



GHOST

Ground-based Hardware for Optical Space Tracking

Project Manager: Jack Toland

Hardware: Kira Altman, Lucas Calvert, Seth Hill, Duncan McGough, Jacob Vendl

Software: Ginger Beerman, Connie Childs, Blaine Covington, Rachel Mamich, Connor Ott

Sponsor: The Aerospace Corporation

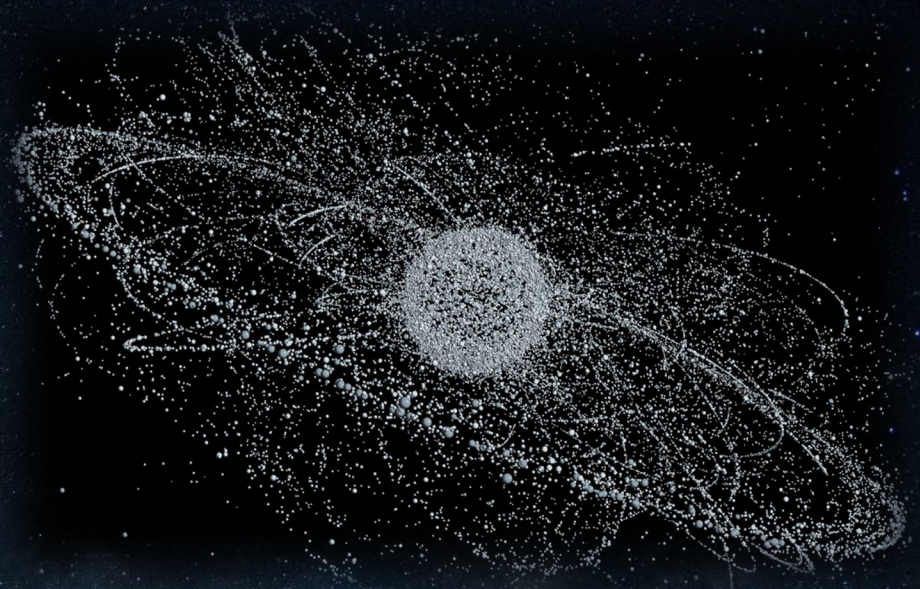
Advisor: Marcus Holzinger

Project Overview



Motivation

- Increasing number of space objects
 - CubeSats
 - Mega Constellations
 - Debris
- International dependence on space
 - Communication
 - Weather
 - National Security



Estimated satellite distribution by 2040

*Courtesy of Daily Mail

Solution

Design a low-cost, ground-based, optical tracking system for space situational awareness (SSA) and space traffic management (STM).

Specific Objectives



Scheduler: Propagate multiple space objects and create an imaging task list based on visibility and operator prioritization.

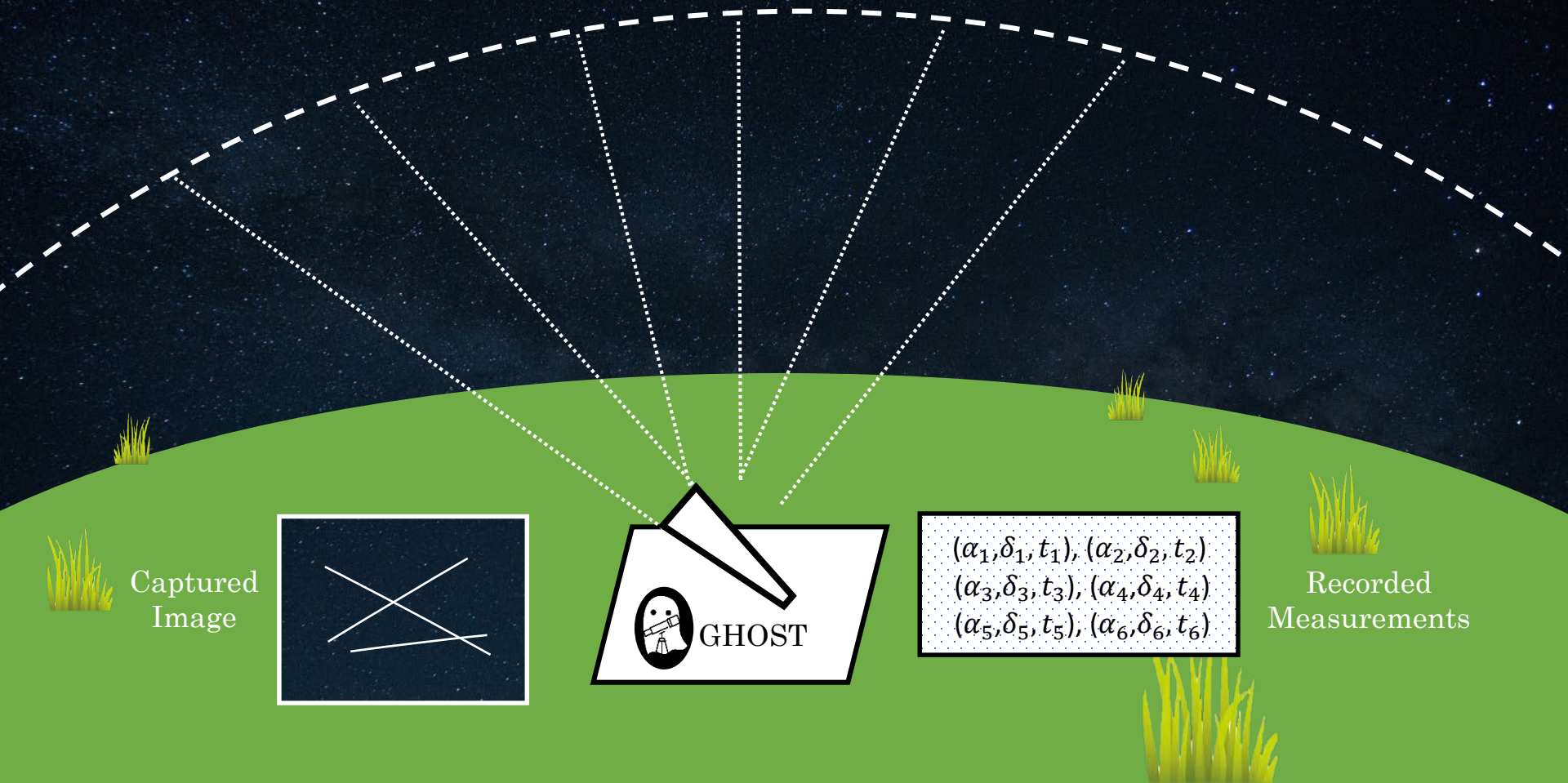
Actuation Hardware: Articulate the imaging system to capture multiple observations per pass for LEO, MEO and GEO space objects.

