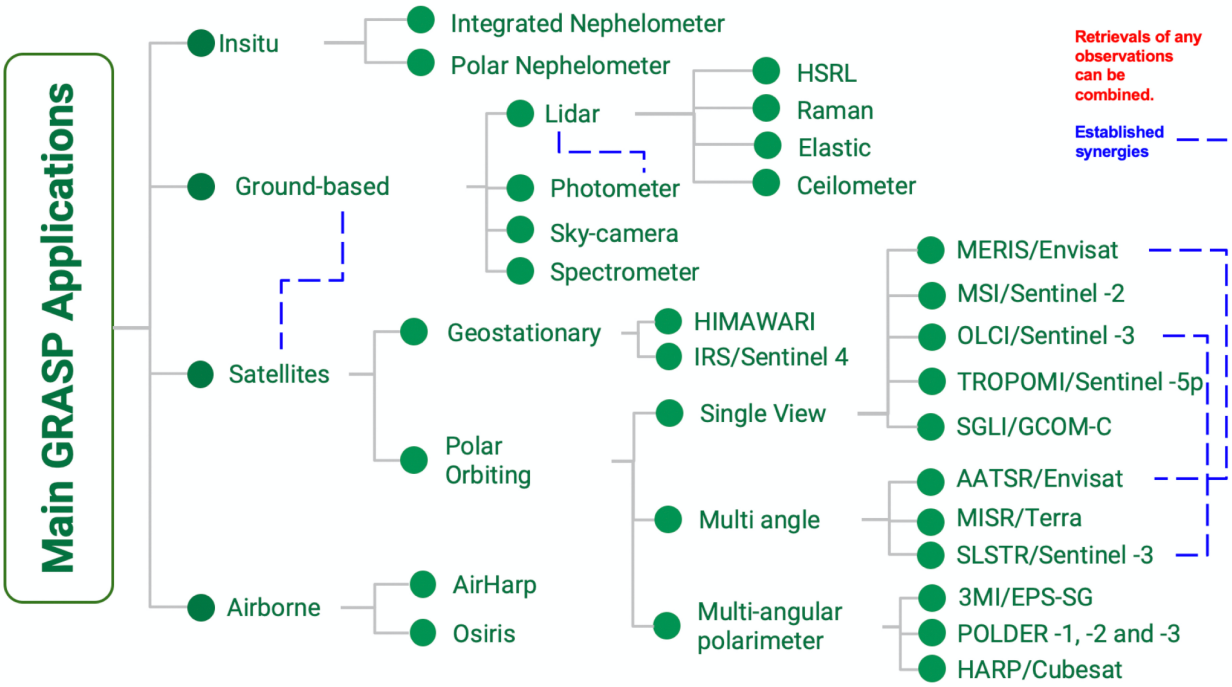

Figure 3. The diagram illustrates the current application of GRASP code from [8].

GRASP is the inversion algorithm that will be used by GAPMAP for producing Level-2 data products. As can be seen in [8] there is a large list of products that can be retrieved from atmosphere like aerosol optical depth, single scattering albedo and advanced particulate matter product for air quality applications, to Bidirectional Reflectance Distribution Function (BRDF) and Bidirectional Polarization Distribution Function (BPDF) surface product. GRASP has been already successfully applied to AirHARP as can be seen in the Illustration 4 from [14].

