WWASP Final Mission Report
HASP Flight 2021 - Payload 10

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Abstract

Project WWASP's (sub-millimeter Water WAve SPectrometer) objective is to answer the question: Is the transparency of the Earth's atmosphere near the frequency of the 557 GHz rotational ground state line of water vapor sufficient for researchers in the future to launch a stratospheric balloon mission to detect water in a protoplanetary disk? The following goals needed to be accomplished in an effort to procure the answer: Taking spectra while looking through the Earth's atmosphere, measuring the transparency at numerous angles, and plotting the data as transparency as a function of frequency. The culmination of the project is demonstrating the capability of balloon-borne water vapor observations. Additional tertiary objectives for Project WWASP included subjecting the submillimeter receiver system and the electronics for the ASTHROS balloon mission (Astrophysics Stratospheric Telescope for High Spectral Resolution Observations at submillimeter-wavelengths) to a test flight.

Contents

1 WWASP Payload

The heart of our payload contains the radiometer which will be continuously taking data while in flight of both the atmospheric water density and the angle of elevation above the horizon. By using a submillimeter receiver, spectrometer, and a tilting radiometer, WWASP will take spectra in 10-degree increments, every 10 seconds, of the 557 GHz water line. A control stepper motor with a driver and Arduino will control the tilt and motion of the mirror. Data will be collected and stored in a SYS-405Q Fanless Industrial Computer. The Smart Power Supply Unit (PSU), developed by JPL for the ASTHROS mission, will provide power for all components on the payload, with exception of the computer. Both the computer and SMART PSU have been provided by the Jet Propulsion Laboratory (JPL). The provided computer will communicate with the Smart PSU that controls the receiver through RS-485 serial interface. RS-485 is an industrial specification that defines the electrical interface and physical layer for point-to-point communication of electrical devices. The RS-485 standard allows for long cabling distances in electrically noisy environments and can support multiple devices on the same bus.

Additionally, we have a calibration subsystem for the radiometer to provide context for the raw data due to the Radiometer only providing a voltage difference. This calibration subsystem will allow the radiometer signal to register off a blackbody system of known temperature before taking data from the atmosphere outside. The voltage difference between the known blackbody temperature and the atmosphere will provide us with the data we need to extrapolate atmospheric transparency as well as subtract any background noise generated by the payload.

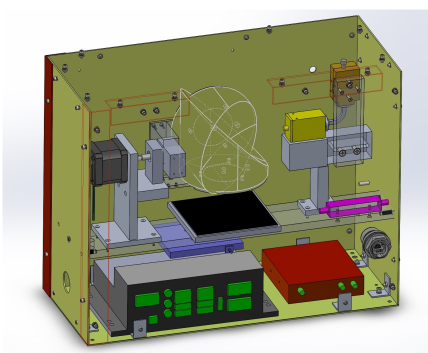

Figure 1: WWASP CAD

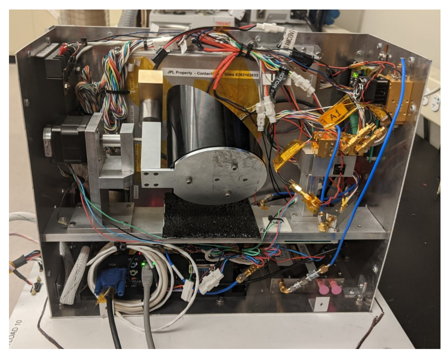

Figure 2: WWASP Payload

2 Scientific Interest

2.1 Mission Statement

Project WWASP attempts to answer the scientific question: is the transparency of the Earth's Atmosphere near the frequency of the 557 GHz rotational ground state line of water vapor sufficient for researchers in the future to launch a stratospheric balloon mission to detect water in a protoplanetary disk? Because these specific water vapor lines cannot be reliably detected from ground-based telescopes due to the water content in the Earth's atmosphere, researchers are forced to rely on space telescopes such as the Hubble Space Telescope (HST) and the James Webb Space Telescope (JWST). However, being granted time on these telescopes is expensive, difficult, and extremely competitive. Project WWASP's intent is to probe into an alternative method for imaging water emission in newly forming star systems. This project will focus on the critical component of measuring water vapor in the Earth's atmosphere.

