

Chapter 4

Tracking, Pointing, and Focus

4.1 Tracking Capabilities

The 12 Meter Telescope can track both stationary (sidereal) sources or fast moving sources such as the Sun, Moon, planets, comets, or satellites (called “ephemeris objects”). The positions of stationary sources may be entered into source catalogs by the observer or directly into the on-line system by the operator. Stationary source positions may be given as

- Apparent equatorial positions (already precessed),
- Equinox B1950 or J2000 equatorial positions, or
- Galactic coordinate positions (III, bII).

An example of the 12m catalog format is the following:

18:27:17.3	01:13:23.0	B1950 SERMM1	8.0	LSR	RAD
18:27:28.0	01:10:45.0	B1950 SERMM2	8.0	LSR	RAD
18:27:27.3	01:11:55.0	B1950 SERMM3	8.0	LSR	RAD
18:27:24.7	01:11:10.0	B1950 SERMM4	8.0	LSR	RAD
18:27:18.9	01:12:02.0	B1950 SERMM5	8.0	LSR	RAD
18:27:25.4	01:12:02.0	B1950 SERMM6	8.0	LSR	RAD
18:27:22.0	01:12:30.0	B1950 SERCTR	8.0	LSR	RAD

where

column 1 = right ascension (HH:MM:SS.S) or galactic longitude (DDD.DDDDD),

column 2 = declination (DD:MM:SS.S) or galactic latitude (DD.DDDDD),

column 3 = coordinate epoch (B1950, J2000, APPARENT, or GALACTIC),

column 4 = source name,

column 5 = source velocity,

column 6 = source velocity reference frame (LSR, HEL, GEO, or TOP), where

LSR = local standard of rest velocity reference frame,

HEL = heliocentric velocity reference frame,

GEO = geocentric velocity reference frame, and

TOP = topocentric velocity reference frame,

column 7 = source velocity type (RAD, OPT, or REL), where

RAD = radial velocity type,

OPT = optical velocity type, and

REL = relativistic velocity type

The sky frequency equations corresponding to the above velocity types are given in Equations 5.4.

4.1.1 Ephemeris Objects

To track ephemeris objects (comets, asteroids, *etc.*), the control system requires three positions, centered upon the present time. The tracking algorithm then makes a cubic spline interpolation to determine the source position at the specific time of observation. The observer must prepare a catalog in the correct format in order to observe ephemeris objects other than the planets and the Moon. The basic format needed by the control system is show below.

OBJ Hyakutake

VELFRAME LSR

VELTYPE RAD

#

Ephemeris for Hyakutake, 0.000 H 9 APR 1996 to 23.700 10 APR 1996

#

D 45.7745 D 41.3975 J 50182.000720 0.00 55.84

D 45.7705 D 41.3822 J 50182.017387 0.00 55.86

D 45.7662 D 41.3670 J 50182.034053 0.00 55.89

D 45.7620 D 41.3517 J 50182.050720 0.00 55.91

D 45.7580 D 41.3363 J 50182.067387 0.00 55.93

D 45.7540 D 41.3212 J 50182.084053 0.00 55.94

D 45.7500 D 41.3058 J 50182.100720 0.00 55.95

D 45.7463 D 41.2907 J 50182.117387 0.00 55.96

D 45.7422 D 41.2755 J 50182.134053 0.00 55.97

D 45.7385 D 41.2603 J 50182.150720 0.00 55.97

D 45.7347 D 41.2452 J 50182.167387 0.00 55.97

D 45.7313 D 41.2300 J 50182.184053 0.00 55.97

where the first three lines are descriptors for the object name, velocity frame, and velocity type. The next three lines are comments. Each column thereafter is defined as follows:

D 45.7745 = the topocentric right ascension in degrees.

D 41.3975 = the topocentric declination in degrees.

NOTE: You can also use a geocentric right ascension and declination in the last two locations, but if you do you must enter the correct horizontal parallax (see below).

J 50182.000720 = the Modified Julian Date (mjd) of this record in the TT (Terrestrial Time, which used to be called Terrestrial Dynamical Time, or TDT) system. Note that TT = UTC + 63.184 sec after June 30, 1997.

0.0= the horizontal parallax (the angle from you to the object to the center of the earth in arc seconds). The horizontal parallax is zero in this case since we are using topocentric coordinates. If one uses geocentric coordinates, the horizontal parallax must be non-zero and is given by:

$$\text{HP} = \arcsin\left(\frac{6378.137}{\rho}\right)$$

$\rho \equiv$ geocentric distance of object

55.84 = the topocentric velocity. Non-planets default to topocentric velocities. Planets default to geocentric positions and velocities.

After you create the ephemeris put it in a file with the extension **eph** in the observers home directory - **/home/obs/ini/comet.eph** for example.

If you do not have an ephemeris generation program, we have a copy of the "TBEG4" two body ephemeris generator program written by Don Yeomans which you can use. This program will produce a 12m-format ephemeris file given a set of orbital elements. Contact Tom Folkers if you would like to use this program.

4.2 Tracking Limits

4.2.1 Elevation Limits

Mechanical limits constrain the movement of the telescope on both the azimuth and elevation axes. Under normal source-tracking operation, the control system software prevents the telescope from moving into these limits. The telescope is also equipped with fail-safe hardware limit switches that will turn the drive motors off and apply the brakes before the telescope can be damaged. When the telescope reaches a lower elevation of 15.0°, it begins to depress a safety spring on the elevation stop. Tracking can continue until the elevation drive motor begins drawing excessive current; this usually occurs at an elevation near 14.5°. A final limit switch is tripped at 13.8° elevation.

The control computer will allow a source to be tracked up to an elevation of 90° . The pointing equations diverge at the zenith, however, and elevations greater than 88° should be strictly avoided during observations. For routine observations, we recommend that you avoid elevations $>80^\circ$ if possible, since both tracking and pointing degrade in that range. For maintenance purposes only, the telescope can be driven to an elevation of 92° before tripping a final limit switch.

4.2.2 Azimuth Limits

To prevent the over-wrapping of cables, the telescope has hardware and software azimuth limits. The control system will not allow the telescope to rotate through 66.8° azimuth to acquire or track a source. As they rise, sources with declinations between 27° and 38.75° will pass through 66.8° azimuth above 15° elevation. When a rising source reaches an azimuth of 66.8° , the telescope will rotate 360° to re-acquire the source. The region of the sky where azimuth transitions occur is displayed in Figure 4.1. If an integration is in progress when the transition azimuth is reached, the integration is halted while the telescope rotates around to re-acquire the source. The integration is resumed when the source is reached again. If it is undesirable for this to happen, you should cease the integration before reaching the transition azimuth.

4.3 Tracking Error Tolerance

The 12 Meter Telescope is vulnerable to tracking errors produced by wind gusts. The tracking software has a provision for rejecting from the integration any data sample that was taken with the telescope off source. The basic timing cycle of the 12m control system is 100 milliseconds (0.1 sec). After each 100 ms interval, the system checks for error conditions such as tracking errors or a loss of frequency phase lock. If an error condition is detected, the data sample collected during the last 100 ms interval is not averaged with the rest of the data.

You can choose how much tracking error you are willing to accept. This number is called the "tracking tolerance" and is displayed on the on-line status monitor in the lower left-hand corner under the heading "TOL". The 12m typically experiences 3-4" tracking errors under calm conditions. The tolerance is usually not set to less than 5" for this reason. Typical choices for the tolerance are 5" for 1.3 mm and shorter wavelength observations, and 10" for 2 and 3 mm observations. Figure 4.2 shows the amount of signal that is lost by a given pointing error, expressed as fractions of a FWHP beamwidth.

4.4 Sequence of Position Computation Operations

The sequence of computer operations that is executed when seeking and then tracking a source is as follows:

1. Input RA-DEC (B1950, J2000, or current epoch) or galactic (III,bII).

2. If B1950 position, precess to current date. If galactic coordinates, first precess to epoch B1950 The precessed position of a source is computed only when the source is first accessed.