Imaging System: Image space objects in Earth orbits with relative visual magnitudes equal to or brighter than 10 under ideal conditions.

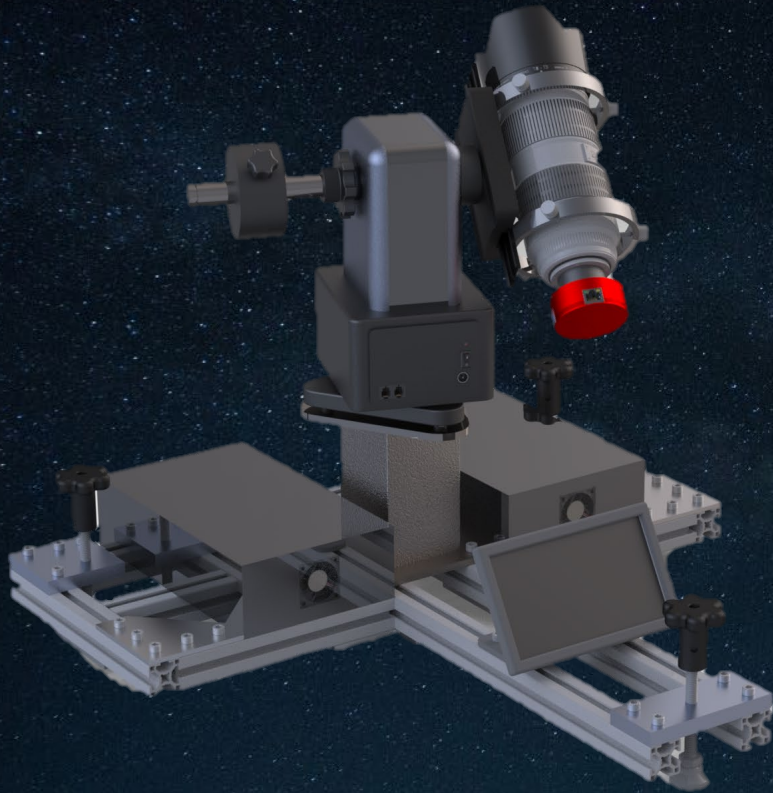
Image Processing: Process images for the boresight and target object right-ascension and declination.

Orbit Determination: Perform an orbit determination using standard advanced filtering methods using angular observations.

