Astronomical Data Analysis Software and Systems IX
ASP Conference Series, Vol. 216, 2000
N. Manset, C. Veillet, and D. Crabtree, eds.

Infrared Surveys with CIRSI—Scientific Objectives and Data Analysis

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Abstract. We report on the scientific progress on a wide field infrared survey being carried out at the 2.5 m Isaac Newton Telescope with CIRSI, a unique infrared camera based on a mosaic of 4 1024×1024 HAWAII arrays. In normal operation the arrays are read out continuously with a sustained rate of two or more complete image datasets per minute.

We have developed a highly automated IRAF-based data reduction package, *CIRDR*, that can be used for both *quick look* data inspection, and generation of astrometrically calibrated science quality 4096×4096 images based on a contiguous 4×4 mosaic.

1. Introduction & Scientific Background

CIRSI, the Cambridge Infra-Red Survey Instrument, is a new near-infrared camera that was built at the Institute of Astronomy. It consists of four 1024×1024 pixel Rockwell HAWAII HgCdTe (Mercury-Cadmium-Telluride) detectors, arranged in a sparse-filled mosaic—making it the largest infrared camera in the world to date. CIRSI's unprecedented wide field of view means it is ideally suited for survey work. The previous generation of infrared detectors (typically 256×256 pixels) tended to have too limited a field of view for panoramic surveys. This was unfortunate, as the near-infrared is very desirable for such survey work. For example, when searching for high-redshift clusters of galaxies in optical wave-bands, one finds that beyond about $z = 0.5$, the contrast against the very high field galaxy counts makes detections less and less reliable. Additionally, the k-correction tends to dim the light of distant early-type galaxies, which kills the cluster contrast at optical wavelengths.

Thus we are able to combine the advantages of searching in the near-infrared wave-bands and CIRSI's ability to cover a large solid angle, an essential feature for finding rare objects like rich clusters of galaxies.

2. The Survey

Most of our observations have been carried out on the 2.5 m Isaac Newton Telescope on the Canary Islands. So far this has consisted of four observing runs, totaling 35 nights.

Table 1 lists our most important cluster observations.

Table 1. The main cluster observations taken at the INT.

Target	Wave-band	Surveyed Area	Total Exposure Time
22h 11	H	0.19 deg^2	201 min
CIS 0218-05	H	0.25 deg^2	75 min
CIS 0340+00	H	0.06 deg^2	222 min
	J	0.06 deg^2	66 min
	J_{OH}	0.06 deg^2	300 min
CIS 0347+24	H	0.25 deg^2	12 min
Lockman Hole 1	H	0.19 deg^2	95 min
Lockman Hole 3	H	0.13 deg^2	81 min
RX J 1716+67	H	0.25 deg^2	93 min

At a scale of 0.45" / pixel on the INT, an image from a single chip has a 7.7' field of view. Hence a filled 4×4 mosaic (see Figure 1) is just over 30'×30' in size.

3. Data Acquisition

The camera is typically read out in non-destructive read mode (NDR)—see Figure 2 for an illustration.

The controller is a standard LSR-AstroCam 4100 CCD controller. Each quadrant on a chip is read out individually, giving $4 \times 4 = 16$ images for each read. Hence, for a typical observation, which would be a 40-second exposure consisting of 3 reads, the data rate would be

0.5 MB [*size of a 512×512 16-bit quadrant image*]
×16 [*number of quadrants*]
×3 [*number of reads*]

giving 24 MB in 40 seconds, i.e. 36 MB a minute which comes to over 2 GB an hour at a sustained rate.

Each observation pointing is then repeated, offset by a small amount (typically 15"). Usually 9 or so of these dithers then make up a pointing.

In order to deal with such large volumes of data, we employed an observing system consisting of several computers and running a variety of operating systems, linked by fast 100 Mb Ethernet. Storage was provided by several 16 GB hot-swappable hard drives, in addition to multiple SCSI disks on the individual machines. Data would be written to DDS-3 tapes during the daytime.

The user interface is provided by a GUI, a program called *PixCel*, running on a Microsoft Windows 95 PC. The raw data is copied across automatically to Linux machines for reduction.