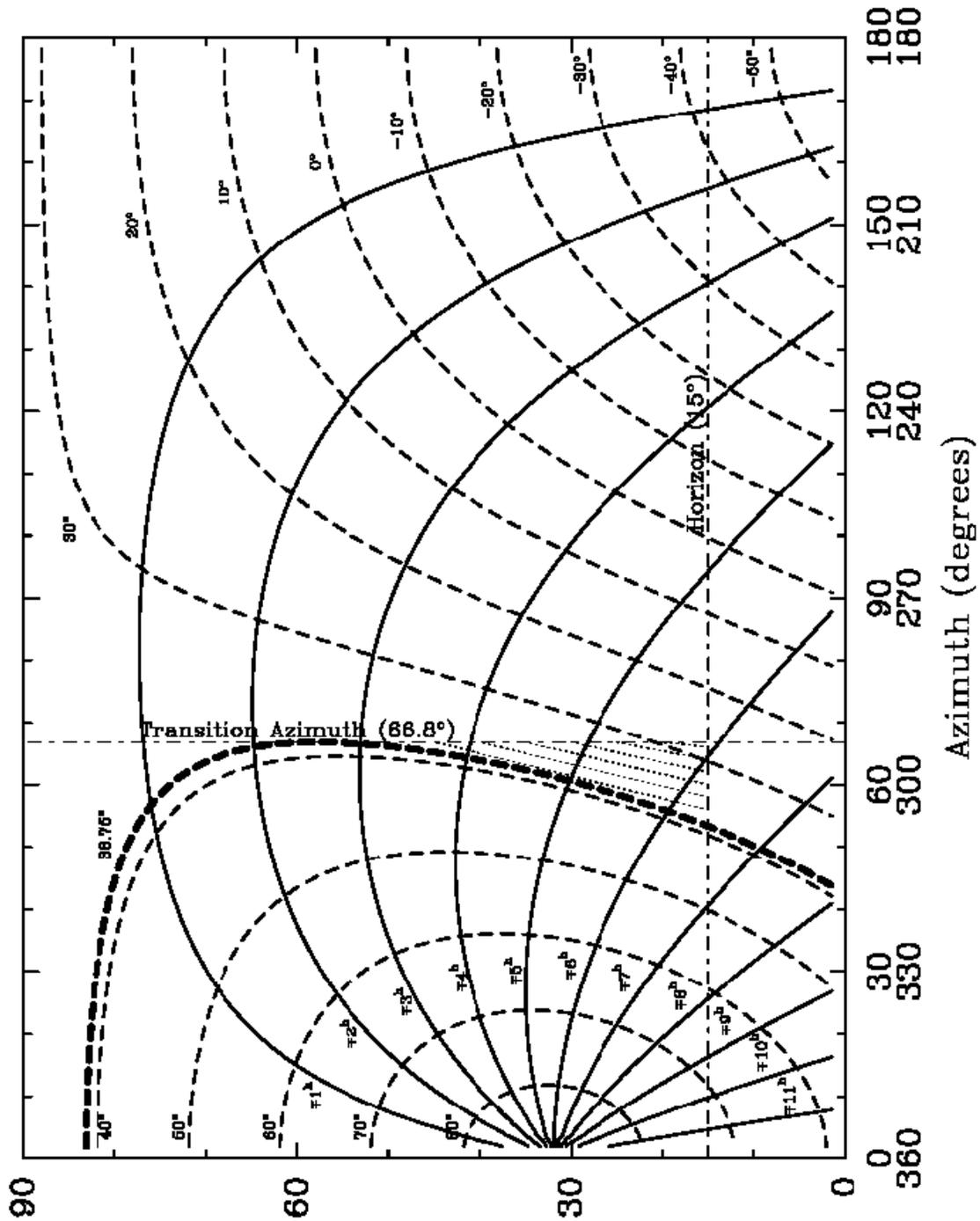


Figure 4.1: Local hour angle and declination versus azimuth and elevation for the 12m. The hatched region indicates the range of source declination where the telescope will undergo a 360° azimuth transition while tracking a rising source.

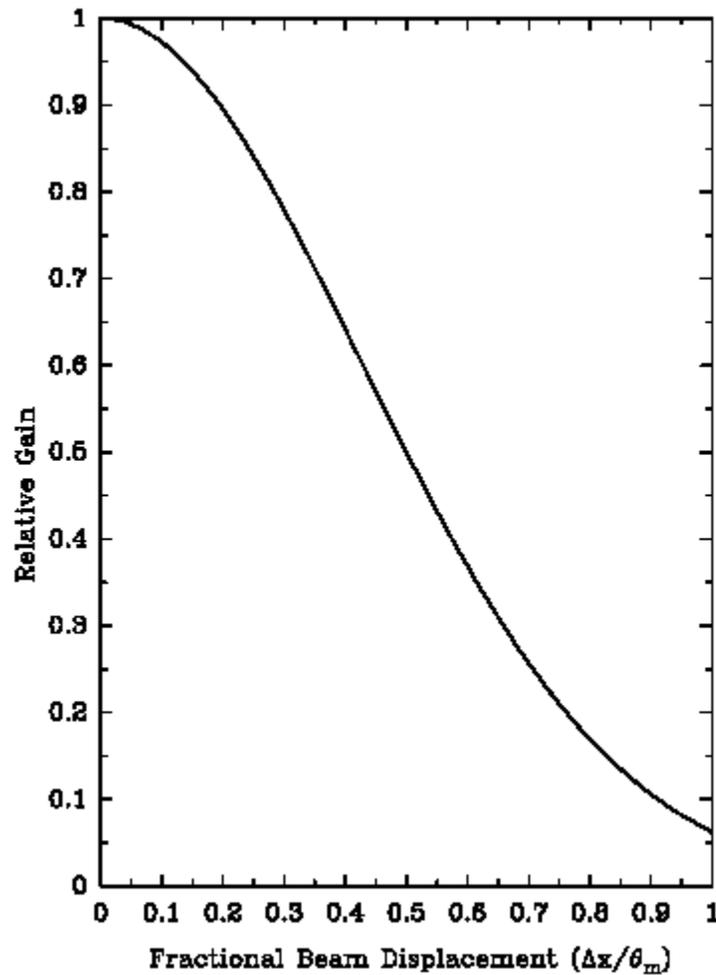


Figure 4.2: Loss of signal due to pointing error.

3. If source is an ephemeris object, interpolate to current UT.
4. Do spherical coordinate conversion from RA-DEC to AZ-EL.
5. Add azimuth and elevation encoder corrections as computed from Equations A.1, A.2, A.9, and A.10 (Appendix A).
6. Add azimuth and elevation pointing corrections.
7. Command telescope to the correct AZ-EL position.
8. Once every 10 seconds, go back to spherical coordinate conversion. Between loops, extrapolate AZ and EL drive rates every 100 ms to compute positions.

4.5 Subreflector Beam Throw

The 12 Meter Telescope is equipped with a nutating (chopping) subreflector that is used for beam-switched observations in both the spectral line and continuum modes. Other observing modes, such as position switching, are made with the subreflector locked in place. Obviously, the throw position of the subreflector, whether it is chopping or locked in place, affects the pointing of the telescope. The current 12m subreflector switches only in azimuth, although mount misalignments may produce a small component in the elevation direction (usually these are less than 1-2"). The pointing equations for the 12m are set up for 0 offset in subreflector position, *i.e.* with the subreflector axis aligned with the electrical axis of the primary reflector. When the subreflector is offset so that the telescope must be moved in the positive azimuth direction to bring the source into the beam, the subreflector is said to be in the "+BEAM". When the telescope must be moved in the negative azimuth direction to acquire the source, at least with respect to the +BEAM, the subreflector is in the "-BEAM". Figure 4.3 illustrates this convention. Both the spectral line and continuum backends are configured so that the +BEAM signal is positive and the -BEAM signal negative.

