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Keck HIRES Echelle Simulator[1]

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1 Introduction

This document describes the operation of the software which is used to simulate the Keck HIgh Resolution Echelle Spectrograph (HIRES). This software is able to provide a preview of the spectral coverage that can be obtained with the HIRES spectrograph and with other Echelle spectrographs. The capabilities, operation, and limitations of the spectrograph can be explored before an astronomer makes any observations. The program can be used to generate configuration files which can be loaded into the Keck data acquisition software. This is intended to allow an astronomer to prepare a complete ensemble of instrumental setups suitable for any observing program.

1.1 Authorship

The HIRES Echelle Simulator program is derived from code originally written by Daniel J. Schroeder in 1985. This code was ported to VMS by C. Pilachowski. It was then obtained by S.S. Vogt and A.P. Hatzes. Hatzes added the first graphical interface to the program using Lick Mongo. Further work on the mathematical models and graphical interface have been added by S.L. Allen.

2 Mathematical Model

The underlying mathematics are described in the textbook by the original author of the code, D.J. Schroeder (*Astronomical Optics*, Academic Press, 1987). These algorithms provide a complete description of the Echelle format within the constraints of the 2–dimensional grating equations. They do not handle the more general problem of modelling the 3–dimensional grating equations. Other important algorithms used in the code are based upon the text by E. Hecht & A. Zajac (*Optics* Addison-Wesley, 1974).

The code is able to model a spectrograph where an Echelle grating is fed by a collimated beam. The beam leaving the Echelle grating may be cross-dispersed by at most 1 cross-dispersing grating and/or up to 9 cross-dispersing prisms.

2.1 Coordinate Systems

There are several coordinate systems which must be documented in order to describe the mathematical model of the Echelle simulator. Each detector has its own natural coordinate system. The detector (possibly more than one) is mounted somewhere on the focal plane of the spectrograph. It may be possible to move the detectors around the focal plane. The Echelle format has a natural coordinate system which is useful for describing it, and this varies with each different setting of the movable parts of the spectrograph.

2.1.1 The Coordinate System of an Individual Detector

Each CCD chip has its own coordinate system. This is to be distinguished from the coordinate system of the focal plane which is handled much further below.

The terminology used to describe this coordinate system is drawn from the early CCDs which were intended for use in standard video applications. Such CCDs had a single readout amplifier located in a position such that the chip could be used to produce a signal quite similar to that of a vidicon. They were designed to be illuminated from one particular side so that the handedness of the output signal would be proper for video applications.

Newer CCDs may have been thinned to allow illumination from the "back" side. They may also have multiple readout amplifiers. These new capabilities require the precise specification of the orientation and/or handedness of a particular detector.

Devices other than CCDs which have rectangular layouts should use the same terms and coordinate orientation.

2.1.1.1 Definition of Detector Layout Terminology

This section describes a standard video CCD for reference. The "x", "horizontal", & "serial" directions are parallel. The "y", "vertical", & "parallel" directions are parallel. A serial shift carries charge in the "minus x" direction. A parallel shift carries charge in the "minus y" direction. The set of all pixels with the same "y" coordinate is a "row". The set of all pixels with the same "x" coordinate is a "column". The words "height" and "width" are associated with "vertical" and "horizontal", respectively.

In most CCDs, the serial shift register has "pixels" which must be read out before the charge from the actual photo- sensitive region of the chip is read. These are known as underscan pixels. Most CCD controllers will also continue to do serial shifts after all the charge from the photo- sensitive region has been read. These are known as overscan, bias, or baseline pixels.

```
Q: This document does not treat the existence of these
Q: underscan and overscan pixels, it refers only to the
Q: "real" photosensitive pixels in the array.
Q: For engineering purposes it will be necessary to store
Q: some images with their under- and overscan pixels.
Q: FITS keywords will be needed which define the number
Q: of these under/overscan pixels.
```

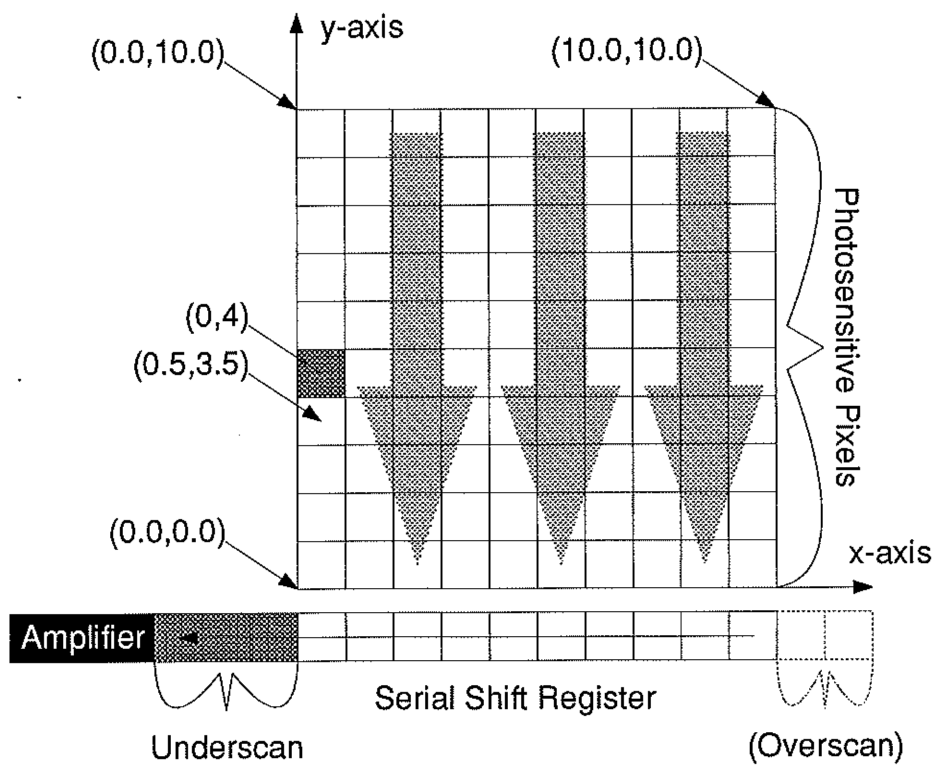
Assume an observer who is looking at the light-sensitive surface of the CCD from a viewpoint which would obscure the incoming light. As seen by this observer, the CCD's coordinate system `(x,y)` is a right-handed coordinate system. The readout amplifier is located at the lower left corner of the chip. This amplifier is closest to the pixel identified as `(0,0)`.

A diagram of a detector intended for video applications when viewed as specified above is presented here:

```
                          ^  (0,YPIX-1)  (1,YPIX-1)  ...  (XPIX-1,YPIX-1)
                          |  (0,YPIX-2)  (1,YPIX-2)  ...  (XPIX-1,YPIX-2)
       y_axis_direction   |   ...         ...        ...       ...
                          |  (0,1)       (1,1)       ...  (XPIX-1,1)
  amplifier_is_here-> a  (0,0)       (1,0)       ...  (XPIX-1,0)
                              ----x_axis_direction------->
```

Parallel shifts move the charge "down" in this picture. Serial shifts move the charge "left" in this picture. The above diagram does not show underscan or overscan pixels in the serial shifts. Underscan pixels would be to the left of the `(0,Y)` pixels and overscan pixels would be to the right of the `(XPIX-1,Y)` pixels. The shift directions used here are those that would be used when a single amplifier is used to readout the chip. With a single amplifier the order of readout is `(0,0), (1,0), (2,0), ... (XPIX-1,0), (0,1), ...`, etc. Thus, row 0 is read, left to right, then row 1, etc. Note again that this is a right-handed coordinate system. See Figure 2.1.1.1.1

Figure 2.1.1.1.1 View of a standard video CCD. Observer blocks incoming light.



Assume that a simple lens makes an image of an object on a video detector as described above. When the image is read in the described order and displayed on a video display in the standard fashion, the image on the video display will appear upright and not reversed. The layout of a standard video display is shown below, for reference:

```
                                ----x_coord_direction------->
   amp_seems_here-> a   (0,0)       , (1,0)       , ..., (XPIX-1,0)       ,
                    |   (0,1)       , (1,1)       , ..., (XPIX-1,1)       ,
 y_coord_direction  |    ...        ,  ...        , ...,      ...         ,
                    |   (0,YPIX-2), (1,YPIX-2), ..., (XPIX-1,YPIX-2),
                    v   (0,YPIX-1), (1,YPIX-1), ..., (XPIX-1,YPIX-1)
```

Parallel shifts appear to move charge "up" in this picture. Serial shifts appear to move charge "left" in this picture. Note that this is a LEFT-handed coordinate system, which is also known as a video-coordinate system.

2.1.1.2 "Left-handed" and Multi-amplifier Detectors

A CCD designed for video use may be thinned and illuminated from the "back" to improve its quantum efficiency. Such a detector will still have its `(0,0)` pixel as the pixel closest to the amplifier. However in such usage the handedness of an image produced by this CCD will be the opposite of standard. In this case, the coordinate system of the CCD (as seen by the observer looking at its light-sensitive surface) is a left-handed coordinate system. This must be indicated in the DETPOS card for this detector (see below).

A CCD with multiple amplifiers is a simple extension of the above rules. One amplifier should be chosen as the reference amplifier, and the pixel nearest that will be designated `(0,0)`. All pixels will be numbered from the designated origin as if they were being read through the reference amplifier. The handedness of the detector will be determined by comparing the handedness of readout through the reference amplifier with the handedness of a standard video detector. See Figure 2.1.1.2.2

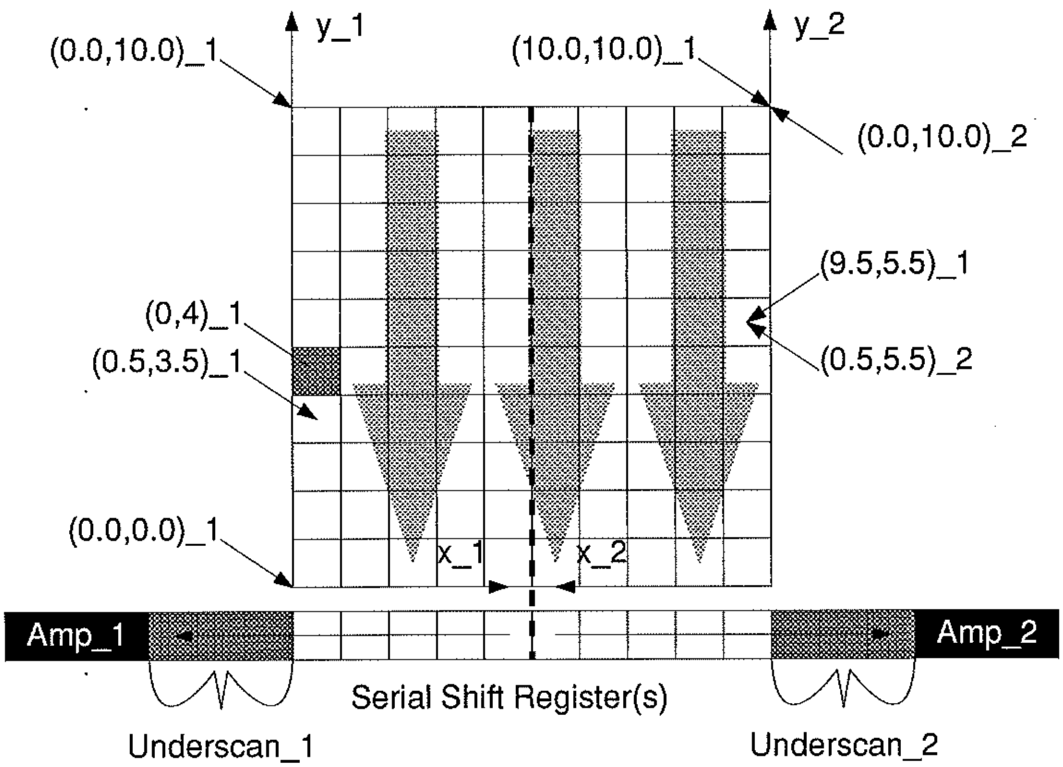
```
Q: How is the (baseline, amplifier bias, overscan)
Q: going to be represented in data where multiple amplifiers
Q: are used to read a single chip's imaging area?
Q: (There are no immediate plans to use multi-amplifier
Q: readout, but the Ford/Loral chips could do it.)
Q: Might considerations of the baseline measurement for a
Q: multi-amp chip make it necessary to treat it as
Q: several separate chips each making separate images?
```

```
A: Our current understanding of this indicates that the
A: multi-amp chips will be treated as separate chips.
A: To facilitate this, the DETPOS cards now have fields
A: to indicate which pixel is at the reference location.
```

2.1.1.3 The Definition of a Pixel

When real-valued coordinates are used, the middle of a pixel is at a half-integral location. The real limits of pixel 0 run from 0. to 1. To convert from real coordinate values to integer coordinate values, use the `floor()` function. To convert from integer coordinate values to real coordinate values, add 0.5 to the integer value. These conventions are generally accepted by the computer graphics community. They also make it easier to compute, because operations which deal with entire pixels should be possible using only integer arithmetic.

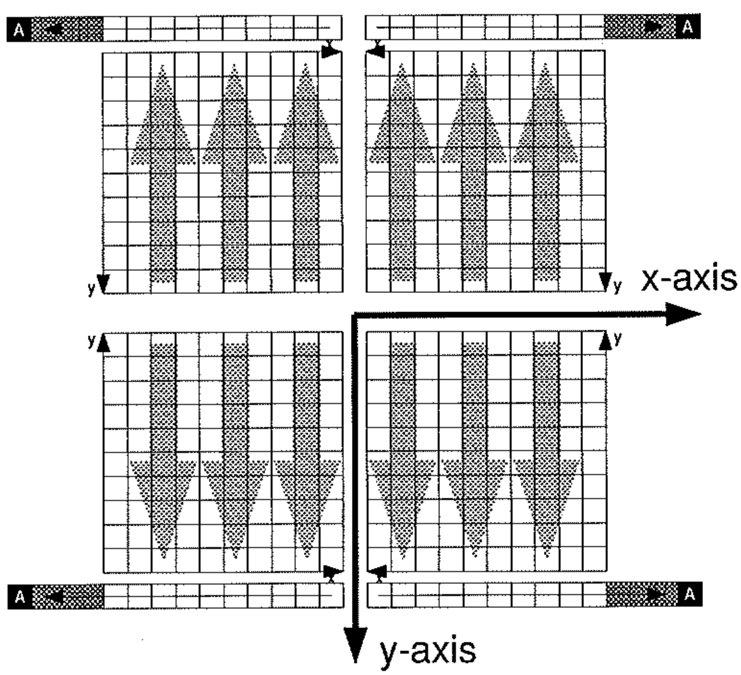
Figure 2.1.1.2.2 View of typical 2–amplifier CCD. Observer blocks incoming light.



2.1.2 The Detector Focal Plane Coordinate System

Assume an observer who is looking at the light-sensitive surface of the detector mosaic from a viewpoint which would obscure the incoming light. The coordinate system for the detector mosaic as seen by that observer is left-handed. The origin (0.,0.) of the Focal Plane system is some well-defined point near the center of the mosaic. The x-axis of the Focal Plane system may be chosen to point in any direction which is convenient. "Convenient" should be defined with consideration of the orientations of the detector and the image or spectrum which will be formed on the detector. It will be convenient for the simulator graphics software if all the coordinate systems of chips and mosaic are aligned with the 4 cardinal directions of compass points. Thus, the x-axis might point "right" and the y-axis point "down" as seen by the observer described above. Alternatively, the x-axis might point "down" and y point "left". In any case, the instrument simulator provides a FITS card which gives the relative orientation of the Focal Plane system and the simulator coordinate system. See Figure 2.1.2.3

Figure 2.1.2.3 View of a hypothetical detector focal plane containing a mosaic of 4 CCDs. This is as seen by an observer who is blocking the incoming light.

