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**DriftScan Controller  
&  
Drift Scan Control Program (DSCP)**

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**Abstract**

This paper describes several methods of performing a drift scan to measure asteroid occultations or similar phenomena. To perform a drift scan, one deliberately causes the scope tracking to drift during a long exposure, thus smearing the star and asteroid trails across the CCD image. I have developed a device that controls the drift scan (or similar) process with a time accuracy  $<0.1$  sec UTC using a simple gps sensor. Drift scan can achieve sensitivity to events 1-2 magnitudes fainter than the standard high sensitivity video cameras and recording. This system can operate unattended.

**Introduction**

Most asteroid occultations are recorded using a telescope equipped with a low light TV camera feeding into a tape recorder (VCR). The video images are analyzed later to determine the presence and timing of an occultation. To provide highly accurate GPS based timing, the video signal may be passed through a device that imprints each video frame with GPS time before it is recorded. It is desirable to know the UTC time and the time resolution of events to better than 0.1 sec, which this system easily provides. This device can be used to allow such a video recording system to operate unattended.

An alternative method of recording the occultation is to use a telescope equipped with a CCD camera whose images are recorded in a computer. Such a camera is more sensitive than most TV cameras; however, a CCD camera is designed for long exposures (seconds to minutes) and requires many seconds to read out each exposure. Using the drift scan method, the camera may be opened (ie, an exposure begun) several seconds before the expected occultation and continued until after the occultation is presumed to occur. When the exposure begins, the stars in the field begin to build an image. If one then shuts off the telescope mount drive, the earth's rotation will move the stars across the field, thus creating star streaks. Knowing the rate of star movement and the time of start of the drift scan, one can measure the timing of any brightness dimunition (occultation). Typical drift rates are 10-15 pixels per second, so 0.1 sec. timing is entirely feasible.

There are several potential problems using drift scan:

- The starting of events (exposure start, drift scan start) must be properly coordinated (on a cold night, with the usual glitches and confusion, this is easy to get wrong)
- The timing of events to the desired accuracy is difficult to do by hand.
- To reduce background light in the image (ie, to improve sensitivity) it is desirable to "squeeze down" to a minimum the wasted drift time.
- Non-target stars may intrude on the drift scan, complicating analysis

The usual approach has been to start the drift, then start the exposure at a known time. Because of uncertain shutter delays, this may require DriftScanControllere electronic or audio pickup to determine when the shutter operates, and its synchronization to a WWV or other time signal.

It is tempting to have a computer program carry out the various timed processes. However, if the computer runs Windows, the timing of any computer initiated process may be off by as much as a second or more, plus whatever error is present in the computer clock setting. In addition, the camera has unknown variable delays so that the actual start and stop times of the image may be in error by many seconds. In the case of a drift scan, while the start and stop of the scan might be uncertain, the drift rate itself is set by the earth's rotation and thus the occultation duration can be determined accurately. We have developed the Drift Scan Control Program (DSCP) to perform these actions (establishing timing marks directly on the scan traces, starting exposures, and running the telescope). DSCP requires ASCOM to be loaded, and works with Maximdl for the camera imaging control.

Finally, there are several different methods of producing drift scans:

- Run the camera on an equatorially driven mount, and use the DriftScanController to interrupt the drive as needed to produce the scan and identifying blips on the trace.
- Setup a scope with drive turned off so that at the time of occultation it is pointing at the correct position in the sky. At the appropriate time, start the image which will produce trailed star images. Because the camera imaging cannot be accurately timed, use the DriftScanController to introduce time mark blips onto the trailed star image by operating the drive for a few seconds at the beginning and end of the trace.

The DriftScanController is a simple electronic device that obtains the UTC time from a simple GPS sensor (or manually from another time source). The DriftScanController then uses the gps time through the guider port to control the drift of the telescope. Tests show that this achieves timing to better than 0.1 sec using an A-P mount. The Scanometer uses a small microcontroller in a simple circuit. Parts cost is about \$50. To use GPS based timing requires purchase of a dedicated GPS sensor that provides a 1 Hz signal (cost about \$90, same one as used in the Kiwi).