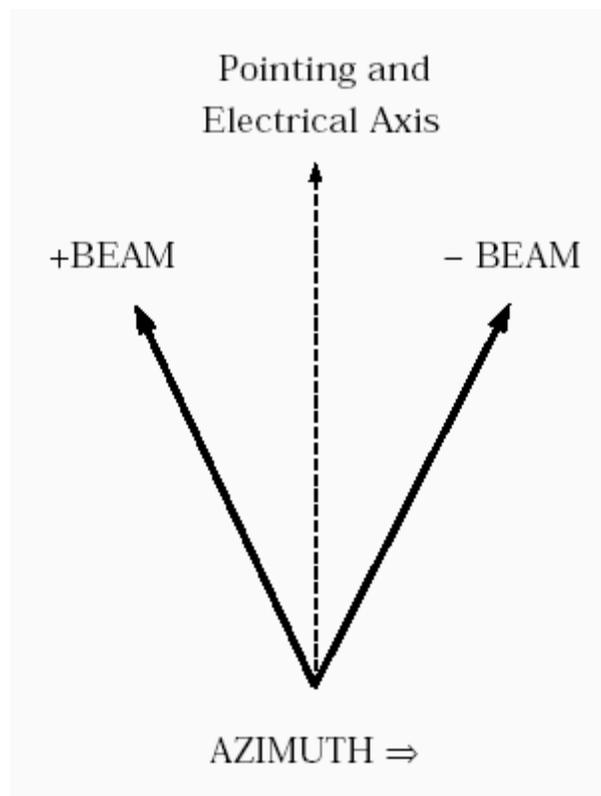


Figure 4.3: Subreflector +Beam/Beam conventions.

The control system software takes account of the subreflector throw setting when positioning the telescope. The computer does not read the subreflector setting automatically, however; it depends upon the operator to manually set the throw value.

The subreflector is physically set by turning two dials on the subreflector control chassis. Default values of subreflector throw are stored in the computer: for example, $\pm 2'$ for 3 mm and $\pm 1'$ for 1 mm. You can check the beam throw by making a continuum cross-scan on a strong source.

Continuum mapping rows are explained in detail in Chapter 6.

4.6 Pointing

You are responsible for determining the residual azimuth and elevation pointing offsets, relative to the nominal telescope pointing. These offsets are usually of the order $10''$ - $20''$ and often vary across the sky. In particular, the offsets often show an elevation dependence. The pointing of the 12m may drift over a period of several months by $10''$ or so, and you are cautioned not to assume that old pointing data are still valid. If a project requires accurate pointing, observers should budget 5 - 10% of their total observing time to pointing checks. High frequency projects, for which the FWHP of the main beam is $30''$ or less, obviously require more attention to the pointing.

You may perform pointing checks in either continuum or spectral line mode. Pointing sources must have an angular brightness distribution that is compact compared to the antenna beam. In addition, they must have well-determined positions and must be strong enough to point on in a reasonable amount of time, *e.g.* 10 minutes or less. The best pointing sources are the major planets Venus, Mars, Jupiter, Saturn, and Uranus, observed in continuum mode. These sources have strong flux densities throughout the millimeter band, although Uranus is faint at 3mm and longer wavelengths. To obtain complete sky coverage, particularly north of the zenith, the planets must be supplemented with other pointing sources. A tabulation of these sources and approximate flux densities at 3 and 1 mm is given in Table 4.1. This table includes the sources traditionally used at the 12m together with sources found useful at the IRAM 30m telescope. The sources with no listed flux density are on the order of 1 Jy in strength. It should be noted that the flux densities of many of the extragalactic sources in the table can be highly time-variable. For an up-to-date listing of measured 3mm fluxes, see <http://dopey.haystack.edu/cmva/quasar.list>.

The spectral line emission from a number of sources can be used for pointing purposes. Emission from rotational transitions of CO, HCN, and SiO are often strong enough and angularly compact enough to provide good pointing results. A list of spectral line pointing sources and their strong molecular emission lines are listed in Table 4.2.

4.6.1 Continuum and Spectral Line Five-Point Measurements

The five-point mapping option is the standard observing technique for determining the antenna pointing of the 12 Meter Telescope. Continuum five-point measurements can also be used to measure the flux density of a strong source with the highest precision, or the flux density of a source whose position is not exactly known. The five-point map consists of five successive **ON/OFF** sequences (for continuum and beam-switched spectral line measurements), or five successive **ON** and **OFF** measurements (for position-switched spectral line measurements), or five successive **ON** measurements with one associated

OFF measurement (for total power spectral line measurements). The five sequences or **ON** measurements are positioned in azimuth and elevation relative to the nominal source position, as shown in Figure 4.4. The numbers identifying the positions give the time order in which the sequences are taken. The offset for each position (“HP” in Figure 4.4), is a selected offset (in arcsec) that is usually chosen to be close to half the HPBW of the telescope at the observing frequency. HP should be somewhat larger if the source is extended; for a planet that is resolved by the beam, chose HP to be approximately the semi-diameter of the source.

Table 4.1: Galactic and Extragalactic Continuum Pointing Sources

Source	(B1950)	(B1950)	Sv(3mm)(Jy)	Sv(2mm)(Jy)
0003+380	00:03:22.300	38:03:33.00	1.4,0.7	
0048-097	00:48:10.000	-09:45:24.00	1.8,0.5	
0106+013	01:06:04.500	01:19:01.00	0.9,0.3-0.6	
0112-017	01:12:43.900	-01:42:55.00		
0119+041	01:19:21.400	04:06:44.00	1.2,0.4	
RSCL	01:24:40.020	-32:48:06.80	Good	
0133+476	01:33:55.100	47:36:13.00	2.8,0.4-1.5	
0135-247	01:35:17.100	-24:46:09.00	1.3,	
0202+149	02:02:07.400	14:59:51.00	3.7,1.5	
MIRA	02:16:49.110	-03:12:22.40	Very	
W3(OH)	02:23:16.500	61:38:57.00	3.8,8.3	
0224+671	02:24:41.200	67:07:40.00	0.8,0.8-1.9	
0235+164	02:35:52.600	16:24:04.00	1.3,0.8-3.5	
0234+285	02:37:52.406	+28:48:08.99		
0300+471	03:00:10.100	47:04:34.00	1.5,0.6	
3C84	03:16:29.600	41:19:52.00	5.5,1.8-8.0	
0316+413	03:19:48.160	+41:30:42.10		
0322+47	03:22:59.100	47:21:22.00	Good	
GL490	03:23:39.220	58:36:35.60	,2.9	
NGC1333	03:26:05.030	31:03:13.00	3	
0336-019	03:36:59.000	-01:56:17.00	2.1,0.9-1.3	
NRAO150	03:55:45.300	50:49:20.00	3.0,1.0-2.0	
0355+508	03:59:29.747	+50:57:50.16		
3C111	04:15:00.610	37:54:19.50	3.7,1.3-9.8	
0420-014	04:23:15.801	-01:20:33.07	4.1,0.8-4.2	
0426-380	04:26:54.700	-38:02:52.00	2.9,	
L1551IRS5	04:28:40.200	18:01:42.00	,1.7	
3C120	04:30:31.600	05:15:00.00	2.0,0.5-1.6	
0430+052	04:33:11.096	+05:21:15.62		
0439+360	04:39:33.800	36:01:15.00	1.1,2.6	
0439+36	04:39:34.040	36:01:16.00	Very	
0454-234	04:54:57.300	-23:29:28.00	2.1,0.4-0.5	
0456+56	04:56:40.600	56:06:28.00	OK	
0458-020	04:58:41.300	-02:03:34.00	1.9,0.6-0.8	
0521-365	05:21:12.900	-36:30:17.00	4.6,2.7-4.2	
0528+134	05:28:06.800	13:29:42.00	5.6,1.9-3.5	
0529+075	05:29:56.490	07:30:38.10	,1.3	
TAUA	05:31:30.000	21:59:00.00		
ORIONA	05:32:47.000	-05:24:21.00		
0552+398	05:52:01.400	39:48:22.00	2.3,0.7-0.9	
0605-085	06:05:36.000	-08:34:20.00	1.6,0.6-1.1	
0607-157	06:07:26.000	-15:42:03.00	4.8,2.7-5.9	