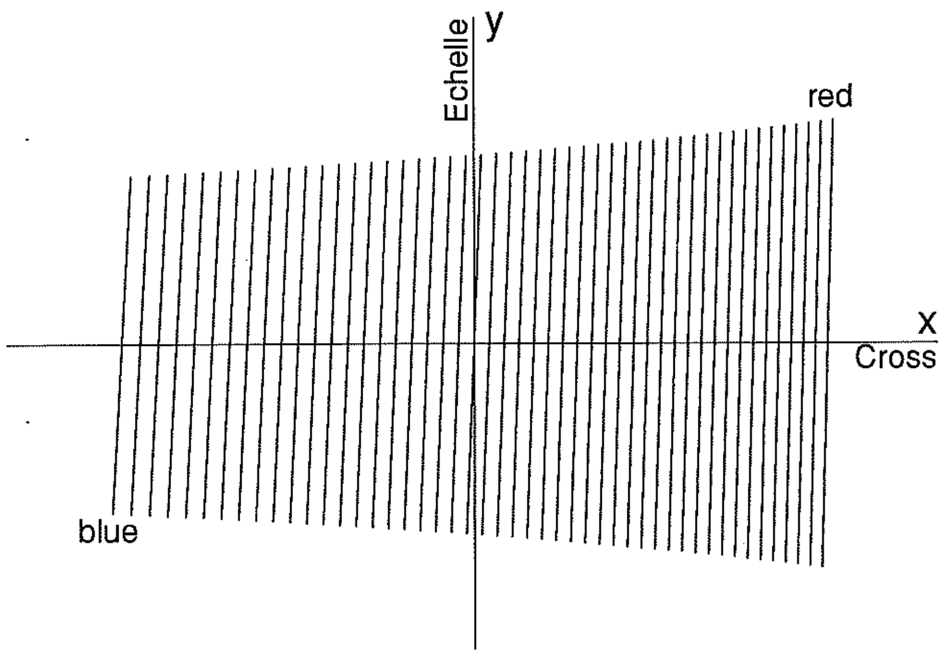


2.1.3 The Echelle Coordinate System

The Echelle Mosaic Coordinate system is the system used by calculations within the Echelle program. Assume an observer who is looking at the focal plane from a viewpoint behind the focal plane, i.e. such that the observer could only see the image if the focal plane were a translucent screen. The Echelle coordinate system as seen by this observer is a right-handed system. The "x" direction is along the cross dispersion direction. The "y" direction is along the Echelle dispersion direction. Orders with longer wavelengths have larger "x" coordinates; thus they are nearer to the "right" of the picture. Orders with shorter wavelength have smaller "x" coordinates; thus they are nearer to the "left" of the picture. The long wavelength end of each order has a larger "y" coordinate; thus it is nearer to the "top" of the picture. The short wavelength end of each order has a smaller "y" coordinate; thus it is nearer to the "bottom" of the picture. Overall, travelling in either the positive "x" or the positive "y" direction takes you to a longer wavelength. The y-origin/x-axis of this system is a horizontal line running along the blaze wavelength of each order. The x-origin of this system is somewhat arbitrary, and it is currently set at the x-position of the blaze wavelength of the bluest (left most) order.

The Echelle coordinate system was defined so as to match the appearance of the coordinate system used by Schroeder in figure 15.10 of his text. This definition also matches that of the original code as written by Schroeder. Internal calculations about the position of a point in the Echelle coordinate system are always carried out under the above definitions of x and y. It is recognized that there will be spectrographs where the handedness of the Echelle and cross dispersion directions will be opposite of that described here. See the definition of the **STDECHFH** parameter in the next chapter for details on flipping the handedness of the Echelle format.

Figure 2.1.3.4 Layout of the Echelle coordinate system as seen by an observer behind the focal plane.



2.1.4 The Lick Mongo Display Coordinates

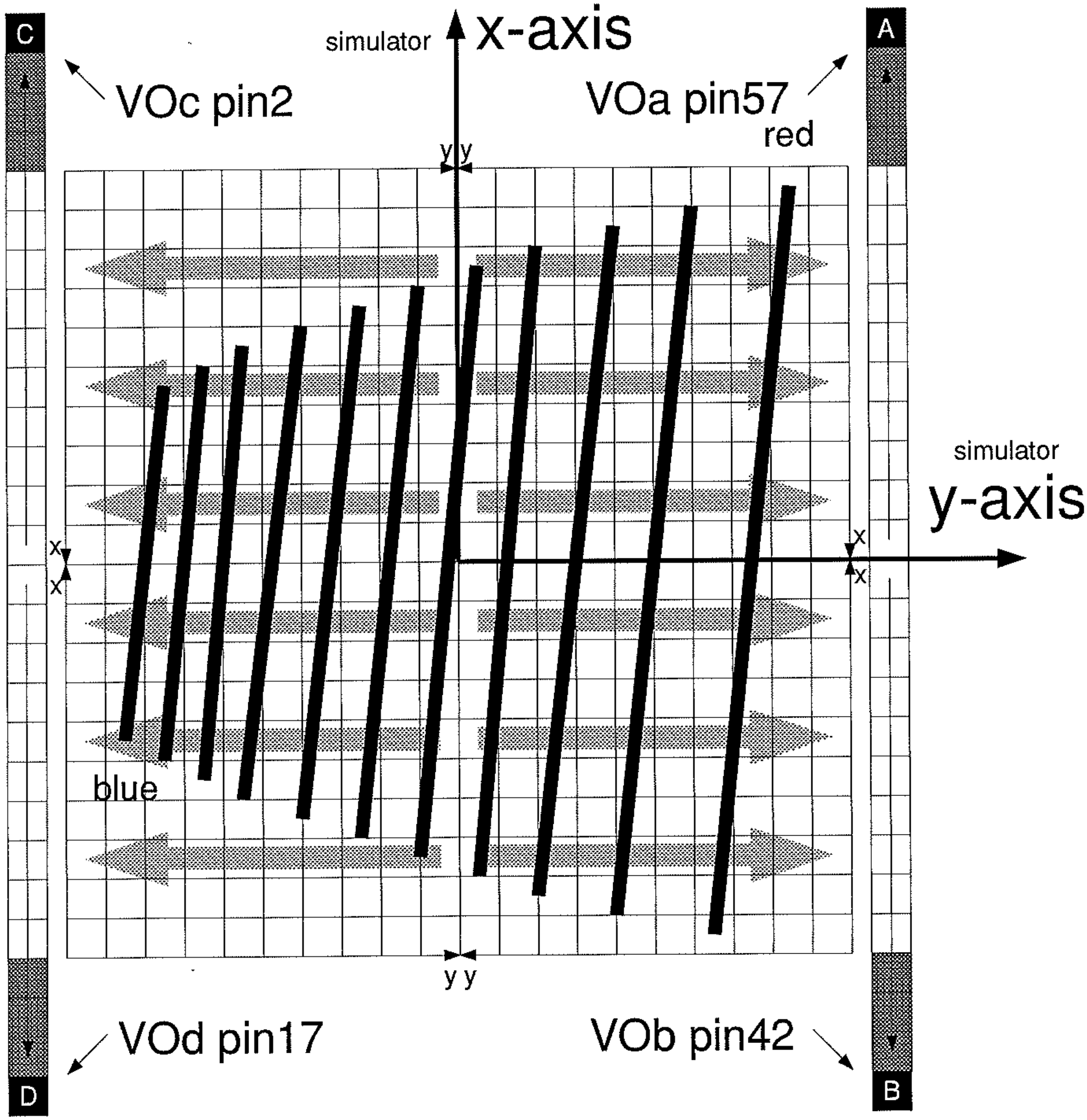
When the Echelle Simulator displays the Echelle format it uses the world coordinates of Lick Mongo. These world coordinates are related to the detector focal plane coordinates. The only difference between these two systems is a pure translation in x and y. However, the Lick Mongo coordinates are as viewed by an observer not blocking the incoming light (i.e., inside the detector). This means that the Lick Mongo coordinates are seen as right-handed because the observer is on the opposite side of the focal plane.

The translation between Lick Mongo coordinates and the detector focal plane coordinates is dynamically updated during the operation of the program whenever the user "moves" the detector. When the display device is an X server, instantaneous readout of the Display coordinates is visible at the lower left corner of the graphics window.

2.1.5 Relative Orientation of Coordinate Systems

The format of the Echelle spectrum is likely to be larger than the solid-state detectors currently in use. Sampling of the entire spectrum requires that the detector and the light be able to move with respect to each other. This may be performed by translating the detector across the focal plane. It may be performed by rotating the dispersing elements. The Echelle software allows for such relative translation of the Echelle and detector coordinate systems. It does this assuming that these coordinate systems do not rotate while translating. The angle between the x-axis of the Echelle and Detector Focal coordinate systems is specified at its constant value. See the definition of the **FPROTANG** parameter in the next chapter for details of this rotation.

Figure 2.1.5.5 View of the Keck HIRES detector focal plane with a Tektronix 2048x2048 CCD reading out through all 4 amplifiers. This is as seen by an observer who is looking throught the field-flattener and blocking the incoming light. The axes indicate the simulator's Detector Focal Plane system.



3 Input and Output Files

The complete description of an Echelle spectrograph requires copious amounts of information. Most of this information does not change, and it is convenient to store it in configuration files. The Echelle simulator searches for configuration files in several directories. The first directory searched is the current working directory. Next, if the environment defines `EFDIR` that directory is searched; otherwise the program looks in the built-in default directory[2].

3.1 Configuration Files

The Echelle Simulator accepts 3 kinds of configuration files. The first 2 kinds of files rarely need changing; they describe the telescope/spectrograph optics (`*.spc`) and the detector at the focal plane (`*.det`). The third kind of file contains the settings of all the moveable parts of the spectrograph which are expected to change from one observation to the next (`*.set`).

The configuration files for the Echelle Simulator look like FITS files. Configuration parameters are stored as keyword/value pairs. In accordance with FITS files, the keywords are up to 8 characters long. (Many of these keywords are identical to the keywords which will be used by the Keck Data Acquisition System when it is documenting actual observation.) Each keyword is followed immediately by "= " in columns 9–10. The values may be found anywhere after the "= " starting in column 11. The principal difference between the Echelle Simulator configuration files and true FITS headers is the existence of carriage control. Echelle Simulator configuration files contain carriage control and are intended to be edited by any text editor.

Each time the Echelle Simulator is run it outputs hidden versions of the three configuration files. These are named `.ech.spc`, `.ech.det`, and `.ech.set`. These can be compared with the original inputs and any changes made by user interaction to verify that the program is working as desired.

Upon request of the user, the program also writes out an observation setup file in either of 2 formats. The first format is identical to the inputs (described below). The second format contains FIORD commands designed to command the Keck HIRES spectrograph to the given configuration.

2 On the UCO/Lick systems this is `/home/hires/sla/echelle/lib`.

There are several keywords which are defined by the Keck HIRES data acquisition system which are not used by the instrument simulator. The instrument simulator accepts these keywords and carries their values from input to output unchanged.

3.1.1 Spectrograph/Telescope Configuration (.spc)

Files which end in "`.spc`" describe the optical characteristics of the telescope and spectrograph. Parameters defined in these files typically do not change because they describe large or unique optical elements.

A concise table of all these keywords and values can be found in Table 1 and an example file can be found in Appendix C.

3.1.1.1 Telescope and Camera Parameters

TELESCOP As defined in the FITS standard. A character string identifying the telescope.

INSTRUME As defined in the FITS standard. A character string identifying the instrument.

PRIMDIAM The diameter of the telescope primary [meter]. In the case of the Keck this is the maximal diameter across the hexagons. This is used for calculating the diameter of the collimated beam inside the spectrograph.

FOCSCALE The image scale at the focus of the telescope [arcsec/mm].

COLFOCLN Focal length of the collimator which feeds the Echelle grating [meter/radian]. Either this card or **COLLDIAM** must be specified. If both exist, **COLFOCLN** will be used and **COLLDIAM** will be recalculated. In an existing spectrograph this parameter is the easier to measure of the two.

COLLDIAM The diameter of the collimated beam which feeds the Echelle grating [meter]. Either this card or **COLFOCLN** must be specified. If both exist, **COLFOCLN** will be used and **COLLDIAM** will be recalculated. This parameter is provided for cases where the instrument simulator is being used to design a new Echelle spectrograph.

CAMFOCLN The focal length of the camera which feeds the detector [meter/radian].

3.1.1.2 Echelle Grating Parameters

ECSIGMA The groove spacing of the Echelle grating [μm/groove]. Either this card or **ECSIGMAI** must be specified. If both exist, **ECSIGMA** will be used and **ECSIGMAI** will be recalculated.

ECSIGMAI The groove frequency of the Echelle grating [groove/mm]. Either this card or **ECSIGMA** must be specified. If both exist, **ECSIGMA** will be used and **ECSIGMAI** will be recalculated.

ECTHETAD

The angle θ of the Echelle grating [degree]. θ is as defined in Schroeder chapters 13 and 15. The angle between the incoming and the central outgoing Echelle beams is 2θ.

ECDELTAD The blaze angle of the Echelle grating [degree].

3.1.1.3 Grating Cross Disperser Parameters

NXDGRAT The number of cross dispersing gratings in the spectrograph. This must be either 0 or 1.

XDSIGMA The groove spacing of the cross dispersing grating [μm/groove]. Either this card or **XDSIGMAI** must be specified. If both exist, **XDSIGMA** will be used and **XDSIGMAI** will be recalculated.

XDSIGMAI The groove frequency of the cross dispersing grating [groove/mm]. Either this card or **XDSIGMA** must be specified. If both exist, **XDSIGMA** will be used and **XDSIGMAI** will be recalculated.

XDDELTAD The blaze angle of the cross dispersing grating [degree].

XDALFBET The total angle of deviation caused by the cross dispersing grating; also referred to as the Echelle-to-Camera angle. This is equivalent to $\alpha - \beta$ in Schroeder's text (see Fig 13.2 and the text following Eq. 13.2.1). This is the angle needed to reflect a central beam from the Echelle into the central axis of the camera. The actual incident (α) and reflected (β) angles vary according to which cross disperser order and wavelength are desired, but their difference is constant on axis.

3.1.1.4 Prism Cross Disperser Parameters

NXDPRISM The number of cross dispersing prisms in the spectrograph. This must be in the range from 0 to 9.

PRANGIND The angle of incidence of light on the face of the first prism [degree]. This is denoted ψ in some of the simulator output displays.

PRAPEX The apex angle of the cross dispersing prisms [degree]. This may be overridden for the ***n***th prism by a **PRAPEX*n*** card.

PRAPEX*n* The apex angle of the ***n***th cross dispersing prism [degree].

PRFACE The angle between the faces of adjacent prisms [degree]. This may be overridden for the ***n***th and ***n+1***st prisms by a **PRFACE*n*** card. This is denoted ϕ in some of the simulator output displays.

PRFACE*n* The angle between the faces of adjacent prisms ***n*** and ***n+1*** [degree].

PRGLAS The name of the type of glass in the prisms. This must be derived from the list of glasses found in the file glass.F of the source code. This may be overridden for the ***n***th prism by a **PRGLAS*n*** card.

PRGLAS*n* The name of the type of glass in the ***n***th cross dispersing prism.

3.1.1.5 Echelle Coordinate System Parameters

STDECHFH This is a boolean parameter which allows the handedness of the Echelle format to be flipped. If this has the value True, then the long wavelength end of each Echelle order has a larger "y" coordinate than the short wavelength end of the same order. If this has the value False, then the Echelle format is flipped about the x-axis of the Echelle Coordinate system.

FPROTANG

This is the angle between the x-axes of the Echelle and Detector Focal coordinate systems [degree]. It is specified at its constant value. It is assumed that the 2 systems are coplanar. This angle is measured in the Echelle Coordinate system. It is measured from the x-axis of the Detector Focal Plane system to the x-axis of the Echelle system. This angle is measured in a counter-clockwise sense as seen by the observer who is behind the detector (i.e., the detector is between the observer and the incoming light). Note that both of these coordinate systems are right-handed (when they have standard orientations and handednesses) as viewed by this observer.

