Atmosphere and Climate Explorer Plus Looking at the Horizon

Innovative atmospheric sounding using active inter-satellite cross-link signals

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Abstract

The Atmosphere and Climate Explorer Plus (ACE+) is an atmospheric sounding mission using radio occultation techniques. The mission is a response to ESA´s 2nd Call for Earth Explorer Opportunity Missions in 2001 and was ranked no. 1 out of 25 candidate missions. ACE+ will considerably advance our knowledge about atmosphere physics and climate change processes. The mission will demonstrate a highly innovative approach using radio occultations for globally measuring profiles of humidity and temperature throughout the atmosphere and stratosphere.

The baseline constellation of 4 small satellites, tracking L-band GPS/GALILEO signals and X/K-band LEO-LEO cross-link signals, will be launched in 2 counter-rotating orbits with 2 satellites in each at 650 and 850 km respectively. The system design is aimed to optimise the science return by proper distribution of the observations in space and time. The LEO-LEO cross-link instrument is driven by accuracy requirements that drive antenna design, transmitter power, and transmitter and receiver stability. Spacecraft design is driven by the relatively high power consumption of the instruments, and their pointing requirements. Satellite characteristics include a mass of 160 kg, and available power of 125 W. Low cost launch is envisaged to be with Rockot or START-1, and can take place in 2006-2007. Finally, the ground segment processes data from all satellites, including GPS satellites, for distribution to the meteorological community.

Introduction

This extended abstract gives a mission overview and describes options and technical solutions for ACE+. SSC has been selected by ESA as to head a team that includes Terma, EMS Technologies, Laben, Astrium, Dutch Space, Danish Meteorological Institute, and the University of Graz, to study the mission in a phase A study. Still being at the start of the study the paper presents different of design solutions and sometimes indicates the most likely solution. This is done for the overall system, the payloads, the satellite, and the ground segment. Finally some of the programmatics of the Earth Explorer Opportunity mission are presented, which are related to ACE+.

Mission Overview

The Atmosphere and Climate Explorer mission (ACE+) was proposed in January 2002 in response to ESA’s 2nd call for Earth Explorer Opportunity Missions. The concept involves systematic gathering of data over a five-year period of precise profiles up through the atmosphere of temperature and humidity around the Earth. These profiles are subsequently used in conjunction with climate modelling and climate prediction techniques developed by meteorological institutions to improve the understanding of the driving forces behind climate change and variability.

The ACE+ mission will contribute in a significant manner to ESA's Living Planet Programme under the themes of “Physical Climate” and “Atmosphere and Marine Environment” with the mission goals:

- To monitor climatic variations and trends at different vertical levels and for each season in order to improve the understanding of the climate system as well as to detect the different fingerprints of global warming
- To improve the understanding of climatic feedbacks defining the magnitude of climate changes in response to given forcings
- To validate the simulated mean climate and its variability in global climate models
- To improve and tune - via data assimilation - the parameterisation of unresolved processes in climate models and to detect inter-annual variations in external forcing of climate.

The mission will demonstrate a highly innovative approach using Radio Occultations for globally measuring profiles of humidity and temperature throughout the troposphere and stratosphere. A constellation of 4 small satellites, tracking L-band GPS/GALILEO signals and X/K-band LEO-LEO cross-link signals, will map the detailed refractivity profile and structure of the global atmosphere using a configuration of 2 counter-rotating orbits with 2 satellites in each at 650 and 850 km respectively.

The Radio Occultation technique illustrated below has so far been studied for ESA using signals from the Global Navigation Satellite System (GNSS) to determine phase and amplitude changes caused by the atmosphere. The observations have been done from Low Earth Orbiting (LEO) satellites. In the ACE+ mission the GRAS-2 instrument will provide such data for GPS and possibly GALILEO with unprecedented coverage.

In order to improve the separation of the contributions of water vapour and temperature in the lower troposphere, without using external data, ACE+ will also actively sound the atmosphere using LEO-to-LEO signal transmission at three frequencies around the 22 GHz water vapour absorption line (10, 17, and 23 GHz). Measurements of the occulted phase and amplitude of the electric field from the LEO transmitter at these frequencies will deduce independent information on temperature and water vapour distributions with an unprecedented accuracy. This technique was suggested in the WATS Core Mission proposal to ESA’s Earth Explorer Programme in 2001 and examined in subsequent pre-phase A studies for the Agency.