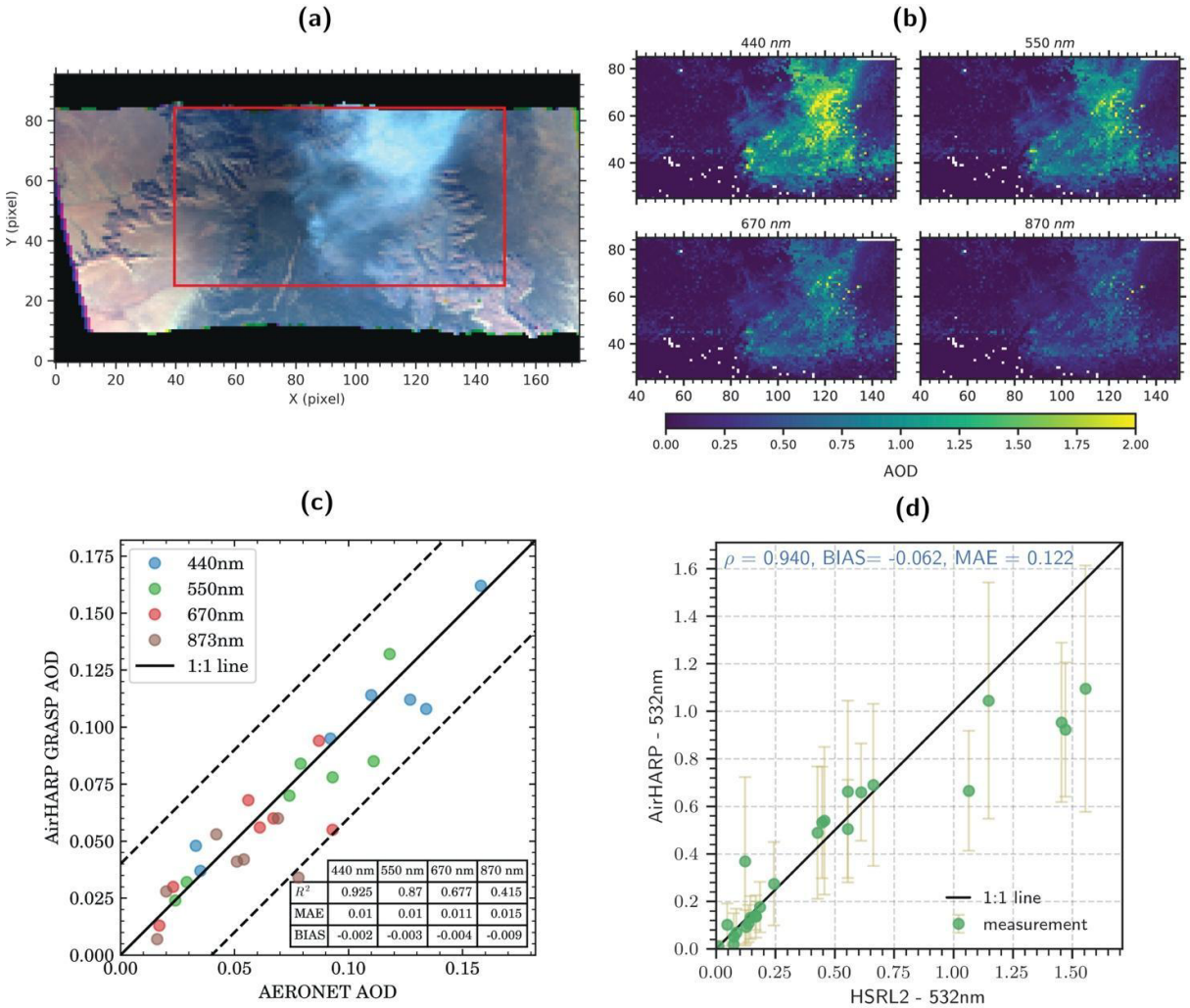

Figure 4. AirHarp/GRASP results during the field campaing ACEPOL 2017 from [4]: (A) RGB of a wildfire event measured the 27th of October 2017 at 18:16 UTC; (B) A map of the AOD obtained from the GRASP retrieval of the red square highlighted in A at the different wavelengths; (C) Comparison of the retrieved AOD from AirHARP-GRASP and the co-located AERONET data; (D) Correlation plot for the HSRL2 AOD at 532 nm vs. AirHARP AOD at 532 nm for the same flight.

4 CONCLUSIONS AND PERSPECTIVES

While MAP observations have proven to be one of the most advanced measurements from space for monitoring air pollution, these measurements are still uncommon. Several missions have flown in the past, PARASOL/POLDER being one of the most relevant, and large space agencies plan to deploy this kind of instrument in upcoming missions. However, for the next several years there is an opportunity for the private sector to fulfill the need for these measurements.

The GAPMAP is the first commercial initiative to deploy a constellation of multi-angle polarimeters. GAPMAP-0, the first demonstrator, will be launched by SPIRE by the end of 2022 as part of the ADLER-2 mission. The payload has a size of 1.7U, it measures radiances and polarization at 4 wavelengths in the range of 440 nm to 870 nm at different angles (the number is configurable) with a ground resolution around 2km per pixel. The data collected from these instruments will be processed using the GRASP algorithm to derive advanced atmosphere and surface products. This data has many applications of the interest of both private and public sectors which can benefit from its use. First targeted applications are an air quality product for policy makers at the federal, state and local levels and industries required to monitor their pollutants. GAPMAP data can also serve as an atmospheric

correction service for any other high resolution satellite constellation. It is expected that GAPMAP will provide for the short-term needs for MAP data and in the long term improve the revisit time which is crucial for air quality and other Earth monitoring applications.

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