CONOPS

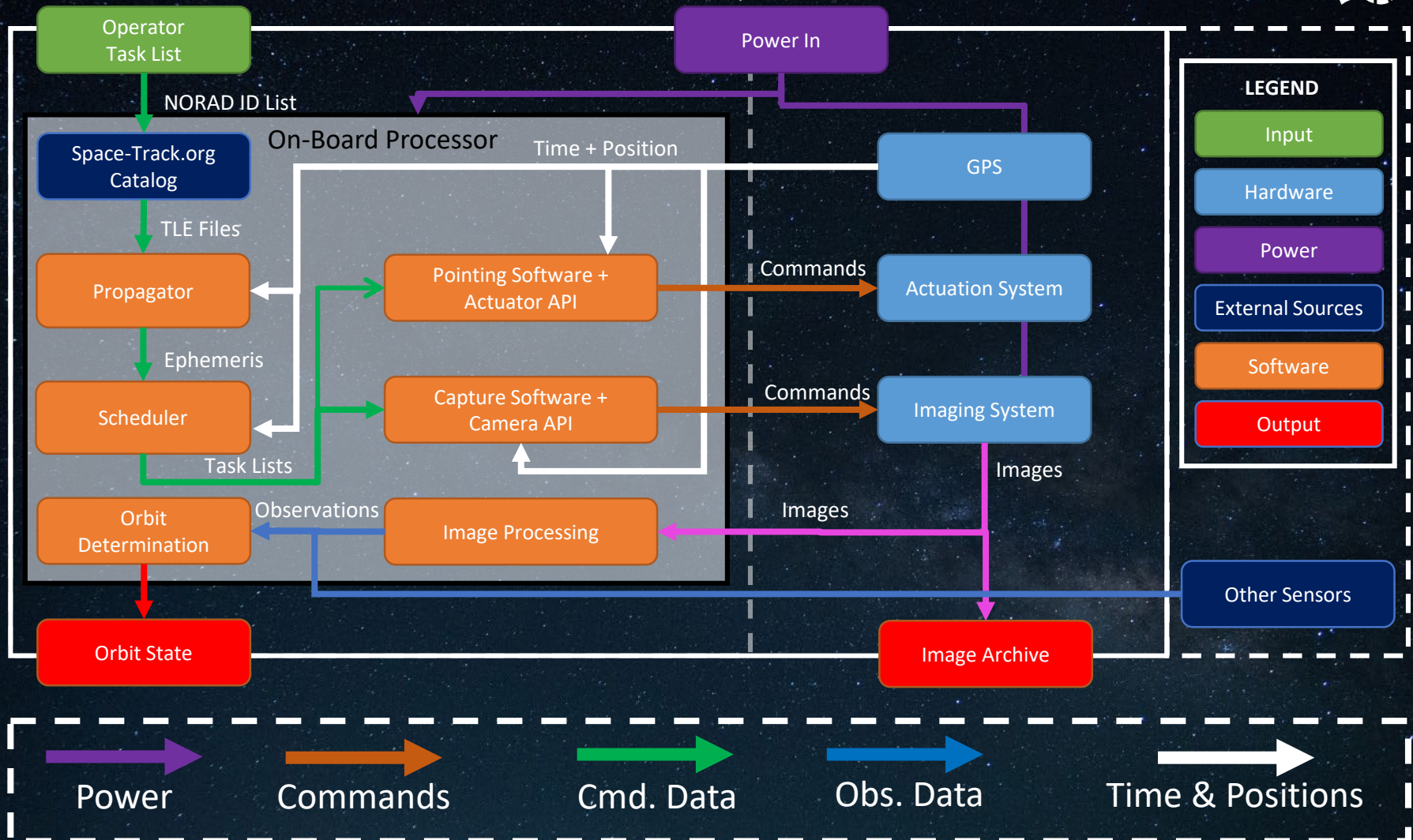


Baseline Design

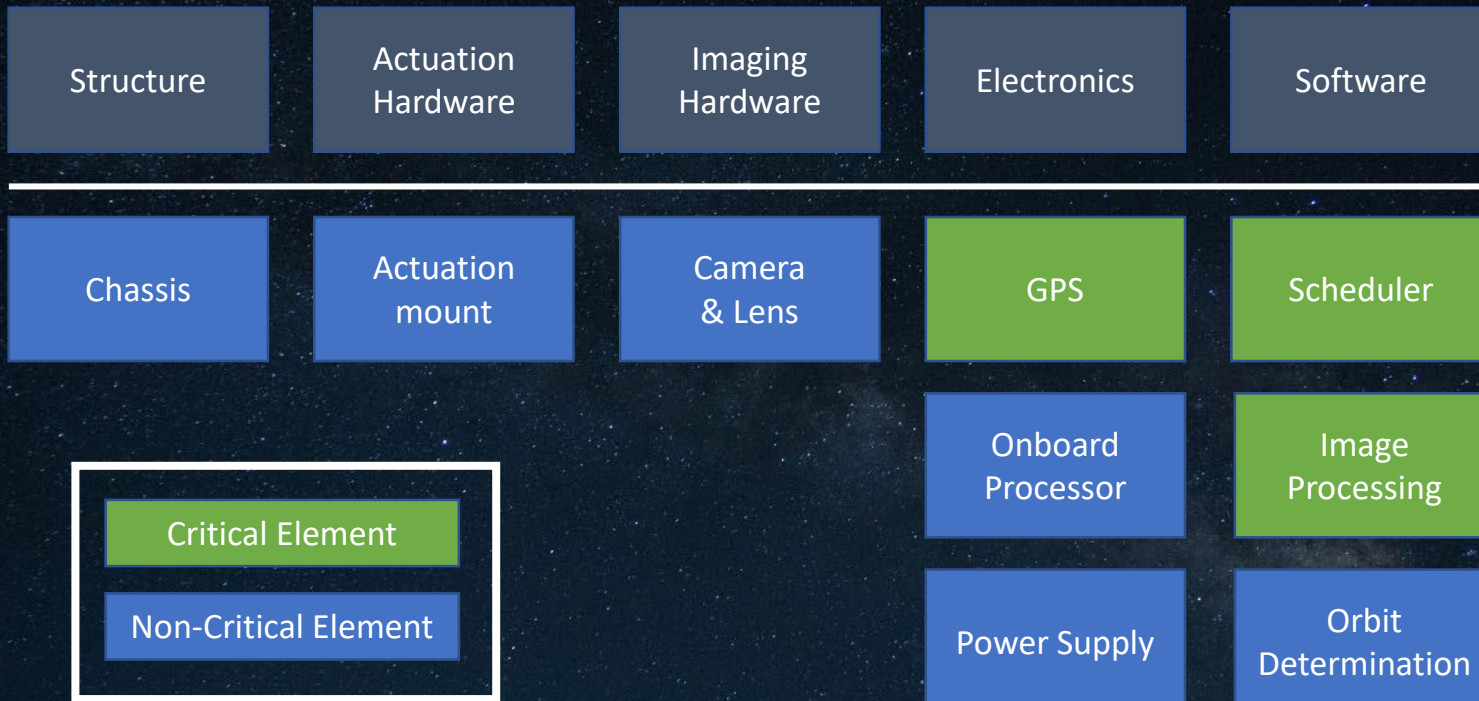


Chassis with Leveling
Dual-Output Power
Supply
Computer and GPS
Actuation Mount
Camera and Lens

