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DUSTER

Aerosol collection in the stratosphere

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Abstract. The DUSTER (Dust in the Upper Stratosphere Tracking Experiment and Retrieval) project is aimed at uncontaminated collection and retrieval of stratospheric solid aerosol particles, in the submicron/micron range. The approach implies: 1) in-situ particles collection; 2) sample recovering; and 3) laboratory analyses, without sample manipulation among the three phases. The aim is to derive: the dust size distribution, the concentration and the mineralogy of stratospheric aerosols. Isotopic abundance can also be measured on single particles for the identification of parent processes. These data are complementary to in-situ measurements (particle counter, gas analyzer) and remote-sensing observations (spectrometer, LIDAR). Dust chemical composition and size distribution lead to the definition of the particles optical properties, essential not only to evaluate and model the radiation balance, but also to interpret optical counter, LIDAR and spectral data. The collection has also an astrophysical interest: the stratospheric aerosol extraterrestrial component will be analysed in laboratory. The DUSTER prototype had a qualification flight in January 2006. A miniaturised version of DUSTER is under realisation and will fly in 2008.

Key words. Interstellar, interplanetary & volcanic dust – stratospheric aerosol collection

1. Introduction

Stratospheric aerosol composed of grains of irregular shapes, variable size and chemical

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composition, strongly influences climate (Lacis et al. 1992)(Wang 2004) because of their role in atmospheric chemistry, e.g. ozone partitioning, heterogeneous reactions (McElroy et al. 1986)(Solomon et al. 1996)(He & Carmichael 1999), and in radiative forcing (Saxena & Yu 1996). It is also considered as a tracer of atmospheric dynamics. The long-term satellite-borne atmospheric experiments of the last two decades yielded global scale data about stratospheric aerosols. But, to provide a complete and reliable estimate of the properties of stratospheric aerosols, it is desirable to validate satellite data with in-situ sampling and remote scattering (Berthet et al. 2002)(Renard et al. 2002)(Renard et al. 2005)(Ackerman et al. 1989) and spectral measurements of twilight sky brightness in visual diapason (Mateshvili & Rietmeijer 2002)(Mateshvili et al. 2005). Laboratory analyses of aerosol collected in situ (Testa et al. 1990)(Xu et al. 2001)(Rietmeijer 1993) is a supplementary investigation critical to provide chemical and physical parameters essential for the interpretation of the above listed measurements. Past in-situ aerosol collections retrieved stratospheric particle size distribution, concentration and composition at elevations of 34-36 km (Testa et al. 1990) and up to 22 km (Xu et al. 2001). At any time the stratosphere contains different components: extraterrestrial dust, from natural terrestrial dust (volcanic dust, wind-blown dust, biomass burning) and dust from anthropogenic activities. Interplanetary dust is permanently replenished by dust ejected from cometary nuclei, the most pristine bodies in the solar system, and released from collisions in the asteroid and Kuiper belts (Divine 1993) (Grun et al. 2001). The motion of the Sun through the interstellar medium results in a stream of interstellar gas and grains moving through the solar system in a direction opposite the Sun's motion. Modelling (Flynn 1997) indicates these ≈ 0.5 to 1 micron diameter interstellar grains survive Earth atmospheric entry without being heated above the silicate melting temperature during a roughly six-week period peaking in August (Flynn 1997). These grains are the primary targets of our collection effort because they have never resided in a parent body and, thus, have avoided being exposed to the thermal and aqueous alteration seen in the meteorites.

Previous experiments collecting stratospheric dust involved several steps in laboratory handling DUSTER is specifically designed to minimize extraneous contamination, by reducing sample manipulation DUSTER will allow reaching the following critical information on solid aerosols:

- relative abundance of different components;
- efficiency of stratosphere injection, residence time and stratosphere mixing;
- chemical and physical properties;
- direct (interaction with radiation, chemical and physical stability) and indirect (aerosol as catalyst of chemical reactions and influence on local physical and chemical conditions) effect on atmospheric chemistry and radiation budget.

