DEPARTMENT OF SPACE & CLIMATE PHYSICS
MULLARD SPACE SCIENCE LABORATORY

Coursework Cover Sheet

Module Name: SPCE0014: Space Science and Engineering Individual Project

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AUTOMATED SKY SURVEY ANALYSIS METHODS: INITIAL REPORT

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1 BACKGROUND

The Japan Astrometry Satellite Mission for Infrared Exploration (JASMINE) is a scientific mission that was selected by the Institute of Space and Astronautical Science (ISAS) and the Japan Aerospace Exploration Agency (JAXA) in May 2019 [1]. The mission will have three main scientific goals [1]:

1. Investigation of the structure of the Milky Way's central core
2. Exploration of the formation history of the Milky Way
3. Discovery of Earth-like habitable planets

These scientific goals will be satisfied with three main targets in the sky: the galactic centre, the galactic mid-plane, and M-type stars [2]. These targets are distributed throughout the sky therefore visibility of each target will vary significantly, both on short and long timescales. This notably affects the galactic centre which will not be visible during winter and summer due to the angular separation between the galactic centre and the Sun introducing "bad thermal conditions for the observation" [1].

The scientific investigations will be conducted using an infrared telescope with a 30 cm primary mirror and 3.9 m focal length [1]. These wavelengths were selected to avoid the absorption and scattering effects of interstellar dust on visible wavelengths which would affect both the number of observable stars and observation accuracy [1].

The JASMINE spacecraft will be launched into a Sun-Synchronous Orbit (SSO) at an approximate altitude of 550 km [1]. The Local Time of the Ascending Node (LTAN) will be either 06:00 or 18:00 [1], therefore the spacecraft will follow the Earth's terminator with constant illumination from the Sun.

2 OBJECTIVES

The primary objective of this project will be to develop the Automated Sky Survey Analysis Methods (ASSAM) software. This will enable the evaluation of sky survey plans for JASMINE, maximising the scientific return of the mission.

A preliminary review of available sky survey software found that although these have been widely created for various missions, access is typically extremely limited. One of the objectives is, therefore, to produce a flexible tool for various different missions which is open source.

The initial code will be lightweight with an emphasis on computational performance to aid with rapid, iterative mission planning. Nevertheless, modularity will enable more detailed models to be added to the software, increasing its ability as needed.

Automated optimisation of the survey schedule will aid with rapid, iterative mission planning, particularly for longer duration missions with an increasing number of observation objectives and constraints. Additionally, it will improve accessibility to this form of sky survey analysis.

3 SUMMARY OF WORK PROGRAMME

A flowchart illustrating the preliminary software design is presented in Figure 3.1, identifying the main inputs, processes, and outputs.

Python [3] will be the language of choice for this project due to its popularity and ease of use. Furthermore, the language has a significant number of libraries, both first and third-party, which will significantly aid development.

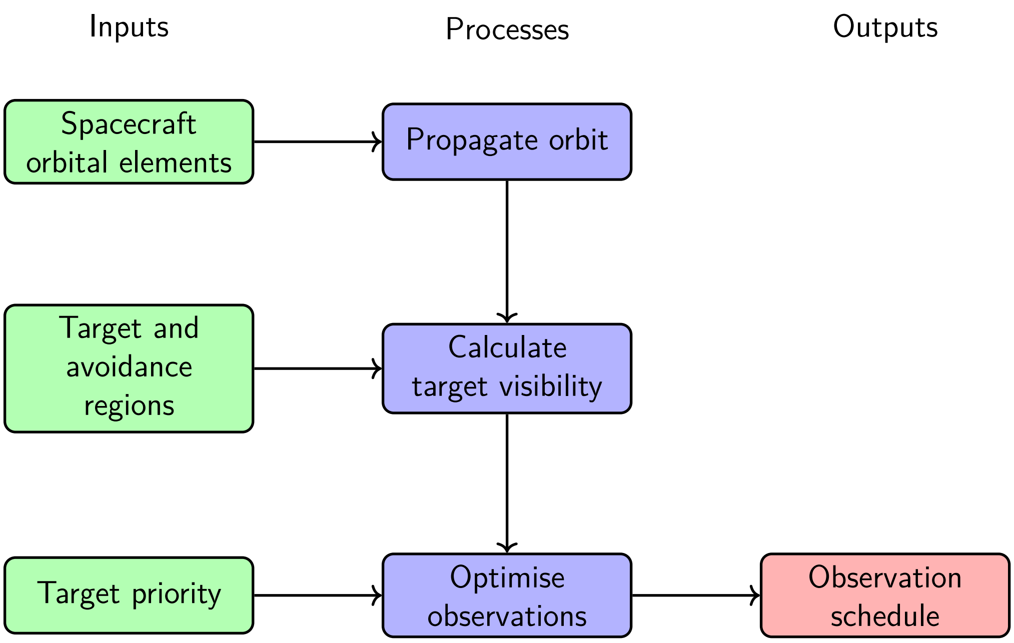


Figure 3.1: Preliminary software flowchart

4 WORK DONE SO FAR

4.1 Version Control

Standard version control practices will be implemented to track changes in the software. Git was chosen due to its widespread popularity, and ease of use with multiple collaborators. A repository was created on Github to enable future collaboration*.