CHAPTER 4. TRACKING, POINTING, AND FOCUS

0642+449	06:42:53.000	44:54:31.00	1.3,0.5	
0716+714	07:16:13.000	71:26:15.00	2.5,0.3-1.5	
VYCM	07:20:54.700	-25:40:12.00		
0716+714	07:21:53.448	+71:20:36.36		
0727-115	07:27:58.100	-11:34:53.00	2.4,0.3-1.1	
0735+178	07:35:14.100	17:49:09.00	3.0,0.7-3.0	
0736+017	07:39:18.034	+01:37:04.62	2.8,0.6-3.5	
0804+499	08:04:58.400	49:59:23.10	,1.3	
0805-077	08:05:49.600	-07:42:22.00	1.2,0.7	
0814+425	08:14:51.700	42:32:08.00	1.3,0.3	
0820+560	08:20:53.200	56:02:27.00	1.0,0.3	
0823+033	08:23:13.560	03:19:15.40	,1.7	
0827+243	08:27:54.400	24:21:08.00		
OJ287	08:51:57.300	20:17:58.00	2.0,1.0-4.0	
0851+202	08:54:48.875	+20:06:30.64		
0923+392	09:23:55.300	39:15:24.00	6.2,0.5-3.0	
RLEO	09:44:52.200	11:39:40.00		
CWLEO	09:45:14.840	13:30:40.50	,1.5	
IRC+10216	09:45:14.890	13:30:40.80	Very	
1013+30	10:13:10.940	30:49:16.70	Very	
1034-293	10:34:55.800	-29:18:27.00	3.0,1.5	
1039+811	10:39:27.800	81:10:24.00	1.0,	
1044+719	10:44:49.700	71:59:27.00	1.4,0.3	
VHYA	10:49:11.300	-20:59:04.90		
1055+018	10:55:55.300	01:50:03.00	3.2,0.8-1.7	
1055+018	10:58:29.605	+01:33:58.82		
1116+128	11:16:20.800	12:51:07.00	1.0,0.5	
1156+295	11:56:57.800	29:31:26.00	2.5,0.4-1.3	
3C273	12:26:33.200	02:19:43.00	20.1,6.0-24.0	
3C273B	12:26:33.200	02:19:43.00	20.1,6.0-24.0	
VIRA	12:28:17.600	12:40:02.00	7.9,1.9	
1226+023	12:29:06.700	+02:03:08.60		
1244-255	12:44:06.700	-25:31:27.00	2.0,1.1	
3C279	12:53:35.800	-05:31:08.00	20.0,4.0-21.0	
1253-055	12:56:11.167	-05:47:21.52		
1308+326	13:08:07.600	32:36:40.00	2.0,0.5-1.5	
1313-333	13:13:20.000	-33:23:10.00	1.4,0.6-1.4	
CENTA	13:22:31.800	-42:45:30.00	9.4,6.1-8.0	
1334-127	13:34:59.800	-12:42:10.00	5.6,2.1-5.5	
WHYA	13:46:12.100	-28:07:09.00		
1354+195	13:54:42.100	19:33:44.00	1.2,0.3	
1413+135	14:13:33.900	13:34:17.00	2.6,0.2-2.2	
1418+546	14:18:06.200	54:36:58.00	1.0,0.3-0.8	
1502+106	15:02:00.200	10:41:18.00	1.0,0.3	
1504-166	15:04:16.400	-16:40:59.00	1.1,0.5	

CHAPTER 4. TRACKING, POINTING, AND FOCUS

1510-089	15:10:08.900	-08:54:48.00	1.3,0.6-1.7	
1514-241	15:14:45.300	-24:11:23.00	1.2,0.5-1.7	
1546+027	15:46:58.300	02:46:06.00	4.1,0.5	
1548+056	15:48:06.900	05:36:11.00	2.0,0.3	
1611+343	16:11:47.900	34:20:20.00	3.2,1.0-1.4	
1622-253	16:22:44.100	-25:20:52.00	2.4,	
1629-242	16:29:21.050	-24:22:15.50	,5.3	
1633+382	16:35:15.493	+38:08:04.50	2.5,0.7-1.0	
1637+574	16:37:17.400	57:26:16.00	1.1,0.5	
1638+398	16:38:48.200	39:52:30.00	1.0,0.6	
3C345	16:41:17.600	39:54:11.00	5.7,0.8-6.0	
1641+399	16:42:58.810	+39:48:36.99		
1655+077	16:55:44.000	07:46:00.00	1.0,0.5	
1657-261	16:57:47.700	-26:06:29.00	1.8,0.8-1.9	
1704-24	17:04:54.600	-24:40:39.00	OK	
NRAO530	17:30:13.500	-13:02:46.00	10.2,3.4-7.0	
1732+389	17:32:40.500	38:59:47.00	1.0,0.6	
1730-130	17:33:02.706	-13:04:49.55		
1739+522	17:39:29.010	52:13:10.40	,1.2	
1741-038	17:43:58.856	-03:50:04.62	2.2,1.1	
1742-29	17:45:40.038	-29:00:28.07		
1749+096	17:51:32.819	+09:39:00.73	6.4,0.9-4.2	
1757-240	17:57:26.800	-24:03:57.00	,14.0	
1803+784	18:03:39.200	78:27:54.00	2.1,1.3-1.6	
1807+698	18:07:18.500	69:48:57.00	1.2,0.4-0.8	
VXSGR	18:08:44.500	-33:52:00.50		
1823+568	18:23:14.900	56:49:18.00	1.0,1.4-1.8	
1828+487	18:28:13.500	48:42:41.00	2.5,0.5	
1830-211	18:33:39.930	-21:03:40.77		
G34.3	18:50:46.100	1:11:12.60	?,25,?	
G45.1	19:11:00.420	10:45:42.90	,3.7	
1921-293	19:21:42.200	-29:20:26.00	11.6,3.8-8.0	
1928+738	19:28:49.300	73:51:45.00	1.2,0.5	
CHICYG	19:48:38.530	32:47:09.90	Very	
1954+513	19:54:22.500	51:23:46.00	1.1,0.6	
CYGA	19:57:44.500	40:35:46.00		
1958-179	19:58:04.600	-17:57:17.00	2.9,1.4-1.5	
K3-50A	19:59:50.100	33:24:19.00	6.5,7.5	
2005+403	20:05:59.600	40:21:02.00	1.5,0.3	
2007+777	20:07:20.400	77:43:58.00	1.5,0.6-1.0	
2007-06	20:07:47.400	-06:25:11.00	OK	
ON1	20:08:09.910	31:22:42.30	,2.9	
2013+370	20:15:28.730	+37:10:59.52		
MWC349	20:30:56.850	40:29:20.20	,1.7	
2037+511	20:37:07.500	51:08:36.00	3.0,0.7	

CHAPTER 4. TRACKING, POINTING, AND FOCUS

DR21	20:37:14.370	42:08:56.50	15.6,	
VCYG	20:39:41.420	47:57:43.20	Very	
EGGNEB	21:00:19.900	36:29:45.00	Very	
NGC7027	21:05:09.400	42:02:03.00	5.2,3.9	
2105+42	21:05:09.500	42:02:04.00	Very	
2128+50	21:28:15.100	50:50:47.00	Very	
2128-123	21:28:52.700	-12:20:21.00	1.0,0.3	
2134+004	21:34:05.200	00:28:25.00	2.1,0.5-0.7	
2135+78	21:35:52.650	78:23:58.70	Very	
2145+067	21:48:05.459	+06:57:38.60	6.2,1.9-3.0	
BLLAC	22:00:39.400	42:02:09.00	3.3,2.0-8.0	
2201+315	22:01:01.400	31:31:06.00	3.0,0.4-0.9	
2200+420	22:02:43.291	+42:16:39.98		
2210-257	22:10:14.100	-25:44:22.00	2.1,0.2	
2216-038	22:16:16.400	-03:50:41.00	1.2,0.3	
2223-052	22:23:11.100	-05:12:18.00	4.0,0.8-4.1	
2230+114	22:32:36.409	+11:43:50.90	3.7,0.8-2.0	
2234+282	22:34:01.700	28:13:23.00	1.2,0.3	
2243-123	22:43:39.800	-12:22:40.00	2.3,0.8-4.5	
3C454.3	22:51:29.500	15:52:54.00	7.1,1.9-10.8	
2251+158	22:53:57.748	+16:08:53.56		
CEPA	22:54:19.000	61:45:47.20	,4.9	
2255-282	22:55:22.500	-28:14:26.00	2.4,0.5-3.0	
NGC7538	23:11:36.700	61:11:50.00	2.1,5.5	
2316+16	23:16:42.400	16:55:10.00	Very	
2318+049	23:18:12.100	04:57:23.00	1.1,0.3-0.8	
CASA	23:21:11.000	58:32:48.00		
2345-167	23:45:27.700	-16:47:53.00	2.2,0.5	
RCAS	23:55:52.070	51:06:37.30	Good	

To make a five-point map proceed as follows:

Continuum Five-Point:

1. Select an appropriate source to point on, such as a planet or other strong continuum source.
2. Using the pointing charts, make an initial guess for the azimuth and elevation pointing offsets.
3. Ask the operator to setup for a continuum five-point measurement on the chosen source. The operator will set the integration time per sample and the

number of **OFF-ON-ON-OFF** sequence pairs to measure on the source. For the stronger sources, 5 seconds and 1 pair is sufficient. For the weaker sources, 10 seconds and 2 or 3 pairs may be needed. If the source is somewhat extended, ask the operator to set the grid spacing to be the semi-diameter of the source. All other parameters will default to reasonable values. Once everything is set, ask the operator to start the measurement.

