Flight Operations for the FIRST Bolometer Instrument

1. OPERATING MODES

The FIRST Bolometer instrument will have N basic operating modes. These will be:

1. *Observe* - The spacecraft will be pointed in a specific direction or, for scan mapping, will slew slowly over a given region of the sky. The instrument will take scientifically meaningful data and use the full telemetry bandwidth. It is assumed that any calibrations required will also be done in the *observe* mode (TBC). There will be N sub-modes of the basic *observe* - see below.

2. *Standby* - The spacecraft may be pointed in an arbitrary direction (observing with another instrument for instance). The instrument will telemeter only housekeeping information, and perhaps some degraded science data - see below, at a rate very much lower than the full telemetry bandwidth.

3. *Real time commanding* - During ground contact it may be necessary to command the instrument in real time and analyse the resultant data on the ground in near real time for instrument testing and debugging purposes. In this case the full telemetry bandwidth will be required for the duration of the instrument test in question. It is not anticipated that this will occur frequently.

4. *Commissioning/calibration mode* - During the commissioning and performance verification phases of mission operations, many housekeeping and other health check parameters will be unknown or poorly defined. This mode allows the limits on selected health check parameters to be ignored by whatever real time monitoring systems are in place on the spacecraft/instrument.

5. *Cooler Recycle* - The ^3He cooler requires recycling every 46 hours (TBC). During this time the instrument will be switched off except for vital housekeeping and cooler functions (TBC). The recycling takes 2 hours (TBC) to complete with another N hours (TBD) before instrument operations can recommence. There will be an increased heat load onto the helium bath (~ N mW for N hours).

6. *On* - The DPU will be switched on and can receive and interpret instrument commands, but no other sub-systems will be switched on. For engineering purposes it will be possible to command the instrument to switch on individual sub-systems from this mode. Full housekeeping data will be telemetered.

7. *Off* - All instrument sub-systems will be switched off - including the DPU and there will be no instrument telemetry.

The *observe* mode will have the following sub-modes:

Obs.1. *Photometer peak up* - if the absolute pointing error of the spacecraft is too poor to allow for instantaneous acquisition of a given target to with N arcsec, then a peak up procedure will be required. This will use the *photometer chop* mode (see below) to identify the position of a source by executing a small cross raster across the pointing given by the spacecraft. If this mode is required it will involve moderately sophisticated on-board signal processing and the ability to communicate the calculated off set to the AOCS independently of ground communication.

Obs.2. *Photometer chop* - the focal plane chopper is used to switch between two separate portions of the sky with the spacecraft pointed at a fixed position, thus modulating the signal onto the detectors. The full telemetry bandwidth will be required. To maintain the absolute calibration of the instrument, periodic calibrations will be done during observations of this type by switching on the on-board photometric calibration source. It is assumed that these calibrations will have no impact on spacecraft operations (TBC).

Obs.3. *Photometer scan* - This is an alternative method of mapping an area of sky larger than the instantaneous field of view of the instrument. The spacecraft will slew slowly over a given area. In this way the signal is modulated by chopping from one pixel to the next. A further variation is to use the focal plane chopper to switch to another portion of the sky in a direction orthogonal to the direction of slew. The speed of slew will be between N and N arcsec/minute and may be in an arbitrary direction with respect to the spacecraft axes. The full telemetry bandwidth will be required.

Obs.4. *Photometer partner mode* - It is envisaged that the PHOC and Bolometer instruments will sometimes be used to make simultaneous observations of the same portion of the sky. In this case a reduced telemetry rate will be available to each instrument. In the case of the bolometer this will mean that either the data will have a reduced resolution (spatial or intensity) or that there will be on-board integration of images (TBC).

Obs.5. *Photometer serendipity mode* - During spacecraft slews scientifically useful information can be obtained without the necessity of using the focal plane chopper - essentially these are rapid scan maps. It is assumed that at least half the bandwidth will be available to the bolometer instrument (PHOC may have a similar mode) and this will be filled with science data from the photometer arrays (only). The chopper and spectrometer mechanisms will be switched off in this mode. Accurate pointing information will be required from the AOCS to reconstruct the slew path in the data analysis on the ground.

Obs.6. *Photometer parallel mode* - When observations are being made with another instrument, that are not partner observations, then scientifically useful data may be obtainable from the photometer, albeit with degraded intensity and spatial resolution. In this mode a science data packet will be telemetered alongside the standard housekeeping data. The chopper and spectrometer mechanisms will be switched off in this mode.

It is assumed that this will be the default standby mode for the bolometer instrument.

Obs.7. *Spectrometer full spectrum* - The spectrometer mirrors will be constantly scanned back and forth over the distance required for the requested spectral resolution. The spacecraft will be pointed at a fixed position and the focal plane chopper will not be switched on. The spectral calibrator will be on during all spectrometer operations. The full telemetry bandwidth will be required and there will be on-board integration of spectra.

