LAGRANGIAN L2 OR GEOSTATIONARY ORBIT: A SYSTEM LEVEL TRADE-OFF FOR THE GAIA MISSION

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ABSTRACT

The Lagrangian L2 and geostationary orbits are being investigated as possibilities for the GAIA astrometric mission. The advantages of each orbit are discussed, and the present baseline is presented.

Key words: space astrometry; orbits.

1. INTRODUCTION

The technical requirements derived from the GAIA scientific requirements all go in the direction of the selection of a very quiet environment for the payload, in terms of mechanical microvibration, thermomechanical stability, and radiation. This puts severe constraints on the satellite concept and on the selection of the corresponding orbit. A number of suitable orbits have therefore been examined and evaluated in a preliminary manner, with the retention of two candidate orbits to be studied in further detail: a Halo/Lissajous type of orbit around the Lagrangian point L2, and a geostationary type orbit.

This paper identifies the main differences between the L2 and the geostationary types of orbit, together with the relevant satellite system level impact due to the selected orbit. An example of the impact is also briefly described. Although with some reservations requiring further study effort, it can be concluded that, at present, the selection of an orbit around the Lagrangian point L2 is favoured for a mission like GAIA.

2. TYPE OF ORBIT UNDER CONSIDERATION FOR GAIA

Two orbit locations are being evaluated at present for GAIA:

- a quasi-stabile Lissajous or Halo type of orbit around the Lagrangian Point L2 of the Sun-Earth system (the same selected for the FIRST and PLANCK missions);
- a geostationary orbit, similar to that planned, but not achieved, for the Hipparcos satellite.

Both final orbit locations are assumed to be reached starting from an Ariane 5 geostationary transfer orbit, with a midnight launch, in multiple configuration, and characterised by a perigee altitude of 620 km, apogee altitude of 36 000 km, inclination of 70°, and argument of perigee of 178°.

3. GEOSTATIONARY VERSUS ORBITS AROUND L2

Table 1 gives a summary of the main characteristics of both the L2 and the geostationary types of orbit, by highlighting the parameters having potential impact on the satellite system, including launch, spacecraft, ground segment, and science and ground operations.

As seen from the table, most of the parameters are in favour of the orbit around L2, the only advantages from a geostationary type of orbit are the transfer time, the operational distance satellite-Earth, and the ground station coverage. However, the distance of 1.7 million km for the L2 orbit could penalise heavily the satellite system, since the problem of transmitting to ground the high science data rate required by GAIA is not trivial and could have a strong impact to the overall satellite system design.

4. SYSTEM LEVEL IMPACT FROM THE ORBIT SELECTION

Table 2 indicates the impact of the main orbit characteristics on the concept, design, architecture, and cost of the whole satellite system, on the in-orbit part as well on the ground part. The qualitative cost impact is indicated with LC, for the Lower Cost impact, and HC, for the Higher Cost impact, by comparing the orbit around L2 with the geostationary.

As seen from the table, also from a qualitative cost assessment the orbit around L2 is advantageous in respect of geostationary type of orbit.

Table 1. Orbits around L2 versus gesotationary: main characteristics.

	Orbit L2	Geostationary
Radiation Environment	low	medium
Thermal Environment	stable no eclipses	variation by Earth radiation and eclipses
Sky Viewing	Earth and Sun close in direction	occultation by Earth
Orbit Injection		
– Delta-V	~800 m/s	~1500 m/s
– Transfer Time	~90 days	1 day LEOP + drift of ~10 days
– Transfer Means	Ariane 5 restartable motor	spacecraft propulsion system
Communications		
– Distance (max)	~1 700 000 km	~ 36 000 km
– Coverage (one station)	~16 h/day	24 h/day

Table 2. System level impact of the orbit selection: LC corresponds to a lower cost impact; HC to a higher cost impact.

Low Radiation	Longer lifetime, better detector performances	LC
More Stable Thermal Environment	Higher probability to meet (severe) stability requirements	LC
Better Sky Viewing	Shorter mission duration for the same scientific goals (or better performance during same mission lifetime)	LC
Lower Delta-V	Less heavy satellite	LC
Longer Transfer Time	Marginal longer mission (+ about 2 months)	HC
Usage of Ariane 5 Rastartable Motor	Possible (no need for spacecraft propulsion system)	LC
Higher Distance from Earth	For high data rate (order of 1 Mbps), impact on: – on-board data processing and storage – communications subsystem – number and type of ground stations (X, K-Band)	HC
Shorter Coverage with One Station Only	Critical with high data rate transfer	HC
No Eclipse	– simplified power supply subsystem – better thermomechanical stability	LC

5. SYSTEM IMPACT OF EARTH DISTANCE IN THE L2 OPTION

It is clear that the rate of the science data acquired by the GAIA interferometers is directly related to the numbers of stars to be observed. To quantify the problem, we assume tentatively for the transmission of the science data to the ground the following satellite data rates (Table 3):

By considering marginal the contribution of the possible radial velocity instrument and the housekeeping data, in particular in the case of direct fringes detection, the transmission of a data rate of 51 Mbps or even 17 Mbps from 1.7 million km is very hard to achieve.

In order to try to characterise the problem, we make the following assumptions for the reduction/compression of the science data before the transmission to the ground, for the data storage on-board, and for the station receiving the data on-ground:

– compression/reduction rate	100
– storage on-board	0
– coverage on-ground	24-hours

With these assumptions the telemetry data rate to the ground, including the contribution of the radial velocity instrument and housekeeping, is somewhere between a lower limit of 400 kbps (for the case of two interferometers and grid detection) and an upper limit of 2 Mbps (for the case of four interferometers, direct fringe detection).

The solution to the problem of transmitting from 1.7 million km a data rate as high as 2 Mbps can be found by applying the methodology described below. Only a system study based on a trade-off at satellite system level can give the definition of a suitable system architecture, involving the space and ground segments of GAIA. These studies should be based on the following approach:

- number of interferometers (2 to 4) and type of detection (grid versus fringes) to be frozen;
- an efficient raw data reduction/compression algorithm to be studied, taking into account a maximum number of observed stars;
- a data dump to ground strategy to be defined, by freezing the maximum outages allowed per great scan, day, month, year, mission lifetime; the number of ground stations; the on-board memory storage capability; the performances of the on-board/ground communications system (S-band, X-band, Ka-band);
- the relevant costs to be evaluated.

From a preliminary assessment of the problem, the transmission from L2 orbit of a data rate of the order of 1 Mbps seems feasible by making use of the

Table 3. Satellite data rates.

For each interferometer	16 Mbps for grid detection 50 Mbps for direct fringe detection
For the radial velocity instrument	1 Mbps
For the spacecraft housekeeping	2 kbps

Ka-band and high gain, phased-array antenna. No problem is expected from geostationary orbit for the transmission of the same data rate of 1 Mbps, but with an omni-directional coverage, making use of low-gain antennae.

6. CONCLUSIONS

Although the telemetry data transmission to ground may represent a not negligible challenge to the conception of GAIA satellite system and bring may be cost impact, all the other considerations indicate that the orbit around L2 is to be preferred for the GAIA mission. At present, the orbit around L2 is, therefore, baselined for the GAIA mission study, to be started with the industry soon after the next summer of this year, 1997, while the geostationary type of orbit is retained as backup.

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