Spectral Line Five-Point:

1. Select an appropriate source. The source listing in Table 4.2 is by no means all-inclusive, but if another source is used, take care that it is really suitable for use as a pointing source. In particular, it should have an angular size that is smaller than, or at least comparable to the antenna beam size and possess an accurately known position.

Table 4.2: Spectral Line Pointing Sources

Source	α (B1950)	δ (B1950)	V_{LSR} (km s ⁻¹)	CO		HCN	SiO
				$T_R^*(1 \rightarrow 0)$	$T_R^*(2 \rightarrow 1)$	$T_R^*(1 \rightarrow 0)$	$T_R^*(2 \rightarrow 1)$
R Scl	01:24:39.9	-32:48:05	-18.0	1	?	?	N.E.
Mira	02:16:49.0	-03:12:12	47.0	1			3 (v)
IK Tau	03:50:43.7	11:15:30	35.0	0.5			5 (v)
GL 618	04:39:33.8	36:01:15	-21.0	1			N.E.
Ori IRC2	05:32:47.0	-05:24:24	4.0				
U Ori	05:52:50.9	20:10:05	-39.0				1 (v)
GL 865	06:01:17.5	07:26:03	42.0	0.5			N.E.
VY CMa	07:20:54.7	-25:40:12	24.0				
R Leo	09:44:52.2	11:39:40	1.0	0.1			8 (v)
IRC+10216	09:45:14.8	13:30:41	-26.0	8	12		N.E.
CIT 6	10:13:11.0	30:49:17	-2.0	2	2		N.E.
V Hya	10:49:11.3	-20:59:03	-18.0	0.5			N.E.
R Hya	13:26:58.4	-23:01:23	-1.0				
W Hya	13:46:21.1	-28:07:08	40.0				
U Her	16:23:34.7	19:00:16	-14.0				1 (v)
IRC+20326	17:29:42.0	17:47:36	-5.0	0.5			N.E.
VX Sgr	18:05:03.2	-22:14:06	6.0				10.0
IRC+20370	18:39:41.7	17:38:16	-1.0	0.8	1		N.E.
W Aql	19:12:41.6	-07:08:08	-25.0	1.0			N.E.
X Cyg	19:48:38.5	32:47:11	10.0	0.7	1.5		5 (v)
V Cyg	20:39:41.3	47:57:44	13.0	1	1		N.E.
NML Cyg	20:44:33.8	39:55:57	0.0				

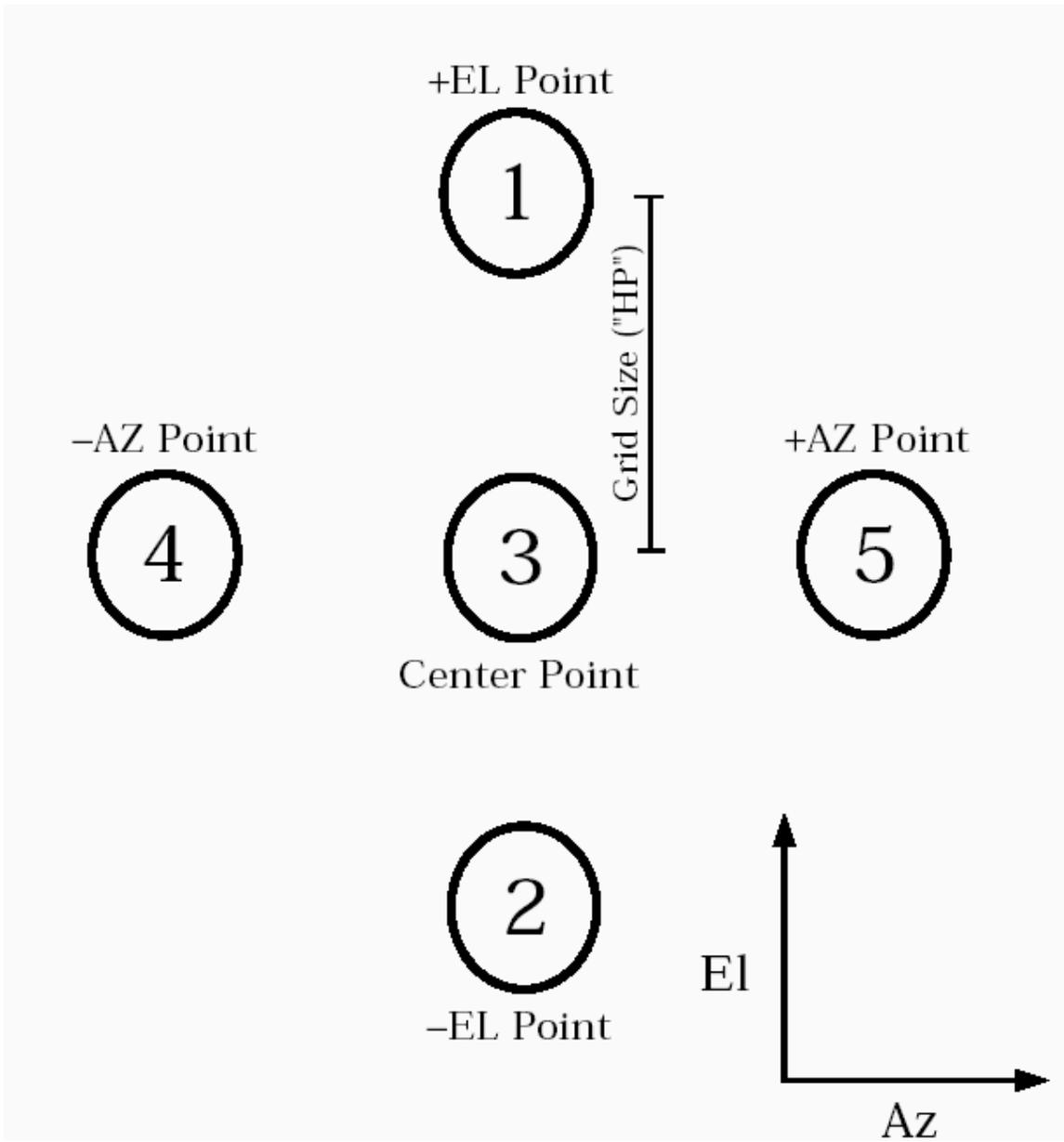


Figure 4.4: Five point mapping scan sequence.

2. Ask the operator to setup for a spectral line five-point measurement on the chosen source. Set the integration time per sample, the number of **ON/OFF** pairs to measure on the source, the number of scans per calibrate, and for a total power five-point the **ON** and **OFF** integration time. Depending on the source size, you may also have to set the grid spacing appropriately. All other parameters will default to reasonable values.
3. Choose an azimuth offset angle for the reference, to be used for position switching.
4. Using the pointing charts, make an initial guess for the azimuth and elevation pointing offsets.
5. Ask the operator to start the measurement.

To process these measurements, there are a number of *condar* and *line* procedures available.

4.6.1.1 Continuum Five-Point Analysis

Continuum five-point measurements are processed automatically by the on-line datserver. The results from these on-line fits are sent automatically to the operator for entry into the control system. To process a continuum five-point measurement manually, use the *condar* resident procedure *five*, which can be abbreviated as *f*. You can look at the results for each channel separately by using the command

Condar > scan number f

Channel 1 is selected by specifying subscan number .01, while channel 2 is selected with subscan .02. The display (Figure 4.5) provides the observer with the best-fit positional offsets in azimuth and elevation, along with the estimated peak flux density of the source, both for a constrained fit of Gaussian half-width HP and an unconstrained solution. The optimum pointing offsets (labeled **CORRECTED OFFSETS**) are also printed, assuming the given position of the source to be correct.