2.2 Mission Background and Justification

Ground-based telescopes are more common relative to a space-based telescope as they are typically much less expensive to build, maintain, and upgrade. Space-based telescopes on the other hand are much more expensive to build, harder to upgrade and repair. That said, space-based telescopes do possess a major advantage over ground-based telescopes: Ground-based telescopes can only detect wavelengths that penetrate the Earth's atmosphere. The rest of the electromagnetic spectrum is blocked by the atmosphere. That's where space-based telescopes come into play as they have the capability to detect x-rays, gamma rays, and even UV-rays from cosmological events that would otherwise be blocked by the atmosphere. Balloon borne telescopes allow near-space observations at a cost far lower than space missions.

The HASP Student Payload has provided project WWASP the opportunity for collaboration on this mission which seeks to provide evidence for an atmosphere transparent enough to measure spectral lines from water vapor using a balloon borne telescope. Previously all water observations have been done exclusively from space. If the atmosphere is proven to be transparent at high altitudes, it would suggest a potential for low-cost, future missions focused on water observations.

3 Science Requirements

3.1 Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirements	Instrumental Functional Requirement	Data Product	System Functional Requirement
Is the transparency of the Earth's Atmosphere near the frequency of the 557 GHz rotational ground state line of water vapor sufficient for researchers in the future to launch a stratospheric balloon mission to detect water in a protoplanetary disk?	Measure atmospheric opacity to ± 0.03 K	Obtain blackbody radiation temperature within ± 1.0 K	Shall be capable of measuring optical depth with an accuracy of ± 0.03 K	Data record of atmospheric transparency vs frequency at various altitudes	Shall demonstrate the radiometer is operable in conditions analogous to space
		Measure atmospheric temperature within ± 1.0 K			
		Obtain radiometer sky spectrum calibrated in K			Payload shall meet HASP payload requirements
	Optical Image to see target	Record image for each spectrum measurements	Camera with field of view of 70°	One time-stamped image for each spectrometer measurement of the sky	

Figure 3: STM for WWASP

The WWASP Team completed the payload build, interfacing, and full system testing. System testing occurred at Arizona State University using a thermal vacuum chamber. Instruments were also subjected temperature variations, similar to conditions at high altitude.

3.2 Data Calibration

The calibration subsystem is a software interface, designed to help the WWASP team collect accurate data through the radiometer. The calibration system will be responsible for making sure the values recorded by the radiometer are able to be processed by the team. The calibration system balances the radiometer by using a known blackbody temperature and recording the radiometer's returns in voltage. This allows the team to use the voltage difference to calculate the atmosphere's temperature. For testing this subsystem, the radiometer takes a second blackbody to produce a voltage difference from the first blackbody. The voltage difference between the known blackbody temperature and the atmosphere will provide us with the data we need to extrapolate atmospheric transparency as well as subtract any background noise generated by the payload.

3.3 Data Collection

The specific data collected during flight consisted of the following: spectra of the sky, spectra of the blackbody, unique time stamps for each, and pre-launch calibration data. This data will be compared to a our predicted value for atmospheric opacity which was created using a Monte Carlo simulation. Our simulation generated a temperature error of ± 1.0K and an error value for τ of ± 0.03. The six data points shown are calculated for every $10°$ of elevation between $20°$ and $70°$.

The data collecting cycle begins once flight altitude has been reached. The cycle is initiated by taking a blackbody reference temperature, followed by a sky-position tilt. A sub-millimeter radiometer receives input from optics into the waveguide feed horn to measure water vapor near 557 GHz. Every 10 seconds, the angle of the mirror adjusts, spectra is collected, timestamped, and recorded by the computer. The timestamp ensures accuracy for location(coordinates, altitude, mirror tilt) and time for each recorded spectrum.

Each data collecting cycle is designed to systematically take house-keeping data. House-keeping data consists of receiving position/altitude versus time from HASP telemetry, monitoring the payload clock, monitoring the ambient temperatures of critical components on board the payload, and monitoring the reference temperature of the calibration blackbody to verify that the payload is running properly. House-keeping data is taken every 10 seconds and reported every 10 minutes. The completion of the flight will produce spectra of the sky, spectra of the blackbody, and pre-launch calibration data. The flight data is sorted and analyzed to create plots of atmospheric transparency as a function of frequency, and atmospheric transparency as a function of time.