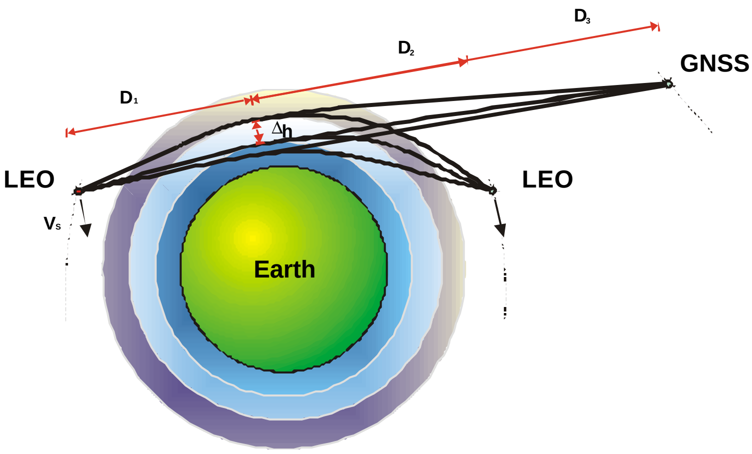

Figure 1: Outline of the Geometry for Radio Occultation Measurements Based on LEO-LEO and GNSS/GALILEO-LEO Observation Schemes

