SHARC Software

Documentation for the CSO Bolometer Array Camera

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Introduction

SHARC (Submillimeter High Angular Resolution Camera) is a bolometer array camera designed to image the sky in submillimeter continuum at the Caltech Submillimeter Observatory on Mauna Kea, Hawaii. The instrument was successfully commissioned in September 1995 and was making beautiful images by October. The instrument was opened for external proposals beginning in spring1996.

The detector itself is a 24-element monolithic silicon bolometer array manufactured at Goddard Space Flight Center in Greenbelt, Maryland. The array operates at 0.3 K in a ^{3}He cryostat and is directly illuminated by re-imaging mirrors without the use of Winston concentrating cones. An off-axis ellipsoidal mirror on the ^{4}He cold plate inside the dewar forms the basis of the optics and instrument stage. Three bandpass filters (broadband 350 & 450 µm filters and a narrowband 870 µm filter) are available on a manually rotating filter wheel assembly mounted just above the aperture stop (at the tertiary image of the primary).

The instrument electronics consist of heated (thermally-isolated) JFETs operating at about 100 K followed by room temperature preamplifiers mounted on the outside of the dewar which, in turn, feed 1 kHz 16-bit A/Ds. The signals from the A/Ds are sent to a DSP board in the Macintosh Quadra 950 that is controlled by a logic board in the A/D box. The DSP chips perform real-time digital lock-in detection on the bolometer signals, returning both in-phase and quadrature data after each chop cycle in the form of 32-bit integer arrays. The DSP control and data acquisition software has been written within the Labview environment on a Macintosh Quadra 950 which receives commands from and communicates data to the CSO control computer (currently a VAXStation 3100) via TCP/IP. This arrangement provides the advantages of central UIP (User Interface Program) control and data storage (analogous to heterodyne observing at CSO) with graphical, interactive data display on the Macintosh.

This manual describes the function and operation of the system hardware and Labview and VAX software required to perform the proper instrument setup for astronomical observing at the CSO. Also, examples are given of the basic uses of the on-the-fly map data reduction software (CAMERA and REGRID) written by Darek Lis.

;Goddard Space Flight Center A/D and DSP Hardware

The A/D unit consists of a logic board and two A/D boards each containing up to 16 channels contained in an isolated electronics box. DC power (+6 and -7V) is connected via 2 3-conductor cables from a ground-isolated battery power supply on the alidade. The A/D output is sent via two 15-meter fiber optic cables (encased in a wire-reinforced plastic hose) to the control room where they connect to a small interface box attached to the Quadra. The interface box connects via a short cable to the DB-37 input port on the DSP NuBus board in the Quadra. In order to eliminate capacitive coupling in the particular fibers and detectors, 3 flat washers are inserted such that the fibers attach only through a single screw thread. Also located on the interface box are BNC ports for "Chop Out"--the output TTL chopping signal from the DSP board and "Chop In"--the input TTL chopping signal. Typically, these two ports are connected together via a short BNC cable such that the output signal is piped right back in as the input. A BNC-Tee is added so that the Chop Out signal can be sent to Martin Houde's chopping secondary control box (to the TTL input port). Another Tee can be added to monitor the TTL signal on the HP digital oscilloscope.

Labview on the Macintosh

Labview is an object-oriented, graphical programming language designed to simulate a multitude of scientific instruments. The building blocks of the language are called Virtual Instruments (VIs) and are analogous to functions or subroutines in other programming languages like C or FORTRAN. Each Labview VI consists of a front-panel display and a programming diagram. The front-panel is a window that can be used to display data in the form of numbers, graphs, strip charts, lights etc. and/or to accept input from the user in the form of data, control switches, dials, etc. VIs have the handy feature that they can be embedded as subVIs with their input and output parameters wired into other VIs. Thus each VI can be run "standalone" or can be called and executed by other VIs. The programming diagram for a VI is a separate window that is configured by the application programmer to perform the appropriate tasks (including arithmetic, file I/O, etc.) required of the VI. Diagrams can contain typical programming structures such as FOR and While loops, and Case and Sequence structures. Operations and conversions on all common datatypes (integer, long integer, float, double, extended precision, string, array, bundle, etc.) are provided. Communication over GPIB, Serial and TCP/IP networks is simplified with the use of built-in VIs.