Functional Block Diagram

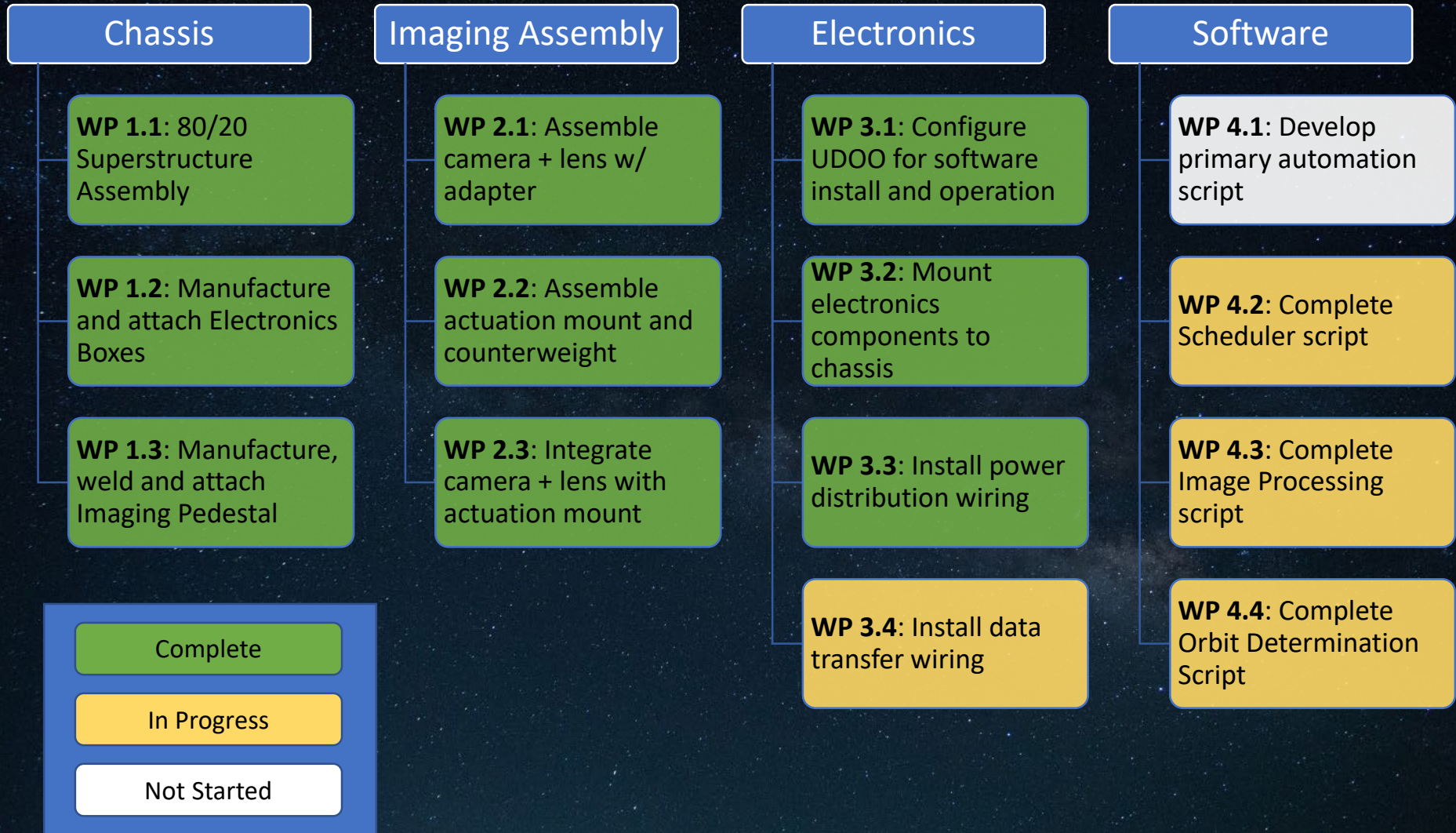


Critical Project Elements



Project Schedule

Work Breakdown Structure



Work Breakdown Structure



WP 4.1: Automation Script

Implement comms
between UDOO and
hardware

Develop event-based
hardware commands

Organize into event-
based structure

Continuously develop
error handling for each
component

WP 4.2: Scheduler

Develop propagator to
locate space object in
local sky

Develop constraints to
remove non-visible
and conflicting passes

Develop hardware
command interface

Integrate with
Automation Script

WP 4.3: Image Processing

Implement matched
filtering

Develop Astrometric
calibration process

Map pixel locations to
(α , δ)

Integrate with
Automation Script

WP 4.4: Orbit Determination

Develop Non-Linear
Batch Filter

Implement
perturbations in model
(SRP, Drag, J2)