4.6.1.2 Spectral Line Five-Point Analysis

The display of the map and the fit for pointing offsets is somewhat more involved than for a continuum five point. There is a standard *line* procedure which processes all types of spectral line five-point measurements. To process a measurement, within *line* type:

Line> center scan number five1 (for channel 1)

Line> center scan number five2 (for channel 2)

You will be asked some questions by the routine:

AVERAGE THE TWO RECEIVERS? (1=YES, 0=NO) - This question is asked only if the data were taken in *series* mode. If the question is answered “yes”, the routine averages the first and second filter bank to improve sensitivity. You should answer “yes” only if you

are reducing the first filter bank; you will usually not need to reduce the two filter banks separately if averaging the two. If the data were taken in parallel mode, the two polarization channels in each filter bank are automatically averaged.

CHAPTER 4. TRACKING, POINTING, AND FOCUS

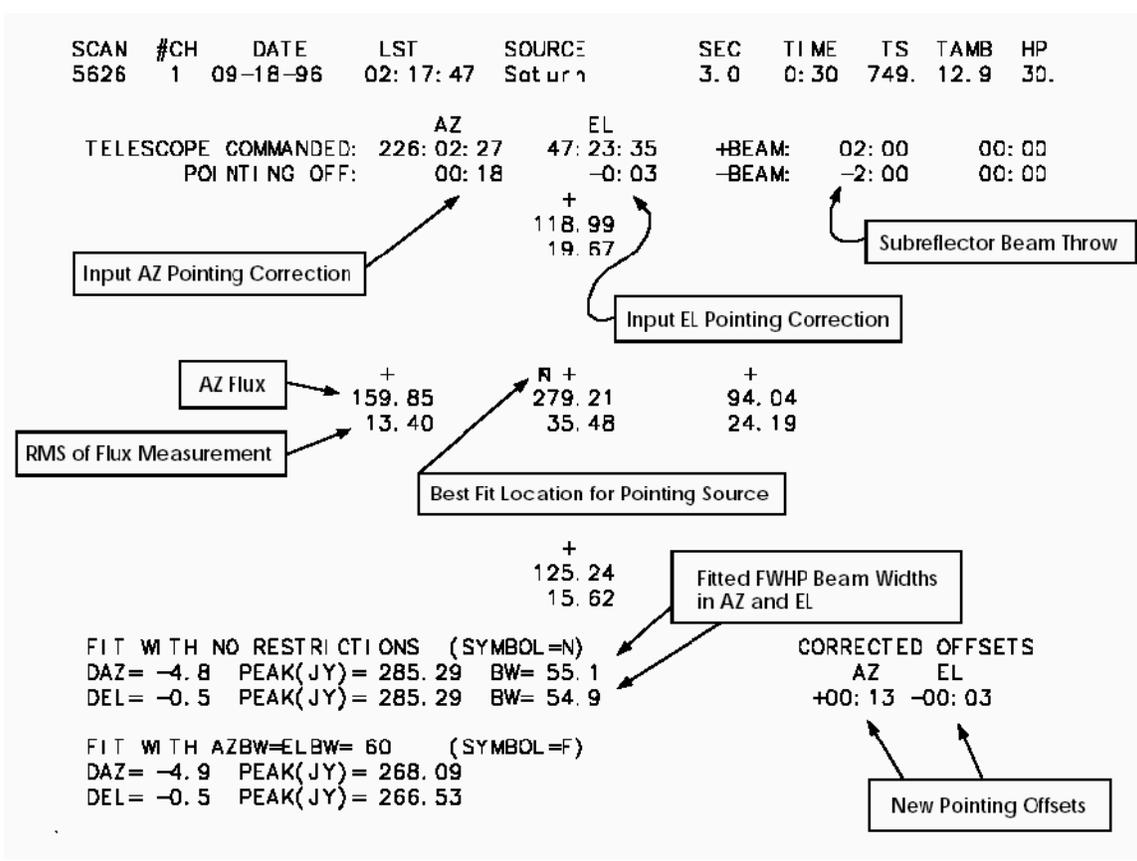


Figure 4.5: Continuum Five-Point Analysis Example

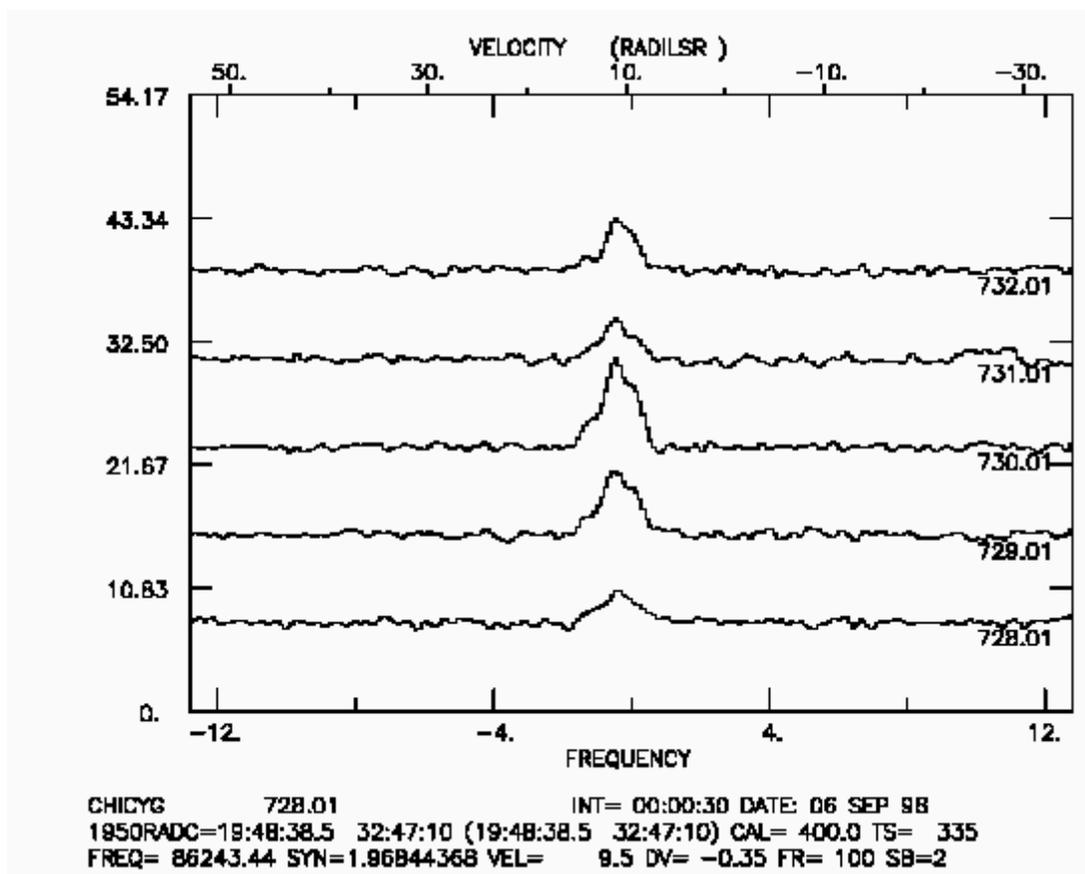


Figure 4.6: Display of each scan produced by the *line* procedure *five*.

USE OLD BASELINE & INTEG. REGIONS? (1=YES, 0=NO) - The observer must define baseline fitting and spectral line integration regions for this routine. If these regions have already been accurately set, as, for example, in a five-point of the same source performed immediately prior to the present one, you can answer “yes” and speed up the reduction process considerably. If you answer “no”, the spectrum at the center of the map is displayed on the screen, and the question **ENTER # OF BL SEGS** is printed. This part of the *f* routine is the same as the *bset* procedure. The observer must enter the number of baseline segments to be used to fit a least-squares baseline. [NOTE: The order of the fit is determined by whatever *nfit* is set to (the default is 1 - see the *line* data reduction manual for a description of the baseline fitting facilities).] When the number of segments to be fit is entered, the graphics crosshairs appear and you must mark off the two ends of each segment with the crosshairs (move the crosshairs to the desired position and strike any mouse button). When this operation is finished, the baseline is removed from the center spectrum and the spectrum is replotted. The prompt **ENTER INTEG. REGIONS** is printed and the crosshairs reappear. You should then mark off the two velocity/frequency extremities of the spectral line (or whatever region you wish to integrate over).

DISPLAY EACH SCAN? (1=YES, 0=NO) - If you answer “no”, the map and the fit for new offsets are printed out. If you answer “yes” each scan of the map, with baselines removed, is displayed on a single plot, one spectrum on top of the other (see Figure

4.6).