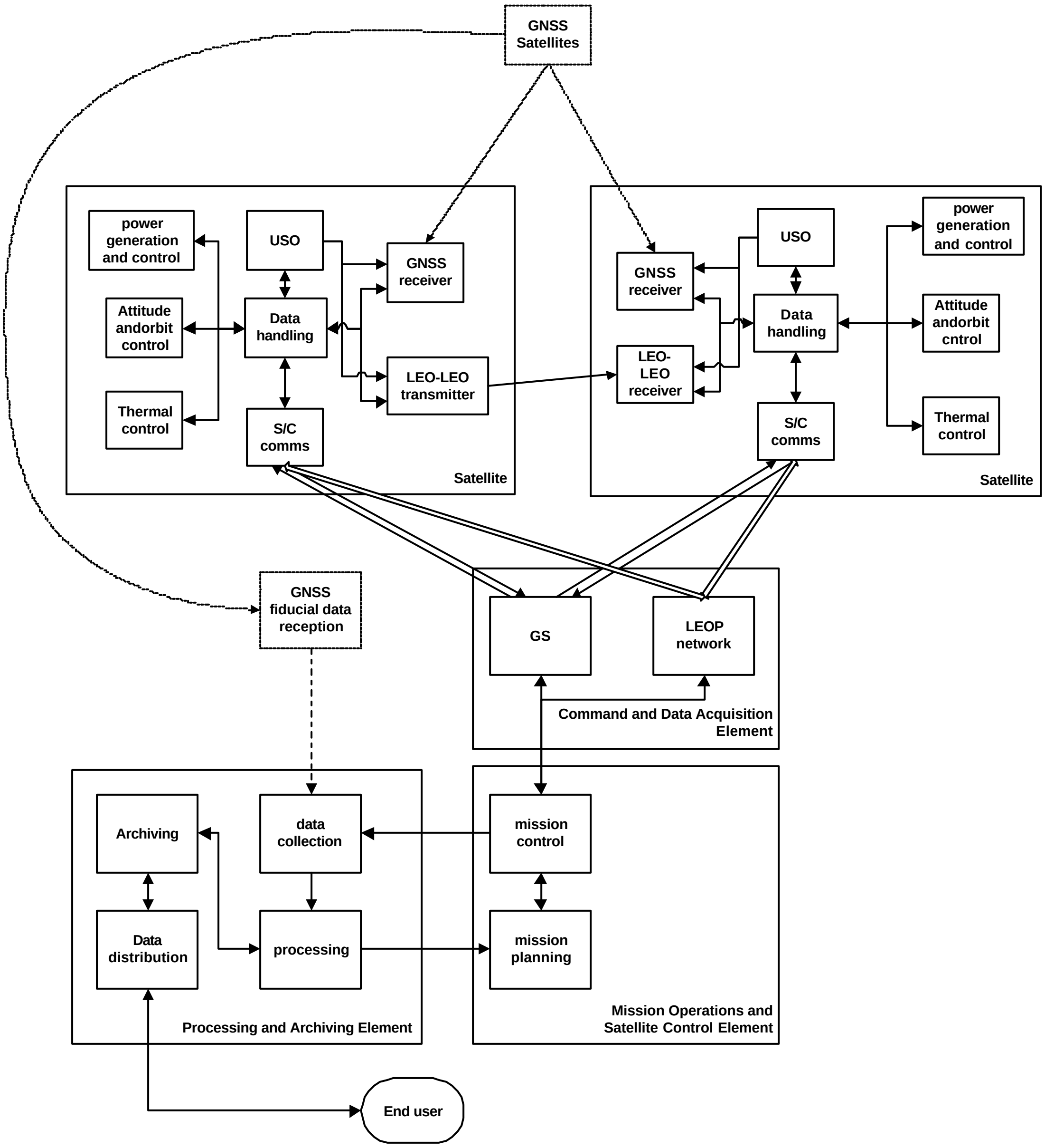

Figure 2: A Functional Architecture of the ACE+ Mission.

System Design

The overall system is quite well defined, following the studies of APEW, ACE and WATS. Figure 2 shows a likely functional architecture for the overall system that consists of the following components

- GRAS-2 receiver for GNSS Radio Occultations (GRO) and navigation, consisting of a multiple channel, high accuracy GNSS receiver, fore and aft antennas pointed at the horizon, and a zenith antenna for navigation. The GNSS timing data will also be used to update the spacecraft onboard time.
- LEO-LEO Radio Occultation (LRO) Instrument, consisting of a transmitter, receiver and antennas to measure bending angle and transmission of at least three frequencies around the water absorption line.
- Ultra Stable Oscillator (USO), which supplies a reference frequency to the instruments, and which can be used to update the on-board time
- Satellite platform, supplying: Data handling services, Communication on S-band with ground, Power generation,

control and distribution, Attitude and orbit control, Thermal control and Structural functions

- Ground Segment, supplying: Mission operations and Satellite Control Element (MSCE) for mission control and planning, Ground station with S-band antennas for nominal operations, Launch and Early Operations Phase (LEOP) network for communication during LEOP and contingencies, Processing and Archiving Element (PAE) providing data collection, processing, archiving, distribution, and Communication channels between the centres, ground station, LEOP network and certain end-users.

Components that are indispensable to the proper functioning of the system, but that are outside the system boundary comprise the GNSS (GPS and possibly Galileo) satellites and their signals, the fiducial network for GNSS ground reference, communication channels between the PAE and the fiducial network, and communication channels between End users and the PAE (i.e. internet)

Constellation Design

A constellation can be characterised by aspects such as the number of satellites, number of orbital planes, inclination, altitude, in orbit separation, etc. Within the budget of the opportunity missions a number of satellites of 4 or less is deemed feasible. Having this in mind we can define a number of options as shown in Figure 3.

The selection of the constellation will be based on coverage of the horizontal domain and local time, skewness of the measurement, ground contact, failure tolerance, impact on satellite design and instrument design, and last but not least cost.

A possible constellation design is as follows (see Figure 3a):

– 2 satellites in a PEO 650 km orbit, separated 90° in-orbit, and carrying the GRAS- 2 receiver and a LEO-LEO TX instrument
– 2 satellites in a PEO 850 km counter-rotating orbit, separated 90° in-orbit, and carrying the GRAS-2 receiver and a LEO-LEO RX instrument