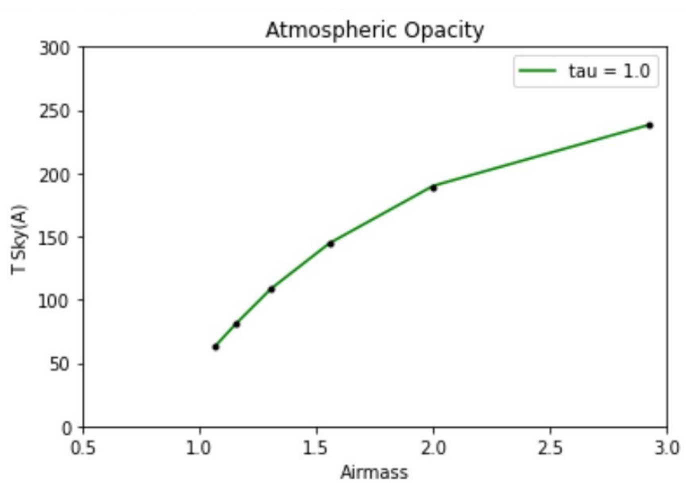

Figure 4: Atmospheric Opacity: $\tau = 1.0$

3.3.1 Subsystems

- Sub-Millimeter Receiver: The receiver continuously takes in data and it alternates between calibration data and atmospheric data. The sample rate is set at $6\frac{GS}{s}$ with a 1 second integration time.
- Calibration System: The motor continuously runs while power is provided to the system. The calibration system reads out a blackbody reference spectra that differentiates between the calibration process and the atmospheric observation process. The thermometer reports the temperature of the blackbody during flight to provide context to the radiometer calibration system.
- Spectrometer: The spectrometer has an integration time of 1 second and is constantly taking data at 1 second rates. This was done to synchronize the orientation data to the radiometer data, providing context to where the mirror is pointing. After each of these subsystems reports their information and the data is stored, the loop will end until it reactivates again by the GPS data string. This process repeats every 10 seconds.

4 Data Analysis

In order to process the data, we matched each spectra taken when the motor was pointing at a source with the spectra taken before and after the data collection. We then calibrate the spectra using the "off" spectras. The average of all the calibrated spectras for the 55 motor steps is shown in the first row. Because of the spikes in some channels, we perform a windowed smoothing on channels past a sigma threshold away from the average, as shown in the second row. There are also instances where the individual calibrated spectras and "off" spectras are problematic. We calculate anomaly scores for these using Reed-Xiaoli and Negative Sampling to filter out anomalous spectra. The average of the spectra after filtering is shown in row three. Row four shows both smoothing and anomaly filtering. The contamination of the spectra we believe, are due to radio frequency interference from the CSBF CIP and potentially other student payloads with wireless transmitters operating in the DC-3 GHz band.