TYPE 1 TO CONTINUE OR 0 TO STOP - If you approve of the fits, answer 1 and the map and fit for new offsets will be displayed. An example of the five-point map with explanatory annotations is given in Figure 4.7.

4.6.2 Pointing Model Equations

In addition to coordinate conversions, the telescope tracking program incorporates pointing corrections. The pointing corrections take into account resolver zero offsets, differences between electrical and mechanical axes, axis tilt, etc. The coefficients of the pointing model equations are determined during dedicated optical and radio pointing source measurements several times during the observing season. The pointing models used for the 12m are described in detail in Appendix A.

4.6.3 Pointing Data Analysis Program

Each time a continuum five-point measurement is made, the on-line data server performs a fit to the results and writes them to a permanent file for later analysis. A program called *gpoint* is available on any of the mountain workstations for display and analysis of the recent pointing history of the telescope.

To start the program, type *gpoint* from any login prompt. *gpoint* is menu-driven, so you need only select the appropriate entries in each menu to configure the data selection and display parameters to suit your needs. An example of a *gpoint* plot is given in Figure 4.8.

4.7 Focus

4.7.1 Axial Focus

To bring the incident radiation to a focus at the receiver feed horn, the subreflector of the 12m may be moved in and out along the electrical axis of the telescope. The focus exhibits an elevation dependence which is automatically corrected by the control system computer, according to the equation

$$F(E) = F_0 + 2.8 \sin(E) \quad (4.1)$$

where $F(E)$ is the focus setting in millimeters, E is the elevation, and F_0 , the subreflector focus setting at 0° elevation, is to be determined by the observer. F_0 is given in millimeters, and larger values of F_0 represent greater distances between the dish surface and the subreflector.

An automatic procedure called a *focalize* (this word really is in the dictionary!) will determine the best value for F_0 . An analysis routine of the same name exists in *condar*

and *line* for displaying and fitting the results. Instructions for performing a *focalize* are given in §4.7.2.

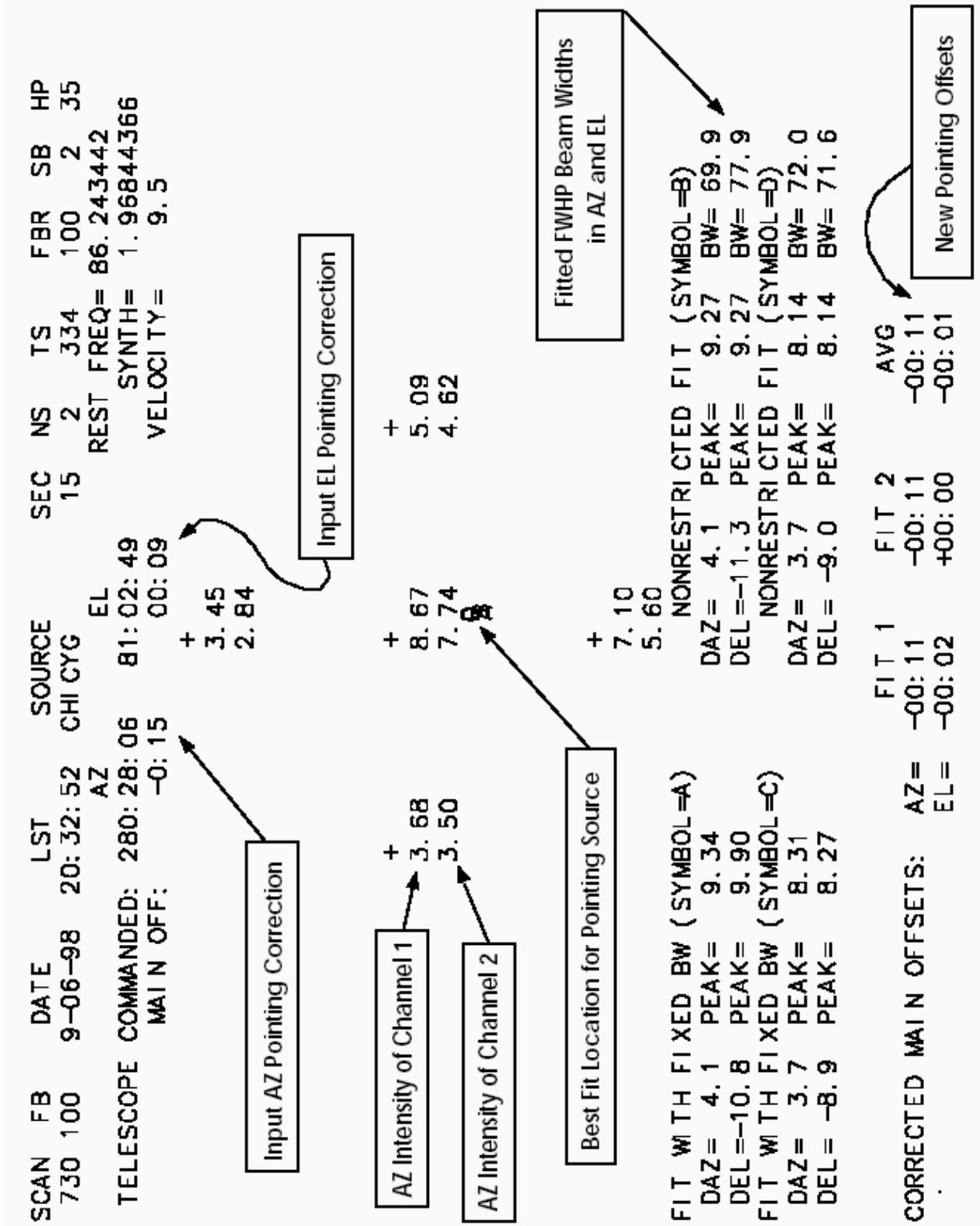


Figure 4.7: Spectral line five-point analysis example.