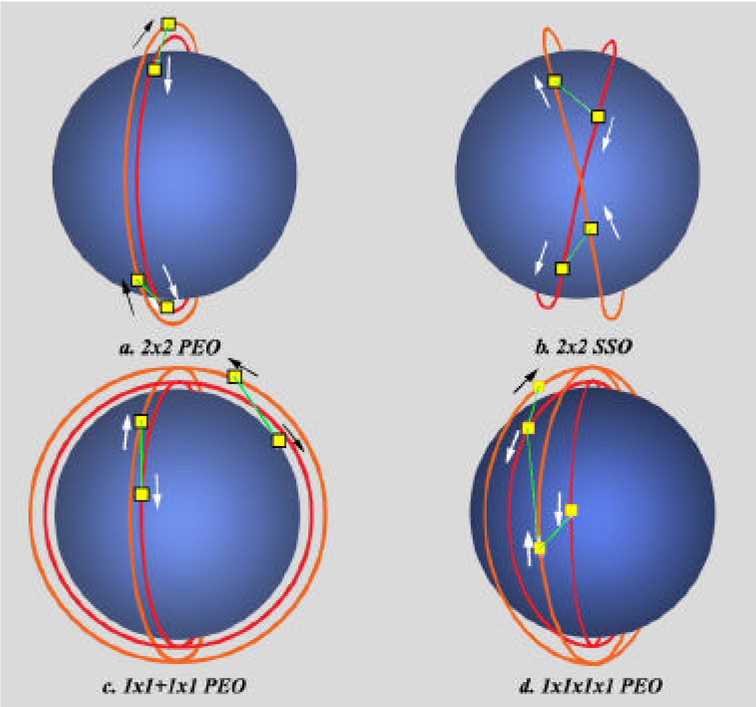

Figure 3: Examples of Possible Constellation Options

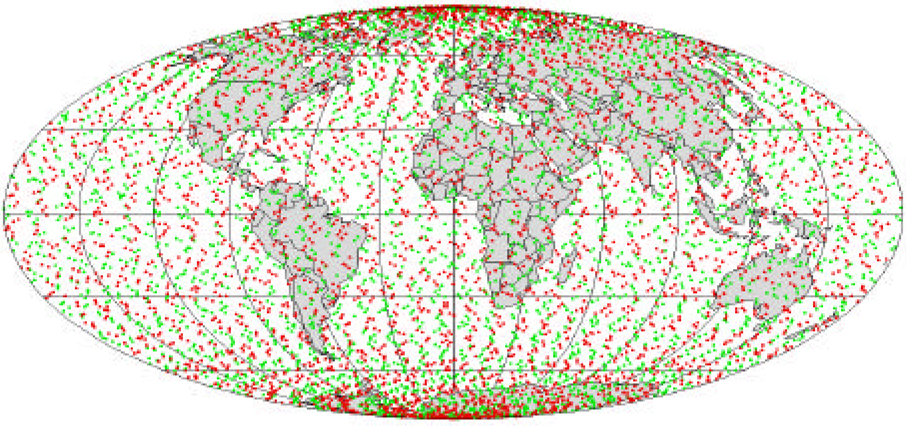

Figure 4: Spatial LEO-LEO RO Coverage During One Month

LEO-LEO Radio Occultation Instrument

The LEO-LEO instrument consists of a signal generator, transmitter, two pairs of antennas (in velocity and anti-velocity direction), a receiver, and a processing back-end. The amplitude measurement is most critical and requires a very good knowledge or control of any gain variation within the system.

The transmitter will probably employ signal modulation and coding similar to GPS, as to take full advantage of the experience in this field. Horn antennas are envisaged that yield high gain, good pattern knowledge, and easy manufacturing. The satellite performs pointing of the narrow beam antennas during an occultation. The receiver will employ the same techniques as the transmitter. Finally, a digital processing backend similar to GRAS-2 is foreseen, with an option of combining the back-end of the two.

GRAS-2 Instrument

The GRAS-2 instrument will be based on current instrument designs such as Lagrange RO from Laben, or GRAS on MetOp.

GRAS-2 is a highly autonomous instrument receiving only the USO signal for its nominal operation, as well as information from the GNSS constellation. Fore and aft antennas will take GRO measurements. A zenith antenna is used to obtain navigation data and timing reference, which can be used by both the platform and the LEO-LEO instrument. All measurement data is supplied to ground, where processing will be performed using auxiliary GNSS data of fiducial stations.

One of the main trade-offs for GRAS-2 is to include the Galileo system, which will impact the instrument due to the number of processing channels needed. Furthermore fiducial data has to be available and the processing chain has to be sized for GPS and Galileo data. The trade-off will probably driven by the estimated availability of Galileo, together with cost and science return consideration.

Spacecraft Design

In order to cope with the main design drivers (occultation antennas free fields of view, power generation on drifting orbits, multiple launch), the ACE+ satellite configuration has the following features (see Figure 5):

- The payload occultation antennas are implemented on the velocity and anti-velocity sides, and are pointed towards the horizon (about 25° tilt);
- The solar array is implemented on the side perpendicular to the velocity, which array features one deployable wing and additional solar panels fixed on the side panels of the structure. Twice during a

year a yaw slew of 180° will be made to keep the panel in the sun;

- The star trackers are implemented also on the velocity and anti-velocity sides: they look in opposite direction, and are tilted from about 30° towards the anti-sun side, in order to minimise the occurrence of star tracker blinding.

The ACE+ satellite is compatible with a 2 m diameter launcher fairing for dual launch in terms of mass and dimensions. Typical figures for the satellites are mass 150 kg, power115 W, 10 Gbit of memory and a 1 Mbps downlink.