## Drift Scan Control Program

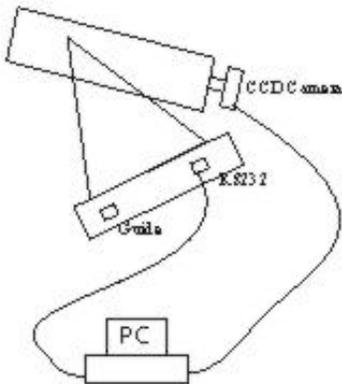
The DSCP program has two distinct modes of operation.

**DSCP Command Mode.** If there is no DriftScanController, then the DSCP program in the PC provides all the timing both for the telescope and for the CCD Camera. The timing of all events will, of course, be subject to the Windows errors. All control is via software.

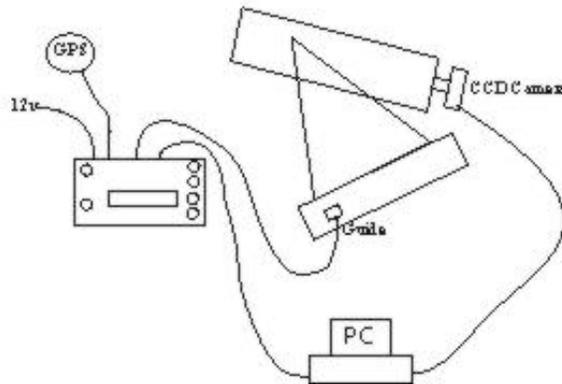
**DriftScanController Command Mode.** If there is a DriftScanController present it will control all the timing including the scope drift (via the Guider port). The timing may be either from a GPS module or by manual time set. The DriftScanController can also supply commands to the PC (via RS232) to control the CCD Camera exposures using MaximDL, or the PC exposure control may be operated manually. All control is via hardware.

When the user turns on DSCP, a screen provides a choice of the two operating modes.

### DSCP Command Mode



### DriftScanController Command Mode



## DSCP Command Mode

The DSCP includes all the settings required to control the drift scan from the PC, including the CCD Camera exposure control and the timing of the drift. The latter is accomplished by sending serial commands to the mount through the RS232 port.

## Configuration Screen

ComPort is the serial port used by the telescope (or the DriftScanController, if used). It is preset for 9600, 8 bit.

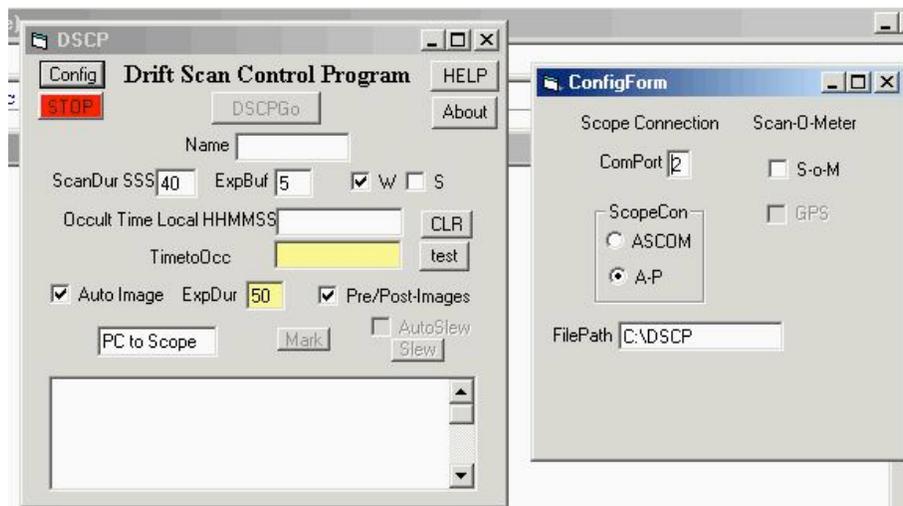
Scope Control allows you to select a direct serial connection to an A-P mount or an ASCOM connection to a variety of scopes. Using the ASCOM connection can be a problem. The ASCOM drivers for the various mounts do not implement many or any of