GSFC Labview Software

Many of the Labview VIs for SHARC based upon similar VIs written by Kevin Boyce for the Kuiper Airborne Observatory infrared bolometer spectrometer instrument. Small modifications have been made to suit our needs at the CSO. In the rest of this chapter, the major top-level Labview VIs will be described individually with a top-down approach.

Getting Started: SHARC Server

The main VI for the bolometer array system is called "SHARC Server". When this VI is executed, it goes into a wait mode and listens for a TCP/IP communication request from the CSO control computer (VAX). Currently, this VI must be started manually on the Macintosh by clicking on the desktop alias “SHARC Server” in the top right-hand corner of the display. Alternatively, it can be started by pulling down the Apple menu to "Todd's Labview", moving right and releasing on "SHARC Server 9/15". The 9/15 refers to the date of the last major revision of the code. (It is possible to place this VI in the Startup Folder of the System Folder so that it will be started upon reboot of the Macintosh. But because the Macintosh is a multi-purpose machine and Labview takes a significant amount of resources, this is not advised on a permanent basis.) This request is issued by a client routine activated on the VAX by the UIP command "SHARC". Like all UIP commands, the SHARC command is implemented by a Pascal subroutine. When the request is received (from port 5000 on the VAX), "SHARC Server" in effect becomes a server program running on the Mac which in turn opens 3 new TCP/IP connections to the VAX for clearing event flags (port 5001), displaying error messages on the operator terminal (port 5002) and storing scan data (port 5003). All commands sent to the Mac must have a standard length due to the apparent constraints of the TCP/IP software available within Labview. Currently, 80 characters is the standard length that I have chosen. The ":" character serves as a command delimiter and the "~" character serves as a command terminator. See "HELP SHARC" from within the CSO UIP program for a description of the available commands. When in the default PRINT mode, the SHARC command will send any new values to the Mac, then immediately requery it for all of the current values and print them on the control terminal so the user knows the current configuration. Occasionally, one of the values printed will be bizarre, perhaps to do some communication glitch. In this case, reissuing the command usually clears up the problem. On rare occasions, the DSP will get screwed up and report an error during a SHARC command. If it continues to do this, try turning the setup display on and off with the commands SHARC/SETUP followed by SHARC/NOSETUP. This should reset the DSP properly.

Another error can occur when you first issue the SHARC command, especially if the telescope is in heterodyne mode beforehand. You way get an error message with error number 324, etc. Simply reissue the SHARC command. It should now start, however the values displayed on the VAX may come up VERY slowly, one at a time. If this happens, then the VAX is still screwed up. Ctrl-Y out of UIP and go back in. Stop the SHARC Server VI on the Mac and restart it. Then issue the command SHARC/RESTART. Things should be fine now.

Bad and/or Dark pixels

As in all array detectors, not all of the pixels are working. In SHARC, pixels 1,5,15 and 16 are dead. These are defined as dead by running the subVI SHARC Set Bad Pixels which updates a file on the Mac containing the current array configuration. When data are taken, the subVI SHARC Read Bad Pixels returns the numbers of the dead channels which are subsequently flagged in the header of the data file so that the data reduction software will ignore them. Also, we have a different field stop slit that darkens pixel 24 in case you would like to get an idea of the level and nature of the correlated pixel noise not associated with sky radiation. Dark pixels are also defined in the subVI SHARC Set Bad Pixels. Once you know the current array configuration you should run this routine to store any changes in the configuration. Note that pixels 17 and 18 are much noisier than the other 18 channels

Pointing

Perhaps the first thing to do at the beginning of the night is to locate and point on a bright source like a planet. Partly for this purpose, the VI SHARC Setup Display has been written. Essentially, it performs the duties of an analog strip-chart while you point up on a source and center the beams using the JOYSTICK command in UIP. Fixed pointing offsets and the nominal focus offset have been measured with SHARC mounted on the right-hand port of the Cassegrain relay optics of CSO and the array aligned in zenith angle with pixel 1 the highest in the sky. These offsets are stored in a standard UIP pointing file called "SHARC" and can be loaded with the UIP command "POINT SHARC". (Rough values are -10 for FAZO and -70 for FZAO for reference pixel 12.) Although a stepper motor controls the rotation of the dewar plate, so far we have always manually aligned the dewar in elevation by using fiducial marks on the relay optics which should be set by the day crew that mounts the dewar. These fiducial marks apply only to the right-hand port of the relay optics. (WARNING: If the dewar is ever mounted on the left-hand side, then the dewar rotation will have to be readjusted. Repointing and refocus would also be recommended in this case.) Generally only small adjustments of a few arc seconds are needed to optimize the pointing during the night. As a superior alternative to JOYSTICK for OTF aficionados, pointing can be done rapidly by making a single-row OTF map of the calibrator and displaying the resulting map in "pointing mode" in the CAMERA software written by Darek Lis. The pointing corrections can then be read from the peak position of the planet in the map.

