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FEASIBILITY STUDY OF DATA RECEIVING STATION IN KOREA FOR CSA UV SPACE TELESCOPE PROJECT

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ABSTRACT

We present a feasibility study of a data receiving station in Korea to be used for a 50cm UV space telescope proposed by CSA. The feasibility was investigated by examining the spacecraft visibility from four different cities in Korea, based on the orbital characteristics of the proposed spacecraft, *i.e.* inclination of 28.5° and circular orbit altitude of 690km. The satellite can be accessed from Korea about 4 times a day, each pass having the duration of 6 to 9 minutes depending on the elevation mask and the latitude of each site. Provided that the X-Band signal can be retrieved from 10° elevation, this study demonstrates that a ground station placed in any of the four cities can be used for a reasonable backup downlink of the science data gathered by the proposed UV space telescope.

1. INTRODUCTION

Space based observatories have made major astronomical discoveries because of the ability to observe in the γ- and X-ray, ultraviolet, infrared, sub-millimeter and low radio-frequency regions. They can also produce much sharper images than ground-based telescopes without being blurred by air turbulence. Recently, the rising costs of large satellites, limiting budgets, and improved data transmission techniques have created new interest in small, relatively inexpensive satellites carrying instrumentation optimized for a specific problem which can take advantage of improvement in detector and related instrument technologies.

The small UV telescope proposed by Center for Space Astrophysics at Yonsei University, hereafter referred to by CSA, is designed to map the global star formation history of galaxies over the redshift range $0 < z < 2$ using the space ultraviolet radiation with wavelength coverage of $1300 - 3000_{\Delta R}$A. This mission is being developed as a cooperative project with Caltech scientists. The spacecraft will be placed in a circular orbit inclined 28.5° with a nominal altitude of 690km (Martin *et al.* 1998).

In this paper, overall orbital characteristics of the spacecraft and orbital event sequence for the space UV observation are described. Then, simulation has been performed for the satellite accessibility from the Korean peninsula in case we place a ground station in one of four candidate cities; Seoul, Taejon, Pusan, and Cheju.

2. ORBIT ANALYSIS AND EVENT SEQUENCE

2.1 Orbital specification

Approximately a third of the cost of a space telescope is associated with launching and maintaining in its operational orbit (Pritchard *et al.* 1993). Therefore, it is essential that the system engineer give careful considerations in selection of appropriate orbit, so that instrument package can function satisfactorily in accordance with mission objectives.

The proposed spacecraft will be placed in a circular orbit at the altitude of 690km and inclination of 28.5°. This altitude is chosen so that the space telescope is not under severe effects of the Van Allen radiation belts (Wertz 1991). Also the altitude of 690 km is high enough to be free from airglow background which is caused by molecules and atoms in the upper atmosphere that slowly release daylight-stored energy. At the altitude of 690 km, the air density is low, but not negligible. Accordingly, as the mission proceeds, the orbit will slowly decay from the initial orbit due to air drag and other perturbing forces unless orbital maneuvers are done periodically (Chobotov & Karrenberg 1991). However, deviation from the initial orbit will not corrupt the planned instrument observations and, therefore, will be allowed with the spacecraft carrying no propulsion system. It will simplify spacecraft bus design tremendously and lead to significant cost reduction.

2.2 Orbital event sequence

The orbital period of the spacecraft is about 98 minutes and science observation will be performed only during the eclipse which is 35 minutes long. During daylight, the battery will be fully charged but the instruments will not make observations (Martin *et al.* 1998). The spacecraft will keep the telescope perpendicular to the Earth-Sun line, preventing both from entering the telescope field of view. This will also make the solar panels faced at the sun directly, eliminating the need for solar array drives. About 6 minutes prior to the start of an eclipse, the spacecraft will slew the telescope to a pre-commanded celestial position while keeping the Earth and Sun from entering the telescope field of view.

During the eclipse the payload performs its observations. At the end of the eclipse, the spacecraft will slew back to its daylight attitude and start to charge its battery. This orbital event sequence is shown in Figure 1.