Move Filter from
MATLAB to Python

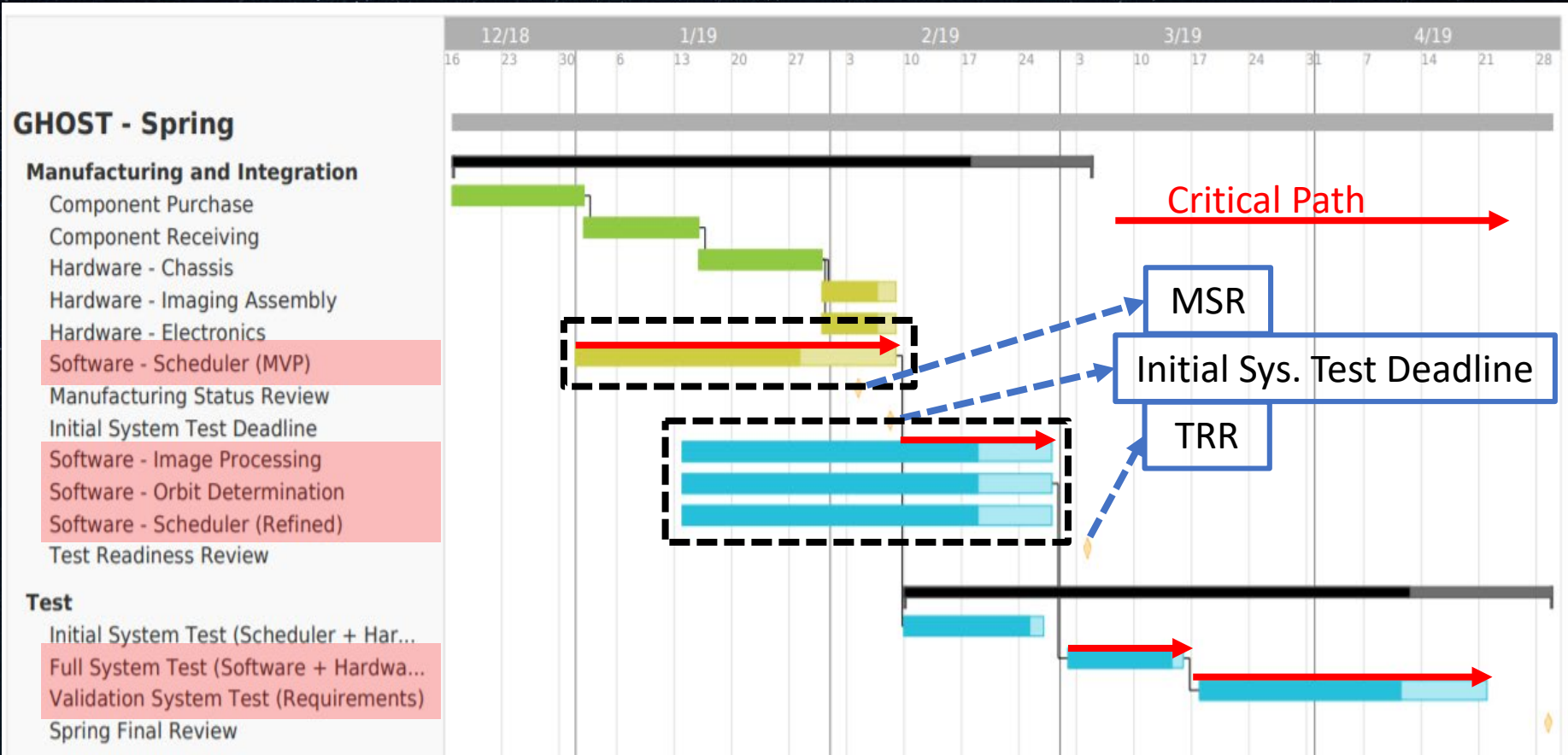
Integrate with
Automation Script

Not Started

In Progress

Complete

Project Schedule



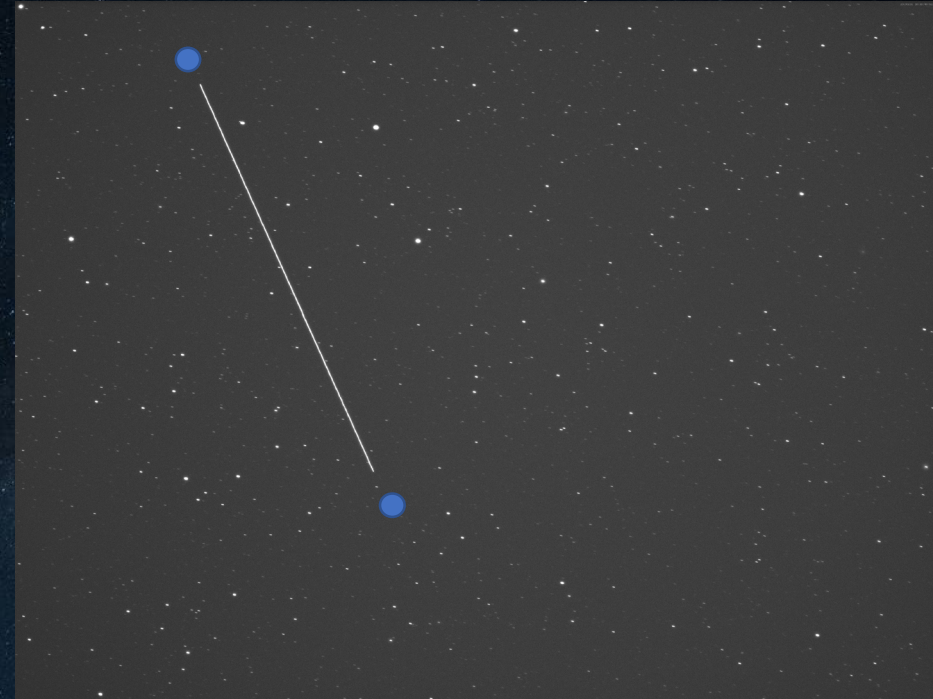
Manufacturing

Imaging System Characterization



Captured w/ GHOST Imaging System (01-Feb-2019)

Example Streaks



Unprocessed images with dim and bright space object streak

Astrometry



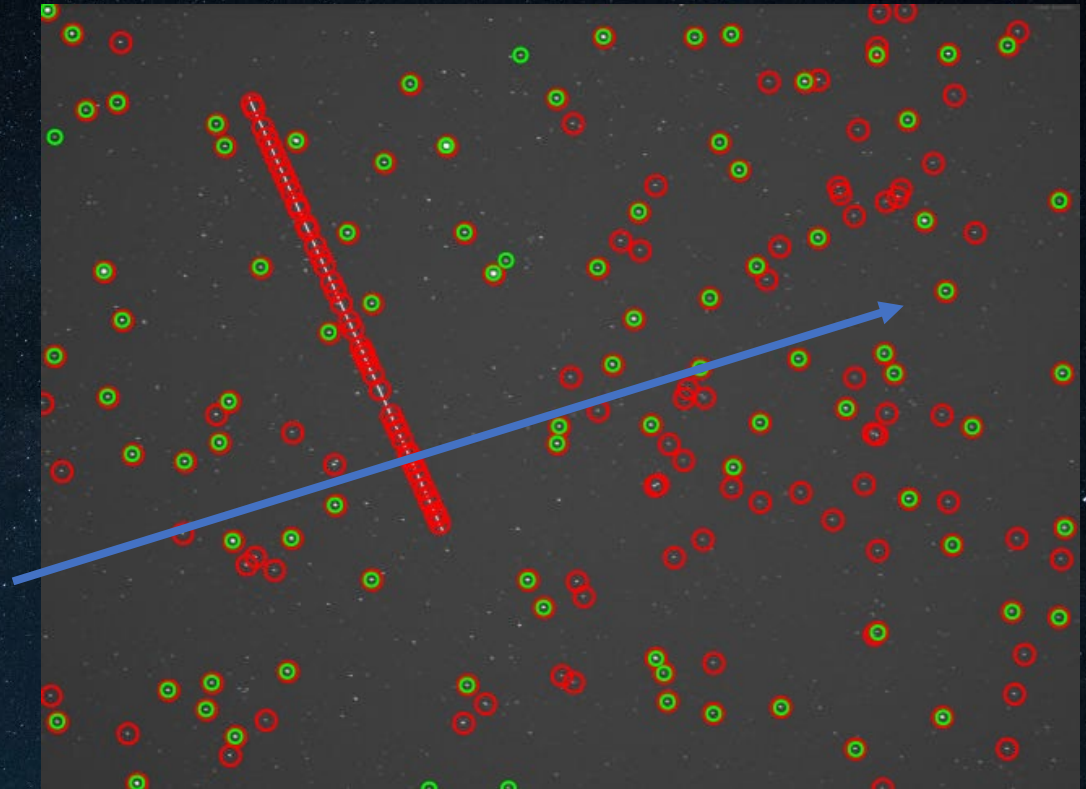
Center (RA, Dec): (117.265, 51.579)
Center (RA, hms): 07^h 49^m 03.647^s
Center (Dec, dms): +51° 34' 43.139"
Size: 5.23 x 3.95 deg
Radius: 3.278 deg
Pixel scale: 4.04 arcsec/pixel
Orientation: Up is 171 degrees E
of N