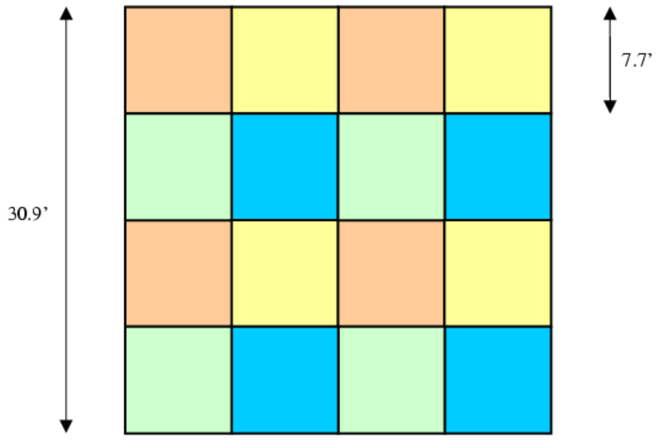

Figure 1. Schematic of a filled mosaic with CIRSI. Due to the arrangement of the four chips this requires four adjacent pointings, shown here in four different shadings.

4. Data Reduction

We have developed *CIRDR*, a highly automated IRAF-based piece of software, for reducing our data. This was initially intended as a *quick look* data inspection facility, but has since evolved into a fully-fledged data reduction package. The requirements for such a package are manifold:

- Speed (possible to process in real time?),
- Reliability (must reduce large amounts of data in one session),
- Ease of use (multiple users relying on package),
- Adaptability (interface with other software before and after),
- Portability (run on a variety of platforms: Linux, Solaris, etc.),
- Automation (minimum input from user).

For these reasons, and to maintain backward compatibility with previous software, we chose to base our package in IRAF. *CIRDR* is essentially a collection of CL scripts, with certain (speed-critical) tasks written in SPP.

The multiple tasks required for reducing are as follows:

- *Reset Correction*: In order to obtain a useable image, the reset frame needs to be subtracted from one of the subsequent reads—typically the last one (except when saturation has occurred);
- *Destriping*: [optional] The earlier runs in particular suffered from quite visible fixed pattern noise in the images. This can be removed by performing a row-by-row multiplicative correction with respect to the median level of the image;
- *Combine Quadrants*: The individual quadrant images are combined—4 at a time—to give an image for the entire chip.
- *Transpose*: The 4 chips all have different electronic orientations with respect to the sky. Hence they need to be transposed in order to result in North being "up" in all of them;

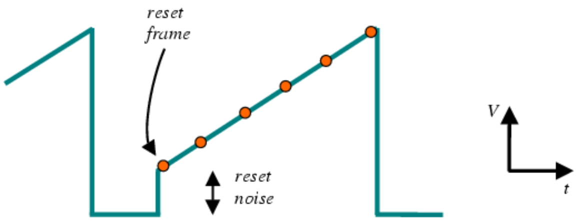

Figure 2. A non-destructive read as performed with CIRSI. Multiple reads are performed "up the ramp" during integration.

- *Dark Subtraction*;
- *Sky Creation & Subtraction*;
- *Flat-fielding*: In cases where the sky subtraction has not proved satisfactory (although typically we are able to achieve an image that is flat to about 1%), flat-fielding with a dome or sky flat can be performed at this point, even though in practice we find the benefits are minimal;
- *2nd Pass Sky Subtraction / Destriping*: Particularly when dealing with frames containing bright objects, we find the sky level is not always estimated correctly. Hence in a 2nd pass, we mask out the objects and re-create a sky image, which is then used for sky subtraction. The same procedure can be used for our destriping algorithm;
- *Co-add Dithers*: The set of images belonging to the same dither sequence (same pointing, but offset by a small amount) are registered and then co-added. Registration is performed automatically, using the image headers to obtain a rough estimate of the offset, and then a centroiding algorithm to get the precise value;
- *Astrometry*: After extracting the sources from the co-added images with *SExtractor*, the catalogue is then compared to the APM POSS1 database for object matching and a plate solution is computed. The image headers are subsequently updated with the WCS information;
- *Mosaicing*: In the case of the observation consisting of a contiguous mosaic, the astrometric information in the image headers is used to tile the individual chip images. In the usual case of a 4×4 mosaic, this results in a final 4096×4096 image.

Even though these steps are all performed by individual sub-packages and tasks (which has the advantage that they are also usable individually, and could be re-used in separate packages), there exists a monolithic blanket task which runs through a large part of them fully automatically after initial input from the user.

Since earlier this year, with the start of CIRSI observations at the 2.5 m DuPont Telescope in Chile, things have changed somewhat. Data is now read out in read-reset-read mode (RRR), and the images are written to disk pre-assembled and reset-corrected. Sky subtraction (and/or flat-fielding) is performed, after which the objects are located and subsequently matched with the on-line APM catalogue. This gives the exact offsets for co-addition, and for mosaicing if it is required. This new version of *CIRDR* is now written in a hybrid of CL and C.