4.2 Astrodynamics

Several Python packages have been investigated for the astrodynamics required to simulate the orbit of JASMINE including poliastro [4], Orekit [5], and Tudat [6]. Several issues were found: poliastro has not been independently validated; Orekit requires a detailed configuration process to interface with Python; and Tudat's Python wrapper was found to be sensitive to Python package versions.

It was decided not to use these packages during the prototyping phase, although this may change at later stages of the project. Initial work will, therefore, be conducted using the General Mission Analysis Tool (GMAT) [7], an astrodynamics package developed by the National Aeronautics and Space Administration (NASA) which runs using an easily generated script file, and outputs to a variety of machine readable formats.

4.3 Coordinate Systems

The equatorial coordinate system at the J2000 epoch was chosen as the primary coordinate system for the project. Due to the spacecraft's close proximity to Earth, an approximation will be made where celestial coordinates at Earth and the spacecraft will be considered equivalent.

Targets may be defined in either the galactic or equatorial coordinate systems, therefore coordinate system transformations will be required. The Python package astropy [8, 9] will be used for this purpose.

4.4 Target Visibility

A scheme for calculating separation between targets and avoidance regions, such as the Sun, Earth, and Moon, is illustrated in Figure 4.1. The targets and avoidance regions will be defined, at least initially, as circles on the sky with known centres and radii. Intersections will be calculated by comparing the radii with the angular separation between the centres. A target would be visible at a particular time if Equation 4.1 was satisfied with all avoidance regions:

$$\theta \geq r_1 + r_2. \tag{4.1}$$

This scheme for calculating valid contacts is limited to circular regions of the sky. The performance of this method, in terms of accurately identifying target visibility for arbitrary regions of the sky, will be limited due to discrepancies between the true region and its bounding circle as shown in Figure 4.2.

*Access available upon request

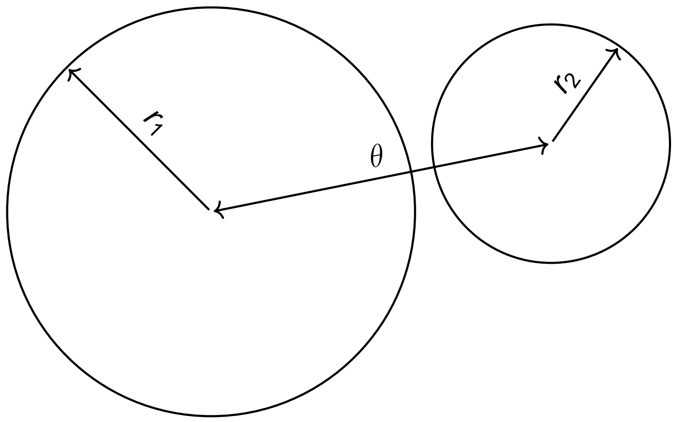


Figure 4.1: View separation geometry for two circular regions.

A potential scheme to mitigate this issue would treat the above scheme as a first pass to provide a coarse estimate of visibility. Where the coarse scheme detects an intersection, an additional pass would carried out with more detailed separation calculations, taking the true geometry into account. The astropy affiliated package, regions, will be investigated for this purpose, although this is still at an early stage of development [10]. It is expected that the two pass method will provide higher computational performance than solely conducting the detailed calculations for every sample time. Nevertheless, this will need to be tested during development.