NGC-2500

Barred Spiral Galaxy

Apparent Mag = 12.2

*NASA Extragalactic Database



Hardware - Future Work



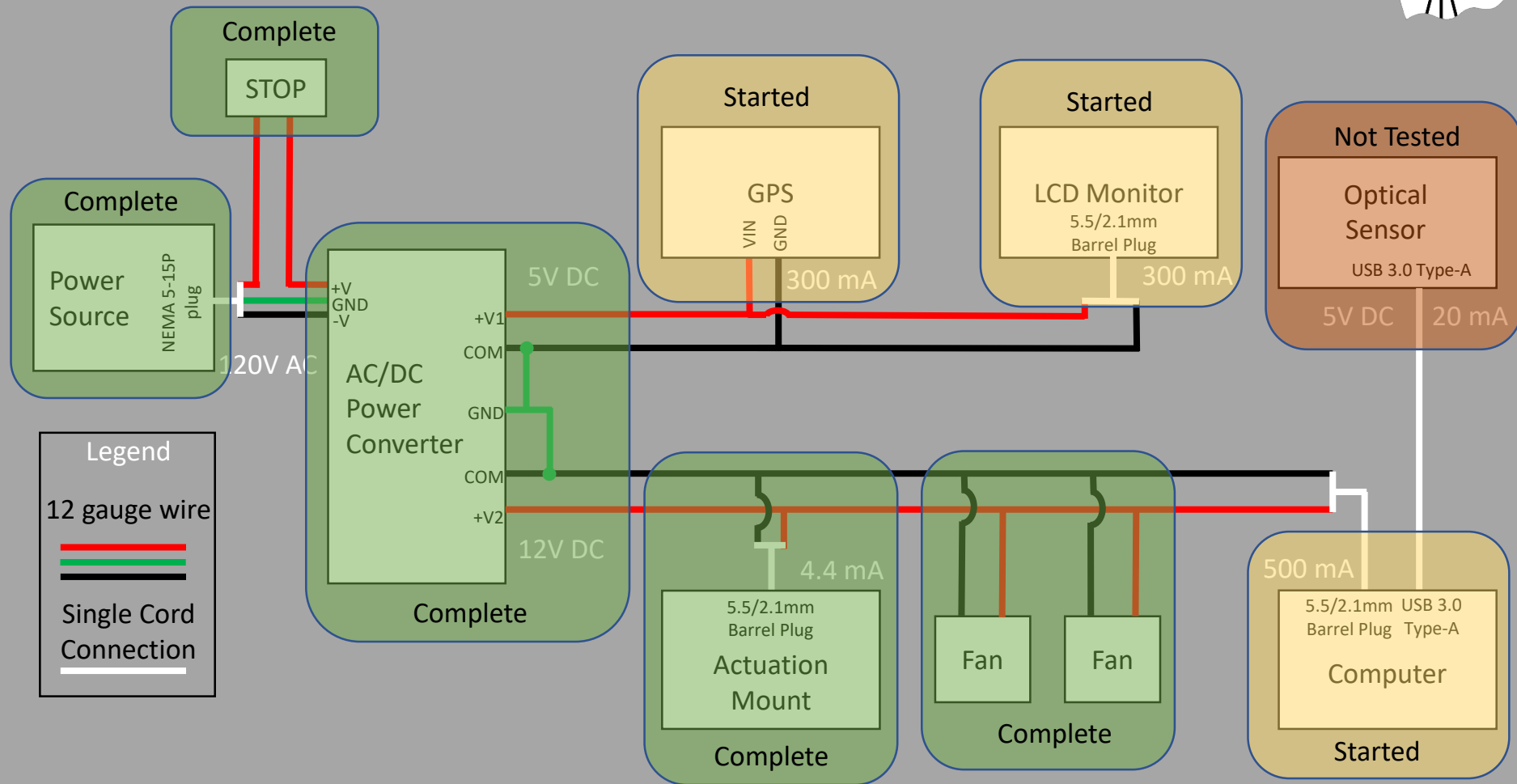
Subsystem	Description	Progress	Anticipated Difficulties	Initial Test Critical?
Actuation	Cable wrap management 3D printed	CAD model completed	Precision of 3D printing and effectiveness of solution	No
Chassis	Monitor mount 3D printed	No design completed	Containing all of the electrically sensitive components	No