3.1.2 Detector Configuration (.det)

Files which end in "`.det`" describe the characteristics of the detector or detectors located in the focal plane of the spectrograph. Parameters defined in these files typically do not change because they describe installed silicon components. It is likely that there will be multiple detectors and thus multiple different detector configuration files.

A concise table of these keywords and values can be found in Table 2 and an example file can be found in Appendix C.

3.1.2.1 Video Orientation Parameters

It is recognized that there are sites which for one reason or another display their video images in a manner which is not standard. For this reason, the Echelle Simulator defines three keywords which can be used to flip the orientation of everything which it displays. This makes it easy to match the Echelle Simulator graphics with the images produced by the actual detector.

Note that the orientation of the video display is actually an artifact of the video display and of the program which is being used to drive the video display. Thus, these keywords are not strictly associated with the detector, but rather with the displayer. Nonetheless, they are included in the detector file for convenience.

STDVIDV This is a boolean parameter. If this is True, then the site displays CCD images with row 0 at the top of video monitors and higher-numbered rows are below row 0. If this is False, the site displays row 0 at the bottom of video monitors.

STDVIDH This is a boolean parameter. If this is True, then the site displays CCD images with column 0 at the left of video monitors and higher-numbered columns are right of column 0. If this is False, the site displays column 0 at the right of video monitors.

STDVIDR This is a boolean parameter. If this is True, then the site displays CCD images with rows horizontal and columns vertical. If this is False, the site has rotated displays from the usual orientation. The instrument simulator currently ignores this parameter.

3.1.2.2 Detector Description Parameters

DETECTOR This is a character string describing the particular detector which is at the focal plane of the spectrograph.

NCHIPS This is an integer denoting how many readout amplifiers will be used to extract data from the detector or mosaic of detectors. There must be this many **CHIPID*n*** cards and **DETPOS*n*** cards.

CHIPID*n* This is a character string uniquely identifying the ***n***th readout amplifier. In the case of a single CCD chip with a single amplifier only **CHIPID1** will be specified. In the case of a multi-chip mosaic detector or a single chip with multiple amplifiers being used there must be **NCHIPS CHIPID** cards, one for each amplifier. The index ***n*** will be used in the following Keyword/Value pairs which describe other aspects of the detector(s).

Every individual CCD chip (or other similar detector) is intended to have a unique ID associated with it. This unique ID should serve to allow lookup of the defects and blemishes which are peculiar to that chip. In the case of a multi-amplifier chip, this must uniquely distinguish each amplifier of the chip. We expect that some kind of defect and blemish database will be established which will identify the nature of the known problems and even tell about problems that change with time (i.e., new defects arise or old ones vanish).

ChipIDs are character strings which will contain information such as that suggested in the example card(s) in Appendix C. Note that in current use the ChipIDs would more precisely be Amplifier IDs. It is possible that the name of these cards might be changed to **AMPID*n*** in the future.

XPIX and XPIX*n* This is the number of real photosensitive pixels which might be readout along the x-direction of each amplifier. **XPIX*n*** refers only to the amplifier described by **CHIPID*n*.**

YPIX and YPIX*n* This is the number of real photosensitive pixels which might be readout along the y-direction of each amplifier. **YPIX*n*** refers only to the amplifier described by **CHIPID*n*.**

```
Q: How is the (baseline, amplifier bias, overscan)
Q: going to be represented in Keck CCD data?
Q: Will it be represented in extra pixels which are not a
Q: part of the image data?  If so, what keyword will
Q: describe this in the final FITS header for the image?
```

PIXXSZ and PIXXSZ*n* This is the spacing between pixels along the x-direction of each amplifier [meter]. **PIXXSZ*n*** refers only to the amplifier described by **CHIPID*n*.**

PIXYSZ and PIXYSZ*n* This is the spacing between pixels along the y-direction of each amplifier [meter]. **PIXYSZ*n*** refers only to the amplifier described by **CHIPID*n*.**

3.1.2.3 Detector Blemish Parameters

Bad spots (dead pixels, hot pixels, etc.) on the CCD chips are described by BSPOT arrays. Bad spots are assumed to describable as rectangular regions on the chip. Bad regions with more complex shapes can be decomposed into rectangles. It is not yet clear whether BSPOTs may overlap. The FITS cards for a given image should simply list the current bad spots of a detector. This should be looked up from a badspot database which may contain a time history of the bad spots and further information on whether particular badspots are hot, dead, have poor charge transfer efficiency (CTE), etc.

```
Q: Everybody agrees that this badspot database is a good idea,
Q: but nobody seems to want to define it.
```

The Instrument Simulator makes use of bad spot information in order to display those regions of the detector to the user. Thus, the user is able to position the elements of the spectrograph such that important portions of the spectrum do not fall onto insensitive portions of the detector.

NBSPOT This is the total number of bad spots or blemishes contained on all of elements of the detector. There must be this many **BSPOT*n*** cards.

BSPOT*n* These values are character strings containing 5 integer elements.

1. The index indicating to which amplifier this **BSPOT** pertains. If this is ***n*** it refers to **CHIPID*n*** located at **DETPOS*n***.
2. The x position (column) of the pixel in this bad rectangle which is closest to the origin.
3. The y position (row) of the pixel in this bad rectangle which is closest to the origin.
4. The width (span in x) of this bad rectangle.
5. The height (span in y) of this bad rectangle.

The software permits the width and height of the bad spot to extend far off the chip. This is for the convenience of persons defining the bad spots by hand. The software will clip the badspot to the actual pixel limits given by **XPIX** and **YPIX**.

3.1.2.4 Focal Plane Position Parameters

DETPOS*n* In order to represent the locations of the Echelle spectrum on the detector plane it is necessary to describe the layout of the detector. There must be **NCHIPS** of these **DETPOS*n*** cards. Each card is a character string containing 4 or 6 elements.

1. x0
2. y0
3. Rot
4. Orient
5. RefX (optional)
6. RefY (optional)

x0, and y0 are the position of the `(0,0)` pixel of the chip measured in meters in the Detector Focal Plane coordinate system. For precision of documentation, and because the software must know, the precise reference point of the `(0,0)` pixel is the corner of the pixel that would be directly between `(0,0)` and `(-1,-1)`, as if pixel `(-1,-1)` actually existed. This is location `(0.,0.)` in the floating point notation. (We do not expect that the actual measurements of the location of this pixel will be precise enough to justify this subtlety.) When there is only 1 detector in the mosaic, the values of x0 and y0 may be ignored by the software; the center of the detector may be placed at the center of the focal plane.

Rot is measured in degrees. Rot is the angle measured from the x-axis of the focal plane coordinate system to the x-axis of the detector. This angle is measured in a clockwise sense as seen by an observer who is blocking the incoming light.

Orient is either +1 or -1, depending on the handedness of the detector. Orient should be +1 for a detector which is being readout with the same handedness as a device intended for standard video applications. Orient should be -1 for a detector with handedness opposite of standard video.

RefX and RefY indicate which pixel on the detector is at the location specified by (x0, y0). These values are optional, and will be presumed to be 0.0 if they are not given. These were added in order to facilitate the description of chips with multiple amplifiers because such chips are treated as separate detectors. Without these fields multi-amplifier chips require tedious and awkward calculations to specify their **DETPOS** cards.

3.1.3 Setup Configuration (.set)

Files which end in "`.set`" describe the easily changeable characteristics of the detector and spectrograph. These include grating rotation angles, camera focus positions, CCD readout regions, etc. Parameters defined in these files typically change for each observation.

A concise table of these keywords and values can be found in Table3 and an example file can be found in Appendix C.

3.1.3.1 Simulator Operation Parameters

SETUP This is a character string giving the name of this setup as it will be known to the Keck FIORD routines.

OBSERVER As defined in the FITS standard. A character string identifying the observer.

DETFILNM A character string giving the full path name of the Detector Description file which should be used along with this Instrumental Setup.

SPCFILNM A character string giving the full path name of the Spectrograph/Telescope Description file which should be used along with this Instrumental Setup.

WAVLMAX The maximum wavelength which should be displayed by the simulator [Ångstrom].

WAVLMIN The minimum wavelength which should be displayed by the simulator [Ångstrom].

XDORDER The cross dispersion order which should be displayed by the simulator.

WAVEFILE A character string giving the full path name of the Spectral Line Wavelength file which should be used to display interesting lines.

RADVEL Radial velocity which should be applied to the non-Telluric spectral lines [m/s].

RADVELZ Redshift which should be applied to the non-Telluric spectral lines [$\Delta\lambda/\lambda$]. If the **RADVEL** card is given it will be used instead.

3.1.3.2 Wavelength Selection Parameters

ECHANGL The Echelle grating rotation angle [degree]. The zero point for Echelle rotation angle is that angle at which the incoming and outgoing light are "on blaze." Positive values move longer wavelengths onto the detector, negative values move shorter wavelengths onto the detector.

XDANGL The cross dispersing grating rotation angle [degree]. The zero point for cross dispersing grating angle is that angle at which the incoming and outgoing light are "on blaze." Positive values move longer wavelengths onto the detector, negative values move shorter wavelengths onto the detector.

HEIGHT The detector height [machine encoder units]. This is for the Hamilton spectrograph only. The Hamilton spectrograph uses fixed cross dispersing prisms and moves the detector up and down to select different wavelengths of cross dispersion.

ECHRAW The Echelle grating rotation angle [machine encoder units]. This is not used by the Instrument Simulator.

3.1.3.3 Decker Parameters

Decker keywords are defined and used differently by almost every data acquisition system on every telescope. The HIRES decker is a metal plate with machined notches (holes). This metal plate is moved parallel to the Echelle dispersion until one of the notches lines up with the slit.

The notch (hole) in the decker plate may actually be several holes. This will presumably prove useful after the image rotator is installed. An observer might want a decker which rejected the light from the bright nucleus of an otherwise faint galaxy. As a result of the possibly disconnected nature of the decker notch, the decker height is defined to be the total vertical extent of the holes in the decker plate.

DECKER A string describing the particular metal plates which are currently installed (by hand) in HIRES. This keyword is obsolete.

DECKPOS The decker plate position [meter]. The value of this card (and the next) will only be applicable to a particular decker plate. Not used by the simulator.

DECKRAW The decker plate position [machine encoder units]. Not used by the simulator.

DECKNAME A character string giving a pet name which is associated with a particular position (usually of a particular notch) of the decker plate.

DECKHGT Total height of the decker [meter]. This keyword is known only to the simulator and not to the HIRES control system.

DECKSIZE Total height of the decker [arcsec]. If **DECKHGT** is given it will be used instead. This keyword is known only to the simulator and not to the HIRES control system.

DECKPIX Total height of the decker [pixel]. If **DECKHGT** or **DECKSIZE** is given it will be used instead. If **DECKPIX** is used the Instrument Simulator makes the additional assumption that the pixels of all detectors are square and that all detectors in the mosaic have pixels of the same size. This keyword is known only to the simulator and not to the HIRES control system.

3.1.3.4 Slit Parameters

The Instrument Simulator allows the user to specify the slit width in 5 different ways. These different ways are presented here in the same order as the simulator looks for them. If the input specifies the slit width by more than one method the top most method in this list will be the one used. Note that the slit width cannot be specified as a given interval in wavelength. Although this would be a natural unit, the dispersion differs in each Echelle order enough to make the concept unusable.

SLITWID Width of the slit [mm].

SLITSIZE Width of the slit [arcsec]. This keyword is known only to the simulator and not to the HIRES control system.

SLITPIX Width of the slit [pixel]. If **SLITPIX** is used the Instrument Simulator makes the additional assumption that the pixels of all detectors are square and that all detectors in the mosaic have pixels of the same size. This keyword is known only to the simulator and not to the HIRES control system.

SLITVEL Width of the slit [m/s]. This allows the user to specify the width of the slit using radial velocity resolution elements. This keyword is known only to the simulator and not to the HIRES control system.

SLITRAW Width of the slit [machine encoder units].

3.1.3.5 Filter and Focus Parameters

The Instrument Simulator does not currently use any of these parameters, but they are passed along for use in predefining setups.

FIL1POS An integer giving the HIRES filter wheel 1 position [1 thru 12].

FIL2POS An integer giving the HIRES filter wheel 2 position [1 thru 12].

FIL1NAME A character string giving the name that the observer has associated with the filter in wheel 1.

FIL2NAME A character string giving the name that the observer has associated with the filter in wheel 2.

COLL A character string specifying which HIRES collimator to use ['RED' or 'BLUE'].

COFOCUS The focus position of the collimator [meter].

CAMERA A character string specifying which HIRES camera mirror to use ['RED' or 'BLUE'].

CAFOCUS The focus position of the camera [meter].

3.1.3.6 Detector Readout Parameters

BINNING and BINNING*n* A character string describing the binning factors to be used along the x- and y-directions of each amplifier [pixel]. **BINNING*n*** refers only to the amplifier described by **CHIPID*n***. Note that the readout hardware of a given detector may not be able to support all the possibilities provided by these cards. In particular, the HIRES control system currently requires that binning be the same for all amplifiers, and the simulator does not propagate **BINNING*n***.

DWINDOW and DWINDOW*n* A character string describing the desired readout window which is to be used for the amplifier described by **CHIPID*n*** as it was described by the astronomer. This is measured in physical pixels, not logical pixels. The readout window is a rectangular region. This character string contains 4 integer elements.

1. X0
2. Y0
3. NAXIS1
4. NAXIS2

X0 and Y0 are the coordinates of the pixel in the readout rectangle which is closest to the origin. NAXIS1 is the extent of the readout rectangle in columns (x), and NAXIS2 is the extent of the readout rectangle in rows (y). The software permits the width and height of the readout rectangle to extend far off the chip. This is for the convenience of persons defining the readout region by hand. The software will clip the readout region to the actual pixel limits given by **XPIX*n*** and **YPIX*n***.

3.2 Spectral Line Wavelength file

The Echelle Simulator will accept a file containing the wavelengths of spectral lines and display those lines on its graphics. The existence of such a file can be indicated using the `WAVEFILE` keyword in the Setup Configuration file and it can also be indicated interactively during the execution of the program. Each line of the file contains a description of one spectral line. The program looks for a wavelength (expressed in Ångstrom), a boolean value (T or F) which describes whether the line is telluric (and thus should not be redshifted), and a statistical weight. The statistical weight is used by the program during the design of new spectrographs. It is intended to assist the program in choosing an Echelle groove spacing which places certain spectral lines near the blaze.

An example file can be found in Appendix C.

3.3 Keck DAS command file

While the Echelle Simulator is running the user can ask the program to output a file suitable for input to the Keck Data Acquisition System (DAS). This file contains "define" commands encompassing each of the user-settable options of the HIRES spectrograph. The name of the file is the same as that of the "setup" name under which the Keck DAS will store the file. See the next chapter for details on the interactive generation of this file. An example file can be found in Appendix C.

4 User Interaction

The most common platform on which the instrument simulator will be used is probably a high-resolution monitor running version 11 of the X Window System from MIT. However, it is essential to note that the instrument simulator is NOT an X11–based program. The instrument simulator uses the Lick Mongo package to do its graphics and user interaction. This allows the instrument simulator to be run on a variety of platforms dating back to Tektronix storage-tube terminals. Because of this the instrument simulator cannot do multiple popup windows and menus as would be expected of a modern, X11–based user interface.

4.1 Starting the Echelle Simulator

Starting the Echelle Simulator can be done by typing the command "`echelle`." If the user is running the X Window System and the user's environment defines the `DISPLAY` variable the simulator will assume that the graphics should be displayed in an X Window. If the `DISPLAY` variable is not set the program will prompt the user to enter one of the terminal types known to Lick Mongo.

The simulator then searches the current directory and the library directory looking for a setup file to be used to display the Echelle format. A list of all the setups found in these directories is presented, and the user is asked to choose one.