the functions needed for drift control. Most do appear to provide for "PulseGuide" which is what DSCP uses for ASCOM telescopes. However, the drivers often do not permit setting the guide rates, thus causing the drift rate to be slower or faster than the 1x sidereal generally desired. In general, the guide rate is usually the mount default rate or the rate last set by the user (via the hand control or other software); however, in at least one case (A-P) the driver evidently sets the rate to 0.25x sidereal. Also, because of the way ASCOM sets the commands, when PulseGuide runs, it puts DSCP to sleep, but the timing will still work properly. Because of these problems, where feasible one should use the A-P connection. This should work for LX200 and scopes with similar commands, so long as the guide rate has been set ahead of time (DSCP does set the guide rate of the A-P scope to 1x sidereal in the A-P mode). As always, be sure to test before using for an occultation!

The FilePath is the prefix to the filename for all DSCP files including the images and the log file.

The S-o-M is to be checked if the Scanometer is present. If it is present, one checks also if there is an attached GPS unit.

UTC Offset is the number of hours to add (subtract) to the local time to get UTC.



## DSCP Screen

About and HELP are as usual. Config brings up the configuration screen.

STOP stops the drift if an A-P scope is being used.

Name is the name of the object (optional, will be used in file names)

Scan settings. ScanDur is the scan duration in seconds, with a 65 sec max. The Exposure Buffer entry is the number of seconds to be added to each end of the drift to get the total

exposure duration. W & S are to be checked to show the desired direction of motion of the drift image. At least one needs to be checked, but both may be checked. W is default.

AutoImage when checked tells DSCP to control the CCD Camera (otherwise, the user must operate the camera, which is quite difficult to do manually to the time precision desired). Pre-Post Images when checked tells DSCP to take and save an image before and after the actual Drift image. These are VERY desirable to help assure that your results are what you expected.

Occult Time is the predicted UTC for the center of the occultation which you enter as shown. DSCP then computes the time till the event, and shows it below. The CLR button clears the occultation time for entry of a new value. Be sure the time to occultation results in an occultation at your expected local time to assure that the UTC entry on the configure screen is correct.

Test Button. On alternate pushes, the test button inserts a fake UTC occultation time set either 7 minutes from "now" or 1 minute from "now". This allows testing the whole 5+ minutes cycle of operation, or will start a quick partial drift scan cycle starting with the drift image. You can observe the test operation either on stars or even in daytime by using TheSky to show drift movements of the scope relative to the "stars".

DSCPGo. Once a valid occultation time has been entered, the DSCPGo button is enabled. When pressed, the button turns green and starts the timing and control process. It also initiates the connection to the scope (if no DriftScanController is present) which turns green the lower left text box. When this happens, the history box at the bottom shows the actions, including the current RA and DEC of the scope (all these items are also logged to the FilePath).

When the scope link is made, the MARK button is enabled. If you push Mark, you record the current position of the scope, which should be the precise scope position for the beginning of the drift scan. Later, SLEW (or AutoSlew, if checked) will send the scope to the proper drift starting position.

The user would normally enter the occultation time into DSCP. Check the Time to Occultation to verify that you have the correct UTC Offset in the config screen, ie., that the time to occultation is correct.

You would then use conventional methods to aim the scope to the correct position for the drift scan. Normally, if W is checked, this would have the target star near the left (East) edge of the CCD frame. Once aimed, the user would hit DSCPGo, then hit MARK. The user could then aim the scope elsewhere for what might be an hour or more of observing.