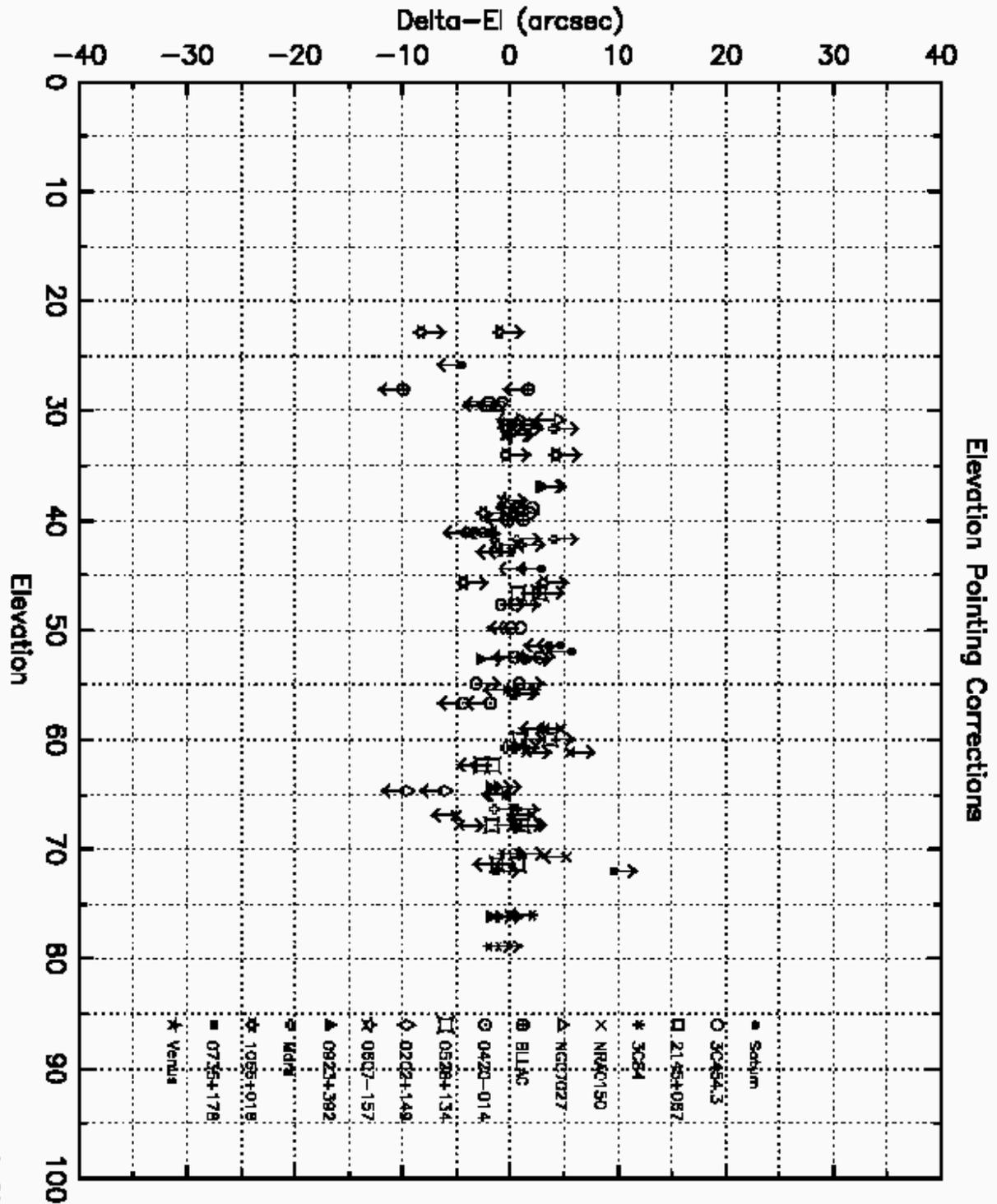


Figure 4.8: GPOINT display example. Each pointing source is indicated by a unique symbol, while the arrow on each symbol indicates whether the source was rising or setting.

4.7.2 Determining the Axial Focus

The axial focus of the telescope should be checked occasionally during an observing run. It is often most convenient to make a focus check after a continuum five-point pointing measurement since both measurements use the same kinds of sources (strong continuum point sources). It is particularly important to check the focus after nightfall and daybreak. Focusing is performed via the *focalize* procedure. This steps the radial distance of the subreflector from the telescope vertex through seven positions centered on the nominal best setting (F0). Larger values of F0 represent greater distances between the dish surface and the subreflector. The incremental movement between positions (WL) is set to half of the observing wavelength by default, but can be set by the observer.

Perform a *focalize* as follows:

1. Choose as bright a continuum source as possible. The planets Jupiter, Venus and Saturn are ideal. If the source is extended relative to the telescope main beam, the accuracy of the *focalize* will be diminished, however.
2. Make a five-point map of the source to optimize the antenna pointing (see §4.6.1).
3. Reasonable default values for the axial subreflector position (F0) have been assigned to each receiver, but, if you find it necessary you can give the operator a value for F0.
4. The default integration time per sample is 5 seconds, but if you are performing a *focalize* measurement on a weak source, you may need to increase this to 10 -15 seconds.
5. If you are satisfied with the setup, ask the operator to start the measurement.

Focalize measurements are processed automatically by the on-line dataserver, the results of which are sent automatically to the operator for entry into the control system. To reduce the *focalize* in condar use the commands,

```
Condar > scan number focalize
```

where each channel is selected by specifying either subscan .01 for channel 1 or .02 for channel 2. The output from the *focalize* procedure is shown in Figure 4.9. The fit should be smooth and “quasi-Gaussian”. (If not, repeat the *focalize*. Increase the value of WL if you think this is necessary.) The display will give a best-fit value for F0. Where appropriate, you should average the values for the two channels.

4.7.3 Lateral Focus

The position of the subreflector for optimum gain shifts in the elevation direction, with changing elevation angle. The change in antenna gain produced by this effect is not significant at 3mm wavelengths but could be as much as 20% or more at 1.3mm and

shorter wavelengths. The 12m is equipped with lateral “north-south” and “east-west” translation stages at the prime focus to eliminate this loss in antenna gain. The computer is able to automatically control the positioning of these stages, simultaneously applying

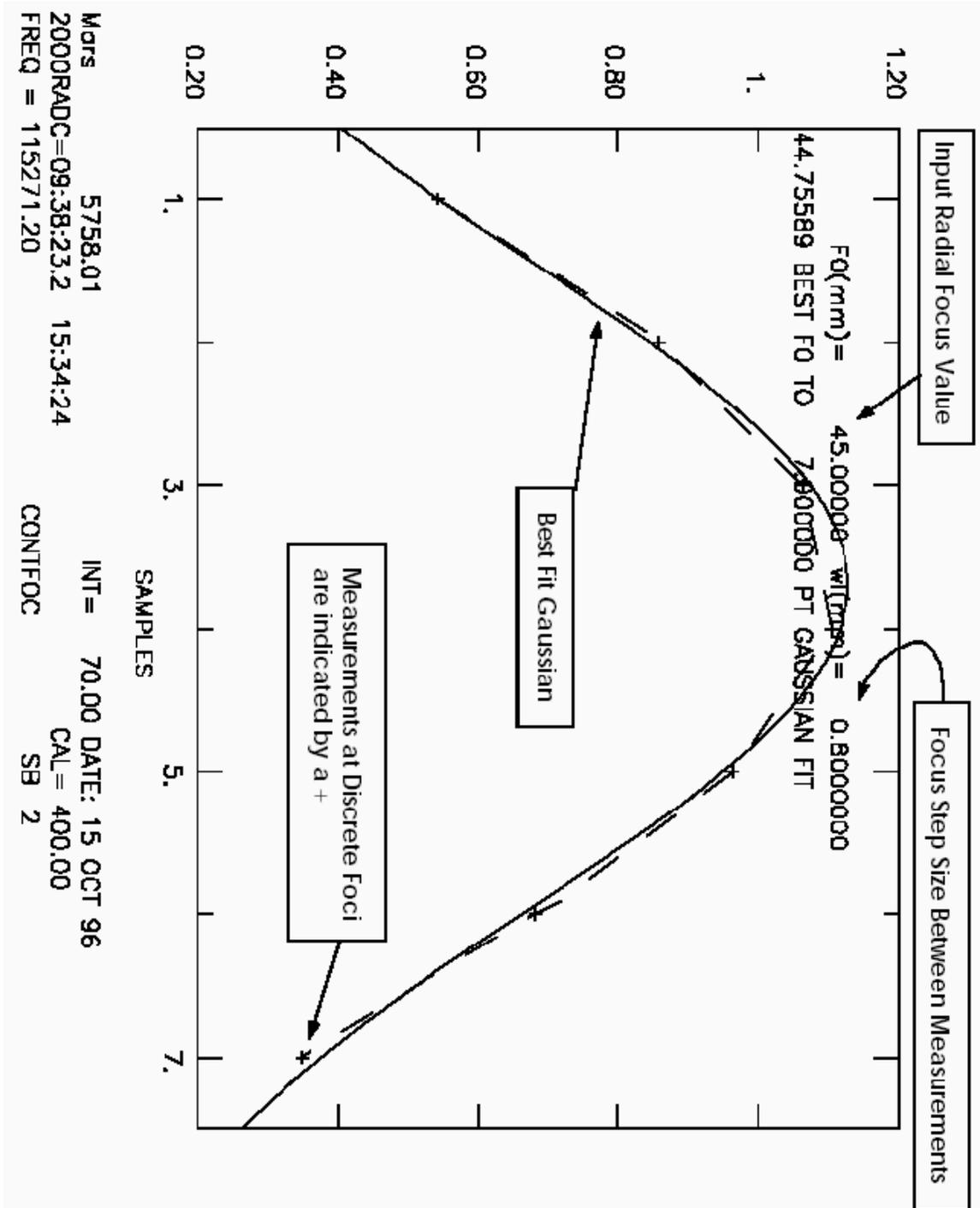


Figure 4.9: Focalize display example.

an appropriate correction to the telescope pointing in elevation and azimuth, respectively. This correction to elevation pointing is $31.5''/\text{mm}$ (which is the prime focus “plate scale” derived in Appendix G) of movement in the north-south focus or east-west focus stages.

In the future, the coefficients necessary to control the movement of the north-south and east-west translation stages will be installed in the computer and applied automatically. At this time, the north-south and east-west translation stages can be set to a given position, but are usually left fixed in this position. Automatic procedures for fitting for maximum north-south or east-west gain, called *nsfocal* and *ewfocal* are available. These routines operate analogously to the *focalize* procedure. Normally, only staff astronomers use these procedures; we do not recommend that observers spend time trying to optimize this further.