3. GROUND STATION VISIBILITY

3.1 Earth coverage

A satellite is visible from the Earth surface at all places within a coverage, centered on the subsatellite point, and whose diameter increases with satellite altitude. However, signals from satellites at near horizon are considerably attenuated by the atmosphere. Assuming that the minimum Gain/Temperature (G/T) of the X-band station is 32dB/°K at an elevation of 10°, the X-band downlink of the proposed spacecraft can be closed at a data rate of 16Mbps, and a bit error rate of 10^{-6} with 3.50dBs of link margin, after a budgeted 2dBs of loss for rain fade (Martin *et al.* 1998).

If it is visible only down to elevation equal to θ, then the semi-angle ϕ of visibility is given by (Fortescue & Stark 1991)

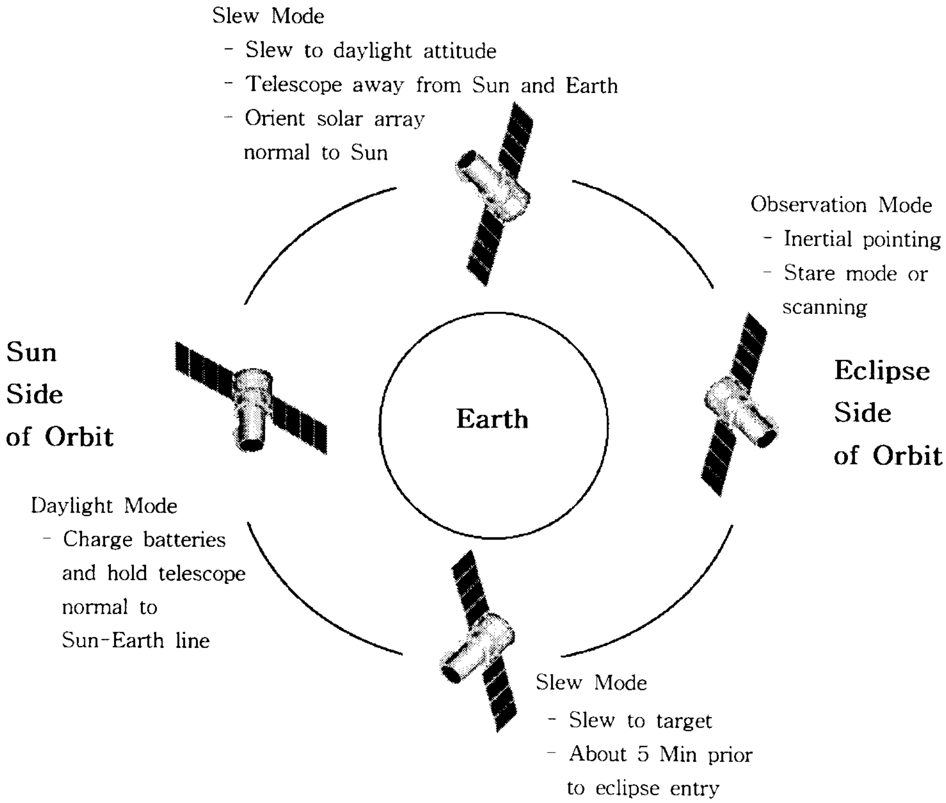

Figure 1. Orbital event sequence.

$$\phi = -\theta + \cos^{-1}\left(\frac{R_E}{R_E + h}\cos\theta\right) \tag{1}$$

where R_E is the equatorial radius for Earth, and h represents the satellite altitude. At the extremes of its visibility, the slant range s is given as

$$s = (R_E + h)\frac{\sin\phi}{\cos\theta} \quad . \tag{2}$$

The duration of a pass with a semi-angle ϕ is

$$\tau = \frac{2\phi}{\omega_{ES}} \tag{3}$$

where ω_{ES} is the orbital angular velocity relative to Earth. ω_{ES} may be obtained from the Earth's angular rate ω_E and the satellite's orbital angular velocity ω, using

$$\omega_{ES}^2 = \omega_E^2 + \omega^2 - 2\omega_E\omega\cos i \tag{4}$$

Table 1. Coverage angle which varies according to the elevation mask.

Elevation mask	Earth coverage semi-angle	Slant range	Maximal duration
0°	25.5°	3042.9km	14.85min
5°	21.0°	2542.7km	12.23min
10°	17.3°	2134.3km	10.07min
15°	14.4°	1819.8km	8.39min

where i is the orbital inclination. Table 1 lists the coverage semi-angle, slant range, and the maximal duration for the proposed UV space telescope.