Interfaces - Future Work

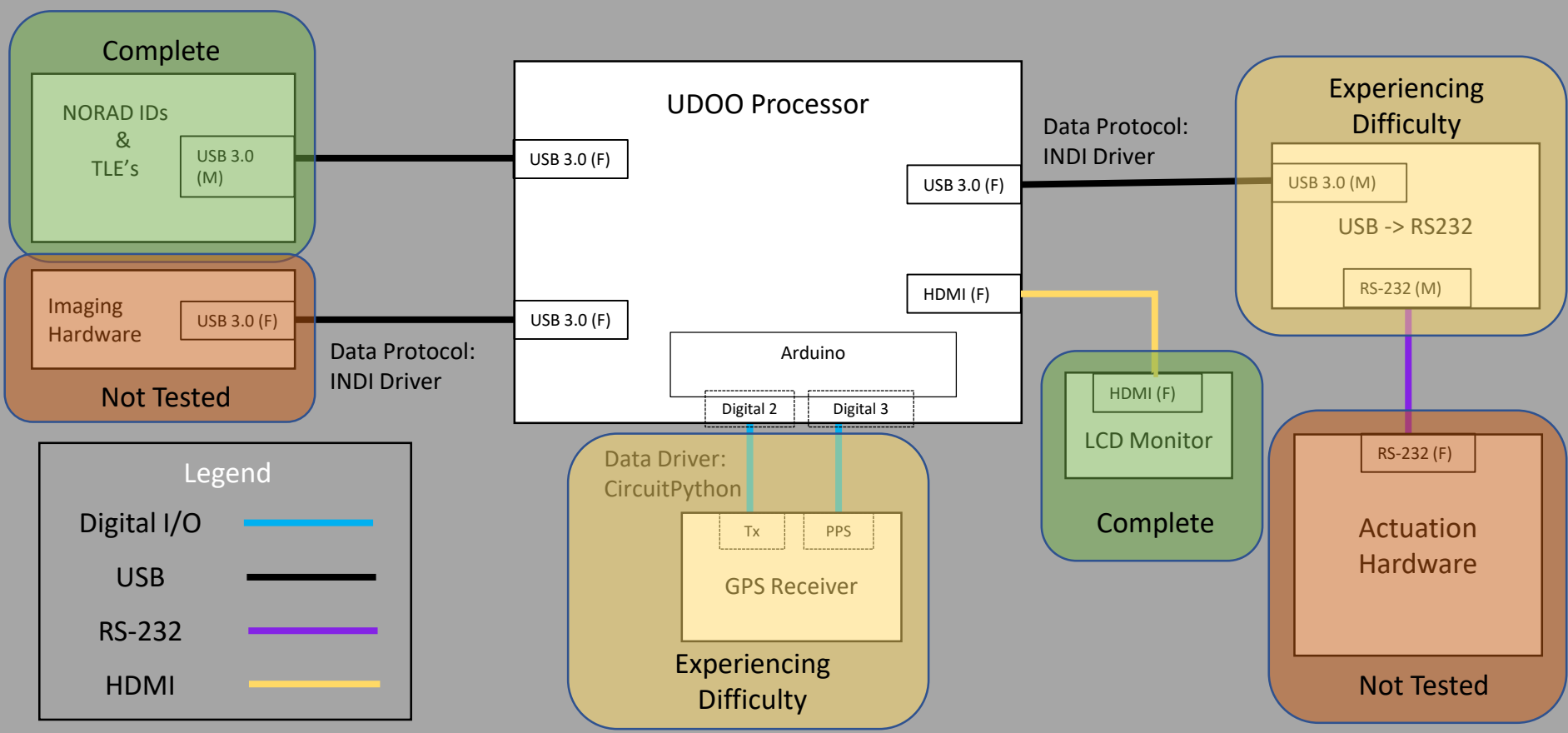
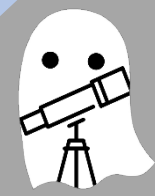


Subsystem	Description	Progress	Anticipated Difficulties	Initial Test Critical?
Imaging	UDOO interfacing with Zwo camera	INDI driver installed and working on PC	Installing INDI driver on UDOO	Yes
Actuation	UDOO interfacing with iOptron mount	INDI driver installed and working on PC	Installing INDI driver on UDOO	Yes
GPS	UDOO interfaced with Adafruit GPS module	USB connection established, but digital pin I/O desired.	Correct drivers installed; Resolving hard-port wiring errors	No

Power Distribution Wiring



Data Wiring



WP 4.1: Automation Script



Status: Behind Schedule

- Some oversight in planning for the main structure of software pipeline.
- Not necessary for initial testing.

Future Work

- Finish design of main structure and implement.

Plans to Complete Task

- Once scheduler in viable state, reallocate software team.
- Allocate resources from hardware team once manufacturing is complete.

WP 4.2/3/4: Software Modules



Subsystem	Status	Description	Known Difficulties	Initial Test Critical?
Scheduler	Close to Minimum Viable Product	Provides times and locations of objects for imaging	Conflict resolution, optimizing for maximum observations	Yes
Image processing	Prototype created with assumed single object	Extracts measurements from images	MF thresholding and eliminating neighboring objects	No
Orbit Determination	Prototype Complete in MATLAB	Provides orbit estimate from batch of measurements	Upgrading dynamics, quantifying measurement uncertainties	No

Budget

Procurement Status



Subsystem	Procurement Status
Chassis	IN PROGRESS
Actuation	COMPLETE
Imaging	COMPLETE
Processing	COMPLETE
GPS	IN PROGRESS
Power	IN PROGRESS

Budget/Account Update



Component	Actual Cost	Budget Allocation	Margin
Chassis	\$498.52	\$600	16.9%
Actuation	\$1,118.88	\$1500	25.4%
Imaging	\$1,947.06	\$2000	2.6%
Processing	\$304.89	\$400	23.8%
GPS	\$55.39	\$100	44.6%
Power	\$218.35	\$400	45.4%
Total	\$4,200.80	\$5000	16.0%