Focus

The nominal focus of the array (+0.25) is stored in the SHARC point file but should be checked occasionally (especially if people or other instruments have been standing on the relay optics.) The peak intensity of the image is fairly insensitive to focus offset changes of ±0.25.

However the shape of the image due to aberrations does vary noticeably over such a range. Thus it is best to optimize the focus for the roundest image and hence the best beam shape. At proper focus, the observed half-power contour of a resolved planet matches well with the almanac values, with the polar flattening of the Jovian planets easily visible. The half-power contour on point sources should be close to the diffraction beamsize. Note: if someone ever removes the secondary mirror, get them to verify the XPOS and YPOS before your observing run!

Phasing the pixels

After pointing, it is wise to phase the pixels individually on a bright source. Place the source in one of the two beams by issuing the UIP command: AZO/CHOP=x, where x = 1/2 the chopper throw. (Using +x will cause the left beam to be negative and right beam to be positive when scanning in the azimuth direction. Vice-versa for -x.) From the UIP, there is a command PHASE_12 which will phase the array automatically if the reference pixel is 12 (the most common). Also, executable command files have been created to perform the phasing for other reference pixels. They are stored in the directory USER:[HUNTER.NEWUIP] and are named using the format PHASE_**.COM where ** indicates the reference pixel being used. These files command the telescope to move to one pixel after another. They are executed by the UIP command: EXECUTE USER:[HUNTER.NEWUIP]PHASE_**.COM. At each point, the Macintosh gathers a data sample and computes the arctangent of the in-phase and quadrature data and determines the phase. This process is accomplished by the subVI SHARC Phases All-or-1. The computed phase is stored in the DSP memory for subsequent lock-in detection. Set SHARC/CHOPS_PER_INT higher if you want to have better S/N on the phase calculation, especially if the source is faint.

It is important to remember that this calculation is valid only for a sine-wave template (the current default). If a different template function is loaded (via the PickTemplate Macintosh program), the results of this calculation will not be accurate. We have tested a modified square wave template function along with a function to compute phase with this template. The subVI Phases All-or-1 contains a manual switch to choose between the 2 functions. Because we found a lower signal to noise ratio on Venus with the square wave template than with the sine wave template, the sine-wave template remains the default and the arctangent function is the default setting of the switch.

A different phasing .COM file is needed for each choice of reference pixel. For obvious reasons, it is useful (especially for mapping an extended source) to choose a pixel near the center of the array as the reference pixel (i.e. the pixel whose lock-in signal is used to point the telescope). We typically use channel 10 (good for pointing because it is in the middle of a series of good pixels) or 12 (good because it is the center of the array) . After phasing, one should make at least two more scans on the calibrator source at different airmasses in order to measure a good milliVolts to Janskys conversion factor for the night.

Pixel Gain Calibration

After phasing, it is necessary to measure the relative gains of the pixels. The pixels vary in their responsivity to astronomical sources for several reasons: differing thermal conductivity of the pixel support legs, varying quality of the optical focal plane, diffraction effects near the ends of the field stop, and possible misalignment effects. The method for removing these effects from imaging data is referred to as flat-fielding. Our method for flat-fielding is to perform scans through a bright calibrator (i.e. Saturn), measure the relative signals among the pixels and create a gain file to be used in data reduction of subsequent target source observations. There are of course several methods to accomplish this goal. In the OTF mapping mode, zenith angle scans are used for gain calibration because the array is aligned in zenith angle and scanned in azimuth in OTF mode.

These calibration scans are accomplished by placing the source in one of the telescope beams and then using the /SIDEWAYS/ALTAZ option of OTF_MAP in UIP and provide a rapid comparison of the signal from each pixel, thus minimizing sky changes during the timescale of the measurement. It is best to make scans in both the + and - beams in order to determine the average response. The gains don't seem to change much from month to month, so if you forget to make these scans, you can get values from other observers. Occasionally, pixels 4, 17 and 18 vary in their noise level but it is uncertain if the gain also changes.