3.2 Satellite longitude change

Ground track of the spacecraft for 1 day is presented in Figure 2. Between successive orbits the subsatellite point on the equator will change in longitude by $\Delta\phi$. The amount of this angle is determined by two effects; the rotation of the Earth and nodal regression. The Earth rotates through one revolution in its sidereal period of $S_E = 86164.09055 + 0.015T$ seconds, where T is measured in centuries from 1900 (Kalke 1994). If the satellite's period is P then the contribution to $\Delta\phi$ which is caused by the Earth's rotation will be given as

$$\Delta\phi_1 = -2\pi \frac{P}{S_E} rad/orbit \quad . \tag{5}$$

The contribution by regression of the line of nodes is (Kalke 1994)

$$\Delta\phi_2 = -\frac{3\pi J_2 R_E^2 \cos i}{a^2(1-e^2)^2} rad/orbit \tag{6}$$

where J_2 is the second zonal harmonic coefficient due to the Earth's oblateness. By applying the spacecraft orbital elements, $P = 5913.83sec$, $a = 7068.137km$, $i = 28.5°$ and other physical constants to Equations (5) and (6), we get the total westward drift at the equator

$$\Delta\phi_1 + \Delta\phi_2 = -25.117° \quad . \tag{7}$$

In Figure 2, we can verify this westward drift in order to plan the observation data downlink schedule.

3.3 Duration of ground contacts

Since two omni directional antennas are supposed to be used to downlink science data via an X-band link, the space telescope will be able to transmit its stored data even while it is performing science observations. Therefore, the satellite accessibility can be examined simply by considering all ground contacts regardless of the spacecraft attitude.

Table 2. Ground contacts and single pass.

Location	Latitude (°N)	Contact (Mins/day)		Single pass (Seconds max)	
		5°	10°	5°	10°
Equator	0	68.56	45.21	733	604
Puerto-Rico	19.0	81.25	58.91	732	603
Cheju	33.5	53.52	37.38	712	580
Pusan	35.1	49.37	33.61	696	560
Taejon	36.4	45.82	30.24	680	539
Seoul	37.5	42.30	26.93	662	516

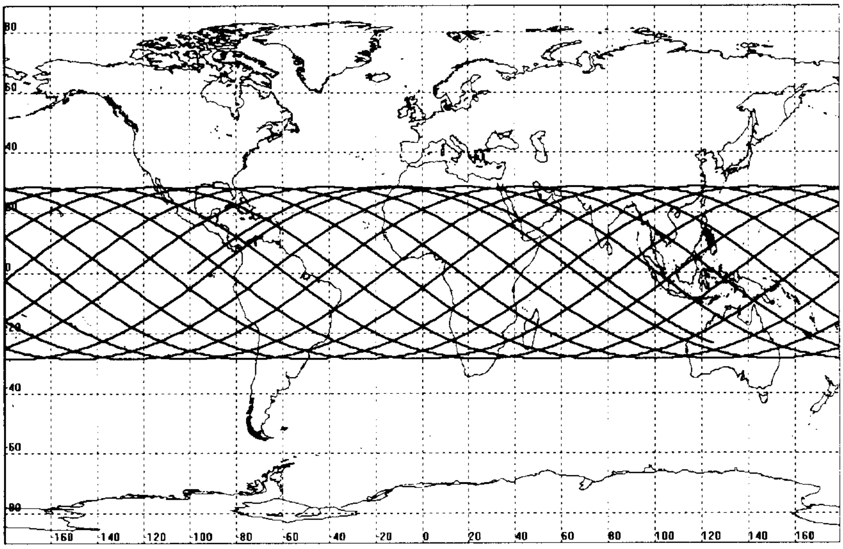

Figure 2. Ground track of CSA UV space telescope.

As shown in Figure 2, the satellite ground trace is limited in the area whose latitude is within ±28.5 degrees, *i.e.* the spacecraft orbit inclination. Generally the satellite accessibility depends upon the latitude of a ground station, given the same topographical condition. The average duration of ground contacts increases as a station moves from the equator to ±28.5°, but beyond the latitude of ±28.5° it starts to decrease. Assuming that we limit the location of the ground station in the Korean Peninsula as shown in Figure 3, a higher latitude will result in shorter duration of contacts.