2. The instrument

The prototype of DUSTER was developed utilizing previous experience (Testa et al. 1990), and following the main technical and operational requirements discussed below. We concentrate on a poorly known stratospheric region (30-40 *Km*), as it is not accessible with frequently operated high-flying aircraft platforms. Ground-based observations are affected by the foreground with much higher signal from the troposphere and the lower stratosphere. Space-based techniques can be more effective, but data interpretation is based on assumed physical and chemical properties of the aerosol. The targeted collection altitudes, the direct and low velocity collection on analytical substrate (see next section), force to mandatory use a stratospheric balloon platform. This will allow low-speed non-destructive and non-contaminant collection by sampling a sufficient volume of gas. We estimated a minimum sampled volume of about 20 m^3 to collect several hundreds of aerosol particles with the inertial impact collection. A well-established technique for solid particle monitoring based on the decoupling between the gas flux and particle trajectory when proper acceleration is induced in the flux. Relative abundance of the different aerosol components does depend on time and position, as different sources have different time dependence and residence time. Multiple sampling at different times and locations either implies an expensive long-term program for multiple dedicated flights, or a piggy-back configuration. The DUSTER prototype is made with gate valves and UHV components to avoid contamination of the collection chamber. Stepping motors connected through a reduction gear operates valve mechanisms. An inlet duct is mounted on the upstream valve and to avoid contaminants collection another valve with passive single-shot mechanism is used. A volumetric carbon vane pump is used to generate the desired pumping capacity of about $0.5 litre/s$ in stratospheric conditions. An on-board computer runs the operation software and controls all instrument inputs/outputs. The battery pack is based on Li-ion elements and power supply includes stabilized DCDC converter. Two different power supply lines are used for safety, giving an average power of $65W$ at $28V$ and total energy of $2.710^7 J$, allowing $4.8 days$ continuous collection. The instrument prototype mechanical configuration is a simple box $0.6x0.6x0.46m^3$ (Fig. 1).

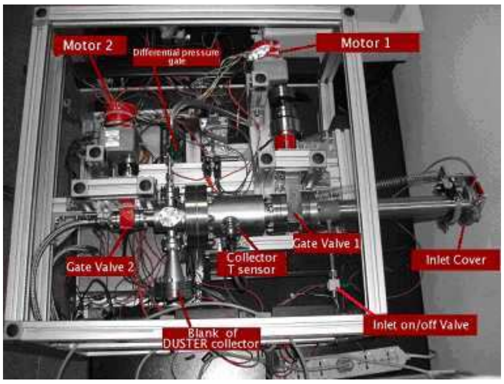

Fig. 1. View of the DUSTER prototype with indications of some components.

Contamination control issues have been carefully taken into account during instrument design and realization. The on-board SW is capable of autonomous management of all operation procedures. Heaters on mechanical critical components are operated based on the values of the relevant temperatures, in order to maintain them within the specified values. Valves and pump operations are commanded on the basis of external pressure; when the instrument reaches the defined working elevation the computer properly switches the two stepping motors and the pump. The same happens at separation, when the elevation decreases and the instrument is set in the landing configuration, with the collector chamber sealed to protect the sample from contamination. We normally procured components specified for aeronautic use (low temperature and pressure) while in some cases it was necessary to perform some environmental and performance tests on specific components. Main issues were the pump and the valves, which have been partially reworked to have them suitable to work down to $-80°C$, which is the lowest temperature expected during operations in stratosphere. We verified the collection efficiency of the system, even if the cut-off dimension (i.e., the dimension of the smaller particle that the system is able to collect) has been evaluated by using empirical trends and with finite-elements modelling. The efficiency was found to be better than 80% in the $0.1 - 1\mu m$ range, slowly decreasing with particle dimension. This effect was expected and it is due to sampling selection occurring at the inlet duct: with the given pressure of $3-8hPa$, sampling efficiency for particles larger than a few μm goes below 20%. We do not consider this as a restriction in the DUSTER prototype performances, as submicron particle dominates the aerosol population not only in number but also in terms of surface and mass e.g. (Renard et al. 2005). The efficiency curve remains flat for small particles, this is marginally in disagreement with our estimate and models, which foresee a cut-off at $0.1\mu m$. The performances we measured guarantee proper working at least in the dimensional range $0.1 - 3\mu m$.

3. Analyses expected results

Aerosol particles are collected by direct deposition on specially designed sample substrate (Fig. 2) that allows multiple analytical techniques without sample manipulation minimizing contamination. These substrates secure the particles without the need for any sticking material or sample manipulation (e.g. particle pressing), thereby avoiding sample contamination and morphology modification.

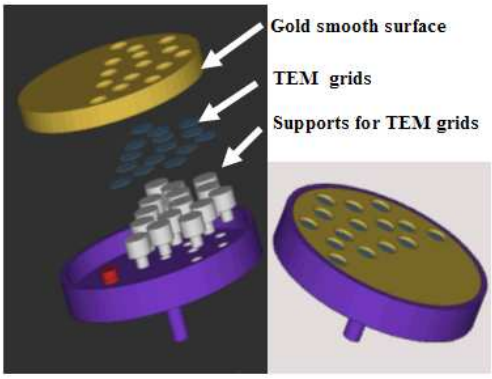

Fig. 2. Exploded view (left) and assembled view (right) of the special sample substrate.