4.1 Data Results

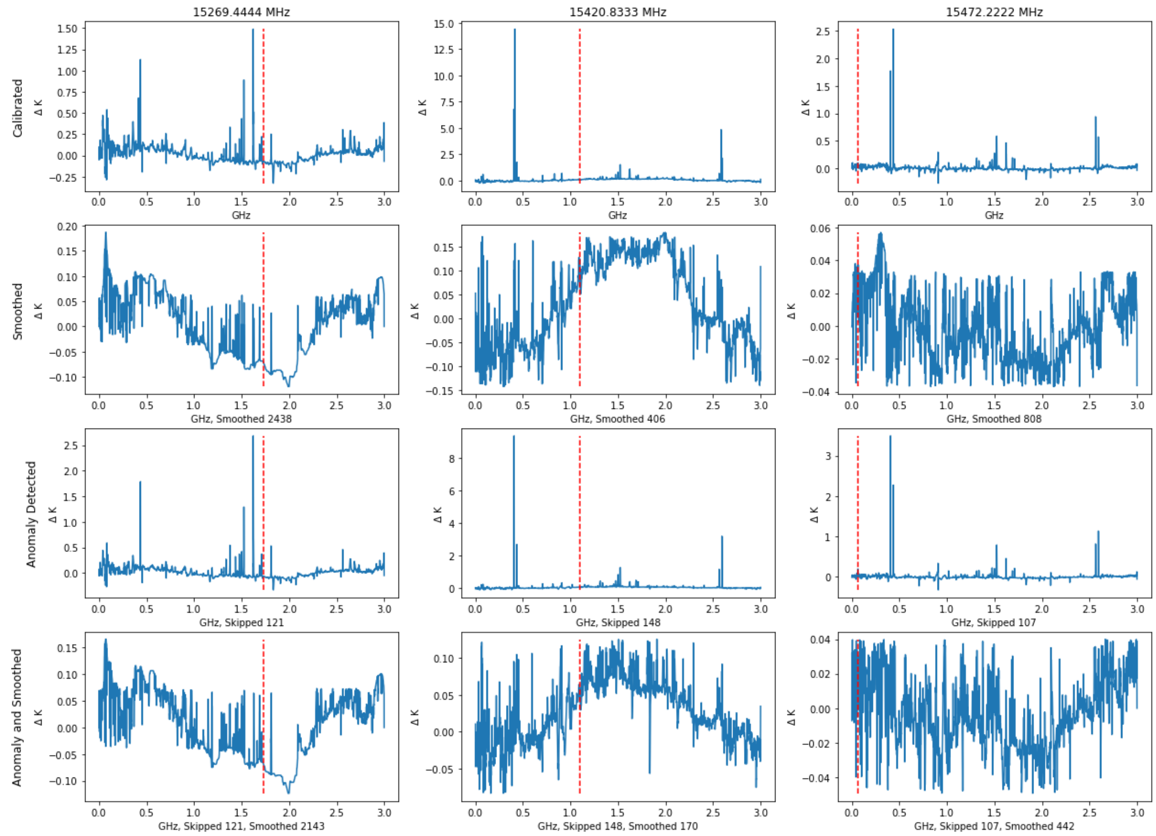

Figure 5: Flight Spectra Data

5 Results and Conclusion

WWASP successfully completed the flight mission on September 14th, 2021, with a fully-functioning payload. Our data results are inconclusive, as the measured slope from the spectra plots did not match our predictive models. We suspect there was an issue with our low noise amplifier becoming compressed either due to the significant RFI signals, or the issue may originate directly with amplifier itself. We are testing the LNA now to determine if it was operating correcting. The payload achieved its goal of collecting sky spectra and maintaining operation throughout peak flight altitude and the associated temperature variations. All components flight tested for the ASTHROS mission operated nominally throughout the flight, and the instrument collected data the entire time. We are optimistic future Capstone groups will augment the WWASP payload to fix the RFI contamination issue and data for their own high-altitude radiometry missions.

6 Media

The WWASP mission in cooperation with HASP was recognized by multiple organizations including ASU's SESE and JPL. WWASP team member Ruben Ortiz presented WWASP's coordination with HASP as the subject of an AAS talk for his Astrophysics 422 course at ASU.

Figure 6: ASU SESE Facebook

Figure 7: JPL Press Release

7 Team Graduation and Career Information

Name	Graduation Date	Degree/Major	Status
Ruben Ortiz	December 2021	Astrophysics	
Jessica Berkheimer	May 2021	Astrophysics	PhD Candidate: Astrophysics
Paul Horton	May 2018	Software Engineering Applied Physics	PhD Candidate: Systems Engineering
Christian Thompson	Current Undergrad	Astrophysics	Student
Kelsey Klingler	Current Undergrad	Astrophysics	Student
Ewan Pringle	Current Undergrad	Astrophysics	Student
Steven Sherman	Current Undergrad	Astrophysics	Student

Figure 8: Student Current Status

8 Team Roles and Responsibilities

Name	Start Date	End Date	Role	Student Status	Race	Ethnicity	Gender	Disability
Jessica Berkheimer	1/1/21	Present	Science and Optics*	Undergrad	White	Caucasian	Female	No
Ruben Ortiz	1/1/21	Present	Team Lead, Electrical Design, Weight and Power Budget, Payload Design	Undergrad	Hispanic	Mexican	Male	No
Paul Horton	1/1/21	Present	Code Engineer	PhD Student	Asian	Filipino	Male	No
Kelsey Klingler	1/1/21	Present	STM Manager	Undergrad	White	Caucasian	Female	No
Ewan Pringle	1/1/21	Present	Calibration Engineer	Undergrad	White	Caucasian	Male	No
Steven Sherman	1/1/21	Present	Mechanical Engineer	Undergrad	White	Caucasian	Male	No
Prof. Chris Groppi	1/1/21	Present	Faculty Advisor	Advisor				
Dr. Jose Siles	1/1/21	Present	JPL technical advisor	Advisor				
Dr. Jonathan Kawamura	1/1/21	Present	JPL technical advisor	Graduate				
Christian Thompson	09/27/21	Present	Code Engineer Assistant	Undergrad	White	Caucasian	Male	No

Figure 9: WWASP Team Roles

Mission References

- http://www.spaceref.com/news/viewpr.html?pid=58435
- https://www.nasa.gov/wallops/2021/feature/fall-2021-hasp-balloon-mission-will-fly-11-student-payloads