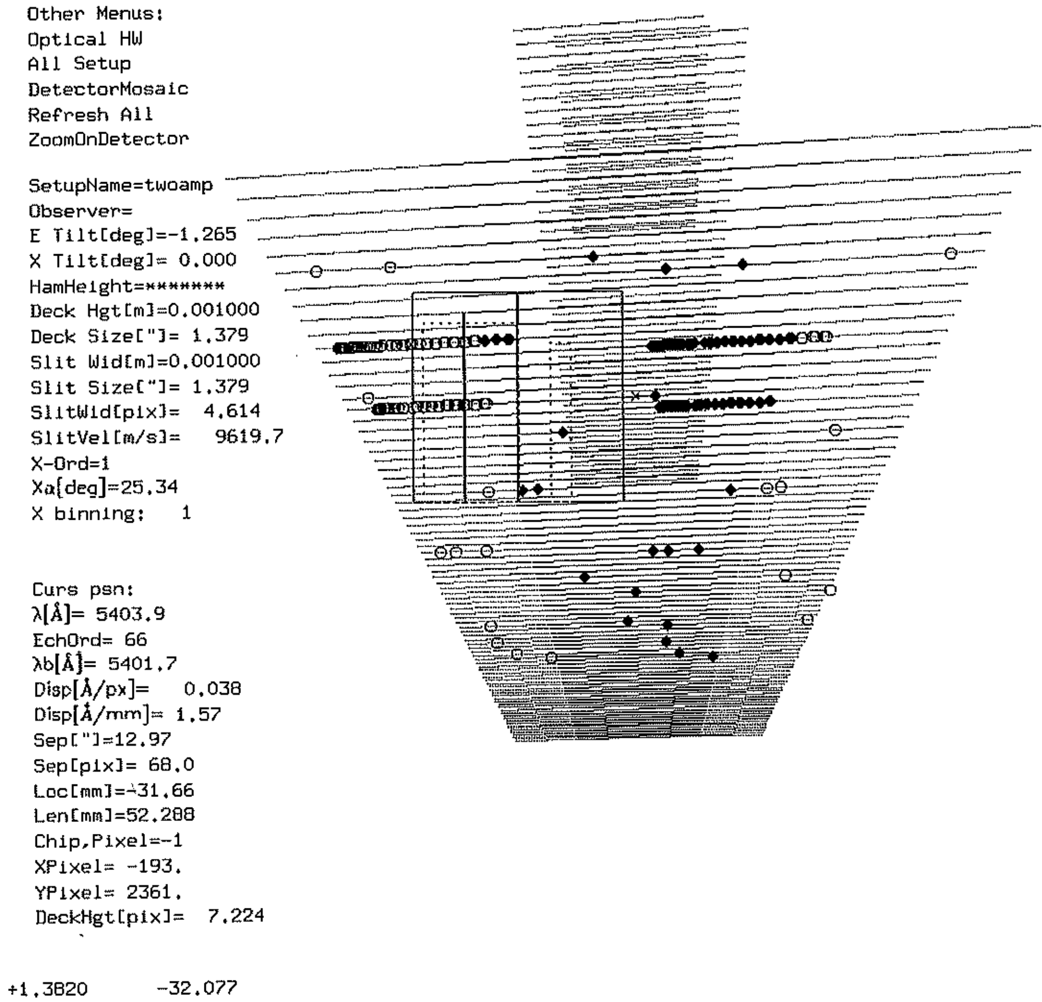
Using the information contained in the setup file, the simulator draws a picture of the Echelle format. For each Echelle order within the specified wavelength limits, one free spectral range (FSR) centered on the Echelle blaze is drawn. Most of the light in any Echelle order is within one FSR of the Echelle blaze wavelength for that order. There is some light in each order more than one FSR away from the blaze, but the intensity drops rapidly.

On a display which supports color the simulator extends the length of each Echelle order by drawing another FSR in grey on either side of the blaze. In the case of an Echelle spectrograph with grating cross dispersers the simulator displays the selected order of cross dispersion and several nearby orders of cross dispersion. Any spectral lines which were defined are plotted on the Echelle format twice. The position of the spectral line closest to the blaze is drawn with a filled dot, and the position next closest to the blaze is drawn as an open dot. It will usually be best to choose to observe a spectral line in the order where it is closest to the blaze. The secondary line locations are shown for cases where the Echelle format is large compared with the detector.

The simulator also draws a schematic of the detector(s) properly positioned on the Echelle format. Any bad spots on the detectors are indicated by rectangular regions on the display. The readout regions are indicated by dotted lines.

The simulator also displays text lists which give the details about the optics, their settings, and the current location of the cursor. At this point the simulator is ready for interactive graphical use.

Figure 4.1.6 Typical appearance of the Instrument Simulator during interactive use



4.2 Graphical Interaction

Most of the user interaction with the program is accomplished with single keystrokes (or mouse clicks) while the graphics are displayed. Many of the possible commands are visible on the "menus" at the left side of the screen. (The scarcity of screen real estate on some types of displays prevent all possible commands from being visible.) There are 3 methods by which the user can graphically interact with the program:

1. Accelerator Key
2. Mouse Drag
3. Menu Click

A glance through the following tables will reveal that some parameters may be modified using more than one of these methods.

Accelerator keys are single keystrokes. An accelerator which is associated with a Boolean parameter will toggle that parameter from one state to the other. An accelerator which is associated with a string or numeric parameter will prompt the user for a new value. If the display is an X11 server, the prompt will change the cursor into a question-mark, and the prompt will be visible at the bottom of the screen. On other displays the prompt will appear on the text screen, if one exists, or on the graphics screen.

Mouse drag can only be used on X11 displays. Dragging can be done with fixed-size objects or with rubber objects. The Instrument Simulator allows the readout window to be indicated by dragging a rubber rectangle over the display. The position of the detector(s) can be modified by dragging a fixed-size rectangle (of the same size as the detector). When dragging a fixed-size rectangle, it may be "grabbed" at any of 9 locations defined by the corners and points halfway between.

Menu click can be used for items which are displayed in the lists of text at the side of the display. It requires that the display have some kind of moveable cursor. The cursor is moved over the menu item and any unassigned key or button is hit. The user will then be prompted for a change in the same manner as for accelerator keys.

4.2.1 Modifying the display

The overall display can be modified by the use of single accelerator keystrokes or menu clicks.

Menu Label	*Accelerator Key*	*Action*
Show OpticalHW	!	Display the complete menu of optical hardware.
Show All Setup	$	Display the complete menu of instrumental setup.

Menu Label	*Accelerator Key*	*Action*
DetectorMosaic	%	Display more information about the detector(s).
Default Setup	^	Restore the originally displayed menus.
Refresh All	R	Redraw everything.
ZoomOnDetector	Z	Zoom the display to show only the region where the detector is currently located.
Exit2CmdLinMod	Q	Quit the graphical interaction and begin command line interaction (see Section 4.3 below).
DisplayWavelen	control-L	(Un)Display the wavelengths of every fifth order.
Display Orders	control-O	(Un)Display the order numbers of every fifth order.
Mark Detector	D	(Un)Plot a temporary outline of the detector(s) at the current location of the detector. These outlines will be visible in a hardcopy.
-	control-I X Mouse 1	Identify the spectral line nearest to the cursor.
-	M X Mouse 2	Move the detector(s) over the Echelle format.
-	W X Mouse 3	Define the readout window of the detector(s).

4.2.2 Modifying the Setup

Keyword Name	*Label on Menus*	*Accelerator Key*
SETUPNM	SetupName=	None

Keyword Name	*Label on Menus*	*Accelerator Key*
DETFILNM	DetectorFile=	None
SPCFILNM	Tel/Spg File=	None
OBSERVER	Observer=	None
ECANGLE	ECangle[deg]=	(M) (X Mouse 2)
XDANGLE	XDangle[deg]=	(M) (X Mouse 2)
HAMHGT	HamHeight=	(M) (X Mouse 2)
ECANGRAW	Raw E Tilt=	(M) (X Mouse 2)
DECKER	Decker Name	None
DECKRAW	RawDeckPos=	None
DECKPOS	DeckerPos[m]=	None
DECKNNAM	DeckPosName=	None
DECKHGT	Deck Hgt[m]=	None
DECKSIZE	Deck Hgt["]=	None
DECKPIX	DeckHgt[pix]=	None
DECKSPEC	DeckSpec=	None
SLITWID	SlitWidth[m]=	None
SLITSIZE	SlitWidth["]=	None
SLITPIX	SlitWid[pix]=	None
SLITVEL	SlitWid[m/s]=	None
SLITRAW	RawSlitWidth=	None
FILTER	Filter 1 Pos=	None
FILTER2	Filter 2 Pos=	None
FILNAME	Filter1 Name=	None
FIL2NAME	Filter2 Name=	None
COLL	Collimator:	None
COFOCUS	CollFocus[m]=	None
CAMERA	Camera:	None

Keyword Name	*Label on Menus*	*Accelerator Key*
CAFOCUS	Cam Focus[m]=	None
XDORDER	XD Order #	O
XBIN	X binning:	None
YBIN	Y binning:	None
XDALPHAD	XDα[deg]=	None
XDBETAD	XDβ[deg]=	None
RADVEL	Rad Vel[m/s]=	None
RADVELZ	Rad Vel as Z=	None
WAVLMAX	MaxDispWavel=	None
WAVLMIN	MinDispWavel=	None

4.2.3 Modifying the Optics

The Echelle Simulator can be used during intial design studies of new Echelle spectrographs. It is possible to modify the properties of many of the optical elements while the program is running. Under normal circumstances these capabilities are not desired by the user, and they are disabled.

Keyword Name	*Label on Menus*	*Accelerator Key*
TELESCOP	Telescope=	None
INSTRUME	Instrument=	None
PRIMDIAM	Dtel[m]=	T
COLLDIAM	Dcoll[m]=	C
CAMFOCLN	CamFocL[m]=	F
COLFOCLN	ColFocL[m]=	None
NXDPRISM	#Prisms=	N
PRAPEXD	Apex[deg]=	A
PRAPEX*n*	Apex*n*[deg]=	None
FOCSCALE	FocScal["/mm]	None

Keyword Name	*Label on Menus*	*Accelerator Key*
FPROTANG	FPRotAng[deg]=	None
NXDGRAT	# XD Grat:	X
PRGLAS	Glass=	None
PRGLAS*n*	Glass*n*=	None
ECTHETAD	ECθ[deg]=	H
ECTHETA	ECθ[rad]=	None
XDSIGMAI	XD[groov/mm]=	I
XDSIGMA	XDσ[μm]=	None
ECSIGMAI	EC[groov/mm]=	S
ECSIGMA	ECσ[μm]=	None
PRANGIND	Ang Ind[deg]=	None
PRFACE*n*	ϕ[deg]=	None
XDALFBET	XDα-β[d]=	None
XDDELTAD	XDblaze[deg]=	None
ECDELTAD	ECblaze[deg]=	B
ECDELTA	ECblaze[rad]=	None

4.3 Command Line Interaction

When the user has "quit" from the graphical interaction, the program enters another mode where the interaction is done on the text screen. All commands in this mode must be followed by a carriage return <CR>.

Command	*Action*
W	Write a file `format.out` describing the Echelle format.
G	Go back to start and ask for new configuration.
F	Get a new file with spectral line wavelengths.
L	Make a PostScript plot.

Command	*Action*
R	Refresh graphics and return to graphical interaction.
M	Minimize deviations of lines from blaze wavelength.
Q	Quit the program.
I	Return to graphical interaction.
D	Write a KICS setup file to disk, and optionally execute it.

5 The Source Code

The primary source code (including the source code for this documentation) resides in and below a directory typically named `echelle`. Accompanying this directory there will be 2 other directories which contain auxiliary portions of code that are shared between the Echelle Simulator and other distinct packages. One of these directories is typically named `token`, and it contains code which parses the FITS-like configuration files. The other directory is typically named `include`, and it contains files with Fortran `PARAMETER` definitions.[3]

The top level directory (`echelle`) contains a `Makefile` whose sole purpose is to use the Unix `tar` utility to pack up all the code (including the auxiliary directories) into a form suitable for distribution via anonymous `ftp`. Other directories include `bin` (the installed binaries), `doc` (this document and others), `lib` (the default configuration and setup files), and `src` (the bulk of the source code).

The `src` directory contains a `Makefile` which will build all executables by default, and another target called "install" which will ensure that they are installed where the other users will find them. The Makefile also contains targets "clean" to remove all binaries and junk files, and "tidy" which simply removes junk files.

5.1 Source code format

The source code is written in FORTRAN 77 plus several common extensions to the Fortran 77 standard. The following extensions which are difficult to work around are used:

1. symbolic names have more than 6 characters
2. The INCLUDE statement is used to replicate segments of code and greatly improve maintainability
3. List-directed Internal I/O is used

3 On the systems at UCO/Lick Observatory, all of these directories can be found in `/home/hires/sla`.

Note that all of the above extensions are part of the new Fortran 90 standard. The other extensions are easy to recode:

1. there are tabs in the code
2. lower case letters are used
3. common blocks contain character and non-character data
4. common block contents are initialized outside of BLOCK DATA
5. real*8 and integer*4 data types are used

The code also probably contains a number of instances where it is assumed that local variables are statically allocated. The code has never been run on a system with a compiler that always uses dynamically allocated local variables. This would be remedied by the insertion of SAVE statements where required.

The code also contains C preprocessor directives. The C preprocessor lines provide for greater portability of the code. For systems where the Fortran compiler does not support C preprocessor lines, the code can be preprocessed before sending it to the Fortran compiler.

5.2 `INCLUDE`ed files

There are two types of files which are `included` into the code. Files which end in `.cmn` contain Fortran COMMON blocks which are shared between several routines. Files which end in `.par` contain Fortran `PARAMETER` definitions which are needed by several routines. Files which end in `.dta` contain Fortran `DATA` statements. Files which end in `.inc` contain Fortran declarations, `PARAMETER`, COMMON, and `EQUIVALENCE` statements which effectively serve as data structure definitions.

Among other things, the `.par` files set the compiled limits of the sizes of the arrays. It has often been necessary to modify these compiled limits. For this reason, the content of the `.par` files is described here.

Parameter file	Description of contents
echelle.par	Default file names, array limits, logical unit numbers, and other symbolic constants.
mathcon.par	generic values of mathematical contants (π, e, etc.)
stdio.par	generic Fortran I/O utilities
token.par	structure of the key/value pair parser
units.par	generic unit conversions

The displayed menus of configuration parameter values are stored in EQUIV-ALENCEd arrays of data which are defined in the .inc files. (This code would have been much better had it been implemented in some other language than Fortran 77.) Modifying the contents of the menus requires changes in three files: the .inc file, the .dta file, and the .F file.

*.inc *.dta *.F files	Description of contents of these menu files
button.*	The main menu which offers other menus.
cdata.*	The menu that displays the information on the current location of the cursor.
detmos.*	The menu that displays the detector description.
setup.*	The menu that displays the instrumental setup description.
spgraf.*	The menu that displays the spectrograph/telescope description.

6 Future Improvements

When work began on the instrument simulator there was no obvious choice about which system should be used to design the graphical user interface. Now that X11 is the de facto standard, it would be desirable to reimplement the simulator as an X11–based program.

Appendix A Input/Output Keywords and Values

This appendix contains summary tables which describe the keyword/value pairs found in the FITS-like cards of the input and output configuration files. For complete descriptions see section 3.1.

A.1 Entries in the Tables

A.1.1 Keyword

This is the FITS keyword. Most of the keywords are defined by the Keck data acquisition system. Some apply only to the instrument simulator.

A.1.2 Value

The value of a keyword can be a string, a floating point number, an integer, or a string array. Strings, floating point numbers, and integers are represented as specified in the FITS standard documents. String arrays are strings which contain a list of related comma-separated values. The number of values in a string array may vary depending on the context and application.

A.1.3 Unit

When the value represents a physical quantity it is represented in this unit. Most units are SI, but some are convenience units for the sake of the astronomer.