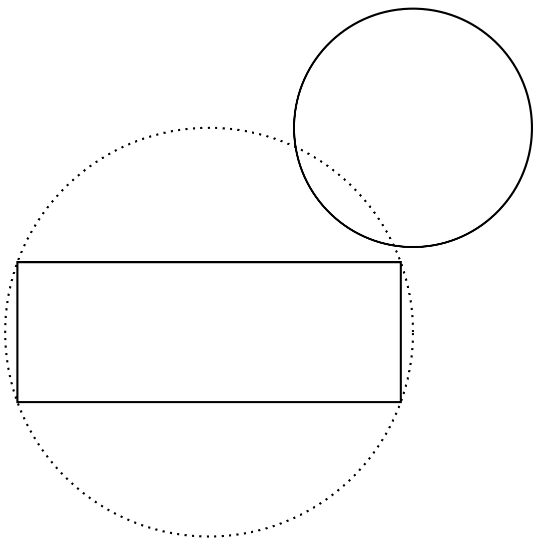


Figure 4.2: View separation geometry for a rectangular region with a bounding circle (dotted) and a circular region. This figure illustrates that the bounding circle calculation, which would detect an intersection, does not accurately capture the separation between the true regions, which do not intersect.

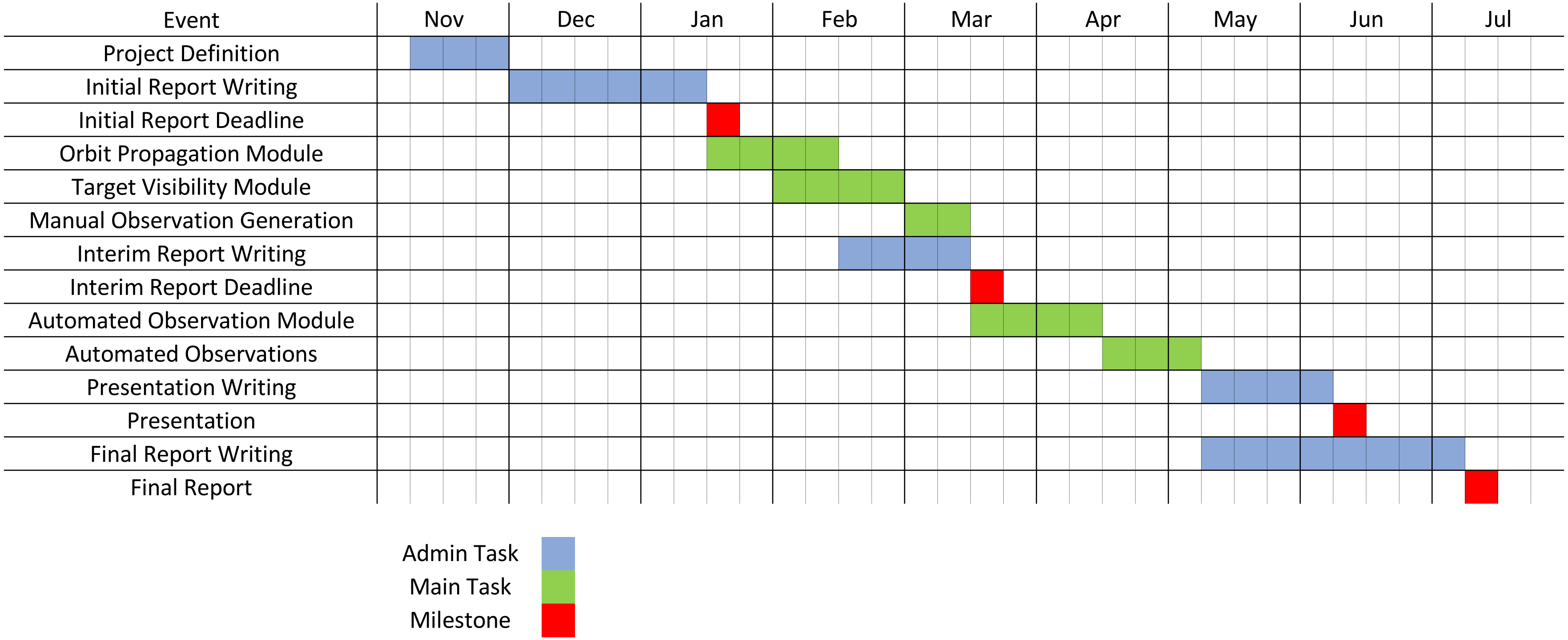
5 PROJECT SCHEDULE OUTLINE

A preliminary project timeline is presented in Table 5.1. The main project milestones, highlighted in red, correspond to the deadlines in January, March, June, and July. Each milestone was assigned a minimum of four weeks to ensure sufficient time to complete the deliverables.

This timeline contains the ambitious objective of developing the first two modules in time to present preliminary results in the interim report. Manual scheduling is currently considered the main objective of the project, with full automatic optimisation of observations as a stretch goal. The option of removing this stretch goal will exist if descoping is necessary due to delays and time constraints.

Nevertheless, it is expected that this timeline will change as the project progresses. The timeline will be evaluated continuously, taking into account the rate at which tasks are completed.

Table 5.1: Preliminary project timeline.



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