DSCP monitors the time until the occultation. At 300 sec. before the occultation, DSCP slews the scope to the MARKed position. DSCP then aborts any image in progress in Maxim, and then exposes and saves a PreImage for the exposure duration (with a clear

filter). DSCP then waits until 1/2 the scan duration plus the exposure buffer before the occultation time, and starts the Drift exposure. Note, this process allows 3-4 minutes for the user to recognize and fix anything that is broken, and also assures that fairly accurate exposure start timing is achieved since the filter wheel is already in place. After the exposure buffer time, DSCP sends commands to the scope to start drifting for 2 sec, then start tracking again for two sec, then drift the remainder of the scan duration. After the Drift exposure is complete and saved, DSCP takes and saves a PostImage. The process is then complete.

The first thing the user should do is to save copies of all three images to a different folder!! The drift scan shows two tiny blobs at the beginning of the drift trace, and one at the end. The drift is likely not exactly horizontal, so use Edit/Rotate to make the drifts horizontal. Then use View/LineProfile to analyze the trace(s) of interest. Hint: you may want to save the scan data, then save a nearby background and subtract them.

The screen shots below show a drift scan (no occultation). The letters track the stars on the various images. The system is a C11 with an ST7E camera, so the FOBV is about 8x12 a-m, which allows about 50 sec of scan max.

### **DriftScanController Command Operation**

As noted, using a DriftScanController (especially with a GPS) allows much more accurate timing. The combination of the DriftScanController (for drift control) and DSCP (for exposure control) is highly accurate, while still preserving unattended operation and automatic imaging.

The DriftScanController is connected to the mount guide port. The DriftScanController will then start/stop the mount drive in the RA and/or Dec direction to produce the drift. The DriftScanController may also be connected to a serial input of the PC. With DSCP and MaximDL running in the PC, the DriftScanController can signal the PC to take a pre- and post exposure and to take the science exposure of the actual drift (alternatively, the user can operate the camera manually, using the timing from the DriftScanController or other source.

The DriftScanController includes a serial display and control buttons by which the user can make menu selections. These include the MenuGo button that advances the menu, and MenuUp/MenuDn buttons that change the value of the setting. All relevant values are saved as defaults for the next operation of the unit. After turning on the unit, the DriftScanController presents the following menu choices:

- Display Brightness-sets the backlight brightness. Allowable values are 128 to 254
- GPS-is a gps unit attached (1 is yes, 0 is no).
- Occultation Hour UTC-the hour of the occultation event
- Occultation Minute UTC-the minute of the occultation event
- Occultation Second UTC-the second of the occultation event

- Power Buffer-the DriftScanController can operate an external relay box to turn power on for the observation period. Set number of minutes before and after the event.
- Video Buffer-the DriftScanController can turn camcorder recording on/off at preset minutes before/after the event
- CCDBuffer-the DriftScanController will command the PC to operate the camera at CCDBuffer minutes before/after the event (assures CCD is ready, and provides reference images).
- TkgOn-Set to 1 if the tracking is normally on (off for the drift scan), 0 if the tracking is normally off (turns on during the drift scan)
- ScanDuration-time in second of the drift scan (unit forces this to be an even number)
- Test Go? -Normally off (0), enter 1 if you wish to test the setup. This will trigger an accelerated version of drift scan operation taking 3-4 minutes, but including the full scan duration and CCD science image. You will need to reset the telescope to the target star.

At this point, if you entered GPS=1, the DriftScanController will enter a GPS waiting time. Once the gps has locked on the satellites, the DriftScanController will enter its normal timing mode.

If you entered GPS=0, you will now manually enter a UTC hour, minute, and second setting (normally in the next minute or so). When the actual time reaches this setting, you push MenuGo for the last time which sets the internal clock. The DriftScanController then enters its normal timing mode.