A.1.4 Used?

There are some keywords whose values are never used by the Instrument Simulator. These keywords and their values are usually read from the input and written to the output without change. Some of the unused values can be modified by the user while running the program.

Other keywords are used if a certain condition applies. For example, keywords describing cross-dispersing grating are only used if there is at least one cross-dispersing grating.

A.1.5 Priority

There are several cases where there is more than one keyword that can be used to set a particular value. The most notable of these are the slit width keywords which allow the slit width to be specified in 5 different ways. Priority describes the order in which the Instrument Simulator reads such keywords. The Instrument Simulator starts by seeking the keyword with priority 1. If that keyword is not found, the Instrument Simulator continues by looking for the keyword with priority 2, etc., until a match is found. Upon output, the Instrument Simulator writes all of these keywords and values.

A.1.6 Description

A quick summary of what this keyword/value pair does.

Table 1 Spectrograph & Telescope Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
TELESCOP	string	-	No	-	The name of the telescope.
INSTRUME	string	-	No	-	The name of the spectrograph.
PRIMDIAM	float	m	Yes	-	Diameter of the telescope primary. Used to calculate COLLDIAM or COLFOCLN.
FOCSCALE	float	arcsec/mm	Yes	-	Image scale at the telescope focus.
COLFOCLN	float	m/radian	Yes	1	Focal length of collimator.
COLLDIAM	float	m		2	Diameter of collimated beam.
ECSIGMA	float	μm/groove	Yes	1	Echelle grating groove separation.
ECSIGMAI	float	groove/mm		2	Echelle grating groove frequency.
ECTHETAD	float	degree	Yes	-	Half the angle between incoming and outgoing Echelle beams.
ECDELTAD	float	degree	Yes	-	Echelle blaze angle.
NXDGRAT	int	-	Yes	-	Number of cross dispersing gratings (must be 0 or 1).
XDSIGMA	float	μm/groove	if NXDGRAT>1	1	Cross dispersing grating groove separation.
XDSIGMAI	float	groove/mm		2	Cross dispersing grating groove frequency.
XDDELTAD	float	degree	if NXDGRAT>1	-	Cross dispersing grating blaze angle.

Table 1 (Continued) Spectrograph & Telescope Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
XDALFBET	float	degree	if NXDGRAT>1	-	Total angle of deviation from the cross dispersing grating. Equivalent to α-β in Schroeder Fig 13.2 and Eq. 13.2.1.
NXDPRISM	int	-	Yes	-	Number of cross dispersing prisms (0 ≤ NXDPRISM ≤ 9).
PRANGIND	float	degree	if NXPRISM>1	-	Angle of incidence of light on first prism.
PRAPEX	float	degree	if NXPRISM>1	2	Apex angle of prisms. (May be overridden by PRAPEXn cards.)
PRAPEXn	float	degree	if NXPRISM>1	1	Apex angle of prism number n.
PRFACE	float	degree	if NXPRISM>1	2	Angle between faces of adjacent prisms. (May be overridden by PRFACEn cards.)
PRFACEn	float	degree	if NXPRISM>1	1	Angle between faces of prisms n and n +1
PRGLAS	string	-	if NXPRISM>1	2	Schott catalog name of glass in prisms. (May be overridden by PRGLASn cards.
PRGLASn	string	-	if NXPRISM>1	1	Schott catalog name of glass in prism n.

Table 1 (Continued) Spectrograph & Telescope Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
STDECHFH	bool	-	Yes	-	Does the handedness of the Echelle format match Schroeder Fig 15.10 (where going to a more positive x or y increases the wavelength)?
FPROTANG	float	degree	Yes	-	Angle in Echelle coordinate system measured counter-clockwise from x-axis of the Detector Focal Plane system to the x-axis of the Echelle Coordinate system.

Table 2 Detector Description Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
`STDVIDV`	bool	-	Yes	-	Does the image display use standard vertical orientation?
`STDVIDH`	bool	-	Yes	-	Does the image display use standard horizontal orientation?
`STDVIDR`	bool	-	No	-	Is the display oriented in landscape mode? (Not currently implemented.)
`DETECTOR`	string	-	No	-	The name of the detector or dewar.
`NCHIPS`	int	-	Yes	-	Number of amplifiers which will be used to read-out rectangular sections of images from the detector(s).
`CHIPID`*n*	string	-	Yes	-	A string which uniquely identifies the detector and amplifier. This will be used as a key into the `BSPOT` database.
`XPIX`	int	pixel	Yes	2	Number of photosensitive pixels along the serial shift direction of each amplifier. (May be overridden by `XPIX`*n*.
`XPIX`*n*	int	pixel		1	Number of photosensitive pixels along the serial shift direction of amplifier number *n*.

Table 2 (Continued) Detector Description Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
YPIX	int	pixel	Yes	2	Number of photosensitive pixels along the parallel shift direction of each amplifier. (May be overridden by XPIX*n*.
YPIX*n*	int	pixel		1	Number of photosensitive pixels along the parallel shift direction of amplifier number *n*.
PIXXSZ	float	m	Yes	2	Spacing between pixels along the serial shift direction of each amplifier. (May be overridden by PIXXSZ*n*.
PIXXSZ*n*	float	m		1	Spacing between pixels along the serial shift direction of amplifier number *n*.
PIXYSZ	float	m	Yes	2	Spacing between pixels along the parallel shift direction of each amplifier. (May be overridden by PIXXSZ*n*.
PIXYSZ*n*	float	m		1	Spacing between pixels along the parallel shift direction of amplifier number *n*.
NBSPOT	int	-	Yes	-	Number of bad spots on the detector(s).

Table 2 (Continued) Detector Description Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
`BSPOTn`	string array	5 int	if NBSPOT>0	-	Describes the *n*th blemish of the mosaic of detectors. See text for details.
`DETPOSn`	string array	5 float (m,m, degree,-, -,-)	Yes	-	Describes the position in the focal plane of the *n*th detector. See text for details.

Table 3 Instrument Setup Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
SETUP	string	-	No	-	Setup name as used in the Keck FIORD routines.
OBSERVER	string	-	No	-	The name of the observer.
DETFILNM	string	-	Yes	-	Absolute pathname of a Detector Configuration file to be used. The program will prompt if this is absent.
SPCFILNM	string	-	Yes	-	Absolute pathname of a Spectrograph/Telescope Configuration file to be used. The program will prompt if this is absent.
ECANGLE	float	degree	Yes	-	Angle "off blaze" to which the Echelle grating is tilted. Positive values move longer wavelengths onto the detector.
XDANGLE	float	degree	Yes	-	Angle "off blaze" to which the Cross Dispersing grating is tilted. Positive values move longer wavelengths onto the detector.
HEIGHT	int	-	If Hamilton	-	For the Hamilton spectrograph: The encoder reading for the dewar height.
DECKER	string	-	No	-	A string describing the HIRES decker plate.
DECKRAW	int	-	No	-	HIRES decker plate position in machine encoder units.
DECKPOS	float	m	No	-	HIRES decker plate position.

Table 3 (Continued) Instrument Setup Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
DECKNNAM	string	-	No	-	Observer's name for a HIRES decker notch.
DECKHGT	float	m	Yes	1	Total height of decker notch.
DECKSIZE	float	arcsec		2	Total height of decker notch.
DECKPIX	float	pixel		3	Total height of decker notch.
DECKSPEC	string array	m	No	-	Describes the number and sizes of holes in decker. See text for full description.
SLITWID	float	mm	Yes	1	Width of spectrograph slit.
SLITSIZE	float	arcsec		2	Width of spectrograph slit.
SLITPIX	float	pixel		3	Width of spectrograph slit.
SLITVEL	float	m/s		4	Width of spectrograph slit.
SLITRAW	int	m.e.u.		5	Width of spectrograph slit.
FIL1POS	int	-	No	-	HIRES filter1 position ($1 \leq$ FILTER ≤ 12).
FIL2POS	int	-	No	-	HIRES filter2 position ($1 \leq$ FILTER2 ≤ 12).
FIL1NAME	string	-	No	-	Observer's name for HIRES filter1.
FIL2NAME	string	-	No	-	Observer's name for HIRES filter2.
COLL	string	-	No	-	Which HIRES collimator? ('RED' or 'BLUE').
COFOCUS	float	m	No	-	HIRES collimator focus position.
CAMERA	string	-	No	-	Which HIRES camera? ('RED' or 'BLUE').
CAFOCUS	float	m	No	-	HIRES camera focus position.

Table 3 (Continued) Instrument Setup Keywords and Values

Keyword	*Value*	*Unit*	*Used?*	*Priority*	*Description*
BINNING	int array	physical pixel	Yes	2	Binning factor along each direction of each detector. First element is serial (X) direction; second element is parallel (Y) direction. (May be overridden by BINNING*n*.)
BINNING*n*	int array	physical pixel		1	Binning factor along each direction of detector *n*. First element is serial (X) direction; second element is parallel (Y) direction.
DWINDOW	int array	physical pixel	Yes	2	User-desired readout window. The elements are Xorigin, Yorigin, Xextent, Yextent. (May be overridden by DWINDOW*n*.)
DWINDOW*n*	int array	physical pixel		1	User-desired readout window of detector *n*. The elements are Xorigin, Yorigin, Xextent, Yextent.
WAVLMAX	float	Ångstrom	Yes	-	Maximum wavelength to be displayed.
WAVLMIN	float	Ångstrom	Yes	-	Minimum wavelength to be displayed.
XDORDER	int	-	Yes	-	Cross disperser order to be displayed.
WAVEFILE	string	-	Yes	-	Absolute pathname of a spectral line wavelength file to be used.
RADVEL	float	m/s	Yes	1	radial velocity to be applied to spectral lines
RADVELZ	float	$\Delta\lambda/\lambda$		2	radial velocity to be applied to spectral lines

Appendix B Diagrams

The following diagrams show some of the Echelle spectrographs which have been simulated using the program.

Keck HIRES 1st order with Tek2048^2

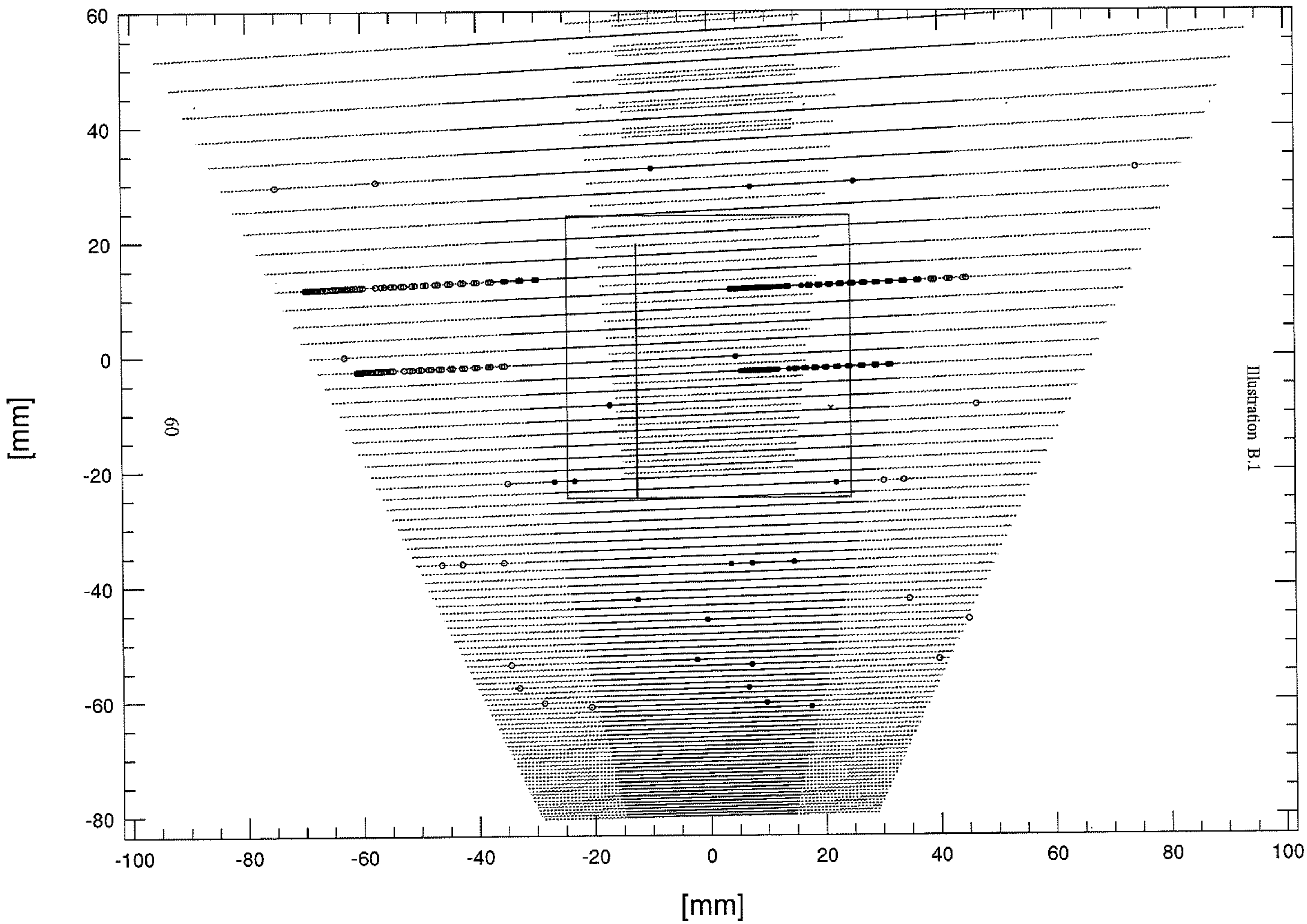
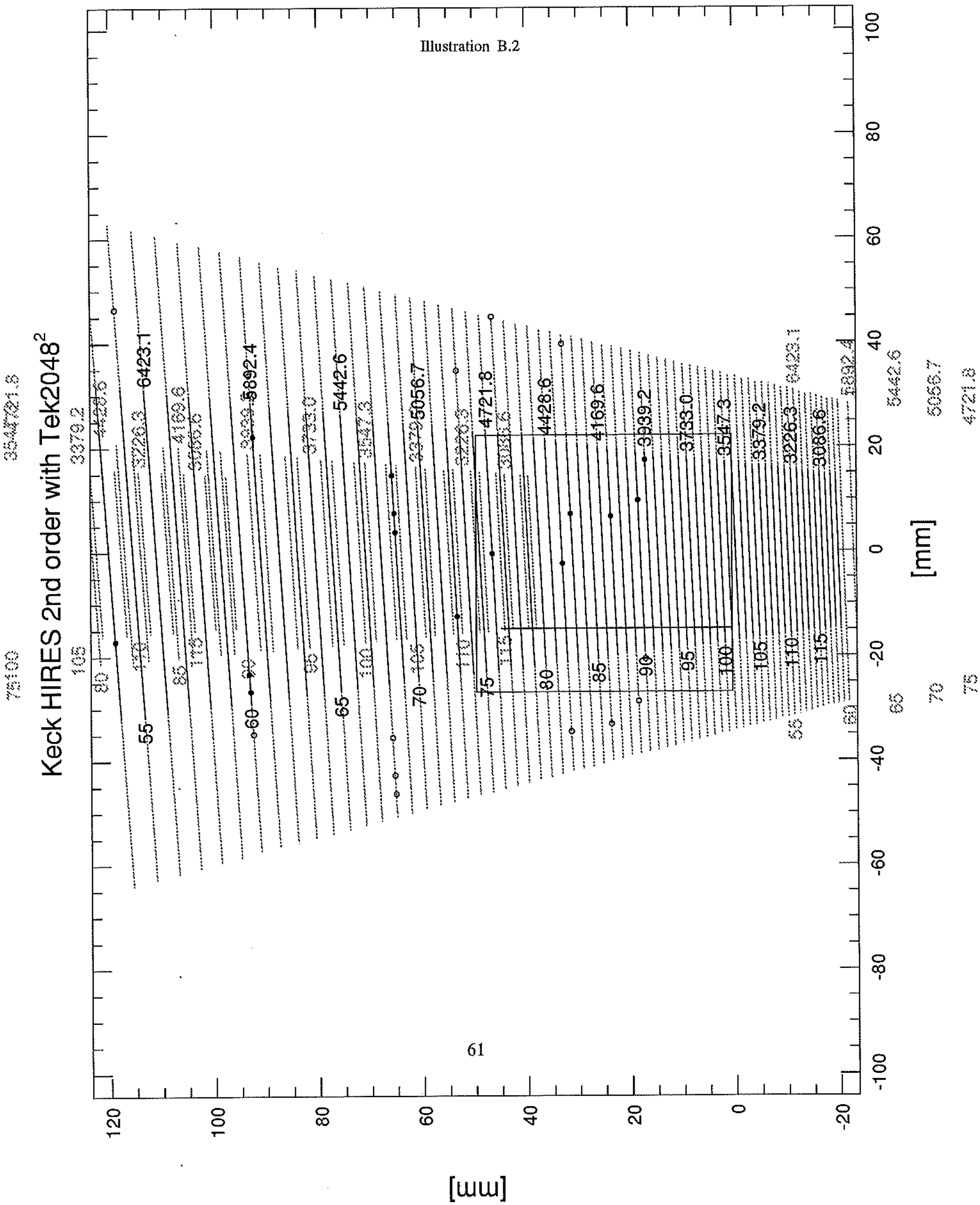
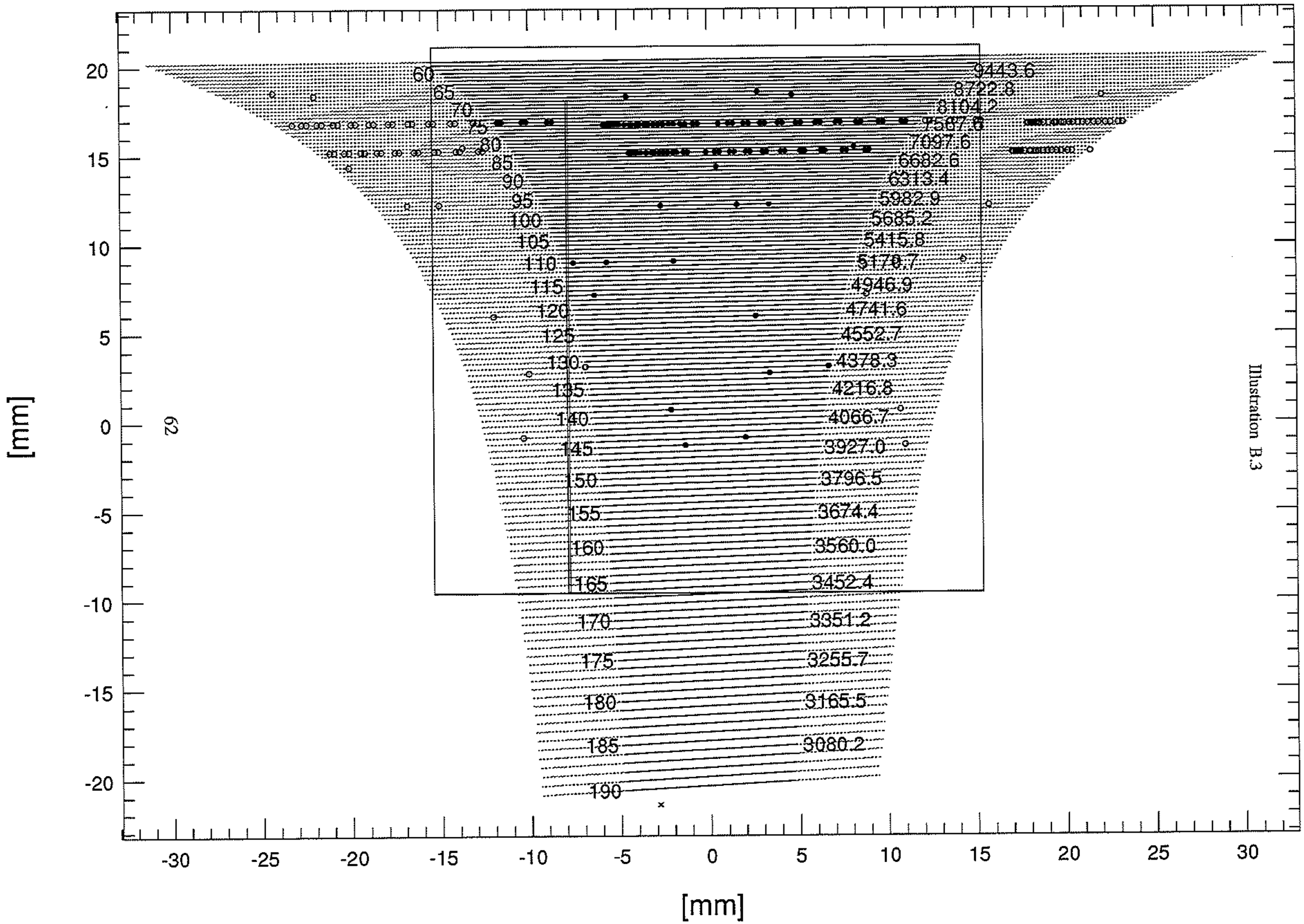