On-the-Fly Mapping

On-the-fly mapping is a indispensable procedure that allows you to point, perform gain calibration and observe real sources. The preferred method for observing of the CSO bolometer crew is OTF (On-The-Fly) mapping. The OTF procedure is similar to that used in heterodyne spectroscopy with the main difference being that continuum OTF is performed in altitude-azimuth coordinates to optimize the sky subtraction performance of an azimuth chopper. See HELP OTF under UIP for details on the UIP command parameters. There are two minor differences between heterodyne OTF mapping and SHARC OTF mapping. The first difference is that the /ALTAZ qualifier is the default and cannot be changed. Because the CSO chopping secondary can only chop in azimuth, and the bolometer OTF scans must be performed in the scan direction in order to get best sky subtraction as well as to perform dual beam restoration of maps. Thus, even if you forget to specify /ALTAZ the program will act as if you had. The second difference in SHARC OTF mapping is in the definition of the longitude resolution of the map. Because the chopping secondary is run during bolometer mapping, the data are quantized in units of 1 chopper cycle (typically 4 Hz). So, the longitude resolution is calculated from the current values of the chopping frequency and the number of chops per integration. The calculated value is displayed when the OTF command is issued. Occasionally, after you type the OTF command, the Mac will speeze and return a 0 for one of the important OTF parameters. The OTF command now traps this case instead of dying with a divide-by-zero error. Simply reissue the OTF command and it will work properly.

On the Macintosh, the subVI SHARC OTF Accumulate handles the data-taking. At the beginning of each row, the Mac awaits the IDLE bit from the antenna computer which indicates that the antenna has reached the beginning of the map (after the ramp up period). The Mac then takes data and sends it to the VAX over the data socket until it has acquired the proper number of data points. Even when sampling each chop cycle at 4 Hz, the Mac can keep up with the data rate. If the map is aborted by issuing Control-C under UIP, the Mac does not know this and will continue to finish the row. Once it finishes, it should be in a healthy state ready for the next UIP command.

There is one remaining (known) bug in the OTF command. Actually, the problem seems to be in the TCP data channel and so far has only been seen during OTF maps. After a couple of hours of mapping, the antenna computer will die at the end of an OTF row. To recover from this situation, you must stop the main SHARC Server VI on the Mac by clicking on the little STOP sign on the window menu bar. Then restart the VI by clicking on the right arrow button. On the VAX, control-Y out of the UIP and type EXIT to kill the image. Finally, re-enter the UIP and type the SHARC/RESTART command to restart the connections. If this command hangs (goes more than 30 seconds without a response) then the SHARC Client on the VAX was not killed properly. Just control-Y out of UIP, type EXIT and go back in and issue the SHARC command, which should now work. As always, be sure to issue the SHARC command before trying to open a new data file because this requires that the Mac connection already be established. Then reissue the secondary command to be sure the chopper throw gets written correctly into the scan headers.

Pointed Observing

For those observers who are interested in point sources only, the routine CHOP_SLEWY is available. In this mode, the telescope executes a sequence of chops and nods in the form +--+. In other words, a specified number of chop periods are integrated in the positive beam, then in the negative beam, the negative beam and back to the positive beam. This sequence is repeated for the number of cycles specified. The data file format is different from the OTF map files (which is why you must always specify which type of file you wish to open in the UIP DATA_FILE command). The current data reduction package for CHOP_SLEWY data is BADAS, available on the VAX in a preliminary form. A data reduction package based on macros in the CLASS package used for heterodyne spectroscopy at IRAM and CSO will be developed in the future. For pointed observing, the option exists to align the array in azimuth or elevation, or to track the parallactic angle of the source. Longer DB-25 cables (than the default cables) will likely be required if the dewar is to be aligned in azimuth. Also, tracking the rotation has not yet been fully tested in software.

When performing CHOP_SLEWY integrations, it is necessary to turn up the integration time. SHARC/CHOPS=16 will take a data point (one of the 4 +--+ points) every 16 chops, usually 4 seconds. SHARC/INT=2 will perform 2 cycles of +--+before storing data. This yields a total time of 32 seconds, with 16 seconds on source.