# Payload Concept Proposal

Astro Phoenix

Palmetto Scholars Academy

Team 3

## 1.0 Introduction

We are Palmetto Scholars Academy's Team 3, Astro Phoenix. We chose this name for two reasons: our school's mascot is a Phoenix, and our team is mostly made out of the members of older InSPIRESS teams, so we were reborn, like the Phoenix. Our slogan is "We don't crack under pressure" because we do not crack under metaphorical scholastic pressures, and our payload is designed to withstand the high pressures of Neptune. Our payload, The Magic Eight Ball, will be going to Neptune as part of the N.O.T.E. (Neptune Orbiter and Triton Explorer) mission. It will be launched out of the UAH orbiter toward Neptune's south pole. The south pole is currently tilted towards the sun, causing it to be 10 degrees warmer than the rest of the planet. This increased heat causes the methane in the atmosphere to melt and disperse, making the south pole of Neptune a lighter blue than the rest of Neptune. Our science objective on Neptune is to find orthocarbonic acid and analyze the circumstances around its existence. Given the potential foundation for new forms of life found in orthocarbonic acid and its precursors, we believe that the information gained would greatly improve our knowledge of the inner workings of Neptune, its atmosphere, and our knowledge of gas giants.

Our payload will deploy into Neptune's atmosphere and complete our science objective, which is to analyze the atmosphere of Neptune using an external spectrometer to determine if orthocarbonic acid is present. Our science objective could confirm the existence of a hypothesized element and allow more faith to be put into simulations made by Dr. Oganov and his team at the MIPT. Also if orthocarbonic acid is proven to exist it could redefine our current ideas for the basis of life.

## 2.0 Science Objective and Instrumentation

The primary science objective of the mission is to search Neptune's atmosphere for orthocarbonic acid. In addition to searching for the acid, the secondary objective will be to analyze the environmental conditions necessary for the formation of orthocarbonic acid. To satisfy the primary objective, the payload will be equipped with a spectrometer to analyze the composition of the atmosphere and an inertial measurement unit to track the location of the Magic Eight Ball. To satisfy the secondary objective, an onboard thermocouple will measure the conditions of the atmosphere at the location of orthocarbonic acid.

**Table 1. Science Traceability Matrix**

| Science Objective | Measurement Objective | Measurement Requirement | Instruments Selected |
|---|---|---|---|
| Finding and locating orthocarbonic acid | Determine if and where orthocarbonic acid is present | Access to atmosphere | Spectrometer<br>IMU |
| Investigating the environmental conditions at the location of orthocarbonic acid | If orthocarbonic acid is present, determine its physical properties and the conditions required for it to be stable/created | Access to atmosphere | Spectrometer<br>IMU<br>Thermocouple |

**Table 2. Instrument Requirements**

| Instrument | Mass (kg) | Power (W) | Data Rate (Kibps) | Dimensions (cm) | Lifetime | Frequency | Duration |
|---|---|---|---|---|---|---|---|
| Spectrometer | .230 | 1.5 | $2.29 \times 10^4$ | 0.45 x 0.5 x 0.8 | 60 hrs | See Figure 1 | See Figure 1 |
| IMU | .013 | 0.22 | $1.64 \times 10^2$ | 0.5 x 0.5 x 0.1 | 60 hrs | Every 0.5 seconds | Continuous |
| Thermocouple | .035 | N/A | $1 \times 10^{-3}$ | 174.54 | 60 hrs | Every 2 seconds | Continuous |