Launch

The launch cost is an important part of the total mission cost because at least two launches are needed to deploy the constellation, and therefore low cost launch is required. A dual launch is foreseen on a vehicle such as Rockot, Cosmos or Dnepr. Figure 5 shows the two ACE+ satellites under a Cosmos fairing.

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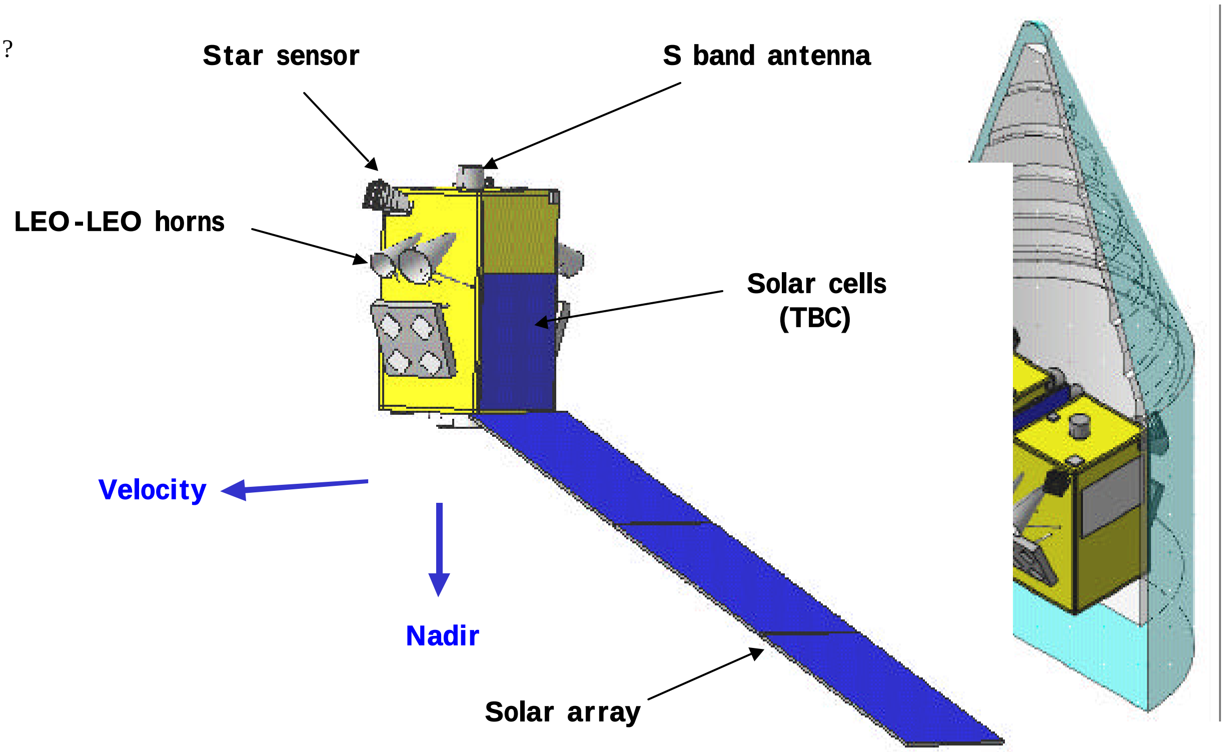

Figure 5: ACE+ Satellite Orbital Configuration and Two ACE+ Satellites under the Cosmos Fairing (Courtesy Astrium SAS)

Ground Segment Concept

The ground segment concept contains the following main facilities

- Data Acquisition and Control Stations (DACS)
- Mission Operations Centre (MOC)
- Science Operations Centre (SOC)
- Science Data Centre (SDC)

Where the latter three collectively may be viewed as Mission Management Centre (MMC) as shown in Figure 6.

The DACS consists of tracking antenna, data acquisition facility, minimal data processing facility and a minimal back-up control facility. The baseline Primary Ground Station is at Kiruna. Two S-band antennas are dedicated to the mission with one antenna providing backup and supporting simultaneous tracking and communication when necessary.

It is expected that a redundant 512 kbps link from the main DACS to the MOC will be sufficient for down linking data and a redundant 62 kbps link for up-link of telecommands between the two sites. Temporary storage of data is provided at the DACS whereby in the worst case of simultaneous dump from two satellites the last telemetry arrives at the MOC in due time for further processing.