The substrate consists of a smooth gold surface ideal for FESEM observations. One half portion it is hollowed to host Transmission Electron Microscope (TEM) grids (Fig. 2) that can be successively removed for High resolution TEM and isotope analyses. After the flight, the sample collector is extracted from the DUSTER prototype under strict cleanliness requirements (class 100 clean room). Once extracted, it is preliminary analyzed by Field Emission Scanning Electron Microscope (FESEM) to map the collected sample. The sample mapping is used as reference for possible contamination or modification during further analyses. Energy Dispersive X-ray (EDX) analyses will be performed on collected samples to define the chemical composition. Micro Infrared spectroscopy will be performed to identify minerals and organics, Micro-Raman spectroscopy for the identification and characterization of amorphous carbons. and mineral identification. High Resolution Transmission Electron Microscopy fro Mineral and petrographic characterization on a grain-by-grain basis. X-Ray Microprobe Chemical Analysis for Minor/trace element contents of selected grains (concentrations of moderately-volatile elements are particularly important for classifying extraterrestrial material by type). Stable Isotope Analysis for the identification of interstellar grains by measuring isotopic excesses of D, 15N, or 16O. Either isotopic imaging (mapping) or analysis of targeted grains will be necessary to identify any interstellar grain collected. A set of substrates (blanks), similar to the sample collector, are deployed to monitor the dust environment around the DUSTER prototype in each phase, i.e. integration, transport, pre-flight operations, post-flight recovery. An additional "blank" is integrated close to the sample collector but out of the air flux, to monitor all the processes experienced by the sample collector, with the only exception of the collection itself. Based on our modelling studies and previous measurements, we anticipate the collection of about 500 particles of terrestrial origin (mainly volcanic), about 30 interplanetary dust grains and about 10 interstellar grains for a 24-hour flight at 40*km* altitude.

4. The first flight and the future

The prototype of the instrument was tested in-flight thanks to the opportunity given by CNES during the flight campaign at Esrange, Kiruna (Sweden) in January 2006. The DUSTER prototype was integrated onboard a small gondola carrying other technical payloads in the validation flight of the campaign. The DUSTER prototype requirements on flight parameters were not the driving ones, as priority was given to campaign validation issues. Thus, the flight characteristics were not the nominal conditions for the DUSTER project, mainly altitude (between 28 and 29*km*) and duration (about 2*h* at floating altitude). The test flight was intended to certify the instrument and verify its performances. The mechanics were qualified for a typical flight environment and we could test the integration, flight, recovery, de-integration and analysis procedures for the sample substrates and contamination control. Aerosol density measured in similar conditions is of the order of 10^-1 particles/cm^3 for size of 0.1 - 1 μm [e.g. (Renard et al. 2005)]. Only about 210^-4 particles/cm^3 refer to the solid component greater than a few tenths of μm [(Pueschel et al. 1995), (Biermann et al. 1996)]. Based on this number, we would have expected about 500 particles collected during the flight. However, the housekeeping data of the instrument show a non-nominal behaviour of the pumping system. The pump suffered overheating and the gas flux through the instrument was probably much lower than the value of 0.45 l/s measured in nominal conditions. This lowered critically the number of collected particles with respect to the expected value given above and equivalent to about 1 particle every 10 grid squares. In these conditions the comparison between post and pre-flight substrate mapping becomes critical, and deriving an upper limit for the number of collected particles by FESEM observation was not possible. Scrutiny using FESEM of the collection substrate and a control (blank) substrate inside the collection chamber showed no increase in the number of solid particles down to $0.1\mu m$. This result supports a negligible level of contamination for particles of $0.1\mu m$ and larger. The experience made with the test flight strongly suggest pre-flight mapping of the whole substrate at proper resolution. Subsequent post-flight analysis with the same observation parameters allows immediate identification of newly deposited particles. The final miniaturised configuration of the DUSTER instrument, with improved performances, has been developed. The dimension and mass has been significantly reduced, a new pumping system has been installed, to overcome the problem encountered for the qualification flight. The collector chamber has been customised and the power requirements has been strongly reduced. This new version was recently launched from Svalbard (Norway) in a campaign leaded by the Italian Space Agency and supported by the Andoya Rocket Range (Palumbo et al. 2008). In addition, the new DUSTER has been proposed to be mounted onboard the SALOMON-N2 gondola, which includes already a spectrometer allowing measurements of UV-visible extinction by aerosols and a particles counter [(Berthet et al. 2002), (Renard et al. 2002), (Renard et al. 2005)]. The combination of the three sets of measurements will help to better document the real nature of aerosols in the stratosphere.

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