**Figure 1. Spectrometer Frequency Graph**

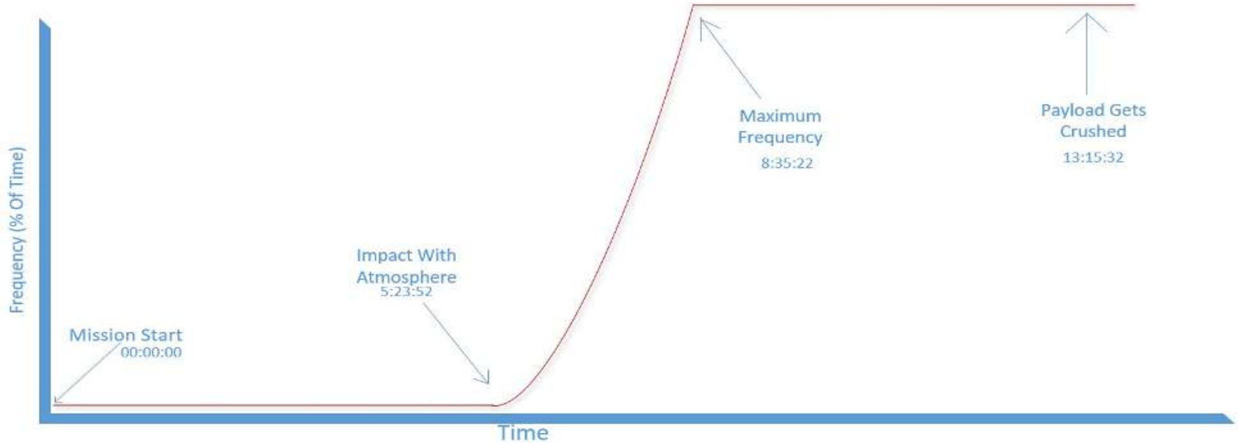



**Table 3. Support Equipment**

| Component | Mass (kg) | Power (W) | Data Rate (Kibps) | Dimensions (cm) |
|---|---|---|---|---|
| On-Board computer | 0.094 | 0.4 | N/A | 2 x 2 x 0.3 |
| Transceiver | 0.085 | 1.7 | 9.375 Rx/ 1.17 Tx | 0.96 x 0.90 x 0.15 |
| Batteries | 0.35 | 140 W-hr | N/A | 2 x 2 x 2 |

## 3.0 Payload Design Requirements

**Table 4. Design Requirements**

| Project Requirements | Functional Requirements | Environmental Requirements |
|---|---|---|
| • No more than 10 kg of mass<br>• Smaller than 44 x 28 x 24 cm when stowed<br>• No harm to main spacecraft<br>• Survive environment | • Deploy from UAH spacecraft<br>• Take measurements<br>• Collect data<br>• Provide power<br>• Send data<br>• House payload | • Temperatures around 60K<br>• Pressures of up to $9x10^6$ atm<br>• Targeting areas of up to $3.5x10^6$ atm<br>• Wind speeds up to 580 m/s<br>• Gravitational pull of 11.15 $m/s^2$<br>• An atmospheric composition of 80% hydrogen, 19% helium, ~1% methane, and >1% other gasses |

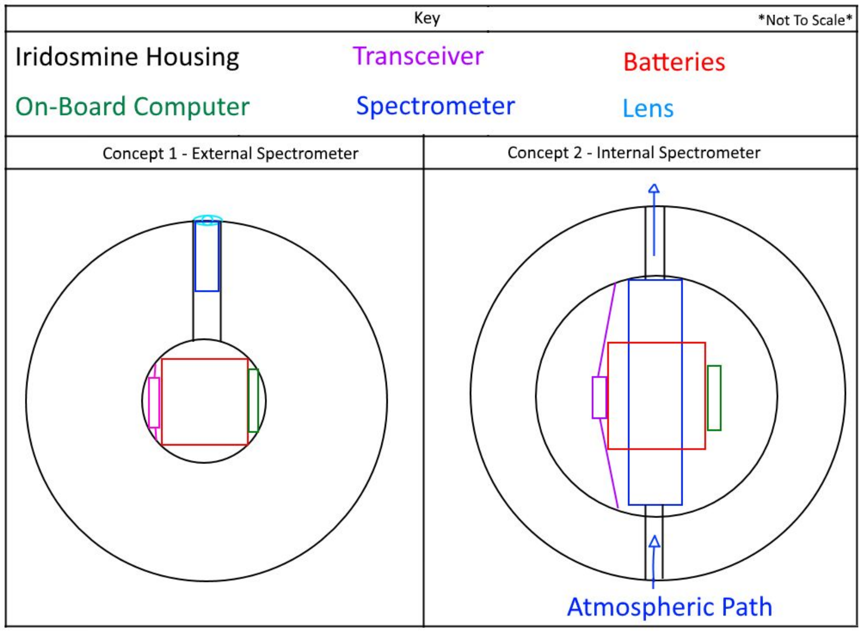
## 4.0 Payload Alternatives

Our two concepts are extremely similar. Both of the concepts drop the payload into the south pole of Neptune. It will drop deep into the atmosphere and search for orthocarbonic acid and record environmental conditions at the location where the acid is formed. Both concepts have a spherical iridosmine shell to protect the internals and a spectrometer to analyze the composition of the atmosphere.