In the normal timing mode, the screen shows

- The Occultation UTC time in HHMMSS
- The Current UTC time in HHMMSS (counts up once/second)
- The time to go in HHMMSS (counts down once/ second)
- Operating code series of letters PVCS040

The operating code reads as follows

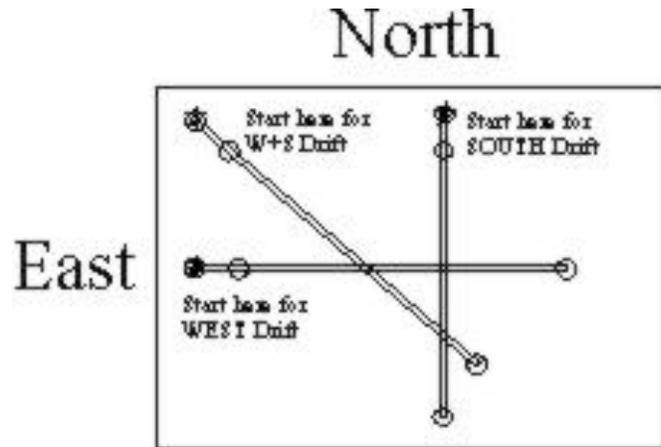
- P is for the power Buffer. Small p when power is off, P when power is energized
- V is for the video buffer. Small v when video is off, V when video is recording
- C is for the CCDBuffer. Small c is before after the CCD imaging, C is pre through post imaging
- 040 is the drift scan in seconds (or whatever the value is)

When using the DriftScanController, the CCD exposure is done manually or by using the DriftScanController serial line connected to the PC. If the latter, start DSCP, and choose the DriftScanController mode. With Maxim running properly, the DriftScanController will command the necessary exposures.

Again, be sure to test the whole process ahead of time. Note, in this mode, there is no automatic slew to the MARKed scope position, that is, you must start with the target star at the correct starting position in the image.

### Typical Operational Considerations

Drift scanning is simple, but it is easy to get confused, especially by directions of movements and directions on the image. We assume a standard image orientation that is East is to the left, North is to the top. If you are looking toward the eastern sky (eg, with a GEM), pushing the EAST button (or physically pushing the scope toward the east) results in the stars moving to the right (west) on the image. Likewise, moving the scope North makes the stars drift to the South (down) on the image. When a GEM is past the meridian, the Left is now west and Up is now East in the image.



- **Timing Considerations.** The user sets the drift scan to, say, 40 sec. Thus, the DriftScanController starts the scan (ie, controls the mount drive) beginning 20 sec before the occultation event time. The drift is for 2 sec, then stops for 3 sec (to provide the time mark), then continues for the remaining 35 sec. Thus, the scan trace on the image represents the actual passage of 37 seconds, which should be used in the drift rate calculations. Also note that the DriftScanController internally sets the CCD exposure to the drift scan plus five seconds at each end, in this case, a total of 50 sec, beginning 25 sec before the occultation time.
- **Evaluate the Scan Duration Needed.** A drift scan of 60 sec will cover 15a-m of sky for an object at Dec=0. A C11 at f6.3 with a camera having 9u pixels (eg., ST7 or 402) will have about 1a-s/pixel. Thus 15a-m will cover 900 pixels. An ST7 has 765 pixels across, so 60 sec will go off the end. In practice, an ST7 (402) will support about 46 sec for an object at Dec=0 and longer at higher Dec. Operating at f3.5 will give longer scans (or use an f6.3 reducer at greater than recommended lens-CCD distance). In practice, simply direct the scope to the star field and try different scan durations to determine what you want to do. Note that long scans require long exposures which increase image background levels that may interfere with the occultation measurement.
- **Guide Rate and Telescope Direction.** Different mounts have slightly different behaviors on the "guide" rate, ie., the rate used by the hand buttons and the guide input cable to control the mount. You will normally want to check that the guide rate is set to 1x, ie., one times the sidereal rate. The usual drift scan goal would be to stop the equatorial drive, ie., the control will actually start driving the mount

1x to the East, counteracting the 1x internal drive to the west that tracks the stars, thus stopping the scope. If North is up on your image, the stars will drift to the right (west), so time will go to the right. Hint: using TheSky, Telescope/MotionControls, MOVE (not jog), GUIDE Rate, you can use the mouse to push and hold the EWNS buttons to move the scope in this same manner. When connected to A-P scope, DSCP sets the guide rate to 1x sidereal. However, when using ASCOM (even with A-P scope), there is no explicit provision for guide rate so it is undefined. Using ASCOM on an A-P scope, the ASCOM driver internally sets the rate to 0.25 sidereal, thus greatly slowing the drift scan (ie, 1/4 the pixels per second). There is no provision at this time in DSCP for setting rates on scopes other than the A-P, though such could be added. If you use TheSky, you can send a serial command to the mount (:RG2# commands an AP mount to 1x Sidereal).