The combined Mission Management Centre (MMC) for cost reasons is located at ESOC as a baseline. It is composed of the Mission Operations Centre, Science Operations Centre and Science Data Centre.

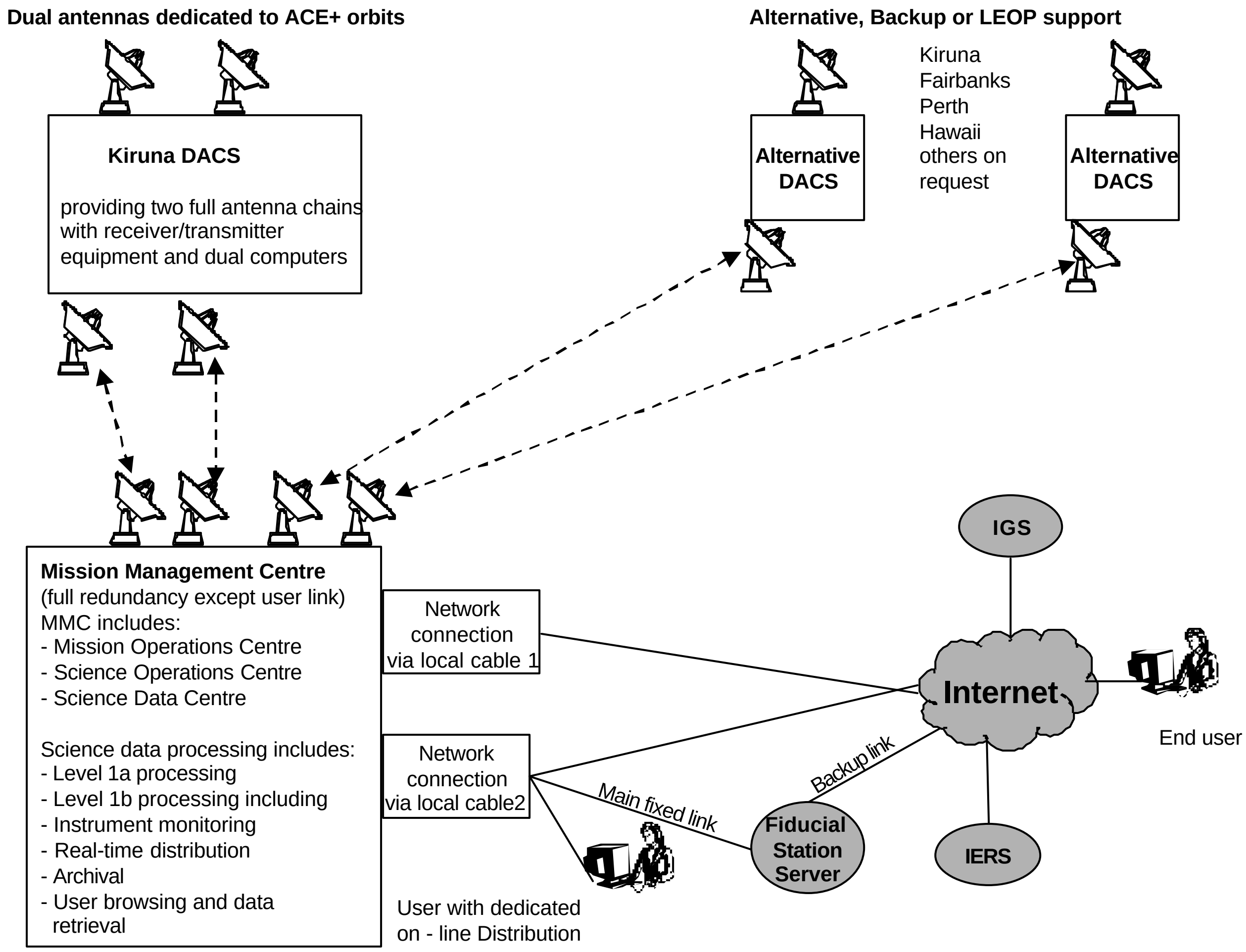

Figure 6: Overview of the ACE+ Ground Segment (Courtesy Terma)

Programmatics

ACE+ will be studied for 10 months in a Phase A, as are the two other missions in the second round of Earth Explorer Opportunity mission: EGPM and SWARM. With the results of all the studies a new ranking of the three missions will be made, and one or two (depending on the available funds) will be selected for implementation. This process is expected to performed in 2004, with a first launch in the 2007/8 time frame.

Acknowledgements

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