**Table 5. Concept Differences**

| Concept 1 - External Spectrometer | Concept 2 - Internal Spectrometer |
|---|---|
| Concept 1 uses an external laser spectrometer with a diamond lens to analyze the outside atmosphere. This concept only has a single structural weak point where the lens meets the shell. | Concept 2 uses an internal spectrometer fed by an atmospheric feed tube. The feed tube requires the structural design to be more complex, and it has a structural weakness throughout the sphere because of this tube. |

**Figure 2. Concept 1** **Figure 3. Concept 2**




## 5.0 Decision Analysis

To weigh the Figures of Merit (FOM), we determined which aspects of our payload were of little importance, moderate importance, or top priority. Then we took them and weighted them as 1, 3, or 9, respectively. Only one FOM was weighted as 1, which was science to mass ratio. This wasn't important to the teams because both payloads use most of their mass on housing; therefore, the science to mass ratio is of little concern to us. ConOps Complexity, Manufacturability, Power Usage, and Design Complexity were all weighted as 3 because FOMs that can define the difference between failure and success should take precedence over them. Finally, we weighed Science Objective, Integrity of Data, Likelihood of Mission Success, Likelihood of Meeting Project Requirements, and Survivability as 9, because if these FOMs are not met satisfactorily, our payload has a high chance of failure. Then, we scored both alternatives based on how well they adhered to the FOMs on a scale of 1, 3, or 9. The external spectrometer scored higher than the internal spectrometer on Science/Mass Ratio because it has less mass, and collects more data. Concept 1 received higher scores on the the FOMs entitled Likelihood of Mission Success, Likelihood of Fulfilling the Project Requirements, and Survivability because it was a more durable design and more likely to complete the mission. Concept 1 also received higher scores on Manufacturability and Design Complexity because it had a simpler design than the internal spectrometer. Concept 2 scored higher on the Integrity of Data FOM because the external spectrometer from Concept 1 has to measure through a lens, potentially gathering inaccurate data. Concept 2 also scored higher on the Power Usage FOM because the internal spectrometer used less power than the external one. The payloads tied on Science Objective and ConOps Complexity, which have been crossed out on the table. After multiplying the scores with the weights of the FOMs, and totalling all of the scores together, the external spectrometer had a higher score, singling it out as the design we would use.

**Table 6. Payload Decision Analysis**

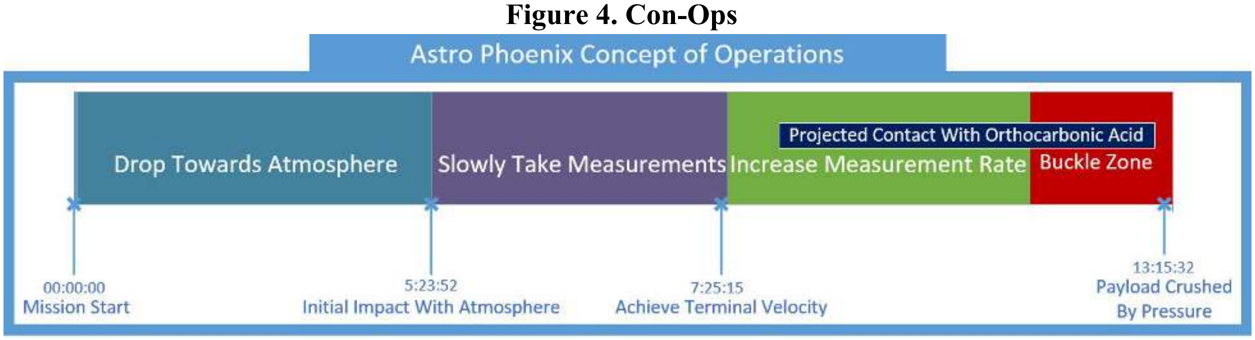
| Category | Figure of Merit | Weight | External Spectrometer (Concept 1) | Internal Spectrometer (Concept 2) |
|---|---|---|---|---|