Illustration B.1

Illustration B.2



Lick Observatory Hamilton Echelle with Tek2048²



Appendix C Example Configuration Files

C.1 Example Spectrograph/Telescope Configuration File

Figure C.1.7 hires.spc: a Spectrograph Configuration

```
SIMPLE  =                     F  /       Not a FITS file
COMMENT FITS file defining telescope, & spectrograph optical parameters
COMMENT This file describes the Keck HIRES Spectrograph
COMMENT         --------------------------------------------------------
COMMENT This is not really a FITS file.  It has carriage control at line ends.
COMMENT Most of the values in here do conform to the formatting and
COMMENT justification required by the FITS standard, but this is not
COMMENT a requirement.
COMMENT This file is intended to be edited by humans who do not really care
COMMENT about precise formatting of the numeric fields.
COMMENT Thus, the parser of this file is more relaxed than true FITS requires.
COMMENT Values may appear anywhere after the '= ', starting in column 11
COMMENT         --------------------------------------------------------
COMMENT References below are to these two books:
COMMENT Astronomical Optics; Daniel J. Schroeder; Academic Press, Inc.; 1987
COMMENT Optics; E. Hecht & A. Zajac; Addison-Wesley; 1974
COMMENT         --------------------------------------------------------
COMMENT         Telescope and Camera Parameters
COMMENT
TELESCOP= 'Keck 10-meter Telescope, Keck Observatory, Mauna Kea'
COMMENT
INSTRUME= 'HIRES High Resolution Echelle Spectrograph'
COMMENT                       this is the maximal diameter of hexagons
PRIMDIAM=                10.9  / diameter of telescope primary [meter]
COMMENT                Harland Epps used the known figure of the Keck secondary
COMMENT                to calculate the focal length in 1991 June.
COMMENT                His figure for focal length is 5888.95 inches.
FOCSCALE=            1.378966  / Nasmythe focus image scale [arcsec/mm]
COMMENT
COMMENT                HIRES collimator was measured by the Anorad profilometer
COMMENT                at Lick by Dave Hilyard.  Resulting focal length
COMMENT                was determined to be 163.570 inches.
COMMENT
COLFOCLN=            4.154678  / collimator focal length [m/radian]
COMMENT
COMMENT                The colldiam is now a derived quantity.
COLLDIAM=               0.305  / spectrograph collimated beam diam. [m]
COMMENT
CAMFOCLN=               0.762  / spectrograph camera focal length [m/radian]
```

Figure C.1.7 (Continued) hires.spc: a Spectrograph Configuration

```
COMMENT         ---------------------------------------------------------
COMMENT         Echelle Grating Parameters
COMMENT
ECSIGMA #                       / echelle grating groove separation [um/groove]
COMMENT         echelle groove freq. is chosen for a 2x2 array of Ford chips
ECSIGMAI=                52.68  / echelle grating groove frequency  [groove/mm]
COMMENT
ECTHETAD=                   5.  / half angle (theta) [degree]
COMMENT
ECDELTAD#                  69.  / echelle blaze angle (delta) [degree] (design)
ECDELTAD=                 70.5  / echelle blaze angle (delta) [degree] (actual)
COMMENT         ---------------------------------------------------------
COMMENT         Grating Cross Disperser Parameters
COMMENT
NXDGRAT =                    1  / number of gratings used for cross dispersion
COMMENT
XDSIGMA #                       / x-dispersing grating groove sep.  [um/groove]
COMMENT   cross disp. groove freq. is chosen for a 2x2 array of Ford chips
XDSIGMAI=                 250.  / x-dispersing grating groove freq. [groove/mm]
COMMENT                 from letter 1990 Oct 25 HIRES optical design notes
XDDELTAD=               5.343   / cross disperser blaze angle [degree]
COMMENT                 Total angle of deviation from the cross disp. grating
COMMENT                 This is equivalent to (alpha - beta) in Schroeder.
COMMENT                 (see Fig 13.2 and the text following Eq. 13.2.1)
COMMENT                 This is the designed angle needed to reflect one
COMMENT                 particular wavelength of light from the echelle into
COMMENT                 the central axis of the camera.  The actual incident
COMMENT                 (alpha) and reflected (beta) angles vary according to
COMMENT                 which cross disp. order and wavelength are desired.
COMMENT                 [degrees]
XDALFBET=                  40.  / (alpha - beta) [degree]
COMMENT         ---------------------------------------------------------
COMMENT         Prism Cross Disperser Parameters
COMMENT
NXDPRISM=                    0  / number of prisms used for cross dispersion
COMMENT
PRANGIND#                       / incident angle on first prism (psi) [degree]
COMMENT
COMMENT
PRAPEX   #                      / avg. x-disp. prism apex angle (alpha) [degree]
PRAPEX1  #                      / x-disp. prism #1 apex angle (alpha) [degree]
PRAPEX2  #                      / x-disp. prism #2 apex angle (alpha) [degree]
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
```

Figure C.1.7 (Continued) hires.spc: a Spectrograph Configuration

```
COMMENT
PRFACE   #                    / angle between adjacent prism faces (phi) [deg]
PRFACE1  #                    / ang. bet. adj. faces of prisms 1&2 (phi) [deg]
PRFACE2  #                    / ang. bet. adj. faces of prisms 2&3 (phi) [deg]
COMMENT
COMMENT
PRGLAS   #                    / Schott catalog name of glass in prisms
PRGLAS1  #                    / Schott catalog name of glass in prism #1
PRGLAS2  #                    / Schott catalog name of glass in prism #2
COMMENT        --------------------------------------------------------
COMMENT                The Echelle Coordinate System
COMMENT        The Echelle Mosaic Coordinate system is the system used by
COMMENT        calculations within the Echelle program.  Assume an observer
COMMENT        who is looking at the focal plane from a viewpoint behind
COMMENT        the focal plane, i.e. such that the observer could only see
COMMENT        the image if the focal plane were a translucent screen.
COMMENT        The echelle coordinate system
COMMENT        as seen by this observer is a right-handed system.
COMMENT        The "x" direction is along the cross dispersion direction.
COMMENT        The "y" direction is along the echelle dispersion direction.
COMMENT        Orders with longer wavelengths have larger "x" coordinates;
COMMENT        thus they are nearer to the "right" of the picture.
COMMENT        Orders with shorter wavelength have smaller "x" coordinates;
COMMENT        thus they are nearer to the "left" of the picture.
COMMENT        The long wavelength end of each order has a larger "y" coord;
COMMENT        thus it is nearer to the "top" of the picture.
COMMENT        The short wavelength end of each order has a smaller "y" coord;
COMMENT        thus it is nearer to the "bottom" of the picture.
COMMENT        Overall, travelling in either the positive "x" or the
COMMENT        positive "y" direction takes you to a longer wavelength.
COMMENT        The y-origin/x-axis of this system is a horizontal line
COMMENT        running along the blaze wavelength of each order.
COMMENT        The x-origin of this system is somewhat arbitrary, and it is
COMMENT        currently set at the x-position of the blaze wavelength of
COMMENT        the bluest (leftmost) order.
COMMENT
COMMENT        The Echelle coordinate system was defined so as to match the
COMMENT        appearance of the coordinate system used by Schroeder in
COMMENT        figure 15.10 of his text.  This definition also matches
COMMENT        that of the original code as written by Schroeder.
COMMENT        Internal calculations about the position of a point in the
COMMENT        Echelle coordinate system are always carried out under the
COMMENT        above definitions of x and y.  It is recognized that there
COMMENT        will be spectrographs where the handedness of the echelle
COMMENT        and cross dispersion directions will be opposite of that
COMMENT        described here.
COMMENT
```

Figure C.1.7 (Continued) hires.spc: a Spectrograph Configuration

```
COMMENT         In order to allow the modelling of such
COMMENT         spectrographs, the following keyword can be used.
COMMENT         If this variable is .false., then the long wavelength end
COMMENT         of each echelle order has a smaller "y" coordinate as seen
COMMENT         by the observer behind the focal plane.  Note that the echelle
COMMENT         coordinate system as described above always holds.
COMMENT         This variable merely introduces a flip in the transformation
COMMENT         matrix between Echelle and Detector coordinate systems.
STDECHFH=                    F  / Does handedness of ech. fmt. match Schroeder?
COMMENT         Note that this variable should be .false. for the
COMMENT         Hamilton Echelle spectrograph.
COMMENT         --------------------------------------------------------
COMMENT                 Relative Orientation of Coordinate Systems
COMMENT         The format of the echelle spectrum is likely to be larger than
COMMENT         the solid-state detectors currently in use.  Sampling of the
COMMENT         entire spectrum requires that the detector and the light be
COMMENT         able to move with respect to each other.  This may be performed
COMMENT         by translating the detector across the focal plane.  It may
COMMENT         be performed by rotating the dispersing elements.  The echelle
COMMENT         software allows for such relative translation of the echelle
COMMENT         and detector coordinate systems.  It does this assuming that
COMMENT         these coordinate systems do not rotate while translating.
COMMENT         The angle between the x-axis of the Echelle and Detector Focal
COMMENT         coordinate systems is specified at its constant value.
COMMENT         (It is assumed that the 2 systems are coplanar.)
COMMENT         This angle is measured in the Echelle Coordinate
COMMENT         system.  It is measured from the x-axis of the Detector Focal
COMMENT         Plane system to the x-axis of the Echelle system.
COMMENT         This angle is measured in a counter-clockwise sense.
COMMENT         Note that as seen by the observer who is behind the detector
COMMENT         (i.e., the detector is between the observer and the incoming
COMMENT         light) both of these coordinate systems are right-handed
COMMENT         (when they have standard orientations and handednesses).
FPROTANG=                  90.  / angle from detector-x to echelle-x [degree]
COMMENT         ========================================================
```