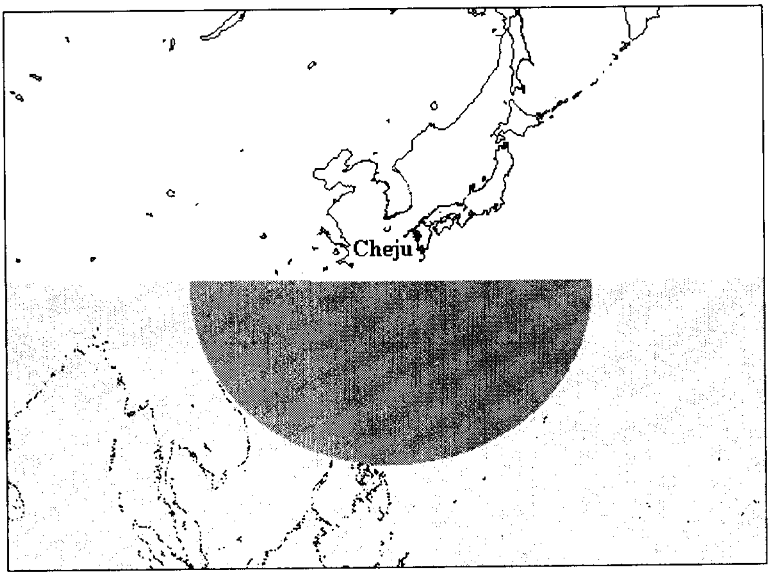

Figure 3. Satellite access area viewed from Cheju.

In Table 2, several locations and their calculated duration of contacts are listed. These values are calculated with the constraint of 5° and 10° elevation mask angle. The equator and Puerto-Rico with the LandSat X-Band station are included for reference. The duration and the single pass are calculated by propagating the spacecraft orbit for 30 days and taking the average and maximum from the satellite access data.

With the nominal X-band data transmission rate of 16 Mbps and also with the total data storage requirement of the planned space UV observation being about 22 Gbits, we need at least 23 minutes of contact per day to receive all of the disc data. A plot of maximal amount of data transmission for each ground station is given in Figure 4.

4. SUMMARY

The orbital characteristics of a UV space telescope proposed by CSA have been described. We then tested the feasibility of a data downlink station in the Korean peninsula by examining Earth coverage angle and ground contact duration. The Earth coverage semi-angle of the spacecraft is expected to be less than 17.3°, assuming that X-Band downlink is allowed only when the satellite elevation is greater than 10°. This will give maximal contact of 10.07 minutes to any ground station whose latitude is less than the orbit inclination. Therefore the ideal place for a ground station for this space telescope will be a site at low latitude. However, sites at higher latitude can be effectively used for the data downlink because a complete downlink for the observation data can be performed within 23 minutes per day. This value is, however, an extreme upper limit, as the on-board data storage of

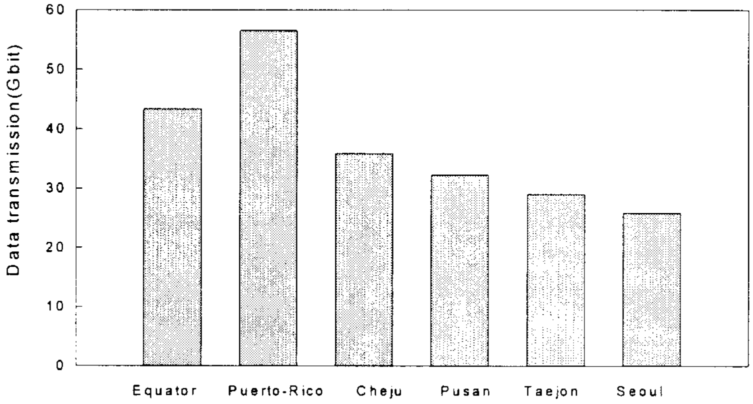

Figure 4. Maximal amount of data transmission per day.

22 Gbits is also with a 40 % safety margin. Actual downlink time can be, therefore, much less.

Although Seoul has the highest latitude among the cities considered, it can provide a contact time long enough to download the spacecraft data in daily basis. At present, the X-Band station in Puerto-Rico is considered for the proposed UV telescope downlink. However, considering the higher weather sensitivity of X-Band communication and possible malfunctions, it is safe to have backup and independent data receiving station for the space telescope. A site in Korea would be a reasonable solution as a backup station.

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