| Category | Figure of Merit | Weight | Raw Score | Weighted Score | Raw Score | Weighted Score |
|---|---|---|---|---|---|---|
| Science Objective | ~~Science Objective~~ | ~~9~~ | ~~9~~ | ~~81~~ | ~~9~~ | ~~81~~ |
| | Integrity of Data* | 9 | 3 | 27 | 9 | 81 |
| | Science Mass Ratio | 1 | 3 | 3 | 1 | 1 |
| Mission | ~~ConOps Complexity~~ | ~~3~~ | ~~9~~ | ~~27~~ | ~~9~~ | ~~27~~ |
| | Likelihood Mission Success | 9 | 9 | 81 | 3 | 27 |
| | Likelihood Project Requirement | 9 | 9 | 81 | 3 | 27 |
| Payload | Manufacturability | 3 | 9 | 27 | 3 | 9 |
| | Survivability* | 9 | 9 | 81 | 3 | 27 |
| | Power Usage* | 3 | 3 | 9 | 9 | 27 |
| | Design Complexity | 3 | 9 | 27 | 3 | 9 |
| * Team generated FOM | **Total:** | | | 444 | | 316 |

## 6.0 Payload Concept of Operations

When the UAH orbiter reaches 144 degrees before our destination of the south pole, helium will be loaded into the tube behind our payload at a pressure of 275,790 Pascals. The helium will launch the payload out of the orbiter with a muzzle velocity of 163.5 m/s. Once deployed from the UAH orbiter, the payload will fall for an estimated 5 hours, 23 minutes until it enters Neptune's atmosphere at a speed of 15,814 m/s. The payload will continue to fall through the atmosphere for an estimated 7 hours. It will take an estimated 2 hours to slow down to a terminal velocity of 864 m/s, in which the measurement frequency of the external spectrometer will continue to increase. After 8 hours, it is expected that the payload will come into contact with orthocarbonic acid, and the measurement frequency will be continuous. After hour 11, the payload housing may begin to buckle from the pressure being too much, and the payload should not last past hour 13.

**Figure 4. Con-Ops**




## 7.0 Engineering Analysis

The first step in the engineering analysis was calculating initial conditions. In order to make sure that the UAH orbiter was in a stable orbit, the calculations had to ensure that centripetal force equaled gravitational force. Once completed and confirmed, the orbital velocity of the UAH orbiter had to be calculated and was found to be 15,724 m/s.

The next step was to calculate the deployment conditions. For deployment, the muzzle velocity was calculated to be just over 1% of the orbital velocity of the craft, which would allow the probe to drop towards the surface. This will require a 44 cm barrel and a pressure of 275,790 Pa. The probe will leave the launch tube at a speed of 163 m/s relative to the UAH orbiter.

After calculating deployment conditions, the terminal velocity were calculated. The terminal velocity of our payload was calculated by using our mass and the local gravity divided by the coefficient of drag, the cross sectional area of our payload and the density of the atmosphere. Which gave us our terminal velocity at 901.7 m/s.

The next step was to calculate the ending conditions. The first thing to calculate was the buckling pressure of the sphere. Instead of directly calculating the pressure at which it would be crushed, we reworked the equations to solve for the thickness of the probe at a given pressure. With the input of pressure at 354 GPa the shell thickness came out to be 3.349 cm.

The final step was to calculate the battery mass, originally it was assumed to be 1 kg of batteries as a baseline. This turned out to weigh too much and was cut down to 0.35 kg, the most it could be without going over the total 10 kg available. After calculating the total power usage of the instruments to be 0.442 W, we can use the total power available of 140 Whrs to find that the payload can run for 316 hours, which is far more than the mission time of 13 hours.