C.2 Example Detector Configuration File

Figure C.2.8 tek2048.det: A detector configuration

```
SIMPLE  =                    F  /       Not a FITS file
COMMENT         --------------------------------------------------------
COMMENT This is not really a FITS file.  It has carriage control at line ends.
COMMENT Most of the values in here do conform to the formatting and
COMMENT justification required by the FITS standard, but this is not
COMMENT a requirement.
COMMENT This file is intended to be edited by humans who do not really care
COMMENT about precise formatting of the numeric fields.
COMMENT Thus, the parser of this file is more relaxed than true FITS requires.
COMMENT Values may appear anywhere after the '= ', starting in column 11
COMMENT         ========================================================
COMMENT                 The Coordinate System of a Detector
COMMENT         Each CCD chip has its own coordinate system.  This is to be
COMMENT         distinguished from the coordinate system of the focal plane
COMMENT         which is handled much further below.
COMMENT
COMMENT         The terminology used to describe this coordinate system is
COMMENT         drawn from the early CCDs which were intended for use in
COMMENT         standard video applications.  Such CCDs had a single
COMMENT         readout amplifier located in a position such that the chip
COMMENT         could be used to produce a signal quite similar to that of
COMMENT         a vidicon.  They were designed to be illuminated from one
COMMENT         particular side so that the handedness of the output signal
COMMENT         would be proper for video applications.
COMMENT
COMMENT         Newer CCDs may have been thinned to allow illumination from
COMMENT         the "back" side.  They may also have multiple readout
COMMENT         amplifiers.  These new capabilities require the precise
COMMENT         specification of the orientation and/or handedness of a
COMMENT         particular detector.
COMMENT
COMMENT         Devices other than CCDs which have rectangular layouts
COMMENT         should use the same terms and coordinate orientation.
COMMENT         --------------------------------------------------------
COMMENT                 Definition of Detector Layout Terminology
COMMENT         This section describes a standard video CCD for reference.
COMMENT
COMMENT         The "x", "horizontal", & "serial" directions are parallel.
COMMENT         The "y", "vertical", & "parallel" directions are parallel.
COMMENT         A serial shift carries charge in the "minus x" direction.
COMMENT         A parallel shift carries charge in the "minus y" direction.
COMMENT         The set of all pixels with the same "y" coordinate is a "row"
COMMENT         The set of all pixels with the same "x" coordinate is a "column"
COMMENT         The words "height" and "width" are associated with
```

Figure C.2.8 (Continued) tek2048.det: A detector configuration

```
COMMENT          "vertical" and "horizontal", respectively.
COMMENT
COMMENT          In most CCDs, the serial shift register has "pixels" which
COMMENT          must be read out before the charge from the actual photo-
COMMENT          sensitive region of the chip is read.  These are known as
COMMENT          underscan pixels.  Most CCD controllers will also continue
COMMENT          to do serial shifts after all the charge from the photo-
COMMENT          sensitive region has been read.  These are known as overscan,
COMMENT          bias, or baseline pixels.
COMMENT
COMMENT          Q: This document does not treat the existence of these
COMMENT          Q: underscan and overscan pixels, it refers only to the
COMMENT          Q: "real" photosensitive pixels in the array.
COMMENT          Q: For engineering purposes it will be necessary to store
COMMENT          Q: some images with their under- and over-scan pixels.
COMMENT          Q: FITS keywords will be needed which define the number
COMMENT          Q: of these under/overscan pixels.
COMMENT
COMMENT          Assume an observer who is looking at the light-sensitive
COMMENT          surface of the CCD from a viewpoint which would obscure the
COMMENT          the incoming light.  As seen by this observer, the CCD's
COMMENT          coordinate system (x,y) is a right-handed coordinate system.
COMMENT          The readout amplifier is located at the lower left corner
COMMENT          of the chip.  This amplifier is closest to the pixel
COMMENT          identified as (0,0).
COMMENT
COMMENT          A diagram of a detector intended for video applications when
COMMENT          viewed as specified above is presented here:
COMMENT                           ^  (0,YPIX-1)  (1,YPIX-1)  ...  (XPIX-1,YPIX-1)
COMMENT                           |  (0,YPIX-2)  (1,YPIX-2)  ...  (XPIX-1,YPIX-2)
COMMENT         y_axis_direction  |  ...           ...        ...      ...
COMMENT                           |  (0,1)       (1,1)       ...  (XPIX-1,1)
COMMENT    amplifier_is_here-> a  (0,0)       (1,0)       ...  (XPIX-1,0)
COMMENT                                ----x_axis_direction------->
COMMENT          Parallel shifts move the charge "down" in this picture.
COMMENT          Serial shifts move the charge "left" in this picture.
COMMENT          The above diagram does not show underscan or overscan pixels
COMMENT          in the serial shifts.  Underscan pixels would be to the
COMMENT          left of the (0,Y) pixels and overscan pixels would be to the
COMMENT          right of the (XPIX-1,Y) pixels.
COMMENT          The shift directions used here are those that would be used
COMMENT          when a single amplifier is used to readout the chip.
COMMENT          With a single amplifier the order of readout is
COMMENT          (0,0), (1,0), (2,0), ... (XPIX-1,0), (0,1), ... etc.
COMMENT          Thus, row 0 is read, left to right, then row 1, etc.
COMMENT          Note again that this is a right-handed coordinate system.
COMMENT
COMMENT          Assume that a simple lens makes an image of an object on a
```

```
COMMENT        video detector as described above.  When the image is read
COMMENT        in the described order and displayed on a video display in
COMMENT        the standard fashion, the image on the video display will
COMMENT        appear upright and not reversed.  The layout of a standard
COMMENT        video display is shown below, for reference:
COMMENT                          ----x_coord_direction------->
COMMENT   amp_seems_here-> a  (0,0)      , (1,0)      , ..., (XPIX-1,0)      ,
COMMENT                    |  (0,1)      , (1,1)      , ..., (XPIX-1,1)      ,
COMMENT  y_coord_direction |   ...       ,  ...       , ...,    ...          ,
COMMENT                    |  (0,YPIX-2), (1,YPIX-2), ..., (XPIX-1,YPIX-2),
COMMENT                    v  (0,YPIX-1), (1,YPIX-1), ..., (XPIX-1,YPIX-1)
COMMENT        Parallel shifts appear to move charge "up" in this picture.
COMMENT        Serial shifts appear to move charge "left" in this picture.
COMMENT        Note that this is a LEFT-handed coordinate system, which is
COMMENT        also known as a video-coordinate system.
COMMENT
COMMENT        --------------------------------------------------------
COMMENT                "Left-handed" and Multi-amplifier Detectors
COMMENT        A CCD designed for video use may be thinned and illuminated
COMMENT        from the "back" to improve its quantum efficiency.  Such a
COMMENT        detector will still have its (0,0) pixel as the pixel closest
COMMENT        to the amplifier.  However in such usage the handedness of
COMMENT        an image produced by this CCD will be the opposite of standard.
COMMENT        In this case, the coordinate system of the CCD (as seen by the
COMMENT        observer looking at its light-sensitive surface) is a
COMMENT        left-handed coordinate system.  This must be indicated in
COMMENT        the DETPOS card for this detector (see below).
COMMENT
COMMENT        A CCD with multiple amplifiers is a simple extension of the
COMMENT        above rules.  One amplifier should be chosen as the reference
COMMENT        amplifier, and the pixel nearest that will be designated (0,0).
COMMENT        All pixels will be numbered from the designated origin as
COMMENT        if they were being read through the reference amplifier.
COMMENT        The handedness of the detector will be determined by
COMMENT        comparing the handedness of readout through the reference
COMMENT        amplifier with the handedness of a standard video detector.
COMMENT        Q: How is the (baseline, amplifier bias, overscan)
COMMENT        Q: going to be represented in data where multiple amplifiers
COMMENT        Q: are used to read a single chip's imaging area?
COMMENT        Q: (There are no immediate plans to use multi-amplifier
COMMENT        Q: readout, but the Ford (Loral?) chips could do it.)
COMMENT        Q: Might considerations of the baseline measurement for a
COMMENT        Q: multi-amp chip make it necessary to treat it as
COMMENT        Q: several separate chips each making separate images?
COMMENT        A: Our current understanding of this indicates that the
COMMENT        A: multi-amp chips will be treated as separate chips.
COMMENT        A: To facilitate this, the DETPOS cards now have fields
COMMENT        A: to indicate which pixel is at the reference location.
```

Figure C.2.8 (Continued) tek2048.det: A detector configuration

```
COMMENT         ========================================================
COMMENT                 Sites which use non-standard video display orientation
COMMENT         It is recognized that there are sites which for one reason
COMMENT         or another display their video images in a manner which
COMMENT         is not standard.  For this reason, the Echelle Simulator
COMMENT         defines three keywords which can be used to flip the
COMMENT         orientation of everything which it displays.  This makes
COMMENT         it easy to match the Echelle Simulator graphics with the
COMMENT         images produced by the actual detector.
COMMENT
COMMENT         Note that the orientation of the video display is actually
COMMENT         an artifact of the video display and of the program which
COMMENT         is being used to drive the video display.  Thus, these
COMMENT         keywords are not strictly associated with the detector,
COMMENT         but rather with the displayer.  Nonetheless, they are
COMMENT         included in the detector file for convenience.
STDVIDV =                    T  / Does display use standard vert. orientation?
STDVIDH =                    T  / Does display use standard horz. orientation?
STDVIDR =                    T  / Is the display oriented in landscape mode?
COMMENT         ========================================================
COMMENT                 The Definition of a Pixel
COMMENT         When real-valued coordinates are used, the middle of a
COMMENT         pixel is at a half-integral location.  The real limits of
COMMENT         pixel 0 run from 0. to 1.  To convert from real coordinate
COMMENT         values to integer coordinate values, use the "floor()" function.
COMMENT         To convert from integer coordinate values to real coordinate
COMMENT         values, add 0.5 to the integer value.  These conventions are
COMMENT         generally accepted by the computer graphics community.
COMMENT         They also make it easier to compute, because operations which
COMMENT         deal with entire pixels should be possible using only integer
COMMENT         arithmetic.
COMMENT         ========================================================
COMMENT                 The Detector Identification
COMMENT         Every individual CCD chip (or other similar detector)
COMMENT         is intended to have a unique number associated with it.
COMMENT         This unique number should serve to allow lookup of the
COMMENT         defects and blemishes which are peculiar to that chip.
COMMENT         We expect that some kind of defect and blemish database
COMMENT         will be established which will identify the nature of
COMMENT         the known problems and even tell about problems that
COMMENT         change with time (i.e., new defects arise or old ones vanish).
COMMENT         Note that ChipIDs are character strings which will contain
COMMENT         information such as that suggested in the example card(s).
DETECTOR= 'Tektronix 2048x2048 24um pixel chip in dewar number ?'
NCHIPS  =                    1  /
CHIPID1 = 'amplifier ? of chip 1 from wafer ? of batch ? made by ? on date ?'
COMMENT
COMMENT
```

Figure C.2.8 (Continued) tek2048.det: A detector configuration

```
COMMENT
COMMENT      ---------------------------------------------------------
COMMENT              The number of Pixels
COMMENT      If XPIXn and YPIXn are specified, they apply to detector "n".
COMMENT      If XPIX and YPIX are specified, they apply to all detectors
COMMENT      which were not explicitly specified with XPIXn and YPIXn.
XPIX    =              2048  / # of real pixels along serial shift direction
YPIX    =              2048  / # of real pixels along parallel shift
COMMENT      Q: How is the (baseline, amplifier bias, overscan)
COMMENT      Q: going to be represented in Keck CCD data?
COMMENT      Q: Will it be represented in extra pixels which are not a
COMMENT      Q: part of the image data?  If so, what keyword will
COMMENT      Q: describe this in the final FITS header for the image?
COMMENT      ---------------------------------------------------------
COMMENT              The spacing of Pixels
COMMENT      Note that PIXXSIZ has become PIXXSZ and likewise for PIXYSIZ.
COMMENT      This was in response to changes made after the 1991 May
COMMENT      DAWG meeting.
COMMENT      The pixel separation in meters is given by PIXXSZn and PIXYSZn.
COMMENT      Al Conrad and Steve Allen agreed on this change 1991 March 22.
COMMENT      If PIXXSIZn and PIXYSIZn are given, they apply to detector "n".
COMMENT      If PIXXSIZ and PIXYSIZ are given, they apply to all detectors
COMMENT      which were not explicitly specified with PIXXSIZn and PIXYSIZn.
PIXXSZ  =            24.E-6  / pixels are 24 micrometers apart
PIXYSZ  =            24.E-6  / pixels are 24 micrometers apart
COMMENT      ---------------------------------------------------------
COMMENT              Blemish Information
COMMENT      Bad spots (dead pixels, hot pixels, etc.) on the CCD chips
COMMENT      are described by BSPOT arrays.  Bad spots are assumed to
COMMENT      describable as rectangular regions on the chip.  Bad regions
COMMENT      with more complex shapes can be decomposed into rectangles.
COMMENT      It is not yet clear whether BSPOTs may overlap.
COMMENT      The FITS cards for a given image should simply list the
COMMENT      current bad spots of a detector.  This should be looked up
COMMENT      from a badspot database which may contain a time history
COMMENT      of the bad spots and further information on whether particular
COMMENT      badspots are hot, dead, have poor CTE, etc.
COMMENT
COMMENT      Q: Everybody agrees that this badspot database is a good idea,
COMMENT      Q: but nobody seems to want to define it.
COMMENT
COMMENT      BSPOT arrays consist of 5 integer elements
COMMENT      Note that the order of the positions has been swapped from
COMMENT      that in the CDR document.  This was to put the elements in
COMMENT      the order (x,y) as opposed to the original specs (y,x).
COMMENT      Al Conrad and Steve Allen agreed on this change 1991 Mar 26.
COMMENT      Note also that BADSPOT has become BSPOTnnn.  This was in
```

Figure C.2.8 (Continued) tek2048.det: A detector configuration

```
COMMENT         response to the 1991 May DAWG meeting which decided that
COMMENT         no keywords should be repeated.  This also introduced NBSPOT.
COMMENT             1) The index indicating which chip has this spot.
COMMENT                If this is n, it refers to CHIPIDn in DETPOSn.
COMMENT             2,3) The column and row (x,y) of the pixel in this
COMMENT                  bad rectangle which is closest to the origin.
COMMENT             4,5) the width and height (dx,dy) of this rectangle.
COMMENT         Note that it is permissible for the height and width of
COMMENT         the bad spot to extend far off the chip.  The software will
COMMENT         clip the badspot to the actual pixel limits.
NBSPOT  =                    2 / there will be this many BSPOTn cards
BSPOT1  = '1, 500, 200, 1, 9999'
BSPOT2  = '1, 508, 200, 1, 9999'
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT         ==========================================================
COMMENT                  The Detector Focal Plane Coordinate System
COMMENT         Assume an observer who is looking at the light-sensitive
COMMENT         surface of the detector mosaic from a viewpoint which would
COMMENT         obscure the incoming light.  The coordinate system for the
COMMENT         detector mosaic as seen by that observer is left-handed.
COMMENT         The origin (0.,0.) of the Focal Plane system is some
COMMENT         well-defined point near the center of the mosaic.
COMMENT         The x-axis of the Focal Plane system may be chosen to
COMMENT         point in any direction which is convenient.
COMMENT         "Convenient" should be defined with consideration of the
COMMENT         orientations of the detector and the image or spectrum which
COMMENT         will be formed on the detector.  It will be convenient for
COMMENT         the simulator graphics software if all the coordinate systems
COMMENT         of chips and mosaic are aligned with the 4 cardinal
COMMENT         directions of compass points.
COMMENT         Thus, the x-axis might point "right" and the
COMMENT         y-axis point "down" as seen by the observer described above.
COMMENT         Alternatively, the x-axis might point "down" and y point "left".
COMMENT         In any case, the instrument simulator provides a
COMMENT         FITS card which gives the relative orientation of the
COMMENT         Focal Plane system and the simulator coordinate system.
COMMENT         ----------------------------------------------------------
COMMENT                  The Detector Position Cards
COMMENT         The content of the array is [ x0, y0, Rot, Orient, RefX, RefY]
COMMENT
COMMENT         x0, and y0 are the position of the (0,0) pixel of the chip
COMMENT         measured in meters in the mosaic coordinate system.
COMMENT         For precision of documentation, and because the software
COMMENT         must know, the precise reference point of the (0,0) pixel is
```