Obs.8. *Spectrometer narrow band photometry* - The FTS can be used as a narrow band photometer by scanning the mirrors over a small distance close to the central maximum of the interferogram. The spectral calibrator will be on during these observations to give a constant reference signal. In this mode no on-board integration will be necessary and the full bandwidth will be used.

2. INSTRUMENT COMMANDING

2.1 High Level Commands

The only high level commanding required from the spacecraft to the instrument is to switch on/off the DC power line to the DPU. All other instrument power lines will be derived from the DC/DC converters within the instrument DPU. All instrument sub-system functions will be controlled via commands sent to the instrument DPU.

2.2 Instrument On-Board Software

The following general description applies to the bolometer instrument On-Board Software (taken from the AO response technical section):

This will be written in the C language and will be designed to allow the instrument to operate in an autonomous fashion for 48 hours as required in the IID part A. The basic implication of this requirement is that there must be the facility to store enough commands for a 48 observing programme and enough mass memory on the satellite to store 48 hours of instrument telemetry. More sophisticated autonomy functions may include the on-board analysis of scientific or housekeeping data and the ability to react on the basis of that analysis. The type of automatic operation undertaken following such an analysis may range from the raising of a warning flag to the switching over to a redundant sub-system or the switching off of a defective sub-system. All autonomy functions will require extensive evaluation and test before they are implemented to avoid the possibility of instrument failure. No instrument autonomy mode will be implemented that will affect the satellite operation.

Memory load commands will be used to send single instructions to the instrument or to command pre-defined sequences of operations. The command words will be interpreted by the OBS according to a given algorithm and the relevant sequence of digital commands sent to the *subsystems. Each command will be formed with a variable number of words having the following general structure:*

1. a Header describing the Command function;
2. the number of words to follow;
3. the new values of the parameters, if any.

There will be at least four types of commands:

1. Macro Commands
2. Subsystems Commands
3. Peek & poke Commands
4. Spare Commands

The macro commands define the timing and sequence of instrument operation . The subsystems commands allow the immediate control of each instrument subsystem. The peek and poke commands will allow the down-link of RAM or ROM content as well as the ability up-link patches, new programmes or tables. There will also be the possibility to run new commands by up-linking the specific code in RAM recalled by the Spare Command.

2.3 Instrument Command Scripts

For in-flight operations a script language consisting of mnemonics plus parameters will be developed to allow the instrument controllers and observers to command the instrument in a straight forward manner. This language will allow simple programme control (do loops, if statements etc.), Boolean algebra and floating point and integer arithmetic. The scripts will then be passed through a translation stage that will check for anomalous instrument operations and convert the mnemonics, parameters etc. into command sequences for subsequent uplink to the instrument.

It is anticipated that the same script language will be employed for ground testing, commissioning phase, performance verification and AOTs. For AOT generation, software will be written that allows the observer to input astronomically meaningful data that is then converted into an instrument command language script.

3. GENERAL REQUIREMENTS FROM THE SPACECRAFT

In addition to the requirements listed in section 1, the following general requirements are requested for the bolometer instrument from the FIRST spacecraft:

1. Some of the operating modes require on-board integration using the instrument's own on-board mass memory. It is required that, although the average data rate from the instrument to the spacecraft on-board data storage does not rise above that permitted by the down link bandwidth, data can be transferred between the instrument and spacecraft mass memories at a much higher rate than permitted by the downlink bandwidth over a short period of time. This then allows the instrument to make full use of the downlink bandwidth whilst reducing the total amount of data

to be telemetered to the ground.

2. The instrument health check parameters must be monitored in near real time (once per N seconds) by the spacecraft on-board control system. If any critical health check parameter goes out of limits the spacecraft must have the ability to react and take the appropriate action - including switching the instrument off.

3. There will be other health check parameters (e.g. the supply current to the instrument) that can only be monitored by the spacecraft systems. It is assumed that these will be monitored by the spacecraft systems and appropriate action (instrument switched off) will be taken in the event of any anomaly occurring.

4. Any instrument on-board software ram patches are required to be held in the spacecraft mass memory. This will greatly speed up the activation of the instrument following a switch off.

5. A special instrument data packet is required for passing data to the spacecraft systems. More specifically the peak up mode will need to pass data to the AOCS for pointing correction - a specialised data packet that can be requested by the spacecraft on-board software must be defined.

6. The heterodyne instrument local oscillators will be switched off during all periods when the bolometer instrument is in any *observe* sub-mode - i.e. including during slews.

4. DATA PACKET TYPES

Three (TBC) basic data packet types have been identified for the bolometer instrument downlink telemetry:

1. Science Packet - This contains all types of science data from the observe and commissioning/verification modes. This packet will be always be produced when the instrument is in any *observe* sub-mode - NOTE: this includes *standby* as parallel and serendipity data will still be taken whenever the instrument is not actually making a pointed observation.

2. Housekeeping - This contains all types of housekeeping and health check data. This packet is always produced when the instrument is on. NOTE: this includes *on* as some housekeeping and health check parameters may be valid for this mode.

3. Event - This contains a history of instrument command events and anomalies. It will be used on the ground as a quick check of the instrument behaviour before further data analysis proceeds.