**Table 7. Design Calculations**

| Design Stage | Objective | Assumptions | Calculations | Results |
|---|---|---|---|---|
| Initial Conditions | Find Orbital velocity of UAH orbiter | Circular orbit | $v = \sqrt{\frac{(1.024*10^{26})*(6.67*10^{-11})}{2.76*10^{7}}}$ | Velocity: 15,724 m/s |
| Deployment | Find velocity and trajectory of payload once launched | Circular orbit, constant in barrel & perfect fit, no friction in barrel, no gravity | $v = 2 * 185.83 * .44$ | Deployment angle: -60º forward<br>Deployment Pressure: 275,790 Pa<br>Muzzle velocity: 163.53 m/s |
| Terminal Velocity | Find terminal velocity and drag force | Constant gravitational force and constant atmospheric density(gets no denser than highest atmospheric data) | $f_d = \frac{6.73*10^{-5}*0.47*8.66*(1.58*10^{4})^2}{2}$<br>$v = \sqrt{\frac{2*9.994*11.15}{8.66*6.73*10^{-5}*0.47}}$ | Drag: 34,277 N<br>Terminal velocity: 901.7 m/s |
| Batteries | Figure out mass of batteries | All instruments running continuously | $m = \frac{(ab+cd+ef..)W*hr}{400\ W*hr/kg}$ | Battery Mass: 0.35 kg<br>Battery Power: 140 W-hr<br>Probe Lifetime: 316 hrs |

| | | | | |
|---|---|---|---|---|
| Ending Conditions | Find a point at which the payload fails | Evenly distributed pressure | $t = \sqrt{\frac{3.54 * 10^8 * 2.14 * 10^{-5}}{1.21 * 5.60 * 10^8}}$ | Buckling pressure: 354.6 GPa<br>Payload diameter: 9.26cm<br>Housing thickness: 3.35 cm<br>Final force: 8.44x10^10 N |

**8.0 Final Design**

As shown in the figure below, the final payload will be an iridosmine shell with batteries, computer, transceiver, and an IMU in a hollowed-out center of the sphere. The diamond lens will be on the side of the payload and near the spectrometer so that the spectrometer can shoot a laser into Neptune's atmosphere to determine which compounds are present.

The Magic Eight Ball is a heavily fortified iridosmine sphere equipped with a laser spectrometer to analyze the atmosphere around the probe. Internally it will have thermocouple rings and an IMU to gather data on the outside conditions. Its surface is entirely iridosmine, apart from a small lens made of diamond. We will shine a laser spectrometer through this lens to search Neptune's atmosphere for orthocarbonic acid. The spectrometer will be positioned inside of the sphere, touching the lens. Our payload also contains an inertial measurement unit, so the payload can detect how far it has fallen, and a transceiver, so it can send the data it gathers back to the UAH orbiter.

**Figure 5. Final Design**

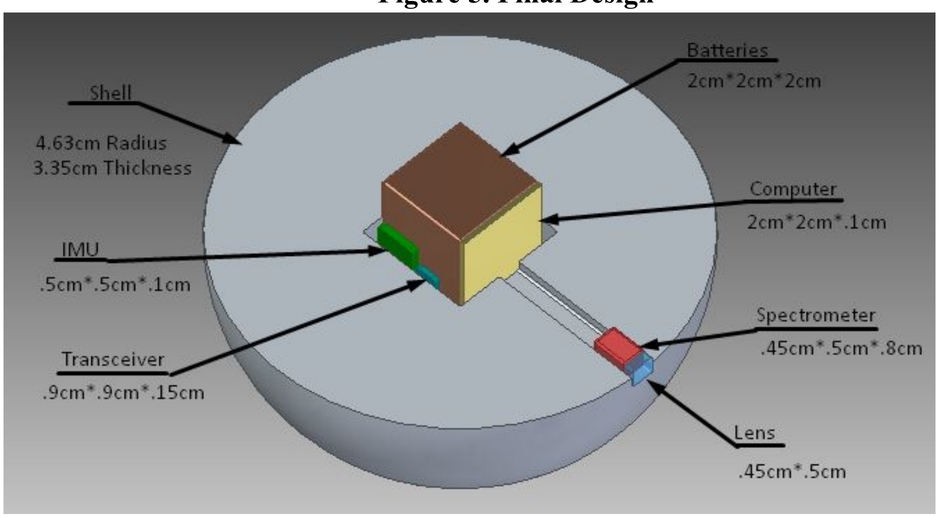



**Table 8. Final Design Mass Table**

| Function | Component(s) | Mass (kg) |
|---|---|---|
| Deploy | Helium Cannon | Part Of UAH Orbiter |
| Measure | IMU, Thermocouple | 0.048 |
| Collect Data | Spectrometer | 0.23 |
| Provide Power | Batteries | 0.35 |
| Send Data | Transceiver, Computer | 0.179 |
| House/Contain Payload | Iridosmine Shell | 9.187 |
| **Total:** | | 9.994 |