Figure C.2.8 (Continued) tek2048.det: A detector configuration

```
COMMENT         the corner of the pixel that would be directly between
COMMENT         (0,0) and (-1,-1), as if pixel (-1,-1) actually existed.
COMMENT         This is location (0.,0.) in the floating point system.
COMMENT         (We do not expect that the actual measurements of the location
COMMENT         of this pixel will be precise enough to justify this subtlety.)
COMMENT         When there is only 1 detector in the mosaic, the values of
COMMENT         x0 and y0 may be ignored by the software; the center of
COMMENT         the detector may be placed at the center of the focal plane.
COMMENT
COMMENT         Rot is measured in degrees.  Rot is the angle measured from
COMMENT         the x-axis of the focal plane coordinate system to the
COMMENT         x-axis of the detector.  This angle is measured in a
COMMENT         clockwise sense as seen by an observer who is blocking the
COMMENT         incoming light.
COMMENT
COMMENT         Orient is either +1 or -1, depending on the handedness of
COMMENT         the detector.  Orient should be +1 for a detector which is
COMMENT         being readout with the same handedness as a device intended
COMMENT         for standard video applications.  Orient should be -1 for
COMMENT         a detector with handedness opposite of standard video.
COMMENT
COMMENT         RefX and RefY indicate which pixel on the detector is at
COMMENT         the location specified by (x0, y0).  These values are
COMMENT         optional, and will be presumed to be 0.0 if they are
COMMENT         not given.  These were added in order to facilitate the
COMMENT         description of chips with multiple amplifiers because
COMMENT         such chips are treated as separate detectors.  Without
COMMENT         these fields multi-amplifier chips require tedious and
COMMENT         awkward calculations to specify their DETPOS cards.
COMMENT
DETPOS1 = ' -0.024576,   0.024576,    0., +1.'
COMMENT ----------------------------------------------------------------
COMMENT
COMMENT
COMMENT
COMMENT         ========================================================
COMMENT  01234567890123456789012345678901234567890123456789012345678901234567890
```

C.3 Example Instrument Setup File

Figure C.3.9 hires1.set: an instrument setup

```
SIMPLE  =                    F  /       Not a FITS file
COMMENT         --------------------------------------------------------
COMMENT This is not really a FITS file.  It has carriage control at line ends.
COMMENT Most of the values in here do conform to the formatting and
COMMENT justification required by the FITS standard, but this is not
COMMENT a requirement.
COMMENT This file is intended to be edited by humans who do not really care
COMMENT about precise formatting of the numeric fields.
COMMENT Thus, the parser of this file is more relaxed than true FITS requires.
COMMENT Values may appear anywhere after the '= ', starting in column 11
COMMENT         ========================================================
COMMENT         This file is intended to represent the information that
COMMENT         an observer would store in advance and bring to the
COMMENT         mountain.  This information contains all of the setup
COMMENT         information needed to describe the state of an Echelle
COMMENT         spectrograph and its detector.
COMMENT         ========================================================
COMMENT         The observer can associate a pet name with a given setup.
COMMENT         This name is used to store and retrieve the entire setup.
SETUP   = 'mystar'              / Setup name as used in the FIORD routines
COMMENT         --------------------------------------------------------
COMMENT         The name of the observer is recorded in the FITS headers of
COMMENT         the images.  It is specfied here.
OBSERVER= 'S.S. Vogt'           / Name of the observer
COMMENT         --------------------------------------------------------
COMMENT         The Echelle simulator program refers to files which define
COMMENT         the layout of the detector and the spectrograph.  Obviously
COMMENT         a given "setup" is intended to be used with a particular
COMMENT         detector and a particular spectrograph.  These are the names
COMMENT         of those files.
DETFILNM= 'tek2048.det'         / Name of detector description file
SPCFILNM= 'hires.spc'           / Name of spectrograph description file
COMMENT         --------------------------------------------------------
COMMENT         The zero point for echelle rotation angle is that angle
COMMENT         at which the incoming and outgoing light are "on blaze".
COMMENT         Positive values move longer wavelengths onto the detector.
ECANGLE =               -1.265  / echelle rotation angle [degree]
COMMENT         The zero point for cross disp. rotation angle is that angle
COMMENT         at which the incoming and outgoing light are "on blaze".
COMMENT         Positive values move longer wavelengths onto the detector.
XDANGLE =                   0.  / cross disperser rotation angle [degree]
COMMENT         With a prism cross disperser there is no XDANGLE.
COMMENT         The Hamilton Echelle spectrograph can move the detector along
COMMENT         the direction of cross dispersion to see different orders.
```

Figure C.3.9 (Continued) hires1.set: an instrument setup

```
COMMENT
HEIGHT  =               500000  / detector height [machine encoder units]
COMMENT         With the Hamilton Echelle spectrograph the user sees the
COMMENT         echelle tilt angle in encoder units.
ECANGRAW=                       / echelle rotation angle [meu]
COMMENT
COMMENT
COMMENT
COMMENT         ----------------------------------------------------------
COMMENT         The DECKER keyword is used differently by almost every
COMMENT         data acquisition system in existence.  In the case of
COMMENT         HIRES, DECKER is a string describing the particular metal
COMMENT         plate which is currently installed (by hand) in HIRES.
DECKER  = 'A string describing the decker'
COMMENT         The HIRES decker is a metal plate with machined notches (holes).
COMMENT         This metal plate is moved parallel to the dispersion
COMMENT         until one of the notches lines up with the slit.  The
COMMENT         FITS keywords to describe how far the metal plate has been
COMMENT         moved are DECKPOS and DECKRAW.  The values of these cards
COMMENT         will only be applicable to a particular decker plate.
COMMENT         The observer may associate a pet name with a particular
COMMENT         notch in the decker plate.
COMMENT
DECKRAW =                       / decker plate position [machine encoder units]
COMMENT
DECKPOS =                       / decker plate position [meter]
DECKNNAM= 'my favorite decker notch'    / Observer's pet name for decker notch
COMMENT         The notch (hole) in the decker plate may actually be
COMMENT         several holes.  This will presumably prove useful after the
COMMENT         image rotator is installed.  An observer might want a
COMMENT         decker which rejected the light from the bright nucleus of
COMMENT         an otherwise faint galaxy.  As a result of the possibly
COMMENT         disconnected nature of the decker notch, the decker height
COMMENT         is defined to be the total vertical extent of the holes
COMMENT         in the decker plate.  The next FITS keywords use this height.
COMMENT         Note that if DECKPIX is used the software will have to
COMMENT         make the assumption that pixels are square and all
COMMENT         detectors in the mosaic are identical.
COMMENT
DECKHGT =                0.001  / total decker height [meter]
COMMENT
COMMENT
COMMENT
DECKSIZE=                       / total decker height [arcsec]
COMMENT
COMMENT
COMMENT
DECKPIX =                       / total decker height [pixel]
```

Figure C.3.9 (Continued) hires1.set: an instrument setup

```
COMMENT
COMMENT
COMMENT        To allow for the documentation of a decker notch (hole) with
COMMENT        multiple apertures, the following keyword has been developed.
COMMENT        The DECKSPEC keyword is a Keck FITS string array.  The
COMMENT        values in the array are
COMMENT        1) an integer describing how many holes there are
COMMENT        2) pairs of real numbers giving the position of top and bottom
COMMENT           of each hole in meters.  The origin should be where
COMMENT           on-axis light strikes the decker plate.
COMMENT
DECKSPEC= '2, -0.0035, -0.0015, 0.0015, 0.0035'
COMMENT        Q: What would the observer specify in advance?
COMMENT        A: Most observers would probably want to specify DECKSIZE.
COMMENT        Q: What should the software do if only that is specified?
COMMENT        Q: Will it know how to pick the available decker height which
COMMENT        Q: most nearly matches?
COMMENT        --------------------------------------------------------
COMMENT        The slit width may be specified by the observer using any
COMMENT        of the following FITS cards.  These cards are listed in the
COMMENT        order they will be sought by the HIRES Instrument Simulator.
COMMENT        Note that if SLITPIX is used the software will have to
COMMENT        make the assumption that pixels are square and all
COMMENT        detectors in the mosaic are identical.
COMMENT
SLITWID =               0.001  / slit width [meter]
COMMENT
COMMENT
COMMENT
SLITSIZE=                      / slit width [arcsec]
COMMENT
COMMENT
COMMENT
SLITPIX =                      / slit width [pixel]
COMMENT
COMMENT
COMMENT
SLITVEL =                      / slit width [meter/second]
COMMENT
COMMENT
COMMENT
SLITRAW =                      / slit width [machine encoder units]
COMMENT
COMMENT
COMMENT        --------------------------------------------------------
COMMENT        The observer probably will not specify the filter positions.
COMMENT        Rather, the observer will probably specify the filter names.
COMMENT
```

Figure C.3.9 (Continued) hires1.set: an instrument setup

```
FILTER  =                    1 / HIRES filter1 position [1 thru 12]
COMMENT
FILTER2 =                   12 / HIRES filter2 position [1 thru 12]
COMMENT
FILNAME = '2-mm NG-4'          / Observer's pet name for filter1
COMMENT
FIL2NAME= 'Spinrad H-alpha'    / Observer's pet name for filter2
COMMENT       --------------------------------------------------------
COMMENT       HIRES can select collimator under computer control.
COLL    = 'RED'                / Which collimator?  'RED' or 'BLUE'
COMMENT       The origin for collimator focus is TBD.
COFOCUS =                  17. / Collimator focus [meter]
COMMENT       HIRES Camera must be changed manually by telescope techs.
COMMENT       At first light there will be only one camera available.
CAMERA  = 'BLUE'               / Which camera?  'RED' or 'BLUE'
COMMENT       The origin for camera focus is TBD.
CAFOCUS =                  42. / Camera focus [meter]
COMMENT       ========================================================
COMMENT       Presumably we may generalize these keywords to XBINn
COMMENT       and YBINn in the unlikely case that an observer wanted
COMMENT       to use different binnings to readout different chips in a
COMMENT       mosaic detector.
XBIN    =                    1 / default to readout every pixel separately
YBIN    =                    1 / default to readout every pixel separately
COMMENT       --------------------------------------------------------
COMMENT       The FITS card WINDOWn refers to the region of readout for
COMMENT       the detector in position "n" of the mosaic.
COMMENT       There will be WINDOWn cards for 1 <= n <= NCHIPS .
COMMENT       The number of rows and columns to be readout may be
COMMENT       a ridiculously large number; the software will clip
COMMENT       the readout regions to be no larger than the detector.
WINDOW1 = '0, 0, 9999, 9999'   / For detector #1, 'X0, Y0, NAXIS1, NAXIS2'
WINDOW2 = '0, 0, 9999, 9999'   / For detector #2, 'X0, Y0, NAXIS1, NAXIS2'
WINDOW3 = '0, 0, 9999, 9999'   / For detector #3, 'X0, Y0, NAXIS1, NAXIS2'
WINDOW4 = '0, 0, 9999, 9999'   / For detector #4, 'X0, Y0, NAXIS1, NAXIS2'
COMMENT       ========================================================
COMMENT       The following keywords have been invented for the sake of
COMMENT       the instrument simulator.  They are not presently
COMMENT       intended to be used in the actual Keck data acquisition
COMMENT       system.
WAVLMAX =               10000. / Maximum wavelength of interest [Aangstrom]
WAVLMIN =                3000. / Minimum wavelength of interest [Aangstrom]
XDORDER =                    1 / Which order of cross dispersion to use?
WAVEFILE= 'waves.dat'          / file with interesting lines
RADVEL  =           299792.458 / radial velocity of interesting lines [m/s]
RADVELZ =                0.001 / radial velocity given as (delta(lam)/lam)
COMMENT       ========================================================
```

Figure C.3.9 (Continued) hires1.set: an instrument setup

```
COMMENT   01234567890123456789012345678901234567890123456789012345678901234567890
```

C.4 Example Line Wavelength File

Figure C.4.10 waves.dat: a line wavelength file

```
3933.7  F  1    CaII (K)
3968.5  F  1    CaII (H)
4101.7  F  1    Hdelta
4300    F  1    CH (G)
4340.5  F  1    Hgamma
4685.7  F  1    HeII
4861.3  F  1    Hbeta (F)
5167.3  F  1    MgI (b)
5172.7  F  1    MgI (b)
5183.6  F  1    MgI (b)
52      F  1    Fe (E)
5876    F  1    He (D3)
5890.0  F  1    Na (D2)
5895.9  F  1    Na (D1)
6562.8  F  1    Halpha (C)
6867.2  T  0    O2 (B)
6867.5  T  0    O2 (B)
6868.1  T  0    O2 (B)
6868.2  T  0    O2 (B)
6868.5  T  0    O2 (B)
6868.8  T  0    O2 (B)
6869.1  T  0    O2 (B)
6869.9  T  0    O2 (B)
6870.9  T  0    O2 (B)
6871.2  T  0    O2 (B)
6872.2  T  0    O2 (B)
6872.8  T  0    O2 (B)
6873.8  T  0    O2 (B)
6874.7  T  0    O2 (B)
6875.6  T  0    O2 (B)
6876.7  T  0    O2 (B)
6877.6  T  0    O2 (B)
6879.0  T  0    O2 (B)
6879.9  T  0    O2 (B)
6883.8  T  0    O2 (B)
6885.7  T  0    O2 (B)
6886.7  T  0    O2 (B)
6888.9  T  0    O2 (B)
6889.9  T  0    O2 (B)
6892.4  T  0    O2 (B)
6893.3  T  0    O2 (B)
6896.0  T  0    O2 (B)
6896.9  T  0    O2 (B)
6899.9  T  0    O2 (B)
```

Figure C.4.10 (Continued) waves.dat: a line wavelength file

```
6900.8  T  0   O2  (B)
6904.1  T  0   O2  (B)
6905.0  T  0   O2  (B)
6908.5  T  0   O2  (B)
6909.4  T  0   O2  (B)
6913.2  T  0   O2  (B)
6914.1  T  0   O2  (B)
6918.1  T  0   O2  (B)
6919.0  T  0   O2  (B)
7000.0  T  0   xdblaze
7593.6  T  0   (A)
7593.9  T  0   (A)
7594.5  T  0   (A)
7594.9  T  0   (A)
7595.2  T  0   (A)
7595.7  T  0   (A)
7596.2  T  0   (A)
7596.5  T  0   (A)
7597.4  T  0   (A)
7598.7  T  0   (A)
7600.0  T  0   (A)
7600.5  T  0   (A)
7601.6  T  0   (A)
7602.3  T  0   (A)
7603.5  T  0   (A)
7604.4  T  0   (A)
7605.6  T  0   (A)
7606.7  T  0   (A)
7607.9  T  0   (A)
7609.3  T  0   (A)
7610.4  T  0   (A)
7612.0  T  0   (A)
7613.2  T  0   (A)
7615.0  T  0   (A)
7616.1  T  0   (A)
7621.0  T  0   (A)
7623.3  T  0   (A)
7624.5  T  0   (A)
7627.0  T  0   (A)
7628.2  T  0   (A)
7631.0  T  0   (A)
7632.1  T  0   (A)
7635.2  T  0   (A)
7636.3  T  0   (A)
7639.5  T  0   (A)
7640.7  T  0   (A)
7644.2  T  0   (A)
```

Figure C.4.10 (Continued) waves.dat: a line wavelength file

```
7645.3  T  0   (A)
7649.0  T  0   (A)
7650.1  T  0   (A)
7654.0  T  0   (A)
7655.1  T  0   (A)
7659.3  T  0   (A)
7660.4  T  0   (A)
7664.8  T  0   (A)
7665.9  T  0   (A)
7670.6  T  0   (A)
7671.6  T  0   (A)
7676.5  T  0   (A)
7677.6  T  0   (A)
7682.7  T  0   (A)
7683.8  T  0   (A)
8498.0  F  1   CaII
8542.1  F  1   CaII
8662.2  F  1   CaII
```

C.5 Example Keck DAS Command File

Figure C.5.11 mystar: a Keck DAS command file

```
define mystar observer=S.S.Vogt
define mystar ecangle=   -6.56448
define mystar xdangle=   -1.00570
define mystar deckpos=  0.
define mystar slitwid=    1.00000E-03
define mystar filter=  1
define mystar filter2=  12
define mystar coll= RED
define mystar cofocus=    17.0000
define mystar cafocus=    42.0000
define mystar binning="  1,  1"
define mystar window="  1,  0,  0,  2048,  2048"
```