- **Pointing the Scope.** Using the CCD camera, find the target star and record a good image. Position the scope to place the target star at the proper place on the FOV for the beginning of the drift (eg., position it near the East side of the image for a west drift, and to the North side of the image for a South drift). To avoid confusion, synch the mount at this point and/or MARK it in DSCP, so it will be easy to return to this starting point. You should do a TEST drift scan ahead of time to verify that the settings are correct.
- **Drift Rate.** The drift rate (pixels per second) on the image will depend on the declination of the object. At Dec=0, if the scope drive is turned off, the RA drift will be 15 a-s/second. Using your plate scale (a-s/pixel, you can calculate the pixels per second of drift (you can also measure it directly). You can compute the drift rate at other Dec by multiplying by sin(Dec). In any case, because you set the scan duration in DSCP, a simple measurement on the image will show pixels/sec, allowing you to measure the occultation duration. Note that scintillation will always reduce the precision of all timing measurements.
- **Evaluate competing stars.** For a West drift, star streaks from stars close to the same dec will overlap the target star if they are as close as the drift scan length (see example below). When planning your drift, you do need to check BOTH up- and down-stream of the target star to be sure you have no overlapping stars. You can choose West Drift (right), South Drift (down), or both (45 deg down drift) to find a drift direction that avoids overlapping stars.
- **Determine Exposure.** You will likely want to start the exposure five sec before the drift scan starts, and continue it 5 sec longer than the drift scan (this gives good star images to mark the ends of the drift scan) (the DriftScanController does this automatically).
- **Expose.** After your science exposure, for safety of your data, before *any* image viewing or manipulation, be sure immediately to copy your raw images (with different file names to a different folder). In addition to the pre and post images,

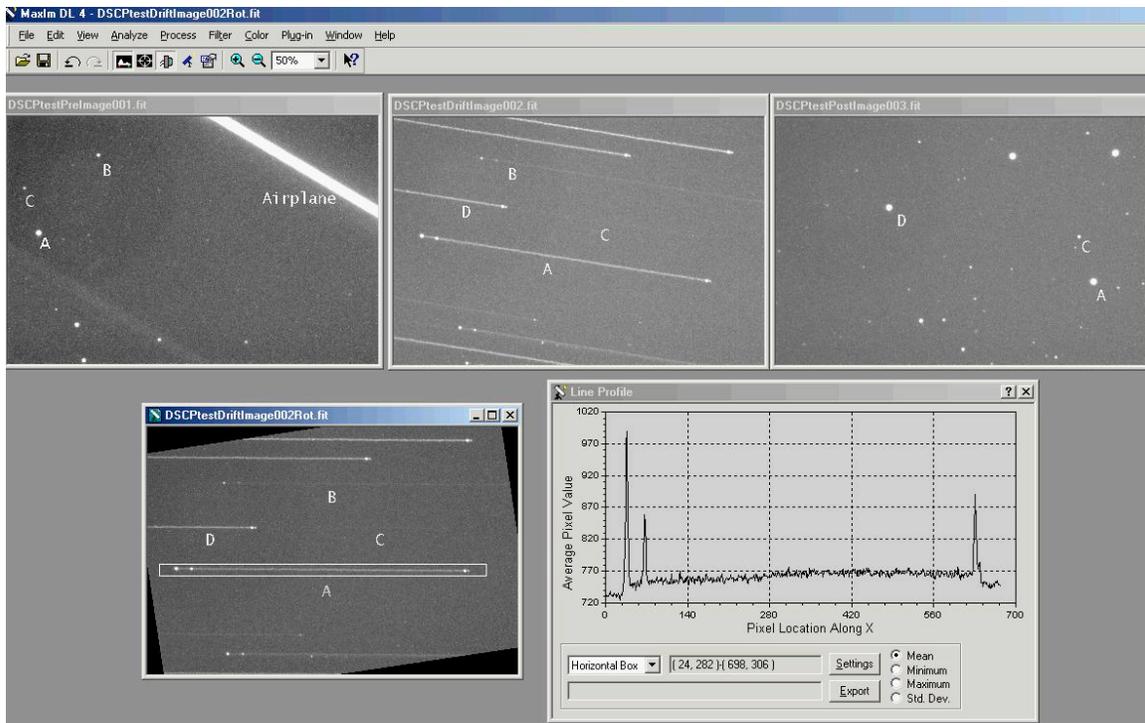
it is often desirable to take a second drift image to allow subtraction of drift scans with and without the presumed occultation. To do the second scan, after the post image, re-slew back to the starting point, then push test1 (or TEST with the DriftScanController) which inserts a fake occultation time one minute from "now". At the proper times, the new drift image will begin and the scope will perform the drift scan.