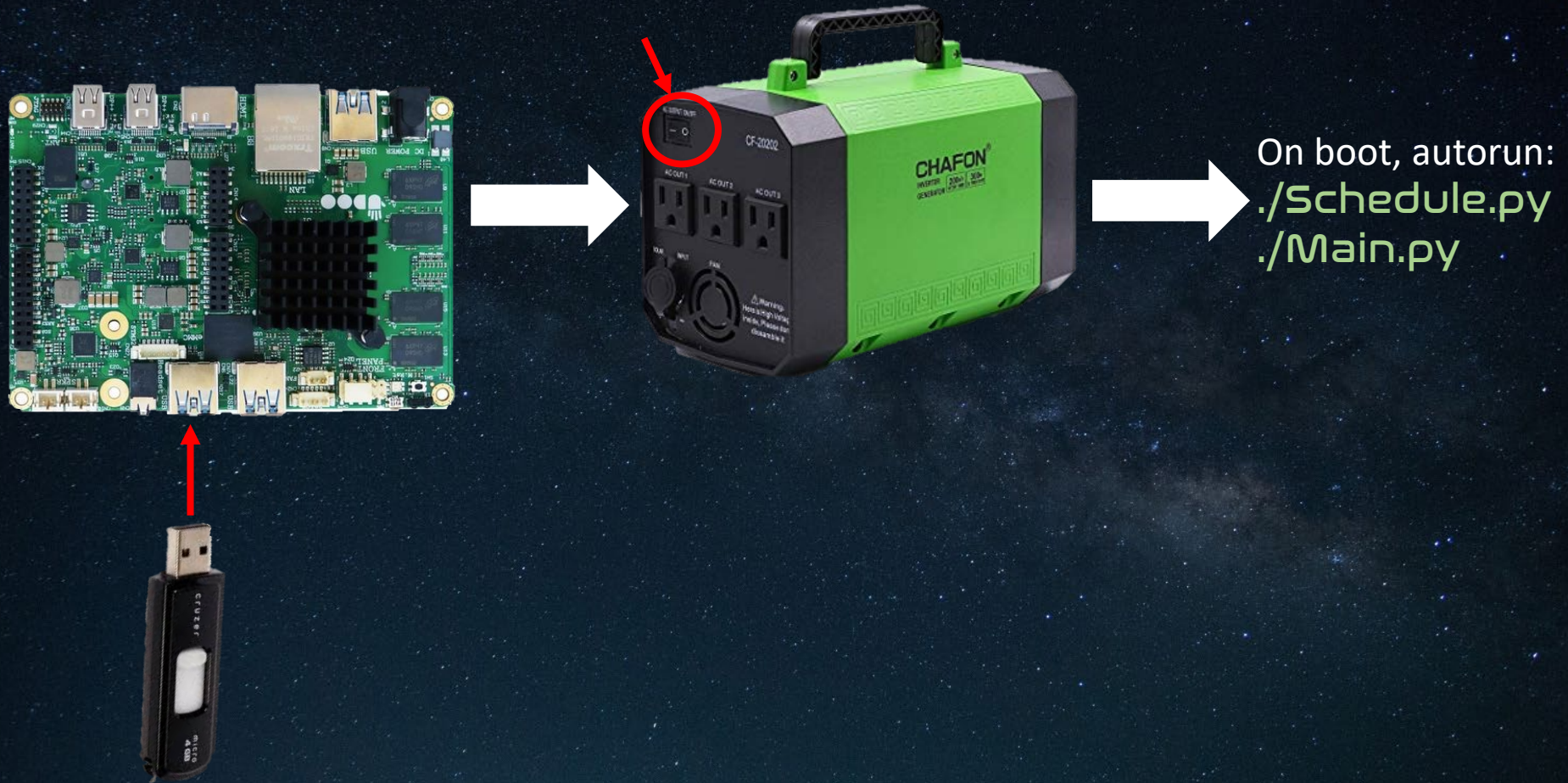
Questions?

Thank you to:

- Professor Marcus Holzinger
- Aerospace Corporation, Daniel Pachura
- ASEN 4028 – TA

Backup Slides

Operator Input



Orbit Determination Status



- Prototype in MATLAB
 - Equations of motion including two-body and J2
- Research
 - Found python equivalents to built in MATLAB functions used
 - Skyfield Github repository
 - Researched SRP and drag models
 - Cannonball model for SRP
 - Jacchia-Roberts for atmospheric density
 - Drag will rely on B^* drag coefficient estimate

Software Architecture



Scheduler

.cmd file

Hardware

Image Processing
(IP)

Orbit Determination
(OD)

Image1.fits
Image2.fits
Image3.fits
Image4.fits
Image5.fits
Image6.fits
Image7.fits

batch_out1.txt
batch_out2.txt
batch_out3.txt

OD_out1.txt
OD_out2.txt
OD_out3.txt

Event-Driven programming

Actuation/Imaging Hardware listens to clock, executes as scheduled.

IP listens for available images, processes from queue.

OD listens for batches of measurements, processes from queue.

Hardware Command and Control



Instrument Neutral Distributed Interface is a protocol designed for astronomical equipment control.

- Compatible with **imaging sensor** and **mount**

For Each line in .cmd file

Satellite ID	Move Time	Begin Time
1	00:00:00	00:00:10
2	00:00:40	00:00:50
3	00:01:00	00:01:25
4	00:01:30	00:01:56

If Current Time > Move time

Command slew to RA/DEC

If Current Time > Begin Time

Command exposure

Software Status



Software Component	Priority for Testing
Scheduler	High
Hardware integration/ commands	High
Image Processing	Low
Orbit Determination	Low
Main Script	Low