- Analyze results. First, of course, calibrate the image and apply any necessary corrections (eg removing gradients). The drift will normally not be exactly horizontal on the image because the camera is not aligned perfectly, so use Edit/Rotate to make the scans horizontal. Then use View/LineProfile, horizontal box, to make a profile of the scan covering the full width of the image and drift scan, and save the file. You may also do a background and comp star. Open a spreadsheet (I can provide a sample), and use WordPad to copy each profile and paste it into the spreadsheet (using Data/TextToCol if needed). Identify the start and stop target star images, and enter the pixel numbers. The spreadsheet will compute the drift rate, etc. The center of the drift scan is the defined occultation time setting. You can then analyze the data, identify the time of the events in the data, etc. Remember that the actual time span of the scan is 3 sec less than the ScanDuration due to the time spent on the blip.

## Results

On the end points of the trace, you will see the exposed stars where the camera exposure had begun, but the drift had not started. You will also see a blip 2 sec after the start where the actual drift scan was interrupted for 3 sec. This identifies the starting end of the trace unambiguously.

Of interest is that star C produced a faint trace whose beginning is overlain by star D. Star D was off the field to the East (left) and drifted over the Star C track. It is important to check the "up- and down-stream" fields before you run, so that you will know what to expect. If there is a likely conflict with another star drift, you cannot solve it by rotating the camera, etc. You can, however, also in DSCP check S for the drift direction which will produce a combined movement (ie, E and N of the scope), ie., a diagonal line across the FOV. You would then put the desired star near the upper left (NW) corner as the starting point. You can reorient the camera to get a more horizontal trace, if desired.



## Mount Response Assumption

The DriftScanController timing accuracy relies on there being a known delay time between the signal sent to stop the drive (ie, to start the drift) and the actual achievement of the new velocity (ie., the actual beginning of the drift). I tested the DriftScanController with an AP900 mount with a C11 and video camera feeding a PC frame grabber. The video camera was equipped with an LED that shone onto the CCD, and was triggered at the beginning of the scan (this causes a bright flash on the video frame). I then triggered the drift scan on several stars, and measured the speed of the start of the drift scan by measuring the number of video frames that pass before the drift begins (ends). In each test, the delay was too small to measure, that is, well under one frame or 1/15th sec. It is likely that most mounts will have delays of under 0.1 sec when using the GUIDE control inputs.

## Check List

In addition to the usual inputs, double check:

- Run TEST of Drift controller
- Assure that you have reset the proper starting location for target star
- Set correct drift switch directions
- Correct Occult time, Cur time, and time to go
- Video camera on
- Maxim Running, camera on, DSCP running
- Set button (drift) rate in mount
- Object Name entered into DSCP

